# Products and services provided by the ‘Space Weather Application Center – Ionosphere’ (SWACI)

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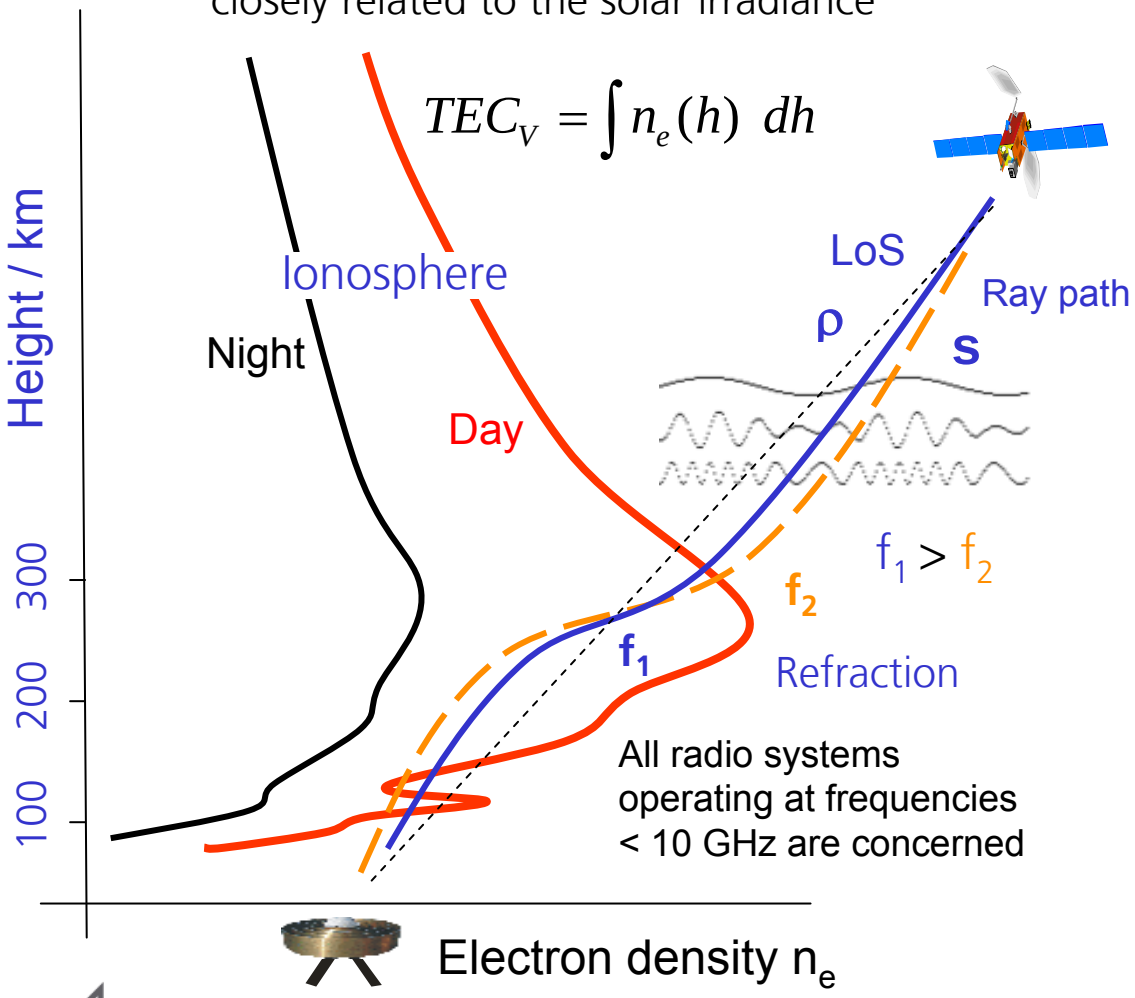
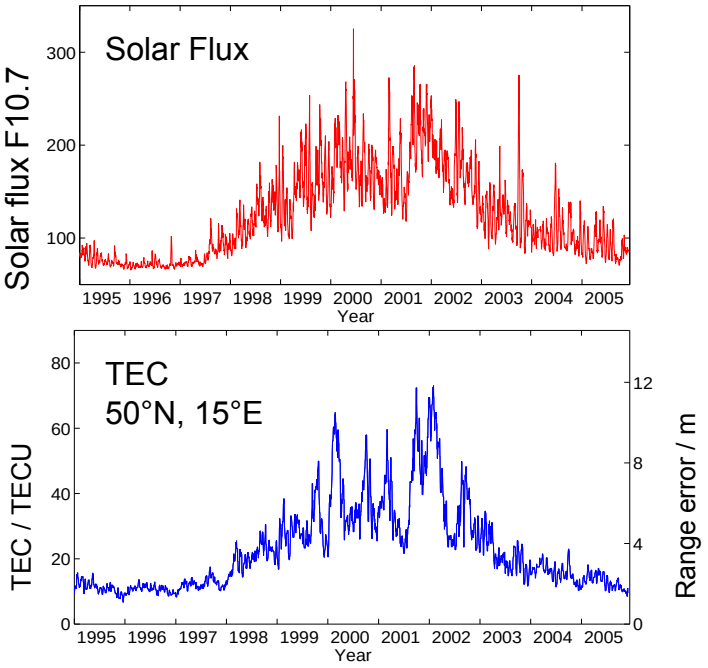
# Outline

- Introduction
- Ionospheric Monitoring
  - Ground based GNSS
  - Space based GNSS
  - Non-GNSS
- SWACI service and products
  - Web site
  - Outlook to new products
- Use of service products
- Summary

# Radio wave propagation in the ionosphere

Electron density $n_e$ & Total Electron Content (TEC) are closely related to the solar irradiance



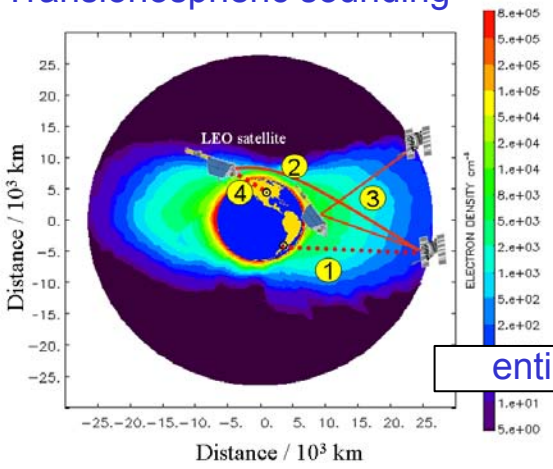




## Ionosphere causes

- Regular effects simply due to the presence of plasma
  - signal delay, bending
  - rotation of polarisation plane
- Irregular effects due to plasma distortions, turbulences
  - perturbed carrier phases
  - radio scintillations

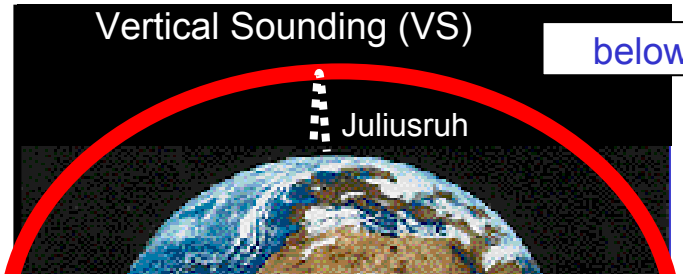
# Ionosphere sounding techniques used in SWACI

Transionospheric sounding

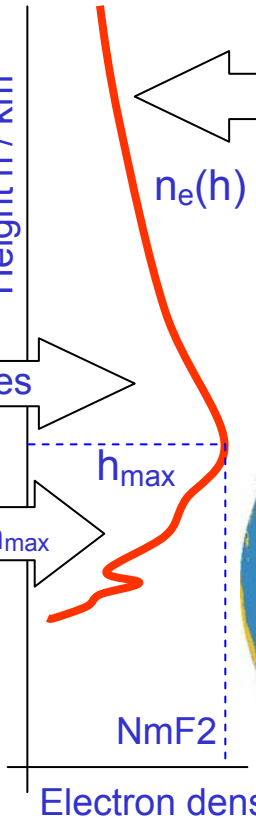



entire profiles

Vertical Sounding (VS)



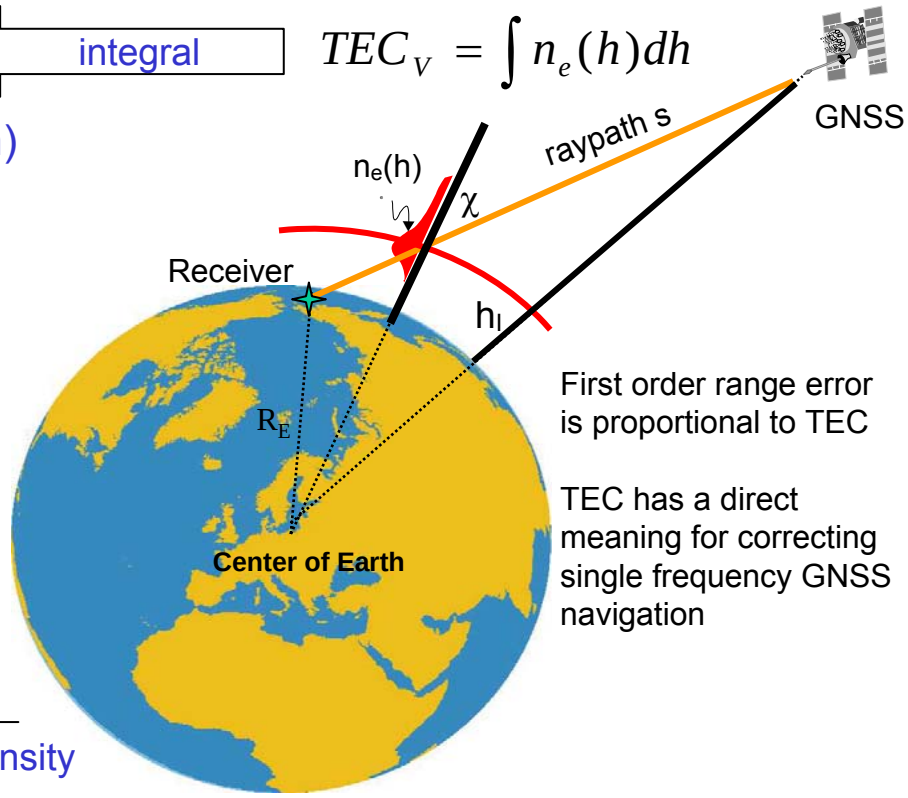

below $h_{max}$




Total Electron Content

integral

$$TEC_V = \int n_e(h)\,dh$$



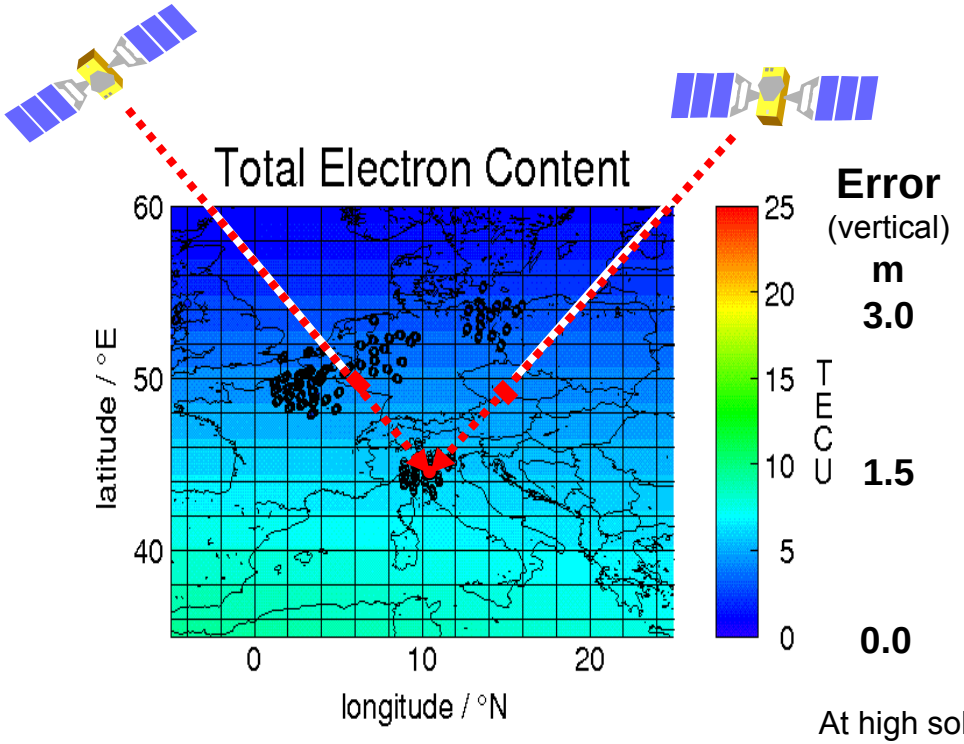

First order range error is proportional to TEC

TEC has a direct meaning for correcting single frequency GNSS navigation

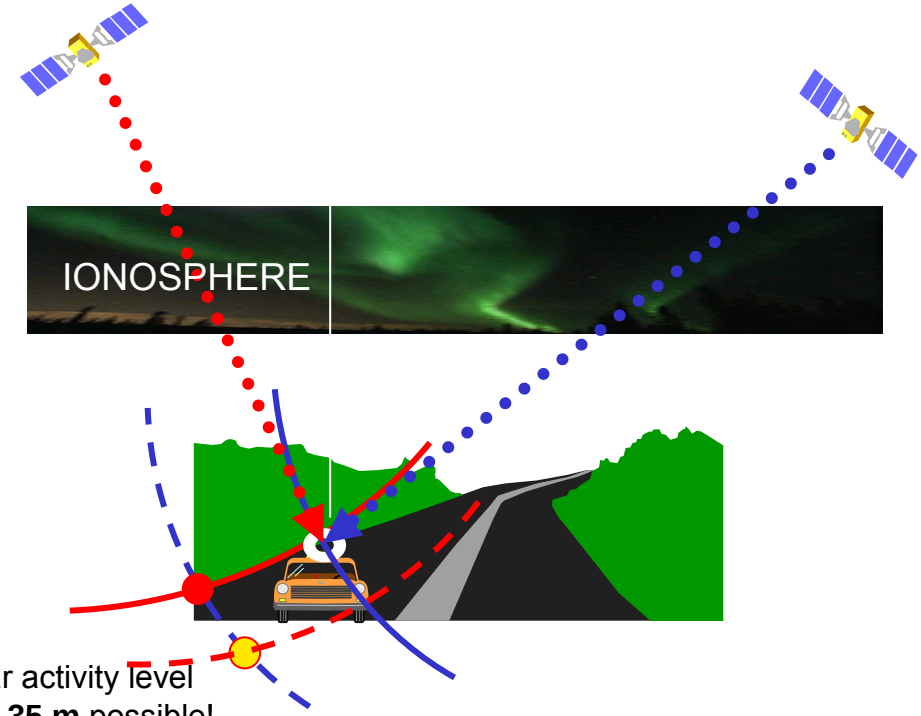
1 GNSS ground
2 Radio occultation
3 Topside TEC
4 Beacon satellite

- Ionospheric information provided by SWACI is mainly obtained by ground and space based GNSS measurements
- Coordination with other measurement techniques
  - Vertical sounding (Juliusruh, inclusion of more ionosondes planned)
  - Beacon satellite measurements (Neustrelitz, Neuwachtberg)

# TEC – monitoring - Navigation errors




Sample:16 GPS stations Time: 01:04:00 UT




At high solar activity level errors up to **35 m** possible!

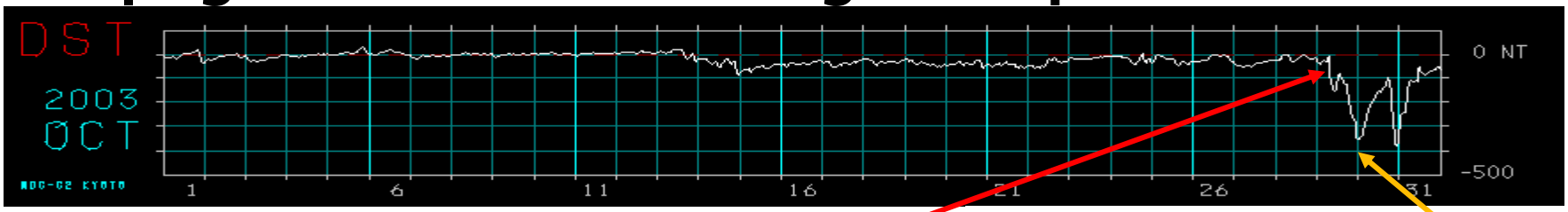
$$d_I^{(1)} = \frac{K}{f^2}\int n_e ds = \frac{K}{f^2}\cdot TEC$$

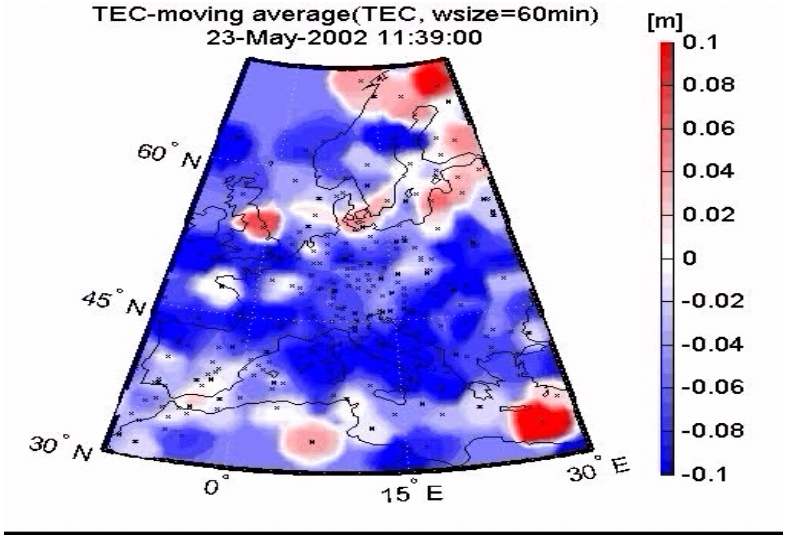
Ionospheric first order range errror $d_I$ is proportional to TEC

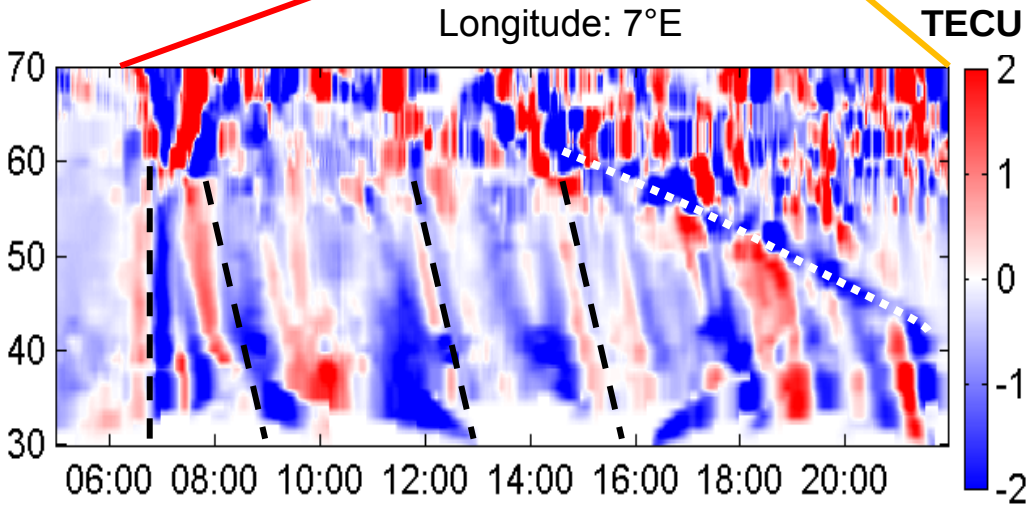
- GNSS*-Data obtained from geodetic networks for TEC Monitoring in streaming mode (IGS, EUREF)
- Empirical modelling of the ionosphere (in DLR: Europe, polar regions, global)
- Near real time monitoring possible

*GNSS- Global Navigation Satellite System

# Propagation of TIDs during ionospheric storms



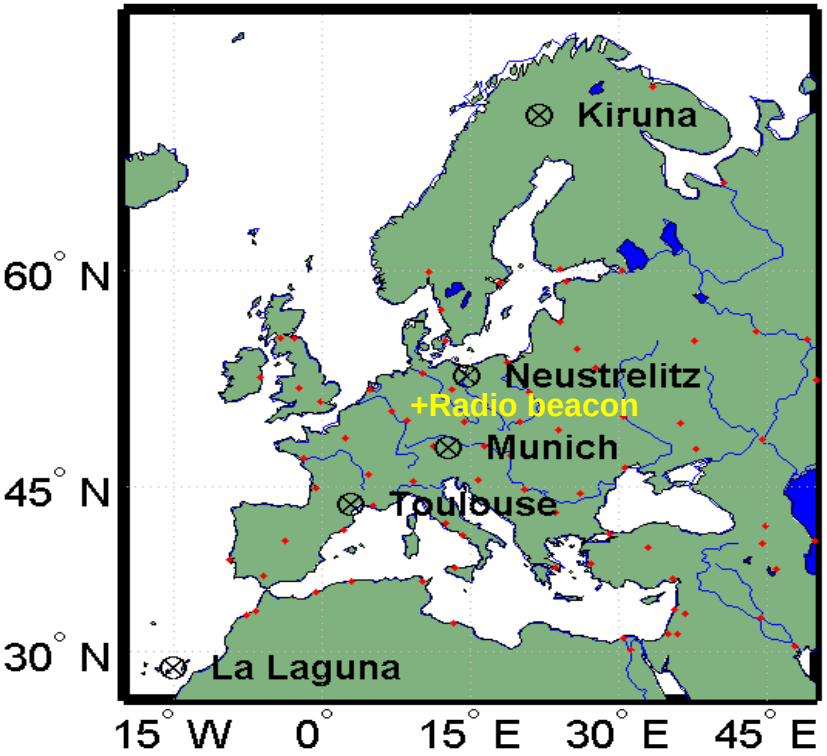



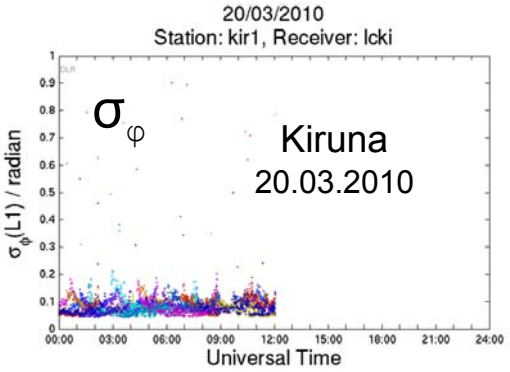



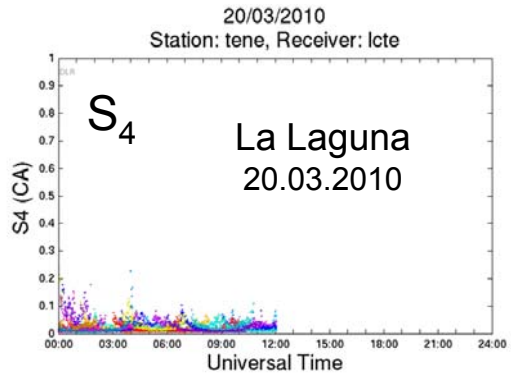

- Immediate propagation of the perturbation at the onset (electric field)
- Wavelike propagation of disturbances during the main phase of the storm on 29 October 2003 (speed ≈ 400 m/s)
- High latitude disturbance zone (northward of the trough) moves also equatorward (speed ≈ 50 m/s)

Borries et al., Ann. Geophys., 27, 1605-1612, 2009

# GPS scintillation monitoring network of DLR



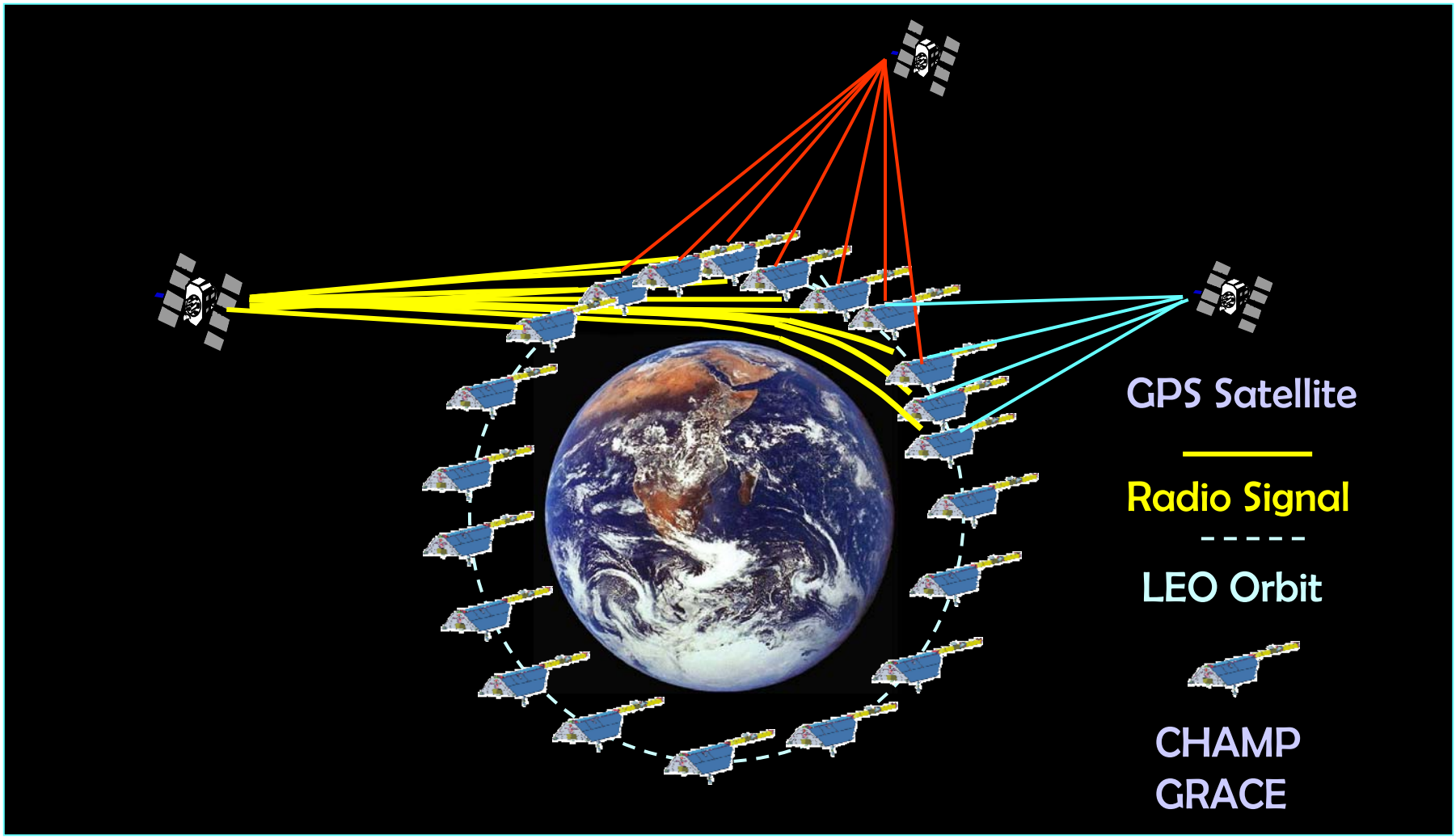

Update: 1 min

Remote access to all stations of the network (EVNet)

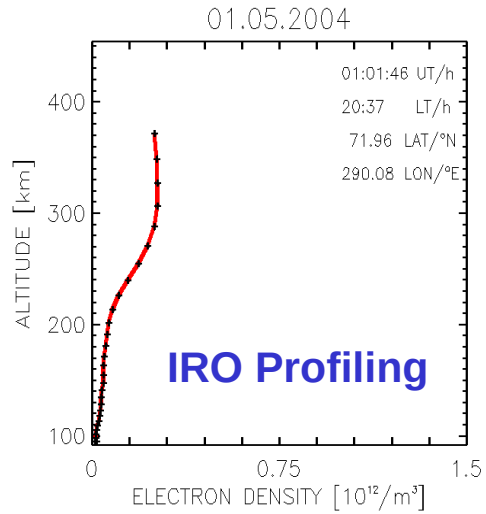
Data reduction on observation site by computing scintillation parameters

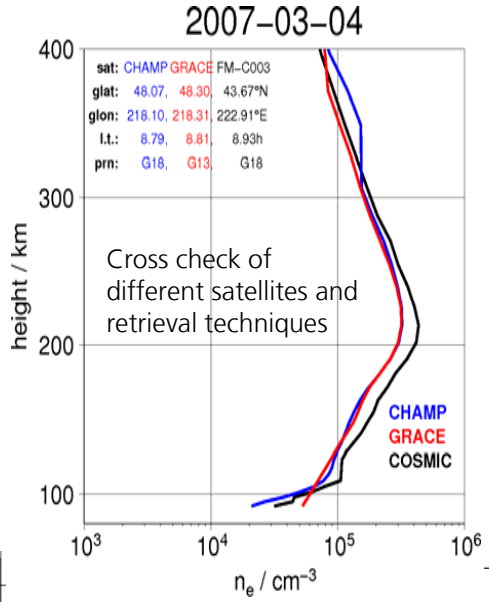
- DLR operates a network of high rate dual frequency GPS receivers (20-50 Hz) for scintillation monitoring
- Network provides actual scintillation data for further distribution via SWACI
- Extension of the network is planned towards North and South, the network includes capabilities to receive Galileo signals

# GPS sounding of the Ionosphere onboard LEO satellites

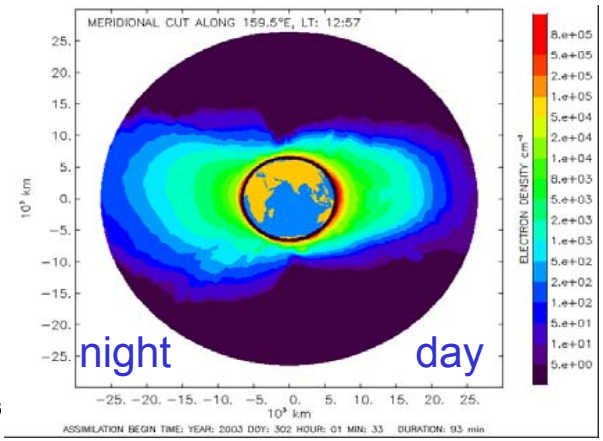


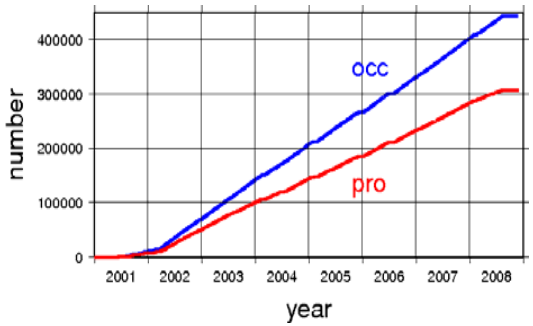
# Space based monitoring onboard CHAMP/GRACE



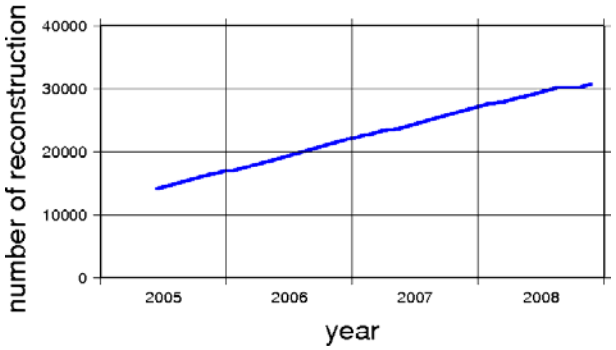




Topside reconstructions
28 / 29 October 2003




Data access via
http://swaciweb.dlr.de



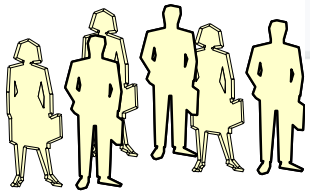

- Automatic retrieval of electron density profiles ( > 70% successfully)
- More than 300,000 profiles on global scale retrieved so far
- 15-16 3D reconstructions/day
- More than 30,000 reconstructions so far

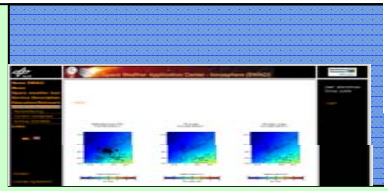
Jakowski et al. (2007), Space Weather, 5, S08006, doi:10.1029/2006SW000271.

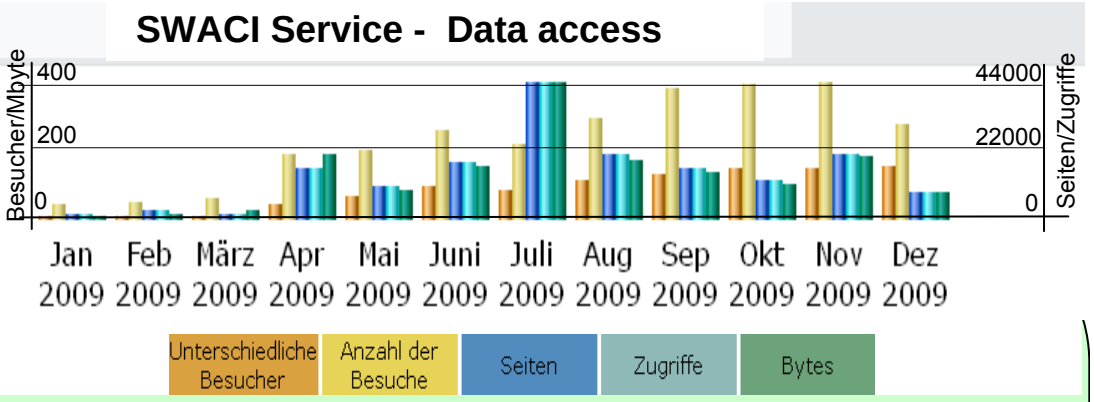
# The SWACI Project

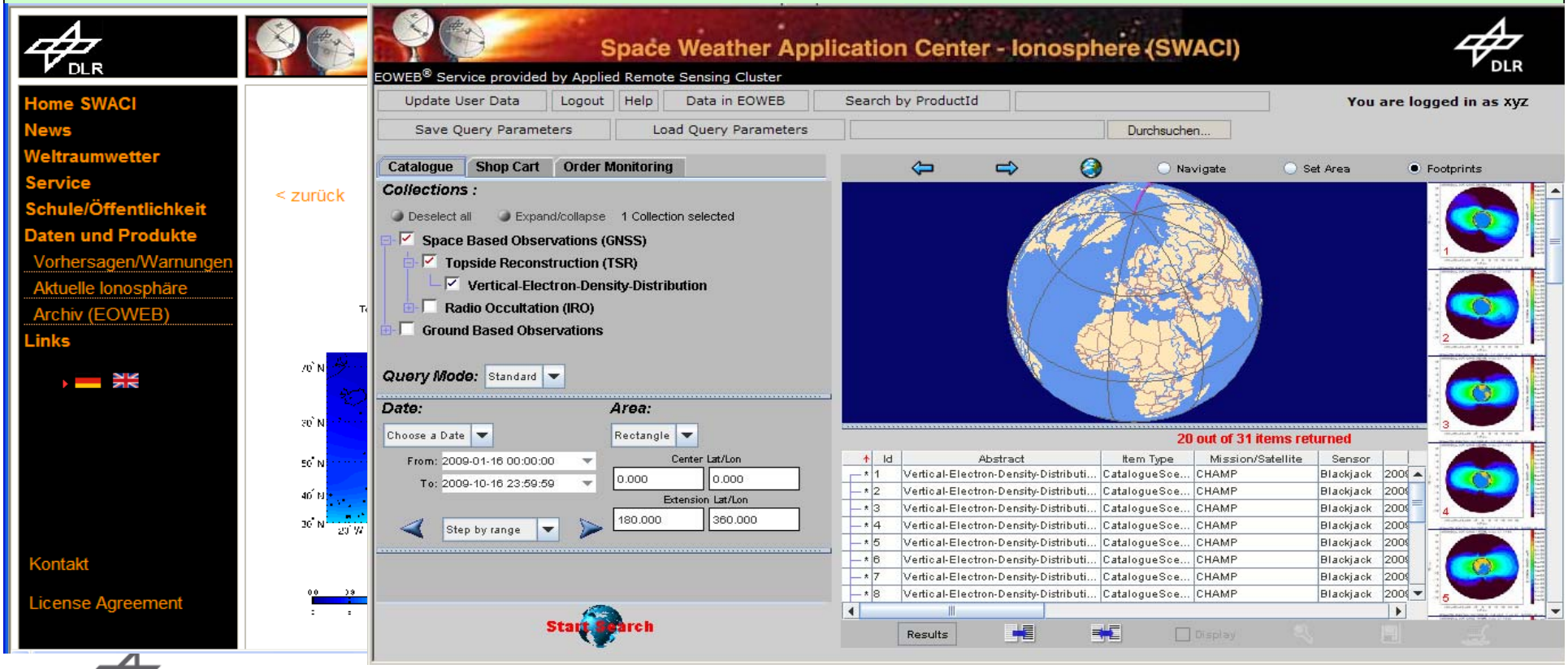
- The 'Space Weather Application Center – Ionosphere' (SWACI) is a joint project of two DLR institutes - the Institute of Communications and Navigation and the German Remote Data Center.
- SWACI services will be focused primarily on ionospheric issues. The project is a successor of the ESA project SWIPPA; it is now essentially supported by the German State Government of Mecklenburg-Vorpommern (North-Eastern part of Germany).
- Ionospheric data are collected, quality checked, calibrated, adjusted, analyzed, fed into models for generating higher-level data products and finally distributed as fast as possible.
- The aim is to provide ready and easy accessible data products. SWACI based service is planned to be ready by the end of 2010.

http://swaciweb.dlr.de



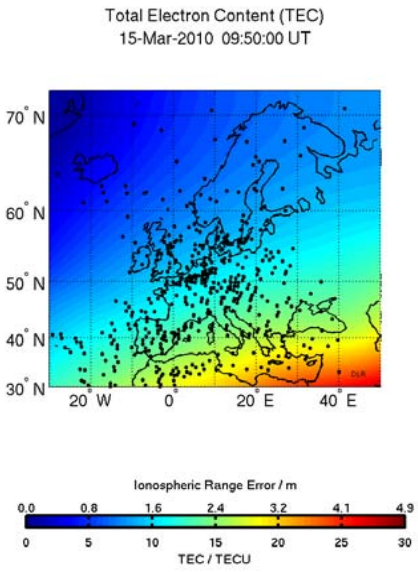




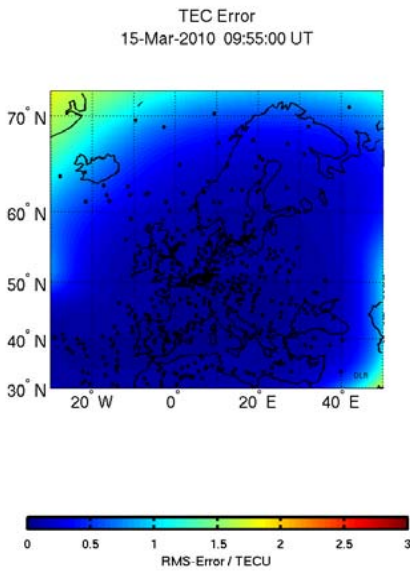



# SWACI- products – ground based measurements

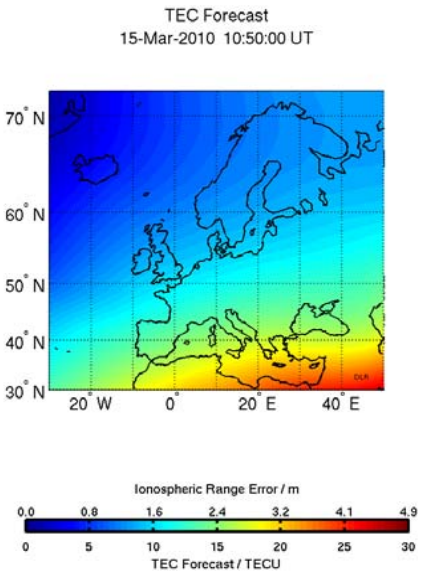
**TEC map**



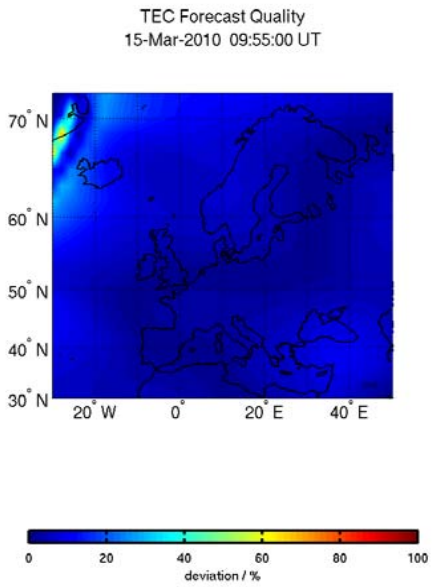

**TEC error**




**1hr TEC Forecast**

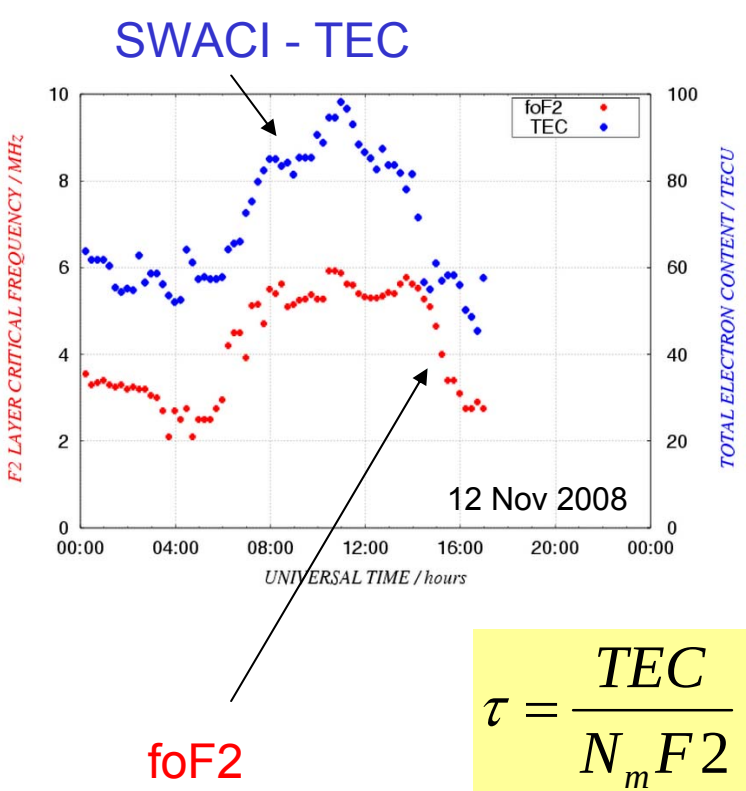



**Quality of forecast**




- GPS data (1s) from geodetic networks such as IGS and EUREF obtained by BKG Frankfurt in streaming mode (NTRIP technology)
- Processing and calibration of GNSS measurements
- Generation of TEC maps and derivatives
- NRT data (5min update rate)

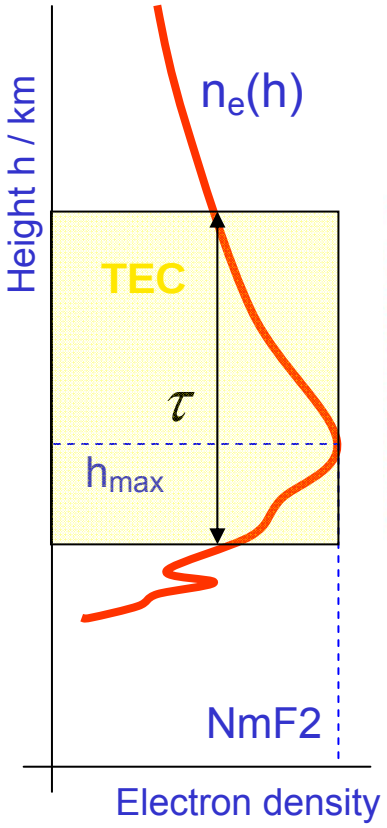
# Equivalent Slab Thickness provided by SWACI

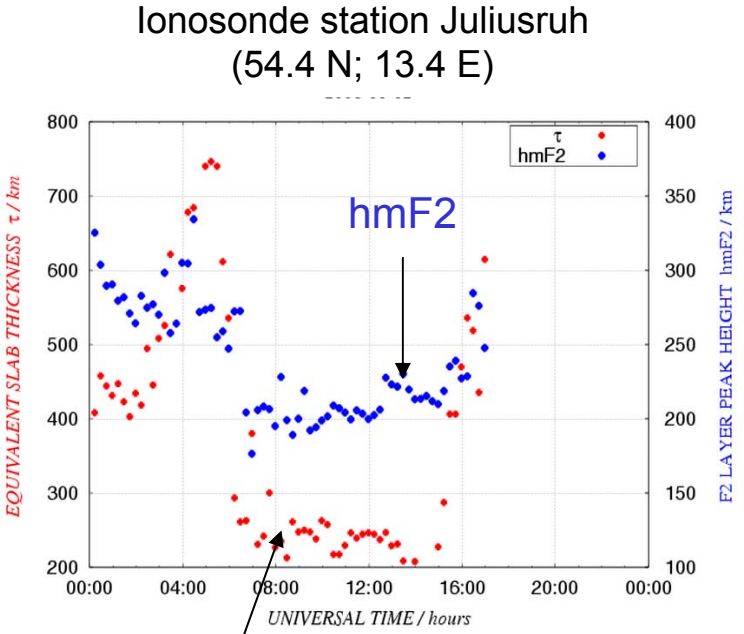



foF2

$$N_m F2 \sim foF2^2$$

$$\tau = \frac{TEC}{N_m F2}$$

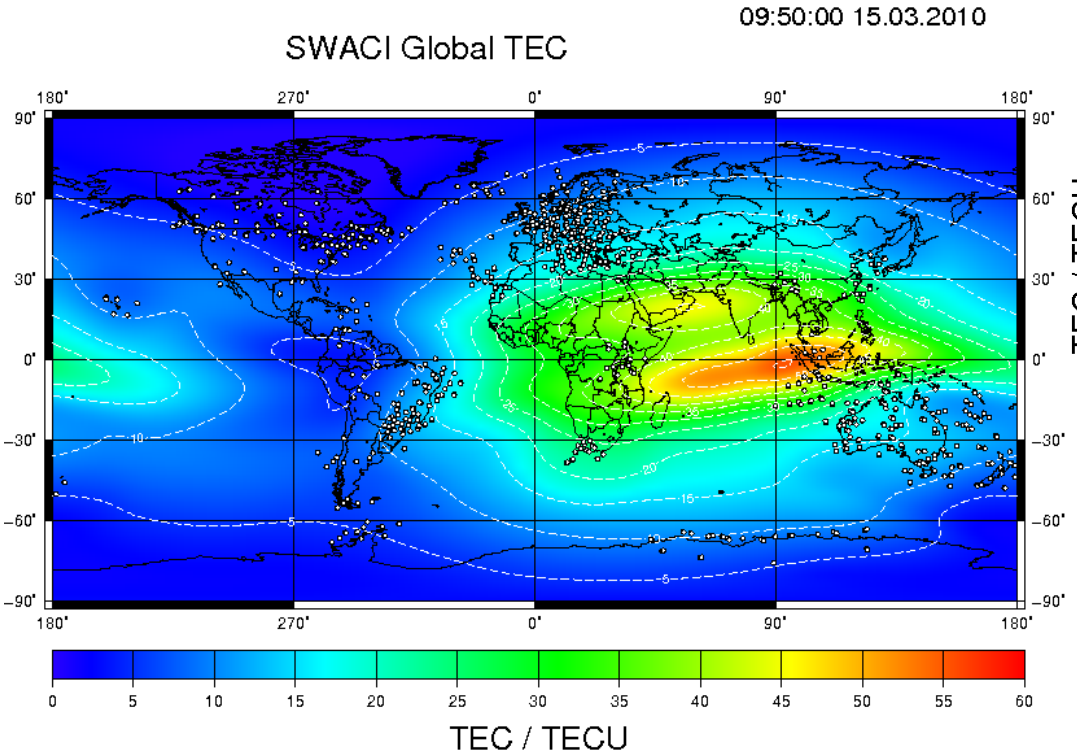


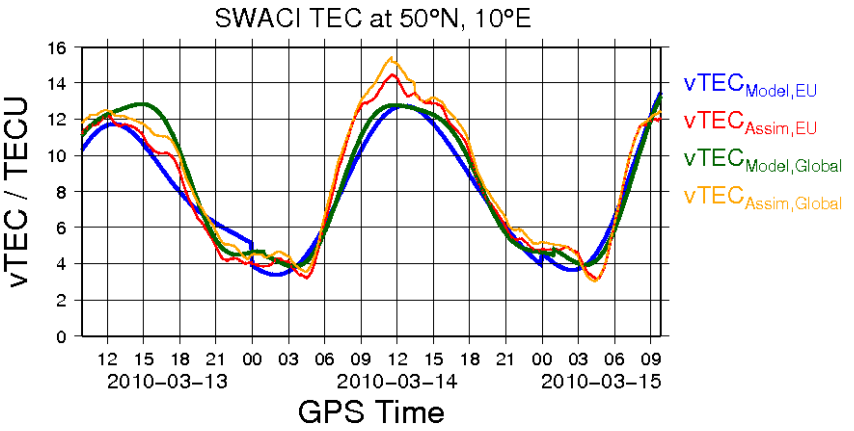




Slab thick thickness $\tau$

- Slab thickness computation in NRT using SWACI-TEC over Juliusruh and corresponding ionosonde data of the IAP Kuehlungsborn (update rate: 15 min)

# New products - Global TEC maps

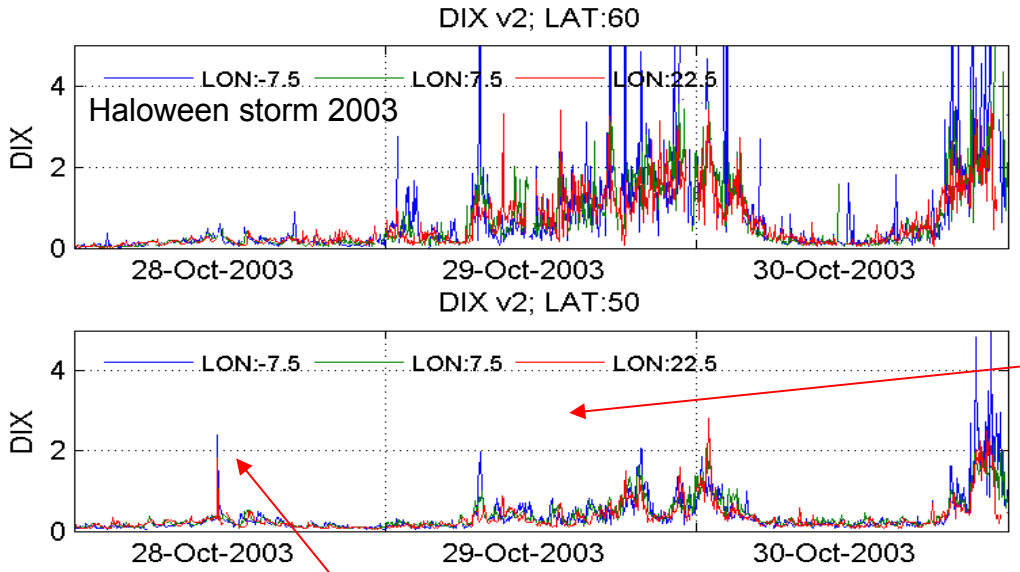


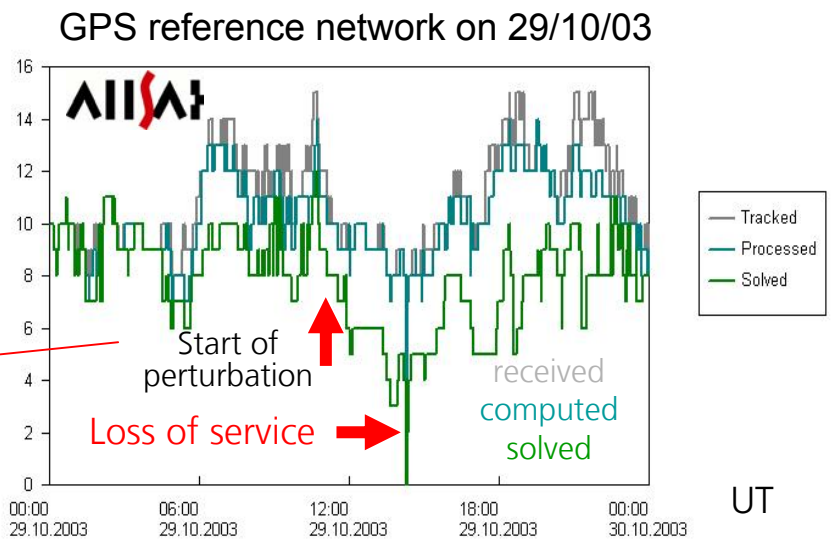



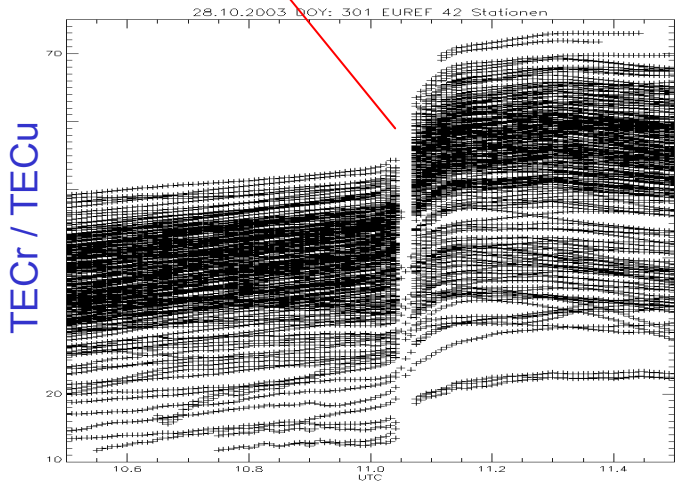

Comparison of regional model and mapping results with global model and mapping results shows good agreement

- The near real time reconstruction of global TEC maps is mainly based on IGS data provided within the IGS Real-Time Pilot Project 2007-2010.
- The maps are updated every 5 minutes and therefore fulfil requirements of single frequency users.
- It is planned to release global TEC maps via SWACI in May 2010.

# New products - Disturbance Ionosphere Index

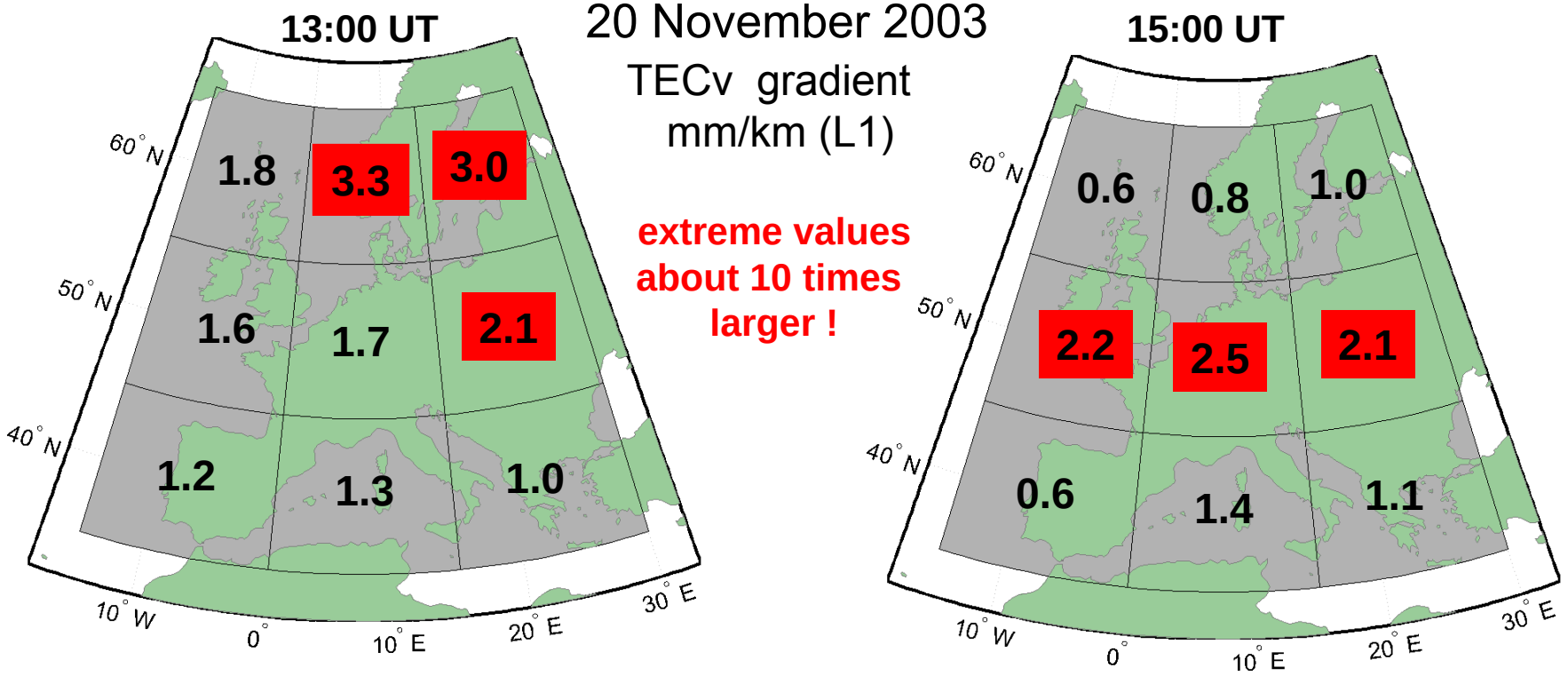



- The Disturbance Ionosphere Index (DIX) is based on GNSS measurements. The index may be defined on local, regional and global scale depending on user needs.
- An experimental DIX version was computed for the Halloween storm at 9 European longitude / latitude sectors.
- The plot indicates the flare on 28 October and strong spatial effects on subsequent days
- It is planned to release regional DIX products via SWACI in June 2010

# Choosing the latitudinal TEC gradient as Ionospheric Perturbation Index




- Regional ionospheric perturbation index provides quantitative measure of perturbation degree over Europe, e.g. for GNSS applications
- New product definition in close dialogue with the users

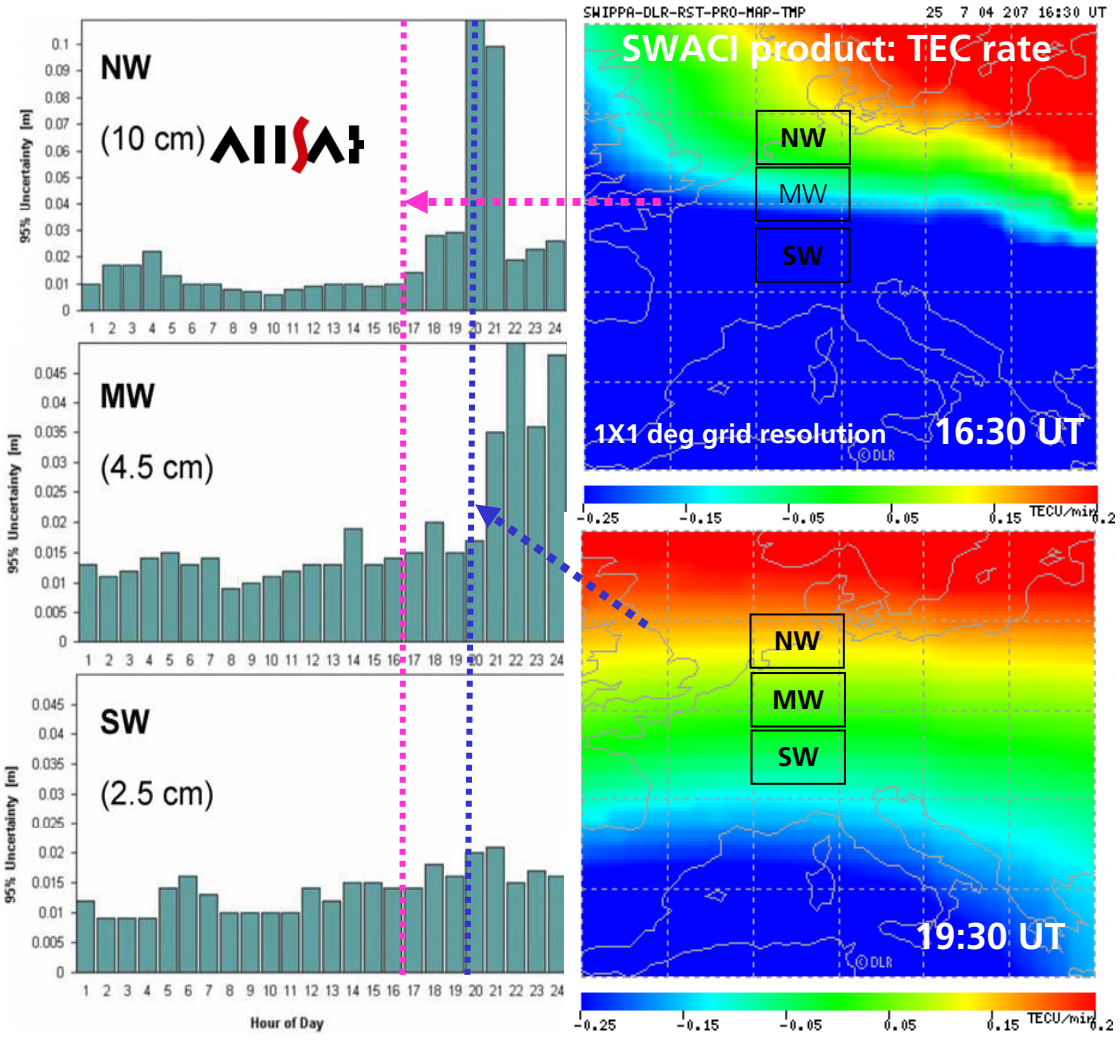
Jakowski et al., Adv. Space Res., doi: 10.1016/j.asr.2005.07.043, 2005

# Performance degradation of the GPS reference network of ascos on 25 July 2004 – impact on accuracy

Performance of the GPS reference network of Allsat GmbH, Hannover degrades during the ionospheric storm on 25 July 2004

Different effects in different network areas over Germany

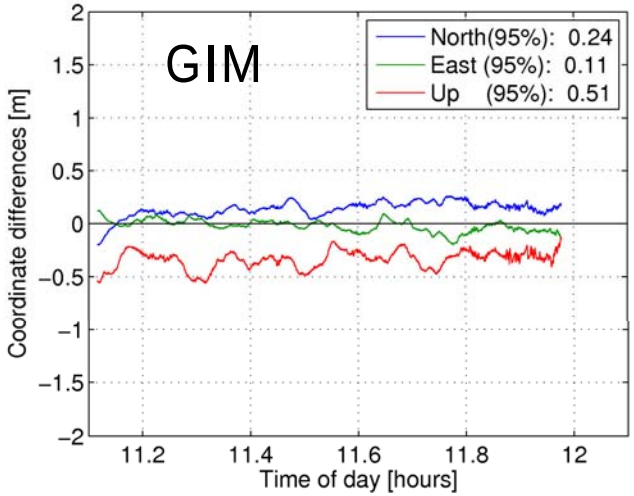
- Propagation of ionospheric perturbation from high to mid-latitudes
- Provision of ionospheric now- and forecast information valuable for users

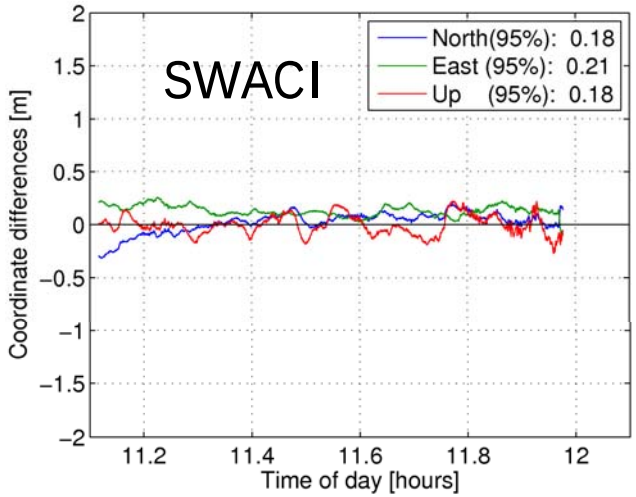


# RTK Positioning
## TU Delft Flight Experiment in Mai 2005


SWACI

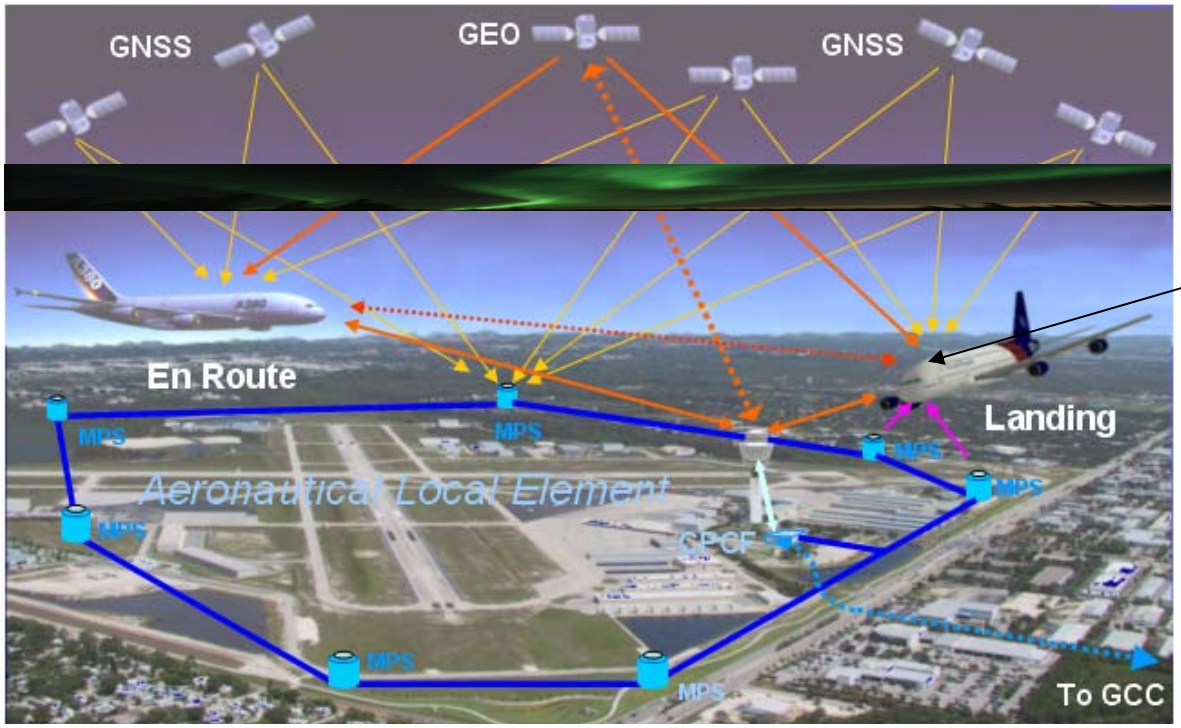
- **Regional coverage**
- **High spatial and temporal resolution**
- **Real-time Positioning experiment:**
  - rather good in flight trial for vertical solution
  - can be improved by covering a larger region

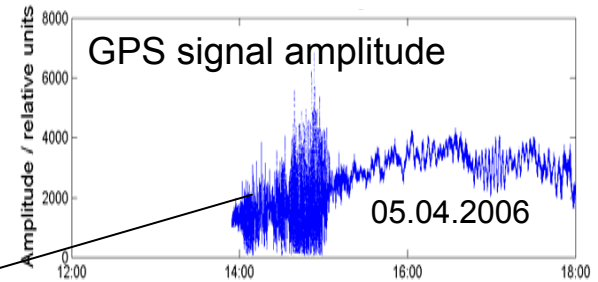


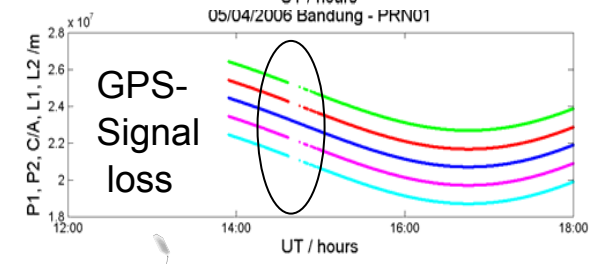



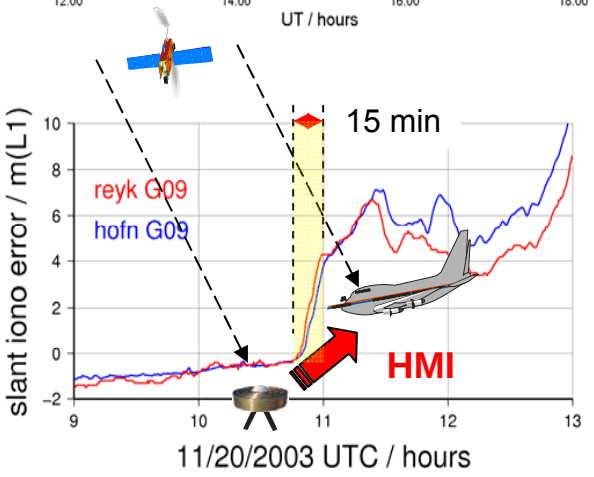

A.Q. Le et al. (2009), Internat. Assoc. of Geodesy Symposia, 133, 759-769, doi 10.1007/978-3-540-85426-5_87

# Safety of Life (SoL) application - aviation




- NAV: Degradation of **accuracy, integrity, availability and continuity** of GNSS signals
- COM: **HF Communication** disturbed or interrupted

Operational **detection** and **modelling** of ionospheric **perturbations** needed

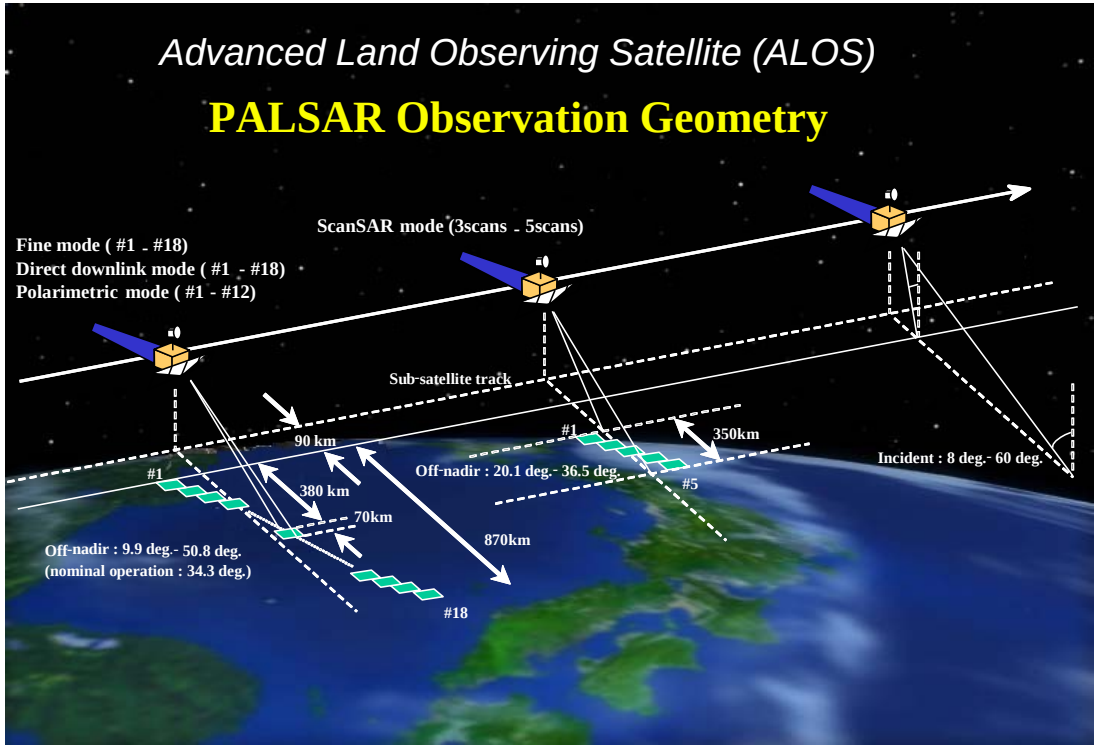
Ionospheric "**Threat-Model**" required

HMI: Hazardous Misleading Information

Mayer et al., ION, 2009

# Remote sensing - Radar measurements

The ionospheric plasma impacts the phase and polarisation angle of trans-ionospheric radio waves in C-, L- und P- bands, i.e. numerous radar systems



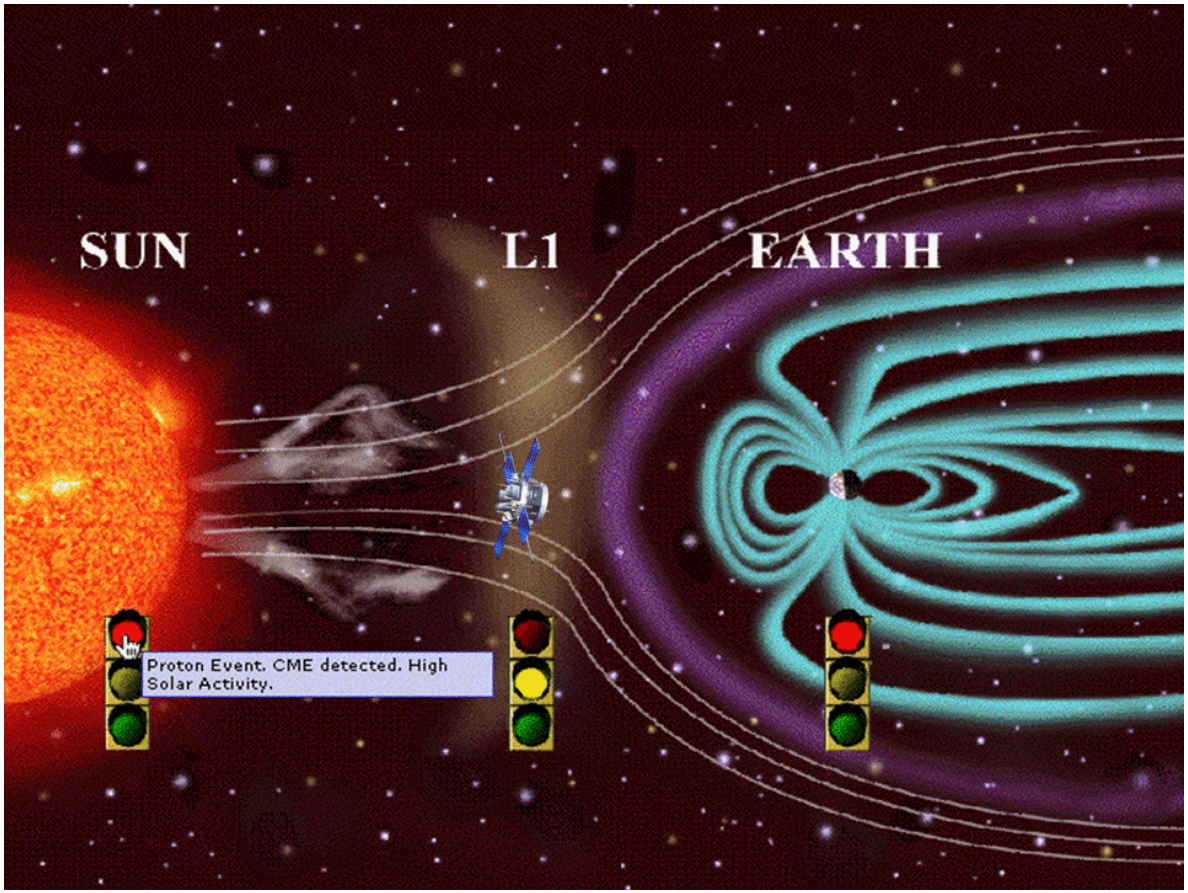

| Band | f (GHz) | $\Omega_F$ [°] (100 TECU) |
|---|---|---|
| C | 5.0 | 2 |
| L | 1.2 | 25 |
| P | 0.4 | 200 |

Development of methods and algorithms for correction and mitigation of ionospheric propagation errors needed

- Plasma turbulences cause defocussing effects in particular in L- and P- band radars
- Planned ESA Biomass Explorer will use P-band radar, strong onospheric impact on polarisation expected

PALSAR: Phased Array L-band Synthetic Aperture Radar at ALOS satellite

# Future products - forecasts of TEC and related parameters




ACE is positioned at the L1 libration point between Sun and Earth (1.5 Mill. km distance from Earth) and measures essential components of the solar wind such as density and speed.

- DLR Neustrelitz is part of the Real Time Solar Wind (RTSW) network of NOAA since 2 September 2009.
- Realtime ACE- data provide a unique opportunity to improve forecasts of ionospheric perturbations essentially.
- Because this task is a long-term one and only solvable via international cooperation, it is considered in an EC - FP7 proposal.

# Summary

- **The „Space Weather Application Center – Ionosphere“ (SWACI) at DLR Neustrelitz provides ionospheric information and data on a routine basis**
  - Ground based TEC and derivatives over Europe (5 min update)
  - TEC forecast and quality control (1 hour in advance)
  - Space based GPS (Radio occultation, topside reconstructions, latency according passes)
  - Beacon measurements (within a few minutes after passes)
  - Equvalent slab thickness (15 min update)
  - Scintillation data over Europe (1 min update)
- **The release of global TEC maps and and Disturbance Ionosphere Index (DIX) is planned to be released next time.**
- **Development of tools for forecasting the perturbed ionosphere is considered as a long term task solvable only via international cooperation.**

# Thank you for your attention !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