Beidou/GNSS based Space weather services in China

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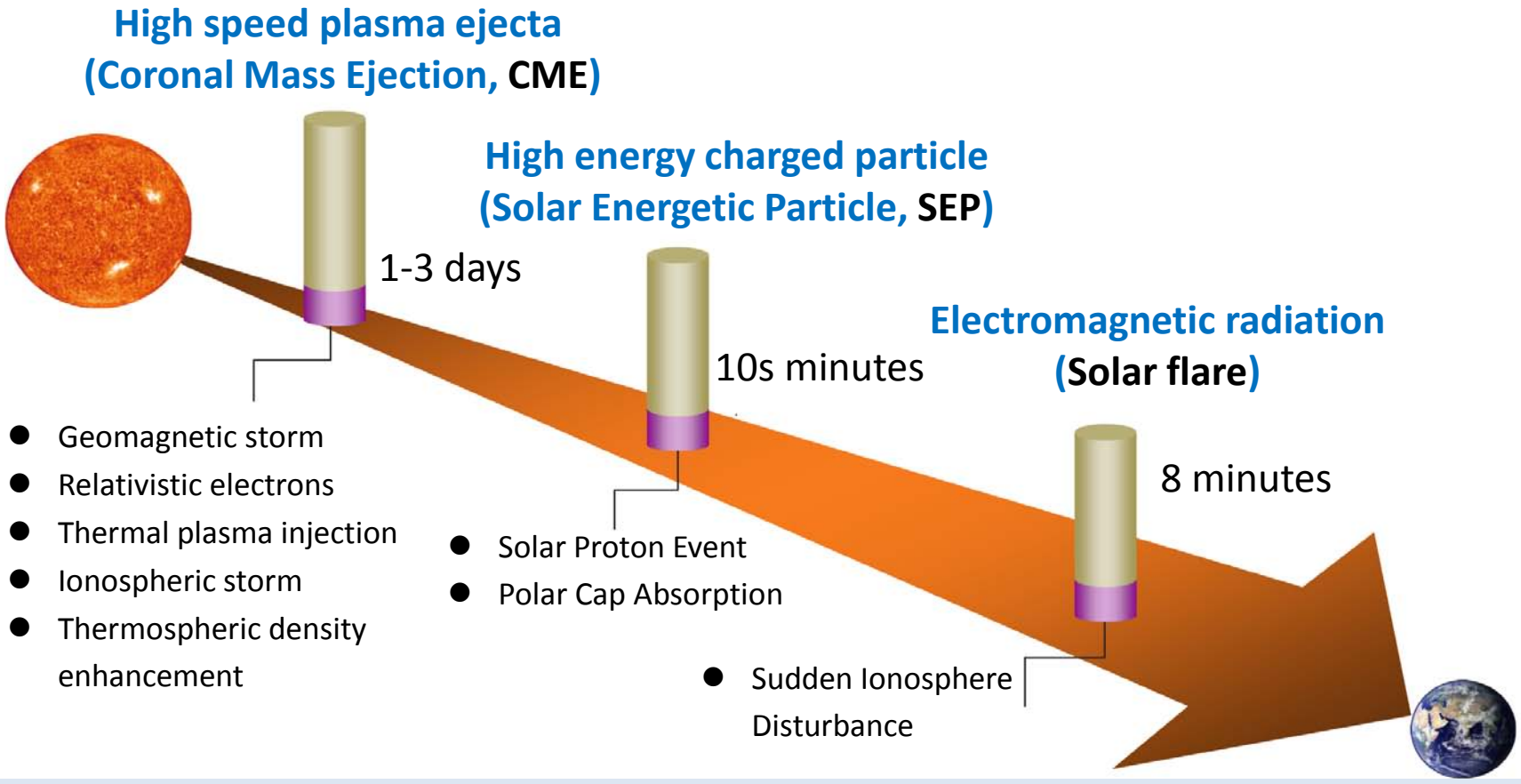
Outline

- **Introduction of space weather services in China**
- BDS/GNSS based space weather services
- Space weather related payload in Beidou II

Three rounds impacts of space weather

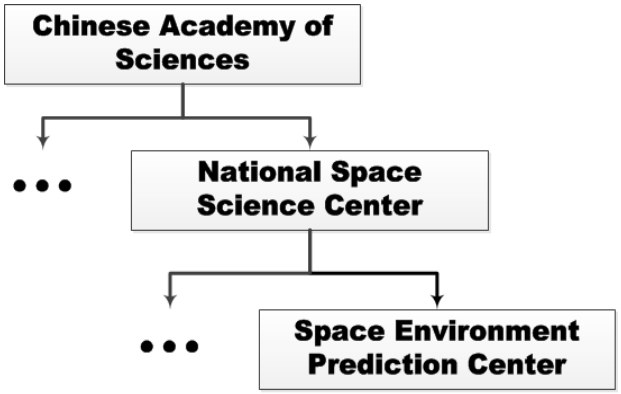
***Space Weather** refers to variations in space that can influence the performance and reliability of space-borne and ground-based technological systems and can pose risk to human health.*

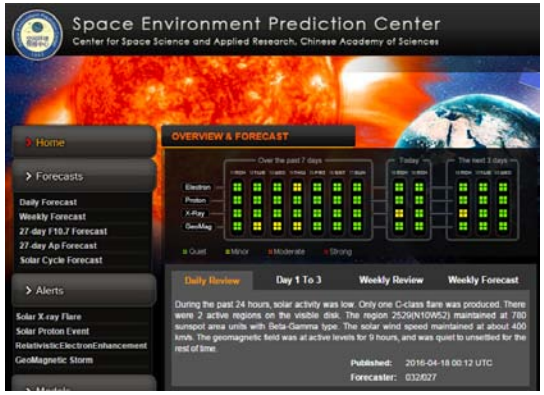


Hazard to GNSS Systems

- Communication Degrade, Positioning Error, Radiation Damage, Atmospheric Drag

Early Stages of Space Weather Service in China





NSSC Established → **SEPC Constructed** → **Issuing Operational Services**

1958

The National Space Science Center (NSSC) of Chinese Academy of Sciences (CAS) was established in 1958 with the mandate to participate in designing the 1_{st} artificial satellite of China, DFH-1.

1992

To meet the space weather need of space mission in, China, Space Environment Prediction Center (SEPC) was established in 1992 in NSSC and became the 1st professional organization providing space weather services in China.

1998

In 1998, SEPC set up the first generation of an operational space weather forecasting system, and since then started to issue operational space weather forecasting services via internet 365 days/year.

Current Space Weather Services in China

Monitoring and Data services

Two ground-based space weather monitoring networks have been constructed to support the operational space weather services in China.

Space Environment Monitoring Network (SEMnet)

17 domestics monitoring stations,
40+ ground-based instruments
For operational now-casting

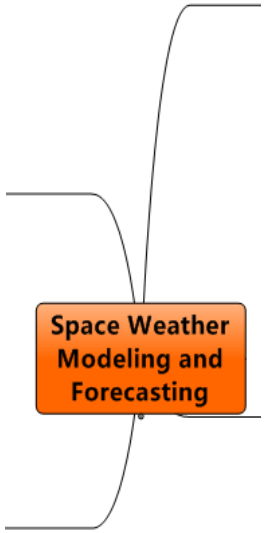
Chinese Meridian Project

15 domestics monitoring stations,
20+ different types of instruments
For space weather modeling

Current Space Weather Services in China

Modeling and Forecasting Services

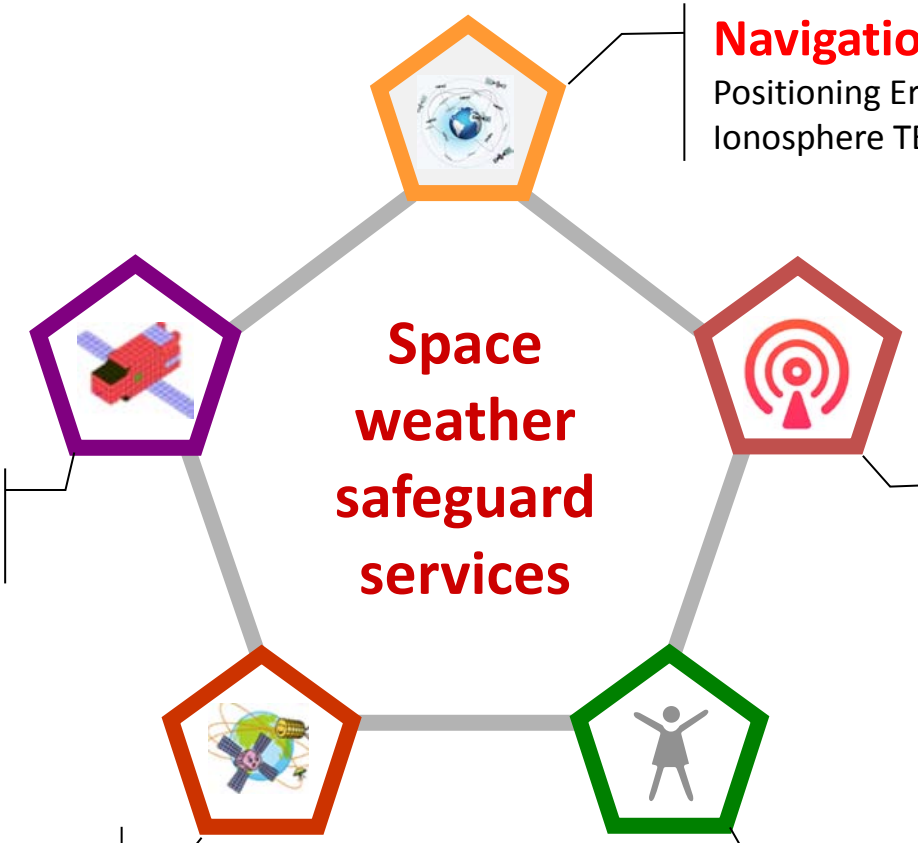
The aim of operational models and forecast products is to specify and predict the space environment in order to assist in providing timely, accurate, and reliable space weather safeguard services.



Current Space Weather Services in China

Safeguard Services

- The aim is to monitor, specify, and forecast the space weather in order to provide timely, accurate, and reliable services for national infrastructure



Navigation & Position
Positioning Error correction
Ionosphere TEC modeling

Satellite Design
Surface Charging analysis
Internal dielectric charging
Single event effects

Radio Communication
Ionosphere scintillation alert
SID and ionosphere storm alert

Space Equipment Safety
Radiation effects analysis
Satellite orbit prediction

Ground-based M/C system
Space weather event alert
Orbit prediction and maintenance

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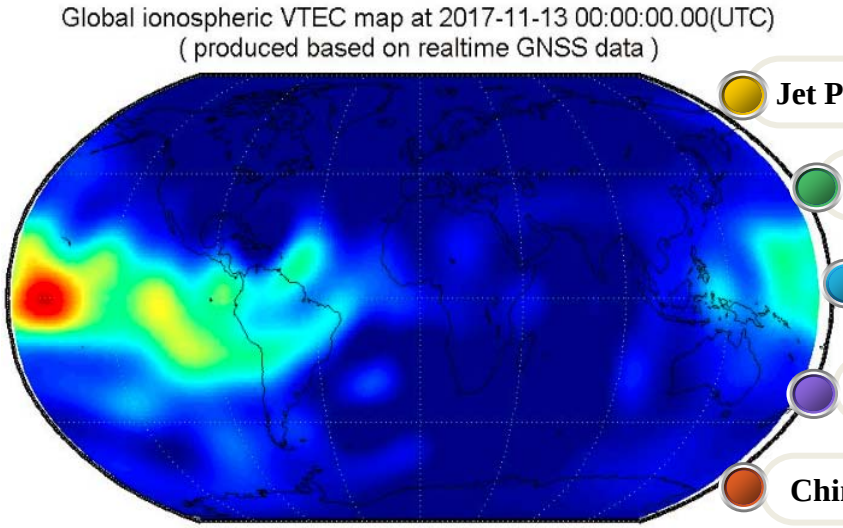
- **BDS/GNSS based space weather services**
- Space weather related payloads in Beidou II

BDS/GNSS based space weather services

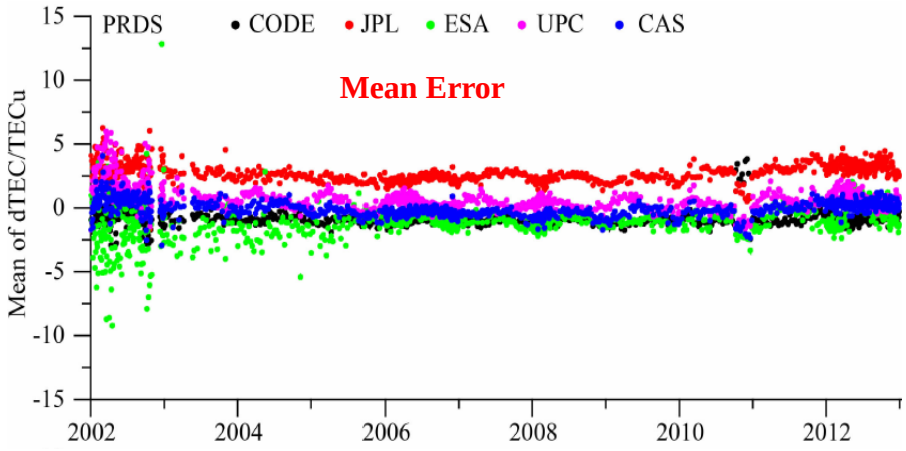
Global Ionosphere Maps of TEC (GIMs)

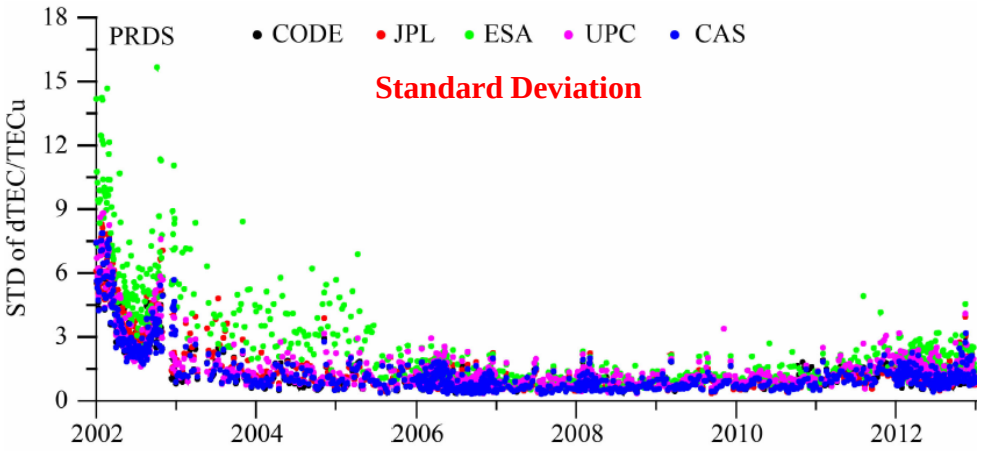
TEC can be used to 1) specify the dynamic feature of ionosphere for scientific study; 2) provide information of error correction and radio scintillation for navigation/communication systems

GIMs are provided by 5 analysis centers of IGS



- Jet Propulsion Laboratory (JPL)
- European Space Agency (ESA)
- Center for Orbit Determination of Europe (CODE)
- Poly-tech University of Catalonia (UPC)
- Chinese Academy of Sciences (CAS) ← Newly Joined in 2016



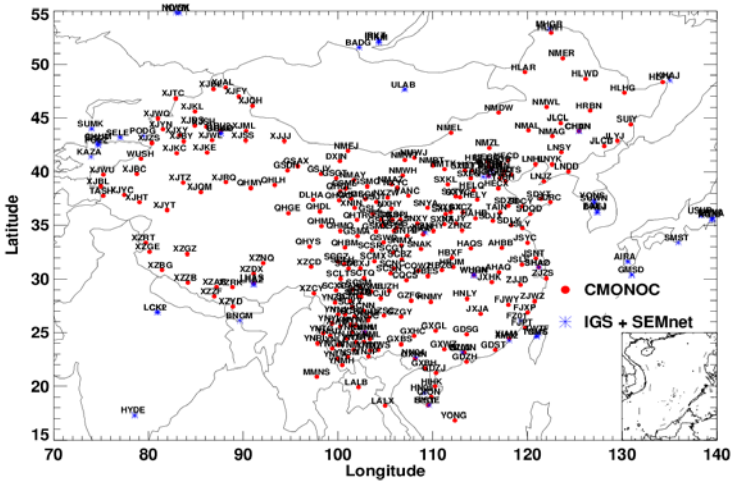


BDS/GNSS based space weather services

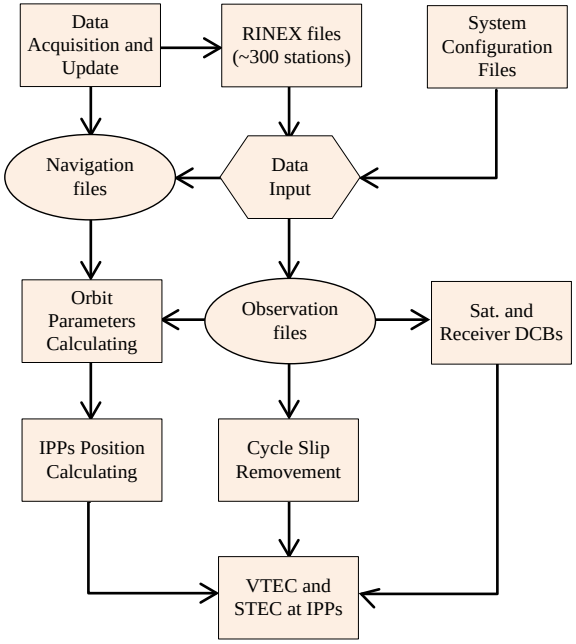
Regional TEC monitoring services

TEC can be used to 1) specify the dynamic feature of ionosphere for scientific study; 2) provide information of error correction and radio scintillation for navigation/communication systems

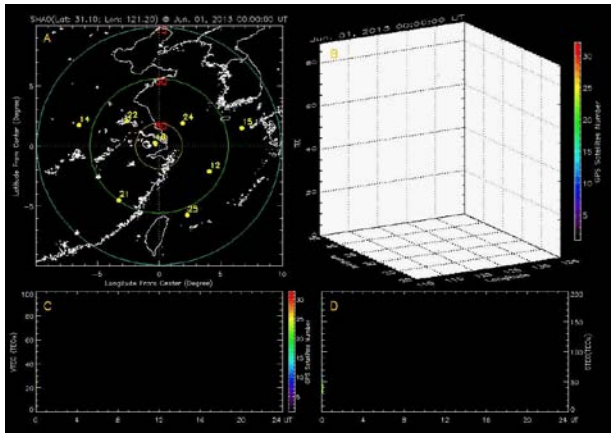
1.Station distribution： ~300 GNSS Stations		
Crust Movement Observation Network of China (CMONOC)	International Global Navigation Satellite System Service (IGS)	Space Environment Monitoring Network (SEMnet)
260+ Stations	38 Stations	9 Stations



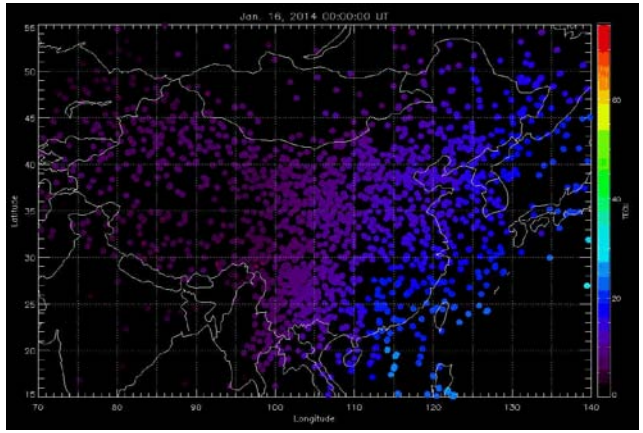
2. TEC Derivation flowchart



3. TEC result at single station



4. TEC Scattering Maps



BDS/GNSS based space weather services

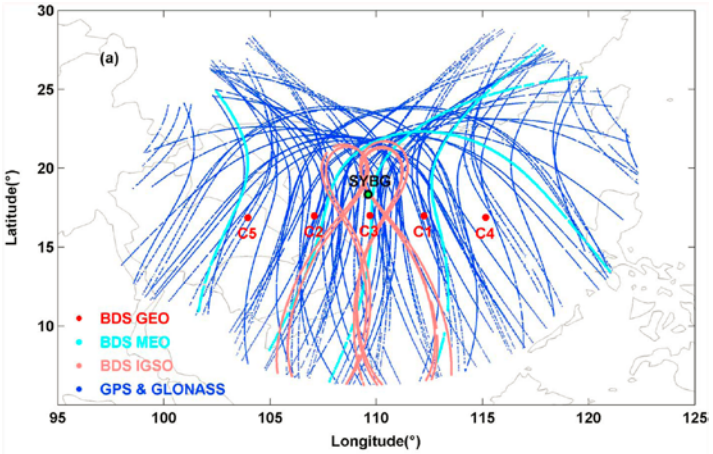
Beidou Ionospheric Observation Network (BION)

BION has 30 observation sites with the scientific objective as following (*Hu et al*., 2017):

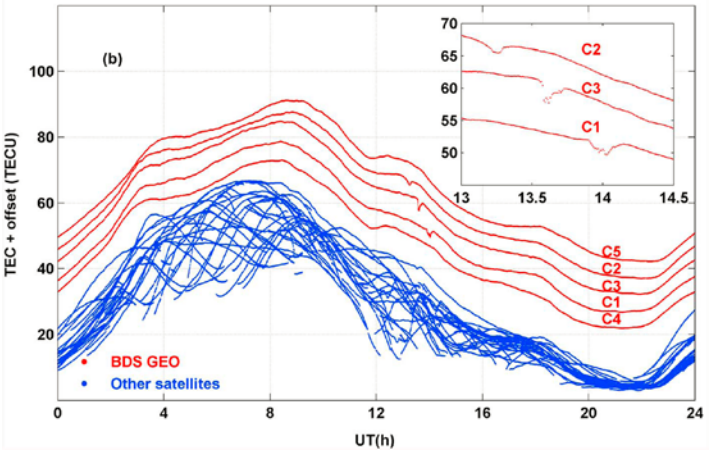
1. Monitoring the latitudinal variation of the ionosphere along the 120°E longitude
2. investigating the ionospheric response during space weather events (e.g., geomagnetic storm) and other non-space weather events (e.g., earthquake, tsunami, and typhoon);
3. Analyzing ionospheric dynamics at middle and low latitudes of East Asia.

Distribution of BION sites

IPPs



TEC

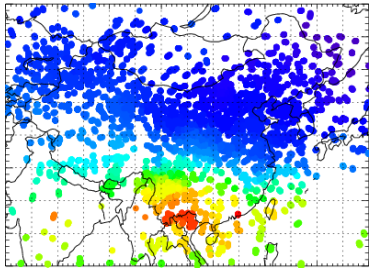


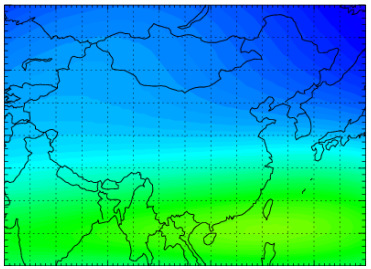
Beidou/GNSS based space weather services

TEC data assimilation and error correction/radio scintillation services

The data assimilation technique has been proved as an effective and efficient way of specifying ionosphere, which is implemented by using certain optimization schemes to incorporate measurements into background models.

TEC Observation + Background Model + Assimilation algorithm → Data Assimi-lation product

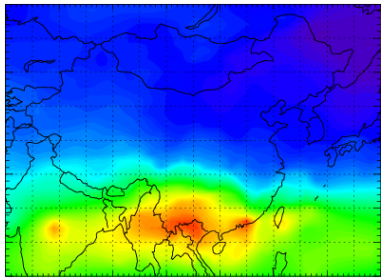




Kalman Filter

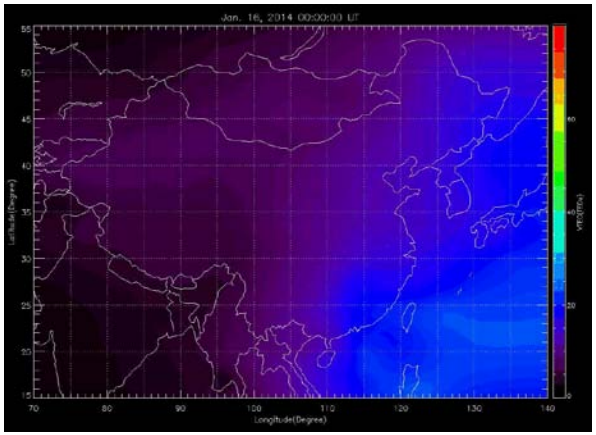
3D Variation

4D Variation



Time Update ("Predict")	
1. Project the state	$\hat{x}_k^- = A\hat{x}_{k-1} + Bu_{k-1}$
2. Project P and R	$P_k^- = AP_{k-1}A^T + Q$

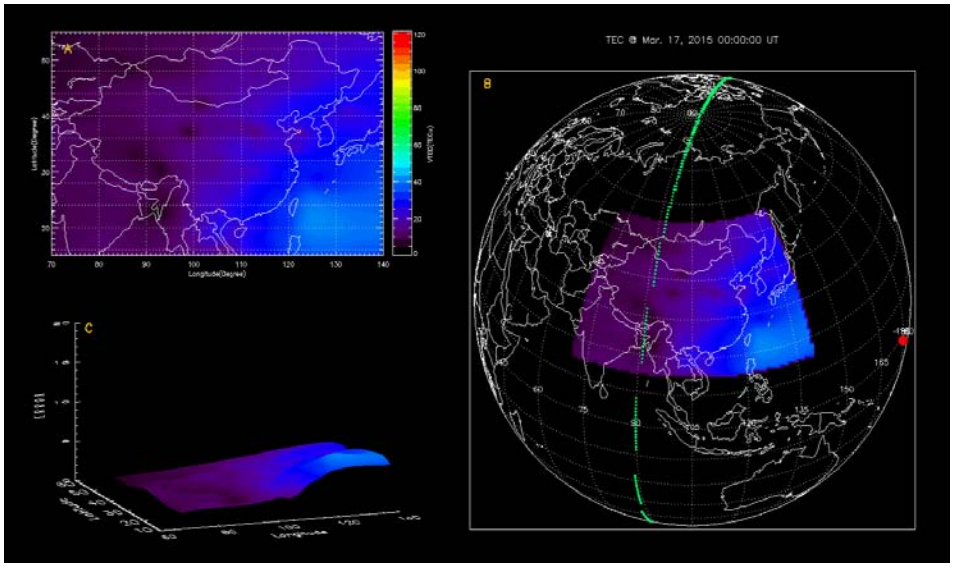
Measurement Update ("Correct")	
3. Calc Kalman gain	$K_k = P_k^- H^T (HP_k^- H^T + R)^{-1}$
4. Update estimate	$\hat{x}_k = \hat{x}_k^- + K_k(z_k - H\hat{x}_k^-)$
5. Update P and R	$P_k = (I - K_k H)P_k^-$



Space weather services to BDS/GNSS system

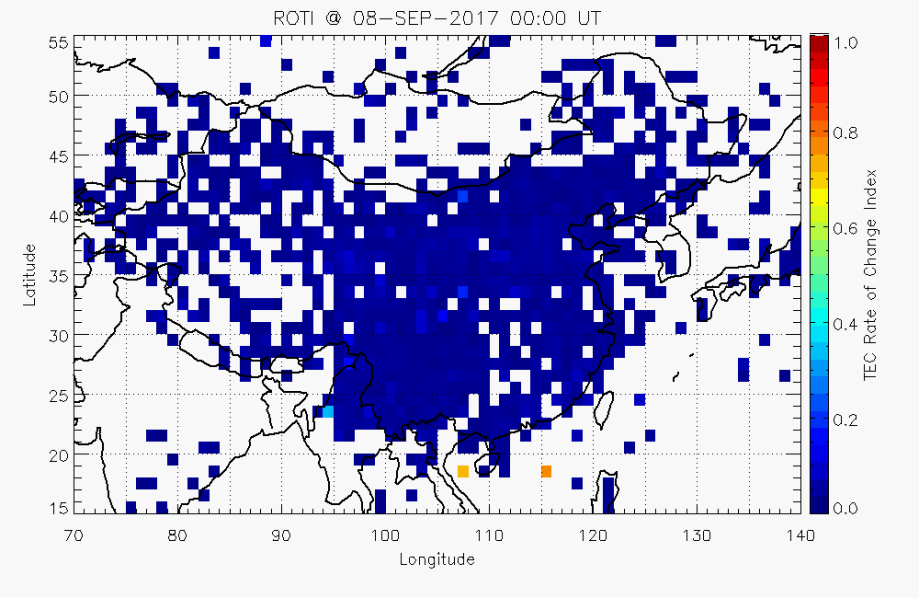
2015 St. Patrick's Day magnetic storm

TEC and GNSS Positioning Error



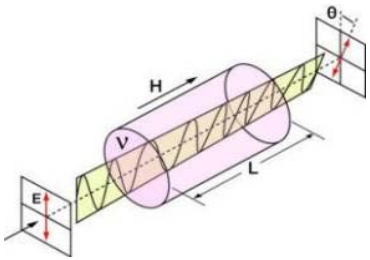
2017 September magnetic storm

TEC rate of change index (ROTI) : Scintillation



TEC related ionospheric services to scientific research and application

Faraday Rotation

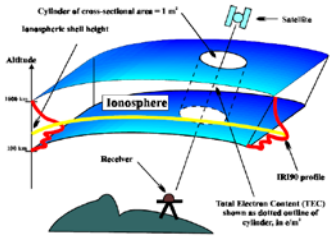


$$\Omega = \frac{K}{f^2} \overline{B_0 \cos\theta \sec\chi} \bullet TEC$$

Chromatic Dispersion

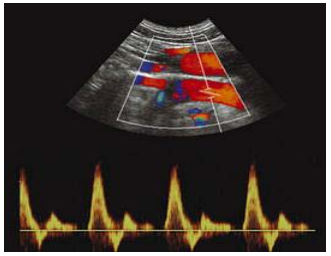
$$\frac{d\phi}{df} = -\frac{b}{2\pi c f^2} TEC = -\frac{8.44\times10^{-7}}{f} TEC$$

Doppler Effect



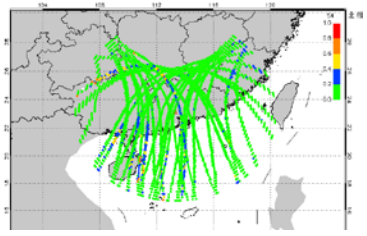
$$\Delta f = -\frac{f}{c}\frac{ds}{dt} + \frac{40.3}{cf}\frac{dTEC}{dt}$$

Ionospheric Delay



$$\Delta\tau \propto \frac{1.343\times10^{-7}}{f^2} TEC$$

Ionosphere Scintillation

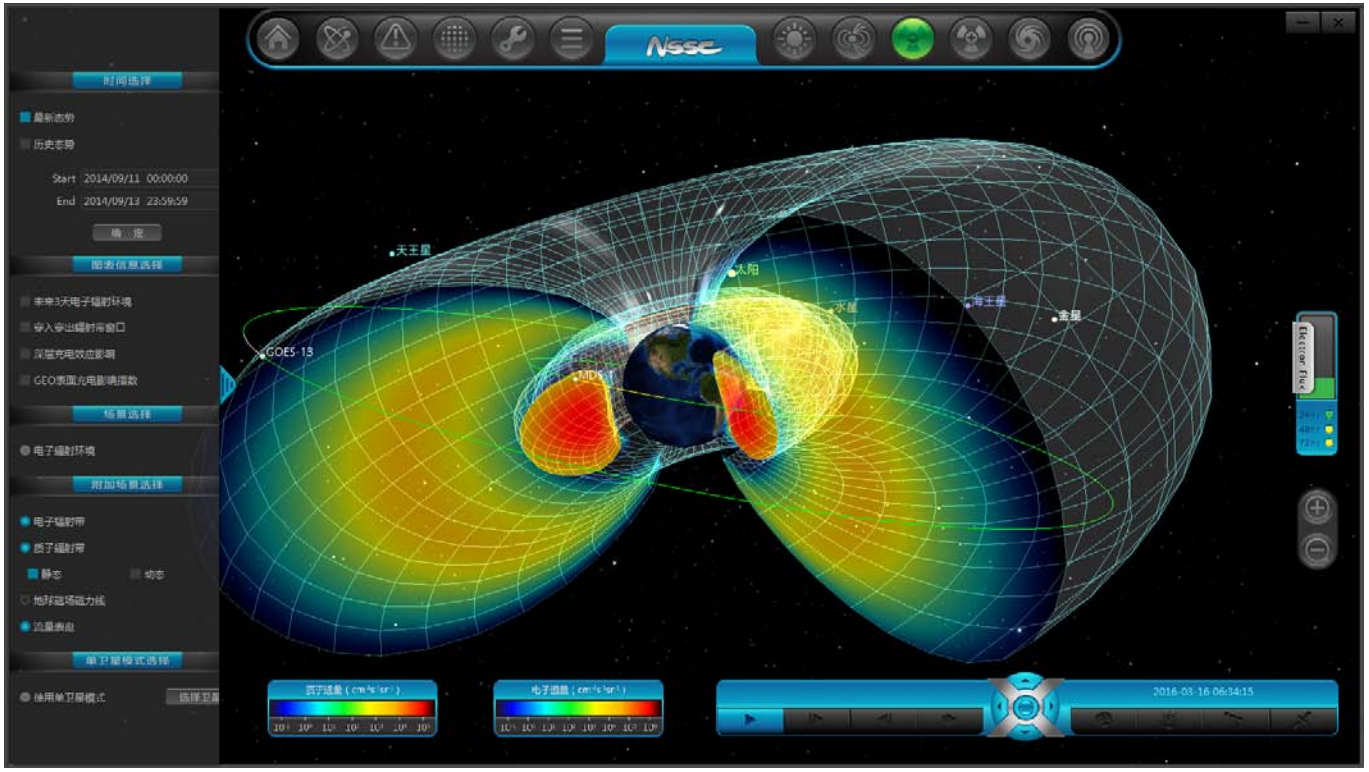


$$S_4 = \sqrt{\frac{E[P^2]-(E[P])^2}{(E[P])^2}}$$

Space Weather Services to BDS/GNSS System

Particle Radiation Analysis

SWSAP (Space Weather Situation Awareness Picture) is used to simulate and predict the space radiation risk to satellites, including Single Event Effects, Surface charging, Deep dielectric or bulk charging, and Total dose effects.



1. Making **statistical analysis of previous anomalies** in Beidou satellites that caused by space weather events in terms of single-particle event, surface charging events, etc.
2. Provide **future predictions and warning** of radiation environment to Beidou MEO/IGSO/GEO satellite, especially on cross-magnetopause events, south-Atlantic anomaly crossing events

Outline

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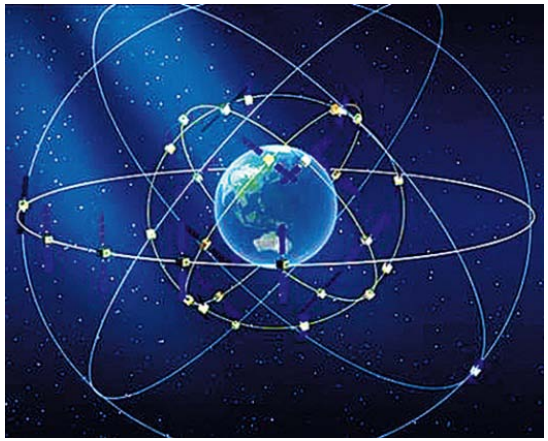
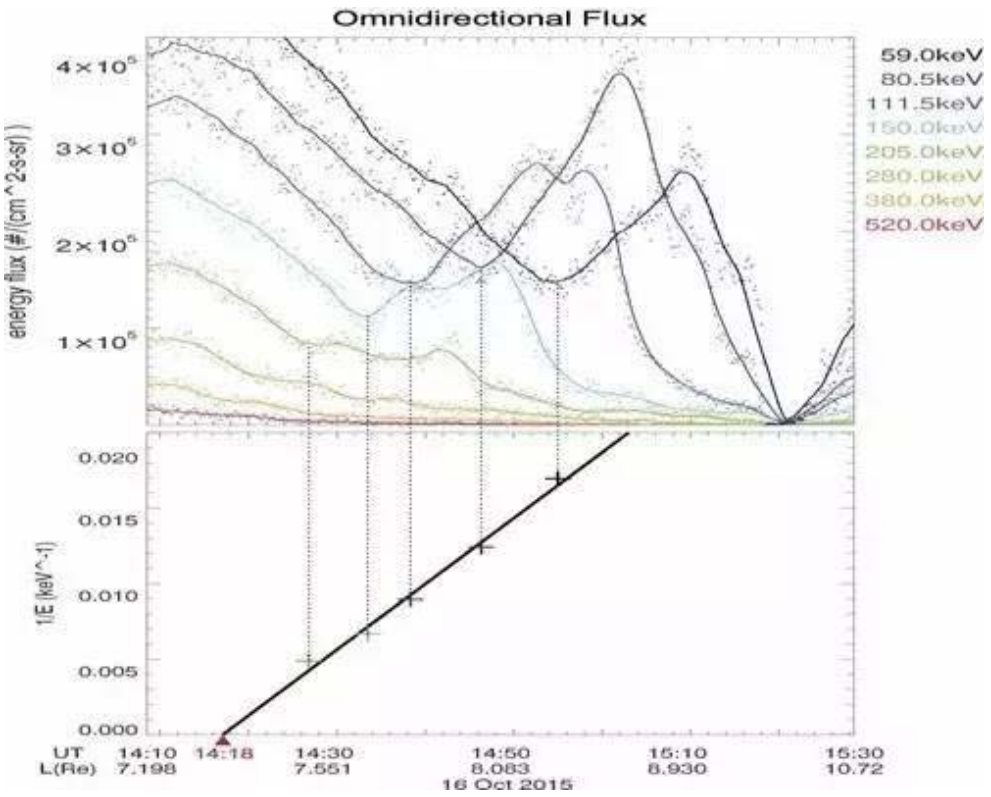
- **Space weather related payloads in Beidou II**

BDS payload for space weather monitoring

Image Electron Spectrometer

- Measurements derived from Image Electron Spectrometer (IES) onboard Beidou IGSO satellite are used to study an relativistic electron injection case during geomagnetic sub-storm event.





Summary

BDS/GNSS based space weather services

- **Ionosphere TEC and error correction**
  - Chinese Academy of Sciences joined IGS analysis centers in routinely generating accurate and reliable GIM products
  - BION networks using BDS ionospheric monitors to provide dense IPP trails and continuous TEC observation
  - CMONOC and SEMnet/Meridian Project network have been used to construct high resolution regional TEC maps over China and adjacent areas for ionospheric error correction of BDS/GNSS system.
- **Ionosphere irregularities and scintillation**
  - High-resolution ROTI maps derived from dense BDS/GNSS networks have been built to represent the regional ionosphere irregularities and radio scintillations.
- **Radiation effects**
  - Space Weather situation awareness picture (SWASP) has been established to simulate and predict the radiation environment of BDS/GNSS systems.

Thank You !