



# Impacts from Assimilating Large Volumes of GNSS RO Observations during ROMEX in NASA's Global Earth Observing System

Michael J. Murphy<sup>1,2</sup>, Mohar Chattopadhyay<sup>1,3</sup>, Amal El Akkraoui<sup>1</sup>,  
Ronald Gelaro<sup>1</sup>, Richard A. Anthes<sup>4</sup>, & Jianjun Jin<sup>1,3\*</sup>

<sup>1</sup>Global Modeling and Assimilation Office, NASA Goddard SFC

<sup>2</sup>GESTAR-II, University of Maryland Baltimore County

<sup>3</sup>Science Systems and Applications, Inc

<sup>4</sup>University Corporation for Atmospheric Research

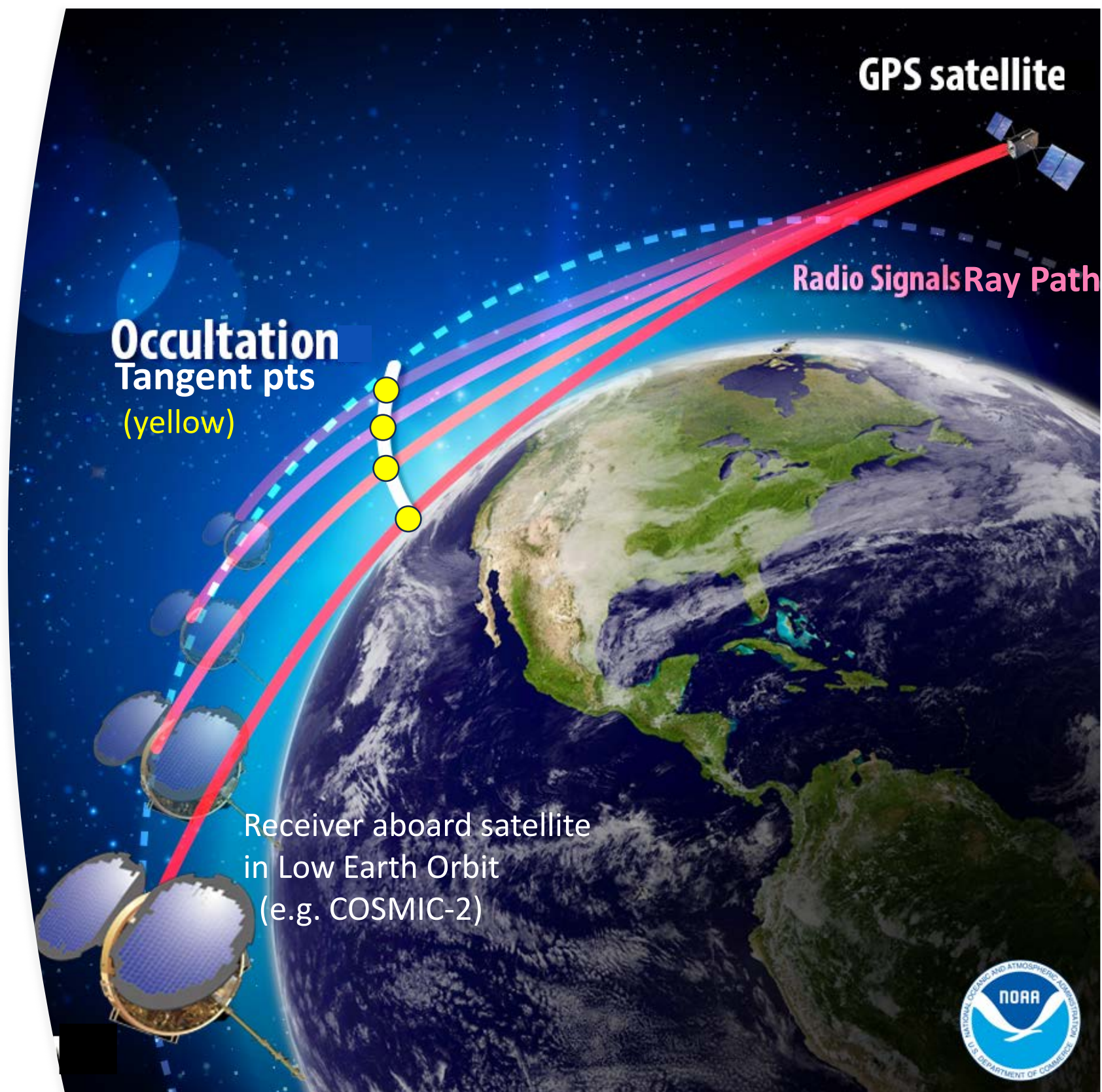
\*Currently at NOAA/NCEP/EMC

AMS Annual Meeting 2025  
New Orleans, Louisiana  
15 January 2025



- Global navigation satellite system (GNSS) uses L-band radio frequencies
  - 1.2276 & 1.57542 GHz
- In GNSS Radio Occultation (RO) the delay of the GNSS signal at a receiver that is setting relative to the emitting GNSS satellite is measured
- The GNSS-RO variables commonly used in numerical weather prediction (NWP) are the *Bending Angle* of the ray from which the *Refractivity* (N) of the atmosphere can be derived:

$$N = (n - 1) \cdot 10^6 = k_1 \frac{P}{T} + k'_2 \frac{e}{T^2}$$



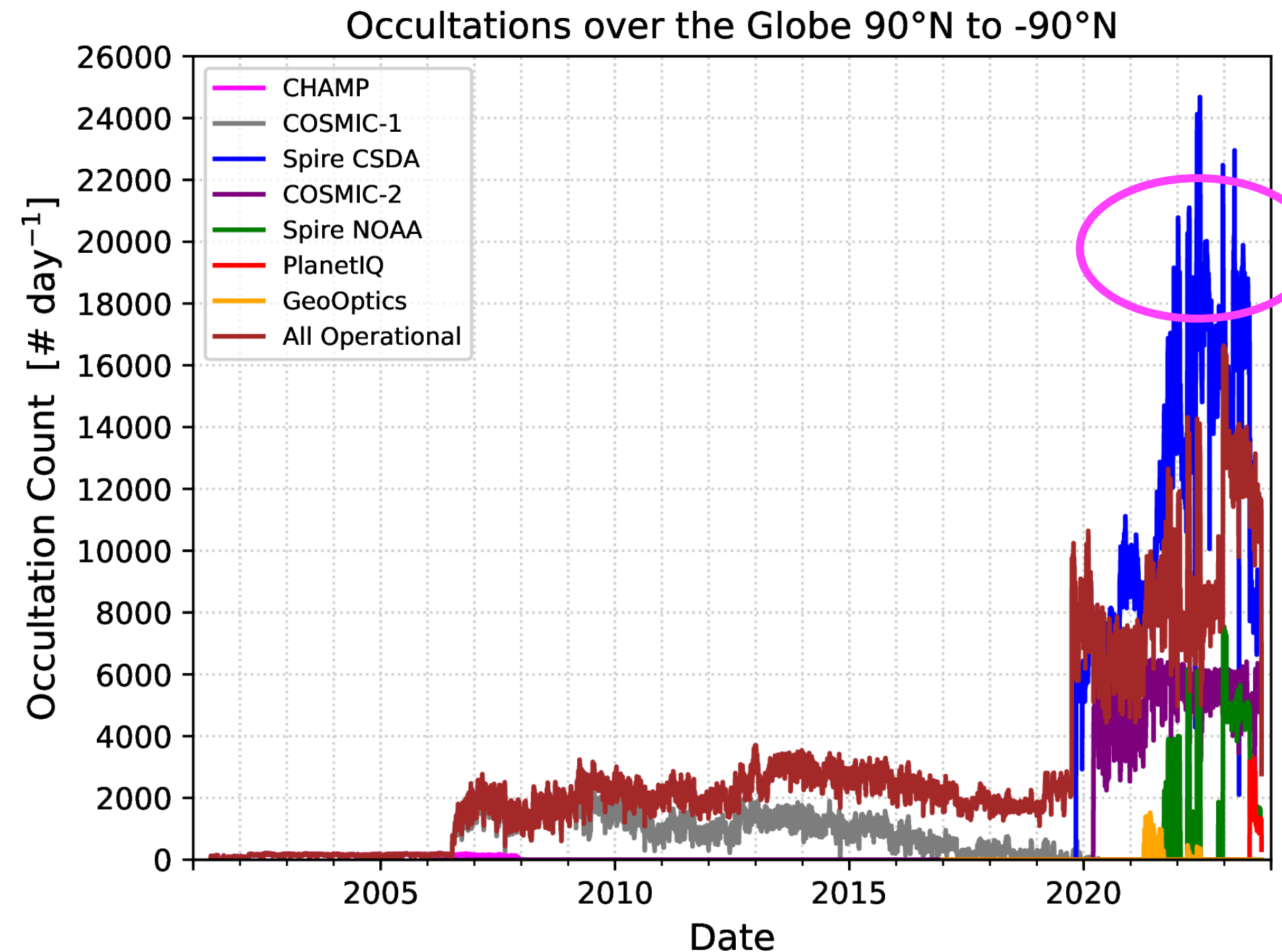
## The RO Modeling Experiment (ROMEX)

The total volume of RO observations assimilated into operational NWP systems has greatly increased in recent years.

- Much of this increase has been from constellations of commercial smallsats
- Only a small fraction of the available commercial RO observations have been purchased and used by NWP centers to date.

**Hypothesis:** Assimilation of the full volume of commercial GNSS-RO observations will improve operational NWP forecasts/analyses

- To test this ROMEX uses as close to the full volume of commercial RO observations available as possible
- Multiple NWP centers are participating



## Design of Numerical Experiments

1. ROMEX Control Exp using the current suite of operationally assimilated GNSS-RO observations except commercial RO
2. ROMEX Exp adds to the Control all available commercial RO

## Model Configuration

- NASA's Global Earth Observing System (GEOS) Atmospheric Data Assimilation System (ADAS) version 5.30.3
- 4D Hybrid EnVar Data Assimilation
- Resolution of 25 km in horizontal & 72 layers in vertical
- Primary model initialization at 00 & 12 UTC (5 day forecasts)
- Additional model initialization at 06 & 18 UTC (shorter forecasts)

## Time period

- Sept. through Dec. 2022

ROMEX Data Volume (estimated)			For 20220906	
Mission	RO/day	Control	Control	Experiment
GRAS	1,200	y	1194	1194
COSMIC-2	6,000	y	5220	5220
Spire	17,000	n		17337
GNOS	2,100	n		2080
PlanetiQ	3,200	n		2900
Yunyao	6,200	n		4165
Tianmu	100	n		305
KOMPSAT-5	300	y	175	175
PAZ	200	y	124	124
TerraSAR-X	100	y	120	120
TanDEM-X	100	y	93	93
Sentinel-6	800	y	838	838
Sum control	8700	y	7771	
ROMEX supplemental	28600	n		26782
Sum ROMEX	37300	n		34553

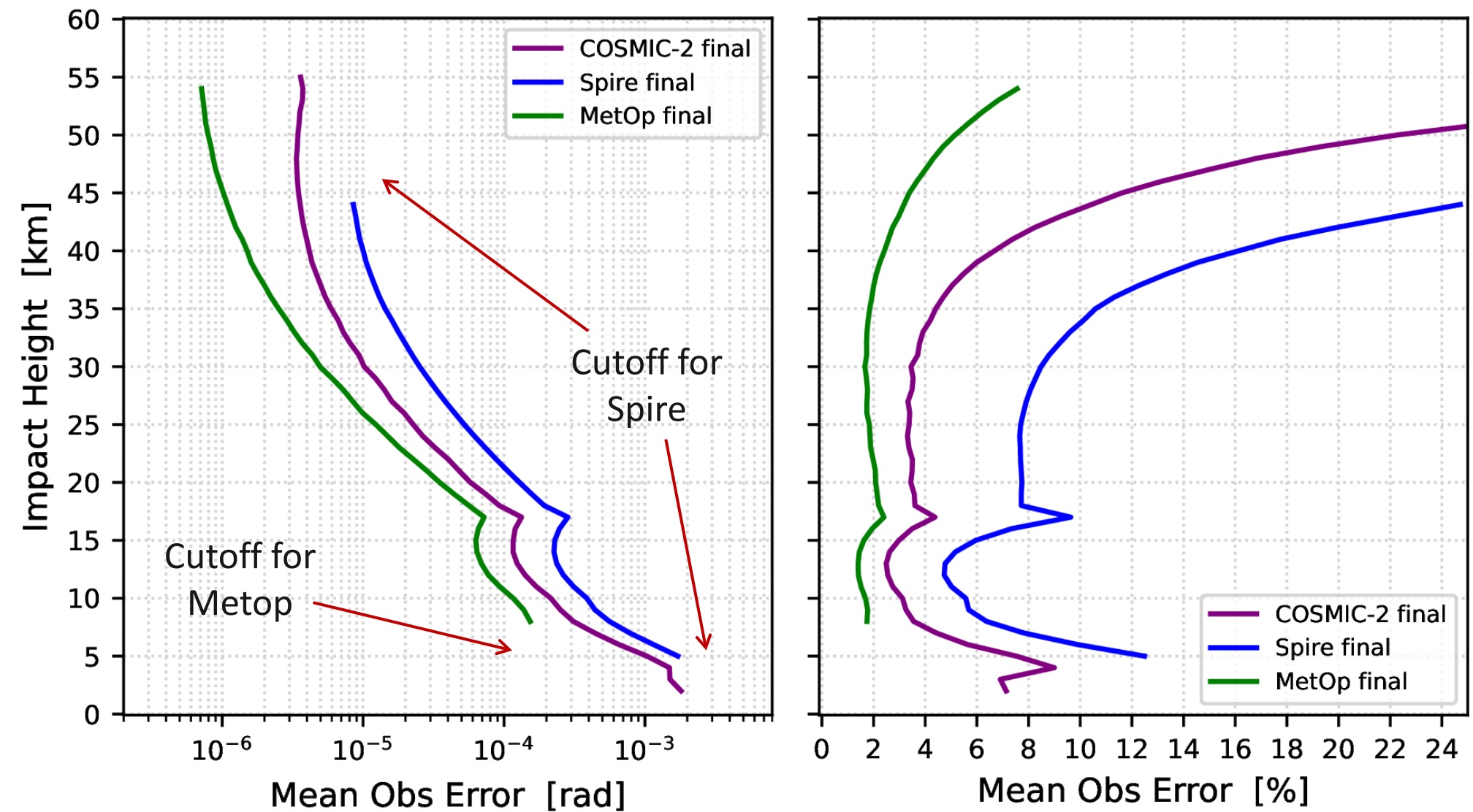
## The Current obs uncertainty model in GEOS

- Based on fit to estimated error using Desroziers method
- Varies by impact height, latitude, & processing center
- Inflated obs errors (factor of 2) for commercial constellations
- “superrobbing” inflated by  $N^{1/2}$  where N is the number of RO obs in a single layer

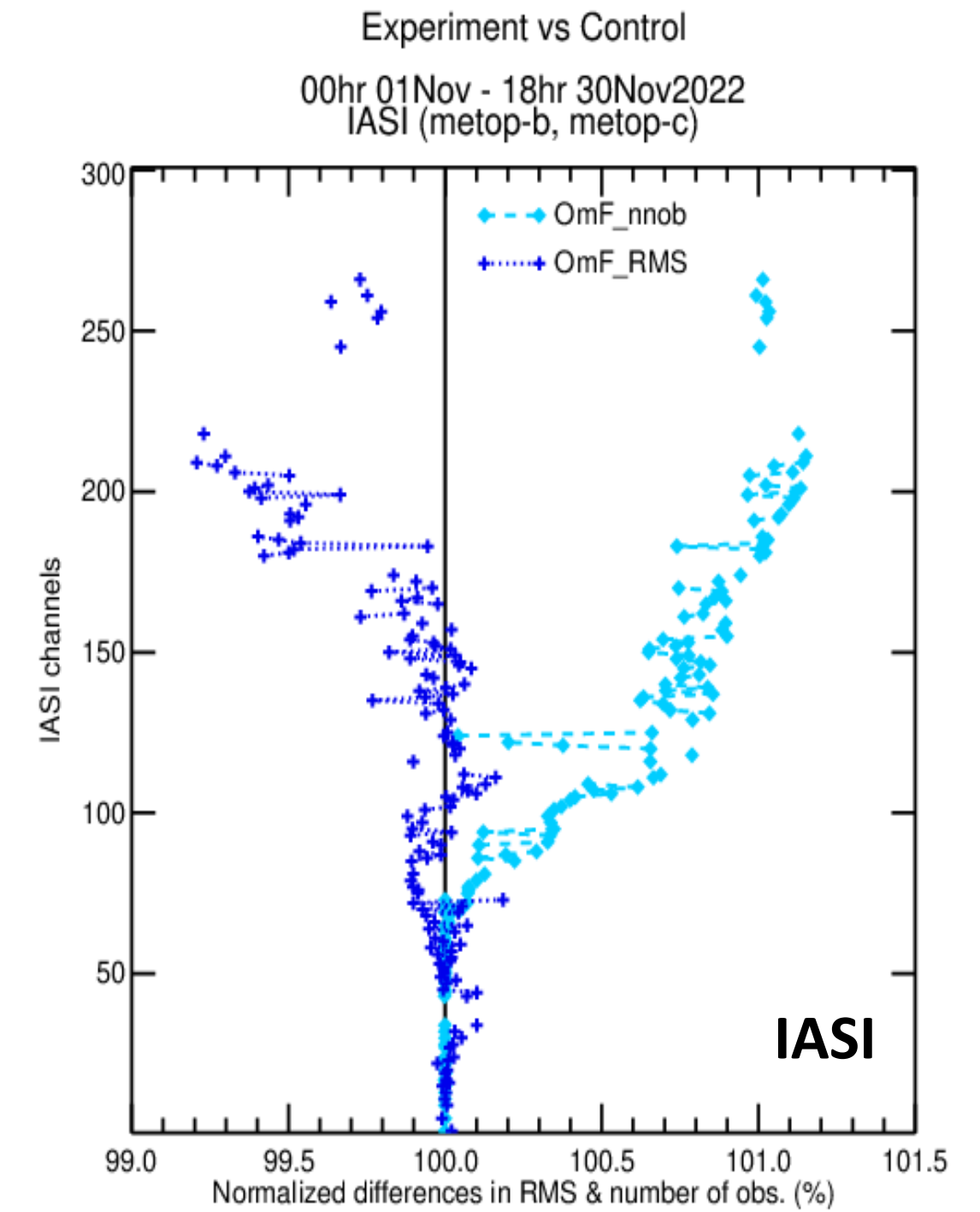
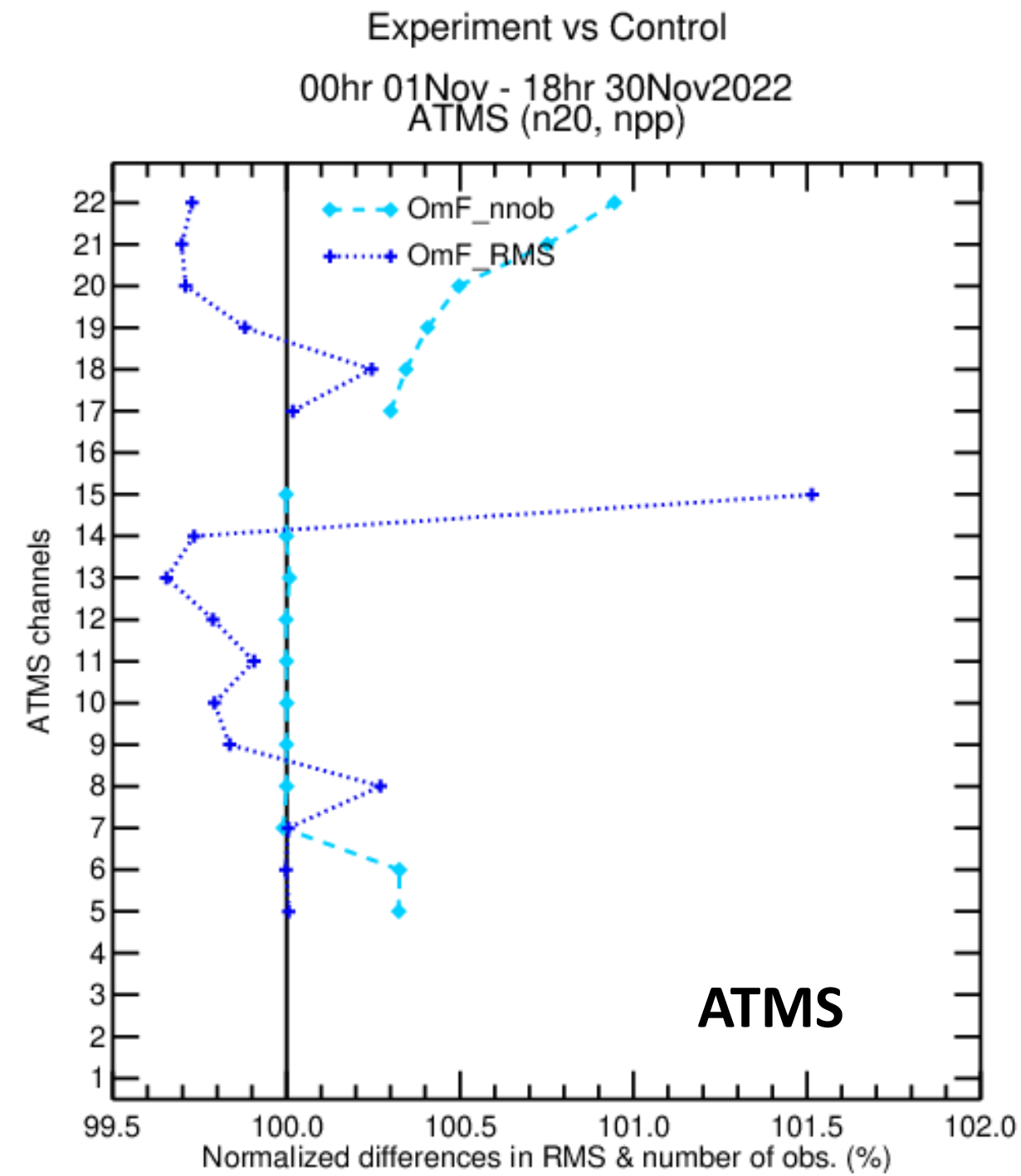
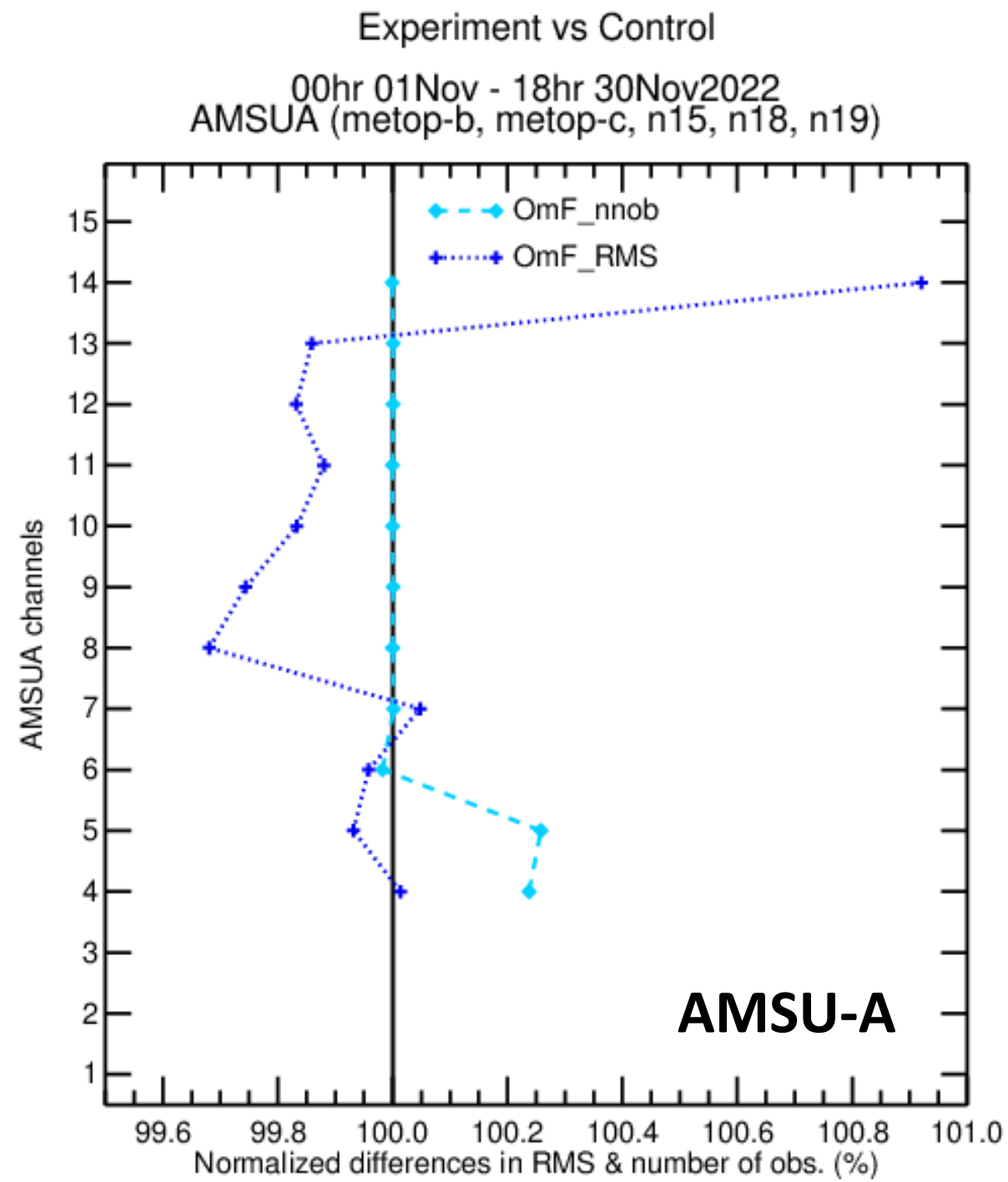
## The Current Quality Control method in GEOS includes:

- Gross error check
  - innovations/E > 10
- Statistical check:
  - OMB/O > X  $\sigma$  ( $\sigma$  varies with 3 regions, transition zones +/- 1 km between regions.  $\sigma$  specified via statistical fit to observed  $\sigma$  based on two months of data)
- Mission specific height cutoffs
  - No MetOp below 8 km
  - No commercial below 5 km & above 45 km

All Occultations over 40°N to -40°N  
at 0000 UTC 2021-12-12



Fit to observations  
Obs minus short-term forecast (OmF)

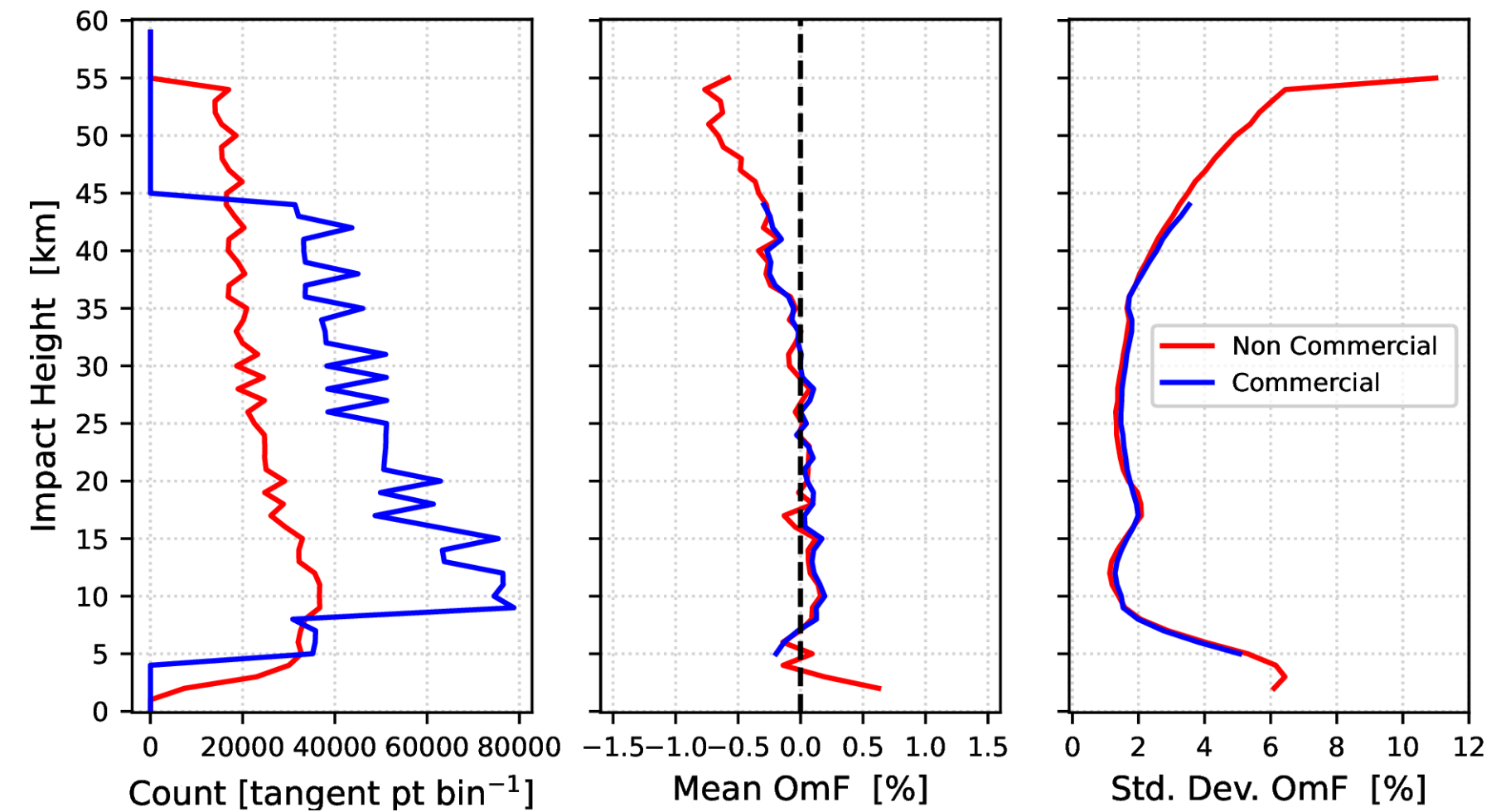
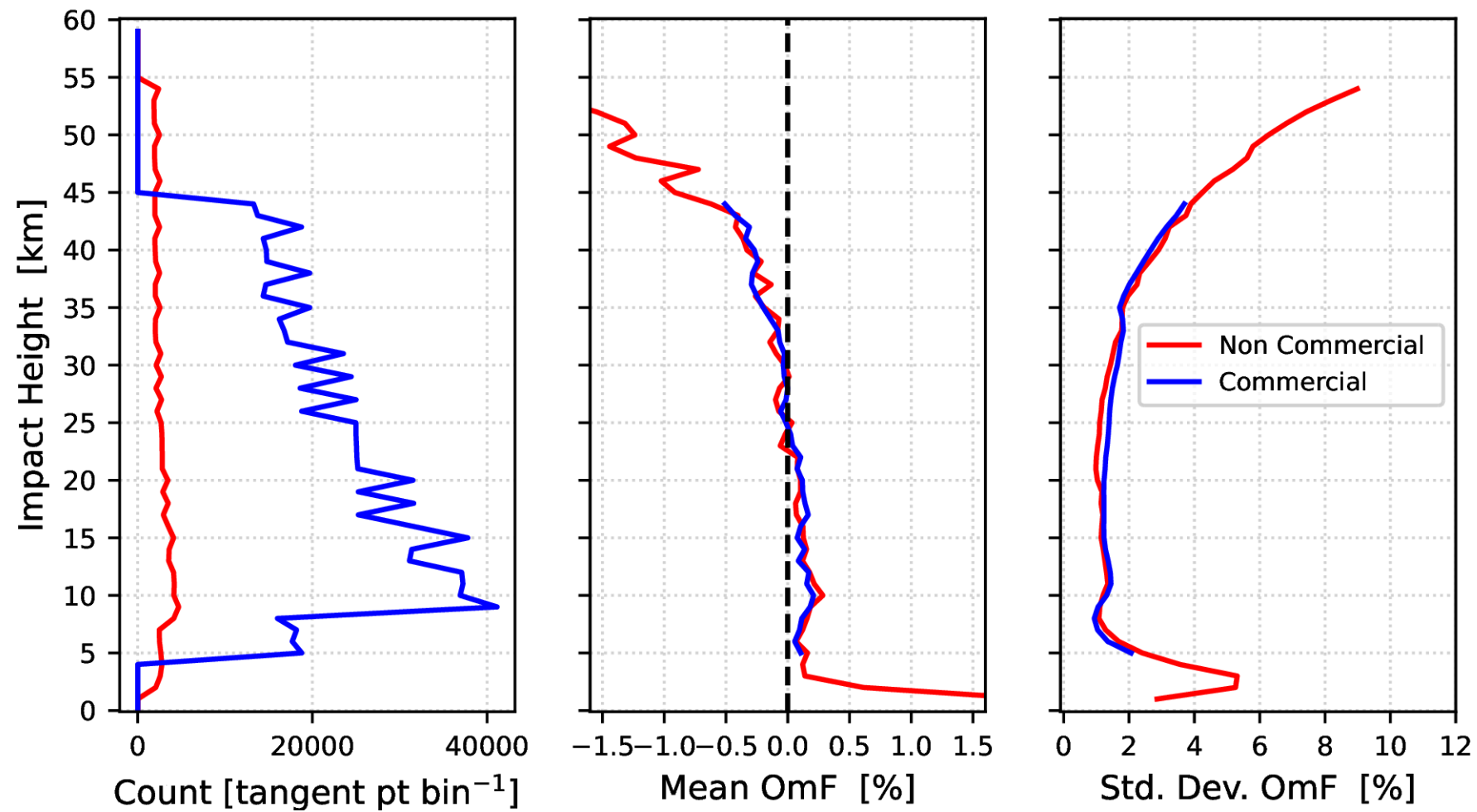


Reduced RMSE in all instruments for most channels indicating improvement for ROMEX Experiment.

For hyperspectral IR (IASI, rightmost panel) RMSE reduced for moisture sensitive channels (180-206) only

### Extra tropics (Southern)

### Tropics (40N to 40S)



Statistics from OmF similar between Commercial & Public RO Missions  
 Example from a single day (06 September 2024)

# Impact on GEOS forecasts

- ROMEX experiment shows broad improvements to forecast skill in Tropics
- Issues with Geopotential height also found at other NWP centers

### Legend

- ▲ far better, significant (99.99% confidence)
- △ better, significant (99% confidence)
- ▤ slightly better, significant (95% confidence)
- no significant difference
- ▥ slightly worse, significant (95% confidence)
- ▽ worse, significant (99% confidence)
- ▼ far worse, significant (99.99% confidence)

Tropics											
Variable	Pressure Level	COR					RMS				
Forecast Day		1	2	3	4	5	1	2	3	4	5
Geopotential Height	10	▼	■	■	■	■	▲	▲	▲	▲	▲
	70	▤	■	■	■	■	▲	▤	■	■	■
	100	▤	■	▤	▤	■	▲	▲	▲	▲	▲
	250	▤	▲	▲	▲	▲	▤	▲	▲	▲	▲
	500	■	▤	▤	▲	▲	▼	▼	▼	▼	▼
	700	■	▥	■	■	■	▼	▼	▼	▼	▼
	850	■	▥	■	■	■	▼	▼	▥	▥	▥
SLP	1000	△	■	■	■	■	▥	▼	▼	▼	▼
Specific Humidity	10	■	■	■	■	■	▲	▲	▲	▲	▲
	70	▲	▲	▲	▲	▲	■	▤	▤	▤	▤
	100	■	■	■	■	■	■	■	■	■	▲
	250	■	■	■	▤	■	△	■	▤	▤	▤
	500	▲	▲	▲	▤	▲	▤	▲	■	■	▲
	700	▲	▲	▲	▤	▤	▲	▲	▲	▲	▲
	850	▤	■	▤	▤	▤	△	▤	■	■	■
Temperature	10	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	70	▲	▲	▲	▤	■	▲	▲	▲	▲	▲
	100	▤	▤	▲	■	■	■	▼	▼	▼	▼
	250	▲	▲	■	▤	■	▲	▲	▲	▲	▲
	500	▲	▲	▲	▤	▤	▲	▲	▲	▲	▤
	700	▲	▤	▲	▤	▤	■	▤	▲	▲	▲
	850	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
U-Wind	10	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼
	70	△	▤	■	■	■	■	■	■	■	■
	100	▤	▤	■	■	■	▲	▲	▲	▲	▲
	250	▲	▤	▲	▤	▤	▲	▤	▤	▤	▤
	500	■	▲	▲	▲	▲	■	▤	▲	▲	▲
	700	▲	▲	▲	▲	▲	▲	▤	■	▲	▲
	850	■	■	■	▤	■	■	■	■	■	■
V-Wind	10	▲	▲	▲	▲	▲	▲	▲	▤	▲	▲
	70	▲	▤	▤	■	■	▲	▤	■	■	■
	100	▲	▤	▤	▤	▤	▲	▲	▲	▤	▤
	250	▲	▤	■	▤	■	▲	▤	■	■	▤
	500	▲	▤	▤	▲	■	▲	▤	▤	■	▤
	700	▲	▲	▲	▤	▤	▲	▲	▤	▤	▤
	850	■	■	■	▤	■	■	■	■	■	■

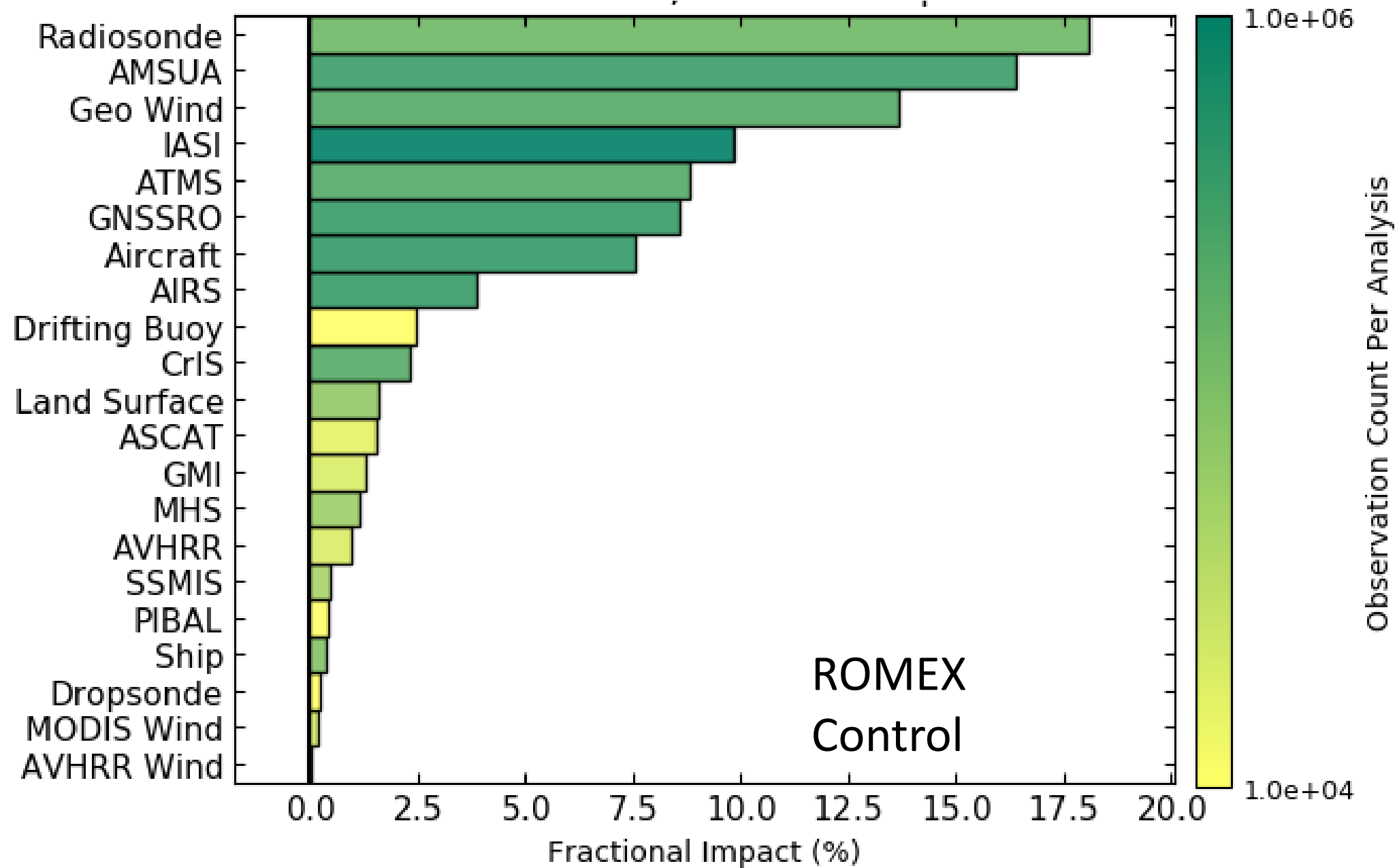
- ROMEX experiment shows improvements to forecast skill in southern hemisphere
- Modest improvement in northern hemisphere at longer forecast ranges.

### Legend

- ▲ far better, significant (99.99% confidence)
- △ better, significant (99% confidence)
- ▤ slightly better, significant (95% confidence)
- no significant difference
- ▥ slightly worse, significant (95% confidence)
- ▼ worse, significant (99% confidence)
- ▼ far worse, significant (99.99% confidence)

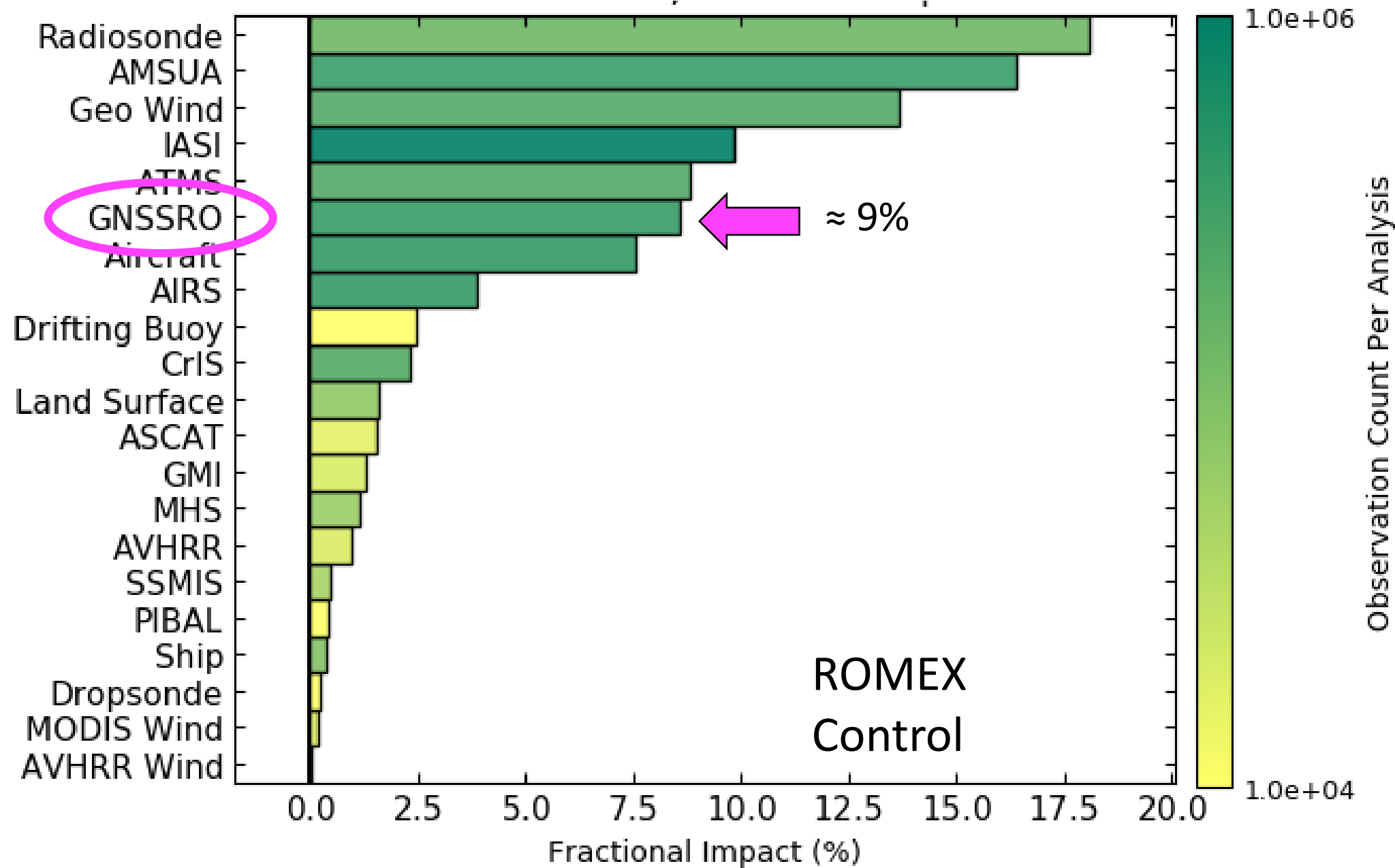
Northern Hemisphere											
Variable	Pressure Level	COR					RMS				
Forecast Day		1	2	3	4	5	1	2	3	4	5
Geopotential Height	10	■					▲▲▲▲▲				
	70	▥					▼▼▼▼▼				
	100	■					▼▼▼▼▼				
	250	■					▼				
	500	▤					▼				
	700	■					▼				
SLP	850	■					▼				
	1000	▼					▼				
Specific Humidity	10	▤▲▲▲▲					▲▲▲▲▲				
	70	▥▥▥▥▥					▤				
	100	▤▲▲					▲▲▲				
	250	▤					▤				
	500	▤▲					▤				
	700	▤▲					▲▲▲				
Temperature	850	▤▲▲					▤▲▲				
	10	▲▲▲▲					▲▲▲▲				
	70	▲▲▲▲					▲▲▲▲				
	100	▲▲▲					▲▲▲				
	250	▲▲					▲				
	500	■					▲				
U-Wind	700	▤					▤				
	850	▤					▤				
	10	▲▲▲▲					▲▲▲▲				
	70	▲▲					▲▲				
	100	▲					▲				
	250	▤					▤				
V-Wind	500	▤					▤				
	700	▤					▤				
	850	▤					▤				
	10	▲▲▲					▲▲▲				
	70	▲▲					▲▲				
	100	▲					▲				

Southern Hemisphere											
Variable	Pressure Level	COR					RMS				
Forecast Day		1	2	3	4	5	1	2	3	4	5
Geopotential Height	10	▲▲▲					▲				
	70	▼					▼▼▼				
	100	■					▼▼▼				
	250	▤					▤				
	500	▤					▤				
	700	■					▼				
SLP	850	▼					▼				
	1000	▼▼▼					▼▼▼				
Specific Humidity	10	▼▼▼▼▼					▲▲▲				
	70	▼▼▼▼▼					▼▼▼▼▼				
	100	▼▼▼▼▼					▼▼▼▼▼				
	250	▤▲					▤▲				
	500	▤▲					▤▲				
	700	▤▲					▤▲				
Temperature	850	▲▲▲▲					▲▲▲▲				
	10	▲▲▲▲					▲▲▲▲				
	70	▲▲▲▲					▲▲▲▲				
	100	▲▲▲					▲▲▲				
	250	▲▲					▲▲				
	500	▲					▲				
U-Wind	700	▤					▤				
	850	▤					▤				
	10	▲▲▲▲					▲▲▲▲				
	70	▲					▲				
	100	▲					▲				
	250	▲▲▲					▲▲▲				
V-Wind	500	▤					▤				
	700	▤					▤				
	850	▤					▤				
	10	▲▲▲▲					▲▲▲▲				
	70	▲▲					▲▲				
	100	▲					▲				



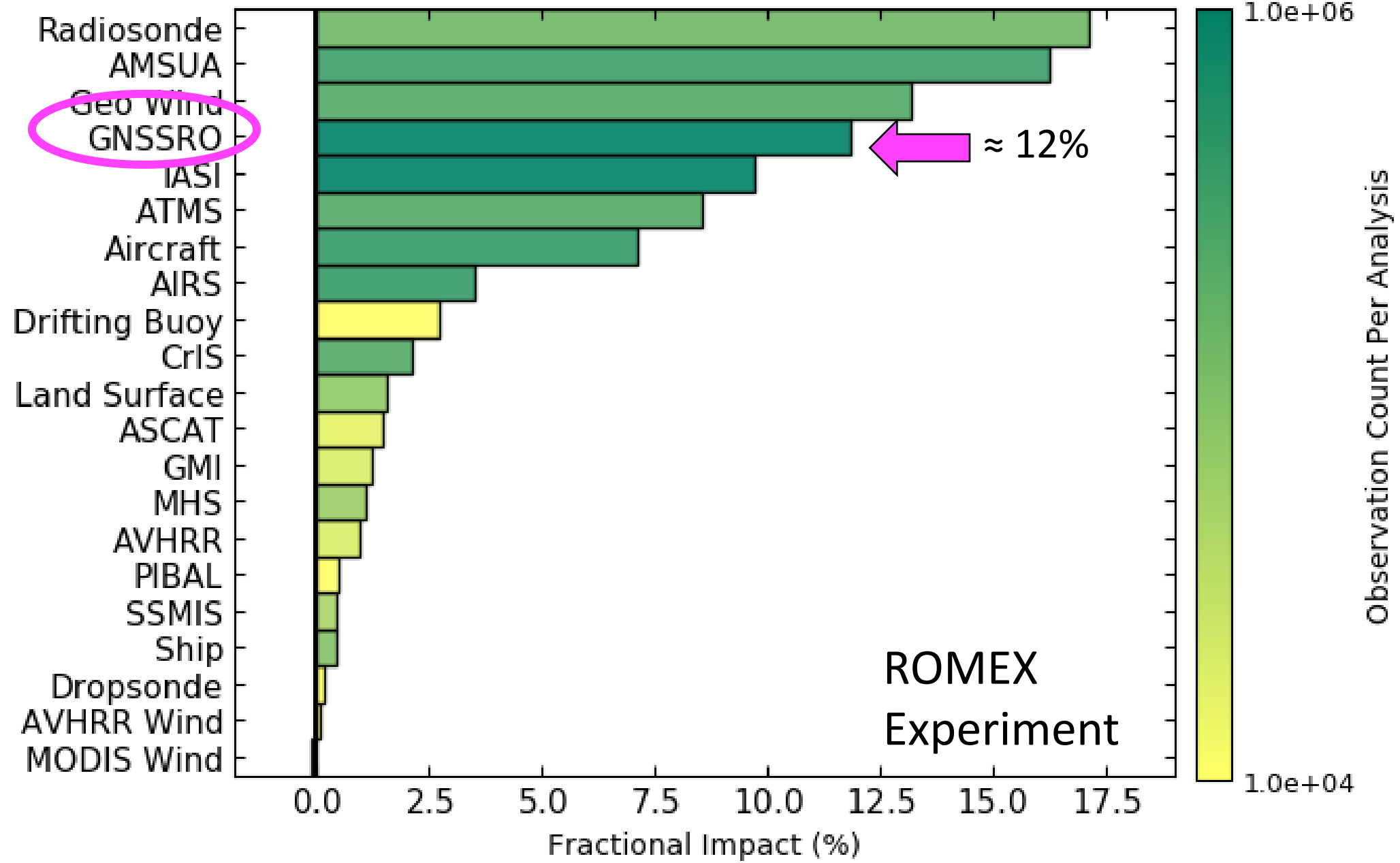
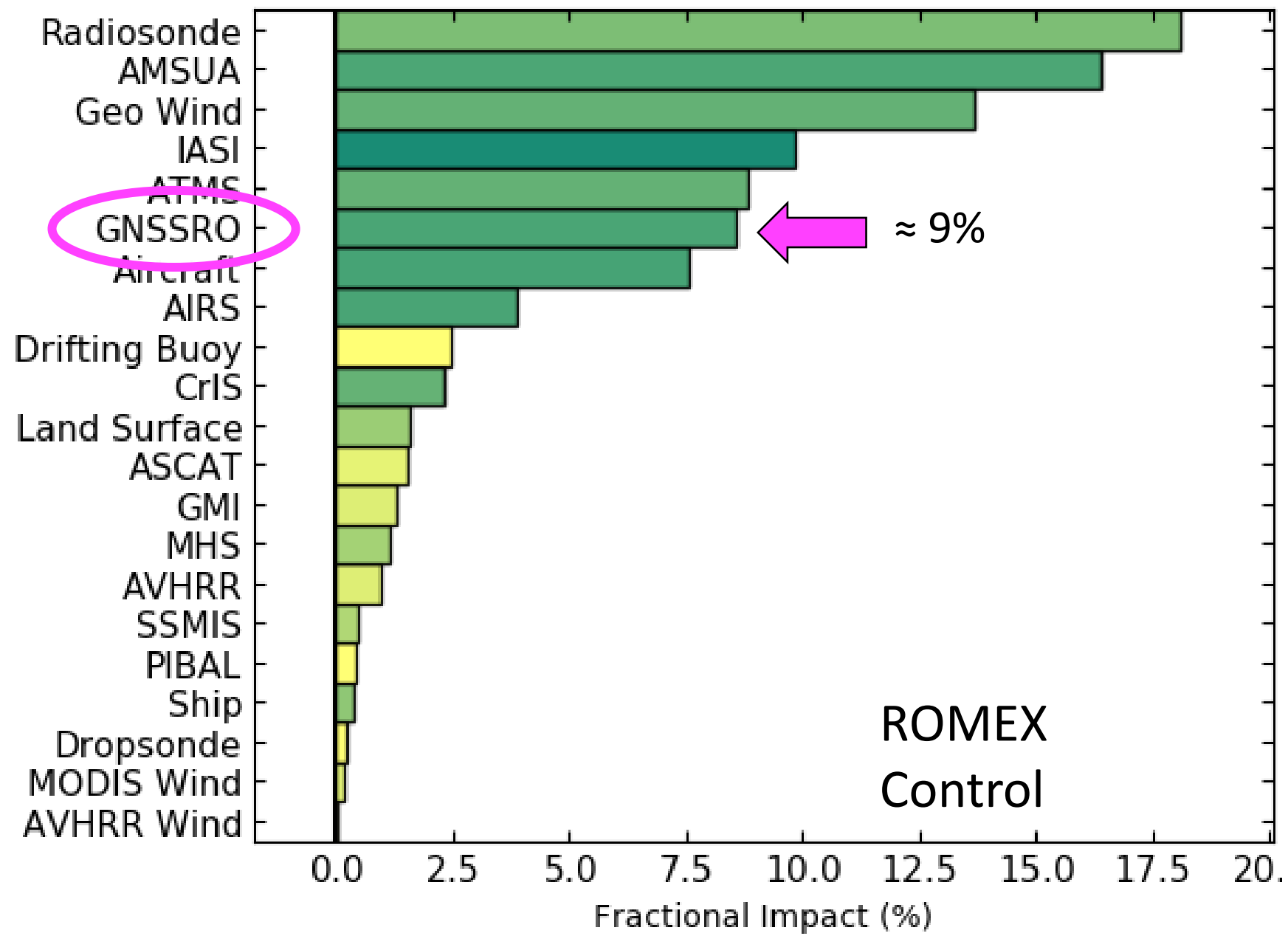
## Forecast Sensitivity-based Observation Impacts (FSOI)

- Utilizes the components of a variational DA system
- Impact is on accuracy of short-term forecast
- Computationally inexpensive (relatively)



## Forecast Sensitivity-based Observation Impacts (FSOI)

- Utilizes the components of a variational DA system
- Impact is on accuracy of short-term forecast
- Computationally inexpensive (relatively)



Increased fractional impact for ROMEX experiment with assimilation of high-volume commercial RO

The ROMEX commercial GNSS-RO obs have similar quality as public RO missions as indicated by short range forecast (OmF) statistics

- Lower troposphere excluded from comparison

Assimilation of the large volume of ROMEX supplemental commercial GNSS-RO leads to improved forecasts out to 5 days compared to the Control experiment

- Increased correlations and decreased RMS
- Found broadly for temperature, winds, & tropospheric humidity

Assimilation of the ROMEX commercial RO leads to issues with geopotential height

- Strongest negative impact on the Tropics
- Degradation of geopotential heights also found by other NWP centers

Ongoing and future work at GMAO is to determine the impact of different observation uncertainties & QC method for RO

The End

Contact:  
Michael Murphy  
[mjmurphy@umbc.edu](mailto:mjmurphy@umbc.edu)