Assessment of foF2 and hmF2 monthly median variability using COSMIC radio-occultation profiles

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Motivation

This work aims to be a contribution toward developing an empirical model of the standard deviation of instantaneous values from the monthly mean of the NmF2 and hmF2 parameters computed by the IRI model.

Error estimation procedure

The error estimation procedure relies upon comparing the modeled values to the ones retrieved from FormoSat-3/COSMIC radio-occultation profiles (ROP):

$$\Delta = \Omega_M - \Omega_R$$

where

Ω = *either* N_mF2 *or* h_mF2 *parameter;*

Ω_M = *modeled value computed with IRI, i.e.: monthly median value of* f_0F2 *or* $M_{3000}F2$ *computed according to the ITUR recommendation, and converted to* N_mF2 *or* h_mF2 *with the Bilitza formula (ref. 1 – 7);*

Ω_R = *retrieved value, i.e.: instantaneous values of* N_mF2 *or* h_mF2 *retrieved from the ROP using the procedure that will be described in the next viewgraph.*

Procedure for retrieving NmF2 and hmf2 from ROP

ROP downloaded from CDAAC database at UCAR (http://cdaac-www.cosmic.ucar.edu/cdaac/products.html) are individually fitted with the La Plata Ionospheric Model (LPIM) (ref. 7).

LPIM uses 3 α-Chapman layers to represent the electron density as function of the height in the E, F1 and F2 layer, and a vary-Chapman function in top-side.

LPIM is parameterized as a function of the electron density, height, and scale height of the F2 layer.

A re-weighted Least Squares algorithm (based on the 'bisquare' weighting function) is used for down-weighting unreliable data (occasionally, entire ROP) and for retrieving the model parameters and their variances.

We tuned the algorithm until it did not accept data that must be indisputably discarded and did not discard measurements that must be indubitably accepted.

These procedure assigned negligible weights (lower than one tenth of the unity of weight) to approximately 20% of the data (including complete ROP).

About half of cases coincided with data (and complete ROP) that are indisputably unrealistic; in the other cases, it is difficult to ascertain whether the misalignment between data and LPIM should be attributed to problems in the data, LPIM or both.

Working hypothesis

The difference between the IRI and retrieved value can be splitted in two components:

$$\Delta = \varepsilon_M + \varepsilon_R$$

ε_R: *error of the retrieved value* → *can be modeled as a randomly distributed variable with zero mean and variance* $\mathrm{var}(\varepsilon_R)$

ε_M: *error of the modeled values*

can be spitted in two components:

$$\varepsilon_M = \varepsilon_B + \varepsilon_D$$

ε_D: *day-to-day deviation w.r.t. the monthly mean bias* → *can be modeled as a randomly distributed variable with zero mean and variance* $\mathrm{var}(\varepsilon_D)$

ε_B: *monthly mean constant bias*

Putting all together:

$$\Delta = \varepsilon_B + \varepsilon_D + \varepsilon_R$$

$$\mathrm{mean}(\Delta) = \varepsilon_\mathrm{B}$$

$$\mathrm{var}(\Delta) = \mathrm{var}(\varepsilon_D) + \mathrm{var}(\varepsilon_R)$$

Computational flux diagram

Retrieve Ω_R *and* $\mathrm{var}(\varepsilon_R)$ *instantaneous values from ROP*

Compute Ω_M *monthly median value with IRI*

Compute the $\Delta = \Omega_M - \Omega_R$ *differences*

Estimate the monthly mean model bias $\varepsilon_\mathrm{B} = \mathrm{mean}(\Delta)$

Estimate the variance of the differences $\mathrm{var}(\Delta)$

Estimate the variance of the day-to-day deviation $\mathrm{var}(\varepsilon_\mathrm{D}) = \mathrm{var}(\Delta) - \mathrm{var}(\varepsilon_\mathrm{R})$

Numerical procedure

The monthly mean bias and the variance of the day-to-day deviation are described in terms of 5 coordinates:

$$\varepsilon_B = f\left(m, IG, A_p, LT, \mu\right)$$

$$\operatorname{var}\left(\varepsilon_D\right) = g\left(m, IG, A_p, LT, \mu\right)$$

month — *solar activity* — *geomagnetic perturbation* — *local time* — *modip latitude*

The computed differences $\Delta = \Omega_M - \Omega_R$ *are binned into a 5-D grid and the statistical parameters are computed within each beam:*

$$\varepsilon_B = \frac{1}{n}\sum \Delta \qquad \operatorname{var}\left(\varepsilon_D\right) = \frac{1}{n-1}\sum\left(\Delta - \varepsilon_B\right)^2 - \operatorname{var}\left(\varepsilon_R\right)$$

The following girding criteria has been applied in this research:

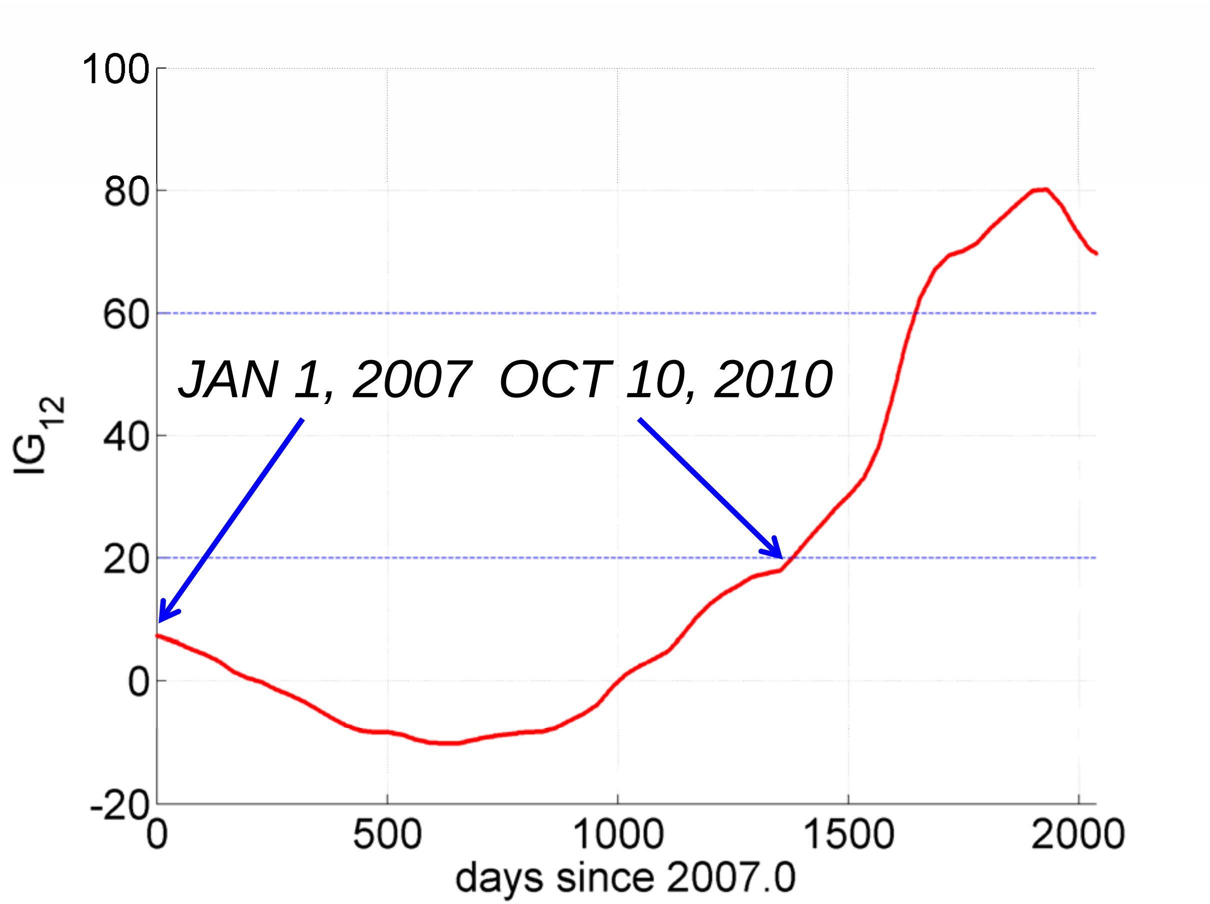
Low solar activity → row IG_{12}; *Quiet geomagnetic conditions* → row A_p

Param	From	To	Step	Param	From	To	Step
m	1	12	1	LT	-1^h	23^h	2^h
IG_{12}	-20	20	40	μ	-60^o	60^o	10^o
A_p	0	15	15				

Dataset

ROP downloaded from CDAAC database at UCAR (http://cdaac-www.cosmic.ucar.edu/cdaac/products.html)

from January 1, 2007 to October 10, 2010



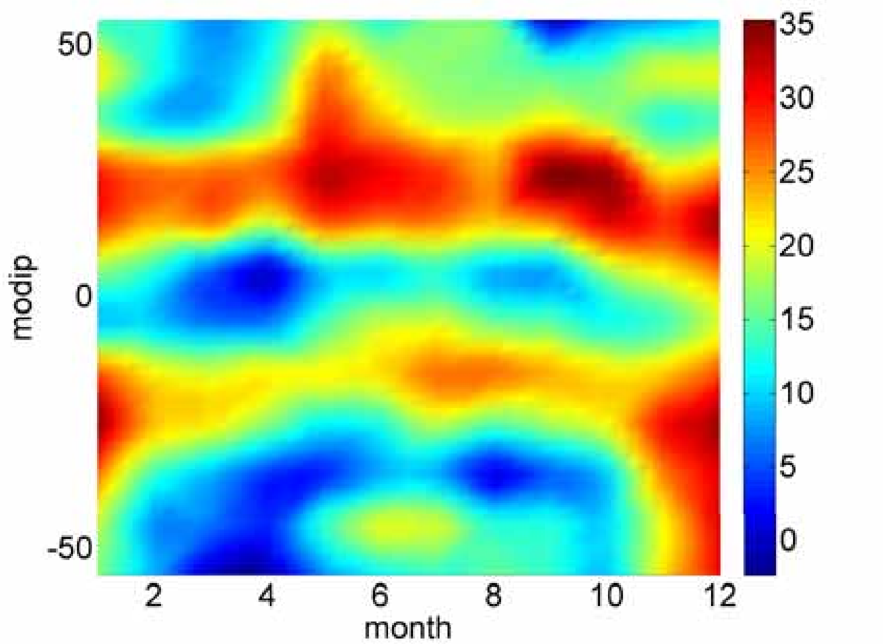
Results for NmF2 at LT 11 - 13

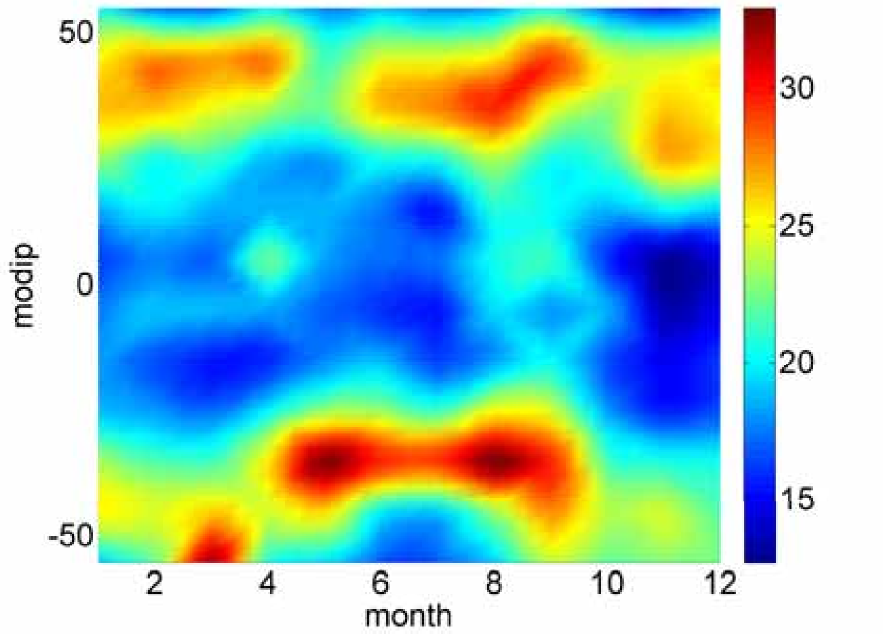
Low Solar Activity (-20 < IG_12 < 20)

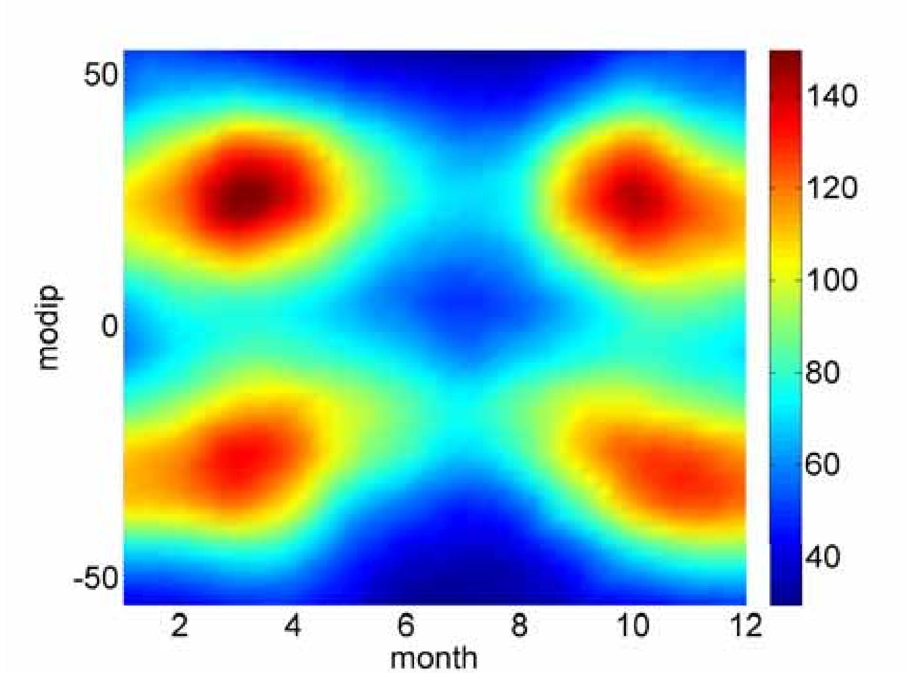
Quiet Geomagnetic Conditions (Ap <15)

Monthly mean model bias (% of the IRI value)

iance of the day-to-day deviation (% of IRI value)







NmF2 computed with IRI (10^{10} elect/cm^3)

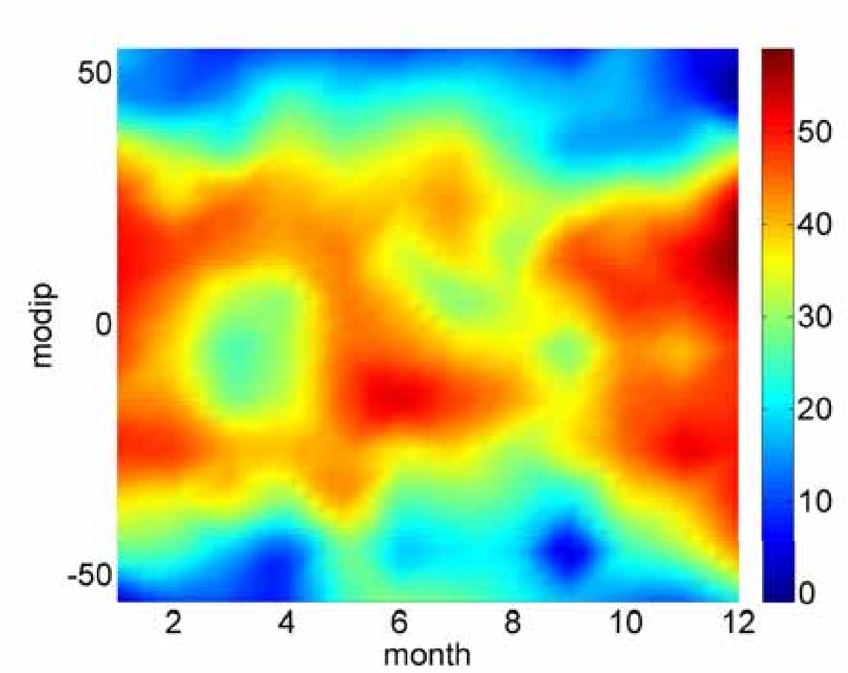
Results for NmF2 at LT 23 - 01

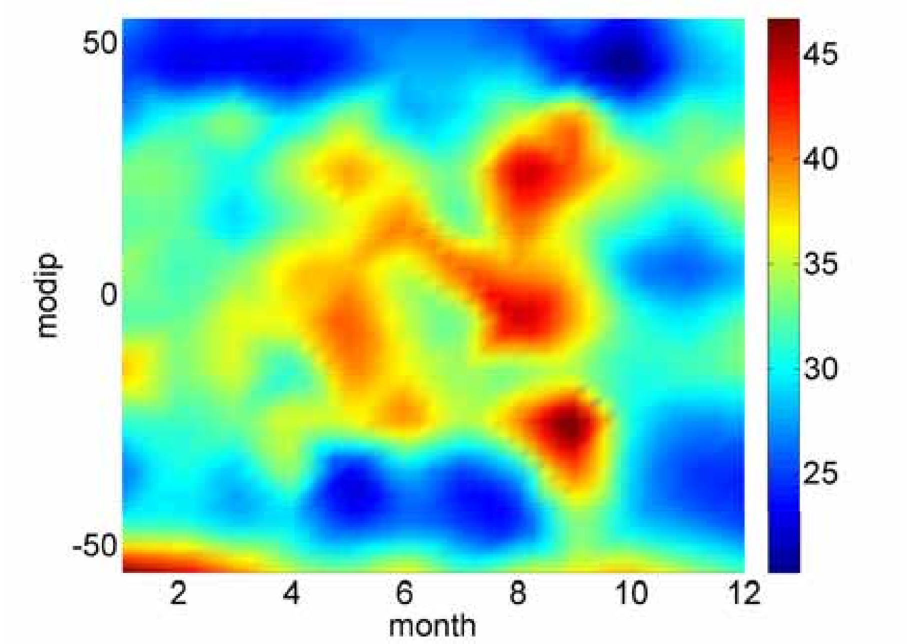
Low Solar Activity (-20 < IG_12 < 20)

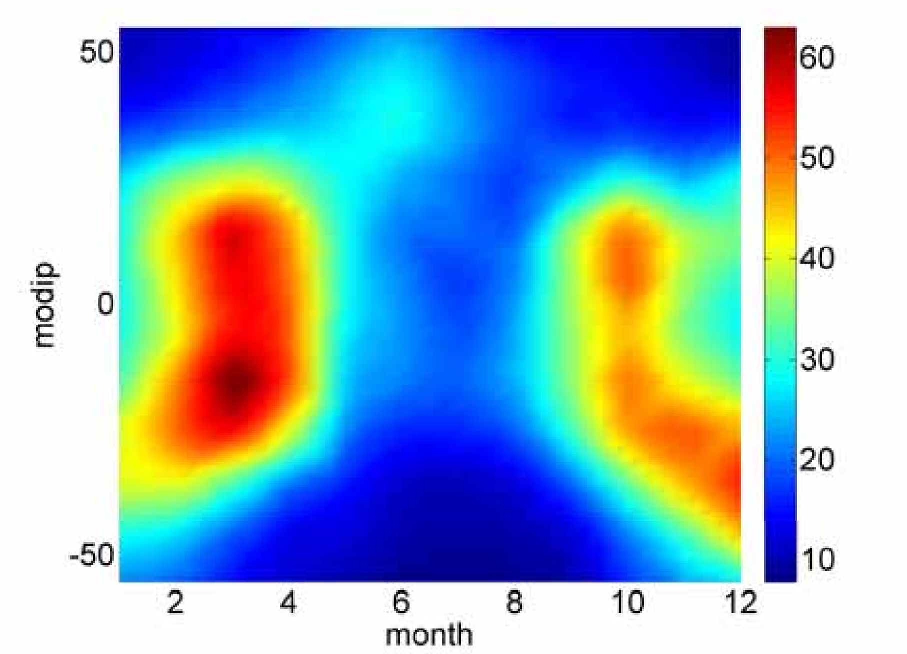
Quiet Geomagnetic Conditions (Ap <15)

Monthly mean model bias (% of the IRI value)

iance of the day-to-day deviation (% of IRI value)







NmF2 computed with IRI (10^{10} elect/cm^3)

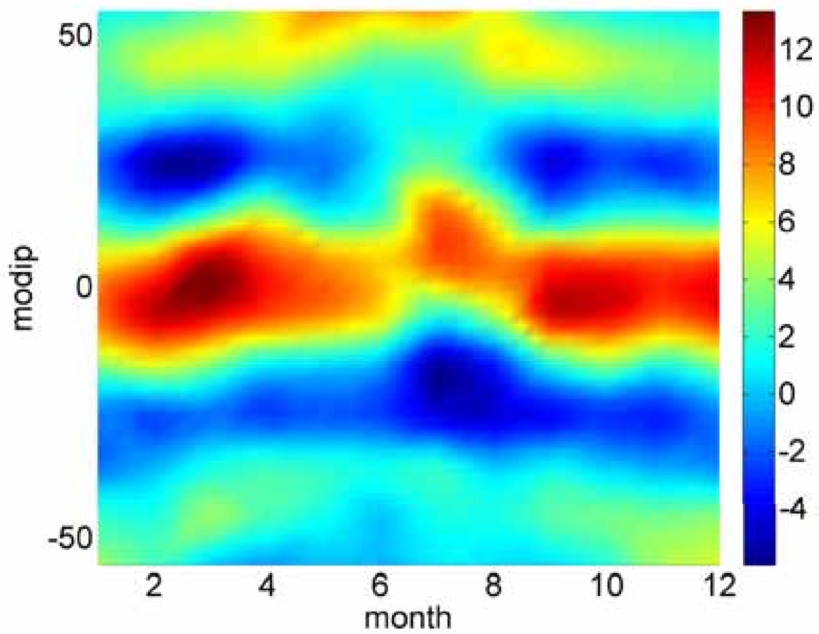
Results for hmF2 at LT 11 - 13

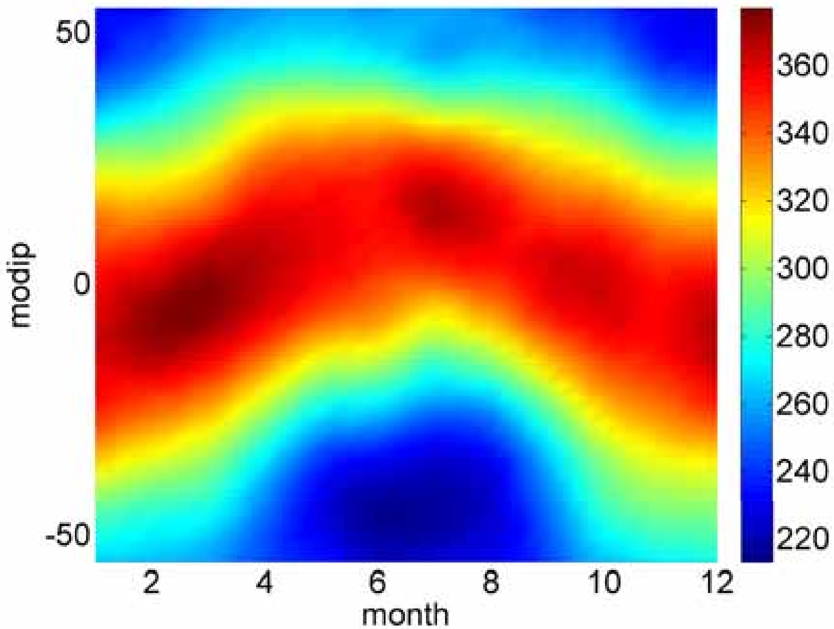
Low Solar Activity (-20 < IG_12 < 20)

Quiet Geomagnetic Conditions (Ap <15)

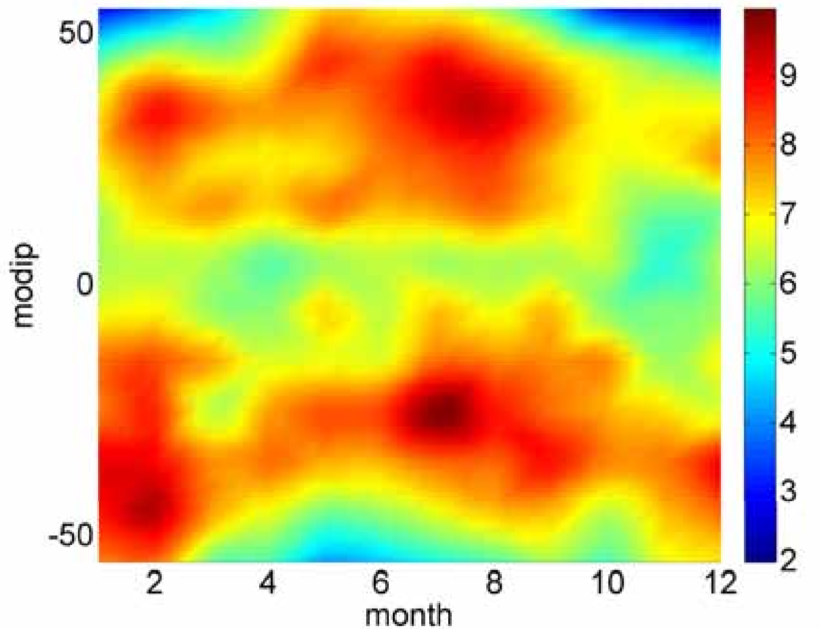
Monthly mean model bias (% of the IRI value)

iance of the day-to-day deviation (% of IRI value)





hmF2 computed with IRI (km)



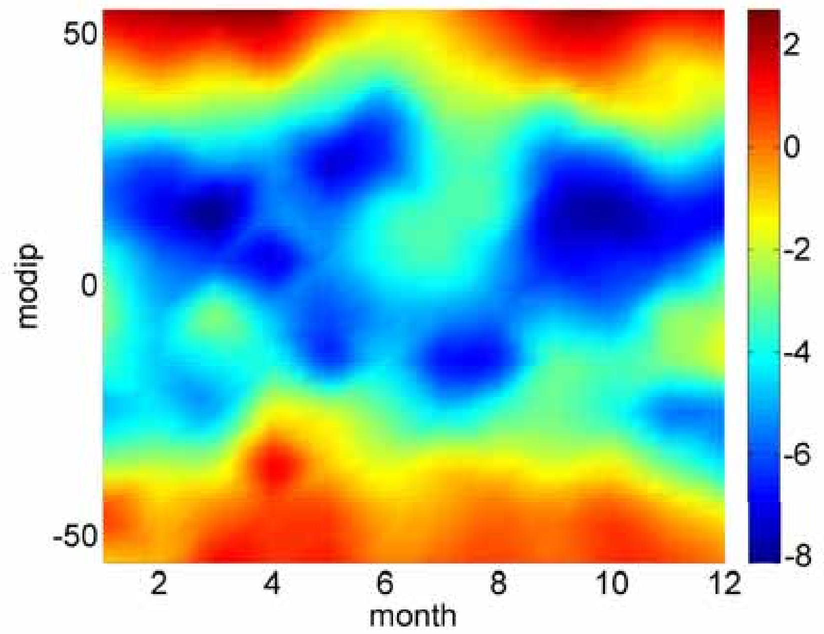
Results for hmF2 at LT 23 - 01

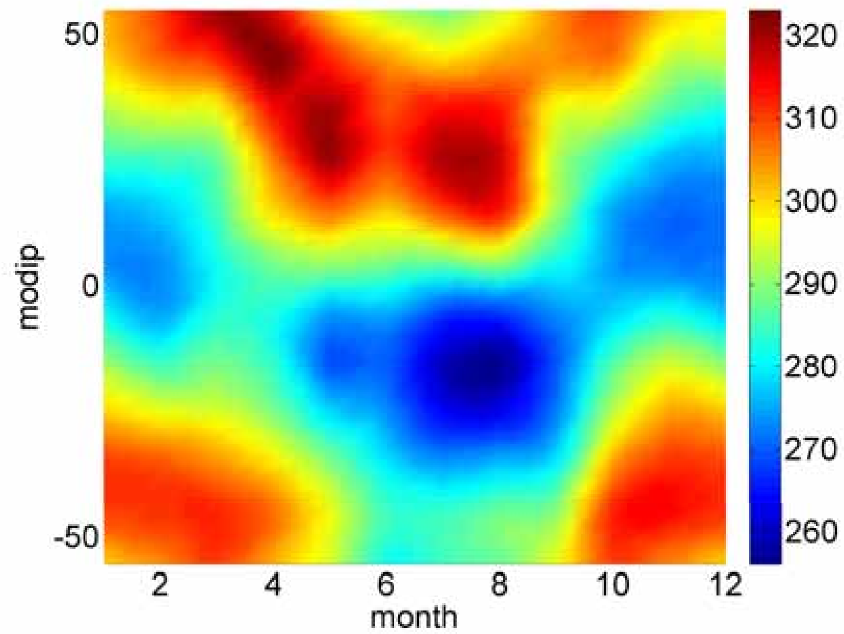
Low Solar Activity (-20 < IG_12 < 20)

Quiet Geomagnetic Conditions (Ap <15)

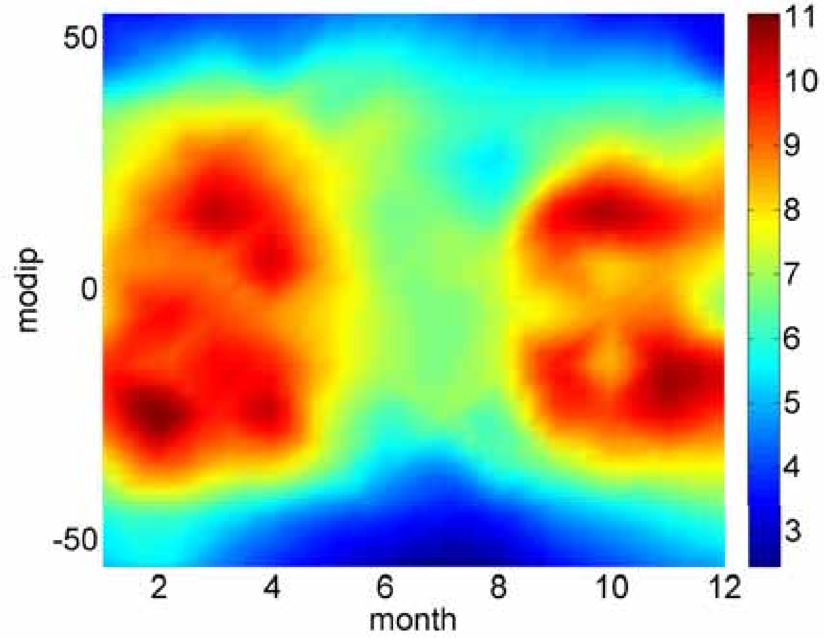
Monthly mean model bias (% of the IRI value)

iance of the day-to-day deviation (% of IRI value)





hmF2 computed with IRI (km)



Summary and conclusion

An attempt was made to establish an empirical model to predict the error of the NmF2 and hmF2 parameters computed by IRI using FormoSat-3/COSMIC radio-occultation profiles.

The differences between the modeled and retrieved parameters was explained in terms of three contributions:

- *errors in the retrieved parameters;*
- *a constant bias in IRI predictions; and*
- *random errors in IRI predictions due to the unaccounted day-to-day variability.*

The errors of the retrieved parameters were estimated using the LPIM model;

The bias and the day-to-day variability of IRI were represented as functions of the month, solar activity, geomagnetic perturbation, modip and local time.

Summary and conclusion

Quiet geomagnetic days in a low solar activity period was analyzed; the obtained results are summarized in the following table:

	NmF2		hmF2	
	bias	day-to-day variation	bias	day-to-day variation
noon time	35%, IRI overestimation; maximums on the crests of the Equatorial Anomaly (EA)	±10% to ±30%; maximums on the northern and southern sides of the EA	-4% to +12%, IRI overestimation over the equator and mid latitude; underestimation over the crest of the EA.	±2% to ±10%; minimum on the modip equator
mid night	50%, IRI overestimation	±20% to ±45%	-8% to +2%, IRI underestimation in general but overestimation at mid latitude	±3% to ±11%; possible modulation by the Annual and Semi-Annual Anomalies

The method employed in this research seems to be appropriated for the intended purpose. Much more work will be needed to establish its validity and reliability.

References

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3. Jones WB, Gallet RM. Representation of diurnal and geographical variations of ionospheric data by numerical methods. ITU Telecomm. J. 29(5), 129-149, 1962.
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5. Jones WB, Obitts DL. Global representation of annual and solar cycle variations of foF2 monthly median 1954-1958. Telecommunications Research Report, OT/ITS/RR3, Washington DC, USA, US Government Printing Office, 1970.
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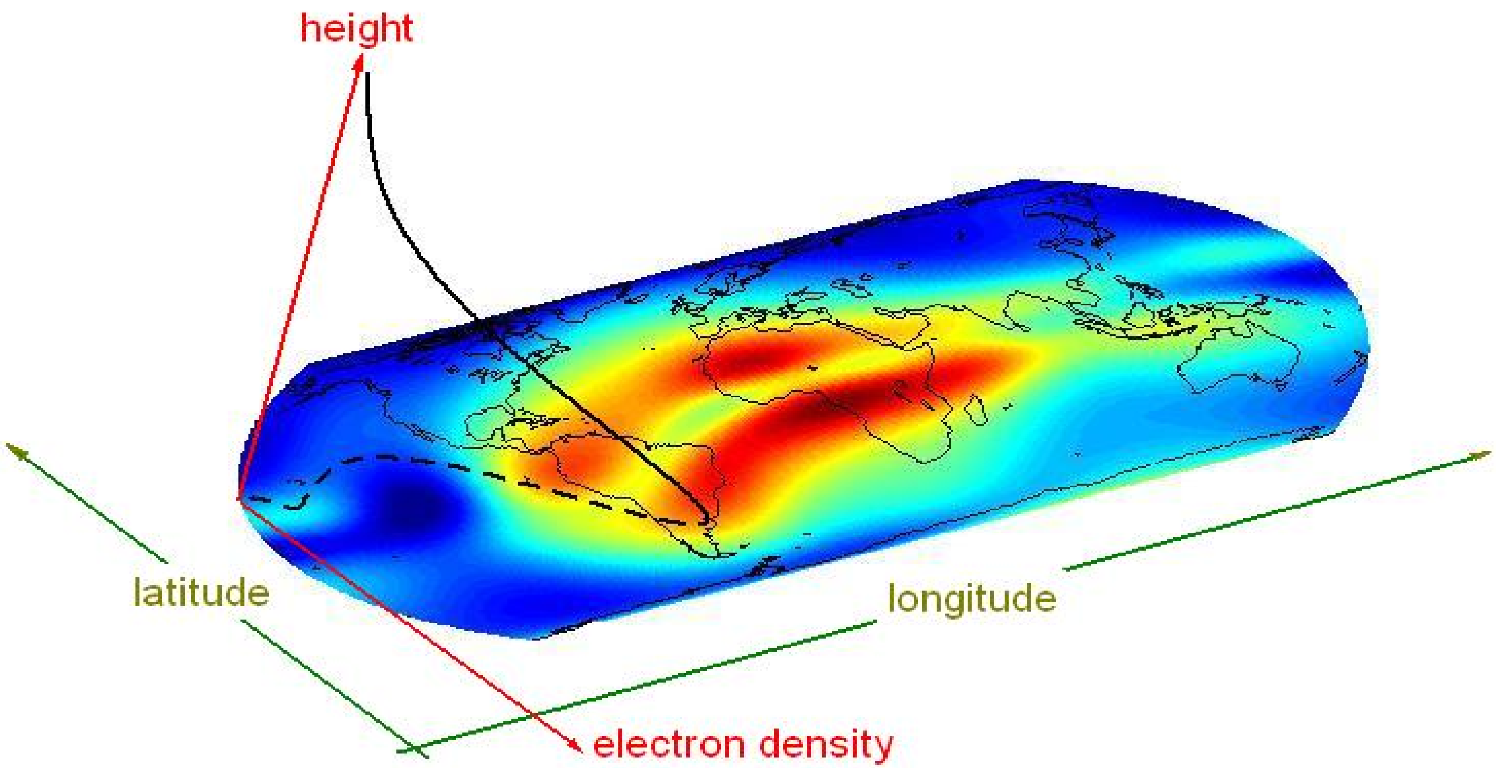
The La Plata Ionospheric Model (LPIM)

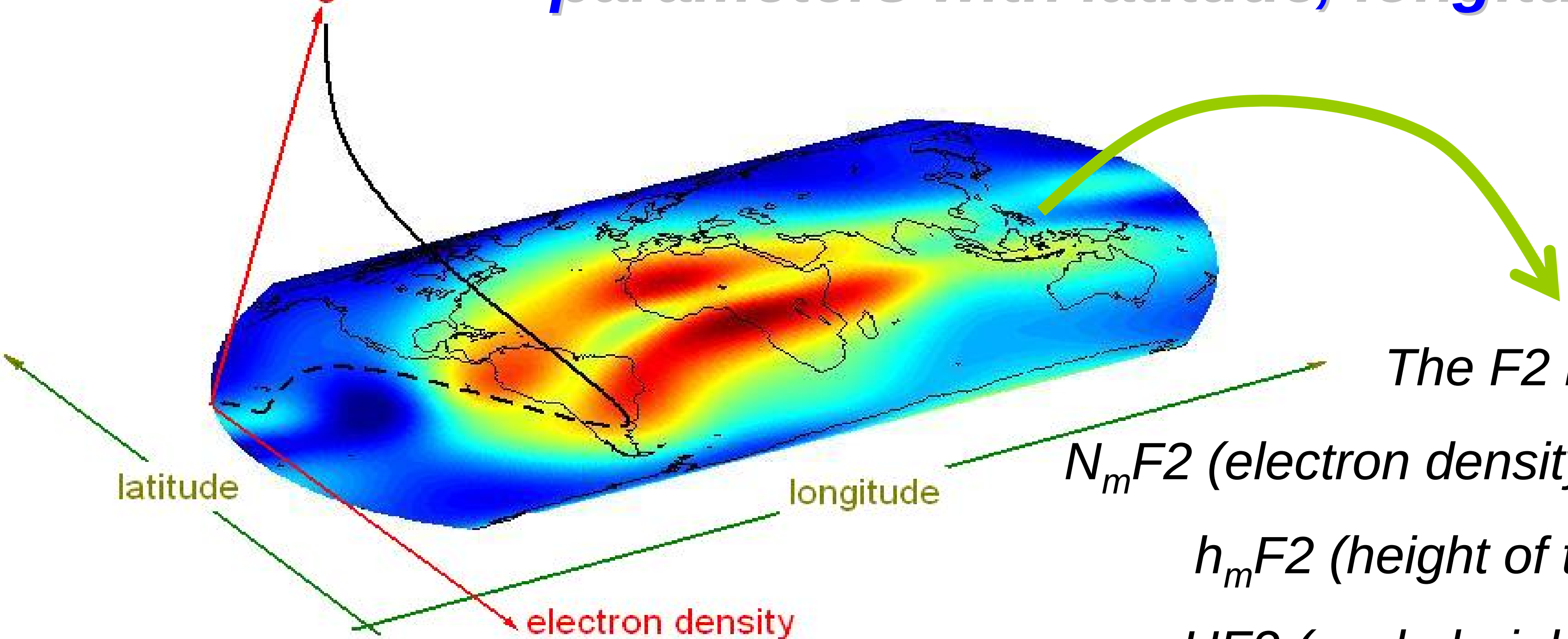
The LPIM version used in this research follow the inspiration of the ***IRI*** *and* ***NeQuick*** *models in the sense that it uses:*

✓*an empirical representation of the geographical (global) and temporal variability of the F2 layer parameters (N_mF2, h_mF2 and HF2);*

✓*a semi-empirical representation of the vertical profile of the ED anchored to the above mentioned F2 layer parameters.*



Global models for the variation of the F2-peak parameters with latitude, longitude and time



The F2 layer parameters:

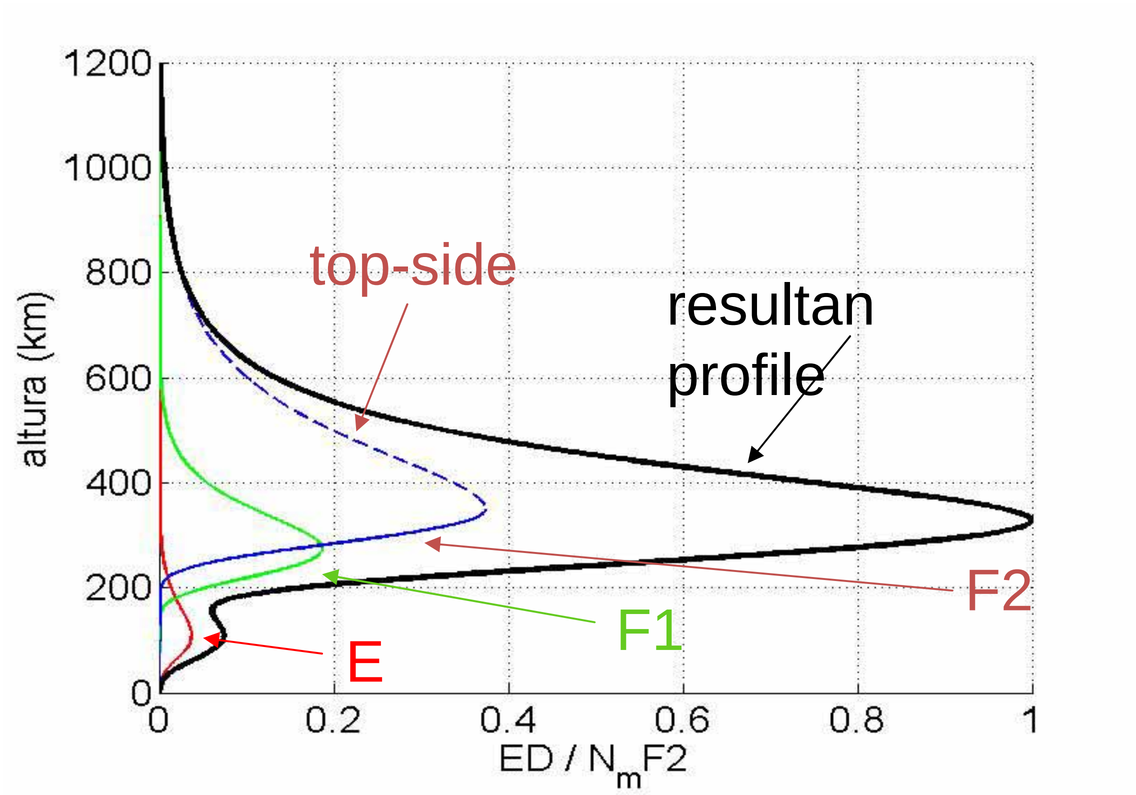
N_mF2 (electron density of the F2 peak);

h_mF2 (height of the F2 peak); and

HF2 (scale height of the F2 layer),

are separately modeled with spherical harmonics expansions dependent on the modip latitude and local time, with time (UT) dependent coefficients:

$$\Omega(\mu,\lambda,t) = a_0(t) + \sum_{l=1}^{L}\sum_{m=1}^{l}\left[a_{lm}(t)\cdot\cos\left(m\cdot\frac{2\pi}{24}\cdot\lambda\right) + b_{lm}(t)\cdot\cos\left(m\cdot\frac{2\pi}{24}\cdot\lambda\right)\right]\cdot P_{lm}(\sin\mu)$$



Model for the variation of the electron density with height

The vertical profile is modeled as a superposition of three Chapman layers for the E, F1 and the bottom-side of the F2 layer and a vary-Chapman layer for the topside.

The main parameters of the E, F1 and for the topside layers are anchored to the parameters of the F2-layer, and modeled in accordance to the ITU-R recommendations.

$$N_e(h) = \sum_{i=1}^{3} N_{m,i} \cdot e^{\frac{1}{2_i}\left[1 - z_i - e^{-z_i}\right]}$$

$$z_i = \frac{h - h_{m,i}}{H_i}$$

$$N_e(h) = N_m F2 \cdot \sqrt{\frac{H(h_m F2)}{H(h)}} \cdot e^{\frac{1}{2}\left[1 - z(h) - e^{-z(h)}\right]}$$

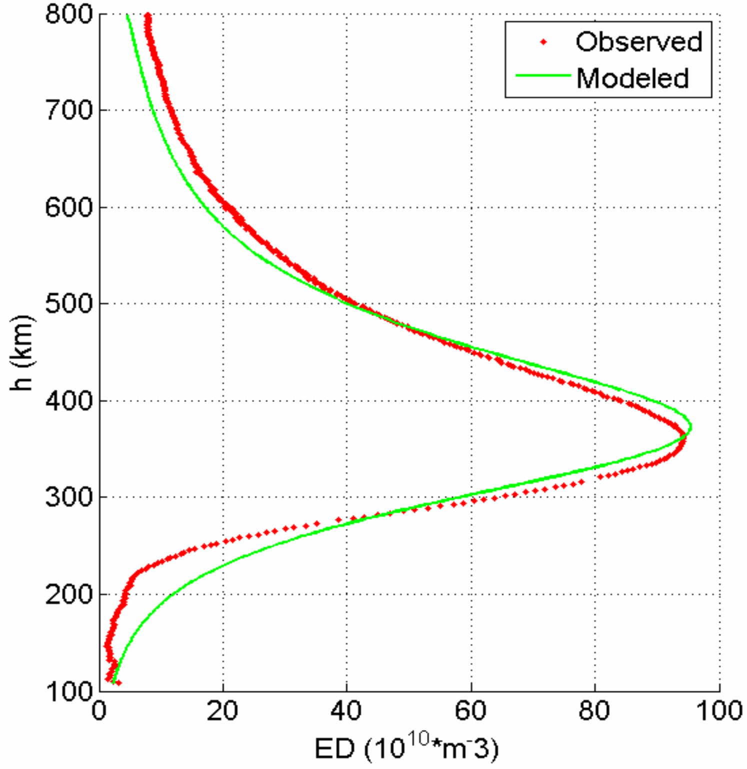
$$z(h) = \int_{h_m F_2}^{h} \frac{d\zeta}{H(\zeta)}$$

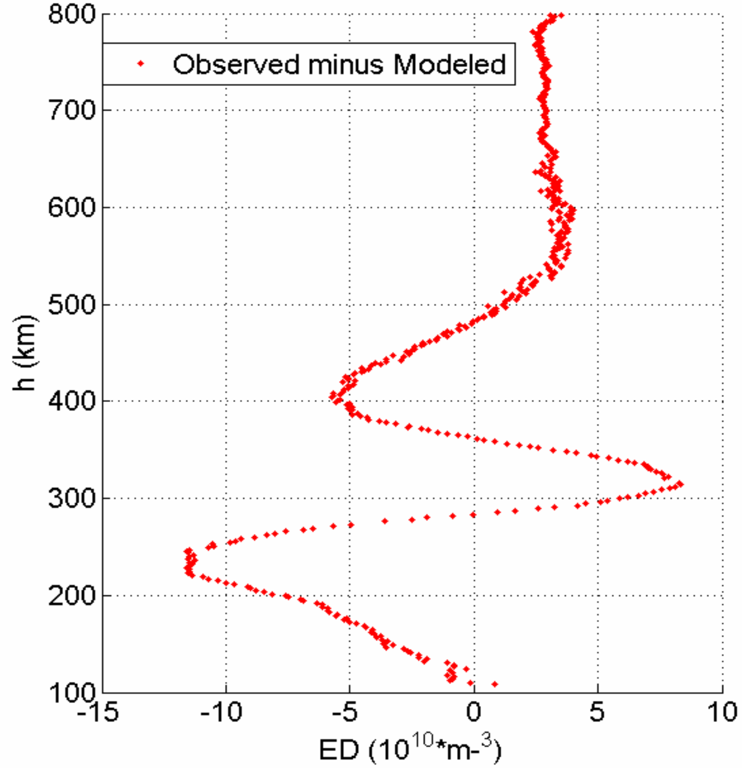
Retrieving technique

The LPIM profile is fitted, by Least Squares, to every measured ROP.

The fitting is done by adjusting the three parameters of the F2 layer: NmF2, hmF2 and HF2.

The Least Squares method allows computing estimate of the parameters along with estimates of their errors (by variance – covariance propagation of the observed minus modeled deviations).



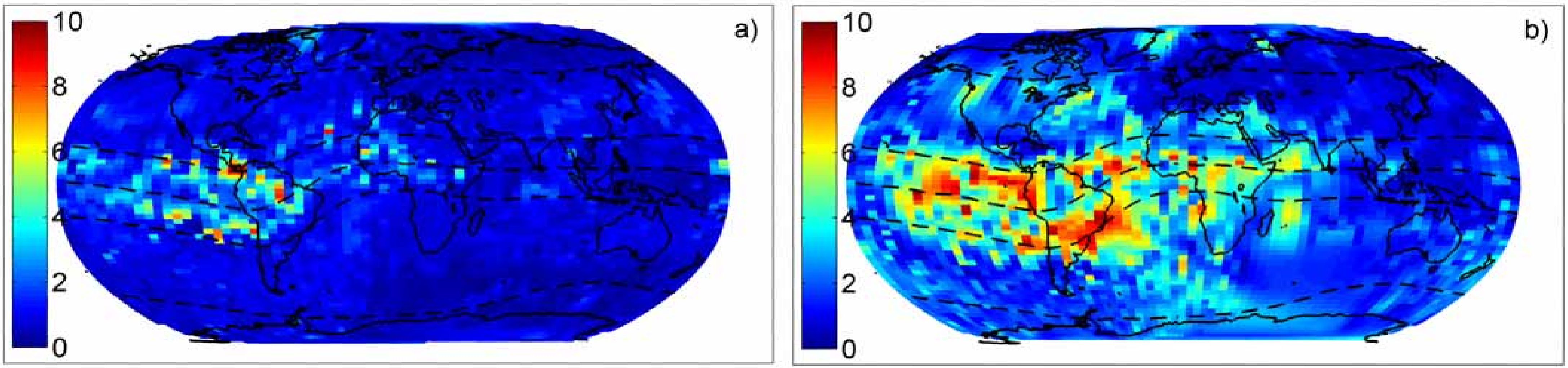


~ 60.000 profiles like this one per month $\sigma = \pm 4.5 \cdot 10^{10}\ m^{-3}$

Example of computed minus modeled electron densities

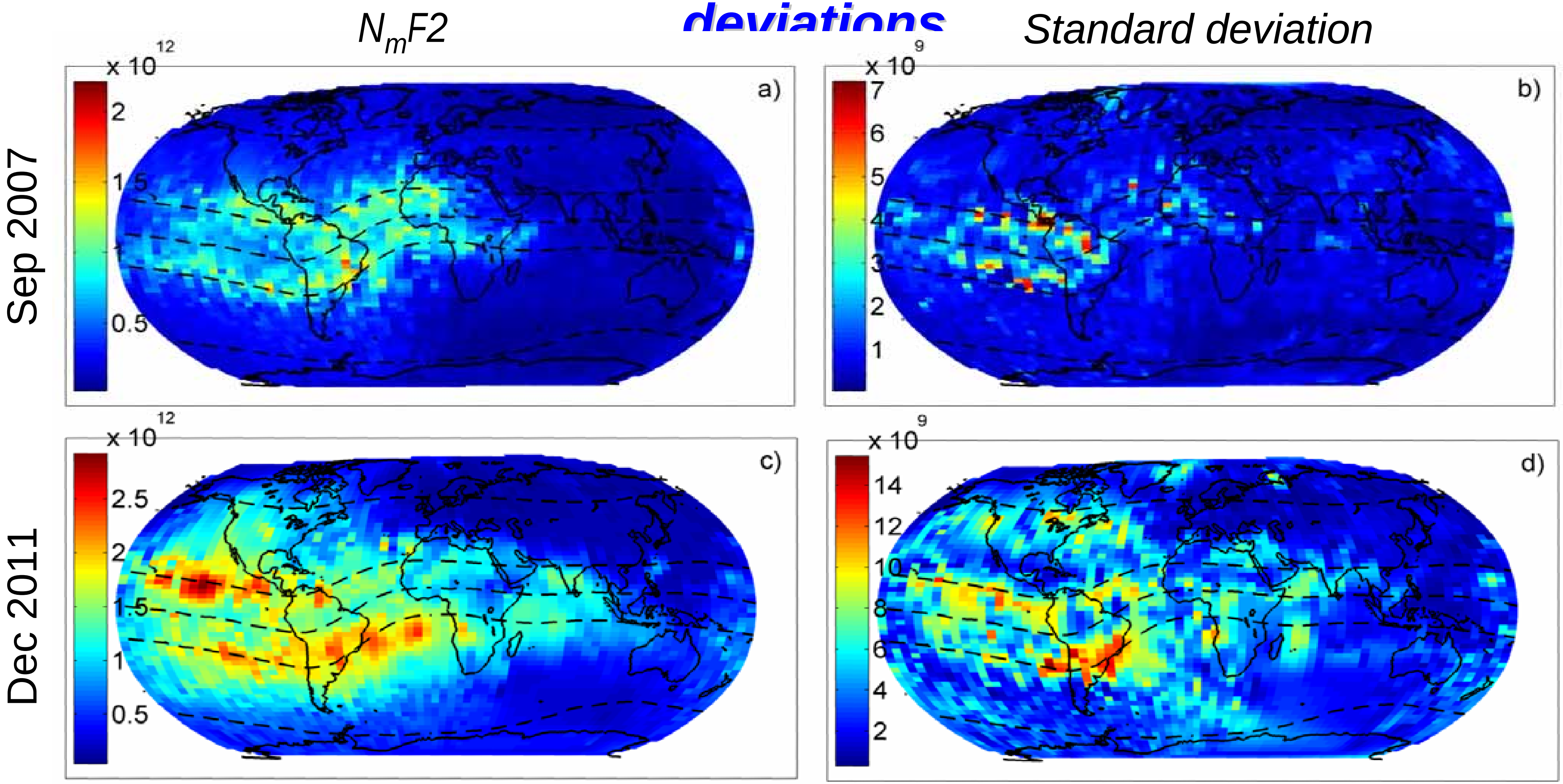
Standard deviation of the computed minus modeled electron densities for the ROP comprised within the 18 – 20 UT interval

Sep 2007 Values in 10^{10} m^{-3} Dec 2011



Standard deviations range around 3% of the measured ED

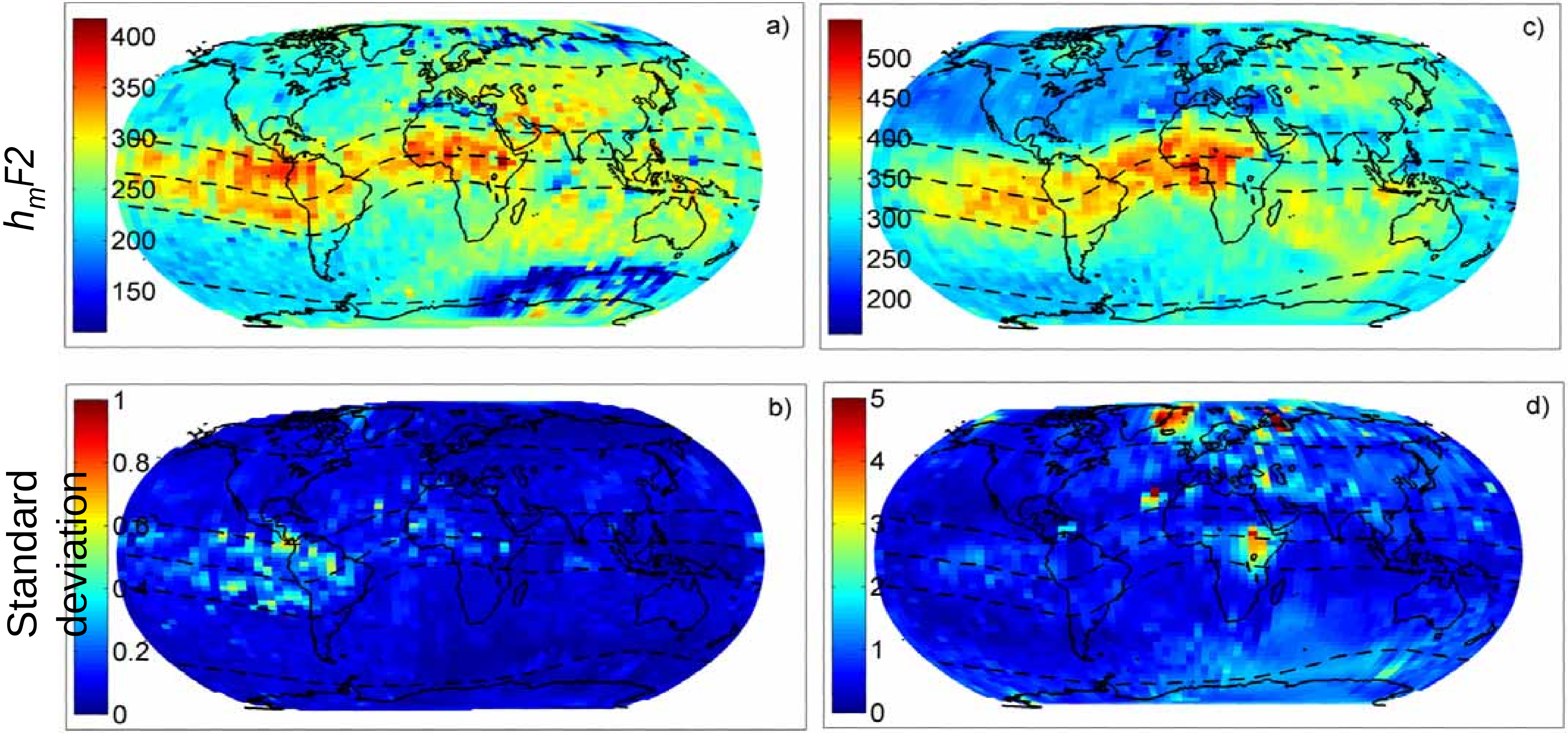
Example of the estimated NmF2 parameters an standard deviations



Standard deviations (obtained by variance – covariance propagation) range around 7% of the estimated value

Example of the estimated hmF2 parameters an standard deviations

Sep 2007 Dec 2011



Standard deviations (obtained by variance – covariance propagation) range around 1% of the estimated value