The Abdus Salam
International Centre for Theoretical Physics

United Nations
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SMR 2333-41

Workshop on Science Applications of GNSS in Developing Countries (11-27 April), followed by the: Seminar on Development and Use of the Ionospheric NeQuick Model (30 April-1 May)

11 April - 1 May, 2012

Ionospheric climate to ionospheric weather modeling: The New Path

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Questions in the new trend of ionospheric modeling

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Workshop on Science Applications of GNSS in Developing Countries (11-27 April 2012)

Why we need Ionospheric Models?

- To understand and reproduce the time and space ionospheric variations observed experimentally.
- To “predict” in time and space ionospheric behavior.
- To specify regionally or globally the ionospheric conditions required for the new technological systems dependent on radio signal propagation.

What types of Models?

- Physics based or first-principles Models.
- Empirical or semi-empirical Models.
- Analytical “profilers”.

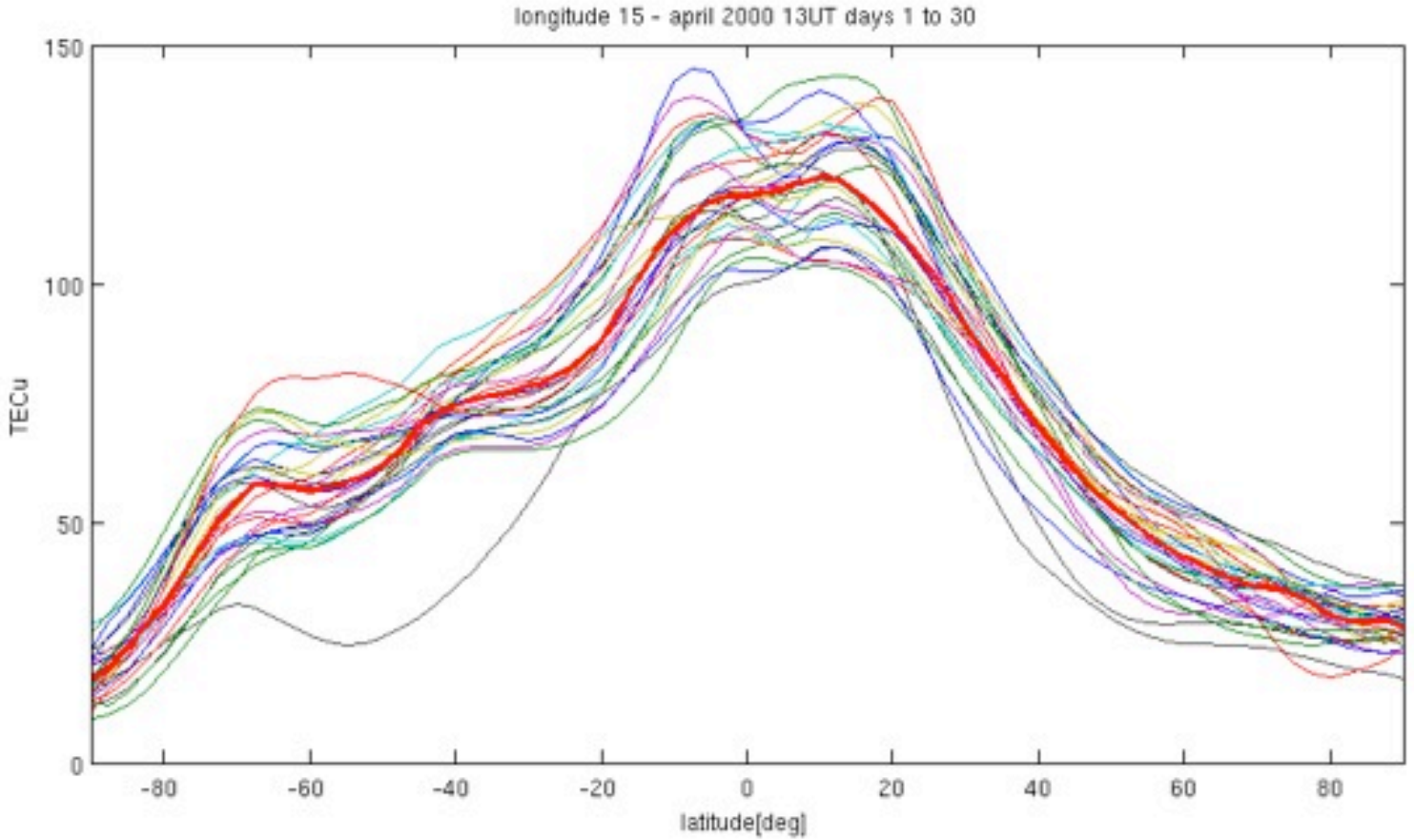
Are models accurate enough?

- It can be assumed that most of the well established models of the three types are able to reproduce with reasonable accuracy the "climatic" behavior of the electron density in time and space at least in middle latitudes.
- Ionospheric "climate" is given basically by month or season median or mean behavior of ionospheric parameters like F2 peak electron density and its altitude or total electron content.
- … and here we start having problems!

Are median or mean values a good representation of "climate"?

- Climate is the statistical description in terms of median or mean and variability (inter-quartile range or standard deviation) of an ionospheric parameter.
- But… is such statistical description always a meaningful "representative" description of the ionospheric behavior?

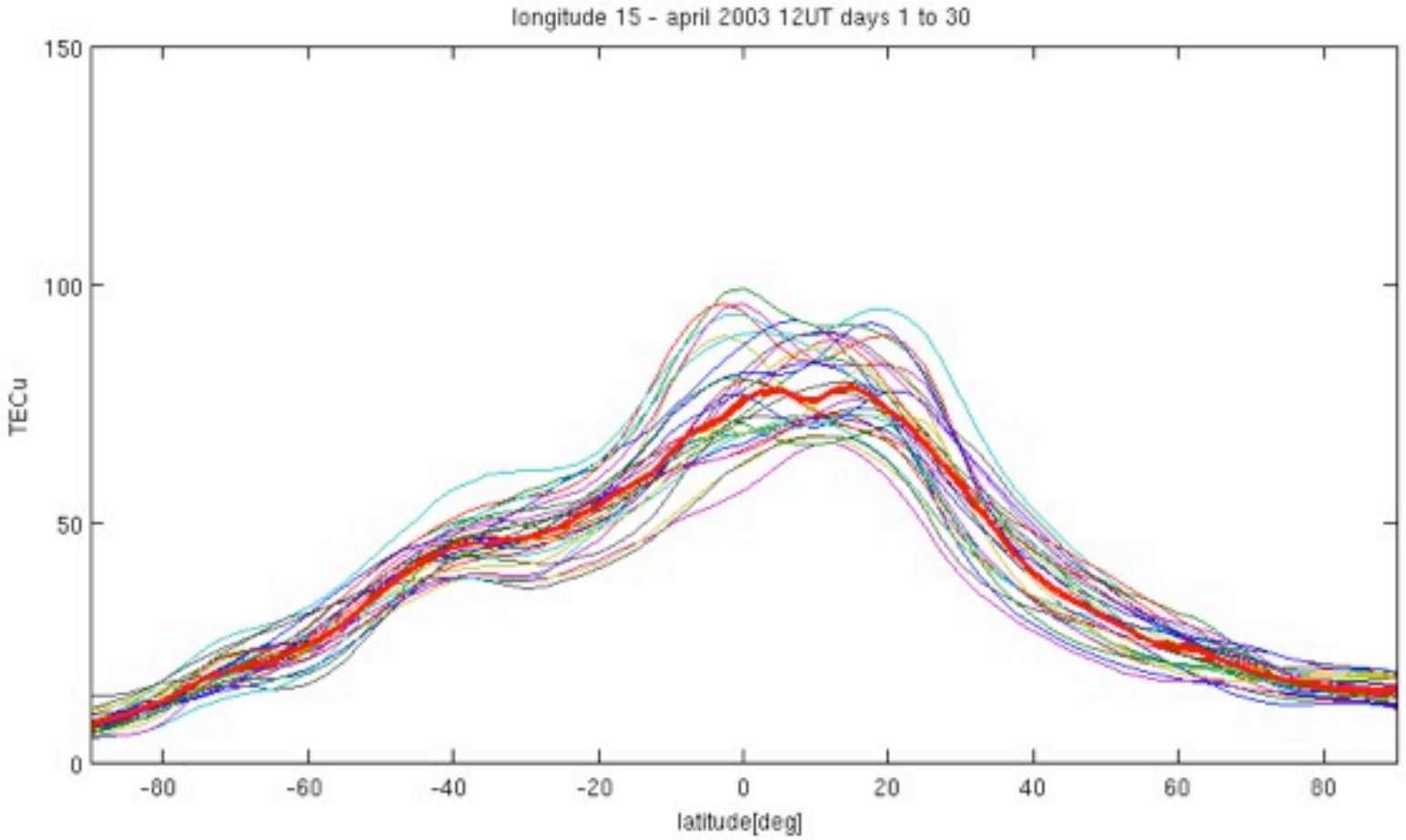
Example 1a



Meridional cross section of vertical TEC from IGS combined maps, April 2000 at 13:00 UT. Day 1 to 30 and median (red thick line)

(IGS TEC COMBINED: M. Hernández-Pajares · J. M. Juan · J. Sanz · R. Orus · A. Garcia-Rigo · J. Feltens · A. Komjathy · S. C. Schaer · A. Krankowski, The IGS VTEC maps: a reliable source of ionospheric information since 1998,J Geod (2009) 83:263–275 DOI 10.1007/s00190-008-0266-1)

Example 1b

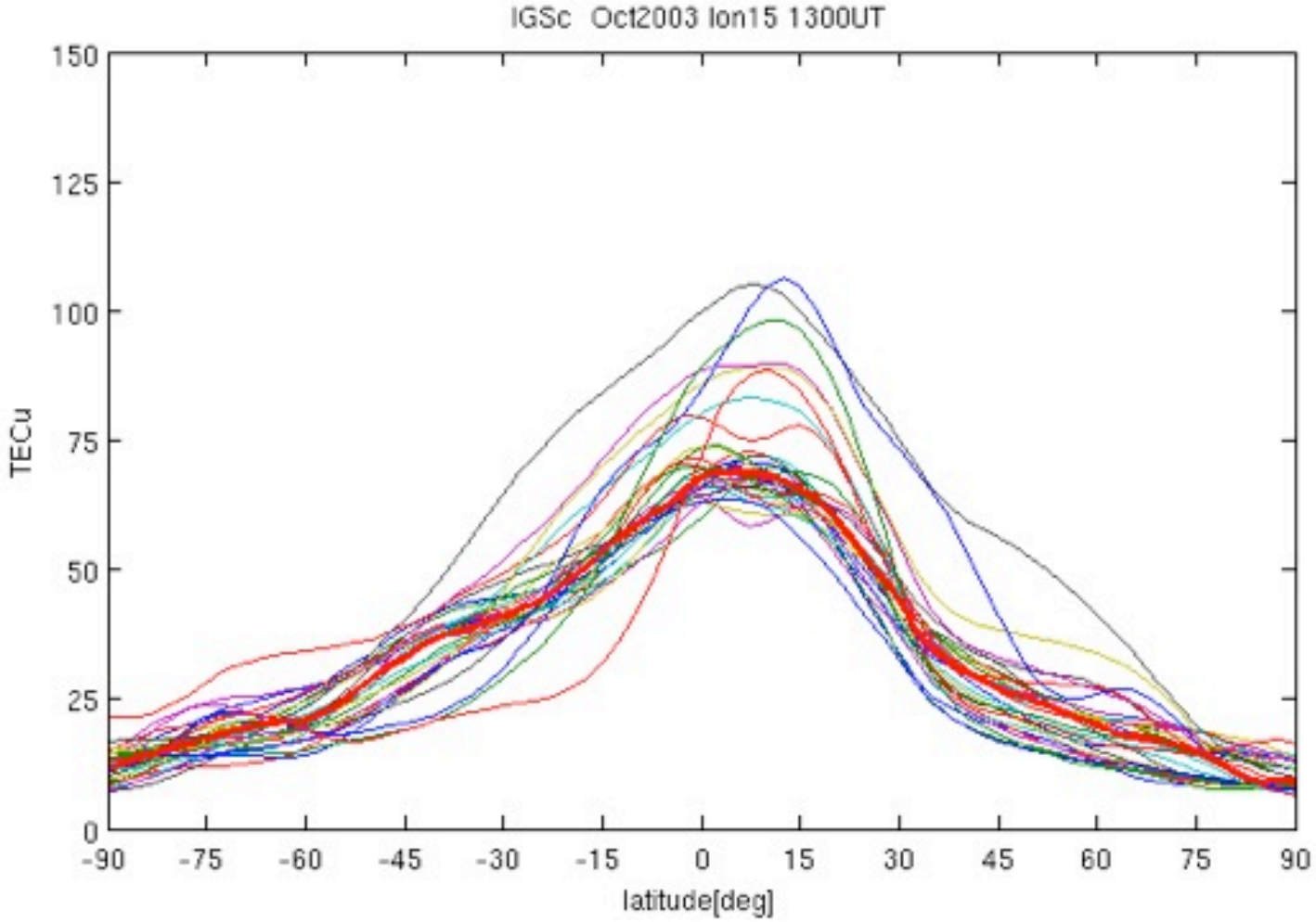


Meridional cross section of vertical TEC from IGS combined maps, April 2003 at 12:00 UT.
Day 1 to 30 and median (red thick line)

Questions about Example 1

- Can the median curve that does not show clearly the very variable equatorial anomaly crests seen in individual days be considered “representative” of TEC at low latitudes?
- Should a “climatic” model try to reproduce the median or what?

Example 2



Meridional cross section of vertical TEC from IGS combined maps, October 2003 at 13:00 UT.
Day 1 to 30 and median (red thick line)

Question about Example 2

- Can variability given by inter-quartile range or standard deviation be considered representative when the distribution is as skew as suggested by the figure?

More questions

- How can a global “climatic” model be compared and validated with experimentally derived data if median or mean values may not be considered “representative” of the ionospheric “climate” in critical geographic areas?
- How has to be treated “variability” at model level?

Another question

Do we need better definitions of ionospheric "climate" and "variability" for model validation?

Data ingestion comes in rescue

- Regardless of “climate” definition, experimental data ingestion in models is required to obtain ionospheric “weather” specifications to be tested and validated against experimental ionospheric behaviour.
- Almost any reasonable “climate” specification can be used as starting background ionosphere.
- This is the winning path of ionospheric modelling that have seen many relevant efforts in recent years.

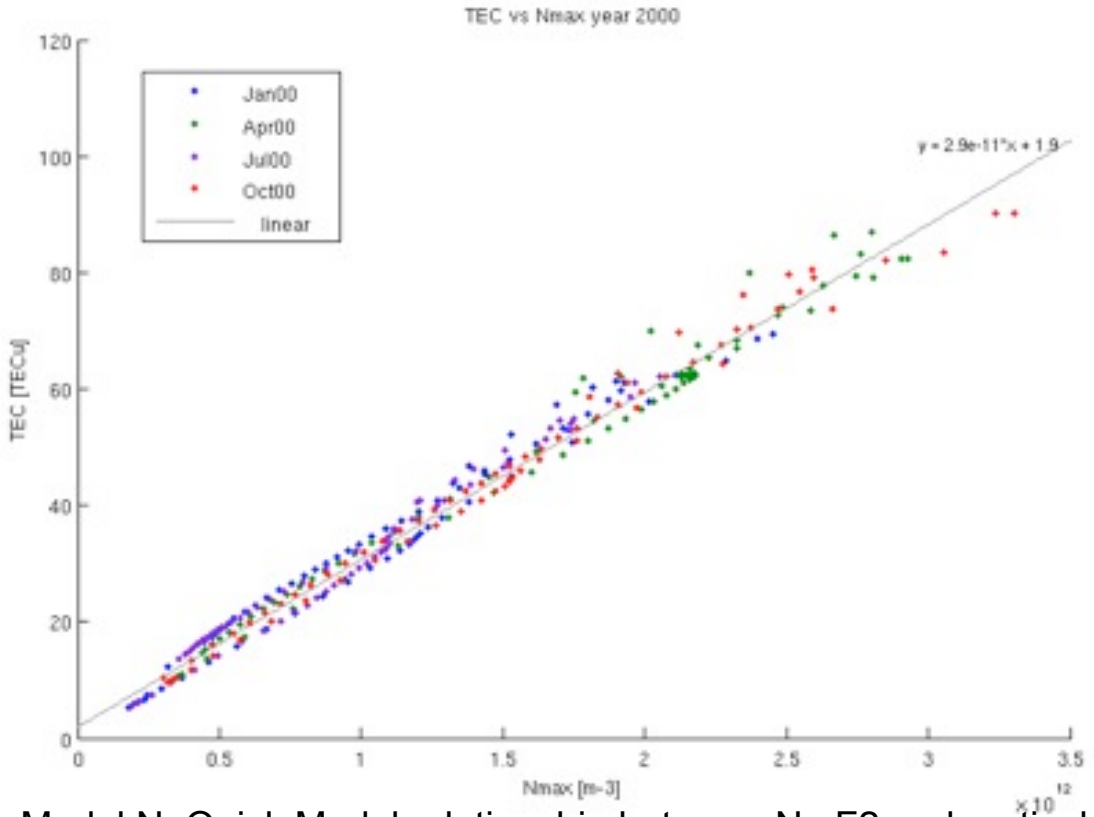
Ionospheric data to be ingested

A favorite parameter to be ingested is TEC (because of the amount of data available).

- TEC to be ingested can be:
  - single or multiple stations slant or vertical GNSS/TEC,
  - altimeter derived vertical TEC (TOPEX/Poseidon, Jason)
  - regional or global vertical TEC maps,
  - RO TEC data
- Other ionospheric data to be ingested are ionosonde or radar derived profiles or

Can we use vertical TEC as a good indicator of ionospheric behavior?

Yes, we can, to a certain degree.



Model NeQuick Model relationship between NmF2 and vertical TEC, for characteristic months of 2000

IGS

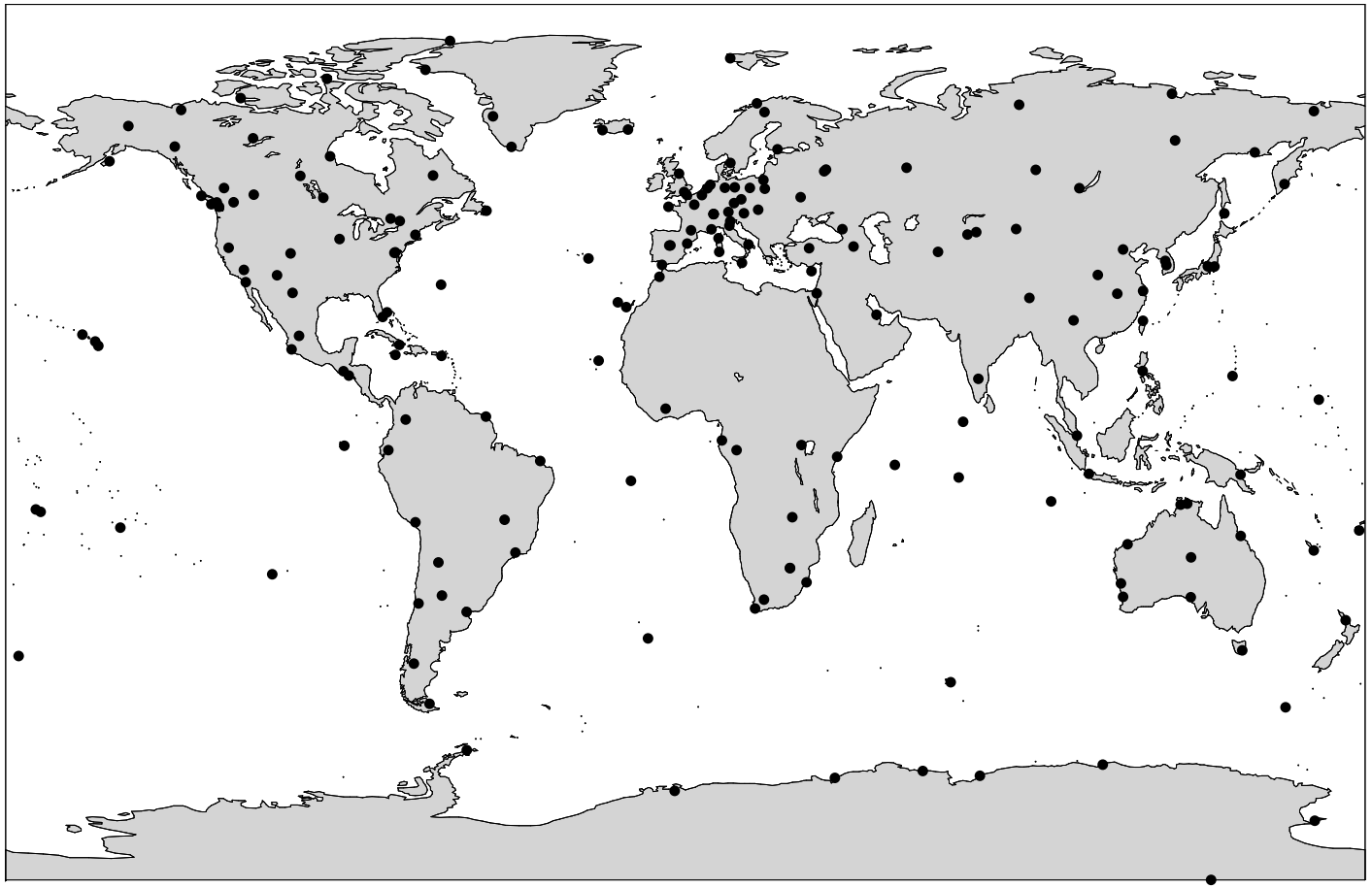
International GNSS Service

The International GNSS Service provides the highest-quality GNSS data and products in support of the terrestrial reference frame, Earth rotation, Earth observation and research, positioning, navigation and timing and other applications that benefit society.

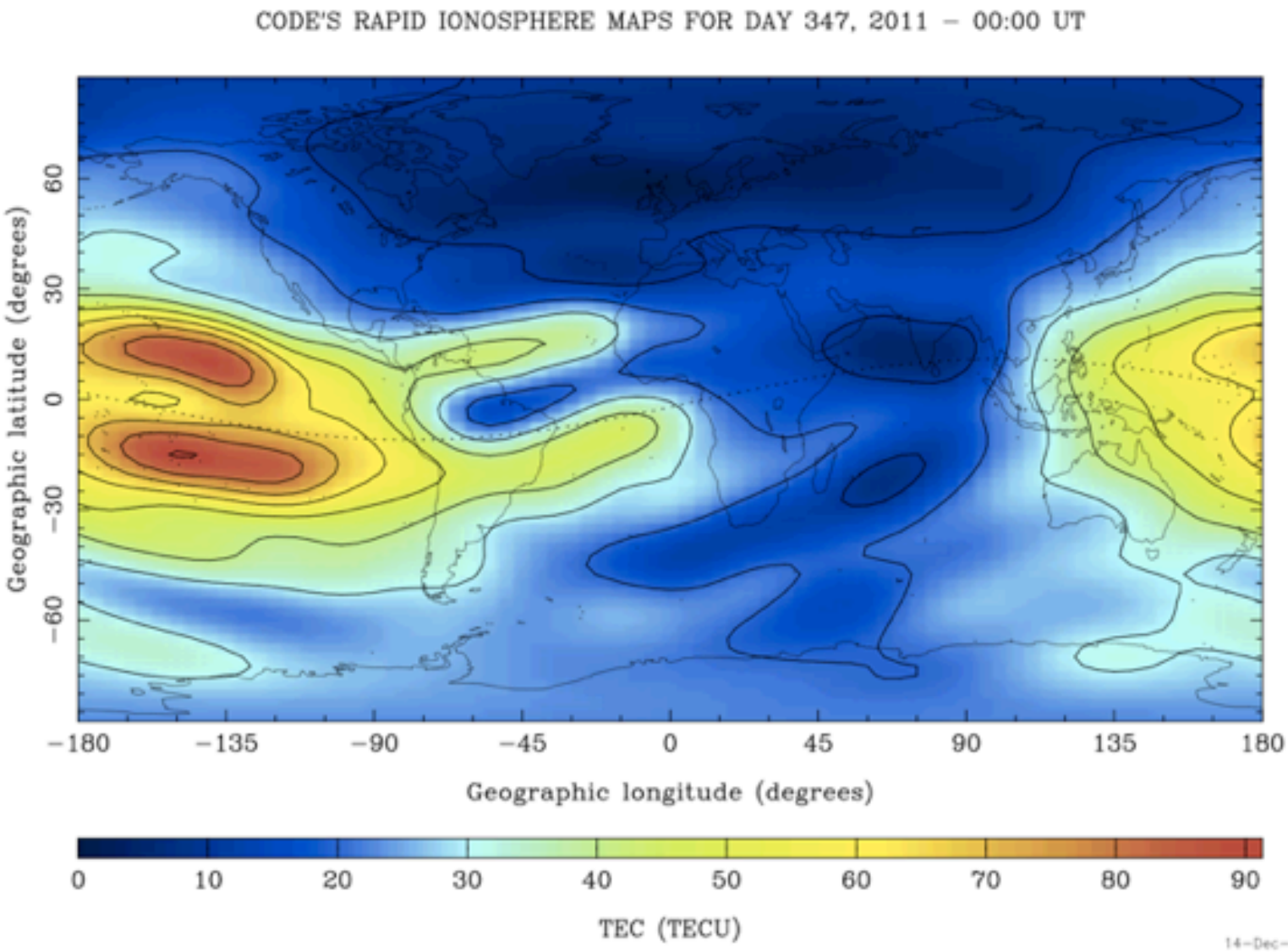
The Ionosphere Working Group of the International GNSS Service (Iono-WG) generates combined IGS vertical TEC maps from maps given by different centers around the world.

CODE Stations

Astronomical Observatory, University of Bern



CODE Vertical TEC Global Map 13/12/2011 at 12:00UT



Model & Technique validation

- Validating the ability of a model to reproduce ionospheric “weather” through data ingestion it is important to test the results against independent data not used in the ingestion process.
- As an example: if mainly TEC data are ingested, ionogram F2 peak characteristics should be used for validation purposes.
- Another example: if GNSS/TEC data are ingested, altimeter TEC could be used for validation.

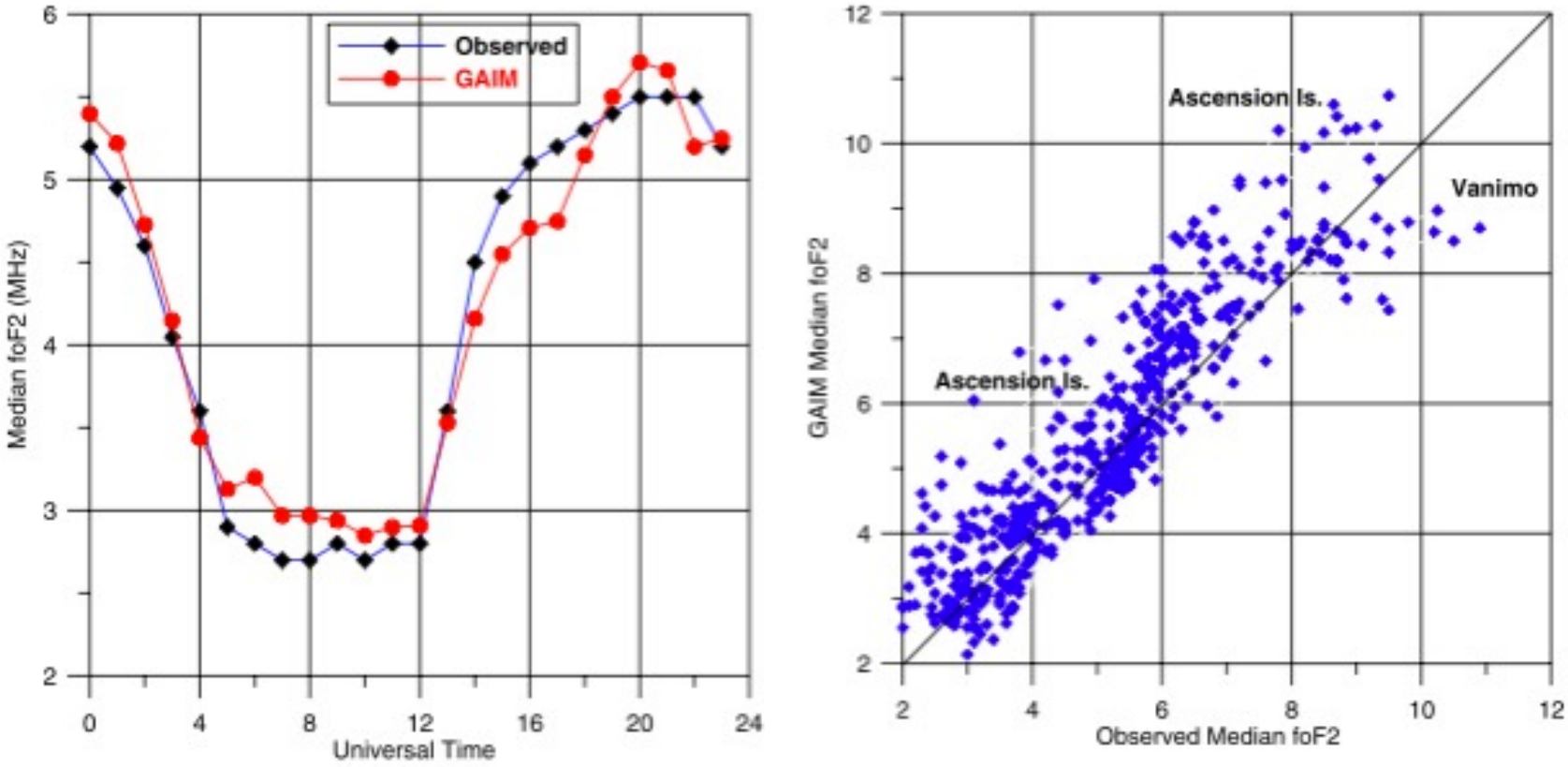
Examples of Models used for data ingestion (1)

- Utah State University Global Assimilation of Ionospheric Measurements (USU-GAIM) Model

  (*Schunk, R.W., L. Scherliess, J.J. Sojka, and D. Thompson, Global Assimilation of Ionospheric Measurements (GAIM), Radio Science, 39, RS1S02, doi:10.1029/2002RS002794, 2004*)

  - **Physics-based** global 3D model of the ionosphere and a Kalman filter as a basis for assimilating a diverse set of real-time (or near real-time) measurements.
  - The Model assimilates bottom-side N_e profiles from a variable number of ionosondes, slant TEC from a variable number of ground GPS/TEC stations, in situ N_e from four DMSP satellites, and line-of-sight UV emissions measured by satellites.

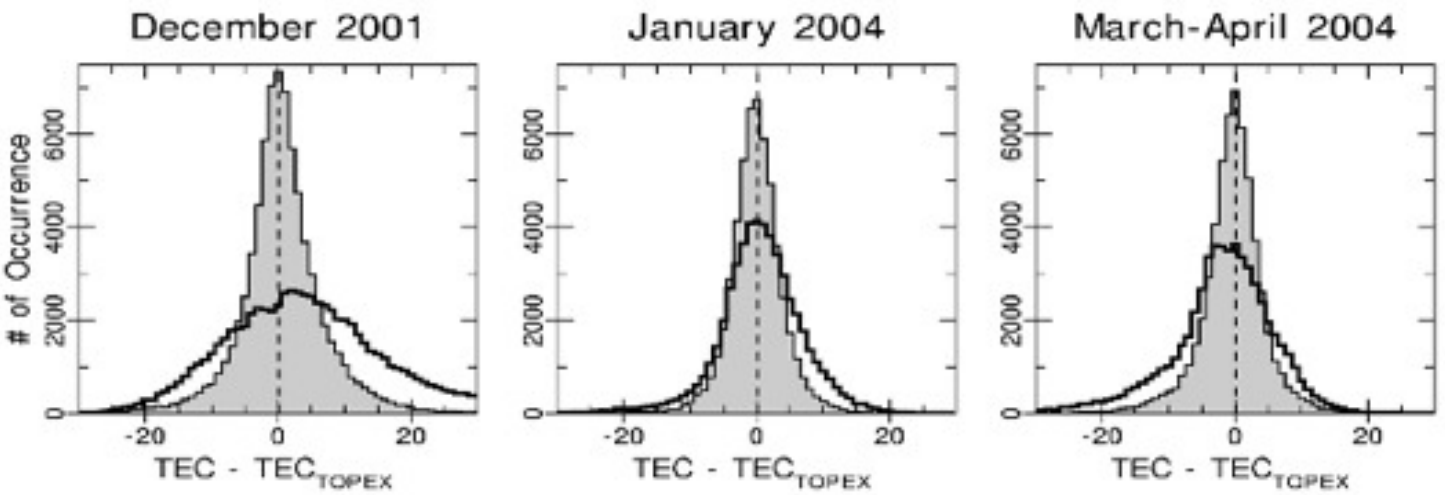
GAIM validation (1)



September 2006 median observed and GAIM values of foF2 for Boulder (*left*) and GAIM median values of foF2 for 21 ionosondes (*right*).

(From: *McNamara, L. F., C. R. Baker, and D. T. Decker (2008), Accuracy of USU-GAIM specifications of foF2 and M(3000)F2 for a worldwide distribution of ionosonde locations, Radio Sci., 43, RS1011, doi:10.1029/2007RS003754*).

GAIM validation (2)



Histogram of the differences between TEC obtained from the TOPEX satellite and TEC from the USU GMKF (filled histogram) and the background model (open histograms). Shown are the histograms for the December 2001 (left), the January 2004 (middle), and the March–April 2004 (right) validation periods, respectively.

(From: *Scherliess, L., R. W. Schunk, J. J. Sojka, D. C. Thompson, and L. Zhu (2006), Utah State University Global Assimilation of Ionospheric Measurements Gauss-Markov Kalman filter model of the ionosphere: Model description and validation, J. Geophys. Res., 111, A11315, doi:10.1029/2006JA011712.*).

Examples of Models used for data ingestion (2)

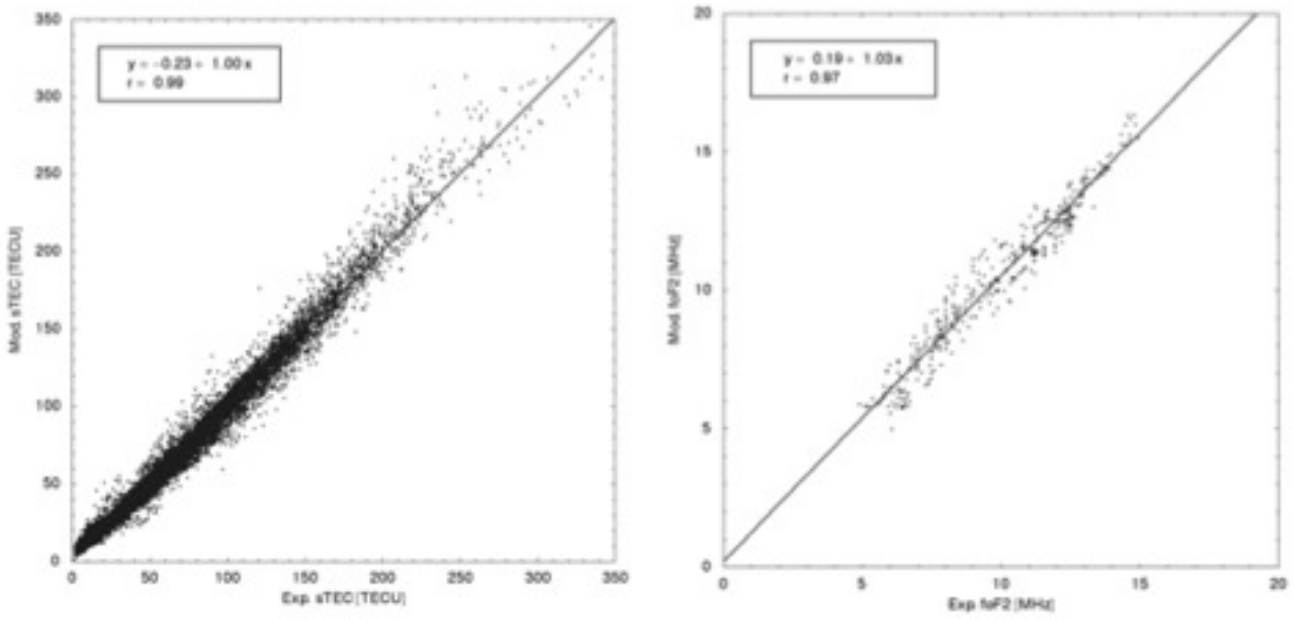
- NeQuick2

  (*Nava, B., P. Coïsson, and S. M. Radicella (2008), A new version of the NeQuick ionosphere electron density model, J. Atmos. Sol. Terr. Phys., 70(15), 1856–1862*)

  – The model is an evolution of the previous version developed at the Aeronomy and Radiopropagation Laboratory of The Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy in collaboration with the Institute for Geophysics, Astrophysics and Meteorology (IGAM) of the University of Graz, Austria.

  – NeQuick 2 uses a modified DGR "**profiler**" formulation which includes five semi-Epstein layers with modeled thickness parameters and three anchor points (E, F1 and F2 peaks).

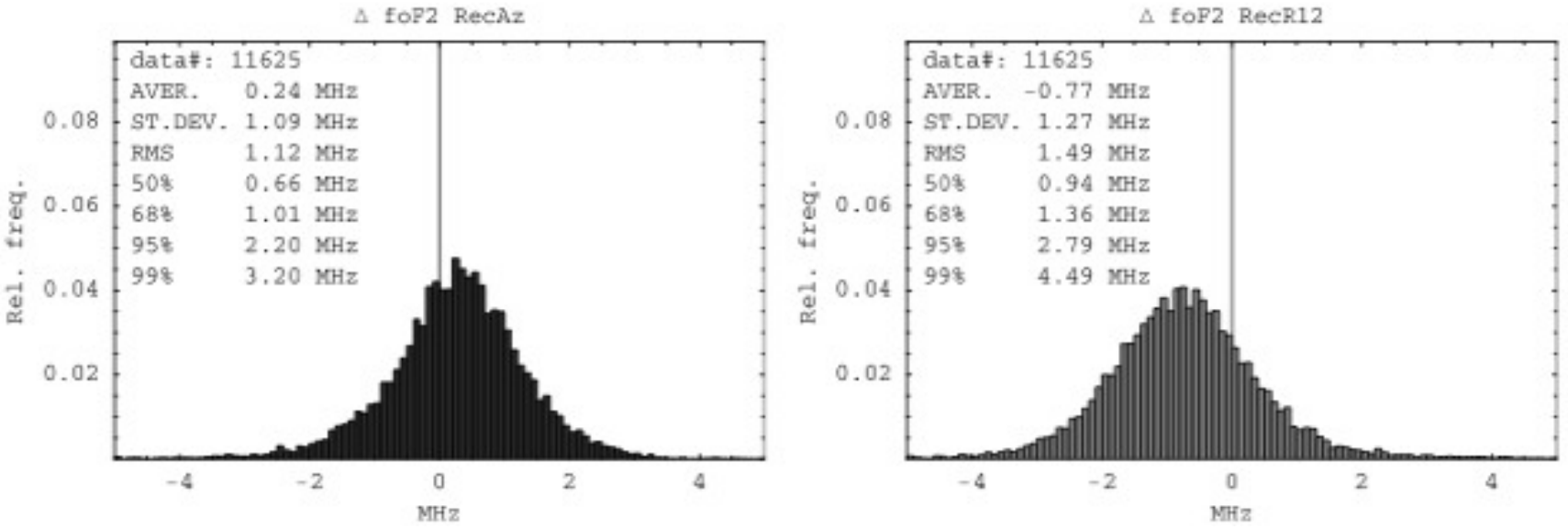
NeQuick2 (with data ingestion) validation (1)



NeQuick driven by data ingestion using the multiple-station technique (*left)* modeled against measured slant TEC data for 25 ground stations and (*right*) modeled against measured foF2 data for six ionosondes for 5 April 2000. The best fit lines are also indicated.

(From: *Nava, B., S. M. Radicella, R. Leitinger, and P. Co ¨isson (2006), A near-real-time model-assisted ionosphere electron density retrieval method, Radio Sci., 41, RS6S16, doi:10.1029/2005RS003386*).

NeQuick2 (with data ingestion) validation (2)



NeQuick 2 driven by R12 (background ionosphere) (*right*) and vertical TEC map ingestion method (*left*): distribution of the differences between model reconstracted and experimental foF2 data for about 20 ionosondes; April 2000.

(From: *Nava, B., S. M. Radicella, and F. Azpilicueta (2011), Data ingestion into NeQuick 2, Radio Sci., 46, RS0D17, doi:10.1029/2010RS004635.*).

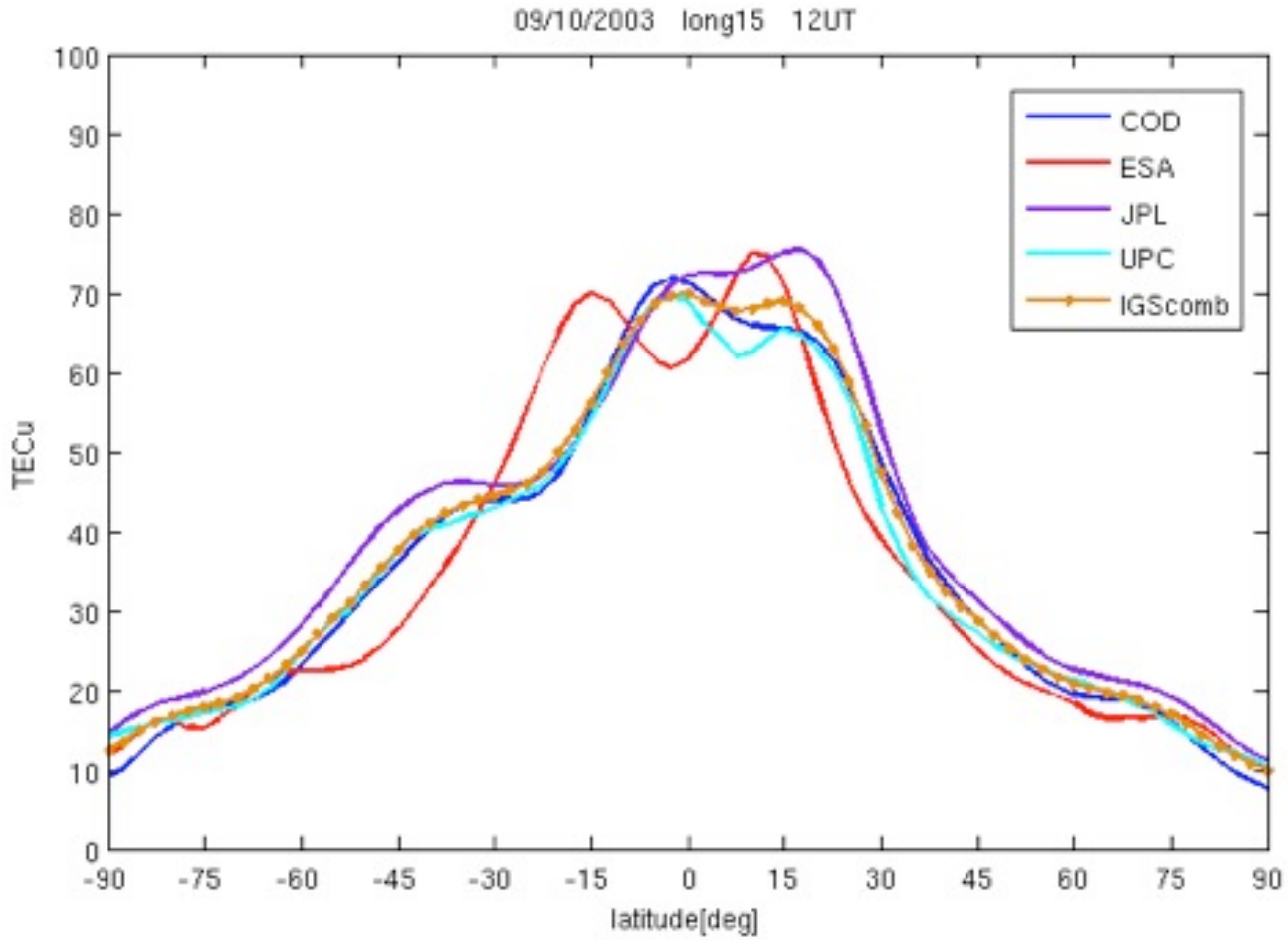
What about these results?

The results of model adaptation through data ingestion (ionospheric weather specification) appears to be reasonable in both cases (GAIM and NeQuick).

But!

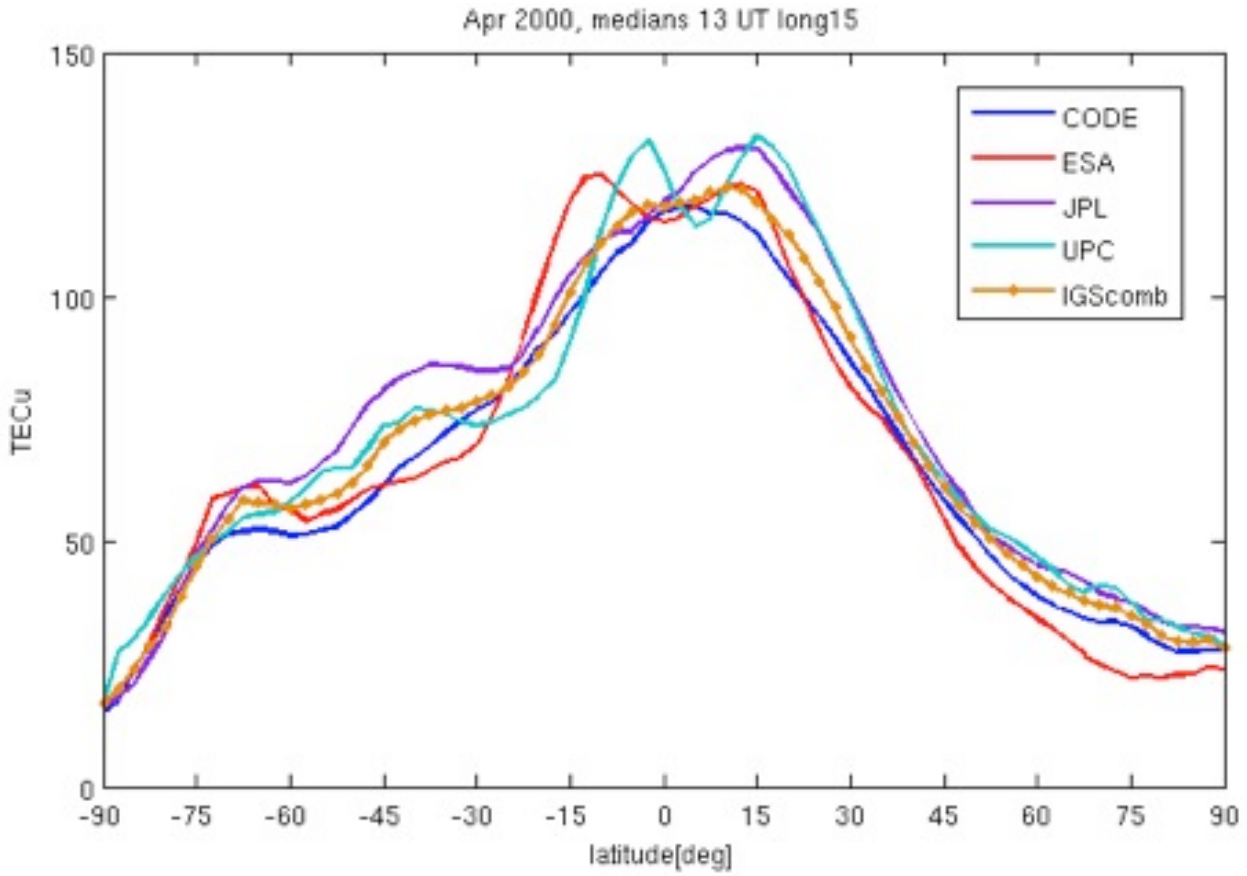
- To estimate the validity of an ingestion technique and a model used for “ionospheric weather specification” we should consider data uncertainties.
- This is not an easy task! See next examples.

Example 1a



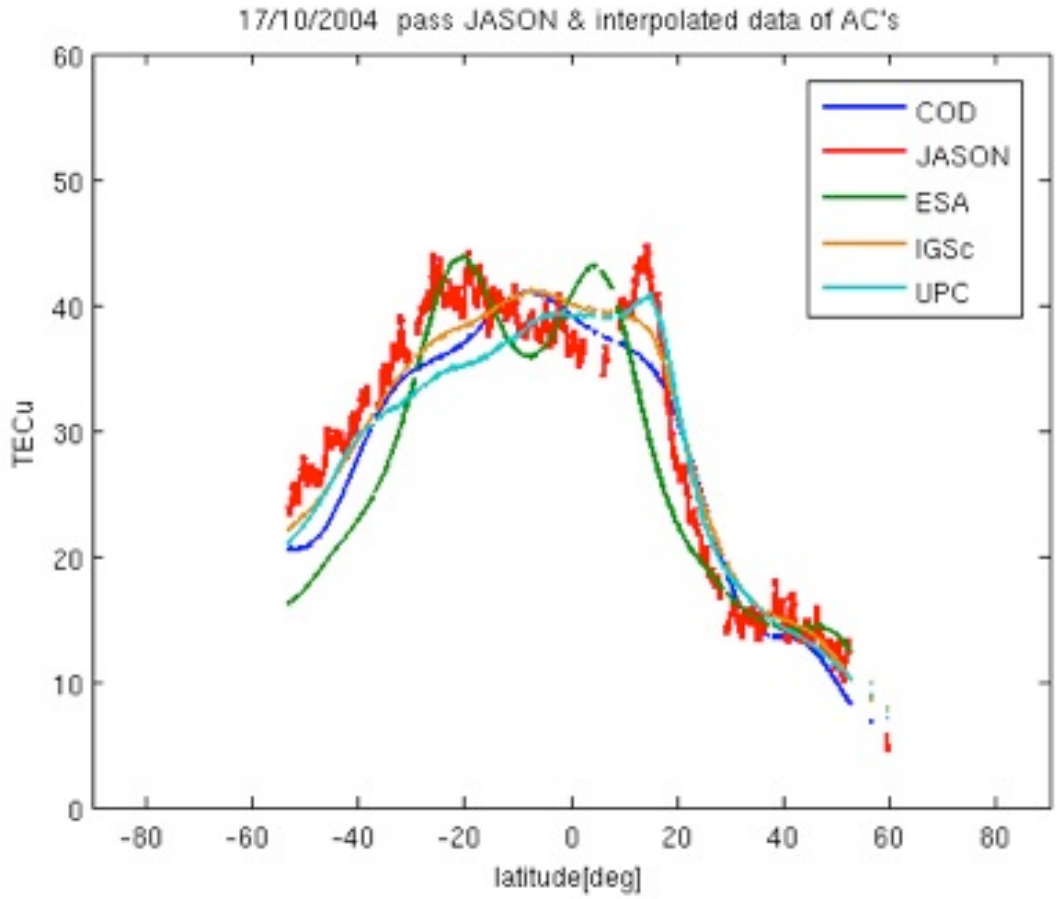
Meridional cross section (15ºE) of vertical TEC from 5 different global maps for 9 October 2003 at 12:00 UT

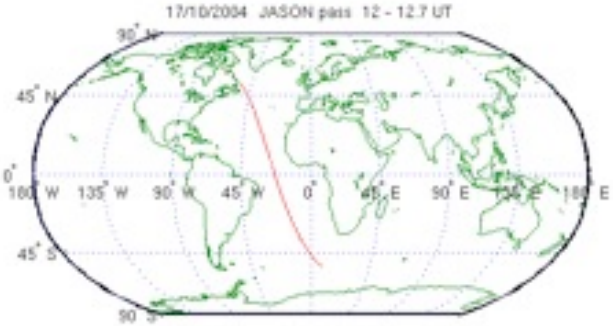
Example 1b



Meridional cross section (15ºE) of median vertical TEC from 5 different global maps for April 2000 at 13:00 UT

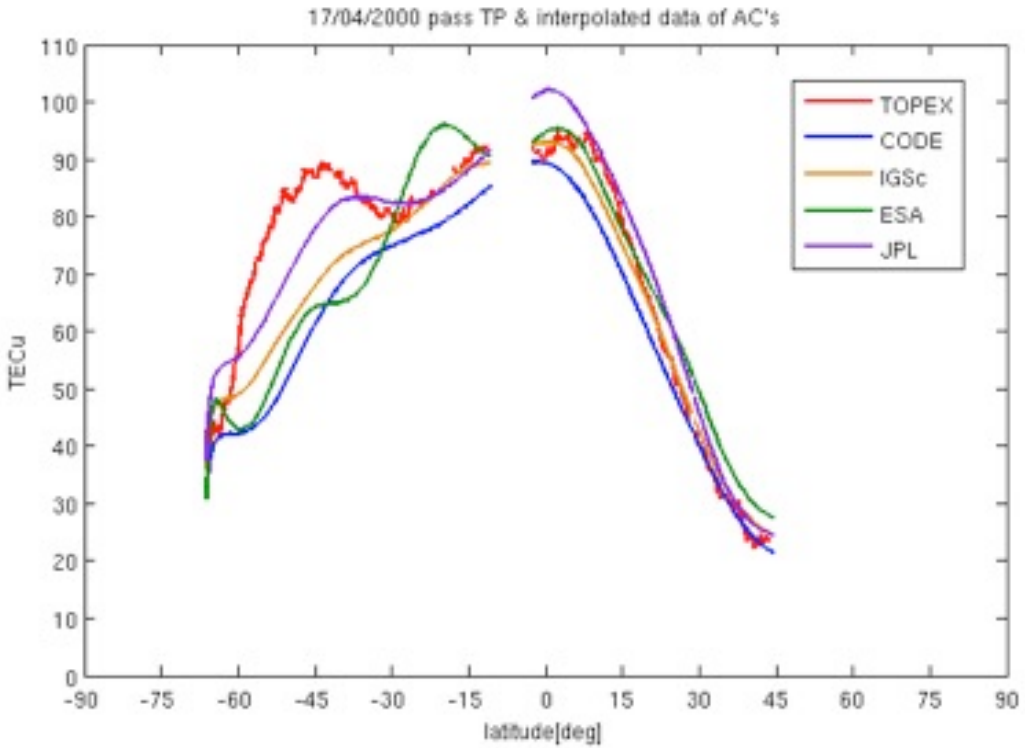
Example 2a

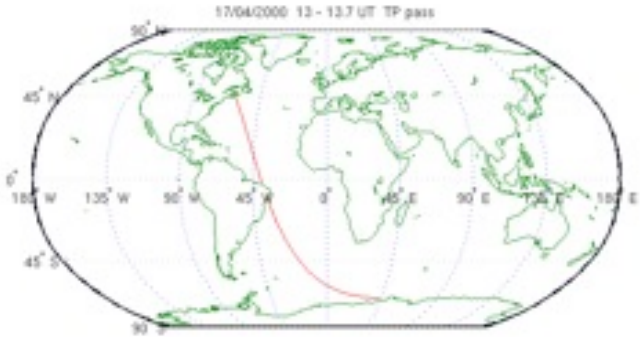




Comparison of JASON vertical TEC with maps derived TEC for the satellite pass indicated in the right figure

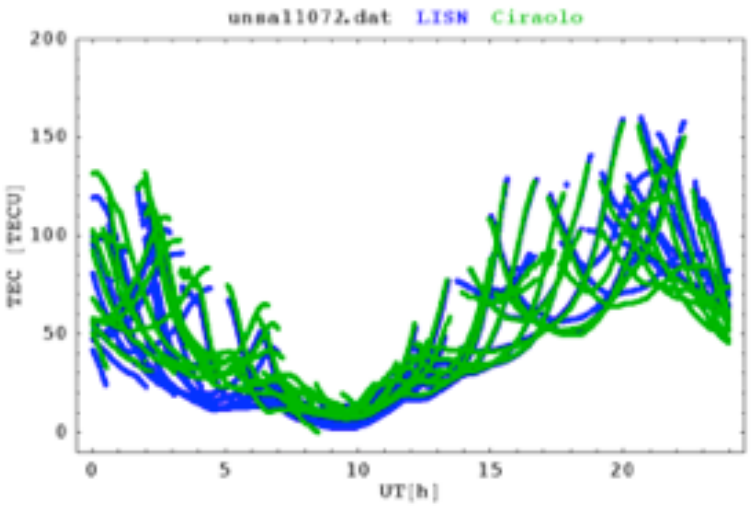
Example 2b

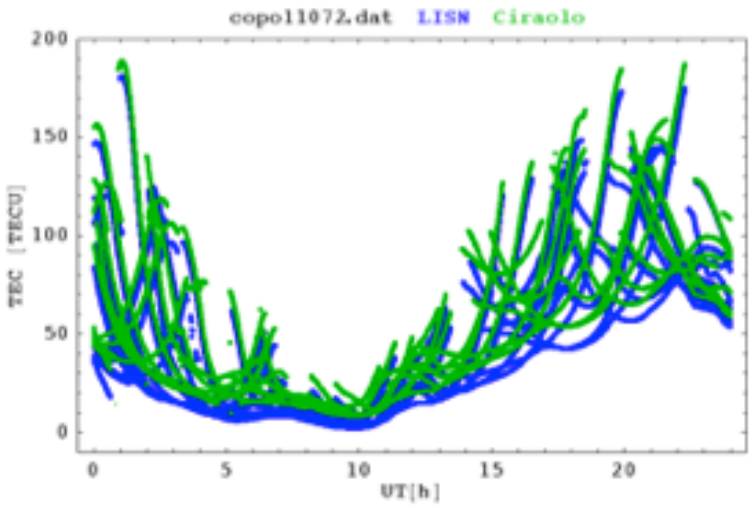




Comparison of TOPEX vertical TEC with maps derived TEC for the satellite pass indicated in the right figure

Example 3





Slant GPS/TEC for two stations at low geomagneti latitudes in South America:
Salta (modip = -22.2) (left) and Copiapó (modip = -25.3) (right). DOY 72 of 2011.
Calibration by LISN [blue] (courtesy of C. Valladares) and Ciraolo [green] (courtesy of L. Ciraolo)

Note 1

All the different vertical TEC map construction and slant TEC calibration techniques shown are well-oiled methods and no *a priori* sound choice can be made among them.

Questions from these examples (1)

If we want to use TEC maps for data ingestion:

- Which map data should the model use for ingestion in order to specify the ionospheric weather conditions?
- If the results do not look good, are the technique and the model or are the data ingested to be blamed?

Questions from these examples (2)

If we want to use slant TEC to be ingested in models:

- How do we select the TEC calibration method to be applied to raw RINEX data?
- If the results do not look good, are the technique and the model or are the data ingested to be blamed?

Note 2

If ionosonde derived ionospheric characteristics are considered for data ingestion in models please note the statement from a recent poster presenation at the ESWW8:

Influence of non-vertical echoes to ionogram scaling

Daniel Kouba and Petra Koucká Knížová

Institute of Atmospheric Physics, Academy of Sciences of the Czech Republic, Prague, Czech Republic, kouba@ufa.cas.cz

parabolic ionospheric electron density profile. The aim of the contribution is to present comparison of the data sets measured by conventional ionosondes and by new digisondes. Errors in scaling parameters could reach several tens of MHz in frequency and several tens of km in height. We show here that it is necessary to be careful in using the old ionospheric ionosonde measurements and scaled data.

A comment

The questions posed hold for any kind of data that contains uncertainties that cannot be properly quantified.

Conclusion

The new path is clear but the final goal is not reached yet because many questions are still without answers.

In Italian we say “Buon lavoro!” to be positive and auspicious.

Thank you for your attention!