Summary and current status of IGS Ionosphere WG activities

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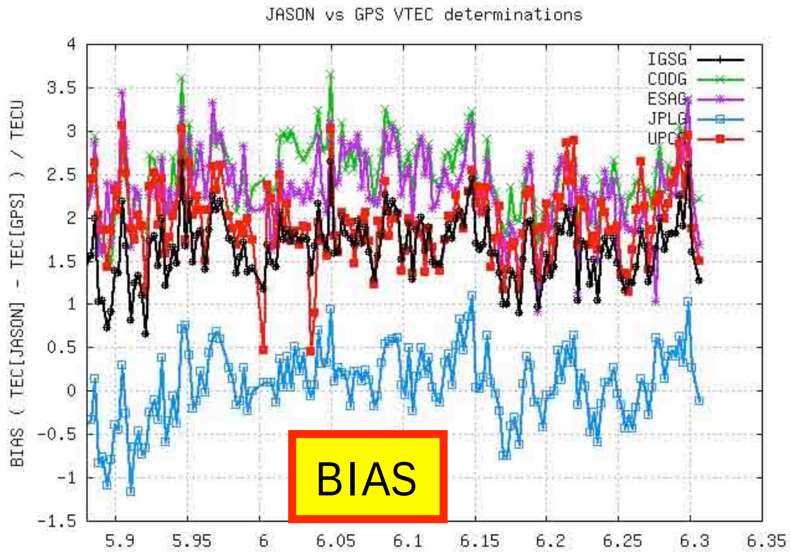
gAGE **Research group** of **A**stronomy and **GE**omatics

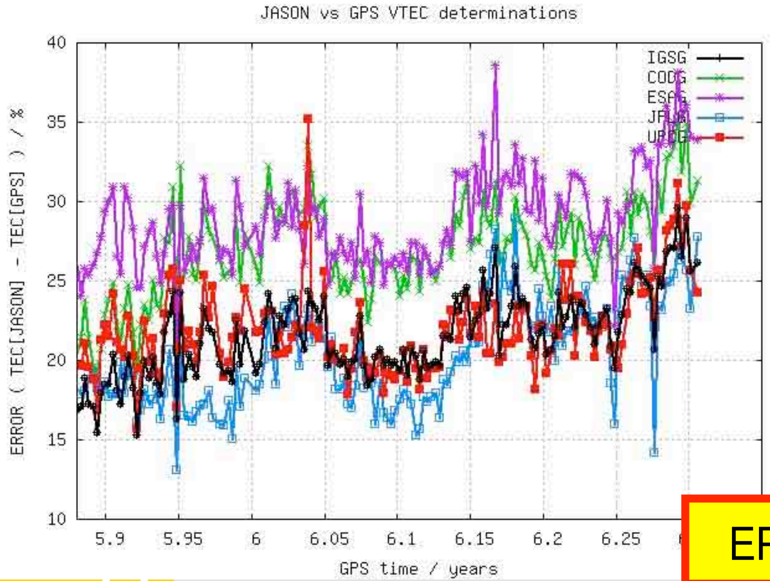
Final and rapid IGS VTEC maps: performance update

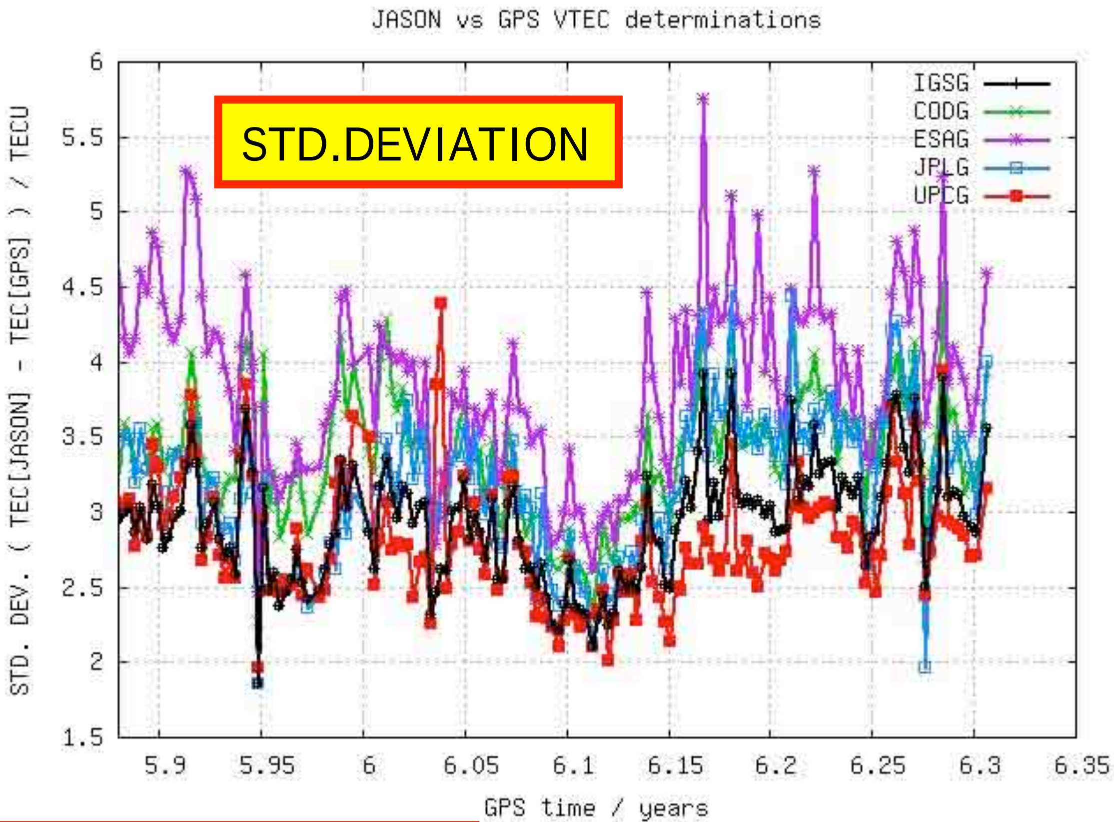
Outline

- ✓ Final and rapid IGS VTEC maps: performance update
  - Comparison with JASON VTEC
  - Stability of instrumental delays
  - Comparison with SBAS(EGNOS) model
  - IGS ionospheric product usage
- ✓ Ways of ionospheric correction improvement: *Companion* maps of ionospheric effective height
  - Definition from ground GPS data
  - Validation with SAC-C data
  - Applications: impact on precise navigation
- ✓ Conclusions and additional activities

Final IGS vs JASON VTEC comparison over the Seas



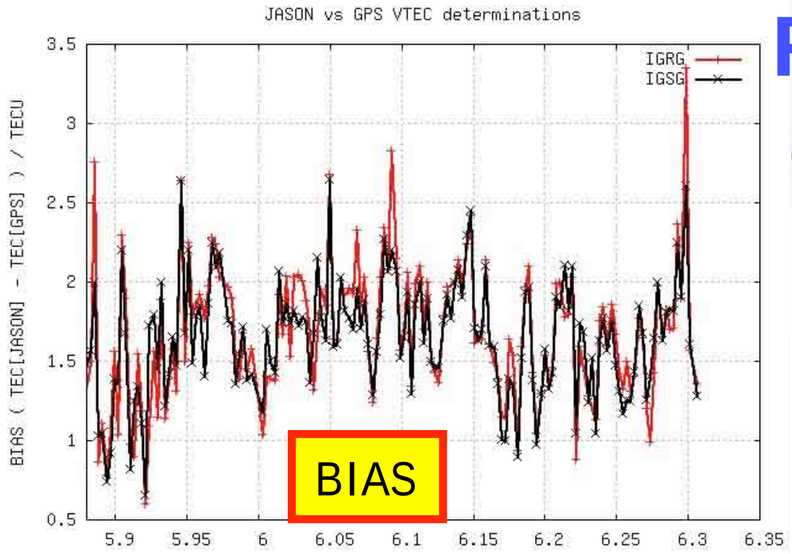


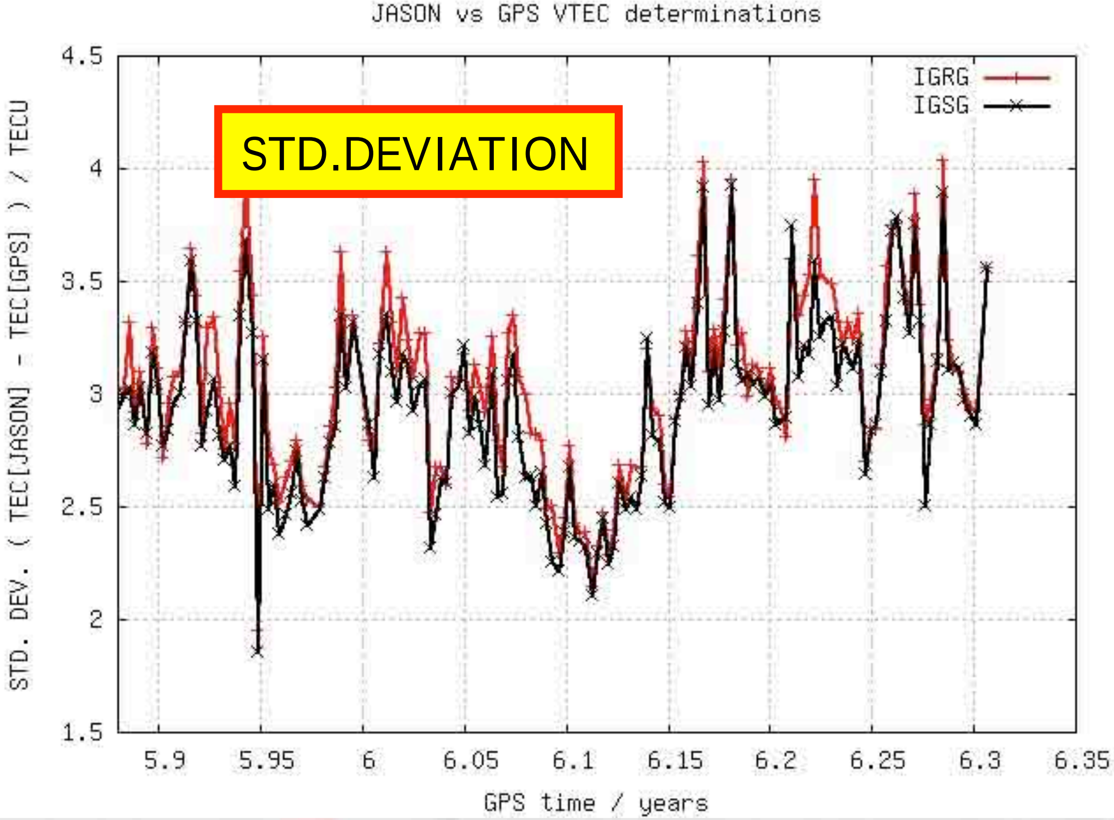


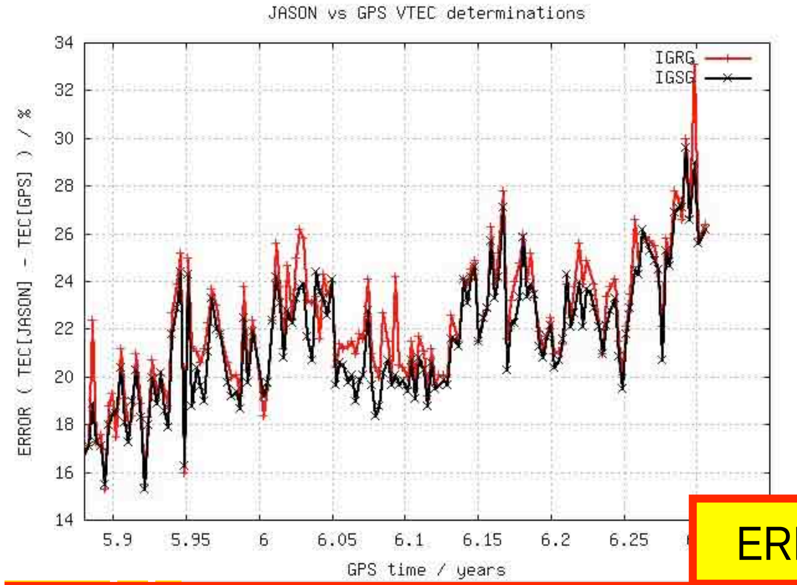
✓Final maps (black) are still in better agreement (standard deviation) after t~2005.95 (~3TECU, ~20% of relative error, increasing due to the Solar cycle VTEC lowering)

✓TOPEX-GPS bias more discrepant: Averaged IGS bias: GPS below TOPEX ~1.5-2 TECU (compatible with the supposed TOPEX VTEC bias)

Rapid IGS vs JASON VTEC comparison over the Seas



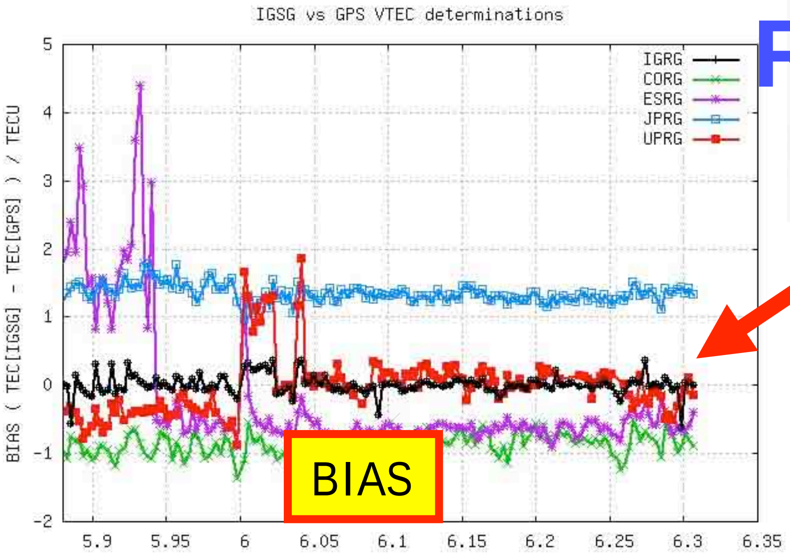


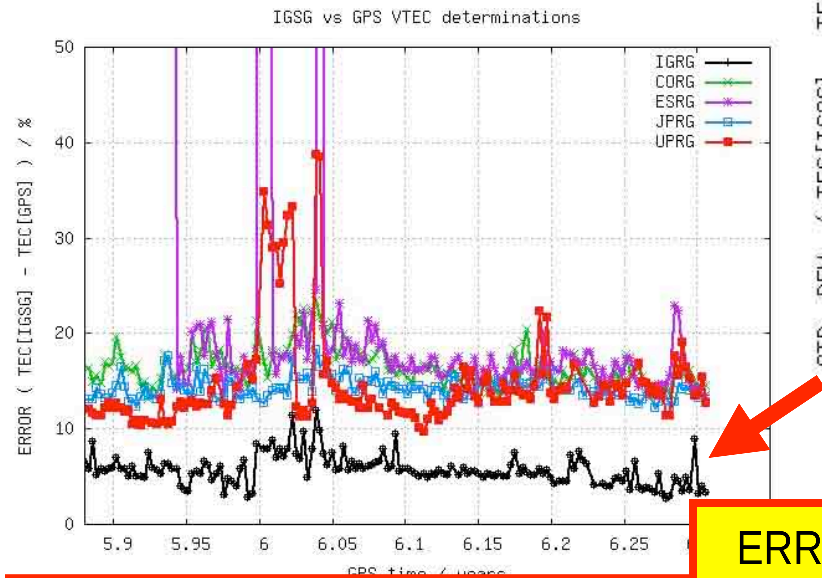


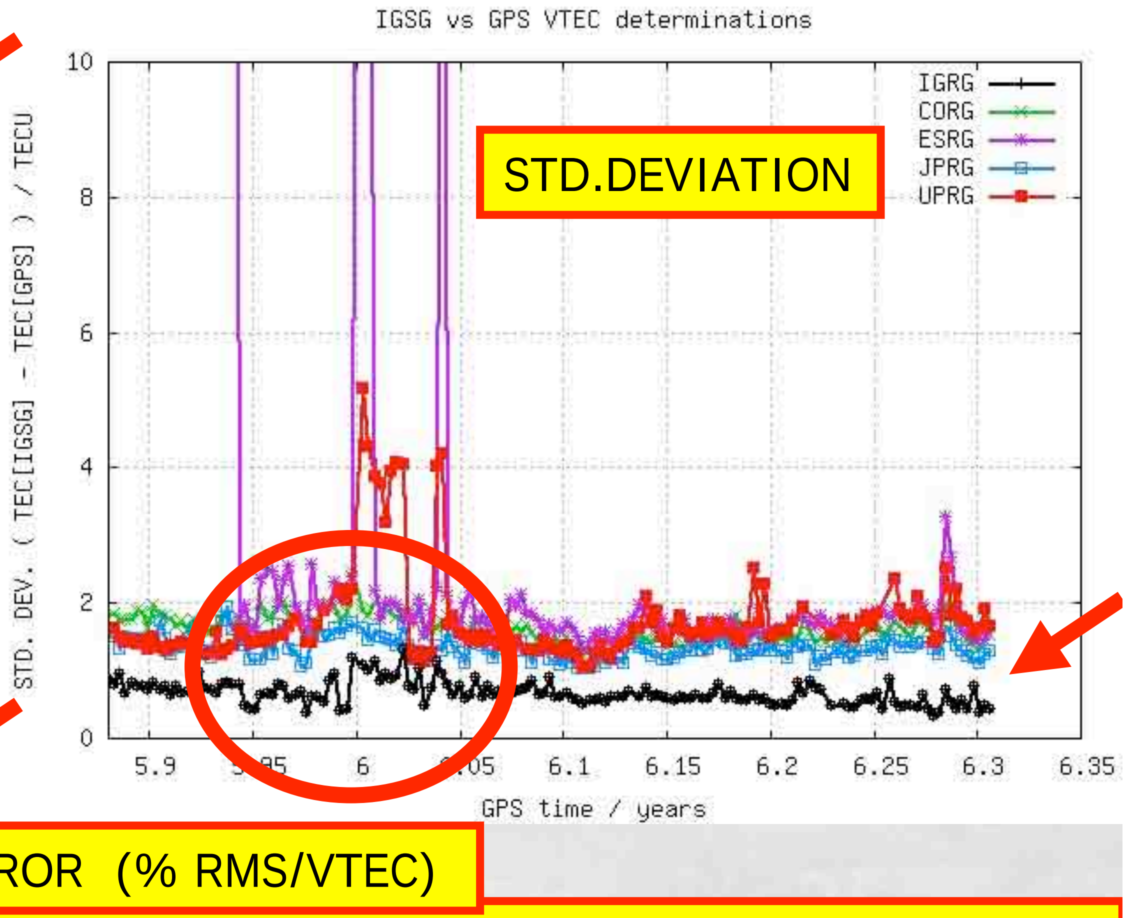
ERROR (% RMS/VTEC)

✓Rapid maps (red line, latency ~24h) are in very good agreement with final ones (Standard Deviation regarding to TOPEX only few tenths of TECU below the final performance...)

Rapid vs Final IGS VTEC global comparison



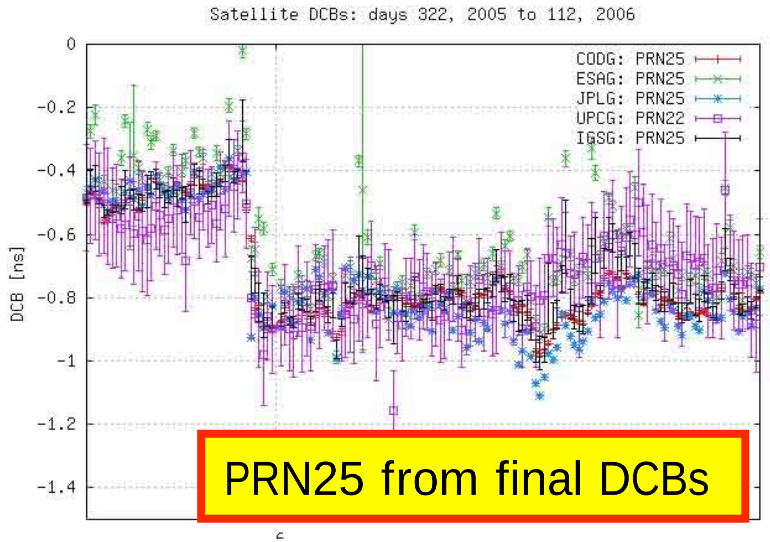




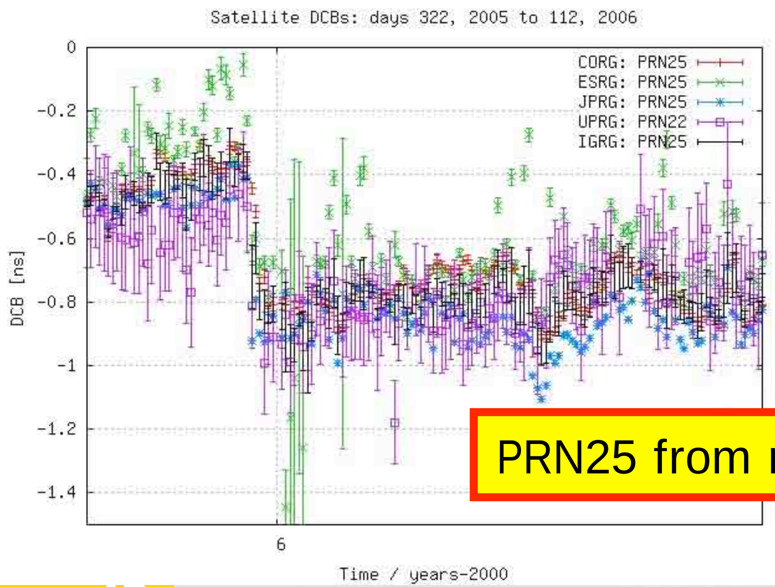
✓Rapid maps are in very good agreement with final ones (black, ~1 TECU in Std.Dev, 0 TECU in Bias, global discrepancy ~5%).

✓Good integrity (quite insensitive to few ESA and UPC problems).

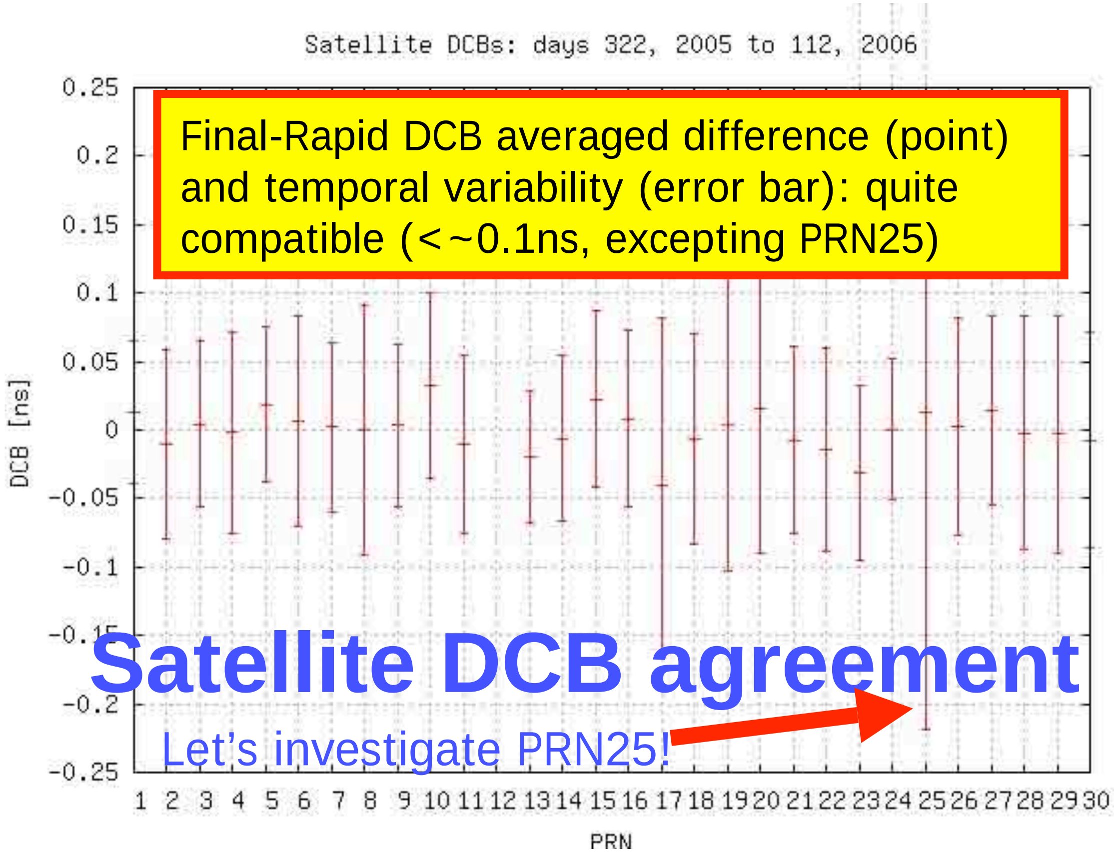
Satellite DCB agreement



PRN25 from final DCBs

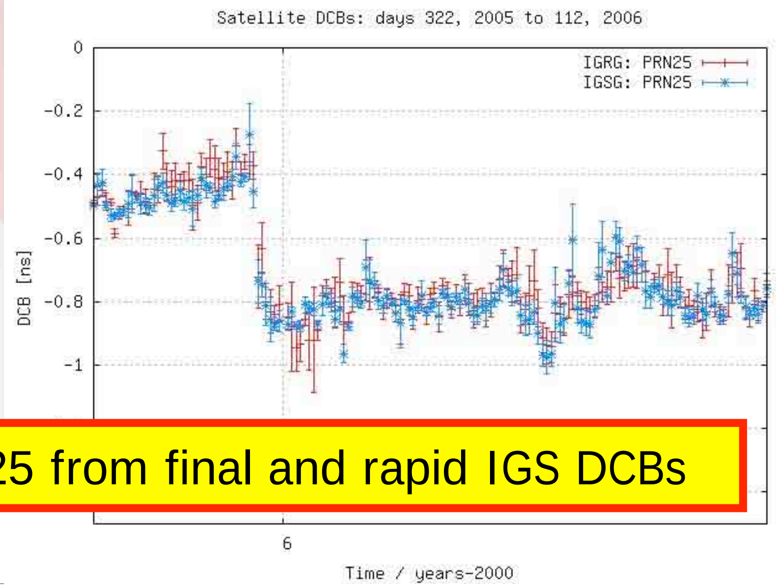


PRN25 from rapid DCBs



Final-Rapid DCB averaged difference (point) and temporal variability (error bar): quite compatible (<~0.1ns, excepting PRN25)

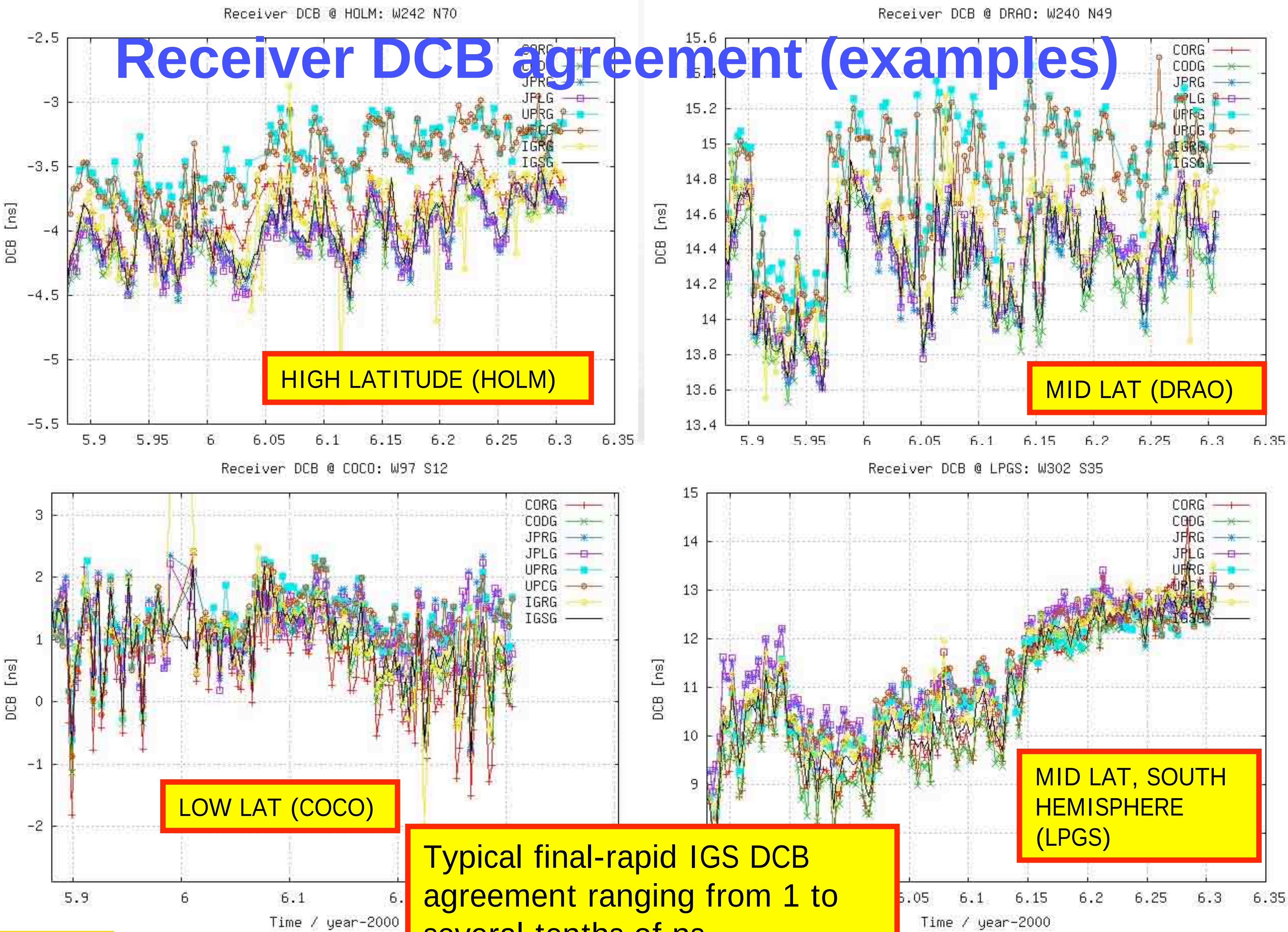
Let's investigate PRN25!



PRN25 from final and rapid IGS DCBs

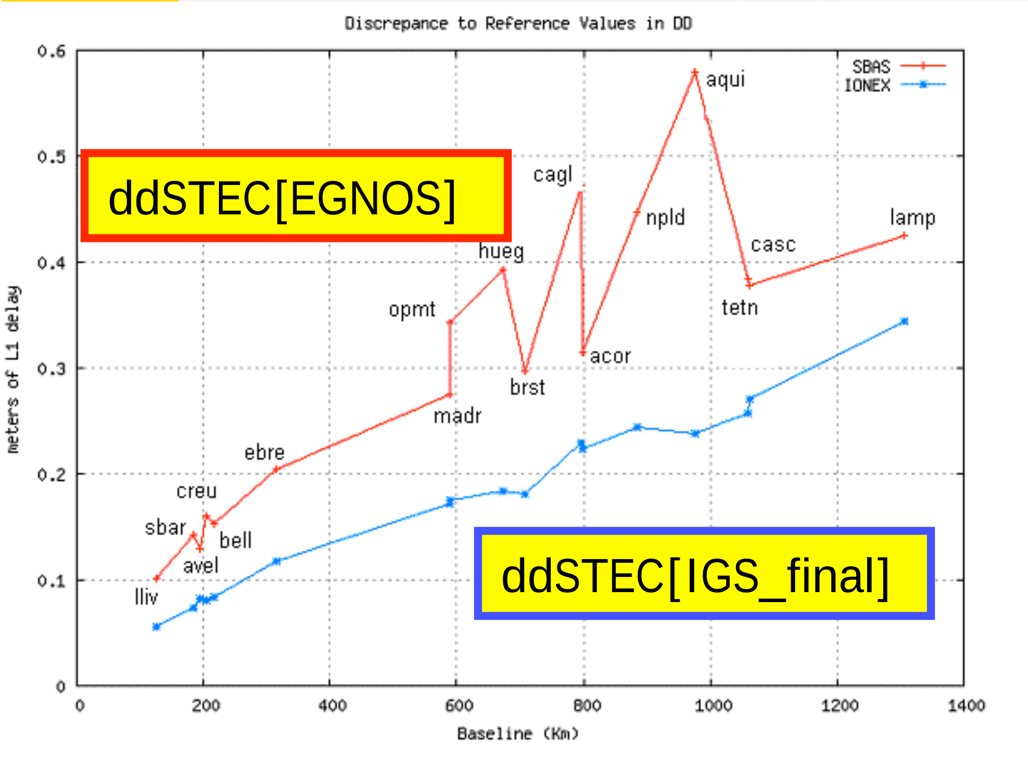
As an example, the change of PRN25 value well tracked from final and rapid DCB estimates...

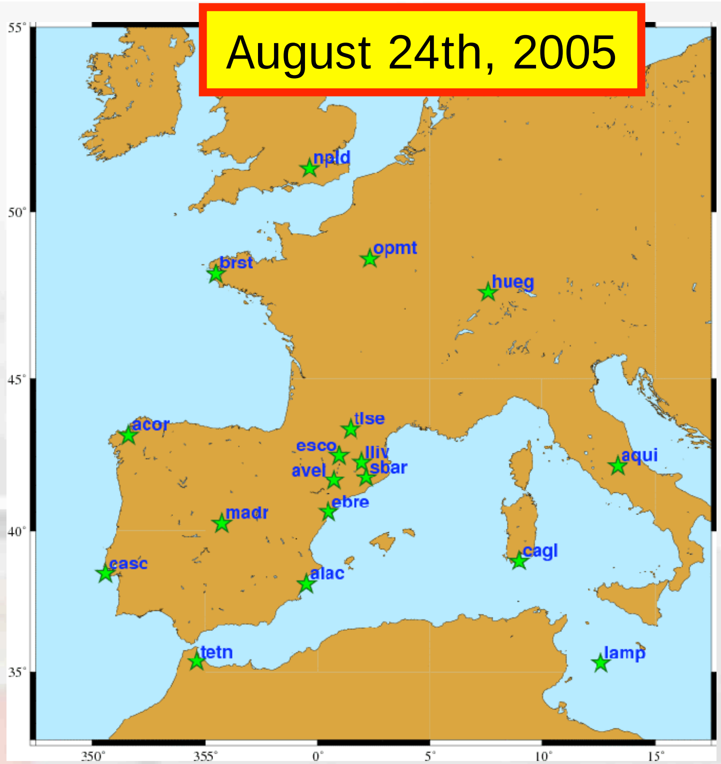
Receiver DCB agreement (examples)



Typical final-rapid IGS DCB agreement ranging from 1 to several tenths of ns.

Comparison between IGS and EGNOS iono models





The performance in double-differenced STEC estimations (the magnitude affecting positioning) is compared between final IGS and real-time EGNOS ionospheric models, over European baselines ranging from 100 to 1300 km (ref. station Toulouse, ground truth provided by WARTK in postprocessing).

The performance is quite good for post-processing IGS model (~30% better), in spite of the poorer temporal resolution (2-hours) compared to real-time SBAS/EGNOS model (~6 minutes) & high geomagnetic activity (noon:Kp ~9)

Usage: IGS Ionospheric files download in 2005 (source: cddis, Carey Noll)

- ✓ Total GPS IONEX Files: 301501
- ✓ GPS IONEX IGRG Files: 6426
- ✓ GPS IONEX CORG Files: 4807
- ✓ GPS IONEX ESRG Files: 6661
- ✓ GPS IONEX JPRG Files: 11910
- ✓ GPS IONEX UPRG Files: 5108
- ✓ GPS IONEX IGSG Files: 39698
- ✓ GPS IONEX CODG Files: 37699
- ✓ GPS IONEX ESAG Files: 30413
- ✓ GPS IONEX JPLG Files: 50367
- ✓ GPS IONEX UPCG Files: 37514

✓More than 800 daily downloads of Ionospheric files

✓Typically ~100 daily downloads or more for each individual final IONEX file

✓The new rapid product show a significant download activity (~100 daily downloads all of them)

Ways of ionospheric correction improvement: *Companion* maps of ionospheric effective height

Motivation

- The relationship between slant (STEC) and vertical total electron content (TEC) -the ionospheric mapping function- is one of the first assumptions to consider in applying GNSS ionospheric corrections.
- On one hand it depends at a given time on the 3D electron content distribution and can vary in terms of local time, latitude, season, Solar cycle epoch or ionospheric activity.
- However the typical mapping function in many GNSS ionospheric and navigation applications is assumed given by a 2D distribution of electron content (a single layer model at a constant effective height (~300-500 km).
- This can introduce a significant and some times very important mismodelling that can affect to different applications such as global VTEC determination and precise navigation.

Tomographic estimation and validation of the effective height

atics

ur goal: to show the feasibility of estimating a more realistic (and accurate) mapping function at global scale, in terms of variable GPS ionospheric effective height (hereinafter Hion), from dual frequency GPS ground stations.

his is done from the output of a Ionospheric Voxel model (hereinafter IVM) feed with ground data, contemplating several shells or layers, solved by means of Kalman filtering of geometry-free carrier phase measurements.

VM is routinely used by UPC to provide VTEC maps to IGS and real-time applications, due to its greater accuracy.

Estimation of the effective height from the tomographic output

he corresponding Hion has been derived by means of the following: averaging the different mapping functions (for different layers), weighted by the partial vertical electron content relative to the total one:

$$M = \frac{S}{V} \simeq \int_{REC}^{TRA} \frac{N}{V} \frac{1}{\cos X} dh \simeq \sum_i \frac{P_i}{V} \frac{r_i}{\sqrt{r_i^2 - p^2}}$$

Shape Function

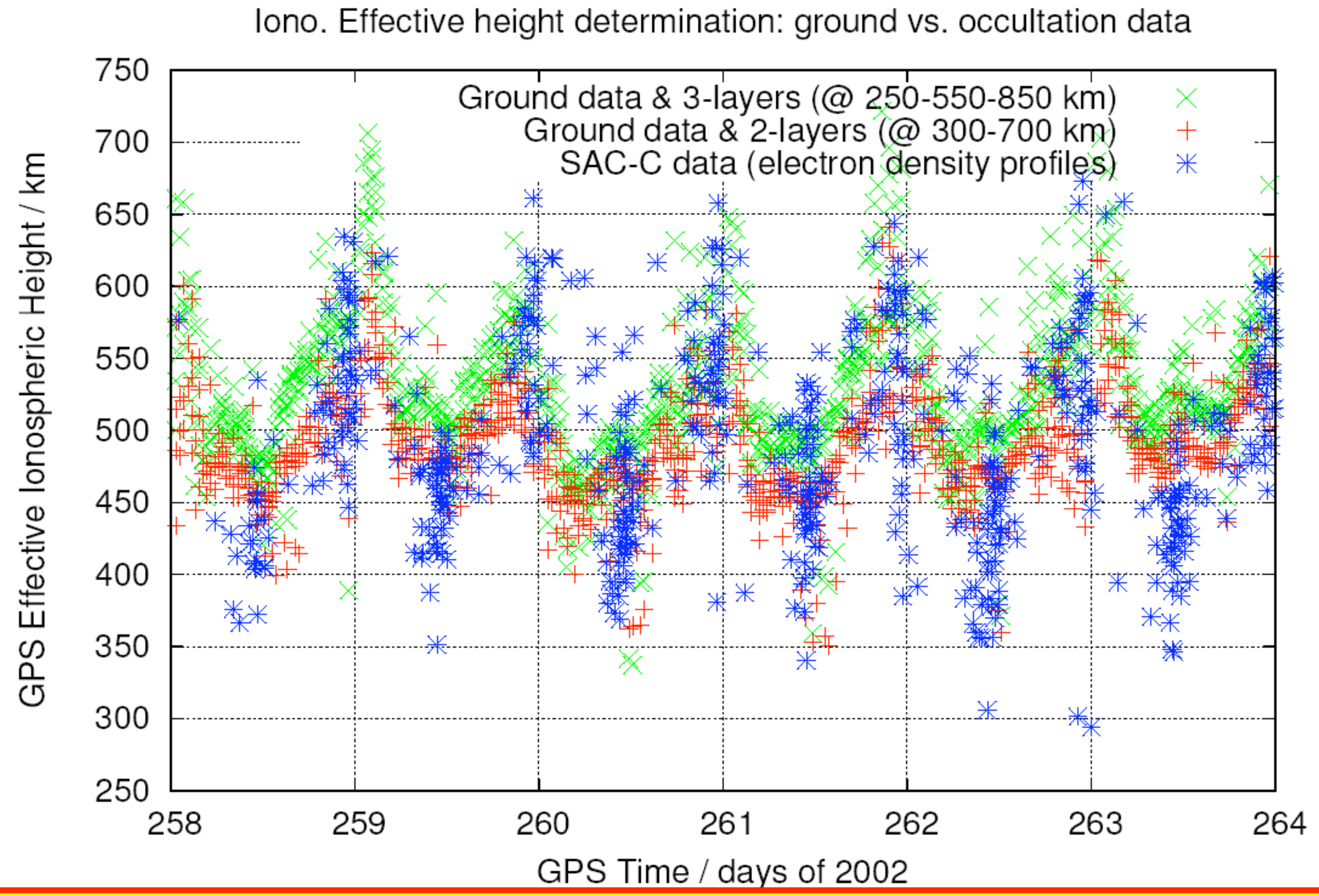
Standard mapping function at each given geocentric distance ri

$$h = \frac{M}{\sqrt{M^2 - 1}} p - r_e$$

eing M the mapping function computed for a ray of impact parameter p (p is taken corresponding to receiver elevation of 20 deg), S the Slant Total Electron Content (STEC), V the Vertical TEC, X is the zenithal angle at the the given height, N the electron density, Pi and ri the partial TEC and geocentric distance corresponding to the i-th layer, and p is the ray impact parameter and re is the Earth radius.

represents the GPS ionospheric effective height (or ionospheric shell height): It corresponds to a thin layer fitting to the estimated mapping by tomographic techniques (typically h > hmF2, due to

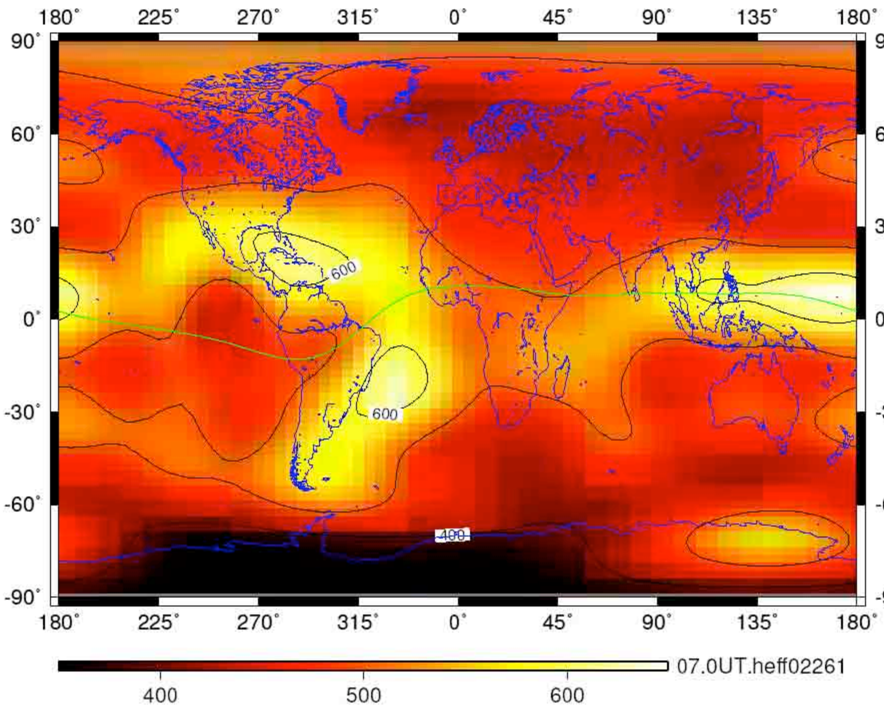
Validation: Ground vs SAC-C GPS iono. effective height

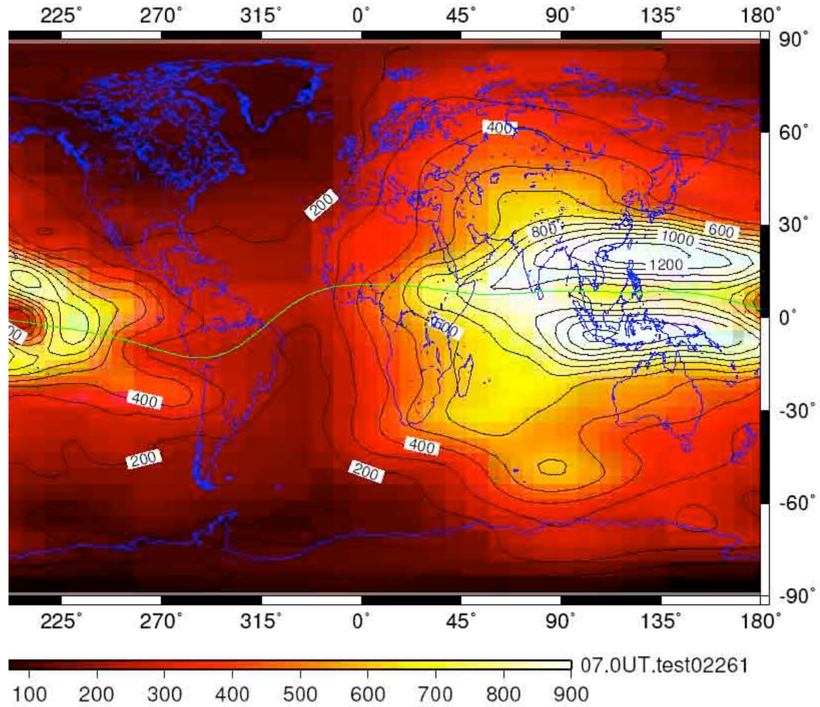


You can see the GPS Ionospheric effective height obtained from tomographic runs with ground data with different vertical layout with 2 and 3 layers (in red and green; similar results are obtained with 10 layers).

They are quite compatible between them and with the value deduced from SAC-C occultation data (blue points, each one obtained from one different occultation). They vary mostly due to the periodic change in Local Time, and latitude, along the LEO orbit.

Global maps of ionospheric effective height





Ionospheric Effective height / km

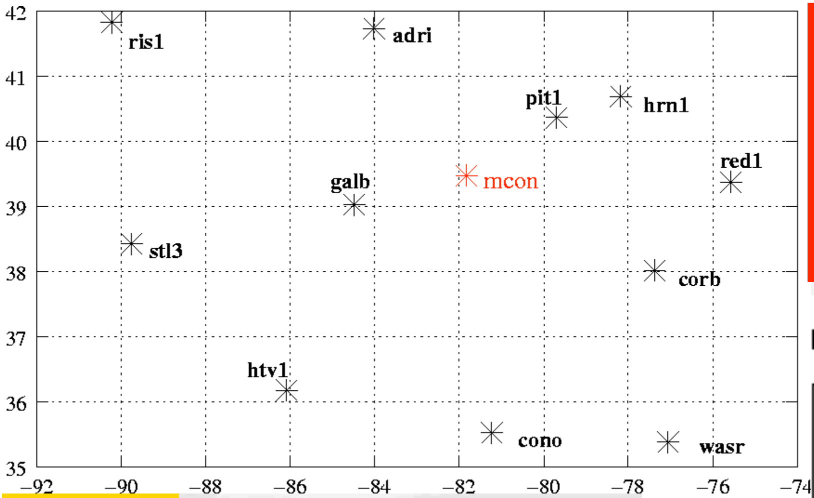
VTEC / 0.1 TECu

As examples you can see typical snapshots of the effective height and VTEC, estimated simultaneously (0700 UT, day 261, 2002).

It can be seen in particular the known increase of effective height in the night.

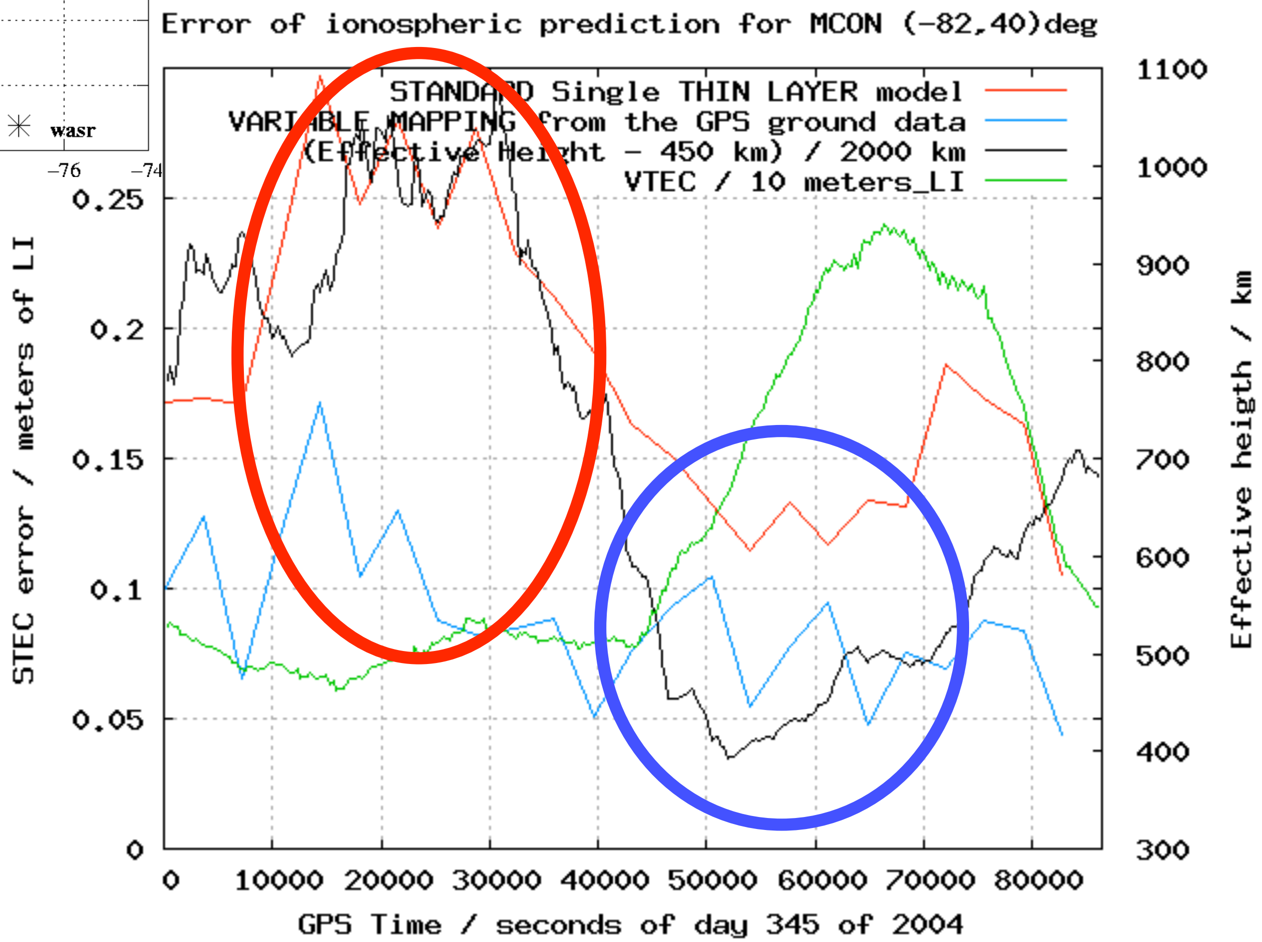
Such increase is more important at low latitudes, and show a bimodal pattern, around the magnetic equator, after the sunset.

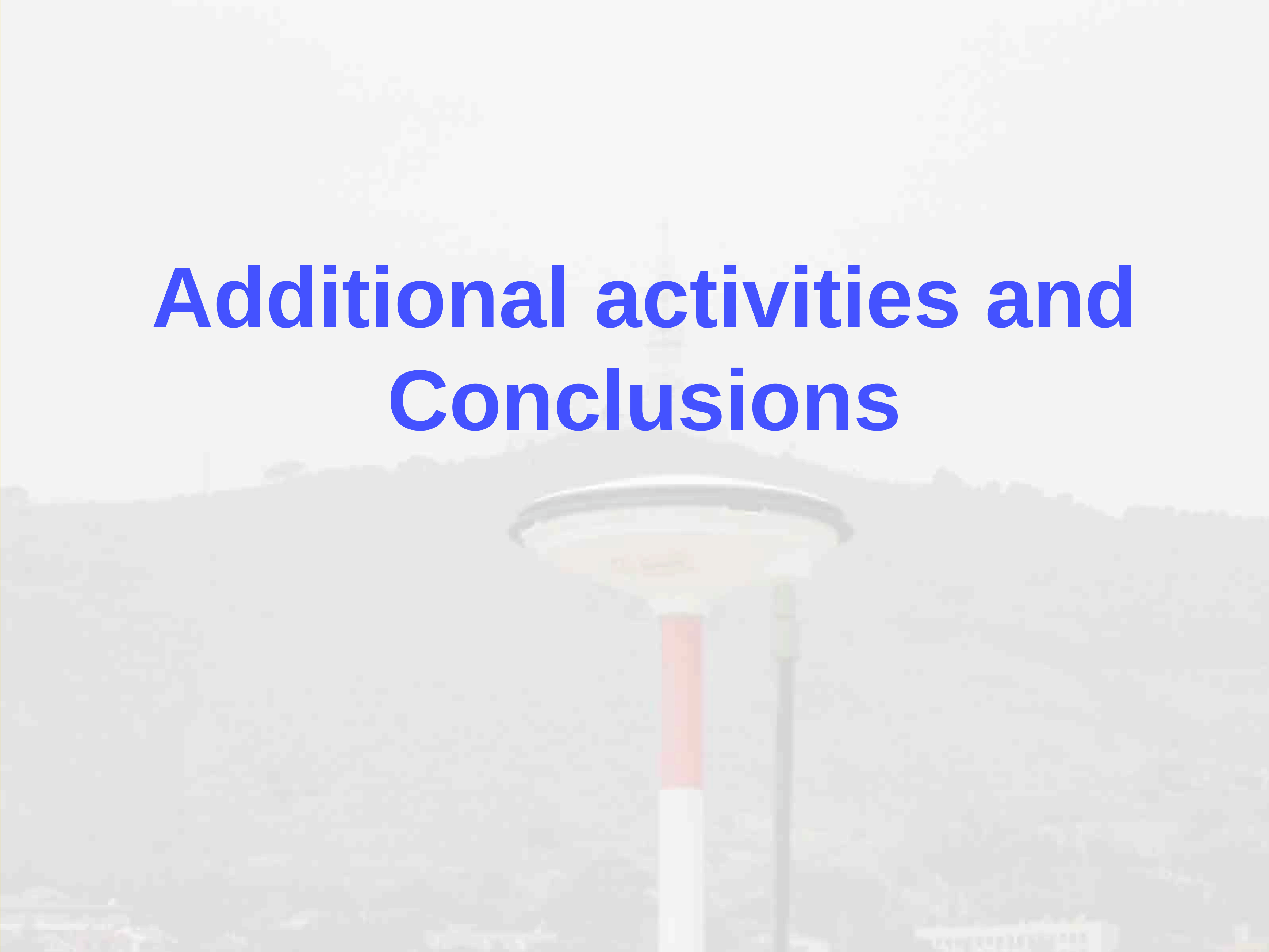
Applications: improvement of ionospheric predictions using the mapping function derived from ground GPS data



Several ground GPS stations of the CORS network have been processed (black) to generate ionospheric corrections which are compared to the true values (obtained by WARTK, fixing phase ambiguities) over an additional station MCON.

The interpolation with standard single thin layer model (red) provides worst results than the results with the mapping obtained from the estimated ionospheric effective height in the network (blue), specially when the effective height (black) diverges regarding to the fixed value of 450km. The VTEC is represented in green.





Additional activities and Conclusions

Conclusions and additional activities

- The updated performance of the rapid and final IGS VTEC and associated DCBs shows good numbers of accuracy and integrity.
- We have shown as well the feasibility of estimating reliable ionospheric effective heights from ground GPS measurements at global scale, providing a way to get more realistic and accurate mapping functions for GPS users.
- Another recent activity: IGS VTEC temporal resolution increase, from 120 to 5 minutes, using all the available receivers, which ionospheric carrier phase combination is aligned with the 2-hours map, and averaged in each pixel without interpolation. It was tested in CAWSES campaign during Sept.05 campaign: ftp://gage152.upc.es/rapid_iono_igs/high_rate/2005
- 2nd order ionospheric term: assesment performed on practical aspects in particular (it can be applied from either VTEC maps or P2-P1 and DCBs, importance of using a more realistic geomagnetic model –reduction of ~50% of error in certain regions-...)

Potential improvements in reprocessing campaign (Monday's talk): Encouraging to analysis centers to commit.

Action item?

Thank you!

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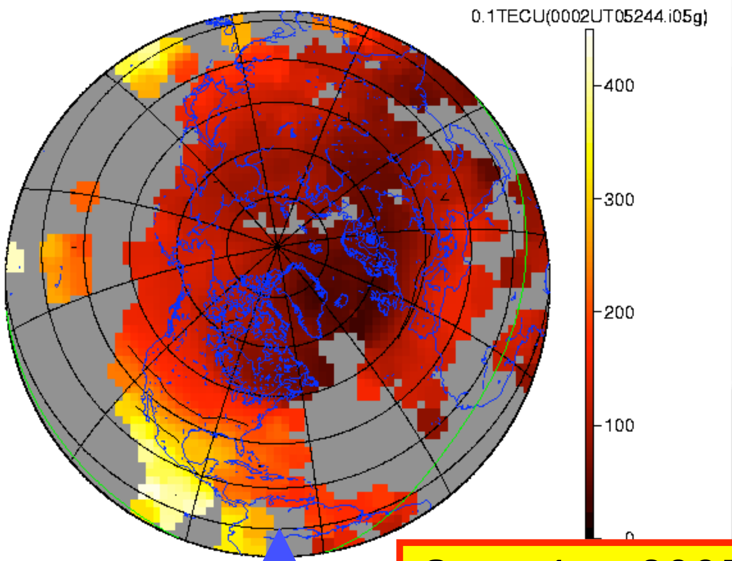
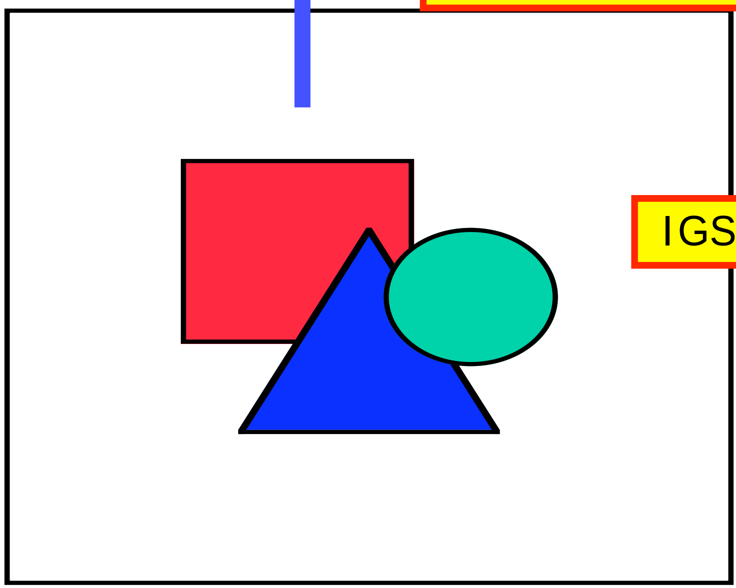
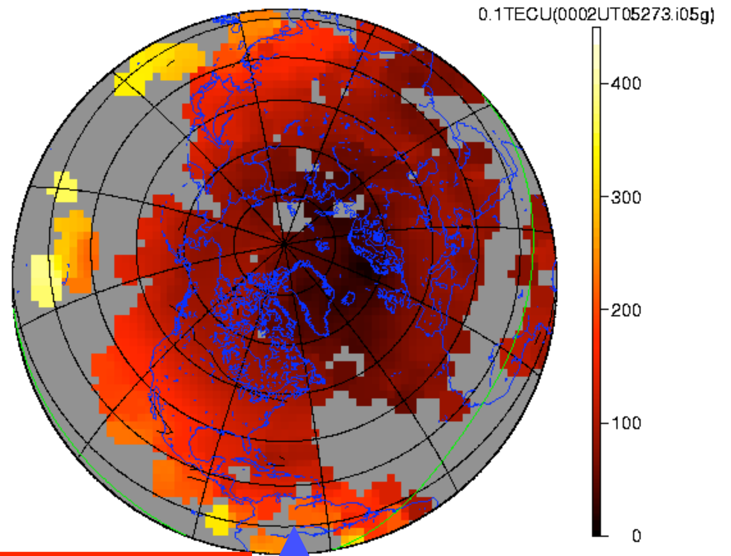
Increasing IGS VTEC temporal resolution (from 2 hours to 5 minutes in Sept.05 CAWSES campaign)

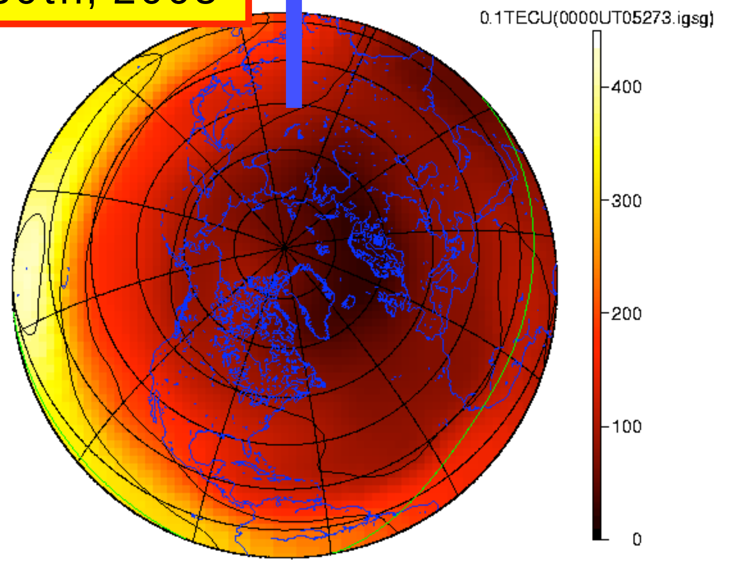


Sept. 1st, 2005





Sept. 30th, 2005



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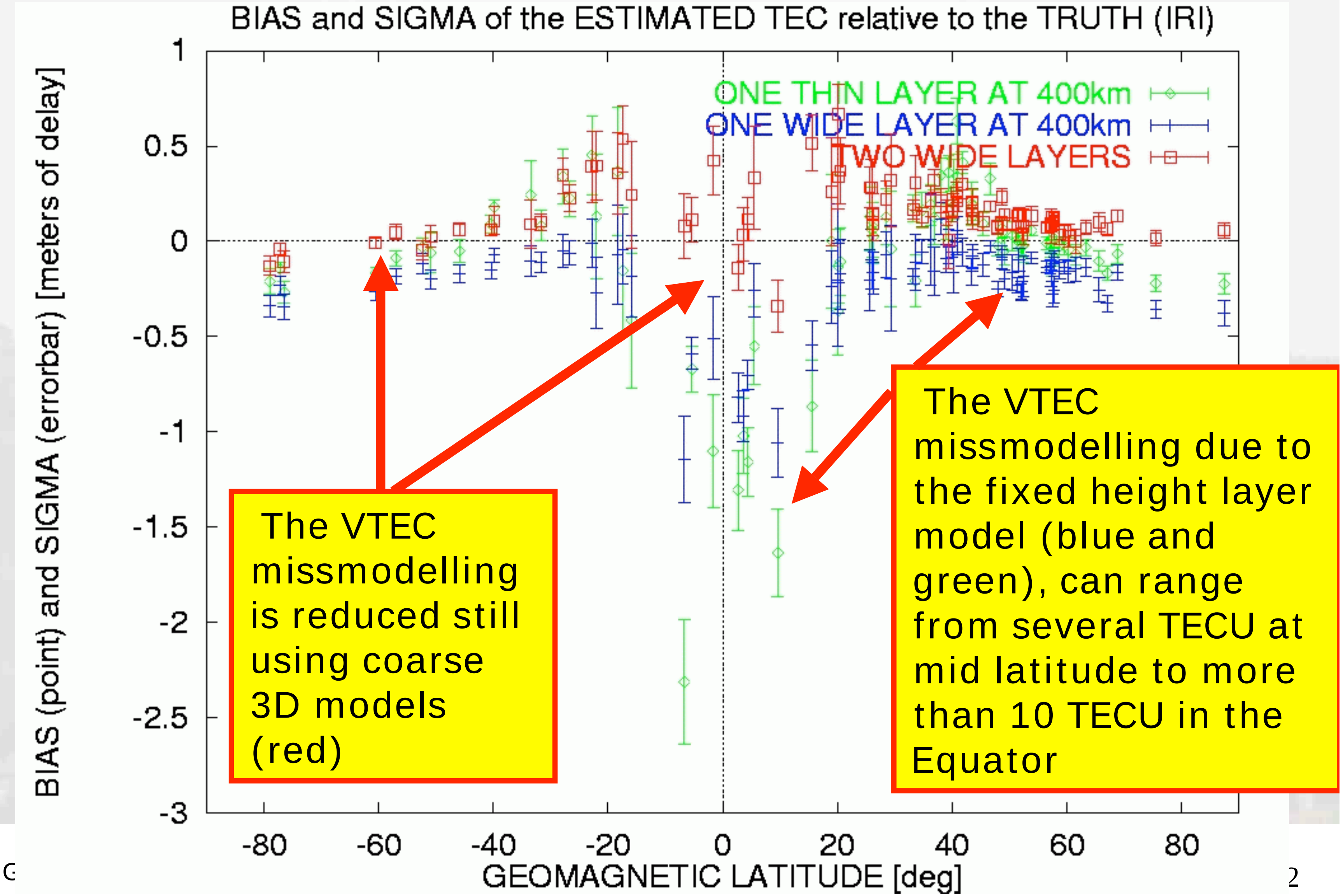
Reducing the VTEC error: from 1 to 2 layers



Ground GPS vs IRI maps of ionospheric effective height (07UT, day 261, 2002)

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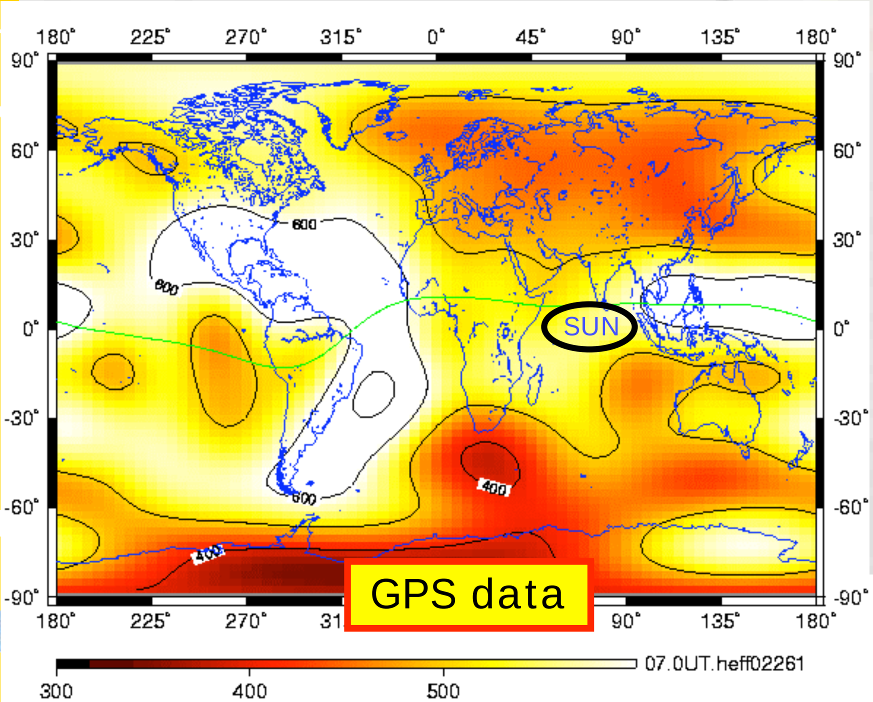
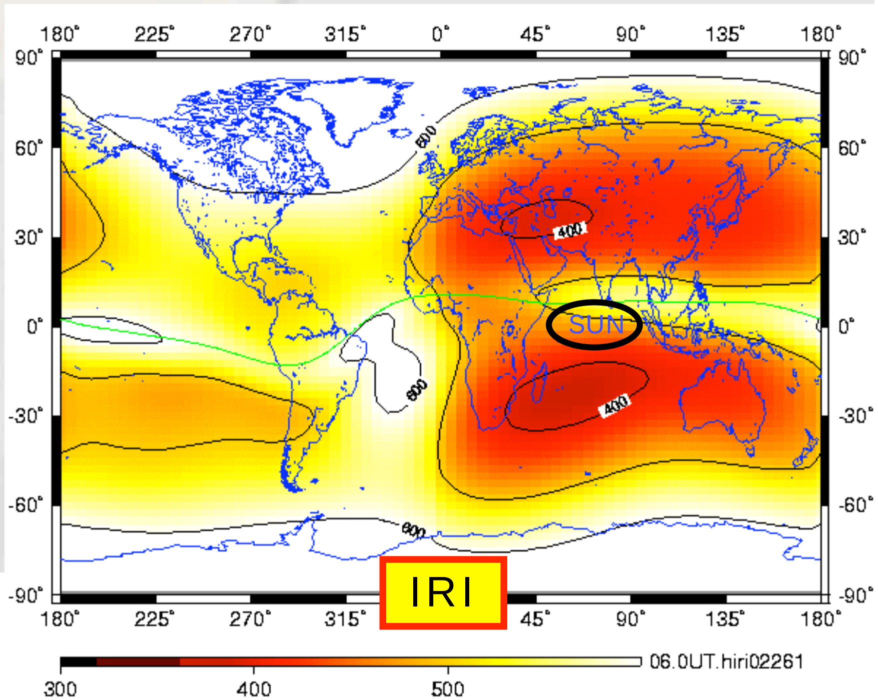
In the daylight hemisphere: the IRI predicts two effective height depresions at both sides of the geomagnetic equator (~400 km), like it has been observed from ground GPS data (but at ~450 km).

In the night hemisphere: the IRI is not clearly predicting a high increase of effective height at both sides typically of the equator, with a local minimum in the middle, clearly observed by GPS around the sunset.

In spite of that this comparison is just done for one single day, this could be related to the IRI uncertainties in night time, related to the topside electron density profiles.



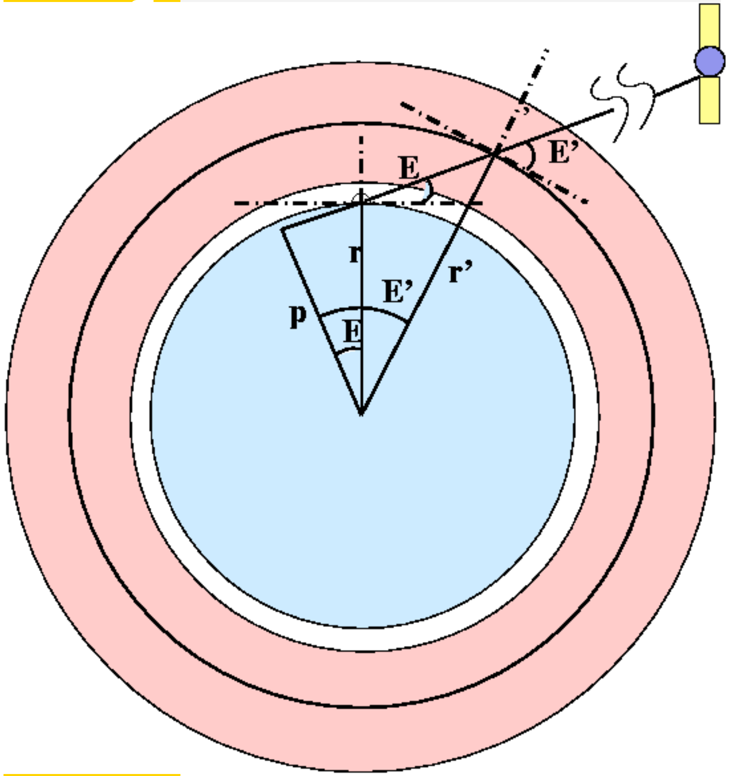


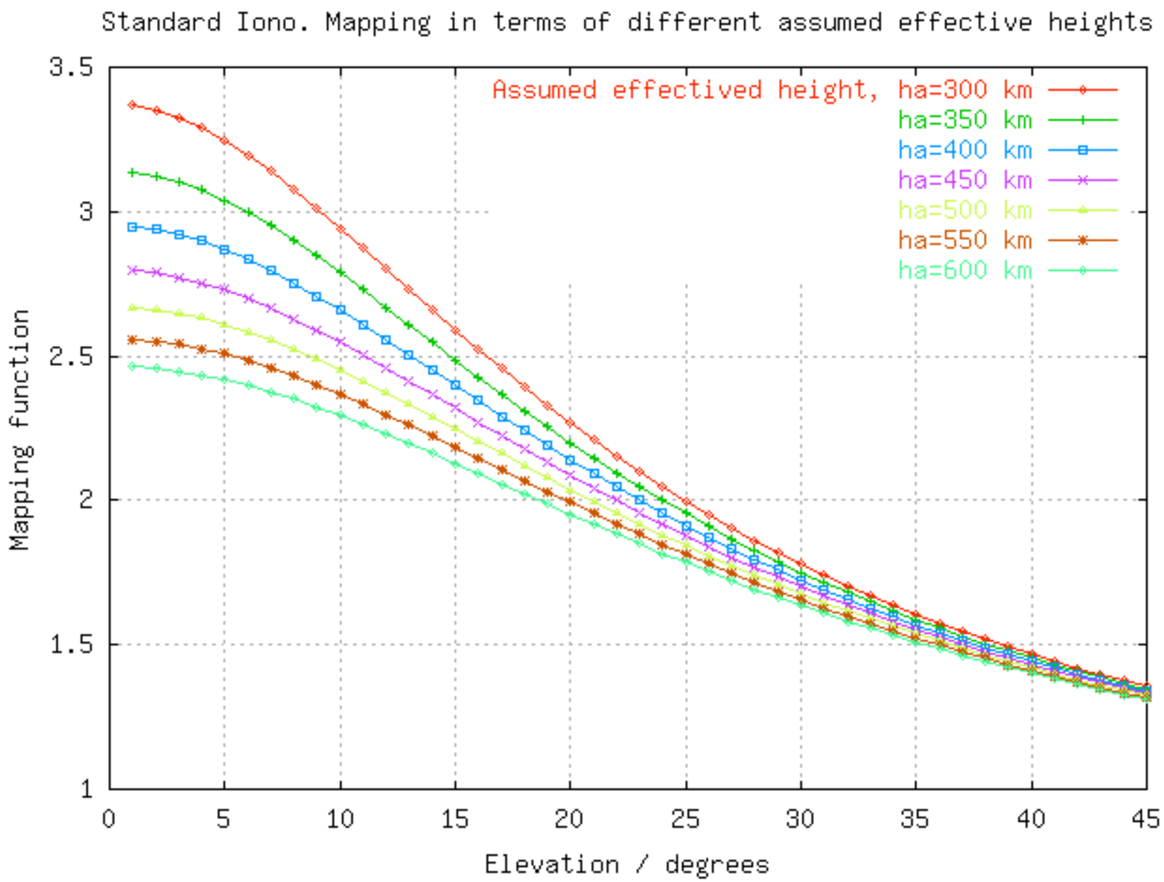
Single-layer mapping function

The mapping function is the factor passing from VTEC to STEC, ranging from 1 at 90 deg of elevation to about 3 at low elevation. Depends on the effective height assumed (up to 30% variation at low elevation -see the plot-).

$$VTEC = STEC \cdot \sqrt{1 - \frac{r^2}{(r+h)^2}\cos^2 E} \Rightarrow$$

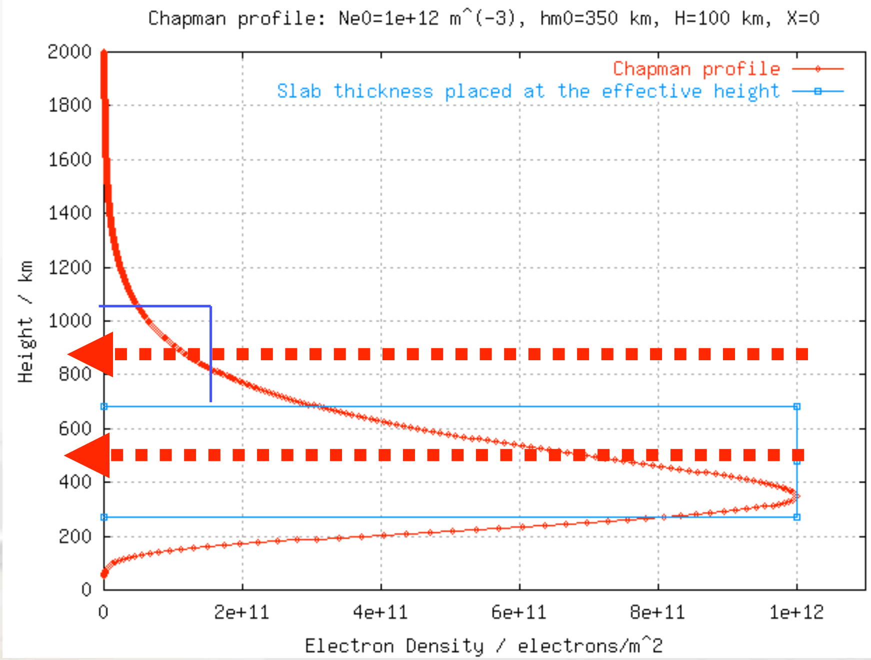
$$\Rightarrow \underbrace{STEC \cdot \sin E}_{h \to 0^+} < VTEC < \underbrace{STEC}_{h \to +\infty}$$

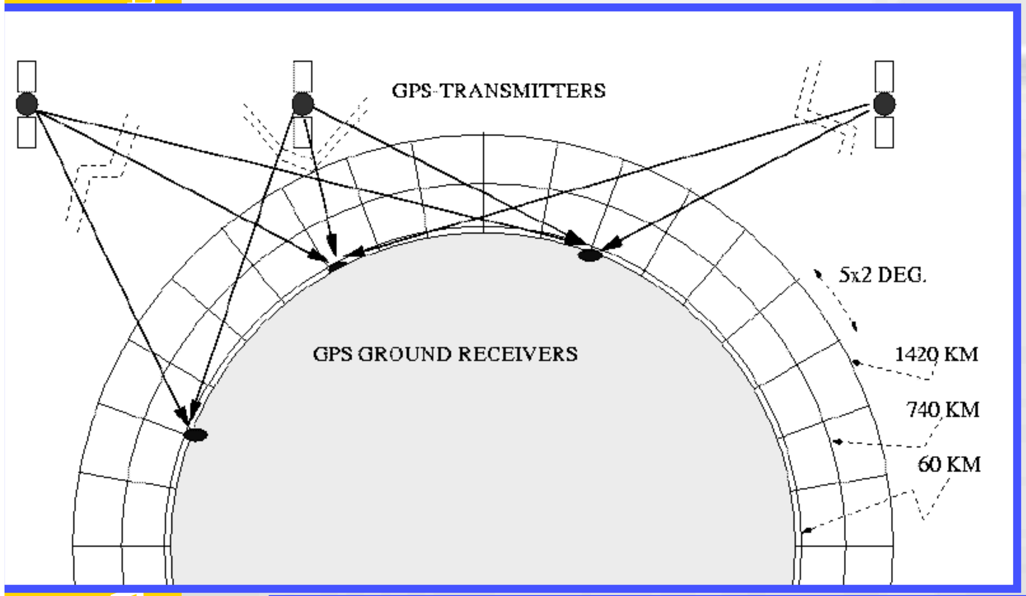




Relaxing the single-layer model

A significant reduction of the single-layer mismodeling can be obtained by relaxing this assumption. This can be done by introducing additional layers and solving for the LI bias and mean electron density unknowns corresponding to each illuminated voxel, in a Kalman filter.





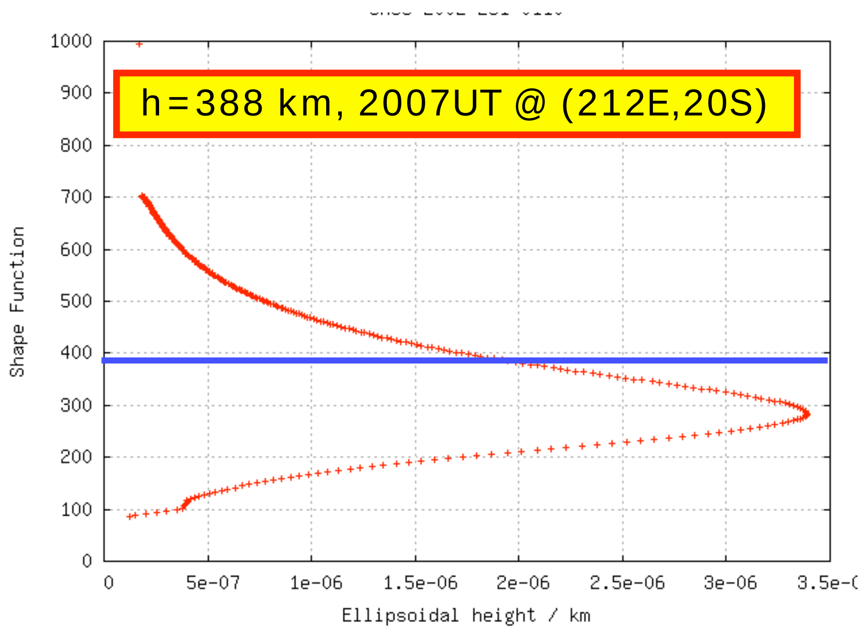
- Only carrier phase data needed
- With tomographic description: more accurate (degree of freedom in vertical distribution).
- DCB's no longer needed
- No affected by pseudorange multipath

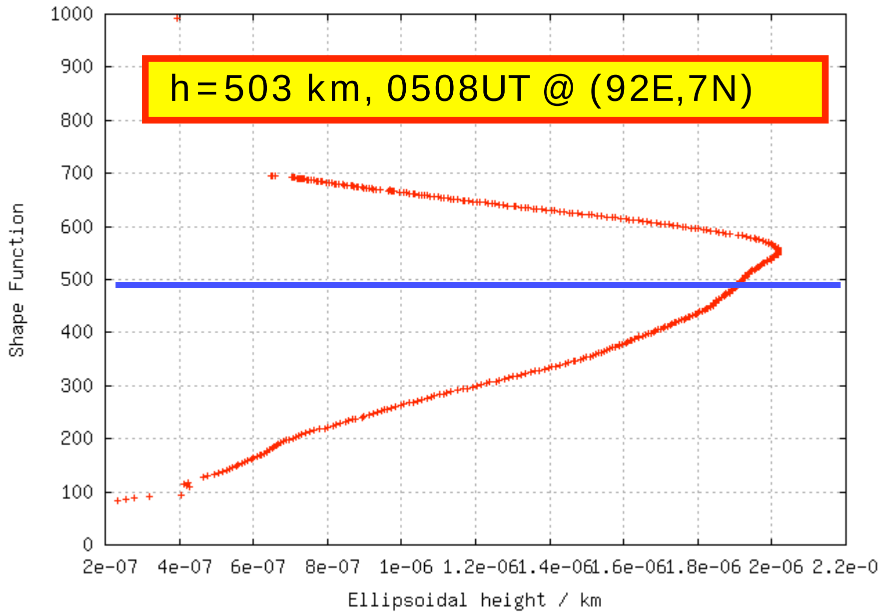
$$L_I = STEC + B_I = \int_{REC}^{SAT} N_e dl + B_I = \sum_i \sum_j \sum_k (N_e)_{i,j,k} \Delta s_{i,j,k} + B_I$$

Improved Abel Transform to validate the ground GPS data derived effective height

-In order to validate such Hion estimation, an independent dataset and tomographic technique is used: occultation SAC-C LEO GPS data during 2002 which provides vertical accurate electron density profiles by applying the improved inverse Abel transform (Hernández-Pajares et al. GRL 2001).

-The profile is integrated weighting the standard mapping function at each given height (impact parameter) by the shape function as it was indicated in the previous expression.





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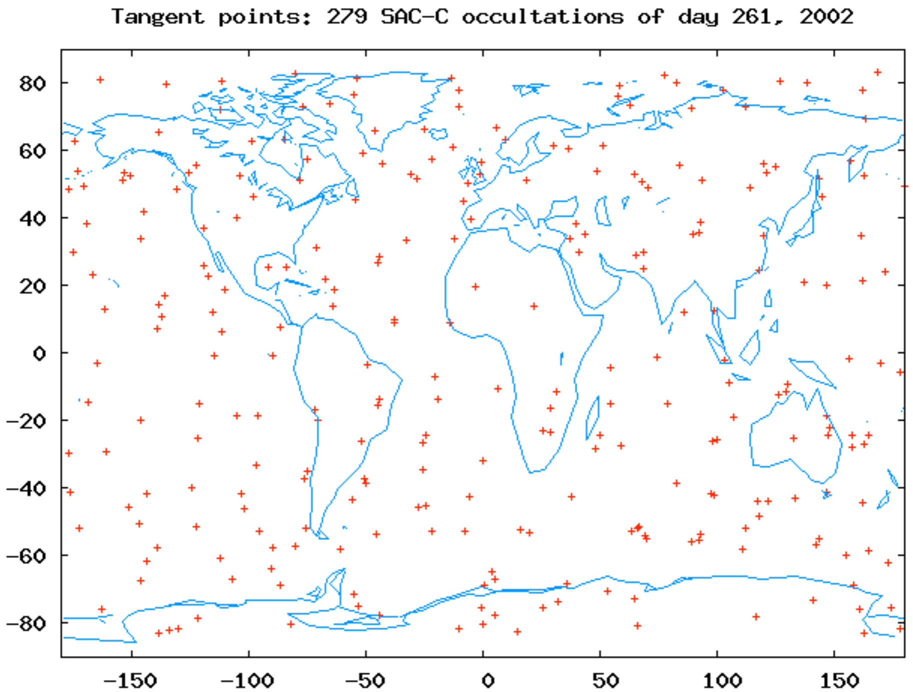
Datasets



he main comparison is performed for six consecutive days (days 258-263 of year 2002) of both global ground IGS data (about 160 permanent selected stations each day) and LEO SAC-C occultation data (about 1600 occultations), still corresponding to the more dificult Solar and Seasonal Maximum conditions.

You can see the typical distribution of the initial tangent points of the GPS occultations in longitude-latitude (top left hand plot) and local time-latitude (bottom right hand plot), corresponding to day 261 of 2002.