CGMS

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Prepared by IROWG
Agenda Item: WGII/5

REPORT OF IROWG ACTIVITIES

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

Executive Summary

The IROWG community has not met since September 2017. The next IROWG-7 meeting will be held on September 19-25, 2019 in Elsinore, Denmark. It will be combined with the EUMETSAT Radio Occultation Meteorology Satellite Applications Facility (ROM SAF) workshop. Therefore, we re-state the four key recommendations previously presented at CGMS-46, endorsed by the IROWG community at IROWG-6 (Estes Park, September 21-27, 2017). However, we note that COSMIC-2 polar was cancelled following IROWG-6.

The four key recommendations carried forward from IROWG-6 are:

- 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 providing good spatial and local time coverage, to be made freely 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 these missions.
- IROWG stresses the importance of long-term archiving of the Level0 data – and all the relevant metadata – from both the agency-led and "commercial" missions. These long-term costs should be included in mission budgets. Researchers, across multiple processing centers, need access to these data, and to information about the GNSS-RO receiver performance, for climate reprocessing activities. Access to just the retrieved products is not considered sufficient for many research applications.

It now seems unlikely that the target number of 20,000 occultations/day will be met with "agency led" missions in the 2020's. Finally, we encourage more collaboration and exchange of results when assessing data from proposed commercial missions.

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.

1 INTRODUCTION

The IROWG community has not met since IROWG-6 in September 2017, and therefore we simply carry forward the four key recommendations previously presented at CGMS-46. Consequently, this report will be brief.

The IROWG-7 workshop will be held September 19-25, 2019 in Elsinore, Denmark. The meeting will be held with the EUMETSAT Radio Occultation Meteorology Satellite Applications Facility (ROM SAF). This workshop will follow the established model, but it will also be a convenient opportunity for meetings by splinter groups. For example, an important recent development for the IROWG community has been an invitation to contribute data to the IPCC Sixth Assessment Report (AR6). The contribution to AR6 will be discussed at a special IROWG-7 session.

The IROWG vision remains a backbone constellation providing at least 20,000 high quality occultations per day, with both good spatial and temporal coverage. These data should be considered *essential (WMO 40)*, and therefore they should be made freely available to the operational and research communities of Numerical Weather Prediction (NWP), Climate and Space Weather.

Given the 20,000 occultations/day target, note that we typically assimilate around 2900 profiles per day in NWP systems. The three Metop satellites now produce around 1900 occultations/day. GNOS data from FY-3C are now being assimilated, and FY-3D data (~450 occultations/day) are currently being monitored. GRACE Follow On (GRACE-FO) and KOMPSAT-5 data are not yet routinely available. COSMIC-2A (equatorial) is due for launch June 30, 2019, and it should provide at least 4000 occultations/day. Despite new data expected in the 2020's, for example from new Chinese satellites, Sentinel-6 (formerly Jason-CS) and EPS-SG, it now seems highly unlikely that data from "agency led" missions will meet the 20,000 occultation/day target, now that COSMIC-2 polar has been cancelled. In addition, these data will not be distributed uniformly in local time.

Users may wish to supplement the backbone constellation with data provided by commercial companies. We acknowledge the excellent progress made by commercial companies in providing radio occultation data in recent years. We also continue to support the aims of projects, such as the NOAA Commercial Weather Data Pilot (CWDP) Study, because detailed studies like this are ***the only way to assess the actual capabilities of the providers***. However, we are concerned that the results from some assessment studies are not being made available to the broader IROWG community. The present situation is unclear, but we believe a number of similar assessment studies are currently being performed in parallel, and the results are not being shared because of non-disclosure agreements (NDAs). Given that a primary purpose of the IROWG workshops is to bring together data providers and users, to freely exchange ideas and information, the use of NDAs is problematic. Therefore, it is hoped that the latest results from the various ongoing assessments will be presented at IROWG-7 and that data can be shared among multiple groups to achieve independent assessments of the same raw data.

We note that members of the GNSS-RO research community remain concerned that they will not be consulted sufficiently when assessments are made of the various agency led and commercial GNSS-RO proposals. The research community continue to emphasize that their requirements may differ from those of operational NWP users. Specifically, the researchers need access to the raw data, not just retrieved Level2 or Level3 products. The provision and funding of long-term archiving of both the raw GNSS-RO data and all the metadata is essential for climate reprocessing activities, for example. The researchers also need access to information about the instrument performance. Overall, it is important that multiple centers have all the information required for them to process and re-process GNSS-RO from both agency led and commercial missions.

The planning of the LEO-LEO microwave occultation OSSEs, suggested in the key recommendations, has not progressed significantly since IROWG-6. The central issue is the lack of a fast forward model for use in assimilation systems. This will be discussed again at IROWG-7, but it is clear that resources need to be committed to this area.

The structure of this report is as follows: Section 2 gives a brief overview of the proposed organization of the IROWG-7 workshop and the sub-groups, Section 3 re-states the main recommendations which were agreed upon at IROWG-6. Section 4 concludes the main section of the report.

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

2 PROPOSED IROWG-7 SETUP

IROWG-7 will be a full workshop, including presentations, posters and sub-group discussions, following previous workshops. The presentations/posters and the sub-group discussions will be focussed on four specific sub-group topics, namely:

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

IROWG-7 participants will be 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 will be discussed in an open plenary session near to the meeting's conclusion.

3 MAIN RECOMMENDATIONS FROM IROWG-6 (2017)

For completeness, in this section we simply re-state the main recommendations and reasoning from IROWG-6, noting that this meeting took place before the decision to cancel the polar component of COSMIC-2.

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 remains 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 providing good spatial and local time coverage, to be made freely 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 certain 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 adequate 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, uncertainty properties) of this dataset.

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

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 a strengthening of 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 stresses the importance of long-term archiving of the Level0 data – and all the relevant metadata – from both the agency-led and "commercial" missions. These long-term costs should be included in mission budgets. Researchers need access to these data, and to information about the GNSS-RO receiver performance, for climate reprocessing activities. Access to just the retrieved products is not considered sufficient for many research applications.

More generally, members of the GNSS-RO research community request that they be consulted when assessing the various agency led and commercial GNSS-RO proposals, and they emphasize that their requirements may differ from those of operational NWP users. Specifically, the researchers need access to the raw data, not just retrieved Level2 or Level3 products. The provision and funding of long-term archiving of both the raw GNSS-RO data and all the metadata is essential for climate reprocessing activities, for example. The researchers also need access to information about the instrument performance. Overall, it is important that multiple centers have all the information required for them to process and re-process GNSS-RO from both agency-led and commercial missions.

4 CONCLUSIONS

The IROWG community has not met since IROWG-6 (September 2017), and the next meeting will be in Elsinore, Denmark on September 19-25, 2019. Therefore, we have carried forward the main recommendations from IROWG-6.

The IROWG vision remains a backbone constellation for 20,000 high quality, occultations/day, which are well distributed in both space and time. These should be considered *essential*, and be freely exchanged. Despite the gradual loss of the COSMIC constellation, around 2900 occultations/day are currently available for NWP applications, because of the three Metop satellites and other new data sources, including FY-3C GNOS. The launch of COSMIC-2 equatorial is expected in 2019, and it will increase data numbers by at least 4000 occultations/day. Despite launches planned for the 2020's, it seems highly unlikely that agency led missions will reach the 20,000/day target.

Data from commercial GNSS-RO providers are currently being assessed in a number of studies. We are concerned that some important information on data quality and impact is not being made available to the broader IROWG community, and we strongly encourage participation in IROWG-7 in order to present the results from these studies.

The GNSS-RO research community should not be neglected when assessing data from new missions. Their requirements may not always be aligned with the operational NWP community. They need access to raw data for reprocessing activities, and the

need and costs of long-term archiving should be included when assessing new missions.

5 APPENDIX

Status of CGMS Actions/Recommendations relevant to IROWG
Actions and recommendations are documented in CGMS-46_LOA_(status_21_Sep_2018).pdf, available at the CGMS web site.

Significant new actions and recommendations related to IROWG emerged from CGMS-46. Three actions levied on IROWG are currently open. The most significant new recommendation from the IROWG perspective is the recommendation adopted by the operational agencies to archive raw RO data (Plenary R46.01).

Plenary

Lead	AGN item	Rec #	Description	STATUS (feedback for completion)	HLPP ref
CGMS space agencies	E.10	R46.01	Report from IROWG (CGMS-46-IROWG-WP-02): IROWG recommends to CGMS:- that raw data and level 1 data (including meta data) be made available for reprocessing/reanalysis of climate data records and for data validation- the long-term archiving of such data (incl. meta data).		1.2

There is a related action on WGIV to consider long-term data preservation (Plenary A46.06). WGIV is “Global data dissemination”.

Plenary

Actionee	AGN item	Action #	Description	Action feedback/closing document	Deadline	Status	HLPP ref
WGIV	(Plenary E.10)	R46.06	Following CGMS-46 plenary discussions related to IROWG and GCOS IP: CGMS WGIV to consider the GCOS IP actions on long-term data preservation (LTDP). Ref. GCOS IP action G 26.		CGMS-47	OPEN	1.2

CGMS initiated a new action relevant to IROWG’s interest in more precise and accurate refractivity constants for climate monitoring purposes. JPL has started a series of laboratory measurements based on prior recommendations of CGMS and funding by NASA. In coordination with Josep Aparicio (Environment Canada) and Uli Foelsche, this has led to the possibility of parallel work at Env Canada, and an appreciation of the difficulty of funding such work in the long term. This led to WGII action A46.01 for CGMS members to document their known unfulfilled spectroscopic needs. This should lead to improved coordination and more timely completion of the work at JPL and elsewhere.

WGII

Actionee	AGN item	Action #	Description	Action feedback/closing document	Deadline	Status	HLPP ref
CGMS members	WGII/5	A46.01	CGMS members to provide a summary of their known unfilled spectroscopy needs, and to develop a means of facilitating interaction between laboratory spectroscopy groups to spur cooperation and mitigate the lack of resources (financial and persons). (Ref.CGMS-46-ITWG-WP-01).		By CGMS-47	OPEN	4.6.1

The new action on IROWG is to develop principles of data quality assessment and impact for heterogeneous data sources: "IROWG to develop process and principles for RO data quality control to ease intercomparison of data from different providers." The action is due in 2019 (WGII A46.08), and should be covered at IROWG-7.

WGII

Actionee	AGN item	Action #	Description	Action feedback/closing document	Deadline	Status	HLPP ref
IROWG	WGII/5	A46.08	IROWG to develop process and principles for RO data quality control to ease intercomparison of data from different providers.	To be raised at the next IROWG meeting (Sept 2019)	2019	OPEN	

The OSSE action on IROWG remains open and is now due at CGMS-47: "IROWG to develop a detailed proposal for OSSEs regarding LEO-LEO MW occultation and GNSS-RO&-reflectometry." (WGII A45.02). A status report was developed and referenced at the meeting, guiding the discussions (StatusReportLEO-LEO OSSE AI A45.02 V2.pdf). It will be placed on the IROWG web site (irowg.org). More work on this action is advised.

WGII

Actionee	AGN item	Action #	Description	Action feedback/closing document	Deadline	Status	HLPP ref
IROWG	4	A46.08	IROWG to develop a detailed proposal for OSSEs regarding LEO-LEO MW occultation and GNSS-RO&-reflectometry.	CGMS-46: Action remains open following WGII discussions. WGII IS#2 15 Mar 2018: No progress information.	CGMS-47(1 Nov 2017, CGMS-46)	OPEN	

				1 Feb 2018/29 Nov 2017: Activity initiated, IROWG has reached out to its members, deadline extended. Regarding the GNSS-R OSSEs, some work has been done to be extended as the global observing system develops. Regarding LEO-LEO occultation OSSEs, limited progress is expected prior to CGMS-46.			

In view of the constellation shortfall, there was a new recommendation on agencies to place RO receivers on their missions (WGII R46.06). It is considered covered by the new CGMS baseline (Sep 2018) and therefore will be closed.

Important action items are still open, including providing science questions for the 7th Impact workshop in 2020 (reference CGMS-45-WMO-WP-02). These questions should be provided to Lars Riishojgaard at lriishojgaard@wmo.int. This is an opportunity for IROWG to pose questions related to NWP impact that are particularly relevant to RO. (Plenary A45.02).

Plenary

Actionee	AGN item	Action #	Description	Deadline	Status	HLPP ref
CGMS space agencies, IROWG, IPWG, IWWG, ICWG, ITWG	C.2	A45.02	CGMS International Science Working Groups and CGMS space agency members to formulate science questions, including the impact of data latency, in view of the 7th Impact WS 2020 (ref. CGMS-45-WMOWP-02) and provide these to lriishojgaard@wmo.int	CGMS-46	OPEN	1.1.2

A space weather-related action remains open: “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.” (WGI A44.08). However, it was noted that “NOAA has no plans to do implement such a service”. Discussions suggested that moving forward on the action could attract interest in the product. This applies most immediately to the MetOP SG satellites which will offer the service and will provide space weather data.

WGI

Actionee	AGN item	Action #	Description	*Status*	Deadline	Status	HLPP ref
CGMS space agencies, IROWG	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.	*See also WGII recommendation R44.38* May 2018: IROWG paper postponed potentially to CGMS-47 Deadline for extended following CGMS-45 and 46 discussions, noting that NOAA has no plans to do implement such a service. CGMS 44: CGMSSEC request IROWG representative to provide and present a paper to WGI to support the discussion on the technical feasibility of a service.	CGMS-47(CGMS-45, 46)	OPEN	1.4

The following recommendation is still open for IROWG members: “To enhance coordination, ISWGs to discuss with ICWG co-chairs key items for collaboration.” (WGII R44.06).

WGII

Lead	AGN item	Rec #	Description	Recommendation feedback/closing document	HLPP ref
IROWG, IPWG, IWWG, ITWG	WGII/4	R44.06	To enhance coordination, ISWGs to discuss with ICWG co-chairs key items for collaboration.	WGII IS#2 15 Mar 2018: Maintain it as a recommendation. Nov '17: Some informal discussions held in IPWG	s

The recommendation regarding GNSS ICDs led to information regarding Beidou being added. (WGII R43.13). IROWG believes this recommendation is currently being followed, and therefore it is closed.

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