Underutilized space-borne GPS observations for Space Weather monitoring

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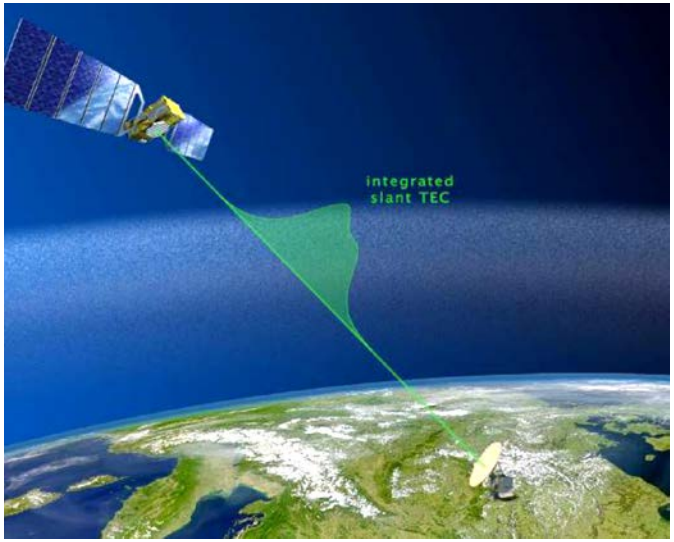
Image credit: ESA

Motivation

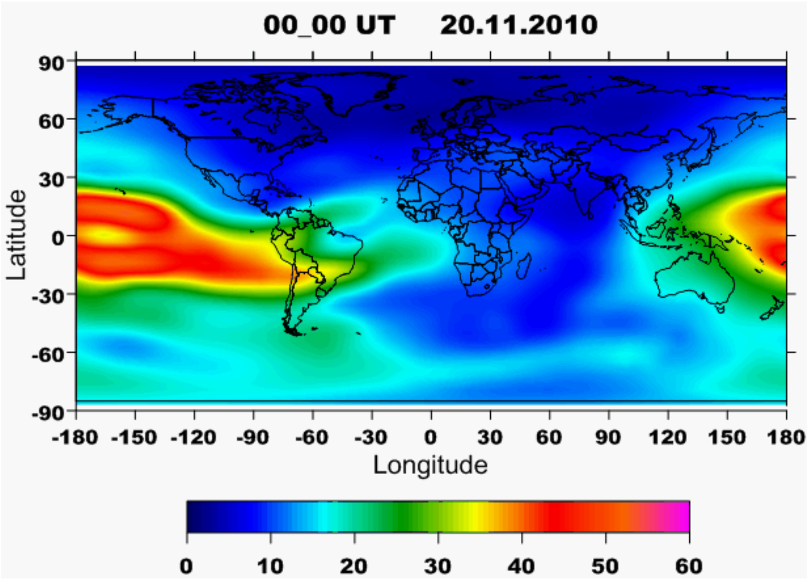
TEC (Total Electron Content) – one of the key parameter used in actual ionospheric research, applications, and space weather monitoring



GPS TEC :
represents the total number of electrons along line-of-sight GPS satellite - GPS receiver.

GPS orbit altitude ~20,000 km

IGS GIM TEC – IONEX TEC



Motivation

International Reference Ionosphere (IRI) model

IRI is the ISO standard for specification the ionospheric plasma densities, temperatures, and TEC in the height interval from 50 km to 1500 km.

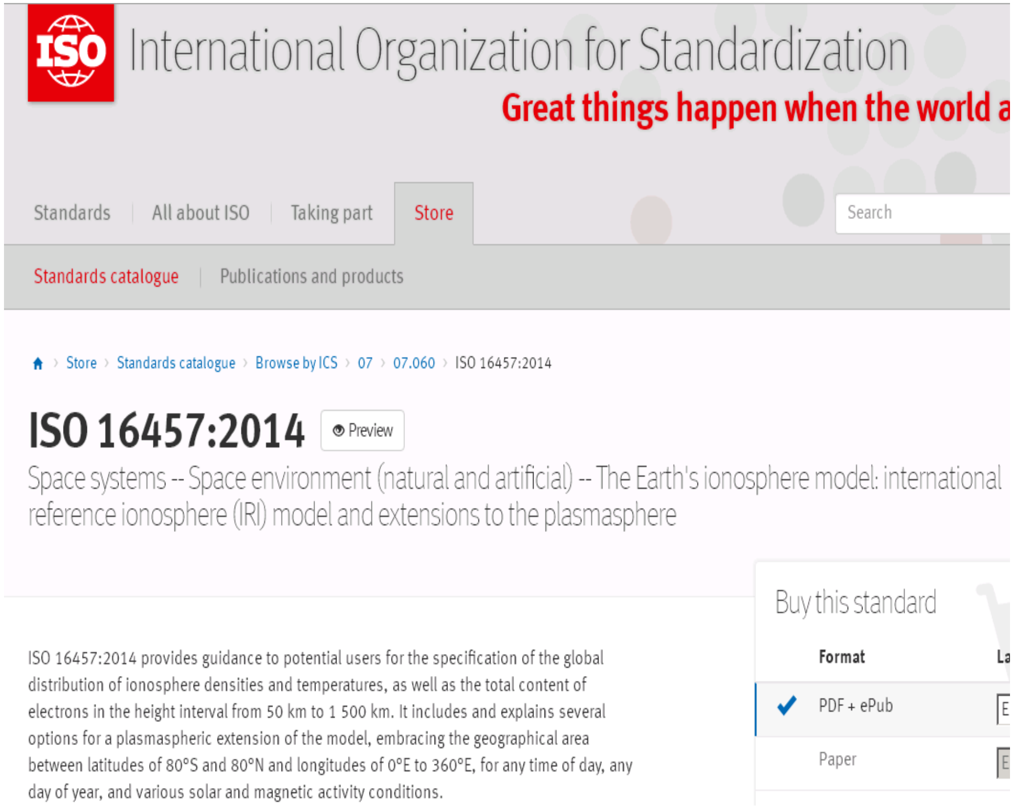
Recommendations – extensions to the plasmasphere, topside improvement

Model Input

Solar indices (F10.7 index, sunspot number),
Ionospheric index (IG)
magnetic indices (Ap and Kp)
URSI/CCIR maps of model coefficients (foF2)

Model Output

Electron density
Electron temperature
Height range: 80 – 2,000 km
Ion density
Ion composition
Ionospheric total electron content (TEC)



NeQuick, NeQuick-G models

Quick calculation of electron density and TEC up to the altitudes of 20,000 km

- Climatological (monthly mean) model of electron density
  - 3D (as opposed to single-layer ionospheric models SBAS, Klobuchar)
  - Driven by monthly-mean Solar Flux F10.7
- Recommended by ITU-R for propagation prediction
- Based on profiles of ionospheric layers
- Adapted in Galileo for nowcasting based on recent observations

Motivation

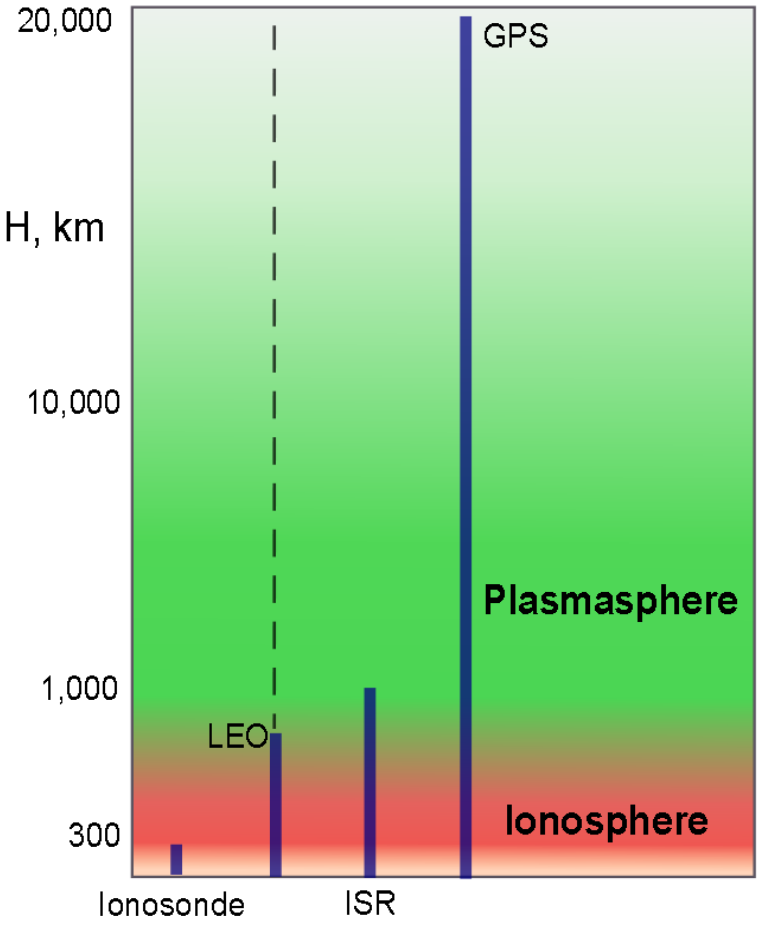
Major challenges for operational climatological ionospheric models:

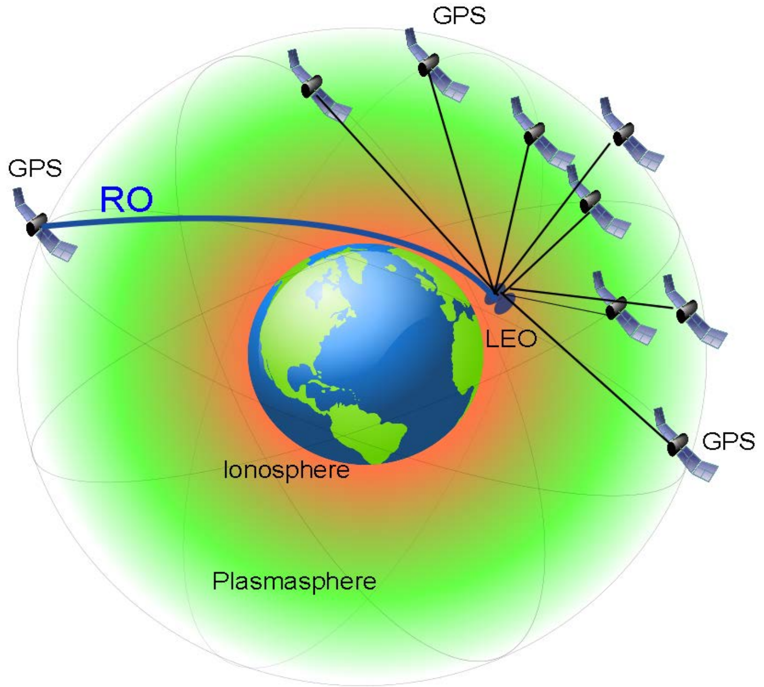
- Extension toward the plasmashere (GPS altitudes)

- Improvement of the topside formulation

- Correct specification of TEC

Altitudinal measuring range of the main observation techniques

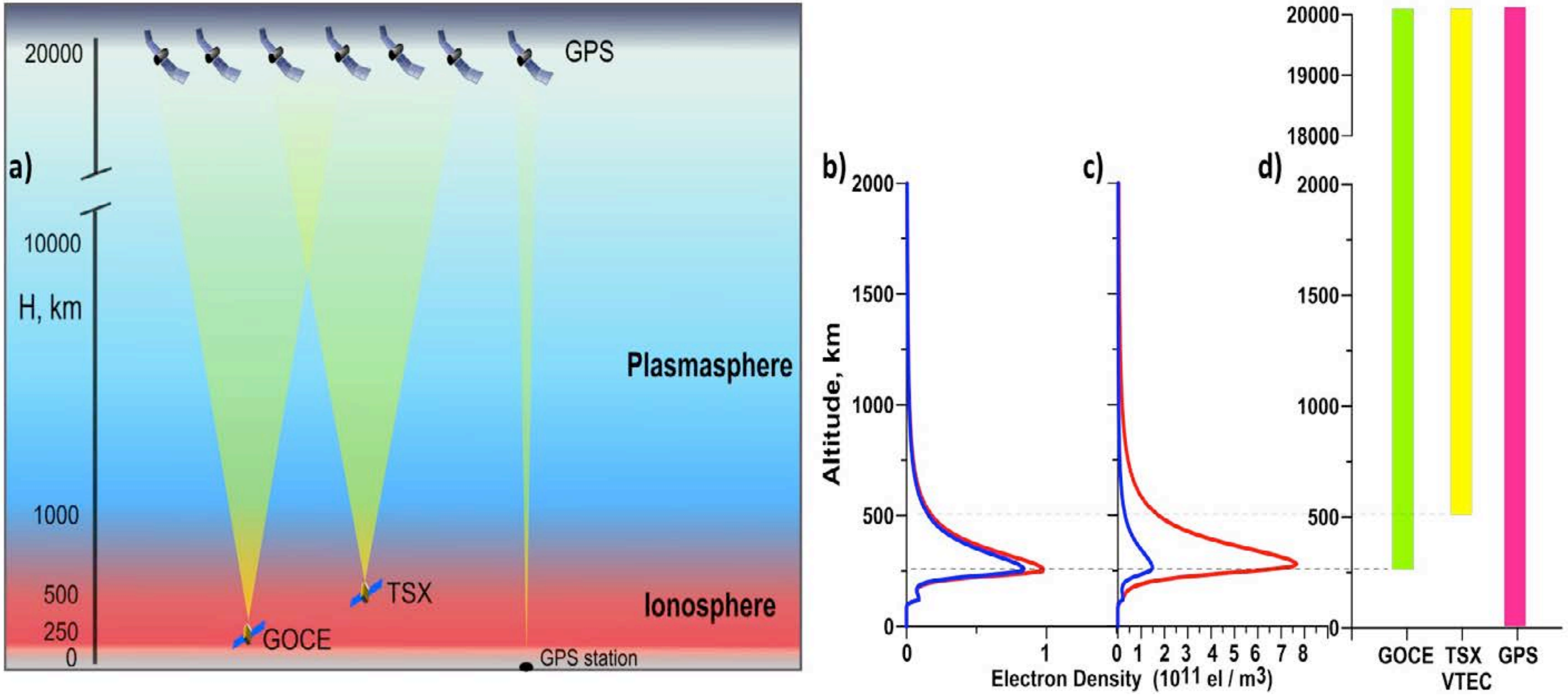




RO – radio occultation

POD – precise orbit determination

Plasmasphere. Topside Impact to TEC



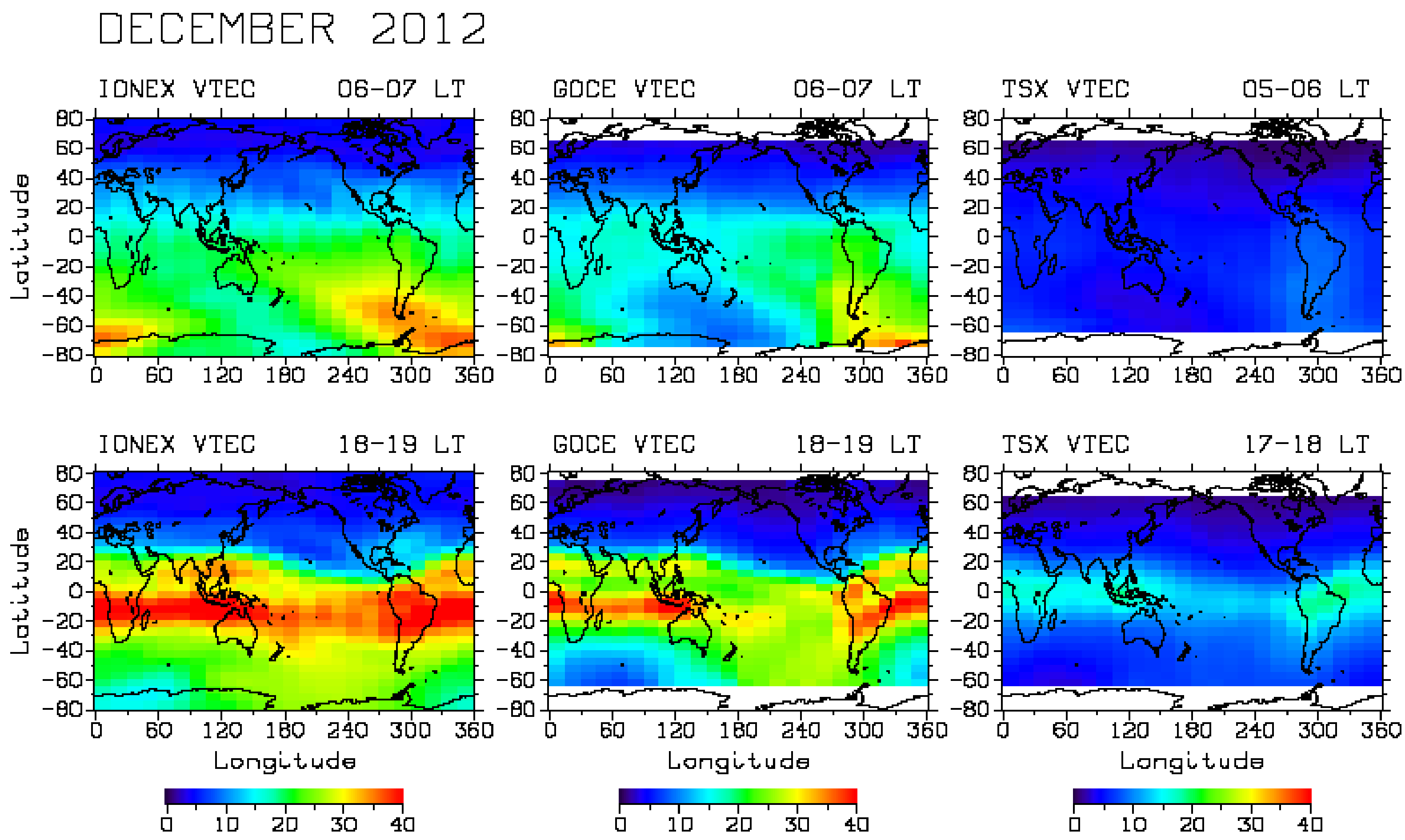
GOCE (Gravity field and steady-state Ocean Circulation Explorer)
Sun-synch. polar orbit, alt. ~250 km

TerraSAR-X - German imaging radar Earth observation satellite
Sun-synch. polar orbit, alt ~500 km

Zakharenkova & Cherniak, Space Weather, 2015

Topside Impact to TEC

December solstice

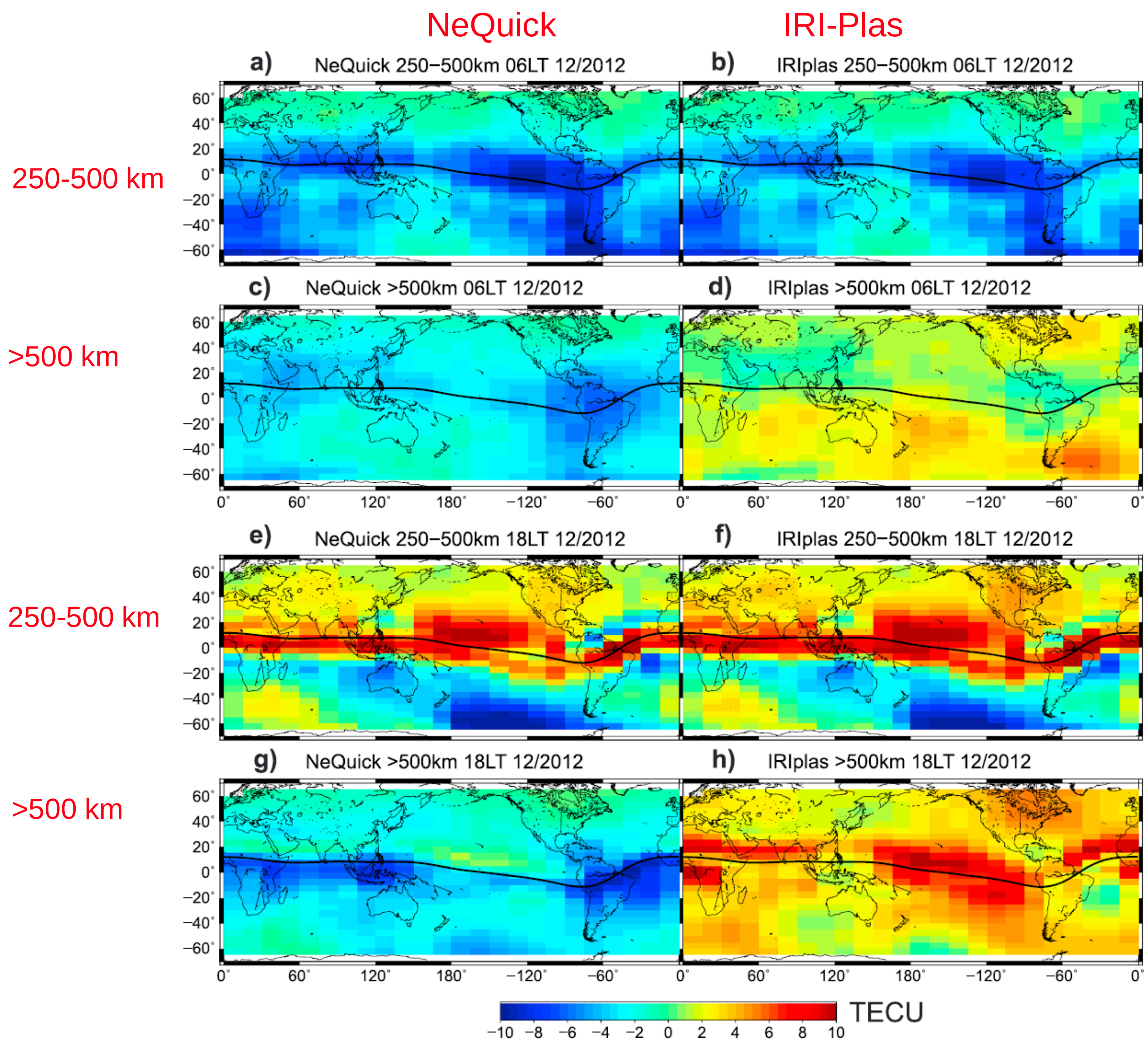


0 - 20,000 km | 250 - 20,000 km | 500 - 20,000 km

Zakharenkova & Cherniak, Space Weather, 2015

Model-Data Difference

December 2012 solstice



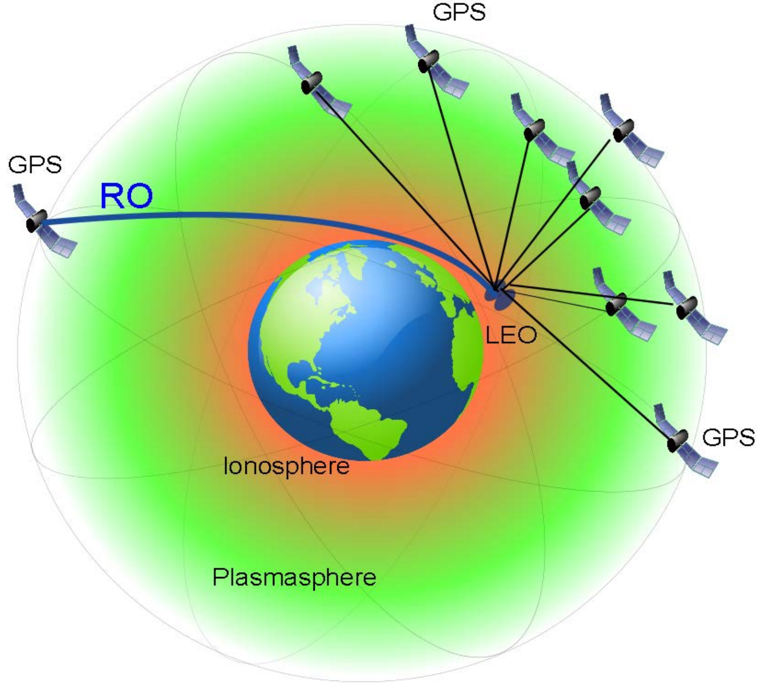
Cherniak & Zakharenkova, Radio Science, 2016

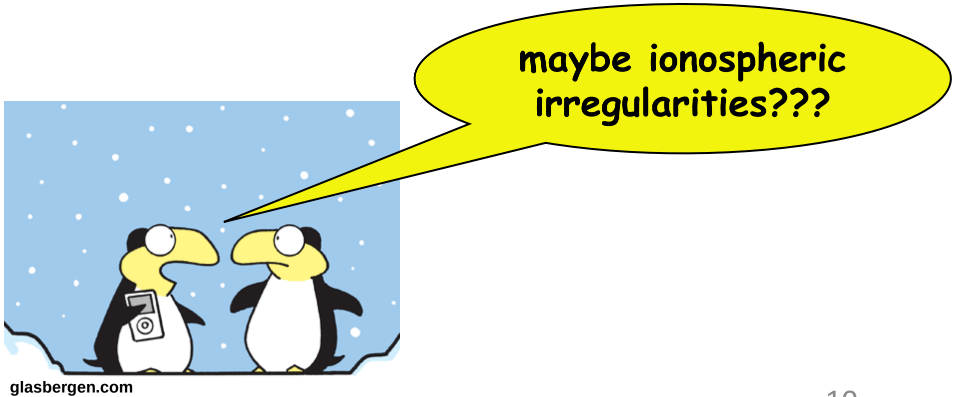
LEO GPS Technique

POD – precise orbit determination

Main objectives:

- ✓ Orbit solution
- ✓ Timing
- ✓ Calibration of accelerometer data
- ✓ Absolute TEC for topside ionosphere / plasmasphere rese
- ✓ something else????





Ionospheric irregularities seen in GPS measurements

Ionospheric irregularities can be characterized by measuring its impact on amplitude and phase of the received GPS signal.

Pi et al. [GRL, 1997] introduced into the use two GPS-based metrics:

• **ROT** (Rate of TEC change, dTEC/dt) as a measure of phase fluctuation activity

$$\mathrm{ROT} = \frac{\mathrm{sTEC}_k^i - \mathrm{sTEC}_{k-1}^i}{t_k - t_{k-1}}$$

• **ROTI** (Rate of TEC Index, standard deviation of ROT) characterizes the severity of the GPS phase fluctuations

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

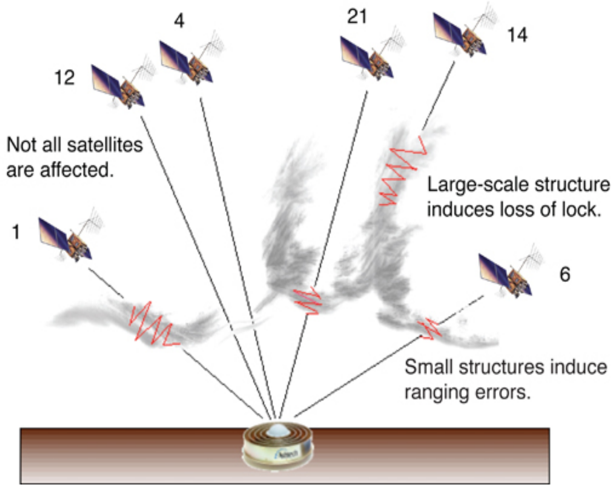
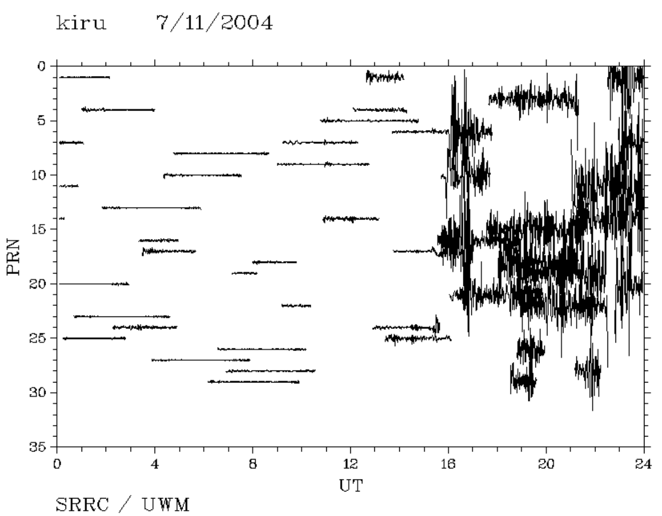


Image credit: GPS World

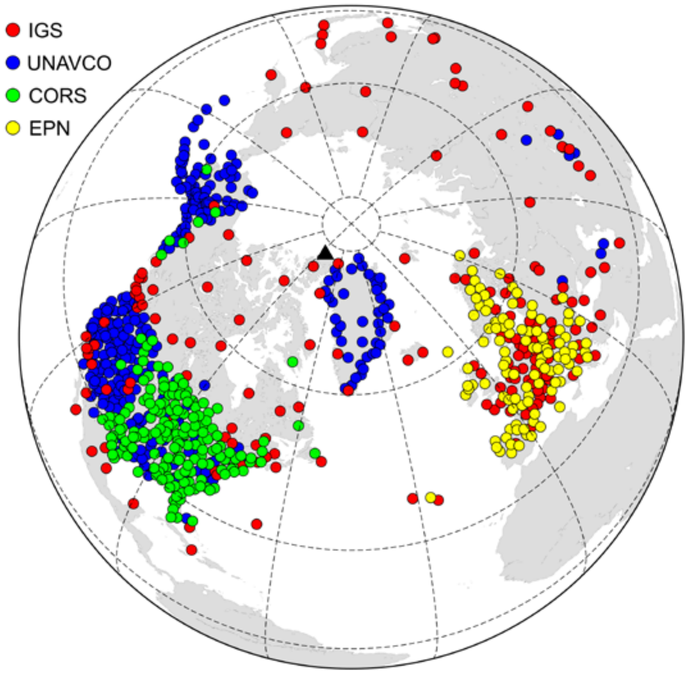
Example of ROT variations:

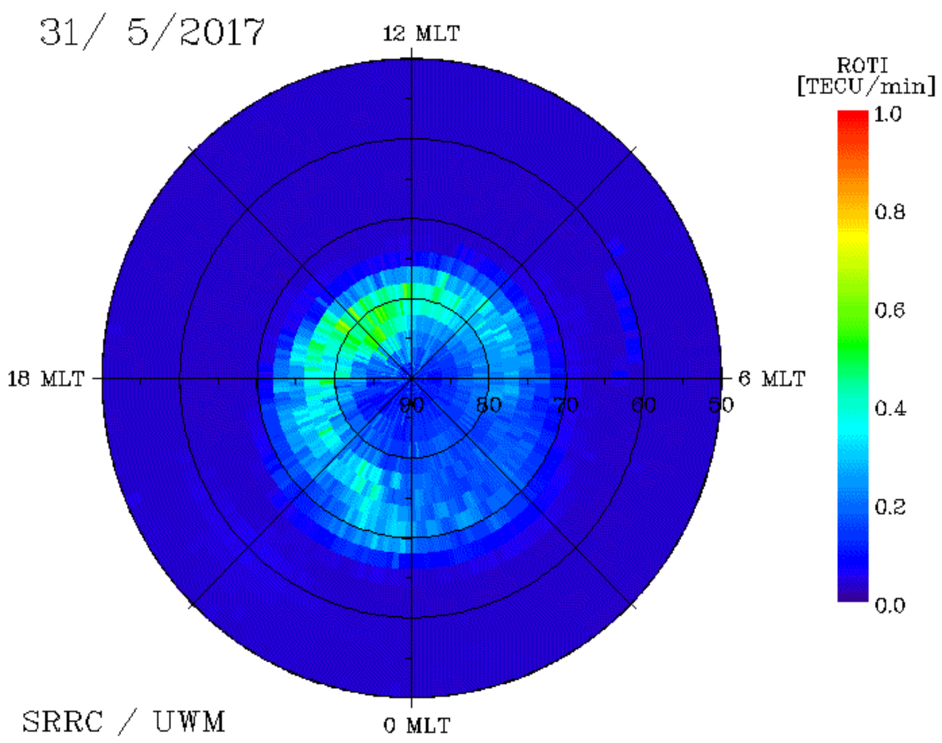


New IGS Ionospheric Fluctuation Product

Daily ROTI Maps:

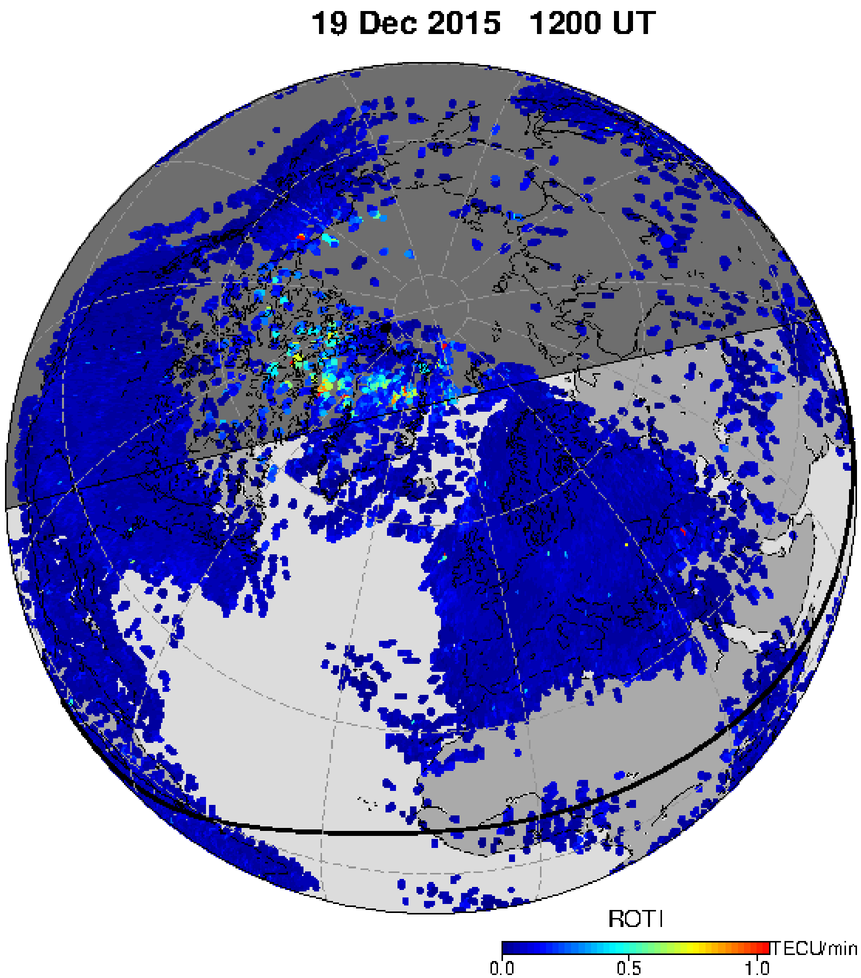
- > 700 stations
- MLAT – MLT domain (50-90 N; 00-24 MLT)
- Spatial resolution 2 x 2 degree
- Available at CDDIS NASA





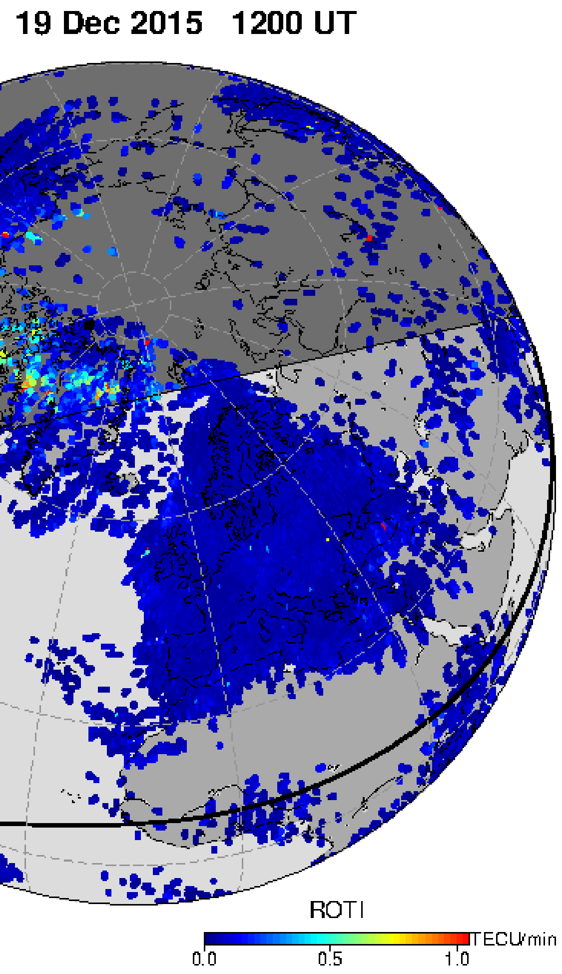
Cherniak et al, GPS Solutions, 2018

19 December



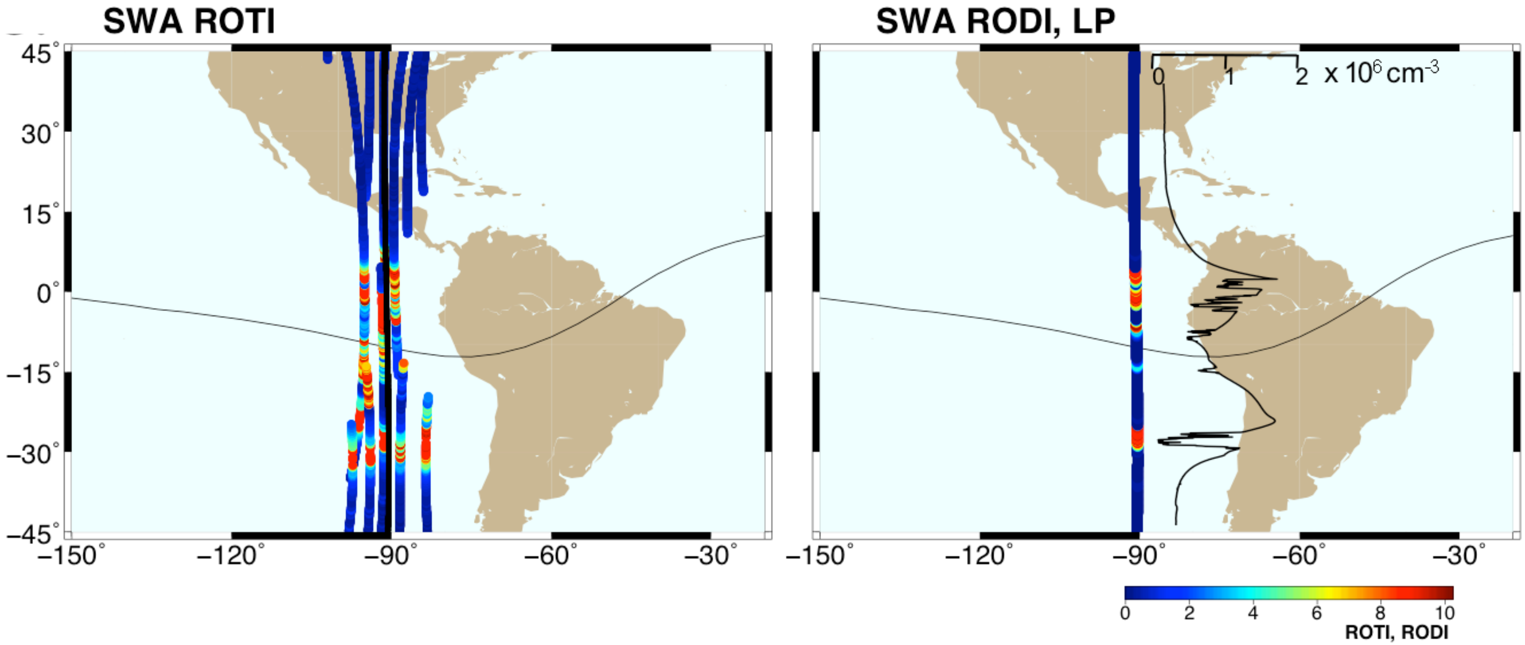
Ground-based ROTI maps

19 December



GPS vs Langmuir Probe

ROTI vs RODI

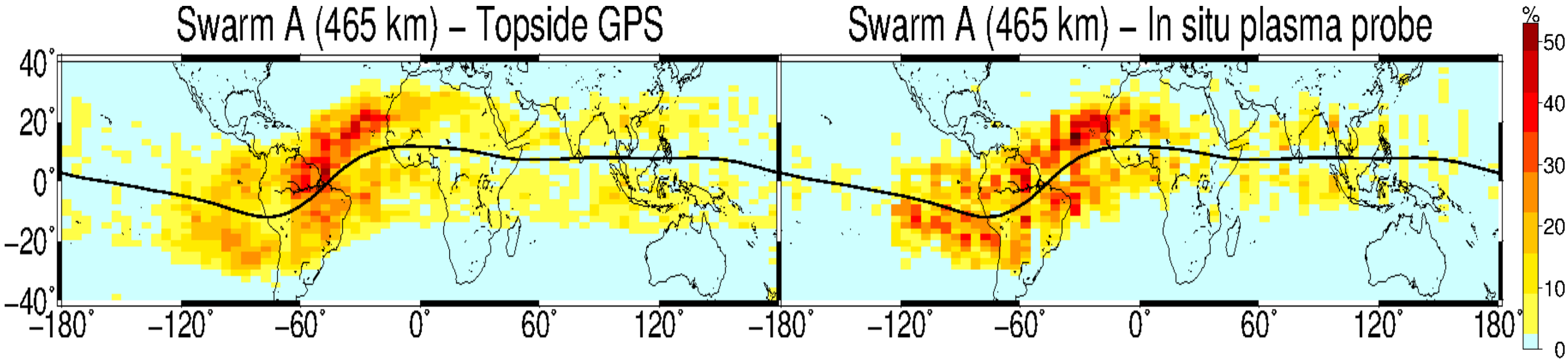


Zakharenkova et al., EPS, 2016

Swarm detection of EPBs: climatology

Quiet Time - March 2015

Occurrence probability of postsunset EPBs



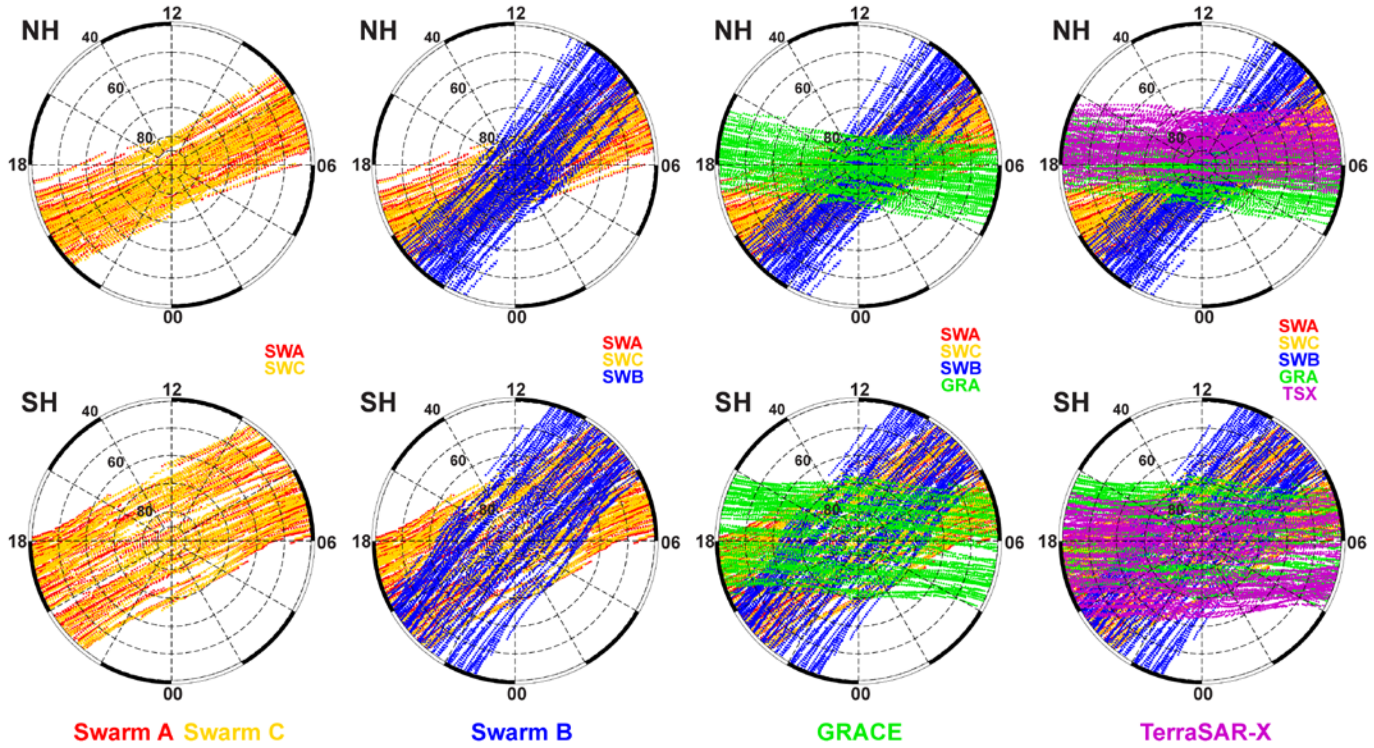
Zakharenkova et al., EPS, 2016

Case of 2015 St. Patrick's Day storm

Data coverage by 5 LEO satellites

Northern Hemisphere

Southern Hemisphere

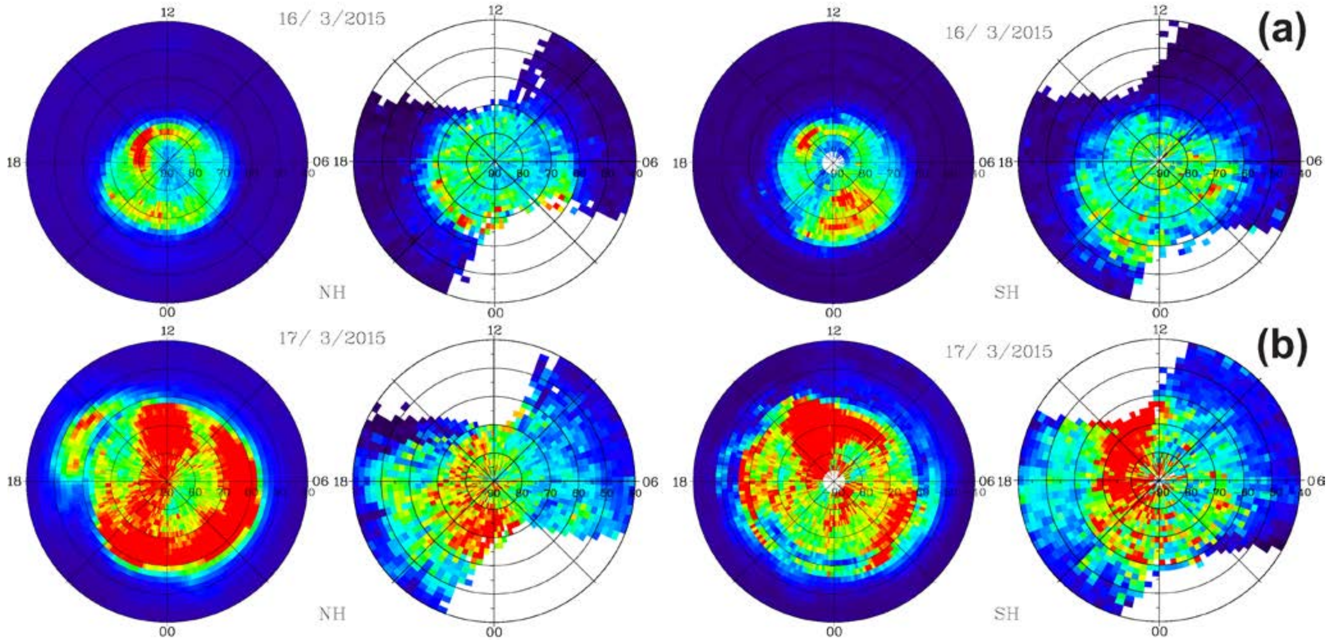


Cherniak & Zakharenkova, EPS, 2016

Ionospheric Irregularities: High Lats

Case of 2015 St. Patrick's Day storm

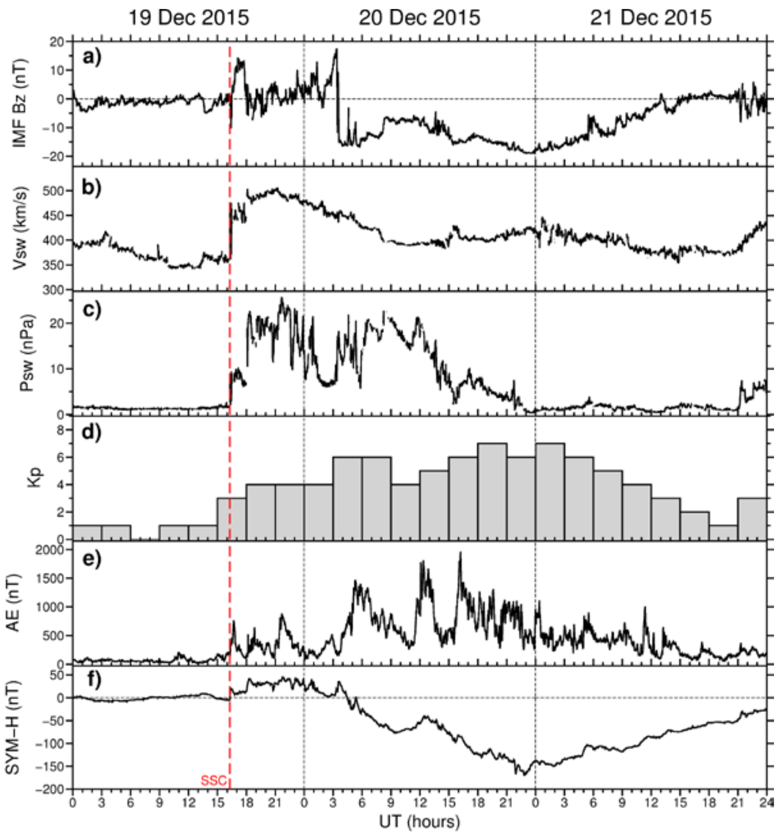
Ground GPS vs LEO GPS



Northern Hemisphere **Southern Hemisphere**

Cherniak & Zakharenkova, EPS, 2016

Case of 19-21 December 2015 storm



Swarm A and B

SWA ~18.7 / 6.7 LT (Orbit ~465 km)

SWB ~21.5 / 9.5 LT (Orbit ~515 km)

MetOP A and B

MTA/MTB ~21.5 / 9.5 LT

Sun-synch. dusk/dawn orbit

Orbit altitude ~835 km

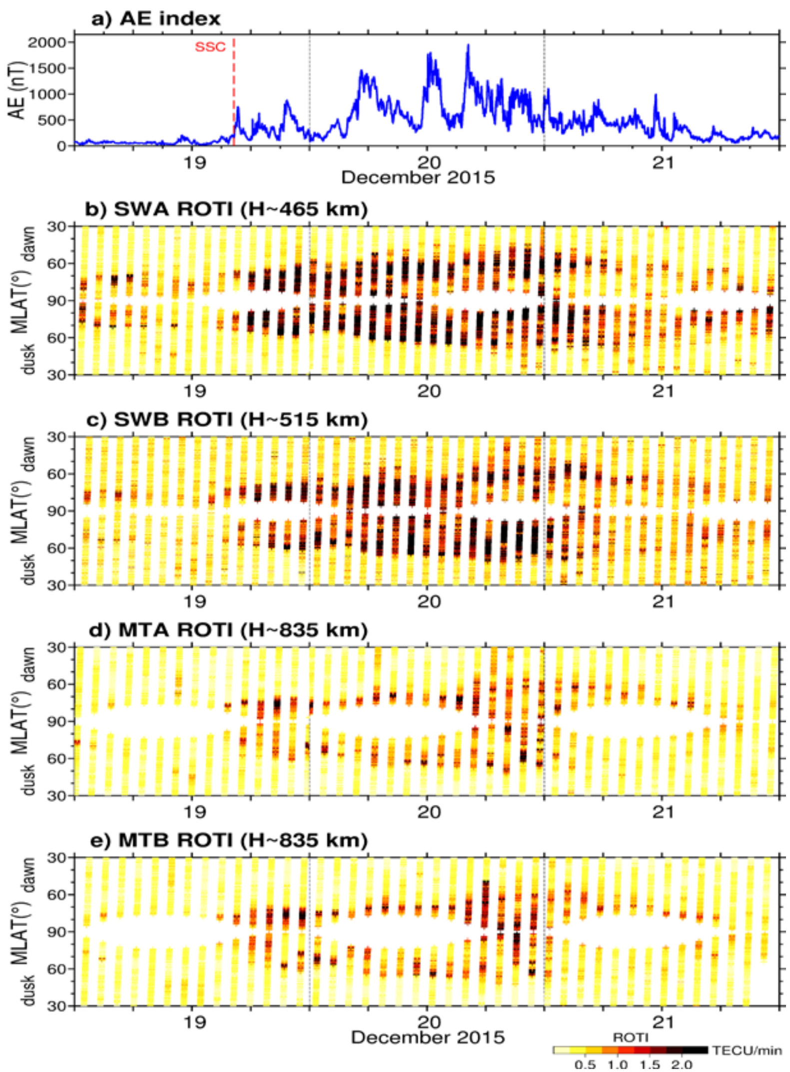
GRAS (Global Navigation Satellite System Receiver for Atmospheric Sounding) instrument

POD

8 channel GPS receiver

Time sampling 1 s

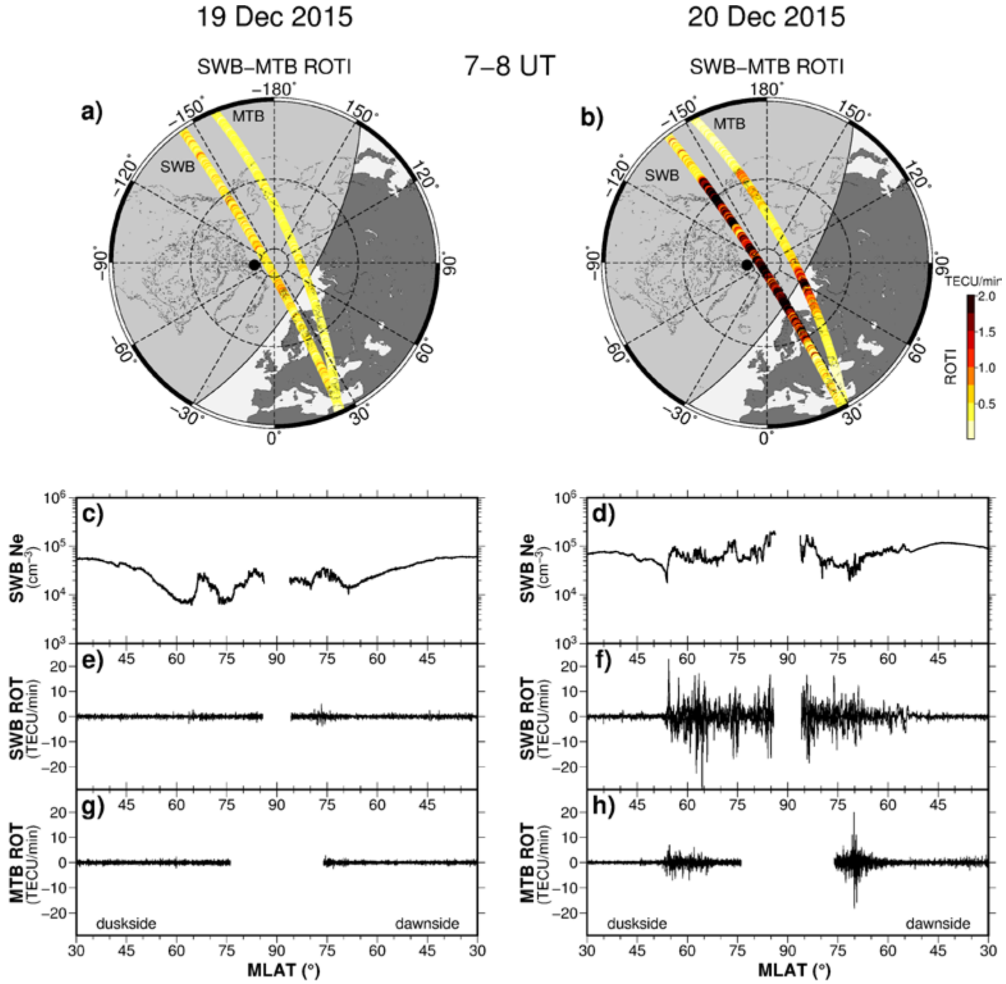
Case of 19-21 December 2015 storm



Satellite-based – **Swarm A/B** and **MetOP A/B** – ROTI values plotted as a function of geomagnetic latitude and UT time.

Continuity leaps (white areas close to 90° N) appear due to satellite pass displacement from the north geomagnetic pole.

Zakharenkova & Cherniak, Space Weather, 2018



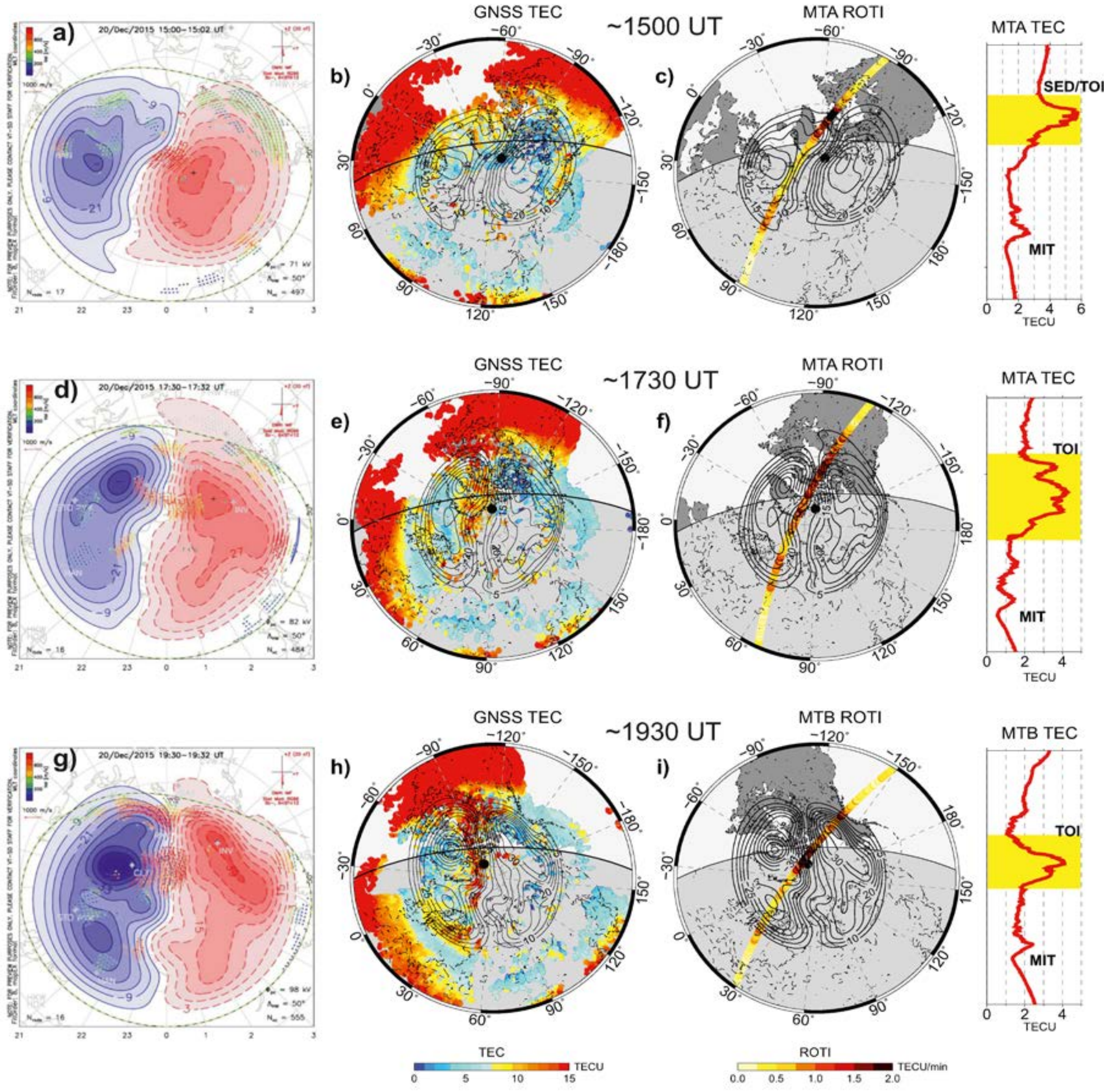
Swarm B Ne (LP)

Swarm B ROT (GPS)

MetOP B ROT (GPS)

Zakharenkova & Cherniak, Space Weather, 2018

Case of 19-21 December 2015 storm



SuperDARN convection maps

GNSS TEC maps

MetOP A/B ROTI values

MetOP A/B TEC values

Zakharenkova & Cherniak, Space Weather, 2018

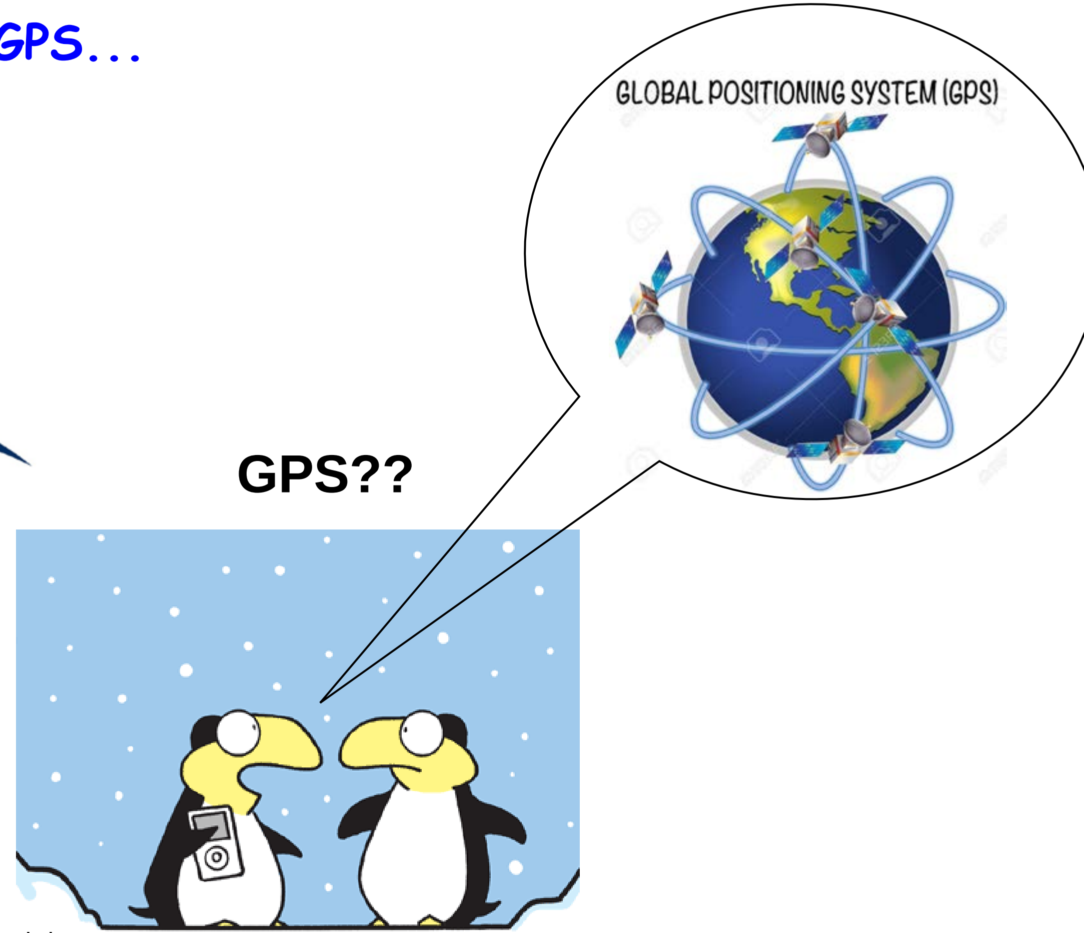
Summary

Space-based GPS POD observations from non-ionospheric missions represent a valuable data source for ionospheric and space weather community:

- Ionospheric/plasmaspheric climatology
- Ionospheric/TEC models evaluation and improvement
- Storm-induced topside plasma density enhancements and gradients
- Monitoring of plasma irregularities in the topside ionosphere

Everyone today is interested in GPS...

GPS
GLOBAL PENGUIN SOCIETY



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Acknowledgements:

- ESA for Swarm and GOCE data
- UCAR CDACC for MetOP and TerraSAR-X GPS data
- VirginiaTech for SuperDARN convection maps products
- Raw GPS/GNSS data were provided by IGS, UNAVCO, CORS, EUREF/EPN, CHAIN Canada, Natural Resources Canada, RBMC Brazil, RAMSAC Argentina, CORS Australia, GeoNet New Zealand, TrigNET ZA, German BKG, IGN France, SWEPOS, SATREF, FGI-FinnRef, Greece NOANET, UK OS-Net, GNSSnet.hu, LatPos, LitPOS, ESTPOS, Ukranian System.Net, Russian HEXAGON and EFT-CORS.