Vicarious calibration monitoring for MWI & ICI using NWP fields

Final Meeting

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EUMETSAT, Darmstadt

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ECMWF

Outline

1) MWI and ICI introduction
2) Project concept
   - Why all-sky monitoring for cal/val?
   - Data selection for cal/val from NWP model output
3) Technical developments – MWIICI and the IFS
4) Comparing IFS simulations to EUMETSAT test data
5) Application of cal/val monitoring system to current sensors
   - GMI, SSMIS, AMSR2
6) Monitoring website
7) Conclusions

MWI & ICI Introduction

The EUMETSAT Polar System (EPS) Second Generation will carry Europe’s first ever microwave imagers

Metop-SG-B will hold two conically-scanning microwave radiometers:

- **MWI** – 26 channels measuring from 18–191 GHz
- **ICI** – 13 channels measuring from 175–668 GHz

- Together they span a *wider frequency range* than any imagers before
- ICI will measure at *higher frequencies* than any operational MW radiometer
- MWI and ICI combined will provide an *unprecedented constraint* for the global hydrological cycle in weather and climate models

Project concept – why all-sky monitoring?

Most of the frequencies observed by MWI are already assimilated at ECMWF in ”all-sky” conditions – radiances are used even in scenes with cloud and precipitation

- The forward model RTTOV-SCATT simulates the emission and scattering from liquid and frozen hydrometeors in the model
- For the assimilation, observation errors scale with cloud amount, as model errors typically increase with cloud

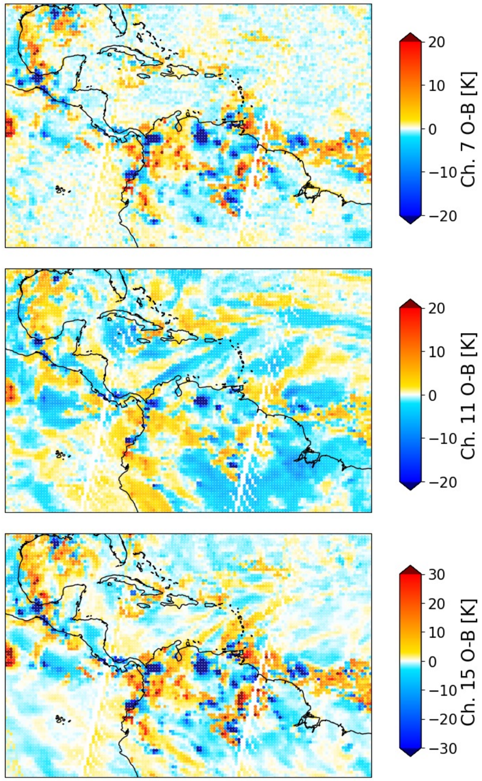
For sub-mm channels of ICI, there is no equivalent sensor in orbit so an external reference (like the NWP model) is required

For cal/val, the ECMWF model allows comparison of observed radiances with model-equivalent radiances *everywhere* and in *near-real time*

frequency [GHz], polarisation	GMI (GPM)	SSMIS-F17	SSMIS-F18	AMSR2 (GCOM-W)	MWRI (FY3D)	MWHS-2 (FY3C,D)	MHS (NOAA-18,19, Metop-A,B,C)
19v	●	●		●	●		
19h	●	●		●	●		
22/24v	●	●		●	●		
22/24h				●	●		
37v	●	●		●	●		
89/92v	●○	●○		●	●		
119 ±2.5h						●	
119 ±1.1h						●●	
119 ±0.8h						●●	
119 ±0.3h						●	
119 ±0.2h						●	
119 ±0.08h						●	
150/166v	●○						
150/166h	●○	●○					
183 ±7v/h	●○	●●	●			●●	●●
183 ±4.5v						●●	
183 ±3v/h	●○	●●●●	●			●●●●	●●●●
183 ±1.8v						●●●●	
183 ±1v/h		●●●●	●			●●●●	●●●●

From *Lonitz et al. (2022)*

Project concept – why all-sky monitoring?



O-B at 118 & 183 GHz channels
From *Duncan et al. (2023)*

By using the ECMWF model as a reference, short-range forecasts of modelled radiances (the model *background*, B) can be compared against all MWI and ICI observations

- Model fields are interpolated to the observation locations
- Producing departure (i.e. O-B) statistics

Departure statistics are then directly comparable to similar microwave imagers in the ECMWF system:

- *GMI – on the GPM Core platform since 2014*
- *SSMIS – on the DMSP F17 & F18 platforms since 2006*
- *AMSR2 – on GCOM-W platform since 2012*

Project concept – data selection for cal/val analysis

We aim to:

- Use as much data as possible in our cal/val sample
- But exclude areas of known model bias (e.g. sea-ice, thick clouds)
- Provide 3 samples for different cal/val applications:
    1) Stringent
    2) Dynamic range
    3) Unified

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- Provide 3 samples for different cal/val applications:
    1) Stringent
    2) Dynamic range
    3) Unified

Define channel-based 'symmetric' cloud impact (CI) parameter that is sensitive to cloud in both the model and the observation:

$$CI_{Ch} = |O_{Ch} - B_{Ch,clr}|/2 + |B_{Ch} - B_{Ch,clr}|/2$$

Obs. Clear-sky B All-sky B

In combination with the surface-to-space transmittance (τ), we can define thresholds to avoid surface and cloud contamination

To simplify the full set of MWI & ICI channels, they are grouped into either 'window' or 'sounder' channel groups:

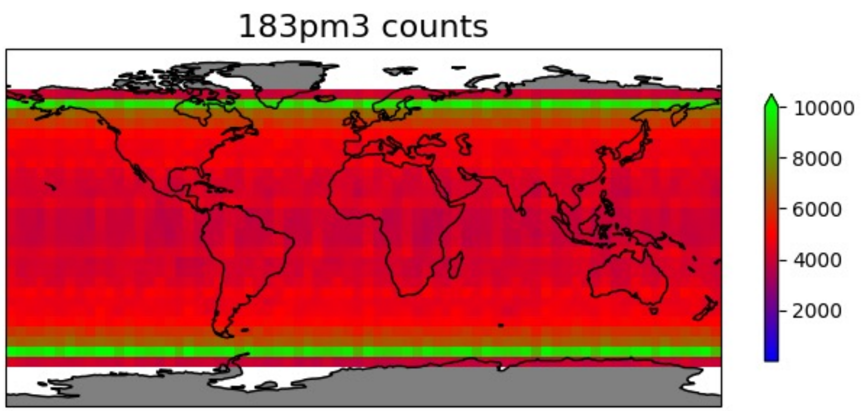
Channel Group	**Stringent**
Window channels	land$< 1\%$, $CI < 2K$, $SST > 277K$
Sounder channels	$\tau < 0.02$ or land< 0.01, $CI < 0.5K$

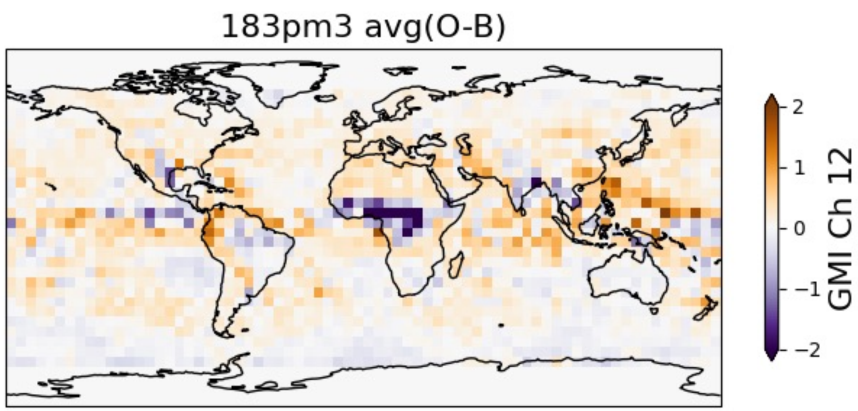
Some final checks are added to avoid possible sea-ice, etc.

GMI 183±3 channel

Project concept – data selection for cal/val analysis

All data





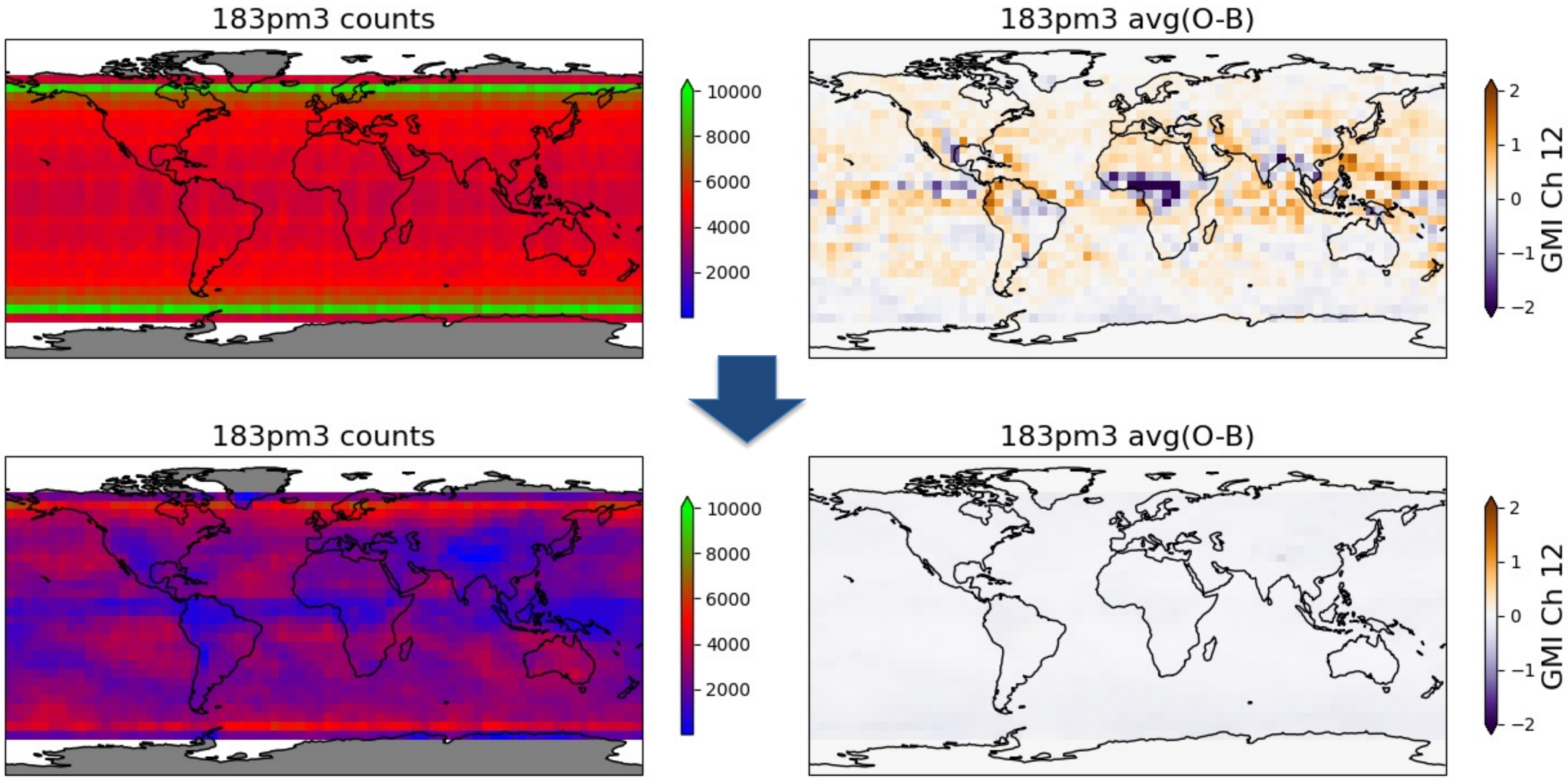
Project concept – data selection for cal/val analysis

GMI 183±3 channel

Stringent data selection applied

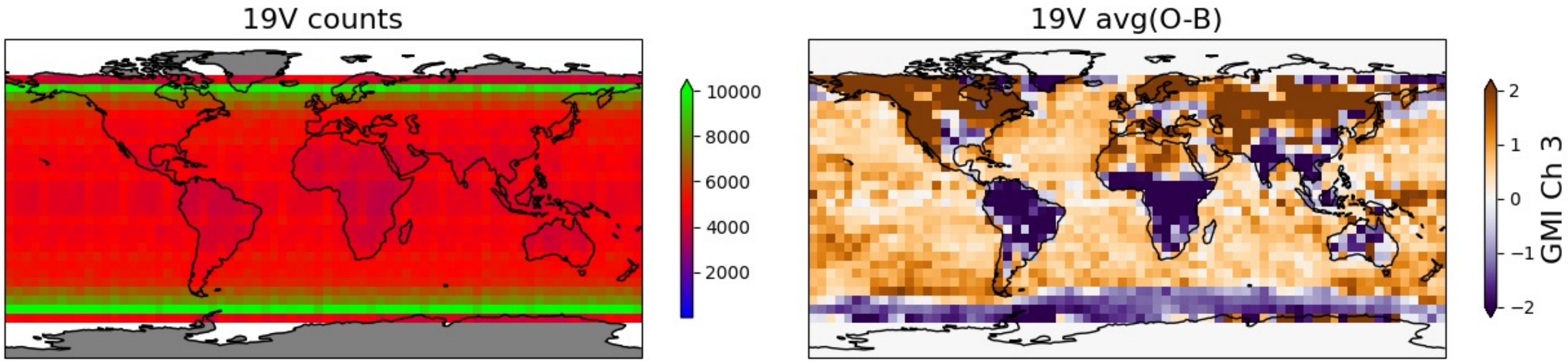
All data

Cal/val sample



Project concept – data selection for cal/val analysis

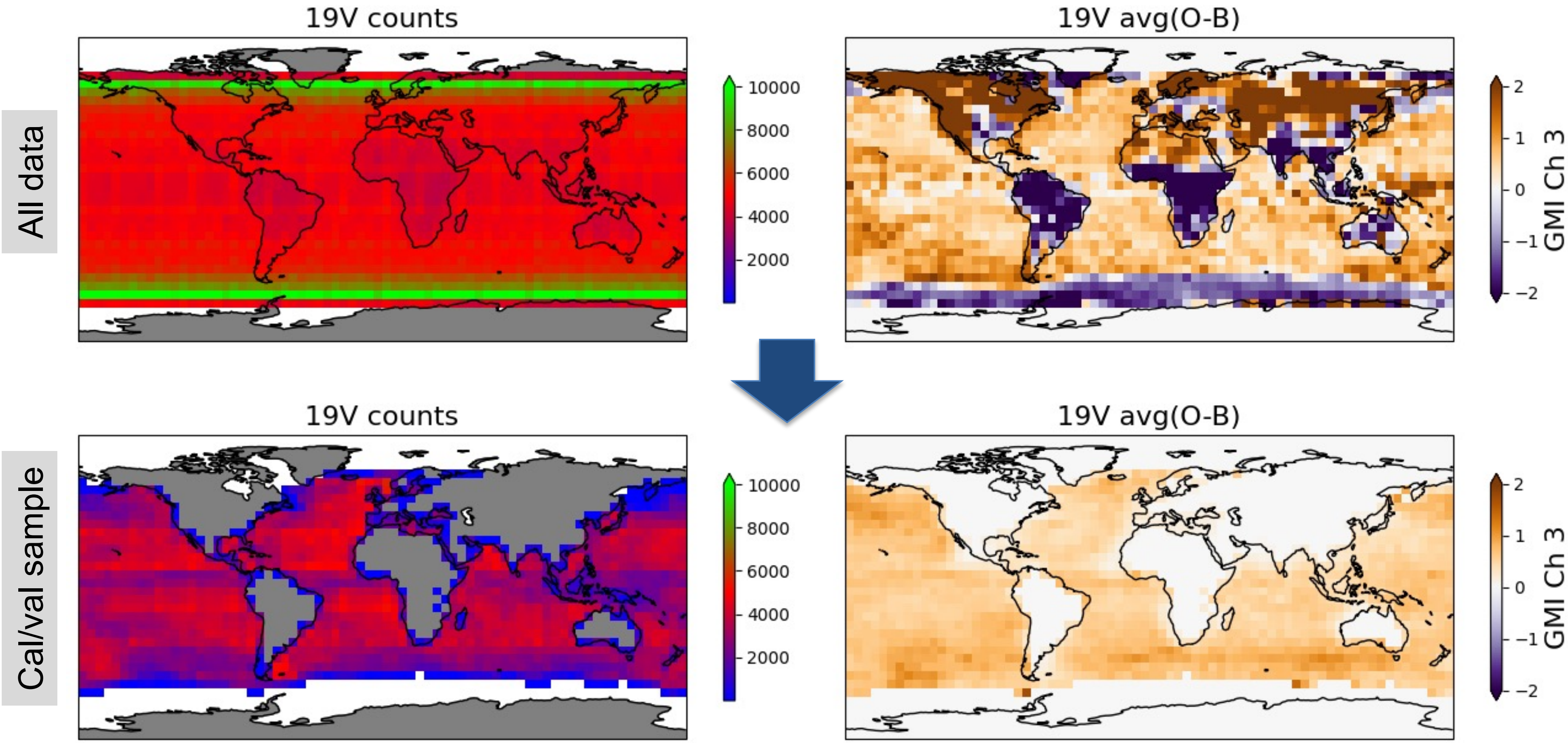
All data



Project concept – data selection for cal/val analysis

GMI 19V channel

Stringent data selection applied



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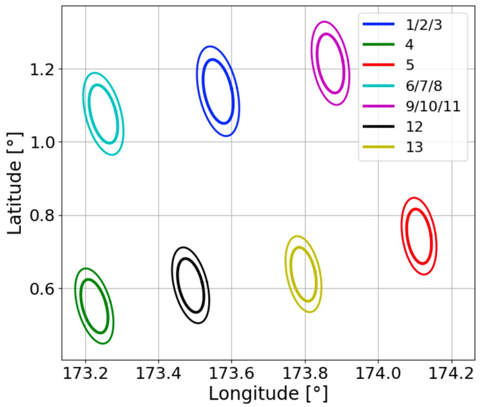
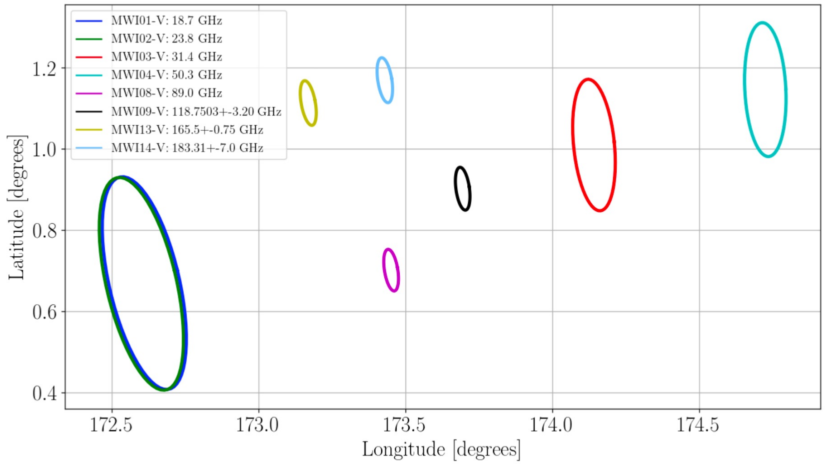
MWIICI and the IFS

The ECMWF data assimilation system is the **Integrated Forecasting System (IFS)**

- The IFS expects (and is optimized for) co-located observation vectors
- Zenith angle can vary by channel

MWI – 26 channels *over 8 horns*
ICI – 13 channels *over 7 horns*
} *15 geolocations!*



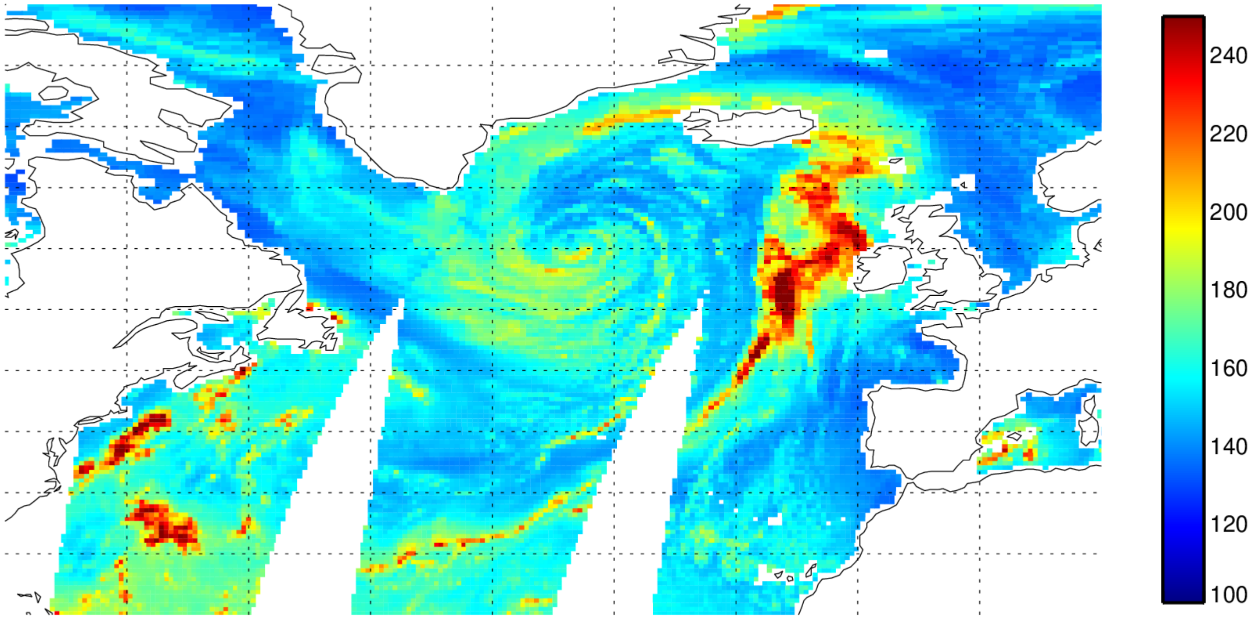


From:
Rydberg & Eriksson (2019)
Eriksson et al. (2019)

MWIICI and the IFS

In the IFS, microwave imager radiances are *superobbed* (averaged into super-observations) at 40 km resolution

Superobbing acts to homogenise observations and make them more representative for assimilation → the model 'effective resolution' for clouds and precipitation is roughly this scale

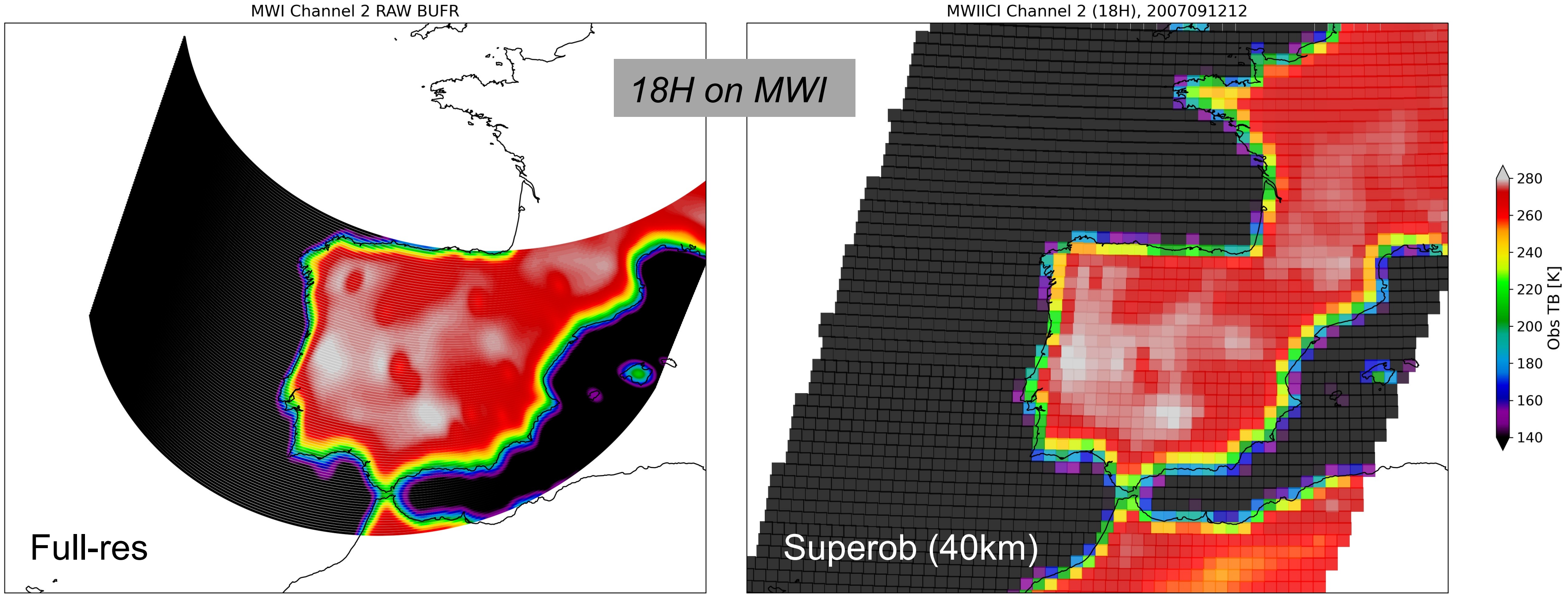


AMSR2 37H
(after superobbing)

MWIICI and the IFS

MWI and ICI feature very heavy spatial over-sampling, even compared to other MW imagers. Superobbing thus decreases data volume very significantly. On average:

- *130 observations per superob for MWI channels*
- *73 observations per superob for ICI channels*



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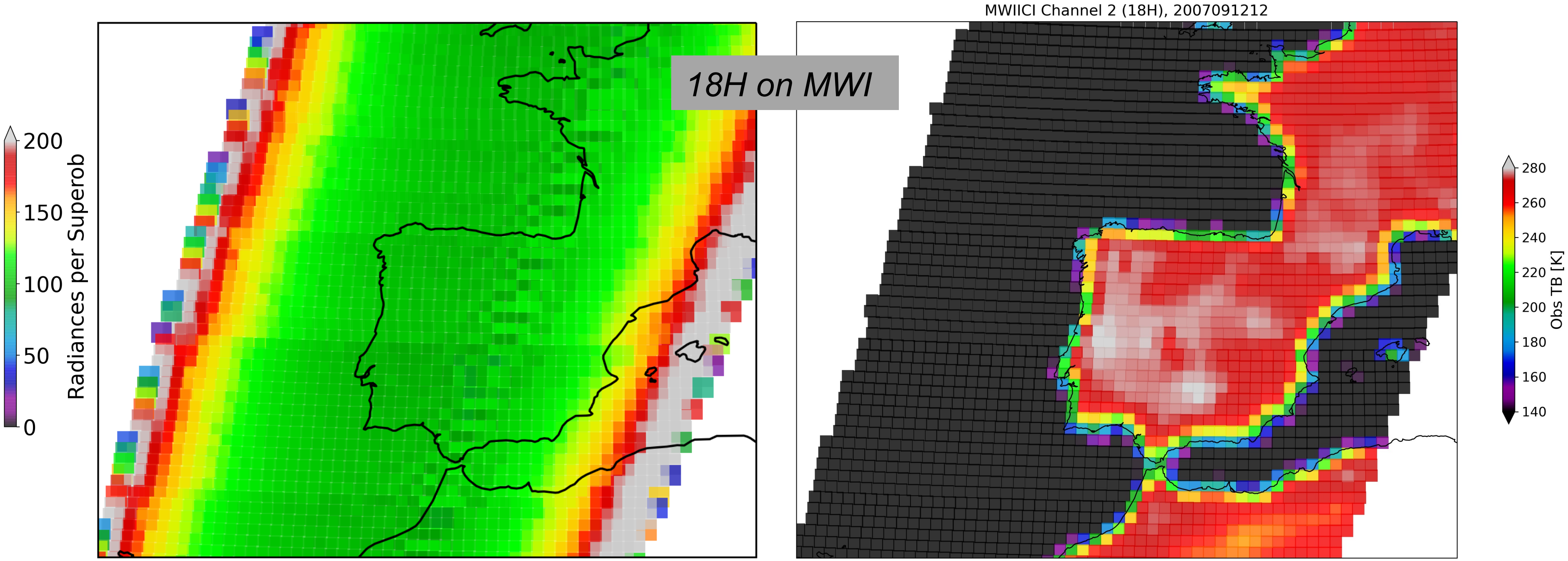


MWIICI and the IFS

In the IFS, the **39 channels and 15 horns** are treated as one **super-sensor**

- *Combine all horns after superobbing step*
- *Provide a single, 39-channel, co-located observation vector to RTTOV-SCATT and the data assimilation system*
- *Can use ICI channels to analyse and constrain the assimilation of MWI channels, and vice versa*
- *Referred to as simply* **MWIICI**

Forward simulations use:

- RTTOV-SCATT v13.2 with the new SURFEM-Ocean emissivity model
- IFS Cycle 49r1 (operational autumn 2024)

Ch. No.	*Freq. [GHz]*	*Horn*	
1, 2	18.7	1	MWI
3, 4	23.8	2	MWI
5, 6	31.4	3	MWI
7, 8	50.3	4	MWI
9, 10	52.70	4	MWI
11, 12	53.24	4	MWI
13, 14	53.75	4	MWI
15, 16	89.0	5	MWI
17	118.7503 ± 3.2	6	MWI
18	118.7503 ± 2.1	6	MWI
19	118.7503 ± 1.4	6	MWI
20	118.7503 ± 1.2	6	MWI
21	165.5 ± 0.725	7	MWI
22	183.31 ± 7.0	8	MWI
23	183.31 ± 6.1	8	MWI
24	183.31 ± 4.9	8	MWI
25	183.31 ± 3.4	8	MWI
26	183.31 ± 2.0	8	MWI
27	183.31 ± 7.0	1	ICI
28	183.31 ± 3.4	1	ICI
29	183.31 ± 2.0	1	ICI
30, 31	243.2 ± 2.5	2/3	ICI
32	325.15 ± 9.5	4	ICI
33	325.15 ± 3.5	4	ICI
34	325.15 ± 1.5	4	ICI
35	448 ± 7.2	5	ICI
36	448 ± 3.0	5	ICI
37	448 ± 1.4	5	ICI
38, 39	664 ± 4.2	6/7	ICI

MWIICI and the IFS

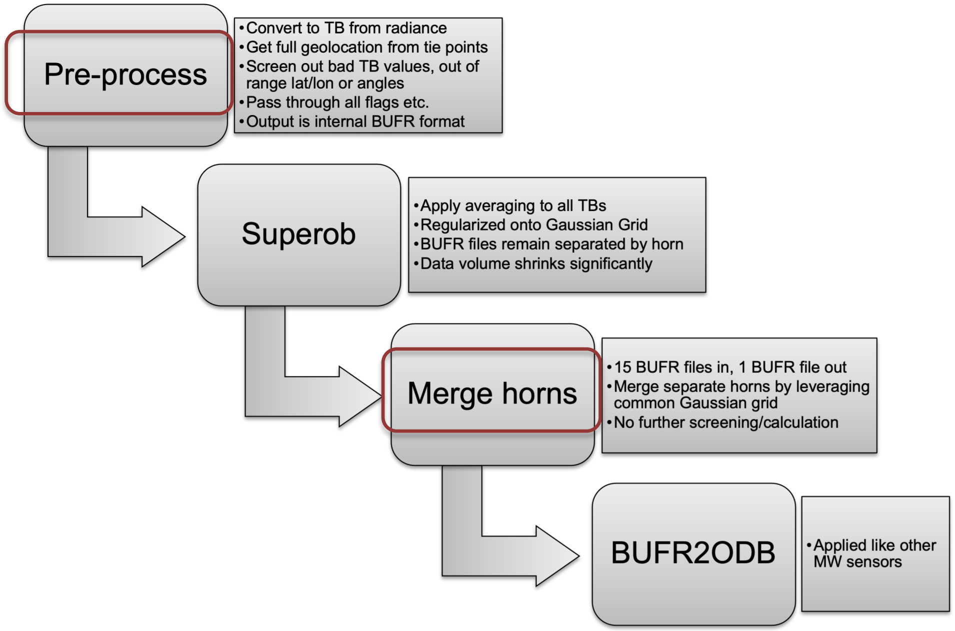
The custom data processing has two steps unique to MWIICI:

- Python/ECcodes-based pre-processing script that converts from EUMETSAT-provided BUFR to own internal format
    - Convert radiance to TB, calculate full geolocation, perform basic screening, and output each horn in own BUFR file
- After superobbing, merge the 15 horns of MWI and ICI into a single BUFR file based on common geolocations

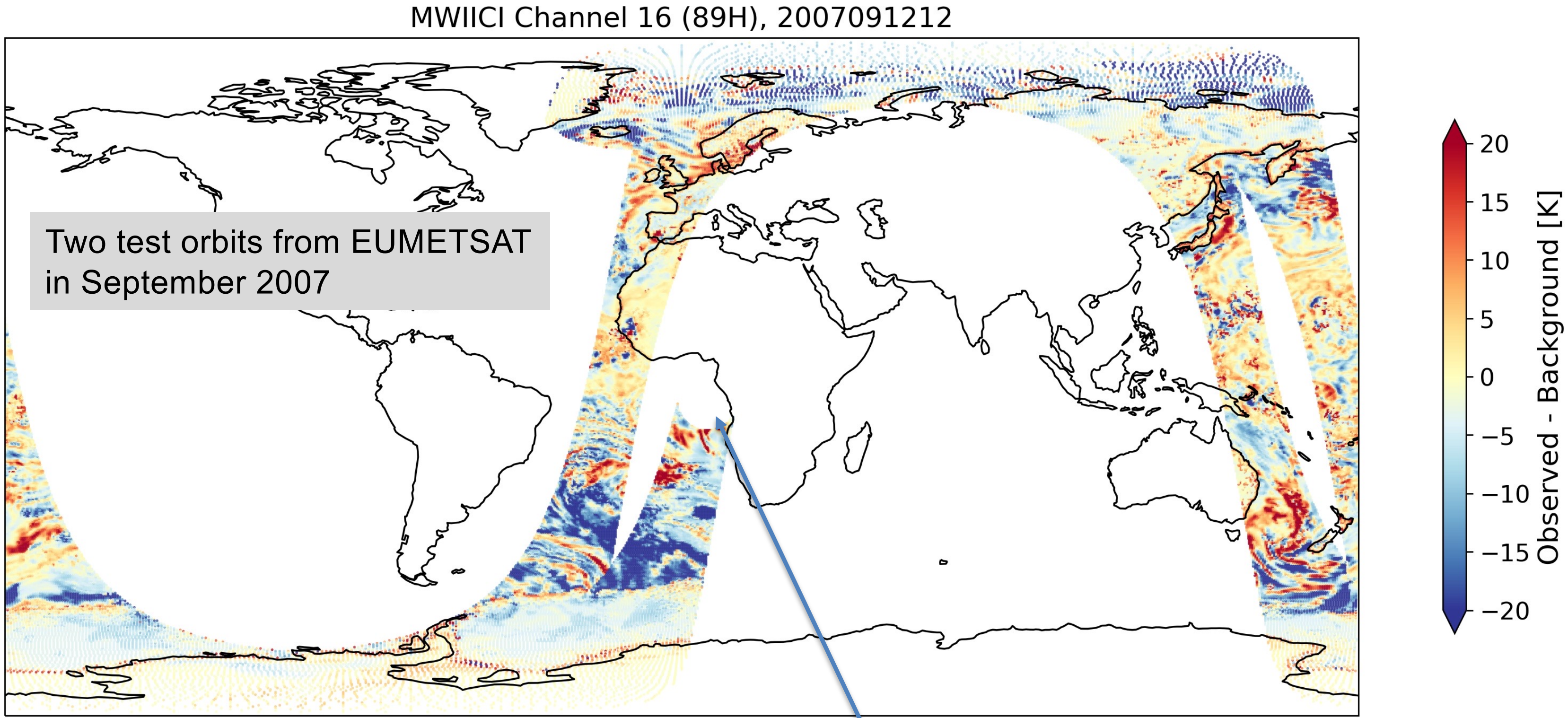
Pre-processing greatly reduces data volume! For one orbit:

- 210m radiances → 1.8m radiances
- 66m geolocations → 60k geolocations

Now we have an MWIICI file in ODB format – ready for ingest to IFS

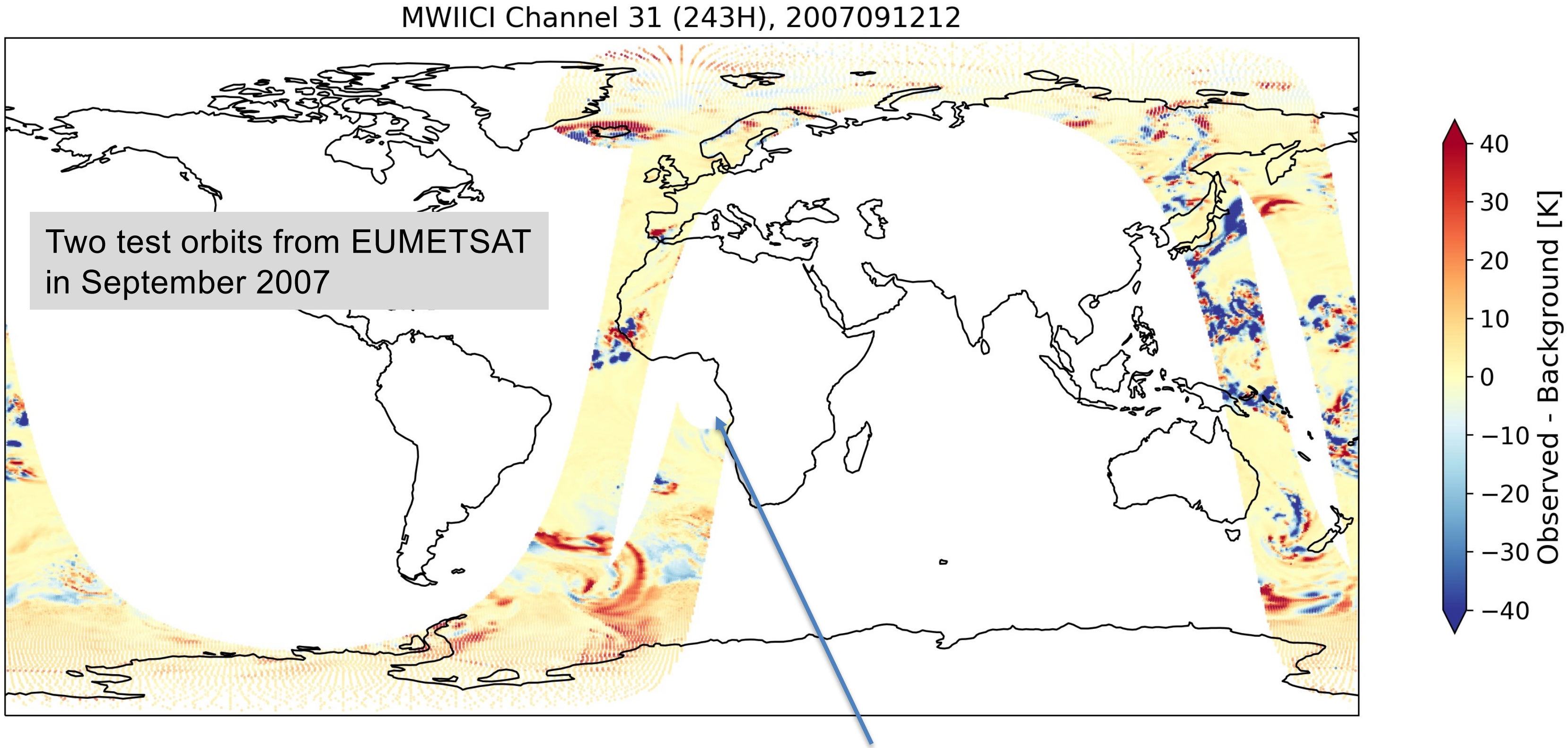


MWIICI and the IFS



Note long-window DA runs 9-21Z for 12Z cycle and orbit 4655 starts at 8:43Z

MWIICI and the IFS

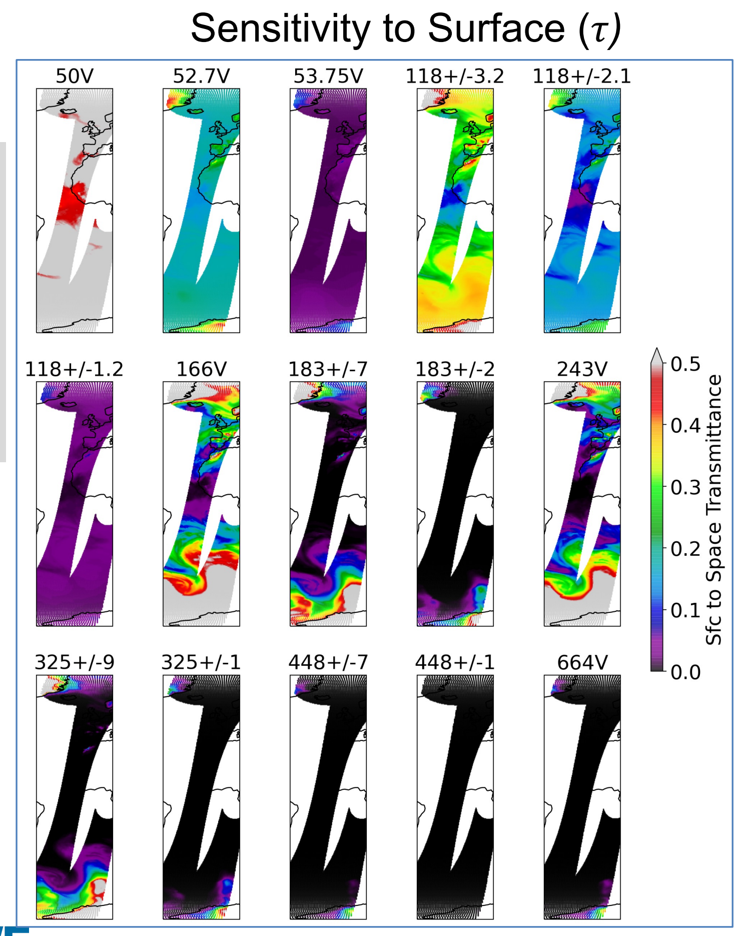


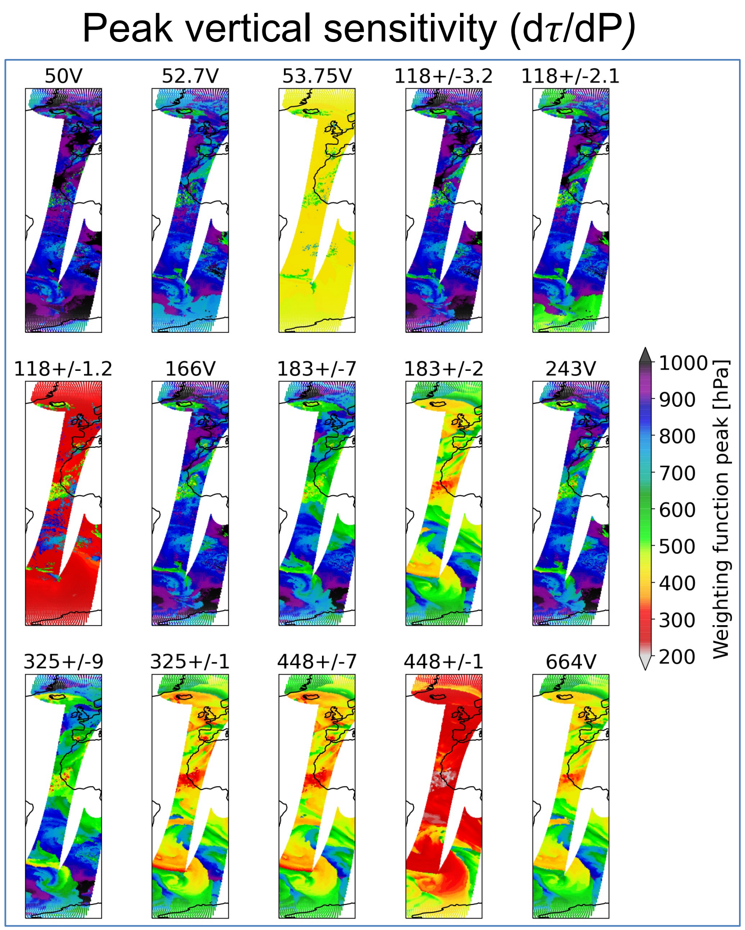
Note long-window DA runs 9-21Z for 12Z cycle and orbit 4655 starts at 8:43Z

MWIICI and the IFS

With MWIICI data going through the IFS, we can analyse various aspects of the sensors

For example:
Sounding sensitivity





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Comparing IFS simulations to EUMETSAT test data

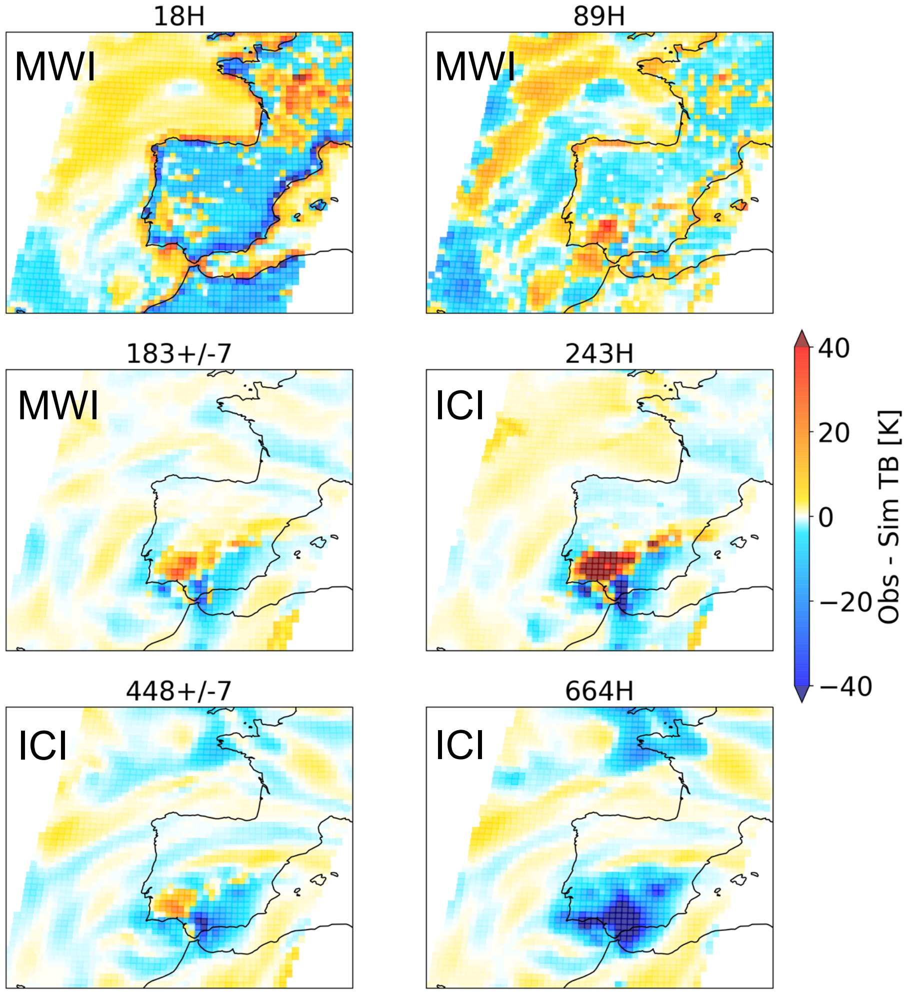
IFS simulations generally compare well with EUMETSAT test data

Several differences in assumptions, so we expect some biases from:

- *Land and ocean emissivity models*
- *Cloud and precipitation microphysics*

The IFS simulates less scattering in sub-mm channels:

- Mostly reasonable given different assumptions
- But 664GHz requires further work—signal from cirrus smaller than expected



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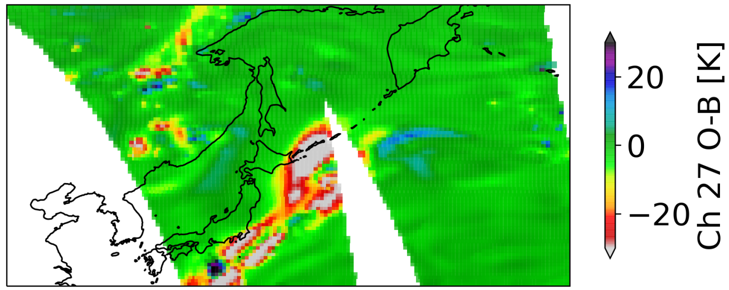

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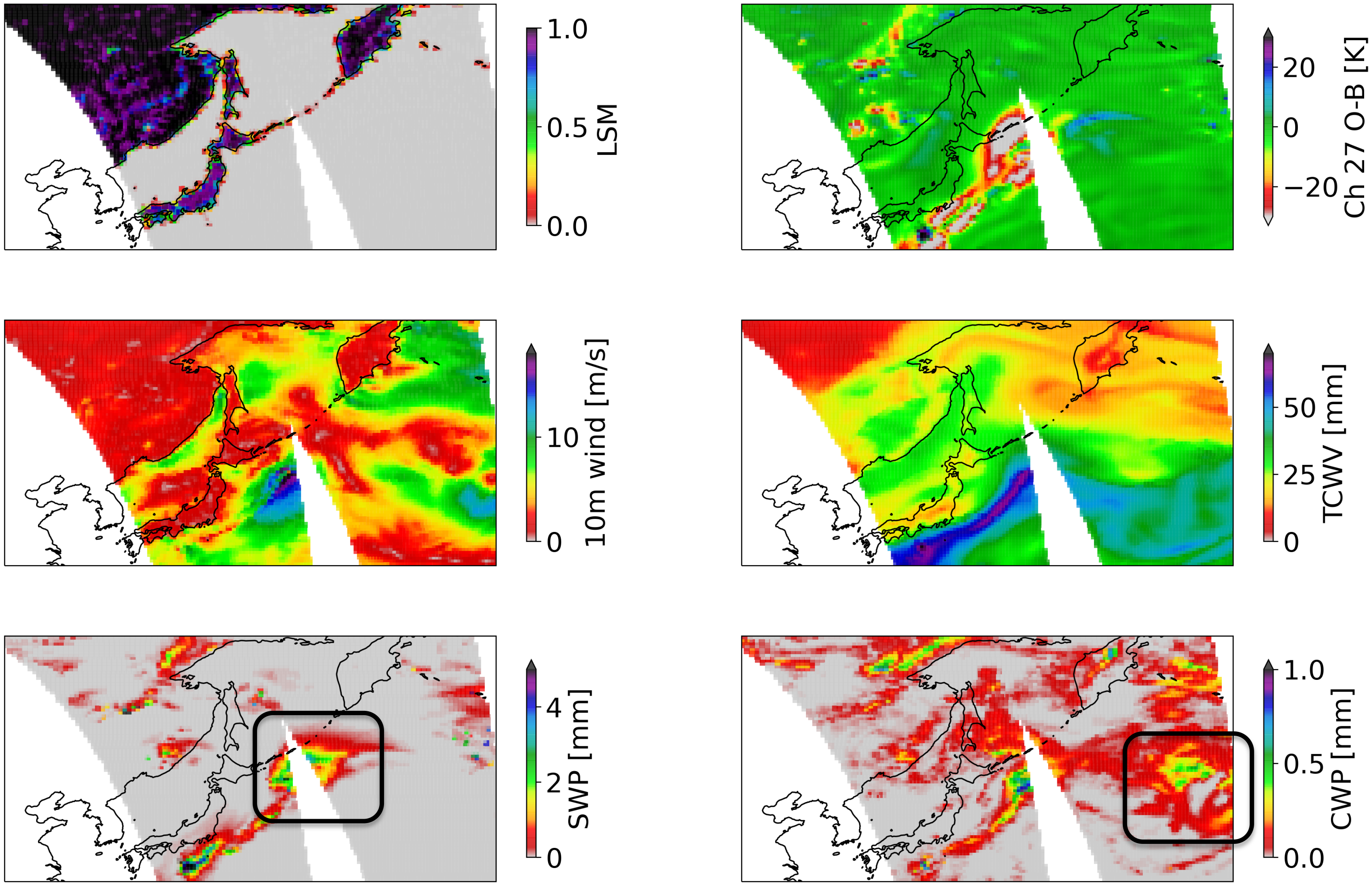

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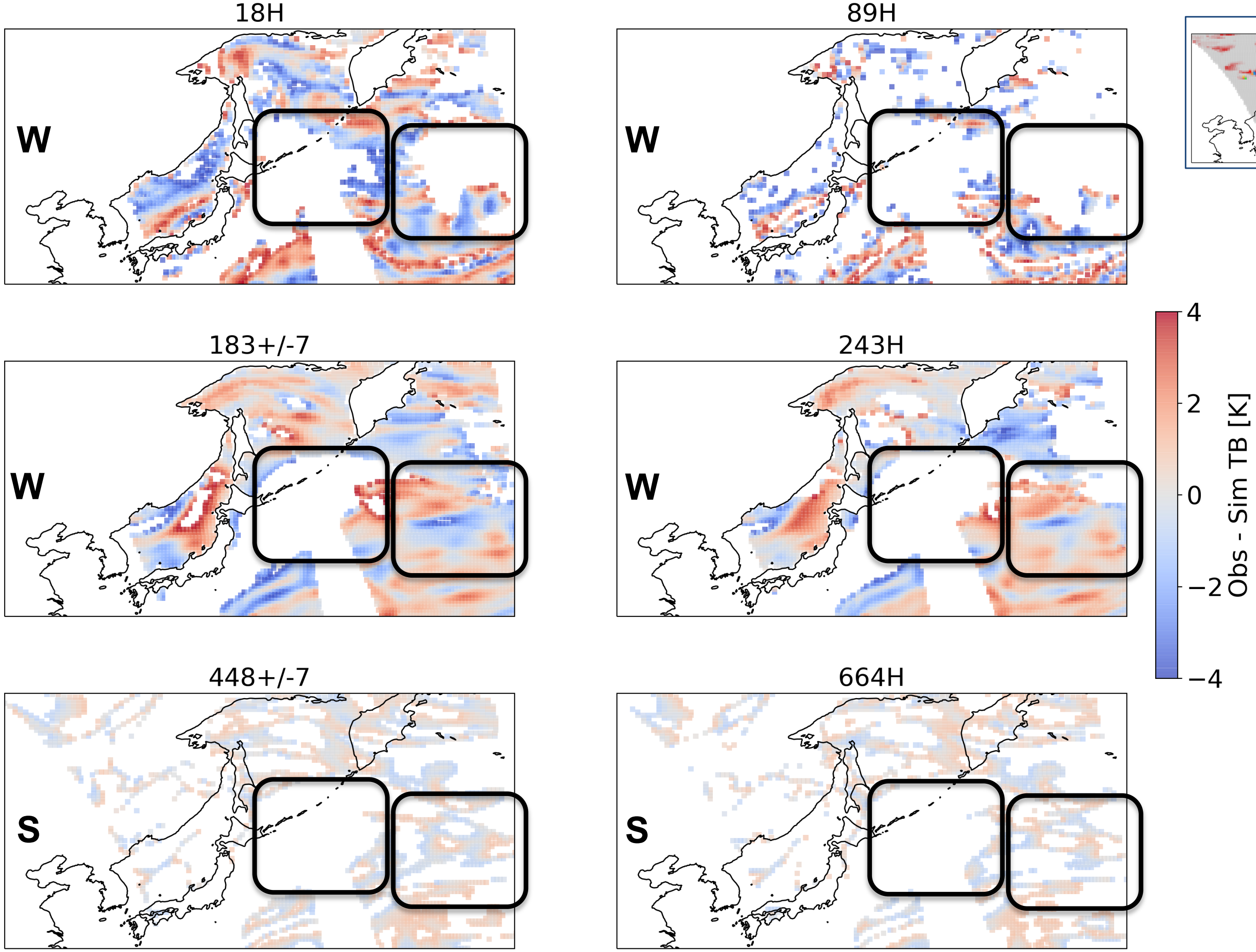
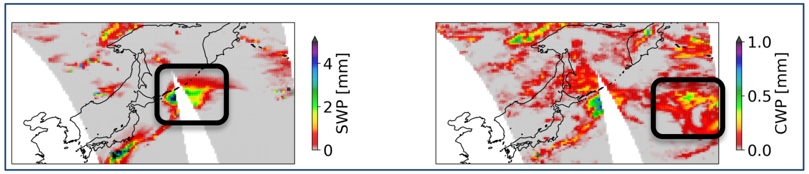




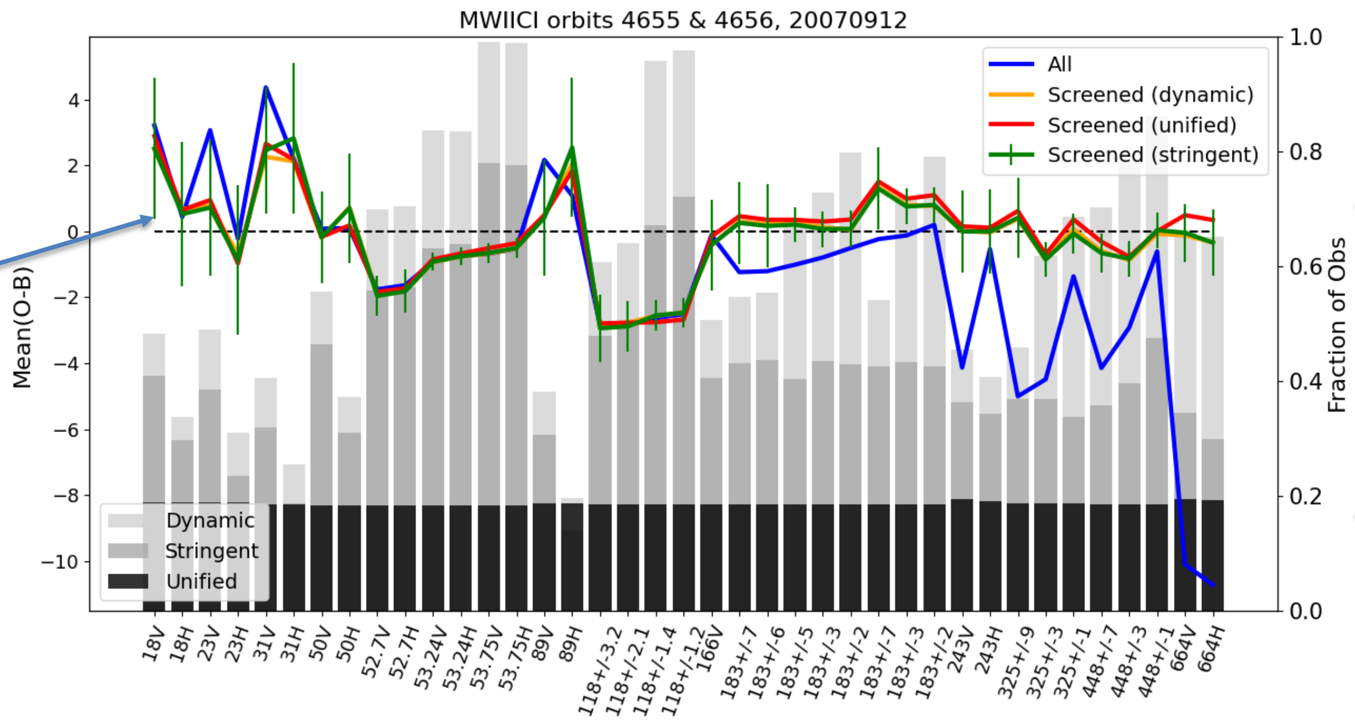
O-B after screening

- Screening (stringent shown here) does well to exclude heavily cloud-affected over land & sea
- Thinner and lower cloud remains in the sample for less sensitive channels
- Sounding channels have tighter CI threshold than window channels

W = window
S = sounder

Comparing IFS simulations to EUMETSAT test data

68% interval (+/- 1σ) for screened obs



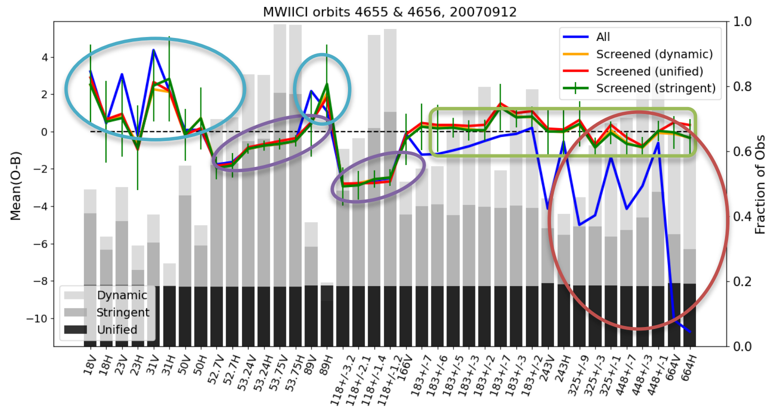
~20-70% of obs after screening

Global statistics, 2 test orbits

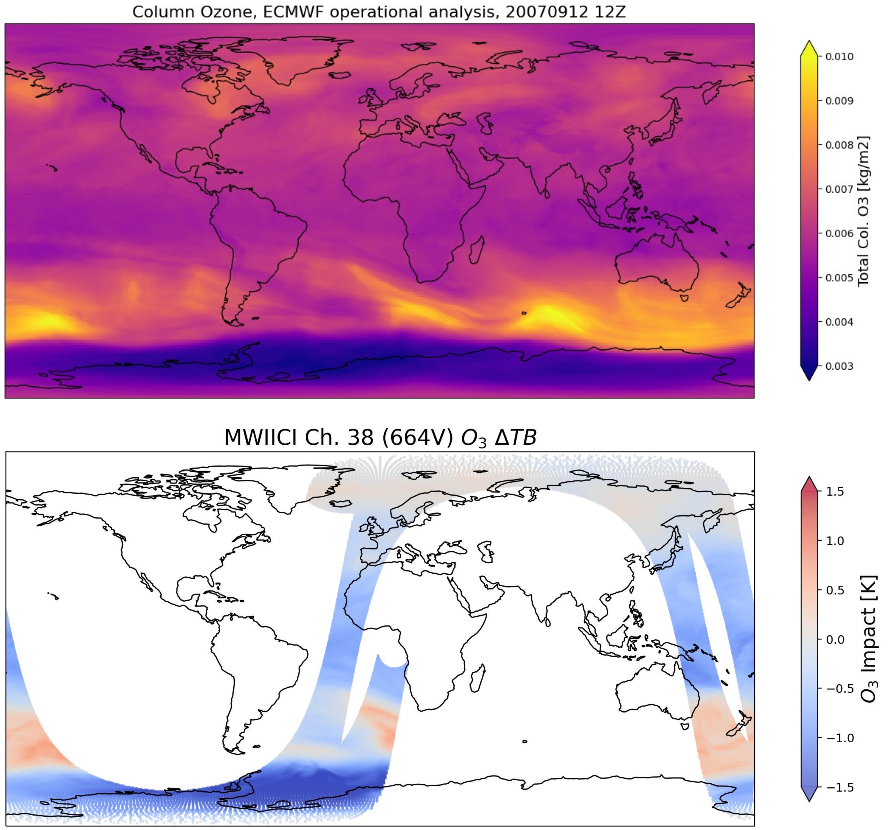
Comparing MWIICI simulations to EUMETSAT test data

Differences & possible causes

- More scattering in test data:
  - PSD in ARTS produces more scattering (all frozen hydrometeors treated like snow)
  - Scattering solver (see Barlakas et al. 2022)
  - Test data uses ERA5 convective precipitation rate converted to mass flux, assuming fixed fall speed
- Sounding biases
  - Rosenkranz (ARTS) vs. AMSUTRAN (RTTOV)
  - SRFs – RTTOV uses measured SRF for ICI vs. 'top hat' SRF for MWI (~0.1K @ ICI-3, ~0.3 @ ICI-10); ARTS used monochromatic assumption in middle of lower passbands
- Window channel biases
  - TESSEM2 (ARTS) vs. SURFEM (IFS) – see Geer et al. Tech Memo (soon to be published) on SURFEM vs. FASTEM performance in the IFS
- Most* higher frequency channels compare well after screening!

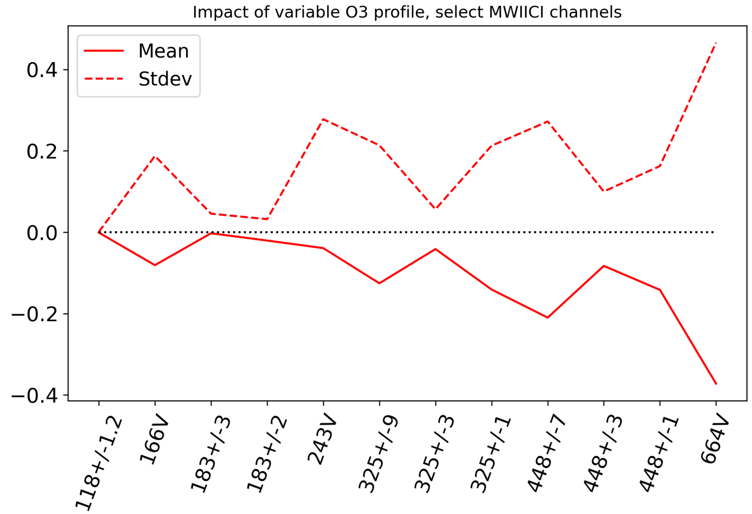


Bonus – ozone effects?



Test data did not include variable ozone in RT, but we expect sub-mm channels to have ozone sensitivity → how much?

- *O_3 profiles from ECMWF analysis added to all-sky RT → we can compare RT simulations with and without O_3 included*
- ~2 K signals seen at 664 GHz
- Non-negligible impact at 166 & 325 GHz (e.g. AWS)
- Variable ozone will be included in RT for MWIICI when launched



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Apply to current imagers

The method can be tested on similar frequency channels on current conically-scanning radiometers used in the IFS

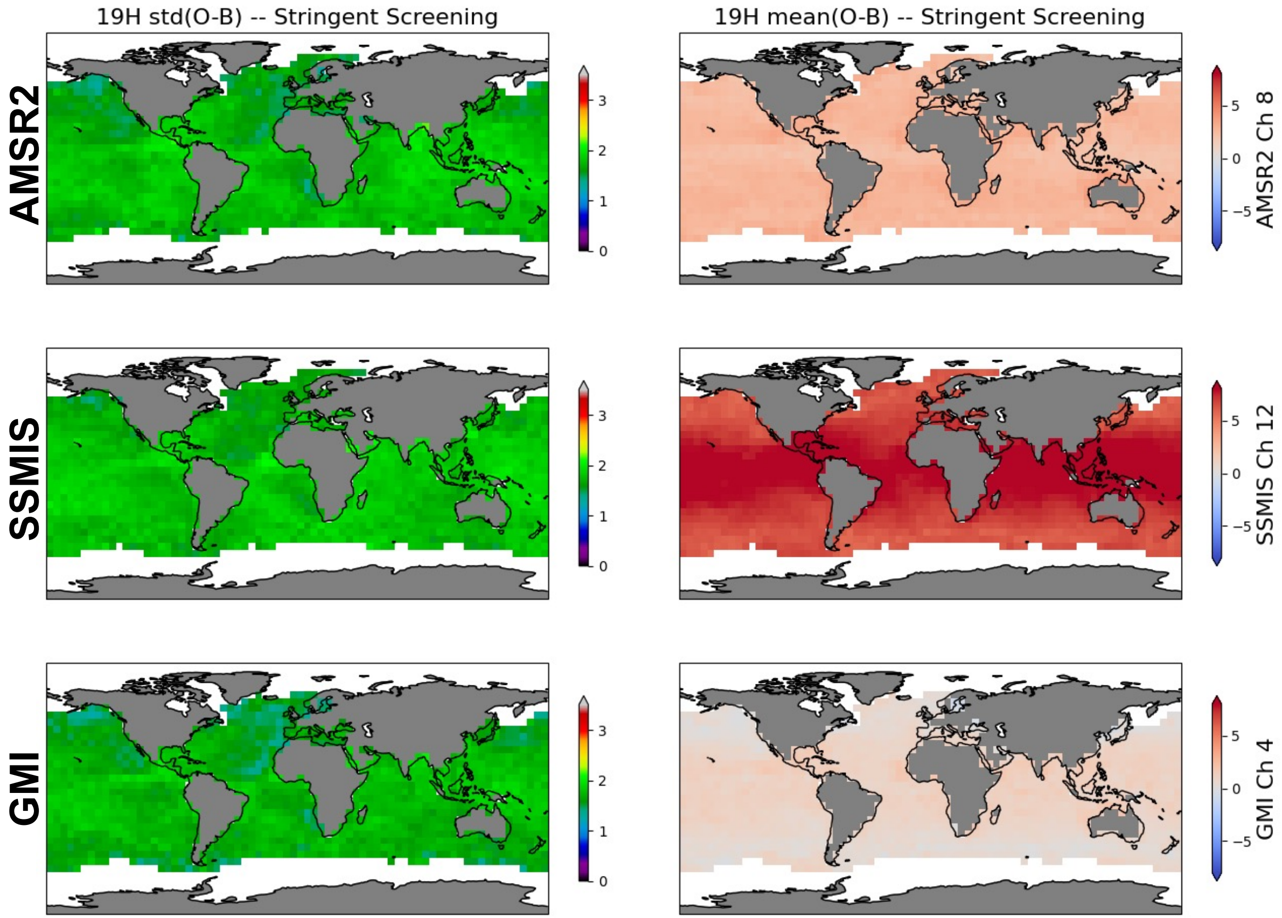
- *GMI, SSMIS, AMSR2* are all assimilated in the IFS
- Focus on common channels (e.g. 18, 89, 183 GHz)
- Analyse one month of data: **May 2023**

How to decide if data selection is adequate for cal/val purposes?

- Limited geographical variability in std(O-B) and bias
- GMI biases look uniform (GMI as reference standard)
- Maximise data sample but avoid problematic regions
- Caveats → frequencies not identical, different orbits

Ch. #	*Freq. [GHz]*	*Horn*	*Type*	*Similar channels*
⇨ 1, 2	18.7	1	W	GMI 3,4; SSMIS 13,12
⇨ 3, 4	23.8	2	W	GMI 5*; SSMIS 14*
⇨ 5, 6	31.4	3	W	GMI 6,7; SSMIS 16,15
7, 8	50.3	4	W	AMSU-A 3*; SSMIS $1^{\pm}$
9, 10	52.70	4	W	AMSU-A 4*; SSMIS $2^{\pm}$
11, 12	53.24	4	S	AMSU-A $5^{\pm}$; SSMIS $3^{\pm}$
13, 14	53.75	4	S	AMSU-A 6
⇨ 15, 16	89.0	5	W	GMI 8,9; SSMIS 17,18
17	118.7503 ± 3.2	6	W	MWHS2 8
18	118.7503 ± 2.1	6	W	MWHS2 7
19	118.7503 ± 1.4	6	S	MWHS2 6
20	118.7503 ± 1.2	6	S	MWHS2 6
⇨ 21	165.5 ± 0.725	7	W	GMI 10
⇨ 22	183.31 ± 7.0	8	W	SSMIS 9; GMI 13
23	183.31 ± 6.1	8	W	-
24	183.31 ± 4.9	8	S	MWHS2 14; ATMS 19
⇨ 25	183.31 ± 3.4	8	S	GMI 12; SSMIS 10
26	183.31 ± 2.0	8	S	ATMS 21; MWHS2 12
⇨ 27	183.31 ± 7.0	1	W	SSMIS 9; GMI 13
⇨ 28	183.31 ± 3.4	1	S	GMI 12; SSMIS 10

Apply to current imagers

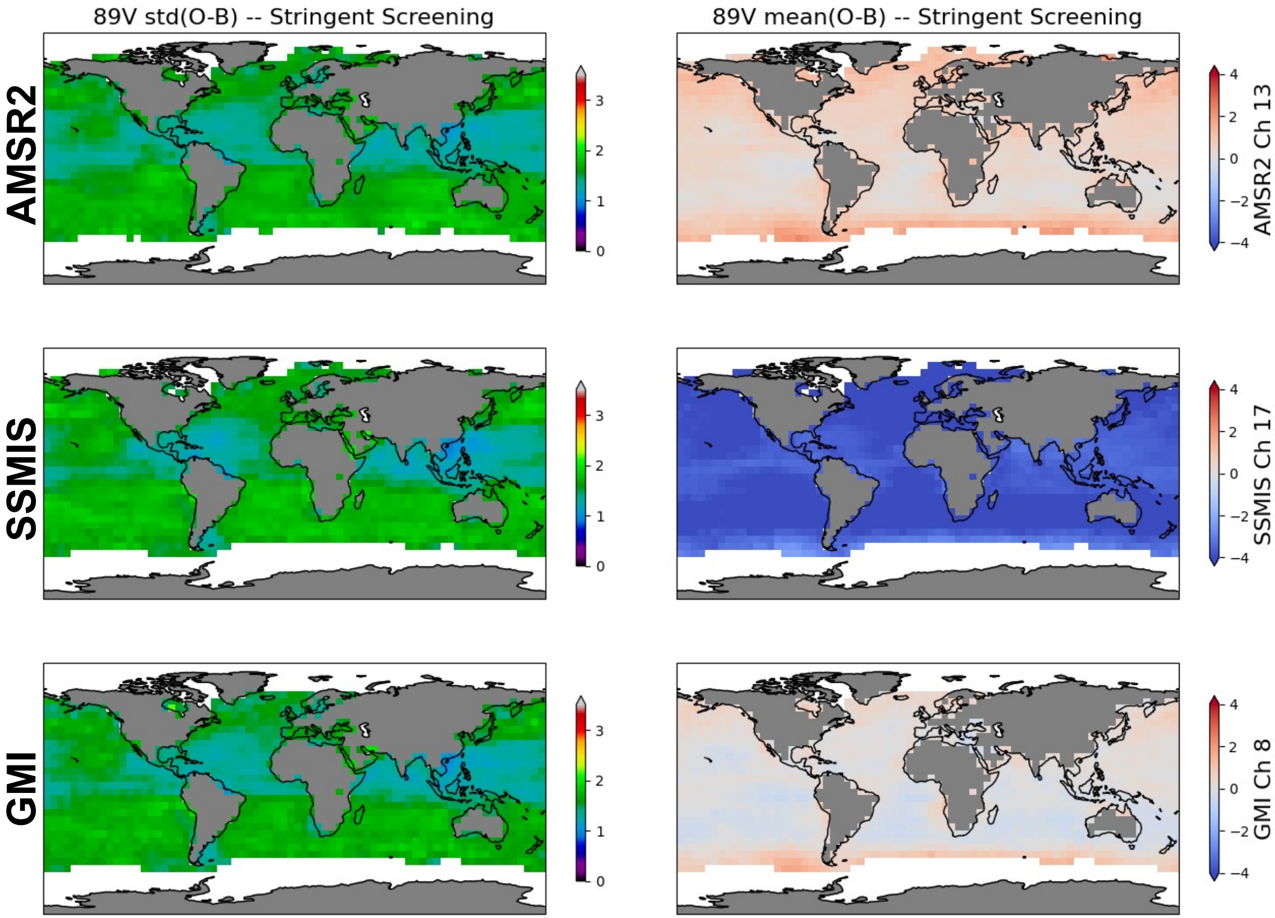


19H channel

From a month of data, May 2023

- Lowest frequency on MWI, 18.6 GHz
- Std(O-B) maps consistent
- GMI with near-zero bias and limited regional variation in bias
- AMSR2 and SSMIS show positive global biases as seen in the literature
- SSMIS exhibits some scene-dependence

Apply to current imagers

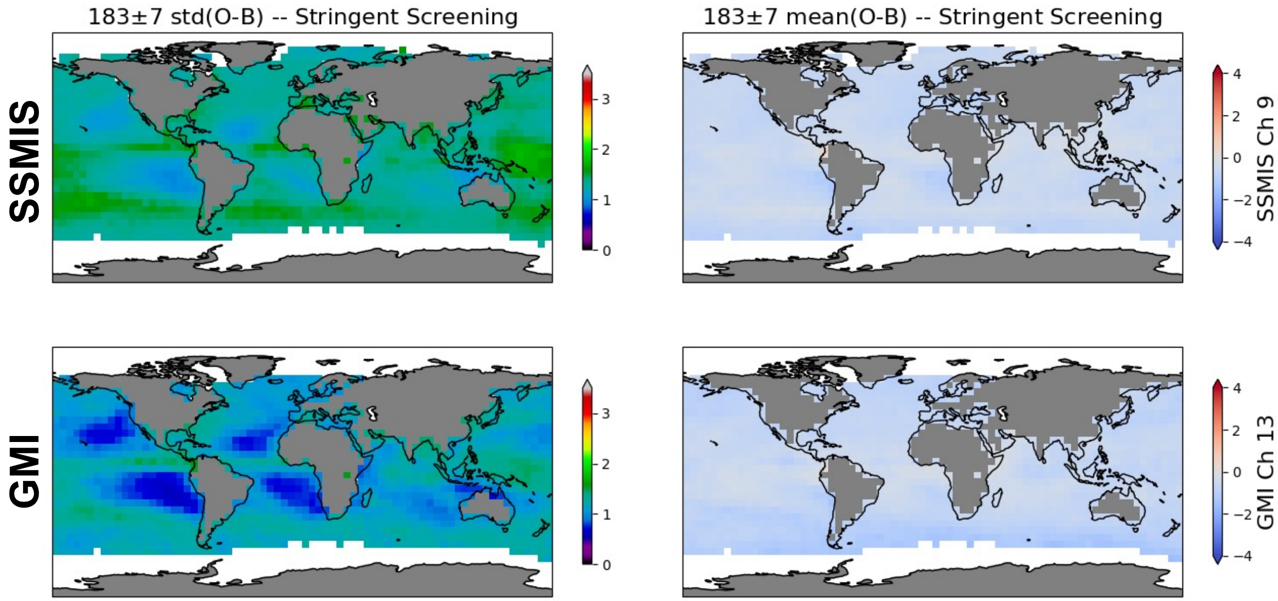


From a month of data, May 2023

- Like MWI 89.0 GHz
- Std(O-B) maps consistent
- GMI with near-zero bias and limited regional variation in bias
- SSMIS shows negative global bias

89V channel

Apply to current imagers



Higher frequencies, just GMI and SSMIS

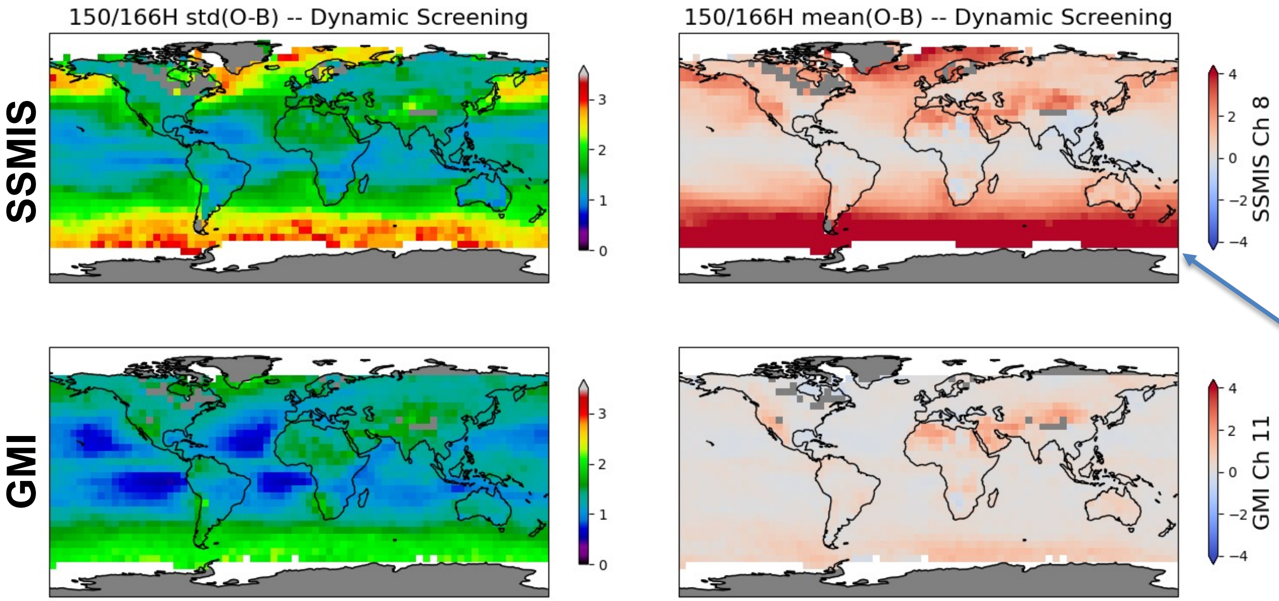
- Like MWI and ICI 183 ± 7.0 GHz
- Std(O-B) lower for GMI → lower noise?
- GMI & SSMIS very consistent, near-zero global biases

183±7 channel

Apply to current imagers

Higher frequencies, just GMI and SSMIS

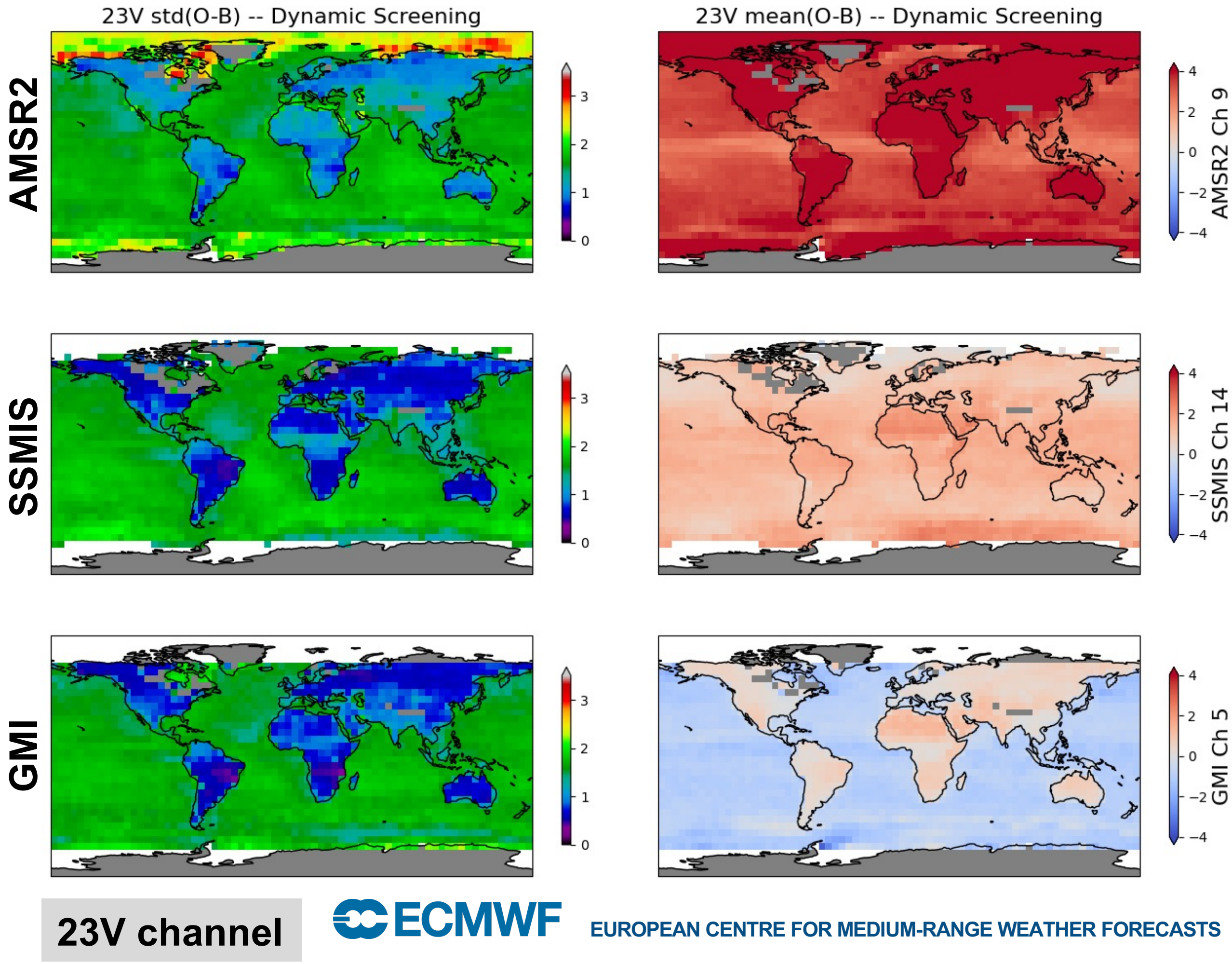
Now look at 'dynamic' selection to add window channels over land



166H channel

- *Approximate comparison, 150H on SSMIS, 166H on GMI*
- Like MWI 165.5 GHz
- Both show imperfect cloud screening in Southern Ocean → very cloud-sensitive
- GMI biases near-zero and mostly homogeneous except desert regions → skin temperature model bias
- SSMIS shows its well-known orbital bias due to solar illumination; also scene-dependent bias not seen in GMI

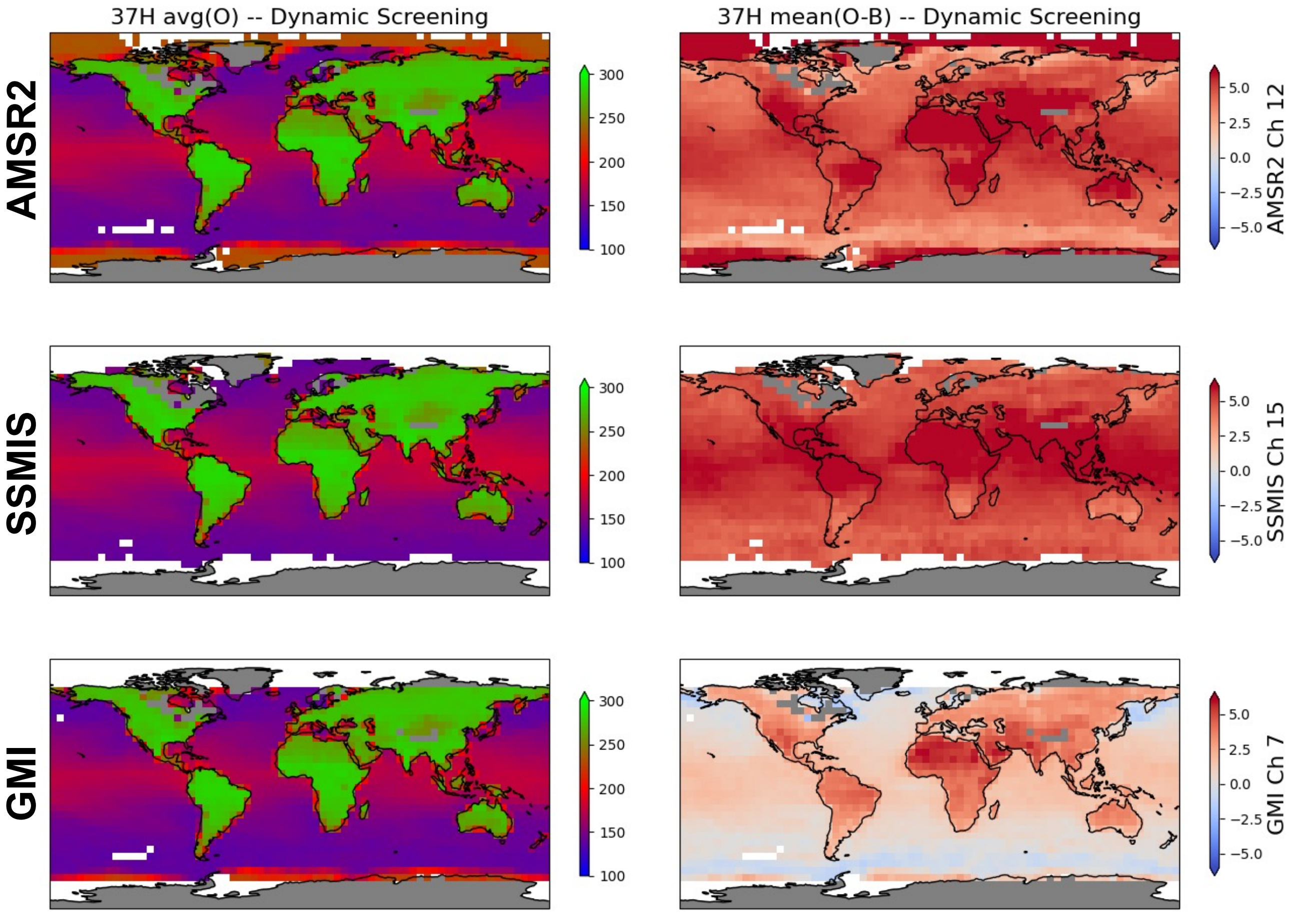
Apply to current imagers



Cutting edge → imager channels over land?

- Like MWI 23.8 GHz
- Lower std(O-B) over land is expected
  - Warm surface → small cloud signals
  - Artefact from dynamic emissivity
- Convective diurnal cycle stronger for AMSR2 (1:30 ECT)
- GMI shows land/sea contrast like AMSR2 → scene-dependent bias?

Apply to current imagers



Cutting edge → imager channels over land?

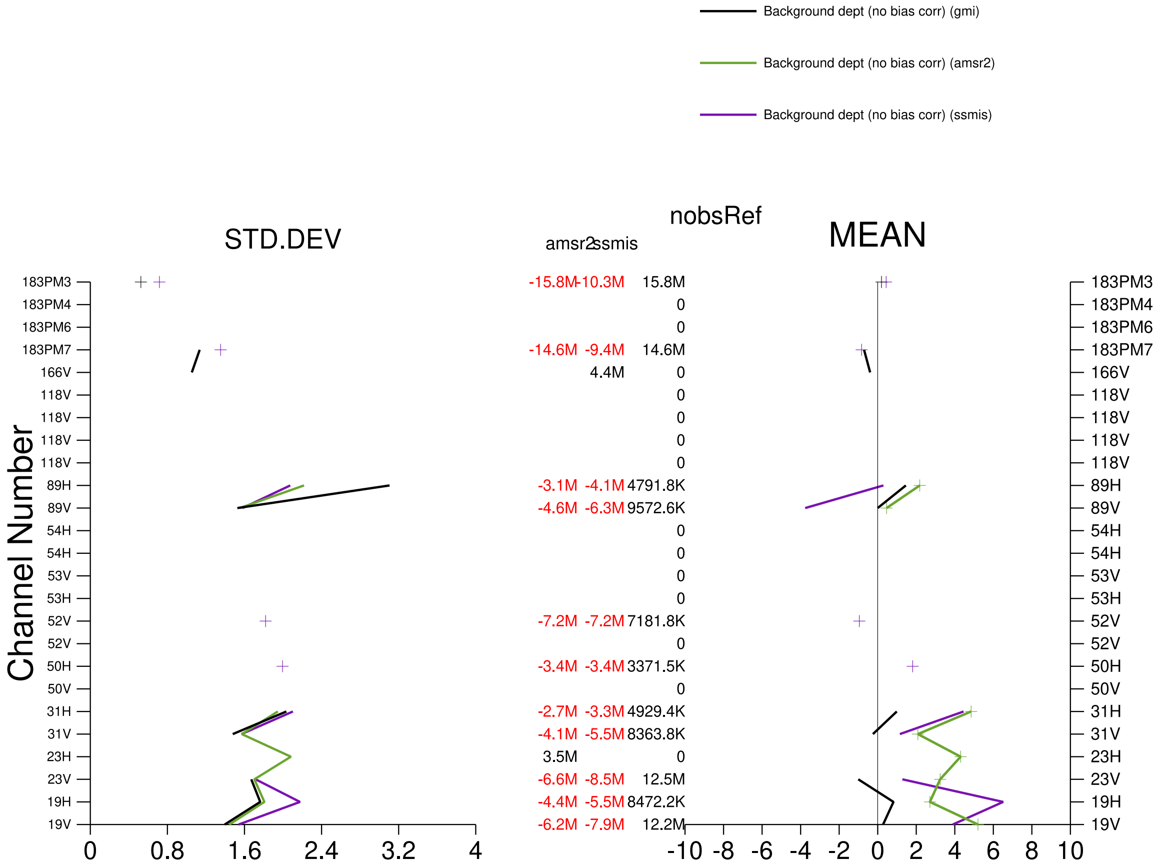
- 37H channel has roughly double TB over land – big dynamic range!
- Some evidence of scene-dependent bias in all three?

37H channel

Apply to current imagers

Compare imager channels directly – using MWIICI channel basis

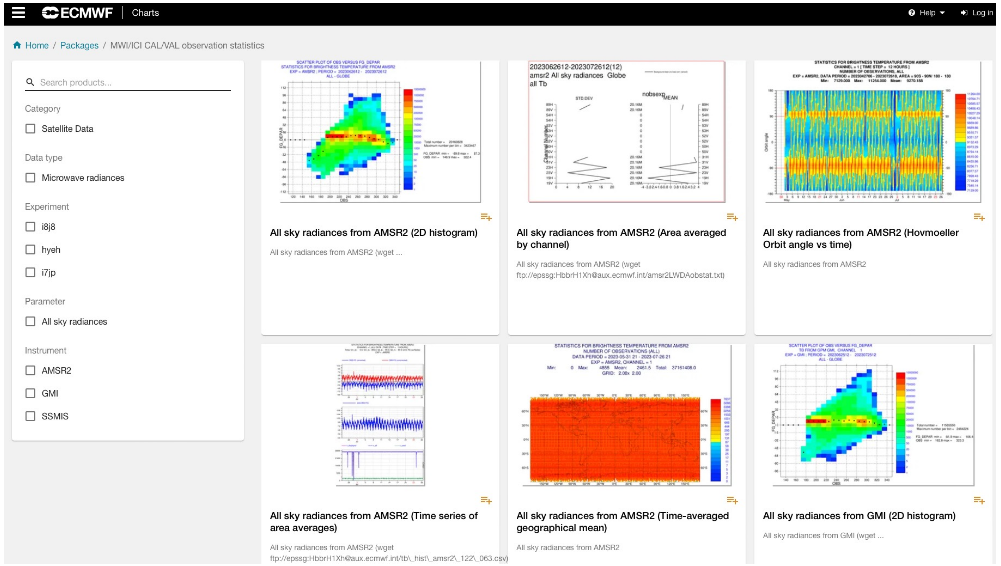
- Most lower frequency channels show similar std(O-B), especially GMI and AMSR2
- GMI shows mean biases of ±1 K against the IFS; 89H is outlier (linked to known model biases)
- 183 GHz channels show good relative and absolute biases for GMI and SSMIS



Outline

1) MWI and ICI introduction
2) Project concept
   - Why all-sky monitoring for cal/val?
   - Data selection for cal/val from NWP model output
3) Technical developments – MWIICI and the IFS
4) Comparing IFS simulations to EUMETSAT test data
5) Application of cal/val monitoring system to current sensors
   - GMI, SSMIS, AMSR2
6) Monitoring website
7) Conclusions

Monitoring website

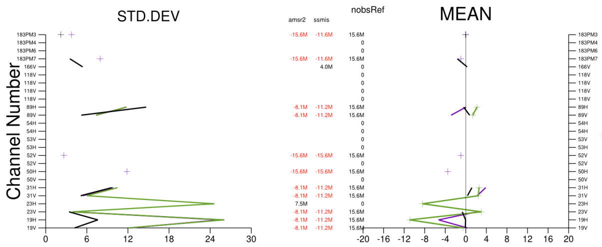


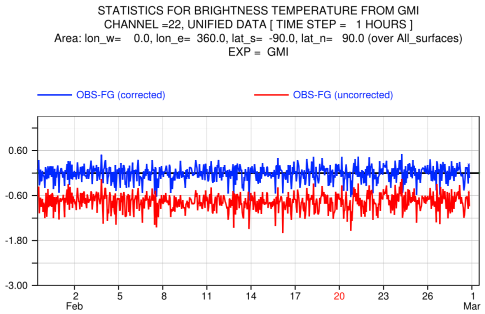
Website produced for this project that leverages the ECMWF observation monitoring suite of tools (Obstat, ecCharts):

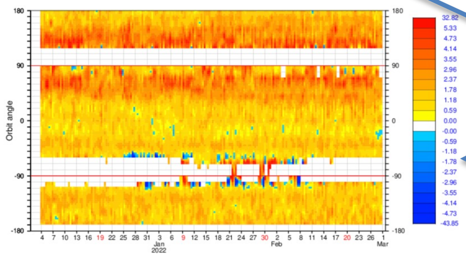
https://charts.ecmwf.int/catalogue/packages/eps_sg/

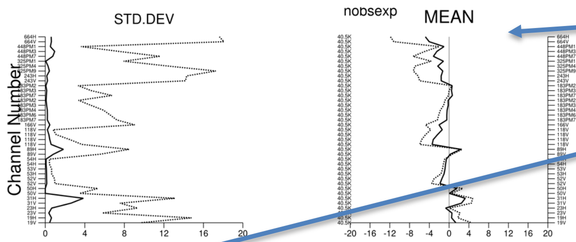
- Compare O-B statistics from MWIICI test data across various dimensions
- Also applied to GMI, SSMIS, AMSR2 for recent dates
- User can view several plot types, apply different data selections, and download statistics files
- All channels indexed to MWIICI channel indicators to facilitate comparison between sensors

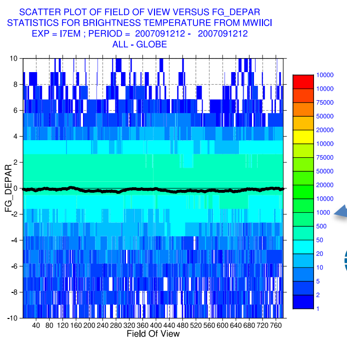
Monitoring website











Link to selection of EURD requirements

- **NEDT** (MWI-05070, ICI-06070) – std(O-B) for sounder channels (e.g. 50GHz) after screening; gross violations of NEDT should be visible for other channels
- **Radiometric bias** (*MWI-05080, ICI-06080*) – viewed relative to the IFS as transfer standard in context of other sensors
- **Orbit stability** (*MWI-05090, ICI-06090*) – Hovmöller-style plot to view orbital stability over time via orbital angle
- **Lifetime stability** (*MWI-05100, ICI-06100*) – global mean per channel as a function of time, per-orbit or per-cycle
- **Inter-channel bias differences** (*MWI-05110, ICI-06110*) – same data selection for all channels from unified sample
- **Inter-footprint bias difference** (*MWI-05120, ICI-06120*) – biases as a function of scan position, can be assessed using normal data stream or non-superobbed data from special experiment

Conclusions

- A monitoring website now exists to analyse MWI and ICI performance against the all-sky ECMWF background in the context of other MW imagers
- The IFS is prepared for assessment of MWI and ICI soon after launch
  - Lots of technical work to get to this stage → the most complex sensor pre-processing chain in the IFS (!)
  - Invaluable experience to test the system by processing of EUMETSAT-provided test data
  - However, full scientific exploitation of MWIICI data not considered in this project → lots left to do especially for sub-mm channels!
- Methodology developed here should benefit potential cal/val analysis of other MW instruments

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