CGMS

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REPORT FROM THE 3RD INTERNATIONAL RADIO OCCULTATION WORKSHOP

Prepared by IROWG (http://www.irowg.org)

This paper summarizes the outcome of the 3rd IROWG Workshop (IROWG-3). The main organizer of the workshop was the Wegener Center for Climate and Global Change at the University of Graz, Austria. The meeting was held at Seggau Castle, Leibnitz near Graz, Austria, from the 5th of September 2013 to the 11th of September 2013.

Radio occultation (RO) data has a major positive impact on Numerical Weather Prediction (NWP), climate monitoring, space weather, and on temperature- and humidity-related atmospheric research. All global assimilation centres are using RO data to derive information on stratospheric temperature, and tropospheric temperature and humidity. In addition, the bias free nature of RO data anchors assimilation models to the true atmospheric state.

Recent NWP studies have shown substantial forecasting improvements with increased number of available occultations. Climate, research users also benefit from more data. The current observing system is providing about 3,000 occultations daily, relying however for more than half of the data on research type missions. The main IROWG-3 recommendations are thus:

- Develop a detailed **GNSS-RO Continuity Plan**, outlining how we move towards a fully operational GNSS RO constellation providing **at least 10,000 observations per day**.
- Take steps to ensure **the continuity of RO measurements**, especially after COSMIC-1. **Operational GNSS RO missions are not only important for weather forecasting, but also for continuous global climate observation**.
- To ensure wherever possible a timely **update of receiver firmware** in order to maximise the receiver performance, e.g. for the Oceansat-2/ROSA instrument to allow L2 tracking, or for the GRAS instrument to extend the covered altitude range to 120 km.
- **Avoid an observation gap at mid- and high latitudes** by funding/launching the FORMOSAT-7/COSMIC-2 Polar mission.
- International space agencies (e.g., NASA, ESA, NSF, NOAA, EUMETSAT and others) to hold an **interagency workshop to define cooperation options for implementing an airborne demonstration and a LEO-LEO research and demonstration mission**.

CGMS is invited to comment.

Report from the 3rd International Radio Occultation Workshop

1 INTRODUCTION

This paper summarizes the outcome of the combined OPAC-IROWG Workshop (OPAC-5 & IROWG-3) of the International Radio Occultation (RO) Working Group and the Occultation for Probing Atmosphere and Climate. The workshop was organized by the Wegener Center for Climate and Global Change at the University of Graz, Austria. The meeting was held at Seggau Castle, Leibnitz near Graz, Austria, from the 5th of September 2013 to the 11th of September 2013.

Background: The CGMS meeting 37 in October 2009 endorsed the establishment of the IROWG. Dave Ector (formerly NOAA, now UCAR) and Axel von Engeln (EUMETSAT) were selected as co-chairs and Mitch Goldberg (NOAA) as rapporteur to CGMS (Mitch was replaced in June 2012 by Anthony Mannucci, JPL/NASA). The first IROWG workshop was held in September 2010, it was a joint OPAC-4 and GRAS-SAF Climate workshop. IROWG-1 provided a platform for discussions and recommendations, while the talks that were given were organized by OPAC-4 and the GRAS SAF. The 2nd and 3rd workshops of IROWG included a full conference agenda with many talks, in addition to the platform for discussions and recommendations. Please refer to our website at http://www.irowg.org for minutes and working papers of previous workshops.

OPAC-5 & IROWG-3 was attended by more than 70 scientists, including representatives from all the major RO processing centres and all major weather prediction centres assimilating RO data. Approximately 60 talks and 25 posters were presented. Recommendations were developed in dedicated sub-working groups and presented in a panel discussion. Additionally, OPAC-5 & IROWG-3 were used by several researchers for dedicated splinter meetings, which are not covered here.

The structure of this report is as follows: Section 2 gives a brief overview of the organization of the workshop and the sub-groups, Section 3 lists the main recommendations which were agreed upon by IROWG, and Section 4 concludes.

This IROWG document provides the summary in a CGMS working paper format. The full minutes / recommendations / discussions of the sub-working groups within IROWG are available http://www.irowg.org.

Furthermore, there have been 2 additional documents provided by IROWG-3:

- Critical Impact of the Potential Delay or Descoping of the COSMIC-2/FORMOSAT-7 Programme, IROWG/DOC/2013/01
- Status of the Global Observing System for Radio Occultation (Update 2013), IROWG/DOC/2013/02

Both documents are available at http://www.irowg.org. These were triggered by the continuing uncertainty regarding the follow-on mission to FORMOSAT-3/COSMIC-1, the FORMOSAT-7/COSMIC-2 one, in particular the high latitude part of this constellation. This uncertainty also dominated the discussions and recommendations of several of the sub-working groups within IROWG-3. It should be pointed out however, that the data flow from FORMOSAT-3/COSMIC-

1 needs to be maintained as long as possible, in order to provide needed occultations at mid- and high-latitudes, even if the first, low latitude FORMOSAT-7/COSMIC-2 constellation is flying.

2 IROWG-3 SETUP

OPAC5 & IROWG-3 was a full workshop, including presentations, posters and sub-group discussions. Both, the presentations/posters and the sub-group discussions were focussed on specific topics, namely:

- Numerical Weather Prediction;
- Climate;
- Receiver Technology and Innovative Occultation Techniques;
- Space Weather.

In contrast to earlier workshops, the sub-group Research to Operations was **not** formed. This is a major policy shift of IROWG, resulting directly from the continuous non-delivery or under-performing of most research missions. The core of a sustainable RO observation system needs to be operational! The earlier separate sub-groups of Receiver Technology and Innovative Occultation Techniques were combined during IROWG-3.

IROWG-3 participants were asked to summarize **relevant activities** within the scope of the sub-group in dedicated meetings and express recommendations which could either be relevant to CGMS, to the GNSS (Global Navigation Satellite System, e.g. GPS) RO community, to providers of RO data, or within the IROWG. These were discussed in the open plenary.

The participants agreed to highlight five main recommendations for CGMS-42; these were endorsed by all participants, and additionally present within this document one main recommendation per sub-group that is relevant at CGMS level. The full set of recommendations per sub-group and further information is made available in a dedicated IROWG publication, available on our website www.irowg.org.

3 MAIN RECOMMENDATIONS

OPAC-5 & IROWG-3 participants noted that the main IROWG-2 recommendations have made some progress; however, further work is required to address them fully. The urgency of the tasks requires that several of them be re-stated here in an updated form. In addition, the continuing uncertainty of the FORMOSAT-7/COSMIC-2 mission dominated the discussions and recommendations.

The following 5 main recommendations have been agreed upon by all participants at IROWG-3:

3.1 Ensure an Operational Continuity Plan for RO – including Troposphere and Ionosphere Measurements

We recommend that CGMS devise a detailed **GNSS-RO Continuity Plan** with the operational agencies, outlining how we move towards a fully operational GNSS RO constellation providing **at least 10,000 observations per day**.

GNSS RO has been demonstrated to be a critical element in the global data observing system for Numerical Weather Prediction (NWP), providing high positive impact to forecast skill in all the major national weather forecasting centres. GNSS RO also provides a very important data record for the global climate observing system, providing essential climate variables of benchmark quality. In addition, these data are critical for space weather observation and input to space weather prediction systems that are currently being developed.

The **continuity of GNSS RO observations in the future is not guaranteed by present operational programs or plans**. As of 2013, the two GRAS instruments remain the only program for GNSS RO with confirmed funding. The operational demonstration COSMIC-1/FORMOSAT-3 mission provided the first GNSS RO data used by the operational centres. However, COSMIC-1 is beyond its expected end of life. RO research missions have been found in the past few years to underperform or do not deliver any data. Two research satellites providing timely data suitable for assimilation are the GRACE and TerraSAR-X missions, but these missions combined provide less than one fifth of the data volume that COSMIC-1 provides. If COSMIC-1 fails before a COSMIC-2/ FORMOSAT-7 mission, an **observation gap at all latitudes** will occur. A **mid- and high-latitude gap with even longer duration** will also occur after COSMIC-1, unless the polar part of the COSMIC-2 mission is funded and executed.

Thus, **research programs or missions of opportunity are not the answer for a fully operational GNSS RO constellation that serves the needs of Numerical Weather Prediction centres**. The amount of investment in GNSS RO and other satellite programs overall should be correlated to the positive impacts they have on NWP, climate, and chemistry, and GNSS RO impacts in NWP are comparable to that of the other major operational instruments. Proper GNSS RO continuity requires a constellation of properly spaced LEO satellites, providing a minimum of 10,000 soundings per day. **It is of highest importance for NWP, climate, and space weather to ensure the continuity of RO measurements**, especially following the COSMIC-1/FORMOSAT-3 constellation mission. The launch of the follow-on COSMIC-2/FORMOSAT-7 constellation contains 6 **low inclination** (24 degrees) satellites that will provide an unprecedented density of low latitude coverage critically needed for tropical storms and space weather monitoring and prediction. It will, however**, not provide any of the mid- and high-latitude coverage** required for NWP, climate, and space weather at those latitudes. The second launch of the COSMIC-2/FORMOSAT-7 is a constellation of six satellites in polar orbit. This part of the mission will provide continuity to COSMIC-1 for mid- and high latitude coverage; however it is not yet completely funded and thus at significant risk.

3.2 Ensure the continuity of RO measurements, in particular after COSMIC-1

GNSS RO has been demonstrated to be a very important data record for the global climate observing system providing essential climate variables of benchmark quality. The continuity of global GNSS RO observations in the future is not guaranteed, particularly the full diurnal coverage provided by COSMIC-1, which is of major concern regarding the provision of continuous climate products. **It is of highest importance to ensure the continuity of RO measurements with global coverage**, especially after COSMIC-1. **Operational GNSS RO missions for continuous global climate observation with full diurnal coverage** need to be established. While research missions are a valuable component, experience has shown that operational missions are required as a backbone to ensure continuity of the data.

3.3 Ensure adequate firmware settings of existing GNSS RO firmware

IROWG recommends to the Italian Space Agency (ASI) that it provides an **update of the firmware** to the ROSA instrument onboard Oceansat-2, that will significantly improve L2 tracking to be comparable to that already achieved for the other ROSA-flying instruments onboard Mega-Tropiques and SAC-D[1]. Furthermore, IROWG recommends to EUMETSAT to explore the feasibility of **modifying the firmware** in the GRAS RO instruments onboard Metop-A, B and C, so that the occultations are continued to at least an altitude of 120 km. This will permit better insights into ionospheric sporadic E-layer signatures, which may be responsible for loss of lock or other tracking errors even at altitudes below 80 km (e.g., if/when E-layers are tilted). Tracking to higher altitudes than 80 km could also help investigations into ionospheric correction improvements at high altitudes as well as help to diagnose possible small mean bending angle biases, which could be important for climate monitoring. Finally, more data at high altitudes can help dynamic error estimation in the operational processing of occultations and ease the identification of bad data due to scintillations/tracking errors in limited vertical intervals.

3.4 Ensure timely launch of the FORMOSAT-7/COSMIC-2 Polar mission[2]

IROWG recommends that all reasonable effort be expended to launch the FORMOSAT-7/COSMIC-2 (FS7/C2) Polar constellation of 6 satellites in the 2018 time frame as originally planned. With the decline of FORMOSAT-3/COSMIC-1 and other research satellites, lack of FS7/C2 Polar will result in the absence of any ionospheric and atmospheric radio occultation measurements above approximately 40° latitude. FS7/C2 first launch is planned for a low inclination orbit that will not provide data at middle and higher latitudes, where significant space weather impacts are present, needing to be monitored.

3.5 Organize an international space agency workshop for cooperation options on airborne and LEO-LEO research missions

IROWG recommends that CGMS adopt an action asking international space agencies (NASA-ESA-NSF-NOAA-EUMETSAT and others) to **hold an interagency workshop** as soon as possible to define how they can cooperate in implementing an airborne demonstration and a LEO-LEO research and demonstration mission. IROWG also recommends that CGMS encourage space agencies to support research towards implementation of LEO-LEO occultation demonstration to pave the way towards developing an authoritative reference standard in the global free atmosphere for upper air WMO/GCOS Essential Climate Variables (ECVs). Initial mountaintop demonstrations have been made at cm, mm and micrometer wavelengths. The next step within the next 2 years should be an airborne occultation demonstration.

[1] An update of the onboard receiver software of ROSA on Oceansat-2 was performed early 2014 and the instrument is currently being tested. It should however be noted that the expected lifetime of Oceansat-2 is in 2015, thus most of the potential data is lost.

[2] Based on the outcome of this IROWG workshop, a letter was sent by WMO to the United States to highlight the impact of RO data and the importance of implementing both, equatorial and polar constellations of FORMOSAT-7/COSMIC-2. In their response, the USA assured WMO that NOAA was “coordinating on program planning and investigating options for acquisition of the second six mission payloads and launch services for the second launch”.

4 CONCLUSIONS

The main recommendations of the third IROWG were summarised above. The full set of recommendations, relevant at CGMS, at satellite operator, and at IROWG level can be found at http://www.irowg.org.

For work in the immediate future CGMS-42 is invited to emphasise the following five main IROWG-3 recommendations:

- Develop a detailed **GNSS-RO Continuity Plan**, outlining how we move towards a fully operational GNSS RO constellation providing **at least 10,000 observations per day**.
- Take steps to ensure **the continuity of RO measurements**, especially after COSMIC-1. **Operational GNSS RO missions are not only important for weather forecasting, but also for continuous global climate observation**.
- To ensure wherever possible a timely **update of receiver firmware** in order to maximise the receiver performance, e.g. for the Oceansat-2/ROSA instrument to allow L2 tracking[3], or for the GRAS instrument to extend the covered altitude range to 120 km.
- **Avoid an observation gap at mid- and high latitudes** by funding/launching the FORMOSAT-7/COSMIC-2 Polar mission[4].
- International space agencies (e.g., NASA, ESA, NSF, NOAA, EUMETSAT and others) to hold an **interagency workshop to define cooperation options for implementing an airborne demonstration and a LEO-LEO research and demonstration mission**.

All given presentations, as well as minutes, this CGMS working paper from IROWG-3 are available at http://www.irowg.org.

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[4] Based on the outcome of this IROWG workshop, a letter was sent by WMO to the United States to highlight the impact of RO data and the importance of implementing both, equatorial and polar constellations of FORMOSAT-7/COSMIC-2. In their response, the USA assured WMO that NOAA was “coordinating on program planning and investigating options for acquisition of the second six mission payloads and launch services for the second launch”.