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# 35 years of International Reference Ionosphere – Karl Rawer's legacy

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**Abstract.** This presentation is given in honor of Prof. Karl Rawer's 90th birthday. It looks back at 35 years of research and development in the framework of the International Reference Ionosphere (IRI) project. K. Rawer initiated this international modeling effort and was the first Chairman of the IRI Working Group. IRI is a joint project of the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI) whose goal it is to establish an international standard model for the ionospheric densities, temperatures and drifts. This year we are celebrating Karl Rawer's 90th birthday and also the 35-year anniversary of the IRI effort. My talk will review the close involvement of Karl Rawer in all stages of the development and improvement of this international standard from early on and his still very active participation in this effort.

## 1 A brief history of Rawer's IRI

In the mid-sixties it became clear that an international standard model for the ionosphere was needed similar to the successfully established COSPAR International Reference Atmosphere (CIRA) for the thermospheric parameters (CIRA, 1961). Such models are required for the specifications of environmental parameters in the thermosphere and ionosphere for the design of space-based instrument, for satellite orbit determination and control, for analysis of radioastronomy data and satellite altimetry data, and many more applications. Foreseeing the need for such a model COSPAR in 1968 initiated the International Reference Ionosphere (IRI) project and asked Karl Rawer to become its first Chairman. Since than Karl Rawer has been closely involved with the IRI effort and has been the main reason for the great success and broad application of this international standard representation of the ionosphere. It is therefore quire appropriate that we are celebrating at this occasion Karl Rawer's 90th birthday as well as IRI's 35th anniversary. Table 1 lists all the major IRI milestones throughout these past 35 years and highlights Karl Rawer's involvement. It also shows that the IRI group under the guidance of Karl Rawer has always tried to keep up with the rapidly changing computer and network environment, to be able to provide the user community with fast and easy access to the IRI model and its parameters.

It is interesting to note that the original IRI charter had only asked "...to provide vertical profiles of the main ionospheric parameters for suitable chosen locations, hours, seasons, and levels of solar activity; representing monthly median conditions based on experimental evidence." The IRI group, of course, quickly moved past the limitations in time and space and its first major release (Rawer et al., 1978) already included global coverage for the electron density. COSPAR's Terms of Reference for the IRI project now states: "The Task Group was established to develop and improve a standard model of the ionospheric plasma parameters. The model should be primarily based on experimental evidence using all available ground and space data sources; theoretical considerations can be helpful in bridging data gaps and for internal consistency checks. Where discrepancies exist between different data sources the IRI team should promote critical discussion to establish the reliability of the different databases. IRI should be updated as new data become available and as old data sources are fully evaluated and exploited. IRI is a joint working group of COSPAR and URSI. 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.

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## 2 IRI members and meetings

K. Rawer used four very important ingredients in establishing the IRI success story:

1. Working group members who provided a good and balanced cross-section in terms of the representation of different countries and continents (see Fig. 1) as well as in terms of the representation of different measurement techniques. This turned out to be great asset in getting the IRI effort access to all essential ground and space data sets for ionospheric parameters.
2. Annual IRI Workshops (see Table 2) that became the many venue for discussing improvements and enhancements of the model and that became the catalyst for a multitude of international collaborations whose goal it was to improve specific aspects of the model. A trademark of this quite informal meetings was (and is) the "Final Discussion" session during which the IRI team decides on the improvements and additions to be included in the next version of the model and during which "volunteers" are enlisted to investigate new data sources and specific modeling questions for future model updates.
3. Publication of the workshop papers first in Space Research, and then in Advances in Space Research (Table 2) has resulted in an excellent record of the IRI activity and has produced a unique series documenting the international efforts in ionospheric modeling. As the main editor of these publications K. Rawer has helped countless non-English speaking colleagues to correct their language and grammar and to publish their important results sometimes for the first time in an English-language journal.
4. Newest technology to make the IRI model quickly and easily accessible to its wide user community and its broad spectrum of applications. IRI was one of the first international projects to distribute its model in the form of computer codes in a number of different computer languages. Following closely in step with the computer revolution of the eighties and nineties, the programs were first provided on 9-track tapes, than on punched tapes and cards, than on floppy disks, than online, and the latest incarnation is the IRIWeb, an interface that lets user compute and plot IRI parameters online (http://nssdc.gsfc.nasa.gov/space/models/iri.html).

## 3 Applications

The great legacy of Karl Rawer's push for an International Reference Ionosphere is best documented by the many applications that depend on this model:

a) Standard for Engineering Applications

- IRI is used as the standard in NASA Guidelines (Anderson, 1994).
- IRI is the standard ionospheric model in the System Engineering Handbook of the European Cooperation for Space Standardization (ECSS, 1997).
- IRI is under consideration to become the ISO standard for the ionospheric parameters.
- IRI is the ionospheric model used in ESA/ESTEC's Space Environment Information System (SPENVIS) http://www.spenvis.oma.be/spenvis/ and in MSFC's Space Environment Effects (SEE) web interface.

b) Visualization Tool for Educational Applications

- IRI Total Electron Content (TEC) world maps (U. Leicester, U. K.) http://ion.le.ac.uk/remote_sensing/models/tec.html
- 3-D electron density visualization using AVS (Watari et al., 2003)

c) Ionospheric Correction for Single-Frequency Satellite Altimeters

- Longtime data record of sea surface heights (Pathfinder Project); updating IRI with ionosonde data (Bilitza et al., 1997)
- ERS Quick-look data (ESA)
- Work with Geosat Follow On (GFO) data (Zhao et al., 2002)

d) Background ionosphere for Evaluation of Data Mapping Techniques

- Testing algorithms that convert GPS measurements into global TEC maps (Hernandez-Pajares et al., 2002)
- TEC from NNSS Doppler measurements (Ciraolo and Spalla, 2002)
- Reliability of tomographic methods.

## 4 Conclusion

On behalf of the IRI Working Group and the many IRI users, I would like to say, "Thank you Karl" and congratulations on your 90th Birthday and on the 35th Birthday of your IRI model.

**Table 1.** IRI Milestones.

| Year | Event | Description | Media | Image |
|---|---|---|---|---|
| **1968** | COSPAR establishes IRI WG | K. Rawer, Chair | |  |
| **1969** | URSI joins in | | | |
| **1972** | Prelimenary set of Tables (Rawer and Ramakrishnan) | IRI parameters at selected locations | Report | |
| **1973** | COSPAR Symposium, Konstanz, Germany (K. Rawer, Organizer) [2] | Guidelines established for data that should be used for D-region modeling | |  |
| **1978** | URSI Special Report: IRI-79 [3] | Global coverage for densities, CCIR Maps for foE, foF1, foF2, and M(3000)F2 | Report ALGOL and FORTRAN code on punched tape and cards |  |
| **1981** | World Data Center A for Solar-Terrestrial Physics Report: IRI-79 [4] | | Graphs and tables of IRI parameters | |
| **1986** | IRI-86 on floppy disk for use on Personal Computers (PCs) | Global coverage for temperatures based on AE-C,-D,-E and AEROS-A,-B data | Floppy disk with DOS interactive program | |
| **1990** | National Space Science Data Center (NSSDC) Report [5] | URSI maps for foF2 | Retrievable from NSSDC's archive via Anonymous ftp and available for online computation as part of NSSDC's Online Data and Infromation Service (NODIS) |  |
| **1995** | IRI-95 online (IRIWeb) | Improvements at low magnetic latitudes | IRIWeb: compute and plot IRI parameters on the internet. |  |
| **1999** | URSI Resolution | IRI recognized as the international standard for the ionosphere | | |
| **2001** | IRI-2001 with many improvements and new parameters [6] | Improvements: D- F1-region, STORM and Intercosmos Te model New paramts.: F1prob., equat. vert. ion drift | | **IRI-2001** |

**Table 2.** IRI Workshops and Publications.

| Year | Location | Topic | Publication |
|---|---|---|---|
| 1971† | Seattle, USA | | Space Res. XII, 1229-1335, 1972 |
| 1973 | Konstanz, FRG | Measurements and Results of Lower Ionosphere | Akademie-Verlag, Berlin, 1974 |
| 1974† | Sao Paulo, Brazil | | Space Res. XV, 295- 334, 1975 |
| 1980† | Budapest, Hungary | International Reference Ionosphere – IRI-79 | WDC-A-STP, UAG-90, 1984 |
| 1982† | Ottawa, Canada | The Upper Atmosphere of the Earth and Planets | Adv. Space Res. (ASR) 2(10) 1982 |
| 1983 | Stara Zagora, Bulgaria | Towards an Improved IRI | ASR 4(1) 1984 |
| 1984† | Graz, Austria | Models of the Atmosphere and Ionosphere | ASR 5(7) 1985 |
| 1985 | Louvain, Belgium | IRI - Status 1985/86 | ASR 5(10) 1985 |
| 1986† | Toulouse, France | IRI - Status 1986/87 | ASR 7(6) 1987 |
| 1987 | Novgorod, Russia | Ionospheric Informatics | ASR 8(4) 1988 |
| 1988† | Espoo, Finland | Ionospheric Informatics and Empirical Modelling | ASR 10(8) 1990 |
| 1989 | Abingdon, UK | Development of IRI-90 | ASR 10(11) 1990 |
| 1990† | The Hague, Netherlands | Enlarged Space and Ground Data Base for | ASR 11(10) 1991 |
| 1991 | Athens, Greece | Adv. in Global/Reg. Descript. of Ionospheric Parameter | ASR 12(7) 1992 |
| 1992† | Washington, DC, USA | Ionospheric Models | ASR 13(3) 1993 |
| 1993 | Trieste, Italy | Off Median Phenomena and IRI | ASR 14(12) 1994 |
| 1994† | Hamburg, FRG | The High Latitudes in the IRI | ASR 16(1) 1995 |
| 1995 | New Dehli, India | Low and Equat. Latitudes in IRI | ASR 18(6) 1996 |
| 1996† | Birmingham, UK | Descript. of Ionospheric Storm Effects and Irregularities | ASR 20(9) 1997 |
| 1997 | Kühlungsborn, Germany | New Develops. in Ionospheric Modeling and Prediction | ASR 22(6) 1998 |
| 1998† | Nagoya, Japan | Lower Ionosphere: Measurements and Models | ASR 25(1) 2000 |
| 1999 | Lowell, MA, USA | IRI- Workshop 1999 | ASR 27(1) 2001 |
| 2000† | Warsaw, Poland | Modelling the Topside Ionosphere and Plasmasphere | ASR 29(6) 2002 |
| 2001 | Sao Jose dos Campos, Brazil | Description of the Low Latitude Ionosphere in the IRI | ASR 31(3) 2003 |
| 2002† | Houston, Texas, USA | Improved Ionosphere Specification and Forecast | ASR in press |
| 2003 | Grahamstown, South Africa | Quantifying ionospheric variability | ASR in preparation |

† IRI session during the General Assembly of the Committee on Space Research.

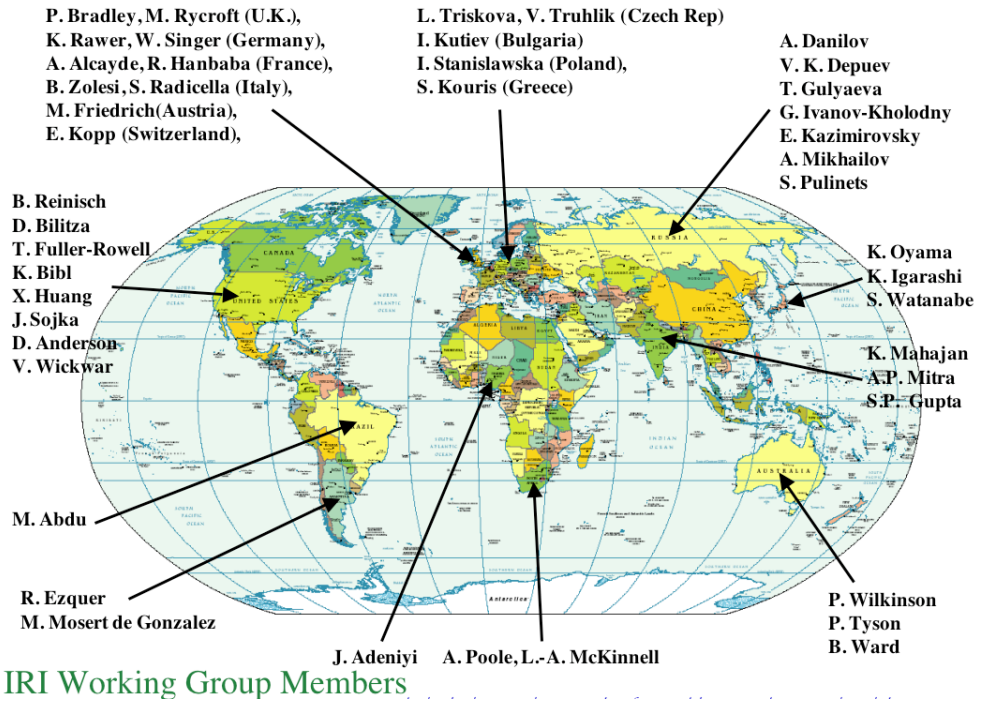


**Fig. 1.** Global distribution of members of the URSI/COSPAR Working Group on the International Reference Ionosphere.

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