3D electron density specification to support LEO and MEO satellite applications

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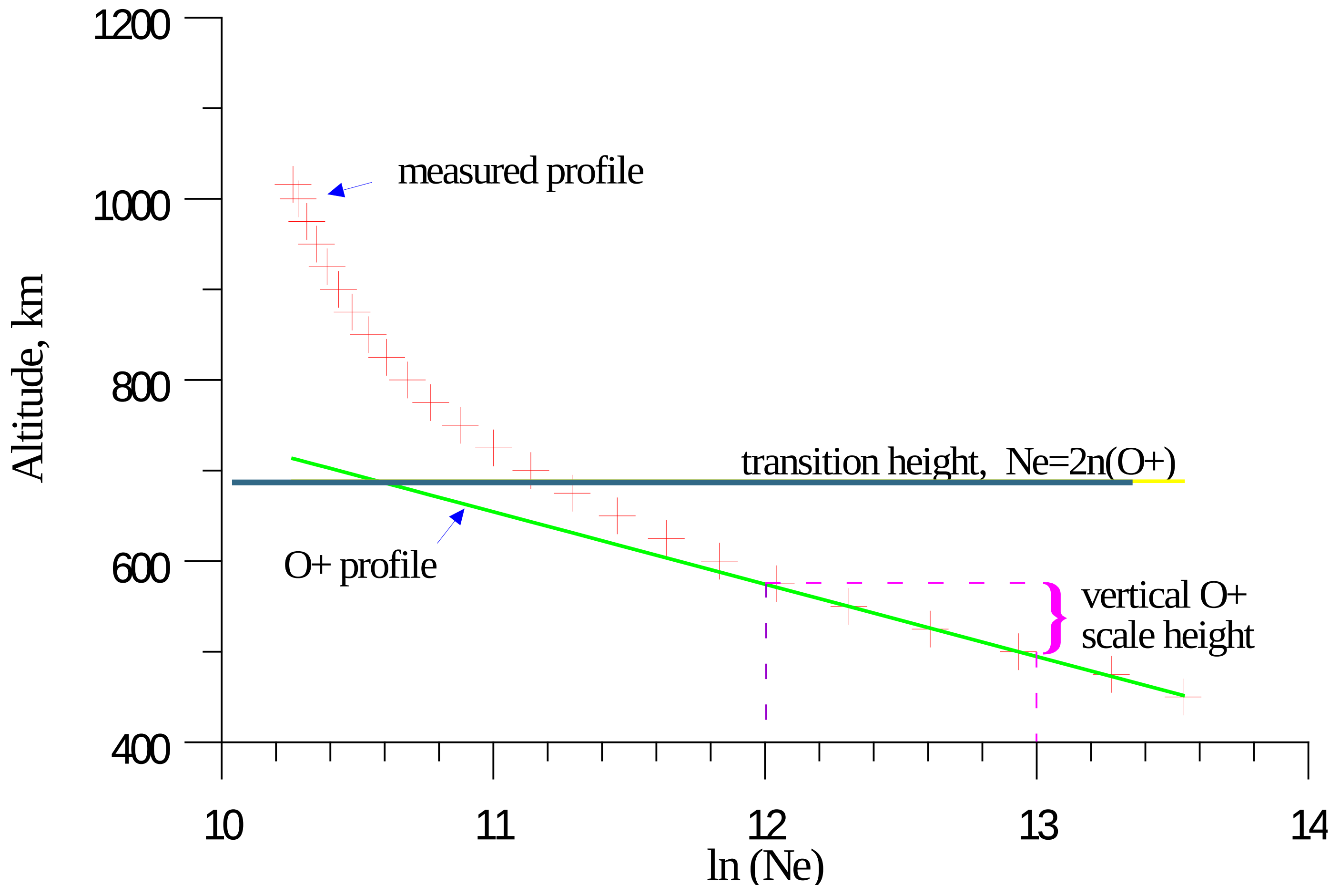
Executive Summary

- The TaD model as a tool to specify 3D Electron Density Distribution
  - Evaluation of the TaD performance at 1D
  - Operational implementation
  - Development of the 3D EDD TaD version and verification
- Comparison of the 3D TaD model results with DEMETER *in situ* electron density was measured by ISL (Instrument Sonde Langmuir)
- Error assessment
- Concluding remarks

The TaD model – basic concept

- Definition of scale height(HT) and transition height (hT) from 176,622 topside electron density (Ne) profiles from the Alouette-1a, -1b, -1c and -2 and ISIS-1 and -2 topside sounders, covering the period 1962-1979 (NSSDC database).
- From each individual Ne profile: the vertical O^+ scale height (HT) and the O^+/H^+ transition height (hT) are extracted.
- HT is defined as the lowest gradient of the measured Ne profiles.
- The hT is defined as the height at which the extrapolated to higher altitudes lowest Ne gradient yields a density which is one half of the measured Ne.



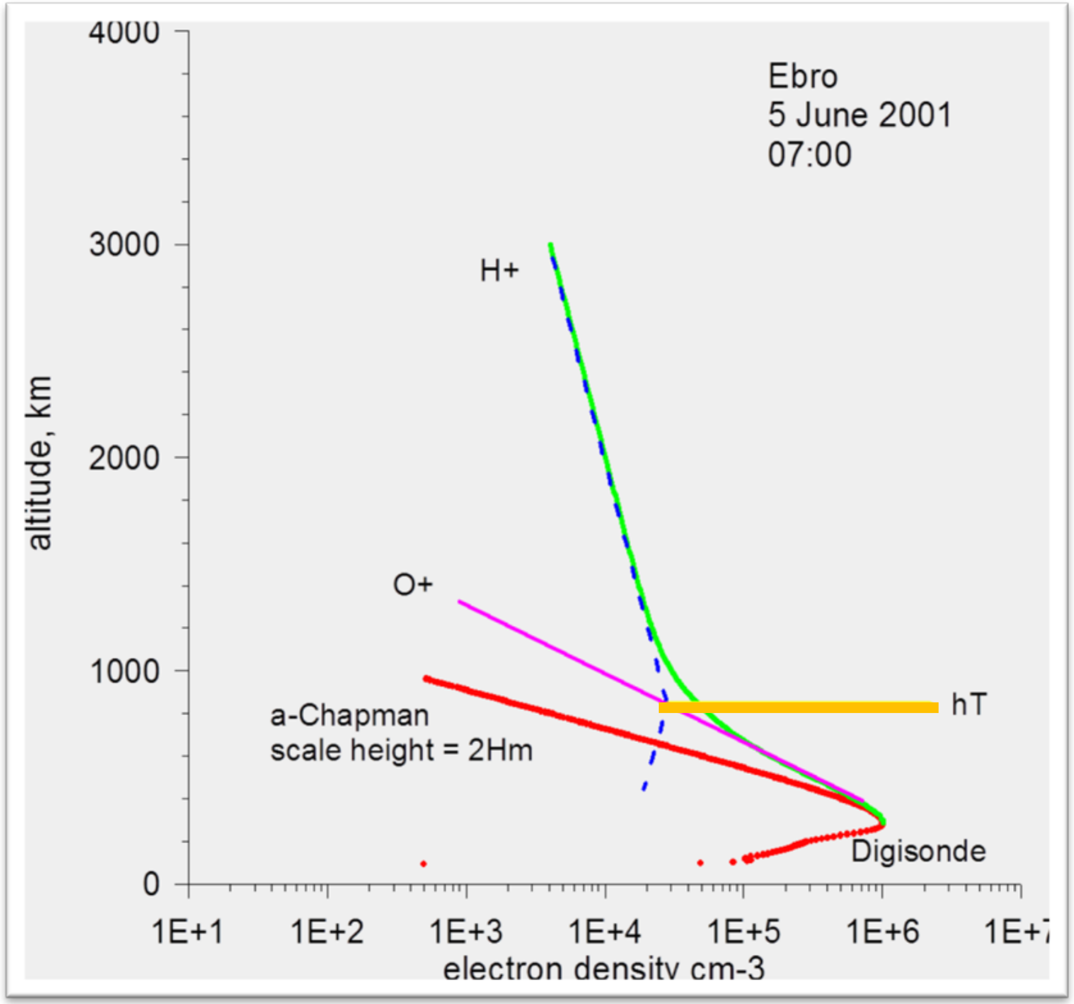
TaD ED profile reconstruction

<u>Step 4</u>: Adjust the TaD EDP to the GNSS-TEC taken from EUREF TEC maps at the Digisonde locations

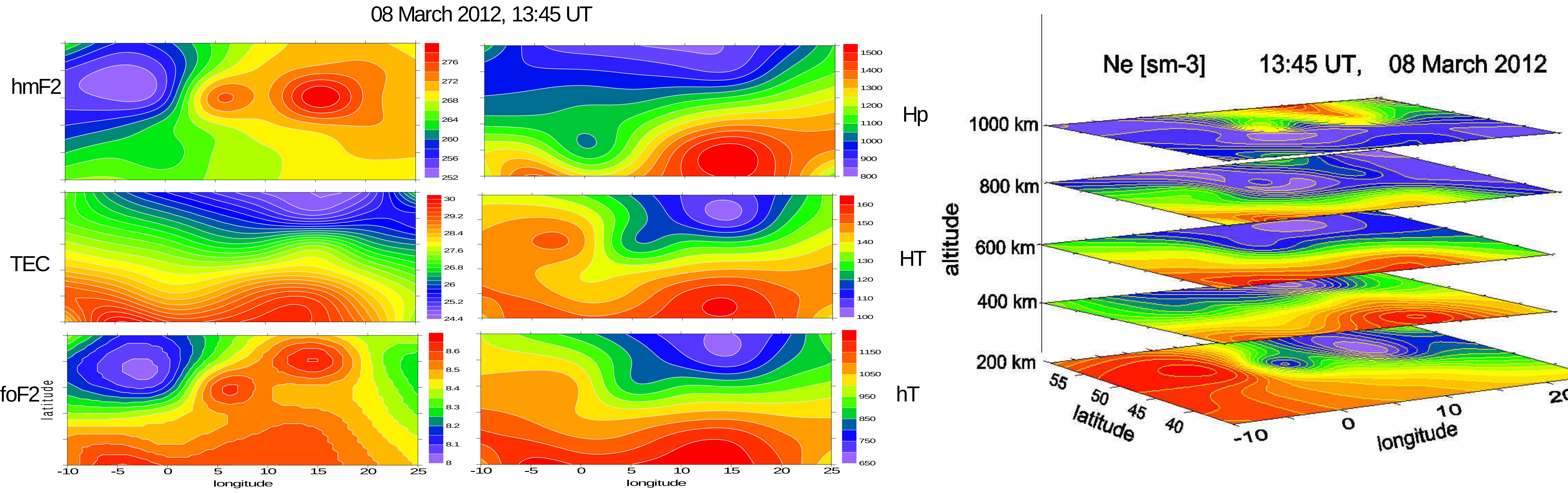
<u>Step 3</u>: Link TSMP to Digisonde Profiler: modify the Digisonde Hm neutral scale height to comply with H_T

<u>Step 2</u>: TSMP defines the shape:
- α-Chapman for O^+
- exponential for H^+

<u>Step 1</u>: TSM provides: H_T, h_T, and their ratio RT depending on gm lat, DoY, LT, solar flux and Kp



TaD maps over Europe

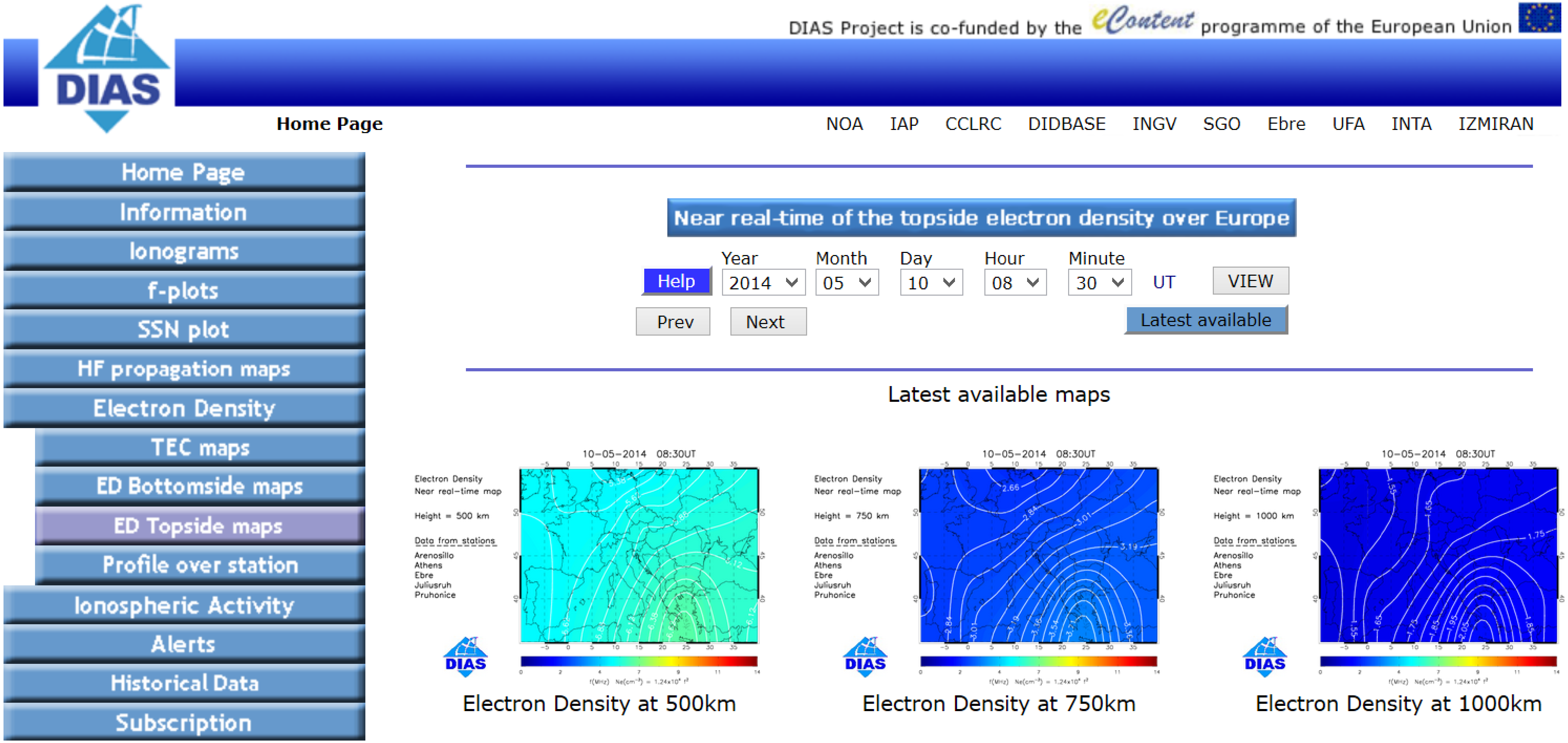


1. Maps are produced by Polyweight interpolation procedure.

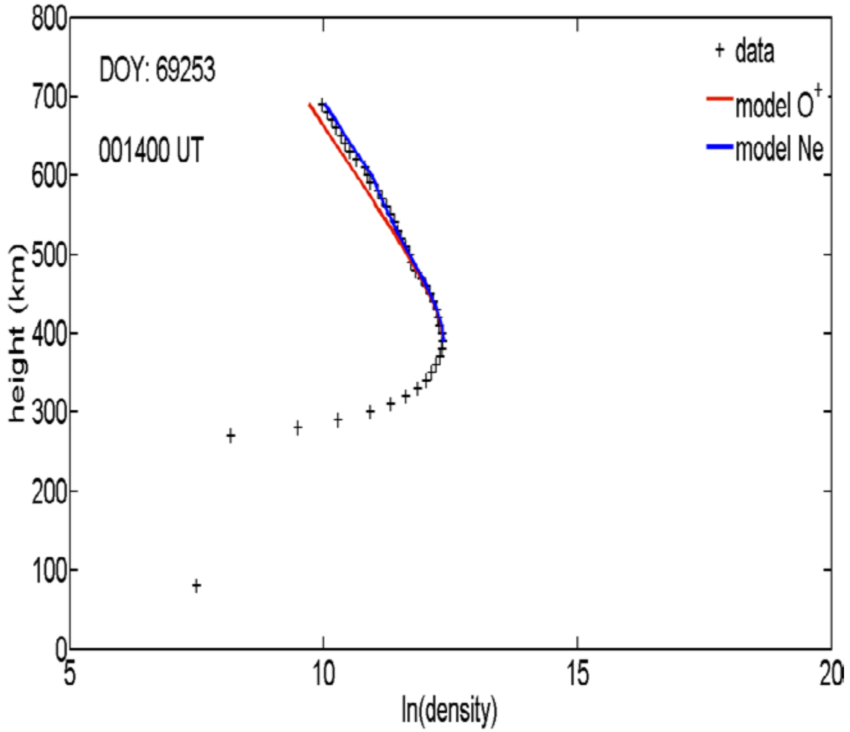
2. The TaD profiles are calculated and adjusted with GNSS-TEC values at each grid node (1˚x1˚) geographic coordinates.

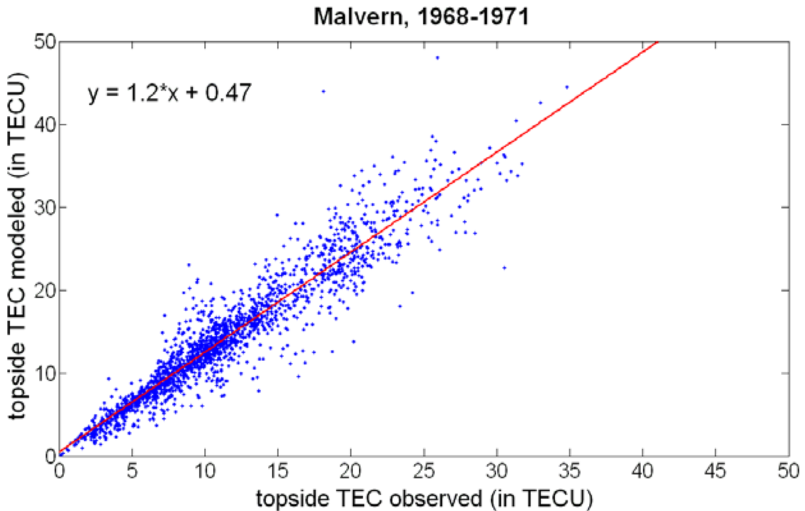
TaD operational implementation in DIAS:

EDD at predefined heights

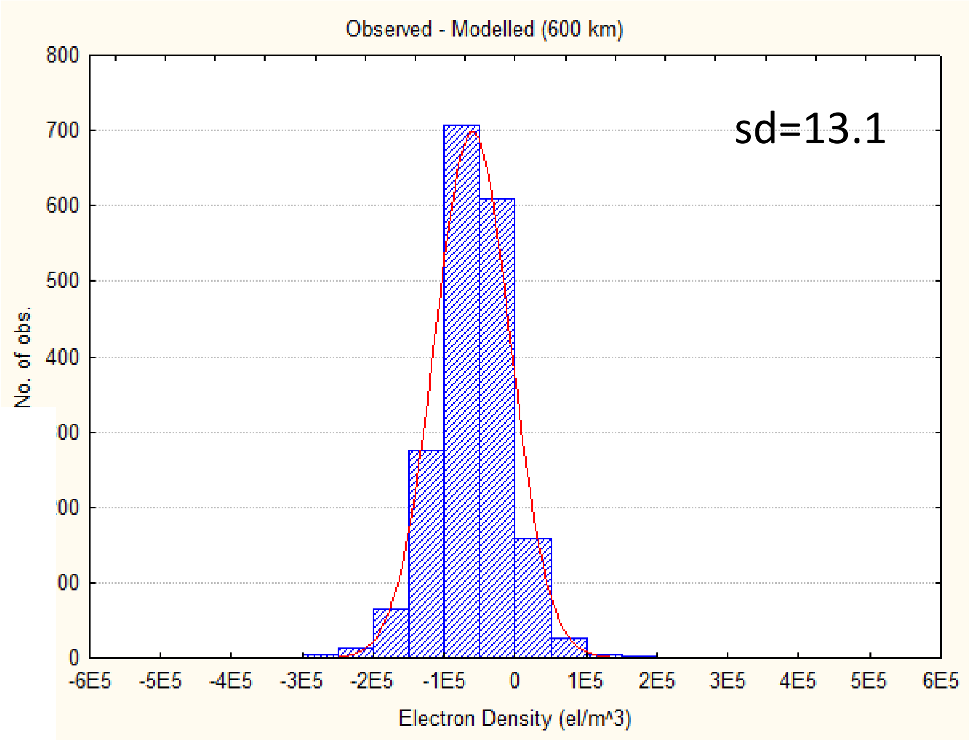


Validation of TaD EDP : comparison with Malvern ISR EDP



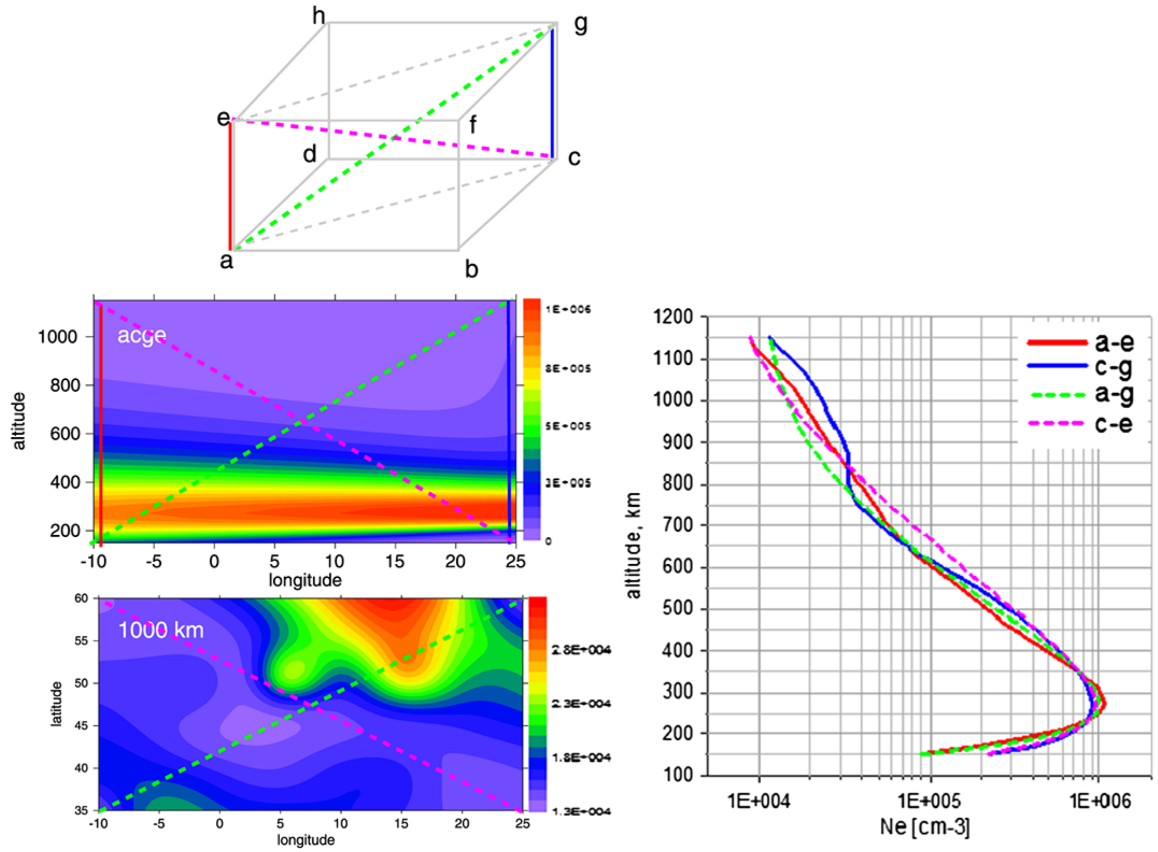


Example for TaD derived profiles based at Malvern site

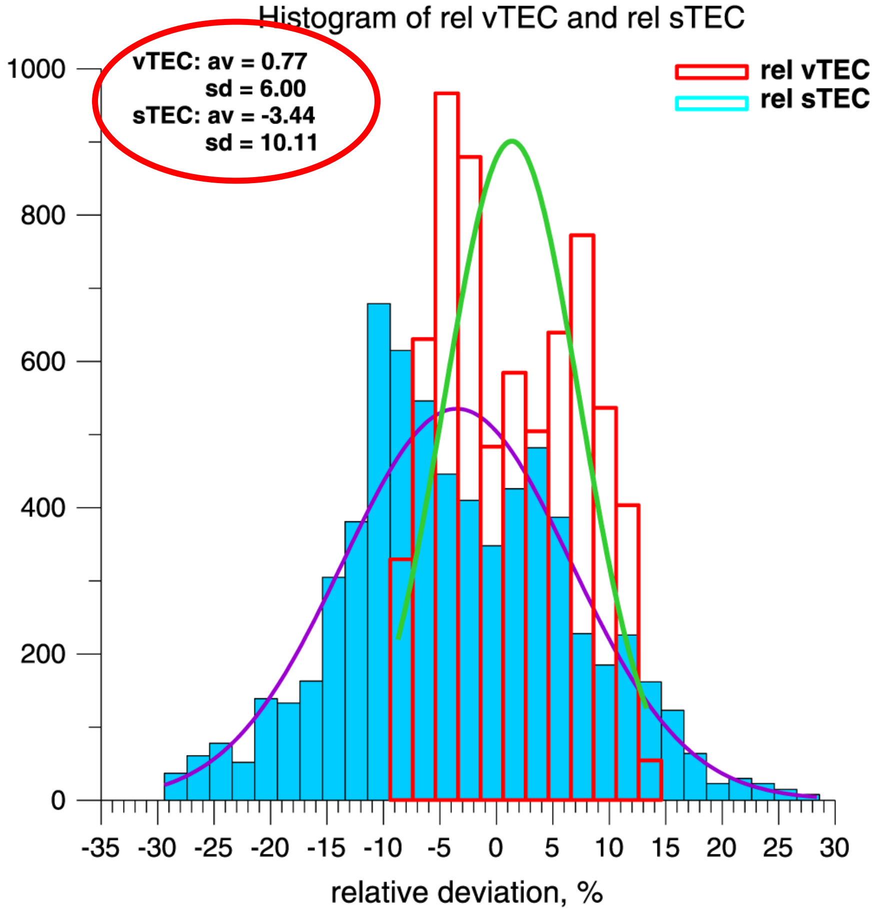


The distribution of the simple difference between the observed ISR and the modeled electron densities at 600 km

Validation of 3D EDD with sTEC data

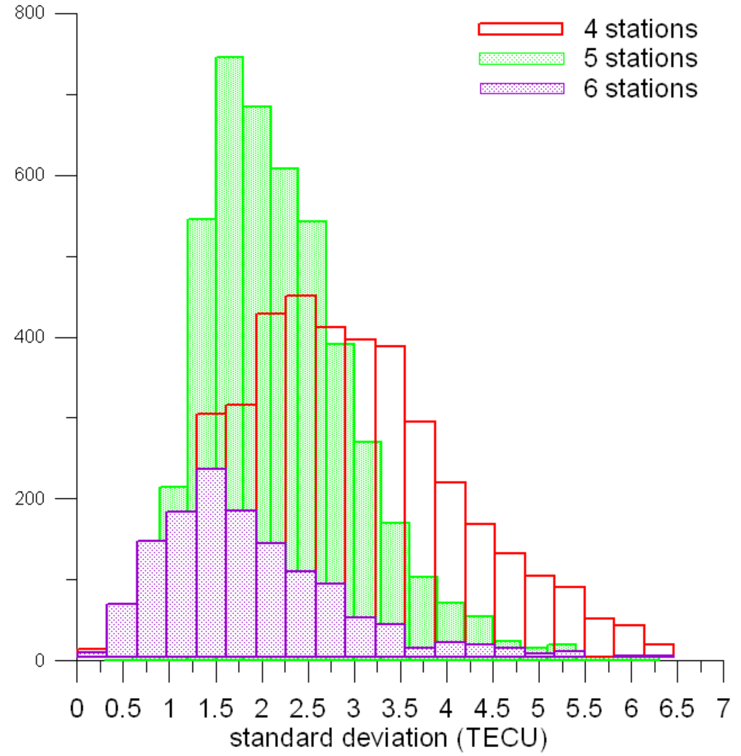


Electron density profiles along the two vertical (red and blue curves) and two slant (green and pink dashed curves) raypaths, all lying on diagonal slice *acge* (the upper map).



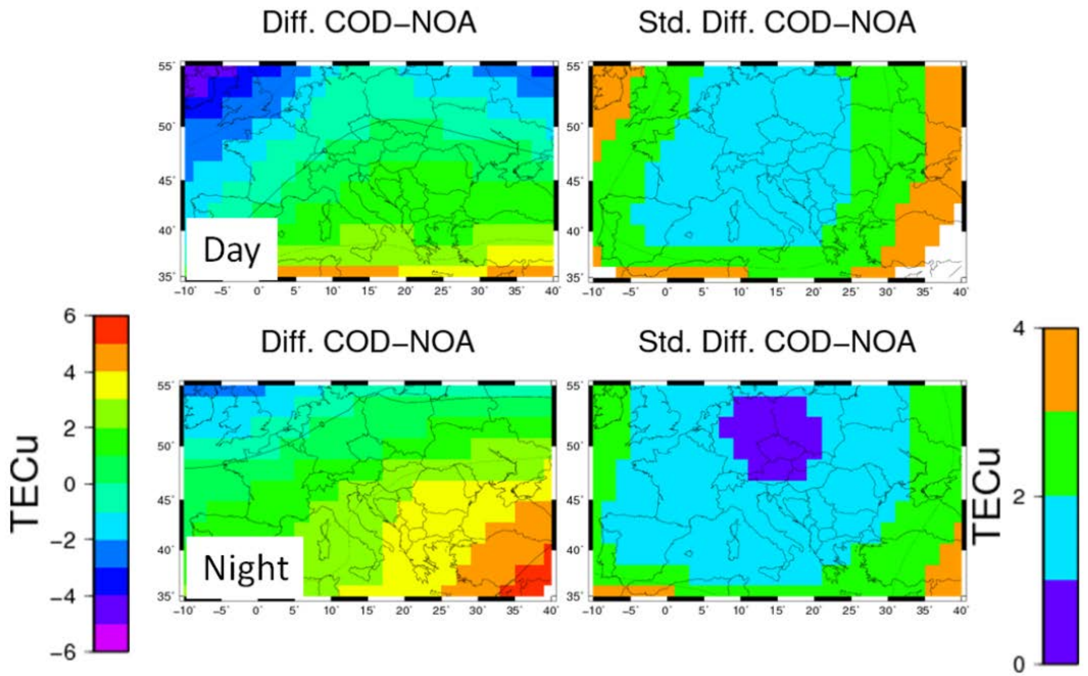
Histogram of relative deviations of model-from-measured sTEC (light blue) and vTEC (unfilled red) bars. The purple curve represents the normal distribution of rel sTEC data, and the dark green curve shows the corresponding normal distribution of rel vTEC.

Quality of TaD TEC derived maps



Comparison of TaD-TEC maps with EUREF-ROB and CODE maps for a period of 12 months (November 2012 – October 2013).

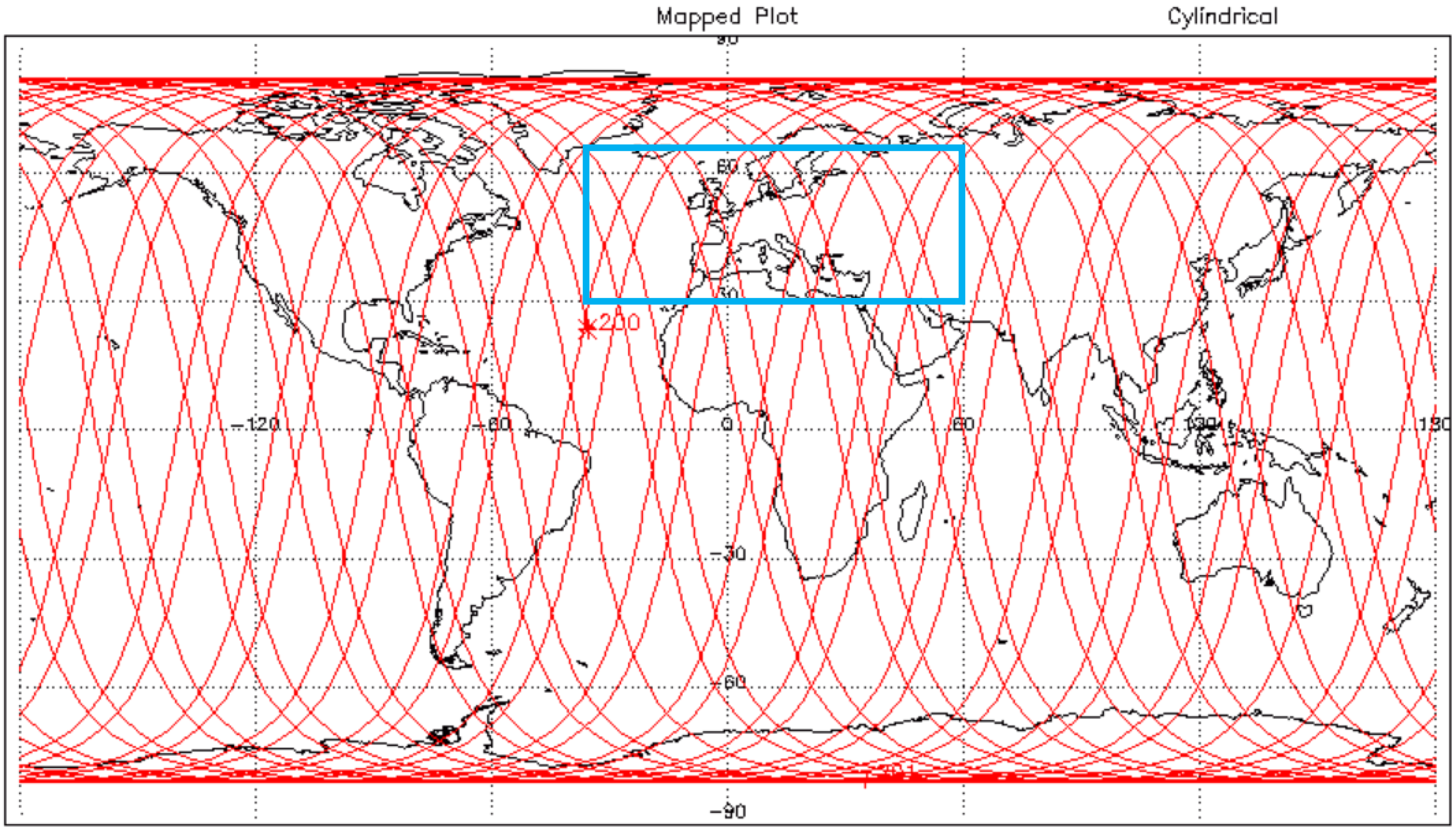
Reasonable agreement with a **maximum discrepancy of 3 TECU for the 96% of the cases**, depending on the latitude of the geographic location under consideration.



Polyweight procedure in the remote regions of the mapped area influences the result

Comparison of the 3D TaD model results with DEMETER *in situ* electron density was measured by ISL (Instrument Sonde Langmuir)

DEMETER orbit



* DEMETER Radial Trace in Geographic Coord.: Time Range 7/19/2009 (200) 0:0 7/20/2009 (201) 23:59

DEMETER satellite was launched on June 29, 2004 on a quasi-Sun-synchronous circular orbit of ~ 660 km and inclination about 98°.

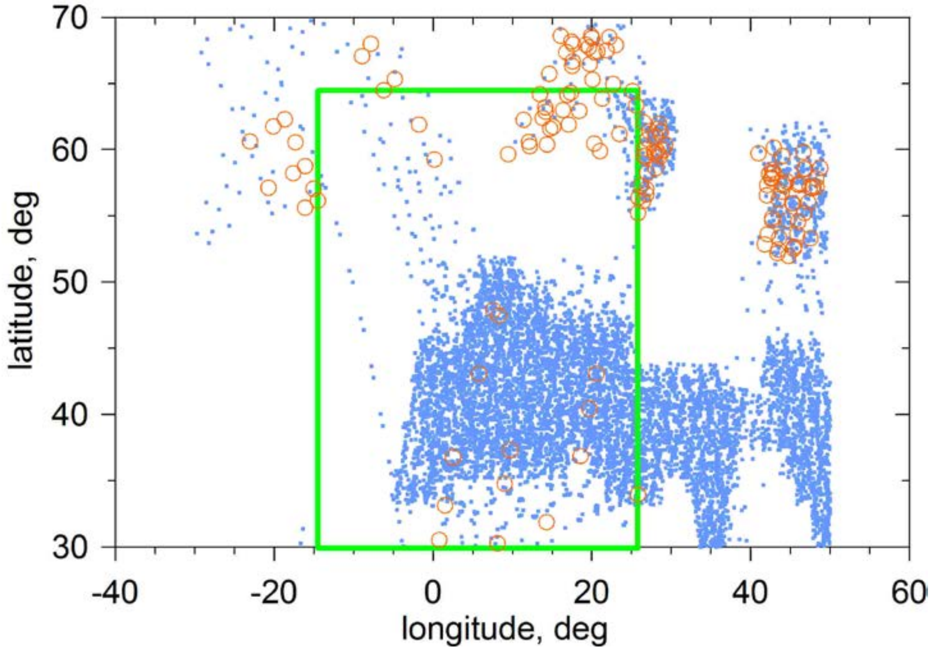
Satellite orbit plane is confined to 10:15 and 22:15 local time sector.

The satellite performs 14 orbits per day.

Comparison between DEMETER and TaD :
Issues to consider

- TEC values needed for TaD profile adjustment are **extracted from the Global ionosphere Maps (GIM),** and not from the EUREF TEC maps as done operationally
- GIM provide globally TEC values at the grid nodes 2.5° x 5.0° in latitude/longitude frame. In TaD 3D procedure, **the grid over the European area is first densified to 0.25° x 0.5°** and then **the TEC values at the grid nodes are interpolated from the global grid by cubic splines**. From this map TEC values at the ionosonde locations are calculated by bi-linear interpolation between neighbor nodes.
- Ionogram-derived foF2 and hmF2 are taken from DIAS Digisonde network. To simplify and speed up calculations, **the bottom EDP at every station is calculated by using the α-Chapman formula with scale height equal to the half of the topside one.**
- DEMETER data have 1-sec sampling rate and are averaged in interval of 1 min.

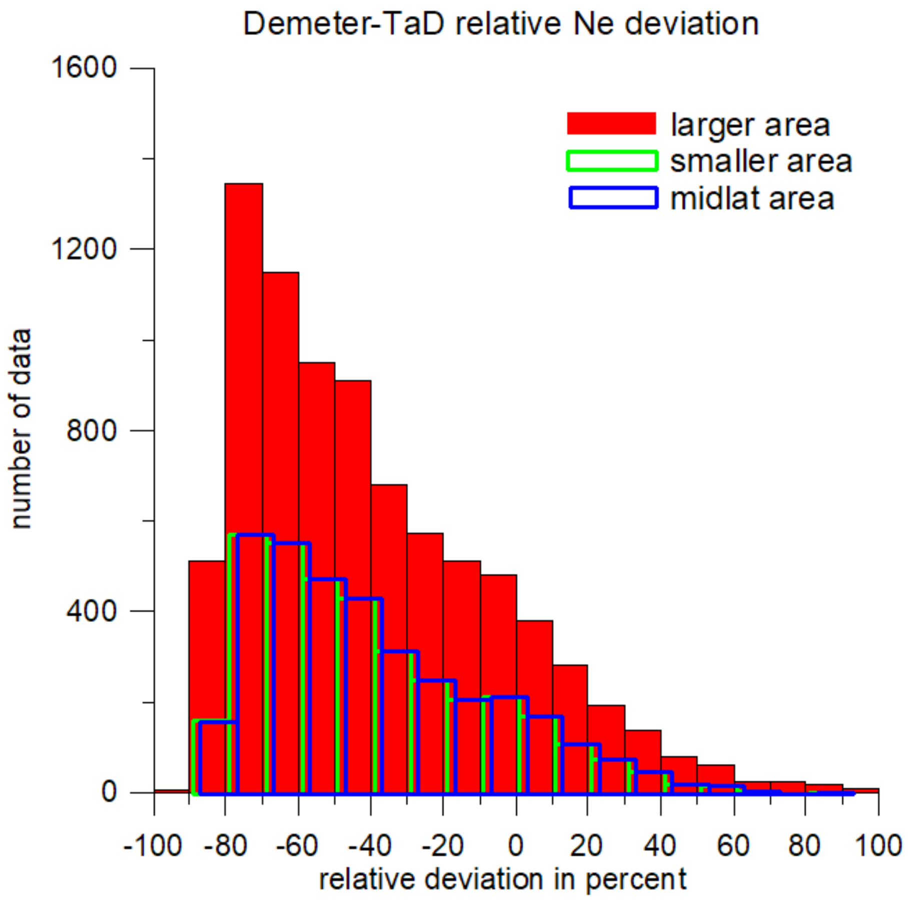
The comparison area



Geographic locations of all comparisons (blue dots) in the larger area. The green frame marks the smaller area. Pink curcules show the comparisons with large discrepances.

We applied the TaD 3D model to both the larger and the smaller areas in order to see to what extent the presumed inaccuracy of Polyweight procedure in the remote regions of the mapped area influences the result.

TaD 3D model performance



To compare modelled and measured Ne, the relative to the model deviation between the two quantities was calculated. The comparisons exceeded the total number of 180,000.

The average relNe is -40%, and the stadard deviation is 34%.

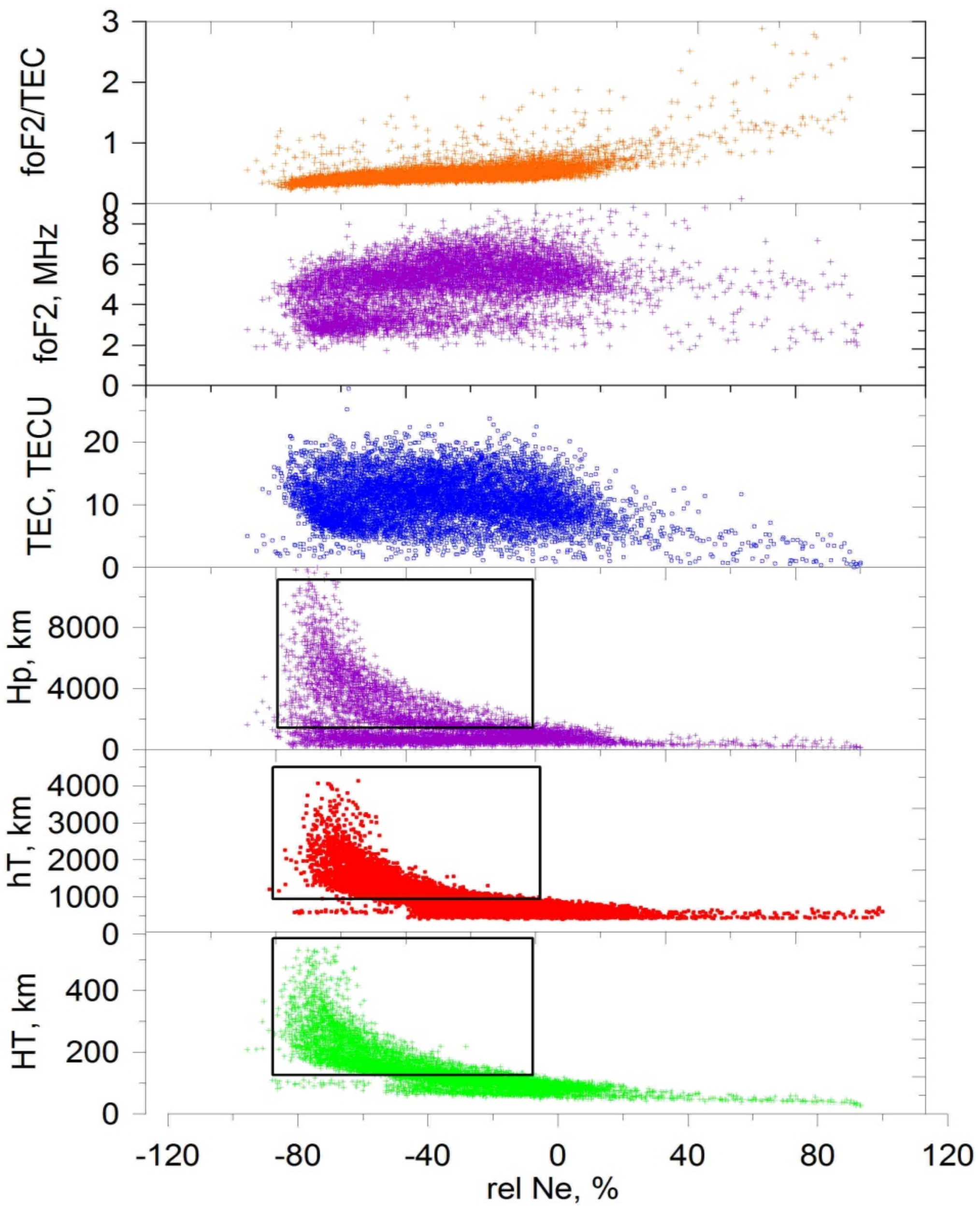
The main conclusion from the histogram shape is the systematic offset of TaD NeM values which exceed with 50-60% those of ISL data.

The large average deviations of TaD Ne specifications from the measured ISL data is somewhat unexpected.

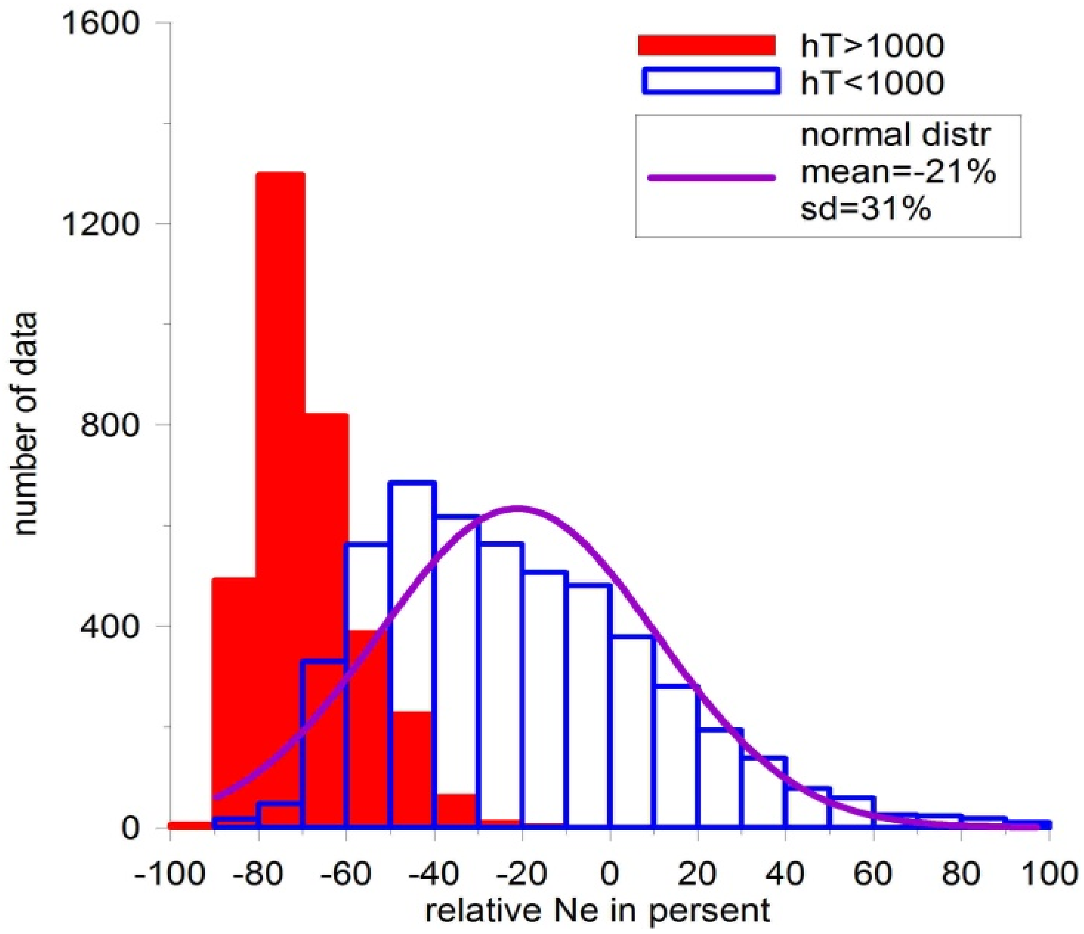
How the deviation is explained

We need to consider:

- the profile shape defined by the topsde and plasmasphere scale heights and transition height
- the ionosonde foF2 and hmF2 maps generated by the Polyweight interpolation program using the limitted number of ionosonde stations,
- TEC maps taken from specialized web-sites (in the present case, the global GIM produced by CODE).

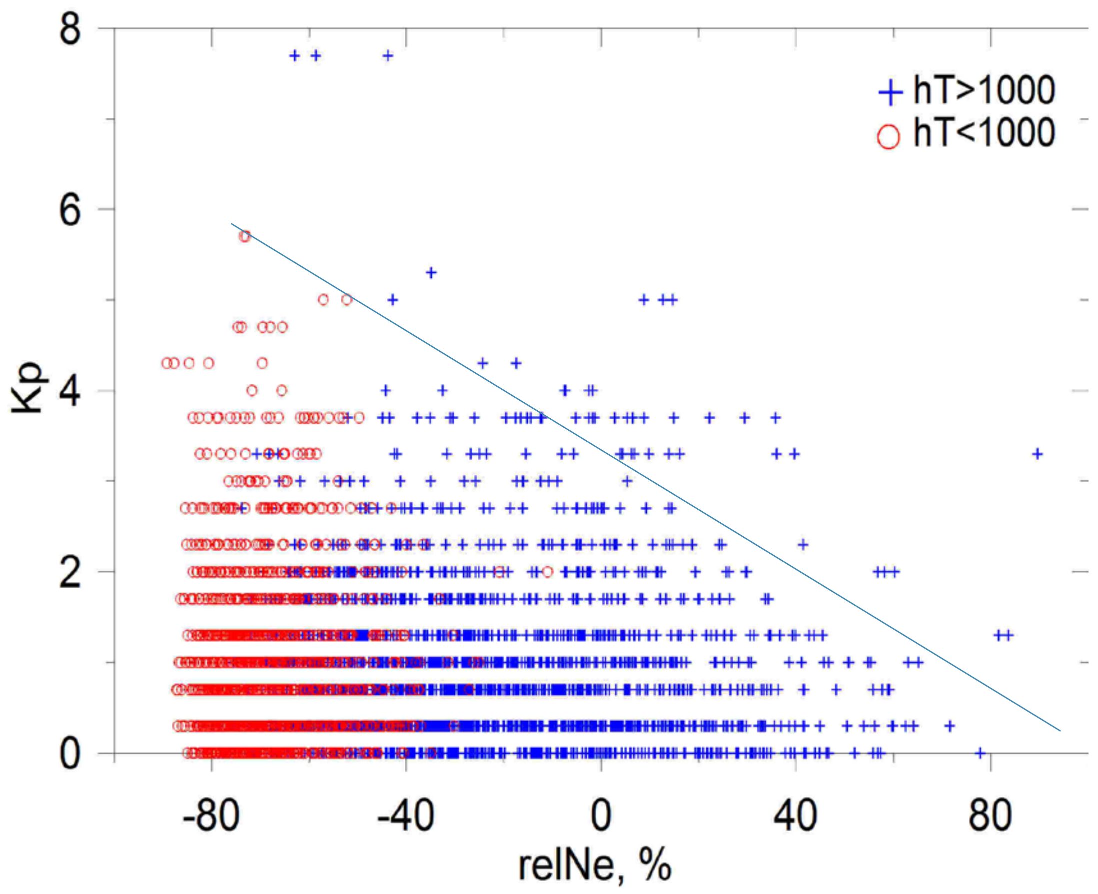


Error analysis: scale height dependence



The distribution of cases with hT<1000, has a form close to the normal one, with a mean offset -21%.

Error analysis : geomagnetic activity dependence

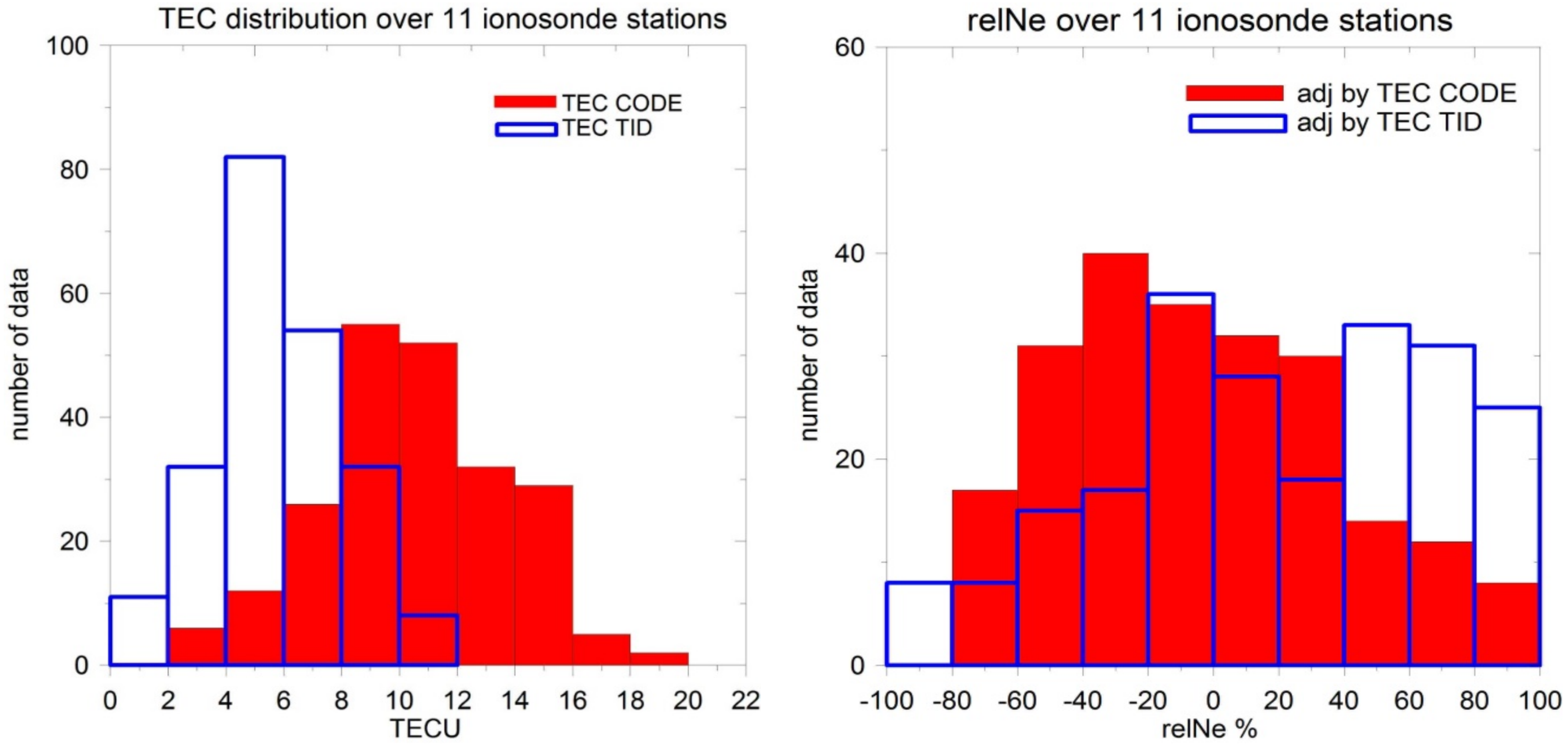


The Kp index was chosen to represent the geomagnetic disturbance level, although it is clear that there is no one-to-one response of Ne to geomagnetic forcing.

Larger Kp values are predominantly found in the range of large negative relNe, especially those with Kp above 3. It means that at higher Kp TaD profiler assigns larger Ne values at orbit height than Demeter measures.

The red circles with TaD parameter hT>1000 km occupy the range with higher negative relNe, independently on the Kp values.

Error analysis: TEC quality dependence



Comparison of results taken using TEC from CODE and TEC calculated with the single station solution algorithm

Concluding remarks

- The performance of the TaD model is closely related to the source of input TEC
  - When EUREF TEC are used as input, TaD gives 3 TECU error (20% avrg offset).
  - When TEC CODE are used as input, TaD deviations from measured Ne at the DEMETER orbit height are very significant, with avrg offset of 50-60%.
  - The large offset comes from the higher model Ne in respect to the measurements.
  - Larger negative deviations are seen during increased geomagnetic activity (higher Kp values), which means that at that times the model Ne at the DEMETER orbit height predominantly exceed the measured values.
- The use of TEC from single GPS receivers in profile adjustment changes the results significantly. Their magnitude is in average twice less than those of TEC CODE and this results in smaller modeled Ne values and hence smaller negative and more positive deviations from the data.
- Present comparison shows the importance of assessing the inconsistency between different measurements being assimilated or ingested in the 3D models.

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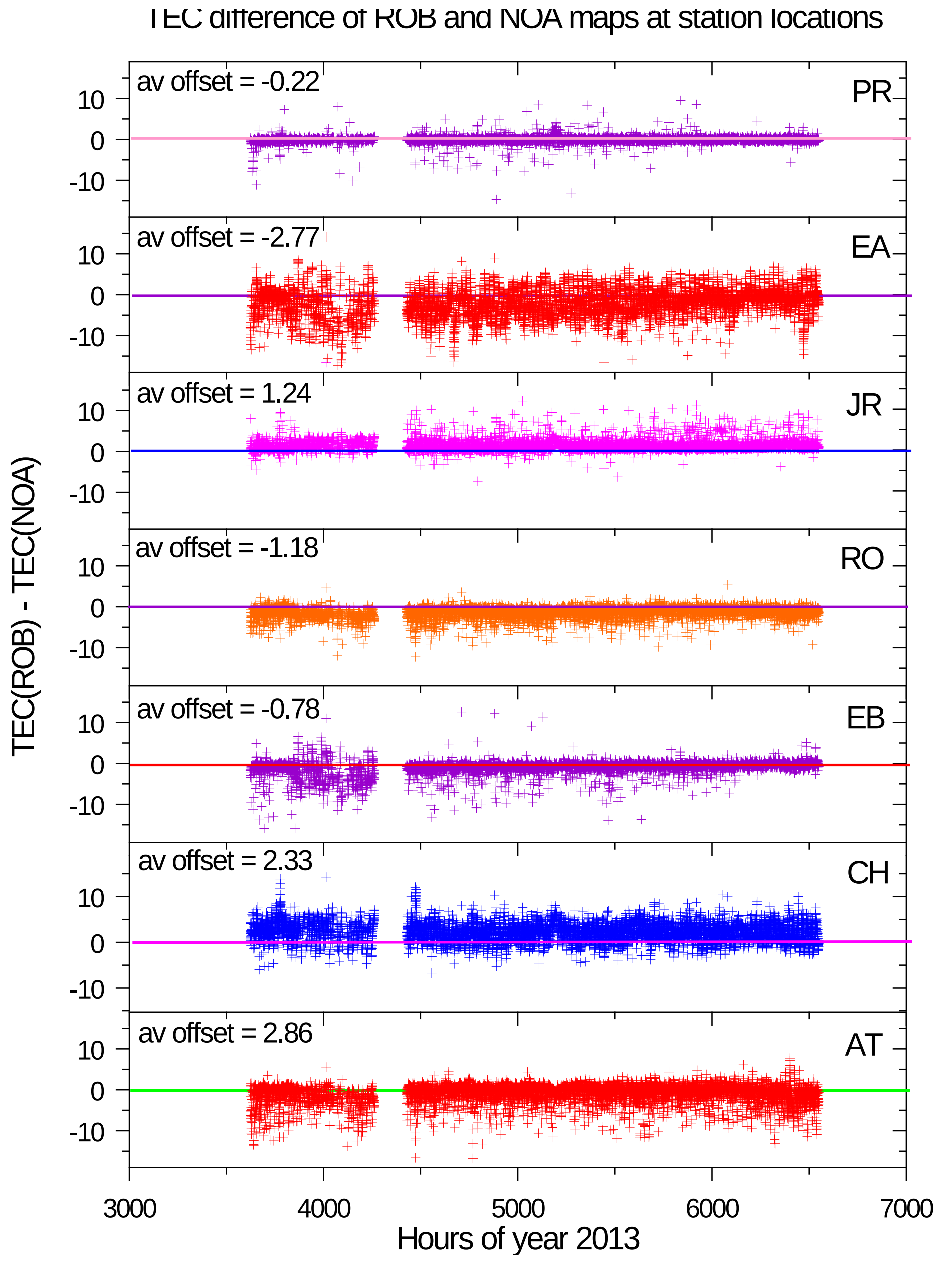
DIAS

esa space situational awareness
European Ionosonde Service

Thank you for your attention!

Input Parameters	Code	Output
Month, LT, glat, f10.7, Kp	TSM: Topside Sounders Model Analytical approximation of Alouette, ISIS-1,-2 topside profiles (Bilitza, 2001)	Empirical functions of H_T: topside scale height h_T : transition height R_T: ratio H_T/h_T
H_T ($\equiv H_{O+}$), h_T, H_m, N_m and *glat*	TSMP: Topside Sounders Model Profiler Analytical approximation of ISIS-1 topside profiles to model plasmaspheric scale height	Empirical functions of H_P: plasmaspheric scale height ($\equiv H_{H+}$) $H_P=H_T(9\cos^2 glat+4)$ *Ne*: electron density profile in the topside ionosphere and plasmasphere $Ne = N_O(h) + gN_O(h_T)\exp\left(-\frac{\lvert h-h_T\rvert}{Hp}\right) + (1-g)N_O(h_T)\exp\left(-\frac{\lvert h-h_T\rvert}{4H_T}\right)$ and $N_O(h) = Nm\exp\left\{-\frac{1}{2}\left[\frac{h-hm}{Hm}+1-\exp\left(\frac{h-hm}{Hm}\right)\right]\right\}$ g is the ratio N_H+ / N_O+ at h_T
Digisonde parameters at the height of maximum density (*hmF2*, *foF2*, H_m) and vTEC (GNSS) at the Digisonde location	TaD: TSM-assisted Digisonde Profiler Calculation of the actual profile over each Digisonde location to update TSMP with current Digisonde and TEC (GNSS) parameters	$Ne = N_O(h) + gN_O(h_T)\exp\left(-\frac{\lvert h-h_T\rvert}{Hp}\right) + (1-g)N_O(h_T)\exp\left(-\frac{\lvert h-h_T\rvert}{skH_m}\right)$ where $s=H_{He+}/kH_m$ k is the correction parameter that converts H_m (the neutral scale height) to make it compliant with H_T The integral of the Ne profile can be adjusted to the measured vTEC by varying solely the correction parameter k


TEC difference of ROB and NOA maps at station locations
av offset = -0.22
PR
av offset = -2.77
EA
av offset = 1.24
JR
av offset = -1.18
RO
av offset = -0.78
EB
av offset = 2.33
CH
av offset = 2.86
AT
TEC(ROB) - TEC(NOA)
10
0
-10
3000
4000
5000
6000
7000
Hours of year 2013