The Real-Time INTERNATIONAL REFERENCE IONOSPHERE Status and Review

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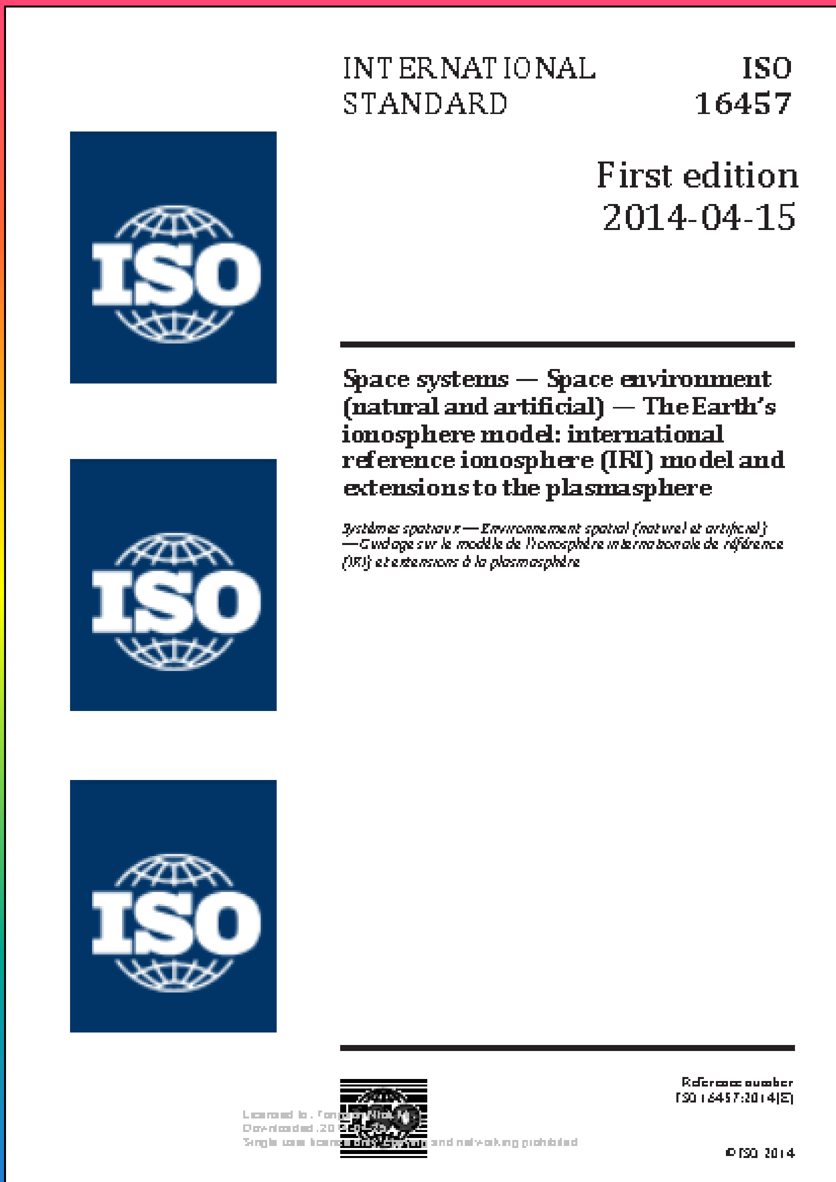
http://IRImodel.org



INTERNATIONAL STANDARD

ISO 16457

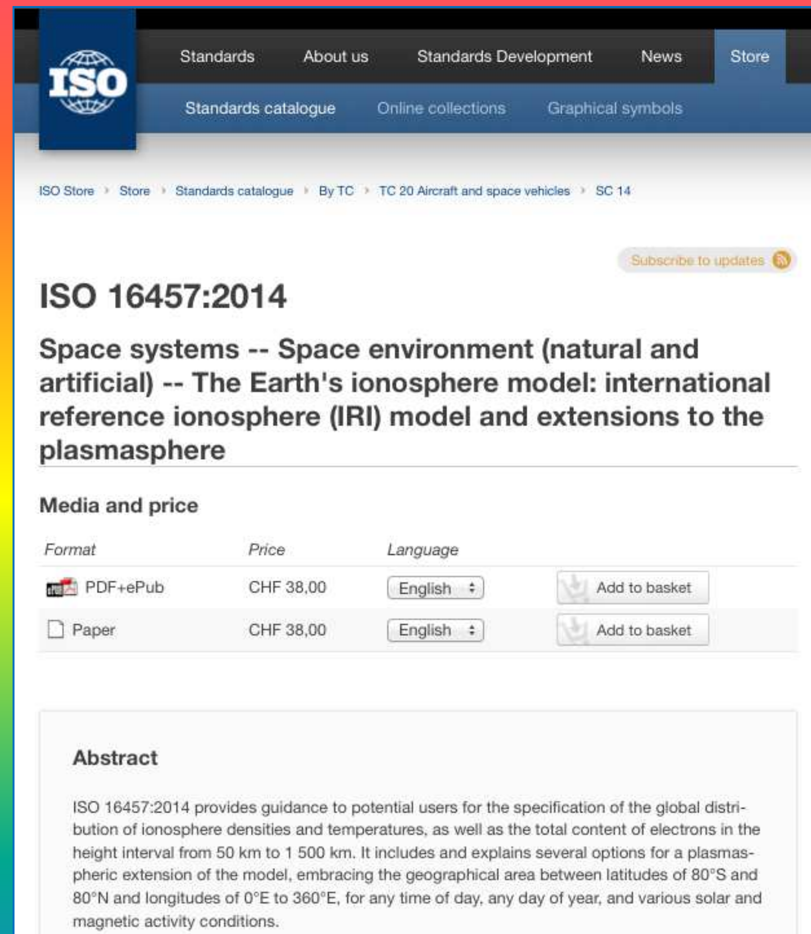
First edition
2014-04-15

Space systems — Space environment (natural and artificial) — The Earth's ionosphere model: international reference ionosphere (IRI) model and extensions to the plasmasphere

Systèmes spatiaux — Environnement spatial (naturel et artificiel) — Guidage sur le modèle de l'ionosphère internationale de référence (IRI) et extensions à la plasmasphère

Reference number
ISO 16457:2014(E)

http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=61556



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ISO 16457:2014

Space systems -- Space environment (natural and artificial) -- The Earth's ionosphere model: international reference ionosphere (IRI) model and extensions to the plasmasphere

Media and price

Format	Price	Language	
PDF+ePub	CHF 38,00	English	Add to basket
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Abstract

ISO 16457:2014 provides guidance to potential users for the specification of the global distribution of ionosphere densities and temperatures, as well as the total content of electrons in the height interval from 50 km to 1 500 km. It includes and explains several options for a plasmaspheric extension of the model, embracing the geographical area between latitudes of 80°S and 80°N and longitudes of 0°E to 360°E, for any time of day, any day of year, and various solar and magnetic activity conditions.

IRI-Real-Time

IRI
Real-Time

- GOAL: Transition from IRI climatological reference model to an ionospheric weather model

- METHOD: Combine IRI with ground and space data (ionosonde, GPS, COSMIC) - Assimilation or Updating

- RESULT: Continuous data set of ionospheric weather for past years (post-processing) as well as a real-time characterization of the ionosphere for operational use

- ACTIVITIES: 2009 Colorado Springs Workshop; 2012 Prague IRI-RT meeting; 2014 Lowell meeting

Techniques

- Updating based on adjusting a solar index to measured data (ionosonde foF2 or GPS TEC)

- Assimilating measured parameters into the IRI background model using various techniques (Kalman filter, Ensemble Kalman filter, NN, 3-D/4-D variational techniques, Gauss-Markov, etc.).

Updating IRI

	USING INDICES
Solar indices	*F10.7M, Rz12*
Magnetic indices	*Ap*
Ionosonde index	*IG12* (based on selected ionosondes)
	USING MEASUREMENTS
Actual measurement	N_e: *foF2/NmF2, foF1/NmF1, foE/NmE, hmF2/M(3000)F2, hmE,* T_e: *N_e(300km), N_e(400 km), N_e(600 km)*
Equivalent solar Index (*ESI*)	Adjusting the solar index until the model fits *ionosonde* or *TEC* data

Open Issues

What is the best solar proxy?

- Rz12 and F10.7M not optimal
- Wavelength-specific solar indices are limited by the availability of EUV measurements

What is the best averaging time period?

- 12-month running mean is used in IRI
- Daily and monthly should be also considered

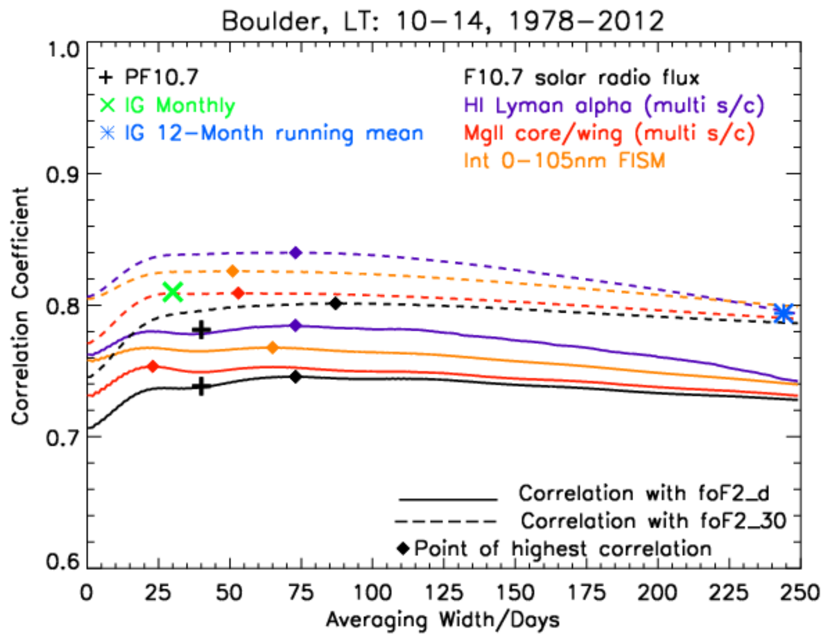
P = (F10.7 + F10.7A)/2 is a good start

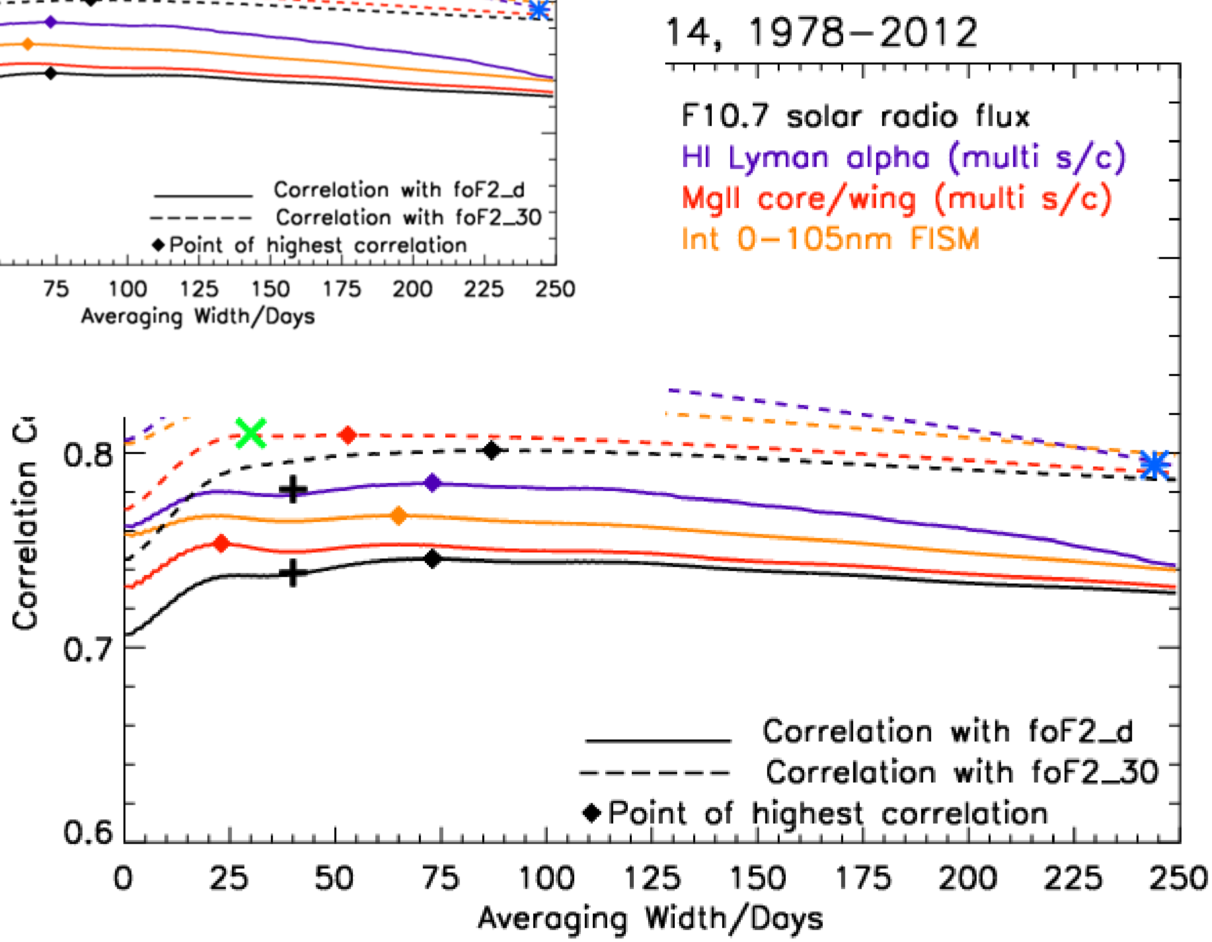
What time lag should be used with daily F10.7?

- Currently no delay considered in IRI
- 1 to 4 day time lags have been reported for ionospheric and thermospheric plasma parameters

Correlation increases to a local maximum at ~27 days and than

d monthly *foF2*: ging interval? differences?





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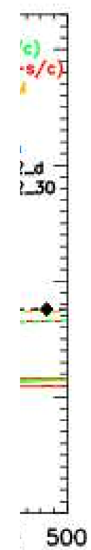
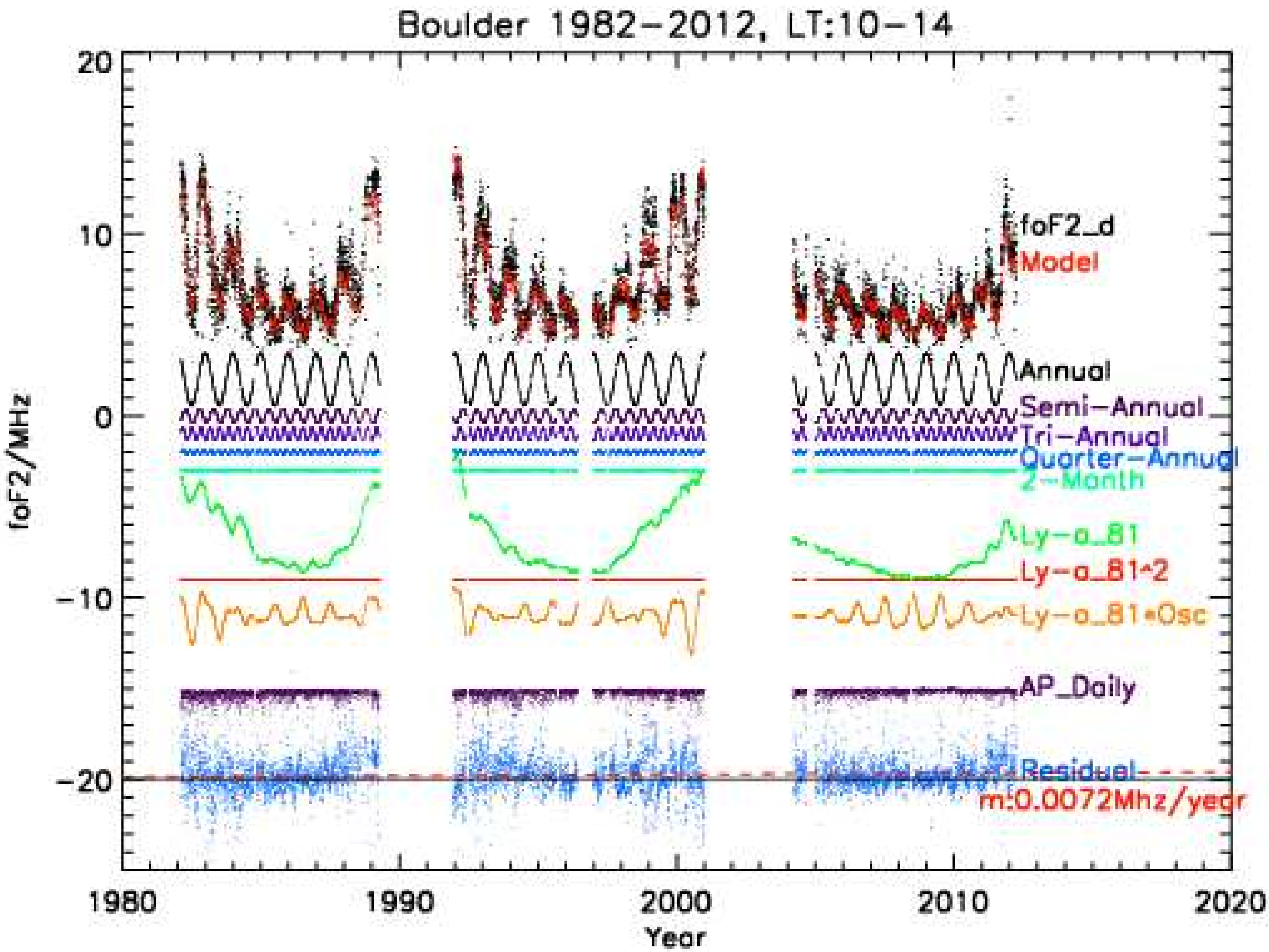
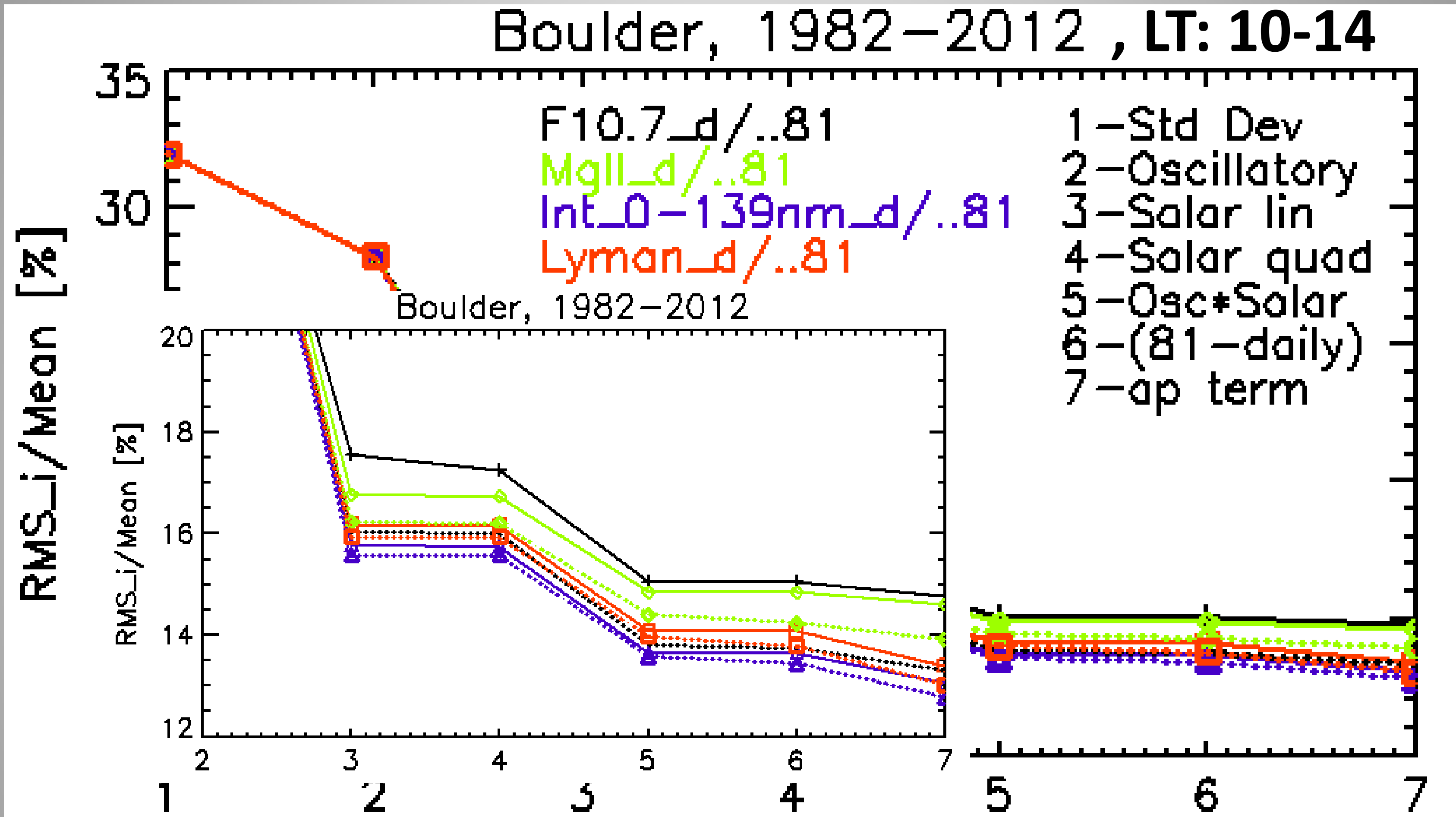




Boulder 1982–2012, LT:10–14
foF2/MHz
Year
20
10
0
–10
–20
1980
1990
2000
2010
2020
foF2_d
Model
Annual
Semi–Annual
Tri–Annual
Quarter–Annual
2–Month
Ly–a_81
Ly–a_81^2
Ly–a_81*Osc
AP_Daily
Residual
m:0.0072Mhz/year

Variability in % (RMS/Mean)



Rest variability of 13-15% due to un-modelled solar and magnetic dependencies (time delay) and to forcing from below (meteorological influences, gravity waves)

SUMMARY

- **Correlation increases to a local maximum at ~27 days and than again to a maximum at 70-80 days.**
- **Correlation is stronger for monthly *foF2* than for daily**
- **Best correlation with HI (Lyman-α) with an 81-day running mean.**
- **IG is the best non-EUV index out-performing the often used PF10.7 index.**
- **Switching to an EUV-based daily index lowers the data-model RMS by 5-10%. But nearly the same reduction can be obtained using an 81-day running mean index of F10.7 .**
- **~50% of variability can be described with the help of oscillatory and solar terms. The rest is due to forcing from below and to non-linear or time-delayed solar and magnetic dependencies.**

Equivalent Solar Index (ESI)

Liu et al., *Telecomm. J.*, 1988

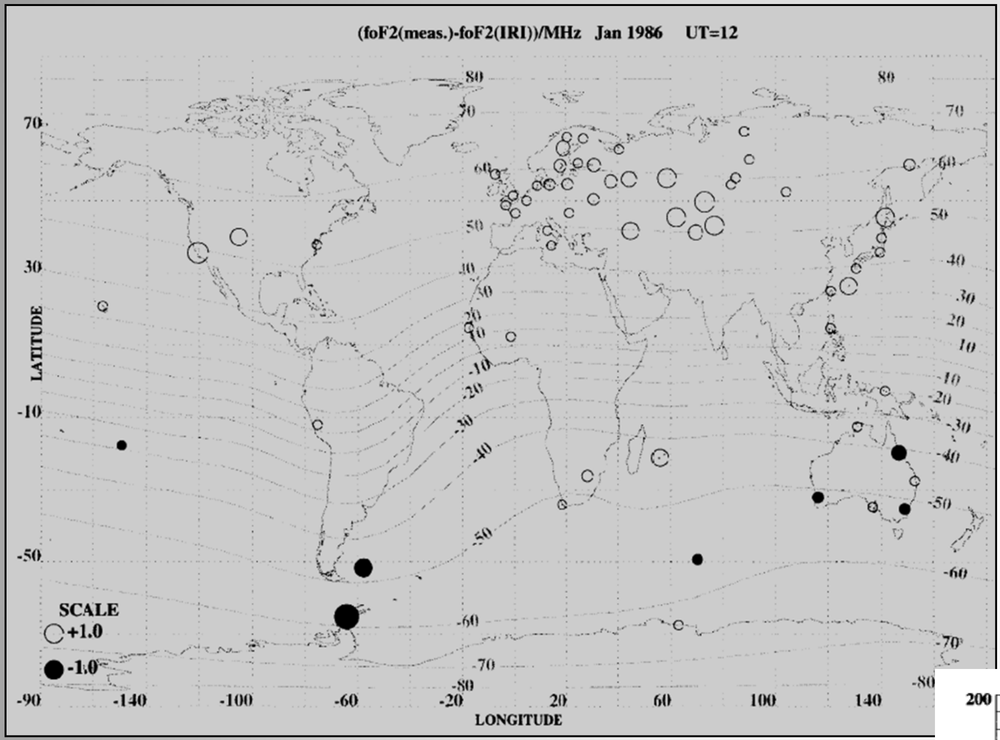
IG: CCIR maps and *foF2* measured by selected ionosondes

- Noontime measurements of *foF2* from 13 globally distributed ionosondes.
- Adjust R12 in CCIR *foF2* model until agreement is achieved between data and model.
- Take median of the 13 adjusted R12 values.

PROBLEMS:

- Stations have varied over time and are now down to 4 (Chilton, Port Stanley, Kokubunji, and Canberra)
- IG-CCIR but not an equivalent IG-URSI
- Only noon time data are being used.

ESI: Updating IRI with ionsonde data

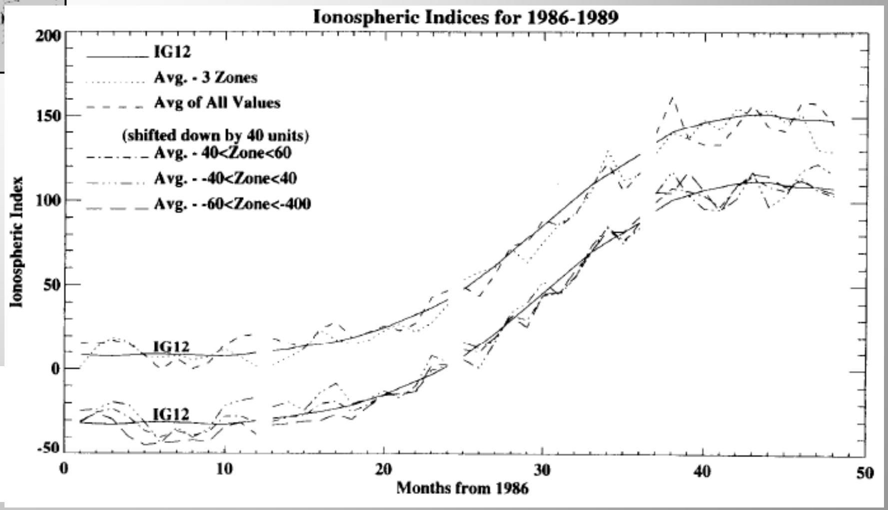


Size of circle indicates the difference between the measured foF2 and the IRI prediction (black circles – negative values) NOTE the significant hemispherical differences.

An equivalent solar EUV index (ESI) was obtained by adjusting IRI F-peak densities to worldwide ionosonde measurements.

Improvement of 10-20% vs unadjusted IRI.

This was done in support of data analysis for the GEOSAT single-frequency altimeter. (*Bilitza et al.*, 1997)



The IG12 index (solid curve) used in IRI and the monthly ESI indices defined in this study for the GEOSAT years 1986 to 1989

ESI: Updating IRI with GPS VTEC data

Komjathy et al., *Adv. Space Res., 22(6), 792– 801, 1998.*
… using VTEC

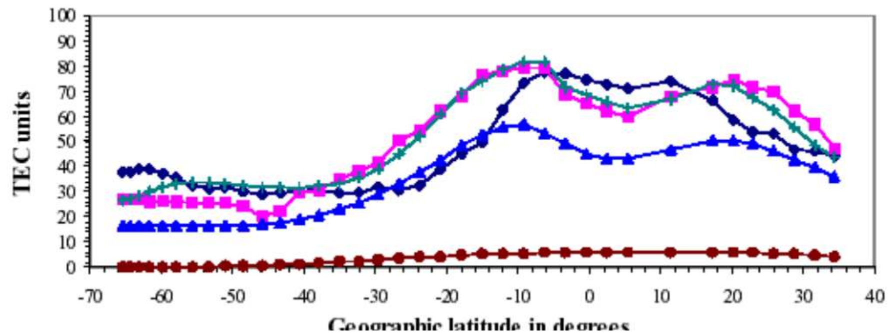


Table 1. Summary of results from the comparison between updated IRI-95 and T/P-derived TEC data.

Day	Original IRI-95 (all units in TECU)			Updated IRI-95 (all units in TECU)		
	average mean	average s.d.	s.d. range (min, max)	average mean	average s.d.	s.d. range (min, max)
13-Mar-93	10.8	8.7	3.5 ≤σ≤14.7	1.7	7.7	3.7 ≤σ≤12.1
14-Mar-93	9.1	9.5	2.5 ≤σ≤ 16.9	0.5	8.8	3.3 ≤σ≤ 16.1
15-Mar-93	6.5	9.2	2.1 ≤σ≤ 15.7	-1.2	8.5	2.6 ≤σ≤ 14.9
06-Apr-95	1.4	3.6	1.3 ≤σ≤ 7.3	2.8	3.2	1.5 ≤σ≤ 6.5
07-Apr-95	3.3	4.9	1.9 ≤σ≤ 9.3	1.8	4.0	1.7 ≤σ≤ 7.2
08-Apr-95	1.2	4.4	0.9 ≤σ≤ 8.6	0.8	3.7	1.1 ≤σ≤ 6.4

Fig. 7. A

TEC units

GIM TEC
Plasmaspheric EC

Fig. 8. An example of the comparison of different techniques with T/P pass 21 between UT 18h 32m and 19h 24m of 8 April 1995.

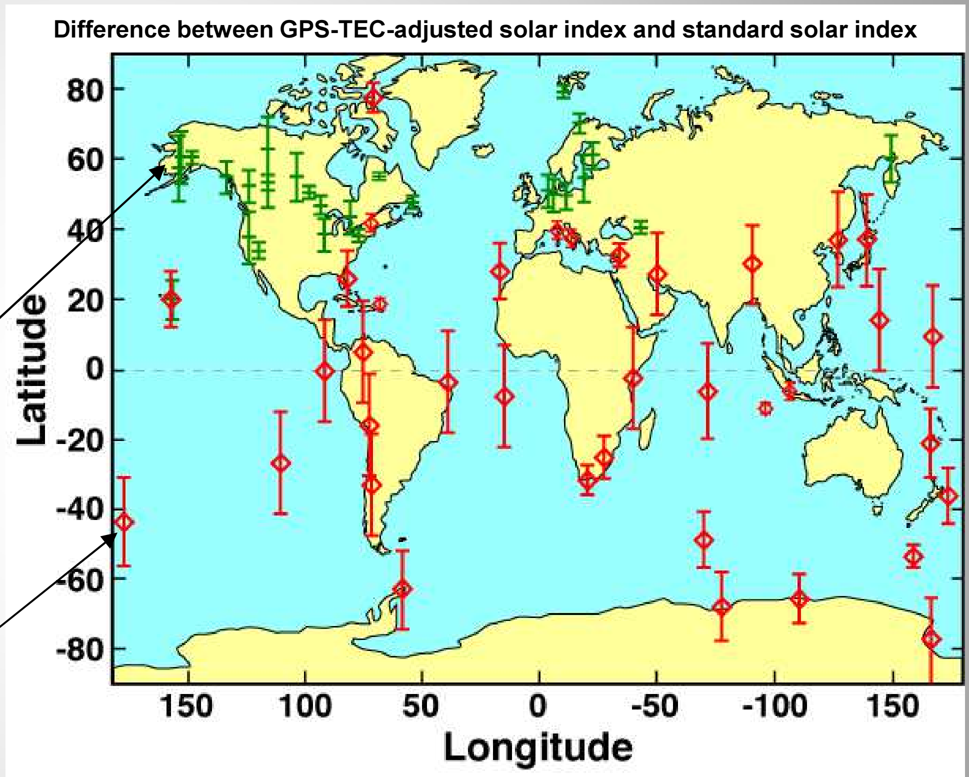
ESI: Updating IRI with GPS slant-TEC data

Hernandez-Pajares, et al., *Adv. Space Res.* 29(6), 949, 2002
… using Slant TEC

upward adjustment

Note the large adjustments needed in the equatorial region and in the Southern hemisphere because the IRI model was built primarily with data from Northern latitudes.

downward adjustment



Wilkinson *et al.*, Real-time Total Electron Content estimates using the International Reference Ionosphere, ASR, 2001.

Australian Government
IPS Radio and Space Services

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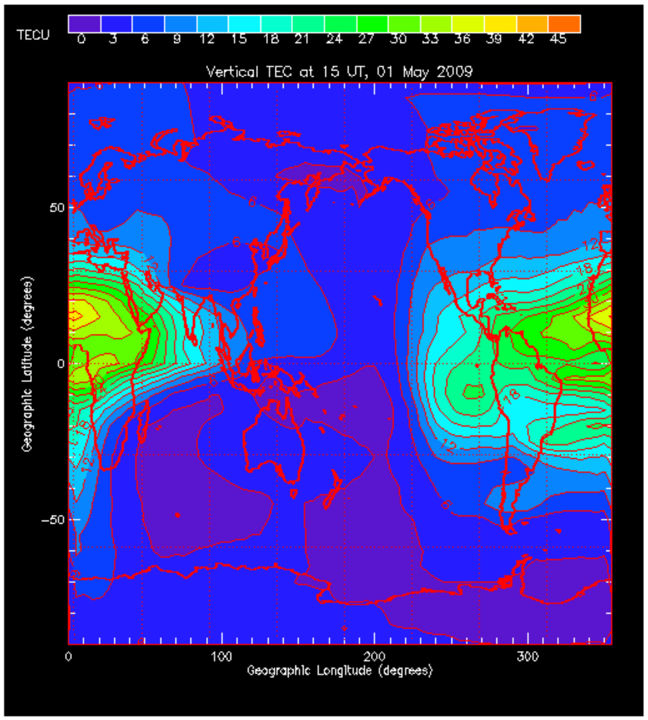
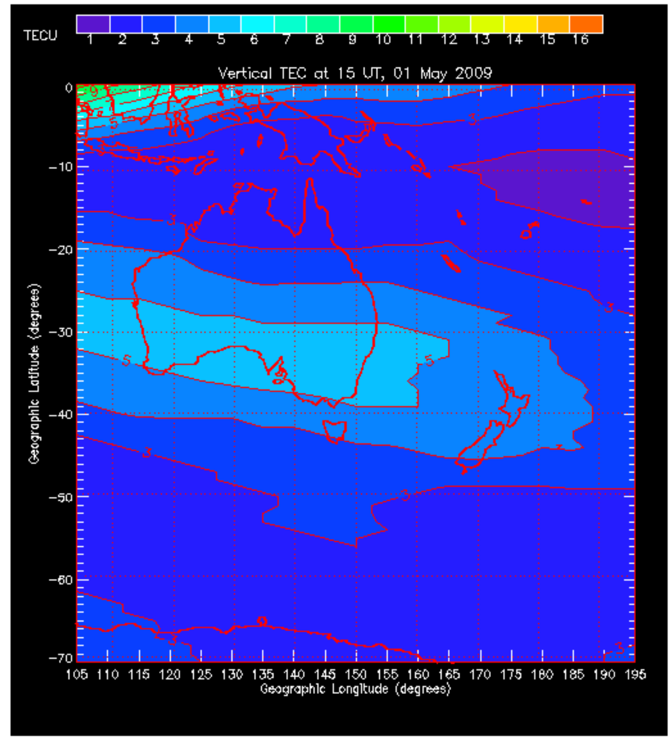
Total Electron Content
World
Updates: Every 60 minutes

TEC - World



Total Electron Content
Australasia
Updates: Every 60 minutes

TEC - Australasia



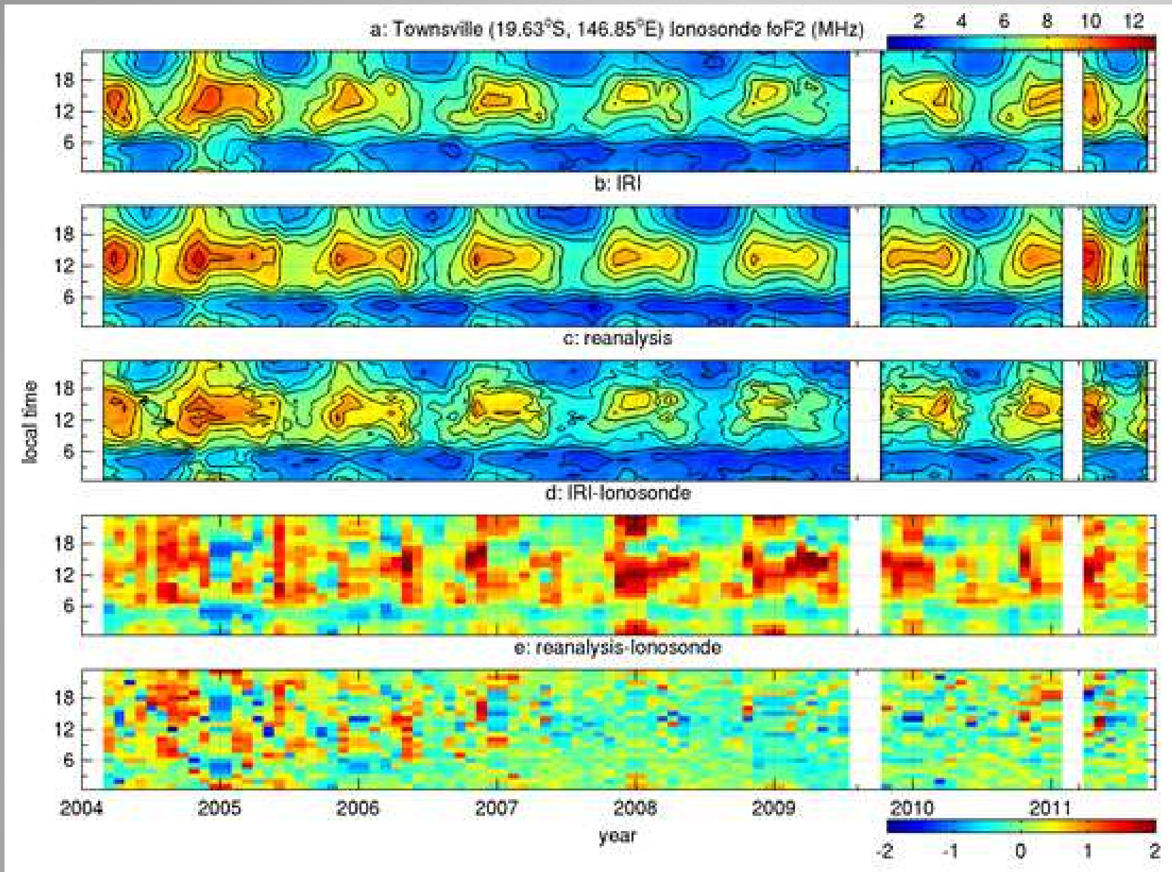
Using IRI with the ionosonde-based T index. Updated hourly.

http://www.ips.gov.au/Satellite/2/1/1

Assimilating data into IRI

TECHNIQUES
Kalman filter, Ensemble Kalman filter, Neural Net, 3-D/4-D variational techniques, Gauss-Markov, Tikhonov method and others
DATA SOURCES
Ionosondes, Radio occultation (COSMIC, CHAMP, SWARM), GPS/GNSS, Imaging (GUVI, SSUSI), In situ (CHAMP, SWARM, DMSP, C/NOFS, SWARM)
DATA ISSUES
• Data quality, discrepancies, and availability • Effect of data sparse and data intense regions • Impact of new data sources on trends

Yue et al., JGR, 2012



Monthly *foF2* (MHz)

(a) Ionosonde measurements

(b) IRI model

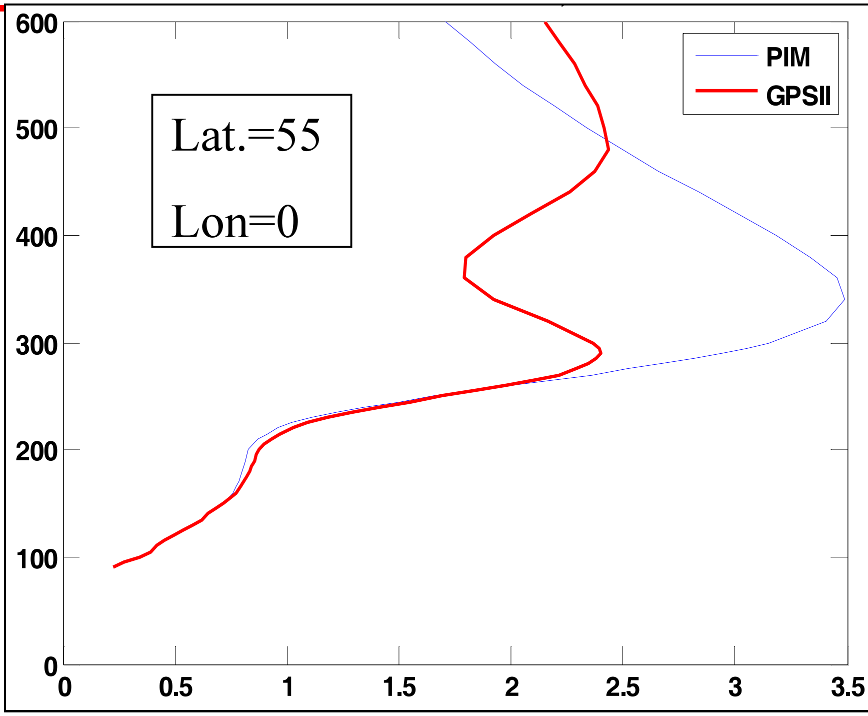
(c) IRI with data assimilation

(d) Difference between the ionosonde and IRI

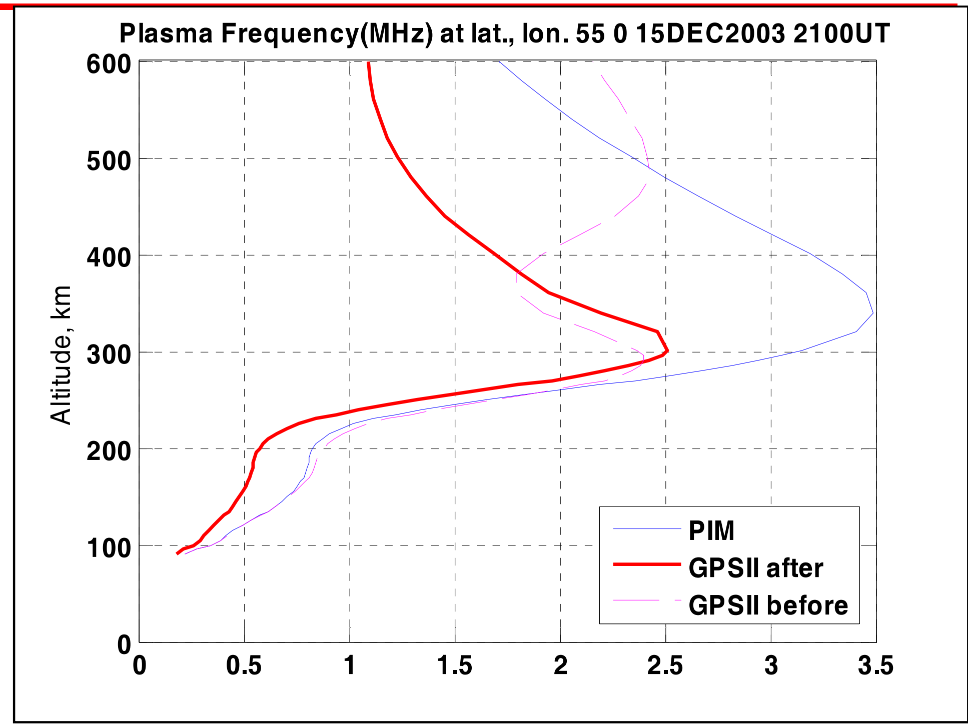
(e) Difference between ionosonde and IRI with data assimilation

Global 3-D ionospheric electron density during 2002-2011 based on assimilating TEC into the International Reference Ionosphere (IRI) 2007 model using the Kalman filter technique. Data sources include TEC from GNSS, radio occultations by CHAMP, GRACE, COSMIC, SAC-C, Metop-A, and TerraSAR-X satellites, and Jason-1 and 2 altimeter TEC measurements.

Fridman et al., RS, 2006   GPSII model, Tikhonov Method



Plasma frequency (MHz)

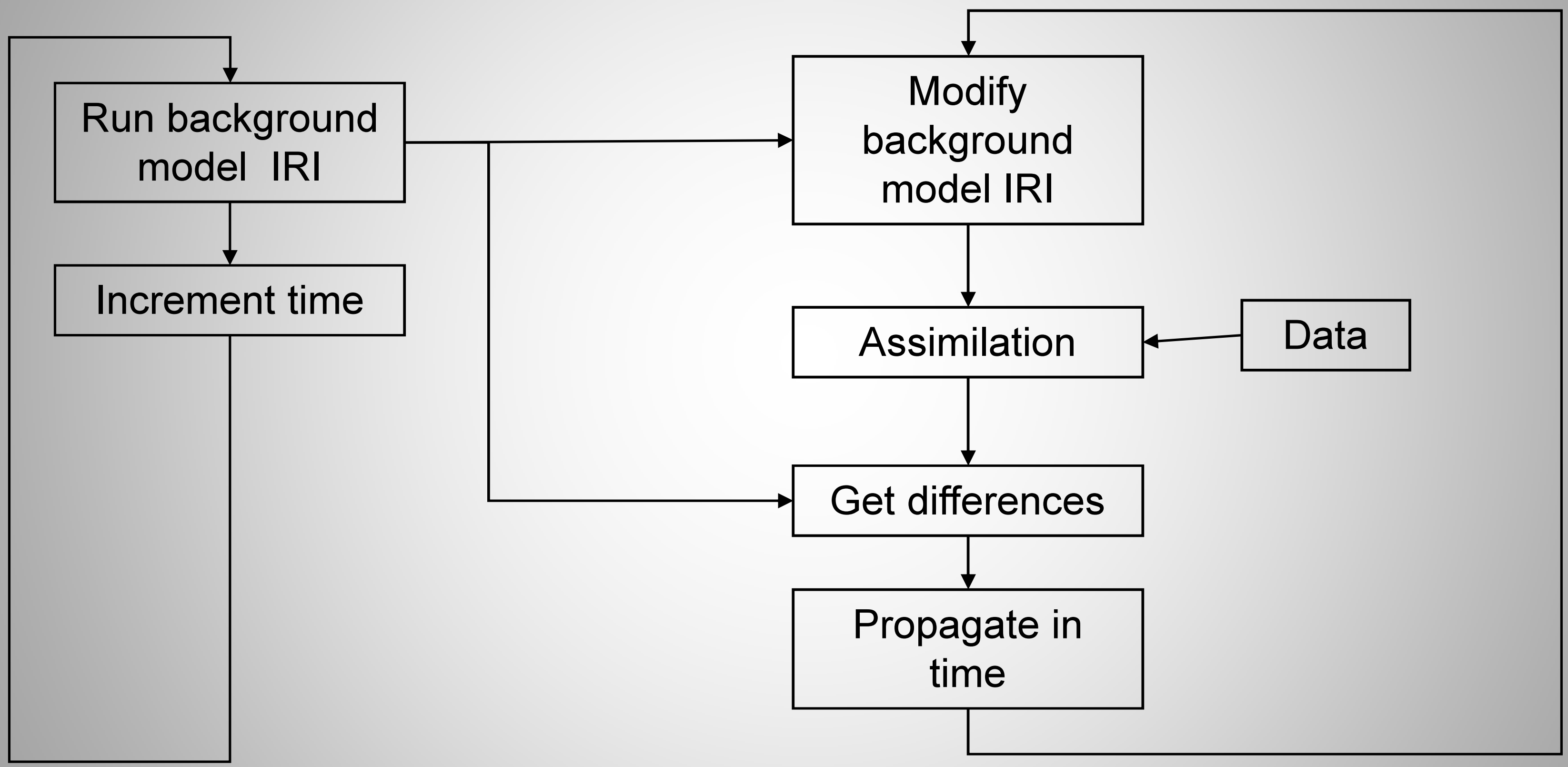


The unrealistic split of the F2-layer is caused by Ne data from CHAMP passing at 370 km altitude

The pseudo-covariance matrix was modified to communicate to the GPSII code that it should try adjusting the height of the F-layer

Angling et al., RS, 2008: EDAM- Electron Density Assimilative Model

Architecture



EDAM uses a weighted, damped least mean squares estimation (also referred to as Best Linear Unbiased Estimation – BLUE) and assimilates mostly GPS data into IRI-2007

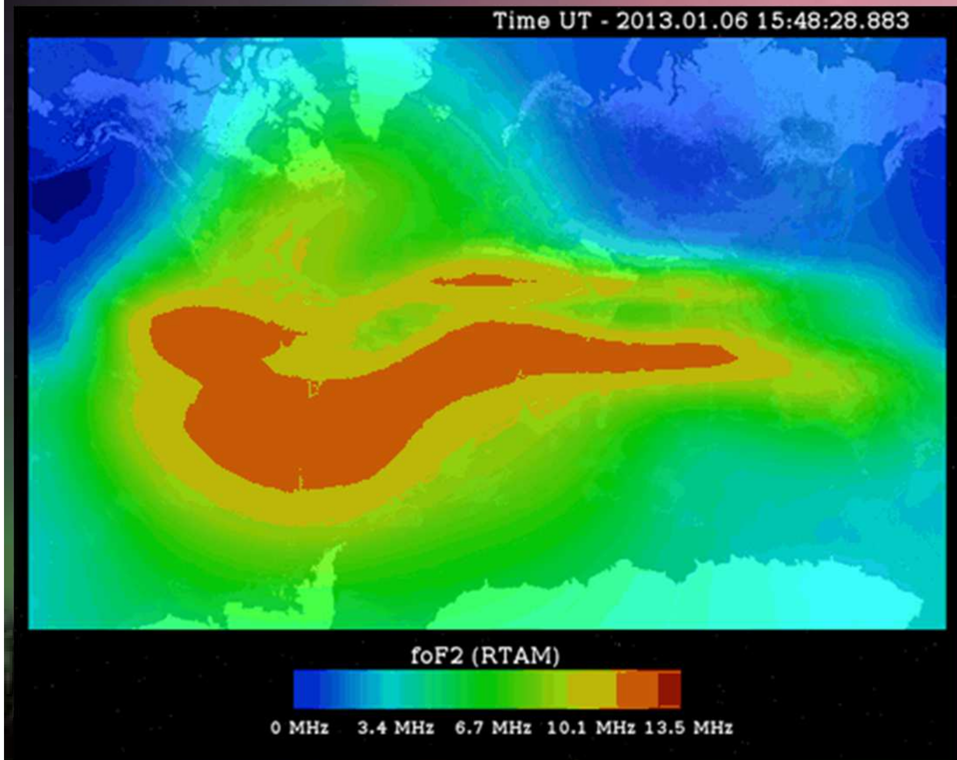
Conclusions

- IRI provides an excellent background model for EDAM
- Wish list for IRI development
  - Reduce bias in median values of NmF2 and TEC
  - Provide error estimates for values returned by IRI
  - Include a well defined median plasmasphere
  - Investigate better geomagnetic coordinate systems
  - Ensure all vertical profiles are continuous and differentiable
  - Restructure code to reduce run time

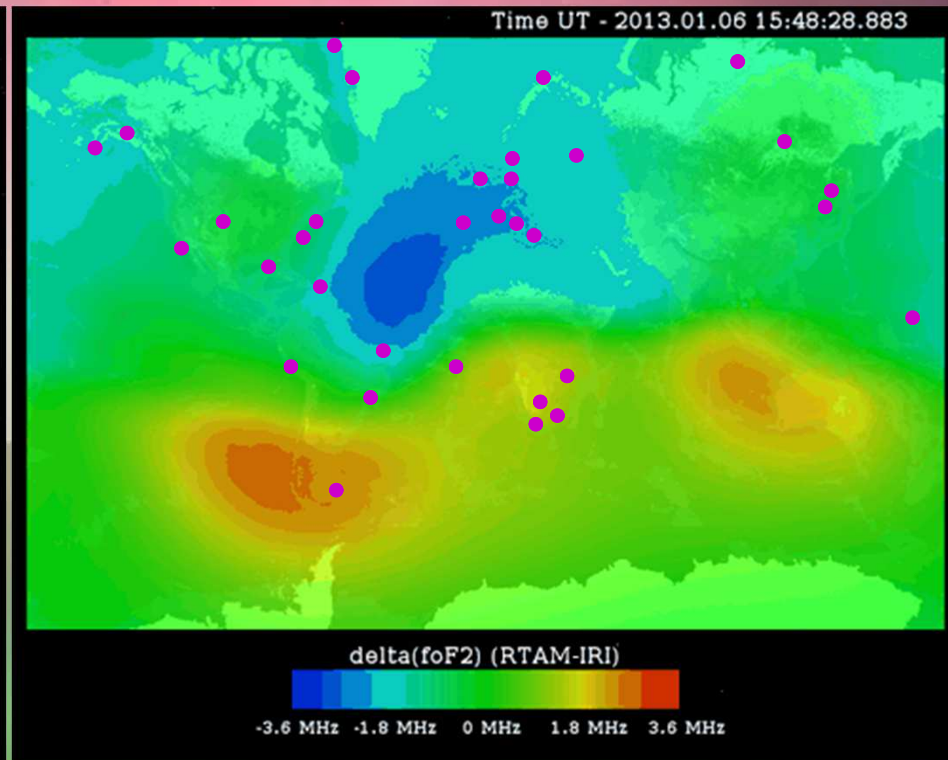
Real-Time Assimilative Mapping (RTAM) for IRI

Global Near-Real-Time F2-layer Critical Frequency

Latest 24-hour foF2



foF2: Weather minus Climate



giro.uml.edu/RTAM

IRI-RT Algorithms

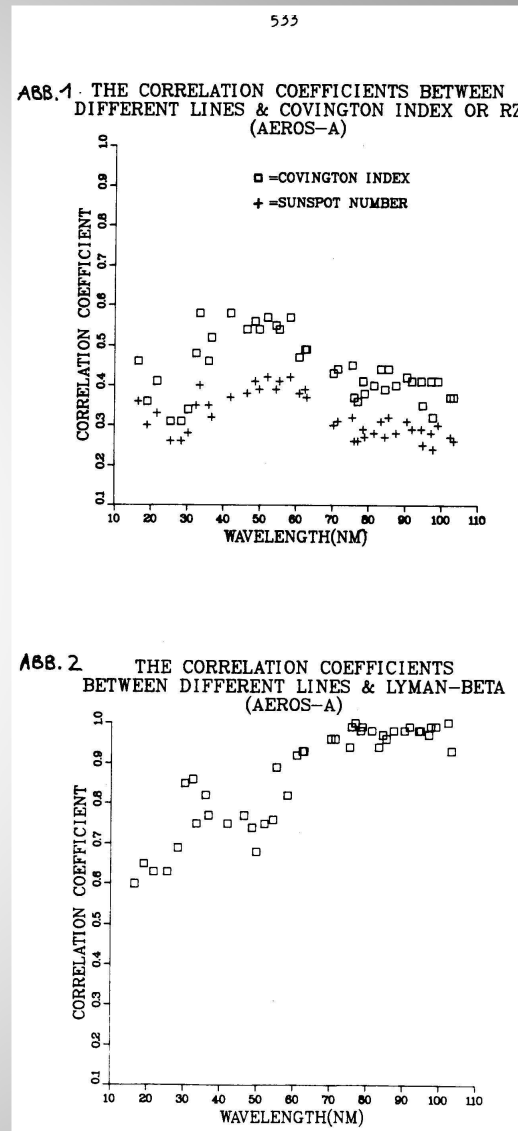
- ADJUSTING WITH DATA:
  - Bilitza et al. (1997) - Equivalent solar index (ESI) with ionosonde data
  - Komjathy et al. (1998) - ESI with GPS VTEC
  - Hernandez-Pajares et al. (2002) - ESI with GPS slant TEC
  - Nava et al. (2011) - Adjusting topside profile with GPS and NmF2 and hmF2 with ionosonde data
  - Zhang et al. (2010) - Auroral boundaries from GUVI and SSUSI
- ASSIMILATING DATA INTO BACKGROUND IRI:
  - Friedman et al. (2006) - GPSII - Tikhonov method with GPS data
  - Angling et al. (2009) - EDAM - Best Linear Unbiased Estimation (BLUE) using GPS data
  - Schmidt et al. (2008) - Multi-dimensional B-spline (scaling) functions with GPS, COSMIC, and TOPEX/Jason
  - Pezzopane et al. (2011) – ESI plus assimilation of ionsonde bottomside profiles
  - Yue et al (2012) – Kalman filter technique with COSMIC radio occultation data (also GPS-TEC, and Jason-vTEC)
  - Galkin et al. (2012) - RTAM – Real-Time Assimilative Mapping with GIRO ionosonde data employing a linear optimization of the CCIR coefficients every 15 minutes.

Problems:

(1) Differences between the solar cycle variations of *R* and *F10.7* and those of the photon fluxes in the wavelengths bands responsible for ionospheric ionization.

(2) Solar indices describe only solar influence (ionization) not dynamics of F region. Good in solar-controlled E and F1 region.

(3) Ionosonde indices work best locally or regionally; averaging over too wide a latitude range greatly diminishes the usefulness of these indices.



Data sources

- Ionosondes
- Radio occultation (COSMIC, CHAMP, SWARM)
- GPS/GNSS
- Imaging: GUVI, SSUSI
- In situ: CHAMP, SWARM, DMSP

Data issues

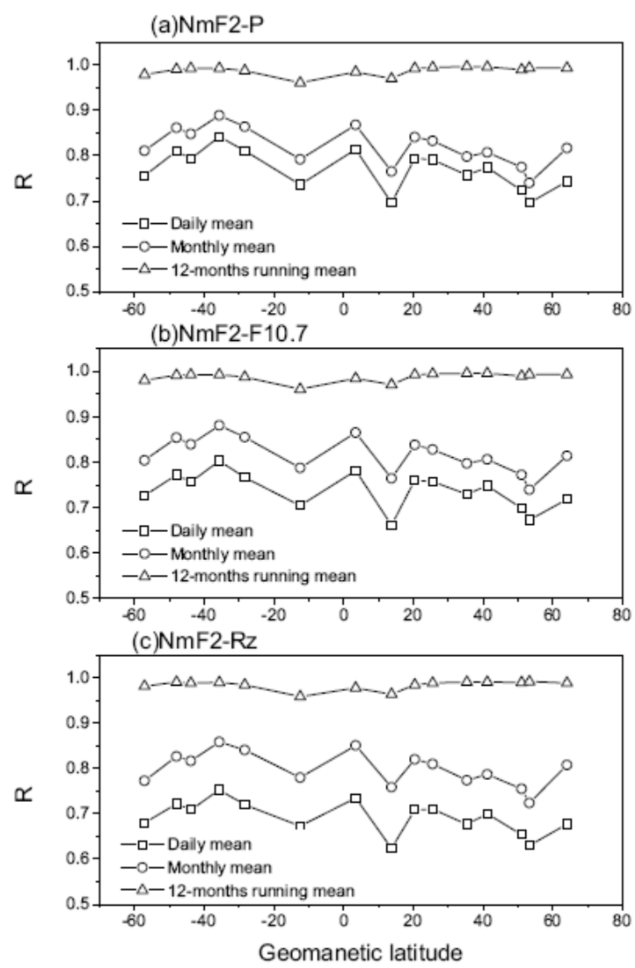
- Data quality, discrepancies, and availability
- Effect of data sparse and data intense regions
- Impact of new data sources on trends

Best correlation for highly averaged indices

IRI currently uses the
12-month-running mean
of
Sunspot Number R
and of the
Ionospheric Global index IG

Highly averaged indices show highest correlation with foF2 because the foF2 variations closely follow the 11-year solar cycle. Coupling to the 27-day solar rotation period is not as significant.

Ma *et al*., 2009



http://IRImodel.org

Rich et al., JGR, 2003: 27-day solar rotation observed in DMSP plasma density measurements at 840 km altitude

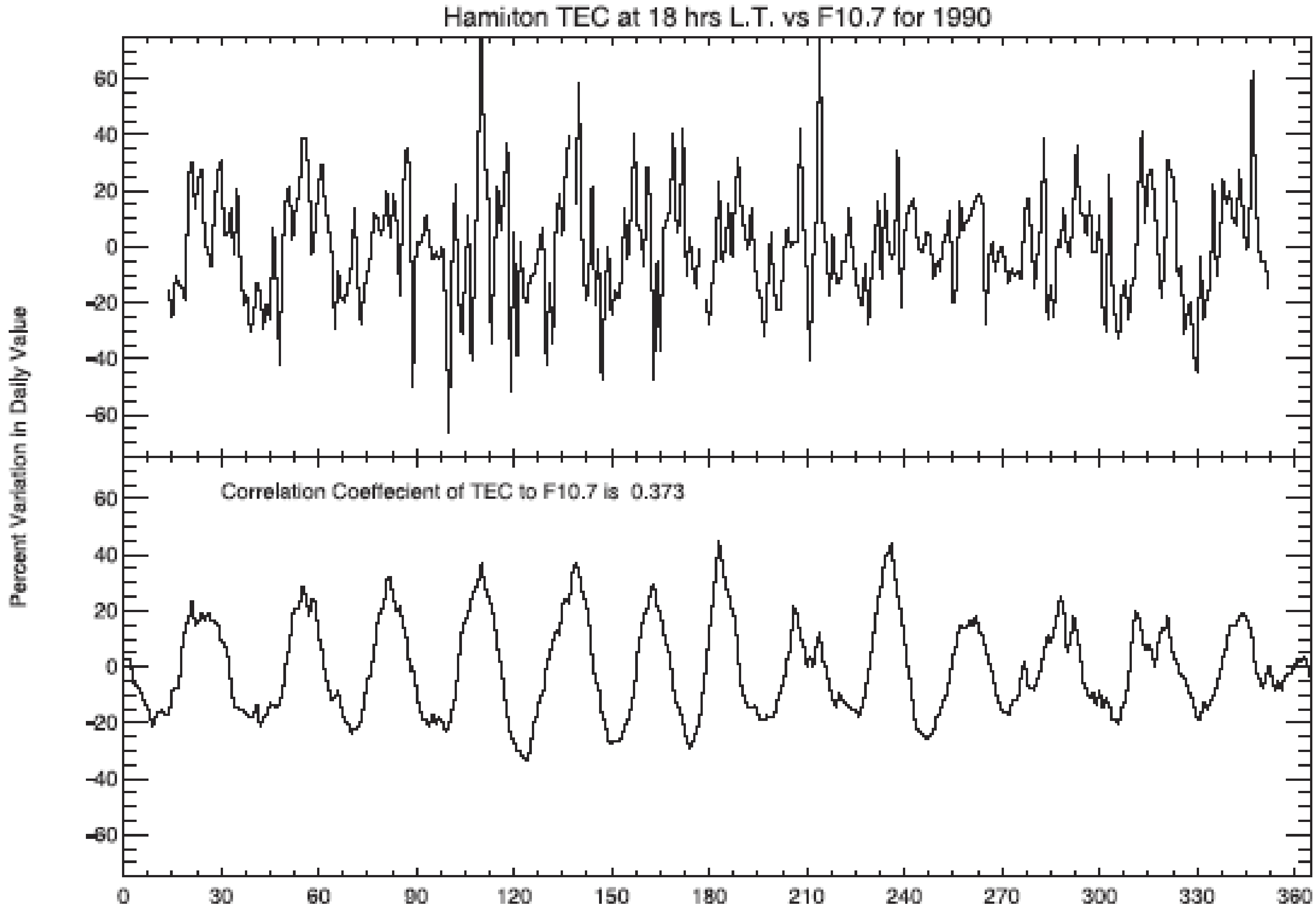


Figure 7. The total electron content (TEC) observations from Hamilton, Massachusetts, and the $F_{10.7}$ daily values for 1990 are shown as percentage variations from their respective 27-day average.

SOME RESULTS

- Intensity ratio for the 27-day variation is ~1.3 compared to ~2 for the solar cycle variation and ~2.2 for the annual variation.

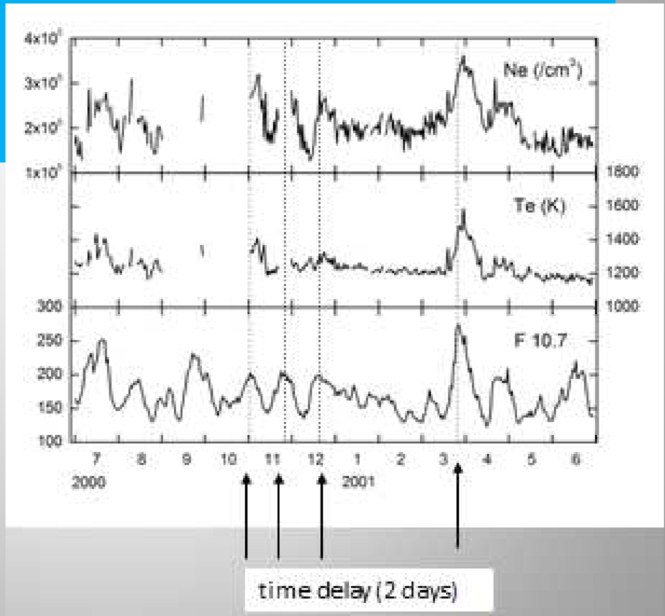
- Correlation as high as 0.82 (70% of day-to-day variability).

- Best correlation at noon worst at night.

- Longer periods of significant correlation in Fall-Winter than in Spring-Summer.

- Stronger for *foF2* than for *TEC* because of stronger influence of meteorological and geomagnetic effects at lower altitudes.

- The 27-day variation of ionospheric/ thermospheric parameters follows the solar variation with a delay of 1-5 days.



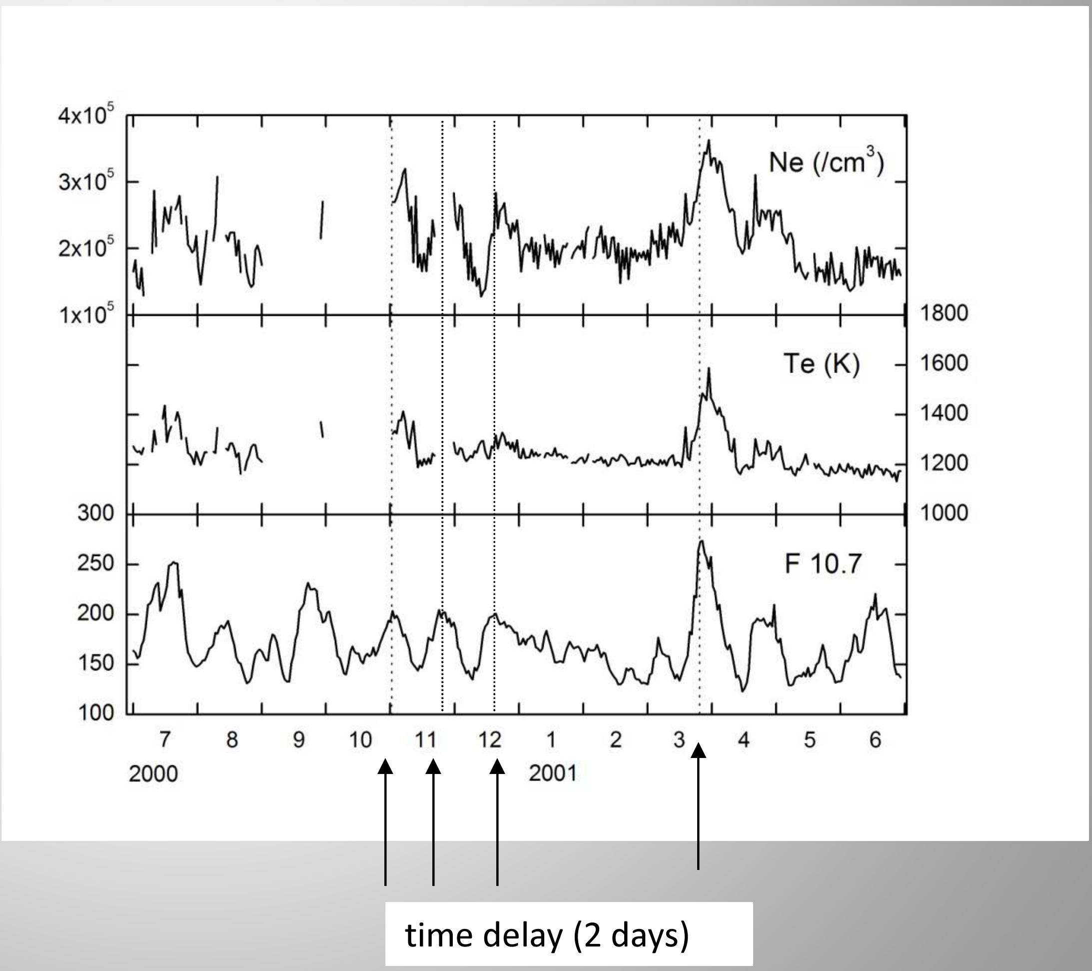
Min *et al.*, 2007: KOMPSAT measurements of topside plasma parameters at 685 km altitude show 27-day modulation and a 2-day time delay to F10.7 Shown are noon-time averages in the low magnetic latitude range for the time period July 1, 2000 – June 30, 2001 (solar maximum).

Min *et al.*, 2007: KOMPSAT measurements of topside plasma parameters at 685 km altitude show 27-day modulation and a 2-day time delay to F10.7

July 1, 2000 – June 30, 2001 (solar maximum)

Noontime averages

Magnetic latitude: 20º N - 20º



Wilkinson *et al.*, Real-time Total Electron Content estimates using the International Reference Ionosphere, ASR, 2001.

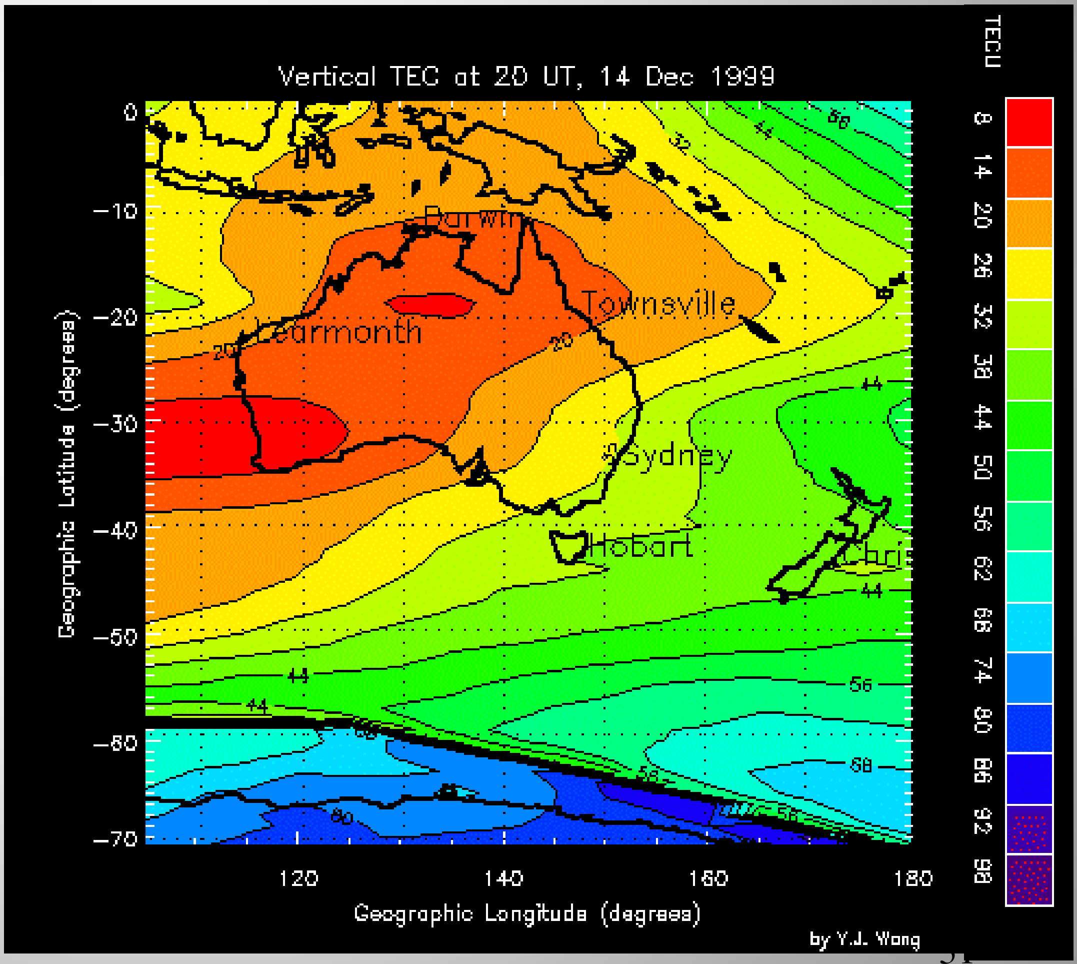
Near real-time ionospheric total electron content (TEC) maps

Australasia, North America, Europe, and World

Using IRI with the ionosonde-based T index

Updated hourly.

http://www.ips.gov.au/Satellite/2/1



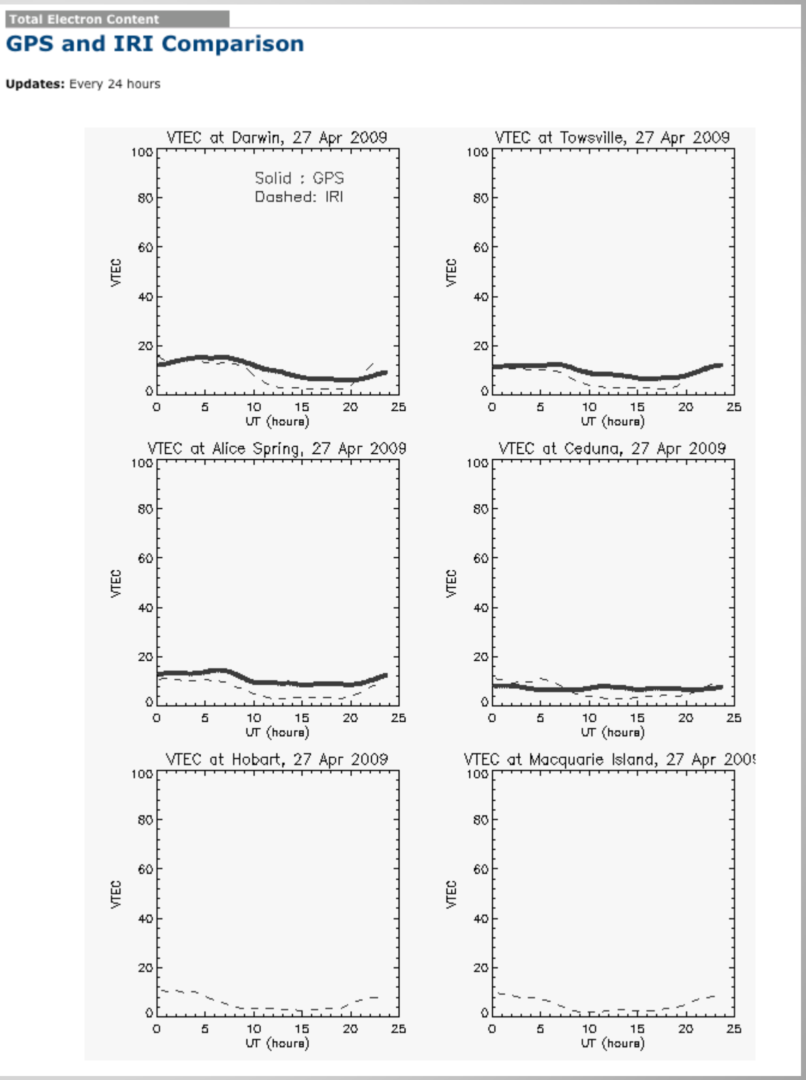
Australian Government
IPS Radio and Space Services

The Australian Space Weather Agency

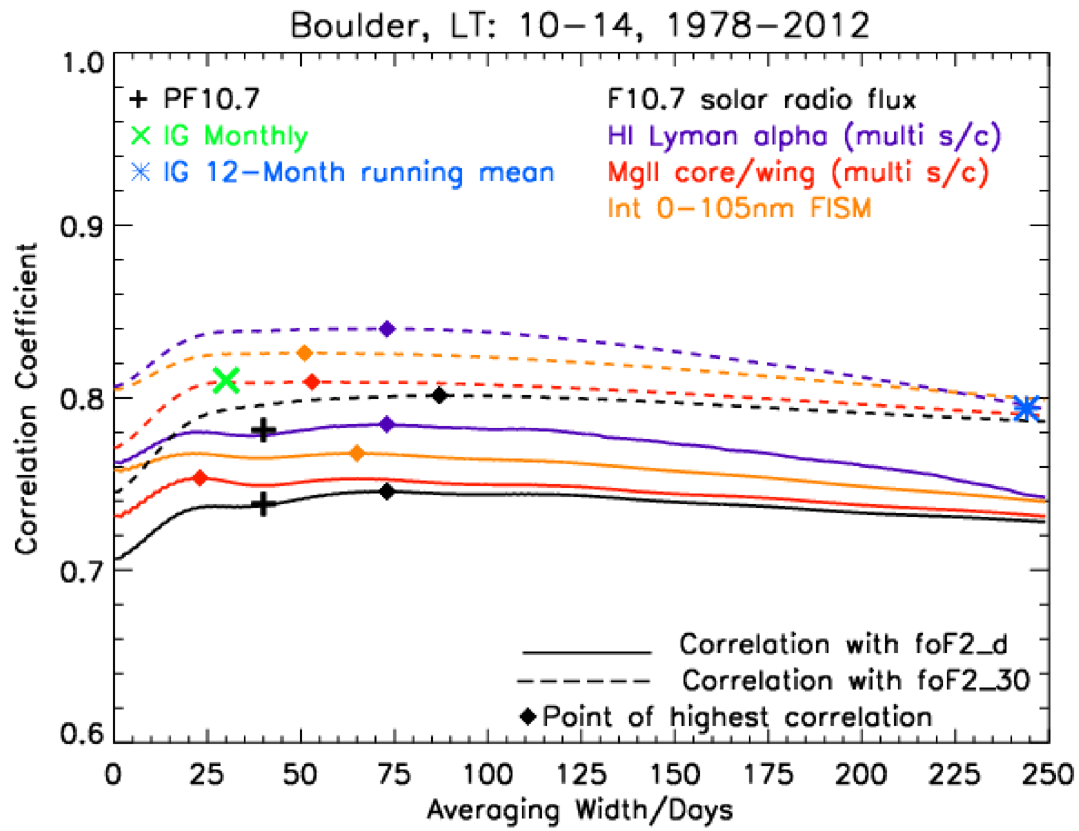
The graphs show the comparison between GPS-derived TEC (solid) and IRI/foF2 TEC values (dashed) above the stations on the day shown in the figures. The comparison provides information on the TEC accuracy of the IRI model.

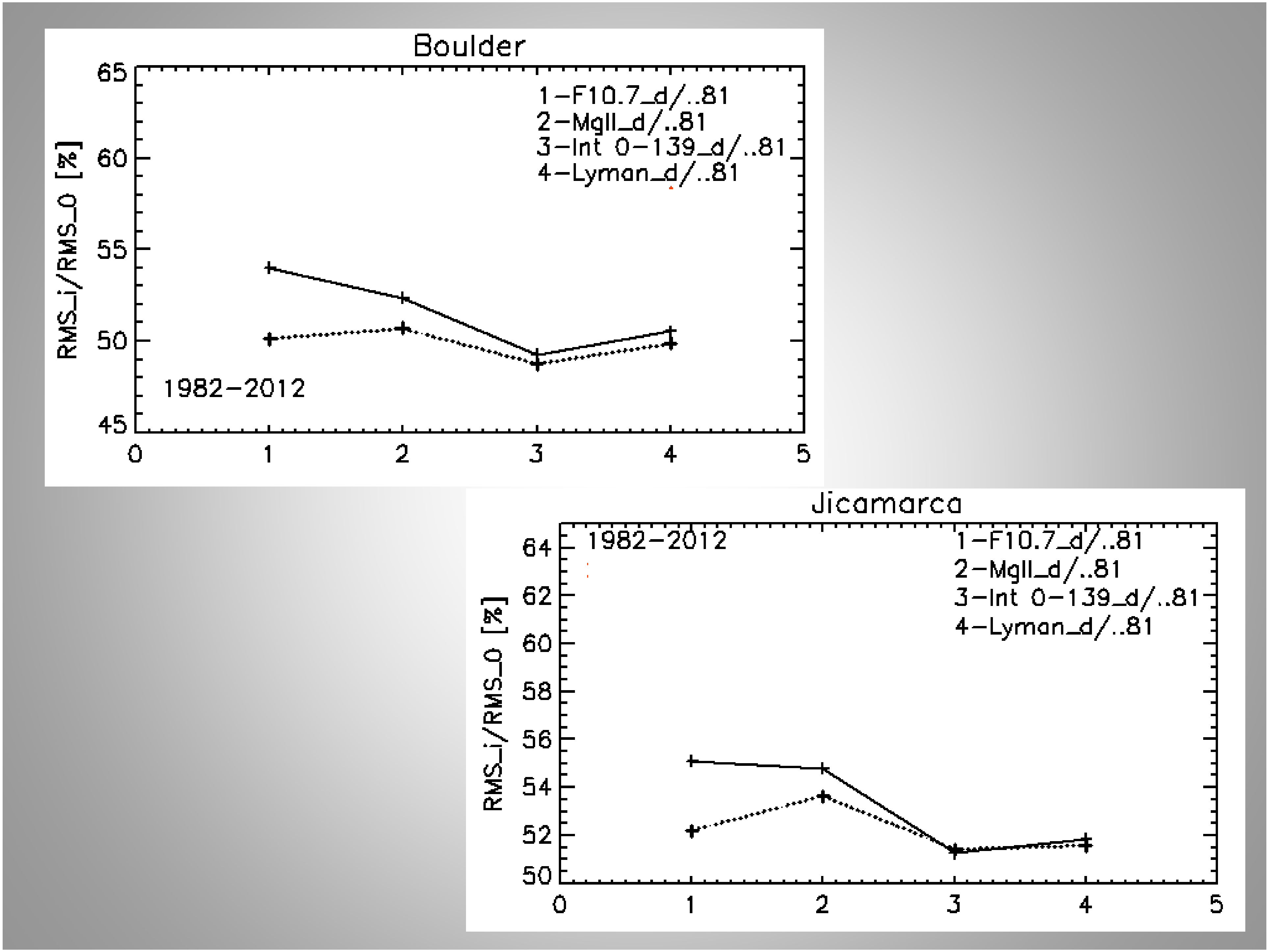
GPS-based TEC values are derived from the GPS observations by the Australian Regional GPS Network (ARGN) which is operated by the National Mapping Division (formerly AUSLIG) of GEOSCIENCE AUSTRALIA.

IRI/foF2 TEC values are computed by using the IRI-90 model, with auto-scaled foF2 ionosonde data observed in Australian region as the input parameter to the model.



Correlation with daily and monthly *foF2*:
Best index? Best averaging interval?
Diurnal and latitudinal differences?




Boulder
1-F10.7_d/..81
2-MgII_d/..81
3-Int 0-139_d/..81
4-Lyman_d/..81
RMS_i/RMS_0 [%]
1982-2012
65
60
55
50
45
0
1
2
3
4
5
Jicamarca
1982-2012
1-F10.7_d/..81
2-MgII_d/..81
3-Int 0-139_d/..81
4-Lyman_d/..81
RMS_i/RMS_0 [%]
64
62
60
58
56
54
52
50
0
1
2
3
4
5