IROWG best practices in support to radio occultation observations for long-term climate studies

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INTRODUCTION

This document presents the IROWG best practices (BP) in support of generating data sets from multiple RO missions for climate applications. The recommendations presented in this BP document are based on the collective agreement of an international group of scientists, RO processing center leads, and RO data providers that forms the IROWG. The initial version of this document was endorsed at IROWG-9 in September of 2022.

This BP document is subject to update at the conclusion of every IROWG meeting, and will be periodically updated at the CGMS web site for Best Practices and mirrored with a Digital Object Identifier on zenodo.org.

1. BP.01 Number and distribution of climate quality RO measurements

Ensure continuity and long-term availability of climate quality RO measurements with global coverage and full local time coverage.

For characterizing the global climate with RO, the following requirements need to be met for an RO constellation that provides climate quality RO data:

a) Establish and maintain continuous operation of the GNSS RO constellation with global coverage.
b) Obtain at least 20,000 occultations per day with global coverage from at least 4 orbital planes evenly spaced in Local Time of the Ascending Node (LTAN).
c) Level 0 (raw) data are archived and freely available for reprocessing.

For climate research and monitoring applications, an RO constellation should continuously supply samples of RO events on a daily basis that are of uniform global and local-time coverage, with at least four-times daily revisiting every 300 km x 300 km area of Earth's surface and at the same time providing at least 100 RO events per month in each revisited area. This coverage can be achieved with 20,000 occultations per day. More details on the rationale for number and distribution of measurements can be found in Appendix A.

We note that the recommended practice of acquiring 20,000 occultations per day aligns with recommendations from the numerical weather prediction community. In a study by Harnisch et al. (2013), an ensemble of data assimilations (EDA) approach was used to assess observation number impact on the ECMWF numerical weather prediction system. They conclude: “the results support a number in the region of 16,000–20,000 globally distributed observations per day, as a minimum observational coverage for the GNSS RO component of the future [global observing system].” A more recent study by Privé et al. (2022) used the NASA Global Modeling and Assimilation Office (GMAO) numerical weather prediction OSSE framework to assess impact up to 100,000 profiles per day. The largest impact was observed at 25,000 profiles per day compared to a control case, with some diminishing returns beyond 50,000 profiles per day. An RO constellation providing 20,000 profiles per day with the necessary coverage will provide significant climate and weather impacts.

2. BP.02 Long-term RO data access

Ensure that all information necessary for independent processing towards climate data products is made freely available, following WMO Unified Data Policy Resolution 1.

To achieve such a task, the following requirements are to be met:

a) Perform long-term archiving of all measured and acquired data without pre-filtering by quality control (QC) criteria. QC will be applied by independent processing centers. The use of quality flags for the data is encouraged. Government agencies are responsible for maintaining access to long-term archives.
b) Provide public data access to assure full climate traceability and transparency.
c) Provide full documentation of instrument/software updates and processing chains.
d) Make available signal phase & amplitude data acquired through the RO antennas, and satellite orbit data acquired through the antennas used for orbit determination.

3. BP.03 RO data processing strategy

Processing centers should ensure parallel data streams of RO climate data products: one regularly updated data version and one uniformly reprocessed version.

Regularly updated processing produces new climate data products incrementally as new data arrives, e.g. on a monthly basis. Uniformly reprocessed data products should cover the complete record of RO observations with a single processing approach. Reprocessing can occur at a reduced cadence, e.g. yearly or as resources allow. Acknowledging the increasing computing requirements and growing data volume, we encourage developing capabilities for future archiving and distribution of large amounts of RO data, e.g., using cloud computing.

Reanalyses (e.g. ERA5) assimilate reprocessed RO data. Reprocessed data products start with the Level 0 data. The reprocessed data products lead to improved reanalyses.

Appendix A: Scientific rationale for coverage requirement

The required coverage is needed to generate reliable global gridded monthly-mean climate data records, with mean, variance, and extreme statistics that resolve all spatial scales down to the inherent RO profile horizontal resolution of 200 to 300 km. Daily sampling is required to adequately capture sub-monthly atmospheric variability, while the number of orbital planes ensures that the diurnal cycle is resolved in climate averages. Monthly means in each grid cell should contain sufficient numbers of profiles such that the random errors in the atmospheric profiles from individual RO events is suppressed by at least one order of magnitude, implying 100 profiles per grid cell per month.

The above coverage requirement, justified by its associated scientific rationale, corresponds to providing at least 19,000 RO events per day for a global gridded climate data product with 100 RO profiles in every 300 x 300 km grid cell. This number of profiles is a simple consequence of fully covering Earth's surface area ($5.1x10^8$ km^2) with 100 profiles per grid cell every 30.4 days (monthly). Near polar orbits are required to achieve global coverage and multiple orbit planes are required to cover the diurnal cycle.

References

Harnisch, F., S. B. Healy, P. Bauer, and S. J. English (2013), Scaling of GNSS Radio Occultation Impact with Observation Number Using an Ensemble of Data Assimilations, *Monthly Weather Review*, *141*, 4395-4413, doi:10.1175/MWR-D-13-00098.1.

Privé, N. C., R. M. Errico, and A. E. Akkraoui (2022), Investigation of the Potential Saturation of Information from Global Navigation Satellite System Radio Occultation Observations with an Observing System Simulation Experiment, *Monthly Weather Review*, *150*(6), 1293-1316, doi:10.1175/mwr-d-21-0230.1.