Data Assimilation Efforts

MW Radiances Over Land

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CISESS
Cooperative Institute for Satellite Earth System Studies

Motivation

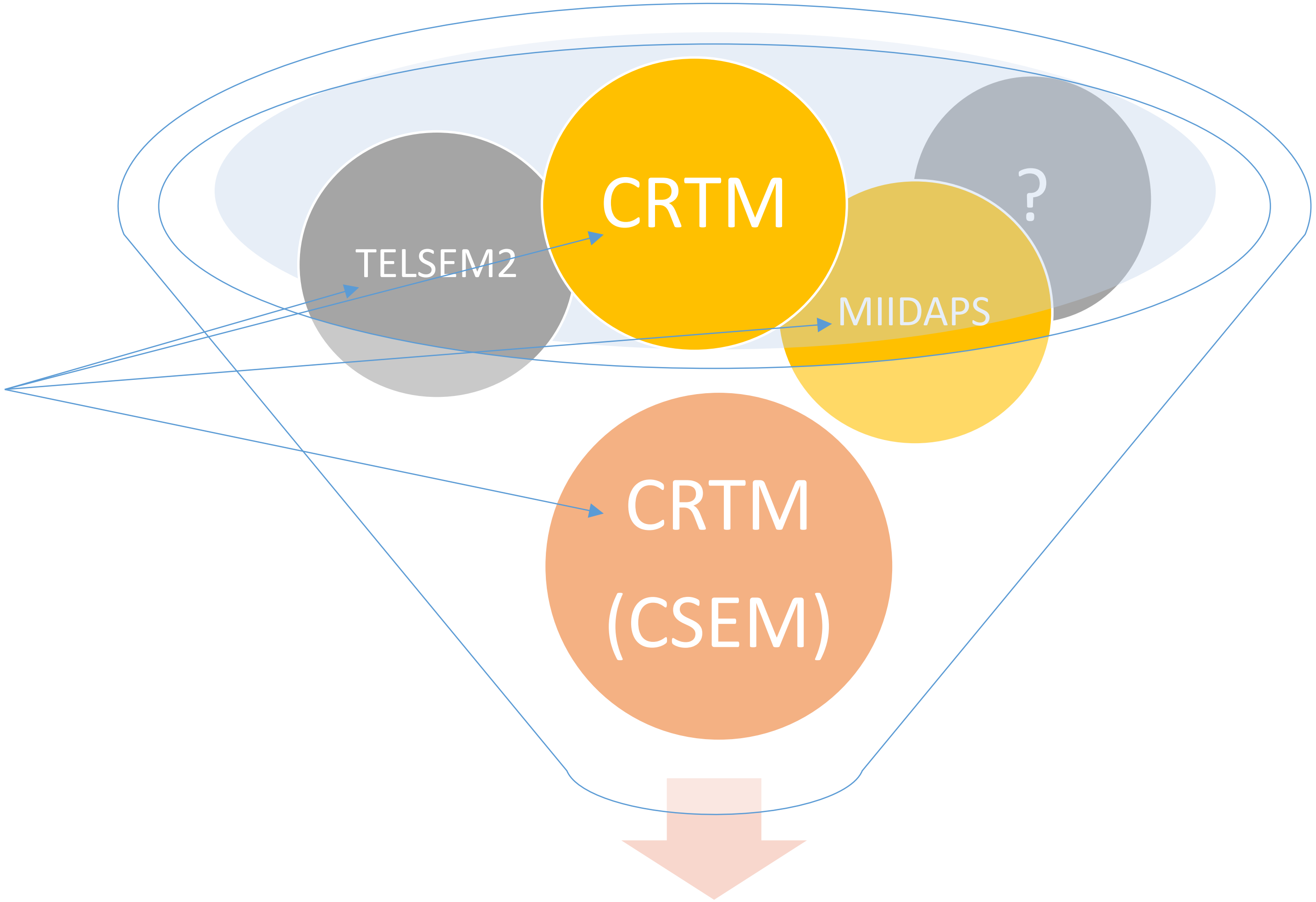
Problem:

- Accurate forward modeling of satellite radiances is a key component for successful assimilation of satellite data into Numerical Weather Prediction models.
- To achieve this goal, radiative transfer models require a solid estimate of surface conditions, surface emissivity in particular.
- While this requirement is relatively easy to meet over the ocean, land surfaces have been a challenge.
- Both radiative transfer and the direct estimate of surface emissivity struggle to reach the desired accuracy.

Steps taken in approach to improve MW radiance assimilation:

1. Provide a better first guess of emissivity to the forward model.
2. Allow the emissivity to vary through the assimilation process (i.e. to be a control variable).
3. Improve QC for MW over land (ATMS sensor presented here).

Examples of different backgrounds (i.e. emissivities)



Emissivity as a control variable in GSI

Goal is to prepare the system for use of any emissivity given as an input, have knowledge and capability to maximize the extraction of available information. Increase the number of assimilated observations over land without degrading the forecast.

1. Providing a better first guess of emissivity to the forward model

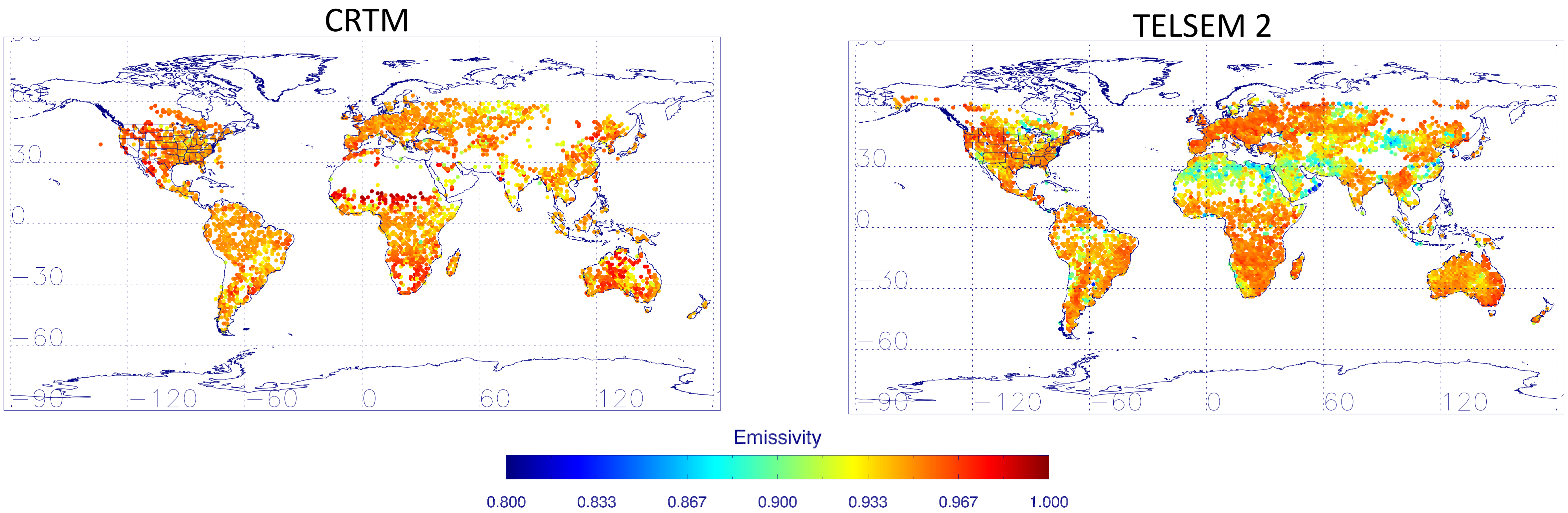
- GSI currently relies on CRTM's emissivity for MW and IR frequencies.
- We explored alternative sources for information on emissivity over land for MW until CSEM is finalized
- Freely available and widely used Tool to Estimate Land Surface Emissivities at Microwave frequencies (TELSEM2)
- Within GSI crtm_interface module TELSEM2 atlas is read to provide the "user emissivity" to the CRTM via its optional flag feature.

	CRTM	TELSEM 2
Surface type	All	Land & sea-ice only
Frequency	3 – 190 GHz	10 – 700 GHz
Polarization	H + V	H + V
Spatial Resolution	0.25°	0.25°
Temporal Resolution	Instantaneous	Monthly
Base	"Physical"	Empirical

Note: TELSEM 1 differs from TELSEM 2 by frequency range and the fact it does not include sea-ice.

First Guess Comparisons

Over land surfaces; ATMS ch. 2 (31.4 GHZ); Bias correction applied; QC applied



	CRTM	TELSEM 2
Number count	**4104**	**8050**
Bias	-0.4	0.05
Std. dev.	2.0	1.9

2. Allow the emissivity to vary through the assimilation process

- control variable -

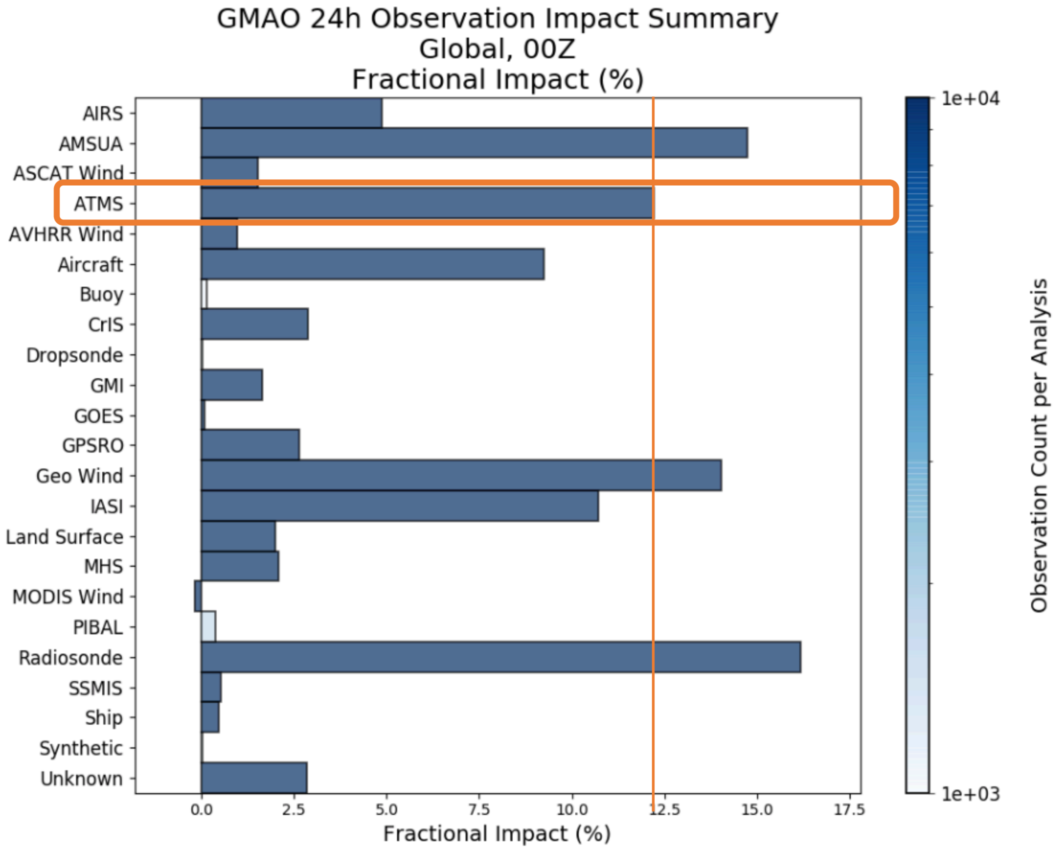
- To allow for improved physically-balanced state vector, emissivity is introduced as a control variable into the GSI system. The approach uses “de-attached” stand-alone implementation.
- The optimal emissivity parameter is obtained by minimizing the incremental cost function
- Minimization involves calculation of the gradient with help of the chain rule
- Implementation is applied to all MW sensors

<u>Possible improvements to implementation:</u>

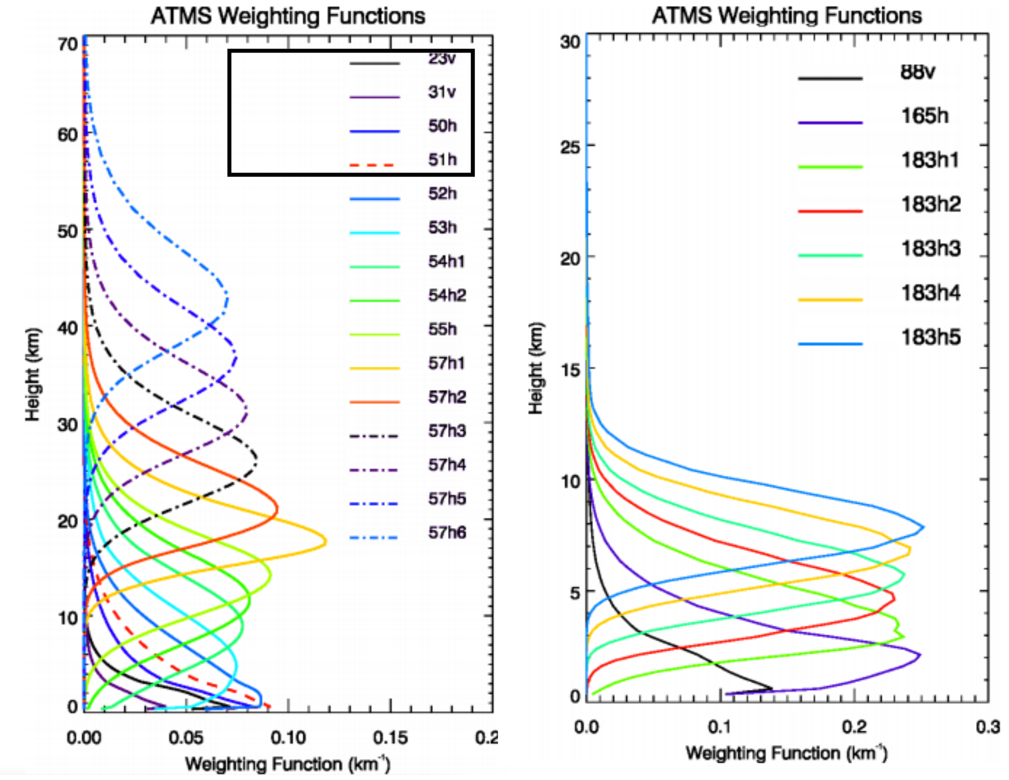
- Correlated errors for emissivity (including non-diagonal elements of covariance matrix)
- Exponential Multiplicative parameter (preserve positive definiteness of the emissivity multiplicative parameter)

Why separating the ATMS impact?

- Advanced Technology Microwave Sounder (ATMS) – Suomi NPP
- Land surface MW sensitive frequencies: CH 1-4, 16-22
- GSI QC improvements were possible
- FSOI shows importance of ATMS sensor in fractional impact summary (shown month: May 2019)



GMAO Observation Impact Summary (http://ios.jcsda.org/)



ATMS response graphs (Garrett et al. 2013 GSI Workshop)

Adding the emissivity to the GSI as a control variable

- implementation -

New control variable is a multiplicative factor β :

$$e = \beta \cdot e_{CRTM}$$

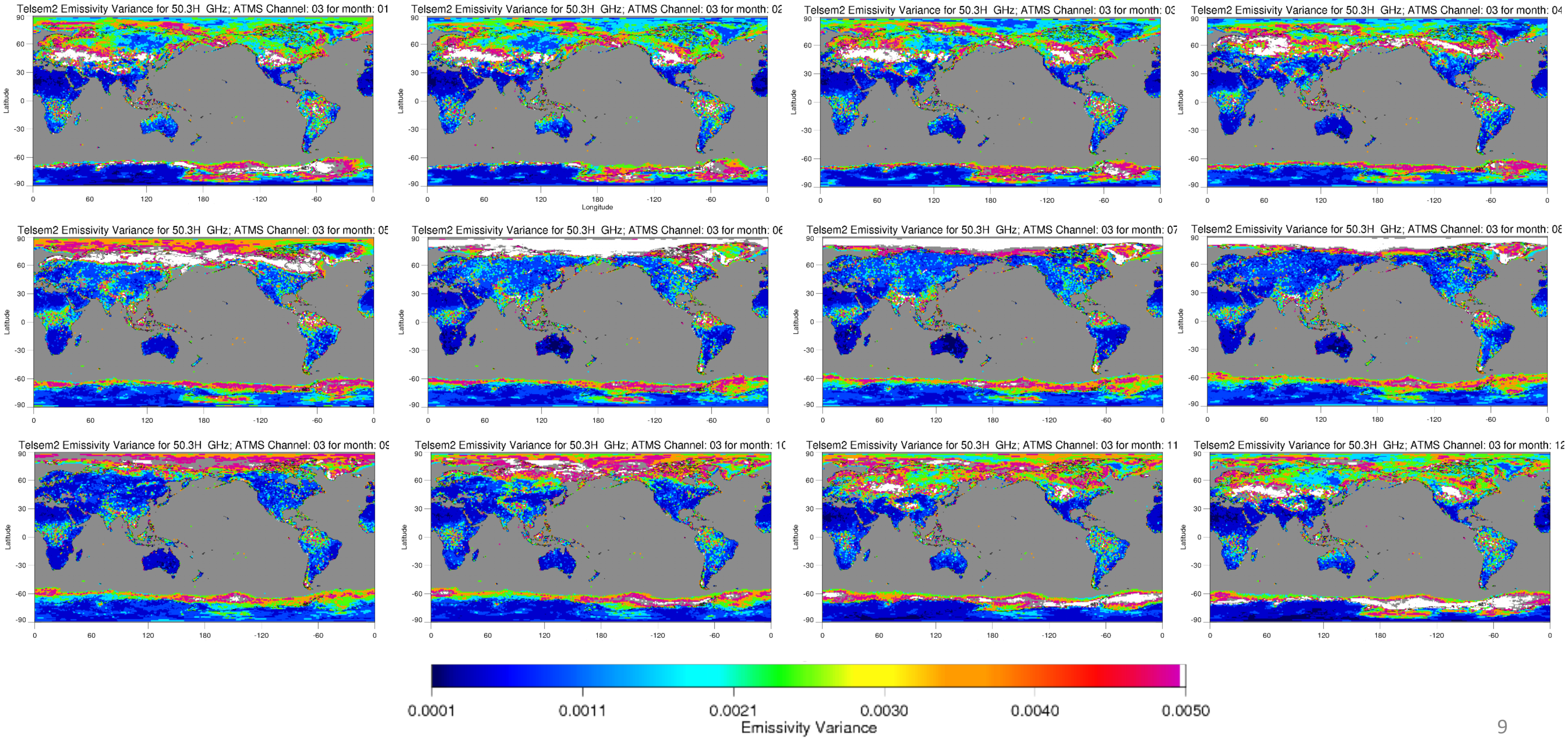
$$\beta = \begin{pmatrix} \beta_1 & \beta_2 & \cdots & \beta_N \end{pmatrix}^T$$

Where:

- *e* denotes emissivity
- subscript *CRTM* refers to the emissivity calculated in CRTM
- β is a vector defined over channels in observation space
- *N* is the total number of channels

- Construct cost function with added parts to account for new control variable β information
- Calculate gradient of the cost function
- Without knowing cross correlations between different parameters the initial choice for parameter error covariance is a diagonal matrix, where σ is the assigned standard deviation of the particular parameter. In case of emissivity, this is determined based on TELSEM2.
- Optimal emissivity parameter is obtained by minimizing the cost function.

TELSEM 2 Emissivity Variance for 50.3 GHz



Out of TELSEM data over the whole year:

For channel 31.4V GHz; ATMS Channel: 2

Variance min: 0.000001

Variance max: 0.036

Variance mean: 0.0027

One new fix-file was added to GSI: global_emiss_error.txt

Sensor ID	CH #	CH use	our error	error use	GSI_CH index
atms_npp	1	1	0.0019	1	1602
atms_npp	2	1	0.0027	1	1603
atms_npp	3	1	0.0029	1	1604
atms_npp	4	1	0.0040	1	1605
atms_npp	5	1	0.0029	1	1606
atms_npp	6	1	0.0029	1	1607
atms_npp	7	1	0.0029	1	1608
atms_npp	8	1	0.0029	1	1609
atms_npp	9	1	0.0030	1	1610
atms_npp	10	1	0.0030	1	1611
atms_npp	11	1	0.0030	1	1612
atms_npp	12	1	0.0030	1	1613
atms_npp	13	1	0.0030	1	1614
atms_npp	14	1	0.0030	1	1615
atms_npp	15	1	0.0024	1	1616
atms_npp	16	1	0.0018	1	1617
atms_npp	17	1	0.0040	1	1618
atms_npp	18	1	0.0040	1	1619
atms_npp	19	1	0.0040	1	1620
atms_npp	20	1	0.0040	1	1621
atms_npp	21	1	0.0040	1	1622
atms_npp	22	1	0.0040	1	1623

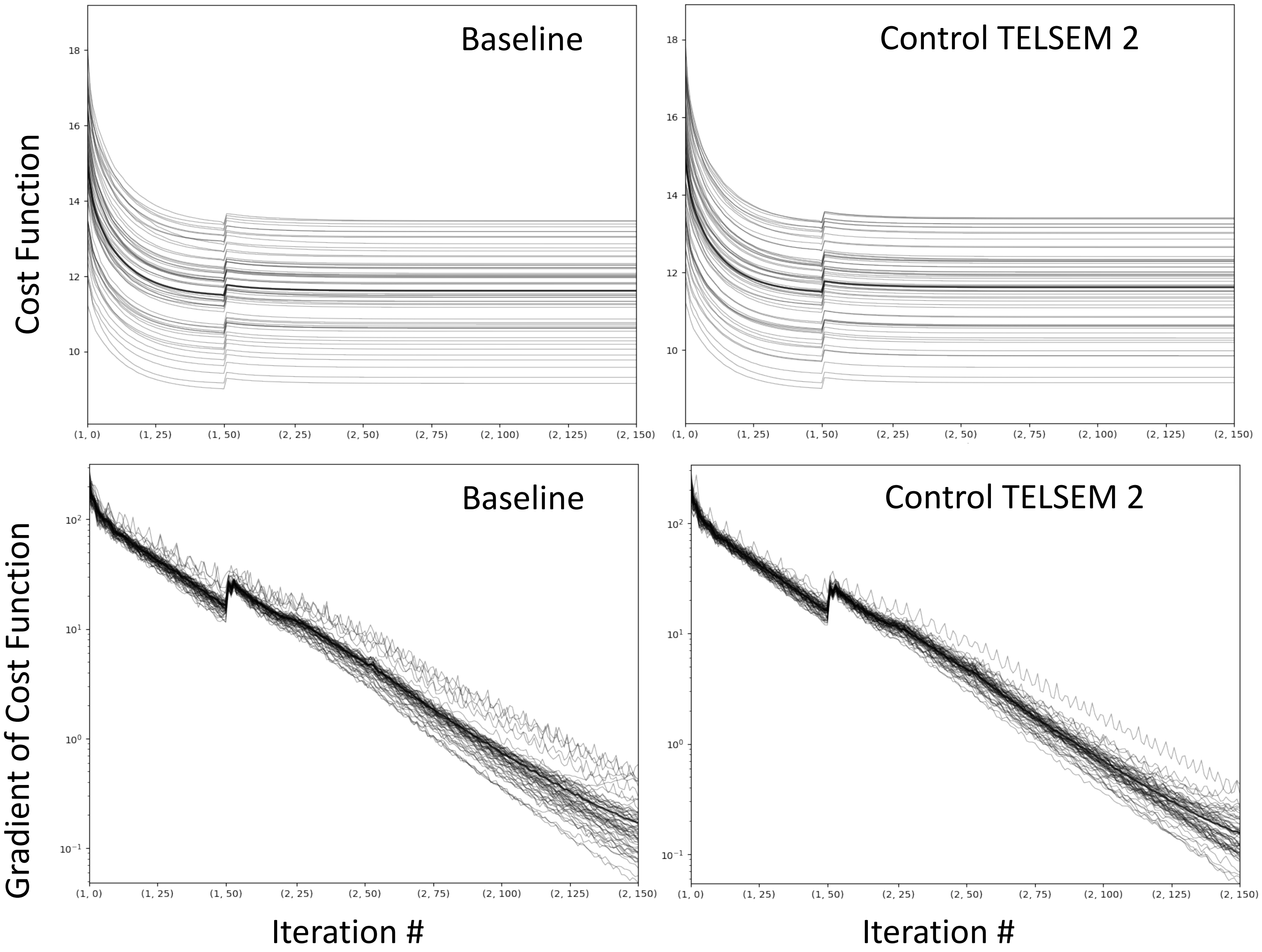
Final errors for ATMS are:

1	0.0019
2	**0.0027**
3	0.0029
4	0.0040
5	0.0029
6	0.0029
7	0.0029
8	0.0030
9	0.0030
10	0.0030
11	0.0030
12	0.0030
13	0.0030
14	0.0030
15	0.0024
16	0.0018
17	0.0040
18	0.0040
19	0.0040
20	0.0040
21	0.0040
22	0.0040

Error covariance of parameter β

$$B_\beta = \begin{pmatrix} \sigma^2_{\beta_1} & 0 & 0 \\ 0 & \sigma^2_{\beta_2} & \vdots \\ & & \ddots & \\ 0 & \cdots & \sigma^2_{\beta_N} \end{pmatrix}$$

Model performance sanity check – 15 days

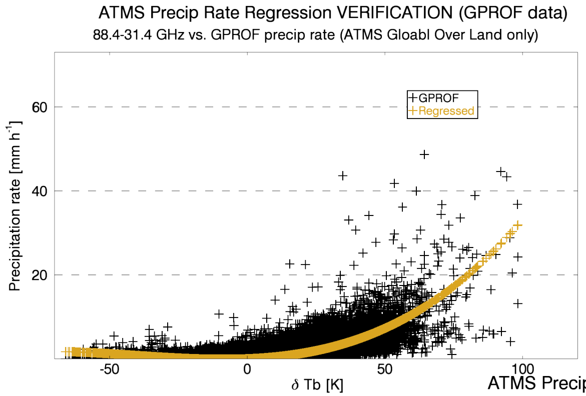


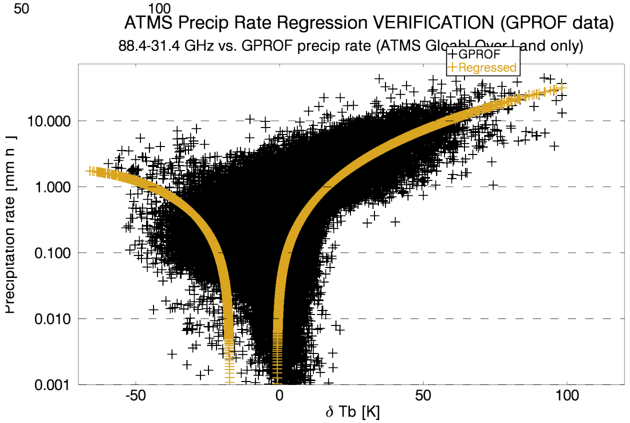
3. Improving QC for ATMS over land

- **Analytic emissivity used for emissivity sensitivity**

$$\varepsilon = \frac{T_b - Tu - Td\Gamma}{(T_s - Td)\Gamma}$$

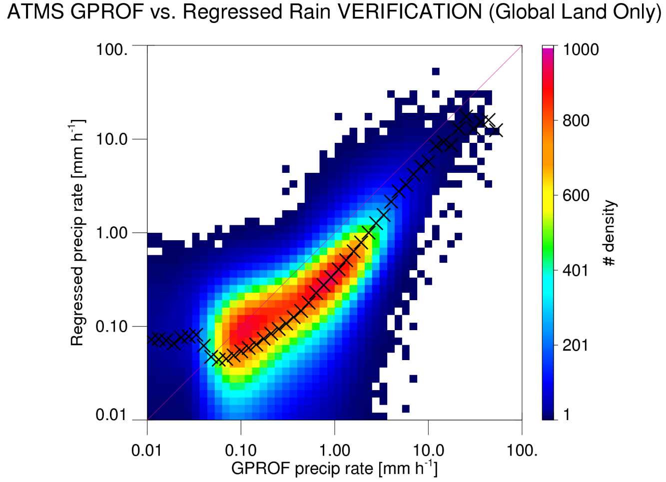
ε - emissivity
Tb - observed brightness temperature
Ts - skin temperature
Tu - upwelling brightness temperature
Td - downwelling brightness temperature
Γ - atmospheric transmittance





- **Screening for rain** (information from GPROF)

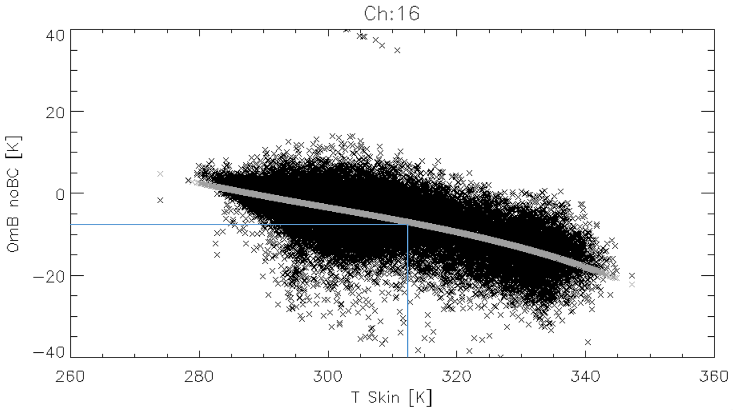
Regression is trained on a week od data in 2016; shown here are 10 days in July 2018 (for validation).
Observed GPROF rain and regressed ATMS TB89-TB31 rain.
Crosses are relationship between 'TB89-TB31' and 'GPROF rain'. Regression is done as polynomial of 3rd order.



Bias : 2.52% Correlation: 0.73

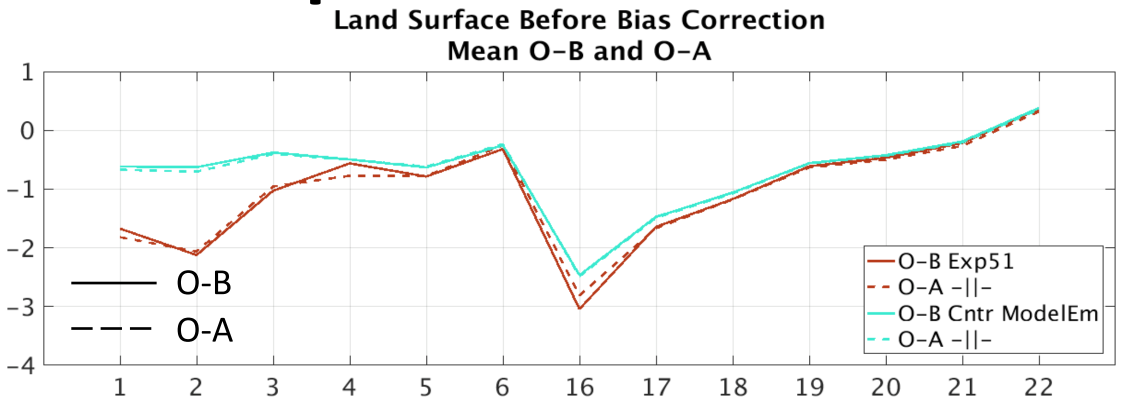
Ts sensitivity on channel 16 (89 GHz)

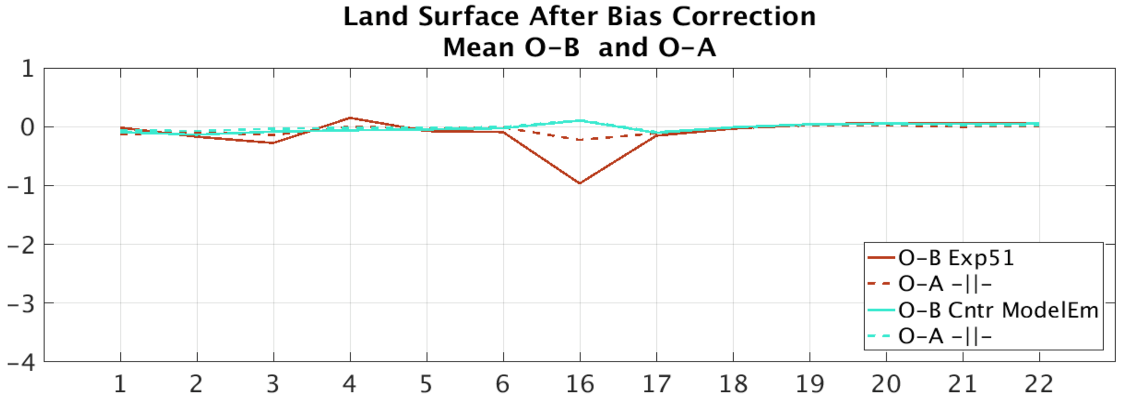
CH number	Correlation to Ts based on OmB_nBC
1	-0.227570
2	-0.181155
3	-0.312302
4	-0.314278
16	-0.658272

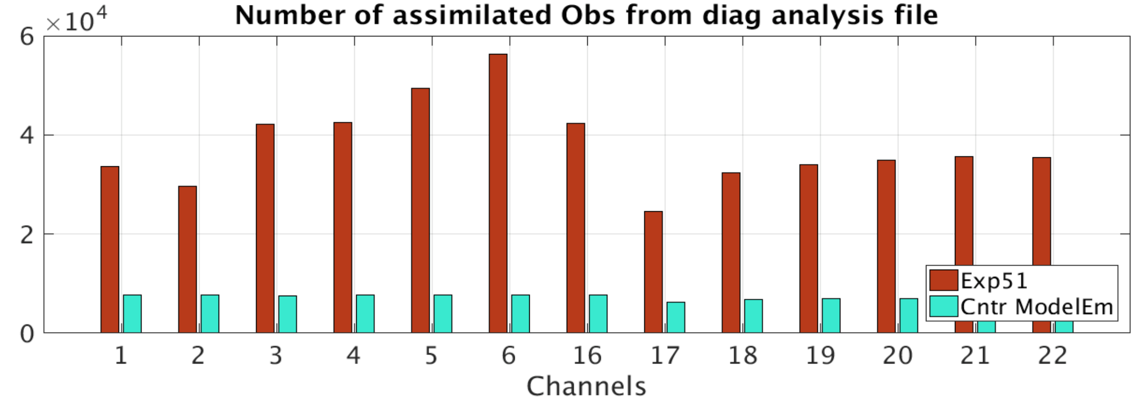


Results

Comparison of O-B and O-A before and after bias correction





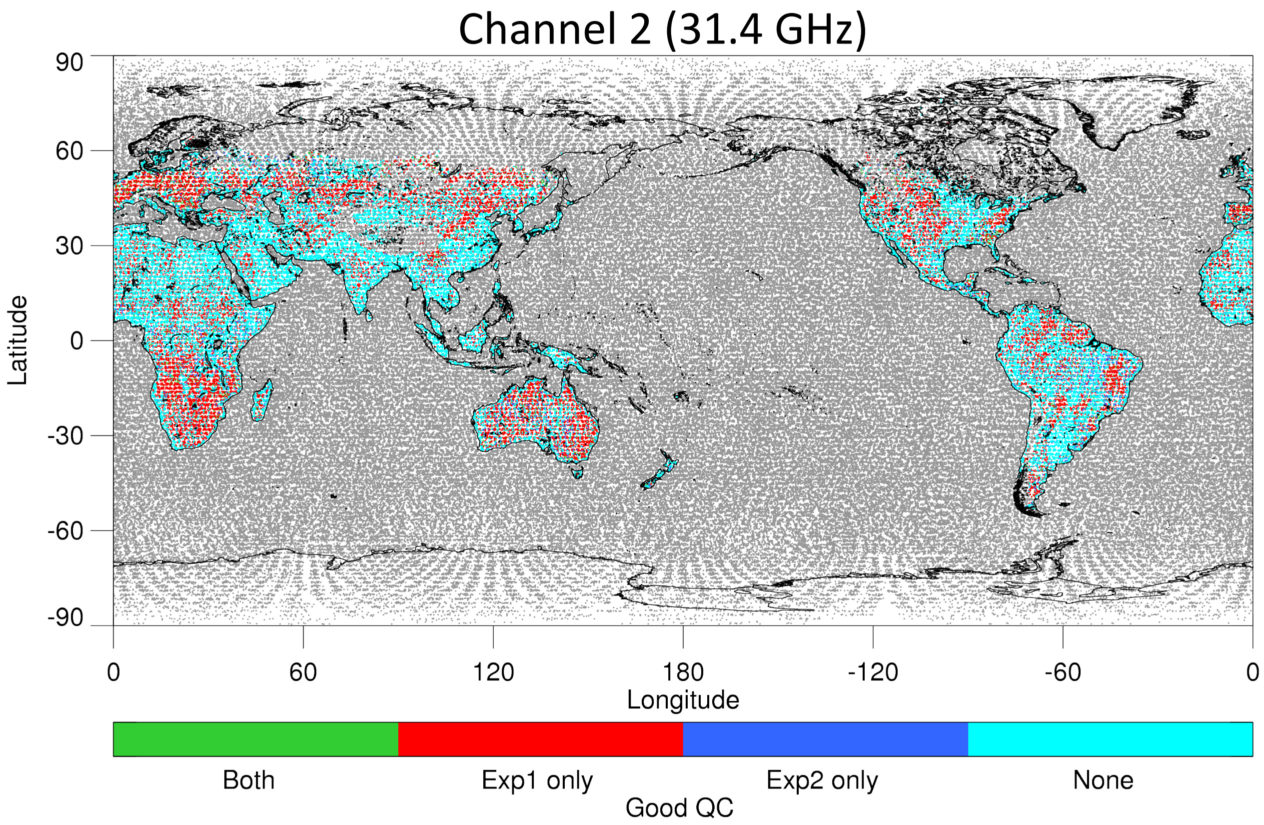


- The best experiment performance (exp51) compared to the operational run result before (top) and after (middle) bias correction
- Observation counts exceed the operational values by factor of 4.
- Mean O-B and O-A show significant improvements after the bias correction
- Channels 7 through 15 (not shown) preserve the same performance

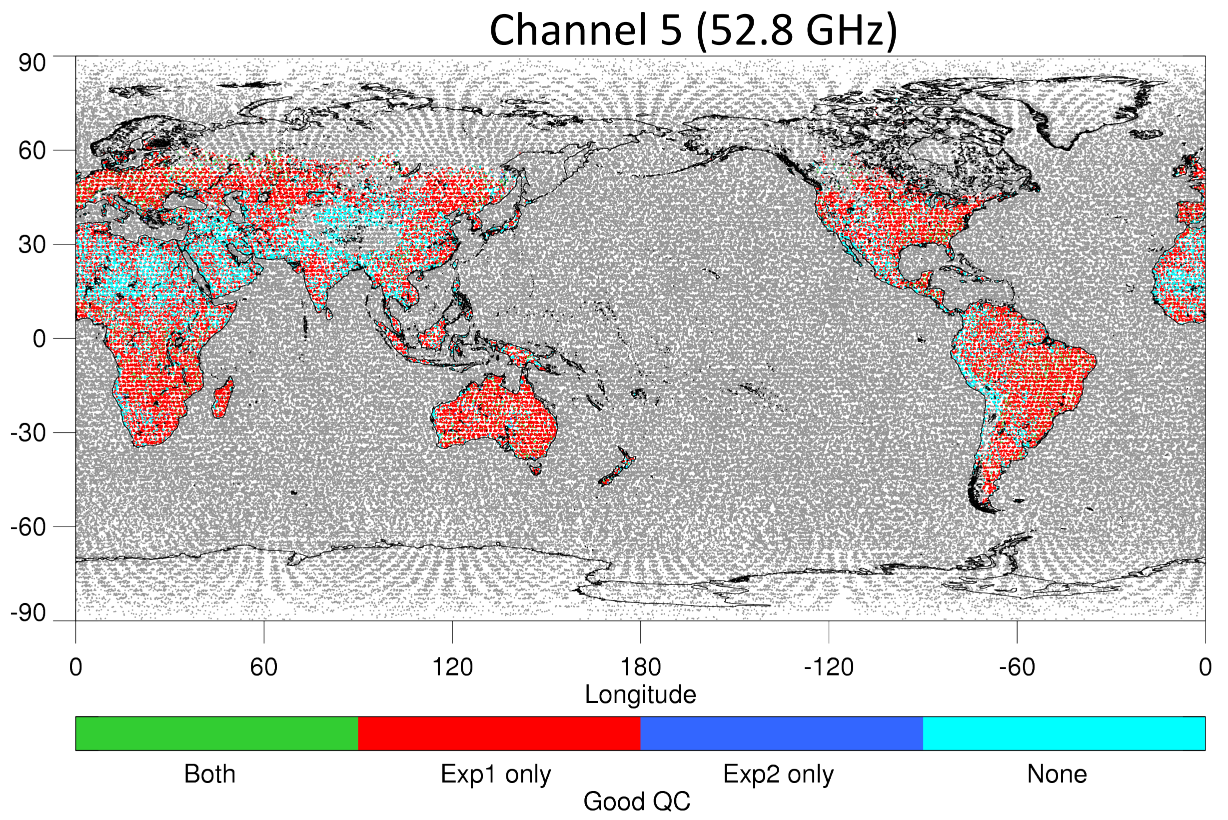
NOTE:
Exp 51: TELSEM as a background new QC constructed of precipitation, Ts and emissivity sensitivity screening with emissivity as analysis variable.
Cntr ModelEm: CRTM provides emissivity which is not treated as a control variable

Comparison of valid observation points

ATMS over land; both ascending and descending orbits



Valid QC	Exp51 STD	Cntr STD	Counts
Exp51	*1.96*	7.80	*28,780*
Cntr	5.36	*1.91*	7,039
Exp51 & Cntr	1.82	*1.87*	4,255



Valid QC	Exp51 STD	Cntr STD	Counts
Exp51	*0.26*	1.28	*48,295*
Cntr	0.47	*0.23*	7,039
Exp51 & Cntr	0.19	*0.23*	6,868

Conclusions

- Using different background in the system makes biggest change to the assimilation

- Using control variable will not increase significantly observation counts as the background will but will make better statistics, meaning the adjustment was in right direction

- QC optimization is necessary with introduction of new or improved background

New future directions:

- Merging this work with FV3 is in progress and once done we will evaluate the implementation for forecast impact in longer verification runs
- Optimize Quality Control (QC) and observation errors for land surface sensitive microwave brightness temperatures assimilation
- Optimize surface emissivity background error covariance and background emissivity
- Optimize bias correction implemented for land surface sensitive microwave brightness temperatures

Questions?