Prepared by IROWG
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Summary of the Seventh International Radio Occultation Workshop

Held in Elsinore, Denmark

From Thursday, 19th September to Wednesday, 25th September 2019

Starting at 09:00 hours on 19th September

Ending at 13:30 hours on 25th September

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: NWP, Climate, Receiver Technology/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.
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.

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.

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 COSMIC-2 mission on 25 June 2019, which helped to counteract the continuous decline of available RO in recent years, but 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.

1 INTRODUCTION

This IROWG report presents the minutes / full recommendations of the combined 6th ROM SAF User Workshop and the seventh 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 perfect organisation of this meeting, which turned out to be one of the most successful of the past years.

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 have 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 COSMIC-2 mission on 25 June 2019, which helped to counteract the continuous decline of available RO in recent years, which was a reason 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 all GNSS constellations are meanwhile exploited.

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 agency funded commercial weather data pilot (Action A47.05). This task could, however, not 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 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.

Members of the GNSS-RO research community are concerned that they will not be consulted sufficiently 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 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 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 recommendations provided by the different subgroups, and Section 4 concludes with the main recommendations for CGMS.

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.

The participants agreed to highlight main recommendations for CGMS-48; these were endorsed by all participants.

3 SUB-GROUP RECOMMENDATIONS / DISCUSSIONS

3.1 Numerical Weather Prediction (NWP) Sub-Group

Co-chairs: Hui Shao (JCSDA/UCAR), Neill Bowler (Met Office)

Members: Francois Vandenberghe (JCSDA/UCAR), Heikki Pohjola (WMO), Ben Ruston (NRL), Sean Healy (ECMWF); Eric DeWeaver (NSF), Harald Anlauf (DWD), Doug Hunt (UCAR), Mayra Oyola (JPL), E H Kim (KMA), M Shimada (JMA), Christian Marquardt (EUMETSAT), Michael Gorbunov (RAS), Vladimir Irisov (Spire), Doug Whiteley (NOAA), Dominique Raspaud (Metéo France), Jennifer Haase (Scripps), Richard Anthes (UCAR)

Recommendations to CGMS

1. IROWG recommends that CGMS and WMO should coordinate any future potential purchase of commercial data to ensure that they are made freely available (world license) for use of operational and research communities.
2. IROWG recommends targeting at least 20,000 occultations/day providing good spatial and local time coverage of at least COSMIC-1[1] quality because IROWG considers GNSS data as essential in the sense of WMO 40.
3. IROWG recommends that CGMS makes a co-ordinated request for results from all commercial data studies to be made public.
4. IROWG recommends that CGMS works with responsible entities, including IGS, to assure that GNSS ground station infrastructure is sufficiently supported so that they can provide the necessary geodetic data for precise orbit determination and provision of data bits from GNSS messages.

Recommendations/Actions within IROWG

1. IROWG appreciates the effort that has been made to make PAZ, KOMPSAT and Feng-Yun (FY) data available in NRT.
2. IROWG encourages the continued exploitation of RO satellites to collect, characterize, and determine appropriate applications of grazing angle GNSS reflections observations (GNSS-R).
3. IROWG encourages further development of both grazing angle and other GNSS-R products and their assimilation to potentially impact NWP and other applications.

[1] COSMIC-1 quality is defined as:

1. Spatial and local time coverage: one sounding per day in each per 5°5° latitude 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 COSMIC-1 receiver is about 500 – 600 V/V in general.

4. All changes made by providers of operational data that may impact users should be flagged. For example, changes in the data affect O-B statistics and vertical correlation structures. Data providers should document software ID numbers in the BUFR files and provide a description of these numbers online.
5. A flexible satellite number system is needed for current and future cubesat missions. Recommend IROWG to coordinate the development of a new BUFR template. Action 1: Heikki to talk with colleague.
   Action 2: DWD to coordinate the BUFR evolution, taking into account the results of IROWG-4 NWP subgroup action 2 (BUFR specifications) and the resulting discussion paper.
6. There is a desire to provide RO data on an increased set of levels. IROWG recommends that ROM SAF (co-ordinated with EUMETSAT and UCAR) should conduct a study to consider vertical spacing and resolution.
7. Action: COSMIC-2 should start with 247 levels, and distribute a test data set with an increased set of levels.
8. Action: Doug Hunt will share test KOMPSAT files.

Actions to IROWG-7 from CGMS:

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 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.
- Action: 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.

- IROWG recommends using orbital planes to providing good spatial and local time coverage

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

- 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)

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.

- Achieve and maintain continuity of the baseline set of RO measurements available to all CGMS members
- Action: B. C. Ruston to produce a state-of-the-science report
- IROWG encourages a study to investigate the baseline number and geographic distribution of occultations which are required to provide a good quality set of anchor observations to the global observing system.

3.2 Climate Sub-Group

Chair: Andrea Steiner (WEGC, Austria)

Rapporteur: Panagiotis Vergados (JPL, USA)

Members: Evans Adom (Univ. Energy & Nat. Res., Ghana), Chi Ao (JPL), Julia Danzer (WEGC, Austria), Michelle Feltz (Univ. Wisconsin-Madison, USA), Ulrich Foelsche (Univ. Graz, Austria), Hans Gleisner (DMI, Denmark), Florian Ladstädter (WEGC, Austria), Kent Lauritsen (DMI, Denmark), Stephen Leroy (AER, USA), Ying Li (Institute of Geodesy and Geophysics, China), Mi Liao (NSMC, China), Johannes Nielsen (DMI, Denmark), Marc Schwärz (WEGC, Austria), Jeremiah Sjoberg (UCAR, USA), Andrea Steiner (WEGC, Austria), Bomin Sun (NOAA/NESDIS, USA), Jordis Tradowsky (Bodeker Scientific, New Zealand), Panagiotis Vergados (JPL, USA), Axel von Engeln (EUMETSAT, Germany), Dong Wu (NASA GSFC, USA).
Visitors: Sean Healy (ECMWF, UK), Rob Kursinski(PlanetIQ, USA), Tony Mannucci (JPL, USA)

Recommendations to CGMS

1. **Ensure continuity and long-term availability of climate quality RO measurements with global coverage over all local times. Operational GNSS RO missions for continuous global climate observations need to be established and maintained as**

backbone to ensure continuity with at least 20,000 occultations per day. The community is currently far short of 20,000 occultations per day. We acknowledge the commercial data providers but currently we do not regard commercial RO missions viable to provide climate data as there is no validation of the data regarding climate quality data requirements.

It has been demonstrated that GNSS RO is a very important data record for global climate observations of benchmark quality and stability. The continuity of GNSS RO observations in the future is not sufficiently guaranteed with research/commercial missions, which is of main concern regarding the provision of continuous climate products. 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., MSU/AMSU, 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 mesoscale 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 six-satellite constellation of the COSMIC-2 mission, launched in June 2019 as follow-on to the severely degrading COSMIC-1 mission, is in low inclination orbit and covers only low to mid-latitudes between 40°N to 40°S. We are facing an imminent observational gap in higher latitudes. Thus, there is an urgent need for satellite missions in high inclination orbits to provide full global and local time coverage in order to ensure global climate monitoring. Overall, the aim should be to take advantage of all available GNSS constellations and RO missions, potentially including the private sector data after careful validation.

2. **Acknowledging CGMS recommendation R46.01 on long-term data storage, we recommend 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 raw (level 0) data, metadata, and associated documentation should be **freely** available to the scientific community, and retrieval software should be open. This is of high importance since the raw data are necessary to achieve full traceability of the retrievals regardless of the source of the data.

3. **Data providers should ensure parallel data streams of RO climate data products: one regularly updated data version and one uniformly reprocessed version.** The reprocessed version should always cover the full data time period until a new processing version takes over. Acknowledging the increasing computing requirements and growing

data volume, we encourage discussing the future handling of data amounts, e.g., usage of cloud computing.

4. **Promote funding of regular reprocessing activities of RO climate data records** from different RO processing centers along the principles for reprocessing climate data records of the WCRP Observation and Assimilation Panel (WOAP; http://www.wcrp-climate.org/documents/WOAP_ReprocessingPrinciples.pdf). Documentation of the historical evolution of processing systems for the provision of climate data records is important. **This should include gridded data together with uncertainty and algorithm descriptions**. This will help to promote use of RO data by the climate community. Furthermore, it is recommended that efforts to provide data in the obs4MIPs format and archive should be continued and extended. Multi-centre ensembles of independently processed RO datasets will be useful in quantifying the structural uncertainty. Derived parameters such as tropopause heights are also important climate records. Continuity of funded efforts is desired.

5. **We acknowledge the success of the 3G meeting which brought together the GNSS RO community, the GRUAN community and the GSICS community in May 2014 in Geneva and recommend organizing such meetings periodically by WMO** with the scope of enhancing collaboration among communities and assessing progress.

6. **We recommend operational data providers to additionally provide occultation prediction products, aiding coordinated ground-based collocated measurements**. We acknowledge that EUMETSAT is already providing this information for the Metop satellites. EUMETSAT's occultation prediction for GRAS and overpass prediction for IASI is used for example at GRUAN sites to time measurements, where possible, to increase direct collocations.

7. **We recommend that the impact of instrument software updates on climate products be carefully evaluated beforehand.** As an example, the MetOp-A and B May 2013 GRAS software update gives large benefits to NWP but also has a visible impact on the climate data record.

Recommendations to satellite operators and data providers

1. Documentation of retrieval processing chains by all processing centers is essential to ensure traceability in climate data (e.g., 1DVar retrieval documentation). Documentation on LEO receiver firmware is also needed. IROWG recommends **fully documenting processing chains, keeping track of any introduced changes/updates to processing or instrument**.

2. In the retrieval processing chains, traceable uncertainty estimation and documentation needs to receive increased attention (as for example raised via Action G-3 on IROWG members by the "3G" community at the WMO-organized workshop)[2]. IROWG recommends that processing centers **increase efforts on uncertainty estimation, make**

[2] https://www.wmo.int/pages/prog/www/WIGOS-WIS/reports/3G-WIGOS-WS2014.pdf

uncertainty calculations publicly available through peer-reviewed publications, including where background information comes into the processing and where the traceability chain may be broken (in accordance with the GCOS-143 Document).

3. All level 0 data providers should **make available phase data, amplitude data, and satellite orbit data in a well-documented netCDF format**. This would enable independent RO processing centers to cross-check their systems and to estimate the overall uncertainties in their retrievals (*see also recommendation #2 to CGMS above*).

Recommendations within IROWG

1. **We acknowledge the inclusion of relevant RO work into the currently generated IPCC Assessment Report 6 and recommend that the IROWG community continues to contribute to IPCC Assessment Reports.**

2. **Issues of ionospheric correction and high altitude initialization should be further investigated to optimize the climate utility in the entire stratosphere.** We acknowledge progress in these areas, e.g. the kappa correction, and recommend that these efforts should continue. We also recommend including the information on higher-order ionospheric correction terms in the output data files.

3. **Encourage research into the benefits of higher SNR and the impact on the estimates of long-term changes**, which is likely to extend the benchmarking capability of GNSS RO more robustly into the troposphere and higher into the stratosphere. Subtle changes in the transmitted GNSS signals over time may affect the estimate of long-term trends from RO data. Such effects need to be assessed and quantified.

4. **Continue to assess the status of RO water vapor products in terms of random and systematic uncertainties, including characterization of the stability and inter-center homogeneity, guided by GEWEX and GCOS requirements.** RO data provide unique high vertical resolution information on tropospheric humidity that is much needed to improve our understanding of the coupling of thermodynamics and large-scale circulation in the lower troposphere, which are critical to climate sensitivity and changes in the water cycle. Any information about tropospheric humidity would be of specific interest to future IPCC reports.

5. **We recommend that the SCOPE-CM initiative, under WMO is continued, and that IROWG continues to contribute to the development of GNSS RO as a climate monitoring system by** a) assessing the structural uncertainty of RO retrieval data, including differences between processing centers and between different RO instruments and missions, and by b) supporting the generation of multi-center ensembles of RO climate data records.

6. **Continue participation in the wider scientific community** (e.g., CMIP, GEWEX, SPARC, ITWG, GRUAN, GSICS, Obs4MIPs, MSU/AMSU community) and

collaboration for the promotion of RO data and the complementary use of different data sets. We acknowledge ongoing activities and efforts.

7. There is an uncertainty in the refractivity coefficients that impacts the accuracy and traceability of RO climate time series and trends. We acknowledge progress and ongoing efforts in new measurements of the refractivity coefficients with higher accuracy (better than 1.E-4). **We recommend continuous coordination among IROWG, bringing in metrology experts, and recommend status reporting from JPL**. Significant progress was made at JPL in implementing experiments to measure the refractivity of air with precisions needed by the climate group. The support of NASA's Earth Science Division is gratefully acknowledged. However, the challenges of the experiment had prevented updated values from being published. At this time progress has stalled due to lack of sufficient time on the part of the JPL experimentalists to chase down and resolve the dominant sources of systematic error.

8. Ensure a complete archive of navigation data bits in a standard format. We recommend making this information available to the community. We acknowledge EUMETSAT providing data used in the GRAS processing.

Actions to IROWG-7 from CGMS:

A46.08: IROWG to develop process and principles for RO data quality control to ease intercomparison of data from different providers. Status: We cannot provide these principles (for QC or evaluation) until the data sets are open to analysis by the IROWG community.

A47.31: IROWG and 7th WMO Impact Workshop needs to validate the current baseline in terms of the coverage, number, quality and sampling of RO. Status: NWP group.

A47.05: IROWG to evaluate outcome of agency funded commercial weather data pilot following IROWG-7 and report to CGMS. Status: This task cannot be taken by the IROWG as the results are not open to the community. It should be requested by CGMS.

IROWG Climate Sub-group Actions: CLOSED

- IROWG-04: RO measurements from past and current missions that have not yet been fully processed (e.g., GPS/MET, KOMPSAT-5, FY-3C) should be made available to the scientific community so that the climate utility of these data can be evaluated. These data could help to fill the gap after COSMIC-1 as well as increase past coverage.

  ACTION CLOSED, data (KOMPSAT-5, FY-3C) have been made available to the community. GPS/Met data will be made available to the community

3.3 Receiver Technology and Innovative RO Techniques

Chair: R. Kursinski (SS&E, USA)

Rapporteur: J. Braun (UCAR, USA)

Members: Rob Kursinski (SS&E, USA), Estel Cardellach (ICE/CSIC-IEEC, Spain), Michel Tossaint (ESA, Netherlands), Kuo-Nung (Eric) Wang (JPL, USA), Jennifer Haase (UCSD, USA), Tom Meehan (JPL, USA), Sun Yueqiang (NSSC, China), Liu Conglinang (NSSC, China), Chen-Joe Fong (NSPO, Taiwan), Gottfried Kirchengast (WEGC/UniGraz, Austria), Wei Xia-Serafino (NOAA,USA) ,John Braun (UCAR, USA), Bill Schreiner (UCAR, USA)It. , Ramon Padulles (JPL, USA), Bin Zhang (University of Maryland, USA) Riley Fitzgerald (MIT, USA), JaeGwan Kim (National Met. Satellite Center, Korea), Chi Ao (JPL, USA), Laurent Lestarquit (CNES, France), Changyong Cao (NOAA, USA), Stig Syndergaard (DMI, Denmark), Yago Andres (EUMETSAT, Germany), Saverio Paolella (EUMETSAT, Germany), Pawel Hordyniec (RMIT, Australia), Evans Adom (UENR, Ghana), Dallas Masters (Spire Global, USA)

Top Recommendations to CGMS

With the launch of both PAZ and FORMOSAT-7/COSMIC-2 missions and the operational collection of grazing angle reflections by Spire satellites, new opportunities in data are now possible. These observations include polarimetric RO observations, high SNR data, deep tracking data, and grazing angle reflections. The IROWG community should capitalize on these observations to explore and demonstrate the scientific value of these emerging technologies.

A GNSS polarimetric radio occultation experiment is orbiting aboard the PAZ satellite since February 22, 2018, and it was activated in 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 above the freezing layer. The initial hypothesis of the experiment was that these observables were induced by large rain droplets, more likely in heavier precipitation. The additional strong signals coming from frozen hydrometeors seem to be always linked to strong precipitation scenarios. These unexpected signals are both an opportunity for new science and a challenge for the retrieval algorithms, and further work is needed to properly understand the measurements and develop both scientific and operational meteorology applications.

1. Regarding progress on LEO-LEO observations, (1) a forum workshop was held in July 2019 in China on scientific questions and objectives, retrieval techniques and payloads; (2) ESA is looking at broadcasting GNSS signals from LEO, presenting a potential opportunity for leo-leo; (3) a key paper (Ward et al., 2019) was published demonstrating water vapor retrievals to 0.5% in clear, cloudy and rainy conditions by probing the 183 GHz water vapor line between mountaintops; and (4) PlanetiQ and China are pursuing LEO-LEO implementations. The previously recommended LEO-LEO OSSE & EDA activity is stalled awaiting development of a forward model or operator.

Regarding deep tracking data, very promising first results from FORMOSAT-7/COSMIC-2 were presented at the IROWG meeting demonstrating unprecedented very high 1 second SNRs $\geq$ 2000 v/v which were used to identify ducting and profile bending angle through the planetary boundary layer down to the surface.

During the last year, two independent studies have shown that GNSS reflections acquired in geometries compatible with the typical RO antenna configuration are suitable for precise sea ice and ocean altimetry. On the one hand, CyGNSS raw data (downloaded to ground at high sampling rate before being processed by the onboard receiver) re-processed with software receivers could find coherent grazing angle reflected signals up to 25º elevation over the Central America coastal waters, providing a few cm level altimetric retrievals in a few tens of millisecond integration. More importantly, Spire modified the open-loop model, through firmware updates, of one of its orbiting cubesats, which has managed to collect a few thousands of altimetric tracks in similar ranges of elevations and precision levels, mostly over sea ice. These firmware modifications do not affect the rest of the RO mission, except for data volume and if needed, correlation channels. These findings open new opportunities for RO missions, even existing orbiting ones, at relatively incremental costs.

Actions Items: In order to support data analysis and interpretation and OSSEs & EDA assessments, The IROWG community should argue to the global NWP centers (+) that there is a need for a forward operator for two types of observations:

1. LEO-LEO observations need a forward operator up to at least 183 GHz to account for absorption, scattering and polarimetric capabilities
2. Now that PAZ has been launched there needs to be significant investment in developing scientific applications for polarimetric observations (phase and amplitude). The investment includes studies to better understand the observations; the creation of a forward modeling operator for scattering observations; 1Dvar and 2Dvar retrieval applications; and others.

1. A standardized level0 file format should be defined that includes all necessary information needed to create RO profiles. The opnGns file format is an example, but there was consensus that it did not contain all necessary meta-data (s/c attitude, nav bits, etc.) to accurately process RO data. It was suggested that there be archiving of all level0 data in at least one location.

Progress from previous actions:

1. International space agencies (in particular NASA, ESA and CAS, 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 & EDAs for the LEO-LEO observations.

REFLECTOMETRY:

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. In 2020, the GNOS-2 payload will be launched aboard FY-3E, with 4 RO antennas, one near-nadir looking Reflection antenna, and another one for POD. In 2021, Taiwan’s Triton (formerly FS-7R) mission with GNSS-R capabilities, will be launched, and ESA PRETTY mission, including a GNSS-R altimetry payload is scheduled for launch in 2022. Furthermore, Spire will also launch two GNSS-R scatterometry satellites in 2019, followed by more in 2020. NASA has two IIP instrument development projects (led by the University of Michigan and JPL respectively) for GNSS-R, and a reflectometry mission using opportunistic signals at P-band will be launched in 2021 (NASA/SNOOPI).

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 the WG is that there is not a need to promote GNSS-R that involves near-nadir 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.
LEO-LEO: see top priority 1.

2. **Require that satellite operators, as part of their services as data providers, make all information available that is necessary for independent scientific processing centers to process from raw level 0 data to atmospheric and climate data products. This should include long-term archiving.** This means that the raw (level 0) data, metadata, and associated documentation should be available to the scientific community. This is of high importance since the raw data are necessary to achieve full traceability of the retrieved atmospheric profiles, regardless of the source of the data. **Promote cross-collaboration and sharing of data and knowledge between the RO R&D community and the satellite operators**.

   See recommendation regarding definition of format similar to opnGns

3. Continuous collaboration and high quality data comparison are of great value for all parties. Accordingly, the IROWG recommends that requirements be incorporated into the Round 2 RFP of the NOAA CWDP to ensure full traceability to raw, Level 0 data, for any higher-level retrievals and that all documentation and/or software/constants/firmware, required to achieve this traceability, be made available to the international scientific community.

High priority recommendations

1. Advance LEO-LEO occultation development towards a demonstration mission

IROWG recommends that CGMS adopt an action asking international space agencies (in particular CAS and ESA, where proposals towards initial LEO-LEO demonstration missions are pending) to **support mission preparation projects** that implement the next steps towards a LEO-LEO microwave occultation (LMO) demonstration mission. Such next steps within the next two to three years include 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 microwave and infrared-laser occultations, 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, as well as transferring the unique accuracy, precision and high resolution of the LEO-LEO observations into the NWP forecasts and reanalyses via assimilation. Initial mountaintop demonstrations have been made successfully at cm, mm and micrometer wavelengths.

2. Encourage the continued development of synergistic GNSS radio occultation and GNSS reflectometry.

IROWG recommends strengthening the scientific and technical activities related to 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, and vegetation index). GNSS reflectometry measurements are potentially also appropriate for atmosphere/ionosphere sounding, in particular, those reflected signals in very slant geometries, such as collected unintentionally with standard RO receivers.

3. Lower troposphere/Boundary layer profiling

The COSMIC-2 RO mission was launched on 25 June 2019. Early data collected demonstrate its capability to collect 1-Hz SNR greater than 2000 V/V for L1 CA. When these instruments are configured to track signals in fully open-loop mode down to the height of straight line to -350 km, they create an opportunity to test the value of high gain, deep tracking RO data to sample the moist lower troposphere. These data may be shown to be useful for studying strong moist convection in the tropics and strong capping inversion layers in the sub-tropics. the IROWG community is strongly encouraged to utilize these data to assess the value of high gain, deep tracking data for potential future missions.

4. GNSS observations from airborne platforms

GNSS observations from airborne platforms offer unique datasets with distinct advantages for weather forecasting and studies of regional weather and climate processes. The techniques include radio occultation, reflectometry/reflection, altimetry, and polarimetry, for sensing the atmosphere (moisture, temperature, hydrometeors), land surface (soil moisture and dielectric constant), and ocean surface (surface roughness, wind, sea ice) and ionosphere (total electron content).

We recommend facilitating radio occultation observations from airborne platforms, such as high altitude aircraft, balloons, and UAVs, that lead to better understanding of the behavior of satellite systems at the limit of their resolution, for example in the lower troposphere for RO, in the presence of wave structures sampled by balloons in the UTLS, over small scale soil moisture variability for GNSS-R, and in intense convection at small spatial scales for GNSS-PRO testing of new instrumentation, algorithms, and assimilation methods that can benefit operations and research. The higher spatial and temporal density of targeted observations over phenomena of interest (i.e., severe thunderstorms and tropical cyclones) can benefit NWP and provide validation for spaceborne missions (future RO missions / RohPAZ / CYGNSS). We recommend pursuing opportunities to exploit GNSS and communication signals of opportunity on these platforms where collaboration benefits the community by sharing technology and expertise, speeding development, and reducing logistical constraints.

5. Modulation on new GNSS signals

The navigation modulation of new GNSS signals and systems (GPS, GLONASS, Galileo, BeiDou, QZSS, and IRNSS) is yielding increasing precise ranging data. The new navigation modulation such as binary offset carrier (BOC) has a more complex autocorrelation function that not only narrows the central peak of the autocorrelation function but also has anti-correlated response at certain time lags. This response makes acquisition of signals in the lower troposphere more challenging and could potentially impact the occultation performances there.

Residual ionosphere after dual frequency calibration remains an important limitation for climate monitoring by GNSS RO. The possibility of using a single frequency ionosphere correction that utilizes the 10X finer ranging resolution on some new GNSS signals to determine the residual bias that remains after applying dual frequency ionosphere correction should be evaluated.

IROWG stimulates in this context also the GNSS industry **to develop combined GNSS RO/R receivers** and related hardware for future missions. Hereby, the application aboard small satellites is especially in focus to allow the installation of future multi-satellite constellation with GNSS remote sensing (GNSS-RO combined with GNSS-R) observations with high spatiotemporal resolution in a cost effective way.

A forerunner for these developments is the ESA **GEROS-ISS** mission, which was proposed in 2011 as a combined GNSS-RO and GNSS-R mission and completed Phase A in 2016. GEROS-ISS is intended to provide unique data especially for the sea surface height and wind speed determination, as well as for land surface monitoring and GNSS-RO with new aspects, as, e.g., precipitation measurements. It is anticipated that the GEROS-ISS data will enable fundamental investigations for the development of both the GNSS-R and GNSS-RO technique individually, as well as for their combined application. The same is expected for the G-TERN mission, which was proposed in response to ESA's recent Earth Explorer 9 call in mid-2017. G-TERN is based on the same observational concept of GEROS-ISS with extended scientific objectives, especially focussing on the cryosphere and related interactions with the hydrosphere and atmosphere.

IROWG focus on recent Observation System Simulation Experiments (OSSE) within the GEROS-ISS Phase A, where a high potential of the relatively new coherent GNSS-R altimetry measurements at low elevations with high precision and high observation density was indicated. These measurements are strongly synergistic with GNSS–RO measurements. **IROWG recommends and stimulates the scientific investigation of the dependency of the coherent GNSS-R technique on the roughness of the reflecting surface** and of potential additional geophysical applications of this method.

IROWG recommend that CGMS

- **Make GNSS developers aware of the important NWP and climate applications of their GNSS systems and how the GNSS signals and systems are being used**
- **Encourage GNSS developers to maintain course resolution C/A (BPSK) like signals**

General recommendations for service providers

1. IROWG recommends to the **Indian Space Research Organization** to make a comprehensive IRNSS signal **ICD available**, so that future missions can make use of the signals from this Navigation System, increasing the number and usefulness of RO

measurements for both NWP and climate.

2. IROWG recommends to operational agencies and instrument developers to also consider the use of **GLONASS FDMA and CDMA signals, as well as the new and emerging constellations** (BeiDou, Galileo, IRNSS, QZSS) in future receivers, in order to increase the number of available RO measurements.
3. IROWG recommends closer cooperation between the RO community and organizations such as IGS (International GNSS Service), IERS (International Earth Rotation and Reference Systems Service), GNSS system operators and others by, e.g., participation in its organizing bodies / governing board for
    a. **the provision, if necessary, of clock biases at higher sampling rate** compatible with RO applications
    b. the **standardisation and eventually the provision of a common GNSS time reference GNSS system**
    c. the **provision of Ultra Rapid Orbits and Clock bias data for Beidou system**
    d. the provision that the IGS community begin collecting high rate (5Hz) observation data to support monitoring of GNSS transmitter clock stability.
4. IROWG recommends that the GNSS constellation operators provide Equivalent Isotropically Radiated Power (EIRP) as a function of the on-board antenna angles (elevation and azimuth) on a satellite per satellite basis, formed from post-launch power measurements combined with transmit antenna gain patterns. This will provide a better understanding about SNR, allowing more accurate link budget estimations, useful for climate control.
5. IROWG recommends that the GNSS satellites transmit significant power levels beyond the limb of the earth, in order to allow radio occultation applications from LEO meteorological satellites.
6. IROWG recommends that the GNSS constellation operators provide Allan deviation and/or phase noise spectra information for transmitter satellites at rates that are significant for RO (5Hz? to 0.01Hz?)

General recommendations for instrument providers

1. IROWG recommends that missions, instrument developers, and RO data processing centres **provide level-0 data format documentation**, and/or necessary software to read data, and payload firmware configuration information.
2. IROWG recommends that the GNSS RO payload manufacturers **publish / make available how the observations are processed**.
3. IROWG recommends that the **new generations of RO receivers will provide measurements with a quality comparable or even better than the one characterizing the receivers currently operated**, especially in view of the attempts to miniaturize receivers for deploying constellations of small satellites.
4. IROWG recommends that the GNSS RO manufacturers and RO data users work together to **identify sources of RFI that affect RO observations**. This includes terrestrial sources such as DME/TACAN and Ligado Networks (formerly LightSquared). In particular, IROWG recommends to initiate a request to agencies and/or the ITU **to better protect**

against known ground-based transmissions (i.e. DME/TACAN and Ligado) which strongly impact RO receivers and could also impact GNSS receivers on board aircraft.

5. IROWG recommends to EUMETSAT to continue 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 to scintillations/tracking errors in limited vertical intervals.
6. IROWG recommends that existing missions including TDX, TSX, and KOMPSAT-5 have firmware updates to include the following features:
    1) If not already in place, load the most up to date and capable firmware version on all instruments.
    2) Test L2C setting occultations on both with the expectation that L2C occultations will be permanently enabled on both TDX, TSC and KOMPSAT-5.
    3) Add capability to output 100 Hz RO phase and SNR on one unit and compare TDX with TSX running at both 50 Hz and 100 Hz rates.
7. Given the large uncertainty in the time of availability of the future signals, IROWG recommends maintaining a proper flexibility in the design of future GNSS-RO receivers. Joint support of L1/E1, L2 (P(Y) and L2C), and L5/E5a is recommended to enable dual-frequency tracking of GPS, QZSS and Galileo.
8. IROWG recommends that an investigation of the GNSS transmitter frequency variations over temperature for durations of a few minutes that can affect un-differenced or single-differenced occultation observations is performed.

Progress regarding previous IROWG recommendations

1. Additional signals on GNSS (e.g. 5 GHz on Galileo)

Current GNSS systems use L-band frequencies between 1 and 2 GHz. Additional use of one or more higher frequencies well separated from L-band would have substantial benefit to RO. For instance, for Galileo, ESA is considering a 5 GHz frequency in the C-band range. This would i**ncrease the useful altitude range of GNSS radio occultation by about 15 km** because sensitivity to the ionosphere is an order of magnitude less at 5 GHz than at L-band frequencies. It would also:

- **Reduce the effects of ionospheric scintillations from F and sporadic E layers**, which introduce large random inversion layers in the stratosphere
- **Reduce any large-scale higher-order ionospheric effects**, which introduces errors for climate applications in the stratosphere
- **Reduce the effects of horizontal electron density gradients** on the retrieved heights of inversion layers in the troposphere

Thus, a C-band frequency would **improve accuracy and increase reliability** of retrieved profiles in many different ways, and be beneficial to both climate and weather applications. In addition, such signals would open the door to new applications of RO signals that exploit the better sensitivity to depolarization and reflection effects in C-band such as **remote sensing of precipitation, capillary wave/gravity wave interactions and surface winds over oceans**. Focus in this area should be given to signal modulation/coding schemes that reduce interference by other signals, improve range resolution and increase SNR.

IROWG recommends that CGMS encourage space agencies **to assess the utility of higher frequencies on next generation GNSS systems** (e.g., 5 GHz on a next generation Galileo) for radio occultation and related applications. In this context, CGMS is also invited to encourage GNSS providers (Galileo, GPS, GLONASS, BeiDou, and IRNSS) to consider implementation of such higher frequencies for the benefit of operational weather and climate monitoring and prediction.

3.4 Space Weather Sub-Group

Chair: Bill Schreiner (UCAR, US)

Rapporteur: Riccardo Notarpietro (EUMETSAT, Europe)

Members: Iurii Cherniak (UCAR), Irina Zakharenkova (UWM/Poland), John Braun (UCAR), Vu Nguyen (Spire), Riccardo Notarpietro (EUMETSAT), Weihua Bai (NSSC/CAS), Haixia Lyu (IEEC), Dong Wu (GSFC), Tony Mannucci (JPL), Tom Meehan (JPL), Estel Cardellach (IEEC), Wei Xia-Serafino (NOAA/NESDIS)

Recommendation to CGMS

1. **The Space Weather sub-group of IROWG recommends that CGMS expend all reasonable effort to acquire high quality near real-time GNSS RO space weather measurements, spanning level-0 data to retrieval products, at middle to high latitudes with full local time coverage in standard formats with needed metadata and documentation.** The quality of these data and products should meet COSMIC-2 requirements, i.e., absolute TEC (3 TECU), relative TEC (0.3 TECU), S4 amplitude scintillation index (0.1), and sigma-Phi phase scintillation index (0.1 rad). The data latency should meet the COSMIC-2 requirement of 30 minutes, with a goal of 15 minutes.
2. **The Space Weather sub-group of IROWG recommends that CGMS encourage non-RO missions that fly GNSS receivers for precise orbit determination to make available to the operational and research communities all necessary level-0 data and metadata required to produce accurate overhead TEC data.** The level-0 GNSS data and metadata should include dual-frequency code and phase measurements, antenna phase center variations, spacecraft attitude orientation, and solar array motion. The level-0 data should have sample intervals < = 10 sec and low latency if possible (goal of 15 minutes).
3. **Per CGMS priority HLPP 1.1.4 (optimized system for atmospheric and ionospheric RO observations), the Space Weather sub-group of IROWG recommends CGMS encourage future GNSS RO missions, including potential commercial providers of RO observations, to incorporate a complete set of ionospheric measurements (including TEC across all elevation angles and 50+ Hz ionospheric scintillation data on all available occulting lines of sight where the**

TEC data are obtained and for which the level of ionospheric scintillation is significant). Future RO missions should strive to overcome antenna field-of-view, hardware and/or software limitations to provide sensors that measure TEC across all elevation angles (particularly from "zenith to negative elevations near the Earth's limb"). It should be noted that measurements of ionospheric/plasmaspheric TEC above satellite orbit altitudes can provide significant benefit for operational and research purposes. For this reason future RO missions should make "overhead TEC" measurements as well as ionospheric occultation measurements.

Recommendations within IROWG

1. **IROWG should continue to explore approaches for reducing ionospheric residual errors in neutral atmospheric retrievals.** Success in this challenging area of work would both improve the upper altitude limit and errors of useful neutral atmospheric products. This would mostly benefit climate applications. Next steps forward should include:
   - (1) Further assessment of recently proposed approaches to reduce residual large-scale ionospheric errors based on the correction term that depends on the electron density distribution (e.g. the "kappa" technique)
   - (2) Further assessment of recently proposed approaches to reduce residual small-scale ionospheric errors (based on back propagation techniques, or other);
   - (3) Development and use of new ionospheric re-analyses in neutral retrievals to assess possible benefits;
   - (4) Determination of ionospheric model accuracy requirements that, if met, would likely lead to a reduction in ionospheric residuals;
   - (5) Evaluation of existing datasets to determine the degree to which current ionospheric residuals conform to known aspects of ionospheric climatology.

   It is noted that progress updates on (1) above were presented at ROMSAF-6/IROWG-7.

Recommendations within Sub-Group

1. **The Space Weather sub-group of IROWG should encourage the development of space weather data assimilation models to take full advantage of the FS7/C2 and other GNSS RO data for specification and prediction of the low latitude ionosphere, including both its large-scale properties such as the F-layer and bottomside, and small-scale properties related to ionospheric scintillation effects.** These new data sets from FS7/C2 Equatorial can be expected to lead to significant advances in the state of the art of ionospheric assimilative modeling, and associated improvements to operational space weather systems, if model development efforts are adequately funded.
2. The IROWG encourages the development of more accurate 1DVAR retrievals of ionospheric electron density profiles. Progress in this area of research was presented at ROMSAF-6/IROWG-7.
3. The sub-group should coordinate with space weather activities throughout WMO, particularly IPT-SWeISS. Whenever possible, members of WMO IPT-SWeISS and the Space Weather sub-group of IROWG should attend these organizations' respective meetings. It was agreed that Bill Schreiner of UCAR will be the IROWG Space Weather

subgroup representative to the IPT-SWeISS until the next IROWG meeting. (The next IPT-SWeISS-3 meeting is in Belgium, Brussels in November 25-27, 2019)

4. **IROWG should verify that the WMO OSCAR database properly documents the abilities of current and future missions to obtain ionospheric data per Recommendations to CGMS #1-3 above.** Capabilities of both RO missions and missions flying dual frequency GNSS receivers should be documented in sufficient detail to understand the ionospheric products. The information in the database for each mission should include the extent to which the mission collects ionospheric profile and overhead TEC data, the mission data latency, and the extent to which ionospheric scintillation data are collected. Bill Schreiner, representative to WMO IPT-SWeISS, should solicit input from the IPT-SWeISS on verification of the OSCAR database.
5. It is desirable to continue to **expand the sub-group membership in the areas of personnel associated with operational space weather support centers and members of the international science community involved in the development and evaluation of assimilative ionospheric and scintillation models**. Team members should advocate for travel support from operational space weather support centers that will enable scientists to support future IROWG meetings.
6. **Space Weather sub-group team members should continue to advocate for and support greater incorporation of ionospheric radio occultation science topics** (such as the development of space weather data assimilation models) within existing ionospheric science venues such as AGU, AMS, CEDAR and IRI workshops. Collaborations within the sub-group membership involving evaluations of ionospheric models using GNSS RO data, or development/refinement of ionospheric or scintillation specification models using GNSS RO data sets, are also encouraged.

Status of Actions from previous IROWG Meetings

Action Items from IROWG-5

Action IROWG5-01: Dr. Straus will discuss possible future collaborations between IROWG and WMO IPT-SWeISS with Dr. Onsager of NOAA/SWPC and report back to the sub-group. Due: IROWG-6.

Dr. Straus met with Dr. Onsager and discussed potential collaborations. Action IROWG5-01 **CLOSED**.

Action Items from IROWG-6

Action IROWG6-01:
IROWG SWSG should verify that the WMO OSCAR database properly documents the abilities of current and future missions to obtain ionospheric data per recommendation within Subgroup #4 above.
OPEN

Action IROWG6-02:
NOAA/SWPC should provide description of Commercial data pilot plans to IROWG SWSG. Due Dec 31, 2017. Bill describe NOAAs CWDP SW plans.
CLOSED

Action IROWG6-03:
IROWG SWSG members should review and provide comments to NOAA on their draft RFP for round #2 of the Commercial Weather Data Pilot (CWDP).
See:
https://www.fbo.gov/index?s=opportunity&mode=form&tab=core&id=6e53dc8fbffe3873c4c81c05e15ebcbc
Due Oct 31, 2017
CLOSED

Action IROWG6-04:
Tony Mannucci should provide IROWG SWSG a summary of GRACE Follow-On plans to collect ionospheric data.
Due Oct 31, 2017
CLOSED: GRACE-FO does not currently plan to acquire ionospheric occultation data. Overhead TEC data should be available.

Action IROWG6-05:
IROWG SWSG members should review COSMIC-2 ionosphere TEC and scintillation data formats and provide comments back to SWSG. See:
TEC:
http://cdaac-www.cosmic.ucar.edu/cdaac/cgi_bin/fileFormats.cgi?type=podTc2
On-board S4:
http://cdaac-www.cosmic.ucar.edu/cdaac/cgi_bin/fileFormats.cgi?type=scn1c2
HR phase/amp:
http://cdaac-www.cosmic.ucar.edu/cdaac/cgi_bin/fileFormats.cgi?type=scnPhs
Ground-computed S4/SigmaPhi:
http://cdaac-www.cosmic.ucar.edu/cdaac/cgi_bin/fileFormats.cgi?type=scnLv2
Spectrograms of HR phase/amp:
http://cdaac-www.cosmic.ucar.edu/cdaac/cgi_bin/fileFormats.cgi?type=scnSpc
Due Oct 31, 2017
OPEN. No comments received to date. We will keep this open until the release of COSMIC-2 data.

Action IROWG6-06:
Bill Schreiner to determine if GTS-distributed space weather products must be BUFR.
Due Dec 31, 2017
CLOSED, since this was absorbed into new Action IROWG7-01

Action IROWG6-07:
Bill Schreiner to determine accessibility of COSMIC-2 space weather products in near real-time. Near real-time COSMIC-2 space weather products will be available at the COSMIC-2 CDAAC website (http://cdaac-www.cosmic.ucar.edu/cdaac/products.html).
CLOSED

New action items from IROWG-7

Action IROWG7-01:
Efforts should also be made, in coordination with WMO IPT-SWeISS, to facilitate data access to raw data, products, metadata and documentation, and to define standard data exchange formats for RO sensor ionospheric products. This is a continuation of IROWG-6 Action 06.
DUE DATE: Next IROWG
Action IROWG7-02:
Action: Check other SG and Main recommendations for inclusion of level-0 data.
Due Now

4 CONCLUSIONS

The workshop presentations are available at:
https://www.romsaf.org/romsaf-irowg-2019/en/content/21/program-agenda-by-day

This summary and the CGMS working paper from IROWG-7 are/will be available at
http://www.irowg.org/workshops/irowg-7/

The suggested high-priority recommendations for CGMS 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.
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.

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.

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 COSMIC-2 mission on 25 June 2019, which helped to counteract the continuous decline of available RO in recent years, but 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.

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