IROWG Update on Recommendations and Activities

Presented to CGMS-52 Working Group II session, agenda item 3.3

Chairs: Hui Shao (Joint Center for Satellite Data Assimilation, UCAR)
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Executive Summary of the WP

The IROWG community has not held a workshop since CGMS-51. IROWG-10 is planned for 12-18 September, 2024 on the UCAR campus in Boulder, Colorado, United States.

The IROWG leadership and chairs and co-chairs of the four sub-groups met virtually on February 26, 2024 to discuss updates since CGMS-51. The following topics are covered in the working paper:

- Update on projected number of RO
- Recent studies on radio occultation (RO) impact to numerical weather prediction (NWP)
- Best Practices document on a backbone RO constellation for climate studies
- Long-term archiving of Level-0 (raw) data
- Progress within the RO Modeling Experiment (ROMEX) (next presentation)
- Updates to the BUFR format
- Topics possibly leading to future recommendations

We add a community highlight to this presentation.

IROWG held a ROMEX workshop on April 17-19 at EUMETSAT, Darmstadt, Germany. The next presentation will give a summary of the workshop outcome.

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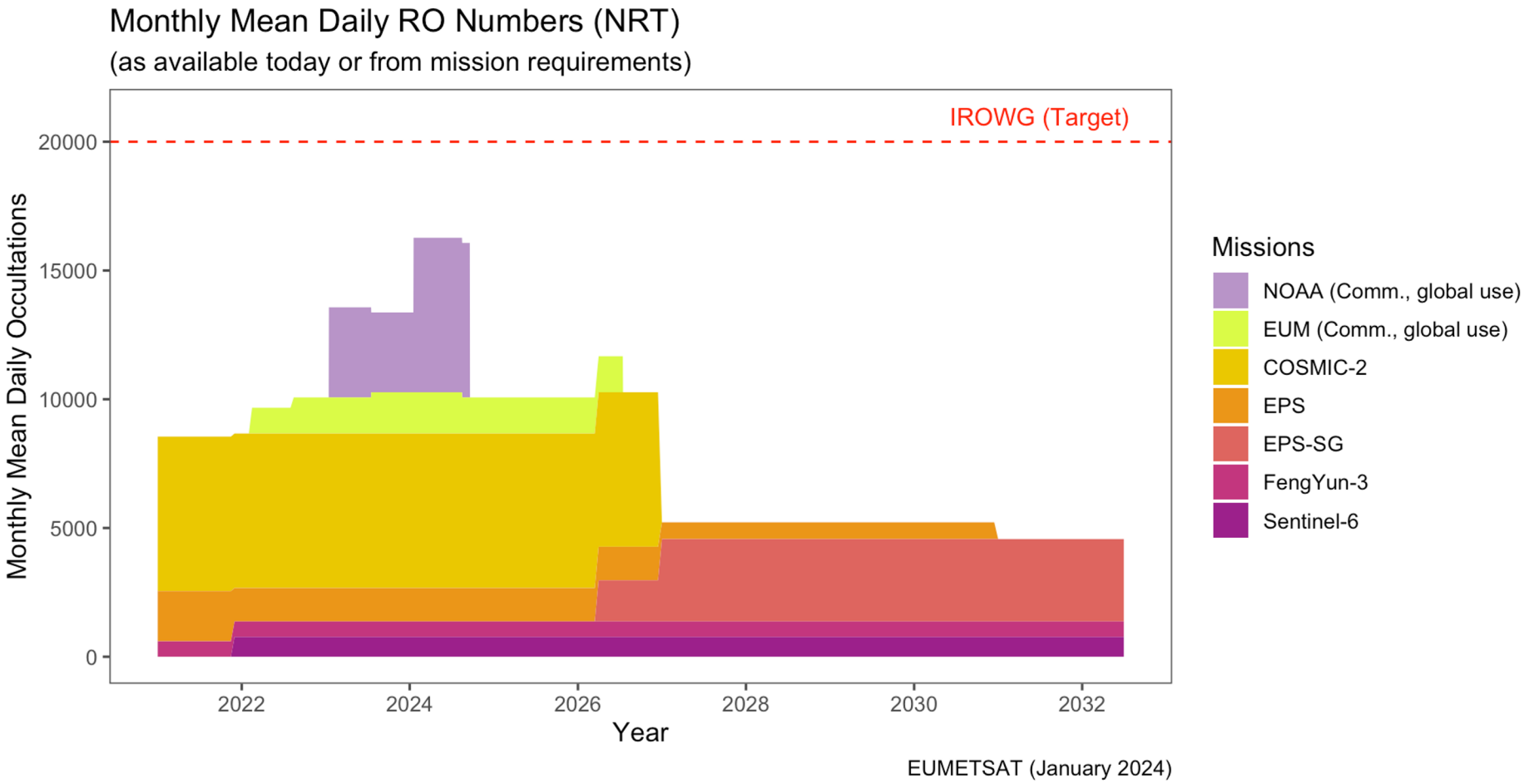
IROWG Highlights: Projected RO observation numbers in next decade



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

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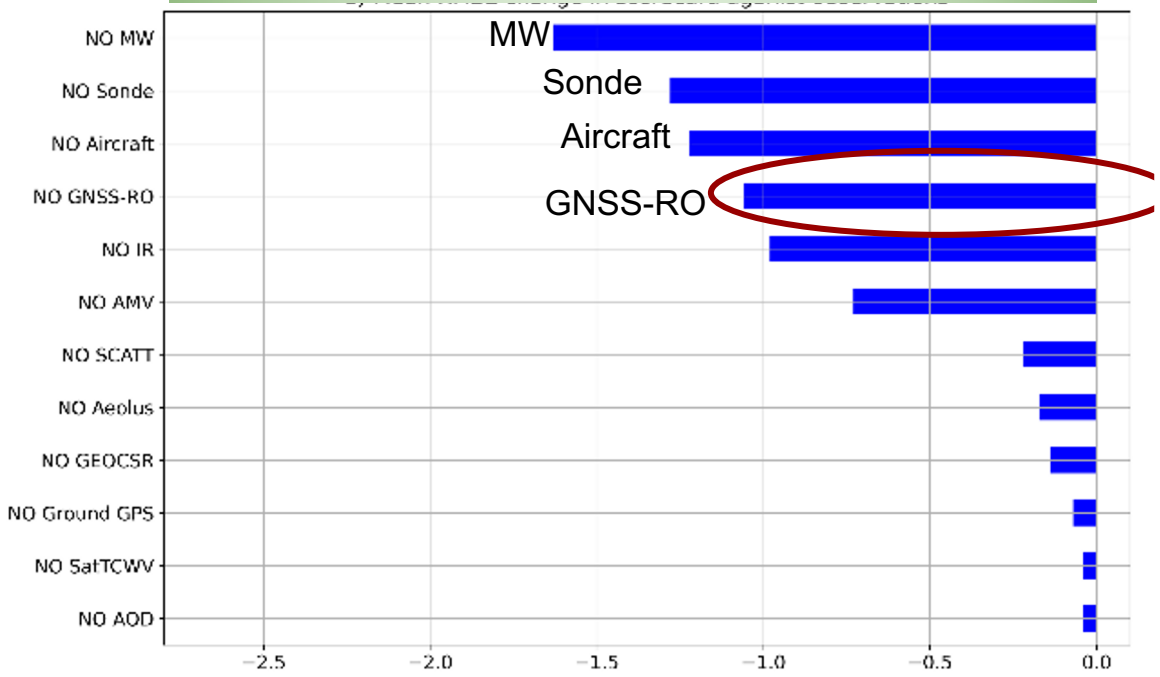
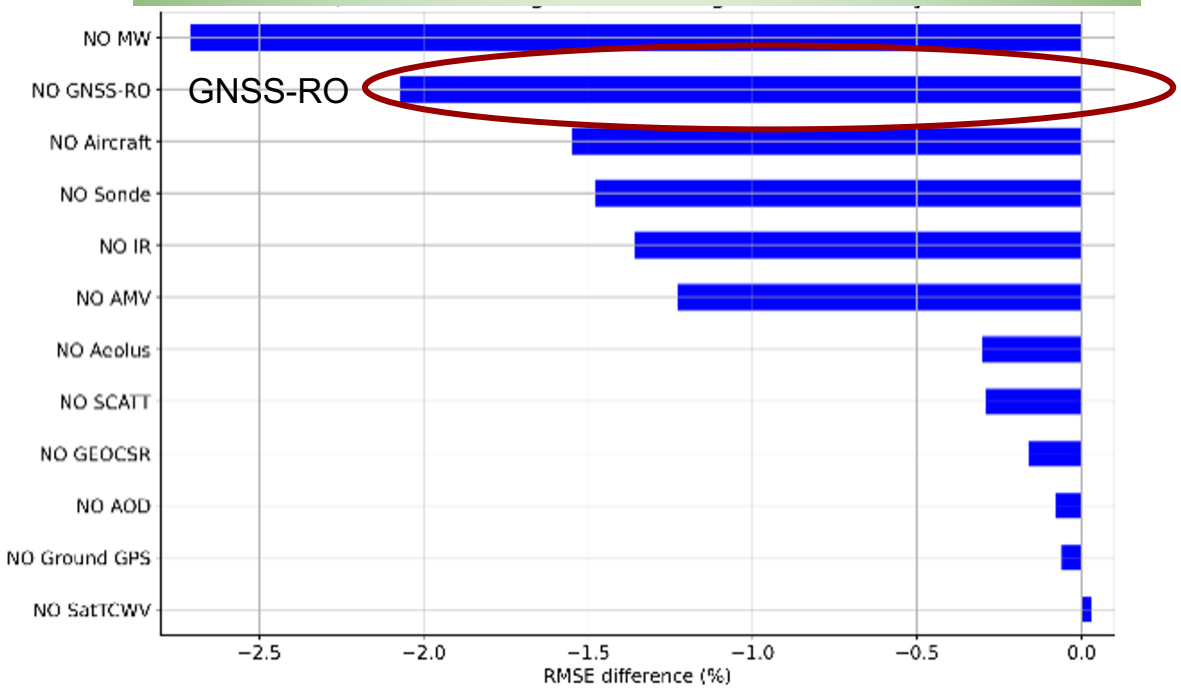
IROWG Highlights: Recent impact studies at operational NWP centers

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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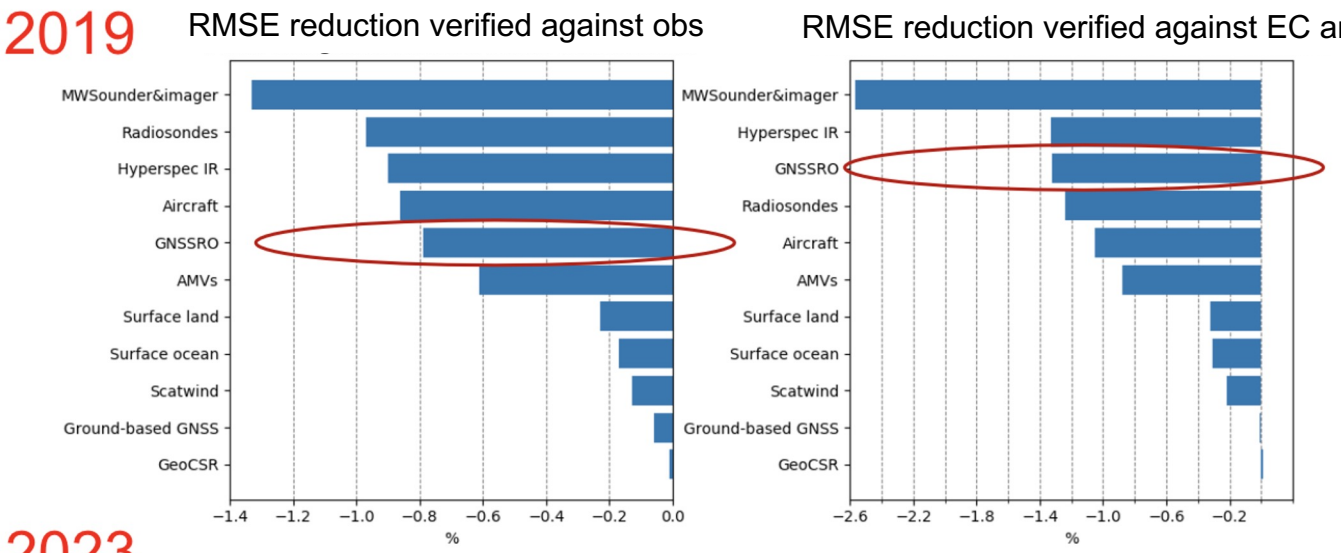
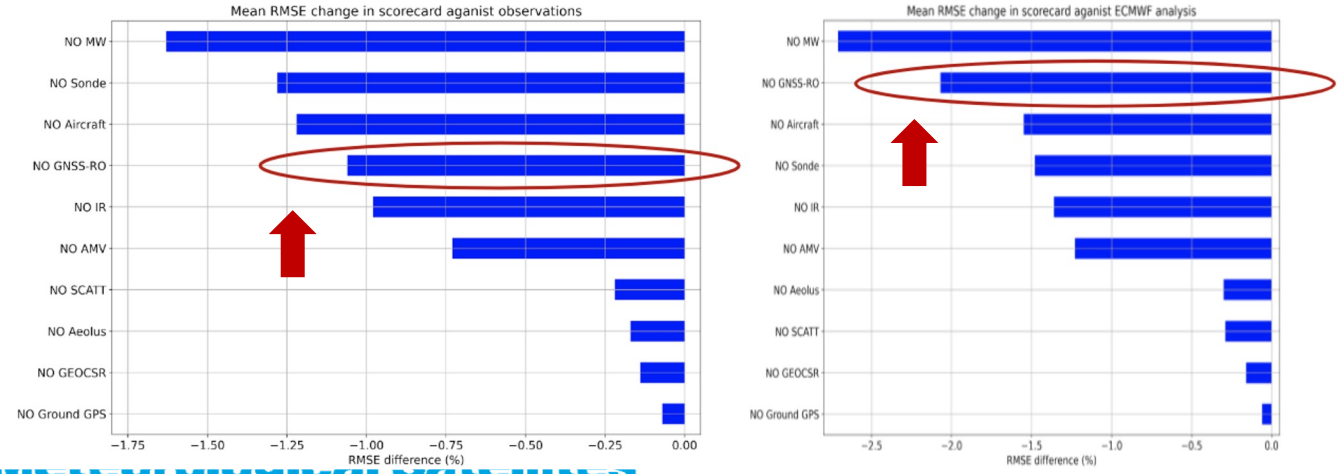
IROWG Highlights: Recent impact studies at operational NWP centers

UK Met Office observation denial experiment results (2024)

2019



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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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

- 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)..."

- IROWG can provide support if WGII wishes to consider this document for adoption by CGMS
  - A draft is available for discussion

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Provisional topics/recommendations to be discussed during IROWG-10

1. Data archiving

- Commercial versus government-owned long-term archives
  - It came to our attention that a commercial provider was being asked to establish a long-term archive for raw and higher-level RO data
- Concerns raised over de-centralized data archives for long-term data preservation
  - For discussion at IROWG-10: long-term data archives should perhaps be government-owned

2. Technology for boundary layer profiling

- IROWG-9 recommendation: develop technology and retrievals for improved planetary boundary layer profiling and utilisation in NWP, including exploitation of RO-derived water vapour.
- Discussion at CGMS-51 suggested the development of use cases for guiding NWP centers
  - Development of use cases will be on the agenda at IROWG-10

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IROWG Highlights: Proposal for new RO BUFR template

Goals:

- Adapt to novel techniques and observation types, e.g., airborne GNSS-RO (ARO) and polarimetric GNSS-RO (PRO).
- Incorporate new data types into the GNSS-RO BUFR template useful for QC:
  - Local Spectral Width (LSW)
  - Signal to Noise Ratio (SNR)
  - Ducting layer detection

Status:

- Formed a sub-committee
- Members meet monthly
- Drafting a revised template (right)
- Plan to present in IROWG-10

N1+2	Short delayed replication factor	0 31 000	0	0	1	Numeric	Indicate presence of PRO variables
N1+3	Impact Parameter	0 07 040	1	62 000 000	22	Metres	6200–6600 km to 10cm (distance from centre of curvature)
N1+4	Calibrated phase difference	New					
N1+5	Estimated error in calibrated phase difference	New					
N2	(end delayed replication)						
N2+1	Short delayed replication factor	0 31 000	0	0	1	Numeric	Indicate presence of absence of following aircraft block
N2+2	Aircraft height	0 07 002	0	-1 000	17	Metres	Geometric altitude, -1km to 100km, wrt EGM-96 geoid (MSL)
N2+3	Atmospheric refractivity (in-situ aircraft N(p,T,rh))	0 15 036	3	0	19	N-units	0-500, to 10^{-3} N-units
N2+4	Partial bending angle	New	8	-100 000	23	Radians	-10^{-3} – $8x10^{-2}$ rad to 10^{-8} rad
N2+5	Estimated error in partial bending angle	New	8	-100 000	23	Radians	-10^{-3} – $8x10^{-2}$ rad to 10^{-8} rad
N3	(end delayed replication)						
	Delayed Replication	1 04 000					Delayed replication of next 4 descriptors
N3+1	Replication factor	0 31 001	0	0	8	Numeric	Number of diagnostic entries
N3+2	Diagnostic type	0 08 027 (New)	0	0	8	Code Table	See Table 9
N3+3	Decimal scale of following significands	0 08 090	0	-127	8	Numeric	Decimal scale (see next descriptor)
N3+4	Scaled diagnostic	0 33 008 (New)	0	-131 071	18	Numeric	Scaled value (actual value = scaled value × $10^{-\text{decimal scale}}$)
N3+5	Decimal scale of following significands	0 08 090	0	-127	8	Numeric	Missing = off
N4	(end delayed replication)						
N5	(end delayed replication)						

Optional section to describe phase difference polarimetric RO observations

Optional section to describe aircraft RO observations

Section to allow for the use of flexibly-defined diagnostics – diagnostic type specified by code table

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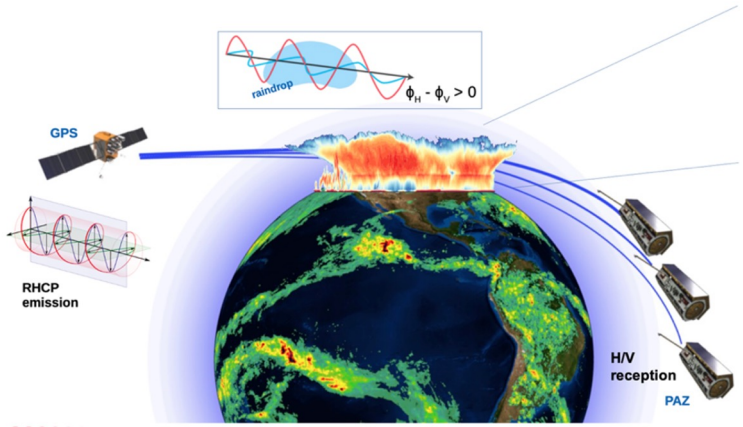
IROWG Community Highlight: 2nd GNSS Polarimetric RO (PRO) User Workshop

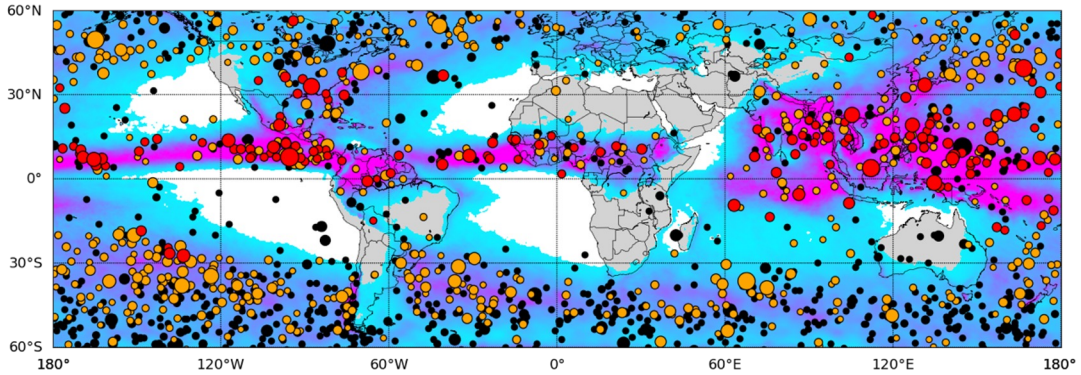
28-29 November 2023, Keck Center, Caltech, Pasadena, US

Over 80 people from 14 countries, 3 continents and over 40 different affiliations, from government agencies, research centers, universities and the commercial space sector

Discussions on the status of PRO technique and applications being developed from current/future observations, with focus on its use for NWP

Workshop summary in now available in the AMS Bulletin





Top 20% of the measured polarimetric phase shift ($\Delta\phi$) from six years (2018-2023) of ROHP observations

(F.J. Turk, et al. (2024) *BAMS*, doi:10.1175/BAMS-D-24-0050.1)

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IROWG-10 organization

- September 12-18, 2024 in Boulder, Colorado, on the UCAR campus
- Hosted by the UCAR Constellation Observing System for Meteorology Ionosphere and Climate (COSMIC) program and the Joint Center for Satellite Data Assimilation (JCSDA), with sponsorship from various entities
- The website for the workshop is at:
  https://www.cosmic.ucar.edu/events/cosmic-jcsda-workshop-irowg-10
- Full workshop, including presentations, posters, sub-group discussions, and social activities.
- Four working subgroup meetings: Numerical Weather Prediction (NWP); Climate; Receiver Technology and Innovative Occultation Techniques; Space Weather
- Feature special ROMEX sessions aimed at constructing ROMEX recommendations
- Outcome: CGMS recommendations (including ROMEX), internal action items, a summary of relevant activities, and meeting minutes

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IROWG continues to support recommendations from IROWG-9

- IROWG strongly supports an **open data policy** towards the purchase of commercial RO data and recommends that all agencies follow this model. IROWG stresses the importance of **free and unrestricted access** to essential RO data including archived raw or low-level (level 0) data
- IROWG recommends **operational** Global Navigation Satellite System (GNSS) RO missions for continuous global climate observations to be established and maintained as **a backbone** to ensure **continuity and long-term availability of climate quality RO**
- IROWG continues to support the previous recommendations that GNSS-RO data - with **at least 20,000 occultations** per day - are **globally distributed** and **provide full sampling of the diurnal cycle**. IROWG also recommends further **investigation of the value of increased target observation quantities**, to provide a sound basis for future statements on the desirable number of observations and insights on satellite mission planning and coordination (HLPP 1.2.9, "CGMS will strive to achieve")
- IROWG recognizes the importance of **space weather applications** of RO data. IROWG recommends that **RO and non-RO missions that use dual-frequency GNSS receivers for their orbit determination** needs should make available to the operational and research communities all necessary low-level (level 0) data and metadata required to produce accurate **overhead TEC data from the GNSS receiver**
- IROWG encourages technology and retrieval developments for improving **planetary boundary layer profiling** from GNSS-RO and their utilization in NWP data assimilation as well as the further exploitation of RO-derived **water vapor**.

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BACKUP

IROWG Community Highlights: RO Backbone Studies

IROWG scientists provide scientific support for ongoing research and studies aligned with its missions and scopes, both within CGMS agencies and the broader research community.

IROWG has been informed that the NESDIS Systems Architecture and Engineering Office (SAE), in collaboration with UCAR, has initiated a project to conduct a GNSS-RO backbone infrastructure study, with a set of requirements for a notional future radio occultation government backbone for tropospheric radio occultation

- *12 or less satellites*
- *8000 daily occultations*
- *Global refresh of 6 hours on a 500 km x 500 km global equal area grid*
- *No more than 3 orbital planes*

The project aims to provide initial insight into potential system architectures to follow the FORMOSAT-7/COSMIC-2 (COSMIC-2) mission and provide RO observations for operational weather and space weather applications, climate studies, and the broader research community

Full report is released and upon request

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Paring Down the Trade Space in Search of Solution Architectures

Requirements-Driven Trade Off

The trade space was pared down using the provided requirements:

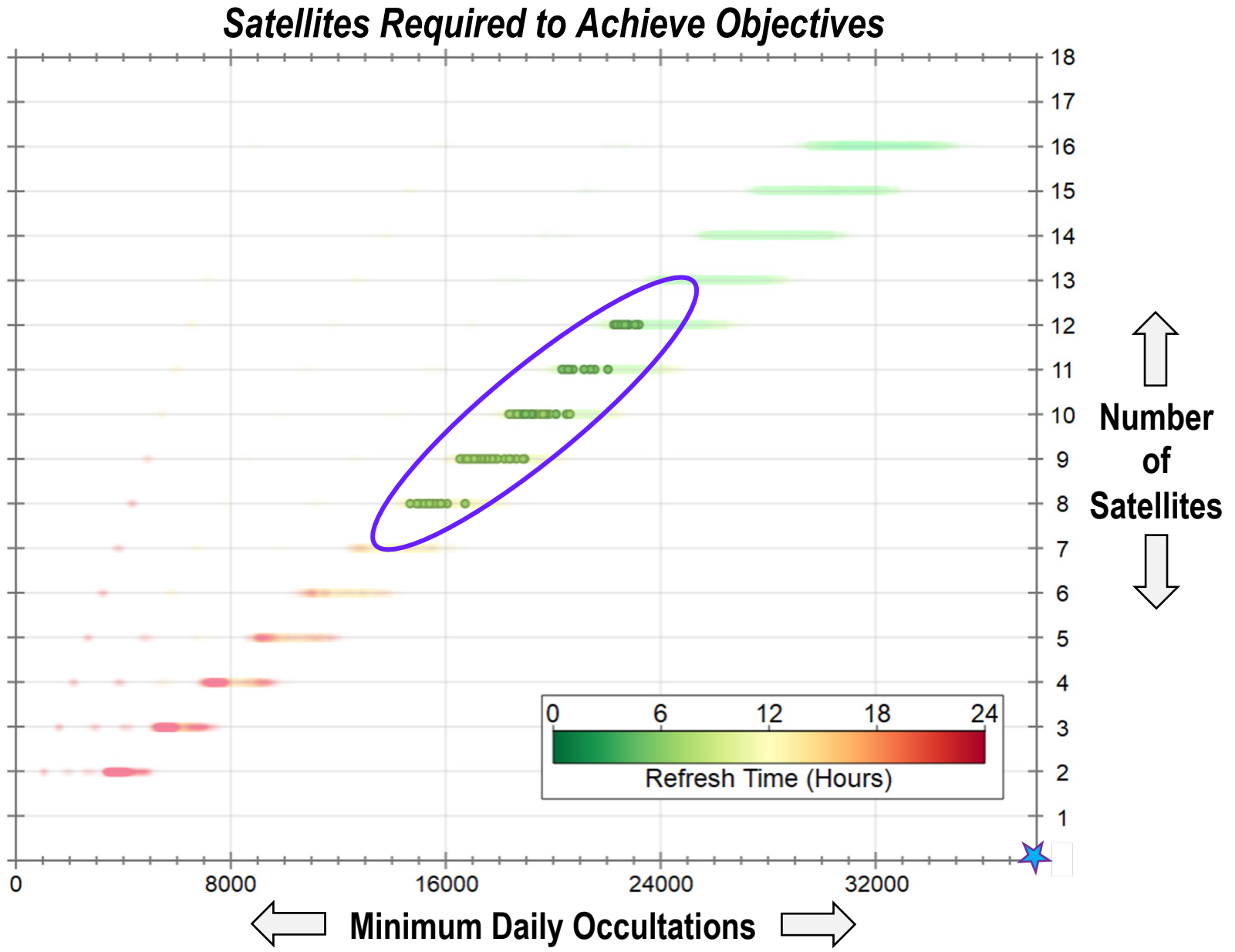
Daily Occultations	≥ 8000
Global Refresh Time	< 6 hours
Local Time Zone Revisit	> 1 per hour
Number of Satellites	< 13
Number of Orbital Planes	< 4

And pared down further using the following assumptions:

Max Inclination	< 110°
Minimum Altitude	≥ 500 km

And as a result:

A minimum of 8 satellites are needed to achieve the requirements globally



Slide from NESDIS, UCAR & Aerospace Corporation