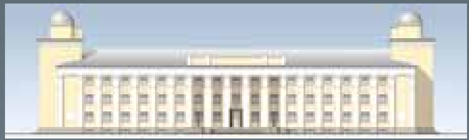

SMF2:
Global model of the F2 layer peak height based on satellite data

Alexander Karpachev*, Valentin Shubin*, <u>Konstantin Tsybulya</u>**

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**Institute of Applied Geophysics, Moscow

International Reference Ionosphere (IRI) Workshop 2013 “IRI and GNSS”

Olsztyn, June 24 - 28, 2013

Approach

IRI:

$h_m F2 = Approximation(M3000, f_o F2/f_o E, R_z)$

SMF2:

$h_m F2 = SHA(\varphi, \lambda) * Fourier(t) * Corr(F_{10.7A})$

Based on a set of 149 x 24 x 12 = 42912 coefficients (for low and high activity)

Data set

2 800 000 COSMIC profiles (http://www.cosmic.ucar.edu)

100 000 GRACE profiles (http://op.gfz-potsdam.de/champ/)

300 000 CHAMP profiles (http://op.gfz-potsdam.de/champ/)

200 000 Interkosmos-19 profiles

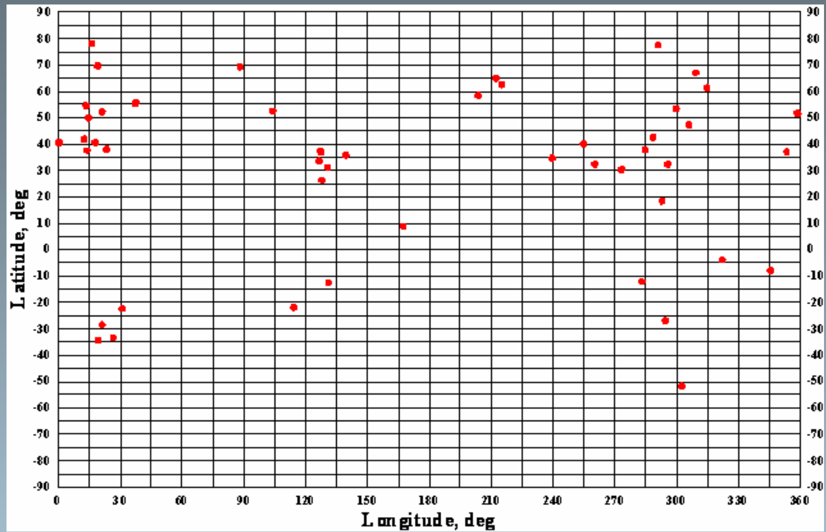
For high solar activity ~60 Digisondes stations were added (http://ulcar.uml.edu)

Low solar activity ($F_{10.7} \leq 80$)

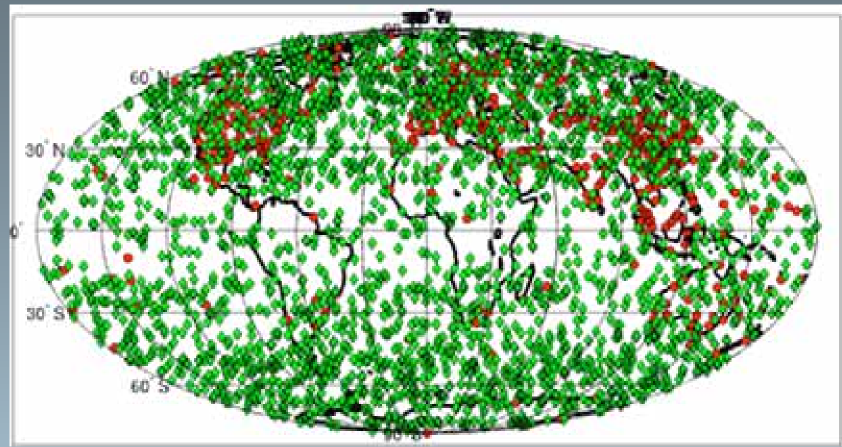
- Mainly COSMIC, also some CHAMP and GRACE data
- GPS radio occultation data
- A form of Abel transform is used to derive profiles and h_mF2
- Ready-for-use profiles were downloaded

Data global distribution

Digisondes

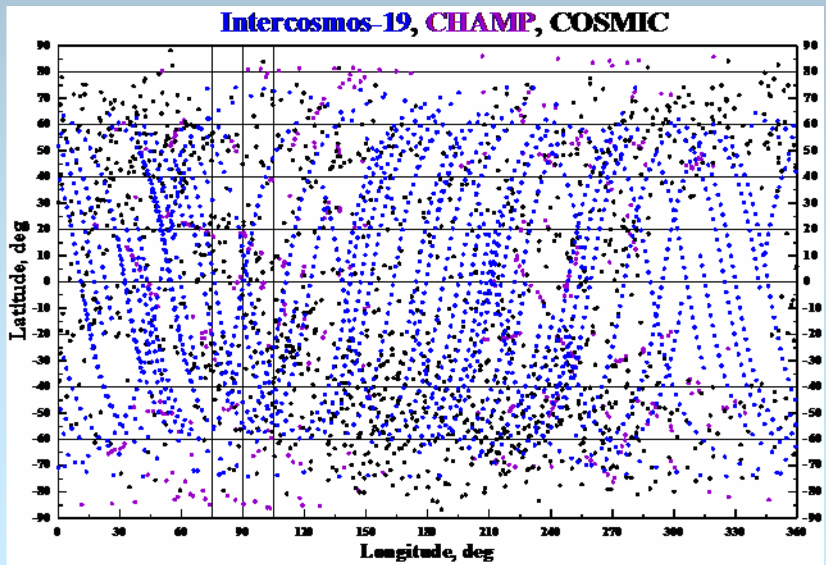


One day COSMIC observations



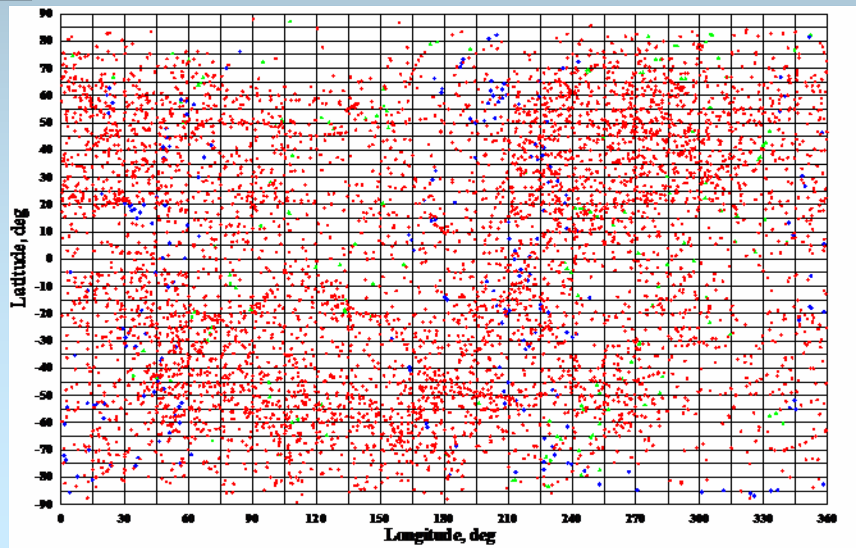
860 bins

High solar activity (F10.7A>140), December, 00 UT

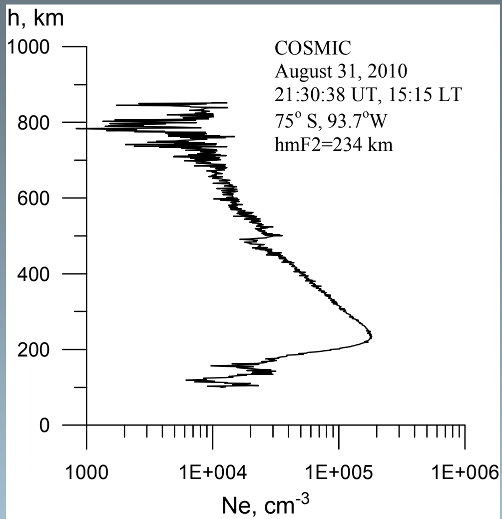


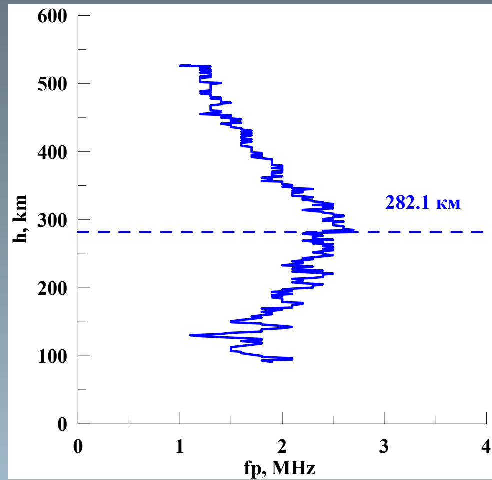
Low solar activity (F10.7A<80), January, 00 UT

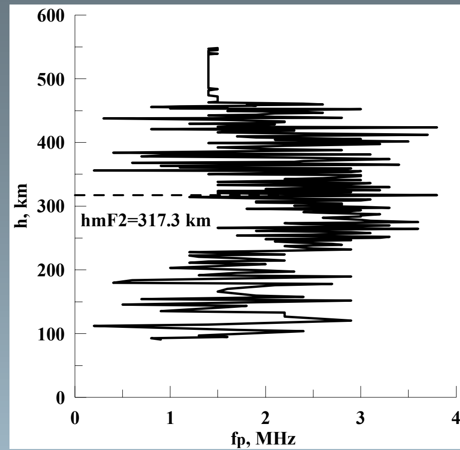
COSMIC, CHAMP, GRACE

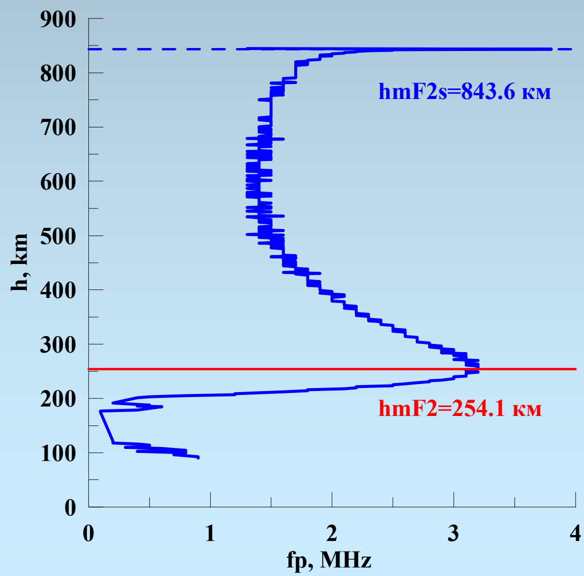


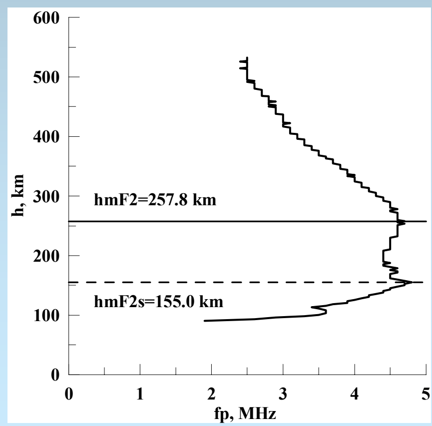
Typical Problems with Occultation Profiles

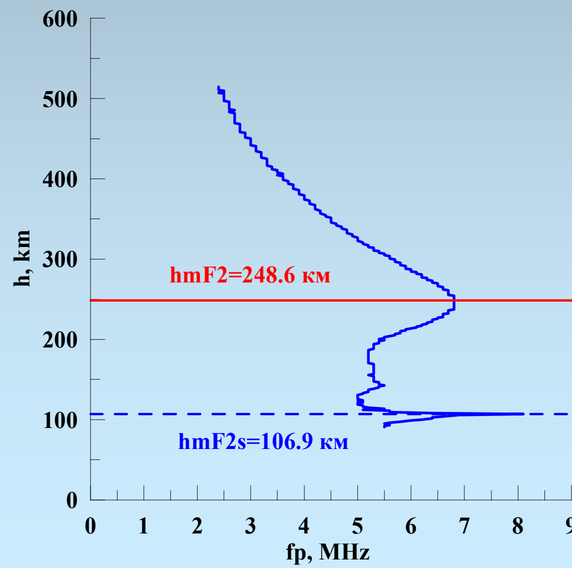










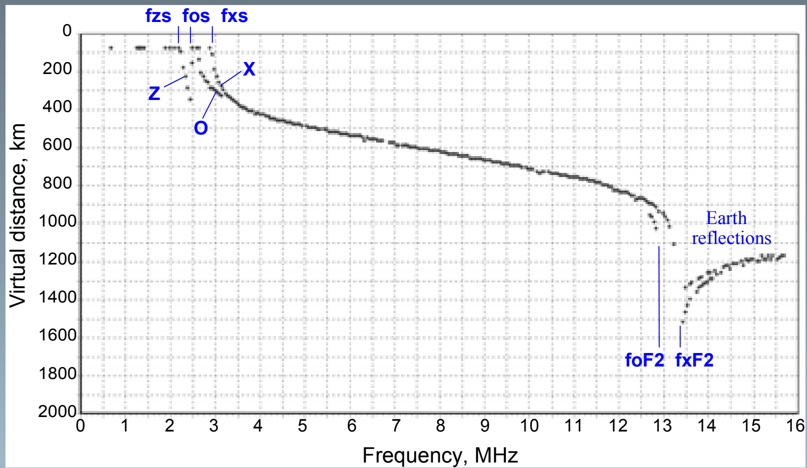


High solar activity ($F_{10.7A}$ >140)

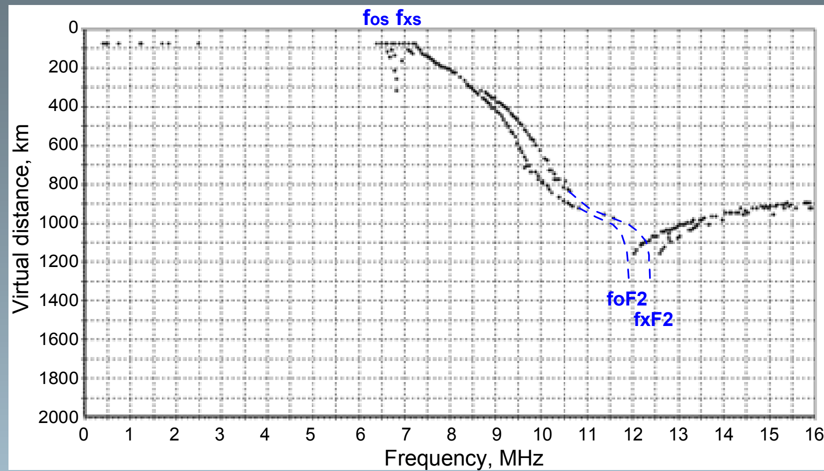
- Mainly Interkosmos-19 data (1979—1981)
- Top-side ionograms
- Close-to-uniform global coverage
- Restored from tapes and prints
- Manually scaled
- A variation of Jackson algorithm is used to derive profiles and h_mF2
- In addition – some CHAMP, GRACE and Digisonde data

Typical Problems with IK-19 data

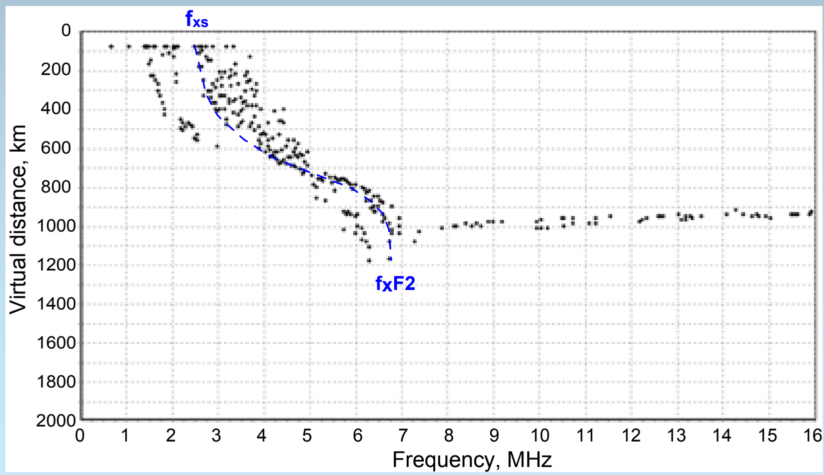
Strong radio signal attenuation near critical frequency



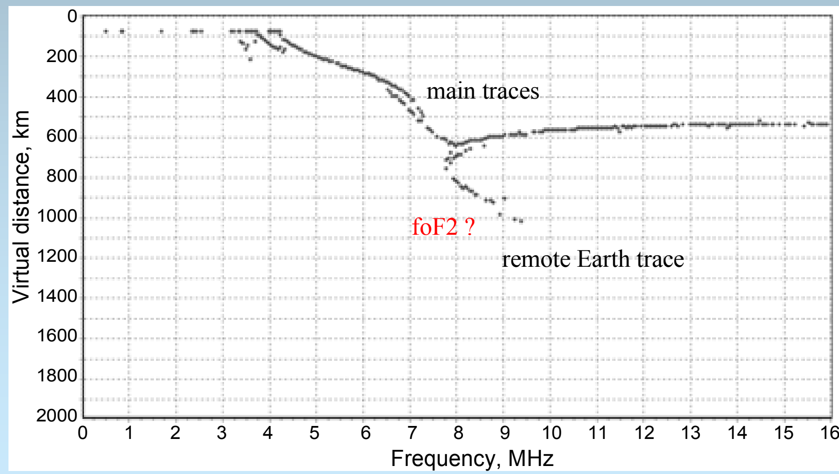
Ionogram with F3-layer



Strong F-spread



Remote reflection from ground



Karpachev et al., 2010, 2011, 2013, Geomagnetism and Aeronomy

Model Construction

Method of the model construction

Modeling of the spatial dependencies is based on expansion of these dependencies in series by a system of orthogonal functions [Chernyshov, Vasilyeva, 1973]. The h_mF2 dependency on latitude φ and longitude λ in some fixed moment of time is expanded as a series:

$$F(\phi,\lambda)=\sum_{m=0}^{M}\sum_{n=m}^{N}\left[g_n^m \cos m\lambda + h_n^m \sin m\lambda\right]\cdot P_n^m(\cos\vartheta), \quad (1)$$

where ϑ=90º–φ, g_n^m and h_n^m are expansion coefficients, and $P_n^m(\cos\vartheta)$ are associated **Legendre functions**. The coefficients in (1) are determined with the least square method. The series (1) could be presented in a shorter form:

$$F(\phi,\lambda)=\sum_{k=0}^{K} D_k \cdot G_k(\phi,\lambda), \quad k=0,1,2..,K, \quad (2)$$

where D_k are complex expansion coefficients and $G_k(\varphi,\lambda)$ are spherical harmonics. The number of the coefficients is determined as $K=m\cdot(2n-m+1)+n+1$. To determine coefficients in (2) we used Gram-Schmidt orthonormalising, as in [*Chernyshov, Vasilyeva*, 1973]. The approximation was considered to be optimal when the standard deviation *SD* was minimized for the given month and UT hour:

$$SD=\sqrt{\frac{1}{n-1}\left[\sum_{i=1}^{n}(h_mF2-h_mF2_{\mathrm{mod}})^2-\frac{1}{n}\left(\sum_{i=1}^{n}(h_mF2-h_mF2_{\mathrm{mod}})\right)^2\right]}, \quad (3)$$

We chose as optimal ***M* = 8** (longitudinal) и ***N* = 12** (latitudinal) numbers. Thus, we need **149** coefficients for one month and UT hour.

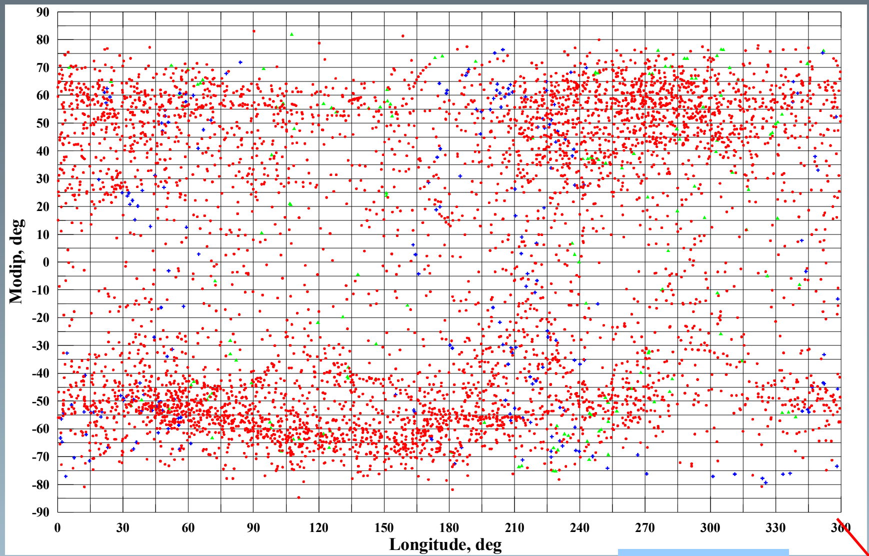
For the diurnal interpolation we have used a **Fourier decomposition** with **3** harmonics:

$$F(t)=\sum_{i=0}^{3}\left[a_i \cos(i\frac{2p}{T}t)+b_i \sin(i\frac{2p}{T}t)\right], \quad (4)$$

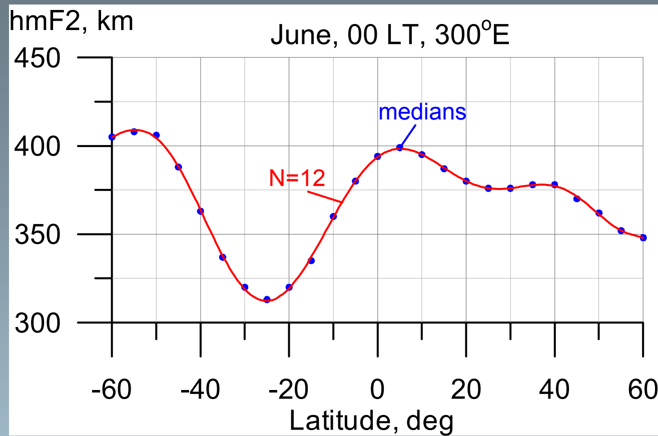
where a_i and b_i are found from h_mF2 diurnal dependency with period T = 24 hours with the help of Gram–Schmidt process.

Model construction

MODIP

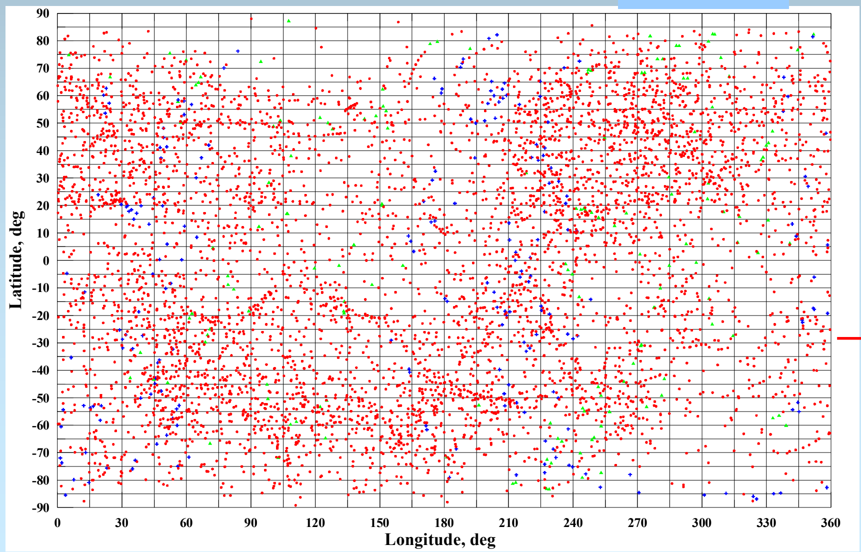


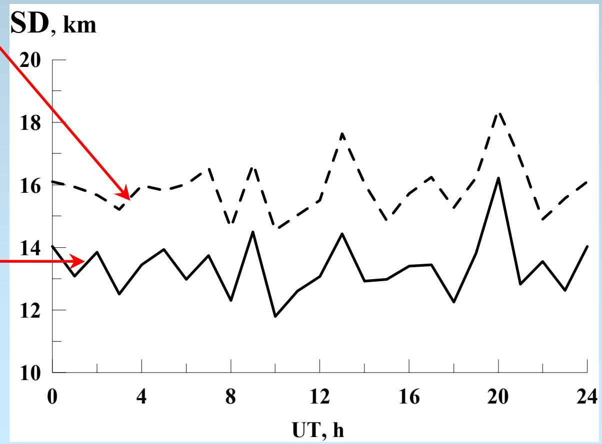
Latitudinal variations, N=12
Longitudinal variations, M=8



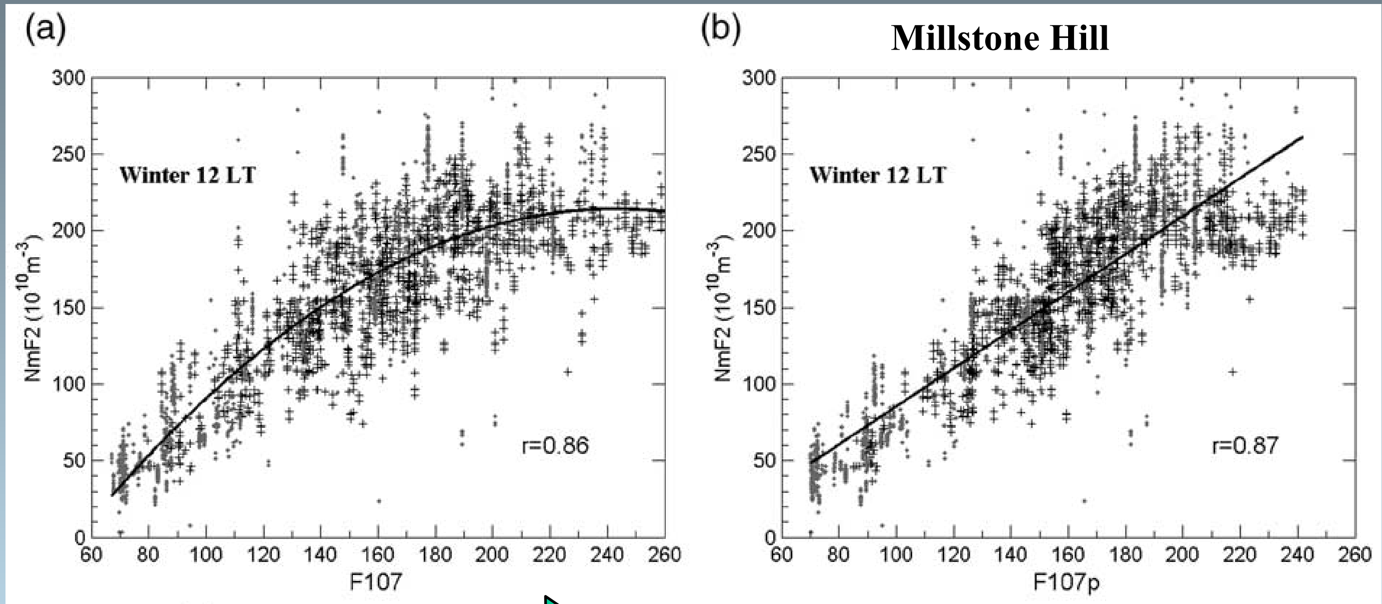
January
00 UT

Geographic latitude





N_mF2 and h_mF2 dependence on solar activity



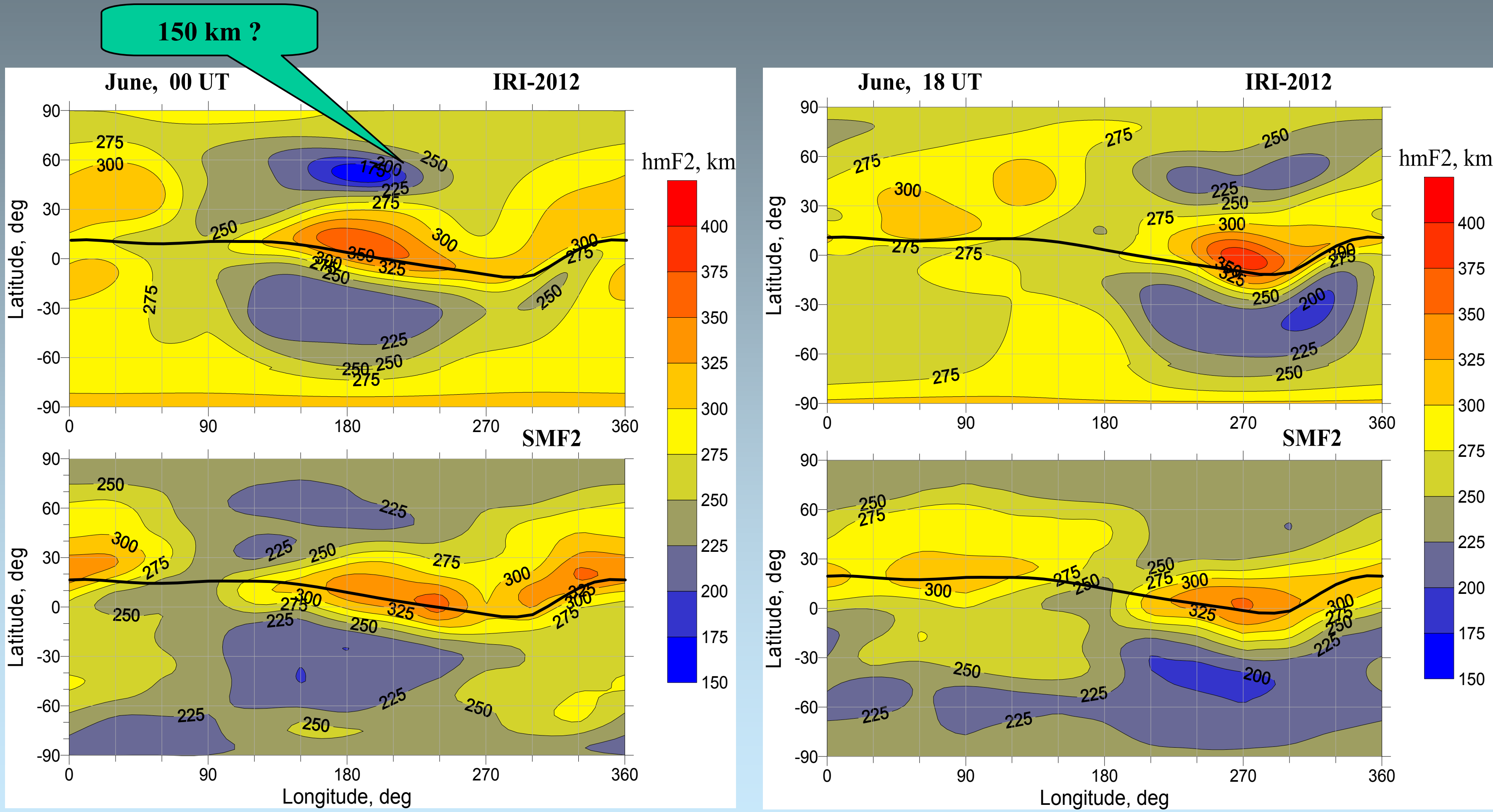
Lei et al., Radio Sci., v.40. 2005.

$F_{10.7A}$ is daily $F_{10.7}$ averaged for 3 rotations of the Sun

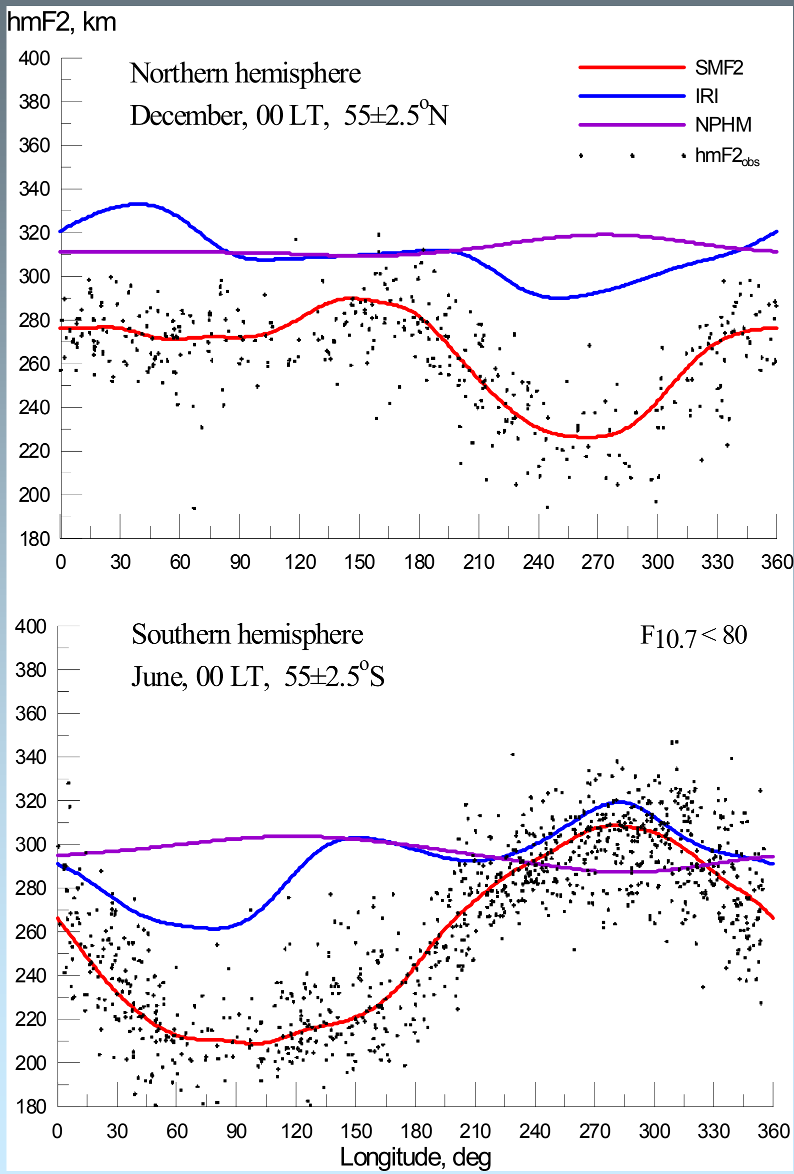
$F_{10.7p}$ (proxy) =$(F_{10.7}+F_{10.7A})$ / 2

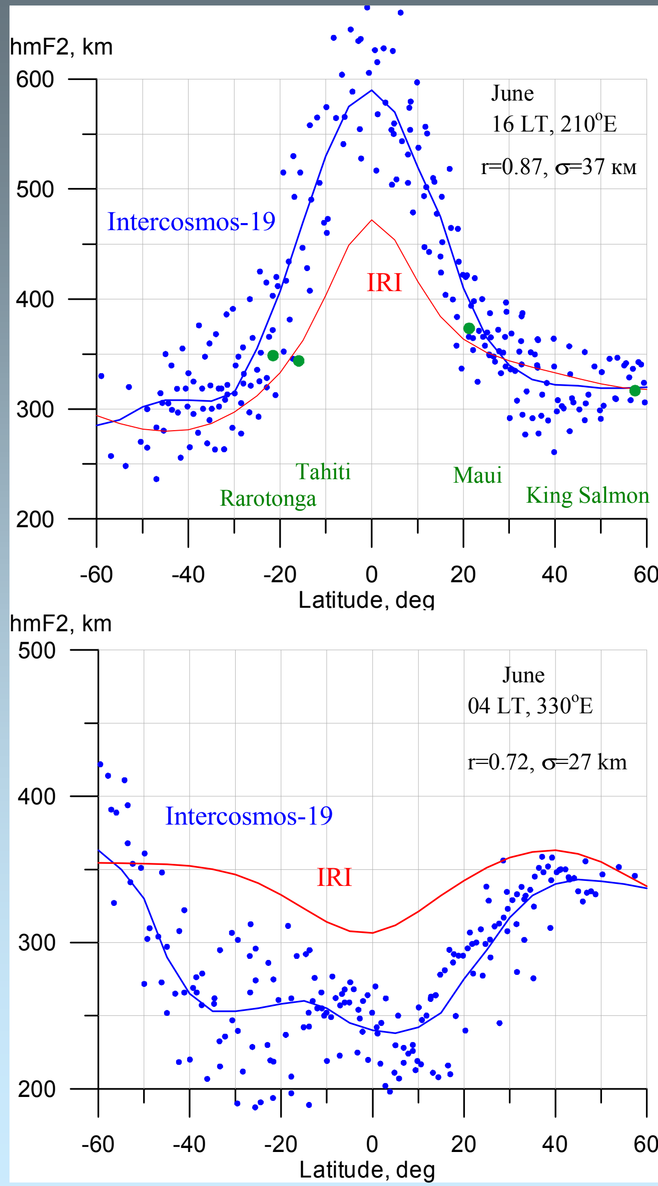
Checking, Testing and Validation of the Model

SMF2 and IRI comparison: Low solar activity

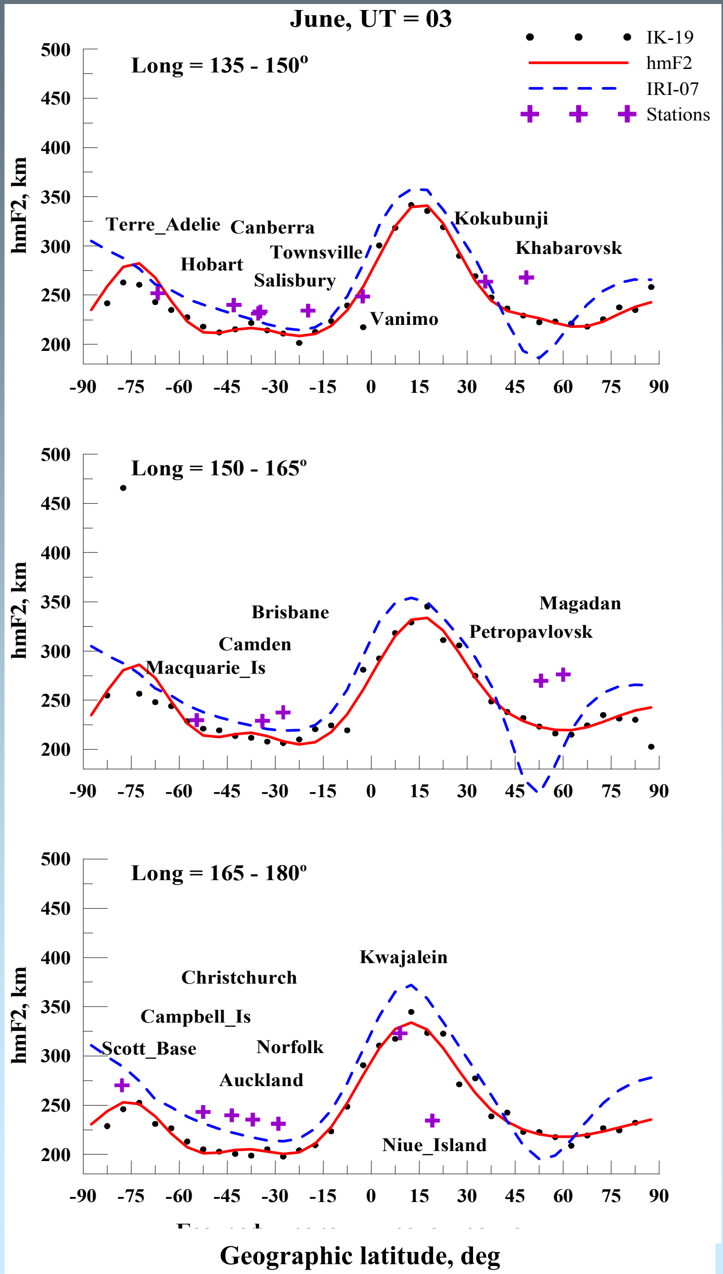


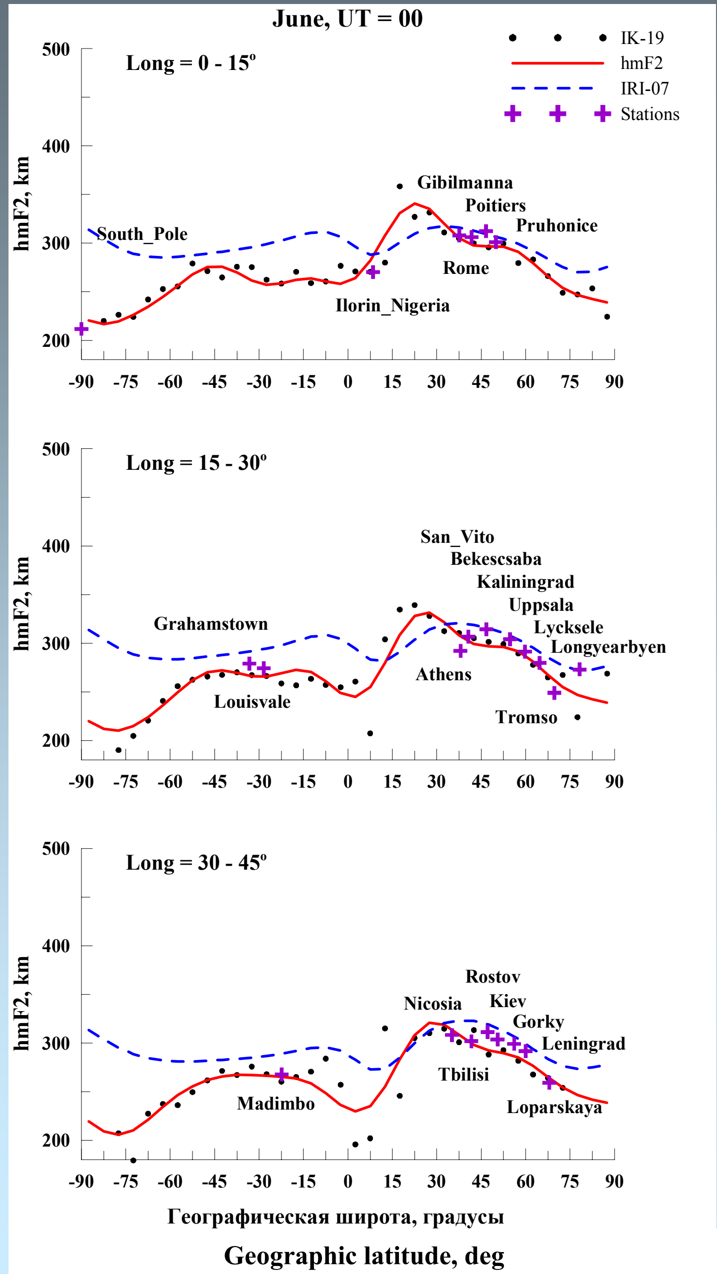
Longitudinal and Latitudinal variations





Latitudinal variations: High solar activity





SMF2-IRI Comparison
(June, High and Low Solar Activity)

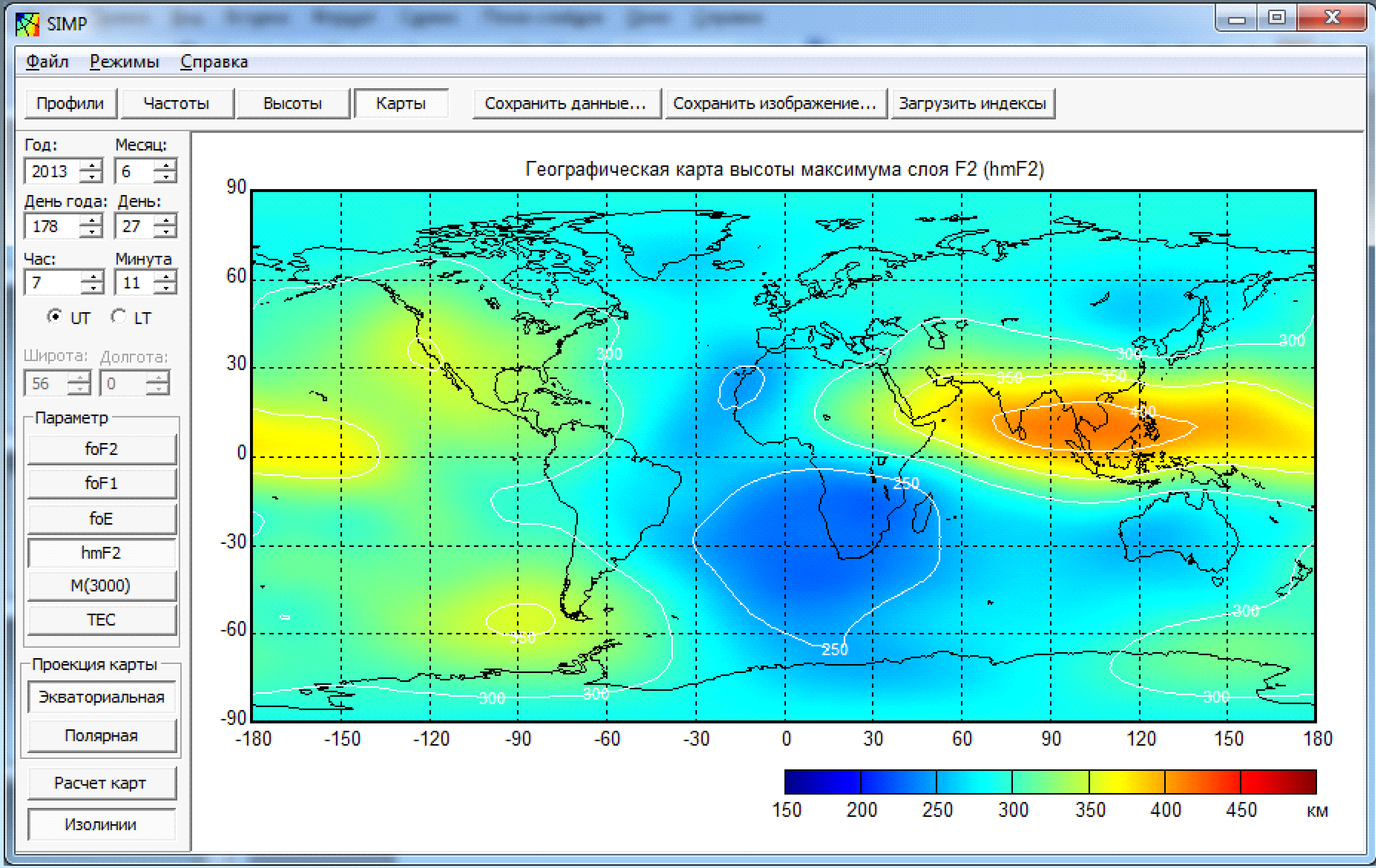
UT, h	N	SMF2 SD, km	SMF2 SCAT, km	SMF2 MRD %	IRI-2012 SD, km	IRI-2012 SCAT km	IRI-2012 MRD %
00	822	11.83	11.82	3	23.96	32.76	11
01	827	11.34	11.33	3	22.97	30.25	10
02	830	10.78	10.78	3	23.04	29.49	10
03	831	13.26	13.25	3	23.14	28.90	9
04	825	11.74	11.73	3	22.23	27.90	9
05	829	12.68	12.67	3	21.59	26.84	8
06	830	12.00	11.99	3	22.80	29.00	9
07	832	11.38	11.38	3	22.74	29.84	10
08	832	11.42	11.41	3	23.44	31.39	10
09	839	10.41	10.40	3	23.53	32.12	11
10	829	11.61	11.61	3	25.64	34.55	12
11	833	11.50	11.49	3	24.75	34.67	12
12	813	12.71	12.71	3	25.51	34.59	12
13	829	11.76	11.76	3	23.96	33.19	11
14	830	9.87	9.87	3	23.99	33.20	11
15	826	10.41	10.40	3	25.53	33.00	11
16	823	10.40	10.39	3	25.46	34.11	11
17	821	12.08	12.08	3	25.60	33.72	11

UT h	N	SMF2 SD km	SMF2 SCAT km	SMF2 MRD %	IRI-2012 SD km	IRI-2012 SCAT km	IRI-2012 MRD %
04	164	21.91	21.84	5	31.34	32.54	7
05	153	22.94	22.89	5	37.53	41.14	9
06	164	19.78	19.74	4	33.35	33.74	8
07	156	21.89	21.85	5	35.50	37.46	8
08	126	17.98	18.00	4	31.72	33.45	7
09	119	18.42	18.35	4	37.18	38.18	8
10	101	19.89	19.81	4	40.03	44.58	8
11	111	16.98	16.97	4	49.25	50.90	10
12	122	20.09	20.03	4	49.90	56.95	9
13	118	19.92	19.90	4	39.13	39.83	9
14	124	17.84	17.77	4	35.83	35.72	9
15	111	19.05	19.04	5	39.44	39.39	9
16	120	25.72	25.75	7	44.87	44.69	12
17	93	21.40	21.34	5	36.44	36.27	8
18	99	25.85	25.91	5	43.26	44.55	9
19	89	21.59	21.56	5	44.00	43.90	10
20	111	17.63	17.59	4	39.08	38.91	11
21	174	19.71	19.66	5	44.42	44.30	11

Technical implementation

- ~400 lines of FORTRAN code
- Compiled for Windows and Linux OS
- Open and free for distribution (in near future)
- Command-line interface
- C++ Windows graphical interface
- Web interface (http://space-weather.ru)

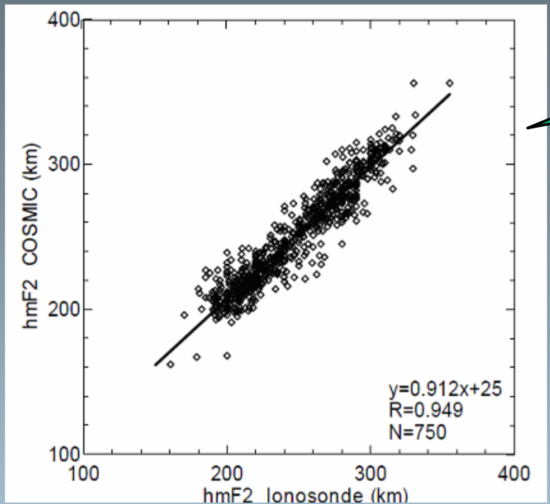
Windows Graphical Interface



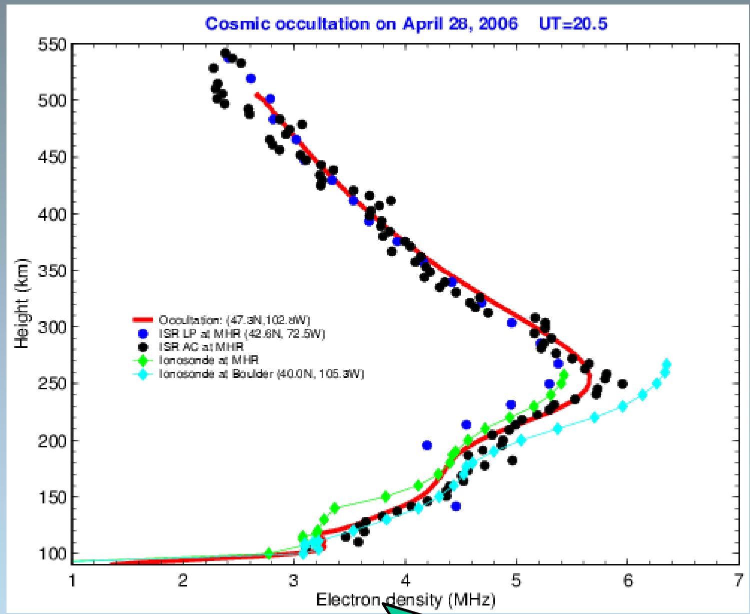
Conclusions

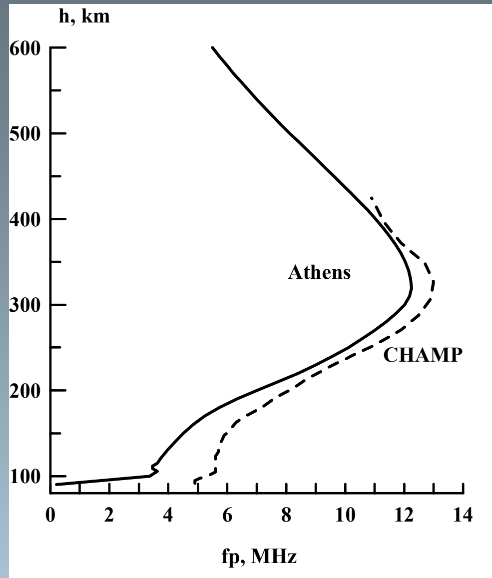
- A global median h_mF2 model based on the vast satellite database is created, with relative deviations (*MRD)* for all months 2–3 times less than in IRI
- The approach looks promising
- More data necessary for high solar activity
- A problem of correct validation is noted

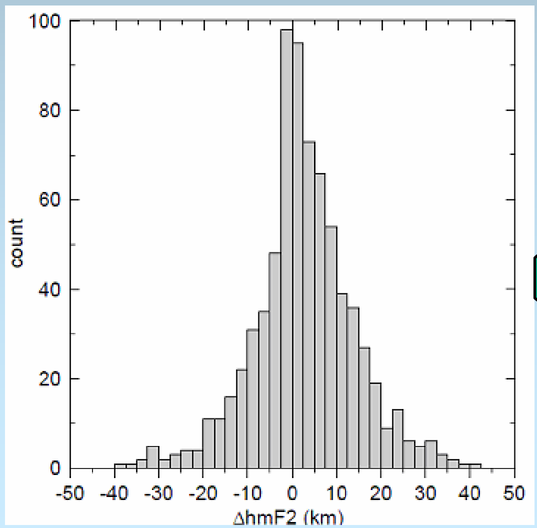
Comparison between COSMIC and ionosondes



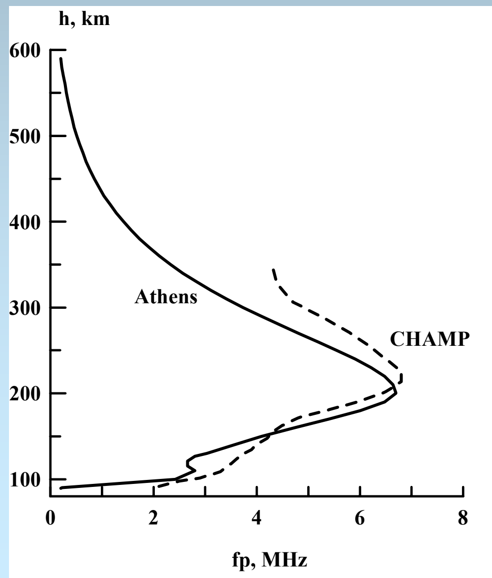
Krankowski et al., J. Geod., 2011.







Cheng et al., 4th ASC, 2008, Taipei, Taiwan



Latitudinal variations:

High solar activity

Low solar activity

18 LT

Pacific