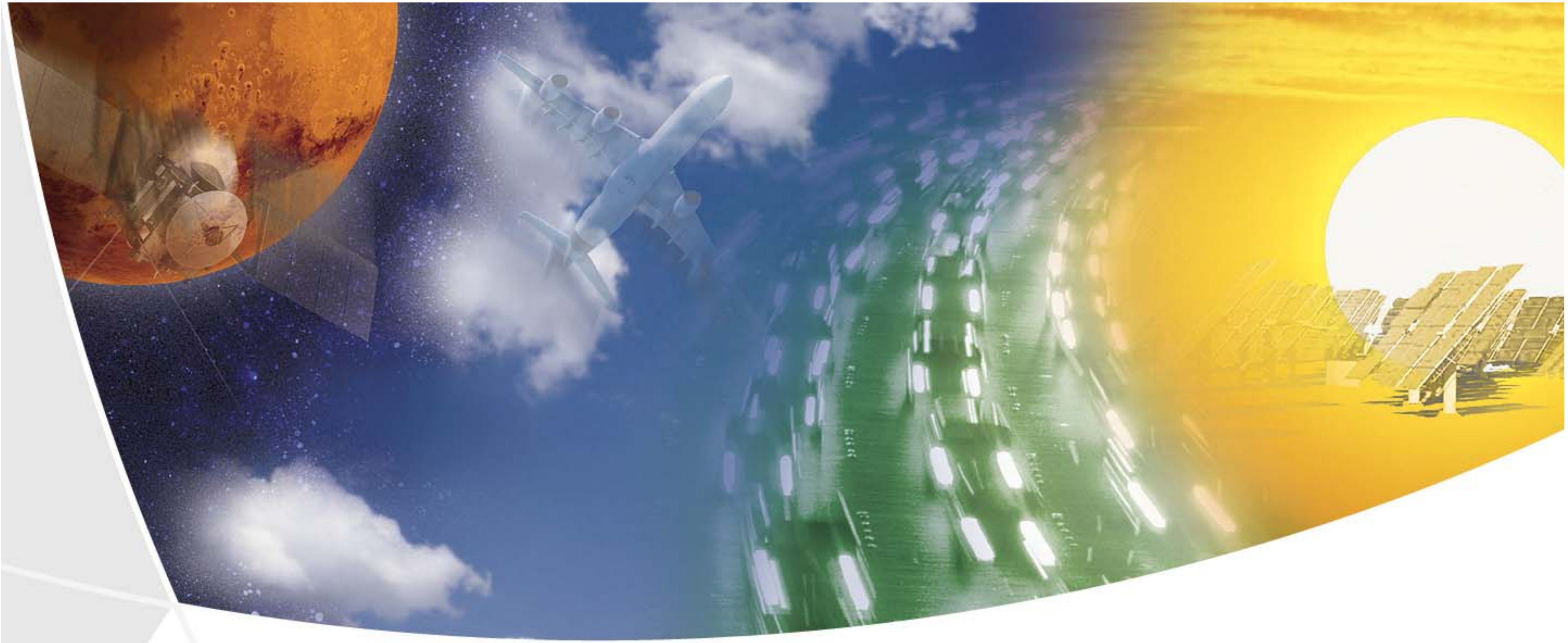

Space weather Application Center – Ionosphere
A Near-Real-Time Service Based on NTRIP Technology

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Institute of Communications and Navigation, Neustrelitz, Germany

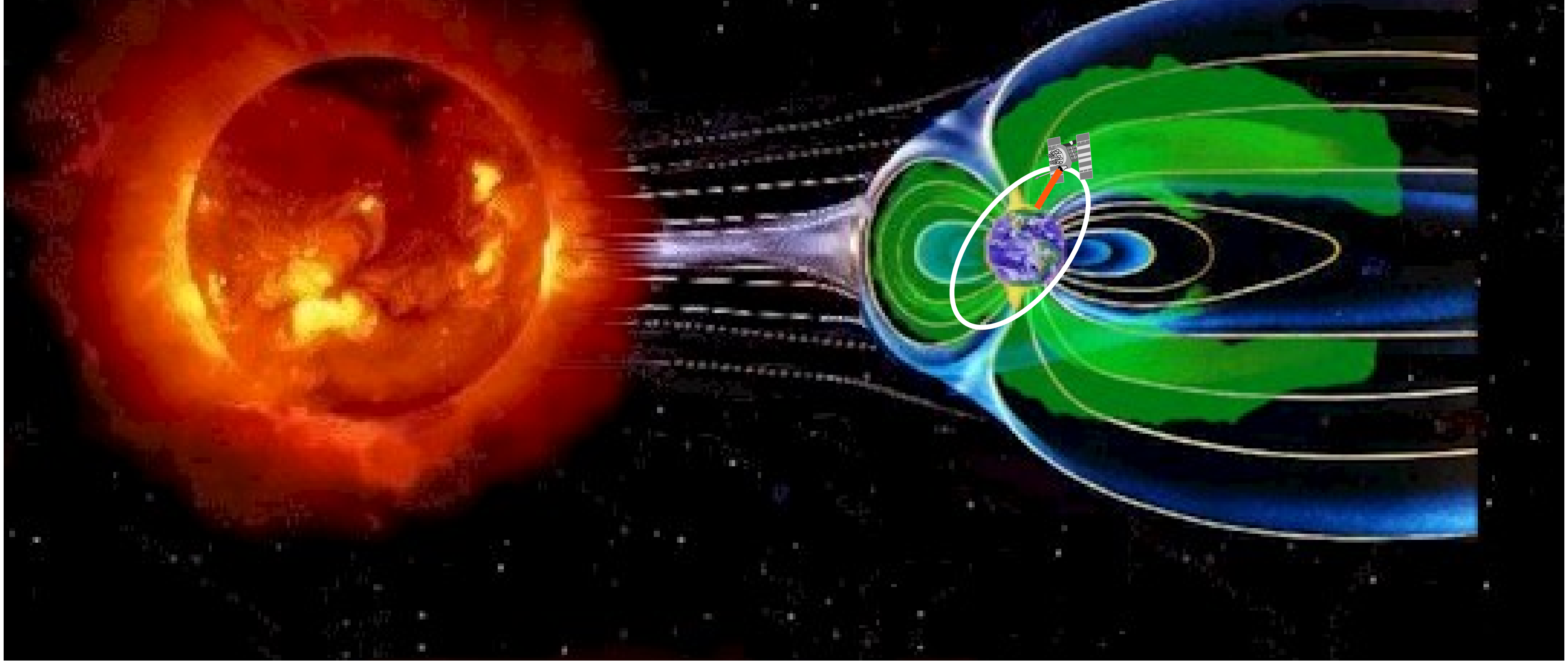
Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Outline

- Introduction
- The SWACI service
- Ionospheric impact on GNSS
- Ionospheric Perturbation Index
- A new ionospheric product distributed via NTRIP?
- Conclusions

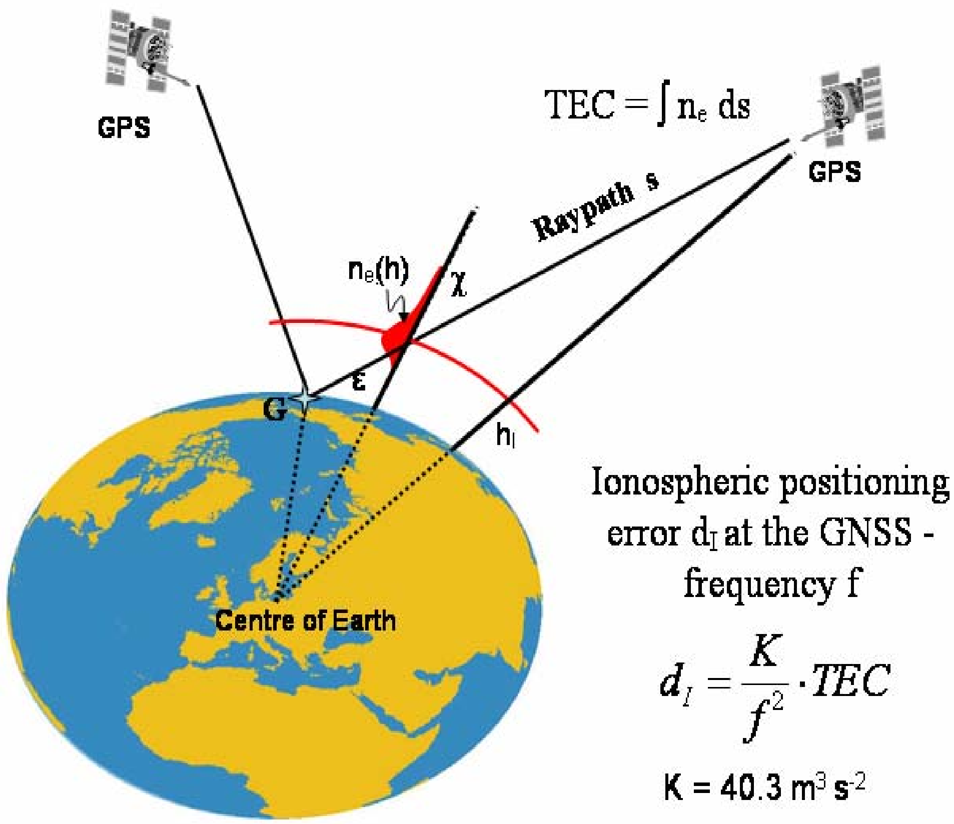
Space Weather

- **Space weather refers to the conditions on the sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health. (Definition NSWP, USA, 1996)**



Ionospheric impact on GNSS signals and ionospheric sounding capabilities

- The refractive index of the ionospheric plasma for radio waves is dispersive, i.e. frequency dependent (~1 / f^2)
- Computing the differential phases at the two measured GPS frequencies L_1 and L_2 the Total Electron Content (TEC) can be determined.
- Measuring at L_1/L_2 GPS frequencies, the first order range error can be mitigated in positioning (ionosphere-free linear combination of phases)



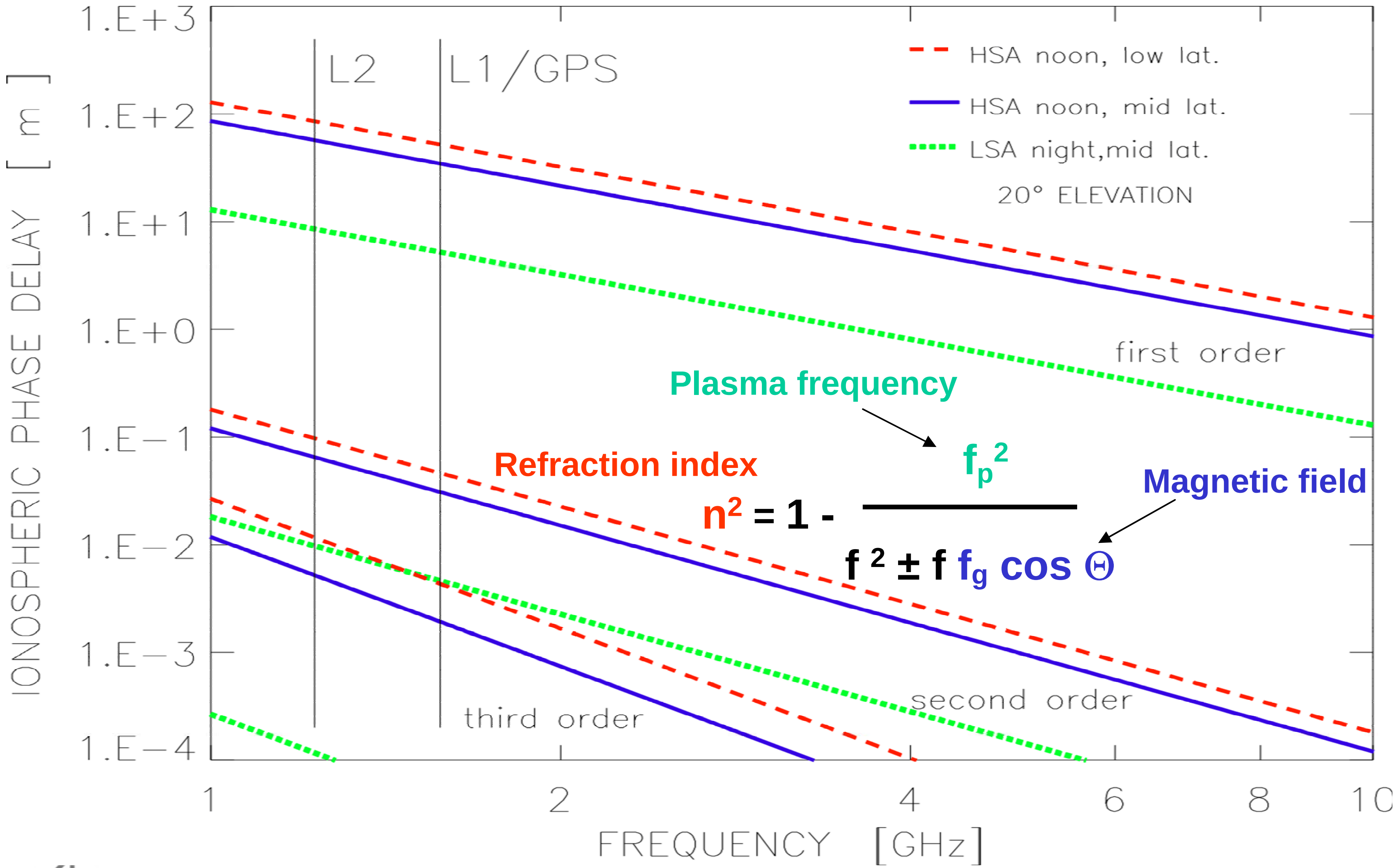
$$TEC = \int n_e \, ds$$

Ionospheric positioning error d_I at the GNSS - frequency f

$$d_I = \frac{K}{f^2} \cdot TEC$$

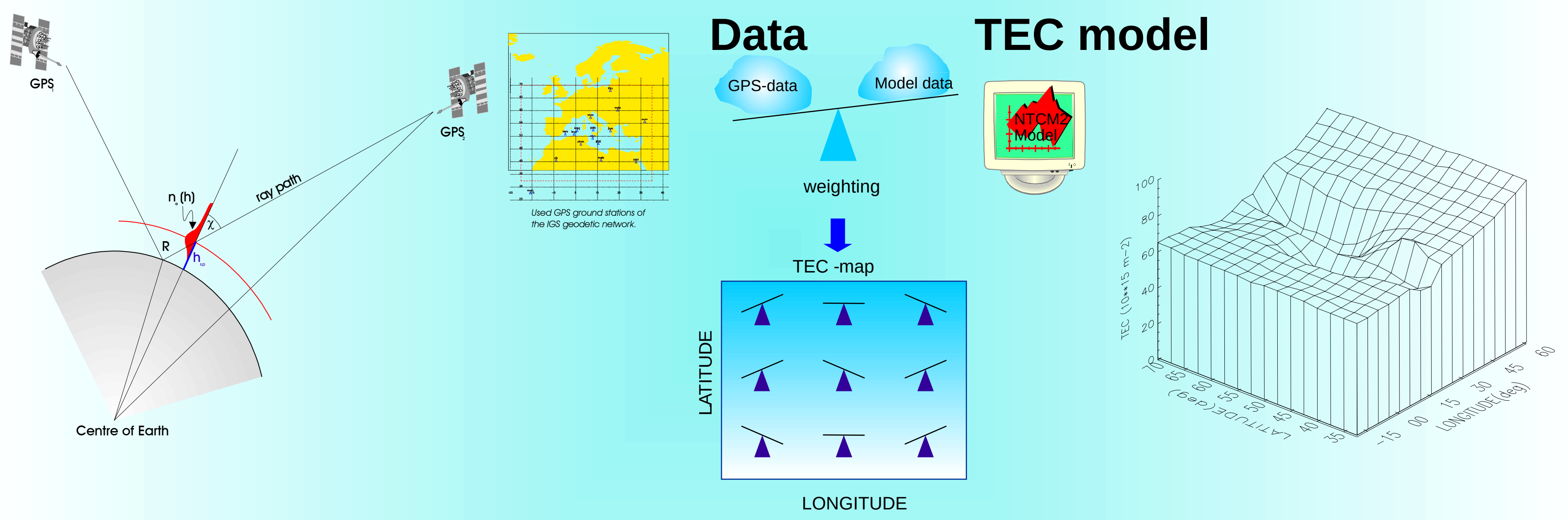
K = 40.3 $m^3 s^{-2}$

Ionospheric range error / Frequency dependence



Principle of TEC-map generation in DLR

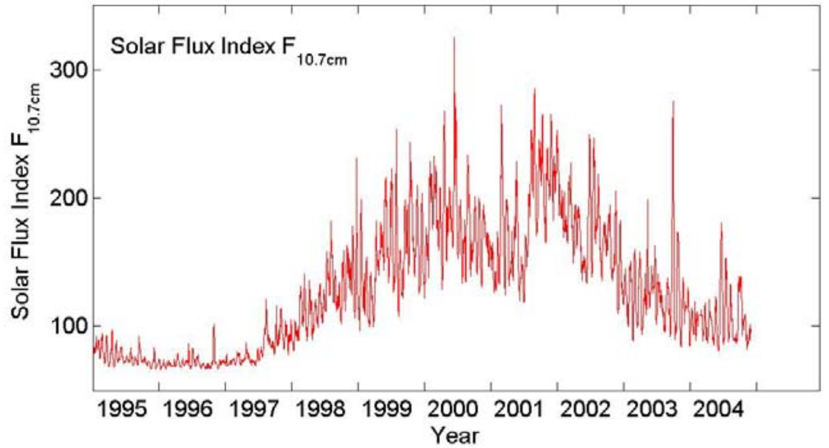
Europe	post proc. (1 day)	http://www.kn.nz.dlr.de/daily/tec-eu
	operational (5 min)	**http://www.kn.nz.dlr.de/swaci**
Polar Cap	post proc. (1 day)	http://www.kn.nz.dlr.de/daily/tec-np

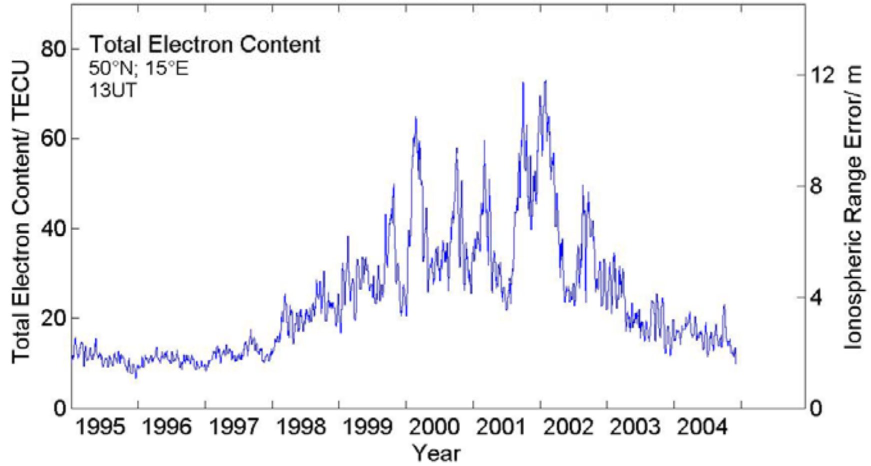


Measurement, Calibration	Conversion to vertical	Assimilation of measurements into the regional TEC model	TEC- Map

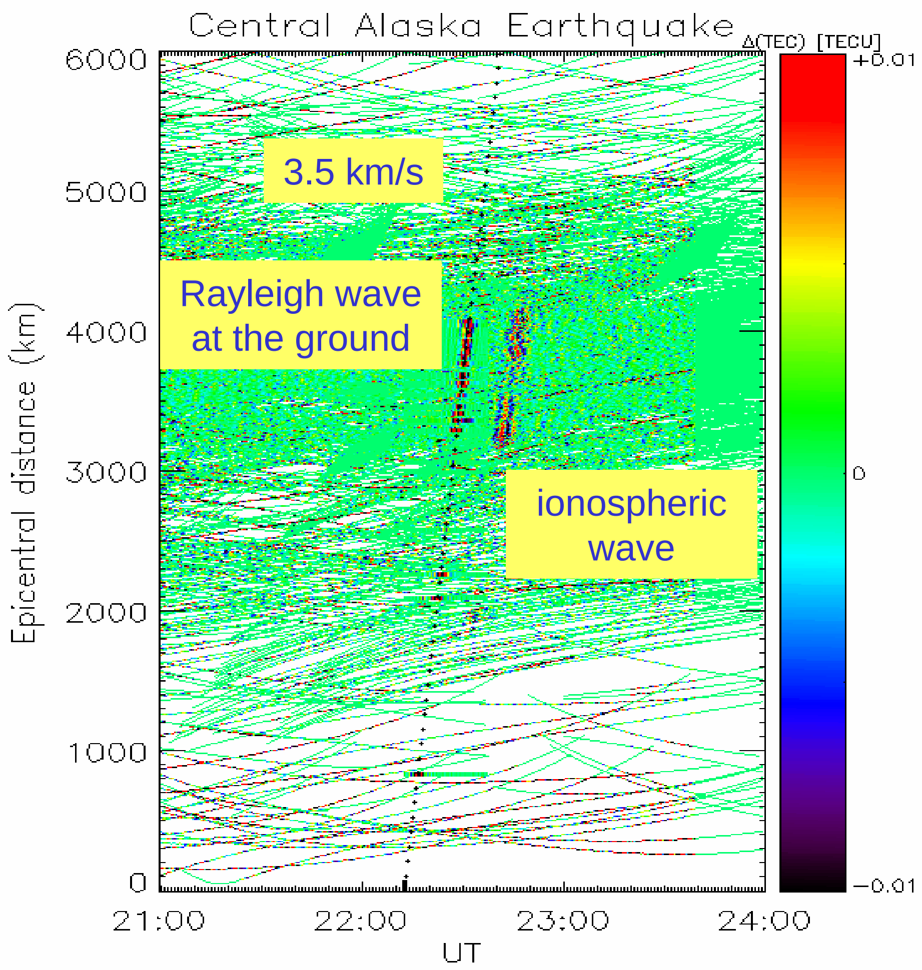
Solar Control of TEC

- **Day-time vertical TEC (7 days average) at 50°N; 15°E since 1995 in comparison with corresponding solar radio flux values F10.7 (daily)**
- **TEC is closely related to the solar activity variation, but shows also seasonal and semiannual variations**





Detection of earthquake signatures in the ionosphere



Alaska Earthquake on November 3, 2002

(63.517 N/-147.444 E) at 22:12:41.0 UTC on NOV. 03, 2002 (DOY: 307) with a Magnitude of $M = 7.9$ ($M_S = 8.5$) in a depth of 5 km.

The Ap-index on that day was 35 (one day before/after: 28/23) and the F10.7-index was 166.5 (one day before/after: 162.1/174.4)

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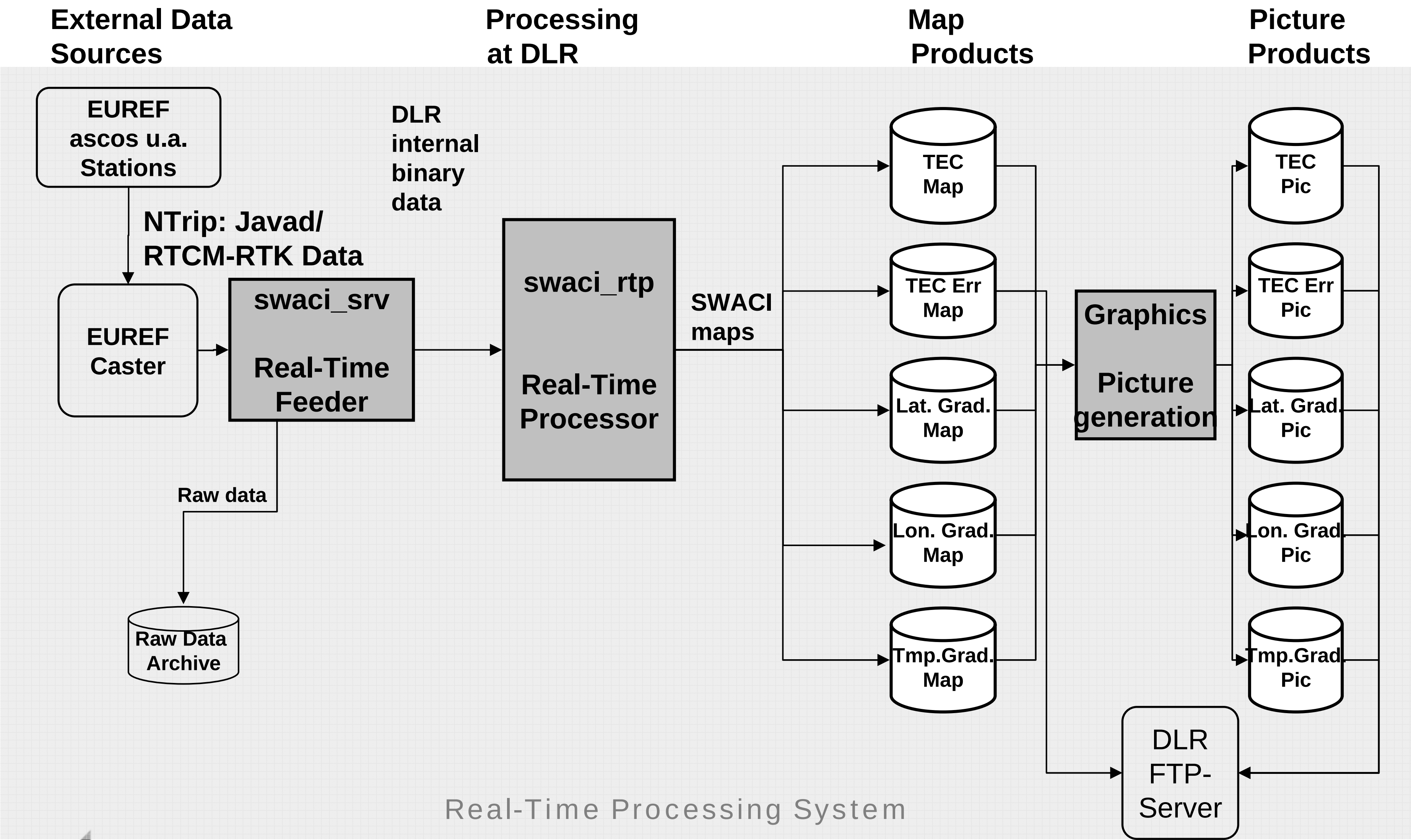
Space Weather Application Center – Ionosphere SWACI

- Joint project of DLR Institutes: *Institute for Communications and Navigation* and *German Remote Sensing Data Center*
- 75% of the budget supported by the state government Mecklenburg-Vorpommern
- Duration: 1 July 2004 – 31. December 2006

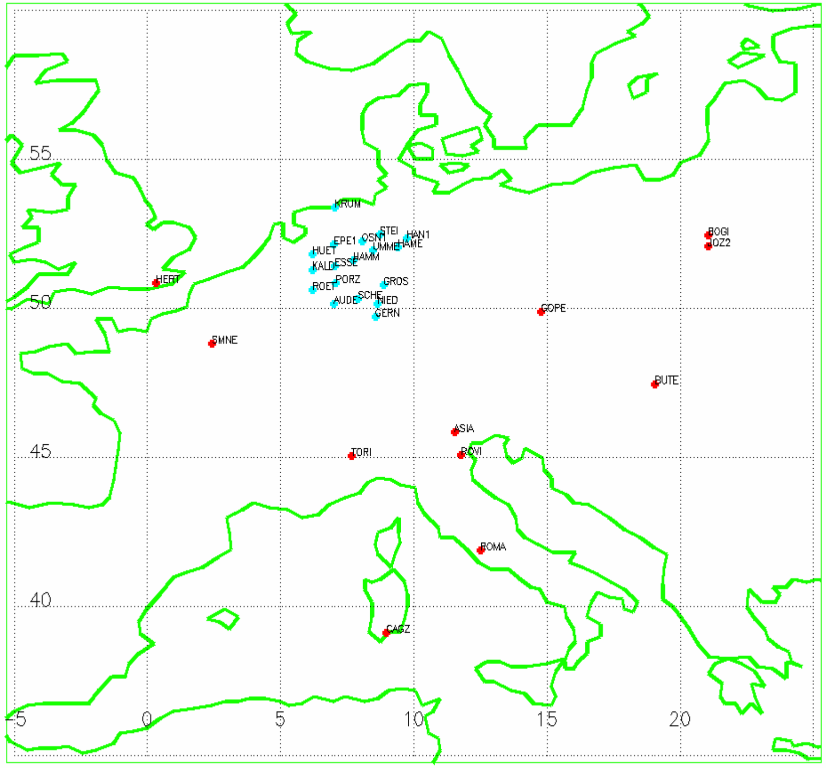
Data Products

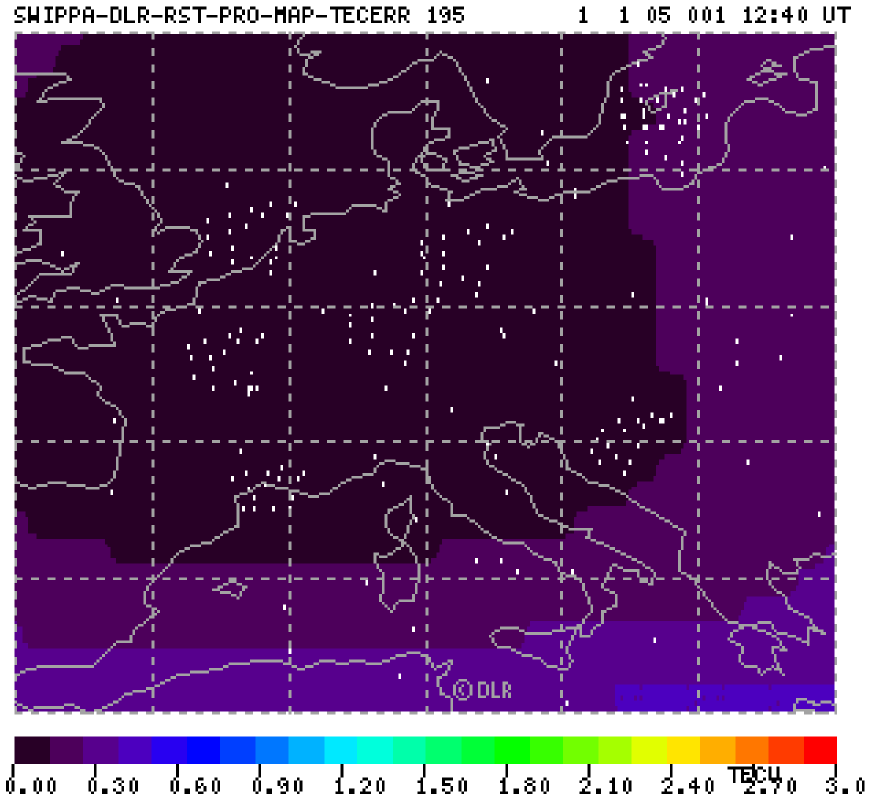
- Electron density profiles from CHAMP radio occultation
- Reconstruction of the topside ionosphere from CHAMP navigation data
- Ground based derived TEC maps and derivatives from EUREF and ascos GPS networks via BKG

SWACI Data Processing System



GPS Receiver distribution over Europe used in SWACI





Ground based monitoring-network used for SWACI

Sub- ionospheric points obtained from all available satellites

Space Weather Application Center- Ionosphere

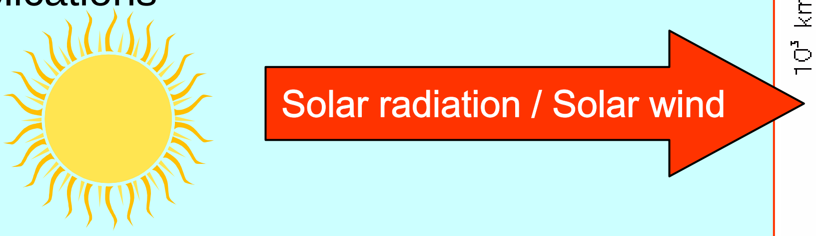
SWACI

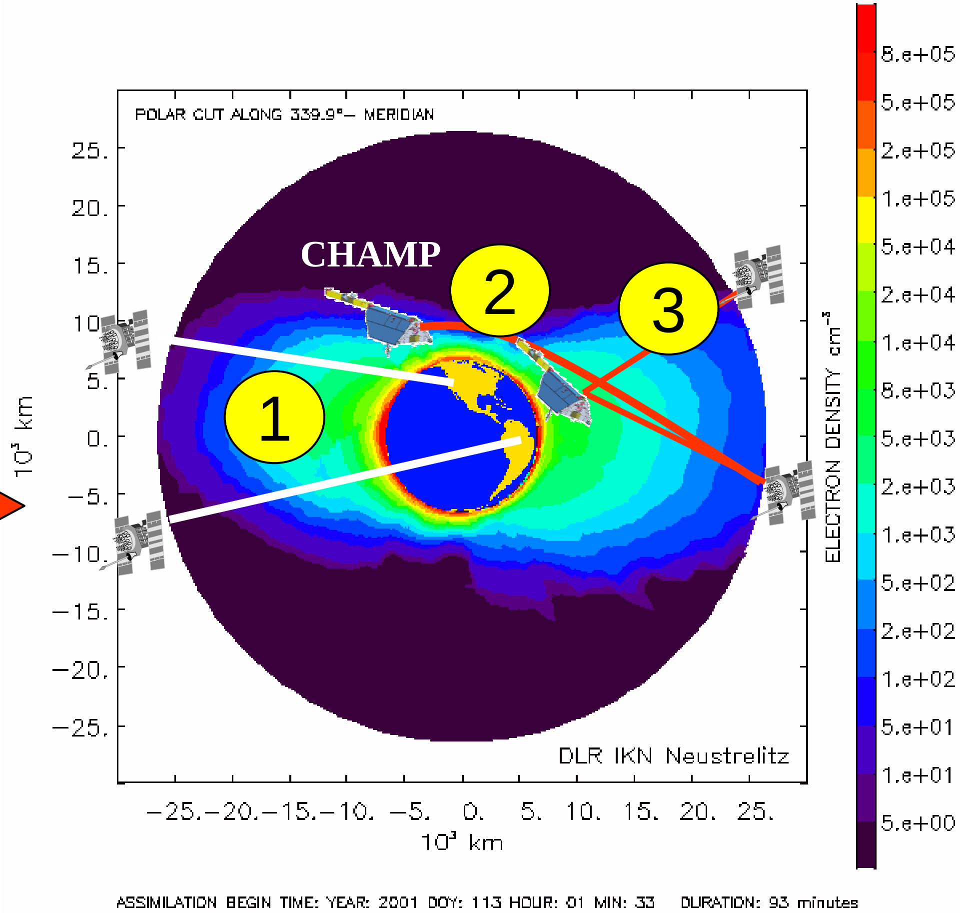
- Operational access to GPS (via NTRIP) and supplementary data which are required
- Preprocessing and calibration
- Generation of TEC maps and derivatives
- NRT provision of data products to users (5 min update rate)
- Development of forecast models and products

SWACI Ionosphere Monitoring by GNSS

Monitoring of the Ionosphere by:
- GNSS Ground stations 1
- LEO Satellites using GNSS-receivers 3
  CHAMP (GRACE, TerraSAR-X). 2

Operational provision of global ionospheric informations for Com/Nav -applications

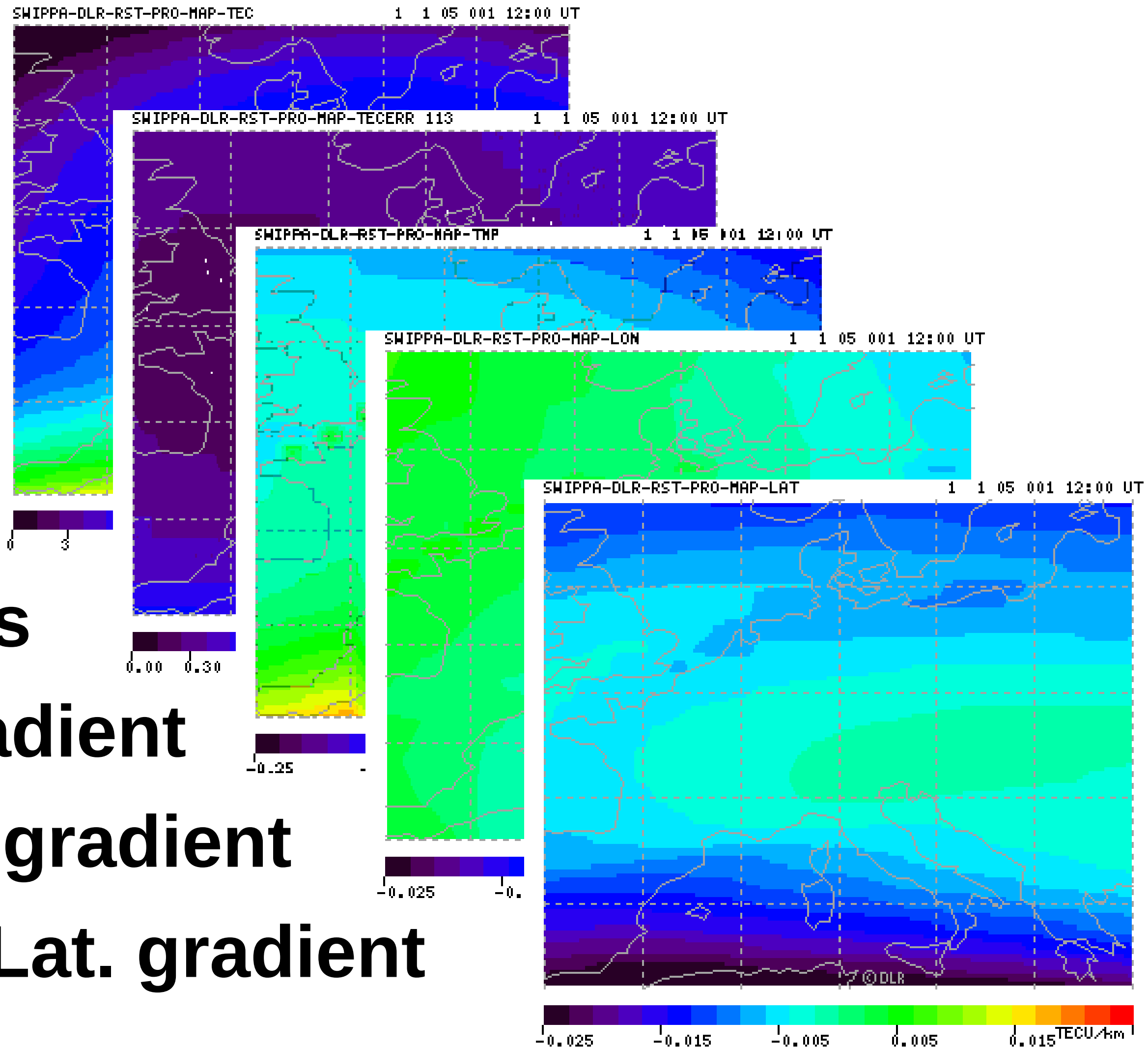




Warnings of severe ionospheric perturbations
Prediction of expected ionospheric propagation conditions for Com/Nav signals
Post-Processing Research

http://www.kn.nz.dlr.de/swaci

SWACI - Ground based products



- **TEC-Map**
- **Error-Maps**
- **Temp. gradient**
- **Long. gradient**
- **Lat. gradient**

SWACI - Data Access Page

DLR-Institut for Communication and Navigation - Microsoft Internet Explorer bereitgestellt von T-Systems SfR

File Edit View Favorites Tools Help

Address http://www.kn.nz.dlr.de/

Institute of Communications and Navigation

Space Weather Application Center - Ionosphere (SWACI)

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- About SWACI
- Space Weather Tour
- Service Description
- Product Access
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  - CONSORTIUM
  - NONCOMMERCIAL
  - COMMERCIAL
  - PUBLIC
- News & Features

Products & Data

The data and products available through SWACI are based on primary data, mostly of them provided by the partners and institutions listed in the section "Service Descriptions".

Furthermore, SWACI uses GPS measurements provided by European GPS ground networks like those of the International GNSS Service (IGS) and EUREF whose data are made available online via the Bundesamt für Kartographie und Geodäsie (BKG).

Space base GPS data are taken from GPS measurements on board the German Geo-Research satellite CHAMP.

We are grateful to the above mentioned institutions, commissions and services for providing such important primary data which our service is based on.

Whereas the ground based data are operational with an update rate of 5 minutes, the CHAMP data are available depending on the CHAMP science data dump received at the DLR/DFD Neustrelitz.

Access

If you are new to this service and would like to have an access to products and documents, please first register by following the link "New Users". There you will get a user name and a password via email. If you have already registered, select the link according to your membership status (CONSORTIUM, COMMERCIAL, NON-COMMERCIAL, PUBLIC). When using the SWACI service, please follow the policy on data usage.

Products

Ground based:

- Space Weather Warnings
- European maps of Total Electron Content (TEC)
- Maps of Temporal Gradients of TEC
- Maps of Latitudinal gradients of TEC
- Maps of longitudinal gradients of TEC
- Forecasts

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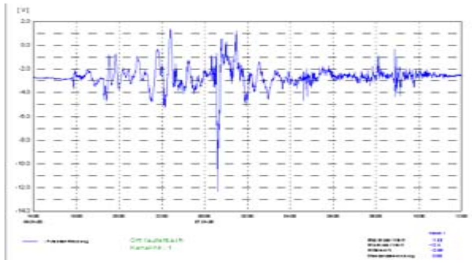
Space Weather Event on 6 April 2000

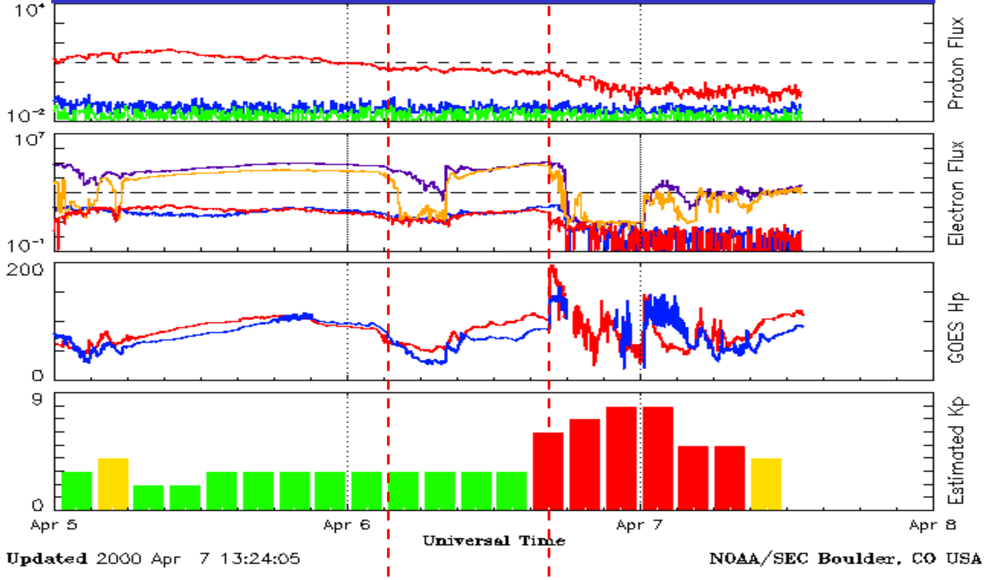
Polar light observed in Potsdam

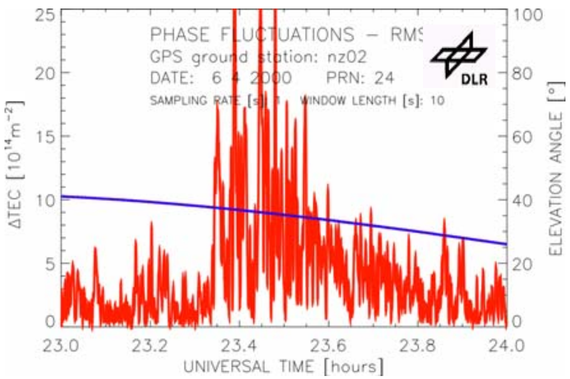
(J. Rendtel)

Voltages on Gas pipelines of Ruhrgas



Electron- und Proton flux measurements on GOES



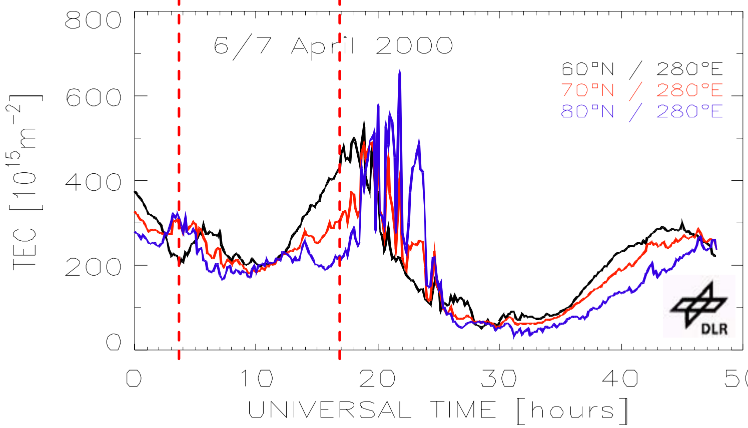


Perturbations of GPS-Measurements

Polar area

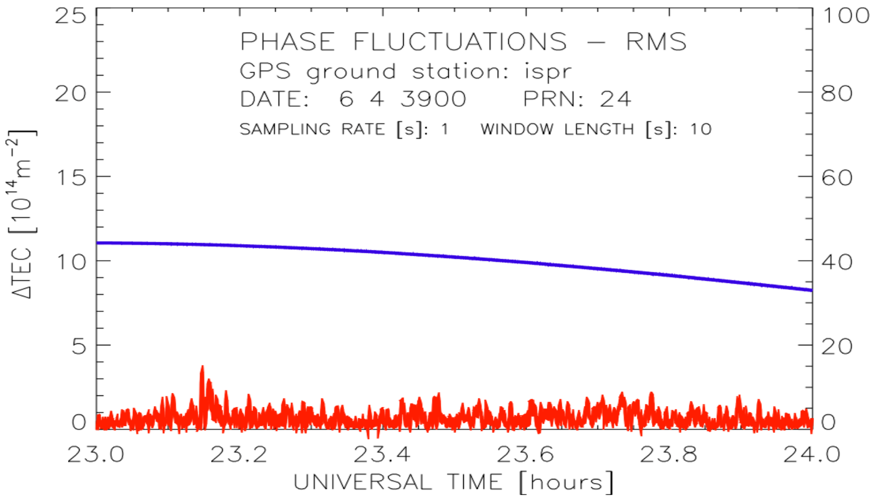
and in

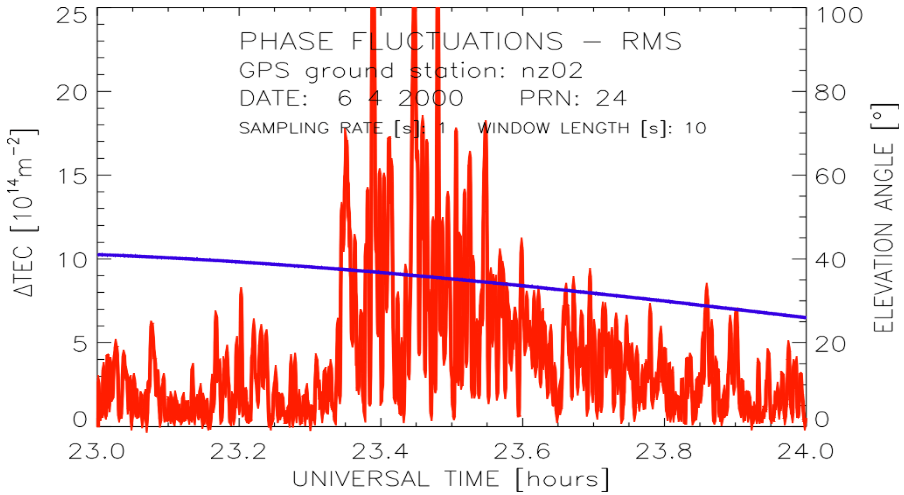
Neustrelitz



GNSS signal phase fluctuations on 6 April 2000

- **Variability of GPS carrier phase of PRN 24 at different sites**
  6 April 2000, 23 - 24 UT, Sampling Rate: 1 Hz, 10s-window





ISPRA / Italy

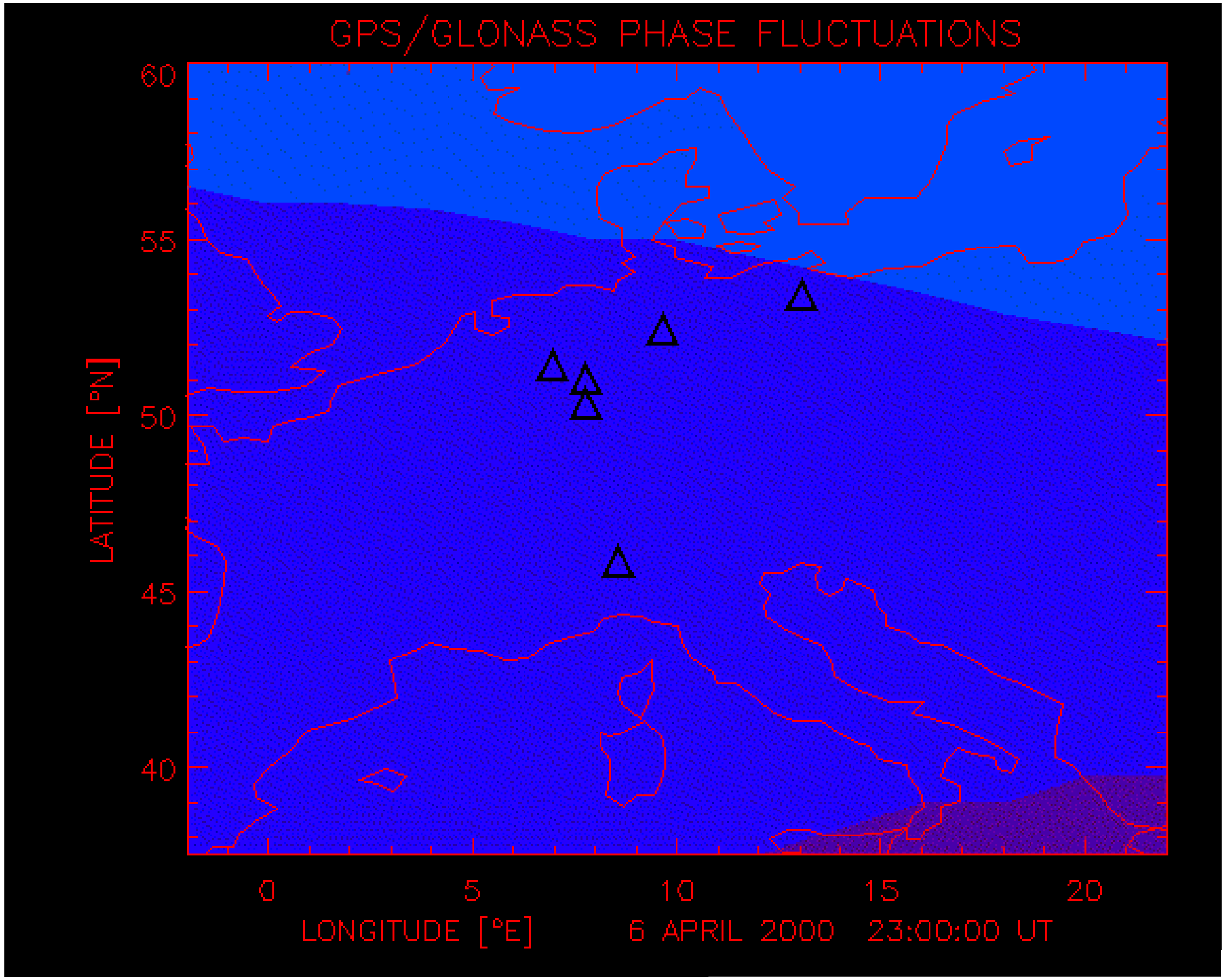
Mean noise level

TEC= $2 x 10^{14} m^{-2}$ ⟷ 3.2 mm

Neustrelitz / Germany

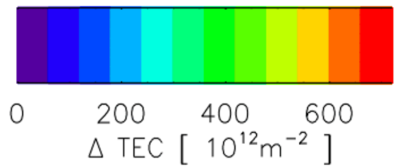
Enhanced perturbation level of GPS carrier phases may cause problems in resolving wave length ambiguities in GPS reference networks (up to 10 cm)

TEC - Fluctuations over Europe on 6 April 2000



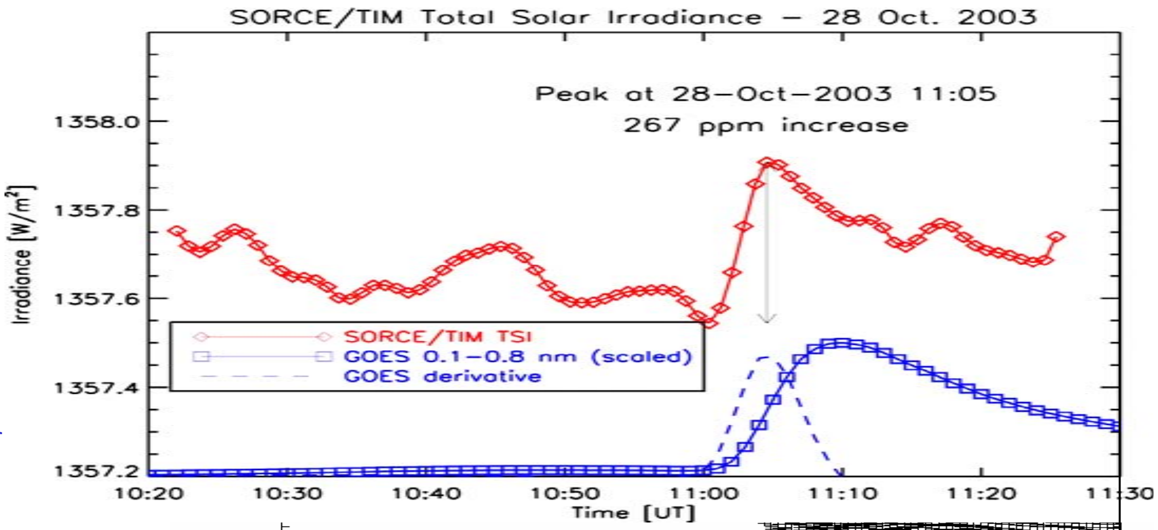
TEC – variability from GPS- und GLONASS-Mesurements derived.
GPS/GLONASS Ground stations: Olpe, Essen, Porz, Hannover, Neustrelitz, Ispra

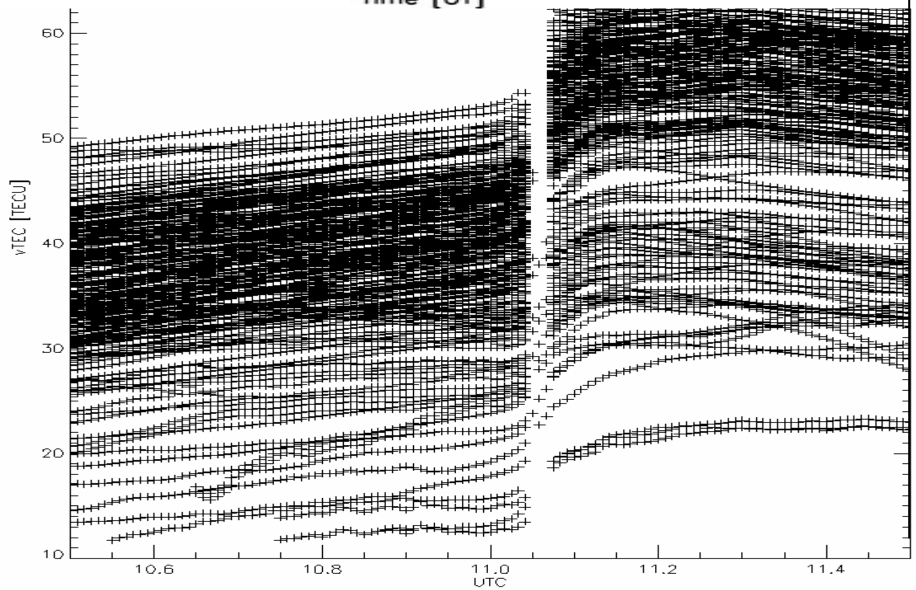
6 April 2000, 23- 24 UT
Data rate:
1 Hz, 10s-window



Solar flare effect on 28 October 2003 over Europe - TEC$_{rel}$

- Strong solar flare on 28 October 2003 at 11:05 UT
- Total irradiance of the sun enhanced within a few minutes by 267 ppm
- TEC data processing indicates loss of data at numerous GPS links
- The number of usable GPS links for TEC processing was reduced rapidly from more than 30 to only 7



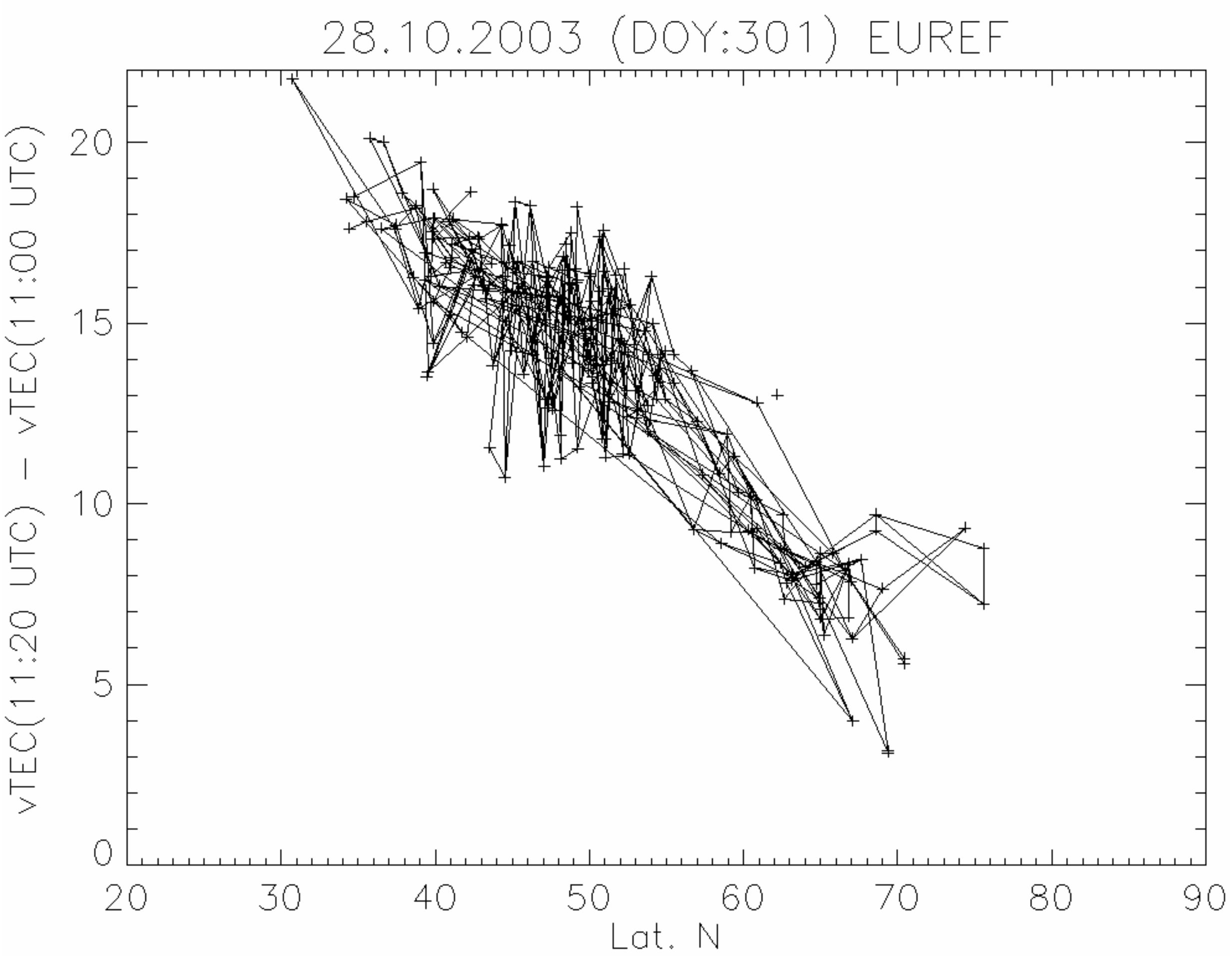


Latitudinal dependency of the flare induced TEC jump

- **Strong latitudinal dependency of the height of the TEC jump observed,**

  up to 20 TECU or 3.2 m at L1 !

- **The CME associated with this flare is larger than the Sun itself causing strong perturbations after reaching the Earth on 29/30 October 2003**



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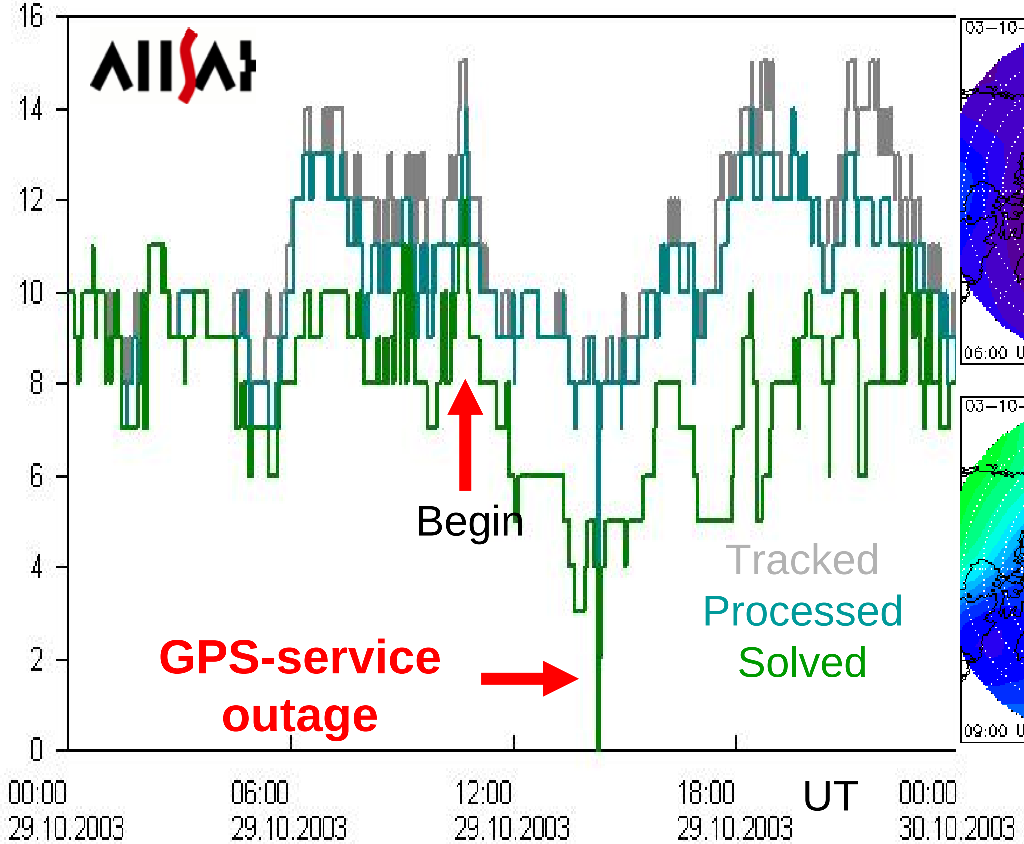
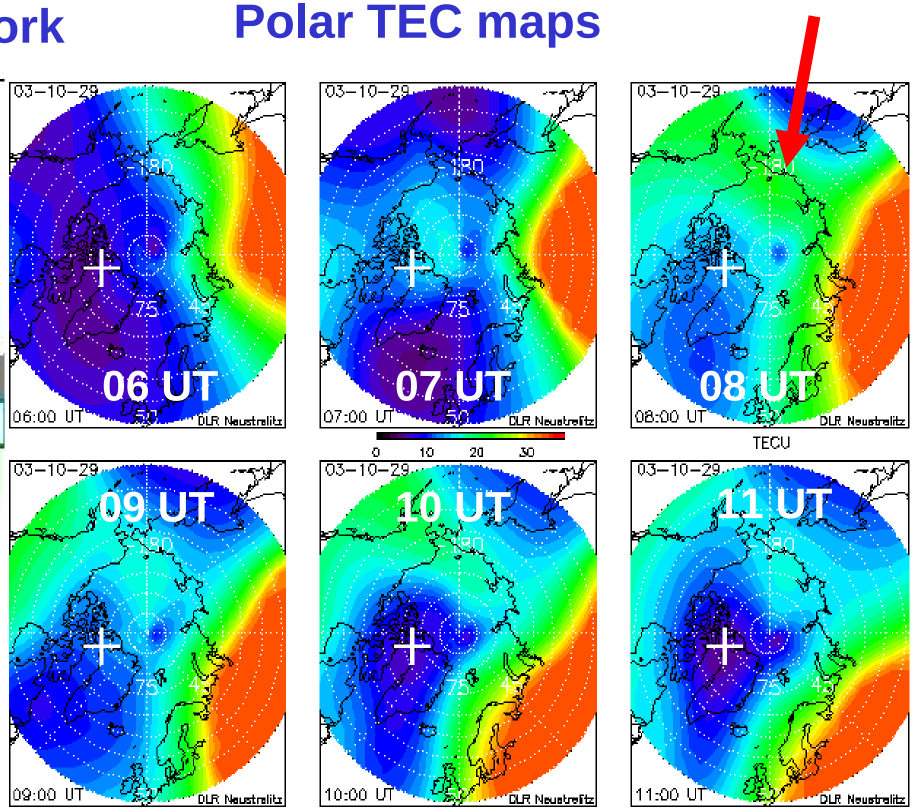
Ionospheric perturbation on 29 October 2003

Performance of the ascos reference network

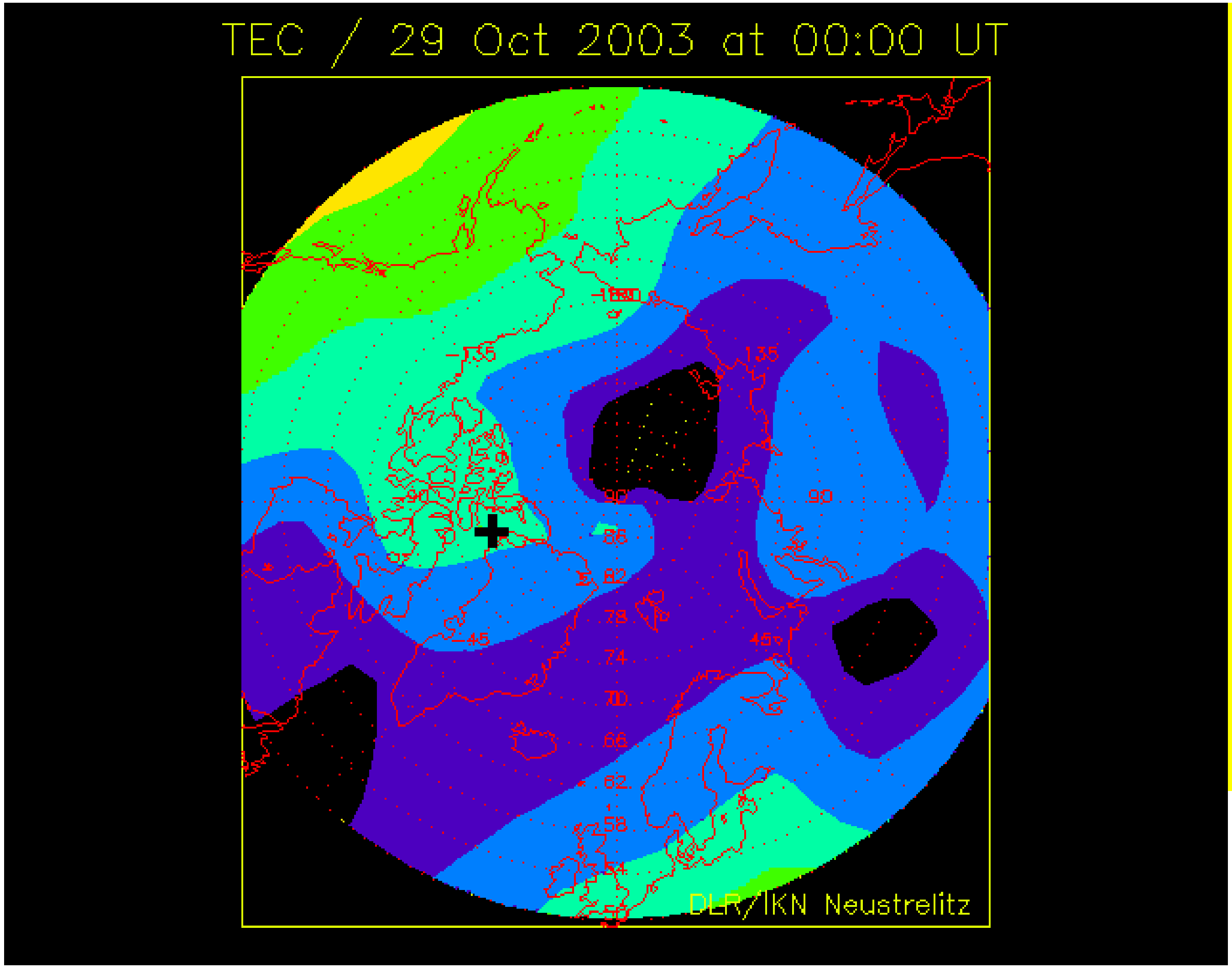


Polar TEC maps



storm develops at high latitudes already before noon

Storm on 29 October 2003 / Polar TEC



Polar TEC on 29 October 2003 derived from IGS ground based measurements

Map resolution
Time: 10 min
Latitude: 2.5 deg
Longitude: 7.5 deg

Space Weather Impact on Network Monitoring Integrity on 25 July 2004

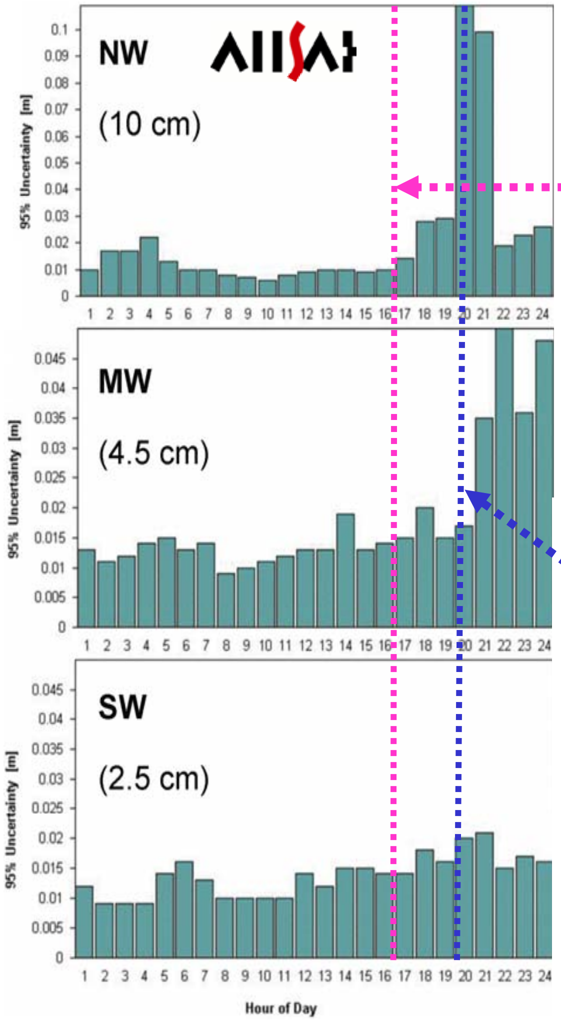
Performance of the GPS reference network of Allsat GmbH, Hannover degrades during the ionospheric storm on 25 July 2004

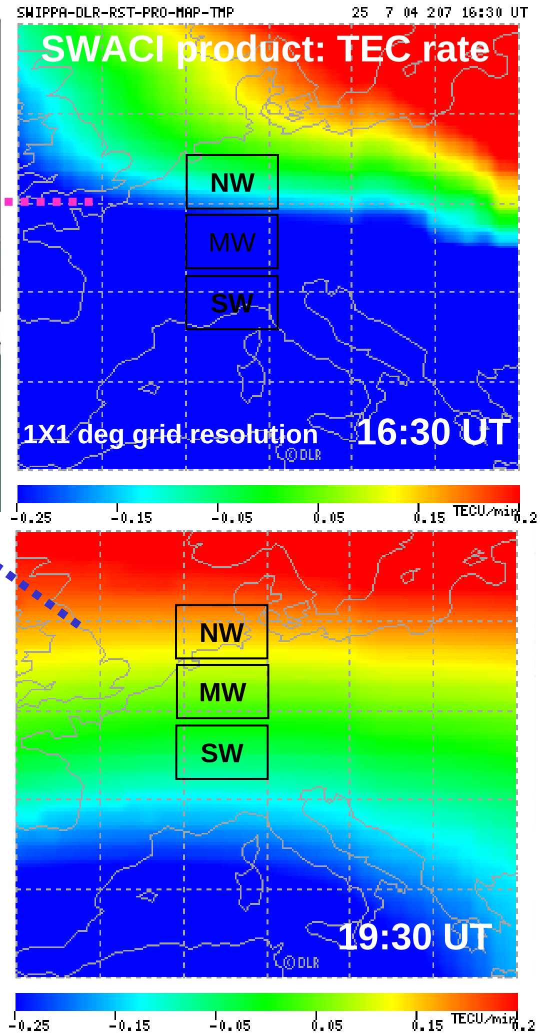
Different effects in different network areas over Germany

- **Propagation of perturbation from high to mid-latitudes**

Provision of users with ionospheric now- and forecast information

- **Information to European users via the Space Weather European Network (SWENET)**
- **Further improvement of temporal and spatial resolution and accuracy**



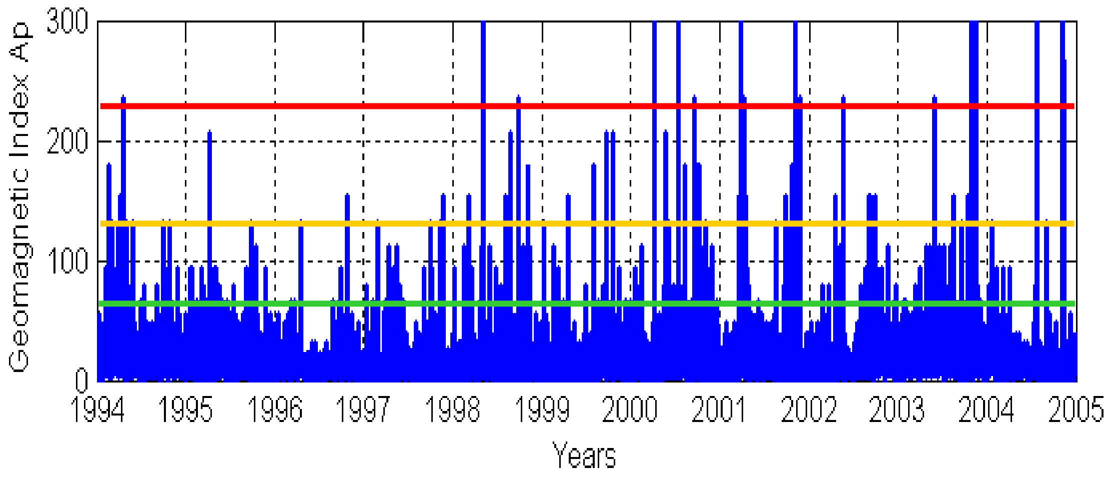


Ionospheric bad weather - conditions

- Ionospheric and geomagnetic disturbances are strongly coupled

⇓

- The planetary magnetic index a_p provides information



Perturbation degree	K_p	Number of events 1994-2004	Meteorologic analogon
Moderate	6	507	Wind
Severe	7	183	Storm
Very strong	8	41	Thunderstorm
Extreme	9	4	Hurricane

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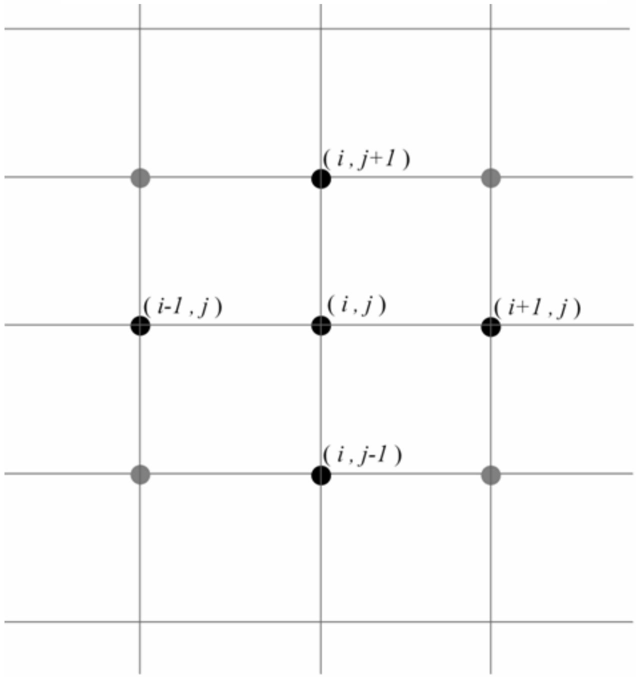
Definition of Perturbation indices

- Information on the strength of ionospheric perturbation is needed in GNSS applications (e.g. GNSS reference networks)
- Definition of indices which meet the practical needs with respect to the ionospheric effect, its temporal and spatial resolution

Gridded TEC values



Examples for perturbation index definitions

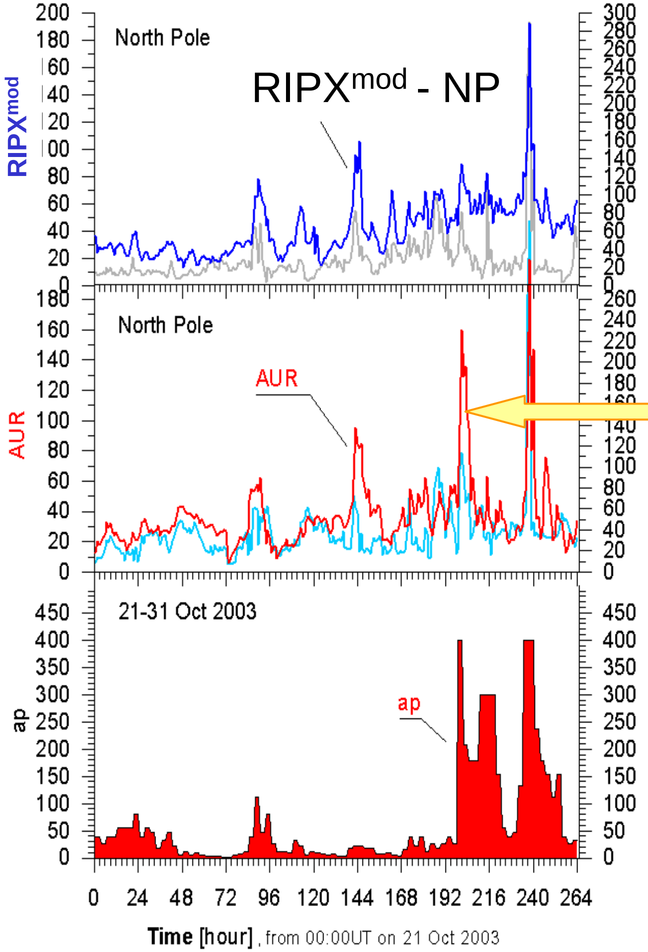
$$GLON_{ij} = \frac{\partial u}{\partial x} = \frac{u_{i+1,j} - u_{i-1,j}}{2\Delta x}$$

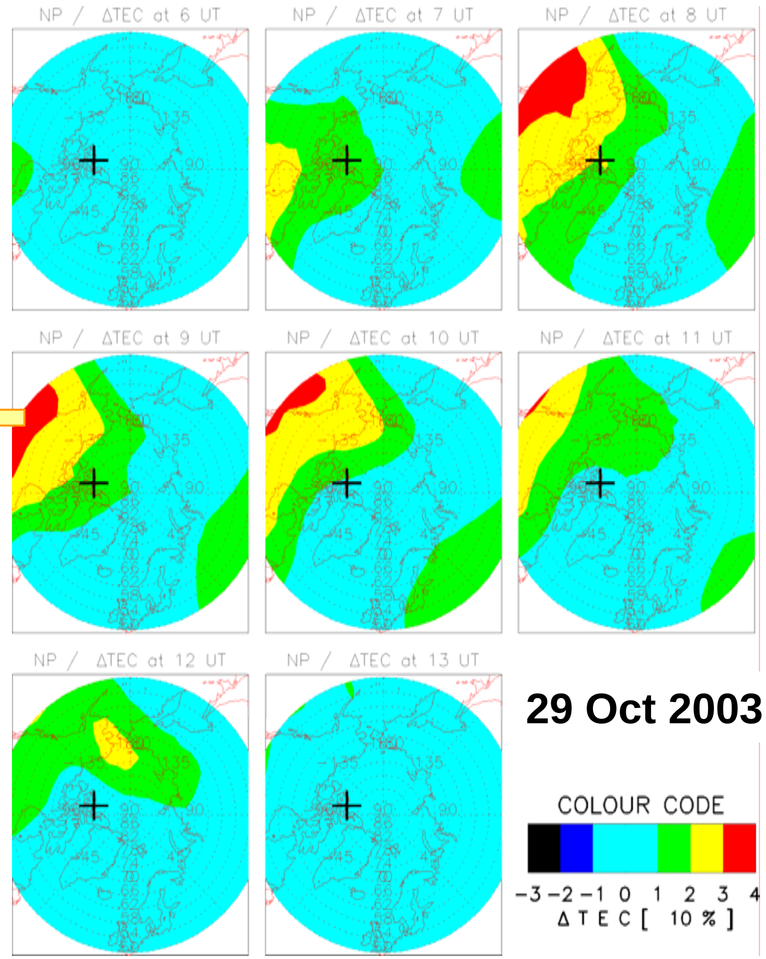
$$GLAT_{ij} = \frac{\partial u}{\partial y} = \frac{u_{i,j+1} - u_{i,j-1}}{2\Delta y}$$

$$GHOR_{\max} = \sqrt{GLAT_{\max}{}^{2} + GLON_{\max}{}^{2}}$$

$$\sigma_p(\lambda,\varphi)^2 = \frac{1}{N_{GP}-1}\sum_{i=1}^{N_{GP}}\left(p_i(\lambda,\varphi) - \overline{p(\lambda,\varphi)}\right)^2$$

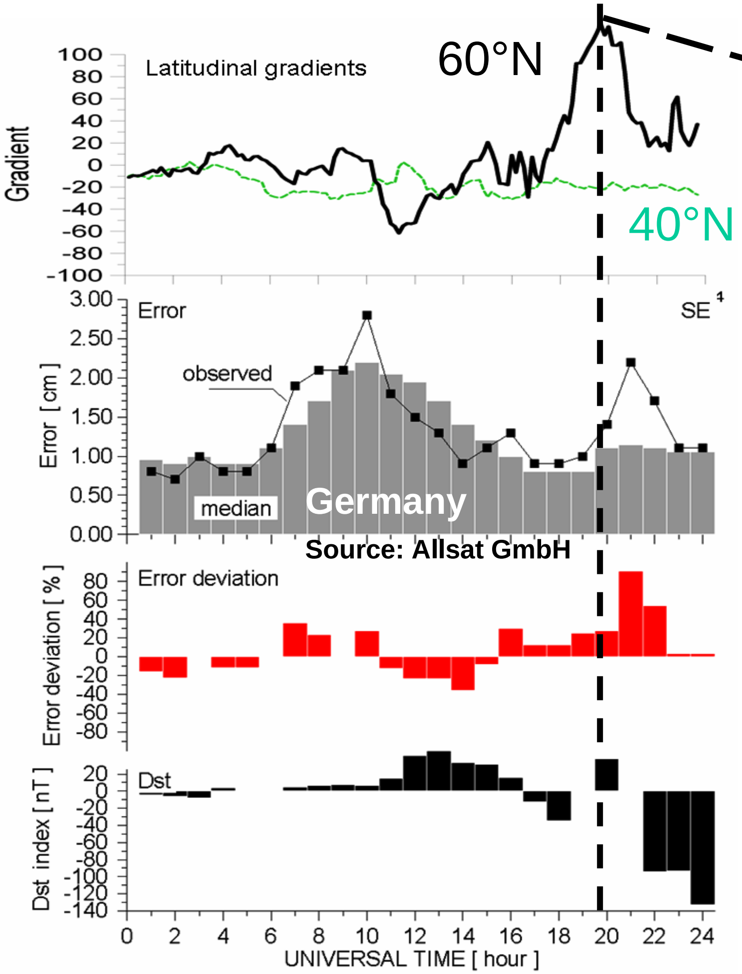
Comparison of different indices with differential TEC maps on 29 Oct 2003 at North pole region

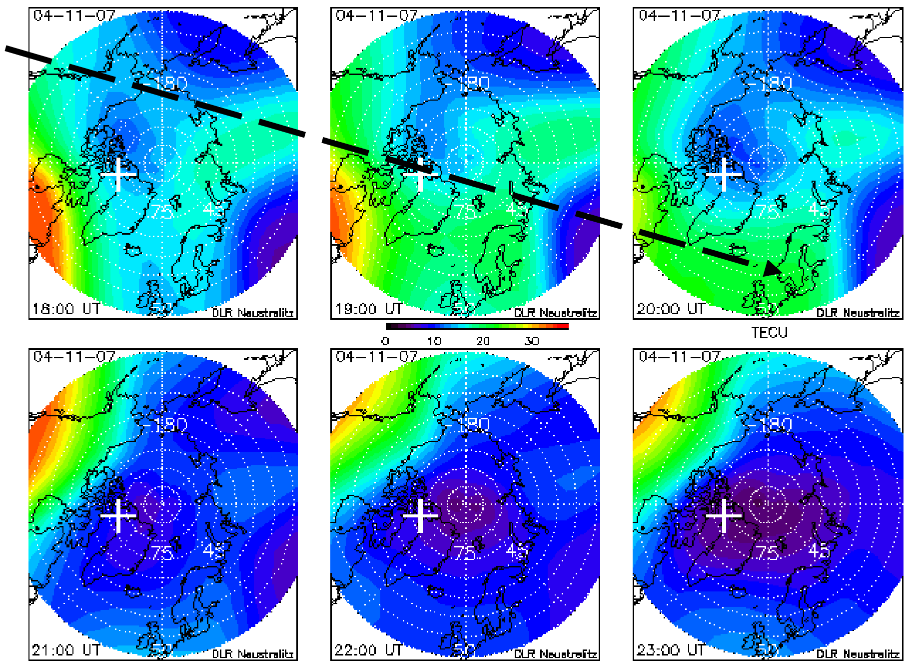




- **North Pole**
  λ > 50 °N
- **Differences between various indices**
  λ > 50 °N
- **Relationship with the geomagnetic index a_p not unique**

Latitudinal gradient index on 7 November 2004





- **High latitude latitudinal gradient index is well correlated with error indication of GPS reference networks (NMI)**
- **Potential for forecasting fixing time problems in reference networks**

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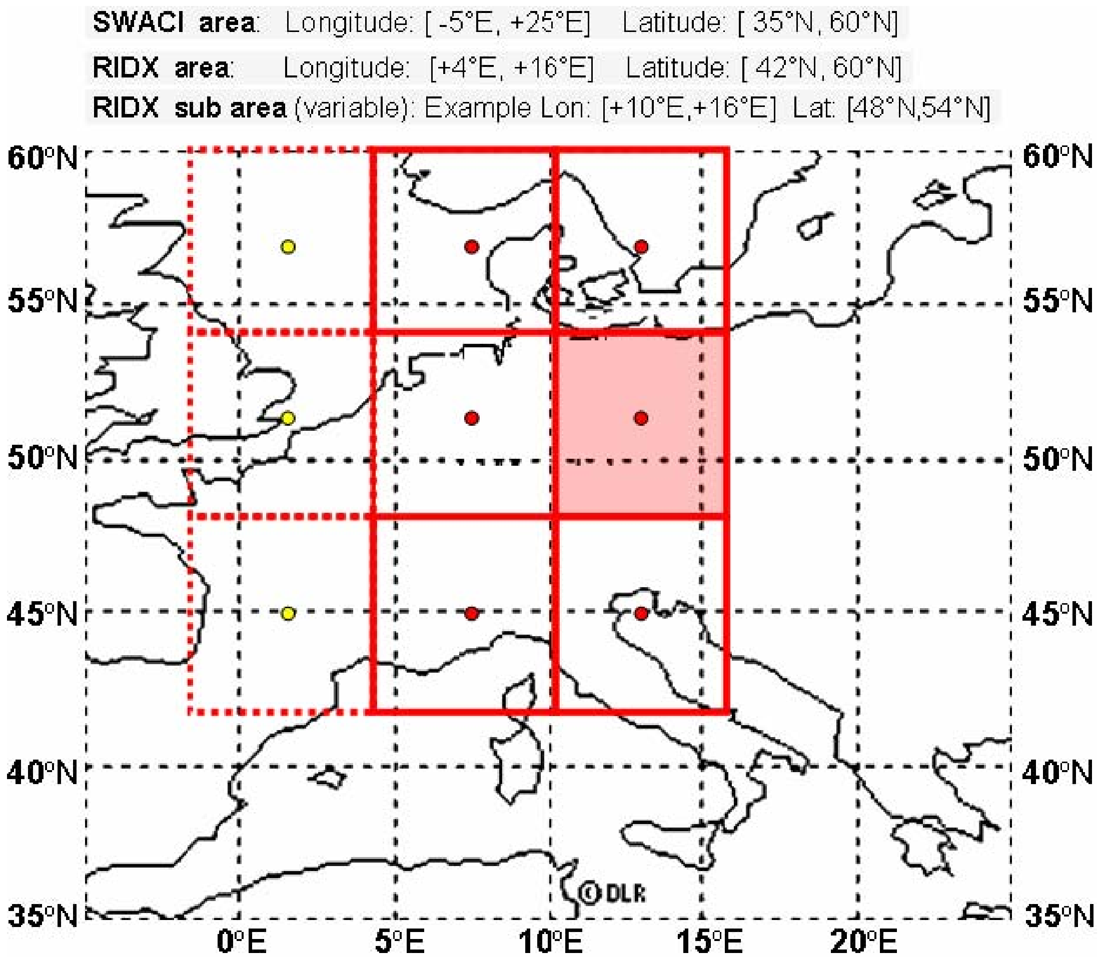
Regional Ionospheric Disturbance Index (RIDX)

Suggestion

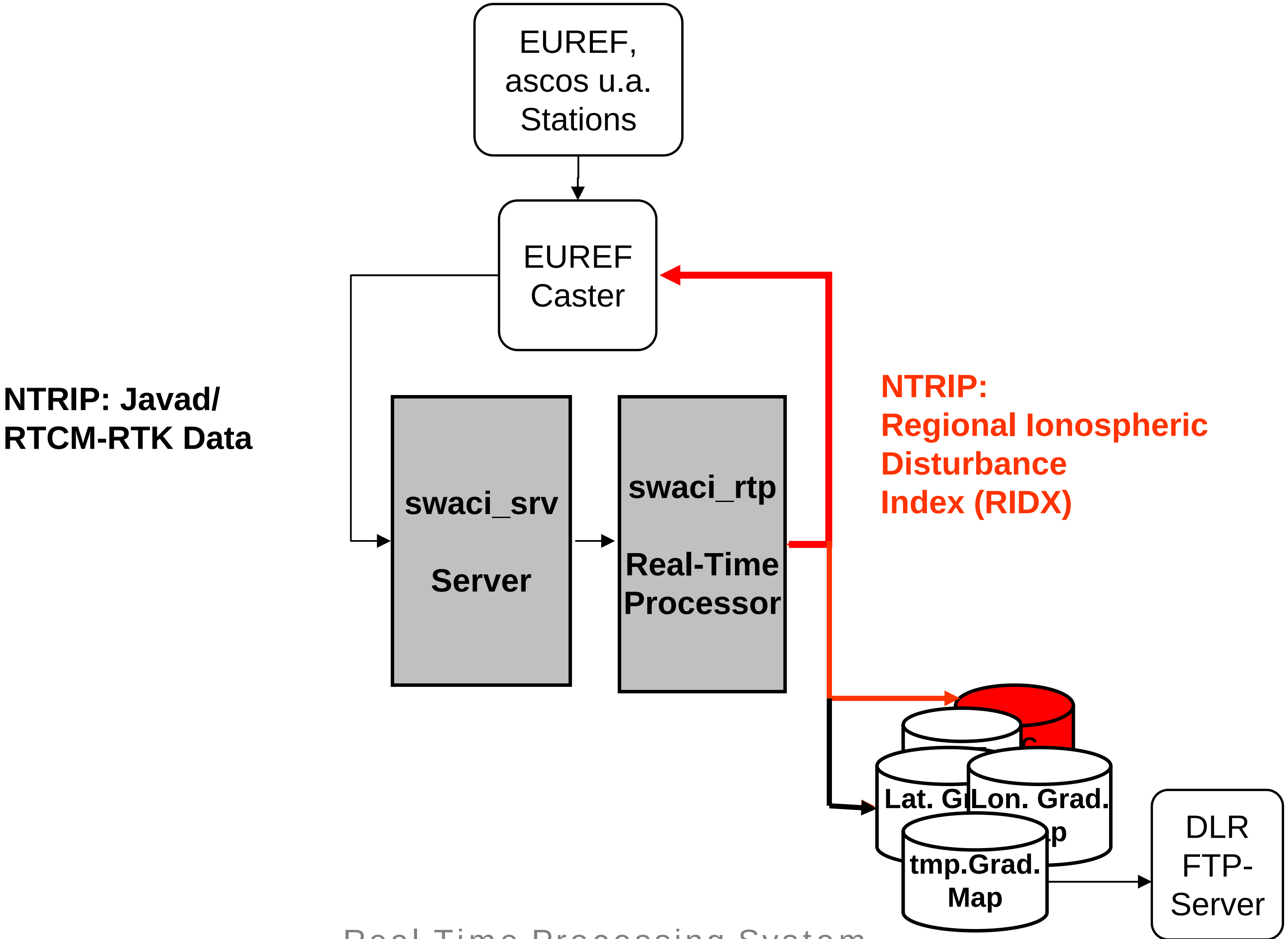
- Continuous computation of regional perturbation indices
- Provision of the index (indices) to users via NTRIP in near real time streaming mode

Question

- Is there a real interest for such a service?



Possible Solution via NTRIP



Real-Time Processing System

Summary & Conclusions

- **NTRIP technology is the basis for the NRT SWACI service**
- **Ionospheric perturbations and irregularities can cause severe impact on precise GNSS applications**
- **A permanent monitoring (nowcast) and forecast of the ionospheric state should help to improve safety and accuracy of GNSS applications**
- **To better and faster quantify the strength and impact of the ionospheric perturbations on GNSS applications, we propose the introduction of an ionospheric index for operational use in Com/Nav systems.**
- **The regional index (related to TEC) could effectively be disseminated via NTRIP technology**
- **To guarantee a broad international usage and comparability of the index we suggest to define ionospheric perturbation indices on an international level (standardization)**

Acknowledgement

- **The following partners contributed essentially to the results obtained in the projects**

  SWIPPA (Space Weather impact on precise Positioning Applications, supported by ESA)

  SWACI (Space weather application center – ionosphere, supported by state government of Mecklenburg-Vorpommern)

  - **AllSat** GmbH Network + Services, Hannover, Germany
  - **LVMV** Land Surveying Office of Mecklenburg-Vorpommern, Schwerin, Germany
  - **SENSYS** Sensorik & Systemtechnologie GmbH, Fuerstenwalde, Germany

- **BKG makes available the real time service via NTRIP**

We thank our partners for fruitful cooperation!