M_ISSION：a MATLAB-based software for multi-GNSS Ionospheric scintil lation index calculation and analysis

User Manual

written by Peicheng Zhang and Dongsheng Zhao

China University of Mining and Technology

December 2024

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1. Introduction

Dense and accurate monitoring of ionospheric scintillation is crucial for underst anding the patterns and driving mechanisms of ionospheric disturbances, and ho lds significant importance for enhancing the reliability and robustness of GNSS positioning and communication systems. Research on ionospheric scintillation in dices derived from geodetic receivers represents one of the key approaches to achieving dense monitoring of ionospheric scintillation. In recent years, numero us scholars have proposed various ionospheric scintillation indices applicable to geodetic receivers. However, there remains a lack of an open-source software p latform capable of integrating multiple ionospheric indices. This limitation indir ectly 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, inc luding ROTI, IAATR, AATR, DIXSG, and $\sigma_{\phi f}$, using 30-second interval obser vation data from geodetic receivers. The software supports batch processing of data from four major satellite navigation systems: GPS, GLONASS, Galileo, an d BDS. Additionally, it enables graphical analysis of regional ionospheric distur bances 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 is recommended to install it in a dedicated directory on a non-system drive (e.g., **D:\MATLAB\M_ISSION** on the D drive) 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 f olders categorized by type and date. Folder names should clearly indicate the d ate 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 elevation angle and azimuth data, cROT, ivtall s hould be stored in MAT format in

D:\MATLAB\M_ISSION\ivELE\24084

D:\MATLAB\M_ISSION\ivELE\cROT

D:\MATLAB\M_ISSION\ivELE\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 t o add the folder containing the M_ISSION source code to the MATLAB searc h 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:\MATLA B\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.

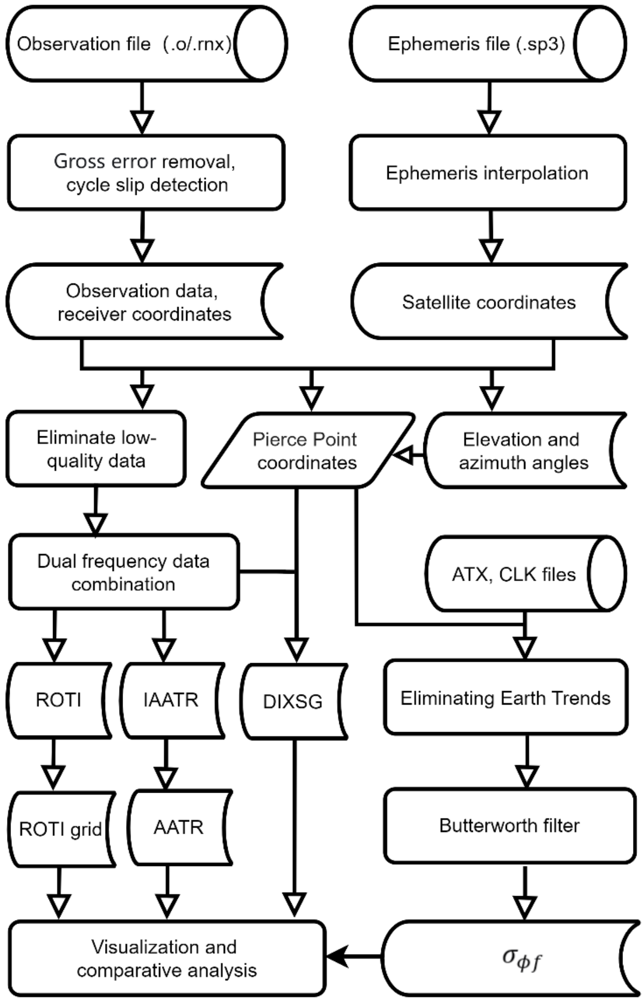

Fig. 1 Implementation flow of M_ISSION software

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 provid es 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.

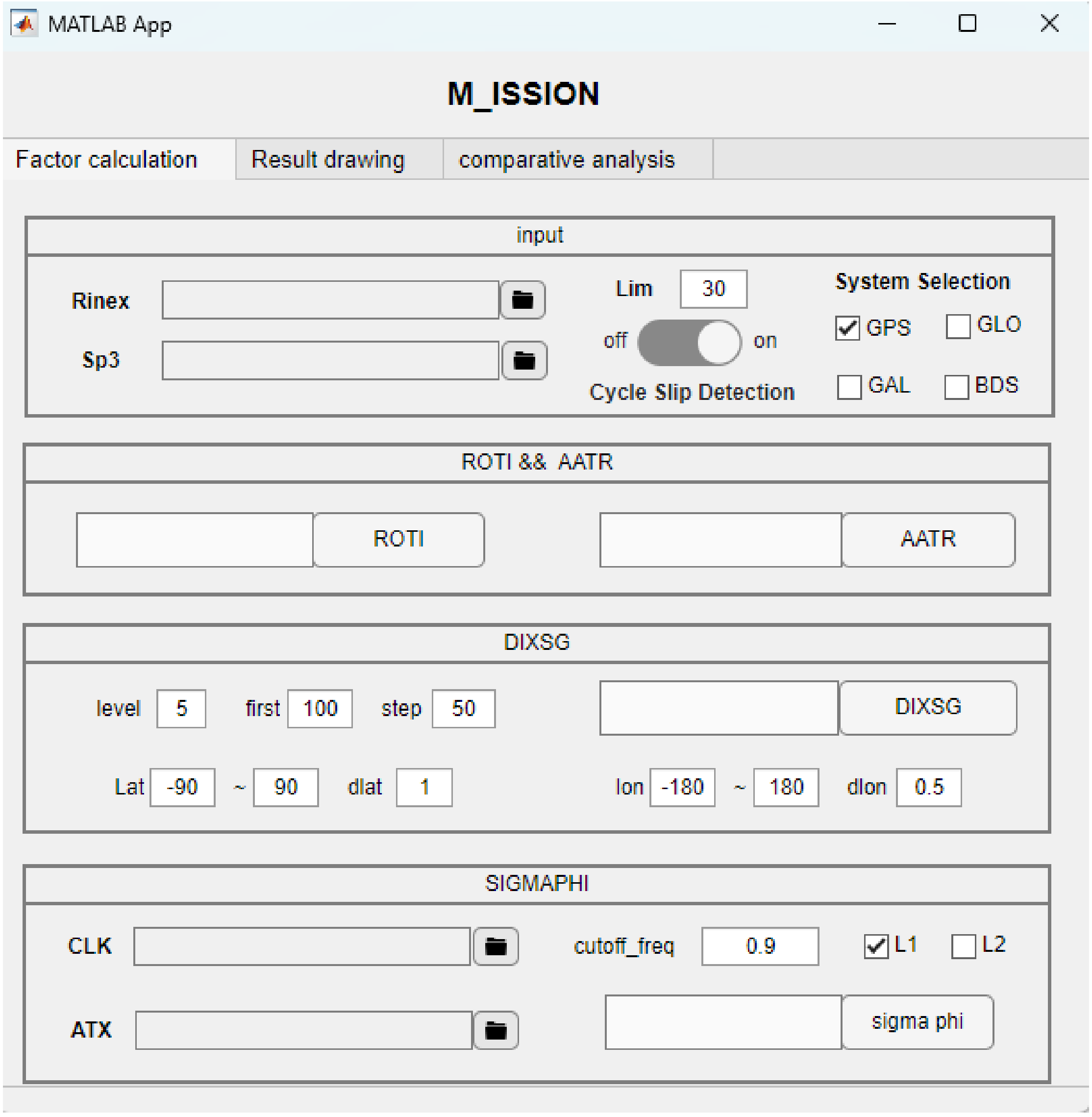

Fig. 2 M_ISSION Software Main Interface

（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 sci ntillation factor calculation, as shown in Fig. 3. During the calculation process, the first step is to select the path of the required data files. For calculating R OTI, AATR, and DIXSG, observation data files (.o/.rnx) and precise ephemeris files (.sp3) are needed. Additionally, For the $\sigma_{\phi f}$ calculation, it is necessary t o additionally include the clock bias files (.clk) and antenna phase files (.atx). Then, parameter settings need to be configured, including cutoff angle, satellite system selection, and cycle slip detection options. Furthermore, for DIXSG calc ulation, latitude and longitude range, as well as sensitivity level, need to be se t. For the $\sigma_{\phi f}$ calculation, users must select the L-band to be calculated and s pecify the normalized cutoff frequency for the Butterworth filter.

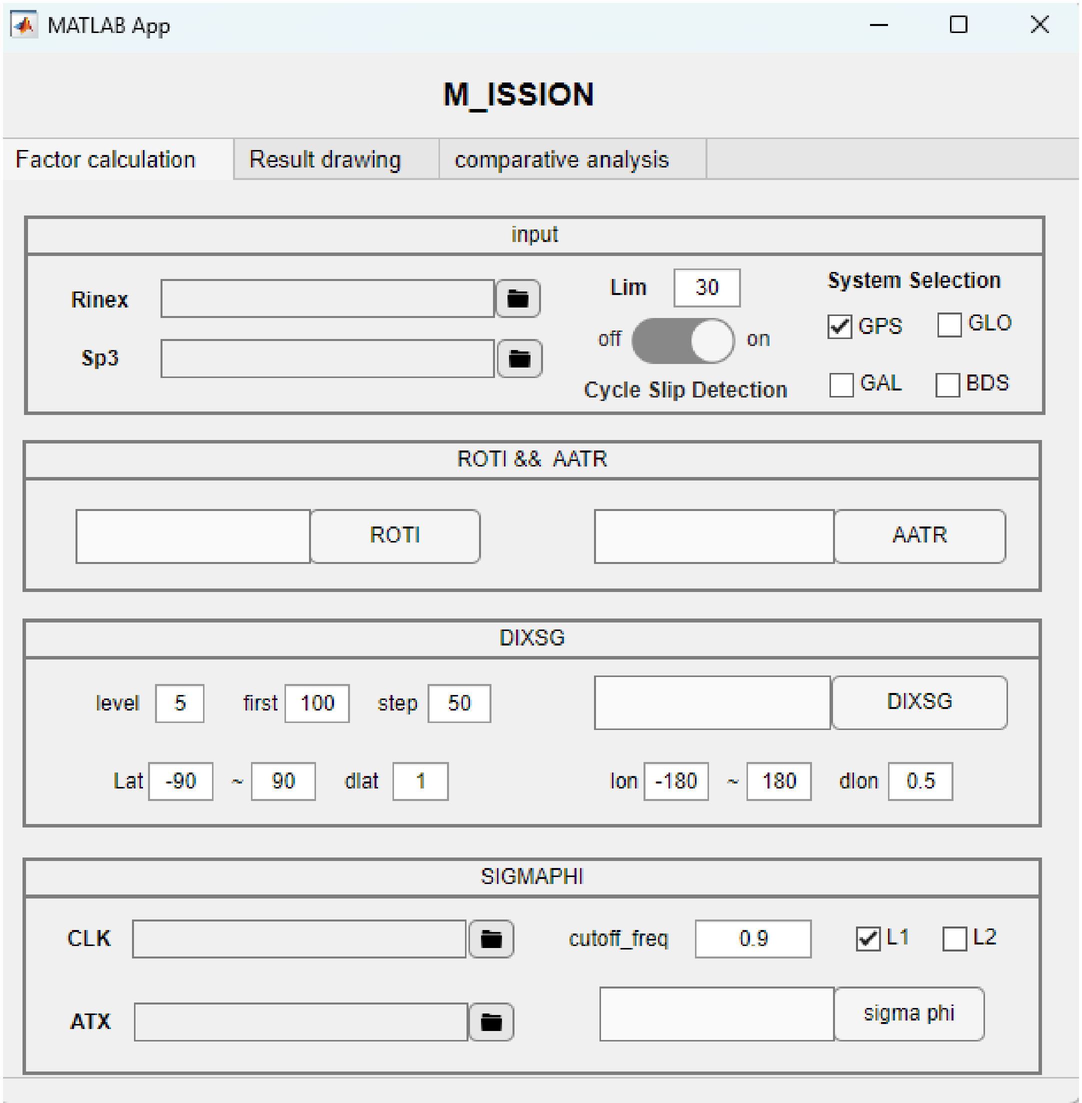

Fig. 3 Ionospheric Scintillation Factor Calculation Interface

Common Parameter Settings

In M_ISSION, the Rinex selection box allows users to choose the folder conta ining the observation data. It supports reading RINEX 2 or 3 format observatio n data for GPS, GLONASS, Galileo, and BeiDou systems. When running the i ndex 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 sate llite ephemeris files. By reading the standard exchange format (SP3) of the sat ellite orbits from the day before, the current day, and the following day, M_IS SION uses 9th-order Lagrange interpolation to calculate the satellite orbit infor mation and save the data in MAT format.

The Lim input box allows users to set the cutoff angle to exclude low-qu ality data. The Cycle Slip Detection option enables or disables cycle slip detec tion. The System Selection option allows users to choose which satellite syste ms will be included in the calculation.

ROTI and AATR Factor Calculation

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

As an example, let’s use data from the YEL2 station for the index calcu lation demonstration. After selecting the observation and precise ephemeris files, set the cutoff angle to 30° and enable cycle slip detection, then check the f our satellite systems: GPS, GLONASS (GLO), Galileo (GAL), and BeiDou (B

DS). 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.

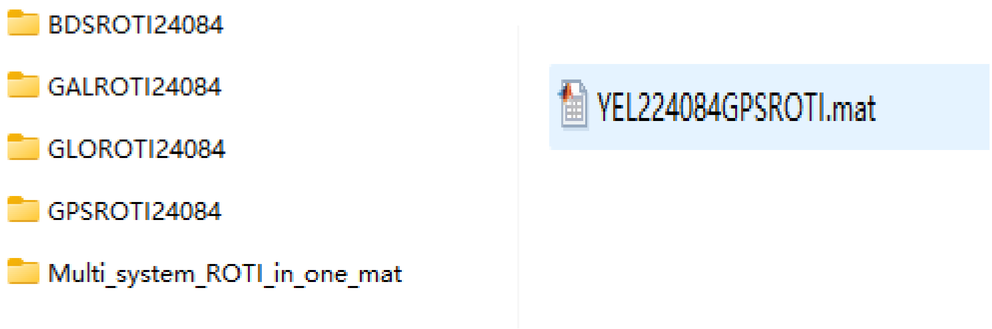

Fig. 4 ROTI Data File Storage Format

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.

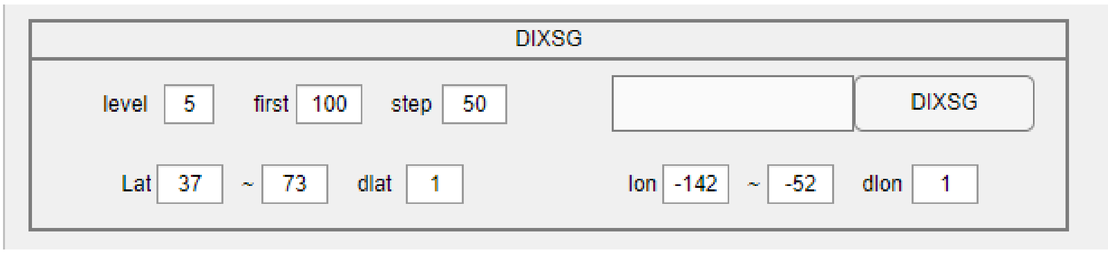

Fig. 6 DIXSG Calculation Interface for Data from 30 Stations

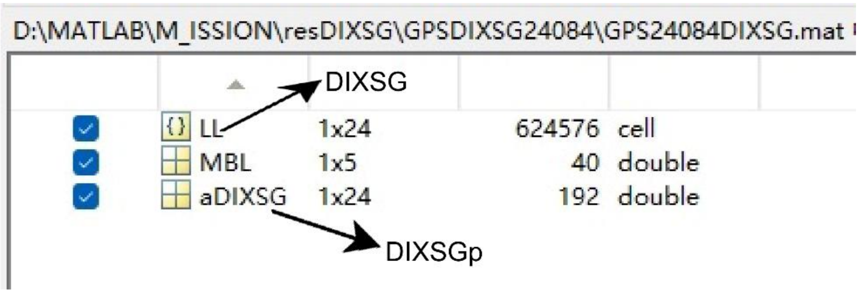

Fig. 7 DIXSG and DIXSGp Data Storage Paths and Format

$\sigma_{\phi f}$ Factor

The calculation of the σ_ϕf 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,the normalized cutoff frequency for the sixth-order high-pass Butterworth filter must be set.The calculation method for the normalized cutoff frequency is as follows:

$$W_n = \frac{f_e}{\frac{f_s}{2}} \tag{1}$$

In the formula, W_n represents the normalized cutoff frequency, f_e is the cutoff frequency in Hz, and f_s is the sampling frequency in Hz.

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 gene rated factor data and click the "Plot" button. For ROTI, AATR, and $\sigma_{\phi f}$ indice s, the corresponding valid data and satellite identifiers will be displayed. You c an choose the valid satellite results based on the displayed information. The nu mbers are separated by commas (e.g., 2, 3, 4) or you can input [2 4] to displ ay 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 FiguresFig. 8 to Fig. 11. The trend plots f or AATR and $\sigma_{\phi f}$ are similar to those for ROTI, as shown in **错误!未找到引用源。**.

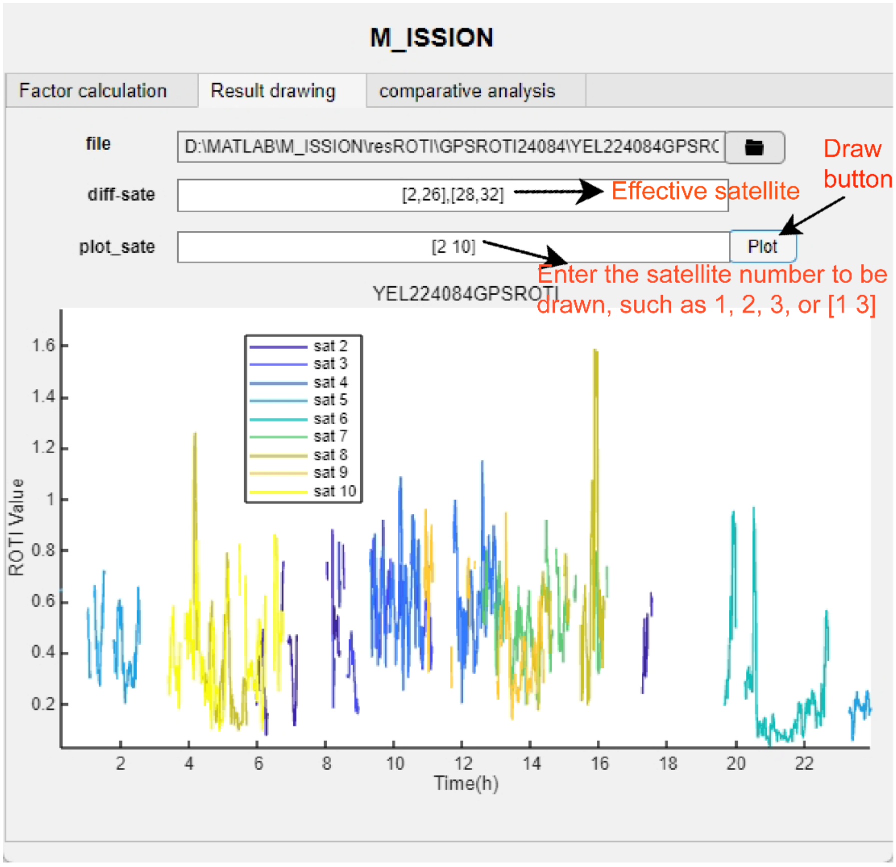

Fig. 8 Trend of ROTI Factor for Satellites 2-10

Fig. 9 Trend of RMSAATR Index

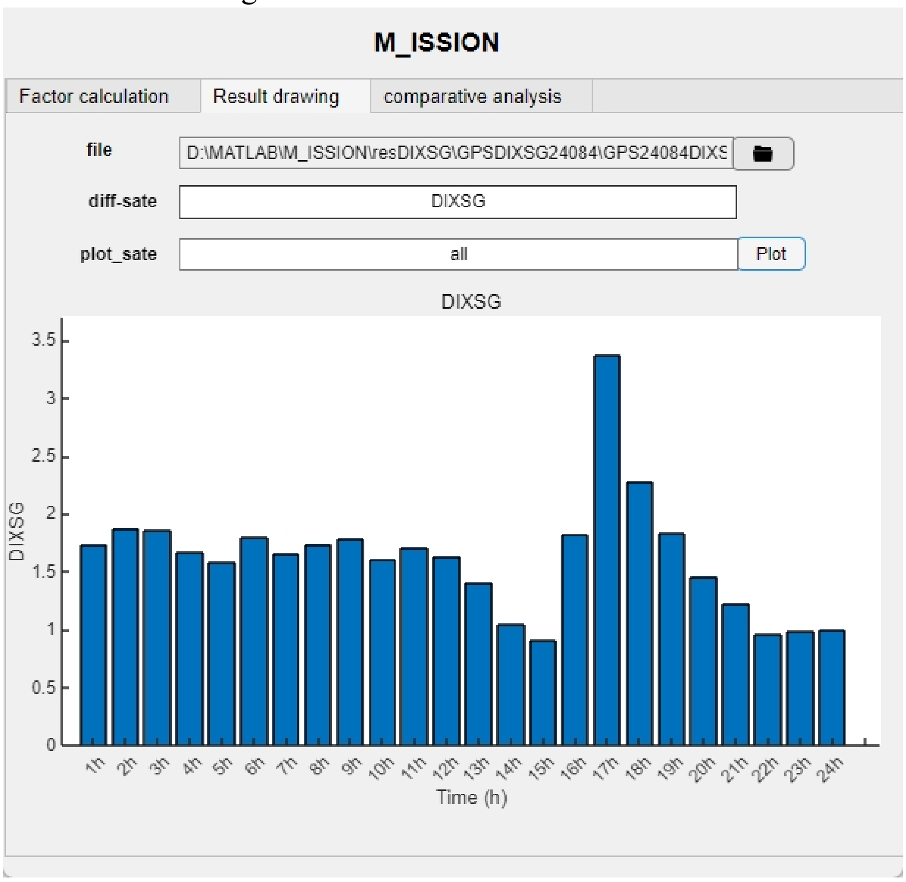

Fig. 10 Global Histogram of DIXSGp Factor

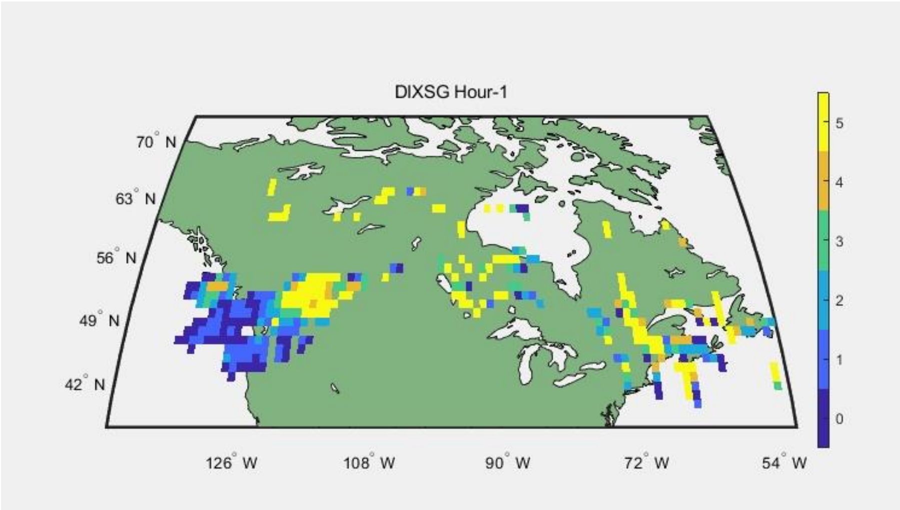

Fig. 11 First Hour Trend Map of DIXSG Factor for the Region

（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.

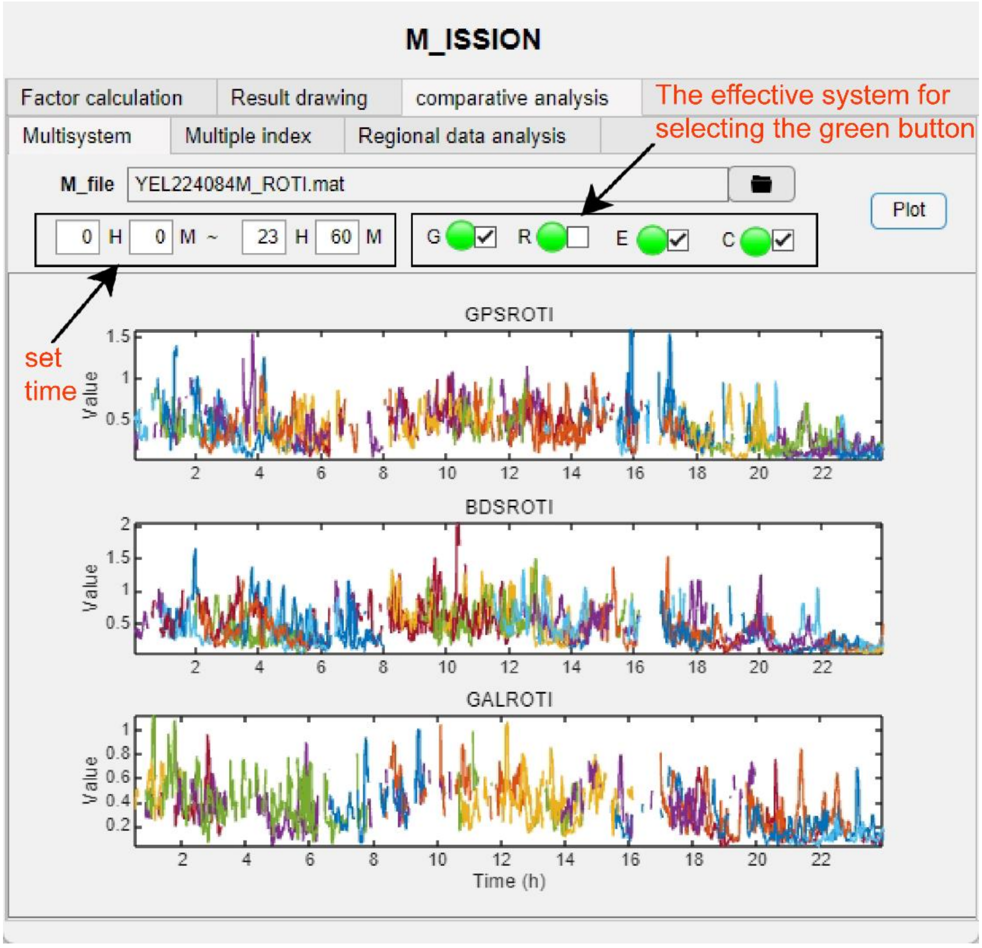

Fig. 12 ROTI Multi-System Comparison Analysis

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.

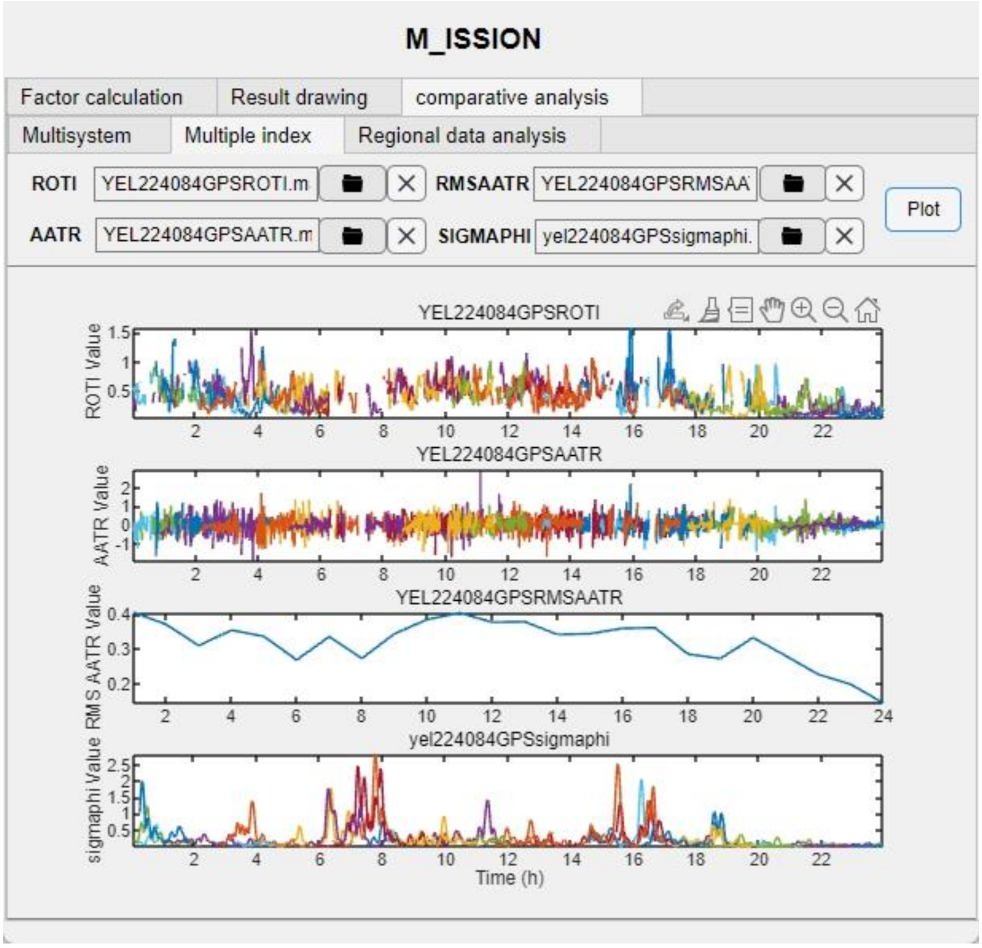

Fig. 13 Cross-Comparison of Four Indices

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.

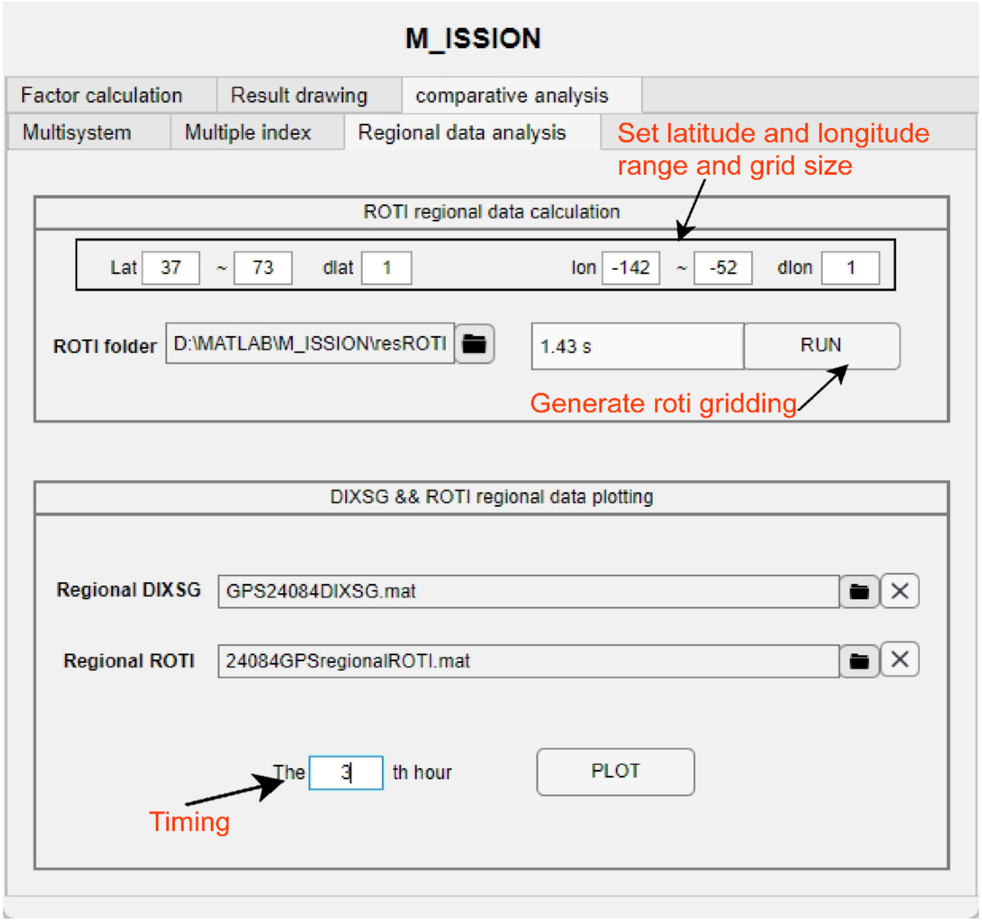

Fig. 14 Running Interface and Related Settings

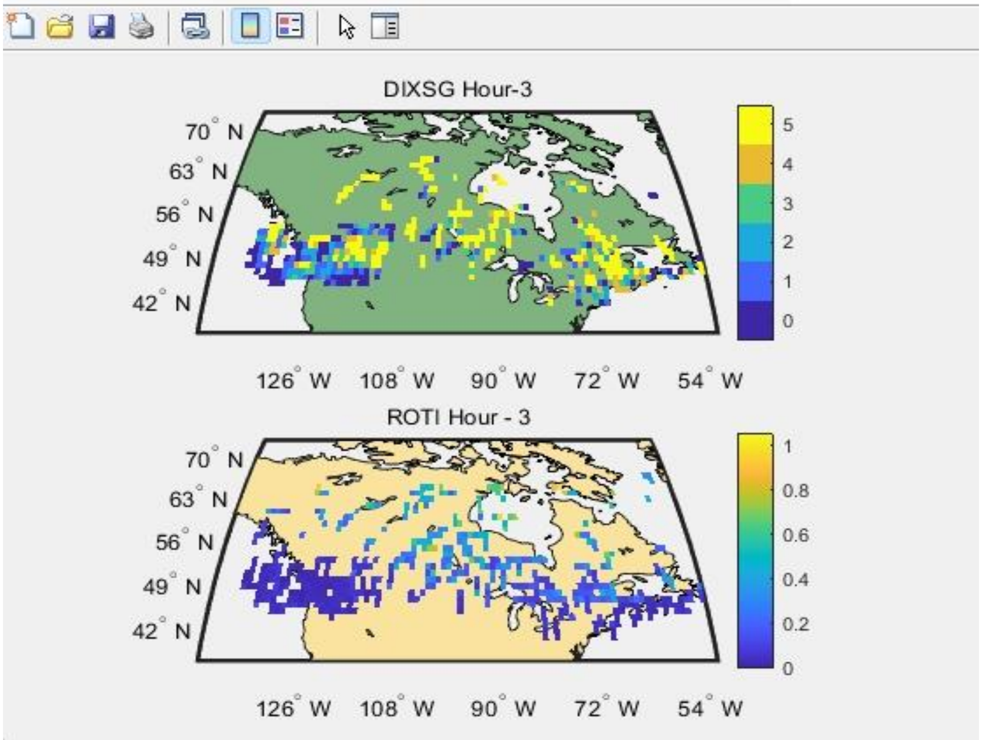

Fig. 15 3rd Hour GPS DIXSG (Top) and GPS ROTI (Bottom) Regional Validation

4. Example Data

To assist users in quickly mastering the usage of the M_ISSION software, we provide example data, which includes the observation data from the YEL2 stati on in the Canadian region for March 24, 2024, covering all four systems, as well as observation data from seven global stations. The longitude range is set from -140° to -105° and the latitude range from 42° to 56°. The exampl e data also includes precise ephemeris files for the day before, the day of, and the day after the observation date, the antenna phase files, and the precise clo ck bias files. Detailed information is provided in Table 2, and the example dat a is included in the example folder within the software package.

Table 2 Experimental Data

Files	Name
Observation	yel20840.24o,albh0840.24o,nano0840.24o,bamf0840.24o, uclu0840.24o, holb0840.24o, chwk0840.24o
Orbit	COD0MGXFIN_20240820000_01D_05M_ORB.SP3 COD0MGXFIN_20240830000_01D_05M_ORB.SP3 COD0MGXFIN_20240840000_01D_05M_ORB.SP3
Clock	COD0MGXFIN_20240840000_01D_30S_CLK.CLK
Antenna	igs20.atx