Key Takeaways from the Second ROMEX Workshop

Presented to CGMS-53 Working Group II session, agenda item 3.2-2

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Executive summary of the WP

The Radio Occultation Modeling Experiment (ROMEX) is an IROWG initiative to evaluate the impact of increasing radio occultation (RO) observations on Numerical Weather Prediction (NWP) using real data, moving beyond previous theoretical studies and simulations. The experiment aims to assess forecast improvements as RO observations increase beyond the IROWG-recommended 20,000 profiles per day and to address the risks of inadequate long-term RO observation efforts.

ROMEX impact studies in leading international NWP models support the IROWG recommendation of at least 20,000 occultations per day, preferably with uniform global and local time coverage.

ROMEX demonstrates, for the first time with real data, that increasing RO profiles up to 35,000 per day (maximum data available) enhances temperature, wind, and water vapor forecasts, with no clear sign of saturation, confirming past studies with simulated data.

RO data from multiple public and commercial providers show that requirements can be met through a multi-source approach, but continued validation, monitoring, and reprocessing are necessary.

Effective use of large RO datasets requires adaptations in assimilation schemes to maximize their impact within NWP systems.

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Workshops

1st ROMEX Workshop:

- 17 – 19 April 2024 in Darmstadt, hosted by EUMETSAT;
- Website: https://www.eventsforce.net/eumetsat/frontend/reg/thome.csp?pageID=24320&eventID=61

IROWG-10 Workshop:

- September 2024 in Boulder, hosted by UCAR;
- Website: https://www.cosmic.ucar.edu/events/cosmic-jcsda-workshop-irowg-10

2nd ROMEX Workshop:

- 25 – 27 February 2025 in Darmstadt, hosted by EUMETSAT;
- Website: https://www.eventsforce.net/eumetsat/frontend/reg/thome.csp?pageID=26230&eventID=66

IROWG ROMEX website 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, 2024

Thanks to EUMETSAT and UCAR for hosting the IROWG meetings!

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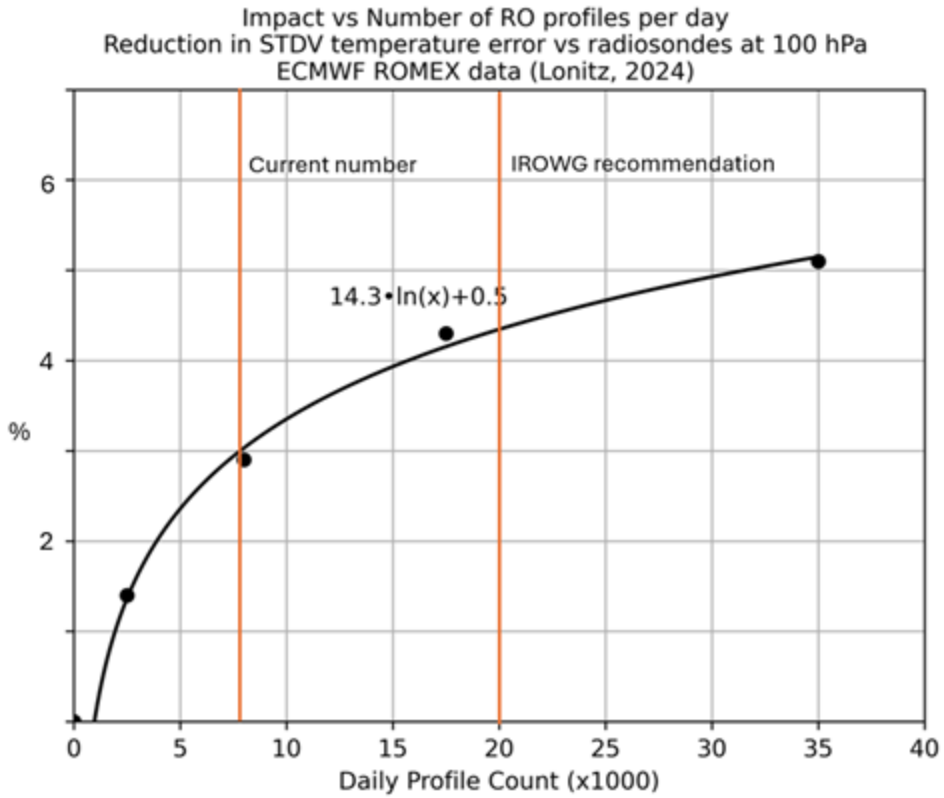
Major ROMEX conclusion

The ROMEX forecast impacts of different numbers of RO profiles up to 35,000 profiles per day (the maximum available in the experiment) in leading international NWP models support the IROWG recommendation of at least 20,000 occultations per day, preferably with uniform global and local time coverage.

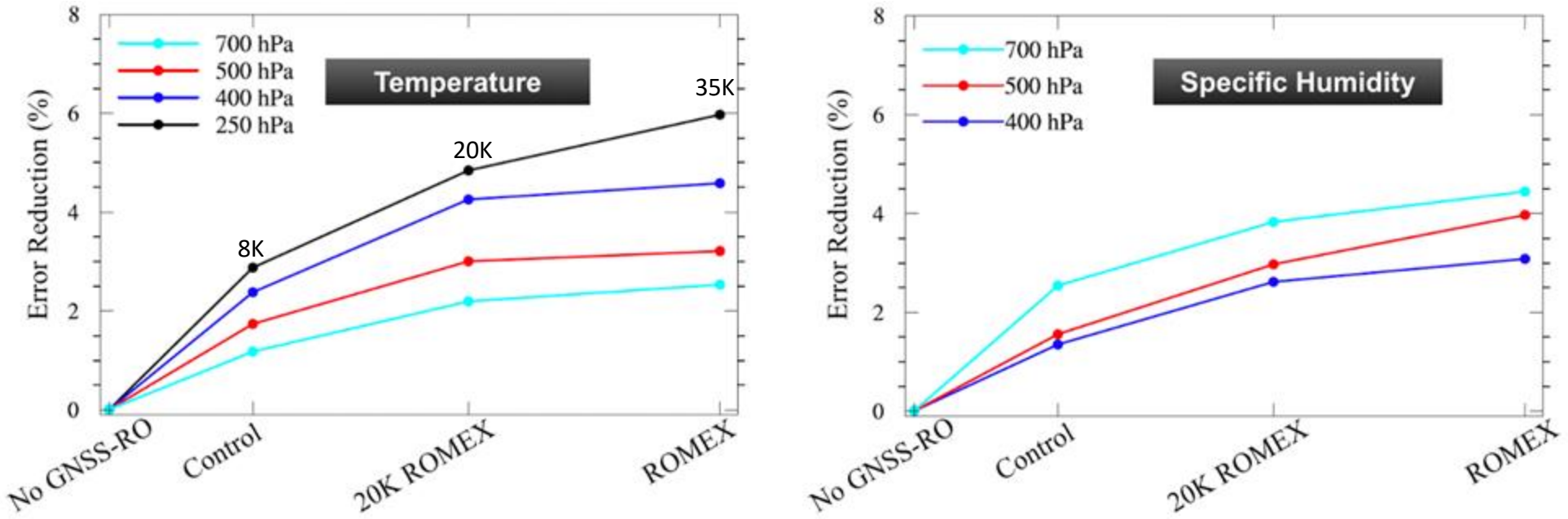
Summary of ROMEX results

- Most NWP experiments show an increasing positive impact up to the ROMEX maximum of 35K profiles per day, consistent with previous simulations, with no clear signs of saturation at this level.
- Positive impacts are seen in temperature and winds in both troposphere and stratosphere, and also in tropospheric water vapor.
- Results are based on relatively uniform global geographic coverage but limited local time coverage.
- ROMEX experiments have led to a better understanding of RO data. NWP centers are using this knowledge to improve their models and DA systems; data centres are using it to improve their processing.



Reduction of upper-level (near jet stream) temperature 12h forecast error against radiosondes in the **ECMWF** system (Lonitz, 2024).

ROMEX Results

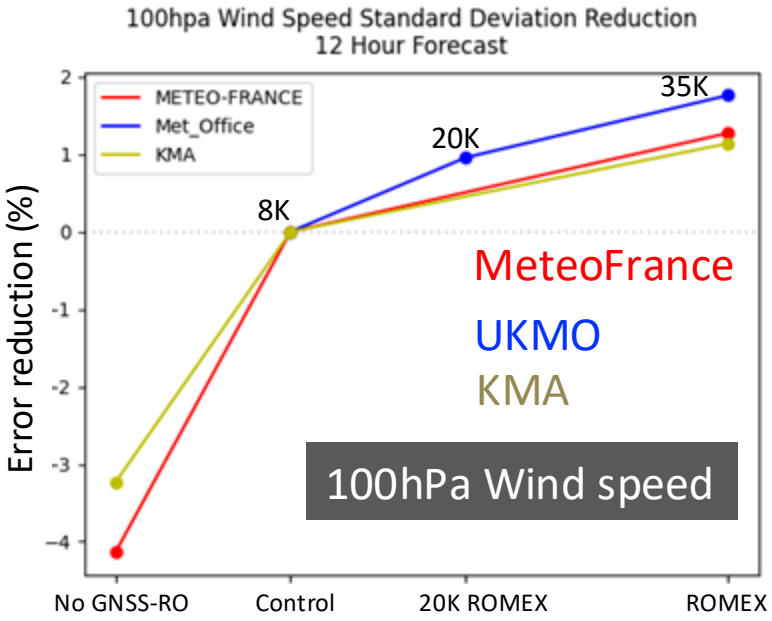


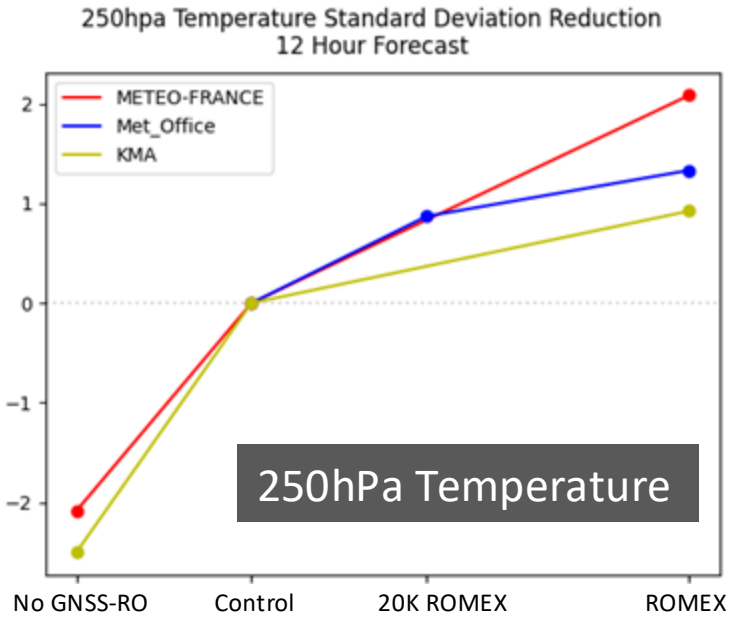
***Error** as determined by the difference of STDV between 6-hour forecast and radiosonde observations

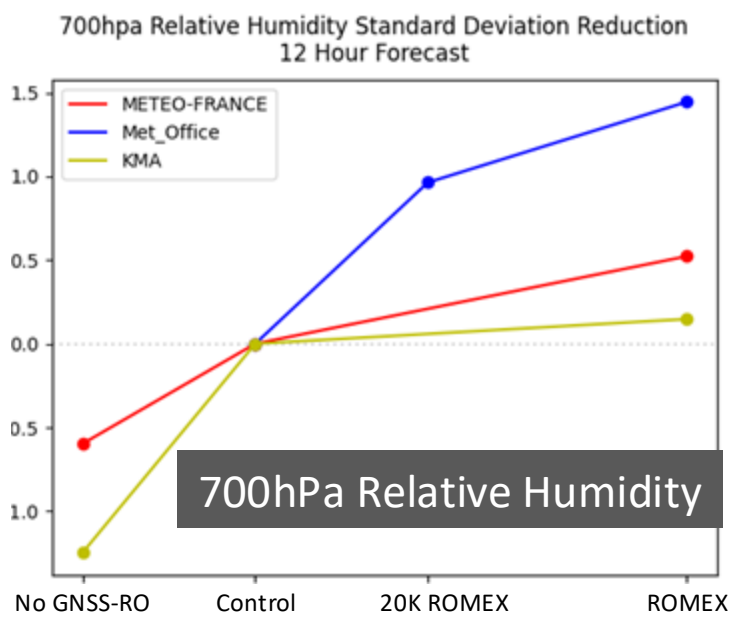
Reduction of 6h forecast errors against radiosonde in the UCAR/JCSDA JEDI assimilation experiments using NOAA's GFS forecast model.

The error is the standard deviation of the difference between 6-hour forecasts and radiosonde observations. The x-axis represents the experiment configurations: No GNSS-RO, Control (~8k RO profiles/day), 20K ROMEX (~20k RO profiles/day), and ROMEX (~35k RO profiles/day). The baseline for the error reduction is the No GNSS-RO experiment.

ROMEX Results







Reduction of 12h forecast errors against radiosonde in the experiments conducted by **UKMO, Meteo-France** and **KMA**.

Note:

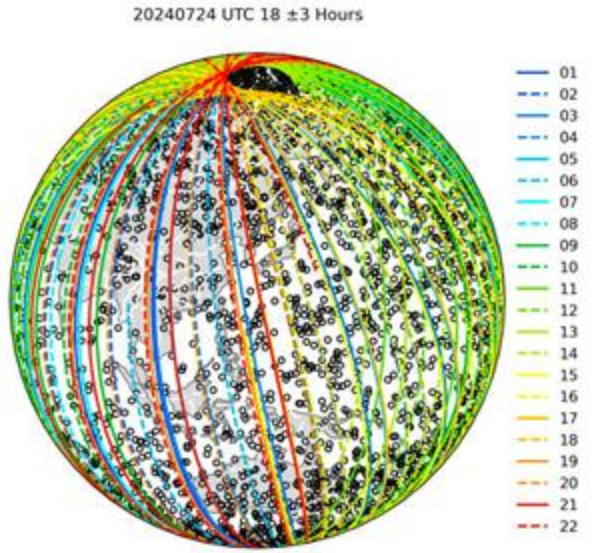
- Not all NWP centers ran No GNSS-RO and 20K ROMEX; baseline is the Control experiment (~8K profiles/day).
- Models and DA systems differ in configuration (e.g., resolution, forward operators, QC, etc.).

Further Considerations

- As for all major changes in the Global Observing System, **optimisation of data assimilation schemes is required** to use large increases in RO numbers efficiently. ROMEX experiments highlighted issues with small biases in forecasts. Researchers are investigating these, and progress is being made toward understanding and mitigating these concerns.
- ROMEX data obtained from different instruments, satellites, orbits, countries, and both public and commercial providers, demonstrates that **RO requirements can be met** with data from multiple sources.
- This mature status of all ROMEX data required validation, cross-comparisons, and, in some cases, reprocessing. Regular monitoring, verification against reference data and processing approaches will be necessary to **ensure the continued high quality** of RO data in the future.

ROMEX: Updates from Commercial missions

- Tianmu: 23 satellites in seven orbital planes, each with unique local time, generating 30,000+ RO profiles daily, including GNSS-RO & GNSS-R measurements.
- Spire: Collecting 6,000 RO profiles per day, with plans to reach 20,000 per day in 2025 through expanded satellite orbits.
- YunYao: 22 RO satellites and 2 GNSS-R satellites in 6 planes, generating 33,000 RO profiles per day.
- PlanetIQ: Providing 4,600 RO profiles per day, with an expected increase to 7,000 in 2025.

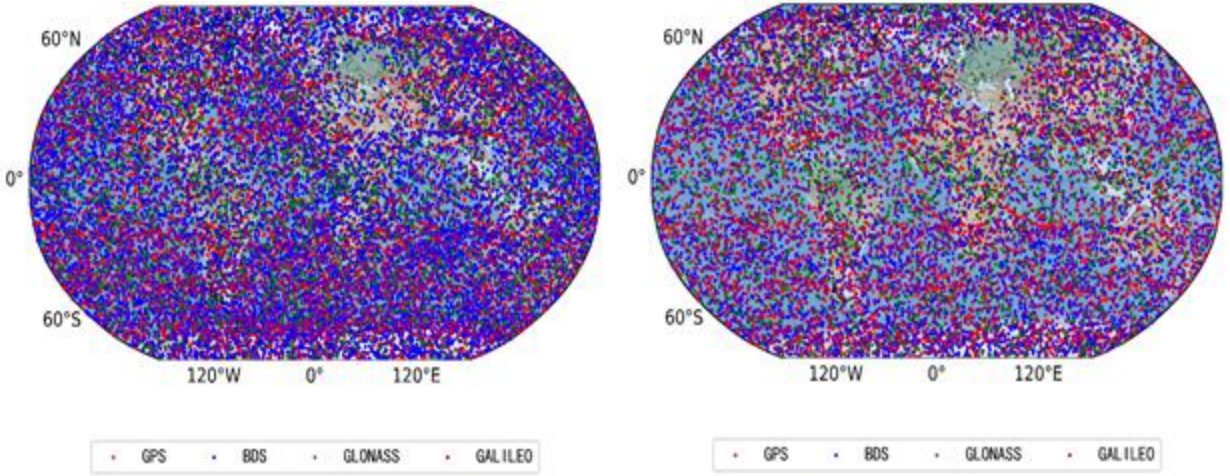


Global distributions of Tianmu 22 LEO orbits (colored curve) and RO profile location during the 6-h window on July 22, 2024.

IROWG encourages CGMS to explore expanded RO capacities and prioritize data archiving for long-term monitoring and reprocessing.

Spire GNSS-RO Satellite Orbits and Ground Stations (Jan 2025)

Yunyao data coverage for neutral atmosphere (atmprf, ~33000/day) and ionosphere (ionprf, ~17000/day)



Further Considerations

- A publicly operated and owned **backbone system, complemented by commercial RO data**, ensures maximum stability and reduces risk, providing a reference for data quality, processing and quality control.
- RO observations provide valuable information to **NWP and Space Weather**; both needs should be considered.
- For a given number of geographically uniformly distributed RO profiles per day, **uniform local time coverage** is preferable for global NWP and essential for regional NWP and space weather.
- Maximising cost-effective impact for NWP requires a **balanced observing system** of IR, MW and RO data. RO adds independent, low-biased data complementing the IR and MW observations, enhancing their effectiveness.

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Summary & plans

- ROMEX shows that increasing RO profiles up to 35,000 per day improves temperature, wind, and water vapor forecasts, with no clear sign of saturation, confirming earlier theoretical studies. ROMEX supports IROWG's recommendation of at least 20,000 occultations per day, preferably with uniform global and local time coverage.
- Further ROMEX takeaways have been discussed in slides 5, 6, 8 and 9.
- ROMEX participants will continue optimizing data assimilation using the ROMEX dataset and publish results.
- Currently, no ROMEX-2 (NWP) experiment is planned.

- ROMEX exemplifies effective collaboration within the scientific community, driven by strategic planning, agency support, and, most importantly, the commitment of data providers, processing centers, and both operational and research institutes.
- The communication along the pipeline, from data providers to users, has accelerated issue resolution and improvements, leading to enhanced data quality and better NWP impacts.

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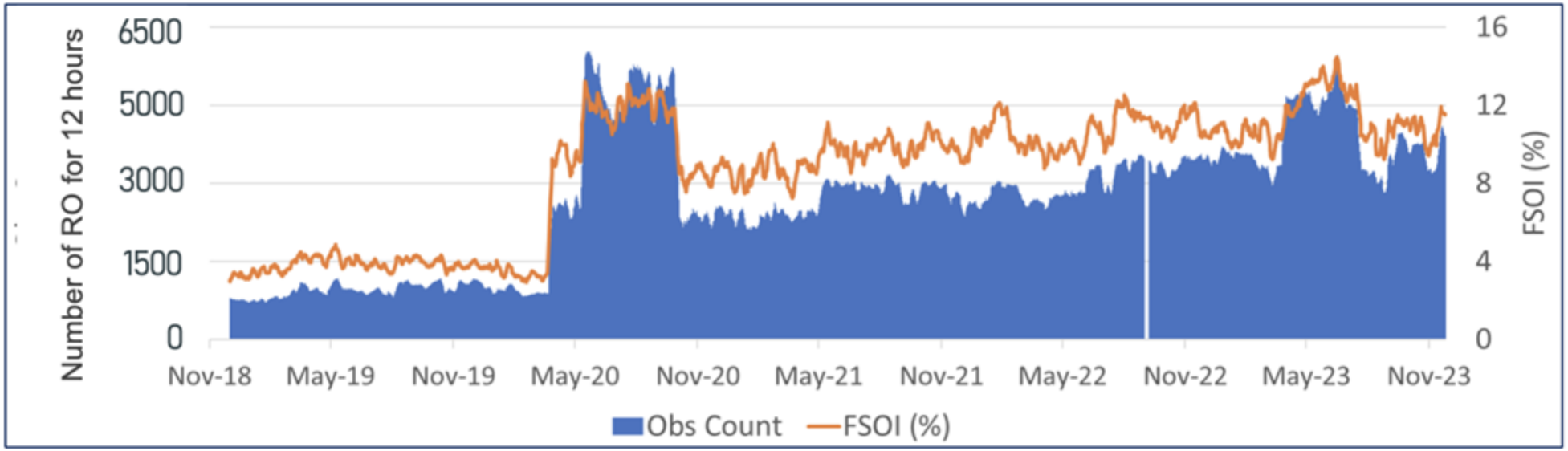
Back Up

ROMEX

- 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 a clear correlation between the number of RO observations and positive forecast impacts (Sean Healy, ECMWF)

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ROMEX Verification Exchange (In progress)

		NOAA-STAR HAFS	NCEP	Met_Office	DWD	METEO-France	KMA	CWA	GMAO NASA	JCSDA
Ref	Ob		X	X		X	X			X
	An	X		X	X		X			
	ECMWF/ERA5		X (ECMF)	X (ECMF)	X (ERA5)	X (ECMF)	X (ECMF)	X (ECMF)	X (ERA5)	X (ECMF)
Var	Geo hgt	X	X	X	X	X	X	X	X	
	Temp	X	X	X	X	X	X	X	X	X
	W speed		X	X	X	X	X	X	X (sep u/v)	X
	Rel H		X (ob only)	X	X	X	X		X (q)	X (q)
	MSLP			X	X					
Score	ME	X	X	X	X	X	X	X	X	X
	MAE			X	X		X		X	X
	RMSE	X	X	X	X	X	X	X	X	X
	StdDev			X	X	X	X		X	X
Exp	No GNSS-RO		X			X	X			X
	Control	X	X	X	X	X	X	X	X	X
	20k ROMEX			X						X
	ROMEX w/oYunyao, Fengyun, Tianmu	X	X							
	ROMEX			X	X	X	X	X	X	X
Time	0	X	X	X	X	X		X	X	X
	6	X		X	X					X
	12	X	X	X	X	X	X		X	X
	18	X		X	X					
	24	X	X	X	X	X	X	X	X	X
	30	X		X	X					
	36	X	X	X	X	X	X		X	X
	42	X		X	X					
	48	X	X	X	X	X	X	X	X	X

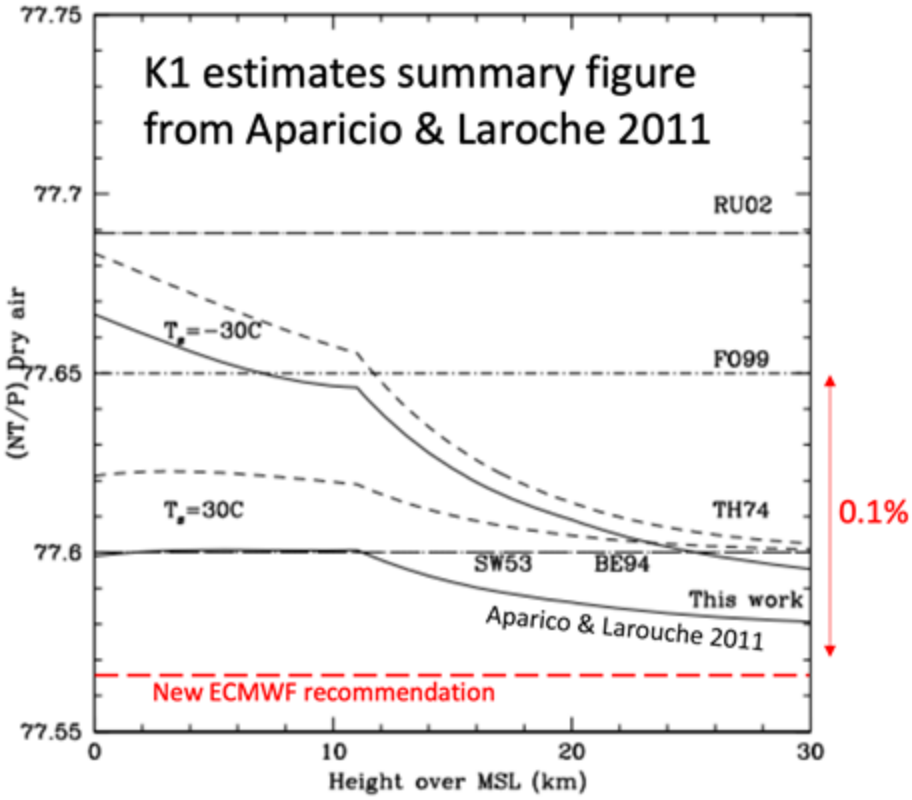
Systematic deviations between models and observations

Systematic deviations (3-5 m) of geopotential height (GH) between model forecasts and in-situ observations were identified during the First ROMEX Workshop.

Some centers have mitigated this issue through limited optimizations in data processing and assimilation forward operators, which is a common practice for assimilating any new/additional data types.

However,

- The reference (from radiosonde) GH precision varies: “Between 1000 and 700 hPa the reporting is to the nearest metre, but at 500 hPa and higher standard levels the reporting is to the nearest 10 m” (B. Ingleby, An assessment of different radiosonde types 2015/2016, ECMWF Technical Memorandum, 2017, 10.21957/0nje0wpsa). – The discovered GH deviation or “biases” are smaller than the precision of radiosonde measurements, raising the possibility that they are not true systematic biases.



- ECMWF and other centers have also proposed a ~0.1% adjustment to the refractivity calculation dry constant, which helps alleviate these “biases.” This adjustment is possibly within the range of uncertainty discussed in previous studies.