International GNSS Service
Formerly the International GPS Service

IGS Workshop 2012, Olsztyn, Poland
July 23-27, 2012

Using of GPS TEC Observations and Radio Occultation Measurements for the Ionosphere's Monitoring

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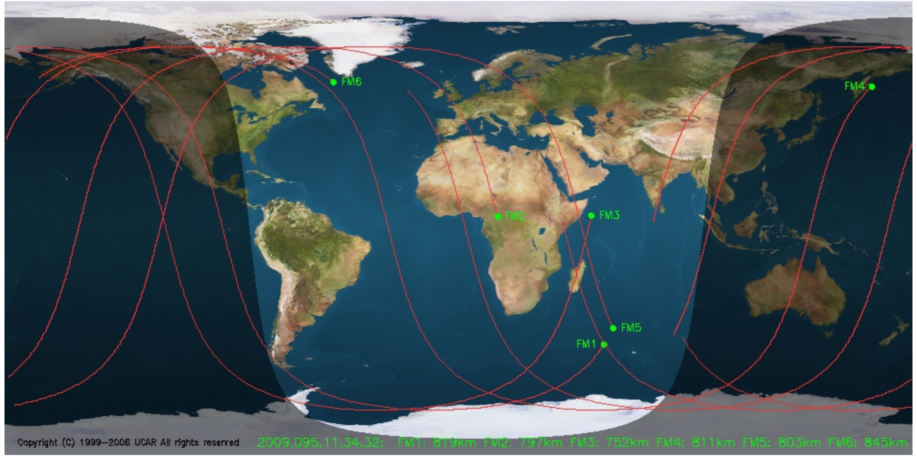
Outline

- Introduction – COSMIC mission
- Validation of COSMIC data with European Digisondes' Data
- Case-study - ionospheric storm on October 11, 2008
- Joint analysis of COSMIC data with ground-based GPS TEC Measurements
- Summary

COSMIC/FORMOSAT-3 is the Constellation Observing System for Meteorology, Ionosphere and Climate and Taiwan's Formosa Satellite Mission #3, a joint Taiwan-U.S. project.



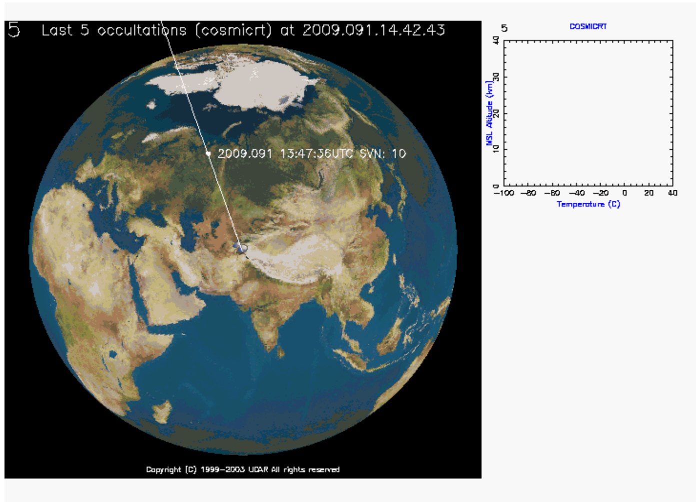
- The COSMIC constellation was launched on April 14, 2006

- Altitude ~700-800 km

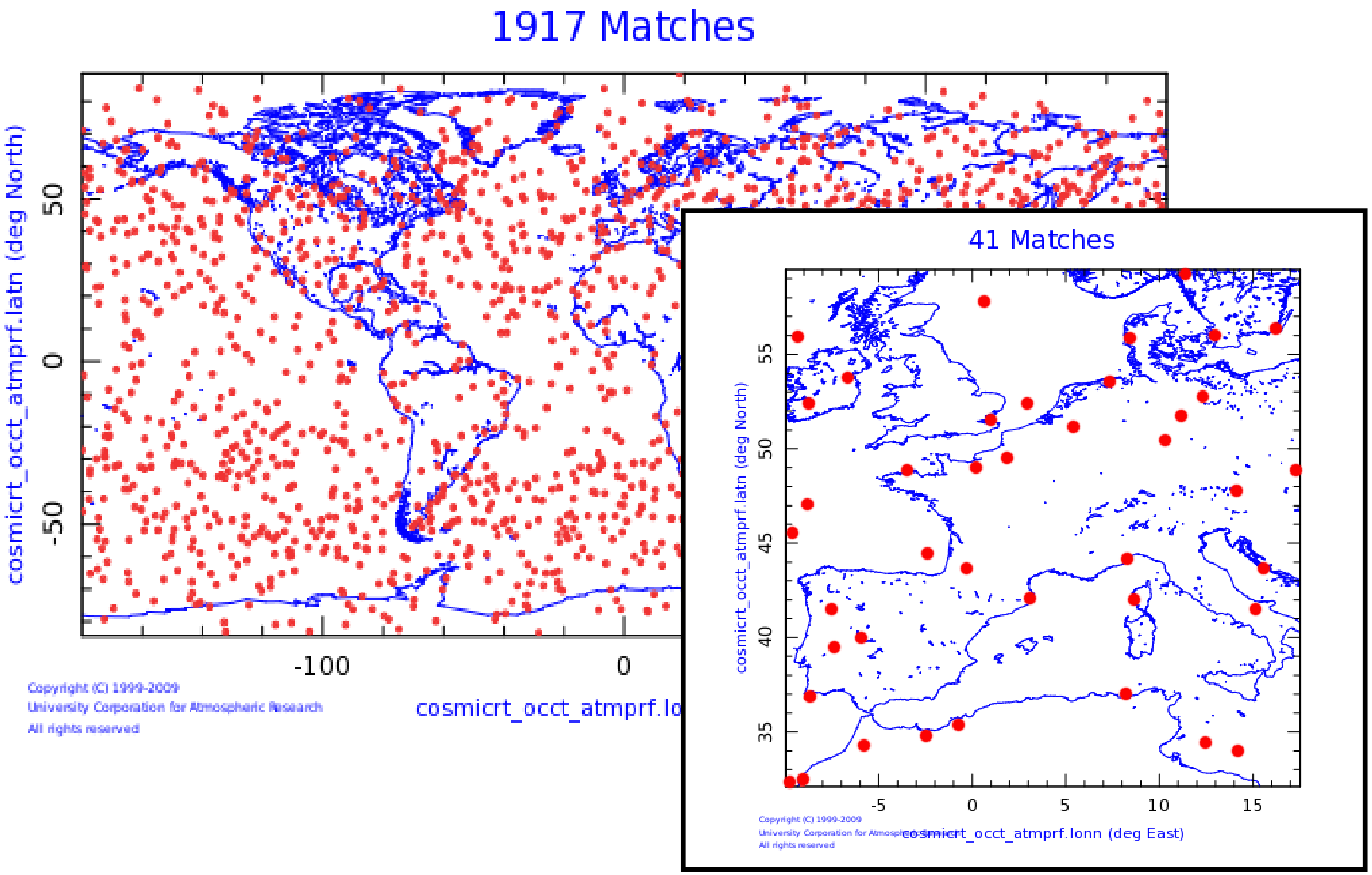
- six spacecrafts

- each with three instruments, including GPS radio occultation receiver, tiny ionospheric photometer, and tri-band beacon

- Depending on the state of the constellation between 1,500 – 2,500 good soundings are obtained per day

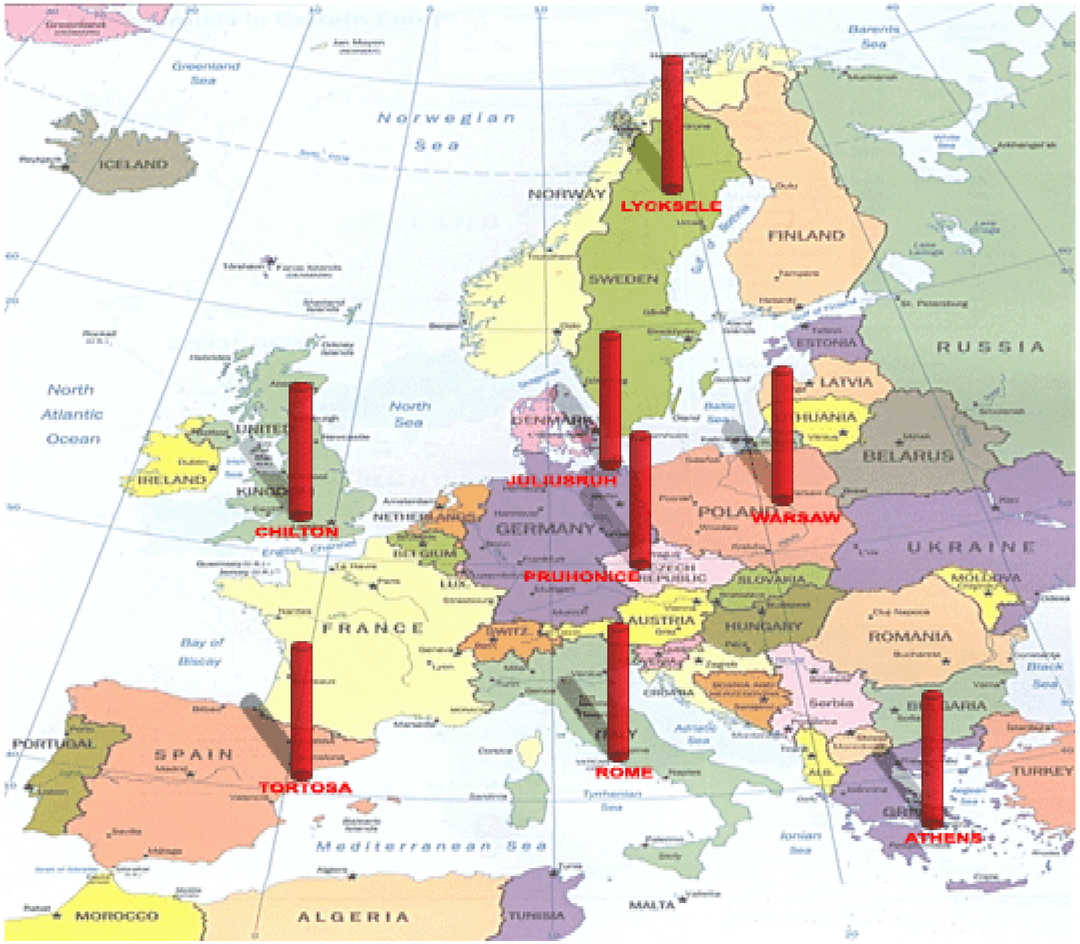


Occultation location for COSMIC, 24 Hrs (01.05.2009)

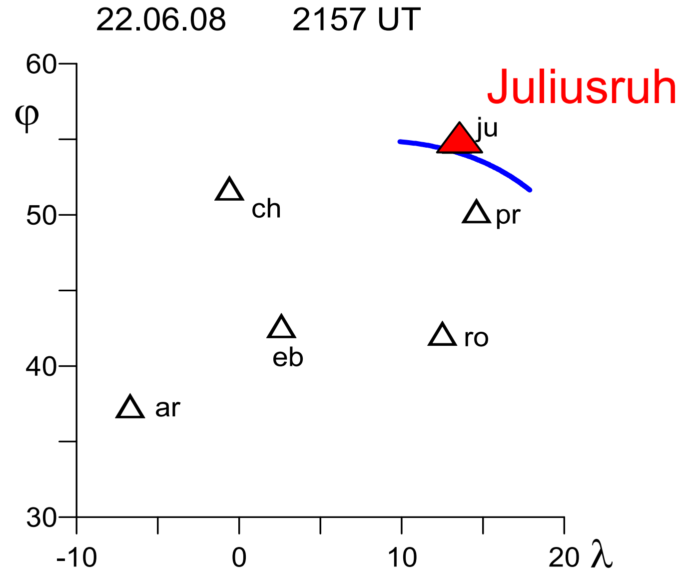


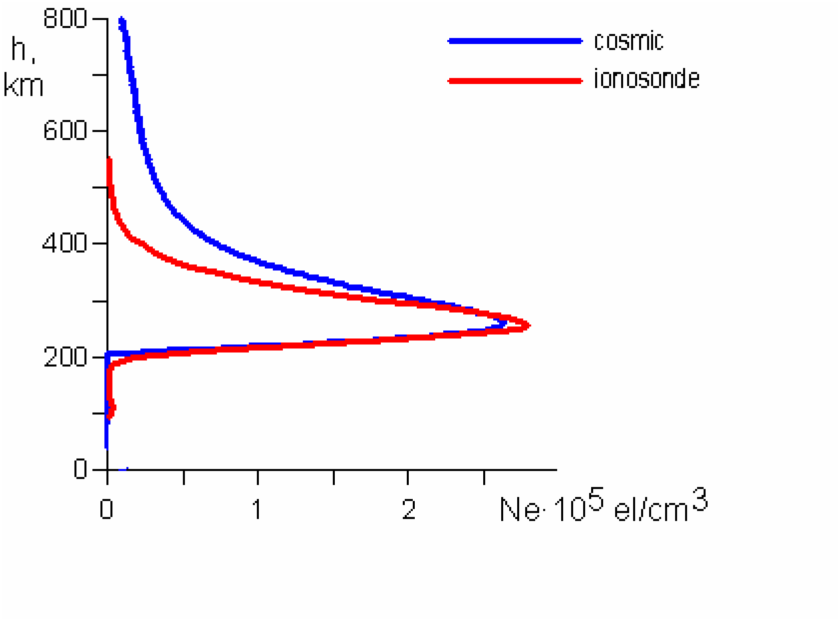
COSMIC RO measurements and products (such as electron density profiles) can be available from the Taiwan Analysis Center for COSMIC (**TACC**, http://tacc.cwb.gov.tw/en/) and the COSMIC Data Analysis and Archive Center (**CDAAC**, http://www.cosmic.ucar.edu/cdaac/).

European Digital Upper Atmosphere Server



Algorithm of the preliminary analysis of COSMIC Profiles





1. Selection of RO points located in European region

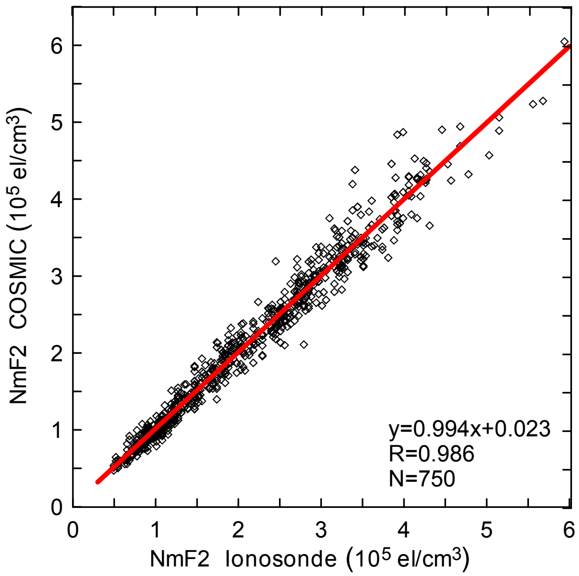
2. Visualization of RO ray path tangent points

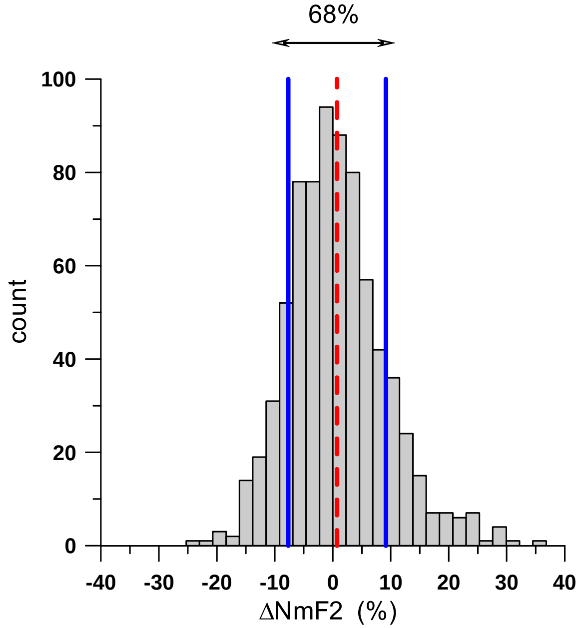
3. Choose of the nearest ionosonde

4. Creation of graphs with RO and ionosonde profiles

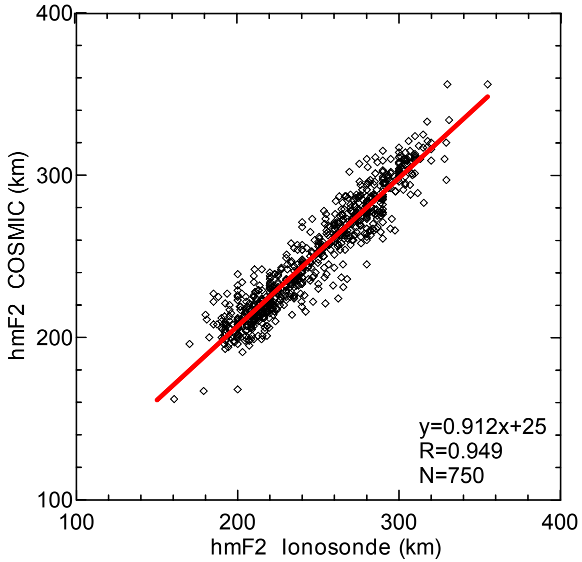
5. Calculations and analysis

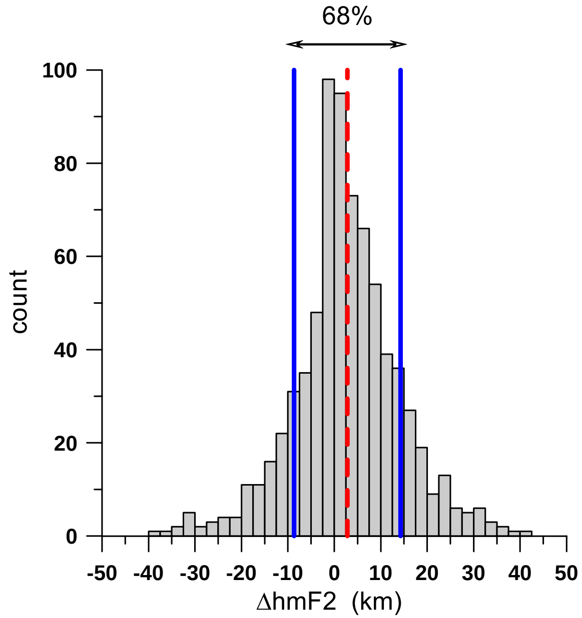
Statistical Results





<x>= 0.72 %
std = 8.42 %

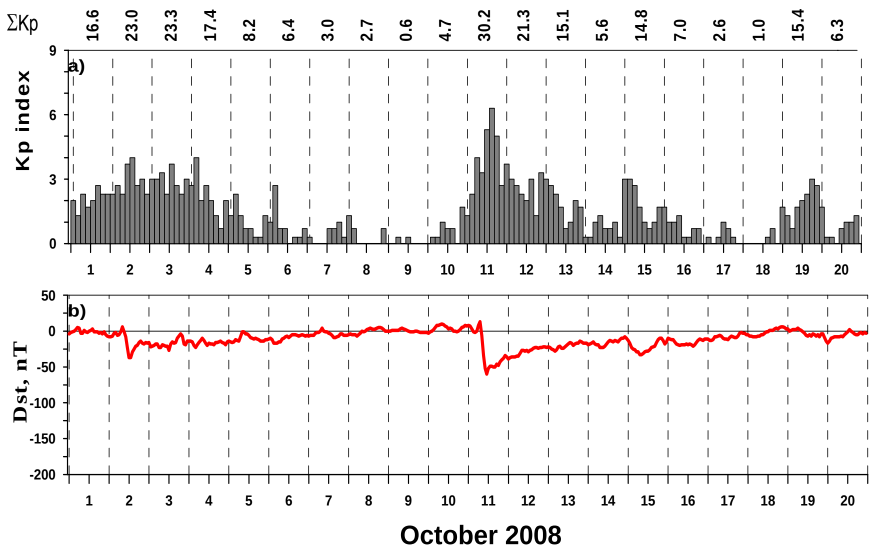


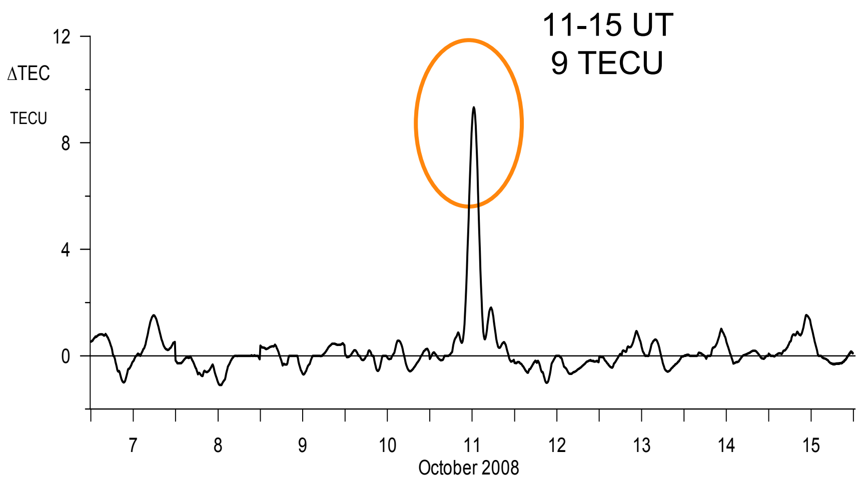


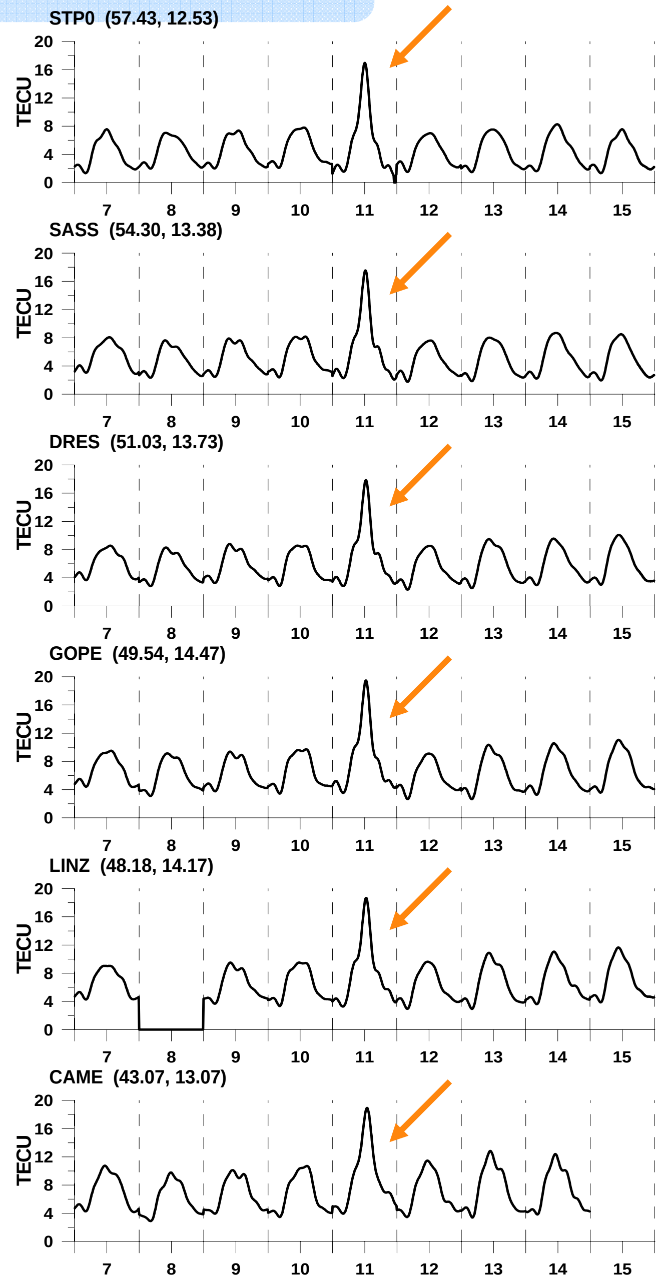
<x>= 2.80 km
std = 11.46 km

<x>= 1.36 %
std = 4.89 %

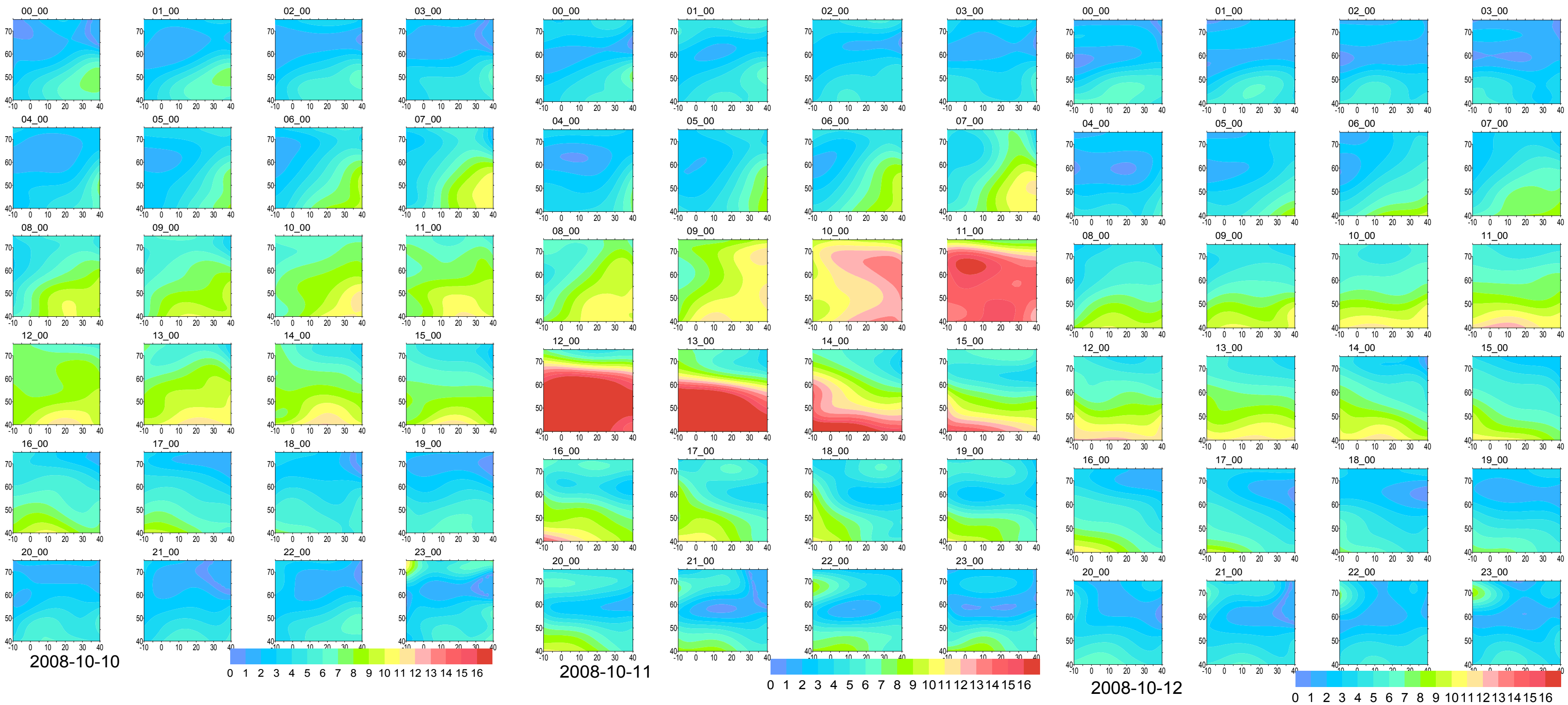
Ionospheric Storm on October 2008





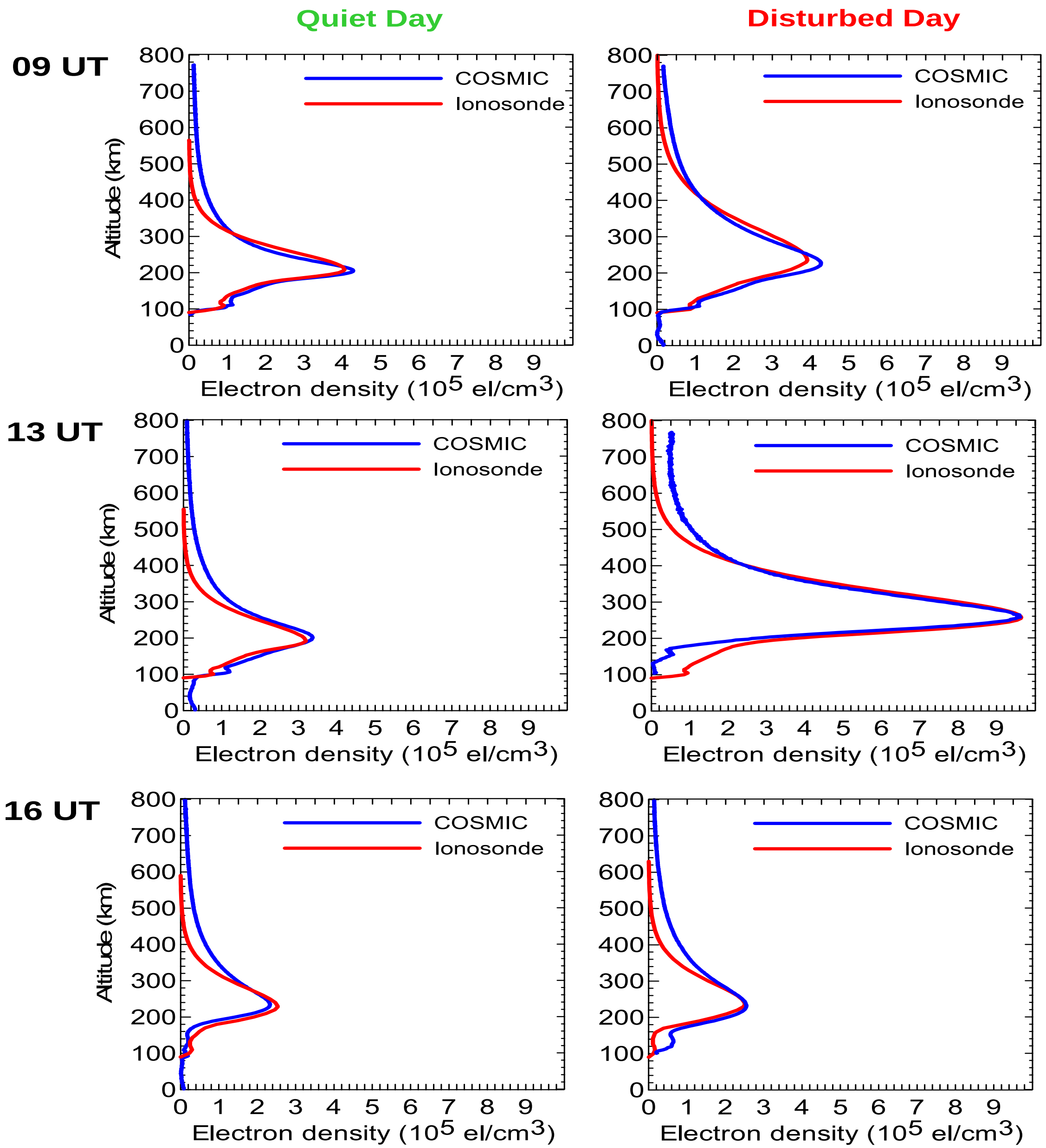


TEC maps over Europe during October 10-12, 2008



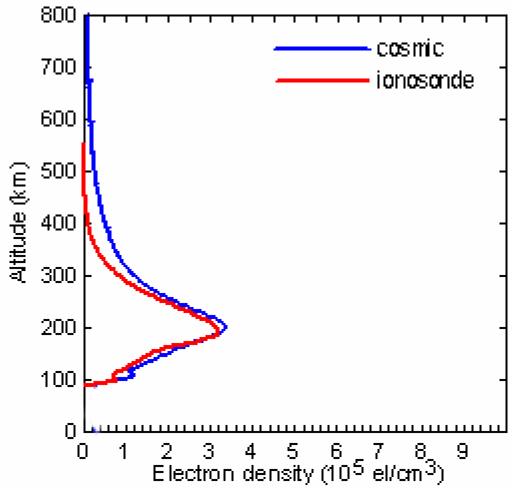
October 10 October 11 October 12

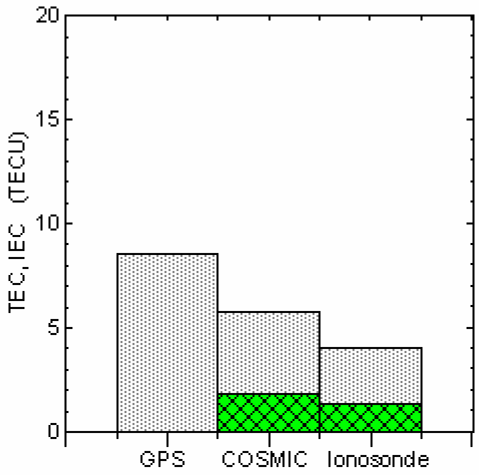
Comparison of COSMIC and ionosonde electron density profiles



Comparison of COSMIC data with GPS TEC

Quiet Day





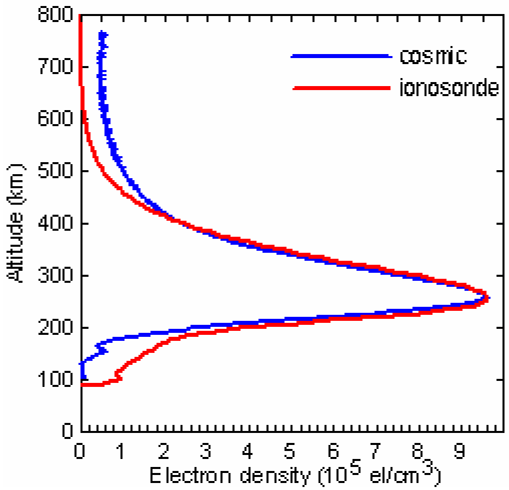
ΔNmF2 = 5.8 %
ΔhmF2 = 9 km

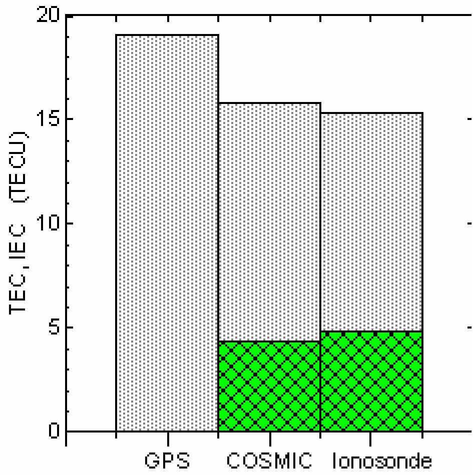
IEC_b / TEC= 24.4 %

IEC_t / TEC= 46.0 %

PEC / TEC= 29.6 %

Disturbed Day





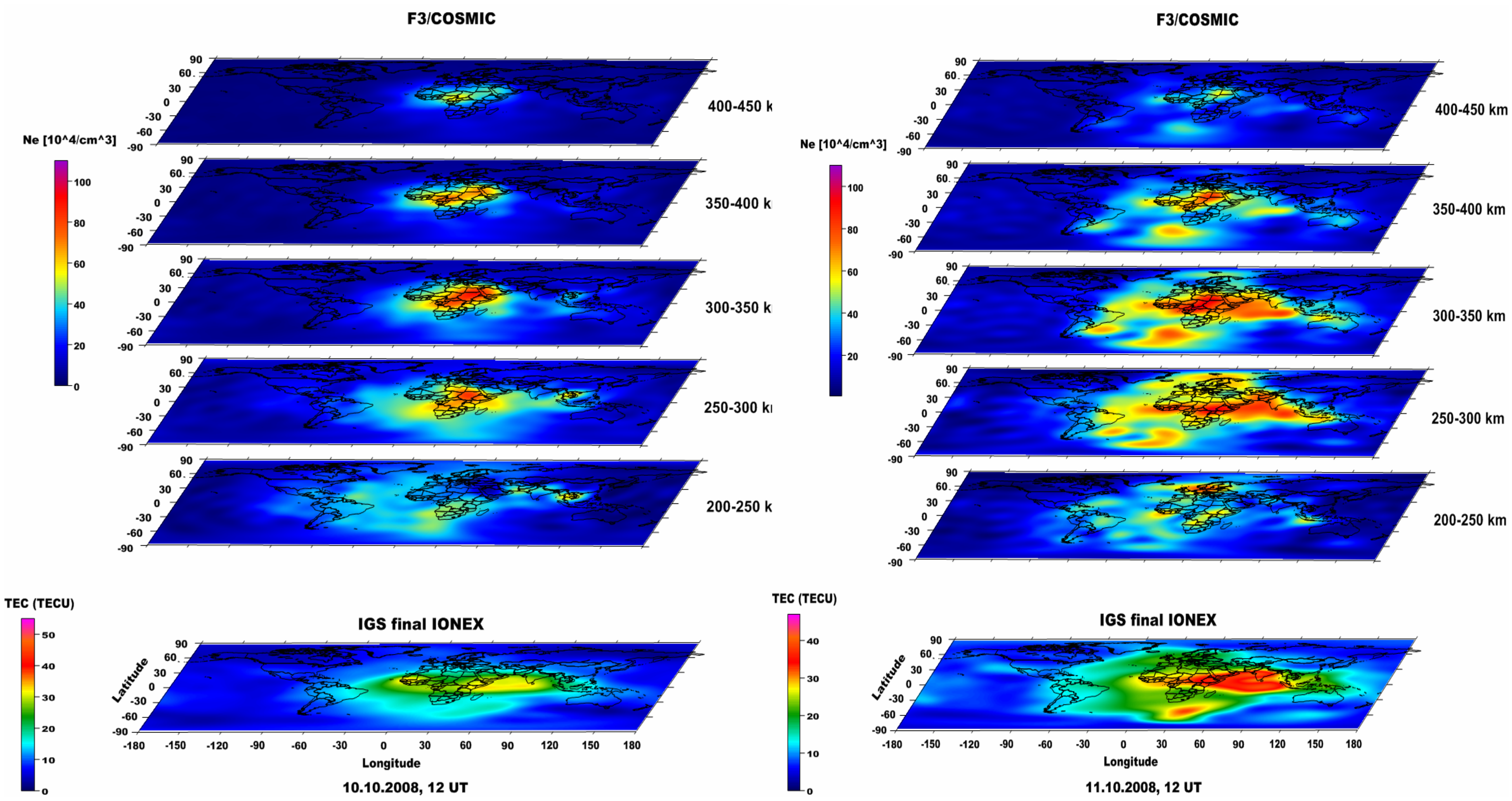
ΔNmF2 = 1 %
ΔhmF2 = 2 km

IEC_b / TEC= 24.0 %

IEC_t / TEC= 60.3 %

PEC / TEC= 15.7 %

Global maps of the ionospheric electron density at various altitudes at 12 UT on October 10 and 11, 2008. The bottom panel presents the IGS TEC maps.



Data Analysis (ionosphere/plasmasphere)

1) In this study, the final **IGS combined GIMs** produced by GRL/UWM were used to calculate the global maps of monthly medians of TEC values. These median TEC maps were generated for months of 2009 that corresponded to the equinoxes and solstices: June, September and December. So, for each month there were calculated 12 GPS TEC median maps (2 h resolution).

2) In order to compare **COSMIC RO data** with GPS TEC estimates the integration of data was done. For the present study the upper limit of the ionosphere has been taken to be at 700 km (altitude of COSMIC satellites).

- All selected COSMIC RO EDPs were integrated up to the height of 700 km, in that way estimates of IEC were retrieved.
- For each month corresponded IEC values were accumulated and then they were divided into 12 data sets by intervals with 2 h duration.
- For the global representation of IEC estimates a spherical harmonics expansion up to degree and order 15 was carried out. Fortran-based software was developed for computation of 12 two-hourly maps illustrated monthly median distribution of IEC, the final outputs are at the same of IONEX format.

3) The quantitative differences **PEC = TEC – IEC** were considered as a measure of the contribution of the PEC to GPS TEC. These values of PEC are corresponded to the part of electron content from ~ 700 km (upper bounder of COSMIC derived Ne profile) to the height of GPS satellite orbit, 20,200 km.

SPIM

We also used the International **Standard Plasmasphere-Ionosphere Model**, SPIM (Gulyaeva et al., 2002), to obtain model-derived estimates of TEC, ECbot, ECtop and ECpl.

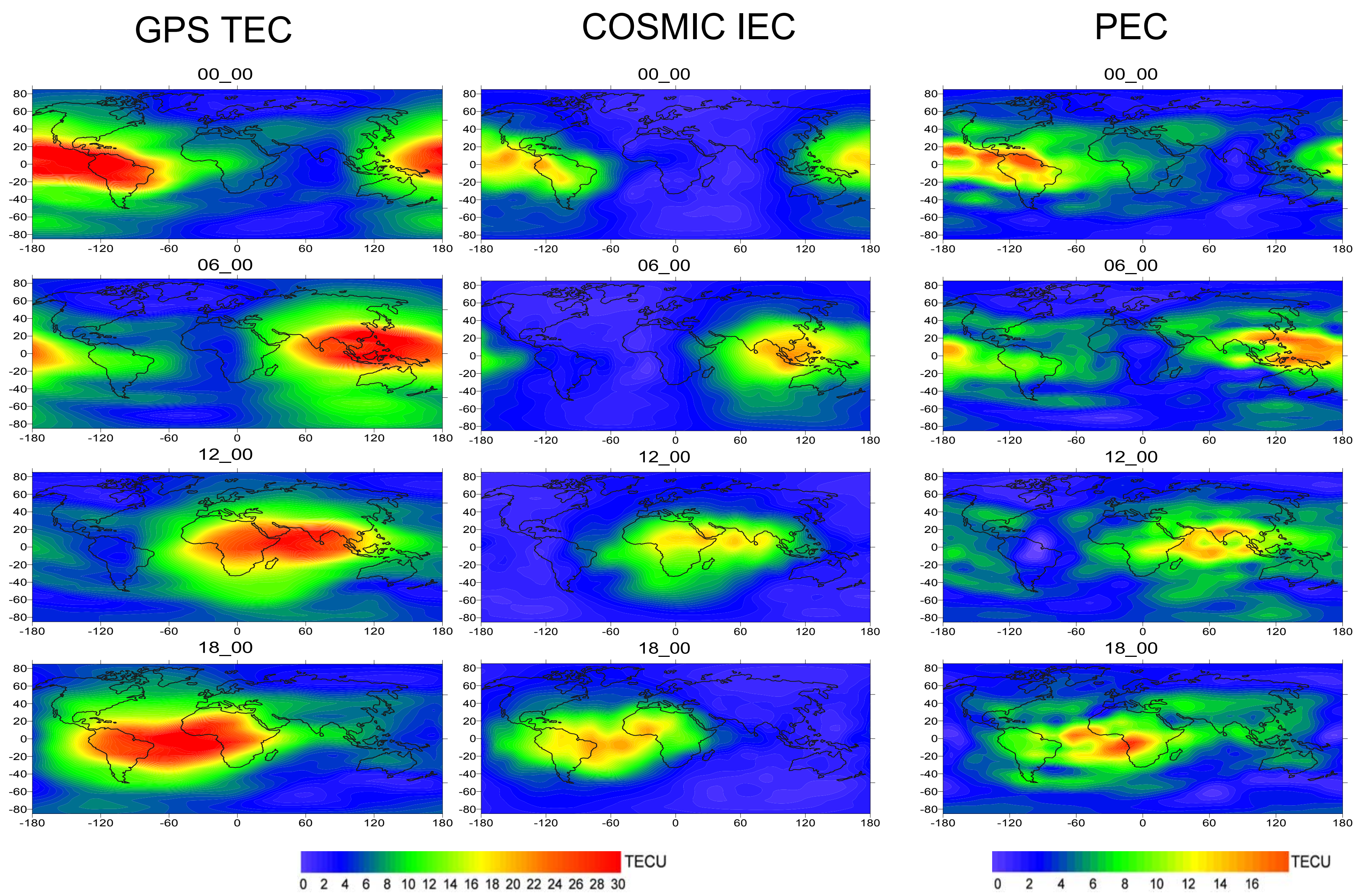
Fortran code of the model is available at (http://ftp.izmiran.ru/pub/izmiran/SPIM/).

SPIM presents the combination of the **International Reference Ionosphere model**, IRI with the **Russian Standard Model of the Ionosphere and Plasmasphere**, SMI.

One of the main advantages of SPIM that it has the plasmasphere extension and is able to provide electron density profiles and total electron content at altitudes of 80 to 35,000 km for any location of the Earth.

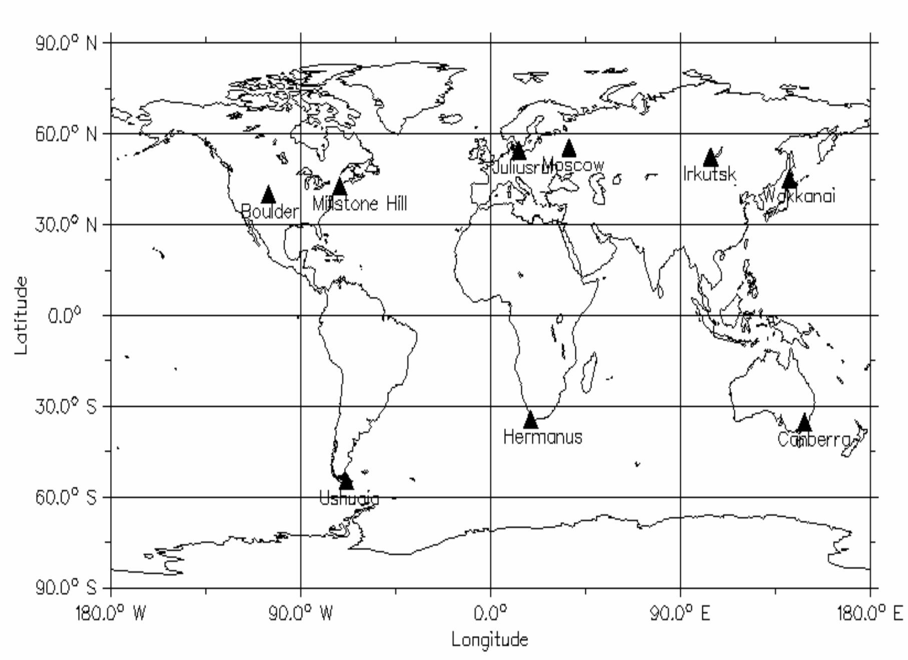
Gulyaeva, T.L., Huang, X., Reinisch, B. Ionosphere-Plasmasphere Model Sowtware for ISO. Acta Geod. Geoph. Hung., 37 (2-3), 143-152, 2002.

Monthly median maps of electron content derived from ground-based GPS TEC, COSMIC IEC and calculated PEC estimates for March 2009.



Specific points

Fig. Geographical position of selected specific points.

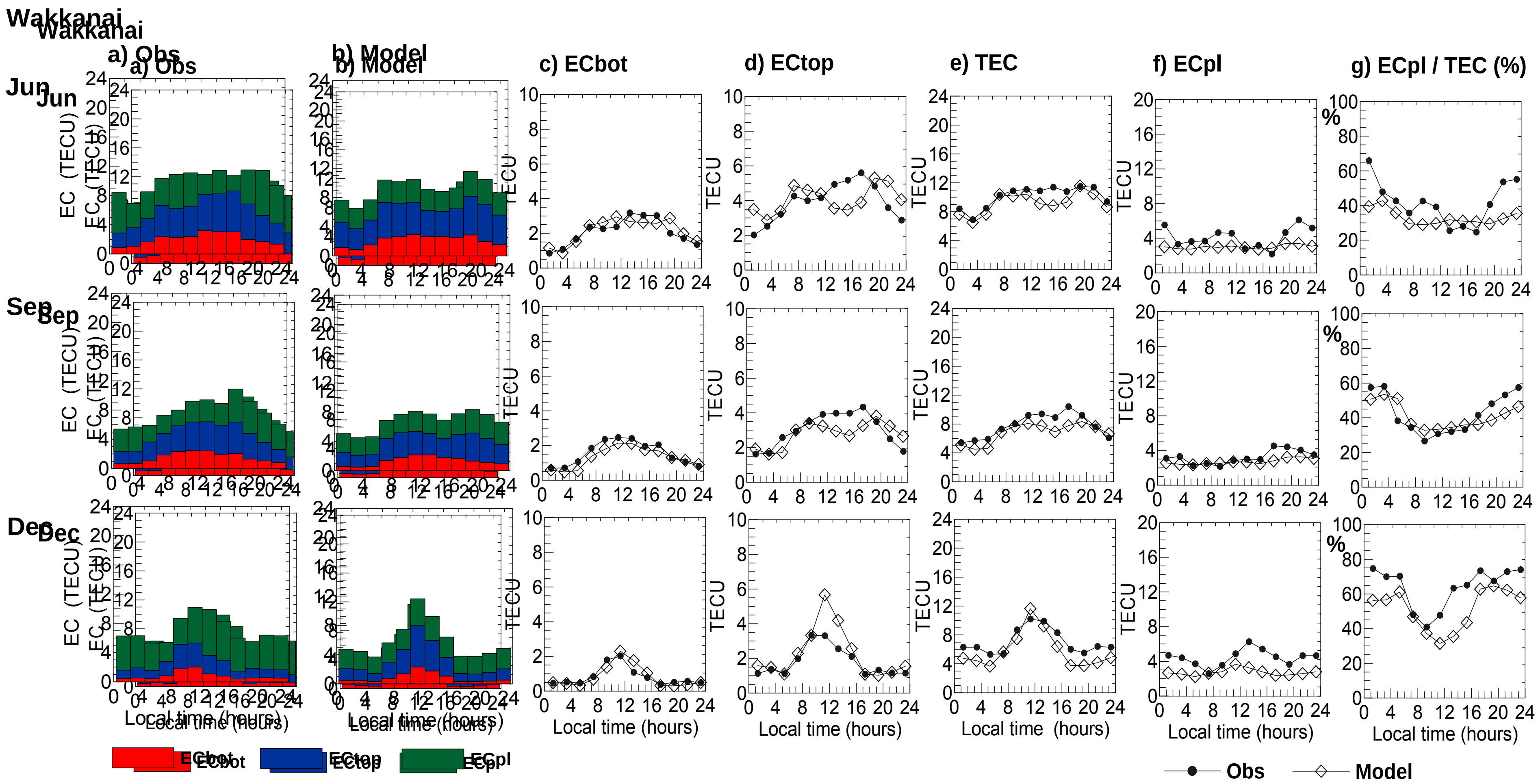


In order to analyze seasonal behaviour of PEC contribution to GPS TEC estimates at the different regions we selected several specific points with coordinates, corresponded to the approximate positions of different, mainly mid-latitude, ionospheric sounding stations. Table 1 lists the names of specific points, their geographical and geomagnetic coordinates.

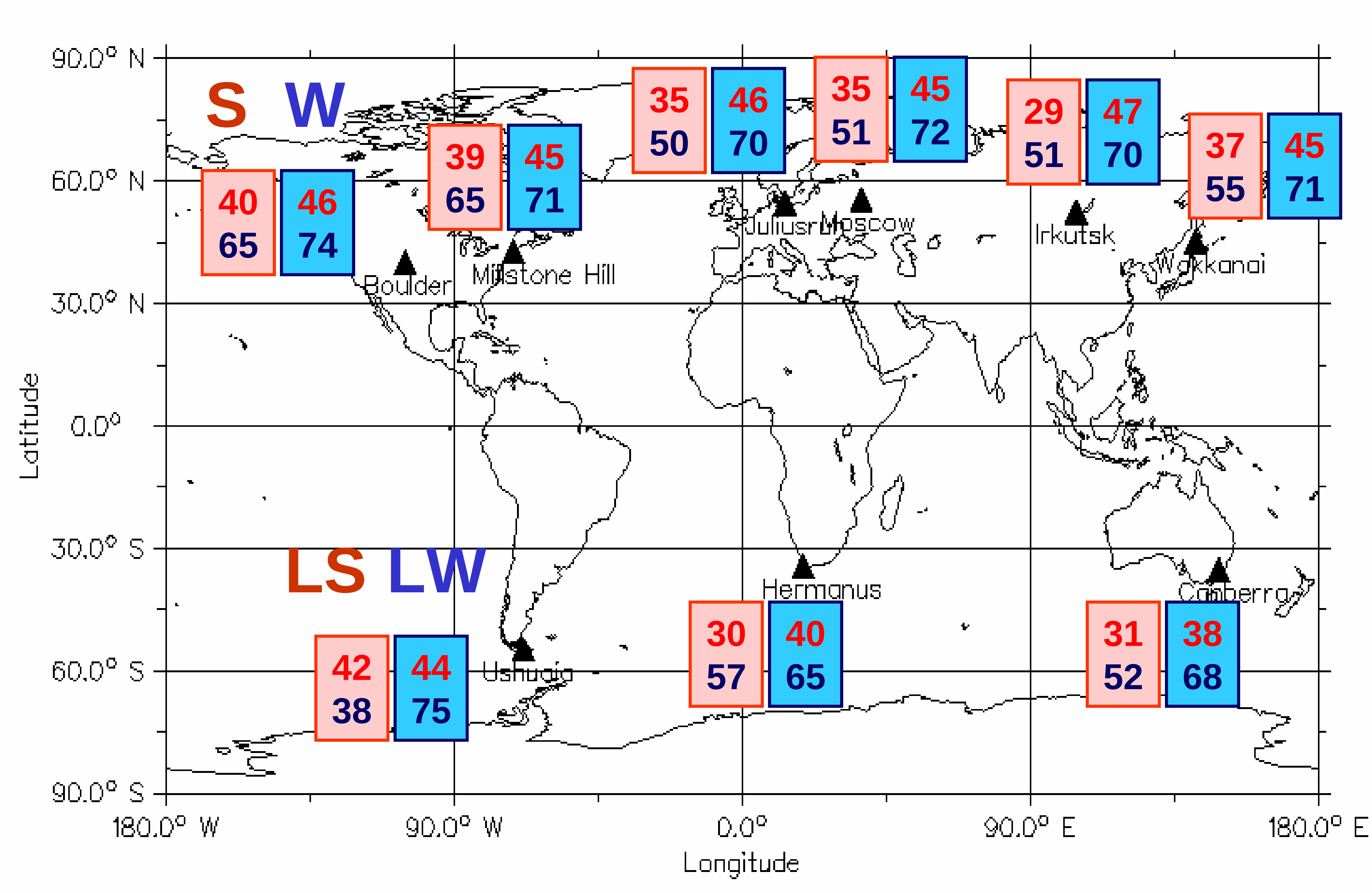
Table 1. List with coordinates of selected specific points.

	Geographic coordinates		Corrected Geomagnetic coordinates	
	Latitude	**longitude**	**latitude**	**longitude**
Northern hemisphere				
Boulder	40.0	254.7	48.6	320.7
Millstone Hill	42.6	288.5	51.9	7.2
Juliusruh	54.6	13.4	50.8	90.3
Moscow	55.5	37.3	51.7	111.7
Irkutsk	52.4	104.3	47.9	177.8
Wakkanai	45.2	141.7	38.7	214.0
Southern hemisphere				
Ushuaia	-54.8	-68.3	-40.6	4.7
Hermanus	-34.4	19.2	-42.5	83.4
Canberra	-35.3	149.0	-45.3	226.8

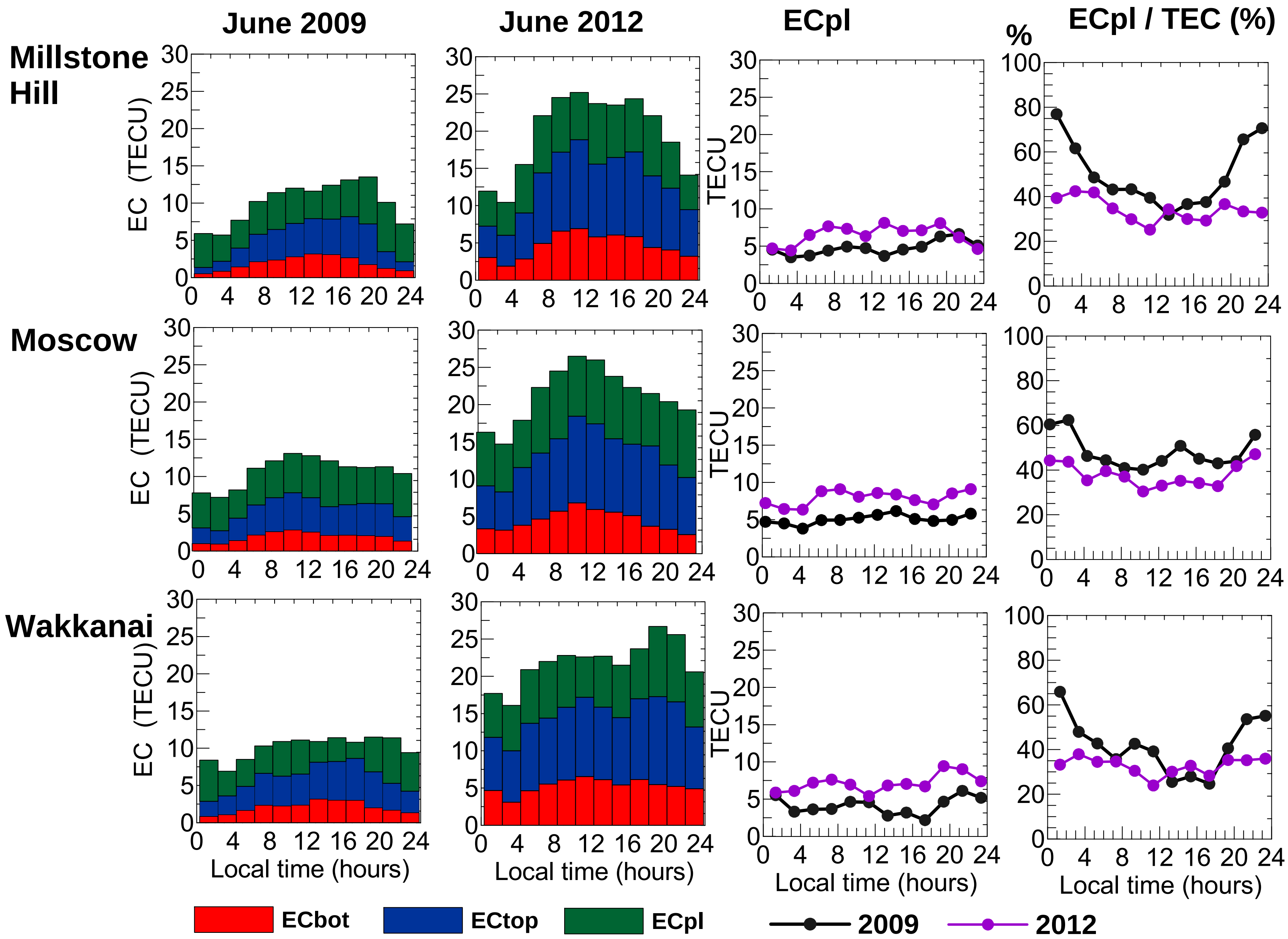
Comparison between observations and SPIM simulations of daily variations of ionosphere/plasmasphere electron content for Wakkanai point



PEC estimates (%) for specific points: summer vs. winter



Estimation of ionosphere/plasmasphere electron content for June 2009 and June 2012



SUMMARY

Analysis of COSMIC RO and GPS TEC data has shown that:

- In general COSMIC RO profiles are in a good agreement with ionosonde's profiles both in the F2 layer peak electron density (NmF2) and the bottom side part of the profiles;
- The obtained statistic deviations between COSMIC and ionosondes' measurements are within the limits admissible for radiophysical ionosphere diagnostics facilities.
- For mid-latitudinal points PEC estimates varied weakly with the time of a day and reached the value of several (**1-6**) TECU for the condition of solar minimum
- Contribution of PEC to GPS TEC becomes most significant at **night** in **all** seasons.
- The contribution has greater values at winter season in comparison with summer.
- The **day-time** percentages are generally in range **30-40%** at **all** seasons.
- The **night-time** percentages are generally in range **50-70%** at **all** seasons.
- On average for mid-latitudinal region bottom-side IEC contributes about **5-10%** of GPS TEC during night and about **20-27%** during day-time. Topside IEC contributes about **15-20%** of GPS TEC during night and about **35-40%** during day-time.
- The obtained results demonstrate qualitative agreement with TEC, IEC and ECpl estimates retrieved by Standard Plasmasphere-Ionosphere Model

Acknowledgments

- We acknowledge the Taiwan's National Space Organization (NSPO) and the University Corporation for Atmospheric Research (UCAR) for providing the COSMIC Data.

- We are also grateful to International GNSS Service (IGS) for GPS Data.

- We acknowledge Tamara Gulyaeva for providing and improvement of SPIM code.