COSMIC Profiles as Ground-Truth Data for Validation of Global Ionospheric Models

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Integrity ★ Service ★ Excellence

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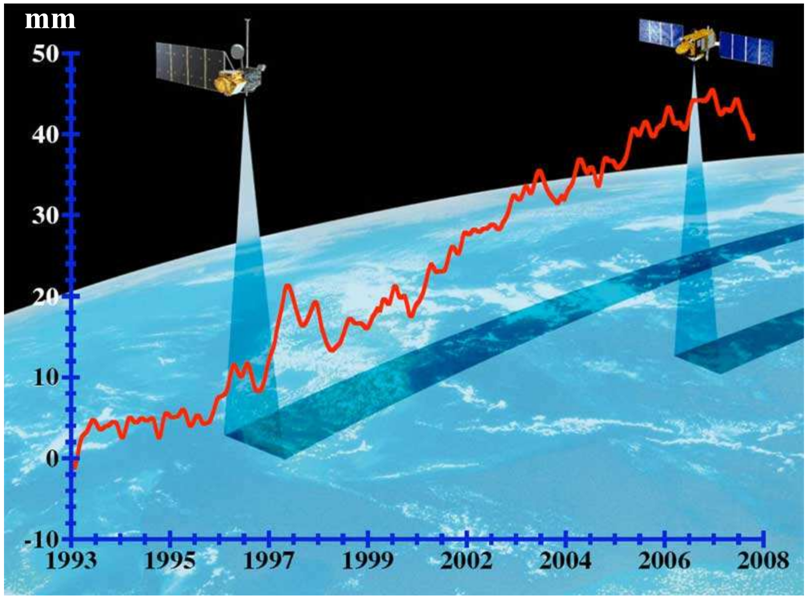
Overview

- **Global ionospheric models have limited value unless they have been independently validated against ground truth observations.**
- **AFRL/RVBX has spend a large amount of effort validating the Air Force real-time assimilative global model of the ionosphere, which is essentially the Utah State University GAIM model.**
- **Hundreds of authors have spent many hours validating different aspects of the International Reference Ionosphere.**
- **None of these validations can be successful without the availability of appropriate and reliable ground truth observations.**

Types of Ground-Truth Data

- **In situ electron density at the CHAMP satellite**
  - **PLP observations validated against Jicamarca Digisonde profiles**
- **Jason observations of vertical TEC over the ocean areas**
  - **Jason altitude is 1337 km.**
  - **GAIM vTEC is integrated up to this altitude.**
- **The maximum usable frequency (MUF) for a one-hop HF communications circuit.**
  - **Limited because of autoscaling issues**
- **Ionosonde values of foF2, M(3000)F2, and hmF2.**
  - **Mostly Australasian ionosondes**
- **Digisonde profiles**
  - **Mostly RSA and CONUS, scaled by ARTIST 5**

Ground-Truth Data [Jason]



Jason's main task is to measure the height of sea level. [~2.3 mm/year GMSL rise.]

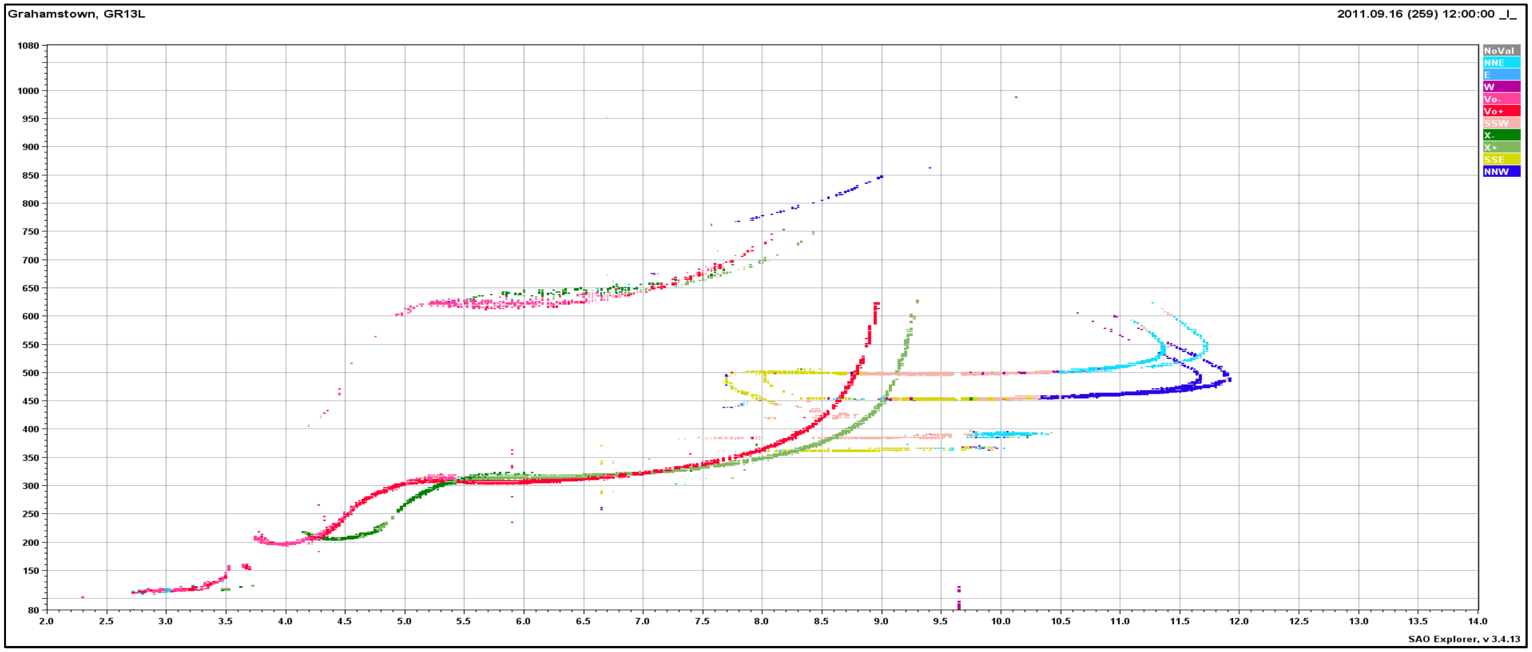
The vertical TEC (vTEC) from Jason to the sea is a by-product. Informed opinion is that the Jason values of vTEC are too high by ~4 TECU.

Jason measures vTEC only over the oceans. GPS TEC that is the prime data source for global assimilative models is mostly land-based.

Thus validating these models against Jason vTEC is a challenge for the models.

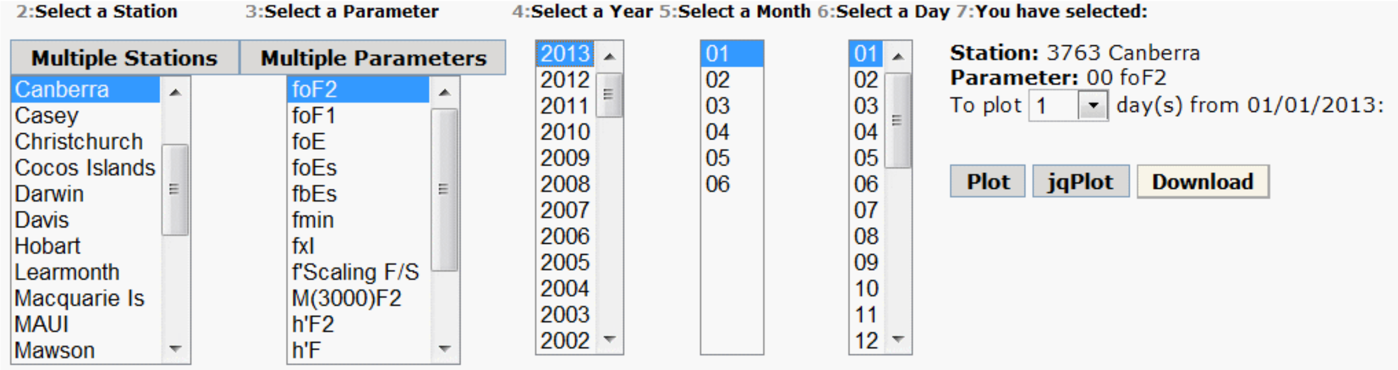
Digisonde Oblique Ionograms

- O-ray MOF from Digisonde oblique ionograms
  - Republic of South Africa HE13N->GR13L, LV12P->GR13L
  - Manual scaling only. TIDs confuse the scaling.
  - Circuit identified by O-X separation of MOFs
  - Validation requires full 3-D raytracing to determine model MOFs



COSMIC as Ground-Truth

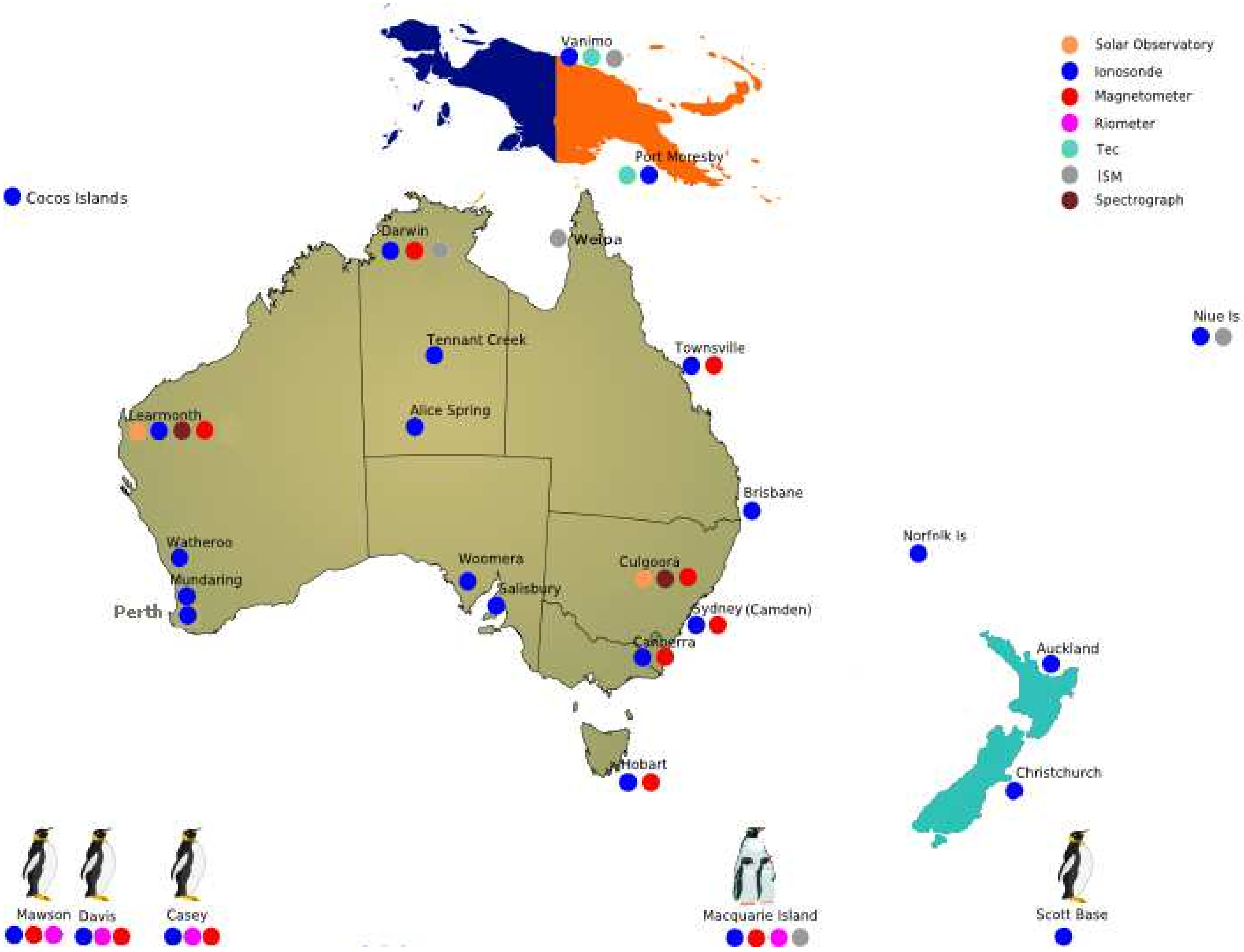
- **The COSMIC profiles and peak parameters foF2 and hmF2 are potential global sources of ground-truth data.**
- **We concentrate here on the <u>COSMIC values of foF2 and M(3000)F2.</u>**
- **We use the Australian ionosonde network observations of foF2 and M(3000)F2 to validate the COSMIC observations.**
- **<u>http://www.ips.gov.au/World_Data_Centre/1/3</u>**
- **Later data overlaps COSMIC era.**



2:Select a Station 3:Select a Parameter 4:Select a Year 5:Select a Month 6:Select a Day 7:You have selected:

Station: 3763 Canberra
Parameter: 00 foF2
To plot 1 day(s) from 01/01/2013:

Australian Ionosonde Network



Filtering of COSMIC Data

- foF2 Observations
  - The IPS ionogram data database contains only hourly values, all hand-scaled.
  - The COSMIC observations are required to lie within 3° latitude and 5° longitude of an ionosonde site.
  - The COSMIC epoch is required to be within 15 minutes of a UT hour.
- M(3000)F2 Observations
  - The COSMIC observations are required to lie within 3° latitude and 5° longitude of an ionosonde site.
  - The COSMIC epoch is required to be within 15 minutes of a UT hour.
  - The 3° by 5° restriction is applied to the location of the COSMIC layer peak, as well as to the first point in the profile.
- Profiles
  - The part of the profiles below 150 km was ignored (very irregular)
  - Profiles with negative electron densities were completely excluded
- There are multiple exclusion philosophies.

Australian Ionosonde Network

Site	Latitude	Longitude	Dip Latitude	ID
Vanimo (PNG)	-2.70	141.30	-11.2	3546
Moresby (PNG)	-9.4	147.1	-18.0	3750
Darwin (Aus)	-12.45	130.95	-23.2	3351
Townsville (Aus)	-19.63	146.85	-29.8	3755
Learmonth (Aus)	-22.25	114.08	-36.6	2856
Brisbane (Aus)	-27.53	152.92	-38.2	3859
Norfolk I. (Aus)	-29.03	167.97	-37.0	4260
Mundaring (Aus)	-31.98	116.22	-49.0	2961
Canberra (Aus)	-35.32	149.0	-48.6	3763
Hobart (Aus)	-42.92	147.32	-58.1	3766
Juliusruh (Germany)	+54.60	13.40	+52.9	0318

Table 1. Locations of ionosondes considered in the comparisons. Some stations have been closed. Vanimo closed in 2009.

The MUF Slider

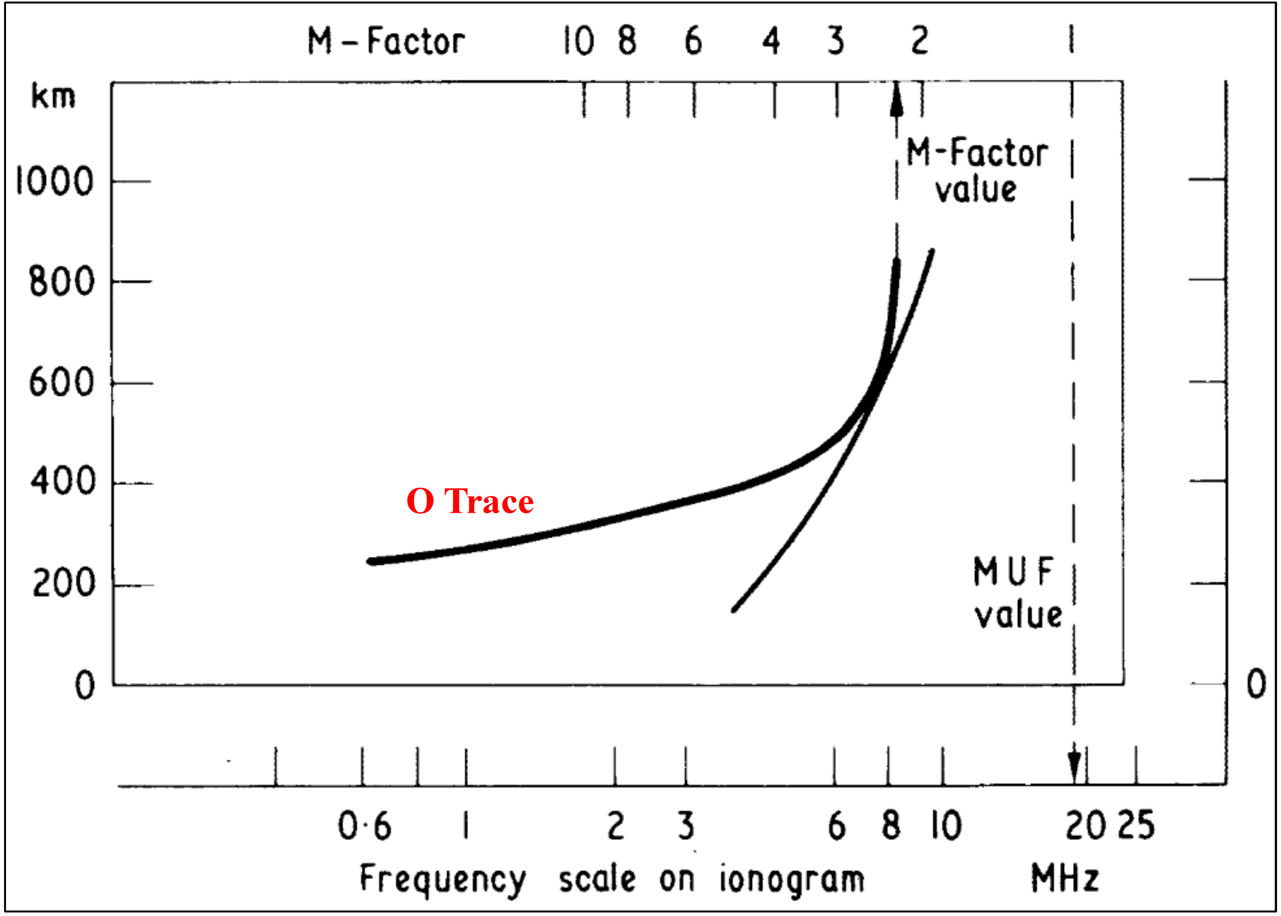


Figure 1. Sketch of the MUF slider and an ionogram

Calculating the COSMIC M(3000)F2

- **The calculation of the COSMIC value of M(3000)F2 starts with the COSMIC profile, and has two steps:**
  - **[1] Calculate the O-ray VI ionogram by integrating the group refractive index up to the reflection height**
  - **[2] Derive the value of M(3000)F2 from the O-ray trace**
- **[1] Numerical integration is required, with several changes of variable, to produce the O trace.**
  - **A subroutine GIND that calculates [μ'-1] is part of John Titheridge's POLAN.**
- **[2] The procedure for deriving M(3000)F2 from the ionogram is discussed in the reference:**
  - **McNamara, L. F., D. T. Decker, J. A. Welsh, and D. G. Cole (2007), Validation of the Utah State University Global Assimilation of Ionospheric Measurements (GAIM) model predictions of the maximum usable frequency for a 3000 km circuit, Radio Sci., 42, RS3015, doi:10.1029/2006RS003589.**

$$\mathrm{M}(h') = (67.6542 - 0.014938\ h')/(h')^{1/2}$$

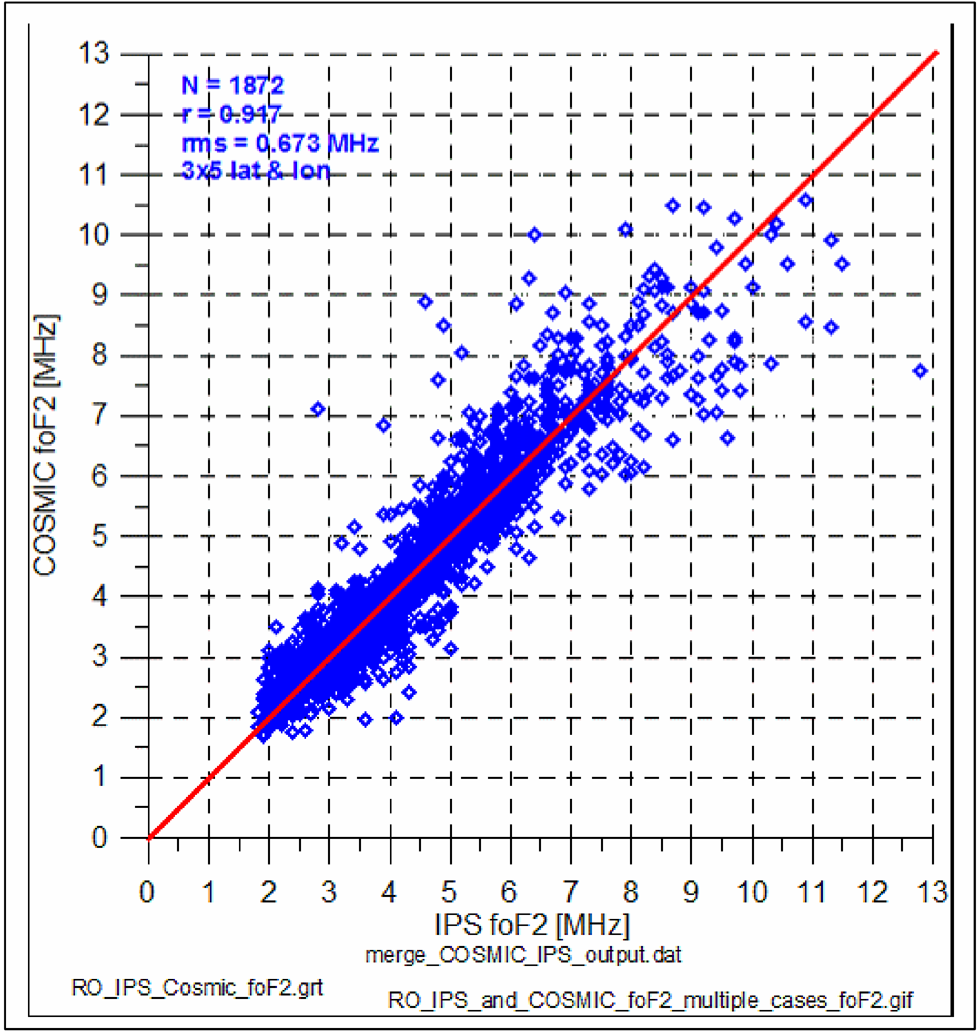
Adolf Paul

COSMIC vs. Ionosonde foF2

STAT	##	LAT	LON	DIPL	RMS	AVER	SIGMA	CORREL
3546	119	-2.70	141.30	-11.20	1.648	-0.429	1.591	0.783
3750	17	-9.40	147.10	-18.00	0.453	-0.010	0.453	0.971
3351	125	-12.45	130.95	-23.20	1.046	0.263	1.012	0.911
3755	250	-19.63	146.85	-29.80	0.608	0.070	0.604	0.933
2856	174	-22.25	114.08	-36.60	0.601	0.145	0.583	0.943
4260	201	-29.03	167.97	-37.00	0.435	0.010	0.435	0.949
3859	221	-27.53	152.92	-38.30	0.546	-0.210	0.504	0.929
3763	175	-35.32	149.00	-48.60	0.391	-0.087	0.382	0.941
2961	94	-31.98	116.22	-49.00	0.374	-0.145	0.345	0.952
0318	254	+54.60	13.40	52.90	0.349	0.037	0.347	0.949
3766	242	-42.92	147.32	-58.10	0.473	0.140	0.452	0.938

Table 2. Details of the correlations between the COSMIC and ionosonde values of foF2 for the individual ionosonde locations. Note that station 0318 (Juliusruh) is in Germany. It has the smallest RMS errors. The station IDs are related to the physical station in Table 1.

Corresponding Values of foF2



N = 1782

r = 0.917

RMS = 0.673 MHz

Figure 2. Overall comparison between the COSMIC and ionosonde values of foF2, 2007, and 2008

The Values of M(3000)F2

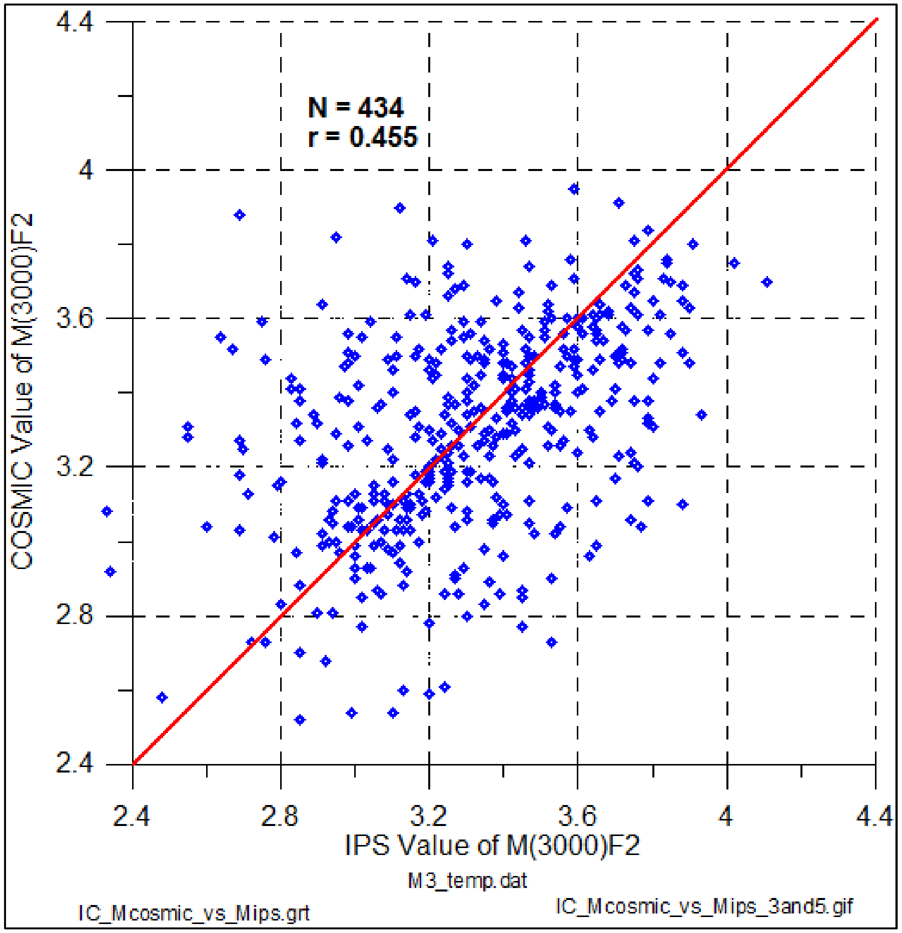


Figure 3. Overall comparison between the COSMIC and ionosonde values of M(3000)F2, January-June 2008

N = 434; r = 0.455

The average ionosonde and COSMIC values of M(3000)F2 are 3.32 and 3.36, so the average difference is small, at 0.04.

However, the standard deviation of the differences is 0.31, or about 10%.

An uncertainty of 0.31 in M(3000)F2 corresponds to ~40 km in hmF2 (Shimazaki formula).

Real-Time Use of COSMIC Observations

- **The COSMIC data can be used as either assimilation data for global ionospheric models or as ground-truth data for model validation.**
- **The Latency of the COSMIC data is an issue for real-time assimilative ionospheric models, as it is with all satellite *in situ* data.**
  - **Latency is the time between the observation and the time at which an updated ionospheric model is made available to users. This is typically 90 to 120 minutes.**
  - **The model must forecast the contribution of the COSMIC data 90 to 120 minutes into the future.**
  - **Ground-based observations [Digisondes; GPS TEC] have very little latency, but they cover only 20% of the Earth.**
- **This latency is irrelevant if the COSMIC data is used as ground-truth data.**
- **The COSMIC data must first be validated off-line, on historical data, establishing representative error bars that can be applied to similar geographical regions and seasons.**

Summary

- **The objective of our study was to determine if COSMIC observations could be used as ground truth for validation of ionospheric models.**
  - Comparisons of <u>filtered</u> COSMIC observations of foF2 with manually scaled Australian ionosonde values showed good agreement, especially at mid latitudes.
  - The <u>foF2 RMS error was less than 0.4 MHz</u>, so the COSMIC values of foF2 could be used as observed values for validation studies that can tolerate this level of accuracy.
  - The errors were significantly larger at low latitudes [1.65 MHz for Vanimo, -2.7° lat].
- **The Australian data does not include hmF2, so we have used M(3000)F2.**
- **The COSMIC errors in M(3000)F2 were too large for the COSMIC values to be used as ground truth.**
  - The RMS error was ~0.31.
  - The day-to-day variability of M(3000)F2 at Learmonth, for example, is ~0.5, not much larger than the COSMIC RMS error.
  - Similar studies by other groups using the Australian data and other methods of filtering the COSMIC data are encouraged.