Assessing potential future constellations of small satellites carrying microwave sounders using the Ensemble of Data Assimilations method

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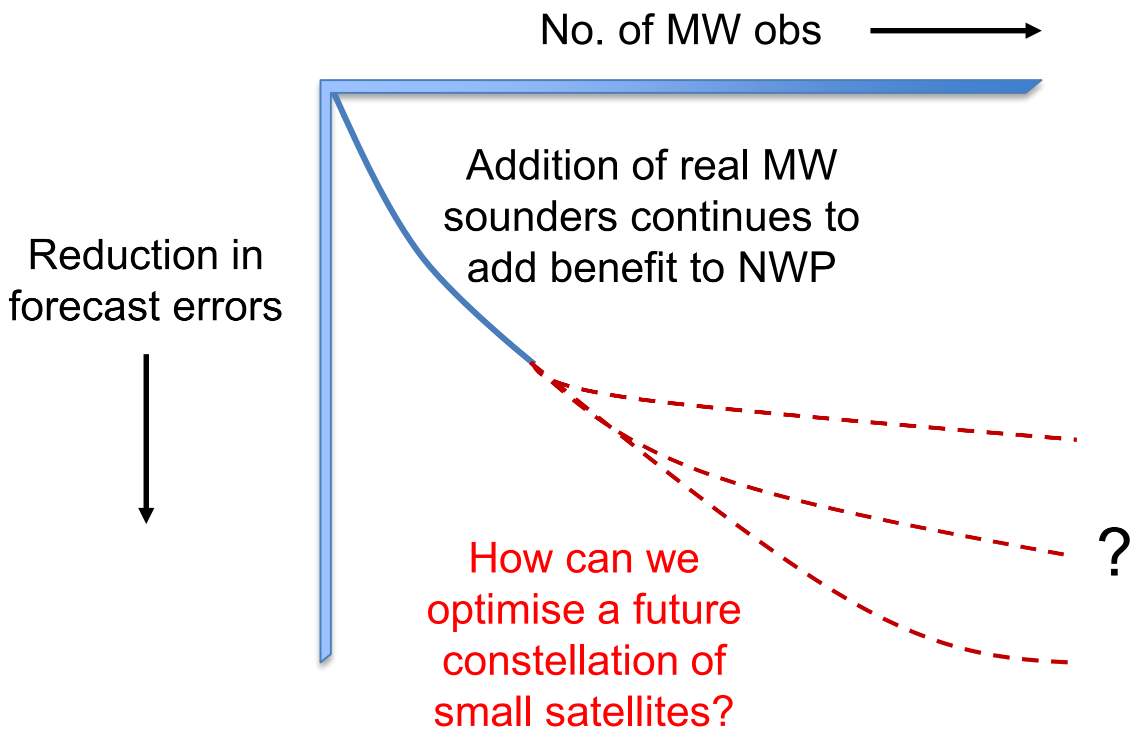
ECMWF

How much benefit can we achieve with MW sounders on small satellites?



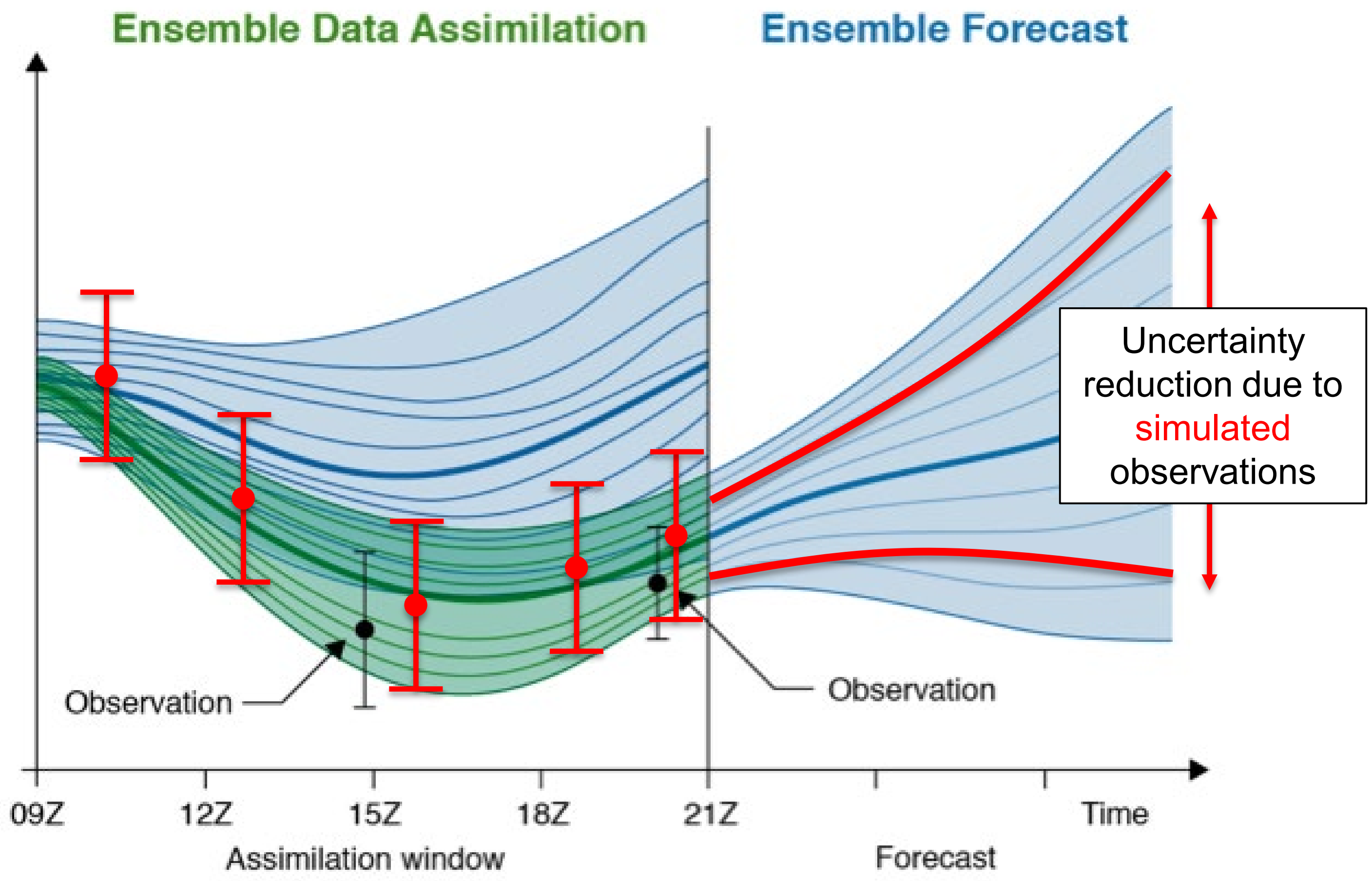
Additional small satellites complement continuing “backbone” constellation of large satellites

ESA study: Address broad questions about design for hypothetical constellations

EUMETSAT study: Build on framework to focus on future Sterna (previously AWS) constellation

The Ensemble of Data Assimilations (EDA) method

- EDA consists of:
  - Finite number of independent cycling assimilation systems
  - Uses real and added simulated observations
  - Observations, forecast model and SSTs perturbed to generate different inputs for each member
- 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



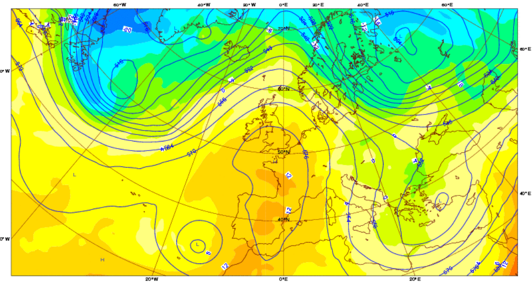
Cheaper alternative but complementary to traditional Observing System Simulation Experiments (OSSEs) to assess potential of future observing systems

ECMWF

Simulation framework of small satellite data

*JCR Systems (2022) "Input Generation for Study to Assess Earth Observation with Small Satellites and their Prospects for Future Global Numerical Weather Prediction (SSat4-GNWP)". ESA Contract No: 400013468, Final Report

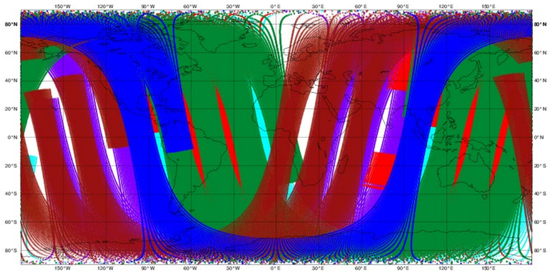
ECMWF NWP analysis → proxy for the 'truth' for the new observations



Orbital parameter files provide temporal/spatial sampling*

interpolate

Observation time and location
Sat zenith/azimuth angles etc.



Observation operator RTTOV-SCATT

Add perturbations reflecting random ***instrument noise***

Simulated MW sounder radiances

Accompanying all-sky observation errors including adaptation for loss of lower frequencies

Follow assimilation steps of existing MW data

Sampling to mimic 3x3 averaging
Thinning (all sats together: 30 min slots, ~110km)

ESA study small sat channel characteristics

Loss of lowest freq < 50GHz

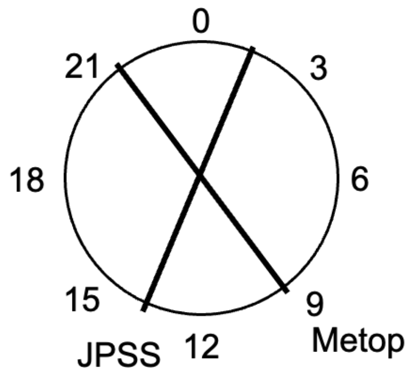
Frequency (GHz)	Bandwidth (MHz)	Sample NEDT* used (K)	Footprint (km)	Utilisation
50.3	180	0.85	40	Temp sounding
52.8	400	0.60	40	Temp sounding
53.596	370	0.60	40	Temp sounding
54.4	400	0.60	40	Temp sounding
54.94	400	0.60	40	Temp sounding
55.5	330	0.65	40	Temp sounding
57.290644	330	0.65	40	Temp sounding
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

Less stratospheric sensitivity

*JCR Systems (2022)

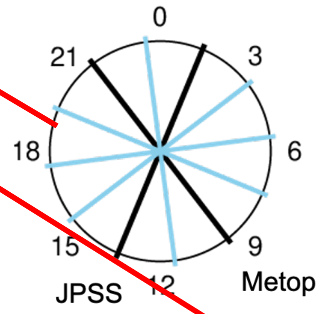
Scenarios probe different design aspects

- Add simulated observations to baseline of existing obs
- Baseline = reduced no. of MW sounders + full observing system
  - 4 MW temp/hum (Metop A/B and SNPP/NOAA-20)
- Small sat orbits minimise time to coverage but do not minimise overlap

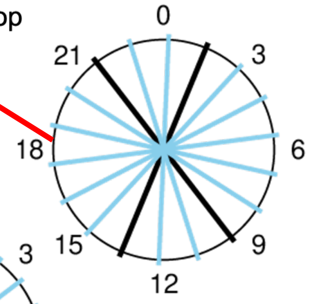


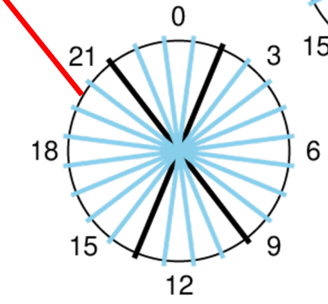
Baseline reflects possible future loss of some large platforms

	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



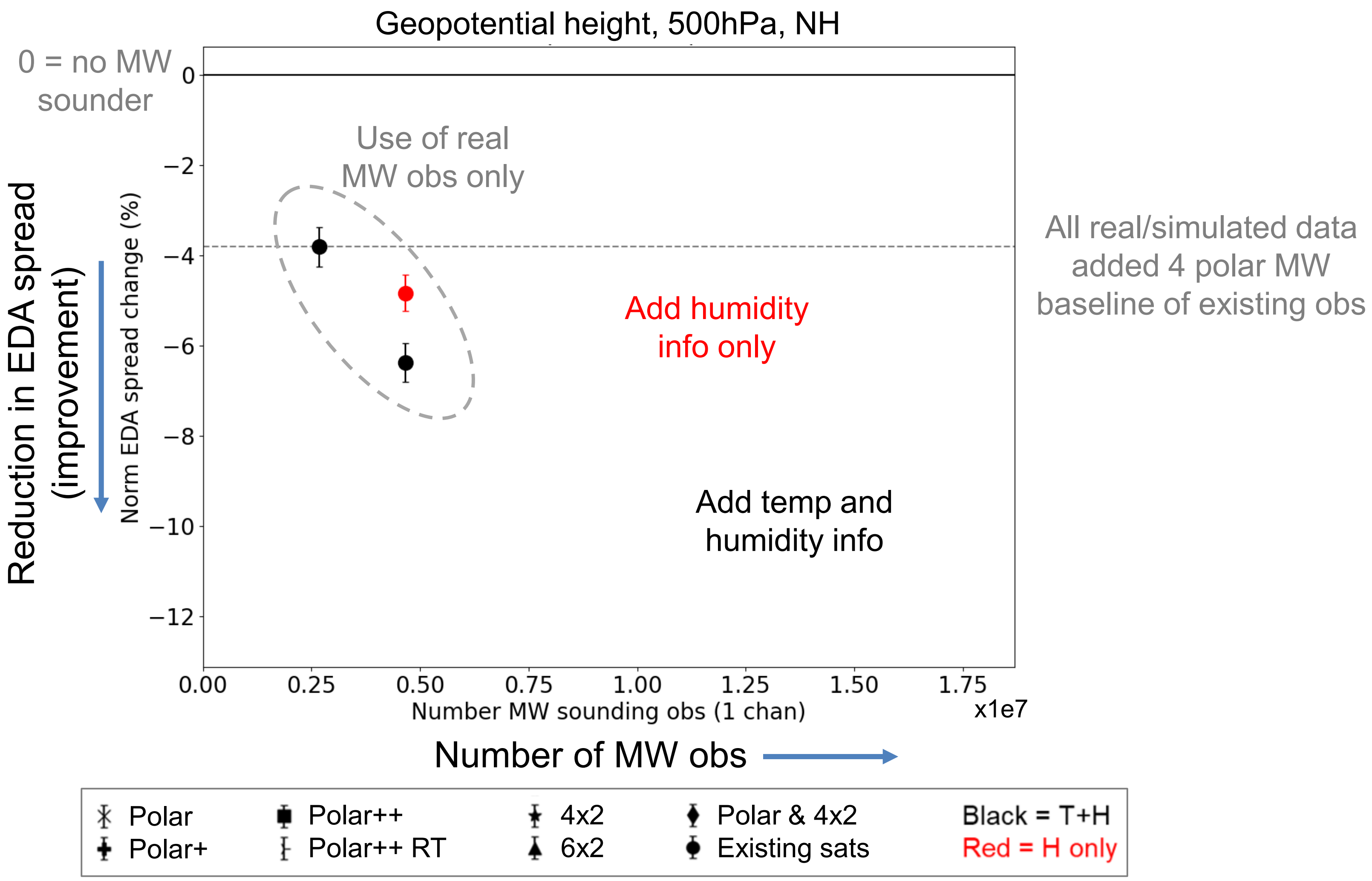


Each constellation run with humidity only* (183GHz) or humidity + temp* (183 + 50 GHz)

*plus complementary window channels

Increasing benefit from adding more MW observations

EDA expt period
8-28 June 2018



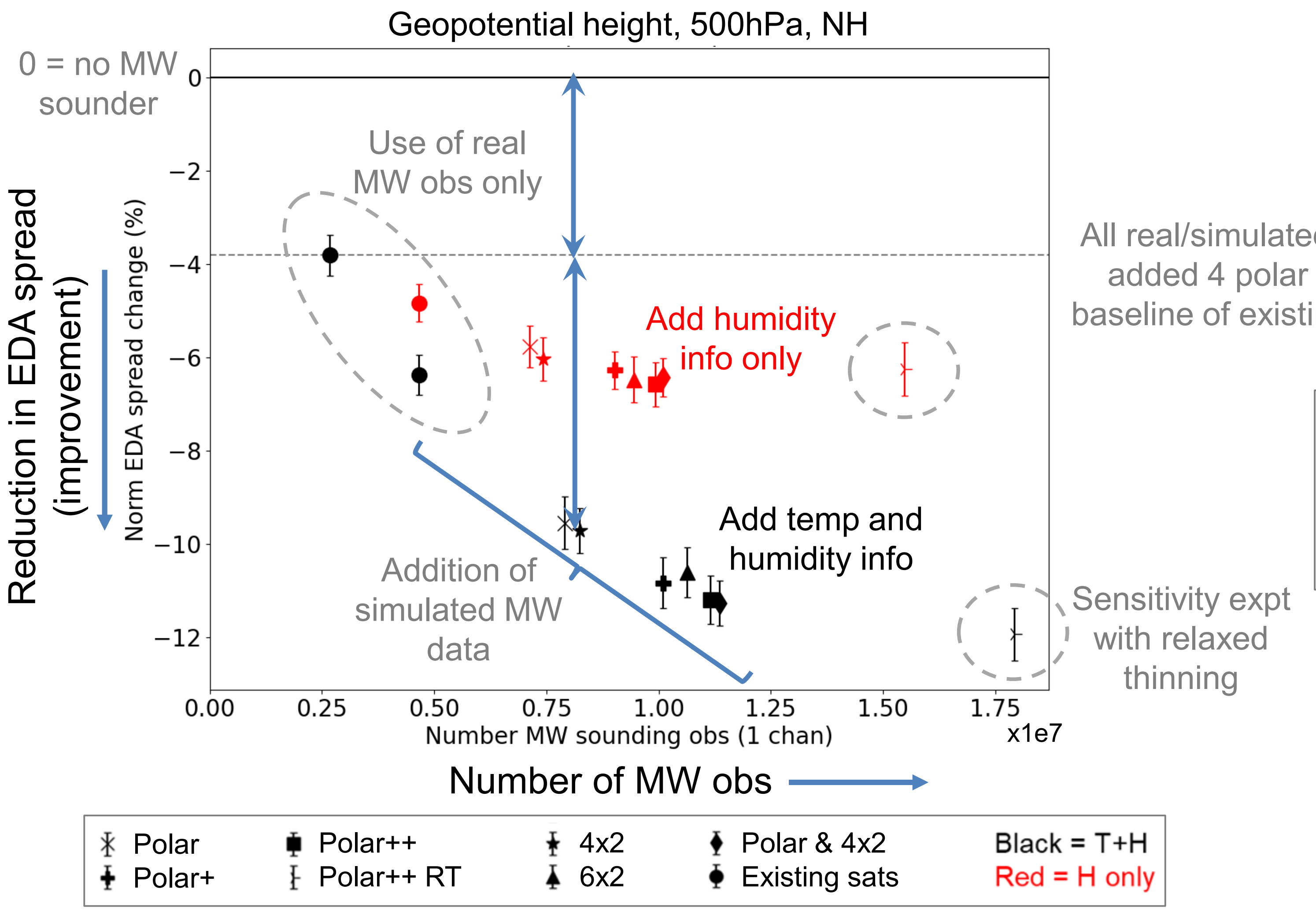
Increasing benefit from adding more MW observations

EDA expt period
8-28 June 2018

Clear additional benefit of temp information

Significant impact for small (8 sat) constellations

Larger spread reduction with more obs but rate of reduction slowing



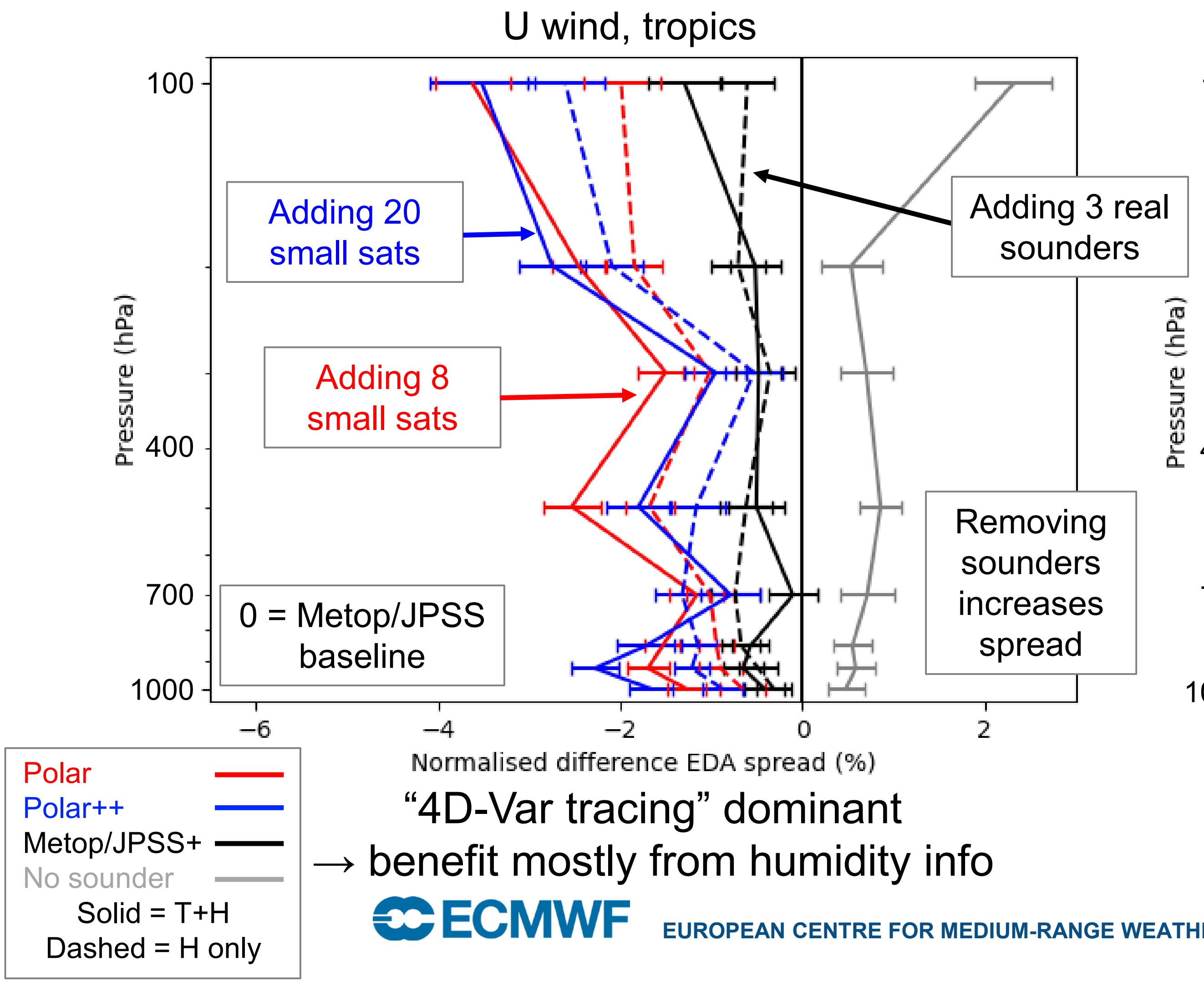
Expts with existing data fit well with simulated data results

Impact on wind from simulated data

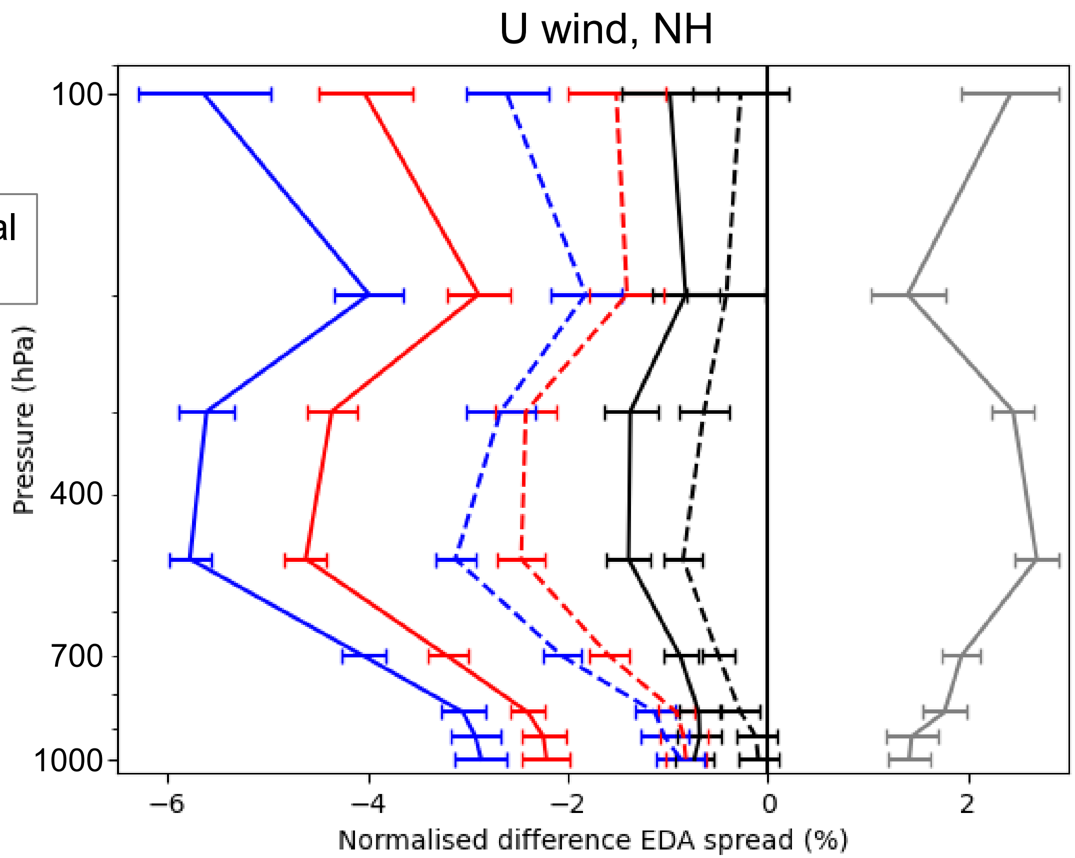
Keys mechanisms to extract wind:

- 4D-Var derives wind info from temporal evolution of humidity/cloud features
- Wind info inferred through balance relationships

Impact also extends into stratosphere



"4D-Var tracing" dominant
→ benefit mostly from humidity info



Geostrophic balance has more influence
→ temp info has clear added benefit

Assessing future Sterna* constellation: building on earlier work

*Previously known as the AWS constellation

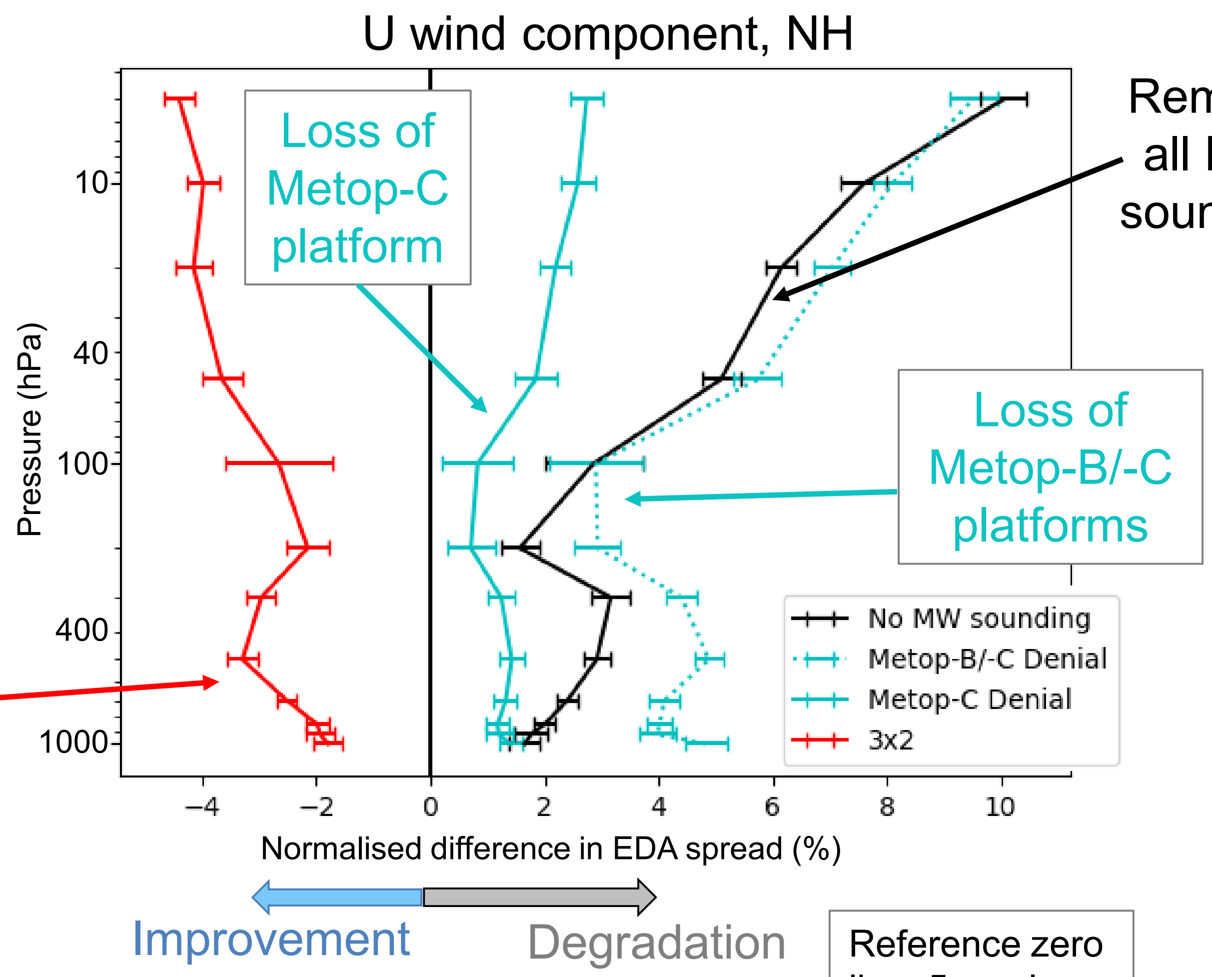
- Pathfinder Arctic Weather Satellite (AWS) expected in 2024
- Future constellation reference configuration: 3 orbital planes, 2 sats in each
- AWS: 19 channels (8 x 50GHz band, 5 x 183GHz band, **4 x 325GHz band**, 1 x 89GHz, 1 x 165GHz)
  - Initial expts use well-established channels (i.e. exclude 325GHz)
- Different reference baseline of existing MW sounders
  - 2 x mid-morning (09:30), 2 x afternoon (13:30), 1 x early morning (~06:30), 1 x inclined orbit (GMI)
- Assess impact of Sterna and compare with existing MW instruments or whole satellite platform changes
- Future work:
  - Develop 325 GHz assimilation strategy
  - Assess additional impact of 325GHz

Impact of reference Sterna between 1 and 2 x full Metop platforms

Results for Sterna scenarios consistent with previous study

Additional denial expts:
1) Entire Metop-C platform from baseline
2) Both Metop-B/-C from baseline

Add reference Sterna (6xAWS)



Sterna EDA spread reduction larger than opposite spread increase for Metop-C denial but smaller than Metop-B/-C denial

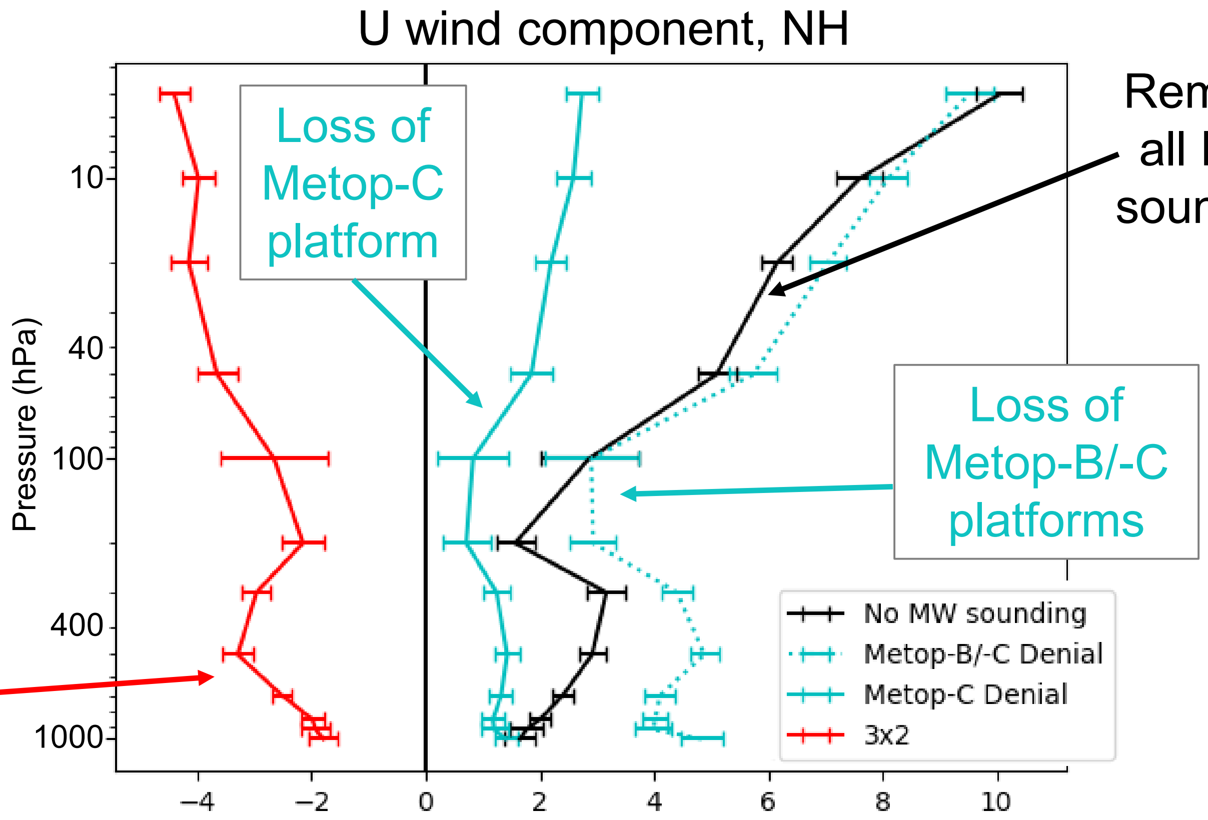
Reference zero line: 5 x polar + GMI (inclined)

8-28 July 2019

Impact of reference Sterna between 1 and 2 x full Metop platforms

Results for Sterna scenarios consistent with previous study

Additional denial expts:
1) Entire Metop-C platform from baseline
2) Both Metop-B/-C from baseline



Remove all MW sounding

Add reference Sterna (6xAWS)

Sterna EDA spread reduction larger than opposite spread increase for Metop-C denial but smaller than Metop-B/-C denial

8-28 July 2019

IMPORTANT NOTE: EDA METRIC DOES NOT FULLY CAPTURE LOSS OF METOP e.g. land surface parameters, surface winds, atmospheric chemistry… Also need high performance platforms for essential calibration information.

Key findings

- Temperature sounding capabilities produce significant additional spread reduction – worthwhile addition where sensibly accommodated

- Smaller constellations shows significant reduction in EDA spread – encouraging potential impacts of future Sterna constellation

- Comparison to real MW/platform denial expt suggest good benefit from Sterna – but future presence of large platforms is still essential

- Continued reduction with adding more observations but rate of reduction slows (more for humidity) – increased benefit gradually less cost effective

Visiting scientist opportunity at ECMWF for US citizens/permanent residents

- Position at CISESS/UMD, mostly based at ECMWF
- Project to study the expected impact of NOAA's planned future MW sounders in global NWP
  - Use ensemble methods to simulate the impact

- **Unique opportunity** for a talented scientist interested in satellite data, data assimilation, NWP
  - US citizenship or permanent residency (Green Card) required

- Duration: 1 year, with possible extension for a further year

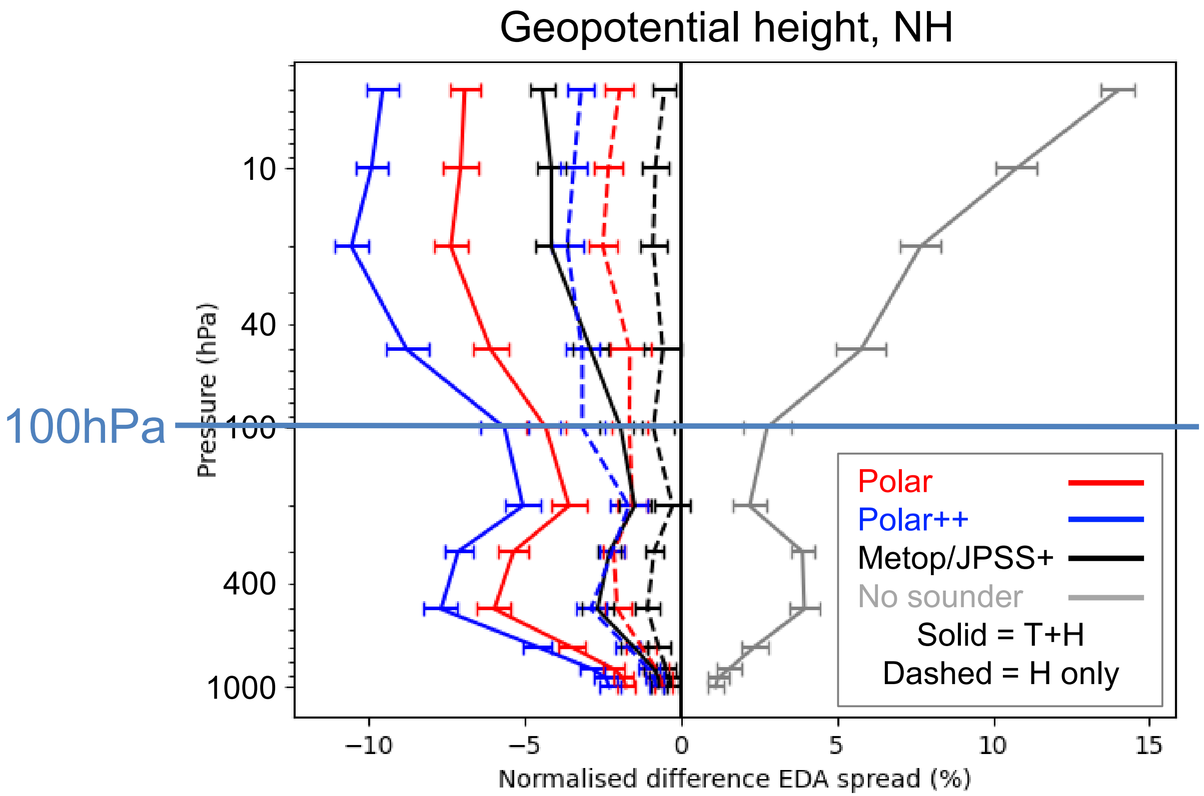
- Contact: Niels.Bormann@ecmwf.int
- Vacancy notice: https://essic.umd.edu/joom2/index.php/employment

Thank you for your attention!

Impact extends into stratosphere

- Weighting functions of MW relatively broad
- Stratospheric sensitivity from highest peaking small sat channel (~80hPa)
- Cycling assimilation propagates changes vertically

- Stratospheric channels from real MW have relatively greater impact in lower pressure

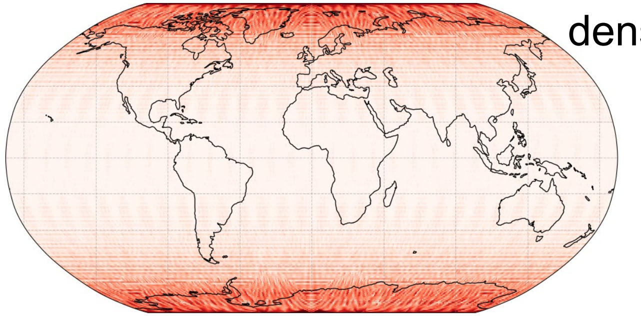


Higher density obs giving advantage

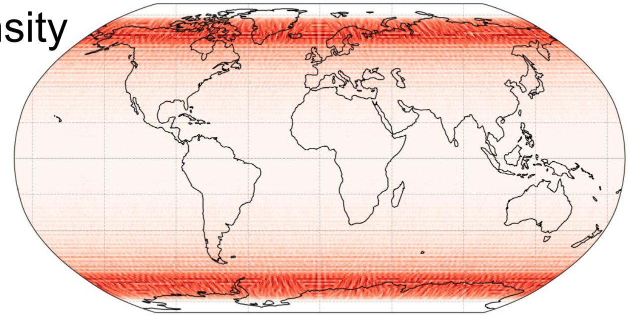
Comparing 8 small satellites in:
inclined orbit only
polar orbit only

Obs density

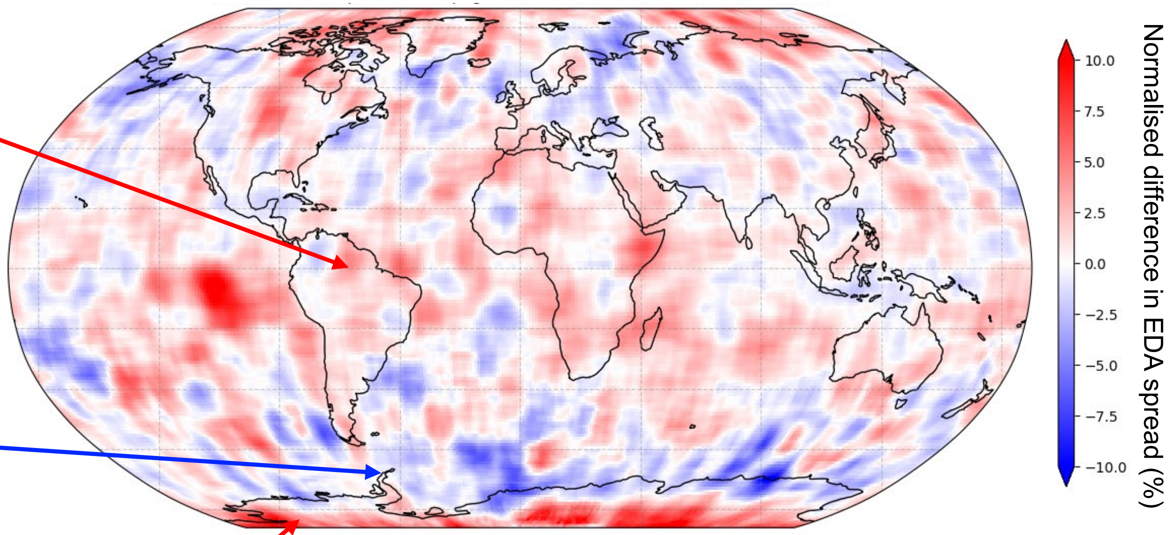
8 x polar



8 x inclined



Inclined – Polar (H+T channels)
U wind, 200hPa



More spread reduction in Polar scenario

More spread reduction in inclined scenario

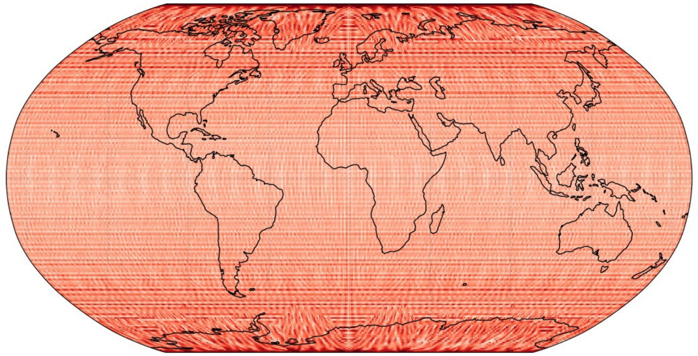
Slightly larger reduction for higher density Polar obs in equatorial regions

Indication of advantage in high mid-lat where inclined orbit obs density is highest

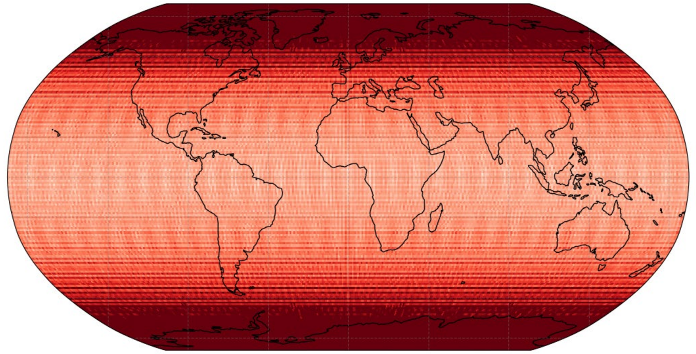
Polar extra direct obs have clear benefit

Higher spatial sampling more beneficial for temperature

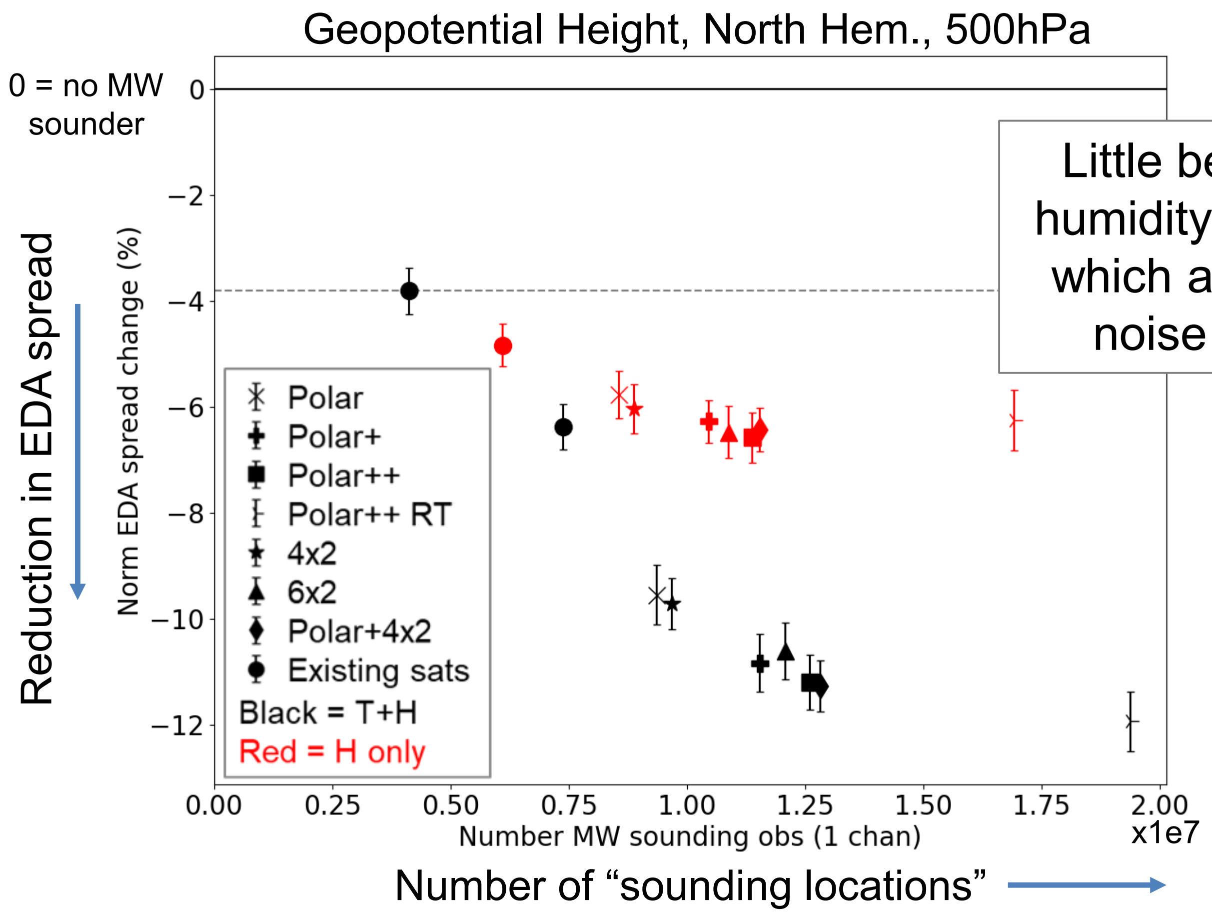
Polar++ (20 sats)
Sats thinned together



Polar++ Reduced Thinning (20 sats)
Sats thinned separately



Additional data observing at similar location and time – not better temporal sampling



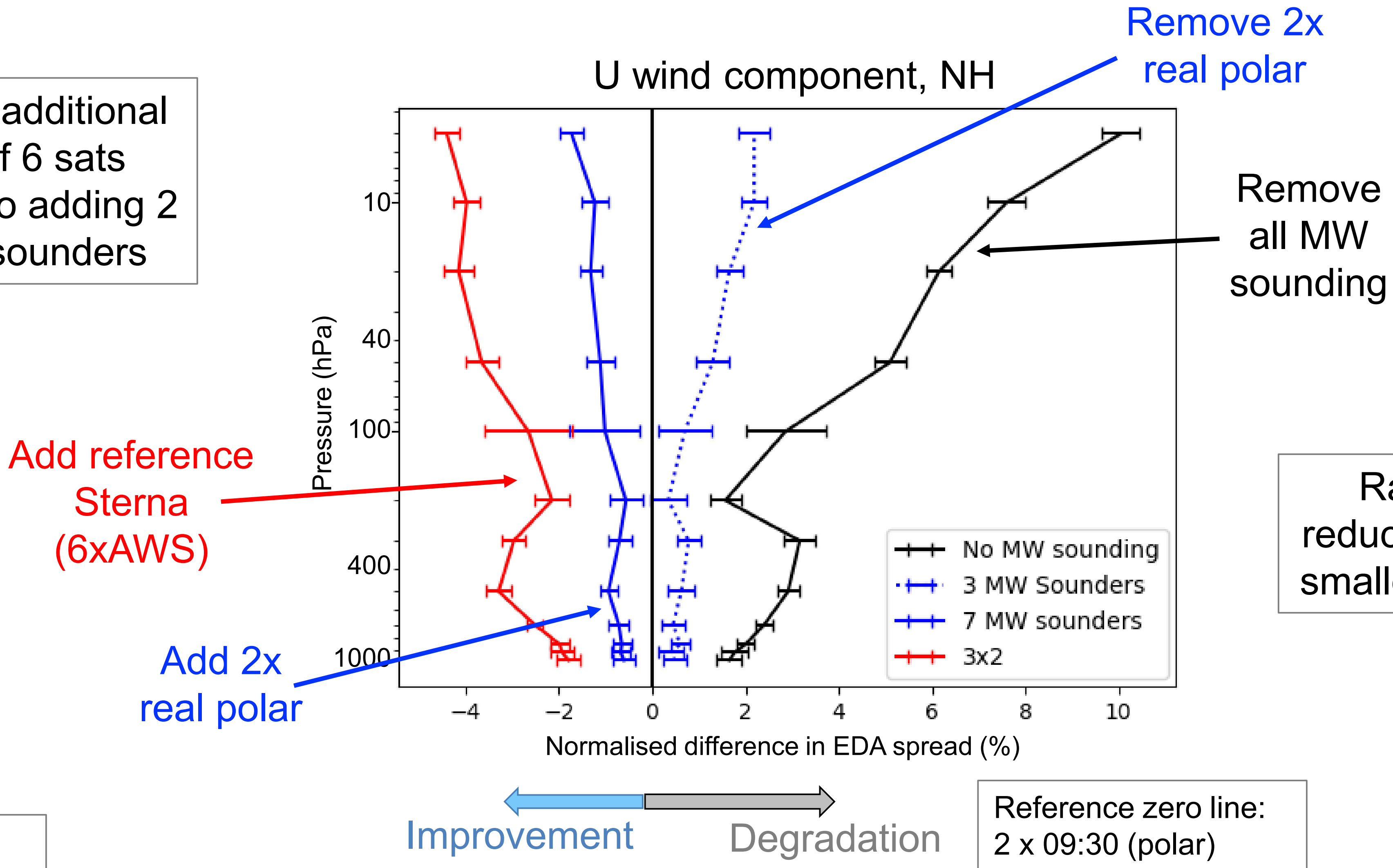
Little benefit for humidity channels which are not as noise limited

Spatial/temporal error correlations not accounted for

Better phasing optimised for temporal sampling may achieve better results

Significant impact of Sterna highlighted by real MW obs

Significant additional impact of 6 sats compared to adding 2 real MW sounders



Rate of spread reduction still high for smaller constellations

8-28 July 2019

Reference zero line:
2 x 09:30 (polar)
2 x 01.30 (polar)
1 x ~06:30 (polar)
+ GMI (inclined)

Limitations and lessons

- Possible under-estimation of humidity impact
  - Simulation from high resolution analyses smoother than reality
  - Resolution of EDA spread calculation
- Sensitivity to practical choices e.g. phasing and thinning
  - Mix polar and even lower inclined orbit to address tropical coverage?
- Dependent on current MW assimilation scheme
  - E.g. treatment of error correlations, use over complex surfaces
- Assume random/systematic obs errors are similar to present MW obs
  - Adequate corrections required using current/new techniques