www.zcyphygeodesy.com

Geodetic Computation for Earth Tide, Load Effects and Deformation Monitoring

ETideLoad4.0 User Reference

Easy for Classroom Teaching and Independent Self-study

Chinese Academy of Surveying & Mapping

January 2022, Beijing, China

Geodetic Computation for Earth Tide, Load Effects and Deformation Monitoring (ETideLoad4.0) is a large Windows package for scientific computing of geophysical geodetic monitoring. Which has five subsystems including the solid Earth tidal effects on various geodetic quantities, processing and analysis on geodetic non-tidal time series, approaching of surface load-deformation field and temporal gravity field, CORS/InSAR collaborative monitoring and ground stability variation estimation as well as editing, calcutating and visualization for geodetic data files.

ETideLoad4.0 is suitable for senior undergraduates, graduate students, scientific researchers, and engineering technicians in geodesy, geophysical, geological disasters, hydrodynamics, satellite dynamics, seismic, and geodynamics. Which considers various potential needs such as classroom teaching, independent self-study, applied computing and scientific research.

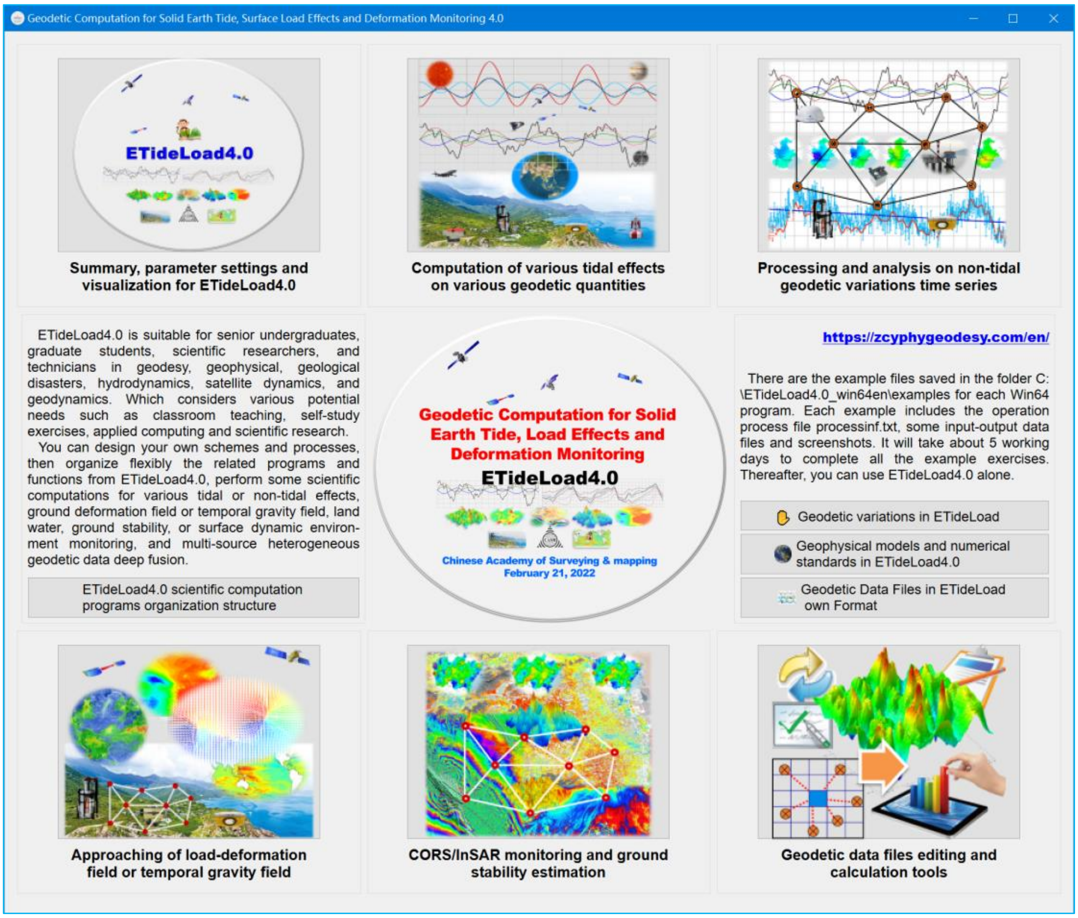
Key words: Geodesy, Geophysics, Earth Tide effect, Loading deformation, Collaborative Monitoring, Groundwater, Ground Stability, Geological Disasters.

https://www.zcyphygeodesy.com/en/
Chinese Academy of Surveying & Mapping
January 2022, Beijing, 100036, China
ZHANG Chuanyin, zhangchy@casm.ac.cn
WANG Wei (wangwei@casm.ac.cn)
JIANG Tao (jiangtao@casm.ac.cn)

Contents

1 ETideLoad4.0's features, strengths, concepts, and usage

Geodetic Computation for Earth Tide, Load Effects and Deformation Monitoring (ETideLoad4.0) is a large Windows package for scientific computing of geophysical geodetic monitoring. Which adopts the scientific uniform numerical standards and analytic compatible geophysical algorithms accurately to compute various tidal and non-tidal effects on various geodetic quantities outside the solid Earth, approach global-reginal load deformation field and temporal Earth’s gravity field, and then quantitatively monitor surface hydrology environment, ground stability variations and geological disasters, in order to promote the collaborative monitoring of multi-geodetic technologies and deep fusion of multi-source heterogeneous geodetic data.

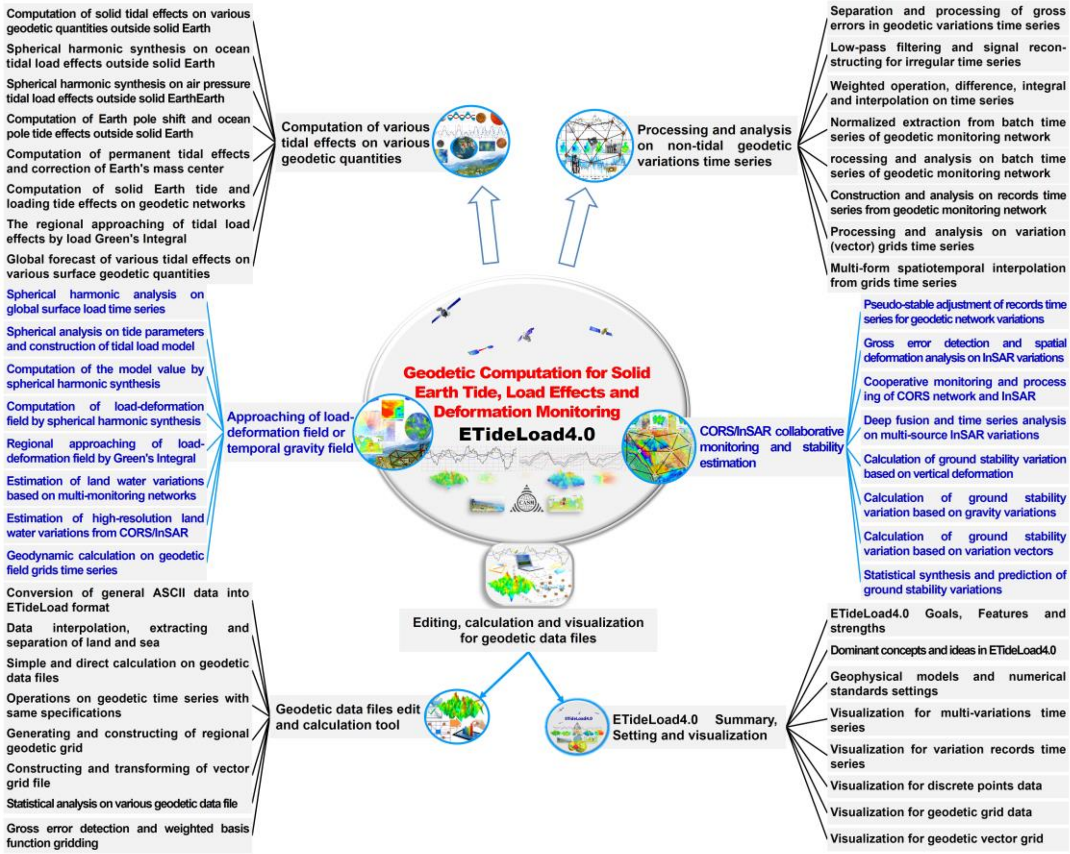


1.1 ETideLoad4.0 structure of computation functions

ETideLoad4.0 has five subsystems, which includes the solid Earth tidal effects on various geodetic quantities, processing and analysis on geodetic non-tidal time series, approaching of surface load-deformation field and temporal gravity field, CORS/InSAR collaborative monitoring and ground stability variation estimation as well as editing, calculation and visualization for geodetic data files.

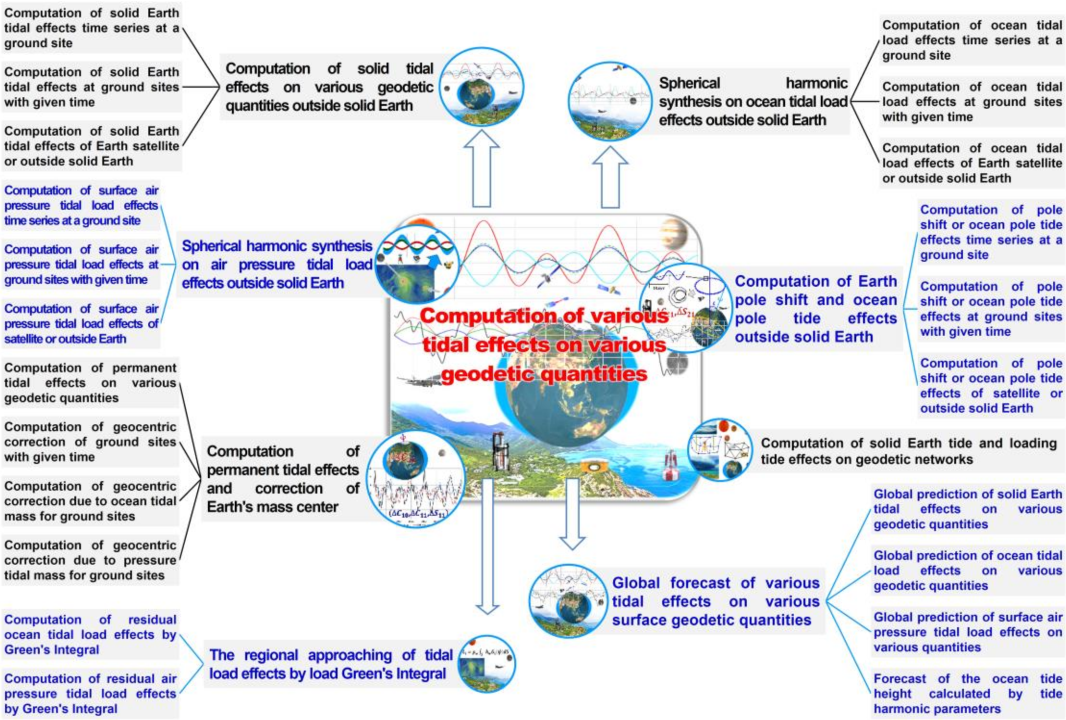
ETideLoad4.0 was developed by QT C++ (Visual C++) for the user interface, Intel Fortran (Fortran90, 132 Columns fixed format) for the core function modules, and mathGL C++ for the geodetic data file visualization in the Visual Studio 2017 x64 integrated environment. Which is composed of more than 50 win64 executable programs with nearly 600 function modules.

ETideLoad4.0 considers various potential needs such as the classroom teaching, self-study exercises, applied computing and scientific research. There are the example files saved in the folder C:\ETideLoad4.0_win64en\examples for each Win64 program. Each example includes the operation process file processinf.txt, some input-output data files and screenshots.



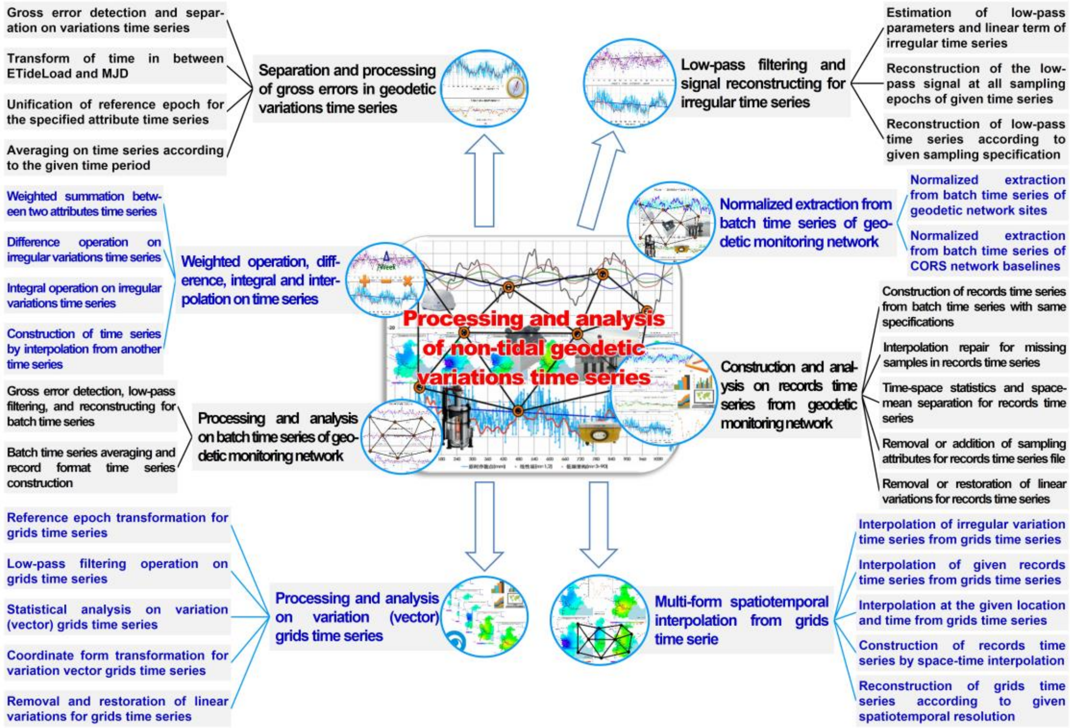
1.1.1 Computation of various tidal effects on various geodetic quantities

Using the consistent geophysical models, the uniform numerical standards, and the compatible geodetic and geodynamic algorithms, compute various geodetic effects of the solid Earth tide, ocean tide loading and surface air pressure tide loading. Which is an important foundation for the collaborative monitoring of multi-geodetic technologies, is also a necessary condition for the deep fusion of multi-source heterogeneous Earth monitoring quantities.



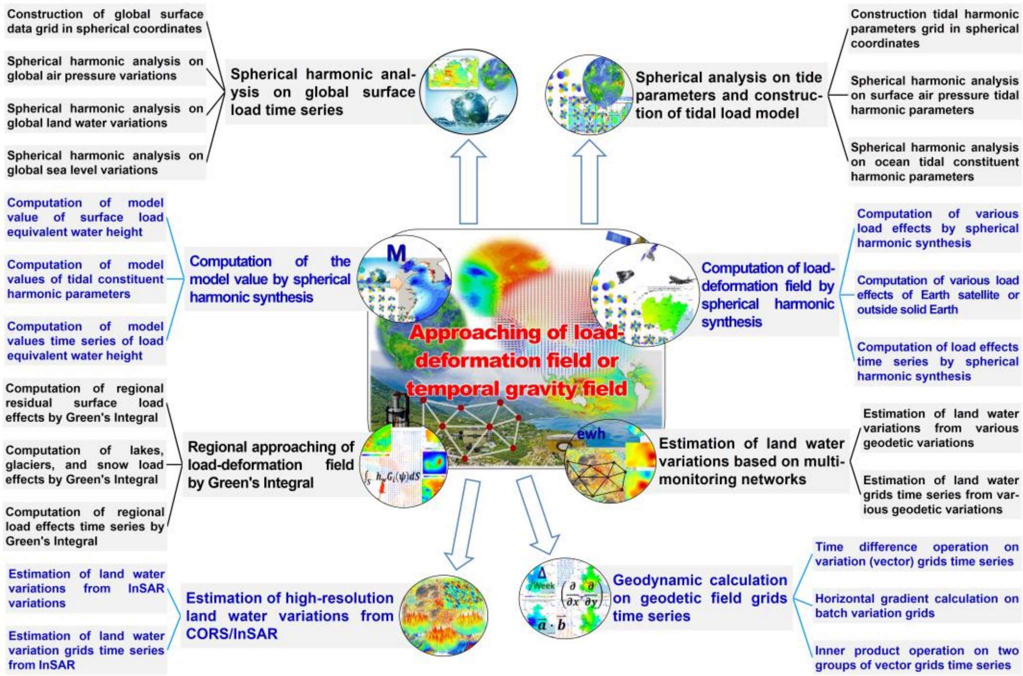
1.1.2 Processing and analysis on non-tidal geodetic variations time series

Based on the characteristics of non-tidal geodetic time series, the group of programs adopt stable and reliable algorithms to uniformly process and analyze massive various geodetic variations time series data.

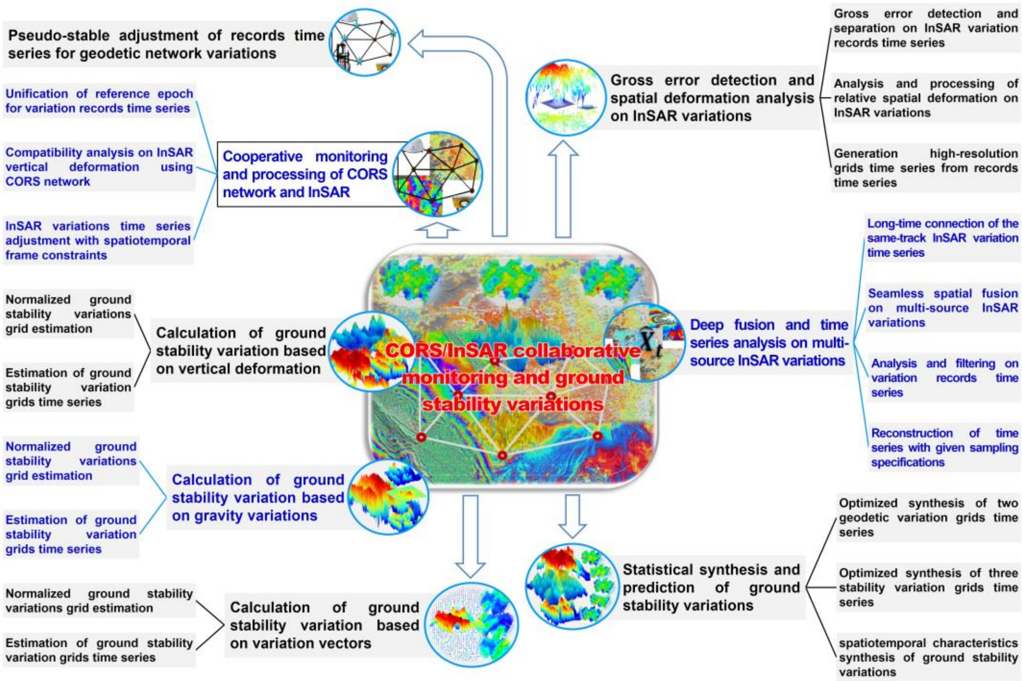


1.1.3 Approaching of load-deformation field or temporal gravity field

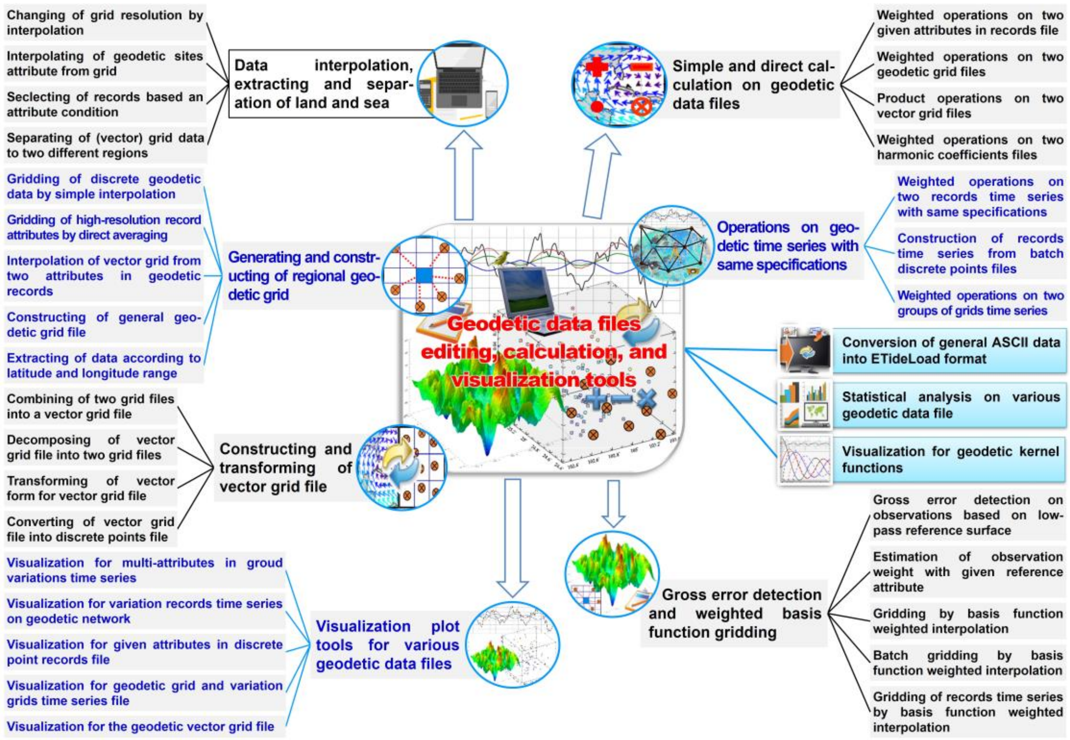
The non-tidal load variations of atmosphere, sea level, soil water, groundwater, lakes, glaciers, and snowy mountains in the Earth's surface layer, excite solid Earth deformation, which can cause variations of various geodetic quantities with time. These variations can also be quantitatively captured by a variety of ground, space, or ocean geodetic technologies.



1.1.4 CORS/InSAR collaborative monitoring and ground stability estimation



1.1.5 Geodetic data files editing, calculation, and visualization tools



1.2 Geodetic variations in ETideLoad4.0

1.2.1 Conventions of the geodetic variations

Geodetic variation in ETideLoad is defined as the difference between the geodetic quantity at the current epoch time and the mean of the quantities over a period or the difference between the geodetic quantity at the current epoch time and the geodetic quantity at a certain reference epoch time. The geodetic quantity may be a geodetic observation or a geodetic parameter, and the geodetic variation refers to the difference in the geodetic quantity with time.

1.2.2 Type and unit of the geodetic variations

(1) Height anomaly or geoidal height variation in the unit of mm, ground gravity or gravity disturbance variation in the unit of μGal, and ground tilt or vertical deflection variation (vector) in the unit of mas namely 0.001".

(2) Ground horizontal displacement in the unit of mm, ground radial displacement namely ground ellipsoidal height variation in the unit of mm, and ground normal or orthometric height variation in the unit of mm.

(3) Gravity gradient variation in the unit of 10μE, and tangential gravity gradient vector variation in the unit of 10μE.

(4) External (outside the Earth) geopotential perturbation in the unit of $0.1m^2/s^2$, gravity perturbation in the unit of μGal, and gravity gradient perturbation in the unit of 10μE.

(5) Land equivalent water height variation in the unit of cm, sea level variation in unit of cm, ocean tidal height in unit of cm, and air pressure variation in unit of hPa.

1.2.3 The geodetic variation vectors

(1) Ground tilt or vertical deflection variation vector (SW). The first component points to the south direction, and the second component points to the west direction, which forms a right-handed rectangular coordinate system with the ground gravity direction. This coordinate system is a natural coordinate system.

(2) Ground horizontal displacement vector (EN). The first component points to the east direction, and the second component points to the north direction, which forms a right-handed rectangular coordinate system with the ground radial displacement direction.

(3) Tangential gravity gradient variation vector (NE). The first component points to the north direction, and the second component points to the east direction, which forms a right-handed rectangular coordinate system with the gravity gradient variation direction.

(4) The harmonic parameters of the tidal constituent. The first component is the prograde amplitude for cos(argument), and the second component is the retrograde amplitude for sin(argument).

1.2.4 Expressions of the date and epoch

Time (date and epoch) are agreed to adopt Greenwich Time (zero time zone), which is expressed in modified Julian Date (MJD, in GPS time, and Julian Date 2000.0 = MJD 51544.5) or a long integer agreed by ETideLoad.

In most cases, the long integer agreed by ETideLoad is used. E.g., 20181224122642 represents 12:26:42 on December 24, 2018, 2018122412 represents 12: 0: 0 on December 24, 2018, and 20181224 represents 0: 0: 0 on December 24, 2018. But 201812, 2018 are not valid date and epoch. Here, the epoch is an instantaneous time.

1.3 Science goals and strengths of ETideLoad4.0

1.3.1 Scientific goals of ETideLoad4.0

(1) Using the consistent geophysical models and uniform numerical standards, accurately compute the various tidal and non-tidal effects on various geometric and physical geodetic quantities on the ground and outside the solid Earth by constructing compatible geodetic and geodynamic algorithms.

(2) Unifying various geodetic spatiotemporal monitoring datum frames and reference epoch time, by constructing geometric and physical geodetic constraints between various monitoring quantities, highlight the spatiotemporal geodynamic relationships between these monitoring quantities to promote the collaborative monitoring of multi-technologies.

(3) Provide a set of scientific and practical geodetic geodynamic computation tools for construction and maintenance of geodetic spatiotemporal monitoring frames, and deep fusion of multi-source heterogeneous Earth monitoring quantities, computation of solid Earth

deformation, monitoring of surface hydrology environment, and surveying of geological disasters.

1.3.2 Geodetic features and strengths

(1) Adopt the scientific uniform numerical standards and analytic compatible geophysical algorithms accurately to compute the Earth tidal, ocean tidal, and surface air pressure tidal, permanent tidal, polar motions, and geocentric motions effects on various geodetic quantities on the ground and outside the solid Earth. Realize global forecasts of various tidal effects on surface various geodetic quantities.

(2) Compute global or regional load-deformation field and temporal gravity field caused by surface non-tidal load variations such as air pressure, sea level, soil water, lakes, rivers, glaciers, and snow. From various geodetic observations time series, assimilate the surface load observations by some constraints of the solid Earth deformation, to monitor the spatiotemporal variations of regional land water, and then to improve the load-deformation field and temporal gravity field.

(3) Construct regional uniform geometric and physical spatiotemporal monitoring datum frames with high robustness to make scientific computations and deep fusion of the CORS, InSAR, and other geodetic variations to promote multi-geodetic collaborative monitoring. Propose the quantitative deterministic criteria of the ground stability reduction based on temporal geodetic field, to realize quantitative monitoring of the ground stability spatiotemporal variations.

1.4 Dominant concepts and ideas integrated into ETideLoad4.0

1.4.1 Deep fusion principles of multi-source heterogeneous geodetic data

(1) Using scientific consistent geophysical models, rigorous uniform numerical standards, and analytic compatible geodetic and geodynamic algorithms, construct the theoretical basis and necessary conditions for geodetic collaborative monitoring by unifying the spatiotemporal monitoring frames and reference epoch.

(2) For the same type of multi-source heterogeneous geodetic monitoring quantities, the basic geodetic constraints or joint adjustment methods with additional monitoring datum parameters as needed are used to deep fusion.

(3) For different types of monitoring quantities, physical geodetic, solid geophysical, or environmental geodynamic constraints with additional dynamic parameters as needed are used to deep fusion.

(4) The purpose of reconstructing the geodetic or geodynamic relationship between various monitoring data is not only to improve the spatiotemporal monitoring capability, but also to further reveal the geodynamic structure and characteristics of the monitored objects.

1.4.2 Tidal deformations of solid Earth and tidal effects on geodetic quantities

(1) The external celestial bodies, ocean tides, and atmospheric tides excite the periodic

deformation of the solid Earth and the periodic change of the gravity field, which are called the tidal deformation of the solid Earth.

(2) The geodetic variations caused by the external celestial bodies, ocean tides, and atmospheric tides are usually called the tidal effects on the geodetic quantities.

(3) The geodetic tidal effects include the solid Earth tidal effects and the load tidal effects. The geodetic solid Earth tidal effects are excited by the external celestial bodies, and the tidal load effects are excited by the ocean tides and atmospheric tides.

(4) The geodetic tidal effects can be modeled and can be accurately removed or restored anytime and anywhere. The geodetic tidal effect is equal to the negative value of the geodetic tidal correction.

The geodetic reference frame with only some tidal effects removed but non-tidal effects neglected is still stationary (unchanged with time). For example, a precision leveling network or a gravity control network, if its observations have been corrected only using some tidal effects, is still stationary.

1.4.3 Non-tidal deformation of solid Earth and their effects on geodetic quantities

(1) In the Earth surface system, surface non-tidal load variations such as soil and vegetation water, lake water, glacier and snow, groundwater, atmosphere, and sea level variations can induce the external geopotential variations, and then excite solid Earth deformation, which is manifested as ground displacement, gravity, and tilt variations. This is called the load-deformation of the solid Earth, which also takes the form of the variation of the Earth's gravity field with time.

(2) Groundwater use, underground mining, underground construction, glacier or ice sheet melting, and other natural or artificial surface mass adjustments can break the mechanical balance state of the surface rock and soil layer, and then the surface rock and soil layer will slowly tend to another equilibrium state under the action of its own gravity or internal stress. The process causes plastic or viscous vertical deformation which is also called isostatic vertical deformation.

(3) The load-deformation is excited by the surface environment load variations, and act on the entire solid Earth. Which is an elastic deformation and can be quantitatively represented by the load Love numbers. The isostatic vertical deformation is induced by environmental geology change. Whose dynamic action is in the underground rock and soil and is transmitted by the rock and soil own as the mechanical medium. The isostatic deformation is a slow plastic or viscous vertical deformation.

(4) The pole shift is the instantaneous loaction shift of the Earth pole relative to a certain reference epoch (such as epoch J2000.0) after removing all solid earth tides and loading tidal effects. Neither the pole shift nor geocentric movement include various tidal effects. Non-tidal effects are difficult to be modeled and are generally measured using geodetic techniques. In most fast or real-time geodetic applications, short-time forecast estimations

of the pole shift are adopted.

The geodetic reference frame that needs to account for non-tidal effects can only be dynamic, and the reference value of the dynamic reference frame corresponds to a specific and unique reference epoch time. The reference value at the current epoch time is equal to the sum of the reference value at the reference epoch time and a correction. The correction is equal to the difference of the non-tidal effects between at the current epoch time and at the reference epoch time. The correction process is also called the (non-tidal effects) epoch reduction.

1.4.4 Representation and approaching of load deformation and temporal gravity field

(1) The non-tidal load effects can be uniquely represented by the variations of the Earth's gravity field with time. The relationship between the non-tidal load effects is completely consistent with the relationship between the parameters of the Earth's gravity field.

(2) Global Earth gravity field can be represented by a geopotential coefficients model (GCM). Similarly, the global load-deformation field (namely temporal global gravity field) can be represented by a global surface load spherical harmonic coefficients model (LCM).

(3) Using a geopotential coefficients model, you can calculate various gravity field quantities on the surface or outside Earth. Similarly using a global load spherical harmonic coefficients model, you can calculate load effects on various geodetic quantities outside the solid Earth.

(4) Regional gravity field (geoid) can be approached by the remove-restore process based on a GCM. Similarly, the regional load-deformation field or temporal gravity field can also be approached by the remove-restore process based on an LCM.

(5) The approach theory of the Earth's gravity field is linear. Similarly, the approach theory of the load-deformation field is also linear. For example, when surface air pressure, land water, and sea level variation are expressed as equivalent water height (EWH) variation, calculating the load effects from the surface air pressure, land water, and sea level variation firstly and then summing them, is equivalent to summing the three EWH variations firstly and then calculating the load effects.

1.4.5 Types of ground vertical deformation and space-time quantitative natures

There are three forms of ground vertical deformation (or ground subsidence), namely, the elastic loading vertical deformation, viscous or plastic isostatic vertical deformation, and plastic tectonic vertical deformation near the compressive geological fracture zone. The latter two are also called the non-loading vertical deformations, both of which are plastic vertical deformations.

(1) The loading vertical deformation is excited by the surface mass redistribution which firstly causes the Earth geopotential variation called as the direct effect, and then by Earth elastic dynamic action, causes the solid Earth deformation simultaneously to generate an

additional geopotential variation called as the indirect effect. The loading vertical deformation synchronizes with the time of the loading redistribution, whose time-varying characteristics are similar to the surface load variations, showing complex nonlinearity and quasi-periodicity.

(2) The isostatic vertical deformation usually manifests as a dynamic process. In the process, the original equilibrium state of the underground rock and soil layer is firstly destroyed by the geology dynamic action, and then under the action of the gravity or internal stress, the rock and soil layer slowly approach another equilibrium state. For example, the compaction effect of the rock and soil layers with voids in the ground after the loss of water and the expansion effect after water infiltration, the deformation of the upper rock layer (wall rock deformation) caused by underground engineering, and plastic isostatic rebound of the rock and soil layer after surface mass migration.

• Spatial quantitative characteristics of the isostatic vertical deformation

The dynamic action is located inside the underground rock and soil layer, and the equilibrium adjustment object is the rock and soil layer above the dynamic action point. The space influence angle of the equilibrium adjustment is about 45°, that is, the spatial range of ground vertical deformation is approximately equal to the buried depth of the action point.

• Temporal quantitative characteristics of the isostatic vertical deformation

The duration of the equilibrium adjustment is approximately proportional to the burial depth of the dynamic action location. The isostatic vertical deformation is the opposite of its acceleration rate sign in a relatively long period of time (several years), and linear time variation in a short period of time (several months).

(3) The tectonic vertical deformation, driven by the horizontal movement of the lithospheric plate, only appears near the compressive fault zone. Whose spatial influence radius is equivalent to the depth of the fault, and the deformation decays rapidly to zero with the distance of the calculated point away from the fault zone. On a centennial timescale, the tectonic vertical deformation rate remained basically unchanged.

1.4.6 CORS and InSAR collaborative monitoring principle for vertical deformation

(1) Through the gross error detection, spatial filtering, and time series analysis, the InSAR vertical variation is separated into two parts, one part is the vertical deformation of the rock and soil layer several meters deep, and the other part is the expansion and contraction of the soil own. Only the former is compatible with most geodetic variations, while the latter is mainly affected by the temperature and rainfall and should not be regarded as a solid Earth deformation.

(2) Using the CORS network ellipsoidal height variations time series as the constraints on the multi-source InSAR vertical variations time series, separate the ground vertical deformation signal, and then realize the collaborative monitoring of the CORS network and multi-source InSAR.

(3) Only the vertical deformation of the rock and soil layer several meters deep is the

useful information needed for monitoring of the ground subsidence, earthquakes, geological disasters, ground stability variations, solid Earth deformation, groundwater variations, and geodynamics.

1.4.7 Continuous quantitative monitoring scheme of ground stability variations

(1) Construct the quantitative criteria for the ground stability reduction from the regional grids time series of the geodetic vertical deformation, ground gravity and tilt variations, and then continuous quantitatively monitor the ground stability variations.

(2) Quantitative criteria of the ground stability reduction mainly include that the ellipsoidal height increases, the gravity decreases, the horizontal gradient of the height or gravity variation is large, and the inner product of the tilt variations and terrain slope vector is greater than zero.

(3) According to the geological disasters that occurred, optimize and synthesize a variety of geodetic ground stability variation grids time series to adapt to the local environmental geology, and then consolidate regional stability variations monitoring capabilities.

1.4.8 Analytical compatibility between various geodetic algorithms

The consistency and analytical compatibility between various geodetic algorithms are the concrete manifestation for the requirement of geodetic theory and the uniqueness of monitoring objects. Which is the smallest requirement for the collaborative monitoring of multi-geodetic technologies and deep fusion of multi-source heterogeneous geodetic data.

Analytical compatibility between geodetic algorithms involves two issues: (1) Compatibility between various geodynamic influences for different types of geodetic quantities. (2) Compatibility between different types of geodynamic influences of one kind of geodetic quantitity.

The first type of compatibility is the basic requirement of geodetic theory. For example, the load effect on the normal height on a site is equal to the Hotine integral of the load effect on gravity disturbances. For another example, the solid tidal effect on the normal height on a site is equal to the sum of the effects on the ellipsoidal height and geoid.

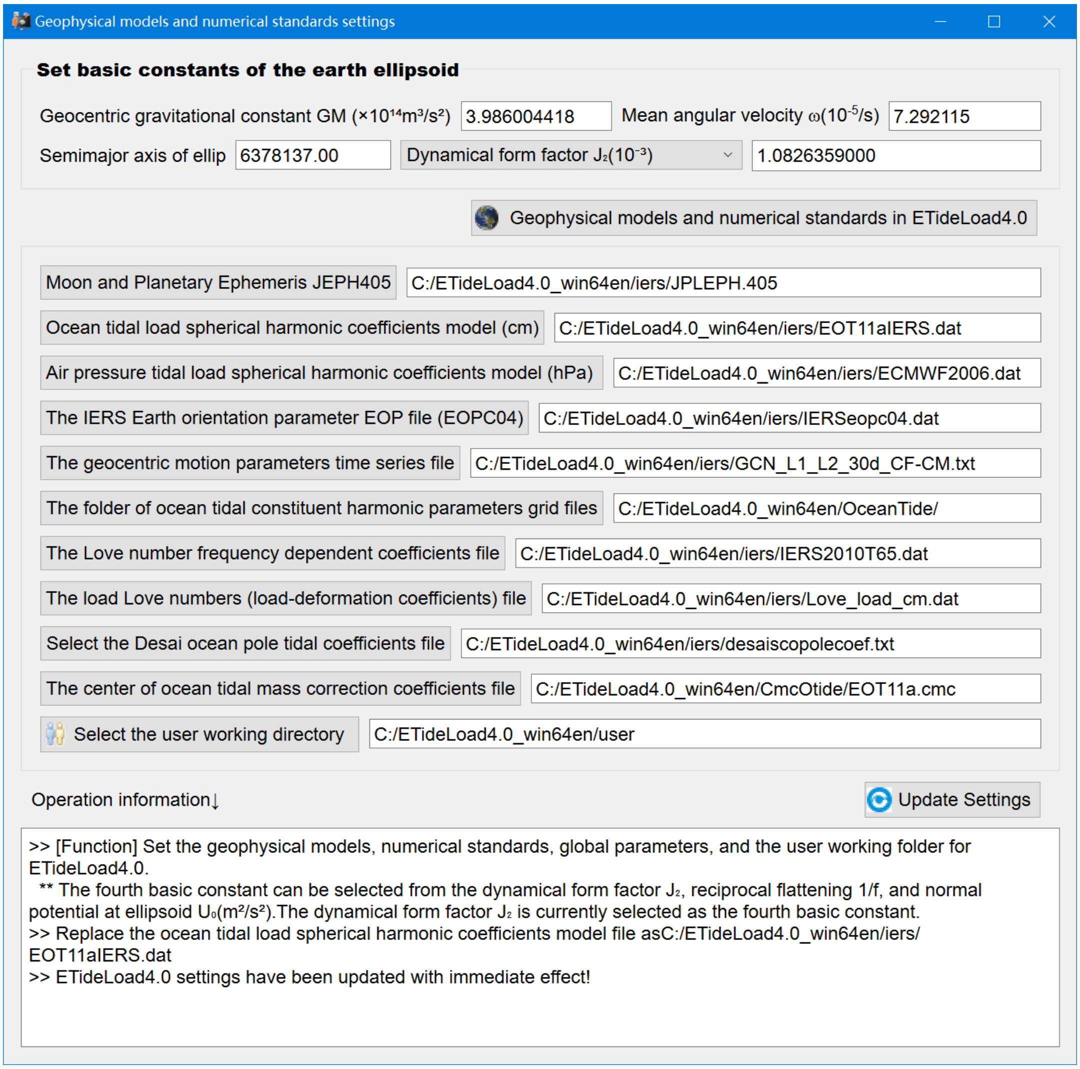
The second type of compatibility is constrained by the solid deformation geodynamic equations (including constitutive equations).

1.5 Conventions, examples and usage in ETideLoad4.0

1.5.1 Geophysical models and numerical standards in ETideLoad4.0

ETideLoade4.0 is mainly based on the geophysical models and numerical standards recommended by IERS Conventions (2010). You can update them from the program [geophysical models and numerical standards settings]. These geophysical models and numerical standards are stored in file form in the folder of C:\ETideLoad4.0_win64cn.

Geophysical models and numerical standards in ETideLoad4.0 mainly include the surface air pressure tidal load spherical harmonic coefficients model, ocean tidal load spherical harmonic coefficients model, Earth's Load Love numbers, IERS Earth orientation parameters time series, geocentric motion parameters time series, ocean tidal constituent harmonic parameters grid model, JPL Moon and Planetary Ephemeris DE405, corrections coefficients of frequency dependence on Love numbers, Desai ocean pole tide coefficients, and center of mass correction coefficients for the ocean tide.



1.5.2 Five kinds of variations time series agreed in ETideLoad4.0

The geodetic variation time series files adopt the ETideLoad own format, which include the ground geodetic variations time series file, geodetic site variation records time series file, geodetic network observation records time series file, variation (vector) grids time series files, and spherical harmonic coefficient (Stokes coefficient) models time series files.

(1) The ground geodetic variations time series

A ground geodetic variations time series file can store the time series data of several kinds of variations on a certain site, a certain baseline or route, and the sampling epochs (here, the epoch is an instantaneous time) of these variations are the same. Such as the CORS station coordinate solution time series, solid tide station observation or analysis result time series, GNSS baseline solution time series, etc.

(2) The geodetic site variation records time series

A geodetic site variation records time series file can store the time series data of one kind of variation for a group of geodetic sites. Such as the station coordinates time series for the CORS network, benchmark heights time series for the leveling network, observations time series for the tide station network, and InSAR monitoring time series, etc.

(3) The geodetic network observation records time series

A geodetic network observation records time series file can store the variation records time series of the baseline component for the CORS network, the variation records time series of the height difference for the leveling network, or the variation records time series of the gravity difference for the gravity control network.

(4) The variation grids time series for geodetic field

A group of variation grids time series files is composed of a series of numerical grid model files of one kind of variation (vector), and the seventh attribute of the header in each grid file is agreed to be the sampling epoch time. Such as the grids time series of the land equivalent water height, sea level variation, and the grids time series of various regional load-deformation fields or temporal gravity fields, etc.

(5) The spherical harmonic coefficient models time series

A group of spherical harmonic coefficient models time series files can store the time series of the spherical harmonic coefficients (Stokes' coefficients) models of the global surface load variations, global load-deformation field, or temporal global gravity field.

The header file occupies one row and consists of three attributes, namely the geocentric gravitational constant GM(×10^{14}m^3/s^2), equatorial radius of the Earth a(m), and sampling epoch time (in ETideLoad format). GM, a are the scale parameters of the model.

The degree n and order m spherical harmonic coefficients are expressed by a record with the format: degree n, order m, C_{nm}, S_{nm} (, C_{nm} error, S_{nm} error). At different sampling epochs, the maximum of the degree need not be the same.

The program [Conversion of general ASCII records data into ETideLoad format], and the function [Normalized extraction of batch time series of geodetic monitoring network] are the important interfaces for ETideLoad to accept external text data. Using the function [Global prediction of solid earth tidal effects on various geodetic quantities], or [lobal prediction of surface air pressure tidal load effects on various geodetic quantities], you can construct a geodetic variations time series with the given location and sampling specifications. Using the program [Generating and constructing of regional geodetic grid], you can construct a numerical grid with the given grid specifications. The other programs or functions only accept the format data generated by ETideLoad own.

1.5.3 Full examples for the classroom teaching and self-study exercises

To ease the classroom teaching and self-study exercises, there are the example files saved in the folder C:\ETideLoad4.0_win64en\examples for each Win64 program. Each example includes the operation process file processinf.txt, some input-output data files and screenshots. The folder name of the example files is the same as the name of the window executable program.

Before using the ETideLoad4.0 programs, it is recommended to perform completely the program example using the input-output example data files by comparing the screenshots according to the process information in processinf.txt. It will take about 5 working days to complete all the example exercises. Thereafter, you can use ETideLoad4.0 alone.

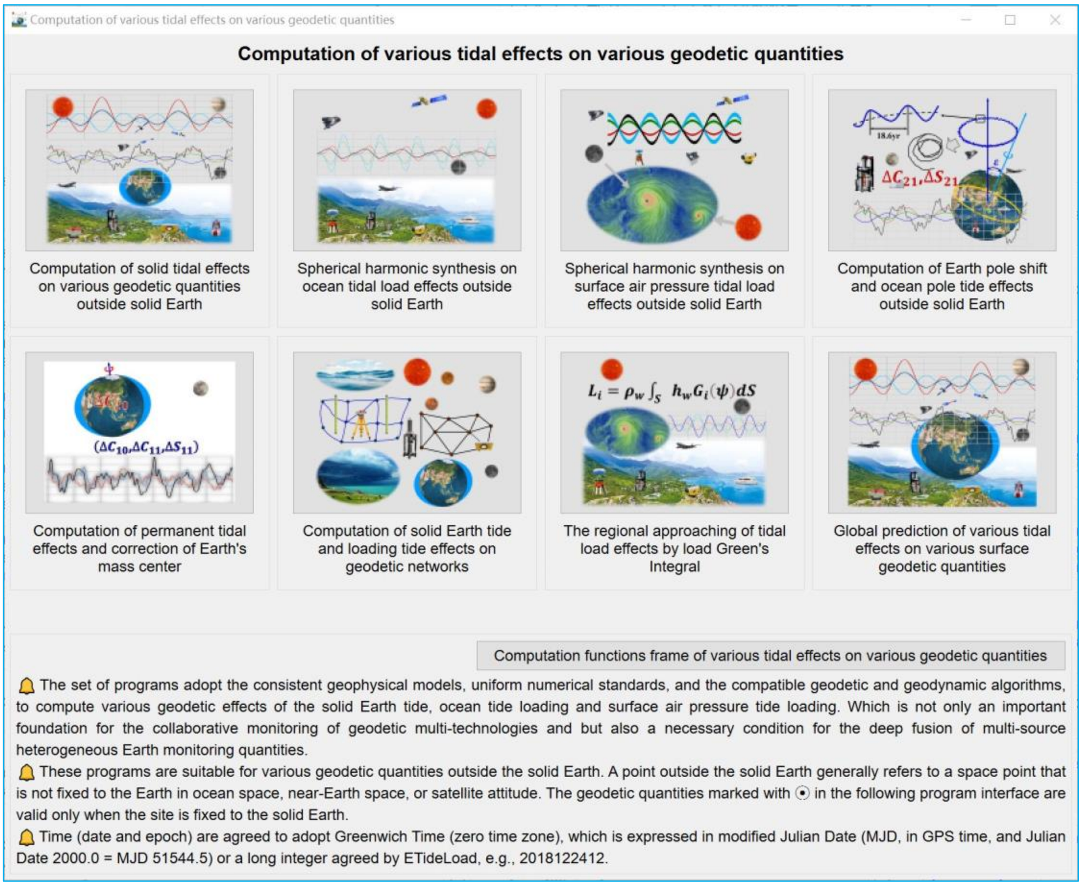
1.5.4 ETideLoad4.0's applicable professional fields and usage instructions

ETideLoad4.0 is suitable for senior undergraduates, graduate students, scientific researchers, and engineering technicians in geodesy, geophysical, geological disasters, hydrodynamics, satellite dynamics, seismic, and geodynamics. ETideLoad4.0 considers various potential needs such as classroom teaching, independent self-study, applied computing and scientific research.

You can design your own schemes and processes, then organize flexibly the related programs and functions from ETideLoad4.0, perform some scientific computations for various tidal or non-tidal effects, ground deformation field or temporal gravity field, land water, ground stability, or surface dynamic environment monitoring, and multi-source heterogeneous geodetic data deep fusion.

2 Computation of various tidal effects on various geodetic quantities

The set of programs adopt the consistent geophysical models, uniform numerical standards, and the compatible geodetic and geodynamic algorithms, to compute various geodetic effects of the solid Earth tide, ocean tide loading and surface air pressure tide loading. Which is not only an important foundation for the collaborative monitoring of geodetic multi-technologies and but also a necessary condition for the deep fusion of multi-source heterogeneous Earth monitoring quantities.



These programs are suitable for various geodetic quantities outside the solid Earth. A point outside the solid Earth generally refers to a space point that is not fixed to the Earth in ocean space, near-Earth space, or satellite altitude. The geodetic quantities marked with ⦿ in the following program interface are valid only when the site is fixed to the solid Earth.

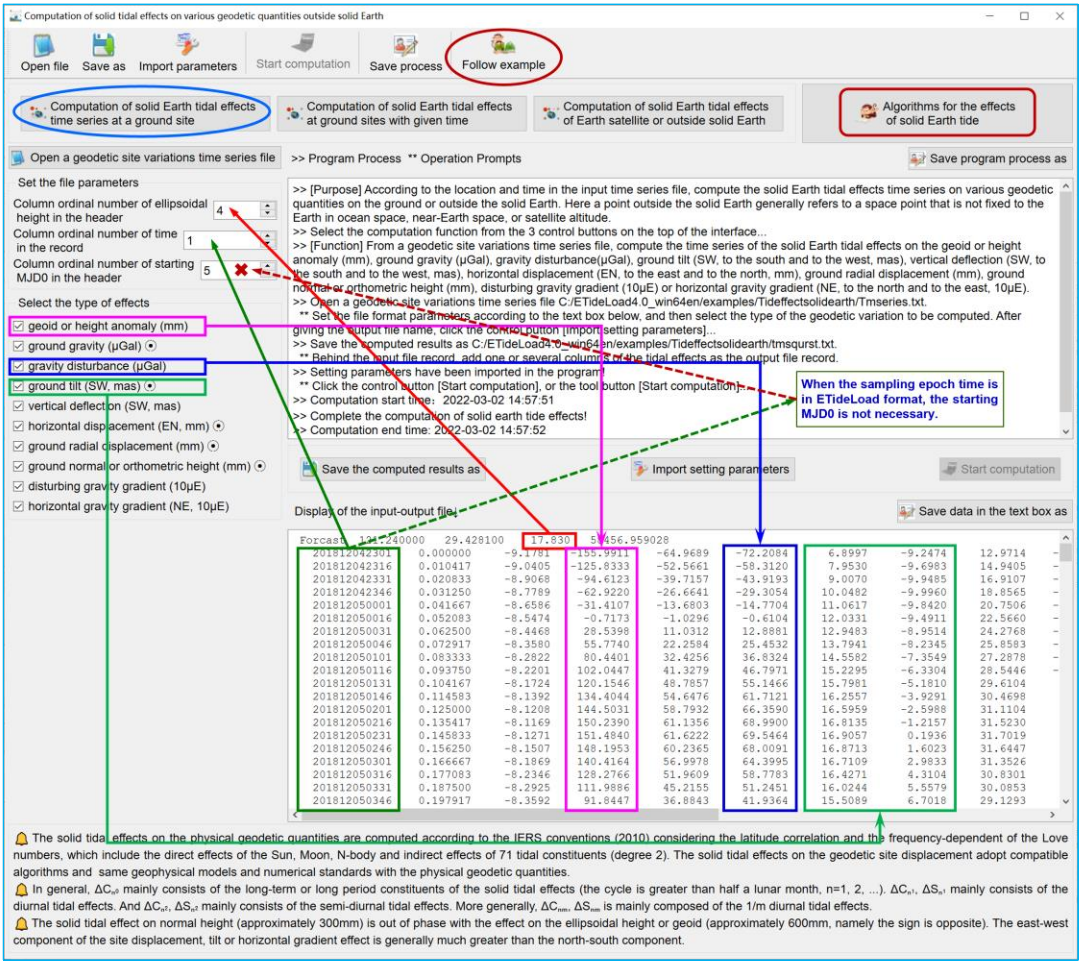
2.1 Computation of solid tidal effects on various geodetic quantities outside solid Earth

[Purpose] According to the location and time in the input time series file, compute the solid Earth tidal effects time series on various geodetic quantities on the ground or outside the solid Earth. Here a point outside the solid Earth generally refers to a space point that is not fixed to the Earth in ocean space, near-Earth space, or satellite altitude.

The solid tidal effects on the physical geodetic quantities are computed according to the IERS conventions (2010) considering the latitude correlation and the frequency-dependent of the Love numbers, which include the direct effects of the Sun, Moon, N-body and indirect effects of 71 tidal constituents (degree 2). The solid tidal effects on the geodetic site displacement adopt compatible algorithms and same geophysical models and numerical standards with the physical geodetic quantities.

2.1.1 Computation of solid Earth tidal effects time series at a ground site

[Function] From a geodetic site variations time series file, compute the time series of the solid Earth tidal effects on the geoid or height anomaly (mm), ground gravity (μGal), gravity disturbance (μGal), ground tilt (SW, to the south and to the west, mas), vertical deflection (SW, to the south and to the west, mas), horizontal displacement (EN, to the east and to the north, mm), ground radial displacement (mm), ground normal or orthometric height (mm), disturbing gravity gradient (10μE) or horizontal gravity gradient (NE, to the north and to the east, 10μE).



[Input file] The geodetic site variations time series file.

The file header contains site name, longitude (degree decimal), latitude (degree decimal), height (m) relative to the ellipsoidal surface, the starting MJD0 (optional)……

Starting from the second row of the file, each row record stores the sampling values of all the variations at one sampling epoch time. At least one column of the attributes in the record is the sampling epoch time.

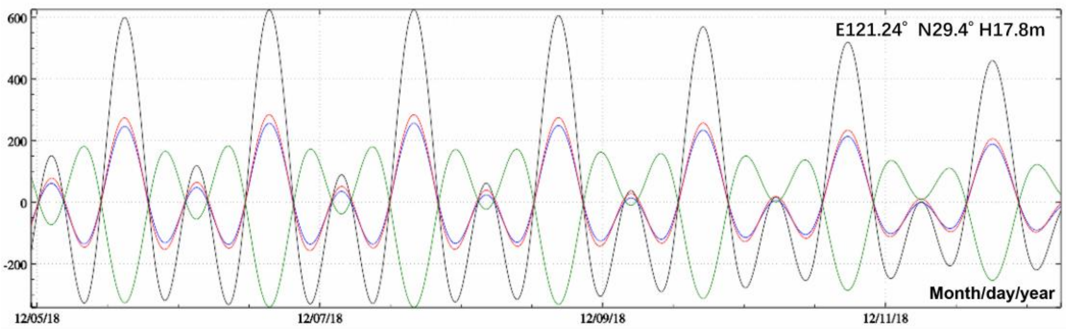
[Parameter settings] Set the input file format parameters, select the type of solid Earth tidal effects.

The geodetic quantities marked with ⊙ are valid only when the site is fixed to the solid Earth.

[Output file] The geodetic site solid Earth tidal effects time series file.

The file header is the same as the input time series file. Behind the input file record, add one or several columns of the tidal effects selected as the output file record. In this example, all types are selected, and there are 14 attributes added to the record.

When the ellipsoidal height of the computed point is equal to the ellipsoidal height of the geoid, the solid tidal effect on the height anomaly is the effect on the geoid.



The solid Earth tidal effects: height anomaly (mm), gravity (μGal), ground radial displacement (mm), ground orthometric height (mm)

2.1.2 Computation of solid Earth tidal effects at ground sites with given time

[Function] According to the location and time in the computed points file, compute the solid Earth tidal effects on the geoid or height anomaly (mm), ground gravity (μGal), gravity disturbance (μGal), ground tilt (SW, to the south and to the west, mas), vertical deflection (SW, to the south and to the west, mas), horizontal displacement (EN, to the east and to the north, mm), ground radial displacement (mm), ground normal or orthometric height (mm), disturbing gravity gradient (10μE) or horizontal gravity gradient (NE, to the north and to the east, 10μE).

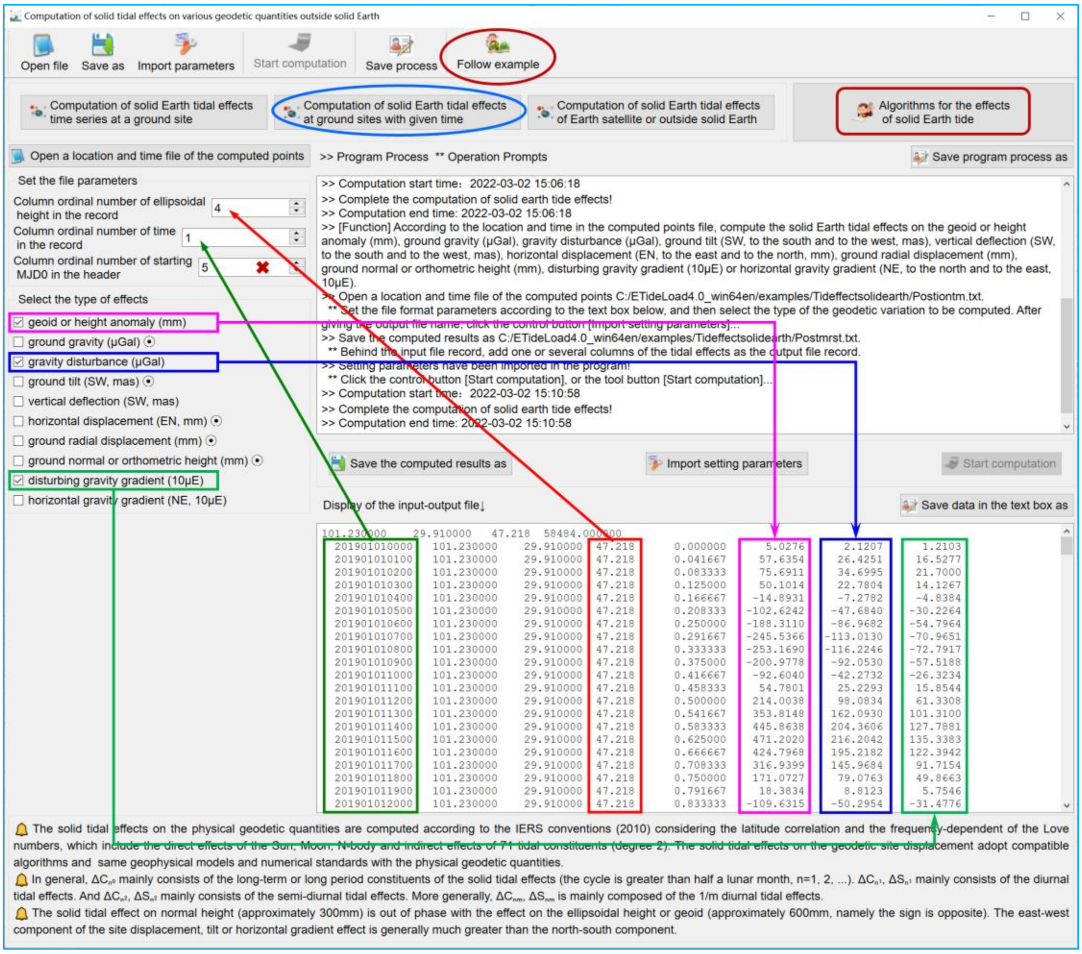
[Input file] The location and time file of the computed points.

The first row is the file header. From the second row onwards, the second and third attributes in the file record are conventionally longitude and latitude (degree decimals), and there are the sampling epoch time and ellipsoidal height attributes in the records.

[Parameter settings] Set the input file format parameters, select the type of solid Earth tidal effects.

[Output file] The solid Earth tidal effects file.

The file header is the same as the input file. Behind the input file record, add one or several columns of the tidal effects selected as the output file record. In this example, the height anomaly, gravity disturbance, and disturbing gravity gradient are selected, and there are 3 attributes added to the record.



The start MJD0 attribute in the input file header is required when the date is in MJD format. In this case, the sampling epoch MJD is equal to the sum of the starting MJD0 and the number of days in the record.

If the time (date) is in the long integer format agreed by ETideLoad, it is not necessary for the starting MJD0 attribute in the input file header, and the program automatically recognizes and ignores the selection.

2.1.3 Computation of solid Earth tidal effects of Earth satellite or outside solid Earth

[Function] According to the location and time in the external points file, compute the solid Earth tidal effects on the geopotential (0.1m²/s²), gravity (μGal) or gravity gradient (10μE) outside the solid Earth.

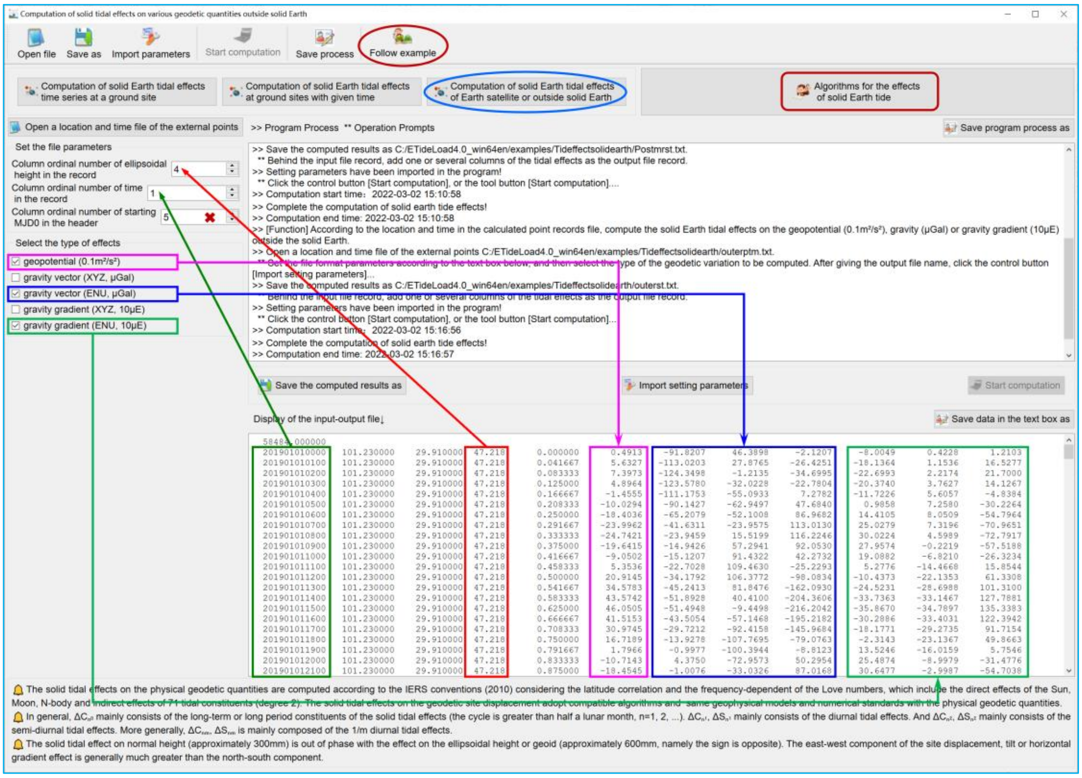
[Input file] The location and time file of the external points.

The first row is the file header. From the second row onwards, the second and third attributes in the file record are conventionally longitude and latitude (degree decimals), and there are the sampling epoch time and ellipsoidal height attributes in the records.

[Parameter settings] Set the input file format parameters, select the type of solid Earth tidal effects.

[Output file] The solid Earth tidal effects file.

The file header is the same as the input file. Behind the input file record, add one or several columns of the tidal effects selected as the output file record. In this example, the geopotential, gravity vector, and gravity gradient are selected, and there are 7 attributes added to the record.



$1+(2h_{nm}-(n+1)k_{nm})/n$ is the solid tidal effect factor of the ground gravity at degree n and order m. $1-(n+1)k_{nm}/n$ is the solid tidal effect factor of the gravity disturbance. $1+k_{nm}-h_{nm}$ is the solid tidal effect factor of the ground tilt. And $1+k_{nm}$ is the solid tidal effect factor of the vertical deflection or height anomaly.

In general, ΔC_{n0} mainly consists of the long-term or long period constituents of the solid tidal effects (the cycle is greater than half a lunar month, n=1, 2, ...). ΔC_{n1}, ΔS_{n1} mainly consists of the diurnal tidal effects. And ΔC_{n2}, ΔS_{n2} mainly consists of the semi-diurnal tidal effects. More generally, ΔC_{nm}, ΔS_{nm} is mainly composed of the 1/m diurnal tidal effects.

The solid tidal effect on normal height (approximately 300mm) is out of phase with the effect on the ellipsoidal height or geoid (approximately 600mm, namely the sign is opposite). The east-west component of the site displacement, tilt or horizontal gradient effect is generally much greater than the north-south component.

2.2 Spherical harmonic synthesis on ocean tidal load effects outside solid Earth

[Purpose] Using the global ocean tidal load spherical harmonic coefficients model (cm), according to the location and time in the input file, compute the ocean tidal load effects on various geodetic quantities on the ground or outside the solid Earth by the spherical harmonic synthesis algorithm. Here a point outside the solid Earth generally refers to a space point that is not fixed to the Earth in ocean space, near-Earth space, or satellite altitude.

2.2.1 Computation of ocean tidal load effects time series at a ground site

[Function] From a geodetic site variations time series file, compute the time series of the ocean tidal load effects on the geoid or height anomaly (mm), ground gravity (μGal), gravity disturbance (μGal), ground tilt (SW, to the south and to the west, mas), vertical deflection (SW, to the south and to the west, mas), horizontal displacement (EN, to the east and to the north, mm), ground radial displacement (mm), ground normal or orthometric height (mm), disturbing gravity gradient (10μE) or horizontal gravity gradient (NE, to the north and to the east, 10μE).

[Input file] The geodetic site variations time series file.

The file header contains site name, longitude (degree decimal), latitude (degree decimal), height (m) relative to the sea surface, the starting MJD0 (optional)……

Starting from the second row of the file, each row record stores the sampling values of all the variations at one sampling epoch time. At least one column of the attributes in the record is the sampling epoch time.

The height of the calculated point is normal or orthometric height relative to the sea surface since the ocean tidal loads are generally considered to be on the sea surface.

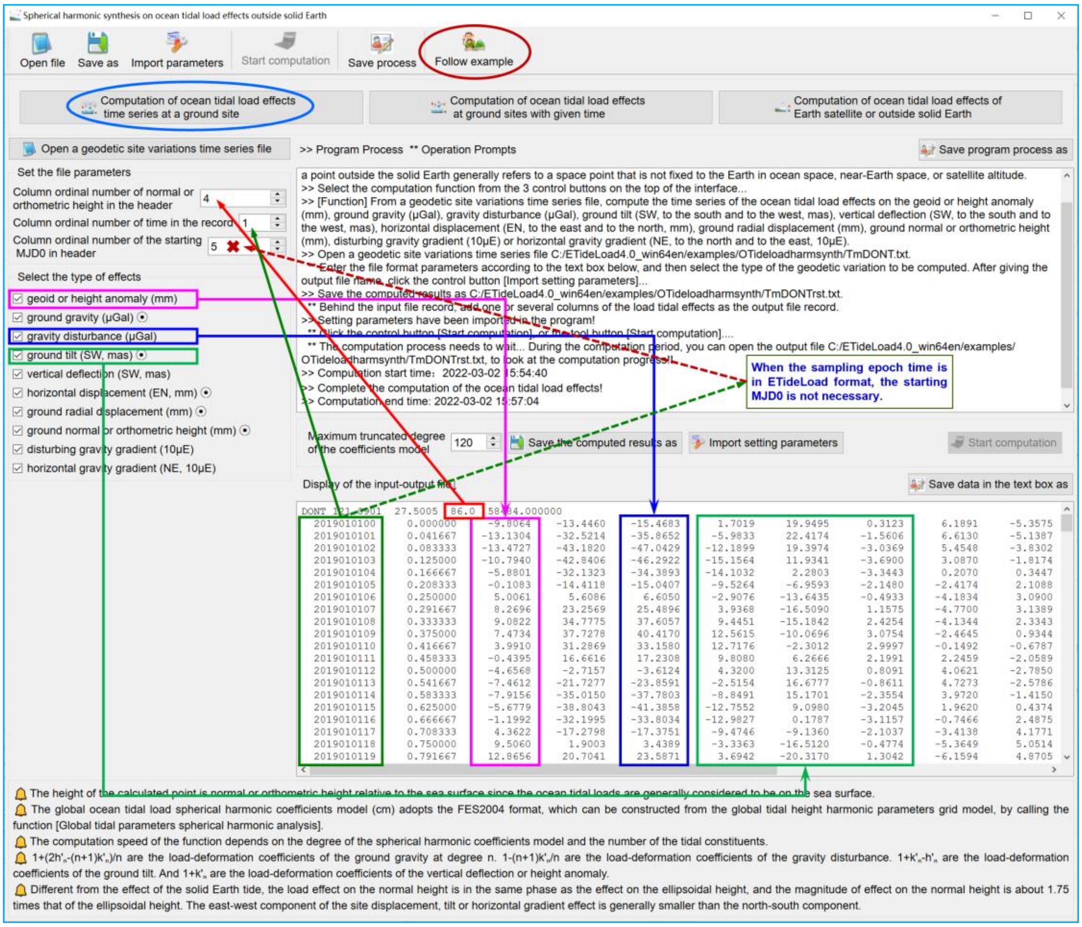
[Parameter settings] Set the input file format parameters, select the type of ocean tidal load effects.

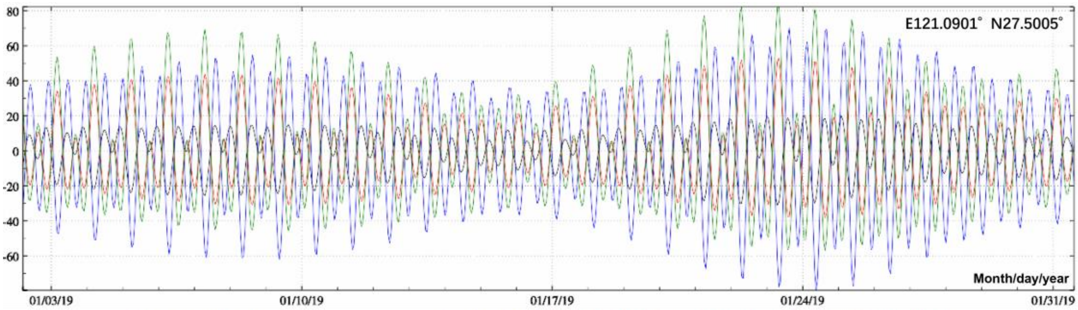
[Output file] The geodetic site ocean tidal effects time series file.

The file header is the same as the input time series file. Behind the input file record, add one or several columns of the tidal effects selected as the output file record. In this example, all types are selected, and there are 14 attributes added to the record.

The program automatically selects the minimum value between the maximum degree of the spherical harmonic coefficients model and the entered maximum degree as the calculated degree.

The computation process needs to wait. During the computation period, you can open the output file to look at the computation progress!





The ocean tidal load effects: height anomaly (mm), gravity (μGal), ground radial displacement (mm), ground orthometric height (mm)

Different from the effect of the solid Earth tide, the load effect on the normal height is in the same phase as the effect on the ellipsoidal height, and the magnitude of effect on the normal height is about 1.75 times that of the ellipsoidal height. The east-west component of the site displacement, tilt or horizontal gradient effect is generally smaller than the north-south component.

$1+(2h'_n-(n+1)k'_n)/n$ are the load-deformation coefficients of the ground gravity at degree n. $1-(n+1)k'_n/n$ are the load-deformation coefficients of the gravity disturbance. $1+k'_n-h'_n$ are the load-deformation coefficients of the ground tilt. And $1+k'_n$ are the load-deformation coefficients of the vertical deflection or height anomaly.

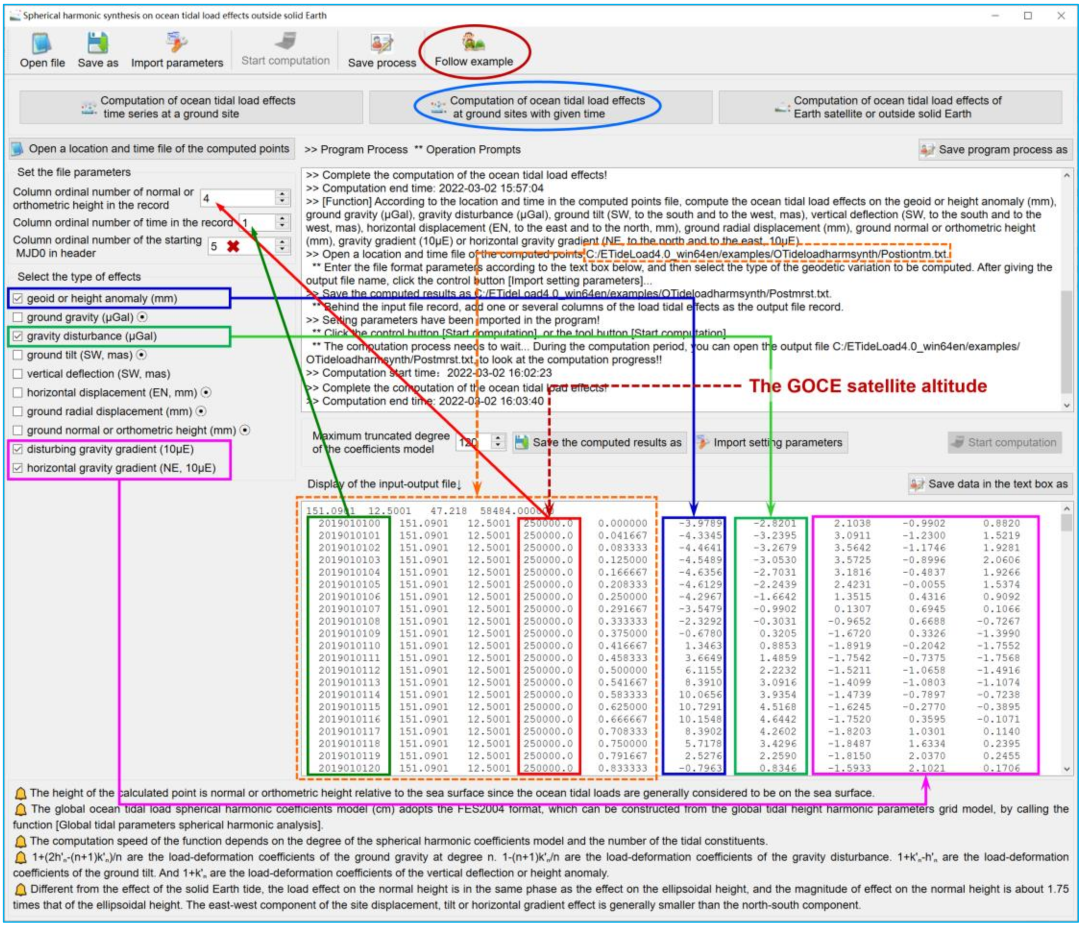
2.2.2 Computation of ocean tidal load effects at ground sites with given time

[Function] According to the location and time in the computed points file, compute the ocean tidal load effects on the geoid or height anomaly (mm), ground gravity (μGal), gravity disturbance (μGal), ground tilt (SW, to the south and to the west, mas), vertical deflection (SW, to the south and to the west, mas), horizontal displacement (EN, to the east and to the north, mm), ground radial displacement (mm), ground normal or orthometric height (mm), gravity gradient (10μE) or horizontal gravity gradient (NE, to the north and to the east, 10μE).

[Input file] The location and time file of the computed points.

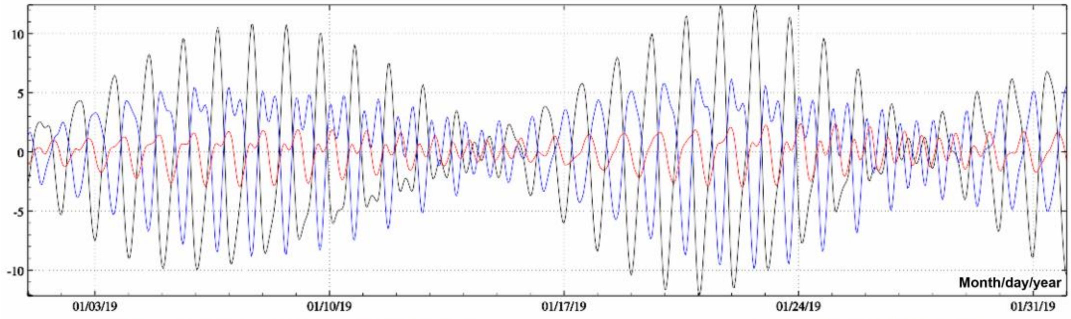
The first row is the file header. From the second row onwards, the second and third attributes in the file record are conventionally longitude and latitude (degree decimals), and there are the sampling epoch time and height attributes in the records.

[Parameter settings] Set the input file format parameters, select the type of ocean tidal load effects.



[Output file] The ocean tidal load effects file.

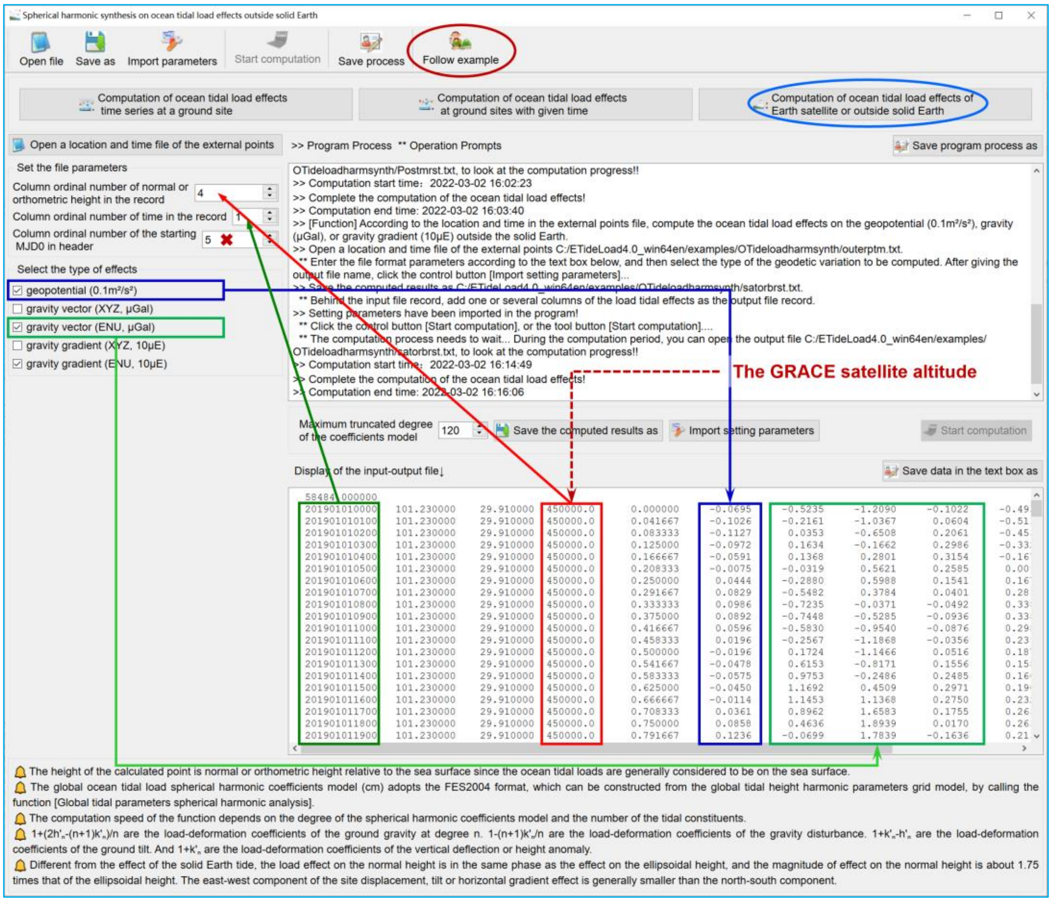
The file header is the same as the input file. Behind the input file record, add one or several columns of the tidal effects selected as the output file record. In this example, the height anomaly, gravity disturbance, disturbing gravity gradient, and horizontal gravity gradient are selected, and there are 5 attributes added to the record.



The ocean tidal load effects at 250km altitude: disturbing gravity gradient (10μE) horizontal gravity gradient (N, 10μE, along the GOCE satellite orbit) horizontal gravity gradient (E, 10μE)

2.2.3 Computation of ocean tidal load effects of Earth satellite or outside solid Earth

[Function] According to the location and time in the external points file, compute the ocean tidal load effects on the geopotential ($0.1m^2/s^2$), gravity (μGal), or gravity gradient (10μE) outside the solid Earth.



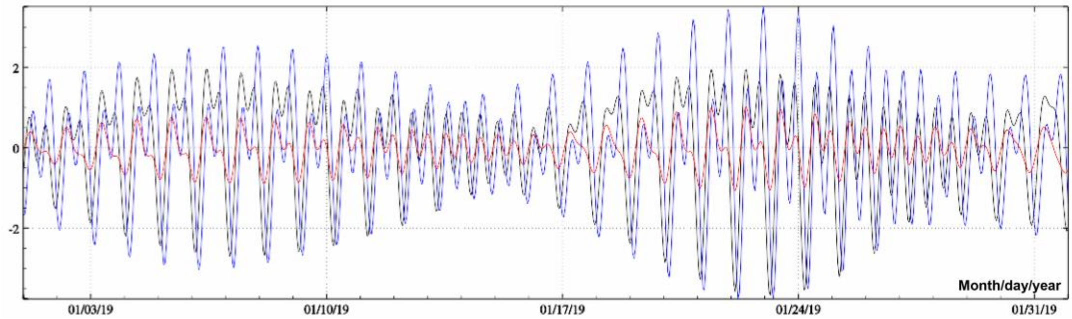
[Input file] The location and time file of the external points.

The first row is the file header. From the second row onwards, the second and third attributes in the file record are conventionally longitude and latitude (degree decimals), and there are the sampling epoch time and ellipsoidal height attributes in the records.

[Parameter settings] Set the input file format parameters, select the type of ocean tidal load effects.

[Output file] The ocean tidal load effects file.

The file header is the same as the input file. Behind the input file record, add one or several columns of the tidal effects selected as the output file record. In this example, the geopotential, gravity vector and gravity gradient are selected, and there are 7 attributes added to the record.



The ocean tidal load effects at 450km altitude: gravity vector (E, N: along the GRACE SST-II, U, μGal)

The global ocean tidal load spherical harmonic coefficients model (cm) adopts the FES2004 format, which can be constructed from the global tidal height harmonic parameters grid model, by calling the function [Global tidal parameters spherical harmonic analysis].

The computation speed of the program depends on the degree of the spherical harmonic coefficients model and the number of the tidal constituents.

The program adopts the default global ocean tidal load spherical harmonic coefficients model. You can select other global ocean tidal load spherical harmonic coefficients models by the program [geophysical model and numerical standard settings].

2.3 Spherical harmonic synthesis on air pressure tidal load effects outside solid Earth

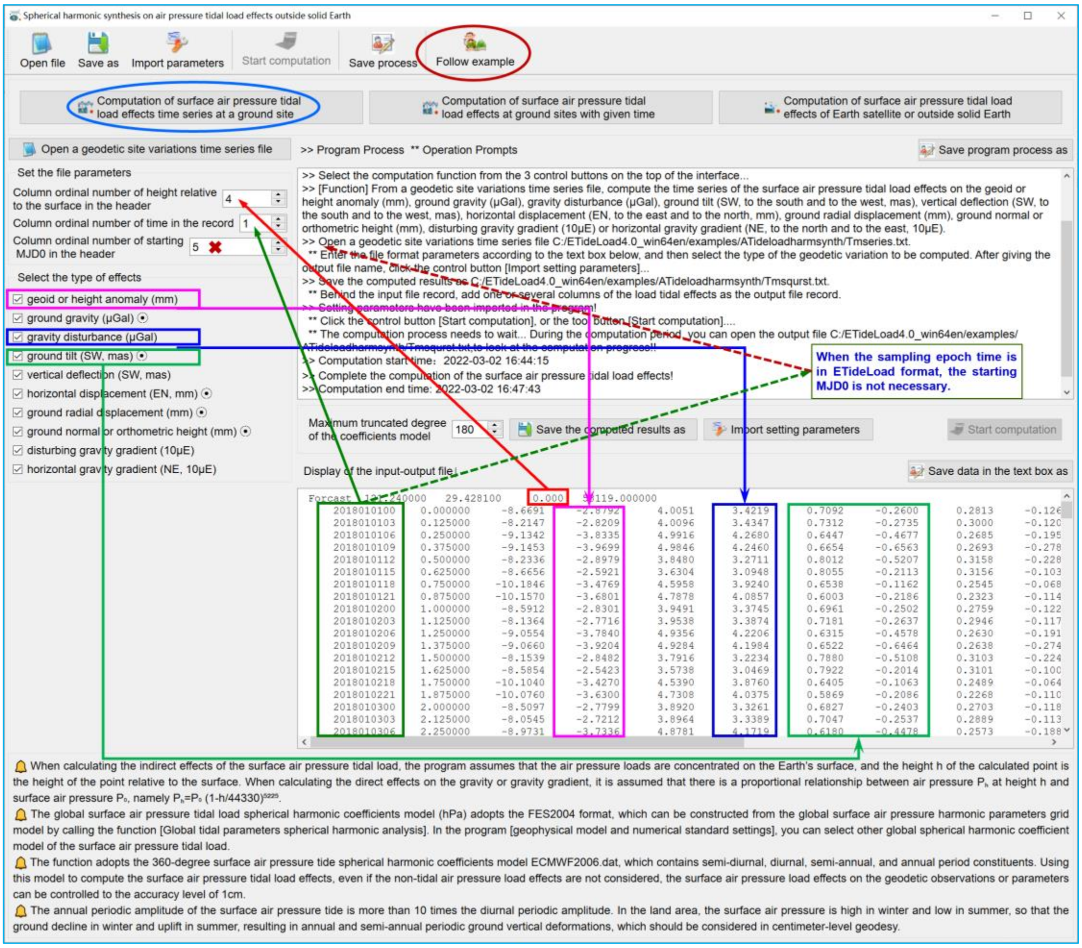
[Purpose] Using the global surface air pressure tidal load spherical harmonic coefficients model (hPa), compute the surface air pressure tidal load effects on various geodetic quantities on the ground or outside the solid Earth according to the location and time in the input file by the spherical harmonic synthesis algorithm. Here a point outside the solid Earth generally refers to a space point that is not fixed to the Earth in ocean space, near-Earth space, or satellite altitude.

The program adopts the 360-degree surface air pressure tide spherical harmonic coefficients model ECMWF2006.dat, which contains semi-diurnal, diurnal, semi-annual, and annual period constituents. Using this model to compute the surface air pressure tidal load effects, even if the non-tidal air pressure load effects are not considered, the surface air pressure load effects on the geodetic observations or parameters can be controlled to the accuracy level of 1cm.

2.3.1 Computation of surface air pressure tidal load effects time series at a ground site

[Function] From a geodetic site variations time series file, compute the time series of the surface air pressure tidal load effects on the geoid or height anomaly (mm), ground gravity (μGal), gravity disturbance (μGal), ground tilt (SW, to the south and to the west, mas), vertical deflection (SW, to the south and to the west, mas), horizontal displacement (EN, to the east and to the north, mm), ground radial displacement (mm), ground normal or orthometric height (mm), disturbing gravity gradient (10μE) or horizontal gravity gradient (NE, to the north and to the east, 10μE).

[Input file] The geodetic site variations time series file.



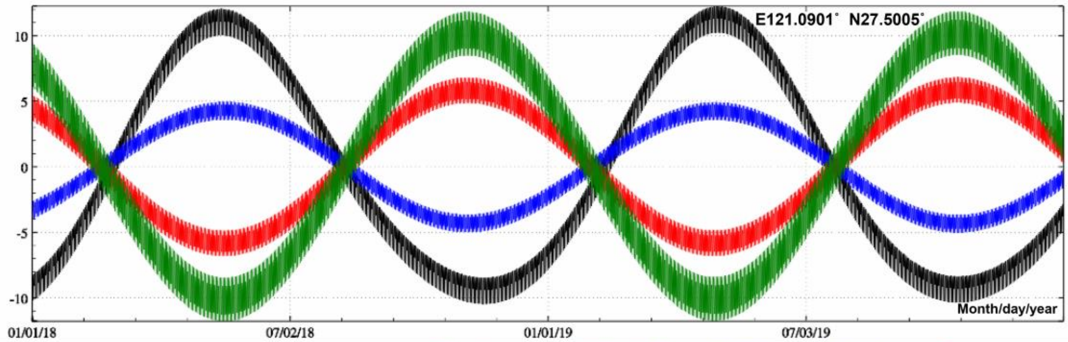
The file header contains site name, longitude (degree decimal), latitude (degree decimal), height (m), starting MJD0 (optional), …

Starting from the second row of the file, each row record stores the sampling values of all the variations at one sampling epoch time. At least one column of the attributes in the record is the sampling epoch time.

[Parameter settings] Set the input file format parameters, select the type of the surface air pressure tidal load effects.

[Output file] The geodetic site surface air pressure tidal load effects time series file.

The file header is the same as the input file. Behind the input file record, add one or several columns of the tidal effects selected as the output file record. In this example, all types are selected, and there are 14 attributes added to the record.



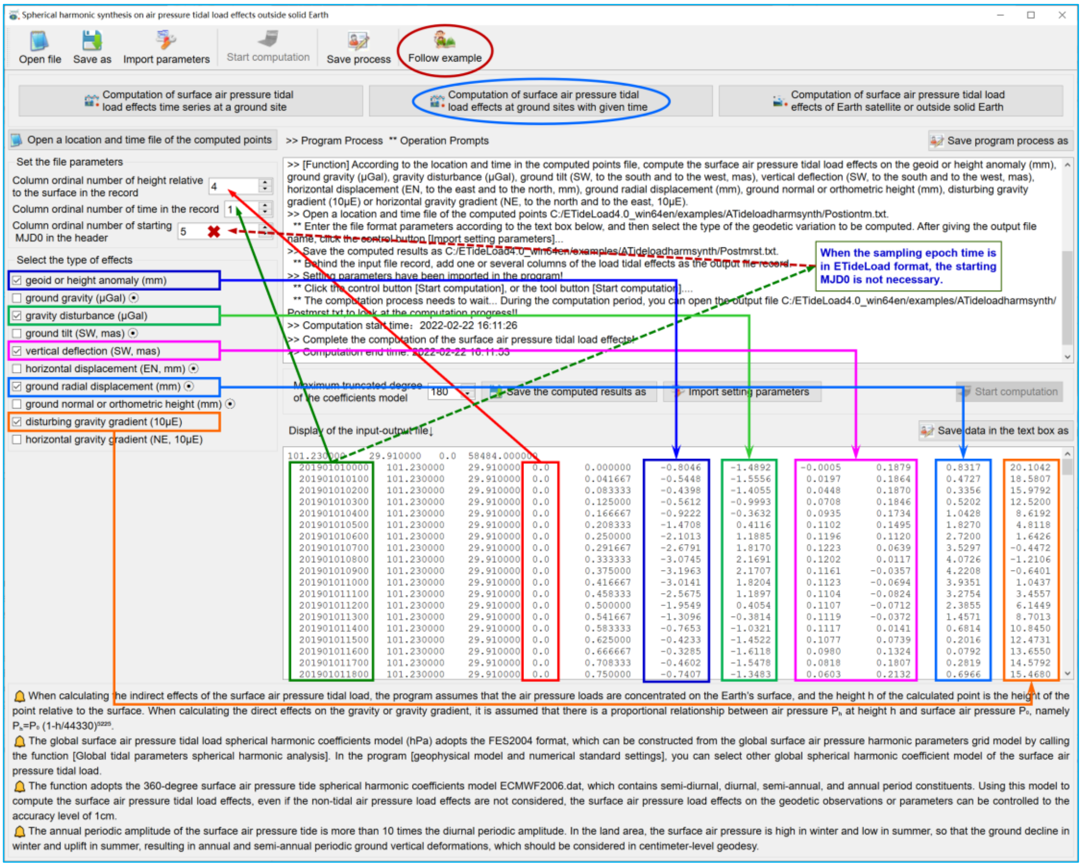
Surface air pressure tide forecast (hPa). The air pressure tidal load effects： height anomaly (mm), ground radial displacement (mm), ground orthometric height (mm)

When calculating the indirect effects of the surface air pressure tidal load, the program assumes that the air pressure loads are concentrated on the Earth's surface, and the height h of the calculated point is the height of the point relative to the surface. When calculating the direct effects on the gravity or gravity gradient, it is assumed that there is a proportional relationship between air pressure P_h at height h and surface air pressure P_0, namely $P_h=P_0(1-h/44330)^{5225}$.

The global surface air pressure tidal load spherical harmonic coefficients model (hPa) adopts the FES2004 format, which can be constructed from the global surface air pressure harmonic parameters grid model by calling the function [Global tidal parameters spherical harmonic analysis]. In the program [geophysical model and numerical standard settings], you can select other global spherical harmonic coefficient model of the surface air pressure tidal load.

2.3.2 Computation of surface air pressure tidal load effects at ground sites with given time

[Function] According to the location and time in the computed points file, compute the surface air pressure tidal load effects on the geoid or height anomaly (mm), ground gravity (μGal), gravity disturbance (μGal), ground tilt (SW, to the south and to the west, mas), vertical deflection (SW, to the south and to the west, mas), horizontal displacement (EN, to the east and to the north, mm), ground radial displacement (mm), ground normal or orthometric height (mm), disturbing gravity gradient (10μE) or horizontal gravity gradient (NE, to the north and to the east, 10μE).



2.3.3 Computation of surface air pressure tidal load effects of satellite or outside Earth

[Function] According to the location and time in the external points file, compute the surface air pressure tidal load effects on the geopotential (0.1m²/s²), gravity(μGal), or gravity gradient (10μE) outside the solid Earth.

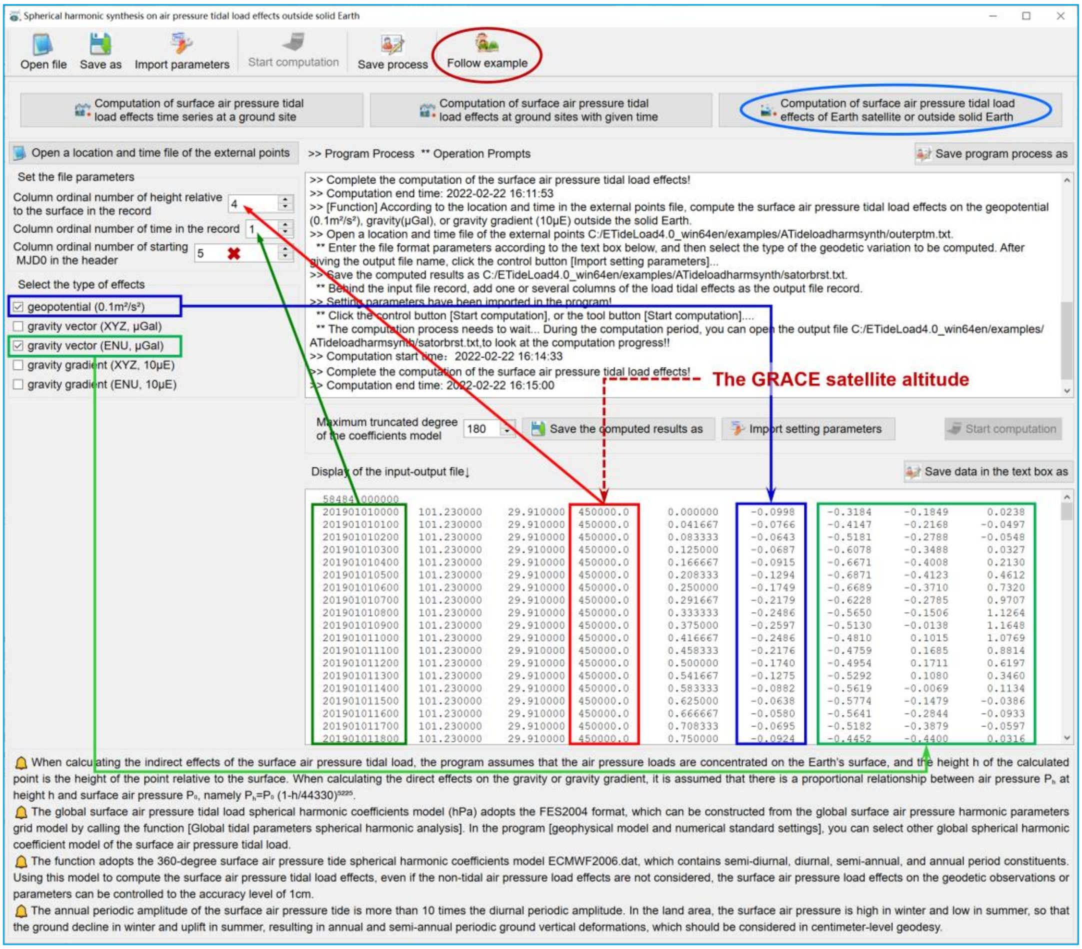
[Input file] The location and time file of the external points.

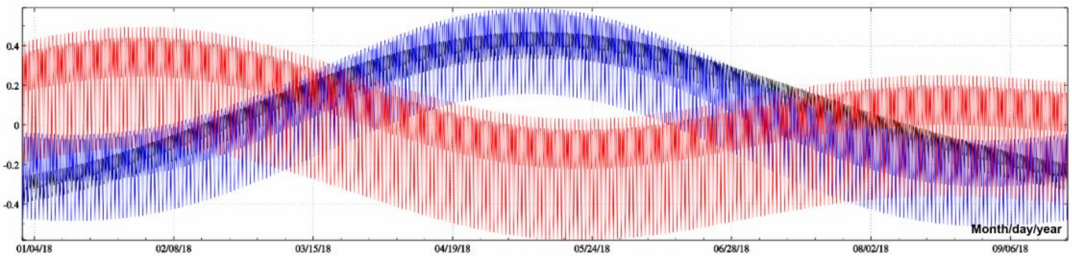
The first row is the file header. From the second row onwards, the second and third attributes in the file record are conventionally longitude and latitude (degree decimals), and there are the sampling epoch time and height attributes in the records.

[Parameter settings] Set the input file format parameters, select the type of ocean tidal load effects.

[Output file] The surface air pressure tidal load effects file.

The file header is the same as the input file. Behind the input file record, add one or several columns of the tidal effects selected as the output file record. In this example, the geopotential and gravity vector are selected, and there are 4 attributes added to the record.





The air pressure tidal load effects at 450km altitude: geopotential (0.1m²/s²), gravity (μGal, E), gravity (μGal, N, along the GRACE SST-II)

The annual periodic amplitude of the surface air pressure tide is more than 10 times the diurnal periodic amplitude. In the land area, the surface air pressure is high in winter and low in summer, so that the ground decline in winter and uplift in summer, resulting in annual and semi-annual periodic ground vertical deformations, which should be considered in centimeter-level geodesy.

The surface air pressure tidal load effects on the east-west component of the site displacement, tilt or horizontal gradient are generally smaller than that on the north-south component.

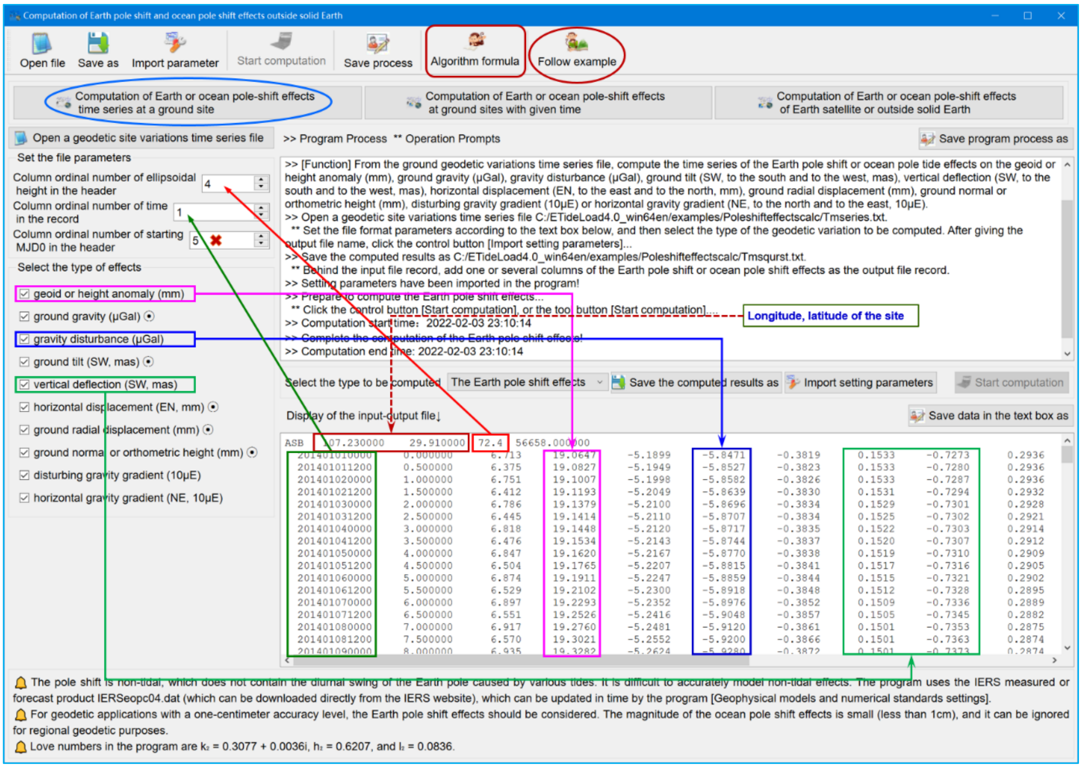
2.4 Computation of Earth pole shift and ocean pole tide effects outside solid Earth

[Purpose] Using IERS Earth orientation parameters (EOP) product file IERSeopc04.dat, compute the Earth pole shift and ocean pole tide effects on various geodetic quantities on the ground or outside the solid Earth according to the location and time in the input file.

2.4.1 Computation of pole shift or ocean pole tide effects time series at a ground site

[Function] From the geodetic site variations time series file, compute the time series of the Earth pole shift or ocean pole tide effects on the geoid or height anomaly (mm), ground gravity (μGal), gravity disturbance (μGal), ground tilt (SW, to the south and to the west, mas), vertical deflection (SW, to the south and to the west, mas), horizontal displacement (EN, to the east and to the north, mm), ground radial displacement (mm), ground normal or orthometric height (mm), disturbing gravity gradient (10μE) or horizontal gravity gradient (NE, to the north and to the east, 10μE).

[Input file] The geodetic site variations time series file.



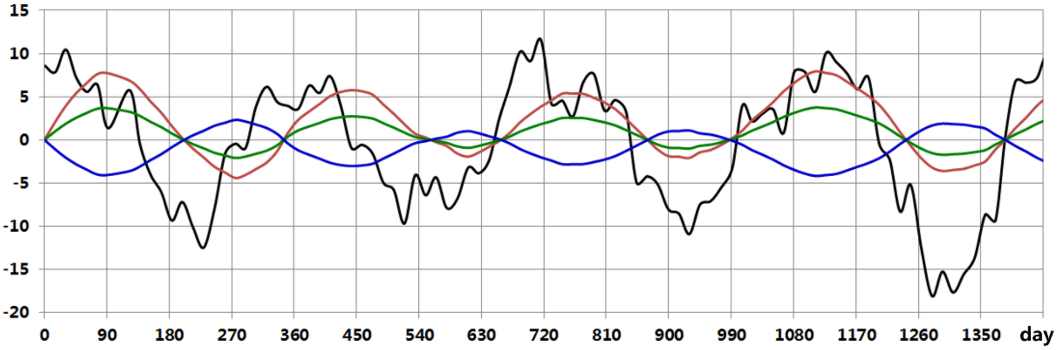
The file header contains site name, longitude (degree decimal), latitude (degree decimal), ellipsoidal height (m), starting MJD0 (optional), …

Starting from the second row of the file, each row record stores the sampling values of all the variations at one sampling epoch time. At least one column of the attributes in the record is the sampling epoch time.

[Parameter settings] Set the input file format parameters, select the type of the pole shift or ocean pole tide effects.

[Output file] The geodetic site Earth or ocean pole-shift effects time series file.

The file header is the same as the input file. Behind the input file record, add one or several columns of the tidal effects selected as the output file record. In this example, all types are selected, and there are 14 attributes added to the record.



Half-month mean (mm) of ellipsoidal height on CORS station

The effects of the Earth pole shift: Height anomaly (mm) Ellipsoidal height (mm) Normal height(mm)

Love numbers in the program are $k_2 = 0.3077 + 0.0036i$, $h_2 = 0.6207$, and $l_2 = 0.0836$.

If the epoch time to be calculated exceeds the time range of the Earth orientation parameters time series file, please update the parameters time series file.

The pole shift is non-tidal, which does not contain the diurnal swing of the Earth pole caused by various tides. It is difficult to accurately model the non-tidal effects. The program adopts the IERS measured or forecast product IERSeopc04.dat (which can be downloaded directly from the IERS website), which can be updated in time by the program [Geophysical models and numerical standards settings].

2.4.2 Computation of pole shift or ocean pole tide effects at ground sites with given time

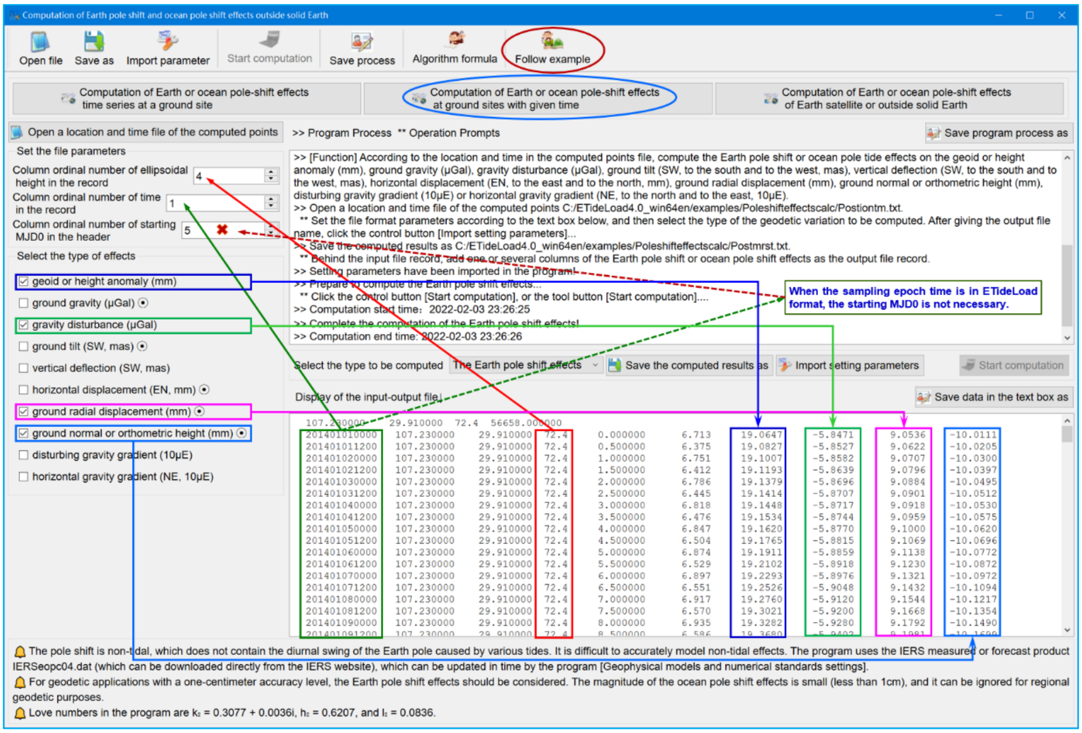
[Function] According to the location and time in the computed points file, compute the Earth pole shift or ocean pole tide effects on the geoid or height anomaly (mm), ground gravity (μGal), gravity disturbance (μGal), ground tilt (SW, to the south and to the west, mas), vertical deflection (SW, to the south and to the west, mas), horizontal displacement (EN, to the east and to the north, mm), ground radial displacement (mm), ground normal or orthometric height (mm), disturbing gravity gradient (10μE) or horizontal gravity gradient (NE, to the north and to the east, 10μE).

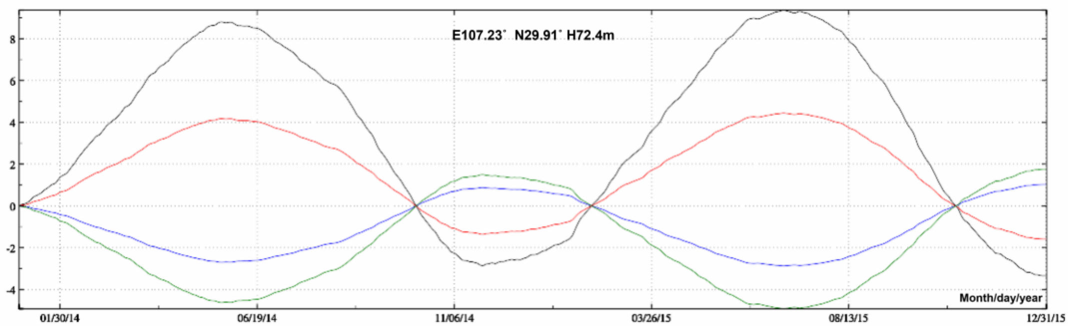
[Input file] The location and time file of the computed points.

The first row is the file header. From the second row onwards, the second and third attributes in the file record are conventionally longitude and latitude (degree decimals), and there are the sampling epoch time and ellipsoidal height attributes in the records.

[Parameter settings] Set the input file format parameters, and select the type of the effects.

[Output file] The Earth pole shift or ocean pole tide effects file.





The effects of the Earth pole shift: Height anomaly (mm) Gravity disturbance (μGal) Ellipsoidal height (mm) Normal height(mm)

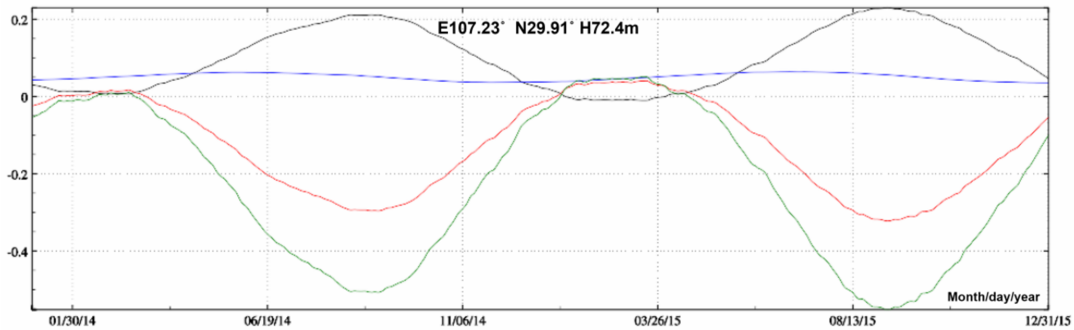
The file header is the same as the input file. Behind the input file record, add one or several columns of the Earth pole shift or ocean pole tide effects selected as the output file record. In this example, select to compute the Earth pole shift effects, and the height anomaly, gravity disturbance, ground radial displacement and ground normal or orthometric height are selected, and there are 4 attributes added to the record.

2.4.3 Computation of pole shift or ocean pole tide effects of satellite or outside solid Earth

[Function] According to the location and time in the external points file, compute the

Earth pole shift or ocean pole tide effects on the geopotential ($0.1m^2/s^2$), gravity(μGal), or gravity gradient(10μE) outside the solid Earth.

For geodetic applications with a one-centimeter accuracy level, the Earth pole shift effects should be considered. The magnitude of the ocean pole shift effects is small (less than 1cm), and it can be ignored for regional geodetic purposes.



The effects of the ocean pole tide: Height anomaly (mm) Gravity disturbance (μGal) Ellipsoidal height (mm) Normal height(mm)

2.5 Computation of permanent tidal effects and correction of Earth's mass center

[Purpose] Compute the permanent tidal effects on various geodetic quantities and the geocentric correction for the coordinates of the ground site.

When calculating the permanent tidal effects, input the geodetic discrete point records file, and when calculating the center of mass correction, input the ground site coordinates file with the epoch time.

2.5.1 Computation of permanent tidal effects on various geodetic quantities

[Function] According to the location in the calculated point records file, compute the permanent tidal effects on the geoid or height anomaly (mm), ground gravity (μGal), gravity disturbance (μGal), ground tilt (SW, to the south and to the west, mas), vertical deflection (SW, to the south and to the west, mas), horizontal displacement (EN, to the east and to the north, mm), ground radial displacement (mm), ground normal or orthometric height (mm), disturbing gravity gradient (10μE) or horizontal gravity gradient (NE, to the north and to the east, 10μE).

[Input file] The computed geodetic point records file.

Multi-row file headers are allowed with unlimited content and format.

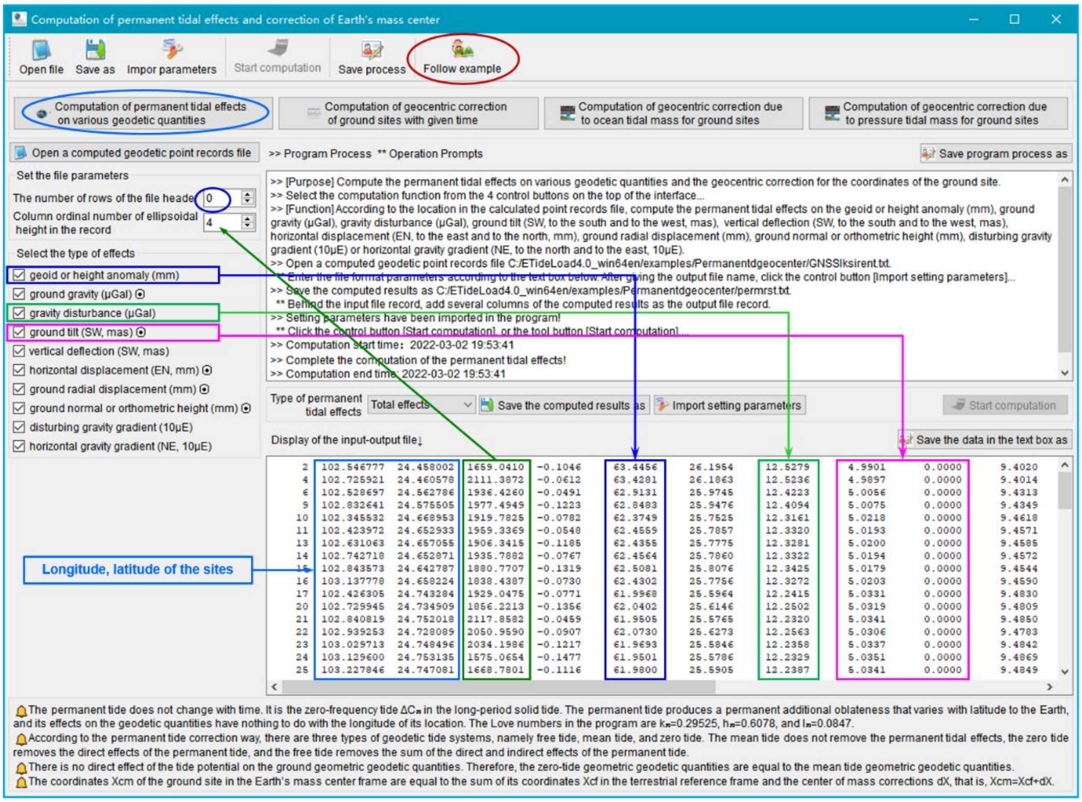
A row of record represents geodetic data for a site. Attributes for each record include site number (name), longitude (degree decimal), latitude (degree decimal), …. There is an ellipsoid height attribute in the record.

[Parameter settings] Set the input file format parameters, select the type of permanent tidal effects.

[Output file] The permanent tidal effects file.

The file header is the same as the input file. Behind the input file record, add one or several columns of the permanent tidal effects selected as the output file record. In this example, all types are selected, and there are 14 attributes added to the record.

The permanent tide does not change with time. It is the zero-frequency tide ΔC_{20} in the long-period solid tide. The permanent tide produces a permanent additional oblateness that varies with latitude to the Earth, and its effects on the geodetic quantities have nothing to do with the longitude of its location.



The Love numbers in the program are k_{20}=0.29525, h_{20}=0.6078, and l_{20}=0.0847.

According to the permanent tide correction way, there are three types of geodetic tide systems, namely free tide, mean tide, and zero tide. The mean tide does not remove the permanent tidal effects, the zero tide removes the direct effects of the permanent tide, and the free tide removes the sum of the direct and indirect effects of the permanent tide.

There is no direct effect of the tide potential on the ground geometric geodetic quantities. Therefore, the zero-tide geometric geodetic quantities are equal to the mean tide geometric geodetic quantities.

2.5.2 Computation of geocentric correction of ground sites with given time

[Function] According to the location and time in the ground site records file, compute the correction (ENU, mm) of Earth center of mass for the coordinates of the ground site using the SLR geocentric motion measurement or prediction parameters time series.

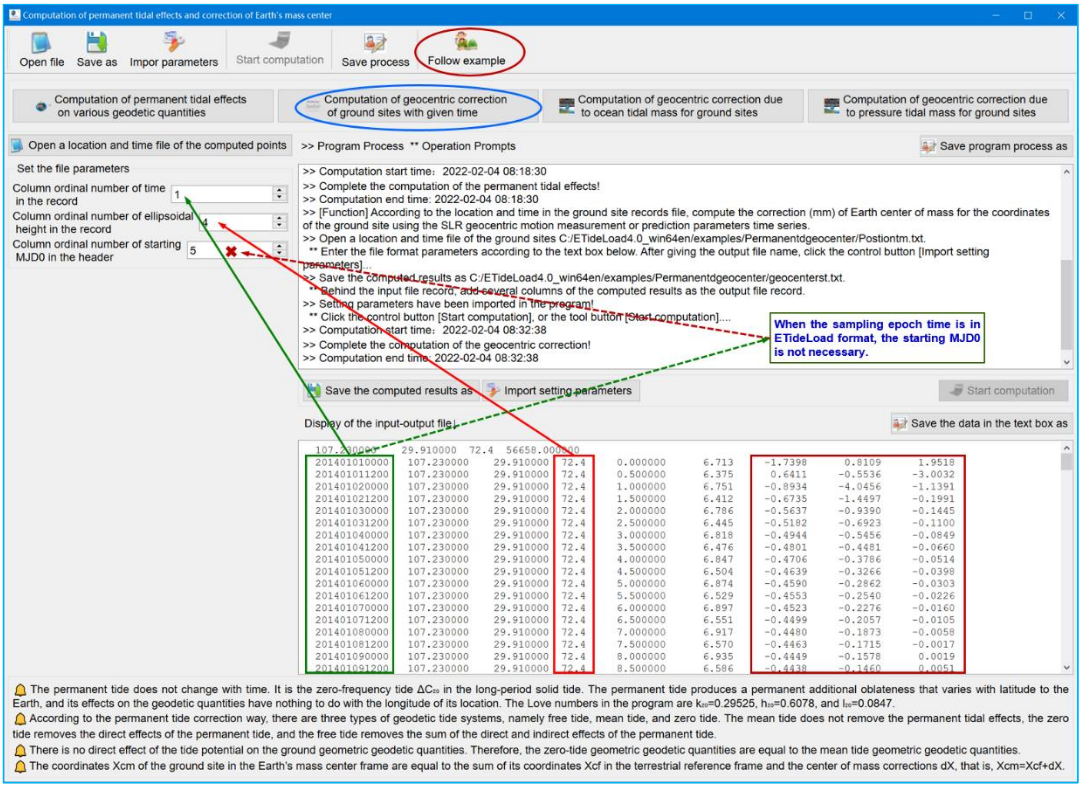
[Input file] The location and time file of the computed points.

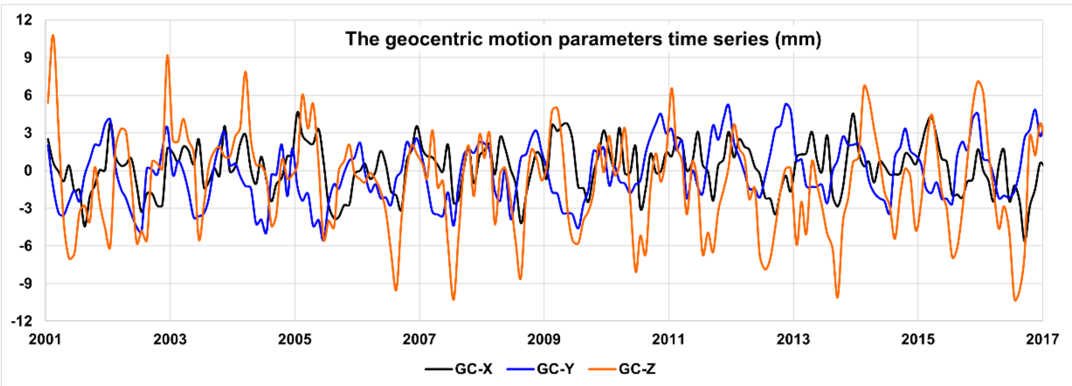
The first row is the file header. From the second row onwards, the second and third attributes in the file record are conventionally longitude and latitude (degree decimals), and there are the sampling epoch time and ellipsoidal height attributes in the records.

[Parameter settings] Set the input file format parameters.

[Output file] The correction of Earth center of mass file.

The file header is the same as the input file. Behind the input file record, add 3 columns of the correction of Earth center of mass as the output file record.





Geocentric motion is non-tidal, which can be represented by the degree 1 geopotential coefficient variations (ΔC_{10}, ΔC_{11}, ΔS_{11}). Physical geodetic observations do not contain geocentric motion information, and the corrections of the center of mass are only for the coordinates of the ground site.

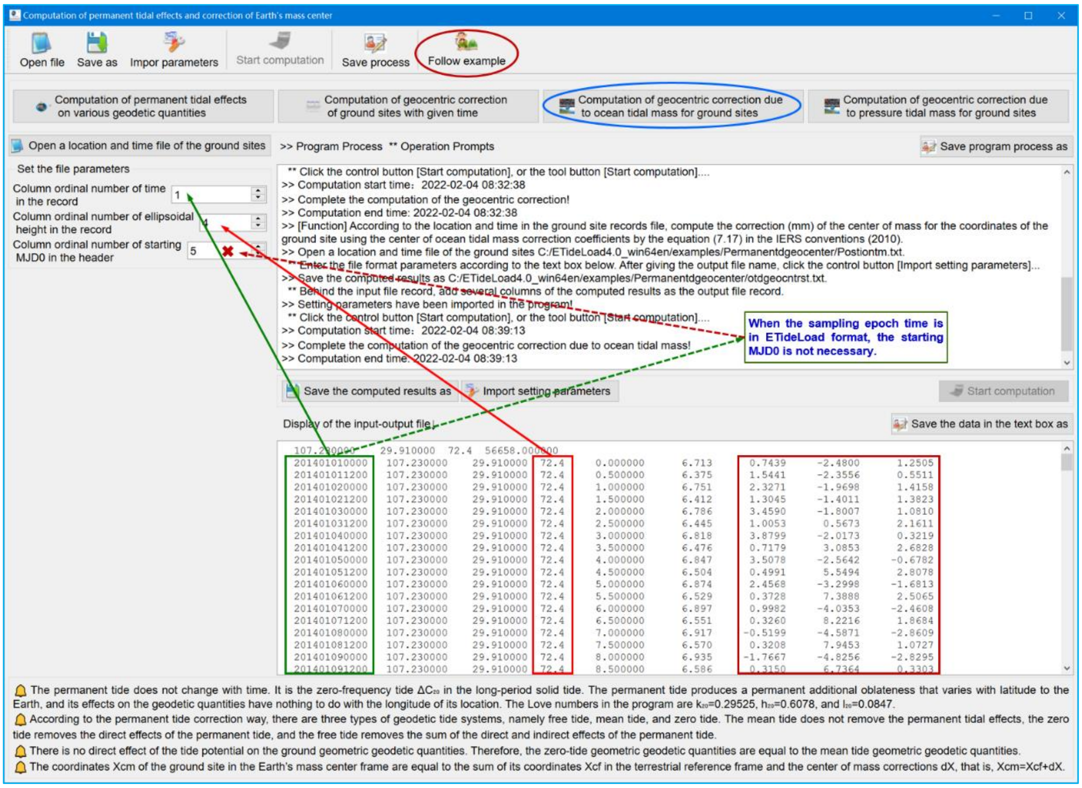
The coordinates Xcm of the ground site in the Earth's mass center frame are equal to the sum of its coordinates Xcf in the terrestrial reference frame and the center of mass corrections dX, that is, Xcm=Xcf+dX.

If the epoch time to be calculated exceeds the time range of the SLR geocentric motion parameters time series, please update the parameters time series file.

2.5.3 Computation of geocentric correction due to ocean tidal mass for ground sites

[Function] According to the location and time in the ground site records file, compute the correction (ENU, mm) of the center of mass for the coordinates of the ground site using the center of ocean tidal mass correction coefficients by the equation (7.17) in the IERS conventions (2010).

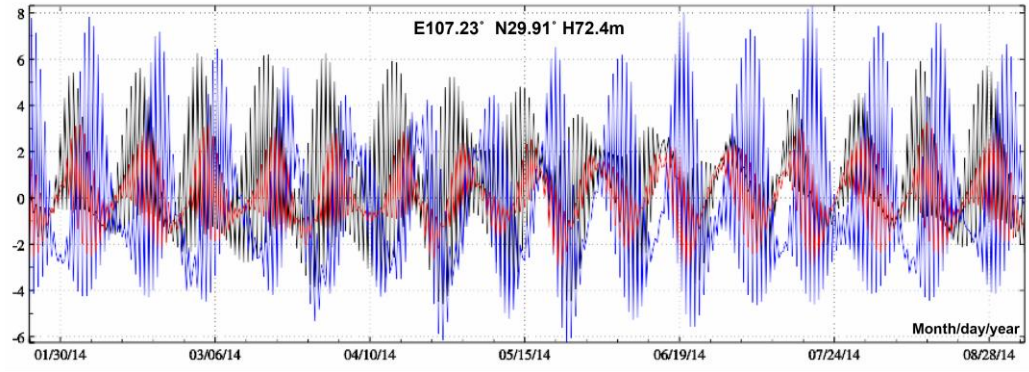
[Input file] The location and time file of the computed points. The Desai ocean pole tide coefficients file (automatically called by the program without manual input, can be updated from the program [geophysical models and numerical standards settings]).



[Parameter settings] Set the input file format parameters.

[Output file] The geocentric correction due to ocean tidal mass file.

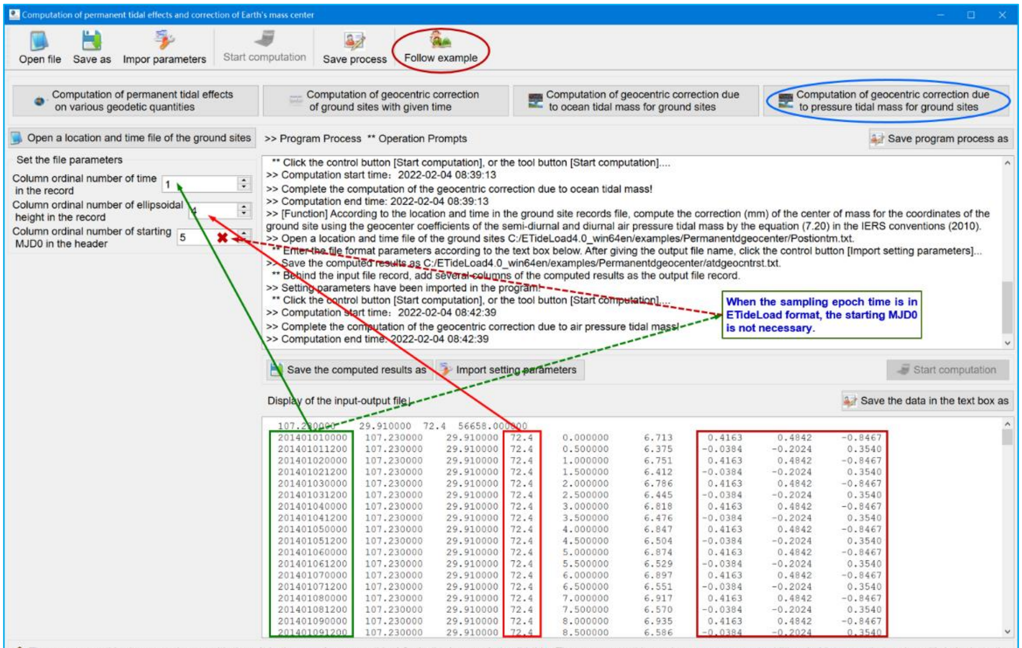
The file header is the same as the input file. Behind the input file record, add 3 columns of the geocentric correction due to ocean tidal mass as the output file record.



The geocentric correction due to ocean tidal mass: East (mm), North (mm), radial displacement (mm)

2.5.4 Computation of geocentric correction due to pressure tidal mass for ground sites

[Function] According to the location and time in the ground site records file, compute the correction (mm) of the center of mass for the coordinates of the ground site using the geocenter coefficients of the semi-diurnal and diurnal air pressure tidal mass by the equation (7.20) in the IERS conventions (2010).



The permanent tide does not change with time. It is the zero-frequency tide ΔC_{20} in the long-period solid tide. The permanent tide produces a permanent additional oblateness that varies with latitude to the Earth, and its effects on the geodetic quantities have nothing to do with the longitude of its location. The Love numbers in the program are k_{20}=0.29525, h_{20}=0.6078, and l_{20}=0.0847.

According to the permanent tide correction way, there are three types of geodetic tide systems, namely free tide, mean tide, and zero tide. The mean tide does not remove the permanent tidal effects, the zero tide removes the direct effects of the permanent tide, and the free tide removes the sum of the direct and indirect effects of the permanent tide.

There is no direct effect of the tide potential on the ground geometric geodetic quantities. Therefore, the zero-tide geometric geodetic quantities are equal to the mean tide geometric geodetic quantities.

The coordinates Xcm of the ground site in the Earth's mass center frame are equal to the sum of its coordinates Xcf in the terrestrial reference frame and the center of mass corrections dX, that is, Xcm=Xcf+dX.

2.6 Computation of solid Earth tide and loading tide effects on geodetic networks

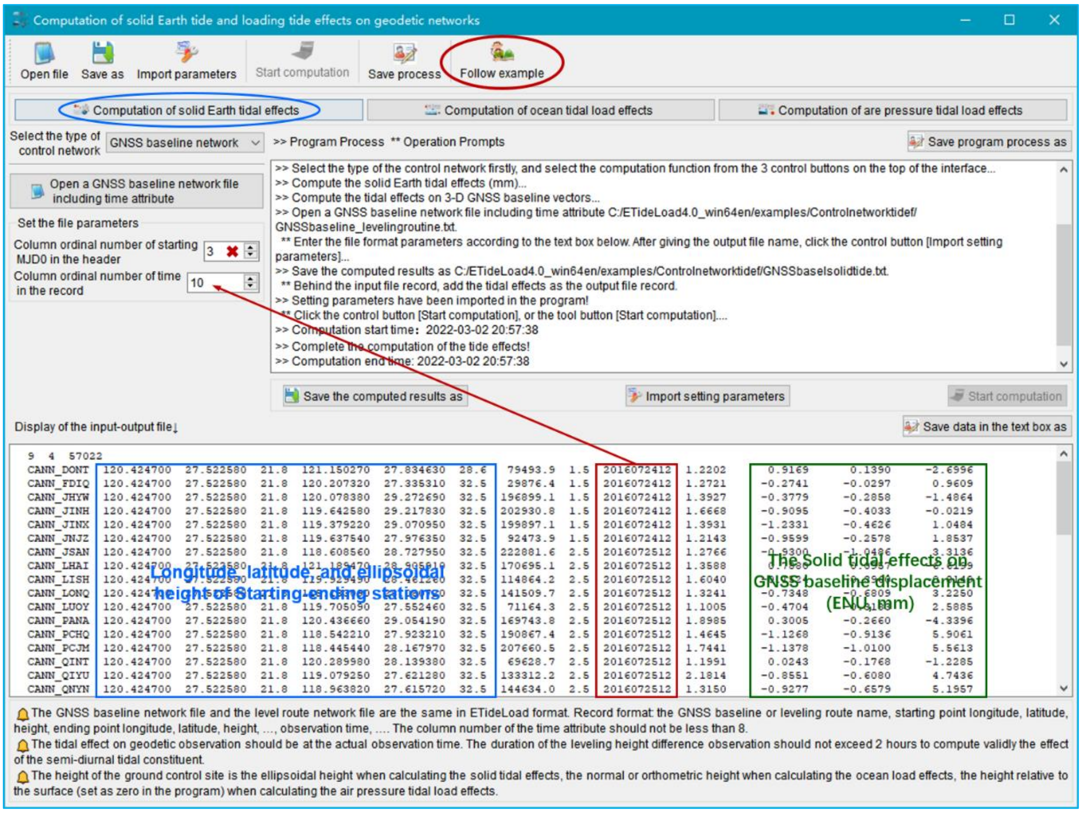
[Purpose] Compute the solid Earth, ocean load, or air pressure load tidal effects on the GNSS baseline or level height difference according to the location and observation time in the input geodetic control network records file.

[Input file] Geodetic network observation records file.

The GNSS baseline network file and the level route network file are the same in ETideLoad format.

The first row is the file header. The record format: the GNSS baseline or leveling route name, starting point longitude, latitude, height, ending point longitude, latitude, height, …, observation time, ….

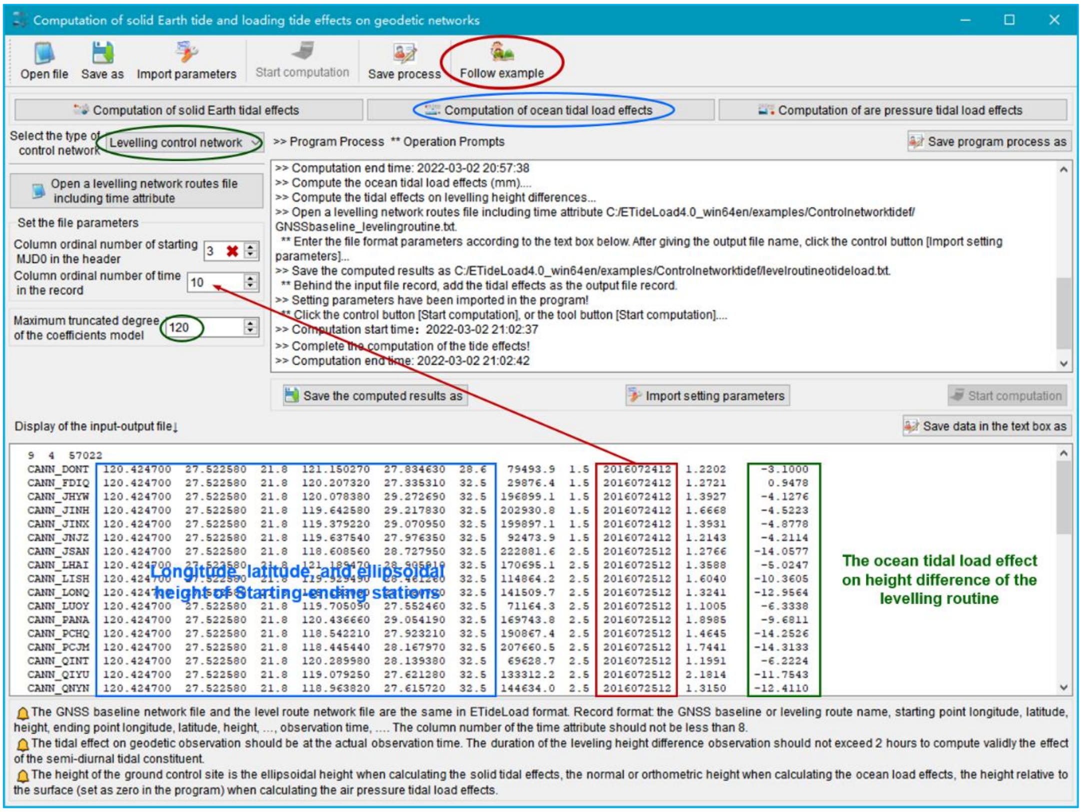
The column ordinal number of the time attribute should not be less than 8.



[Parameter settings] Set the input file format parameters, select the type of geodetic control network, and enter maximum truncated degree of the coefficients model when computing the tidal load effects.

The tidal effect on geodetic observation should be at the actual observation time. The duration of the leveling height difference observation should not exceed 2 hours to compute validly the effect of the semi-diurnal tidal constituent.

The height of the ground control site is the ellipsoidal height when calculating the solid tidal effects, the normal or orthometric height when calculating the ocean load effects, the height relative to the surface (set as zero in the program) when calculating the air pressure tidal load effects.



2.7 The regional approaching of tidal load effects by load Green's Integral

[Purpose] From the regional residual ocean tide or surface air pressure tide harmonic parameters grid, compute the residual ocean or air pressure tidal load effects near-Earth space by Green's integral.

Here, the residual harmonic parameters are equal to the regional harmonic parameters minus the model value of the harmonic parameters calculated by the global load spherical harmonic coefficients model.

The program requires that residual harmonic parameter grids files of all tidal constituents are stored in a folder. The harmonic parameter grid file is saved in the form of a vector grid, and the seventh attribute of the file header is the Doodson constant.

ETideLoad4.0 takes the regional harmonic parameters grid as the observations, uses global tidal load spherical harmonic coefficients model as a tidal load reference field, and refines the regional residual tidal load effects by Green's integral. Which is also called the remove-restore process.

2.7.1 Computation of residual ocean tidal load effects by Green's Integral

[Function] From the regional residual ocean tide harmonic parameters grid, compute the residual ocean tidal load effects on the geoid or height anomaly (mm), ground gravity (μGal), gravity disturbance (μGal), ground tilt (SW, to the south and to the west, mas), vertical deflection (SW, to the south and to the west, mas), horizontal displacement (EN, to the east and to the north, mm), ground radial displacement (mm), ground normal or orthometric height (mm) by Green's integral, and compute the direct or indirect residual tidal effects on disturbing gravity gradient (mE) or horizontal gravity gradient (NE, to the north and to the east, mE) by Green's Integral.

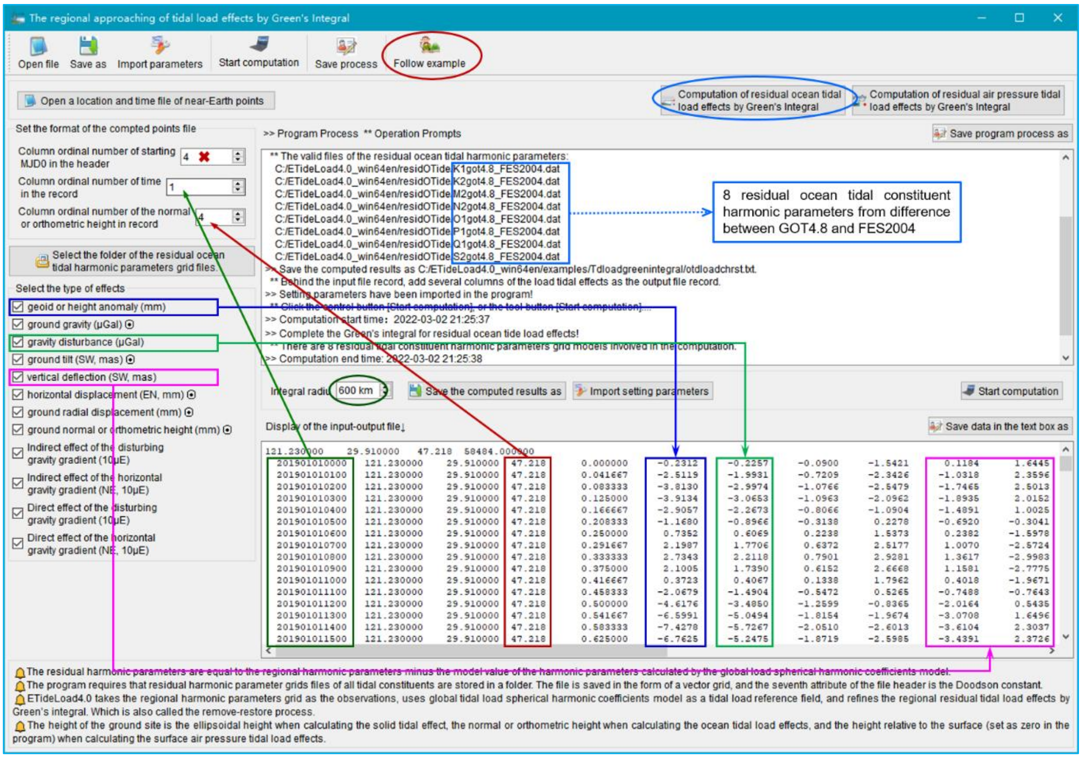
[Input file] The location and time file of near-Earth points, and the residual ocean tide harmonic parameters regional grid files.

The location and time file of near-Earth points. The first row is the file header. From the second row onwards, the second and third attributes in the file record are conventionally longitude and latitude (degree decimals), and there are the sampling epoch time and height attributes in the records.

In this example, 8 residual ocean tidal constituent harmonic parameters grid files are selected from the difference between the ocean tide height model GOT4.8 (0.5°×0.5° harmonic parameters grid) and FES2004.

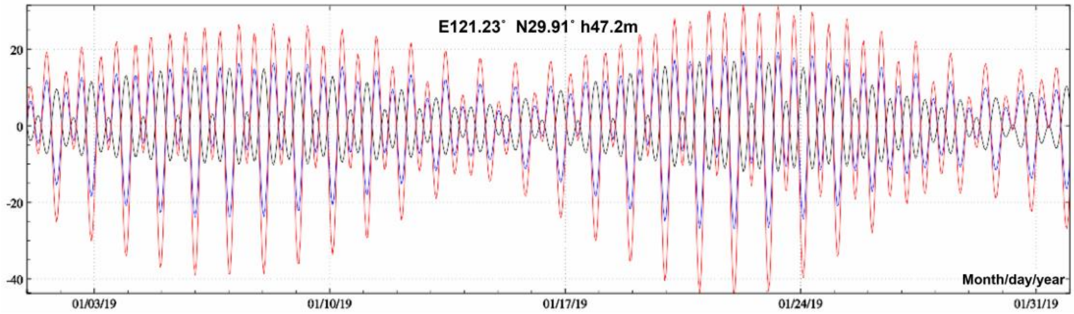
[Parameter settings] Set the input file format parameters, select the type of ocean tidal load effects, and enter Green's integral radiu.

The height of the calculated point is normal or orthometric height relative to the sea surface since the ocean tidal loads are generally considered to be on the sea surface.

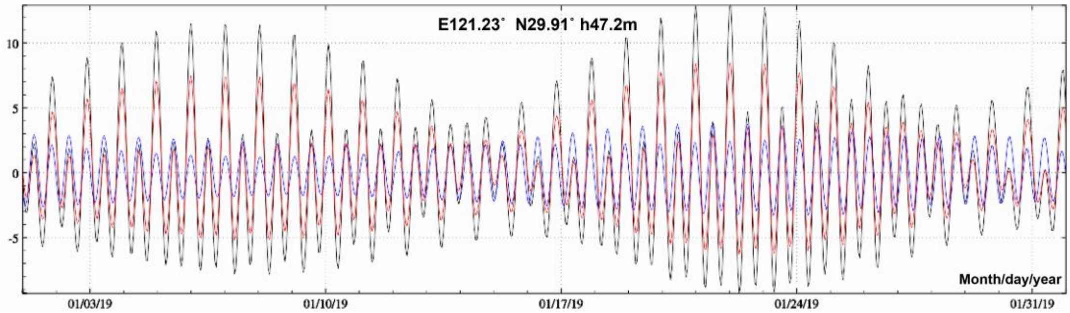


[Output file] The residual ocean tidal load effects file.

The file header is the same as the input file. Behind the input file record, add one or several columns of the residual tidal effects selected as the output file record. In this example, all types are selected, and there are seventeen attributes added to the record.



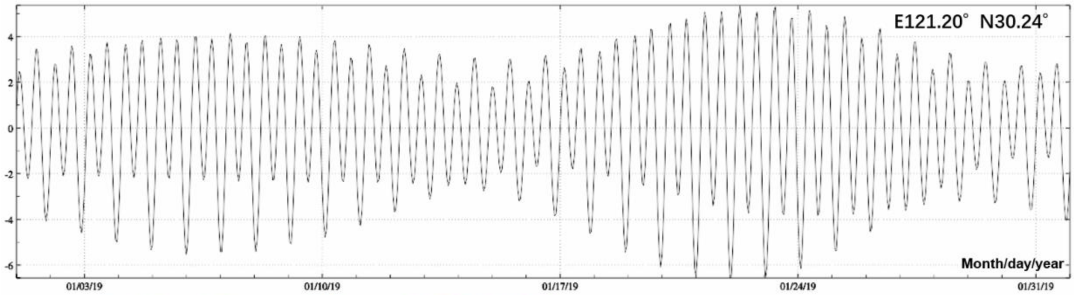
The residual ocean tidal load effects: height anomaly (mm), ground radial displacement (mm), ground orthometric height (mm)



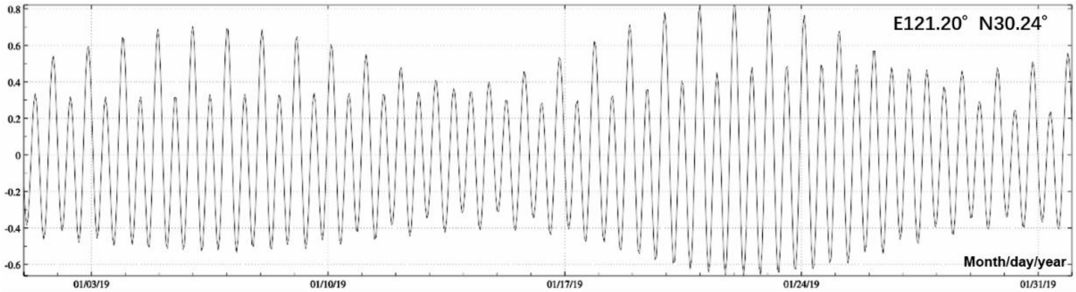
The residual ocean tidal load effects: ground gravity (μGal), ground tilt (S, mas), ground tilt (W, mas)

The ocean tidal load is located on the surface, and its load effects are all-wavelength. Gravity gradient ultrashort waves are dominant, and its ocean tide load effects are bigger. In order to fully display the spatial inhomogeneity of direct and indirect effects on gravity gradient, the program divides the ocean tidal effects on gravity gradient into two parts namely the direct and indirect effects with their unit enlarged from 10μE to mE.

Let the 8 residual tidal constituent harmonic parameters as the ocean tidal modelling error. The calculation results show that the ocean tide modelling error influence on the indirect load effect of the northward component of the horizontal gravity gradient can reach tens of mEs, and the direct effect can reach 600mE. The indirect load effect of the eastward component is more than 10mE, and the direct load effect is more than 200mE.

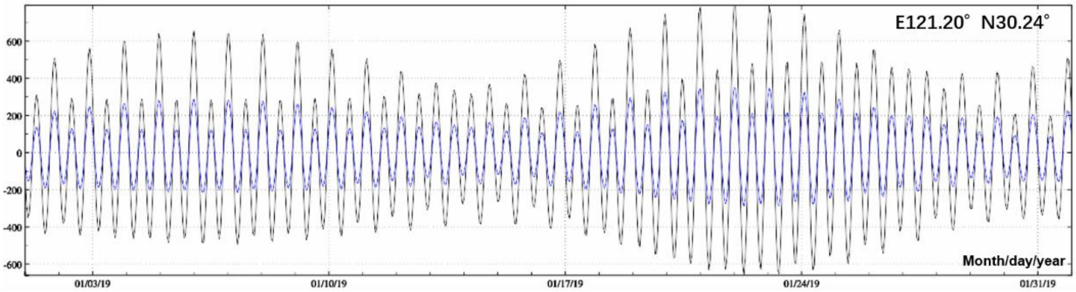


The tide modelling error influence (GOT4.8-FES2004): Direct effect of disturbing gravity gradient (mE)

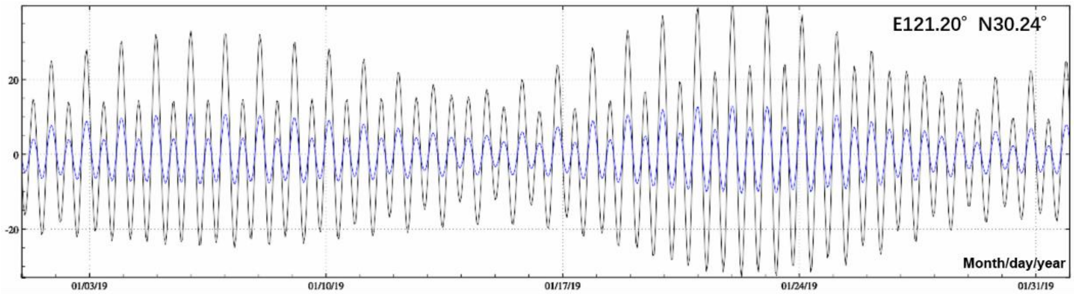


The tide modelling error influence (GOT4.8-FES2004): Indirect effect of disturbing gravity gradient (mE)

In coastal areas, it is difficult for gravity gradient measurement with the mE level of accuracy without a high-precision, high-resolution regional accurate tide model or sea surface height synchronous observations. In sea and coastal areas, the vertical gravity gradient observation scheme should be preferred, and the direct measurement of the horizontal gravity gradient should be avoided as much as possible.



The tide modelling error influence (GOT4.8-FES2004): Direct effect of horizontal gravity gradient (N, E; mE)



The tide modelling error influence (GOT4.8-FES2004): Indirect effect of horizontal gravity gradient (N, E; mE)

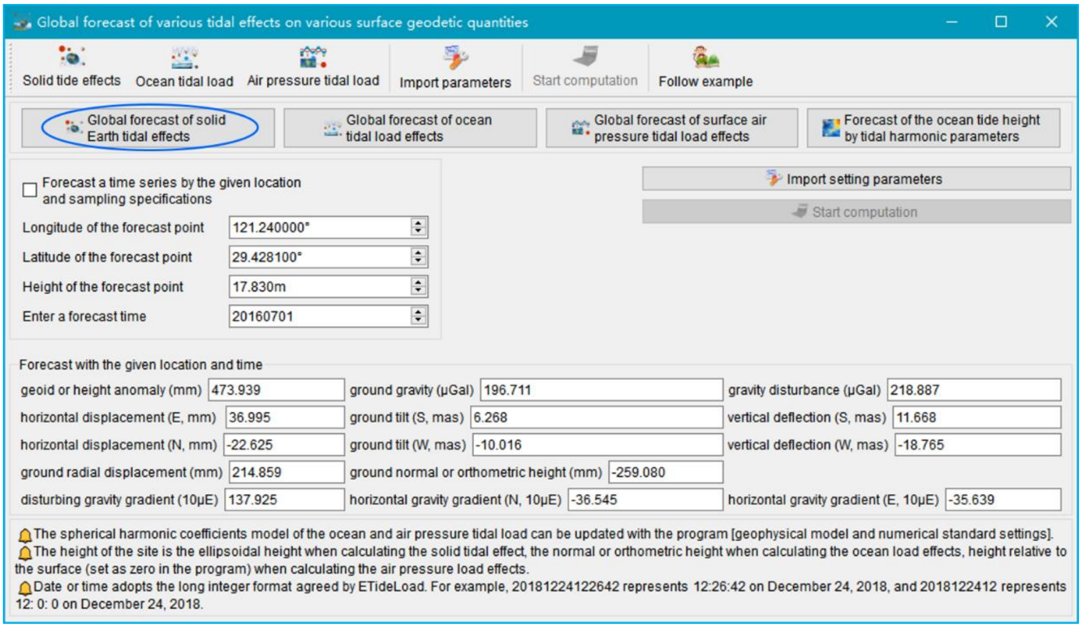
2.7.2 Computation of residual air pressure tidal load effects by Green's Integral

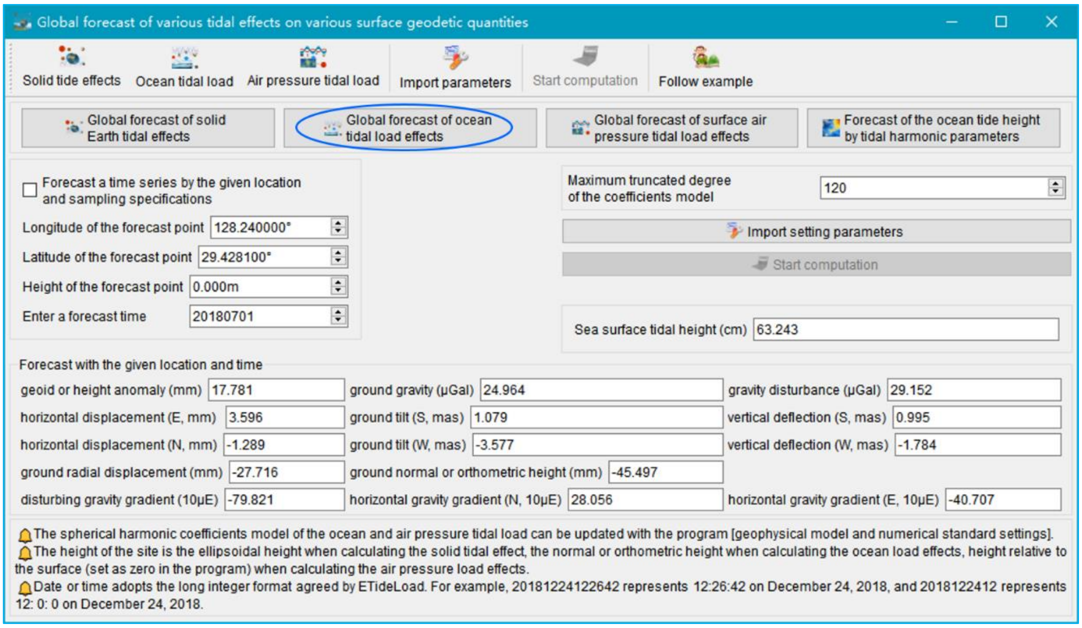
[Function] From the regional residual surface air pressure tide harmonic parameters grid, compute the residual tidal load effects on the geoid or height anomaly (mm), ground gravity (μGal), gravity disturbance (μGal), ground tilt (SW, to the south and to the west, mas), vertical deflection (SW, to the south and to the west, mas), horizontal displacement (EN, to the east and to the north, mm), ground radial displacement (mm), ground normal or orthometric height (mm), by Green's integral, and compute the direct or indirect residual tidal effects on disturbing gravity gradient (mE) or horizontal gravity gradient (NE, to the north and to the east, mE).

The height of the ground site is the normal or orthometric height when calculating the ocean tidal load effects, and the height relative to the surface (set as zero in the program) when calculating the surface air pressure tidal load effects.

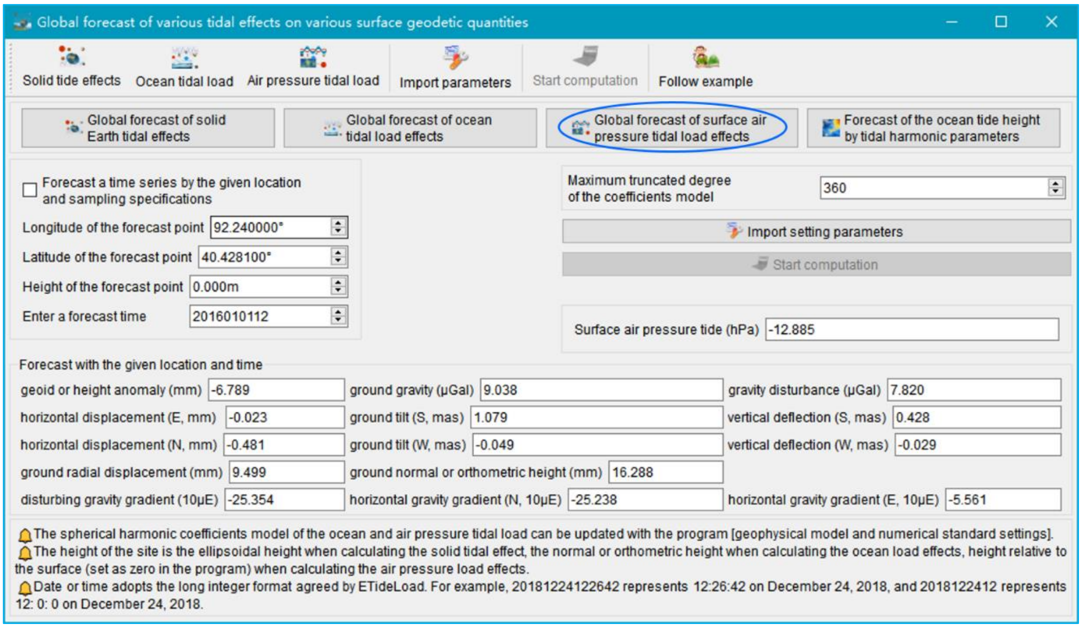
2.8 Global forecast of various tidal effects on various surface geodetic quantities

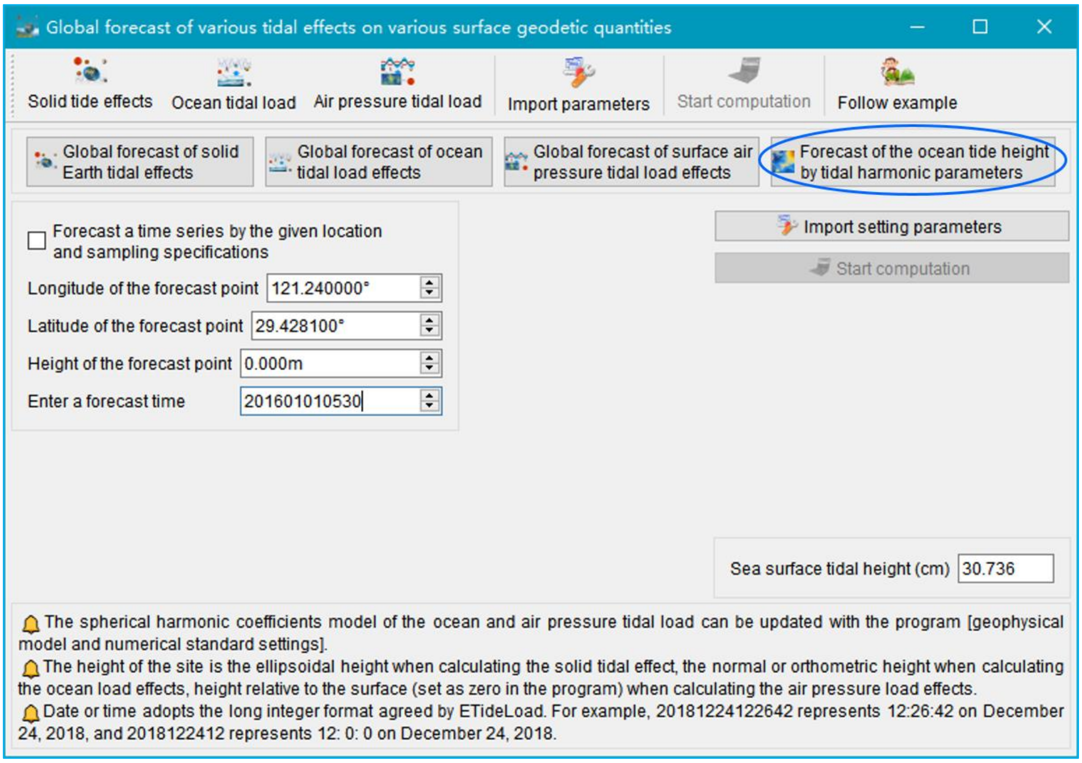
[Purpose] Forecast the solid Earth tidal, ocean tidal load, or surface air pressure tidal load effects on various surface geodetic quantities anywhere and anytime.





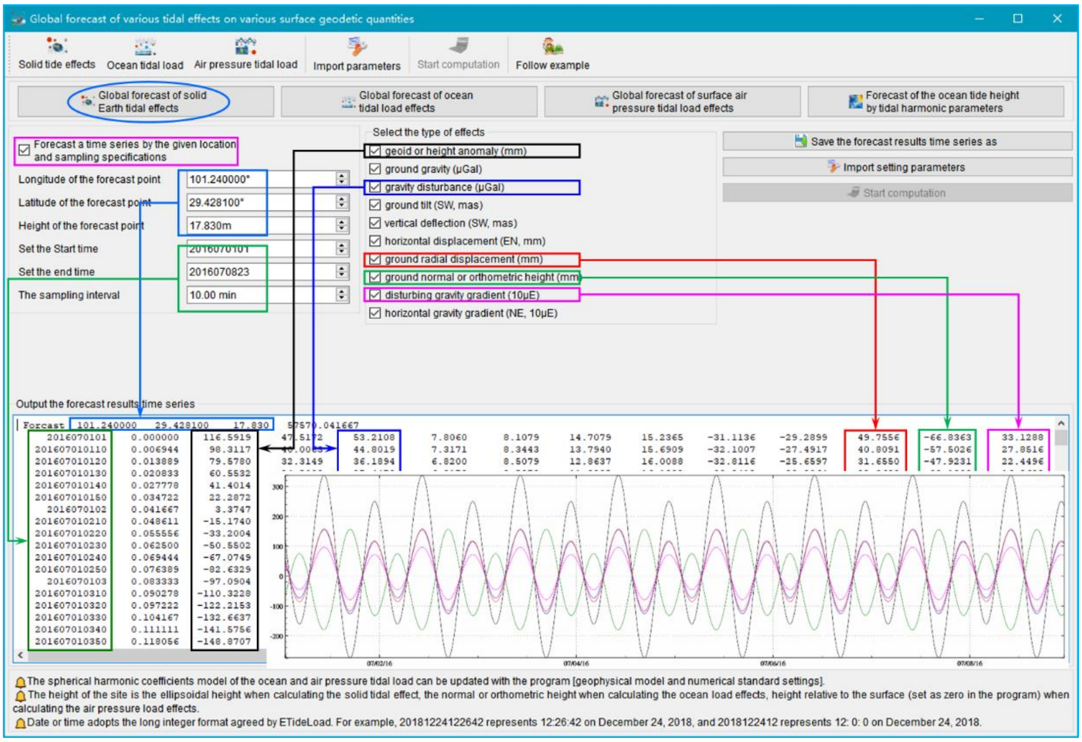
The height of the site is the ellipsoidal height when calculating the solid tidal effect, the normal or orthometric height when calculating the ocean load effects, height relative to the surface (set as zero in the program) when calculating the air pressure load effects.





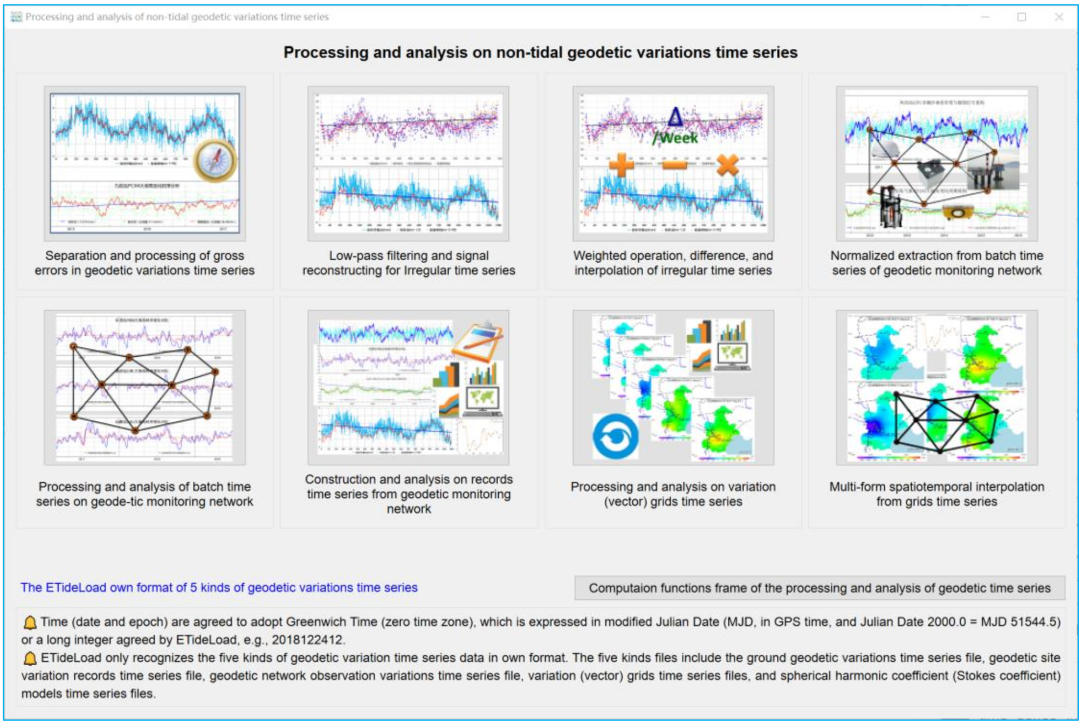
Date or time adopts the long integer format agreed by ETideLoad. E.g., 201812241226 represents 12:26:00 on December 24, 2018, and 2018122412 represents 12: 0: 0 on December 24, 2018.

The spherical harmonic coefficients model of the ocean tidal load and surface air pressure tidal load can be updated with the program [geophysical model and numerical standard settings].



3 Processing and analysis on non-tidal geodetic variations time series

Based on the characteristics of non-tidal geodetic time series, the group of programs adopt stable and reliable algorithms to uniformly process and analyze massive various geodetic variations time series data.



ETideLoad only recognizes the five kinds of geodetic variation time series data in own format. The five kinds files include the ground geodetic variations time series file, geodetic site variation records time series file, geodetic network observation variations time series file, variation (vector) grids time series files, and spherical harmonic coefficient (Stokes coefficient) models time series files.

3.1 Separation and processing of gross errors in geodetic variations time series

[Purpose] On the irregular sampling time series in the given input file, perform preprocessing such as gross error detection and separation, time format transform, reference epoch unification of multi-columns time series or averaging according to the given time period.

In the record of the geodetic variations time series file, each attribute except the sampling epoch time represents a type of variations time series, and the sampling epoch time of all types of variations time series are the same.

3.1.1 Gross error detection and separation on variations time series

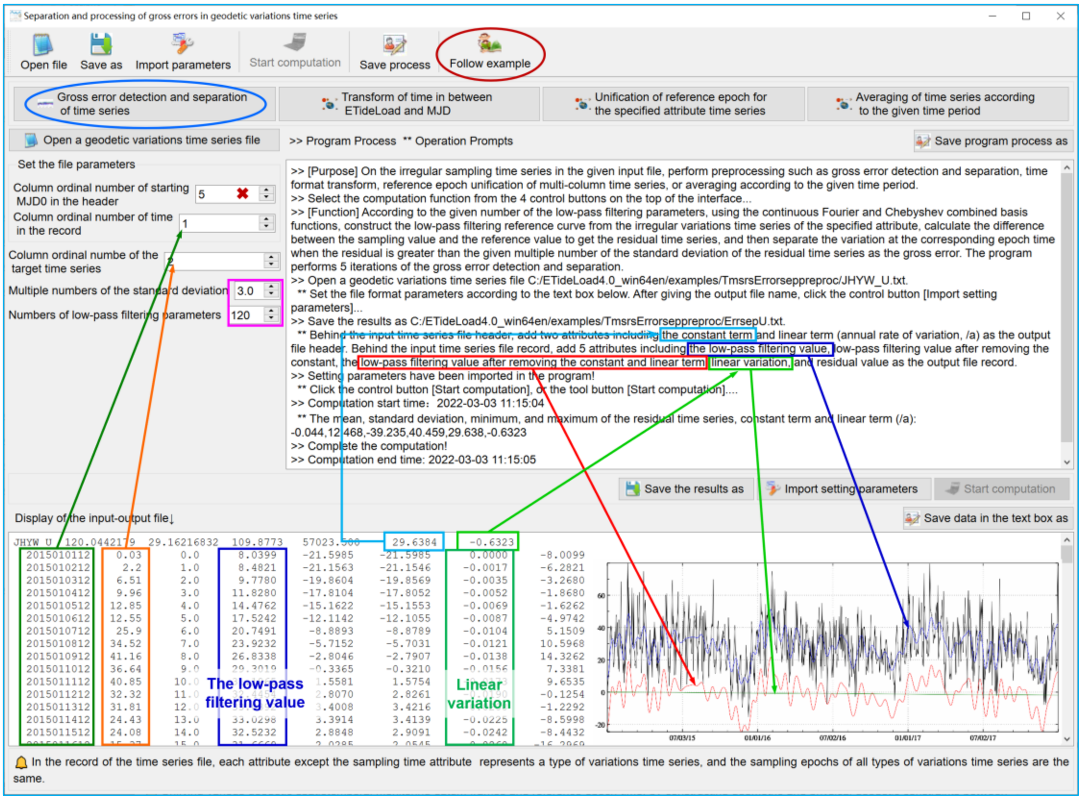
[Function] According to the given number of the low-pass filtering parameters, using the continuous Fourier and Chebyshev combined basis functions, construct the low-pass filtering reference curve from the irregular variations time series of the specified attribute, calculate the difference between the sampling value and the reference value to get the residual time series, and then separate the variation at the corresponding epoch time when the residual is greater than the given multiple of the standard deviation of the residual time series as the gross error. The program performs 5 iterations of the gross error detection and separation.

[Input file] The geodetic variations time series file.

The first row is the file header. Starting from the second row of the file, each row record stores the sampling values of all the variations at one sampling epoch time. At least one column of the attributes in the record is the sampling epoch time.

[Parameter settings] Set the input file format parameters, enter column ordinal number of the epoch time and target attribute time series to be detected in the record, and enter the multiple of the standard deviation and the number of low-pass filtering parameters.

The entered number of the low-pass filtering parameters is not more than 1/2 of the number of time series samples, and not less than 1/30 of the number of samples. When the entered number exceed this range, the program automatically takes the minimum or maximum value.

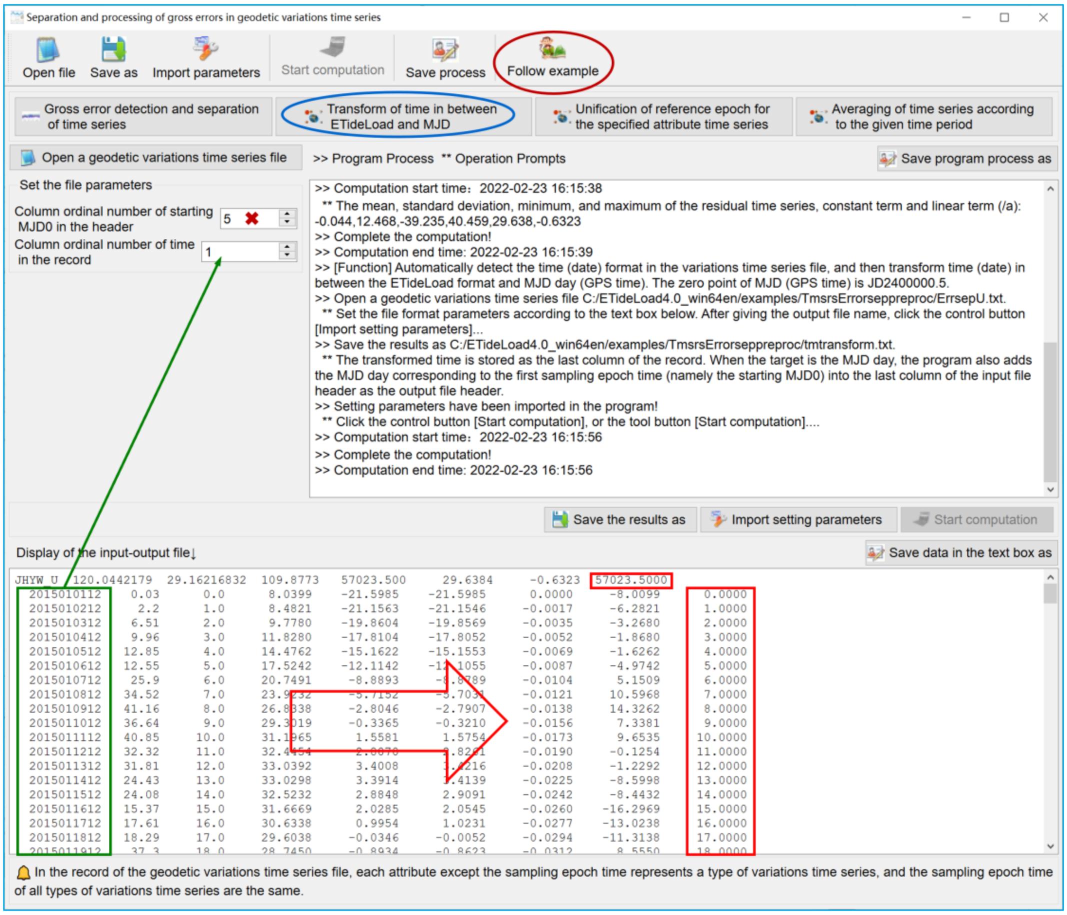


[Output file] The variations time series analysis file after removing gross errors.

Behind the input time series file header, add two attributes including the constant term and linear term (annual rate of variation, /a) as the output file hearder. Behind the input time series file record, add 5 attributes including the low-pass filtering value, low-pass filtering value after removing the constant, low-pass filtering value after removing the constant and linear term, linear variation, and residual value as the output file record.

3.1.2 Transform of time in between ETideLoad and MJD

[Function] Automatically detect the time (date) format in the variations time series file, and then transform time (date) in between the ETideLoad format and MJD day (GPS time). The zero point of MJD (GPS time) is JD2400000.5.



The transformed time is stored as the last column of the record. When the target is the MJD day, the program also adds the MJD day corresponding to the first sampling epoch time (namely the starting MJD0) into the last column of the input file header as the output file header.

3.1.3 Unification of reference epoch for the specified attribute time series

[Function] Using the cubic spline or Gaussian function interpolation method, interpolate the sampling value of the specified attribute time series at the given reference epoch time, and then remove the corresponding sampling values from the time series, thereby unifying the reference epoch time. At the reference epoch time, the sampling value of the specified attribute time series is always zero.

[Input file] The geodetic variations time series file.

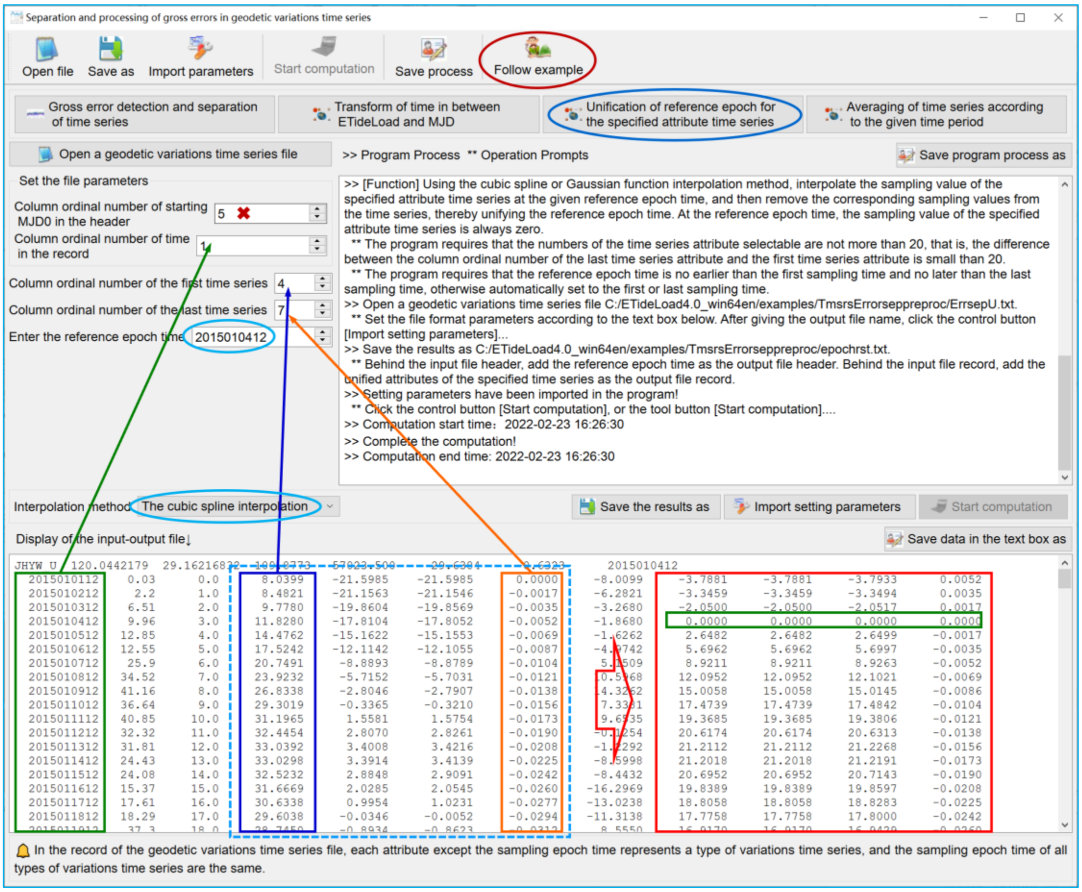
[Parameter settings] Set the input file format parameters, enter column ordinal number of the first and last attribute time series, the reference epoch time (ETideLoad long integer format), and select interpolation method.

The program requires that the reference epoch time is no earlier than the first sampling time and no later than the last sampling time, otherwise automatically set to the first or last sampling time.

The program requires that the number of the time series attributes selected are not more than 20, that is, the difference between the column ordinal number of the last attribute time series and the first attribute time series is small than 20.

The reference epoch time need not be one of the sampling epochs of the input variations time series.

When there are more noise or missing samples in time series signals, Gaussian function interpolation is recommended.



[Output file] The variations time series analysis file.

Behind the input file header, add the reference epoch time as the output file header. Behind the input file record, add the unified attributes of the specified time series as the output file record.

The unification of reference epoch time for multi-source data is the most basic requirement for geodynamics monitoring.

3.1.4 Averaging on time series according to the given time period

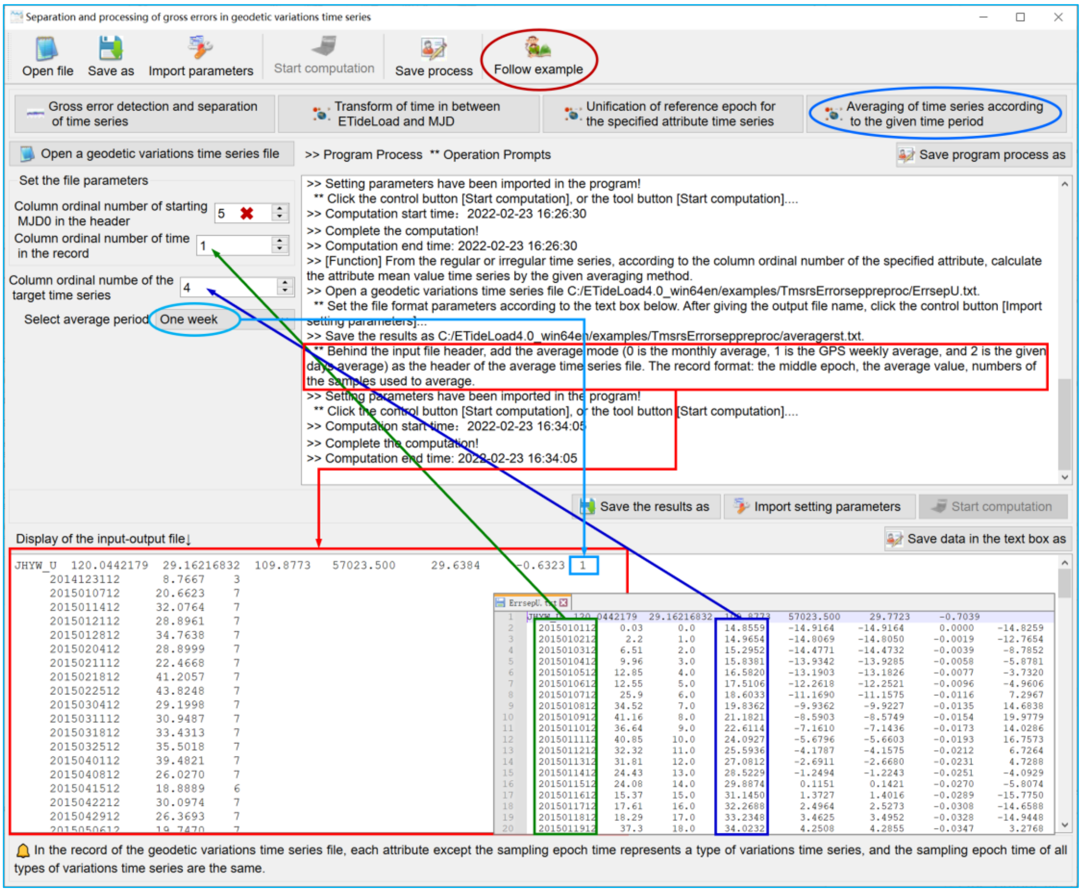
[Function] From the regular or irregular time series, according to the column ordinal number of the specified attribute, calculate the attribute mean value time series by the given averaging method.

[Input file] The geodetic variations time series file.

[Parameter settings] Set the input file format parameters, enter column ordinal number of the the specified attribute, and select average period.

[Output file] The variations average time series file.

Behind the input file header, add the average mode (0 is the monthly average, 1 is the GPS weekly average, and 2 is the given days average) as the header of the average time series file. The record format: the middle epoch, the average value, the number of the samples used to average.



3.2 Low-pass filtering and signal reconstructing for irregular time series

[Purpose] Using the continuous Chebyshev and triangular base function combination method, estimate the low-pass parameters of the irregular time series, separate the constant term and linear term, and then reconstruct the time series according to the user's requirements.

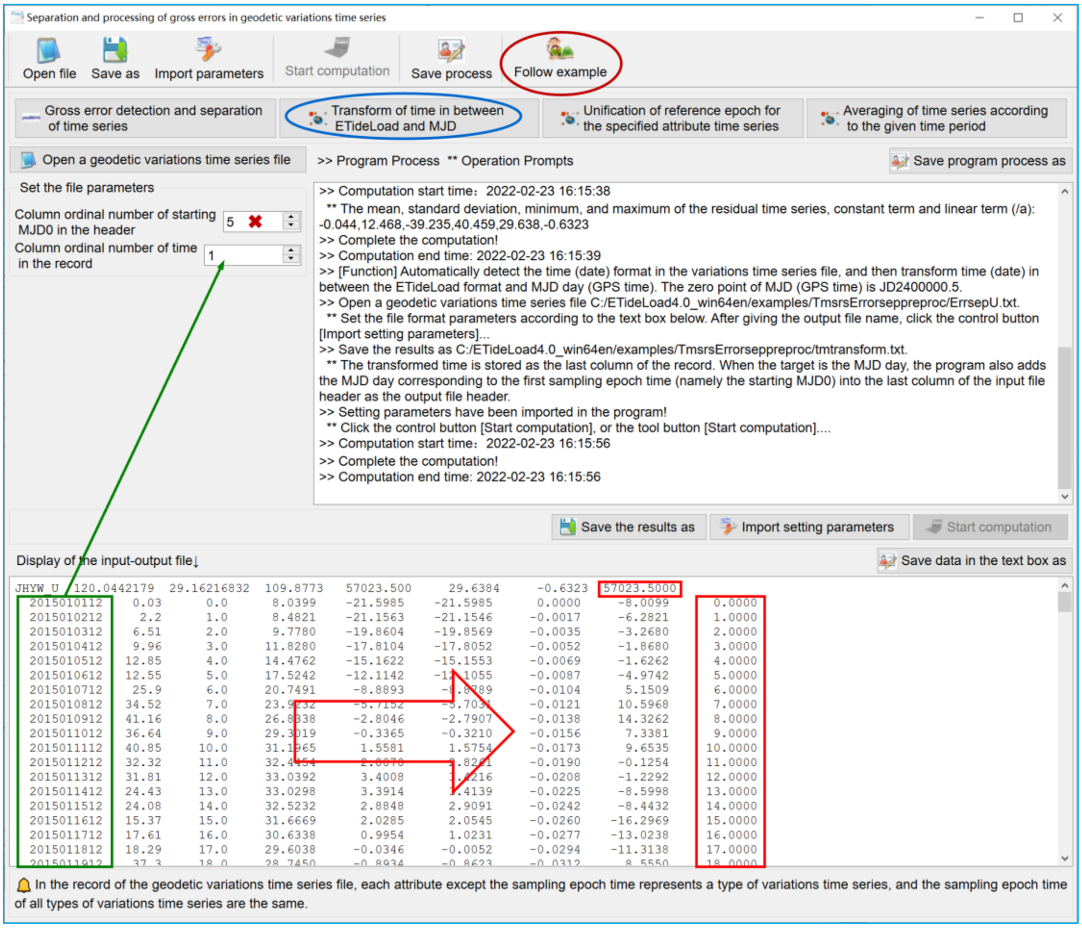
The program can separate the constant term, linear term, and noise, and realize the short-time interpolation and bidirectional prediction of various irregular variations time series.

3.2.1 Estimation of low-pass parameters and linear term of irregular time series

[Function] Using the continuous Chebyshev and triangular base function combination method, estimate the constant term, linear term, and low-pass parameters of the irregular time series according to the entered number of estimated parameters.

[Input file] The geodetic variations time series file.

The first row is the file header. Starting from the second row of the file, each row record stores the sampling values of all the variations at one sampling epoch time. At least one column of the attributes in the record is the sampling epoch time.



[Parameter settings] Set the input file format parameters, enter column ordinal number of the epoch time and target attribute time series in the record, and enter the number of low-pass filtering parameters.

The total number of the estimated low-pass parameters should not be greater than 1 / 2 of the number of samples in the input time series and should not be less than 1 / 30 of the number of samples. If the total number exceeds the range, the program automatically takes the minimum or maximum values.

[Output file] The low-pass filtering parameters file. The low-pass filter variations time series analysis file.

The low-pass filtering parameters file. Behind the input time series file header, add the 5 attributes including the constant term, linear term (annual rate of variation, /a), number of the estimated parameters, starting MJD0, and ending MJD as the parameters file header. And then all low-pass filter parameter values be saved into the file in order.

The low-pass filter variations time series analysis file *.rst. Here, * is the input geodetic variations time series file name.

Behind the input time series file header, add two attributes including the constant term and linear term (annual rate of variation, /a) as the output file header. Behind the input time series file record, add 5 attributes including the low-pass filtering value, low-pass filtering value after removing the constant, low-pass filtering value after removing the constant and linear term, linear variation, and residual value as the output file record.

3.2.2 Reconstruction of the low-pass signal at all sampling epochs of given time series

[Function] According to the entered number of the low-pass parameters (here, the entered number should be no greater than the maximum number of the estimated low-pass parameters), reconstruct the low-pass time series with the sampling epochs corresponding to the given time series.

[Input files] The geodetic variations time series file to be reconstructed. The low-pass filtering parameters file, which be automatically called by the program without manual input.

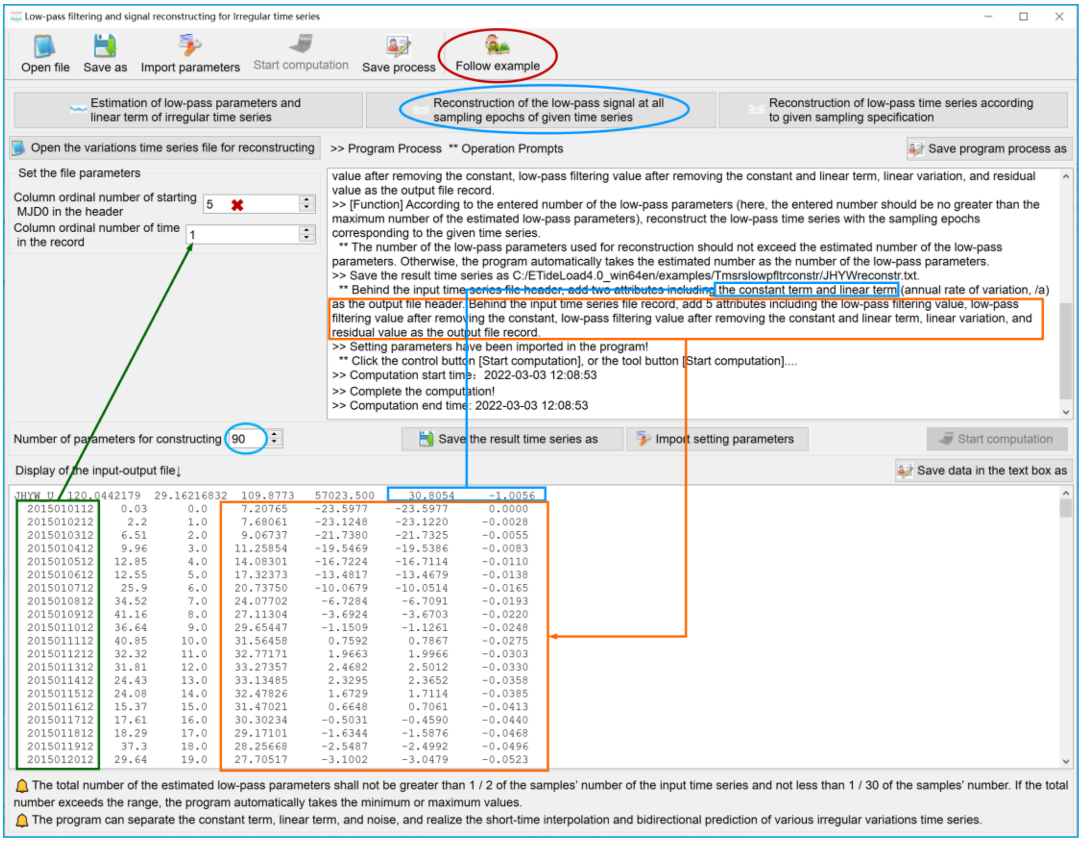
[Parameter settings] Set the column ordinal number of the epoch time in the input file record, enter the number of the low-pass parameters to be reconstructed.

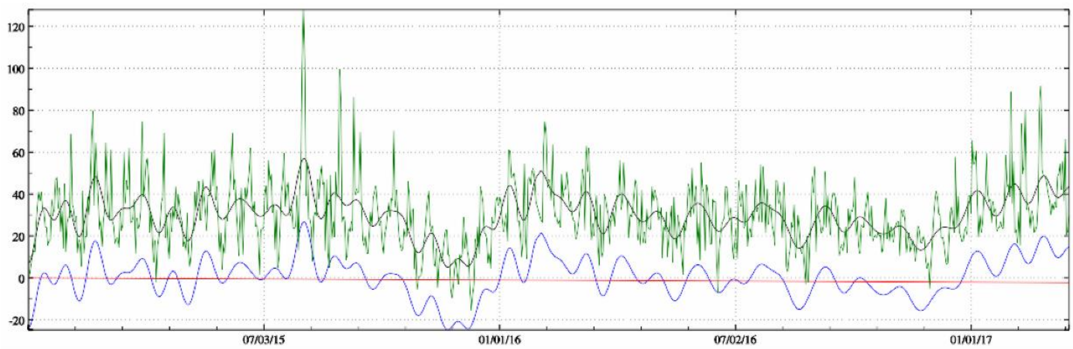
The number of the low-pass parameters used for reconstruction should not exceed the estimated number of the low-pass parameters. Otherwise, the program automatically takes the estimated number as the number of the low-pass parameters.

[Output file] The low-pass reconstruction variations time series file.

Behind the input time series file header, add two attributes including the constant term and linear term (annual rate of variation, /a) as the output file header.

Behind the input time series file record, add 4 attributes including the low-pass filtering value, low-pass filtering value after removing the constant, low-pass filtering value after removing the constant and linear term, and linear variation as the output file record.





The input time series Low-pass reconstruction time series Reconstruction time series after removing constant term Linear variation time series

3.2.3 Reconstruction of low-pass time series according to given sampling specification

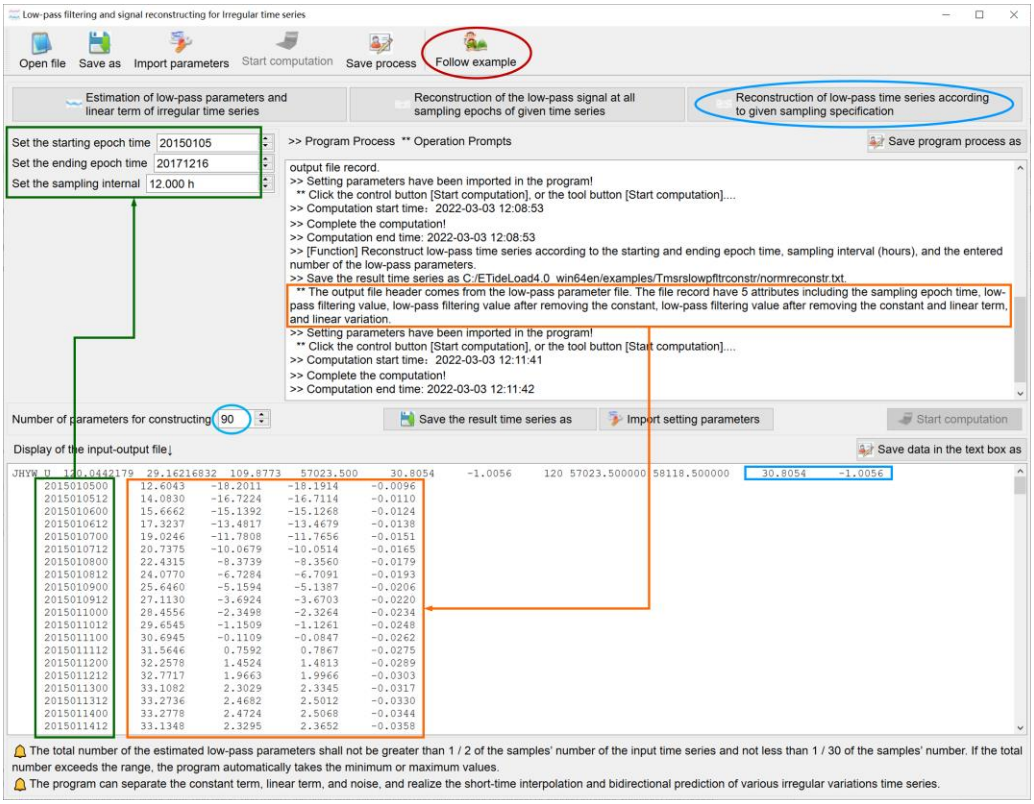
[Function] Reconstruct low-pass time series according to the starting and ending epoch time, sampling interval (hours), and the entered number of the low-pass parameters.

[Input files] The low-pass filtering parameters file, which be automatically called by the program without manual input.

[Output file] The low-pass reconstruction variations time series file.

The output file header comes from the low-pass parameter file. The file record have 5 attributes including the sampling epoch time, low-pass filtering value, low-pass filtering value after removing the constant, low-pass filtering value after removing the constant and linear term, and linear variation.

The starting-ending epoch time should be not earlier (or slightly earlier) than the starting time of the time series used to estimate the low-pass parameters, and not later (or slightly later) than the ending time of the time series.



3.3 Weighted operation, difference, integral and interpolation on time series

[Purpose] Directly perform weighted operation, difference, integral and interpolation operations on the irregular time series in the given manner.

3.3.1 Weighted operation between two attributes time series

[Function] Perform weighted plus, minus, or multiply operation between two attributes time series in the irregular time series file.

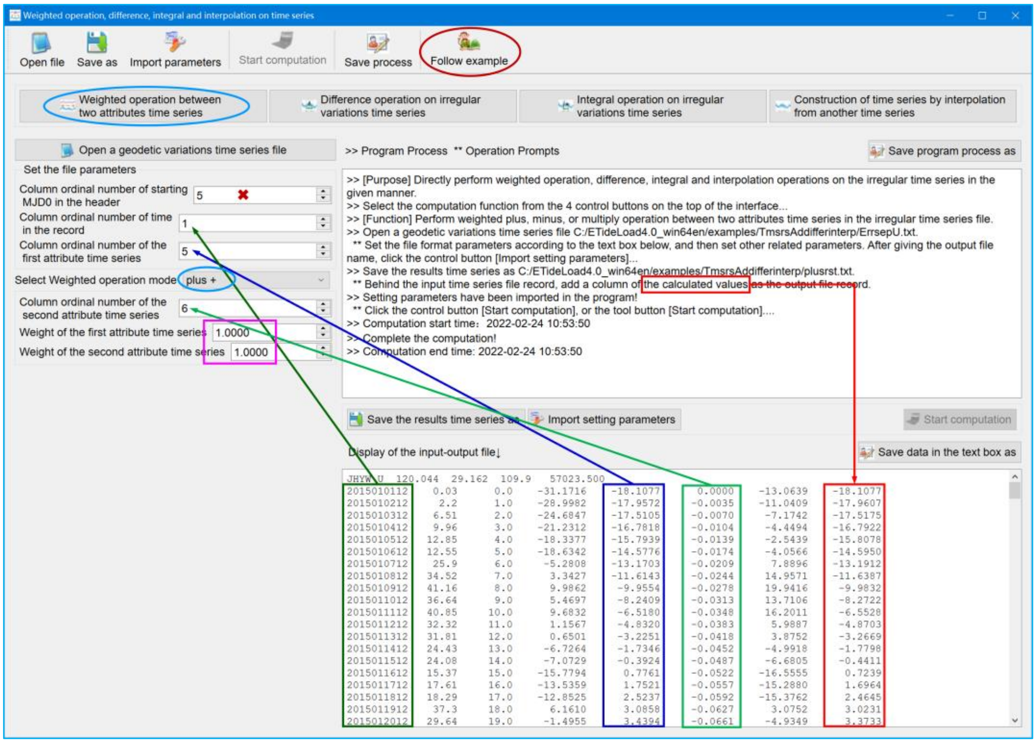
[Input file] The geodetic variations time series file.

The first row is the file header. Starting from the second row of the file, each row record stores the sampling values of all the variations at one sampling epoch time. The attributes in the record include the sampling epoch time and two attributes time series to be operated.

[Parameter settings] Set the input file format parameters, enter column ordinal number of the epoch time and two attributes time series to be operated in the record, and enter the two attribute weights.

[Output file] The weighted operation result variations time series file.

Behind the input time series file record, add a column of the calculated values as the output file record.



3.3.2 Difference operation on irregular variations time series

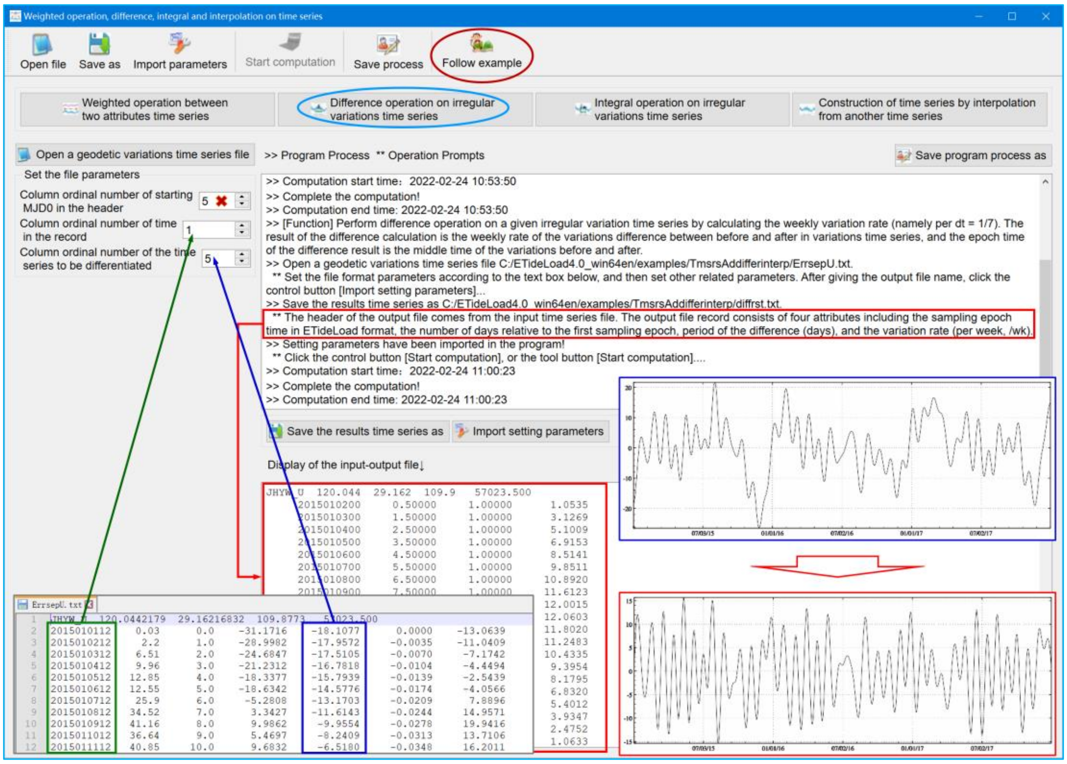
[Function] Perform difference operation on a given irregular variations time series by calculating the weekly variation rate (namely per dt = 1/7). The result of the difference calculation is the weekly rate of the variations difference between before and after in variations time series, and the epoch time of the difference result is the middle time of the variations before and after.

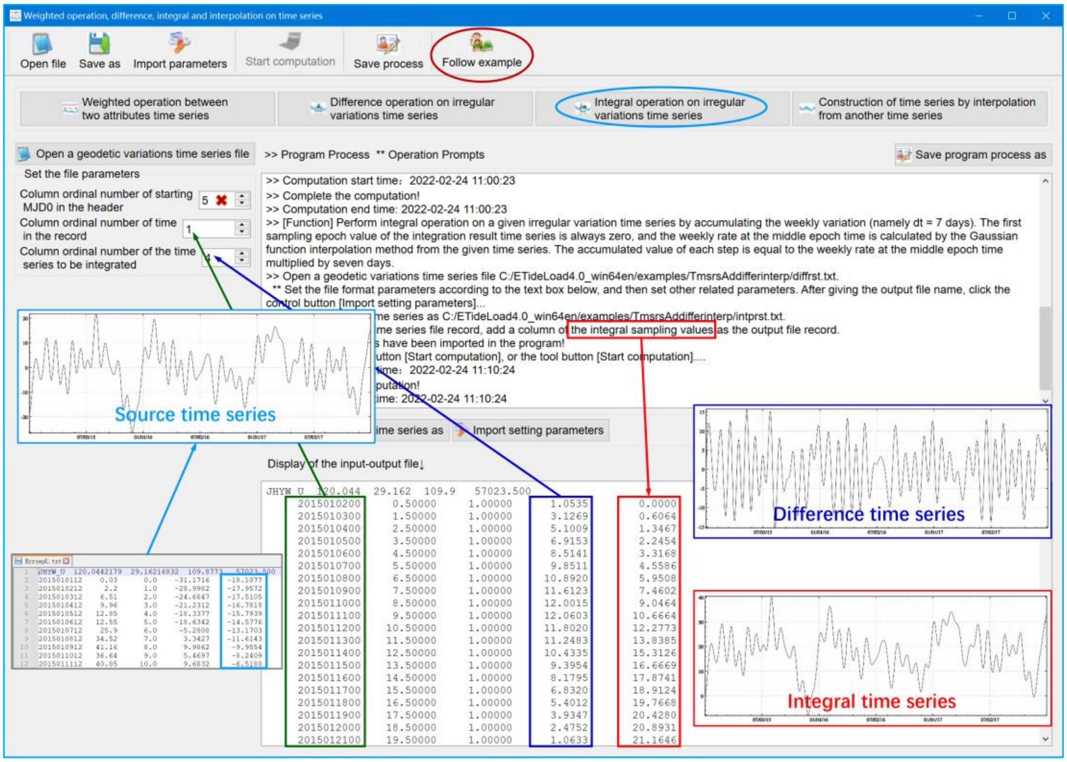
The output file header comes from the input time series file. The output file record consists of four attributes including the sampling epoch time in ETideLoad format, number of days relative to the first sampling epoch, period of the difference (days), and the variation rate (per week, /wk).

3.3.3 Integral operation on irregular variations time series

[Function] Perform integral operation on a given irregular variation time series by accumulating the weekly variation (namely dt = 7 days). The first sampling epoch value of the integration result time series is always zero, and the weekly rate at the middle epoch time is calculated by the Gaussian function interpolation method from the given time series. The accumulated value of each step is equal to the weekly rate at the middle epoch time multiplied by seven days.

The output file header comes from the input time series file. Behind the input time series file record, add a column of the calculated values as the output file record.





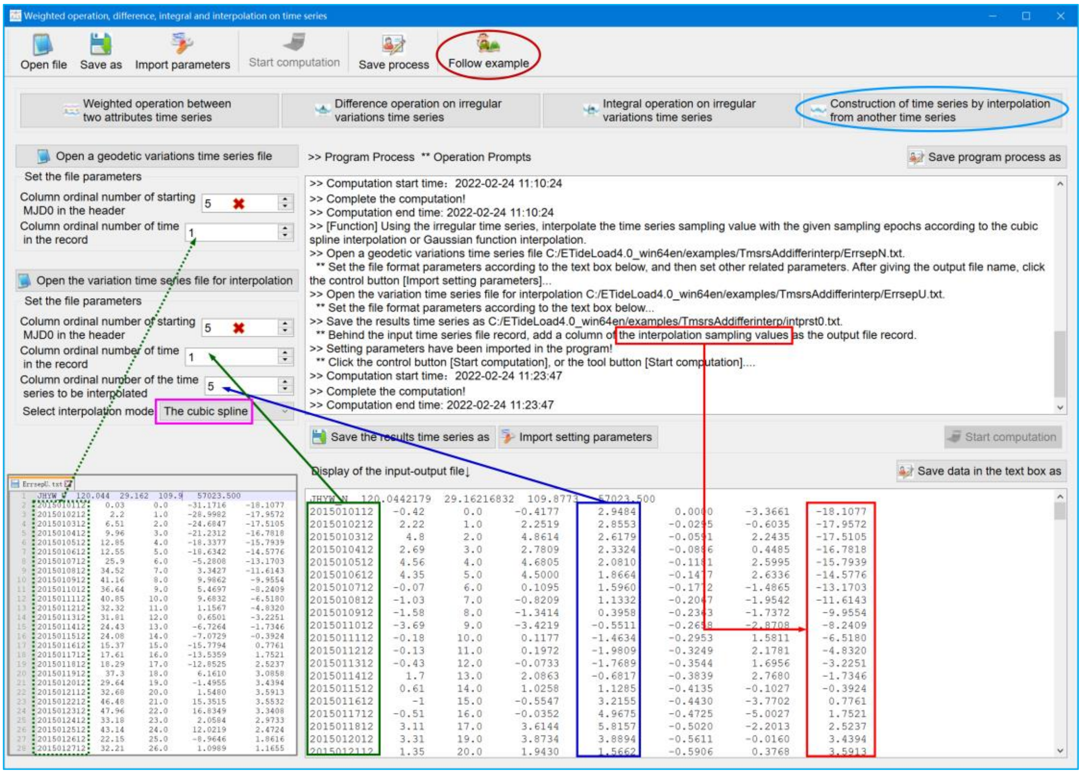
3.3.4 Construction of time series by interpolation from another time series

[Function] Using the irregular time series, interpolate the time series sampling value with the given sampling epochs according to the cubic spline interpolation or Gaussian function interpolation.

[Input file] The geodetic variations time series file to be interpolated. The geodetic variations time series file used for interpolation.

[Output] The interpolation result variations time series file.

The output file header comes from the input time series file. Behind the input time series file record, add a column of the interpolation sampling values as the output file record.



3.4 Normalized extraction from batch time series of geodetic monitoring network

[Purpose] From the text files of batch geodetic sites or batch CORS network baselines that contain the specified time series data and are in the same format, extract data and generate the corresponding time series files according to the ETideLoad format.

The program requires all the source text files stored in a folder, and the source file name contains the site name or baseline name with the same number of. The extracted time series files are saved into another folder.

3.4.1 Normalized extraction from batch time series of geodetic network sites

[Function] From the text files of batch geodetic network sites that contain the specified time series data with the same file format, according to the ETideLoad format, extract data and generate the corresponding time series files, which are saved in the specified folder.

[Parameter settings]

The program requires that wildcards can uniquely identify files in the folder, and their instance characters will be also used as the extracted time series file name.

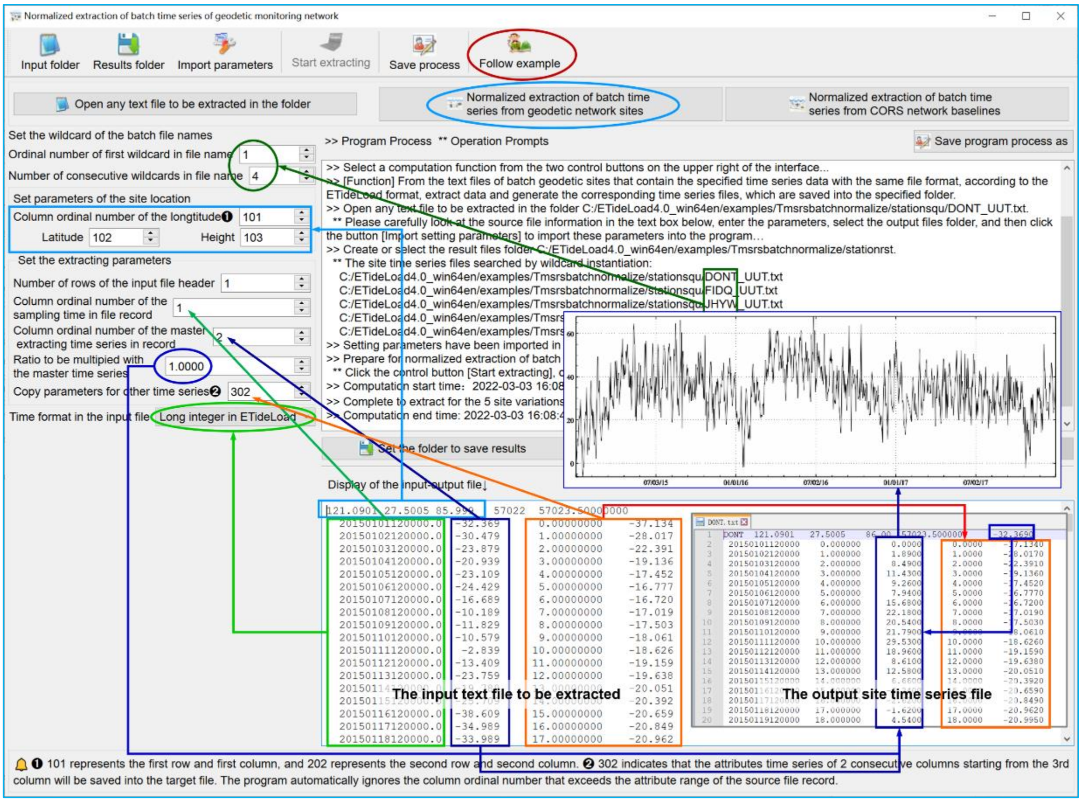
If there is no height attribute in the source file, or the entered height column ordinal number exceeds the maximum number of the attributes, the program automatically sets the height to zero.

If there is not the starting MJD0 in the header of the source file, please enter the starting time agreed in ETideLoad format. After entering the epoch time in ETideLoad format, the program would automatically calculate MJD day.

[Output files] Batch geodetic variations time series files in ETideLoad format.

The file header: The site name (instance of the file name wildcard), longitude, latitude, height, starting MJD0, and constant term (the first sampling value of the target time series).

The record format: The sampling epoch time, days relative to the starting MJD0, sampling value which has removed the first sampling value, other copy attributes.



The sum of the starting MJD0 in the header and the sampling epoch time (day) is equal to the sampling epoch time of MJD day in the record. When the sampling epoch time is in ETideLoad format, the starting MJD0 is not necessary for the file header.

3.4.2 Normalized extraction from batch time series of CORS network baselines

[Function] From batch baseline solution files of the CORS network that contain the specified time series data with the same file format, according to the ETideLoad format, extract data and generate the corresponding baseline solution time series files, which are saved in the specified folder.

The program extracts the time series of one-dimension components of the ENU baseline solutions at a time.

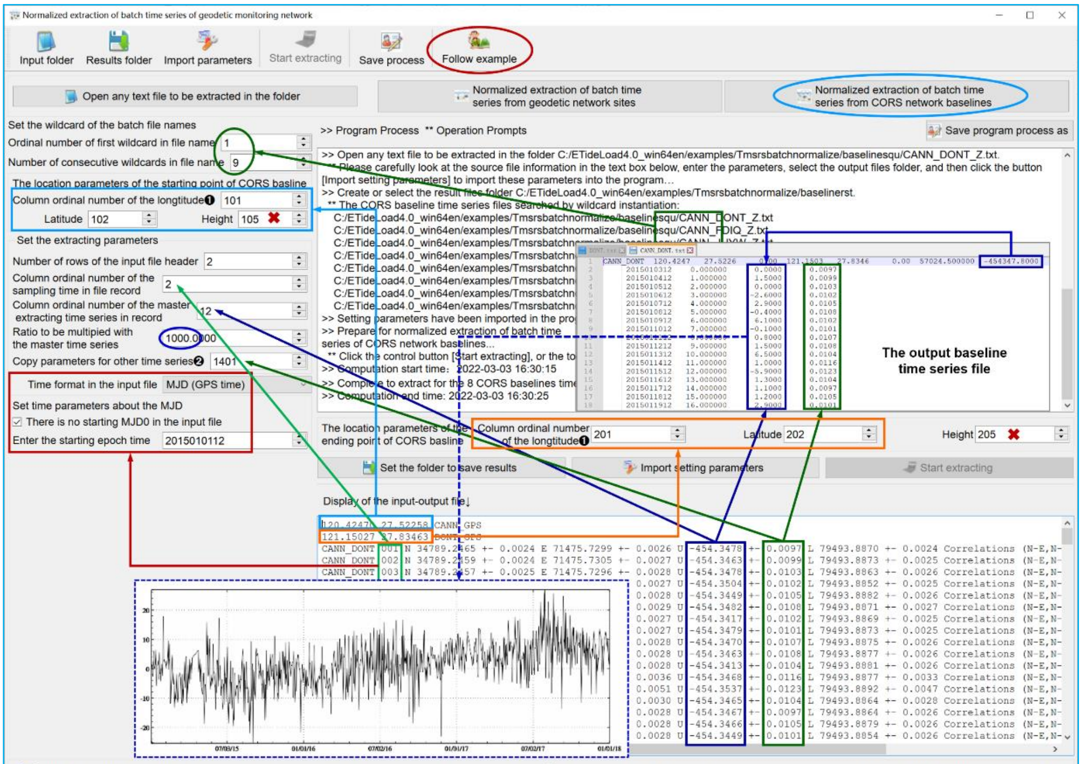
❶ 101 represents the first row and first column, and 202 represents the second row and second column.

❷ 302 indicates that the attributes time series of 2 consecutive columns starting from the 3rd column will be saved into the target file. The program automatically ignores the column ordinal number that exceeds the attribute range of the source file record.

[Output files] Batch CORS baseline solutions time series files in ETideLoad format.

The file header: The baseline name (instance of the file name wildcard), starting station longitude, latitude, height, ending station longitude, latitude, height, starting MJD0, and constant term (the first sampling value of the target time series).

The record format: The sampling epoch time, days relative to the starting MJD0, sampling value which has removed the first sampling value, other copy attributes.



❶ 101 represents the first row and first column, and 202 represents the second row and second column. ❷ 302 indicates that the attributes time series of 2 consecutive columns starting from the 3rd column will be saved into the target file. The program automatically ignores the column ordinal number that exceeds the attribute range of the source file record.

3.5 Processing and analysis on batch time series of geodetic monitoring network

[Purpose] On the specified attribute time series from batch variations time series files with the same format, perform gross error detection, linear term separation, low-pass filtering, and signal reconstructing, or calculate the mean time series according to the given period.

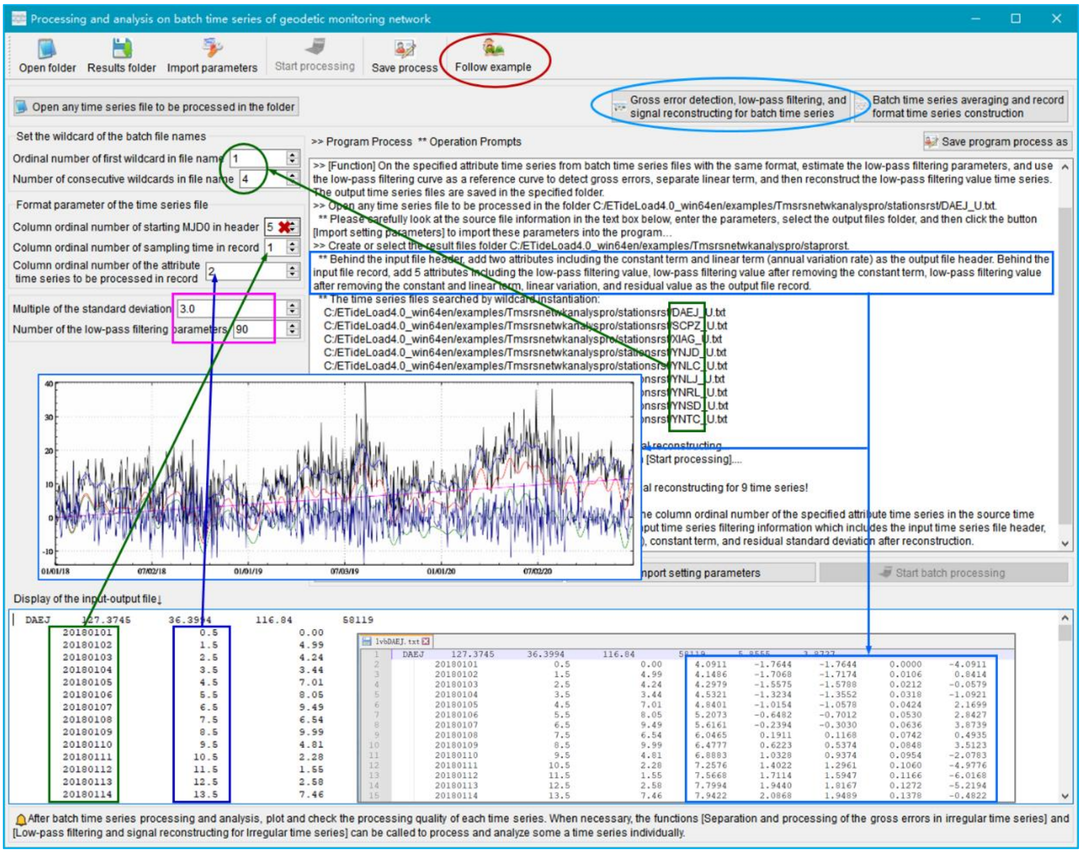
The program requires all source time series files saved in a folder. The output time series files are saved into the specified folder.

3.5.1 Gross error detection, low-pass filtering, and reconstructing for batch time series

[Function] On the specified attribute time series from batch time series files with the same format, estimate the low-pass filtering parameters, and use the low-pass filtering curve as a reference curve to detect gross errors, separate linear term, and then reconstruct the low-pass filtering value time series. The output time series files are saved in the specified folder.

[Input files] Batch geodetic variations time series files with the same formats.

The first row is the file header. Starting from the second row of the file, each row record stores the sampling values of all the variations at one sampling epoch time. At least one column of the attributes in the record is the sampling epoch time.



[Parameter settings] Set the wildcard patameters for batch variations time series files, enter column ordinal number of the epoch time and target attribute time series in the record, and enter the multiple of the standard deviation and number of low-pass filtering parameters.

The entered number of the low-pass filtering parameters is not more than 1/2 of the number of time series samples, and not less than 1/30 of the number of samples. When the entered number exceeds this range, the program automatically takes the minimum or maximum value.

[Output files] Batch low-pass filtering time series files. The linear variation file.

The low-pass filtering time series file. Behind the input file header, add two attributes including the constant term and linear term (annual variation rate) as the output file header. Behind the input file record, add 5 attributes including the low-pass filtering value, low-pass filtering value after removing the constant term, low-pass filtering value after removing the constant and linear term, linear variation, and residual value as the output file record.

The linear variation file TsqLinear#.txt (# is the column ordinal number of the specified attribute time series in the source time series file) without the file header. Each record of the file stores an input time series filtering information which includes the input time series file header, number of the filtering parameters, annual variation rate (per year, /a), constant term, and residual standard deviation after reconstruction.

3.5.2 Batch time series averaging and record format time series construction

[Function] On the specified attribute time series from batch time series files with the same format, perform the average according to the given mode. The output time series is stored in two ways. The one is each time series saved as a file. The other is to arrange all the time series in rows, each record store a time series, and all the time series are stored into a records time series file.

[Input files] Batch variations time series files with the same format.

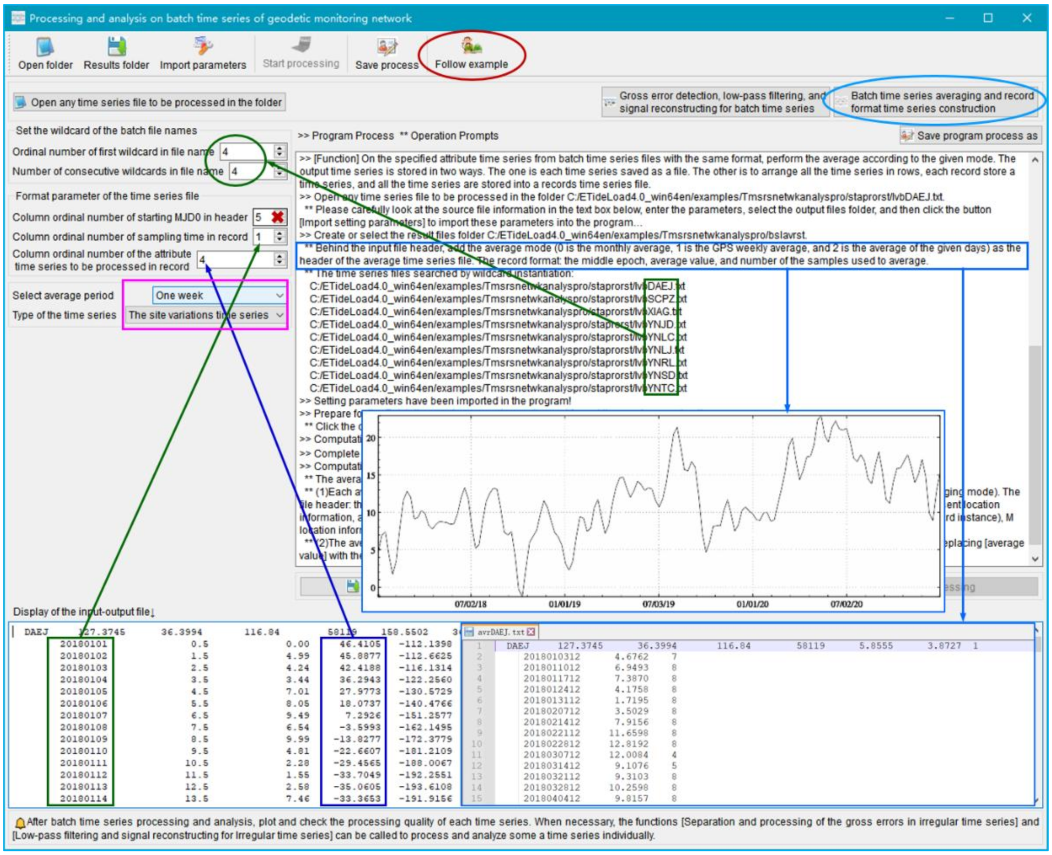
[Parameter settings] Set the wildcard patameters for batch variations time series files and input file format parameters, enter column ordinal number of the epoch time and target attribute time series in the record, and select the average period and type of the input time series files.

"The site variations time series" means that the sample of time series is the coordinate component, gravity, normal (orthometric) height, or tilt component of the ground site.

"Geodetic network time series" means that sample of the time series is the GNSS baseline component, leveling height difference, or gravity difference of the ground geodetic network.

[Output files] Batch mean variations time series files.

Behind the input file header, add the average mode (0 is the monthly average, 1 is the GPS weekly average, and 2 is the average of the given days) as the header of the average time series file. The record format: the middle epoch, average value, and number of the samples used to average.



The program output the average values time series in the record format in the following two files.

(1) The average value records time series file. Each average time series is arranged as a row record into the records time series file, and the file name is TsqavrRow#.txt (# is averaging mode).

The file header: the number of chatacter of the time series name (equal to the number of wildcards), the number of the attributes (M) that represent location information, average mode (0~2), the number of samples (N), N sampling epochs.

The file record format: average time series name (wildcard instance), M location information, N average value (default 9999).

(2) The average number file TsqavrRkk#.txt (# is averaging mode). The file is in the same format as the records time series file, only replacing "average value" with the number of samples used to average.

After batch time series processing and analysis, plot and check the processing quality of each time series. When necessary, the functions [Separation and processing of the gross errors in irregular time series] and [Low-pass filtering and signal reconstructing for Irregular time series] can be called to process and analyze some a time series individually.

3.6 Construction and analysis on records time series from geodetic network

[Purpose] Construct and analyze the variation records time series composed of multi-periods or continuous data of the geodetic monitoring network.

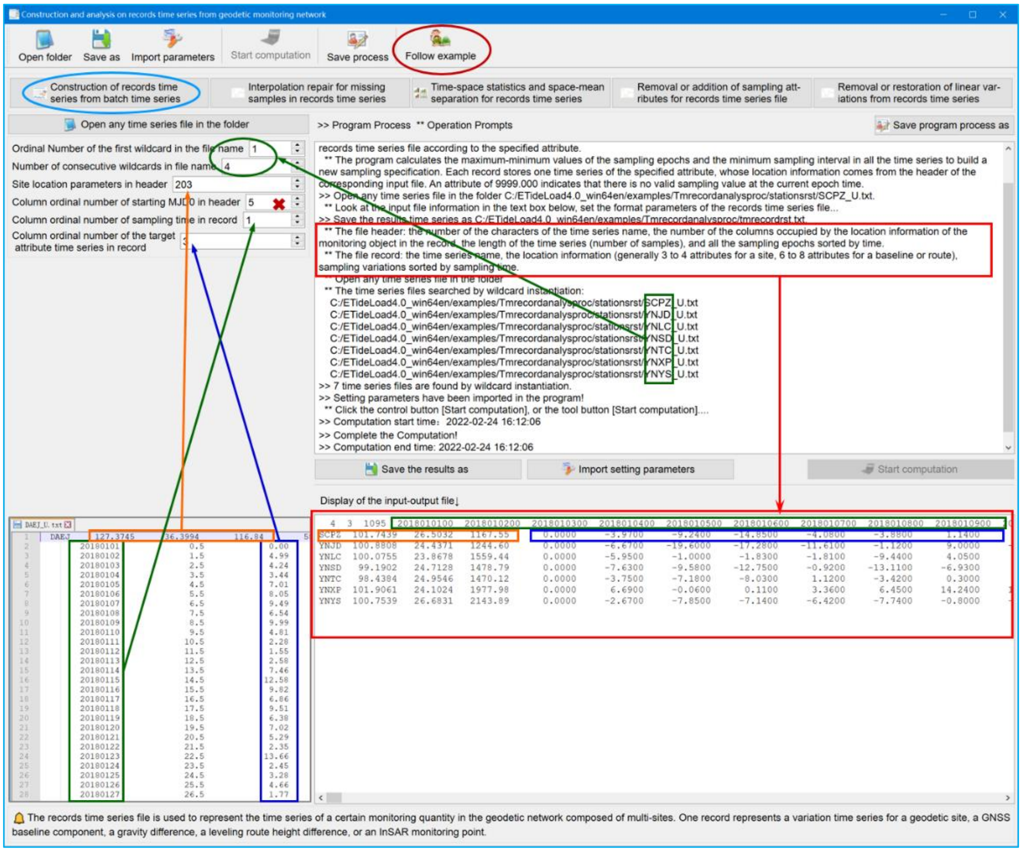
The records time series file is used to represent the time series of a certain monitoring quantity in the geodetic network composed of multi-sites. One record represents a variation time series for a geodetic site, a GNSS baseline component, a gravity difference, a leveling route height difference, or an InSAR monitoring point.

3.6.1 Construction of records time series from batch time series with same specifications

[Function] From batch time series files with the same specifications (same sampling time span and interval) stored in a folder, construct a records time series file according to the specified attribute.

The program calculates the maximum-minimum values of the sampling epochs and the minimum sampling interval in all the time series to build a new sampling specification. Each record stores one time series of the specified attribute, whose location information comes from the header of the corresponding input file. An attribute of 9999.000 indicates that there is no valid sampling value at the current epoch time.

[Input files] Batch time series files with the same sampling specifications.



[Parameter settings] Set the wildcard patameters for batch variations time series files and site location parameters in the input file header, enter column ordinal number of the epoch time and target attribute time series in the record.

[Output files] The variation records time series file.

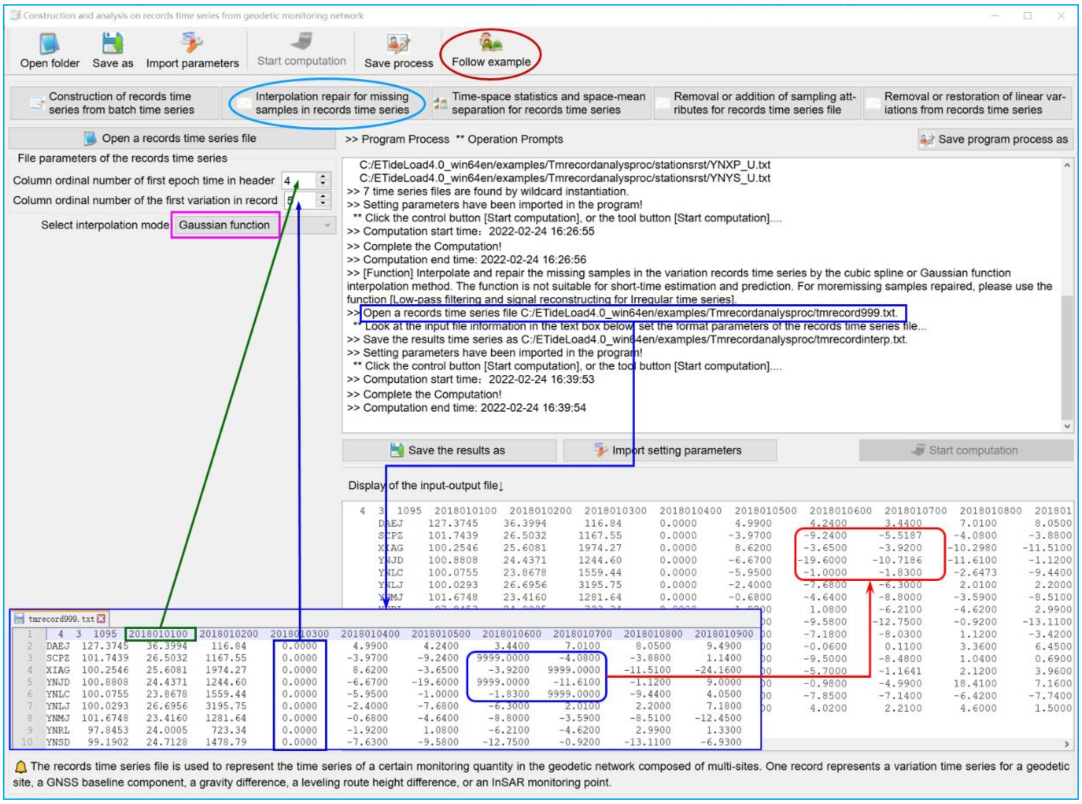
The file header: the number of characters of the time series name, number of columns occupied by the location information of the monitoring object in the record, length of the time series (number of samples), and all the sampling epochs arranged with time.

The file record: the time series name, location information (generally 3 to 4 attributes for a site, 6 to 8 attributes for a baseline or route), sampling variations arranged with sampling time.

3.6.2 Interpolation repair for missing samples in records time series

[Function] Interpolate and repair the missing samples in the variation records time series by the cubic spline or Gaussian function interpolation method. The function is not suitable for short-time estimation and prediction. For more missing samples repaired, please use the function [Low-pass filtering and signal reconstructing for Irregular time series].

When there are more noise or missing samples in time series signals, Gaussian function interpolation is recommended.



3.6.3 Time-space statistics and space-mean separation for records time series

[Function] Firstly, calculate the time average, standard deviation, minimum and maximum of each variation record time series during the entire sampling period. Then calculate the spatial average, standard deviation, minimum and maximum of all variations at each sampling epoch time. Finally, calculate the spatiotemporal average, standard deviation, minimum and maximum of all variations during the entire sampling period.

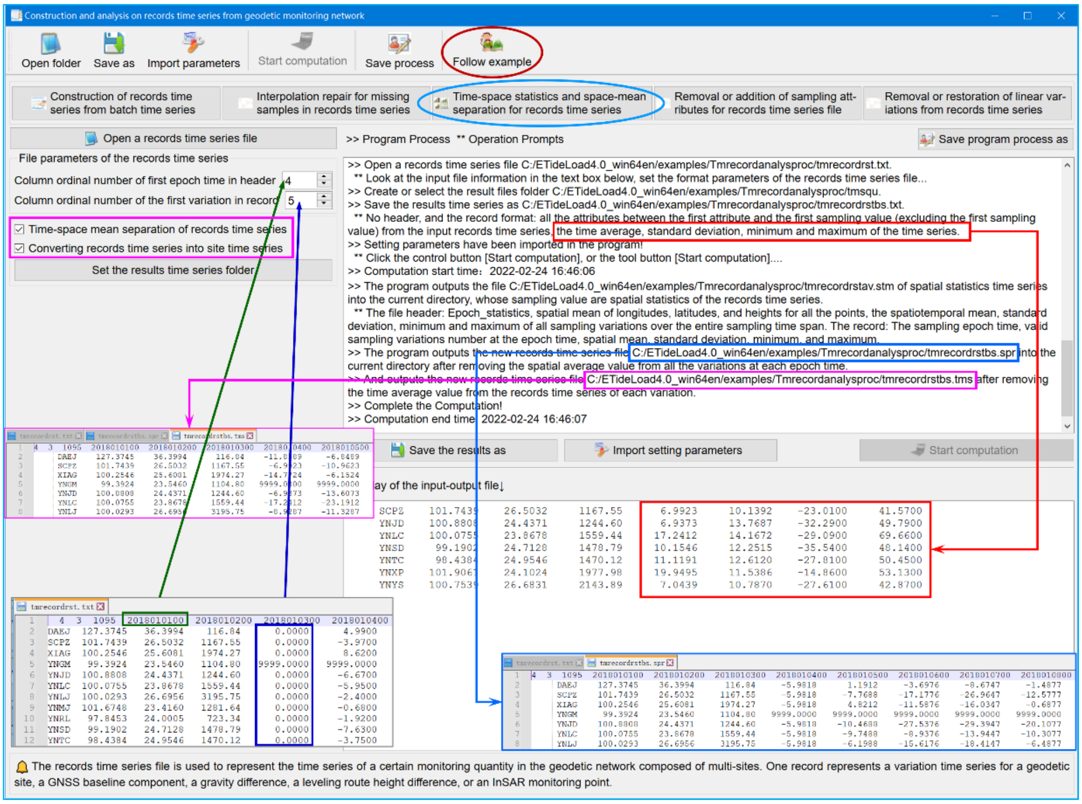
[Input file] The variation records time series file.

The sampling epochs in the header are no one-by-one correspondence with the sampling variations in the record.

[Parameter settings] Set the input file format parameters, enter column ordinal number of the epoch time in the header and target attribute time series in the record, and select the checkbox of time-space separation of records time series and converting records time series into site time series.

[Output files] The statistics results file on records time series, the variation records time series file after removing the space average, the variation records time series file after removing the time average, and the spatial statistics time series file.

The statistics results file on records time series file. No file header, and the record format: all the attributes between the first attribute and the first sampling value (excluding the first sampling value) from the input records time series, the time average, standard deviation, minimum and maximum of the time series.

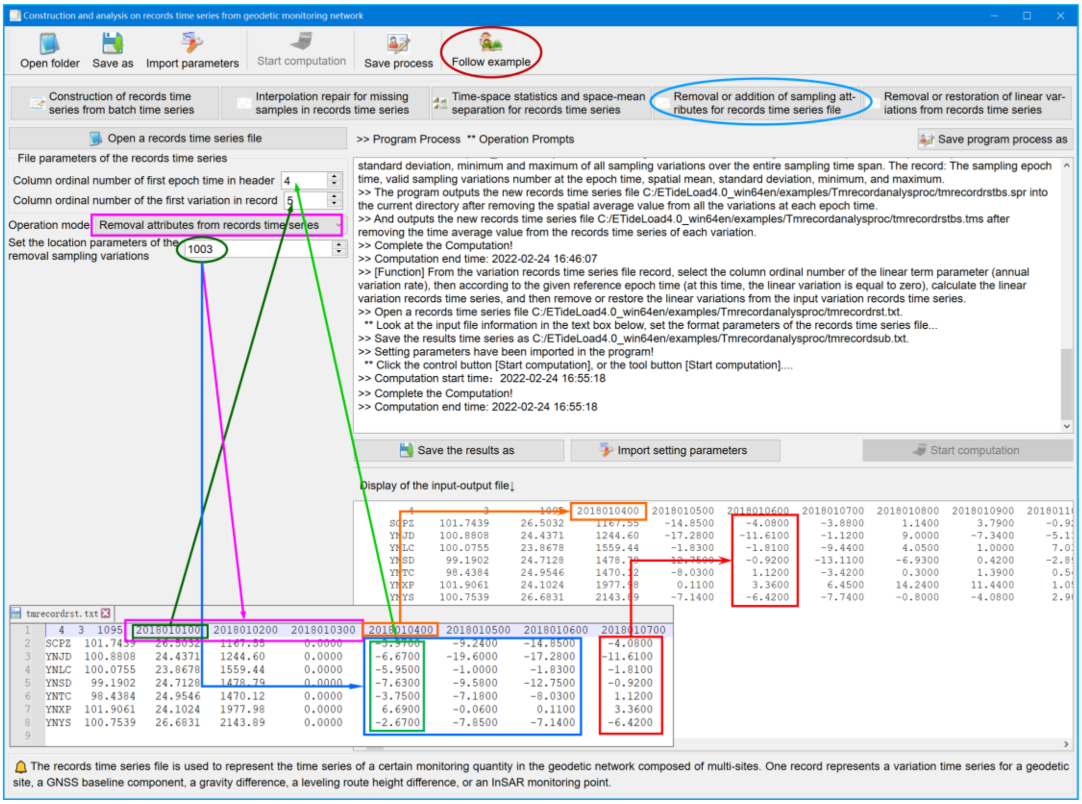


The spatial statistics time series file. The file header: Epoch_statistics, spatial mean of longitudes, latitudes, and heights for all the points, the spatiotemporal mean, standard deviation, minimum and maximum of all sampling variations over the entire sampling time span. The record: The sampling epoch time, valid sampling variations number at the epoch time, spatial mean, standard deviation, minimum, and maximum.

3.6.4 Removal or addition of sampling attributes for records time series file

[Function] Remove several consecutive columns of the sampling attributes from the record in the records time series file, and then remove the corresponding sampling epoch time in the file header. Or extract several consecutive columns of the attributes in the discrete point records file and add them before the first sampling attribute in the record of the time series file.

When adding some sampling attributes from the discrete point records file to records time series, the program requires the point value records file to have one and only a row header and the location of discrete points and the location of monitoring quantities of the records time series correspond one to one.



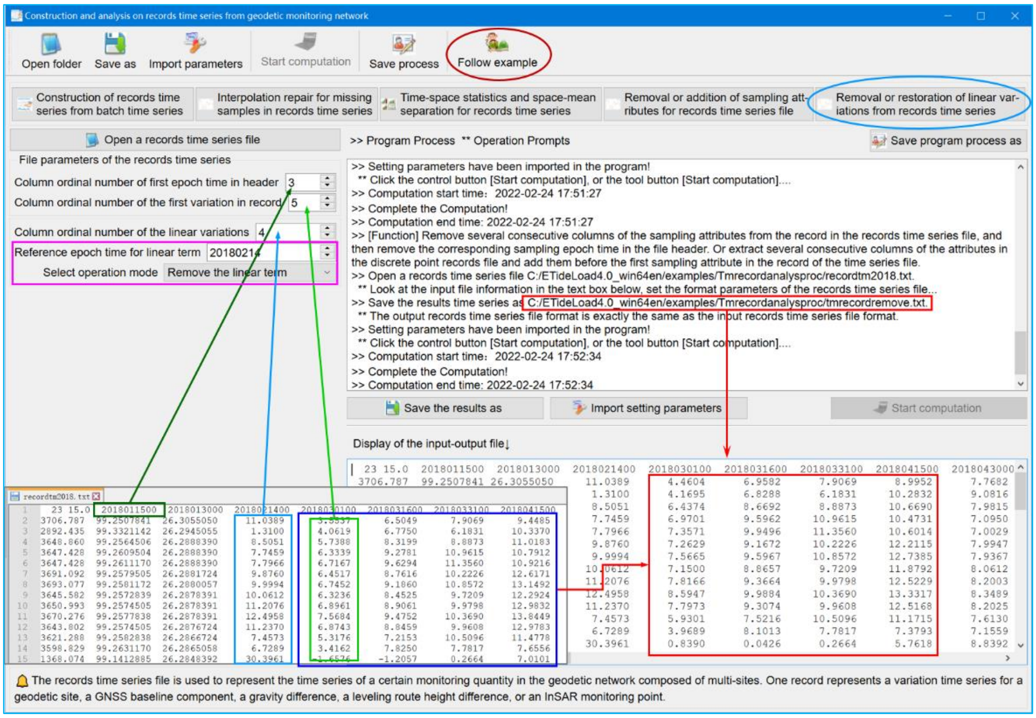
3.6.5 Removal or restoration of linear variations for records time series

[Function] From the variation records time series file record, select the column ordinal number of the linear term parameter (annual variation rate), then according to the given reference epoch time (at this time, the linear variation is equal to zero), calculate the linear variation records time series, and then remove or restore the linear variations from the input variation records time series.

[Input file] The variation records time series file.

[Parameter settings] Set the input file format parameters, enter column ordinal number of the linear term parameter in the record and the reference epoch time, and select to remove or restore the linear term.

[Output files] The result variation records time series file. The result file format is the same as that in the input records time series file.



3.7 Processing and analysis on variation (vector) grids time series

[Purpose] Perform operations such as the reference epoch transformation, difference, and statistical analysis on the variation (vector) grids time series in the specified folder. The variation (vector) grids time series files are extracted according to the given wildcards.

The variation (vector) grids time series is composed of a series of numericall grid files of a certain kind of variation (vector), and the seventh attribute of the file header in each grid file is agreed to be the sampling epoch.

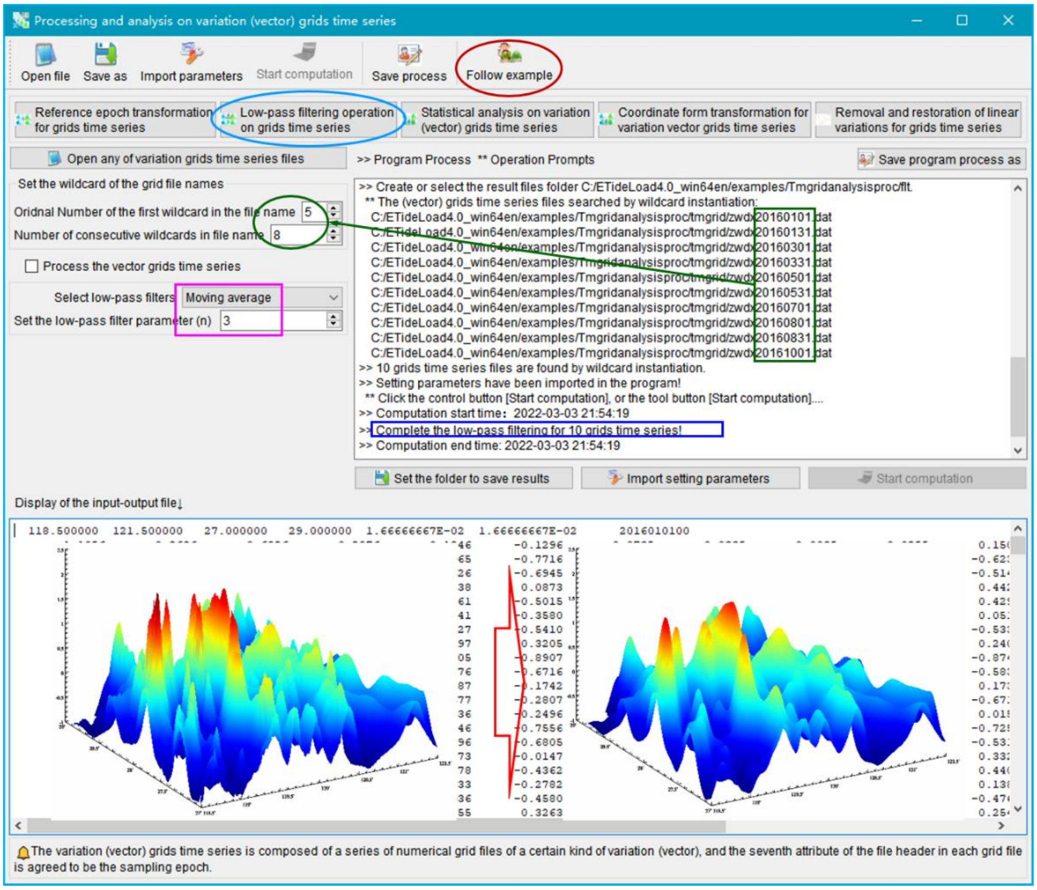
3.7.1 Reference epoch transformation for grids time series

[Function] Unify the reference epoch time for all the variation (vector) grids time series by subtracting the variation (vector) grid at the given sampling time. After the epoch is unified, the variation grid values on the reference epoch time are always zero.

3.7.2 Low-pass filtering operation on grids time series

[Function] Using the low-pass filters such as the moving average, Gaussian, exponential, or Butterworth, perform low-pass filtering on the variation grids time series. Before and after filtering, the grid specifications (Latitude and longitude range and spatial resolution) remain unchanged.

For the moving average filtering, the greater the filtering parameter n, the greater the filtering strength. For "Gaussian", "Exponential" or "Butterworth" filters, the smaller the n, the greater the filtering strength.



3.7.3 Statistical analysis on variation (vector) grids time series

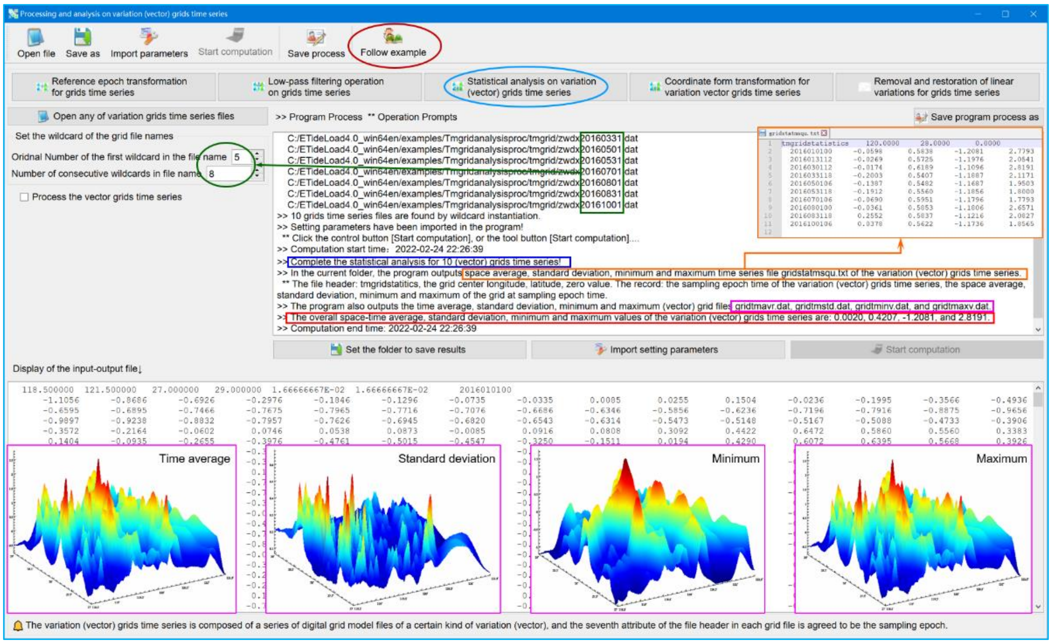
[Function] Calculate the space average, standard deviation, minimum and maximum of the variation (vector) grids time series at each sampling epoch time, to generate the space average, standard deviation, minimum and maximum (four attributes) time series file. Then generate a new variation (vector) grids time series by removing the space average grid at each epoch time. Finally, calculate the time average, standard deviation, minimum and maximum of the time series of each (vector) grid element, to generate time average, standard deviation, minimum and maximum (vector) four grids files.

The program outputs the space average, standard deviation, minimum and maximum time series file gridstatmsqu.txt of the variation (vector) grids time series.

The file header: tmgridstatitics, the grid center longitude, latitude, zero value. The record:

the sampling epoch time of the variation (vector) grids time series, the space average, standard deviation, minimum and maximum of the grid at sampling epoch time.

The program also outputs the time average, standard deviation, minimum and maximum (vector) grid files gridtmavr.dat, gridtmstd.dat, gridtminv.dat, and gridtmaxv.dat.



3.7.4 Coordinate form transformation for variation vector grids time series

[Function] The variation vector representation in the variation vector grids time series is transformed between the polar coordinate form (r, a) and the plane rectangular coordinate form (E, N).

3.7.5 Removal and restoration of linear variations for grids time series

[Function] Using the annual variation (vector) rates grid, calculate the linear variation (vector) grids time series according to the given reference epoch time (the linear variation at reference epoch time is always equal to zero), and then remove or restore the linear variations of the variation (vector) grids time series.

3.8 Multi-form spatiotemporal interpolation from grids time series

[Purpose] From the variation (vector) grids time series files in the specified folder, construct the variations time series according to the location and sampling specifications by the specified space and time interpolation method. The variation (vector) grids time series files are extracted according to the given wildcards.

The latitude and longitude of the site to be interpolated should not exceed the latitude and longitude range of the grids time series, and the interpolated epoch should not exceed the sampling time range of the grids time series by too much.

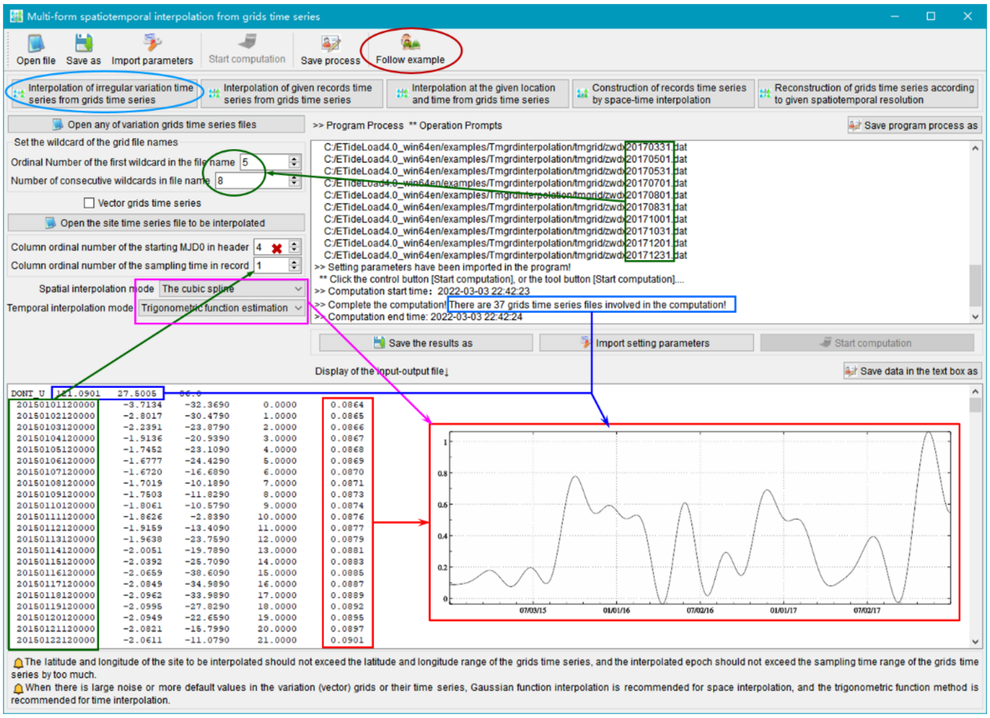
When there is large noise or more default values in the variation (vector) grids or their time series, Gaussian function interpolation is recommended for space interpolation, and the trigonometric function method is recommended for time interpolation.

3.8.1 Interpolation of irregular variation time series from grids time series

[Function] From the variation (vector) grids time series files, construct the irregular variations time series according to the location and sampling specification in the input irregular time series by the specified two-dimensional space interpolation and one-dimensional time interpolation method.

[Input file] The variation (vector) grids time series files. The site variations time series file to be interpolated.

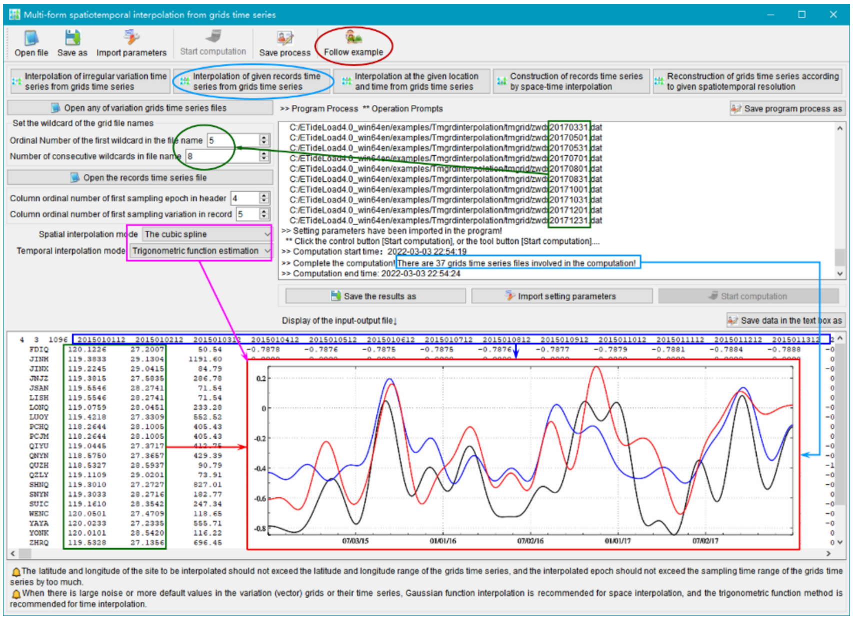
[Parameter settings] Set the wildcard patameters for the variation (vector) grids time series files and the site variations time series file format parameters. Select the space interpolation and time interpolation method.



3.8.2 Interpolation of given records time series from grids time series

[Function] Using the specified two-dimensional space interpolation and one-dimensional time interpolation method, interpolate to obtain all the sampling values of the input records time series from the variation grids time series files. The output records time series file format is the same as the input records time series file.

The program also outputs the remnant variation records time series file (file extension rnt) into the current folder. The format is the same as the input records time series file. Here the remnant variation is equal to the difference between the input sample value and the interpolation.

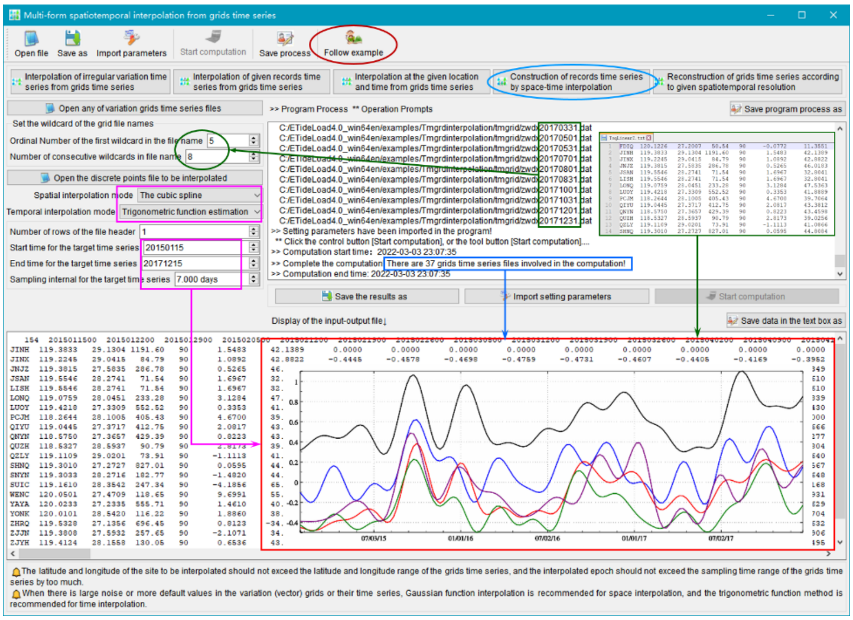


3.8.3 Interpolation at the given location and time from grids time series

[Function] Using the specified two-dimensional space interpolation and one-dimensional time interpolation method, interpolate or estimate the sampling value at the given location and epoch time from the variation grids time series files.

3.8.4 Construction of records time series by space-time interpolation

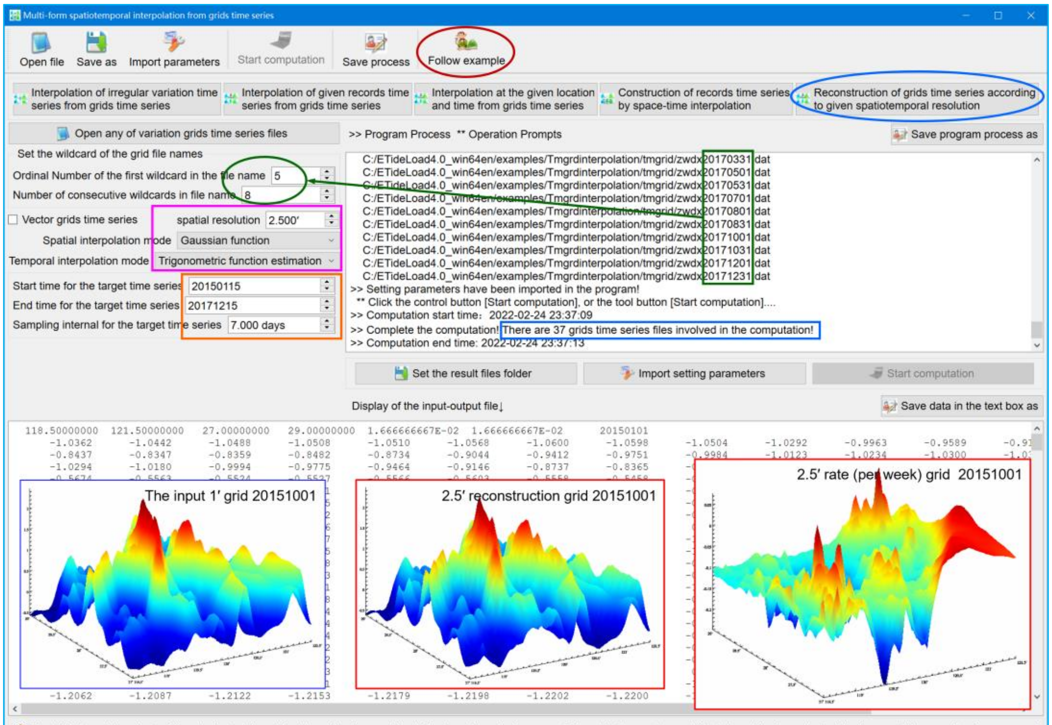
[Function] Using the specifed two-dimensional space interpolation and one-dimensional time interpolation method, from the variation grids time series files, construct the records time series at the given location sites in the input discrete points file according to the given sampling time specifications.



3.8.5 Reconstruction of grids time series according to given spatiotemporal resolution

[Function] Using the specified two-dimensional spatial interpolation and one-dimensional time interpolation or estimation method, increase or decrease the spatial and temporal resolution of the grids time series according to the given grid spatial resolution and time sampling specification, and then calculate time-derivative (per week, /wk) of the variation grids time series.

The program output the variation (vector) grids time series files grdtmsp*.dat and their time-derivative (vector) grids time series files grdtmdf.dat (per week, /wk).



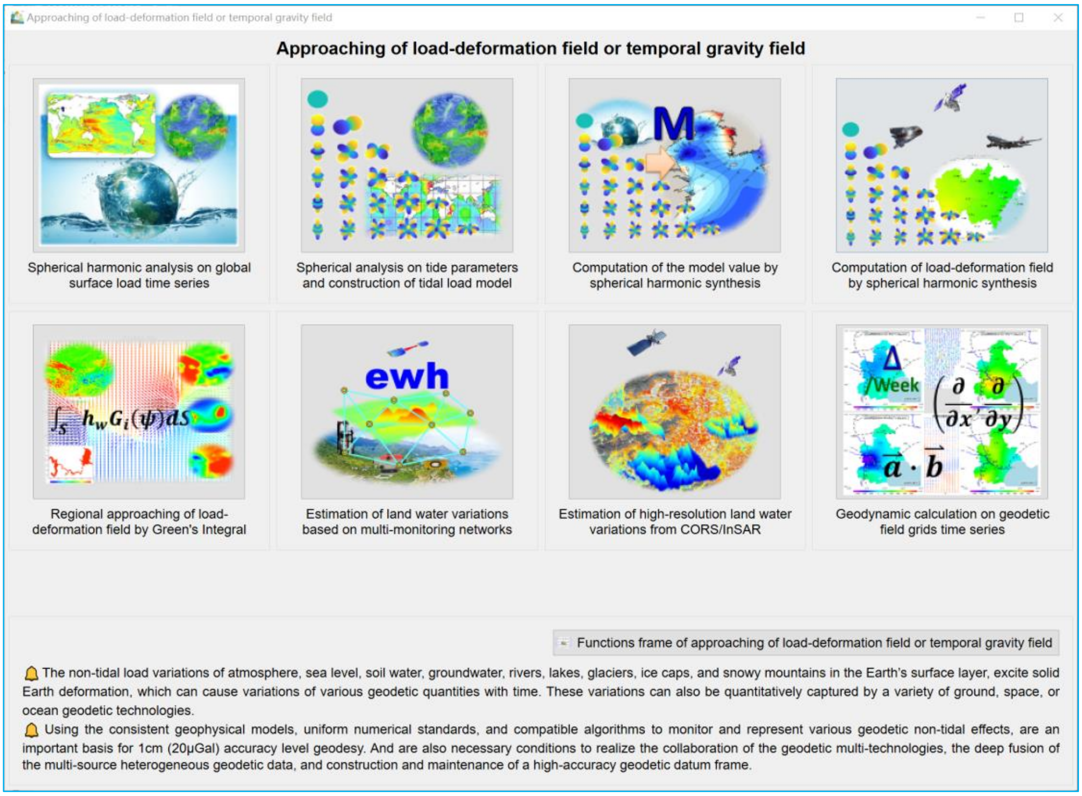
🔔 The latitude and longitude of the site to be interpolated should not exceed the latitude and longitude range of the grids time series, and the interpolated epoch should not exceed the sampling time range of the grids time series by too much.

🔔 If the variation (vector) grids or their time series have large noise or more default values, it is recommended to choose the Gaussian function method for space interpolation and the trigonometric function method for time interpolation.

4 Approaching of load-deformation field or temporal gravity field

The non-tidal load variations of atmosphere, sea level, soil water, groundwater, rivers, lakes, glaciers, ice caps, and snowy mountains in the Earth's surface layer, excite solid Earth deformation, which can cause variations of various geodetic quantities with time. These variations can also be quantitatively captured by a variety of ground, space, or ocean geodetic technologies.

Using the consistent geophysical models, uniform numerical standards, and compatible algorithms to monitor and represent various geodetic non-tidal effects, are an important basis for 1cm (20μGal) accuracy level geodesy. And are also necessary conditions to realize the collaboration of the geodetic multi-technologies, the deep fusion of the multi-source heterogeneous geodetic data, and construction and maintenance of a high-accuracy geodetic datum frame.



4.1 Spherical harmonic analysis on global surface load time series

[Purpose] From the global grid model of the surface loads such as land/sea surface air pressure, land water, and sea level variation, generate a normalized surface load spherical harmonic coefficients model by spherical harmonic analysis. Using the model, the non-tidal load effects on various geodetic quantities outside the solid Earth can be computed by the spherical harmonic synthesis method.

The spherical harmonic coefficient degree n is equal to the number of grid-elements of global surface load grid in the latitude direction. For example, the 0.25° × 0.25° global surface load grid corresponds to n=720.

4.1.1 Construction of global surface data grid in spherical coordinates

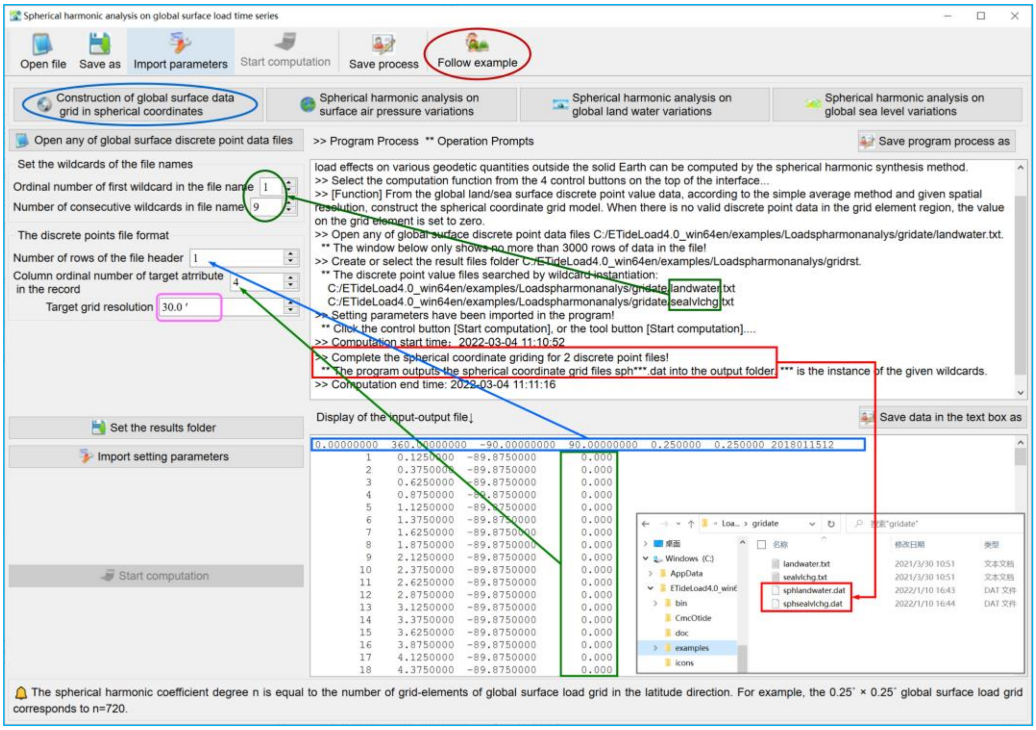
[Function] From the global land/sea surface discrete point value data, according to the simple average method and given spatial resolution, construct the spherical coordinate grid model. When there is no valid discrete point data in the grid element region, the value on the grid element is set to zero.

[Input files] A series of global land/sea surface discrete point value data files with the same format.

The file record format: Point number (name), longitude, latitude (decimal degrees), …, attribute to be gridded, ….

[Parameter settings] Set the wildcard patameters of the input file names. enter the number of rows of the input file header, row ordinal number of target attribute in the file record, and grid resolution.

[Output files] A series of spherical coordinate grid files that correspond one-to-one with the input discrete point value files.



4.1.2 Spherical harmonic analysis on global surface air pressure variations

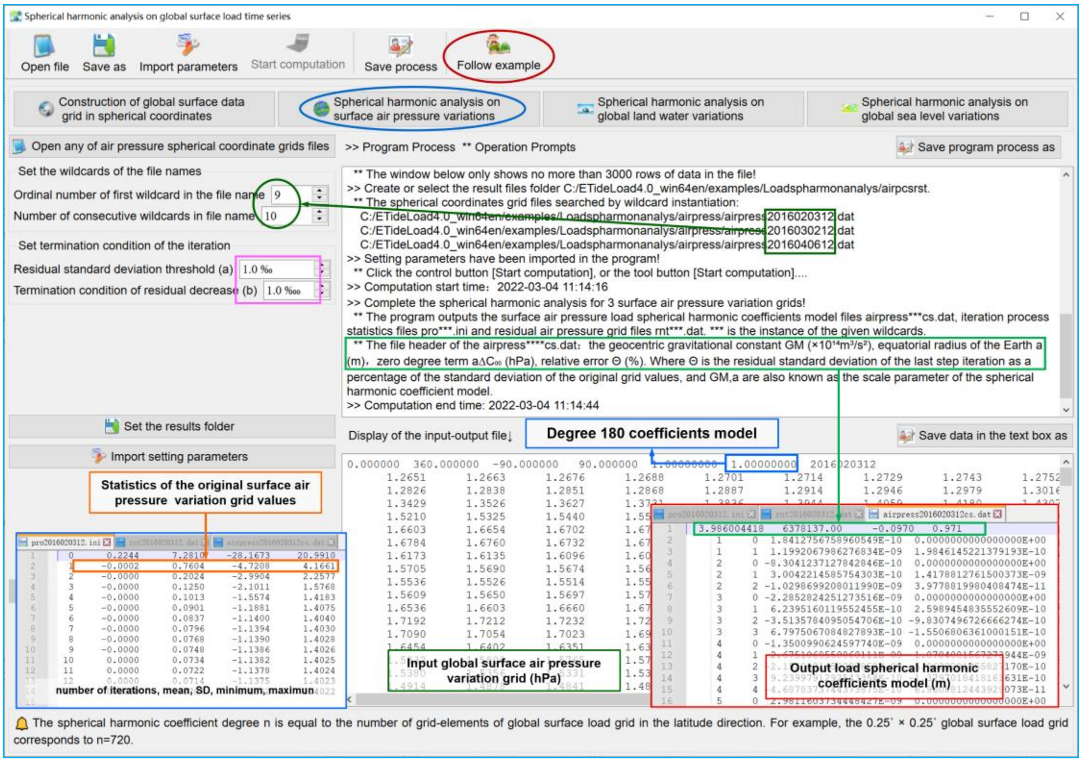
[Function] From the global land/sea surface air pressure variation (in unit hPa) spherical coordinate grids time series, compute the air pressure non-tidal load spherical harmonic coefficient models (in unit m) time series by normalized spherical harmonic analysis.

The spherical coordinate grids time series files are extracted according to the given wildcards.

[Input files] The global land/sea surface air pressure variation spherical coordinate grids time series files.

[Parameter settings] Set the wildcard patameters for the file names of grids time series and enter the iteration condition parameters.

[Output files] The surface air pressure load spherical harmonic coefficients model files airpress***cs.dat, iteration process statistics file pro***.ini and residual air pressure grid file rnt***.dat. Here, *** are the instance of the given wildcards.



The file header of the airpress****cs.dat: the geocentric gravitational constant GM ($\times10^{14}$m³/s²), equatorial radius of the Earth a (m), zero degree term $a\Delta C_{00}$ (hPa), relative error Θ (%). Where Θ is the residual standard deviation of the last step iteration as a percentage of the standard deviation of the original grid values, and GM, a are also known as the scale parameter of the spherical harmonic coefficient model.

The zero degree term represents the variations of the total atmospheric mass caused by the variation of global atmospheric pressure, which is meaningless under the condition of Earth's atmospheric mass conservation. The three first degree spherical harmonic coefficients (ΔC_{10}, ΔC_{11}, ΔS_{11}) represent variations of the Earth's center of mass due to the variations of global atmospheric pressure.

4.1.3 Spherical harmonic analysis on global land water variations

[Function] From the global land equivalent water height variation (in unit cm) spherical coordinate grids time series, compute the land water non-tidal load spherical harmonic coefficient models (in unit m) time series by normalized spherical harmonic analysis.

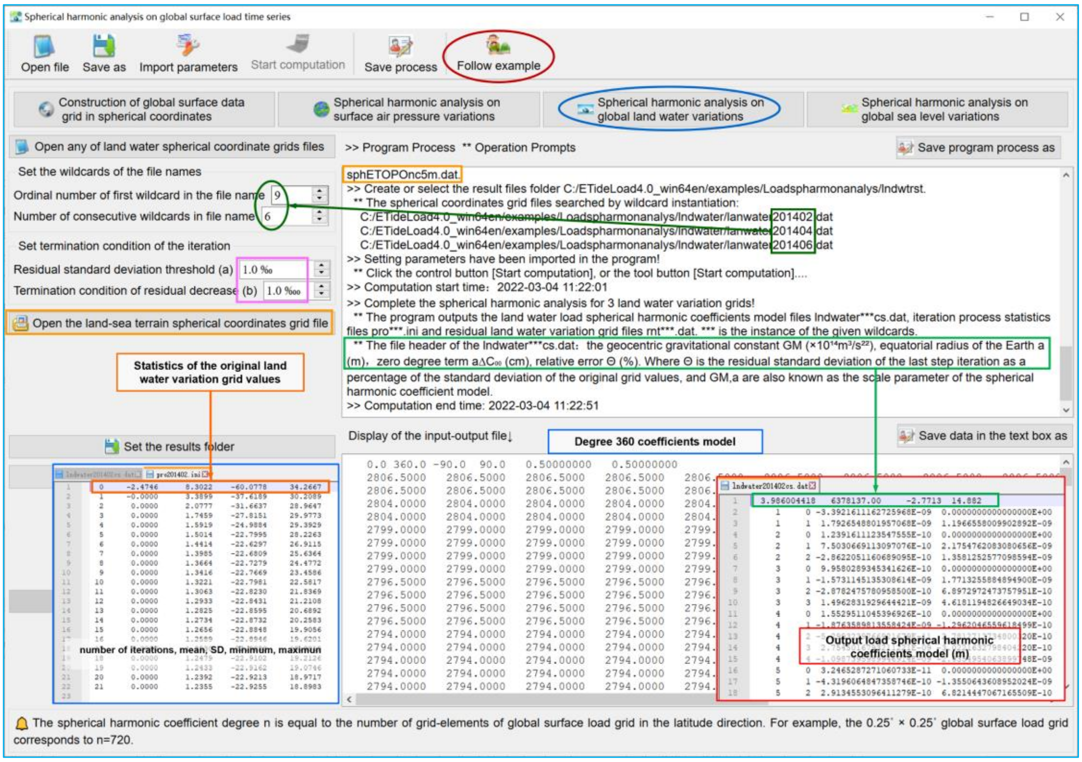
[Input files] The global land equivalent water height variation spherical coordinate grids time series files. The land-sea terrain spherical coordinates grid file.

The spatial resolution of the land-sea terrain grid should not be lower than the spatial resolution of the surface loads grid.

[Parameter settings] Set the wildcard patameters for the file names of grids time series and enter the iteration condition parameters.

[Output files] The global land water load spherical harmonic coefficients model files lndwater***cs.dat, Iteration process statistics file pro***.ini and Residual air pressure grid file rnt***.dat. Here, *** are the instance of the given wildcards.

The file header of the lndwater***cs.dat： the geocentric gravitational constant GM ($\times10^{14}m^3/s^2$), equatorial radius of the Earth a (m)，zero degree term $a\Delta C_{00}$ (cm), relative error ϴ (%).



The three first degree spherical harmonic coefficients (ΔC_{10}, ΔC_{11}, ΔS_{11}) represent variations of the Earth's center of mass due to variations of global land water. For global geodetic purposes, the first degree spherical harmonic coefficients needs to be taken into account. The zero-order term can be controlled to a small value by adjusting the time datum.

4.1.4 Spherical harmonic analysis on global sea level variations

[Function] From the global sea level variation (in unit cm) spherical coordinate grids time series, compute the sea level variation non-tidal load spherical harmonic coefficient models (in unit m) time series by normalized spherical harmonic analysis.

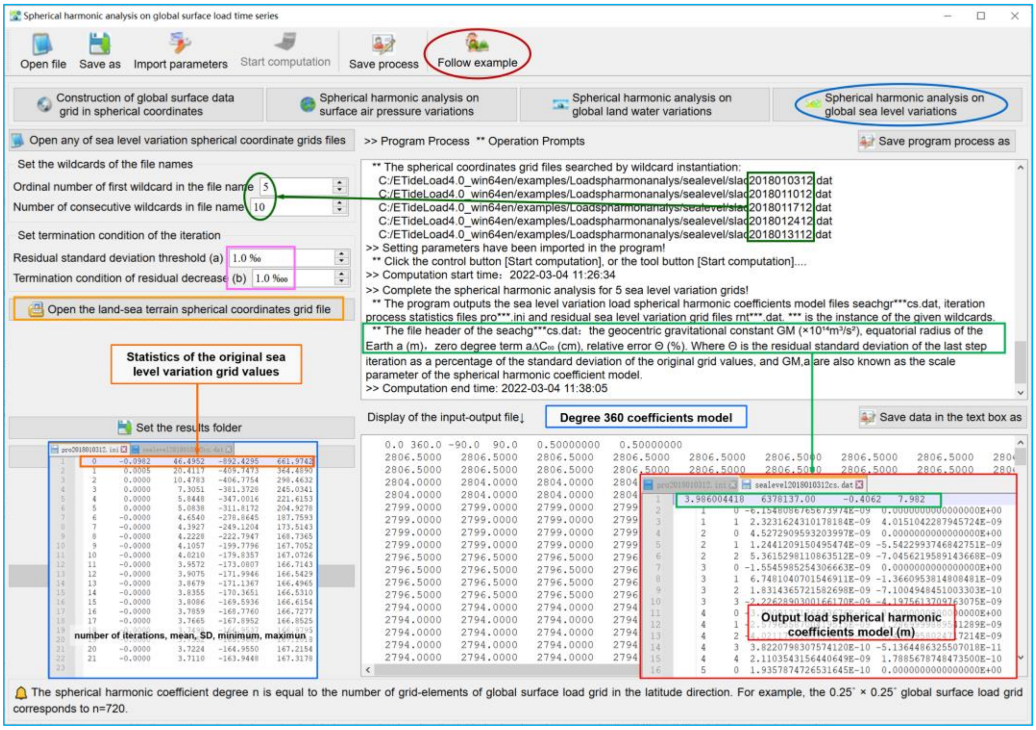
[Input files] The global sea level variation spherical coordinate grids time series files. The land-sea terrain spherical coordinates grid file.

The spatial resolution of the land-sea terrain grid should not be lower than the spatial resolution of the surface loads grid.

[Parameter settings] Set the wildcard patameters for the file names of grids time series and enter the iteration condition parameters.

Iteration termination condition: The standard deviation of the residual grid value is less than a% of the standard deviation of the original grid value, or the difference of the residual standard deviation of the previous step iteration relative to the current step iteration is less than b‰ of the standard deviation of the original grid values.

[Output files] The global sea level variation load spherical harmonic coefficients model files seachg***cs.dat, iteration process statistics files pro***.ini and residual sea level variation grid files rnt***.dat. Here, *** are the instance of the given wildcards.



The three first degree spherical harmonic coefficients (ΔC_{10}, ΔC_{11}, ΔS_{11}) represent variations of the Earth's center of mass due to global sea level variations. For global geodetic purposes, the first degree spherical harmonic coefficients needs to be taken into account. The zero-order term can be controlled to a small value by adjusting the time datum.

For global geodetic purposes, the zero constraint should be considered that the sum of the zero-order terms of sea, land and atmosphere at any epoch time is equal to zero, that is, the total loads of sea level, land water and atmospheric pressure variations is conserved.

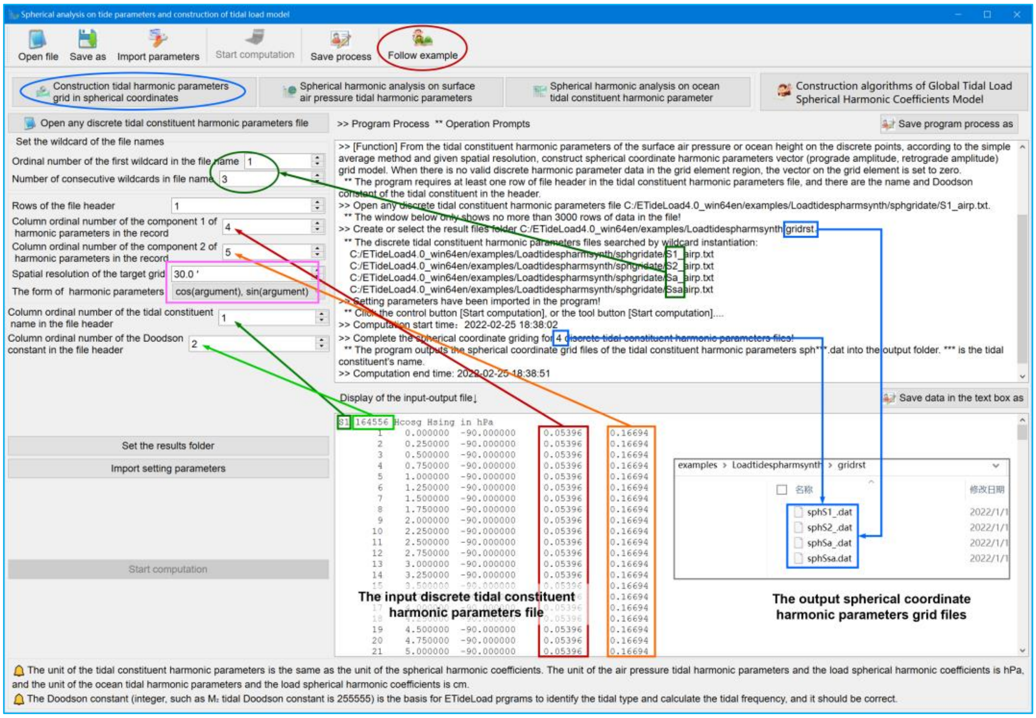
4.2 Spherical analysis on tide parameters and construction of tidal load model

[Purpose] From the tidal constituent harmonic parameters grid of the global land/sea air pressure or ocean height, generate a normalized tidal load spherical harmonic coefficients model by spherical harmonic analysis. The model format is the same as FES2004 ocean tidal load model in the IERS conventions (2010). Using the model, the tidal load effects on various geodetic quantities outside the solid Earth can be computed by the spherical harmonic synthesis method.

4.2.1 Construction tidal harmonic parameters grid in spherical coordinates

[Function] From the tidal constituent harmonic parameters of the surface air pressure or ocean height on the discrete points, according to the simple average method and given spatial resolution, construct spherical coordinate harmonic parameters vector (prograde amplitude, retrograde amplitude) grid model. When there is no valid discrete harmonic parameter data in the grid element region, the vector on the grid element is set to zero.

[Input files] A series of global discrete tidal constituent harmonic parameters files with the same format.



The program requires at least one row of file header in the tidal constituent harmonic parameters file, and there are the name and Doodson constant of the tidal constituent in the file header.

The Doodson constant (integer, such as M_2 tidal Doodson constant is 255555) is the basis for ETideLoad prgrams to identify the tidal type and calculate the tidal frequency, and it should be correct.

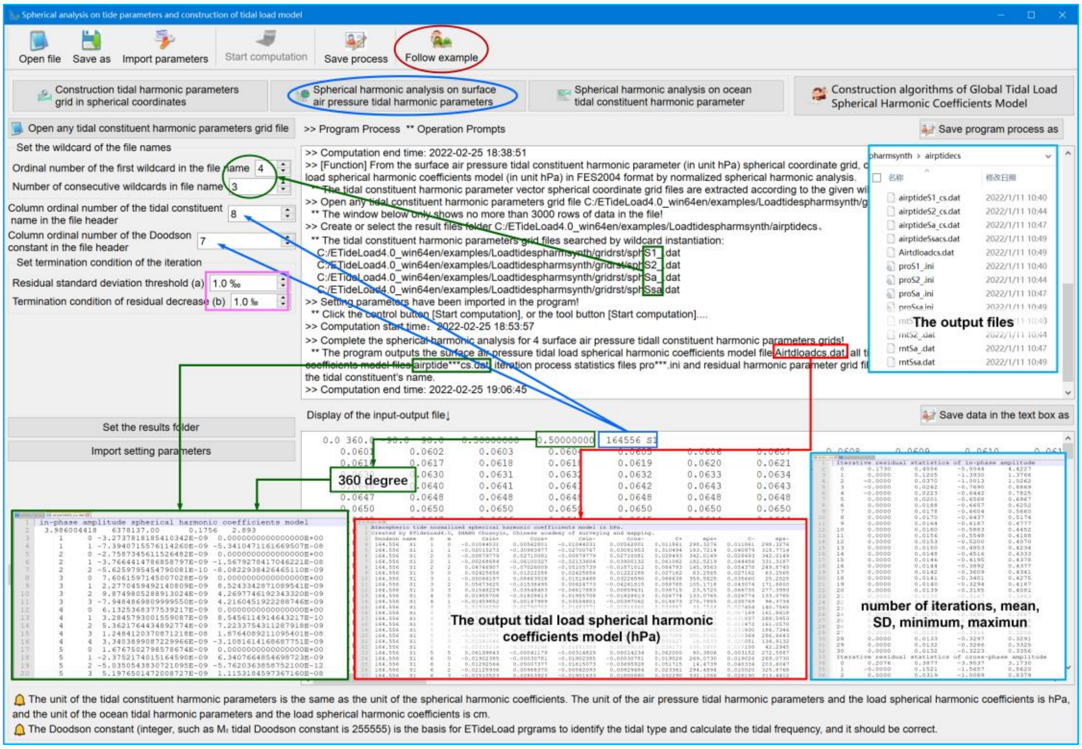
[Parameter settings] Set the wildcard patameters of the input file names. Enter the number of rows of the input file header, column ordinal number of the tidal constituent name and its Doodson constant the input file header, column ordinal number of the component 1 and 2 of harmonic parameters in the record, and select the form of harmonic parameters.

[Output files] The spherical coordinate grid files of the tidal constituent harmonic parameters sph***.dat. Here, *** are the tidal constituent's name.

4.2.2 Spherical harmonic analysis on surface air pressure tidal harmonic parameters

[Function] From the surface air pressure tidal constituent harmonic parameter (in unit hPa) spherical coordinate grid, compute the surface air pressure tidal load spherical harmonic coefficients model (in unit hPa) in FES2004 format by normalized spherical harmonic analysis.

The tidal constituent harmonic parameter vector spherical coordinate grid files are extracted according to the given wildcards.



[Input files] All the surface air pressure tidal constituent harmonic parameter vector spherical coordinate grid files.

[Parameter settings] Set the wildcard patameters for the file names, enter the column ordinal number of the tidal constituent's name and its Doodson constant the input file header, and set the iteration condition parameters.

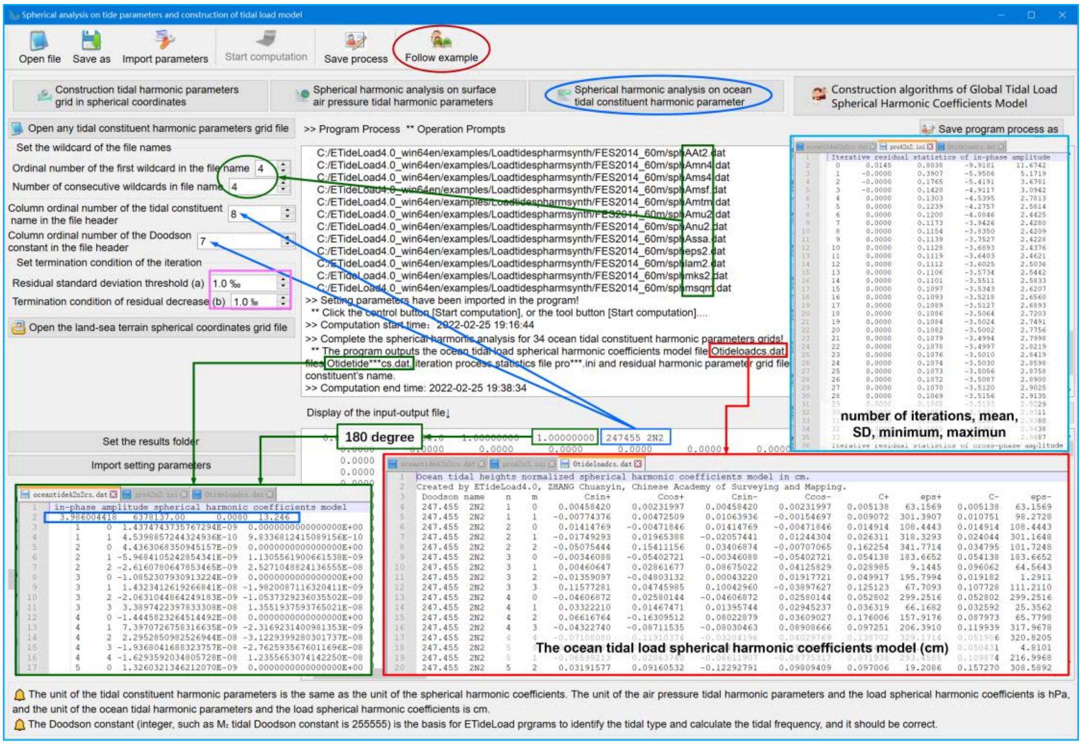
[Output files] The surface air pressure tidal load spherical harmonic coefficients model file Airtdloadcs.dat, all tidal constituent spherical harmonic coefficients model files airptide***cs.dat, iteration process statistics files pro***.ini and residual harmonic parameter grid files rnt***.dat. Here, *** are the tidal constituent's name.

4.2.3 Spherical harmonic analysis on ocean tidal constituent harmonic parameters

[Function] From the ocean tidal constituent harmonic parameter (in unit cm) spherical coordinate grid, compute the ocean tidal load spherical harmonic coefficients model (in unit cm) in FES2004 format by spherical harmonic analysis.

[Input files] All the ocean tidal constituent harmonic parameter vector spherical coordinate grid files. The land-sea terrain spherical coordinates grid file.

The land-sea terrain spherical coordinates grid is used for the land-sea separation for the ocean tidal harmonic parameters, whose resolution should not be lower than the resolution of the ocean tidal constituent harmonic parameters grid.



[Output files] The ocean tidal load spherical harmonic coefficients model file Otideloadcs.dat, all tidal constituent spherical harmonic coefficients model files Otidetide***cs.dat, iteration process statistics file pro***.ini and residual harmonic parameter grid file rnt***.dat. Here, *** are the tidal constituent's name.

The unit of the tidal constituent harmonic parameters is the same as the unit of the spherical harmonic coefficients. The unit of the surface air pressure tidal harmonic parameters and the load spherical harmonic coefficients is hPa, and the unit of the ocean tidal harmonic parameters and the load spherical harmonic coefficients is cm.

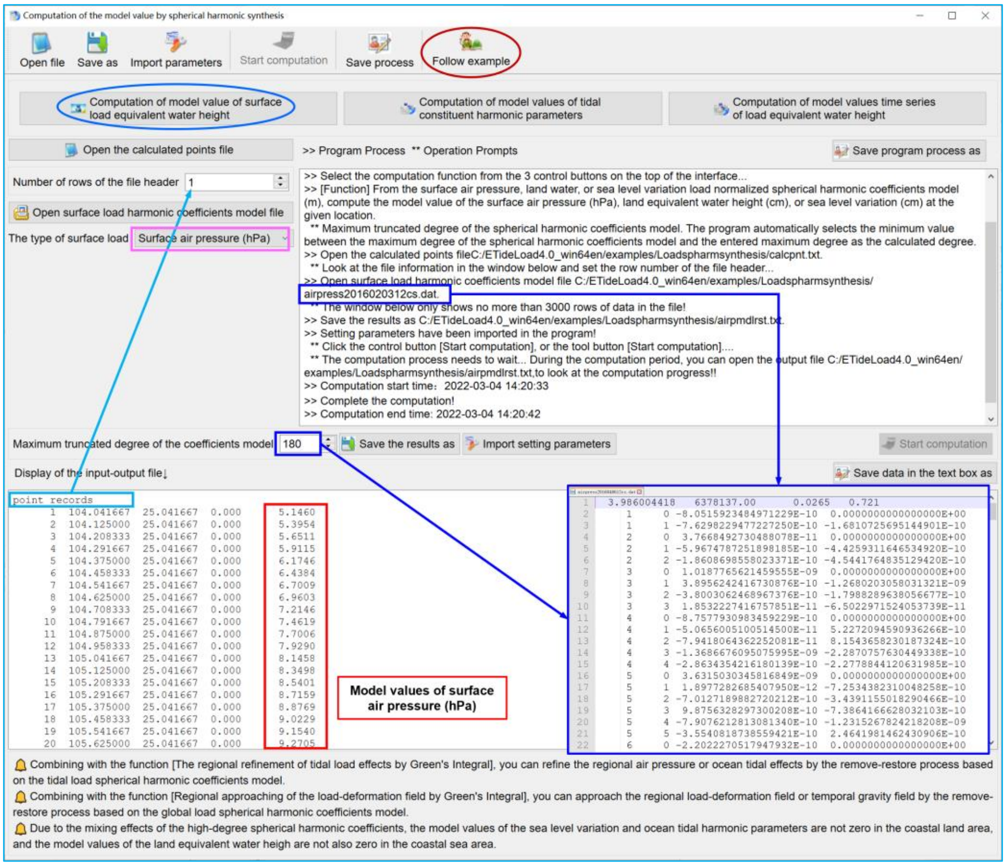
4.3 Computation of the model value by spherical harmonic synthesis

[Purpose] From the tidal load spherical harmonic coefficients model or the surface non-tidal load spherical harmonic coefficients model, calculate the model values of the tidal harmonic parameters or the non-tidal surface loads by spherical harmonic synthesis.

Adopting the remove-restore process, the program can be used for regional tidal load effects refinement based on the tidal load spherical harmonic coefficients model, and for regional load-deformation field and temporal gravity field approaching based on the surface load spherical harmonic model.

4.3.1 Computation of model value of surface load equivalent water height

[Function] From the surface air pressure, land water, or sea level variation load normalized spherical harmonic coefficients model (m), compute the model value of the surface air pressure (hPa), land equivalent water height (cm), or sea level variation (cm) at the given location.



[Input files] The discrete calculated points file. The surface load spherical harmonic coefficients model file.

The calculated points file record format: Point number (name), longitude, latitude (decimal degrees), ….

[Parameter settings] Enter maximum truncated degree of the coefficients model, and select the type of surface loads.

The program automatically selects the minimum value between the maximum degree of the spherical harmonic coefficients model and the entered maximum degree as the calculated degree.

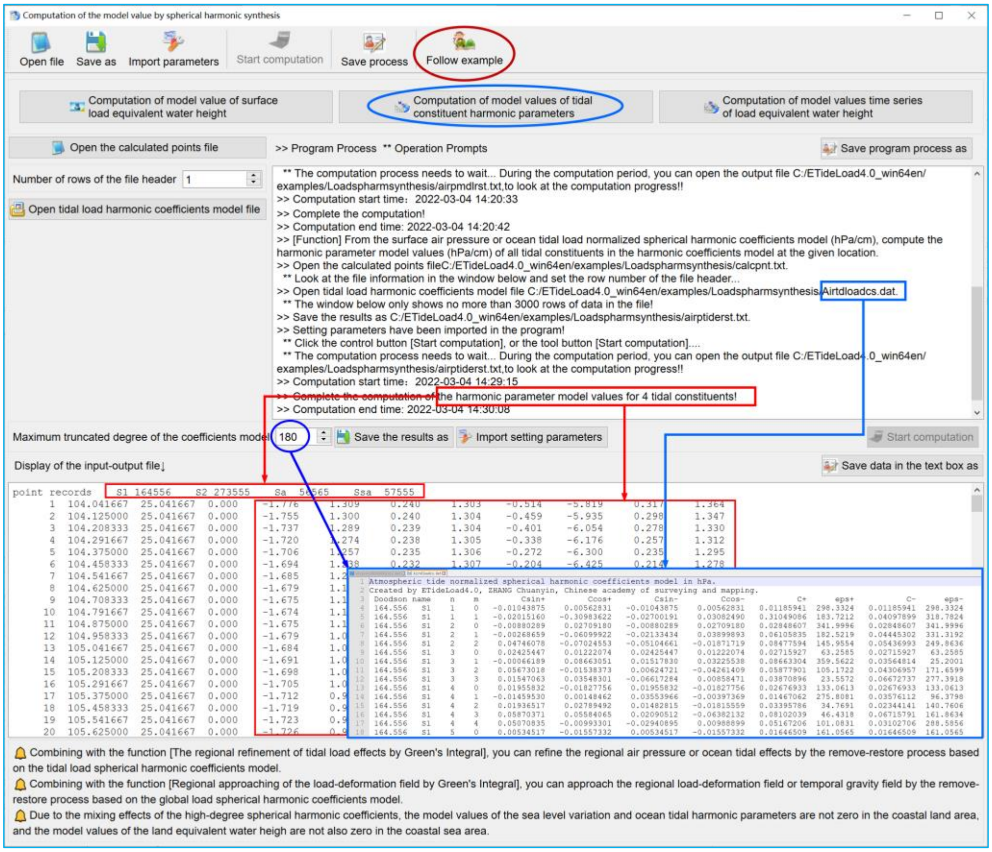
[Output file] The surface load model values file.

The output file header comes from the input calculated points file. Behind the input file record, add a column of the model value of surface load as the output file record.

4.3.2 Computation of model values of tidal constituent harmonic parameters

[Function] From the surface air pressure or ocean tidal load normalized spherical harmonic coefficients model (hPa/cm), compute the harmonic parameter model values (hPa/cm) of all tidal constituents in the harmonic coefficients model at the given location.

[Input files] The discrete calculated points file. The tidal load spherical harmonic coefficients model file.



[Output file] The tidal harmonic parameter model values file.

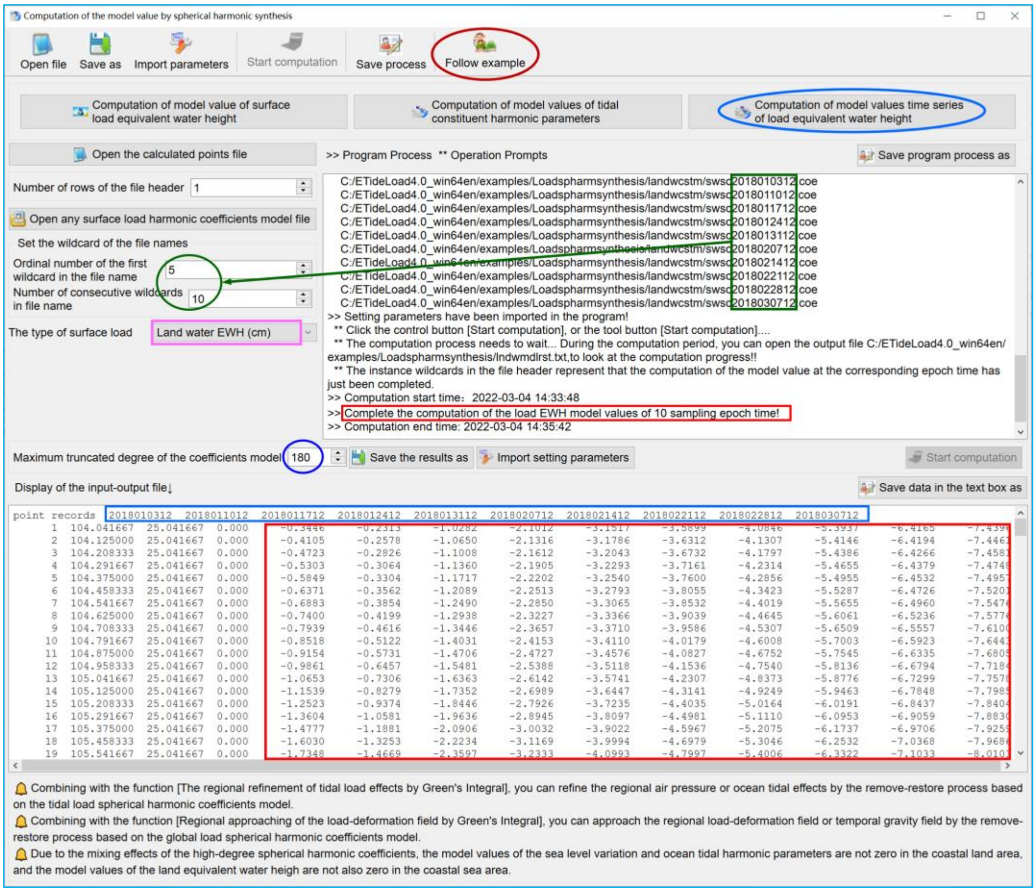
The output file header comes from the input calculated points file. Behind the input file record, add 2n columns of the tidal harmonic parameter model values as the output file record. Here, n is the number of tidal constituents in the harmonic coefficients model.

4.3.3 Computation of model values time series of load equivalent water height

[Function] From the surface air pressure, land water, or sea level variation load normalized spherical harmonic coefficients model (m) time series, compute the records time series of the model value of the air pressure (hPa), land equivalent water height (cm), or sea level variation (cm) on the given points in the input file.

[Input files] The discrete calculated points file. The surface load spherical harmonic coefficients model time series files.

[Parameter settings] Set the wildcard patameters for the surface load spherical harmonic coefficients model time series files. Enter the number of rows of the input file header, row ordinal number of target attribute, and grid resolution.



[Output file] The surface load model value records time series file.

Behind the input file header, add n sampling epoch times of the surface load spherical harmonic coefficients model time series as the output file header. Behind the input file record, add n load model values as the output record. Here, n is the sampling number.

The computation process needs to wait... During the computation period, you can open the output files to look at the computation progress!

The instance wildcards in the file header represent that the computation of the model value at the corresponding epoch time has just been completed.

Combining with the function [The regional refinement of tidal load effects by Green's Integral], you can refine the regional air pressure or ocean tidal effects by the remove-restore process based on the tidal load spherical harmonic coefficients model.

Combining with the function [Regional approaching of the load-deformation field by Green's Integral], you can approach the regional load-deformation field or temporal gravity field by remove-restore process based on global load spherical harmonic coefficients model.

Due to the mixing effects of the high-degree spherical harmonic coefficients, the model values of the sea level variation and ocean tidal harmonic parameters are not zero in the coastal land area, and the model values of the land equivalent water heigh are not also zero in the coastal sea area.

4.4 Computation of load-deformation field by spherical harmonic synthesis

[Purpose] From the surface air pressure, land water, and sea level variation load spherical harmonic coefficients model (m), compute the load effects on various geodetic variations on the ground or outside the solid Earth by the spherical harmonic synthesis algorithm.

The time of the load effects is equal to the sampling epoch time of the load spherical harmonic coefficients model.

When computing the load effects of sea level variations, the height of the calculated point is the normal or orthometric height. When computing the load effects of surface air pressure or land water variations, the height of the calculated point is the height relative to the Earth’s surface.

4.4.1 Computation of various load effects by spherical harmonic synthesis

[Function] From the surface air pressure, land water, and sea level variation load spherical harmonic coefficients model (m), compute the load effects on the geoid or height anomaly (mm), ground gravity (μGal), gravity disturbance (μGal), ground tilt (SW, to the south and to the west, mas), vertical deflection (SW, to the south and to the west, mas), horizontal displacement (EN, to the east and to the north, mm), ground radial displacement (mm), ground normal or orthometric height (mm), disturbing gravity gradient (10μE) or horizontal gravity gradient (NE, to the north and to the east, 10μE) by the spherical harmonic synthesis.

[Input files] The discrete calculated points file. The surface load spherical harmonic coefficients model file.

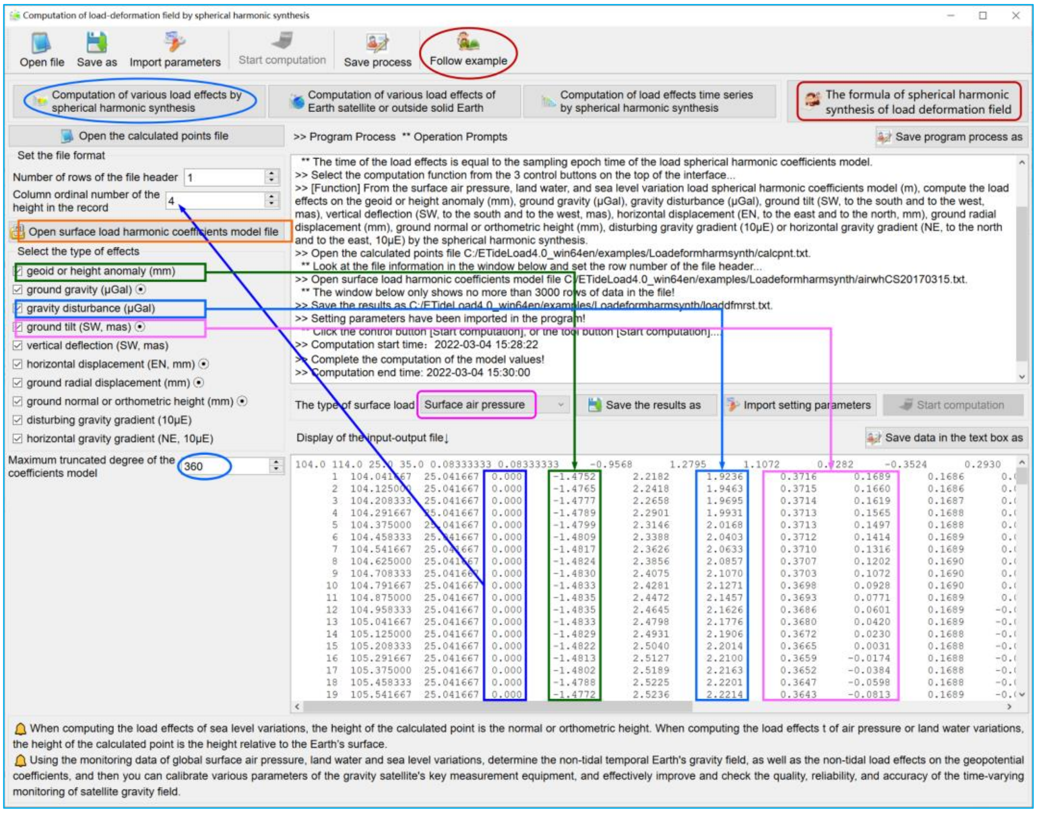
The calculated points file record format: Point number (name), longitude, latitude (decimal degrees), height….

[Parameter settings] Enter column ordinal number of the height in the input file record and maximum truncated degree of the spherical harmonic coefficients model, and select the type of surface loads.

The program automatically selects the minimum value between the maximum degree of the spherical harmonic coefficients model and the entered maximum degree as the calculated degree.

[Output file] The surface load effects file.

The file header is the same as the input file. Behind the input file record, add one or several columns of the surface load effects selected as the output file record. In this example, all types are selected, and there are 14 attributes added to the record.



4.4.2 Computation of various load effects of Earth satellite or outside solid Earth

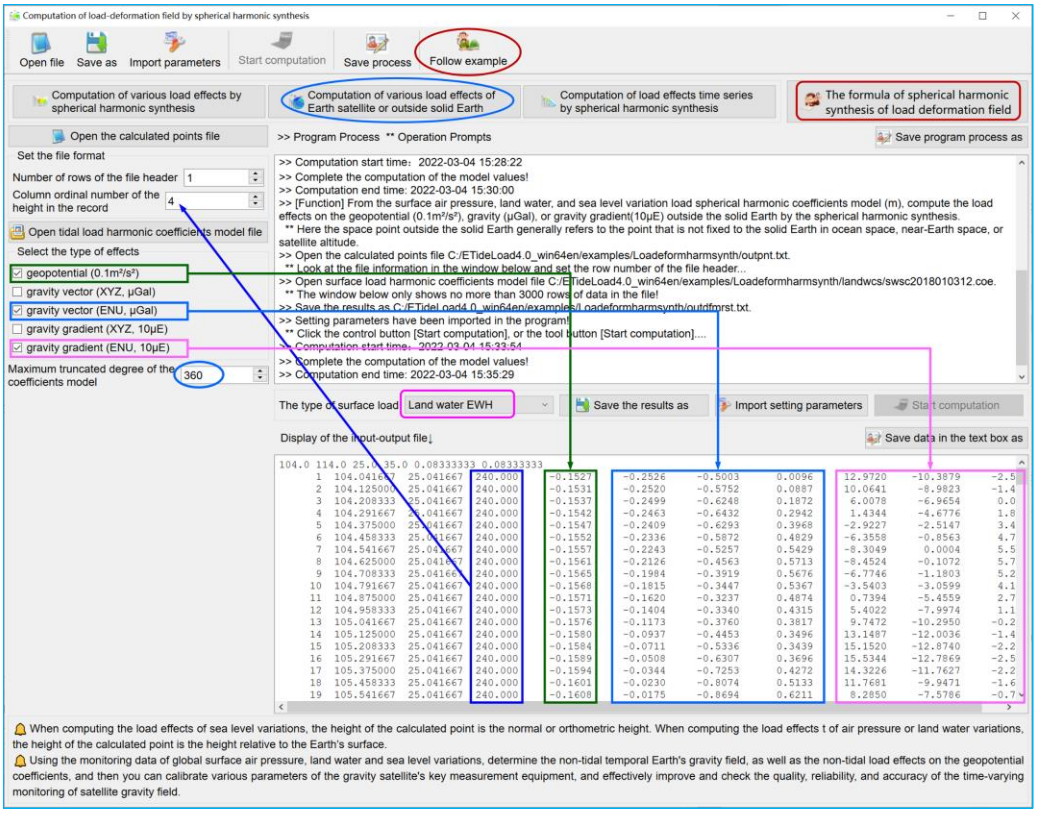
[Function] From the surface air pressure, land water, and sea level variation load spherical harmonic coefficients model (m), compute the load effects on the geopotential (0.1m²/s²), gravity (μGal), or gravity gradient(10μE) outside the solid Earth by the spherical harmonic synthesis.

Here the space point outside the solid Earth generally refers to the point that is not fixed to the solid Earth in ocean space, near-Earth space, or satellite altitude.

[Input files] The discrete calculated points file. The surface load spherical harmonic coefficients model file.

[Output file] The surface load effects file.

The file header is the same as the input file. Behind the input file record, add one or several columns of the surface load effects selected as the output file record.



4.4.3 Computation of load effects time series by spherical harmonic synthesis

[Function] From the surface air pressure, land water, and sea level variation load spherical harmonic coefficients model (m) time series, compute the time series of the load effects on various variations on the computed points in the input file by the spherical harmonic synthesis.

[Input files] The discrete calculated points file. The surface load spherical harmonic coefficients model time series file.

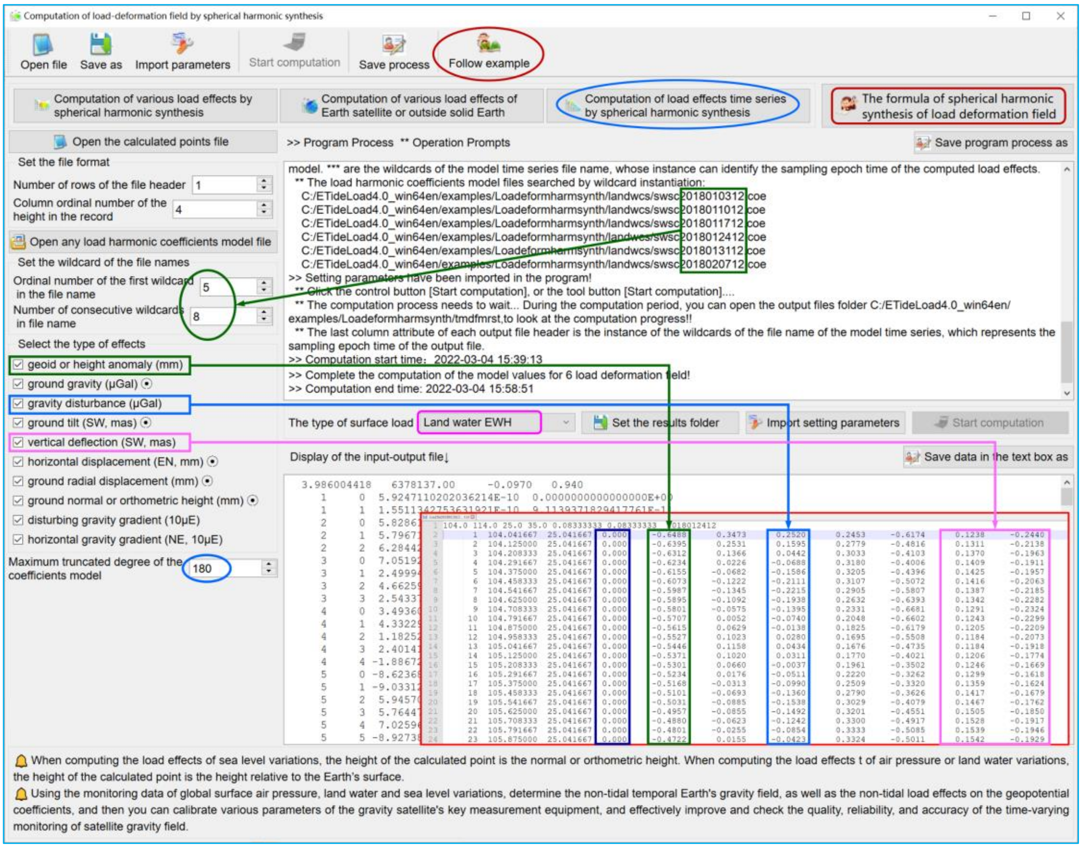
The time series files of the load spherical harmonic coefficients model are extracted according to the given wildcards.

[Output file] The surface load effects files load***.txt.

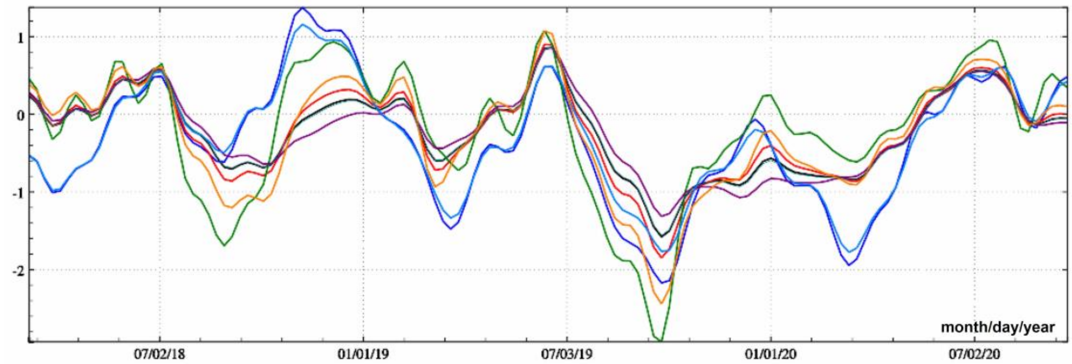
The number of output files is equal to the number of the time series files of the load spherical harmonic coefficients model. Here, *** are the wildcards of the model time series file name, whose instance can identify the sampling epoch time of the computed load effects.

The computation process needs to wait... During the computation period, you can open the output files folder to look at the computation progress!

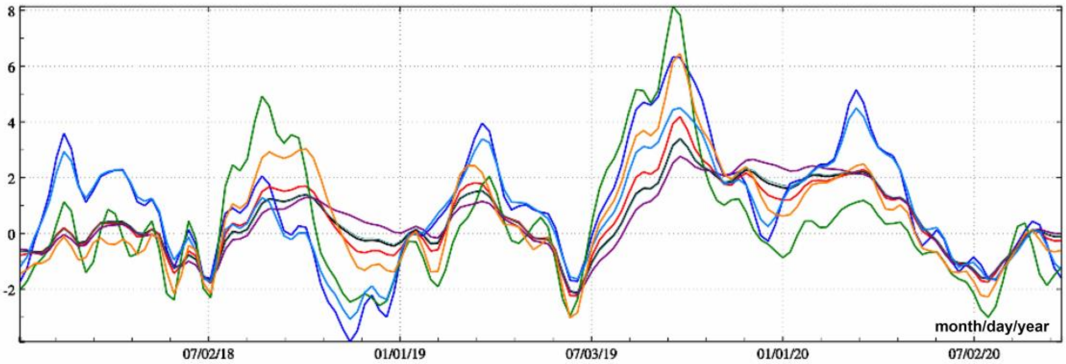
The last column attribute of each output file header is the instance of the wildcards of the file name of the model time series, which represents the sampling epoch time of the output file.



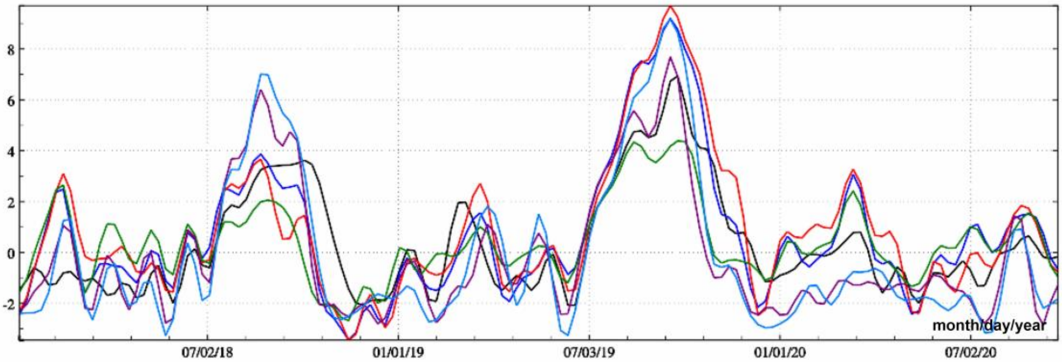
Using the monitoring data of global surface air pressure, land water and sea level variations, determine the non-tidal temporal Earth's gravity field, as well as the non-tidal load effects on the geopotential coefficients, and then you can calibrate various parameters of the gravity satellite's key measurement equipment, and effectively improve and check the quality, reliability, and accuracy of the time-varying monitoring of satellite gravity field.



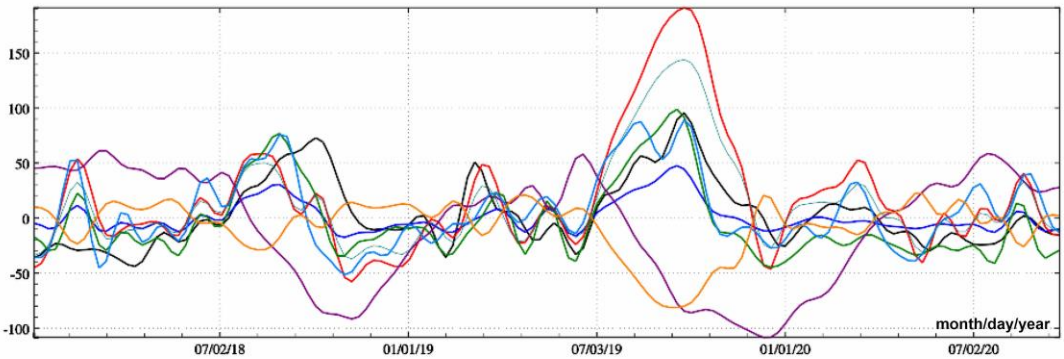
Soil water load deformation with time in Chinese mainland (360 degree model): geoidal variation (mm)



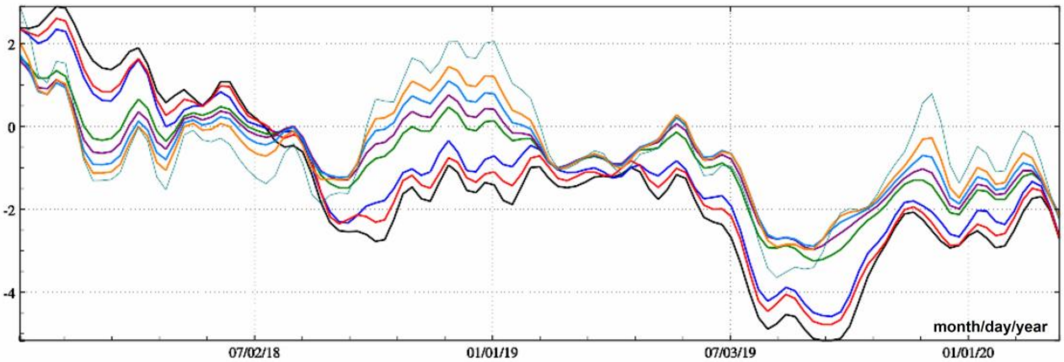
Soil water load deformation with time in Chinese mainland (360 degree model): ground normal height variation (mm)



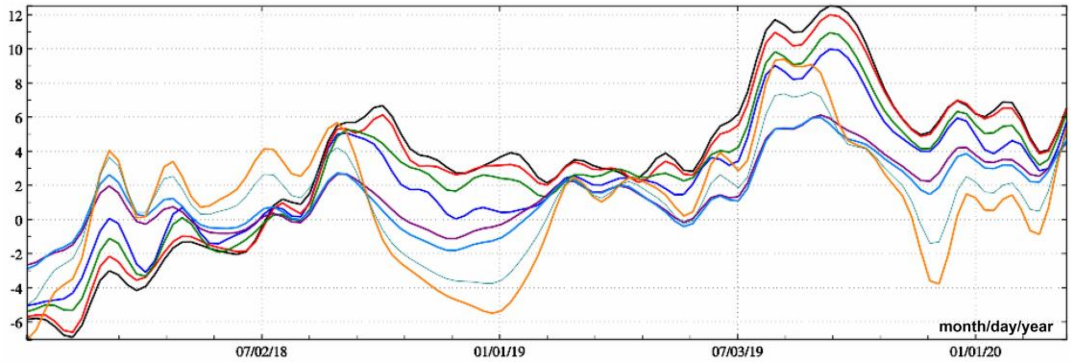
Soil water load deformation with time in Chinese mainland (360 degree model): gravity disturbance variation (μGal)



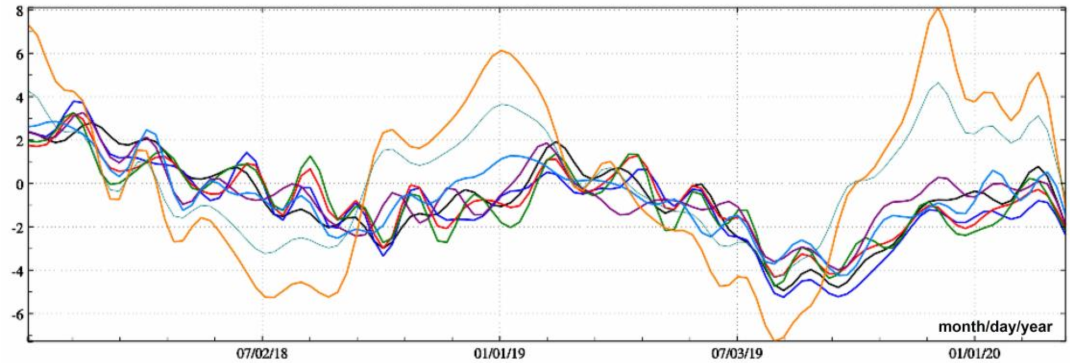
Soil water load deformation with time in Chinese mainland (360 degree model): disturbing gravity gradient variation (10μE)



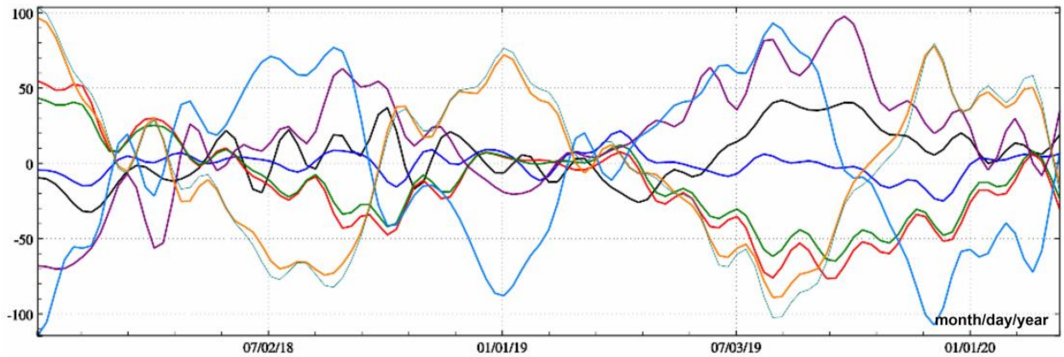
Sea level load deformation with time in Chinese coastal zone (360 degree model): geoidal variation (mm)



Sea level load deformation with time in Chinese coastal zone (360 degree model): normal height variation (mm)



Sea level load deformation with time in Chinese coastal zone (360 degree model): gravity disturbance variation (μGal)



Sea level load deformation with time in Chinese coastal zone (360 degree model): disturbing gravity gradient variation (10μE)

4.5 Regional approaching of load-deformation field by Green's Integral

[Purpose] Firstly, execute the program [Computation of tide and load model value by spherical harmonic synthesis] to calculate and remove the load model values from the regional surface air pressure, land water, or sea level variation to obtain the residual load grid. Then, calculate the residual load-deformation field and the temporal gravity field grid by Green's integral. Finally, execute the program [Computation of load-deformation field by spherical harmonic synthesis] to calculate and restore the model values grid of the load effects, to approach the regional load-deformation field and temporal gravity field.

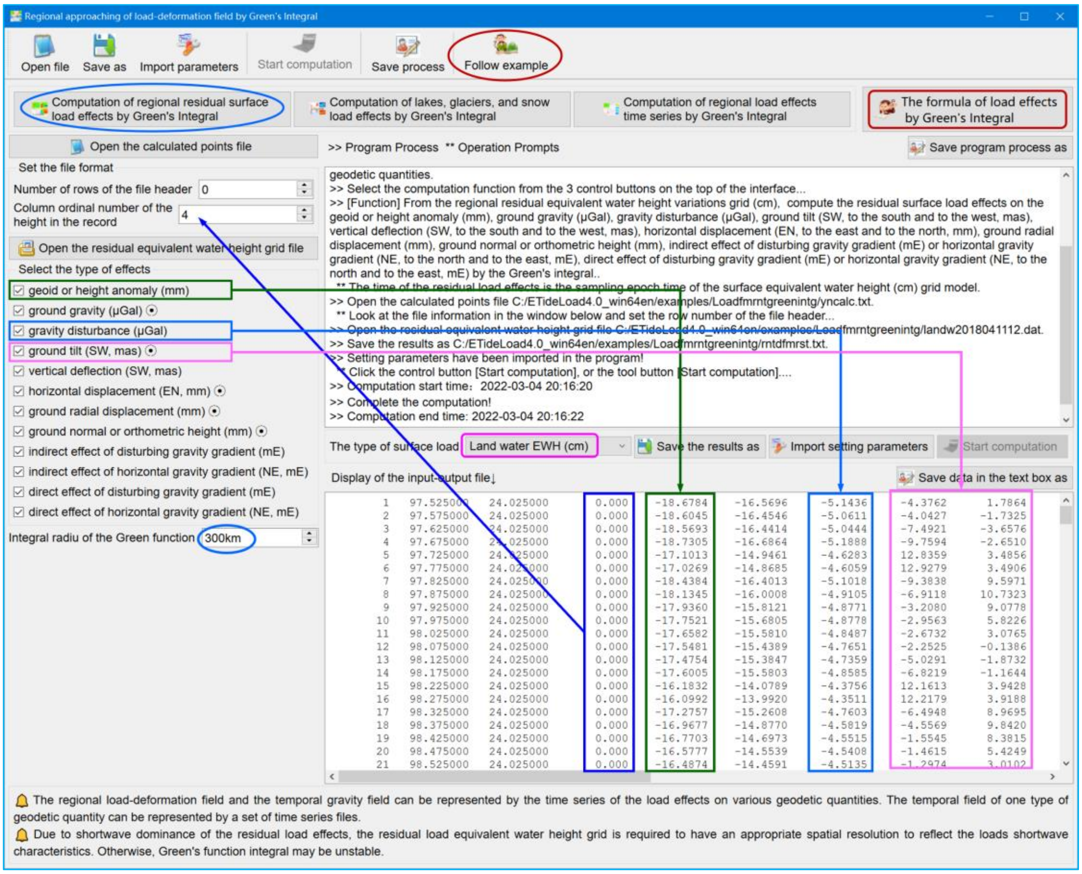
The regional load-deformation field and the temporal gravity field can be represented by the time series of the load effects on various geodetic quantities. The temporal field of one type of geodetic quantity can be represented by a set of time series files.

4.5.1 Computation of regional residual surface load effects by Green's Integral

[Function] From the regional residual equivalent water height variations grid (cm), compute the residual surface load effects on the geoid or height anomaly (mm), ground gravity (μGal), gravity disturbance (μGal), ground tilt (SW, to the south and to the west, mas), vertical deflection (SW, to the south and to the west, mas), horizontal displacement (EN, to the east and to the north, mm), ground radial displacement (mm), ground normal or orthometric height (mm), indirect effect of disturbing gravity gradient (mE) or horizontal gravity gradient (NE, to the north and to the east, mE), direct effect of disturbing gravity gradient (mE) or horizontal gravity gradient (NE, to the north and to the east, mE) by the Green's integral.

[Input files] The discrete calculated points file. The regional residual equivalent water height variations grid file.

The calculated points file record format: Point number (name), longitude, latitude (decimal degrees), height….



[Parameter settings] Set the calculated points file format parameter, enter the load Green's integral radiu, and select the type of surface loads.

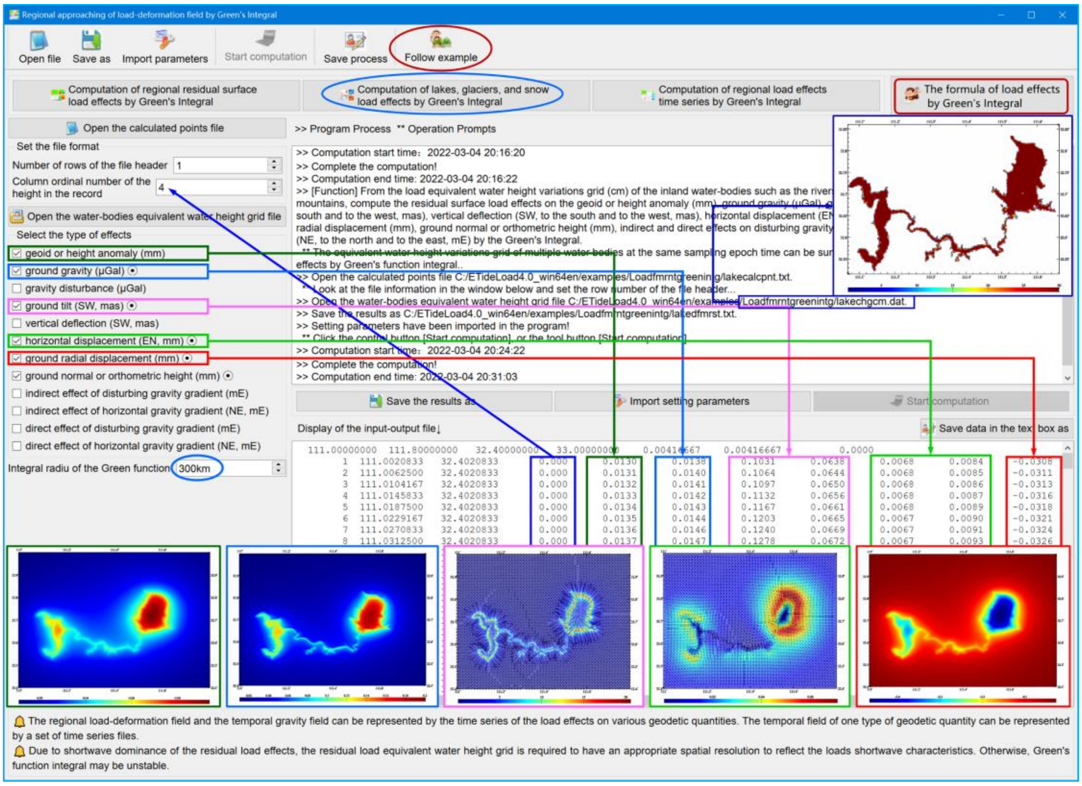
[Output file] The regional surface load effects file.

The file header is the same as the input file. Behind the input file record, add one or several columns of the surface load effects selected as the output file record. In this example, all types are selected, and there are 16 attributes added to the record.

When computing the load effects of sea level variations, the height of the calculated point is the normal or orthometric height. When computing the load effects of surface air pressure or land water variations, the height of the calculated point is the height relative to the Earth's surface.

4.5.2 Computation of lakes, glaciers, and snow load effects by Green's Integral

[Function] From the load equivalent water height variations grid (cm) of the inland water-bodies such as the rivers, lakes, reservoirs, glaciers, and snow-capped mountains, compute the water-bodies load effects on the geoid or height anomaly (mm), ground gravity (μGal), gravity disturbance (μGal), ground tilt (SW, to the south and to the west, mas), vertical deflection (SW, to the south and to the west, mas), horizontal displacement (EN, to the east and to the north, mm), ground radial displacement (mm), ground normal or orthometric height (mm), indirect and direct effects on disturbing gravity gradient (mE) or horizontal gravity gradient (NE, to the north and to the east, mE) by the Green's Integral.



[Input files] The discrete calculated points file. The water-bodies equivalent water height variations grid file.

[Parameter settings] Set the calculated points file format parameter, and enter the load Green’s integral radius.

[Output file] The inland water bodies load effects file.

The file header is the same as the input file. Behind the input file record, add one or several columns of the surface load effects selected as the output file record. In this example, the geoid or height anomaly, ground gravity, ground tilt, horizontal displacement and ground radial displacement are selected, and there are 7 attributes added to the record.

The equivalent water height variations grid of multiple water bodies at the same sampling epoch time can be sumed directly, and then you can get the total load effects by Green's function integral.

If the changes of the inland water bodies such as the rivers, lakes, reservoirs, glaciers, and snow-capped mountains are represented by the load equivalent water height variations grid, the program can accurately compute these load effects on various geodetic quantities.

Due to shortwave dominance of the residual load effects, the residual load equivalent water height grid is required to have an appropriate spatial resolution to reflect the loads shortwave characteristics. Otherwise, Green's function integral may be unstable.

4.5.3 Computation of regional load effects time series by Green's Integral

[Function] From the regional residual equivalent water height (cm) grids time series, compute the time series of the residual value of the load effects on various variations on the computed points in the input file by Green's integral. The residual equivalent water height variation (cm) grids time series files are extracted according to the given wildcards.

[Input files] The discrete calculated points file. The regional residual equivalent water height grids time series file.

The time series files of the equivalent water height grids are extracted according to the given wildcards.

[Parameter settings] Set the calculated points file format parameter and the wildcard patameters for the surface load equivalent water height grids time series files, enter the load Green’s integral radiu, and select the type of surface loads.

[Output file] The residual surface load effects files rent ***.txt.

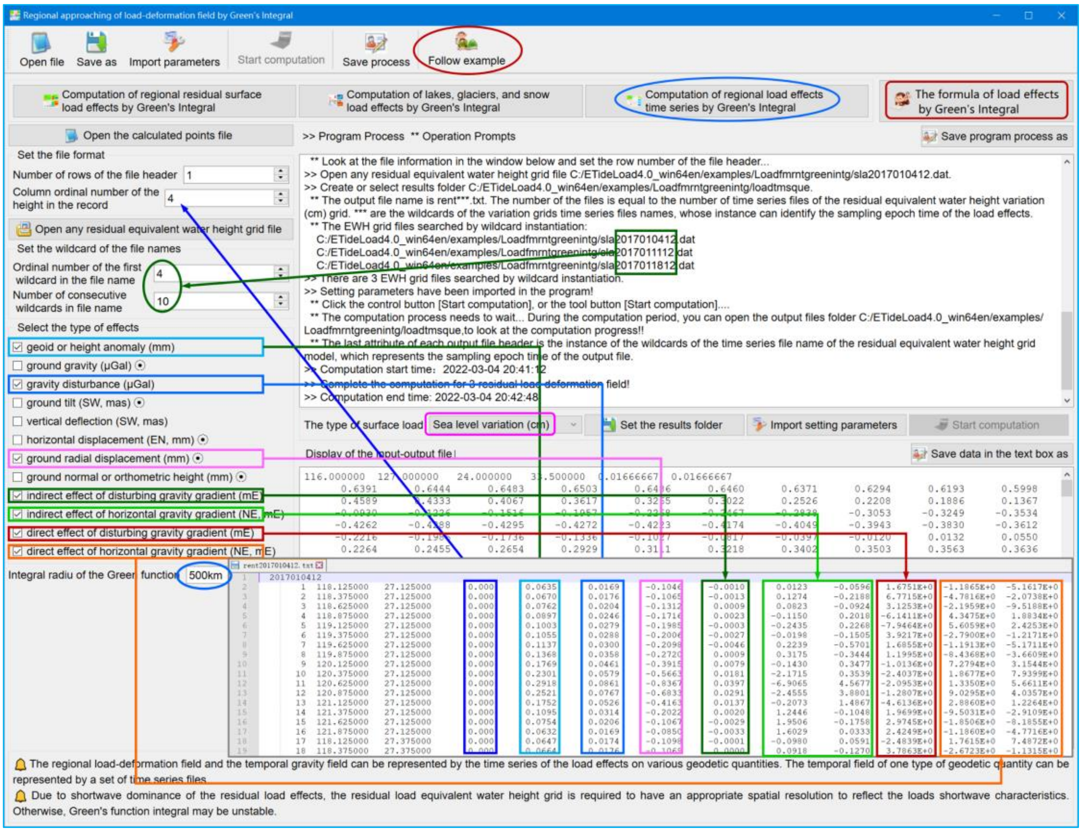
The time of the residual load effects is the sampling epoch time of the surface equivalent water height grid model.

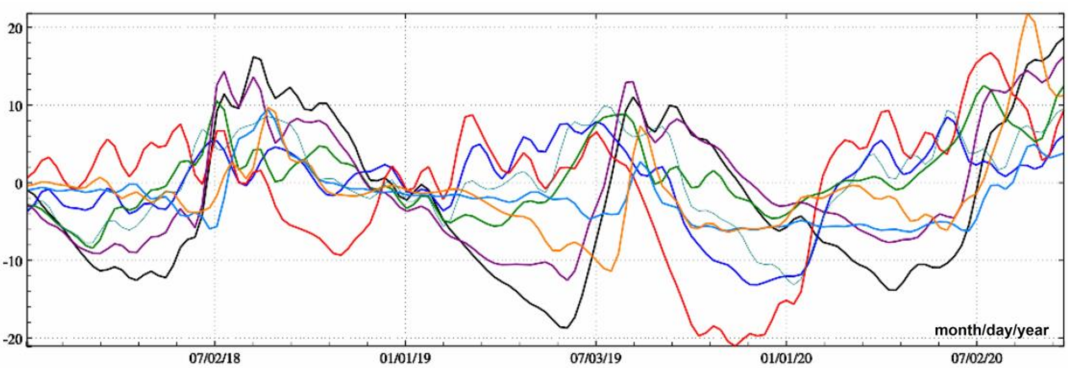
The number of the output files is equal to the number of time series files of the residual equivalent water height variation grid. Here, *** are the wildcards of the variation grids time series files names, whose instance can identify the sampling epoch time of the load effects.

The computation process needs to wait...During the period, you can open the output files folder to look at the computation progress!

The last attribute of each output file header is the instance of the wildcards of the time series file name of the residual equivalent water height grid model, which represents the sampling epoch time of the output file.

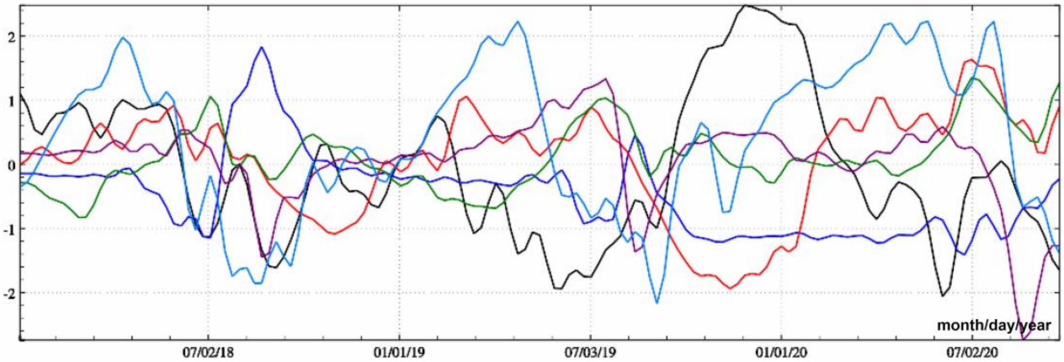
Gravity gradient ultrashort waves are dominant, and its surface load effects are bigger. In order to fully display the spatial inhomogeneity of direct and indirect load effects on gravity gradient, the program divides the load effects on gravity gradient into the direct and indirect effects with their unit enlarged from 10μE to mE.



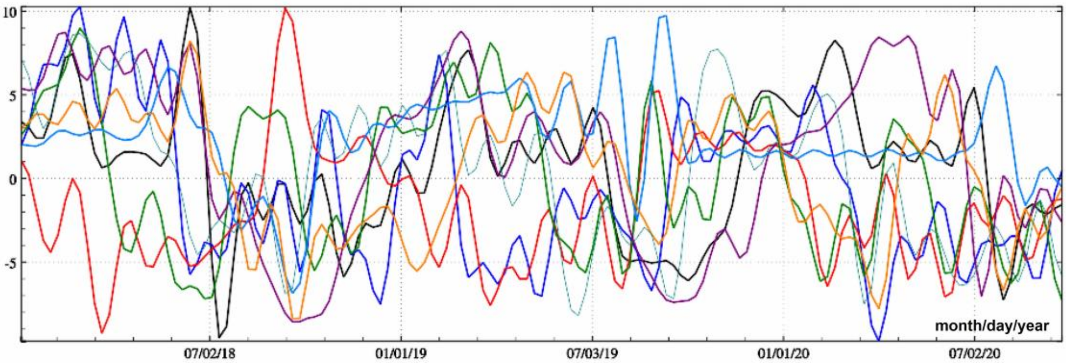


30′×30′ Residual soil water load effects on gravity disturbance (μGal) on in Chinese mainland (Green integral)

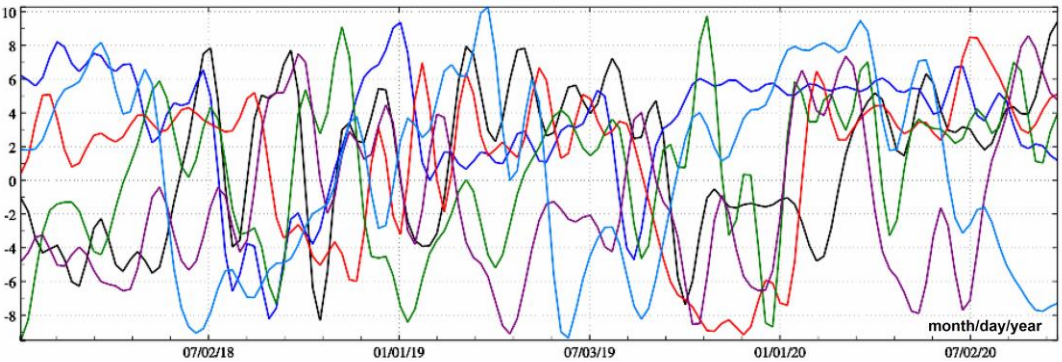
The Green integral computations show that the residual soil water variations in medium and short waves (30′ spatial resolution) can cause time-varying gravity gradients above the mE level which is no obvious time-varying feature (difficult to model).



Indirect effects of 30′×30′ Residual soil water on disturbing gravity gradient (mE) on in Chinese mainland (Green integral)



Direct effects of 30′×30′ Residual soil water on disturbing gravity gradient (mE) on in Chinese mainland (Green integral)



Direct effects of 30′×30′ Residual soil water on horizontal gravity gradient (East, mE) on in Chinese mainland (Green integral)

After superimposing the effects of ultrashort-wave surface water and groundwater loads, the time-varying magnitude of the ground disturbance gravity gradient can reach 100 mE, while that of the horizontal gravity gradient can reach hundreds of mE. This complex dynamic environment without obvious spatiotemporal features will seriously restrict the realization of ground gravity gradient measurement with mE level accuracy. So, it is not recommended to measure the horizontal gravity gradient directly on the ground or at low altitudes.

4.6 Estimation of land water variations based on multi-monitoring networks

[Purpose] Using various geodetic variations of the ground sites such as the regional CORS network, solid Earth tide stations, or various geodetic networks as the observations, and the regional load Green’s integral as the geodynamic constraints, estimate the spatiotemporal variations of the land water.

The program requires that the long-wave parts of the load effects on the geodetic variations should be removed in advance either by calculating the known load effects with the air pressure, surface water, and sea level variations, or using the temporal satellite gravity field model, to suppress the far-region effects and meet the condition of the local Green's integral.

Furtherly combining the function [Computation of tide and load model value by spherical harmonic synthesis], [Computation of load-deformation field by spherical harmonic synthesis], and [Regional approaching of the load-deformation field by Green's Integral], you can effectively monitor regional land water variations, load-deformation field, and temporal gravity field.

Please refer to the program [CORS/InSAR collaborative monitoring and ground stability variations estimation] for the unified method of spatiotemporal datum frame for various geodetic variations.

4.6.1 Estimation of land water variations from various geodetic variations

[Function] Using the ground ellipsoidal height (mm), ground gravity (μGal), ground normal or orthometric height (mm) variations unified in the spatiotemporal frame as the observations, and the load Green's integral as the geodynamic constraints, estimate the equivalent water height variations (cm) grid of the regional land water.

[Input files] The geodetic variation records time series file. The estimated region zero value grid file.

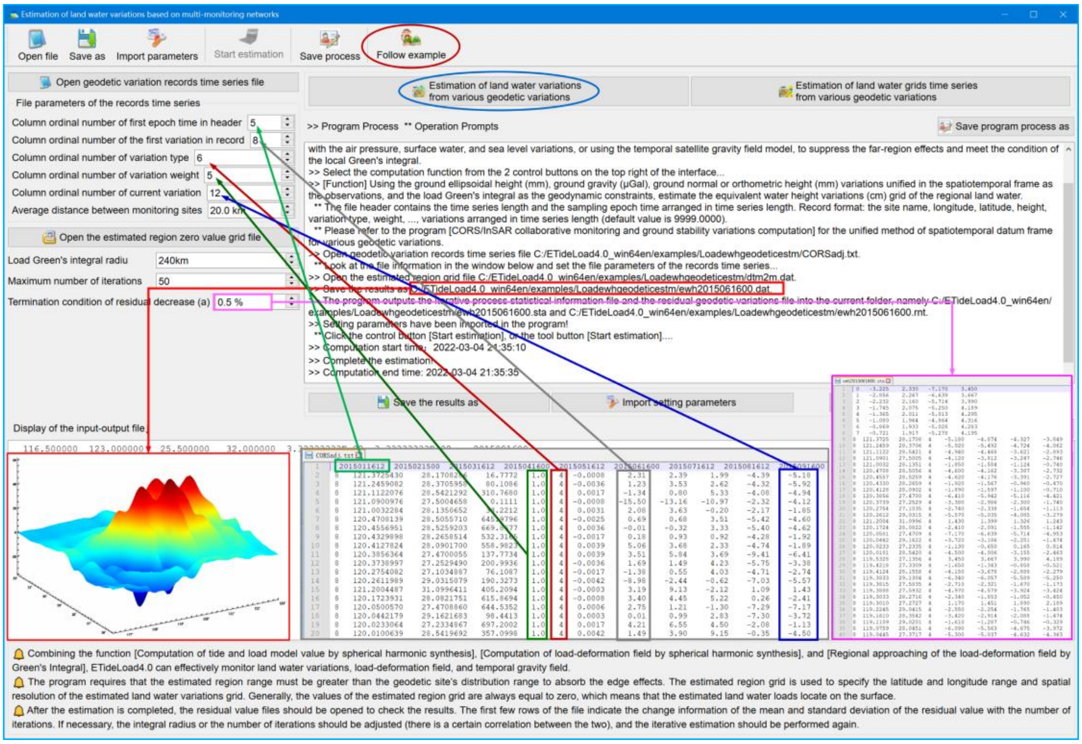
The geodetic variation records time series file. The file header contains the time series length and the sampling epoch time arranged with time. Record format: the site name, longitude, latitude, height, variation type, weight, ..., variations arranged in time series length (default value is 9999.0000).

Variation type = 1 represents the height anomaly (mm), = 2 represents gravity disturbance (μGal), = 3 represents ground gravity (μGal), = 4 represents ground ellipsoidal height (mm), = 5 represents ground normal or orthometric height (mm).

The program requires that the estimated region range must be greater than the geodetic site’s distribution range to absorb the edge effects. The estimated region grid is used to specify the latitude and longitude range and spatial resolution of the estimated land water variations grid. Generally, the values of the estimated region grid are always equal to zero, which means that the estimated land water loads locate on the surface.

[Parameter settings] Set the geodetic variation records time series file format parameter and the iteration conditio patameters, enter the column ordinal number of current variation, load Green’s integral radiu and average distance between sites.

Termination condition of the iteration: the sign of the average of the residual values of the geodetic variations occurs reverse, or the difference between the current residual standard deviation and the previous iteration residual standard deviation is less than a% of the standard deviation of the source geodetic variations.



[Output files] The equivalent water height variations grid file, the iterative process statistical information file, and the residual geodetic variations file.

4.6.2 Estimation of land water grids time series from various geodetic variations

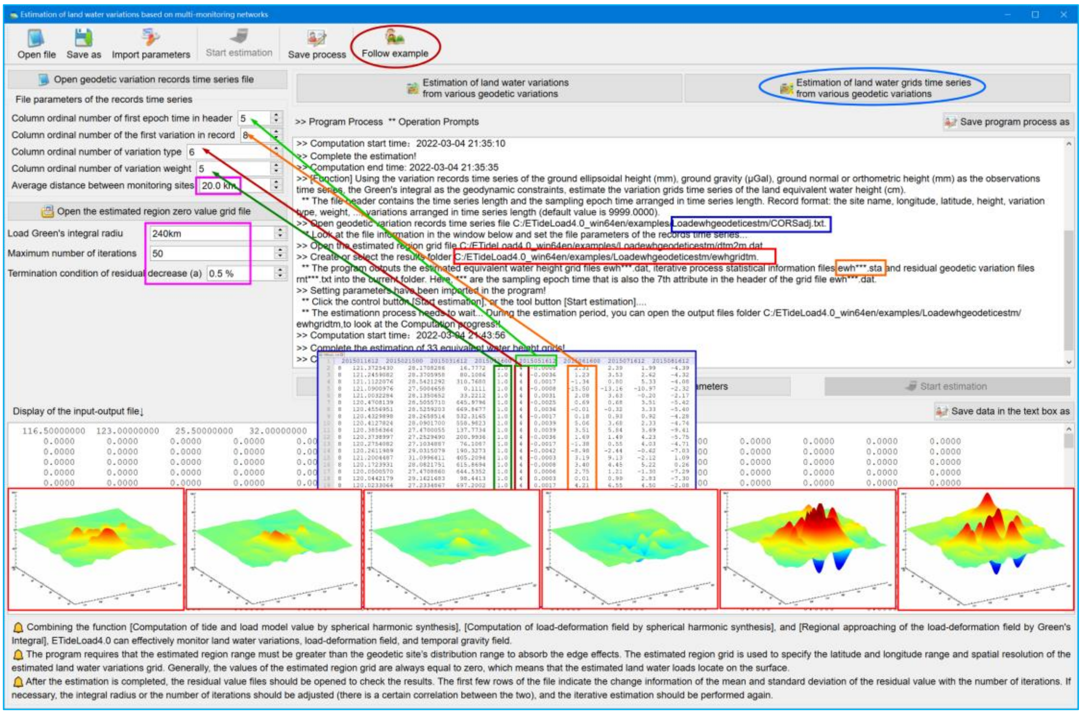
[Function] Using the variation records time series of the ground ellipsoidal height (mm), ground gravity (μGal), ground normal or orthometric height (mm) as the observations time series, the Green's integral as the geodynamic constraints, estimate the variation grids time series of the land equivalent water height (cm).

[Input files] The geodetic variation records time series file. The estimated region zero value grid file.

[Parameter settings] Set the geodetic variation records time series file format parameter and the iteration conditio patameters, enter the load Green’s integral radiu and average distance between sites.

[Output files] The estimated equivalent water height grid file ewh***.dat, iterative process statistical information file ewh***.sta and residual geodetic variations file rnt***.txt. Here, *** are the sampling epoch time that is also the 7th attribute in the header of the grid file ewh***.dat.

The residual variations time series (a residual variations file at each sampling epoch time) can be furtherly used to evaluate the stability of the sites and the quality of the geodetic monitoring data.



After the estimation is completed, the residual value files should be opened to check the results. The first few rows of the file indicate the change information of the mean and standard deviation of the residual value with the number of iterations. If necessary, the integral radius or the number of iterations (there is a certain correlation between the two) should be adjusted, and the iterative estimation should be performed again.

4.7 Estimation of high-resolution land water variations from CORS/InSAR

[Purpose] Using the high-resolution InSAR variations unified in the CORS network monitoring frame as observations, the regional load Green's integral as the geodynamic constraints, estimate the land water variations with high spatiotemporal resolution.

The program requires that the long-wave parts of the load effects on the InSAR variations should be removed in advance either by calculating the known load effects with air pressure, surface water, and sea level variations, or using the temporal satellite gravity field model, to suppress the far-region effects and meet the condition of the local Green's integral.

Please refer to the program [CORS/InSAR collaborative monitoring and ground stability variations estimation] for the unified method of the spatiotemporal monitoring frame for multi-source InSAR vertical deformation.

4.7.1 Estimation of land water variations from InSAR variations

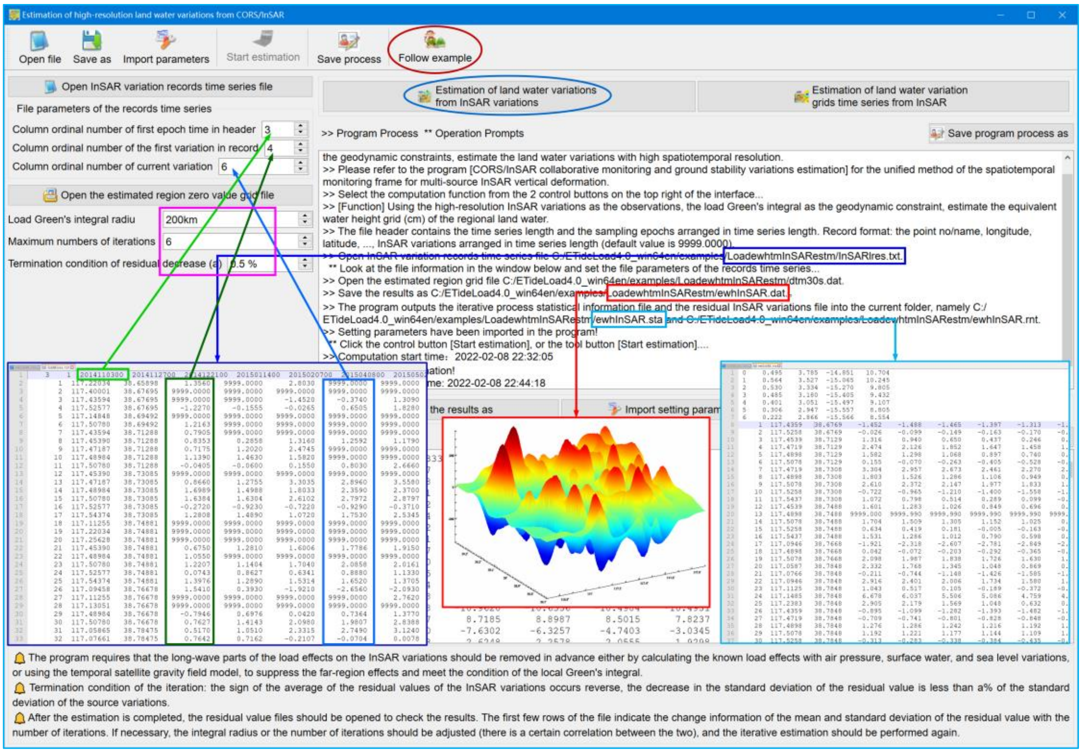
[Function] Using the high-resolution InSAR variations as the observations, the load Green's integral as the geodynamic constraint, estimate the equivalent water height grid (cm) of the regional land water.

[Input files] The InSAR variation records time series file. The estimated region zero value grid file.

The InSAR variation records time series file. The file header contains the time series length and the sampling epochs arranged in time series length. Record format: the point no/name, longitude, latitude, ..., InSAR variations arranged in time series length (default value is 9999.0000).

[Parameter settings] Set InSAR variation records time series file format parameter and the iteration conditio patameters, enter the column ordinal number of current variation and load Green's integral radiu.

Termination condition of the iteration: the sign of the average of the residual values of the geodetic variations occurs reverse, the difference between the current residual standard deviation and the previous iteration residual standard deviation is less than a% of the standard deviation of the source geodetic variations.



[Output files] The equivalent water height variations grid file, the iterative process statistical information file, and the residual InSAR variations file.

4.7.2 Estimation of land water variation grids time series from InSAR

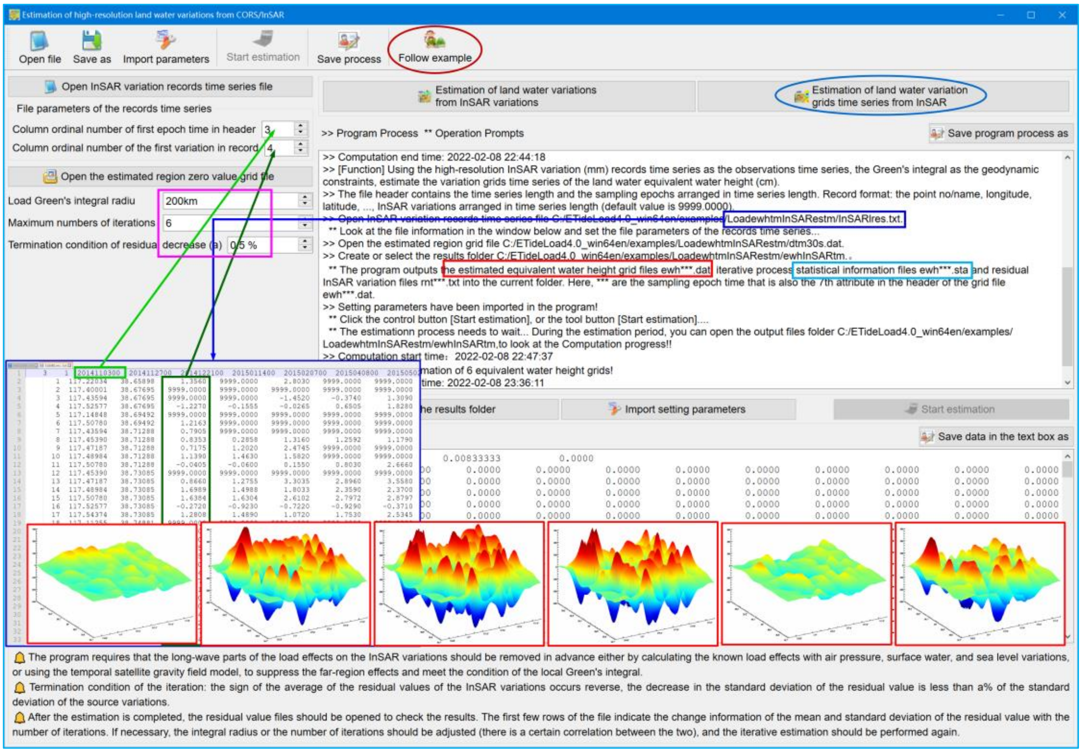
[Function] Using the high-resolution InSAR variation (mm) records time series as the observations time series, the Green's integral as the geodynamic constraints, estimate the variation grids time series of the land water equivalent water height (cm).

[Input files] The InSAR variation records time series file. The estimated region zero value grid file.

[Parameter settings] Set InSAR variation records time series file format parameter and the iteration conditio patameters, enter the load Green’s integral radiu.

[Output files] The estimated equivalent water height grid files ewh***.dat, iterative process statistical information files ewh***.sta and residual InSAR variations files rnt***.txt. Here, *** are the sampling epoch time that is also the 7th attribute in the header of the grid file ewh***.dat.

After the estimation is completed, the residual value files should be opened to check the results. The first few rows of the file indicate the change information of the mean and standard deviation of the residual value with the number of iterations. If necessary, the integral radius or the number of iterations (there is a certain correlation between the two) should be adjusted, and the iterative estimation should be performed again.



4.8 Geodynamic calculation on geodetic field grids time series

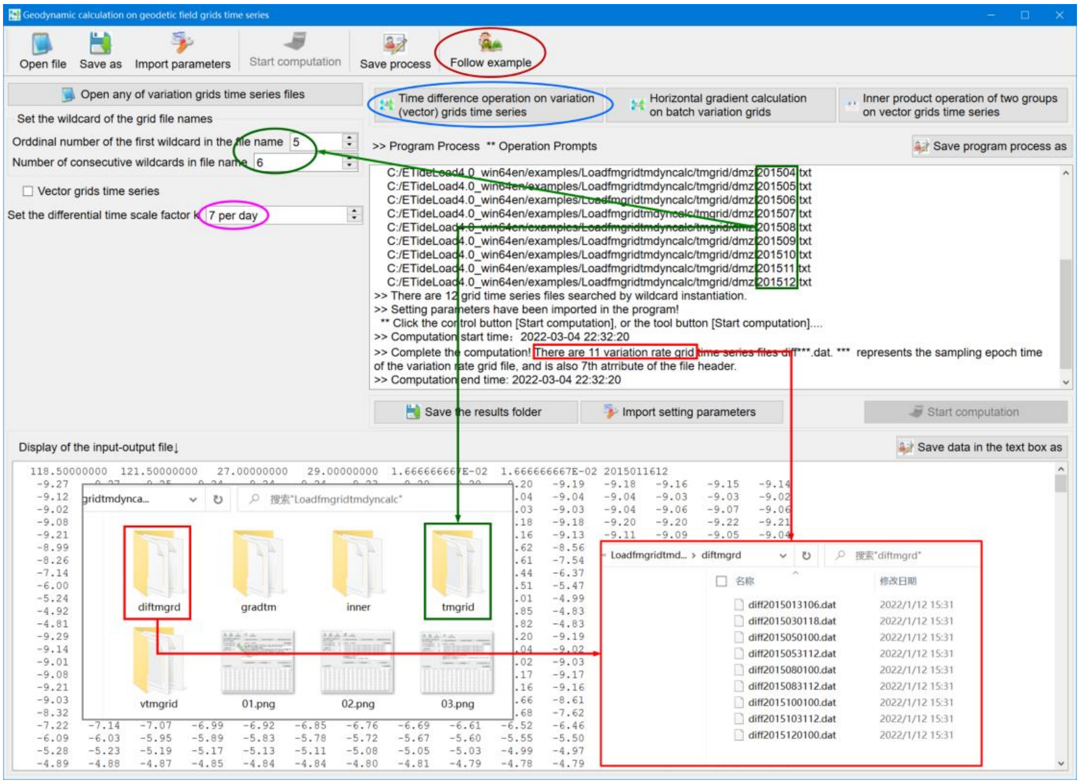
[Purpose] Calculate the time difference, space horizontal gradient, or two vector grids inner product of the ground deformation field grids time series to display their spatiotemporal geodynamic characteristics.

4.8.1 Time difference operation on variation (vector) grids time series

[Function] Sort the input variation (vector) grids time series files according to the sampling epoch time (the seventh attribute of the file header), and then calculate the variation rate at two neighboring sampling epochs to generate the variation (vector) rate grids time series. Here, the sampling epoch time of the current grid is equal to the average of the before and after sampling epochs of the variation (vector) grids, the unit of the variation rate is per k day, and k is the given differential time scale factor.

The variation (vector) grids time series files are extracted according to the given wildcards. For the variation vector grids time series, the program requires them to be in the form of horizontal coordinates.

[Input files] The variation (vector) grids time series files.

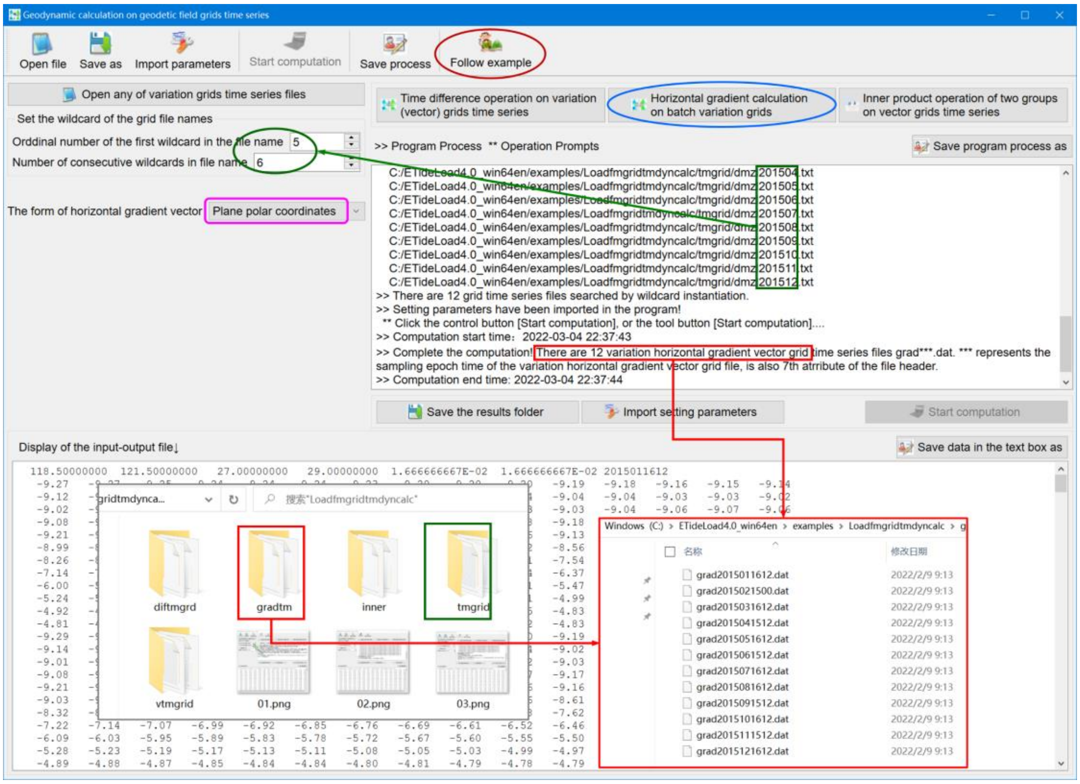


[Parameter settings] Set the wildcard patameters for the variation (vector) grids time series files, enter the differential time scale factor k.

[Output files] The variation (vector) rate grids time series files.

4.8.2 Horizontal gradient calculation on batch variation grids

[Function] From batch variation grids files with the same grid specifications in the specified folder, calculate horizontal gradient vector grids (per km). The horizontal gradient vector can be output in the form of polar coordinates or EN horizontal coordinates. The variation grid files are extracted according to the given wildcards.



4.8.3 Inner product operation on two groups of vector grids time series

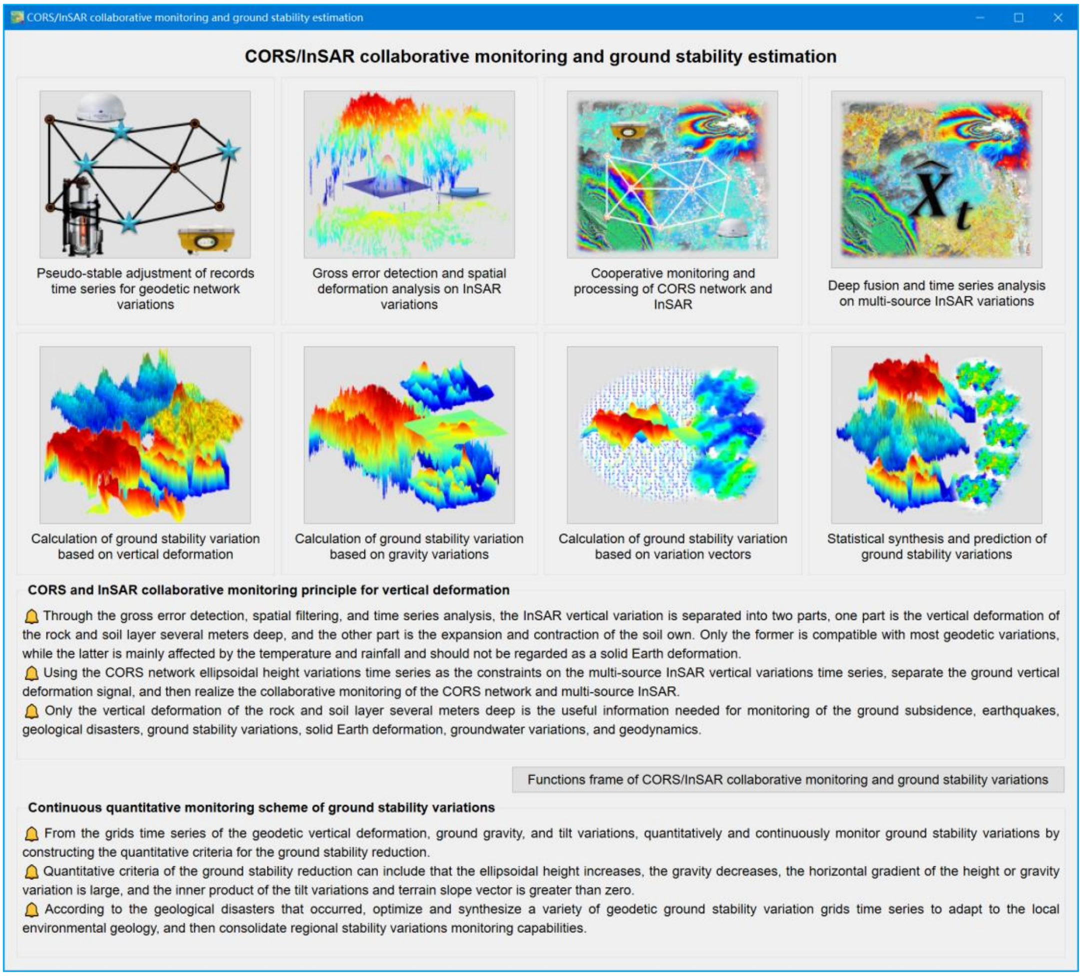
[Function] Calculate the inner product grids time series from two groups of variation vector grids time series in the form of the EN horizontal rectangular coordinates with the same grid specifications.

The variation vector grid files are extracted according to the given wildcards.

The program allows a group of vector grid files with only one sampling time. When the two groups are both vector grids time series, the program requires one-by-one correspondence between the sampling epochs.

5 CORS/InSAR collaborative monitoring and stability estimation

The group of programs can be used to construct an accurate geometric and physical spatiotemporal monitoring frame with regional unification, long-term stability, and high robustness performance, and then perform scientific computations for the collaborative monitoring of the CORS network and multi-source InSAR. From the variation grids time series of the geodetic deformation field, quantitatively and continuously monitor the regional ground stability variations by constructing some quantitative criteria for the ground stability reduction.



CORS and InSAR collaborative monitoring principle for vertical deformation:

(1) Through the gross error detection, spatial filtering, and time series analysis, the InSAR vertical variation is separated into two parts, one part is the vertical deformation of the rock and soil layer several meters deep, and the other part is the expansion and contraction of the soil own. Only the former is compatible with most geodetic variations, while the latter is mainly affected by the temperature and rainfall and should not be regarded as a solid Earth deformation.

(2) Using the CORS network ellipsoidal height variations time series as the constraints on the multi-source InSAR vertical variations time series, separate the ground vertical deformation signal, and then realize the collaborative monitoring of the CORS network and multi-source InSAR.

(3) Only the vertical deformation of the rock and soil layer several meters deep is the useful information needed for monitoring of the ground subsidence, earthquakes, geological disasters, ground stability variations, solid Earth deformation, groundwater variations, and geodynamics.

Continuous quantitative monitoring scheme of ground stability variations:

(1) From the grids time series of the geodetic vertical deformation, ground gravity, and tilt variations, quantitatively and continuously monitor ground stability variations by constructing the quantitative criteria for the ground stability reduction.

(2) Quantitative criteria of the ground stability reduction can include that the ground ellipsoidal height increases, the gravity decreases, the horizontal gradient of the height or gravity variation is large, and the inner product of the tilt variations and terrain slope vector is greater than zero.

(3) According to the geological disasters that occurred, optimize and synthesize a variety of geodetic ground stability variation grids time series to adapt to the local environmental geology, and then consolidate regional stability variations monitoring capabilities.

5.1 Pseudo-stable adjustment of records time series for geodetic network variations

[Function] Using the variations time series of the GNSS baseline components, height differences of the leveling route, or gravity differences of the gravity control network as the observations, and a given group of sites reference values time series as the pseudo-stable references, estimate the variations time series of the coordinate component of the CORS network sites, the height of the leveling network sites or the gravity of the gravity network sites by the indirect least squares adjustment method.

The program can be used to construct an accurate geometric and physical spatiotemporal monitoring frame with regional unification, long-term stability, and high robustness performance.

The program requires that all the variations are strictly synchronized at each sampling epoch time, and the reference epochs of all the records time series of all the variations need be unique.

[Input files] The observed variation records time series file of the geodetic network. The reference variation records time series file of the reference sites.

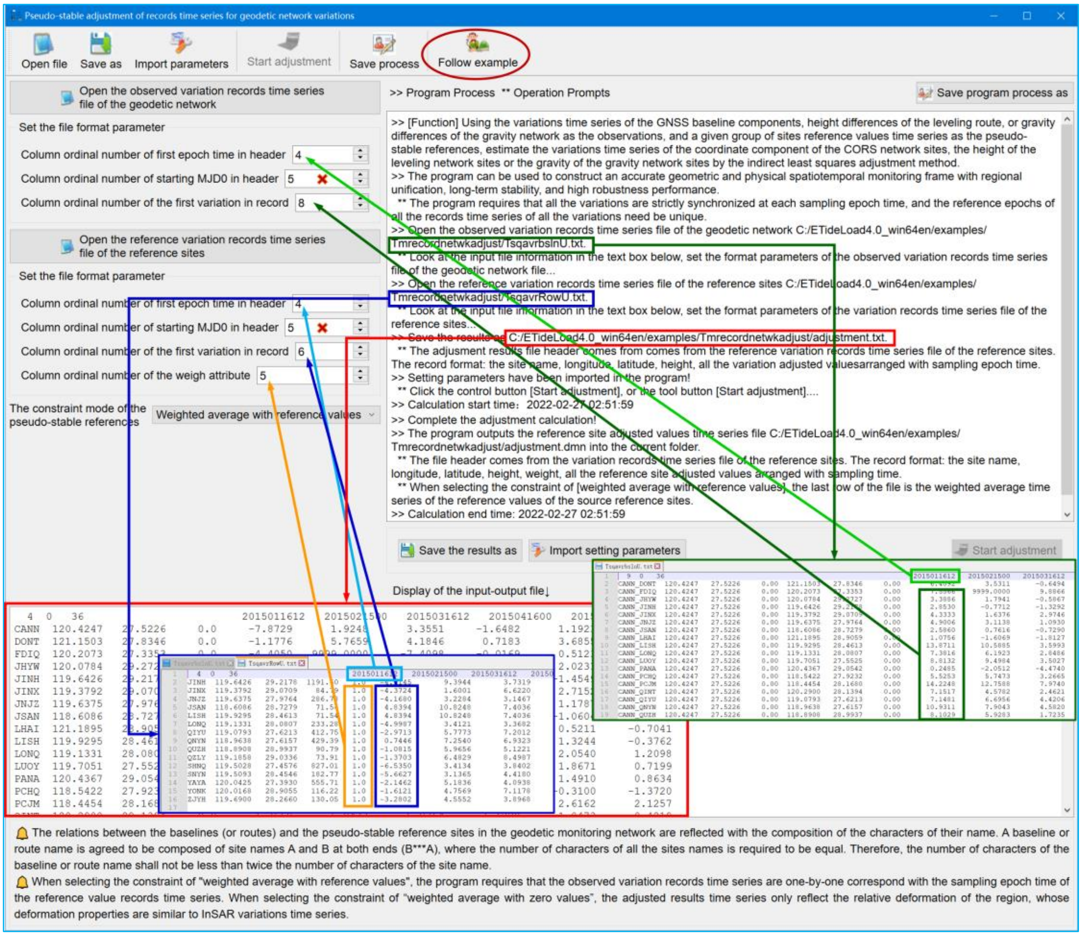
(1) The observed variation records time series file of the geodetic network (consists of the baselines or routes). The file header includes the number of characters of the baseline

or route name, the number of characters of the site name, the sampling length, ……, all the sampling epochs arranged with time.

The record includes the baseline or route name, the starting site (longitude, latitude, height), the ending site (longitude, latitude, height), ……, all the observed variations arranged with sampling time (default value is 9999).

(2) The variation records time series file of the reference sites. The file header contains all the sampling epochs arranged with time. The record format: the site name, longitude, latitude, height, ..., all the variations arranged with sampling time (default value is 9999).

The relations between the baselines (or routes) and the pseudo-stable reference sites in the geodetic monitoring network are reflected with the composition of the characters of their name. A baseline or route name is agreed to be composed of site names A and B at both ends (B***A), where the number of characters of all the sites names is required to be equal. Therefore, the number of characters of the baseline or route name shall not be less than twice the number of characters of the site name.



[Parameter settings] Set the records time series files format patameters for the observed variations of the geodetic network and the reference variations of the reference sites, set the constraint mode of the pseudo-stable references.

When selecting the constraint of "weighted average with reference values", the program requires that the observed variation records time series are one-by-one correspond with the sampling epoch time of the reference value records time series.

When selecting the constraint of “weighted average with zero values”, the adjusted results time series only reflect the relative deformation of the region, whose deformation properties are similar to InSAR variations time series.

[Output files] The variation adjusted value records time series file of the geodetic network sites.

The file header comes from the reference variation records time series file of the reference sites. The record format: the site name, longitude, latitude, height, all the variation adjusted values arranged with sampling epoch time.

When selecting the constraint of "weighted average with reference values", the program outputs the reference site adjusted values time series file ***.dmn into the current folder.

The file header comes from the variation records time series file of the reference sites. The record format: the site name, longitude, latitude, height, weight, all the reference site adjusted values arranged with sampling time. The last row of the file is the weighted average time series of the reference values of the source reference sites. Here, *** are the output file name of the variation adusted value records time series.

5.2 Gross error detection and spatial deformation analysis on InSAR variations

[Purpose] Construct InSAR variations spatial analysis algorithms according to the spatial distribution natures of the ground deformation under the action of the environmental geology and load geodynamics, separate the outliers and gross errors in InSAR variations, suppress and weaken the impact of the soil own variations, and then extract the InSAR ground vertical deformation which is compatible with the other geodetic variations.

5.2.1 Gross error detection and separation on InSAR variation records time series

[Function] According to the spatial high-correlation characteristics of the ground deformation, construct a reference surface respectively at each sampling epoch time with the given low-pass filter to separate the outliers, gross error, and abrupt signals from the input InSAR variation records time series.

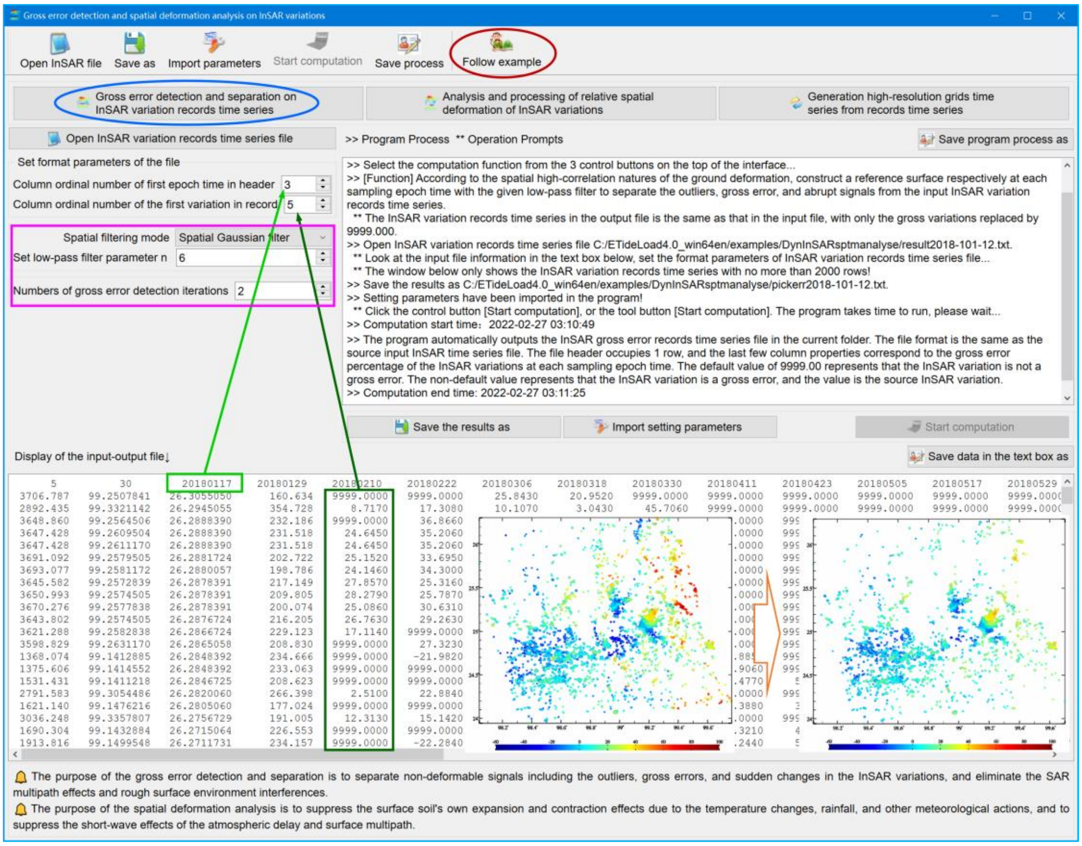
[Input file] The InSAR variation records time series file.

InSAR variations time series is agreed in the records time series format, and the sampling epoch time is agreed in ETideLoad format.

[Parameter settings] Set the InSAR variation records time series files format patameters, select the spatial filtering mode, and enter the number of gross error detection iterations.

[Output file] The InSAR variation records time series file.

The InSAR variation records time series in the output file is the same as that in the input file, with only the gross variations replaced by 9999.000.



The program automatically outputs the InSAR gross error records time series file in the current folder. The file format is the same as the source input InSAR time series file. The file header occupies 1 row, and the last few column properties correspond to the gross error percentage of the InSAR variations at each sampling epoch time. The default value of 9999.00 in the record represents that the InSAR variation is not a gross error. The non-default value represents that the InSAR variation is a gross error, and the value is the source InSAR variation.

The purpose of the gross error detection and separation is to separate non-deformable signals including the outliers, gross errors, and sudden changes in the InSAR variations, and eliminate the SAR multipath effects and rough surface environment interferences.

5.2.2 Analysis and processing of relative spatial deformation on InSAR variations

[Function] According to the spatial distribution natures that the ground vertical deformation is inversely proportional to the distance away from the dynamic source, suppress or weaken the local changes due to non-geological dynamics on the shallow surface from the input InSAR variation records time series using the specified spatial filtering algorithm.

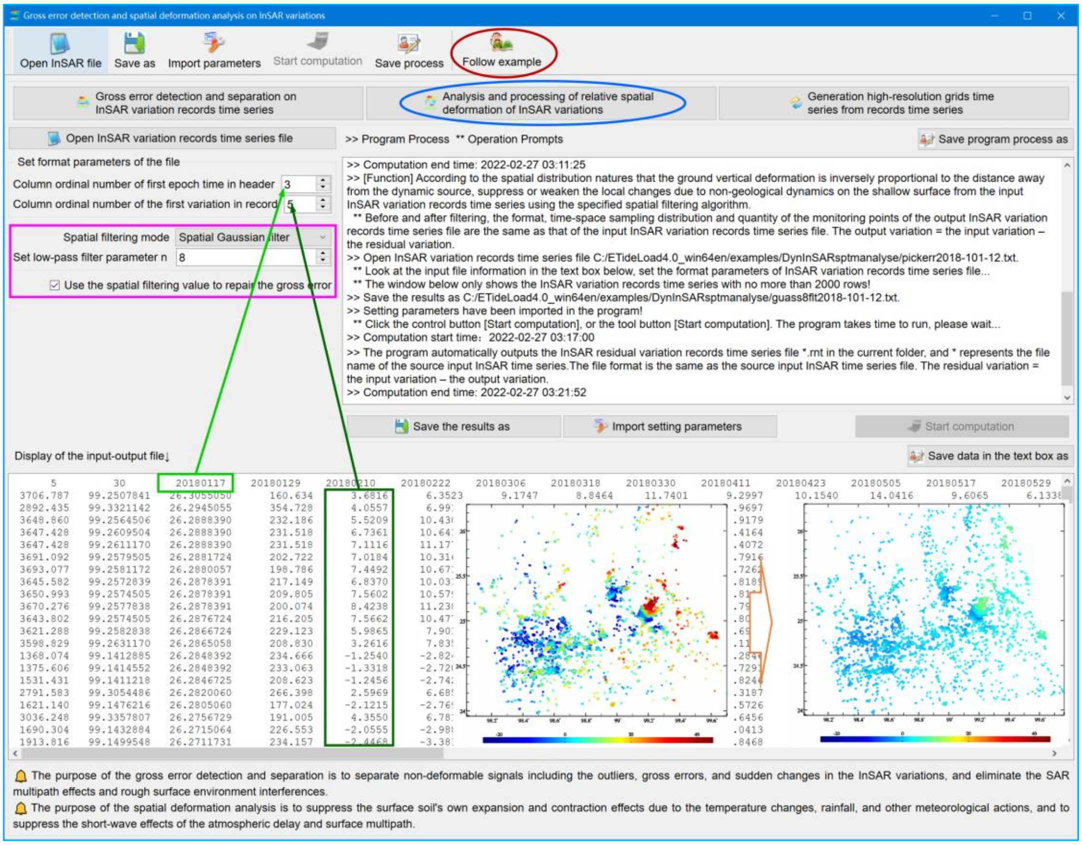
[Input file] The InSAR variation records time series file.

[Parameter settings] Set the InSAR variation records time series files format patameters, select the spatial filtering mode, enter spatial low-pass filter times, and set the checkbox of [use the spatial filtering value to repair the gross error].

For the moving average filter, the greater the filtering parameter n, the greater the filtering strength. For the spatial Gaussian filter, the smaller the n, the greater the filtering strength.

[Output file] The InSAR variation records time series file.

Before and after filtering, the format, time-space sampling distribution and quantity of the monitoring points of the output InSAR variation records time series file are the same as that of the input InSAR variation records time series file. The output variation = the input variation – the residual variation.



The program automatically outputs the InSAR residual variation records time series file in the current folder. The file format is the same as the source input InSAR time series file. The residual variation = the input variation – the output variation.

The purpose of the spatial deformation analysis is to suppress the surface soil's own expansion and contraction effects due to the temperature changes, rainfall, and other meteorological actions, and to suppress the short-wave effects of the atmospheric delay and surface multipath.

5.2.3 Generation high-resolution grids time series from records time series

[Function] According to the given minimum number of the effective monitoring points in a grid element, generate the high-resolution variation grids time series by the direct averaging or Gaussian function interpolation method. The number of the output grids time series files are equal to the number of sampling epochs of the variation records time series. The grid value on the invalid grid element is represented by 9999.0.

[Input file] The InSAR variation records time series file.

[Parameter settings] Set the InSAR variation records time series files format patameters and enter the grid spatial resolution.

[Output file] The results file names are grid***.dat. The number of files is equal to the sampling number of the variation records time series, and *** are the sampling epoch time in the long ineger format agreed by the ETideLoad.

5.3 Cooperative monitoring and processing of CORS network and InSAR

[Purpose] Unify the reference epoch time of multi-source InSAR variations time series and CORS network height variation records time series, and then through the compatibility analysis of vertical deformation of the CORS network and InSAR, InSAR variations adjustment with the constraint of the CORS network, unify the spatiotemporal monitoring frame of the InSAR variations time series and control the accumulation of the InSAR monitoring errors over time.

The purpose of cooperative monitoring and processing of the CORS network and InSAR: (1) Repair the tidal and non-tidal load effects on the InSAR variations, compensate the spatial long-wave troposphere model errors. (2) Compensate the temporal information which spatial wavelength larger than the InSAR monitoring region, control the cumulative error of the InSAR variations over time. (3) When there are no less than 3 CORS stations, can precisely repair the InSAR differential interference scale error and compensate the other medium-long wave errors.

5.3.1 Unification of reference epoch for variation records time series

[Function] Using the cubic spline interpolation, Gaussian function interpolation, or low-pass filtering method, estimate and remove the sampling value of all the variation records time series at the given reference epoch time, thereby unify the reference epoch time of all the variation records time series. At the reference epoch time, the sampling values of all the variations are always zero.

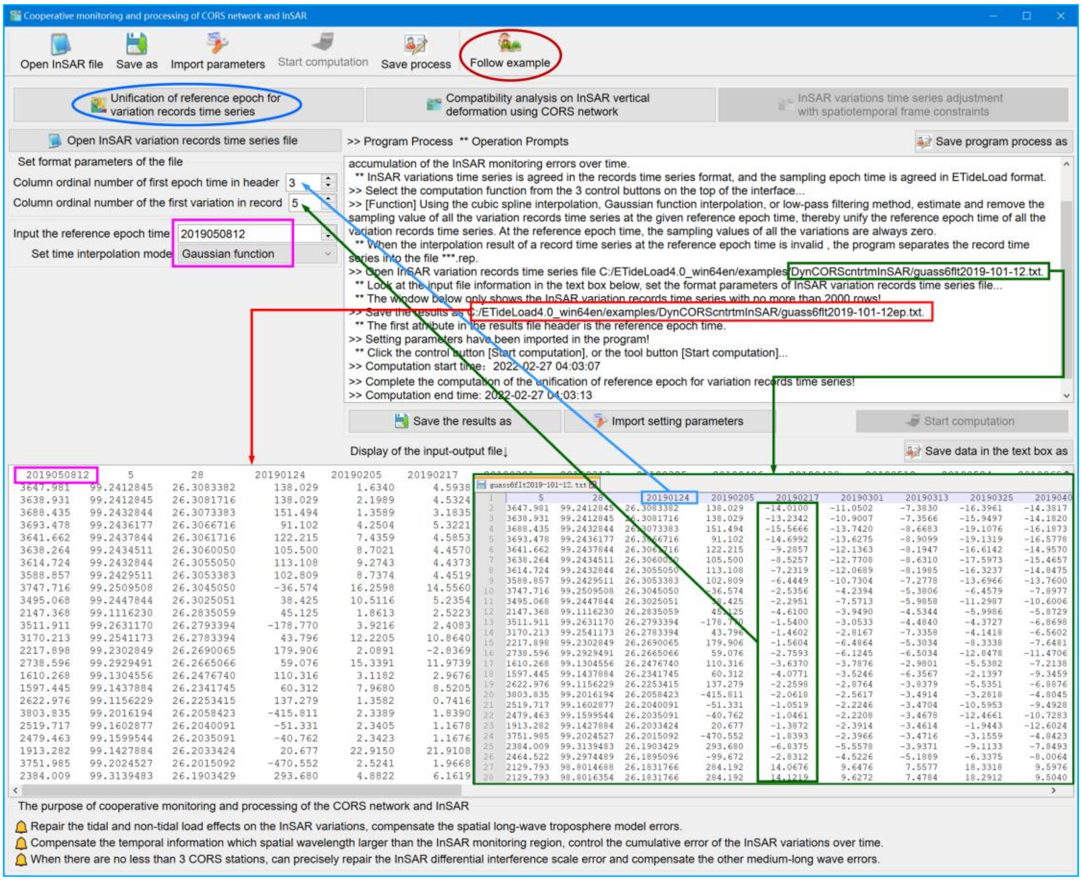
The program requires that the reference epoch time be no earlier than the first sampling time and no later than the last sampling time, otherwise automatically set to the first or last sampling time.

[Input file] The InSAR variation records time series file.

[Parameter settings] Set the InSAR variation records time series files format patameters, select the time interpolation mode, and enter the reference epoch time.

[Output file] The InSAR variation records time series file.

When the interpolation result of a record time series at the reference epoch time is invalid , the program separates the record time series into the file ***.rep.



When there are more noise or missing samples in the variation records time series, Gaussian function interpolation is recommended.

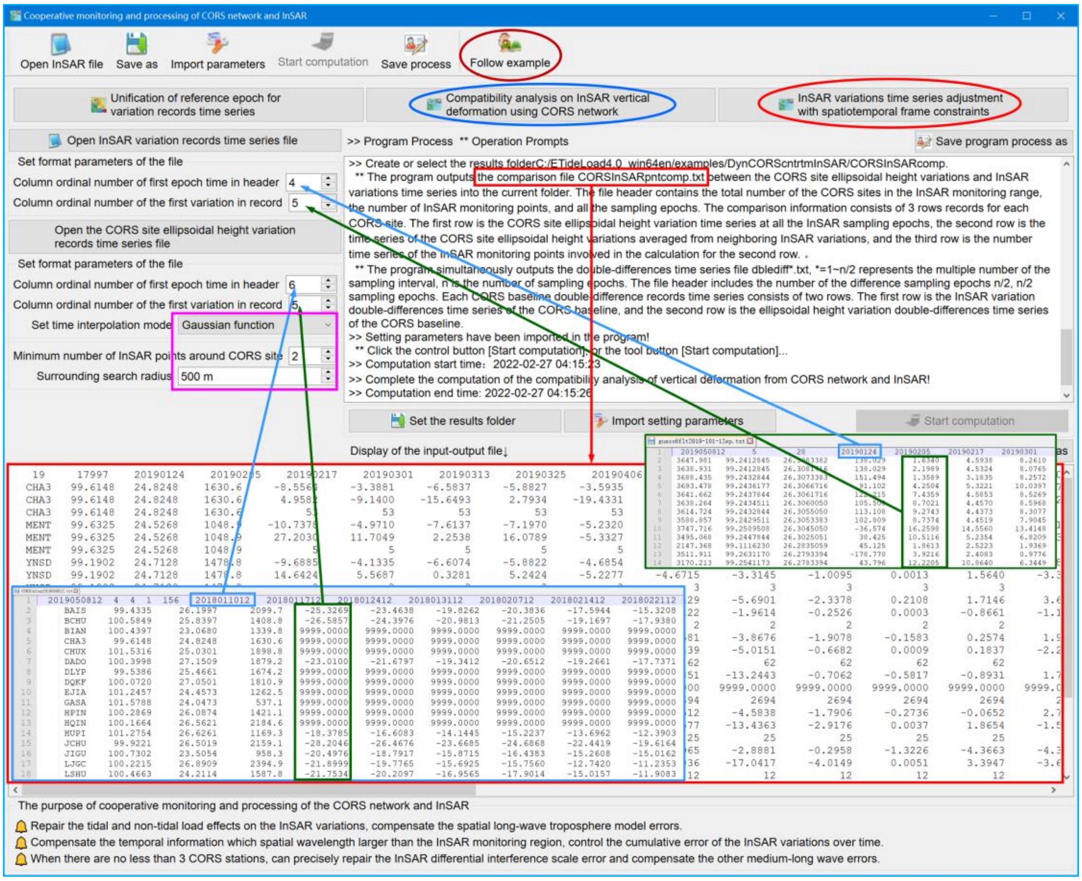
When the reference epoch time exceeds the effective time range of a record time series, if the cubic spline interpolation is still selected, the program automatically extrapolates the sampling value of the reference epoch time of the records time series by the Gaussian basis function method.

5.3.2 Compatibility analysis on InSAR vertical deformation using CORS network

[Function] Calculate the ellipsoidal height variations time series on the CORS site from InSAR variations time series near the CORS site by the direct average method. Interpolate the CORS site ellipsoidal height variations at sampling epochs of the InSAR time series from the CORS site ellipsoidal height variations time series. And then construct the CORS baselines by the complete combinations of the CORS sites, calculate all the double-difference time series respectively from the two kinds of CORS site ellipsoidal height variations time series. Evaluate the compatibility of the vertical deformation between the CORS network and InSAR and analyze the effectiveness of the InSAR variations gross error detection and spatial analysis algorithm.

The double-difference algorithm of the InSAR variations time series on the CORS baseline: firstly, calculate the InSAR variation at the current epoch time on the CORS site by the direct average method using the InSAR variations around the CORS site, and then calculate the InSAR variation difference between the two ends of the CORS baseline at the current epoch time, and finally calculate the time difference between the InSAR variation differences after and before the epoch time to obstain the InSAR variation double-differences time series of the CORS baseline.

[Input file] The InSAR variation records time series file. The CORS site ellipsoidal height variation records time series file.



[Parameter settings] Set the InSAR and CORS site variation records time series files format patameters, select the time interpolation mode, and enter the minimum number of InSAR points around CORS site and surrounding search radius.

When there are more noise or missing samples in the CORS height variation records time series, Gaussian function interpolation is recommended.

[Output file] The comparison file CORSInSARpntcomp.txt between the CORS site ellipsoidal height variations and InSAR variations time series.

The file header contains the total number of the CORS sites in the InSAR monitoring range, the number of InSAR monitoring points, and all the sampling epochs. The comparison information consists of 3 rows records for each CORS site. The first row is the CORS site ellipsoidal height variation time series at all the InSAR sampling epochs, the second row is the time series of the CORS site ellipsoidal height variations averaged from neighboring InSAR variations, and the third row is the number time series of the InSAR monitoring points involved in the calculation for the second row.

The program simultaneously outputs the double-differences time series file dblediff*.txt, *=1~n/2 represents the multiple number of the sampling interval, n is the number of sampling epochs. The file header includes the number of the difference sampling epochs n/2, n/2 sampling epochs. Each CORS baseline double-difference records time series consists of two rows. The first row is the InSAR variation double-differences time series of the CORS baseline, and the second row is the ellipsoidal height variation double-differences time series of the CORS baseline.

5.3.3 InSAR variations time series adjustment with spatiotemporal frame constraints

[Function] From the comparison file CORSInSARpntcomp.txt output by the function [Compatibility analysis of vertical deformation from CORS network and InSAR], estimate spatiotemporal monitoring datum transfer parameters, construct spatiotemporal frame constraint equations, perform the adjustment for the InSAR variation records time series, so as to unify the spatiotemporal monitoring frame of the InSAR variation records time series into the CORS network spatiotemporal monitoring frame.

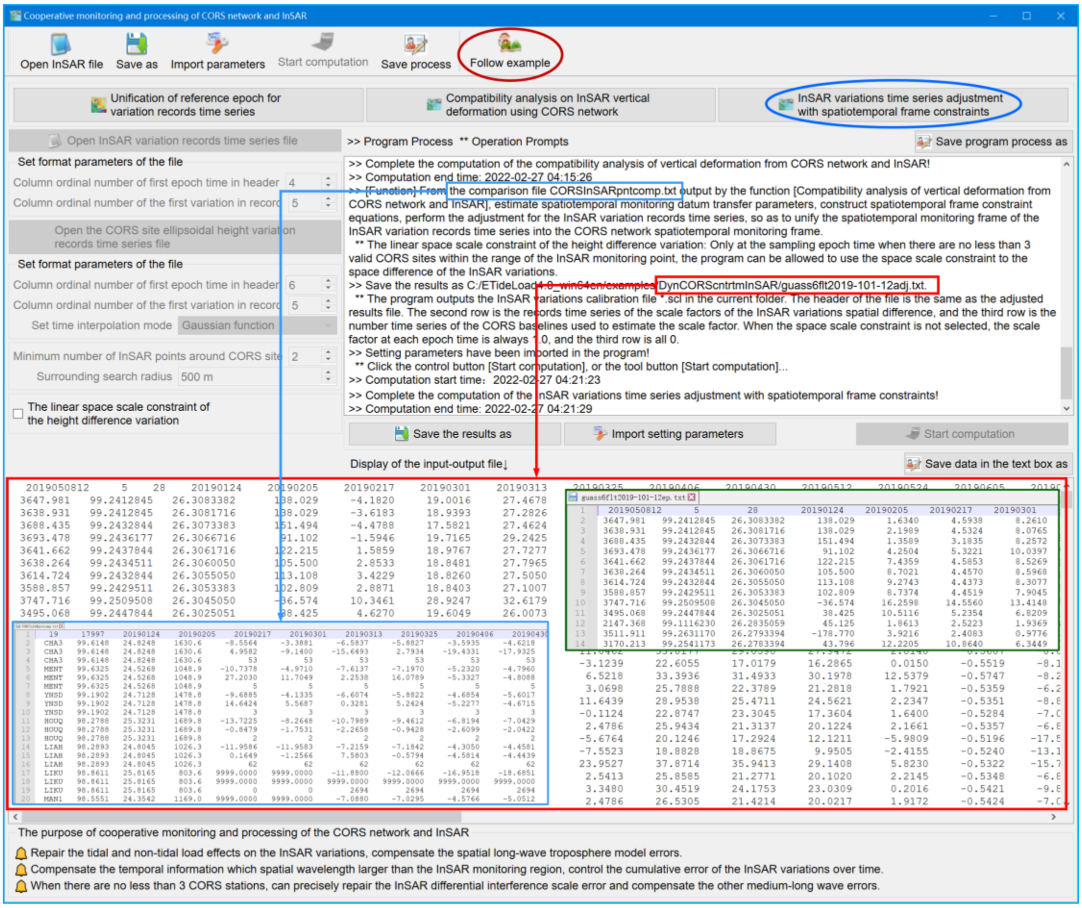
[Input files] The InSAR variation records time series file. The geodetic variations time series file to be reconstructed. The comparison file CORSInSARpntcomp.txt between the CORS site ellipsoidal height variations and InSAR variations time series. The two files can be automatically called by the program without manual input.

[Parameter settings] Set the checkbox [The linear space scale constraint of the height difference variation].

[Output file] The InSAR variation adjusted value records time series file. Whose format is same as the input InSAR variation records time series file.

The program outputs the InSAR variations calibration file ***.scl in the current folder. Here *** are the output adjusted results file name.

The header of the file is the same as the adjusted results file. The second row is the records time series of the scale factors of the InSAR variations spatial difference, and the third row is the number time series of the CORS baselines used to estimate the scale factor. When the space scale constraint is not selected, the scale factor at each epoch time is always 1.0, and the third row is all 0.



The scale factor is an important quantitative indicator to evaluate the performance of the InSAR deformation monitoring. At sampling epoch time whose scale factor exceeds (0.5, 2.0), the vertical deformation separation of the InSAR variations is insufficient, or the quality of the InSAR variations is poor.

The linear space scale constraint of the height difference variation: Only at the sampling epoch time when there are no less than 3 valid CORS sites within the range of the InSAR monitoring point, the program can be allowed to use the space scale constraint to the space difference of the InSAR variations.

5.4 Deep fusion and time series analysis on multi-source InSAR variations

[Purpose] Firstly, deeply fuse multi-source InSAR variation records time series into the uniform spatiotemporal monitoring frame and reference epoch represented by the CORS variations time series respectively in time and space, and then perform time series analysis for all InSAR variation monitoring points, to realize multi-source InSAR collaborative monitoring.

5.4.1 Long-time connection of the same-track InSAR variation time series

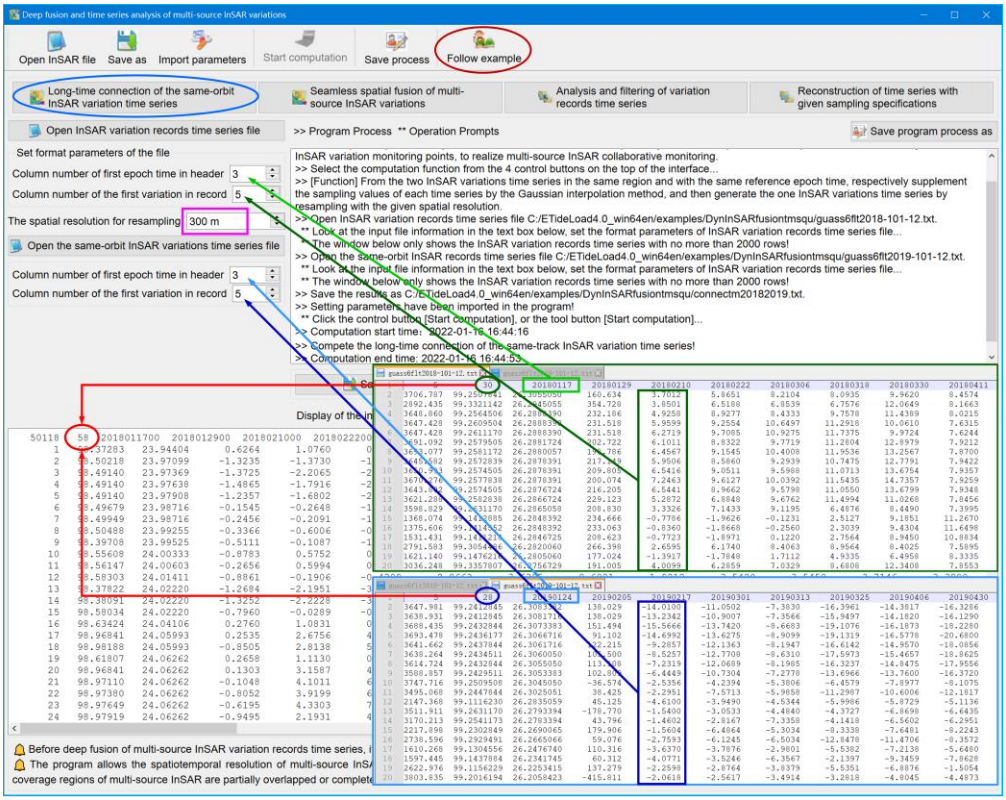
[Function] From the two InSAR variation records time series in the same region and with the same reference epoch time, respectively supplement the sampling values of each time series by the Gaussian interpolation method, and then generate the one InSAR variations time series by resampling with the given spatial resolution.

[Input files] The two InSAR variation records time series files in the same region and with the same reference epoch time.

[Parameter settings] Set the two InSAR variation records time series files format patameters and enter the resampling spatial resolution.

[Output file] The connected InSAR variation records time series file.

The output file format and reference epoch are same as that of the input InSAR variation records time series file.



5.4.2 Seamless spatial fusion on multi-source InSAR variations

[Function] According to the given spatial resolution, resample the input multi-source InSAR variation records time series to generate a new InSAR variation records time series. The input InSAR variation records time series files are extracted according to the given wildcards, and all the input files are in the same format.

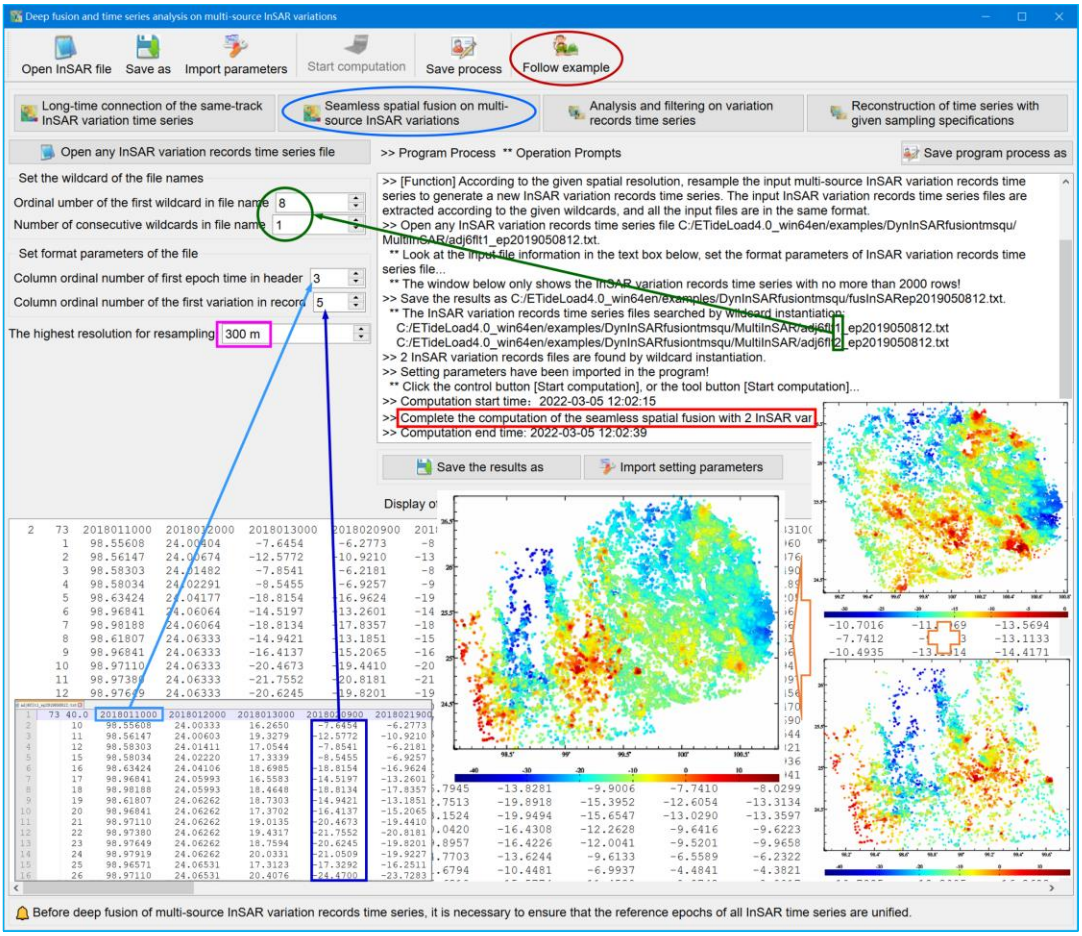
Before deep fusion of multi-source InSAR variation records time series, it is necessary to ensure that the reference epochs of all InSAR time series are unified.

[Input files] Multi-source InSAR variation records time series files.

In this example, two InSAR variation records time series are on adjacent areas, and a small number in the two groups of InSAR monitoring points are cross-distributed.

[Parameter settings] Set the file name wildcards and file format patameters of multi-source InSAR variation records time series and enter the resampling spatial resolution.

[Output file] The fused InSAR variation records time series file. The format is the same as that of the input InSAR variation records time series file.



5.4.3 Analysis and filtering on variation records time series

[Function] Using the continuous Chebyshev and triangular basis function combination method, estimate the low-pass filtering parameters for variation records time series on each monitoring point, and then calculate the filtering value and the linear variation (per year, /a) at source sampling epochs.

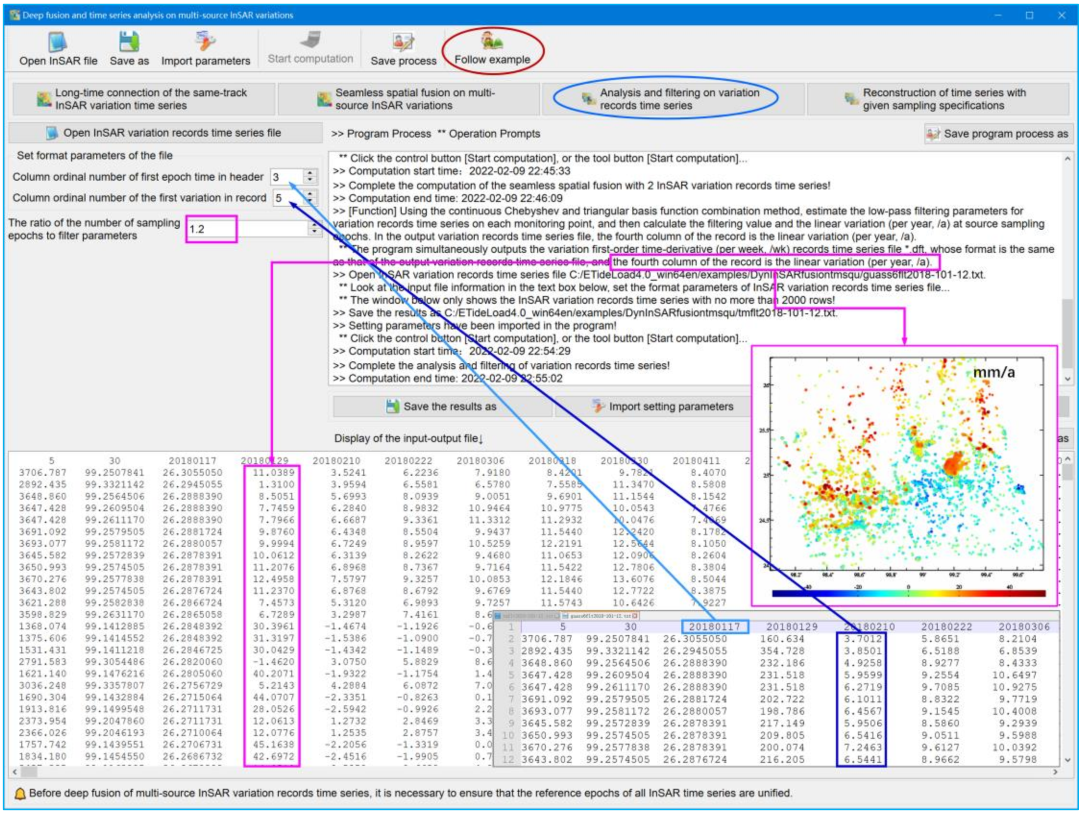
[Input files] The InSAR variation records time series files.

[Parameter settings] Set the file format patameters of InSAR variation records time series and enter the ratio of the number of sampling epochs to filter parameters.

[Output file] The filtered InSAR variation records time series file ***.txt. The InSAR variation first-order time-derivative (per week, /wk) records time series file ***.dft. Here, *** are the output file name.

The filtered variation records time series file. The file format is the same as that of the input InSAR variation records time series file and the fourth column in the file record is the linear variation (per year, /a).

The InSAR variation first-order time-derivative (per week, /wk) records time series file *.dft. The file format is the same as that of the output InSAR variation records time series file, and the fourth column in the record is the linear variation (per year, /a).



5.4.4 Reconstruction of time series with given sampling specifications

[Function] Using the continuous Chebyshev and triangular basis function combination method, estimate the filtering parameters for variation records time series of each monitoring point, and then reconstruct the variation records time series according to the given time series sampling specifications.

The program has time-domain interpolation and short-time forecasting capabilities.

[Input files] The InSAR variation records time series files.

[Parameter settings] Set the file format patameters of InSAR variation records time series and enter the ratio of the number of sampling epochs to filter parameters and time series sampling specifications.

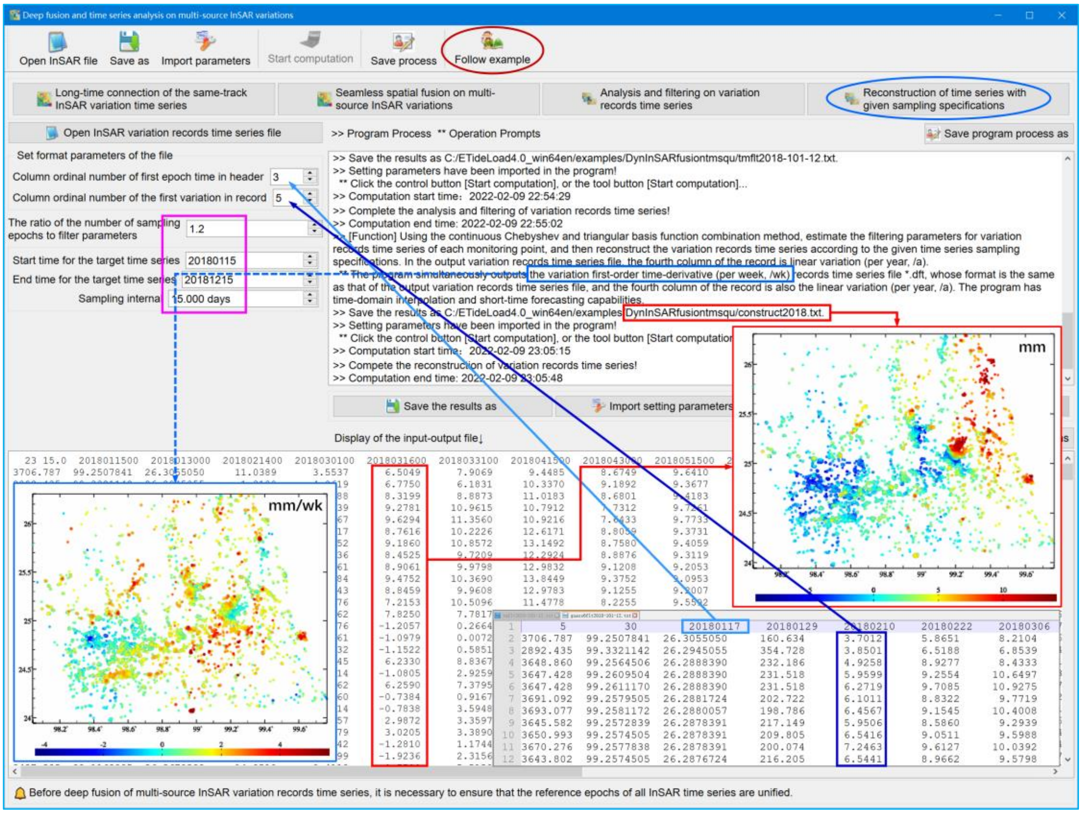
When the starting time is earlier than the first sampling epoch time of the source variation records time series, the program lets the starting time = the first sampling epoch time - sampling interval * total number of the samples * 5%.

When the ending time is later than the last sampling epoch time of the source variation records time series, the program lets the ending time = the last sampling epoch time + sampling interval * total number of the samples * 5%.

[Output file] The reconstructed InSAR variation records time series file ***.txt. The InSAR variation first-order time-derivative (per week, /wk) records time series file ***.dft. Here, *** are the output file name.

The filtered variation records time series file. The file format is the same as that of the input InSAR variation records time series file and the fourth column in the file record is the linear variation (per year, /a).

The InSAR variation first-order time-derivative (per week, /wk) records time series file *.dft. The file format is the same as that of the output InSAR variation records time series file, and the fourth column in the record is the linear variation (per year, /a).



5.5 Calculation of ground stability variation based on vertical deformation

[Purpose] From the ground vertical deformation rate and its horizontal gradient grid model, using the normalized statistical synthesis algorithm, quantitatively estimate the ground stability variations grid according to the quantitative criteria of the ground stability reduction defined by ETideLoad.

Quantitative criteria defined by ETideLoad for the ground stability reduction based on the vertical deformation grids time series are in the following.

(1) The ground vertical deformation rate is relatively large (greater than zero). At this time, the ground here is rising upward.

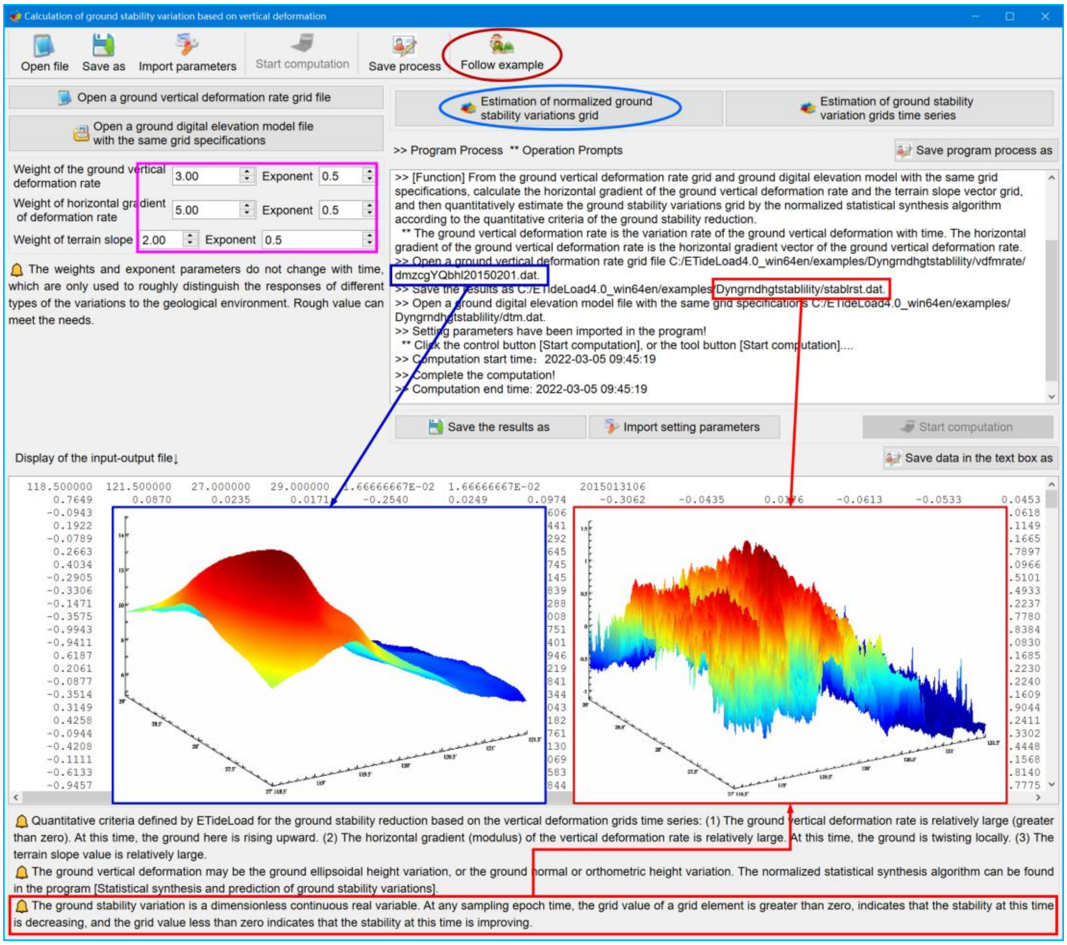
(2) The horizontal gradient (modulus) of the vertical deformation rate is relatively large. At this time, the ground is twisting locally.

(3) The terrain slope value is relatively large.

5.5.1 Estimation of normalized ground stability variations grid

[Function] From the ground vertical deformation rate grid and ground digital elevation model with the same grid specifications, calculate the horizontal gradient of the ground vertical deformation rate and the terrain slope vector grid, and then quantitatively estimate the ground stability variations grid by the normalized statistical synthesis algorithm according to the quantitative criteria of the ground stability reduction.

[Input files] The ground vertical deformation rate grid file and ground digital elevation model file with the same grid specifications.



[Parameter settings] Set the weights and exponents for ground vertical deformation rate, horizontal gradient of the ground vertical deformation rate and terrain slope.

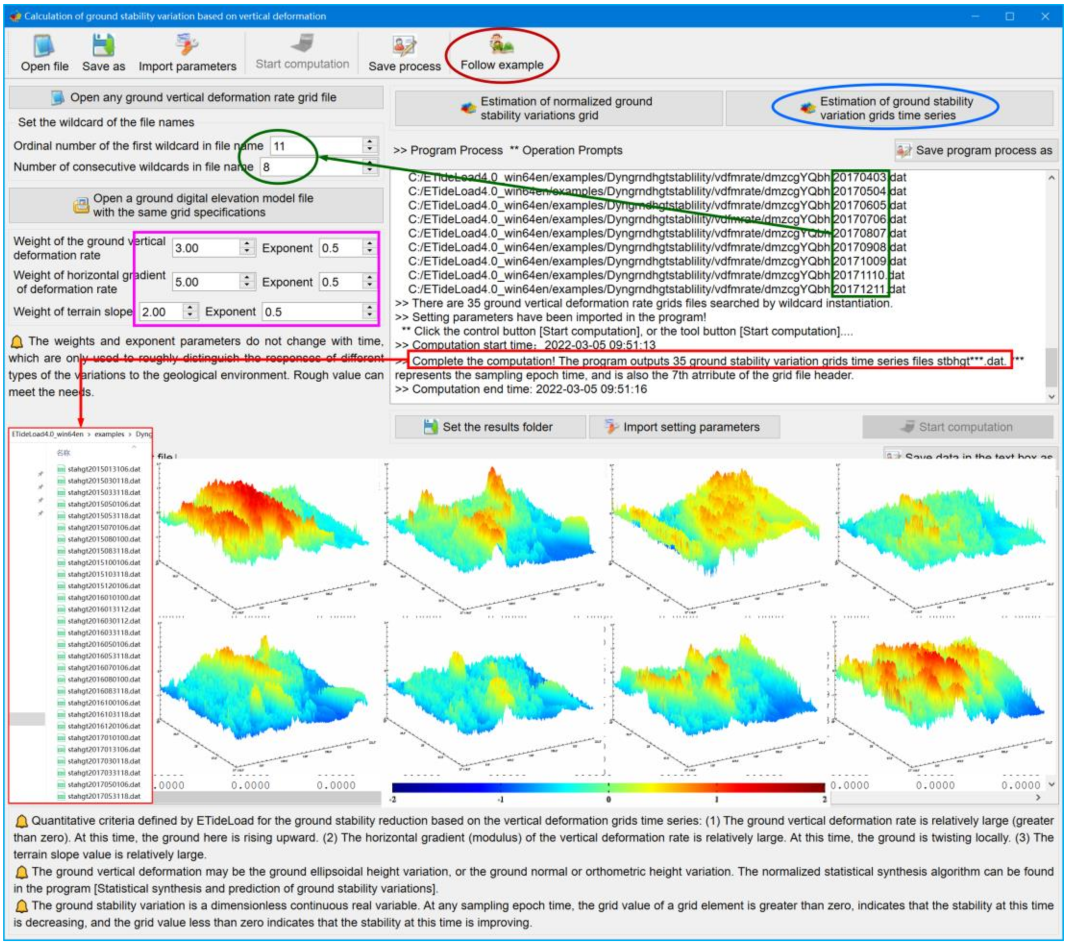
The ground vertical deformation rate is the variation rate of the ground vertical deformation with time. The horizontal gradient of the ground vertical deformation rate is the horizontal gradient vector of the ground vertical deformation rate.

[Output file] The normalized ground stability variations grid file.

The weights and exponent parameters do not change with time, which are only used to roughly distinguish the responses of different types of the variations to the geological environment. Rough value can meet the needs.

5.5.2 Estimation of ground stability variation grids time series

[Function] From the ground vertical deformation rate grids time series and ground digital elevation model with the same grid specifications, calculate the terrain slope vector grid and the vector grids time series of the horizontal gradient of the ground vertical deformation rate, and then quantitatively estimate the ground stability variation grids time series by the normalized statistical synthesis algorithm according to the quantitative criteria of the ground stability reduction.



[Input files] The ground vertical deformation rate grid time series files and ground digital elevation model file with the same grid specifications.

[Parameter settings] Set the wildcard patameters for the deformation rate grids time series files, enter the weights and exponents for ground vertical deformation rate, horizontal gradient of the ground vertical deformation rate and terrain slope.

[Output file] The normalized ground stability variations grid time series files.

The ground vertical deformation may be the ground ellipsoidal height variation, or the ground normal or orthometric height variation. The normalized statistical synthesis algorithm can be found in the program [Statistical synthesis and prediction of ground stability variations].

The ground stability variation is a dimensionless continuous real variable. At any sampling epoch time, the grid value of a grid element is greater than zero, indicates that the stability at this time is decreasing, and the grid value less than zero indicates that the stability at this time is improving.

The ground stability variation grids time series can quantitatively express the time and location of the ground stability reduction phenomenon, the continuous influence time, and the spatial influence range.

5.6 Calculation of ground stability variation based on gravity variations

[Purpose] From the ground gravity (or gravity disturbance) variation rate and its horizontal gradient grid model, using the normalized statistical synthesis algorithm, quantitatively estimate the ground stability variations grid according to the quantitative criteria of the ground stability reduction defined by ETideLoad.

Quantitative criteria defined by ETideLoad for the ground stability reduction based on the gravity variation grids time series are in the following.

(1) The ground gravity variation rate is relatively large (less than zero). At this time, the ground here is rising upward.

(2) The horizontal gradient (modulus) of the gravity variation rate is relatively large. At this time, the ground is twisting locally.

(3) The local terrain effect of the gravity disturbance is relatively large (less than zero).

The ground gravity variation may be the ground gravity variation, or the ground gravity disturbance variation.

5.6.1 Normalized ground stability variations grid estimation

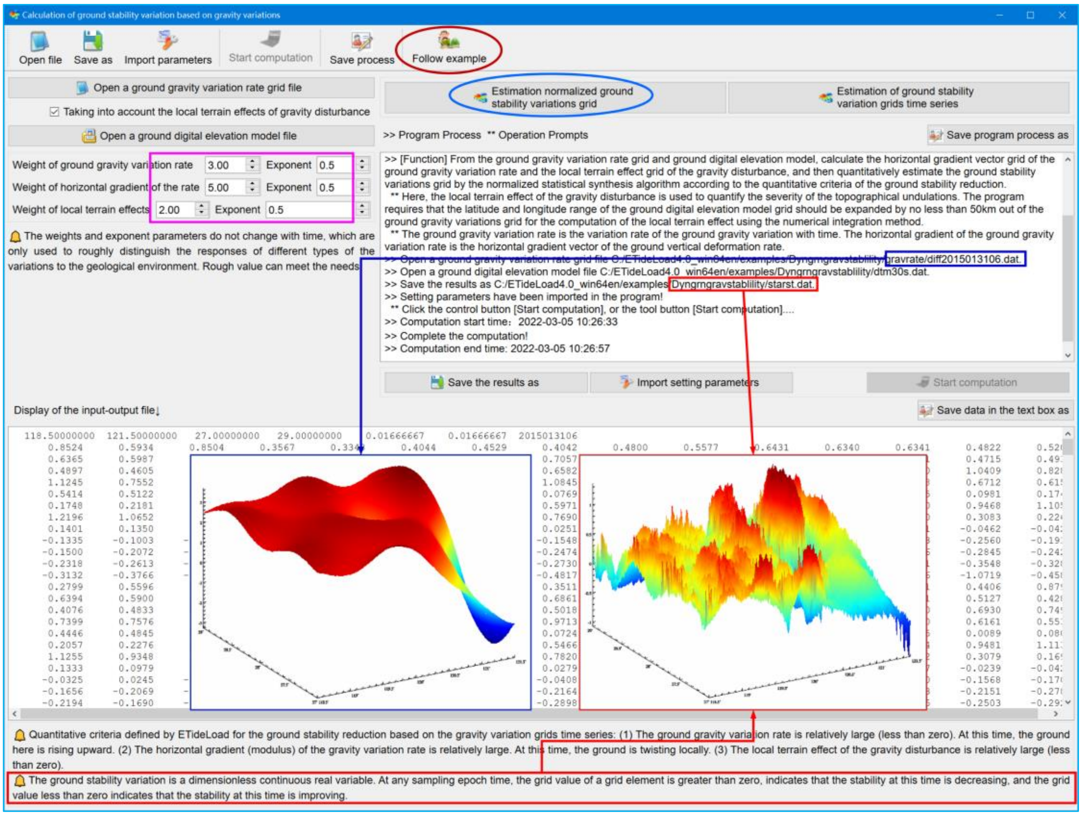
[Function] From the ground gravity variation rate grid and ground digital elevation model, calculate the horizontal gradient vector grid of the ground gravity variation rate and the local terrain effect grid of the gravity disturbance, and then quantitatively estimate the ground stability variations grid by the normalized statistical synthesis algorithm according to the quantitative criteria of the ground stability reduction.

[Input files] The ground gravity variation rate grid file. The ground digital elevation model grid file.

[Parameter settings] Set the weights and exponents for ground gravity variation rate, horizontal gradient of the ground gravity variation rate and local terrain effect, set the checkbox [Taking into account the local terrain effects of gravity disturbance].

The ground gravity variation is the variation rate of the ground gravity variation with time. The horizontal gradient of the ground gravity variation rate is the horizontal gradient vector of the ground gravity variation rate.

[Output file] The normalized ground stability variations grid file.



5.6.2 Estimation of ground stability variation grids time series

[Function] From the ground gravity variation rate grids time series and ground digital elevation model, calculate the local terrain effect grid of the gravity disturbance and the vector grids time series of the horizontal gradient of the ground gravity variation rate, and then quantitatively estimate the ground stability variation grids time series by the normalized statistical synthesis algorithm according to the quantitative criteria of the ground stability reduction.

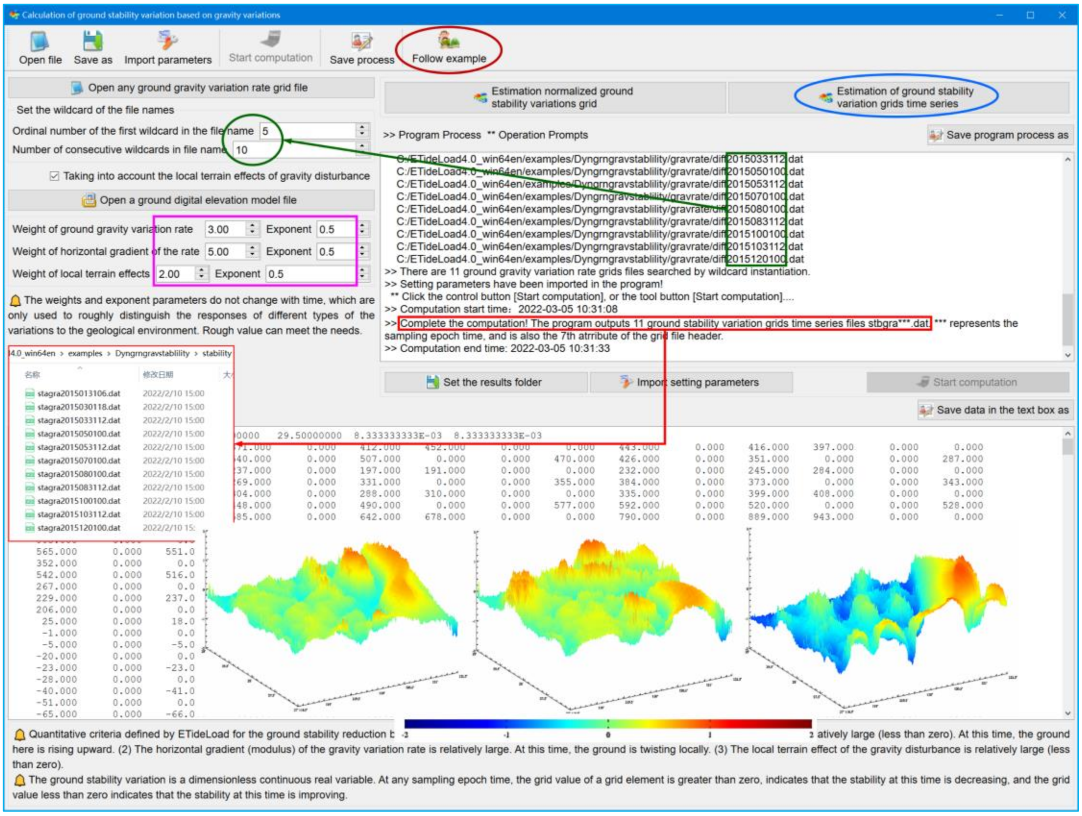
[Input files] The ground gravity variation rate grid time series files and ground digital elevation model file.

[Parameter settings] Set the wildcard patameters for the gravity variation rate grids time series files, enter the weights and exponents for ground gravity variation rate, horizontal gradient of the ground gravity variation rate and local terrain effect.

Here, the local terrain effect of the gravity disturbance is used to quantify the severity of the topographical undulations. The program requires that the latitude and longitude range of the ground digital elevation model grid should be expanded by no less than 50km out of the ground gravity variations grid for the computation of the local terrain effect using the numerical integration method.

The weights and exponent parameters do not change with time, which are only used to roughly distinguish the responses of different types of the variations to the geological environment. Rough value can meet the needs.

[Output file] The normalized ground stability variations grid time series files.



5.7 Calculation of ground stability variation based on variation vectors

[Purpose] From the ground tilt (vertical deflection or horizontal displacement) variation rate vector grid and ground digital elevation model, using the normalized statistical synthesis algorithm, quantitatively estimate the ground stability variations grid according to the quantitative criteria of the ground stability reduction defined by ETideLoad.

Quantitative criteria defined by ETideLoad for the ground stability reduction based on the variation vector grids time series are in the following.

(1) The directions of the ground tilt (vertical deflection or horizontal displacement) variations are gathering or diverging. At this time, the ground nearby here is being squeezed or stretched.

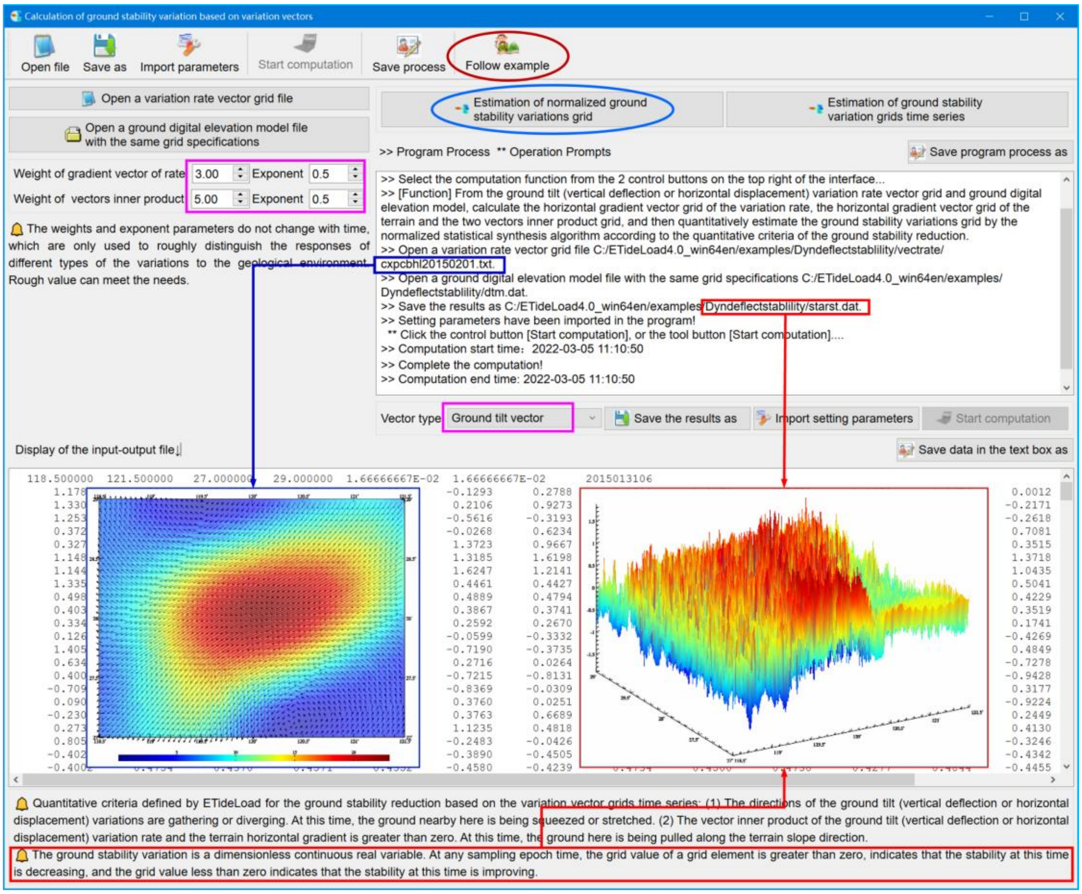
(2) The vector inner product of the ground tilt (vertical deflection or horizontal displacement) variation rate and the terrain horizontal gradient is greater than zero. At this time, the ground here is being pulled along the terrain slope direction.

The variation vector may be the ground tilt variation, vertical deflection variation, or ground horizontal displacement.

5.7.1 Estimation of normalized ground stability variations grid

[Function] From the ground tilt (vertical deflection or horizontal displacement) variation rate vector grid and ground digital elevation model, calculate the horizontal gradient vector grid of the variation rate, the horizontal gradient vector grid of the terrain and the two vectors inner product grid, and then quantitatively estimate the ground stability variations grid by the normalized statistical synthesis algorithm according to the quantitative criteria of the ground stability reduction.

[Input files] The ground variation rate vector grid file and ground digital elevation model file with the same grid specifications.



[Parameter settings] Set the weights and exponents for the rate gradient and two vectors inner product, select the vector type.

[Output file] The normalized ground stability variations grid file.

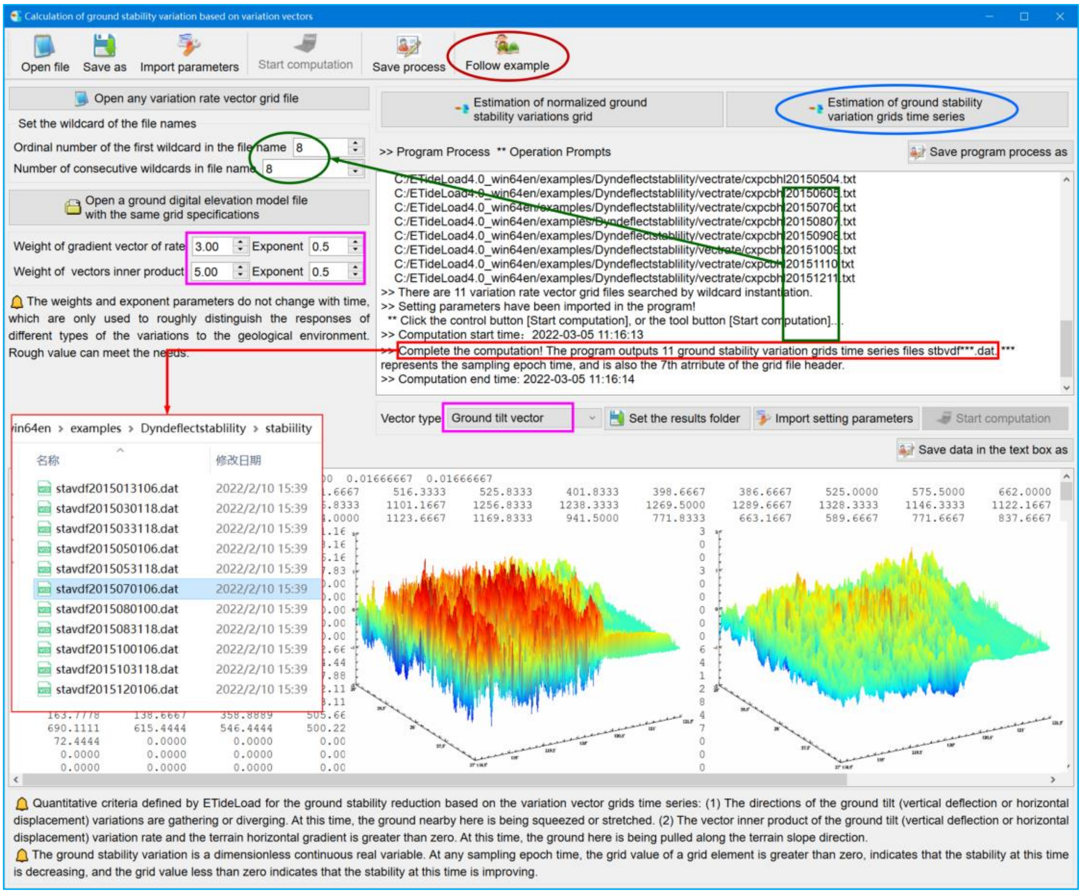
5.7.2 Estimation of ground stability variation grids time series

[Function] From the ground tilt (vertical deflection or horizontal displacement) variation rate vector grids time series and ground digital elevation model, calculate the horizontal gradient vector grids time series of the variation rate, the horizontal gradient vector grid of the terrain, and the two vectors inner product grids time series, and then quantitatively estimate the ground stability variation grids time series by the normalized statistical synthesis algorithm according to the quantitative criteria of the ground stability reduction.

[Input files] The ground variation rate vector grids time series files and ground digital elevation model file with the same grid specifications.

[Parameter settings] Set the wildcard patameters for the rate vector grids time series files, enter the weights and exponents for the rate gradient and two vectors inner product, select the vector type.

[Output file] The normalized ground stability variations grid time series files.



5.8 Statistical synthesis and prediction of ground stability variations

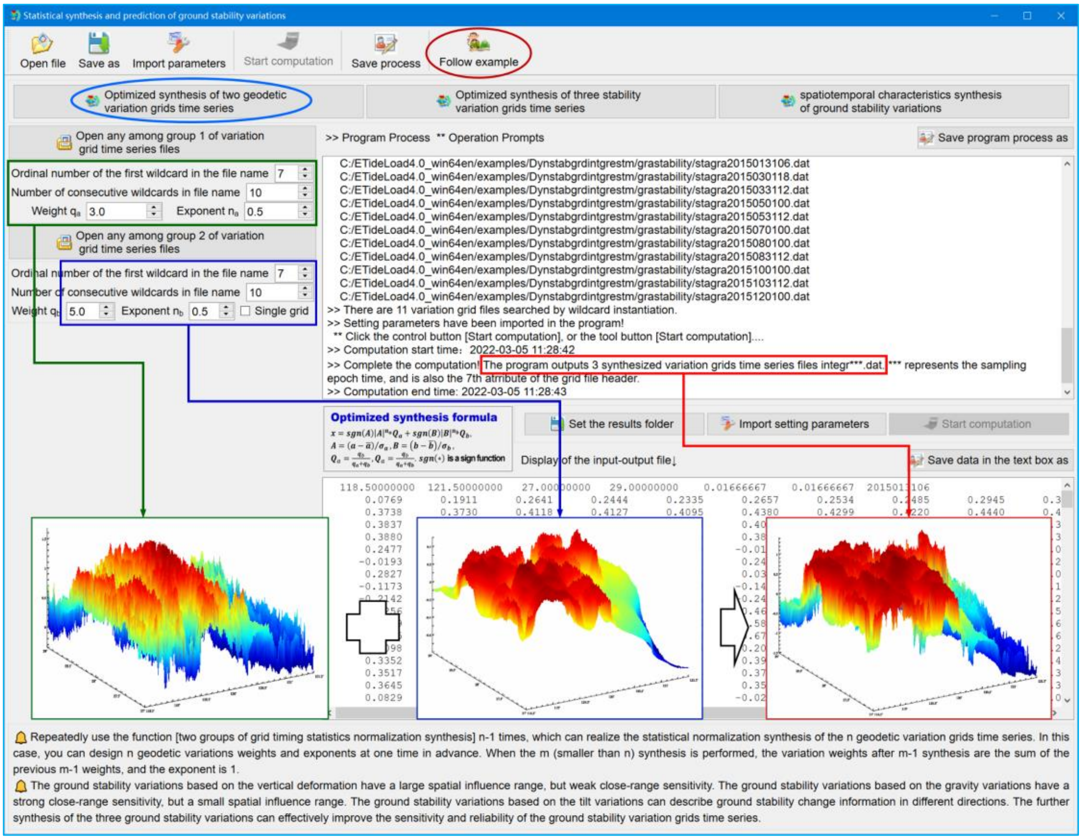
[Purpose] According to historical disasters events during the monitoring period, by adjusting the weights and exponents of multiple stability variations based on various geodetic variations, optimize the ground stability variation grids time series by the statistical normalized synthesis algorithms, to reflect the spatial distribution and temporal natures of the regional ground stability variations.

5.8.1 Optimized synthesis of two geodetic variation grids time series

[Function] From two groups of geodetic variation grids time series with the same space-grid and time-sampling specifications, generate the coupled geodetic variation grids time series by the statistical normalized synthesis algorithms, to reflect the spatiotemporal dynamic effects of the two kinds of geodetic joint monitoring.

[Input files] The two groups of geodetic variation grids time series files with the same space-grid and time-sampling specifications.

[Parameter settings] Set the wildcard patameters for grids time series files, enter the weights and exponents.



[Output file] The synthesized variation grids time series files.

If all the characters of the file name are set as wildcards, the variation grids time series only is an epoch sampling grid. In this case, the program can realize the normalized synthesis between a group of the grids time series and a single grid.

With the two geodetic variation grids time series $\boldsymbol{a}$, $\boldsymbol{b}$, the synthesized variation grids time series $\boldsymbol{x}$ can be calculated by the following formula.

$\boldsymbol{x} = \boldsymbol{sgn}(\boldsymbol{A})|\boldsymbol{A}|^{n_a}\boldsymbol{Q_a} + \boldsymbol{sgn}(\boldsymbol{B})|\boldsymbol{B}|^{n_b}\boldsymbol{Q_b}$, Where, $\boldsymbol{sgn}(*)$ is a sign function,

$\boldsymbol{A} = (\boldsymbol{a} - \overline{\boldsymbol{a}})/\boldsymbol{\sigma_a}\,, \boldsymbol{B} = \left(\boldsymbol{b} - \overline{\boldsymbol{b}}\right)/\boldsymbol{\sigma_b}\,, \boldsymbol{Q}_a = \frac{q_b}{q_a+q_b}, \boldsymbol{Q}_a = \frac{q_b}{q_a+q_b}$.

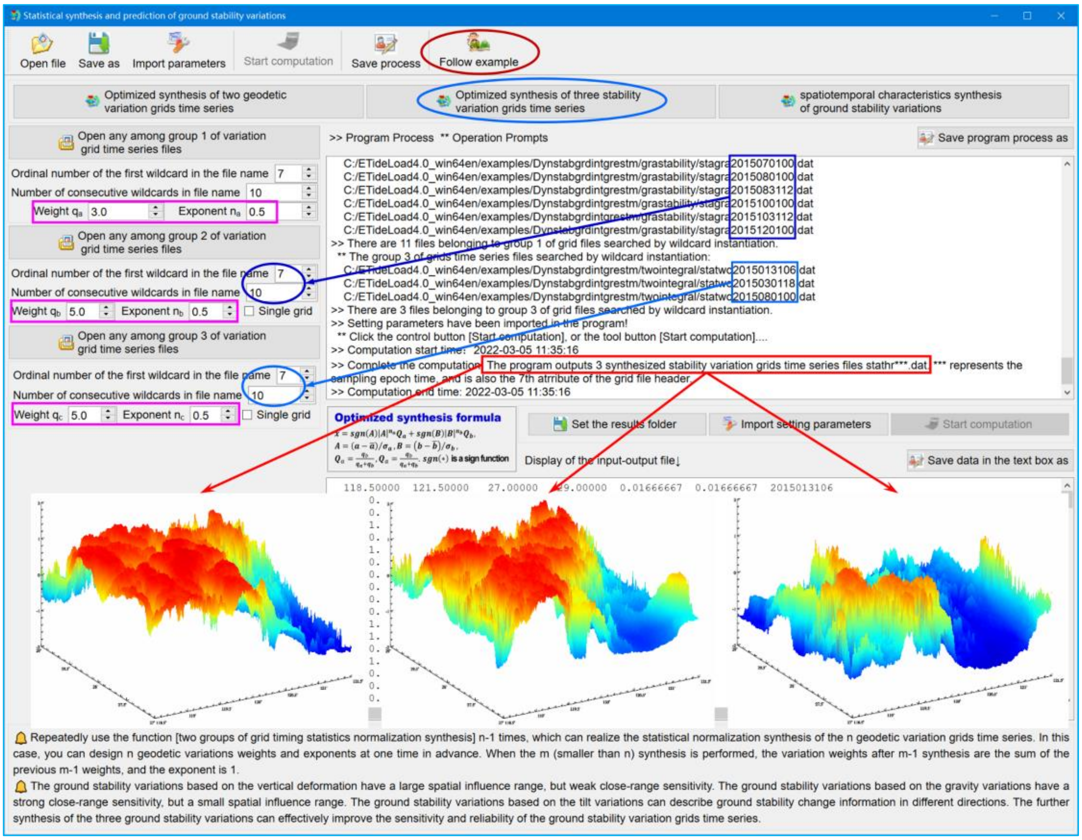
5.8.2 Optimized synthesis of three stability variation grids time series

[Function] From three groups of ground stability variation grids time series with the same space-grid and time-sampling specifications, generate the ground stability variation grids time series with spatiotemporal dynamic feature information, higher sensitivity, and reliability by the statistical normalized synthesis algorithms.

[Input files] The three groups of stability variation grids time series files with the same space-grid and time-sampling specifications.

[Parameter settings] Set the wildcard patameters for grids time series files, enter the weights and exponents.

[Output file] The synthesized stability variation grids time series files.

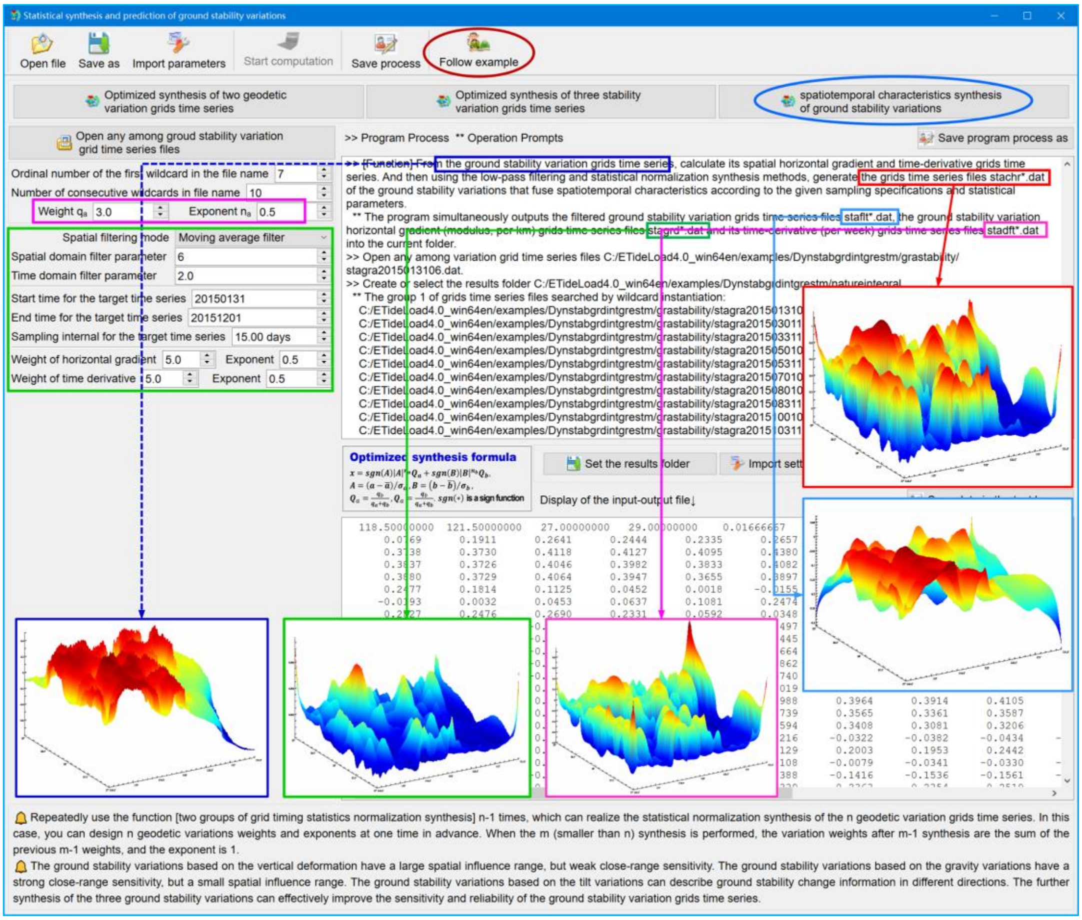


The ground stability variations based on the vertical deformation have a large spatial influence range, but weak close-range sensitivity. The ground stability variations based on the gravity variations have a strong close-range sensitivity, but a small spatial influence range. The ground stability variations based on the tilt variations can describe ground stability change information in different directions. The further synthesis of the three ground stability variations can effectively improve the sensitivity and reliability of the ground stability variation grids time series.

5.8.3 spatiotemporal characteristics synthesis of ground stability variations

[Function] From the ground stability variation grids time series, calculate its spatial horizontal gradient and time-derivative grids time series. And then using the low-pass filtering and statistical normalization synthesis methods, generate the grids time series files stachr*.dat of the ground stability variations that fuse spatiotemporal characteristics according to the given sampling specifications and statistical parameters.

[Input files] The ground stability variation grids time series files.



[Parameter settings] Enter the weights and exponents for the ground stability variation, its horizontal gradient and time-derivative, set spatial and time domain filter parameters, and set the sampling specificationsl parameters.

When the starting time is earlier than the first sampling epoch time of the source variation grids time series, the program lets the starting time = the first sampling epoch time - sampling interval * total number of the samples * 5%.

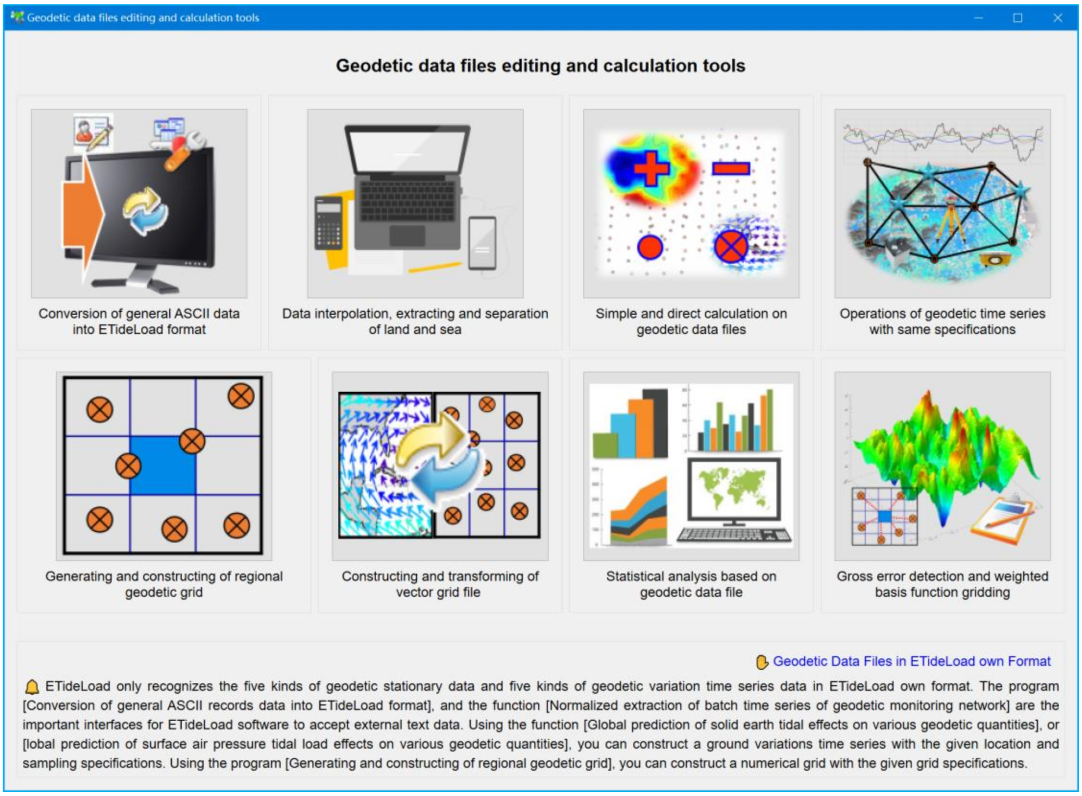
When the ending time is later than the last sampling epoch time of the source variation grids time series, the program lets the ending time = the last sampling epoch time + sampling interval * total number of the samples * 5%.

[Output file] The synthesized ground stability variation grids time series files stachr*.dat, filtered ground stability variation grids time series files staflt*.dat, ground stability variation horizontal gradient (modulus, per km) grids time series files stagrd*.dat and its time-derivative (per week) grids time series files stadft*.dat.

Repeatedly use the function [two groups of grid timing statistics normalization synthesis] n-1 times, which can realize the statistical normalization synthesis of the n geodetic variation grids time series. In this case, you can design n geodetic variations weights and exponents at one time in advance. When the m (<n) synthesis is performed, the variation weights after m-1 synthesis are the sum of the previous m-1 weights, and the exponent is 1.

6 Editing, calculation and visualization for geodetic data files

The group of programs can be used to construct of geodetic data files in ETideLoad format, convert between data formats, and edit, interpolate, grid, extract, separate, merge, detect the gross errors, directly calculate, and visualize on geodetic data files.



6.1 Conversion of general ASCII data into ETideLoad format

[Function] Convert the general ASCII data records file from different sources and non-standard formats into the discrete geodetic records file in ETideLoad format.

[Input file] The general ASCII data records file.

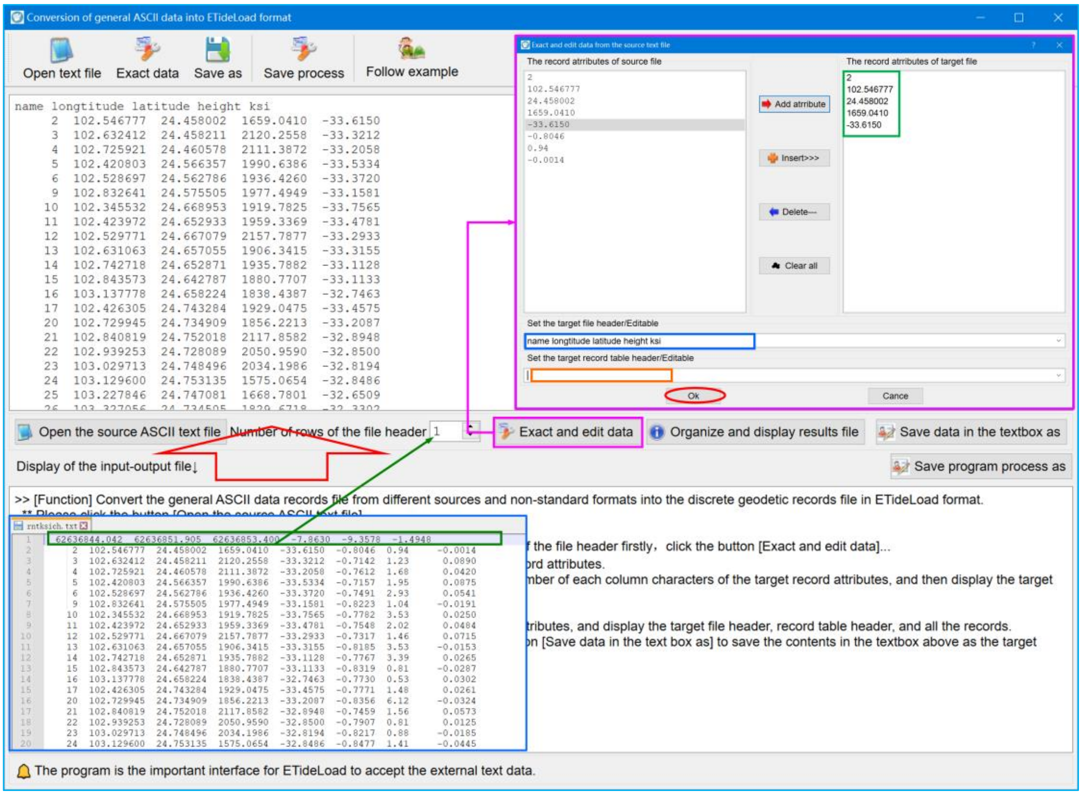
After entering the number of rows of the input file header, click the control button [Exact and edit data] to open the dialog [Exact and edit data from the source text file].

Set the format parameters about the target file header, record table header, and record attributes.

When the target file does not need the record table header, please clear the text corresponding to the input text box.

Click the button [Ok] to close the dialog. Click the control button [Organize and display results file] to count the maximum number of each column characters of the target record attributes, and then display the target file header, record table header, and all the records. It takes some time to organize the target record attributes, please wait…

Complete the statistics of the maximum number of characters of the target record attributes, and display the target file header, record table header, and all the records.



[Output file] The discrete geodetic records file in ETideLoad format.

Check the target records file displayed in the editable textbox. Click the control button [Save data in the textbox as] to save the contents in the textbox above as the target file...

The program is the important interface for ETideLoad to accept the external text data.

6.2 Data interpolation, extracting and separation of land and sea

6.2.1 Changing of grid resolution by interpolation

[Function] Increase or decrease the grid spatial resolution according to the given grid resolution and specified interpolation method.

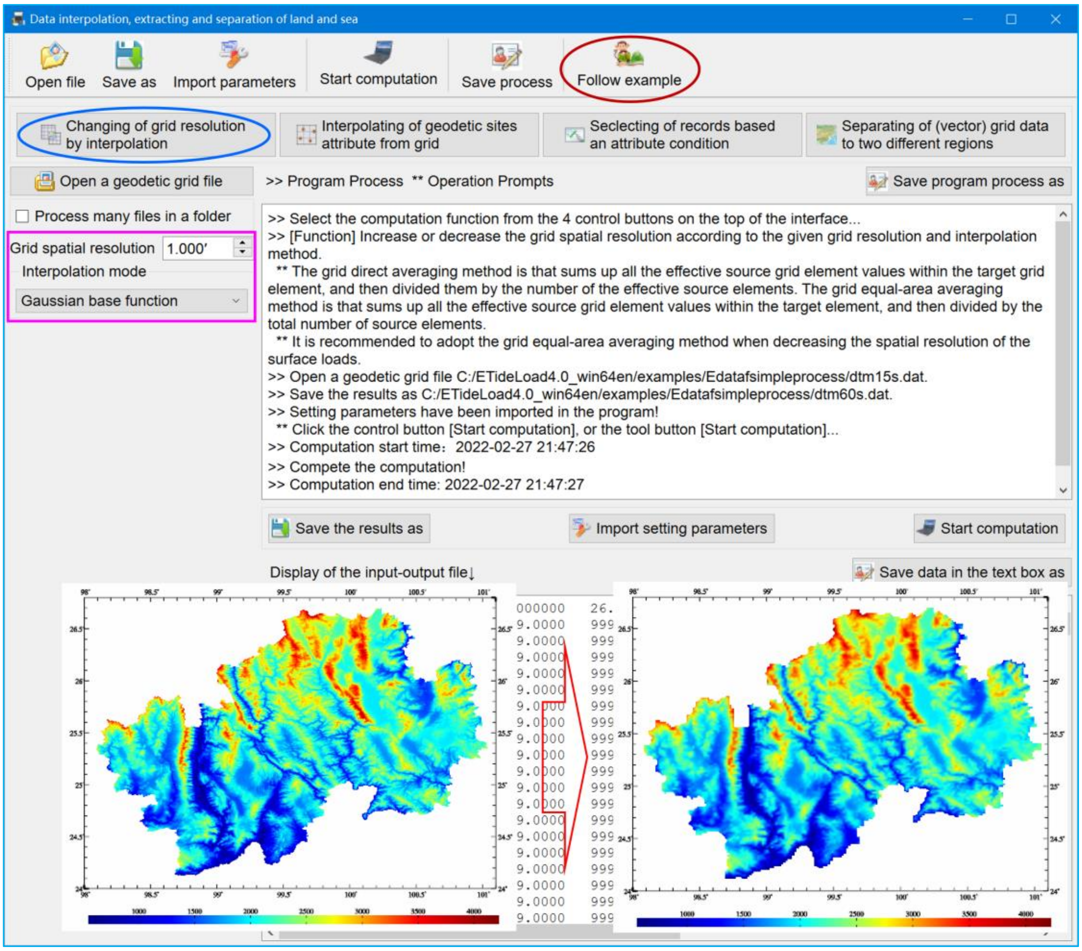
[Input file] The geodetic numerical grid file.

[Parameter settings] Enter the spatial resolution for target grid and select the interpolation mode.

[Output file] The target geodetic numerical grid file.

The grid direct averaging method is that sums up all the effective source grid element values within the target grid element, and then divided them by the number of the effective source elements. The grid equal-area averaging method is that sums up all the effective source grid element values within the target element, and then divided by the total number of source elements.

It is recommended to adopt the grid equal-area averaging method when decreasing the spatial resolution of the surface loads.



The grid direct averaging method or the grid equal-area averaging method can be used to decrease grid resolution. When the resolution of the target grid is lower than that of the source grid, the program automatically adopts the inverse distance weighted interpolation method.

6.2.2 Interpolating of geodetic sites attribute from grid

[Function] From a numerical grid, interpolate the attribute values of the geodetic sites according to the specified interpolation method.

[Input files] The discrete geodetic points file to be interpolated. The geodetic numerical grid file for interpolation.

[Parameter settings] Enter number of rows of the discrete geodetic points file header and select the interpolation mode.

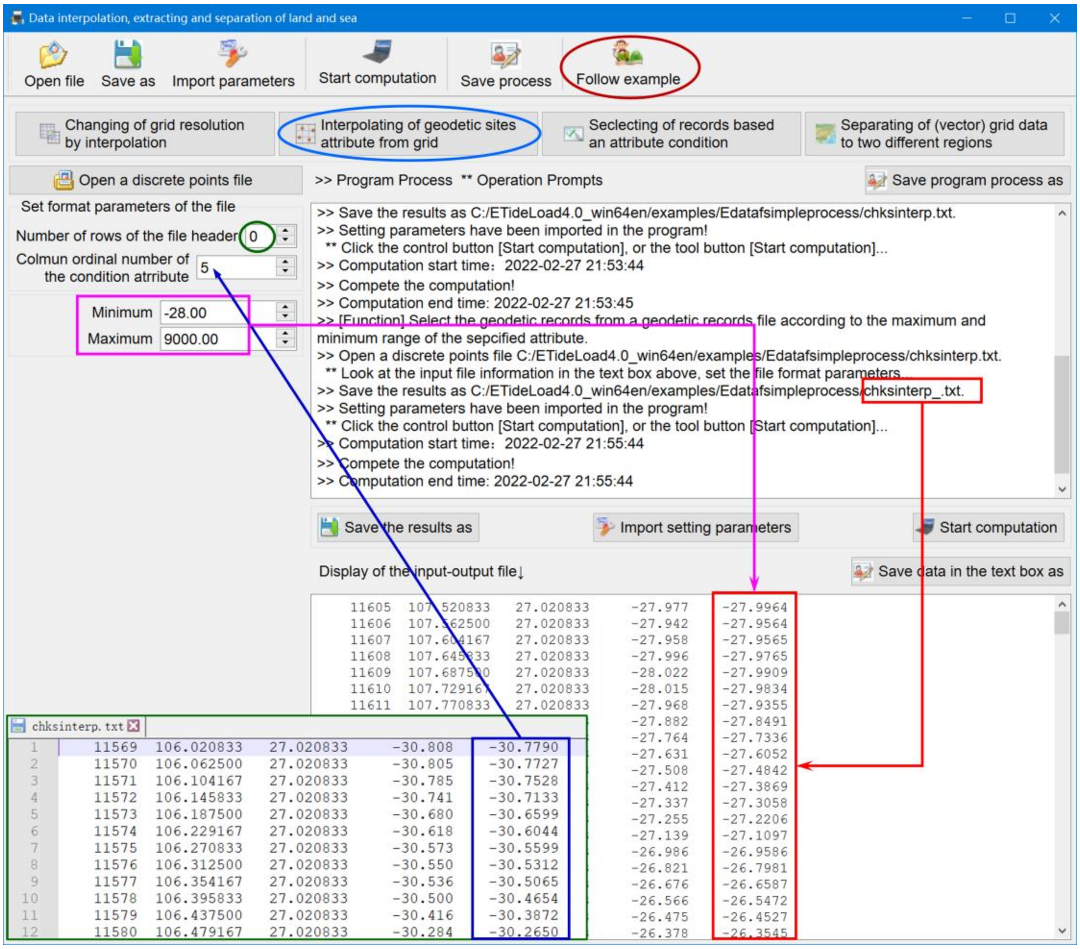
[Output file] The interpolated discrete geodetic points file.

The file format is the same as the input discrete geodetic points file file. Behind the input file record, add one column of the interpolated value as the output file record.

6.2.3 Selecting of records based an attribute condition

[Function] Select the geodetic records from a geodetic records file according to the maximum and minimum range of the specified attribute.

[Parameter settings] Enter number of rows of the input file header, colmun ordinal number of the condition attribute in the file record, and minimum and maximum of the attribute.



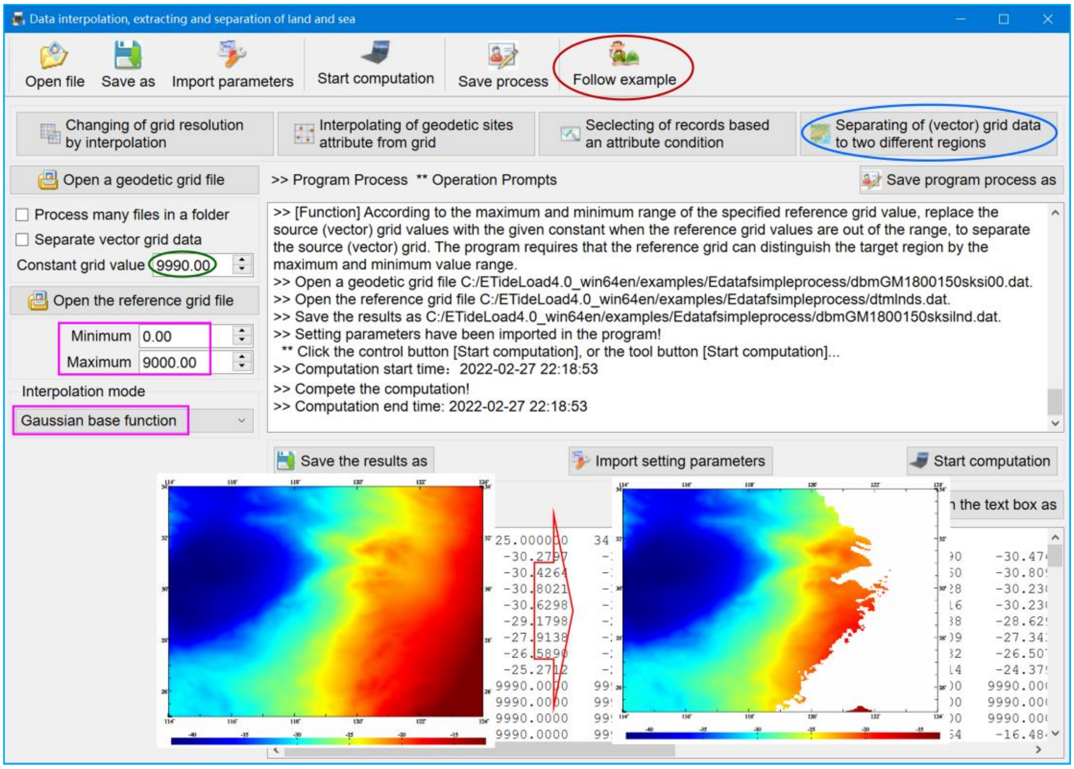
6.2.4 Separating of (vector) grid data to two different regions

[Function] According to the maximum and minimum range of the specified reference grid value, replace the source (vector) grid values with the given constant when the reference grid values are out of the range, to separate the source (vector) grid.

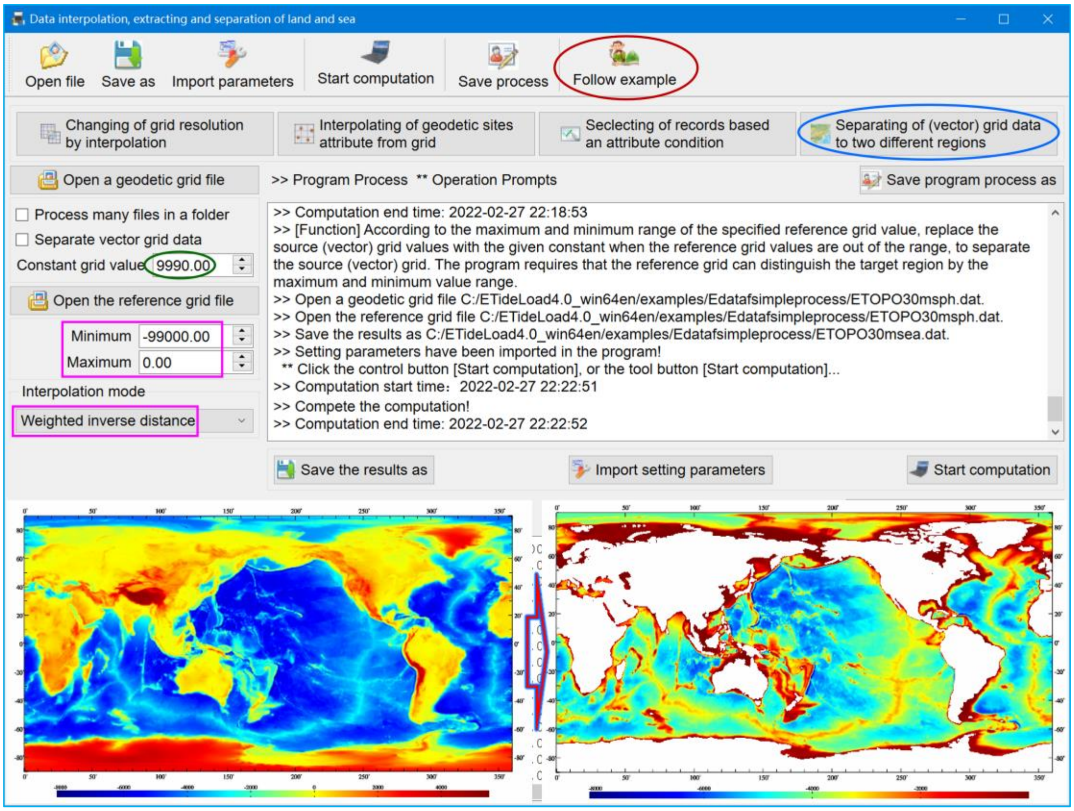
The program requires that the reference grid can distinguish the target region by the maximum and minimum value range.

The program can realize the separation of land or sea (vector) grid. The resolution of the source grid may be different from that of the reference grid.

[Input files] The source geodetic (vector) grid file. The reference grid file whose grid range and resolution are not smaller than that of the source grid file.



Data interpolation, extracting and separation of land and sea
Open file
Save as
Import parameters
Start computation
Save process
Follow example
Changing of grid resolution by interpolation
Interpolating of geodetic sites attribute from grid
Seclecting of records based an attribute condition
Separating of (vector) grid data to two different regions
Open a geodetic grid file
>> Program Process ** Operation Prompts
Save program process as
Process many files in a folder
Separate vector grid data
Constant grid value 9990.00
Open the reference grid file
Minimum 0.00
Maximum 9000.00
Interpolation mode
Gaussian base function
>> [Function] According to the maximum and minimum range of the specified reference grid value, replace the source (vector) grid values with the given constant when the reference grid values are out of the range, to separate the source (vector) grid. The program requires that the reference grid can distinguish the target region by the maximum and minimum value range.
>> Open a geodetic grid file C:/ETideLoad4.0_win64en/examples/Edatafsimpleprocess/dbmGM1800150sksi00.dat.
>> Open the reference grid file C:/ETideLoad4.0_win64en/examples/Edatafsimpleprocess/dtmlnds.dat.
>> Save the results as C:/ETideLoad4.0_win64en/examples/Edatafsimpleprocess/dbmGM1800150sksilnd.dat.
>> Setting parameters have been imported in the program!
** Click the control button [Start computation], or the tool button [Start computation]...
>> Computation start time: 2022-02-27 22:18:53
>> Compete the computation!
>> Computation end time: 2022-02-27 22:18:53
Save the results as
Import setting parameters
Start computation



Data interpolation, extracting and separation of land and sea
Open file
Save as
Import parameters
Start computation
Save process
Follow example
Changing of grid resolution by interpolation
Interpolating of geodetic sites attribute from grid
Seclecting of records based an attribute condition
Separating of (vector) grid data to two different regions
Open a geodetic grid file
>> Program Process ** Operation Prompts
Save program process as
Process many files in a folder
Separate vector grid data
Constant grid value 9990.00
Open the reference grid file
Minimum -99000.00
Maximum 0.00
Interpolation mode
Weighted inverse distance
>> Computation end time: 2022-02-27 22:18:53
>> [Function] According to the maximum and minimum range of the specified reference grid value, replace the source (vector) grid values with the given constant when the reference grid values are out of the range, to separate the source (vector) grid. The program requires that the reference grid can distinguish the target region by the maximum and minimum value range.
>> Open a geodetic grid file C:/ETideLoad4.0_win64en/examples/Edatafsimpleprocess/ETOPO30msph.dat.
>> Open the reference grid file C:/ETideLoad4.0_win64en/examples/Edatafsimpleprocess/ETOPO30msph.dat.
>> Save the results as C:/ETideLoad4.0_win64en/examples/Edatafsimpleprocess/ETOPO30msea.dat.
>> Setting parameters have been imported in the program!
** Click the control button [Start computation], or the tool button [Start computation]...
>> Computation start time: 2022-02-27 22:22:51
>> Compete the computation!
>> Computation end time: 2022-02-27 22:22:52
Save the results as
Import setting parameters
Start computation

6.3 Simple and direct calculation on geodetic data files

6.3.1 Weighted operations on two specified attributes in records file

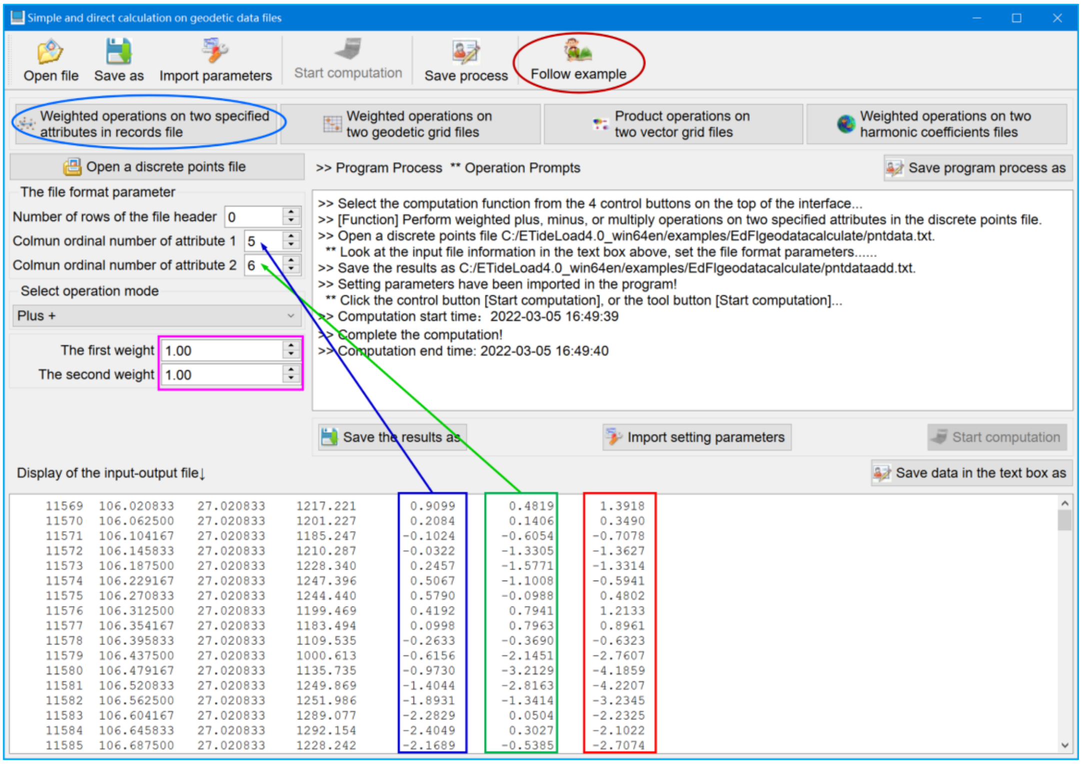
[Function] Perform weighted plus, minus, or multiply operations on two specified attributes in the discrete points file.

[Input file] The discrete geodetic points file.

[Parameter settings] Enter number of rows of the discrete geodetic points file header, colmun ordinal number and weight of the attribute 1, and colmun ordinal number and weight of attribute 2. Select operation mode.

[Output file] The operated discrete geodetic points file.

The file format is the same as the input discrete geodetic points file file. Behind the input file record, add one column of the computed result as the output file record.



6.3.2 Weighted operations on two geodetic grid files

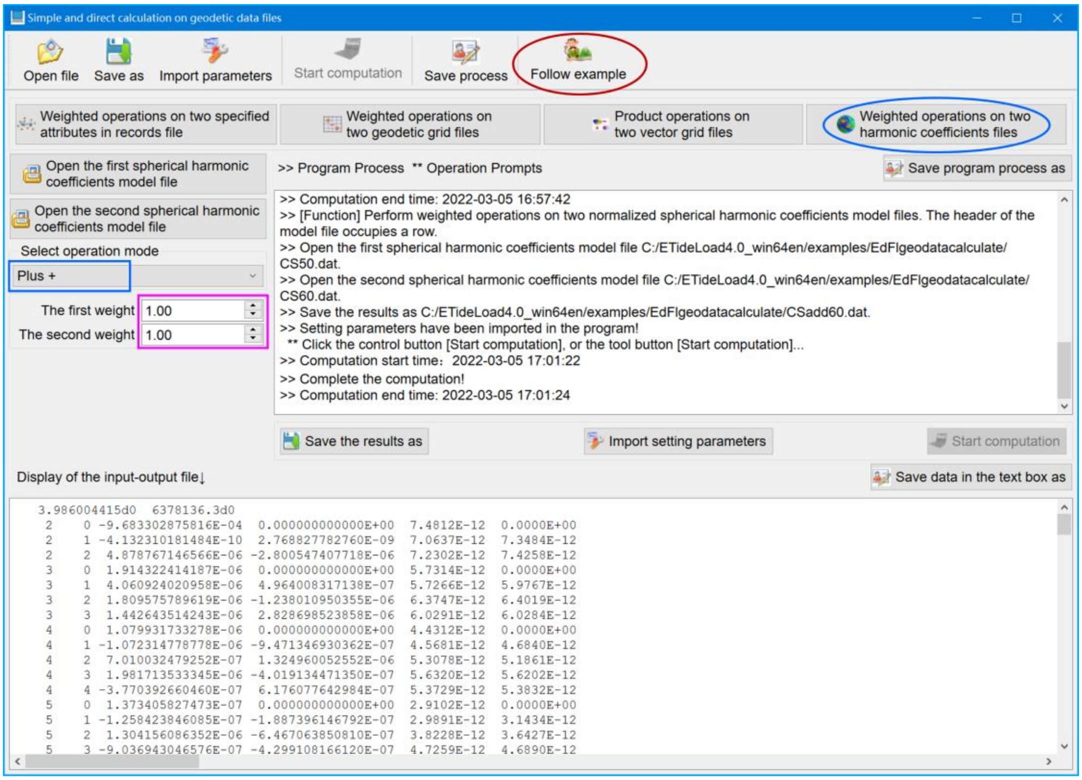
[Function] Perform weighted plus, minus, or multiply operations on grid elements in two (vectors) grid files with the same specifications.

6.3.3 Product operations on two vector grid files

[Function] Perform outer product or inner product operations on vectors grid elements in two vectors grid files with the same specifications.

6.3.4 Weighted operations on two harmonic coefficients files

[Function] Perform weighted operations on two normalized spherical harmonic coefficients model files.



The file header occupies a row and consists of two attributes for scaling parameters of the spherical harmonic coefficients model, namely the geocentric gravitational constant GM (×10^{14}m^2/s^2) and equatorial radius of the Earth a (m).

6.4 Operations on geodetic time series with same specifications

6.4.1 Weighted operations on two records time series with same specifications

[Function] Perform weighted plus, minus, or multiply operations on two variations at the same sampling epochs from two records time series.

The program requires that the records of two groups of time series are one-by-one correspondence in location and sampling epoch.

[Input files] The two groups of variation records time series files.

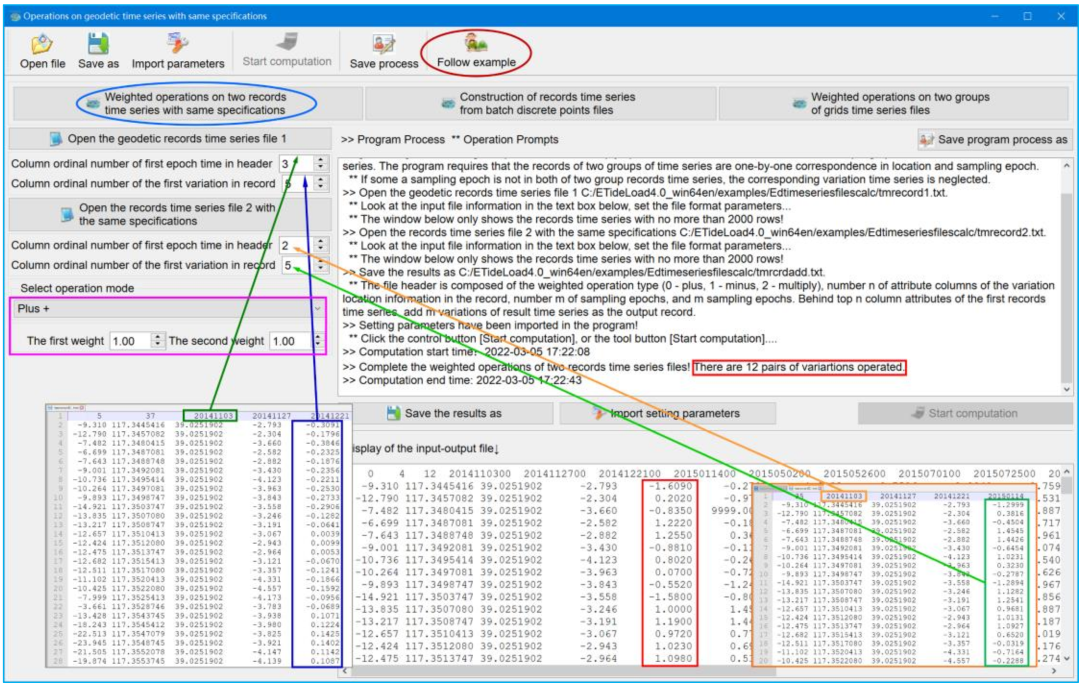
[Parameter settings] Set the records time series file format parameters, enter the weighs , and select operation mode..

If some a sampling epoch is not in both of two group records time series, the corresponding variation time series is neglected.

[Output file] The operated discrete geodetic points file.

The file header is composed of the weighted operation type (0 - plus, 1 - minus, 2 - multiply), number n of attribute columns of the variation location information in the record, number m of sampling epochs, and m sampling epochs.

Behind top n columns attributes of the first records time series, add m variations of result time series as the output record.



6.4.2 Construction of records time series from batch discrete points files

[Function] From a series of discrete points files with the same specifications including the sampling epoch time, extract the specified attribute variation, and compose a time series by sorting with time, and then generate a records time series file with several kinds of variations.

[Input files] A series of discrete points files with the same specifications.

The program requires that the file header occupies a row that contains a sampling epoch in ETideLoad format.

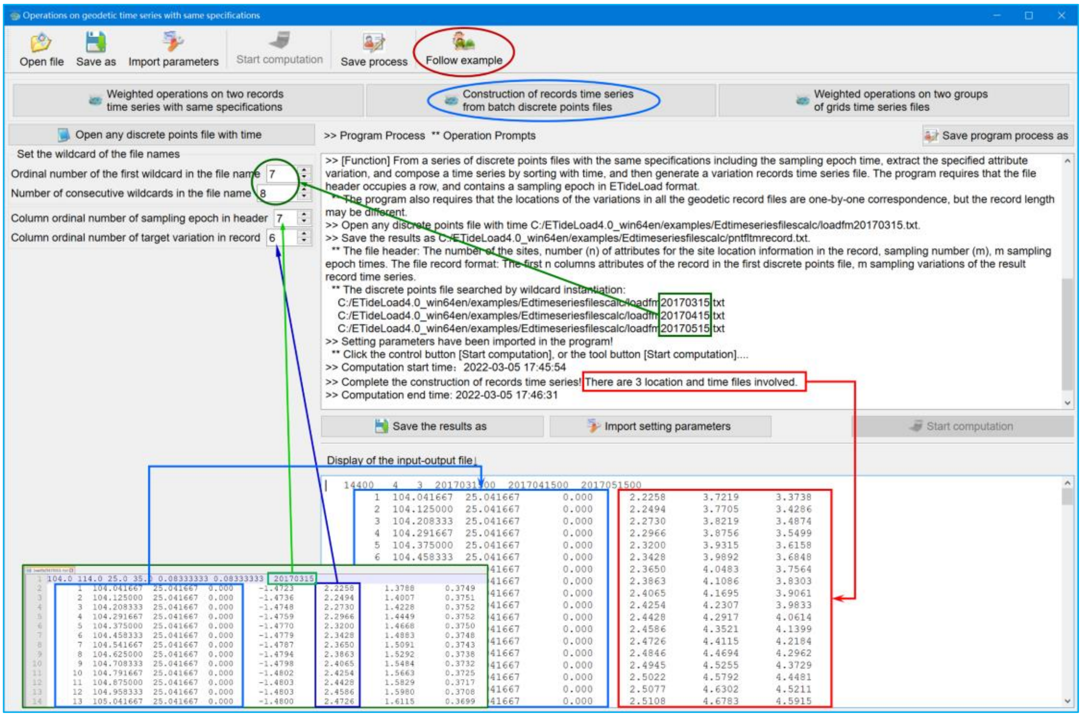
The program also requires that the locations of the variations in all the geodetic record files are one-by-one correspondence, but the record length may be different.

[Parameter settings] Set the wildcard patameters for a series of discrete points files and the file format parameters, enter column ordinal number of the epoch time in the input file header and target attributes time series in the input file record.

[Output file] The variation records time series file.

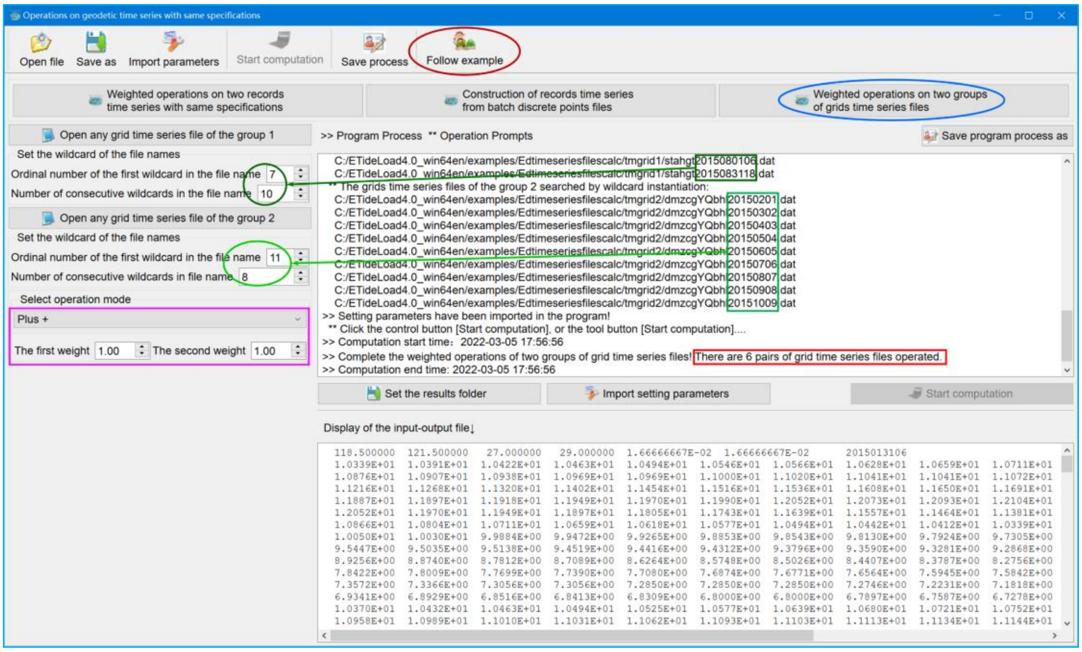
The output file header: The number of the sites, number (n) of attributes for the site location information in the record, sampling number (m), m sampling epoch times.

The output file record format: The first n columns of attributes of the record in the first discrete points file, m sampling variations of the result record time series.



6.4.3 Weighted operations on two groups of grids time series

[Function] From two groups of variation grids time series with the same specifications, sort the two groups of grids with time and then perform weighted plus, minus, or multiply operations.



The program automatically ignores the grid file whose sampling epoch is not one-by-one correspondence.

6.5 Generating and constructing of regional geodetic grid

6.5.1 Gridding of discrete geodetic data by simple interpolation

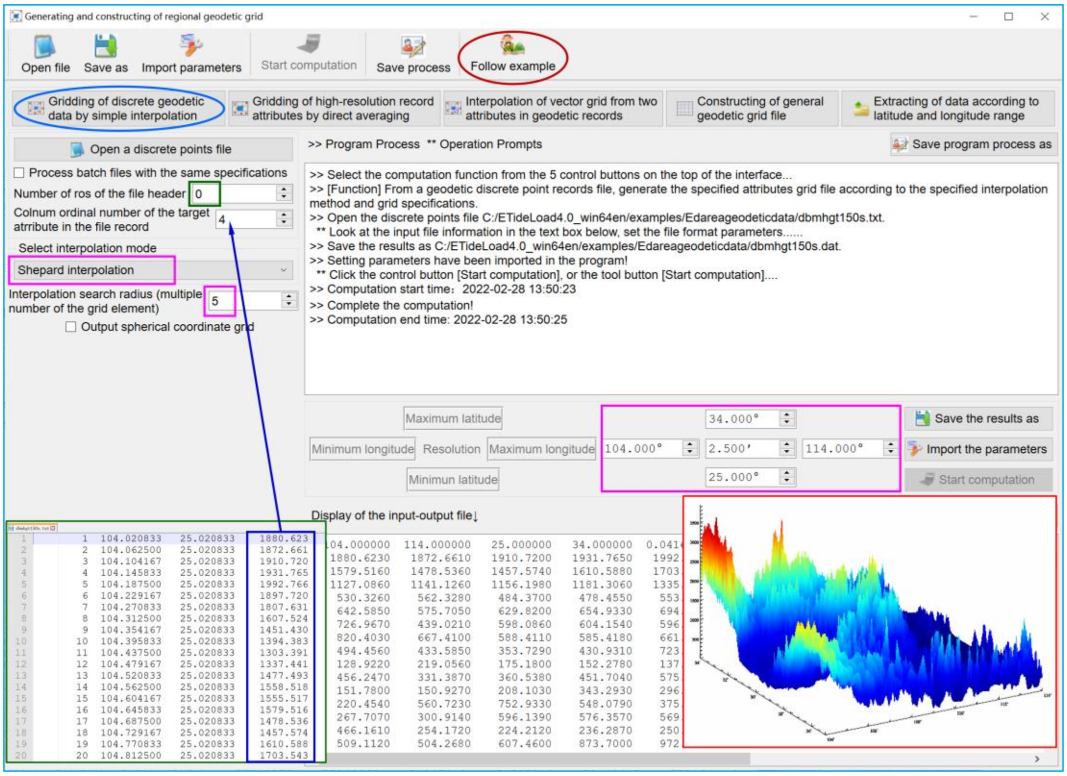
[Function] From a geodetic discrete point records file, generate the specified attributes grid file according to the specified interpolation method and grid specifications.

[Input files] The discrete geodetic points file to be interpolated. The geodetic numerical grid file for interpolation.

[Parameter settings] Enter number of rows of the discrete points file header, colnum ordinal number of the target atrribute in the file record, interpolation search radius (multiple of the grid element) and grid specifications parameters. Select the interpolation mode.

[Output file] The operated discrete geodetic points file.

The file format is the same as the input discrete points file. Behind the input file record, add one column of the interpolated result as the output file record.

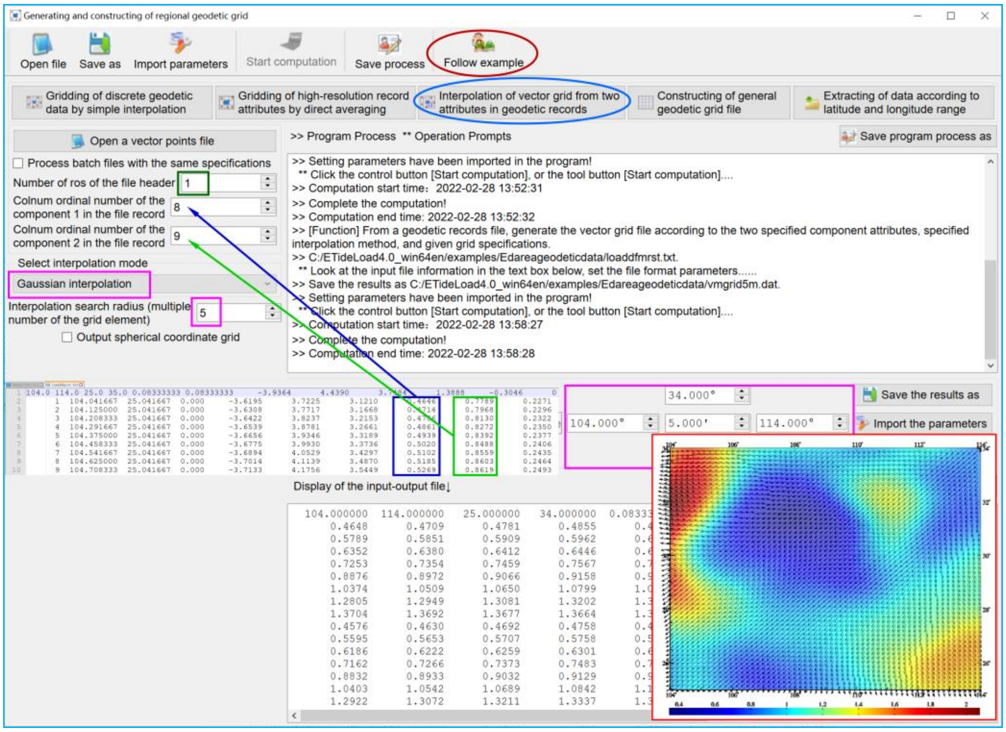


6.5.2 Gridding of high-resolution record attributes by direct averaging

[Function] Using the direct averaging method, grid the high-resolution discrete observations.

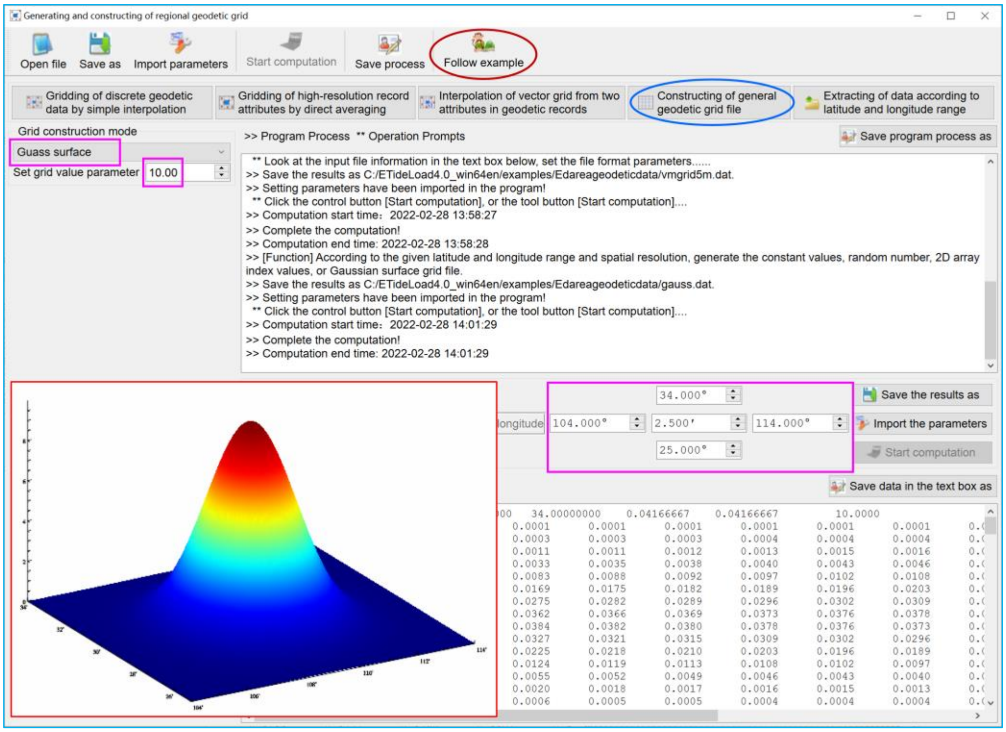
6.5.3 Interpolation of vector grid from two attributes in geodetic records

[Function] From a geodetic discrete points file, generate the vector grid file according to the two specified component attributes, specified interpolation method, and given grid specifications.



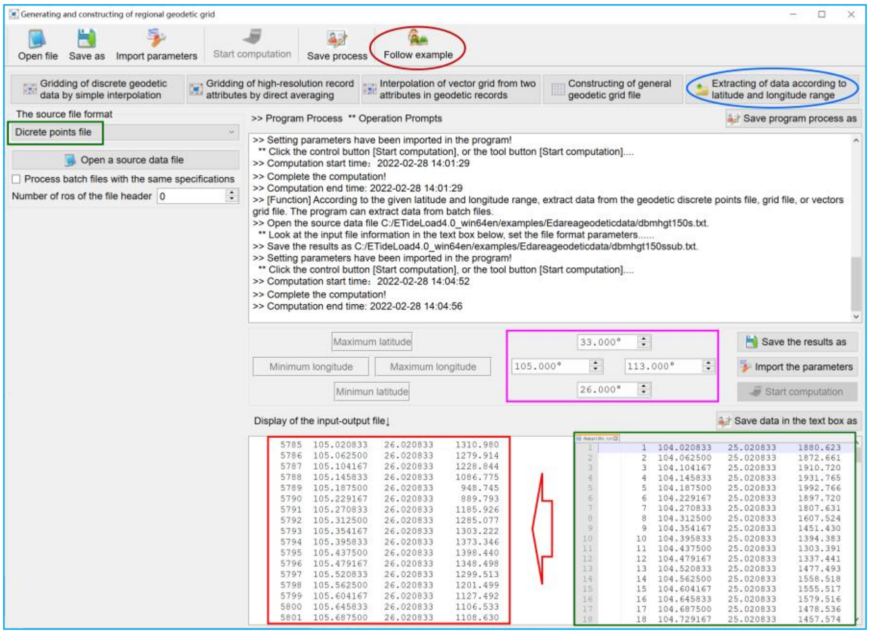
6.5.4 Constructing of general geodetic grid file

[Function] According to the given latitude and longitude range and spatial resolution, generate the constant values, random number, 2D array index values, or Gaussian surface grid file.



6.5.5 Extracting of data according to latitude and longitude range

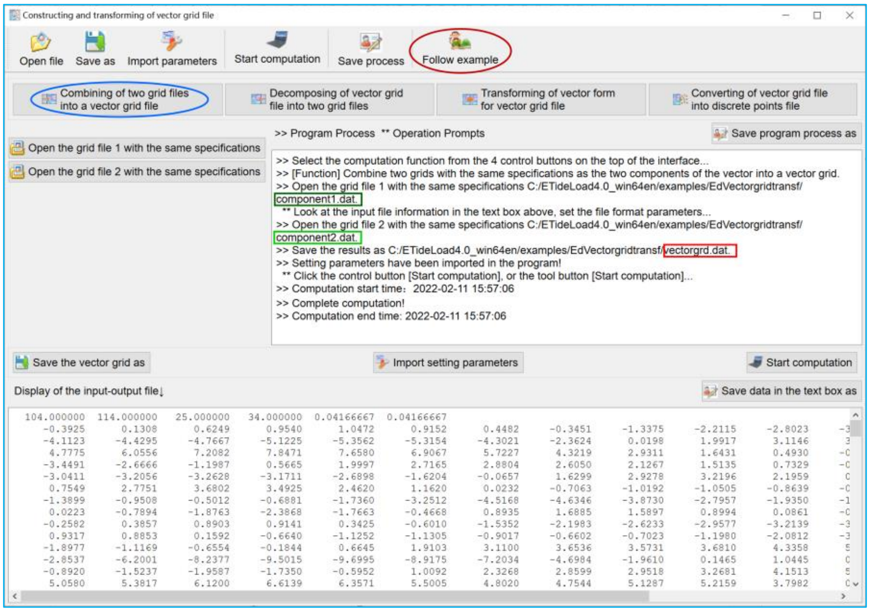
[Function] According to the given latitude and longitude range, extract data from the geodetic discrete points file, grid file, or vectors grid file. The program can extract data from batch files.



6.6 Constructing and transforming of vector grid file

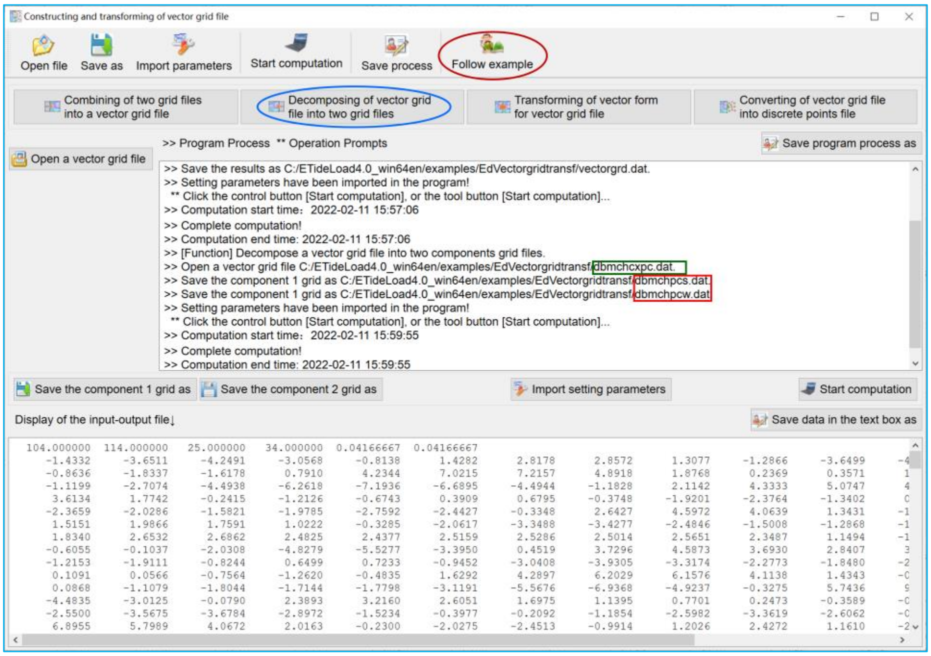
6.6.1 Combining of two grid files into a vector grid file

[Function] Combine two grids with the same specifications as the two components of the vector into a vector grid.



6.6.2 Decomposing of vector grid file into two grid files

[Function] Decompose a vector grid file into two components grid files.

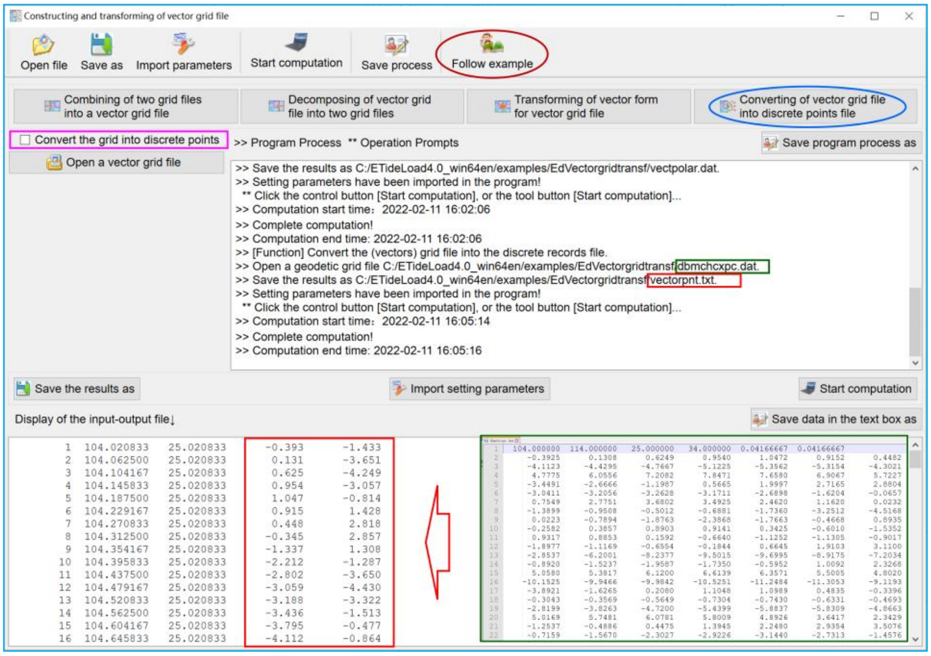


6.6.3 Transforming of vector form for vector grid file

[Function] Transform the vectors in a vector grid file between plane coordinates (in-phase/cross-phase amplitude) and polar coordinates (amplitude/phase).

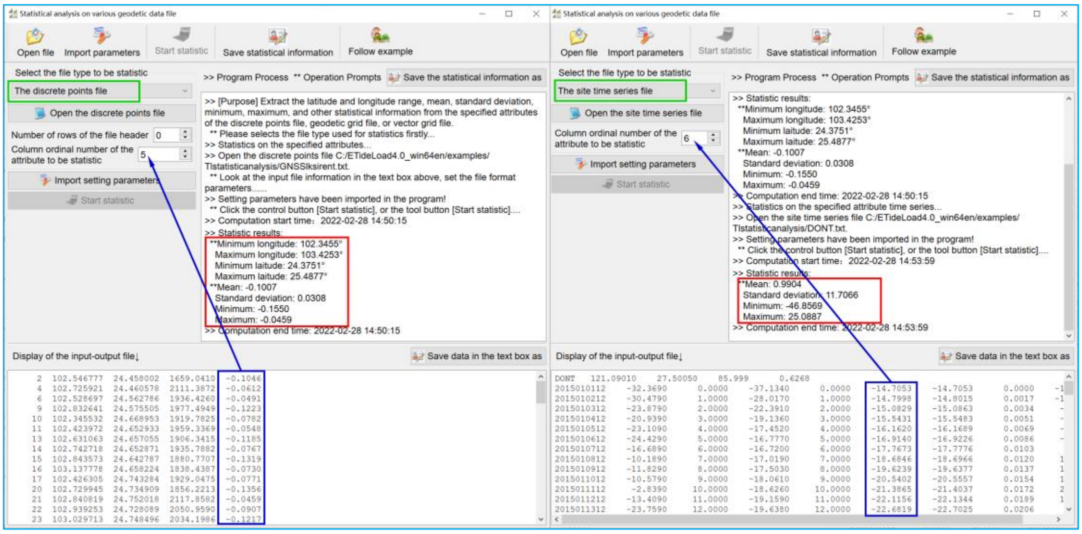
6.6.4 Converting of vector grid file into discrete points file

[Function] Convert the (vectors) grid file into the discrete points file.



6.7 Statistical analysis on various geodetic data file

[Purpose] Extract the latitude and longitude range, mean, standard deviation, minimum, maximum, and other statistical information from the specified attributes of the discrete points file, geodetic grid file, or vector grid file.



6.8 Gross error detection and weighted basis function gridding

6.8.1 Gross error detection on observations based on low-pass reference surface

[Function] Select the low-pass grid as the reference surface, interpolate the reference value of the specified attribute value at the discrete point, and then detect and separate the gross error records according to the statistical properties of the differences between the specified attribute value and reference value.

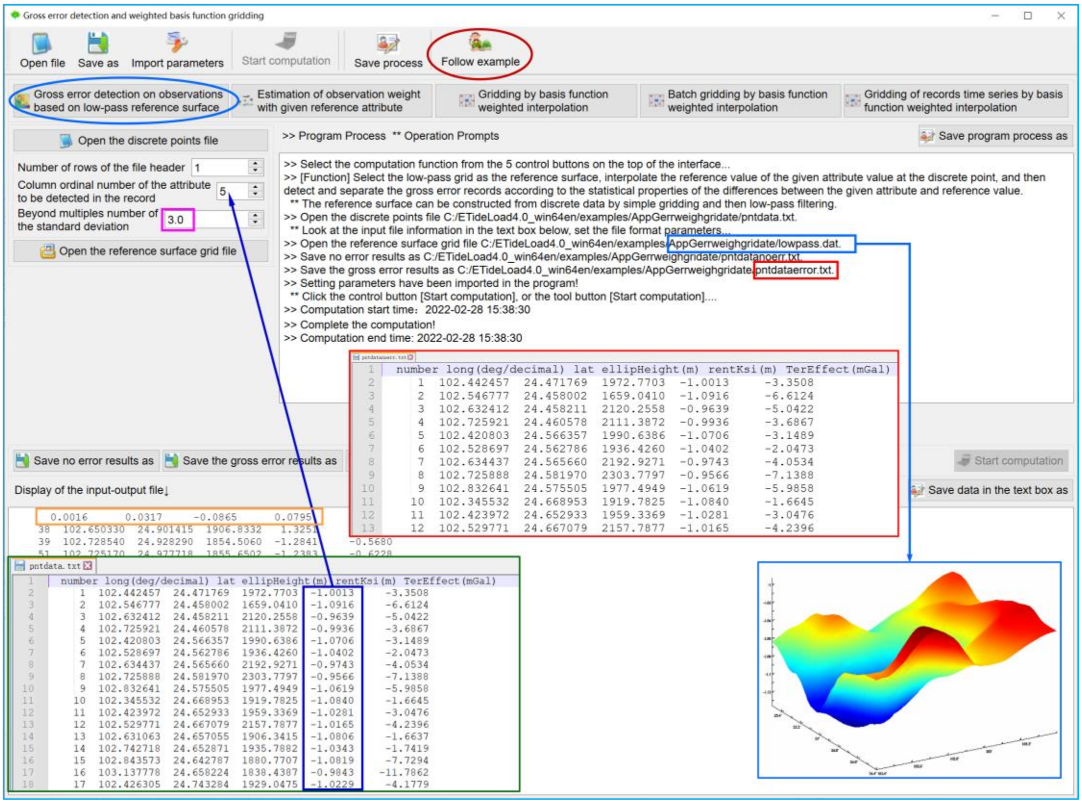
[Input files] The discrete geodetic points file to be detected. The low-pass reference surface grid file.

The reference surface can be constructed from discrete data by simple gridding and then low-pass filtering, and can also be the specified attribute grid constructed by weighted basis function gridding.

[Parameter settings] Enter number of rows of the discrete geodetic points file header, column ordinal number of the attribute to be detected in the record, and beyond multiples of the standard deviation.

When the absolute value of the difference between the attribute and its mean is greater than n times the attribute standard deviation, the record in which attribute is a gross error record.

[Output file] The operated discrete geodetic points file without gross error, whose format is the same with the input discrete points file. The gross error points file, whose file header include the average, standard deviation, minimum and maximum of the differences.



6.8.2 Estimation of observation weight with given reference attribute

[Function] Using the weight function defined by ETideLoad, estimate the observation weight according to the statistical property of the specified reference attribute in the input geodetic records file.

Weight function defined by ETideLoad4.0 $w(x,a) = 10\sigma\sqrt{\sigma^2 + (ax)^2}$, here x is the reference attribute, a is the given smoothing factor of the weight function, σ is the standard deviation of x calculated automatically by the program.

The larger the weight function smoothing factor a, the slower the weight function w decays with distance.

6.8.3 Gridding by basis function weighted interpolation

[Function] According to the given grid specifications (grid range and spatial resolution), and speccified basis function, grid the sepecified attribute in the input discrete geodetic records file by the weighted basis function interpolation method.

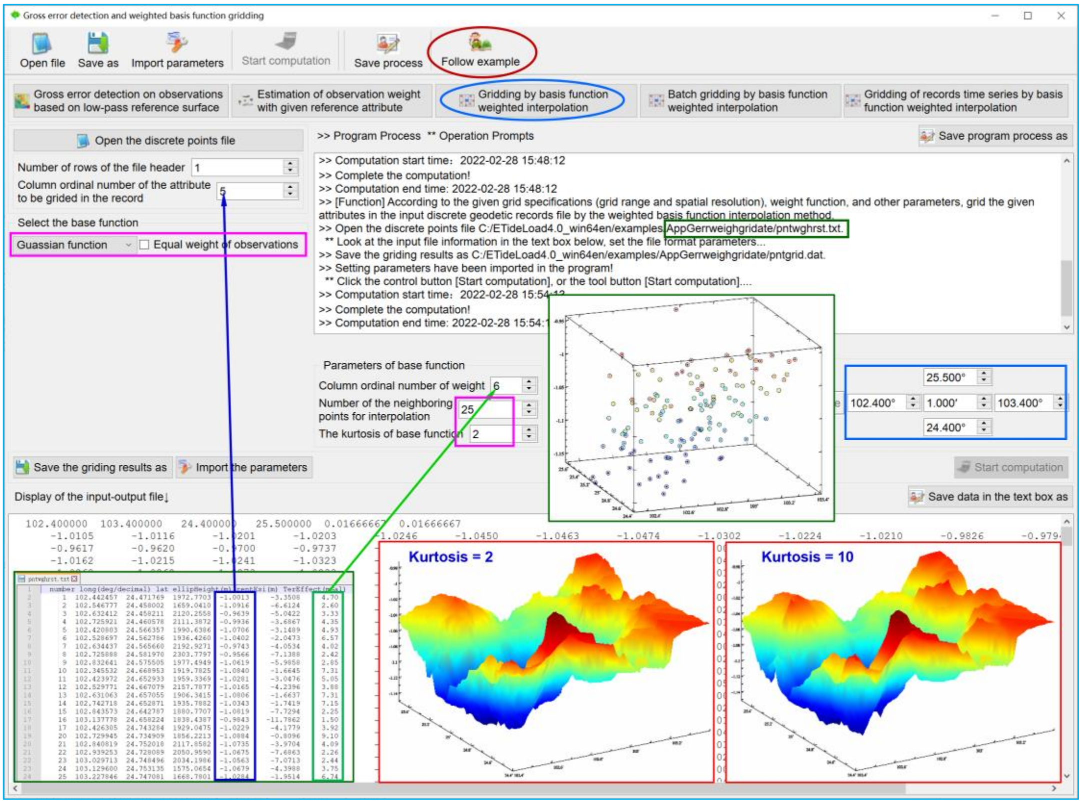
[Input files] The discrete geodetic points file.

[Parameter settings] Enter number of rows of the discrete points file header, colnum ordinal number of the target atrribute in the file record, and grid specifications parameters. And set the base function and its parameters.

The smaller the kurtosis is (the slower the basis function decays with distance), the larger the number of neighboring points in the interpolation, the smoother the interpolation, the weaker the edge effect, and the stronger the interpolation ability for sparse data.

The interpolation weight is equal to the product of the attribute weight and base function.

[Output file] The geodetic grid file.



The program of the gridding by basis function weighted interpolation is specially designed by ETideload 4.0 based on the properties of general geophysical fields, and it is suitable for griding of single types of multi-source heterogeneous geophysical fields.

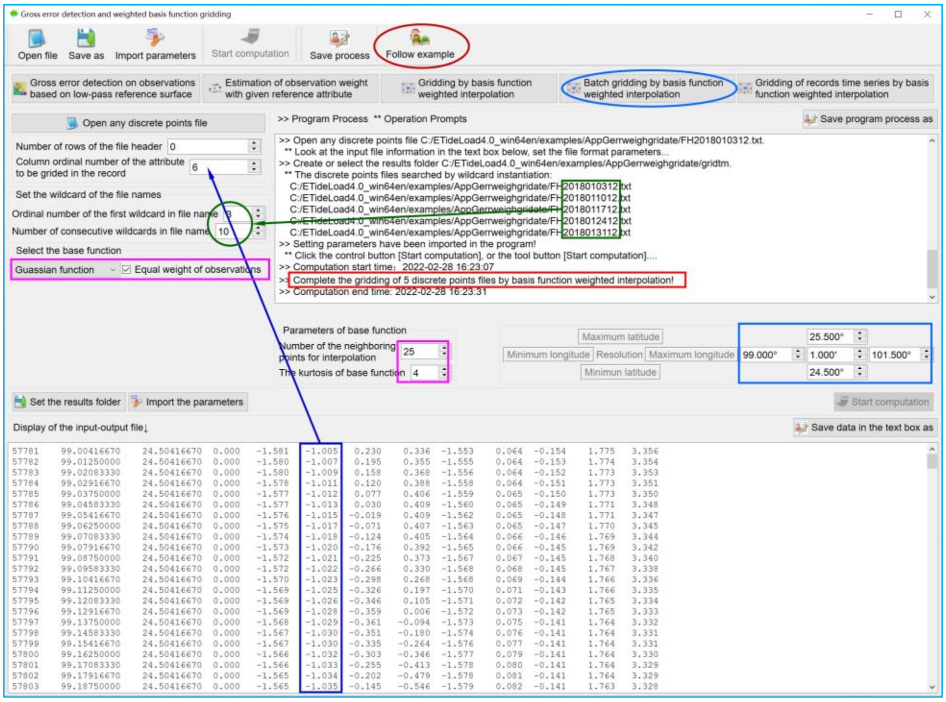
6.8.4 Batch gridding by basis function weighted interpolation

[Function] According to the given grid specifications, base function, and other parameters, respectively grid the specified attribute in each of the input discrete points files saved in a folder by the weighted basis function interpolation method.

[Input files] Batch discrete geodetic points files with same format.

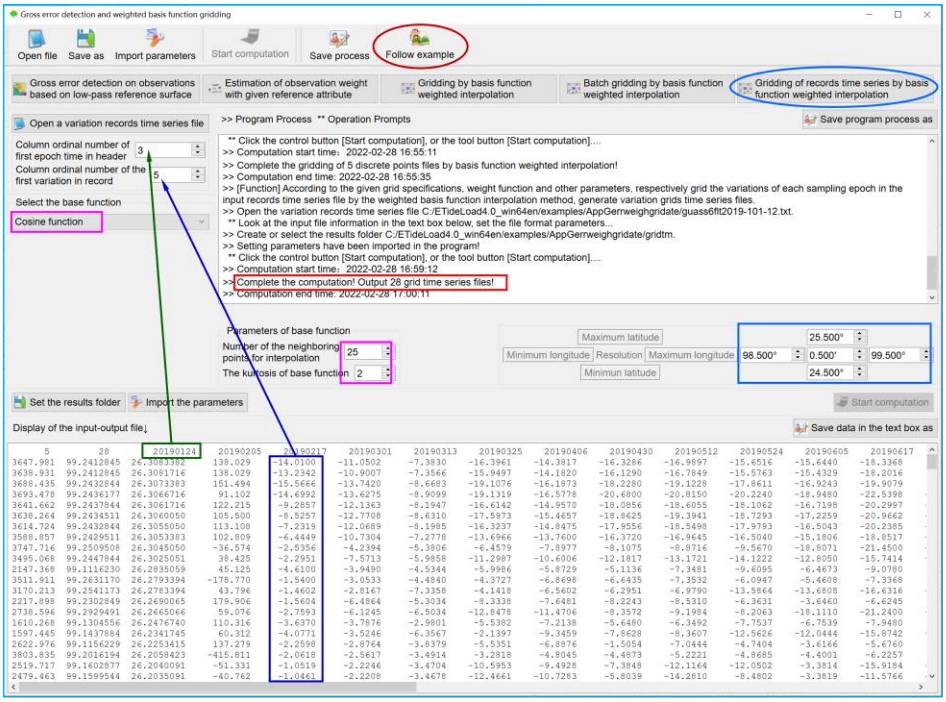
[Parameter settings] Set the wildcard patameters for batch discrete geodetic points files, Enter number of rows of the discrete points file header, colnum ordinal number of the target atrribute in the file record, and grid specifications parameters. Select the base function, and set the number of the neighboring points and kurtosis of base function.

[Output files] A series of numerical grid files bsfgrd***.dat that correspond one-to-one with the input discrete point value files. Here, *** are the instance of the input discrete points file name wildcards.



6.8.5 Gridding of records time series by basis function weighted interpolation

[Function] According to the given grid specifications, weight function and other parameters, respectively grid the variations of each sampling epoch in the input records time series file by the weighted basis function interpolation method, generate variation grids time series files.



6.9 Visualization plot tools for various geodetic data files

6.9.1 Visualization for multi-attributes in groud variation time series

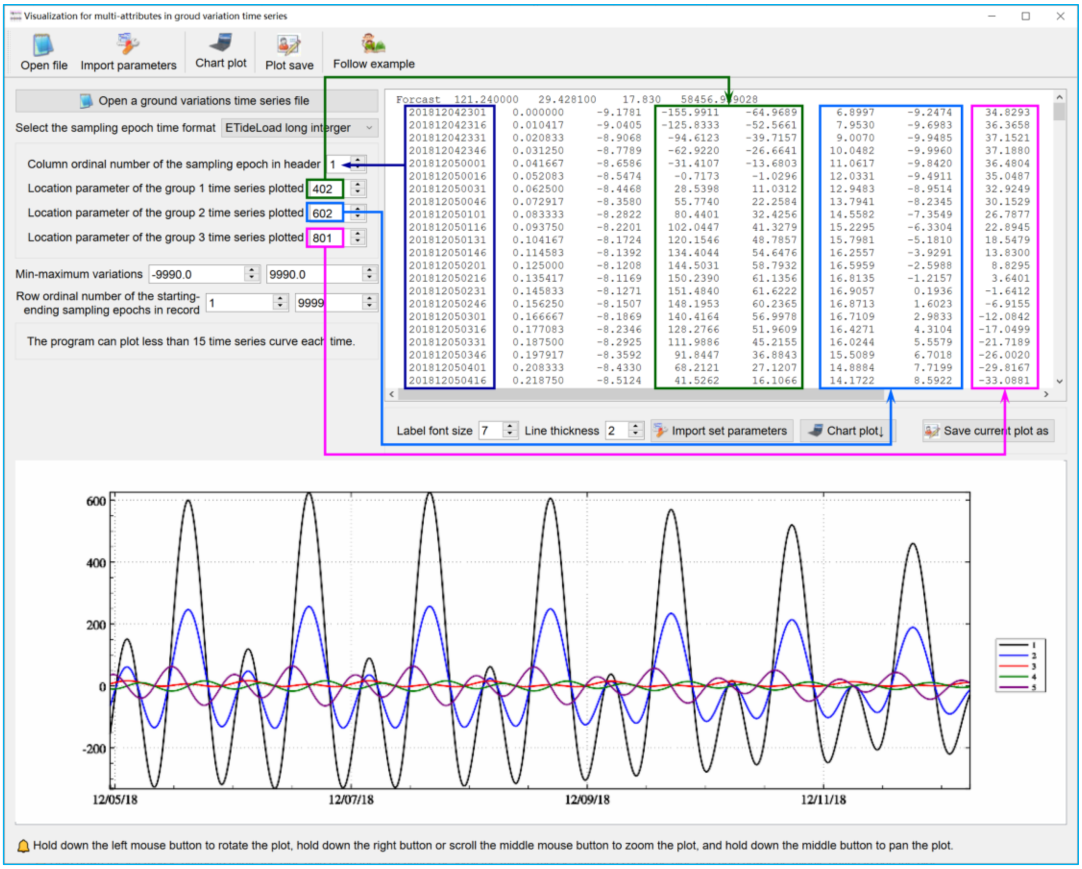
[Function] Plot multi-variations time series curves stored in a groud geodetic variations time series file.

The program can plot less than 15 time series curve each time.

[Parameter settings] Select the sampling epoch time format, enter the column number of the sampling epoch time in the file record, set the location parameters of the time series plotted, and enter minimum-maximum of the plotted variations and row ordinal number of the starting-ending sampling epochs.

When the location parameter corresponding to the column ordinal number in the record is greater than the record maximum column number, the program automatically sets the location parameter as the serial number of the record maximum column.

When the column ordinal number of the end sampling variations is greater than the number of samples of the time series, the program automatically sets the number of samples of the time series as the column ordinal number of the end sampling variations.



Hold down the left mouse button to rotate the plot, hold down the right button or scroll the middle mouse button to zoom the plot, and hold down the middle button to pan the plot.

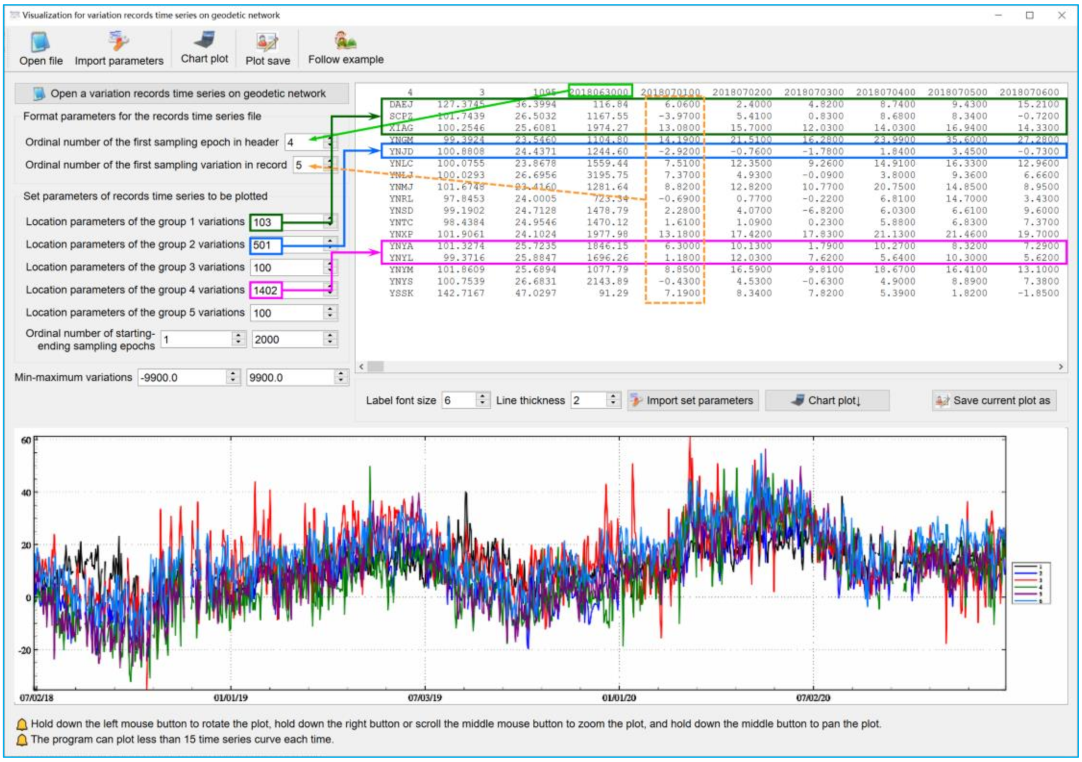
6.9.2 Visualization for variation records time series on geodetic network

[Function] Plot multi-variations time series curves stored in a variation records time series file.

[Parameter settings] Enter the ordinal number of the first sampling epoch in file header and the first sampling variation in record, set the location parameters of the time series plotted, and enter the ordinal number of starting-ending sampling epochs and minimum-maximum of the plotted variations.

When the location parameter corresponds to the row ordinal number of the record is greater than the number of rows of the file records, the program automatically sets number of rows of the file records as the row ordinal number of the last record.

The program can plot less than 15 time series curve each time. When different groups of location parameters correspond to the same variation, the program is automatically merged, counted and plot according to one variation.



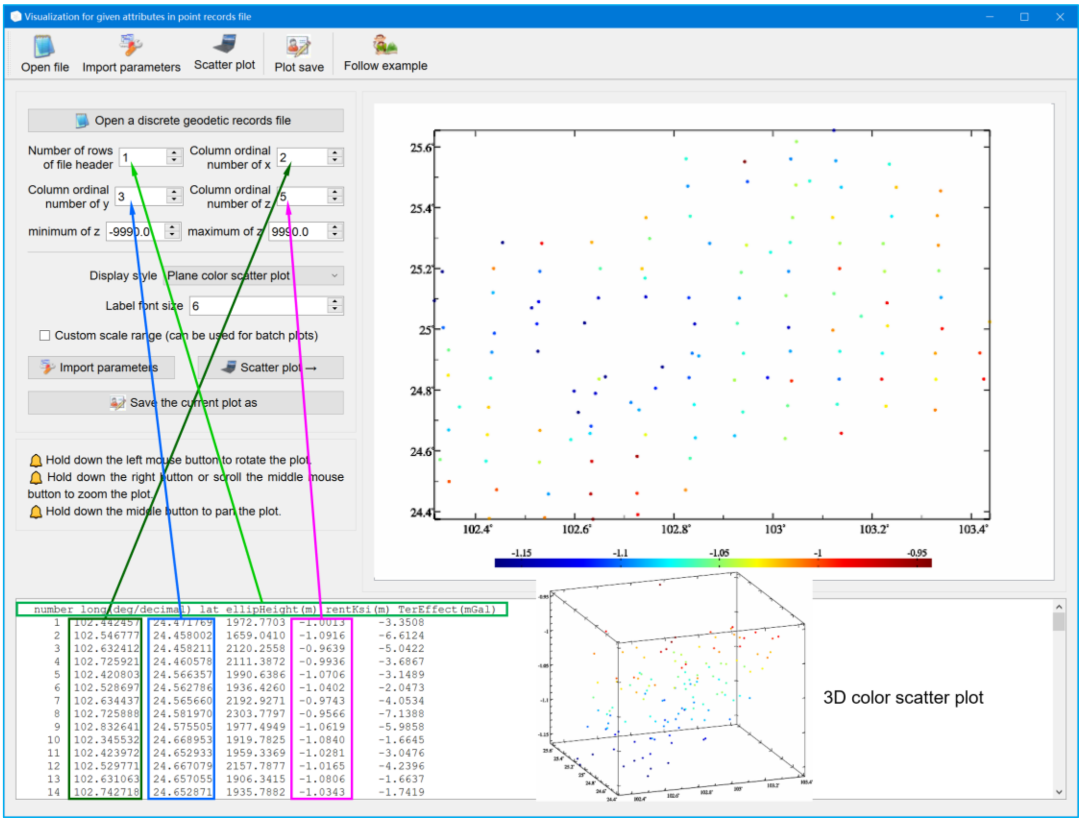
6.9.3 Visualization for specified attribute in discrete point records file

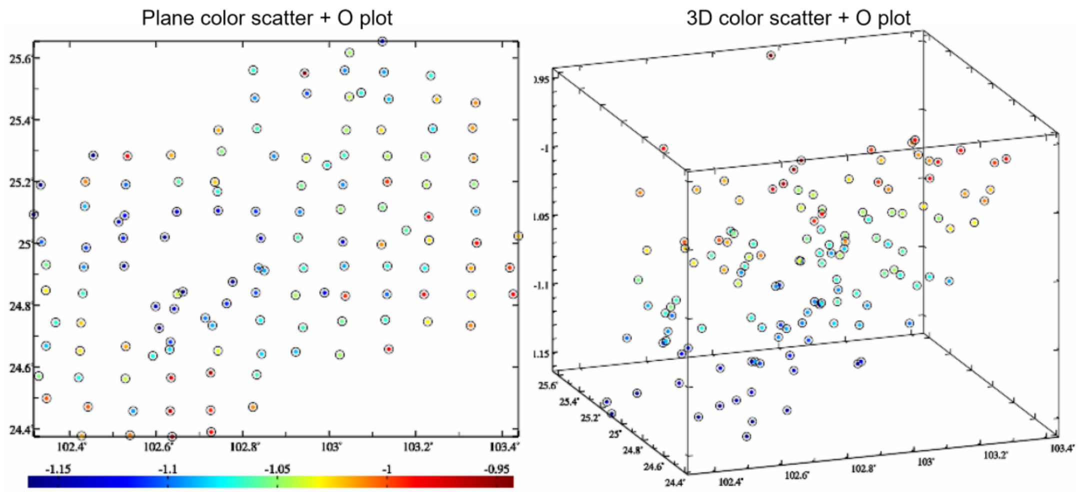
[Function] Displays the point locations and their specified attributes in a geodetic discrete points file.

After changing the input data file, z attribute, or other parameters, you need to click the control button [Import setting parameters] again to update the graph.

If needing a larger scale plot, enlarge the graphics window on the right firstly, and then click the control button [Scatter plot].

Hold down the left mouse button to rotate the plot, hold down the right button or scroll the middle mouse button to zoom the plot, and hold down the middle button to pan the plot.



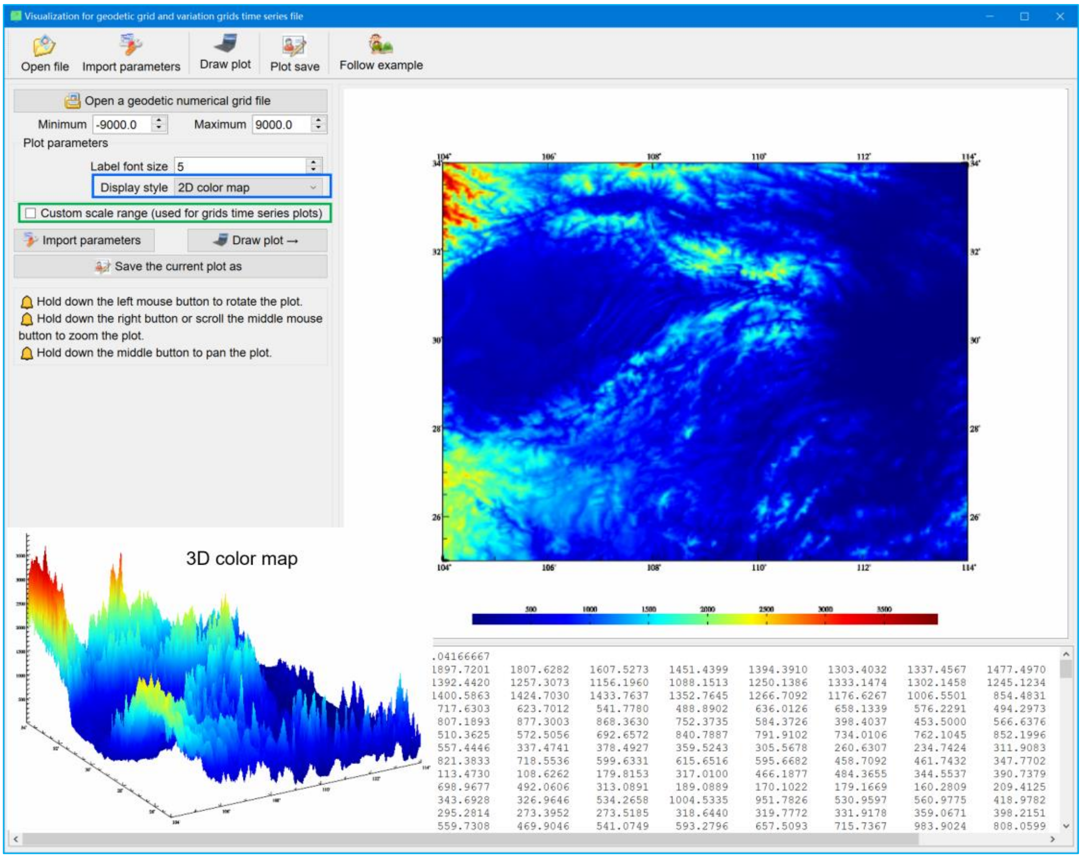


You can unify the scales by fixing the scale range for batch plots. Adjust the size of the plot window on the right and the plot requirements to an appropriate state before drawing batch plots. During plot period, the parameters and the size of the plot window are kept unchanged, and no mouse operation is performed on the plot.

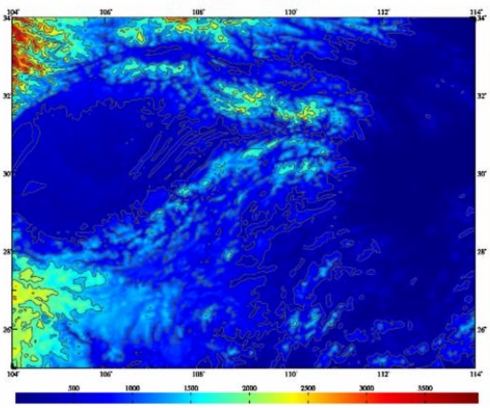
6.9.4 Visualization for geodetic grid and variation grids time series file

[Function] Plot for geodetic grid or grid time series files.

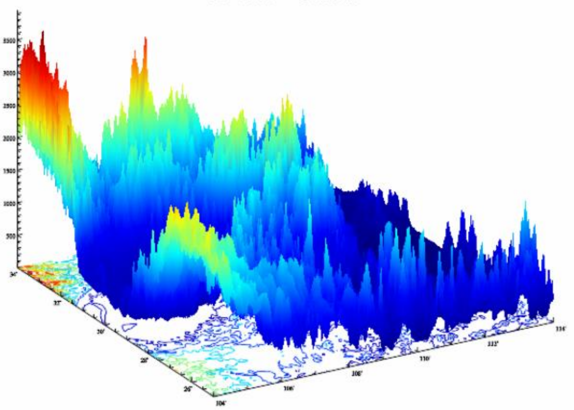
[Parameter settings] Seleclt display style and set the checkbox [Custom scale range (used for grids time series plots)].



2D color + Contour



3D color + Contour



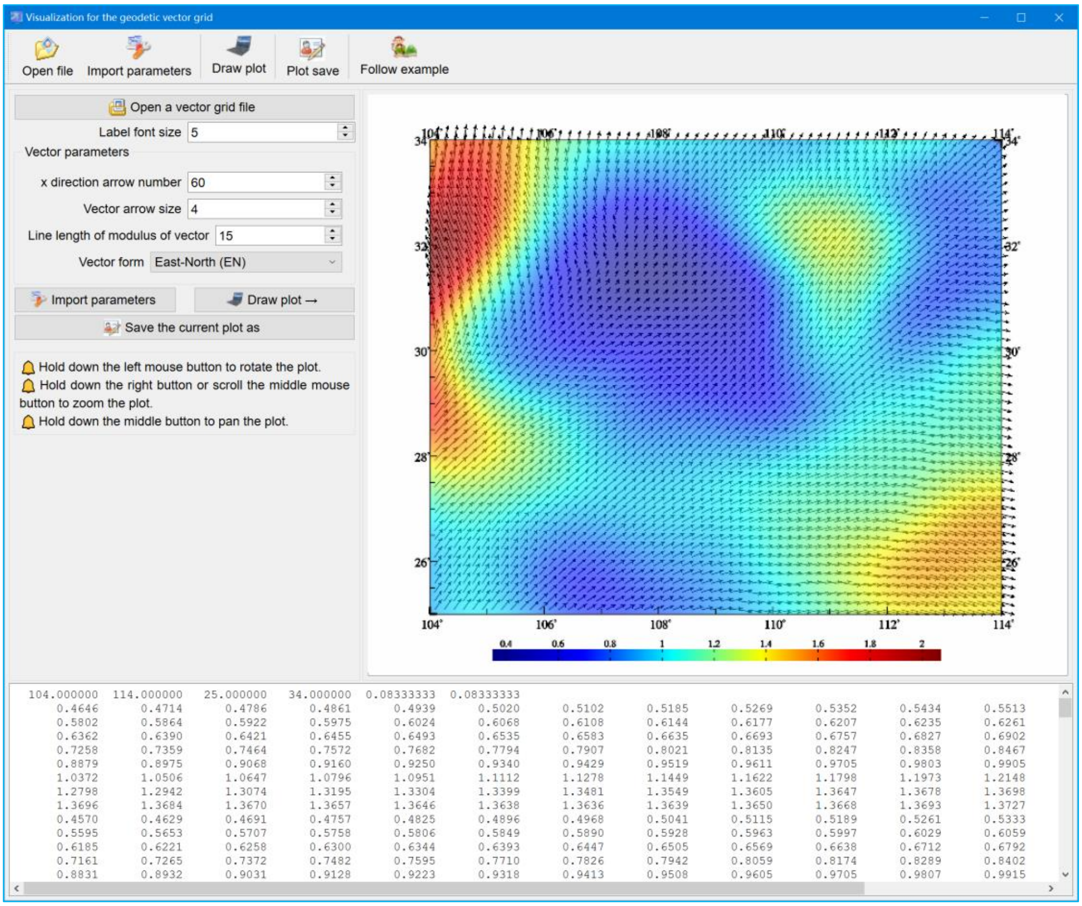
Allows the first component of a vector grid to be displayed as grid data.

After seting the custom scale range, you can plot a series of figures for grids time series.

6.9.5 Visualization for the geodetic vector grid file

The X-axis and Y-axis of the plotting coordinate system respectively point east and north (EN), which is the same with horizontal displacement vector.

Vector form: East-North (EN, e.g., horizontal displacement vector), South-West (SW, e.g., vertical deflection vector), North - East (NE, e.g., Tangential gravity gradient vector).



7 Data files format, geophysical models and numerical standards

7.1 Geodetic Data Files in ETideLoad own Format

ETideLoad only recognizes the five kinds of geodetic stationary data and five kinds of geodetic variation time series data in ETideLoad own format. The geodetic stationary data files include the discrete geodetic records file, geodetic network observation records file, numerical grid file, vector grid file, and spherical harmonic coefficients (Stokes coefficients) file. The variation time series files include the ground variations time series file, geodetic network site records time series file, geodetic network observations time series file, variation (vector) grids time series files, and spherical harmonic coefficient (Stokes coefficient) models time series files.

The program [Conversion of general ASCII records data into ETideLoad format], and the function [Normalized extraction of batch time series of geodetic monitoring network] are the important interfaces for ETideLoad to accept external text data. Using the function [Global prediction of solid earth tidal effects on various geodetic quantities], or [lobal prediction of surface air pressure tidal load effects on various geodetic quantities], you can construct a ground variations time series with the given location and sampling specifications. Using the program [Generating and constructing of regional geodetic grid], you can construct a numerical grid with the given grid specifications. The other programs or functions only accept the format data generated by ETideLoad own.

7.2 The files format of 5 kinds of stationary geodetic data

7.2.1 The discrete geodetic records file

A discrete geodetic records data is represented by a one-dimensional array.

rdgravpntmxdx.txt

1	102.392927	24.494402	2227.4900	25.8548	22.8415	2210.7385	22.9157
2	102.395920	24.508898	2169.5000	19.2278	23.3482	2220.1556	23.1268
3	102.392718	24.529614	2012.6300	-2.5982	23.5704	2112.7810	23.1433
4	102.396602	24.545253	2121.8000	8.5305	22.2493	2071.2506	22.4506
5	102.396873	24.563563	1970.5800	-7.6153	21.1752	2045.8186	20.8999
6	102.393754	24.581317	1939.6100	-9.4593	19.2625	1962.1555	19.1874
7	102.395223	24.603553	1964.8800	-7.7358	16.3706	1985.6935	16.3132
8	102.393104	24.617811	1997.0200	-5.1529	14.5630	1978.1810	14.6096
9	102.393520	24.638369	1915.4500	-11.6028	12.4719	1947.9042	12.4048
10	102.397107	24.653500	2009.9700	-0.2375	10.8712	1974.4709	10.9325
11	102.396963	24.675343	1945.3300	-7.3841	9.6422	1981.4985	9.5877
12	102.395819	24.692939	1980.3300	-3.7480	9.0670	1966.7684	9.0868
13	102.395371	24.708913	2029.0300	2.5687	8.8403	1957.6558	8.9453
14	102.395350	24.727566	1902.2900	-12.2454	9.0661	1903.0214	9.0650
15	102.396700	24.745993	1869.7500	-15.8731	8.9810	1891.7180	8.9468
16	102.395841	24.764933	2083.6400	7.3406	8.5926	2073.5757	8.6092
17	102.393966	24.781787	2268.9800	26.9402	8.1585	2196.5105	8.2855
18	102.394006	24.801727	1938.9900	-7.5474	7.5344	2020.5270	7.3956
19	102.398417	24.817405	1904.2900	-10.6788	4.8800	1984.9395	4.7832
20	102.396456	24.874484	1880.3900	-11.4857	-2.6543	1930.2448	-2.6614

(1) Multiple rows of the file headers are allowed, whose content and format are not restricted.

(2) One record represents the geodetic data of one site. The attributes of each record include site number (name), longitude (degree decimal), latitude (degree decimal), attribute 4, …, attribute n.

(3) The attribute convention is a numeric format, the number of the attributes (n) is not more than 80, and the attributes are separated by spaces.

(4) A record reading statement in Fortran language is:

```
read(fileno,*)(record(i),i=1,n)    ! real*8 record(n)
```

7.2.2 The geodetic network observations file

A geodetic network observations file can store the baseline component data for the CORS network, height differences for the levelling network, or travity differences for the gravity network.

(1) The file header occupies a row and includes the number of characters of the baseline or route name, number of characters of the site name, ……

(2) The file record includes the baseline or route name, starting site (longitude, latitude, height), ending site (longitude, latitude, height), ……, observations (default value is 9999).

(3) The relations between the baselines (or routes) and the sites in the geodetic monitoring network are reflected with the composition of the characters of their name. A baseline or route name is agreed to be composed of site names A and B at both ends (B***A), where the number of characters of all the sites names is required to be equal.

Therefore, the number of characters of the baseline or route name shall not be less than twice the number of characters of the site name.

7.2.3 The geodetic numerical grid file

The geodetic numerical grid data is represented by a two-dimensional array.

(1) There is a row of file header at the beginning of the file. The file header contains minimum longitude, maximum longitude, minimum latitude, maximum latitude, grid cell interval along longitude, grid cell interval along latitude. The units of all the attributes are decimal degrees.

(2) The grid elements are sequentially stored in an increasing manner of row latitude and column longitude until all data is stored. The elements are separated by spaces.

(3) The Fortran reading program for the entire grid data in a geodetic grid file:

```
open(unit=fileno,file=filename,status="old")
read(fileno,*)(hd(i),i=1,6)           ! hd(6) - the file header
nlon=nint((hd(2)-hd(1))/hd(5))    ! nlon - the number of grid columns along longitude direction
nlat=nint((hd(4)-hd(3))/hd(6))      ! nlat - the number of grid rows along latitude direction
do i=1,nlat
   read(fileno,*)(gr(i,j),j=1,nlon)    ! gr(nlat,nlon)- two dimension array used to store grid values
enddo
```

The grid value of grid cell represents the average value of the grid cell. In the numerical integral operation, the location of the center point of the grid cell is used to calculate the integral distance from the grid cell to the calculation point.

dbmhgt150s.dat

```
 104.000000  114.000000   25.000000   34.000000  0.04166667  0.04166667
     1880.6233      1872.6612      1910.7203      1931.7653      1992.7665      1897.7199
     1579.5158      1478.5360      1457.5736      1610.5877      1703.5435      1392.4407
     1127.0862      1141.1257      1156.1979      1181.3065      1335.4466      1400.5901
      530.3264       562.3283       484.3702       478.4546       553.5518       717.6379
      642.5849       575.7052       629.8202       654.9330       694.0609       807.1985
      726.9670       439.0212       598.0862       604.1542       596.2404       510.3528
      820.4032       667.4105       588.4110       585.4184       661.4350       557.4490
      494.4559       433.5850       353.7288       430.9312       723.1754       821.3956
      128.9223       219.0560       175.1799       152.2779       137.3618       113.4669
      456.2471       331.3871       360.5383       451.7036       575.8641       698.9905
      151.7805       150.9271       208.1027       343.2925       296.4793       343.6893
      220.4542       560.7228       752.9326       548.0788       375.1834       295.2821
      267.7073       300.9139       596.1386       576.3569       569.5556       559.7308
      466.1608       254.1723       224.2118       236.2868       250.4018       331.5582
      509.1123       504.2678       607.4595       873.6999       972.9491       777.1609
      129.8216       112.8806       145.9967       223.1369       239.2738       219.4003
     1868.6248      1859.6737      1903.7419      2051.7911      2088.7992      1910.7605
     1475.5124      1382.5200      1476.5441      1626.5437      1580.4903      1318.3843
     1155.2158      1193.2735      1209.3569      1255.4640      1365.5851      1386.7009
      603.2370       489.2430       499.3152       525.4287       630.5491       820.6481
      436.4368       493.5515       611.6602       584.7656       649.9001       678.0571
```

7.2.4 The geodetic vector grid file

A vector grid file is composed of the first components grid and the second components grid of the vector. The header file and the first components grid in the vectors grid file are same as that in the geodetic grid file, and the second components grid follow the first components grid closely with the same way.

Vector grid such as vertical deviation and horizontal gradient vector grid in ETideLoad are stored in the form of vector grid file.

7.2.5 The spherical harmonic coefficients file

(1) The file header occupies a row and consists of two attributes for scaling parameters of the spherical harmonic coefficients model, namely the geocentric gravitational constant GM (×$10^{14}$$m^2/s^2$) and equatorial radius of the Earth a (m).

(2) The Earth's geopotential coefficients model and surface loads spherical harmonic coefficients model in ETideLoad are stored in the form of spherical harmonic coefficients file.

(3)The spherical harmonic coefficients correspond to the scaling parameters of GM and a. For different spherical harmonic coefficient models, GM and a are not necessarily the same.

(4) The n-th degree m-th order spherical harmonic coefficient is expressed by a record with the format "degree n, order m, C_{nm}, S_{nm} (, C_{nm} error, S_{nm} error)".

ETideLoad does not require the degrees and orders of harmonic coefficients to be arranged and allows to exist insufficient orders. For the harmonic coefficient of insufficient order, ETideLoad automatically sets to zero.

7.3 The files format of 5 kinds of geodetic variations time series

The variation time series files adopt the ETideLoad own format, which includes the ground variations time series file, geodetic network site records time series file, geodetic network observation records time series file, variation (vector) grids time series files, and spherical harmonic coefficient (Stokes coefficient) models time series files.

7.3.1 The ground variations time series file

A ground variations time series file can store the time series data of several kinds of variations of a certain site, a certain baseline or route, and the sampling epochs (here, the epoch is an instantaneous time) of these variations are the same. Such as CORS station coordinate solution time series, solid tide station observation or analysis result time series, GNSS baseline solution time series, etc.

(1) The file header occupies a row and contains site name, longitude (degree decimal), latitude (degree decimal), height (m) relative to the ellipsoidal surface (sea level, or the ground), the starting MJD (optional), ……

(2) Starting from the second row of the file, each row of records stores the sampling values of all the variations at one sampling epoch time. At least one column of attribute in the record is the sampling epoch time.

(3) Each attribute in the record (except the sampling epoch time) represents a type of variations time series, and the sampling epoch time of different types of variations is the same.

(4) The sum of the starting MJD0 in the header and the sampling epoch time (day) is equal to the sampling epoch time of MJD day in the record. When the sampling epoch time is in ETideLoad format, the starting MJD0 is not necessary in the file header.

tmsqurst.txt

```
NYB 101.230000    29.910000  47.218  58484.000000
2019010100    0.000000    2.764     5.0173      1.5712     0.3849   10.3234   -5.2424   19.3396
2019010101    0.041667    2.778    57.5174     23.2452    10.8146   12.7102   -3.1452   23.8048
2019010102    0.083333    2.762    75.5361     30.5675    14.2375   13.9736    0.1439   26.1911
2019010103    0.125000    2.724    49.9989     19.8264     8.9137   13.8655    3.6134   26.0285
2019010104    0.166667    2.675   -14.8626     -7.1040    -4.1257   12.4479    6.1922   23.4162
2019010105    0.208333    2.626  -102.4140    -43.2138   -21.3751   10.0693    7.0460   18.9862
2019010106    0.250000    2.582  -187.9254    -78.2261   -37.8487    7.2674    5.8002   13.7343
2019010107    0.291667    2.546  -245.0339   -101.3204   -48.4404    4.6323    2.6332    8.7685
2019010108    0.333333    2.517  -252.6506   -103.9667   -49.2598    2.6643   -1.7744    5.0436
2019010109    0.375000    2.489  -200.5663    -82.1562   -38.6091    1.6655   -6.4133    3.1473
2019010110    0.416667    2.455   -92.4143    -37.5190   -17.4012    1.6833  -10.1887    3.1848
2019010111    0.458333    2.410    54.6679     22.8880    11.0186    2.5175  -12.1759    4.7817
2019010112    0.500000    2.354   213.5656     88.0350    41.5647    3.7816  -11.8314    7.1990
2019010113    0.541667    2.288   353.0904    145.2782    68.4536    5.0033   -9.1200    9.5289
2019010114    0.583333    2.223   444.9509    183.1245    86.4011    5.7439   -4.5343   10.9299
2019010115    0.625000    2.169   470.2372    193.8160    91.7570    5.7101    1.0003   10.8461
2019010116    0.666667    2.139   423.9270    175.1684    83.3590    4.8356    6.3198    9.1633
2019010117    0.708333    2.140   316.2909    131.2080    62.8992    3.3117   10.2823    6.2600
2019010118    0.750000    2.176   170.7224     71.3813    34.6611    1.5535   12.0396    2.9335
2019010119    0.791667    2.245    18.3457      8.4289     4.6113    0.1037   11.2554    0.2101
2019010120    0.833333    2.337  -109.4070    -44.6375   -20.9983   -0.5077    8.2071   -0.9215
2019010121    0.875000    2.439  -188.4457    -77.7247   -37.1906    0.0868    3.7328    0.2122
2019010122    0.916667    2.535  -207.9073    -86.1738   -41.5571    1.9732   -0.9763    3.7572
2019010123    0.958333    2.611  -172.6479    -71.8776   -34.8890    4.9074   -4.6886    9.2487
2019010124    1.000000    2.657  -101.5732    -42.6368   -20.9177    8.3545   -6.4671   15.6899
2019010201    1.041667    2.671   -22.1804     -9.8860    -5.2050   11.6122   -5.9287   21.7785
2019010202    1.083333    2.655    37.2344     14.5931     6.5038   13.9841   -3.3501   26.2240
2019010203    1.125000    2.617    55.5611     22.0431     9.9729   14.9570    0.4130   28.0700
2019010204    1.166667    2.568    24.8430      9.2293     3.7078   14.3301    4.1694   26.9320
```

7.3.2 The geodetic site variation records time series file

A geodetic site variation records time series file can store the time series data of one kind of variations for a group of geodetic sites. Such as the station coordinates time series for the CORS network, benchmark heights time series for the levelling network, observations time series for the tide station network, and InSAR monitoring time series, etc.

(1) The file header occupies a row and contains all the sampling epochs arranged with time.

(2) The file Record: the site name, longitude, latitude, height, ……, all the sampling variations arranged with sampling time.

(3) ETideLoad stipulates that the number of sampling epochs in the file header is equal to the number of sampling variations in the record, and the sampling epochs are one-by-one correspondence with the sampling variations.

(4) When receiving the input record time series file from the program interface, it is generally required to specify the column ordinal number of the first sampling epoch in the file header and the column ordinal number of the first sampling variation in the record.

TsqavrRowU.txt | TsqavrbslnU.txt

4	0 36				2015011612	2015021500	2015031612	2015041600	2015051612	2015061600
JINH	119.6426	29.2178	1191.60	1.0	-4.9145	9.3944	3.7319	0.4720	1.1566	2.7777
JINX	119.3792	29.0709	84.79	1.0	-4.3724	1.6001	6.6220	0.8372	2.9622	1.8461
JNJZ	119.6375	27.9764	286.78	1.0	-4.1680	3.2284	3.1467	-0.4777	2.3145	1.8212
JSAN	118.6086	28.7279	71.54	1.0	4.8394	10.8248	7.4036	2.4828	0.3532	-2.2769
LISH	119.9295	28.4613	71.54	1.0	4.8394	10.8248	7.4036	2.4828	0.3532	-2.2769
LONQ	119.1331	28.0807	233.28	1.0	-4.9987	3.4121	3.3682	-2.0458	-2.0137	-1.6199
QIYU	119.0793	27.6213	412.75	1.0	-2.9713	5.7773	7.2012	1.1874	-3.3157	-3.4728
QNYN	118.9638	27.6157	429.39	1.0	0.7446	7.2540	6.9323	0.2500	-1.3013	-1.8433
QUZH	118.8908	28.9937	90.79	1.0	-1.0815	5.9656	5.1221	-1.1572	0.5323	-1.6064
QZLY	119.1858	29.0336	73.91	1.0	-1.3703	6.4829	8.4987	1.9209	1.5578	0.7378
SHNQ	119.5028	27.4576	827.01	1.0	-6.5350	3.4134	3.8402	1.0473	3.2554	-2.4524
SNYN	119.5093	28.4546	182.77	1.0	-5.6627	3.1365	4.4180	0.4287	2.1431	2.2420
YAYA	120.0425	27.3930	555.71	1.0	-2.1462	5.1836	4.0938	3.6248	4.5640	1.2865
YONK	120.0168	28.9055	116.22	1.0	-1.6121	4.7569	7.1178	2.7207	0.1517	0.6173
ZJYH	119.6900	28.2660	130.05	1.0	-3.2802	4.5552	3.8968	-0.2975	0.4079	-0.3378

TsqavrRowU.txt | TsqavrbslnU.txt | InSARspdfmrst.txt

5	37			20141103	20141127	20141221	20150114	20150207	20150408	20150502	20150526
-9.310	117.3445416	39.0251902	-2.793	-0.3091	0.0866	0.0482	0.2194	0.2865	0.5720	0.3395	0.4760
-12.790	117.3457082	39.0251902	-2.304	-0.1796	0.2752	0.1906	0.2887	0.3340	0.5632	0.2861	0.2759
-7.482	117.3480415	39.0251902	-3.660	-0.3846	9999.0000	-0.0523	0.0135	0.1783	-0.0167	-0.5455	-0.1440
-6.699	117.3487081	39.0251902	-2.582	-0.2325	0.2301	0.0701	0.2610	0.4179	0.7154	0.4377	0.7507
-7.643	117.3488748	39.0251902	-2.882	-0.1876	0.3087	0.1757	0.3743	0.5347	0.9182	0.6967	0.9859
-9.001	117.3492081	39.0251902	-3.430	-0.2356	0.2486	0.2282	0.4480	0.5863	1.0390	0.8643	1.1080
-10.736	117.3495414	39.0251902	-4.123	-0.2211	0.1605	0.0977	0.4040	0.4816	1.0206	0.9163	1.0519
-10.264	117.3497081	39.0251902	-3.963	-0.2530	0.0627	0.0174	0.2817	0.3735	0.9470	0.9182	0.9979
-9.893	117.3498747	39.0251902	-3.843	-0.2733	0.0120	-0.0196	0.2078	0.3072	0.8895	0.8983	0.9588
-14.921	117.3503747	39.0251902	-3.558	-0.2906	0.0654	0.0359	0.2029	0.2907	0.8569	0.8558	0.8677
-13.835	117.3507080	39.0251902	-3.246	-0.1282	0.2632	0.1912	0.3657	0.4738	1.0386	1.0551	1.0863
-13.217	117.3508747	39.0251902	-3.191	-0.0641	0.3303	0.2465	0.4314	0.5473	1.1231	1.1658	1.2188
-12.657	117.3510413	39.0251902	-3.067	0.0039	0.3831	0.2929	0.4991	0.6149	1.2231	1.3072	1.3714
-12.424	117.3512080	39.0251902	-2.943	0.0099	0.3579	0.2776	0.4952	0.6110	1.2489	1.3458	1.3795
-12.475	117.3513747	39.0251902	-2.964	0.0053	0.3079	0.2478	0.4779	0.5912	1.2806	1.3846	1.3793
-12.682	117.3515413	39.0251902	-3.121	-0.0670	0.2179	0.1862	0.4278	0.5167	1.2285	1.3064	1.2891
-12.511	117.3517080	39.0251902	-3.357	-0.1241	0.1493	0.1503	0.3968	0.4565	1.1697	1.2314	1.2168
-11.102	117.3520413	39.0251902	-4.331	-0.1866	0.0288	0.1581	0.3671	0.4031	1.0231	1.0748	1.0342
-10.425	117.3522080	39.0251902	-4.557	-0.1592	0.0754	0.2553	0.4129	0.4636	1.0229	1.0912	1.0074
-7.999	117.3525413	39.0251902	-4.173	-0.0956	0.1919	0.4448	0.5395	0.5774	1.1620	1.2013	1.0798
-3.661	117.3528746	39.0251902	-3.783	-0.0689	9999.0000	0.4497	0.5472	0.5783	1.3511	1.2092	1.1608
-13.428	117.3543745	39.0251902	-3.938	0.1071	0.4859	0.6632	0.7978	0.9730	1.2854	1.6207	1.6274
-18.243	117.3545412	39.0251902	-3.980	0.1224	0.5127	0.6954	0.7888	0.9869	1.2956	1.6312	1.6339
-22.513	117.3547079	39.0251902	-3.825	0.1425	0.5367	0.7026	0.7356	0.9890	1.3448	1.6335	1.6239

7.3.3 The geodetic network observation records time series file

A geodetic network observation records time series file can store the variation records time series of the baseline component for the CORS network, the variation records time series of the height difference for the levelling network, or the variation records time series of the gravity difference for the gravity network.

(1) The file header occupies a row and includes the number of characters of the baseline or route name, number of characters of the site name, sampling length, ……, all the sampling epochs arranged with time.

(2) The file record includes the baseline or route name, starting site (longitude, latitude, height), ending site (longitude, latitude, height), ……, all the observed variations arranged with sampling time (default value is 9999).

(3) The relations between the baselines (or routes) and the sites in the geodetic monitoring network are reflected with the composition of the characters of their name. A

baseline or route name is agreed to be composed of site names A and B at both ends (B***A), where the number of characters of all the sites names (such as A and B) is required to be equal.

Therefore, the number of characters of the baseline or route name shall not be less than twice the number of characters of the site name.

TsqavrRowU.txt | TsqavrbslnU.txt

9 0 36							2015011612	2015021500	2015031612	2015041600	2015051612	2015061600
CANN_DONT	120.4247	27.5226	0.00	121.1503	27.8346	0.00	6.4092	3.5311	-0.6494	3.4802	1.9057	-0.3761
CANN_FDIQ	120.4247	27.5226	0.00	120.2073	27.3353	0.00	7.5566	9999.0000	9.8866	4.9806	-3.7116	0.3579
CANN_JHYW	120.4247	27.5226	0.00	120.0784	29.2727	0.00	3.3886	1.7941	-0.5867	-0.4076	0.7054	-0.2796
CANN_JINH	120.4247	27.5226	0.00	119.6426	29.2178	0.00	2.8530	-0.7712	-1.3292	1.3058	-1.2947	-2.4476
CANN_JINX	120.4247	27.5226	0.00	119.3792	29.0709	0.00	4.3333	1.6376	2.9746	3.5908	1.9899	-1.6367
CANN_JNJZ	120.4247	27.5226	0.00	119.6375	27.9764	0.00	4.9006	3.1138	1.0930	0.3909	0.8296	-1.6116
CANN_JSAN	120.4247	27.5226	0.00	118.6086	28.7279	0.00	2.5860	0.7616	-0.7290	-0.5568	-4.1410	-5.3632
CANN_LHAI	120.4247	27.5226	0.00	121.1895	28.9059	0.00	1.0756	-1.6069	-1.8127	-0.4355	-0.0362	-0.7623
CANN_LISH	120.4247	27.5226	0.00	119.9295	28.4613	0.00	13.8711	10.5885	3.5993	4.5791	-0.7531	-6.0081
CANN_LONQ	120.4247	27.5226	0.00	119.1331	28.0807	0.00	7.3816	6.1923	2.8486	1.8460	-1.9823	-3.9091
CANN_LUOY	120.4247	27.5226	0.00	119.7051	27.5525	0.00	8.8132	9.4984	3.5027	4.0624	0.1673	-1.3212
CANN_PANA	120.4247	27.5226	0.00	120.4367	29.0542	0.00	0.2485	-2.0512	-4.4740	-2.9385	-0.0623	-0.7816
CANN_PCHQ	120.4247	27.5226	0.00	118.5422	27.9232	0.00	5.5253	5.7473	3.2665	1.6373	-1.4516	-6.3300
CANN_PCJM	120.4247	27.5226	0.00	118.4454	28.1680	0.00	14.2248	12.7588	7.9740	8.5291	3.1970	1.6813
CANN_QINT	120.4247	27.5226	0.00	120.2900	28.1394	0.00	7.1517	4.5782	2.4621	4.4460	-0.4966	-3.3975
CANN_QIYU	120.4247	27.5226	0.00	119.0793	27.6213	0.00	7.1481	6.6956	4.4206	1.9230	-5.9045	-7.7402
CANN_QNYN	120.4247	27.5226	0.00	118.9638	27.6157	0.00	10.9311	7.9043	4.5820	1.4154	-3.5702	-5.8564
CANN_QUZH	120.4247	27.5226	0.00	118.8908	28.9937	0.00	8.1029	5.9283	1.7235	1.2962	-0.8214	-5.2339
CANN_QZLY	120.4247	27.5226	0.00	119.1858	29.0336	0.00	7.1312	6.3296	4.8051	4.9249	0.4817	-2.6667
CANN_RUIA	120.4247	27.5226	0.00	120.6490	27.7833	0.00	8.9624	7.8483	0.2735	0.8812	-0.2184	-3.3412
CANN_SHNQ	120.4247	27.5226	0.00	119.5028	27.4576	0.00	4.8563	4.6628	0.3999	3.4718	0.5071	-6.6786
CANN_SNYN	120.4247	27.5226	0.00	119.5093	28.4546	0.00	3.3183	3.1267	1.3992	1.8621	1.0732	-1.1970
CANN_SUIC	120.4247	27.5226	0.00	119.2693	28.5951	0.00	14.7246	7.6386	10.1070	4.5706	6.3427	0.2411
CANN_TAIZ	120.4247	27.5226	0.00	121.4164	28.6183	0.00	4.0291	3.2741	0.3639	1.5962	-0.2033	-1.0270

7.3.4 The variation grids time series files for geodetic field

A group of variation grids time series files are composed of a series of numerical grid model files of a certain kind of variation (vector), and the seventh attribute of the header in each grid file is agreed to be the sampling epoch time. Such as the grids time series of land water equivalent height, sea level variation, and grids time series of various regional load-deformation fields or temporal gravity fields, etc.

zwdx20150331.dat | zwdx20150531.dat | zwdx20150831.dat

118.500000	121.500000	27.000000	29.000000	1.66666667E-02	1.66666667E-02	2015033118			
-0.3746	-0.5686	-0.6666	-0.9356	-1.0686	-1.0836	-1.0606	-1.0586	-1.0586	-1.0566
-0.5445	-0.4746	-0.4986	-0.6746	-0.8176	-0.8646	-0.9356	-0.9356	-0.9575	-0.9565
-0.9326	-0.9128	-0.9132	-0.8647	-0.7606	-0.7255	-0.6170	-0.5403	-0.4534	-0.4873
-0.5622	-0.5214	-0.4842	-0.4644	-0.4832	-0.4767	-0.5045	-0.4994	-0.4972	-0.4458
-0.1776	-0.0795	0.0535	0.0904	0.1088	0.0885	-0.0087	-0.1460	-0.2341	-0.2686
-0.0685	0.1893	0.3498	0.4787	0.5169	0.4660	0.2675	0.1964	0.1144	0.0974
0.1248	-0.0175	-0.1520	-0.2620	-0.3917	-0.4810	-0.5751	-0.6501	-0.7137	-0.7640
-0.2918	-0.1304	0.0015	0.1363	0.2607	0.3785	0.4382	0.4686	0.4562	0.3953
-0.4998	-0.6231	-0.7580	-0.8453	-0.9315	-0.9857	-1.0331	-1.0529	-1.0680	-1.0697
-1.0796	-1.0936	-1.0966	-1.0966	-1.0996	-1.1006	-1.1006	-1.0996	-1.0997	-1.0978
-1.0184	-0.9872	-0.9330	-0.8807	-0.8047	-0.7382	-0.6460	-0.5719	-0.4788	-0.3955
-0.2513	-0.3094	-0.3723	-0.4617	-0.5417	-0.6397	-0.7159	-0.7967	-0.8500	-0.8985
-0.4647	-0.6176	-0.7077	-0.9746	-1.0456	-1.0596	-1.0546	-1.0526	-1.0576	-1.0416
-0.4536	-0.3635	-0.4356	-0.6346	-0.7596	-0.8306	-0.9016	-0.9016	-0.9385	-0.9385
-0.9086	-0.9138	-0.9142	-0.8636	-0.7696	-0.7325	-0.6810	-0.6283	-0.5264	-0.5533
-0.5762	-0.5344	-0.5152	-0.4914	-0.5093	-0.5217	-0.5505	-0.5446	-0.5243	-0.4589
-0.1982	-0.1410	-0.0271	0.0068	0.0242	0.0178	-0.0763	-0.1896	-0.2368	-0.2702
-0.0970	0.1349	0.3035	0.4214	0.4327	0.4208	0.2203	0.1393	0.0803	0.0864
0.0868	-0.0434	-0.1649	-0.2578	-0.4047	-0.5100	-0.5791	-0.6770	-0.7527	-0.7781

7.3.5 The spherical harmonic coefficient models time series files

A group of spherical harmonic coefficient models time series files can store the time series of the spherical harmonic coefficient (Stokes' coefficient) models of global surface load variations, global load-deformation fields, or temporal global gravity field.

(1) The header file occupies one row and consists of three attributes, namely the geocentric gravitational constant GM ($\times 10^{14} m^2/s^2$), equatorial radius of the Earth a (m), and sampling epoch (in ETideLoad format).

(2) The spherical harmonic coefficients correspond to the scaling parameters of GM and a. For different spherical harmonic coefficients models, GM and a are not necessarily

the same.

(3) The n-th degree m-th order spherical harmonic coefficient is expressed by a record with the format: degree n, order m, C_{nm}, S_{nm} (, C_{nm} error, S_{nm} error). At different sampling epochs, n of the model files can be not the same.

(4) ETideLoad does not require the degrees and orders of harmonic coefficients to be arranged and allows to exist insufficient orders. For the harmonic coefficient of insufficient order, ETideLoad automatically sets to zero.

7.4 Geophysical models and numerical standards in ETideLoad4.0

ETideLoade4.0 is mainly based on the geophysical models and numerical standards recommended by IERS Conventions (2010). You can update them from the program [geophysical models and numerical standards settings]. These geophysical models and numerical standards are stored in file form.

7.4.1 The surface air pressure tidal load spherical harmonic coefficients model file

The 360-degree surface air pressure tidal load spherical harmonic coefficients model file ECMWF2006.dat is stored in the folder C:\ETideLoad4.0_win64en\iers in FES2004 format, which were constructed by the spherical harmonic analysis programs of ETideLoad4.0 using 0.5°× 0.5° global harmonic parameter grids of four atmospheric tidal constituents, to meet the basic needs of centimeter-level geodesy. The four tidal constituents are respectively the diurnal, semi-diurnal, semi-annual and annual periodic tidal constituents (S_1, S_2, Ss_a, Sa) whose harmonic parameter grids come from ECMWF-DCDA2006 of European Centre for Medium-Range Weather Forecasts.

ECMWF2006.dat

Atmospheric tide model: ECMWF-DCDA2006 normalized model up to (360,360) in hPa
半日/周日/半年/年周期

Doodson	Darw	n	m	Csin+	Ccos+	Csin-	Ccos-	C+	eps+	C-	eps-
164.556	S1	1	0	-0.01055351	0.00555959	-0.01055351	0.00555959	0.01192835	297.7803	0.01192835	297.7803
164.556	S1	2	0	-0.00898730	0.02713172	-0.00898730	0.02713172	0.02858149	341.6727	0.02858149	341.6727
164.556	S1	3	0	0.02416514	0.01232573	0.02416514	0.01232573	0.02712707	62.9756	0.02712707	62.9756
164.556	S1	4	0	0.01971779	-0.01808456	0.01971779	-0.01808456	0.02675523	132.5261	0.02675523	132.5261
164.556	S1	5	0	0.00538826	-0.01556217	0.00538826	-0.01556217	0.01646859	160.9021	0.01646859	160.9021
164.556	S1	6	0	-0.01896560	-0.00055330	-0.01896560	-0.00055330	0.01897366	268.3289	0.01897366	268.3289
164.556	S1	7	0	0.00163224	0.00711629	0.00163224	0.00711629	0.00730108	12.9183	0.00730108	12.9183
164.556	S1	8	0	0.00341644	0.00607435	0.00341644	0.00607435	0.00696920	29.3550	0.00696920	29.3550
164.556	S1	9	0	-0.00469730	-0.00311697	-0.00469730	-0.00311697	0.00563739	236.4331	0.00563739	236.4331
164.556	S1	10	0	0.00442735	-0.01563001	0.00442735	-0.01563001	0.01624496	164.1847	0.01624496	164.1847
164.556	S1	11	0	0.00941838	-0.00082619	0.00941838	-0.00082619	0.00945455	95.0132	0.00945455	95.0132
164.556	S1	12	0	-0.00454013	0.00688423	-0.00454013	0.00688423	0.00824654	326.5953	0.00824654	326.5953
164.556	S1	13	0	-0.01227672	0.00310149	-0.01227672	0.00310149	0.01266243	284.1781	0.01266243	284.1781
164.556	S1	14	0	0.00203678	0.00166923	0.00203678	0.00166923	0.00263340	50.6638	0.00263340	50.6638
164.556	S1	15	0	0.00253994	0.00381849	0.00253994	0.00381849	0.00458608	33.6306	0.00458608	33.6306
164.556	S1	16	0	0.00613602	-0.00041704	0.00613602	-0.00041704	0.00615017	93.8882	0.00615017	93.8882
164.556	S1	17	0	-0.00113104	-0.00413462	-0.00113104	-0.00413462	0.00428652	195.2992	0.00428652	195.2992
164.556	S1	18	0	-0.00311700	0.00136741	-0.00311700	0.00136741	0.00340375	293.6868	0.00340375	293.6868
164.556	S1	19	0	-0.00217138	0.00053937	-0.00217138	0.00053937	0.00223737	283.9498	0.00223737	283.9498
164.556	S1	20	0	-0.00017645	0.00369644	-0.00017645	0.00369644	0.00370065	357.2671	0.00370065	357.2671
164.556	S1	21	0	0.00068441	-0.00165216	0.00068441	-0.00165216	0.00178831	157.4980	0.00178831	157.4980
164.556	S1	22	0	0.00100221	-0.00214635	0.00100221	-0.00214635	0.00236881	154.9703	0.00236881	154.9703
164.556	S1	23	0	0.00461395	-0.00179653	0.00461395	-0.00179653	0.00495136	111.2744	0.00495136	111.2744
164.556	S1	24	0	-0.00143873	0.00014453	-0.00143873	0.00014453	0.00144597	275.7366	0.00144597	275.7366
164.556	S1	25	0	-0.00083151	-0.00001238	-0.00083151	-0.00001238	0.00083160	269.1470	0.00083160	269.1470
164.556	S1	26	0	-0.00272792	-0.00095240	-0.00272792	-0.00095240	0.00288940	250.7543	0.00288940	250.7543
164.556	S1	27	0	-0.00183890	0.00217563	-0.00183890	0.00217563	0.00284868	319.7946	0.00284868	319.7946

In ECMWF-DCDA2006 model, the diurnal and semidiurnal constituents (S_1, S_2) of atmospheric pressure can constitute RP03 model.

The surface air pressure tides, their tidal constituent harmonic parameters and tidal load spherical harmonic coefficients are all in hPa as unit.

7.4.2 The ocean tidal load spherical harmonic coefficients model file

The 100-degree ocean tidal load spherical harmonic coefficients model file FES2004S1.dat is stored in the folder C:\ETideLoad4.0_win64en\iers in FES2004 format. The relationship between the ocean tidal load normalized spherical harmonic coefficients and the geopotential coefficients is as the formula (6.15) in the IERS Conventions (2010).

```
ECMWF2006.dat   FES2004S1.dat
Ocean tide model: FES2004 normalized model (fev. 2004) up to (100,100) in cm
(long period from FES2002 up to (50,50) + equilibrium Om1/Om2, atmospheric tide NOT included)
Doodson Darw   n   m    Csin+     Ccos+       Csin-     Ccos-       C+    eps+    C-      eps-
  55.565 Om1   2   0 -0.540594  0.000000    0.000000  0.000000   0.5406 270.000 0.0000   0.000
  55.575 Om2   2   0 -0.005218  0.000000    0.000000  0.000000   0.0052 270.000 0.0000   0.000
  56.554 Sa    1   0  0.017233  0.000013    0.000000  0.000000   0.0172  89.957 0.0000   0.000
  56.554 Sa    2   0 -0.046604 -0.000903    0.000000  0.000000   0.0466 268.890 0.0000   0.000
  56.554 Sa    3   0 -0.000889  0.000049    0.000000  0.000000   0.0009 273.155 0.0000   0.000
  56.554 Sa    4   0  0.012069 -0.000413    0.000000  0.000000   0.0121  91.960 0.0000   0.000
  56.554 Sa    5   0 -0.009780 -0.000421    0.000000  0.000000   0.0098 267.535 0.0000   0.000
  56.554 Sa    6   0  0.006895  0.000043    0.000000  0.000000   0.0069  89.643 0.0000   0.000
  56.554 Sa    7   0 -0.010515 -0.000287    0.000000  0.000000   0.0105 268.437 0.0000   0.000
  56.554 Sa    8   0  0.002067 -0.000011    0.000000  0.000000   0.0021  90.305 0.0000   0.000
  56.554 Sa    9   0 -0.004236 -0.000110    0.000000  0.000000   0.0042 268.512 0.0000   0.000
  56.554 Sa   10   0 -0.001781 -0.000085    0.000000  0.000000   0.0018 267.268 0.0000   0.000
  56.554 Sa   11   0 -0.001372 -0.000068    0.000000  0.000000   0.0014 267.163 0.0000   0.000
  56.554 Sa   12   0 -0.004081 -0.000048    0.000000  0.000000   0.0041 269.326 0.0000   0.000
  56.554 Sa   13   0 -0.000116 -0.000041    0.000000  0.000000   0.0001 250.534 0.0000   0.000
  56.554 Sa   14   0 -0.003043 -0.000007    0.000000  0.000000   0.0030 269.868 0.0000   0.000
  56.554 Sa   15   0  0.001109 -0.000028    0.000000  0.000000   0.0011  91.446 0.0000   0.000
  56.554 Sa   16   0 -0.002596 -0.000034    0.000000  0.000000   0.0026 269.250 0.0000   0.000
  56.554 Sa   17   0 -0.000674  0.000022    0.000000  0.000000   0.0007 271.870 0.0000   0.000
  56.554 Sa   18   0  0.000546  0.000006    0.000000  0.000000   0.0005  89.370 0.0000   0.000
  56.554 Sa   19   0 -0.000024  0.000023    0.000000  0.000000   0.0000 313.781 0.0000   0.000
  56.554 Sa   20   0  0.000867  0.000014    0.000000  0.000000   0.0009  89.075 0.0000   0.000
```

In order to meet the basic needs of satellite, coastal zone and ocean gravity gradient data processing, we adopted AVISO+'s FES2014b global tidal height harmonic parameters grid models and constructed the 360-degree ocean tidal height spherical harmonic coefficients model file FES2014cs.dat in FES2004 format by the spherical harmonic analysis programs of ETideLoad4.0.

FES2014cs.dat includes spherical harmonic coefficients of the 36 tidal constituents (Ω1, Ω2; 2N2, Eps2, J1, K1, K2, L2, La2, M2, M3, M4, M6, M8, Mf, MKS2, Mm, MN4, MS4, MSf, MSqm, Mtm, Mu2, N2, N4, Nu2, O1, P1, Q1, R2, S1, S2, S4, Sa, Ssa, T2), in which the spherical harmonic coefficients of the two balance tidal constituents (Ω1, Ω2) come from FES2004S1.dat.

The ocean tidal height, harmonic parameters of the tidal constituent and tidal load spherical harmonic coefficients are all in cm as unit.

7.4.3 The Earth's Load Love numbers file

The Earth's load Love numbers also called the load deformation coefficients (LDC) can be calculated using the spherically symmetric non-rotating elastic earth model REF6371. The Load Love numbers in ETideLoad4.0 come from a Regional ElRstic Rebound calculator (REAR1.0, 2015.11), using the file Love_load_cm.dat stored in the folder C:\ETideLoad4.0_win64en\iers. The file includes the load Love numbers of the radial displacement, horizontal displacement and geopotential $(h'_n, l'_n, k'_n), n = 1, \cdots, 32768$ from 1 to 32768 degree, as shown in the figure.

In order to suppress the high-degree oscillations of the load Green's function, the load

Green's function is calculated to 54000 degree in ETideLoad, and the load Love numbers exceeding 32768 degree (n>32768) are calculated with the following asymptotic formula

h'_n =-6.209114, l'_n =1.890061/n, k'_n =-2.682697/n.

Love_load_cm.dat

```
The load Love numbers from the REAR package are attached. There are no
more of these oscillations at high degree, and they go up to degree 32768.
November 20, 2015, Jean-Paul
CM: center of mass reference frame
    n     h' (vert)          l' (horiz)          k' (potent)
    0   0.0000000000D+00  0.0000000000D+00  -1.0000000000D+00
    1  -0.0287112988D+01  0.1045044062D+00  -1.0000000000D+00
    2  -0.9945870591D+00  0.2411251588D-01  -0.3057703360D+00
    3  -0.1054653021D+01  0.7085493677D-01  -0.1962722363D+00
    4  -0.1057783895D+01  0.5958723183D-01  -0.1337905897D+00
    5  -0.1091185915D+01  0.4702627503D-01  -0.1047617976D+00
    6  -0.1149253656D+01  0.3940811757D-01  -0.9034958051D-01
    7  -0.1218363201D+01  0.3499400649D-01  -0.8205733906D-01
    8  -0.1290473661D+01  0.3225123202D-01  -0.7652348967D-01
    9  -0.1361847865D+01  0.3038562458D-01  -0.7239287690D-01
   10  -0.1430981761D+01  0.2902258995D-01  -0.6907768441D-01
   11  -0.1497377458D+01  0.2798156018D-01  -0.6629382122D-01
   12  -0.1560934855D+01  0.2716367080D-01  -0.6388475059D-01
   13  -0.1621715593D+01  0.2650554043D-01  -0.6175536119D-01
   14  -0.1679770379D+01  0.2596800569D-01  -0.5983856019D-01
   15  -0.1735198310D+01  0.2551661917D-01  -0.5808965155D-01
   16  -0.1788088250D+01  0.2512667367D-01  -0.5647488828D-01
   17  -0.1838448069D+01  0.2478452380D-01  -0.5496610314D-01
   18  -0.1886440474D+01  0.2447083426D-01  -0.5354901315D-01
   19  -0.1932084480D+01  0.2417919471D-01  -0.5220607051D-01
   20  -0.1975465902D+01  0.2389862142D-01  -0.5092726303D-01
   21  -0.2016677975D+01  0.2362510597D-01  -0.4970406011D-01
   22  -0.2055800328D+01  0.2335504487D-01  -0.4853059813D-01
```

7.4.4 The IERS Earth orientation parameters time series file

The IERS Earth orientation parameters (EOP) time series file IERSeopc04.dat (ITRF2008) were stored in the folder C:\ETideLoad4.0_win64en\iers. You can update the EOP time series from the IERS website. For future epochs, the forecast EOP products can be used. Considering the non-tidal nature of the polar motion, the forecast time should be controlled within half a year.

ECMWF2006.dat FES2004S1.dat IERSeopc04.dat

```


                    INTERNATIONAL EARTH ROTATION AND REFERENCE SYSTEMS SERVICE
                         EARTH ORIENTATION PARAMETERS
                           EOP (IERS) 14 C04


             FORMAT(3(I4),I7,2(F11.6),2(F12.7),2(F11.6),2(F11.6),2(F11.7),2(F12.6))
##################################################################################

      Date      MJD      x          y        UT1-UTC       LOD         dX        dY        x Err      y Err    UT1-UTC Err  LOD Err     dX Err       dY Err
                         "          "           s           s          "         "           "          "          s          s          "            "
     (0h UTC)

2001   1   1  51910  -0.073506   0.398095   0.0931626   0.0006630   0.000150  -0.000109   0.000061   0.000048  0.0000107  0.0000131   0.000028   0.000030
2001   1   2  51911  -0.072651   0.399806   0.0924546   0.0007596   0.000141  -0.000092   0.000061   0.000048  0.0000070  0.0000131   0.000028   0.000031
2001   1   3  51912  -0.071557   0.401864   0.0916573   0.0008515   0.000132  -0.000074   0.000061   0.000047  0.0000034  0.0000131   0.000028   0.000031
2001   1   4  51913  -0.071024   0.403840   0.0907195   0.0008969   0.000149  -0.000084   0.000061   0.000047  0.0000084  0.0000132   0.000029   0.000031
2001   1   5  51914  -0.070723   0.405333   0.0897667   0.0008872   0.000174  -0.000103   0.000060   0.000047  0.0000163  0.0000132   0.000029   0.000031
2001   1   6  51915  -0.070378   0.406725   0.0889292   0.0008068   0.000199  -0.000122   0.000060   0.000047  0.0000221  0.0000132   0.000029   0.000031
2001   1   7  51916  -0.070068   0.408041   0.0882375   0.0006463   0.000224  -0.000141   0.000060   0.000047  0.0000163  0.0000132   0.000029   0.000031
2001   1   8  51917  -0.070205   0.409479   0.0876861   0.0004933   0.000250  -0.000160   0.000060   0.000047  0.0000104  0.0000132   0.000029   0.000031
2001   1   9  51918  -0.070220   0.410814   0.0872445   0.0004441   0.000275  -0.000179   0.000060   0.000046  0.0000046  0.0000132   0.000029   0.000032
2001   1  10  51919  -0.069861   0.412336   0.0868199   0.0004186   0.000270  -0.000158   0.000060   0.000046  0.0000043  0.0000133   0.000029   0.000031
2001   1  11  51920  -0.069330   0.414004   0.0864003   0.0004447   0.000155  -0.000180   0.000059   0.000046  0.0000039  0.0000133   0.000029   0.000031
2001   1  12  51921  -0.068456   0.416120   0.0858451   0.0005855   0.000106  -0.000203   0.000059   0.000046  0.0000088  0.0000133   0.000028   0.000030
2001   1  13  51922  -0.067463   0.418251   0.0851161   0.0007422   0.000095  -0.000222   0.000059   0.000046  0.0000138  0.0000133   0.000028   0.000030
2001   1  14  51923  -0.066479   0.420226   0.0842390   0.0008823   0.000084  -0.000241   0.000059   0.000046  0.0000112  0.0000134   0.000028   0.000029
2001   1  15  51924  -0.065406   0.422044   0.0833100   0.0009404   0.000072  -0.000259   0.000059   0.000046  0.0000086  0.0000134   0.000027   0.000028
2001   1  16  51925  -0.063999   0.423541   0.0824180   0.0009155   0.000061  -0.000278   0.000059   0.000046  0.0000060  0.0000134   0.000027   0.000028
2001   1  17  51926  -0.062602   0.425076   0.0816384   0.0007815   0.000050  -0.000297   0.000059   0.000046  0.0000034  0.0000135   0.000027   0.000027
2001   1  18  51927  -0.061434   0.426438   0.0809369   0.0005717   0.000307  -0.000078   0.000060   0.000046  0.0000060  0.0000135   0.000026   0.000026
2001   1  19  51928  -0.060301   0.428009   0.0803992   0.0004021   0.000387  -0.000005   0.000060   0.000046  0.0000114  0.0000135   0.000026   0.000025
2001   1  20  51929  -0.059175   0.429380   0.0801026   0.0002618   0.000335  -0.000045   0.000060   0.000046  0.0000197  0.0000136   0.000025   0.000025
2001   1  21  51930  -0.058122   0.430418   0.0799970   0.0000786   0.000284  -0.000085   0.000060   0.000046  0.0000198  0.0000136   0.000025   0.000024
2001   1  22  51931  -0.056745   0.431190   0.0799904  -0.0000387   0.000232  -0.000124   0.000060   0.000047  0.0000199  0.0000136   0.000024   0.000023
2001   1  23  51932  -0.055378   0.432515   0.0800354  -0.0000794   0.000180  -0.000164   0.000061   0.000047  0.0000200  0.0000137   0.000024   0.000022
2001   1  24  51933  -0.054038   0.434299   0.0801054  -0.0000531   0.000189  -0.000183   0.000061   0.000047  0.0000090  0.0000137   0.000024   0.000022
2001   1  25  51934  -0.052227   0.436048   0.0801105   0.0000481   0.000130  -0.000240   0.000061   0.000047  0.0000025  0.0000137   0.000023   0.000021
2001   1  26  51935  -0.050435   0.438026   0.0799589   0.0001715   0.000101  -0.000252   0.000062   0.000048  0.0000160  0.0000137   0.000023   0.000021
2001   1  27  51936  -0.049130   0.439812   0.0796787   0.0002940   0.000094  -0.000242   0.000062   0.000048  0.0000312  0.0000137   0.000022   0.000020
2001   1  28  51937  -0.047602   0.441607   0.0792944   0.0004503   0.000086  -0.000232   0.000062   0.000048  0.0000276  0.0000137   0.000022   0.000019
2001   1  29  51938  -0.045537   0.443509   0.0788172   0.0005621   0.000079  -0.000221   0.000063   0.000048  0.0000239  0.0000138   0.000021   0.000019
2001   1  30  51939  -0.043660   0.444974   0.0782782   0.0006019   0.000072  -0.000211   0.000063   0.000048  0.0000203  0.0000138   0.000021   0.000018
2001   1  31  51940  -0.042067   0.446396   0.0777060   0.0005437   0.000254  -0.000159   0.000063   0.000049  0.0000063  0.0000138   0.000021   0.000019
2001   2   1  51941  -0.040683   0.447325   0.0772066   0.0004689   0.000298  -0.000141   0.000064   0.000049  0.0000064  0.0000138   0.000022   0.000020
2001   2   2  51942  -0.039012   0.448060   0.0767917   0.0003692   0.000290  -0.000134   0.000064   0.000049  0.0000143  0.0000138   0.000022   0.000020
2001   2   3  51943  -0.037722   0.448868   0.0764837   0.0002097   0.000283  -0.000128   0.000064   0.000049  0.0000284  0.0000138   0.000023   0.000021
2001   2   4  51944  -0.036102   0.449525   0.0763497   0.0000712   0.000275  -0.000122   0.000064   0.000049  0.0000205  0.0000138   0.000023   0.000022
2001   2   5  51945  -0.034057   0.450440   0.0763128  -0.0000019   0.000268  -0.000115   0.000064   0.000050  0.0000125  0.0000138   0.000024   0.000022
```

7.4.5 The geocentric motion parameters time series file

The geocentric motion parameters time series file GCN_L1_L2_30d_CF-CM.txt (ITRF2005) were stored in the folder C:\ETideLoad4.0_win64en\iers, which are monthly variation time series products of geocentric motion parameters measured by 5 satellite laser ranging (SLR) provided by UT/CSR. For future epochs, the forecast products can be used, but the forecast time should be controlled within three months.

ECMWF2006.dat | FES2004S1.dat | IERSeopc04.dat | GCN_L1_L2_30d_CF-CM.txt

Year	X	Y	Z	X_sig	Y_sig	Z_sig
2001.0402	2.50	2.00	5.40	1.78	1.48	4.24
2001.1248	0.65	-1.35	10.75	1.61	1.34	3.68
2001.2128	-0.10	-3.40	3.05	1.61	1.41	3.51
2001.2932	-0.85	-3.55	-4.10	2.82	2.15	3.79
2001.3784	0.40	-2.50	-7.00	1.70	2.30	3.05
2001.4646	-1.65	-1.60	-6.60	1.62	3.30	3.11
2001.5456	-1.55	-2.45	-3.35	1.27	1.85	3.00
2001.6278	-4.45	-0.40	-2.80	1.44	1.90	3.22
2001.7120	-2.05	0.85	-4.05	1.44	1.95	3.34
2001.7911	-1.20	2.05	0.25	1.27	2.05	3.28
2001.8708	0.05	2.05	-2.60	1.44	1.55	3.11
2001.9569	0.05	3.70	-4.60	1.53	1.41	3.39
2002.0399	3.85	4.05	-6.05	1.70	1.75	3.39
2002.1250	1.10	0.25	1.75	1.36	1.27	3.17
2002.2103	0.40	-1.45	3.30	1.44	1.20	2.94
2002.2899	0.50	-2.20	3.10	1.53	1.27	3.34
2002.3769	0.95	-3.45	-0.80	1.44	1.55	5.36
2002.4625	-1.15	-4.50	-5.75	1.62	1.27	2.94
2002.5412	-3.30	-4.90	-4.80	2.16	1.48	2.94
2002.6263	-1.85	0.15	-5.55	1.78	2.35	3.17
2002.7114	-1.85	0.05	0.70	1.53	2.05	3.90
2002.7952	-2.80	-0.30	0.55	1.44	1.90	3.73
2002.8744	-2.75	1.70	0.15	1.44	3.10	3.62
2002.9543	1.75	3.45	9.15	1.95	1.56	5.72
2003.0438	1.40	-0.35	2.40	1.61	1.95	4.19
2003.1279	0.70	0.75	2.30	1.44	1.25	3.28
2003.2108	1.90	-0.05	4.10	1.36	1.55	2.77
2003.2952	1.60	-1.70	2.35	1.78	1.48	3.28
2003.3796	0.50	-3.75	1.35	1.53	1.27	3.16

7.4.6 Ocean tidal constituent harmonic parameters grid model files

(1) The ocean tidal height model is composed of multiple grids models of all tidal constituent harmonic parameters. Each tidal constituent harmonic parameters are stored as a vector grid file.

(2) All the tidal constituent grids files from an ocean tidal height model should be in a folder with the same grid specifications.

(3) The 10 vector grid files in the folder C:\ ETideLoad4.0_win64cn\OceanTide represent the ocean tide model GOT4.8 with 10 global grid models of 10 tidal constituent harmonic parameters.

(4) The type of the tidal constituent is identified by the seventh attribute (Doodson constant) in its grid file header. These files can be named at will.

M2_got4.8.dat

0.000000	360.000000	-90.000000	90.000000	0.50000000	0.50000000	255555						
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(5) The ocean tidal height model can be global or regional, and the ETideLoad program can be automatically identified. The ocean tidal height and the harmonic parameters are all in cm as unit.

7.4.7 The JPL Planetary Ephemeris DE405 file

The JPL Planetary Ephemeris DE405 file JEPH.405 was stored in the folder C:\ETideLoad4.0_win64en\iers. The ephemeris starts at 0:00 on 9 December 1599 (JD2305424. 5) and ends at 0: 00 on 20 February 2201 (JD2525008. 5).

7.4.8 The corrections file of frequency dependence for Love numbers

The corrections file IERS2010T65.dat of frequency dependence was generated from Table 6.5a、6.5b and 6.5c in IERS Conventions (2010), to calculate the corrections of frequency dependence of geopotential Love numbers to obtain the high-accuracy solid tide effect on the Earth's external geopotential.

7.4.9 The Desai ocean pole tide coefficients file

The ocean pole tide is generated by the centrifugal effect of polar motion on the oceans. Desai (2002) presents a self-consistent equilibrium model of the ocean pole tide. This model accounts for continental boundaries, mass conservation over the oceans, self-gravitation, and loading of the ocean floor. Using this model, the ocean pole tide produces the following perturbations to the normalized geopotential coefficients, as a function of the pole shift parameters (m_1, m_2).

ECMWF2006.dat | FES2004S1.dat | IERSeopc04.dat | GCN_L1_L2_30d_CF-CM.txt | desaiscopolecoef.txt

n	m	Anm(Real)	Bnm(Real)	Anm(Imaginary)	Bnm(Imaginary)
1	0	1.8736759805448e-02	0.0000000000000e+00	2.9688884960424e-02	0.0000000000000e+00
1	1	2.8258913146935e-02	2.1774643075236e-02	2.3898264393684e-02	5.6771602236635e-02
2	0	-3.9555099024374e-03	0.0000000000000e+00	6.8390464271953e-04	0.0000000000000e+00
2	1	-2.4325330521304e-01	5.4680741193318e-03	5.4680741193318e-03	-1.9252111185300e-01
2	2	1.9102047023374e-02	1.1158297399424e-02	-1.5123770169928e-02	-2.4857839911518e-04
3	0	-2.0869478248378e-02	0.0000000000000e+00	-1.0775272844125e-02	0.0000000000000e+00
3	1	3.0809252024501e-02	7.4552838003486e-03	5.5937937407386e-03	6.6496877724041e-02
3	2	2.3295703062692e-02	3.7984356463618e-02	-2.1678456242839e-03	1.1232359168959e-02
3	3	7.9776020803848e-03	1.2502542787182e-02	-2.2341399966187e-02	-2.2979590161975e-02
4	0	-1.0612668622736e-02	0.0000000000000e+00	-1.5569196271270e-02	0.0000000000000e+00
4	1	1.3606306893006e-04	2.2051992576636e-03	2.0130037501025e-03	1.6323514549038e-02
4	2	1.1139374002795e-02	1.7031544962514e-02	-7.9621127289889e-03	-8.4440848505132e-04
4	3	-1.6100794768731e-02	1.4681986705593e-02	9.5178410813713e-03	-2.1017136590507e-02
4	4	4.3132021252707e-03	-4.6836271624465e-03	-2.9309550249205e-03	1.3175690530653e-02
5	0	7.0731357453056e-03	0.0000000000000e+00	-1.8023029843730e-03	0.0000000000000e+00
5	1	2.5644907587134e-03	-1.0076857169607e-02	-9.6273922883022e-03	-1.1684145258283e-02
5	2	-7.9615162895536e-03	2.0820461332209e-03	-3.0274671879191e-03	-1.0475800274156e-02
5	3	-1.1818705609675e-02	1.2063416189422e-02	-1.6584597520384e-02	-2.8253596831795e-02
5	4	9.2731253376468e-03	1.8353138561674e-02	-1.0870088052722e-02	4.7120935900411e-03
5	5	1.4460712839068e-02	-8.5510747244577e-03	8.9167437380844e-04	1.6048852898081e-02
6	0	7.4439256593180e-03	0.0000000000000e+00	-1.0670986469176e-03	0.0000000000000e+00
6	1	1.8261459881891e-02	-3.7775168887123e-03	-3.6768761254667e-03	-1.4329108864964e-03
6	2	-8.4568708595335e-03	2.5640802224787e-03	8.0976103423504e-03	-6.3983905389798e-03
6	3	-1.5355186088842e-02	1.8642889355748e-03	-9.6956523287846e-03	-2.2353328754893e-02
6	4	1.4142224508565e-03	-2.2076728030274e-03	-6.1060835758971e-03	1.4301205310949e-02
6	5	3.7744391579465e-03	1.6205935938625e-02	-7.4210466275681e-03	-2.8879881476777e-03
6	6	3.2420227193323e-03	-1.0204123402364e-03	6.5738366845630e-03	-6.6744309720085e-03
7	0	-1.3403793397592e-03	0.0000000000000e+00	-8.9119937331666e-04	0.0000000000000e+00
7	1	-1.1987665799148e-02	3.7952628984046e-03	3.0548620901213e-03	-2.4656687484472e-02
7	2	1.3964996790643e-03	1.7659797083036e-03	-9.6345882913594e-04	5.1931284495957e-04
7	3	-1.7567622661385e-02	6.8385783341764e-04	9.3943264784830e-03	4.5672879067042e-03
7	4	2.8083751020130e-03	4.6098055178789e-04	-9.4429840592558e-03	2.6160014372180e-03
7	5	1.3438573148260e-02	-4.9709663788905e-03	5.4401137615611e-03	1.2610209142217e-02
7	6	2.3574978727809e-03	-1.8507773876743e-03	-8.8485482473243e-03	-1.7275571315203e-03
7	7	1.7687501823906e-03	-3.8588288830715e-03	5.1311168222451e-03	-3.4729764622333e-03
8	0	2.4179833053297e-03	0.0000000000000e+00	6.3989330948214e-04	0.0000000000000e+00
8	1	5.4747795444986e-03	-4.1645492784766e-03	-3.5505342447356e-03	9.2109717009068e-03
8	2	-3.5541696851032e-03	-1.0507455458039e-02	-2.8591215118039e-03	-5.7895937048006e-05
8	3	-3.6234392832446e-03	5.2650936441460e-03	2.0052526194323e-03	5.9074589159813e-03

The Desai calculating formula of the ocean pole tide adopts the formula (6.23) in the

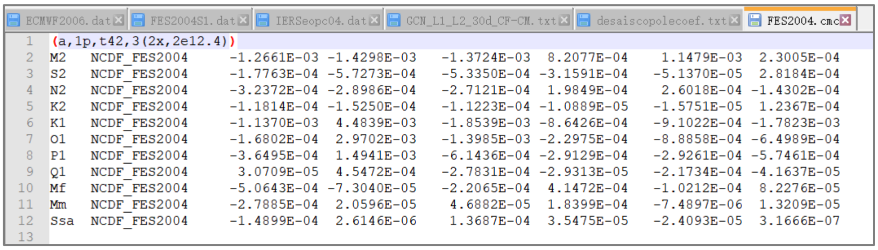
IERS Convertions (2010), and the 360-degree ocean pole tide coefficients file desaiscopolecoef.txt is stored in the folder C:\ETideLoad4.0_win64en\iers.

7.4.10 The center of mass correction coefficients file for the ocean tide

(1) The center of mass correction formula of ocean tide adopts the formula (1.17) in the IERS Convertions (2010). The object of correction is the three-dimensional coordinates of the ground site in the terrestrial reference frame。

(2) When different tidal models are used to calculate the tidal load effect on the ground site displacement, the corresponding correction coefficients of ocean tide should be used to calculate the center of mass correction.

(3) There are some center of mass correction coefficients files for common ocean tide models stored in the folder C:\ETideLoad4.0_ win64en\ CmcOtide. In which, the center of mass correction coefficients for the ocean tide model FES2004:




```
(a,1p,t42,3(2x,2e12.4))
M2   NCDF_FES2004     -1.2661E-03 -1.4298E-03   -1.3724E-03  8.2077E-04    1.1479E-03  2.3005E-04
S2   NCDF_FES2004     -1.7763E-04 -5.7273E-04   -5.3350E-04 -3.1591E-04   -5.1370E-05  2.8184E-04
N2   NCDF_FES2004     -3.2372E-04 -2.8986E-04   -2.7121E-04  1.9849E-04    2.6018E-04 -1.4302E-04
K2   NCDF_FES2004     -1.1814E-04 -1.5250E-04   -1.1223E-04 -1.0889E-05   -1.5751E-05  1.2367E-04
K1   NCDF_FES2004     -1.1370E-03  4.4839E-03   -1.8539E-03 -8.6426E-04   -9.1022E-04 -1.7823E-03
O1   NCDF_FES2004     -1.6802E-04  2.9702E-03   -1.3985E-03 -2.2975E-04   -8.8858E-04 -6.4989E-04
P1   NCDF_FES2004     -3.6495E-04  1.4941E-03   -6.1436E-04 -2.9129E-04   -2.9261E-04 -5.7461E-04
Q1   NCDF_FES2004      3.0709E-05  4.5472E-04   -2.7831E-04 -2.9313E-05   -2.1734E-04 -4.1637E-05
Mf   NCDF_FES2004     -5.0643E-04 -7.3040E-05   -2.2065E-04  4.1472E-04   -1.0212E-04  8.2276E-05
Mm   NCDF_FES2004     -2.7885E-04  2.0596E-05    4.6882E-05  1.8399E-04   -7.4897E-06  1.3209E-05
Ssa  NCDF_FES2004     -1.4899E-04  2.6146E-06    1.3687E-04  3.5475E-05   -2.4093E-05  3.1666E-07
```

8 Main Algorithms and Formulas used in ETideLoad4.0

8.1 Solid tidal effects on various geodetic quantities outside solid Earth

8.1.1 The tidal generating potentials of celestial bodies

The celestial bodies' tidal direct effects on the Earth's external geopotential can be expressed by the variations of geopotential coefficients in the Earth-fixed coordinate system

$$\Delta\bar{C}_{nm} - i\Delta\bar{S}_{nm} = \frac{1}{2n+1}\sum_{j=2}^{10}\frac{GM_j}{GM}\left(\frac{a}{r_j}\right)^{n+1}\bar{P}_{nm}(sin\varphi_j)e^{im\lambda_j}, \quad (1)$$

where $j = 2{\sim}10$ represent the moon, sun, Mercury, Venus, Mars, Jupiter, Saturn, Uranus and Neptune. $\Delta\bar{C}_{nm} - i\Delta\bar{S}_{nm}$ are the variations of the normalize geopotential coefficients with degree n and order m (with $\Delta\bar{S}_{n0} = 0$), $\bar{P}_{nm}$ are the normalized associated Legendre functions, $n = 2,3$ for the moon, and $n = 2$ for the other celestial bodies. $GM_j, r_j, \varphi_j, \lambda_j$ are respectively the gravitational parameter, distance from geocenter, geocentric latitude, and longitude (from Greenwich) of the celestial body j. GM, a are respectively the geocentric gravitational constant and Equatorial radius of the Earth.

8.1.2 Nominal values of solid Earth tide external geopotentials

The tidal generating potentials cause the deformation of the solid Earth, leading to the re-adjustment of the Earth's mass, resulting in additional external geopotentials, known as the indirect effects of the external geopotential, whose can be quantitatively represented by the geopotential Love numbers.

The solid earth tide effects of geopotential coefficients are equal to the sum of the direct effects and indirect effects of the tidal generating potentials.

For the elastic earth, the Love numbers are independent of the frequency, and such a Love number is called the nominal Love number, as shown in Table 1.

Table 1 Nominal values of solid Earth tidal external potential Love numbers

n	m	periods of tidal constituents	k_{nm}	h_{nm}	l_{nm}
2	0	long period	0.29525	0.6078	0.0847
2	1	diurnal	0.29470	0.6078	0.0847
2	2	semi-diurnal	0.29801	0.6078	0.0847
3	0	long period	0.093	0.2920	0.0150
3	1	diurnal	0.093	0.2920	0.0150
3	2	semi-diurnal	0.093	0.2920	0.0150
3	3	1/3-diurnal	0.094	0.2920	0.0150

(1) Nominal solid tidal effects on geopotential coefficients

$$\Delta\bar{C}_{nm} - i\Delta\bar{S}_{nm} = \frac{1+k_{nm}}{2n+1}\sum_{j=2}^{10}\frac{GM_j}{GM}\left(\frac{a}{r_j}\right)^{n+1}\bar{P}_{nm}(sin\varphi_j)e^{im\lambda_j}, \quad (2)$$

where k_{nm} are the nominal geopotential love numbers with degree n and order m.

(2) Nominal solid tidal effect on height anomaly/geoid height

$$\zeta=\frac{GM}{\gamma r}\sum_{n=2}^{3}\left(\frac{a}{r}\right)^{n}\sum_{m=0}^{n}(1+k_{nm})(\Delta\bar{C}_{nm}cosm\lambda+\Delta\bar{S}_{nm}sinm\lambda)\bar{P}_{nm}. \quad (3)$$

(3) Nominal solid tidal effect on ground gravity⦿

$$g_t=\frac{GM}{r^2}\sum_{n=2}^{3}(n+1)\left(\frac{a}{r}\right)^{n}\sum_{m=0}^{n}\left(1+\frac{2}{n}h_{nm}-\frac{n+1}{n}k_{nm}\right)(\Delta\bar{C}_{nm}cosm\lambda+\Delta\bar{S}_{nm}sinm\lambda)\bar{P}_{nm}, \quad (4)$$

(4) Nominal solid tidal effect on gravity disturbance

$$\delta g=\frac{GM}{r^2}\sum_{n=2}^{3}(n+1)\left(\frac{a}{r}\right)^{n}\sum_{m=0}^{n}(1+k_{nm})(\Delta\bar{C}_{nm}cosm\lambda+\Delta\bar{S}_{nm}sinm\lambda)\bar{P}_{nm}. \quad (5)$$

(5) Nominal solid tidal effects on ground tilt⦿

South: $$\xi^s=\frac{GM}{\gamma r^2}\sin\theta\sum_{n=2}^{3}\left(\frac{a}{r}\right)^{n}\sum_{m=0}^{n}(1+k_{nm}-h_{nm})(\Delta\bar{C}_{nm}cosm\lambda+\Delta\bar{S}_{nm}sinm\lambda)\frac{\partial}{\partial\theta}\bar{P}_{nm}. \quad (6)$$

West: $$\eta^s=\frac{GM}{\gamma r^2\sin\theta}\sum_{n=2}^{3}\left(\frac{a}{r}\right)^{n}\sum_{m=1}^{n}(1+k_{nm}-h_{nm})m(\Delta\bar{C}_{nm}sinm\lambda-\Delta\bar{S}_{nm}cosm\lambda)\bar{P}_{nm}. \quad (7)$$

(6) Nominal solid tidal effects on vertical deflection

South: $$\xi=\frac{GM}{\gamma r^2}\sin\theta\sum_{n=2}^{3}\left(\frac{a}{r}\right)^{n}\sum_{m=0}^{n}(1+k_{nm})(\Delta\bar{C}_{nm}cosm\lambda+\Delta\bar{S}_{nm}sinm\lambda)\frac{\partial}{\partial\theta}\bar{P}_{nm}. \quad (8)$$

West: $$\eta=\frac{GM}{\gamma r^2\sin\theta}\sum_{n=2}^{3}\left(\frac{a}{r}\right)^{n}\sum_{m=1}^{n}(1+k_{nm})m(\Delta\bar{C}_{nm}sinm\lambda-\Delta\bar{S}_{nm}cosm\lambda)\bar{P}_{nm}. \quad (9)$$

(7) Nominal solid tidal effects on ground site displacement⦿

East: $$e=-\frac{GM}{\gamma r^2\sin\theta}\sum_{n=2}^{3}\left(\frac{a}{r}\right)^{n}\sum_{m=0}^{n}l_{nm}m(\Delta\bar{C}_{nm}sinm\lambda-\Delta\bar{S}_{nm}cosm\lambda)\bar{P}_{nm}. \quad (10)$$

North: $$n=-\frac{GM}{\gamma r^2}\sin\theta\sum_{n=2}^{3}\left(\frac{a}{r}\right)^{n}\sum_{m=0}^{n}l_{nm}(\Delta\bar{C}_{nm}cosm\lambda+\Delta\bar{S}_{nm}sinm\lambda)\frac{\partial}{\partial\theta}\bar{P}_{nm}. \quad (11)$$

Radial: $$r=\frac{GM}{\gamma r}\sum_{n=2}^{3}\left(\frac{a}{r}\right)^{n}\sum_{m=0}^{n}h_{nm}(\Delta\bar{C}_{nm}cosm\lambda+\Delta\bar{S}_{nm}sinm\lambda)\bar{P}_{nm}. \quad (12)$$

(8) Nominal solid tidal effect on disturbing gravity gradient

$$T_{nn}=-\frac{GM}{r^3}\sum_{n=2}^{3}(n+1)(n+2)\left(\frac{a}{r}\right)^{n}\sum_{m=0}^{n}(1+k_{nm})(\Delta\bar{C}_{nm}cosm\lambda+\Delta\bar{S}_{nm}sinm\lambda)\bar{P}_{nm}. \quad (13)$$

(9) Nominal solid tidal effect on horizontal gravity gradient

North: $$T_{\varphi\varphi}=-\frac{GM}{r^3}\sum_{n=2}^{3}\left(\frac{a}{r}\right)^{n}\sum_{m=0}^{n}(1+k_{nm})(\Delta\bar{C}_{nm}cosm\lambda+\Delta\bar{S}_{nm}sinm\lambda)\frac{\partial^2}{\partial\theta^2}\bar{P}_{nm}. \quad (14)$$

East: $$T_{\lambda\lambda}=-\frac{GM}{r^3cos^2\varphi}\sum_{n=2}^{3}\left(\frac{a}{r}\right)^{n}\sum_{m=1}^{n}(1+k_{nm})m^2(\Delta\bar{C}_{nm}sinm\lambda+\Delta\bar{S}_{nm}cosm\lambda)\bar{P}_{nm}. \quad (15)$$

The geodetic quantities above marked with ⦿ are valid only when the sites are fixed to the solid Earth. The other geodetic quantities can be on ground or outside the solid Earth.

8.1.3 The frequency dependent corrections to geopotential coefficients

In order to represent the variations of geopotential coefficients caused by the external geopotentials of the anelastic Earth, three forms of the geopotential Love numbers are needed, namely $k_{nm}^{(0)}, k_{nm}^{(\pm)}(n>2)$, and here $k_{2m}^{(-)}=0$ due to the mass conservation of the deformation Earth, as shown in Table 2.

Table 2 The frequency dependent of external potential Love numbers

nm		periods of tidal constituents	Elastic Earth		Anelastic Earth		
n	m		k_{nm}	$k_{nm}^{(+)}$	Re(k_{nm})	Im(k_{nm})	$k_{nm}^{(+)}$
2	0	long period	0.29525	-0.00087	0.30190	-0.00000	-0.00089
2	1	diurnal	0.29470	-0.00079	0.29830	-0.00144	-0.00080
2	2	semi-diurnal	0.29801	-0.00057	0.30102	-0.00130	-0.00057
3	0	long period	0.093	···			
3	1	diurnal	0.093	···			
3	2	semi-diurnal	0.093	···			
3	3	1/3-diurnal	0.094	···			

The viscous nature of the mantle causes a delay in the response of the Earth's external potential, so that the Love number k varies with frequency, and $k_{nm}^{(0)}$ and $k_{2m}^{(+)}$ have small imaginary parts. The following two steps are usually used to deal with the variations of geopotential coefficients caused by additional external geopotentials.

(1) Using of the geopotential Love numbers $k_{2m}^{(+)}, (m = 0,1,2)$ with the frequency dependent, compute the variations of degree 4 geopotential coefficients from the degree 2 geopotential

$$\Delta\bar{C}_{4m} - i\Delta\bar{S}_{4m} = \frac{k_{2m}^{(+)}}{5}\sum_{j=2}^{10}\frac{GM_j}{GM}\left(\frac{a}{r_j}\right)^3\bar{P}_{2m}(sin\varphi_j)e^{im\lambda_j}. \quad (16)$$

(2) Using the frequency dependent corrections $\delta k_{2m}^{(0)} = k_{2m}^{(0)} - k_{2m}$ for degree 2 Love numbers, compute the corrections of degree 2 geopotential coefficients. The corrections involve the contributions of 71 tidal constituents including the long period, diurnal and semi-diurnal tidal constituents to the imaginary parts of the geopotential Love numbers.

8.1.4 The solid Earth tidal effects on ground site displacement

The tidal generating potentials' indirect effects on the site displacement can be quantitatively represented by the displacement Love numbers. For the viscoelastic Earth, the displacement Love numbers depend on both station latitude and tidal frequency. The solid Earth tidal effects on ground site displacement are usually computed in two steps.

(1) Using the Nominal displacement Love numbers $h_{2m}^{(0)}, l_{2m}^{(0)} (m = 0,1,2)$, compute the indirect effects of the degree 2 and 3 tidal generating potentials on site displacement by formula (10) ~ (12).

(2) Considering the deviation between the frequency-dependent degree 2 displacement Love numbers and their nominal value, compute the corrections to results of step 1. The corrections involve the contributions of all tidal constituents to the imaginary parts of the

displacement Love numbers.

8.2 Earth pole shift effects on various geodetic quantities outside solid Earth

The Earth pole shift parameters (m_1, m_2) can be accurately measured by the space geodetic method. In modern geodesy, the pole shift parameters are expressed by the non-tidal variations of geopotential coefficient $(\Delta\bar{C}_{21}, \Delta\bar{S}_{21})$ after removing the effects of the solid Earth tide and load tide.

8.2.1 The pole shift effect on the external geopotential

The pole shift effect on the external geopotential is caused by the centrifugal effect of the pole shift, the pole shift effect is non-tidal. The direct effect ΔV of the pole shift on the external geopotential can be expressed as

$$\Delta V = -\frac{\omega^2 r^2}{2} sin2\theta Re[(m_1 - im_2)(cos\lambda + isin\lambda)], \quad (1)$$

where r, θ, λ are respectively the distance from geocenter, geocentric co-latitude, and longitude of the calculated point, ω is the angular velocity of the Earth's rotation.

The pole shift causes the solid earth to deform, resulting in the additional geopotential, that is, the indirect effect V^a of the pole shift on the external geopotential, which can be quantitatively represented by the degree 2 Love number k_2

$$V^a = k_2 \Delta V = -\frac{\omega^2 r^2}{2} sin2\theta Re[k_2(m_1 - im_2)(cos\lambda + isin\lambda)]. \quad (2)$$

The total effect V_t of the pole shift on the external geopotential is equal to the sum of its direct and indirect effects

$$V_t = (1 + k_2)\Delta V = -\frac{\omega^2 r^2}{2} sin2\theta Re[(1 + k_2)(m_1 - im_2)(cos\lambda + isin\lambda)]$$
$$= -\frac{\omega^2 r^2}{2} sin2\theta Re\{(1 + k_2)[(m_1 cos\lambda + m_2 sin\lambda) + i(m_1 sin\lambda - m_2 cos\lambda)]\}. \quad (3)$$

8.2.2 The pole shift effects on height anomaly/geoid

Given the degree 2 Love numbers, $k_2 = 0.3077 + 0.0036i$, $h_2 = 0.6207$, $l_2 = 0.0836$, the pole shift effects on various physical and geometric geodetic quantities on the ground and outside the solid Earth can be calculated.

$$\zeta_t = \frac{1+k_2}{\gamma}\Delta V = -\frac{\omega^2 r^2}{2\gamma} sin2\theta Re[(1 + k_2)(m_1 cos\lambda + m_2 sin\lambda) + i(m_1 sin\lambda - m_2 cos\lambda)]$$
$$= -\frac{\omega^2 r^2}{2\gamma} sin2\theta Re\{(1.3077 + 0.0036i)[(m_1 cos\lambda + m_2 sin\lambda) + i(m_1 sin\lambda - m_2 cos\lambda)]\}$$
$$= -\frac{\omega^2 r^2}{2\gamma} sin2\theta[(1.3077m_1 + 0.0036m_2)cos\lambda + (1.3077m_2 - 0.0036m_1)sin\lambda], \quad (4)$$

where γ is the normal gravity on the calculated point.

8.2.3 The pole shift effect on ground gravity⦿

$$g_t = -\frac{\left(1+h_2-\frac{3}{2}k_2\right)\partial\Delta V}{\partial r} = \omega^2 r sin2\theta Re\left[\left(1 + h_2 - \frac{3}{2}k_2\right)(m_1 - im_2)(cos\lambda + isin\lambda)\right]$$
$$= \omega^2 r sin2\theta Re\{(1.15915 - 0.0054i)[(m_1 cos\lambda + m_2 sin\lambda) + i(m_1 sin\lambda - m_2 cos\lambda)]\}$$
$$= \omega^2 r sin2\theta[(1.15915m_1 - 0.0054m_2)cos\lambda + (1.15915m_2 + 0.0054m_1)sin\lambda]. \quad (5)$$

8.2.4 The pole shift effect on gravity disturbance

$$\delta g_t = -(1+k_2)\frac{\partial \Delta V}{\partial r} = \omega^2 r sin2\theta Re[(1+k_2)(m_1 - im_2)(cos\lambda + isin\lambda)] = -\frac{2\gamma}{r}\zeta_t$$
$$= \omega^2 r sin2\theta[(1.3077m_1 + 0.0036m_2)cos\lambda + (1.3077m_2 - 0.0036m_1)sin\lambda]. \quad (6)$$

8.2.5 The pole shift effects on ground tilt⦿

South: $\xi_t^s = (1+k_2-h_2)\frac{\partial \Delta V}{\gamma r \partial \theta} = -\frac{\omega^2 r}{\gamma}cos2\theta Re[(1+k_2-h_2)(m_1 - im_2)(cos\lambda + isin\lambda)]$
$$= -\frac{\omega^2 r}{\gamma}cos2\theta[(0.687m_1 + 0.0036m_2)cos\lambda + (0.687m_2 - 0.0036m_1)sin\lambda]. \quad (7)$$

West: $\eta_t^s = (1+k_2-h_2)\frac{\partial \Delta V}{\gamma r sin\theta \partial \lambda} = \frac{\omega^2 r}{\gamma}cos\theta Re[(1+k_2-h_2)(m_1 - im_2)(sin\lambda - icos\lambda)]$
$$= \frac{\omega^2 r}{\gamma}cos\theta Re\{(0.687 + 0.0036i)[(m_1 sin\lambda + m_2 cos\lambda) - i(m_1 cos\lambda + m_2 sin\lambda)]\}$$
$$= \frac{\omega^2 r}{\gamma}cos\theta[(0.687m_1 + 0.0036m_2)sin\lambda + (0.0036m_1 + 0.687m_2)cos\lambda]. \quad (8)$$

8.2.6 The pole shift effects on vertical deflection

South: $\xi_t = \frac{(1+k_2)\partial \Delta V}{\gamma r \partial \theta} = \frac{-\omega^2 r}{\gamma}cos2\theta[(1+k_2)(m_1 - im_2)(cos\lambda + isin\lambda)] = \frac{2\zeta_t}{r}ctg2\theta$. (9)

West: $\eta_t = (1+k_2)\frac{\partial \Delta V}{\gamma r sin\theta \partial \lambda} = \frac{\omega^2 r}{\gamma}cos\theta Re[(1+k_2)(m_1 - im_2)(sin\lambda - icos\lambda)]$
$$= \frac{\omega^2 r}{\gamma}cos\theta[(1.3077m_1 + 0.0036m_2)sin\lambda + (0.0036m_1 + 1.3077m_2)cos\lambda]. \quad (10)$$

8.2.7 The pole shift effects on ground site displacement⦿

East: $e = \frac{l_2 \partial \Delta V}{\gamma sin\theta \partial \lambda} = l_2 \frac{\omega^2 r^2}{\gamma}cos\theta Re[(m_1 - im_2)(sin\lambda - icos\lambda)]$
$$= 0.0836\frac{\omega^2 r^2}{\gamma}cos\theta(m_1 sin\lambda - m_2 cos\lambda). \quad (11)$$

North: $n = -\frac{l_2 \partial \Delta V}{\gamma \partial \theta} = -l_2\frac{\omega^2 r^2}{\gamma}cos2\theta Re[(m_1 - im_2)(cos\lambda + isin\lambda)]$
$$= -0.0836\frac{\omega^2 r^2}{\gamma}cos2\theta(m_1 cos\lambda + m_2 sin\lambda). \quad (12)$$

Radial: $r = \frac{h_2 \Delta V}{\gamma} = -0.6207\frac{\omega^2 r^2}{2\gamma}sin2\theta(m_1 cos\lambda + m_2 sin\lambda)$. (13)

8.2.8 The pole shift effect on disturbing gravity gradient

$$T_{nn} = -\frac{(1+k_2)\partial^2 \Delta V}{\partial r^2} = \omega^2 sin2\theta Re[(1+k_2)(m_1 - im_2)(cos\lambda + isin\lambda)] = \frac{\delta g_t}{r}$$
$$= \omega^2 sin2\theta[(1.3077m_1 + 0.0036m_2)cos\lambda + (1.3077m_2 - 0.0036m_1)sin\lambda]. \quad (14)$$

8.2.9 The pole shift effects on horizontal gravity gradient

North: $T_{\varphi\varphi} = -T_{\theta\theta} = -(1+k_2)\omega^2 sin2\theta[(m_1 - im_2)(cos\lambda + isin\lambda)]$
$$= -\omega^2 sin2\theta[(1.3077m_1 + 0.0036m_2)cos\lambda + (1.3077m_2 - 0.0036m_1)sin\lambda]. \quad (15)$$

East: $T_{\lambda\lambda} = \frac{(1+k_2)\partial^2 \Delta V}{r^2 sin^2\theta \partial \lambda^2} = (1+k_2)\omega^2 ctg\theta[(m_1 - im_2)(cos\lambda + isin\lambda)]$
$$= 2T_{nn}cos^2\theta = -2T_{\varphi\varphi}cos^2\theta = 2\frac{\delta g_t}{r}cos^2\theta. \quad (16)$$

The geodetic quantities above marked with ⦿ are valid only when the sites are fixed to the solid Earth. The other geodetic quantities can be on the ground or outside the solid Earth.

The pole shift is the polar location shift of the instantaneous relative to a certain reference epoch (such as the epoch J2000.0) after removing all the solid Earth tidal and loading tidal effects. Both the pole shift and geocentric movement do not include various tidal effects. Non-tidal effects are difficult to be modeled and are generally measured using geodetic techniques. In most fast or real-time geodetic applications, short-time forecast estimations are adopted.

The Earth orientation parameters product EOP_C04 recommended by the IERS Conventions (2010), has not removed the annual and semi-annual tidal effects of the atmospheric load. Therefore, the Earth pole shift parameters (m_1, m_2) calculated by the product EOP_C04 obviously contain annual and semi-annual components.

8.3 Spherical harmonic synthesis on load deformation field

8.3.1 The surface loads and the effects on geopotential coefficients

In the Earth surface system, surface non-tidal load variations such as soil and vegetation water, lake water, glacier and snow, groundwater, atmosphere, and sea level variations can be uniformly expressed by variations of the surface equivalent water height. The equivalent water height variation h_w at the surface point (R, θ, λ) can be expressed as a load normalized spherical harmonic series

$$h_w(R, \theta, \lambda) = R \sum_{n=1}^{\infty} \sum_{m=0}^{n} [\Delta C_{nm}^{w} cosm\lambda + \Delta S_{nm}^{w} sinm\lambda] \bar{P}_{nm}(cos\theta), \quad (1)$$

where R is the mean radius of the Earth, $\Delta C_{nm}^{w}, \Delta S_{nm}^{w}$ are the load normalized spherical harmonic coefficients with degree n and order m, $\bar{P}_{nm}(t = cos\theta) = \bar{P}_{nm}$ are the normalized associated Legendre functions with degree n and order m.

The variations of global surface equivalent water height directly cause the variations of the surface geopotential

$$\Phi^{d}(R, \theta, \lambda) = \sum_{n=1}^{\infty} \frac{4\pi G \rho_w R^2}{2n+1} \sum_{m=0}^{n} [\Delta C_{nm}^{w} cosm\lambda + \Delta S_{nm}^{w} sinm\lambda] \bar{P}_{nm}, \quad (2)$$

where G is the Newtonian gravitational constant, ρ_w is the density of the water.

According to the theory of the earth's gravity field, the variations of the surface geopotential Φ^{d} can also be expressed by the variations of the geopotential coefficients $(\Delta\bar{C}_{nm}, \Delta\bar{S}_{nm})$ as

$$\Phi^{d} = \frac{GM}{R} \sum_{n=1}^{\infty} \sum_{m=0}^{\infty} (\Delta\bar{C}_{nm} cosm\lambda + \Delta\bar{S}_{nm} sinm\lambda) \bar{P}_{nm}(cos\theta). \quad (3)$$

Comparing the formulas (2) and (3), we have

$$\Delta\bar{C}_{nm} = \frac{4\pi R^3}{M} \frac{\rho_w}{2n+1} \Delta C_{nm}^{w} = \frac{4\pi R^3}{\rho_e V} \frac{\rho_w}{2n+1} \Delta C_{nm}^{w} = \frac{4\pi R^3}{4\pi R^3 \rho_e/3} \frac{\rho_w}{2n+1} \Delta C_{nm}^{w} = \frac{3}{2n+1} \frac{\rho_w}{\rho_e} \Delta C_{nm}^{w},$$

similarly, we have $\Delta\bar{S}_{nm} = \frac{3}{2n+1} \frac{\rho_w}{\rho_e} \Delta S_{nm}^{w}$. (4)

Where ρ_e, M, V are the mean density, total mass, and total volume of the Earth, respectively.

The surface load effects on various geodetic quantities on the ground or outside the solid Earth can also be expressed by the variations of the geopotential coefficients $(\Delta\bar{C}_{nm}, \Delta\bar{S}_{nm})$.

8.3.2 The surface load effect on height anomaly/geoid

$$\zeta = \frac{GM}{\gamma r} \sum_{n=2}^{\infty} \left(\frac{a}{r}\right)^{n} (1 + k_n') \sum_{m=0}^{n} (\Delta\bar{C}_{nm} cosm\lambda + \Delta\bar{S}_{nm} sinm\lambda) \bar{P}_{nm}. \quad (5)$$

8.3.3 The surface load effect on ground gravity⦿

$$g_t = \frac{GM}{r^2}\sum_{n=2}^{\infty}(n+1)\left(1+\frac{2}{n}h'_n-\frac{n+1}{n}k'_n\right)\left(\frac{a}{r}\right)^n\sum_{m=0}^{n}(\Delta\bar{C}_{nm}cosm\lambda+\Delta\bar{S}_{nm}sinm\lambda)\bar{P}_{nm}. \quad (6)$$

8.3.4 The surface load effect on gravity disturbance

$$\delta g = \frac{GM}{r^2}\sum_{n=2}^{\infty}(n+1)(1+k'_n)\left(\frac{a}{r}\right)^n\sum_{m=0}^{n}(\Delta\bar{C}_{nm}cosm\lambda+\Delta\bar{S}_{nm}sinm\lambda)\bar{P}_{nm}. \quad (7)$$

8.3.5 The surface load effects on ground tilt⦿

South: $$\xi^s = \frac{GM}{\gamma r^2}\sin\theta\sum_{n=2}^{\infty}(1+k'_n-h'_n)\left(\frac{a}{r}\right)^n\sum_{m=0}^{n}(\Delta\bar{C}_{nm}cosm\lambda+\Delta\bar{S}_{nm}sinm\lambda)\frac{\partial}{\partial\theta}\bar{P}_{nm}. \quad (8)$$

West: $$\eta^s = \frac{GM}{\gamma r^2\sin\theta}\sum_{n=2}^{\infty}(1+k'_n-h'_n)\left(\frac{a}{r}\right)^n\sum_{m=1}^{n}m(\Delta\bar{C}_{nm}sinm\lambda-\Delta\bar{S}_{nm}cosm\lambda)\bar{P}_{nm}. \quad (9)$$

8.3.6 The surface load effects on vertical deflection

South: $$\xi = \frac{GM}{\gamma r^2}\sin\theta\sum_{n=2}^{\infty}(1+k'_n)\left(\frac{a}{r}\right)^n\sum_{m=0}^{n}(\Delta\bar{C}_{nm}cosm\lambda+\Delta\bar{S}_{nm}sinm\lambda)\frac{\partial}{\partial\theta}\bar{P}_{nm}. \quad (10)$$

West: $$\eta = \frac{GM}{\gamma r^2\sin\theta}\sum_{n=2}^{\infty}(1+k'_n)\left(\frac{a}{r}\right)^n\sum_{m=1}^{n}m(\Delta\bar{C}_{nm}sinm\lambda-\Delta\bar{S}_{nm}cosm\lambda)\bar{P}_{nm}. \quad (11)$$

8.3.7 The surface load effects on ground site displacement⦿

East: $$e = -\frac{GM}{\gamma r^2\sin\theta}\sum_{n=2}^{\infty}l'_n\left(\frac{a}{r}\right)^n\sum_{m=1}^{n}m(\Delta\bar{C}_{nm}sinm\lambda-\Delta\bar{S}_{nm}cosm\lambda)\bar{P}_{nm}. \quad (12)$$

North: $$n = -\frac{GM}{\gamma r^2}\sin\theta\sum_{n=2}^{\infty}l'_n\left(\frac{a}{r}\right)^n\sum_{m=0}^{n}(\Delta\bar{C}_{nm}cosm\lambda+\Delta\bar{S}_{nm}sinm\lambda)\frac{\partial}{\partial\theta}\bar{P}_{nm}. \quad (13)$$

Radial: $$r = \frac{GM}{\gamma r}\sum_{n=2}^{\infty}\left(\frac{a}{r}\right)^n h'_n\sum_{m=0}^{n}(\Delta\bar{C}_{nm}cosm\lambda+\Delta\bar{S}_{nm}sinm\lambda)\bar{P}_{nm}. \quad (14)$$

8.3.8 The surface load effect on disturbing gravity gradient

$$T_{nn} = -\frac{GM}{r^3}\sum_{n=2}^{\infty}(n+1)(n+2)(1+k'_n)\left(\frac{a}{r}\right)^n \sum_{m=0}^{n}(\Delta\bar{C}_{nm}cosm\lambda+\Delta\bar{S}_{nm}sinm\lambda)\bar{P}_{nm}. \quad (15)$$

8.3.9 The surface load effects on horizontal gravity gradient

North: $$T_{\varphi\varphi} = -\frac{GM}{r^3}\sum_{n=2}^{\infty}(1+k'_n)\left(\frac{a}{r}\right)^n \sum_{m=0}^{n}(\Delta\bar{C}_{nm}cosm\lambda+\Delta\bar{S}_{nm}sinm\lambda)\frac{\partial^2}{\partial\theta^2}\bar{P}_{nm}. \quad (16)$$

East: $$T_{\lambda\lambda} = -\frac{GM}{r^3\cos^2\varphi}\sum_{n=2}^{\infty}(1+k'_n)\left(\frac{a}{r}\right)^n \sum_{m=1}^{n}(1+k_{nm})m^2(\Delta\bar{C}_{nm}sinm\lambda+\Delta\bar{S}_{nm}cosm\lambda)\bar{P}_{nm}. \quad (17)$$

The geodetic quantities above marked with ⦿ are valid only when the sites are fixed to the solid Earth. The other geodetic quantities can be on the ground or outside the solid Earth.

In the Formulas (5) ~ (17), h'_n , l'_n, k'_n are the radial displacement, horizontal displacement and geopotential load Love numbers, respectively.

8.4 Surface load effects on various geodetic quantities by Green's Integral

8.4.1 The Integral formulas of the direct effects of surface loads

(1) The integral formula of the direct effect on geopotential of surface loads

Given the surface load equivalent water heights h_w, whose direct effect V_w on the geopotential near Earth space directly given by the universal gravitation formula

$$V_w = G\rho_w \int_S \frac{h_w}{L} dS, \quad L = \sqrt{r^2 + r'^2 - 2rr'cos\psi}, \tag{1}$$

where L is the spatial distance between the calculated point (r, θ, λ) near Earth space and the center (r', θ', λ') of integral area element on the surface, r, θ, λ are the spherical geocentric coordinates of the calculated point, namely distance from geocenter, co-latitude and longitude, respectively. G is Newton's gravitational constant, $\rho_w = 1000kg/m^3$ is the water density. ψ is the spherical angle between the calculated point (r, θ, λ) and the center (r', θ', λ') of the area element.

$$cos\psi = cos\theta cos\theta' + sin\theta sin\theta' cos(\lambda' - \lambda), \quad sin\psi = sin\theta cos\theta' + cos\theta sin\theta' cos(\lambda' - \lambda), \tag{2}$$

$$sin\psi cos\alpha = sin\theta cos\theta' - cos\theta sin\theta' cos(\lambda' - \lambda), \quad sin\psi sin\alpha = sin\theta' sin(\lambda' - \lambda), \tag{3}$$

$$\frac{\partial\psi}{\partial\theta} = -\frac{\partial\psi}{\partial\varphi} = cos\alpha, \quad \frac{\partial\psi}{\partial\lambda} = -sin\alpha sin\theta. \tag{4}$$

When the calculated point is located on the surface and overlaps with the center of integral area element, we have

$$L = r\psi, \quad r - r'cos\psi = r\psi^2/2, \tag{5}$$

$$A = dS = r^2 \int_{\alpha=0}^{2\pi} \int_0^{\psi_0} \psi d\psi d\alpha = \pi r^2 \psi_0^2 \to \psi_0 = \frac{1}{r}\sqrt{\frac{A}{\pi}}, \tag{6}$$

here $A = dS$ is the area of integral area element. In this case, the formula (1) on the calculated point is an integral singularity

$$V_0 = G\rho_w r^2 \int_{\alpha=0}^{2\pi} \int_0^{\psi_0} \frac{h_w}{r\psi} \psi d\psi d\alpha = 2\pi G\rho_w h_w r\psi_0. \tag{7}$$

(2) The integral formula of the direct effect on gravity disturbance of surface loads

According to the definition of gravity disturbance, we have

$$\delta g = -\frac{\partial V_w}{\partial r} = -G\rho_w \int_S h_w \frac{\partial}{\partial r}\left(\frac{1}{L}\right) dS = G\rho_w \int_S h_w \frac{r - r'cos\psi}{L^3} dS. \tag{8}$$

When the calculated point is located on the surface and overlaps with the center of integral area element, the formula (8) on the calculated point is an integral singularity

$$\delta g_0 = 2\pi G\rho_w h_w \int_0^{\psi_0} \frac{\psi^2/2}{\psi^3} \psi d\psi = \pi G\rho_w h_w \psi_0. \tag{9}$$

(3) The integral formula of the direct effect on vertical deflection of surface loads

$$\Theta = \frac{1}{\gamma r}\frac{\partial V_w}{\partial \psi} = \frac{G\rho_w}{\gamma r}\int_S h_w \frac{\partial}{\partial\psi}\left(\frac{1}{L}\right) dS = -\frac{G\rho_w}{\gamma}\int_S h_w r' \frac{sin\psi}{L^3} dS, \tag{10}$$

$$\xi = \Theta\frac{\partial\psi}{\partial\theta} = -\frac{G\rho_w}{\gamma}\int_S h_w r' \frac{sin\psi}{L^3} cos\alpha dS, \quad \eta = -\Theta\frac{\partial\psi}{\partial\lambda} = -\frac{G\rho_w}{\gamma} sin\theta \int_S h_w r' \frac{sin\psi}{L^3} sin\alpha dS. \tag{11}$$

Where γ is the normal gravity on the calculated point.

(4) The integral formula of the direct effect on disturbing gravity gradient of surface loads

According to the definition of disturbing gravity gradient, we have

$$T_{nn} = -T_{rr} = -\frac{\partial^2 V_w}{\partial r^2} = G\rho_w \int_S h_w \frac{\partial}{\partial r}\left(\frac{r - r'cos\psi}{L^3}\right) dS = G\rho_w \int_S h_w \left[\frac{1}{L^3} - \frac{3(r - r'cos\psi)^2}{L^5}\right] dS, \tag{12}$$

$$\frac{\partial}{\partial r}\left(\frac{r - r'cos\psi}{L^3}\right) = \frac{1}{L^3} - \frac{3(r - r'cos\psi)}{L^4}\frac{\partial}{\partial r}L = \frac{1}{L^3} - \frac{3(r - r'cos\psi)^2}{L^5}, \quad \frac{\partial}{\partial r}L = \frac{r - r'cos\psi}{L}.$$

When the calculated point is located on the surface and overlaps with the center of integral area element, the formula (12) on the calculated point is an integral singularity

$$T_{nn}^{0} = 2\pi G\rho_w h_w r^2 \int_0^{\psi_0}\left(\frac{1}{r^3\psi^3}-\frac{3\psi^4}{4r^3\psi^5}\right)\psi d\psi = \frac{2\pi G\rho_w h_w}{r}\int_0^{\psi_0}\left(\frac{1}{\psi^2}-\frac{3}{4}\right)d\psi \approx -\frac{\pi G\rho_w h_w}{r\psi_0^2}.(?)(13)$$

(5) The integral formula of the direct effect on horizontal gravity gradient of surface loads

$$\Gamma = \frac{\partial^2 V_w}{r^2\partial\psi^2} = -\frac{G\rho_w}{r}\int_S h_w r' \frac{\partial}{\partial\psi}\left(\frac{sin\psi}{L^3}\right)dS = -\frac{G\rho_w}{r}\int_S h_w r'\left(\frac{cos\psi}{L^3}-\frac{3rr'sin^2\psi}{L^5}\right)dS, \quad (14)$$

$$T_{\varphi\varphi} = -\Gamma\frac{\partial^2\psi}{\partial\theta^2} = \frac{G\rho_w}{r}\int_S h_w r'\left(\frac{cos\psi}{L^3}-\frac{3rr'sin^2\psi}{L^5}\right)ctg\psi(1-cos\alpha)dS, \quad (15)$$

$$T_{\lambda\lambda} = \Gamma\frac{\partial^2\psi}{\partial\lambda^2} = \frac{G\rho_w}{r}\int_S h_w r'\left(\frac{cos\psi}{L^3}-\frac{3rr'sin^2\psi}{L^5}\right)\left[ctg\psi - ctg\psi(sin\theta sin\alpha)^2 - \frac{cos\theta cos\theta'}{sin\psi}\right]dS, \quad (16)$$

$$\frac{\partial^2\psi}{\partial\theta^2} = \frac{\partial}{\partial\theta}cos\alpha = \frac{\partial}{\partial\theta}\frac{sin\theta cos\theta' - cos\theta sin\theta' cos(\lambda'-\lambda)}{sin\psi} = ctg\psi(1-cos^2\alpha), \quad (17)$$

$$\frac{\partial^2\psi}{\partial\lambda^2} = -sin\theta\frac{\partial}{\partial\lambda}sin\alpha = -sin\theta sin\theta'\frac{\partial}{\partial\lambda}\frac{sin(\lambda'-\lambda)}{sin\psi} = sin\theta sin\theta'\left[\frac{cos(\lambda'-\lambda)}{sin\psi}-\frac{sin(\lambda'-\lambda)cos\psi}{sin^2\psi}sin\alpha sin\theta\right]$$

$$= \frac{cos\psi - cos\theta cos\theta'}{sin\psi} - \frac{cos\psi}{sin\psi}(sin\theta sin\alpha)^2 = (1-sin^2\theta sin^2\alpha)ctg\psi - \frac{cos\theta cos\theta'}{sin\psi}. \quad (18)$$

8.4.2 Green's functions formula of the indirect effects of surface loads

The effects of unit point-mass load $q_w = \rho_w h_w$ (kg/m^2) on various ground geodetic quantities can be expressed by load Green's function. Let $t = cos\psi$, k'_n, h'_n, l'_n represent the load love numbers of geopotential, ground radial displacement, and horizontal displacement, respectively. The Green's functions algorithm formula of the load indirect effects on various ground geodetic quantities are given in following.

(1) Green's function of the indirect effect on ground geopotential / height anomaly (G_i^V/G_i^ζ)

$$G_i^V(\psi) = \gamma G_i^\zeta(\psi) = \frac{a\gamma}{M}\frac{k'_\infty}{2sin\frac{\psi}{2}} + \frac{a\gamma}{M}\sum_{n=0}^{\infty}(k'_n - k'_\infty)P_n(t), \quad (19)$$

where M is the total mass of the Earth, a is the Equatorial radius of the Earth, and $P_n(t)$ is n degree Legendre function with t as its independent variable.

(2) Green's function of the indirect effect on ground gravity

$$G_i^g(\psi) = -\frac{\gamma}{M}\frac{k'_\infty - 2h'_\infty}{2sin\frac{\psi}{2}} - \frac{\gamma}{M}\sum_{n=0}^{\infty}[(n+1)k'_n - k'_\infty - 2(h'_n - h'_\infty)]P_n(t). \quad (20)$$

(3) Green's function of the indirect effect on gravity disturbance

$$G_i^{\delta g}(\psi) = -\frac{\gamma}{M}\frac{k'_\infty}{2sin\frac{\psi}{2}} - \frac{\gamma}{M}\sum_{n=0}^{\infty}[(n+1)k'_n - k'_\infty]P_n(t). \quad (21)$$

(4) Green's function of the indirect effect on ground tilt

$$G_i^t(\psi) = -\frac{1}{M}\frac{h'_\infty cos\frac{\psi}{2}}{4sin^2\frac{\psi}{2}} + \frac{1}{M}\frac{k'_\infty cos\frac{\psi}{2}\left(1+2sin\frac{\psi}{2}\right)}{2sin\frac{\psi}{2}\left(1+sin\frac{\psi}{2}\right)} - \frac{1}{M}\sum_{n=1}^{\infty}\left(k'_n - \frac{k'_\infty}{n} - h'_n + h'_\infty\right)\frac{\partial P_n(t)}{\partial\psi}. \quad (22)$$

(5) Green's function of the indirect effect on vertical deflection

$$G_i^\Theta(\psi) = \frac{1}{M}\frac{k'_\infty cos\frac{\psi}{2}\left(1+2sin\frac{\psi}{2}\right)}{2sin\frac{\psi}{2}\left(1+sin\frac{\psi}{2}\right)} - \frac{1}{M}\sum_{n=1}^{\infty}\left(k'_n - \frac{k'_\infty}{n}\right)\frac{\partial P_n(t)}{\partial\psi}. \quad (23)$$

(6) Green's function of the indirect effect on ground horizontal displacement

$$G^l(\psi) = -\frac{a}{M}\frac{l'_\infty cos\frac{\psi}{2}\left(1+2sin\frac{\psi}{2}\right)}{2sin\frac{\psi}{2}\left(1+sin\frac{\psi}{2}\right)} + \frac{a}{M}\sum_{n=1}^{\infty}\left(l'_n - \frac{l'_\infty}{n}\right)\frac{\partial P_n(t)}{\partial\psi}. \quad (24)$$

(7) Green's function of the indirect effect on ground radial displacement

$$G^r(\psi) = \frac{a}{M}\frac{h'_\infty}{2sin\frac{\psi}{2}} + \frac{a}{M}\sum_{n=0}^{\infty}(h'_n - h'_\infty)P_n(t). \quad (25)$$

(8) Green's function of the indirect effect on disturbing gravity gradient

$$G^{T_{nn}}(\psi)=-\frac{\gamma}{aM}\sum_{n=0}^{\infty}(n+1)(n+2)k_n'P_n(t) \tag{26}$$

(9) Green's function of the indirect effect on horizontal gravity gradient

$$G_i^{T_{ss}}(\psi)=\frac{\gamma}{aM}\sum_{n=0}^{\infty}k_n'\frac{\partial^2P_n(t)}{\partial\psi^2}. \tag{27}$$

Let $\mathcal{G}_i(l)=2a\sin\frac{\psi}{2}G_i(\psi)=lG_i(\psi)$, then after substituting the load Love numbers into the formula (19) ~ (27), obtain the Green's function values, such as table 1.

Table 1 Green's function values of the indirect effects of surface loads

l(km)	$\mathcal{G}_i^{\zeta}\times10^{-13}$	$\mathcal{G}_i^{g}\times10^{-17}$	$\mathcal{G}_i^{\delta g}\times10^{-18}$	$\mathcal{G}_i^{t}\times10^{-14}$	$\mathcal{G}_i^{\Theta}\times10^{-19}$	$\mathcal{G}^{l}\times10^{-12}$	$\mathcal{G}^{r}\times10^{-11}$	$\mathcal{G}_i^{nn}\times10^{-15}$	$\mathcal{G}_i^{ss}\times10^{-15}$
0.1	-0.0249	-11.3315	15.8795	42.2955	-2.1192	-0.8369	-42.1264	40.7525	20.0337
0.2	-0.0439	-9.8972	29.6981	21.1510	-8.0632	-3.1842	-41.9553	73.6102	34.1831
0.3	-0.0625	-8.8334	39.7946	14.1058	-16.6878	-6.5901	-41.7788	92.3770	37.9744
0.4	-0.0804	-8.2348	45.2182	10.5853	-26.3601	-10.4097	-41.5956	93.8712	29.4189
0.5	-0.0975	-8.1095	45.8894	8.4739	-35.3064	-13.9425	-41.4057	78.5612	9.4993
0.6	-0.1139	-8.3807	42.5773	7.0657	-41.9834	-16.5790	-41.2101	50.3867	-18.0490
0.7	-0.1294	-8.9073	36.7009	6.0583	-45.3905	-17.9241	-41.0109	15.8142	-47.6055
0.8	-0.1444	-9.5157	30.0034	5.3006	-45.2558	-17.8704	-40.8109	-17.6468	-72.9744
1.0	-0.1727	-10.3454	20.4992	4.2343	-36.8762	-14.5596	-40.4173	-55.8494	-91.9157
1.2	-0.1998	-10.1321	21.4749	3.5210	-26.2416	-10.3574	-40.0402	-39.6641	-61.0517
1.4	-0.2261	-9.1669	30.0077	3.0153	-22.8895	-9.0304	-39.6752	8.4433	-7.5471
1.6	-0.2518	-8.3519	37.0350	2.6419	-28.6871	-11.3158	-39.3091	42.4515	24.9158
2.0	-0.3003	-8.9633	28.5858	2.1198	-40.5309	-15.9830	-38.5476	-4.3817	-24.2022
2.5	-0.3570	-9.1242	24.1119	1.6843	-25.9871	-10.2232	-37.6133	-17.0612	-27.2278
3.0	-0.4112	-7.9718	32.8632	1.4080	-35.2424	-13.8576	-36.7093	28.7167	17.2271
3.5	-0.4621	-8.9437	20.3140	1.2022	-32.5321	-12.7629	-35.7866	-31.1746	-40.2655
4.0	-0.5112	-7.7218	29.8481	1.0465	-28.2814	-11.0562	-34.9109	22.8507	15.9355
5.0	-0.6036	-7.8959	22.7679	0.8291	-26.3578	-10.2305	-33.1702	-5.9459	-11.1019
6.0	-0.6903	-7.8527	18.1028	0.6858	-29.9324	-11.5649	-31.5082	-23.6048	-28.4842
7.0	-0.7725	-7.2943	18.8748	0.5827	-33.7803	-12.9988	-29.9389	-13.5281	-18.2480
8.0	-0.8510	-6.5206	22.0921	0.5013	-33.1161	-12.6452	-28.4652	9.3638	5.3150
10.0	-0.9991	-6.0125	18.9937	0.3784	-24.7530	-9.1540	-25.7982	5.3162	2.8950
12.0	-1.1387	-5.9045	13.1167	0.2999	-27.9718	-10.2454	-23.5296	-16.1892	-18.4692

14.0	-1.2726	-4.9048	17.3988	0.2398	-26.5722	-9.5373	-21.6664	13.0654	11.2087
16.0	-1.4019	-4.8896	12.8941	0.1911	-21.0009	-7.2164	-20.1480	-4.3047	-5.5888
20.0	-1.6520	-4.0437	14.8205	0.1306	-20.9145	-7.0582	-18.0179	12.2601	11.2369
25.0	-1.9534	-3.6904	13.7959	0.0872	-19.8016	-6.6584	-16.5317	10.0949	9.3198
30.0	-2.2455	-3.5544	12.9067	0.0638	-18.9897	-6.5141	-15.7982	5.5325	4.9129
35.0	-2.5296	-3.5250	12.0811	0.0505	-18.1729	-6.4230	-15.4331	0.0753	-0.4331
40.0	-2.8059	-3.5272	11.4345	0.0423	-17.1945	-6.2698	-15.2297	-4.7358	-5.1568
50.0	-3.3365	-3.4643	11.2395	0.0322	-14.9772	-5.7725	-14.9607	-8.1685	-8.4622
60.0	-3.8395	-3.2518	12.5464	0.0262	-13.6029	-5.4612	-14.6941	-2.7549	-2.9775
70.0	-4.3177	-3.0073	14.0654	0.0229	-13.9783	-5.7205	-14.3923	4.6469	4.4506
80.0	-4.7741	-2.8804	14.3310	0.0210	-15.3999	-6.3101	-14.0649	6.2127	6.0235
100.0	-5.6311	-2.9117	11.9306	0.0171	-15.7804	-6.3810	-13.3843	-4.6763	-4.8316
120.0	-6.4270	-2.6545	12.4755	0.0129	-14.0249	-5.5346	-12.7235	0.1761	0.0607
140.0	-7.1738	-2.4359	12.7461	0.0120	-15.5946	-5.9880	-12.0989	3.7448	3.6348
160.0	-7.8804	-2.4586	10.7233	0.0100	-14.9953	-5.5941	-11.5133	-4.4893	-4.5820
180.0	-8.5536	-2.2087	11.5710	0.0080	-13.8312	-4.9933	-10.9748	1.9062	1.8299
200.0	-9.1986	-2.0952	11.1758	0.0080	-15.1075	-5.3733	-10.4758	1.7439	1.6689
250.0	-10.7136	-1.8097	10.7082	0.0058	-14.0435	-4.7072	-9.3924	3.2869	3.2307
300.0	-12.1238	-1.5962	10.1419	0.0042	-12.9077	-4.0819	-8.5118	3.2916	3.2481
350.0	-13.4587	-1.4397	9.5227	0.0030	-11.9089	-3.5581	-7.7994	2.1184	2.0836
400.0	-14.7375	-1.3210	8.9521	0.0023	-11.1503	-3.1625	-7.2265	0.4258	0.3969
500.0	-17.1749	-1.1331	8.3207	0.0016	-10.3019	-2.7029	-6.4078	-2.1612	-2.1831
600.0	-19.4980	-0.9603	8.5053	0.0014	-9.8691	-2.4641	-5.9044	-2.3040	-2.3219
800.0	-23.8986	-0.6720	9.9646	0.0010	-9.0007	-2.0628	-5.4405	0.1041	0.0908

8.4.3 Legendre function and its first and second derivatives to ψ

Let $t = \cos\psi, \quad u = \sin\psi,$ (26)

$P_n(t) = \frac{2n-1}{n} t P_{n-1}(t) - \frac{n-1}{n} P_{n-2}(t),$ (27)

$P_1 = t, \quad P_2 = \frac{1}{2}(3t^2 - 1).$ (28)

$\frac{\partial}{\partial\psi} P_n(t) = \frac{2n-1}{n} t \frac{\partial}{\partial\psi} P_{n-1}(t) - \frac{2n-1}{n} u P_{n-1}(t) - \frac{n-1}{n} \frac{\partial}{\partial\psi} P_{n-2}(t).$ (29)

$\frac{\partial}{\partial\psi} P_1(t) = -u, \quad \frac{\partial}{\partial\psi} P_2(t) = -3ut.$ (30)

$$\frac{\partial^2}{\partial\psi^2}P_n(t)=\frac{2n-1}{n}\left(t\frac{\partial^2}{\partial\psi^2}P_{n-1}-2u\frac{\partial}{\partial\psi}P_{n-1}-tP_{n-1}\right)-\frac{n-1}{n}\frac{\partial^2}{\partial\psi^2}P_{n-2}, \quad (31)$$

$$\frac{\partial^2}{\partial\psi^2}P_1(t)=-t,\quad \frac{\partial^2}{\partial\psi^2}P_2(t)=3(1-2t^2). \quad (32)$$

8.5 Algorithms for global tidal load spherical harmonic coefficients model

8.5.1 Construction of tidal load spherical harmonic coefficients model

General procedure of construction of the global ocean tidal load normalized spherical harmonic coefficients model (in FES2004 format) from global ocean tidal height harmonic parameters grids are:

(1) From the global ocean tidal harmonic parameters grid model of each tidal constituent, generate the normalized spherical harmonic coefficients model of each tidal constituent by spherical harmonic analysis method.

(2) According to the astronomical tide height algorithm, convert the normalized spherical harmonic coefficients based on the harmonic parameters of the tidal constituent into the normalized spherical harmonic coefficient based on the tidal load of the tidal constituent.

(3) Merging the global tidal load normalized spherical harmonic coefficients of all tidal constituents, generate the global ocean tide load normalized spherical harmonic coefficients model in FES2004 format.

Astronomical tidal height $T(t)$, expressed as the height of the astronomical tidal level relative to the local long-term mean sea surface, is equal to the sum of M tidal constituent heights

$$T(\varphi,\lambda,t)=\sum_{i=1}^{M}T_i(\varphi,\lambda,t)=\sum_{i=1}^{M}H_i(\varphi,\lambda)cos[\theta_i(t)-g_i(\varphi,\lambda)], \quad (1)$$

where M is the number of the ocean tidal constituents, θ_i,H_i,g_i are respectively the astronomical argument, the amplitude and the phase of the tidal constituent i.

The astronomical tide height T_i of the tidal constituent i can be expanded as

$$\begin{aligned}T_i(\varphi,\lambda,t)&=H_i(\varphi,\lambda)cosg_i(\varphi,\lambda)cos\theta_i(t)+H_i(\varphi,\lambda)sing_i(\varphi,\lambda)sin\theta_i(t)\\&=H_i^+(\varphi,\lambda)cos\theta_i(t)+H_i^-(\varphi,\lambda)sin\theta_i(t)=H_i^+cos\theta_i+H_i^-sin\theta_i. \quad (2)\end{aligned}$$

Through the spherical harmonic analysis, the tidal height T_i of the tidal constituent i can be also expressed as the normalized spherical harmonic series

$$T_i(\varphi,\lambda,t)=\sum_{n=1}^{N}\sum_{m=0}^{n}\bar{P}_{nm}(sin\varphi)\left[T_{i,nm}^+(\lambda,t)+T_{i,nm}^-(\lambda,t)\right], \quad (3)$$

where $T_{i,nm}^+(\lambda,t)=\bar{C}_{i,nm}^+cos(\theta_i+m\lambda)+\bar{S}_{i,nm}^+sin(\theta_i+m\lambda)$, (4)

$$T_{i,nm}^-(\lambda,t)=\bar{C}_{i,nm}^-cos(\theta_i-m\lambda)+\bar{S}_{i,nm}^-sin(\theta_i-m\lambda). \quad (5)$$

Expand the trigonometric functions in the formulas (4) and (5), we have

$$\begin{aligned}T_{i,nm}^+(\lambda,t)&=\bar{C}^+[cos\theta_icosm\lambda-sin\theta_isinm\lambda]+\bar{S}^+[sin\theta_icosm\lambda+cos\theta_isinm\lambda]\\&=[\bar{C}^+cosm\lambda+\bar{S}^+sinm\lambda]cos\theta_i+[-\bar{C}^+sinm\lambda+\bar{S}^+cosm\lambda]sin\theta_i, \quad (6)\end{aligned}$$

$$\begin{aligned}T_{i,nm}^-(\lambda,t)&=\bar{C}^-[cos\theta_icosm\lambda+sin\theta_isinm\lambda]+\bar{S}^-[sin\theta_icosm\lambda-cos\theta_isinm\lambda]\\&=[\bar{C}^-cosm\lambda-\bar{S}^-sinm\lambda]cos\theta_i+[\bar{C}^-sinm\lambda+\bar{S}^-cosm\lambda]sin\theta_i. \quad (7)\end{aligned}$$

Comparing the formula (2) and formula (3), for the tidal constituent i, (any tidal constituent number i is omitted below), we have

$$H^{+} = \sum_{n=1}^{N}\sum_{m=0}^{n}\bar{P}_{nm}\left(\bar{C}^{+}cosm\lambda + \bar{S}^{+}sinm\lambda + \bar{C}^{-}cosm\lambda + \bar{S}^{-}sinm\lambda\right), \quad (8)$$

$$H^{-} = \sum_{n=1}^{N}\sum_{m=0}^{n}\bar{P}_{nm}\left(-\bar{C}^{+}sinm\lambda + \bar{S}^{+}cosm\lambda + \bar{C}^{-}sinm\lambda + \bar{S}^{-}cosm\lambda\right), \quad (9)$$

$$H^{+} = \sum_{n=1}^{N}\sum_{m=0}^{n}\bar{P}_{nm}\left[(\bar{C}^{+} + \bar{C}^{-})cosm\lambda + (\bar{S}^{+} - \bar{S}^{-})sinm\lambda\right], \quad (10)$$

$$H^{-} = \sum_{n=1}^{N}\sum_{m=0}^{n}\bar{P}_{nm}\left[(\bar{S}^{+} + \bar{S}^{-})cosm\lambda + (-\bar{C}^{+} + \bar{C}^{-})sinm\lambda\right], \quad (11)$$

$$\bar{C}^{+} = \hat{C}^{+}sin\varepsilon^{+},\quad \bar{C}^{-} = \hat{C}^{-}sin\varepsilon^{-},\quad \bar{S}^{+} = \hat{C}^{+}cos\varepsilon^{+}, \bar{S}^{-} = \hat{C}^{-}cos\varepsilon^{-}\ . \quad (12)$$

Similarly, from the global surface air pressure tidal harmonic parameter grid models, can construct the surface air pressure tidal load spherical harmonic coefficients model by the spherical harmonic analysis. The 360-degree surface air pressure tidal load spherical harmonic coefficients model ECMWF2006.dat in ETideLoad4.0 were constructed according to the process above from the 0.5°× 0.5° global harmonic parameter grids of the four atmospheric pressure tidal constituents (S_1, S_2, Ss_a, Sa).

8.5.2 Ocean tidal load effects on geopotential coefficients

According to Farrell's (1972) theory, the external geopotential of ocean tidal load V^{ot} can be be expressed by Green's function integral

$$V^{ot}(\varphi,\lambda,t) = G\rho_w \iint_S H(\varphi',\lambda',t)G^{V}(\psi)dS, \quad (13)$$

where H is the ocean tidal height, S means the whole sea, ψ is the spherical angular between the calculation point (φ,λ) and the sea surface moving point (φ',λ'), $G^{V}(\psi)$ is the load Green's function of the external geopotential.

The load Green's function $G^{V}(\psi)$ can be expressed in the form of a spherical harmonic series with the load love numbers k_n':

$$G^{V}(\psi) = \sum_{n=1}^{\infty}(1 + k_n')P_n(cos\psi). \quad (14)$$

Substituting (14) into (13), the integral relationship between the global ocean tidal height H and the variations of the geopotential coefficient $(\Delta\bar{C}_{nm}, \Delta\bar{S}_{nm})$ can be obtained:

$$\begin{bmatrix}\Delta\bar{C}_{nm}\\ \Delta\bar{S}_{nm}\end{bmatrix} = \frac{G\rho_w(1+k_n')}{g_0(2n+1)}\int_0^{2\pi}\int_0^{\pi} H\bar{P}_{nm}(sin\varphi)\begin{bmatrix}cosm\lambda\\ sinm\lambda\end{bmatrix}cos\varphi d\varphi d\lambda, \quad (15)$$

here $g_0 = \frac{GM}{a^2}$ is the average gravity of the sea surface.

Given an ocean tidal height model expressed by the harmonic constants (amplitudes and phases) grids of all the tidal constituent (angular frequency σ), on the sea surface(φ,λ) at epoch time t, the instantaneous ocean tidal height:

$$H(t,\varphi,\lambda) = H_t(\varphi,\lambda) = \sum_{\sigma} H_{\sigma}(\varphi,\lambda)cos[\theta_{\sigma}(t,\varphi,\lambda) - g_{\sigma}], \quad (16)$$

here H_{σ} is the amplitude of the tidal constituent σ, $\theta_{\sigma}(\varphi,\lambda,t)$ is the astronomical argument of the tidal constituent σ on the sea surface(φ,λ) at epoch time t, g_{σ} is the phase at Greenwich of the tidal constituent σ.

The in-phase amplitude $H_{\sigma}cosg_{\sigma}$ and the cross-phase amplitude $H_{\sigma}sing_{\sigma}$ are represent by spherical harmonic series, and they are brought into formula (16) to obtain

$$H_t(\varphi,\lambda)=\sum_\sigma\sum_{n=1}^{N}\sum_{m=0}^{n}\bar{P}_{nm}(cos\varphi)\sum_{+}^{-}H_{\sigma,nm}^{\pm}(\lambda,t) \quad (17)$$

$$H_{\sigma,nm}^{\pm}(t,\lambda)=\bar{C}_{\sigma,nm}^{\pm}cos(g_\sigma+\varepsilon_\sigma\pm m\lambda)+\bar{S}_{\sigma,nm}^{\pm}sin(g_\sigma+\varepsilon_\sigma\pm m\lambda) \quad (18)$$

Here $\left(\bar{C}_{\sigma,nm}^{\pm},\bar{S}_{\sigma,nm}^{\pm}\right)$ are called as the prograde and retrograde normalized spherical harmonic coefficients of the tidal constituent σ with degree n and order m, which can be expressed in terms of harmonic amplitude $\hat{C}_{\sigma,nm}^{\pm}$ and phase $\varepsilon_{\sigma,nm}^{\pm}$ as:

$$\bar{C}_{\sigma,nm}^{\pm}=\hat{C}_{\sigma,nm}^{\pm}sin\varepsilon_{\sigma,nm}^{\pm},\quad \bar{S}_{\sigma,nm}^{\pm}=\hat{C}_{\sigma,nm}^{\pm}cos\varepsilon_{\sigma,nm}^{\pm} \quad (19)$$

In formula (18), ε_σ is called as the phase bias of the tidal constituent σ, which can be defined according to the sign of H_σ (Cartwright & Eden, 1973) as Table 1.

Table 1 Values of the phase bias ε_σ according to the sign of H_σ

The phase bias ε_σ		$H_\sigma>0$	$H_\sigma<0$
$m=0$	long period	π	0
$m=1$	diurnal	$\pi/2$	$-\pi/2$
$m=2$	semi-diurnal	0	π

Substituting (17) into (15), taking into account (18) and (19), the external geopotential coefficient variations can be expressed as:

$$\Delta\bar{C}_{nm}-i\Delta\bar{S}_{nm}=\sum_\sigma\left(C_{\sigma,nm}^{\pm},\mp iS_{\sigma,nm}^{\pm}\right)e^{\pm i\theta_\sigma} \quad (20)$$

Comparing equations (20) and (16), we have:

$$C_{\sigma,nm}^{\pm}=\frac{4\pi G\rho_w(1+k_n')}{g_0(2n+1)}\hat{C}_{\sigma,nm}^{\pm}sin\left(\varepsilon_{\sigma,nm}^{\pm}+\varepsilon_\sigma\right) \quad (21)$$

$$S_{\sigma,nm}^{\pm}=\frac{4\pi G\rho_w(1+k_n')}{g_0(2n+1)}\hat{C}_{\sigma,nm}^{\pm}cos\left(\varepsilon_{\sigma,nm}^{\pm}+\varepsilon_\sigma\right) \quad (22)$$

Using formulas (21) and (22), the ocean tide harmonic constants grid model represented can be converted into the harmonic amplitude, and then the geopotential coefficient variations can be calculated according to the formula (20).

8.6 Fast recursion algorithm for $\bar{P}_{mn}$(t) and their derivatives to θ

Let $t=cos\theta,u=sin\theta.$ (1)

8.6.1 Standard forward column recursion algorithm for $\bar{P}_{nm}(t)$ $(n<1900)$

$$\begin{cases}\bar{P}_{nm}(t)=a_{nm}t\bar{P}_{n-1,m}(t)-b_{nm}\bar{P}_{n-2,m}(t) & \forall n>1,m<n\\ \bar{P}_{nn}(t)=\sqrt{\frac{2n+1}{2n}}\bar{P}_{n-1,n-1}\end{cases} \quad (2)$$

$$a_{nm}=\sqrt{\frac{(2n-1)(2n+1)}{(n+m)(n-m)}},\quad b_{nm}=\sqrt{\frac{(2n+1)(n+m+1)(n-m-1)}{(2n-3)(n+m)(n-m)}}$$

$$\bar{P}_{00}(t)=1,\quad \bar{P}_{10}(t)=\sqrt{3}t,\quad \bar{P}_{11}(t)=\sqrt{3}u \quad (3)$$

8.6.2 Improved Belikov recursion algorithm for $\bar{P}_{nm}(t)$ $(n<64800)$

When n=0,1, use formula (3) to calculate $\bar{P}_{nm}(t)$. When $n\geq 2$:

$$\bar{P}_{n0}(t)=a_nt\bar{P}_{n-1,0}(t)-b_n\frac{u}{2}\bar{P}_{n-1,1}(t),\quad m=0 \quad (4)$$

$$\bar{P}_{nm}(t) = c_{nm} t \bar{P}_{n-1,m}(t) - d_{nm} u \bar{P}_{n-1,m+1}(t) + e_{nm} u \bar{P}_{n-1,m-1}(t),\ m > 0 \tag{5}$$

$$a_n = \sqrt{\frac{2n+1}{2n-1}}, \quad b_n = \sqrt{\frac{2(n-1)(2n+1)}{n(2n-1)}} \tag{6}$$

$$c_{nm} = \frac{1}{n}\sqrt{\frac{(n+m)(n-m)(2n+1)}{2n-1}}, \quad d_{nm} = \frac{1}{2n}\sqrt{\frac{(n-m)(n-m-1)(2n+1)}{2n-1}} \tag{7}$$

When $m > 0$:

$$e_{nm} = \frac{1}{2n}\sqrt{\frac{2}{2-\delta_0^{m-1}}}\sqrt{\frac{(n+m)(n+m-1)(2n+1)}{2n-1}} \tag{8}$$

ETideLoad4.0 adopts mainly the improved Belikov recursion algorithm to calculate the normalized associated Legendre functions $\bar{P}_{nm}(t)$。

8.6.3 Cross-degree recursive algorithm for $\bar{P}_{nm}(t)$ $(n < 20000)$

When n=0,1, use formula (3) to calculate $\bar{P}_{nm}(t)$. When $n \geq 2$:

$$\bar{P}_{nm}(t) = \alpha_{nm}\bar{P}_{n-2,m}(t) + \beta_{nm}\bar{P}_{n-2,m-2}(t) - \gamma_{nm}\bar{P}_{n,m-2}(t) \tag{9}$$

$$\begin{aligned} \alpha_{nm} &= \sqrt{\frac{(2n+1)(n-m)(n-m-1)}{(2n-3)(n+m)(n+m-1)}} \\ \beta_{nm} &= \sqrt{1+\delta_0^{m-2}}\sqrt{\frac{(2n+1)(n+m-2)(n+m-3)}{(2n-3)(n+m)(n+m-1)}} \\ \gamma_{nm} &= \sqrt{1+\delta_0^{m-2}}\sqrt{\frac{(n-m+1)(n+m-3)}{(n+m)(n+m-1)}} \end{aligned} \tag{10}$$

8.6.4 Non-singular recursive algorithm for $\frac{\partial}{\partial\theta}\bar{P}_{nm}(\cos\theta)$

$$\frac{\partial}{\partial\theta}\bar{P}_{nm}(\cos\theta) = -\sin\theta\frac{\partial}{\partial t}\bar{P}_{nm}(t) \tag{11}$$

$$\begin{cases} \frac{\partial}{\partial\theta}\bar{P}_{n0} = -\sqrt{\frac{n(n+1)}{2}}\bar{P}_{n1}, \quad \frac{\partial}{\partial\theta}\bar{P}_{n1} = \sqrt{\frac{n(n+1)}{2}}\bar{P}_{n0} - \frac{\sqrt{(n-1)(n+2)}}{2}\bar{P}_{n2} \\ \frac{\partial}{\partial\theta}\bar{P}_{nm} = \frac{\sqrt{(n+m)(n-m+1)}}{2}\bar{P}_{n,m-1} - \frac{\sqrt{(n-m)(n+m+1)}}{2}\bar{P}_{n,m+1}, \quad m > 2 \end{cases} \tag{12}$$

$$\frac{\partial}{\partial\theta}\bar{P}_{00}(t) = 0, \quad \frac{\partial}{\partial\theta}\bar{P}_{10}(t) = -\sqrt{3}u, \quad \frac{\partial}{\partial\theta}\bar{P}_{11}(t) = \sqrt{3}t \tag{13}$$

8.6.5 Non-singular recursive algorithm for $\frac{\partial^2}{\partial\theta^2}\bar{P}_{nm}$

$$\begin{cases} \frac{\partial^2}{\partial\theta^2}\bar{P}_{n0} = -\frac{n(n+1)}{2}\bar{P}_{n0} + \sqrt{\frac{n(n-1)(n+1)(n+2)}{8}}\bar{P}_{n2} \\ \frac{\partial^2}{\partial\theta^2}\bar{P}_{n1} = -\frac{2n(n+1)+(n-1)(n+2)}{4}\bar{P}_{n1} + \frac{\sqrt{(n-2)(n-1)(n+2)(n+3)}}{4}\bar{P}_{n3} \end{cases} \tag{14}$$

$$\begin{aligned} \frac{\partial^2}{\partial\theta^2}\bar{P}_{nm} = &\frac{\sqrt{(n-m+1)(n-m+2)(n+m-1)(n+m)}}{4}\bar{P}_{n,m-2} - \frac{(n+m)(n-m+1)+(n-m)(n+m+1)}{4}\bar{P}_{nm} \\ &- \frac{(n+m)(n-m+1)+(n-m)(n+m+1)}{4}\bar{P}_{nm} \\ &+ \frac{\sqrt{(n-m-1)(n-m)(n+m+1)(n+m+2)}}{4}\bar{P}_{n,m+2}, \quad m > 2 \end{aligned} \tag{15}$$

$$\frac{\partial^2}{\partial\theta^2}\bar{P}_{00}(t) = 0, \quad \frac{\partial^2}{\partial\theta^2}\bar{P}_{10}(t) = -\sqrt{3}t, \quad \frac{\partial^2}{\partial\theta^2}\bar{P}_{11}(t) = -\sqrt{3}u \tag{16}$$

Index for ETideLoad4.0 scientific computing functions

Names table of the sample directories and executable files

No	Program name	Sample directory name / Executable program name
1	Computation of solid tidal effects on various geodetic quantities outside solid Earth	Tideffectsolidearth
2	Spherical harmonic synthesis on ocean tidal load effects outside solid Earth	OTideloadharmsynth
3	Spherical harmonic synthesis on air pressure tidal load effects outside solid Earth	ATideloadharmsynth
4	Computation of Earth pole shift and ocean pole tide effects outside solid Earth	Poleshifteffectscalc
5	Computation of permanent tidal effects and correction of Earth's mass center	Permanentdgeocenter
6	Computation of solid Earth tide and loading tide effects on geodetic networks	Controlnetworktidef
7	The regional approaching of tidal load effects by load Green's Integral	Tdloadgreenintegral
8	Global forecast of various tidal effects on various surface geodetic quantities	SolidLoadtidecalctl
9	Separation and processing of gross errors in geodetic variations time series	TmsrsErrorseppreproc
10	Low-pass filtering and signal reconstructing for irregular time series	Tmsrslowpfltrconstr
11	Weighted operation, difference, integral and interpolation on time series	TmsrsAddifferinterp
12	Normalized extraction from batch time series of geodetic monitoring network	Tmsrsbatchnormalize
13	Processing and analysis on batch time series of geodetic monitoring network	Tmsrsnetwkanalyspro
14	Construction and analysis on records time series from geodetic network	Tmrecordanalysproc
15	Processing and analysis on variation (vector) grids time series	Tmgridanalysisproc
16	Multi-form spatiotemporal interpolation from grids time series	Tmgrdinterpolation
17	Spherical harmonic analysis on global surface load time series	Loadspharmonanalys
18	Spherical analysis on tide parameters and construction of tidal load model	Loadtidespharmsynth
19	Computation of the model value by spherical harmonic synthesis	Loadspharmsynthesis
20	Computation of load-deformation field by spherical harmonic synthesis	Loadeformharmsynth
21	Regional approaching of load-deformation field by Green's Integral	Loadfmrntgreenintg

22	Estimation of land water variations based on multi-monitoring networks	Loadewhgeodeticestm
23	Estimation of high-resolution land water variations from CORS/InSAR	LoadewhtmInSARestm
24	Geodynamic calculation on geodetic field grids time series	Loadfmgridtmdyncalc
25	Pseudo-stable adjustment of records time series for geodetic network variations	Tmrecordnetwkadjust
26	Gross error detection and spatial deformation analysis on InSAR variations	DynInSARsptmanalyse
27	Cooperative monitoring and processing of CORS network and InSAR	DynCORScntrtmInSAR
28	Deep fusion and time series analysis on multi-source InSAR variations	DynInSARfusiontmsqu
29	Calculation of ground stability variation based on vertical deformation	Dyngrndhgtstablility
30	Calculation of ground stability variation based on gravity variations	Dyngrngravstablility
31	Calculation of ground stability variation based on variation vectors	Dyndeflectstablility
32	Statistical synthesis and prediction of ground stability variations	Dynstabgrdintgrestm
33	Conversion of general ASCII data into ETideLoad format	EdPntrecordstandard
34	Data interpolation, extracting and separation of land and sea	Edatafsimpleprocess
35	Simple and direct calculation on geodetic data files	EdFlgeodatacalculate
36	Operations on geodetic time series with same specifications	Edtimeseriesfilescalc
37	Generating and constructing of regional geodetic grid	Edareageodeticdata
38	Constructing and transforming of vector grid file	EdVectorgridtransf
39	Statistical analysis on various geodetic data file	Tlstatisticanalysis
40	Gross error detection and weighted basis function gridding	AppGerrweighgridate
41	Visualization for multi-attributes in groud variation time series	Veiwtimesqu
42	Visualization for variation records time series on geodetic network	Viewtmrecords
43	Visualization for specified attribute in discrete point records file	Viewpntdata
44	Visualization for geodetic grid and variation grids time series file	Viewgridata
45	Visualization for the geodetic vector grid file	Viewvectgrd