Using the Ensemble of Data Assimilations method to investigate future constellations of microwave sounding instruments on small satellites

Katie Lean[1], Niels Bormann[1], Sean Healy[1], Dirk Schűttemeyer[2], Janet Charlton[3], Ralf Bennartz[4], Peter Senior[5], Frank Fell[4], Bruno Picard[6], Jean-Christophe Angevain[2], Stephen English[1]

[1]ECMWF, [2]ESA-ESTEC, [3]JCR Systems, [4]Informus, GmbH, [5]In-Space Missions, [6]Fluctus SAS

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Contact: katie.lean@ecmwf.int

Continued benefit from additional MW sounder data

- Previous study at ECMWF* showed continued benefit from adding existing MW sounder data
- No “saturation” point found with existing data
- Number of large, high performance platforms expected to decrease in future
- A constellation of small satellites with MW sounders could significantly improve temporal sampling available in a cost-effective way
- What is the optimal design for a future constellation of small satellites carrying AWS-based MW sounders?

*Duncan, D. I., N. Bormann and E. V. Hólm (2021): On the addition of microwave sounders and numerical weather prediction skill, vol. 147, issue 740, pp. 3703-3718 https://doi.org/10.1002/qj.4149

Considering broad questions of constellation design

- Additional small satellites complement continuing “backbone” constellation of large satellites
- Use AWS-based instrument to form potential small sat constellations
- Key aspects of optimal constellation design to consider:

No. of satellites?

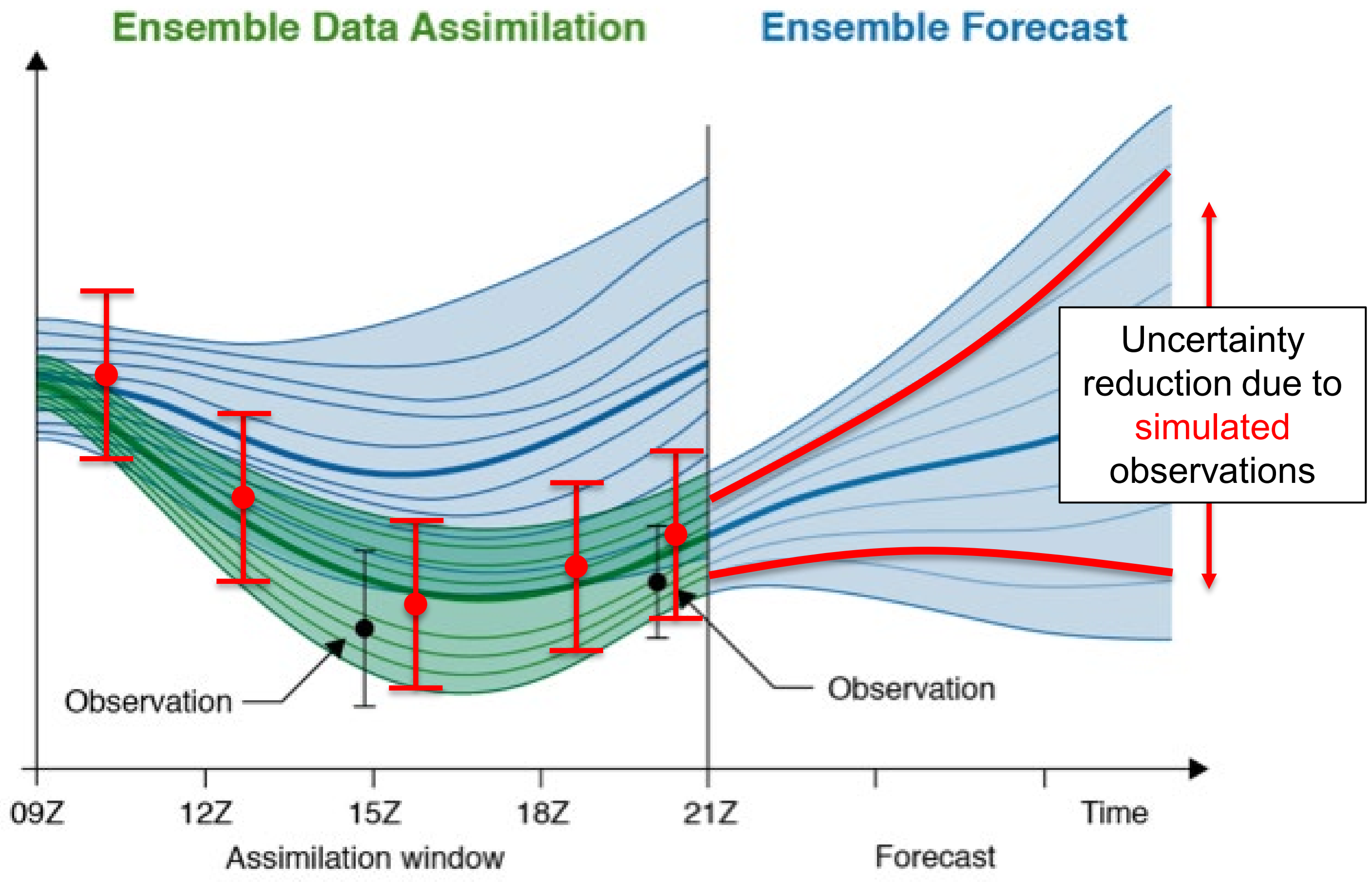
Humidity only or temp + humidity?

Types of orbit (polar/low inclination)?

- Impact of different potential future constellations to be evaluated using Ensemble of Data Assimilations (EDA) method

The EDA method

- EDA consists of:
  - Finite number of independent cycling assimilation systems
  - Uses real and added simulated observations
  - Observations and the forecast model are 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



Used for previous ESA and EUMETSAT studies for Aeolus and Radio Occultation. K Lonitz: "Using ensemble spread as a measure of GNSS-RO impact", Friday poster session
Cheaper alternative to traditional Observing System Simulation Experiments (OSSEs) to assess potential of future observing systems

ECMWF

EDA experiments

Baseline	Name
1	No MW sounders (otherwise full observing system)
2	(1) + 4 MW temp/hum (Metop A/B and SNPP/NOAA-20)
3	(2) + 3 MW temp/hum
4	(2) + 3 MW hum only

Simulated data added to 4 existing MW sounders baseline (2) - reflect possible future loss of some large platforms

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

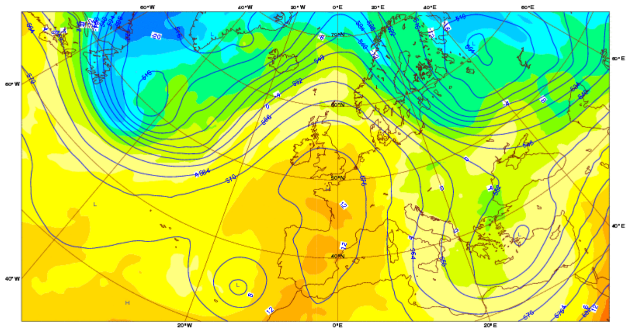
2 satellites in each plane

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

325 GHz not considered here

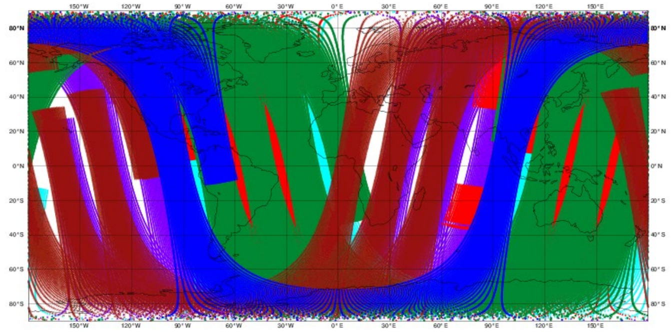
Simulation of new observations

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



interpolate

Observation time and location
Sat zenith/azimuth angles etc.



Observation operator RTTOV-SCAT *<u>(channel specs, AWS channel set)</u>*

Add perturbations reflecting random *<u>instrument noise</u>* *(using AWS estimates)*

Simulated MW sounder radiances

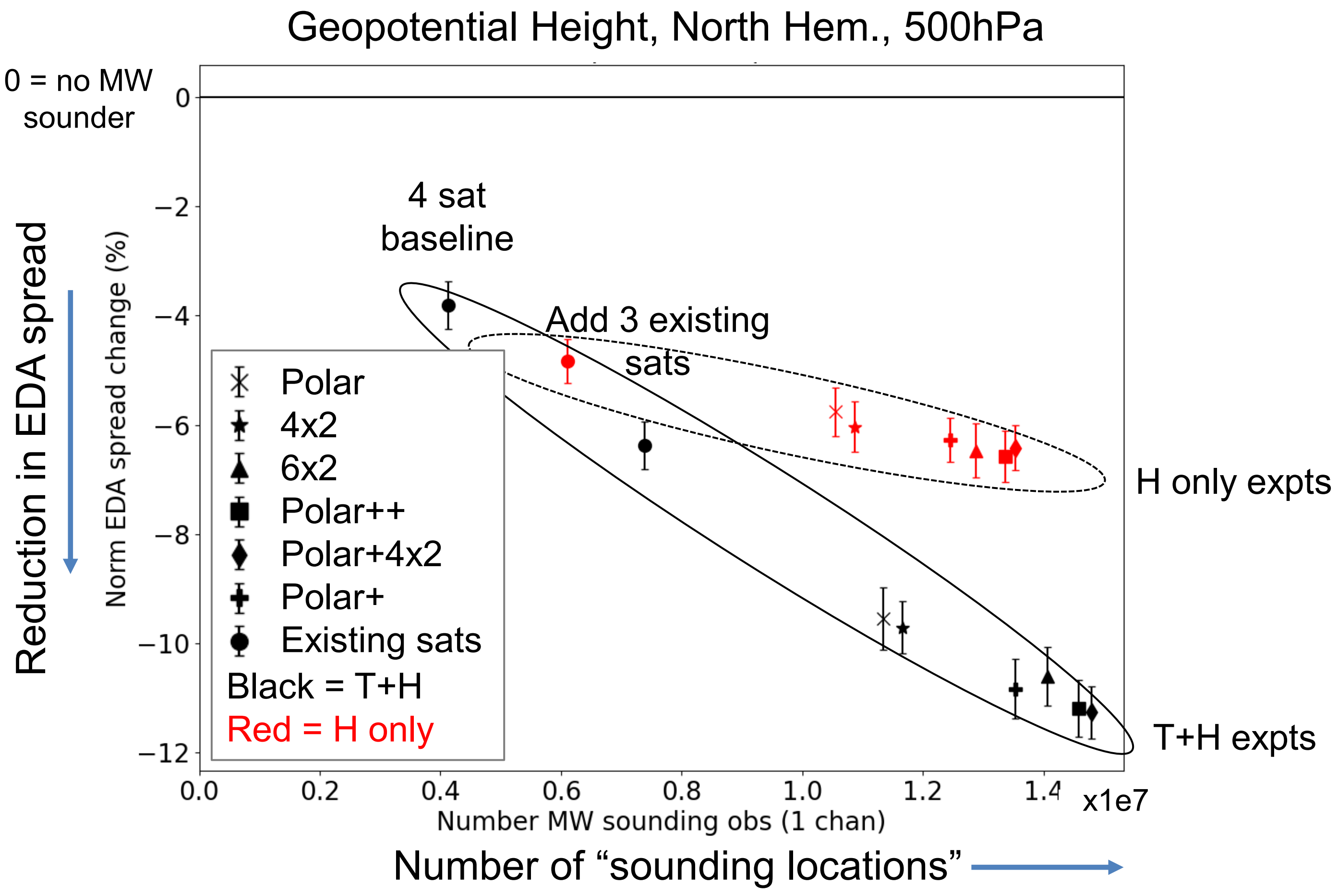
Accompanying observation errors including adaptation for loss of lower frequencies

Thinning

EDA spread reduction results

Larger spread reduction with more observations

8-28 June 2018



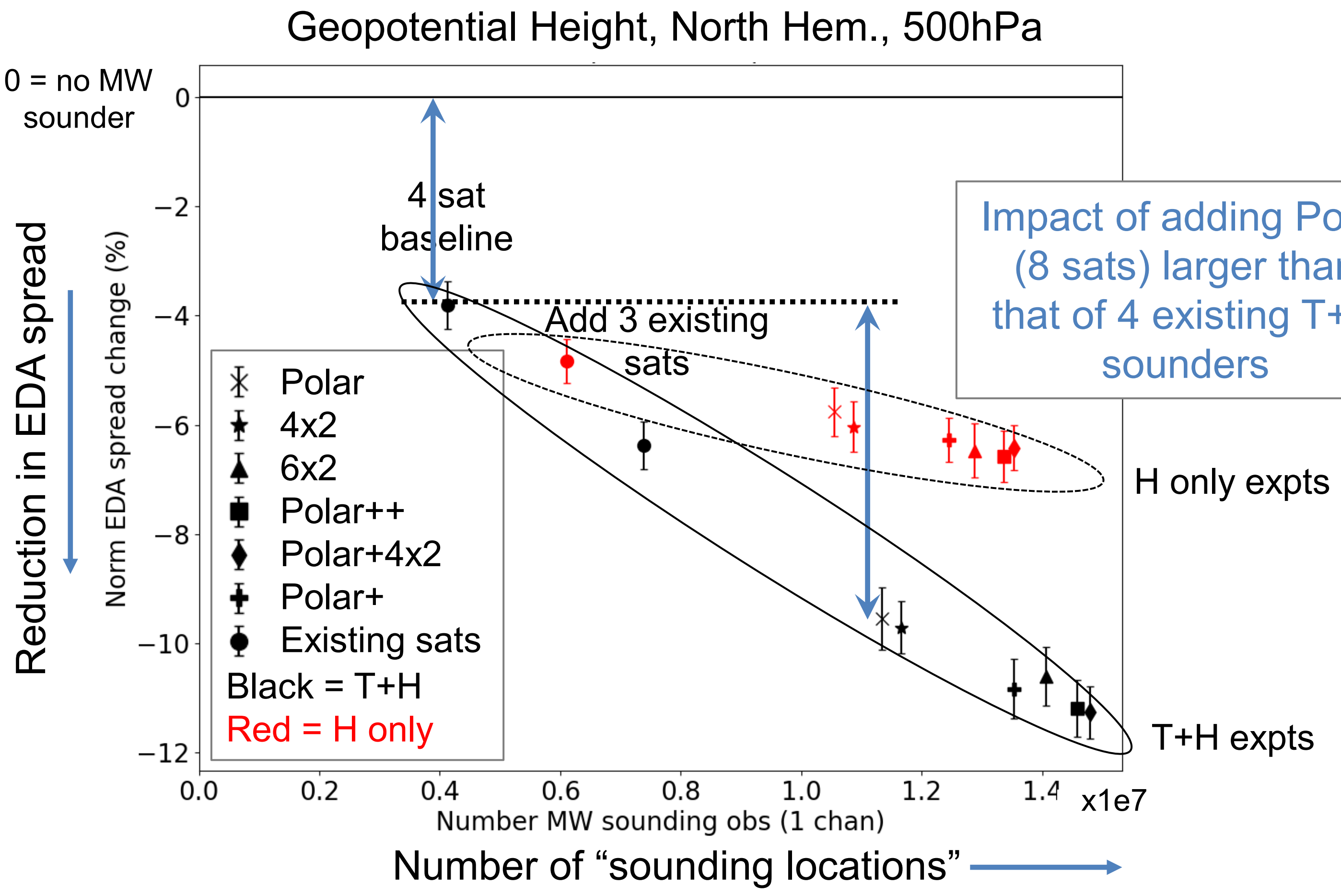
Clear additional benefit of temp sounding channels

Expts with existing data fit well with simulated data results

Larger spread reduction with more observations

8-28 June 2018

H only in smaller "cluster" - rate of spread reduction slowing more for H only?



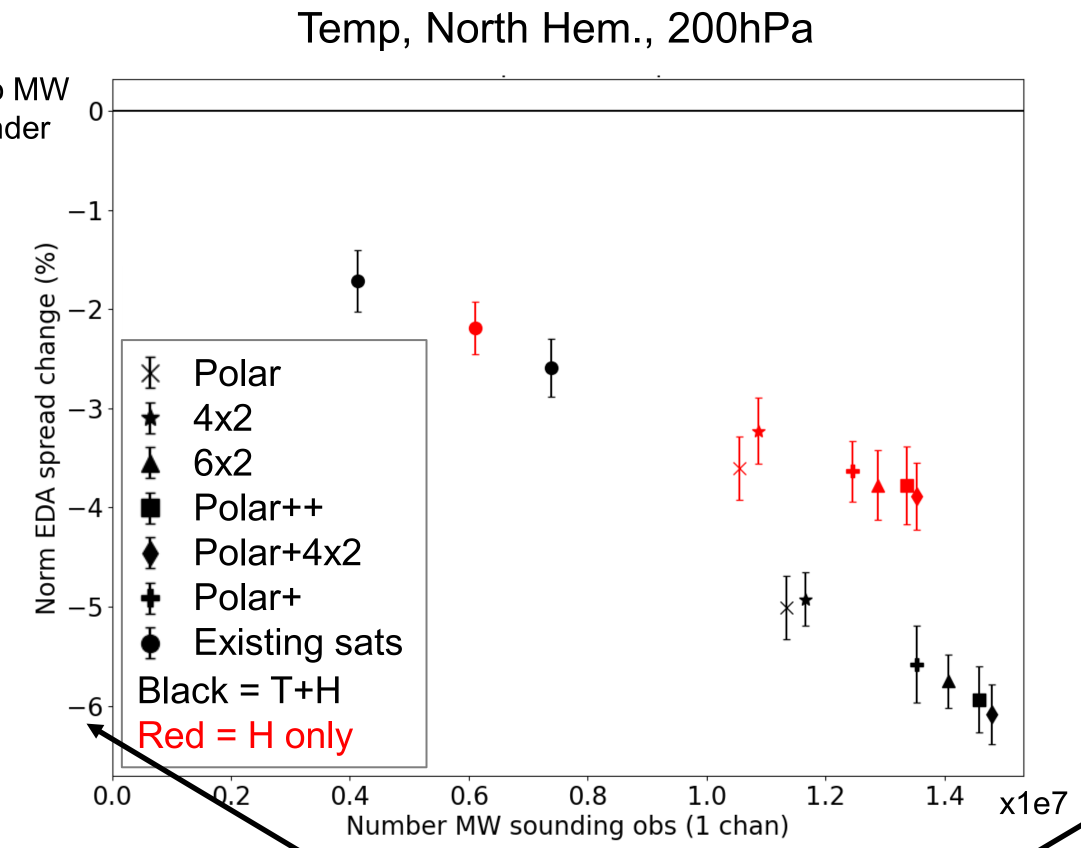
Impact of adding Polar (8 sats) larger than that of 4 existing T+H sounders

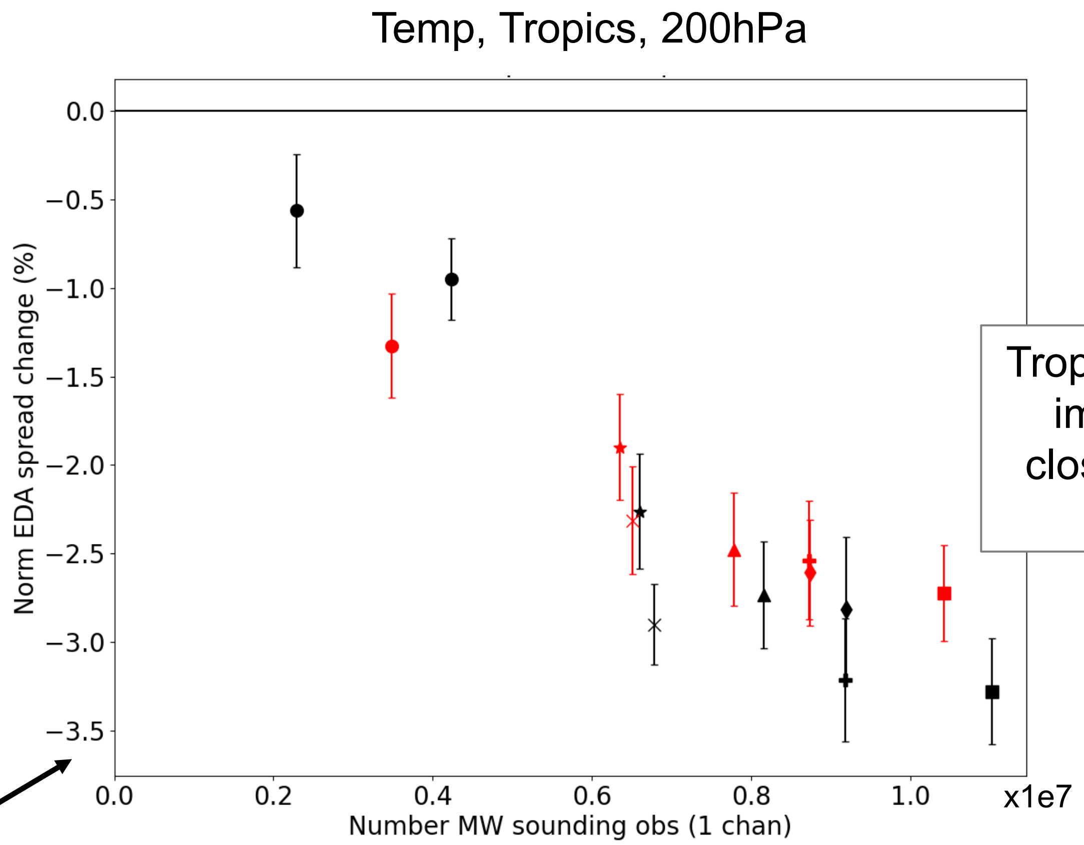
Clear additional benefit of temp sounding channels

Expts with existing data fit well with simulated data results

Different behaviour between extra-tropics and tropics

0 = no MW sounder



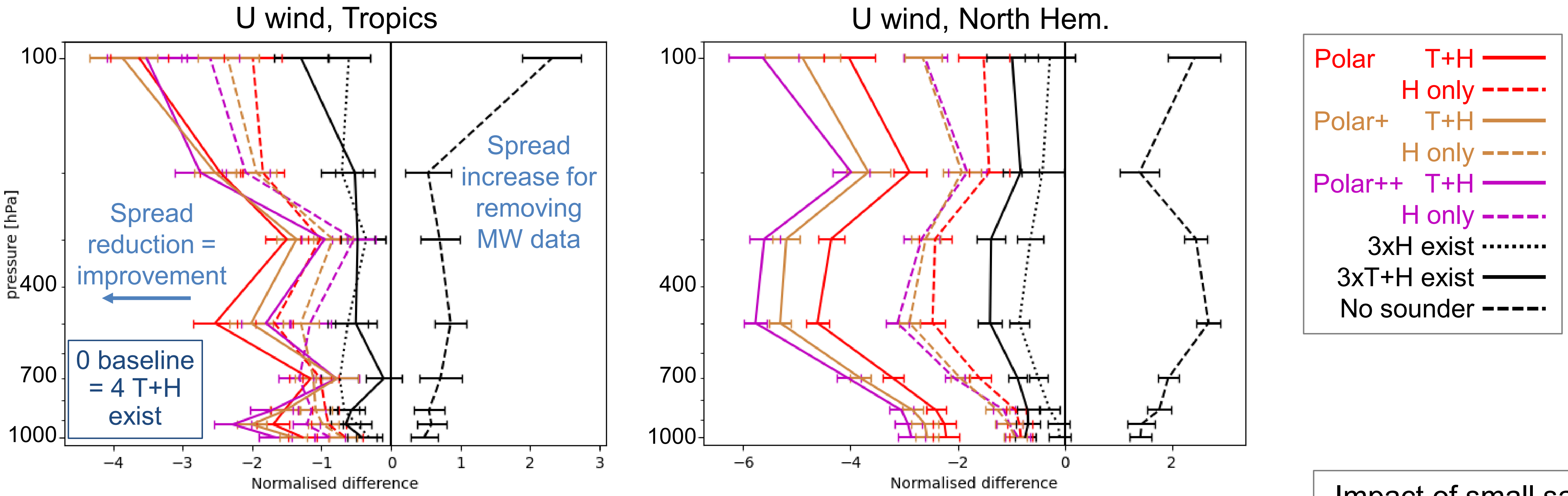


Tropical T+H impacts closer to H only

Smaller impacts in tropics

Tropics generally show slower rate of EDA spread reduction with obs increase

Different processes responsible for different importance of humidity/temperature channels in the extra-tropics vs tropics



Humidity info higher proportion of impact for wind in tropics…

…additional temp info becomes more important in extra-tropics

Impact of small sat extends into the stratosphere – cycling assimilation propagates changes

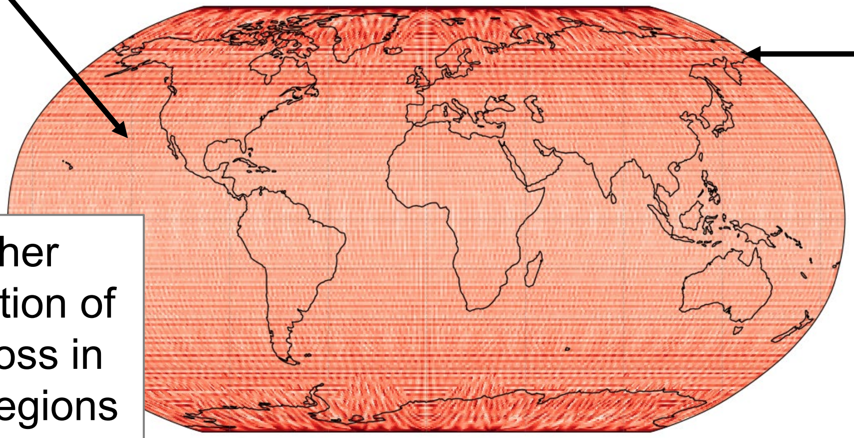
- Importance of factors affecting extraction of wind varies
  - humidity tracing dominant effect in tropics
  - geostrophic balance in extra-tropics

Important interaction between thinning and satellite phasing

8-9th Jun 2018
All obs locations

Even coverage across globe

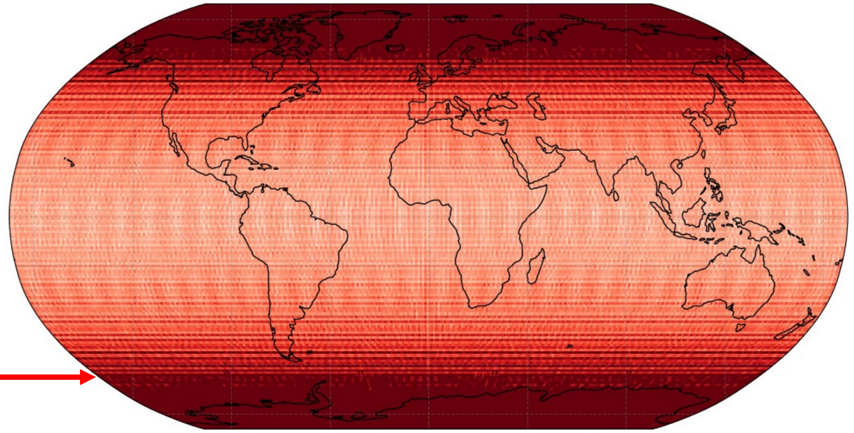
Polar++ (20 sats)



All satellites thinned together

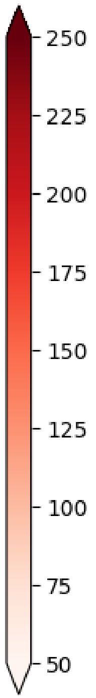
Higher proportion of data loss in polar regions due to higher overlap

Polar++ Reduced Thinning

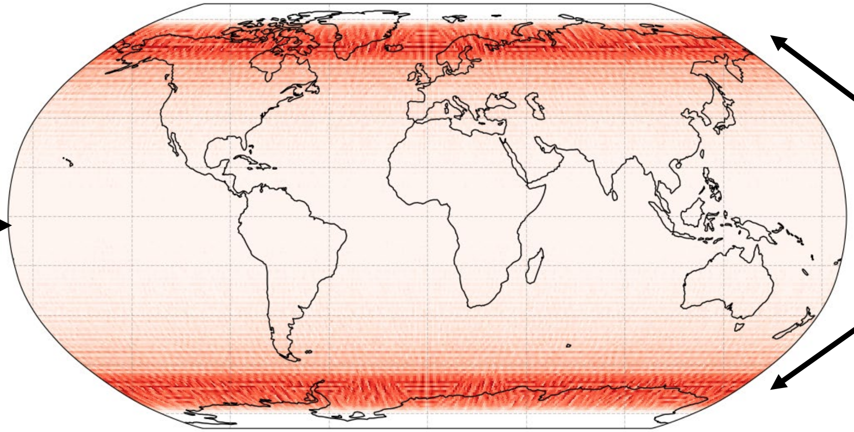


Satellites thinned individually

EDA expt still ongoing!



4x2



Tropical regions have slightly fewer obs than Polar (8 sat) configuration

Inclined orbit constellations have high density in 60-75°N/S

Summary

- 8 sat polar constellation already shows significant reductions
- Clear value of additional temperature sounding channels. In general:
  - For NH/SH, impact T+H ~2-3 x H only
  - For tropics, impact T+H ~1.5-2 x H only
- Different behaviour in extra-tropics vs tropics
  - Spread reductions in extra-tropics may show less “saturation” than tropics
  - Different atmospheric processes affect relative impacts

Further analysis to include:

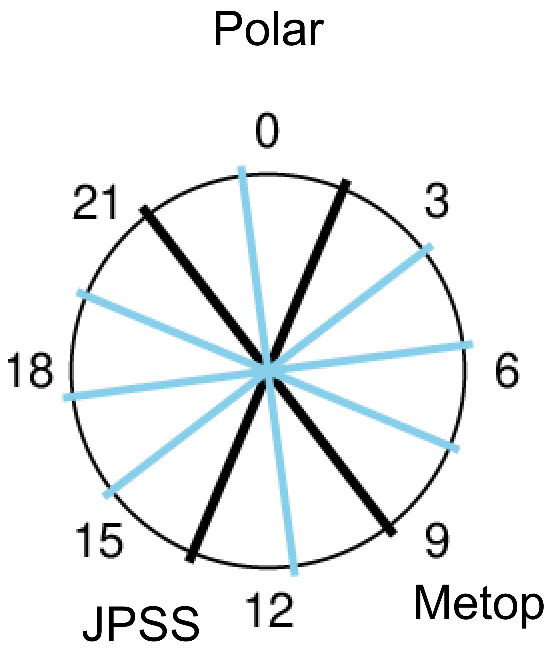
- Incorporate Polar++ with no multi-sat thinning – will a more extreme number point show “saturation” in NH/SH?
- Consider polar regions more closely
- Influence from distribution differences (polar vs. inclined orbit)

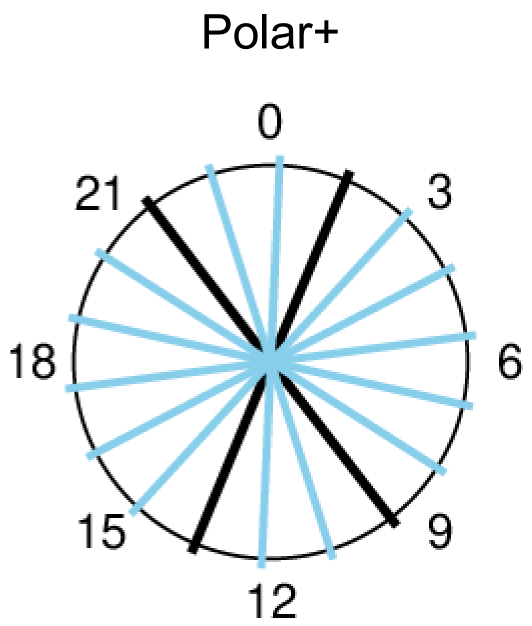
Thank you for your attention!

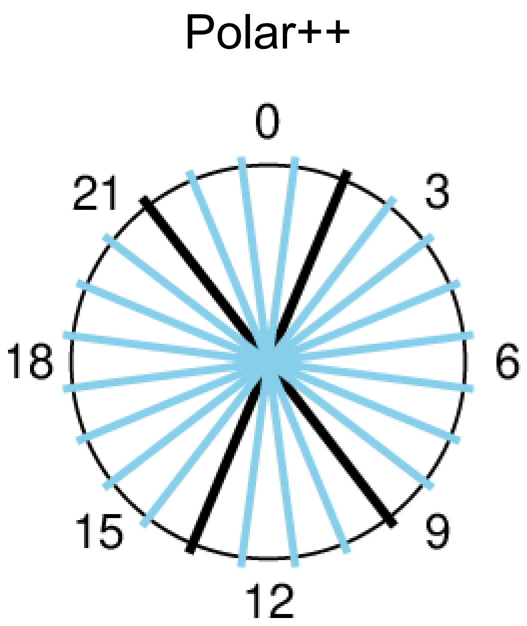
AWS channel characteristics

Channel	Frequency (GHz)	Bandwidth (MHz)	NEDT used (K)	Footprint (km)	Utilisation
AWS-11	50.3	180	0.85	40	Temp sounding
AWS-12	52.8	400	0.60	40	Temp sounding
AWS-13	53.246	300	0.65	40	Temp sounding
AWS-14	53.596	370	0.60	40	Temp sounding
AWS-15	54.4	400	0.60	40	Temp sounding
AWS-16	54.94	400	0.60	40	Temp sounding
AWS-17	55.5	330	0.65	40	Temp sounding
AWS-18	57.290644	330	0.65	40	Temp sounding
AWS-21	89	4000	0.25	20	Window/cloud detection
AWS-31	165.5	2800	0.55	10	Window/hum sounding
AWS-32	176.811	2000	0.65	10	Hum sounding
AWS-33	178.811	2000	0.65	10	Hum sounding
AWS-34	180.811	1000	0.80	10	Hum sounding
AWS-35	181.511	1000	0.80	10	Hum sounding
AWS-36	182.311	500	1.05	10	Hum sounding

Polar orbit distributions in time

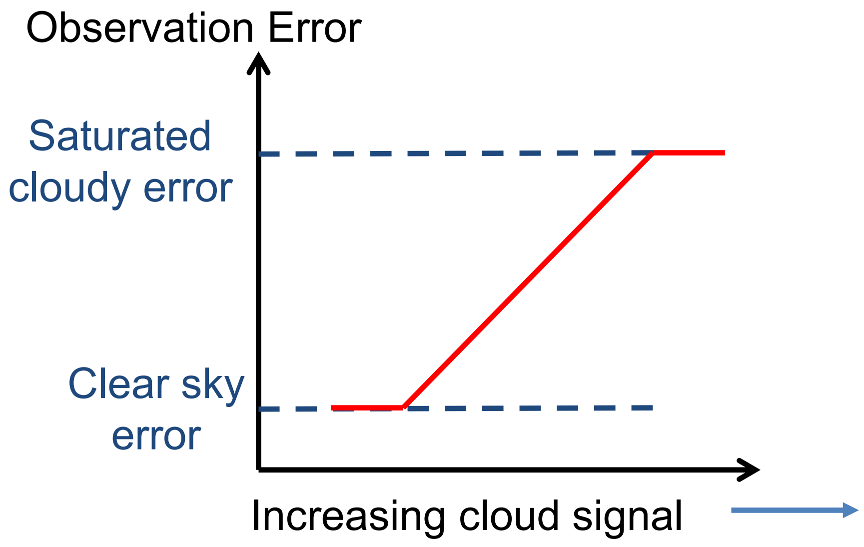


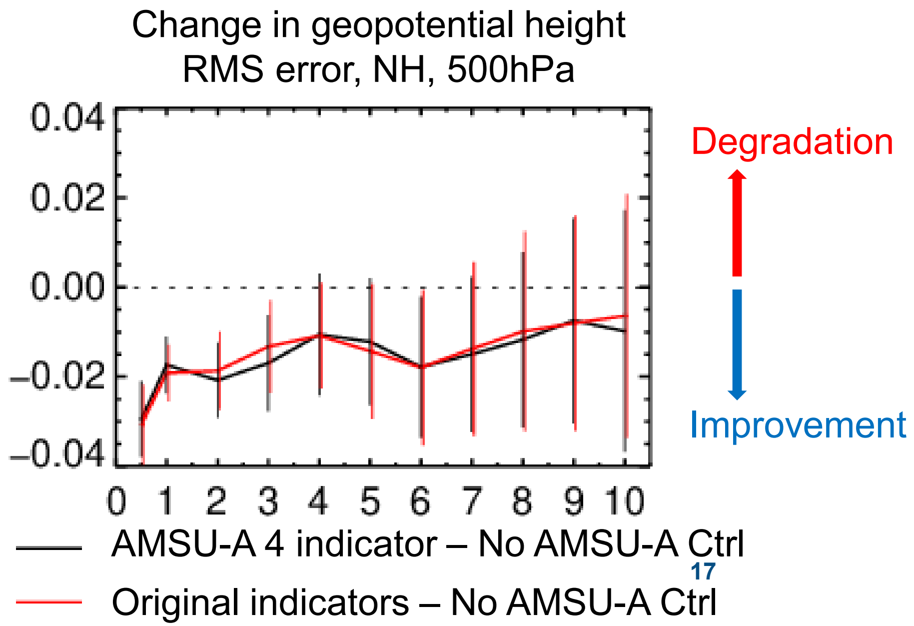




Adapting the all sky error model for loss of low frequencies

- All sky model increases observation error in presence of cloudy signals from observation or model
- Accounts for different representativeness of clouds in observations and model
- Obs errors determine weighting in the assimilation and perturbations applied in the EDA
- Current MW **temp** sounders scheme uses 23.8 and 31.4GHz channels as indicator of cloud – unavailable for AWS
- New indicator of cloud uses 52.8 GHz window channel
- Based on absolute difference in cloudy and clear sky BT estimates for observation and model
- Experiments with AMSU-A showed new cloud indicator could retain much of positive impact of all sky MW use

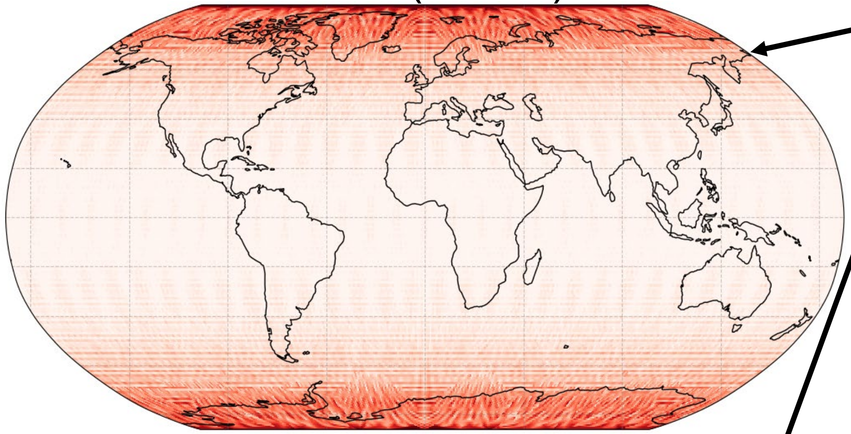




Important interaction between thinning and satellite phasing

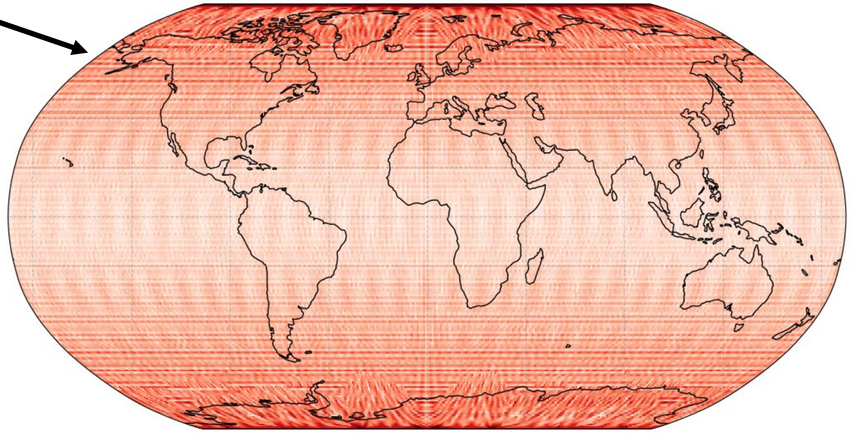
8-9th Jun 2018
All obs locations

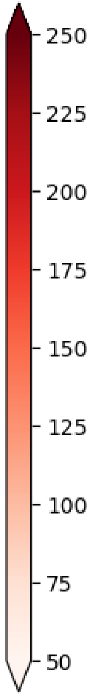
Polar (8 sats)



All satellites thinned together

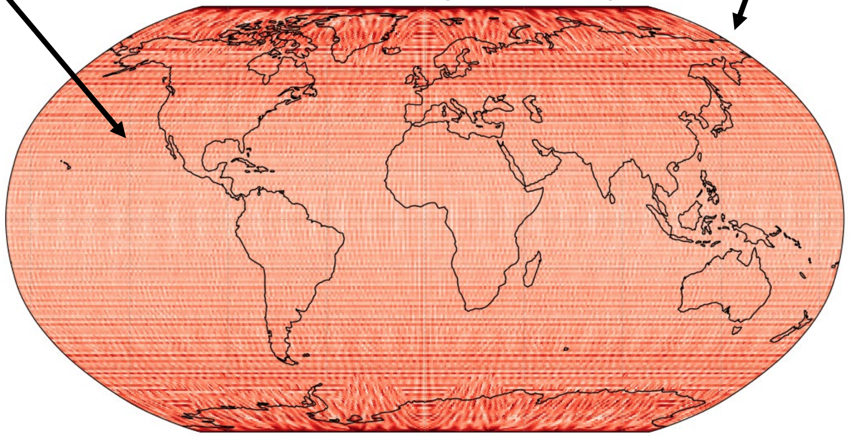
Polar+ (14 sats)





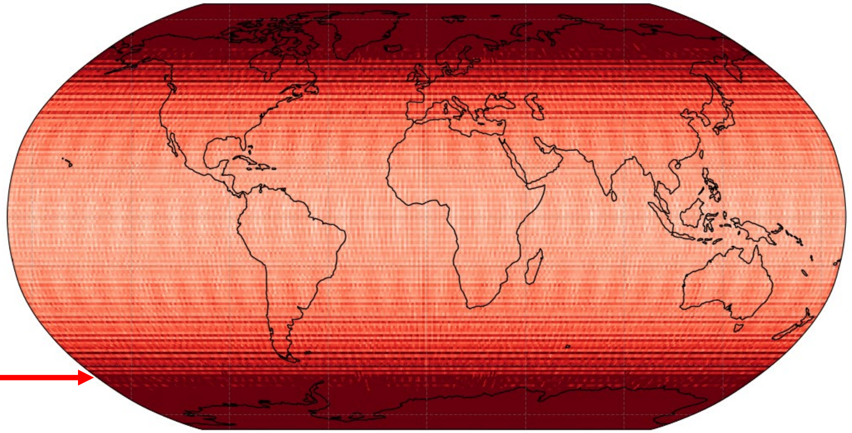
Even coverage across globe

Polar++ (20 sats)



Higher proportion of data loss in polar regions due to higher overlap

Polar++ Reduced Thinning



Satellites thinned individually

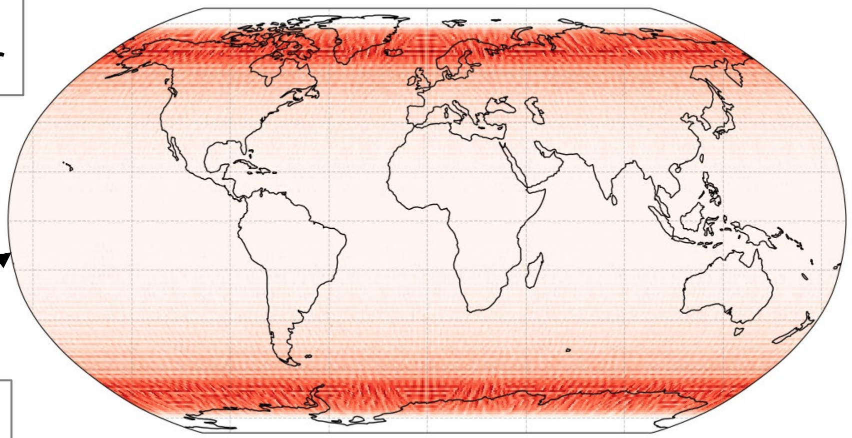
EDA expt still ongoing!

Higher density 60-75°N/S for inclined orbits

8-9th Jun 2018
All obs locations

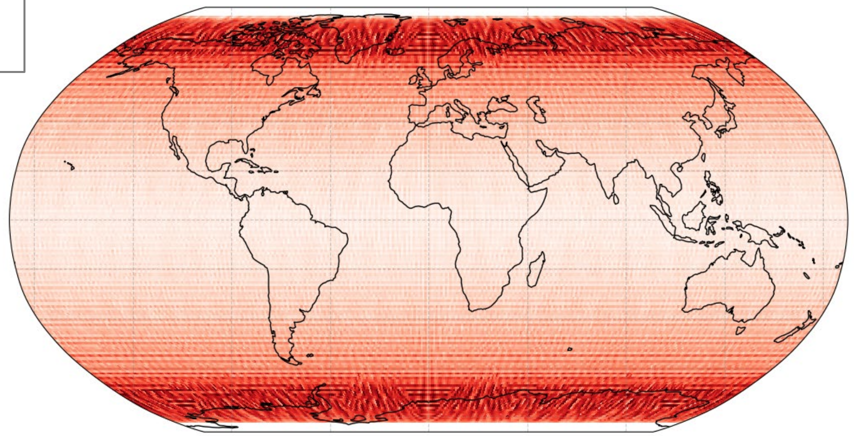
All satellites thinned together

4x2

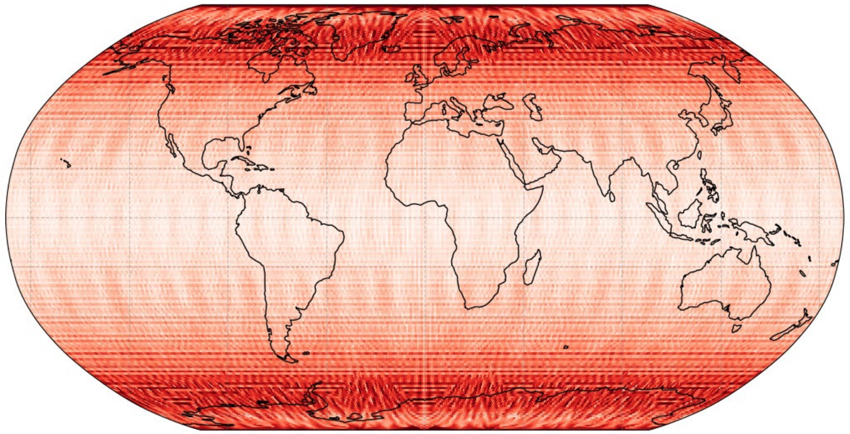


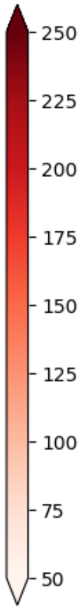
Tropical regions have slightly fewer obs than Polar configuration

6x2



Polar + 4x2

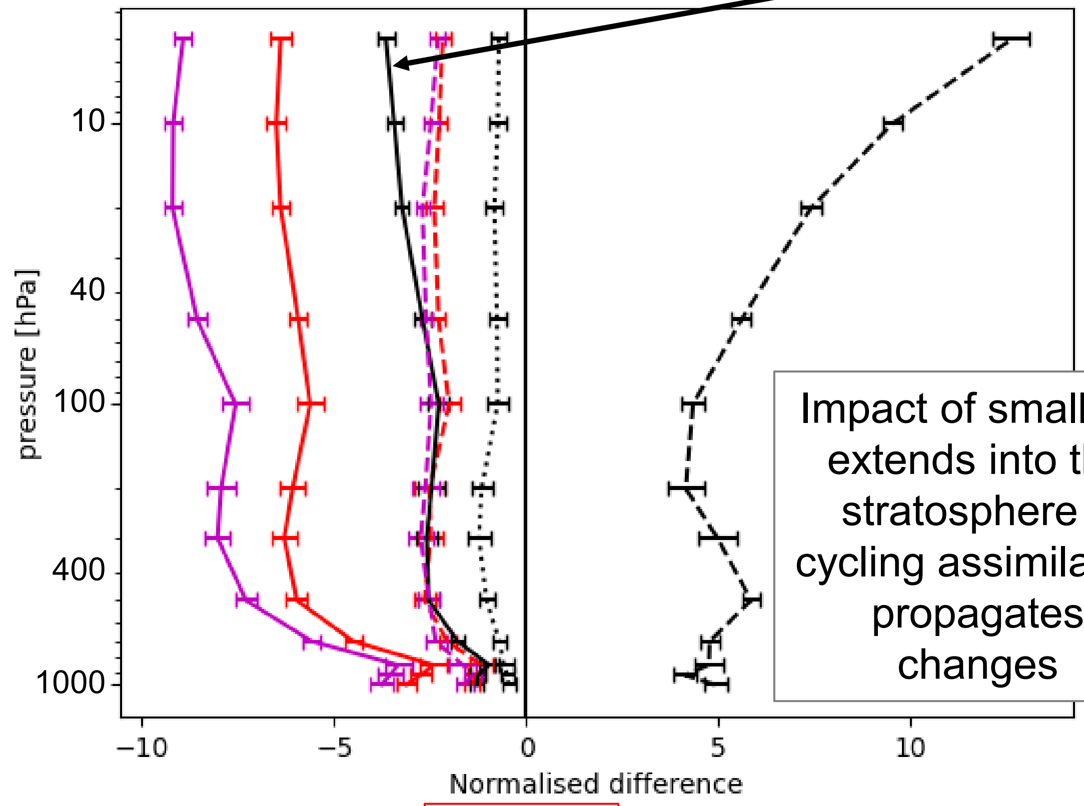




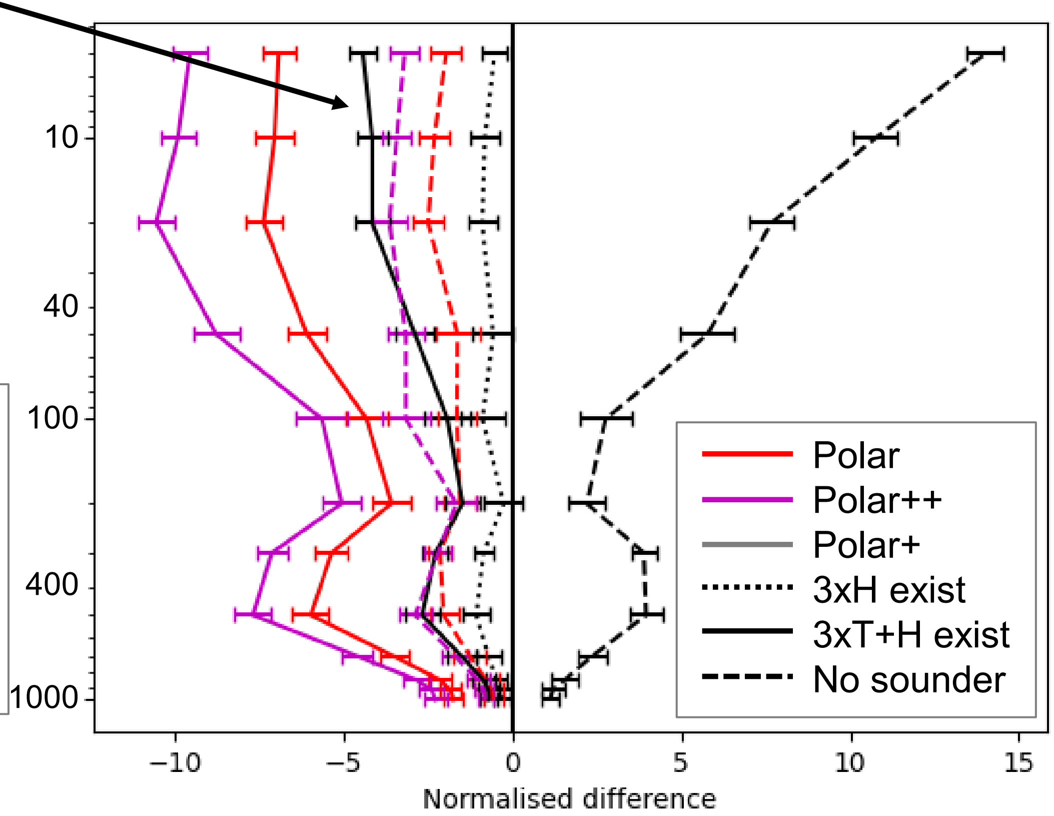
Impacts propagate into stratosphere

Real data with stratospheric channels increases spread reduction further

Temp, South Hem.



Geopotential Height, North Hem.



Impact of small sat extends into the stratosphere – cycling assimilation propagates changes

0=4 T+H exist

For NH/SH, impact T+H ~2-3 x H only
For tropics, impact T+H ~1.5-2 x H only