CGMS

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Prepared by IROWG
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REPORT OF IROWG ACTIVITIES: OUTCOME AND RECOMMENDATIONS FROM THE IROWG-7

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

Executive Summary

This report summarizes the IROWG-7 meeting held on September 19-25, 2019 in Elsinore, Denmark, in conjunction with the 6th ROM SAF User Workshop. It provides the recommendations from the four IROWG sub-groups: Numerical Weather Prediction; Climate; Receiver Technology and Innovative Occultation Techniques; and Space Weather. The key recommendations for CGMS – endorsed by the IROWG community at the plenary session – are:

- IROWG encourages all providers of RO observations to classify these as essential in the sense of WMO Res 40. IROWG stresses the importance of free and unrestricted access to essential RO data including archived raw data.
- IROWG recommends that WMO and CGMS should co-ordinate any GNSS-RO data purchases to avoid duplication amongst agencies. If purchased, the commercial GNSS-RO data should be bought with a world license, so that the data are equally available to all agencies.
- IROWG recommends that GNSS-RO data - with at least 20,000 occultations per day - are globally distributed and provide good sampling of the diurnal cycle. This is important for NWP, Climate, and Space Weather.

It 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 the results of commercial data buys.

Full workshop minutes and this CGMS working paper from IROWG-7 are/will be made available at http://irowg.org/workshops/irowg-7/. All given workshop presentations can be found at http://www.romsaf.org/romsaf-irowg-2019/en/.

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

This IROWG working paper reports on the combined 6th ROM SAF User Workshop and the 7th workshop of the International Radio Occultation Working Group (IROWG-7). The meeting was organized by ROM SAF (Radio Occultation Meteorology Satellite Application Facility) and DMI (Danish Meteorological Institute) and held in Elsinore (Helsingør), Denmark, from September 19-25, 2019. IROWG wants to express its gratitude for the excellent organisation of this meeting, which turned out to be one of the most successful in recent years.

The workshop minutes and full recommendations are available at:
http://irowg.org/workshops/irowg-7/. All the workshop presentations are at:
http://www.romsaf.org/romsaf-irowg-2019/en/

The workshop was attended by more than 100 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. 73 talks and 25 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, the workshop was used by several researchers for dedicated specialist/splinter meetings, such as SCOPE-CM or contributions to the upcoming IPCC report. These meetings are not covered here.

Two years had passed since IROWG-6 (September 2017) and important progress has been achieved in this period. A very significant event was the successful launch of the FORMOSAT-7/COSMIC-2 mission on 25 June 2019, delivering data with a very high Signal-to-Noise ratio SNR (> 2000 V/V). This helped to counteract the continuous decline of available RO data in recent years, which was a source of serious concern for the community. It should, however, be noted that COSMIC-2 data are confined to latitudes below ~40°, leaving a serious gap in local time coverage at high latitudes.

The “GPS” Radio Occultation (RO) Technique has evolved to a true “GNSS” RO Technique, where signals from several Global Navigation Satellite System constellations are meanwhile exploited.

A GNSS polarimetric radio occultation experiment is orbiting aboard the PAZ satellite since February 22, 2018, and it was activated on May 10, 2018. RO observables at two linear polarizations are being acquired and they have proved sensitivity to heavy rain as well as other hydrometeors.

Polarimetric RO observations, high SNR data, deep tracking data, and grazing angle reflections allow for exciting new scientific applications.

Great progress has been made in the field of GNSS reflectometry (GNSS-R) since the previous IROWG. In addition to the extensive GNSS-R data set being obtained from NASA/CyGNSS, other future missions are under preparation, some of which are ready for launch. NOTE: Given that there exists a reflection community already within the IEEE

society, and given that near-nadir reflectometry involves different technology, challenges and developer communities, the consensus within IROWG is that there is not a need to promote GNSS-R that involves near-nadir left-hand circularly polarized (LHCP) scenarios within the IROWG. The RO community should pursue low grazing angle reflections that can be conducted with GNSS RO payloads using slightly modified firmware.

The meeting was an important opportunity for the IROWG community to hear the progress of 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. There remains strong support for the CWDP within IROWG because it is essential for assessing the actual capabilities of the various GNSS-RO mission options. We hope that we can maintain a good dialogue between the IROWG and the NOAA CWDP team in the coming years.

IROWG was asked by CGMS to evaluate the outcome of the agency-funded commercial weather data pilot (Action A47.05). This task could not, however, be taken by the IROWG as the results are not open to the community. IROWG therefore encourages the institutes evaluating commercial data to share their reports publicly. Based on the evidence provided during the meeting, IROWG notes that the commercial GNSS-RO missions (in particular Spire) continue to make very good progress.

Nevertheless, there remains strong support for a “backbone” of agency-funded GNSS-RO missions with long-term commitment. 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. Specifically, the researchers need access to the raw data, not just retrieved 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 government sponsored and commercial missions.

The value of GNSS-RO data for climate monitoring in increasingly acknowledged by the broader climate science community. IROWG has been invited by the IPCC to contribute to the upcoming assessment report.

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. The status of actions and recommendations is covered in the Appendix.

2 IROWG-7 SETUP

IROWG-7 (in conjunction with the 6th ROM SAF User Workshop) was a full workshop, including presentations, posters and sub-group discussions. The presentations/posters and the sub-groups were organized according to the following specific topics, namely:

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

IROWG-7 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. Furthermore, the subgroups assessed the status of the relevant CGMS actions.

3 MAIN RECOMMENDATIONS FROM IROWG-7

3.1 IROWG encourages all providers of RO observations to classify these as essential in the sense of WMO Res 40. IROWG stresses the importance of free and unrestricted access to essential RO data including archived raw data.

Acknowledging CGMS recommendation R46.01 on long-term data storage, IROWG recommends that CGMS agencies ensure that all information necessary for independent processing centers to process raw level 0 data to climate data products is freely available (following WMO Resolution 40), including long-term archiving and public data access. This is equally important for data from commercial providers.

The provision and funding of long-term archiving of both the raw GNSS-RO data and all the metadata is essential (e.g. for climate reprocessing activities). 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.

3.2 IROWG recommends that WMO and CGMS should co-ordinate any GNSS-RO data purchases to avoid duplication amongst agencies. If purchased, the commercial GNSS-RO data should be bought with a world license, so that the data are equally available to all agencies.

IROWG acknowledges the valuable potential role played by commercial providers of RO data. The data purchases should include raw level 0 data and all necessary metadata to ensure optimal use for weather and climate purposes.

3.3 IROWG recommends that GNSS-RO data - with at least 20,000 occultations per day - are globally distributed and provide good sampling of the diurnal cycle. This is important for NWP, Climate, and Space Weather.

The community is currently far short of 20,000 occultations per day – a target number, which has already been endorsed by previous CGMS meetings. IROWG acknowledges the successful launch of the COSMIC-2 mission on 25 June 2019, which helped to counteract the continuous decline of available RO data in recent years, but it should be noted that COSMIC-2 data are confined to latitudes below ~40°, leaving a serious gap in local time coverage at high latitudes.

These 20,000 occultations per day should have at least COSMIC-1 quality, defined as:

1. Spatial and local time coverage: one sounding per day in each 5° x 5° latitude-longitude box for COSMIC-1, and distributed nearly uniformly in local time.
2. Penetration: about 80% of COSMIC-1 data penetrate below 2 km altitude.
3. Noise: Signal-to-Noise ratio (SNR) of the COSMIC-1 receiver is about 500 – 600 V/V in general.

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).

4 CONCLUSIONS

The “GPS” RO Technique has evolved to a true “GNSS” RO Technique, where signals from all GNSS constellations are on a path to being exploited.

The FORMOSAT-7/COSMIC-2 constellation provides RO data with very high SNR. The PAZ satellite provides the first GNSS polarimetric radio occultation data. Great progress has been made in the field of GNSS reflectometry.

Based on the evidence provided during the meeting, IROWG notes that the commercial GNSS-RO missions (in particular Spire) continue to make very good progress. Nevertheless, there remains strong support for a “backbone” of agency-funded RO missions with long-term commitment.

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. Specifically, the researchers need access to the raw data, not just retrieved products.

5 APPENDIX

Status of CGMS Actions/Recommendations relevant to IROWG

A45.02: IROWG to develop a detailed proposal for OSSEs regarding LEO-LEO MW occultation and GNSS-RO &-reflectometry.

- Important progress has been made in the field of GNSS reflectometry (GNSS-R). This part of the action is therefore regarded as not relevant anymore.
- A key missing element has been identified: LEO-LEO OSSEs require the development of a LEO-LEO forward operator that can be used in NWP systems, it should operate up to at least 183 GHz to account for absorption, scattering and polarimetric capabilities. Development of the forward operator could be achieved with support for a two-year postdoctoral researcher, and 25% of senior researchers in the areas of (1) LEO-LEO instrument/observations, (2) radiative transfer, (3) microphysics and (4) NWP system integration (i.e. two senior researcher years in total), with nominal support for travel and publication.
- IROWG recommends to close or reformulate action A45.02.

A46.08: IROWG to develop process and principles for RO data quality control to ease intercomparison of data from different providers.

- IROWG acknowledges there are about 10-30% observations rejected during the data processing and retrieval procedures for current missions. However, the quality control (QC) procedures are not consistent among different data providers and processing centers. They are very likely to differ between the current and future missions as well. Providers should document their QC procedures (e.g., QC pertains to orbits, space sampling/inhomogeneity, neutral atmosphere or space weather products, etc.) and share with IROWG.
- IROWG recommends an action to data providers to document data processing QC processes (including a month of QC statistics, e.g. rejection percentage at each QC step) and space sampling information and provide to IROWG.

A47.04: IROWG to provide recommendation on orbital planes in order to improve coverage.

- It is mandatory, that RO data are globally distributed and provide a good sampling of the diurnal cycle. This can be either achieved with a dedicated constellation with orbits that drift sufficiently fast in local time (such as COSMIC-2 **equatorial + polar**), or with satellites in six or more sun-synchronous orbit planes that provide an adequate sampling of the diurnal cycle.
- The current (and near future) situation is unsatisfactory: Due to the cancellation of its polar component, COSMIC-2 data are confined to latitudes below ~40°, leaving a serious gap in local time coverage at high latitudes – even more pronounced for ionospheric data, which are not provided by the first generation of MetOp satellites.

A47.05: IROWG to evaluate the outcome of agency funded commercial weather data pilot following IROWG-7 and report to CGMS-48.

- Status: This task cannot be taken by the IROWG as the results are not open to the community.
- IROWG encourages the institutes evaluating commercial data to share their reports publicly.
- It is noted that the following institutions are currently performing an evaluation:
  NOAA (Spire and GeoOptics, level 1-2, supported by EUMETSAT),
  NRL (Spire and GeoOptics, level 2 bending angle, level 1 podTEC),
  NASA, USAF, MetOffice (Spire, L1b),
  ESA (supported by EUMETSAT and U. Graz, Spire; level 1-2)
- IROWG recommends that CGMS makes a co-ordinated request for results from all commercial data studies to be made public.

A47.31: CGMS baseline and RO: IROWG and 7th WMO Impact Workshop needs to validate the current baseline in terms of the coverage, number, quality and sampling of RO
and
A47.32: IROWG to review the CGMS baseline and validate wording that captures CGMS member contribution to RO data in terms of coverage, number, quality and sampling: and share impact studies of RO data between the CGMS baseline and WIGOS 2040 vision observing targets.

- IROWG shares the concern, expressed in the recent WGIII risk assessment (March 2020), that there is “Continuity risk for the number and geographic distribution of radio occultations; especially in the low- to mid- latitudes”

- IROWG understands the “baseline” as the “missions that are currently being, or planned on being flown”.
- This baseline is currently not sufficient to meet the HLPP objective (1.2) to advance the atmospheric Radio Occultation constellation, with the long-term goal of providing 20000 occultations per day on a sustained basis

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.