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Prepared by IROWG
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REPORT FROM THE 1ST INTERNATIONAL RADIO OCCULTATION WORKSHOP

The first workshop of the IROWG (IROW1) was hosted by the Wegener Center / University of Graz and was organized together with the OPAC-4 (Occultations for Probing Atmosphere and Climate) and GRAS SAF (Satellite Application Facility) Climate workshops in Graz, Austria. IROW1 was held on Friday, 10th of September 2010 and Saturday, 11th of September 2010; it was attended by more than 60 scientists, including all the major centres providing and all major centres assimilating RO data. IROWG has just been endorsed by CGMS and this was the first workshop of this group. Generally, all participants considered it a big honour to have been selected as the fourth working group under the auspices of CGMS.

After a general introduction on the work of CGMS and IROWG, IROW1 participants were asked to work in sub-groups, covering the main fields of radio occultation observations: (1) Numerical Weather Prediction; (2) Climate; (3) Research to Operations / Payload Technology; (4) Innovative Occultation Techniques; (5) Space Weather; discuss activities within their field and express recommendations. The recommendations were presented and discussed in a plenary meeting. The main recommendations from each sub-group are presented in this paper.

Action/Recommendation proposed:
CGMS is invited to comment.

Report from the 1st International Radio Occultation Workshop

1 INTRODUCTION

This paper summarizes the outcome of the 1st International Radio Occultation (RO) Working Group Workshop (IROW1). The workshop was hosted by the Wegener Center / University of Graz, Austria. It took place together with the OPAC-4 and GRAS SAF Climate Workshops; these ran from the 6th of September 2010 to the 10th of September (mid day) and IROW1 was taking place on the 10th and 11th. IROW1 focused on sub-group discussion and recommendation and finished with a panel discussion.

IROW1 was attended by more than 60 scientists, including all the major centres providing and all major centres assimilating RO data.

Members of the workshop's organizing/scientific committee were: A.K. Steiner, U. Foelsche, G. Kirchengast (Wegener Center / U. Graz, Austria), K.B. Lauritsen and H. Gleisner (DMI, Copenhagen, Denmark / GRAS-SAF), A. von Engeln and D.R. Ector (Co-Chairs IROWG), R. Anthes (UCAR, Boulder, USA), T. Tsuda (RISH, U. Kyoto, Japan).

The structure of this paper is as follows: Section 2 gives a brief overview of the organization of the workshop and the sub-groups, Section 3 lists and the main recommendations given in the sub-groups, and Section 4 concludes.

2 IROW1 Setup

CGMS meeting 37 in October 2009 endorsed the establishment of the IROWG. Dave Ector (NOAA) and Axel von Engeln (EUMETSAT) have been selected as co-chairs and Mitch Goldberg (NOAA) as rapporteur to CGMS. In order to have a first IROWG workshop in 2010, the co-chairs and the rapporteur decided to join with the already scheduled workshops of OPAC-4 and the GRAS-SAF Climate workshops in September 2010. IROWG is grateful in particular to the hosting Wegener Center at the University of Graz, Austria, and to the sponsors EUMETSAT, CGMS, WMO, and NOAA.

The aim of IROW1 was on focused sub-group discussions after the OPAC-4 and GRAS-SAF workshops. IROW1 participants were asked to summarize relevant activities within the scope of the sub-group and express recommendations which could either be relevant to CGMS, to the RO community, or to providers of RO data. The co-chairs suggested 6 sub-groups: (1) Numerical Weather Prediction; (2) Climate; (3) Research to Operations; (4) Payload Technology; (5) Innovative Occultation Techniques; (6) Space Weather, out of which 5 were selected and sub-group (4) was joined with sub-group (3) to Research to Operations / Payload Technology.

3 Sub-Group Recommendations / Discussions

This section is a summary of the main recommendations of each sub-group. Note that not all of these are relevant at CGMS level. Note also that some sub-groups arrived at similar recommendations; these were kept here since they have thus higher relevance for the IROWG community.

3.1 Numerical Weather Prediction (NWP) Sub-Group

Chair: J. Aparicio (Environment Canada)
Rapporteur: L. Cucurull (NOAA/NWS/NCEP/EMC)

Main Recommendations:

1. GPSRO has demonstrated to be a very important element in the global data observing system for NWP. The continuity of GPSRO observations in the future is not sufficiently guaranteed. IROWG recommends that **CGMS coordinates efforts between operational data providers and NWP agencies to establish long term continuity plans**.
2. Operational NWP centers should be aware of a substantial reduction of available GPSRO data in real time, that has already begun, and will continue (CHAMP down, COSMIC degrading, COSMIC II planned to be commissioned only in 2015). Processing of research data could fill the gap (TERRASAR-X, TANDEM-X, OCEANSAT-2, SAC-D, PAZ, etc, where the first 3 have already been launched). IROWG recommends that **CGMS coordinates efforts between operational data providers, NWP agencies, and research agencies, to investigate and potentially support NRT infrastructure for these data** (downlink, processing, dissemination and archiving).
3. The saturation level of GPSRO data might depend on the application (e.g. global -, regional forecasting, climate) and is not known today. IROWG recommends **to encourage observing system simulation experiments (OSSE) to determine the optimal number of observations for different applications.**
4. There is an uncertainty in the refractivity coefficients that impacts NWP biases, also with potential implications in climate monitoring. IROWG recommends that CGMS **coordinates efforts to determine the refractive coefficients at the GPS wavelengths**.

3.2 Climate Sub-Group

Chair: U. Foelsche (Wegener Center, U. Graz)
Rapporteur: S. Leroy (Harvard University)

Main Recommendations:

1. **Future missions should consider covering 360° in ascending node.** The sampling need not be regular in ascending node, but it should definitely extend well beyond 180°. If all 360° is not covered, sinusoidal sampling biases pole wards of 50° latitude with the period of constellation precession is present due to selected local time sampling.
2. Documentation on retrieval processing chains by all processing centers (UCAR, GFZ, Wegener Center, JPL, GRAS-SAF, EUMETSAT) is essential to assure traceability in climate data. Documentation on LEO receiver firmware is also needed. IROWG recommends to **fully document processing chains, keeping track of any introduced changes/updates to processing or instrument**.

3.3 Research to Operations Sub-Group

Chair: B. Schreiner (UCAR)
Rapporteur: C. Marquardt (EUMETSAT)

Main Recommendations:

1. RO measurements are a valuable information source for NWP and climate. Within NWP, the number of RO instruments has not reached saturation level. Hence IROWG recommends that **operational and research organizations consider adding Global Navigation Satellite System (GNSS) RO payloads on all suitable satellite systems**.
2. In light of the upcoming drop in the number of available radio occultations due to COSMIC nearing its end-of-life, IROWG recommends that **operational agencies consider supporting research missions to provide their GNSS RO data and format information to research and operational communities in Near Real Time as early as possible after launch**, e.g. by providing or funding as needed (1) downlink and dissemination capabilities; (2) processing capabilities; (3) consultation on best practices in processing and design. It should also be considered to maintain the COSMIC constellation beyond its current lift time (April 2011), as long as a valuable number (~500) of high-quality soundings per day are being obtained.
3. Processing of RO data requires access to GNSS ground station networks to derive orbit and clock data. IROWG recommends to **maintain and improve these networks as required for the Near Real Time and research operation of RO missions**. Products and data obtained from these networks should be publicly available like other meteorological data.

3.4 Innovative Occultation Technique

Chair: R. Kursinski (U. Arizona)
Rapporteur: V. Proschek / K. Zhang (U. Graz / RMIT)

Main Recommendations

1. **CGMS member space agencies are invited to support implementation of LEO-LEO occultation that would serve as an authoritative reference standard in the global free atmosphere for upper air WMO/GCOS Essential Climate Variables (ECV)**. It is encouraged to hold an interagency workshop (e.g. ESA-NASA-NSF-NOAA-EUMETSAT) as soon as possible to define how one can cooperate in implementing a LEO-LEO research and demonstration mission and related preparatory activities (joint precursor demonstration experiments, scientific impact studies, instrument development and mission design).
2. CGMS is invited to encourage **space agencies to assess the utility of higher frequencies on next generation GNSS systems (e.g., 5 GHz on a next generation Galileo) for radio occultation applications**. GNSS providers (e.g. Galileo, GPS, GLONASS, COMPASS, and IRNSS) are invited to consider implementation of such higher frequencies for the benefit of operational weather, climate and space weather monitoring and prediction.

3.5 Space Weather Sub-Group

Chair: P.R. Straus (Aerospace Cooperation)
Rapporteur: P.R. Straus (Aerospace Cooperation)

Main Recommendations:

1. While RO has demonstrated an effective capability to measure ionospheric total electron content and electron density profiles, the impact on ionospheric specification accuracy when used in assimilative ionospheric models is yet to be quantified. IROWG thus recommends to **encourage the development of uniform metrics for evaluating assimilative ionospheric models together with a framework wherein comparisons between assimilative models in terms of these metrics can be made with and without RO data incorporation**.
2. The value of RO data to ionospheric modeling is expected to grow as the amount of available data increases over time. A variety of science and operational missions are in the planning stages, and it seems likely that more may be planned in the near future. IROWG thus recommends to **encourage missions flying RO sensors to include a robust ionospheric measurement capability without interference to collection of lower atmosphere data**. IROWG also recommends to encourage the development of a standardized ionospheric scintillation measurement capability for RO sensors.
3. Advancement of ionospheric model science depends on collection of both ionospheric density information, such as is obtained from RO sensors, and coincident observations of other thermospheric parameters such as neutral composition, winds, and ionospheric plasma drifts. It is unlikely that the ultimate solution to ionospheric specification problems can be accomplished with RO observations alone. IROWG thus recommends to **encourage missions flying RO sensors to also fly secondary payloads supporting thermosphere/ionospheric measurements**.

4 CONCLUSIONS

The recommendations of the first IROWG were summarised above. Concerning recommendations for work in the immediate future CGMS 38 is invited to emphasise the following aspects:

- Encourage long term continuity of RO observations e.g. by considering RO instruments for upcoming missions
- Encourage mitigation of possible data gaps in operational RO observations by bringing research missions into the Near Real Time stream
- Support unbiased local time sampling through appropriate orbits for climate application, as also expressed in the GCOS Climate Monitoring Principles
- Endorse to include / maintain ionospheric capabilities of RO receivers
- Encourage to explore other occultation techniques such as LEO-LEO

Workshop proceedings of the OPAC-4 and GRAS SAF Climate workshops are planned to be published in a peer-review journal. All given presentations will be made available at http://www.uni-graz.at/opac2010/, minutes from IROW1 will be made available at http://www.irowg.org .