Applications of RO data (L1B and L2) in NWP

Sean Healy and Axel Von Engeln

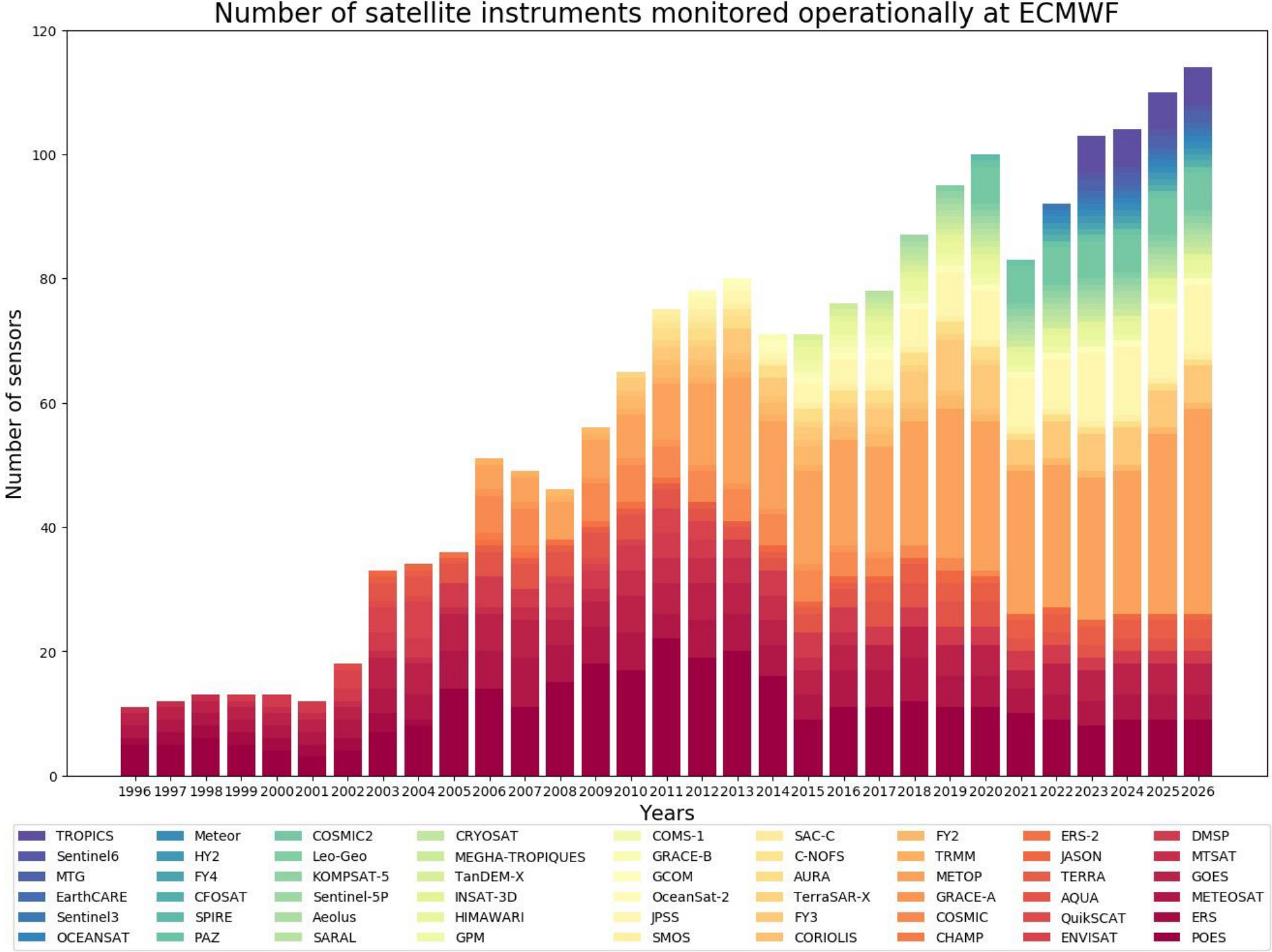
October 28, 2021

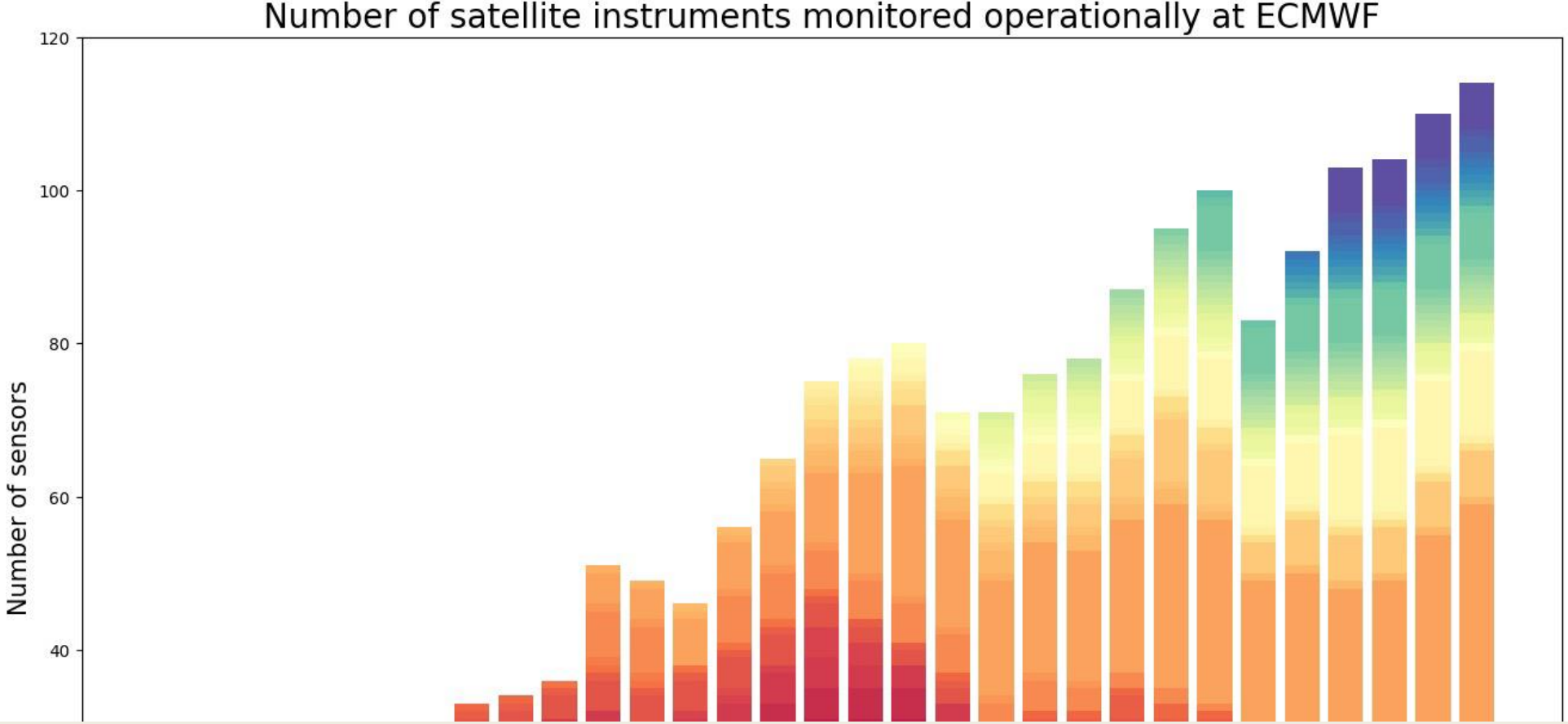
Acknowledge: **Niels Bormann** for providing OSE results

ECMWF EUMETSAT EUMETSAT ROM SAF RADIO OCCULTATION METEOROLOGY

Outline

- Evolution of satellite numbers since 1990s
- **Recap**: GNSS-RO geometry/information content
- Recent observing system experiments (Niels Bormann) that demonstrate the current contribution of GNSS-RO in the ECMWF NWP system
- Forecast Sensitivity to Observation Impact (FSOI) time series
- Use of level 2 data
- Summary


Number of satellite instruments monitored operationally at ECMWF
Number of sensors
0
20
40
60
80
100
120
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026
Years
TROPICS
Sentinel6
MTG
EarthCARE
Sentinel3
OCEANSAT
Meteor
HY2
FY4
CFOSAT
SPIRE
PAZ
COSMIC2
Leo-Geo
KOMPSAT-5
Sentinel-5P
Aeolus
SARAL
CRYOSAT
MEGHA-TROPIQUES
TanDEM-X
INSAT-3D
HIMAWARI
GPM
COMS-1
GRACE-B
GCOM
OceanSat-2
JPSS
SMOS
SAC-C
C-NOFS
AURA
TerraSAR-X
FY3
CORIOLIS
FY2
TRMM
METOP
GRACE-A
COSMIC
CHAMP
ERS-2
JASON
TERRA
AQUA
QuikSCAT
ENVISAT
DMSP
MTSAT
GOES
METEOSAT
ERS
POES



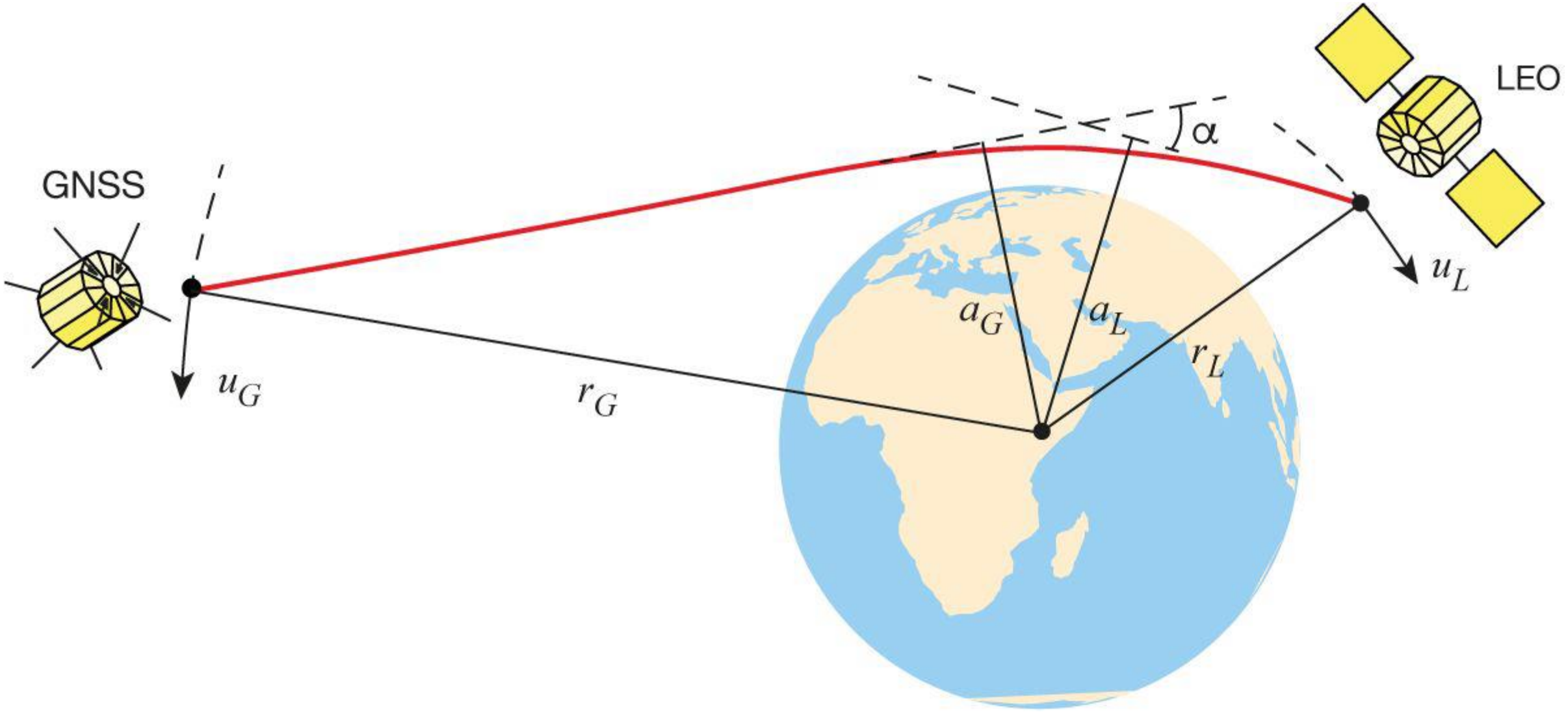
All satellite observing systems have strengths/weaknesses

Key question: What additional information does GNSS-RO bring to the global observing system?

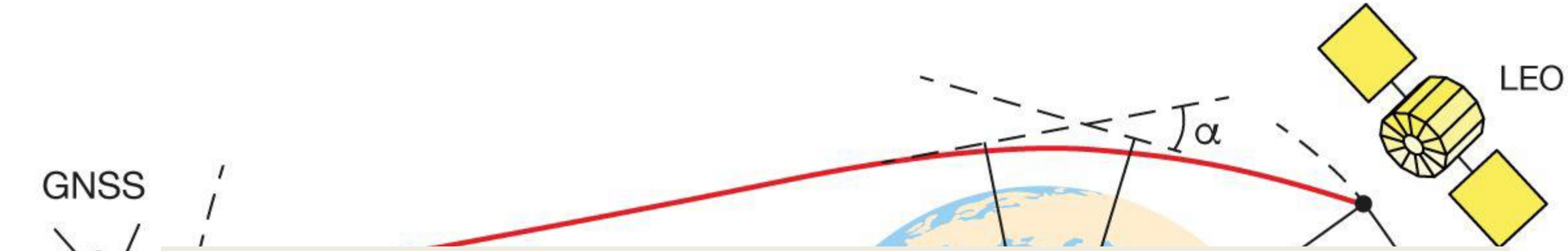
"*Information content*" is relative: depends on what you already know!

TROPICS	Meteor	COSMIC2	CRYOSAT	COMS-1	SAC-C	FY2	ERS-2	DMSP
Sentinel6	HY2	Leo-Geo	MEGHA-TROPIQUES	GRACE-B	C-NOFS	TRMM	JASON	MTSAT
MTG	FY4	KOMPSAT-5	TanDEM-X	GCOM	AURA	METOP	TERRA	GOES
EarthCARE	CFOSAT	Sentinel-5P	INSAT-3D	OceanSat-2	TerraSAR-X	GRACE-A	AQUA	METEOSAT
Sentinel3	SPIRE	Aeolus	HIMAWARI	JPSS	FY3	COSMIC	QuikSCAT	ERS
OCEANSAT	PAZ	SARAL	GPM	SMOS	CORIOLIS	CHAMP	ENVISAT	POES

GNSS-RO geometry



GNSS-RO geometry



We retrieve bending angles, α, as a function of impact parameter, a

The bending is related to temperature and humidity profile information. Most operational NWP centres assimilate bending angle (L1B)

- We have a forward model, H, that computes bending angles from the atmospheric state, $\mathbf{x}$

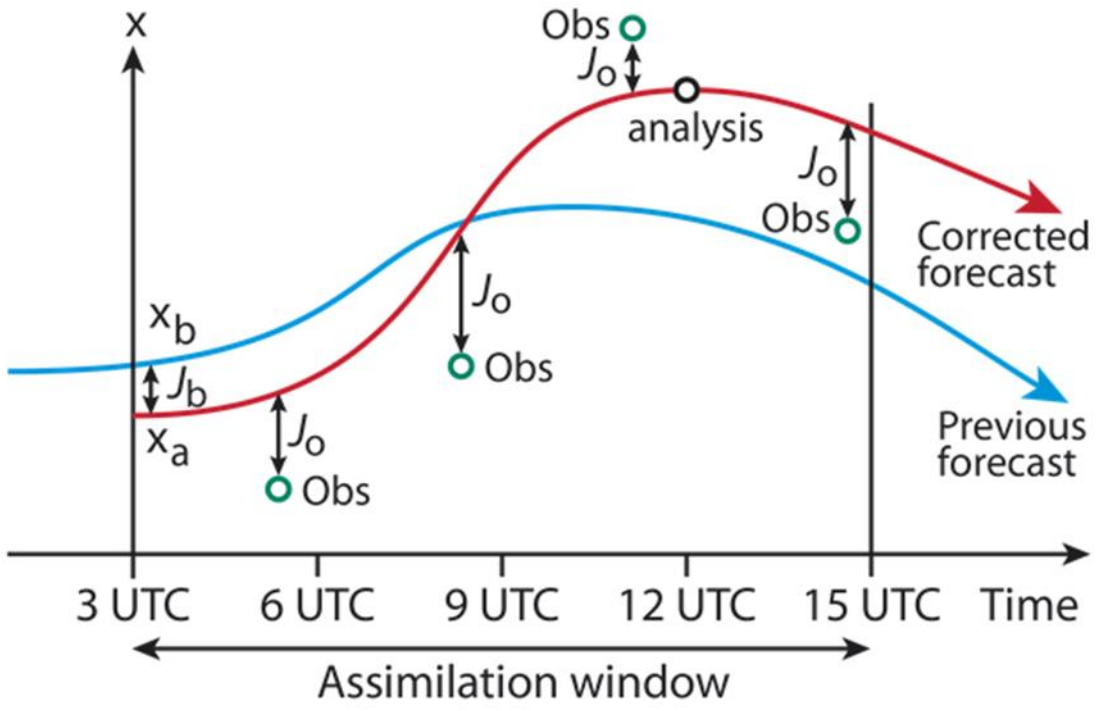
Key characteristics that make it a useful addition to the global observing (GOS) include:

- Assimilation without bias correction
- Good vertical resolution compared to radiances

4D-Var assimilation

Its fancy least squares. Optimal estimation:

$$\mathbf{J(x)} = (\mathbf{x} - \mathbf{x_b})^T \mathbf{B}^{-1} (\mathbf{x} - \mathbf{x_b}) + (\mathbf{y_m} - \mathbf{H(x)})^T \mathbf{R}^{-1} (\mathbf{y_m} - \mathbf{H(x)})$$



NWP model integration to time and location of the observation

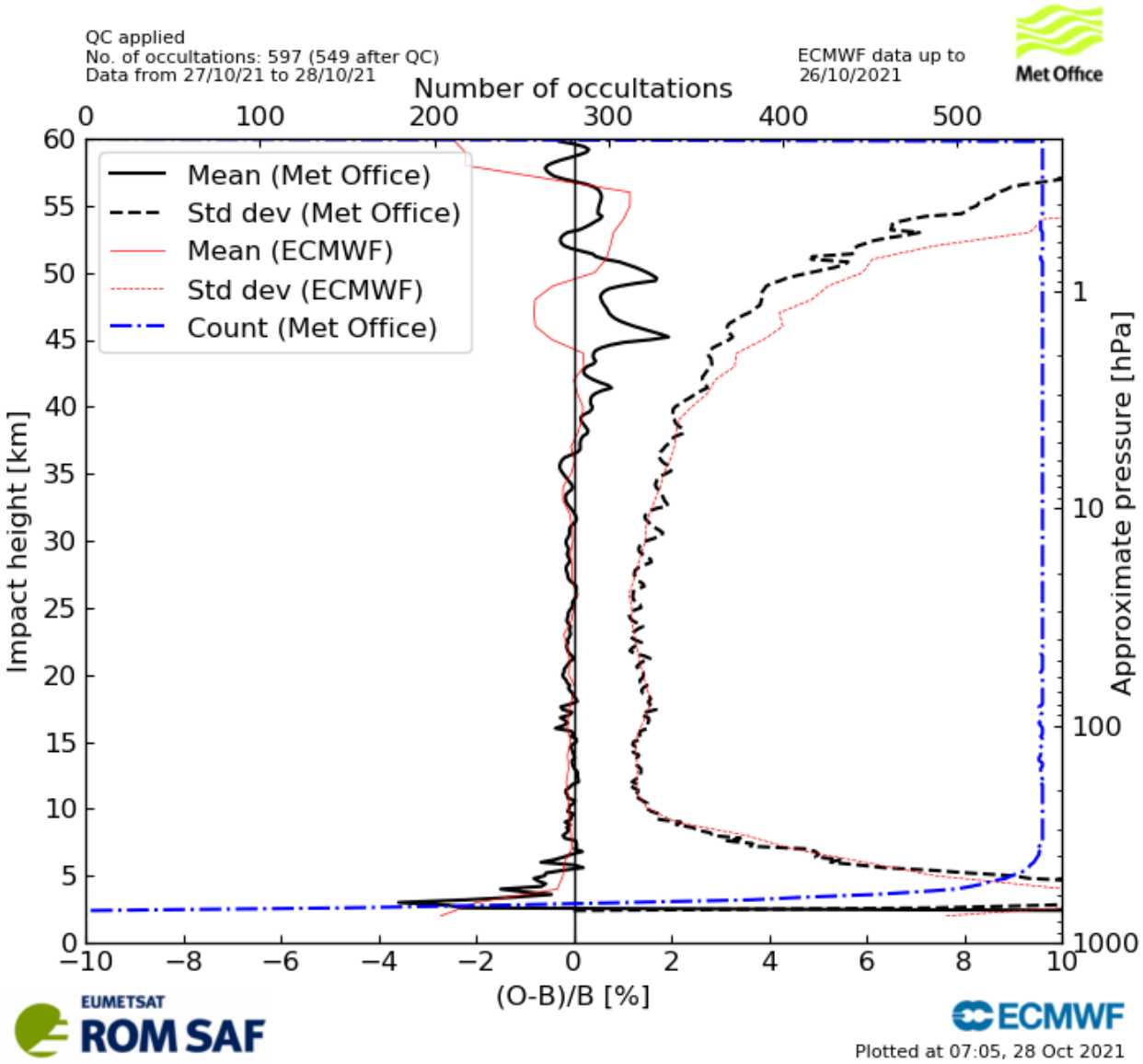
+

<u>forward model</u> to compute the bending angles.

Metop-A GRAS short-range forecast departure statistics

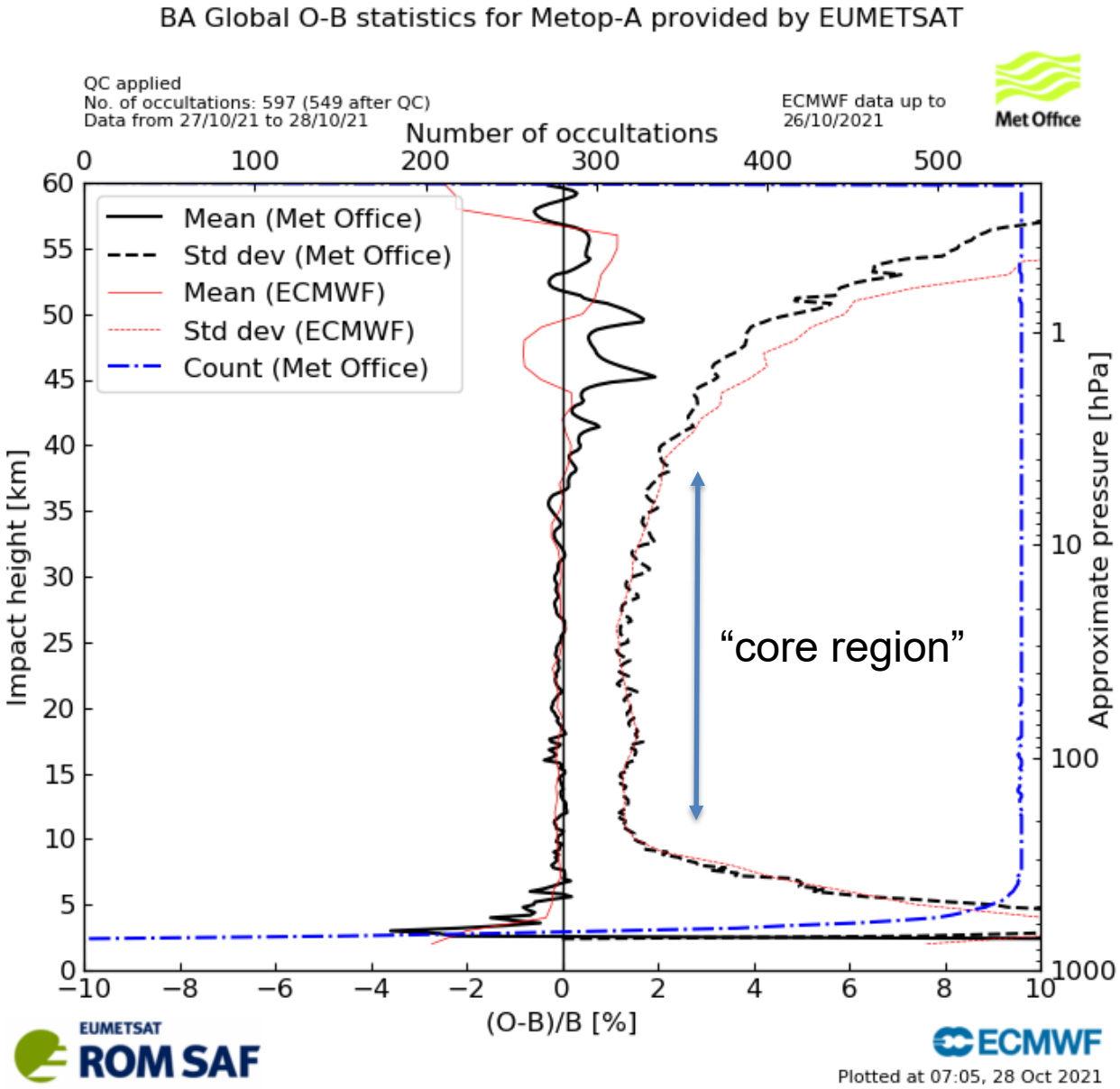
https://www.romsaf.org/monitoring/index.php

BA Global O-B statistics for Metop-A provided by EUMETSAT



Metop-A GRAS short-range forecast departure statistics

https://www.romsaf.org/monitoring/index.php



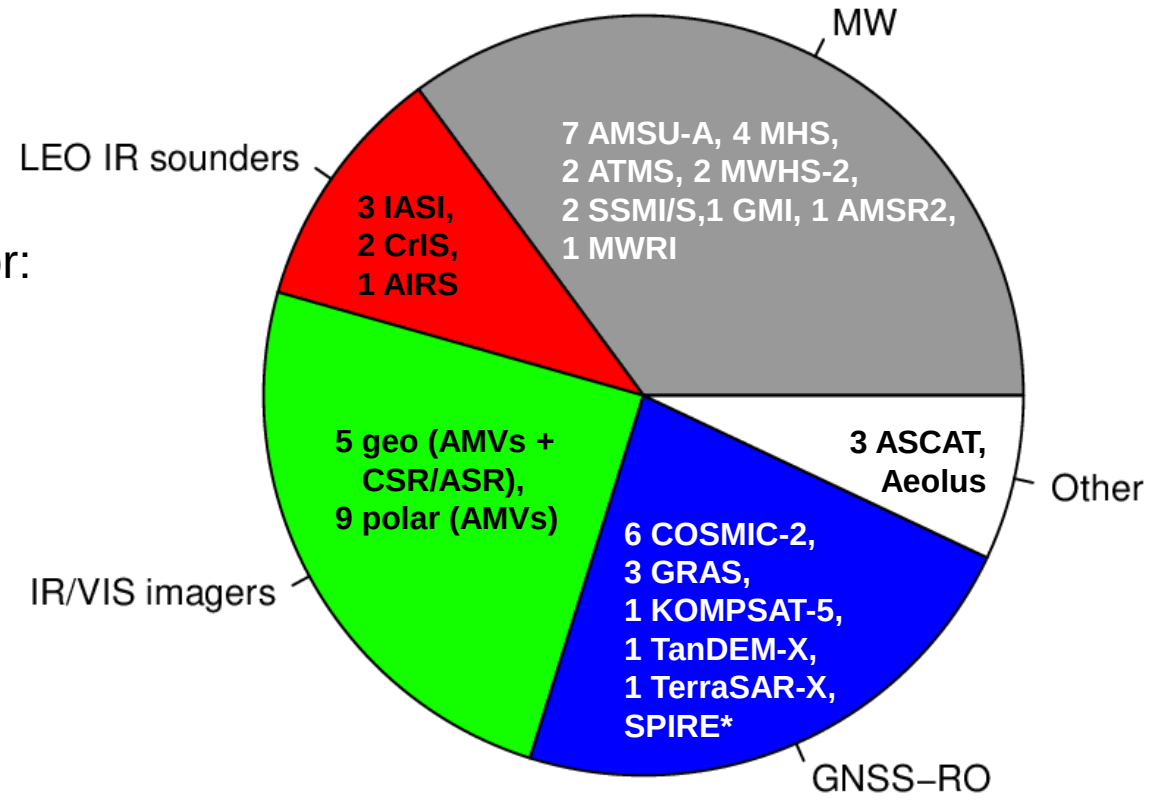
NWP impact: Recent observing system experiments by **Niels Bormann**

- Periods, 6 months in total:
  5 Sept – 2 Nov 2020
  1 Jan – 28 Feb 2021
  1 May – 30 June 2021
  (each + 4 days spin-up prior)

- Denial experiments compared to a full system for:
  - Conventional in-situ observations
  - MW radiances
  - IR sounders from LEO
  - IR/VIS imagers (AMVs + IR radiances)
  - GNSS-RO

- Resolution: T_{CO} 399 (~25 km)
- Background error from operational system

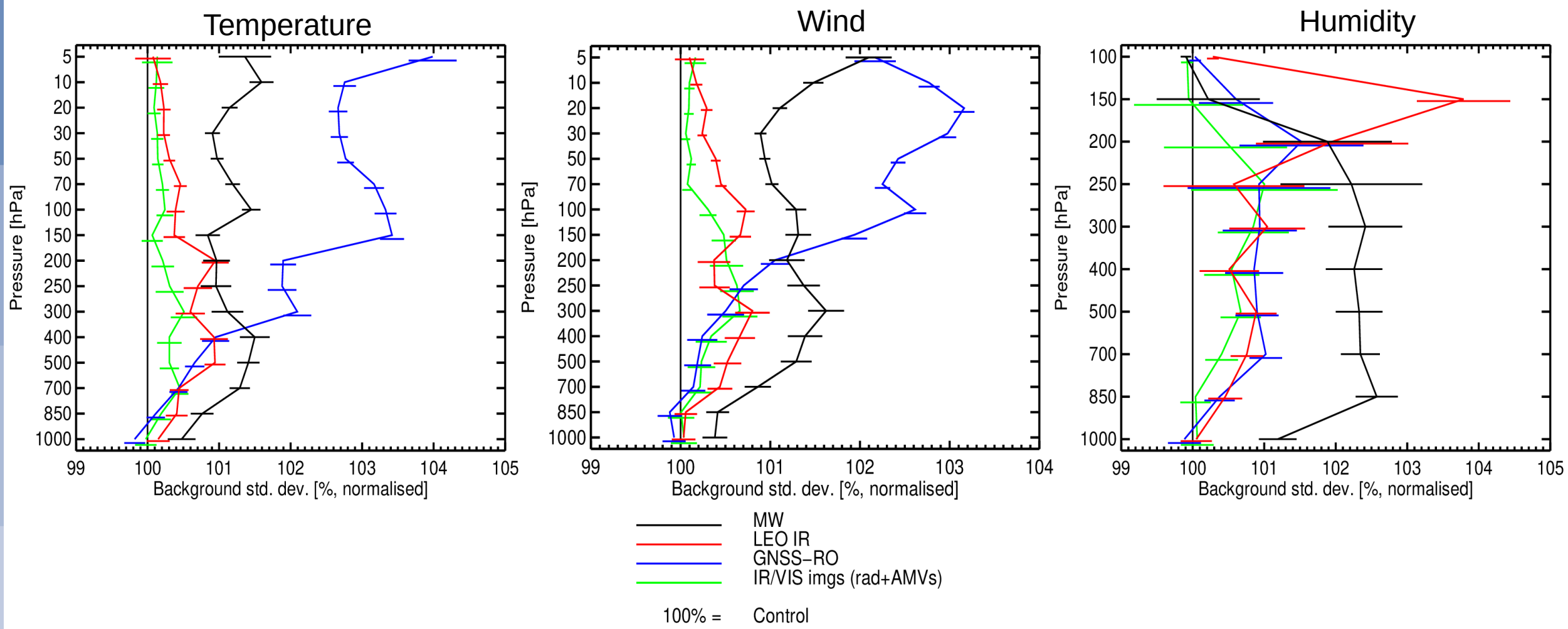
Number of assimilated satellite instruments



* SPIRE: Sept 2020 only

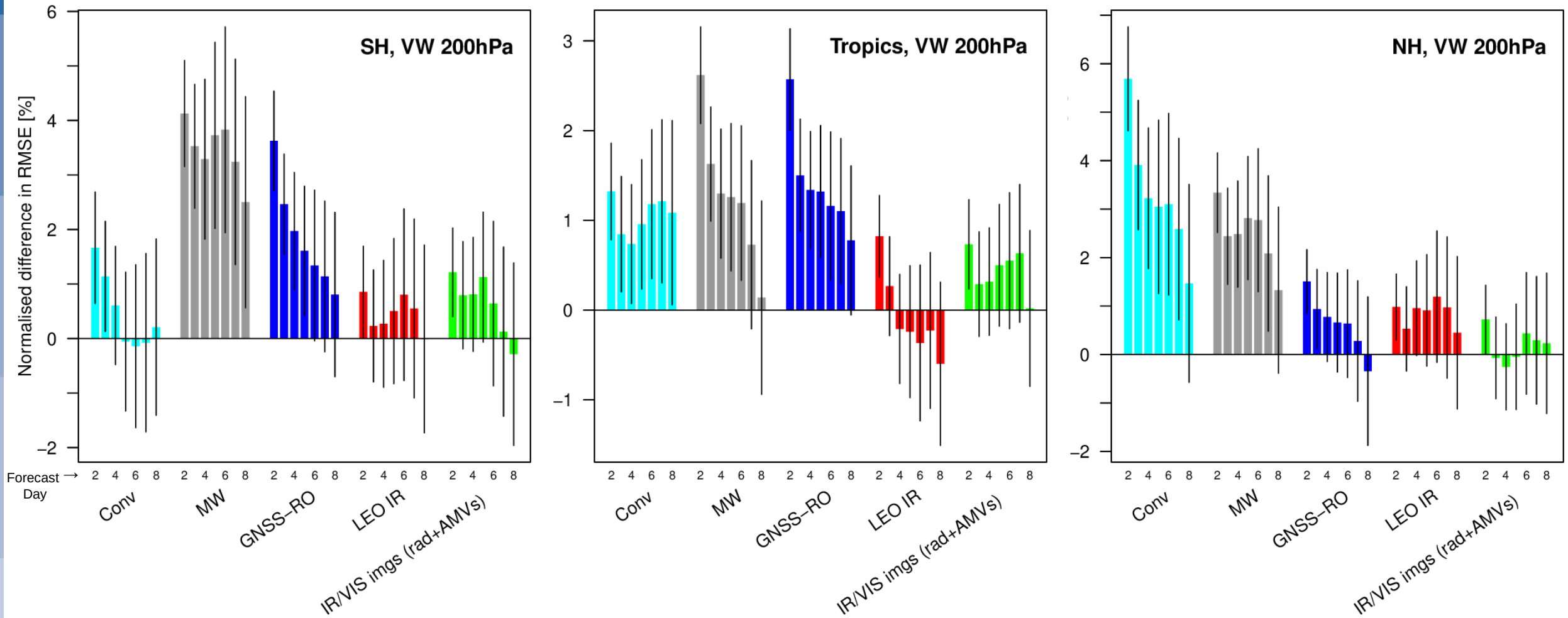
Short-range impact evaluated against in-situ observations: Stdev(o-b)

Global, 3 periods combined



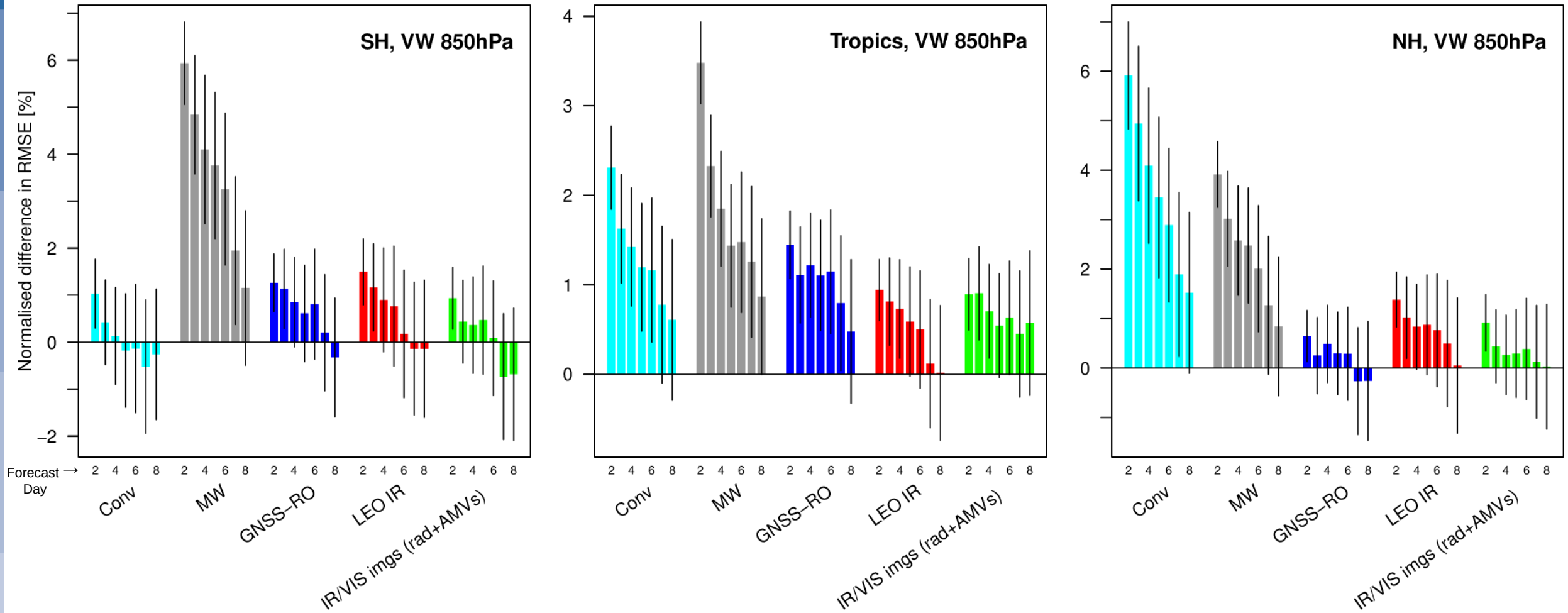
Forecast impact, day 2-8: Wind at 200 hPa

Verified against operational analyses, 3 periods combined



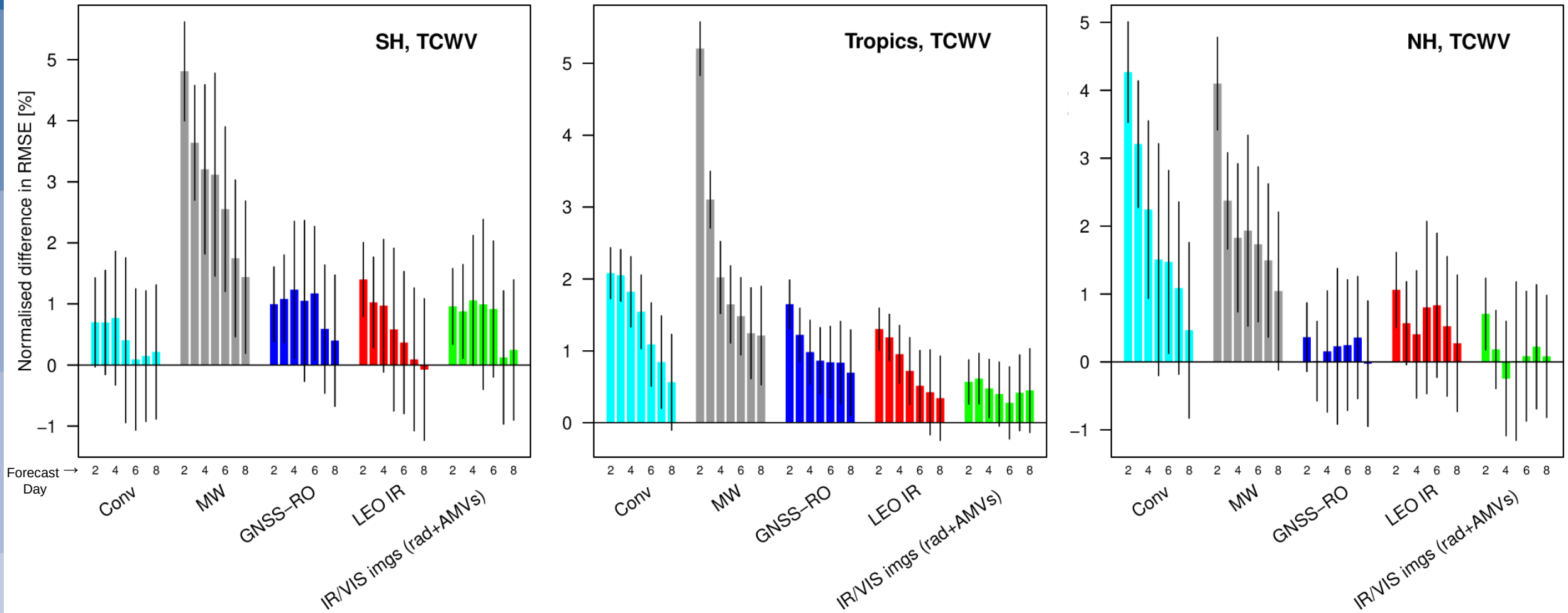
Forecast impact, day 2-8: Wind at 850 hPa

Verified against operational analyses, 3 periods combined



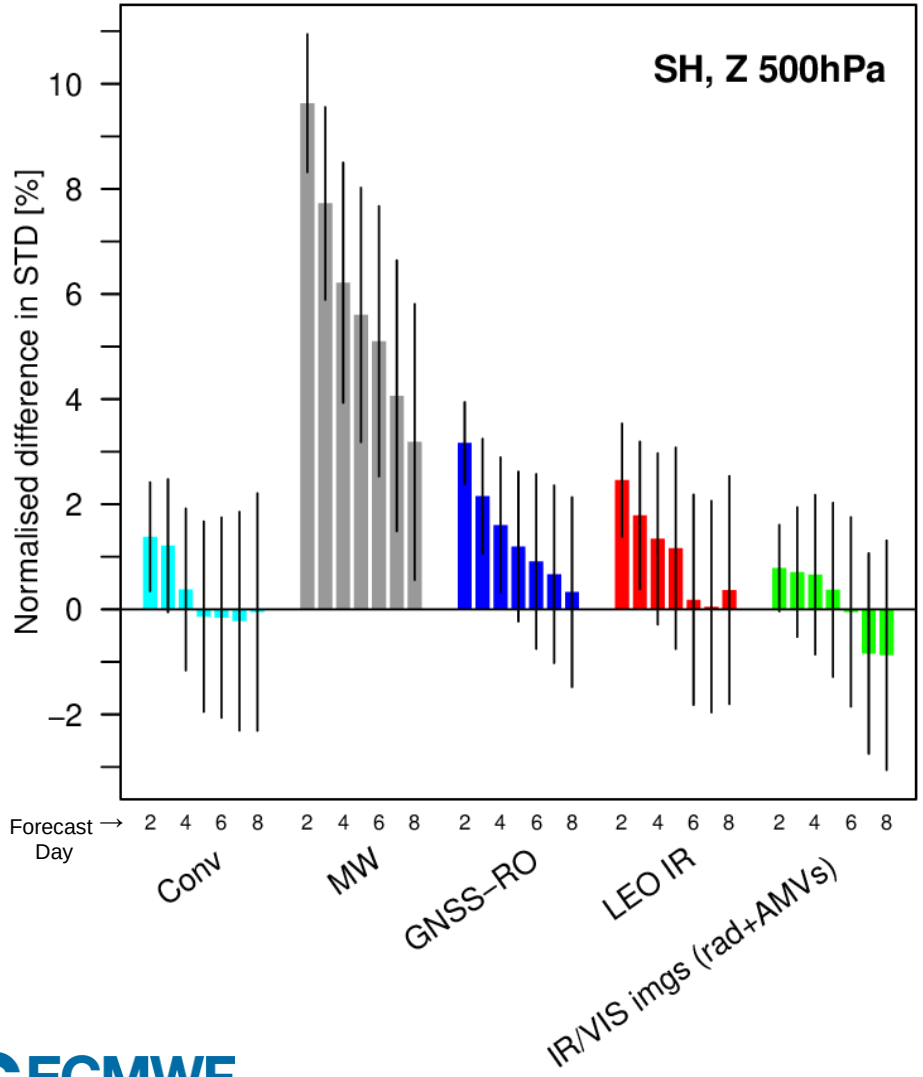
Forecast impact, day 2-8: Total column water vapour

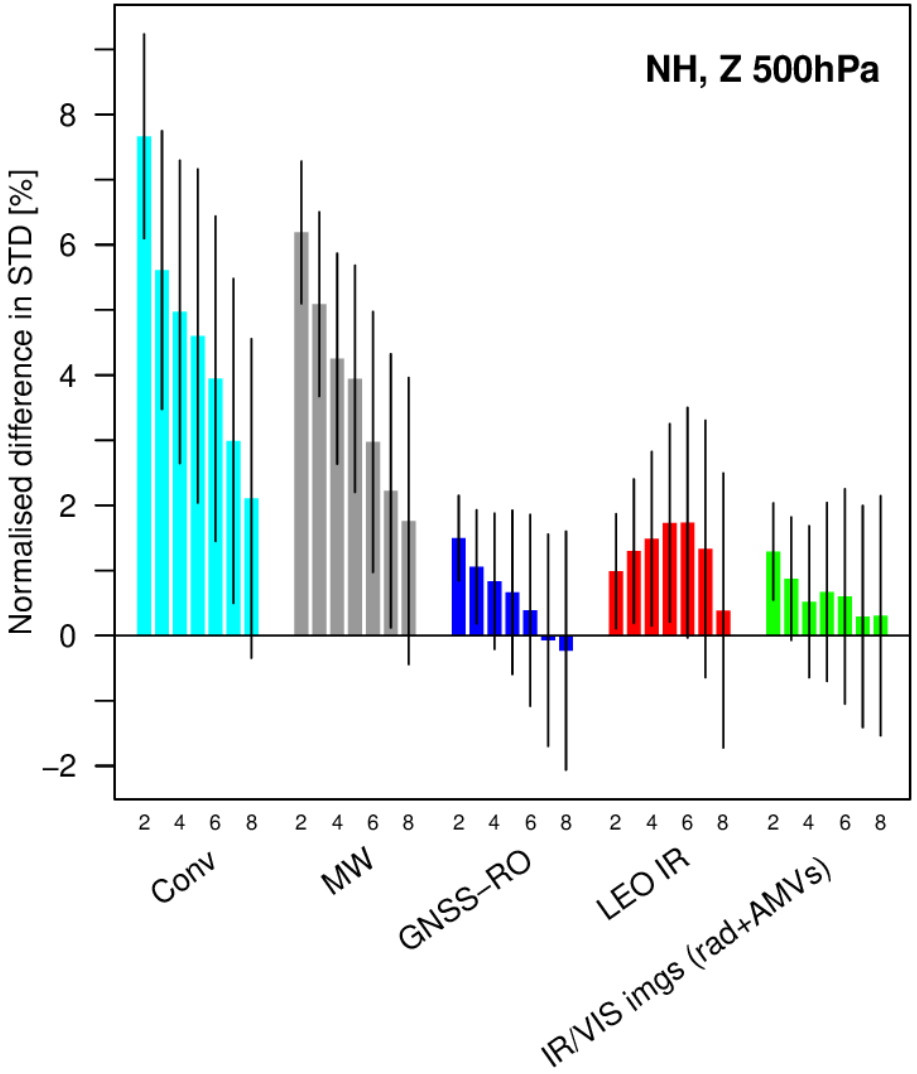
Verified against operational analyses, 3 periods combined



Forecast impact, day 2-8: 500 hPa geopotential

Verified against operational analyses, 3 periods combined





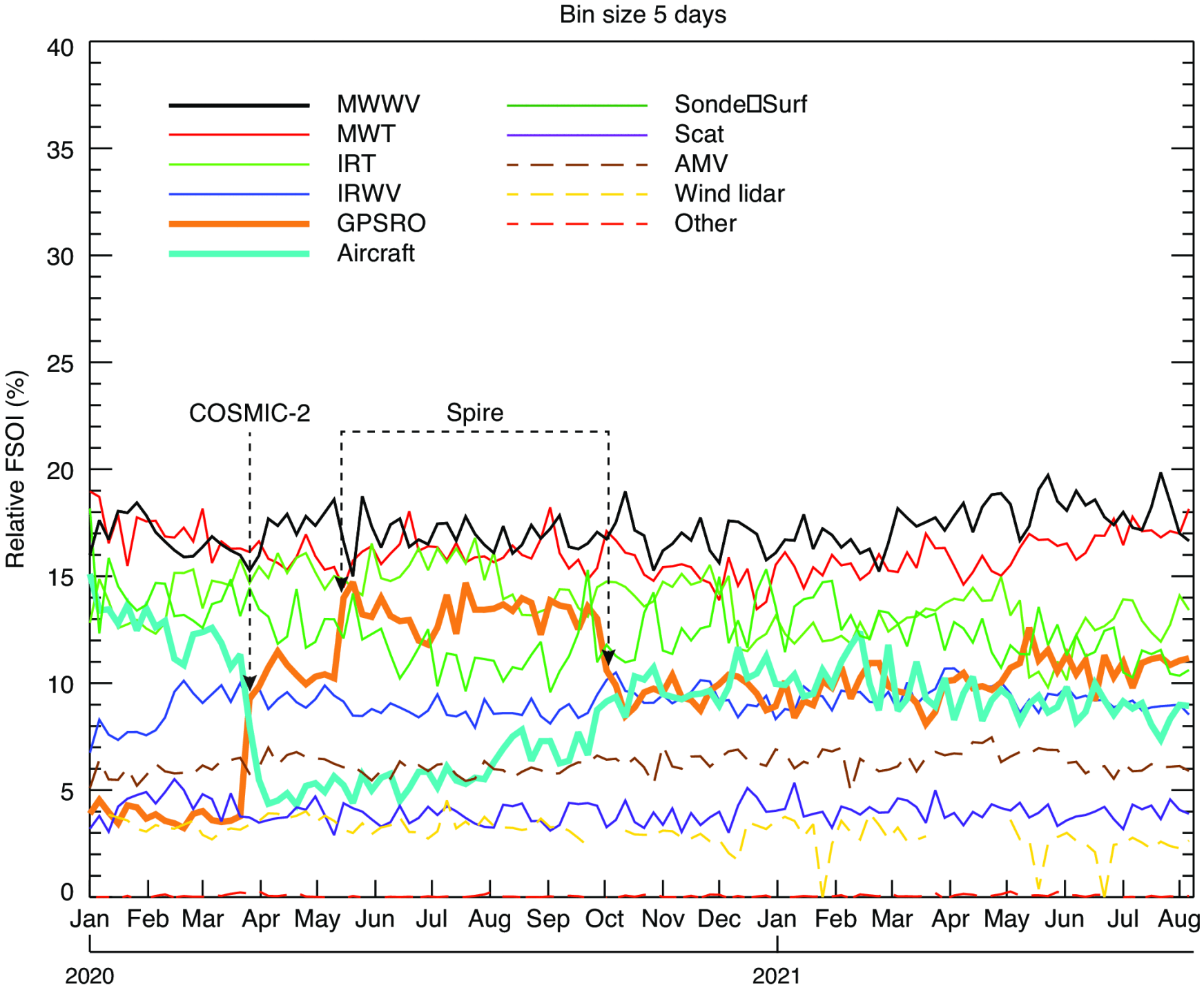
FSOI % for 2020/21

- Forecast sensitivity to observation impact: estimate of how important obs subsets are for T+24 forecast

- RO: steps from start of COSMIC-2+Spire, Spire stopped end Sept

- Aircraft: drop in Mar/Apr then ~level
- Then increase (SH+)
- 2021: seasonal cycle?

- Aeolus: ~3% (gaps)



Applications of L2 RO data in NWP

EUMETSAT / ROM SAF Level 2 NWP Products

Following Level 2 products are provided by the ROM SAF global (*global: timeliness: 2.5 h; regional 125 min*):

- Refractivity profile
- Temperature profile
- Pressure profile
- Dry temperature profile
- Specific humidity profile
- Surface pressure
- Tropopause height
- Planetary boundary layer height

EUMETSAT Level 2 NWP Users / Applications

Global NWP Users (refractivity):

- Assimilation with advanced uncertainty characteristics (Environment Canada)
- For quality control before assimilating the bending angle profile (e.g. Météo France)

Regional NWP Users (refractivity):

- Primarily study application, e.g. to improve Hurricane/Typhoon forecasting (with increasing daily numbers being available and shorter timeliness, interest will grow)
- Refractivity is an alternative to bending angle as e.g. regional models have a lower top altitude and the forward operator is simpler

“Real Time” Climate application and Monitoring:

- All products are suitable for climate monitoring / Interim Climate Data Record (ICDR)

Other applications:

- Assessing instrument stabilities within GSICS (e.g. for microwave instruments)
- Or e.g. Chemistry models to use NRT temperature profiles (if numbers are high enough)

Summary

- Recap of the GNSS-RO measurement technique

- Current impact of GNSS-RO in the ECMWF system compared to other systems
  - Impact in upper-troposphere and stratosphere well established
  - Strong impact on tropical winds
  - Now seeing impact on total column water vapour

- Level 2 products
  - Direct assimilation of refractivity at Environment Canada
  - Use of refractivity for QC
  - Use in regional models with “lower-lid”