ICG Workshop on GNSS Spectrum Protection and Interference Detection and Mitigation, Changsha, China 17 May 2016

# ③ Research on IDM technology

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# Content

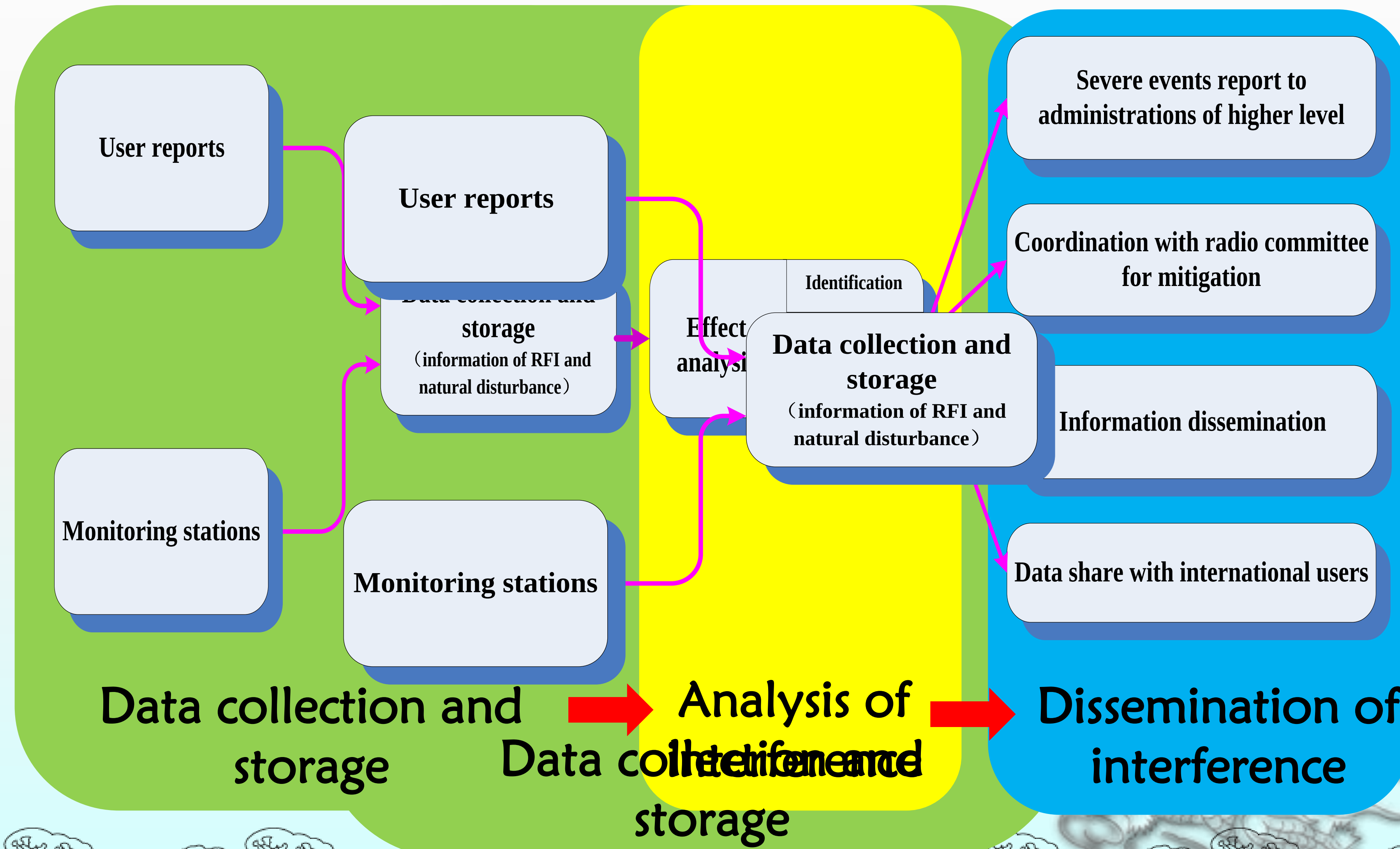
1. Function analysis of IDM data center
2. Techniques of interference detection, localization and identification
3. Summary

# 1. Function analysis of IDM data center

IDM data center is the core of IDM system. It is urgent for us to construct the IDM data center at present. We have programmed the function of IDM data center, including:

- Data collection and storage;
- Analysis of interference information;
- Dissemination of interference information.

# 1. Function analysis of IDM data center



# Data collection and storage

## (1) Create template

To collect and store the information, a template is necessary.

| | | | | | |
|---|---|---|---|---|---|
| Information of GNSS user | Name * | | | Email* | |
| | Nationality | | | Address | |
| | Telephone number* | Fixed | | Preferred method for necessary contact | ☐Email<br>☐telephone |
| | | Mobile | | Preferred time for necessary contact | ☐morning<br>☐afternoon<br>☐evening<br>☐no restriction |
| Information of GNSS anomaly | Equipment name | | | Equipment installation type | |
| | Equipment model | | | GNSS frequency using | |
| | Antenna elevation of receiver | | | Polarization of the receiving antenna or observed polarization | |
| | Start time *(date/time/zone) | | | Position*(longitude/latitude) | |
| | Current status of interference* | | ☐continuing<br>☐stopped<br>☐Intermittent | Time duration of interference | |
| | Occurrence of interference | | ☐occasionally<br>☐frequently | Frequency of interfering signal | |
| | GNSS system interfered (BDS,GPS…) | | | Signal interfered (B1,B2,B3,L1,L2,L5…) | |
| | Satellite being tracked when interfered | | | Satellite interfered | |
| | Class of emission | | | Bearings or other particulars | |
| | Signal status (Location Fault, Time fault, accuracy decreasing…) | | | Field strength or power flux-density of the wanted emission at the receiving station experiencing the interference | |
| | Ionospheric scintillation occurs during interference | | ☐yes | Ionospheric scintillation index | |
| | | | ☐no | | |
| Information of interference source | Name of source | | | Organization | |
| | Frequency measured (frequency/date /time of measurement) | | | Class of emission | |
| | Bandwidth (measured or estimated) | | | Observed polarization | |
| | Measured field strength or power flux-density | | | Class of interfering source and nature of service | |
| | Location/position/area/bearing (QTE3) | | | Location of the facility which made the above measurements | |
| Analysis of interfering and actions | Record of the interference sources detection | | Connection graph of used equipment for interferer detection, parameters setting, detection procedure etc. | | |
| | Analysis of interfering | | Interfering characteristics, how is the interfering formed, Spectrum measurement plot of interfering signal etc. | | |
| | Action requested * | | | | |
| | Remark | | | | |

# Data collection and storage

## (2) Implementation of software

Besides data collection of interference, IDM data center also provide inquiry and download functions for users.



Storage and inquiry of interference events

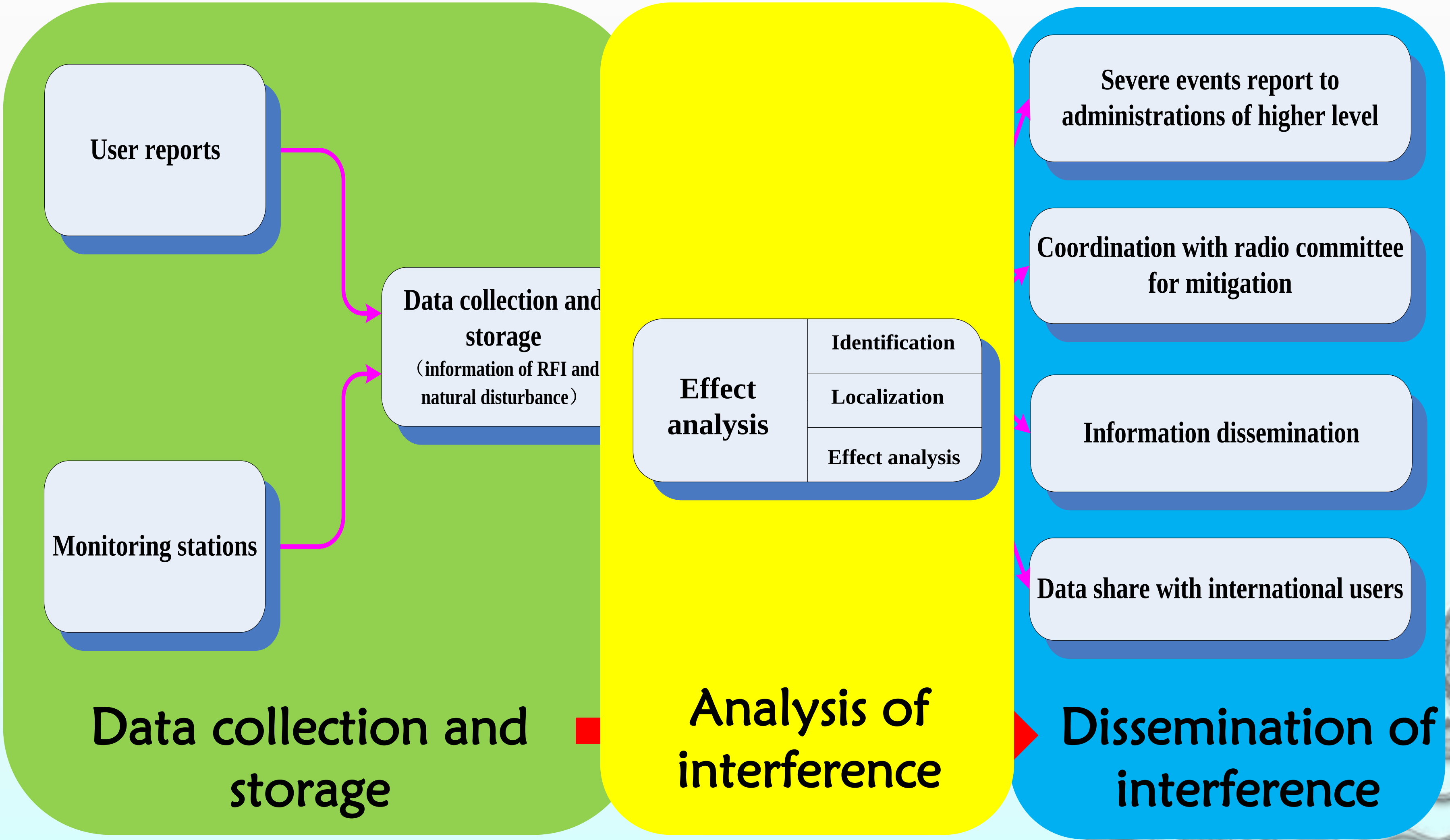


Storage and inquiry of interference source



Storage and inquiry of ionospheric scintillation

# Analysis of interference information

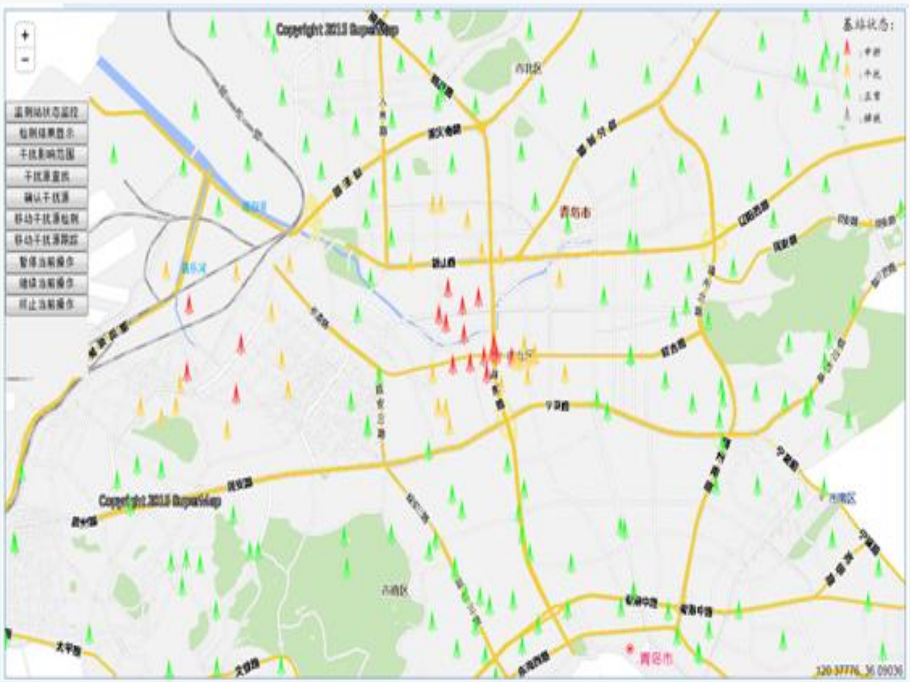


# Analysis of interference information

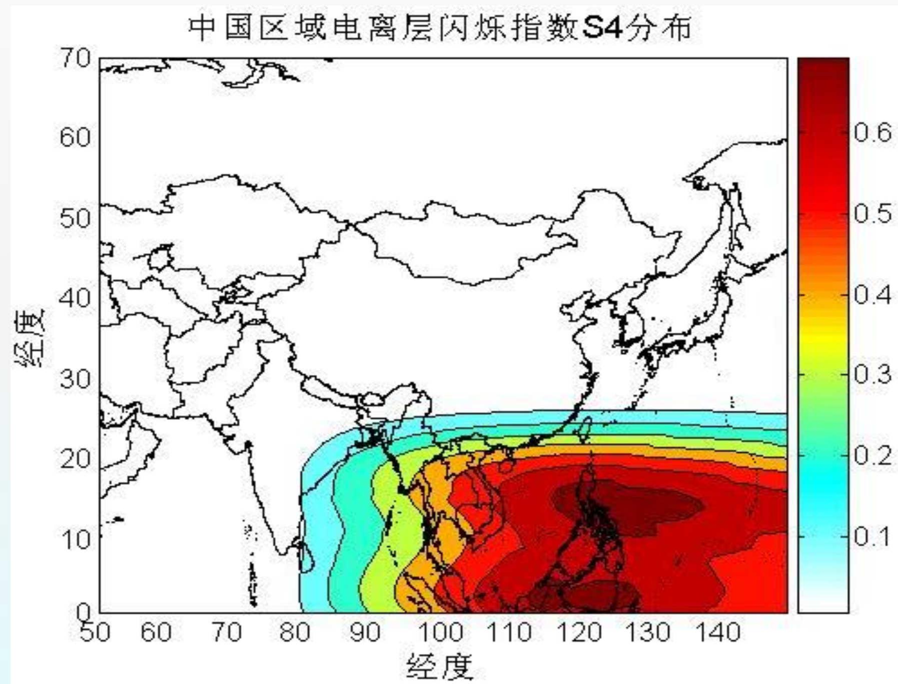
## (1) Data fusion and identification

Data fusion of radio interference and natural disturbance will help to identify the cause of system service deterioration and outage.

The area influenced by natural disturbance is wider than radio interference. Ionospheric scintillation index S4 can be used to identify natural disturbance from other sources.



**Radio interference**
**(hundreds of meters to several kilometers)**



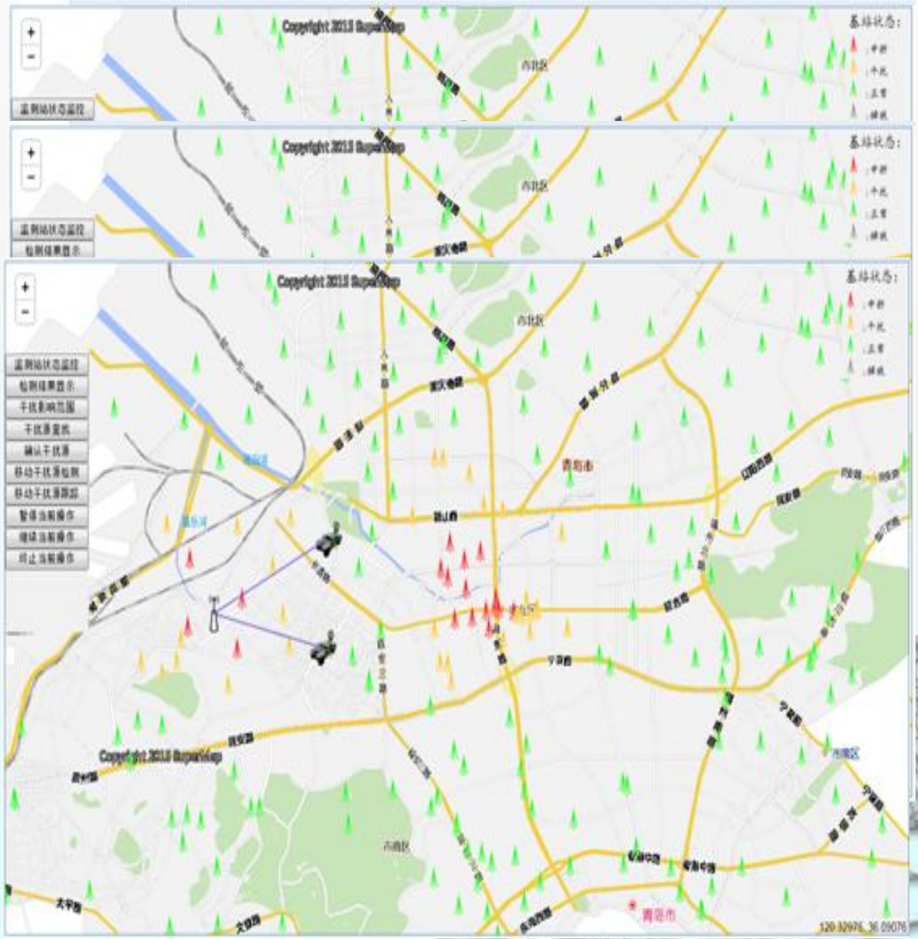

**Natural disturbance**
**(hundreds to thousands kilometers)**

# Analysis of interference information

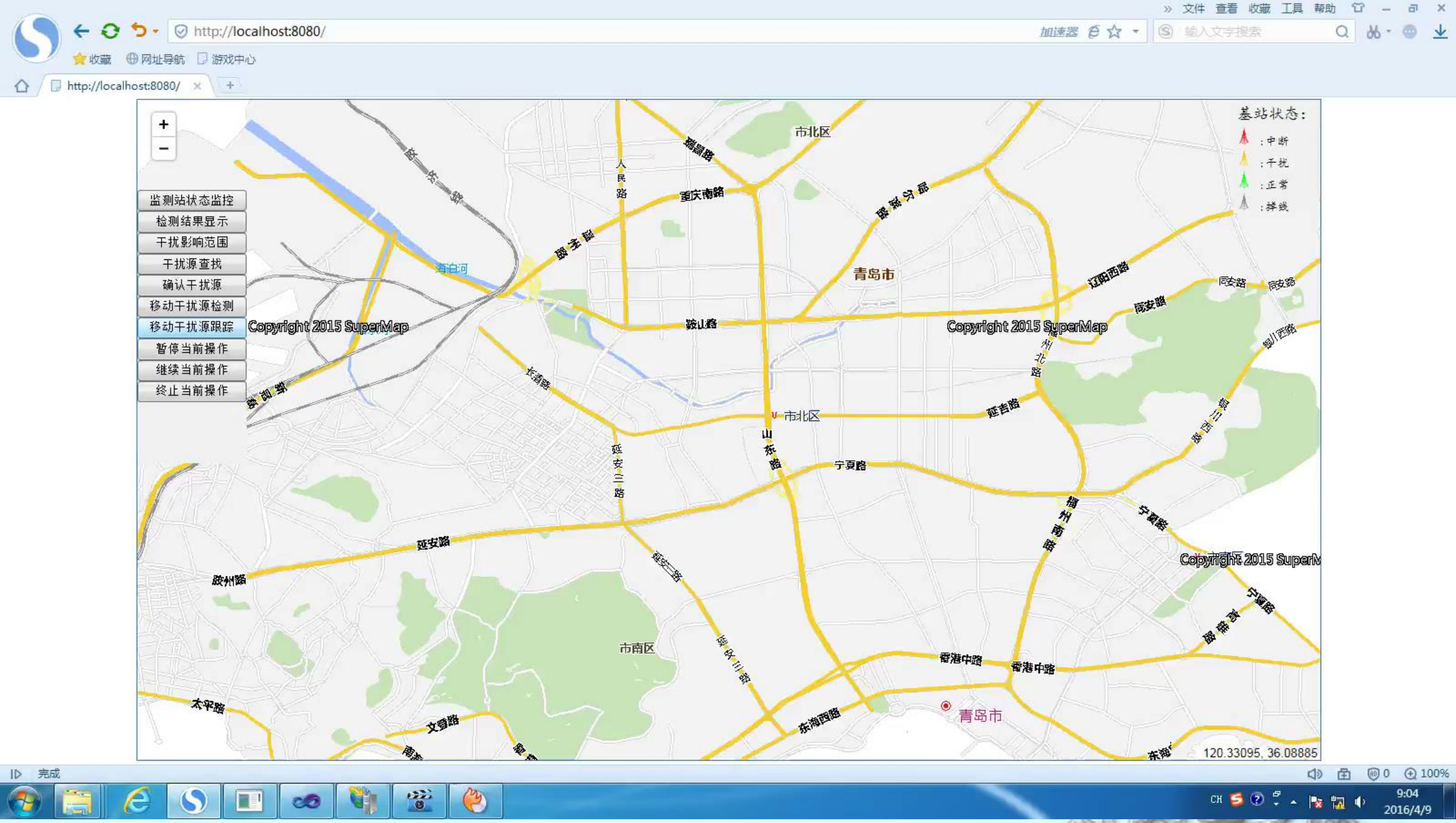
## (2) Localization of interference source

Three steps for localization of static interference source:

1. Calculate rough area where the source lies;
2. Find accurate location of the source;
3. Confirm relevant parameters and store.



Localization of static interference source

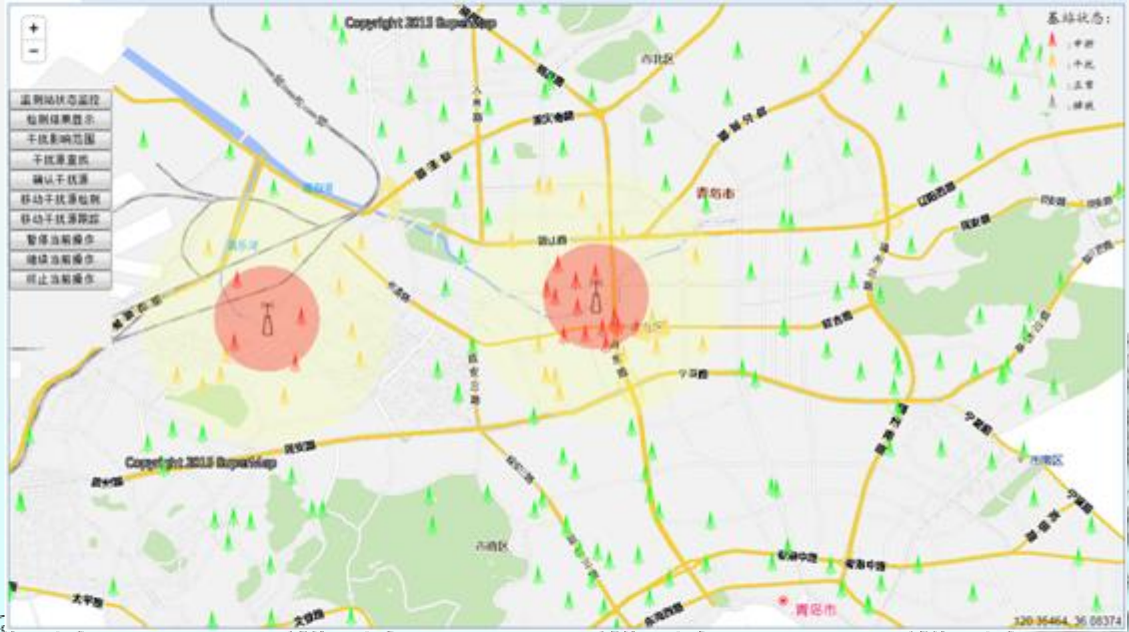



**Localization of dynamic interference source**

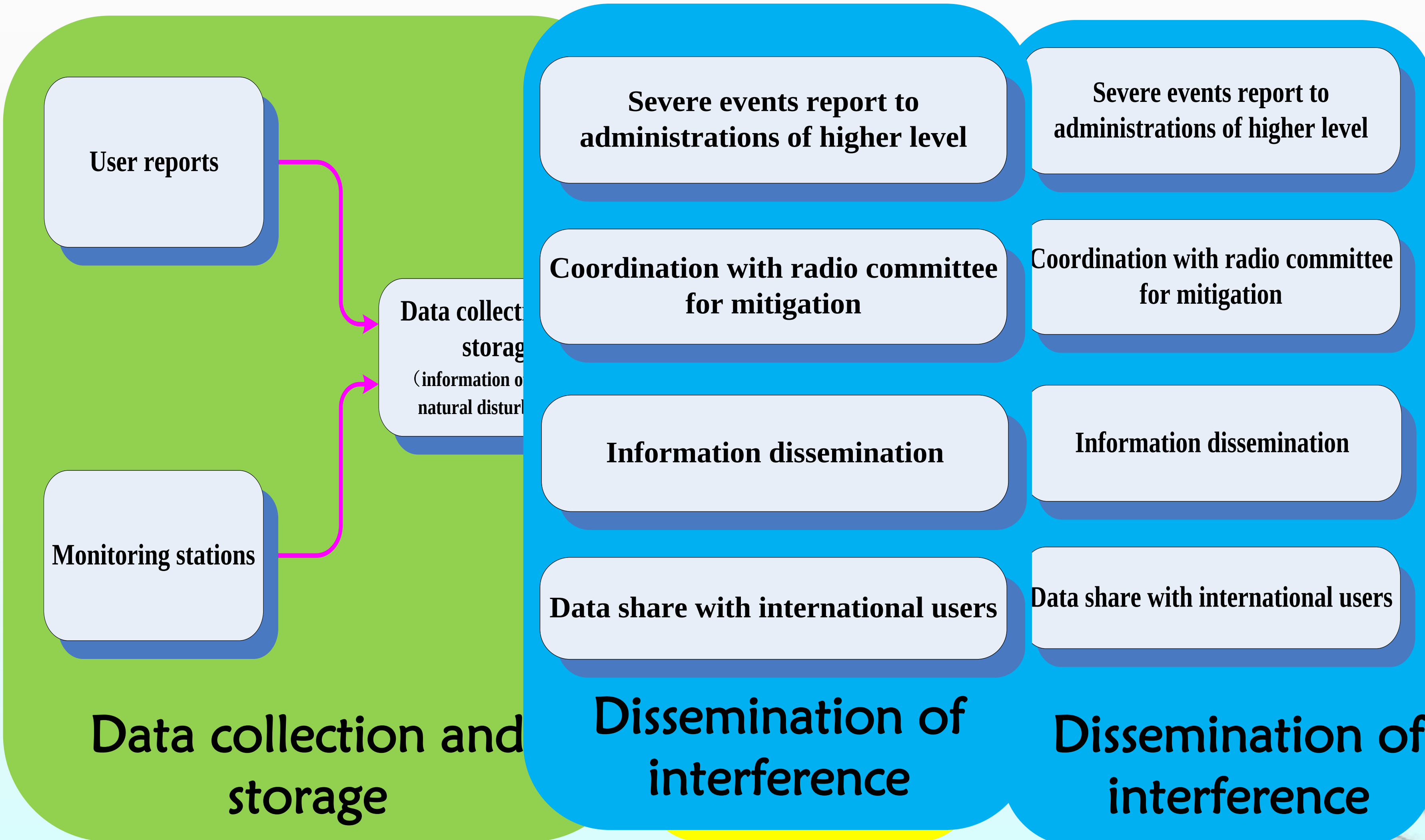
# Analysis of interference information

## (3) Effect evaluation

According to the characteristics of the source, the influenced area can be shown in GIS considering radiowave propagation effect.



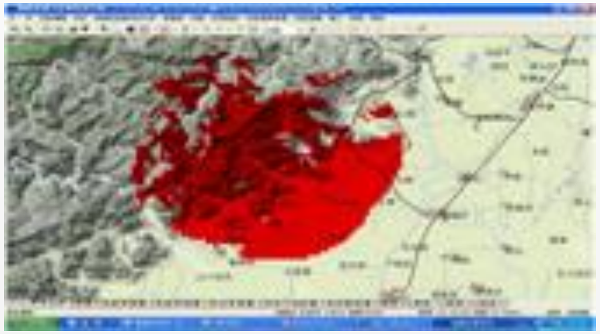
# Dissemination of interference information



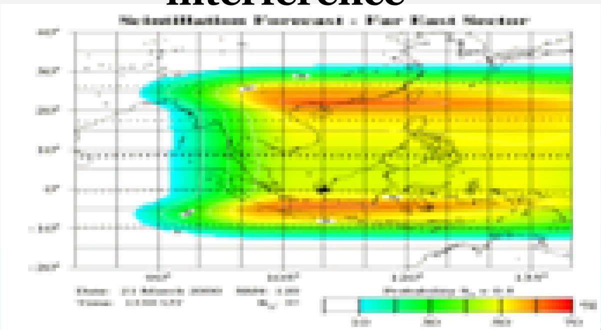
# Dissemination of interference information

The information of interference can be disseminated in four different ways:

- Severe events report to administrations of higher level;
- Disseminate by military network;
- Disseminate by civil network;
- Data share of processed data with international users.



**Information of radio interference**

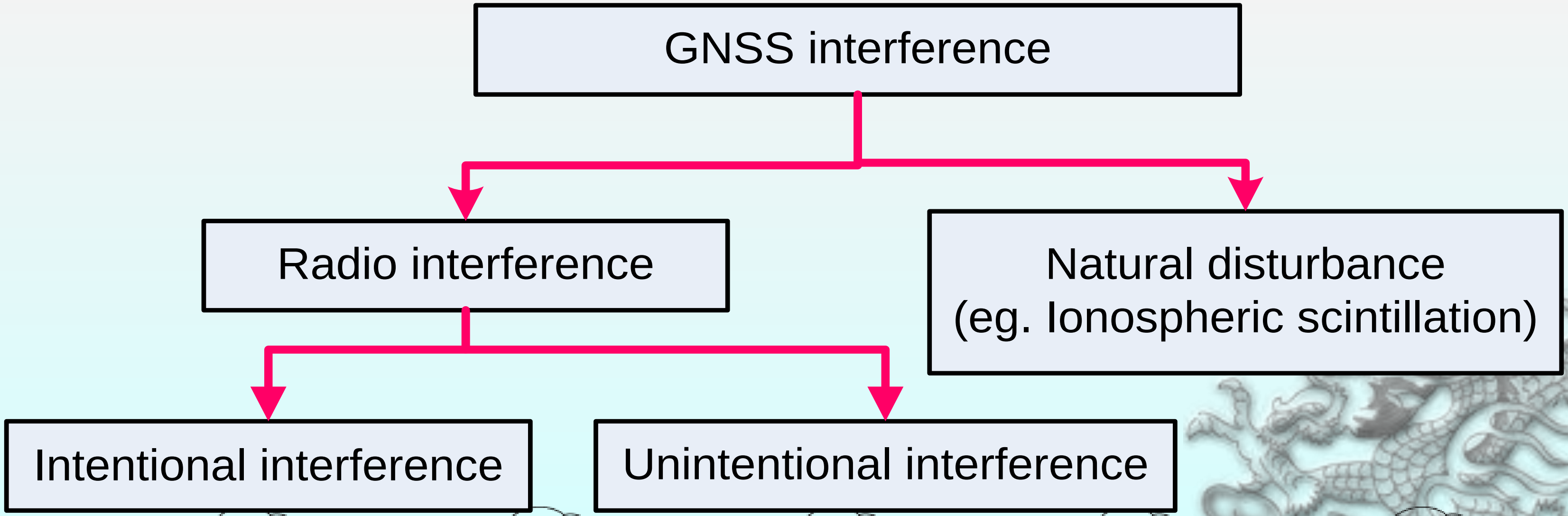


**Information of natural disturbance**

# 2. Techniques of interference detection, identification and localization

***GNSS Interference---- classified in ICG-7***

- **Radio interference (Interference from radio systems)**
  - *Intentional interference*
  - *Unintentional interference*
- **Natural Disturbance (mainly ionospheric scintillation)**



# 2. Techniques of interference detection, identification and localization

- **Radio interference**
  - Detection
  - Identification
  - Localization
- **Ionospheric scintillation**
  - Effect
  - Monitor
  - Forecast and mitigation

# 2.1 Detection of radio interference

Interference detection is the base of identification and localization. High sensitive receivers which can overcome interference of different intensity will be the direction of future development for interference detection.

Dr. Humphreys and his colleagues at the University of Texas, Austin, heightened interest in spoofing detection and sent a super yacht off course without raising any alarms on its bridge. Since then, the importance of spoofing detection has been realized.

# Spoofing detection

**Spoofing detection techniques**

- **Signal encryption**
- **Residual signal detection**
- **Signal propagation delay detection**
- **Angle of arrival detection**
- **Angle difference of arrival detection**

# Comparison of spoofing detection techniques

| Types of technique | Detection ability | Difficulty for implementation | Detection effect |
|---|---|---|---|
| Signal encryption | Detect produced spoofing signal only; Significant latency | Medium | Medium |
| Residual signal | Detect both kinds of spoofing signals | High | Medium |
| Signal propagation delay | Detect retransmission spoofing signal | Medium | Common |
| Angle of arrival | Detect both kinds of spoofing signals | High | Good |
| Angle difference of arrival | Detect both kinds of spoofing signals | High | Good |

Each spoofing detection technique has its limitation. However, combination of these techniques are the future direction so as to obtain the best spoofing detection effect at the lowest cost.

# 2.2 Identification of radio interference

Several kinds of radio interference exist in the space environment. Quick identification ability is needed to cope with radio interference so as to achieve the goal that GNSS works regularly.

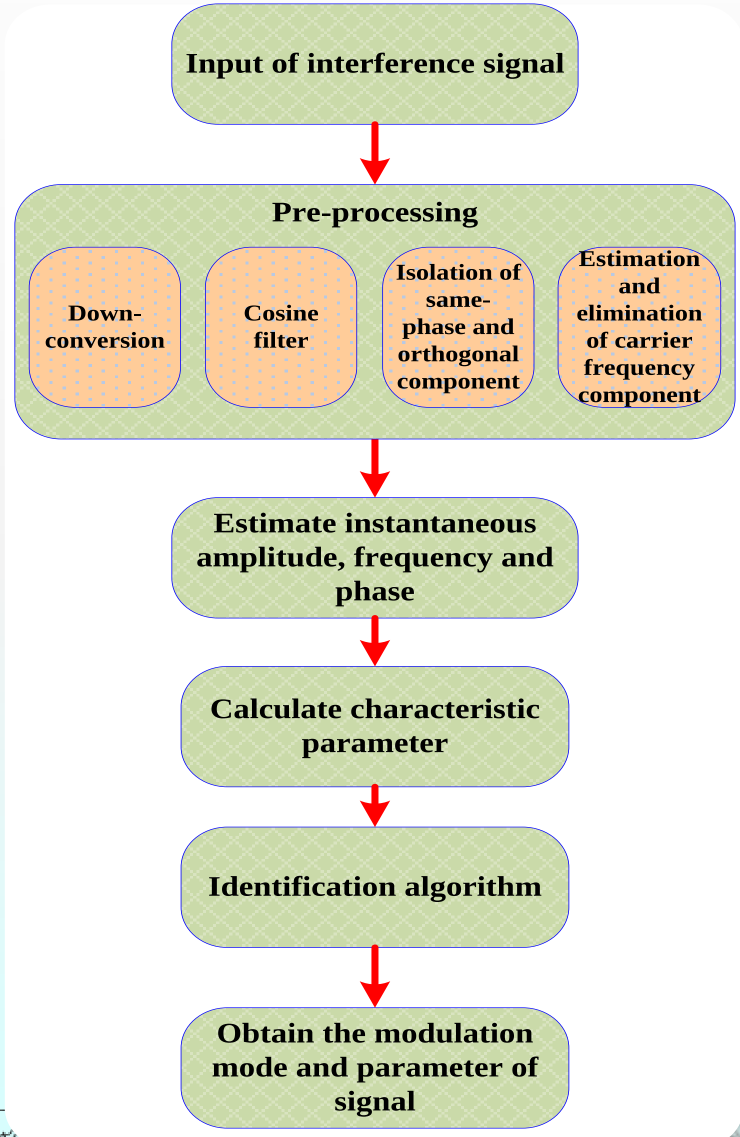
# 2.2 Identification of radio interference

| Type | | Potential source |
|---|---|---|
| Wide band | Band-limit Gauss | Intentional jammer with matching bandwidth |
| | Phase/frequency modulation | Harmonic wave from TV transmitter that overloads the filter of GNSS front-end |
| | Matching spectrum | Matching spectrum jammer of pseudo-satellite nearby |
| | Pulse | Pulse transmitter |
| Narrow band | Phase/frequency modulation | Harmonic wave from AM radio station, civil band and amateur radio station |
| | Continuous sweeping wave | Intentional sweeping CW jammer or harmonic wave of FM transmitter |
| | Continuous wave | Intentional CW jammer |

# 2.2 Identification of radio interference

Identification of radio interference source is based on long-time observation:

- Create interference database;
- Extract the feature from the modulation of interference;
- Compare with database and identify the type of interference.



# 2.3 Localization of radio interference

Based on the direction finding of single monitoring station, localization of the interference can be implemented by multi-stations.

Three localization techniques have been studied recently:

- Cross localization
- Grid localization

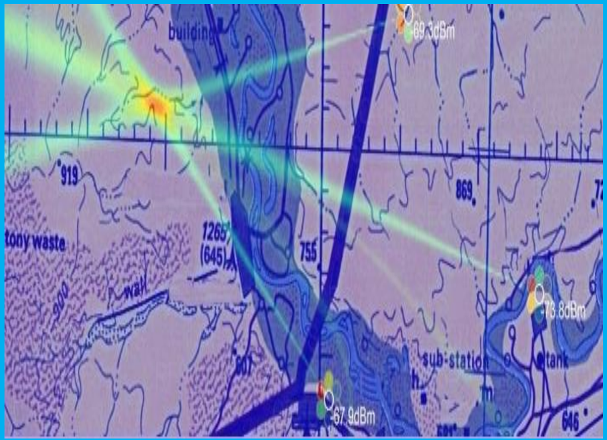
# a） Cross localization

Angle of arrival (AOA) localization is a typical cross localization technique.

**AOA localization**

**Principle of algorithm**: **Single station can find the direction of jammer, however several directions will be found while the station is moving (or with multi-stations), and the jammer lies in the common area of directions.**

**Requirement**: **Direction finding receivers should be available in the monitoring stations.**

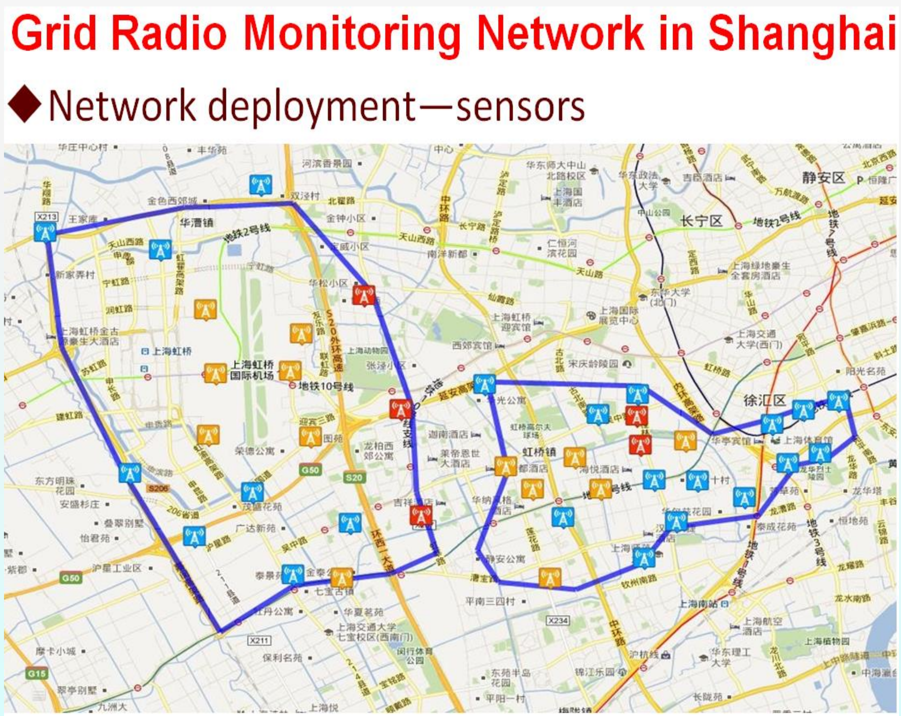




**Moveable direction finding vehicle**

# b） Grid localization

Grid localization technique is based on the network of multi-sensors. The method has been discussed under the frame of ICG.




Antenna

Sensor

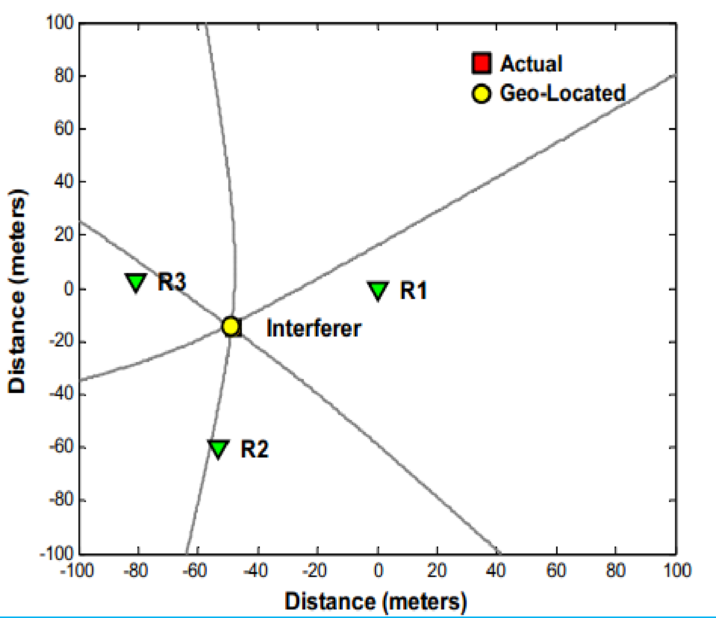
# b）Grid localization

TDOA technique is usually used in grid localization.

**TDOA localization**

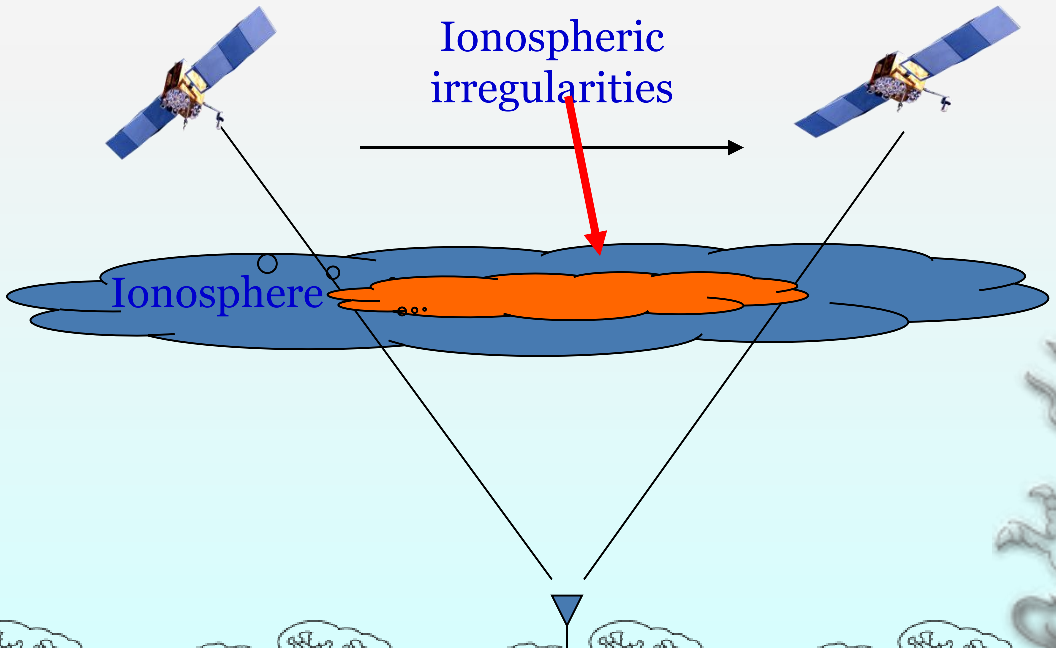
**Principle of algorithm：If the receivers are time synchronization between two stations, a hyperbolic curve is defined according to the time difference when signals arrive. The location of jammer lies in the common area of multi-hyperbolic curves.**

**Requirement：Time synchronization as well as accurate timing of monitoring stations.**



# 2.4 Effect of ionospheric scintillation

Ionospheric irregularities are the main cause of scintillation. The accuracy of ionospheric models and GNSS localization results can be greatly affected by scintillation.

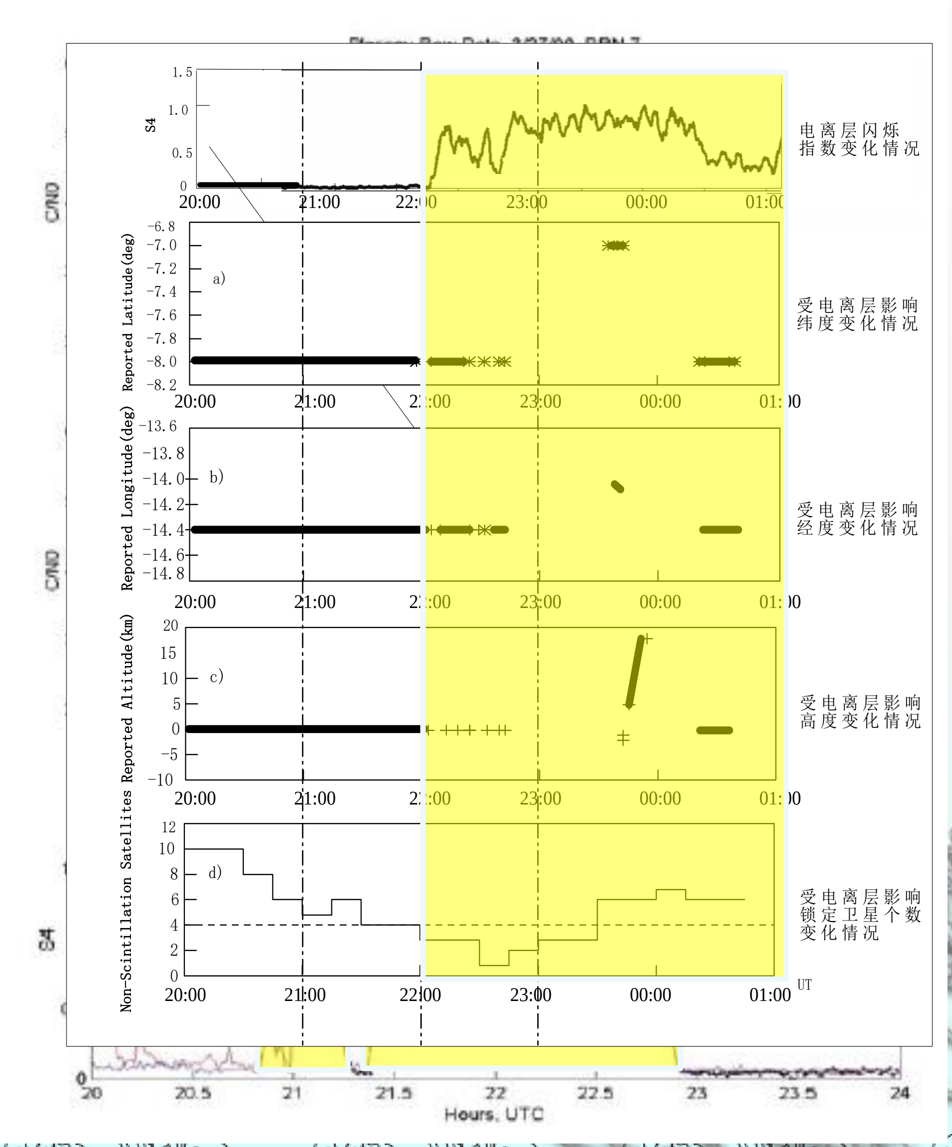


The effect of ionospheric scintillation on the performance of GNSS can be concluded as:

- Received signals;
- Cycle slip in carrier phase;
- Measuring accuracy;
- Localization result.

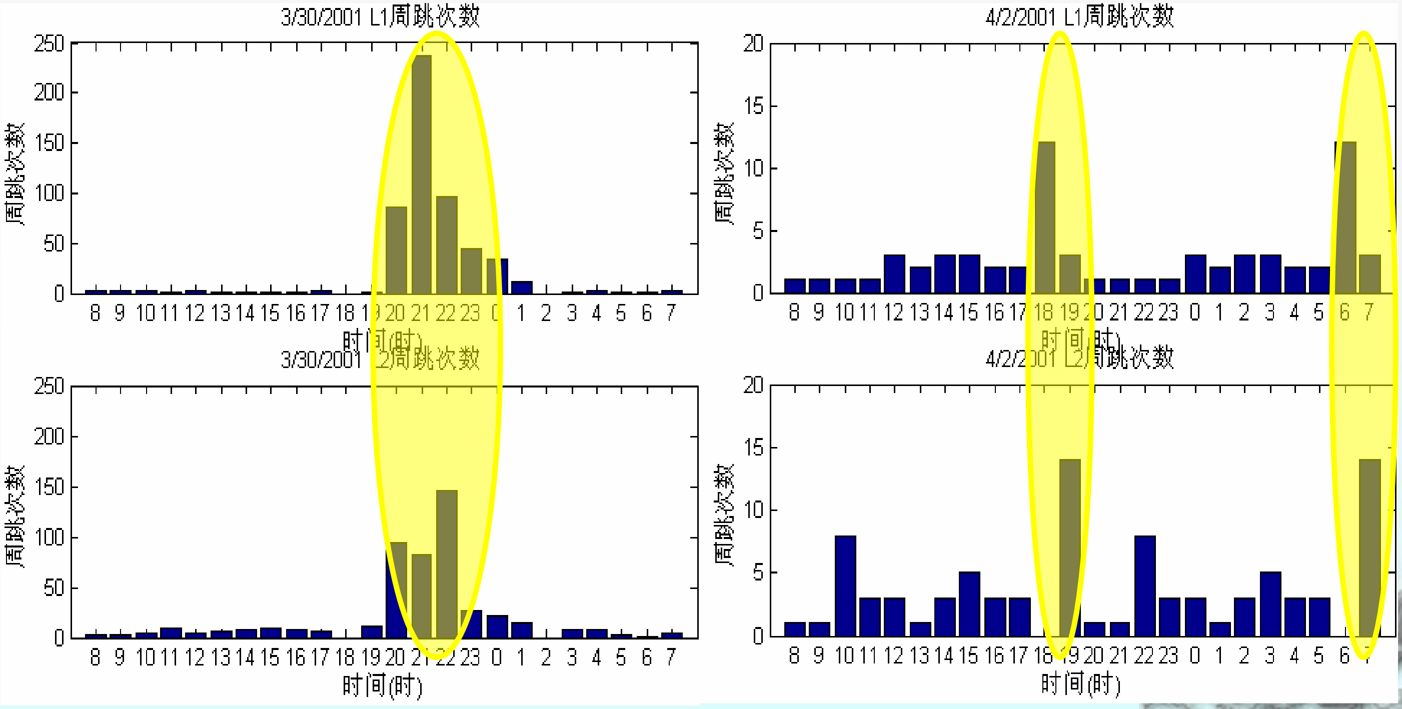
# Received signals

- Degradation in carrier to noise ratio；
- Losing lock, service outage.



## Cycle slip in carrier phase

The frequency of cycle slips emerging in carrier phase during scintillation is far more than the time without scintillation, no matter for L1 or L2.



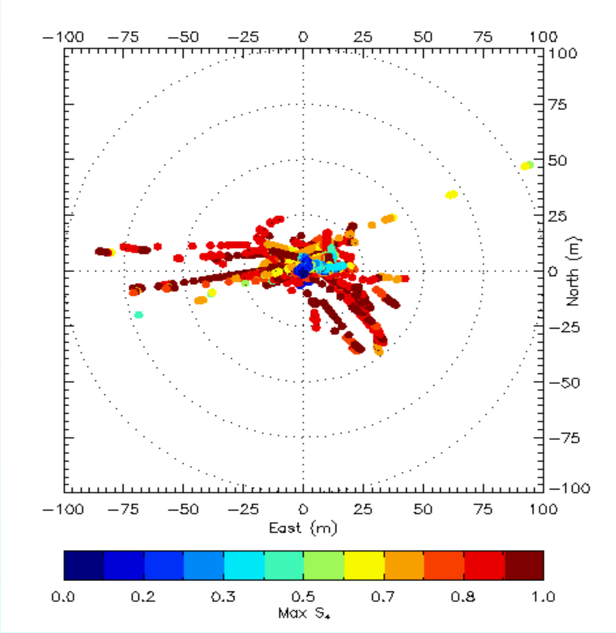
# Measuring accuracy

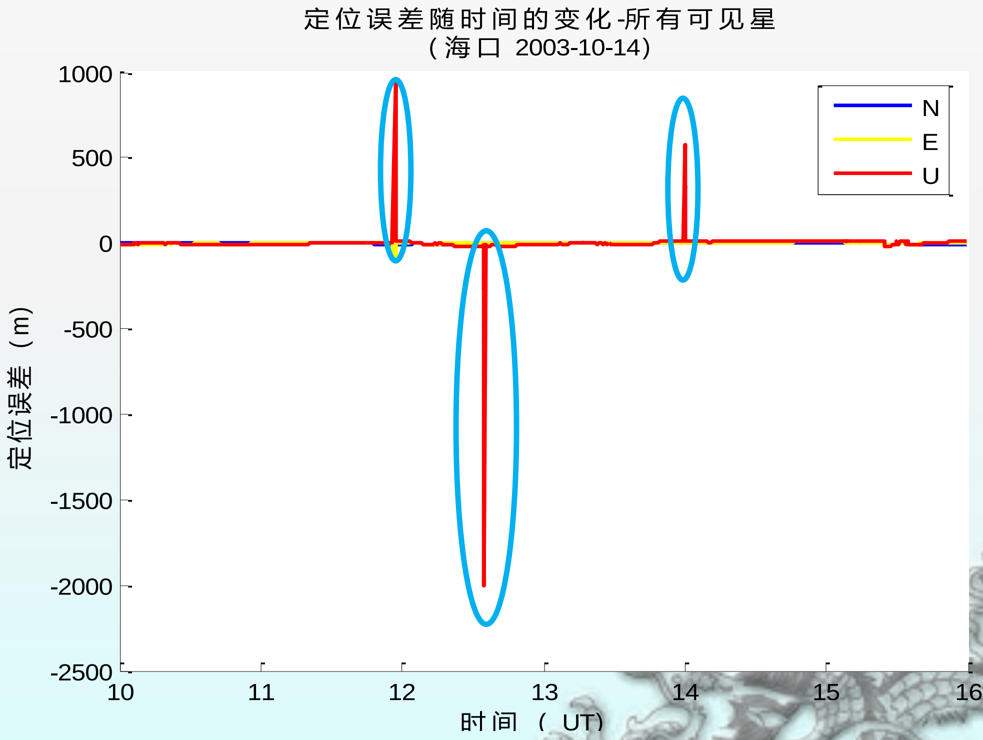
Ionospheric scintillation will lead to the reduce of the measuring accuracy, especially for the condition when losing lock.

| 卫 星 号 | Measuring accuracy（m） 2014.10.13 （without scintillation） | Measuring accuracy（m） 2014.10.14 （scintillation） |
|---|---|---|
| PRN 4 | 0.156 | 0.229 |
| PRN 7 | 0.178 | 0.247 |
| PRN 8 | 0.151 | 1476223.336 |
| PRN 10 | 0.138 | 0.137 |
| PRN 11 | 0.104 | 0.144 |
| PRN 20 | 0.142 | 0.174 |
| PRN 24 | 0.147 | 0.169 |
| PRN 27 | 0.105 | 0.436 |
| PRN 28 | 0.192 | 0.219 |
| PRN 31 | 0.107 | 0.128 |

# Localization results

Ionospheric scintillation will lead to large localization error, varying from several meters to several kilometers.



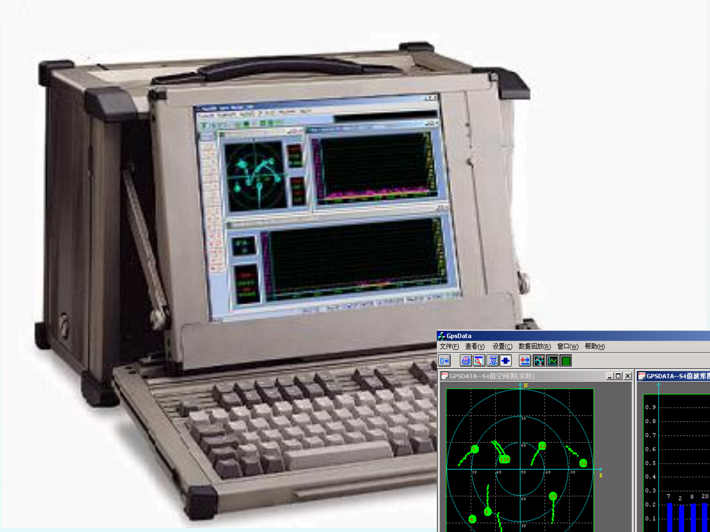
# 2.5 Ionospheric scintillation monitoring

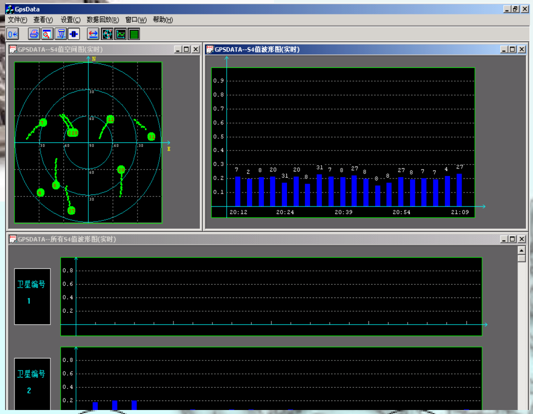
Ionospheric scintillation monitoring will provide safeguards for GNSS through:

- Scintillation status observation (help to analyze the cause of GNSS service performance afterwards);
- Scintillation distribution obtained from scintillation network (help to forecast scintillation for GNSS);
- Scintillation mitigation technique study (help to promote anti-scintillation capability of GNSS receiver).

Ionospheric scintillation monitoring maybe implemented by scintillation monitoring receivers which can be split into several types such as stationary and portable. The received signals contain:

- BDS
- GPS
- GLONASS
- GALILEO

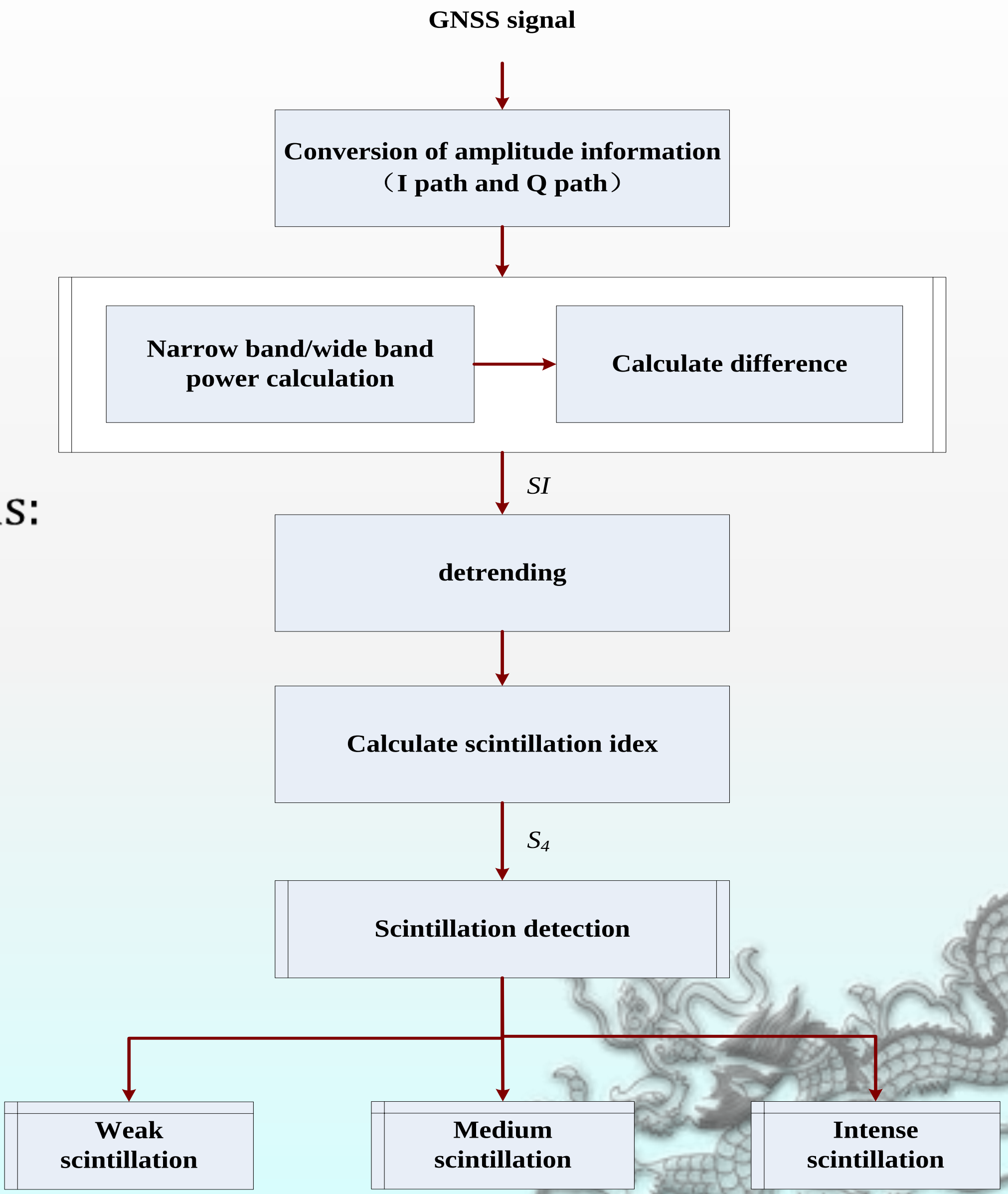




Scintillation can be detected by calculating the amplitude scintillation index (S4). The index depends on the power variation of received signal. It can be described as:

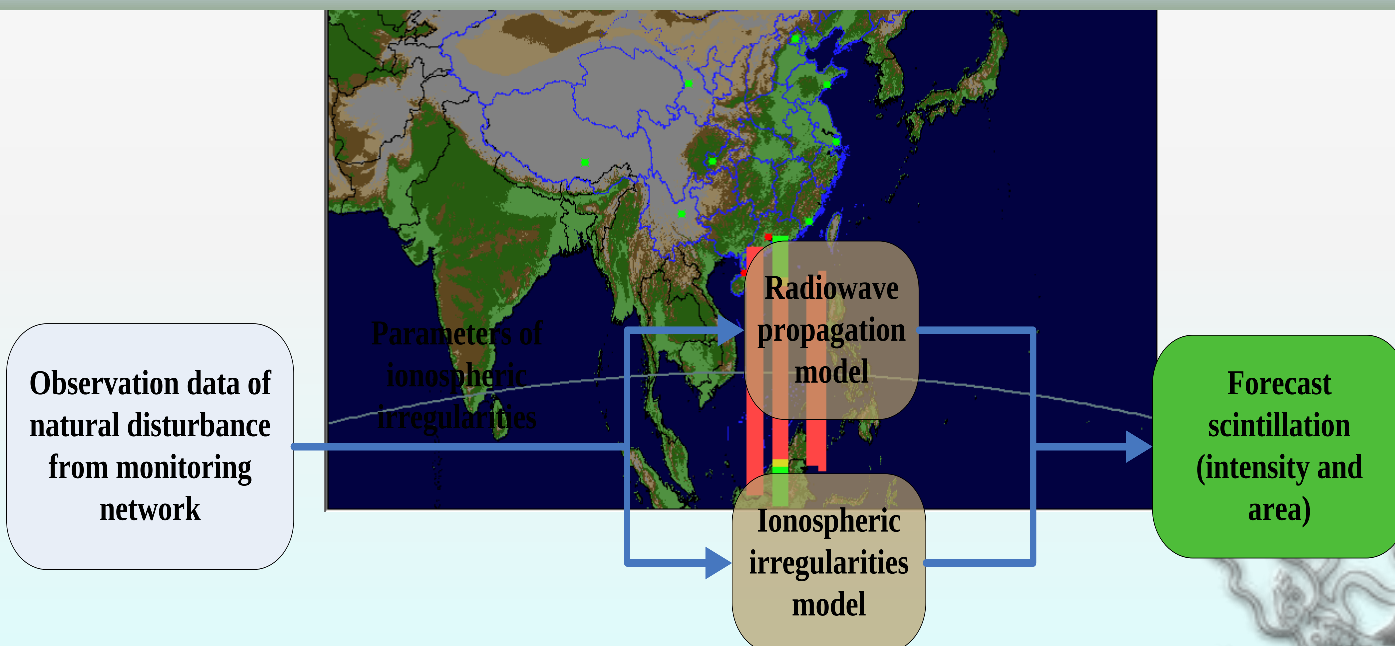
$$S4 = \sqrt{\frac{\langle P^2 \rangle - \langle P \rangle^2}{\langle P \rangle^2}}$$

- Weak (0.1<S4<0.3);
- Medium (0.3≤S4≤0.6);
- Intense (S4>0.6).



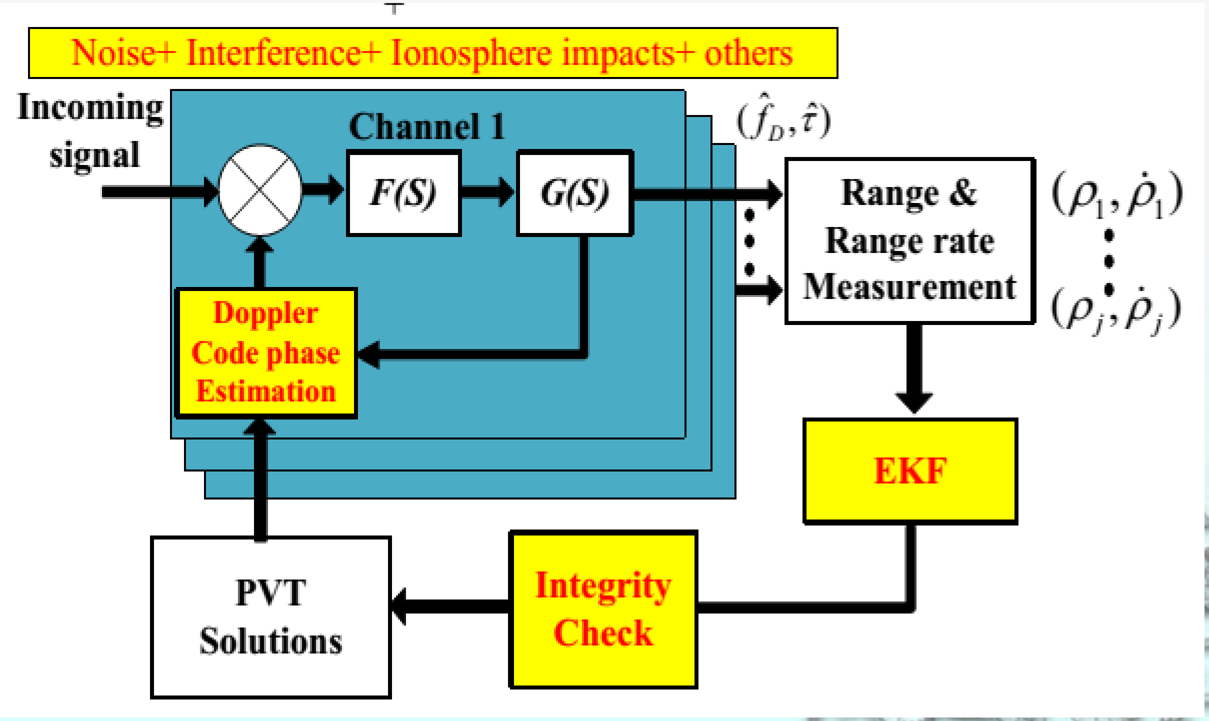
# 2.6 Ionospheric scintillation forecast and mitigation

Observation data of natural disturbance from scintillation monitoring network help to forecast scintillation in short-term:



*Carrier tracking loop is the most vulnerable part of receiver to be affected by scintillation. The mitigation measure is to improve the carrier tracking loop, including:*

- *Inertial aided carrier tracking loop;*
- *New type of carrier tracking loop design (vector tracking loop)*



# 3. Summary

1. ***The initial imagine of the base functions and workflow in IDM data center have been programmed which will be a guidance for the construction of IDM system;***
2. ***Based on the effect of radio interference on the performance of GNSS service, methods of detection, identification and localization for radio interference (including spoofing) have also been studied;***
3. ***Take ionospheric scintillation as an example, techniques for natural disturbance monitoring have been studied:***
   - ***Analyze the effect of scintillation on GNSS performance;***
   - ***Introduce the techniques for scintillation monitor, forecast and mitigate.***

***Thank You!***