USE OF GPS-DERIVED TEC MEASUREMENTS TO MAPPING AND FORECASTING OF foF2 OVER EUROPE

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GPS observations of the European Permanent Network (EPN) were used to study the possibility of evaluating foF2 parameter on the base of TEC data. The slab thickness parameter (τ) served as a factor to convert the TEC to foF2. The TEC data over Europe have been obtained from TEC maps. When creating TEC maps the GPS measurements of EPN network were used. The dense network of GPS stations in Europe provided high spatial and temporal resolution of TEC maps as well as foF2. The time resolution of TEC maps is about 15 min.

For simplification, only the value of τ was used to obtain foF2 for one month time interval. The good agreement between GPS-derived TEC data and measured foF2 took place for quiet and moderate geomagnetic conditions. The rms of foF2 obtained from TEC data and measurements has reached 1.0-1.5 MHz for all middle-latitude European ionosonde stations in November 2003.

In the paper the possibility of foF2 forecasting on the base of short-term forecasting of TEC is also discussed. The Autocovariance and Autoregressive Moving Average (ARMA) methods were used in this study. The forecasts of foF2 time series obtained from GPS TEC maps were computed for one, two and three hours ahead at a single European ionosonde station, and compared with the corresponding real values of foF2.

GPS DATA SOURCE AND ESTIMATION TECHNIQUE

- GPS measurements of European IGS stations for 1996-2005 were used to obtain TEC data.
- For TEC estimation we used the single site algorithm. The TEC was approximated as a function of the local time (LT) and difference between the receiver latitude and the latitude of the subionospheric point (sp) along satellite passes.
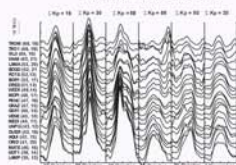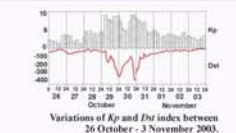- The absolute TEC and the instrumental biases were estimated using the single site algorithm.

Geographic map of GPS stations used for retrieving TEC over Europe

The diurnal variation of TEC:

$$TEC = a_0 + \sum_{i=1}^{6} a_i \cos is + \sum_{i=1}^{6} b_i \sin is + c_1 \Delta\varphi + c_2 \Delta\varphi s + c_3 \Delta\varphi^2$$
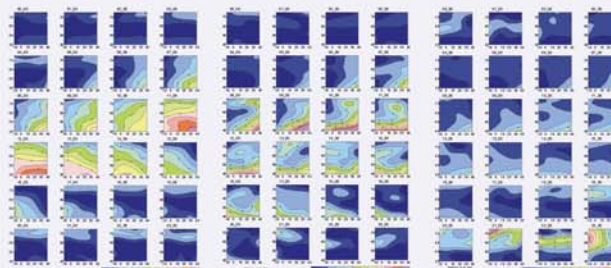
MAPPING OF TEC OVER EUROPE BASED ON GPS PERMANENT OBSERVATIONS

Variations of Kp and Dst index between 26 October - 3 November 2003.

Diurnal variations of TEC at different latitudes during storm of 27 October - 1 November 2003.

Storm-time dynamics of diurnal variations of TEC

The TEC maps over Europe for 28, 29 and 30 October 2003

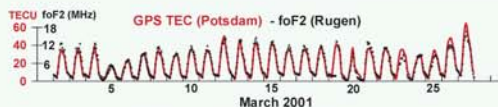## COMPARISON OF foF2 DATA BASED ON GPS-DERIVED TEC MAPS WITH REAL foF2 DATA

The critical frequency foF2 is a key parameter for radio wave propagation. For HF radio communication it is necessary to known the foF2 parameter with high spatial and temporal resolution in near-real-time.

Such assessment could be provided with the monitoring of ionospheric parameters by continuously ionosonde measurements. But the available ionosonde network does not provide the sufficient spatial resolution and especially during disturbances the information from ionosonde can be lacked.

In contrast to the ionosonde network, the GPS permanent networks (IGS and EPN) are broad and provide the TEC measurements even during severe geophysical condition with 30 sec time resolution.

In the report we present the comparison of foF2 data based on TEC maps with real foF2 data over European stations (Chilton, Anhens, Tromso and Tortosa) for periods of moderate and high solar activity.

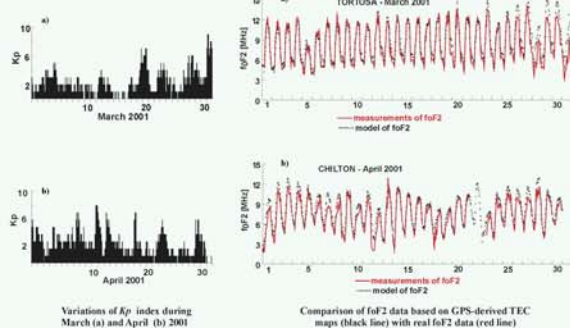### CONVERSION OF TEC OBTAINED FROM MAPS TO foF2 DATA

GPS TEC (Potsdam) - foF2 (Rugen)

The variations of GPS-derived TEC over Potsdam and foF2 measuremests over Rugen station during March 2001

The relation between the TEC and the critical frequency foF2 using the slab thickness parameter (τ):

$$\tau = \frac{TEC \cdot 10^{16}}{1,24(foF2)^2 \cdot 10^{10}}$$
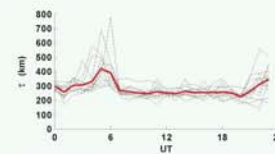
The day by day variations of τ for November 2003 over Chilton

March and April 2001 maximum solar activity

Variations of Kp index during March (a) and April (b) 2001

TORTOSA - March 2001
— measurements of foF2
— model of foF2

CHILTON - April 2001
— measurements of foF2
— model of foF2

Comparison of foF2 data based on GPS-derived TEC maps (black line) with real foF2 data (red line) over Tortosa (a) and Chilton (b)

October 2003 moderate solar activity
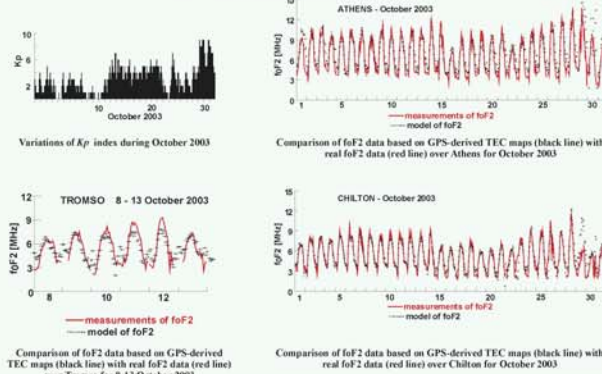
Variations of Kp index during October 2003

ATHENS - October 2003
— measurements of foF2
— model of foF2

Comparison of foF2 data based on GPS-derived TEC maps (black line) with real foF2 data (red line) over Athens for October 2003

TROMSO 8 - 13 October 2003
— measurements of foF2
— model of foF2

Comparison of foF2 data based on GPS-derived TEC maps (black line) with real foF2 data (red line) over Tromso for 8-13 October 2003

CHILTON - October 2003
— measurements of foF2
— model of foF2

Comparison of foF2 data based on GPS-derived TEC maps (black line) with real foF2 data (red line) over Chilton for October 2003

FORECASTING OF TOTAL ELECTRON CONTENT

- The TEC measurements for all European IGS permanent stations were used to study day-to-day prediction of the TEC.
- The TEC forecasts were done using the two methods: autocovariance and ARMA. Forecasting of TEC data was calculated 1, 2, and 4 hours ahead for ionospheric quiet and disturbed conditions from 1995 to 2004.
- The results for middle-latitude stations Borowiec, Matera and Hers from different disturbed periods: October 27-31, 2003 and November 5 - 12, 2004 are presented, respectively.

AUTOCOVARIANCE prediction metod

In the Autocovariance prediction the first prediction point satisfies the following condition:

$$R(x_{n+1}) = \sum_{i=1}^{n} \left[\tilde{c}_{xx}^{(i)}(k) - \tilde{c}_{xx}^{(n+1)}(k) \right]^2 = \min,$$

where:

$$\tilde{c}_{xx}^{(i)}(k) = \frac{1}{n} \sum_{i=1}^{n-k} x_i x_{i+k} \quad \text{for} \quad k = 0, \ 1,...,n-1$$

$$\tilde{c}_{xx}^{(n+1)}(k) = \frac{1}{n+1} \sum_{i=1}^{n+1} x_i x_{i+k} \quad \text{for} \quad k = 0, \ 1,...,n$$

The first predicted point:

$$x_{n+1} = \frac{\sum_{k=1}^{n} \tilde{c}_{xx}^{(n)}(k) x_{n-k+1}}{\sum_{k=1}^{n} x_{n-k+1}^2}$$

For the prediction computation, the last 50 days of the TEC values were taken.

ARMA prediction method

The Autoregressive-Moving Average process ARMA(p,q):

$$y_t = \sum_{i=1}^{p} \alpha_i y_{t-i} + \sum_{i=0}^{q} \phi_i n_{t-i}$$

B - backshift operator $\quad B^k z_t = z_{t-k}$

$$y_t = \frac{\phi(B)}{\alpha(B)} n_t = \psi(B) n_t$$

ARMA FORECAST

$$\hat{y}_{t+L} = \left\{ \frac{\psi(B)}{B^L} \right\}_+ \frac{y_t}{\psi(B)}$$

$\left\{ \frac{\psi(B)}{B^L} \right\}_+$ the part of the operator containing only nonnegative powers of B

For the prediction computation, the last 5 - 7 days of the TEC values were taken.

MATERA
October 27-31, 2003

HERS
October 27-31, 2003

BOROWIEC
November 5 - 12, 2004
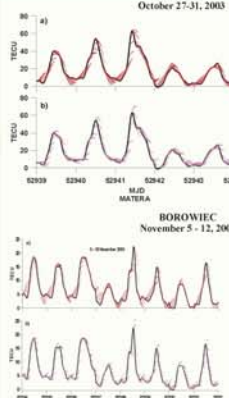
Three-hour ahead forecast of TEC over Matera, Hers and Borowiec using Autocovariance (a, red points) and ARMA (b- pink points) at different starting prediction epochs: October 27-31, 2003 and November 5 - 12, 2004. For comparison, the real TEC data over Matera, Hers and Borowiec are also shown (black line). c) the mean Autocovariance (red line) and ARMA (pink line) prediction errors of TEC data at Matera, Hers and Borowiec during October 27-31, 2003 and November 5 - 12, 2004.

CONCLUSIONS

GPS observations of the European Permanent Network (EPN) were used to study the possibility of evaluating foF2 parameter on the base of TEC data. Our research has led to the following conclusions:

- The slab thickness parameter (τ) served as a factor to convert the TEC to foF2.
- The good agreement between GPS-derived TEC data and measured foF2 took place for quiet and moderate geomagnetic

- The rms of foF2 obtained from TEC data and measurements has reached 1.0-1.5 MHz for all middle-latitude European ionosonde stations in March-April 2001 (maximum solar activity) and October 2003 (moderate solar activity).

- During disturbed geomagnetic conditions the rms of foF2 obtained from TEC data and measurements was bigger.

- The Autocovariance and ARMA methods are very simple and do not require any a priori information about the process, or additional inputs such as solar or magnetic activity indices.

- In contrast to the Autocovariance method, TEC values for only several previous days are needed to calculate ARMA forecasts.

- Today the IGS / EPN networks are broader and denser than the ionosonde one. Joint foF2 obtained from TEC maps data and foF2 ionosonde measurements can be used in the investigations aiming at creating the near-real and predicted foF2 maps over Europe.