Use and impact of MW sounders at ECMWF and perspectives for future systems

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ECMWF

Outline

1. Impact of MW radiances
2. Ingredients for MW-sounder impact
   - Instruments and key characteristics
   - All-sky/all-surface use
   - Multiple orbits
3. Future evolution of the MW sounder constellation

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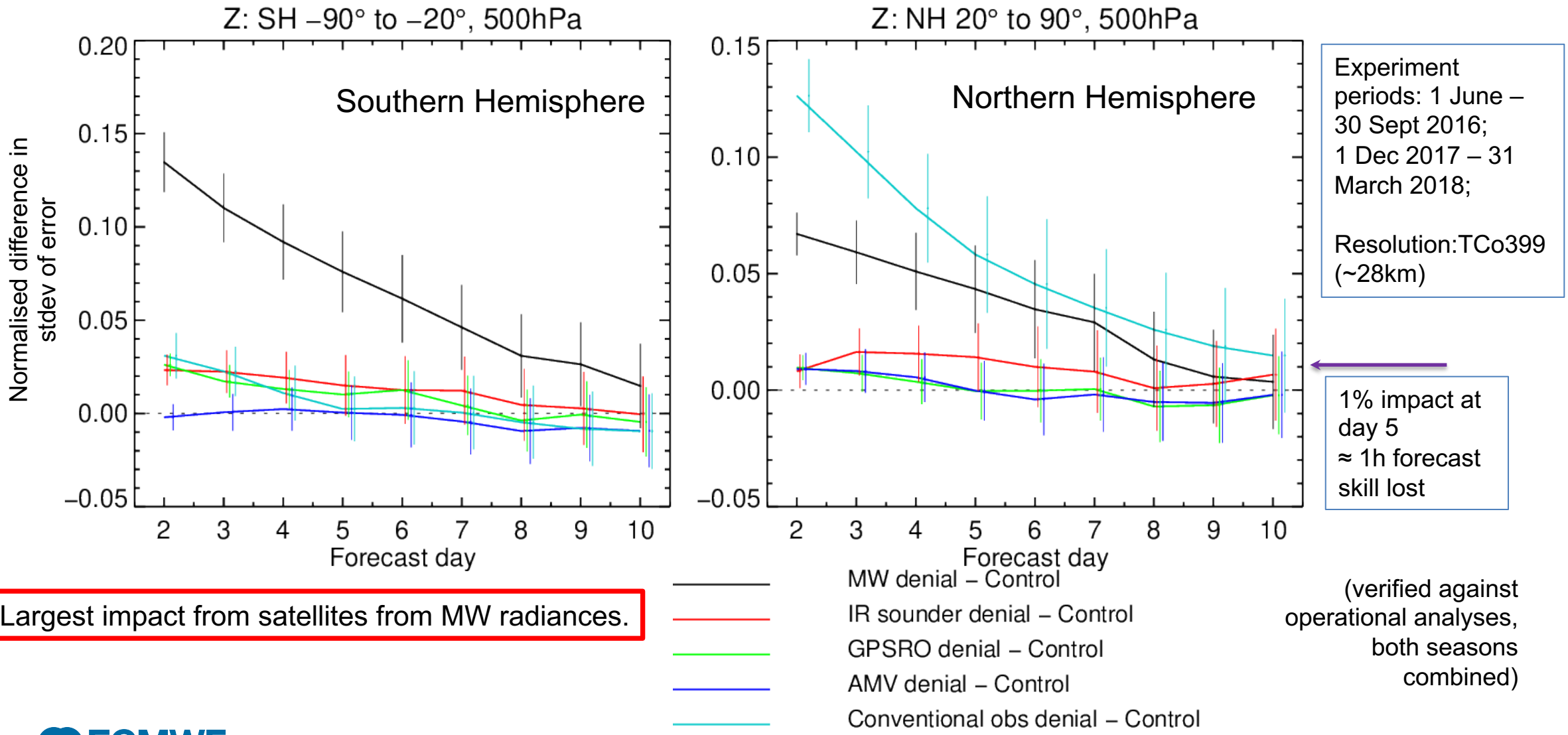
Current impact of MW radiances in the ECMWF atmospheric system: Z500 hPa



Experiment periods: 1 June – 30 Sept 2016; 1 Dec 2017 – 31 March 2018;

Resolution:TCo399 (~28km)

1% impact at day 5
≈ 1h forecast skill lost

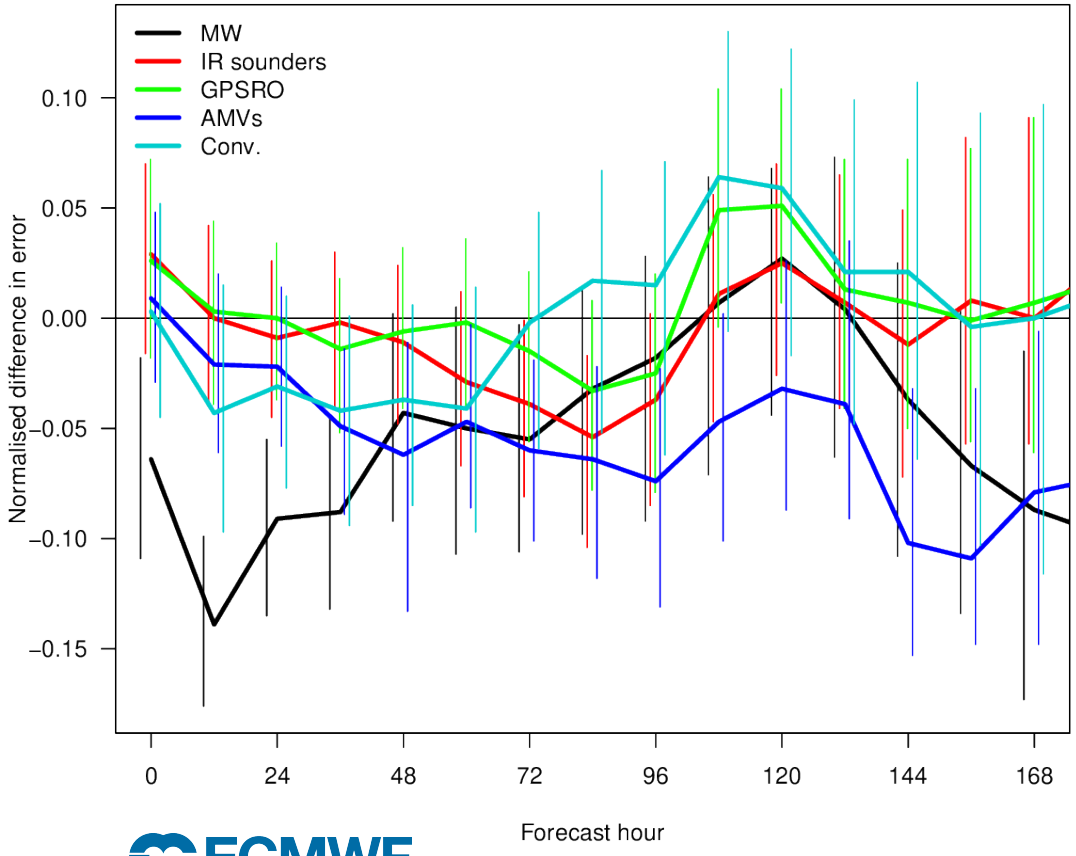
(verified against operational analyses, both seasons combined)

- Largest impact from satellites from MW radiances.

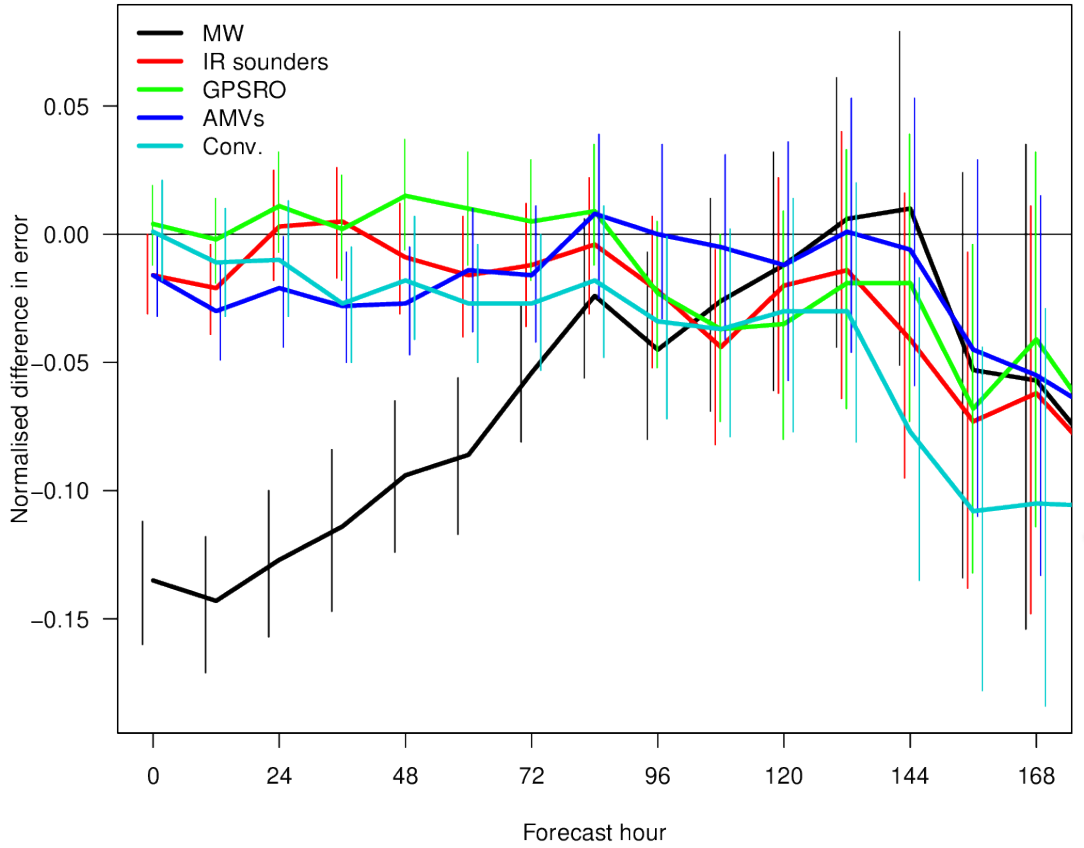
Impact on tropical cyclone prediction

All basins, homogeneous samples,
1 June – 30 September 2016; 1 December 2017 – 31 March 2018; (2 x 4 months)

Position error, normalised difference



Absolute intensity error, normalised difference

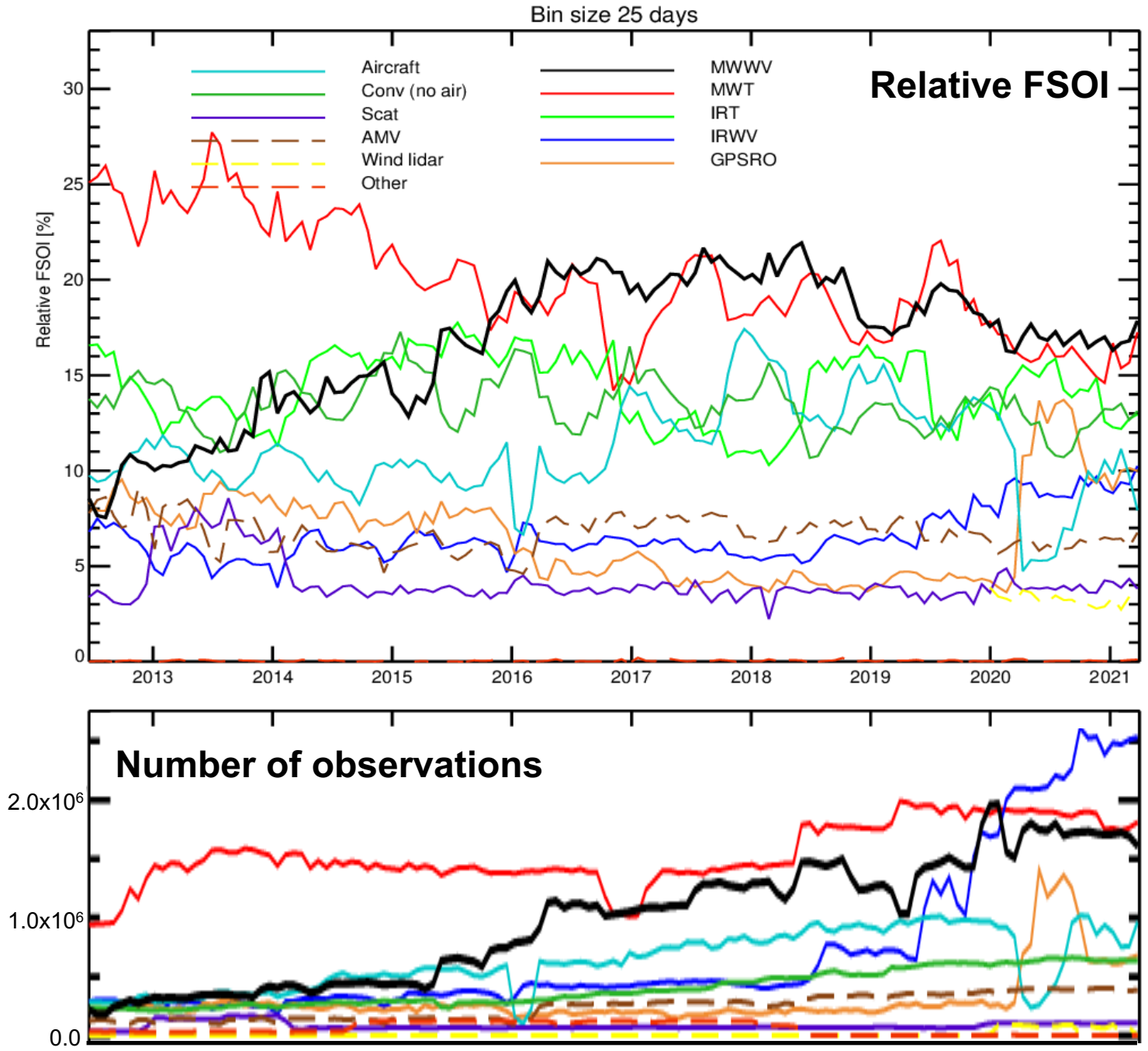


Evolution of impact according to FSOI

Growing impact of humidity-sensitive MW radiances:

- All-sky use
- Increased number of sensors

Now roughly equal impact from temperature-sounding and humidity-sensitive MW radiances.



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Current use of passive MW instruments at ECMWF

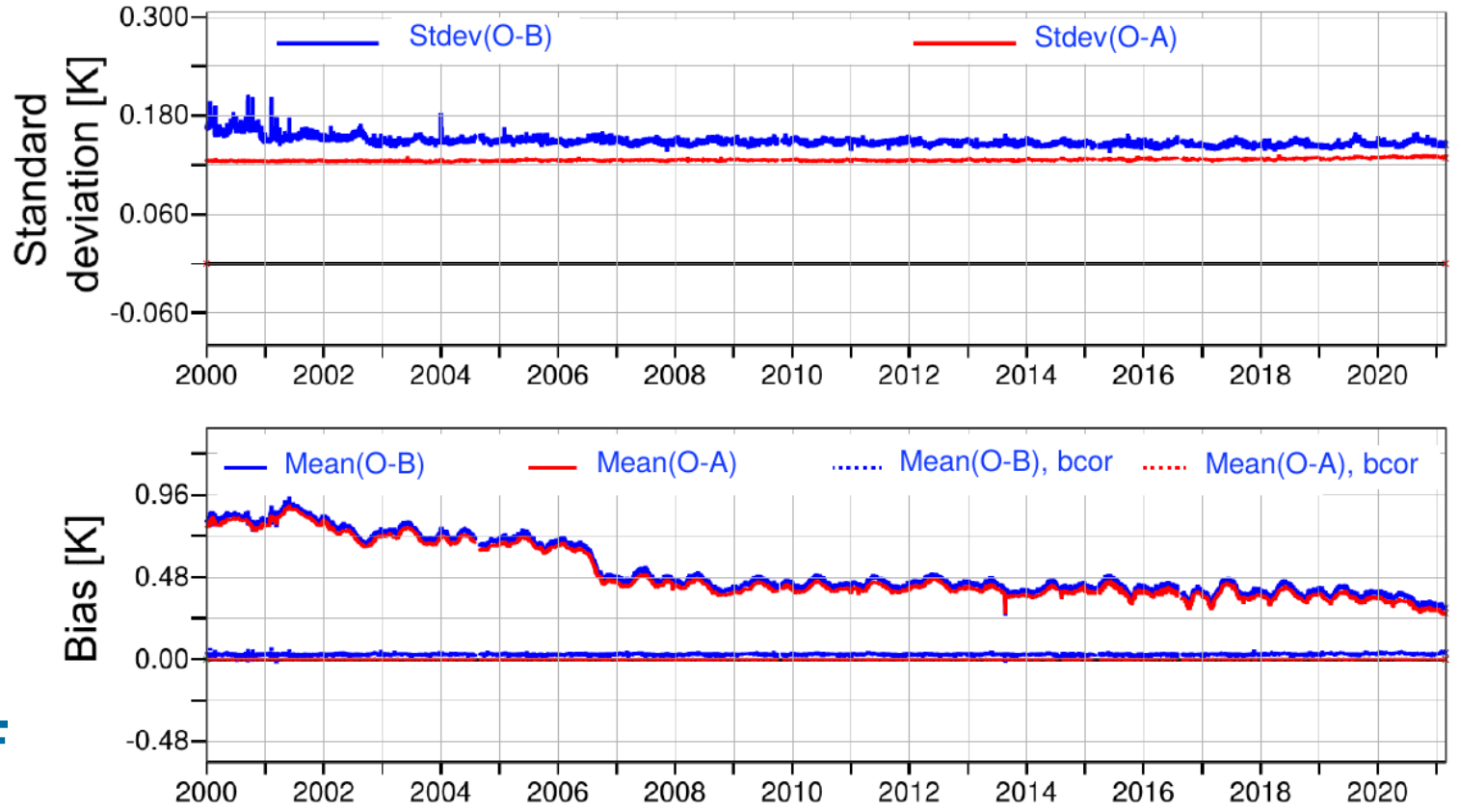
Bands	Instruments used	Usage
Temperature-sounding (52-57 GHz)	6 AMSU-A; 2 ATMS	Clear channels only; AMSU-A to be moved to all-sky in Oct 2021
Temperature-sounding (118 GHz)	2 MWHS-2	All-sky
Humidity-sounding (183 GHz)	4 MHS; 2 ATMS; 2 MWHS-2; 2 SSMI/S; GMI	Mostly all-sky (except ATMS)
Window/imager channels (19, 24, 37, 89/91, 150/166 GHz)	1 SSMI/S; AMSR2; GMI; MWRI	All-sky

- Window channels on sounding instruments are used to estimate surface emissivity or cloud-related uncertainty.
- Most MW sounding data is used over all surface types.

Key characteristics of impactful MW sounders

- Channels in the 50-57 GHz, 183 GHz bands, combined with window channels
- Good noise performance, good calibration stability (long-term and within-orbit)
  - Especially important for temperature-sounding channels
- Good timeliness, contiguous spatial sampling, etc.
- Long lifetime

NOAA-15 AMSU-A ch 8 vs ERA5: > 20 years of quality observations!



Stdev(O-B) ≈ 0.15 K

NEDT: ~ 0.13 K at 50km

Error from background ~ 0.1K

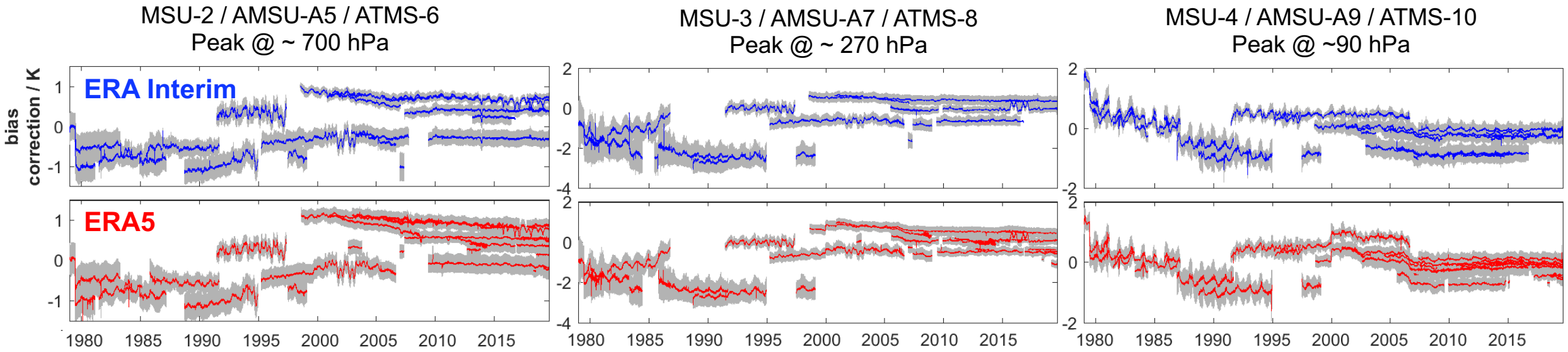
Instrument noise performance is critical for tropospheric temperature-sounding channels!

ECMWF

Key characteristics of impactful MW sounders

- Radiometric uncertainties increasingly important for climate **reanalyses**.
  - To estimate and minimise mean state uncertainties – globally and locally
- Clear improvements with newer sensors: Inter-satellite biases are now well within ±1K for the latest sensors

Mean bias corrections (**bold**) ± STDEV of bias corrections (grey)

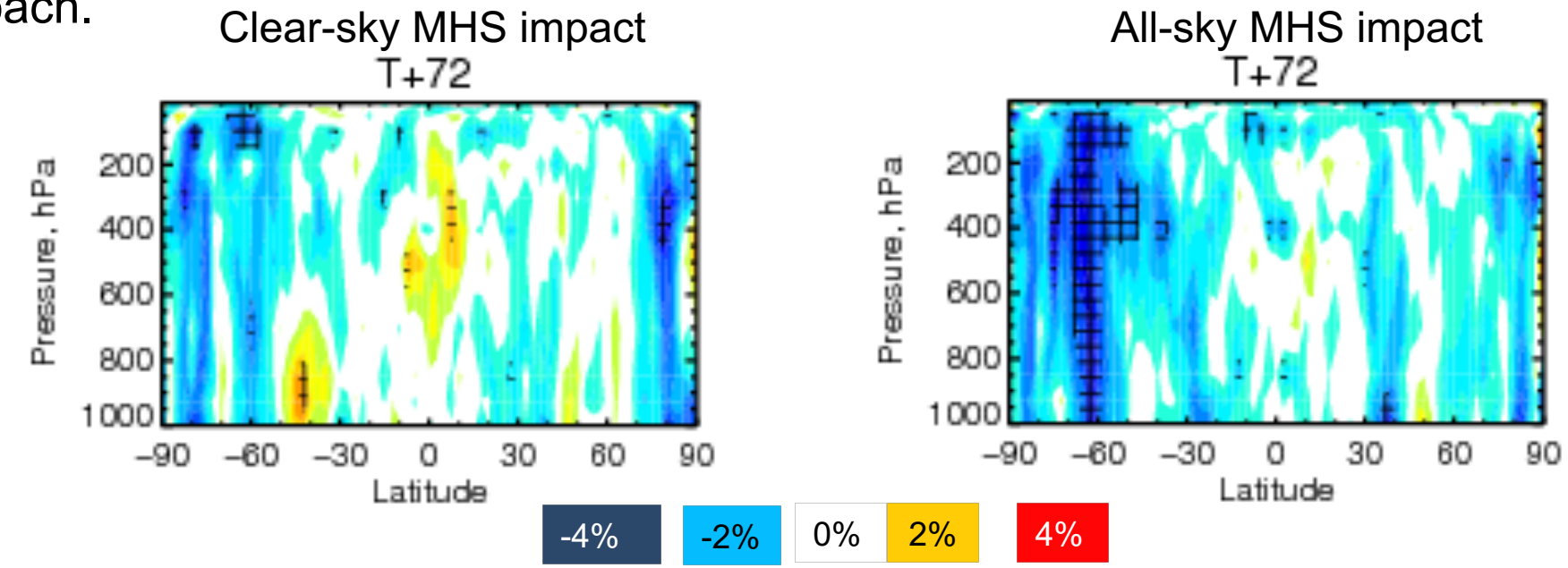


All-sky/all-surface assimilation

Assimilation in clear, cloudy, rainy conditions = all-sky assimilation

- Enables sampling of sensitive meteorological areas.
- 4D-Var assimilation of MW radiances gives wind information via tracer effect – esp. with an all-sky approach.

T+72 Vector Wind RMS difference normalised by RMS of control

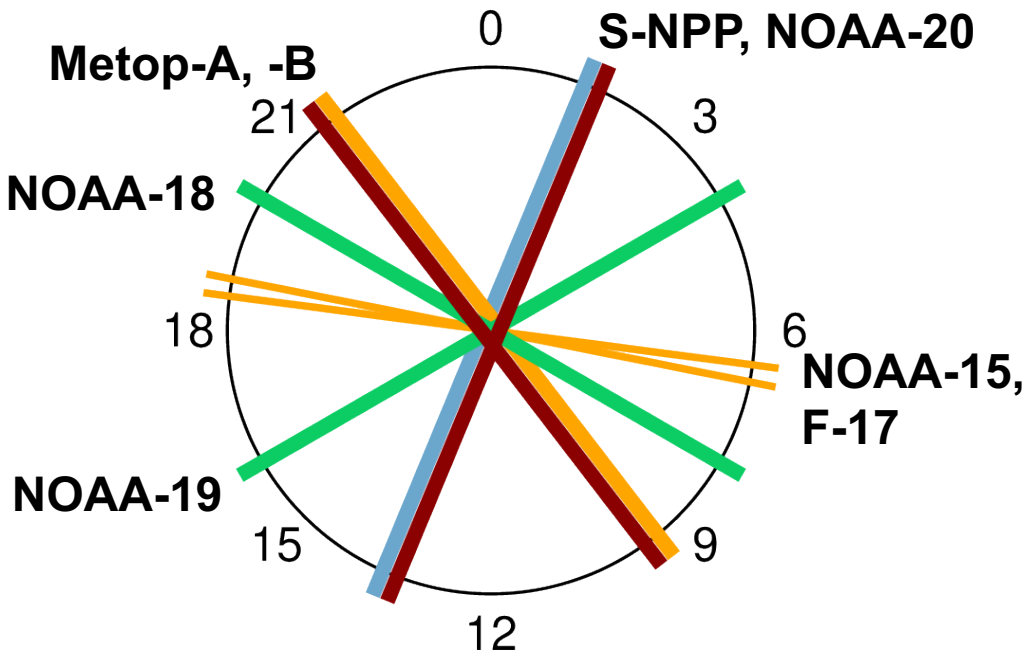


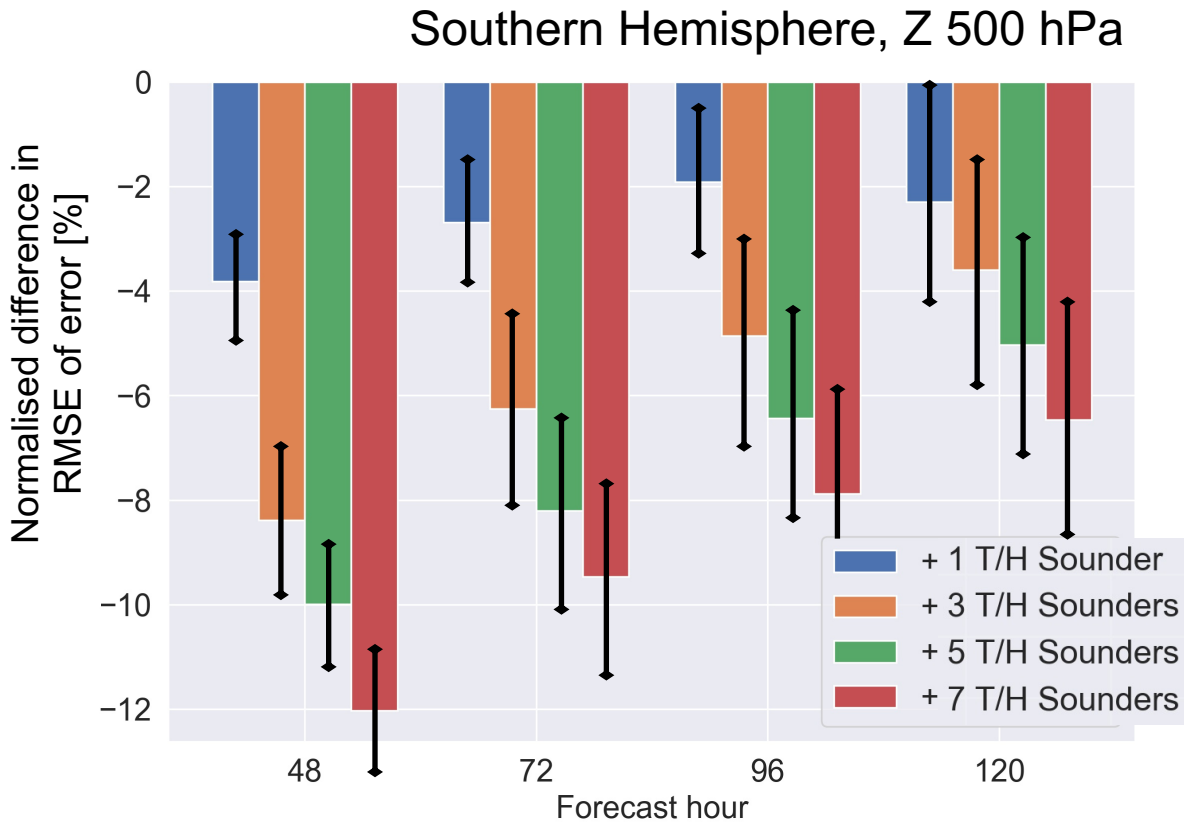
Most sounding channels are assimilated over all surface types

- Requires adequate description of surface contributions (via window channels)

(David Duncan)

Benefit from multiple MW sounders



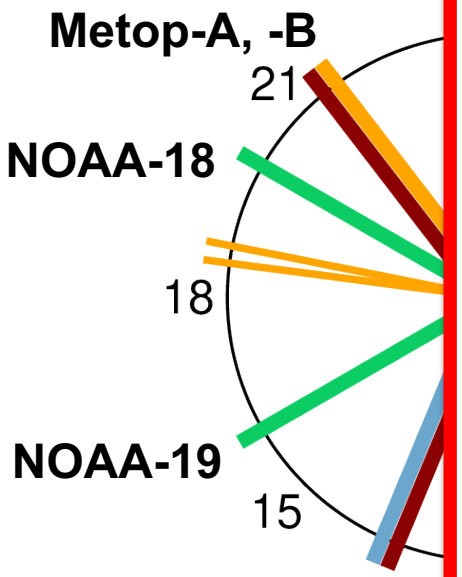


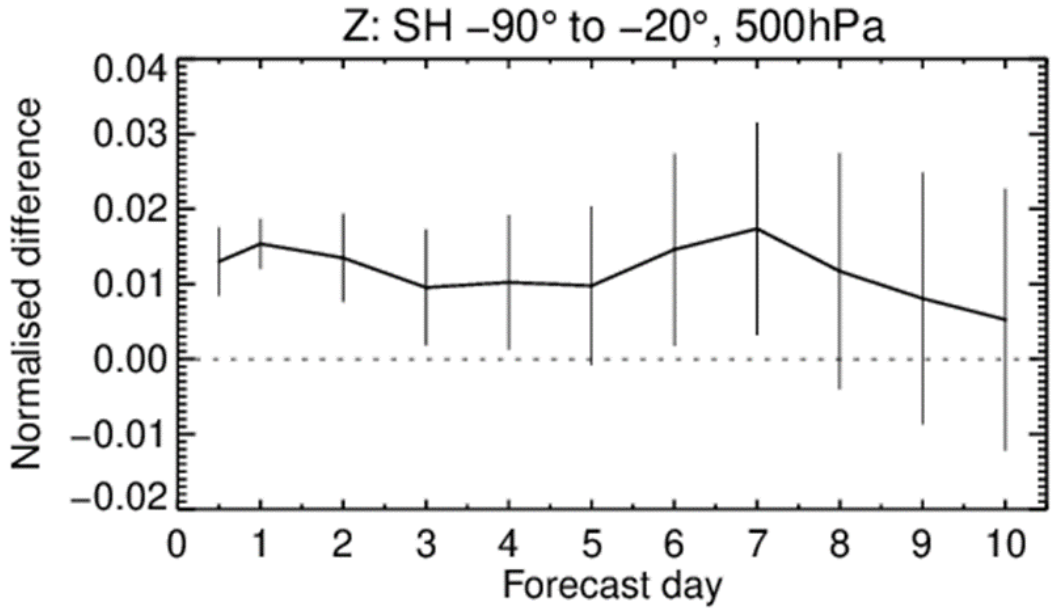
Control: Full observing system, **but no microwave sounding data**
Experiments: Control + either 1 / 3 / 5 / 7 MW sounders
Period: 1 June – 15 September 2018

Continued benefit from adding further MW sounders.

(David Duncan)

Benefit from multiple MW sounders

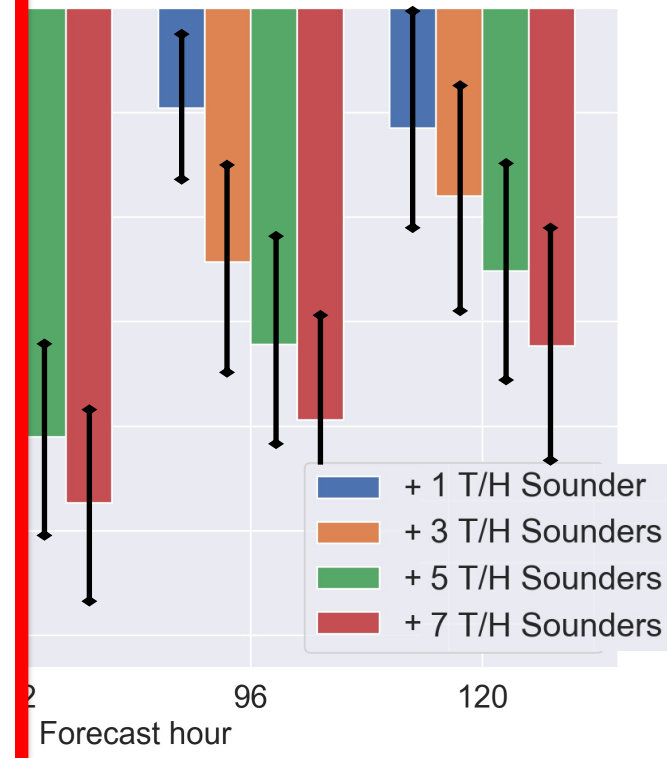




Combined impact of withdrawing NOAA-15,18 and 19 from a full system ~ 1.5 %.

→Recommend to keep these going for as long as health of the instruments allows.

Southern Hemisphere, Z 500 hPa



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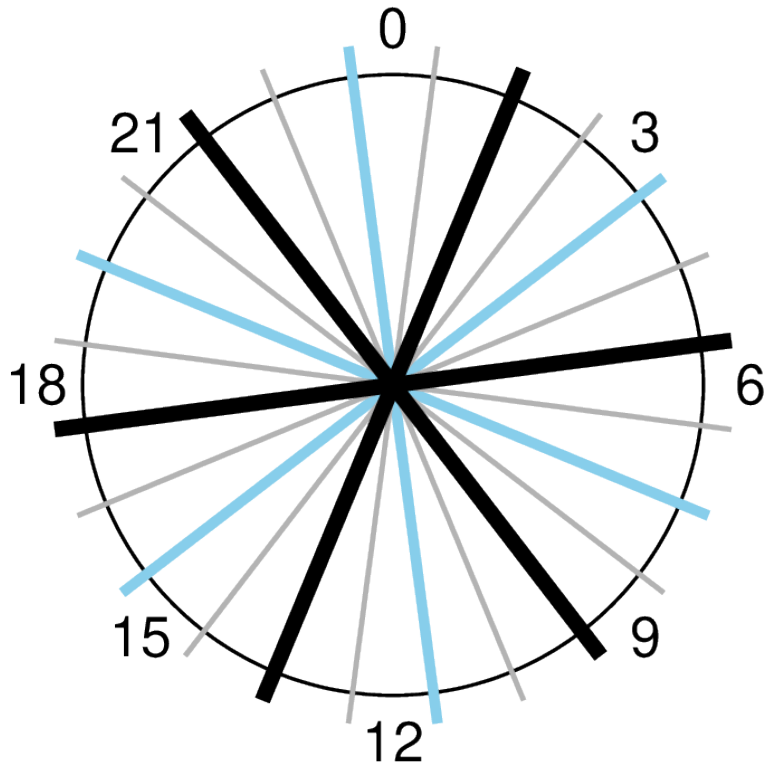
A future two-tier evolution of MW sounding capabilities ? (WIGOS Vision 2040)

- **Tier 1: 3-orbit backbone system (CGMS baseline)**
  - Critical “reference” system, with high-end capabilities and performance, long life-times, excellent stability, calibration accuracy, etc
  - Continuity, ideally with **improved** capabilities and performance (minimum ATMS or EPS-SG-MWS-like)



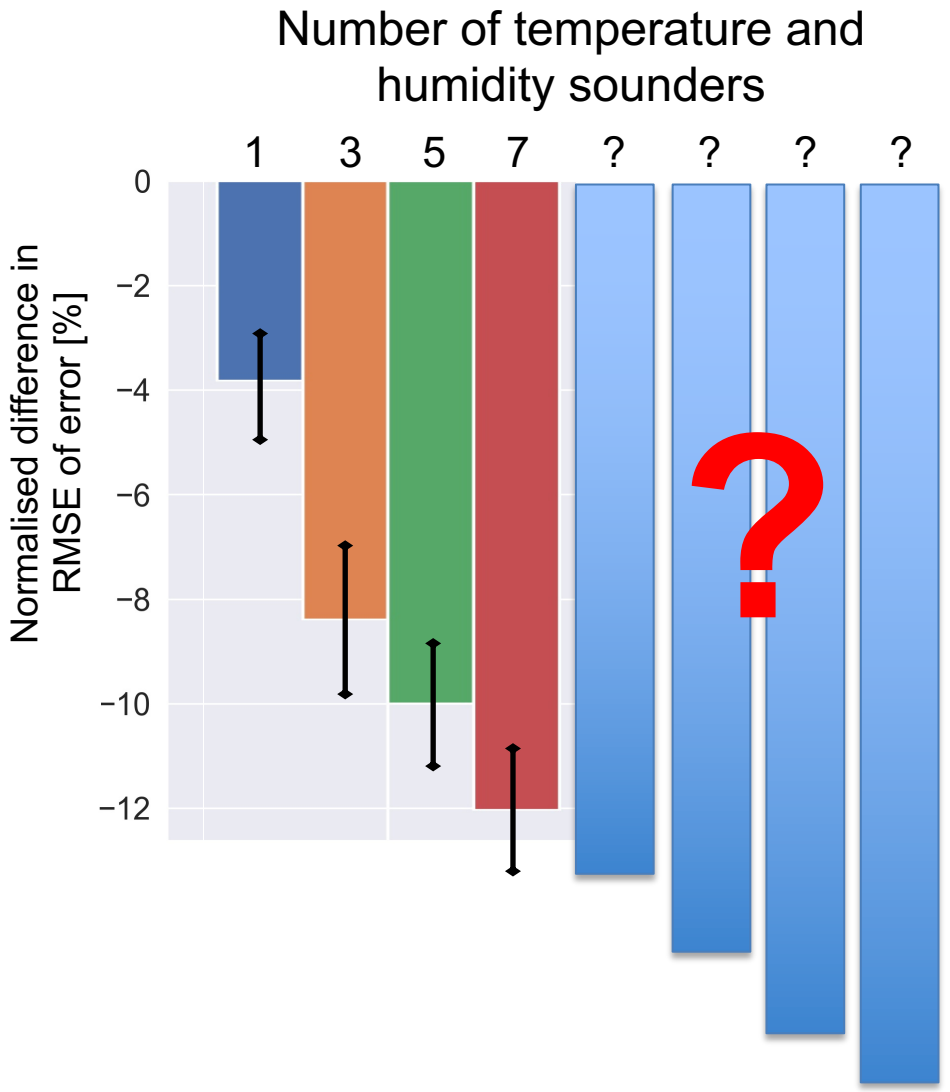
- **Tier 2: Supplemental orbits, possibly with varying capabilities**
  - Possibilities with small satellite/cubesat systems

Tier 1: High-level requirements for the backbone system

Aspect	Requirement
Channel set	EPS-SG-MWS-like or better; RFI aware (ch4 of ATMS outside protected bands)
Noise performance	Better than ATMS performance (over comparable footprints) (ideally much better for T-sounding channels)
Stability	Within one orbit: << noise performance Over a few days: < noise performance
Absolute calibration	Can we do better than 0.5 K?
Lifetime	> 5 years
Horizontal resolution/ sampling	Comparable to ATMS/EPS-SG-MWS or better Contiguous/over-sampled

Tier 2: What MW sounding systems should complement the 3-orbit baseline?

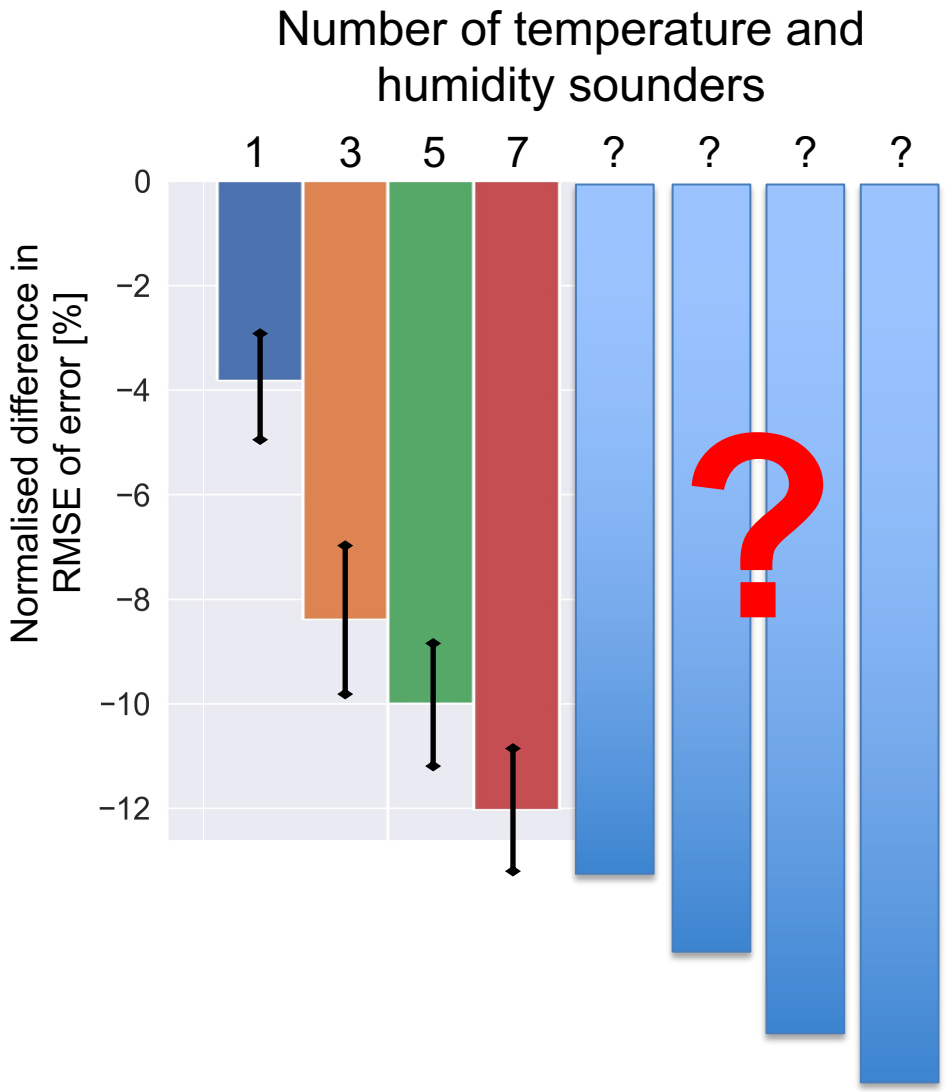
- **Simulation study at ECMWF:**
  - **Motivated by possibility of constellations of small satellites.**
  - ***Key questions:***
    - How many and what type of additional orbits (polar/low-inclination)?
    - What is the influence of instrument capabilities (e.g., **humidity** sounding vs **humidity+temperature**? instrument noise performance?)?
  - Ensemble approach, with simulated new observations added to existing real observations.
    - Measure of impact: Change in ensemble spread
    - Alternative to OSSEs; used before for Aeolus and RO
    - ESA-funded; **results expected Sept 2022**



(Katie Lean)

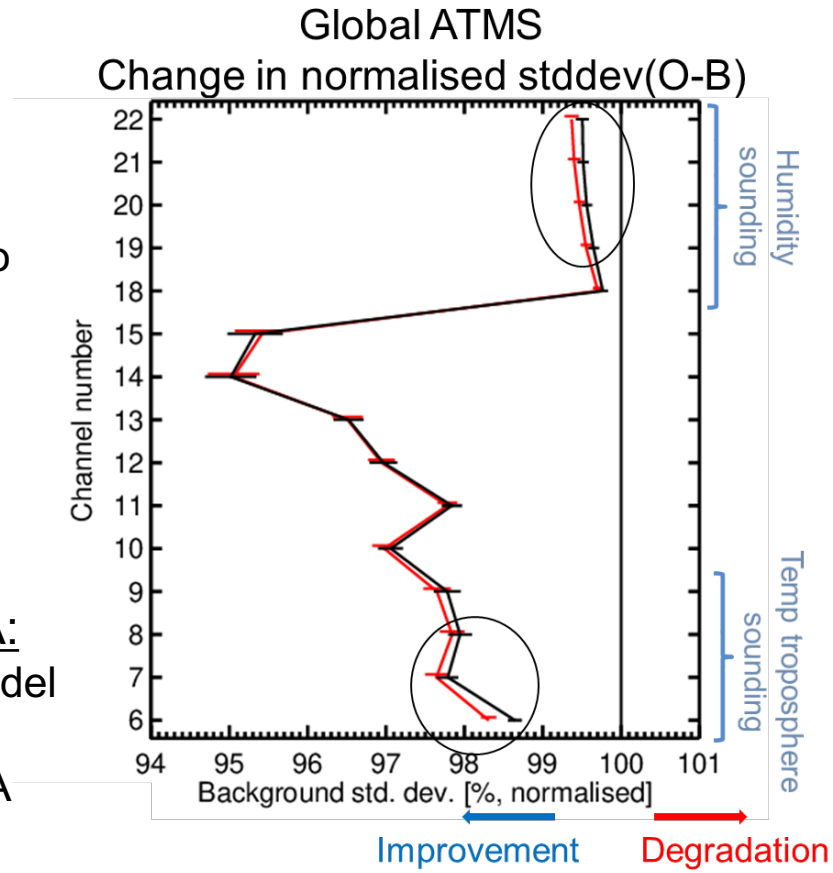
Tier 2: For which channels would better temporal sampling be most beneficial?

- **Different arguments for different channels from supplemental orbits:**
  - **Humidity-sounding channels:** Short time-scales, need for better temporal sampling
  - **Tropospheric temperature-sounding channels:** Noise-limited – multiple observations achieve effective noise reduction
  - It is not clear which of these mechanisms dominates – need to study!



Tier 2: Value of 50-GHz temperature sounding without lower frequencies?

- **Would 50-57 GHz sounding channels in supplemental orbits be useful without 24 and 31 GHz channels?**
  - For all-sky AMSU-A assimilation, 24 & 31 GHz channels are used for observation-error modelling for the lower sounding channels.
  - But an alternative error model (based on 52.8 GHz channel) allows to replicate a large proportion of the impact.
  - Provided data quality is sufficient, 50-57-GHz channels are still expected to be useful without lower frequencies.
- **50-57 GHz best suited for high-quality temperature sounding from MW (118 GHz is <u>not</u> a replacement)**



Impact of ch 5-14 AMSU-A:

Alternative error model

Original error model

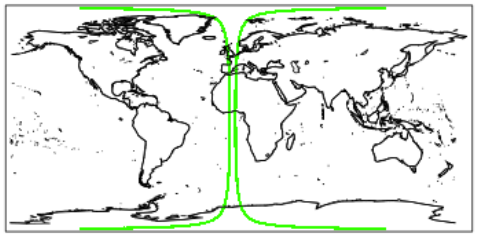
100% = No ch 5-14 AMSU-A

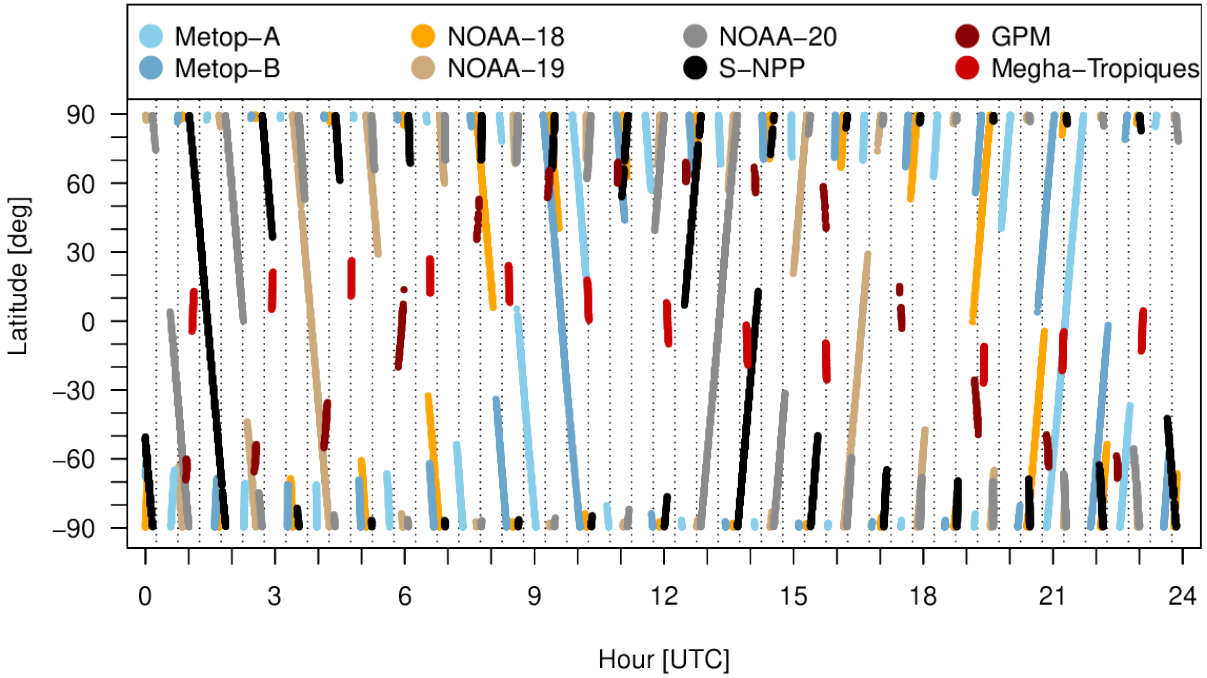
(Katie Lean)

Other thoughts on supplemental orbits augmenting the 3-orbit backbone

- **Choice of orbits**
  - Temporal coverage from MW sounding instruments is particularly lacking at lower latitudes.
  - Low-inclination orbits can address this (like Megha-Tropiques, GPM).

Temporal coverage over 500 km stripe around 0º meridian on 15 July 2018





- Should hyperspectral MW sounders be considered?

MW sounders on small satellites/cubesats for operational NWP: caveats

- **There is currently no experience with the use of MW sounders on small satellites/cubesats for operational NWP.**
  - Is the **data quality** sufficient? (e.g., noise performance, calibration, geolocation, etc)
  - Need to gain more experience with **actual performance** before committing to operational small satellite/cubesat constellations.
    - E.g., with NASA's TROPICS mission, ESA's Arctic Weather Satellite
  - Shorter life-times will pose a challenge for operational use in NWP
    - Currently, it takes 6-12 months to get new data into an operational NWP system
    - Shorter life-time will significantly increase maintenance efforts

Summary of main points

- **MW sounders are critical for operational NWP and reanalyses**
  - Large impact through good-quality observations in multiple orbits, all-sky usage
- **Continued benefit from assimilating more MW sounders**
  - Established benefit beyond the 3-orbit backbone system
- **Old POES satellites still provide useful impact through complementing orbits**
  - Strongly recommend continued data provision as long as instrument health allows
- **MW sounding from small-satellites/cubesats is attractive to supplement the 3-orbit back-bone system long-term**
  - Need to establish whether actual achieved performance is adequate for operational NWP (e.g., in terms of noise, calibration, geo-location, etc)
  - Studies needed to trade-off capabilities/performance/sampling/cost etc
  - Recommend international cooperation to ensure best complementarity of systems
- **The 3-orbit back-bone system remains critical**
  - Need to ensure continuity and **<u>further advancement</u>** of high-end MW sounding with full capabilities.