National Institute of Information and Communications Technology

NICT's Space Weather Research & Operation for GNSS

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Space Weather

space weather from sun to earth

Sun

CME

Flare

Coronal Hole

Energetic Particles

Travel Time to Earth
30 min ~ 2 days

Flare X-ray 8 min

Solar Wind

Solar Wind Disturbance
2~3 days

Magnetosphere

Satellite's Exposure

Astronaut's Exposure

Satellite Anomaly

Ionosphere

Communications Trouble

Radiation Belt

Changes in Radiation Belt

Earth

Ionospheric Disturbance

Current Induction

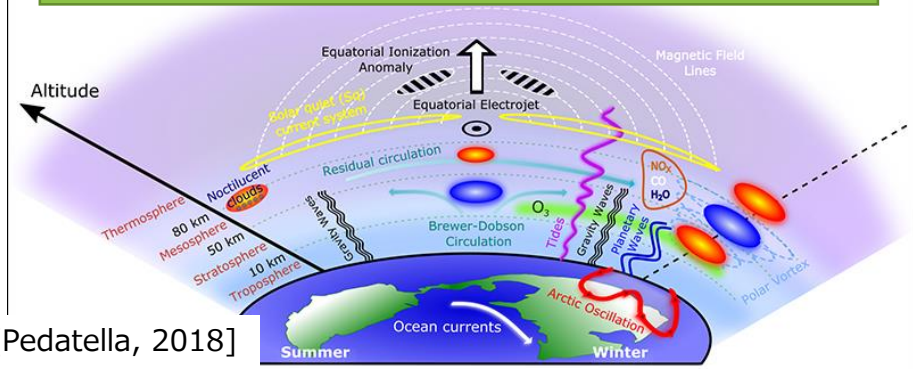
Satellite Orbit Fluctuation

Atmospheric Disturbance

Auroral Activity

Geomagnetic Storms

Effects from lower to upper atmosphere



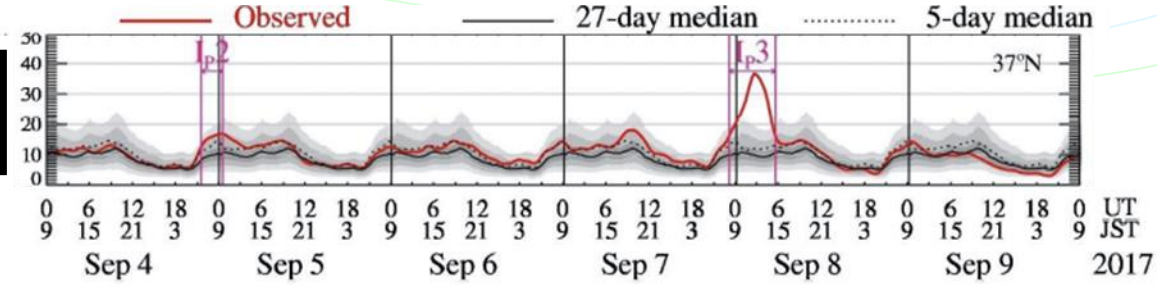
[Pedatella, 2018]

Impact of SW on GNSS

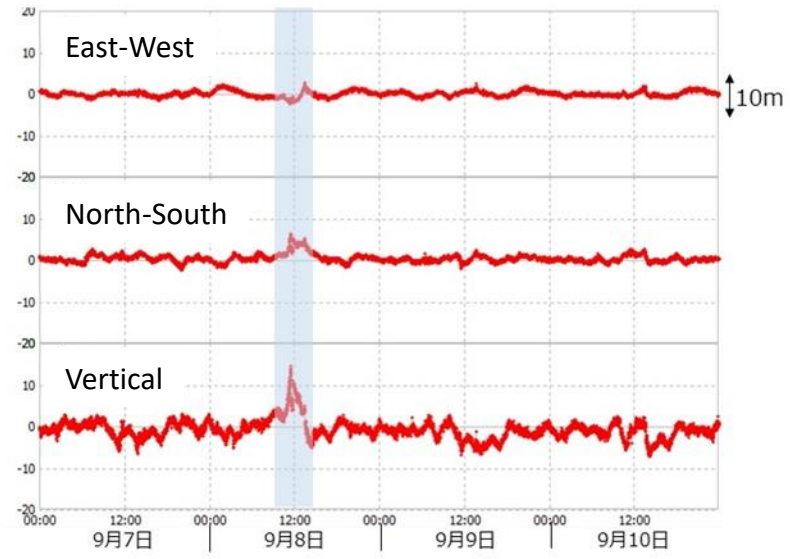
X2.2 X9.3 Dst ～-124nT

※ X-ray flux measured by NOAA/GOES satellites
※ Dst index provided by WDC Geomagnetism, Kyoto

Vertical TEC



GPS positioning error



(From GSI web site: www.gsi.go.jp/denshi/denshi40001.html)

- The Ionospheric storm on Sep. 8, 2017 made GPS positioning error ～3 times larger.
- X 9.3 flare caused rapid TEC increase (SID) on dayside, causing loss-of-lock for GNSS signals, degradation of SBAS availability, degradation of Precise Point Positioning (PPP) accuracy [Berdermann et al., 2018].

NICT Space Weather Forecast Center

Operational SW nowcast/forecast as an ISES member

- Solar flare occurrence
- High-energy particle condition at geosynchronous orbit
- Geomagnetic field condition over Japan
- Ionospheric condition over Japan

Web access : 160,000/month
No. of e-mail address : 10,000
And also on Facebook, twitter

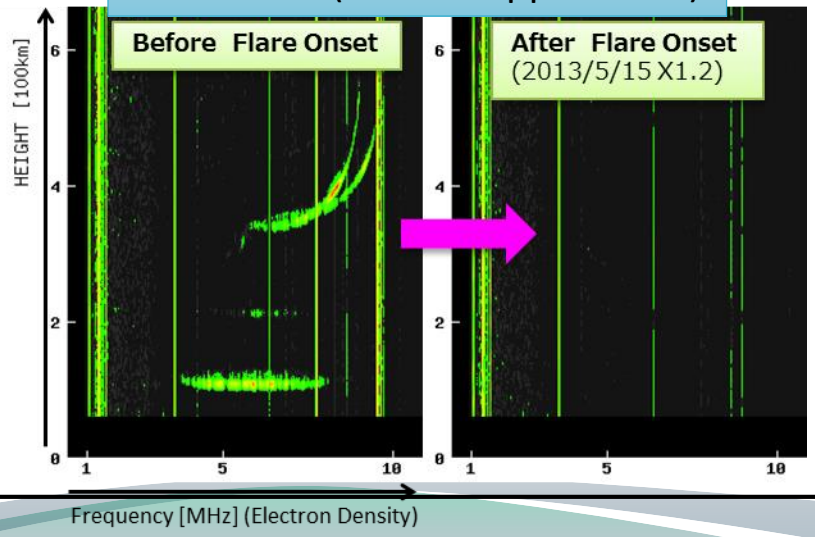
Domestic Users:

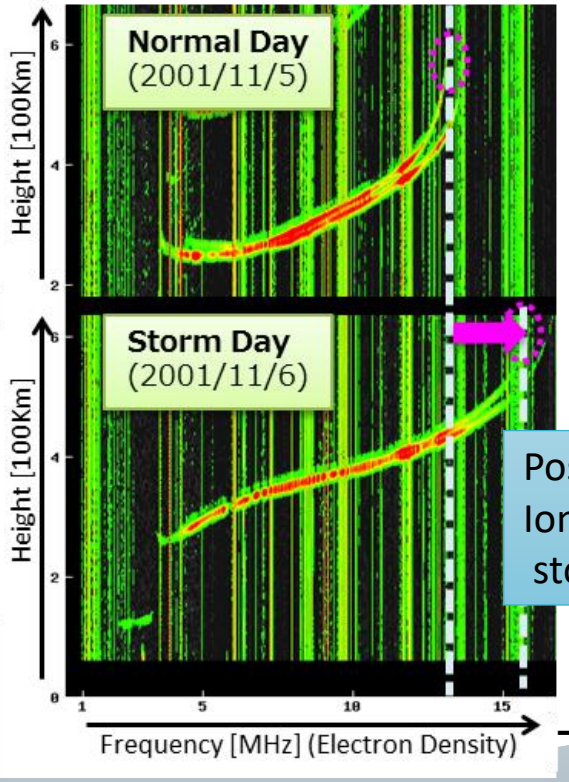
satellite operator, aviation office and companies, power plant companies, HF telecommunicators / broadcasters, resource survey, Univ. and research institutes, amateur radio operators

Ionospheric Monitoring by Ionosonde

- Ionospheric sounding from the ground, 4 sites in Japan and 1 in the Antarctica
- First observation in 1937, and regular operation from 1957, normally 15 minutes interval
- Monitoring of Ionospheric storms, Flare effects, and so on.

Flare effect (Echo disappearance)

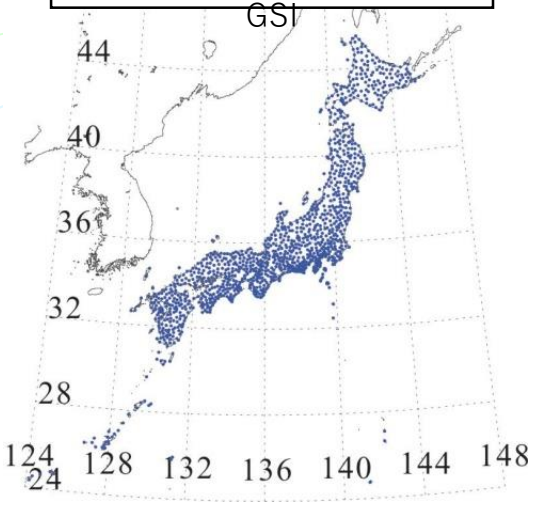




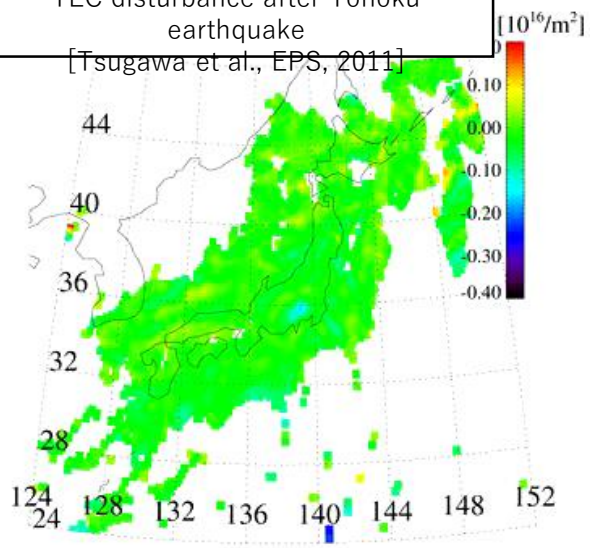
Positive Ionospheric storm

Ionospheric Monitoring by TEC

GNSS receiver network (1,240points) provided by GSI

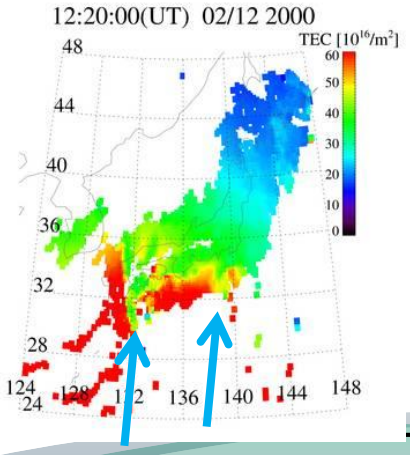


TEC disturbance after Tohoku earthquake [Tsugawa et al., EPS, 2011]

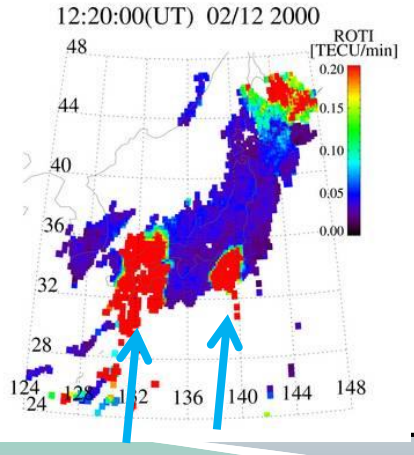


- Total Electron Content (TEC) map is derived from a dense GNSS receiver network in Japan (GEONET) provided by GSI
- High resolution (30sec, 0.15 by 0.15 deg)
- Monitoring of Ionospheric storms, Traveling Ionospheric disturbances (TIDs), Plasma bubble, and so on.
- Global version -> DRAWING TEC project (see our ICG-12 presentation [Tsugawa et al])

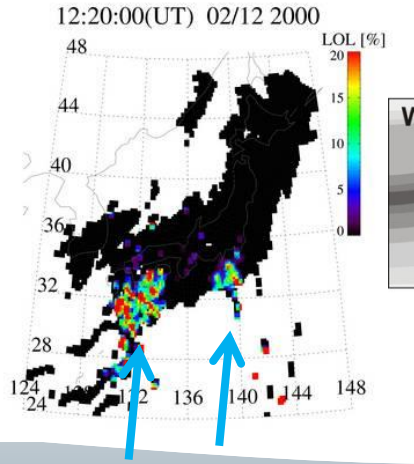
TEC



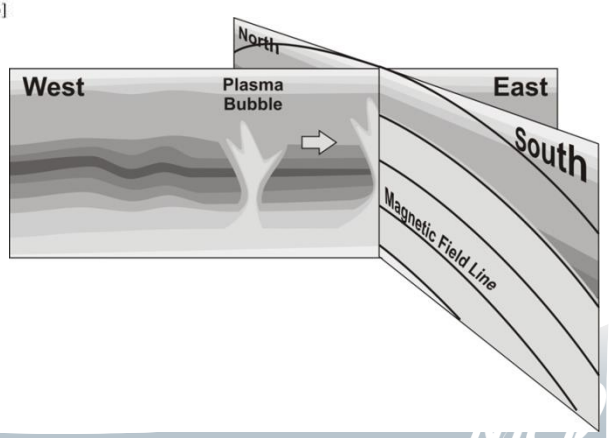
ROTI



Loss of Lock



Plasma bubble observation



Update of GNSS-TEC Exchange Format (GTEX, v 3.0)


```
     3.00           GTEX DATA
                                        20180525 021508 UTC
16
  TEC values in 10^16 el/m^2 (1 TEC Unit)
  Types of data    = Rd : Raw slant TEC including bias
                          derived from d
                     Ad : Absolute slant TEC
                          derived from d
                          d are combination of carrier
                          phase and pseudorange
                     ZNI: Satellite zenith angle
                     AZI: Satellite azimuth angle

  Satellite System = G : GPS
                     R : GLONAS
                     E : Galileo
                     S : SBAS
                     J : QZSS
                     C : BeiDou
                     I : IRNSS

  OBSERVATION records format is as follow
   -Satellite number                  A1,I2.2
   -m(Observation, TEC status flag)   m(F10.4,I1,X1)
    TEC status flag= 0 or blank : Normal data
                     1 : Lack of observables(TEC=99999.9999)
                     2 : Too large TEC (TEC=99999.9999)
                     4 : Cycle slip (TEC discontinuity)
                     5 : Cycle slip (LLI)
                     6 : Beginning of arc
    when set ZNI or AZI, TEC status flag is blank.
    If ZNI, AZI can not be calculated, set 99999.9999.
MTKB1060.18o  MTKB1070.18o  MTKB1080.18o
MTKB
                     JAVAD Alpha-G3T
                     NOV750.R4     NOVS
 -3947739.2646  3364424.9821  3699425.5842
        0.0000        0.0000        0.0000
```

Header

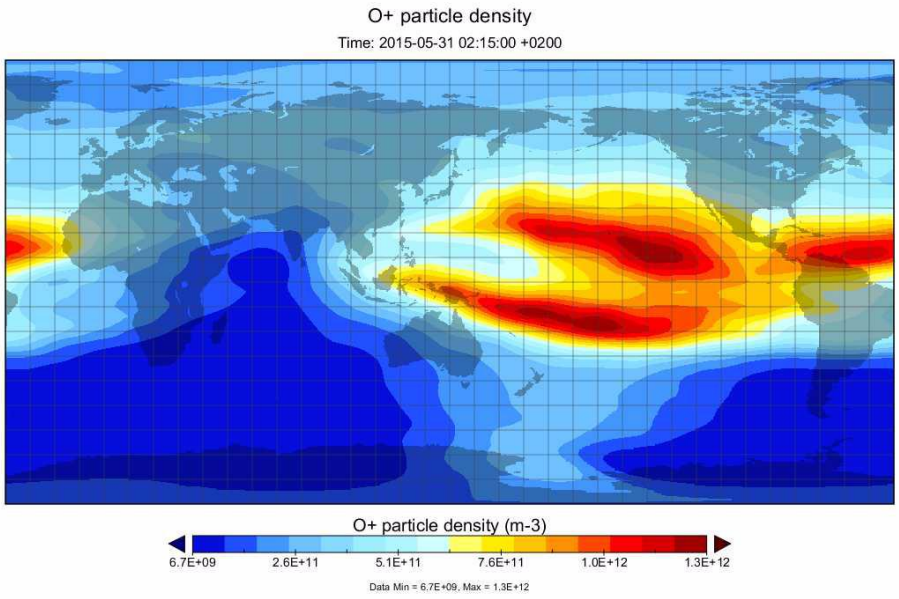
```
G    3 RL1CL2WC1CC2W            ZNI            AZI
R    3 RL1CL2CC1CC2C            ZNI            AZI
E    3 RL1XL5XC1XC5X            ZNI            AZI
J    3 RL1CL2XC1CC2X            ZNI            AZI
   30.000
  2018     4    17     0     0     0.0000000     GPS
  2018     4    17    23    59    30.0000000     GPS

> 2018  4 17  0  0  0.0000000  0 13                .
G10   21.4241      40.7626     238.3033  .
G12  -11.7632      34.4779      54.8018  .
G14    1.5530      64.5740     311.0501  .
G15   21.6359      78.3918     126.8403  .
R01   75.1004      49.8949     164.4638  .
R02   97.7056      19.0021     303.6347  .
R03   83.8726      71.1253     329.1059  .
R11   60.6147      59.4903      34.7255  .
E03   32.4284      38.7892     309.3641  .
E05   33.5361      20.4626     165.0767  .
E09   47.5795      71.4971     145.3941  .
E24  113.5677      37.0608      37.5892  .
J01   -2.7978      42.1784     197.5812  .
> 2018  4 17  0  0 30.0000000  0 14                .
G10   21.4749      40.9104     237.9890  .
G12  -11.7528      34.6676      54.5400  .
G14    1.5085      64.3911     311.1354  .
```

Header

TEC data section

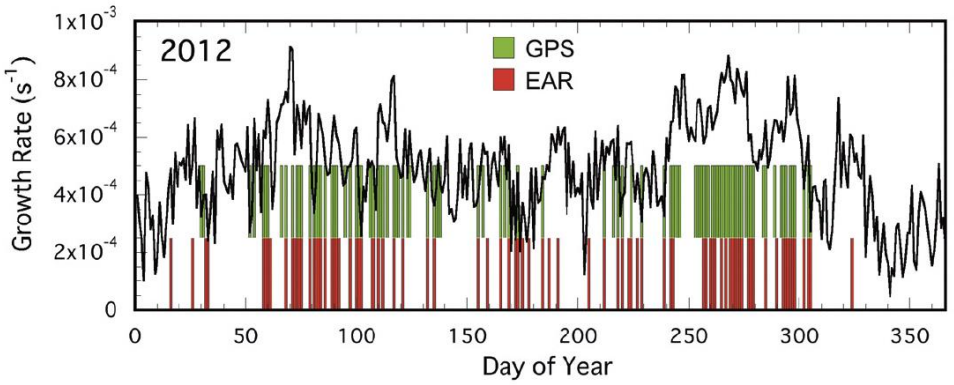
- GTEX is a format of slant TEC data
- By sharing slant TEC, various researches would be possible without affected by specific analysis procedures (e.g., bias estimation)
- GTEX v3.0 can treat data from multi-GNSS satellites, and the format similar to RINEX 3

Research for Ionospheric Forecast: Global model of Whole Atmosphere and Ionosphere



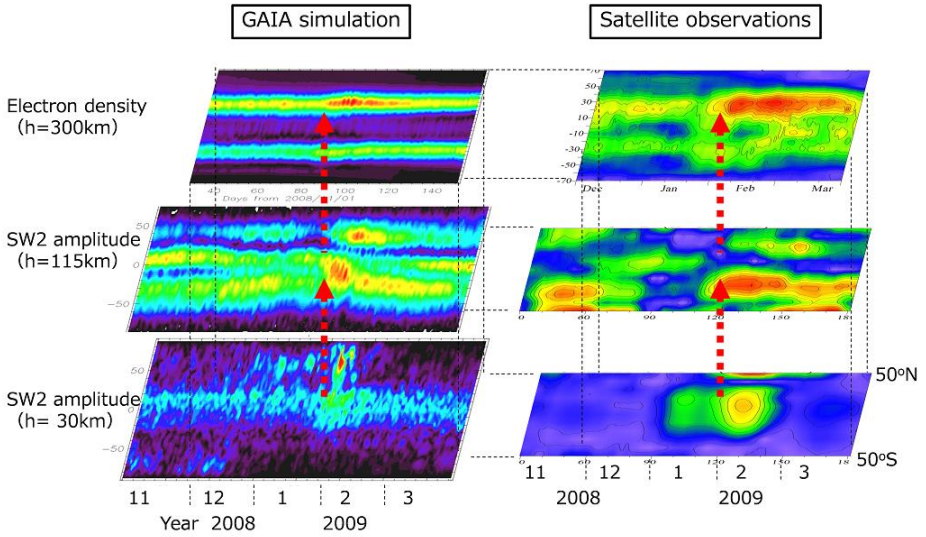
- GAIA is a 3D global model from troposphere to thermosphere and ionosphere
- GAIA reproduces meteorological phenomena, vertical coupling, neutral-plasma interaction, ….
- Meteorological Reanalysis has been assimilated into GAIA. Assimilation of upper atmospheric observations are underway

Comparison of plasma bubble occurrence



[Shinagawa et al., 2018]

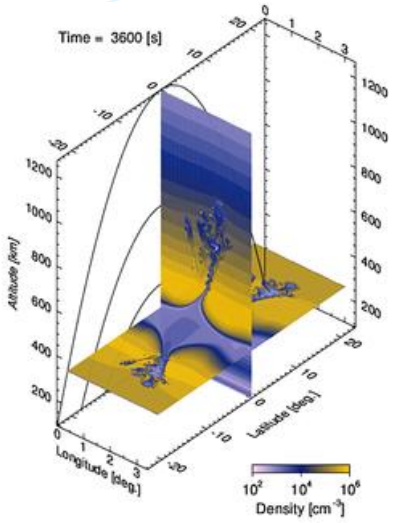
Effects of Stratospheric sudden warming on Ionosphere



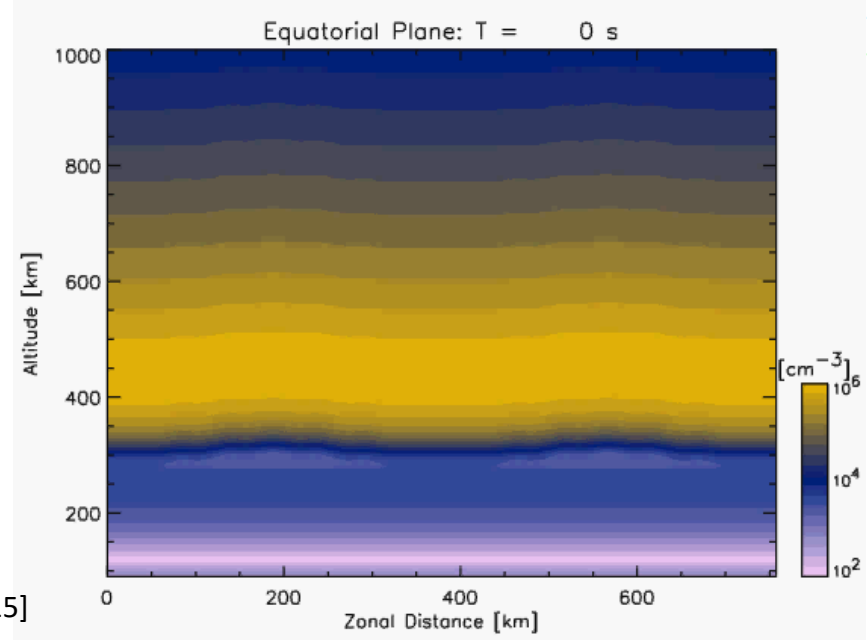
[Jin et al., 2012]

Research for Ionospheric Forecast: Regional model of Equatorial Ionosphere

Simulation of plasma bubbles



[Yokoyama et al., 2014; 2015]



Radar observation of plasma bubble

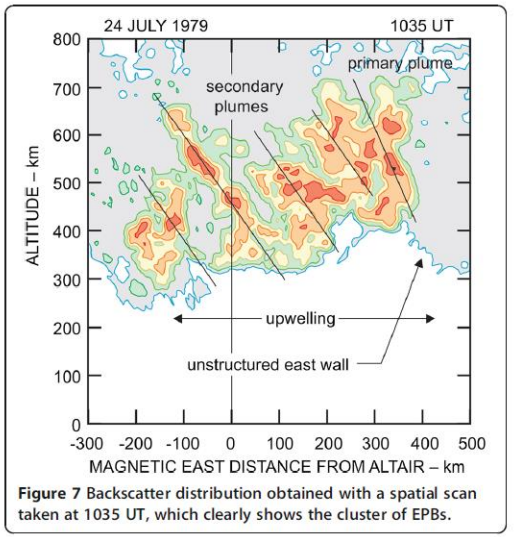


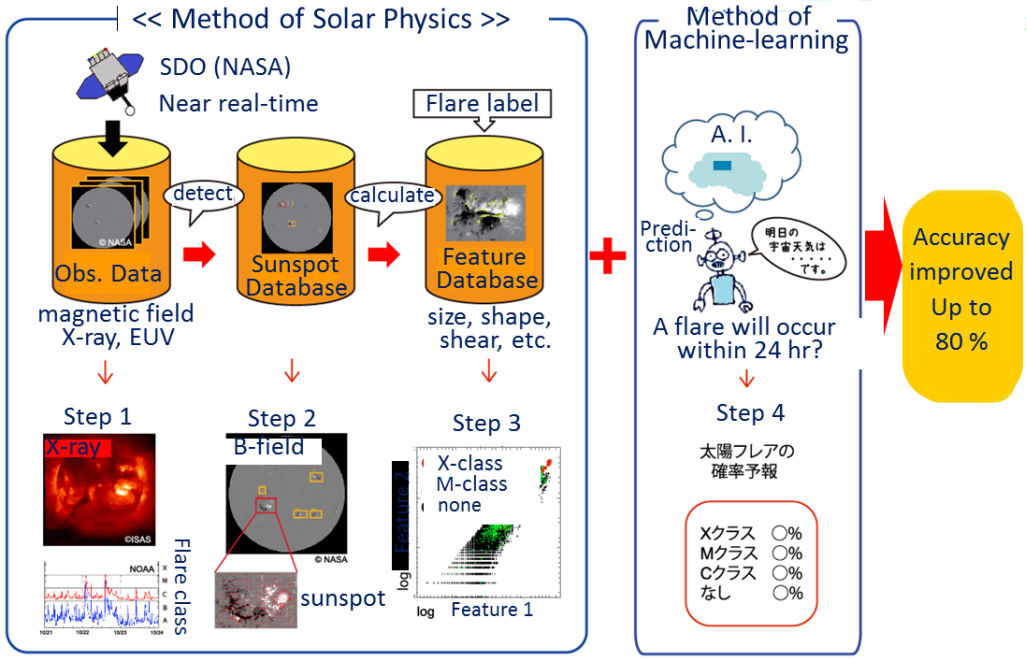
Figure 7 Backscatter distribution obtained with a spatial scan taken at 1035 UT, which clearly shows the cluster of EPBs.

[Tsunoda., 2015]

- HIRB is a high-resolution model of equatorial ionosphere, which reproduces detail structures and features of plasma bubbles
- Global-regional model coupling is on-going, and forecast of plasma bubble occurrence and growth will be treated by HIRB

Research for Space Weather Forecast: Prediction using Machine Learning Techniques

Solar Flare Prediction



[Nishizuka et al.]

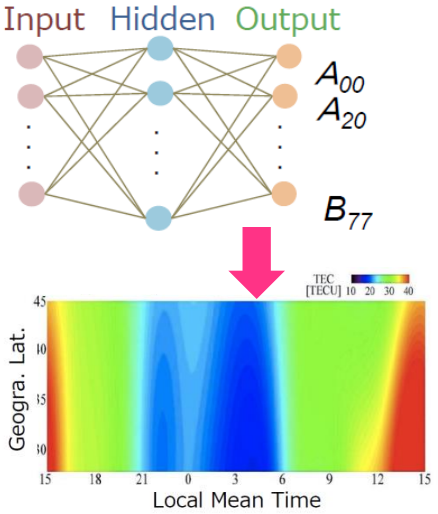
Prediction of Ionospheric TEC

Data available on realtime bases

Quiet model
【Sun】F10.7, SSN、MgII
【Time】DOY
【Iono.】
Previous-day TEC

Disturbed Model
【Iono.】Q-model output
【SW】IMF-Bt
【Mag.】K-index, Dst

7000-day data from 1997年 were used

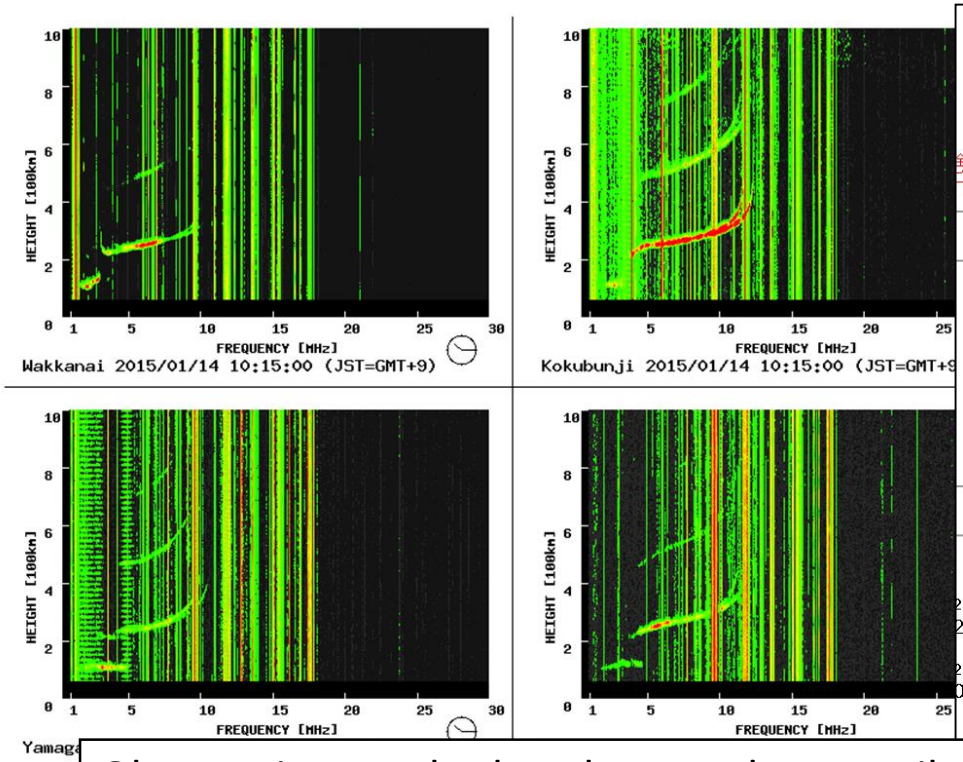


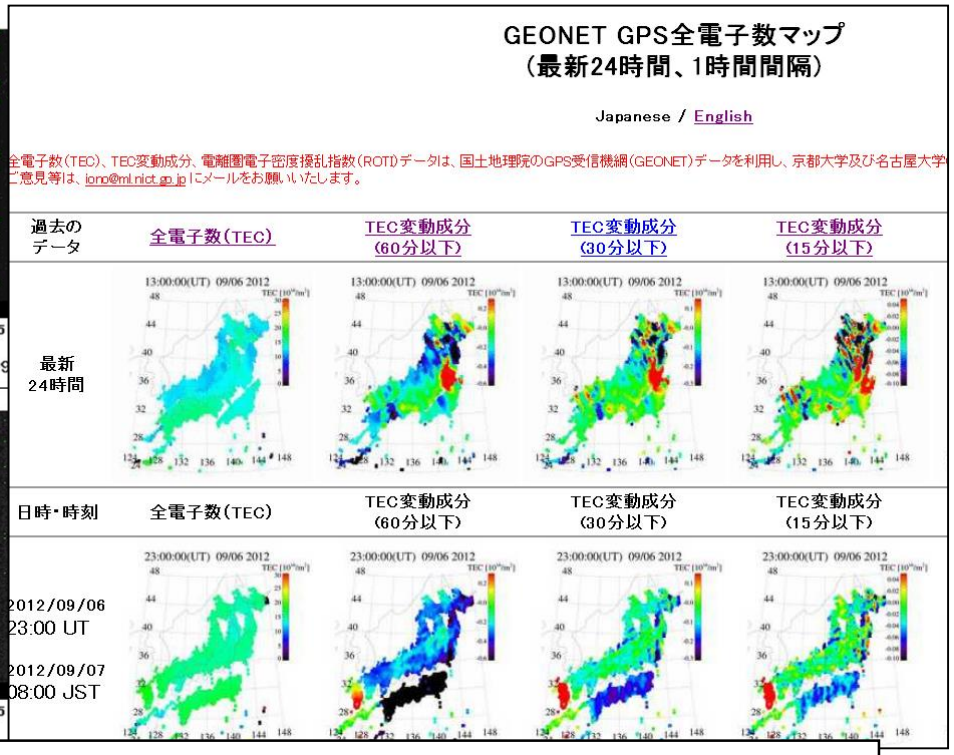
(Based on Maruyama [2007])

- Solar flare prediction method has been developed using deep learning technique, which gives categorical prediction with occurrence probability at each active region
- The real-time operation using Deep Flare Net (DeFN) will start in FY2018.
- Prediction of 2D TEC map against latitude and LT has been developed using a neural network technique.

Summary

- We are operationally providing space weather nowcast and forecast information as a member of ISES.
- The ionospheric nowcast is based on observations by ionosonde and TEC, which have long history.
- For ionospheric forecast, we are developing physics based models, machine learning models, and data assimilation.





Observations and other data products available at: http://wdc.nict.go.jp/IONO/