

M\_SSION: a MATLAB-based software for multi-GNSS Ionospheric  
scintillation index calculation and analysis

User Manual

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## 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 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 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 elevation angle and azimuth data, cROT, ivtall should be stored in MAT format in

**D:\MATLAB\M\_ISSION\ivELE\24084**

**D:\MATLAB\M\_ISSION\ivELE\cROT**

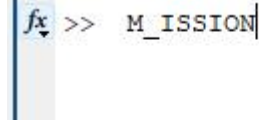
**D:\MATLAB\M\_ISSION\ivELE\ivtall.**

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 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,

A screenshot of a MATLAB command window. The prompt 'fX >>' is visible, followed by the command 'M\_ISSION' which is currently being typed, indicated by a vertical cursor line at the end of the text.

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.

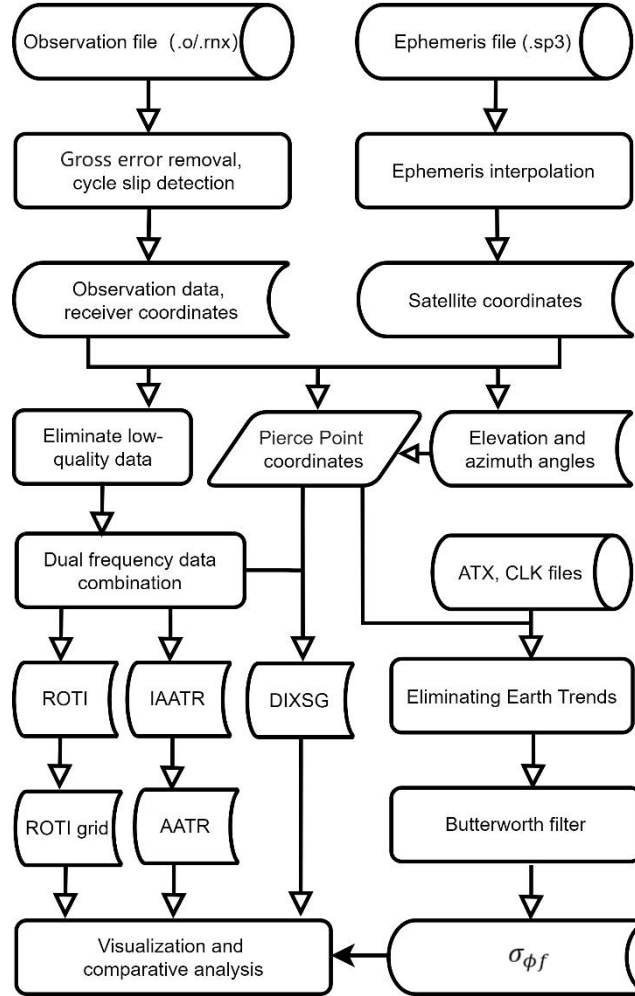


Fig. 1 Implementation flow of M\_SSION software

Fig. 2 M\_SSION Software Main Interface illustrates the graphical interface of the M\_SSION 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\_SSION\input\_o\_and\_r\_file\24084.

Fig. 2 M\_SSION Software Main Interface

### (1) Ionospheric Scintillation Factor Calculation Interface

The first module of M\_SSION 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. During the calculation process, the first step is to select the path of the required data files. For calculating ROTI, 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 to 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 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 calculated and specify the normalized cutoff frequency for the Butterworth filter.

The screenshot shows the MATLAB App window titled "M\_ISSION". The "Factor calculation" tab is selected. The interface is organized into several sections:

- input**: Contains fields for "Rinex" and "Sp3" with file selection icons. It also has a "Lim" field set to 30, a "Cycle Slip Detection" toggle switch (currently off), and a "System Selection" section with checkboxes for GPS (checked), GLO, GAL, and BDS.
- ROTI & AATR**: Contains two input fields, one for "ROTI" and one for "AATR".
- DIXSG**: Contains fields for "level" (5), "first" (100), "step" (50), "Lat" (-90 ~ 90), "dlat" (1), "lon" (-180 ~ 180), and "dlon" (0.5). There is a "DIXSG" button.
- SIGMAPHI**: Contains fields for "CLK" and "ATX" with file selection icons. It also has a "cutoff\_freq" field set to 0.9, checkboxes for "L1" (checked) and "L2", and a "sigma phi" button.

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  $30^\circ$  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  $30^\circ$  with cycle slip detection enabled, and the four satellite systems (GPS, GLONASS, Galileo, and BeiDou) are selected. The longitude range is set from  $-142^\circ$  to  $-52^\circ$ , the latitude range is from  $37^\circ$  to  $73^\circ$ , and the grid size is set to  $1^\circ \times 1^\circ$ . 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.

The figure shows a MATLAB GUI window titled "DIXSG". It contains several input fields and a button. The fields are: "level" with value 5, "first" with value 100, "step" with value 50, "Lat" with value 37, "dlat" with value 1, "lon" with value -142, and "dlon" with value 1. There is a "DIXSG" button on the right side of the window.

Fig. 6 DIXSG Calculation Interface for Data from 30 Stations

The figure shows a MATLAB workspace window with the path **D:\MATLAB\M\_ISSION\resDIXSG\GPSDIXSG24084\GPS24084DIXSG.mat**. It displays three variables: LL (1x24 cell), MBL (1x5 double), and aDIXSG (1x24 double). Arrows indicate that LL is stored in DIXSG and aDIXSG is stored in DIXSGp.

Variable	Size	Format	Storage Path
LL	1x24	cell	DIXSG
MBL	1x5	double	
aDIXSG	1x24	double	DIXSGp

Fig. 7 DIXSG and DIXSGp Data Storage Paths and Format

## $\sigma_{\phi f}$ 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, 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:

$$W_n = \frac{f_e}{\frac{f_s}{2}} \quad (1)$$

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 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 Figures Fig. 8 to Fig. 11. The trend plots for AATR and  $\sigma_{\phi f}$  are similar to those for ROTI.

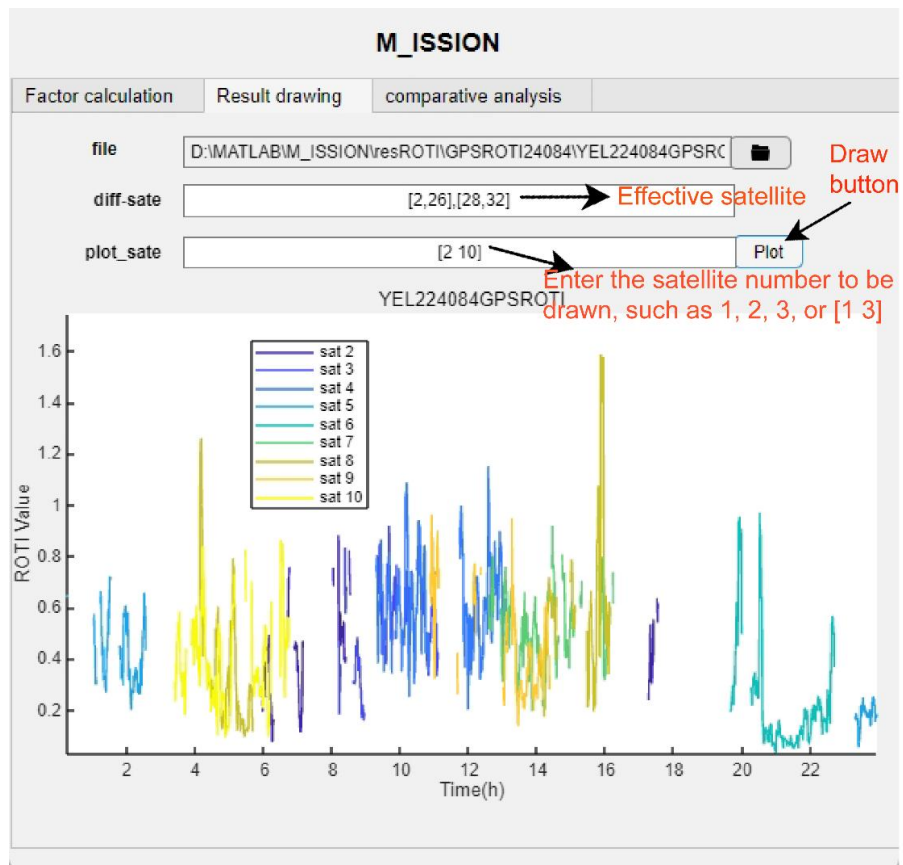


Fig. 8 Trend of ROTI Factor for Satellites 2-10

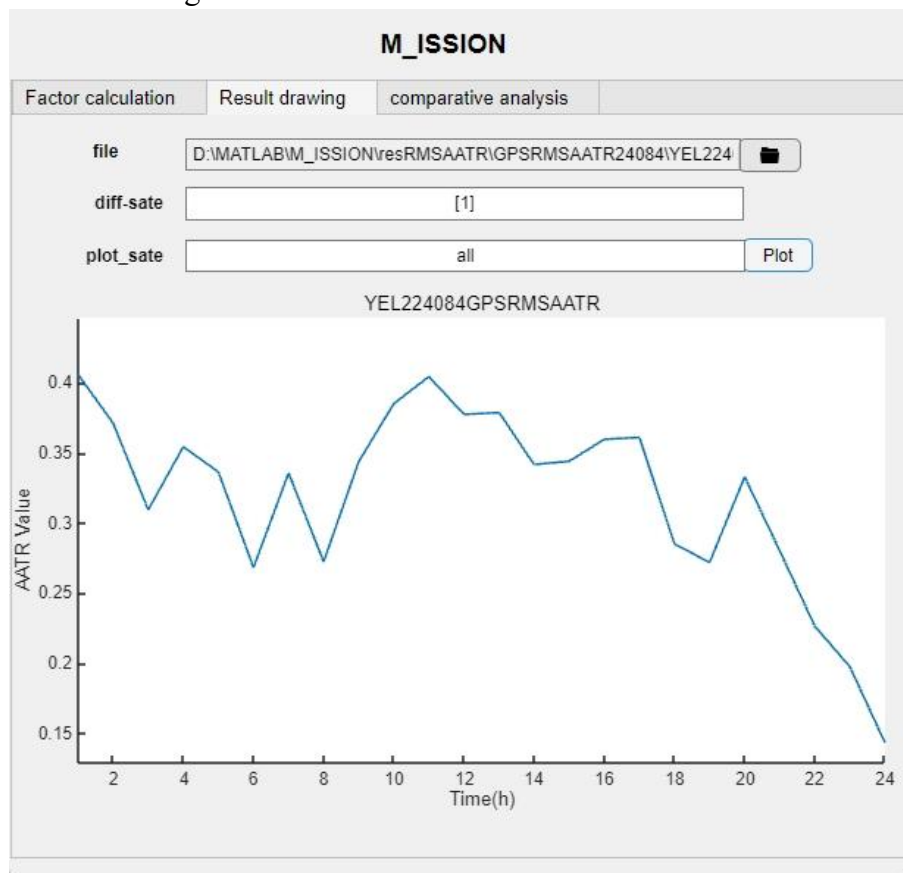


Fig. 9 Trend of RMSAATR Index

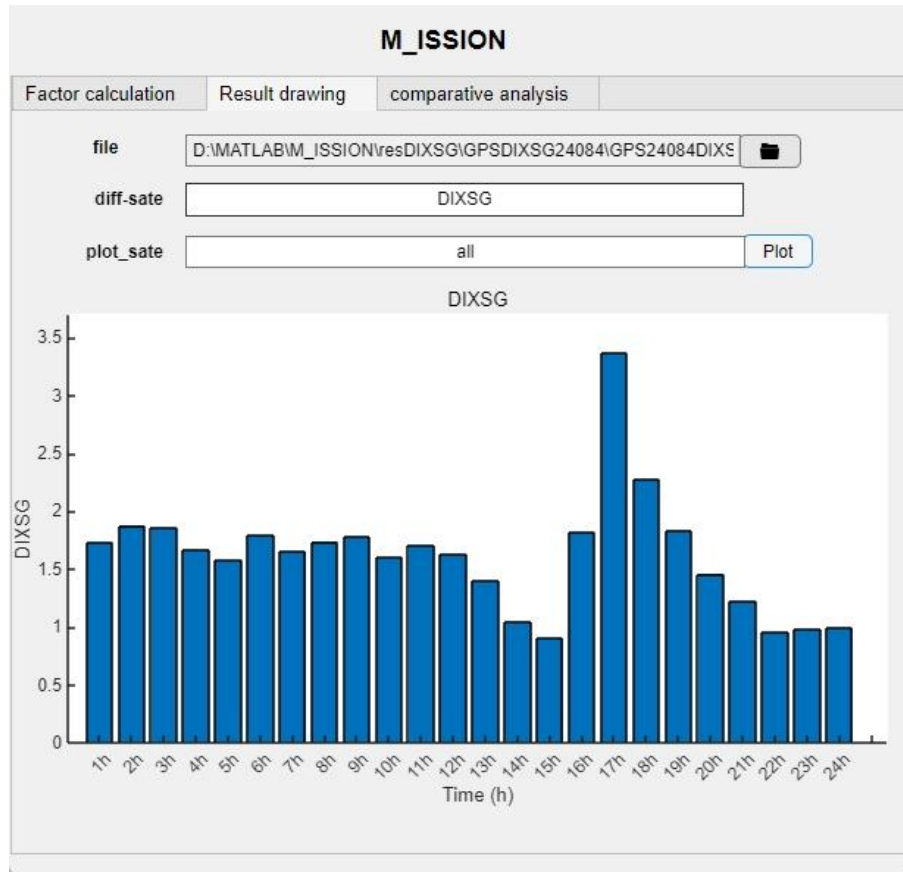


Fig. 10 Global Histogram of DIXSGp Factor

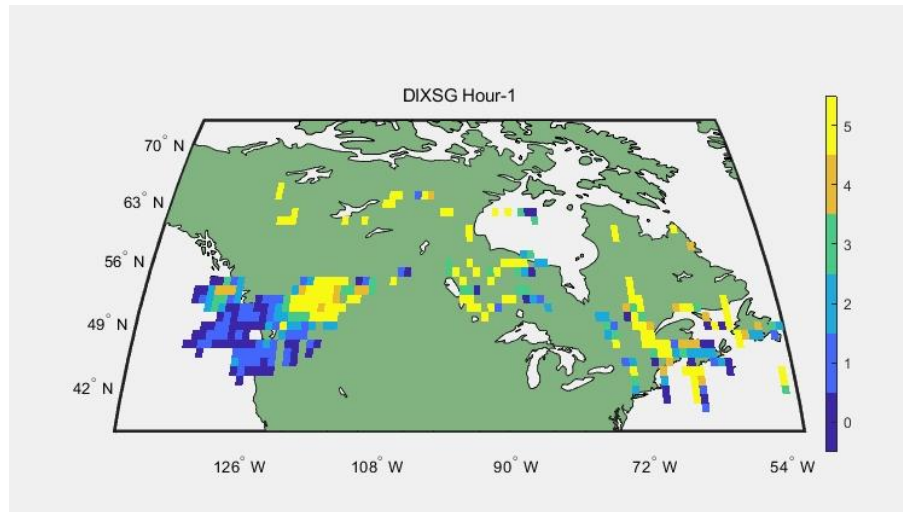


Fig. 11 First Hour Trend Map of DIXSG Factor for the Region

### (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.

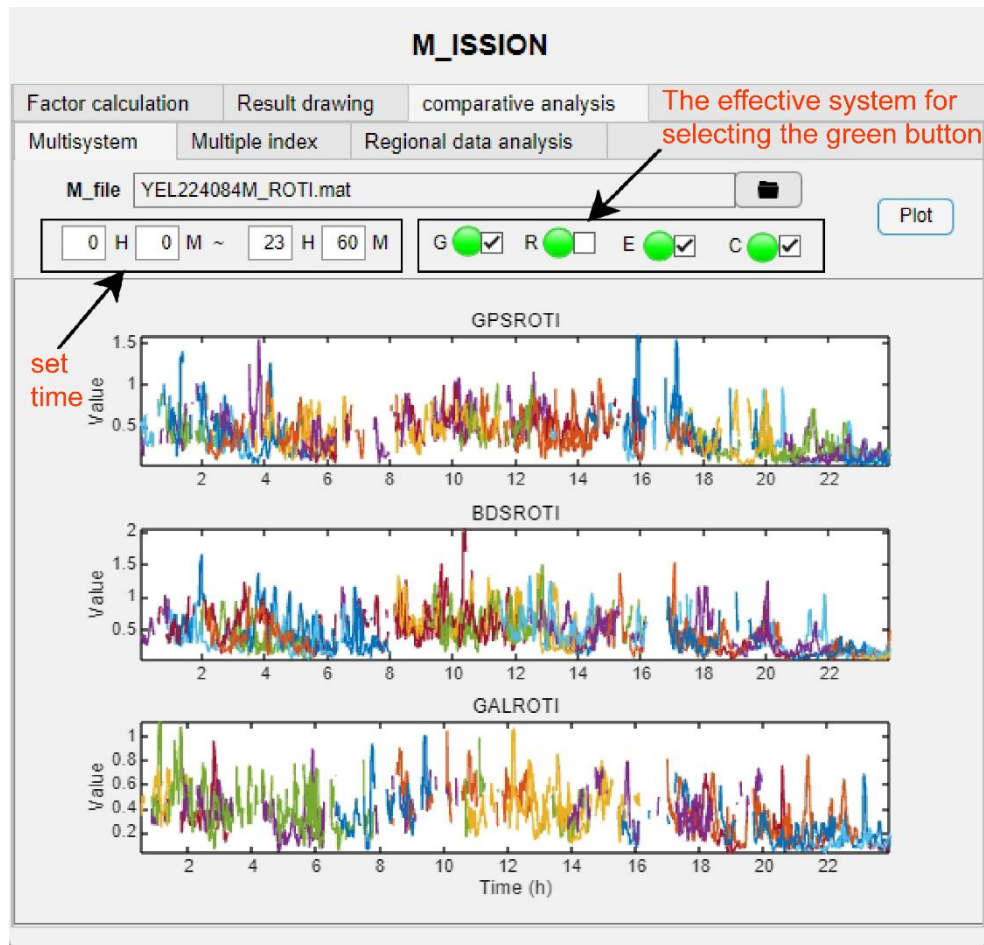


Fig. 12 ROTI Multi-System Comparison Analysis

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 Figure Fig. 13.



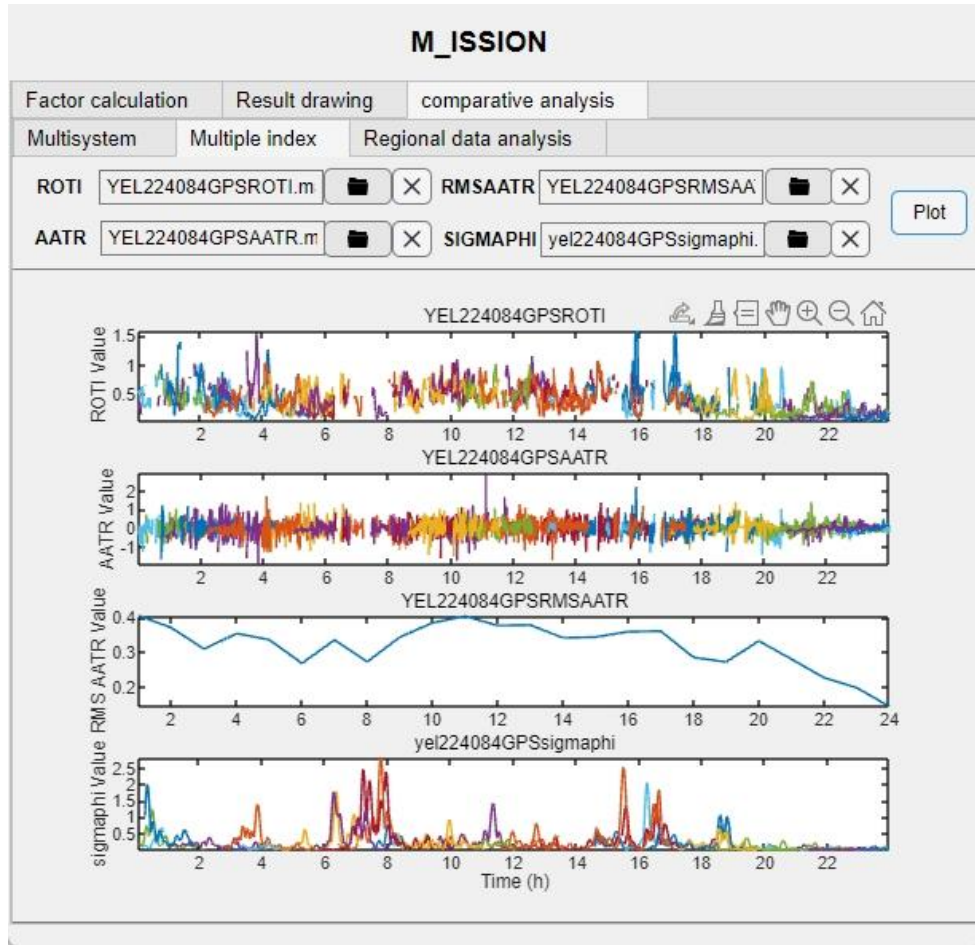


Fig. 13 Cross-Comparison of Four Indices

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.

**M\_ISSION**

Factor calculation
Result drawing
comparative analysis

Multisystem
Multiple index
Regional data analysis
Set latitude and longitude range and grid size

ROTI regional data calculation

Lat  ~  dlat

lon  ~  dlon

ROTI folder

1.43 s

RUN

Generate roti gridding

DIXSG && ROTI regional data plotting

Regional DIXSG

Regional ROTI

Timing

The  th hour

PLOT

Fig. 14 Running Interface and Related Settings

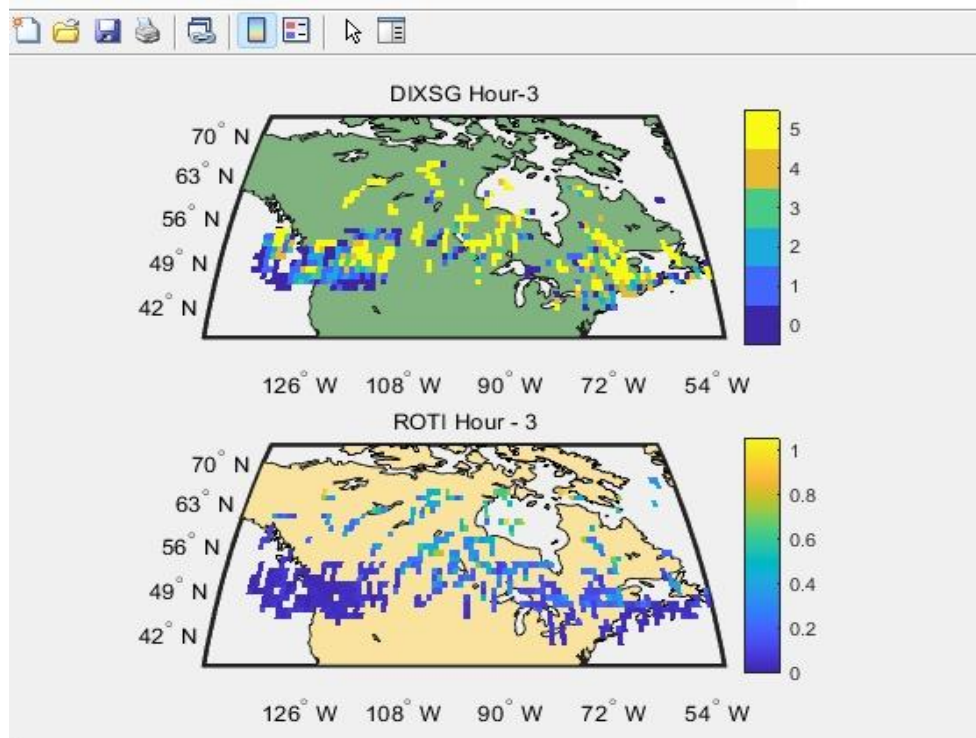


Fig. 15 3rd Hour GPS DIXSG (Top) and GPS ROTI (Bottom) Regional Validation

#### 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 station 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  $-140^{\circ}$  to  $-105^{\circ}$  and the latitude range from  $42^{\circ}$  to  $56^{\circ}$ . The example 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 clock bias files. Detailed information is provided in Table 2, and the example data 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

## 5. Acknowledgments

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