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 ($\equiv H_{H+}$) $H_P=H_T(9cos^2 glat+4)$ *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

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

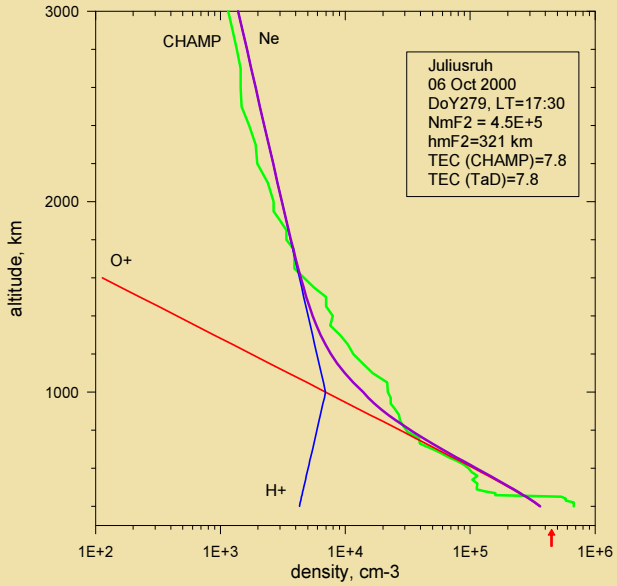
TaD is extensively tested and verified using independent observations:

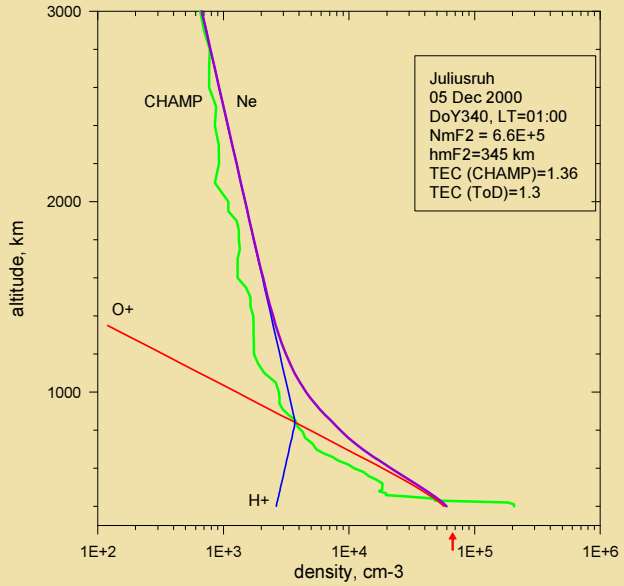
- CHAMP TEC and profiling;
- ground-based GPS-TEC;
- Malvern Incoherent Scatter Radar (ISR);
- RPI sounder on IMAGE

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

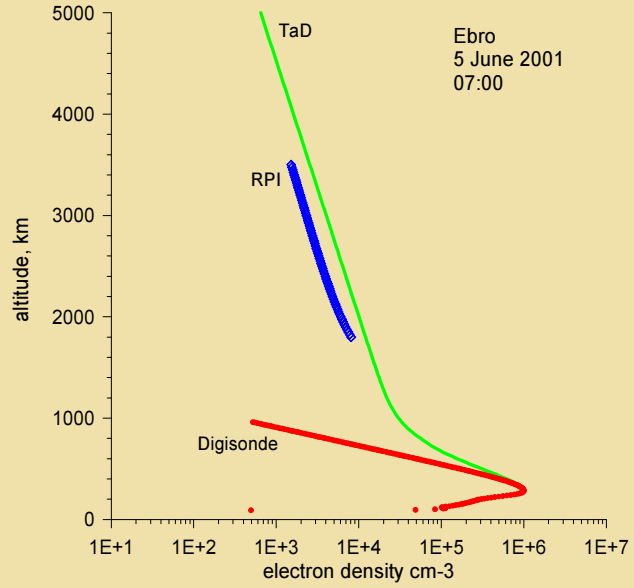
TaD verification results
Comparison with CHAMP and IMAGE/RPI derived profiles

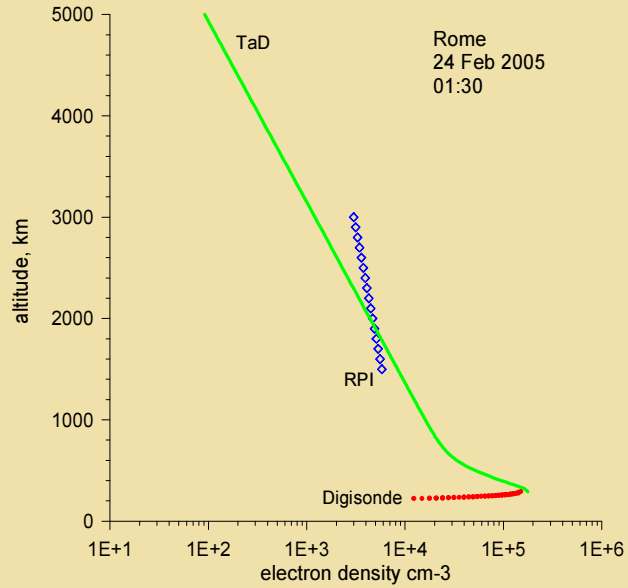
CHAMP





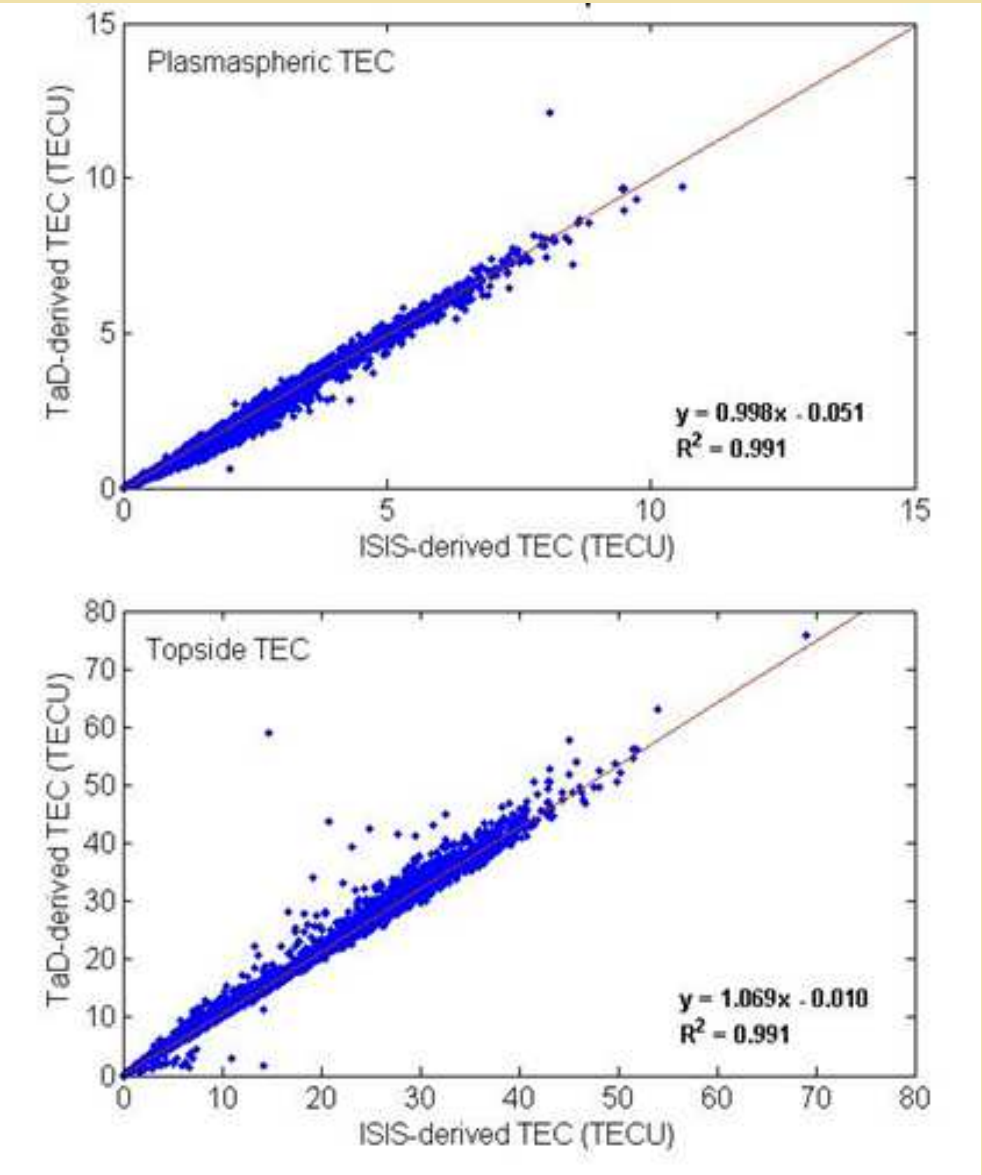
IMAGE





Belehaki et al.,
Acta Geo., 2009

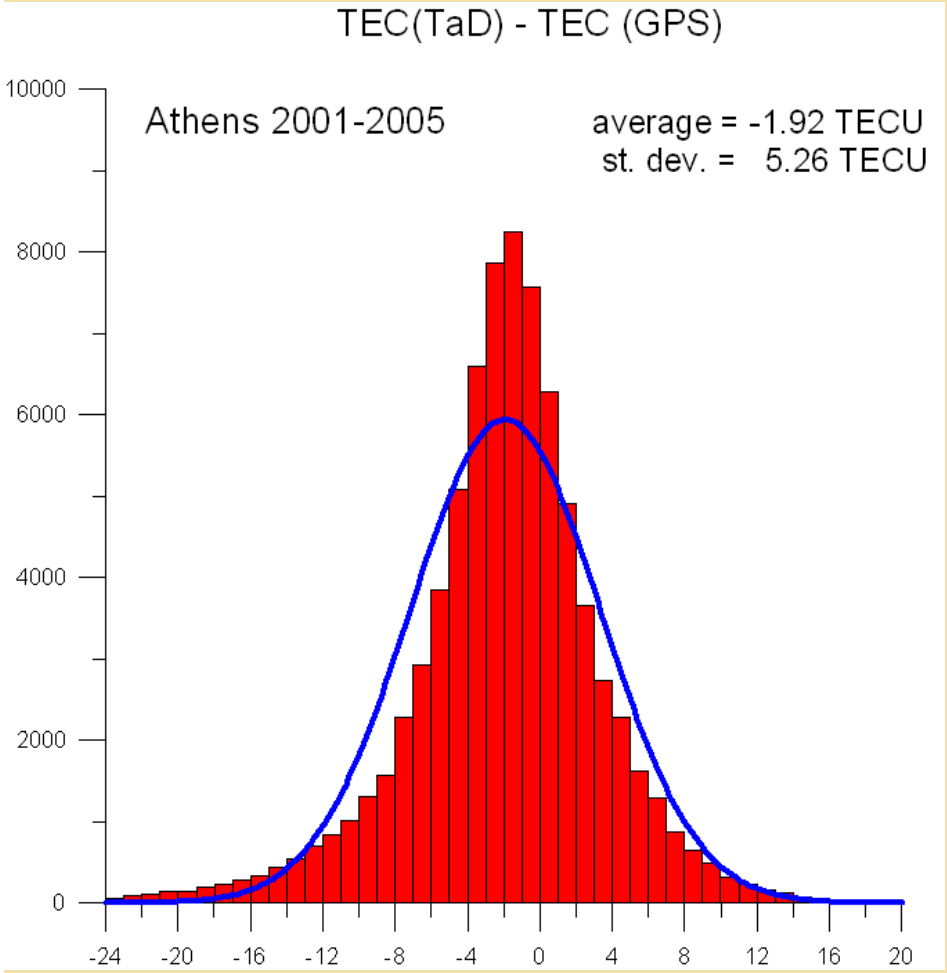
TaD verification results

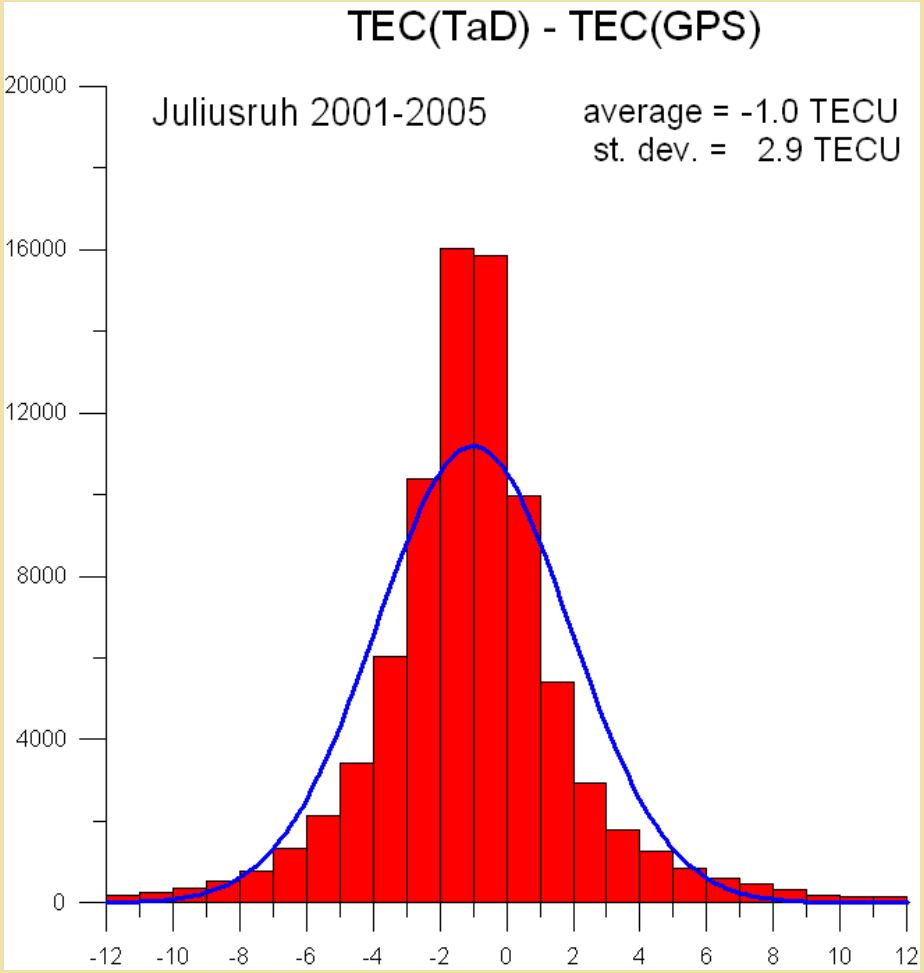


Internal consistency check: how well the model can reproduce ISIS-2 derived TEC

From
Belehaki et al., SWSC, 2012

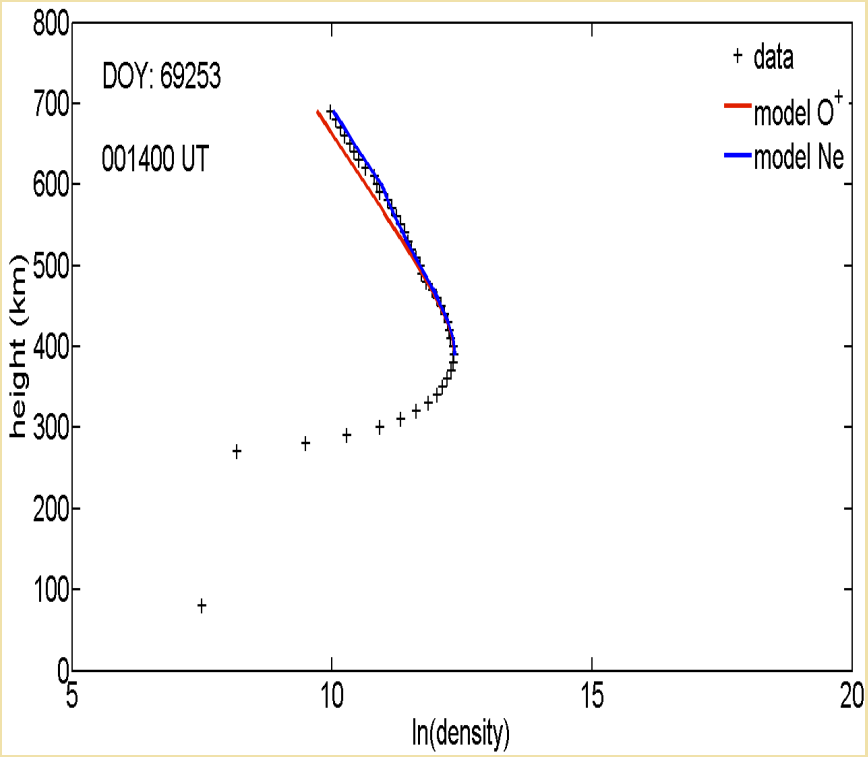
TaD verification results
Comparison with TEC-GNSS ground based receivers



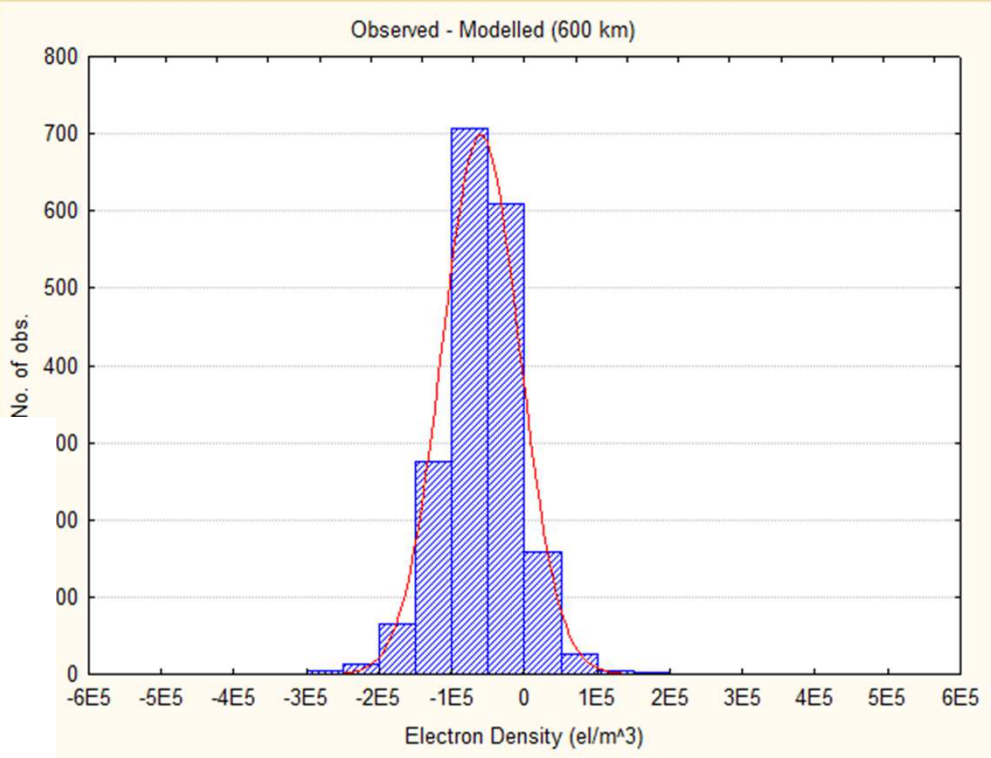


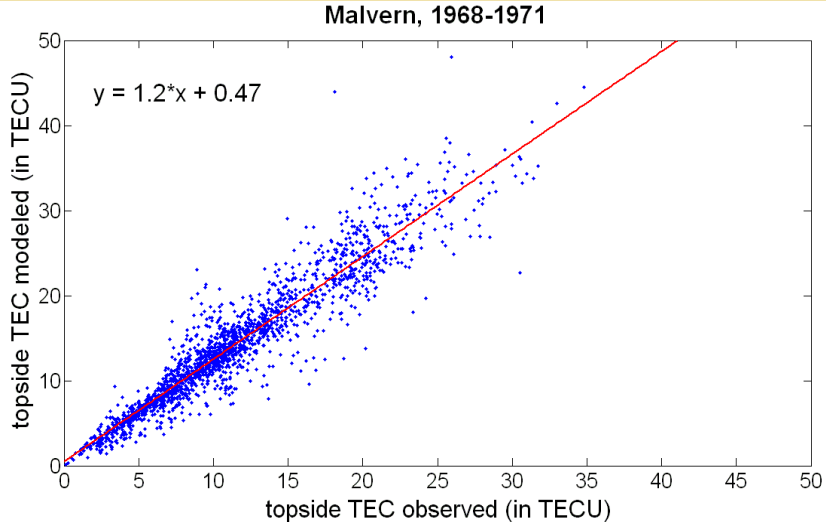
Kutiev et al.,
Acta Geo., 2009

TaD verification results
Topside ED: comparison with Malvern ISR



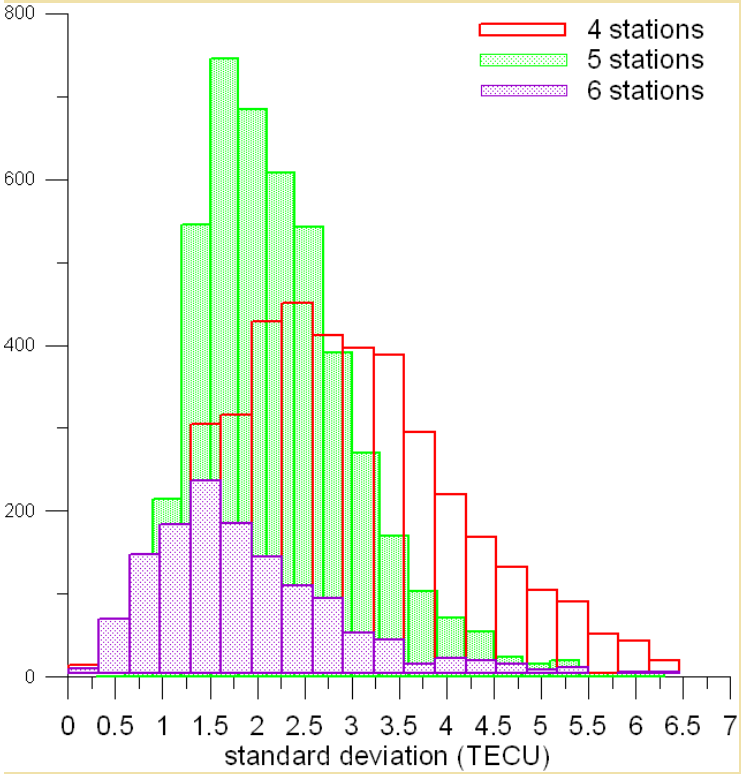
Example for TaD derived profiles based at Malvern site



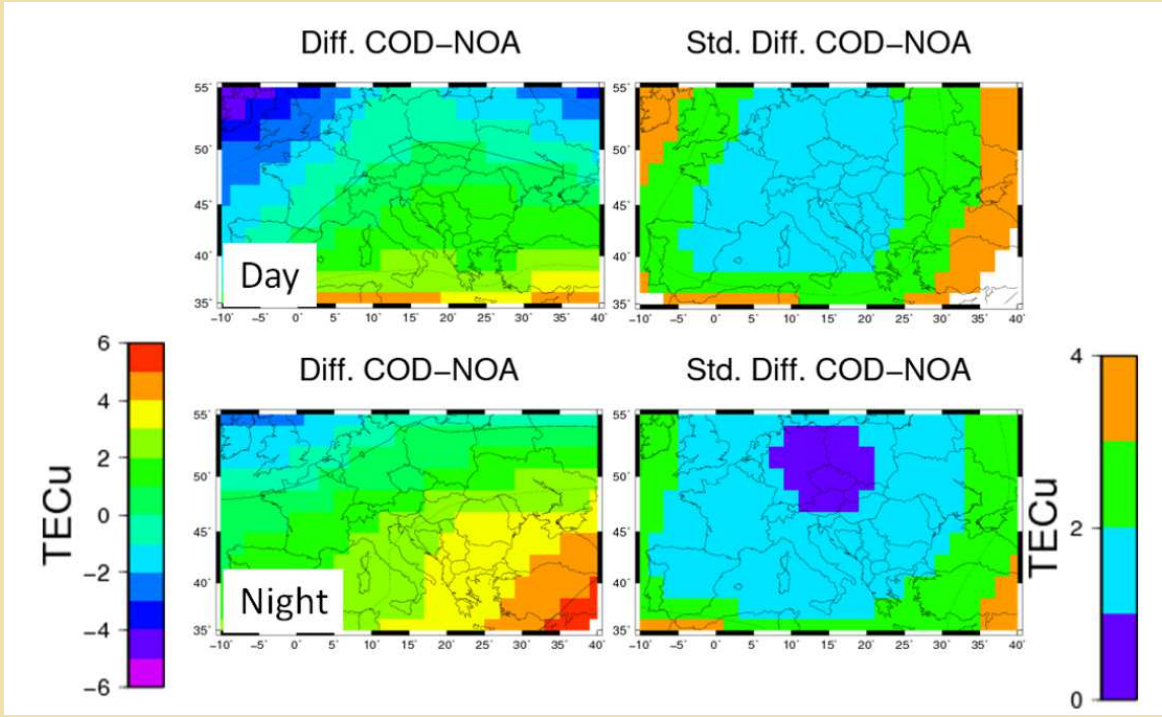


The distribution of the simple difference between the observed ISR and the modeled electron densities at 600 km

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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Near real-time of the topside electron density over Europe

Help | Year 2014 | Month 05 | Day 10 | Hour 08 | Minute 30 | UT | VIEW

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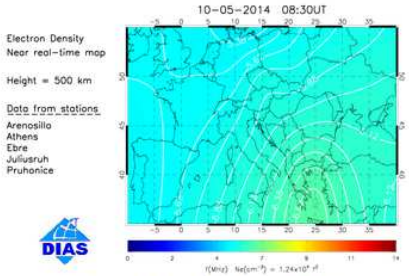
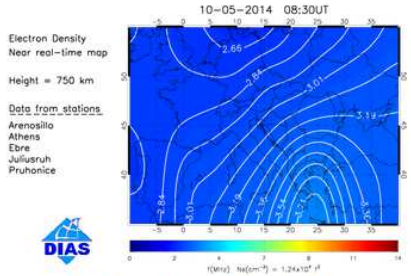
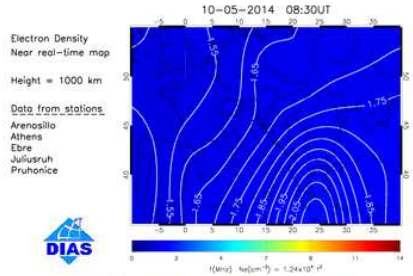
Latest available maps



Electron Density at 500km



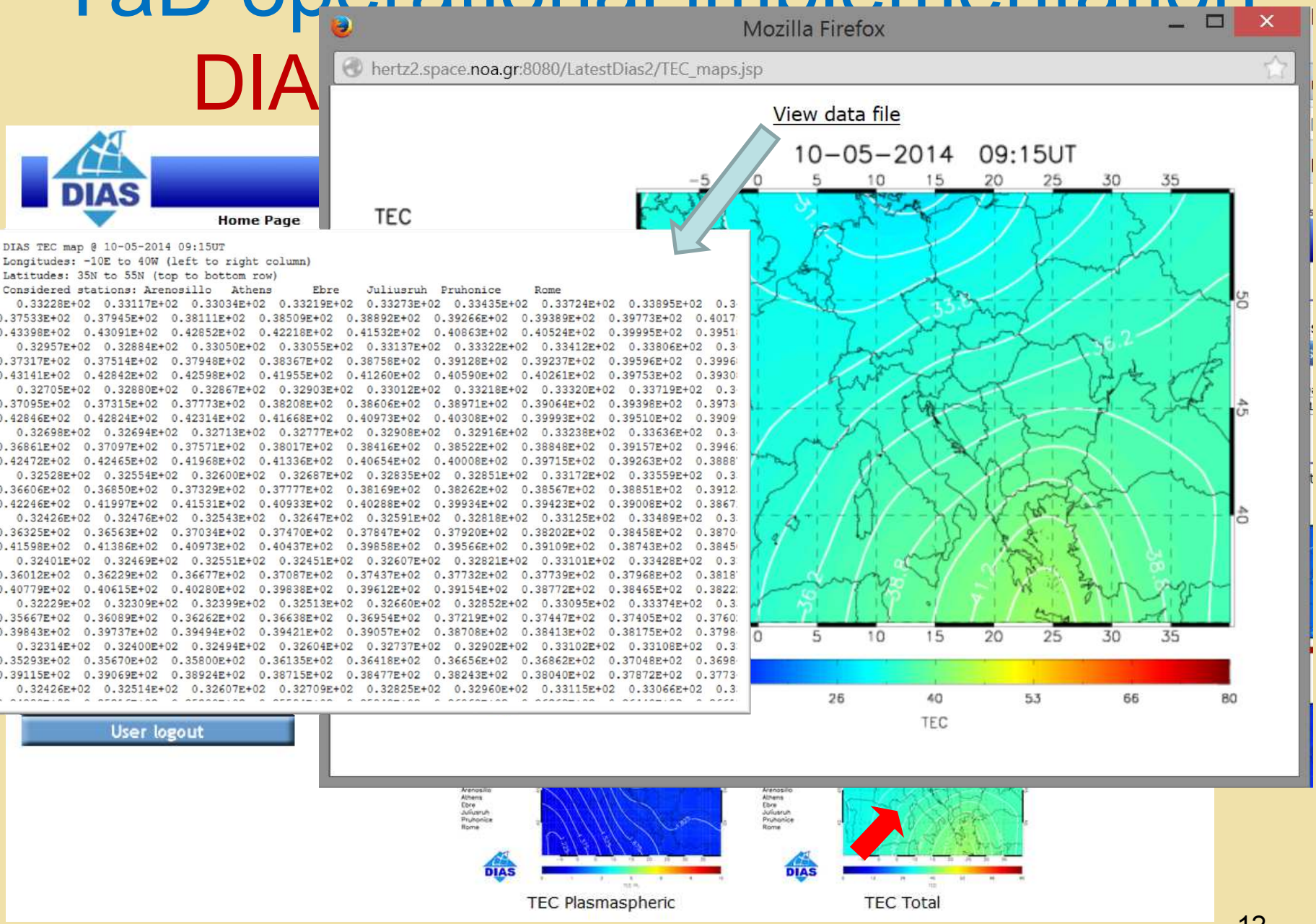
Electron Density at 750km



Electron Density at 1000km

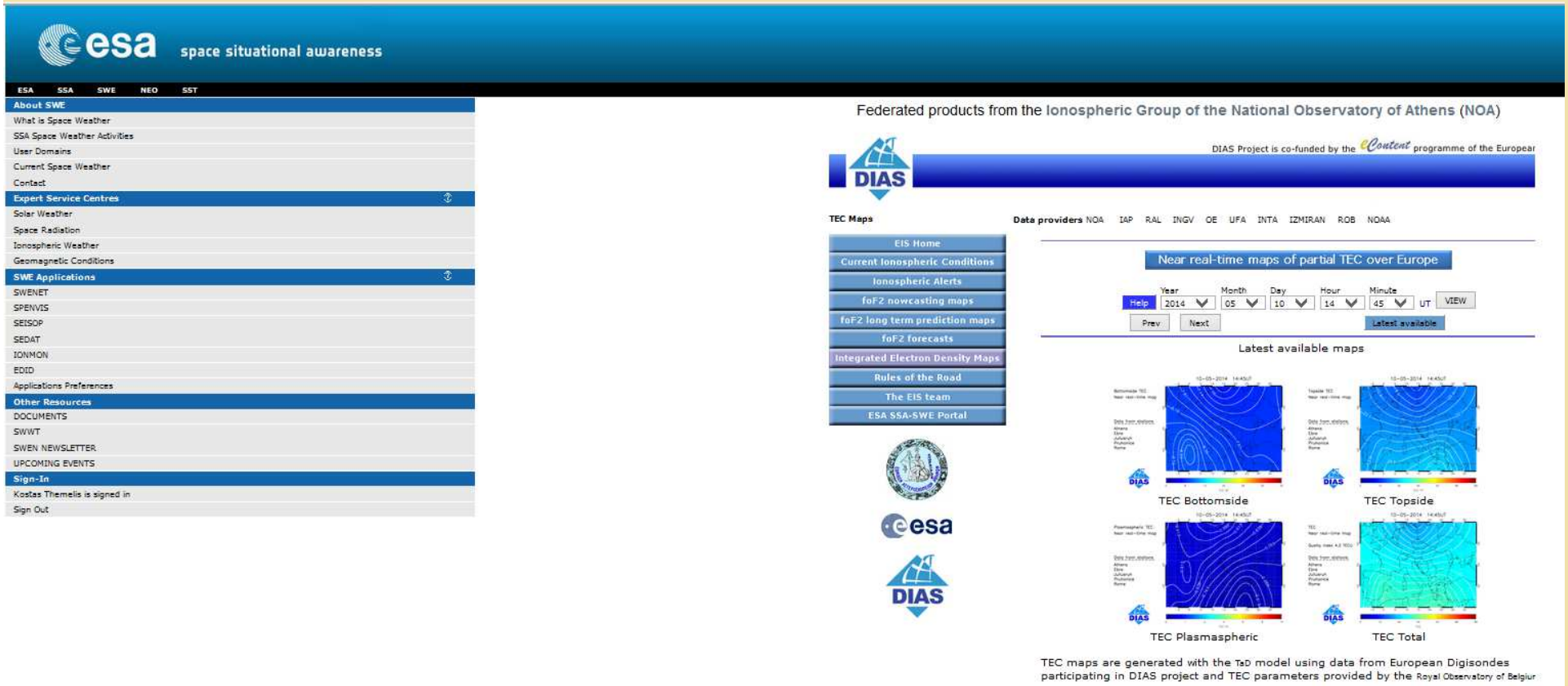
TaD operational implementation

DIA



TaD operational implementation

ESA-SSA SWE: TEC and partial TEC



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