International Reference Ionosphere

Electron density, ion composition, electron and ion temperature, vertical electron column density

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irimodel.org

IRI – Terms of Reference

☆ IRI is an international project jointly sponsored by the *Committee on Space Research (COSPAR)* and the *International Union of Radioscience (URSI)* to develop and improve a reference model for the most important plasma parameters in the Earth ionosphere

☆ COSPAR's prime interest is in a general description of the ionosphere as part of the terrestrial environment for the evaluation of environmental effects on spacecraft and experiments in space.

☆ URSI's prime interest is in the electron density part of IRI for defining the background ionosphere for radiowave propagation studies and applications.

☆ By charter the model should be primarily based on *experimental evidence* using all available ground and space data sources and should not depend on the evolving theoretical understanding of ionospheric processes.

☆ As new data become available and as older data sources are fully evaluated and exploited, the model should be *revised* in accordance with these new results.

☆ Where discrepancies exist between different data sources the IRI team should facilitate critical review and discussions to determine the *reliability of the different data sets* and to establish guidelines on which data should be used for IRI modeling.

IRI Working Group Members

60+ members representing ground and space measurement techniques and 26 countries

Which Parameters in What Range?

IRI describes monthly averages of

- electron density
- electron temperature
- ion temperature
- ion composition (O^+, H^+, He^+, N^+, NO^+, O_2^+, Cluster ions)

IRI represents variations with

- altitude (50km – 2000 km)
- latitude, longitude (geographic or geomagnetic)
- date and time of day

External drivers:

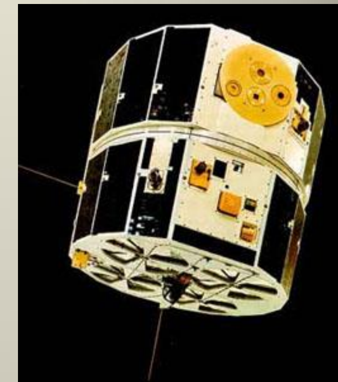
- solar indices (F10.7, sunspot number)
- ionospheric index (IG)
- magnetic indices (ap and kp)

Additional output parameters:

- vertical ionospheric total electron content (vITEC)
- ion drift at equator
- occurrence probability for spread-F and for F1 layer

Data Sources

Instrument	*Platform*	*Parameter*	*Comments*
Ionosonde	Worldwide ~170 stations	N_e from E to F peak	From fifties to now
Incoherent Scatter Radar	Jicamarca, Arecibo, EISCAT Millst. Hill, Kharkiv	N_e whole profile incl. E-Valley T_e, T_i N_i, v_i	Few radars, Many param. Also: Malvern, St. Santin, Sondrestrom
Topside Sounder	Alouette 1, 2 ISIS 1, 2	N_e topside profile	Newer data from Ohzora, ISS-b, IK-19
Insitu	AE-C,-D,-E Aeros-A,-B IK-24, DE-2	N_e, T_e, T_i, N_i, v_i	many more: DMSP, TIMED
Rocket	Rocket data compilations	D-region parameters	sparse data set
GNSS	Glob. Ground sta. network	TEC	GPS, Glonass Baidou,Galileo
LEO GPS (radio occultation)	COSMIC, CHAMP, others	Ne profile	data quality issues



IRI-2012:

model providers, their affiliation, country and the year of the related publication

Parameter	Region	Main Author	Institution	Country	Year
Ne	D-Region	Bilitza	IPW, Freiburg	Germany	1981
		Friedrich	TU, Graz	Austria	2001
		Danilov	IAG, Moscow	Russia	1995
	E-Peak	Kouris	U Thessaloniki	Greece	1973
		Bilitza	IPW, Freiburg	Germany	1990
		Mertens	NASA, Langley	USA	2013
		McKinnell	SANSA, Hermanus	South Africa	2006
	E-valley	Bilitza	IPW, Freiburg	Germany	1990
	F1-layer	Scotto	INVG, Rome	Italy	1997
		Ducharme	CRC, Ottawa	Canada	1973
		Reinisch&Huang	UML, Lowell	USA	2000
	Bottomside	Bilitza&Radicella	ICTP, Trieste	Italy	2000
		Gulyaeva	IZMIRAN, Moscow	Russia	1987
		Altadill	Ebro Obs, Ebro	Spain	2008
	foF2	Jones&Gallet	ITSA/ESSA, Boulder	USA	1965
		Rush	ITS, NTIA, Boulder	USA	1989
		Fuller-R&Araujo-P	CIRES/SWPC, Boulder	USA	2002
	M(3000)F2	Jones&Gallet	ITSA/ESSA, Boulder	USA	1965
	hmF2	Bilitza&Eyfrig	IPW, Freiburg	Germany	1979
	Topside	Rawer&Ramakrishna	IPW, Freiburg	Germany	1978
		Bilitza	Raytheon, Reston	USA	2004
		Radicella&Coisson	ICTP, Trieste	Italy	2001, 2006
Te	Whole	Bilitza	IPW, Freiburg	Germany	1981
	Topside	Truhlik	IAP, Prague	Czech Republic	2012
	Plasmasphere	Kutiev&Oyama	ISAS, Tokyo	Japan	2002
Ti	Whole	Bilitza	IPW, Freiburg	Germany	1981
Ni	Whole	Rawer	IPW, Freiburg	Germany	1978
	Whole	Danilov	IAG, Moscow	Russia	1985, 1995
	Topside	Triskova	IAP, Prague	Czech Republic	2003
	Bottomside	Richards	GMU, Fairfax	USA	2010
Spread-F		Abdu&Souza	INPE, Sao Jose Campos	Brazil	2003
Auroral Boundaries		Zhang	APL, Baltimore	USA	2010

Built-up of the IRI electron density profile

Mathematical functions:

Global Variations:

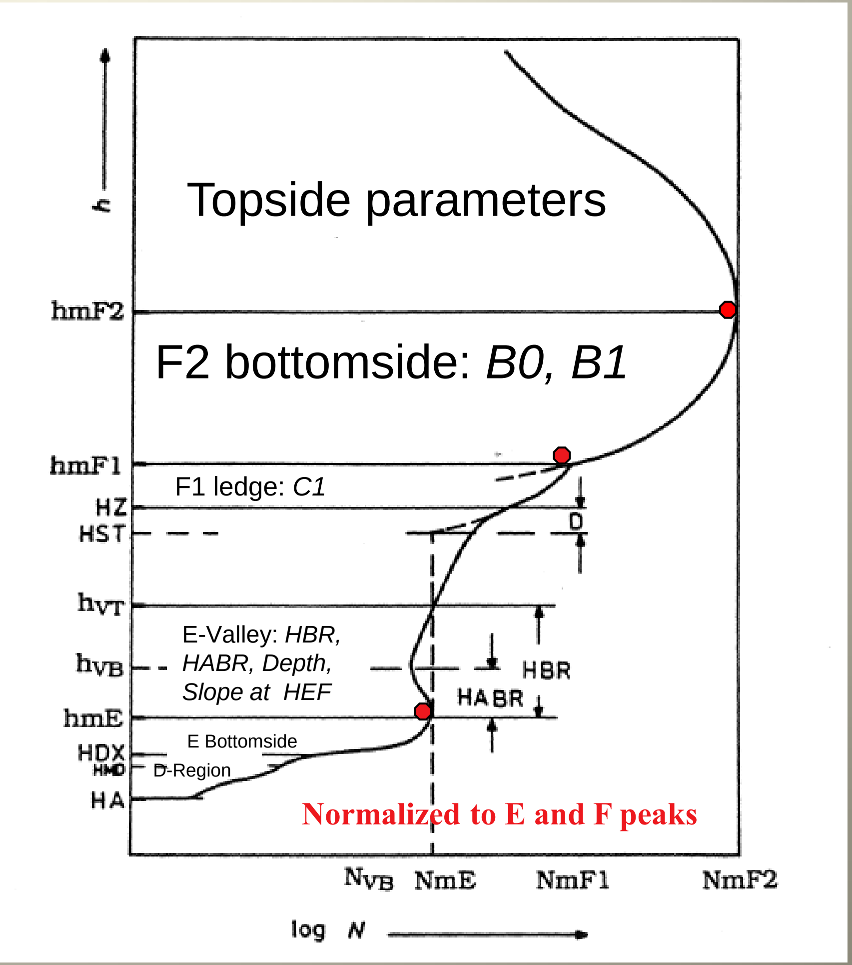
- Special spherical harmonic functions using modified magnetic coordinates (modip, invdip)
- Interpolation/transition functions (Epstein, others)

Time Variations:

- Harmonics of different order
- Smooth transitions between day and night values (Epstein)

Height Variations:

- Epstein skeleton function approach
- Chapman function (varying scale-height)



Global models for anchor points:

foF2/NmF2 foF1/NmF1, foE/NmE, foD/NmD, hmF2/M(3000)F2, hmF1 , hmE, hmD

IRI Specifics

☆ **Combining the global picture recorded by satellites for different LTs and levels over solar activity with the 24/7 356 analysis provided by ground stations.**

☆ **Modular approach, e.g., global models for profile anchor points: Te at different heights from ISIS, AE, IK connected by Epstein skeleton function.**

☆ **Options to switch on a different model: 3 model options for hmF2 using different data sources (Ionosonde M(3000)F2 or hmF2, COSMIC/RO); 3 model options for topside Ne profile using different formalism.**
New, better models are easily phased in with validation help from the users

☆ **Avoid introducing interdependence between parameters because replacing one parameter model will affect the related parameter.**

☆ **IRI drivers: F10.7 (daily, 81-day, 356-day), R (13-month), IG (13-month), Ap, Kp (3-hour, daily)**

☆ **User input of measured parameters: NmF2/foF2, hmF2/M(3000)F2, NmF1/foF1, NmE/foE, hmE, NmD/foD, hmD, B0**

IRI +/-

- \+ Synthesis of almost all available and reliable ionospheric data.
- \+ Widely used and validated; IRI is often the reference against which a satellite/rocket team compare their new data.
- \+ Recognized standard by COSPAR, URSI, ITU, ECCS, and ISO
- \+ Improvements continue as new data become available.
- \+ Includes effects not yet discovered/explained by theory (4-wave pattern, Weddell Sea and Yakutsk Anomalies)
- \+ IRI team's global distribution guarantees access to the global data base
- \+ Fared very well in model validation studies including the CEDAR Challenge

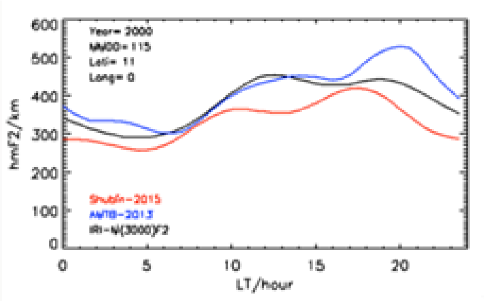
- − Only as good as the data foundation on which it was build.
  - − Bias towards Northern mid-latitudes.
  - − Data-sparse regions/times require inter/extra-polation
  - − Recent very low and broad solar minimum brought conditions not covered by previous solar minimum data sets.
- − Funding

IRI-2016

New options for hmF2

(1) Altadill et al. (2013)

- Data from 26 digisonde stations 1998–2006.
- Spherical harmonics in longitude/LT and latitude. Total of 610 coefficients including variation with solar activity and season
- Screen points (24) along stations' modip lines.
- New model improves the fit to the observations by 10% on average compared to old IRI, and by up to 30% at high and low latitudes.



Evening peak well developed in AMTB and Shubin but at different times.

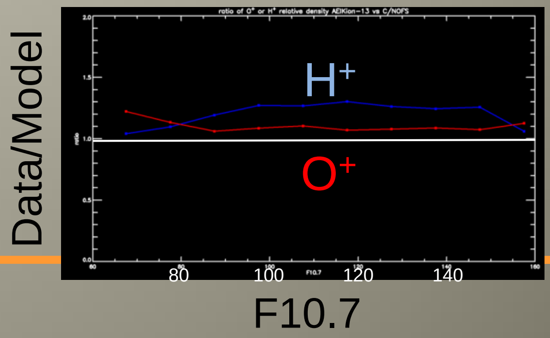
(2) Shubin (2015)

- Radio-occultation data from CHAMP (100,000 profiles), GRACE (70,000) and COSMIC (2,000,000)
- Legendre expansion in latitude and UT Fourier expansion ; total of 149 coefficients
- RMS between data and model is 10–16 km (3-4%), IRI: 13–29km (9-12%) ~10% of RO hmF2 values were discarded because of data quality issues

Improvement of ion composition

Truhlik et al. (2013)

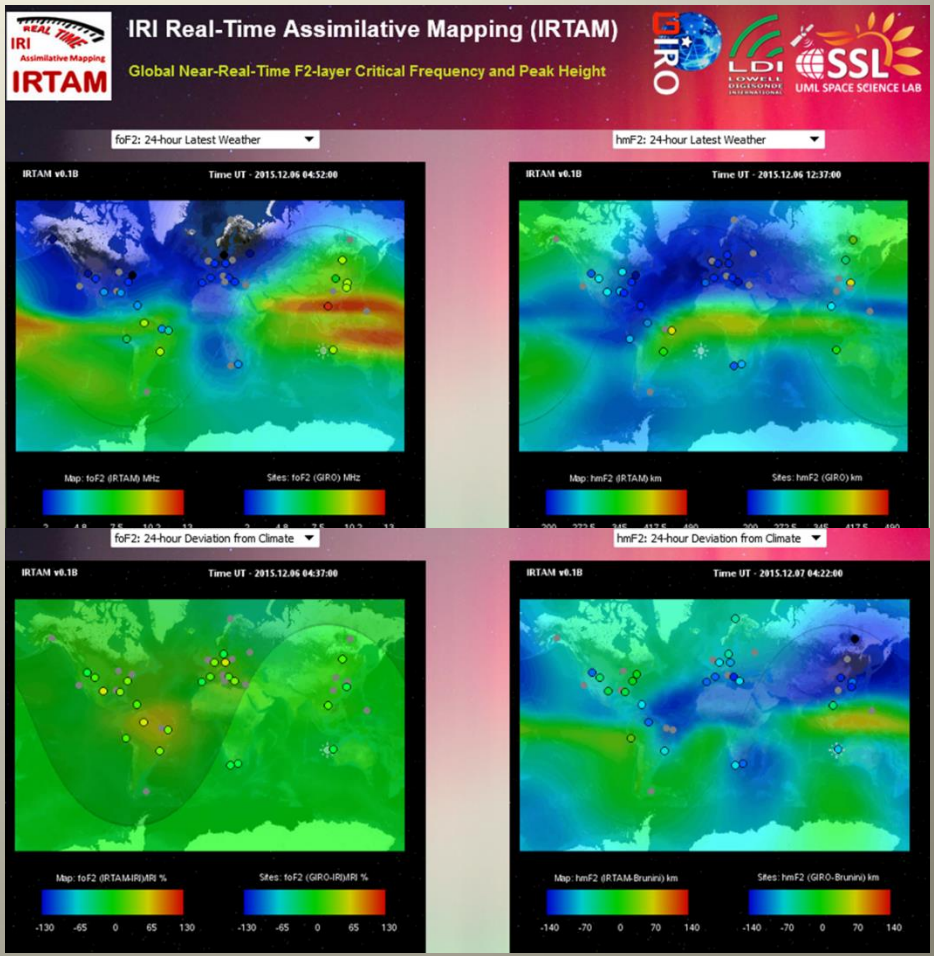
- IK-24, AE-C, AE-E, and C/NOFS data
- Improvement at high and low solar activity
- Noontime transition height (n(O^+) = n(H^+)) at the equator in 2008 drops from ~850km to ~670km



IRI-Real-Time

Galkin et al. (2012), IRTAM (IRI Real-Time Assimilative Mapping)

☆ Ionosonde data from 61+ stations of the Global Ionosphere Radio Observatory (GIRO) network.
☆ Using CCIR formalism (988 coefficients) to describe the difference between ionosonde fof2 and CCIR model.
☆ Using previous 24-hour history.
☆ Using same approach for hmF2.
☆ Using Neural Network Inter-polator (NECTAR) to fill the gaps between stations.



http://giro.uml.edu/IRTAM

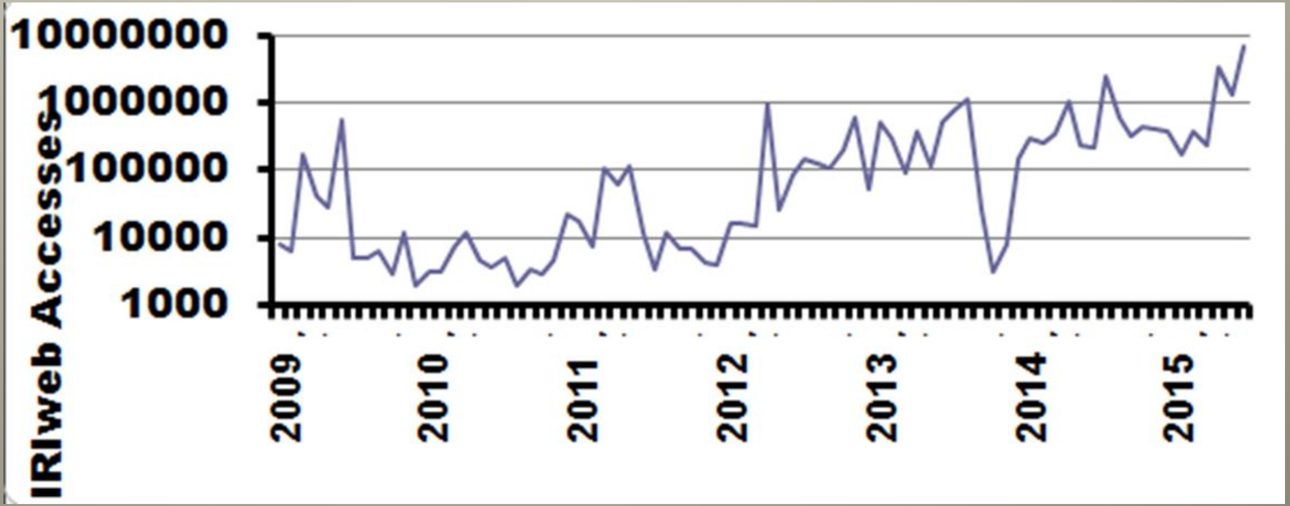
IRI Usage

Year	JGR	GRL	SW	RS
2009	5.0%	3.6%	0.0%	10.5%
2010	5.6%	4.7%	5.6%	11.8%
2011	7.1%	1.6%	8.1%	14.2%
2012	7.6%	2.7%	4.8%	13.8%
2013	5.1%	1.7%	2.3%	8.2%
2014	6.6%	0.5%	5.7%	10.7%
2015	**8.3%**	**2.3%**	**1.6%**	**9.6%**

JGR = Journal of Geophysical Research
GRL = Geophysical Research Letters
RS = Radio Science
SW = Space Weather journal

Percentage of papers in the AGU journals JGR, GRL, RS and SW that make use of the IRI model (validated text search).

Accesses to the IRIweb online computation of values (CCMC version not included)



IRI Workshops and Publications

2010 — **COSPAR**, Bremen, Germany — **Representation of the Auroral and Polar Ionosphere in IRI**

Advances in Space Research **Volume 51, Number 4,**

2011 — **IRI Workshop**, SANSA, Hermanus, South Africa — **Improving IRI over the African Sector**

ASR, Volume 52 Number 10

2012 — **COSPAR**, Mysore, India — **Global representation of ionospheric peak parameters for space weather applications**

2013 — **IRI Workshop**, UWM, Olsztyn, Poland — **IRI and GNSS Data**

Advances in Space Research **Volume 55 Number 8**

2014 — **COSPAR**, Moscow, Russia — **Representation of the ionosphere in real-time and in retrospective mode**

2015 — **IRI CCBW**, Bangkok, Thailand — **IRI at equatorial latitudes and progress towards Real-Time IRI**

Advances in Space Research **Submission deadline: July 31**

2016 — **COSPAR**, Istanbul, Turkey — **Improved Description of the Iono-sphere through Data Assimilation**

2017 — **IRI CCBW**, Taipei, Taiwan — **IRI and COSMIC data for ionospheric weather predictions**