Simulation and Evaluation of NOAA Next-gen Microwave Satellite Observation with the ECMWF EDA method

Zaizhong Ma[1,2], Niels Bormann[2], Katie Lean[2], David Duncan[2], Ernesto Hugo Berbery[1] and Satya Kalluri[3]

[1]Earth System Science Interdisciplinary Center, University of Maryland, College Park, USA
[2]European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom
[3]NOAA/NESDIS, College Park, USA

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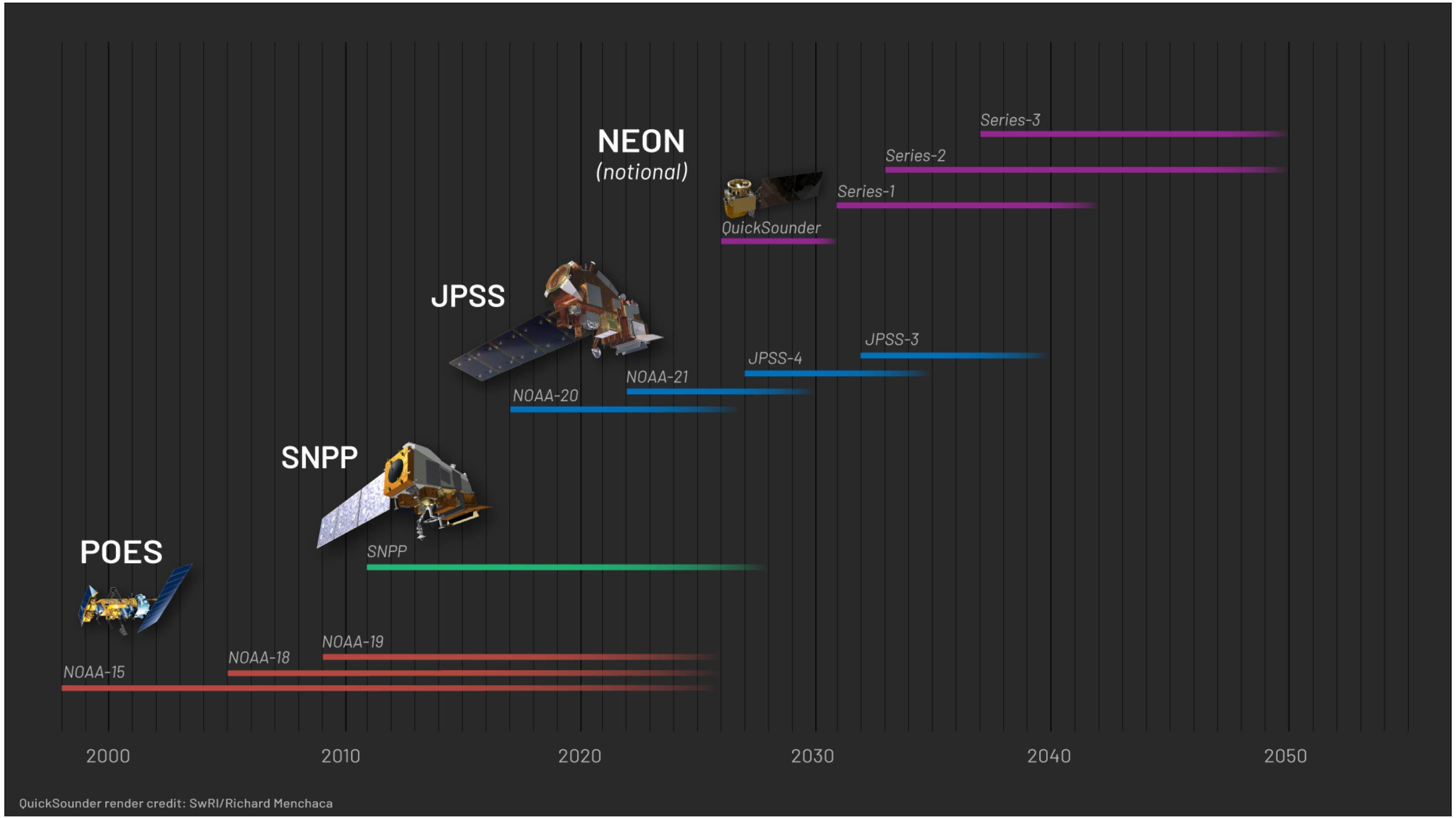
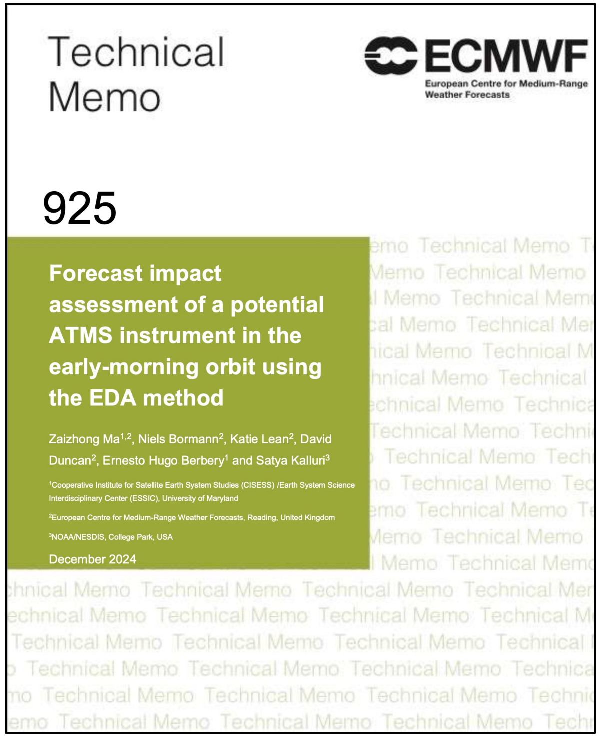
NOAA's Near Earth Orbit Network (NEON) Program





- **QuickSounder: Refurbished ATMS in 1730 orbit**
- **SMBA: Sounder for Microwave Brightness and Analysis** is expected to be a hyperspectral sounder, but here we assume traditional channel characteristics.

Sounder for Microwave Brightness and Analysis (SMBA) instrument characteristics

More channels than ATMS

- **SMBA is expected to be hyperspectral, but we don't simulate that in this study.**
- **For the technical implementation of SMBA we are assuming the following:**
  - Channels as defined in the table;
  - Geographical sampling same as ATMS (to be simulated by EUMETSAT).

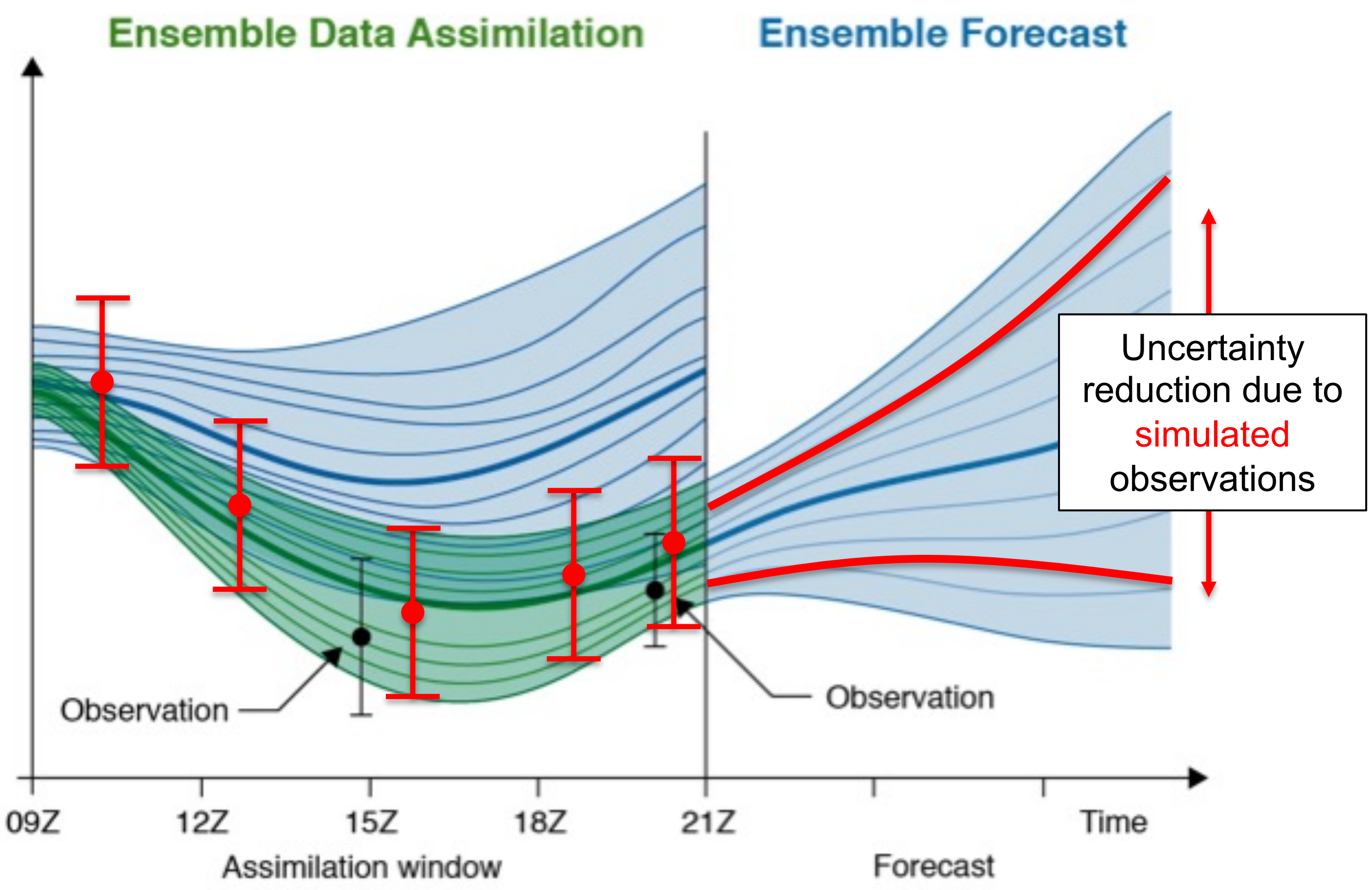
Table 4.1-1. NEON Program Microwave Sounder Baseline Requirements (TBS) (This table can be revised to reflect the specifics of the instrument chosen)

Priority	Center Frequency [(1)] (GHz)	Center Frequency Stability[(2)] (MHz)	Channel Bandwidth [(3)] (GHz)	Calibration Accuracy (K)	Temperature Sensitivity NEDT @300K (K)
(III) (IV)	23.8	5	0.27	0.5	0.24
(III) (IV)	31.4	5	0.18	0.5	0.28
(I) (IV)	50.3	4	0.18	0.5	0.33
	51.76	4	0.4	0.5	0.22
	52.8	4	0.4	0.5	0.22
	53.596 ± 0.115	3	0.17	0.5	0.24
	54.4	2	0.4	0.5	0.22
	54.94	3	0.4	0.5	0.22
	55.5	3	0.33	0.5	0.30
	57.290344	0.3	0.33	0.5	0.35
	57.290344 ± 0.217	0.4	0.078	0.5	0.45
	57.290344 ± 0.3222 ± 0.048	0.9	0.036	0.5	0.50
	57.290344 ± 0.322 ± 0.022	0.4	0.016	0.5	0.75
	57.290344 ± 0.322 ± 0.010	0.4	0.008	0.5	1.00
	57.290344 ± 0.3222 ± 0.0045	0.5	0.003	0.5	1.60
(III) (IV)	88.2	18	2	0.5	0.20
(I)	114.50	1	1	0.5	0.30
	115.95	1	0.8	0.5	0.30
	116.65	1	0.6	0.5	0.30
	117.25	1	0.6	0.5	0.30
	117.80	1	0.5	0.5	0.40
	118.24	1	0.38	0.5	0.40
	118.58	1	0.30	0.5	0.50
(III)	165.5	22	3	0.4	0.30
(II) (IV)	183.31 ± 7	14	2	0.4	0.26
	183.31 ± 4.5	14	2	0.4	0.26
	183.31 ± 3	16	1	0.4	0.36
	183.31 ± 1.8	10	1	0.4	0.36
	183.31 ± 1	9	0.5	0.4	0.50
(III)	229	22	2	0.5	0.36

(1) Number of passbands per channel, listed in "Center Frequency" column, is maximum allowed. Fewer passbands may be used, provided the Temperature Sensitivity requirements are met. For example, Table 4.1-1 lists two passbands centered at (183.31 + 7) = 190.31 GHz and (183.31-7) = 176.31 GHz. The channel may be implemented using only one of these passbands, provided the temperature sensitivity value of no greater than 0.3 K is achieved.
(2) Channel center frequency stability is defined as the maximum deviation from the channel center frequency for both long-term and short-term periods over the operational life of the instrument.
(3) Channel bandwidth is defined as the spectral width between the half-power points per passband.
(I) Performance Capability Priority 1: Temperature Sounding
(II) Performance Capability Priority 2: Moisture Sounding
(III) Performance Capability Priority 3: Additional Channels
(IV) Performance Capability Priority 11: ATMS Channel Continuity

Ensemble of Data Assimilations (EDA) method to assess future observations

- 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
- Focus on spread changes at 12-hour forecast range

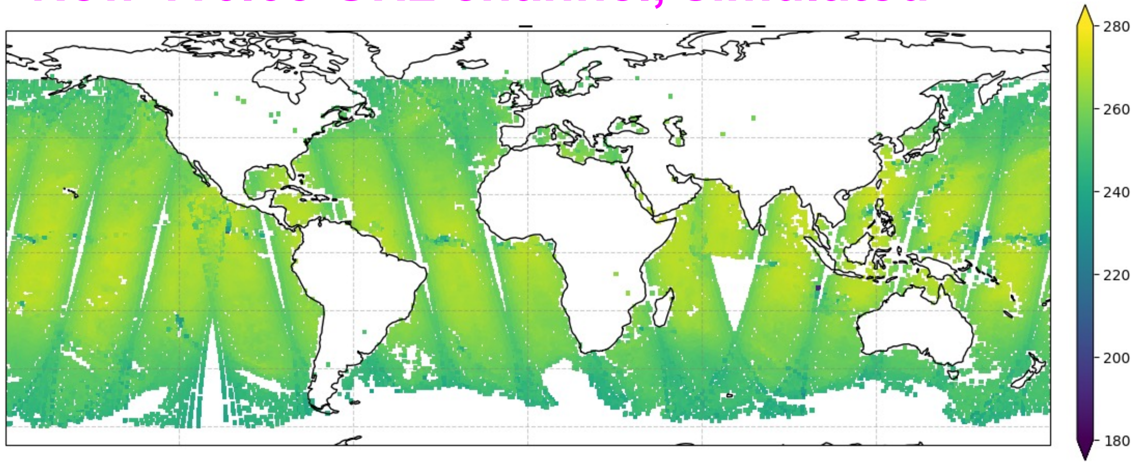


EDA spread = standard deviation of ensemble members around the ensemble mean

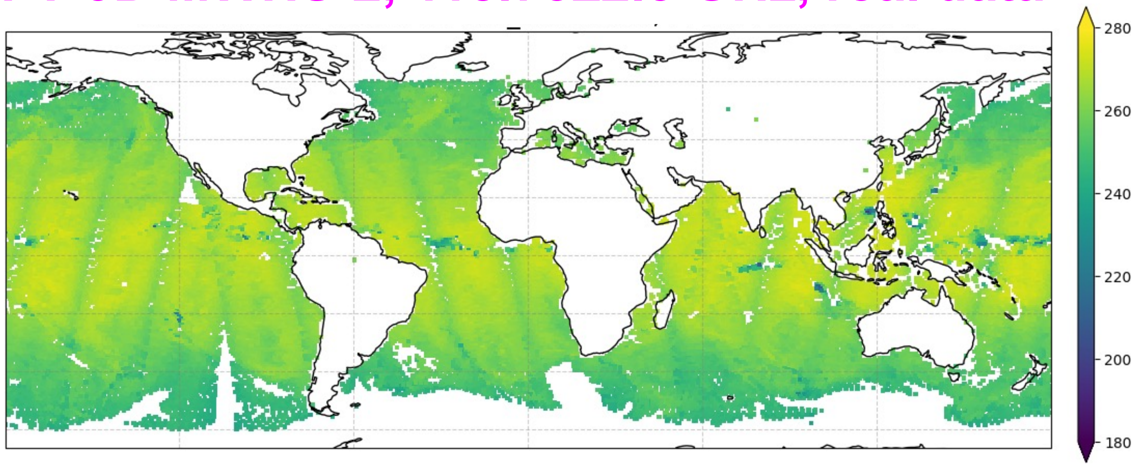
Aims of SMBA EDA impact study

– Simulate the impact of a hypothetical future sounder using the EDA
  - 30 channels, with seven 118 GHz channels and one 229 GHz channel added to the ATMS channel set
  - Used in 13:30 and 17:30 LTAN orbits (replacing ATMS)
  - Assess the added impact of the 118 and 229 GHz channels and the sensitivity to the noise-performance

New 116.65 GHz channel, simulated



FY-3D MWHS-2, 118.75±2.5 GHz, real data



SMBA EDA experiments with two sets of observation errors

– Two settings for assigned observation errors are used:

  - **Idealised**: Use specified NEDT values in empirical formula as in Lean et al (2025)
    – Assumes ideal white-noise performance can be achieved for NEDT
  - **Baseline**: Values as used for real NOAA-20 ATMS for 50 and 183 GHz channels, otherwise results of empirical formula * 1.2
    – Assumes performance similar to ATMS for heritage channels

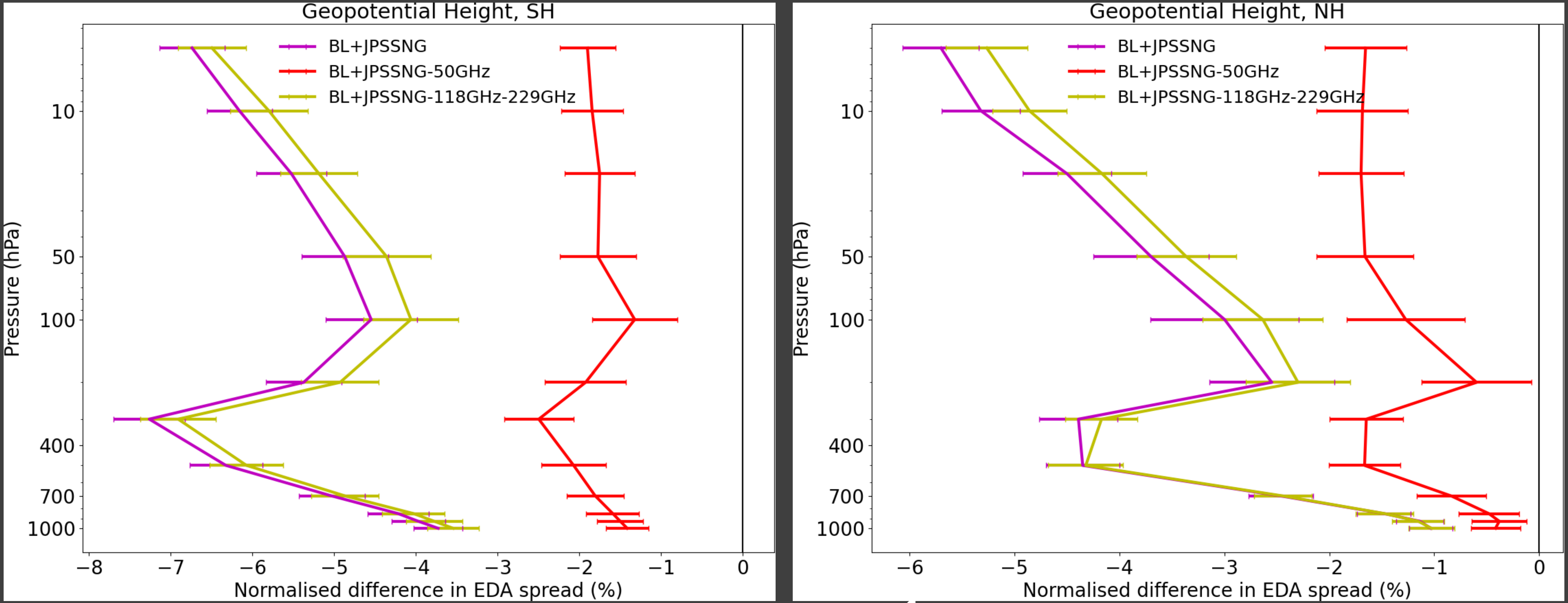
– Tests the sensitivity of the results to the assumed error characteristics.

System Setup for SMBA EDA impact study

- **EDA System:** IFS Cycle 48r1, MW in all-sky
- **Baseline (BL) observing system:**
  - All non-MW observations used operationally at ECMWF at the time
  - A reduced set of MW instruments: MW sounders from 2 Metop satellites and AMSR2, GMI, SSMIS (window channels only)
  - Excluded observations: MWHS-2 (from FY-3C and FY-4D) and Sounding channels from two SSMIS instruments
- **EDA period: 1-30, June 2021**
- **EDA Scenarios:**

Scenario Name	Observing system other than MW sounding	MW sounding in 9:30 orbit	MW sounding in 13:30 orbit	MW sounding in 5:30 orbit	MW obs error setting
BL	Full*	Two Metop	-	-	
BL+JPSSNG	Full*	Two Metop	Two SMBA	-	Ideal values
BL+JPSSNG-50ghz	Full*	Two Metop	Two SMBA, **without 50 GHz**	-	Ideal values
BL+JPSSNG-118GHz-229GHz	Full*	Two Metop	Two SMBA, **without 118 &229 GHz**	-	Ideal values

SMBA and two denial scenarios

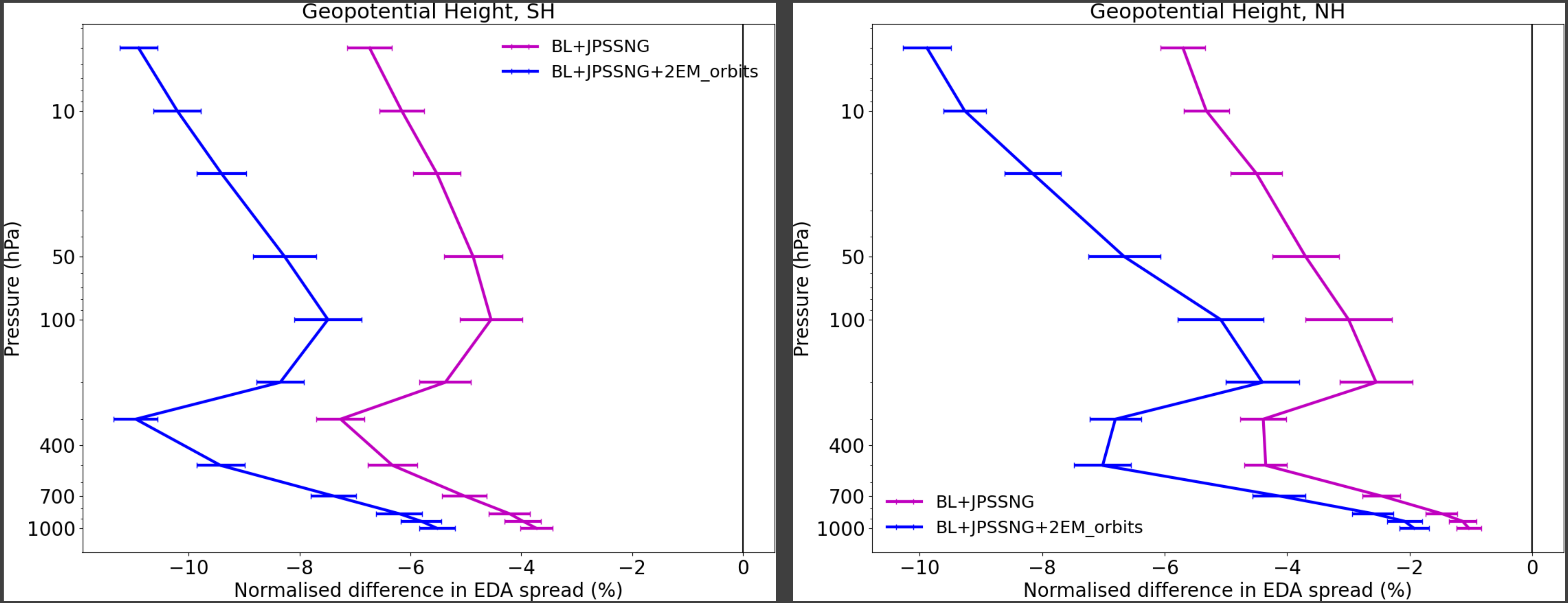


Improvement

Key findings:

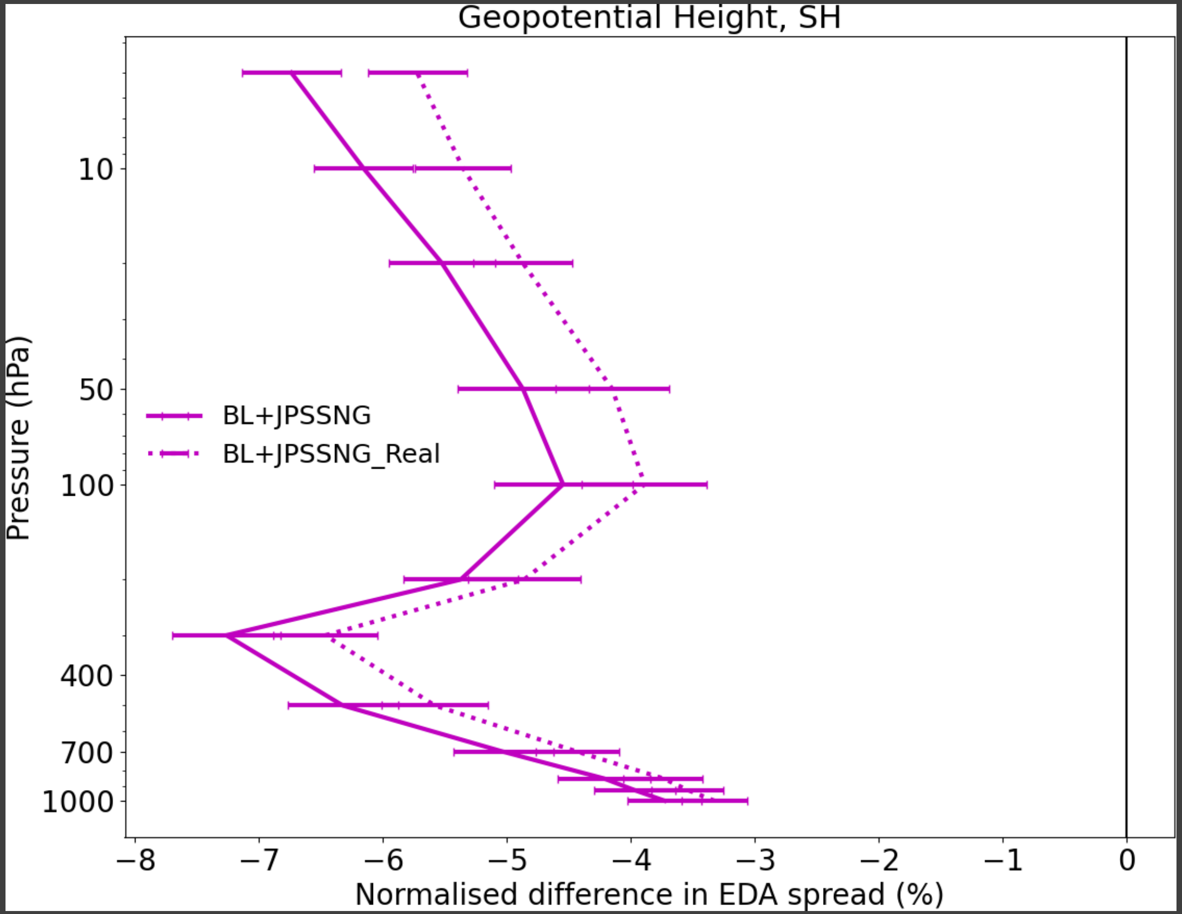
1) purple vs yellow - The addition of the 118 & 229 GHz channels to 50 and 183 GHz gives a small benefit
2) purple vs red - 50 GHz temperature-sounding channels are important to maintain

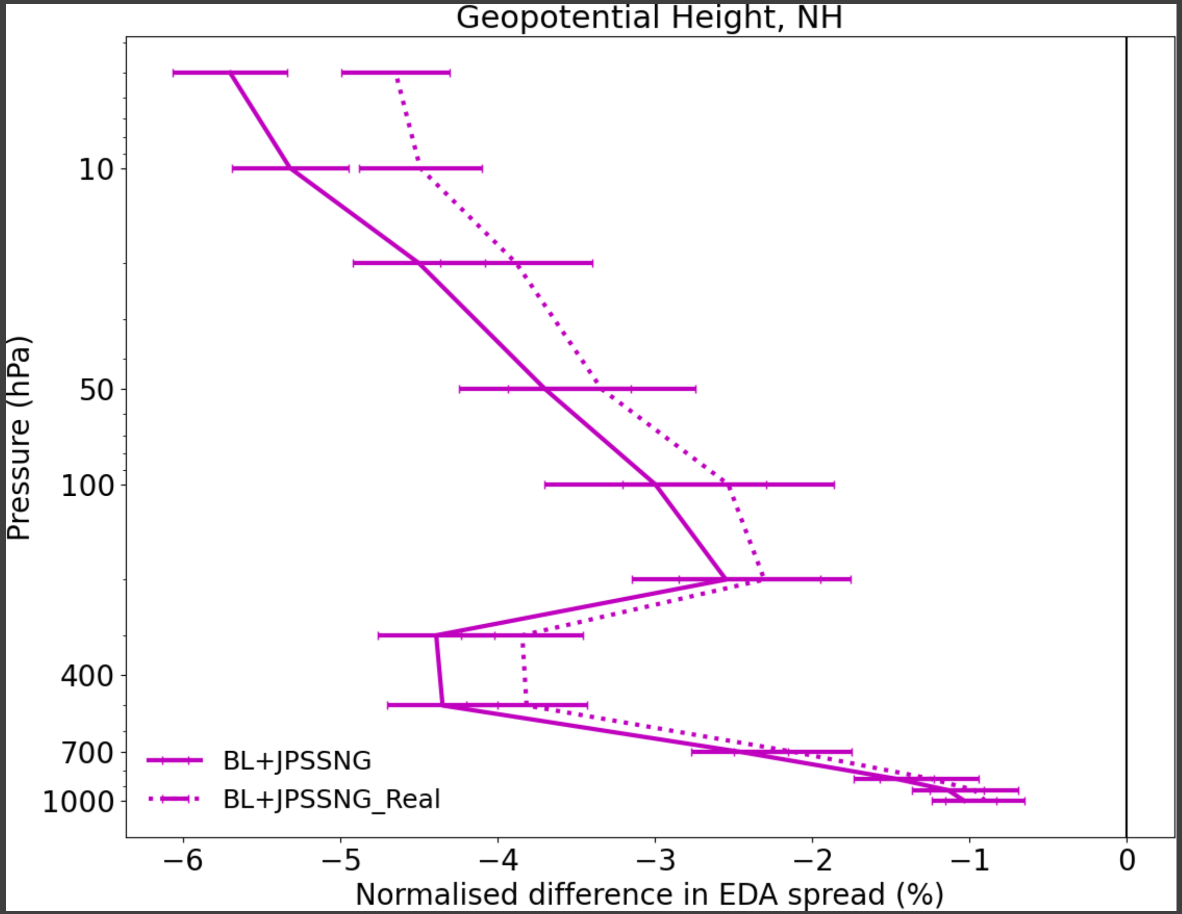
Addition scenarios with more SMBA in the Early-Morning orbit



Key findings: We get the largest impact if we have the new sensor in the afternoon and early morning orbits

SMBA Noise Sensitivity scenarios from afternoon orbit (Idealised vs Baseline)





Key findings: Strong sensitivity to noise—low noise performance is critical

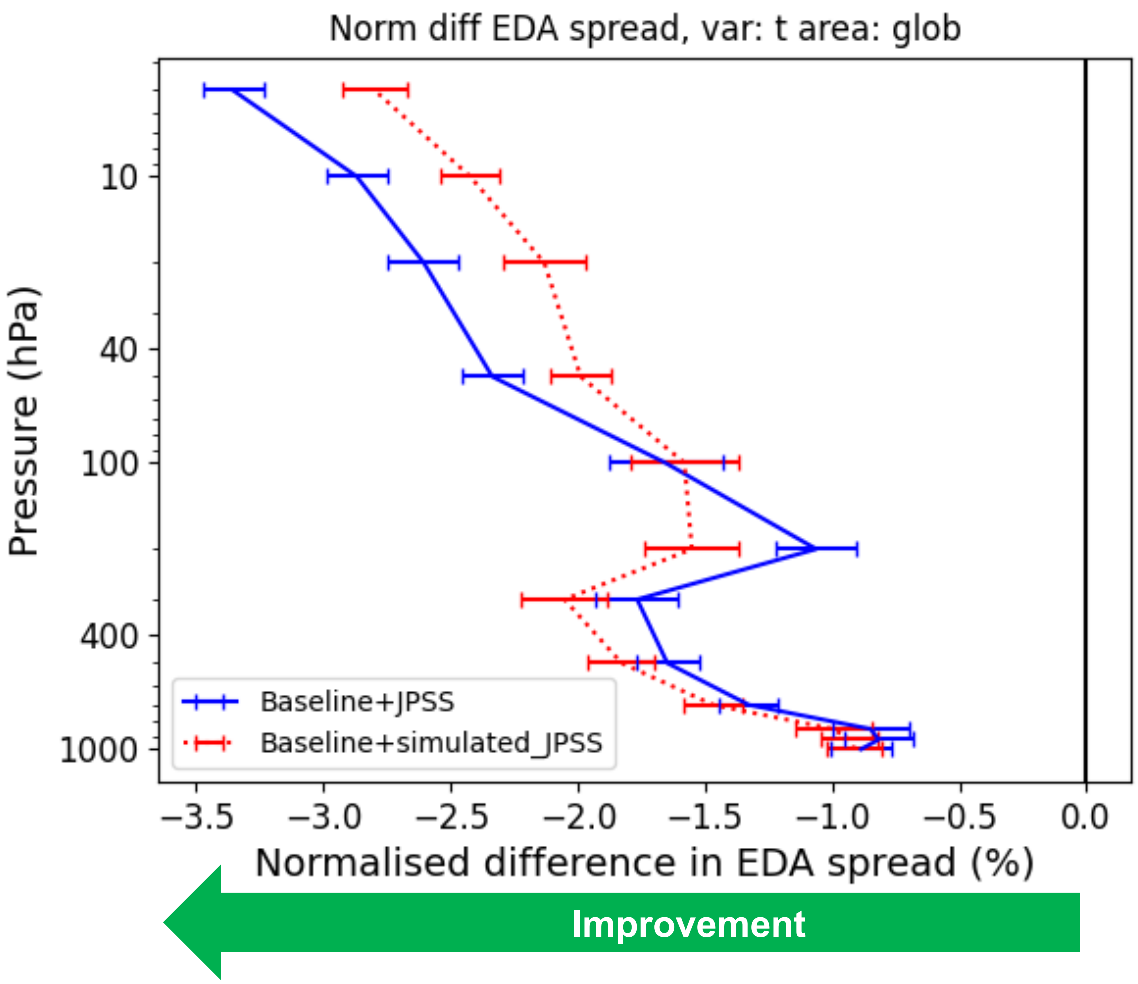
Summary & Future Plan:

- NOAA is collaborating with CISESS and ECMWF to investigate the impact of the future microwave missions using ECMWF EDA method.
- SMBA EDA impact studies:
  - Expanded EDA study to 30 channels, adding **Seven 118 GHz channels** and **One 229 GHz channel more than ATMS**
  - **Key Findings:**
    - Adding 118 & 229 GHz to 50 & 183 GHz channels yields **modest improvements**
    - **50 GHz channels remain essential**—118 GHz is **not a full replacement**
    - **Strong sensitivity to noise—low noise performance is critical**
    - **Largest benefit** when sensors cover **both afternoon and early-morning** orbits
- Future plan: EDA for hyperspectral microwave-sounding if available

Back-up slides!!!

Milestones-1: Similarity of simulated and real ATMS in EDA framework

Scenario Name	Observing system other than MW sounding	MW sounding in 9:30 orbit	MW sounding in 13:30 orbit
Baseline	Full*	Two Metop	-
Baseline+JPSS	Full*	Two Metop	Two Real ATMS (S-NPP, NOAA-20)
Baseline+simJPSS	Full*	Two Metop	Two simulated ATMS (S-NPP, NOAA-20)

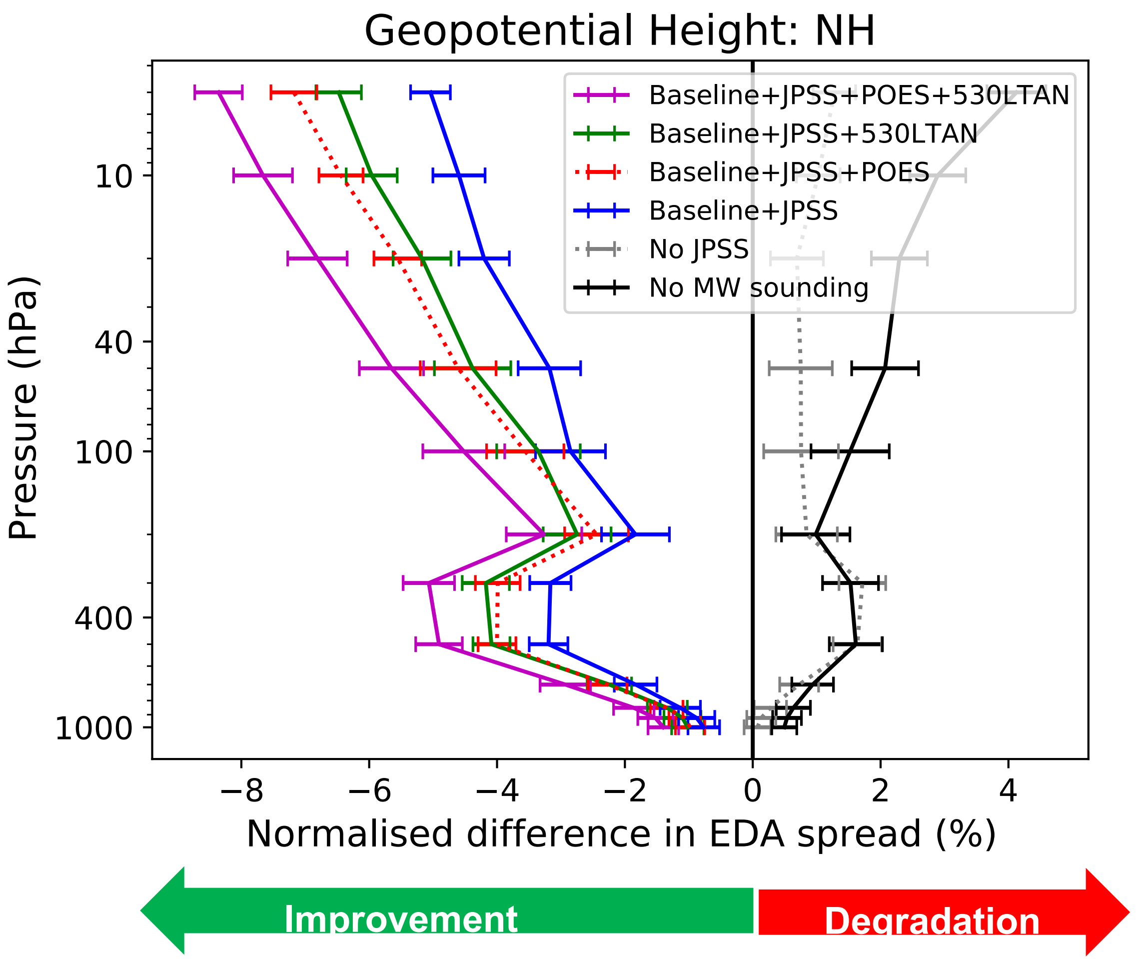


The results show the performance is broadly similar.

Milestones-2: EDA impact study for refurbished ATMS in 17:30 LTAN

Key Findings:

- The EDA analysis demonstrated the incremental benefit of adding MW observations in the 17:30 LTAN, provided the data quality is comparable to that of the S-NPP ATMS.
- Results align with previous findings, indicating that NWP models have not yet reached saturation in terms of MW sounder impact beyond the Metop and JPSS orbits.
- Findings are consistent with real data from MWHS-2 on FY-3D in the early-morning orbit, which also showed a positive impact.



Ma, Z., N. Bormann, K. Lean, D. Duncan, E. Berbery and S. Kalluri, **2024**: Forecast impact assessment of a potential ATMS instrument in the early-morning orbit using the EDA method. *ECMWF Technical Memorandum*, 925, https://doi.org/10.21957/59eb3a9b44

SMBA data simulation

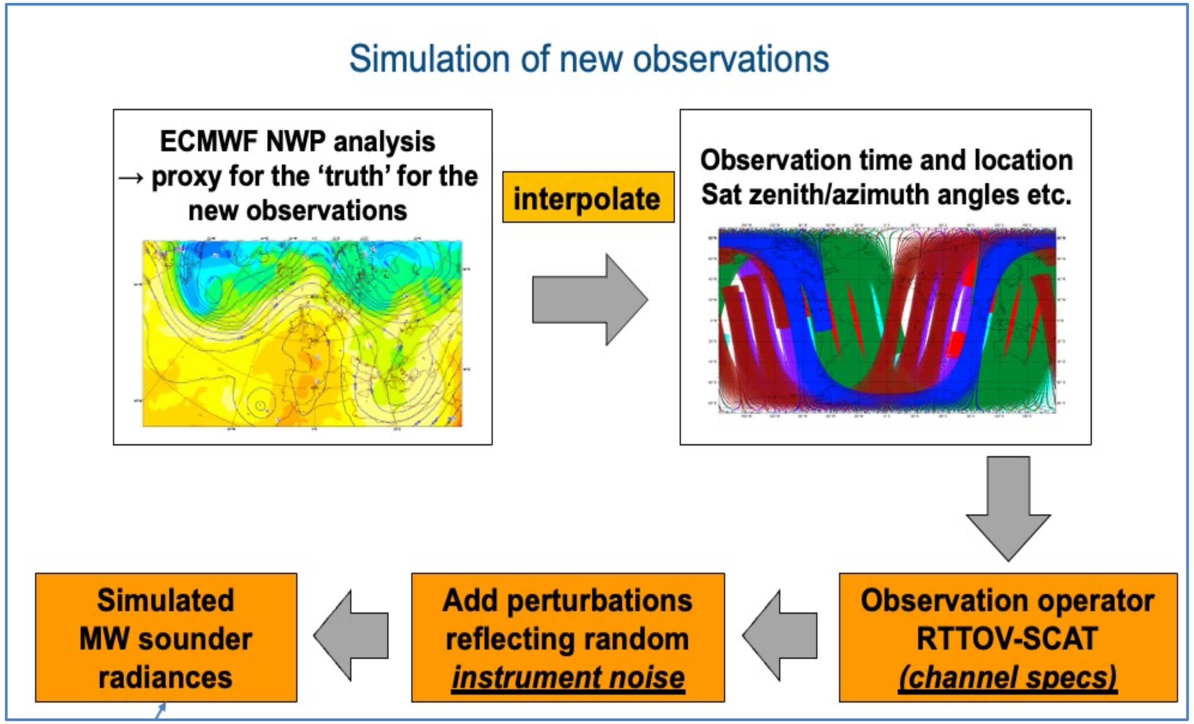
- **Coefficients for SMBA:**

  provided by NWP SAF

- **Orbital parameter (sampling):**

  provided by EUMETSAT (thanks to Joerg Ackermann)

Name	Satellite identifier	Sensor	Report Type	Orbit-sampling
NG1_SMBA	1001	SMBA=51	98001	NPP
NG2_SMBA	1002	SMBA=51	98002	N20
NG3_SMBA	1003	SMBA=51	98003	NX1
NG4_SMBA	1004	SMBA=51	98004	NX2



(From Katie's ESA report)

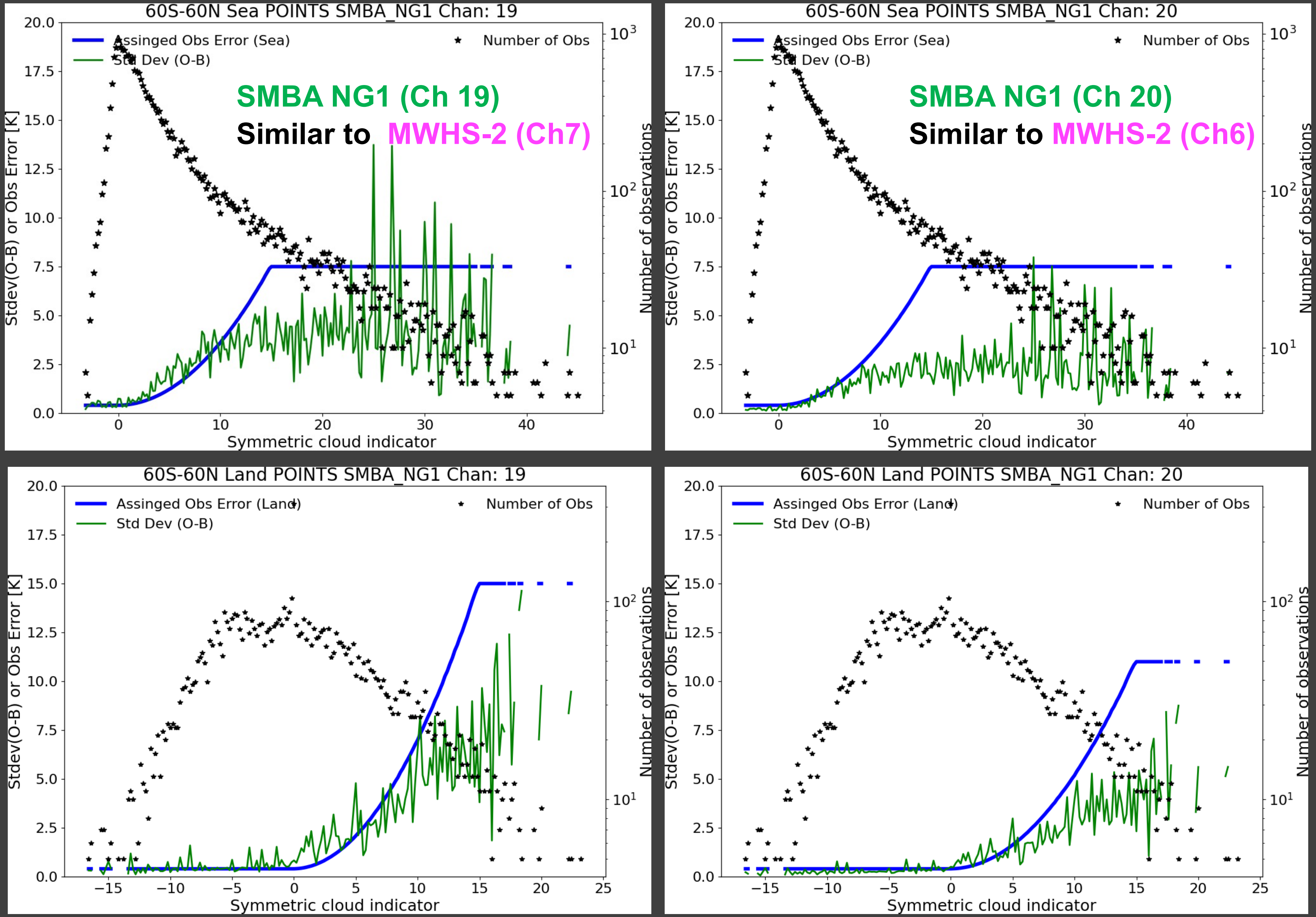
NPP: Suomi NPP ATMS simulation

N20: NOAA-20 ATMS simulation

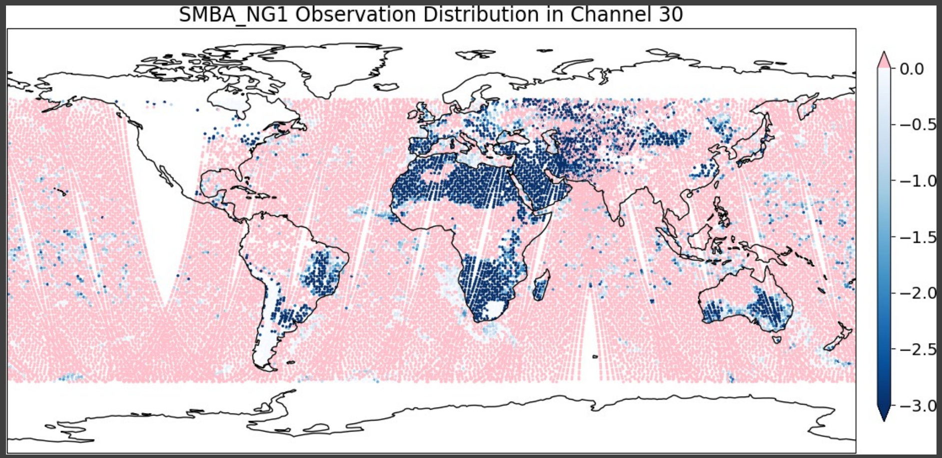
NX1: simulation of an ATMS on board a fictional satellite NX1 with 90 deg shift wrt. to S-NPP and an LTAN of app. 17:30 UTC

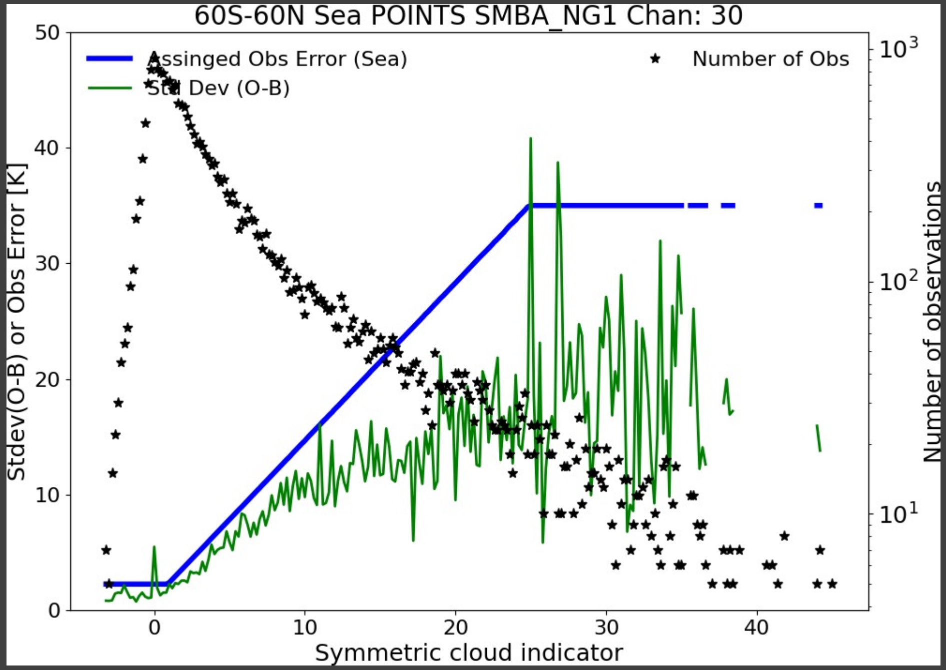
NX2: simulation of an ATMS on board a fictional satellite NX2 with 90 deg shift wrt. to NOAA-20 and an LTAN of app. 17:30 UTC

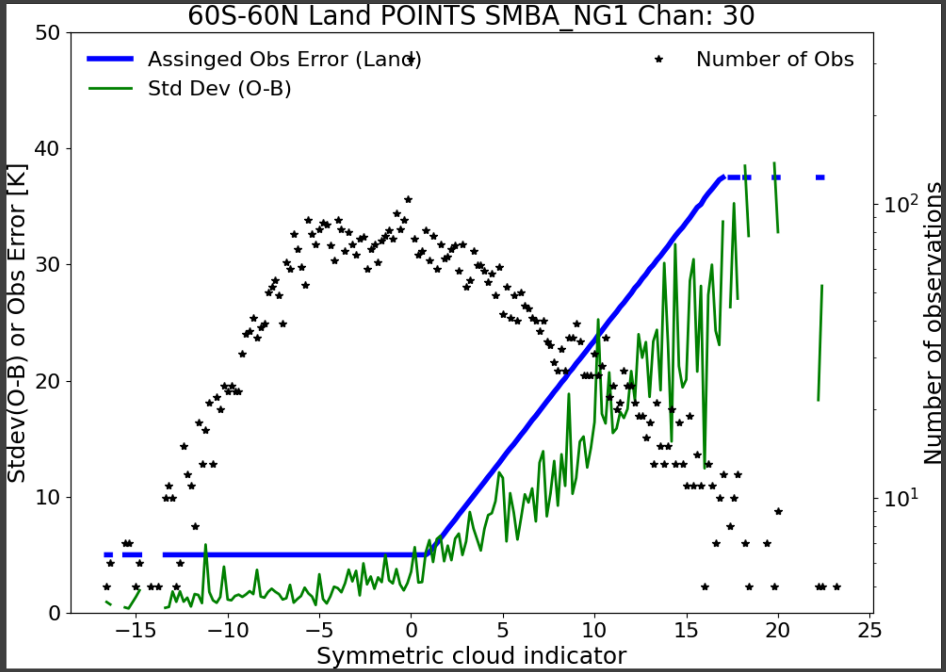
4D-Var exp: Assigned values with stdev(O-B) vs cloud-indicator (118 GHz)



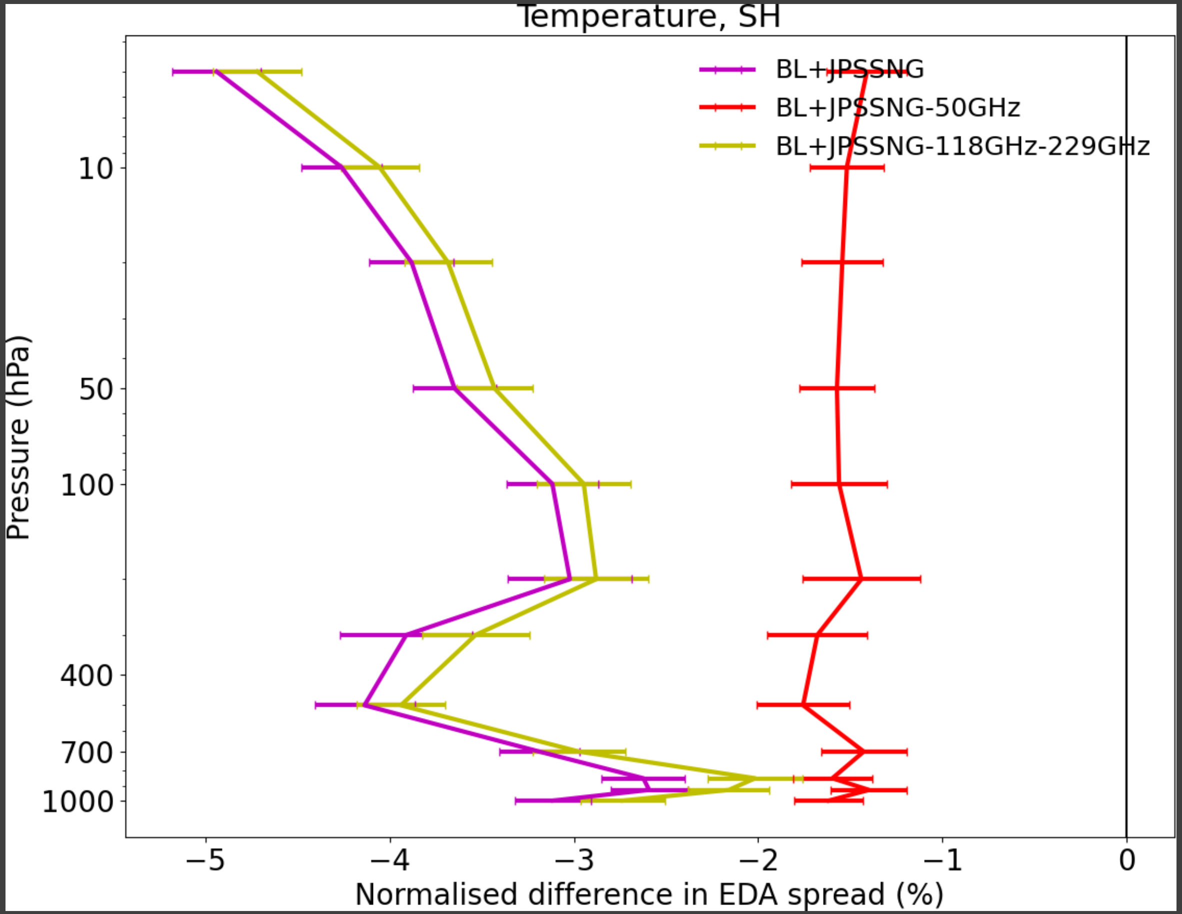
4D-Var exp: Assigned values with stdev(O-B) vs cloud-indicator (229 GHz)

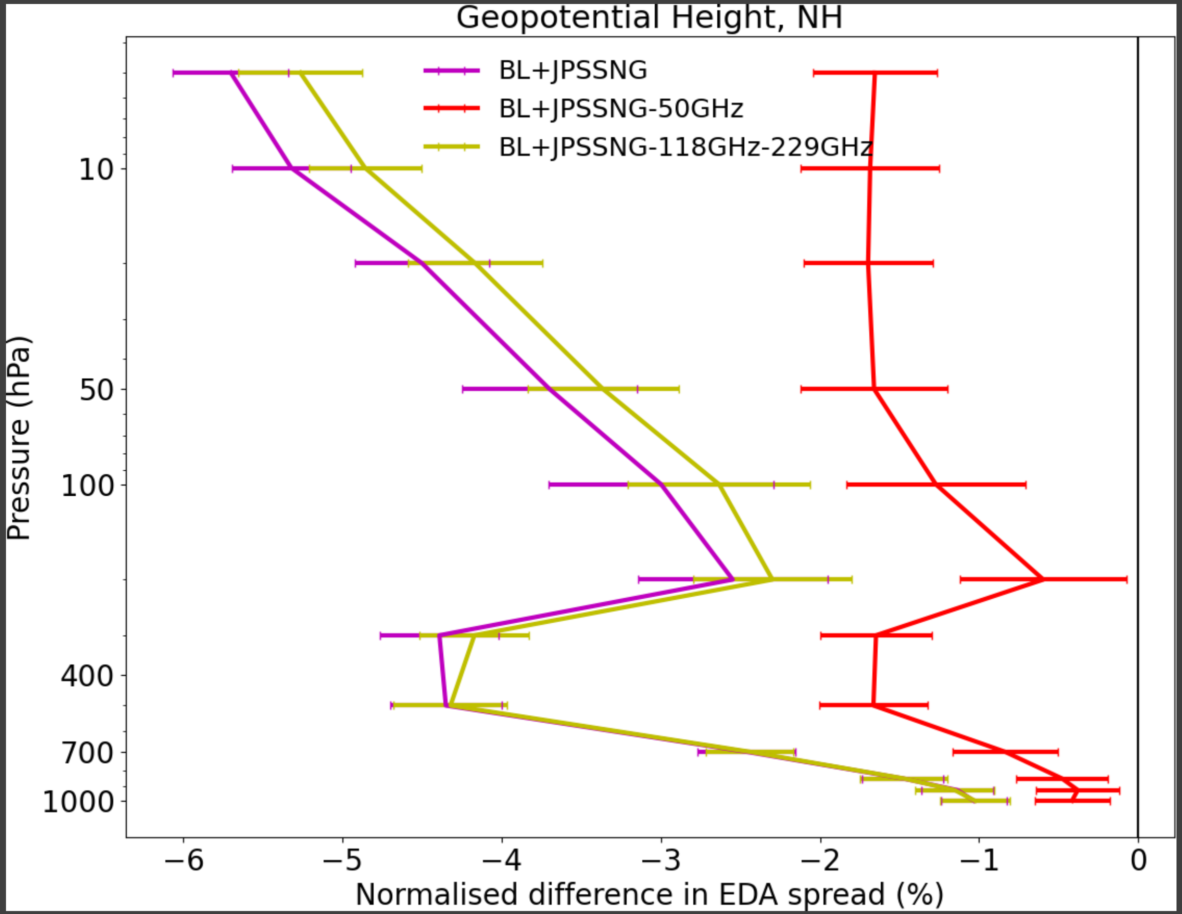






SMBA and two denial scenarios (Temp)





Key findings:

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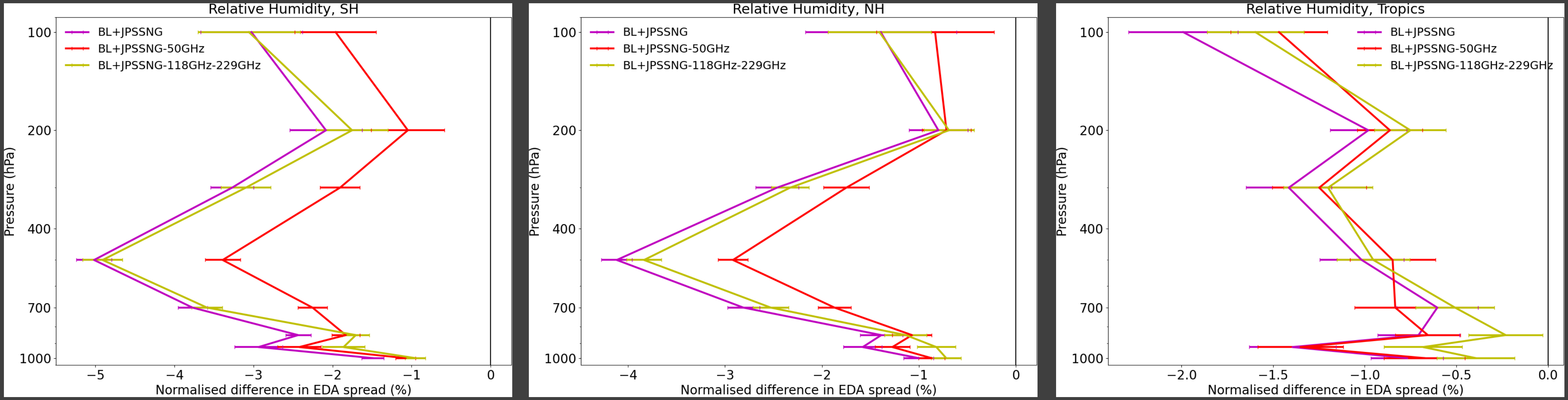
SMBA and two denial scenarios (RH)



Key findings:

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