Prospects for MW sounding constellations and use of CYGNSS data at ECMWF

Niels Bormann, Katie Lean, Dave Duncan, Sean Healy

With special thanks to: Dirk Schüttemeyer(1), Jean-Christophe Angevain(1), Ralf Bennartz(2), Janet Charlton(3), Frank Fell(4), Bruno Picard(5), Peter Senior(6)

(1) ESA/ESTEC, (2) Vanderbilt Uni., (3) JCR Systems Ltd, (4) Informus GmbH, (6) Fluctus SAS, (6) In-Space Missions Ltd

Outline

1. Benefit from more MW sounders
2. A glimpse at validated TROPICS pathfinder data
3. Plans for using CYGNSS data

ECMWF

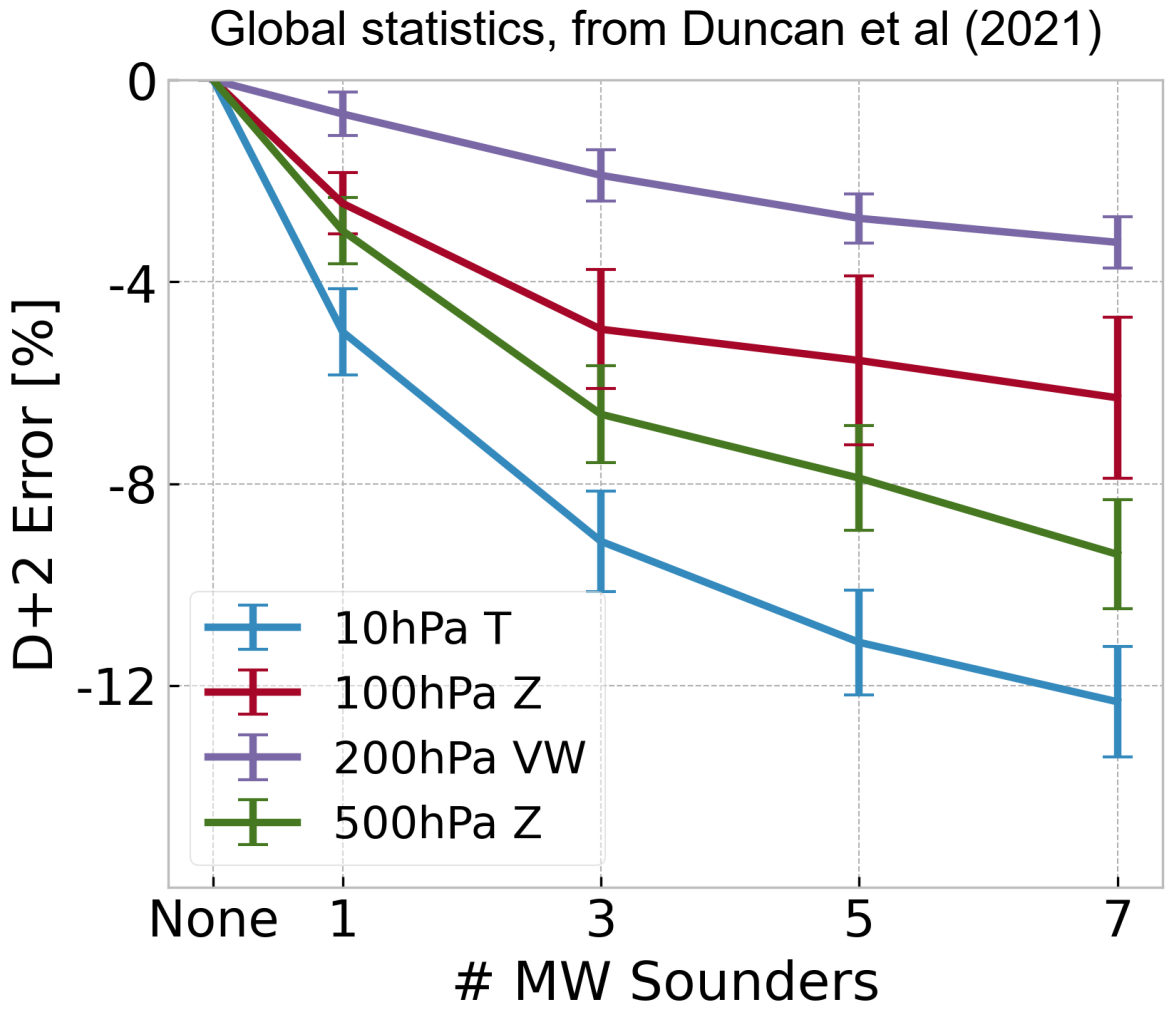
More MW sounders, better impact

Experience with existing real MW sounders: The more sounders we add, the better the forecast impact.

- Based on experimentation with current heritage instruments from NOAA, JPSS, Metop, and DMSP satellites (see Duncan et al 2021, QJRMS)

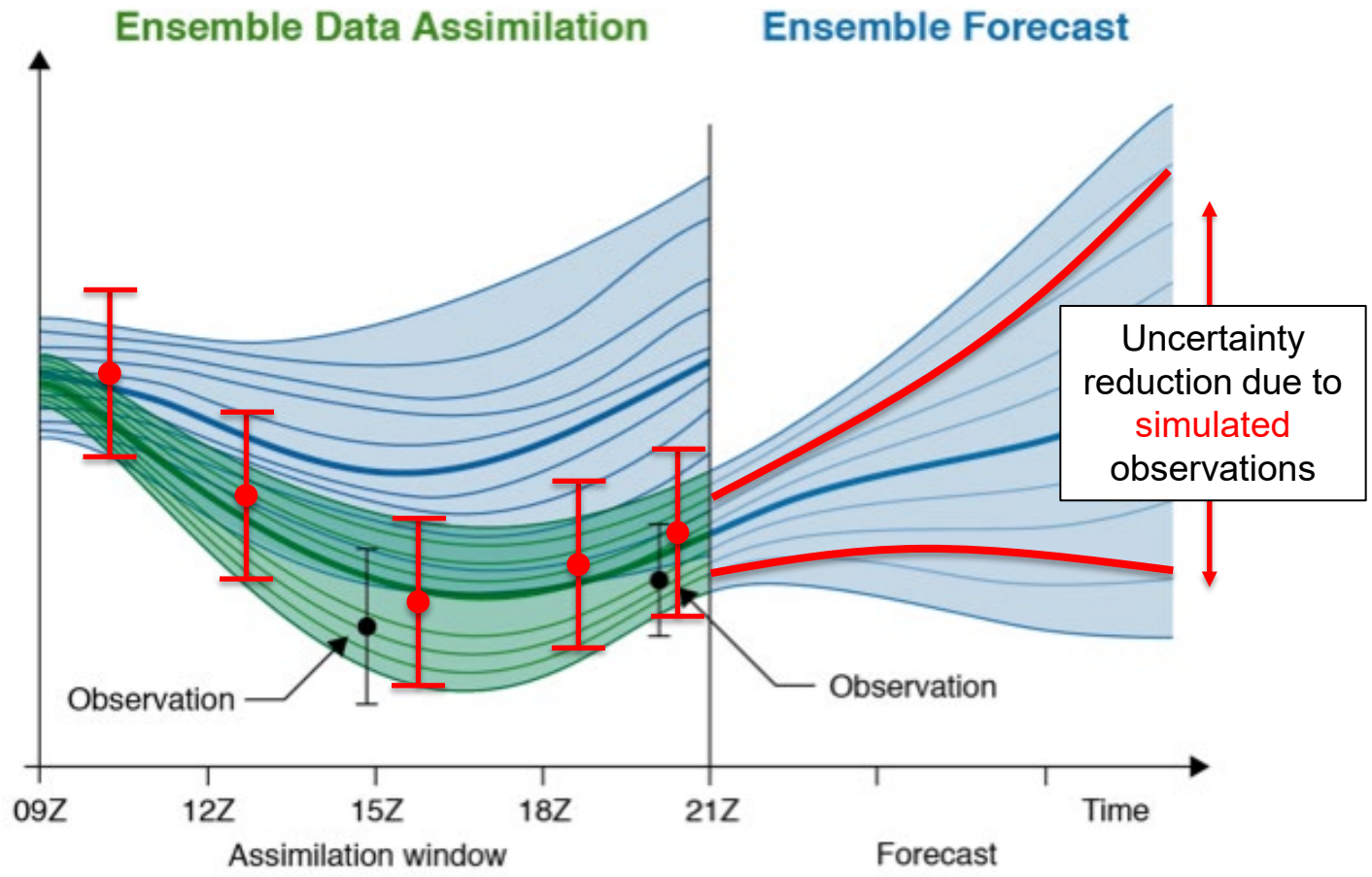
Even more MW sounders
= even better impact?

- Simulate expected impact using the EDA method (ESA-funded study)



The Ensemble of Data Assimilations (EDA) method

- EDA consists of:
  - Finite number of independent cycling assimilation systems
  - Observations, forecast model and SSTs perturbed to generate different inputs for each member
  - Uses real and added simulated observations
- Benefit of additional data measured by reduction in variation across different members – "EDA spread" → reducing forecast/analysis uncertainties
- Assumes errors of the simulated observations are realistic



Cheaper and complementary alternative to traditional Observing System Simulation Experiments (OSSEs) to assess potential of future observing systems

ECMWF

Assumed channel characteristics (inspired by Arctic Weather Satellite/Sterna)

Frequency (GHz)	Bandwidth (MHz)	Sample NEDT used (K)	Footprint at nadir (km)	Utilisation
50.3	180	0.85	40	Temp sounding
52.8	400	0.60	40	Temp sounding
53.596	370	0.60	40	Temp sounding
54.4	400	0.60	40	Temp sounding
54.94	400	0.60	40	Temp sounding
55.5	330	0.65	40	Temp sounding
57.290644	330	0.65	40	Temp sounding
89	4000	0.25	20	Window/cloud detection
165.5	2800	0.55	10	Window/hum sounding
176.811	2000	0.65	10	Hum sounding
178.811	2000	0.65	10	Hum sounding
180.811	1000	0.80	10	Hum sounding
181.511	1000	0.80	10	Hum sounding
182.311	500	1.05	10	Hum sounding

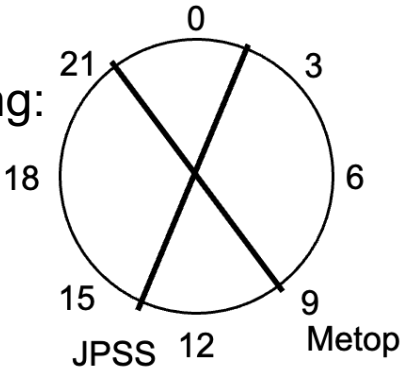
(all channels sampled at 10 km at nadir)

Humidity-sounding capability only

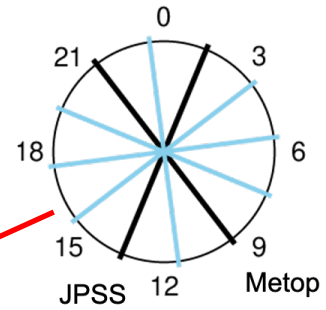
Constellation scenarios

- Future observations added to a baseline of existing observations
  - Baseline: Current full observing system, but MW sounding from JPSS and Metop orbits only (ie S-NPP, NOAA-20 and Metop-A, -B)
- Chosen constellation scenarios:

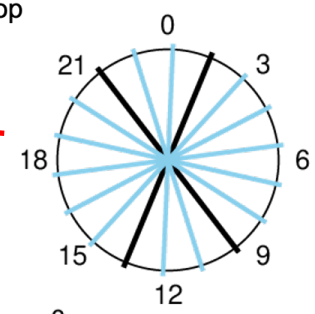
Baseline MW sounding:

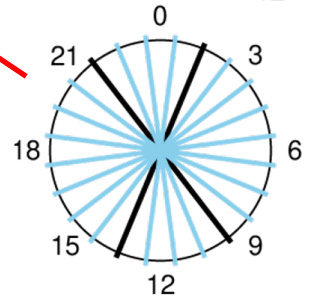


	Simulated small sat scenarios	Total platform no.
Polar orbit only	Polar	8
	Polar+	14
	Polar++	20
60° inclined orbit	4x2	8
	6x2	12
Combination	Polar+4x2	16



2 satellites in each plane



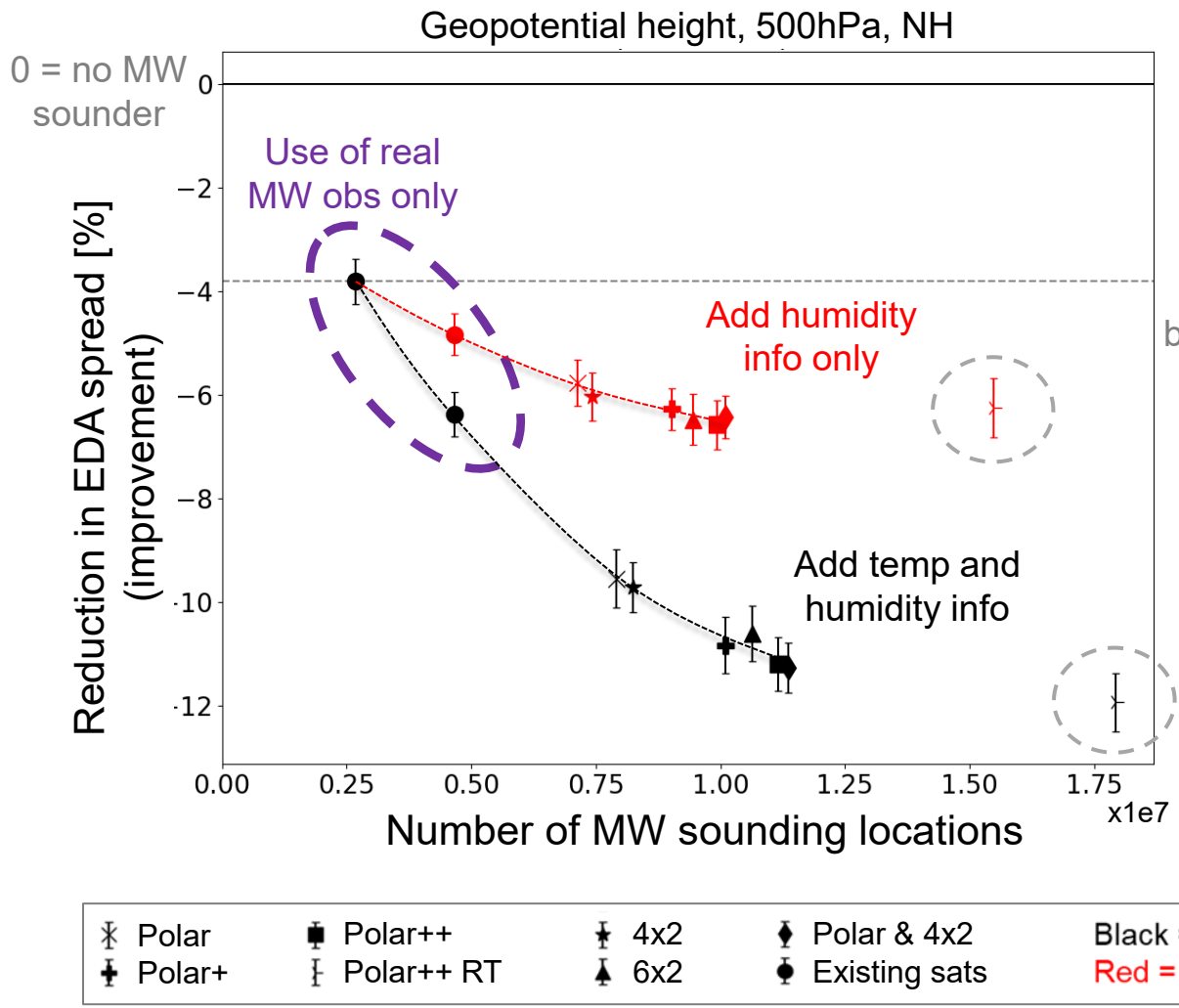


- Each constellation run with full channels set and humidity-sounding capabilities only.
- Period: July 2018

Increasing benefit from adding more MW sounding observations

(Katie Lean)

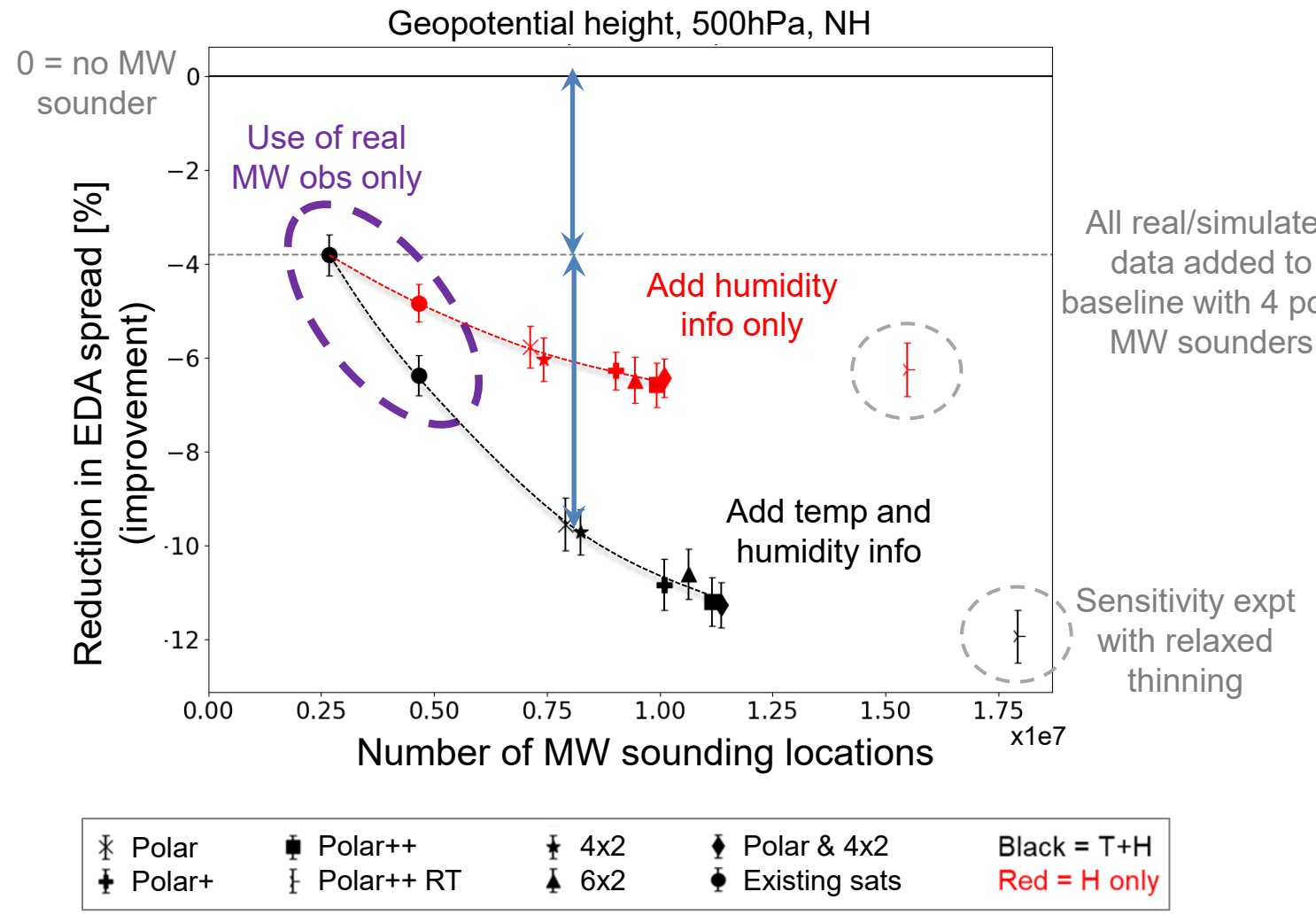
- Clear benefit of adding 50 GHz temperature-sounding channels compared to humidity-only



Increasing benefit from adding more MW sounding observations

(Katie Lean)

- Clear benefit of adding 50 GHz temperature-sounding channels compared to humidity-only
- Significant benefit from the 8-satellite constellations
- Rate of spread reduction slowing with many more satellites
- Much more in Lean et al (2022)
- Caveat:
  - Assumes specific data quality incl. biases in line with current sensors
  - **Can it be achieved from cubesats/small satellites?**



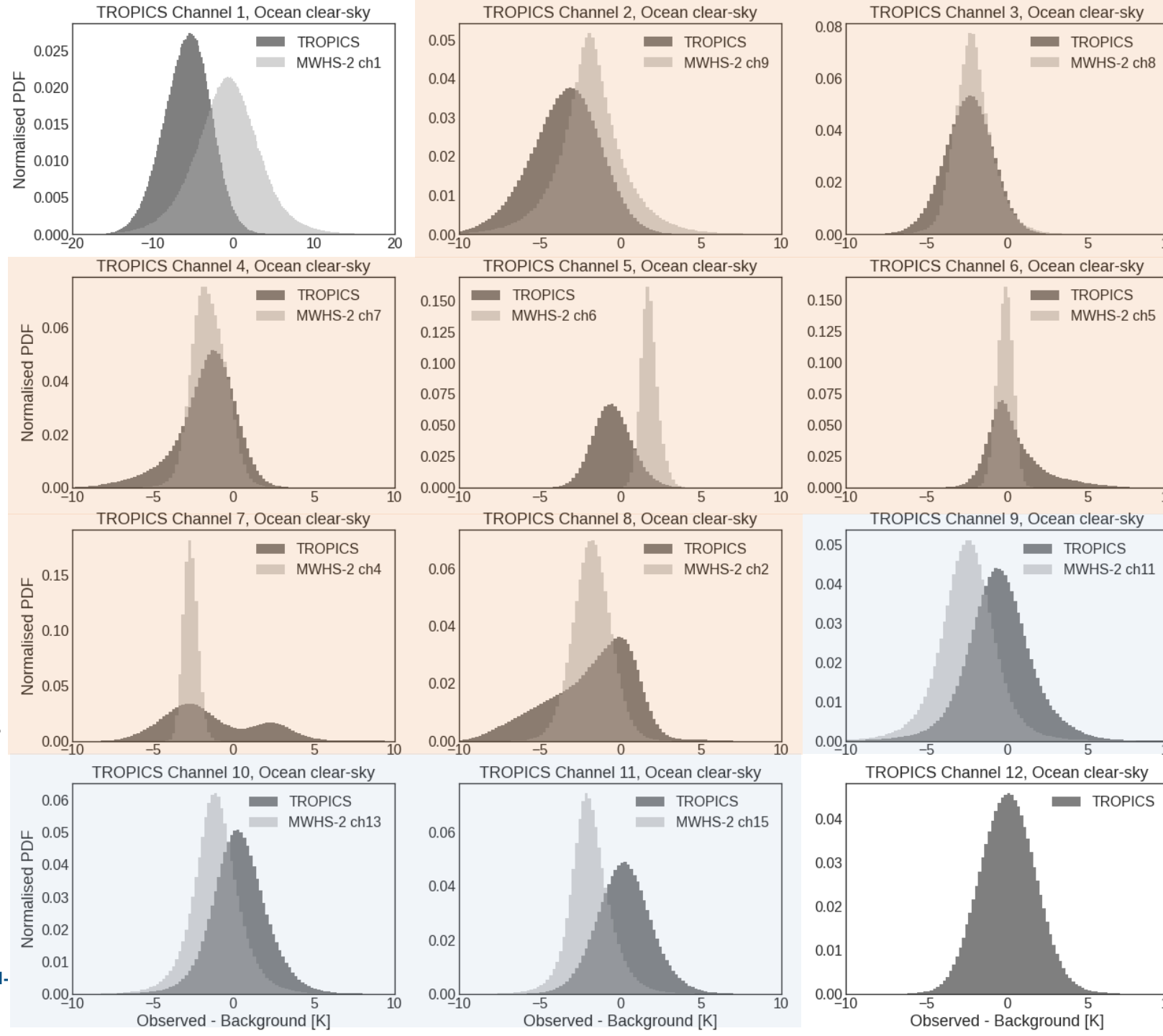
A first glimpse at the TROPICS-Pathfinder validated dataset

(Dave Duncan)

Compare TROPICS to ECMWF short-range forecasts (“O-B”)
Period: 15-21 Jan 2023

- Histograms of O-B before bias correction (clear-sky, ocean; updated RTTOV coefs with measured SRFs)
- For comparison: statistics for MWHS-2 on FY-3D

- Larger O-Bs for TROPICS 118 GHz channels than for MWHS-2 channels peaking at similar altitudes (esp. ch 5-8)
- 183 GHz channels show a better match



A first glimpse at the TROPICS-Pathfinder validated dataset: O-B after bias correction (using standard bias models in VarBC)

(Dave Duncan)

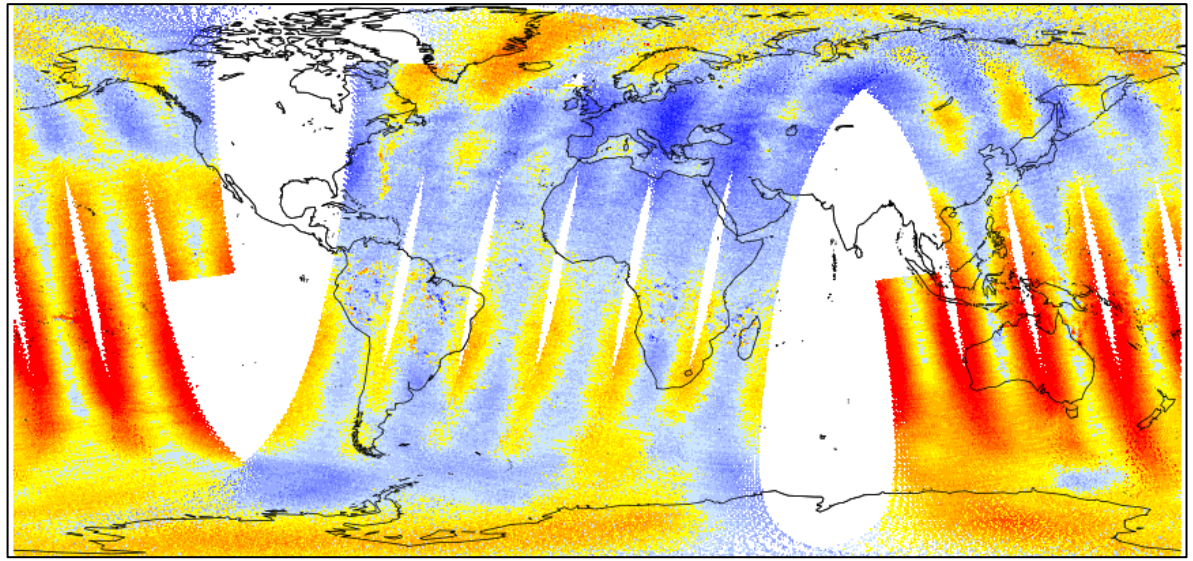
118 GHz sounding channels (ch 5-8):

- Dominant signals are residual scan-biases and orbital biases
- Note: random error in short-range forecasts in clear-sky regions for these channels: ~ 0.1 K
- Significant work required to correct remaining biases

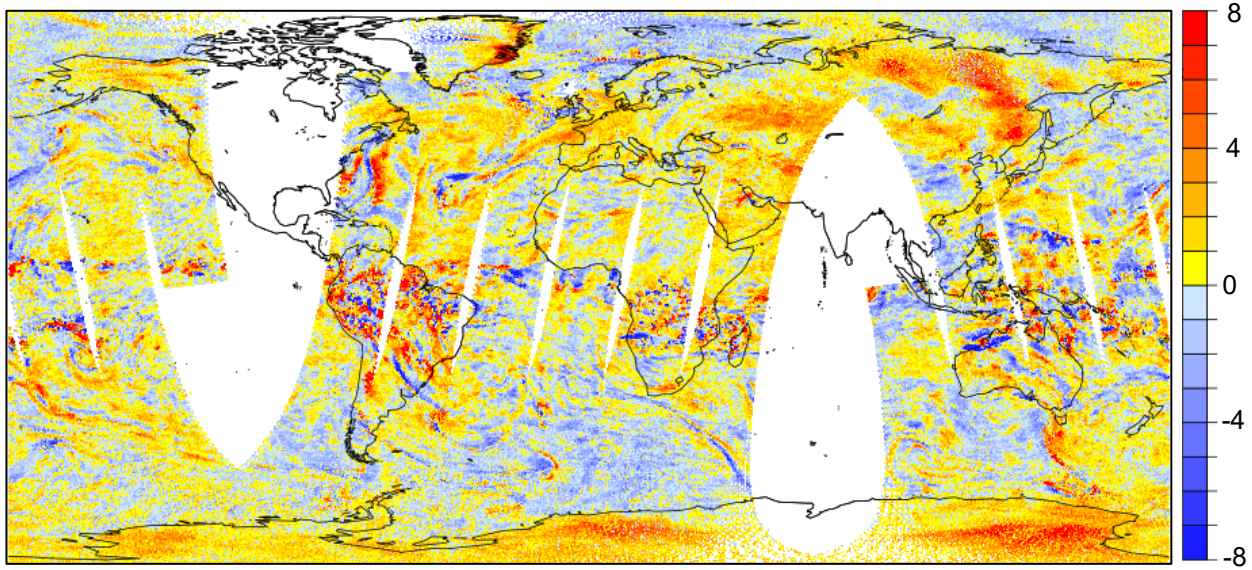
183 GHz humidity-sounding channels (9-11):

- Some small orbital biases apparent
- Overall, departure statistics are more in line with that of other instruments used in the ECMWF system

TROPICS channel 6; peaking around 300 hPa



TROPICS channel 9; highest humidity channel



14 Jan 2023, 9-21 Z

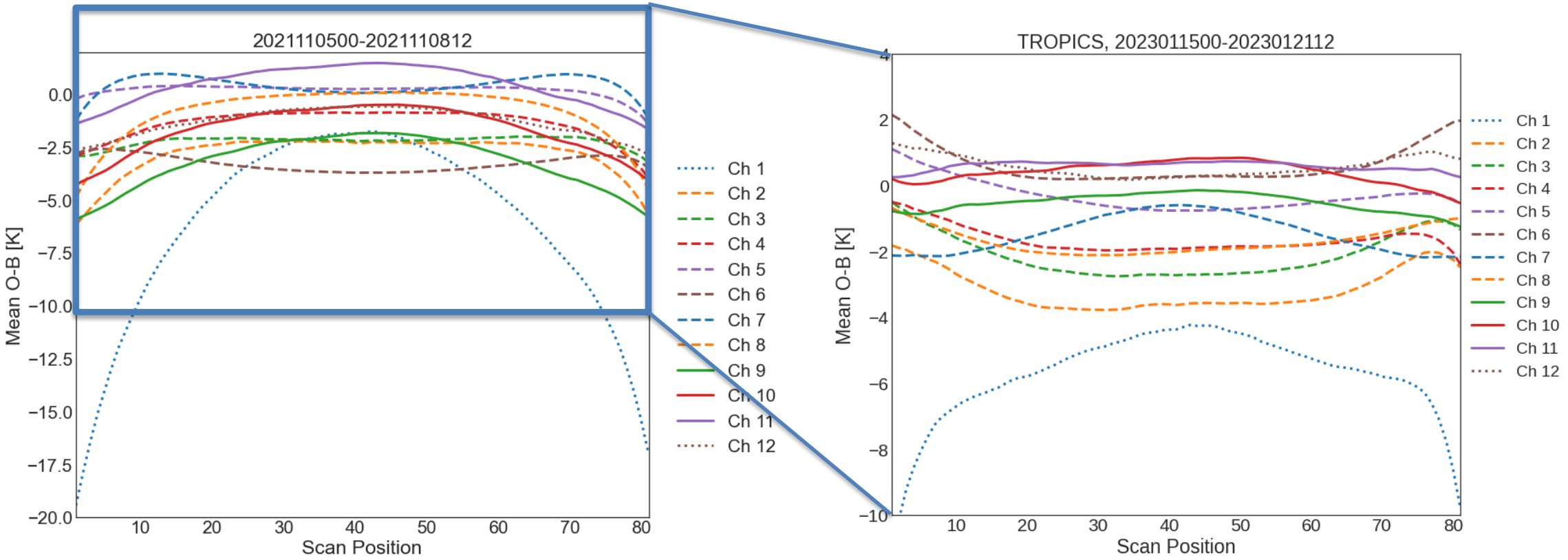
Improvements in scan-biases compared to the provisional dataset

(Dave Duncan)

Statistics based on clear-sky data over ocean, before bias correction

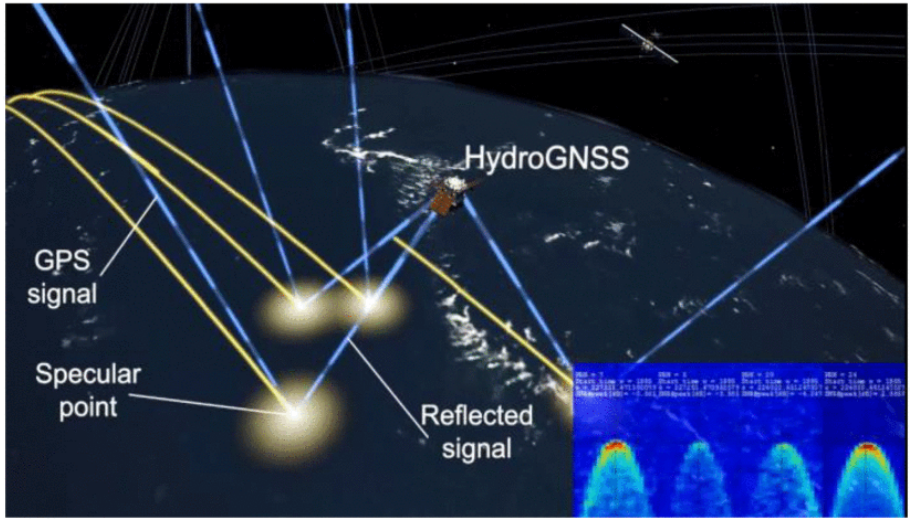
Provisional data,
RTTOV using tophat SRFs, old polarization,
5-8 Nov 2021

Validated data,
RTTOV using measured SRFs, updated polarization,
15-21 Jan 2023



Planned study for ESA: NWP impact of GNSS-R ocean wind information (Sean Healy)

- **Background**
  - To date, ECMWF has not tested the assimilation of GNSS-R wind speed information over oceans. *CYGNSS not NRT, so not considered a priority*
  - But ESA will provide GNSS-R observations as part of the hydroGNSS mission and they are also considering the quality of commercial missions (e.g., Spire)
- **Study Aim**
  - Assess the NWP impact of GNSS-R measurements in two NWP systems when added to a **full observing system, including scatterometers**
- **Approach**
  - Develop **"sigma0"** assimilation at ECMWF
  - Plan to assimilate CYGNSS data to ensure sufficient data volume (3 months+).
  - Assess SPIRE GNSS-R departure statistics and compare with CYGNSS
- **Partners:** *National Oceanography Centre:* provision of CYGNSS data
  Met Office: test assimilation of retrieved wind speed



New area for ECMWF.
Appreciate any feedback:
sean.healy@ecmwf.int

A first glimpse at the TROPICS-Pathfinder validated dataset: O-B after bias correction (using standard bias models in VarBC)

(Dave Duncan)

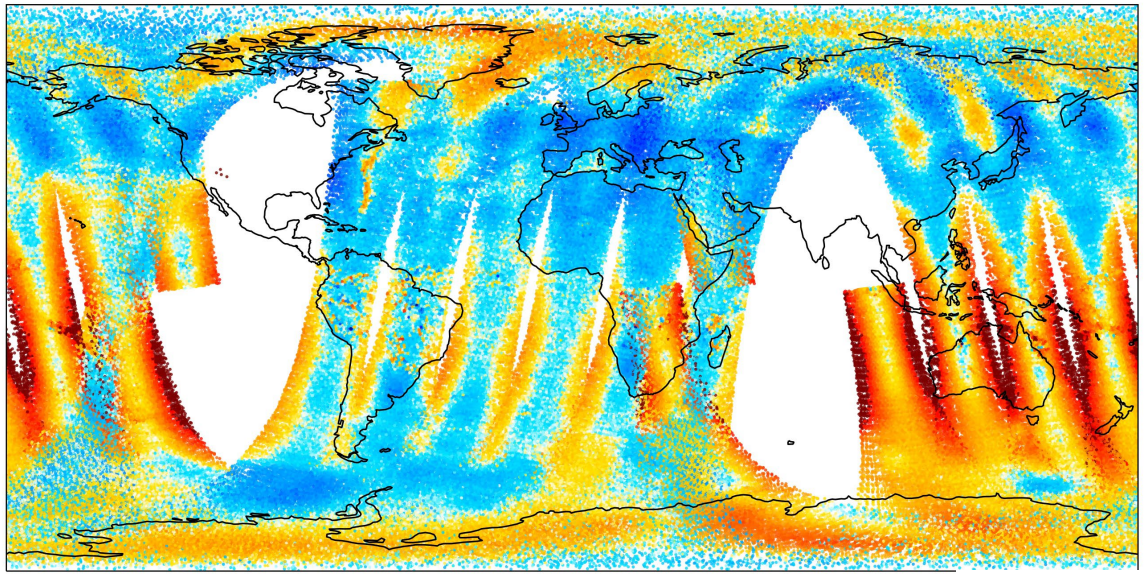
118 GHz sounding channels (ch 5-8):

- Dominant signals are residual scan-biases and orbital biases
- Note: random error in short-range forecasts in clear-sky regions for these channels: ~ 0.1 K
- Significant work required to correct remaining biases

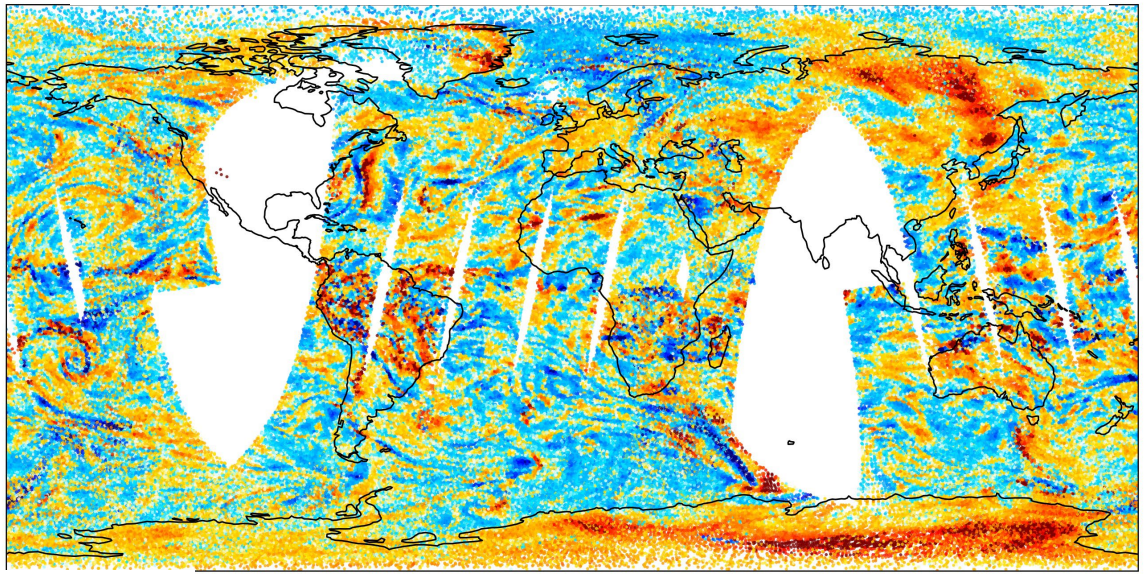
183 GHz humidity-sounding channels (9-11):

- Some small orbital biases apparent
- Overall, departure statistics are more in line with that of other instruments used in the ECMWF system

TROPICS channel 6; peaking around 300 hPa



TROPICS channel 9; highest humidity channel



14 Jan 2023, 9-21 Z

Summary of key points

- **Simulations suggest clear benefit in global NWP from adding further MW sounders**
  - Smaller (8-satellite) constellations considered show already very significant benefits; rate of improvement slows with larger (20-satellite) constellations
- **Temperature-sounding channels in the 50-GHz band produce significant additional benefits compared to humidity-sounding capabilities only**
- **Adequate data quality will be important to achieve these forecast impacts**

- **Validated TROPICS-Pathfinder dataset shows improvements compared to provisional data, but some issues remain:**
  - Scan and orbital biases for 118 GHz channels
  - Quality of the 183 GHz channels is closer to that of data already used in the ECMWF system

- **CYGNSS constellation will be used at ECMWF to develop direct assimilation of sigma0 over ocean from GNSS-R**