# M_ISSION：a MATLAB-based software for multi-GNSS Ionospheric scintillation index calculation and analysis

User Manual

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## Contents

## 1. Introduction

Dense and accurate monitoring of ionospheric scintillation is crucial for understanding the patterns and driving mechanisms of ionospheric disturbances, and holds significant importance for enhancing the reliability and robustness of GNSS positioning and communication systems. Research on ionospheric scintillation indices derived from geodetic receivers represents one of the key approaches to achieving dense monitoring of ionospheric scintillation. In recent years, numerous scholars have proposed various ionospheric scintillation indices applicable to geodetic receivers. However, there remains a lack of an open-source software platform capable of integrating multiple ionospheric indices. This limitation indirectly hinders the widespread utilization of these diverse scintillation indices and restricts the broader application of globally distributed, dense geodetic receiver networks in ionospheric scintillation monitoring. To address this gap, we have developed M_ISSION—a MATLAB-based software for multi-GNSS Ionospheric scintillation index calculation and analysis

The primary function of M_ISSION is to compute scintillation indices, including ROTI, IAATR, AATR, DIXSG, and $\sigma_{\phi f}$, using 30-second interval observation data from geodetic receivers. The software supports batch processing of data from four major satellite navigation systems: GPS, GLONASS, Galileo, and BDS. Additionally, it enables graphical analysis of regional ionospheric disturbances based on computed scintillation indices.

**Table 1** Definitions of Terms

| No. | Term or Abbreviation | Descriptive Definition |
|---|---|---|
| 1 | GNSS | Global Navigation Satellite System |
| 2 | ROTI | Rate of change of TEC index |
| 3 | AATR | The Along Arc TEC Rate |
| 4 | RMSAATR | The Along Arc TEC Rate Index |
| 5 | DIXSG | Disturbance Ionosphere Index Spatial Gradient |
| 6 | DIXSGp | Global DIXSG Index |
| 7 | $\sigma_{\phi f}$ | 30-second sampling interval phase scintillation index |

## 2. Development Environment and Configuration

### （1）Software Installation

This software is developed under the MATLAB environment. It has been developed and tested on MATLAB R2023b and R2024a; therefore, using version R2023b or newer is highly recommended to ensure full functionality and compatibility.

It is recommended to install the software in a dedicated directory on a non-system drive (e.g., **D:\MATLAB\M_ISSION**) to avoid system disk space constraints or permission issues. Users do not require additional MATLAB toolboxes for calculating scintillation indices with M_ISSION. However, installation of the MATLAB geographic mapping toolbox M_map is necessary if plotting DIXSG results is required, enabling subsequent data visualization and analysis.

### （2）Data File Processing

If the downloaded data is in ZIP format, please extract it to a designated location first. The software does not support direct reading of data within compressed files.

### （3）Data Organization Structure

To facilitate management and usage, please store downloaded data in separate folders categorized by type and date. Folder names should clearly indicate the date and data type to enable efficient retrieval and referencing. For example, for observation data with GPS time 2024 March 24 (day of year, DOY = 84), the folder path should be structured as:

**D:\MATLAB\M_ISSION\input_o_and_r_file\24084**

Precise ephemeris files should be stored in

**D:\MATLAB\M_ISSION\input_sp3_file\24084**

Clock and antenna phase files should be stored in

**D:\MATLAB\M_ISSION\input_clk_and_atx_file\24084**

The read observation data should be stored in MAT format in

**D:\MATLAB\M_ISSION\OBS\24084**

The read ephemeris data should be stored in MAT format in

**D:\MATLAB\M_ISSION\SP3\24084**

Intermediate data such as cROT, ivtall should be stored in MAT format in

**D:\MATLAB\M_ISSION\ivcROT**

**D:\MATLAB\M_ISSION\ivtall**

For other result files, the paths will be introduced in detail in the relevant computation modules along with examples.

### （4）Software Launch

To enable MATLAB to recognize and run the code of M_ISSION, you need to add the folder containing the M_ISSION source code to the MATLAB search path. In MATLAB, go to the Home tab, click on Set Path, and then select Add Folder. Choose the folder where M_ISSION is installed (e.g., **D:\MATLAB\M_ISSION**), and click Save. After the folder has been added to the search path, you can launch the software by typing the following command in the MATLAB command window,

```
>>  M_ISSION
```

For direct access, double-click M_ISSION.mlapp to open the MATLAB App Designer interface, which allows for software modification or direct launching. Ensure all prerequisite files are correctly located in their designated directories prior to initialization.

## 3. M_ISSION

The M_ISSION software uses graphical user interface (GUI) programming techniques and is designed with three main functional modules: the Ionospheric Scintillation Factor Calculation Module, the Scintillation Factor Visualization Module, and the Scintillation Factor Analysis Module. In the Ionospheric Scintillation Factor Calculation Module, users can perform tasks such as calculating ROTI, AATR, DIXSG, and $\sigma_{\phi f}$ indices, as well as configure various common parameters, including the paths for observation data and precise ephemeris data, system options, adjustment of cutoff elevation angles, and configuration of cycle slip detection parameters. This module also supports custom settings for the sensitivity of DIXSG, grid size, latitude and longitude range, as well as the specification of paths for clock bias, antenna phase files, and adjustment of filtering thresholds. The Scintillation Factor Visualization Module focuses on interpreting the results of any scintillation factor calculation for specific satellites, while the Scintillation Factor Analysis Module emphasizes comparing and validating the accuracy of ROTI, AATR, DIXSG, and $\sigma_{\phi f}$ factor time series, and provides a two-dimensional gridding function for ROTI and DIXSG factors. The implementation process of the software is shown in Figure Fig. 1 Implementation flow of M_ISSION software.

The M_ISSION software is specifically designed to process geodetic receiver data with a 30-second sampling interval. It is fully compatible with both Rinex 3 and Rinex 2 formats and can quickly output and validate intermediate files, including cROT, elevation angle, and azimuth angle. Additionally, it supports batch calculations of ROTI, IAATR, AATR, DIXSG ionospheric scintillation factors for GPS, Galileo (GAL), GLONASS (GLO), and BeiDou (BDS) systems, as well as the $\sigma_{\phi f}$ factor for the GPS system.

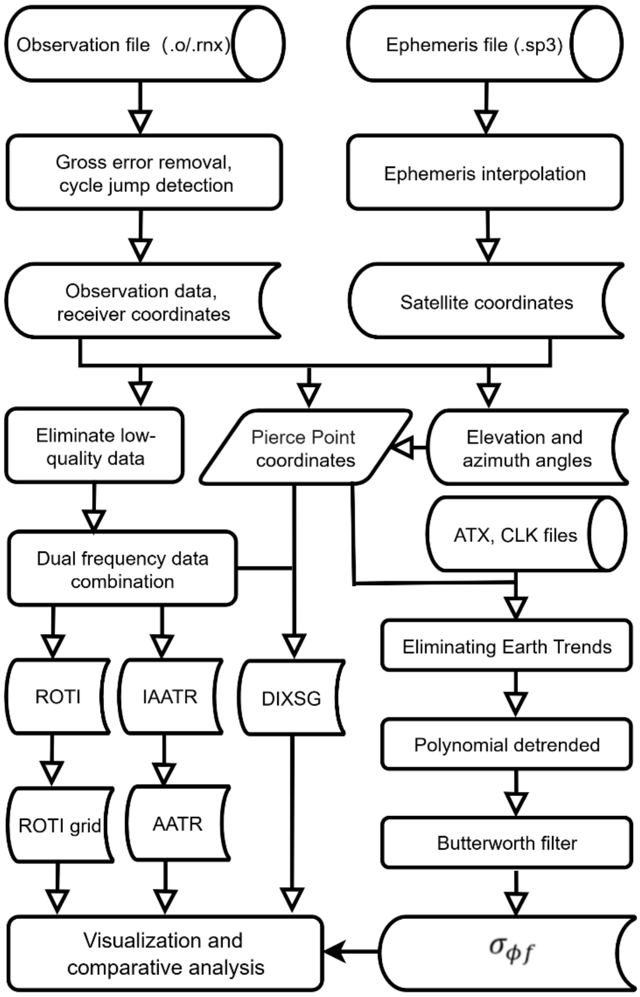



Fig. 1 Implementation flow of M_ISSION software

Fig. 2 M_ISSION Software Main Interface illustrates the graphical interface of the M_ISSION software, featuring three core modules accessible via the top navigation bar. The default interface corresponds to Module 1, which provides configurable parameters for scintillation index computation. To demonstrate module functionalities, we utilize observational data from 30 Canadian stations acquired on March 24, 2024 (GPS time), stored in the directory:

**D:\MATLAB\M_ISSION\input_o_and_r_file\24084**

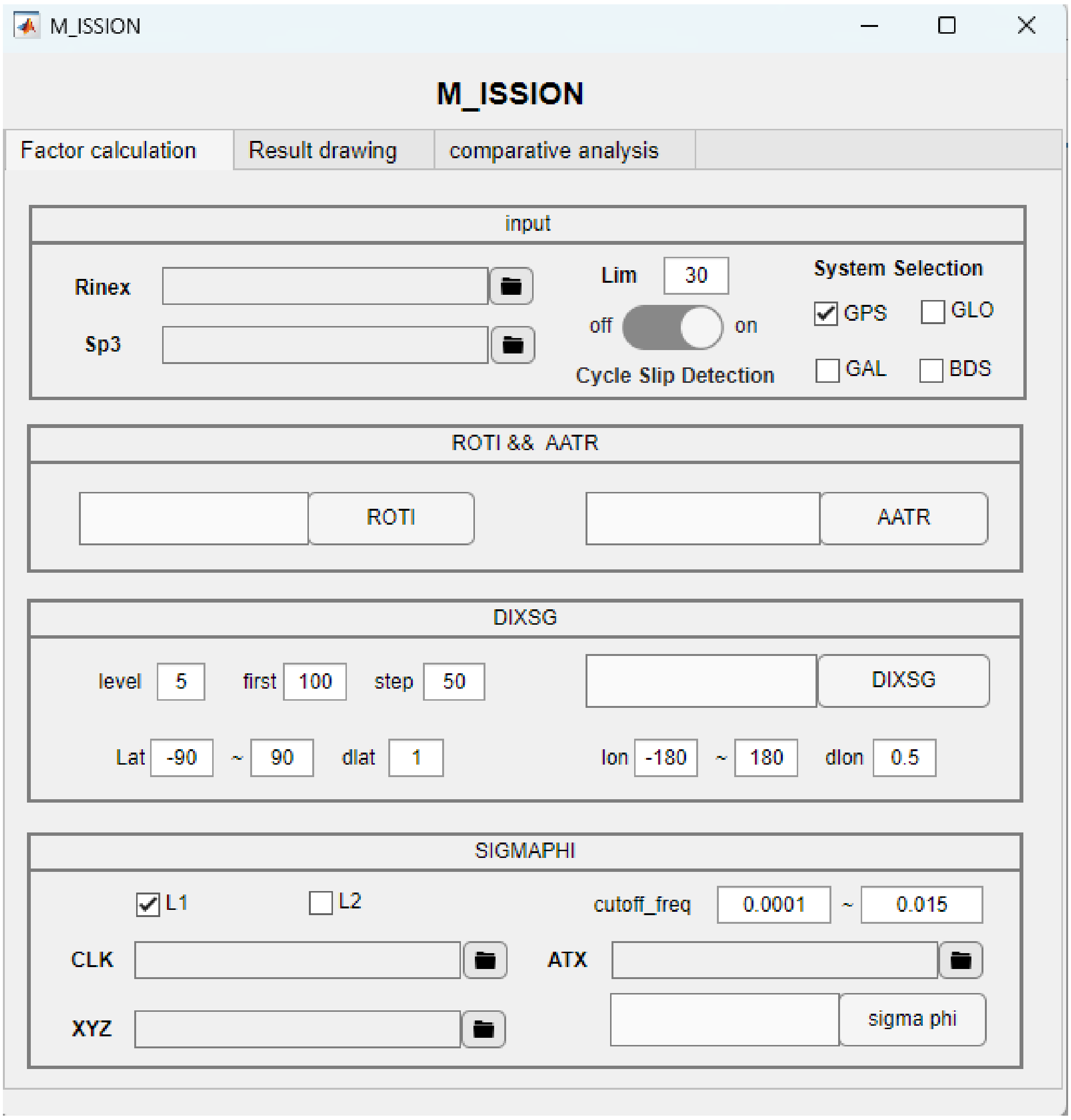



Fig. 2 M_ISSION Software Main Interface

**(1) Ionospheric Scintillation Factor Calculation Interface**

The first module of M_ISSION is the Ionospheric Scintillation Factor Calculation Module, which is divided into two parts: common parameter design and scintillation factor calculation, as shown in Fig. 3. The calculation process is initiated by selecting the paths for the required data files. For the computation of ROTI, AATR, and DIXSG, observation data files (.o/.rnx) and precise ephemeris files (.sp3) are required. Furthermore, the calculation of the phase scintillation factor $\sigma_{\phi f}$ necessitates additional data inputs. Besides needing clock bias files (.clk) and antenna phase files (.atx), this specific calculation depends on precise station coordinates. The system acquires these coordinates through a three-level selection strategy. The preferred method is for the user to supply a space-delimited text file containing the station identifier and its corresponding three-dimensional XYZ coordinates. An example of the required format is shown below:

AAAA 123456 135791 246810

BBBB 654321 147852 369258

...

If this file is not provided, the system defaults to invoking the GLAB toolkit to perform precise point positioning. As a final contingency, should the positioning process fail, the approximate coordinates available within the observation file header are utilized instead. Then, parameter settings need to be configured, including cutoff angle, satellite system selection, and cycle slip detection options. Furthermore, for DIXSG calculation, latitude and longitude range, as well as sensitivity level, need to be set. For the $\sigma_{\phi f}$ calculation, users must select the L-band to be processed and specify the cutoff frequencies for the sixth-order band-pass Butterworth filter.

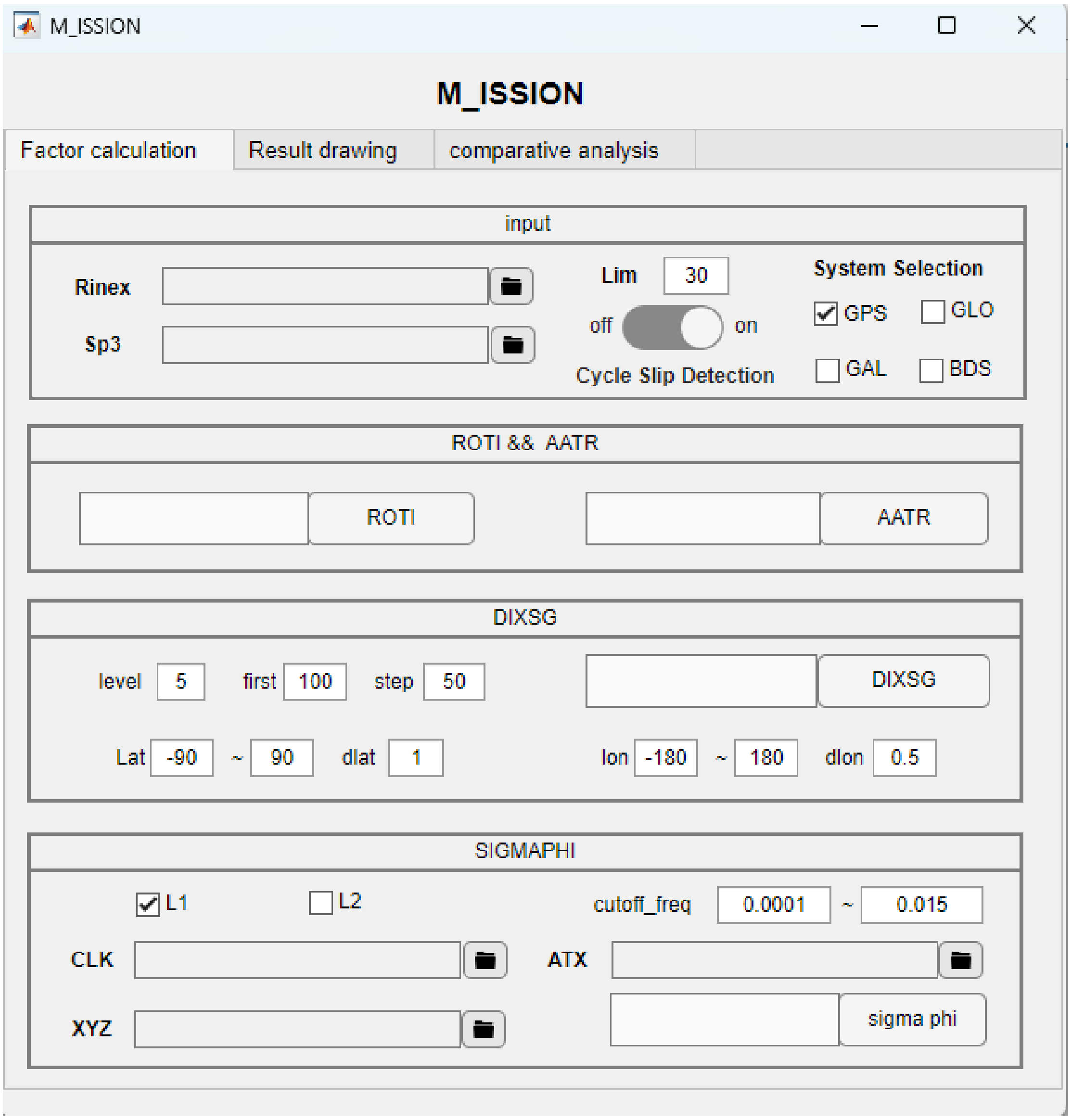



Fig. 3 Ionospheric Scintillation Factor Calculation Interface

Common Parameter Settings

In M_ISSION, the Rinex selection box allows users to choose the folder containing the observation data. It supports reading RINEX 2 or 3 format observation data for GPS, GLONASS, Galileo, and BeiDou systems. When running the index calculation program, it automatically reads carrier phase data and receiver coordinates for all four navigation satellite systems, saving the corresponding MAT data in the specified folder.

The Sp3 selection box allows users to select the folder containing the satellite ephemeris files. By reading the standard exchange format (SP3) of the satellite orbits from the day before, the current day, and the following day, M_ISSION uses 9th-order Lagrange interpolation to calculate the satellite orbit information and save the data in MAT format.

The Lim input box allows users to set the cutoff angle to exclude low-quality data. The Cycle Slip Detection option enables or disables cycle slip detection. The System Selection option allows users to choose which satellite systems will be included in the calculation.

ROTI and AATR Factor Calculation

The calculation of ROTI and AATR factors requires only the setting of common parameters. After that, click the corresponding Run button. Upon completion of the program, the program runtime is displayed in the text box. During AATR calculation, both the instantaneous AATR parameter and RMSAATR are saved.

As an example, let’s use data from the YEL2 station for the index calculation demonstration. After selecting the observation and precise ephemeris files, set the cutoff angle to 30° and enable cycle slip detection, then check the four satellite systems: GPS, GLONASS (GLO), Galileo (GAL), and BeiDou (BDS). Clicking the ROTI button will start the corresponding calculation. The calculation time will be displayed within the software window. The resulting data is automatically stored in MAT file format in the following folders:

**D:\MATLAB\M_ISSION\resROTI** (for individual system ROTI data)

**D:\MATLAB\M_ISSION\resROTI\Multi_system_ROTI_in_one_mat** (for the integrated ROTI data from all four systems).

The storage folders and data formats are shown in Fig. 4 and Fig. 5.

Similarly, AATR data can be calculated. AATR will generate the AATR and RMSAATR data for each system, as well as for the integrated data from all four systems.

The storage paths and formats are the same as for ROTI.

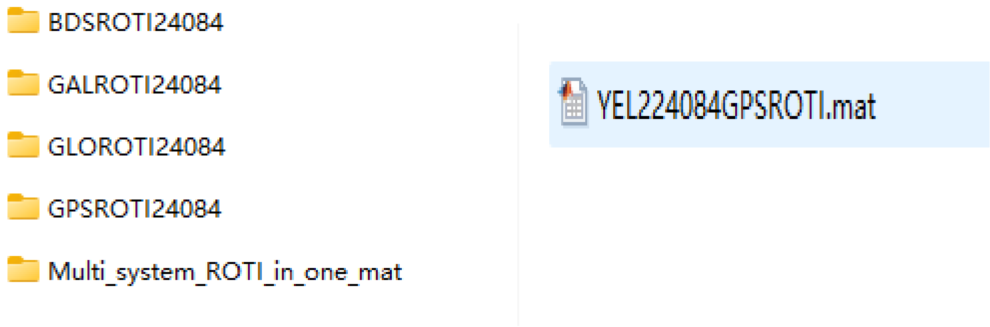
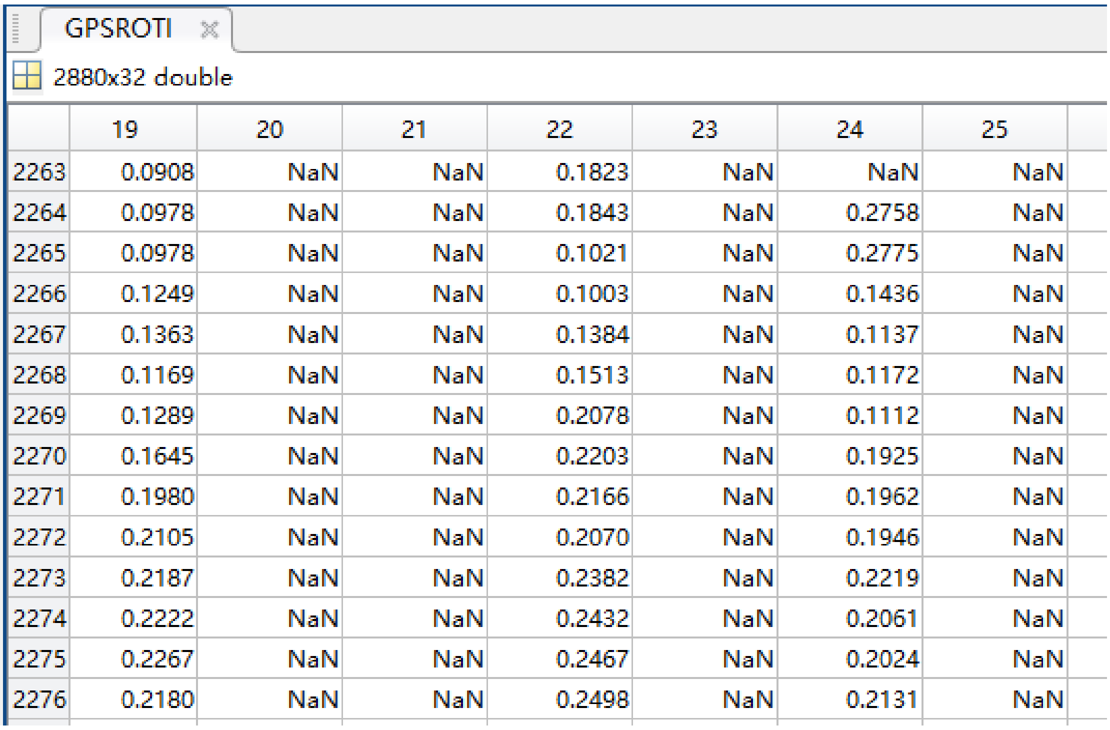



Fig. 4 ROTI Data File Storage Format



GPSROTI

2880x32 double

| | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|
| 2263 | 0.0908 | NaN | NaN | 0.1823 | NaN | NaN | NaN |
| 2264 | 0.0978 | NaN | NaN | 0.1843 | NaN | 0.2758 | NaN |
| 2265 | 0.0978 | NaN | NaN | 0.1021 | NaN | 0.2775 | NaN |
| 2266 | 0.1249 | NaN | NaN | 0.1003 | NaN | 0.1436 | NaN |
| 2267 | 0.1363 | NaN | NaN | 0.1384 | NaN | 0.1137 | NaN |
| 2268 | 0.1169 | NaN | NaN | 0.1513 | NaN | 0.1172 | NaN |
| 2269 | 0.1289 | NaN | NaN | 0.2078 | NaN | 0.1112 | NaN |
| 2270 | 0.1645 | NaN | NaN | 0.2203 | NaN | 0.1925 | NaN |
| 2271 | 0.1980 | NaN | NaN | 0.2166 | NaN | 0.1962 | NaN |
| 2272 | 0.2105 | NaN | NaN | 0.2070 | NaN | 0.1946 | NaN |
| 2273 | 0.2187 | NaN | NaN | 0.2382 | NaN | 0.2219 | NaN |
| 2274 | 0.2222 | NaN | NaN | 0.2432 | NaN | 0.2061 | NaN |
| 2275 | 0.2267 | NaN | NaN | 0.2467 | NaN | 0.2024 | NaN |
| 2276 | 0.2180 | NaN | NaN | 0.2498 | NaN | 0.2131 | NaN |

Fig. 5 ROTI Data Format

DIXSG Factor

The calculation of the DIXSG index requires setting the latitude and longitude range of the data, the unit size of the grid, as well as sensitivity and step size to reduce the runtime, making grid division and plotting easier. The default setting is for a global range. As an example, for the data of 30 stations in Canada on March 24, 2024, the cutoff angle is set to 30° with cycle slip detection enabled, and the four satellite systems (GPS, GLONASS, Galileo, and BeiDou) are selected. The longitude range is set from -142° to -52°, the latitude range is from 37° to 73°, and the grid size is set to 1° ×1°. The sensitivity is set to 5, incrementing from 100 to 250.

Upon running the program, the results are stored in **D:\MATLAB\M_ISSION\resDIXSG\GPSDIXSG24084**, with similar storage paths for the other satellite navigation system results. The results are divided into regional DIXSG data and global DIXSGp data. The parameter settings and storage path format are shown in Fig. 6 and Fig. 7.

It should be noted that the software calculates DIXSG by constraining the distance between effective piercing points to 1000 km. While this threshold is applicable to both global and regional scales, it is not a fixed parameter and requires adjustment based on factors such as station network configuration and data quality. In the Appendix of Part VI of the User Manual, we have provided partial experimental explanations specifically addressing this scenario.

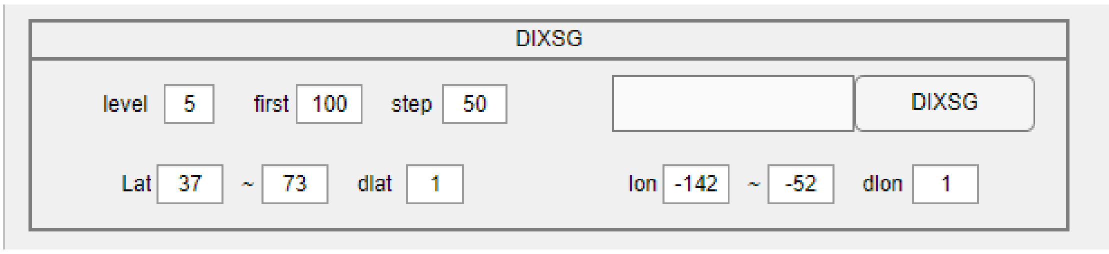



Fig. 6 DIXSG Calculation Interface for Data from 30 Stations

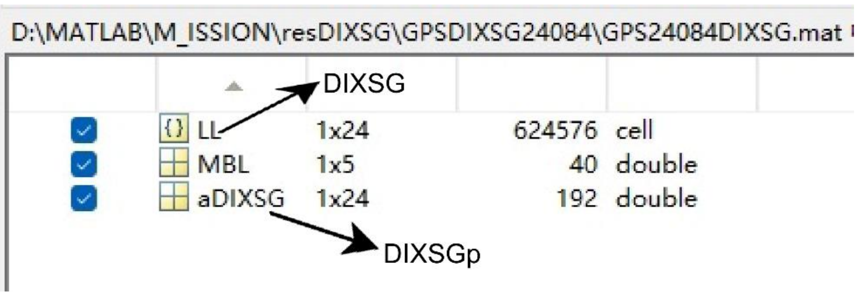



Fig. 7 DIXSG and DIXSGp Data Storage Paths and Format

$\boldsymbol{\sigma_{\phi f}}$ Factor

The calculation of the $\sigma_{\phi f}$ factor requires the additional selection of the precise clock file and antenna phase correction file. Furthermore, the phase carrier band should be selected as either L1 or L2. Next, for the sixth-order band-pass Butterworth filter, users must directly specify the cutoff frequencies (e.g., in Hz) that define the passband.

The generated $\sigma_{\phi f}$ result data is stored in the folder **D:\MATLAB\M_ISSION\resSIGMAPHI\GPSsigmaphi24084**. The data format is similar to that of ROTI and AATR, and will not be further elaborated here.

### （2） Factor Visualization Interface

After the ionospheric scintillation factor calculations are completed, time-series trend plots can be generated in this interface. First, select the path to the generated factor data and click the "Plot" button. For ROTI, AATR, and $\sigma_{\phi f}$ indices, the corresponding valid data and satellite identifiers will be displayed. You can choose the valid satellite results based on the displayed information. The numbers are separated by commas (e.g., 2, 3, 4) or you can input [2 4] to display the results for satellites 2, 3, and 4 individually for that specific index.

For example, using the YEL2 station data from March 24, 2024, and data from 30 stations in the region, the visualization results for ROTI, RMSAATR, DIXSGp, and DIXSG are shown in Fig. 8 to Fig. 11. The trend plots for AATR and $\sigma_{\phi f}$ are similar to those for ROTI.

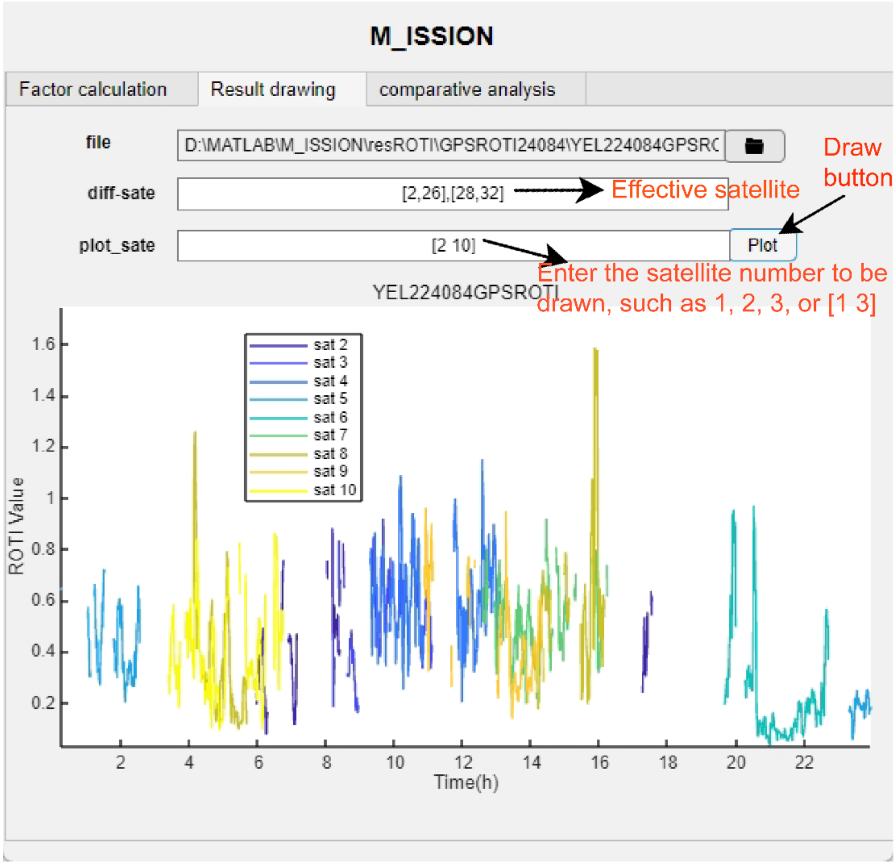



Fig. 8 Trend of ROTI Factor for Satellites 2-10

Fig. 9 Trend of RMSAATR Index

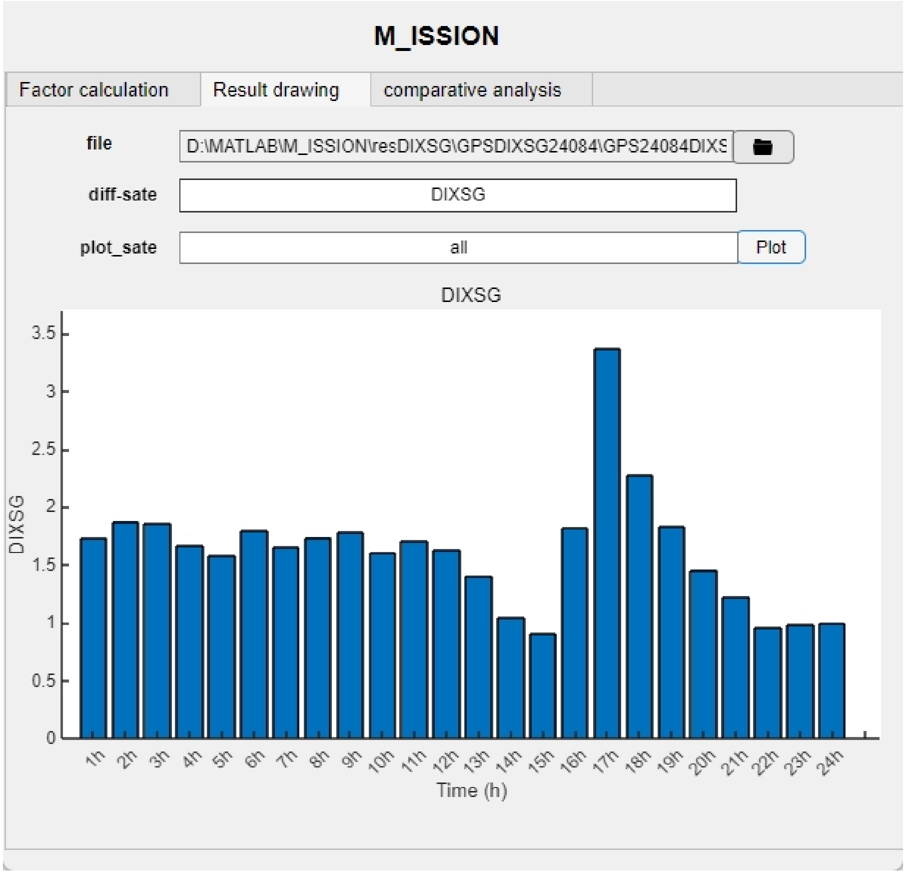



Fig. 10 Global Histogram of DIXSGp Factor

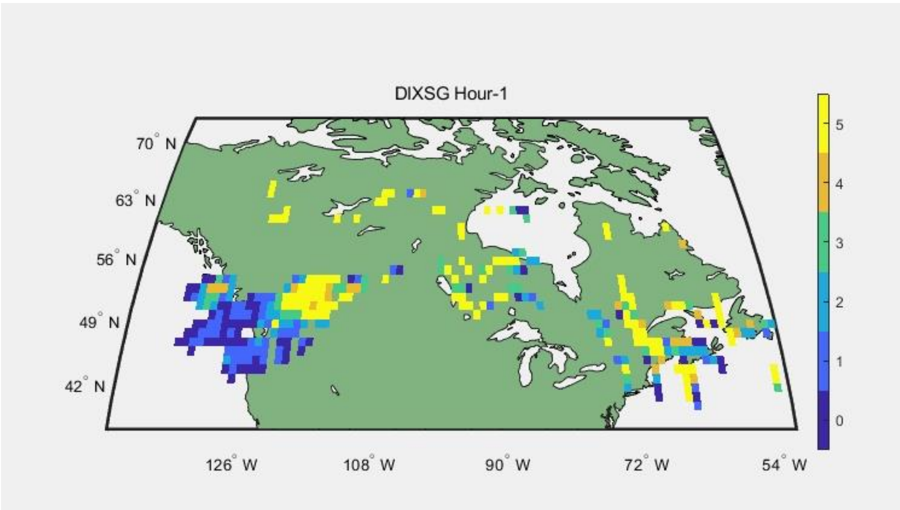



Fig. 11 First Hour Trend Map of DIXSG Factor for the Region

### （3）Scintillation Factor Analysis Interface

The Scintillation Factor Analysis Interface is divided into three submodules: Multi-

System Index Validation, Multi-Index Validation, and Regional ROTI and DIXSG Validation. The first submodule, Multi-System Index Validation, takes the ROTI data from the YEL2 station on March 24, 2024, as an example. The mat data containing the results from all four systems is selected. After the data selection, the indicators for the valid navigation systems will turn green. At this point, you can either check or uncheck the corresponding system with the green indicator, and you can also set the time interval for the data display. The results are shown in Figure Fig. 12.

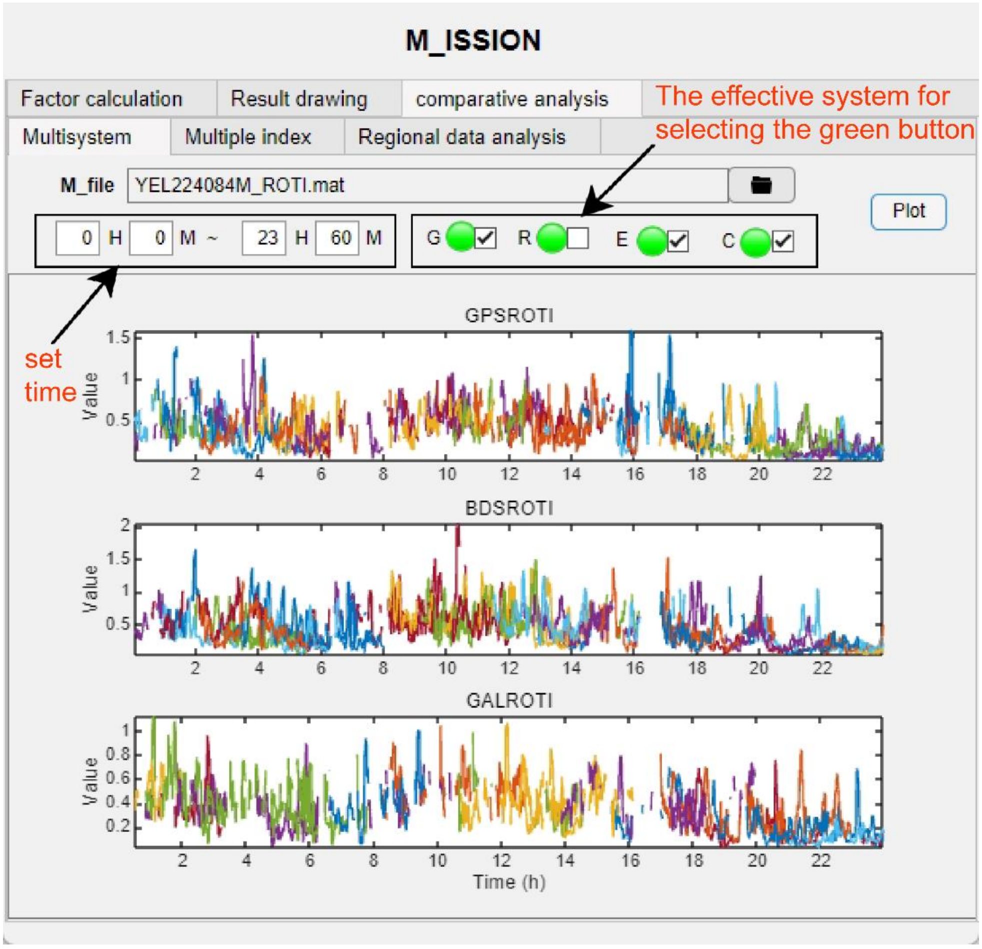



Fig. 12 ROTI Multi-System Comparison Analysis

The second submodule is Multi-Index Validation, where up to four indices can be selected for cross-validation. After selecting the relevant indices, click "Run" to execute the process. Additionally, selections can be canceled by clicking the "×" symbol. Using the YEL2 station data from March 24, 2024, as an example, the results are shown in FigureFig. 13.

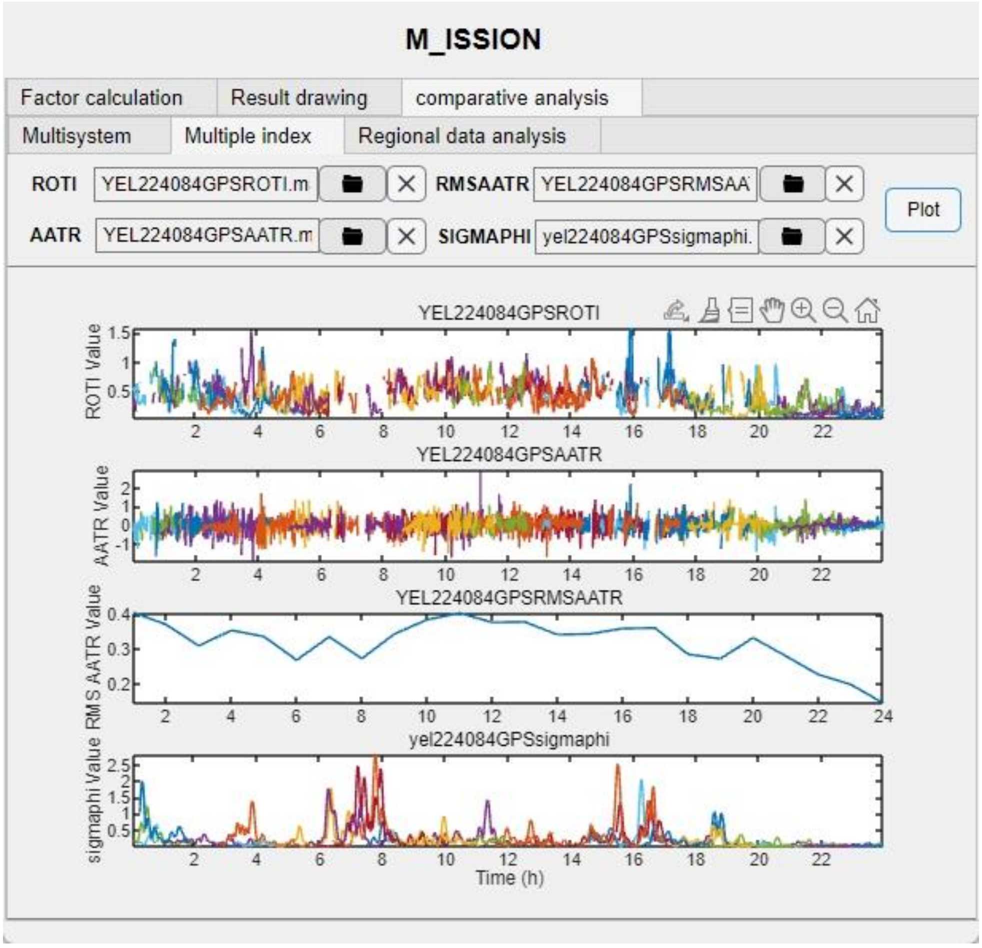



Fig. 13 Cross-Comparison of Four Indices

The third submodule is Regional DIXSG and ROTI Validation. This module has two functions: the first function involves selecting the folder where the ROTI data generated by the ionospheric scintillation factor calculation module is stored. Users can set the latitude and longitude range and grid size, and run the program to obtain the regional ROTI data. The generated regional ROTI data will be stored in the **D:\MATLAB\M_ISSION\resROTI\regionalROTI** folder. The second function allows users to select the generated regional ROTI data and DIXSG data. After inputting the corresponding time (1-24 hours) and clicking "Run," regional validation can be performed. The module interface and results are shown in Figures Fig. 14 and Fig. 15.

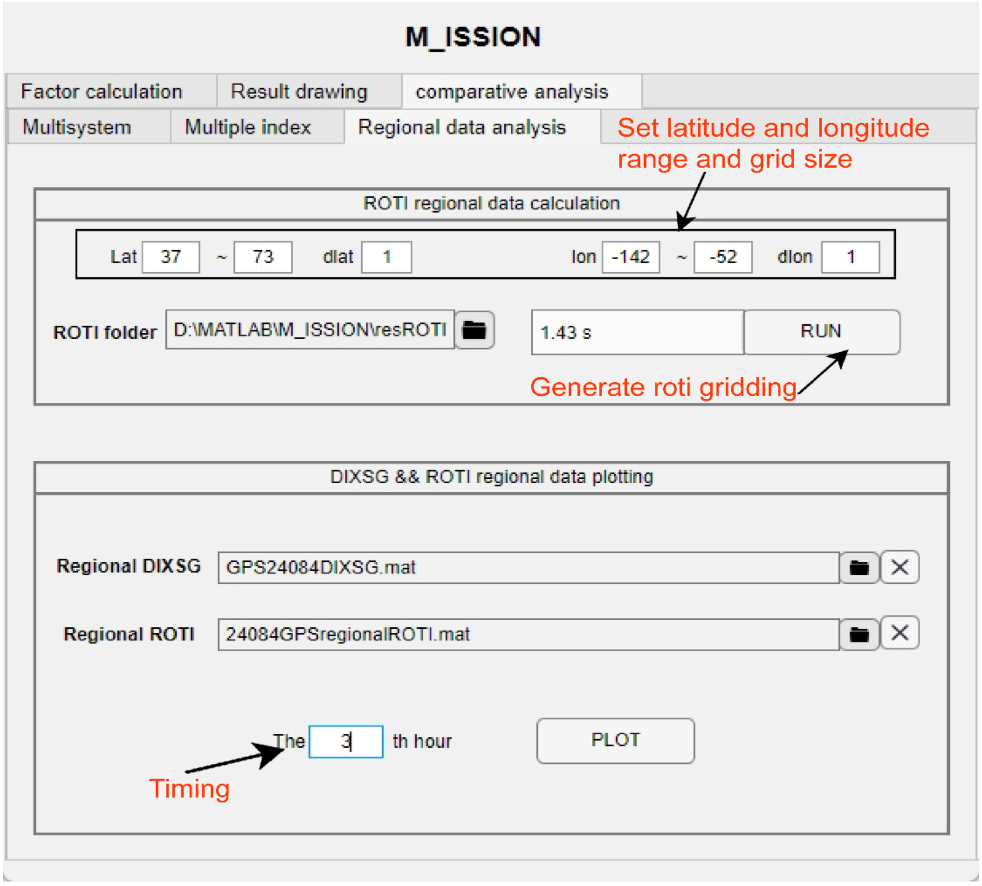



Fig. 14 Running Interface and Related Settings

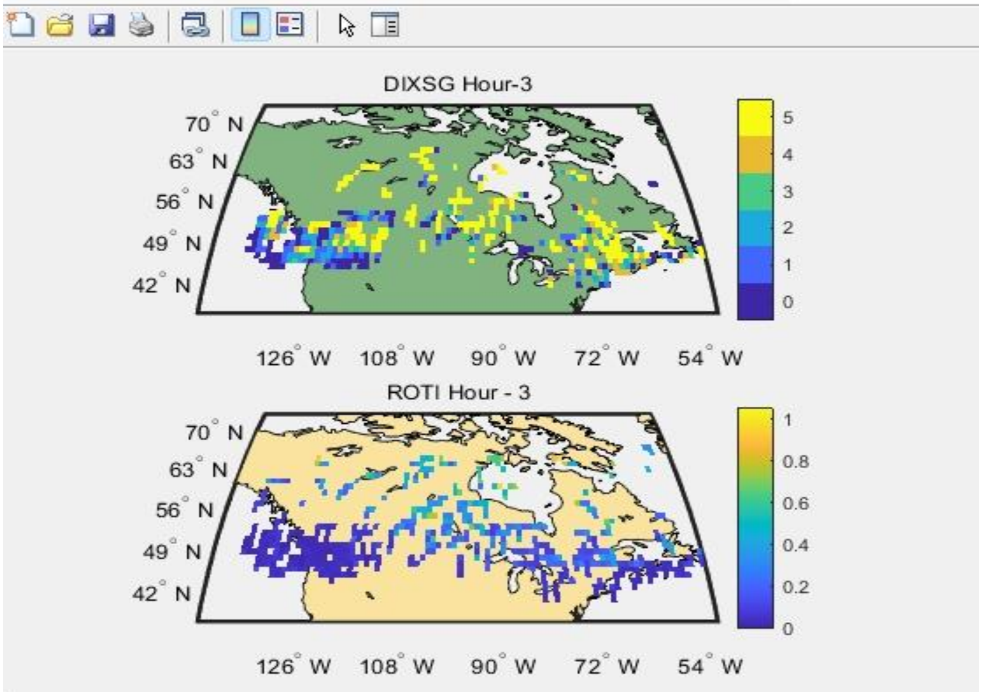



Fig. 15 3rd Hour GPS DIXSG (Top) and GPS ROTI (Bottom) Regional Validation

## 4. Example Data

To help users quickly master the usage of M_ISSION software, we provide sample data, including observation data from the four-system observation station YEL2 in the Canadian region on March 24, 2024 for four-system index calculation experiments, and observation data from 6 other stations for calculating the regional DIXSG index. The longitude range is set to -140° to -105°, and the latitude range is set to 42° to 56°. We also provide precise ephemeris files for the day before, the current day, and the day after the observation time; antenna phase files; and precise clock difference files. The details are shown in Table 2, and the sample data is included in the example folder of the software package. In actual calculations, the DIXSG index calculation for a region should include data from more stations to provide sufficient data coverage. In this sample data, only a small regional range was selected for demonstration and convenient data upload purposes.

**Table 2** Experimental Data

| Files | Name |
|---|---|
| Observation | yel20840.24o,albh0840.24o,nano0840.24o,bamf0840.24o, |
| | uclu0840.24o, holb0840.24o, chwk0840.24o |
| Orbit | COD0MGXFIN_20240830000_01D_05M_ORB.SP3 |
| | COD0MGXFIN_20240840000_01D_05M_ORB.SP3 |
| | COD0MGXFIN_20240850000_01D_05M_ORB.SP3 |
| Clock | COD0MGXFIN_20240840000_01D_30S_CLK.CLK |
| Antenna | igs20.atx |

## 5. Acknowledgments

We would like to thank IGS (https://www.igs.org/data-products-overview/), CHAIN (http://chain.physics.unb.ca/chain/pages/data_download), and CODE, CDDIS MGEX product archives (https://cddis.nasa.gov/archive/gnss/products), as well as other organizations for providing the data and products. The software draws on the design concepts and open-source code from the GPS Solutions Toolbox (https://geodesy.noaa.gov/gps-toolbox/) . Special thanks go to the authors of the following software: M_GIM (https://doi.org/10.1007/s10291-022-01370-9), authored by Chunyuan Zhou, Ling Yang, Bofeng Li, and Timo Balz; PPPH (https://doi.org/10.1007/s10291-018-0777-z), authored by Berkay Bahadur and Metin Nohutcu; and GLAB (https://doi.org/10.1109/NAVITEC.2018.8642707), authored by Ibáñez D., Rovira-García A., Sanz J., Juan JM., Gonzalez-Casado G., Jimenez-Baños D., López-Echazarreta C., and Lapin I.

## 6. Appendix

### Selected Experiments on DIXSG Parameter D Selection

We utilized data from the Canadian region on March 24, 2024, to conduct experiments addressing the distance selection issue in DIXSG factor validation prior to software construction, as illustrated in Figure 16. Selected distances D were 200, 500, 1000, 2000, and 3000 km (d < D). The results indicate that DIXSGp values across all distance ranges generally exhibited a negative correlation with Dst value variations. At the 12th time interval, the DIXSGp value for the 1000 km distance displayed a declining trend, contrary to the Dst value changes, while other distances showed rising trends consistent with the Dst index. Overall, DIXSGp values calculated using the 1000 km distance demonstrated higher magnitudes during magnetic storms compared to other distances, yet approached zero-state more closely during subsequent geomagnetic quiet periods. This suggests enhanced representation of rapid variations and superior sensitivity compared to other distance thresholds.

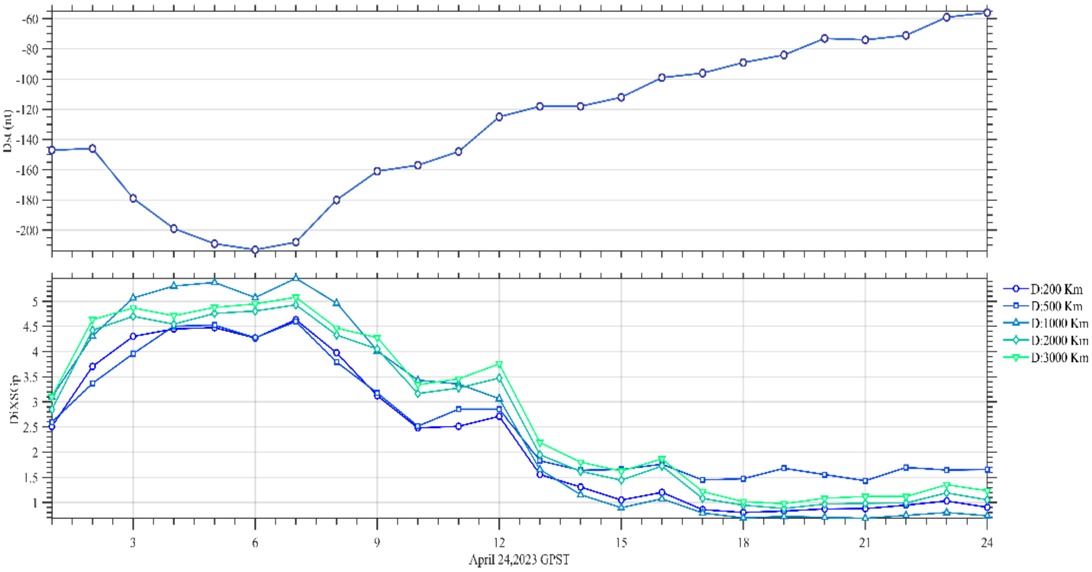



Fig. 16 The Dst index and DIXSGp values calculated under varying distance parameters

In the software, we have designed the distance threshold as 1000 km, and the calculated DIXSG values were compared with ROTI values as shown in Figures 17 and 18. DIXSG values under distances of 200, 500, 2000, and 3000 km are presented in

Figures 19 to 22. The results demonstrate similar variation patterns to those mentioned earlier. Using ROTI as a reference, excessively small D values result in an excessively sparse DIXSG distribution, while overly large D parameters induce spurious overestimation of values. This observation aligns with our earlier analysis of distance-dependent sensitivity characteristics.

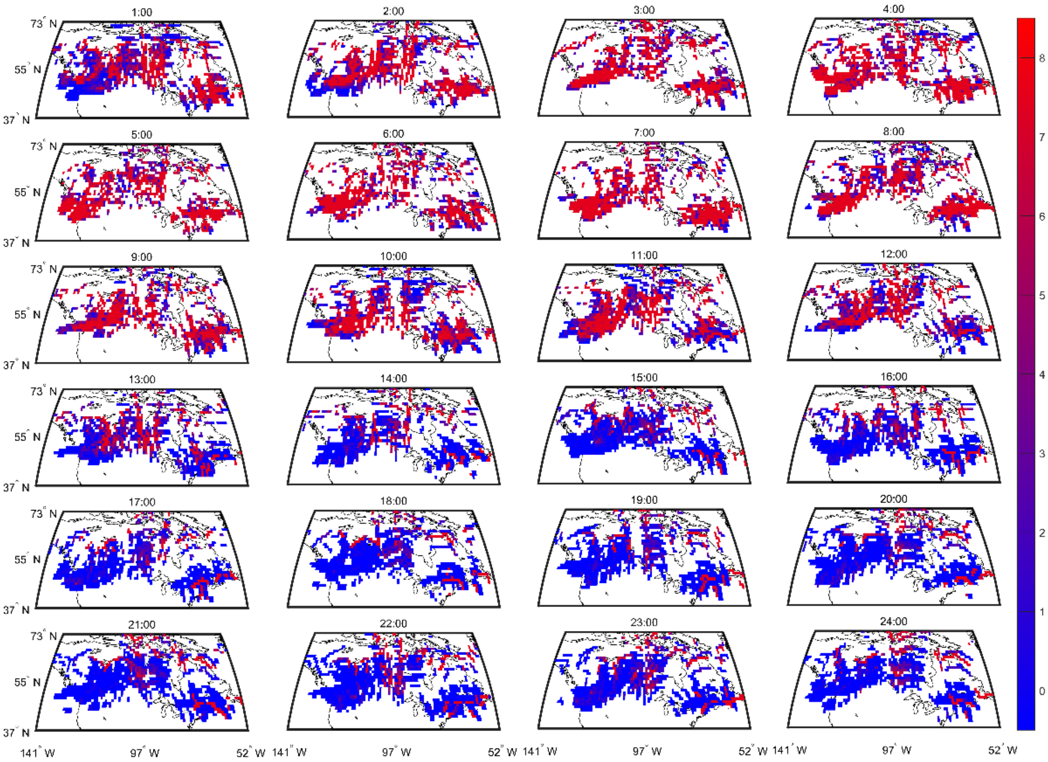



Fig. 17 D=1000km，DIXSG variation in the Canadian region from 1:00 to 24:00 (UTC) o n April 24, 2023.

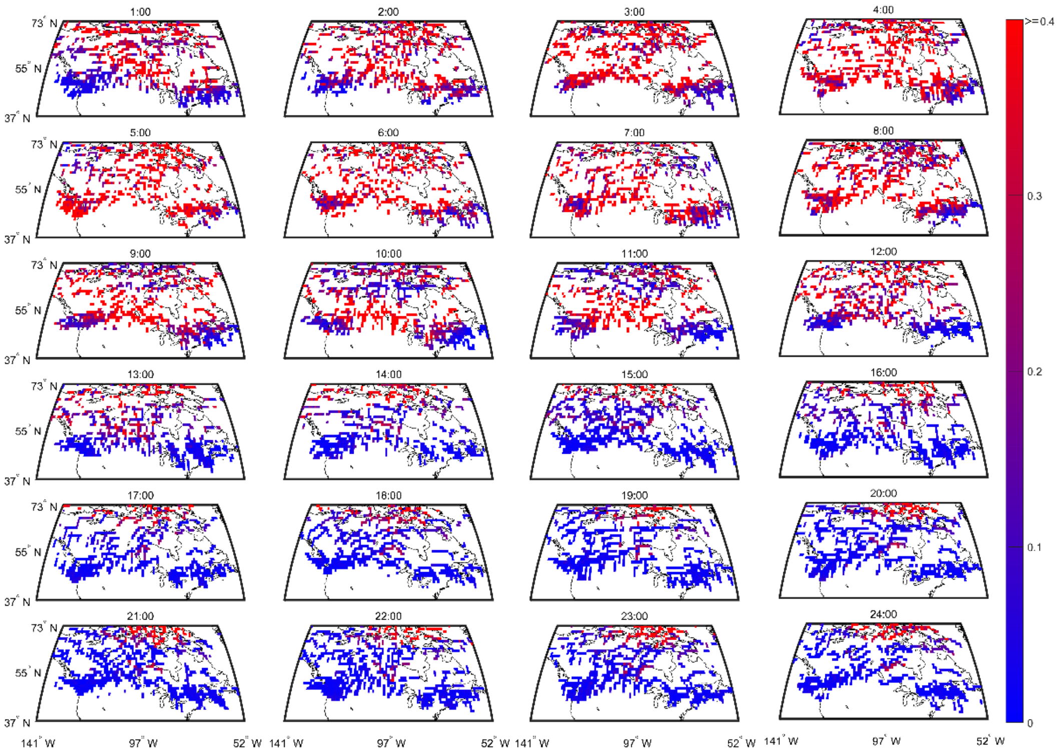



Fig. 18 ROTI variation in the Canadian region from 1:00 to 24:00 (UTC) on April 24, 2023

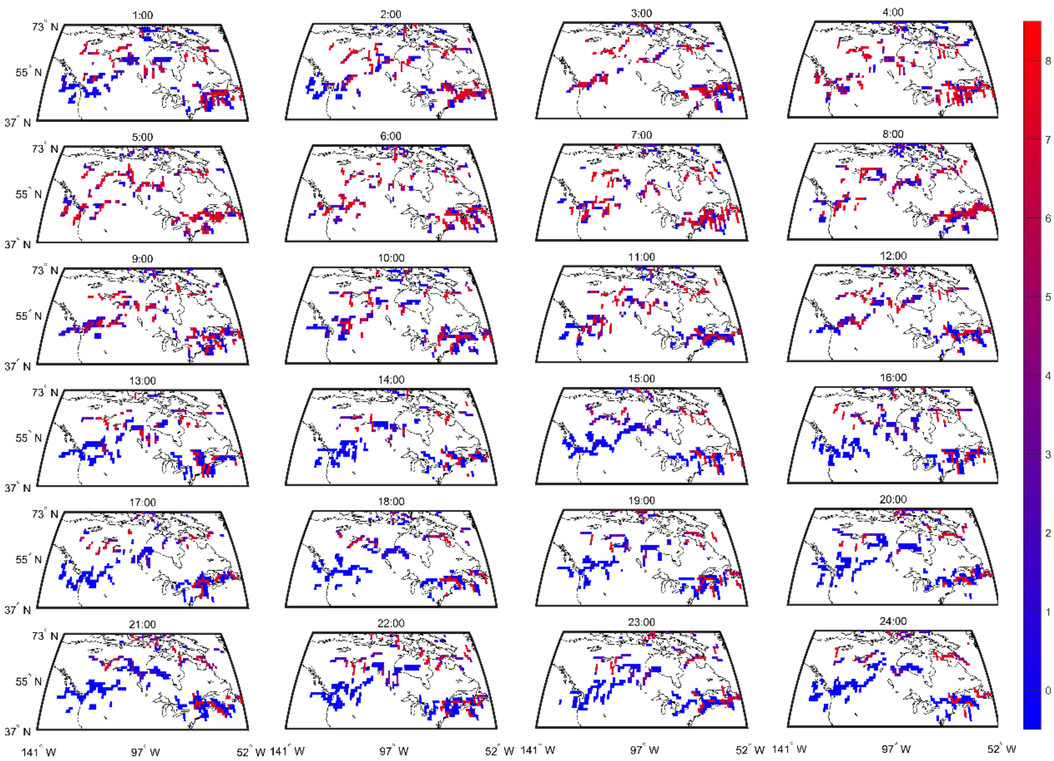



Fig. 19 D=200km，DIXSG variation in the Canadian region from 1:00 to 24:00 (UTC) on April 24, 2023.

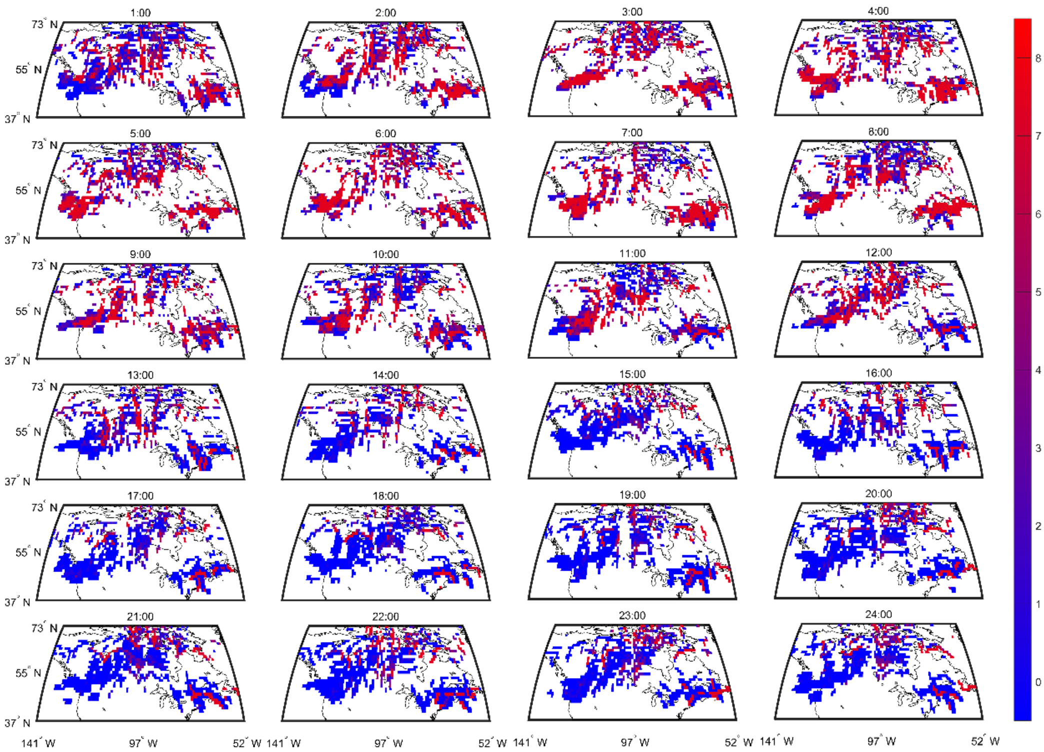


Fig. 20 D=500km，DIXSG variation in the Canadian region from 1:00 to 24:00 (UTC) on April 24, 2023.

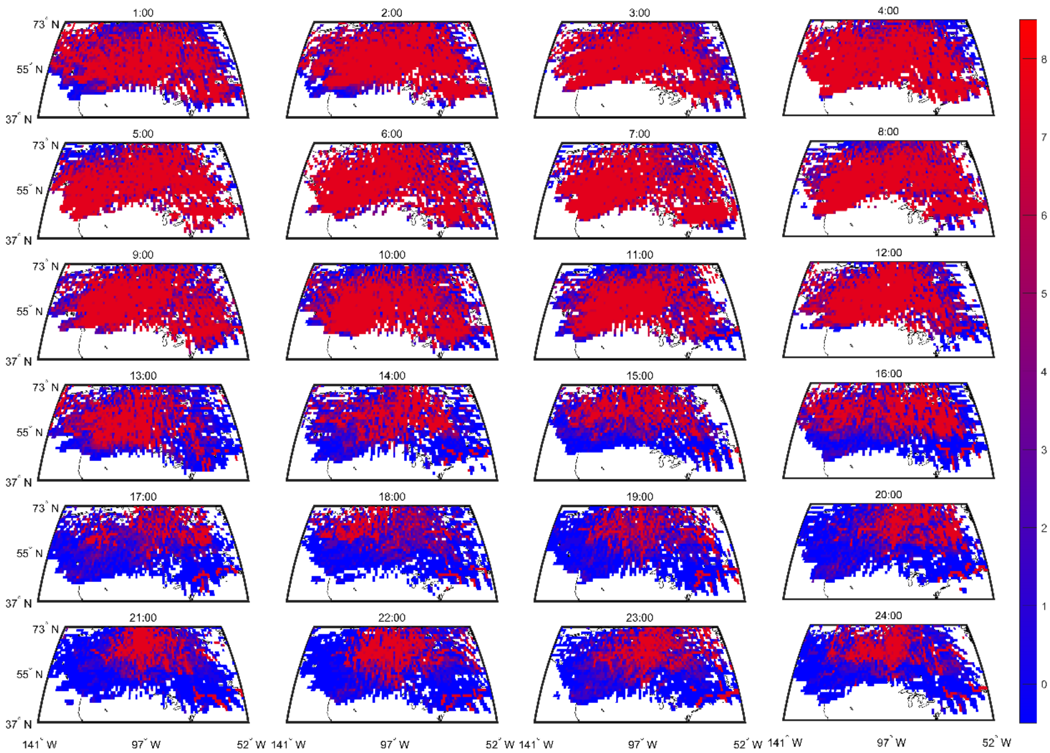


Fig. 21 D=2000km，DIXSG variation in the Canadian region from 1:00 to 24:00 (UTC) on April 24, 2023.

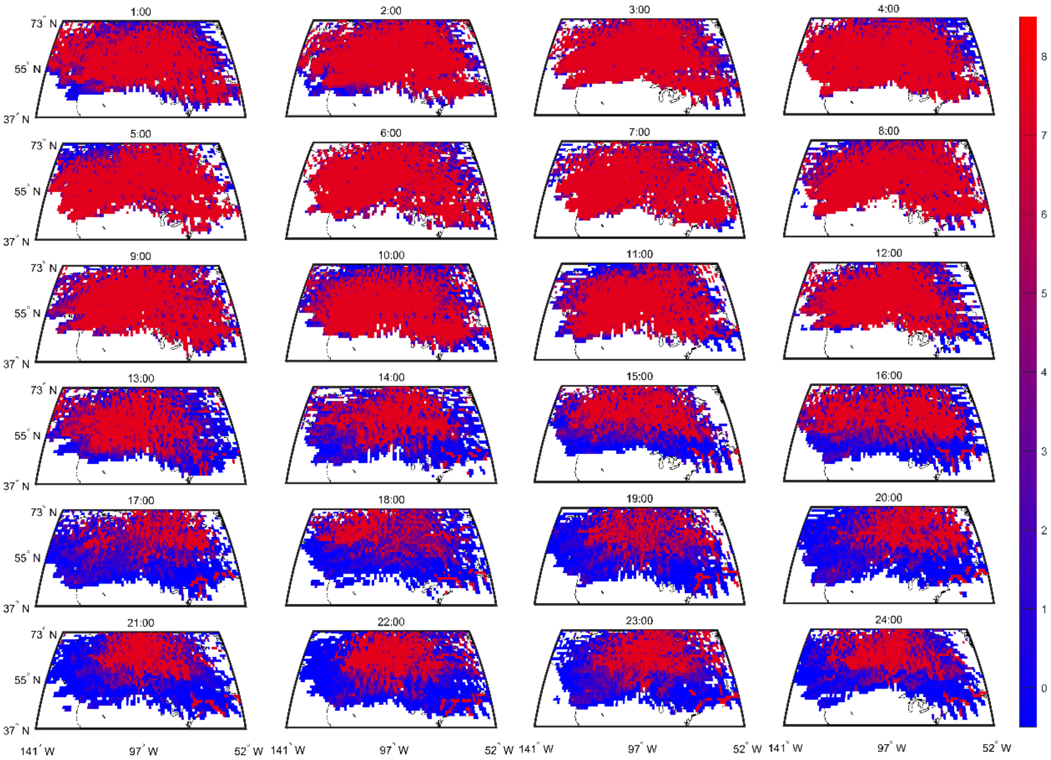



Fig. 22 D=3000km，DIXSG variation in the Canadian region from 1:00 to 24:00 (UTC) on April 24, 2023.

In addition, we conducted analogous analyses on global datasets to identify D parameter selections with optimal regional and global compatibility. Below we present partial global validation results, using January 1, 2025 as an example. Notably, Figure 24 employs over 400 global stations for computation (D=1000 km), while Figure 25 utilizes our curated network of 80 stations (D=5000 km). This approach explicitly considers the influence of reference station distribution and configuration on parameter selection. The results demonstrate that the 1000 km threshold achieves favorable compatibility under dense station coverage, whereas sparser networks may adopt larger D values to enhance spatial resolution. However, larger D values risk introducing extraneous noise that obscures precise characterization of ionospheric gradient variations. Therefore, D parameter selection should be dynamically adapted based on station distribution patterns and data quality metrics. In our software, we recommend the 1000 km distance threshold as a compatible default while retaining flexibility for context-specific adjustments.

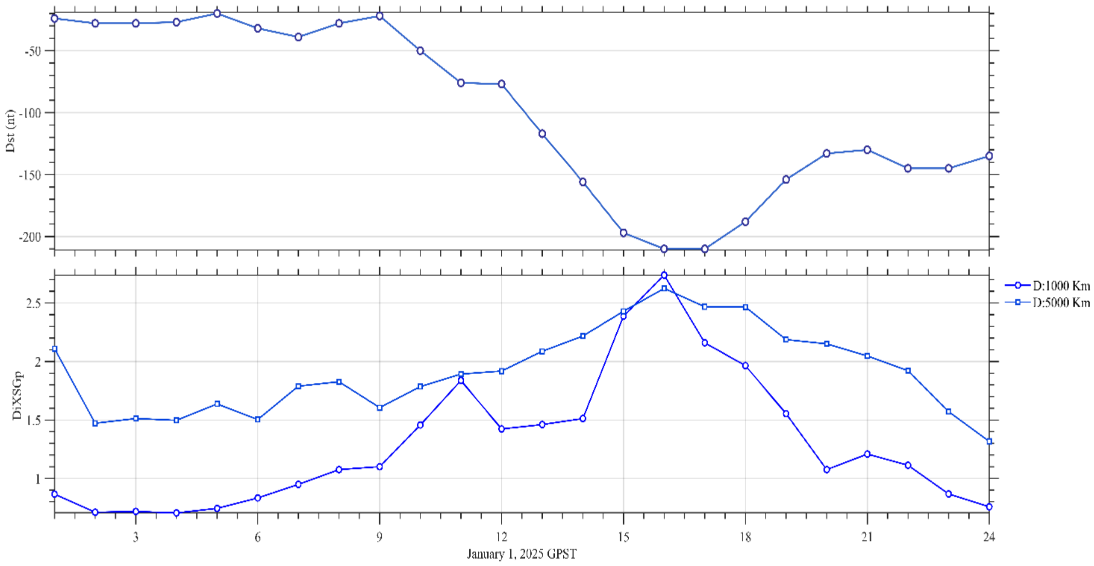



Fig. 23 On January 1, 2025, the Dst index and DIXSGp index

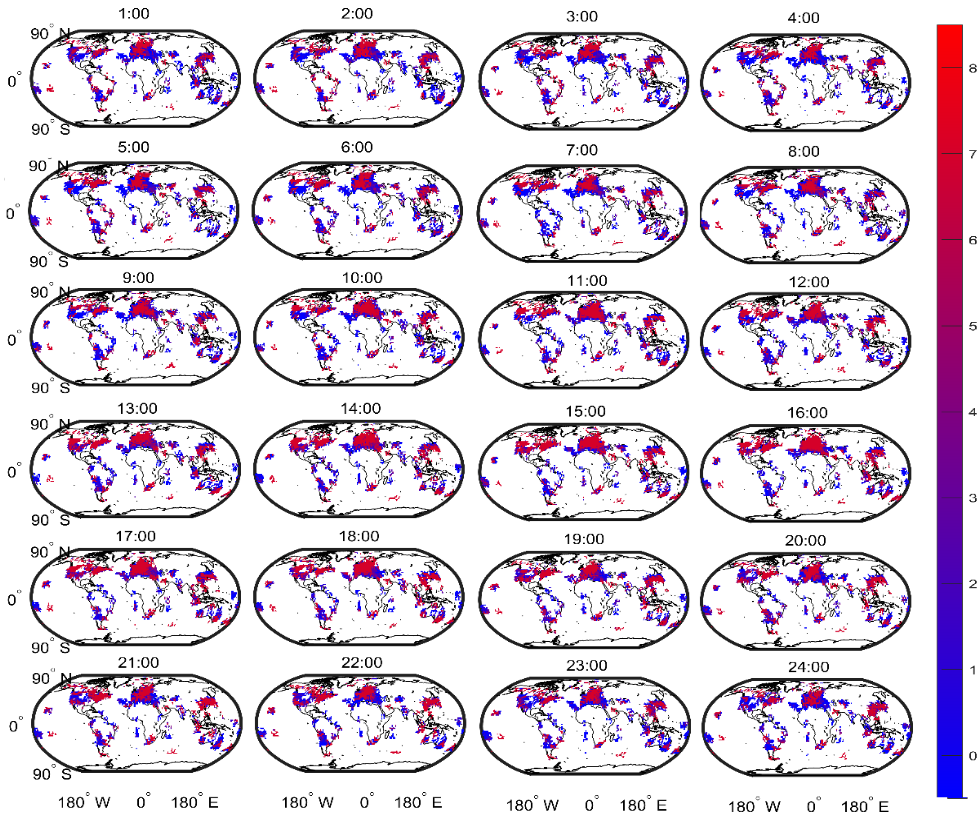



Fig. 24 400 sites，D=1000km，24-hour Globally Computed DIXSG Map

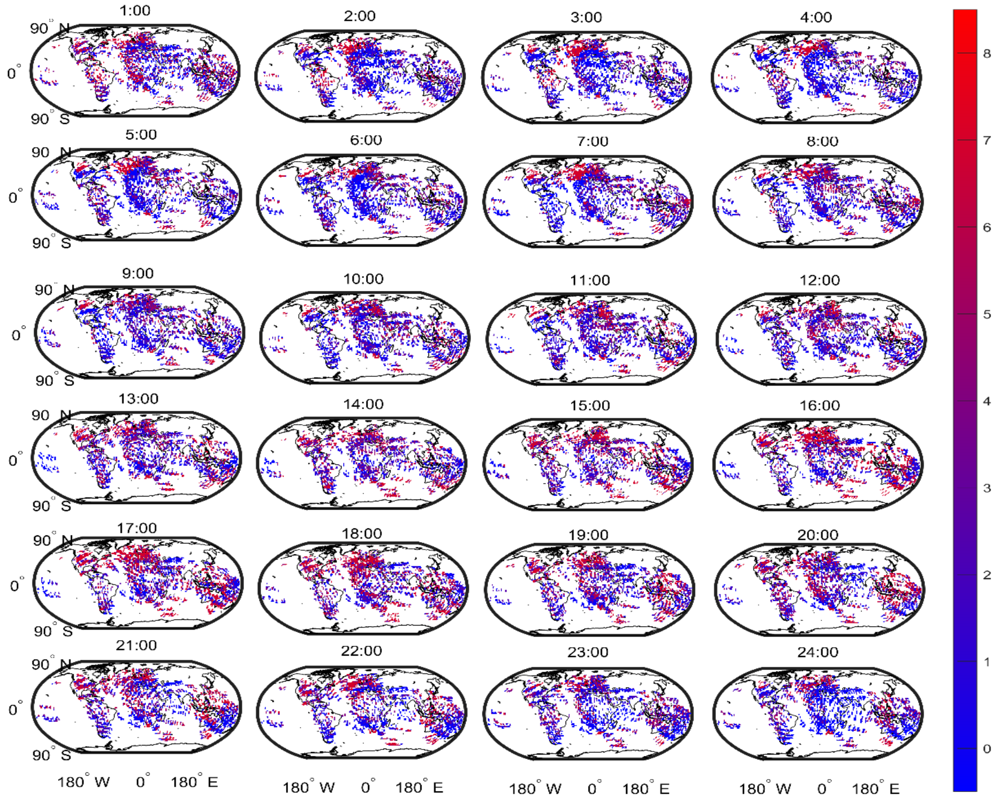



Fig. 25 80 sites，D=5000km，24-hour Globally Computed DIXSG Map