

# Using satellite soundings at ECMWF and future plans

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- A light gray world map with the 34 member and co-operating states of the ECMWF highlighted in a darker blue color. These states are primarily located in Europe, North Africa, and the Middle East.
- 34 Member and Co-operating States
  - 350 staff +, from 30 countries

Operational global NWP system:

- High-resolution model at  $T_{Co}$  1279 (9 km)
- 4D-Var, 12-hour window, final incremental resolution  $T_L$  399 (50km)
- EDA, ENS, SEAS5, NEMO, ...
- Reanalyses, Atmospheric Chemistry analyses



# Outline

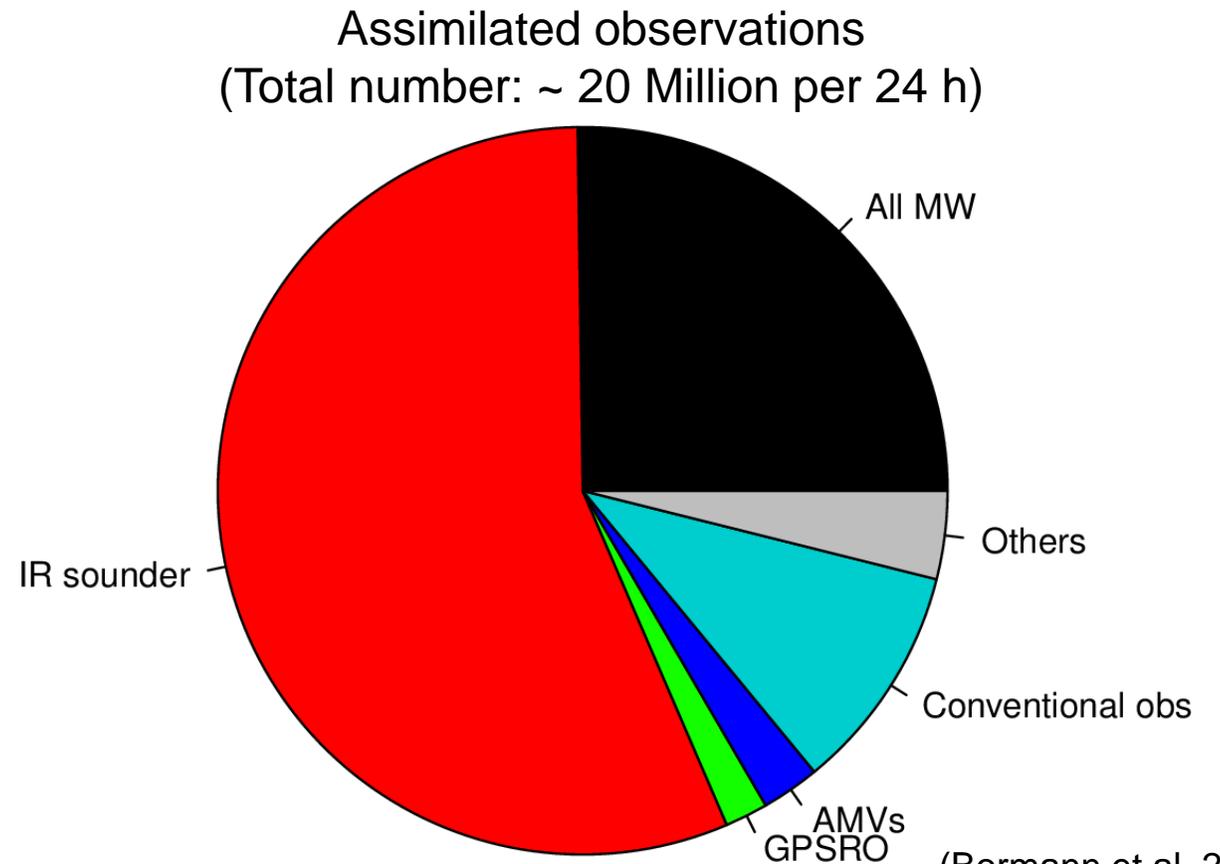
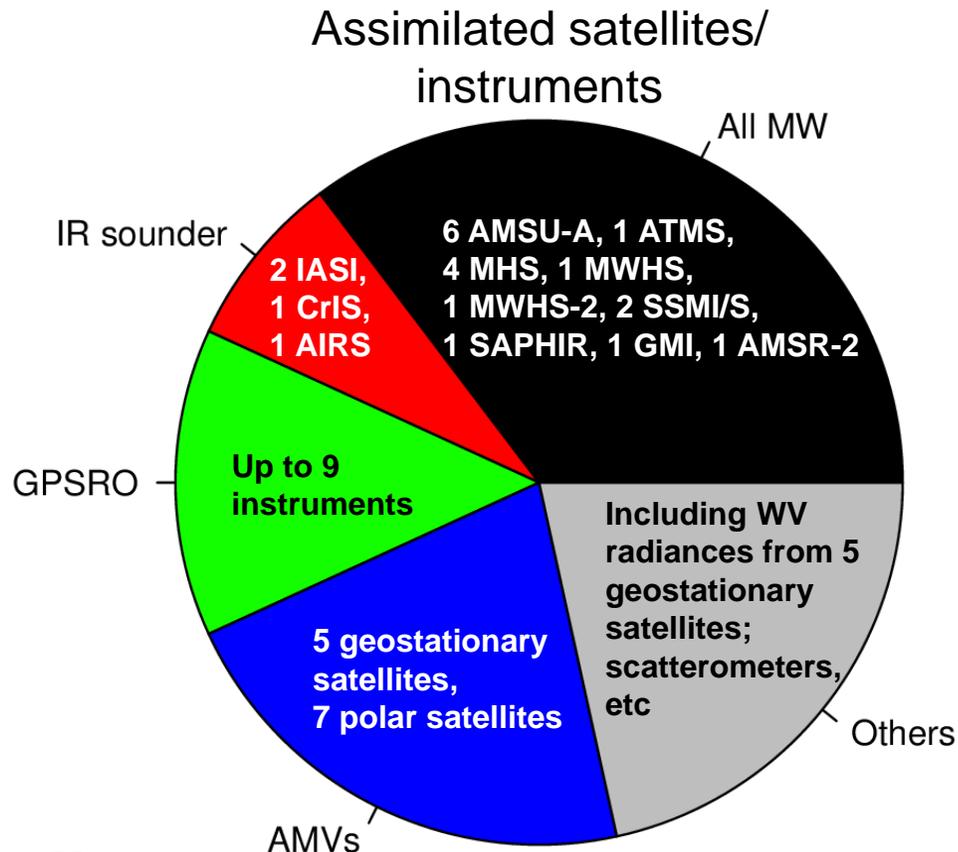
- 1. What satellite data do we assimilate? What is the impact?**
- 2. A look at the MW sounder constellation**
- 3. New observations and recent trends**
- 4. Additional points**
- 5. Summary and outlook**

# What satellite data do we assimilate?

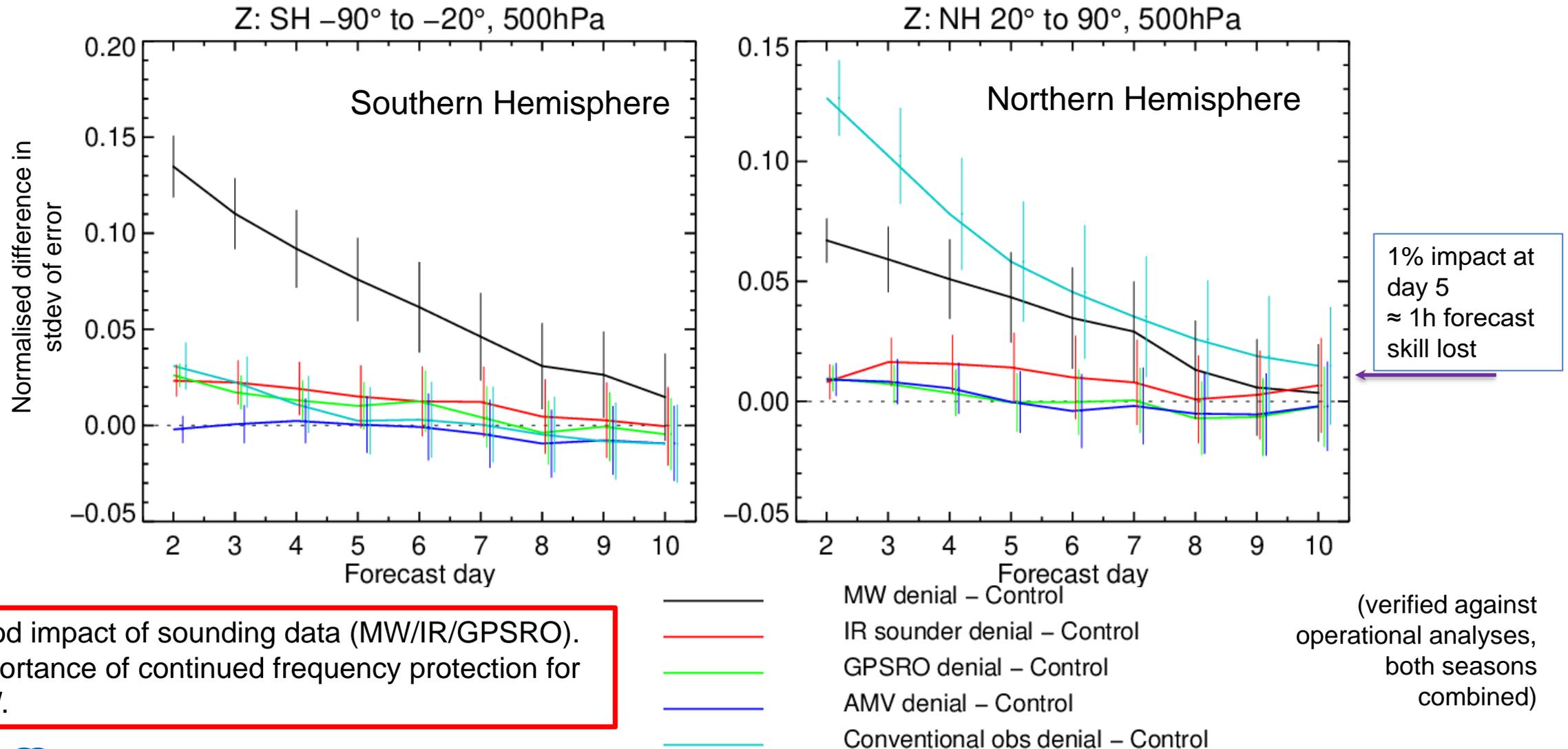
Observing system	
<b>Atmospheric sounding radiances</b>	AMSU-A: NOAA-15, -18, -19; Aqua; Metop-A, -B, -C MHS: NOAA-19; Metop-A, -B, -C ATMS: S-NPP, NOAA-20 MWHS-2: FY-3C, -3D SSMI/S: F-17, -18  AIRS: Aqua IASI: Metop-A, -B, -C CrIS: S-NPP, CrIS
<b>Radiances from atmospheric imagers</b>	SSMI/S (F-17); AMSR-2; GMI; MWRI (FY-3D)  CSR/ASR from Meteosat-8, 11; Himawari-8; GOES-16, -17
<b>Atmospheric Motion Vectors (single level winds)</b>	Meteosat-8, -11; Himawari-8; GOES-16, -17  Metop-A, -B, -C, dual Metop; NOAA-15, -18, -19; S-NPP, NOAA-20; Aqua
<b>GPS-RO (bending angles)</b>	Metop-A, -B, -C; COSMIC-1, -2 constellations; FY-3C; KOMPSAT-5; TERRASAR-X; TANDEM-X; SPIRE (13 May - 30 Sept 2020)
<b>Wind lidar (line-of-sight wind profiles)</b>	Aeolus
<b>Scatterometer (ocean surface winds)</b>	Metop-A, -B, -C

# How do we assess their impact? Observing system experiments

- Denial experiments compared to a full system for:
  - Conventional observations, MW radiances, AMVs,
  - IR sounders, GPSRO
- Periods: 1 June – 30 September 2016; 1 December 2017 – 31 March 2018; (ie 2 x 4 months)



# Medium-range impact: Z 500 hPa



- Good impact of sounding data (MW/IR/GPSRO).
- Importance of continued frequency protection for MW.

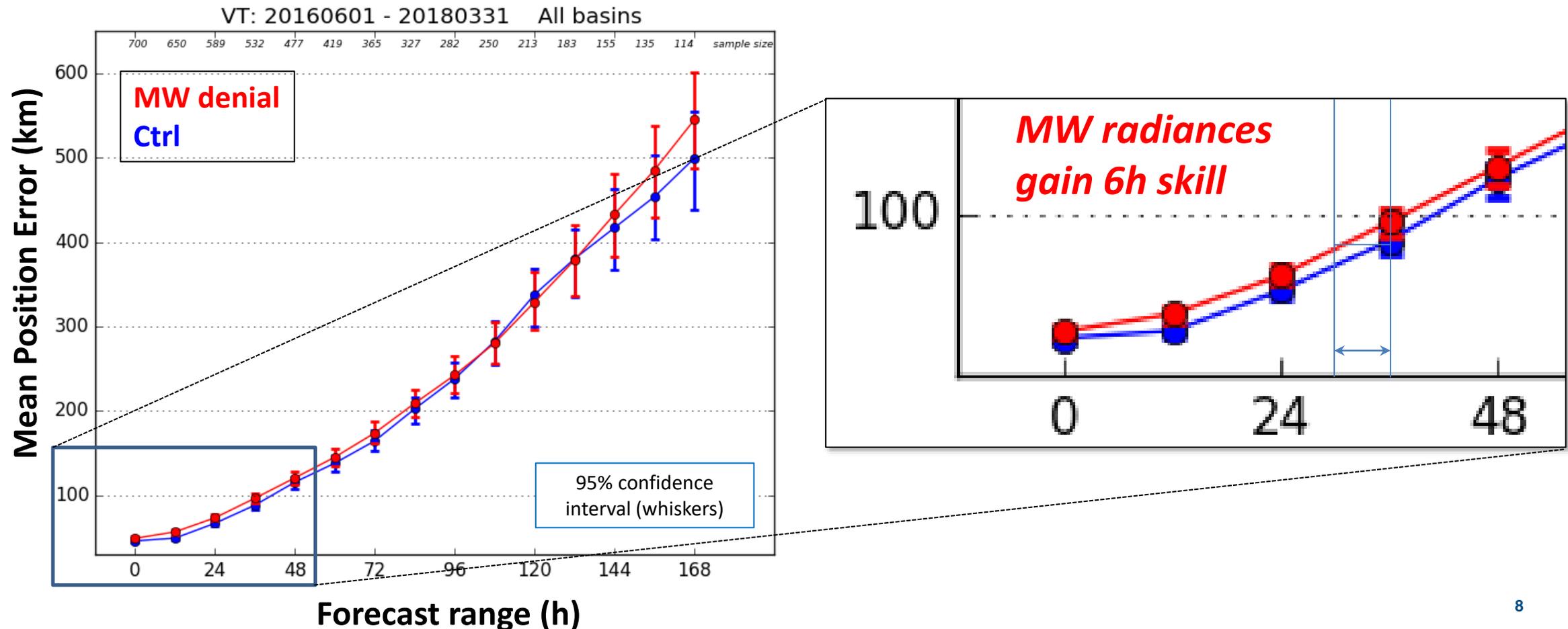
# Impact of MW radiances on tropical cyclone forecasts

(Fernando Prates)

All basins, homogeneous samples,

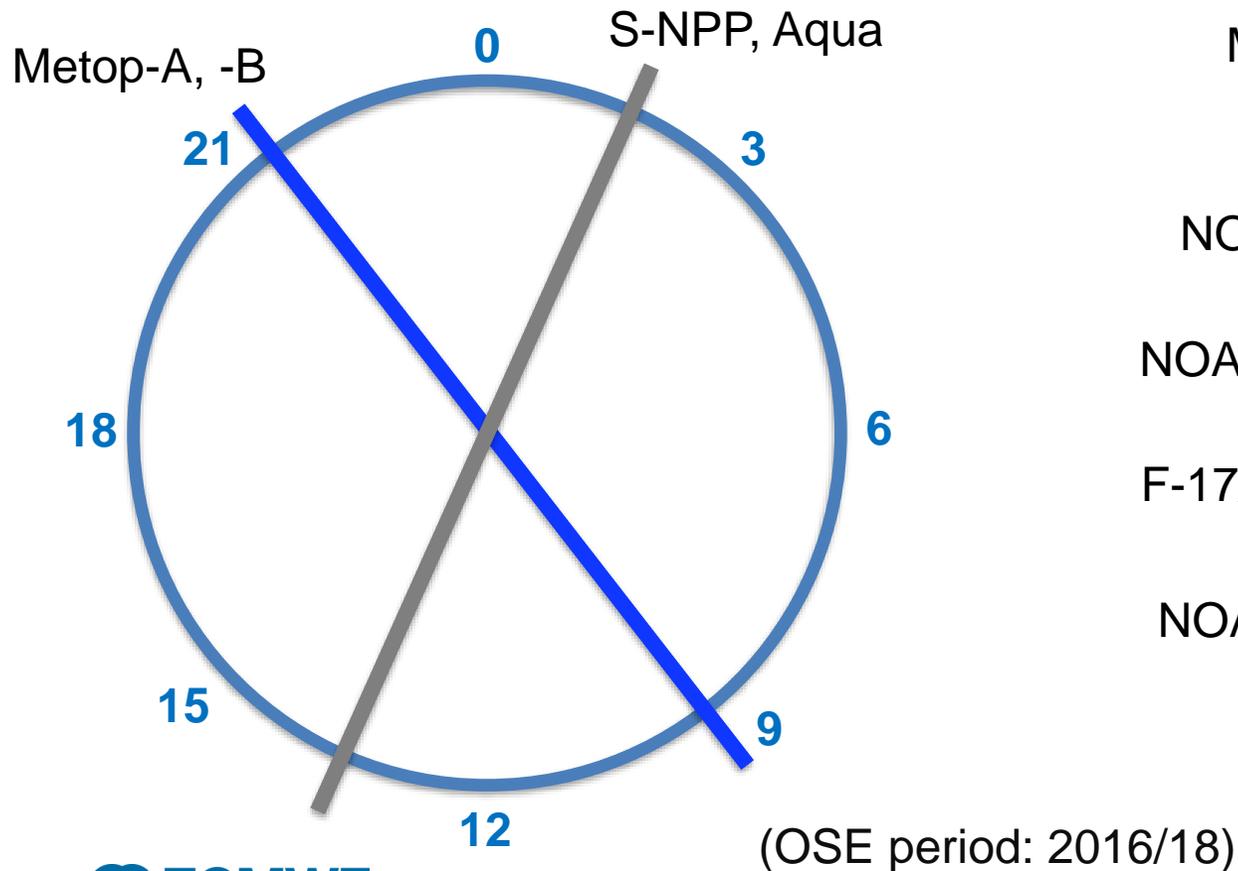
1 June – 30 September 2016; 1 December 2017 – 31 March 2018; (ie 2 x 4 months)

*Note: Spatial resolution TCo399 (~28km) much lower than operations*

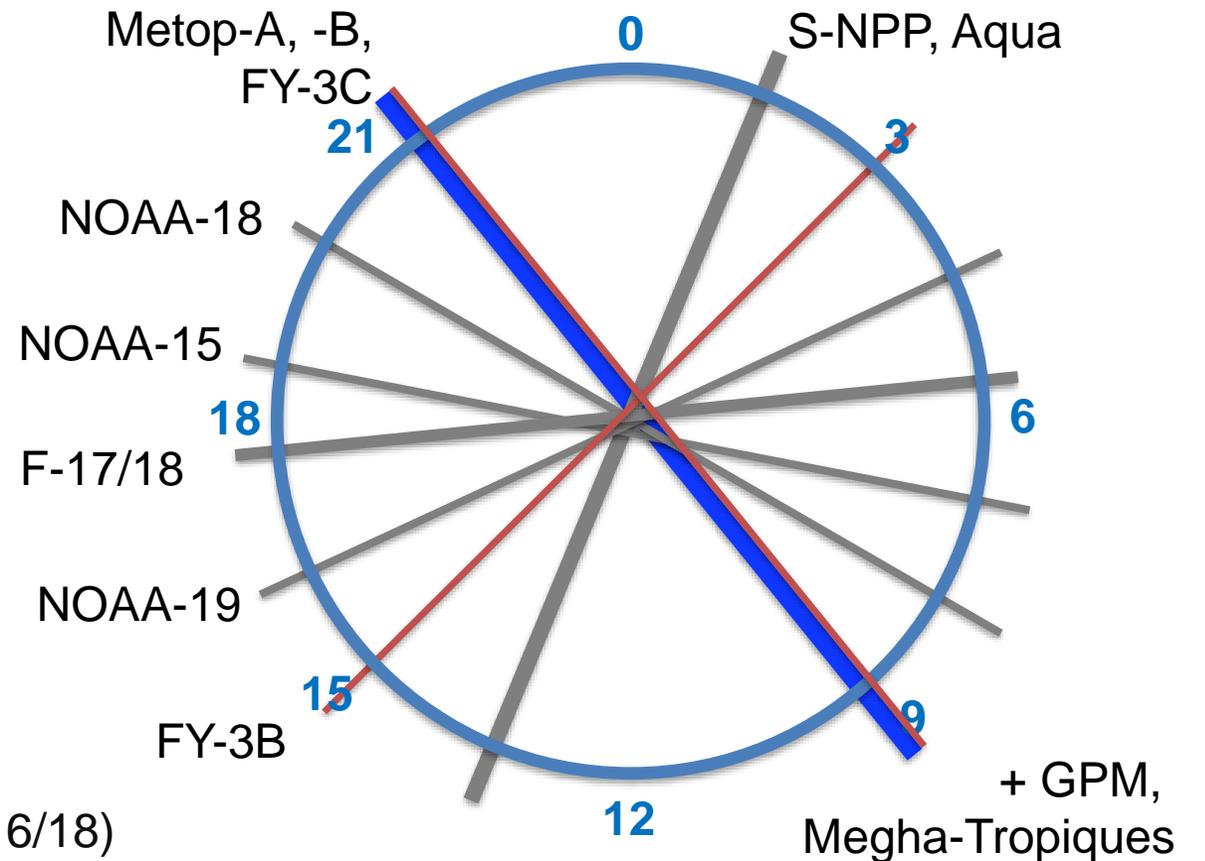


# Why is there such a strong impact from MW radiances?

**Hyperspectral IR:**  
2 orbital planes;  
Only clear channels assimilated



**MW sounding:**  
Many orbital planes;  
Increasingly assimilated in **all-sky**



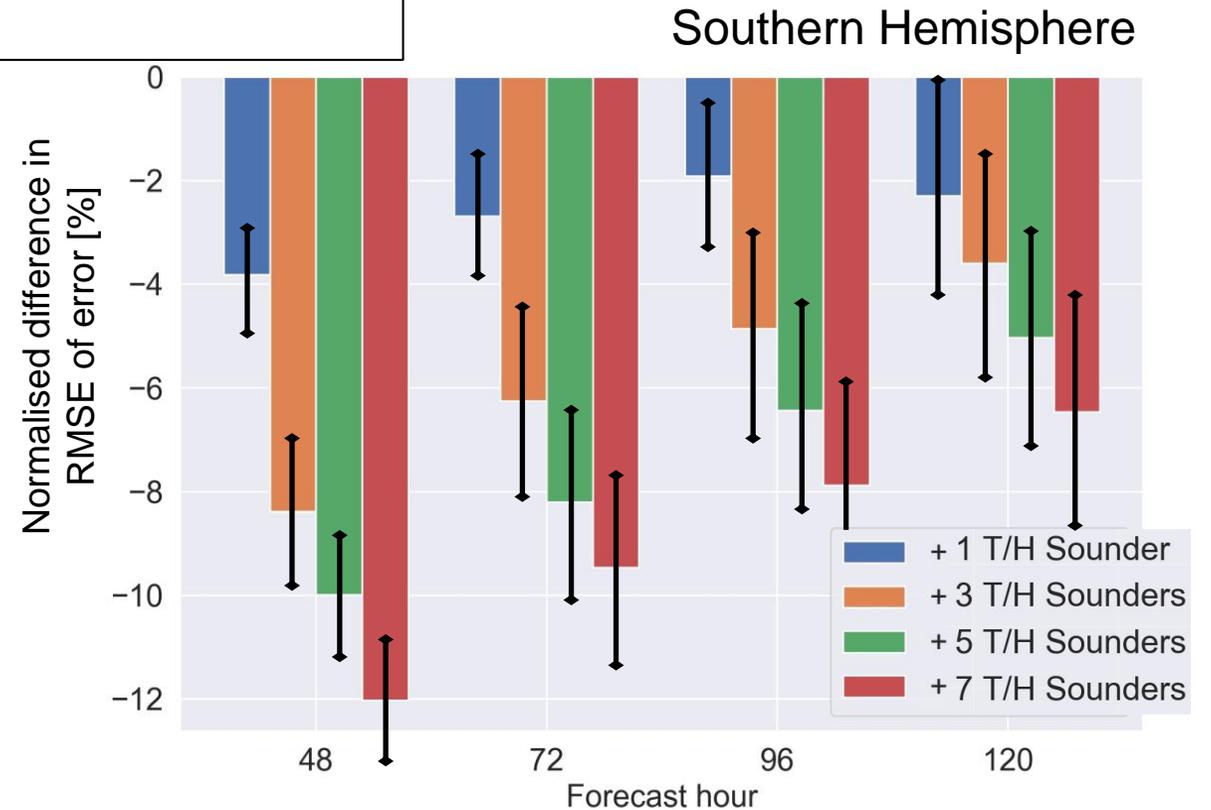
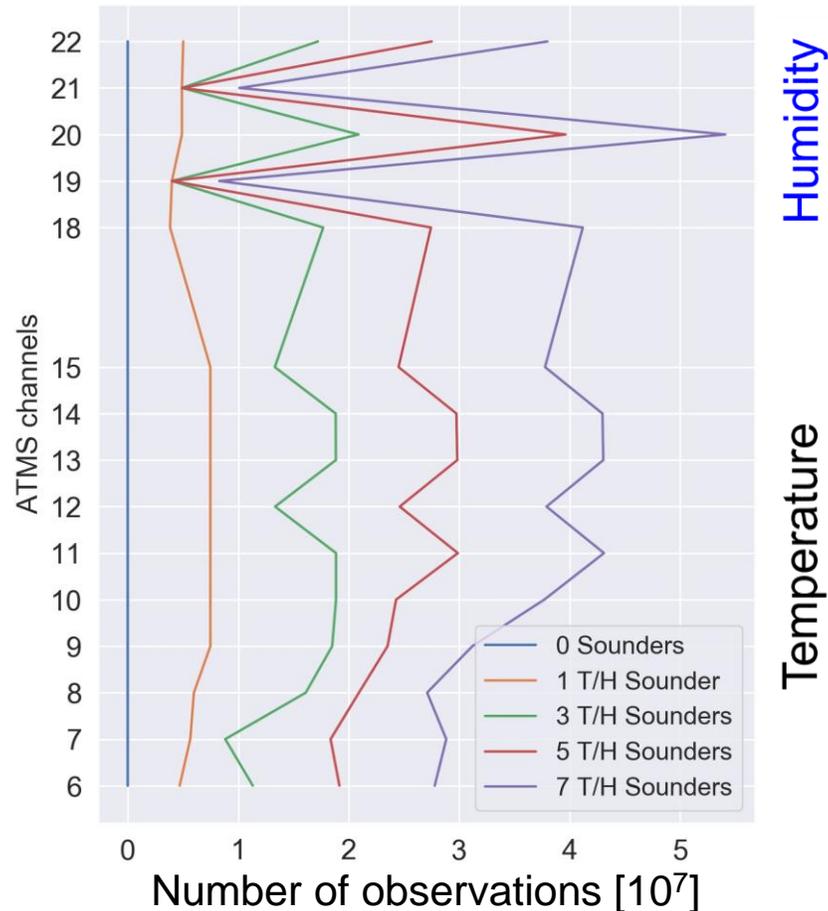
# Continuing benefits from additional MW sounders: Z 500 hPa RMSE

(David Duncan)

**Control:** Full observing system, but no microwave sounding data

**Experiments:** Control + either 1 / 3 / 5 / 7 MW sounders

**Period:** 1 June – 15 September 2018



**No indication of saturation of further benefits.**

Further improvements from even better temporal sampling?  
How to maintain this constellation?

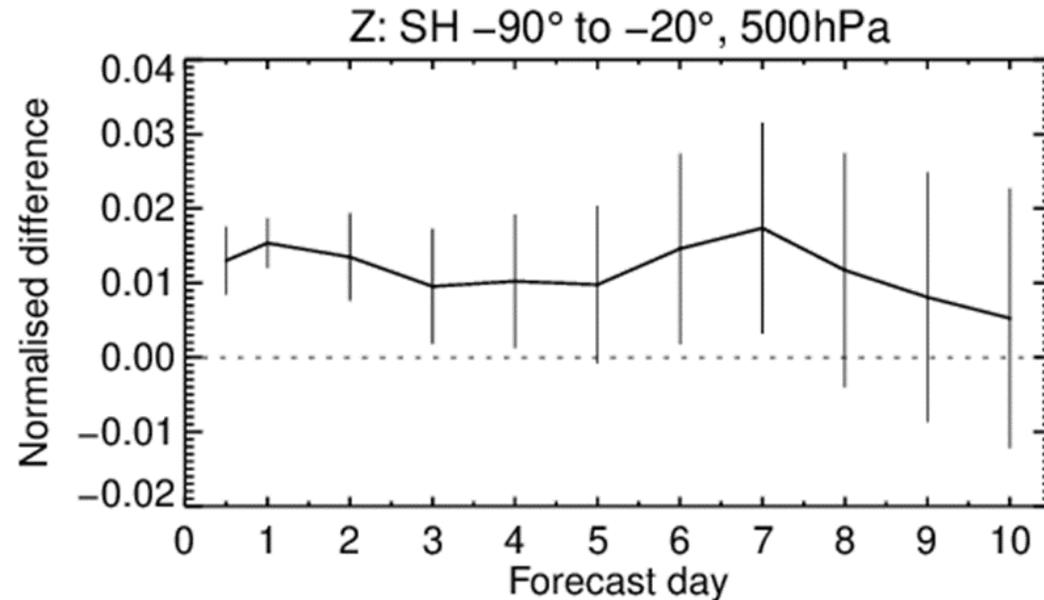
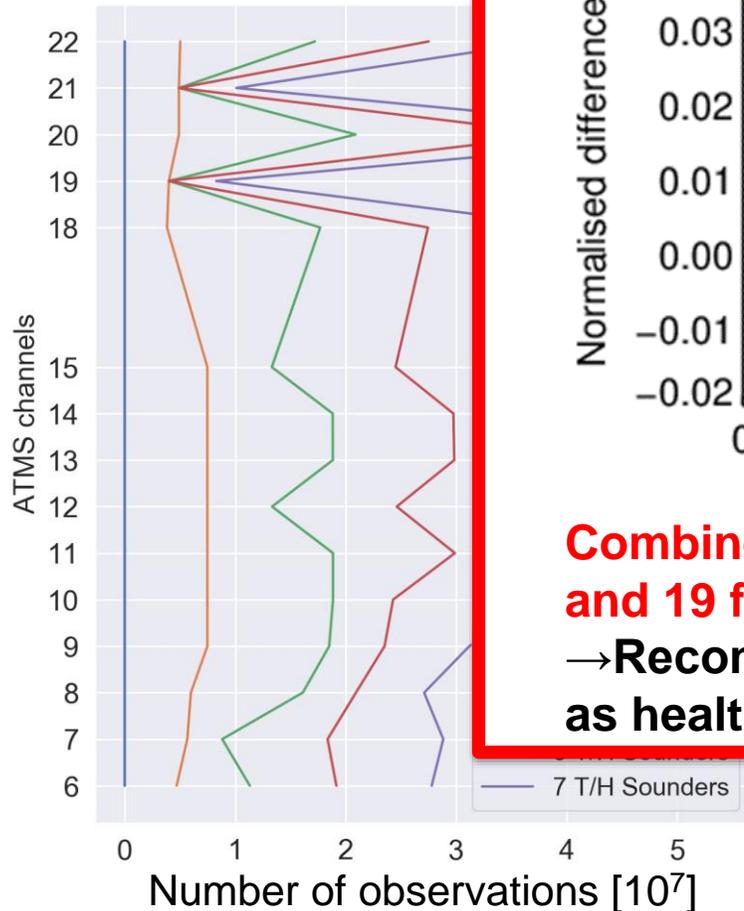
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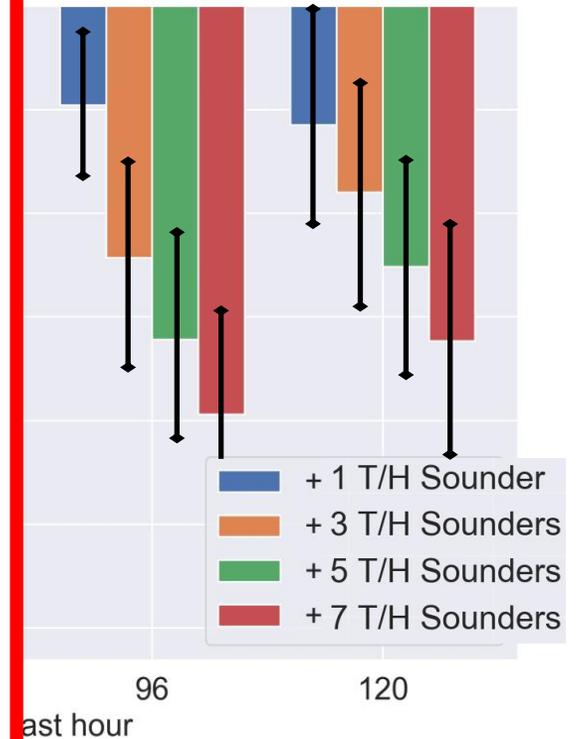
**Period:** 1 June – 15 Sep



**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



**No indication of saturation of further benefits.**

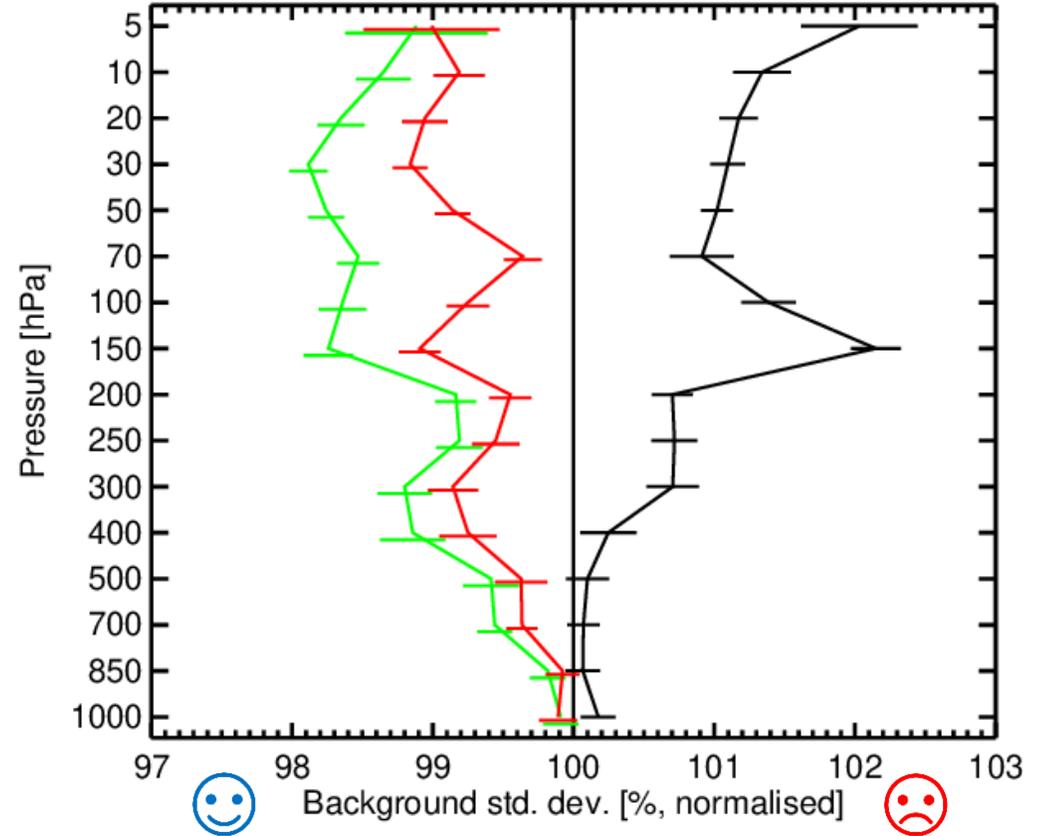
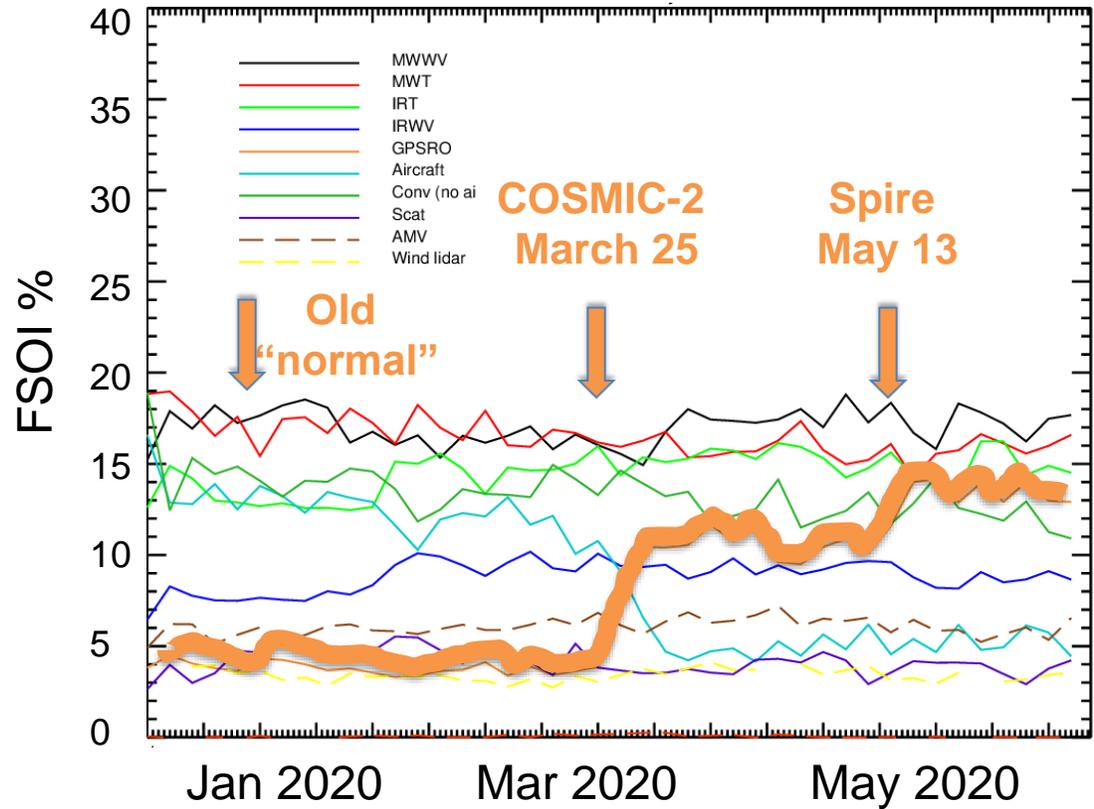
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# Increasing impact from more GPS-RO data: COSMIC-2, Spire

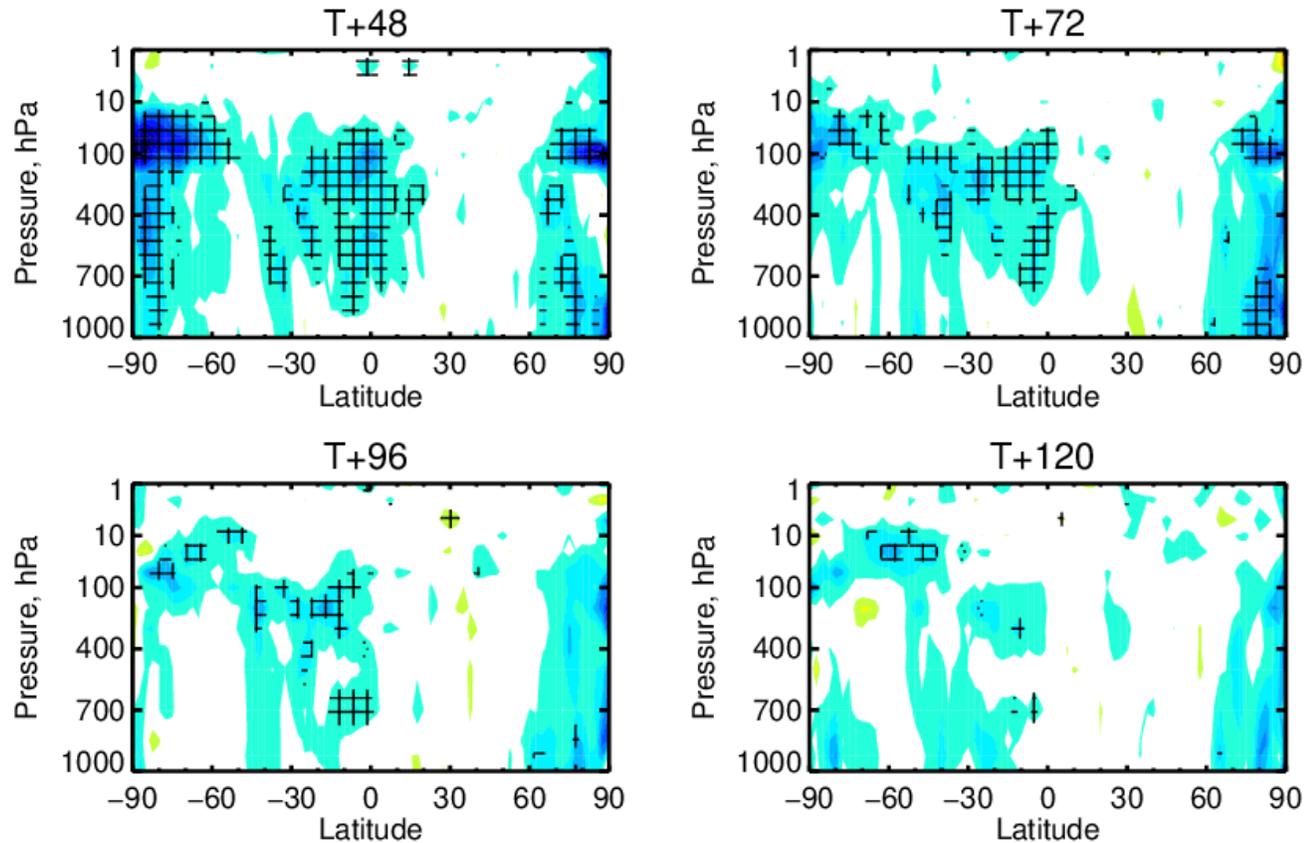
Radiosonde temperatures, global,  
(1 Jan – 31 March 2020)



Large increase in assimilated GPS-RO data (5 times!)  
→ large increase in impact; incl **tropospheric humidity in tropics**

# New observations: Strong impact from Aeolus line-of-sight wind profiles

Relative change in wind RMSE, 2 April – 1 Sept 2020



**First wind lidar in space**, flown by ESA.

Good **positive impact** from assimilating Rayleigh-clear and Mie-cloudy winds.

Note: Aeolus <1 % of the total number of assimilated observations!

**Operationally assimilated since 9 January 2020.**

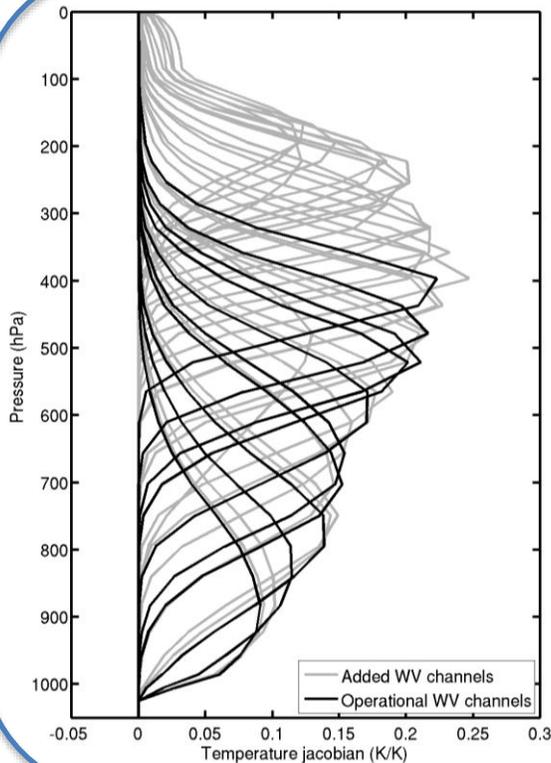
**How do we ensure a follow-on?**



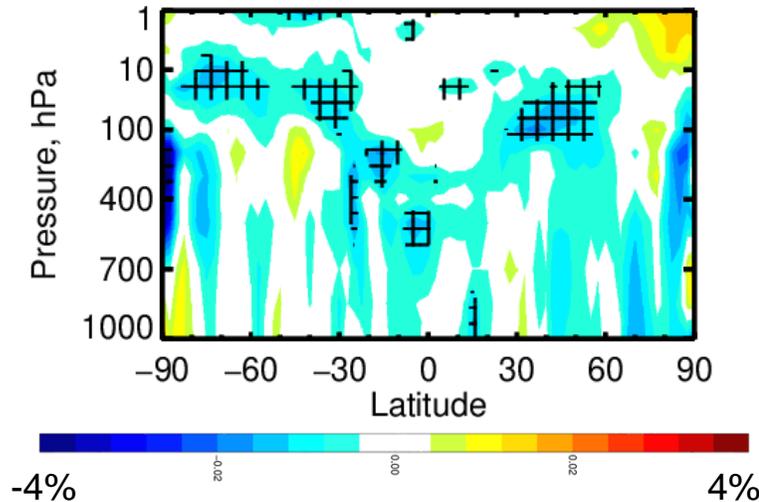
**Better with Aeolus**

# Increased impact of IR observations

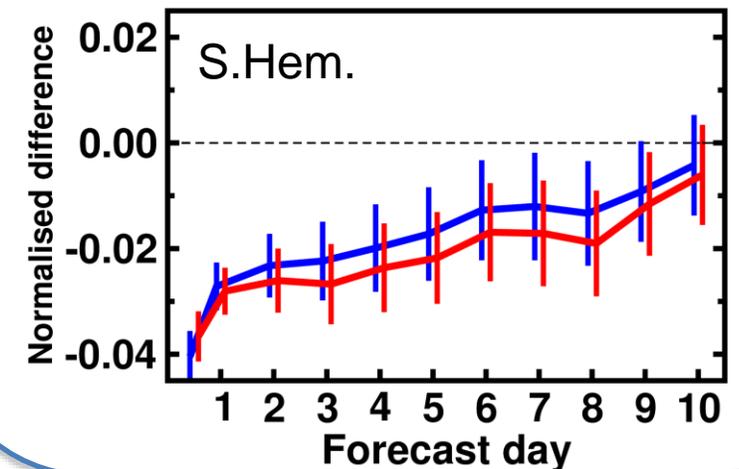
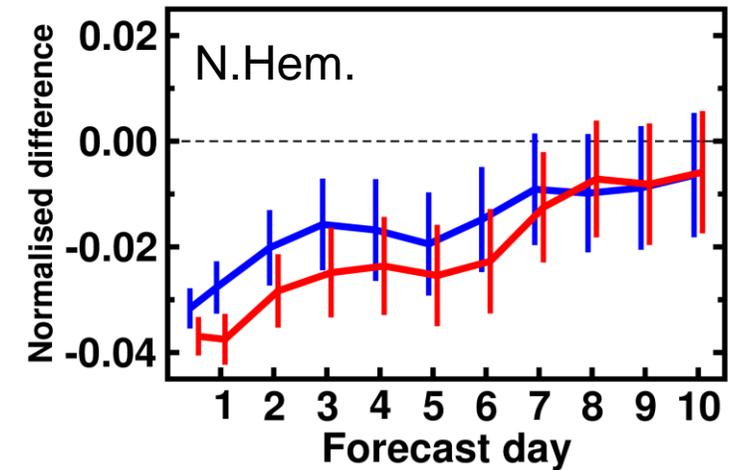
- Added data over land
- Added more WV channels
- Looking into adding data from Russian or Chinese instruments



Impact of assimilating 39 rather than 10 WV channels from IASI, change in RMSE Z at T+72h

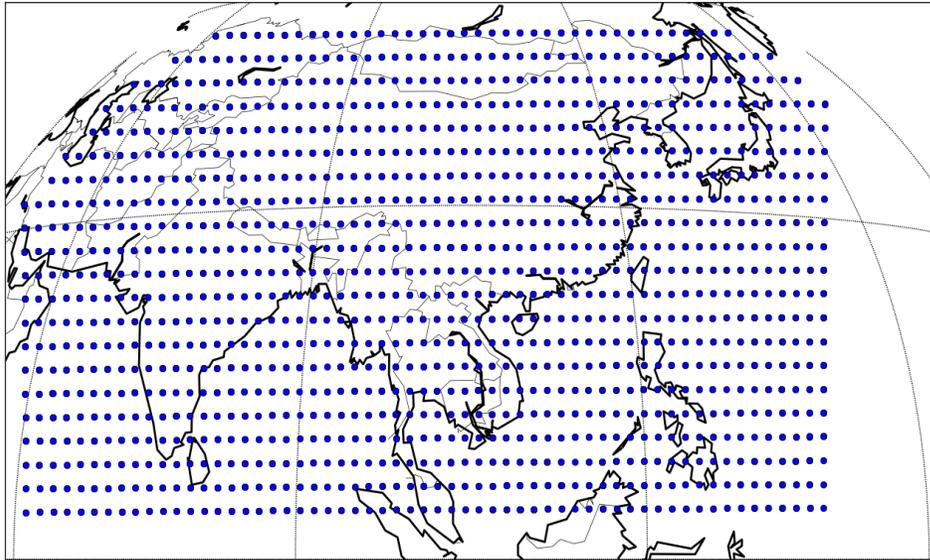


Impact of IR observations **with** and **without** adding data over land on Z500 RMSE.

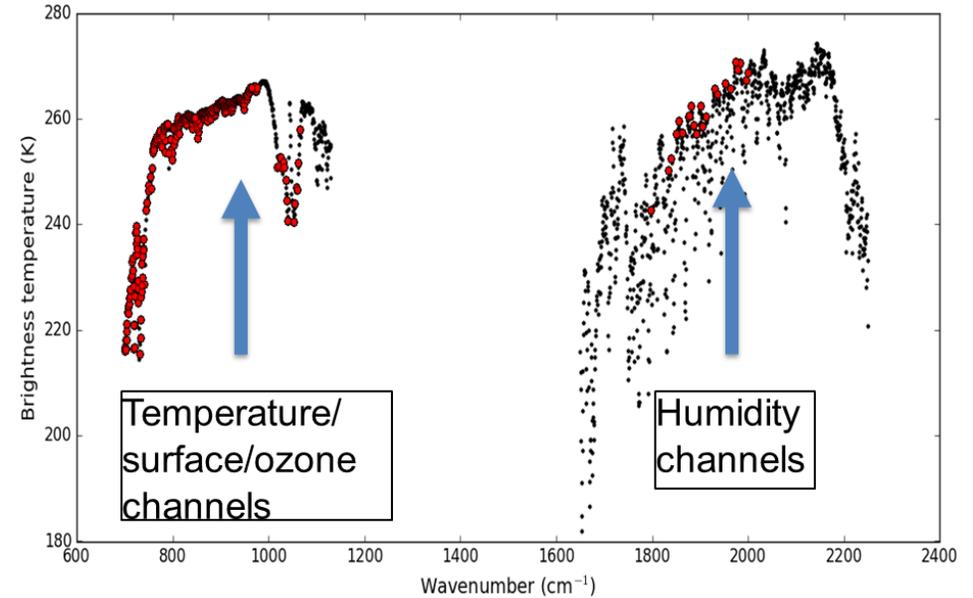


# Geostationary hyperspectral IR: GIIRS and looking towards MTG-IRS

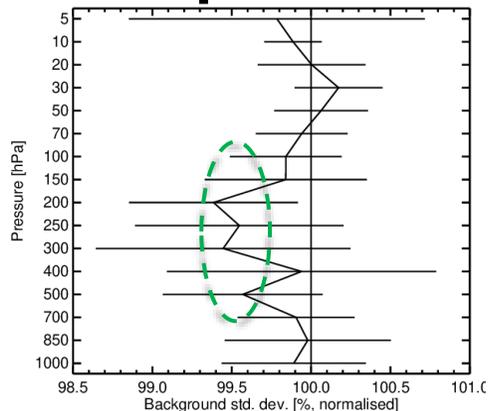
## GIIRS spatial data selection (2hr repeat)



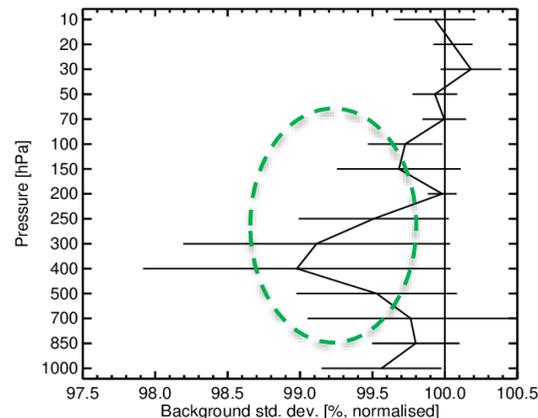
## GIIRS spectral channel selection (red)



## Temperature



## Wind



The GIIRS hyperspectral GEO already showing a positive impact!

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## Additional points

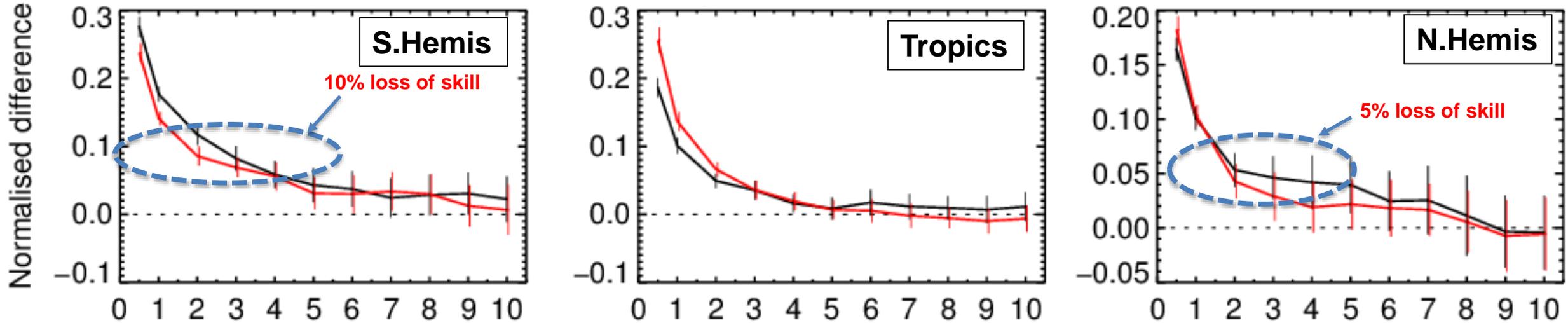
- **Data quality**, stability, pre-launch characterisation, usability, etc are all critical.
- Importance of a **back-bone satellite sounding system** as outlined in the **Vision for WIGOS 2040**.
- **Timeliness** is critical for operational NWP.
  - The observations that have last seen the atmosphere are the most valuable. Any reduction in data timeliness will lead to better impact in the ECMWF system.
- Importance **of inter-agency cooperation and data exchange**.

# Importance of data exchange

What if we only had US satellites? What if we only had European satellites?



Medium-range forecast error degradation compared to **control** (500hPa)



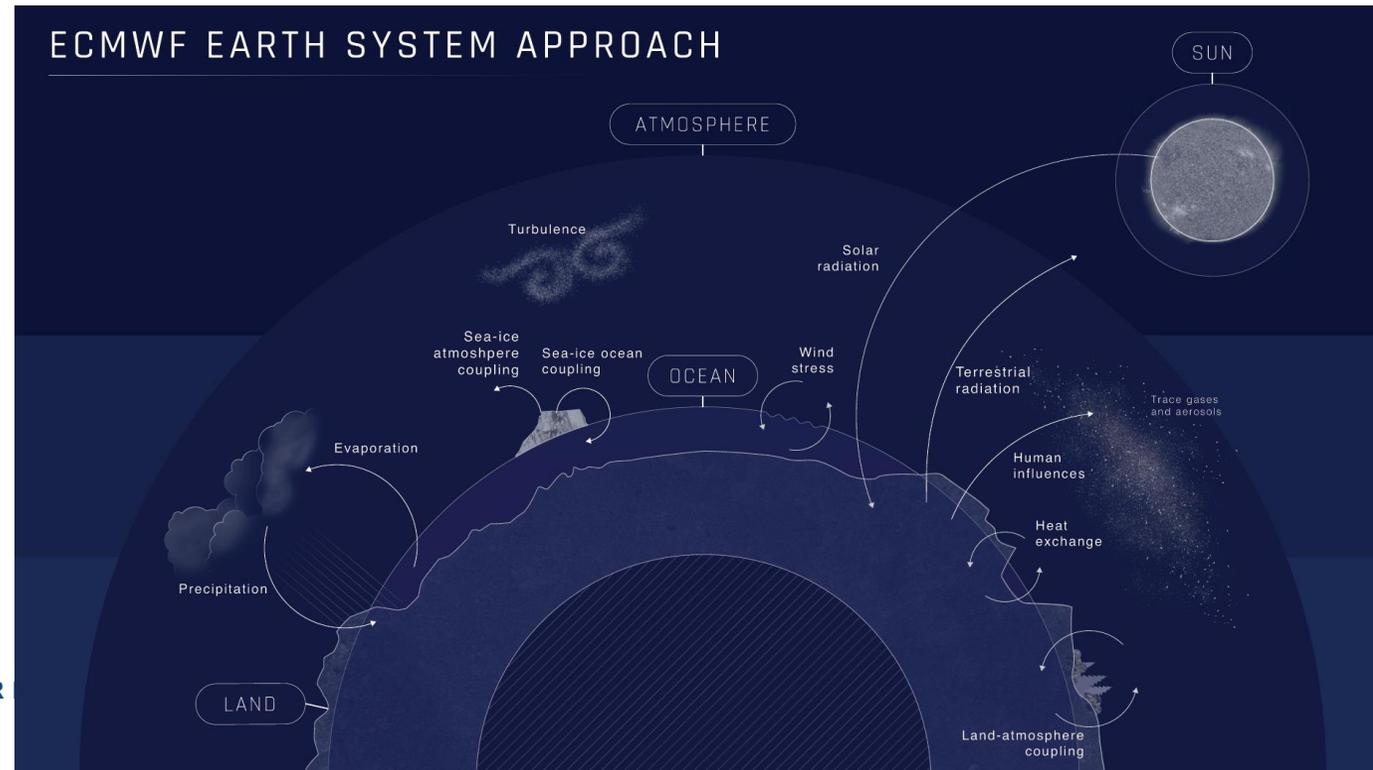
- Using **only US** or **only EU** satellite data gives forecasts **significantly inferior to the control**. ....successful inter-agency data exchange continues to be vital.
- Combined benefit of **old NOAA satellites** (different orbital planes) and microwave imagers produces a slight US advantage over Europe...

# Summary

- **Satellite sounding data is essential for NWP**
  - Complementing impact from MW, IR, GPSRO; essential back-bone (→Vision for WIGOS 2040)
  - Achieved with stable, good quality data with long life-times
- **Strong impact from MW data – and benefits from adding more MW sounders**
  - All-sky usage + current diversity of orbits
  - Vital to protect these frequencies from Radio Frequency Interference
- **Old POES satellites still provide useful impact through complementing orbits**
  - Strongly recommend continued data provision as long as instrument health allows.
- **Excellent impact from new and additional observations**
  - GPS-RO data, including COSMIC-2
  - Aeolus wind lidar. How do we ensure a follow-on?
  - Continued benefits from a better exploitation of existing data; prospects for geo hyperspectral IR
- **Importance of inter-agency cooperation and data exchange**

# Outlook

- **Looking forward to new data, e.g.:**
  - FY-3E (early-morning), EPS-SG (including completely new capabilities, e.g.: Ice Cloud Imager), JPSS-2, etc
  - MTG, including IRS
  - Constellations of small satellites, e.g., TROPICS
  - EarthCare
  - **New opportunities for observing humidity dynamics, cloud characteristics and evolution, etc**
- **Data assimilation for NWP is moving towards high-resolution Earth System Assimilation:**
  - Coupled systems, incl. ocean, land, cryosphere, etc
  - “All-sky, all-surface” assimilation: use information currently discarded



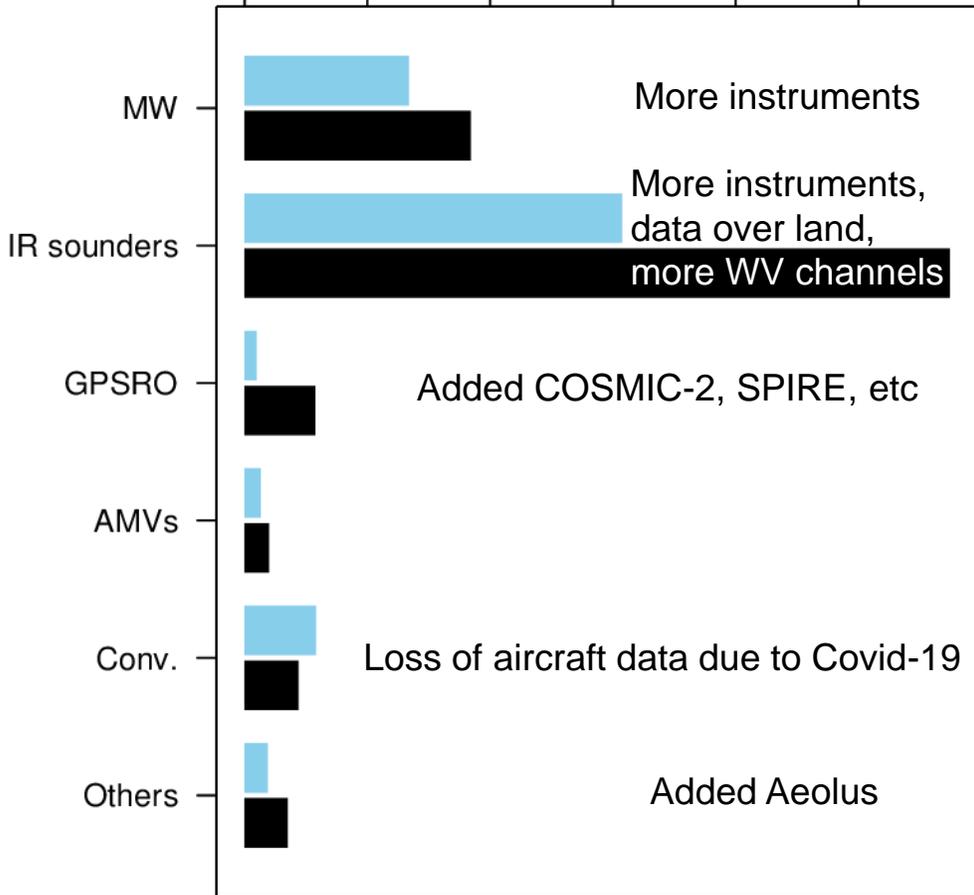


# Forecast Sensitivity to Observation Impact (FSOI) then and now

Number of observations per 12h [Million]

0 2 4 6 8 10

OSE periods (2016/2018)  
May 2020



**Slightly less impact from MW data**

**Slightly more impact from IR data**

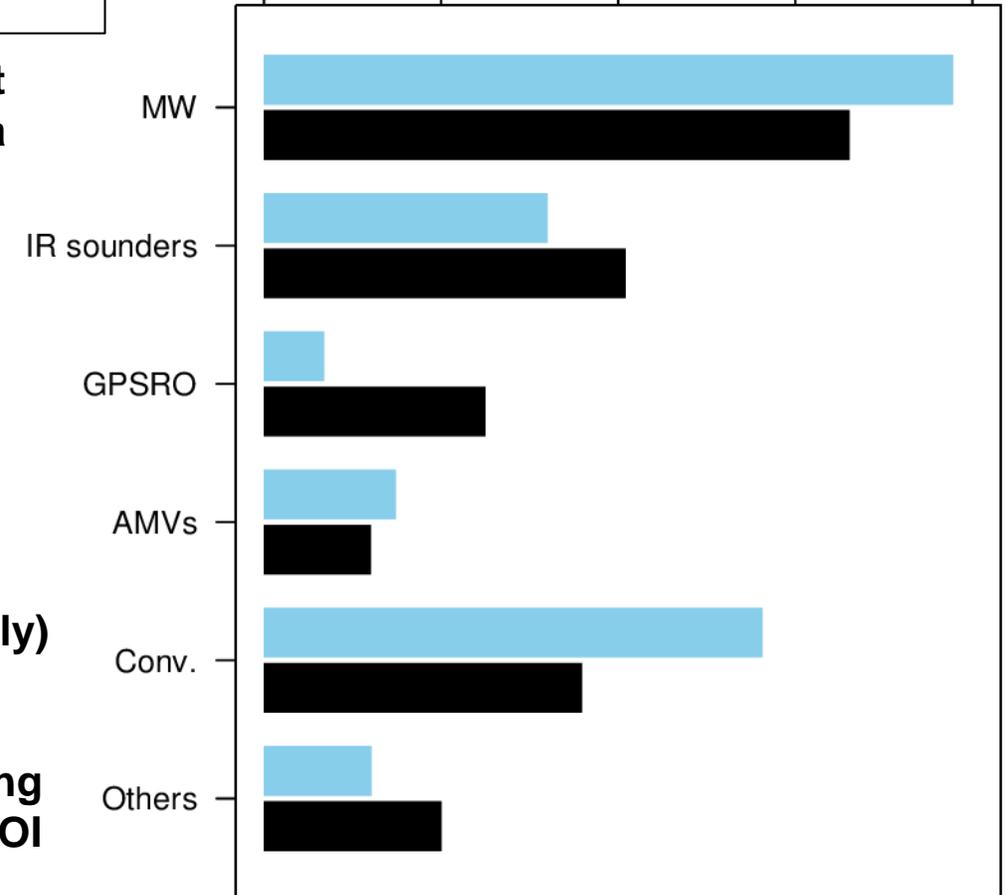
**Much more impact due to 6x as much data**

**Less impact (temporarily)**

**Aeolus contributing ~ 3% FSOI**

Total FSOI [%]

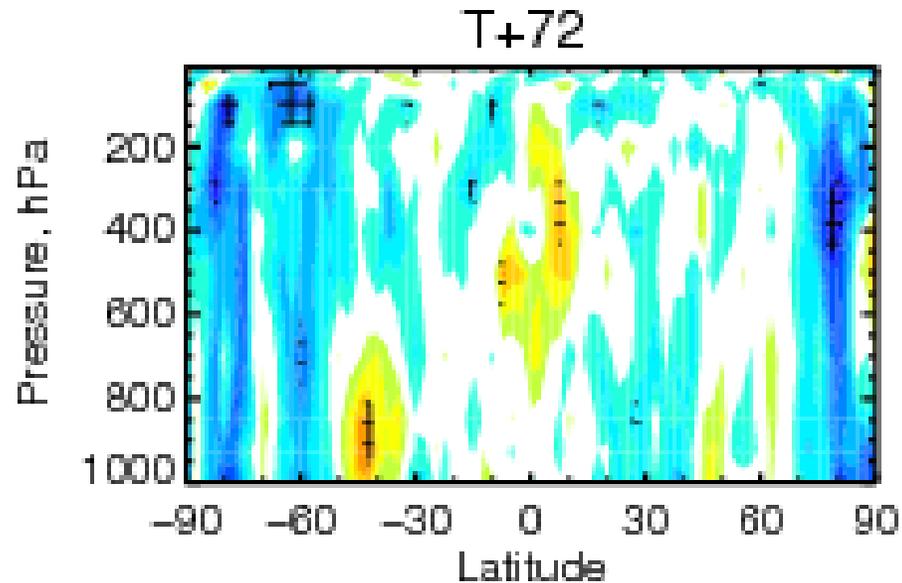
0 10 20 30 40



# All-sky assimilation

Radiance assimilation in 4D-Var also provides wind information through tracer effect e.g. MHS.  
Much enhanced with an all-sky assimilation approach.

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



-4%

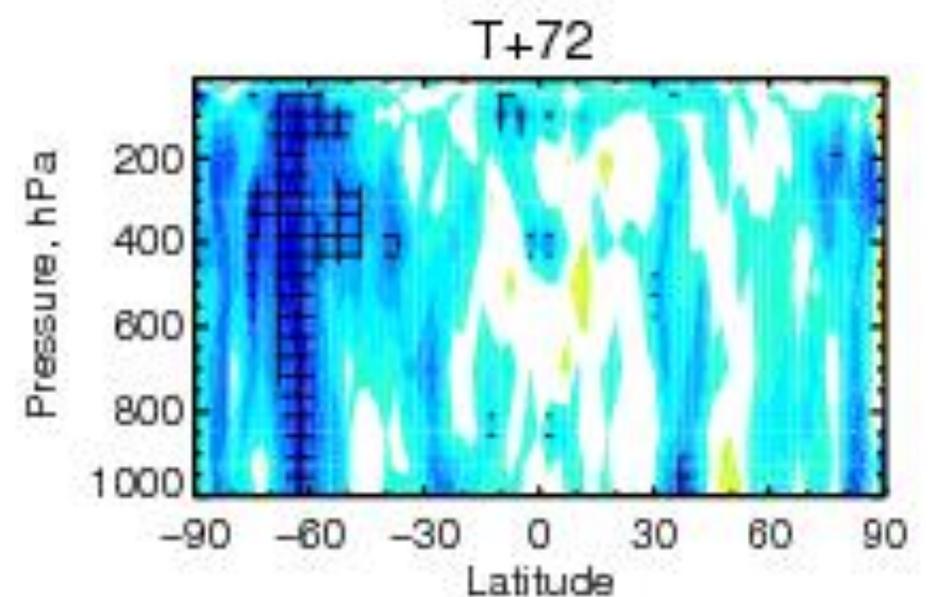
-2%

0%

2%

4%

Clear-sky MHS impact



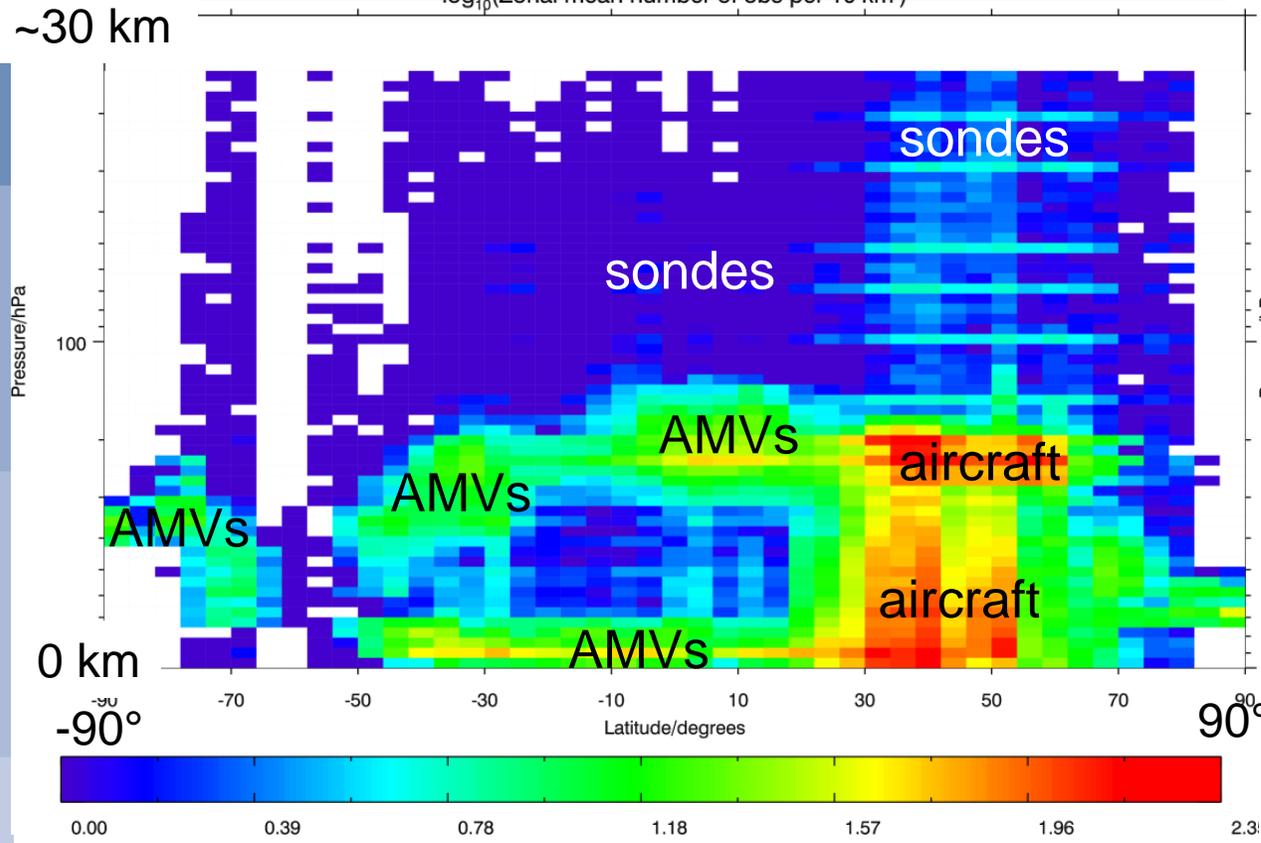
All-sky MHS impact

Achieved through consistent microphysics, sophisticated description of obs error, realistic RTM, moist physics in linear model in 4D-Var (though evidence EnKF can do the same job).

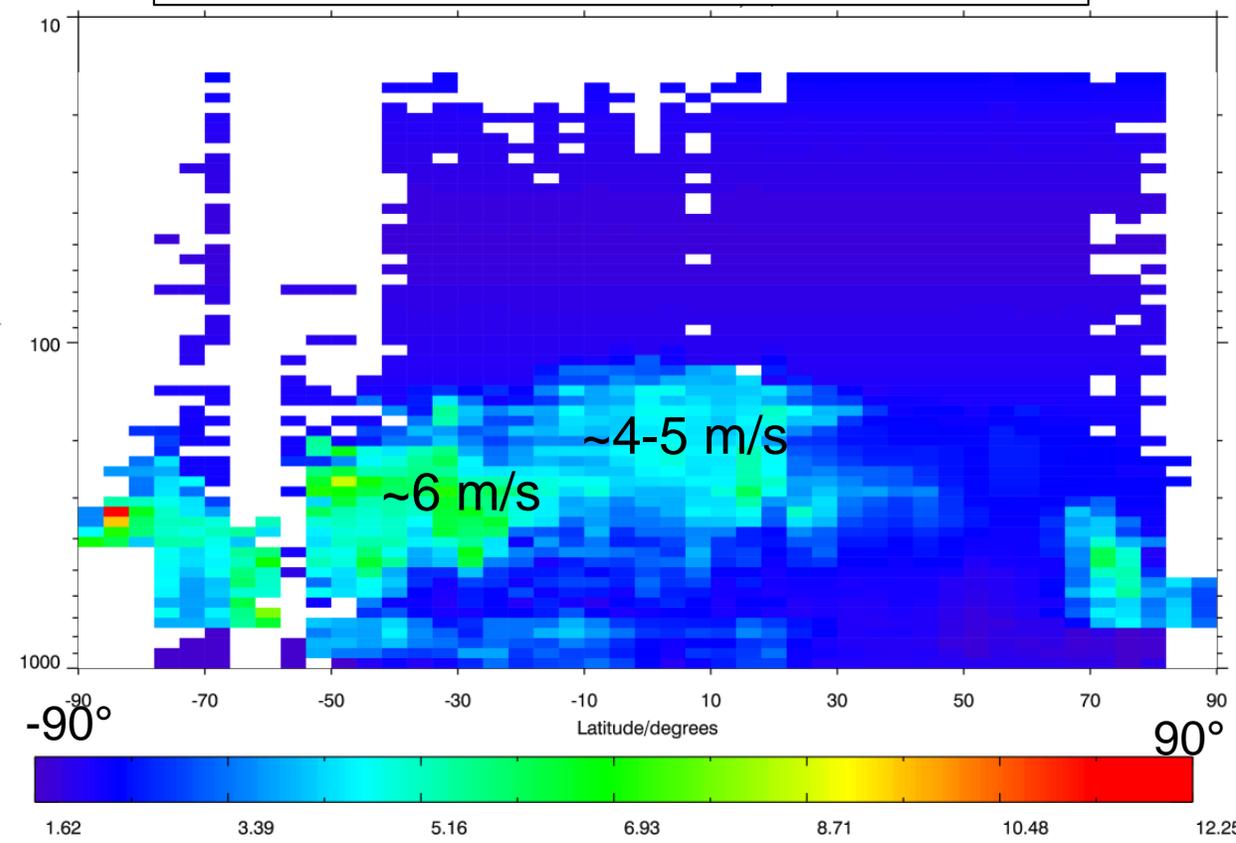
# Gap analysis – lack of wind observations recognised

AMVs, Scatterometer, Radiosonde, Pilot, Aircraft...all well known, none fully meet the requirement

Zonal mean:  $\log_{10}(\text{number of obs per area})$



Zonal mean: assigned obs error (m/s)



Aeolus wind errors are larger than conventional and scatterometer, but mostly smaller than AMVs

# NWP is using more observations => Better forecasts

