Regional Ionospheric Irregularities Mapping at Different Temporal Scales Using GNSS Networks and Its Applications

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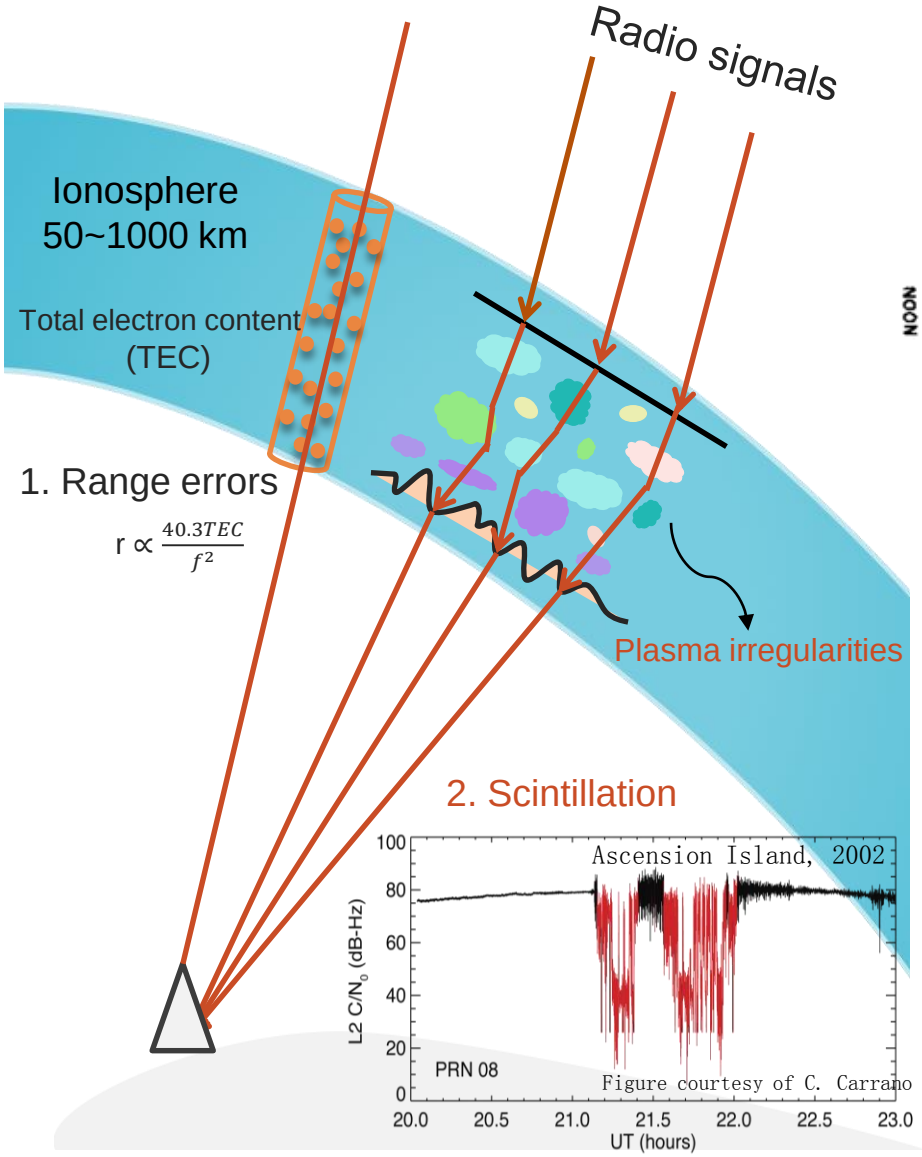
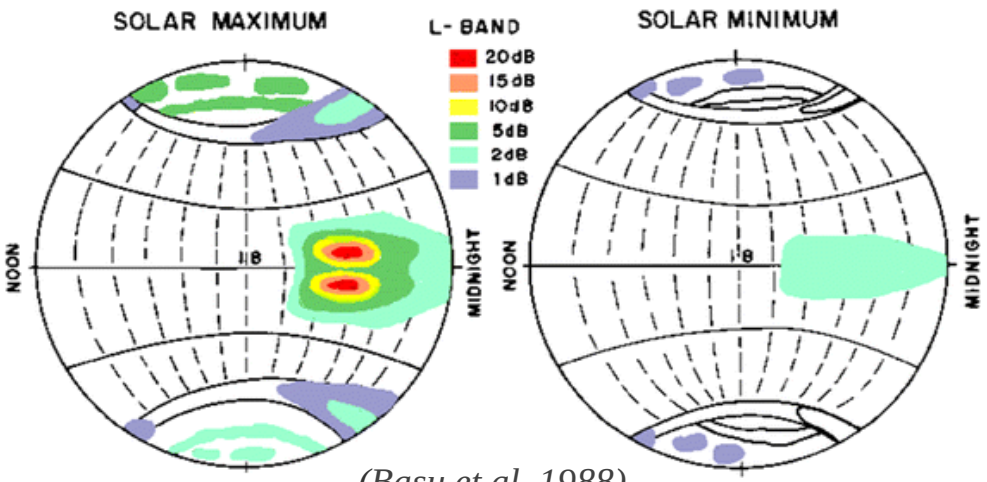
Outline

- Ionospheric Irregularities/Scintillation
  - ROTI and scintillation indices
  - Irregularities monitoring using GNSS
- Regional Ionospheric Irregularities Mapping
  - Crustal Movement Observation Network of China
  - ROTI at different sampling rates
  - ROTI maps
- Summary

Ionospheric Irregularities/Scintillation





(Basu et al. 1988)

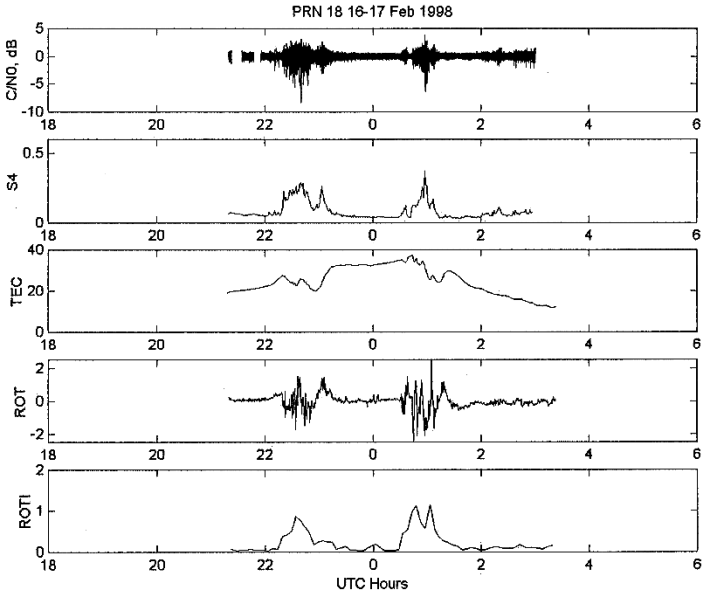
- **Rate of change of TEC index (ROTI)**

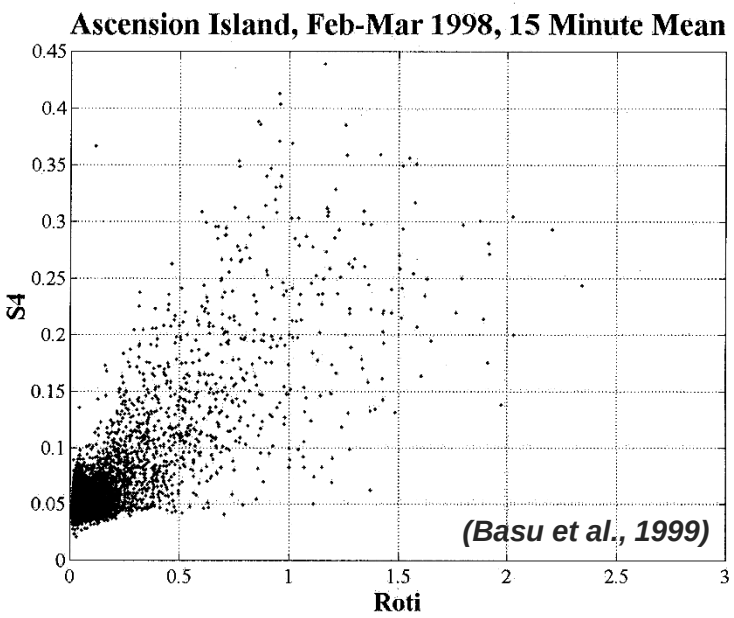
$$ROTI = \sqrt{\langle ROT^2 \rangle - \langle ROT \rangle^2} \qquad ROT = \frac{TEC(i) - TEC(i-1)}{(t_i - t_{i-1})}$$

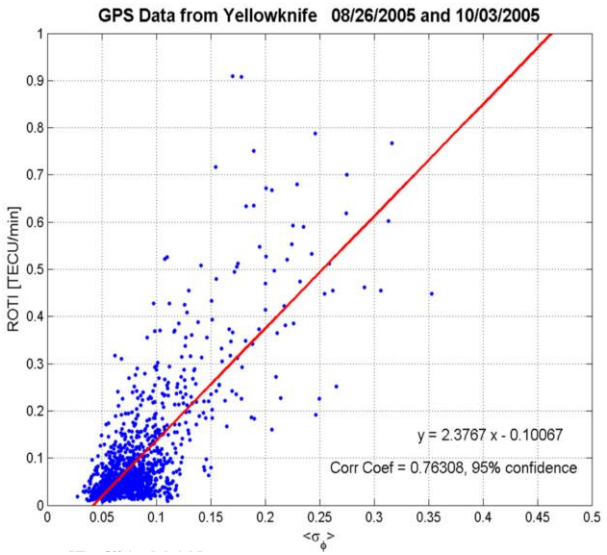
Low frequency GNSS data (e.g., 30s, 1s) (Pi et al., 1997)

- **ROTI**, detect the presence of ionospheric irregularities that cause scintillations.

ROTI and Scintillation Indices



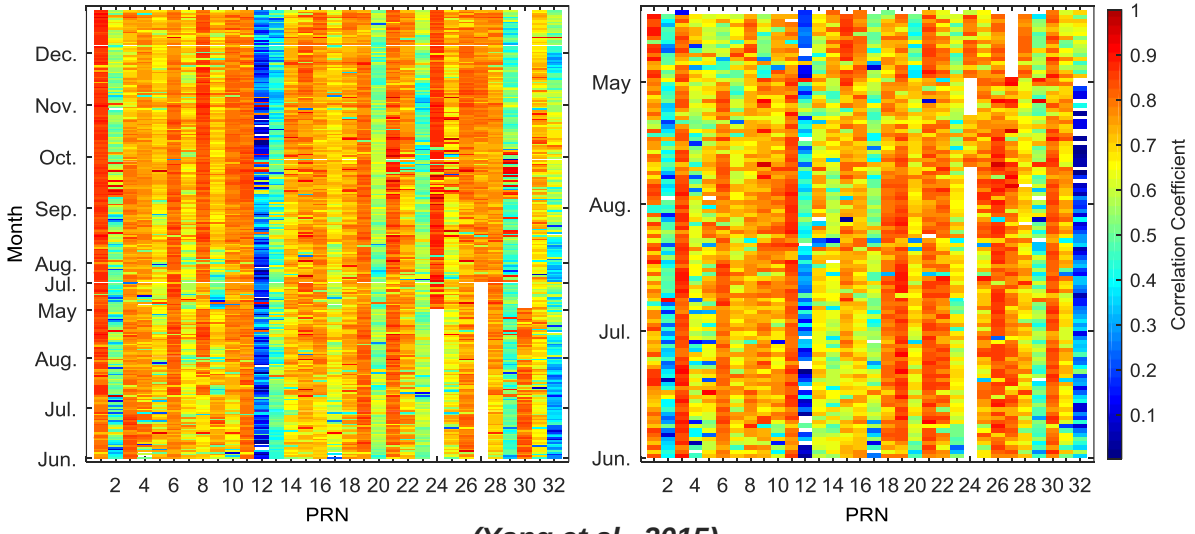




(Pi et al., 2013)

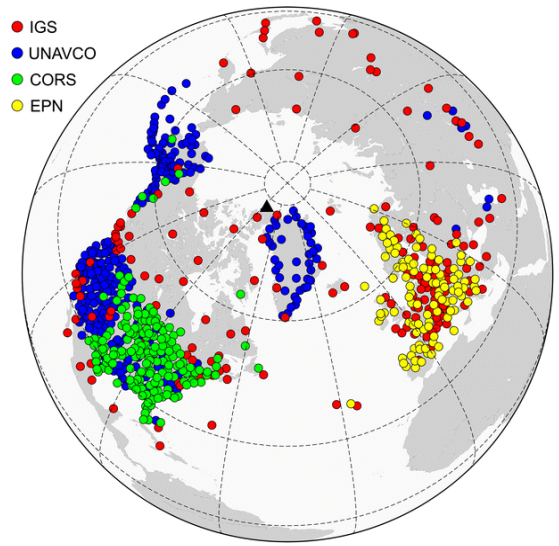
(a) ROTI & S_4

(b) ROTI & σ_Φ



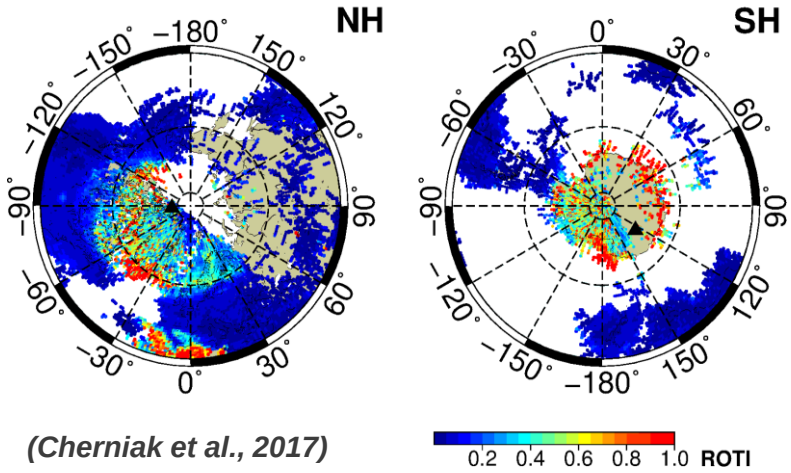
(Yang et al., 2015)

Irregularities Monitoring Using GNSS



(Cherniak et al., 2018)

23/06/2015 00:00



(Cherniak et al., 2017)

ROTI maps: IGS new official ionospheric product

1.0 IGS ROTI maps
UWM ROTIPOLARMAP product
The daily ROTI map are generated on an regular basis
at UWM using data from more than 700 GPS permanent
stations of the IGS, UNAVCO and EUREF networks.
The Rate of TEC index is presented
in a Magnetic Local Time reference frame.
00-24 MLT time frame.
8 min MLT bin.
89.0-51.0 magnetic latitude range.
2.0 magnetic latitude bin.

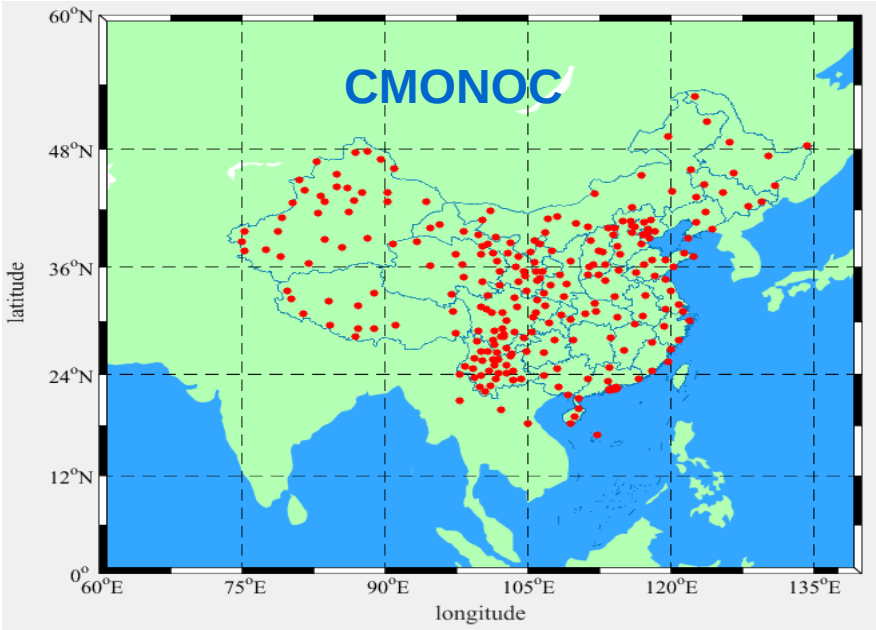
Please make reference when using this product on
Cherniak,I., A. Krankowski, I. Zakharenkova (2014)
"Observation of the ionospheric irregularities over
the Northern Hemisphere: Methodology and service",
Radio Sci., 49, 653?62,doi:10.1002/2014RS005433.
Contact Address:
iurii.cherniak@uwm.edu.pl or tcherniak@ukr.net

START OF ROTIPOLARMAP
2017 1 1
89.0 1.0 359.0

0.1083	0.0914	0.0704	0.1002	0.0675	0.0766	0.1109	0.1007	0.0771	0.0874
0.0756	0.0850	0.0921	0.0930	0.1194	0.0976	0.0965	0.1187	0.0789	0.0764
0.0599	0.0662	0.0782	0.1100	0.0933	0.0795	0.0617	0.0692	0.0637	0.0706
0.0455	0.0603	0.0728	0.0604	0.0536	0.0764	0.0768	0.0712	0.1088	0.0967
0.0820	0.0773	0.0845	0.0673	0.0642	0.0604	0.0668	0.0610	0.0611	0.0973
0.0745	0.0835	0.0743	0.0683	0.0721	0.1057	0.0886	0.1157	0.0913	0.0963
0.0867	0.1058	0.0726	0.1268	0.0882	0.0694	0.1099	0.0813	0.0838	0.0769
0.0689	0.1058	0.0983	0.0874	0.0717	0.0778	0.0741	0.0597	0.1054	0.1278
0.0669	0.0693	0.0941	0.0801	0.0832	0.0833	0.0863	0.0660	0.0900	0.0880
0.0910	0.0875	0.0920	0.0942	0.0950	0.0936	0.1031	0.0945	0.1329	0.0744

Regional Ionospheric Irregularities Mapping

- **GNSS network, CMONOC**
  - Crustal Movement Observation Network of China
  - more than 260 GNSS sites (Trimble receiver)
  - 1s, 30s GPS data
  - March-April, 2015



- **ROTI calculated based on**

$$ROTI = \sqrt{\langle ROT^2 \rangle - \langle ROT \rangle^2}$$

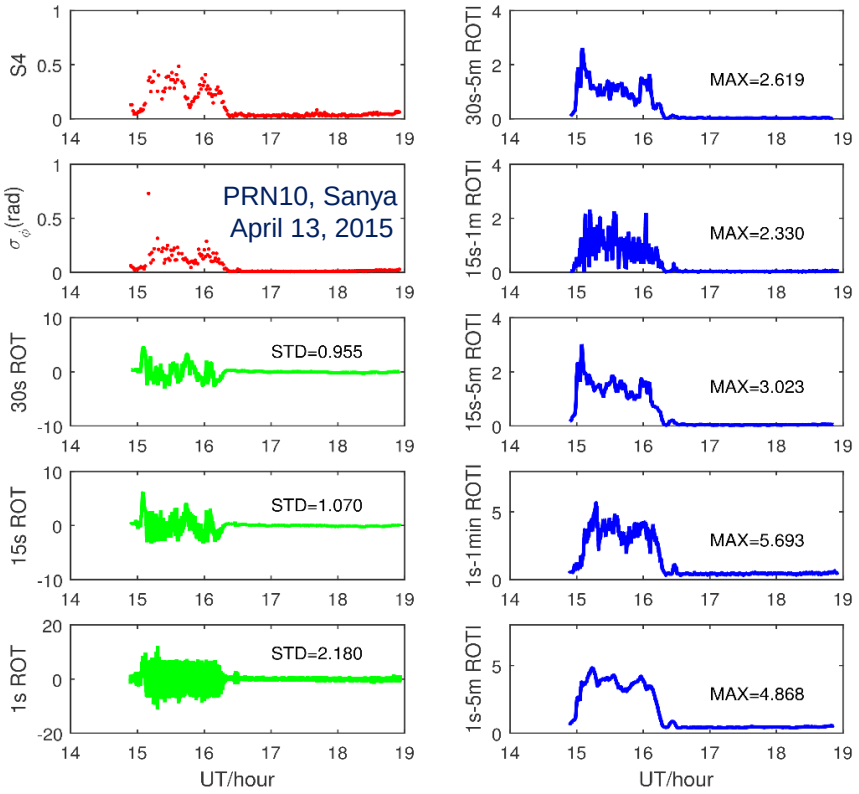
$$L_{GF}(i) = L1(i) \times \lambda_1 - L2(i) \times \lambda_2$$

$$ROT = \frac{L_{GF}(i) - L_{GF}(i-1)}{\Delta t \times 10^{16} \times 40.3 \times \left(\frac{1}{f_1^2 - f_2^2}\right)}$$

Sampling	Time interval (running window)	Samples (Number)
1s	5 min	300
5s	5 min	60
15s	5 min	20
30s	5 min	10

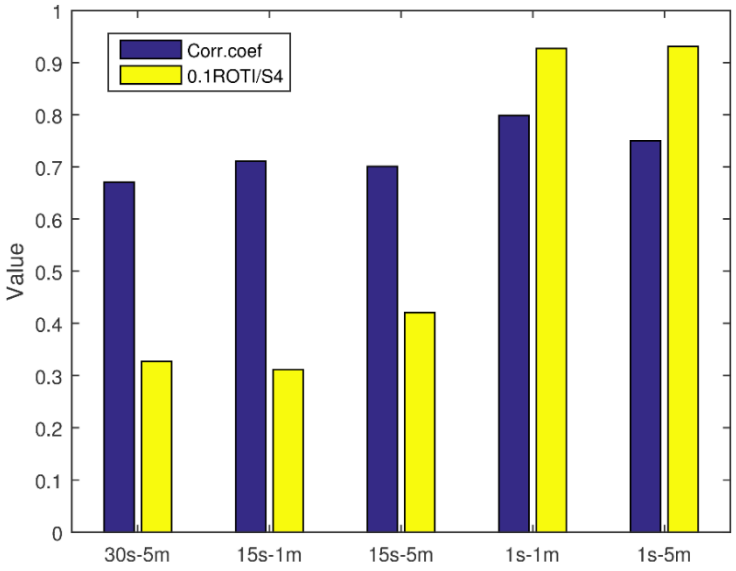
- **ROTI, at different sampling rates**
  -1s, 5s, 15s and 30s
- **ROTI mapping over China region**
  -260 GPS sites, CMONOC
  -every 10 min, 30 min and 1 hour
  -ionospheric response to geomagnetic storms

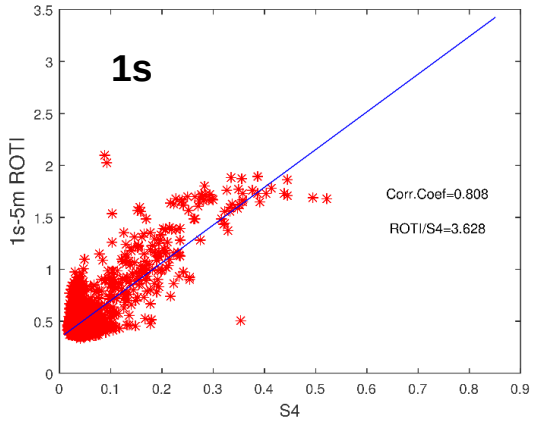
ROTI at different sampling rates

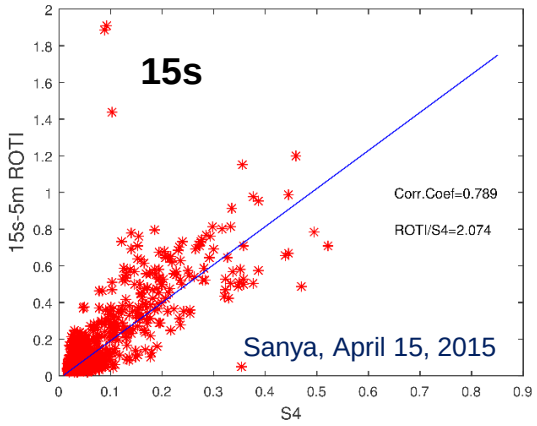


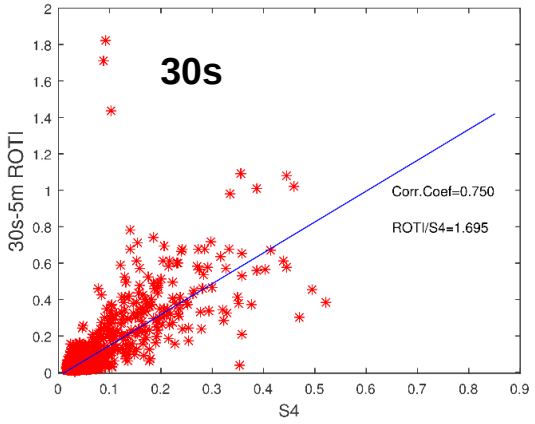
Correlation coefficient between ROTI and S4

Sanya, April of 2015







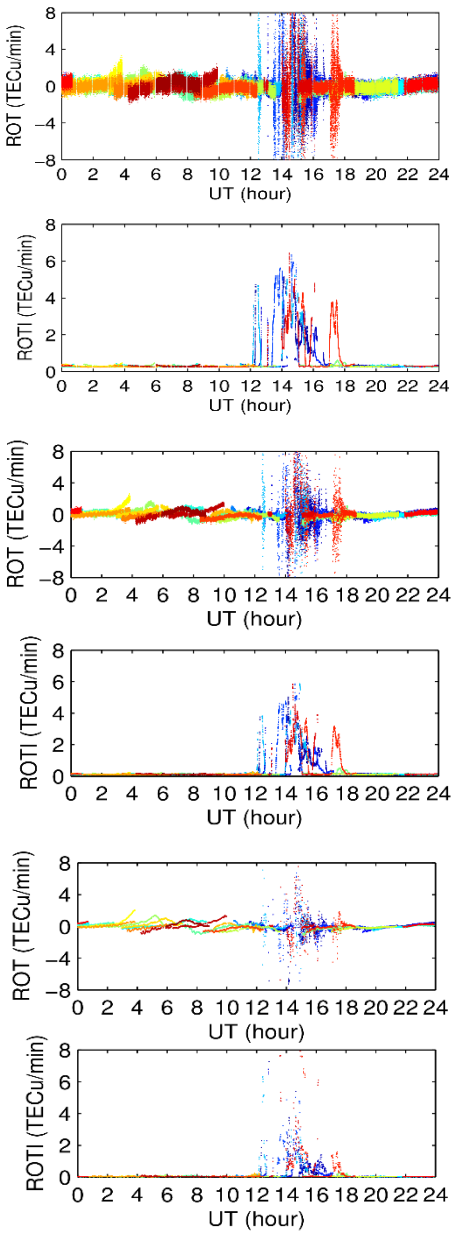


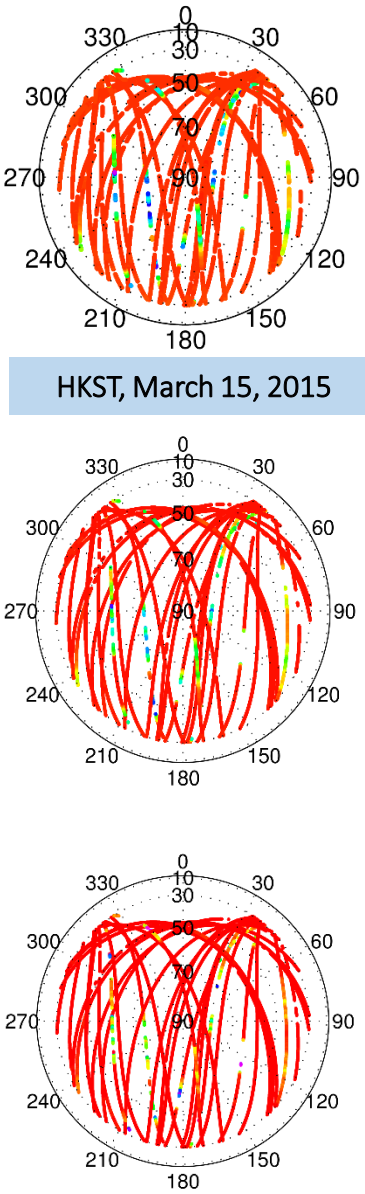
ROTI at different sampling rates (cont.)

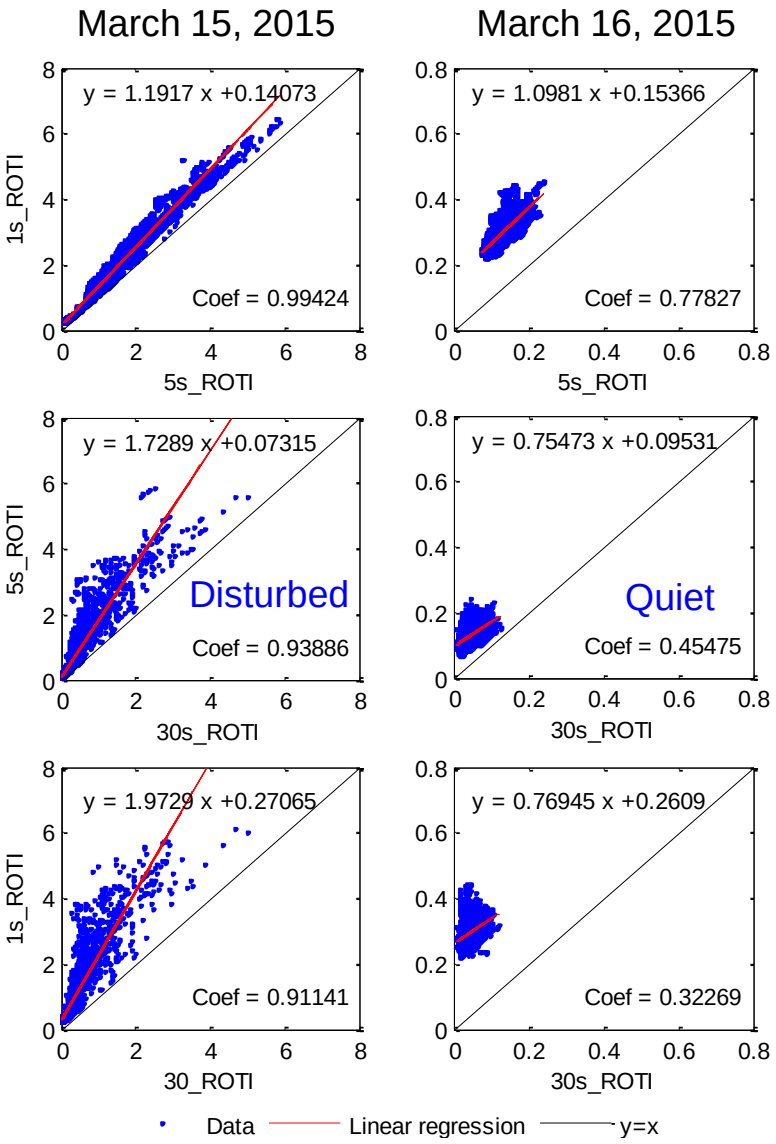
1s

5s

30s

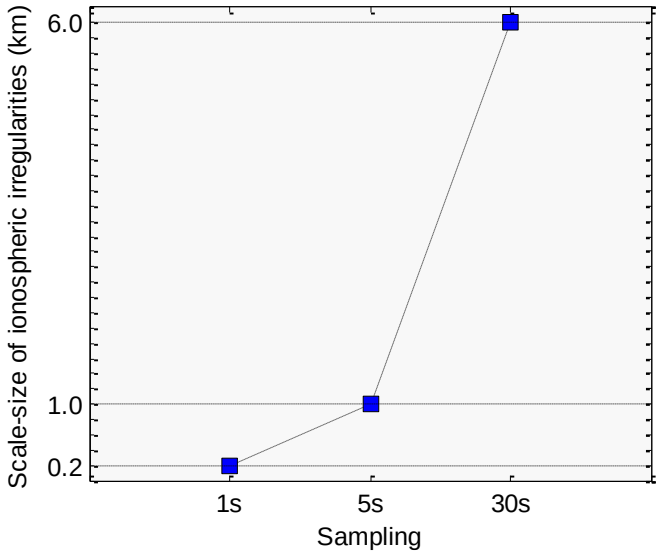




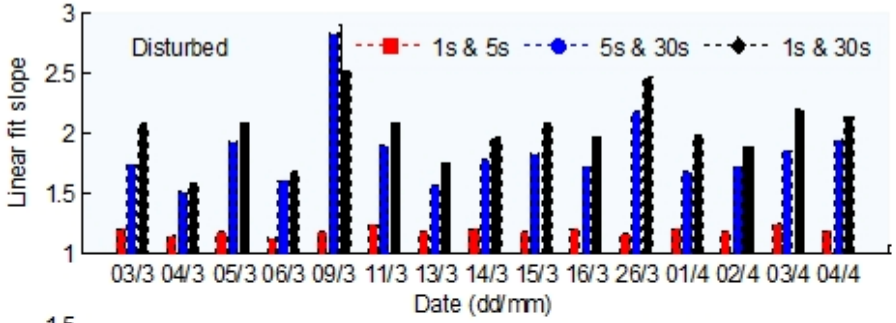


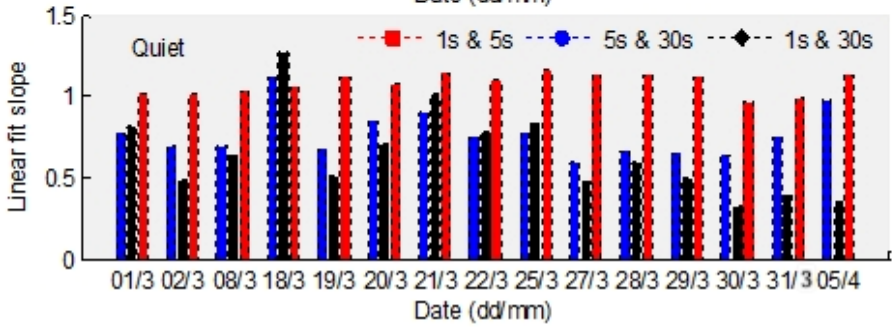
ROTI at different sampling rates (cont.)

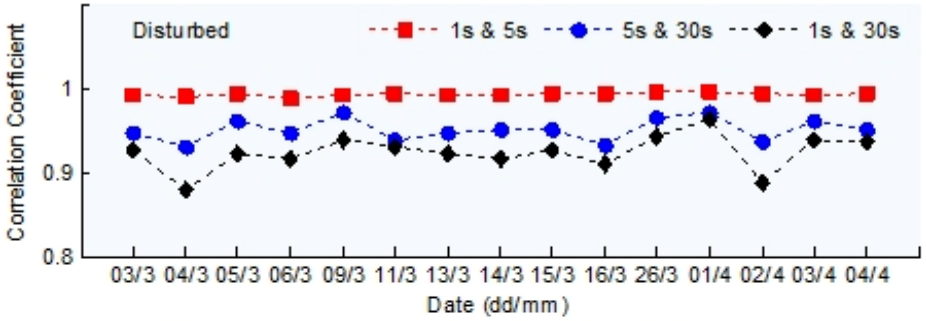
- **ROTI with a high sampling rate**
  - represents small scale-size of ionospheric irregularities (1s-ROTI, 200 m; 5s-ROTI, 1 km; 30s-ROTI, 6 km)
  - 1s-ROTI may indicate irregularities (~400 m scale-size) that cause scintillations of GPS L1 signal.
  - a larger magnitude (high-frequency parts of the ROT spectrum)

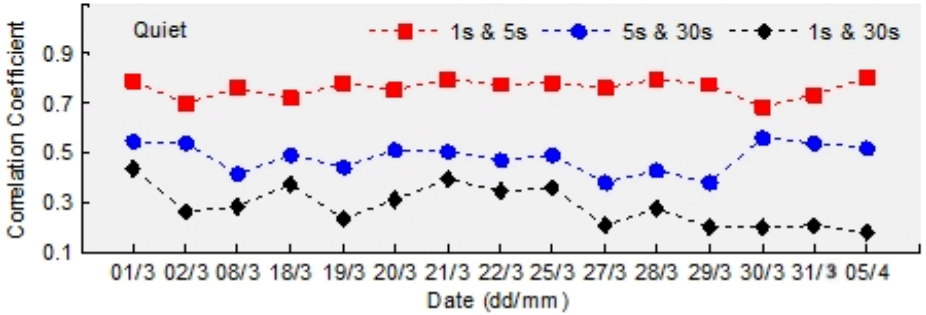


- **Correlation between ROTIs**
  - 1s and 5s ROTIs, higher correlation
  - 1s and 30s ROTIs, lower correlation
  - correlation level is higher on disturbed days

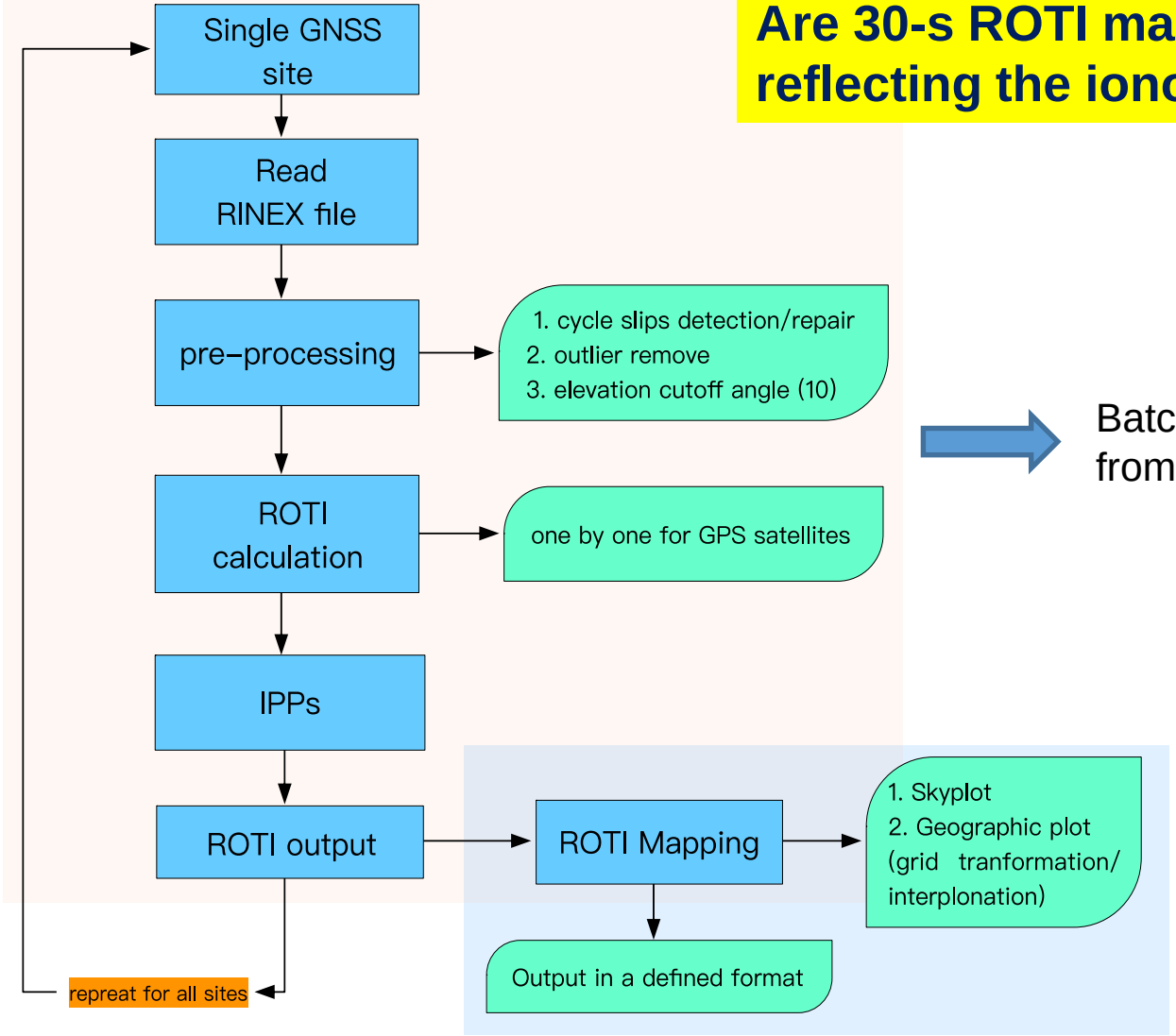








Flowchart of ROTI Mapping



Are 30-s ROTI maps capable of reflecting the ionospheric irregularity?

Batch processing GPS data from CMONOC (**1s, 30s**)

Ready for 1s, 30s GPS data from CMONOC

ROTI Maps over China

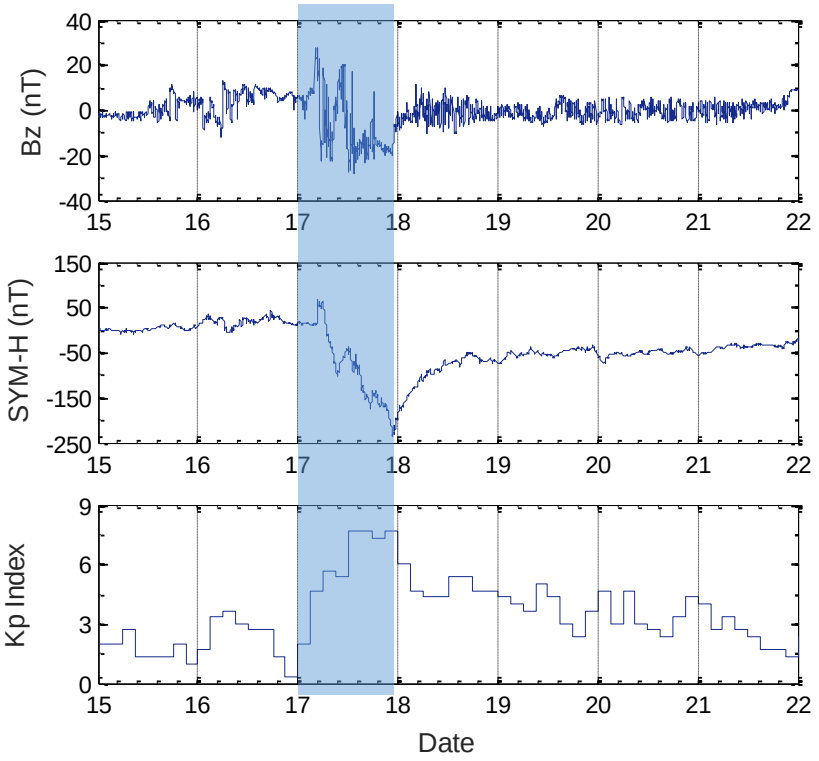
- **ROTI maps, output in the IONEX-like format**

Region: 10ºN-55ºN, 70ºE-140ºE;
Grid: 2º in latitude and 2º in longitude;
Height: 350 km at IPPs;

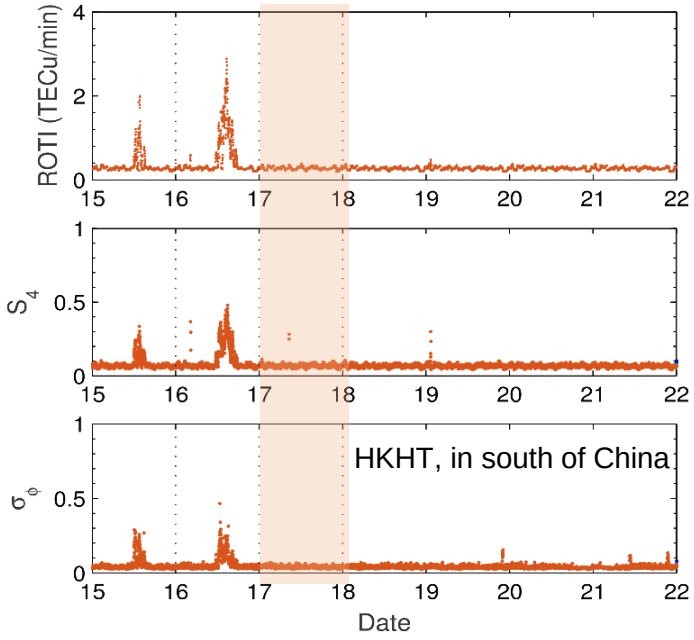
```
     1.0                 ROTI MAPS     GPS                 IONEX VERSION / TYPE
ROTIMAP V1.0        SHAO           28- 9-2018 21:58      PGM / RUN BY / DATE
Regional ROTI maps are generated on a daily basis at SHAO   DESCRIPTION
using data from about 260 GNSS sites of Crustal Movement    DESCRIPTION
Observation Network of China.                               DESCRIPTION
    20.0                                                    ELEVATION CUTOFF
  350.0 350.0   0.0                                         HGT1 / HGT2 / DHGT
   10.0  54.0   2.0                                         LAT1 / LAT2 / DLAT
   70.0 140.0   2.0                                         LON1 / LON2 / DLON
ROTI values in 1.0 TECU; NaN , if no value available       COMMENT
                                                            END OF HEADER
START OF ROTIMAP
       2015 3 17 10 0 0
    24.0    70.0   140.0
     NaN     NaN     NaN   0.202   0.136   0.316   0.164   0.053   0.084   0.076
   0.054   0.091   0.037   0.047   0.046   0.057   0.065   0.055   0.059   0.072
   0.051   0.062   0.067   0.086   0.062   0.085   0.053   0.056   0.072   0.159
     NaN     NaN     NaN     NaN     NaN
    26.0    70.0   140.0
     NaN     NaN     NaN   0.176     NaN   0.261   0.088   0.167   0.065   0.075
   0.070   0.081   0.088   0.066   0.061   0.055   0.058   0.055   0.058   0.080
   0.067   0.079   0.067   0.055   0.055   0.052   0.054   0.065   0.063   0.103
     NaN     NaN     NaN     NaN     NaN
```

ROTI Mapping during a geomagnetic storm

- **Geomagnetic storm, on March 17, 2015**
  - The most intensive one in the solar cycle 24 so far;
  - Kp index had a maximum value of 8-;
  - A sudden commencement, at around 04:45 UT;
  - Recovery phase started on March 18, 2015;



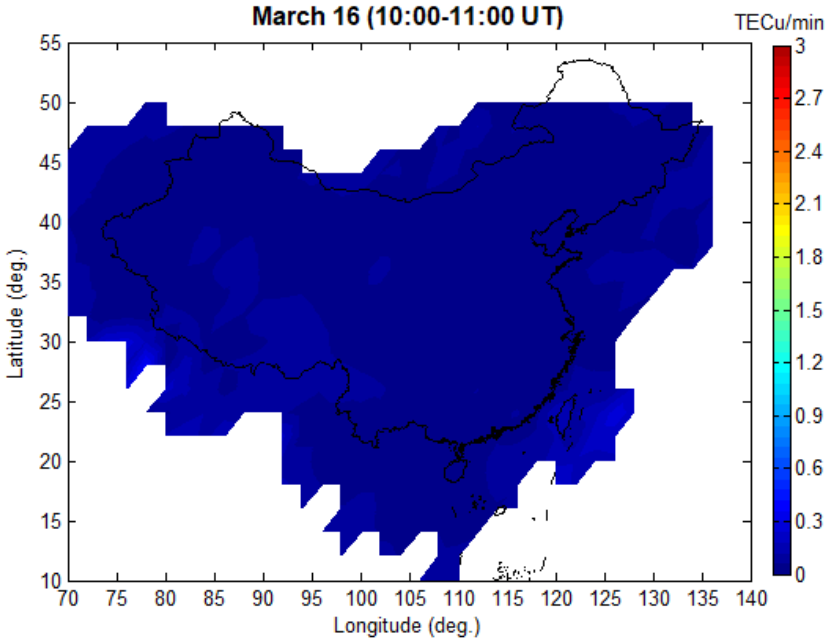
- **Ionospheric irregularities/scintillations**
  - occurred before the storm commenced;
  - but absent in the south of China on March 17, 2015;

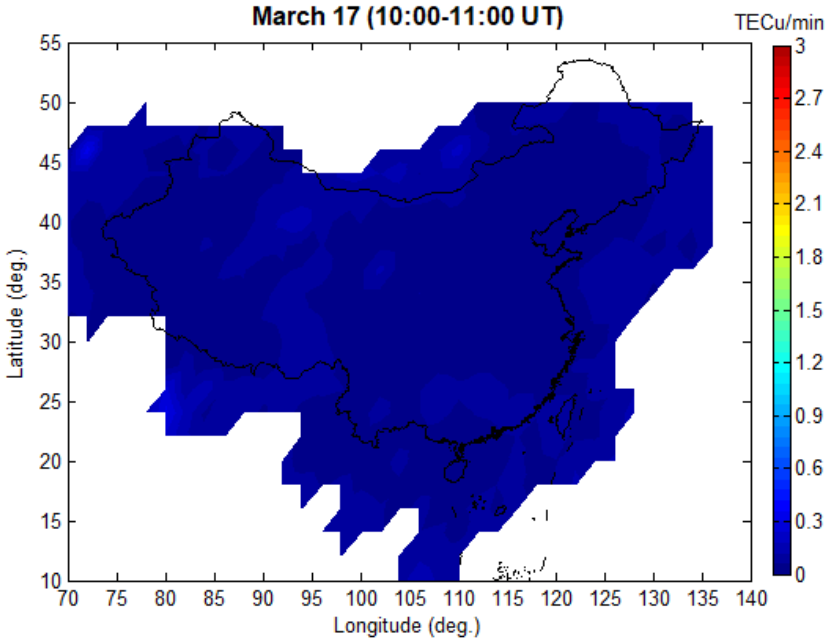


- **ROTI mapping during this large storm**
  - 1s and 30s GPS data from CMONOC;
  - 10-18 UT (18-02 LT), March 16-17, 2015;
  - 10 min, 30 min and 1 hour;
  - Grid: 2º in latitude and 2º in longitude;
  - Height: 350 km at IPPs;

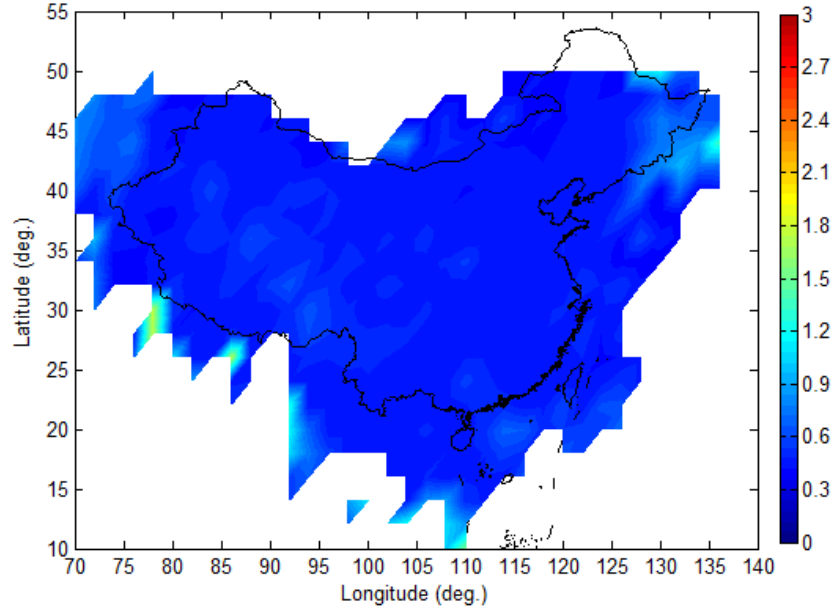
ROTI Maps (March 16-17, 1 hour)

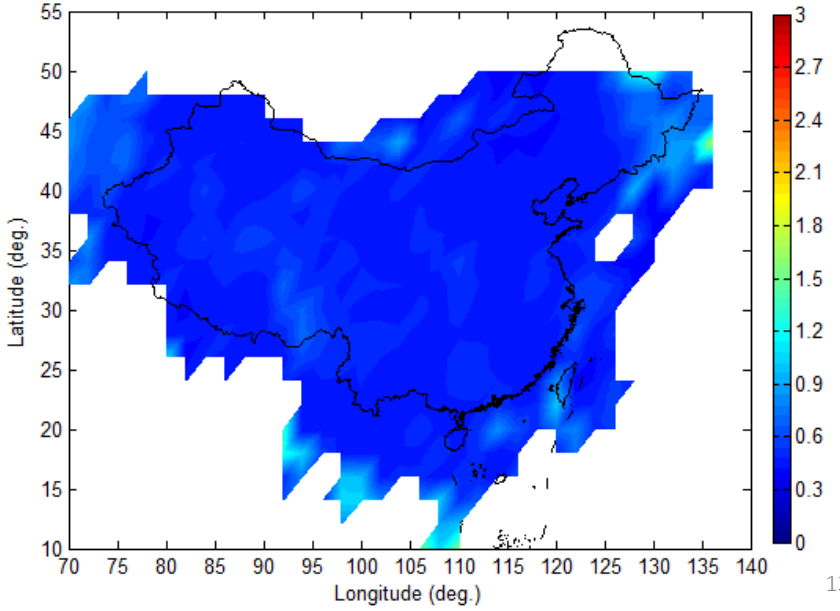
30s





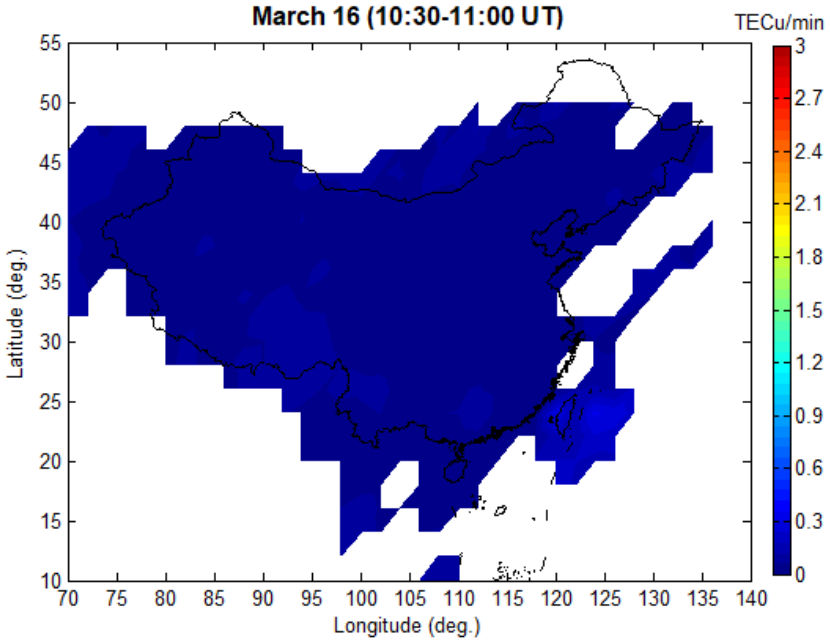
1s

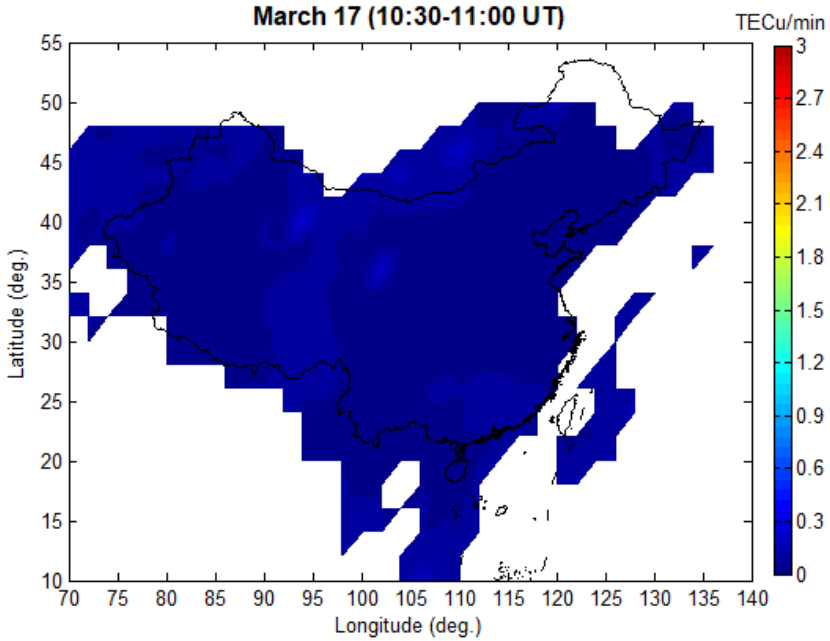




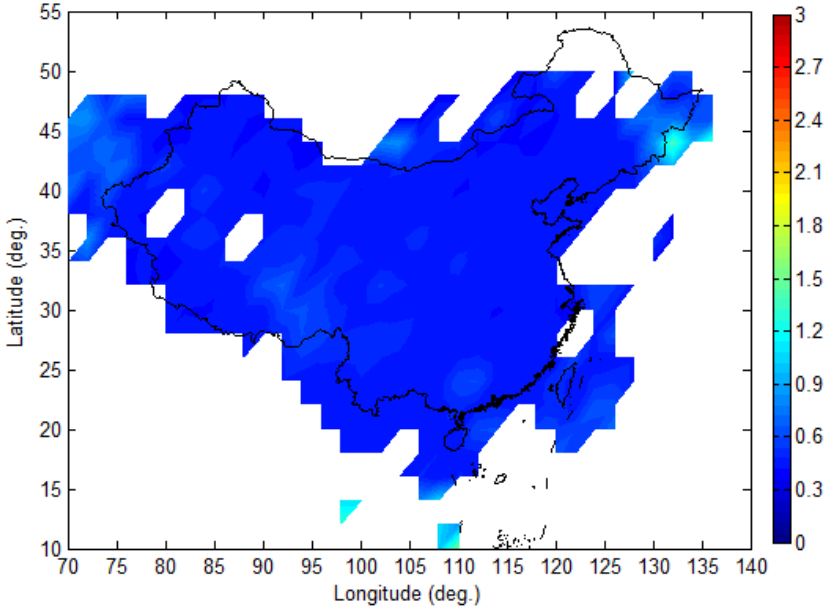
ROTI Maps (March 16-17, 30 min)

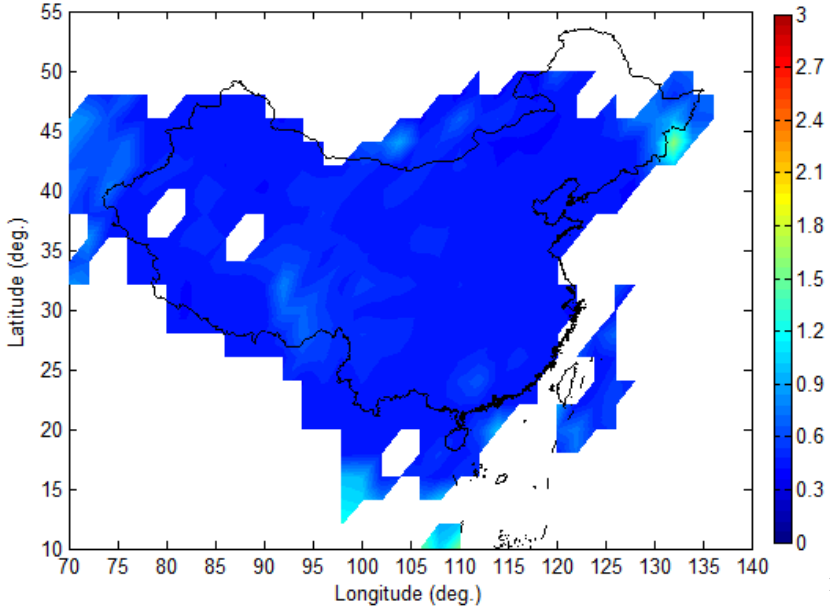
30s





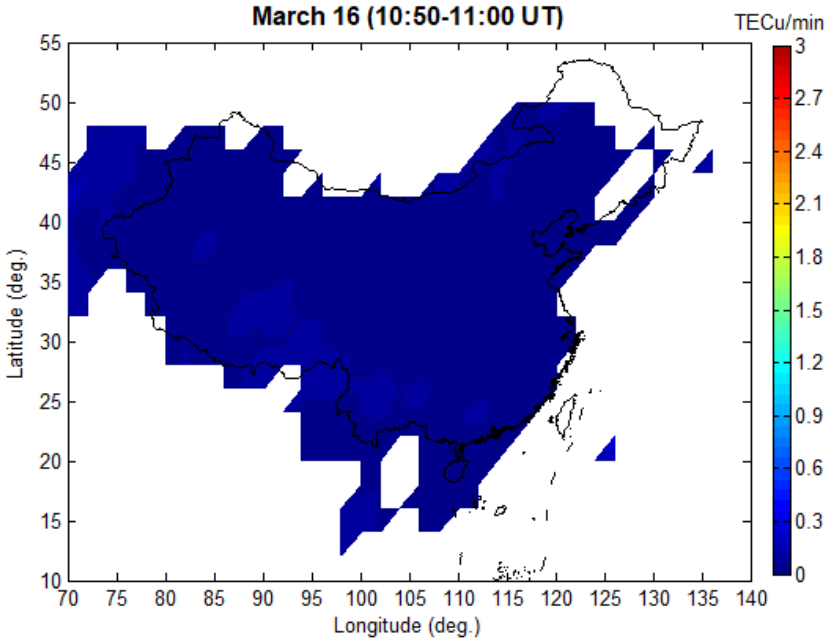
1s

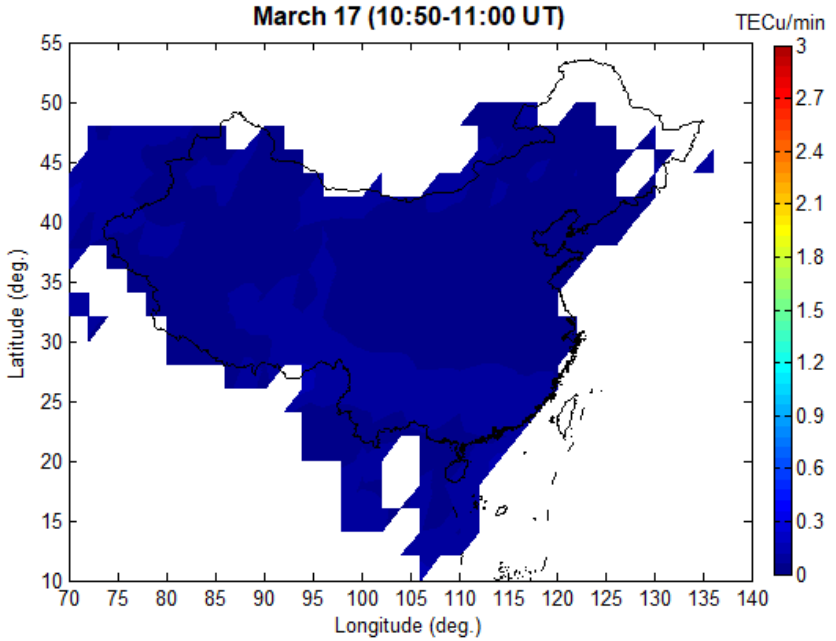




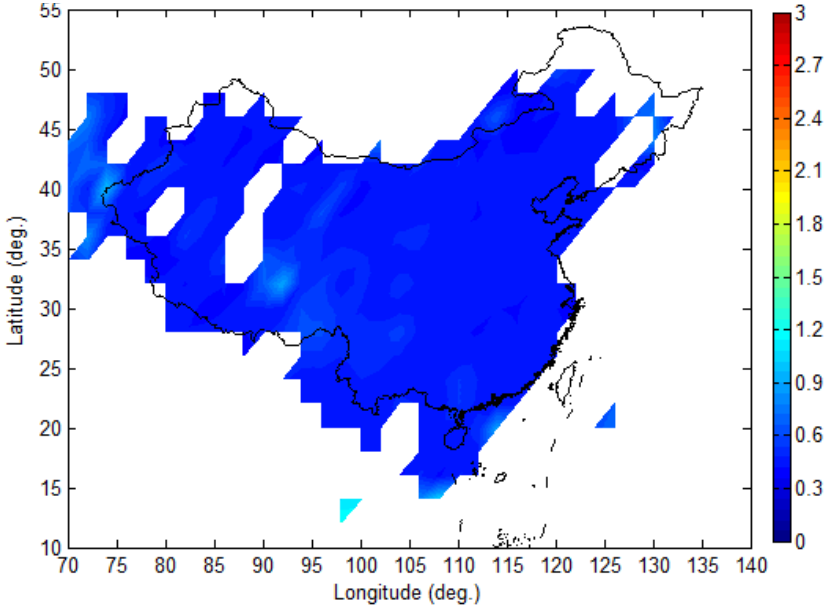
ROTI Maps (March 16-17, 10 min)

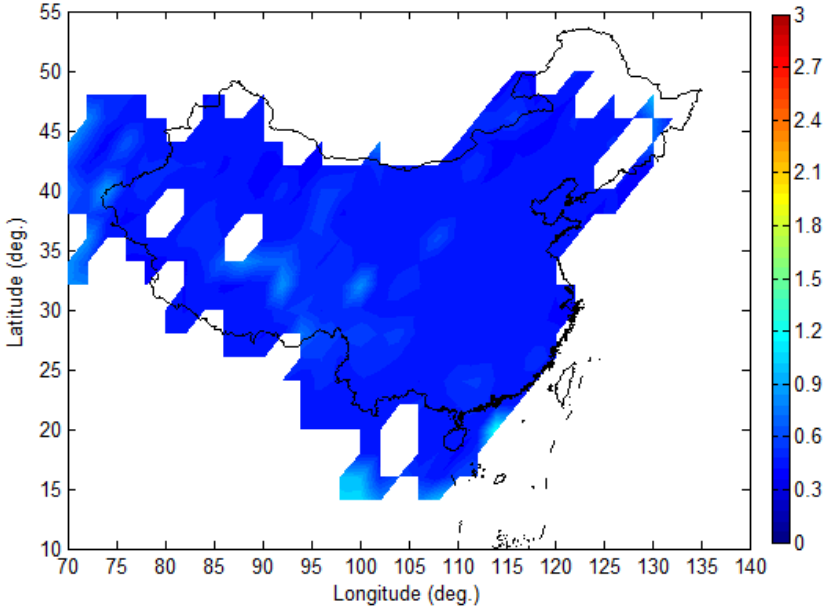
30s





1s





Summary

- **ROTIs at 1s, 5s, 30s sampling rates**
  - ROTIs correlated with scintillation indices
  - show a high correlation level on disturbed days

- **ROTI maps, 10-min, 30-min and 1-hour GPS data**
  - can reveal temporal/spatial evolutions of ionospheric irregularities
  - representation effect: 30-s ROTI maps are comparable to 1-s ROTI maps
  - **30-s observation is capable in irregularities monitoring.**
  - **The quantitative difference between 1-s ROTI and 30-s ROTI for monitoring the ionospheric irregularities will be studied further.**

- **ROTI maps, developed as one of routine products at SHAO**

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Thank You!

IGS Workshop 2018
29 October to 2 November, Wuhan, China