Radio Occultation Modeling Experiment (ROMEX)

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

Chairs: Hui Shao (Joint Center for Satellite Data Assimilation, UCAR)
Ulrich Foelsche (University of Graz)
Rapporteur: Tony Mannucci (Jet Propulsion Laboratory, NASA)

With contributions from Richard Anthes (UCAR), Christian Marquardt (EUMETSAT), Benjamin Ruston (JCSDA), and the ROMEX team

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Executive Summary of the WP

IROWG held a ROMEX Workshop on April 17-19, 2024, at EUMETSAT, Darmstadt, Germany. The following summarizes the outcome of the workshop (two months after data release):

- ROMEX has progressed well since last year.
- RO data providers have sent their Level 1-2 data (excess phase, bending angle) to EUMETSAT.
- ROMEX collected 30,000-40,000 RO profiles per day for September-November 2022.
- EUMETSAT has processed all the data and submitted the bending angle data to ROM-SAF.
- The NWP community has begun downloading the data since mid-February and commenced experiments.
- ROMEX data have been evaluated by several centers and shown to be of high quality and useful for NWP.
- Preliminary results suggest a positive impact of ROMEX data on NWP forecasts, but no conclusions can be drawn at this early stage, and there are a few technical and scientific issues to address.

We expect more conclusive results by IROWG-10 on September 12-18, 2024, in Boulder, CO, US.

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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

IROWG ROMEX webpage and BAMS article

- https://irowg.org/ro-modeling-experiment-romex/
- Anthes, R.A., C. Marquardt, B. Ruston, H. Shao, 2024: Radio Occultation Modeling Experiment (ROMEX). **BAMS**, accepted with minor revisions.

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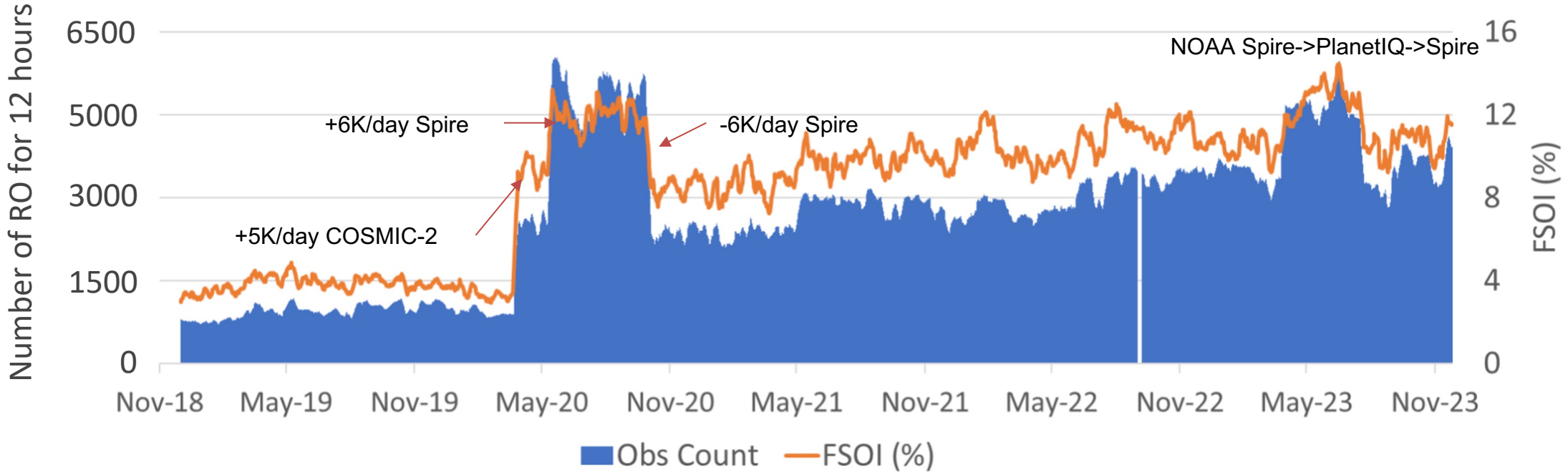
Motivation

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)

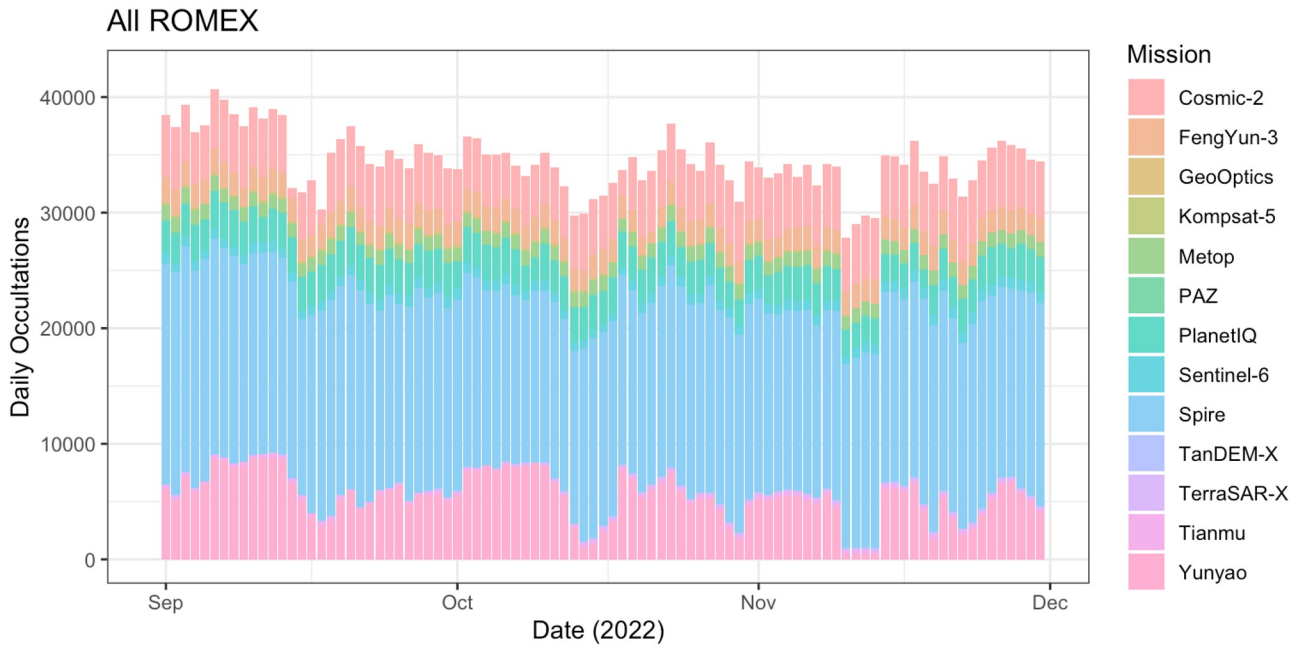
Address the risk of inadequate sustained RO observation efforts over the next decade



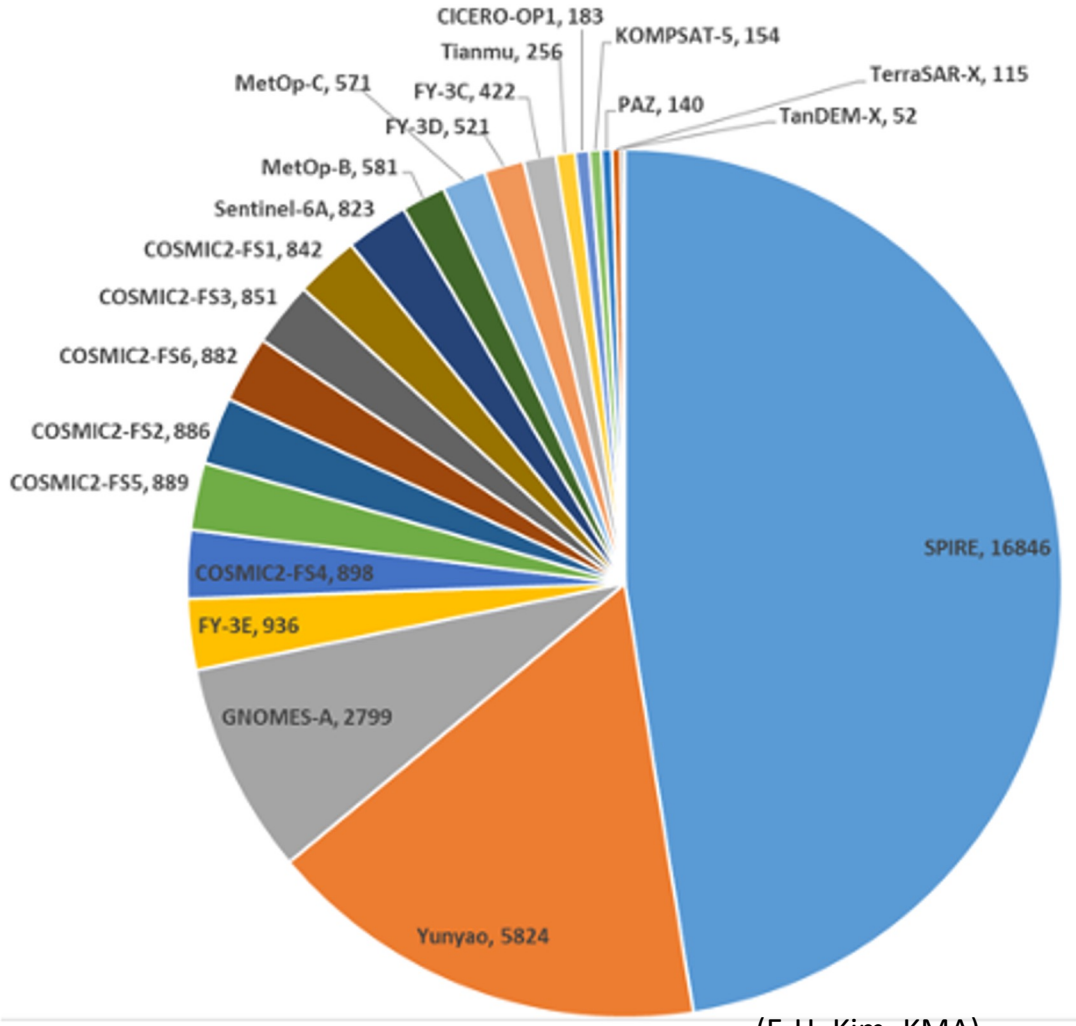
ECMWF 2023 forecast results show clear correlation between number of RO observations and forecasts positive impacts (Sean Healy, ECMWF)

Status of ROMEX: Data

- **30,000~40,000** profiles per day Sep-Nov 2022
- Data from CGMS agencies and commercial providers
- Processing by EUMETSAT ROM-SAF, UCAR and NOAA STAR
- Processed data were released to ROMEX participants in February 2024 through the ROM-SAF



(C. Marquardt, EUMETSAT)



(E-H. Kim, KMA)

Status of ROMEX: Impact studies

- NWP community has successfully downloaded the data beginning in mid February and have started experiments
- Two common experiments:
  - Baseline: baseline missions (~6K profiles/day)
  - ROMEX: baseline missions + supplemental missions (~35K 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: Participating Institutions

Data providers:

CMA (China)
EUMETSAT (EU)
GeoOptics (US)
NASA/Spire (US, EU)
NOAA (US)
NSSC/Tianmu (China)
PlanetIQ (US)
UCAR (US)
Yunyao (China)

Processing and assessment:

CMA
CWA (formerly CWB)
DMI
DWD
ECCC
ECMWF
EUMETSAT
IEEC
KMA
Meteo France
NASA
NCEP/EMC
NESDIS/SAE/CDP
NOAA/OAR/QOSAP
NESDIS/STAR
NRL
NSSC/CAS
Spire
UCAR
UK MetOffice
UMD/CISESS
NESDIS/STAR
NRL
NSSC/CAS
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UK MetOffice
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Some of us met in person at the IROWG ROMEX Workshop, 17-19 April 2024, hosted by EUMETSAT, Darmstadt, Germany

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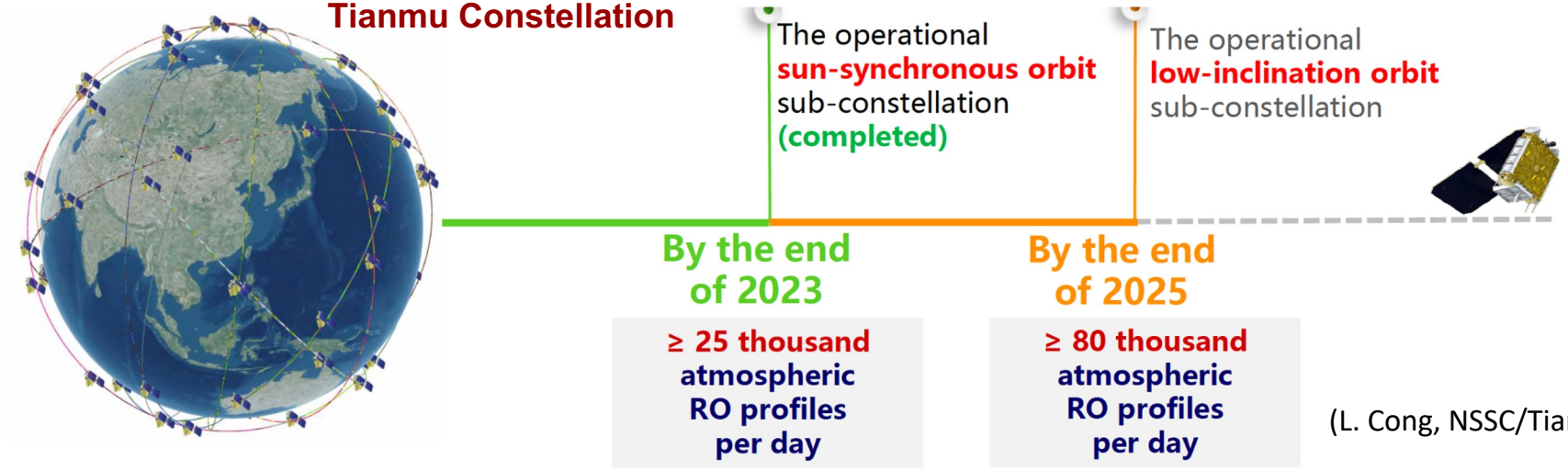
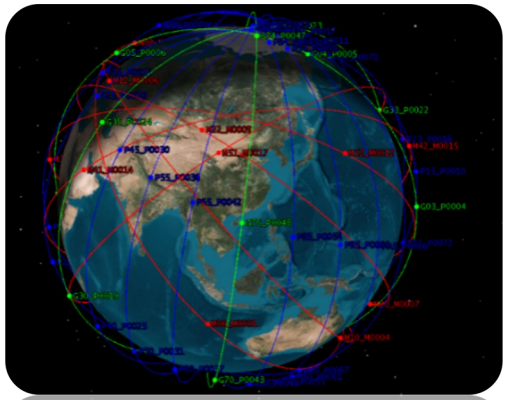
ROMEX Workshop Highlights: Current and future RO missions

- 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)



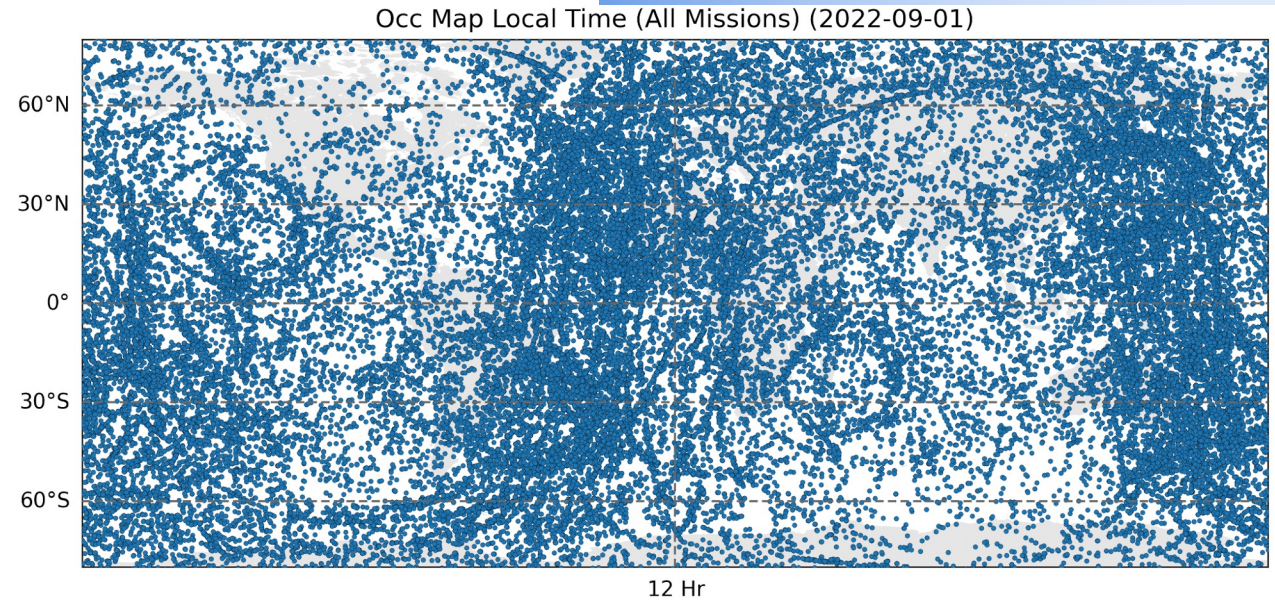
Yuanyao Constellation:
By end of 2025, more than 150,000 atmospheric occultation profiles and over 60,000 ionospheric profiles can be obtained every day

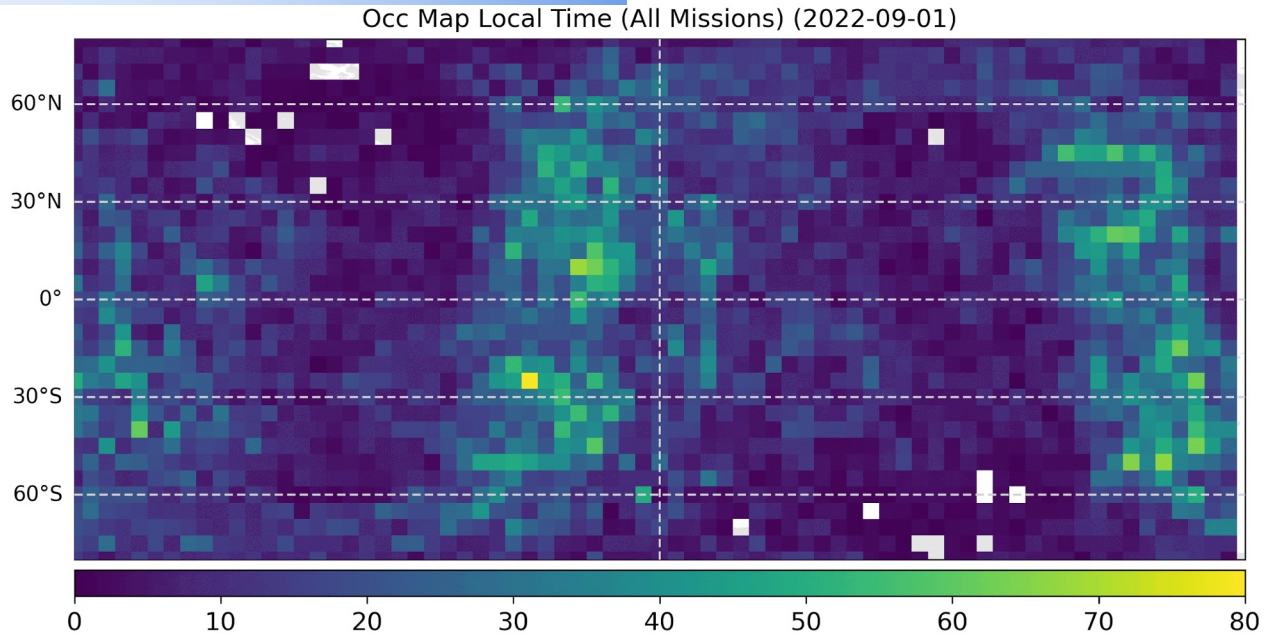
(Y. Cheng, Yunyao)

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
- Reference HLPP 1.2.9: Advance the atmospheric radio occultation constellation, with the long-term goal of providing 20000 occultations per day on a sustained basis
  - While ROMEX further investigates forecast impacts of limited local time coverage, IROWG would like to propose a modification to current HLPP 1.2.9 statement: "...occultations per day ***with uniform spatial and local time coverage*** on a sustained basis"

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)

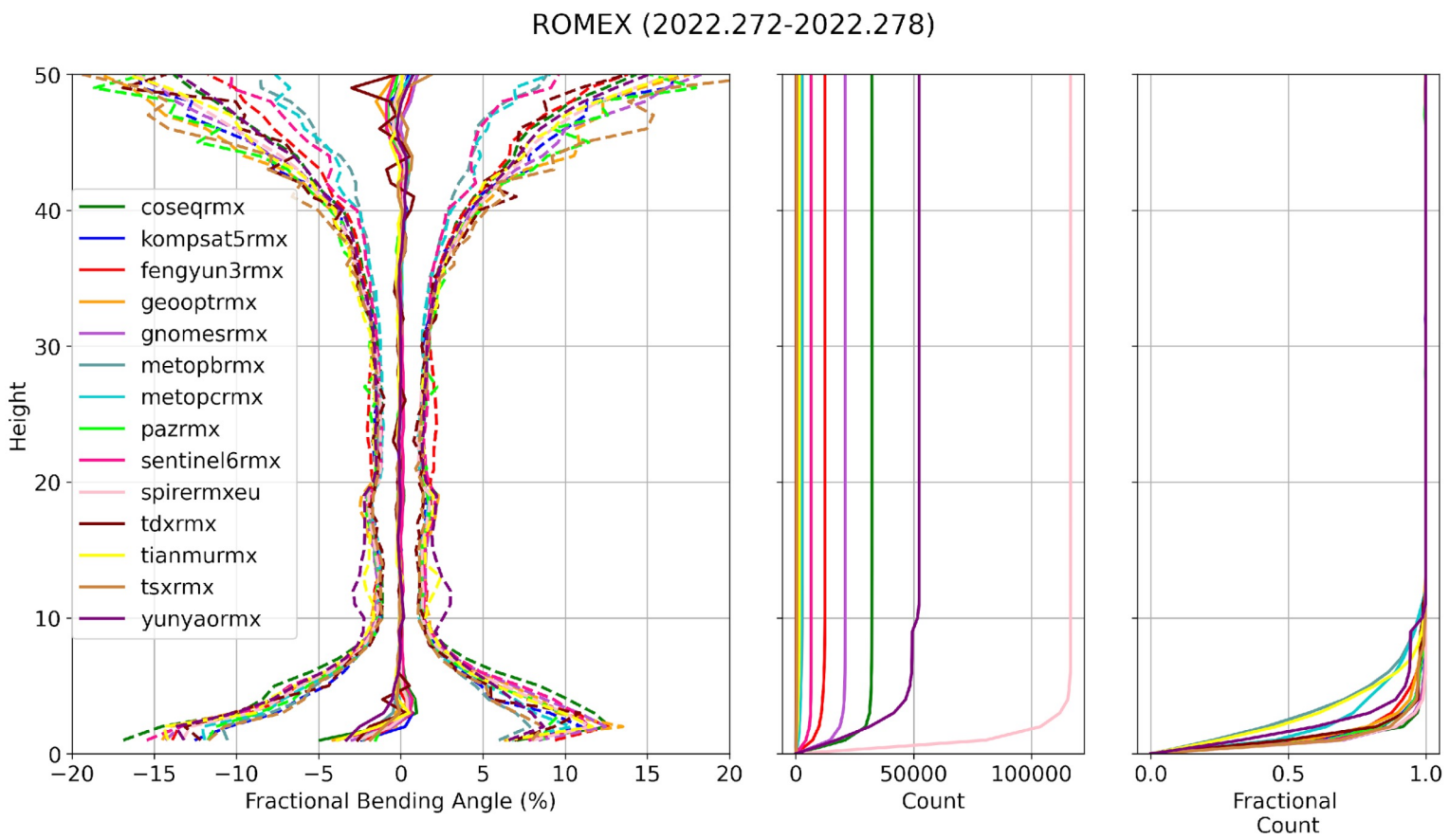
ROMEX Workshop Highlights: RO processing

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

- All data sets exhibit high data quality sufficient to perform ROMEX experiments;
- Minor differences between data provided by different processing centres warrant further analysis, but will not have a significant impact on ROMEX results.

Global Bending Angle vs. ECMWF (All ROMEX Missions)

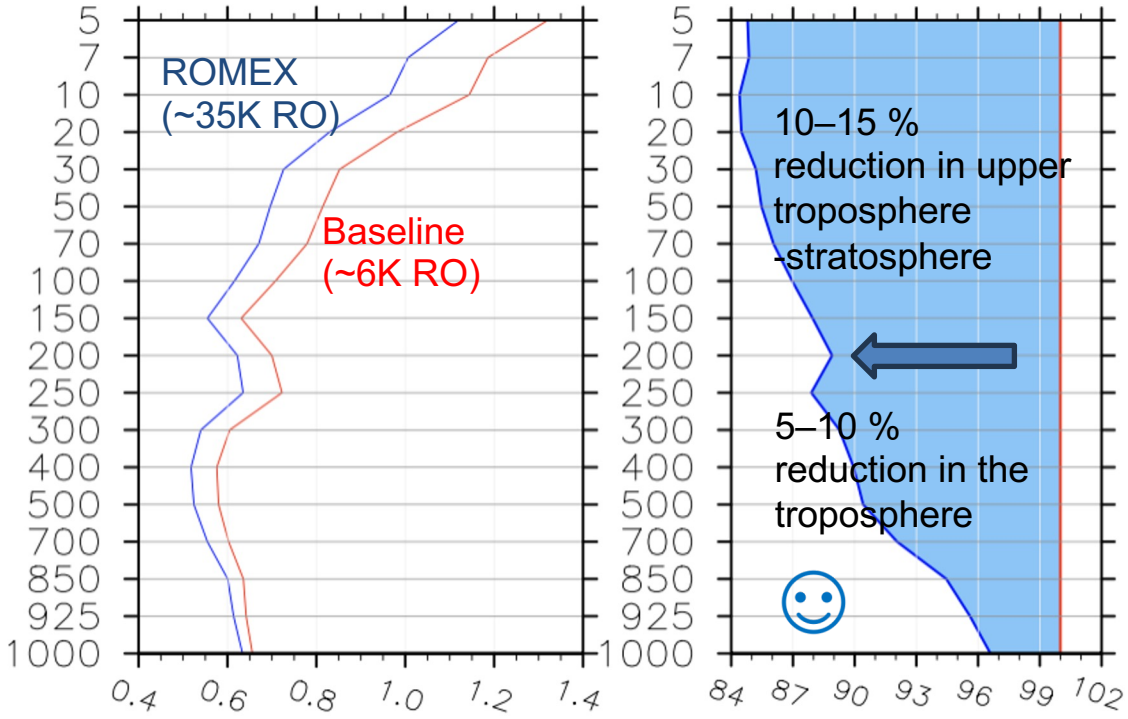
Example week shows generally consistent mean and st dev vs. altitude



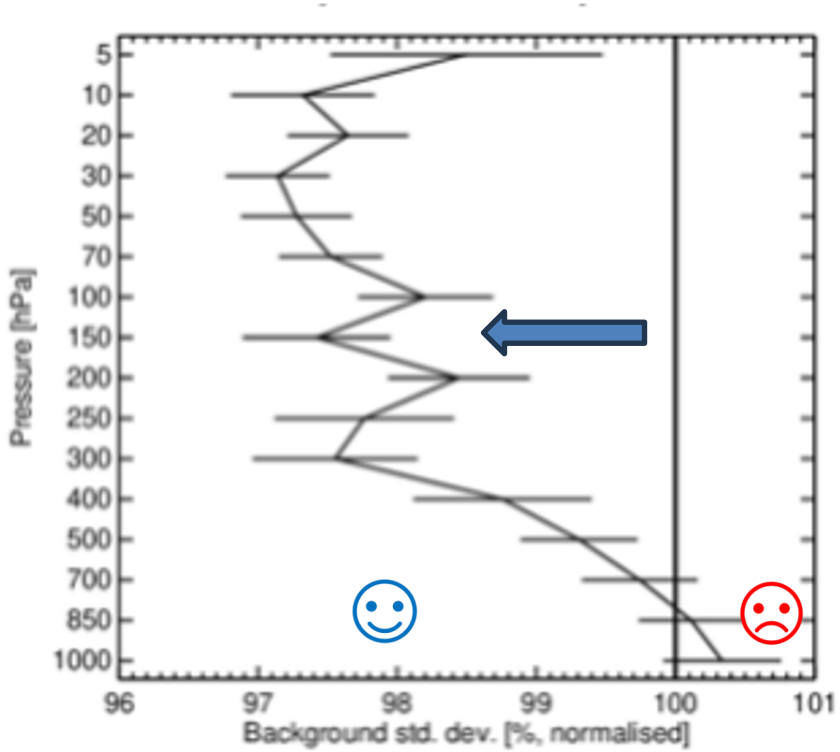
(J-P Weiss, UCAR/COSMIC)

ROMEX Workshop Highlights: NWP Impacts

Preliminary results suggest a positive impact of ROMEX data on NWP forecasts, however, it is still premature to draw any conclusions given the experiments are fully completed and there are a few technical and scientific issues to be addressed



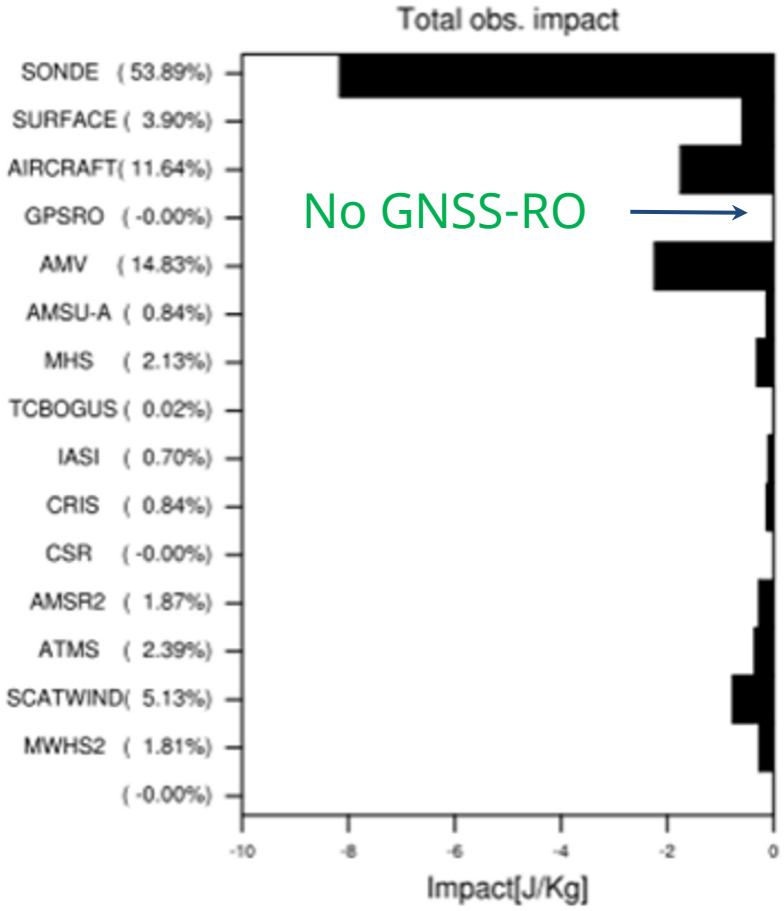
3-h forecast ensemble spread of temperature at radiosonde locations reduced after ROMEX data were assimilated (H. Anlauf, DWD)

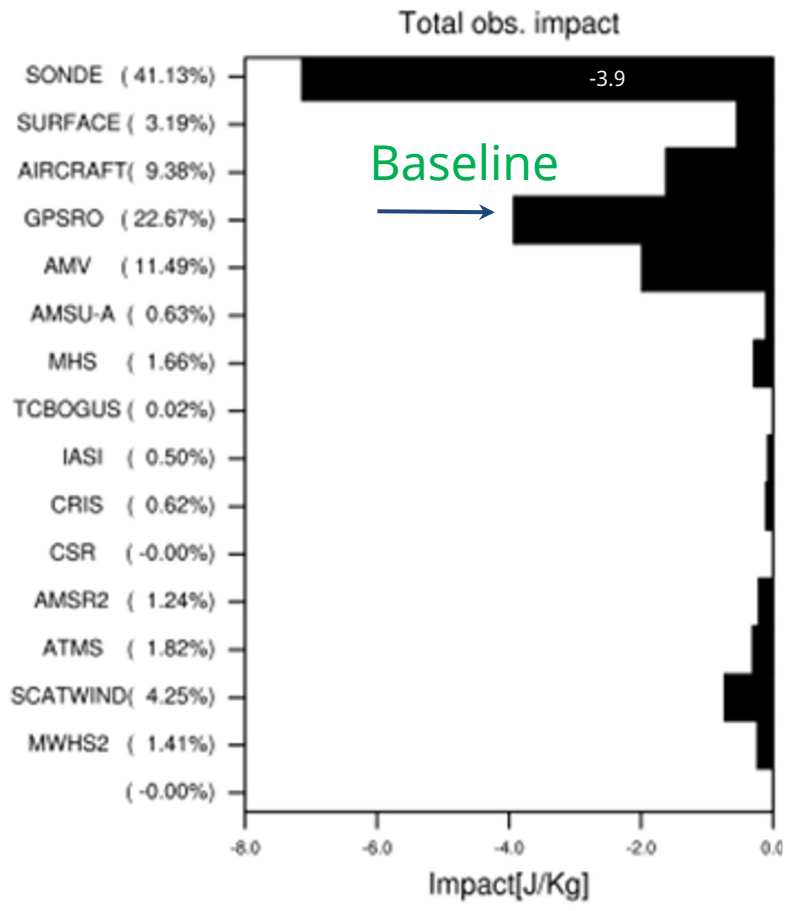


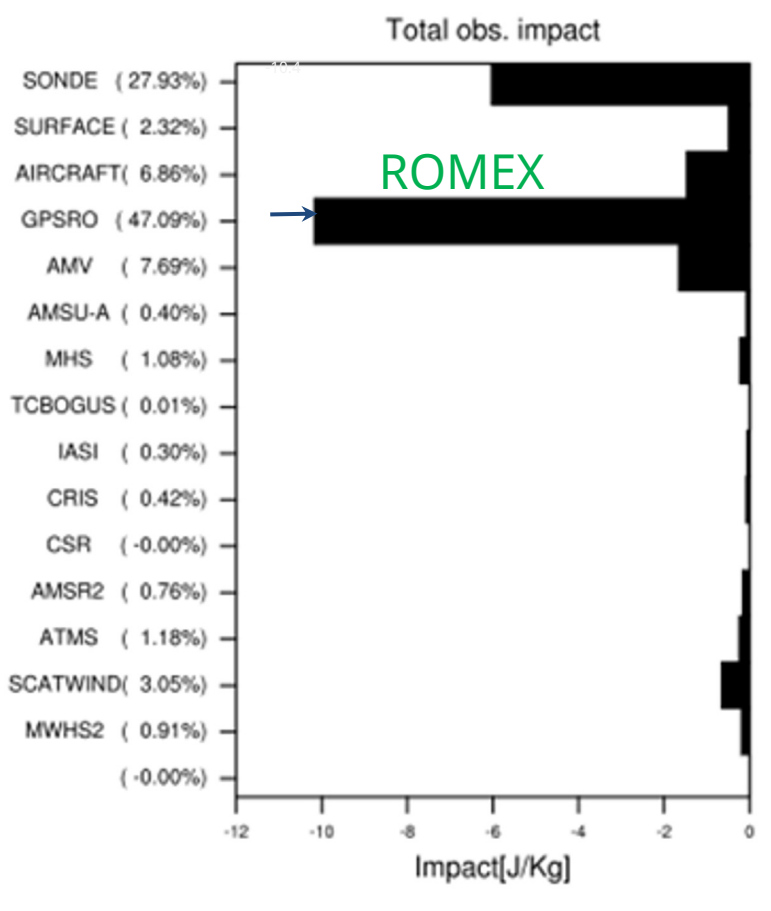
6-h temperature forecast standard deviation reduced 2% averaged by 24-day forecast runs with ROMEX supplemental data assimilated (K. Lonitz, ECMWF)

ROMEX Workshop Highlights: NWP Impacts

Ensemble Forecast Sensitivity to Observation Impact (EFSOI) study indicates relative contributions from GNSS-RO increases with increasing number







Results from KMA's initial ROMEX impact experiments for September and October 2022 (two out of three months of ROMEX tests) (E-H Kim, KMA)

ROMEX Workshop Highlights: NWP Impacts

However, it should be noted that there are areas for continued work, including inconsistencies in the impact results across different fields and verification metrics. The ROMEX workshop also prepared internal action items so that we can follow up and address these issues.

Summary

- ROMEX is progressing well
- Strong participation and cooperation among data providers, processing, and NWP teams
- 30-40K profiles per day for Sep-Nov 2024 available
- All data is high quality and useful for NWP and science studies
- Initial results suggest a positive impact on NWP forecasts at independent centers
- Working areas and action items were identified within the ROMEX team and discussions and coordination will continue in the following months
- More complete results and evaluation to be available at IROWG-10 in Boulder, CO, September 2024

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