

Recent upgrades in the Topside Sounders Model codes and possible links with IRI-2012

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TSM set of codes

Present profiling technique combines:

- **a core empirical model (TSM)** providing the topside scale height and upper transition (O^+ - H^+) height,
- **a profiler (TSMP)** providing the shape of the vertical electron density profile in the topside and plasmasphere as a sum of O^+ , H^+ , and He^+ partial distributions,
- **a TSM-assisted Digisonde (TaD) profiler** ingesting Digisonde-derived parameters peak altitude, density, and topside scale height into TSMP, allowing real-time update of TSMP.

Input Parameters	Code	Output
Month, LT, glat, f10.7, Kp	TSM: Topside Sounders Model Analysis 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 Analysis 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 $Ne = N_{O^+}(h) + gN_{O^+}(h_T) \exp\left(-\frac{ h - h_T }{H_p}\right) + (1 - g)N_{O^+}(h_T) \exp\left(-\frac{ h - h_T }{4H_T}\right)$ 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	$Ne = N_{O^+}(h) + gN_{O^+}(h_T) \exp\left(-\frac{ h - h_T }{H_p}\right) + (1 - g)N_{O^+}(h_T) \exp\left(-\frac{ h - h_T }{skH_m}\right)$ 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

TSM-TSMP-TaD basic references

- Kutiev, I., and P. Marinov, Topside sounder model of scale height and transition height characteristics of the ionosphere, *Adv. Space Res.*, **39**, 759–766, 2007
- Kutiev, I., P. Marinov, A. Belehaki, N. Jakowski, B. Reinisch, C. Mayer, and I. Tsagouri, Plasmaspheric electron density reconstruction based on the Topside Sounder Model Profiler, *Acta Geophys.*, **58 (3)**, 420–431, 2009
- Belehaki, A., I. Kutiev, B. Reinisch, N. Jakowski, P. Marinov, I. Galkin, C. Mayer, I. Tsagouri, and T. Herekakis, Verification of the TSMP-assisted Digisonde (TaD) topside profiling technique, *Acta Geophys.*, **58 (3)**, 432–452, 2009
- Kutiev, I., P. Marinov, S. Fidanova, A. Belehaki, and I. Tsagouri, Adjustments of the TaD electron density reconstruction model with GNSS TEC parameters for operational application purposes, *J. Space Weather Space Clim.*, **2**, A21, 2012
- Belehaki, A., I. Tsagouri, I. Kutiev, P. Marinov, and S. Fidanova, Upgrades to the Topside Sounders Model assisted by Digisonde (TaD) and its validation at the topside ionosphere, *J. Space Weather Space Clim.*, **2**, A20, 2012

Verification of TaD at a single site location

TaD is extensively tested and verified using independent observations:

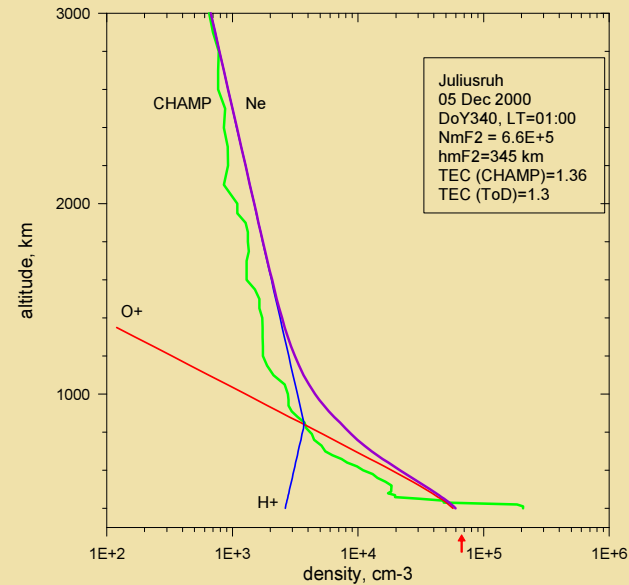
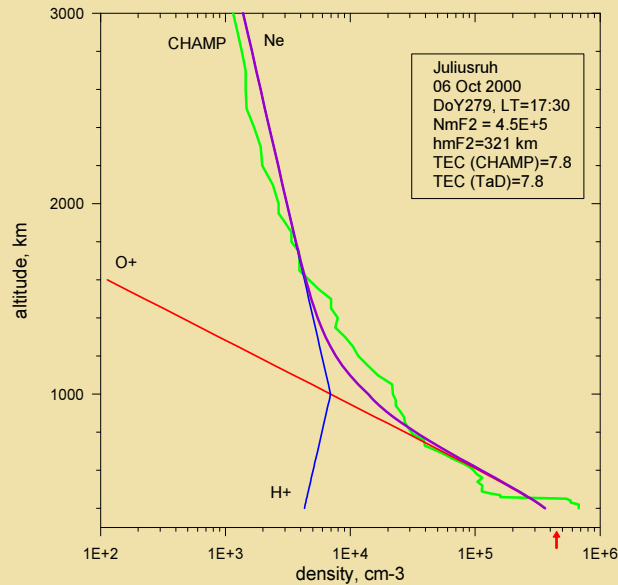
- CHAMP TEC and profiling;
- ground-based GPS-TEC;
- Malvern Incoherent Scatter Radar (ISR);
- RPI sounder on IMAGE

Latest improvement, allows adjustment of TaD integral with GPS-derived TEC, increasing the accuracy of the method.

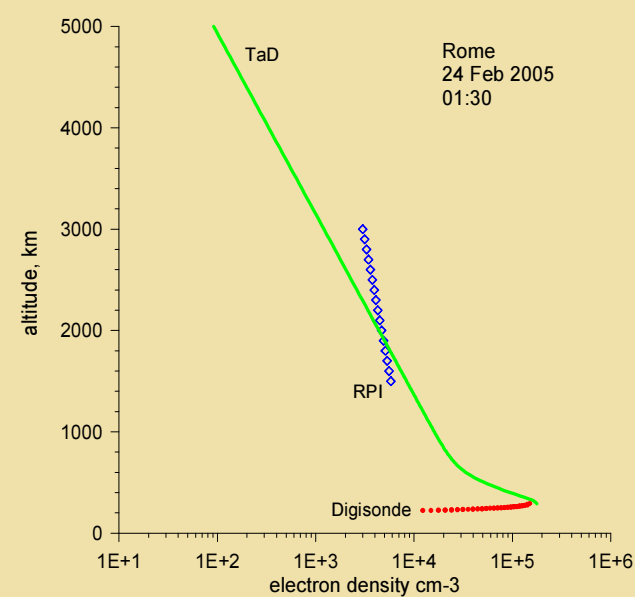
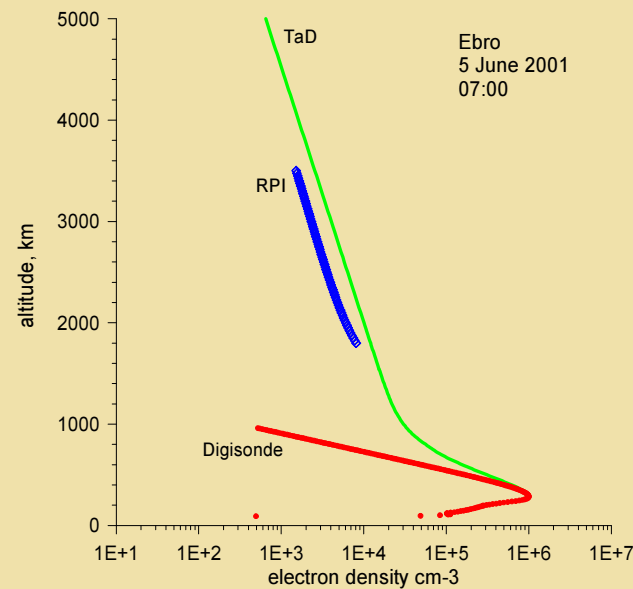
TaD verification results

Comparison with CHAMP and IMAGE/RPI derived profiles

CHAMP

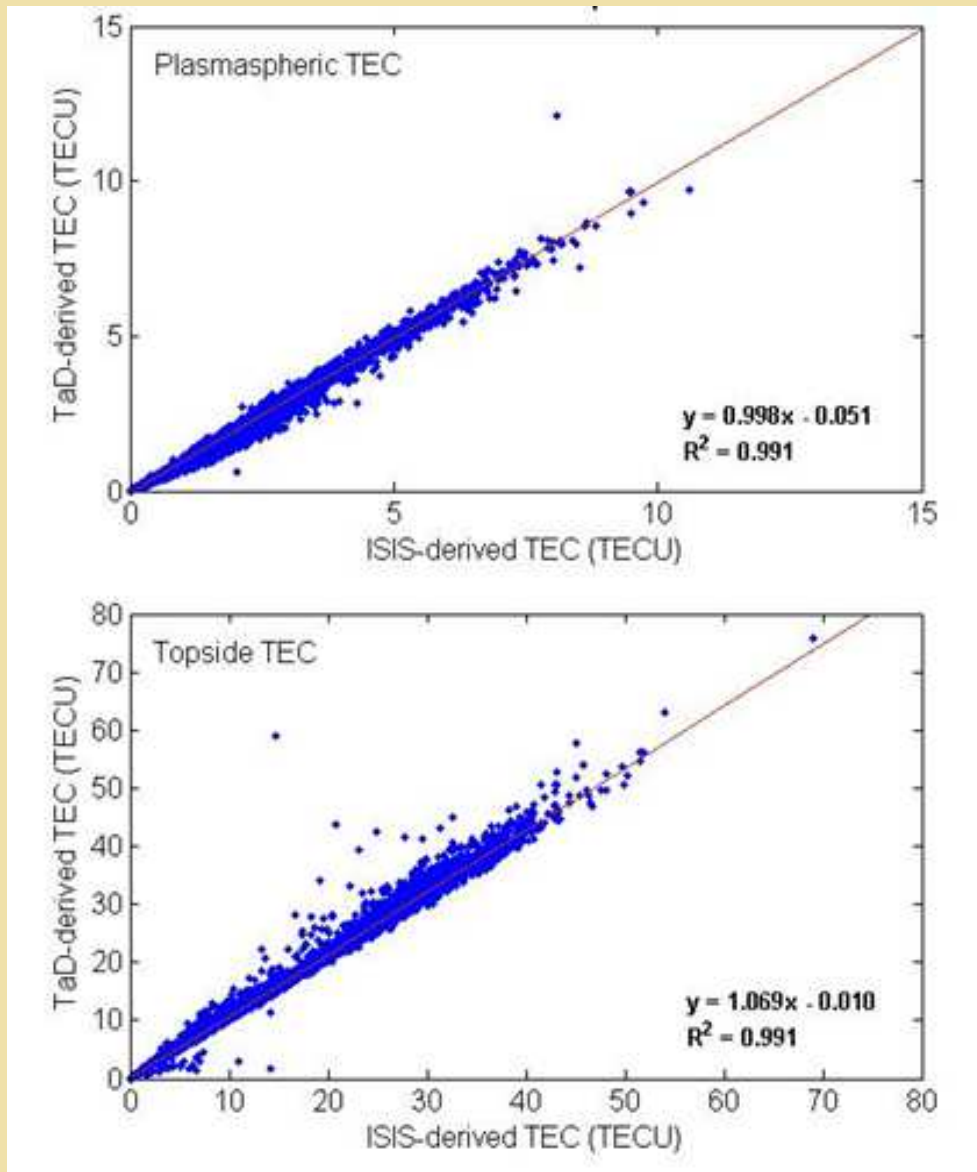


IMAGE



Belehaki et al.,
Acta Geo., 2009

TaD verification results

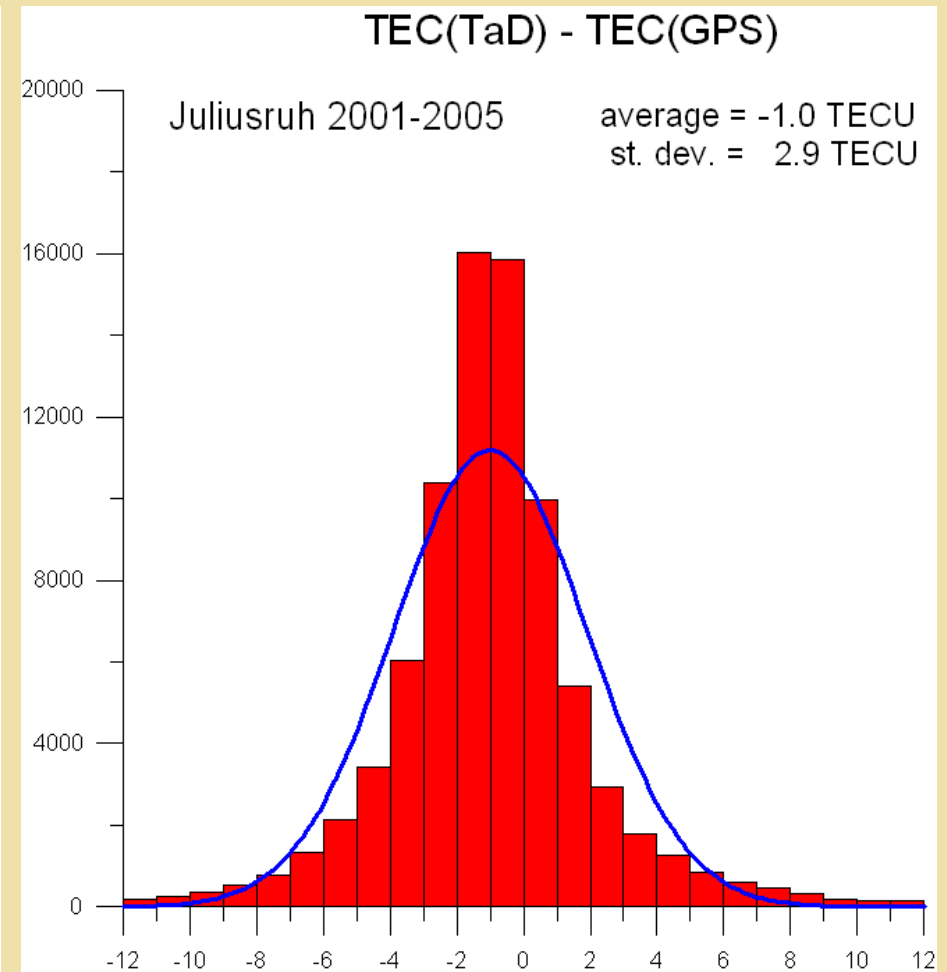
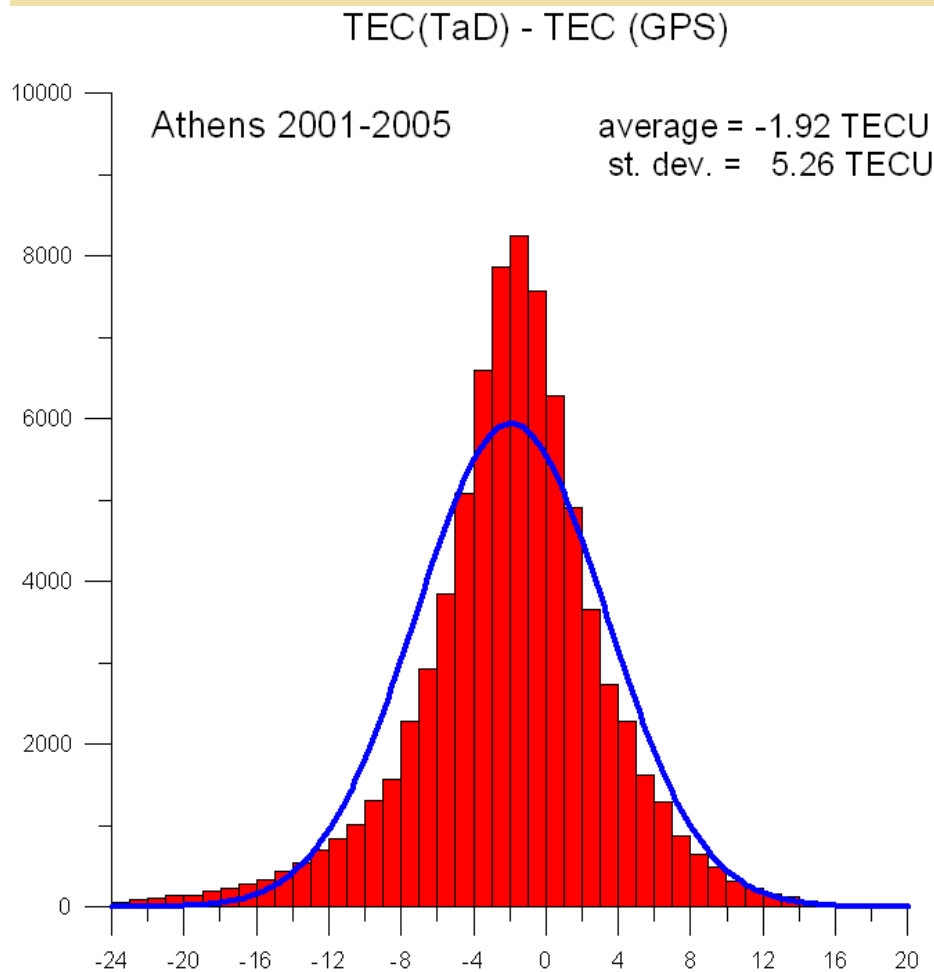


Internal consistency check:
how well the model can
reproduce ISIS-2 derived
TEC

From
Belehaki et al., SWSC,
2012

TaD verification results

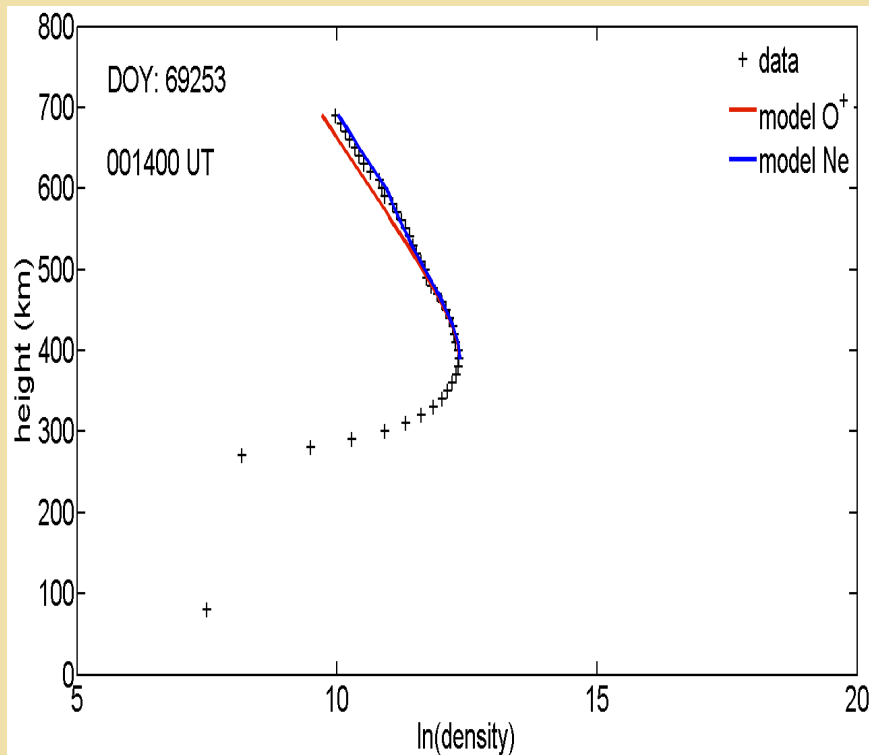
Comparison with TEC-GNSS ground based receivers



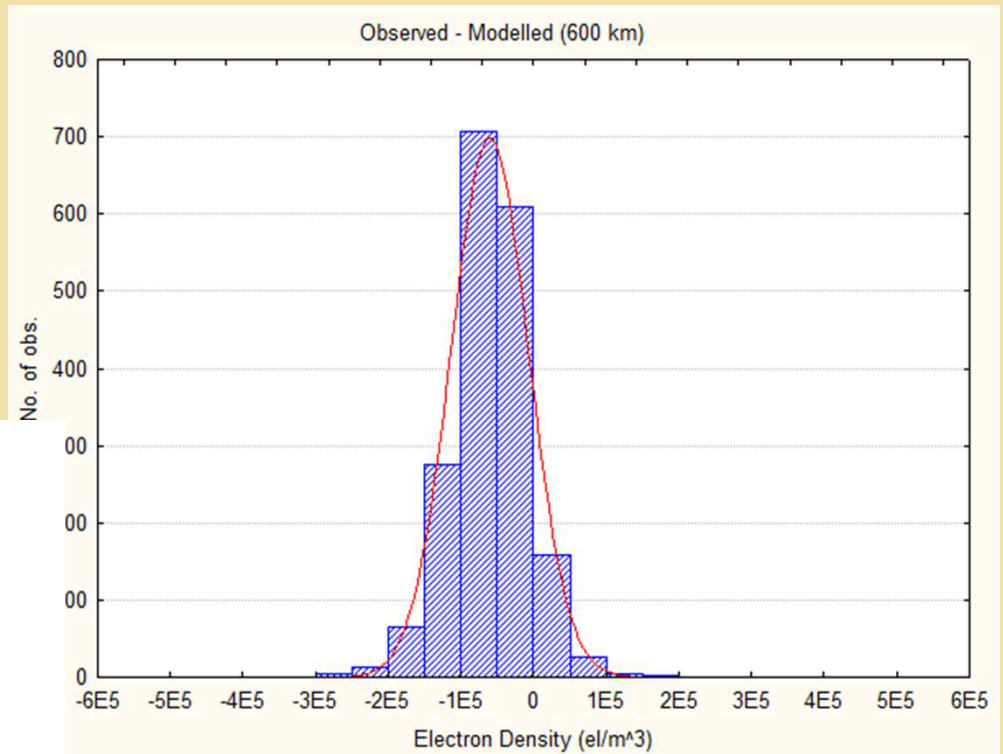
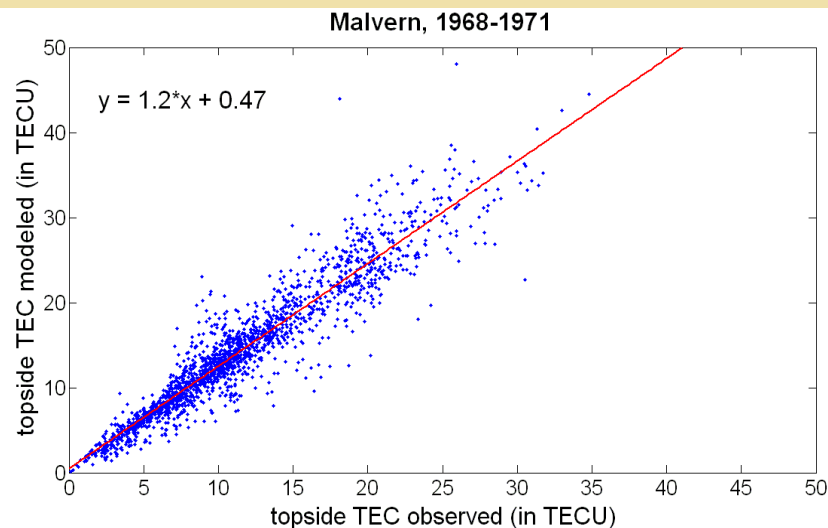
Kutiev et al.,
Acta Geo., 2009

TaD verification results

Topside ED: comparison with Malvern ISR

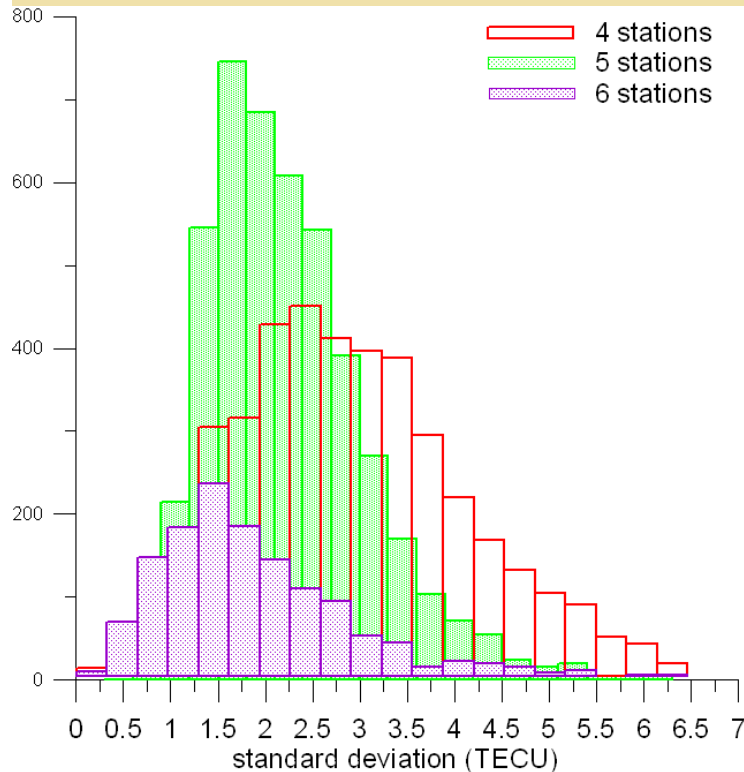


Example for TaD derived profiles based at Malvern site



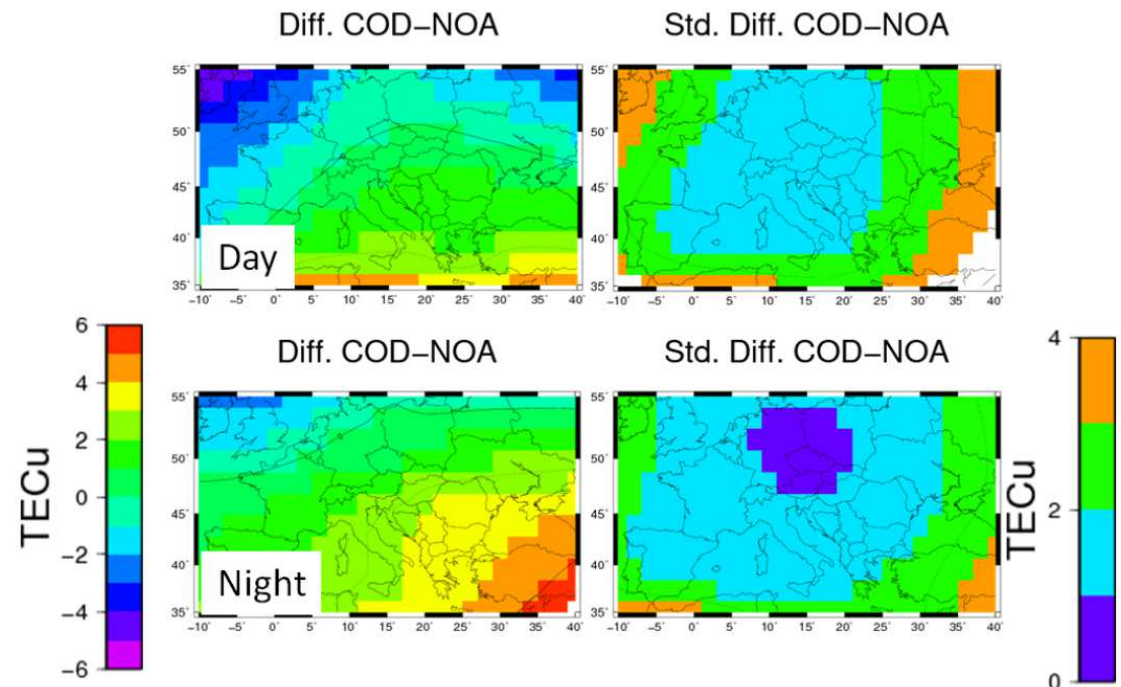
The distribution of the simple difference between the observed ISR and the modeled electron densities at 600 km

Validation of TaD 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.



TaD operational implementation

DIAS: EDD at predefined heights



DIAS Project is co-funded by the *eContent* programme of the European Union 

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f-plots

SSN plot

HF propagation maps

Electron Density

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ED Bottomside maps

ED Topside maps

Profile over station

Ionospheric Activity

Alerts

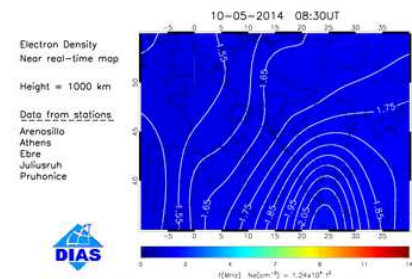
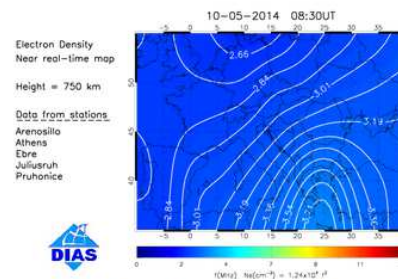
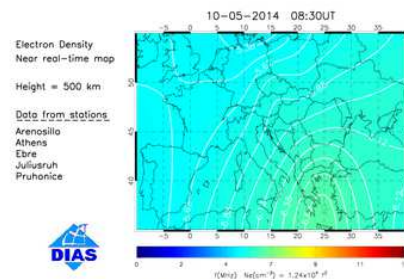
Historical Data

Subscription

Near real-time of the topside electron density over Europe

Help Year Month Day Hour Minute UT VIEW
2014 05 10 08 30
Prev Next Latest available

Latest available maps



TaD operational implementation

DIA

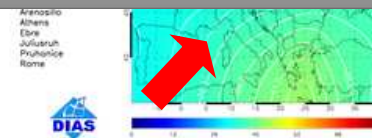
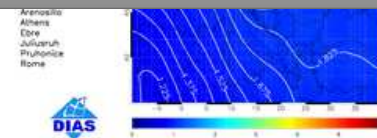
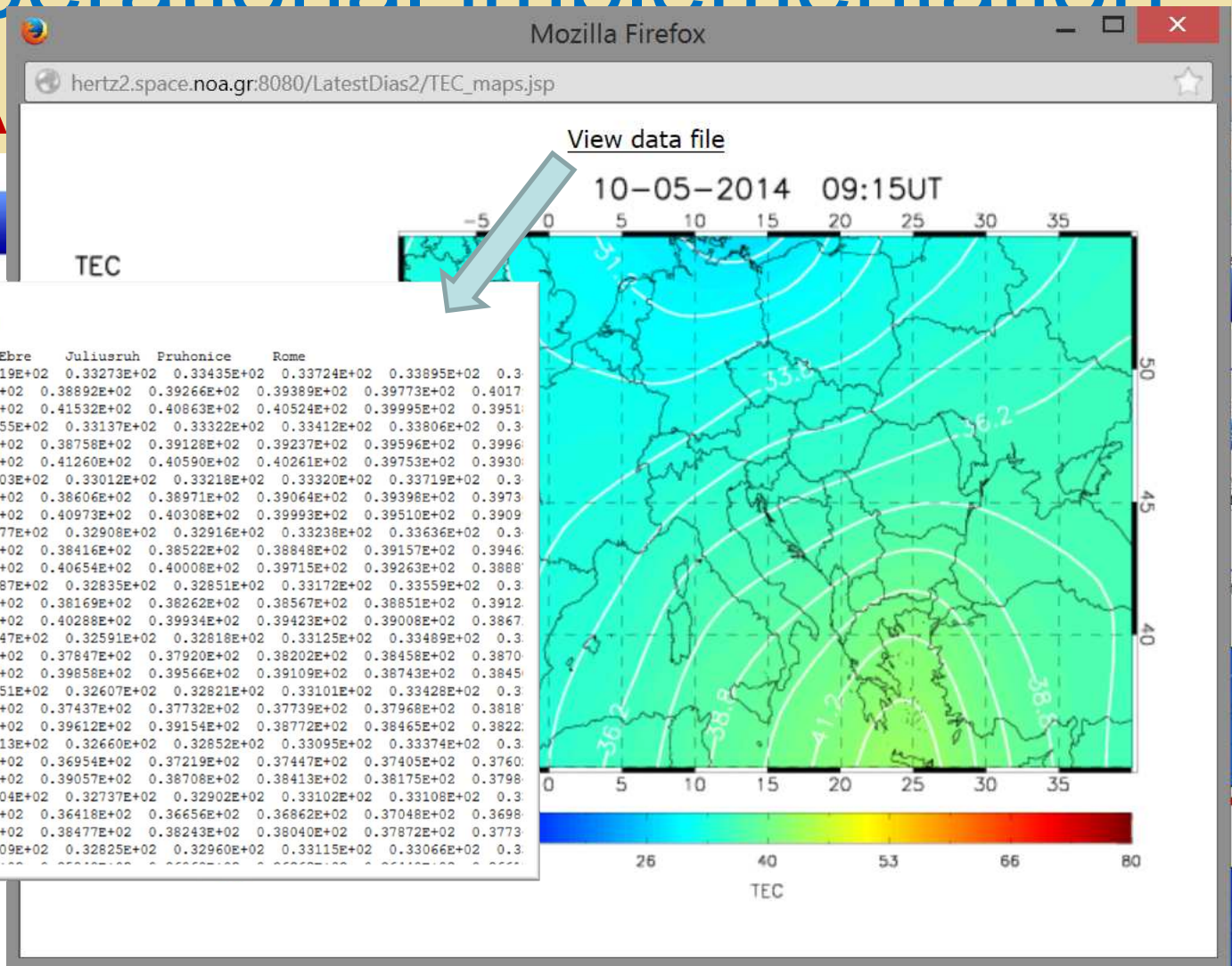


DIAS TEC map @ 10-05-2014 09:15UT
Longitudes: -10E to 40W (left to right column)
Latitudes: 35N to 55N (top to bottom row)

Considered stations: Arenosillo Athens Ebre Juliusruh Pruhonice Rome


0.33228E+02	0.33117E+02	0.33034E+02	0.33219E+02	0.33273E+02	0.33435E+02	0.33724E+02	0.33895E+02	0.3
0.37533E+02	0.37945E+02	0.38111E+02	0.38509E+02	0.38892E+02	0.39266E+02	0.39389E+02	0.39773E+02	0.4017
0.43398E+02	0.43091E+02	0.42852E+02	0.42218E+02	0.41532E+02	0.40863E+02	0.40524E+02	0.39995E+02	0.3951
0.32957E+02	0.32884E+02	0.33050E+02	0.33055E+02	0.33137E+02	0.33322E+02	0.33412E+02	0.33806E+02	0.3
0.37317E+02	0.37514E+02	0.37948E+02	0.38367E+02	0.38758E+02	0.39128E+02	0.39237E+02	0.39596E+02	0.3996
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0.37095E+02	0.37315E+02	0.37773E+02	0.38208E+02	0.38606E+02	0.38971E+02	0.39064E+02	0.39398E+02	0.3973
0.42846E+02	0.42824E+02	0.42314E+02	0.41668E+02	0.40973E+02	0.40308E+02	0.39993E+02	0.39510E+02	0.3909
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0.36861E+02	0.37097E+02	0.37571E+02	0.38017E+02	0.38416E+02	0.38522E+02	0.38848E+02	0.39157E+02	0.3946
0.42472E+02	0.42465E+02	0.41968E+02	0.41336E+02	0.40654E+02	0.40008E+02	0.39715E+02	0.39263E+02	0.3888
0.32528E+02	0.32554E+02	0.32600E+02	0.32687E+02	0.32835E+02	0.32851E+02	0.33172E+02	0.33559E+02	0.3
0.36606E+02	0.36850E+02	0.37329E+02	0.37777E+02	0.38169E+02	0.38262E+02	0.38567E+02	0.38851E+02	0.3912
0.42246E+02	0.41997E+02	0.41531E+02	0.40933E+02	0.40288E+02	0.39934E+02	0.39423E+02	0.39008E+02	0.3867
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0.32229E+02	0.32309E+02	0.32399E+02	0.32513E+02	0.32660E+02	0.32852E+02	0.33095E+02	0.33374E+02	0.3
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0.32314E+02	0.32400E+02	0.32494E+02	0.32604E+02	0.32737E+02	0.32902E+02	0.33102E+02	0.33108E+02	0.3
0.35293E+02	0.35670E+02	0.35800E+02	0.36135E+02	0.36418E+02	0.36656E+02	0.36862E+02	0.37048E+02	0.3698
0.39115E+02	0.39069E+02	0.38924E+02	0.38715E+02	0.38477E+02	0.38243E+02	0.38040E+02	0.37872E+02	0.3773
0.32426E+02	0.32514E+02	0.32607E+02	0.32709E+02	0.32825E+02	0.32960E+02	0.33115E+02	0.33066E+02	0.3

User logout



TaD operational implementation


ESA-SSA SWE: TEC and partial TEC


esa space situational awareness

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TEC Maps

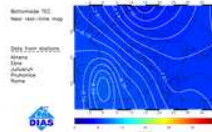
Data providers NOA IAP RAL INGV CE UFA INTA IZMIRAN ROB NOAA

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Ionospheric Alerts
foF2 nowcasting maps
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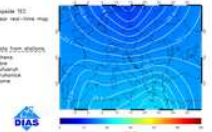
Near real-time maps of partial TEC over Europe

Year
Month
Day
Hour
Minute
UT

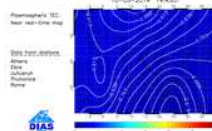
Latest available maps



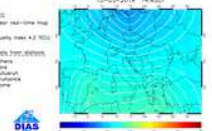
Bottomside TEC
Near real-time map
10-05-2014 14:45UT



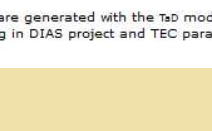
Topside TEC
Near real-time map
10-05-2014 14:45UT




TEC Bottomside
10-05-2014 14:45UT



TEC Topside
10-05-2014 14:45UT



TEC Plasmaspheric
10-05-2014 14:45UT



TEC Total
10-05-2014 14:45UT

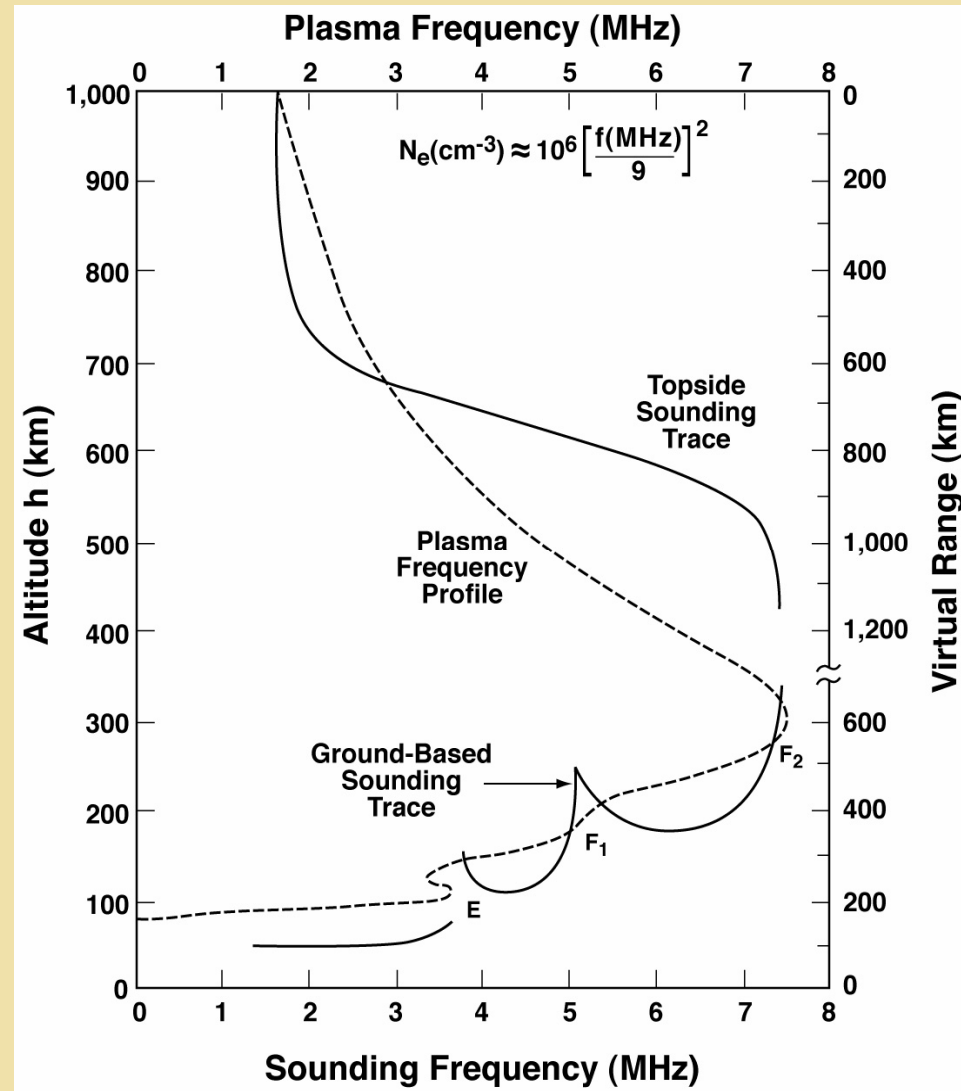
TEC maps are generated with the TSD model using data from European Digisondes participating in DIAS project and TEC parameters provided by the Royal Observatory of Belgium

Conclusions

- TSMP provides the **electron density profile in the topside ionosphere and plasmasphere**, based on the modeling of Alouette, ISIS-1 and ISIS-2 data
- TSMP depends on TSM parameters H_T and h_T and on the independent parameters month, LT, glat, Kp and F10.7
- TSMP offers the basic empirical functions based on which TaD calculates 3D electron density profiles and TEC maps over the area of the DIAS network. The service is running for more than a year, demonstrating **operational reliability even with autoscaled F2 parameters**.
- Through IRI-2012, TSMP can be provided as an additional option, to allow **further validation** by the community of IRI users

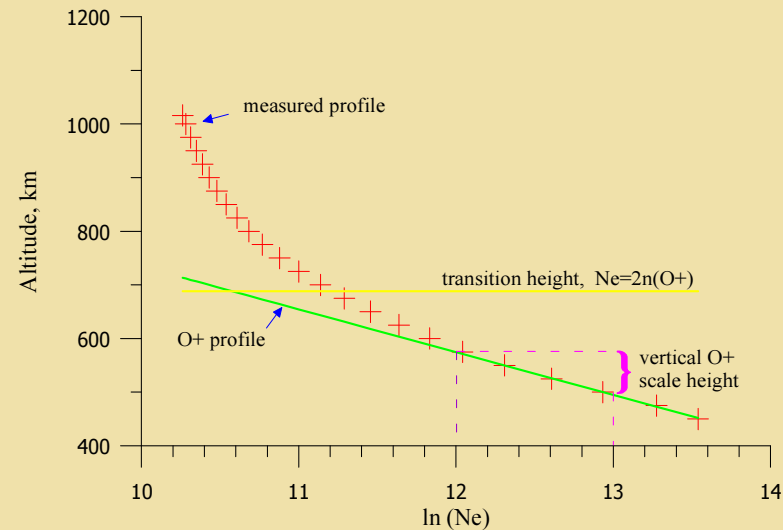
Backup slides

Alouette 1 over flight
of Wallops Island
Ionosonde Alouette-
1651 UT, 10 June
1968
Adapted from
Jackson et al. [1980]



Definition of H_T and h_T

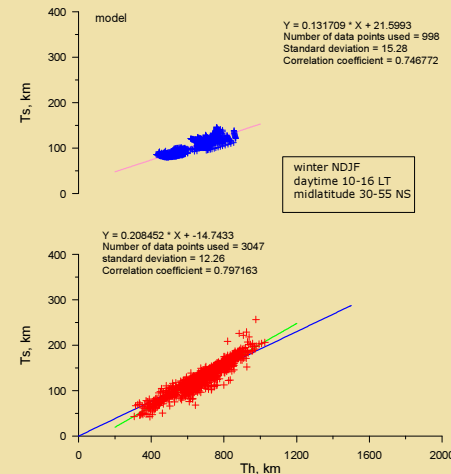
The database, archived at the National Space Science Data Center (NSSDC), Greenbelt, MA, includes 176,622 topside electron density (N_e) profiles from the Alouette-1a, -1b, -1c and -2 and ISIS-1 and -2 topside sounders, covering the period 1962-1979. A detailed description of the database is given by *Bilitza (2001)*.



Two parameters are extracted from each individual N_e profile: the vertical O^+ scale height (H_T) and the O^+-H^+ transition height (h_T). H_T is defined as the lowest gradient of the measured N_e profiles. The h_T is defined as the height at which the extrapolated to higher altitudes lowest N_e gradient yields a density which is one half of the measured N_e .

H_T/h_T ratio

- It was found that the scale height and transition O^+-H^+ height, extracted from each individual measured Ne profile, highly correlate, with a correlation coefficient exceeding 0.8 at midlatitudes. The upper panel shows the model prediction, while the lower panel shows individual values in a H_T/h_T plot, taken from $\pm(30, 50)$ geomagnetic latitude in daytime winter.
- The ratio $R_T=H_T/h_T$ obtained from the individual profiles is modelled as a function of same input parameters as H_T and h_T .



The Topside Sounder Model (TSM)

The scale height H_T , transition height h_T and their ratio R_T are modeled separately by the same type of base functions.

month:	$c_0 + c_1 \sin(x) + c_2 \cos(x) + c_3 \sin(2x) + c_4 \cos(2x)$
local time:	$c_0 + c_1 \sin(x) + c_2 \cos(x) + c_3 \sin(2x) + c_4 \cos(2x)$
glat:	$c_0 + c_1 x + c_2 x^2 + c_3 x^3 + c_4 x^4 + c_5 x^5 + c_6 x^6$
sf:	$c_0 + c_1 x + c_2 x^2$
Kp:	$c_0 + c_1 x + c_2 x^2$

The new Topside Sounder Model (TSM) provides H_T , h_T and R_T for any set of above shown parameters in their defined ranges.

TSMP – the topside sounder-based Ne profiler

We consider α -Chapman shape for N_{O^+} and exponential for N_{H^+}
 N_m is N_{O^+} density at the maximum F layer height hm .

α -Chapman for O^+ :
$$N_{O^+} = N_m \exp \left[1 - \frac{h - hm}{H_{O^+}} - \exp \left(- \frac{h - hm}{H_{O^+}} \right) \right]$$

exponential for H^+ :
$$N_{H^+} = N_{O^+}(h_T) \exp \left(- \frac{|h - h_T|}{H_{H^+}} \right)$$

h_T is the transition height

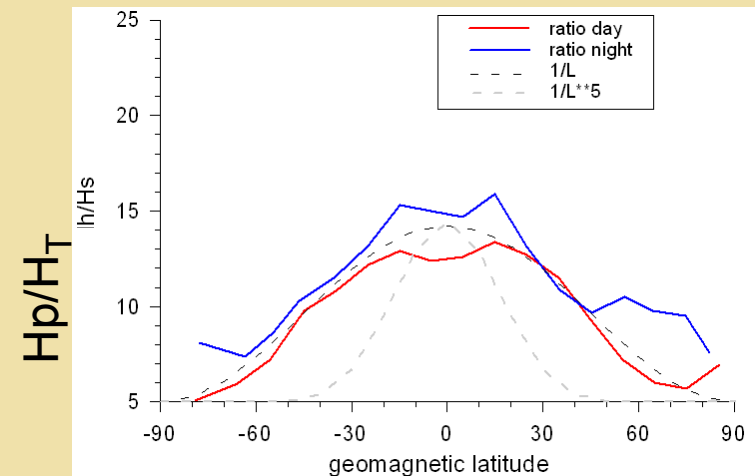
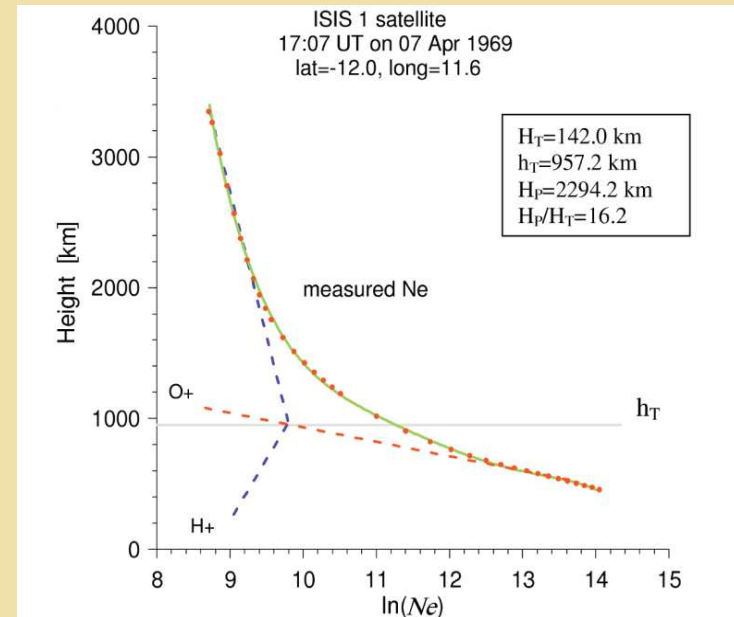
Plasmasphere extension of TSMP

ISIS-1 topside sounder data were used to extract H^+ scale height, further denoted as H_p .

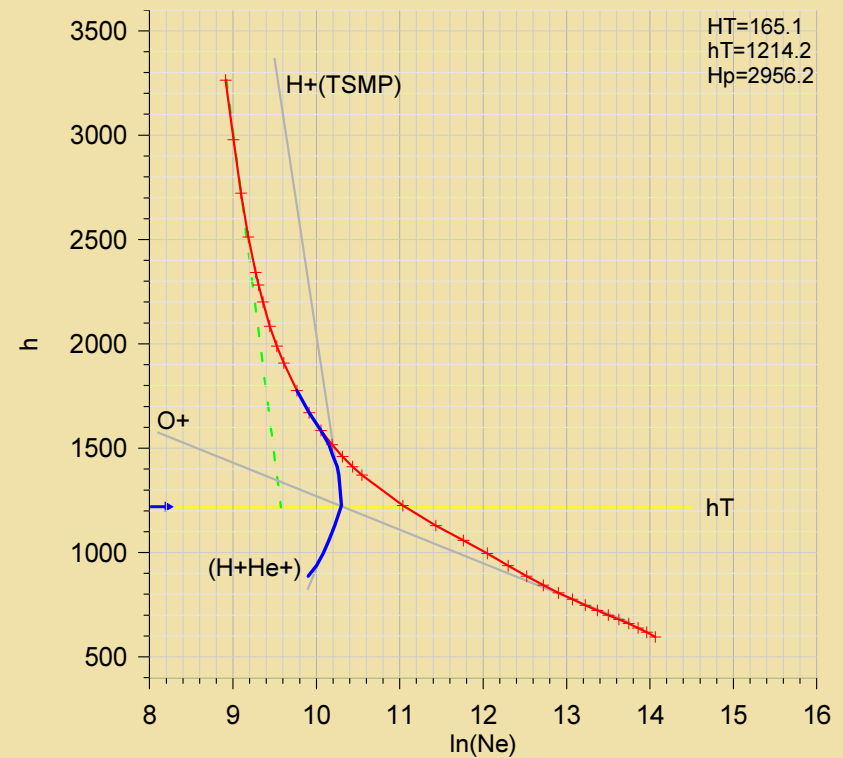
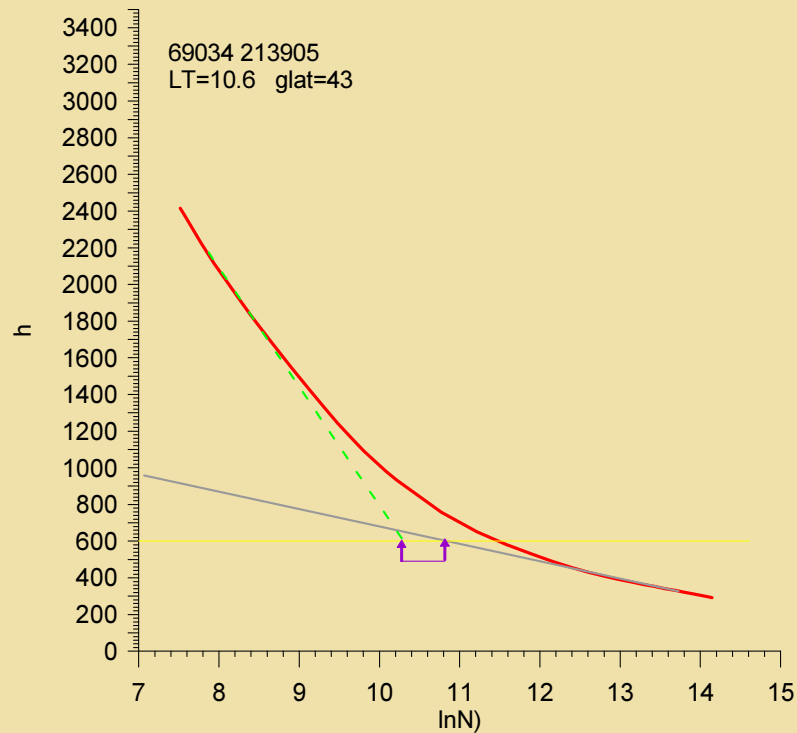
$$H_T \equiv H_{O^+}, \quad H_p \equiv H_{H^+}$$

Ratio H_p/H_T is plotted as function of geomagnetic latitude. It is well approximated by $1/L$. The expression set up is:

$$H_p = [9\cos^2(gl\text{at})+4]H_T$$



Introducing He^+ into TSMP



Topside Sounder Model Profiler (TSMP)

$$Ne = N_{O^+}(h) + gN_{O^+}(h_T) \exp\left(-\frac{|h-h_T|}{H_p}\right) + (1-g)N_{O^+}(h_T) \exp\left(-\frac{|h-h_T|}{4H_T}\right)$$

where $N_{O^+}(h)$ is expressed by α -Chapman function:

$$N_{O^+}(h) = Nm \exp\left\{-\frac{1}{2}\left[\frac{h-hm}{Hm} + 1 - \exp\left(\frac{h-hm}{Hm}\right)\right]\right\}$$

Nm is the F layer peak density NmF2,

Hm is the neutral scale height;

g is the ratio N_{H^+} / N_{O^+} at h_T

h_T is the upper transition height;

H_T is O^+ (topside) scale height

Linking TSMP to Digisonde profiler

In the topside: TSM provides scale height H_T , transition height h_T , and their ratio $R_T = H_T / h_T$

At the F layer peak: Digisonde provides $NmF2$, $hmF2$, and the topside scale height H_m

Key idea:

In TSMP: Digisonde scale height H_m replaces H_T and new transition height is obtained multiplying H_m by $1/R_T$.

caution:

H_m is a neutral scale height; it has to be modified to comply with H_T

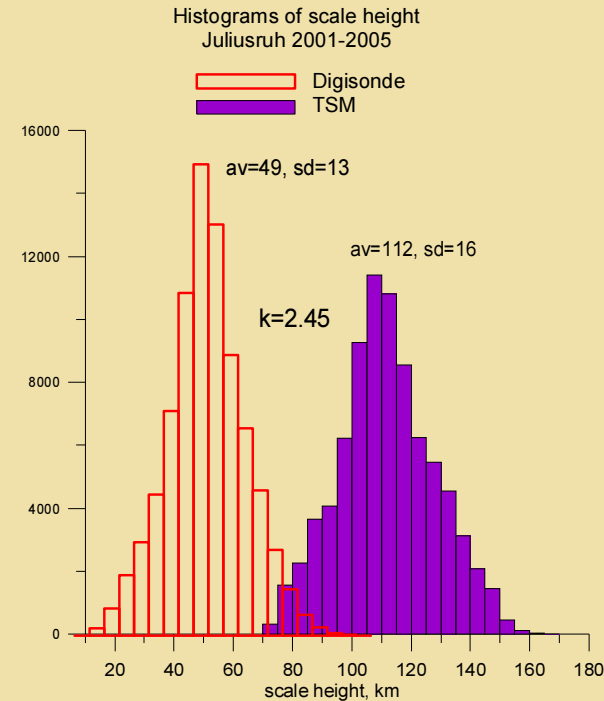
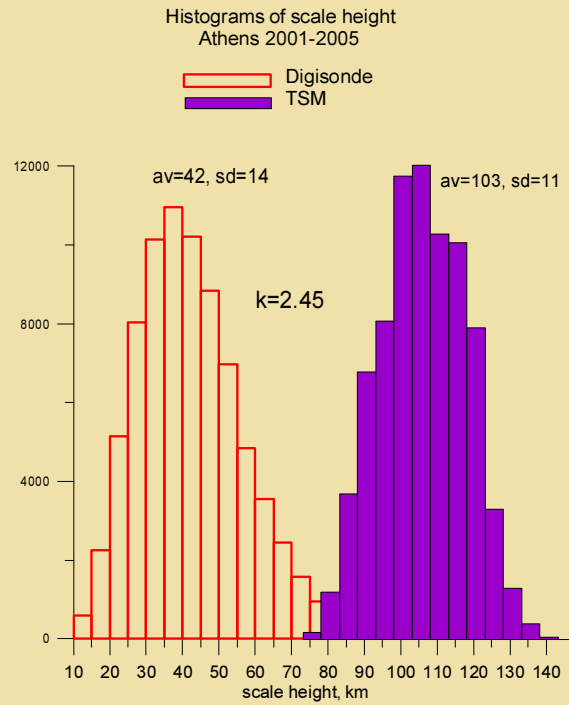
TSMP-assisted Digisonde profiler (TaD)

We couple TSMP with Digisonde by substituting H_T in TSMP with H_m and specifying $hmF2$ and $NmF2$ at the F layer peak.

The new hybrid profiler is named TSMP-assisted Digisonde (**TaD**) profiler.

TaD now provides electron density profiles in topside ionosphere and plasmasphere in time of Digisonde sounding, e.g. in real time.

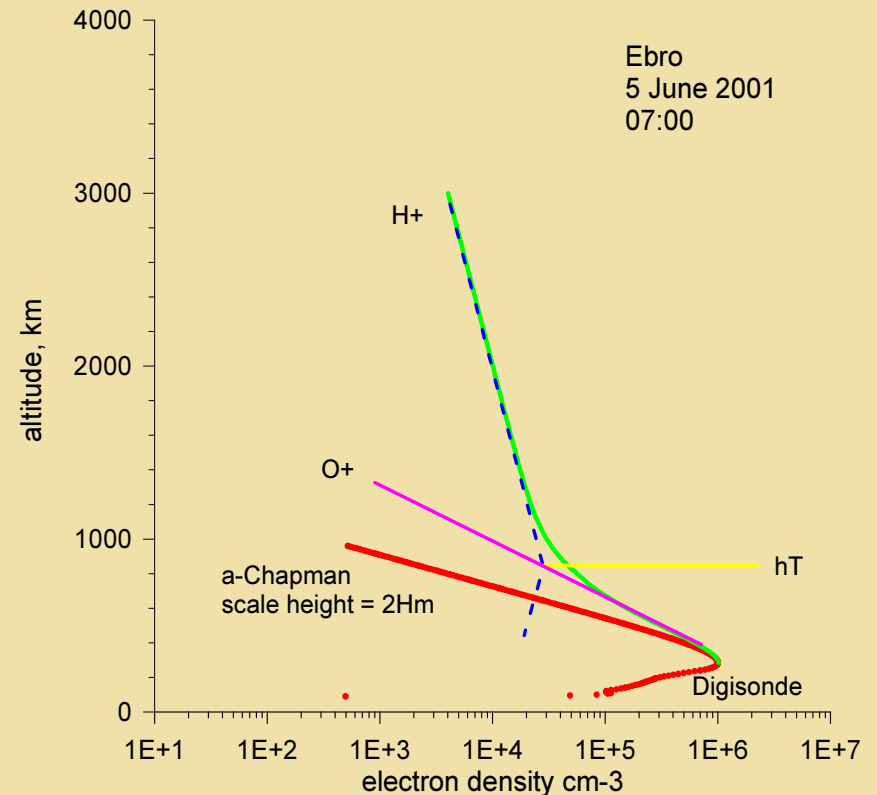
Modifying Digisonde scale height Hm



Although average values of H_m and H_T for Athens and Juliusruh differ, their ratio H_T/H_m remains steady. In TaD the topside scale height H_T is taken now as $2.5 H_m$, and the transition height $h_T = H_T / R_T$.

α -Chapman and TaD profiles

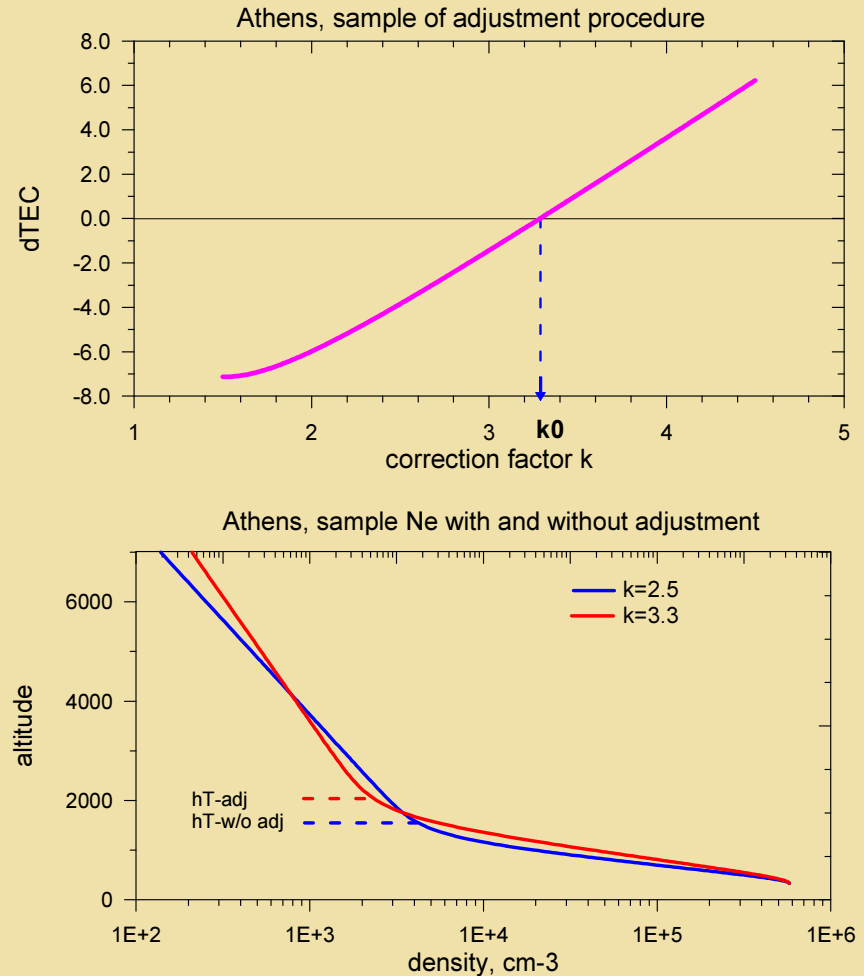
Digisonde topside profile is expressed by the α -Chapman formula. At higher altitudes the profile decreases with a scale height $2H_m$, which represent a plasma scale height with plasma temperature $T_p = 2T_n$ ($T_n = T_i = T_e$). The O^+ scale height, produced by TaD, is 1.25 times the α -Chapman plasma scale height. This is because the topside plasma temperature is larger than $2T_n$.



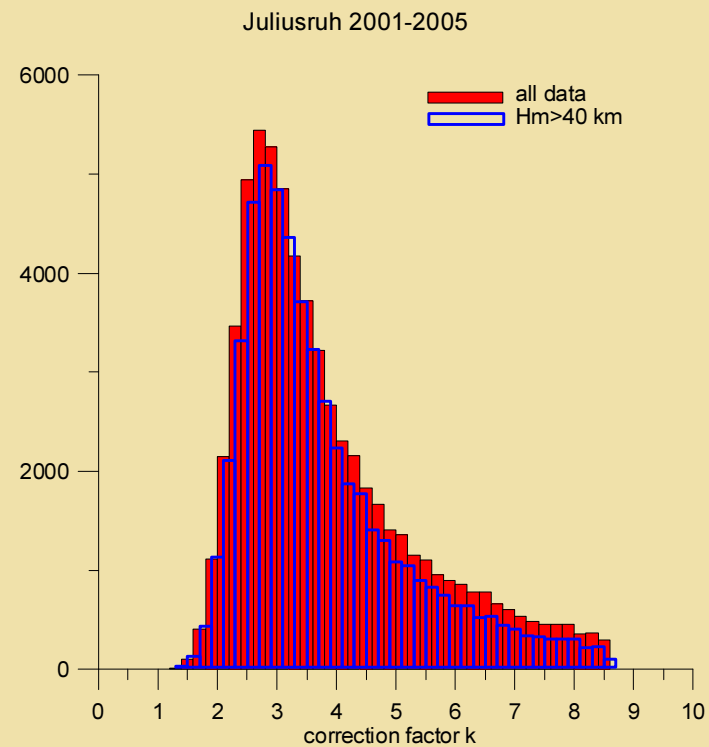
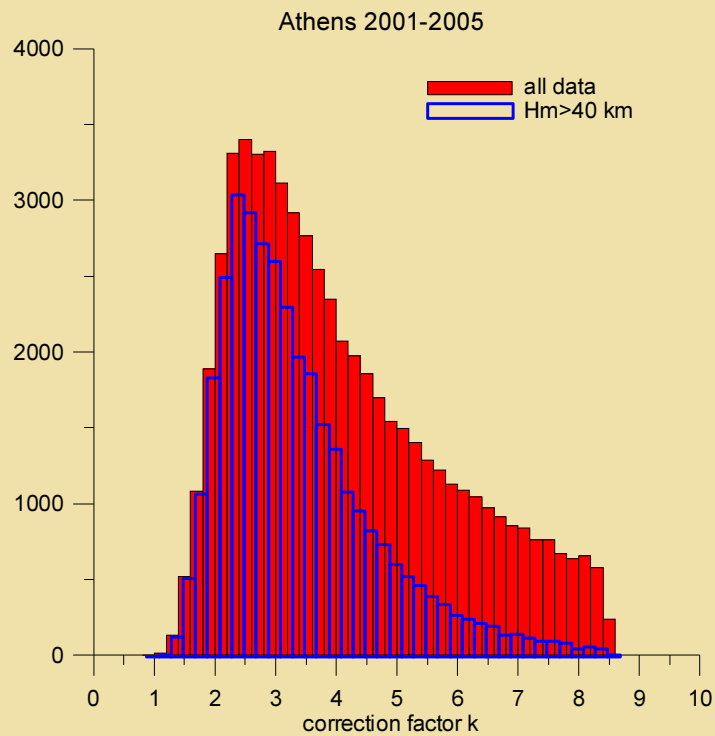
Adjustment procedure

Correction factor k varies between 1.5 and 5 with a step 0.01. The zero value k_0 marks the correction factor to H_m , at which the integral of TaD profile plus the bottomside TEC equal the measured GPS_TEC (dTEC=0).

In this sample $k_0 = 3.3$ and corresponding Ne profile is shown by the red line.



Scale height correction



$H_m < 40$ km are 42% of the cases for Athens and 16% for Juliusruh

Error assessment - 1

Transition height h_T and plasmasphere scale height H_p are obtained by statistically defined dependences with H_m :

$$h_T = k H_m / R_T \quad \text{and} \quad H_p = k H_m (9 \cos^2(\text{glat}) + 4)$$

They introduce errors (uncertainties) even TaD_TEC is adjusted to GPS_TEC with a good accuracy. To estimate the errors coming from all parameters in the TaD profile when varying k , we consider the total change of the integral T as:

$$\Delta T = \frac{\partial T}{\partial k} \Delta k + \frac{\partial T}{\partial H_m} \Delta H_m + \frac{\partial T}{\partial h_T} \Delta h_T + \frac{\partial T}{\partial H_p} \Delta H_p$$

The total differential ΔT is a sum of partial derivatives of T on the parameters at the zero value k_0 ($d\text{TEC}=0$), multiplied by their respective shifts.

Error assessment - 2

At 10% shift of parameter values taken around k_0 , the partial contributions in percent to the total change of T , obtained over the whole Athens data set, are:

$$\begin{aligned} 0.1k \frac{\partial T}{\partial k} &= (91 \pm 6)\% & 0.1Hm \frac{\partial T}{\partial Hm} &= (9 \pm 6)\% \\ 0.1h_T \frac{\partial T}{\partial h_T} &= (4 \times 10^{-5})\% & 0.1Hp \frac{\partial T}{\partial Hp} &= (2 \times 10^{-9})\% \end{aligned}$$

Similar results are obtained for Juliusruh data.

important clue:

With acceptable accuracy the TaD profile can be adjusted to the measured GPS_TEC by **varying solely** the correction parameter **k**

Summary of the results

- The **Topside Sounder Model (TSM)** provides topside scale height H_T , upper transition height h_T , and their ratio R_T depending on geomagnetic latitude, DoY, local time, solar flux and K_p .
- **TSM-based profiler (TSMP)** provides the shape of topside ionosphere and plasmasphere vertical ion distribution.
- **TSMP-assisted Digisonde (TaD)** provides in real time electron density profiles up to GPS heights at Digisonde locations.
- **TaD** was extensively tested and verified by all available independent source of data. The average error compared with measured TEC does not exceed 3 TECU.
- **TaD** profiling accuracy is significantly increased when the profiles are adjusted with GPS-derived TEC from co-located receiver.