Improvement and validation of retrieved FORMOSAT-3/COSMIC electron densities using Jicamarca DPS

A. Aragón-Angel, Y.-A. Liou, C.-C. Lee,
M. Hernández-Pajares, J.M. Juan, J. Sanz,
B.W. Reinisch

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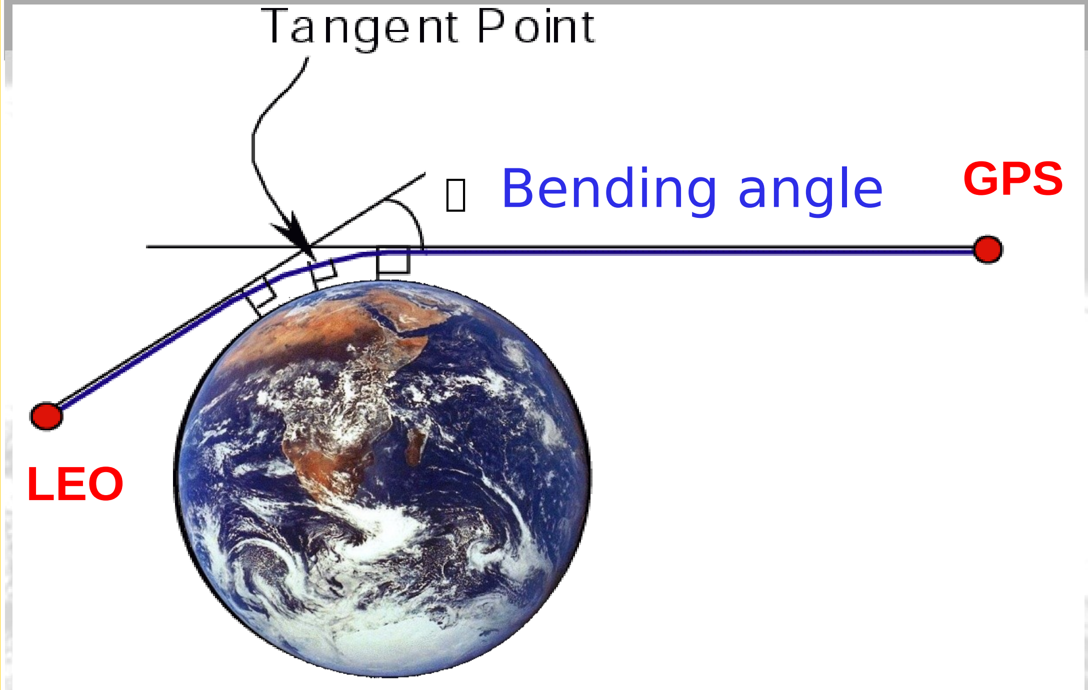
Outline

1. RO: Classical Abel transform applied to L1 phase excess
2. Clock calibration
3. Improved Abel transform
4. Results
5. Topside estimation
6. Future work
7. Conclusions

Electron density from RO data

Basic observable:

- Linear combination of dual frequencies LI → Assumption of L1&L2 same pa
- Bending angle of L1 → Clock calibratic



The GPS receiver on the LEO observes the change in the delay of the signal path between the GPS and the LEO satellite

This change in the delay includes the effect of the atmosphere which delays and bends the

Classical Abel transform applied to L_1 excess phase

The basic measurement is the phase path:

$$L = \int_{GPS}^{LEO} n\, ds$$

From it, the excess phase is defined:

$$\Delta L = L - |\vec{r}_{LEO} - \vec{r}_{GPS}|$$

The change rate of the excess phase, called excess Doppler, is what is going to become our input observable:

$$\Delta D = \frac{d(\Delta L)}{dt}$$

The projection of satellite orbital motion along signal ray-path produces a Doppler shift at both the transmitter and the receiver. The fundamental observable is the signal Doppler shift, which is different than expected from only velocities due to the satellite and receiver clock drifts and the atmospheric bending of the signal (ionosphere and

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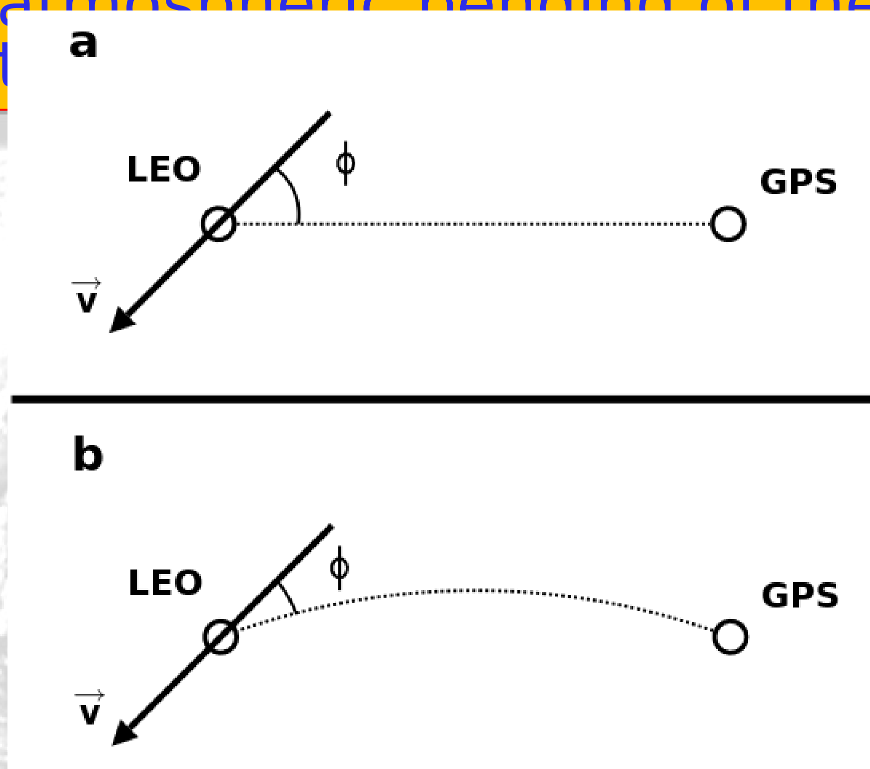


a) In a vacuum

b) In the presence of a medium, such as the ionosphere

Calibration of the excess phase

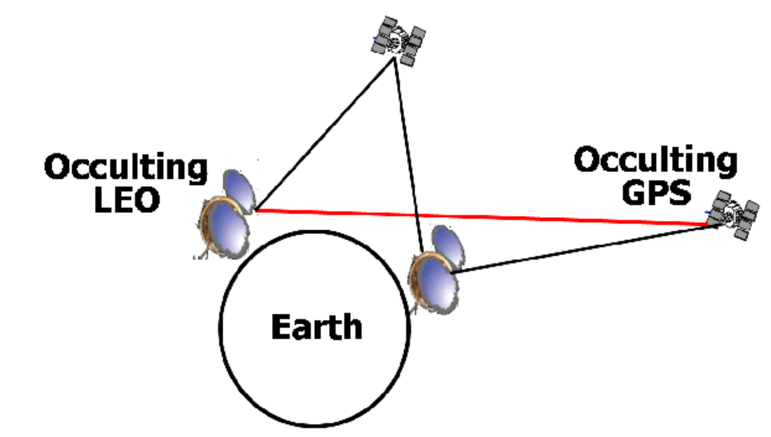
To compute accurate RO, need to remove the drifts of GPS transmitter and LEO receiver clocks from the raw phase data.:

$$\Delta D = \frac{d(\Delta L)}{dt}$$

Classically:

Double Difference

- Advantage: Clock errors removed
- Problem: Fid. site MP, thermal noise



With a LEO constellation deployed (FORMOSAT-3/COSMIC), complete double differencing coverage can be provided avoiding the fiducial site.

Single Difference

- LEO clock errors removed
- Use solved-for GPS clocks
- Advantage: Minimizes double difference

Bending angle: Calibration of excess phase delay

Alternative approach for a two-frequency receiver:

The ionospheric free combination , Lc, has been used to remove the clock drift.

$$\Delta\alpha_i \propto \Delta f_i \propto \frac{d(\Delta L_i)}{dt} - \frac{dT}{dt} \;\Rightarrow\; \Delta f_i \propto \frac{d}{dt}\left(\Delta L_i - T\right)$$

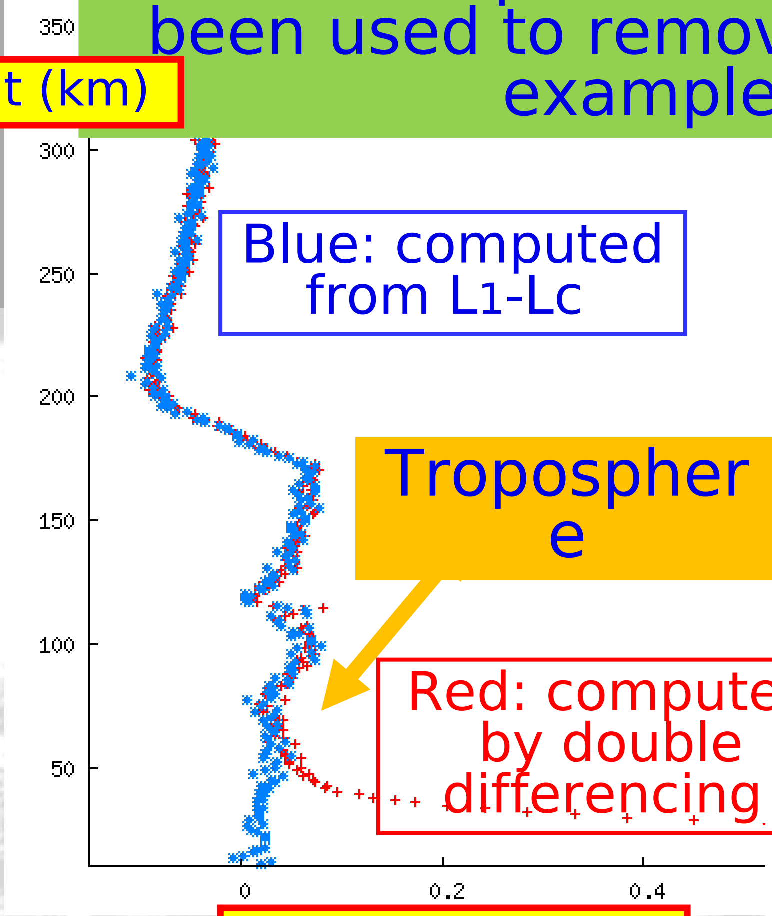
$$0 = \frac{f_1^2 \cdot \Delta f_1 - f_2^2 \cdot \Delta f_2}{f_1^2 - f_2^2} = \frac{d}{dt}\left(\Delta L_C - T\right)$$

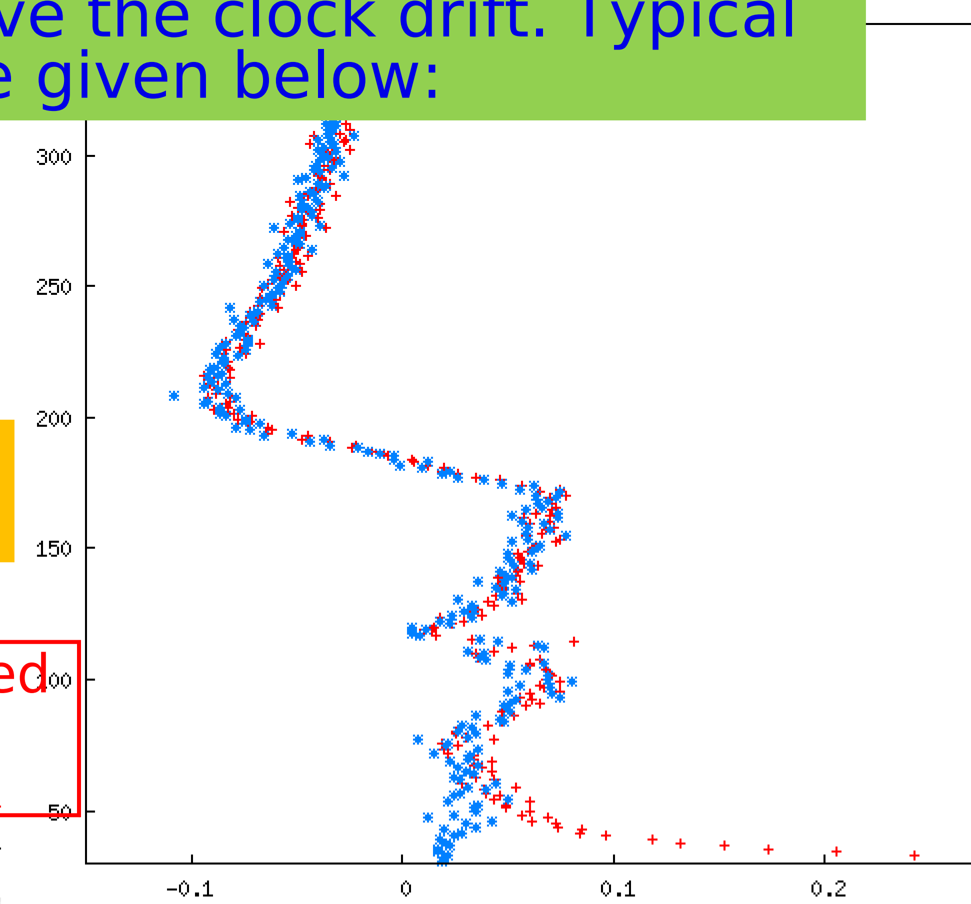
$$\frac{d}{dt}\left(\Delta L_C\right) = \frac{dT}{dt}$$

Bending angle: Calibration of excess phase delay

Alternative approach for a two frequency receiver:

The ionosphere free combination, Lc, has been used to remove the clock drift. Typical example given below:





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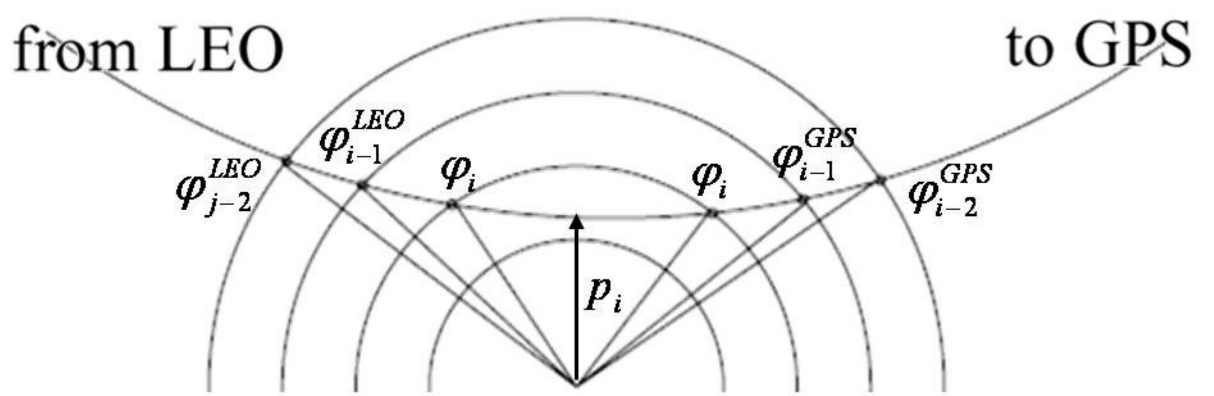
Classical Abel transform applied to bending angles

Signal Doppler shift

Just the given occultation GPS data are processed.



$$\alpha_i = \sum_{j=1}^{i-1} \alpha_j^{LEO} + \sum_{j=1}^{i-1} \alpha_j^{GPS} - \tan\varphi_i \cdot \frac{(n_i - n_{i-1})}{n_{i-1}}$$

$$\alpha_j^{receiver} = -\tan\varphi_j^{receiver} \cdot \frac{(n_j - n_{j-1})}{n_{j-1}}$$

The classical spherical symmetry hypothesis can be expressed as:

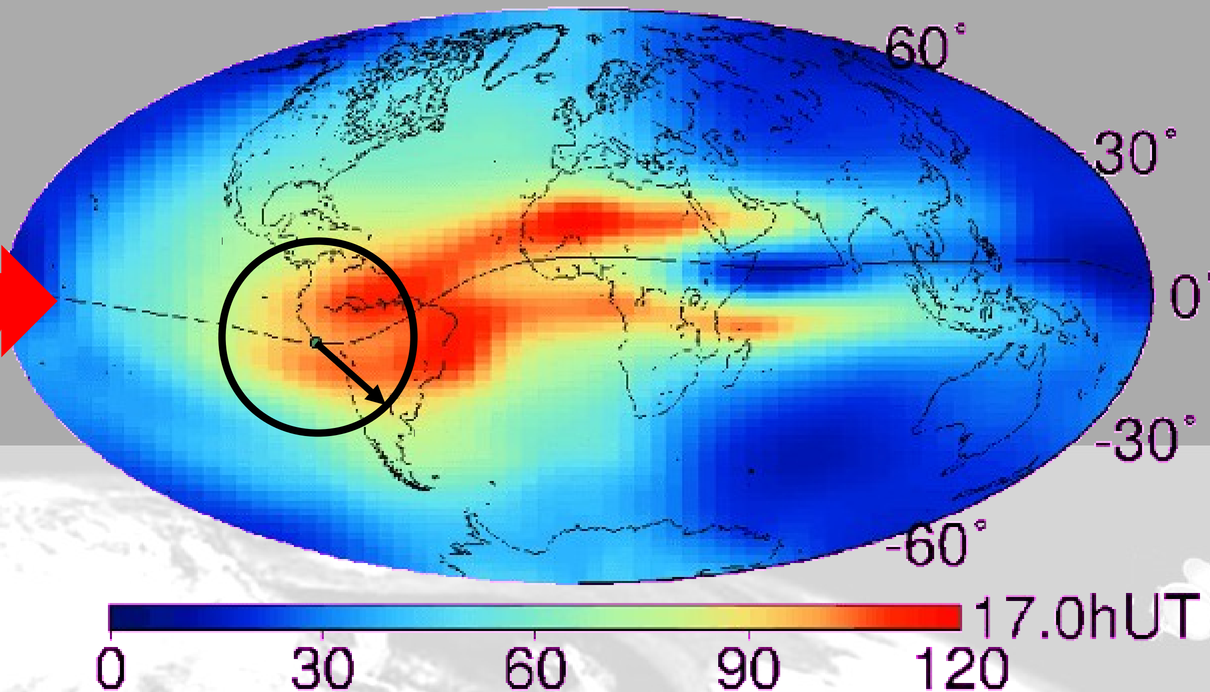
Unknown to be solved is Ne

$$N_e(LT, LAT, H) = \Phi(H)$$

- Recursive solution starting from the outer ray.
- □*i* corresponds to the bending angle of the ray with impact parameter *pi*.

Improved Abel transform

Problem: Electron density is equal for points at the same height but a RO footprint ~ 3000km



IGS Global Ionospheric Map (GIM)

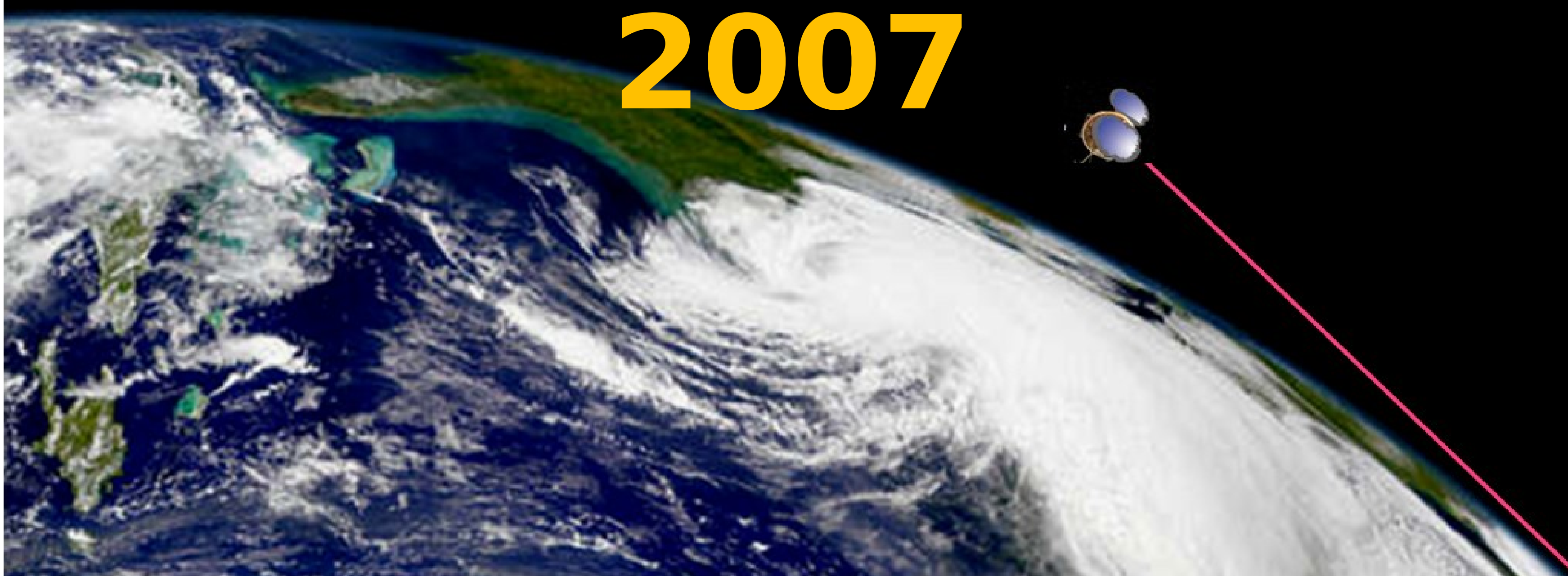
A more general approximation than the spherical symmetry was assumed introduced by [Hernández-Pajares, Juan, Sanz (2000)] applied to the ionospheric combination LI:

New unknown instead of Ne

VTEC information externally provided

Shape function

Analysis of F-3/C derived Ne profiles at the dip equator Jan - Dec 2007



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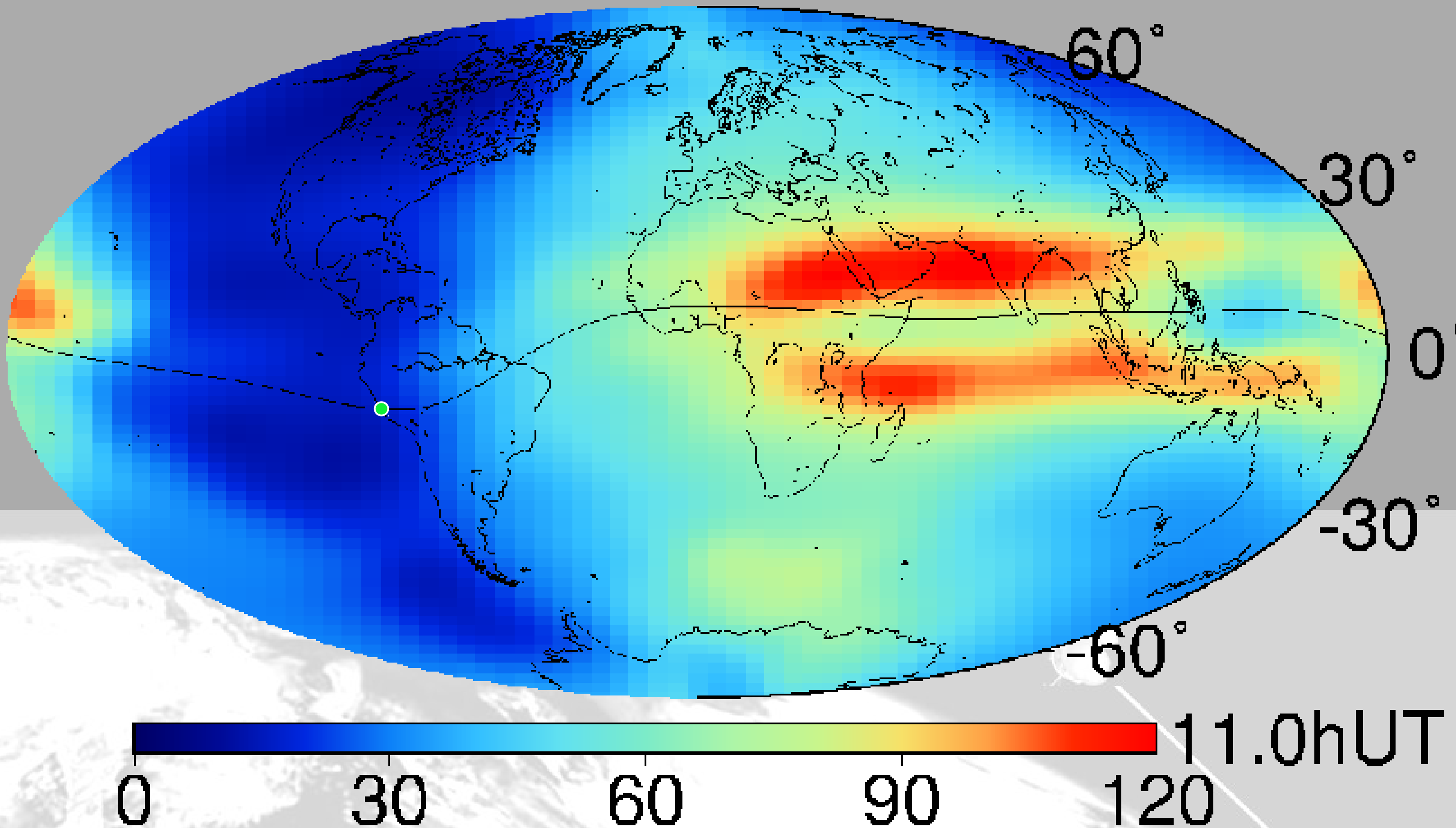
Experiment @ Jicamarca



ROJ
DPS

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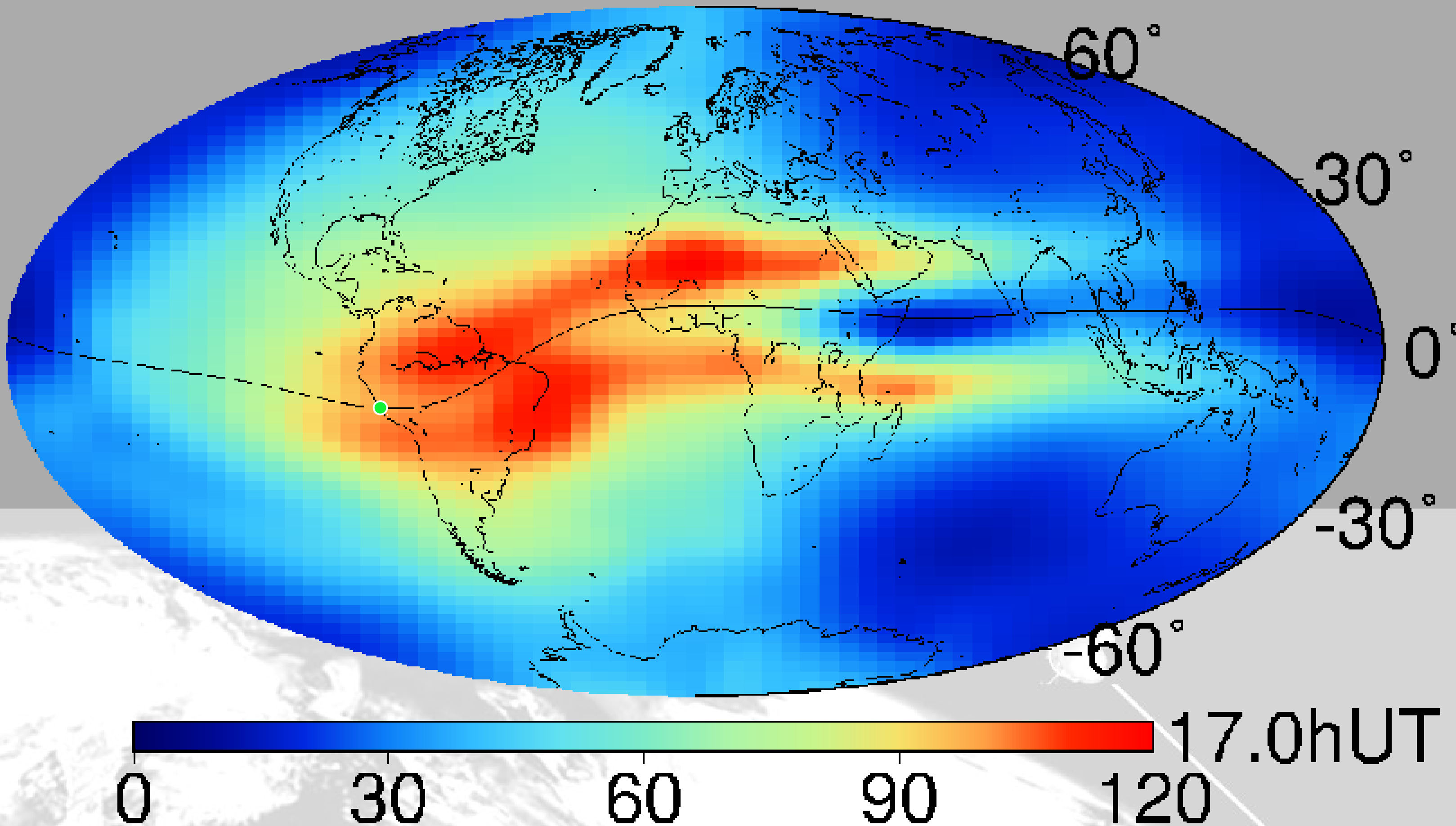
Experiment @ Jicamarca



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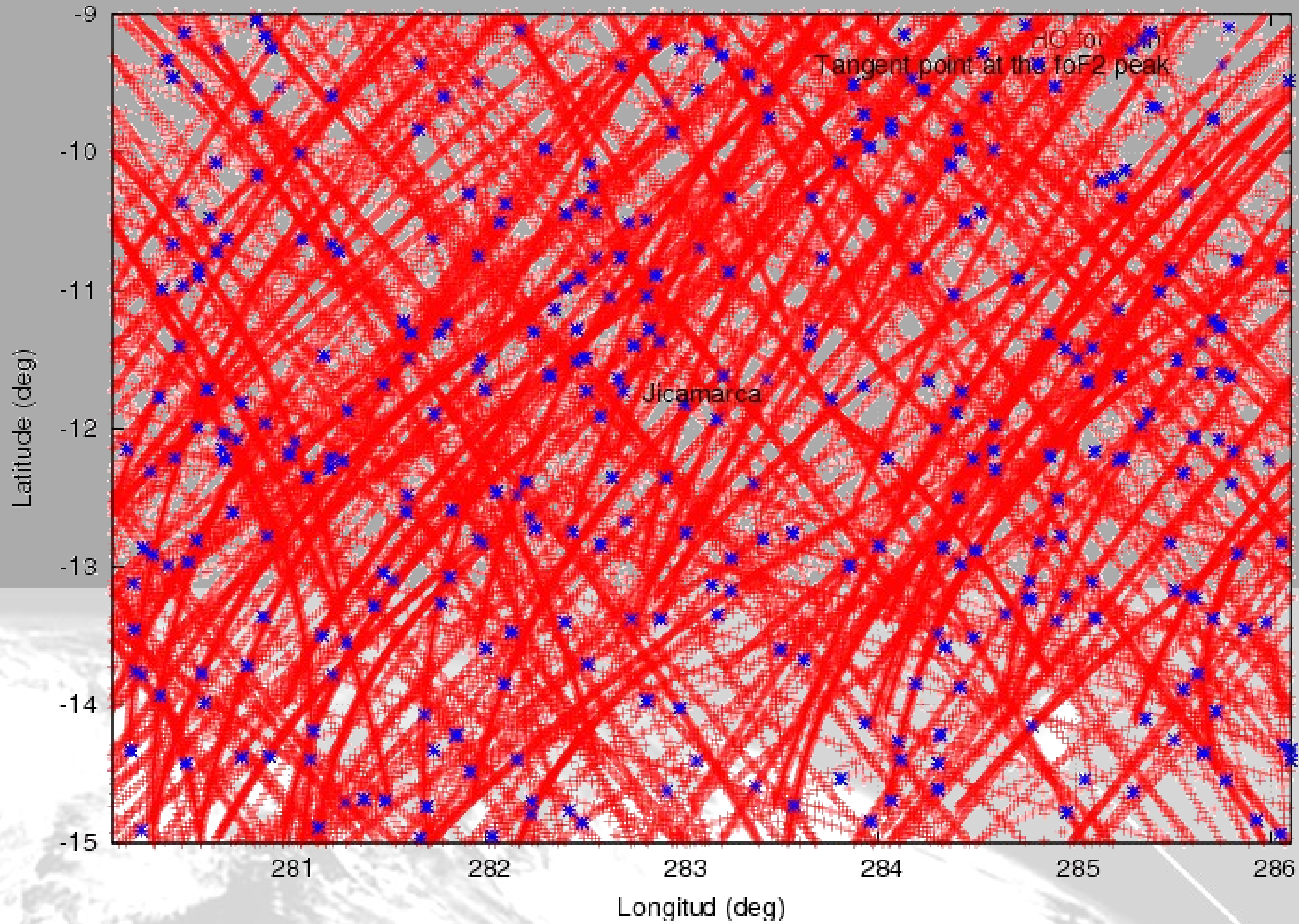
Experiment



Scenario:

- Time span: Jan 2007 until Dec 2007
- Jicamarca DPS location (+/- 3 degrees)

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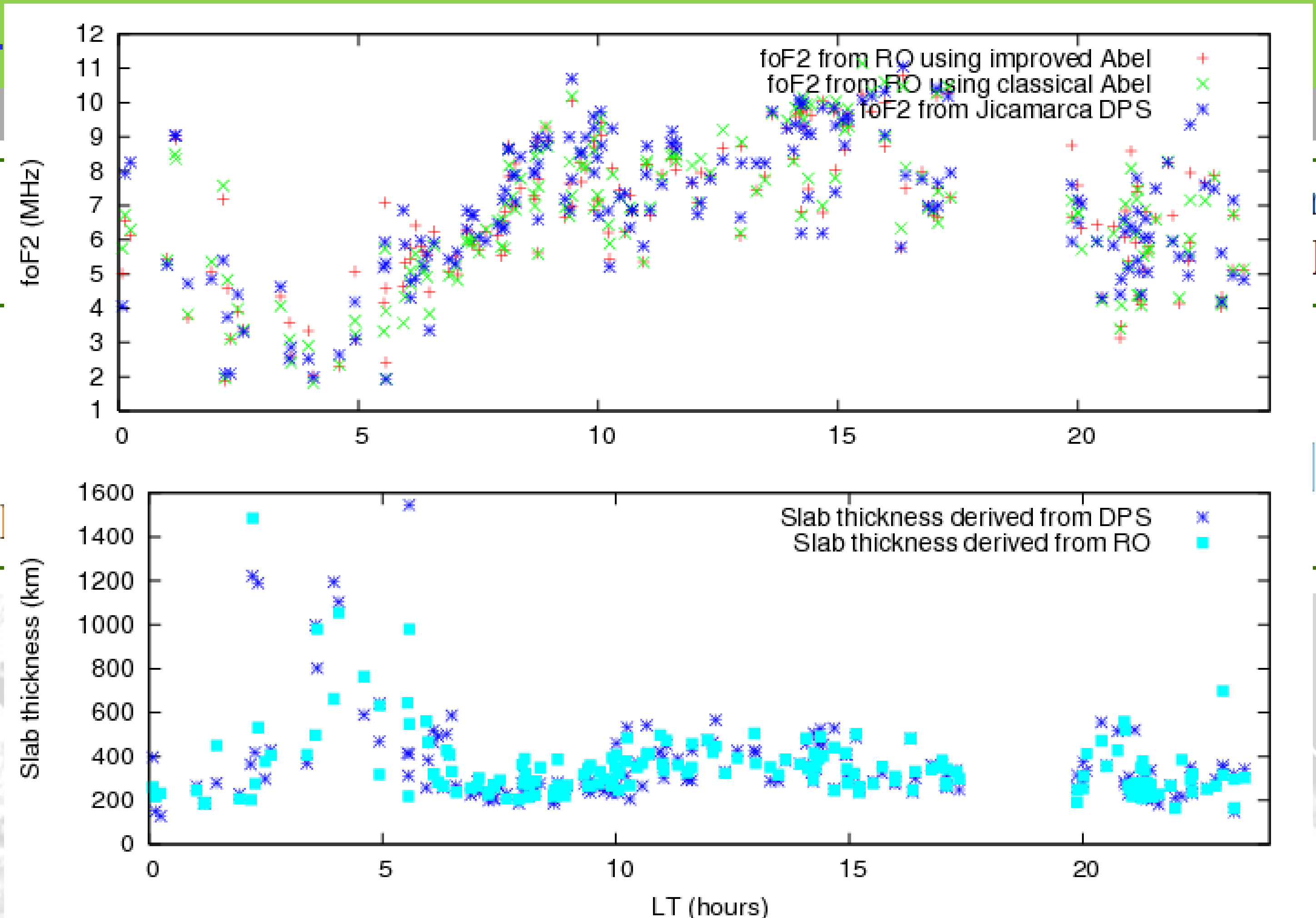
foF2 comparisons

Manually calibrated density profiles from Jicamarca DPS:
- Spatial co-location (+/- 3 degrees)
-



rsion
MS %]

Day
D&D
Night
Global

LT effect on NmF2: Day

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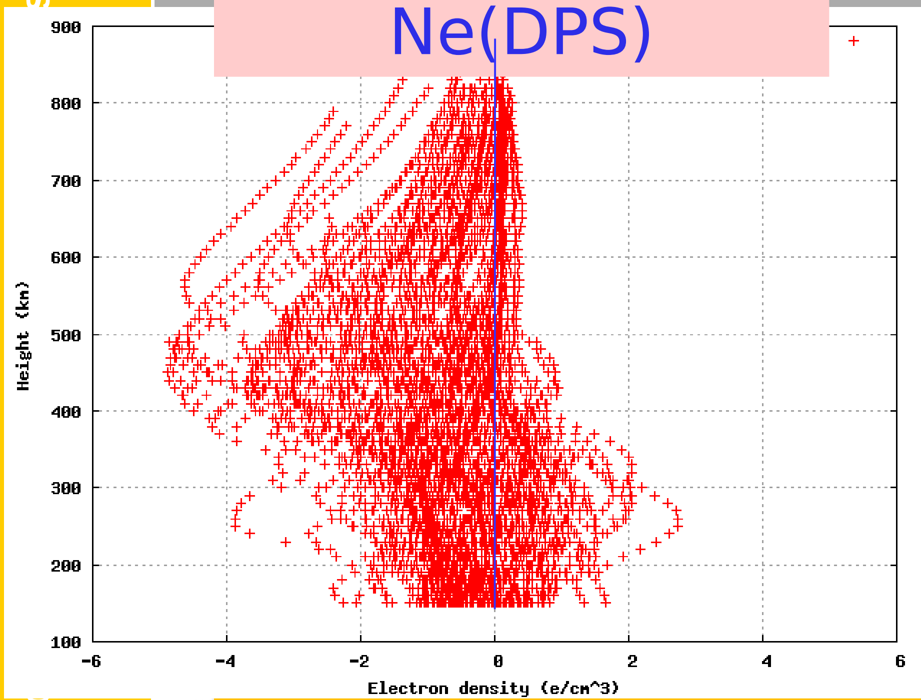
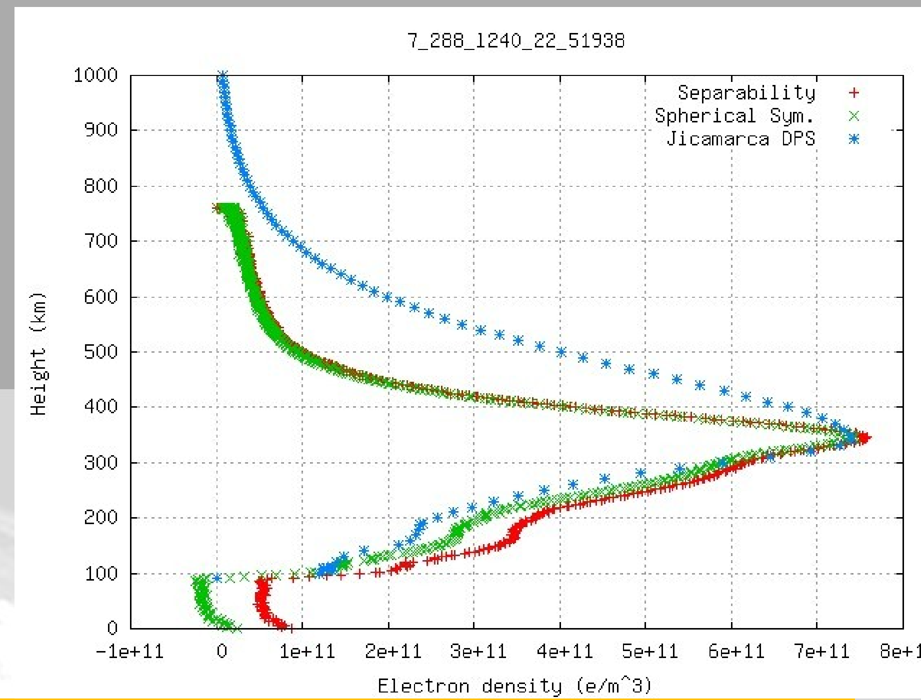
Improved Abel

Ne(F-3/C) – Ne(DPS)



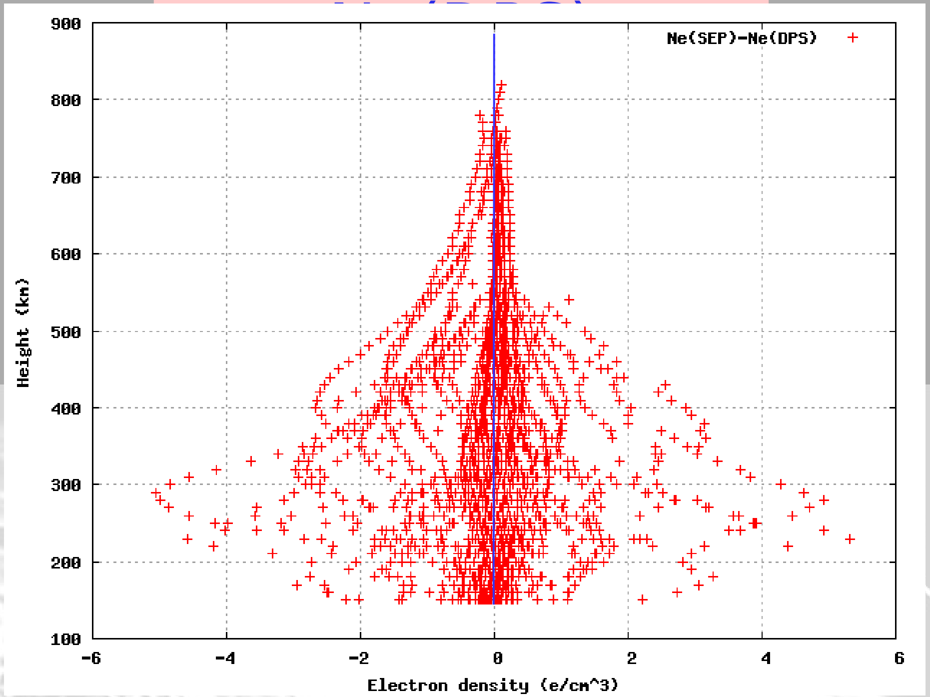


A clear underestimation of the electron density profiles during daytime (LT) from F3-C data would be derived observing figure corresponding to Ne(F-3/C)-Ne(DPS). Nevertheless, the DPS topside Ne is overestimated → need to revisit the

LT effect on NmF2: Night

Improved Abel

Ne(F-3/C) –



Even distribution of the differences btw the electron density profiles derived from F3-C data and Jicamarca DPS measurements during nighttime (LT)

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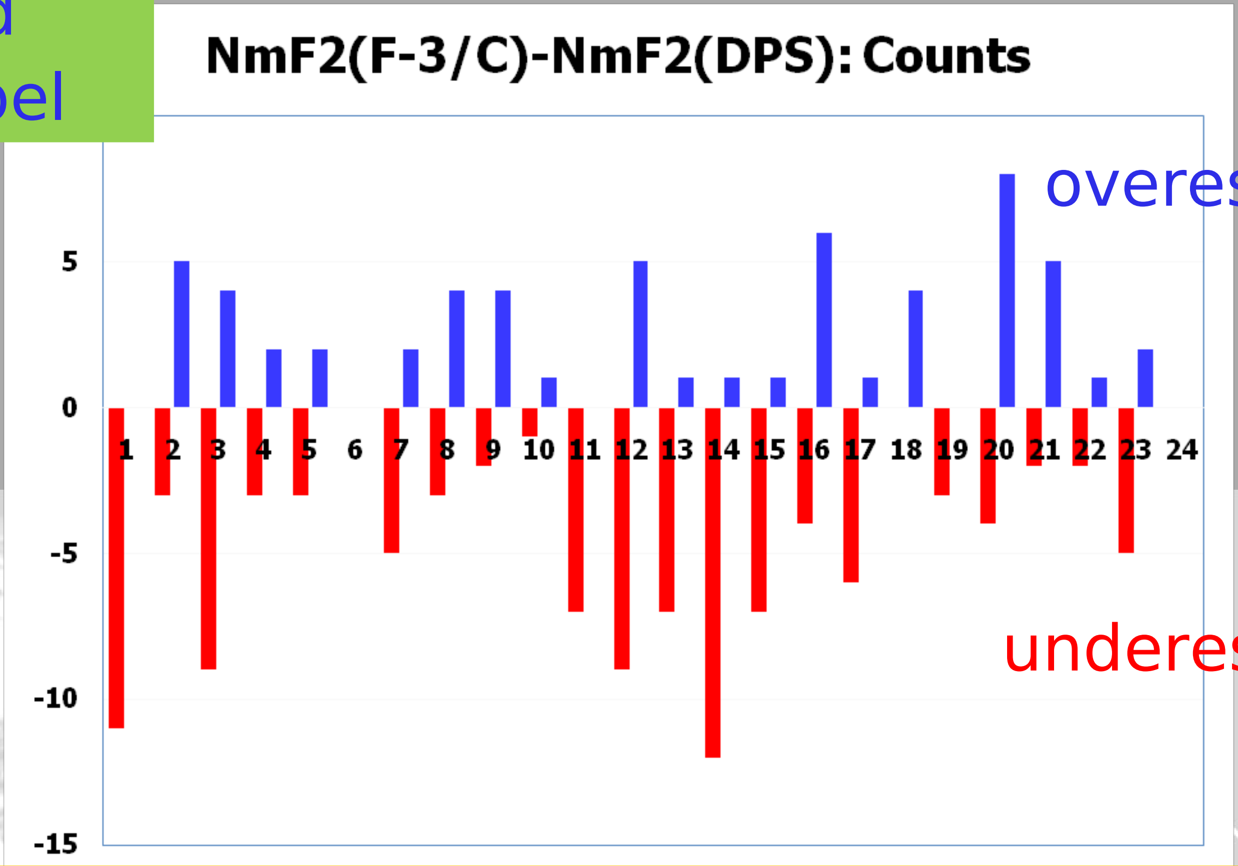
LT effect on NmF2

Improved Abel



overestimation

underestimation

Comparison of the values of the electron density peaks btw the electron density profiles derived from F3-C data and Jicamarca DPS measurements

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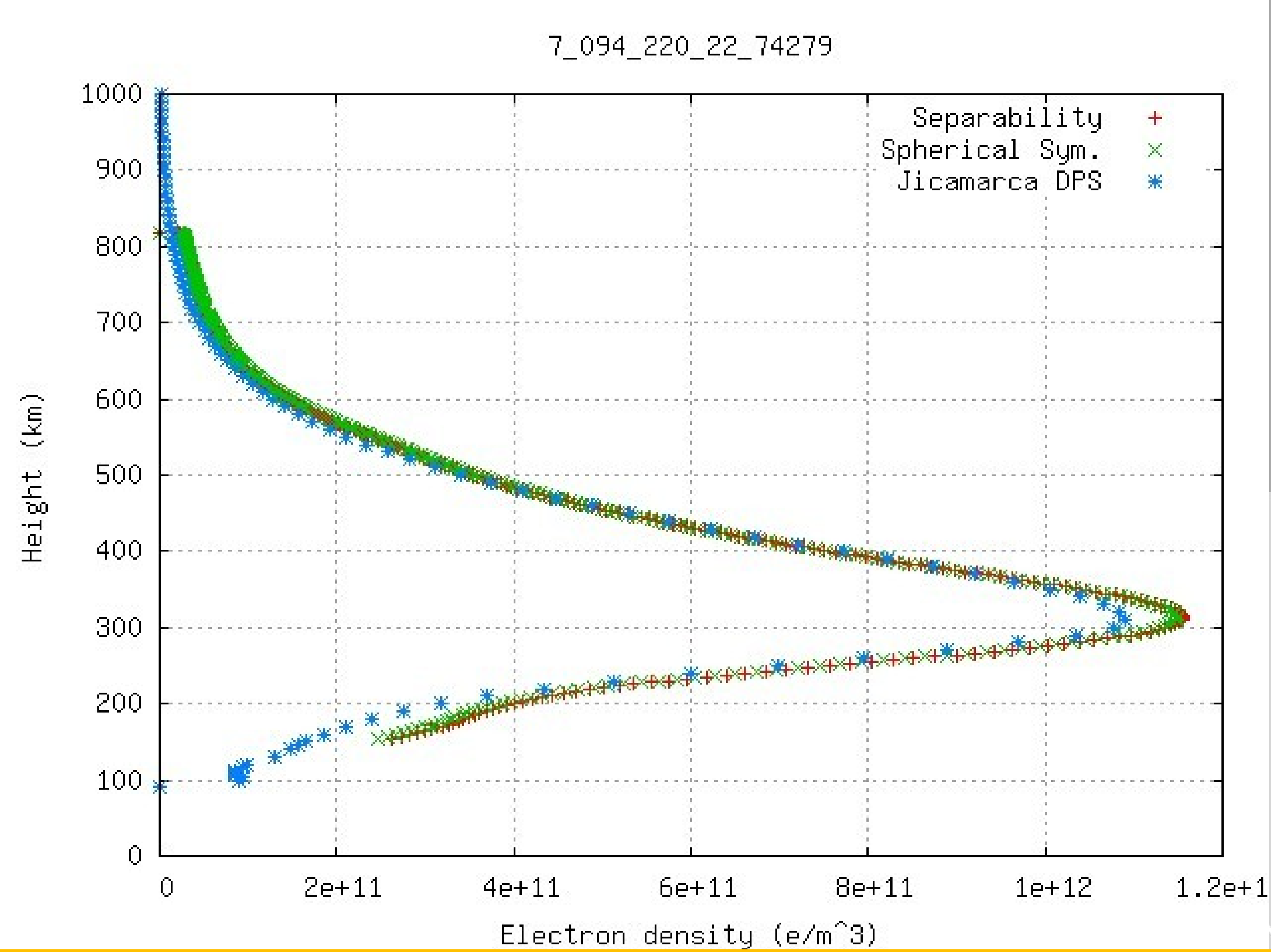
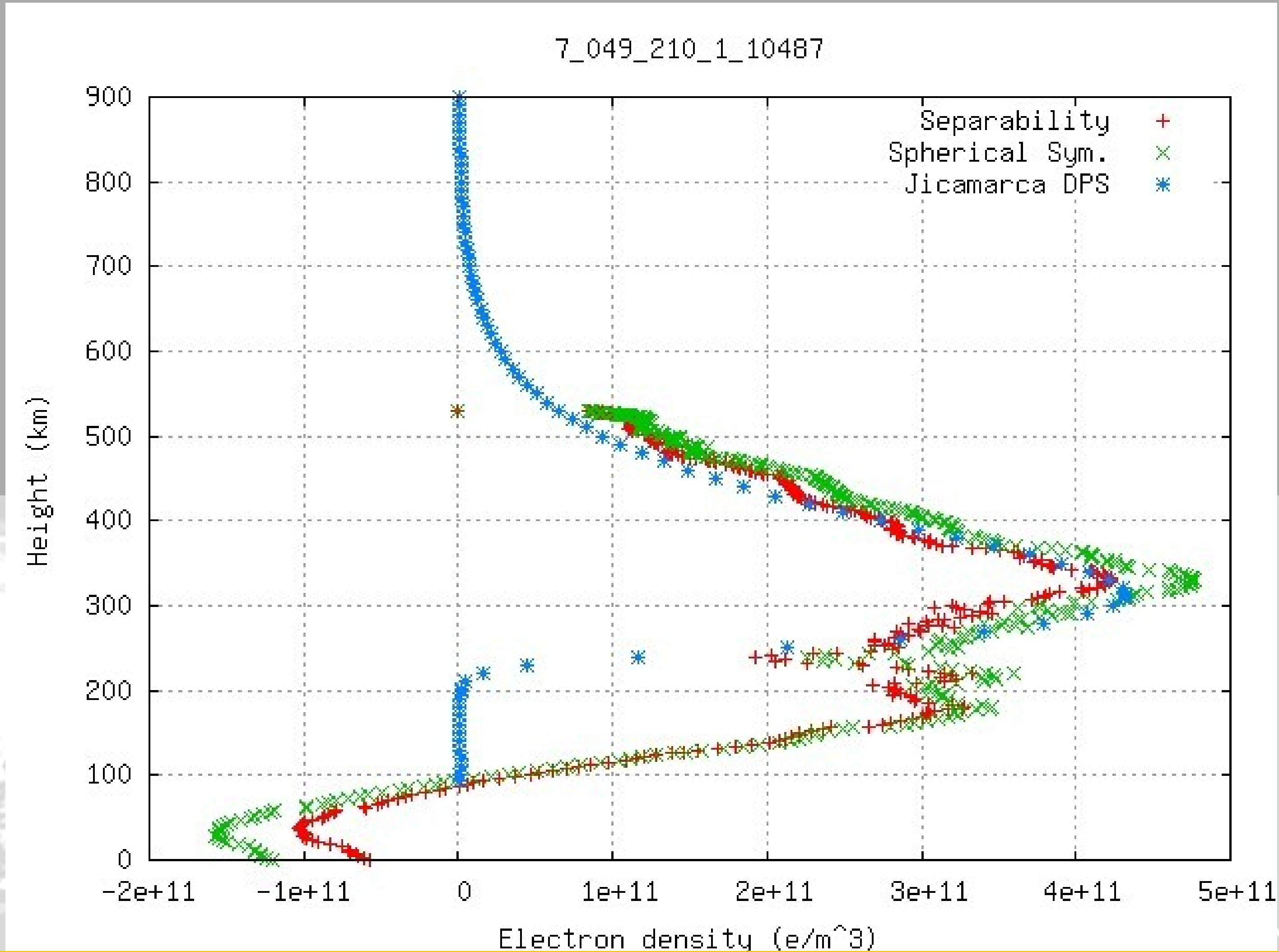
Some interesting profiles at Jicamarca



Example of agreement between all measurements: F-3/C derived profiles (classic + impr.) and Jicamarca DPS data

Some interesting profiles at Jicamarca



The DPS does not provide any information regarding the behavior of the density profile below the foF2 peak

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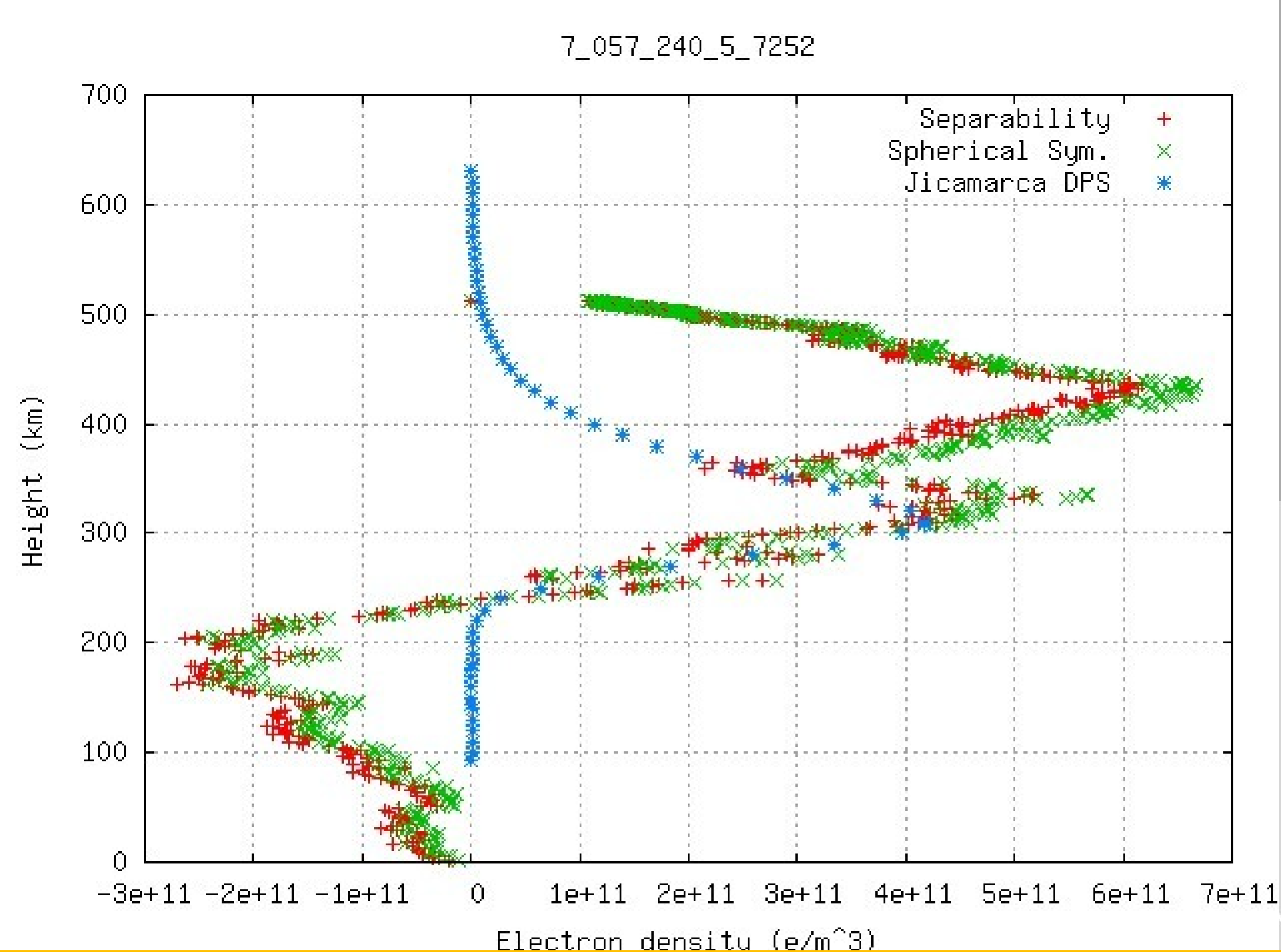
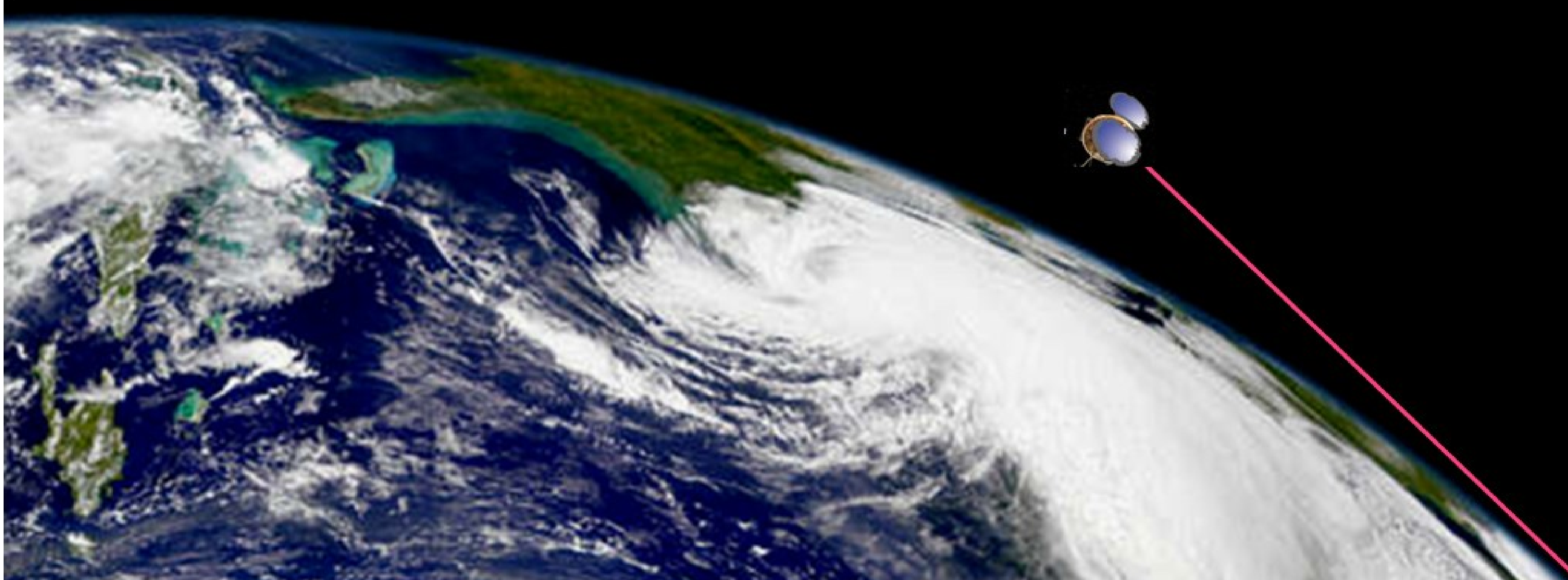
Some interesting profiles at Jicamarca



The DPS does not provide any information regarding the secondary peak at F-layer: F3 peak referred in literature

Upper ionospheric estimation



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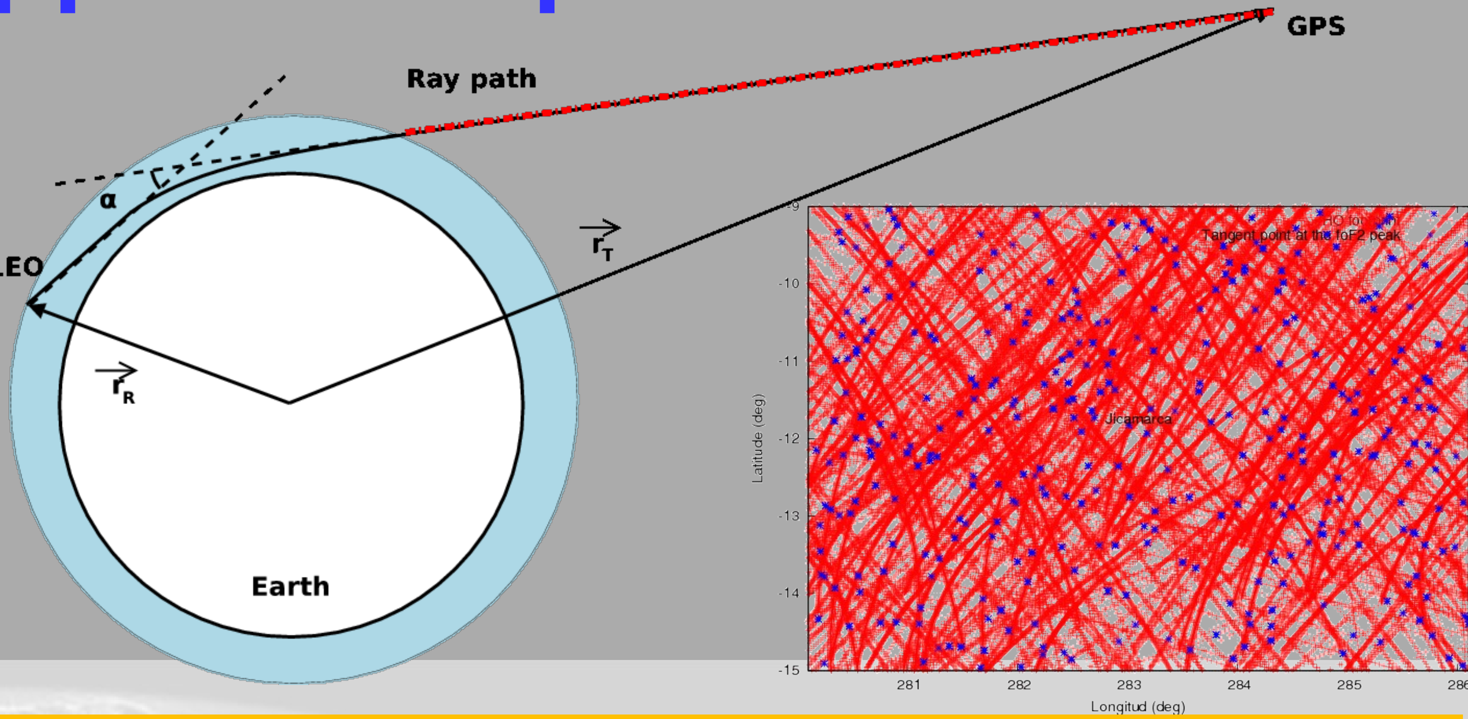
Upper ionosphere estimation



- No upper ionospheric contribution considered √
- Climatological model
- Extrapolation scheme
- Using the separability nature of the electron

Experiment: One year data for 2007 of co-located DPS measurements at Jicamarca vs. FORMOSAT-3/COSMIC RO derived profiles of electron density

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Upper ionosphere estimation

- No upper ionospheric contribution considered √
- Climatological model: NeQuick √
- Extrapolation scheme
- Using the separability nature of the electron

No upper Ne

	Nr. comp.	Improved Abel inversion Bias +/- σ [Rel. RMS %]	Classical Abel inversion Bias +/- σ [Rel. RMS %]
Day	102	-0.2 +/- 0.4 [6.3]	-0.1 +/- 0.4 [6.4]
D&D	22	0.1 +/- 0.5 [9.2]	-0.1 +/- 0.5 [9.7]
Night	15	0.0 +/- 0.4 [8.8]	-0.1 +/- 0.6 [13.3]
Global	139	-0.1 +/- 0.4 [6.9]	-0.1 +/- 0.5 [7.4]

NeQuick

	Nr. comp.	Improved Abel inversion Bias +/- σ [Rel. RMS %]	Classical Abel inversion Bias +/- σ [Rel. RMS %]
Day	93	-0.1 +/- 0.4 [6.0]	0.0 +/- 0.5 [6.5]
D&D	20	0.0 +/- 0.5 [8.4]	-0.1 +/- 0.6 [11.4]
Night	18	0.0 +/- 0.4 [9.7]	0.0 +/- 0.6 [13.0]
Global	131	0.0 +/- 0.4 [6.7]	0.0 +/- 0.5 [7.8]

Upper ionosphere estimation

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- No upper ionospheric contribution considered √
- Climatological model: NeQuick √
- Extrapolation scheme: Exponential decay √
- Using the separability nature of the electron

No upper Ne

	Nr. comp.	Improved Abel inversion Bias +/- σ [Rel. RMS %]	Classical Abel inversion Bias +/- σ [Rel. RMS %]
Day	102	-0.2 +/- 0.4 [6.3]	-0.1 +/- 0.4 [6.4]
D&D	22	0.1 +/- 0.5 [9.2]	-0.1 +/- 0.5 [9.7]
Night	15	0.0 +/- 0.4 [8.8]	-0.1 +/- 0.6 [13.3]
Global	139	-0.1 +/- 0.4 [6.9]	-0.1 +/- 0.5 [7.4]

Extrapolation

	Nr. comp.	Improved Abel inversion Bias +/- σ [Rel. RMS %]	Classical Abel inversion Bias +/- σ [Rel. RMS %]
Day	83	-0.2 +/- 0.4 [6.0]	-0.1 +/- 0.4 [6.2]
D&D	12	0.1 +/- 0.5 [9.1]	-0.1 +/- 0.5 [9.4]
Night	14	0.2 +/- 0.3 [8.1]	0.0 +/- 0.6 [13.5]
Global	109	-0.1 +/- 0.4 [6.6]	-0.1 +/- 0.5 [7.5]

Upper ionosphere estimation

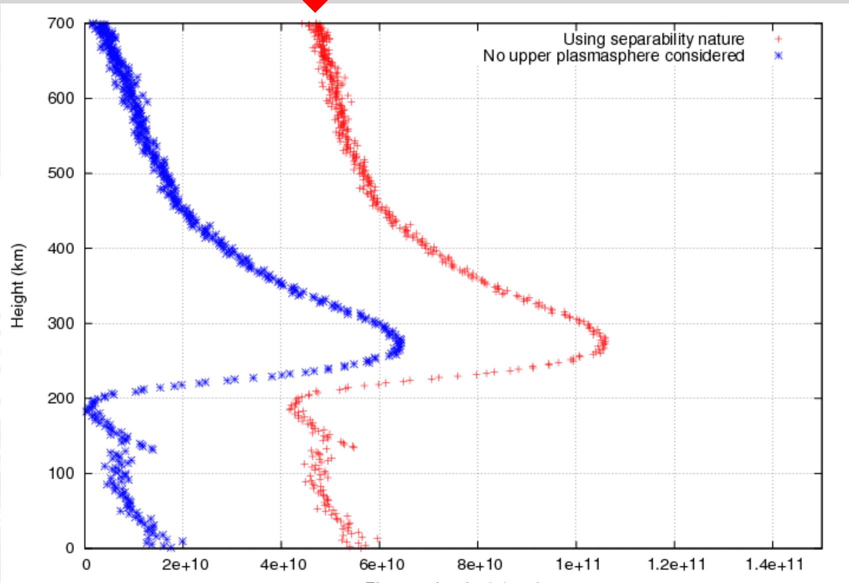
- No upper ionospheric contribution considered √
- Climatological model: NeQuick √
- Extrapolation scheme: Exponential decay √
- Using the separability nature of the electron density

$$N_e(LT,LAT,H) = VTEC(LT,LAT)\cdot F(H)$$

$$F(h_1)=\frac{1}{h_1-h_n}\left[1-\sum_{i=1}\Delta F_i\cdot(h_{i+1}-h_n)\right]$$

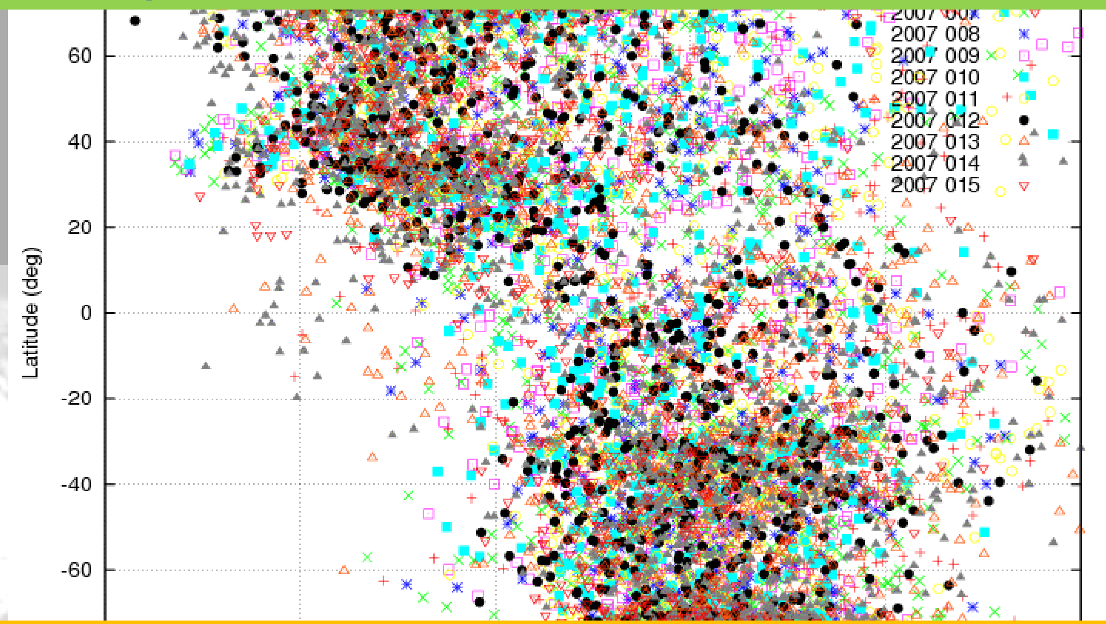
$$\int_{h_n} F(h)\,dh=1$$

$$F(h_1)=0$$



Upper ionosphere estimation

When using the Improved Abel Transform to retrieve electron densities from RO events, the value of the integral of the shape function along the RO path should theoretically be 1 (in practice, a value close to 1)



Surprisingly, for the first processed FORMOSAT-3/COSMIC data belonging to the first two weeks of 2007, with more than 17.000 solved and accepted occultations, these integral values

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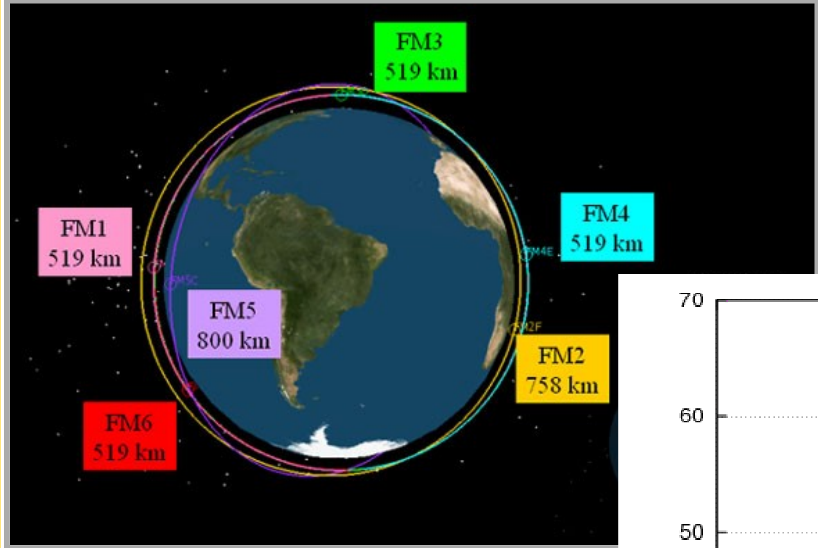
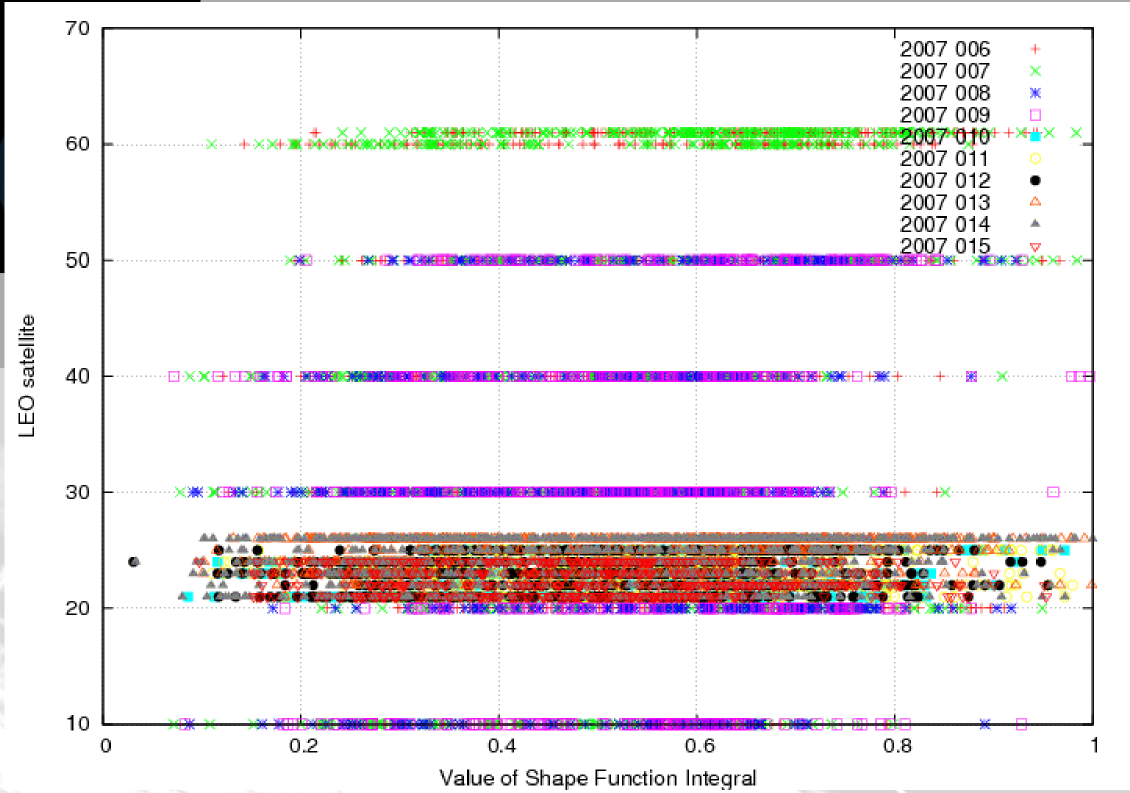
Upper ionosphere estimation

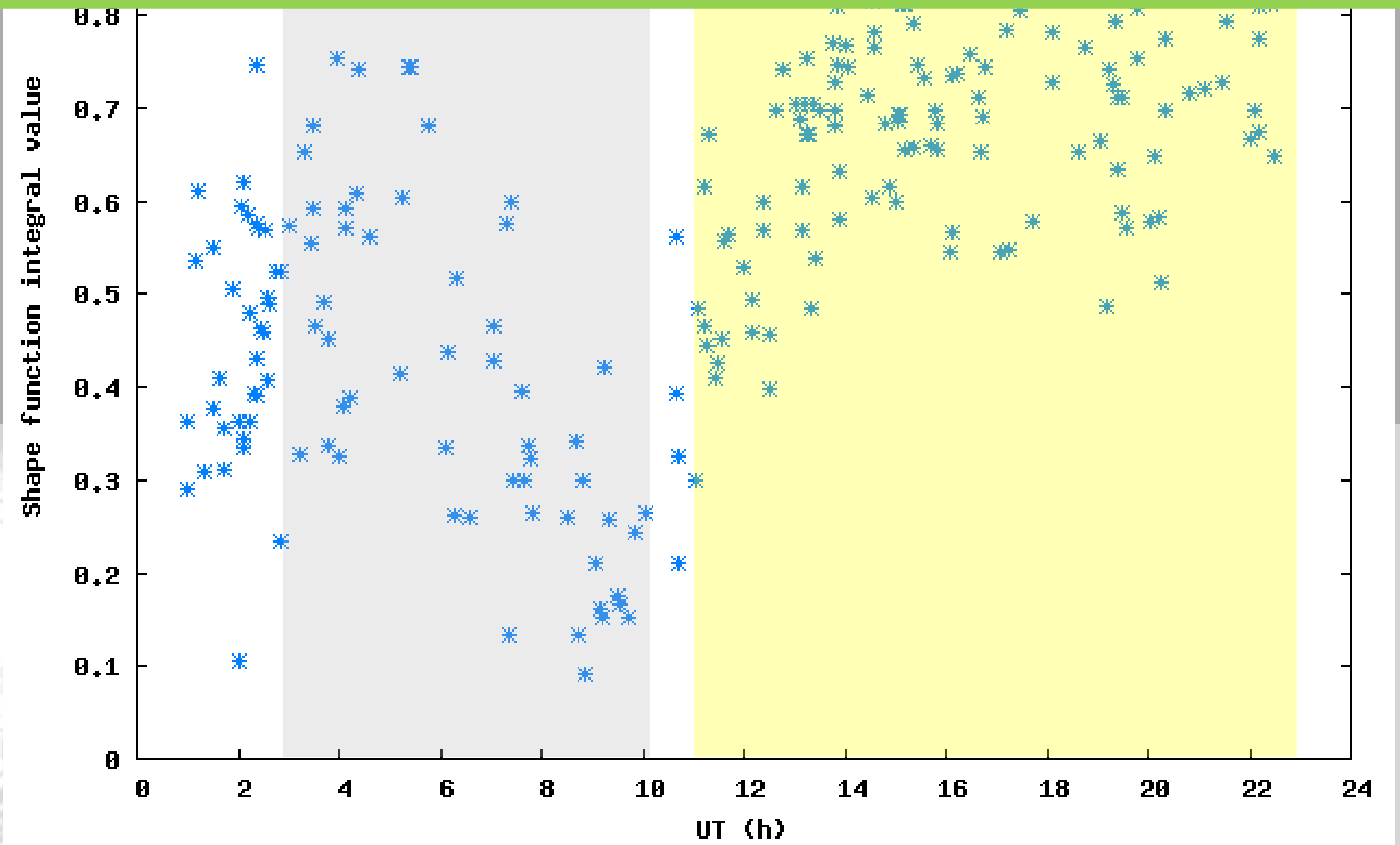




Distribution of the values of the shape function integral taking into account the different LEO spacecrafts.

Upper ionosphere estimation

Since plasmasphere is more important during night, this fraction of VTEC is smaller during night rather than day.



The shape function integral value gives a comparison btw VTEC GPS derived and VTEC RO derived. RO are mainly sensitive to IONO,

Conclusions

The results from this work show:

- Alternative way to calibrate clocks by means of the ionospheric-free combination of carrier phases avoiding double differencing strategies (valid for ionospheric heights).
- Analysis of an Implementation of Separability technique for the retrieval of electron densities from L1 excess phase at a very ionospheric variable location (mitigating the effect of co-location). The Improved Abel transform provides more accurate determination of foF2.
- Several strategies to account for the upper ionospheric content have been explored.
- It has been shown that Radio Occultations are basically sensitive to the ionosphere rather than the plasmasphere. Hence, the electron content accounts for the iononospheric contribution.

Thank you

Gràcies!