ROMEX Unveiled: International Collaboration Unlocking the Potentials and Futures of RO

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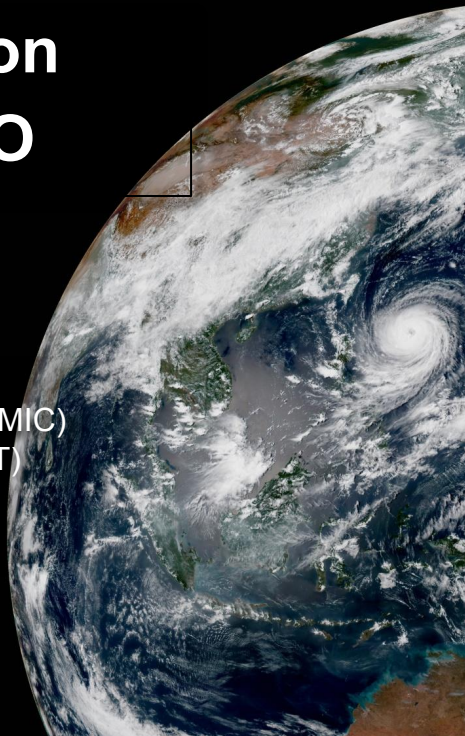
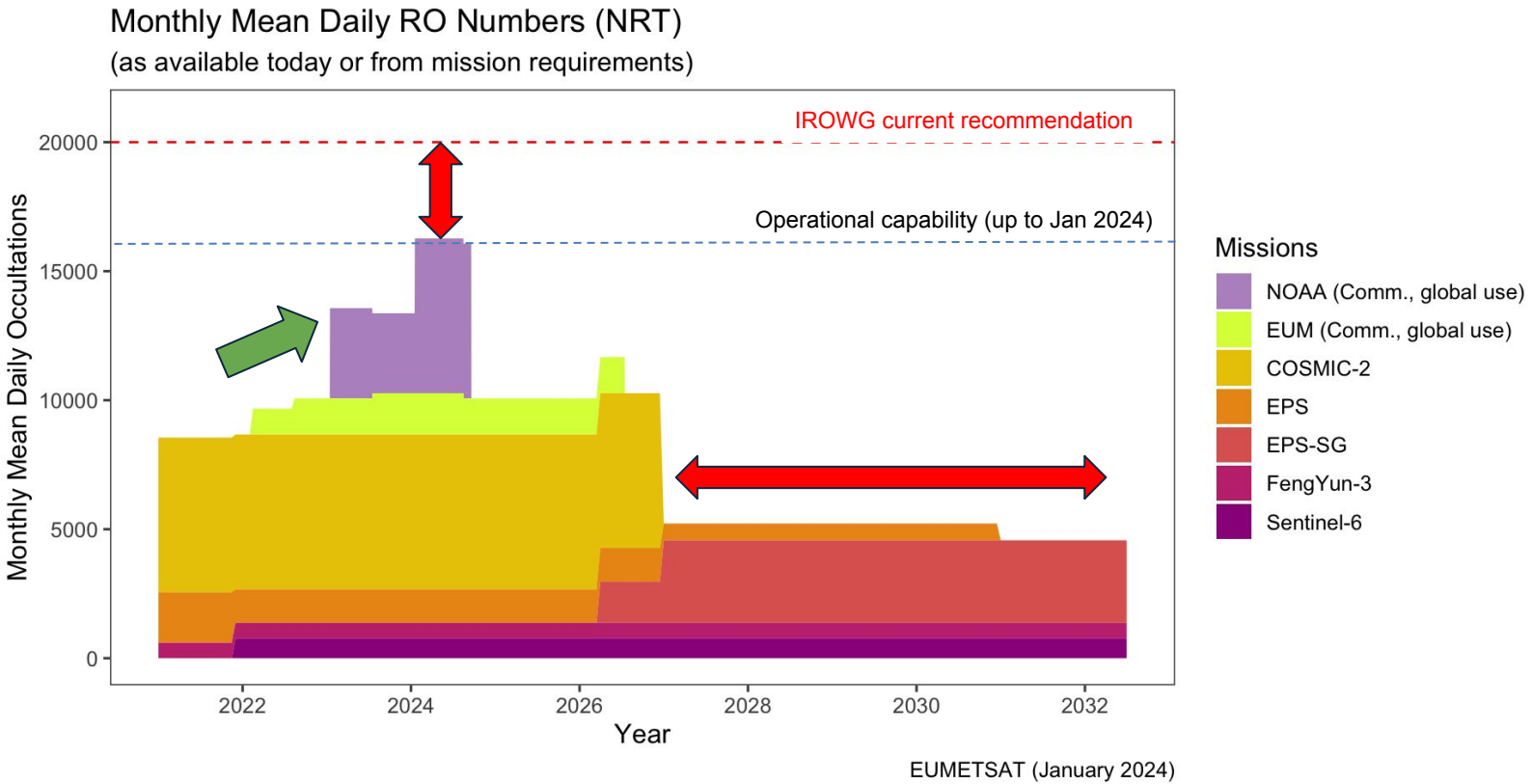
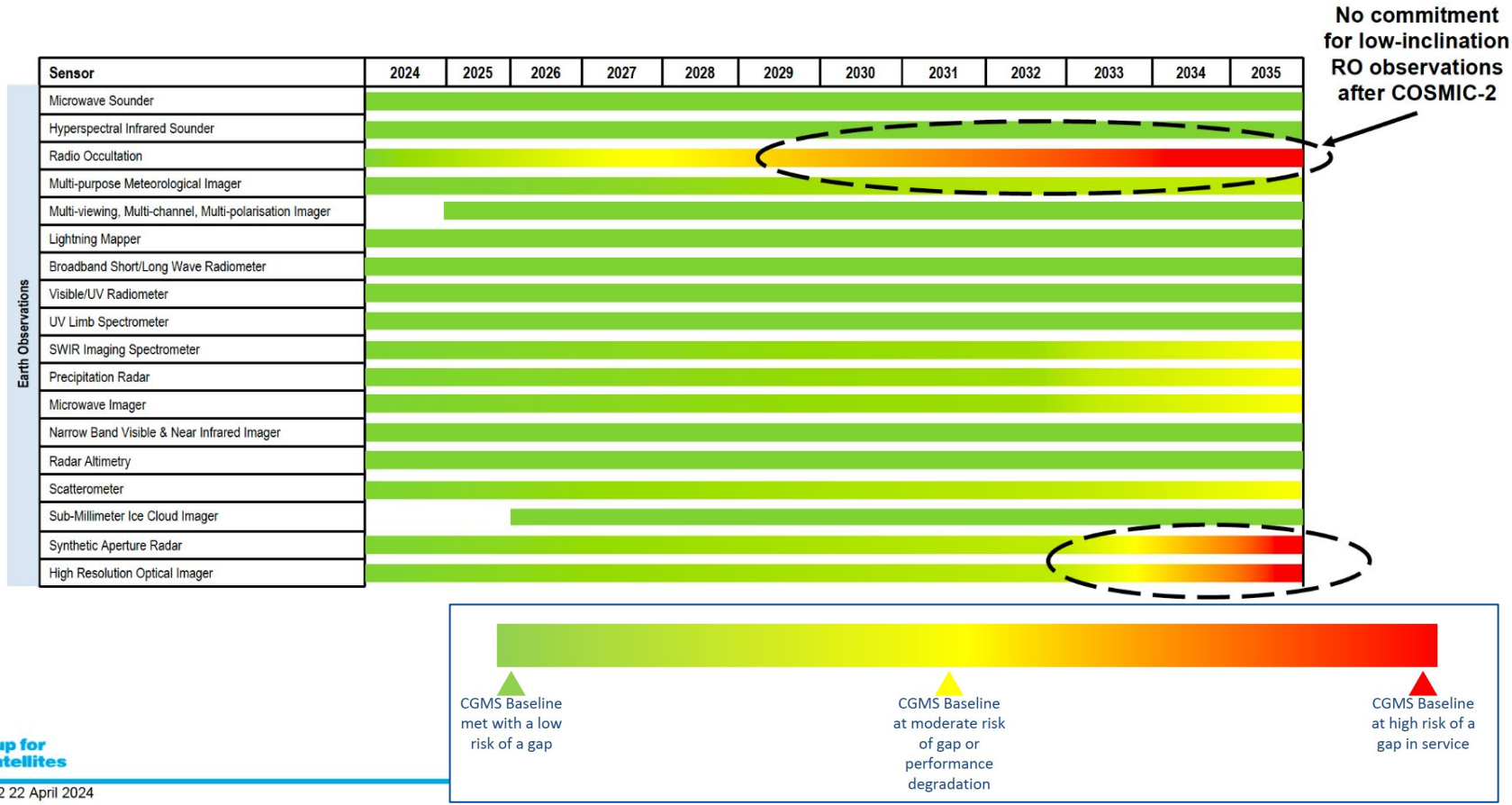


Joint COSMIC / JCSDA Workshop and IROWG-10, 12-18 September 2024, Boulder, CO, US

Projected RO Observation Numbers in Next Decade



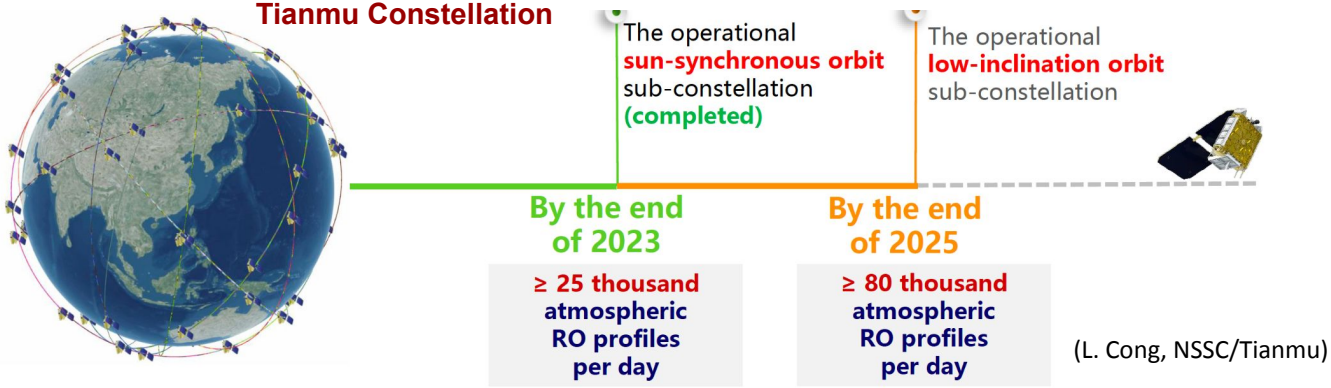
Top-Level Risk Assessment - Earth Observations (2024)



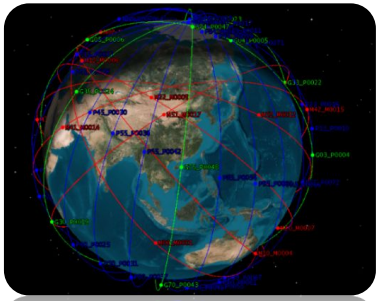
ROMEX Workshop Highlights: Current and future RO missions

- CGMS agencies continue to support commercial programs
- It is likely that Chinese commercial companies may be producing over 100,000 profiles per day within one year—an order of magnitude more than we have now!
- Spire and PlanetiQ, and likely other companies, can provide high-quality data as well.

IROWG encourages CGMS to explore the potential expanded RO capacities while **this window of opportunity remains open**



(L. Cong, NSSC/Tianmu)



Yuanyao Constellation:

By end of 2025, more than 150,000 atmospheric occultation profiles and over 60,000 ionospheric profiles can be obtained every day

(Y. Cheng, Yuanyao)

What is ROMEX: Radio Occultation Modeling Experiment

ROMEX is a collaborative effort to collect as many RO observations as possible and to quantify the benefits of increasing the number of RO observations for NWP by using additional data that were not available to weather centers in their real-time operational systems.

First introduced Dr. Richard Anthes in May 2022, in response to questions from by NOAA for input on future RO needs.

The proposal for ROMEX was endorsed by the IROWG in September, 2022 (IROWG-9) as one of the internal actions

- Provide evidence of impact on NWP forecasts for increasing numbers of RO up to and beyond 20K radio occultations per day (current IROWG recommended level)
- Address the risk of inadequate sustained RO observation efforts over the next decade
- Provide an unprecedented number of high-quality RO data for research

Future RO data needs

Rick Anthes

27 June 2022

Presented to NOAA Systems Performance Assessment Team

ROMEX Evolution

The overall response from data providers, data processing centers, and NWP centers has been highly positive.

Still, coordination with agencies, institutes, and the private sector requires significant iterative effort.

29 November 2022
Kick-off meeting: introduction to ROMEX. Sign up sheet for ROMEX participants

January - May, 2023
Data agreement and license document. Meetings with individual data providers

19-20 December 2022
Meeting. Set up subgroup discussions: Processing and Experiment Design

February - November 2023
Data collection and assemble

August - December, 2023
Data prelim evaluation and processing discussions with individual providers

31 January, 2024
Data release

17-19 April 2024
ROMEX Workshop, EUMETSAT, Darmstadt, Germany

Establish working group → Define ROMEX scope → Negotiate with data providers (data use agreement) → Collect data set → Data evaluation → (Re)-process data set → Data release (user TnC) → NWP experiments

IROWG-9 IROWG-10

IROWG-ROMEX Workshop

- April 17-18, 2024 in Darmstadt, Germany
- Hosted by EUMETSAT
- The web site for the workshop is at:
  https://www.eventsforce.net/eumetsat/frontend/reg/thome.csp?pageID=24320&eventID=61
- Four sessions: Current and future RO satellite missions and commercial activities; ROMEX data processing and evaluation; Methods and applications; NWP impact studies and results
- Two afternoon discussion sessions and one-half day plenary discussion session
- Outcome: workshop summary and plans

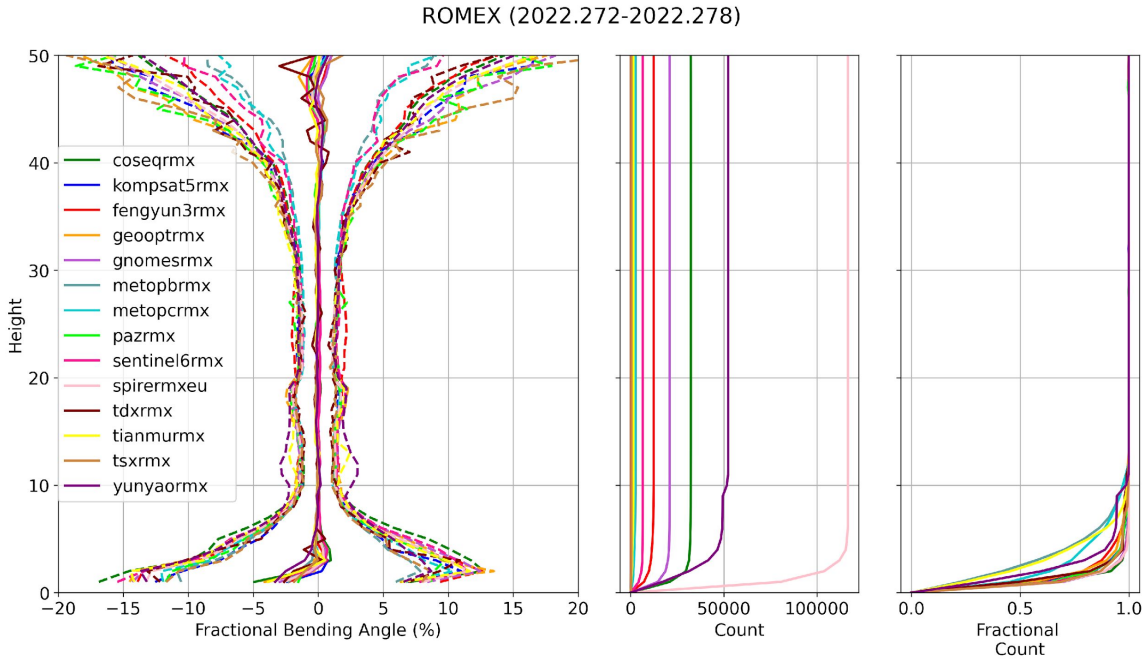
ROMEX Workshop Highlights: RO processing

Analysis of the various ROMEX missions performed by various groups confirm:

- All data sets exhibit data quality sufficient to perform ROMEX experiments;
- Differences between data provided by different processing centres warrant further analysis

Global Bending Angle vs. ECMWF (All ROMEX Missions)

Example week shows generally consistent mean and st dev vs. altitude



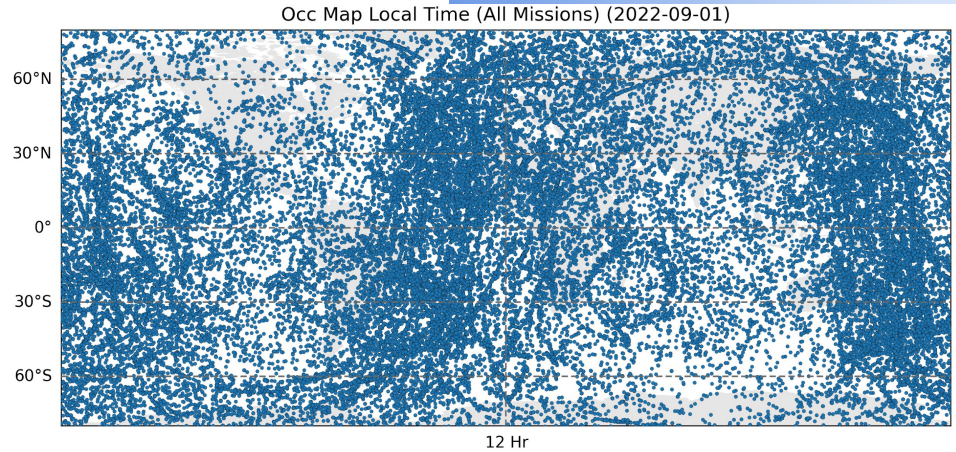
(J-P Weiss, UCAR/COSMIC)

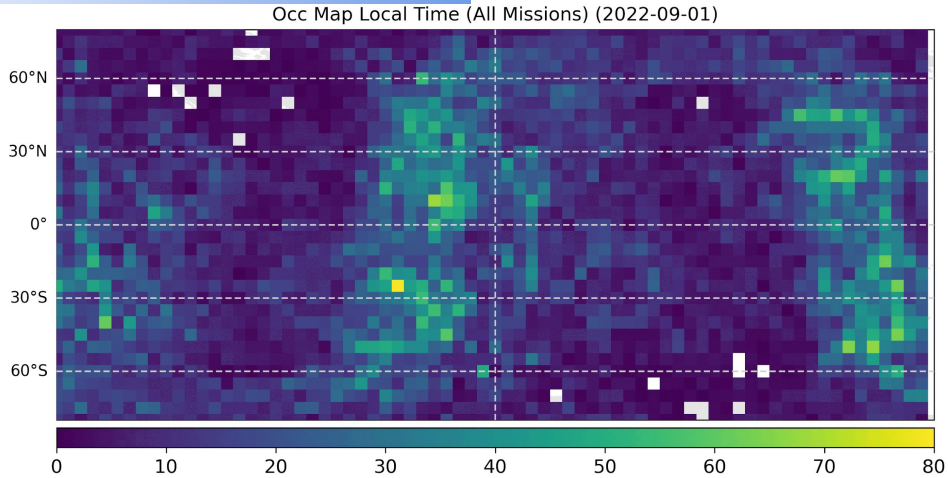
ROMEX Workshop Highlights: RO processing

The ROMEX Workshop found that the local time coverage is a potential risk for appropriately representing diurnal variations of weather systems

- IROWG proposed changes to CGMS High Level Priority Plan (HLPP) 1.2.9: Advance the atmospheric radio occultation constellation, with the long-term goal of providing 20000 occultations per day ***with uniform spatial and local time coverage*** on a sustained basis
- CGMS accepted the proposal in CGMS-52, June, 2024

Local Time Coverage (All ROMEX Missions)





Showing daily occultation locations (left) and daily count in 5x5 deg lat/lon bins (right)

(J-P Weiss, UCAR/COSMIC)

Status of ROMEX: Impact studies

- NWP community has successfully downloaded the data beginning in mid February and have started experiments
- Two common experiments:
  - Control: baseline missions (~6K profiles/day)
  - ROMEX: baseline missions + supplemental missions (~35K profiles/day)
- During the workshop, another experiment was also recommended but not required
  - ROMEX20K: selected ~20K profiles/day
- NWP centers started performing experiments and progress varies. Three-month experiments not completed yet.
- ROMEX team discussed validation metrics and exchange file format
- More complete results to be reported at the IROWG-10 Workshop, September 2024, Boulder, CO, US

Mission	Baseline	Average Profiles/Day
COSMIC-2	Yes	5745
FY3		1988
GeoOptics		138
PlanetiQ		3070
KOMPSAT-5	Yes	153
MetOp-B	Yes	414
MetOp-C	Yes	398
PAZ	Yes	179
Sentinel-6A	Yes	945
Spire		17777
TanDEM-X	Yes	135
TianMu		229
TerraSAR-X	Yes	199
Yunyao		6244

Status of ROMEX: Experiments and Verification Exchange (incomplete)

Organizations	Experiments	model/DA	resolution	RO observations assimilationed	verification period
KMA	NORO	Operational Korean Integrated Model (KIM3.9)/Hybrid 4DEnVar	ne180(~ 25 km); DA: ne144 (~ 32 km) / 50 ens members	none	20220901~ 20221130
	Control			Baseline missions	
	ROMEX			plus ROMEX supplemental	
MetOffice	**control**	UM/hybrid 4D-Var	N320 (~40km at mid-lat)/N108 (~130km)/N216 (~60km)	Baseline missions	20220901~ 20221130
	ROMEX			plus ROMEX supplemental	
	ROMEX+increasing all bending angle by 0.05%				
	ROMEX+increasing all bending angle by 0.1%				
	ROMEX+changing refractivity K1 coeff				
	ROMEX+bias correction above 34km				
NRL	NORO	NAVGEM/strong constrain 4DVar hybrid system	T681L60 (~19km with a model top at 0.04hPa)	None	20220901~ 20221130
	Control			RO similar to operational NAVGEM except data sources are from commercial and Chinese providers	
	ROMEX			plus ROMEX supplemental	

Organizations	Experiments	model/DA	resolution	RO observations assimilationed	verification period
CWA	NORO	TGFS v1.1/hybrid 4DEnVar	25-km (C384)	None	20220901~ 20220926
	Control			Baseline missions	
	ROMEX			plus ROMEX supplemental	
	ROMEX_strictQC				
	ROMEX_passive (ongoing)				
	ROMEX_CDAAC (planned)				
DWD	**Control**			Baseline missions	20220901~ 20221130
	ROMEX			plus ROMEX supplemental	
	adjusted QC for FY and some commercial data				
ECMWF	NORO	48R1 (both deterministics and EDA)	TCO 399	None	20220901~ 20221130 (excluding the first 9 days for spinup)
	Control			Baseline missions	
	ROMEX			plus ROMEX supplemental	
	contrl+setting from Chinese and commercial				
	control+rising from Chinese and commercial				
	modification of refractivity coefficient by 0.1%				
	modification in conversion between geometric and geopotential height				
EMC	NORO	GFS v17/GDAS hybrid 4DEnvar	C384 (25km)/80 ens members	none	20220901-20220929
	Control			Baseline missions	
	ROMEX*			*plus Spire, GeoOptics, and PlanetiQ	

Table was created based on the information received so far (not the full list of ROMEX experiments)

ROMEX Workshop Findings: NWP Impacts

- Preliminary results indicate a significant positive impact of incorporating increasing amounts of RO (Radio Occultation) data on NWP (Numerical Weather Prediction) forecasts. The ensemble spread is notably reduced, and (E)FSOI exhibits positive outcomes in ROMEX experiments. Additionally, several centers report substantial improvements in temperature and moisture predictions, verified against in-situ observations.
- However, despite these promising results, inconsistencies across centers persist, with some showing significant degradation in some fields. Among them, geopotential height (GH) degradation is a noteworthy issue requiring further attention.
- In response, offline discussions and various trials have been conducted to address and mitigate these challenges.

Summary

- The RO (Radio Occultation) community is currently at a pivotal moment, facing both challenges and opportunities. While long-term backbone mission planning remains unclear, there is significant growth in commercial RO data anticipated over the next couple of years.
- However, this window of opportunity may be short-lived due to uncertainties in sustaining data availability and the potential commercialization of other observation types.
- The current CGMS recommendation on the required number of RO observations is grounded in historical OSSE (Observing System Simulation Experiments) studies.
- ROMEX has successfully collected 30,000–40,000 profiles per day during September–November 2024, all of which are available to the community. The data quality is sufficient for use in both NWP and broader scientific studies.
- ROMEX represents a truly international collaboration within the IROWG community, aimed at exploring both the potential and challenges of utilizing RO observations for NWP (Numerical Weather Prediction).
- We are grateful for the strong participation and cooperation among data providers, processing centers, and NWP teams – thank you!
- The ROMEX teams have consistently exchanged progress reports, identified key areas for improvement, and established action items. Discussions and coordination continue to move forward. The target is to form recommendations and provide scientific evidence for CGMS-53 WGII in April, 2024

First Lessons Learned

Collaboration:

- Strong support from data providers, processing centers, and NWP centers has been critical to reaching our current stage.

Challenges:

- Acquiring and licensing data from diverse sources requires significant effort.
- Government support and funding were crucial for accessing certain commercial datasets.

Data Quality:

- All datasets exhibit high quality, suitable for ROMEX experiments.
- Data quality depends on appropriate processing and quality control.

Consistency and Risk Mitigation:

- To ensure consistent data quality and avoid potential data loss (e.g., from vendor discontinuation), access to Level 1 and 0 data is essential.

Recommendations:

- In addition to the overall number of RO observations, attention must be given to spatial and local time coverage, as well as other data quality factors when acquiring datasets.

Acknowledgements

All the data providers, especially private sectors (GeoOptics, Tianmu, PlanetIQ, Spire and Yunyao) for providing their data.

EUMETSAT for processing the core data and ROM SAF for making them available on their servers.

NASA for helping obtain the ROMEX data.

NOAA'S Commercial Data Program for sponsoring UCAR ROMEX work.

All the sponsors of RO research in many countries over the past 30 years…..

Most important, everyone who has been actively involved and contributing to this ROMEX effort

ROMEX collaborators:
CMA/CEMC
CMA/NSMC
CWA (formerly CWB)
DMI
DWD
ECCC
EUMETSAT
ECMWF
GeoOptics (commercial)
IEEC
ISRO
KMA
Meteo France
NASA
NOAA/NESDIS/SAE
NOAA/NCEP/EMC
NOAA/OAR/QOSAP
NOAA/NESDIS/STAR
NRL
NSSC/CAS
Tianmu (commercial)
PlanetIQ (commercial)
Spire (commercial)
UCAR/COSMIC
UCAR/JCSDA
UK MetOffice
UMD/CISESS
Yunyao (commercial)

IROWG/ROMEX

Steering Committee:
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Benjamin Ruston (JCSDA)
Hui Shao (JCSDA, IROWG co-chair)

List created in alphabetical order

Reference

webpage: **https://irowg.org/ro-modeling-experiment-romex/**

Anthes, R. A., C. Marquardt, B. Ruston, and H. Shao, 2024: Radio Occultation Modeling Experiment (ROMEX): Determining the impact of radio occultation observations on numerical weather prediction. Bull. Amer. Meteor. Soc., https://doi.org/10.1175/BAMS-D-23-0326.1