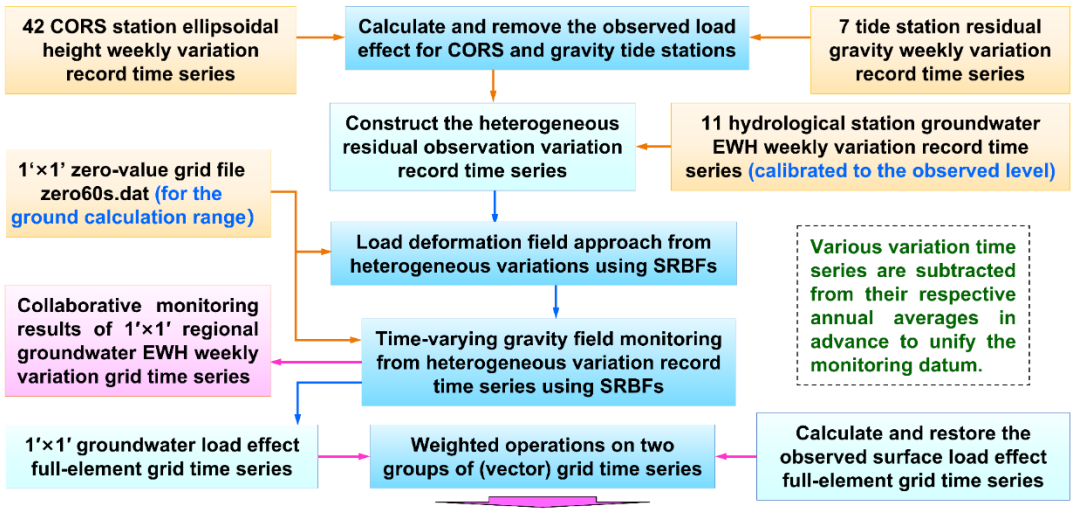
Heterogeneous collaborative monitoring process of groundwater variations and load deformation field

From the heterogeneous observation variation record time series from CORS station, gravity tide station and groundwater monitoring station, compute the groundwater variations and load deformation field full-element grid time series in the five-step to realize the heterogeneous collaborative monitoring to regional groundwater and time-vary gravity field according to the remove-restore scheme based on the observed surface load.

The target monitoring area: 98°~101°E, 24°~26.5°N. Observation point distribution: 97.5°~101.5°E, 23.5°~27.0°N. Monitoring time interval: one week. Starting and ending time: March 2019 to August 2019. Spatial resolution: 1′×1′.



Heterogeneous collaborative monitoring process of groundwater variations and load deformation field

Step 1: Data preparation and preprocessing of various geodetic and surface load observations.

(1) CORS network data processing and calculation of the ellipsoidal height weekly variations time series at 42 CORS stations, and calculation of gravity weekly variation time series at 7 gravity tide stations.

(2) Various geodetic and surface load observation variation time series are subtracted from their respective annual averages in advance to unify variation monitoring datum.

(3) Calculation of groundwater equivalent water height (EWH) weekly variation time series at 11 hydrological monitoring stations.

According to the process of this section, calculate the regional groundwater EWH weekly variation grid time series in advance only from CORS and gravity tide monitoring data, whose monitoring time span was not less than two years. Then, interpolate the calculated groundwater EWH grid into the hydrological monitoring station to calibrate the parameters,

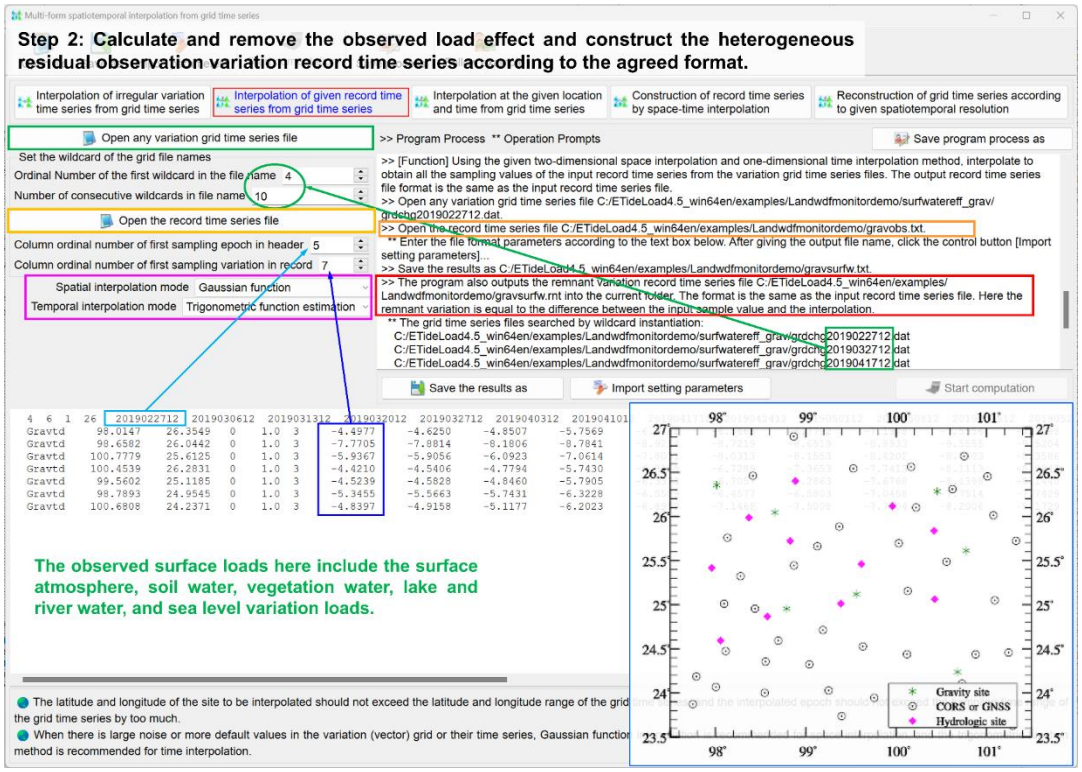
to transform the variation of observed groundwater level (head) into the variation of groundwater EWH at each hydrological monitoring station.

The process in step 1 is omitted in this example.

Step 2: Calculate and remove the observed load effect and construct the heterogeneous residual observation variation record time series according to ETideLoad4.5 agreed format.

According to the computation process of section 4.10.1, calculate the observed load effect weekly variation grid time series on ground ellipsoidal height and gravity.

Call the function [Interpolation of given record time series from grid time series], remove the observed load effects from the gravity weekly variation time series at gravity tide stations to generate the residual gravity weekly variation time series, and remove the observed load effects from the ellipsoidal height weekly variation time series at CORS stations to generate the residual ellipsoidal height weekly variation time series.



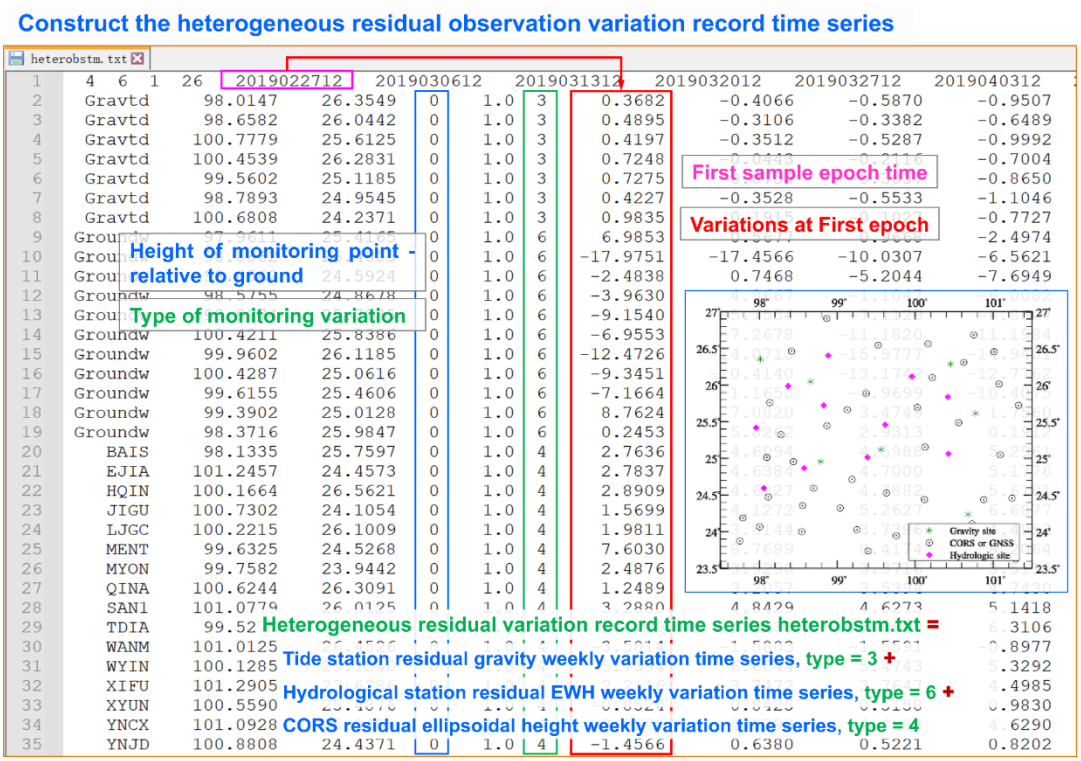
The observed surface loads in this example include surface atmosphere, soil water, vegetation water, lake and river water, and sea level variation loads.

According to the agreed format in ETideLoad4.5, merge the 11 hydrological station groundwater EWH weekly variation, 7 tide station residual gravity weekly variation and 42 CORS residual ellipsoidal height weekly variation record time series to generate the heterogeneous residual observation variation record time series file.

The file header contains the time series length and the sampling epoch time arranged

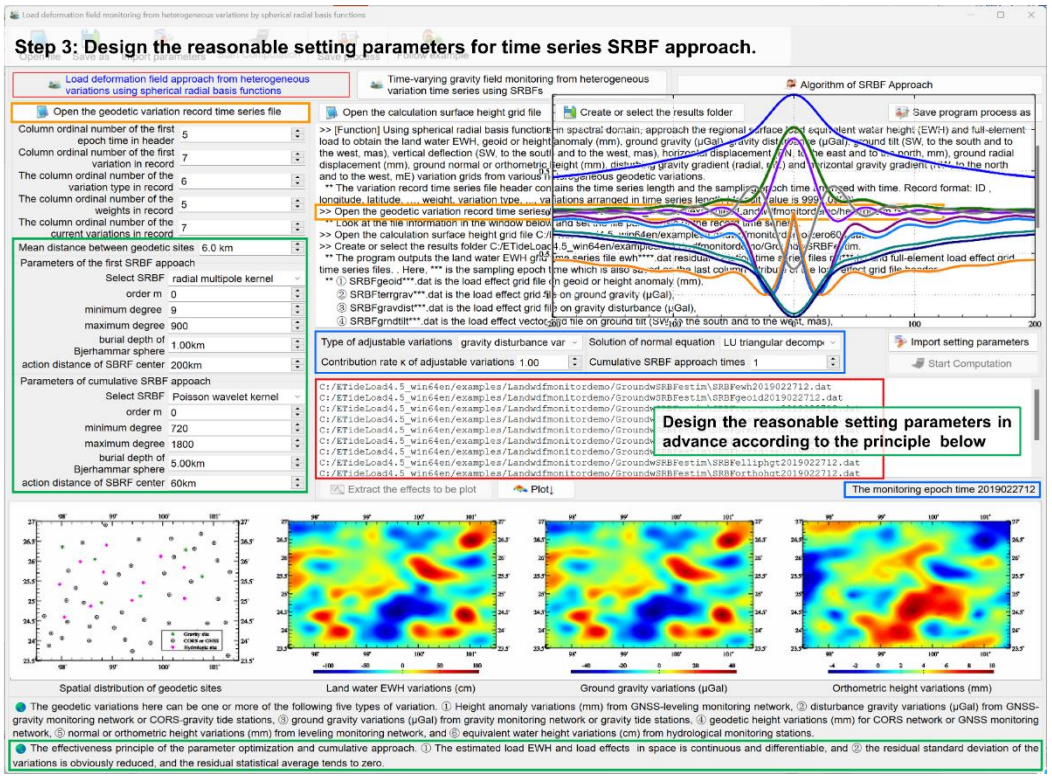
with time. Record format: ID (the site name / no), longitude, latitude, …, weight, variation type, ..., variations arranged in time series length (default value is 9999.0000).

Variation type = 3 represents residual gravity variation (μGal), = 4 represents residual ellipsoidal height variation (mm), = 6 represents EWH variation (cm).



Step 3: Call the function [Load deformation field approach from heterogeneous variations using spherical radial basis functions] to design the reasonable setting parameters for time series SRBF approach.

Call the function [Load deformation field approach from heterogeneous variations using spherical radial basis functions], input the 1'×1' zero-value grid file zero60s.dat, which is employed to give the calculation range and the zero value represents the calculation surface as the ground, estimate the residual EWH variation and 10 kinds of load effect grids from the heterogeneous residual observation variation record time series file at any epoch time to design the reasonable setting parameters according to the principle of parameter setting optimization and cumulative approach effectiveness given below the program interface.



Step 4: Estimate the residual EWH and 10 kinds of residual load effect weekly variation grid time series.

Call the function [Time-varying gravity field monitoring from heterogeneous variation time series using SRBFs], input the 1'×1' zero-value grid file zero60s.dat, and estimate the residual EWH weekly variation grid time series ewh***.dat and the following 10 kinds of residual load effect weekly variation grid time series files from the heterogeneous residual observation variation record time series file with the setting parameters above, while output residual variation time series files rnt***.txt.

①SRBFgeoid***.dat is the residual load effect grid file on geoid or height anomaly (mm),

②SRBFterrgrav***.dat is the residual load effect grid file on ground gravity (μGal),

③SRBFgravdist***.dat is the residual load effect grid file on gravity disturbance (μGal),

④SRBFgrndtilt***.dat is the residual load effect vector grid file on ground tilt (SW, to the south and to the west, mas),

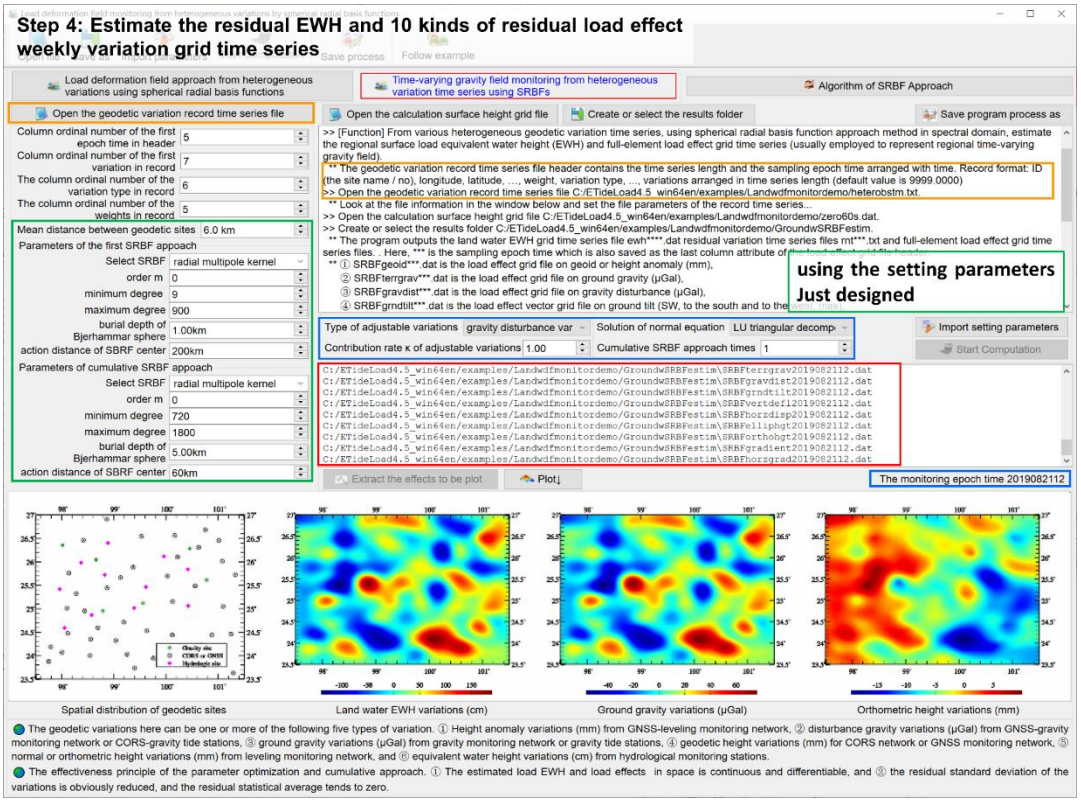
⑤SRBFvertdefl***.dat is the residual load effect vector grid file on vertical deflection (SW, to the south and to the west, mas),

⑥SRBFhorzdisp***.dat is the residual load effect vector grid file on horizontal displacement (EN, to the east and to the north, mm),

⑦SRBFelliphgt***.dat is the residual load effect grid file on ground radial displacement (mm),

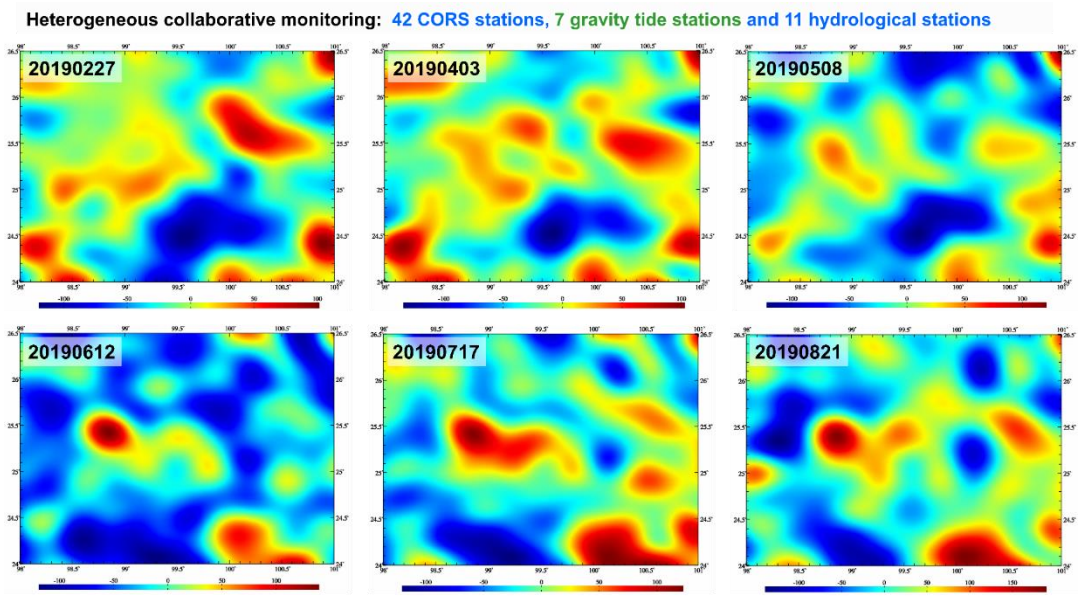
⑧SRBForthohgt***.dat is the residual load effect grid file on ground normal or orthometric height (mm),

⑨SRBFgradient***.dat is the residual load effect grid file on gravity gradient (radial, mE) and ⑩SRBFhorzgrad***.dat is the residual load effect vector grid file on horizontal gravity gradient (NW, to the north and to the west, mE).



The geodetic variations here can be one or more of the following five types of variation. ① Height anomaly variations (mm) from GNSS-leveling monitoring network, ② disturbance gravity variations (μGal) from GNSS-gravity monitoring network or CORS-gravity tide stations, ③ ground gravity variations (μGal) from gravity monitoring network or gravity tide stations, ④ geodetic height variations (mm) for CORS network or GNSS monitoring network, ⑤ normal or orthometric height variations (mm) from leveling monitoring network, and ⑥ equivalent water height variations (cm) from hydrological monitoring stations.

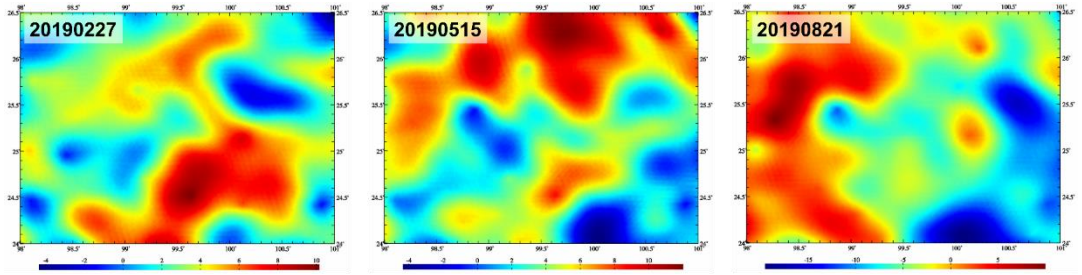
The effectiveness principle of the parameter optimization and cumulative approach. ① The estimated load EWH and load effects in space is continuous and differentiable, and ② the residual standard deviation of the variations is obviously reduced, and the residual statistical average tends to zero.



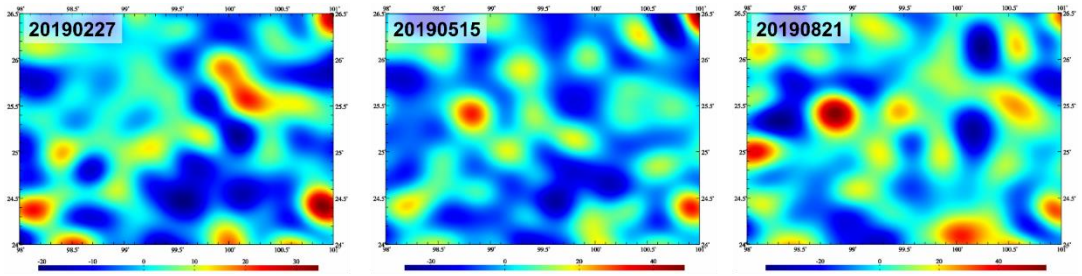
Collaborative monitoring results of 1′×1′ regional groundwater EWH weekly variation grid time series

Where *** is the sampling epoch time from the heterogeneous variation record time series file header, which is also saved as the last column attribute of the load effect grid file header.

The residual load EWH variation here does not contain surface observed load variation, which can be considered as groundwater EWH variation. Therefore ewh***.dat are the heterogeneous collaborative monitoring results of the groundwater EWH weekly variations, while the residual load effect weekly variation can be considered as the groundwater load effect weekly variation.



1′×1′ regional groundwater load effect weekly variation (mm) grid time series on ground orthometric height

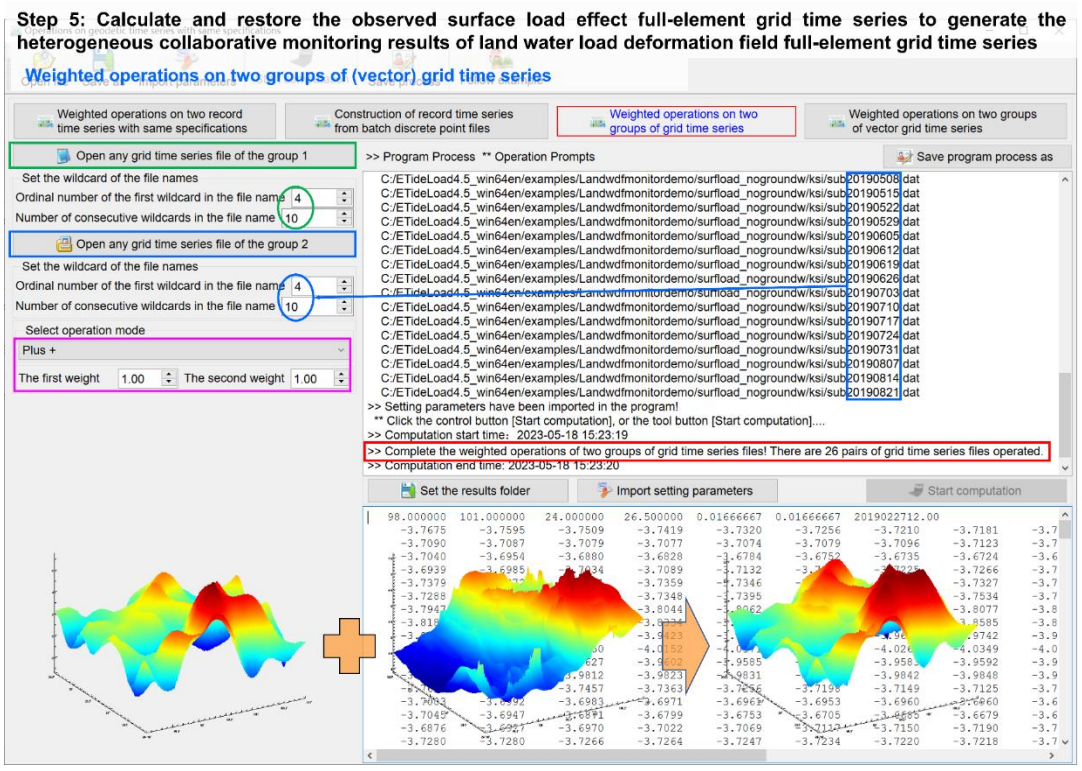


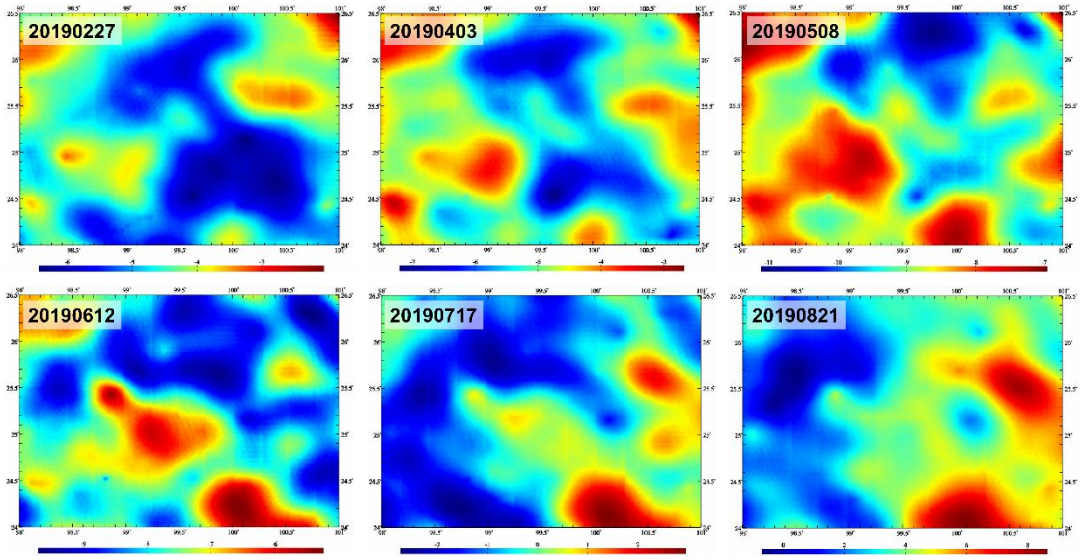
1′×1′ regional groundwater load effect weekly variation (mE) grid time series on gravity gradient

Step 5: Calculate and restore the observed surface load effect full-element grid time series to generate the heterogeneous collaborative monitoring results of land water load deformation field full-element grid time series.

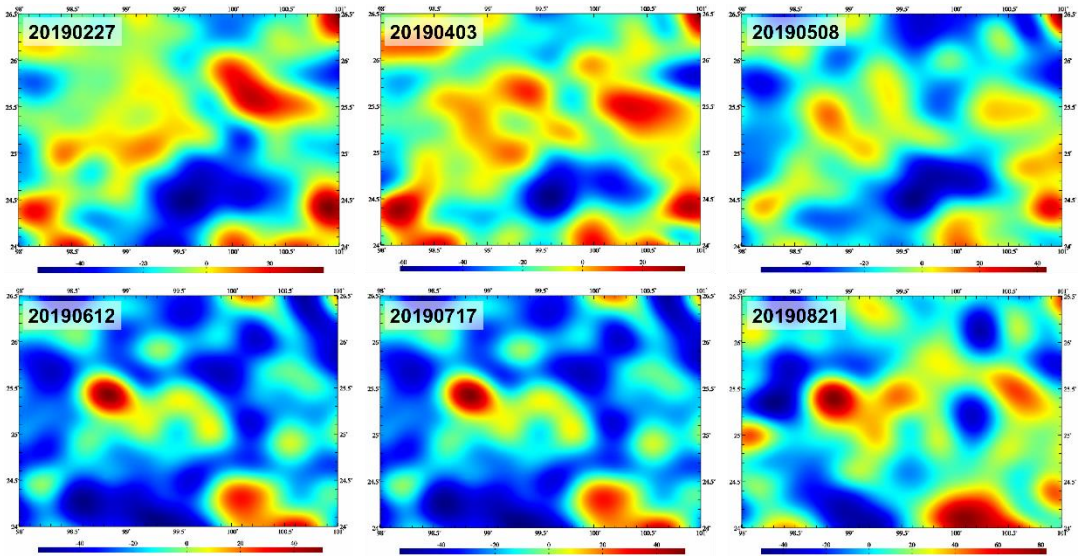
According to the computation process of section 4.10.1, calculate the full element weekly variation grid time series of the observed surface load effect. The process is omitted in this example.

Call the function [Weighted operations on two groups of grid time series], directly add the full element weekly variation grid time series of the observed surface load effects to the full element weekly variation grid time series of the residual (groundwater) load effects, respectively, to generate the regional 1'×1' full-element weekly variation grid time series of land water load effects, which are the heterogeneous collaborative monitoring results of land water full-element load deformation field.





Collaborative monitoring results of 1′×1′ surface load effect weekly variation (mm) grid time series on geoid



Collaborative monitoring results of 1′×1′ load effect weekly variation (μGal) grid time series on ground gravity

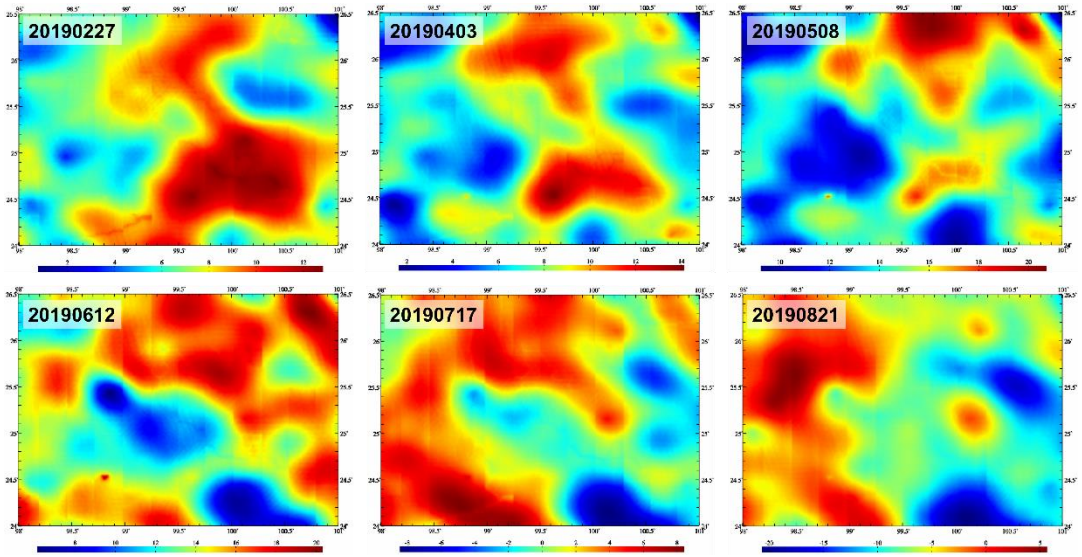
The main technical features of ETideLoad4.5's algorithm of the heterogeneous collaborative monitoring to surface load and time-vary gravity field are in following.

(1) The algorithm can effectively solve the problems of high-degree oscillation and poor convergence of Green′s function and spectrum leakage and singularity of Green′s integral in the near area around the calculation point, and then realize the collaborative monitoring of GNSS, gravity, leveling, ground tilt and groundwater strictly according to solid geophysical analytical constraints.

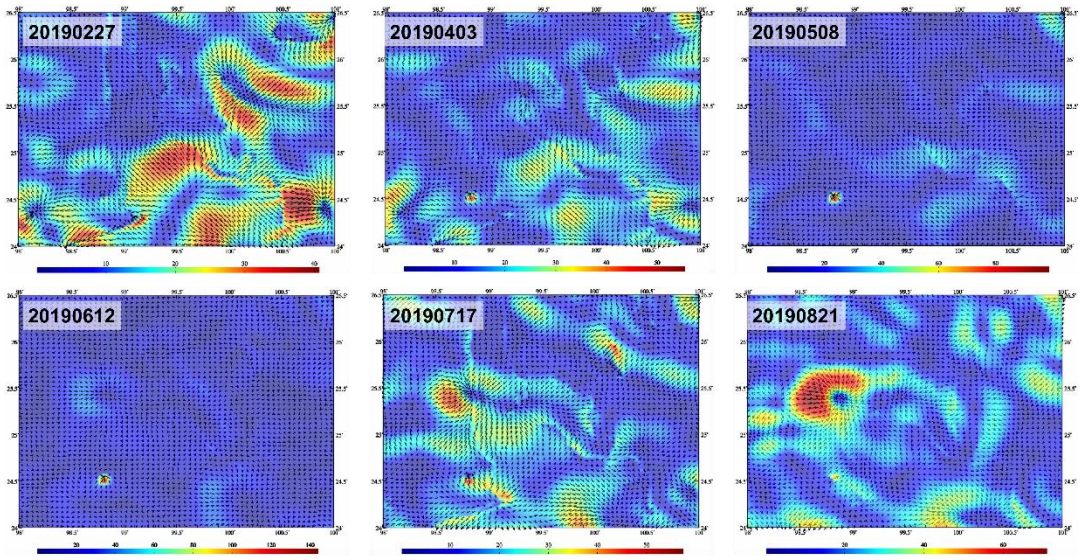
(2) There are rigorous analytical relationships between observation equations in the algorithm, and heterogeneous observation variations are deeply fused according to the

standard deviation of cofactor matrix to avoid the load deformation field affected by the observation errors. The algorithm has high stability and universality, which is suitable for massive computation of multiple time series collaborative monitoring.

(3) The algorithm has the functions of geophysical signal spatial and spectrum domain separation and measurement equipment parameter calibration, which can improve the medium and long-term monitoring ability of gravity tide station, groundwater monitoring station and ground tilt station, and enhance the level of collaborative monitoring of space, terrestrial and marine geodesy.



Collaborative monitoring results of 1′×1′ load effect weekly variation (mm) grid time series on ground ellipsoidal height



Collaborative monitoring results of 1′×1′ load effect weekly variation (mas) vector grid time series on ground tilt