CGMS

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Prepared by IROWG
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Discussed in
WGII/5, Plenary

REPORT OF IROWG ACTIVITIES: OUTCOME AND RECOMMENDATIONS FROM THE IROWG-6

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

Executive Summary

This report summarizes the IROWG-6 meeting held on September 21-27, 2017 in Estes Park, USA. It provides the recommendations from the four IROWG sub-groups: NWP, Climate, Space Weather and Receiver Technology/Innovative Occultation Techniques. The four key recommendations for CGMS-46 – endorsed by the IROWG community at the plenary session – 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 meta data – from both the agency-led and "commercial" missions. These long term costs should be included in mission budgets. Researchers need access to this 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.

Workshop minutes and this CGMS working paper from IROWG-6 are/will be made available at http://www.irowg.org. Workshop presentations available at

https://cpaess.ucar.edu/cosmic-10th-data-users-workshop-irowg-6-about

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-6

1 INTRODUCTION

This IROWG working paper reports on the combined-tenth COSMIC Data User' Workshop and the sixth workshop of the International Radio Occultation Working Group (IROWG-6). The combined meeting was organized by University Corporation for Atmospheric Research (UCAR) and held in Estes Park, USA, from September 21-27, 2017.

The workshop was attended by more than 130 scientists, including representatives from all the major RO processing centers, space agencies, the weather prediction centers assimilating RO data, the research community, and representatives of commercial data providers. Overall, this was a very good workshop, with a particularly strong representation from the US research community. Approximately 70 talks and 50 posters were presented. Recommendations were developed in dedicated sub-working groups, and then presented and agreed upon in a plenary discussion on the last day. Additionally, IROWG-6 was used by several researchers for dedicated specialist/splinter meetings, such as SCOPE-CM for example.

As it was only one year since IROWG-5 (September 2016), many of the key discussion points throughout the IROWG-6 workshop remained the same, and in fact three of the four main IROWG-6 recommendations to CGMS are essentially carried forward from IROWG-5. However, this meeting was seen as an important opportunity for the IROWG community to hear the progress and plans for the NOAA Commercial Weather Data Pilot (CWDP) Study. The NOAA CWDP team was active throughout the meeting, in both the oral sessions and working groups. Furthermore, NOAA requested the IROWG community provide feedback on a forthcoming Commercial Weather Data Pilot Study Request for Proposals (RFP) expected in 2018. There remains strong support for the CWDP within IROWG because it is essential for assessing the actual capabilities of the various GNSS-RO commercial mission options. We hope that we can maintain a good dialogue between the IROWG and the NOAA CWDP team in the coming years.

The meeting showed that the commercial GNSS-RO missions continue to make good progress. SPIRE, in particular, have moved from showing individual cases at the meeting in 2016 to now showing measurement departure statistics in 2017, which is encouraging. Nevertheless, there remains strong support for a fully funded COSMIC-2 mission within IROWG. Overall, the aim of the community is to ensure the long-term continuity of the GNSS-RO measurements, and to maximize the number of high-quality GNSS-RO observations, providing good spatial and local time coverage, which can be freely exchanged.

Members of the GNSS-RO research community expressed concern that they will not be consulted sufficiently when assessments are made of the various agency led and commercial GNSS-RO proposals, and the research community emphasized 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 meta-data 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.

There is also concern within IROWG about how the NWP impact of future GNSS-RO missions is being assessed in simulations. This concern is because of apparently contradictory results between OSSEs and the Ensemble of Data Assimilations (EDA) approach in some COSMIC-2 simulations. Collaboration in this area is encouraged.

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 the main section of the report with the four main recommendations for CGMS. An additional section is added that contains a science highlight courtesy of Adrian Simmons of ECMWF. Additional information on the highlight is found in presentation from IROWG.

For reference, an appendix has also been added that gives a brief summary of CGMS actions and recommendations that are relevant to 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-6 are available at http://www.irowg.org. The workshop presentations are available at the website https://cpaess.ucar.edu/cosmic-10th-data-users-workshop-irowg-6-about

2 IROWG-6 SETUP

IROWG-6 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-6 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 an open plenary session near to the meeting's conclusion.

The participants agreed to highlight four main recommendations for CGMS-46; 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

Three of our IROWG-5 recommendations are carried forward again, and we note that IROWG-6 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 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 stresses the importance of long-term archiving of the Level0 data – and all the relevant meta data – 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 meta-data 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

IROWG-6 came only one year after IROWG-5 (September, 2016), and many of the main discussion points and key recommendations are carried forward.

There remains strong support for a fully funded COSMIC-2 mission, for NWP, climate and space weather applications. The aim of the IROWG community is still to maximize the number of high-quality GNSS-RO observations with both good spatial and local time coverage, which can be freely exchanged.

SPIRE continues to make progress, but a detailed analysis of all the commercially available data is still required, and therefore IROWG fully supports the ongoing NOAA Commercial Weather Data Pilot activities. However, we note that the GNSS-RO research community are concerned that they will not be consulted sufficiently when the various "agency-led" and commercial GNSS-RO missions are being assessed. Furthermore, the researchers are emphasizing the need for the provision and funding of long-term archiving of the raw GNSS-RO data and all relevant meta-data, and that

access to just Level2 or Level3 products is not sufficient for their needs.

The suggested high-priority recommendations for CGMS 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 plus Reflectometry 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.

- IROWG stresses the importance of long-term archiving of the Level0 data – and all the relevant meta data – 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.

Acknowledgements

IROWG notes and thanks for financial support to this sixth workshop the following organisations: NSF, NASA, EUMETSAT, ESA, SPIRE, GeoOptics, Planet-IQ, IHI, and WMO.

5 SCIENCE HIGHLIGHT

GNSS-RO measurements are now considered an essential observation type for climate reanalyses because they can be assimilated with bias correction to the forecast model. Recent results produced by Adrian Simmons (ECMWF) have demonstrated that the consistency of the lower/middle stratospheric temperature reanalyses provided by the major centres has improved significantly since 2006, as a result of the active assimilation of measurements from COSMIC and subsequent missions such as Metop-GRAS. For example, Figure 1 shows the time-series of 100 hPa temperatures in the tropics from the latest generation of reanalyses, highlighting the consistency of MERRA2, JRA55, ERA-Interim and ERA5 since 2006. MERRA did not assimilate GNSS-RO.

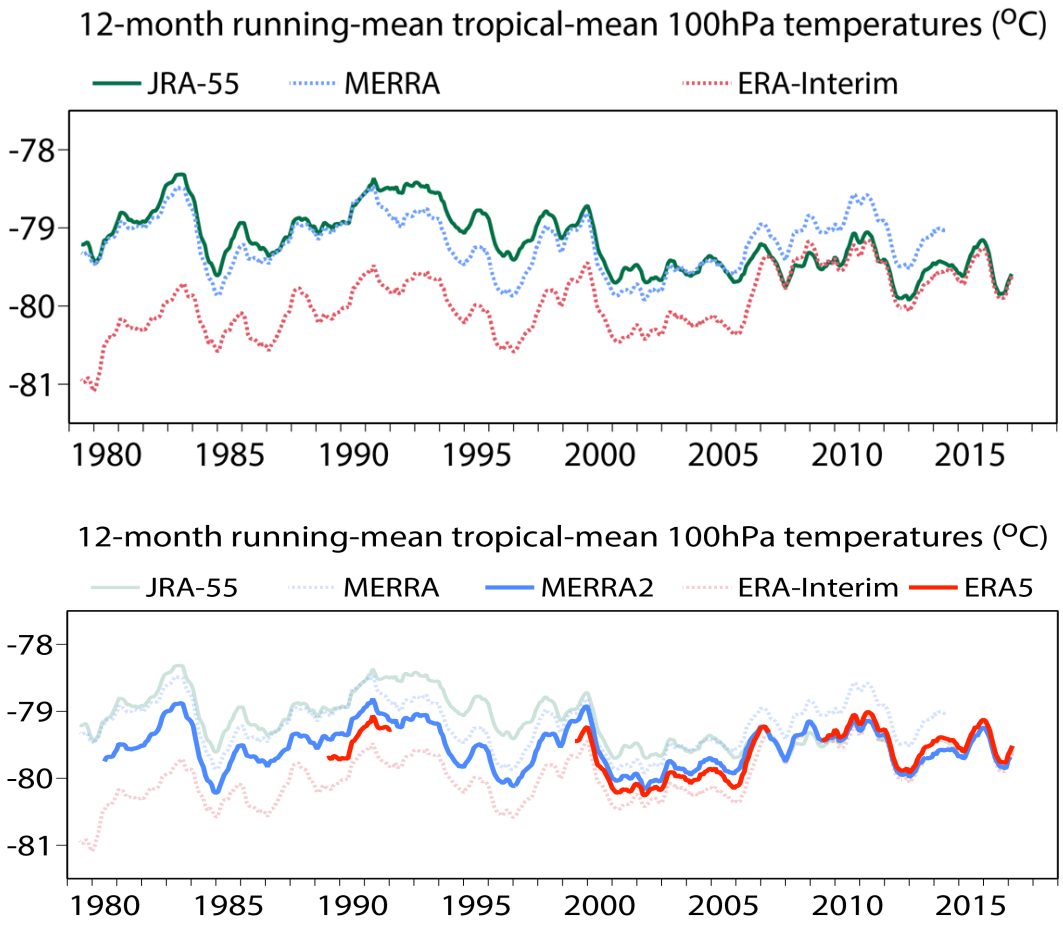

Figure 1: The 12-month running mean of the 100 hPa temperature in the tropics from the major reanalysis centres. The GNSS-RO measurement numbers increased in 2006 with the introduction of the COSMIC data. Note that MERRA does not assimilate GNSS-RO, but MERRA2 does.

6 APPENDIX

Status of CGMS Actions/Recommendations relevant to IROWG

From Plenary

CGMS-45 actions – 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

The above action was levied on all scientific working groups. This refers to the series of workshops on impact of various observing systems on NWP. IROWG members were requested, via the mailing list, to respond directly to Lars Riishojgaard regarding science questions to be addressed.

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

Actionee	AGN item	Action #	Description	*Status*	Deadline
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.	~~*May 18 dedicated WP for next WGI meeting CGMS-46 IROWG-WP-02*~~ *Mar 2018 CGMSSEC to contact IROWG and request a paper accordingly.* Deadline extended following CGMS-45 discussions. CGMSSEC to request IROWG representative to provide a paper to WGI to this purpose (and present it in WGI) NOAA does not have any ability to use RARS for RO data	(CGMS-45) CGMS-46

This action is being re-worked. There is potential interest by the space weather community in low-latency data enabled by direct broadcast. Discussions on feasibility of direct broadcast is planned at CGMS-46.

WG II (data and products):

CGMS-45 actions – WGII						
"Actionee"	AGN item	Action #	Description	Deadline	Status	HLPP ref
IROWG	4	A45.02	IROWG to develop a detailed proposal for OSSEs regarding LEO-LEO MW occultation and GNSS-RO&-reflectometry.	~~1 Nov 2017~~ CGMS-46	OPEN	1.1.4

The above action was levied on IROWG and is now due at CMGS-46. This action was assigned to Gottfried Kirchengast and Rob Kursinski (LEO-LEO) and Anthony Mannucci (GNSS-R). Proposals will be available for review at CGMS-46, and later at the IROWG web site.

WGII actions open from previous plenary sessions (at CGMS-45)							
"Actionee"	AGN item	Action #	Description	Recommendation feedback/closing document	Deadline	Status	HLPP ref
IROWG	WGII/8	A44.13	IROWG to define the requirements on timeliness for RO observations.	CGMS-45: IROWG-WP-01: 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. IROWG to look at the implications of the requirement on ionospheric processing. IROWG rapporteur to check status (space weather-related); state-of-the-art to be reported out through IROWG	New deadline: CGMS-46 (CGMS-45)	OPEN	1.1.4

The above action relates to desired timeliness of RO observations. The requirement was clarified as pertaining to space weather. For NWP, existing requirements for FORMOSAT-7/COSMIC-2, METOP-GRAS data, and FY-3-GNOS are being combined to report the “state-of-the-art” for timeliness. These are:
MetOp: Data are to be available for processing within 135 minutes (2:15).
COSMIC-2 (planned): average latency of processed profiles is 45 minutes.
GNOS: 90% of the data are to be available within 3 hours.

This closes the action, pending further discussion at CGMS-46.

Recommendations:

CGMS-45 WGII Recommendations							
"Actionee"	AGN item	Rec #	Description	Recommendation feedback/closing document	Deadline	Status	HLPP ref
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			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.