CGMS

CGMS-45 IROWG-WP
v2, 15 May 2017

Prepared by IROWG
Agenda Item: WGII/4
Discussed in
WGII/4, Plenary

REPORT OF IROWG ACTIVITIES: OUTCOME AND RECOMMENDATIONS FROM THE IROWG-5

Prepared by IROWG[1] (www.irowg.org)

Executive Summary

This report summarizes the IROWG-5 meeting held on September 8-14, 2016 near Graz in Austria. It is based on the recommendations from the four IROWG sub-groups: NWP, Climate, Space Weather and Receiver Technology/Innovative Occultation Techniques. The four key recommendations for CGMS – endorsed by the IROWG community at the plenary session – are summarised below. The full set of recommendations, relevant at CGMS level, at satellite operator level, and at IROWG level, is available at www.irowg.org.

For work in the immediate future CGMS-45 is invited to emphasise the following four main IROWG-5 recommendations:

- **Ensure that both equatorial and polar components of COSMIC-2 are fully funded and launched; this is required for Numerical Weather Prediction, Climate, and Space Weather**
- IROWG recommends targeting at least 20,000 occultations/day, to be made available to the operational and research communities of Numerical Weather Prediction, Climate, and Space Weather
- International space agencies (in particular NASA, ESA and CNSA, where LEO-LEO and GNSS-RO&-Reflectometry proposals are pending) to support **mission preparation and implementation projects towards LEO-LEO microwave occultation and GNSS-RO&-Reflectometry demonstration missions**. This should include recommending new OSSEs for the LEO-LEO observations.
- **IROWG recommends that CGMS should encourage GNSS providers and agencies to make ICDs of GLONASS and Beidou Open Service** signals available as soon as possible, in order to allow RO instrument providers to design and develop the future receivers without uncertainties due to missing information.

Workshop minutes and this CGMS working paper from IROWG-5 are/will be made available at http://www.irowg.org, all given presentations at http://wegcwww.uni-graz.at/opacirowg2016.

Action/Recommendation proposed: CGMS is invited to take note and comment.

[1] International Radio Occultation Working Group, represented by the rapporteur Anthony Mannucci and the co-chairs Ulrich Foelsche and Sean Healy. Affiliations are listed at the end of this document

Outcome and Recommendations from the IROWG-5

1 INTRODUCTION

This report summarizes the outcome of the combined OPAC-IROWG 2016 workshop (http://wegcwww.uni-graz.at/opacirowg2016), the 6th implementation of the workshop on *Occultations for Probing Atmosphere and Climate* (OPAC-6) in combination with the 5th workshop of the International Radio Occultation (RO) Working Group (IROWG-5). 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 September 8-14, 2016.

The workshop was attended by more than 70 scientists, including representatives from all the major RO processing centres, space agencies, the weather prediction centres assimilating RO data and representatives of commercial data providers.

This was one of the best workshops on GNSS-RO for many years. 62 talks and 16 posters were presented. Recommendations were developed in dedicated sub-working groups and presented and agreed upon in a plenary discussion on the last day. Additionally, IROWG-5 was used by several researchers for dedicated specialist/splinter meetings, which are not covered here.

A key issue throughout the meeting was the relationship between the new agency-led GNSS-RO missions and the commercial GNSS-RO proposals. The latest results from SPIRE, demonstrating their ability to measure and process GNSS-RO measurements made with CubeSats, was one of the highlights of the meeting. This is an impressive first step. However, it was recognized that a detailed analysis of the SPIRE data, and data from other commercial options, is required. Therefore IROWG fully supports the aims of the NOAA Commercial Data Pilot Study, and will assist this process if required. Similarly, IROWG would like to support the NOAA OSSE activities related to the future provision of GNSS-RO measurements.

There remains strong support for a fully funded COSMIC-2 mission (the full mission name is FORMOSAT-7/COSMIC-2). Overall, the aim of the community is to maximize the number of high-quality GNSS-RO observations, which can be freely exchanged.

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 with the four main recommendations for CGMS.

For reference, an appendix has also been added that gives a brief summary of relevant CGMS actions and recommendations that are impacted by IROWG.

This IROWG document provides the summary in a CGMS working paper format. The full minutes / recommendations / discussions of the sub-working groups within IROWG-5 are available at http://www.irowg.org. The workshop presentations are available at the website http://wegcwww.uni-graz.at/opacirowg2016

2 IROWG-5 SETUP

IROWG-5 was a full workshop, including presentations, posters and sub-group discussions. The presentations/posters and the sub-group discussions were focussed on specific topics, namely:

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

IROWG-5 participants were asked to summarize **relevant activities** within the scope of the sub-group in dedicated sub-group 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 four main recommendations for CGMS-45; these were endorsed by all participants. The full set of recommendations per sub-group and further information is available in a dedicated IROWG publication, on our website www.irowg.org.

3 MAIN RECOMMENDATIONS

Many of our IROWG-4 recommendations are carried forward again. We acknowledge the significant progress made for COSMIC-2. The launch of the equatorial component is scheduled for late 2017. However, the polar component of COSMIC-2 has not yet been completely secured, thus risking a substantial gap in RO observations in the middle and high latitudes. To avoid this gap and to increase the substantial positive impact of RO observations on global weather prediction, **we recommend completion of the full COSMIC-2 program**. At this moment, **the completion of the polar component of COSMIC-2 is perceived as the least risky way to obtain global coverage of RO data in the short and medium term**. Updated assimilation studies shown at IROWG-5 again showed the importance of the full COSMIC-2 data.

The following 4 main recommendations have been agreed upon by all participants at IROWG-5, where recommendations 1 and 2 are the top priority recommendations within each of the 3 sub-groups NWP, Climate, and Space Weather:

3.1 Ensure that both equatorial and polar components of COSMIC-2 are fully funded and launched; this is required for Numerical Weather Prediction, Climate, and Space Weather

It is of highest importance to ensure the continuity and long-term availability of high quality RO measurements with global coverage. 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 and stability. The continuity of GNSS RO observations in the future is not sufficiently guaranteed, which is of main concern regarding the provision of continuous climate products, especially after COSMIC-1, with long-term (decadal) commitments to resolve the climate variabilities at different timescales. **Operational GNSS RO missions for continuous global climate observation need to be established**. **While research missions are a valuable component, operational missions (like the planned COSMIC-2 equatorial and polar constellations) are required as a backbone to ensure continuity**.

COSMIC-2 is a long term, reference mission. It is advanced and well-defined, and is based on extensive heritage in hardware, software and team experience, including a decade of COSMIC-1 in-orbit operations, research and development. There is no other project, public or private, with this level of definition and heritage. Consideration of future proposals, including commercial, should be based on **well demonstrated** levels of attained capability and operational readiness.

With the decline of COSMIC-1, lack of COSMIC-2 Polar will result in a dearth of ionospheric radio occultation measurements above approximately 40° latitude. We note that the COSMIC-2 Equatorial launch will not provide data at middle and higher latitudes, where significant space weather impacts are present, which need to be monitored.

3.2 IROWG recommends targeting at least 20,000 occultations/day, to be made available to the operational and research communities of Numerical Weather Prediction, Climate, and Space Weather.

Global coverage and coverage of all local times needs to be ensured for a climate observing system and GNSS RO should contribute at least 20,000 occultations per day. For reference, a monthly mean record utilizing the effective horizontal resolution of about 300 km with a 6-hour resolution of the diurnal cycle requires at least 20,000 occultations per day. GNSS RO is also valuable for checking the reliability of climate data records estimated from other satellite-based instruments (e.g., A/MSU, which requires correction of local time drifts).

While large-scale climate monitoring and research questions can be successfully tackled with less than 20,000 occultations, the study and improved understanding of many regional-scale and large-scale climate processes critically depends on diurnal-cycle and meso-scale resolution. Further needs for higher RO density include the analysis of atmospheric blocking situations with middle and upper troposphere data, and relation to extreme climate events such as heat waves, analysis of thermodynamic imprints of deep convective systems such as tropical cyclones, volcanic eruptions, and many others.

Regarding the status of RO coverage, the current and future Metop satellite series only cover certain local times. The COSMIC-1 mission has already severely degraded, and we are facing an imminent observational gap. A COSMIC-1 follow-on mission is needed urgently. The first satellites of the planned COSMIC-2 mission will be in low inclination orbits and will cover low latitudes only. Thus there is an especially urgent need for a COSMIC-2 second satellite constellation in high inclination orbits to provide global and local time coverages. Overall, the aim should be to take advantage of all available GNSS constellations to maximize coverage.

IROWG welcomes the ongoing NOAA Commercial Data Pilot Study, which is requesting industry to demonstrate current and immediate capabilities. It is important to verify what the actual capabilities are. Regardless of the future possibility of commercial provision of data, IROWG recommends provider agencies to **support a backbone of instruments**, technologically **state-of-the-art**, and **labelled** as **essential** (WMO Res 40), and that at least **match the current operational data**. This backbone should target to provide the highest level of performance, and become a reference asset. Observations from this backbone should be freely available. Besides this backbone, IROWG recommends that a supplementary set of instruments provide further data, perhaps commercial, **not necessarily** labelled essential. **IROWG strongly recommends that this supplementary data are nevertheless as freely available as possible**. Regardless of the operational availability, it is important that there is a clear characterization of the properties (accuracy, error properties) of this dataset.

3.3 International space agencies (in particular NASA, ESA and CNSA, where LEO-LEO and GNSS-RO&-Reflectometry proposals are pending) to **support mission preparation and implementation projects towards LEO-LEO microwave occultation and GNSS-RO&-Reflectometry demonstration missions.** This should include recommending new OSSEs for the LEO-LEO observations.

Such next steps within the next two to three years include LEO-LEO microwave occultation (LMO) instrument developments towards flight instrumentation, microsat platform design and preparation, and dedicated Phase A/B studies towards mission implementation. IROWG also recommends that CGMS encourage space agencies to support R&D towards implementation of LEO-LEO demonstration in a broader sense, including on infrared-laser occultation in addition to microwave occultation, in order to pave the way towards developing an authoritative reference standard in the global free atmosphere for upper air WMO/GCOS Essential Climate Variables (ECVs) on composition (greenhouse gases) and climate. Initial mountaintop demonstrations have been successfully made at cm, mm and micrometer wavelengths.

IROWG also recommends to strengthen the scientific and technical activities for the exploitation of the potential to combine the application of the GNSS radio occultation technique with GNSS reflectometry (GNSS-R) for global monitoring of several geophysical Earth Surface parameters (e.g., altimetric height of water and ice surfaces, wave heights and wind speed/direction over the oceans, soil moisture, vegetation index). GNSS reflectometry measurements are also appropriate for atmosphere/ionosphere sounding.

3.4 IROWG recommends that CGMS should encourage GNSS providers and agencies to make ICDs (Interface Control Documents) **of GLONASS and Beidou Open Service signals available** as soon as possible, in order to allow RO instrument providers to design and develop the future receivers without uncertainties due to missing information

4 CONCLUSIONS

In summary, there remains strong support for a fully funded COSMIC-2 mission, for NWP, climate and space weather applications. More generally, the aim of the community is to maximize the number of high-quality GNSS-RO observations, which can be freely exchanged. The impressive progress made by SPIRE should be noted. However, a detailed analysis of all the commercially available data is required, and therefore IROWG fully supports the NOAA Commercial Data Pilot Study. IROWG would like to support the ongoing OSSE activities related to the future provision of GNSS-RO measurements.

The main recommendations of the fifth IROWG meeting were briefly summarised above - the full set of recommendations, relevant at CGMS level, at satellite operator level, and at IROWG level, is made available at http://www.irowg.org. The workshop presentations are available at http://wegcwww.uni-graz.at/opacirowg2016

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Acknowledgements

IROWG notes and thanks for financial support to this fifth workshop the following organisations: EUMETSAT, CGMS, ESA, FFG-ALR and WMO.

Appendix

CGMS Actions/Recommendations relevant to IROWG

From WG I (Global issues on satellite systems and telecommunication):

CGMS space agencies	WGI/6.1	A44.08	CGMS agencies with satellites with DB and RO occultation sensors to assess the technical feasibility of a RARS/DBNet RO occultation service in support of the Space Weather community.	CGMSSEC to request IROWG representative to provide a paper to WGI to this purpose (and present it in WGI)	CGMS-45	**OPEN**	HLPP 1.4

WG II (data and products):

IROWG	WGII/8	A44.13	IROWG to define the requirements on timeliness for RO observations	IROWG rapporteur to check status (space weather-related); state-of-the-art to be reported out through IROWG	CGMS-45	**OPEN**	1.1.4

Information: The Space Weather Sub-Group discussed this during IROWG-5 and concluded:
In response to CGMS action A44.13 (“IROWG to define requirements on timeliness for RO observations”), we recommend that future RO missions include communications infrastructure that will enable 95 % of the measurements to be available for use in operational models within 30 minutes or less. Data older than 30 minutes is of lower value for current models. Near-real time data latency would be optimal, but is not always practical, and should be considered to be a useful goal for future missions when possible. **In the specific case of COSMIC-2 Polar, south polar ground stations (e.g., McMurdo, Troll) should be deployed to reduce data latency.**
Suggestion: Closure after report at CGMS 45

Recommendations:

NOAA	WGII/4	R44.11	NOAA to ensure that both, equatorial and polar components of COSMIC-2 are fully funded and launched.		
CGMS members	WGII/4	R44.12	CGMS agencies to target at least 20,000 occultations/day, at appropriate global distribution, to be made available to the operational and research communities, based on recent impact studies (NWP, climate and space weather)		
CGMS members	WGII/4	R44.13	CGMS agencies to ensure that the RO receiver design includes sufficient software/firmware flexibility to allow changes in the signal processing including processing of new GNSS signals/constellations, including ionospheric measurements		
CGMS space agencies	WGII/8	R44.28	Agencies to explore the possibilities to develop suitable processing packages to support a direct broadcast implementation of RO processing, within the DBNet to improve timeliness for space weather applications	CGMS-45 (for update)	**OPEN**

WGIII recommendation

CGMS members	WGIII/2.2	R43.01	CGMS members are encouraged to consider including RO capabilities on all future polar-orbiting satellites.	Ongoing	**OPEN**

Affiliations

Anthony Mannucci is with the Jet Propulsion Laboratory, California Institute of Technology. Sean Healy is with the European Center for Medium Range Weather Forecasts. Ulrich Foelsche is with the University of Graz, Austria.