Outcomes and recommendations from the IROWG-10 workshop

Presented to CGMS-53 Working Group II session, agenda item 3.2

Co-Chairs: Ulrich Foelsche (University of Graz)

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With contributions from the IROWG members

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IROWG-10 Meeting

IROWG-10 was held on the UCAR campus in Boulder, Colorado, United States, 12-18 September, 2024 in conjunction with the COSMIC/JCSDA Workshop. It was the largest IROWG workshop so far, with approximately 180 abstracts and over 150 participants attending in person.

IROWG wants to express its gratitude for the perfect organization of this meeting by UCAR and JCSDA.

Full workshop minutes and CGMS working papers from IROWG-10 will be made available at http://irowg.org/workshops/irowg-10/

Workshops

IROWG-10

- Opening address by the Governor of Colorado, Jared Polis
- 60th anniversary of the first radio occultation – Mariner IV, Mars, July 1965
- 30th anniversary of the first terrestrial RO – GPS/MET, launched April 1995
- 20th anniversary (upcoming): COSMIC-1 / FORMOSAT-3, launched April 2006
- Many science highlights, see the workshop presentations: www.cosmic.ucar.edu/events/cosmic-jcsda-workshop-irowg-10
- Splinter meetings: Updates to the BUFR format, ROMEX

IROWG held ROMEX workshops on April 17 – 19, 2024 and on 25 – 27 February 2025 at EUMETSAT, Darmstadt, Germany (see next presentation).

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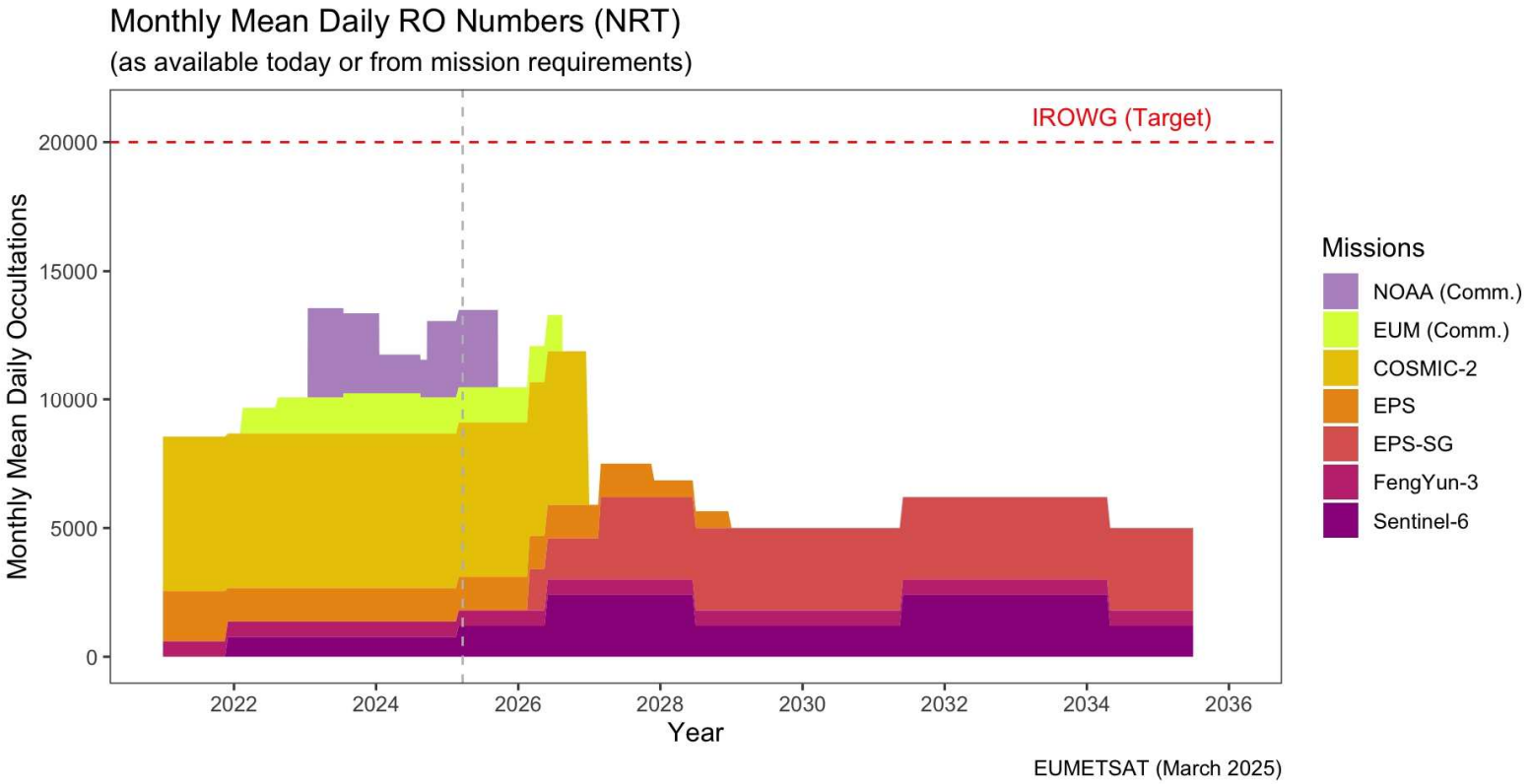
Projected RO observation numbers in next decade



- COSMIC-2 profiles are limited to latitudes between ± 40°
- This update reflects a revised schedule for EPS-SG, Sentinel-6 Michael Freilich Galileo RO
- It is imperative to recognize the potential risks associated with the lack of future planning for (low-inclination) RO observations after COSMIC-2.

Credit: Christian Marquardt (EUMETSAT)

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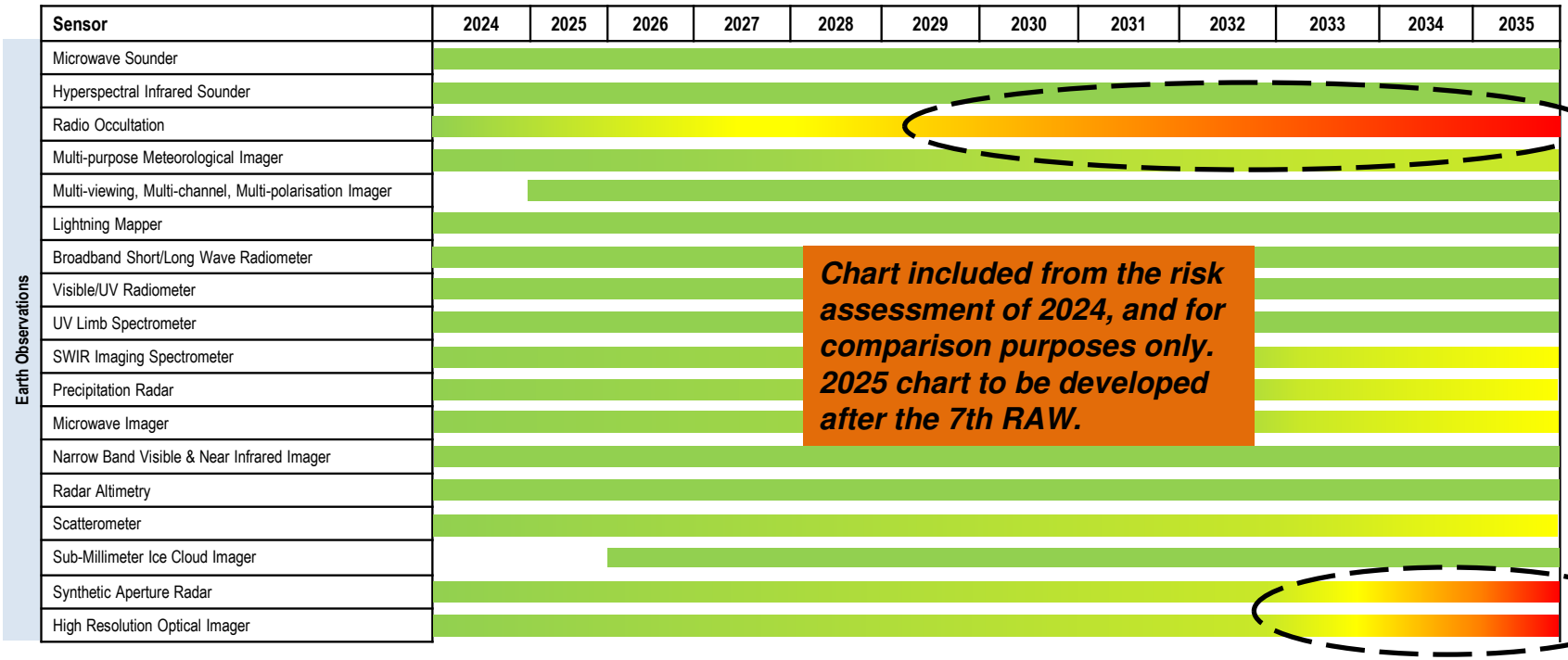
CGMS Top-Level Risk Assessment - Earth Observations (2024)



No commitment for low-inclination RO observations after COSMIC-2

We note the recent Request For Information from NOAA issued on March 11, 2025: "Global Navigation Satellite System Radio Occultation Instruments and Spacecraft Request for Information"

No long-term commitments for observations

- CGMS is aware of this risk

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MAIN RECOMMENDATIONS FROM IROWG-10 PLENARY TO CGMS

1. **IROWG recommends that a reliable replacement for the FORMOSAT-7/COSMIC-2 tropical and subtropical radio occultation observations be in place by 2030 at the latest. As FORMOSAT-7/COSMIC-2 is past its nominal end of life, there is a high risk of serious degradation to numerical weather prediction (NWP) accuracy due to the degradation of the current RO observing system, as FORMOSAT-7/COSMIC-2 satellites stop acquiring observations over the coming years.**

   FORMOSAT-7/COSMIC-2 reached nominal end of life in June 2024. While all six satellites continue to operate nominally, most currently have subsystems with single points of failure such that a malfunction of the subsystem will lead to loss of RO measurements from the affected satellite. The potential impact on NWP accuracy and climate monitoring is a growing concern, underscoring the urgency of establishing a robust long-term solution.

MAIN RECOMMENDATIONS FROM IROWG-10 PLENARY TO CGMS

2. IROWG notes that the current radio occultation observational network is highly beneficial to NWP and is among the top two or three observational systems in terms of forecast impact. IROWG therefore recommends the continuation and expansion of the RO observational network. Initial results from ROMEX suggest that increasing the numbers of daily radio occultation profiles with global coverage provides significant additional positive impact on the accuracy of NWP forecasts.

The RO Modeling Experiment (ROMEX) study, using different numbers of RO profiles up to 35,000 profiles per day (the maximum available in the experiment) in leading international NWP models, demonstrates the increasing benefits of RO with increasing numbers of profiles, supporting the IROWG recommendation which is to acquire at least 20,000 occultations per day with uniform spatial and local time coverage (HLPP 1.2.8).

Besides **uniform spatial and local time coverage** also **refresh** should be considered.

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MAIN RECOMMENDATIONS FROM IROWG-10 PLENARY TO CGMS

3. **IROWG recommends that Level 0 (raw) data from RO missions be permanently archived and that the government agencies that purchase the data be responsible for its archiving with an open data policy. All data acquired by RO instruments should be archived without pre-filtering or editing and without intentional degradation.**

   The full record of acquired Level 0 observations should be available, without data removed based on quality metrics or other criteria. Archived raw data are re-used for scientific research and in reanalysis. Intentionally degraded commercial Level 0 data are sub-optimal for such purposes and therefore represent less “value for money” compared to the data as it is acquired. For reference: Level 0 data are defined according to the CEOS definition of raw data. There are Level 0 RO data that are collected but not archived anywhere (at least, not by governments).

MAIN RECOMMENDATIONS FROM IROWG-10 PLENARY TO CGMS

4. IROWG recommends that relevant agencies undertake a ROMEX-like study for space weather.

Ionospheric RO data have begun to be assimilated in operational models. A ROMEXlike study for the space weather domain (ROMEX-SWx) would help to quantify the benefits of RO measurements in improving global ionospheric specification.
To lay the groundwork for this effort, a precursor workshop on Observation System Simulation Experiment (OSSE) capabilities in the space weather domain is desirable prior to the first ROMEX-SWx workshop. As with ROMEX, the active support of government agencies will be crucial for the success of ROMEX-SWx.

MAIN RECOMMENDATIONS FROM IROWG-10 PLENARY TO CGMS

5. **IROWG recommends improving planetary boundary layer (PBL) profiling from GNSS-RO through technology and retrieval developments, and utilization of information from the PBL in NWP data assimilation as well as the further exploitation of RO-derived water vapor.**

   Recently published work on assimilating PBL height into global reanalyses represents a significant development for exploiting lower-troposphere information from GNSS-RO that can also be considered for NWP. Intercomparisons of retrievals within the PBL (refractivity, water vapor pressure, and other direct products) between different processing centers should be analyzed to gain fundamental insight into PBL products, with particular attention to the role of signal-to-noise ratio, which varies significantly between GNSS-RO instruments.

Further recommendations by the subgroups (NWP, Climate, Space Weather, and Innovation) can be found in the working paper.

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For consideration by CGMS: Best Practices document "IROWG best practices in support to radio occultation observations for long-term climate studies"

- IROWG proposes a Best Practices (BP) draft document "IROWG best practices in support to radio occultation observations for long-term climate studies"
  - Started within the climate sub-group at IROWG-9 but that also addresses numerical weather prediction applications, endorsed by IROWG-10

- This document might be useful to support CGMS-51 Plenary Action A51.08
  - Action to "develop…a CGMS statement on the optimum composition of hybrid architectures (combining reference platforms, small satellites and procurement of commercial data)..."

- A further document "Roadmap towards full exploitation of the GNSS Polarimetric Radio Occultations" was developed by the Innovation Sub-Group of the IROWG. It may be of great interest to agencies in WGII and may merit publication on the CGMS web site.

Both documents have been sent to the WGII rapporteurs.

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IROWG-11 organization

- September 10 – 16, 2026, Seggau Castle, Austria, together with OPAC-8
- Hosted by the University of Graz
- The website for the workshop will be: http://irowg.org/workshops/irowg-11/
- Full workshop, including presentations, posters, sub-group discussions, and social activities.
- Four working subgroup meetings: Numerical Weather Prediction (NWP); Climate; Innovation; Space Weather
- Feature special ROMEX sessions
- Outcome: CGMS recommendations (including ROMEX), internal action items, a summary of relevant activities, and meeting minutes

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Thank you for your attention !

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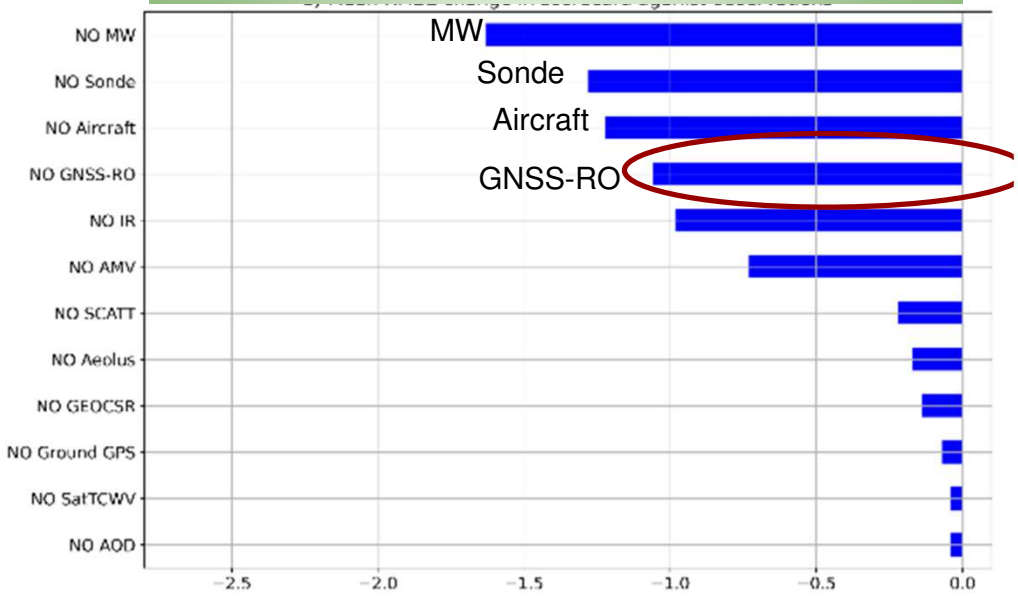
BACKUP

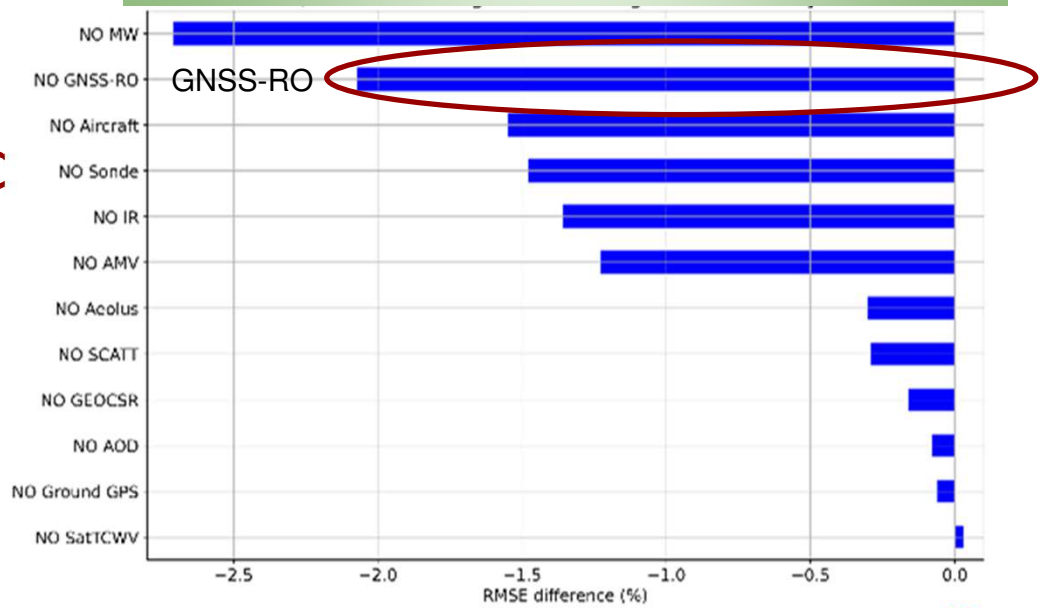
IROWG Highlights: Recent impact studies at operational NWP centers

Observation denial experiments show GNSS-RO ranks fourth against observations and second against ECMWF analysis.

Forecast Error reduction verified against observations



Forecast Error reduction verified against ECMWF analysis



Mean root-mean-squared-error (RMSE) reduction due to different observation types verified against observations (left) and against ECMWF analysis (right) by the UK Met Office.

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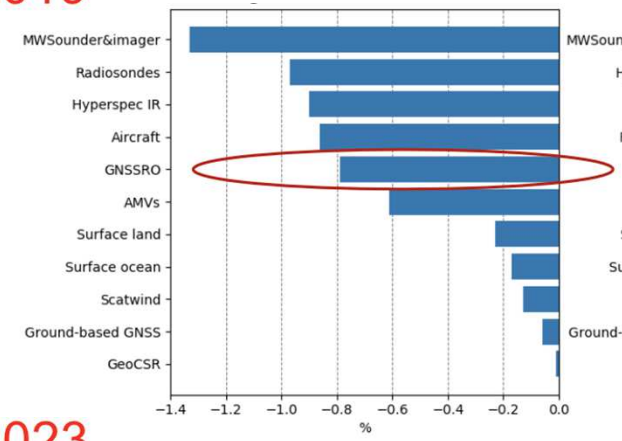
IROWG Highlights: Recent impact studies at operational NWP centers

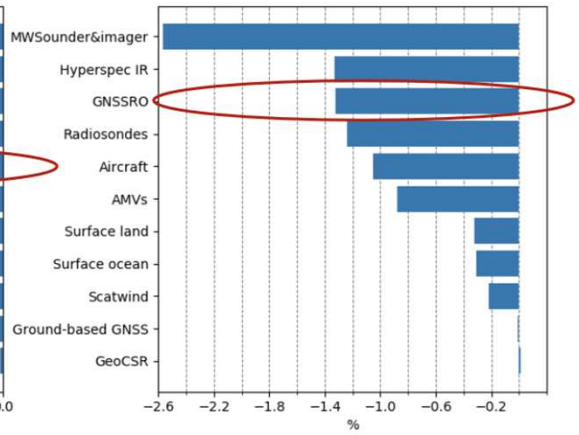
UK Met Office observation denial experiment results (2024)

2019

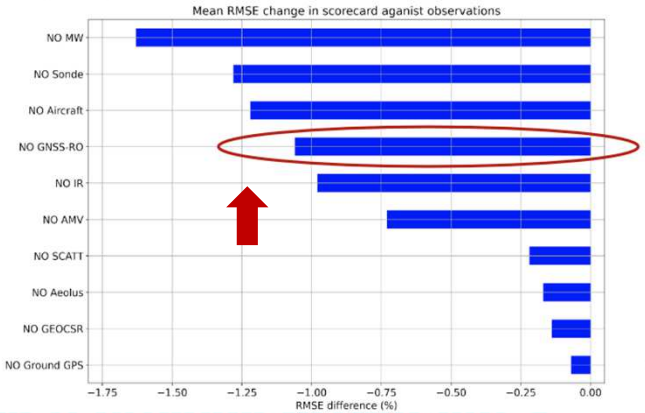
RMSE reduction verified against obs

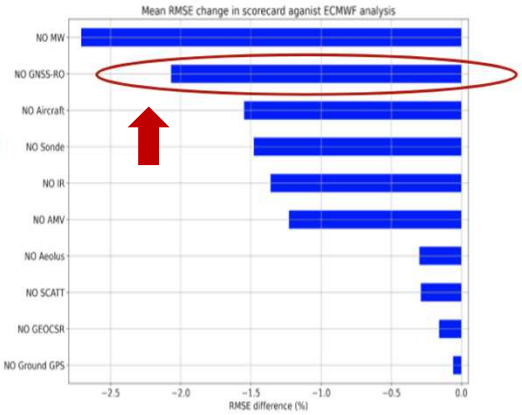


RMSE reduction verified against EC ana



2023





- The rank of GNSS-RO contribution to forecast improvement has shifted from 5th to 4th when verified against observations, and from 3rd to 2nd when verified against ECMWF analysis.
- The increased impacts of RO (Radio Occultation) are a result of the rising number of RO profiles in 2023.

Mean RMSE reductions in scorecard against observations (left) and the ECMWF analysis (right) calculated from the observation denial experiments performed in 2019 (upper panel) and 2023 (lower panel) by the UK Met Office.

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