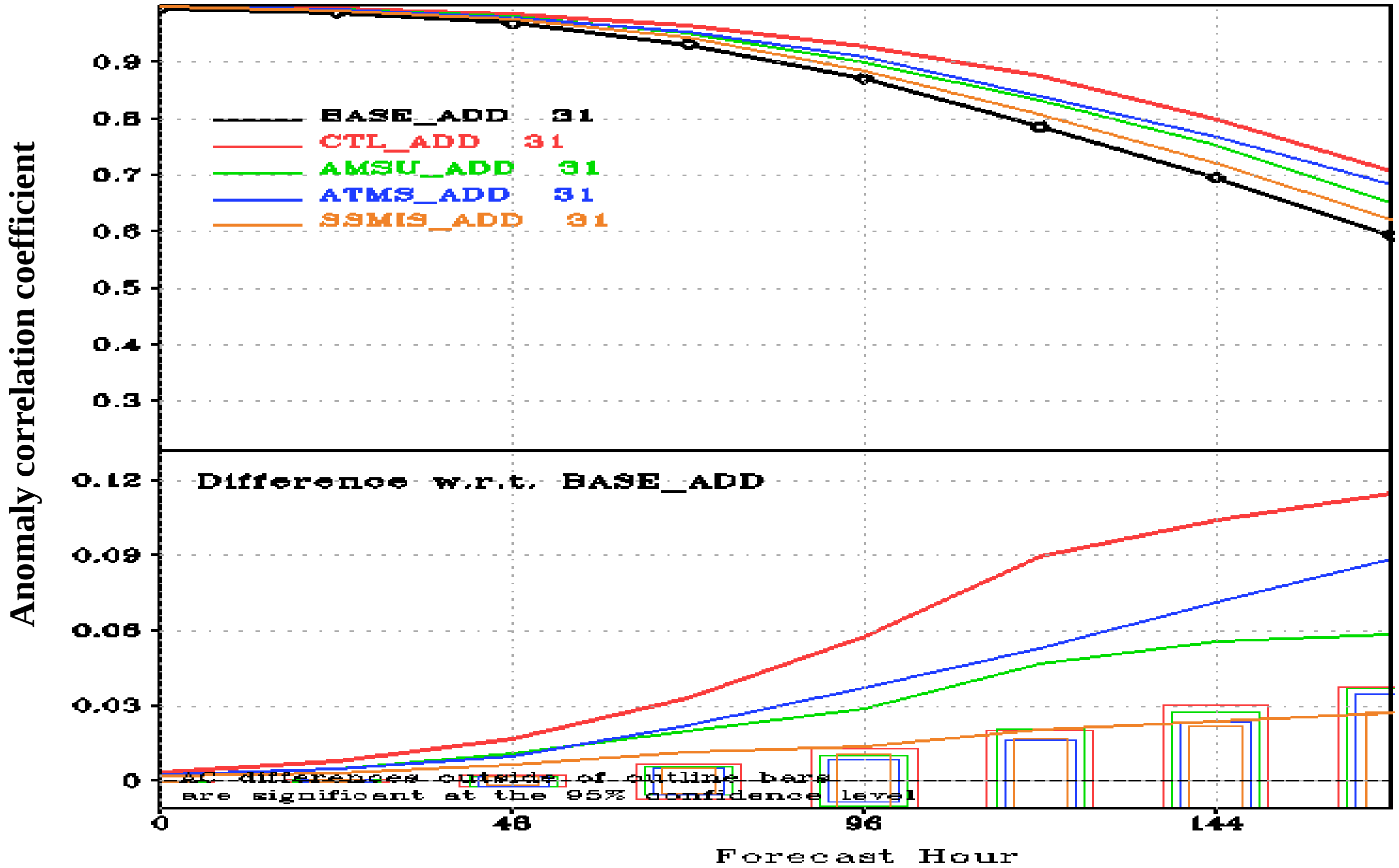
Maximize Benefits of Satellite Microwave Sounding Data on Weather Forecast

Fuzhong Weng

State Key Laboratory of Severe Weather, Beijing, China

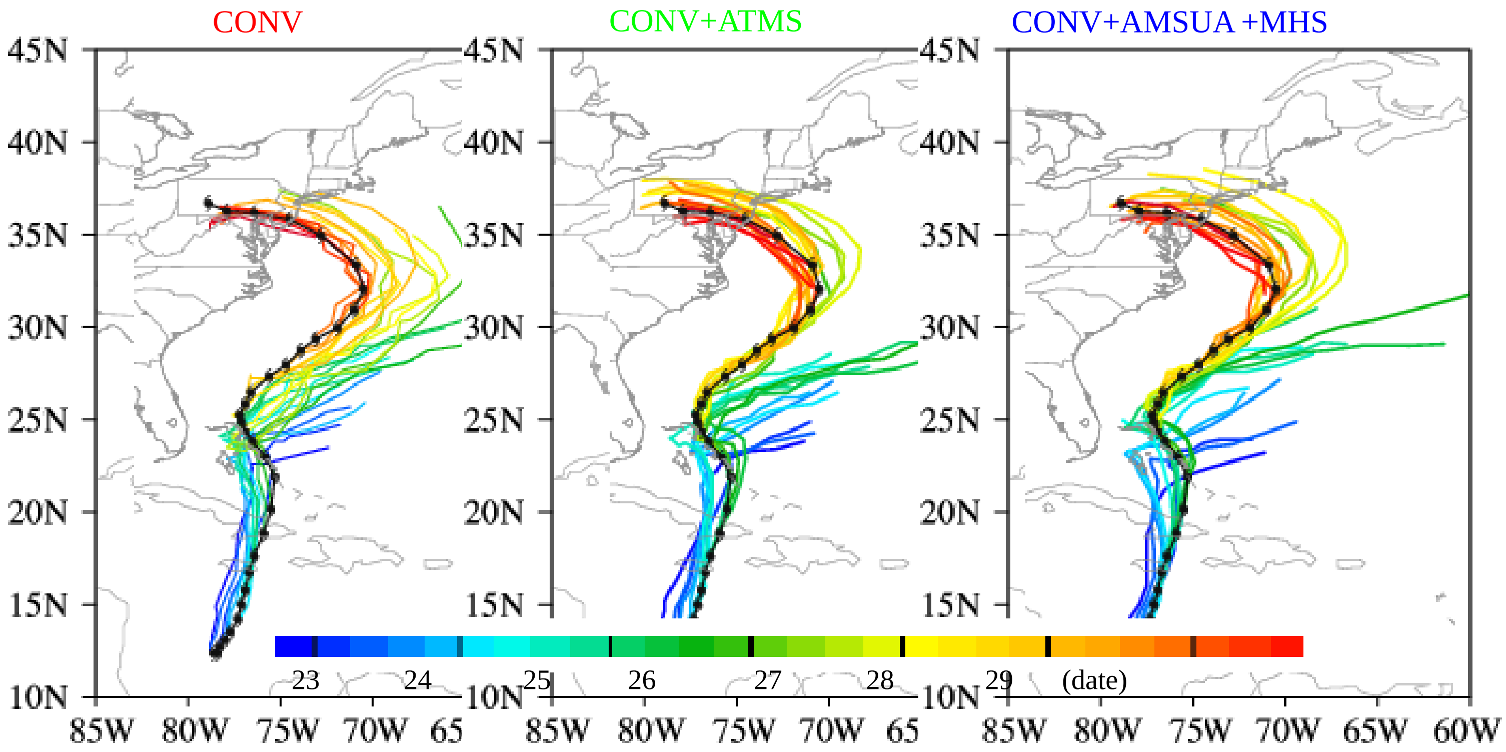
Impacts of Microwave Sounders in NCEP GFS

500 hPa Southern Hemisphere AC scores for 20140101 – 20140131 00Z



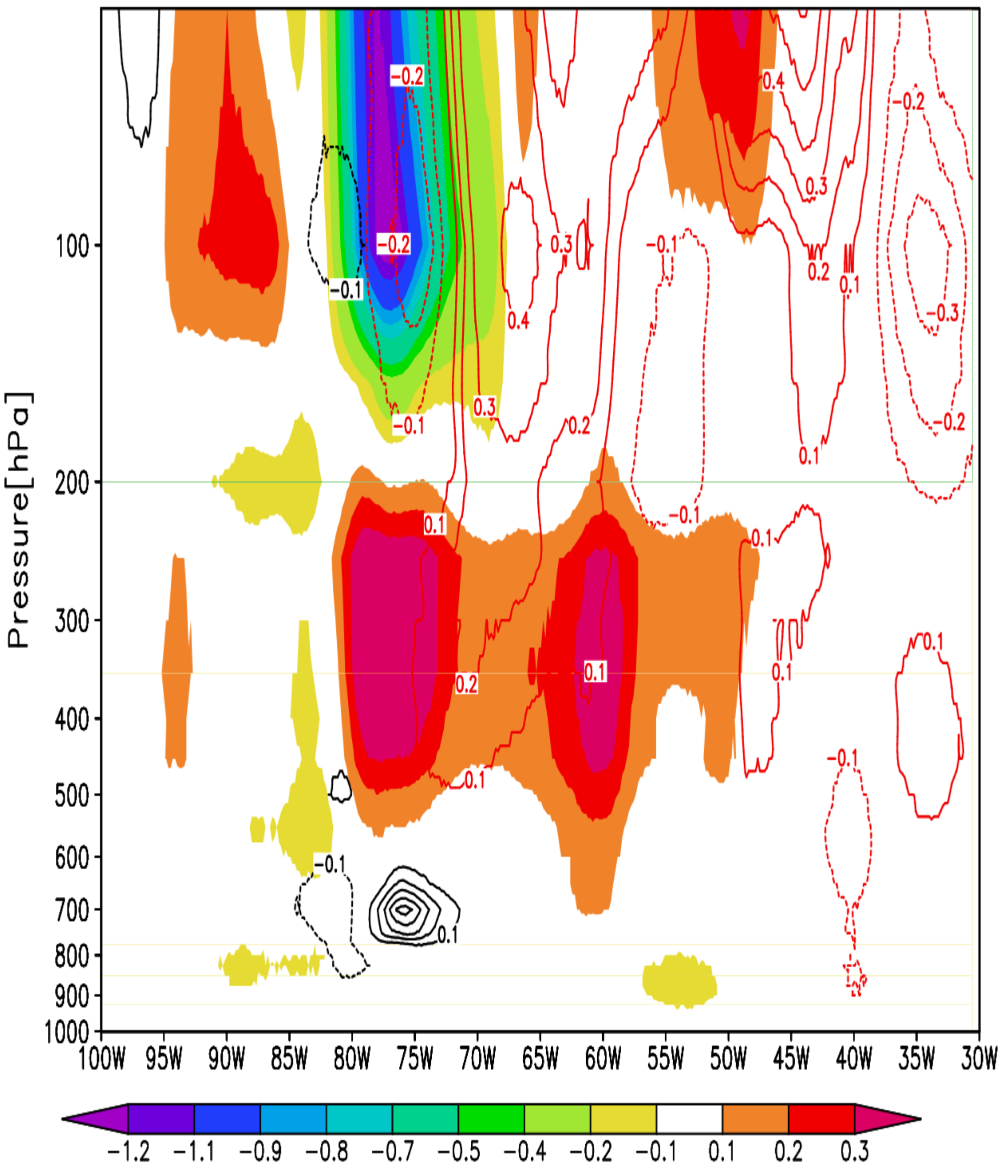
Assimilation of ATMS radiances in NCEP GFS produces a largest impact on global medium range forecast, especially in southern hemisphere. With respect to the baseline experiment that includes the conventional and GPSRO data, ATMS largely contributes to the forecast score increase in comparison with other sounding instruments

Forecasting the Track of Hurricane Sandy Using HWRF



Operational HWRF model was updated with higher model top (0.5 mb) and more vertical levels (61). The model was started with its own 6 hour forecasting field (warm start) and GSI is used for assimilation of satellite data in all the domains. Conventional data include radiosonders and aircraft reports, ship/buoy,surf obs, pival winds/wind profilers, VAD wind, dropsondes. ***ATMS has higher positive impacts on Sandy's track forecasts after October 26.***

Temperature Innovation from ATMS and AMSU-A



Shaded: ATMS

Red contour: AMSU-A

Black contour: Conventional

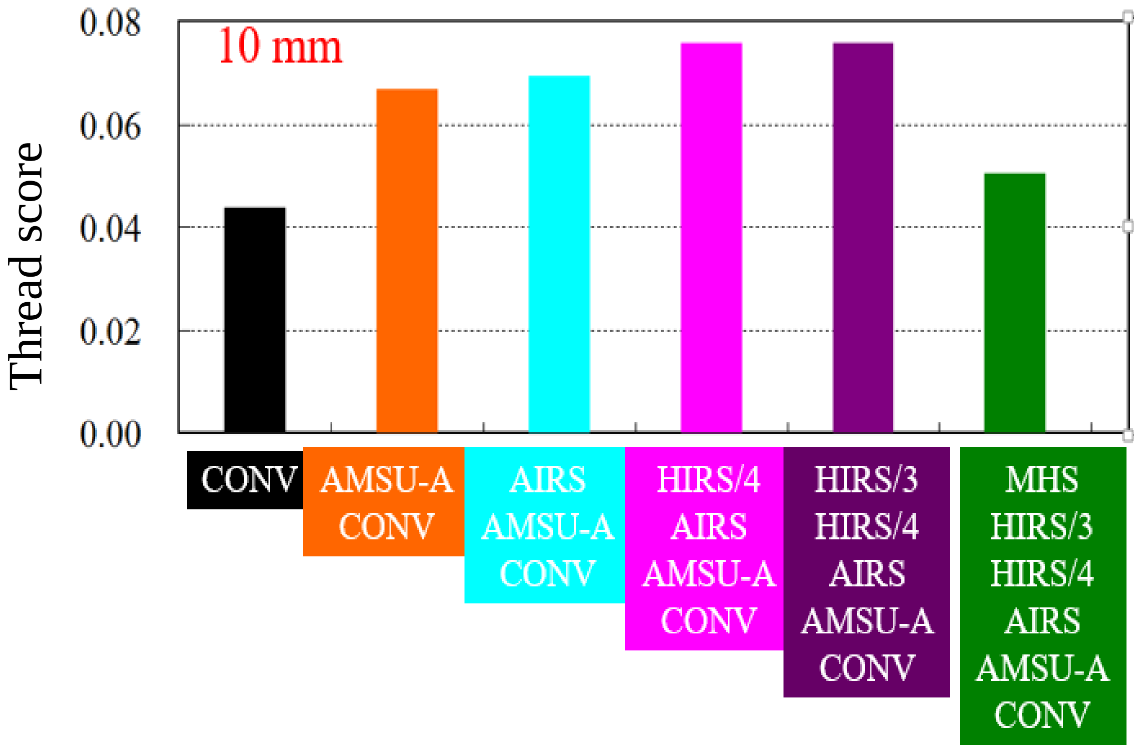
ATMS and AMSU-A (NOAA-19) both have temperature innovation near 100 mb at 80W but the magnitude from ATMS is much larger in the overlapping regions of ATMS and AMSU

Quantitative Precipitation Forecast- A Negative Impact from MHS Data Assimilation

Advanced Research WRF (ARW)
Model/ GSI 3D-Var

Resolution: 10 km, 27 layers
Domain size: 250x200x27
Observations: Conventional data + satellite data

Cycling interval: 6 hours



DA period: 1200-2400 UTC, May 22, 2008
Forecast Period:0000-24000 UTC May 23, 2008

ATMS versus AMSU-A and MHS

Why did the assimilation of Suomi ATMS produce consistently higher positive improvements to hurricane forecast skill. Assimilation of MHS data in regional forecast model tends to downgrade the precipitation forecasts?

- Not all AMSU-A and MHS FOVs are spatially collocated perfectly
- AMSU-A and MHS channels are put into two separate BURF files

- ATMS temperature channels and humidity channels are automatically collocated
- ATMS temperature channels and humidity channels are in the same BURF file

Three Steps for MHS Data Rejection in GSI

Step I:

$$TPW_{index} > 1$$

Step II:

$$|O-B| > 3\left(e_i \times \left(1 - TPW_{index}^2\right) \times f_H \times \tau_i^{top}\right)$$

or: $|O-B| > 6\text{K}$

e_i is accuracy of obs.

f_H=2000/H, H is terrain height>2km

τ_i^{top} is the transmittance at model top

Step III:

All five channels if data of any other channel was removed by the first two QC steps

MHS QC in GSI

- An LWP index is calculated as follows:

$$LWP_{index}^{ocean} = \begin{cases} 0.13 \times \left\{ \left(T_{b,1}^{o} - T_{b,1}^{m}\right) - 33.58 \times \dfrac{\left(T_{b,2}^{o} - T_{b,2}^{m}\right)}{300 - T_{b,2}^{o}} \right\}, & \text{if } T_{b,2}^{o} \le 300 \\ 9, & \text{otherwise} \end{cases}$$

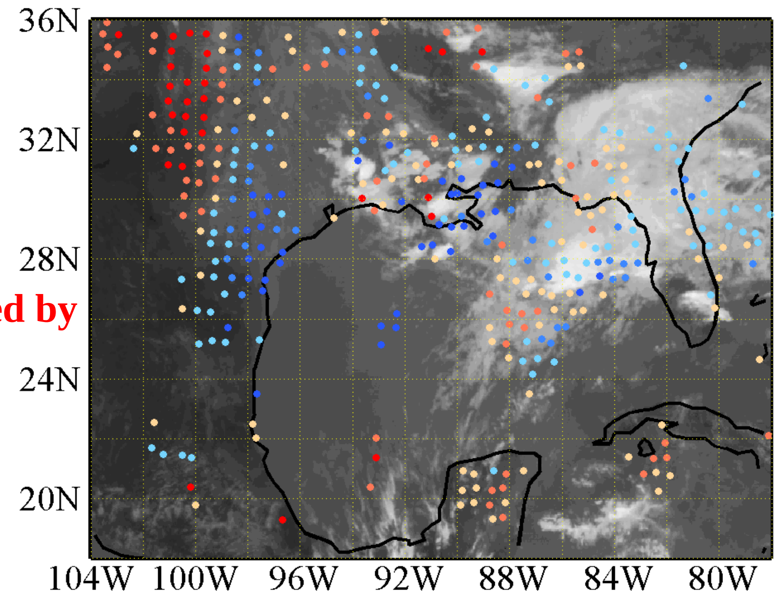
$$LWP_{index}^{land} = 0.85 \times \left(T_{b,1}^{o} - T_{b,1}^{m}\right) - \left(T_{b,2}^{o} - T_{b,2}^{m}\right)$$

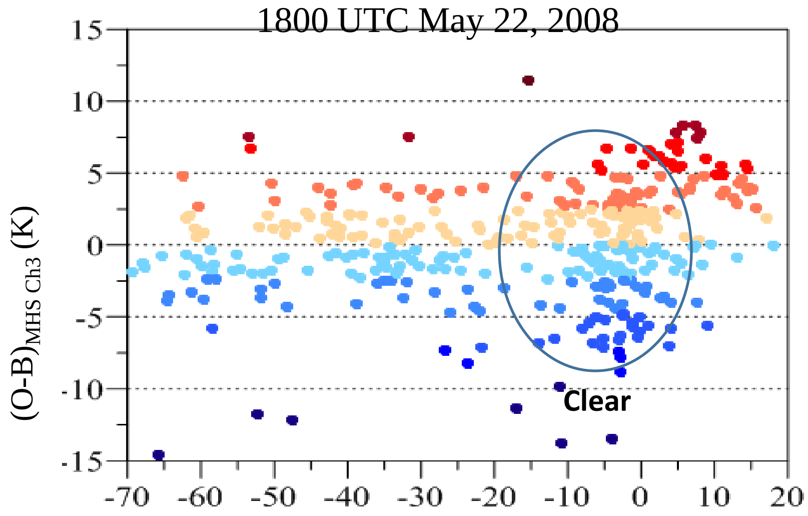
- An TPW index is calculated as follows:

$$TPW_{index} = \left\{ \left[\left(T_{b,1}^{o} - T_{b,1}^{m}\right) - 7.5 \times LWP_{index} \right] / 10.0 \right\}^{2} + LWP_{index}^{2}$$

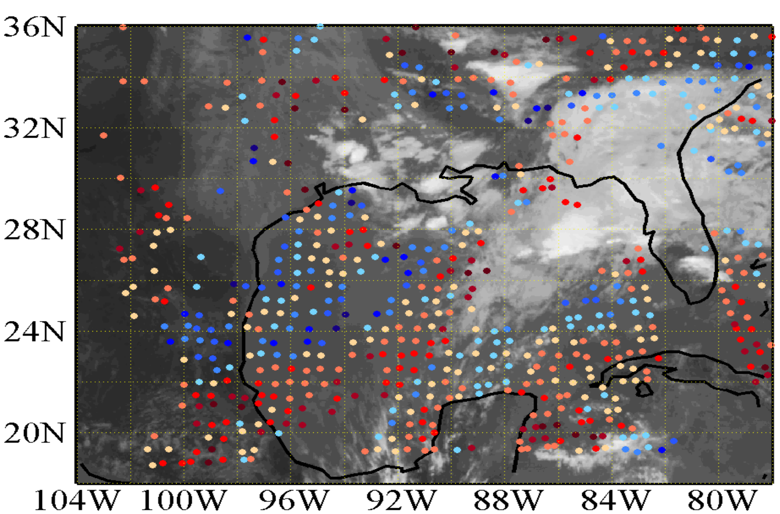
Diagnosis of MHS QC in GSI

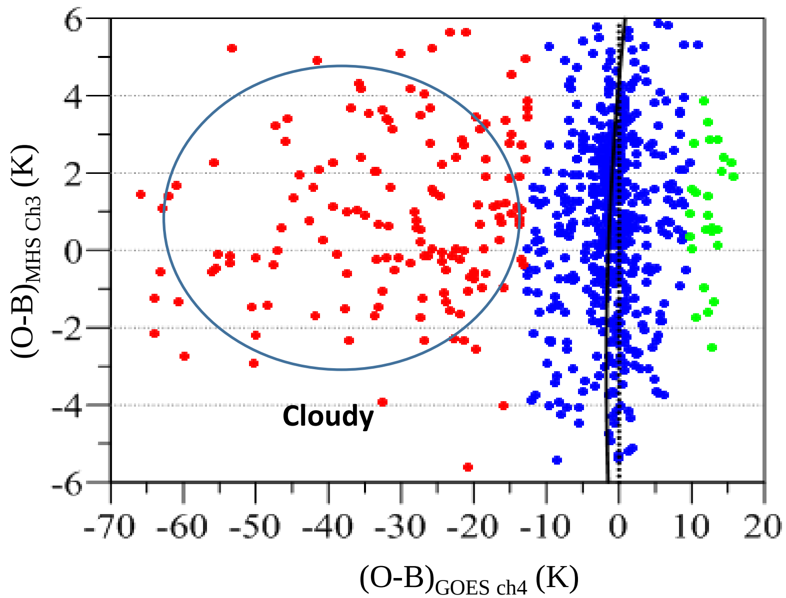
Data removed by GSI QC

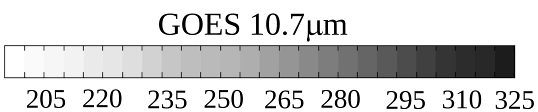


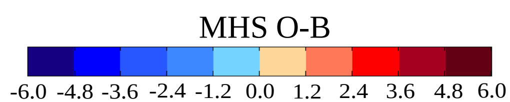


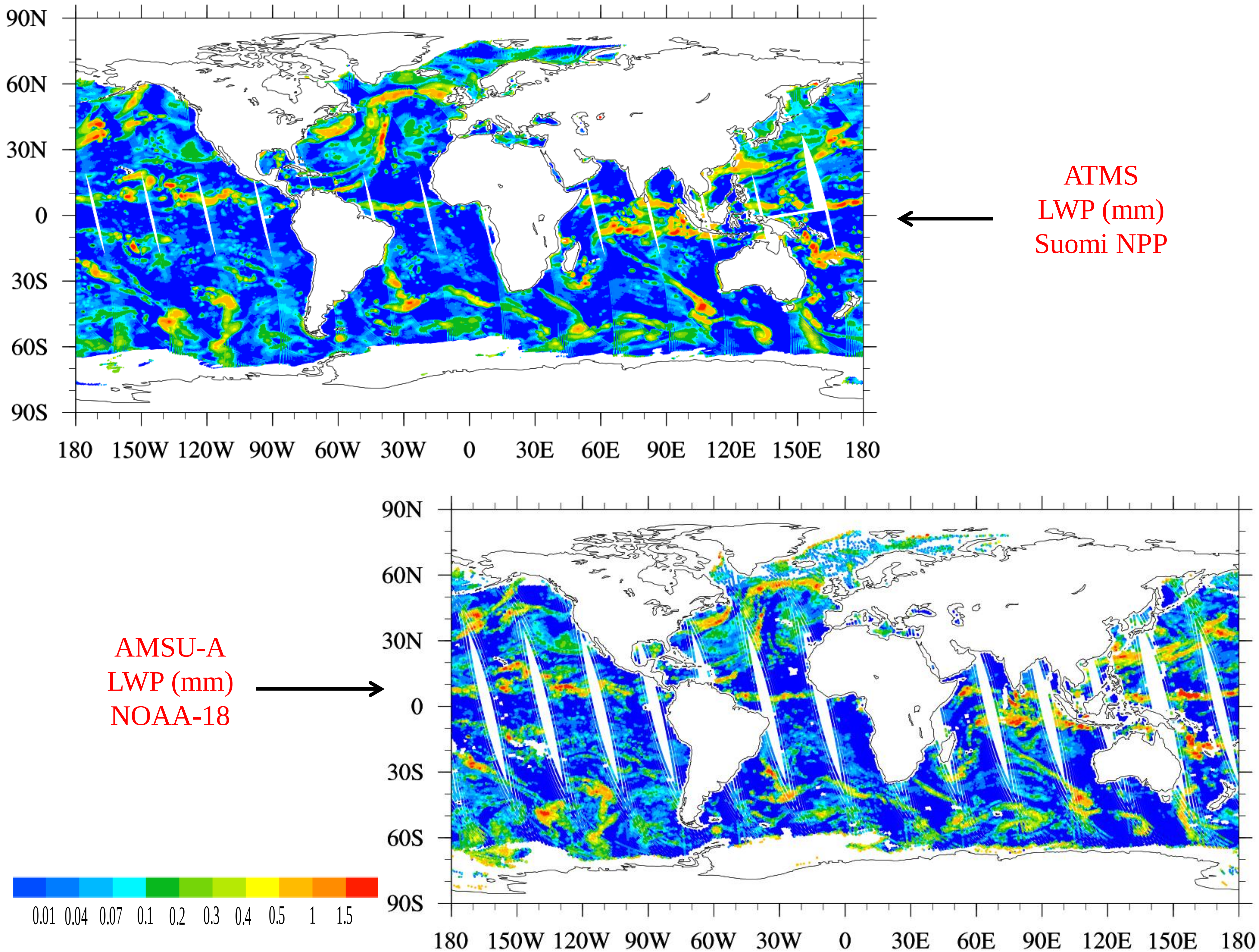
Data that pass GSI QC





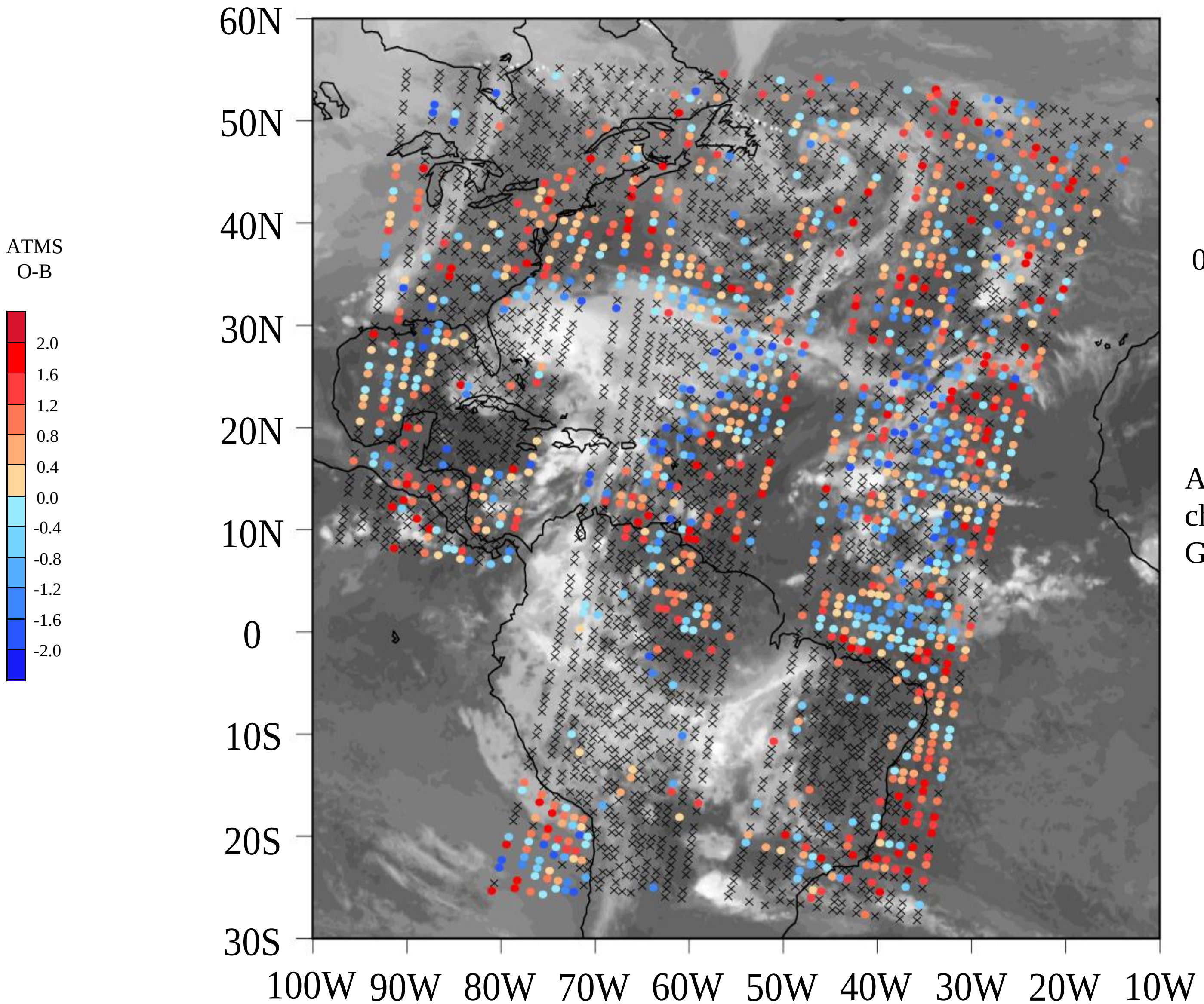






90N
60N
30N
0
30S
60S
90S
180
150W
120W
90W
60W
30W
0
30E
60E
90E
120E
150E
180
ATMS
LWP (mm)
Suomi NPP
AMSU-A
LWP (mm)
NOAA-18
0.01 0.04 0.07 0.1 0.2 0.3 0.4 0.5 1 1.5

Diagnosis of GSI QC for ATMS



0600 UTC October 26, 2012

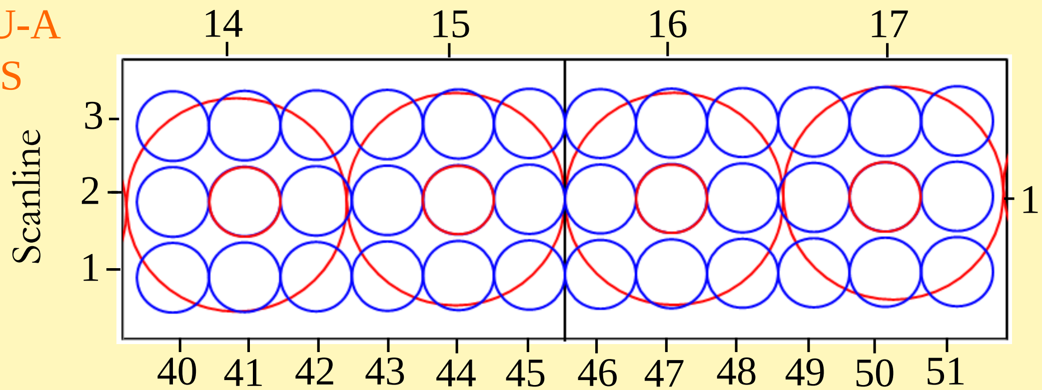
ATMS water vapor channel data that passing GSI QC

Channel Characteristics of ATMS and AMSU

Channel		Frequency (GHz)		NEΔT (K)		Beam width (°)		Peak WF (hPa)	
ATMS	AMSU	ATMS	AMSU/MHS	ATMS	AMSU/MHS	ATMS	AMSU/MHS	ATMS	AMSU/MHS
1		23.8		0.50	0.30	5.2	3.3	Surface	
2		31.4	31.399	0.60	0.30	5.2	3.3	Surface	
3		50.3	50.299	0.70	0.40	2.2	3.3	Surface	
4		51.76		0.50		2.2		Surface	
5	4	52.8		0.50	0.25	2.2	3.3	1000	
6	5	53.596±0.115		0.50	0.25	2.2	3.3	700	
7	6	54.4		0.50	0.25	2.2	3.3	400	
8	7	54.94		0.50	0.25	2.2	3.3	270	
9	8	55.5		0.50	0.25	2.2	3.3	180	
10	9	57.29		0.75	0.25	2.2	3.3	90	
11	10	57.29± 0.217		1.00	0.40	2.2	3.3	50	
12	11	57.29± 0.322± 0.048		1.00	0.40	2.2	3.3	25	
13	12	57.29± 0.322 ± 0.022		1.25	0.60	2.2	3.3	12	
14	13	57.29± 0.322 ± 0.010		2.20	0.80	2.2	3.3	5	
15	14	57.29± 0.322± 0.0045		3.60	1.20	2.2	3.3	2	
16	15	88.2	89.0	0.30	0.50	2.2	3.3	Surface	
17	16	165.5	89.0	0.60	0.84	1.1	1.1	1000	Surface
18	17	183.31±7.0	157.0	0.80	0.84	1.1	1.1	800	Surface
19	18	183.31±4.5	183.31±1.0	0.80	0.60	1.1	1.1	700	400
20	19	183.31±3.0		0.80	0.70	1.1	1.1	600	
21	20	183.31±1.8	183.31±7.0	0.80	1.06	1.1	1.1	500	800
22		183.31±1.0		0.90		1.1		400	

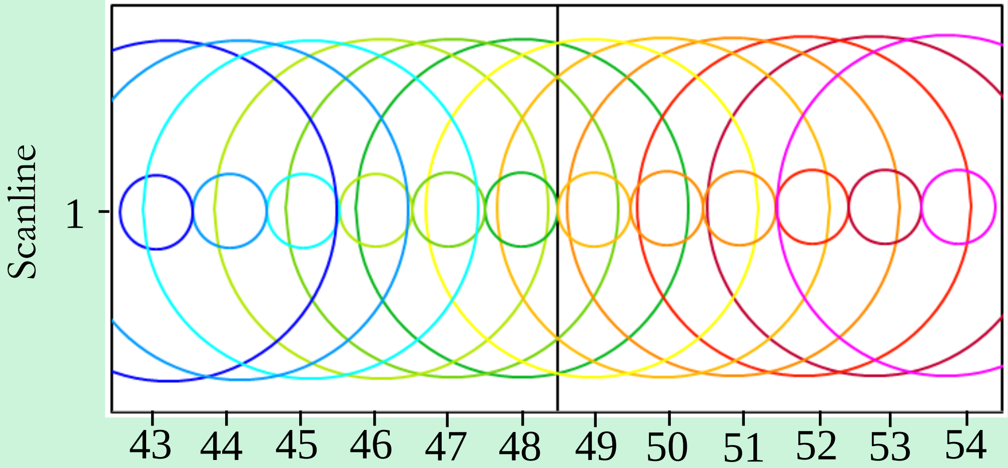
FOV Comparison between ATMS and AMSU-A/MHS

AMSU-A
MHS

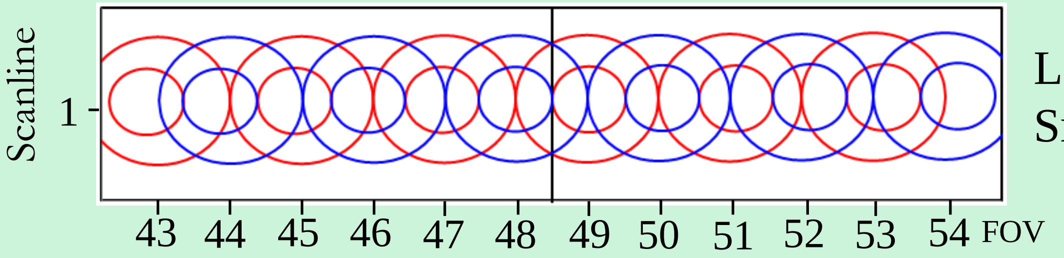


Larger FOVs: AMSU-A (LWP)
Smaller FOVs: MHS (IWP)

ATMS



Larger FOVs: ATMS Ch1-2 (LWP)
Smaller FOVs: ATMS Ch17-22 (IWP)



Larger FOVs: ATMS Ch3-16
Smaller FOVs: ATMS Ch17-22

An automatic collocation between temperature and humidity channels from ATMS makes it possible to detect both liquid and ice clouds simultaneously!

Spatial Differences: ATMS vs. AMSU/MHS

Beamwidth (degrees)

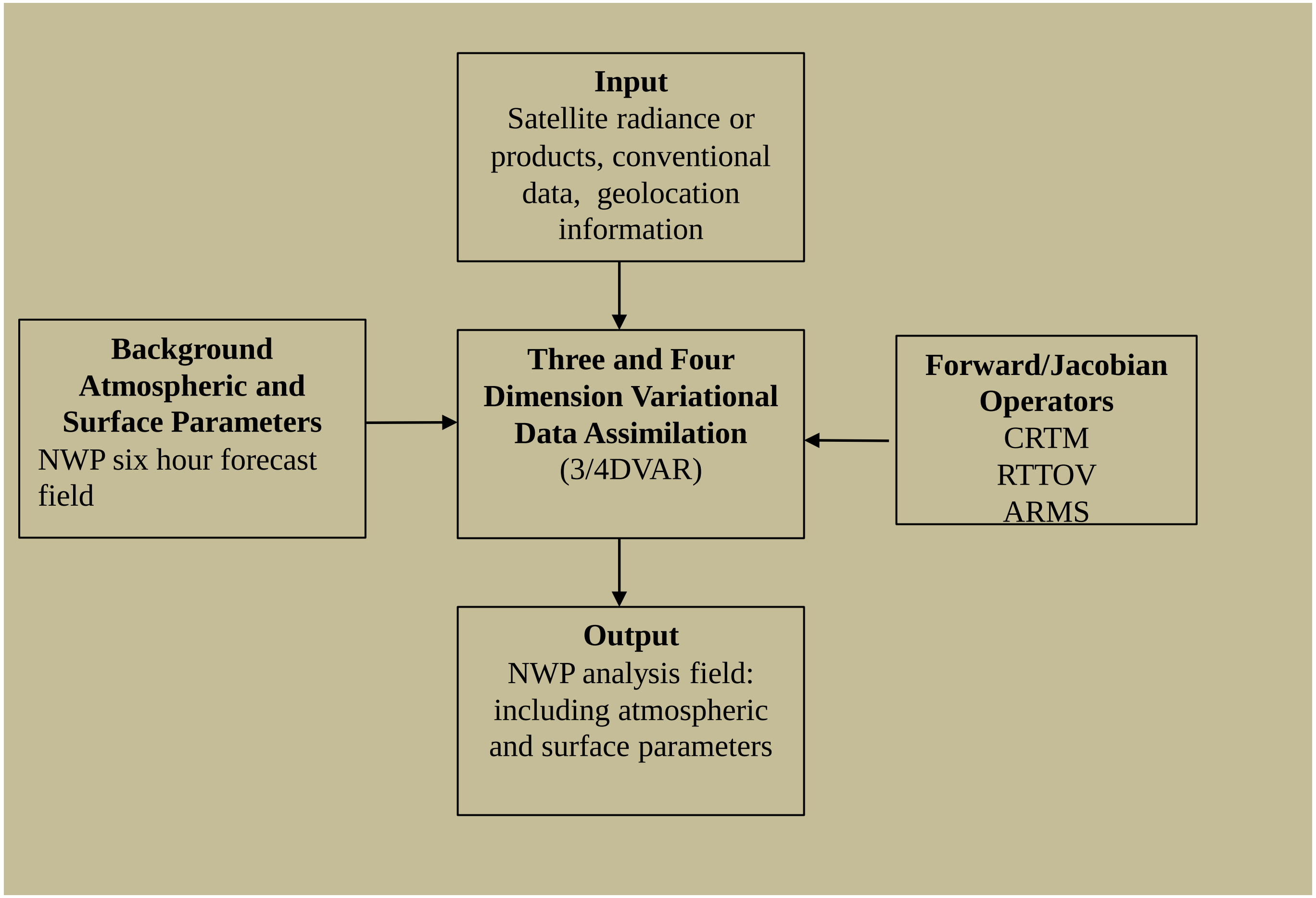
	ATMS	AMSU/MHS
23/31 GHz	5.2	3.3
50-60 GHz	2.2	3.3
89-GHz	2.2	1.1
160-183 GHz	1.1	1.1

Spatial sampling

	ATMS	AMSU/MHS
23/31 GHz	1.11	3.33
50-60 GHz	1.11	3.33
89-GHz	1.11	1.11
160-183 GHz	1.11	1.11
Swath (km)	~2600	~2200

ATMS scan period: 8/3 sec; AMSU-A scan period: 8 sec

Satellite Data Assimilation System



- Demonstrate the impacts of new observations on forecasts
- Understand future observations on forecast

Parameters Affecting Satellite Data Assimilation

A process of incorporating all observations into weather forecast models to produce the "*best*" description of the atmospheric state at a desired resolution. Physical understanding of observations and weather structures and applicable mathematical optimal control and statistical estimate theories that match computer capabilities and are important for any success of satellite data assimilation.

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x} - \mathbf{x}_b)^T \mathbf{B}^{-1}(\mathbf{x} - \mathbf{x}_b) + \frac{1}{2}(H(\mathbf{x}) - \mathbf{y}^{obs})^T (\mathbf{O}+\mathbf{F})^{-1}(H(\mathbf{x}) - \mathbf{y}^{obs})$$

$$J(\mathbf{x}_a) = \min_{\mathbf{x}} J(\mathbf{x}) \quad " \ \mathbf{x} \text{ near } \mathbf{x}_b$$

- $\mathbf{x}$ - analysis variable
- $\mathbf{x}_a$ - final analysis
- $\mathbf{x}_b$ - background
- $\mathbf{B}$ - background error covariance
- $\mathbf{y}^{obs}$ - observations
- $\mathbf{O}$ - observation error covariance
- H - observation operator
- $\mathbf{F}$ - forward model error covariance

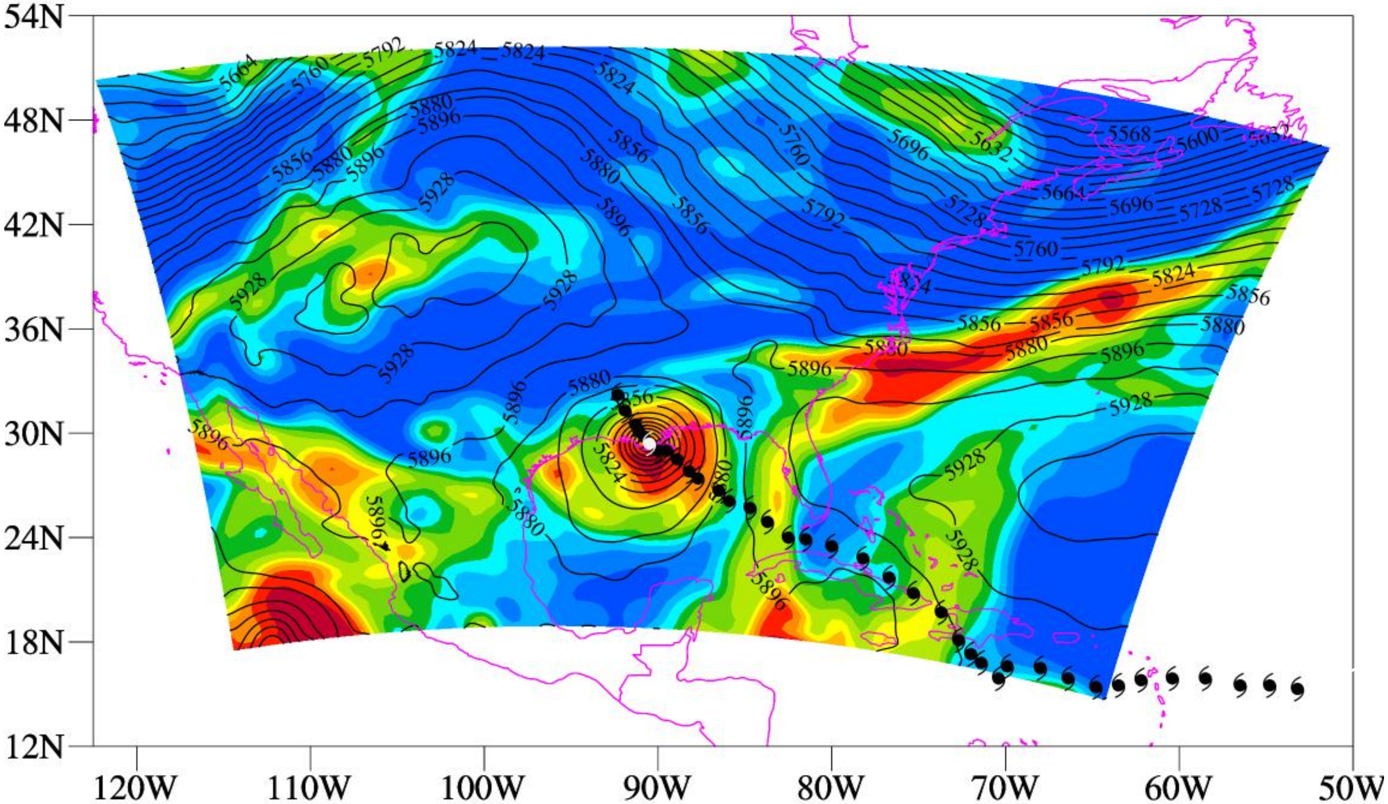
The success of satellite DA of any instruments requires the science of satellite data and NWP be effectively integrated together into a DA system and the results from the DA system be carefully analyzed and interpreted.

AMSU/MHS Single Data Assimilation Experiments

DA system: NCEP GSI analysis system
Observation: Conventional data, AMSU-A and MHS
(NOAA-18, -19, MetOp-A)
DA cycling: 12 hours at a 6-h interval
Experiment: CTRL — AMSU-A and MHS as two data streams (CTRL)
ODS — AMSU-A and MHS as one data stream (ODS)

Model: Advanced Research WRF (ARW)
Resolution: 10 km, 27 levels, model top at ~50 hPa
Microphysics: WRF single-moment 3-class scheme
PBL: Yonsei University scheme
Cumulus: Kain-Fritsch scheme
Radiation: Dudhia scheme

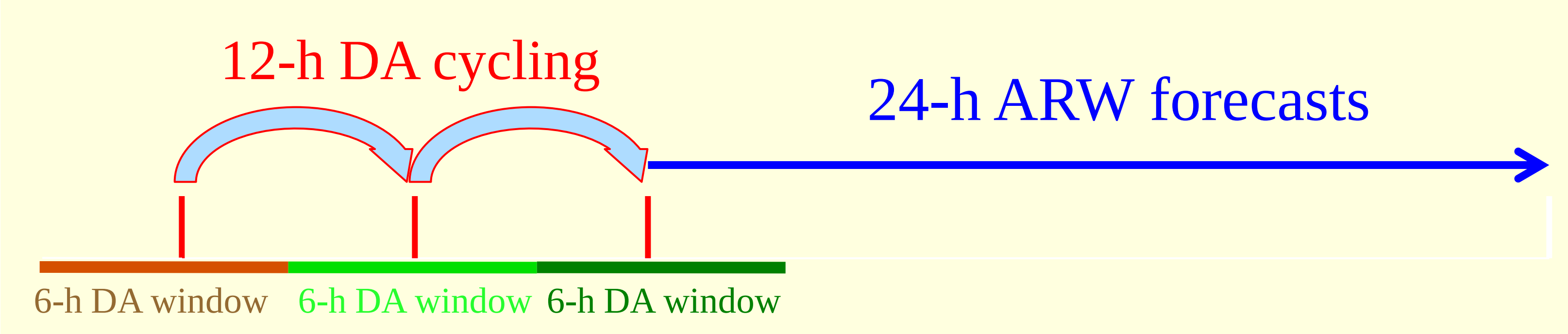
Model Domain and DA Cycling



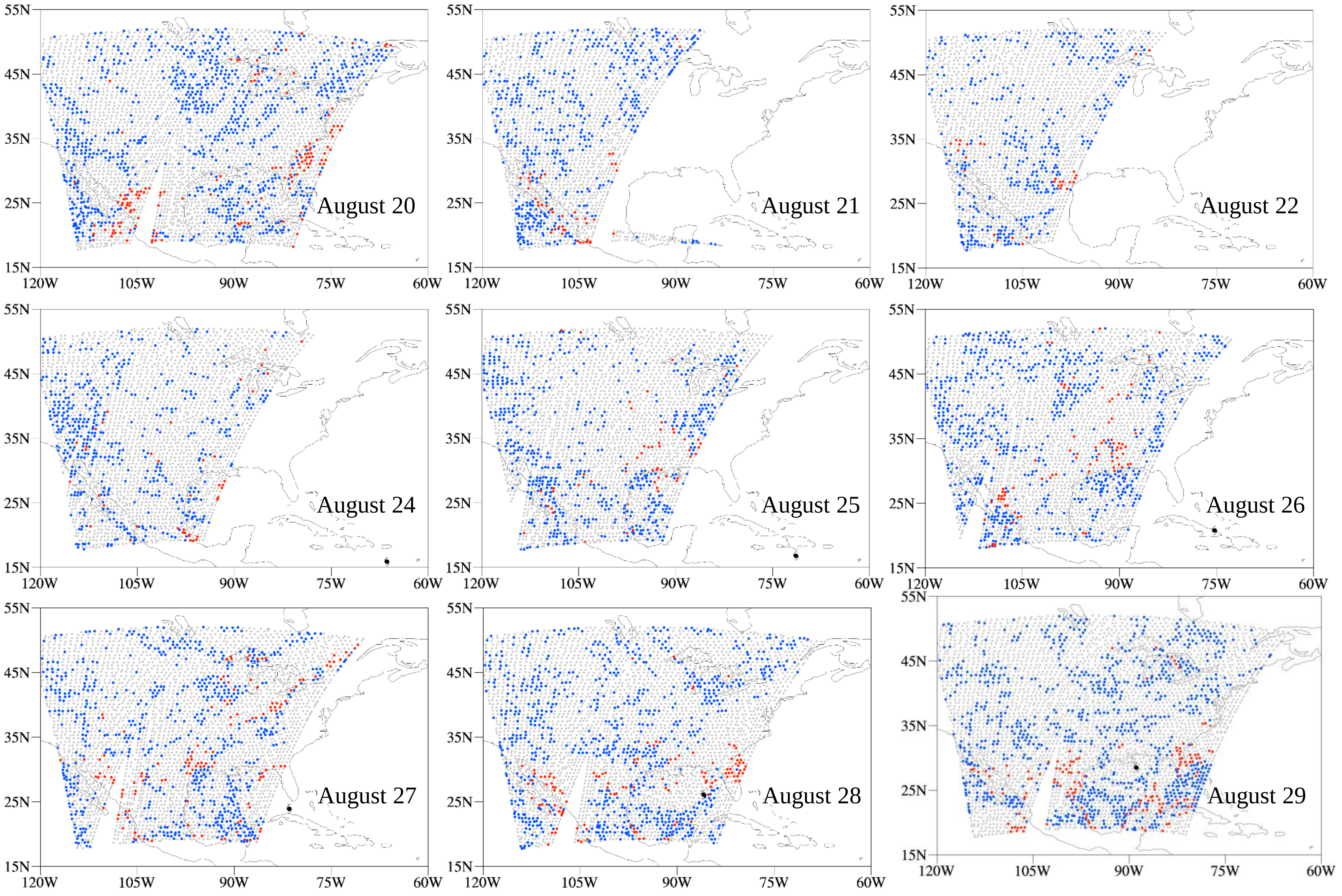
Isaac (2012)

500 hPa
Geopotential
relative humidity
1200 UTC
29/08/12

1800 UTC 20 August to 1800 UTC 31 August

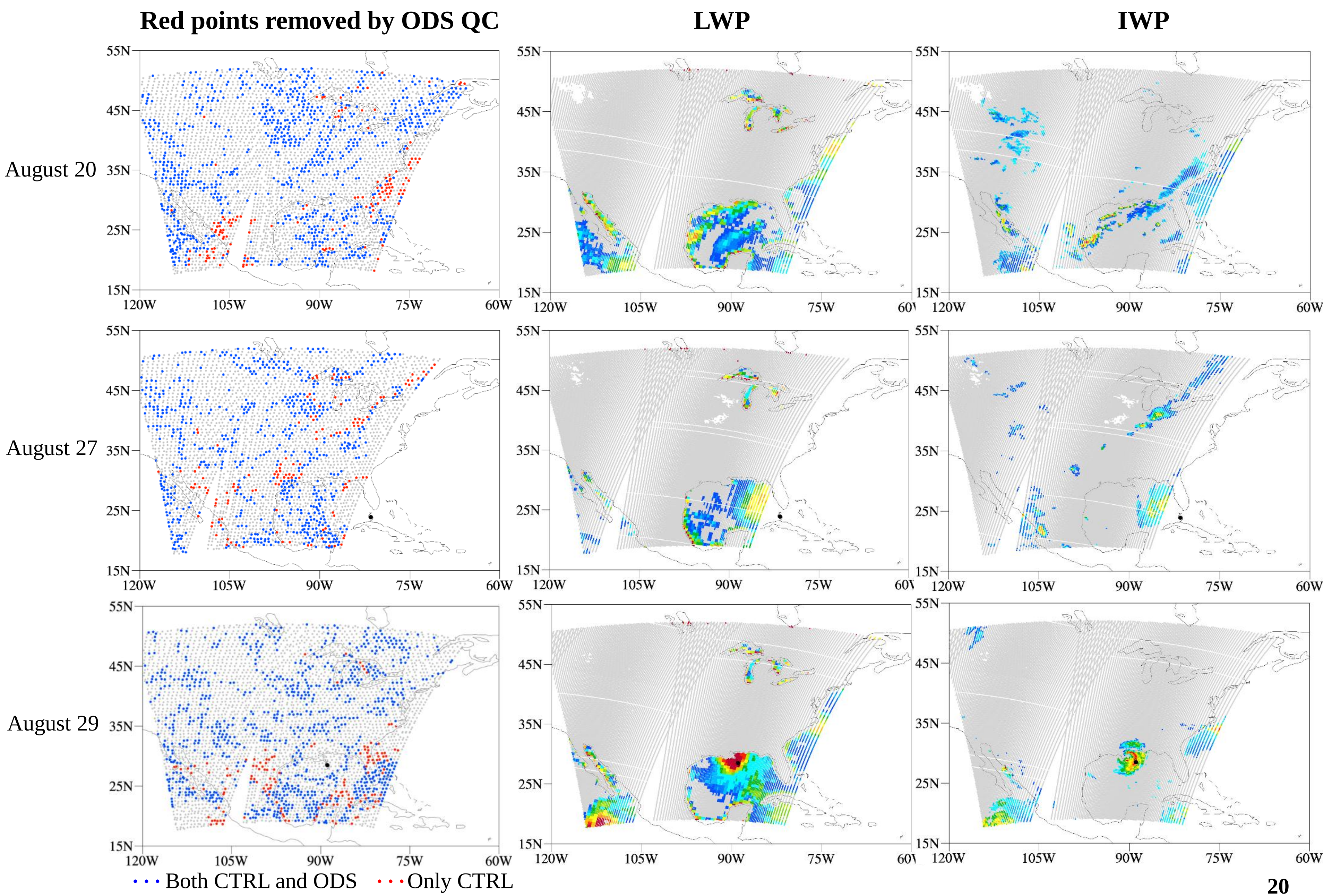


MHS Data Assimilated at 1200 UTC August 20-29, 2012



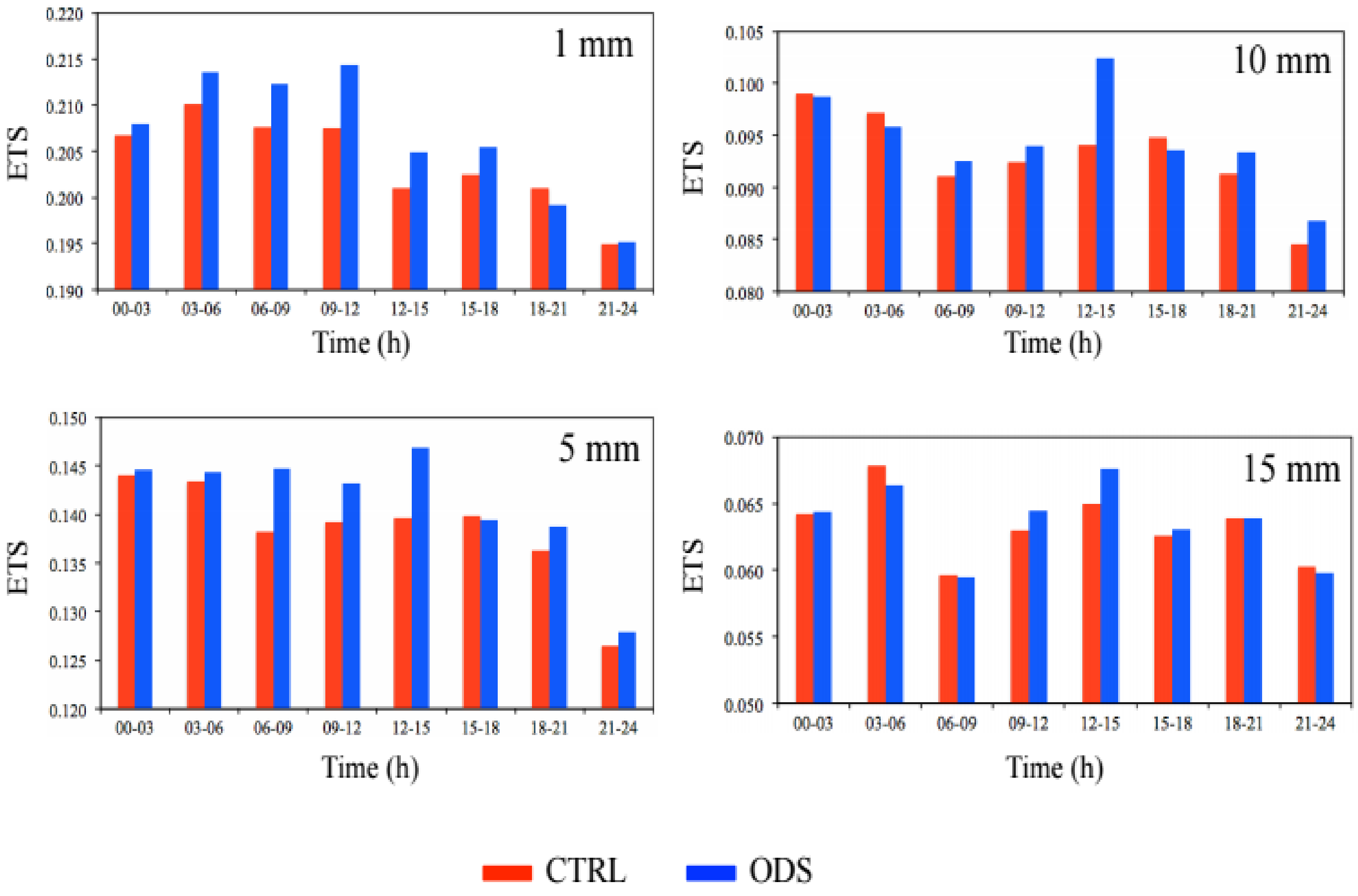
• • • • • • Both CTRL and ODS • • • • • • Only CTRL

MHS Data Removed in the ODS Experiment



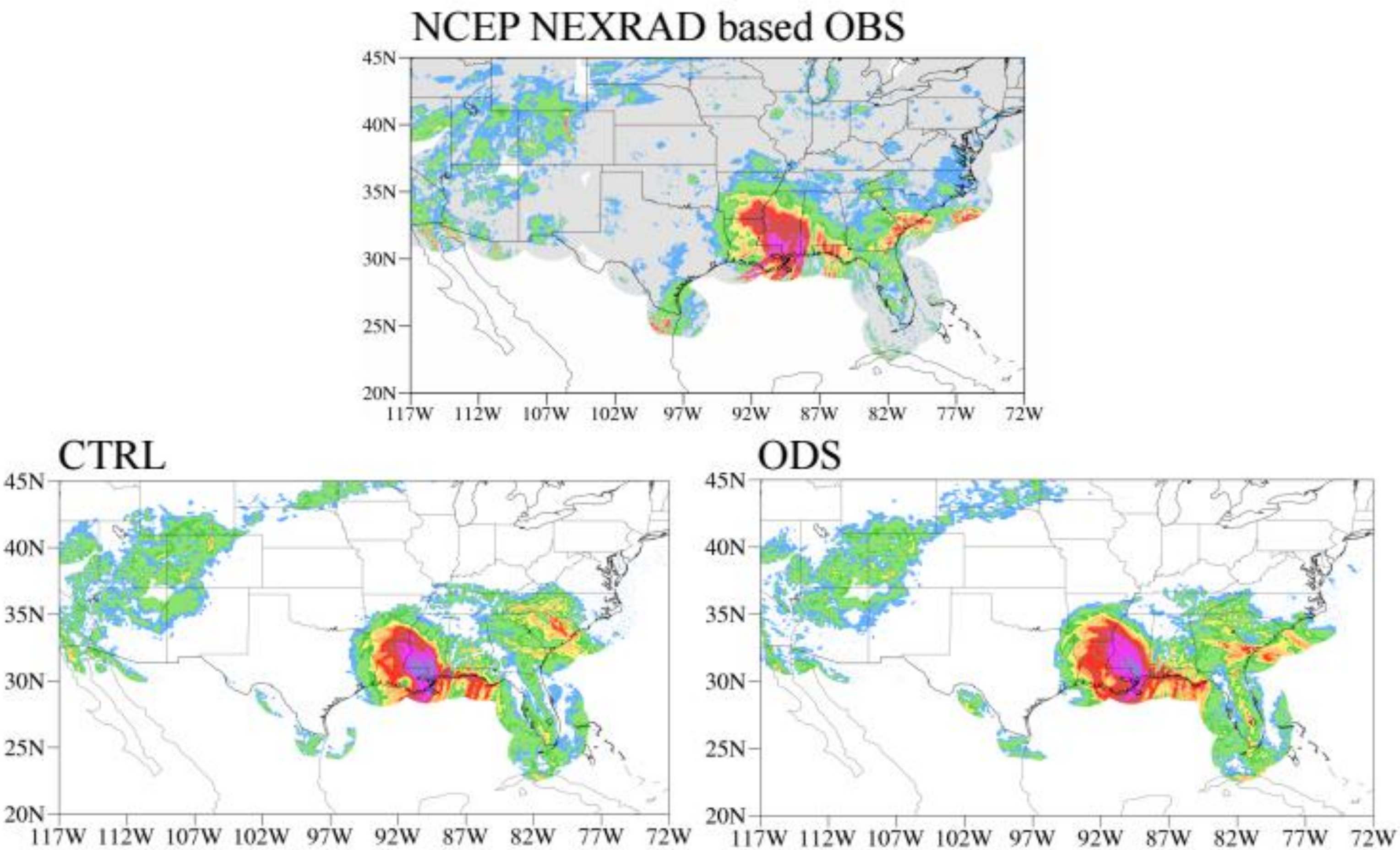
Impacts of One Data Stream (AMSU-A+MHS) on Coastal QPF

Statistical Performance of QPFs Averaged over 40 Forecasts



Impacts of One Data Stream (AMSU-A+MHS) on Coastal QPF

24-h Accumulative Rainfall on August 2012

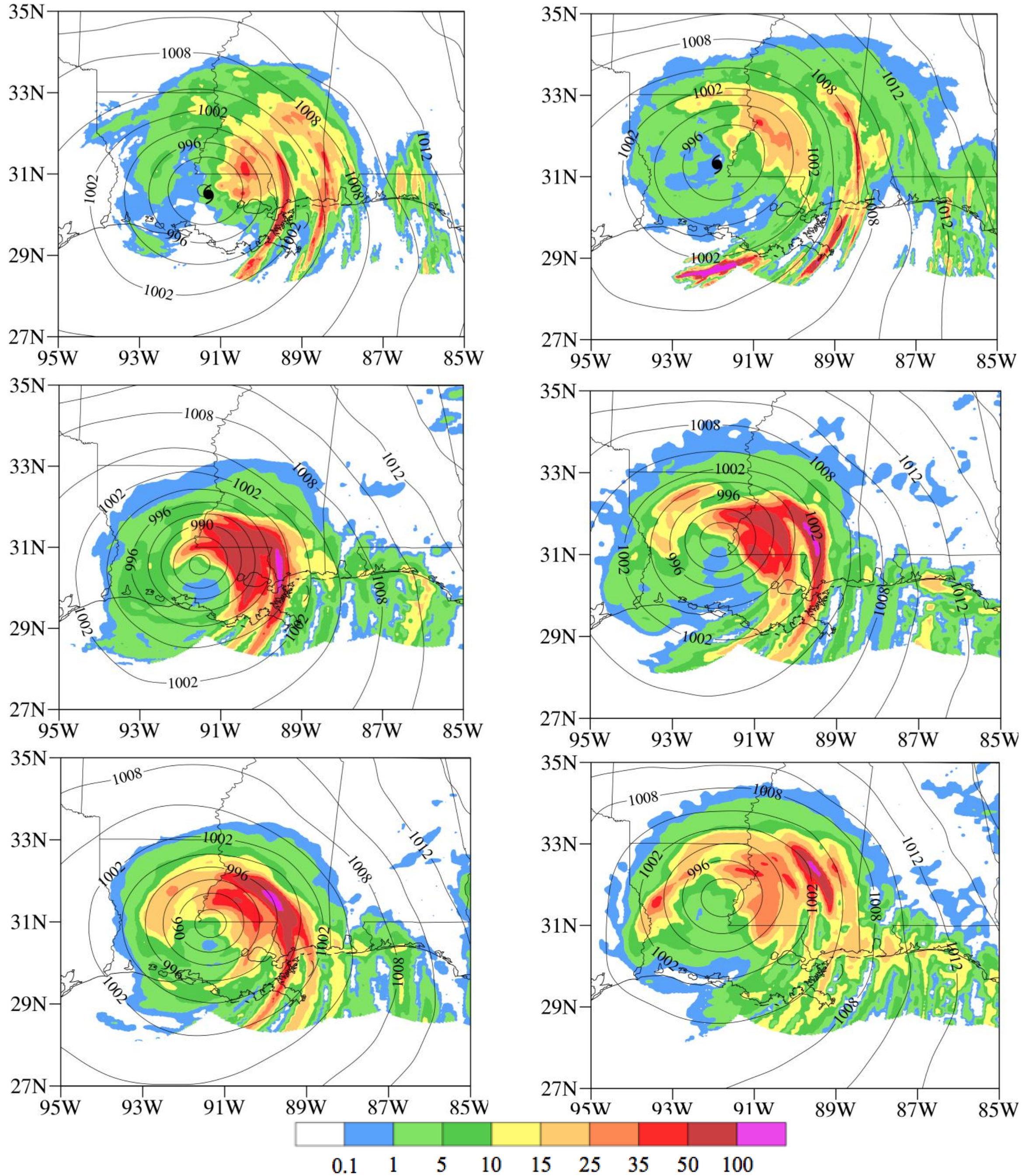


Hurricane Rainbands

August 30, 2012

0600-0900 UTC

1200-1500 UTC

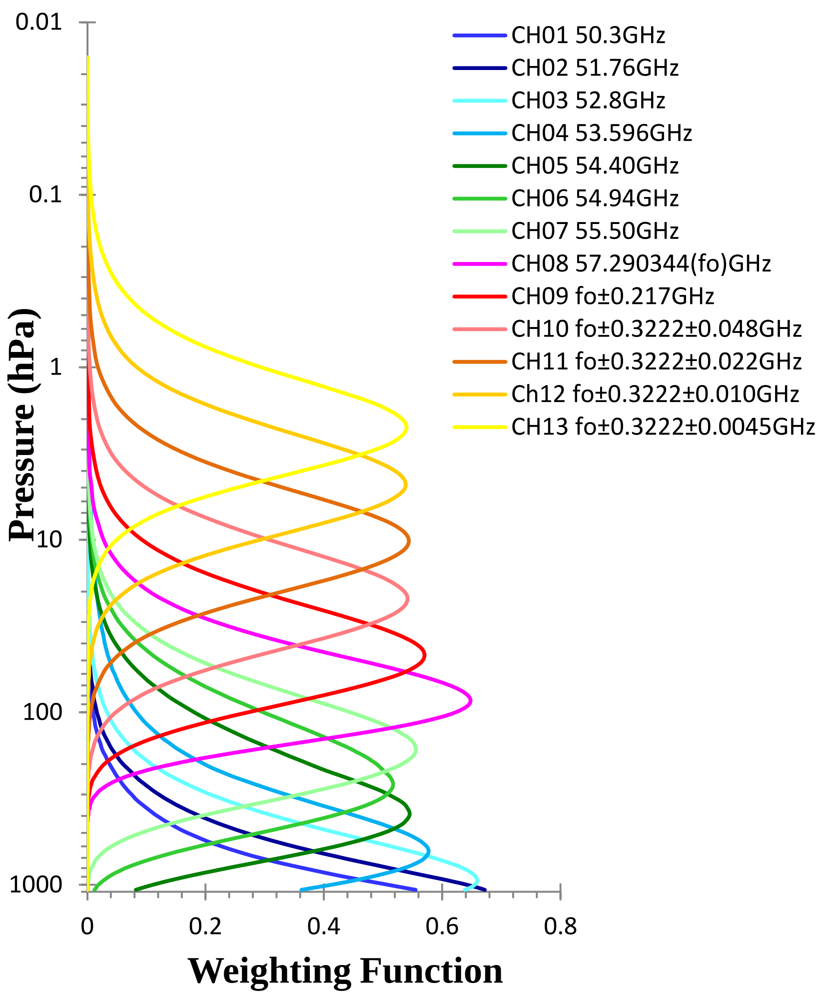


OBS

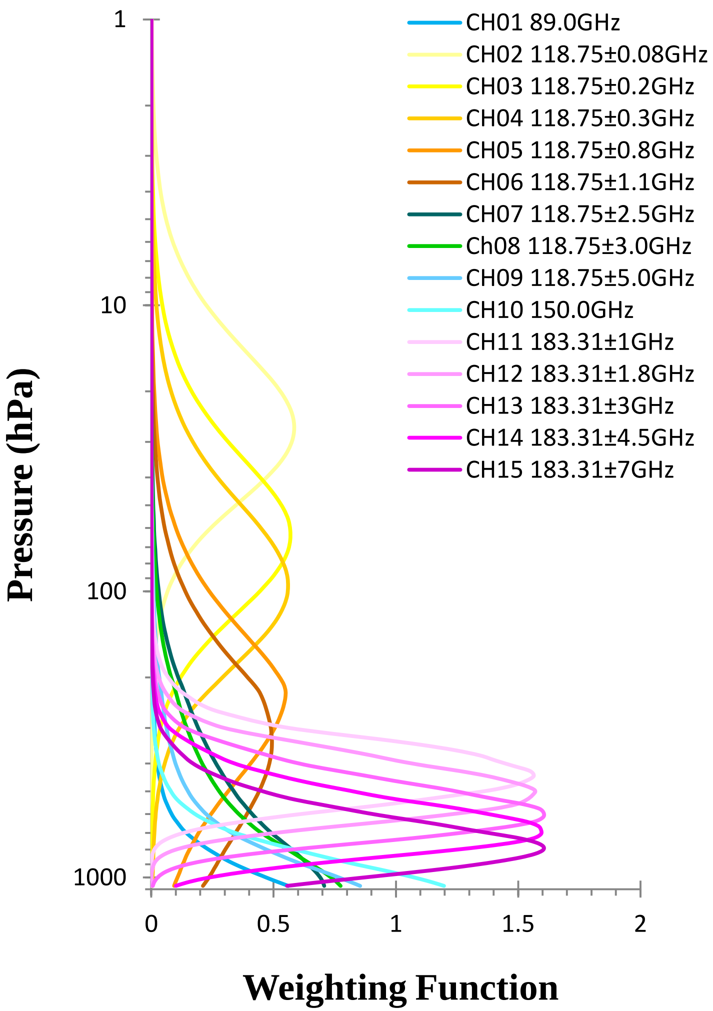
CTRL

ODS

FY-3D Microwave Sounder Weighting Functions



MWTS



MWHS

Lessons Learned from Uses of Existing Microwave Sounder Data

- It is difficult to perform a quality control of MHS data if the MHS is a separate data stream

- ATMS data structure is designed very well and contains all temperature and water vapor channels into one data stream

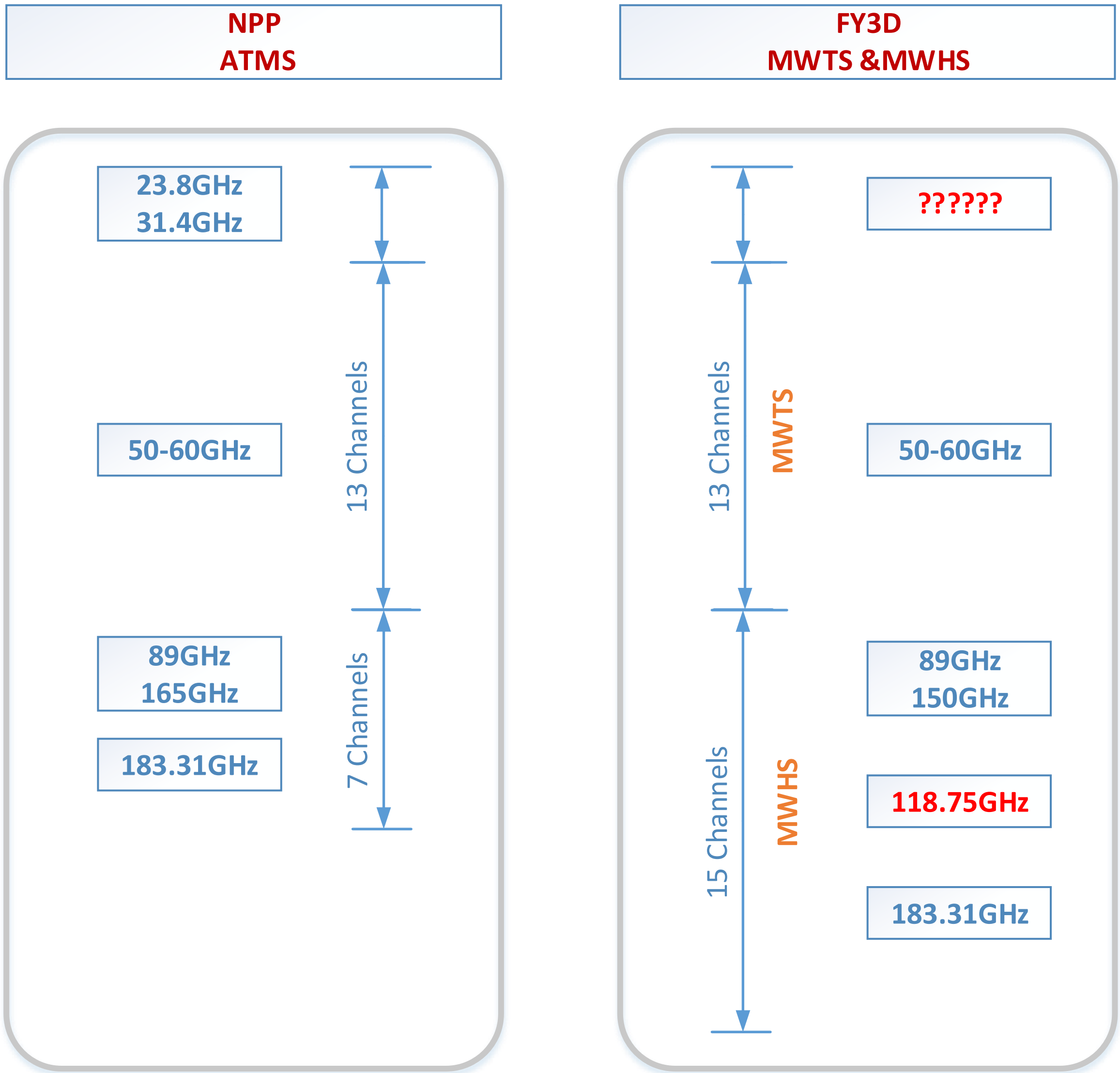
- It is recommended that AMSU-A and MHS be combined into one data stream and MWTS and MWHS be also combined into a single data stream

- While MWTS and MWHS can be foot-print matched, we still expect the information at 23.8 and 31.4 GHz similar to ATMS and AMSU so that we can use similar techniques developed in the past for quality control.

Solution to FY-3D Quality Control in NWP

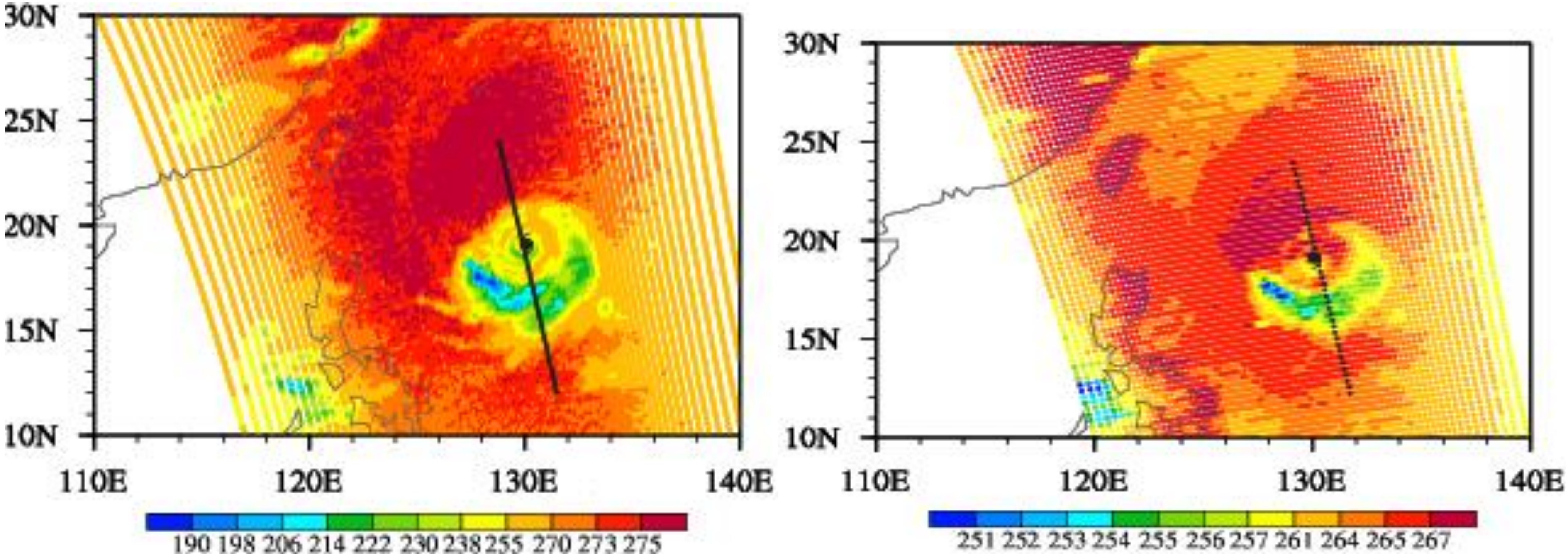
- Combine MWTS and MWHS into a single data stream. The new data stream is referred as combined microwave sounder (CMWS) data
- Generate proxy brightness temperatures at 23.8 and 31.4 GHz from other channels through AI trained model
- ATMS 22 channels are used to train the model using random forest machine learning algorithm
- One caveat: the synthetic brightness temperatures at 23.8 and 31.4 GHz are affected by the quality of rest of MWTS and MWHS sounding channels. They are not independent measurements of atmosphere and surface.

Synthetic MWTS Radiances at 23.8 and 31.4 GHz through Machine-Learning



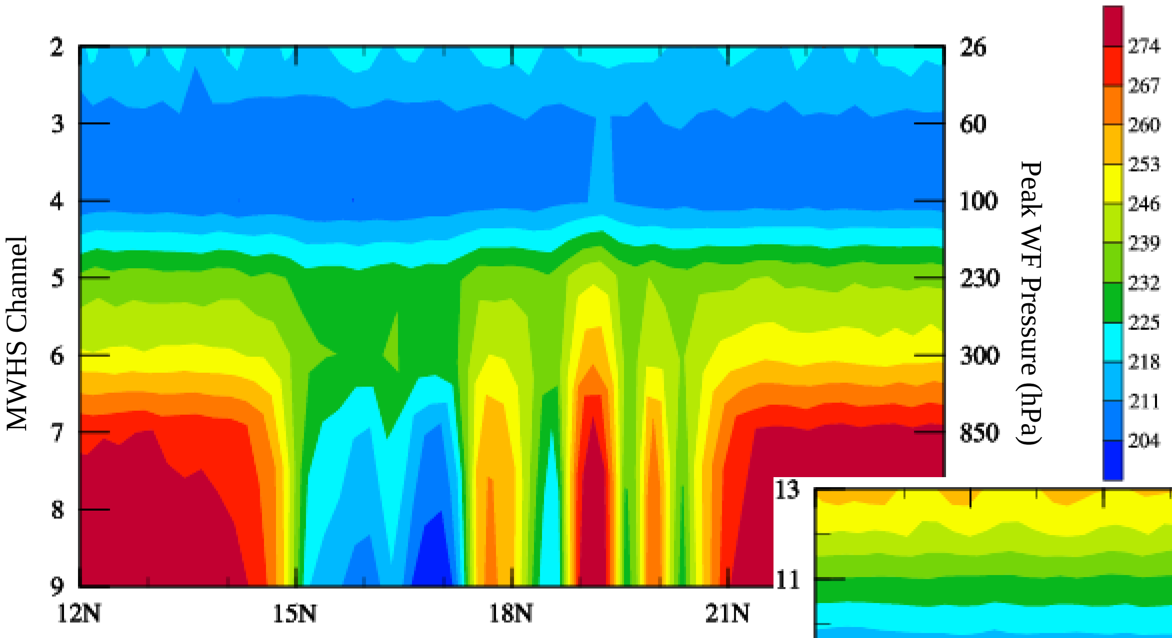
MWHS CH7(118.75±2.5GHz) VS MWTS CH3(52.8GHz) (940 hPa)

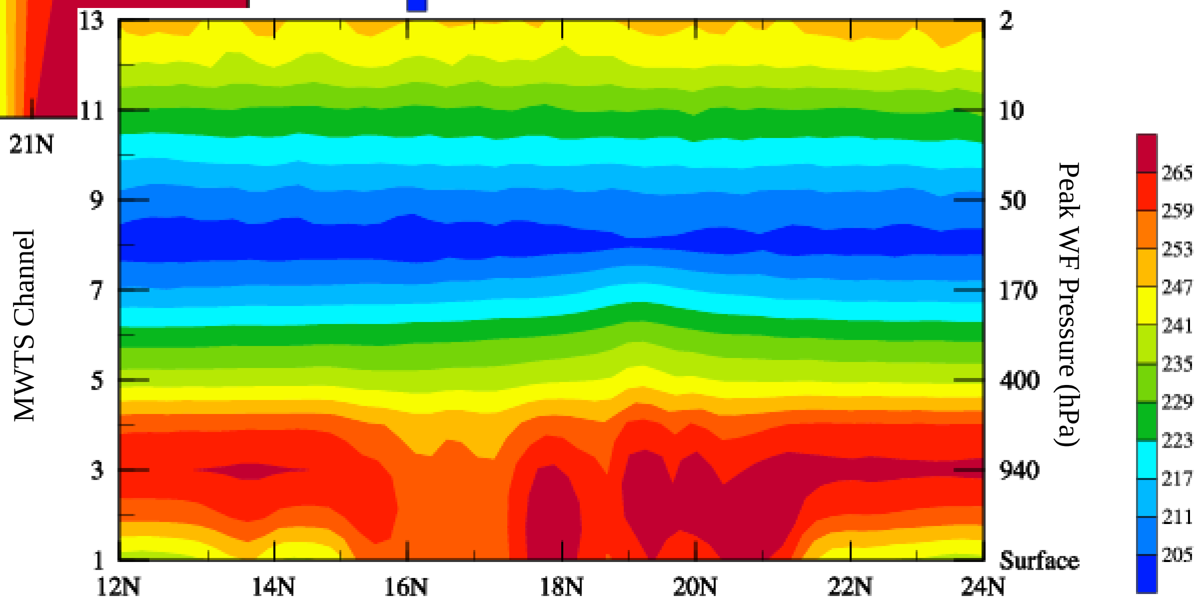
Super Typhoon Neoguri, 1236 UTC July 6, 2014



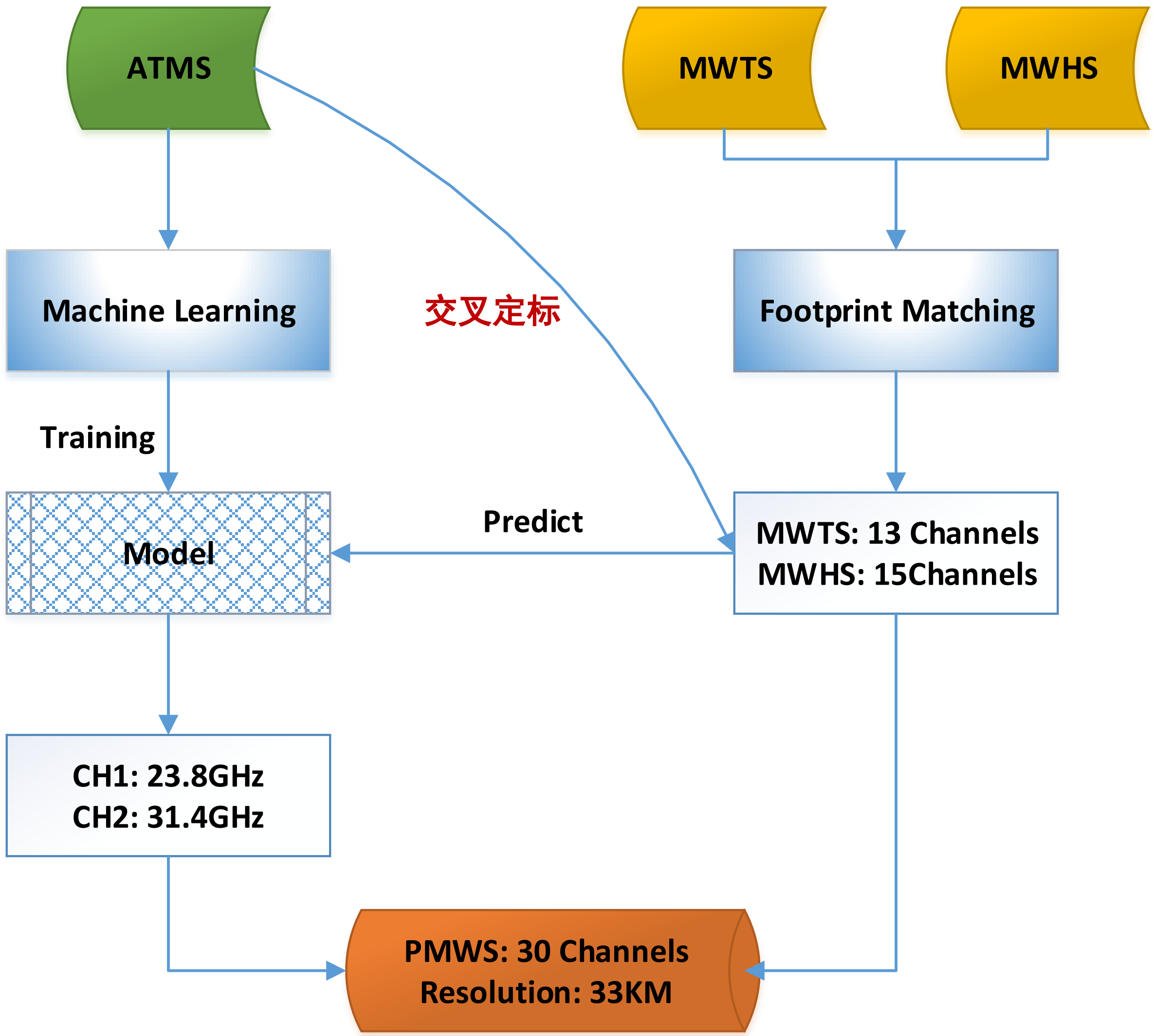
FY-3C MWHS (left panel) and MWTS (right panel) observations with weighting function peak at 940 hPa.

Super Typhoon Neoguri Structures Observed from MWTS and MWHS (July 6, 2014)



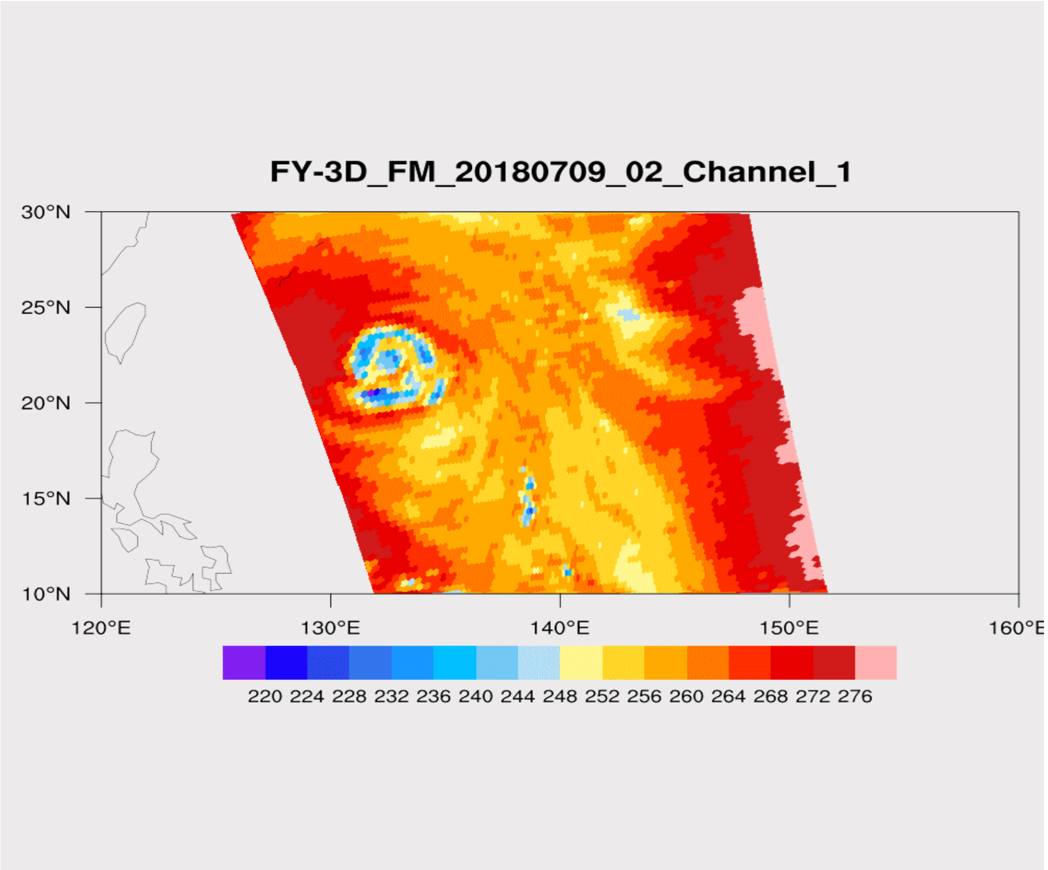


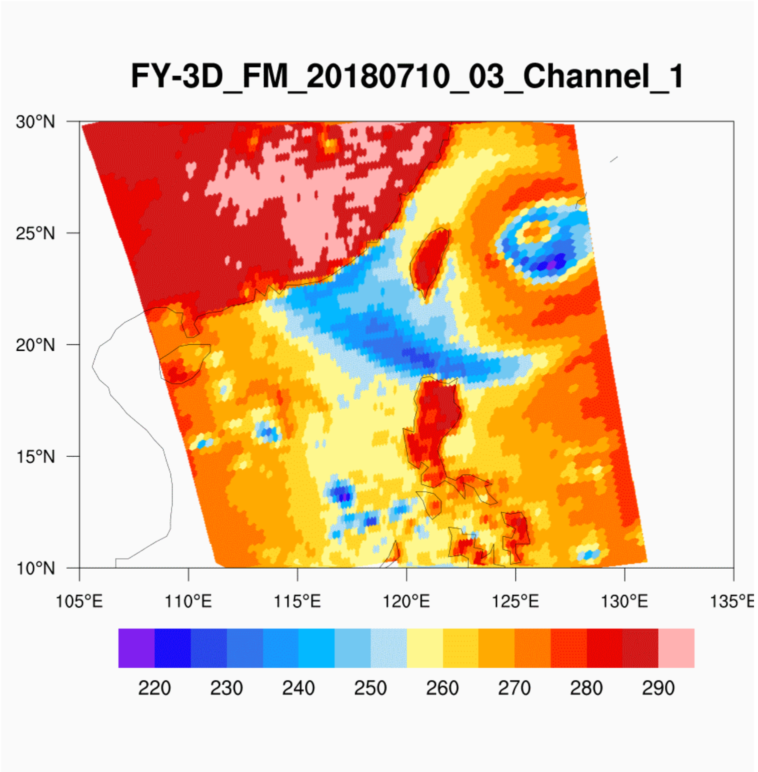
Synthetic Process of FY-3D Brightness Temperatures at 23.8 and 31.4 GHz using Machine-Learning Process



CMWS: Combined Microwave Sounder

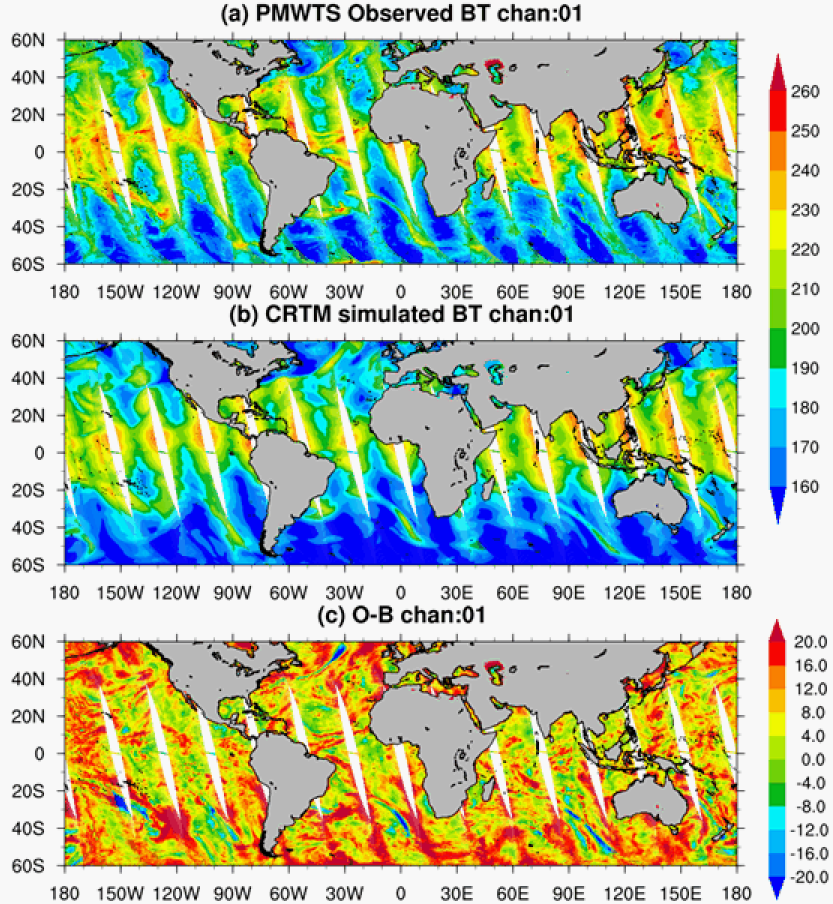
MWTS and MWTS Footprint Matching

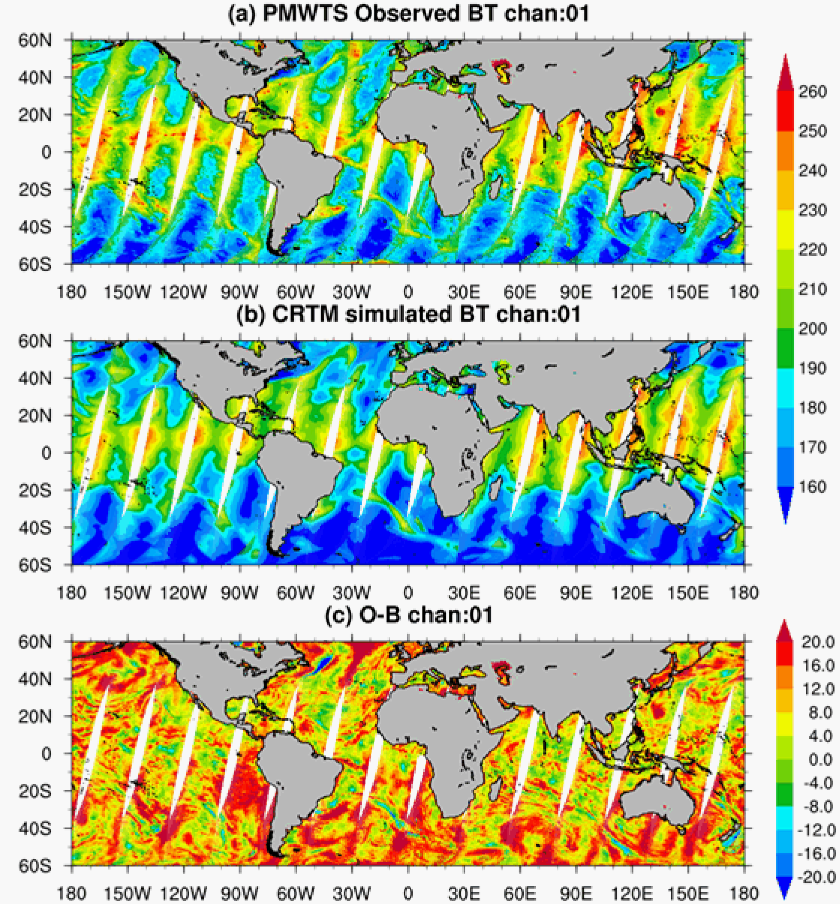




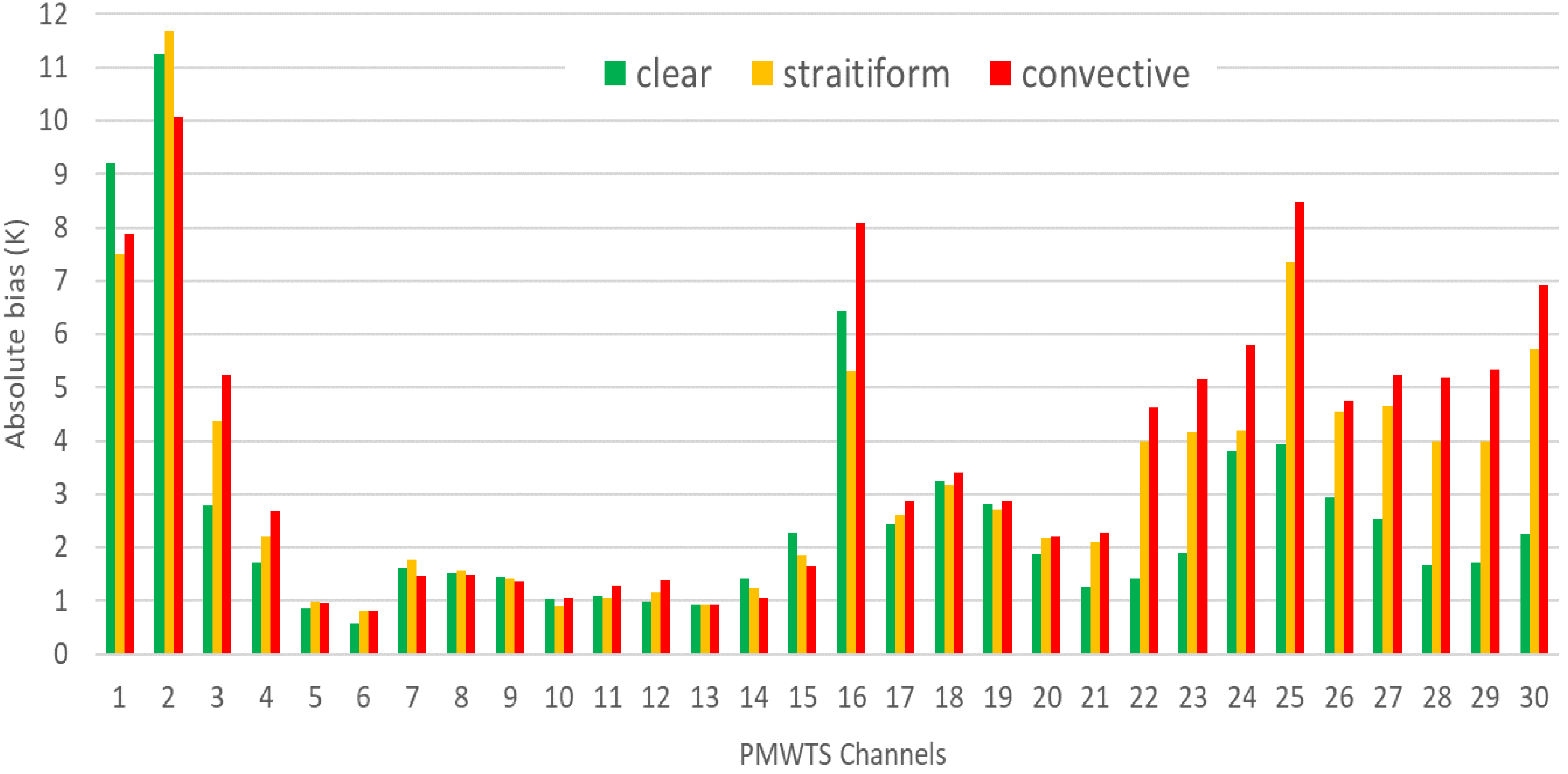
A new data stream is formed as CMWS with a resolution of 33 km, a total of 28 channels

Assessments of FY-3D MWTS and MWHS (O-B) Data Quality



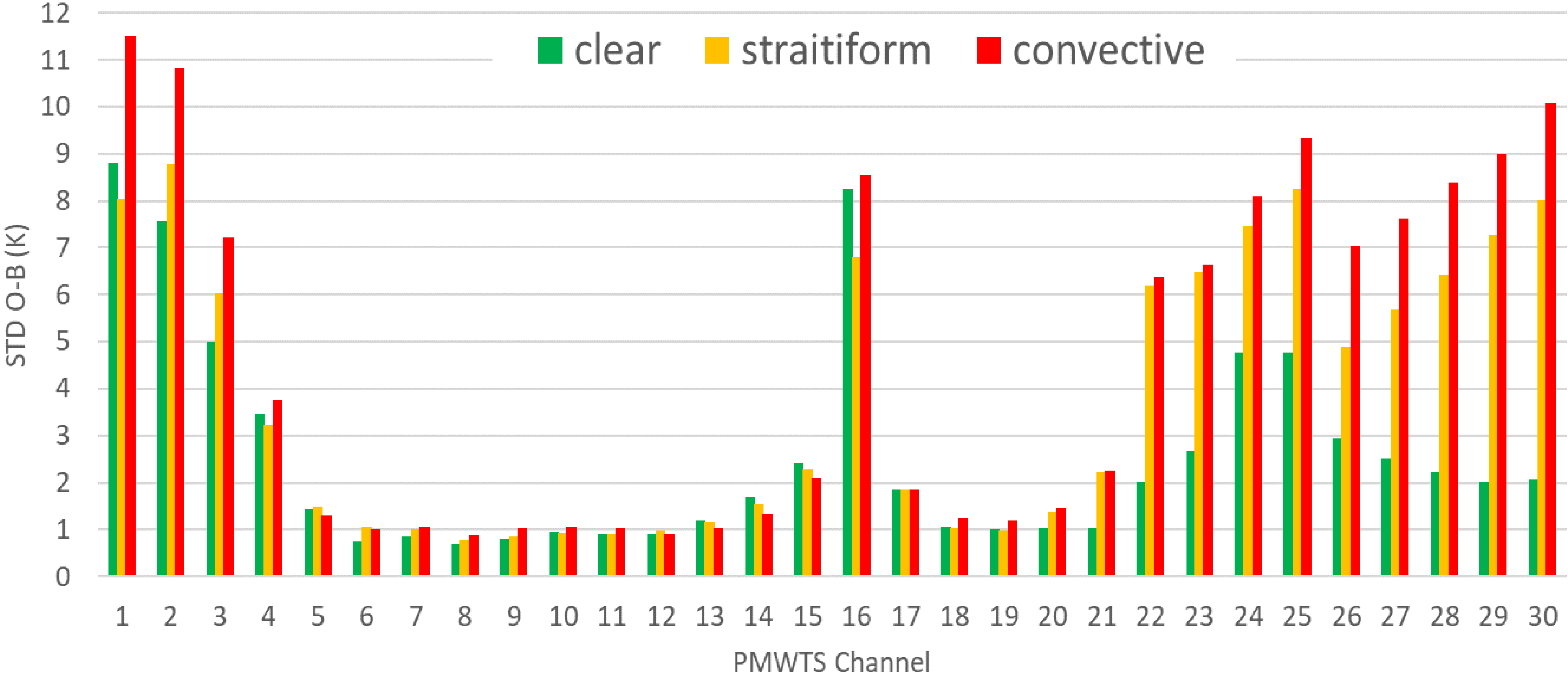


Mean O-B (30S-30N)



Note: Extremely large bias FOVs (O-B>50K) have been eliminated. The classification of the cloud type is based on the cloud liquid water path and cloud ice water path in ERA_Interim dataset.

Standard Deviation of O-B within Latitudes of 30S-30N



classification of the cloud type is based on the cloud liquid water path and cloud ice water path in ERA_Interim dataset.

Correction for Cross-Scan Asymmetry

- Following Weng et al. (2003), the bias Tb (O-B) are fitted with the equation:

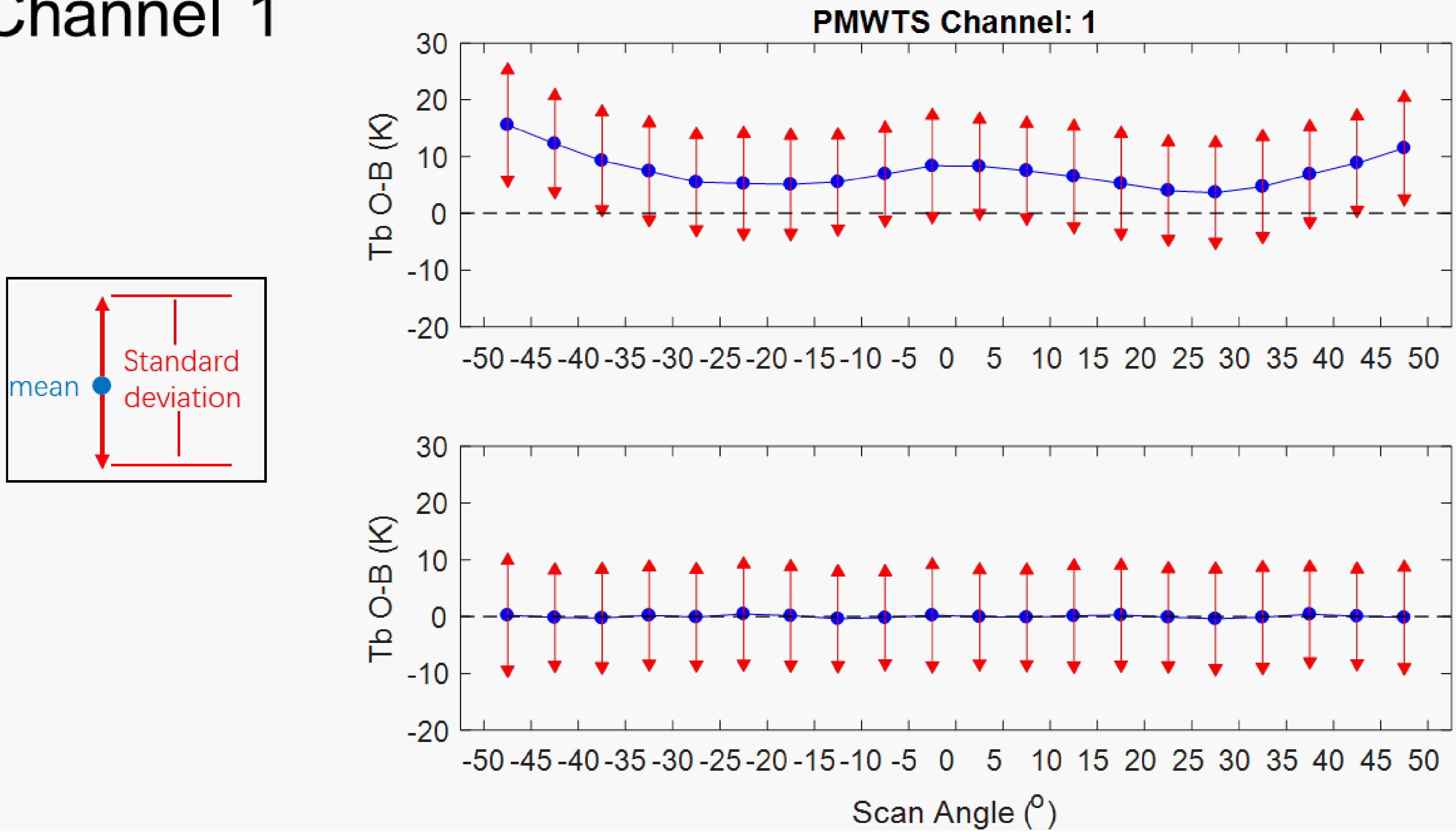
$$\Delta T_b = A_0 exp\left\{-\frac{1}{2}[(\theta_s - A_1)/A_2]^2\right\} + A_3 + A_4\theta_s + A_5{\theta_s}^2,$$

Where T_b is the observed brightness temperature and θ_s is the zenith angle. The coefficient A_{0-5} are fitted using ΔT_b and θ_s on Jul-08, 2018 under clear sky condition ($clwp_{era}$<0.01 and $ciwp_{era}$<0.01) over ocean.

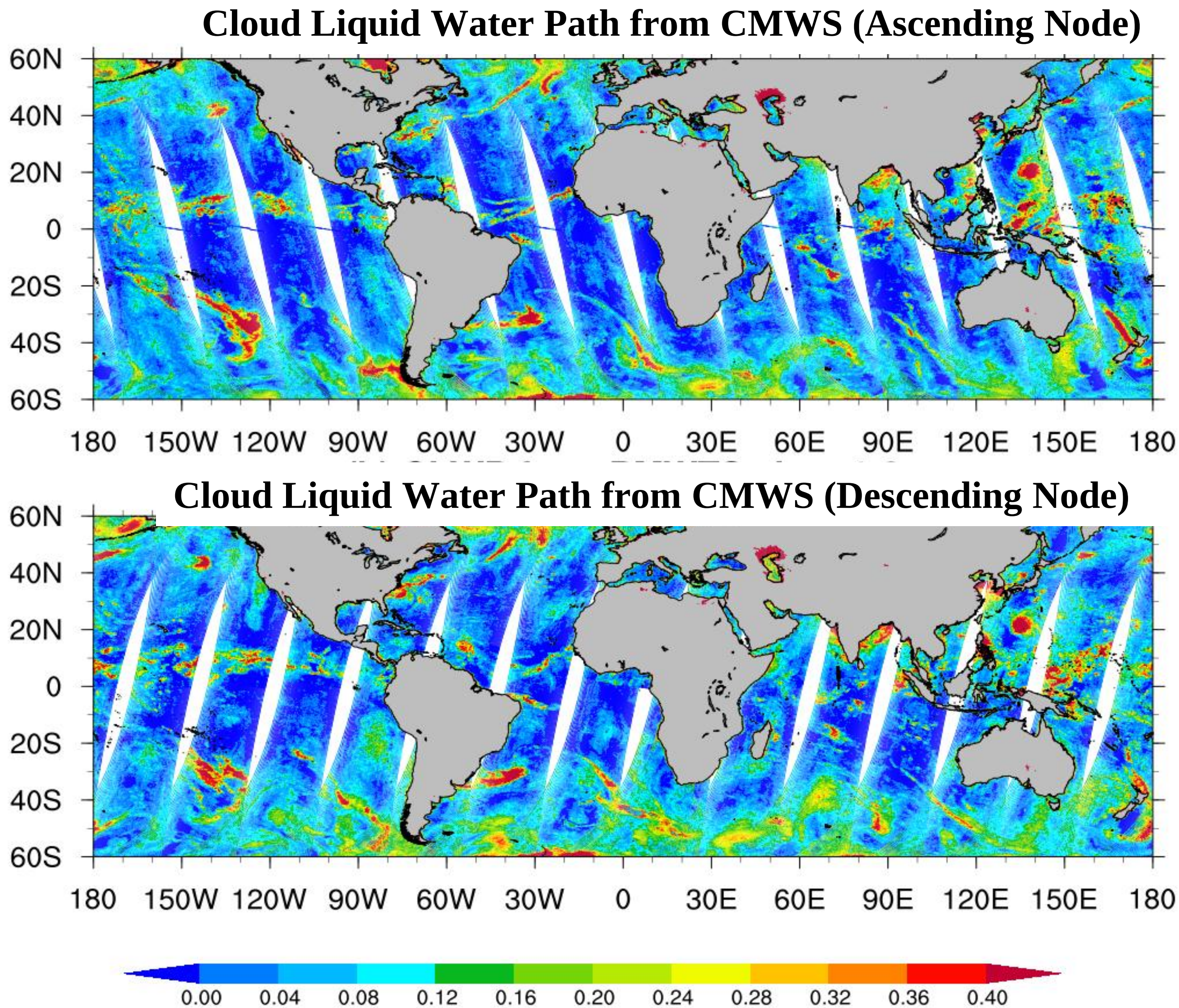
- After that, the asymmetry corrected TB is defined as Tb - ΔT_b.

Correction for Cross-Scan Asymmetry

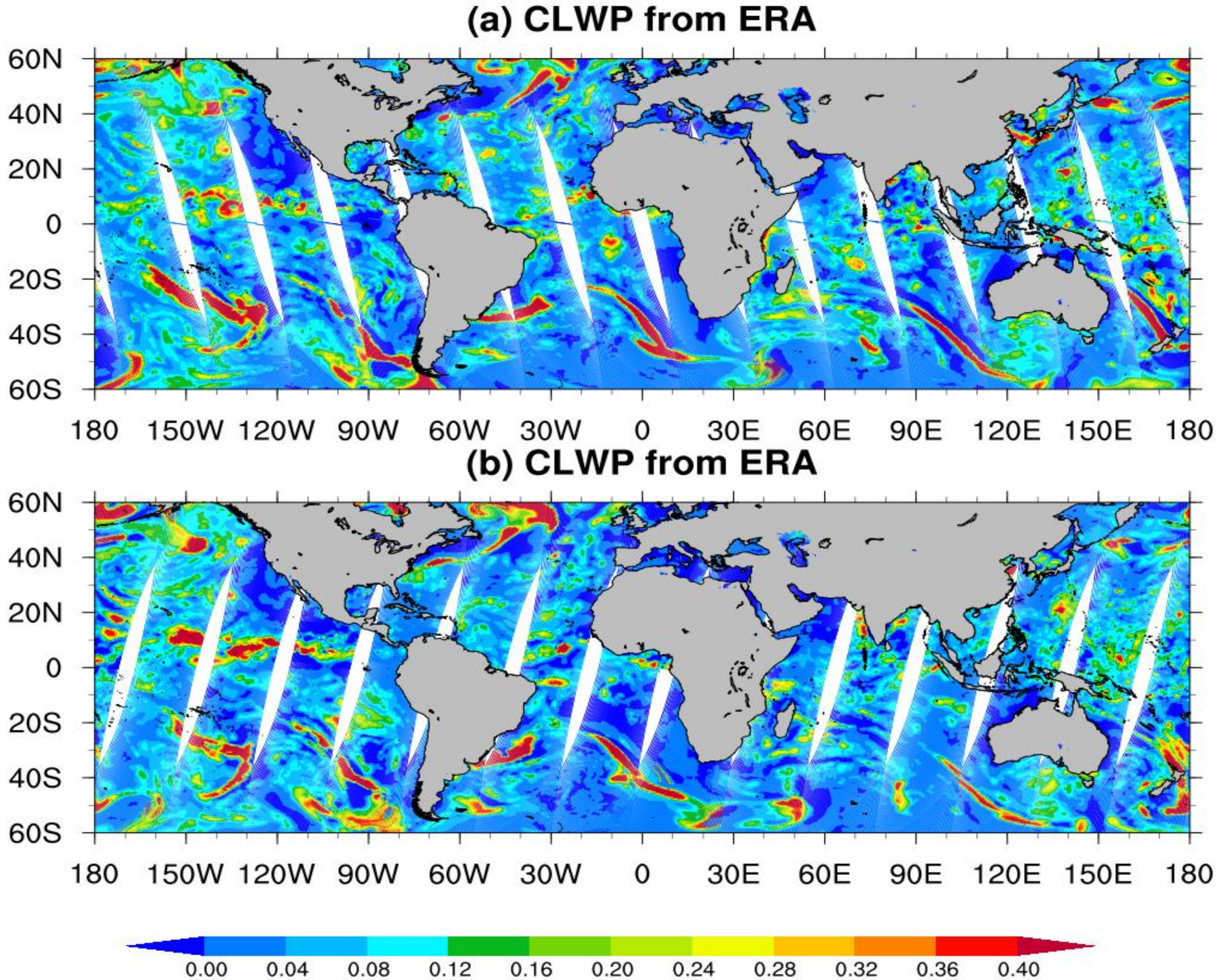
Channel 1

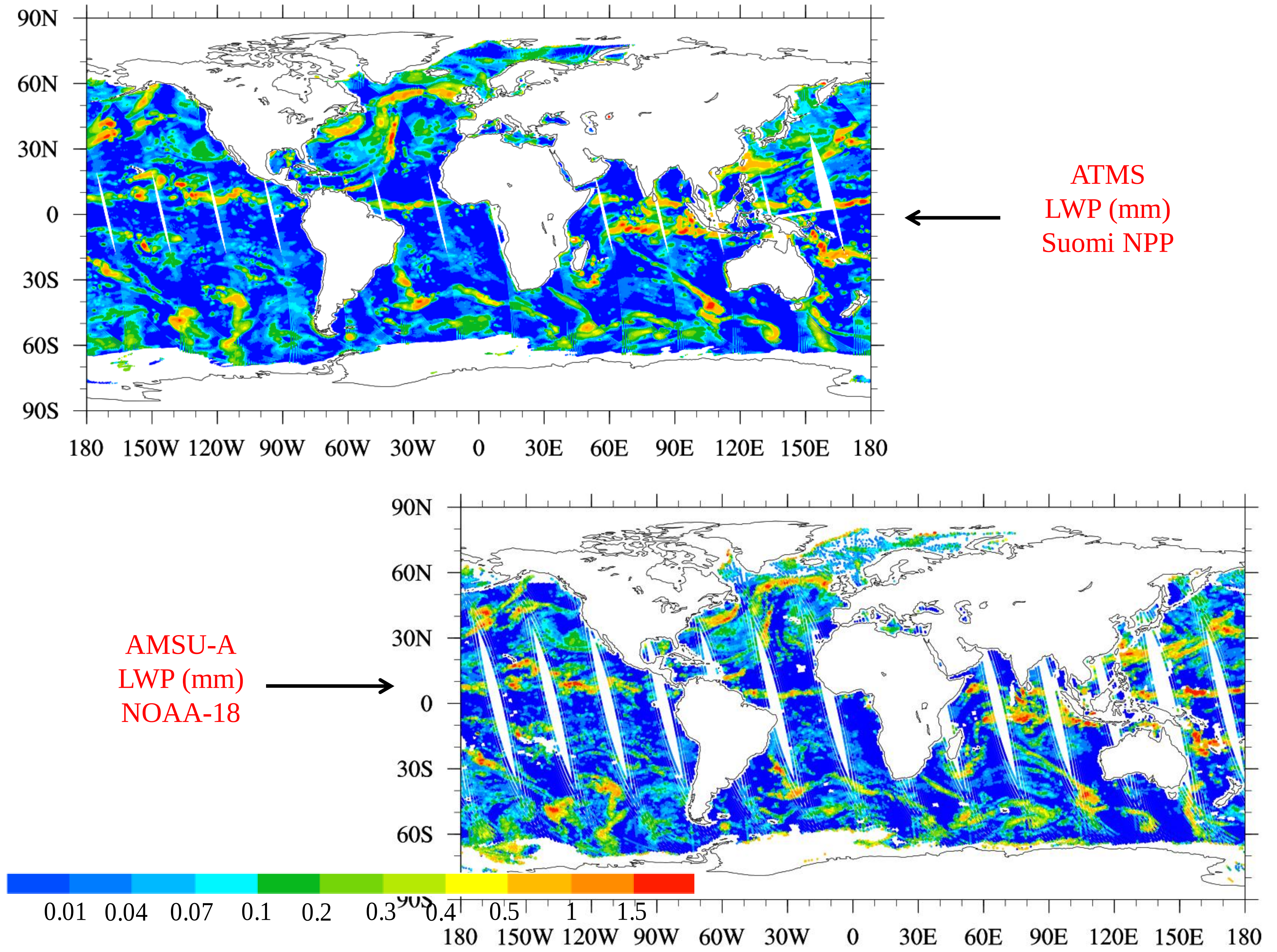


FY-3D Cloud Liquid Water Path from Combined MWTS and MWHS, aka, “CMWS”



FY-3D CLWP from ECWMF Analysis





90N
60N
30N
0
30S
60S
90S
180
150W
120W
90W
60W
30W
0
30E
60E
90E
120E
150E
180
ATMS
LWP (mm)
Suomi NPP
AMSU-A
LWP (mm)
NOAA-18
0.01
0.04
0.07
0.1
0.2
0.3
0.4
0.5
1
1.5

FY3D MWTS Data Collocation with FY3C GNOS

- **Time period of data search:**

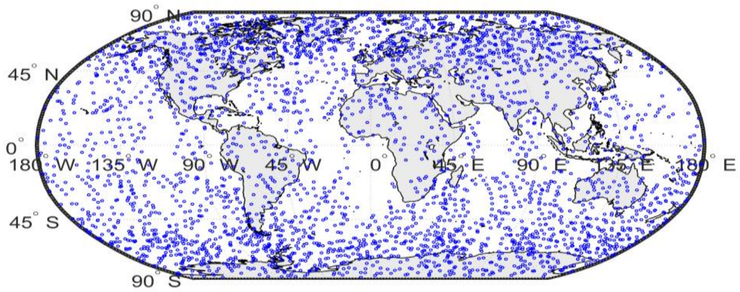
  2018. 06.27 - 07.16

- **MWTS collocation with GNOS data:**

  Time difference < 3 hour

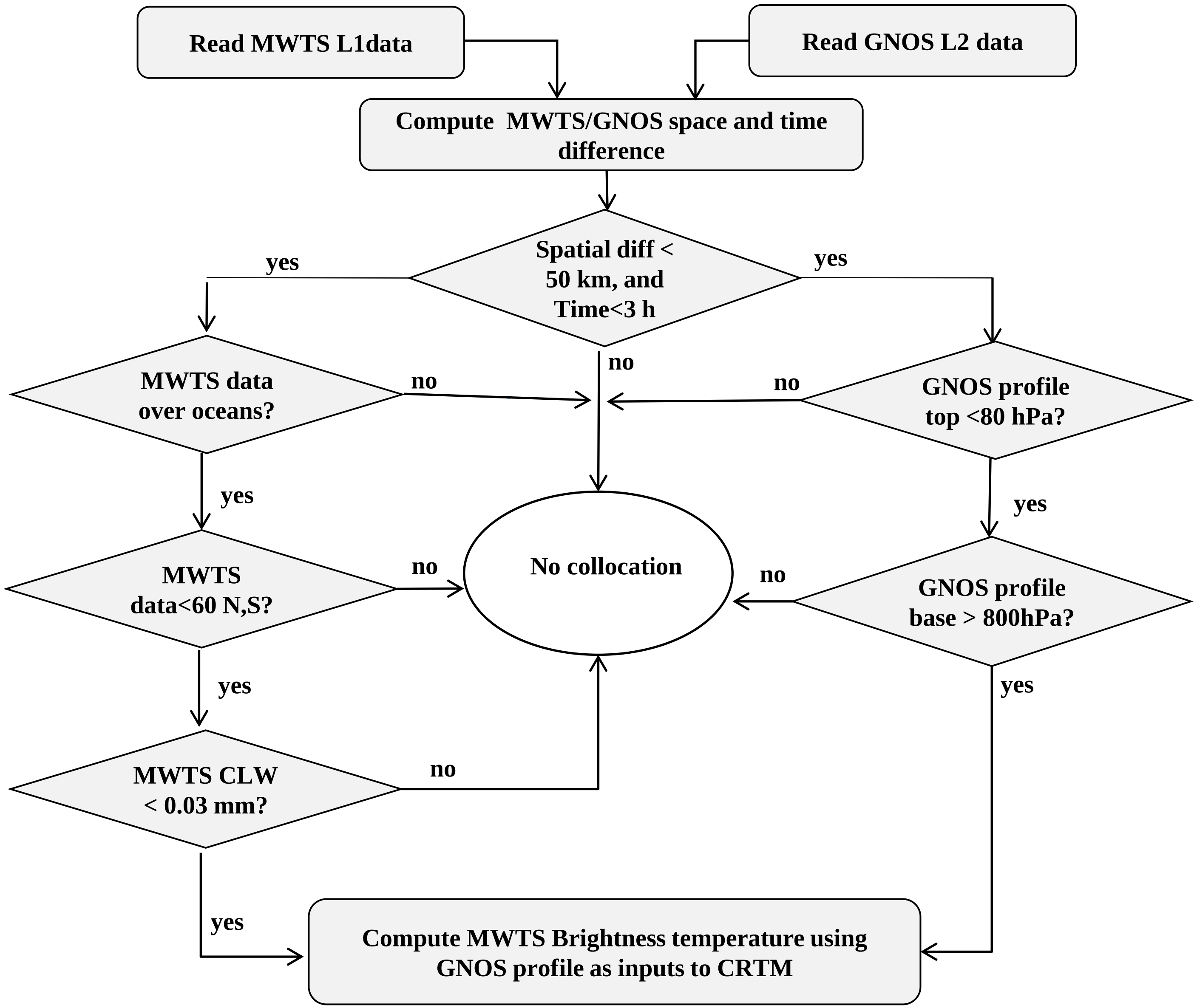
  Spatial distance < 50 km

Distribution of collocated MWTS from June 27 to July 16, 2018

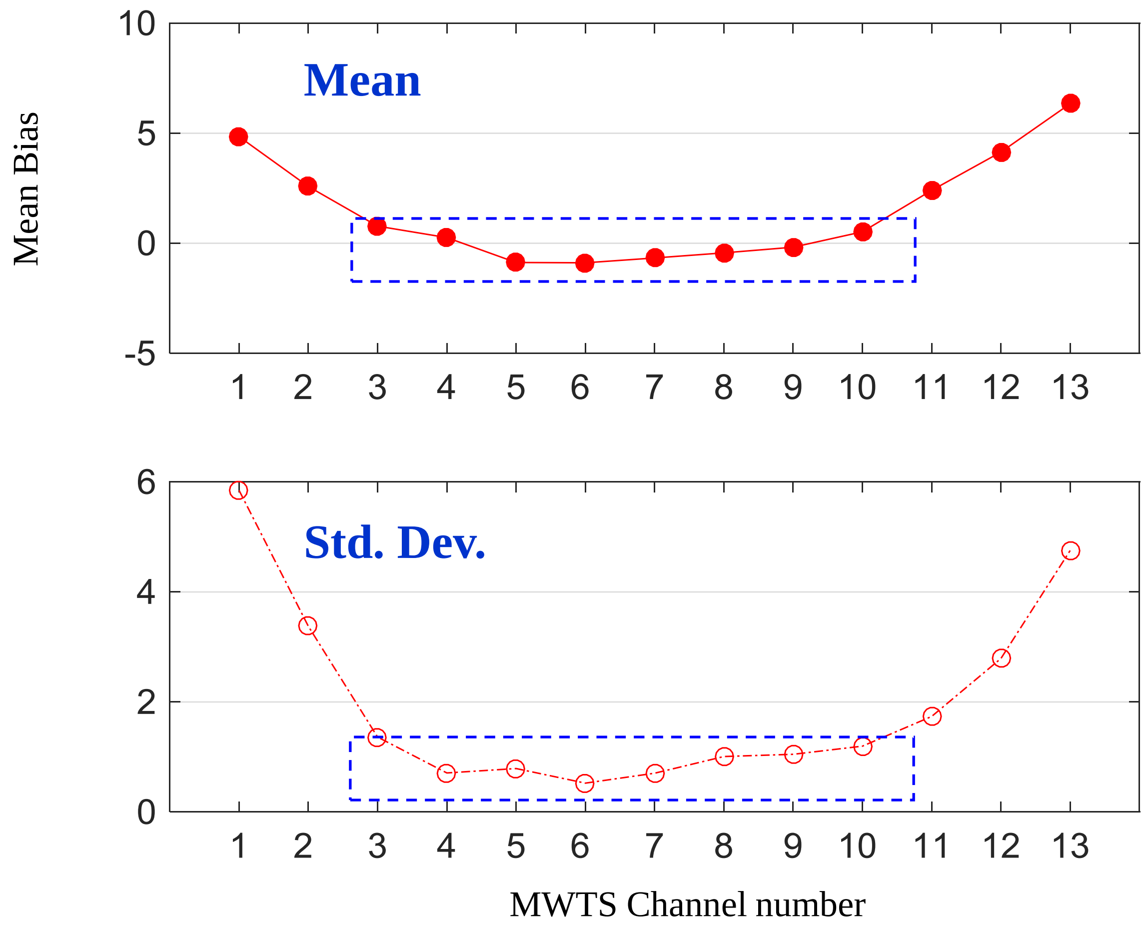


3388 collocated measurements

MWTS and GNOS Collocation Flowchart

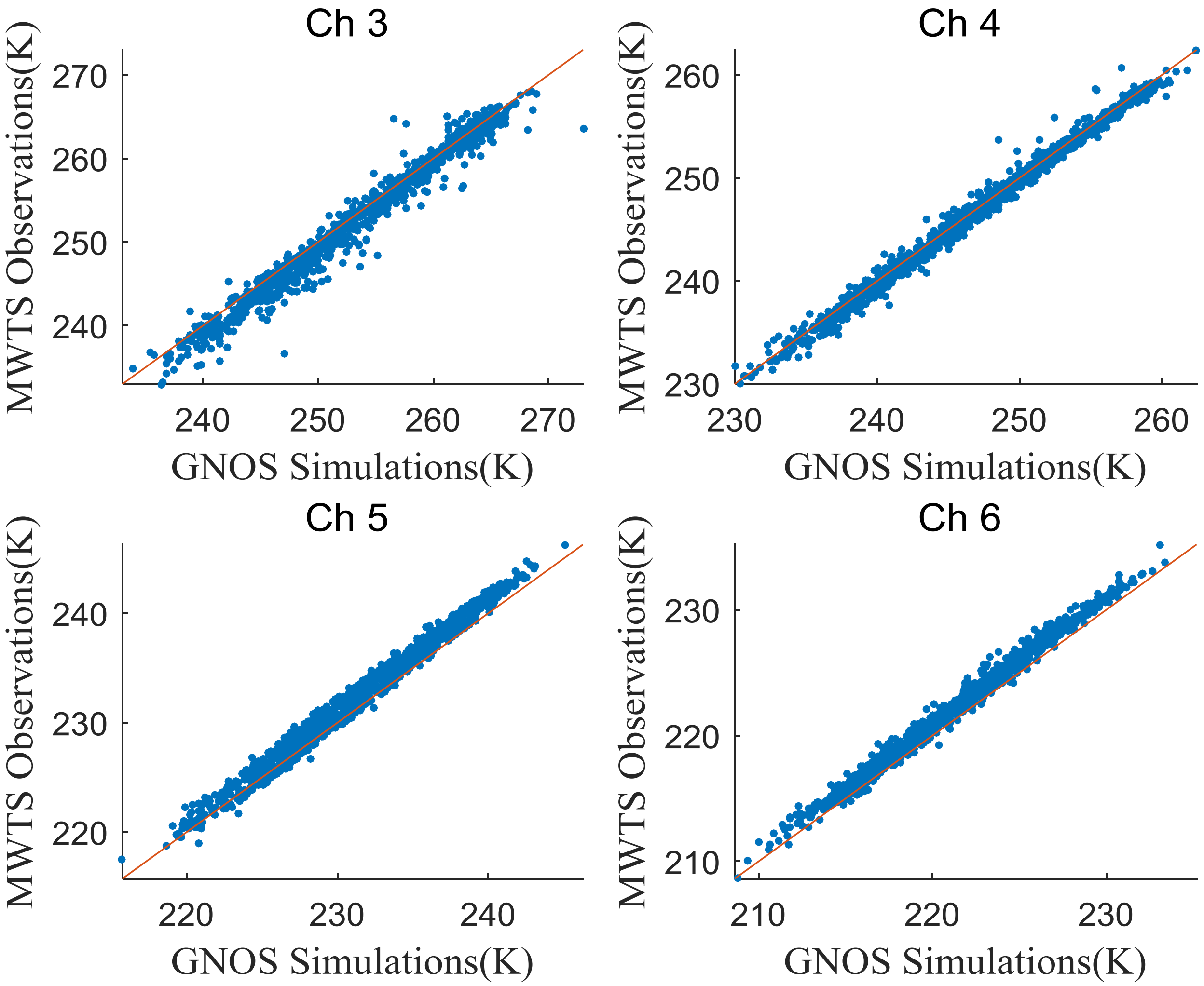


MWTS Mean Bias and Standard Deviation

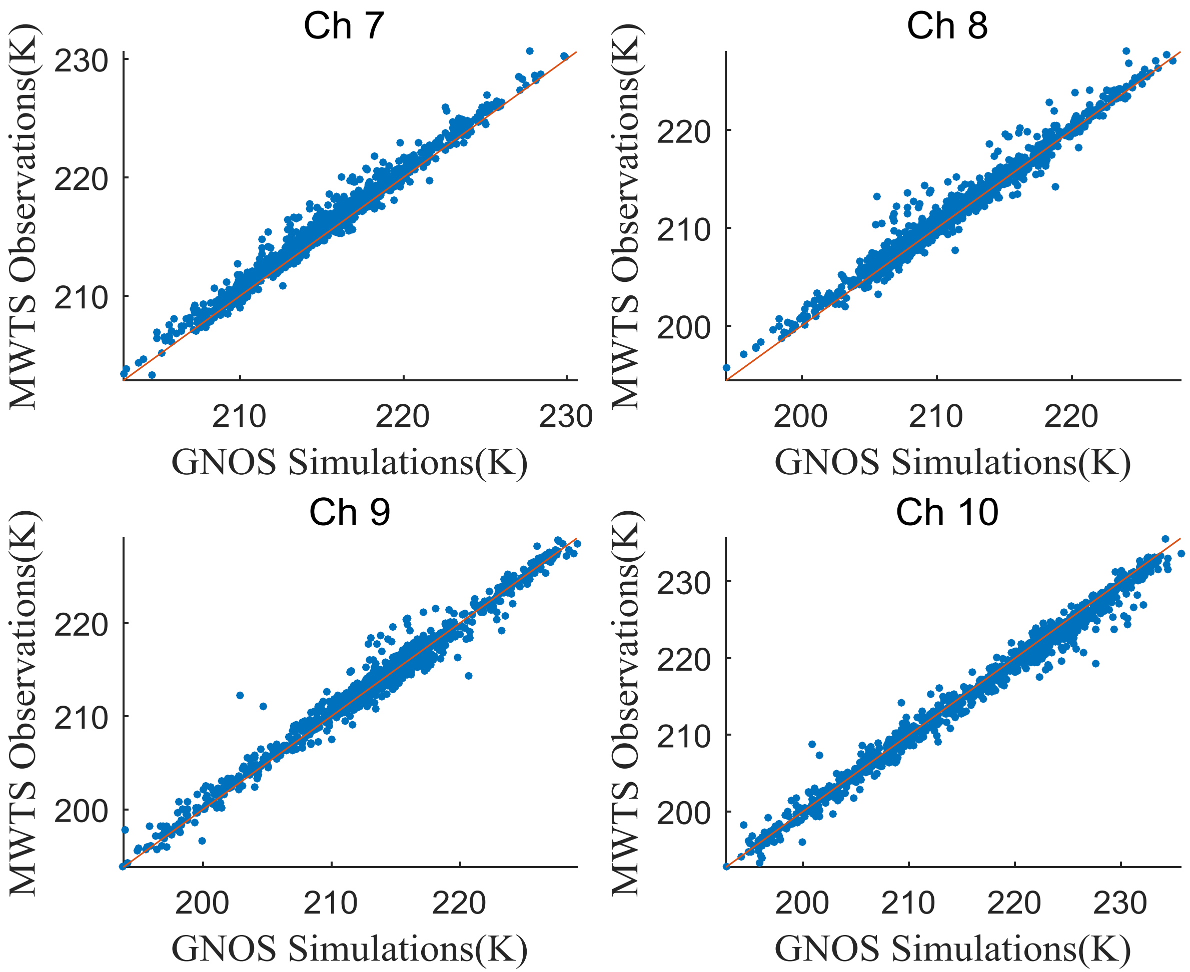


- MWTS 13个通道的模拟结果中，通道3-10的模拟效果较好，偏差绝对值小于2，估计原因是受水汽和地表发射影响较小。

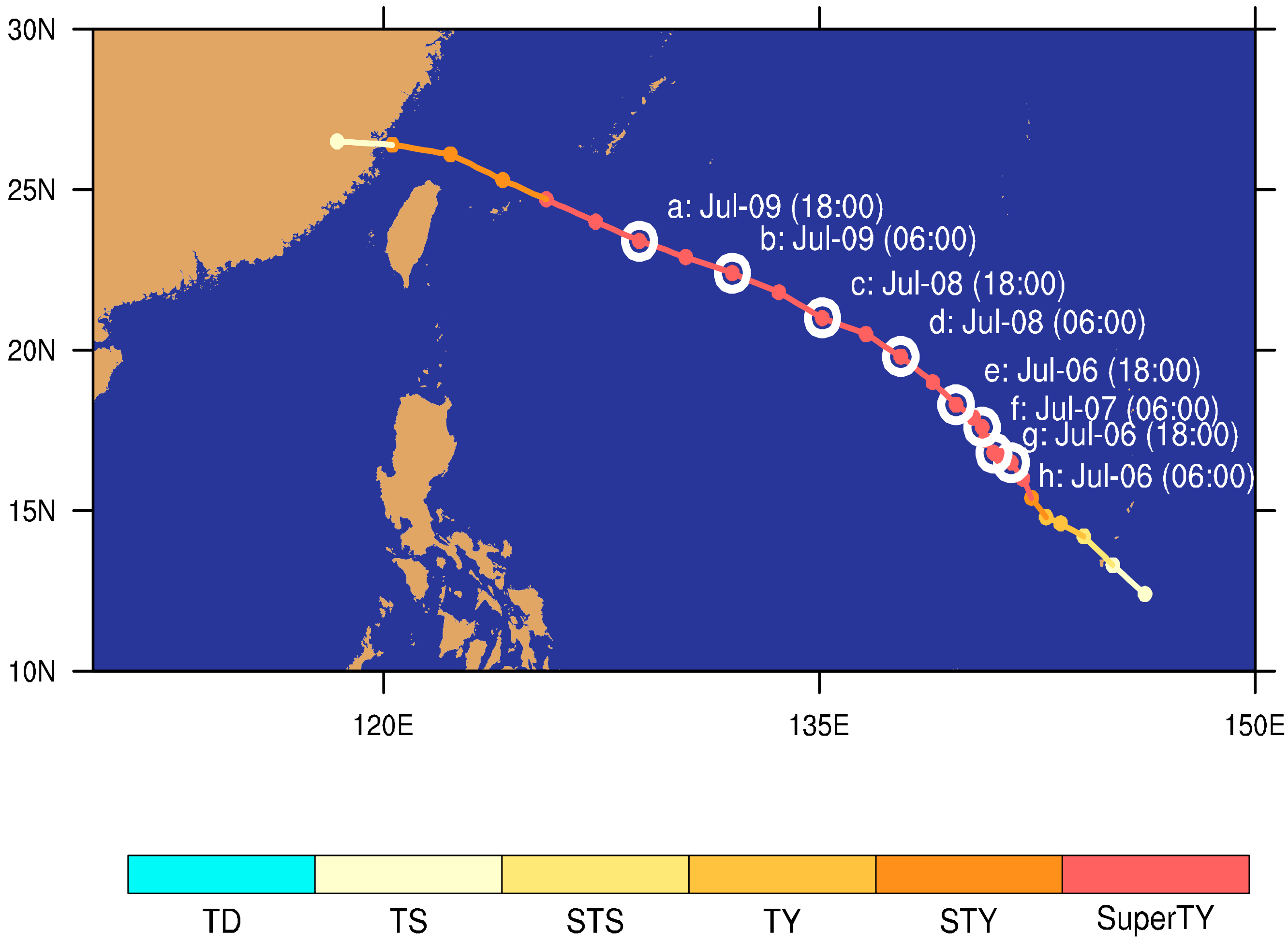
Scatter Plots of $O^{(Obs)}$-$B^{(GNOS)}$ (Channels 3-6)



Scatter Plots of $O^{(Obs)}$-$B^{(GNOS)}$ (Channels 7-10)



Super Typhoon Maria

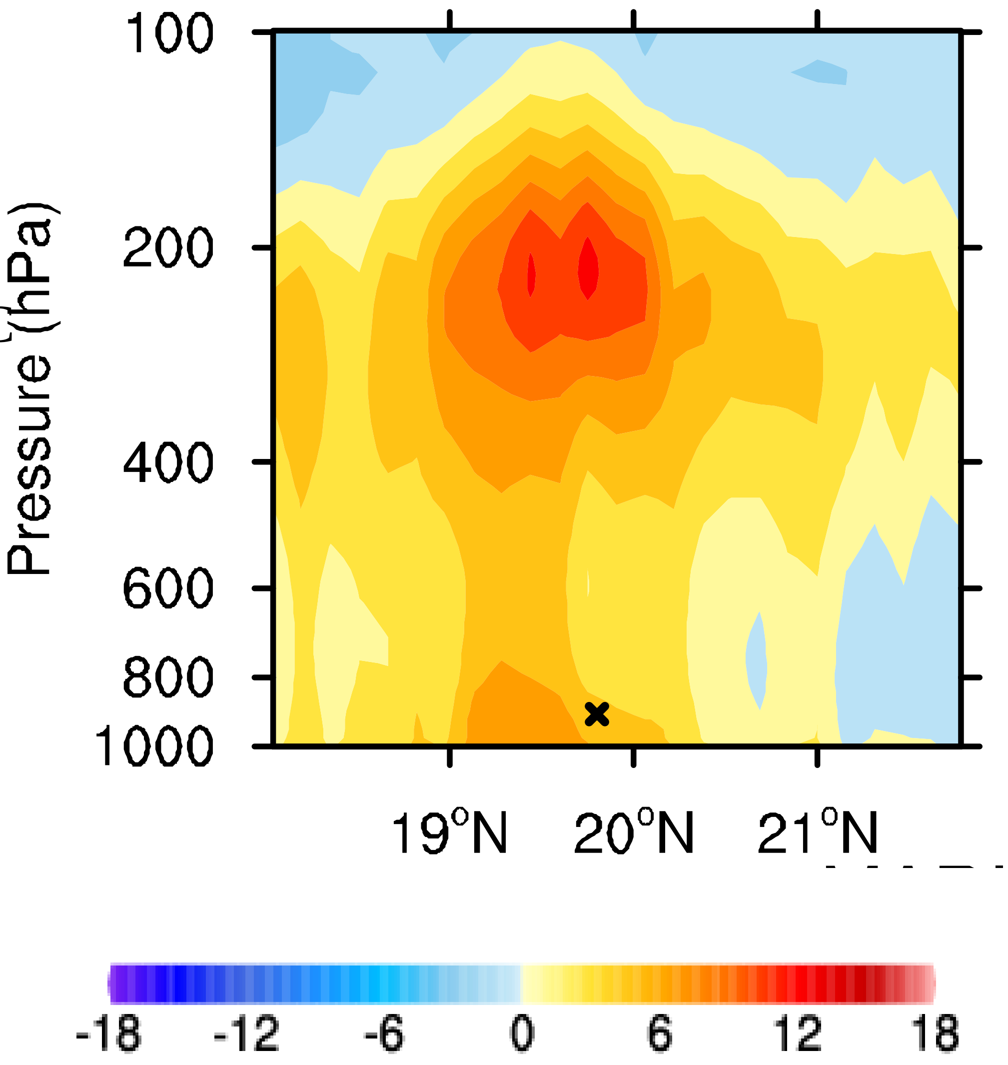


Typhoon Maria Warm Core from SNPP ATMS

Typhoon Maria
Date: 2018-07-08
Time: around 06:00 UTC
Intensity: 135 kt

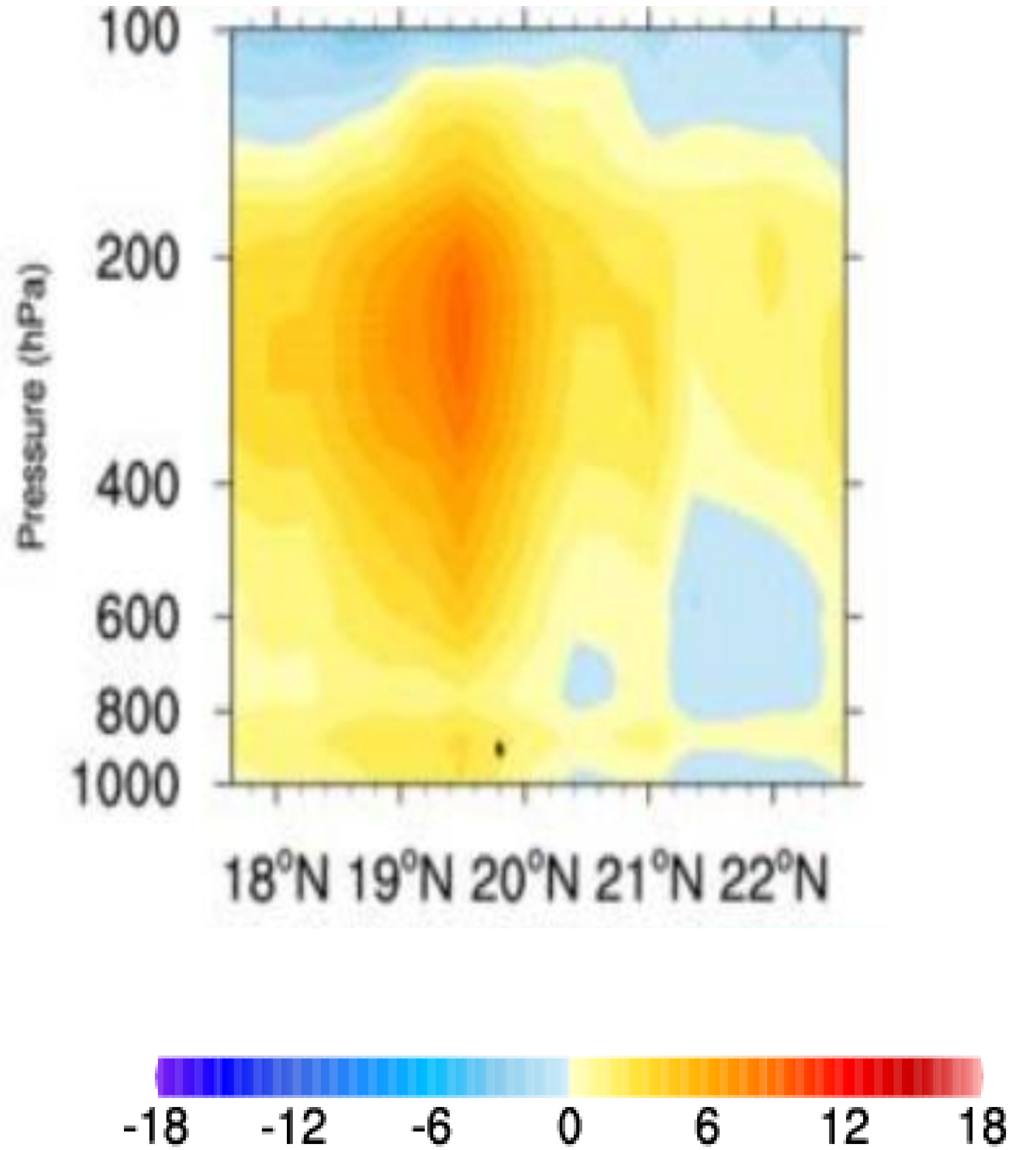
Channel Selection

SNPP ATMS: 3-22



Typhoon Maria Warm Core from FY-3D MWTS/MWHS

Typhoon Maria
Date: 2018-07-08
Time: around 06:00 UTC
Intensity: 135 kt



Channel Selection

FY3D CMWS: ATMS like
22 channels

Summary and Conclusions

- It is recommended that satellite observations from microwave temperature and water vapor sounders be combined into a single data stream

- For FY-3D MWTS and MWHS, the brightness temperatures at 23.8 and 31.4 GHz can be synthetically generated through a machine-learning technique

- MWTS and MWHS O-B (observation minus background brightness temperature) displays a scan-angle dependent bias and is also asymmetric across the scan line. Also, striping noise is obvious on MWTS O-B field

- Absolute calibration accuracy of MWTS upper air sounding channels is performed using GNOS data and it is about 0.5-1.0K

- Retrieval of Typhoon Maria from MWTS/MWHS data is derived and shows a pattern consistent with the data from ATMS.