Dense Regional And Worldwide INternational GNSS-TEC observation (DRAWING-TEC) project

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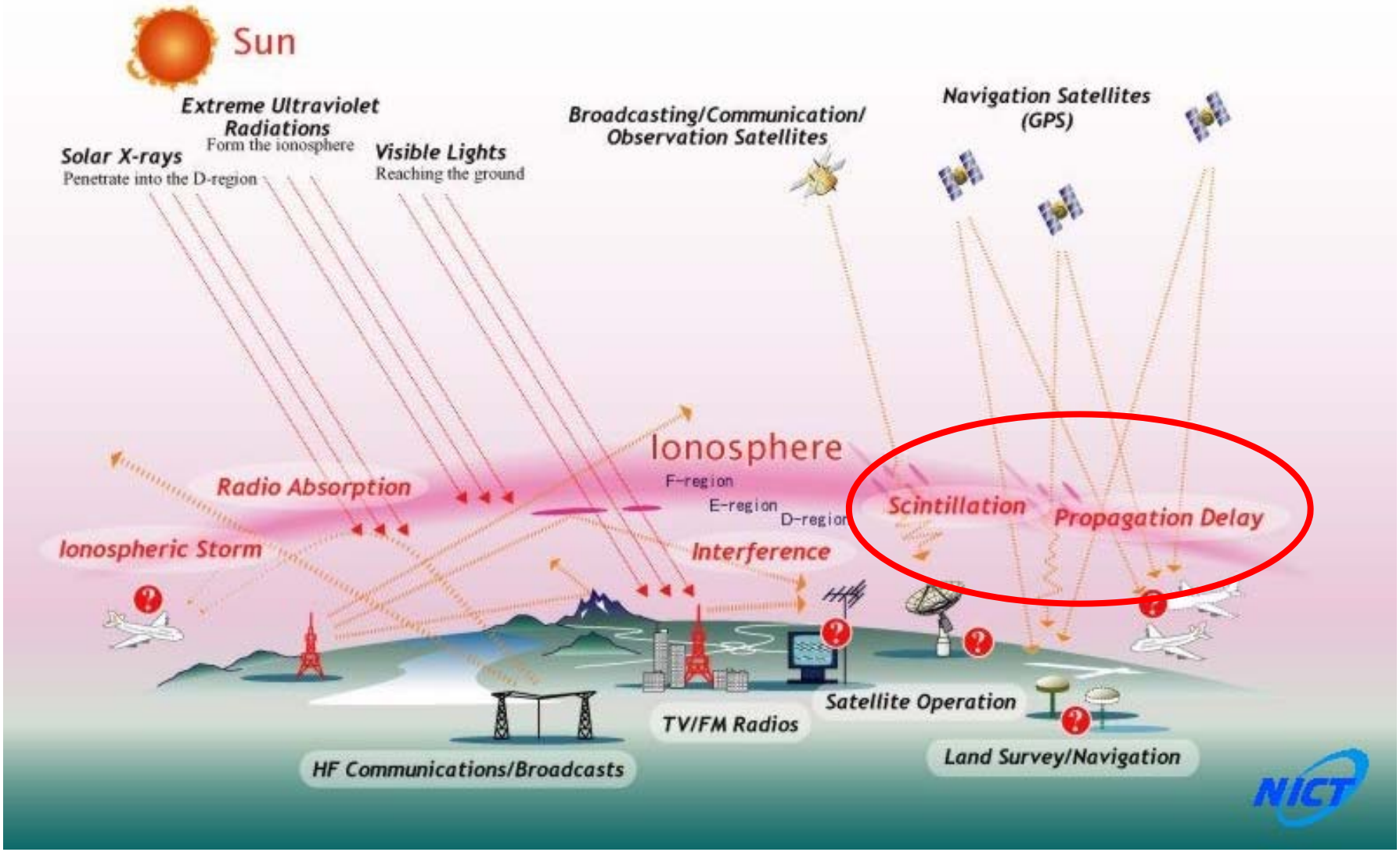
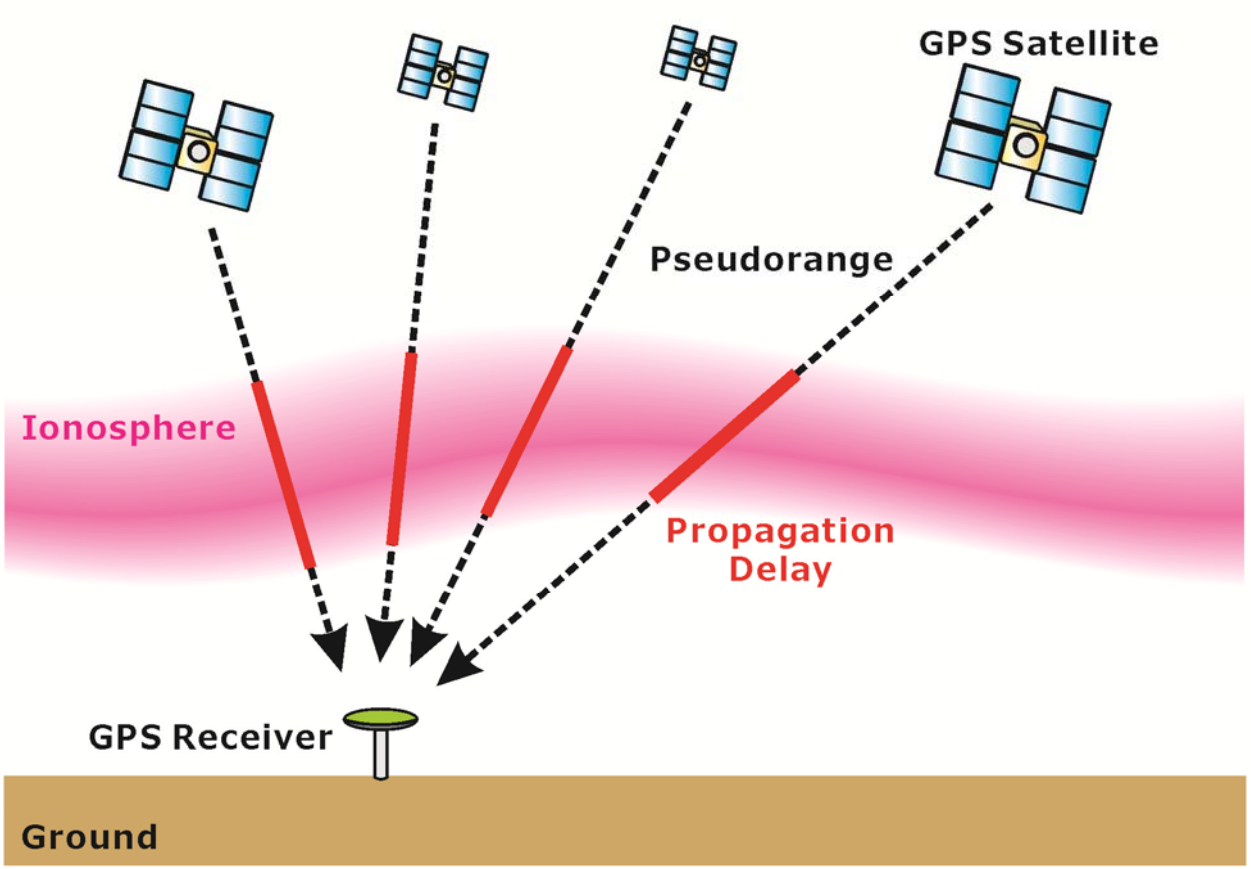
[1] NICT, [2] ENRI, [3] Kyoto University, [4] Nagoya University

Ionospheric effects on radio applications

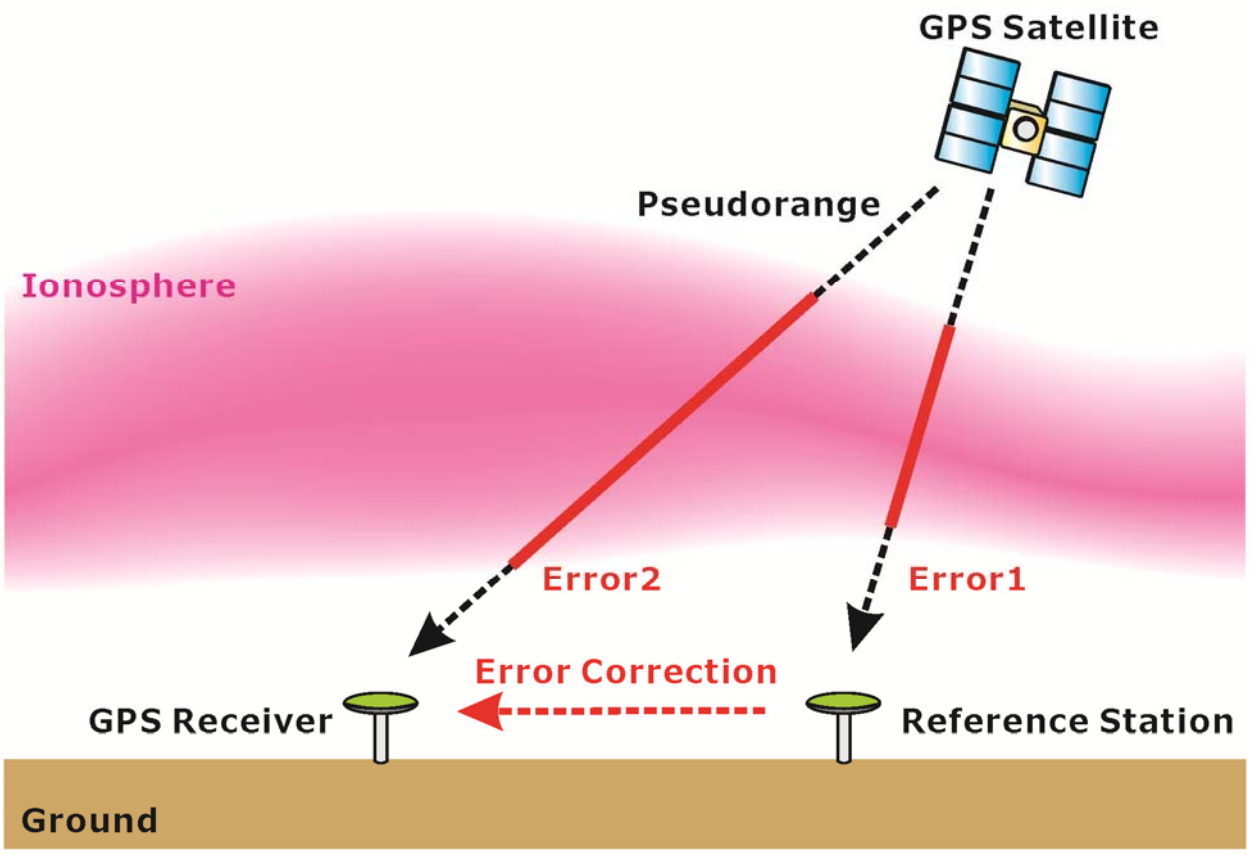


GPS navigation and positioning



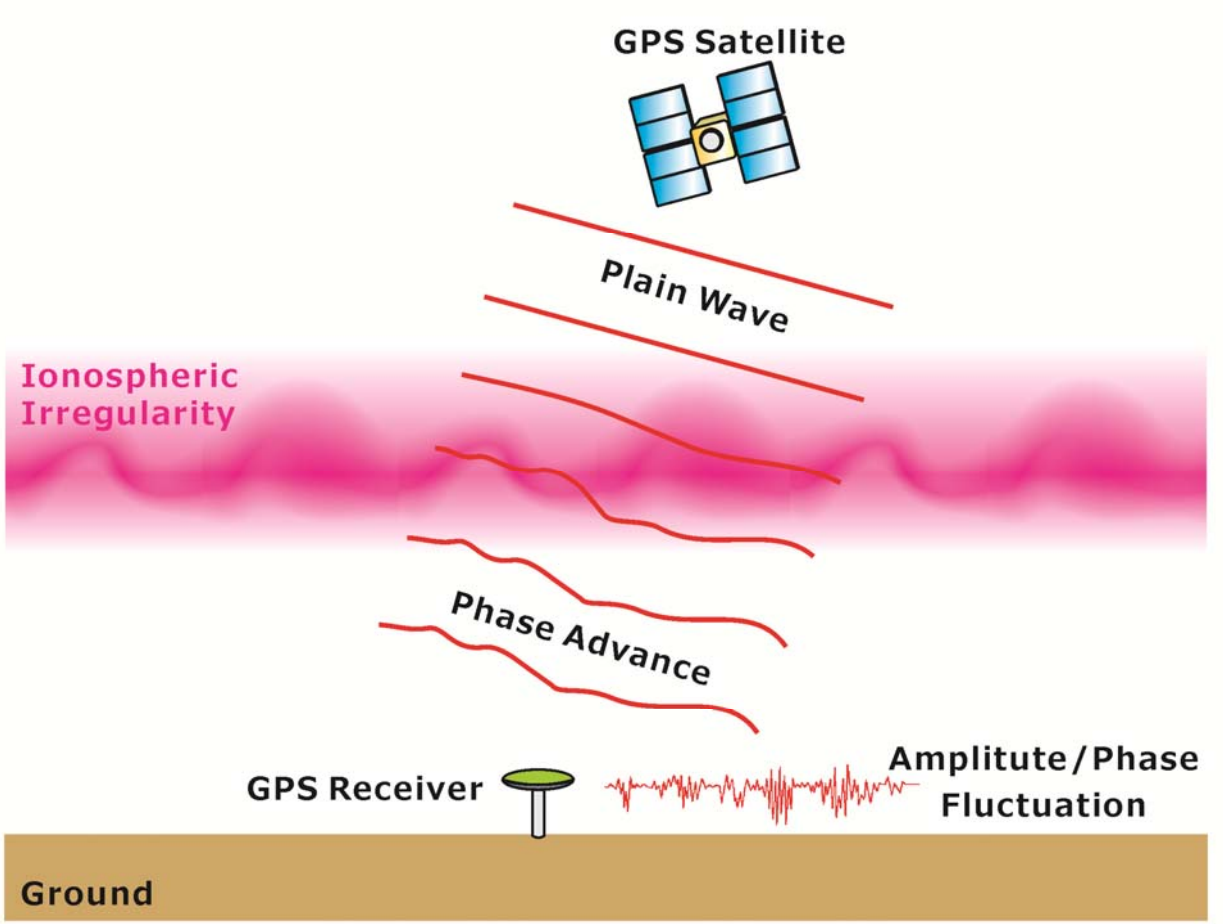
- Pseudorange includes ionospheric propagation delay which is the largest error of GPS positioning/navigation for general single-frequency GPS receivers.

Differential GPS positioning



- Steep spatial gradient of ionospheric electron density causes differential GPS positioning errors.

GPS scintillation



- Several 100m scale ionospheric irregularity causes GPS scintillation which results in loss-of-lock on GPS signals in the worst case.

Derivation of TEC using GPS

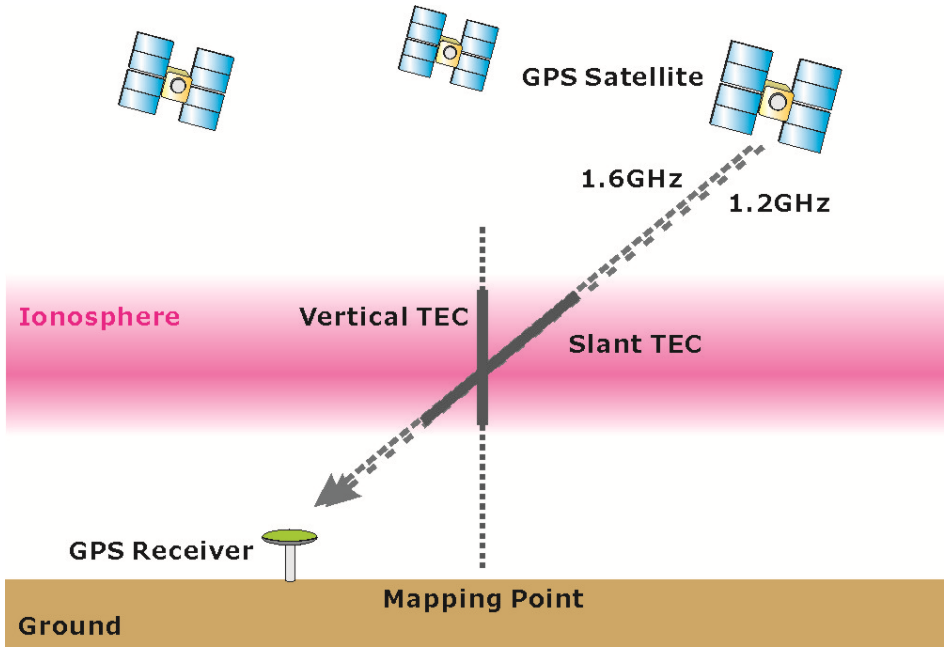
- Total electron content (TEC) can be derived by comparing the pseudorange/phase delays of the two GPS signals.

$$
\begin{aligned}
P_1 &= \rho + I/f_1^2 + \tau_1^r + \tau_1^s \\
P_2 &= \rho + I/f_2^2 + \tau_2^r + \tau_2^s \\
L_1 &= \rho - I/f_1^2 + \lambda_1 n_1 + \epsilon_1^r + \epsilon_1^s \\
L_2 &= \rho - I/f_2^2 + \lambda_2 n_2 + \epsilon_2^r + \epsilon_2^s
\end{aligned}
$$

P_1 P_2: Pseudorange
L_1 L_2: Carrier phase
I: Total electron content
f_1, f_2: Frequency
ρ: True range between the GPS satellite and receiver

- TEC is a measure of integrated electron density in 1m^2 column.

- 1 TECU(=10^{16}electrons/m^2) is frequently used as a measuring unit of TEC.



GPS-TEC maps in Japan

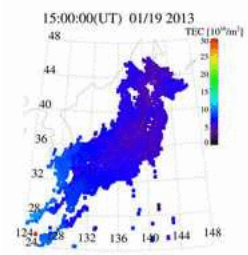
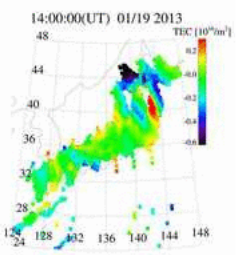
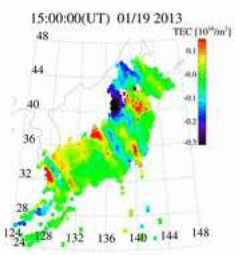
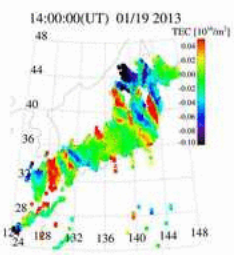
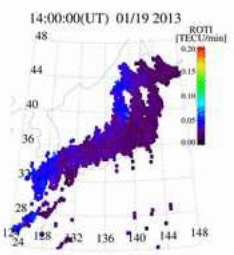
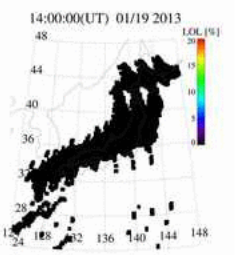
http://seg-web.nict.go.jp/GPS/GEONET

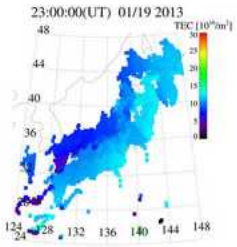
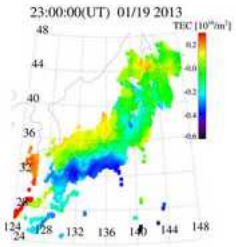
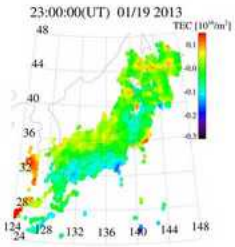
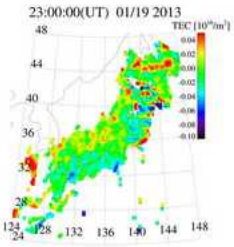
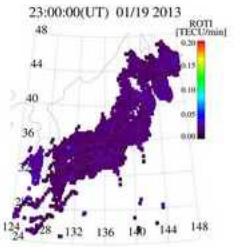
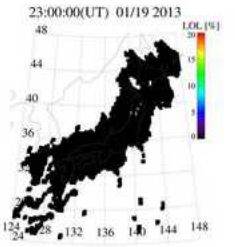
DRAWING-TEC: Home
GEONET GPS-TEC maps: Final | Quasi-Realtime | Realtime (β ver.)

GEONET GPS-TEC maps over Japan
(latest 24 hours with 1-hour interval)

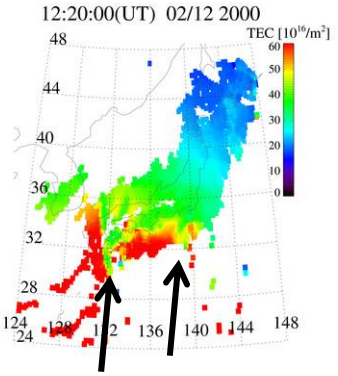
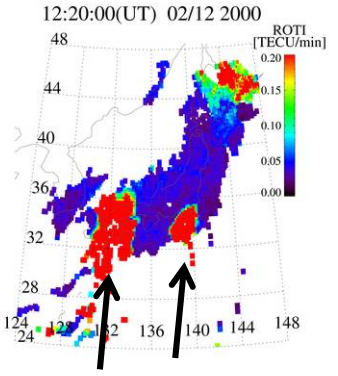
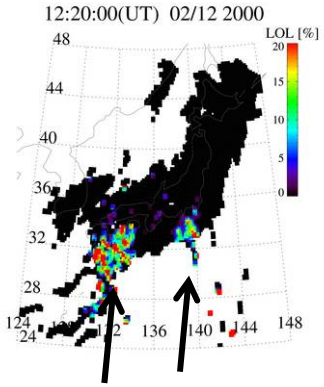
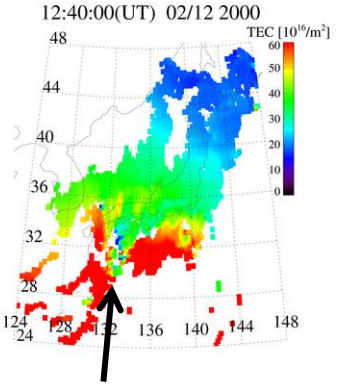
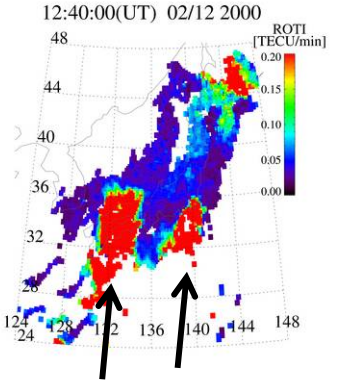
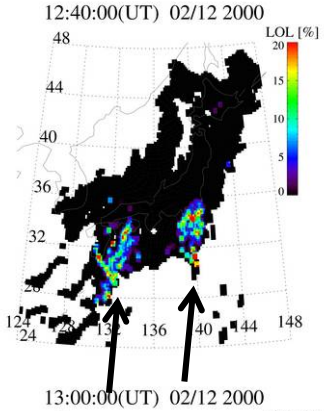
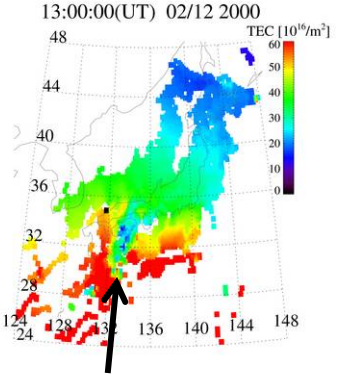
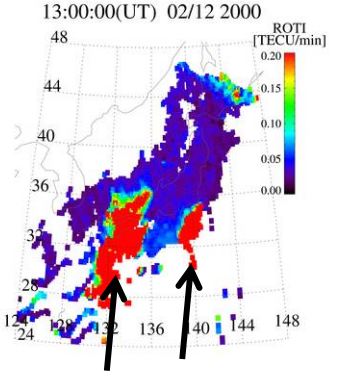
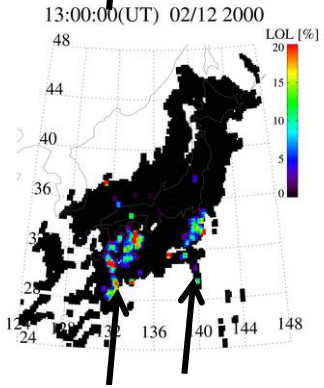
Japanese / English

The TEC (total electron content) data for TEC, detrended TEC, and ROTI maps are calculated by NICT under collaboration with Kyoto University and Nagoya University using GEONET GPS data provided by Geospatial Information Authority of Japan. If you have any questions or comments, please e-mail to iono@ml.nict.go.jp .

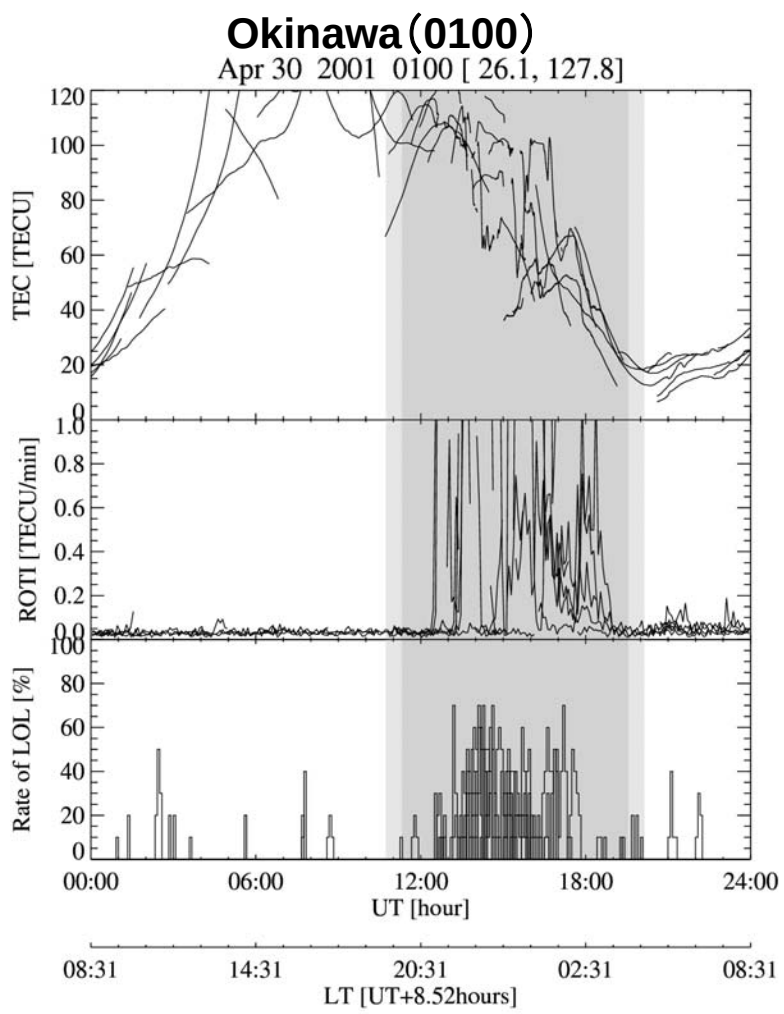
Data Archive	TEC	Detrended with 60-min window	Detrended with 30-min window	Detrended with 15-min window	Rate of TEC change index	Rate of loss of lock on GPS
Latest 24 hours						

Time	TEC	Detrended with 60-min window	Detrended with 30-min window	Detrended with 15-min window	Rate of TEC change index	Rate of loss of lock on GPS
2013/01/19 23:00 UT 2013/01/20 08:00 JST						

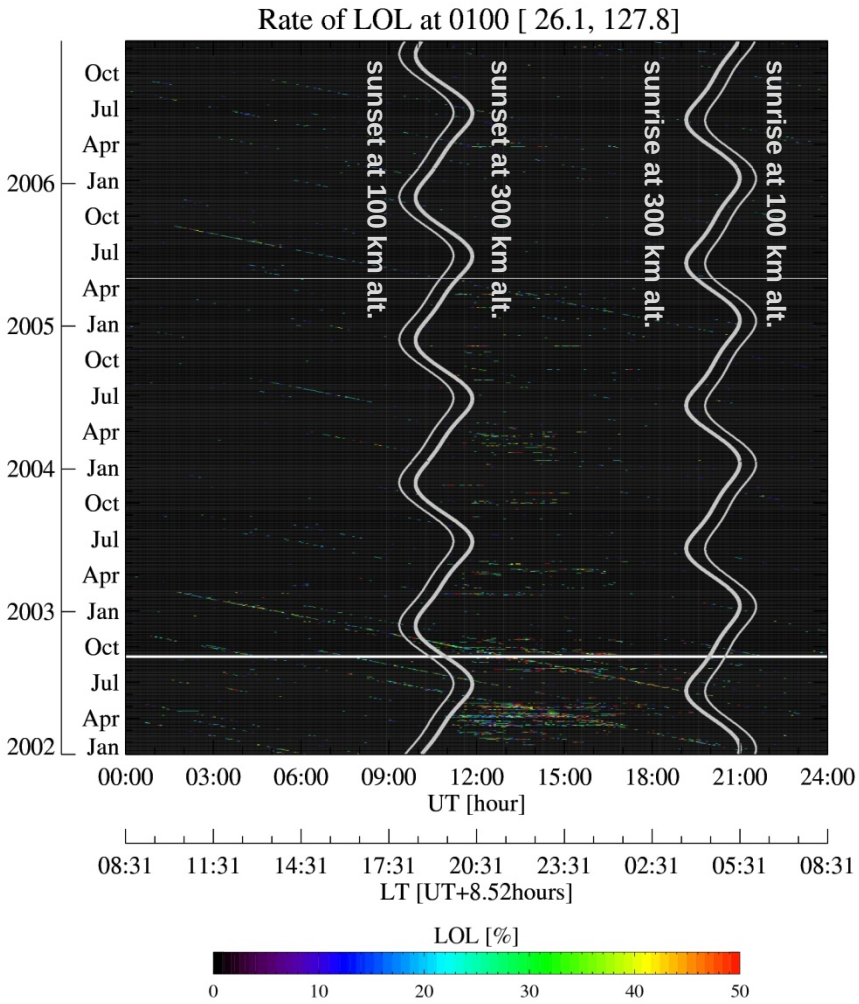
High resolution GPS-TEC maps in Japan

	Absolute TEC	ROTI (~10km scale irregularity)	Loss-of-Lock (~100m scale irregularity)
12:20 UT (21:20 JST)			
12:40 UT (21:40 JST)			
13:00 UT (22:00 JST)			

ROTI and LOL at Okinawa, Japan

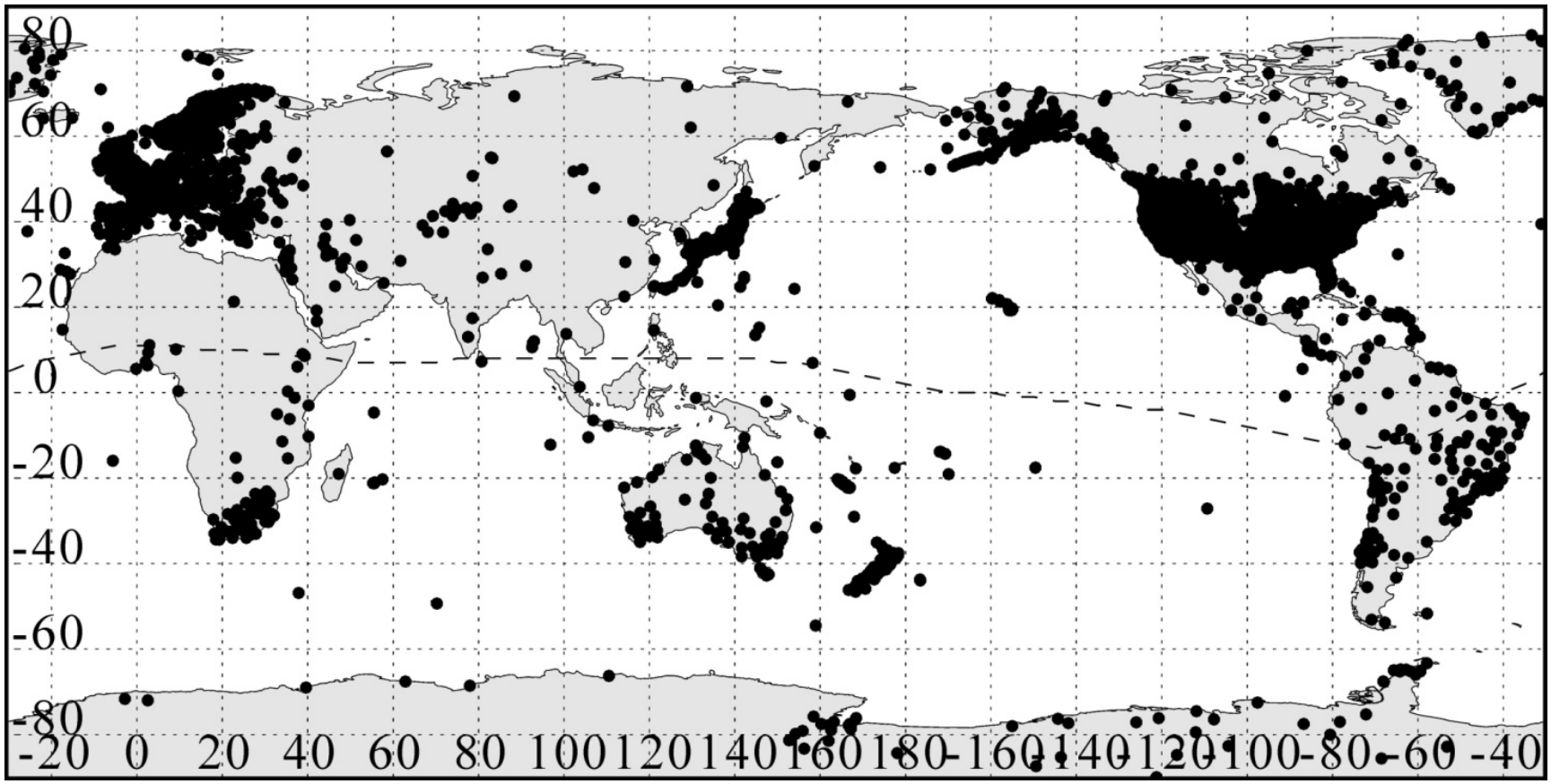


- Slant TEC, ROTI, and Rate of GPS-LOL (5-min window) on Apr 30, 2001.
- Sat. zenith angle: < 45 deg.



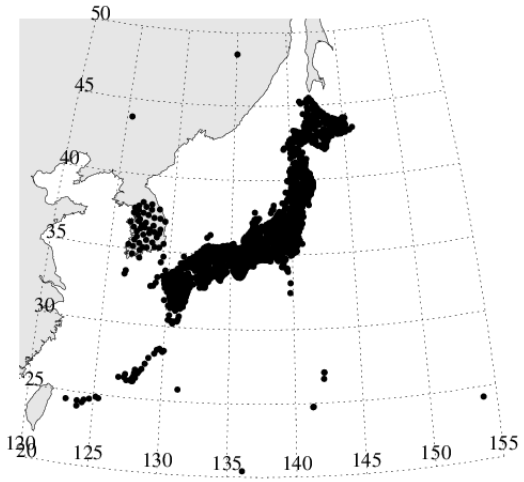
- Rate of LOL of 2 or more GPS satellites during 2002-2006.
- During Mar-Apr in 2002, the RLOL in the nighttime (21-24 JST) exceeds 30% (once per three days on the average).

Global GNSS Receiver Networks



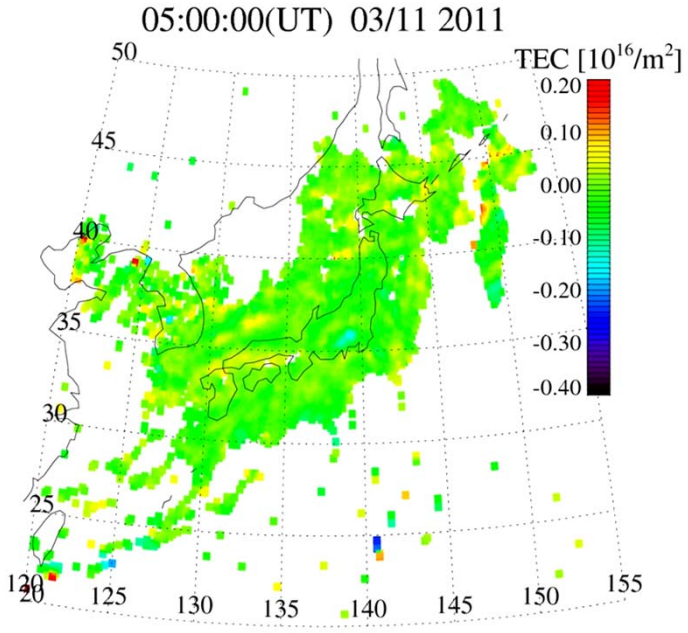
- We have collected all the available GPS receiver data (more than 6,000 receivers as of Jan. 2012) and made the database of TEC.

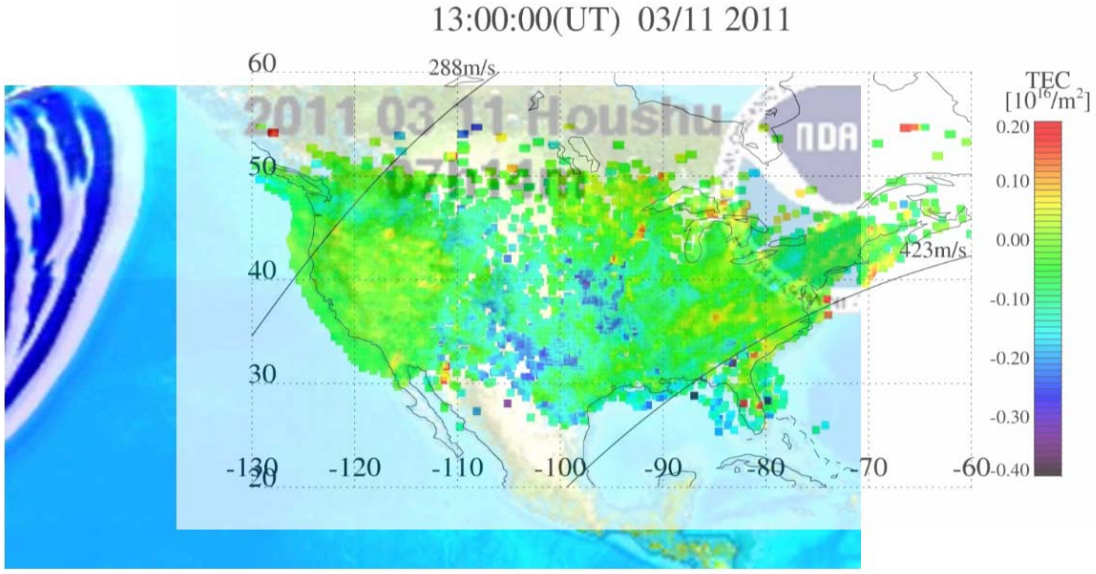
Earthquake- and Tsunami-induced TEC variations



Japan (GEONET): ~1,200 receivers

Korea (KMA): ~80 receivers
(KMA collects Korean GPS receiver data and provides GTEX data)



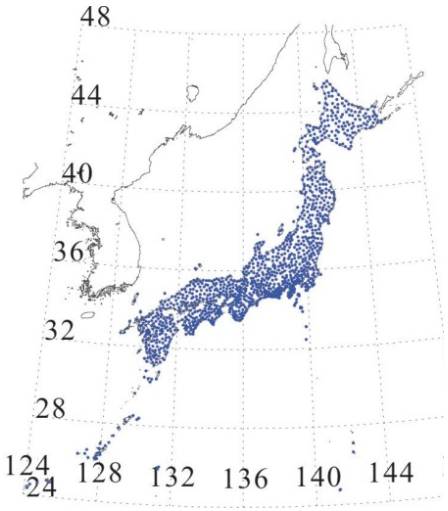


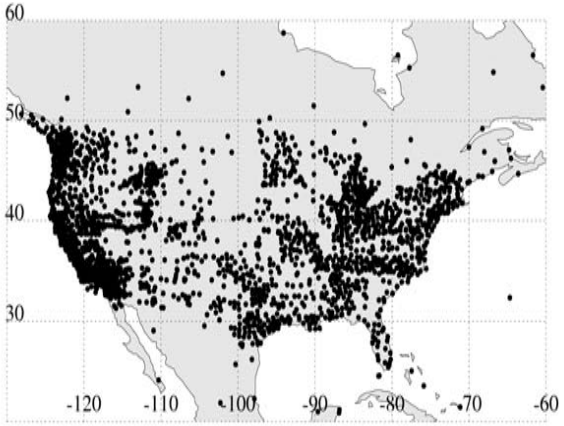
[Tsugawa et al., EPS, 2011].

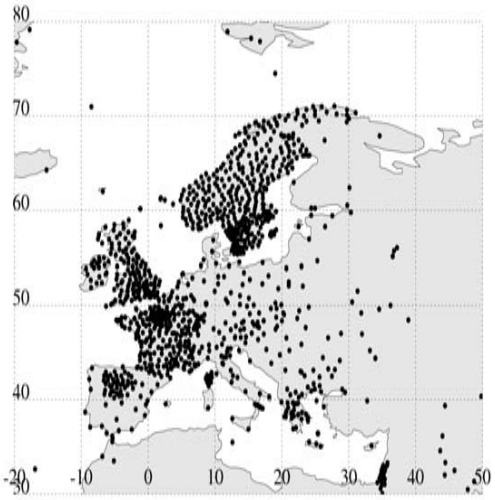
High resolution GPS-TEC maps

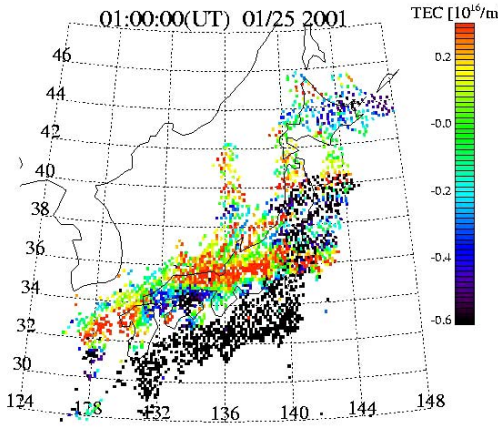
Region	**JAPAN**	**N. America**	**Europe**
# of GPS Rec.	~1,200 receivers	~2,700 receivers	~1,200 receivers

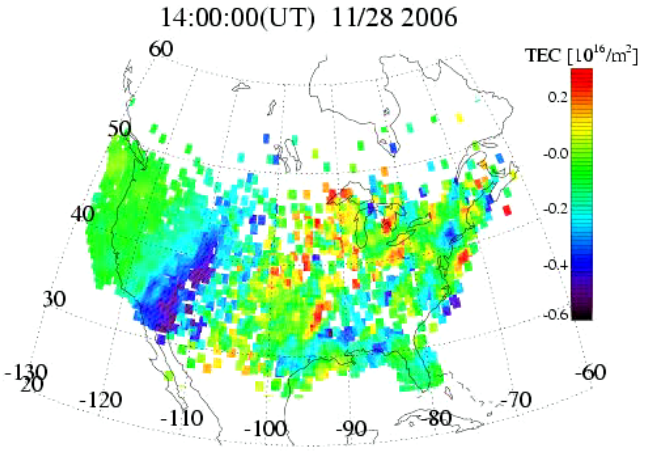
Detrended TEC Map (60-min Window)



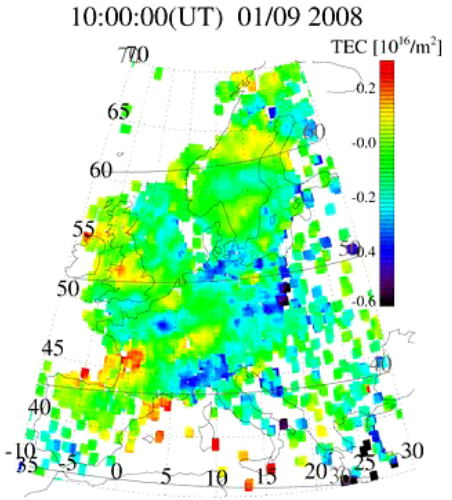






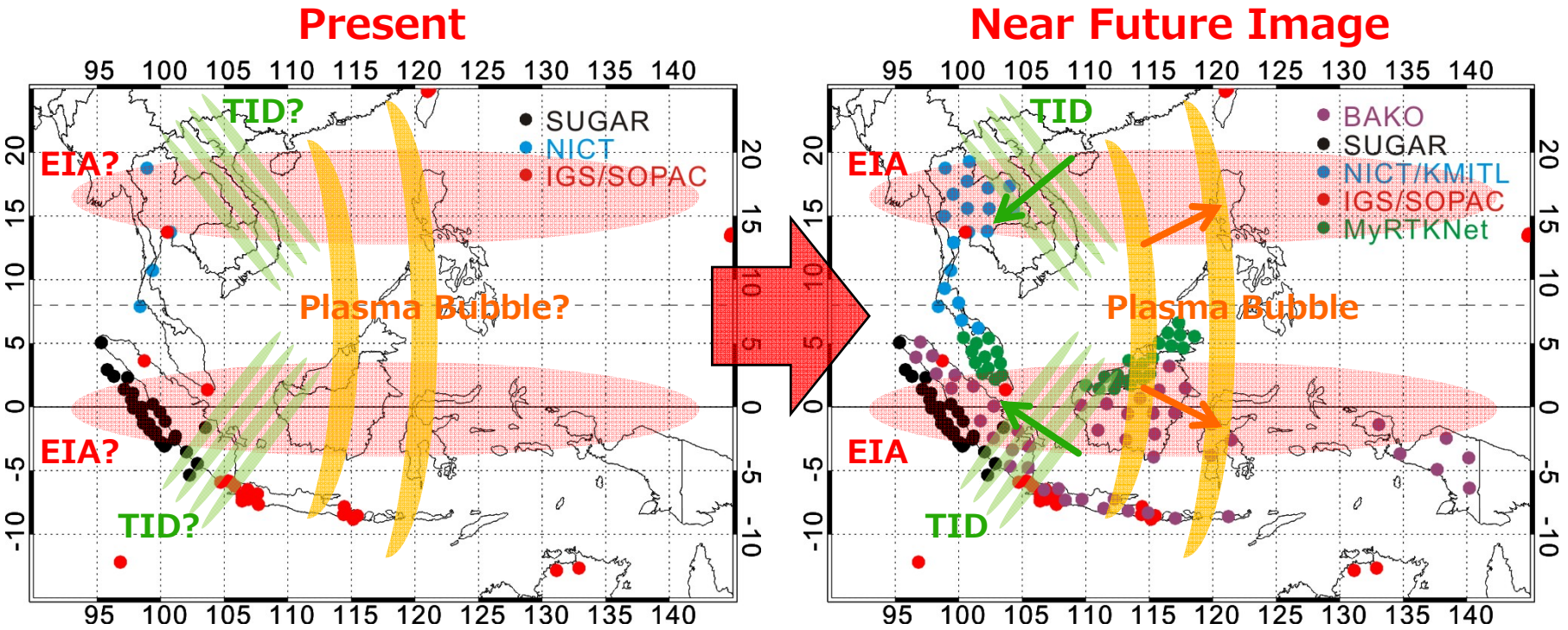


[Tsugawa et al., 2007].



[Otsuka et al., 2012].

Southeast Asian GNSS Networks Available for Ionospheric Researches



- Dense and wide-coverage GPS receiver network can reveal their spatial structures, propagation directions, and temporal evolutions.
- The GPS-TEC maps greatly contribute to the ionospheric researches and the nowcast/forecast of space weather.
- However, it is difficult to collect or share the GNSS data in some countries due to government or institute data policy.

DRAWING-TEC project

(Dense Regional and Worldwide International GNSS-TEC observation)

1. Standardizing GNSS-TEC data for high-resolution TEC maps.

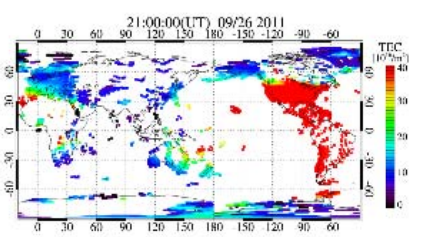
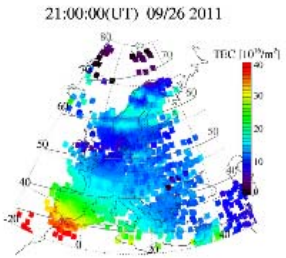
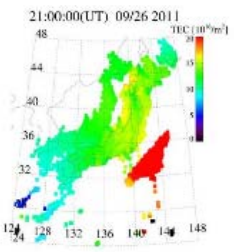
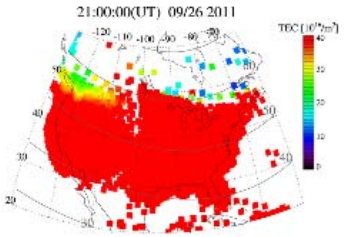
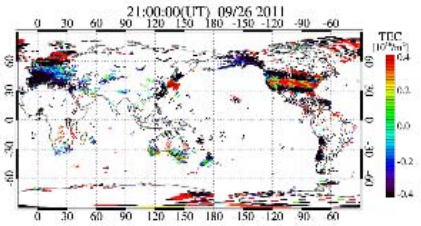
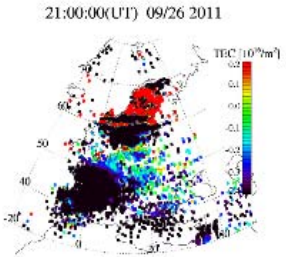
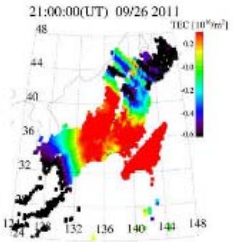
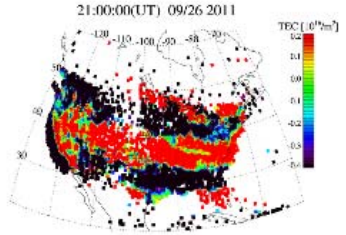
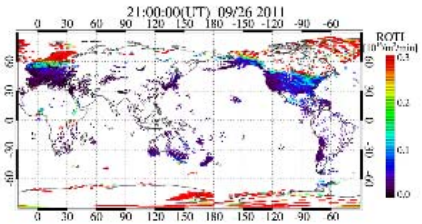
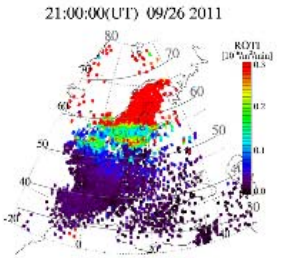
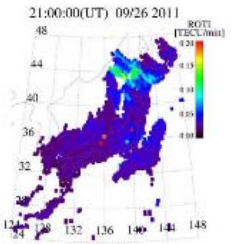
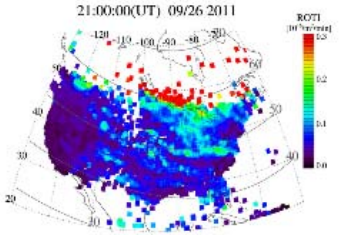
2. Developing a new high-resolution TEC mapping technique using the standardized TEC data.

3. Sharing the standardized TEC data and the data or the information of GNSS receiver network among the international ionosphere and GNSS researcher community.

DRAWING-TEC Website

http://seg-web.nict.go.jp/GPS/DRAWING-TEC

Quicklook

	Global	Europe	Japan	N. America
Absolute TEC				
Detrended TEC				
ROTI				

GPS Observation Data （RINEX format)

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GSI, JAPAN          GEOGRAPHICAL SURVEY INSTITUTE, JAPAN    OBSERVER / AGENCY
440101351           TRIMBLE 5700        Nav 1.05 Sig 0.00   REC # / TYPE / VERS
                    TRM41249.00                             ANT # / TYPE
0001                                                        MARKER NAME
                                                            MARKER NUMBER
 -3522845.0167  2777141.5661  4518959.0276                 APPROX POSITION XYZ
        0.0000        0.0000        0.0000                 ANTENNA: DELTA H/E/N

     1     1                                              WAVELENGTH FACT L1/2

     4    L1    C1    L2    P2                           # / TYPES OF OBSERV
    30.0000                                             INTERVAL
  2002     3     9     0     0    0.0000000     GPS      TIME OF FIRST OBS
HP-UX 10.20|PA-RISC|cc A.10.32.03|=+|=|                 COMMENT
***** RINEX HEADER SPECIFICATION 1.00 *****              COMMENT
                                                        END OF HEADER
 02  3  9  0  0  0.0000000  0  9G 1G 2G 3G13G15G17G22G25G31
 -19012371.666    23282028.969   -14792202.9624   23282034.2034
 -20059488.864    22333773.945   -15610299.0404   22333776.2234
 -29405637.893    20488342.148   -22886235.5684   20488343.6844
 -10611214.715    23501437.734    -8249844.7244   23501441.9304
 -21574253.491    21813118.625   -16787240.0654   21813121.3794
 -19466956.219    22672753.922   -15147494.2964   22672757.9924
 -38120076.083    20147969.977   -29678594.7674   20147970.2814
 -34642202.746    23479338.891   -26972367.3494   23479343.8204
  -8256352.111    22876974.961    -6407292.0364   22876978.9264
 02  3  9  0  0 30.0000000  0  9G 1G 2G 3G13G15G17G22G25G31
 -18996599.842    23285030.305   -14779913.4304   23285036.4574
 -20169633.218    22312814.289   -15696125.7734   22312816.5204
```

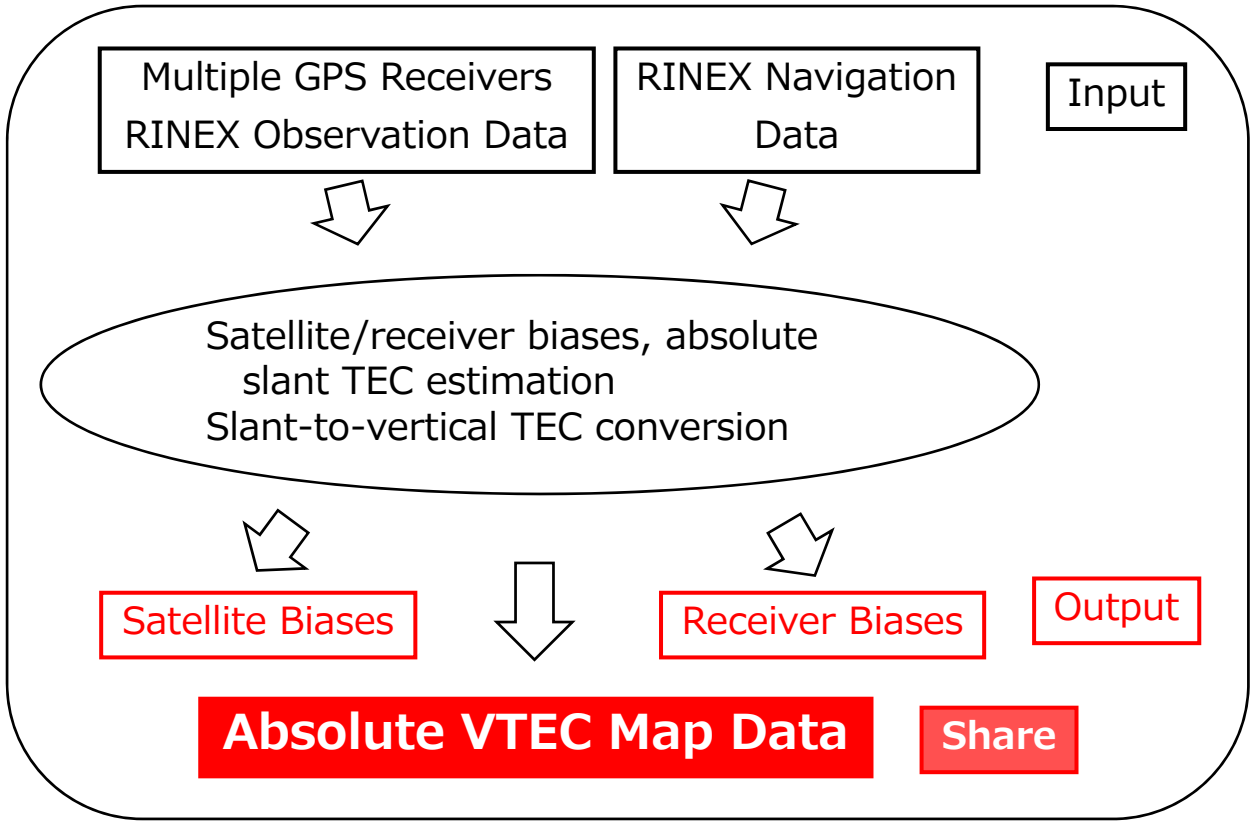
Filename: ssssdddh.yyo
ssss: marker name
ddd: day of the year
h: file sequence number
yy: 2-digit year

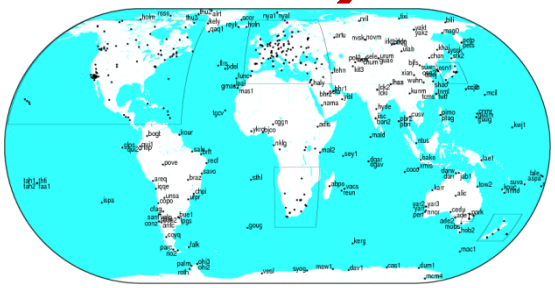
Header Part

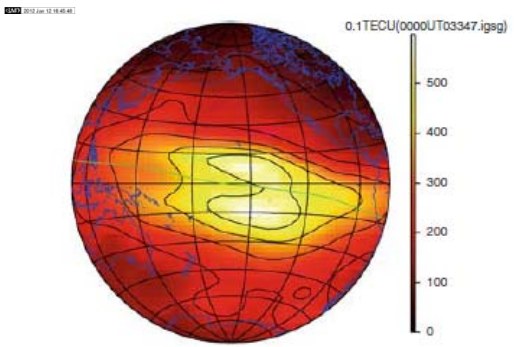
year, month, day, hour, min, sec, flag, # of PRNs, PRNs

1 epoch

General GNSS-TEC data (ex. IONEX)







An example of IGS TEC map with spatial resolution of 5° in longitude, 2.5° in latitude and temporal resolution of 2 hours (Hernández-Pajares, 2009).

- Vertical absolute TEC (VTEC) map data and instrumental biases of satellite and receiver are simultaneously derived from the data of multiple GPS receivers and satellite orbit.
- Temporal and spatial resolution of VTEC Map data are too low to observe small-scale ionospheric disturbances such as plasma bubble and ionospheric waves.

IONEX format (v1.0)

```
     1.0            IONOSPHERE MAPS     MIX                 IONEX VERSION / TYPE
cmpcmb v1.2          GRL/UWM             25-sep-12 21:16     PGM / RUN BY / DATE
ionex file containing IGS COMBINED Ionosphere maps           COMMENT
global ionosphere maps for day 257, 2012                     DESCRIPTION
IONEX file containing the COMBINED IGS TEC MAPS and DCBs     DESCRIPTION
      IONEX files of the following IAACs were combined: cod  DESCRIPTION
                                                        esa  DESCRIPTION
                                                        jpl  DESCRIPTION
                                                        upc  DESCRIPTION
  2012     9    13     0     0     0                       EPOCH OF FIRST MAP
  2012     9    14     0     0     0                       EPOCH OF LAST MAP
  7200                                                      INTERVAL
    13                                                      # OF MAPS IN FILE
  COSZ                                                      MAPPING FUNCTION
    0.0                                                     ELEVATION CUTOFF
combined TEC calculated as weighted mean of input TEC valuesOBSERVABLES USED
   418                                                      # OF STATIONS
    32                                                      # OF SATELLITES
  6371.0                                                    BASE RADIUS
     2                                                      MAP DIMENSION
   450.0 450.0   0.0                                       HGT1 / HGT2 / DHGT
    87.5 -87.5  -2.5                                       LAT1 / LAT2 / DLAT
  -180.0 180.0   5.0                                       LON1 / LON2 / DLON
    -1                                                      EXPONENT
TEC values in 0.1 tec units;  9999, if no value available   COMMENT
DCB values in nanoseconds, reference is Sum_of_SatDCBs = 0  COMMENT
DIFFERENTIAL CODE BIASES                                    START OF AUX DATA
   G01   -10.719     0.084                                  PRN / BIAS / RMS
   G02     6.092     0.058                                  PRN / BIAS / RMS
...
   G  7odm                   8.485     0.000                STATION / BIAS / RMS
   G  abmf                 -11.313     0.000                STATION / BIAS / RMS
...
DIFFERENTIAL CODE BIASES                                    END OF AUX DATA
                                                            END OF HEADER
     1                                                      START OF TEC MAP
  2012     9    13     0     0     0                       EPOCH OF CURRENT MAP
    87.5-180.0 180.0   5.0 450.0                           LAT/LON1/LON2/DLON/H
  139  139  139  138  138  138  138  137  137  136  136  135  135  134  134  133
  132  132  131  131  130  129  130  130  130  131  130  130  130  130  130  130
  130  130  130  131  131  131  132  132  133  133  134  134  135  135  136  136
  136  137  137  137  137  137  137  137  137  137  137  137  138  138  138  138
  139  138  138  139  139  139  139  139  139
    85.0-180.0 180.0   5.0 450.0                           LAT/LON1/LON2/DLON/H
```

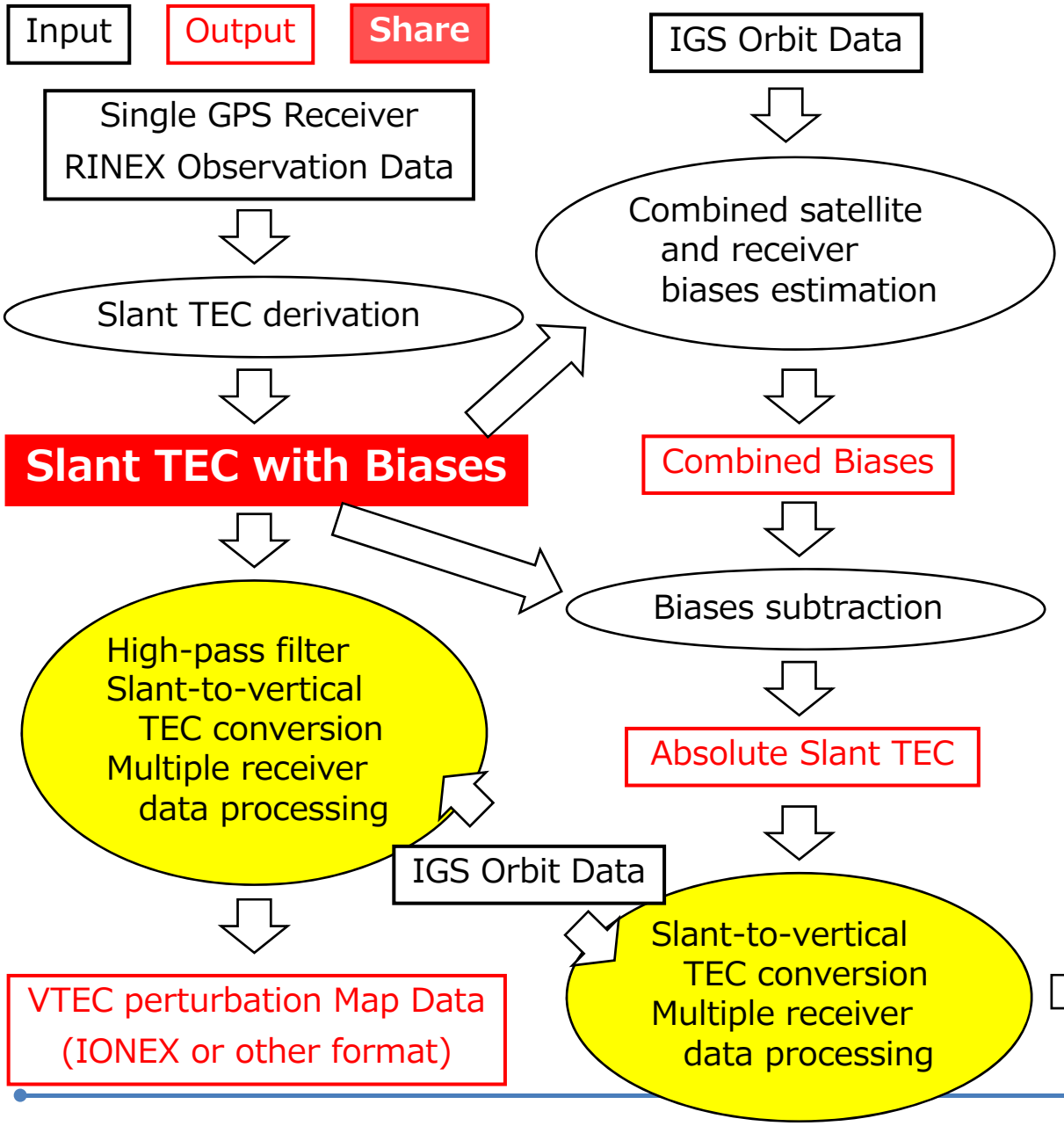
Filename: cccedddh.yyI
ccc: Analysis Center designator
e: extension or region code
ddd: day of the year
h: file sequence number
yy: 2-digit year
I: file type

Header Part

epoch start

VTEC values for longitude bins at a latitude bin

Proposed GNSS-TEC data for data sharing



- Slant TEC data including satellite and receiver biases are derived from GPS data of one receiver.
- VTEC maps can be derived using the slant TEC data from multi GPS receivers.
- The VTEC data can have high temporal and spatial resolution.
- The Slant TEC data would be suitable for data sharing in the Southeast Asia.

GNSS-TEC exchange (GTEX) format (v1.0)

```
     1.0            GTEX DATA            GNSS                GTEX VERSION / TYPE
RNX2GTEX V1.0       NICT, JAPAN                              PGM / RUN BY
     0                                                       EXPONENT OF TECU
     TEC values in 10^16 el/m^2 (1 TEC Unit)                 COMMENT
     TEC Status Flag = 0 : Normal data                       COMMENT
                     = 1 : Lack of observables (TEC=999.)    COMMENT
                     = 2 : Too large TEC (TEC=999.)          COMMENT
                     = 4 : Cycle slip (TEC discontinuity)    COMMENT
                     = 5 : Cycle slip (LLI)                  COMMENT
                     = 6 : Beginning of arc                  COMMENT
     TYPES OF DATA   = R1 : Raw slant TEC including bias     COMMENT
                       A1 : Absolute slant TEC               COMMENT
                            R1 or A1 is necessary            COMMENT
                       1F : TEC status flag                  COMMENT
                       1O : Observation data used for TEC    COMMENT
                       ZN : Satellite zenith angle           COMMENT
                       AZ : Satellite azimuth angle          COMMENT
                                                             BIAS ESTIMATION PGM
01321310.12o  01321320.12o  01321330.12o                     RINEX FILE NAME
0132                                                         MARKER NAME
00000               TPS NETG3           3.4 EG3 Jul,02,2010 REC # / TYPE / VERS
                    TRM29659.00     GSI                     ANT # / TYPE
 -3690821.3891  2897721.3097  4305504.4426                  APPROX POSITION XYZ
       42.7294       141.8640        0.0486                 POSITION LAT LON ALT
     6    L1    C1    L2    P2    S1    S2                  # / TYPES OF OBSERV
     5    R1    1F    1O    ZN    AZ                        # / TYPES OF DATA
    30.000                                                   INTERVAL
  2012    5     11     0     0    0.0000000     GPS         TIME OF FIRST OBS
                                                             END OF HEADER
 12  5 11  0  0  0.0000000  0  9G21G 9G18G15G28G 5G27G 8G26
 -61.7242  0  L1L2C1P2  32.45  194.42
 -33.4733  0  L1L2C1P2   9.32   14.04
 -49.7988  0  L1L2C1P2  20.39    9.03
 -55.8391  0  L1L2C1P2  83.27   39.34
 -43.6837  0  L1L2C1P2  32.21   44.21
 -38.7060  0  L1L2C1P2   8.31    3.34
 -44.8228  0  L1L2C1P2  74.42  265.99
 -31.3004  0  L1L2C1P2  23.01  343.20
 -48.7904  0  L1L2C1P2  50.12  115.79
 12  5 11  0  0 30.0000000  0  9G21G 9G18G15G28G 5G27G 8G26
```

Filename: ssssdddh.yy_TEC
ssss: marker name
ddd: day of the year
h: file sequence number
yy: 2-digit year

Header Part

RINEX files used to derive slant TEC

Rec. Position in Lat, Lon, Alt

Types of obs. in RINEX

Types of data product

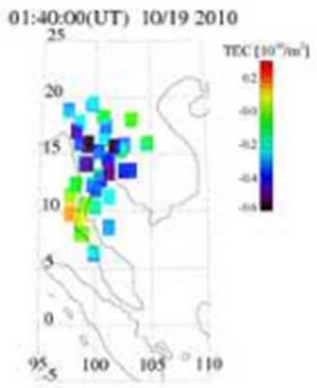
Interval according to RINEX

year, month, day, hour, min, sec, flag, # of PRNs, PRNs

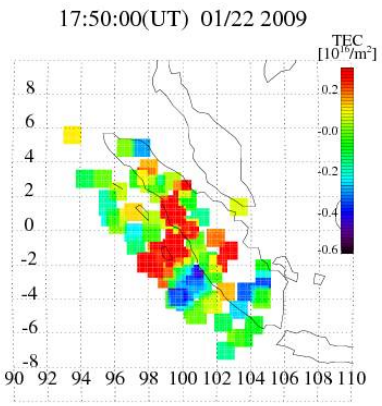
1 epoch

GNSS-TEC data sharing based on GTEX

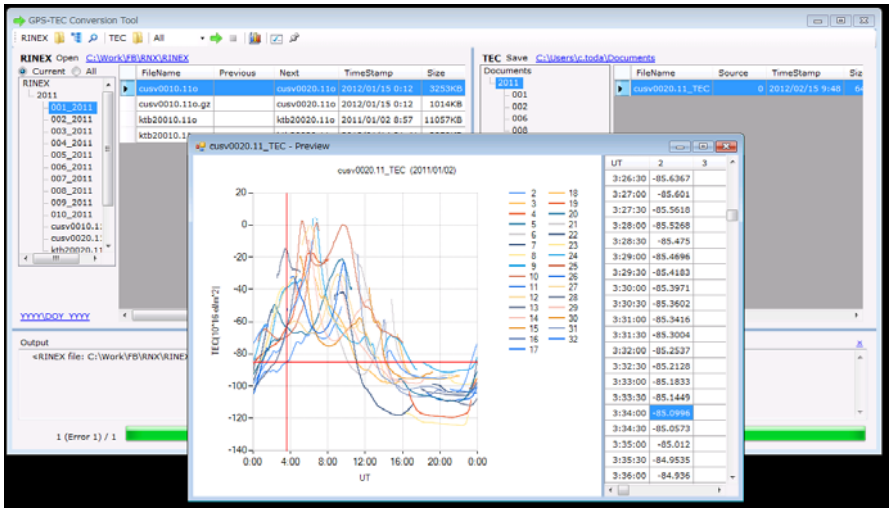
- NICT have developed the database of “GTEX” data for more than 6,000 GNSS receivers in the world. These data are available via the NICT science cloud, OneSpaceNet (OSN).
- Since the 1st AOSWA workshop held in Chiang Mai, Thailand in February 2012, we are now developing the GTEX data of Thailand, Indonesia, South Korea, and China collaborated with KMA, KMITL, LAPAN, and CMA, respectively.
- We can provide software products to convert RINEX data to GTEX data (Fortran 77) , and to make high-resolution TEC grid data (Fortran 77) and map images (IDL).
- NICT recently released a Windows software “RNX2GTEX” which are available via the NICT website.



Detrended TEC over Thailand. [Courtesy of K. Watthanasangmechai (KMITL)]



Detrended TEC over Indonesia by SUGAR network.



Asia-Oceania Space Weather Alliance: AOSWA

http://aoswa.nict.go.jp

- Objective: make a regional linkage of information of space weather for operations and researches
- GTEX data sharing is one of important topics.

The 1st AOSWA workshop at Chiang Mai, Thailand during 22-24 February 2012.

- 10 countries, 30 organizations, 76 participants
- 41 oral presentations, 21 poster presentations, 1 tutorial lecture

The 2nd AOSWA workshop at Kunming, China will be held in 4-7 Nov 2013, hosted by CSERF and CAS.

ICAO Asia and Pacific
Ionospheric studies task force (ISTF)

- ICAO plans to use aviation navigations based on GNSS, such as GBAS and SBAS. ICAO recognizes a necessity to evaluate the ionospheric effects on such navigations.
- ICAO Asia and Pacific have discussed about the effect of low-latitude ionospheric disturbances such as plasma bubble since 2009 and established the ionospheric studies task force (ISTF) in July 2011.

- In the 2nd meeting of ISTF held at Bangkok in Oct. 2012, the ionospheric data format for data sharing among countries were discussed.
- The GTEX format proposed by Japan (ENRI, NICT) were adopted as the sharing format in ISTF.
- GTEX format will be fixed by the next meeting (Jul. 2013).

Summary

- High-resolution TEC observations using dense GNSS receiver networks can be a powerful tool to monitor and research medium-scale (~100-1,000 km) ionospheric disturbances such as plasma bubble.

- NICT started “DRAWING-TEC” project to expand the high-resolution TEC observation area with collaboration of ionosphere and GNSS researchers in the world (especially in the Asia-Oceania region).

- We hope that the DRAWING-TEC project would contribute to improvements (e.g., higher resolution) in GIM and IRI model .

Acknowledgement

GNSS receiver data or GTEX-TEC data are provided by GSI, UNAVCO, IGS, SOPAC, CORS, WCDA, CHAIN, PANGA, KASI, KMA, EPN, BKGE, OLG, IGNE, DUT, ASI, ITACyL, ESEAS, SWEPOS, SATREF, BIGF, TrigNet, Geoscience Australia, IPS, RBMC, SUGAR, DPT, LAPAN, and KMITL.