



# GPS TEC Measurements Utilized for Monitoring Recent Space Weather Events and Effects in Europe

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Session 3 (Ionosphere - positioning and telecommunication), 16 November 2005  
Splinter Session (Recent space weather events and space weather services performance)

**Ground and space based GNSS observations –  
the German Aerospace Center (DLR) experience**

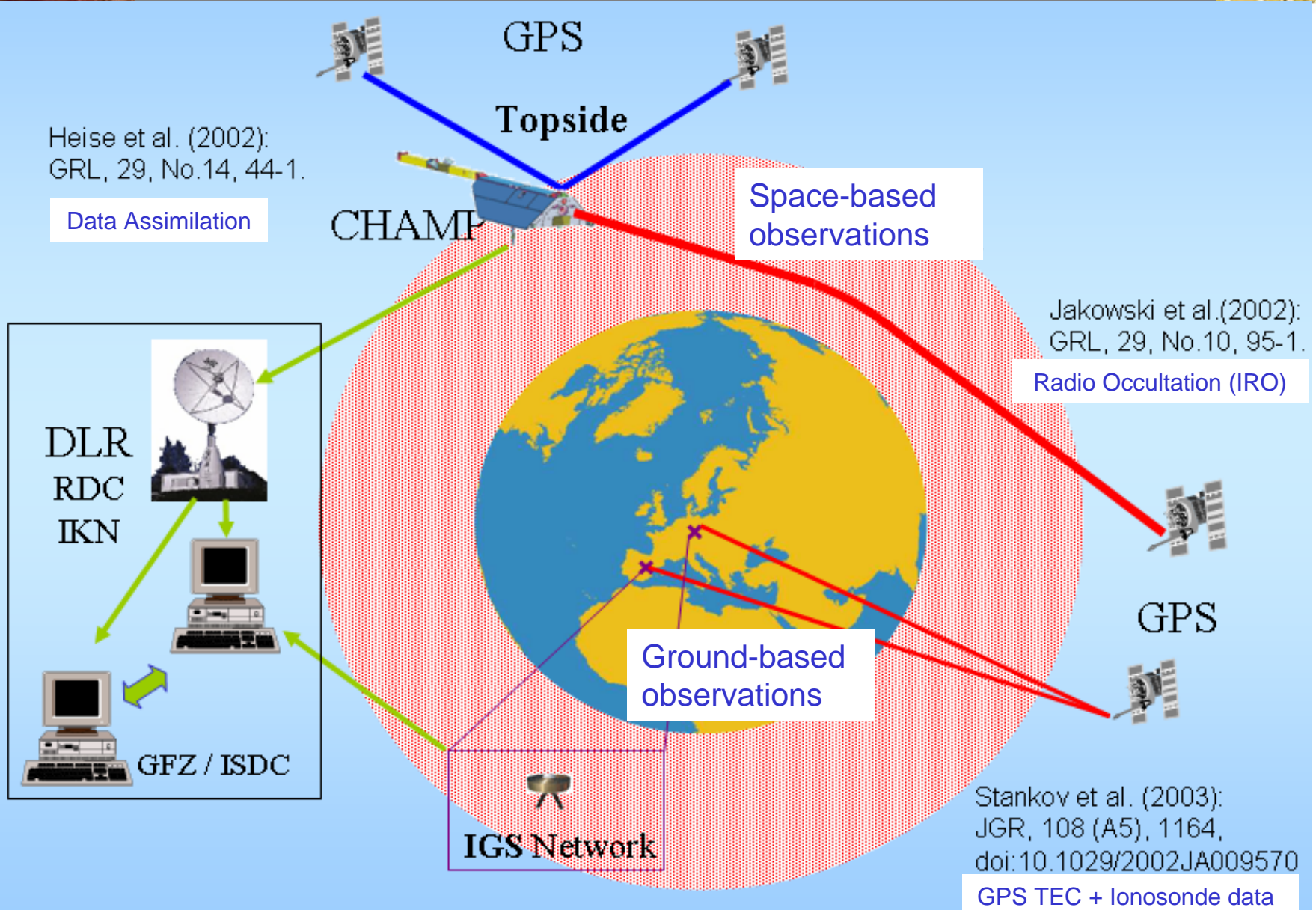
**Generation of ionospheric disturbances –  
the importance of polar TEC monitoring**

**Propagation of ionospheric disturbances –  
TEC monitoring (Europe)**

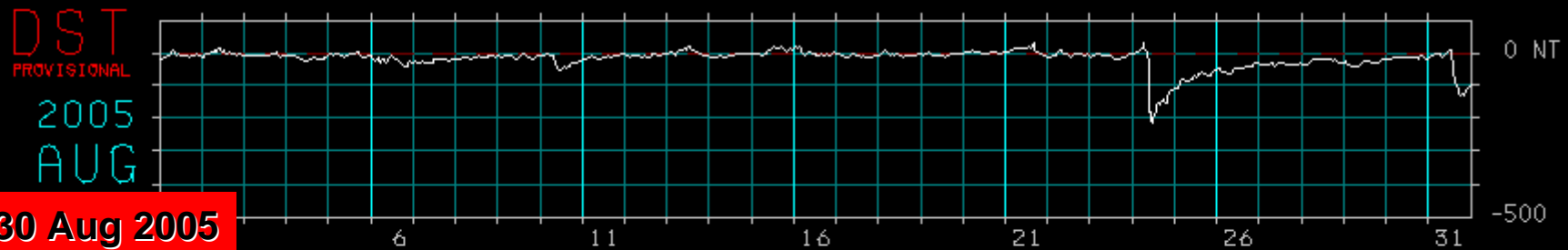
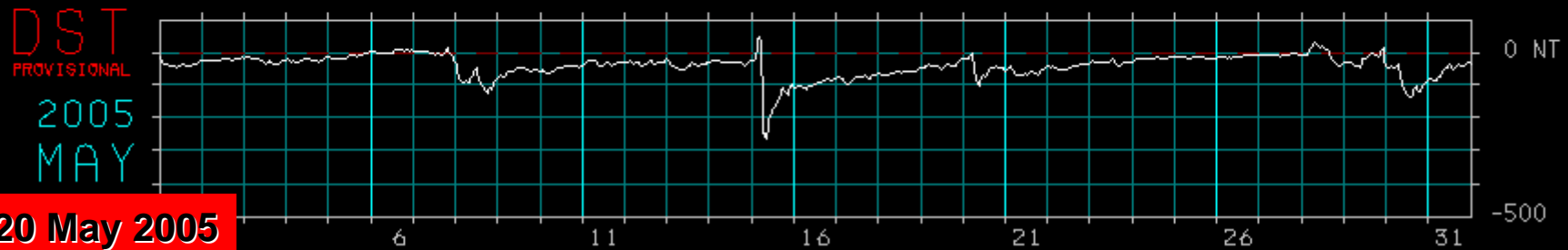
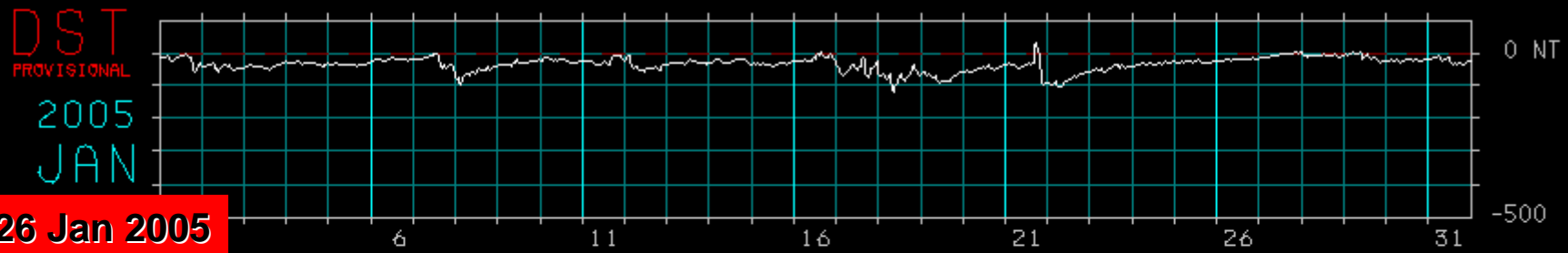
**Propagation of ionospheric disturbances –  
case and statistical storm studies**

**Adverse effects on GNSS reference network operations  
caused by ionospheric disturbances**

# DLR ionosphere observation experience

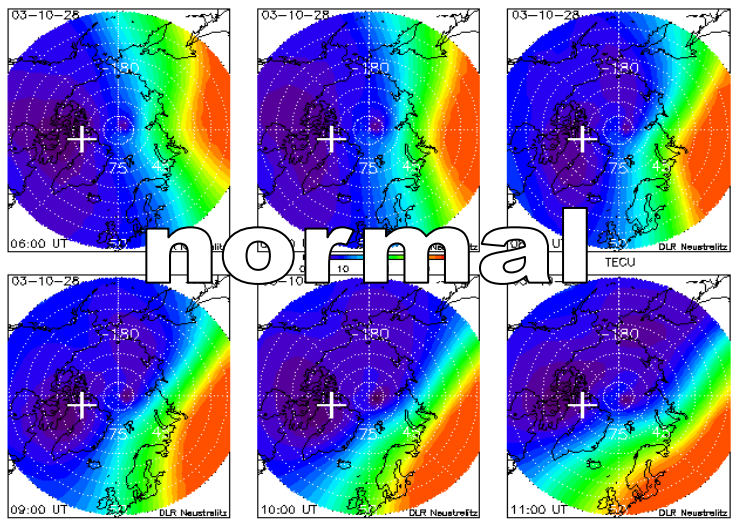
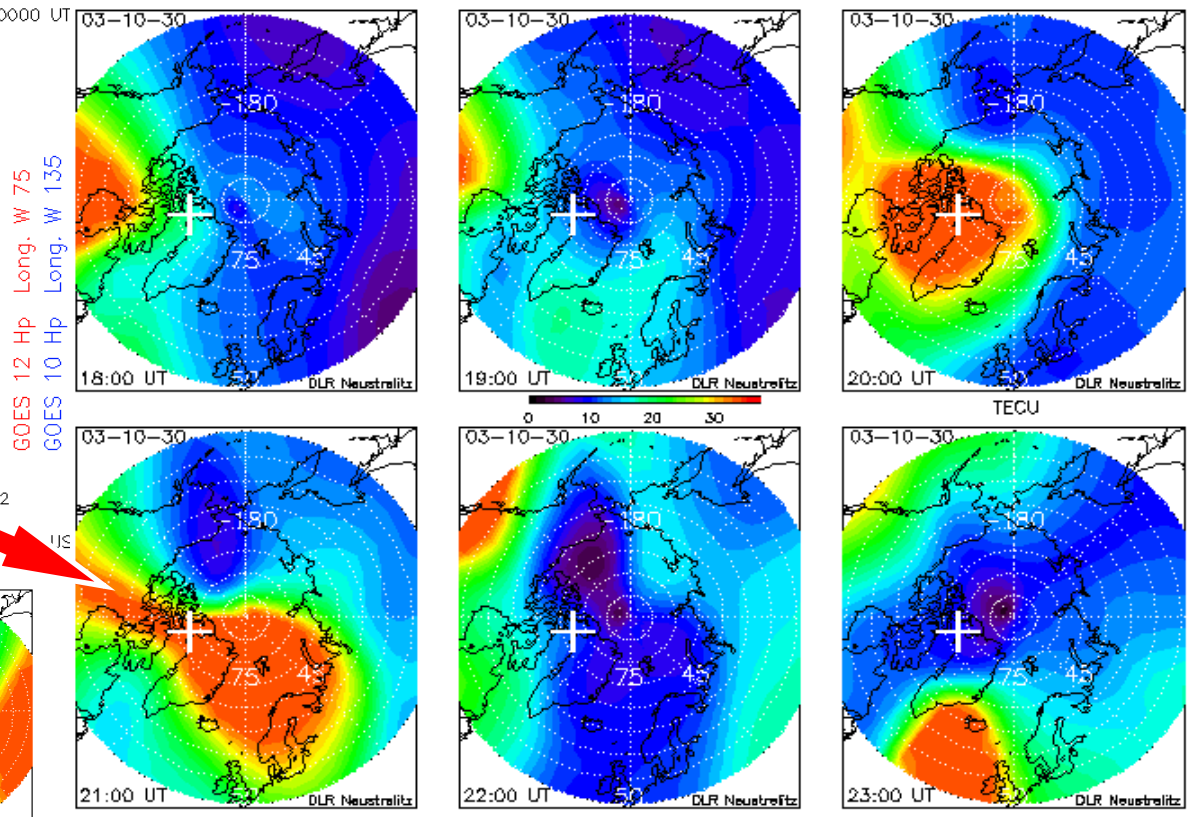
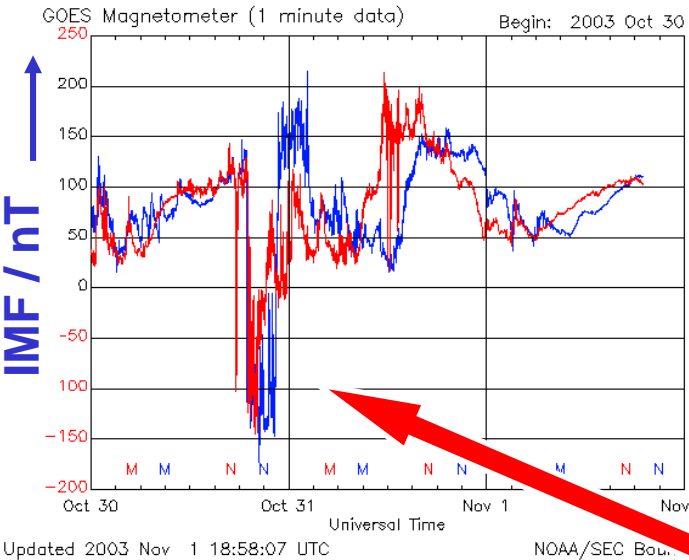


# Major Space Weather Events in 2005





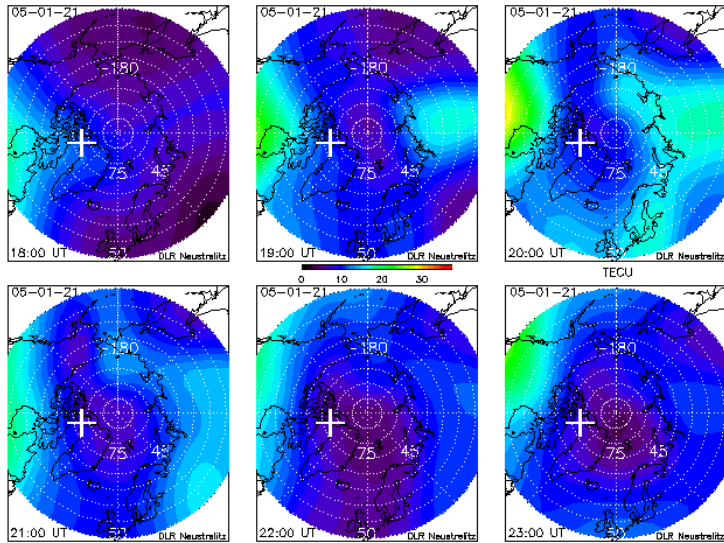
# 29 - 31 October 2003



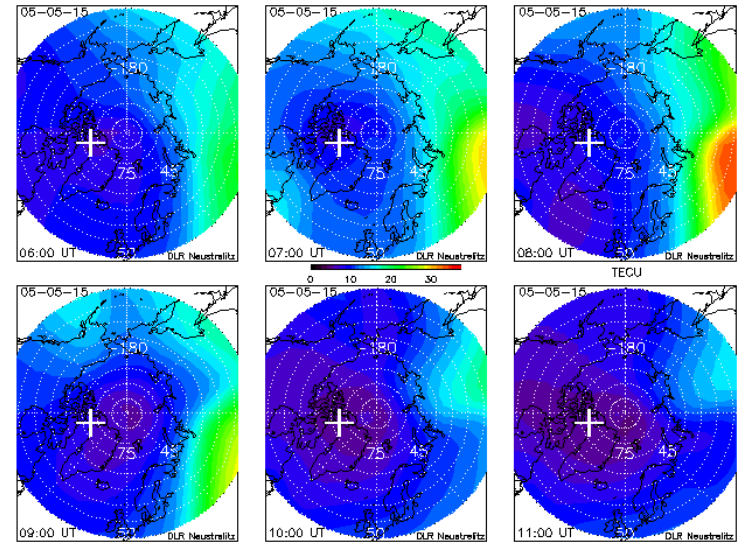
Close correlation between  
TEC value behaviour  
and  
IMF southward component behaviour

# Polar TEC observations

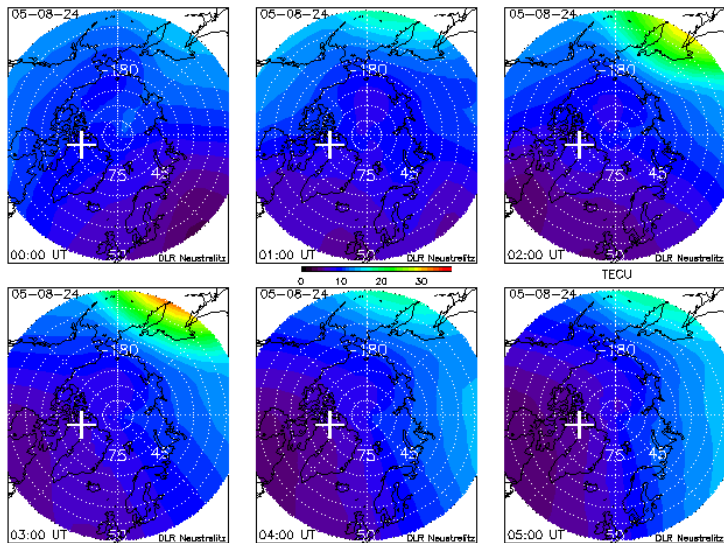
**21 Jan 2005**



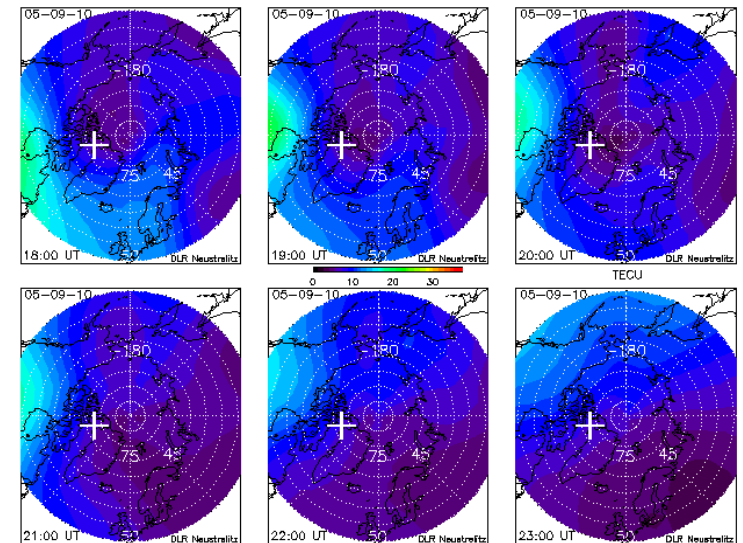
**15 May 2005**



**24 Aug 2005**



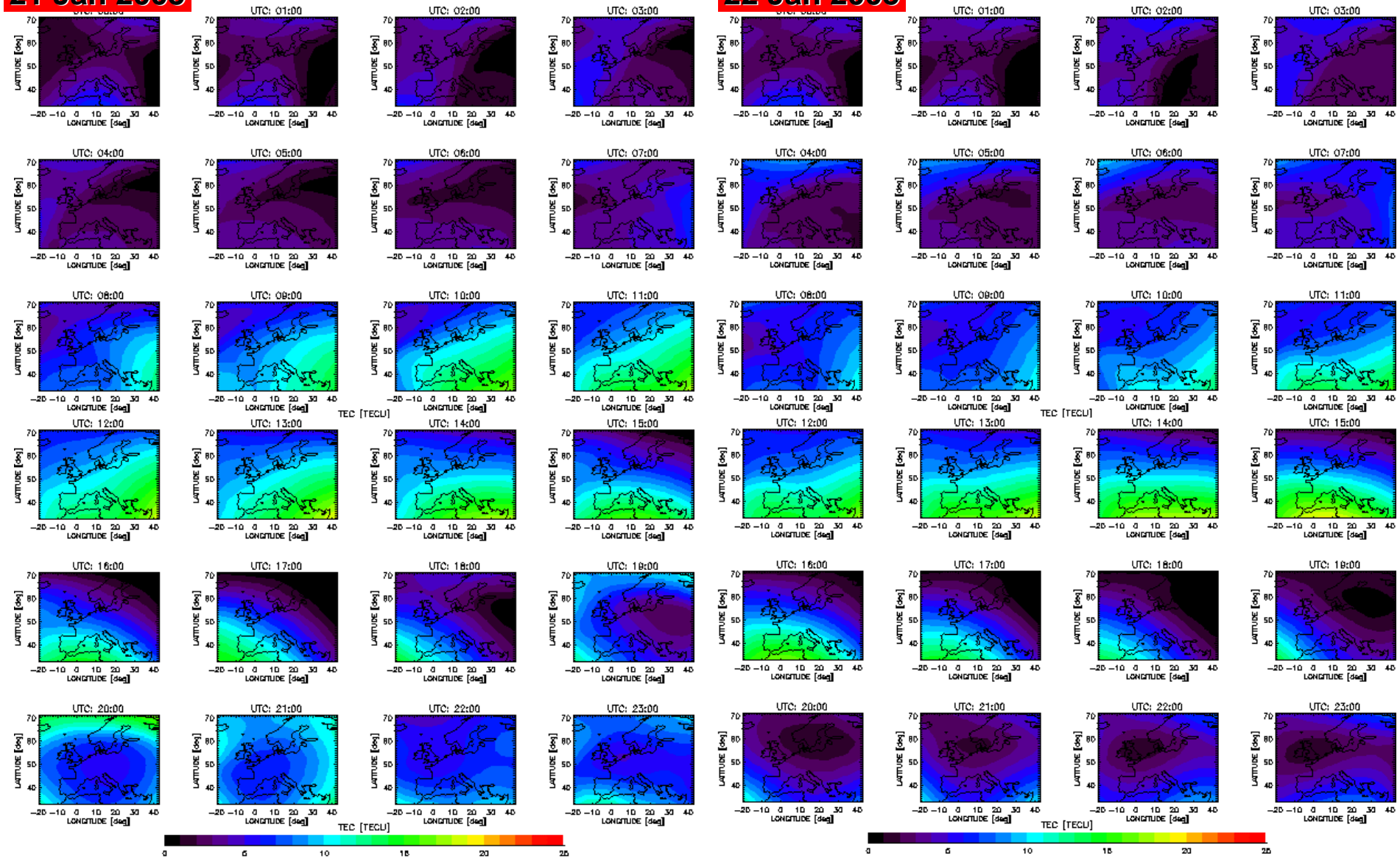
**10 Sep 2005**



# European TEC observations

21 Jan 2005

22 Jan 2005

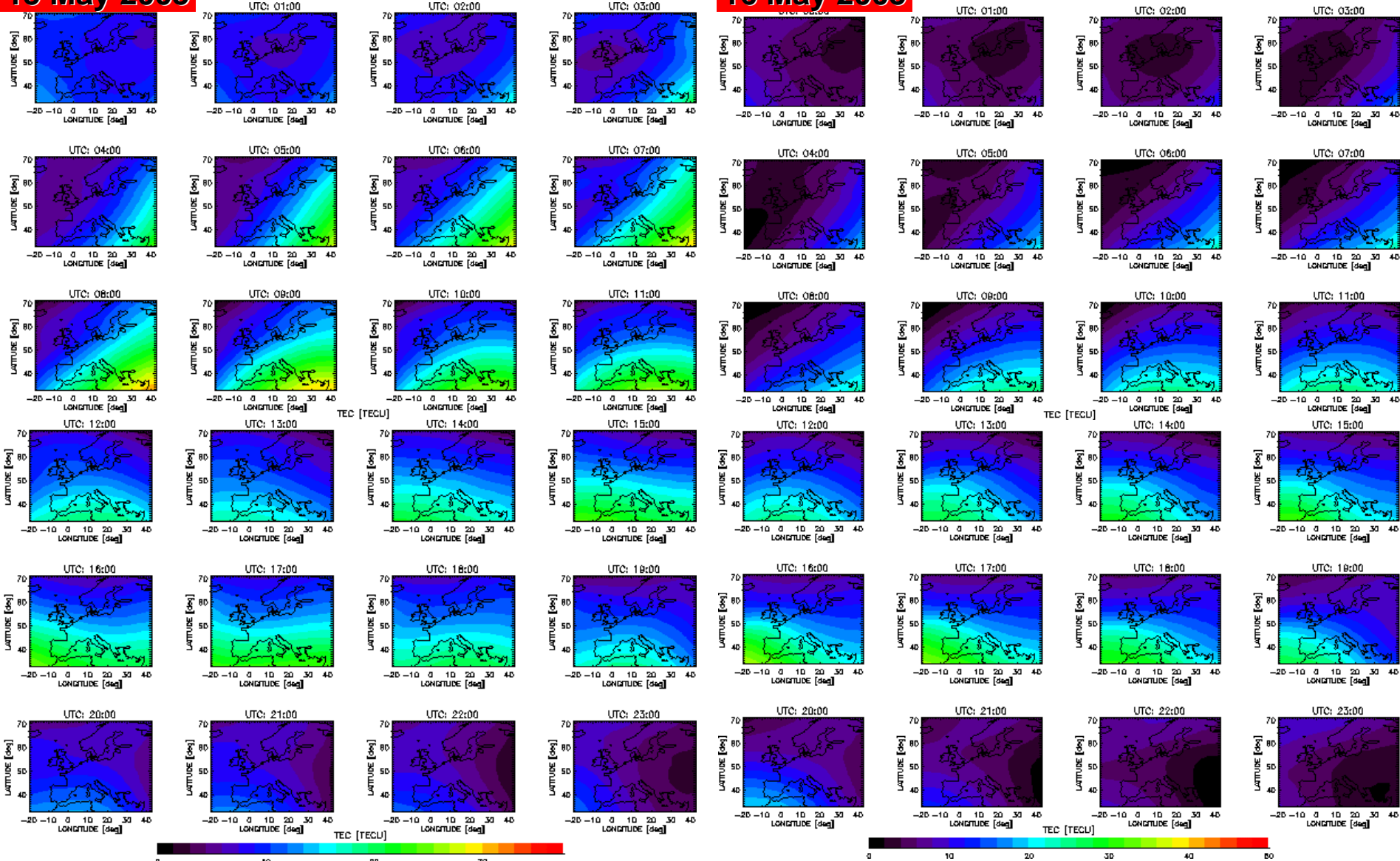




# European TEC observations

15 May 2005

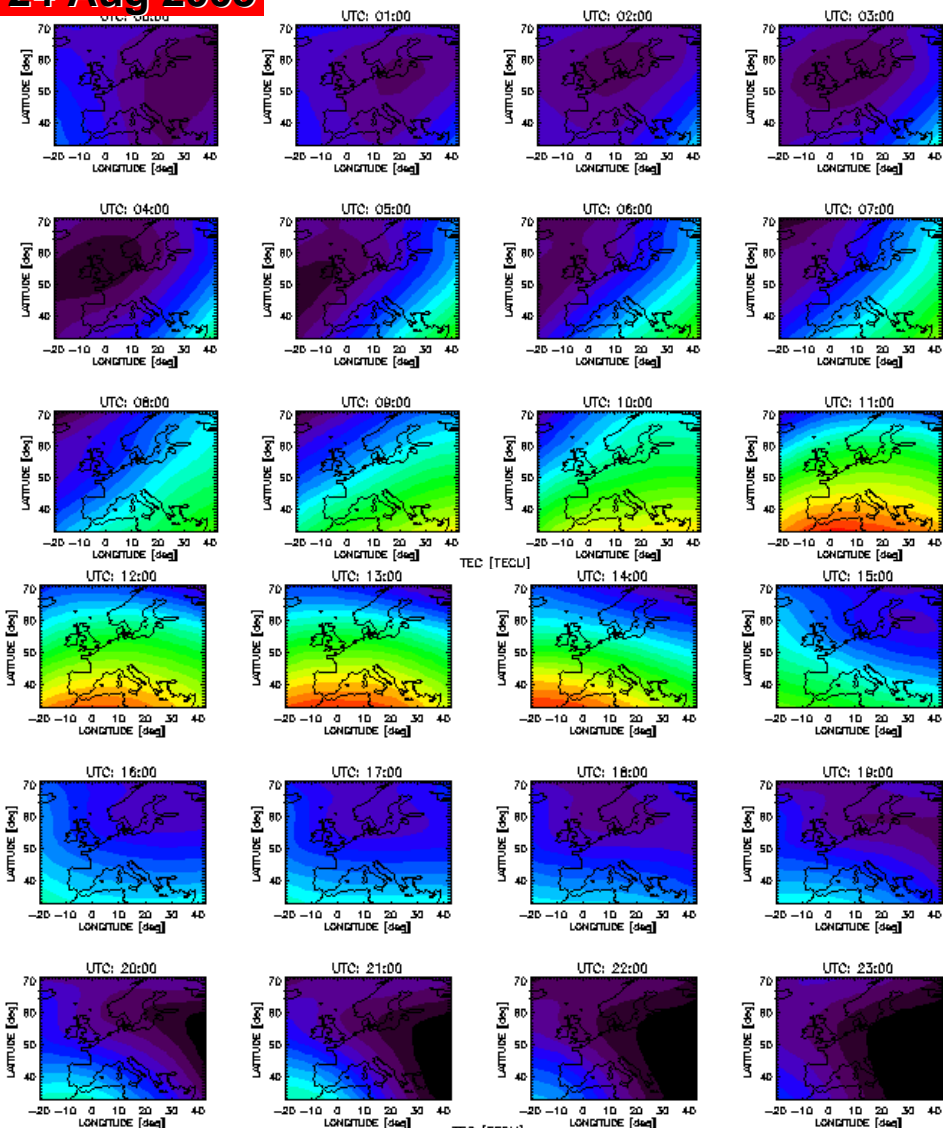
16 May 2005



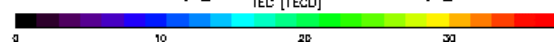
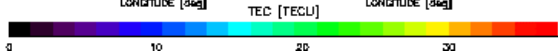
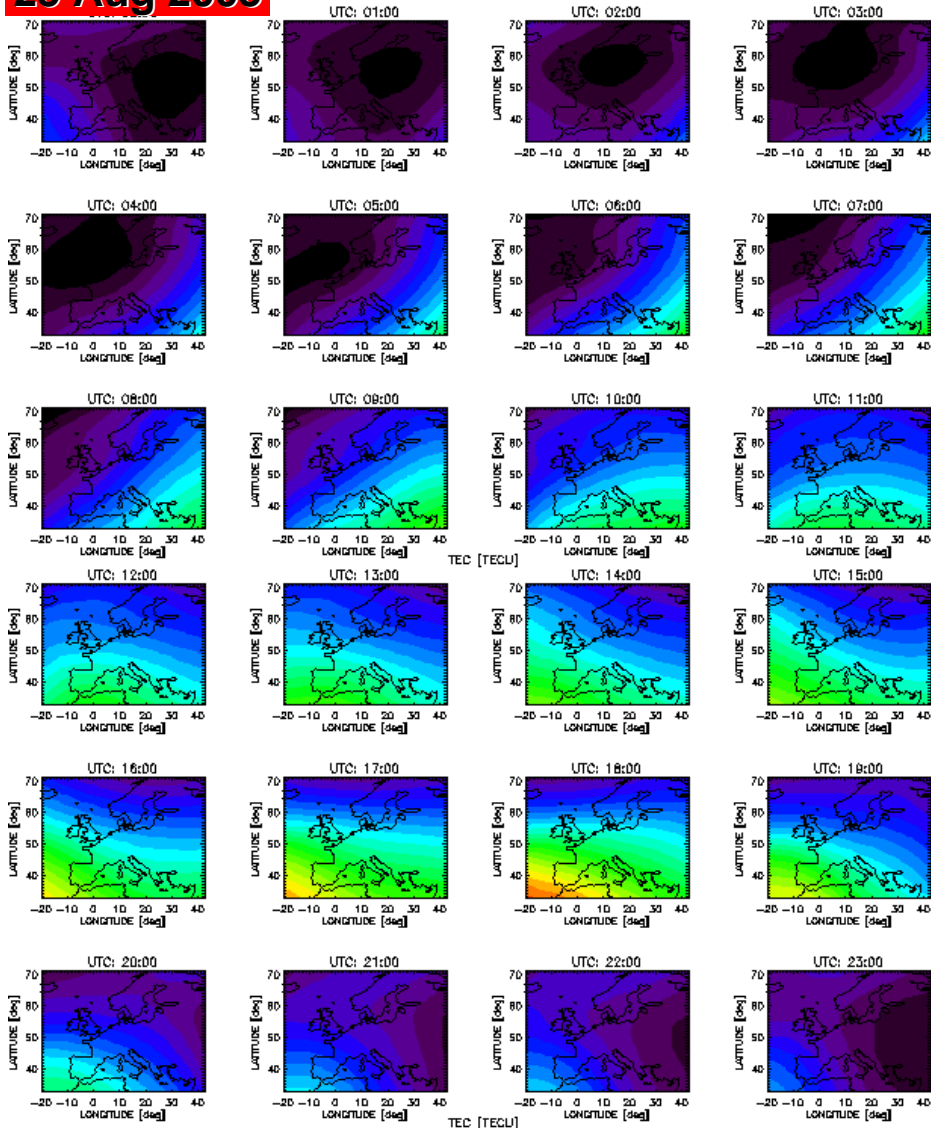


# European TEC observations

24 Aug 2005



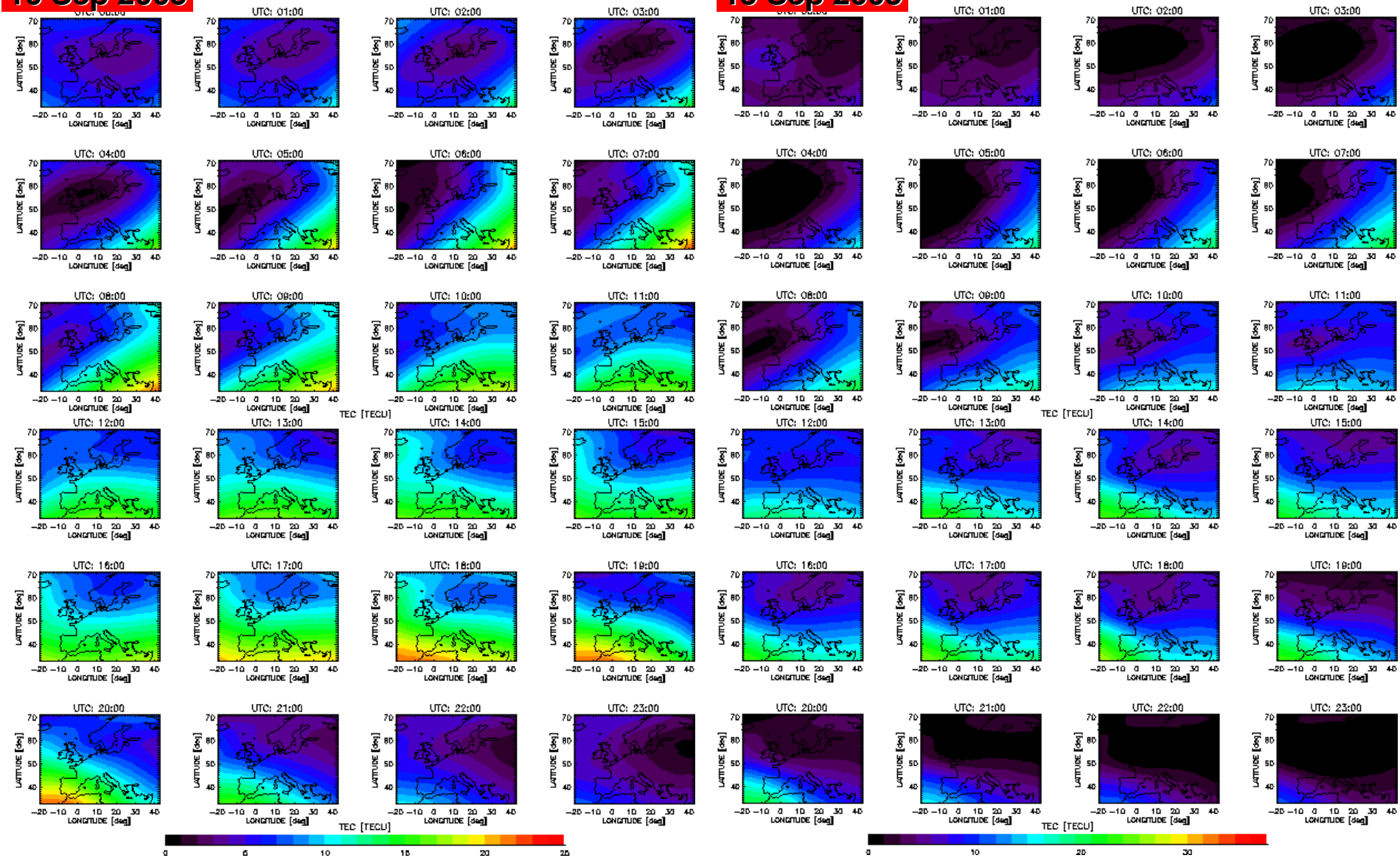
25 Aug 2005



# European TEC observations

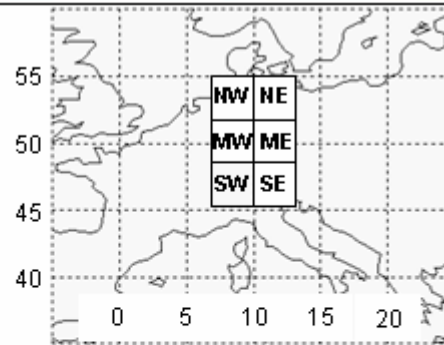
10 Sep 2005

15 Sep 2005



# GNSS reference network integrity during ionospheric disturbances

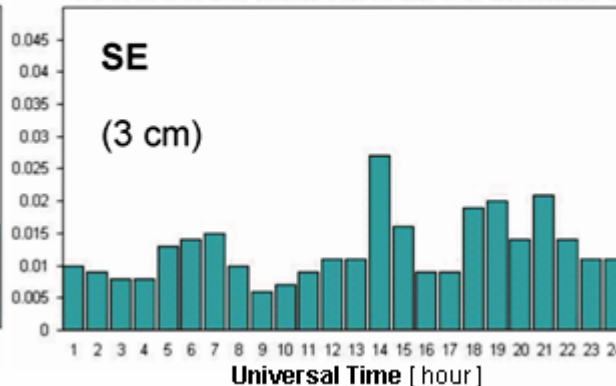
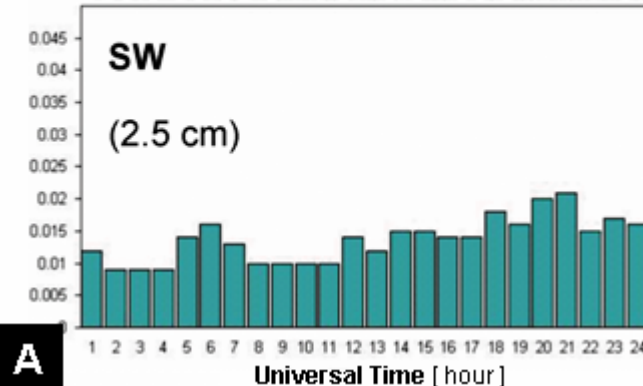
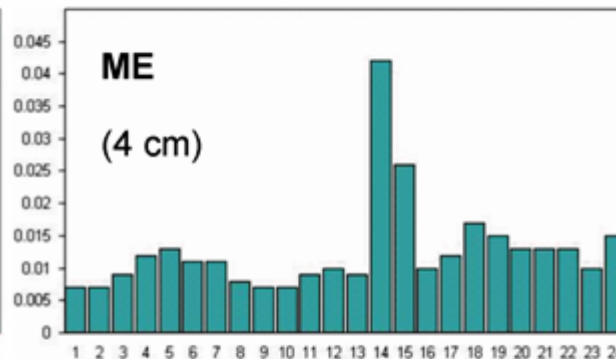
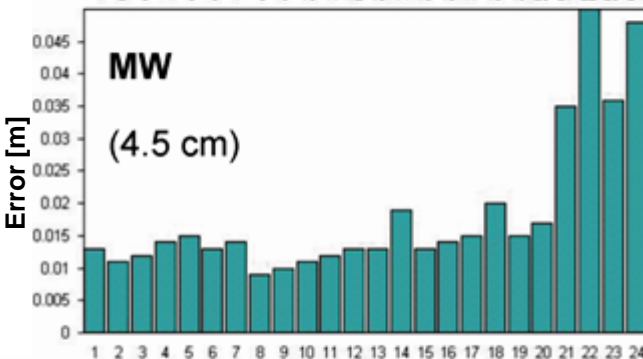
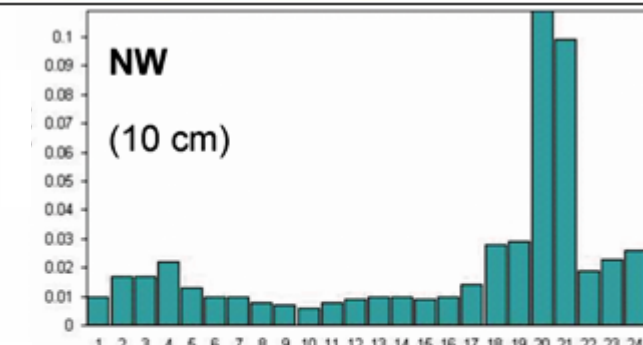
25 July 2004



## Non-linear Error

### Estimation:

- . ionospheric influence on GNSS signals determined;
- . linear parts of these effects removed by applying ionospheric and geometric corrections;
- . influence on user position is interpolated from the influence determined on surrounding reference stations;
- . predicted error is compared with measured values and ionospheric and geometric errors are estimated.

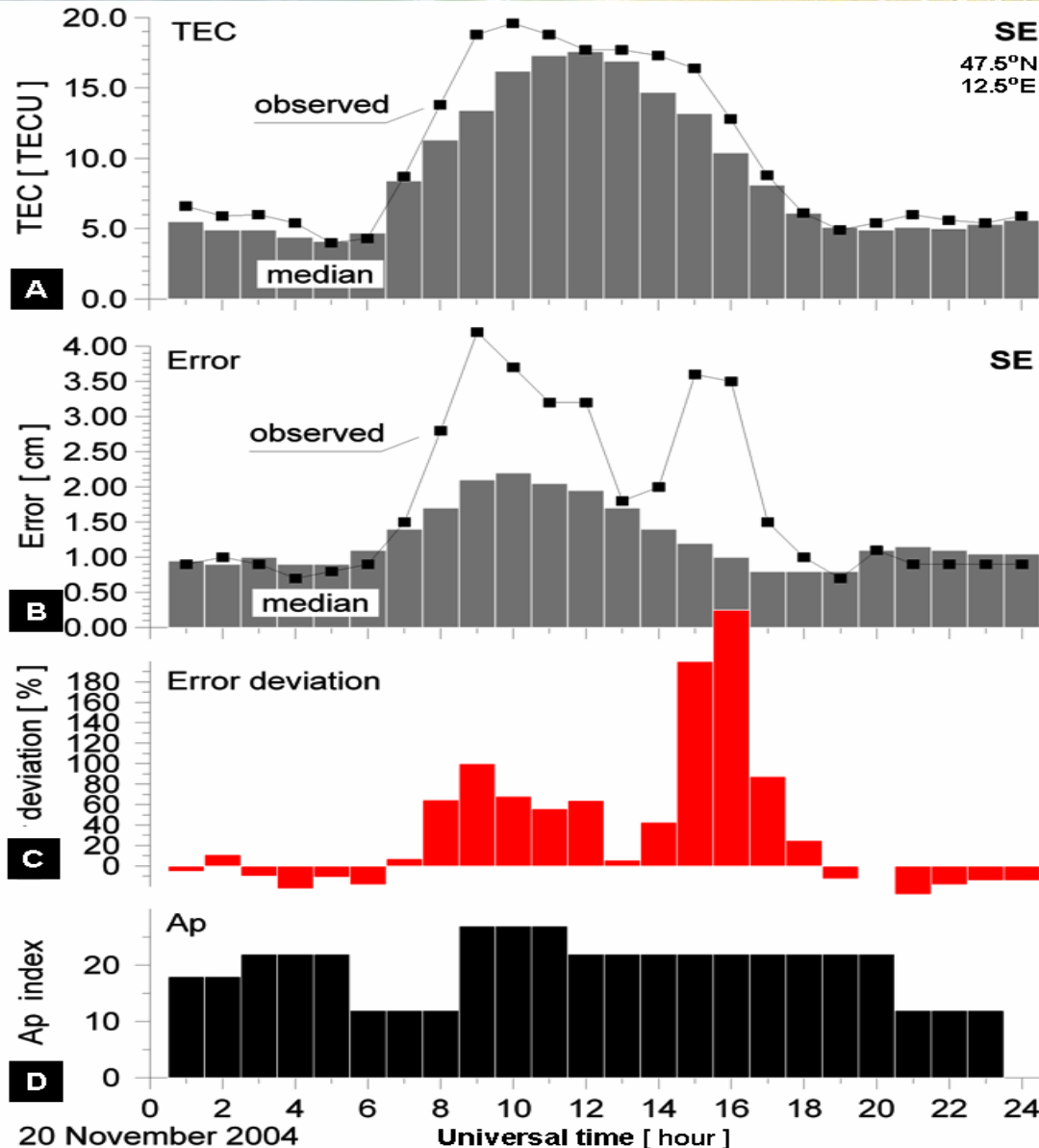
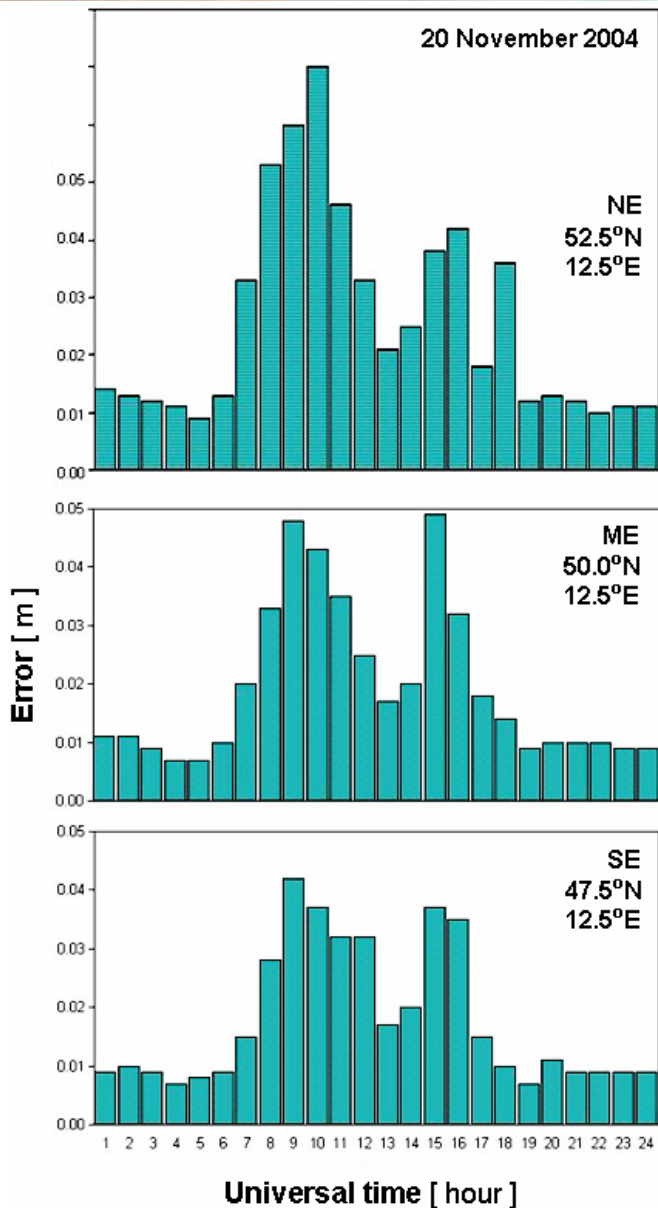


## REFERENCE NETWORK MODEL INTEGRITY



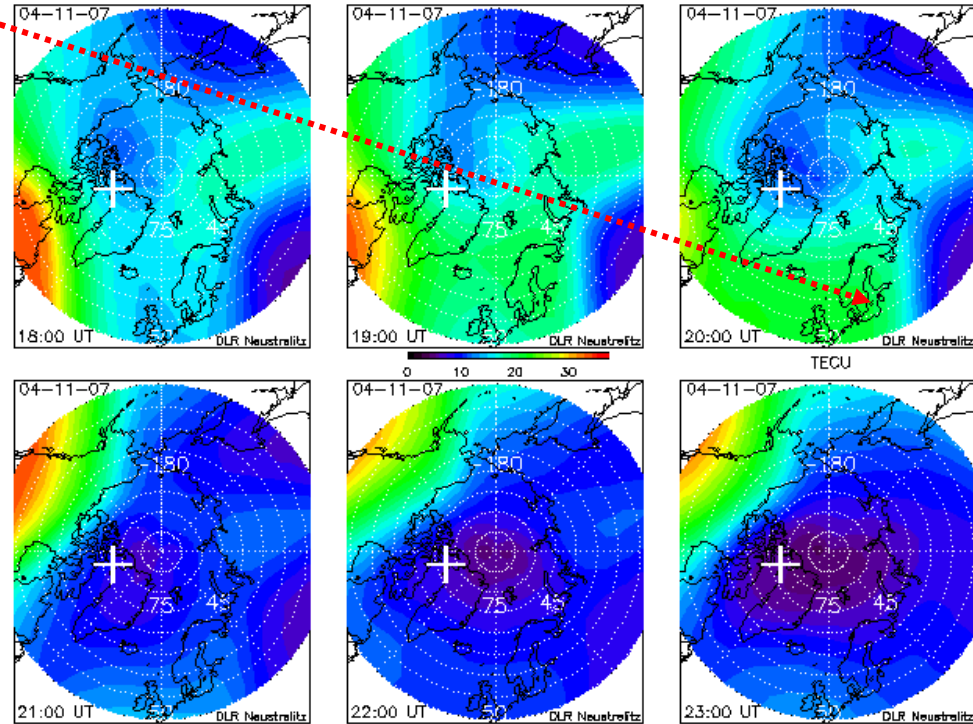
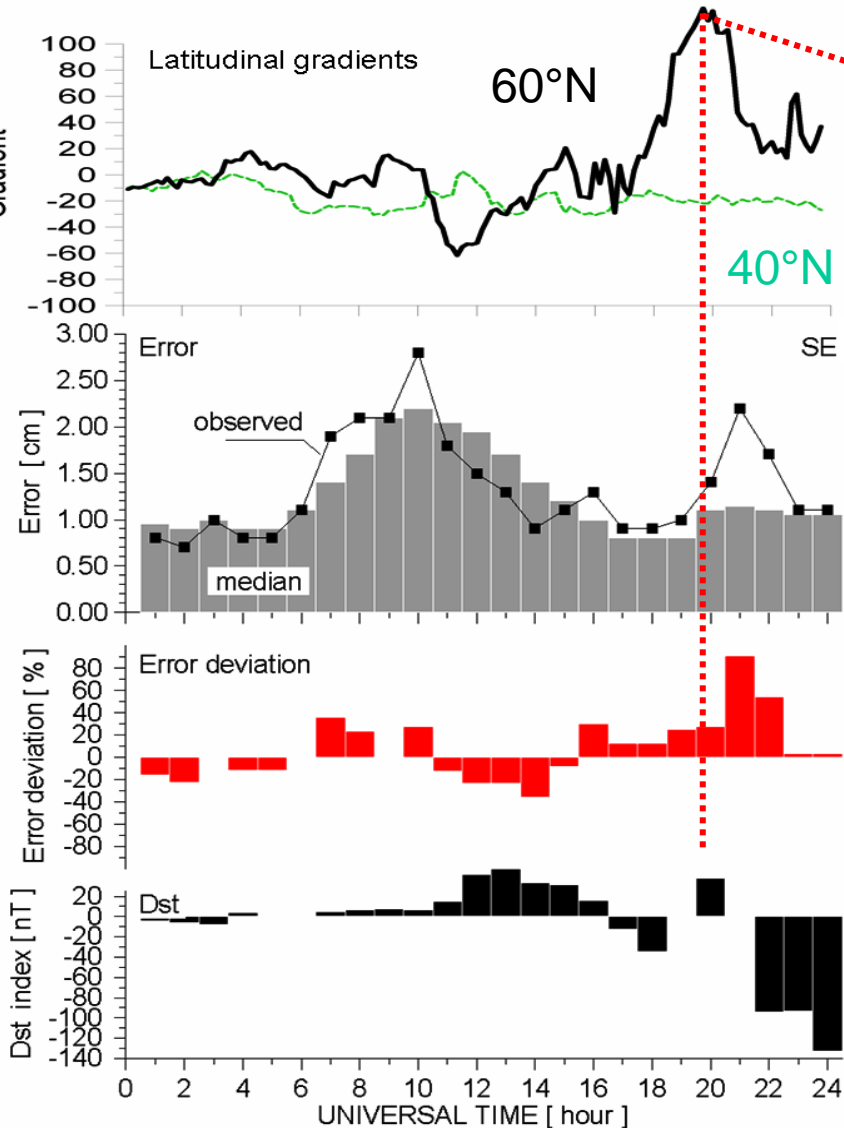


Error Propagation – storm time pattern



## Latitude Gradient Index

7 November 2004



- The latitudinal gradient index (at high latitudes) is correlated with the (relative) residual error in GPS reference networks and therefore, with the network model integrity/performance
- The latitudinal gradient index is a potential tool for forecasting problems in GNSS reference networks, e.g. increased time to fix ambiguities

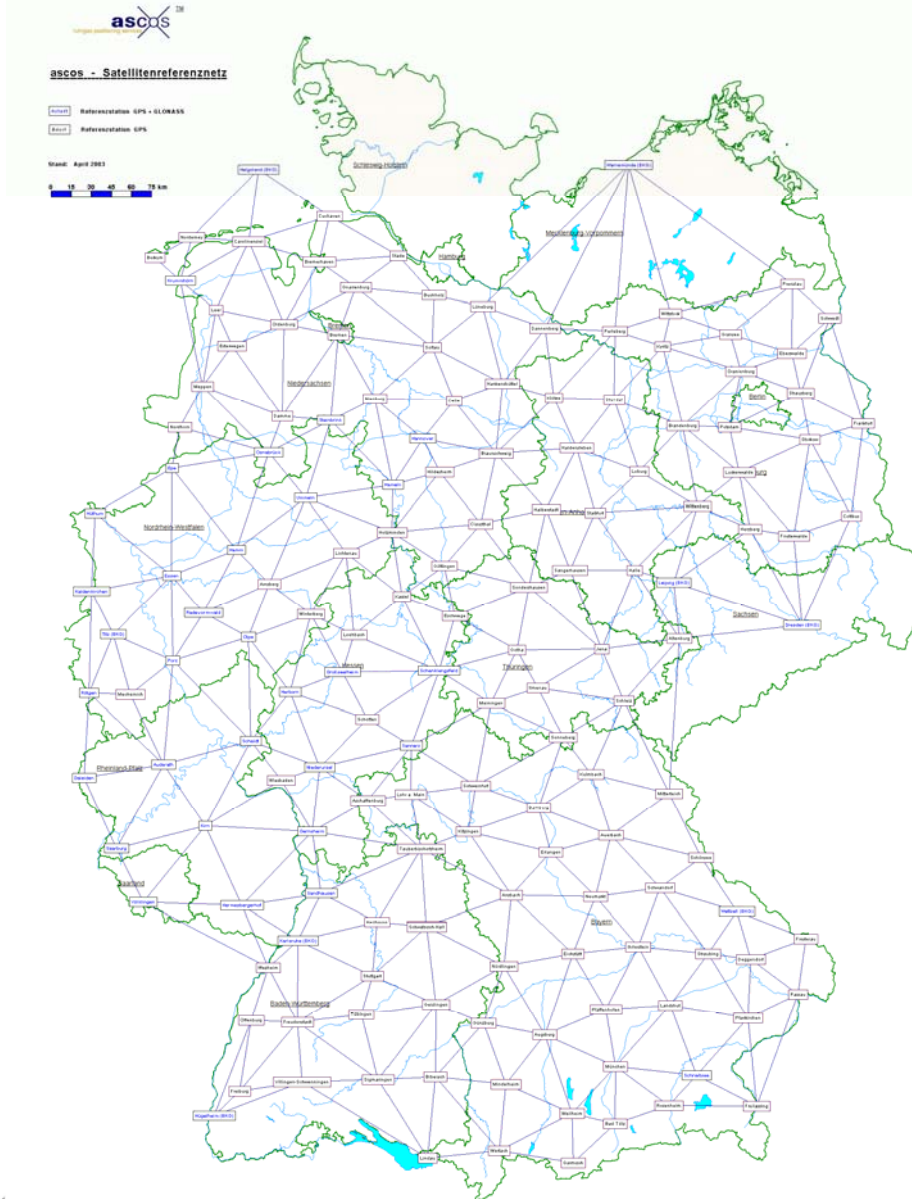
# DLR Operational Space Weather Service - Ionosphere



- Operational provision of GPS data
- Pre-processing and calibration
- Generation of TEC maps and derivatives
- Development of forecast models
- Post-processing and analysis of space weather effects
- Analysis of benefit for service users

<http://www.kn.nz.dlr.de/swippa/index.htm>





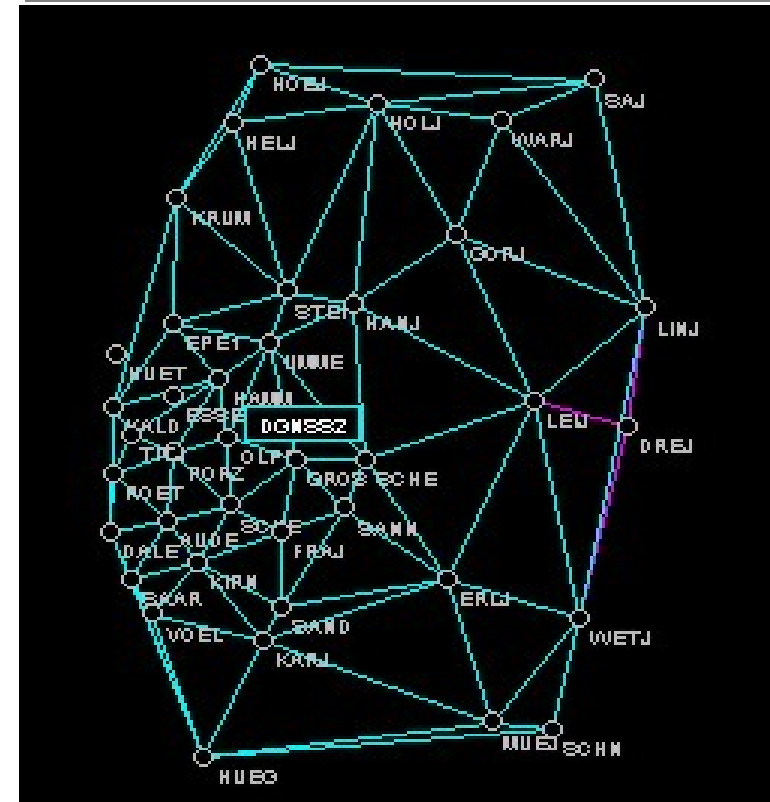
GPS / GLONASS stations

ascos reference network

RINEX format

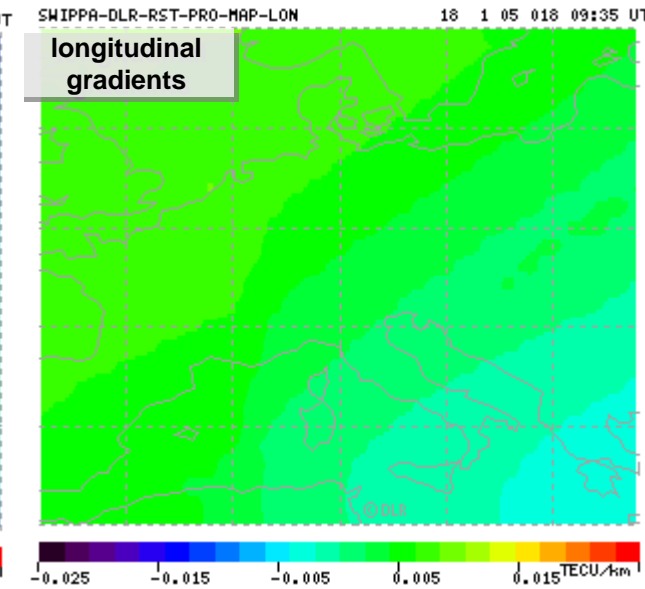
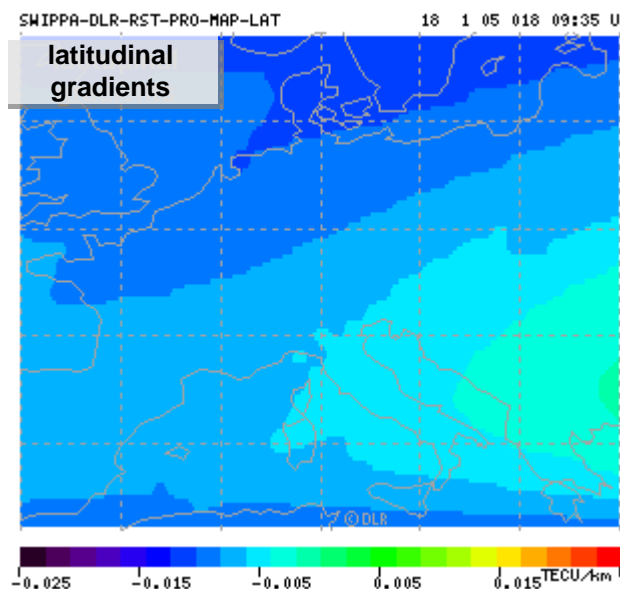
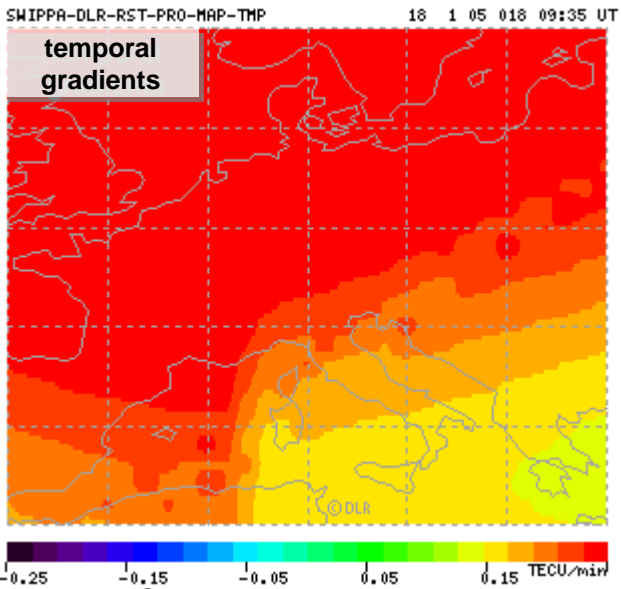
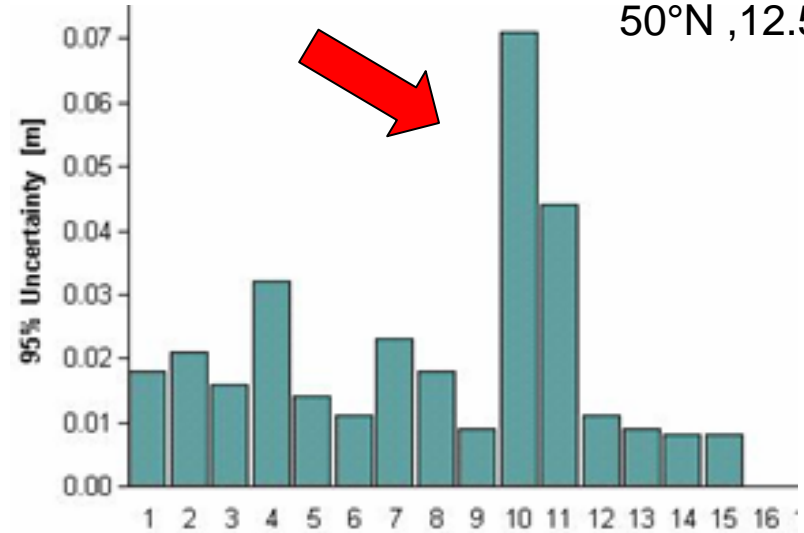
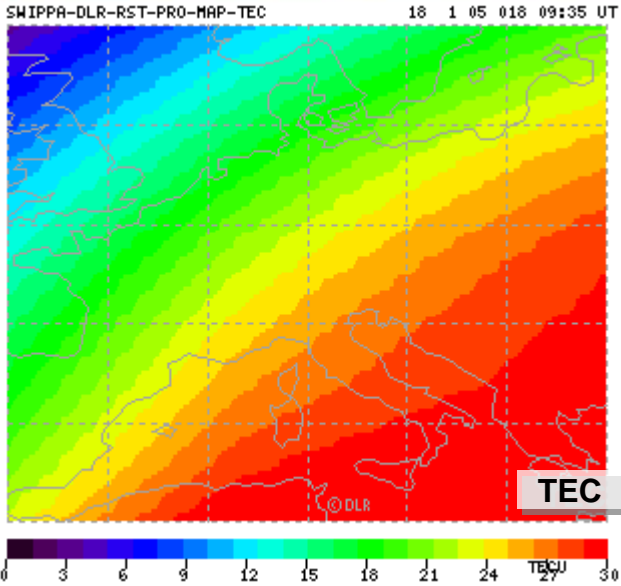
6 sub networks

35 stations used



**18 Jan 2005**

50°N, 12.5°E



DLR-Institut für Kommunikation und Navigation - Microsoft Internet Explorer

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

**Institute of Communications and Navigation**

**SWENET**

Home IKN  
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Rules of Use

**SWENET Contents**

- Introduction
- SWENET Services
- Look for Services
- Latest Data
- Space Weather Data
- Data Browsing
- FTP Mirror
- Latest SEC Plots
- Latest Indices
- Statistics
- Daily Reports
- Message of the Day
- Report Browsing
- User Area
- Login
- Register

**SWENET Services**

- GIC Effects
- Ionospheric Effects
- Spacecraft Effects

**Welcome to SWENET**  
**Space Weather European Network**

With the increasing importance of space weather aspects in space missions, it is important to provide industry and other users with the means to access space weather data and services. The Service Development Activities (SDA) being currently developed as part of ESA's Space Weather Applications Pilot Project will provide a series of applications, services and data products involving all space weather aspects for a wide range of users. The products resulting from these activities will be available through the Space Weather European Network - SWENET.

The SWENET Infrastructure is a central resource centre for space weather activities, providing interested users access to space weather data and services.

To access the different sections of the SWENET Infrastructure use the menu on the left.

**Geomagnetic field disturbance**  
*Provided by GAFS (DMI)*

Level of disturbance of the geomagnetic field expected over the next two days at *Brorfelde (BFE) - Denmark*.

	0-3 hrs	3-12 hrs	12-48 hrs
f_pos	0	0	3
f_neg	0	0	3
d_pos	0	0	3
d_neg	0	0	3
i_pos	0	0	3
i_neg	0	0	3

Last update: 2005-07-15 12:35

**TEC Maps over Europe**  
*Provided by SWIPPA (DLR)*

TEC maps with a 5 minute resolution presenting the vertical TEC (in TECU) over Europe.

Last update: 2005-07-15 12:55

**Current Space Weather Forecast, provided by SIDC (ROB/BIRA)**

es: Eruptive    Geomagnetism: Minor geomagnetic storm expected    Protons:

**SWENET: Showroom - Microsoft Internet Explorer**

Address: <http://www.esa-spaceweather.net/sw/>

This table contains TEC maps with a 5 minute resolution presenting the vertical TEC (in TECU) over Europe. Data courtesy of SWIPPA (DLR).

DLR-RST-PRO-MAP-TEC    15 7 05 196 12:55 UT

0 3 6 9 12 15 18 21 24 27 30

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warranty.html



**Pronounced seasonal and latitudinal differences** in ionospheric storm generation/development

Positive ionospheric storms – more frequent and much stronger during winter

Ionospheric irregularities - higher frequency during night and higher intensity during winter

TEC – basic parameter for monitoring the ionospheric storm generation and propagation

Permanent combined ground- and space- based observations of several ionospheric parameters  
– the key to understanding space weather / ionosphere storm effects and their prediction

**Operational space weather / ionosphere monitoring is required**

in present-day GNSS-based precise positioning services

High resolution mapping – absolutely necessary if small-scale phenomena are targeted

Positive feedback from end users / customers

TEC (and derivatives) mapping - optimal resolution: spatial - 1 deg, time - 5 min

Space Weather Warnings / Alerts – optimal update rate: 5 min

**Requirements for even higher resolution products and user friendly services**