

Assessment of AHI Level-1 Data for HWRF Assimilation

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December 23-24, 2015

Outline

- Concept on Satellite Data Assimilation (DA)
- A Baseline HWRF System for Satellite DA
- Impacts of GOES Imager Radiance Assimilation
on Hurricane Track and Intensity Forecasts
- Assessment of AHI Data Applications to HWRF DA
- Summary and Conclusions

Concept of 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.

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

$$J(\mathbf{x}_a) = \min_{\mathbf{x}} J(\mathbf{x}) \quad \forall \mathbf{x} \text{ near } \mathbf{x}_b \quad \text{<— Maximum likelihood Estimate}$$

\mathbf{x} — analysis variable

\mathbf{x}_a — final analysis

\mathbf{x}_b — background

\mathbf{B} — background error covariance

μ — bias

\mathbf{y}^{obs} — observations

\mathbf{O} — observation error covariance

H — observation operator

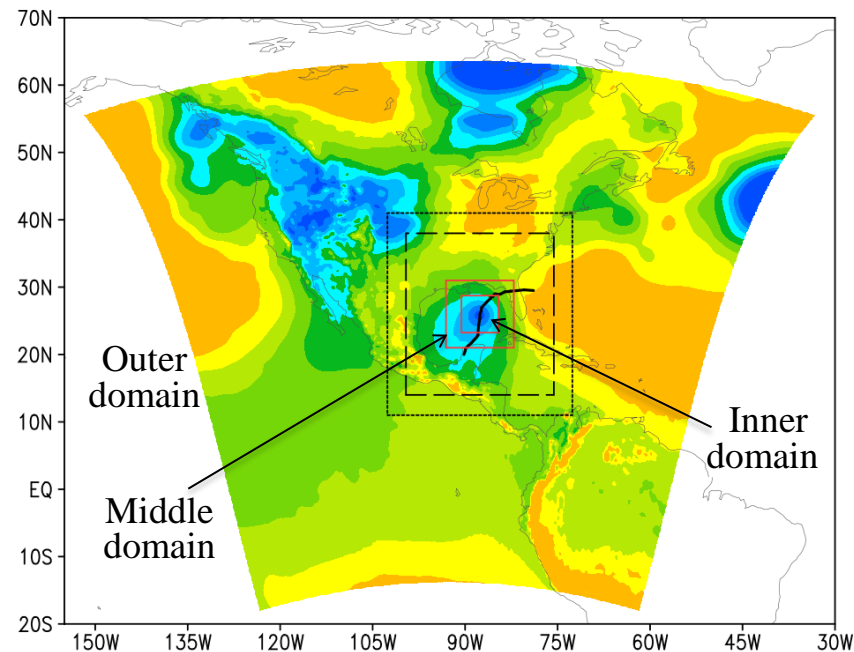
\mathbf{F} — forward model error covariance

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.

A Baseline HWRF System for Satellite Data Assimilation

- 2012 NCEP-trunk version 934 HWRF (three nested domains)
- System Modifications
 - Higher model top (0.5 hPa, 61 levels)
 - Warm start
 - Asymmetric vortex initialization
- Advanced POES and GOES DA
 - POES sounding instruments: AMSU, ATMS, CrIS, IASI, AIRS
 - New quality control (QC) for MHS
 - GOES-13/15 imager radiance
 - POES microwave imager radiance (AMSR2, GMI)
 - Surface sensitive channels through Community Surface Emissivity Model (CSEM)

Model Domains



Three telescoping model domains:

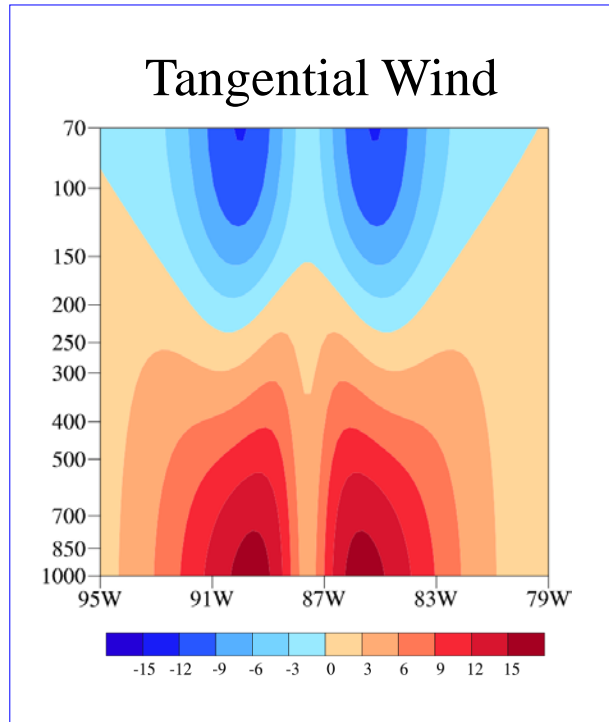
Outer domain: 27 km (fixed)

Middle domain: 9 km (moving)

Inner domain: 3 km (moving)

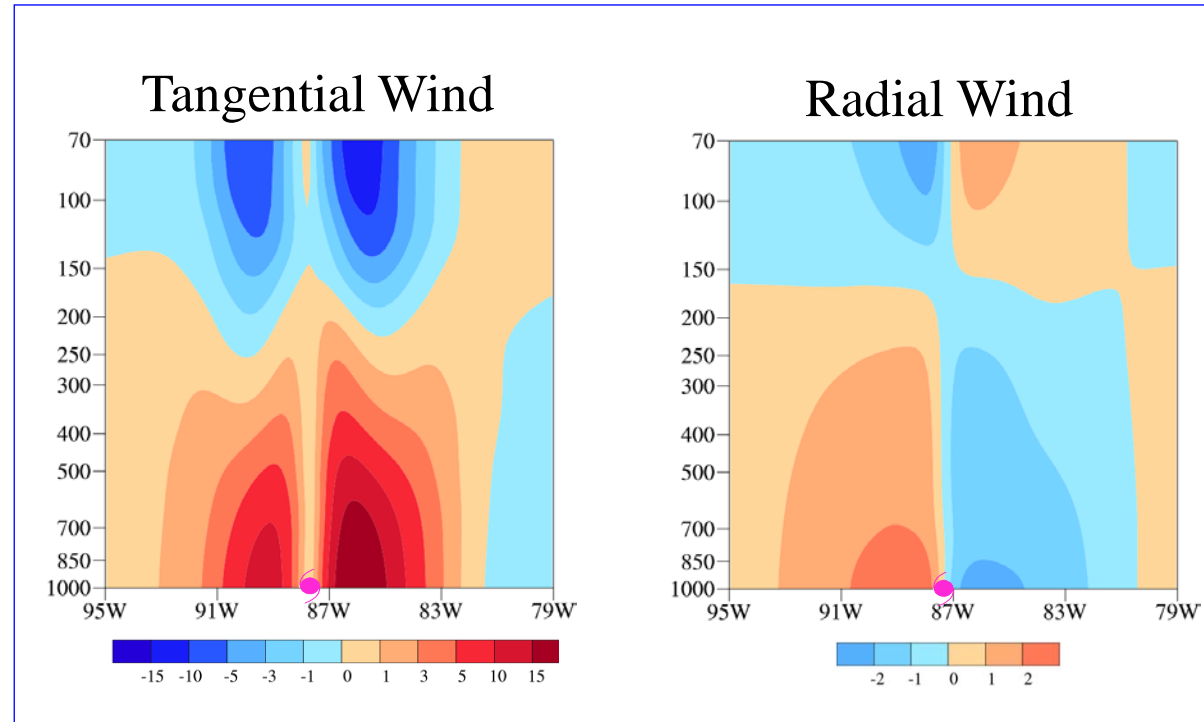
A Newly Added Asymmetric Bogus Vortex to HWRF

Symmetric Vortex



Operational HWRF

Asymmetric Vortex

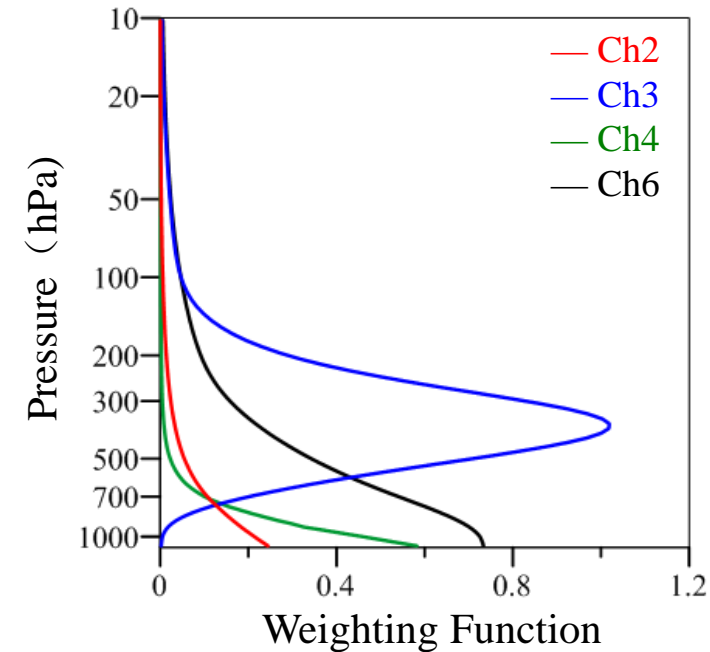


Baseline HWRF/DA System

Tropical storm Debby at 1800 UTC June 23, 2012

GOES-13/15 Imager Channel Characteristics

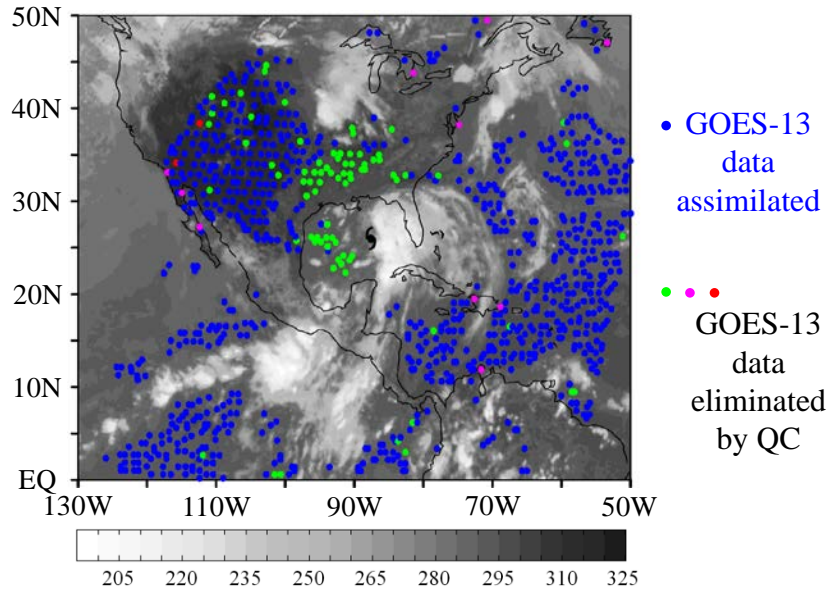
Channel	Central Frequency (μm)	Band Width (μm)	Spatial Resolution (km)		Observation Error (K)	
			GOES-13	GOES-15	GOES-13	GOES-15
1	0.65	0.19	1.0	1.0	$\pm 5\%$	$\pm 5\%$
2	3.90	0.34	4.0	4.0	0.051	0.063
3	6.55	1.50	4.0	4.0	0.140	0.170
4	10.7	1.00	4.0	4.0	0.053	0.059
6	13.35	0.70	8.0	4.0	0.061	0.130



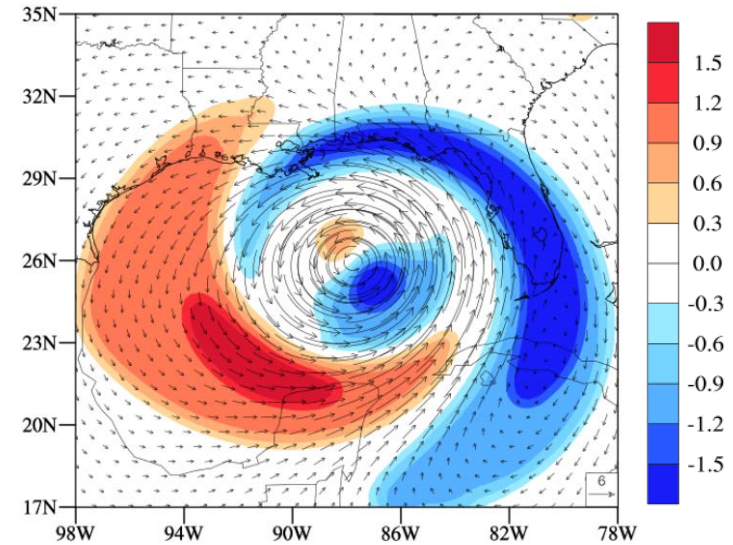
- Imager channels 2-4 are to be assimilated in NCEP GSI system
- GOES channel 5 (12.0 μm) has been changed to channel 6 (13.35 μm) since the launch of GOES-12

GOES-13/15 DA with an Asymmetric Vortex Initialization

Channel 3 Data Assimilated after QC

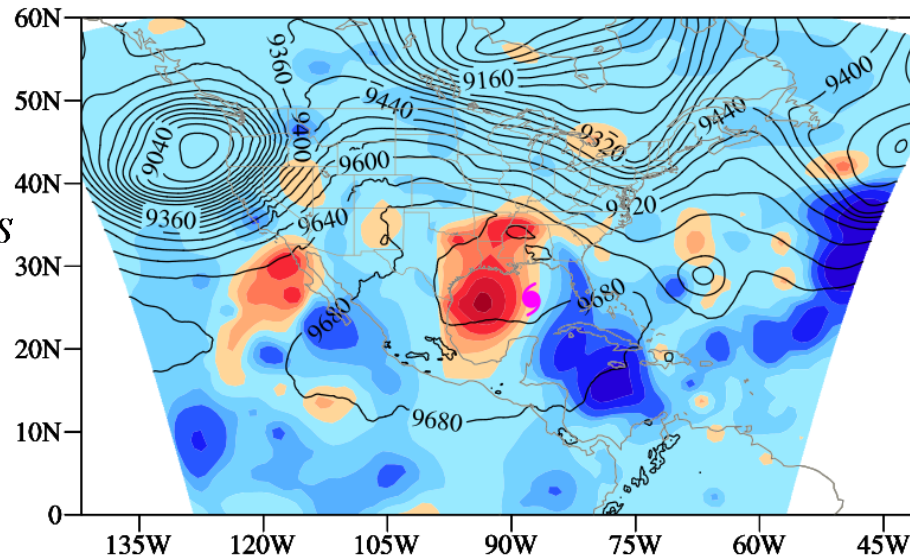


Asymmetric Relative Vorticity



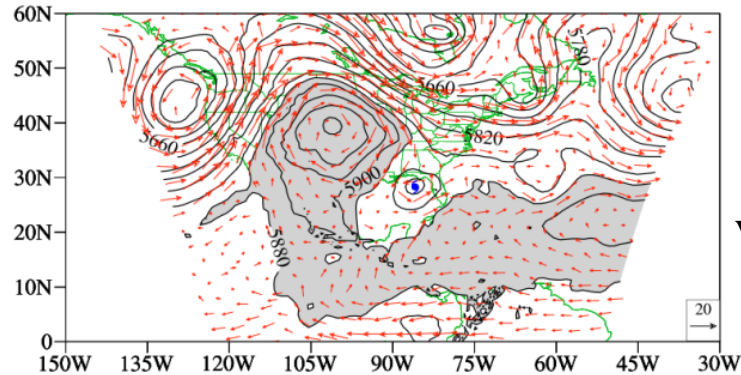
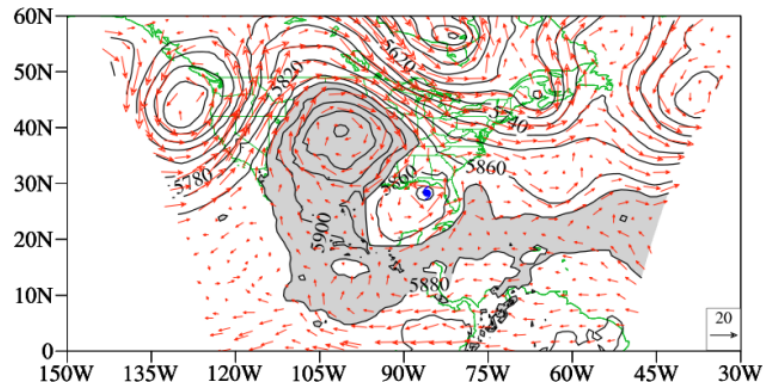
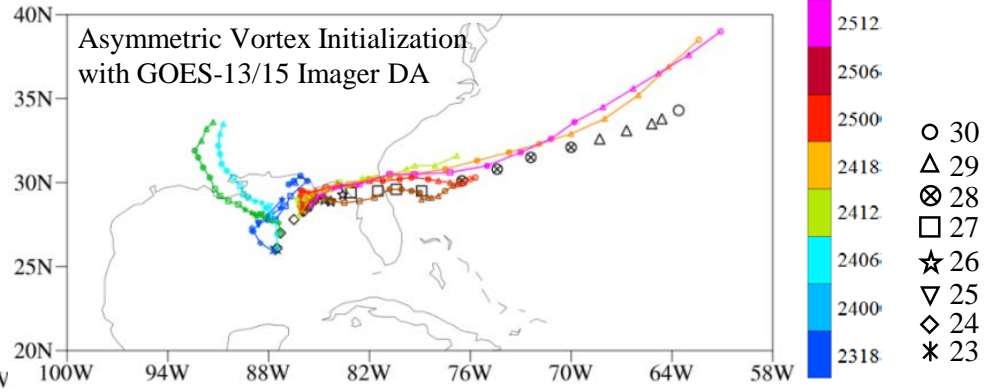
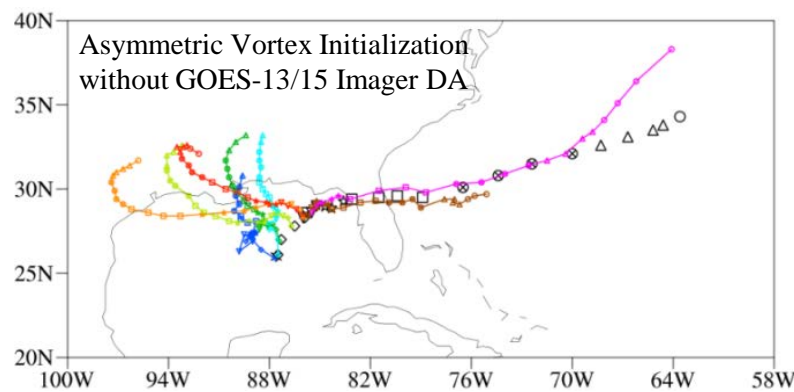
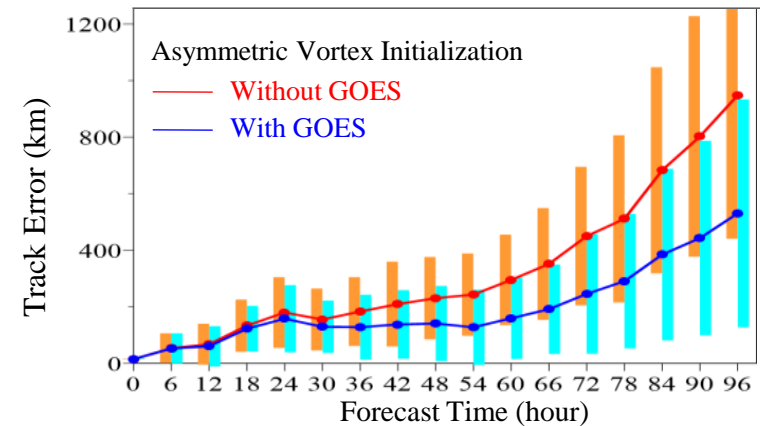
Analysis Difference

$$\Phi_{ana, 300 hPa}^{GOES DA} - \Phi_{300 hPa}^{without GOES}$$



Tropical Storm Debby at
1800 UTC June 23, 2012

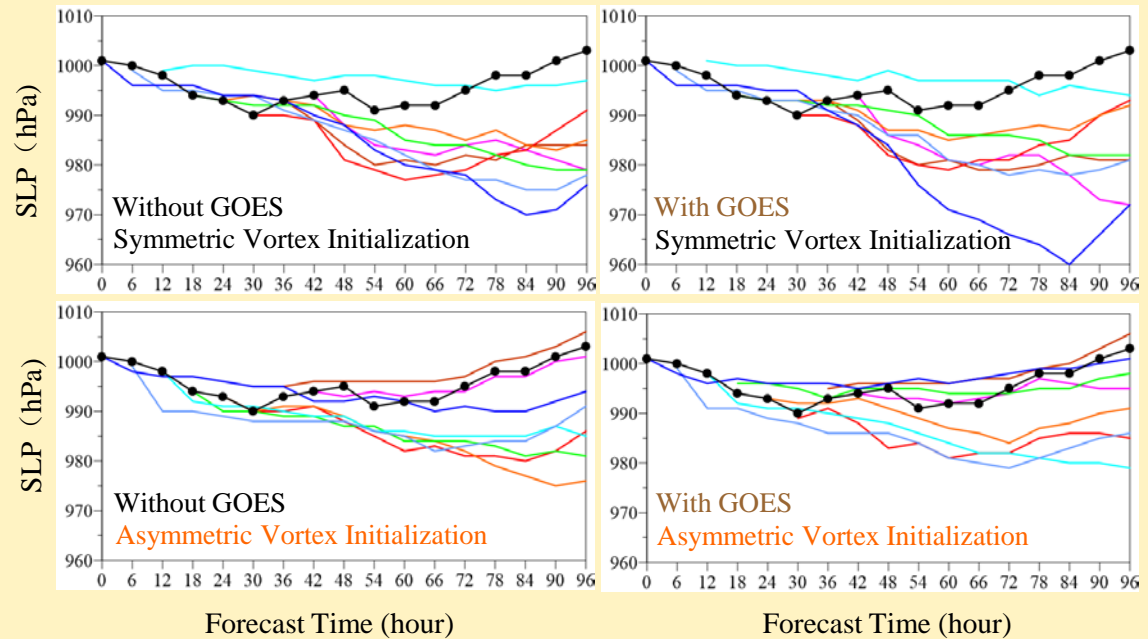
Impacts of GOES-13/15 Imager Radiance DA on Track Prediction



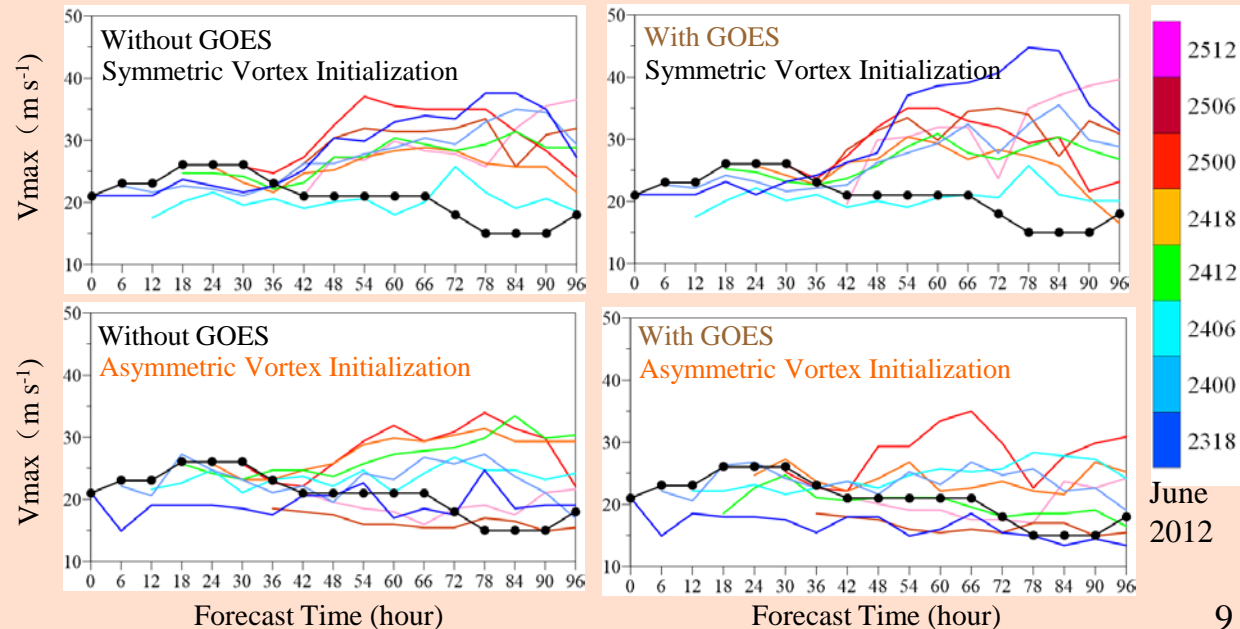
Zou, X., Z. Qin and Y. Zheng, 2015: Improved tropical storm forecasts with GOES-13/15 imager radiance assimilation and asymmetric vortex initialization in HWRF. *Mon. Wea. Rev.*, **143**(7), 2485-2505.

Impacts of GOES-13/15 Imager Radiance DA on Intensity Forecasts

Central Sea-Level
Pressure
(SLP)



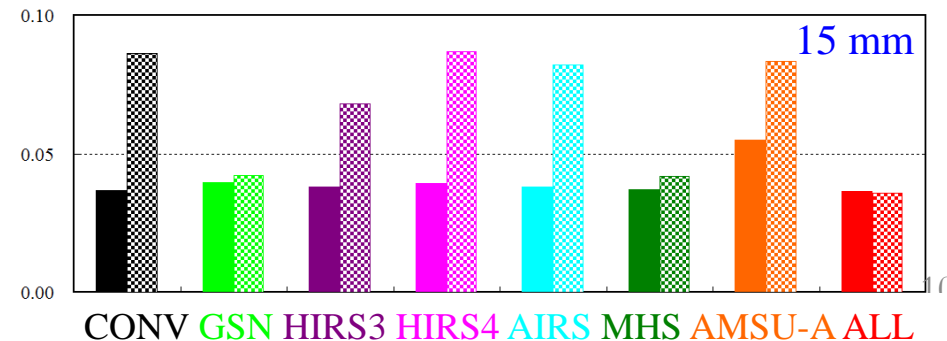
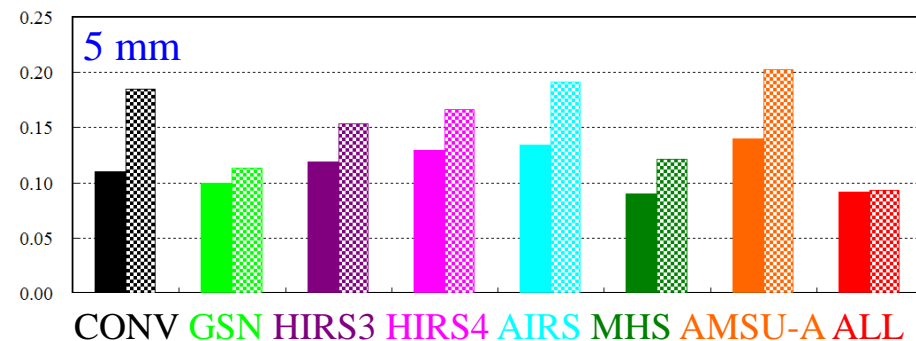
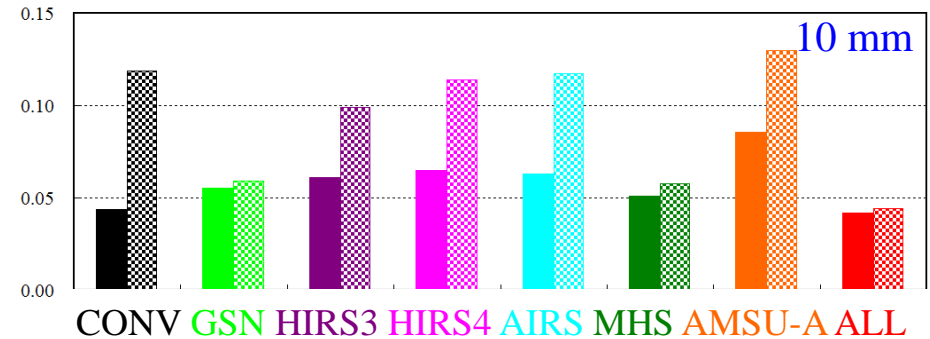
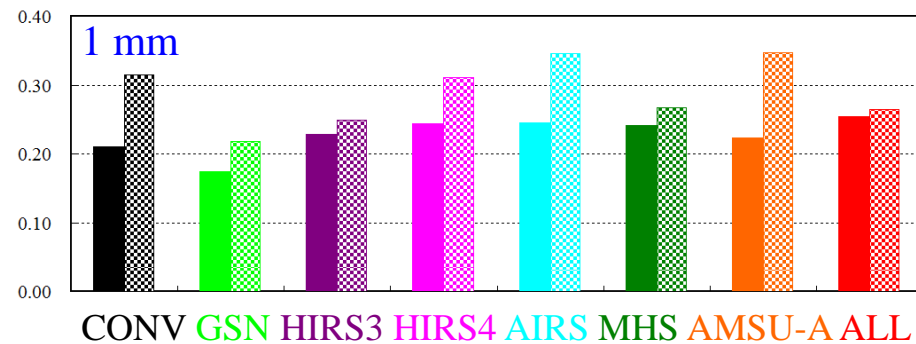
Maximum Surface
Wind Speed
(V_{\max})



Impacts of GOES-11/-12 Imager Radiance DA on QPFs

- The added impacts of GOES imager radiance DA to different types of satellite data (AMSU-A, HIRS/4, HIRS/3, GSN, AIRS, MHS) was consistently positive on QPFs
- The analysis and forecast errors are significantly reduced by GOES imager radiance DA when verified with independent observations from GOES sounders and AIRS

Threat Scores of 3-h Accumulative Rainfall Averaged over 24 Hours

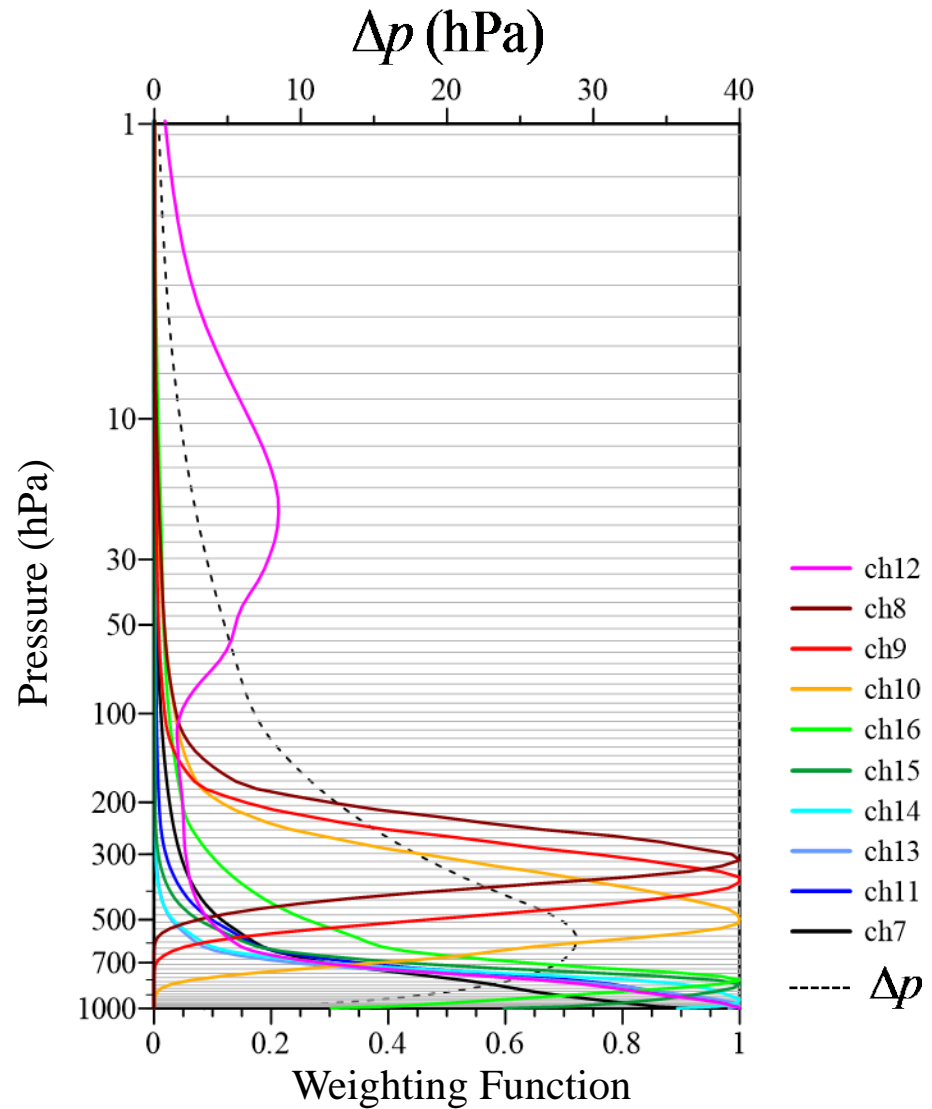


without GOES with GOES

Qin, Z., X., Zou, and F. Weng, 2013: Evaluating added benefits of assimilating GOES imager radiance data in GSI for coastal QPFs. *Mon. Wea. Rev.*, **141**(1), 75-92.

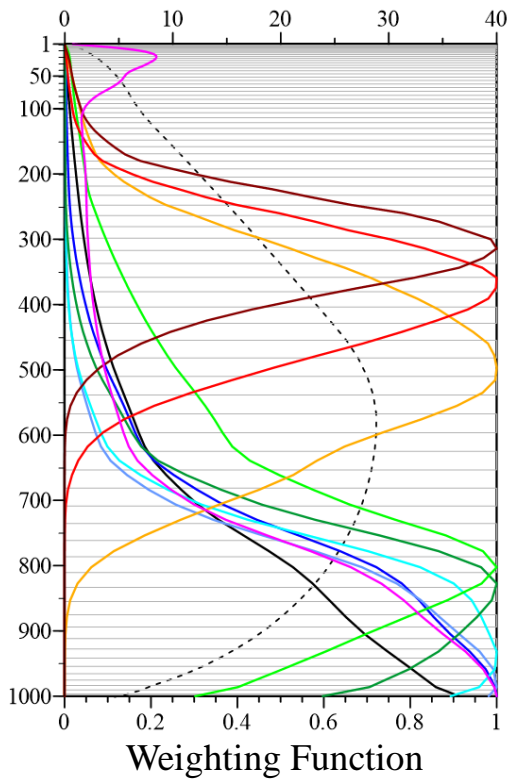
Himawari-8 AHI Channels 7-16

Channel Number	Central Wavelength
7	3.9 mm
8	6.2 mm
9	6.9 mm
10	7.3 mm
11	8.6 mm
12	9.6 mm
13	10.4 mm
14	11.2 mm
15	12.4 mm
16	13.3 mm

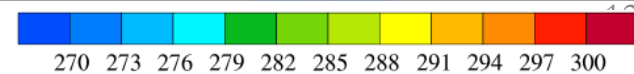
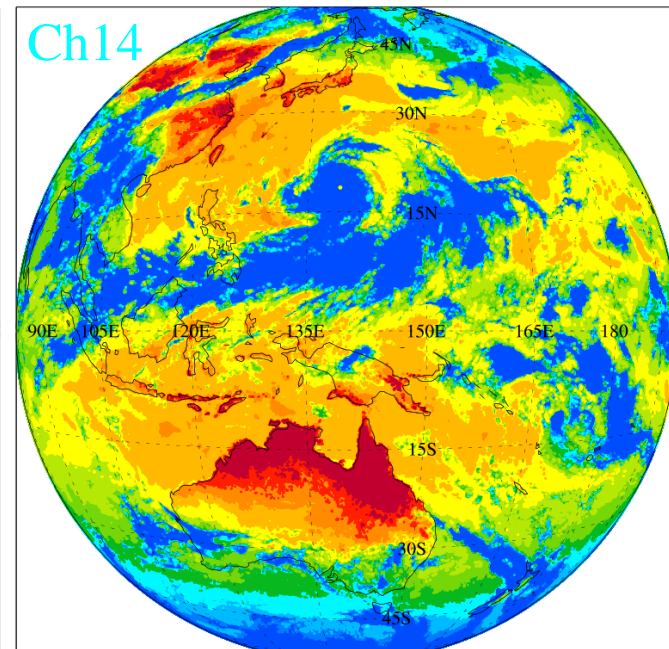
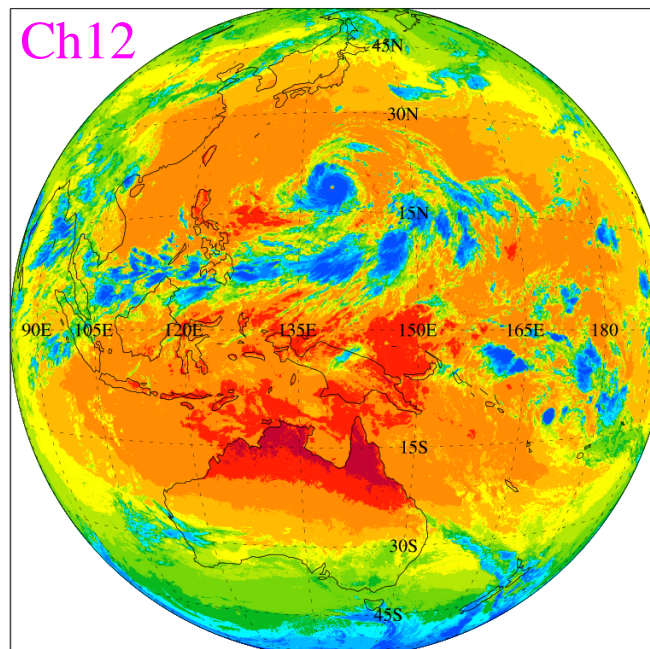
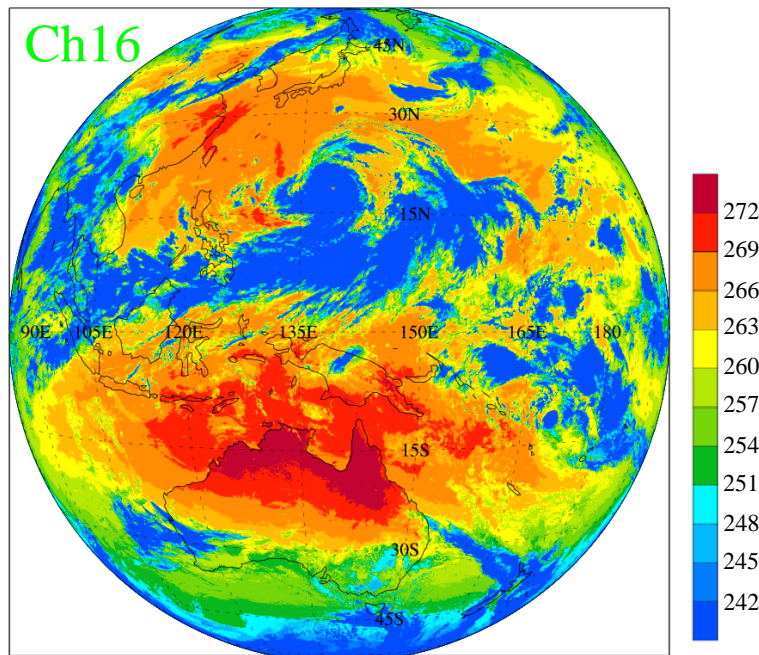


AHI Data

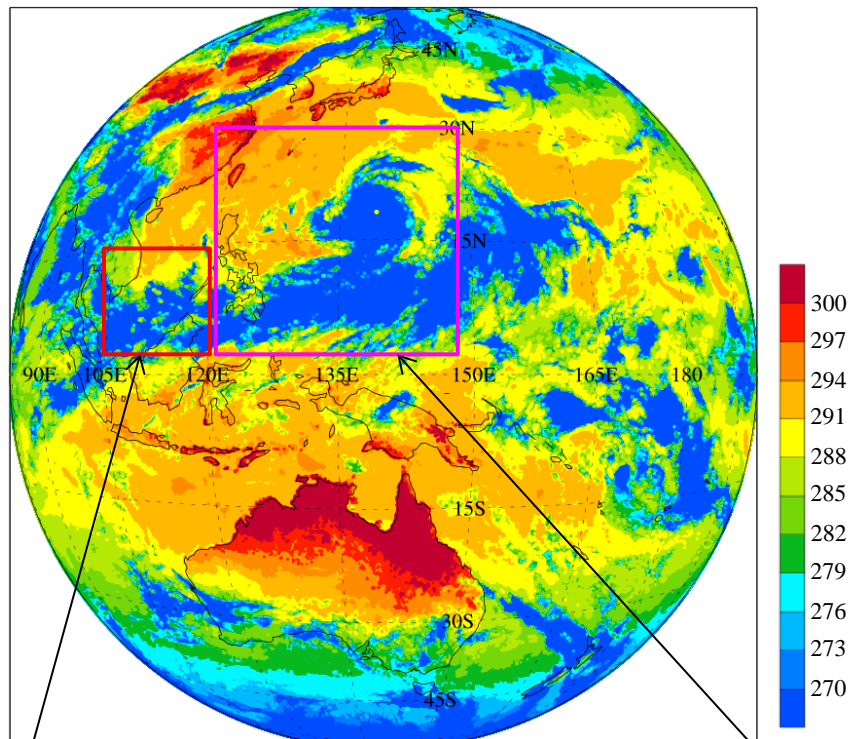
0130 UTC
August 4, 2015



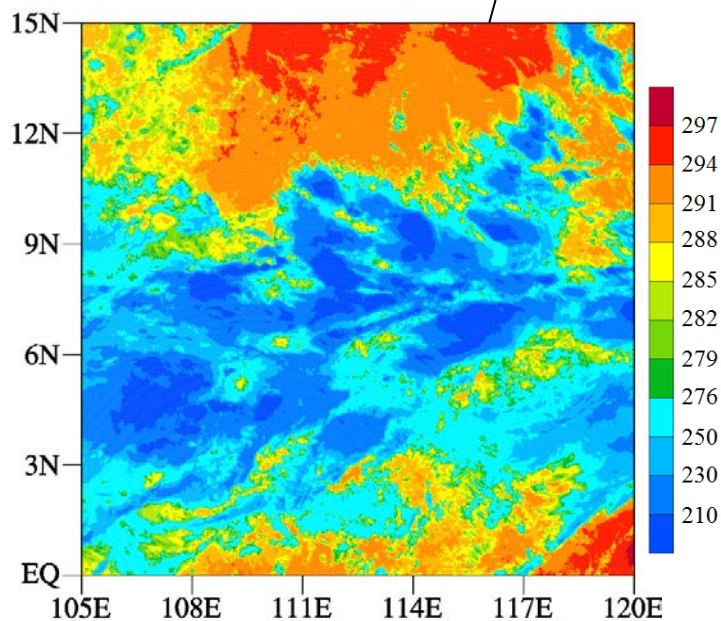
ch12	ch10	ch14
ch8	ch16	ch13
ch9	ch15	ch11
	ch7	



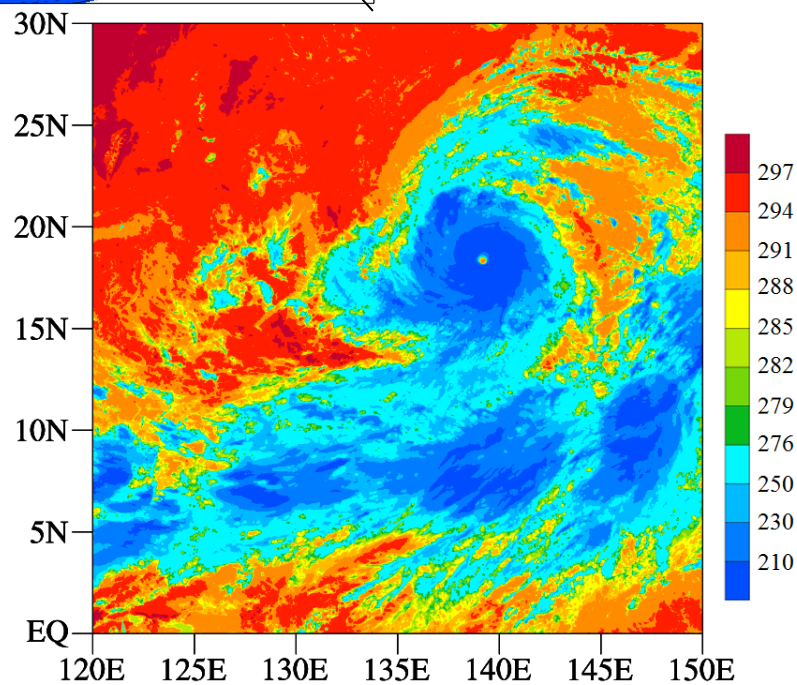
Brightness Temperatures of AHI Ch14



Tropical
Convection



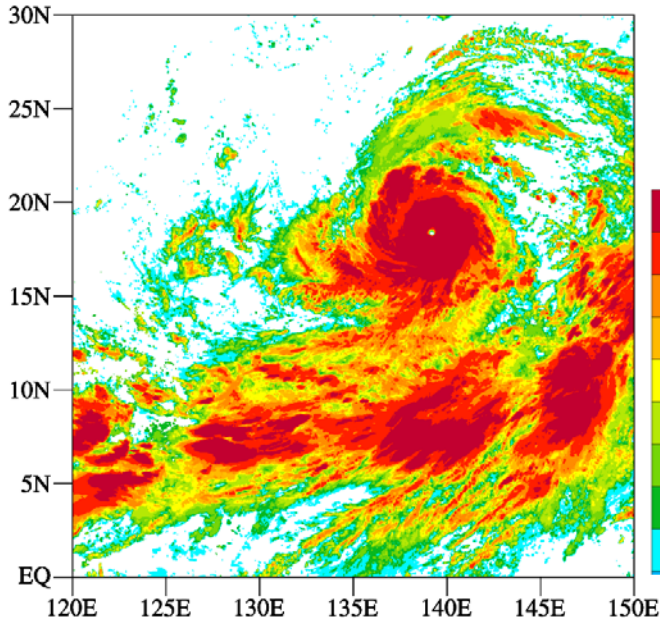
Typhoon
Soudelor



Cloud Mask within Typhoon Soudelor (1/2)

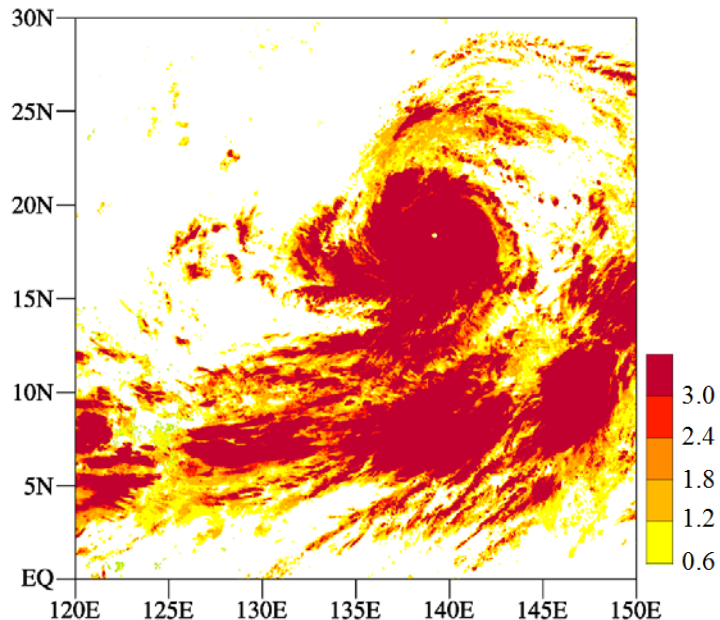
ETROP

Channel 14
Emissivity
Referenced
to the
Tropopause



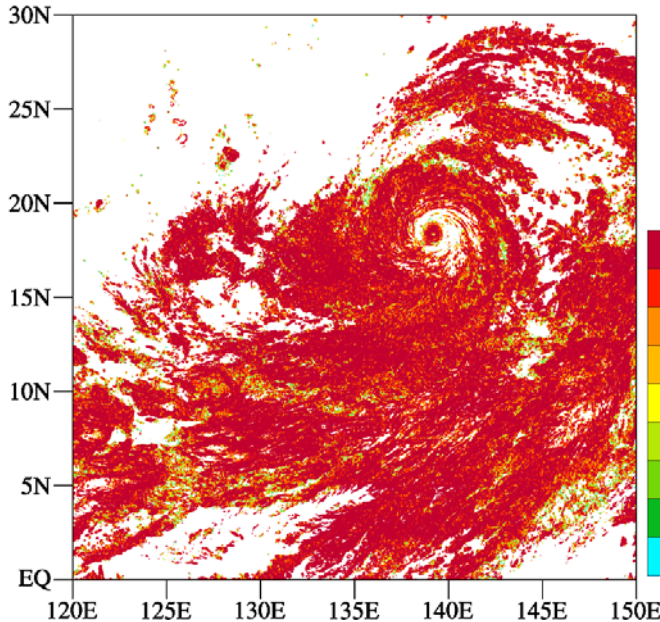
EMISS

Emissivity
Test at
 $4\mu\text{m}$



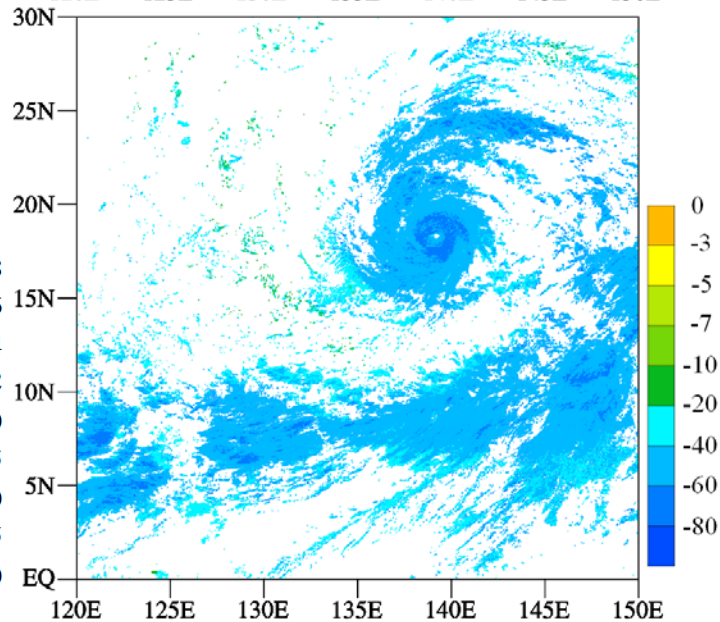
CIRH2O

Cirrus
Water
Vapor
Test



NFMFT

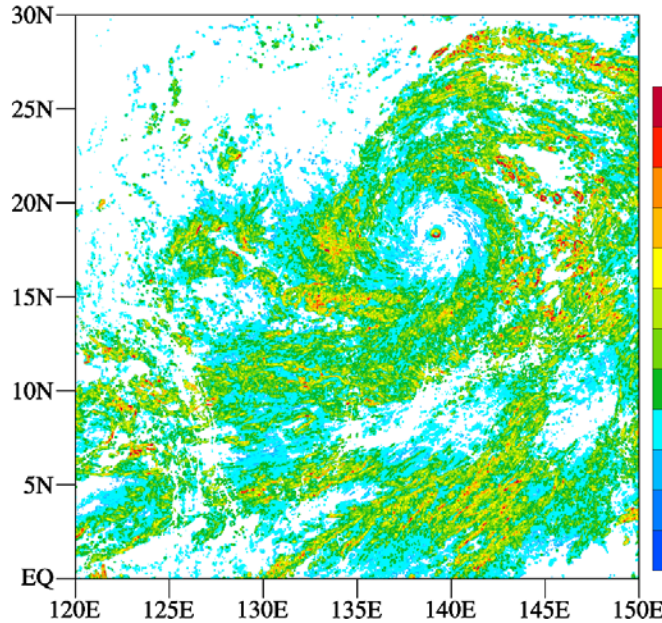
Negative
Four
Minus
Five Test



Cloud Mask within Typhoon Soudelor (2/2)

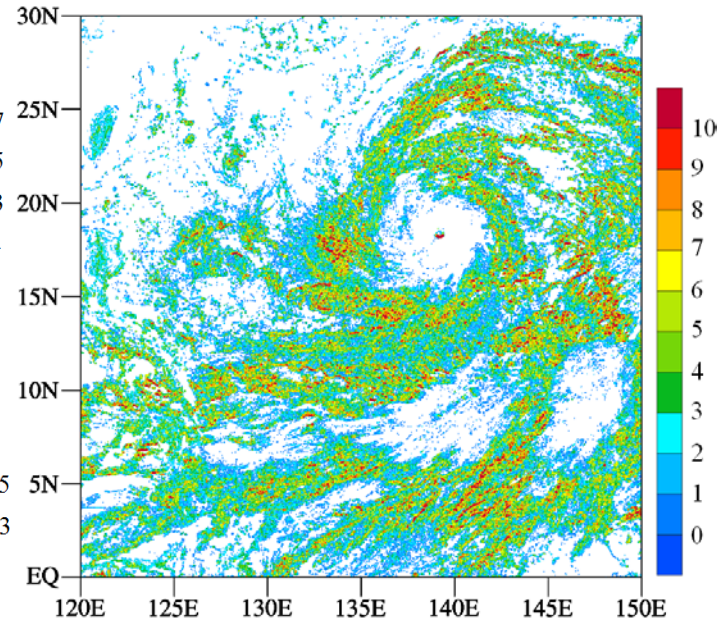
TUT

Thermal
Uniformity
Test



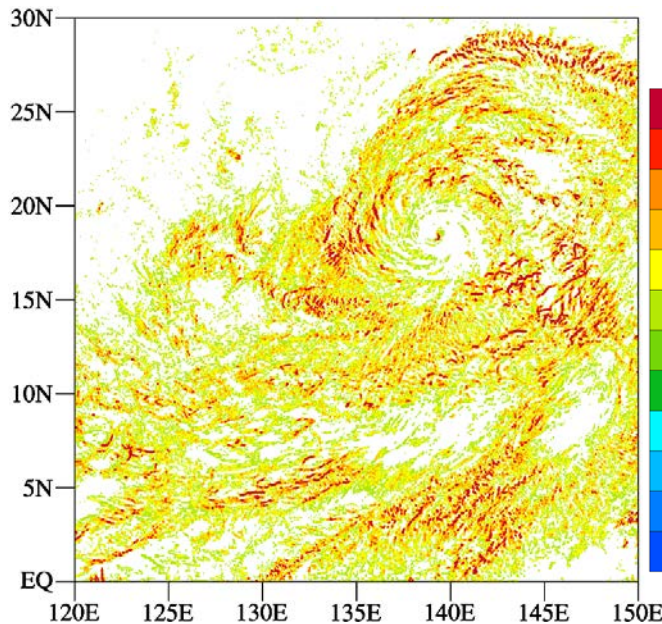
RFMFT

Relative
Four
Minus
Five Test



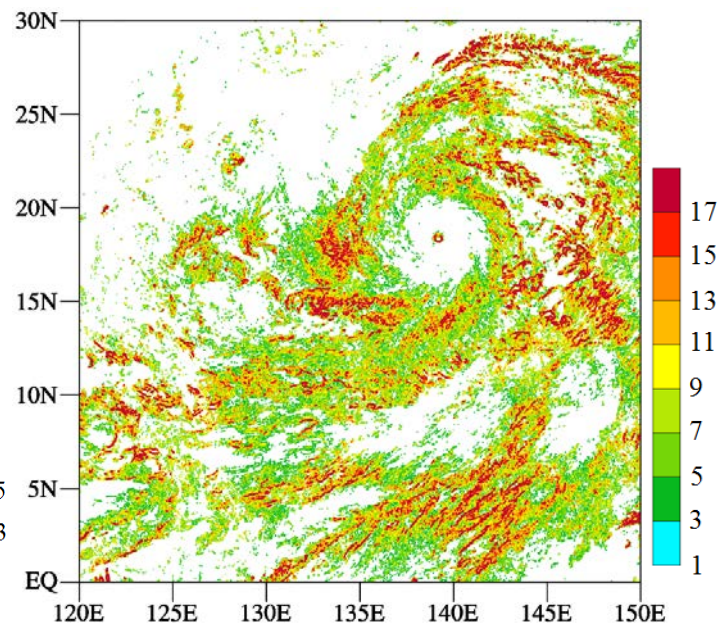
TEMPIR

Temporal
Infrared
Test



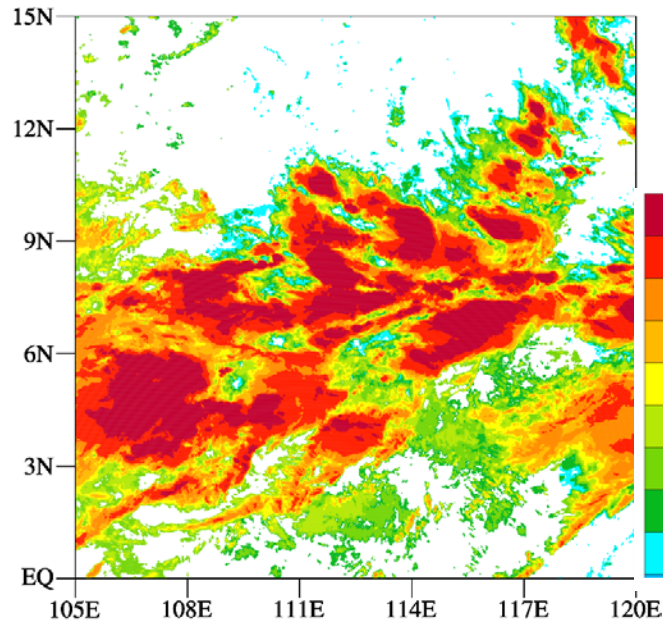
RTCT

Relative
Thermal
Contrast
Test

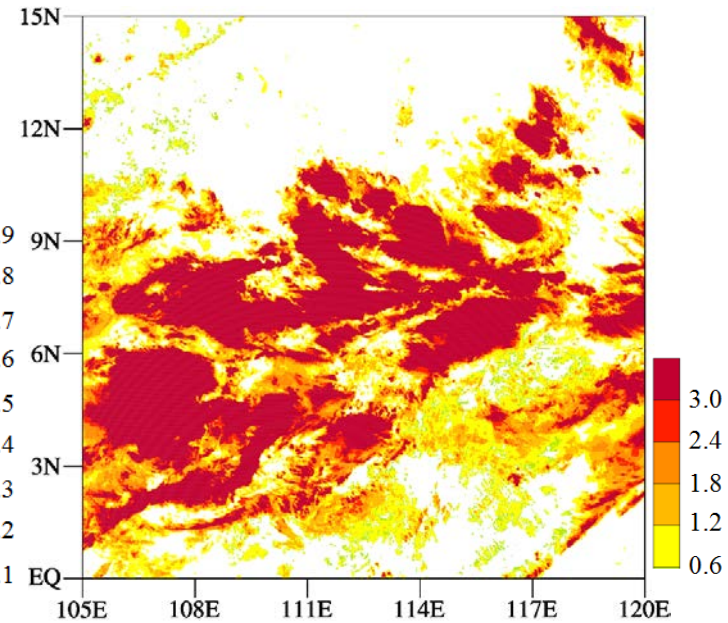


Cloud Mask within Tropical Convection (1/2)

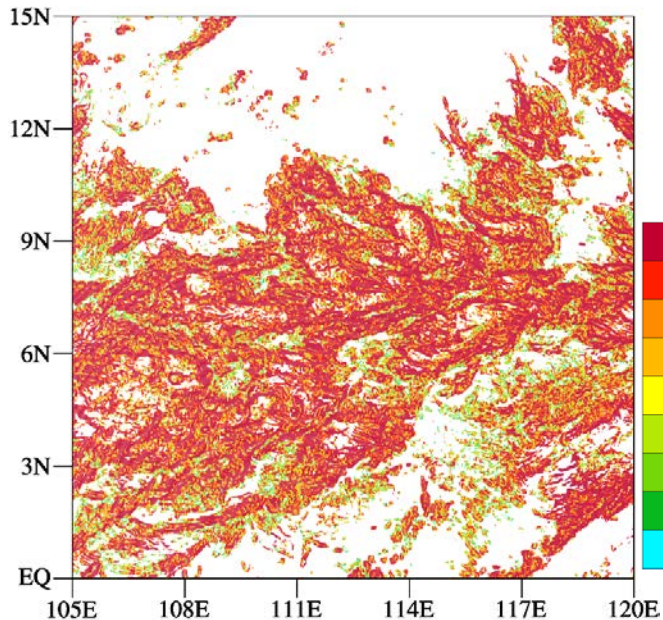
ETROP



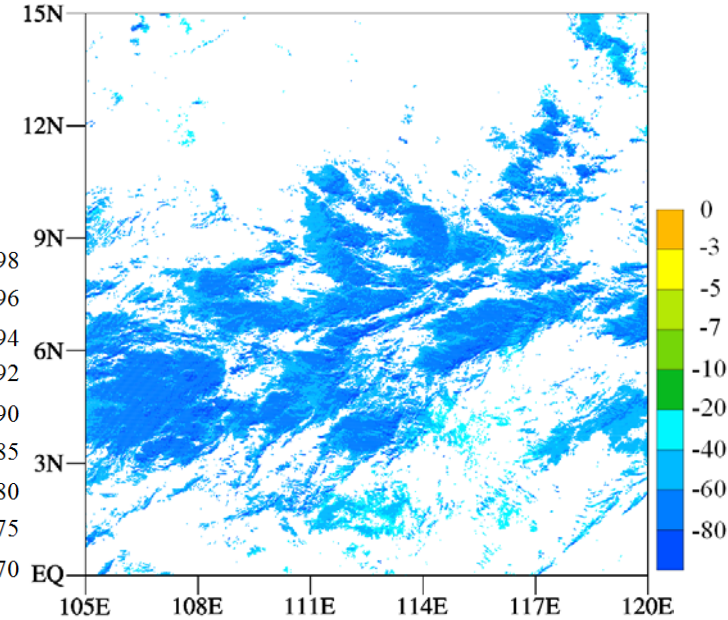
EMISS



CIRH2O

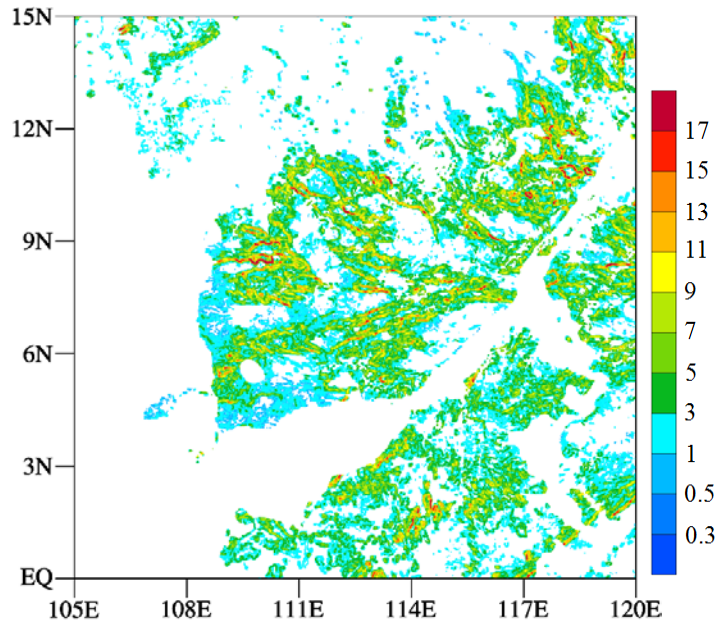


NFMFT

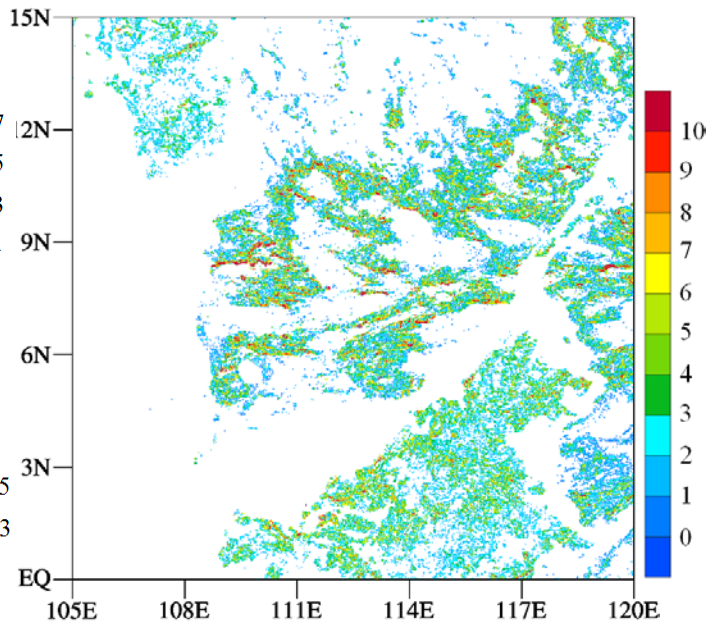


Cloud Mask within Tropical Convection (2/2)

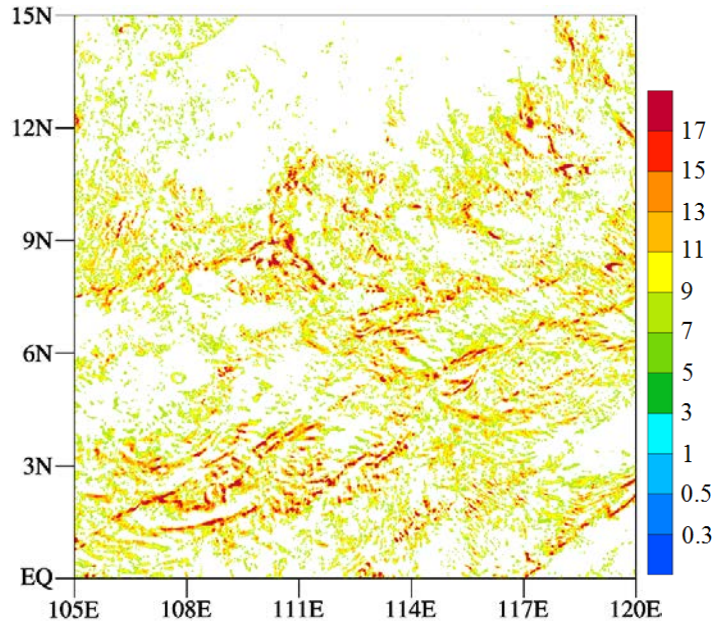
TUT



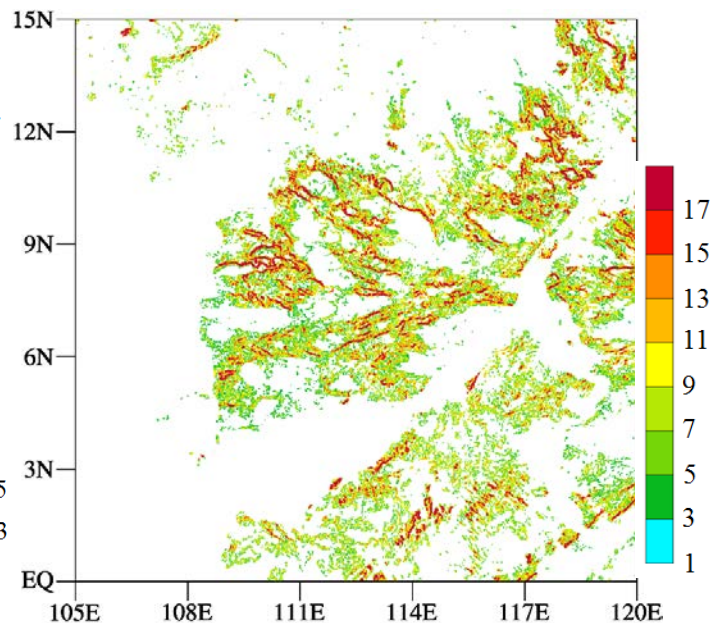
RFMFT



TEMPIR



RTCT

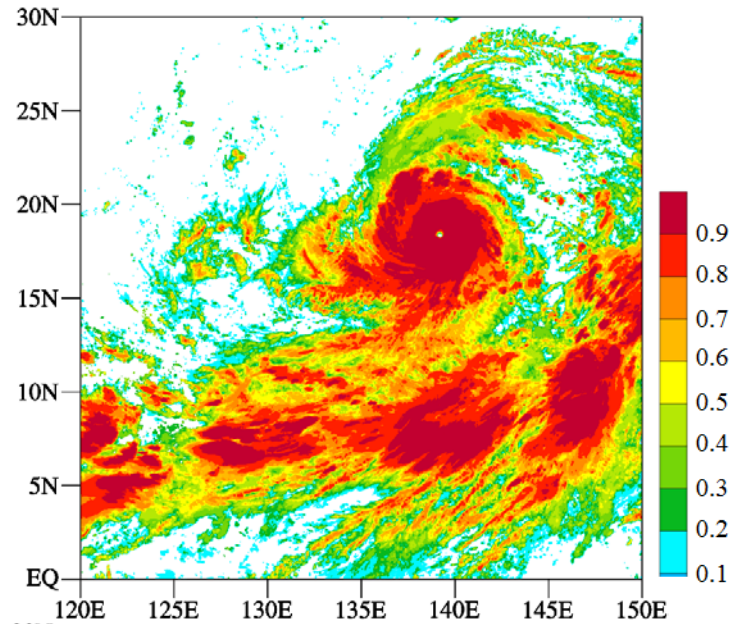


Comparison between Two Different Cloud Masks

Typhoon Soudelor

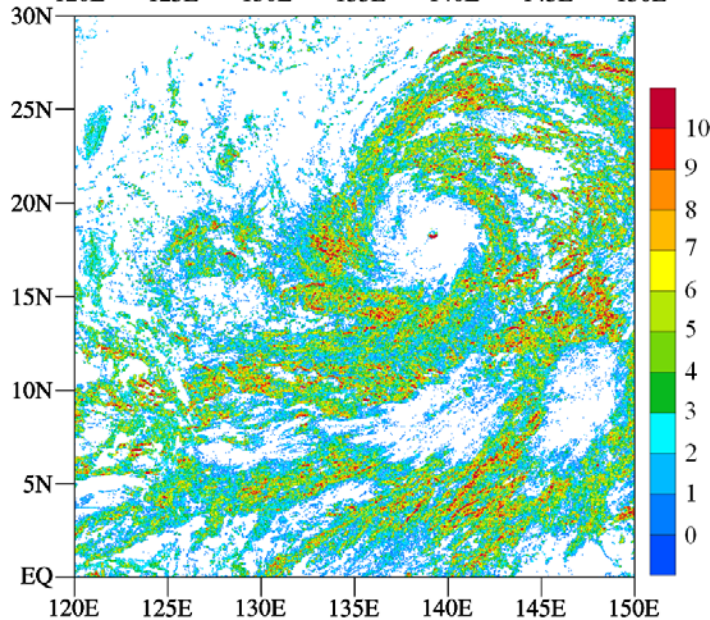
ETROP

Channel 14
Emissivity
Referenced to
the Tropopause

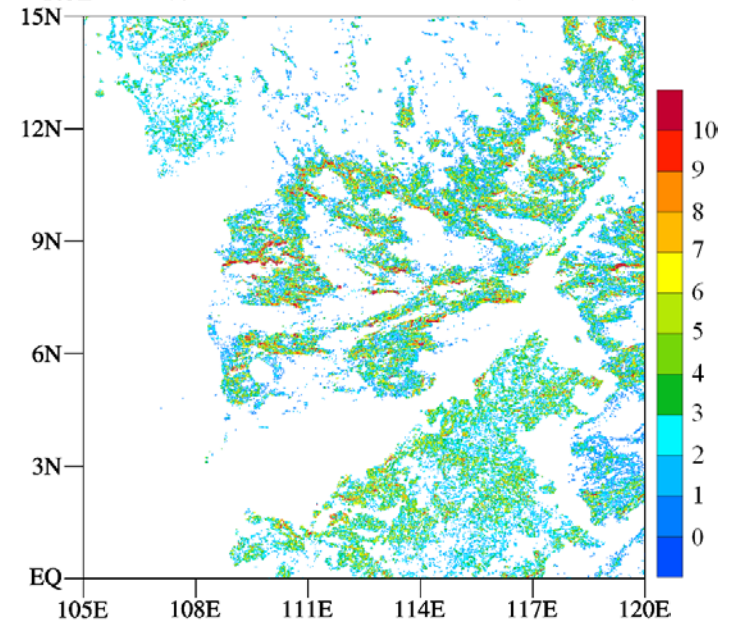
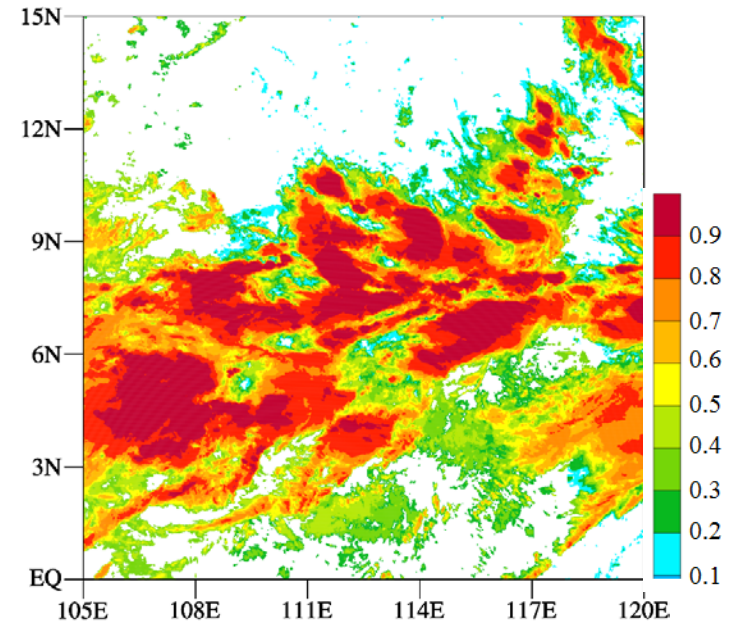


RFMFT

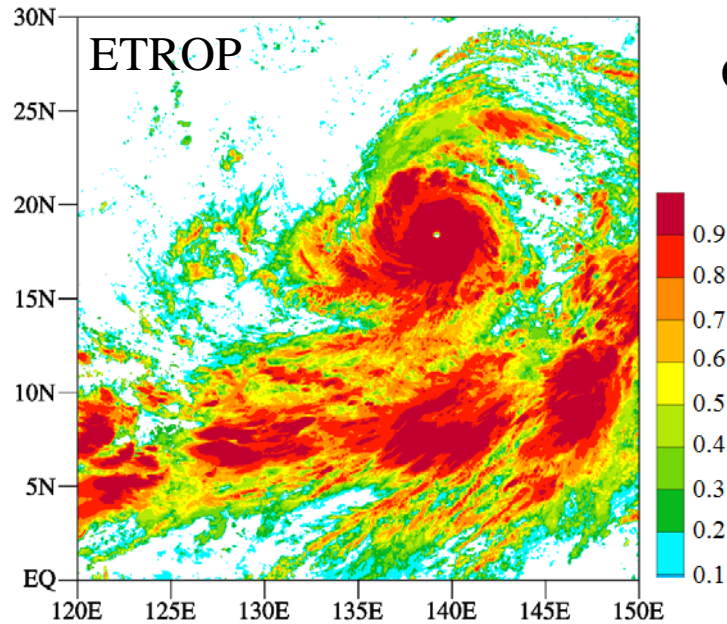
Relative
Four
Minus
Five Test



Tropical Convection



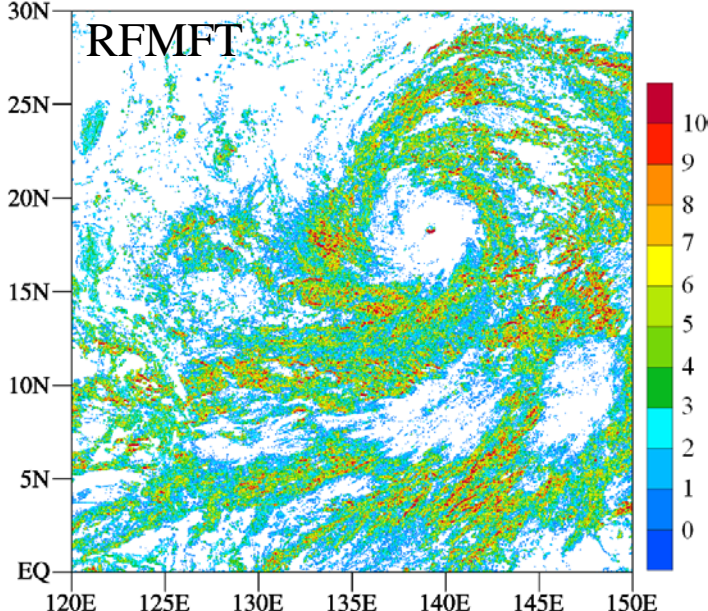
Comparison of Cloud Mask between Two Methods



Channel 14 Emissivity Referenced to the Tropopause

$$\epsilon_{ETROP} = \frac{I_{11.2\mu m}^{obs} - I_{clear-sky}^{CRTM}}{I_{blackbody} - I_{clear-sky}^{CRTM}}$$

The ETROP test assumes that clouds produce colder $11.2\mu m$ brightness temperatures than what would have been observed under clear-sky conditions.



Positive Four Minus Five Test

$$\chi_{RFMFT} = \max_{5 \times 5} \Delta I_{11.2-12.3}^{obs, NWC} - \Delta I_{11.2-12.3}^{CRTM clear-sky}$$

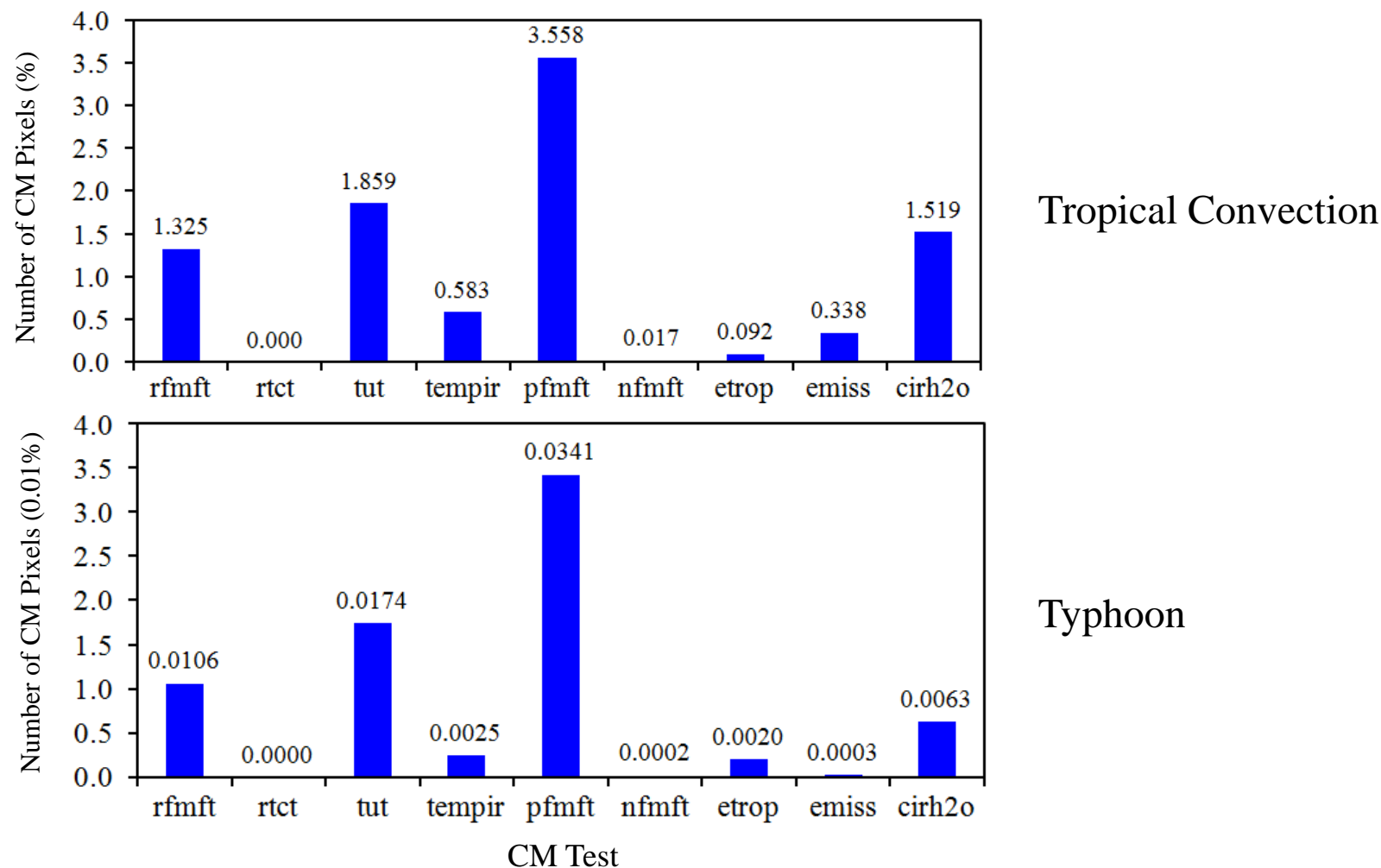
$$\Delta I_{11.2-12.3}^{obs} = I_{11.2\mu m}^{obs} - I_{12.3\mu m}^{obs}$$

$$\Delta I_{11.2-12.3}^{CRTM clear-sky} = I_{11.2\mu m}^{CRTM clear-sky} - I_{12.3\mu m}^{CRTM clear-sky}$$

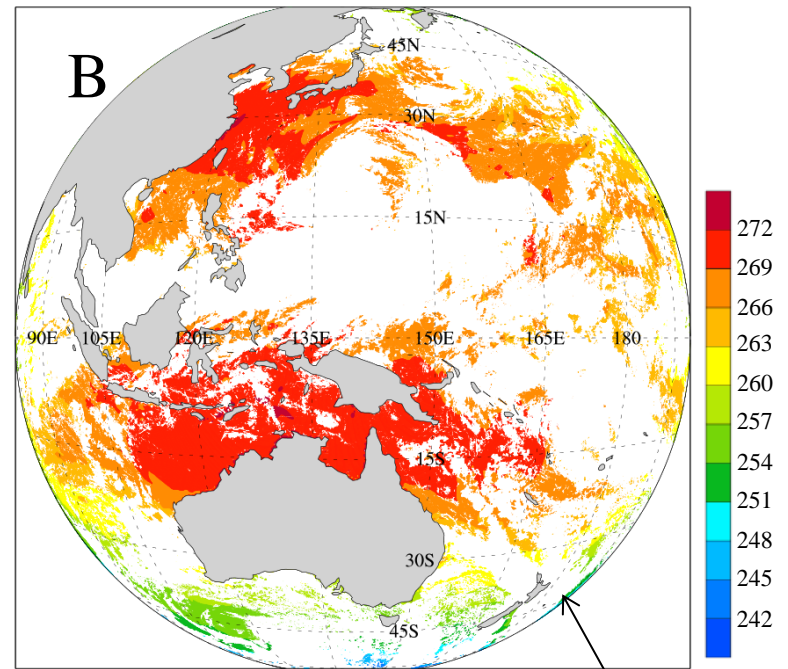
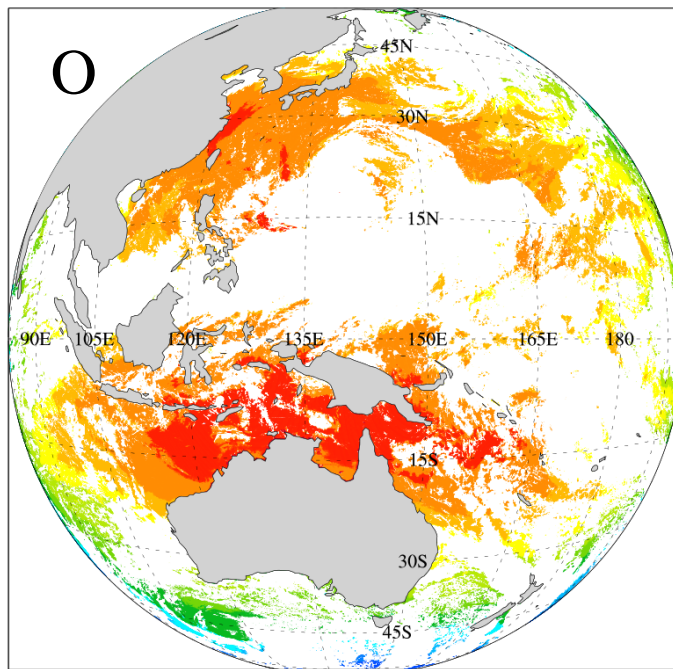
The basis for the RFMFT test is the variation in

$$\Delta I_{11.2-12.3}^{obs} \text{ for cloudy conditions.}$$

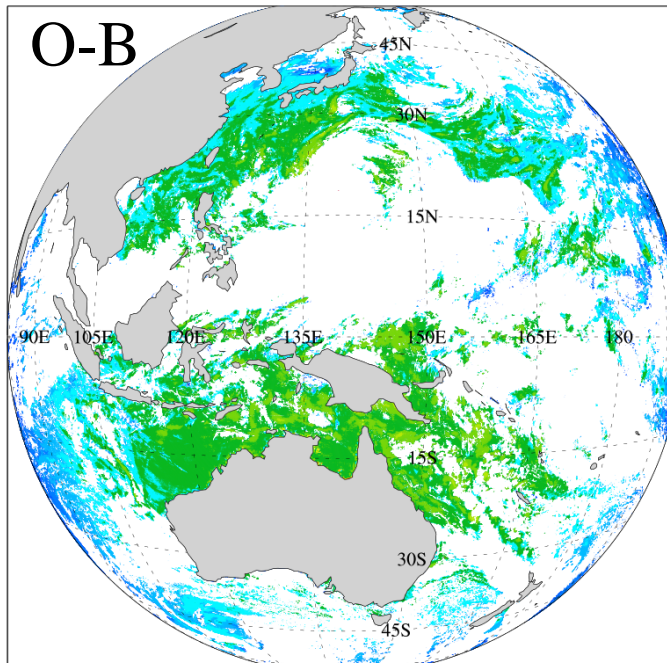
Overlap of Cloudy Pixels Found by Nine Cloud Masks



Percentage of cloudy pixels detected by one CM but not by any other CMs for AHI data within two selected regions (105E-120E, 0-15N; 120E-150E, 0-30N) at 0130 UTC August 4, 2015. The total number of cloudy pixels within the two regions detected by nine CMs are 551,384 and 2,382,845.



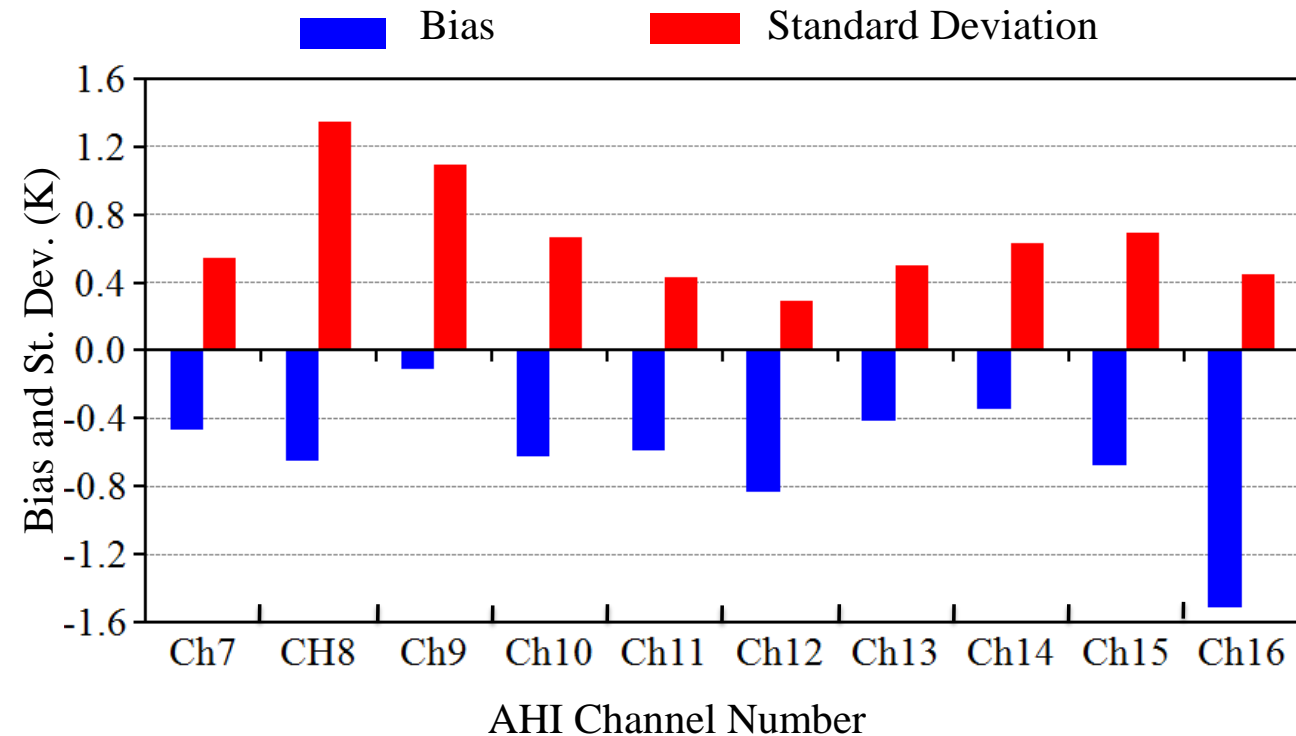
**AHI Observed
and
CRTM/ECMWF
Simulated
Brightness
Temperatures
of Channel 16
in Clear-Sky
Conditions**



CRTM/ECMWF

0130 UTC
August 4, 2015

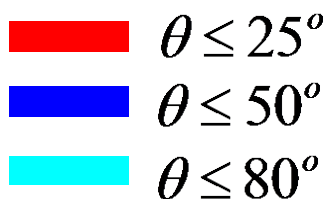
Bias and Standard Deviation between AHI Observations and CRTM/ECMWF Simulations



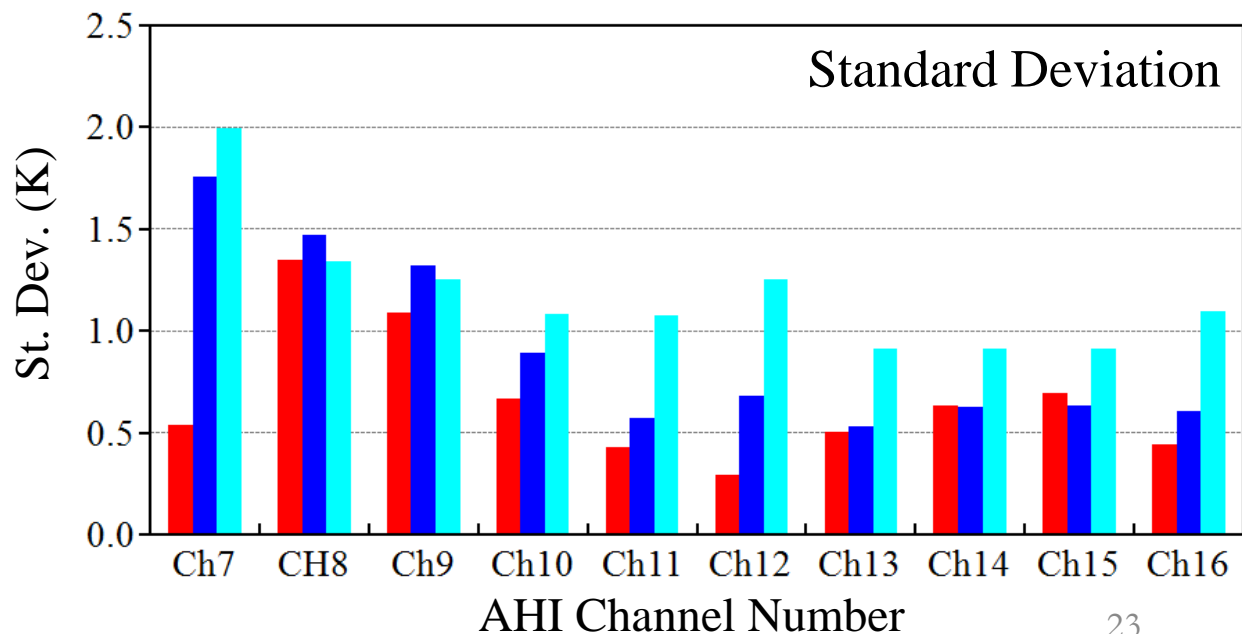
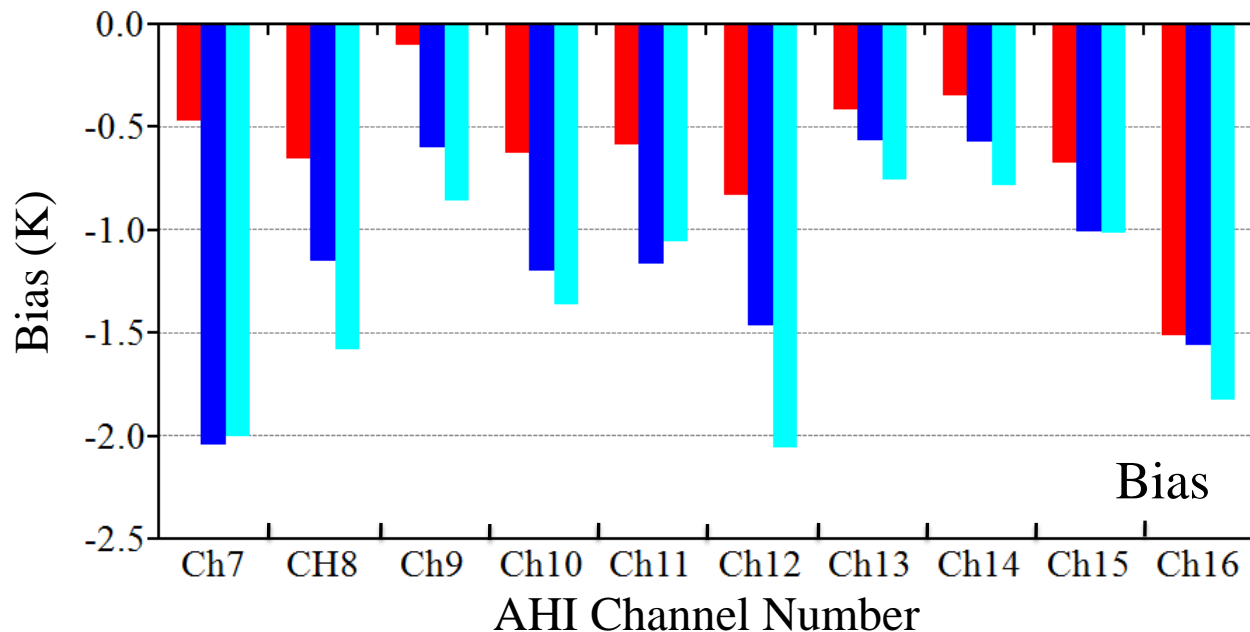
Channel	Bias (K)	Std. (K)
7	-0.47	0.54
8	-0.65	1.34
9	-0.11	1.09
10	-0.62	0.67
11	-0.58	0.43
12	-0.83	0.29
13	-0.41	0.50
14	-0.34	0.63
15	-0.67	0.69
16	-1.51	0.44

All clear-sky data with satellite zenith angle being less than 25° over ocean in clear-sky conditions on August 4, 2015 at half-hour interval.

Estimated AHI O-B Biases and Standard Deviations



All clear-sky data over
ocean on August 4, 2015
at half hour interval.

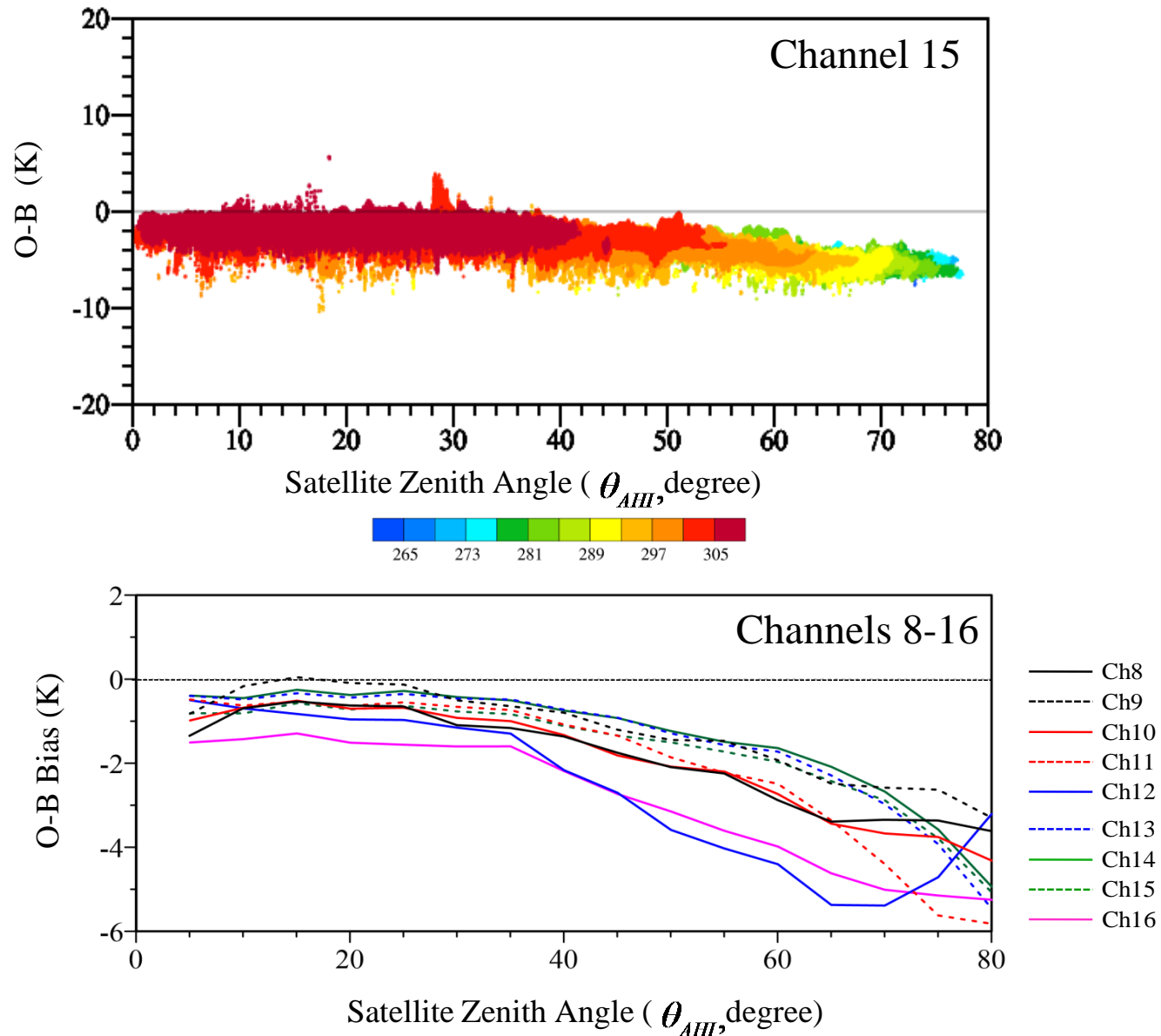


Bias and Standard Deviation between AHI Observations and CRTM/ECMWF Simulations

Channel Number	Bias (K)			Std. (K)		
	$\theta \leq 25^\circ$	$\theta \leq 50^\circ$	$\theta \leq 80^\circ$	$\theta \leq 25^\circ$	$\theta \leq 50^\circ$	$\theta \leq 80^\circ$
7	-0.47	-2.04	-2.00	0.54	1.75	1.99
8	-0.65	-1.15	-1.58	1.34	1.47	1.34
9	-0.11	-0.60	-0.86	1.09	1.32	1.25
10	-0.62	-1.20	-1.36	0.67	0.89	1.08
11	-0.58	-1.16	-1.06	0.43	0.57	1.07
12	-0.83	-1.46	-2.05	0.29	0.68	1.25
13	-0.41	-0.56	-0.76	0.50	0.53	0.91
14	-0.34	-0.57	-0.78	0.63	0.62	0.91
15	-0.67	-1.00	-1.01	0.69	0.63	0.91
16	-1.51	-1.55	-1.82	0.44	0.61	1.09

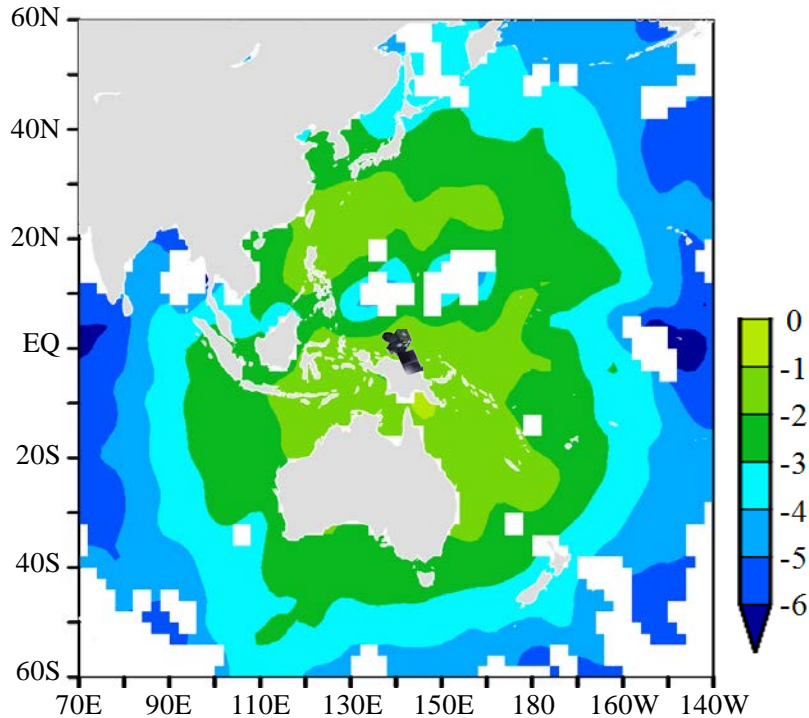
All data at half-hour interval over ocean in clear-sky conditions on August 4, 2015.

AHI O-B Bias Dependence on Zenith Angle

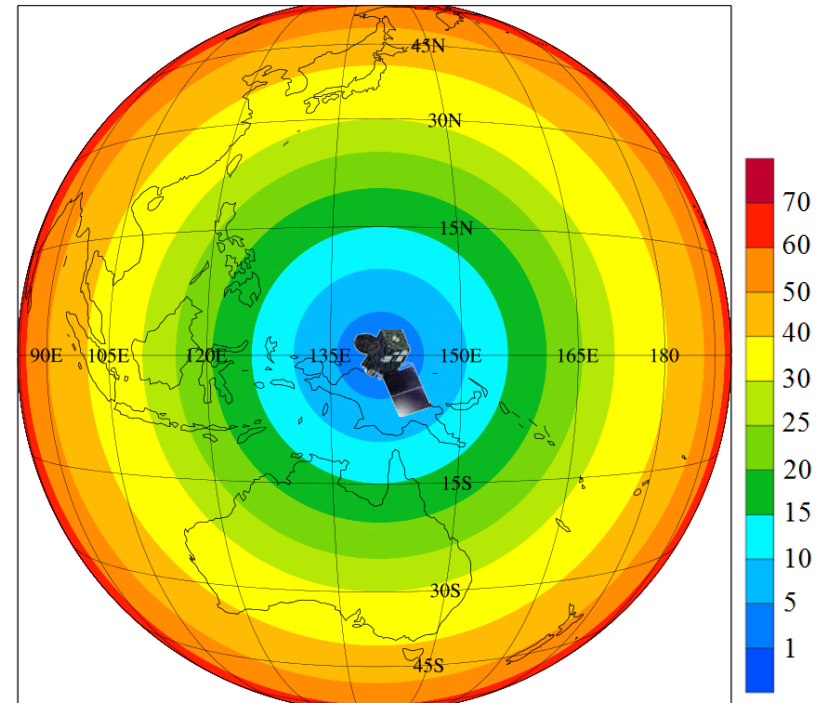


Spatial Distribution of AHI O-B Bias of Channel 16

Channel 16



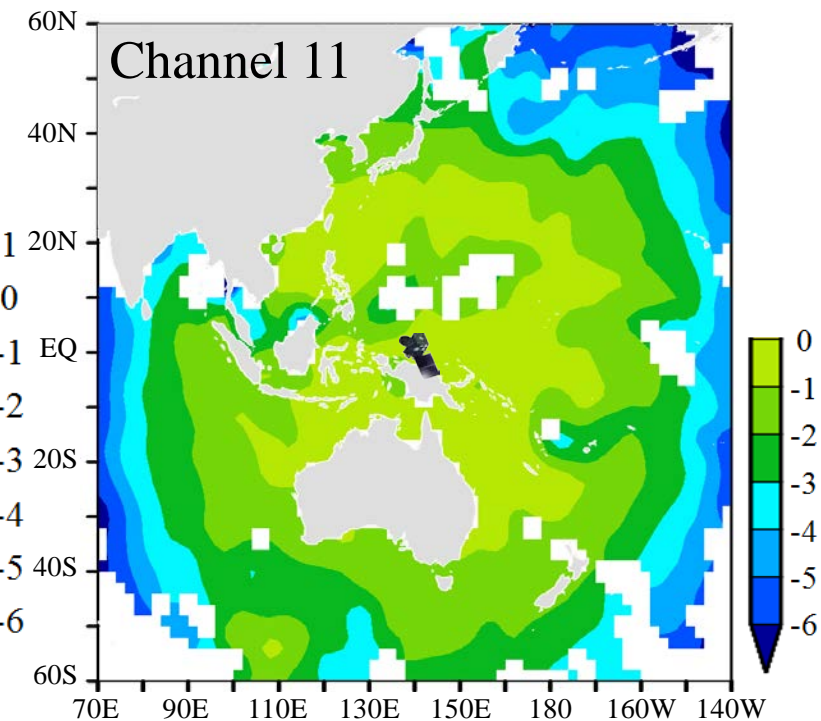
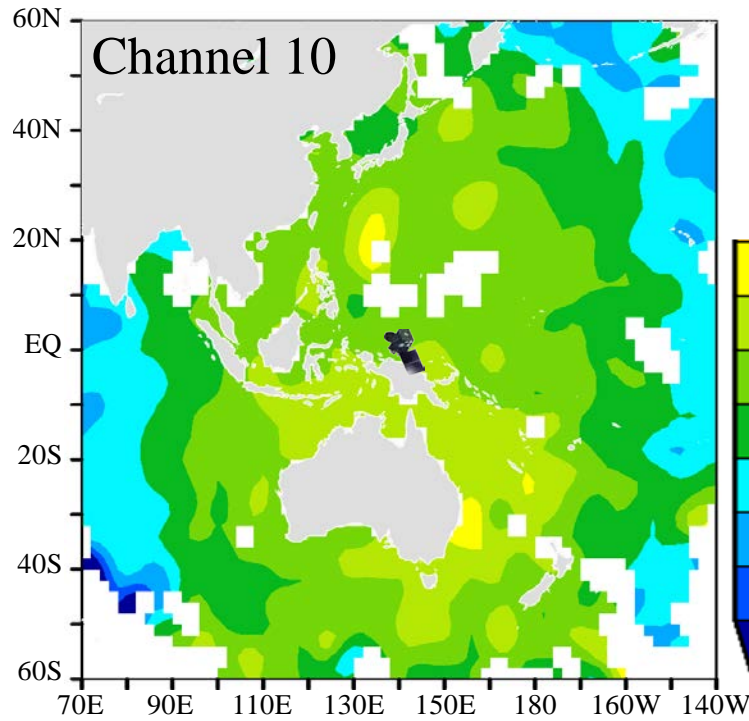
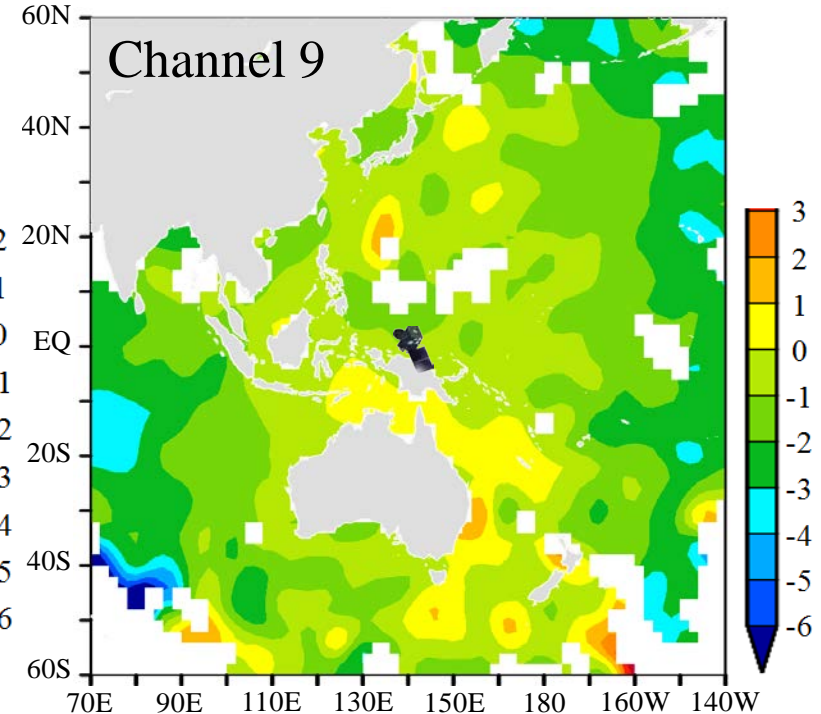
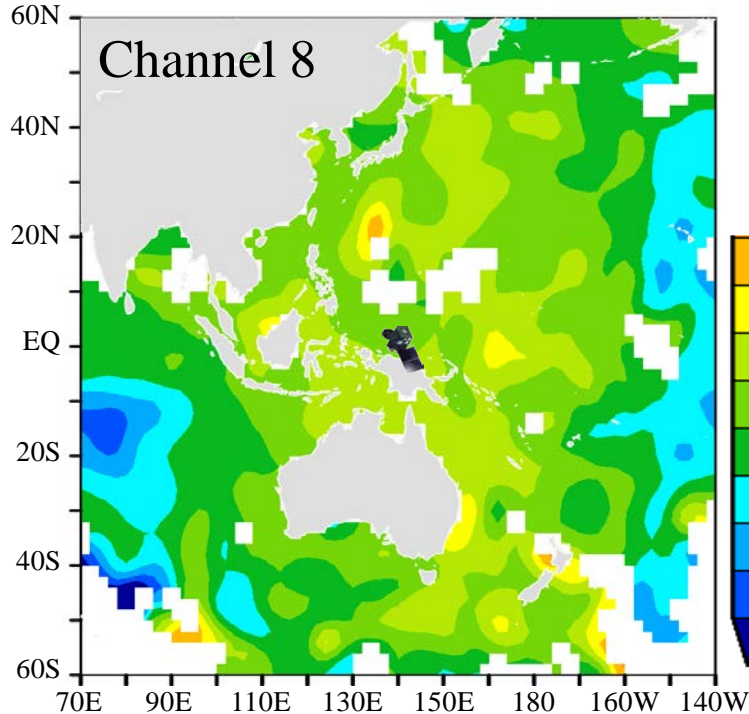
θ_{AHI}



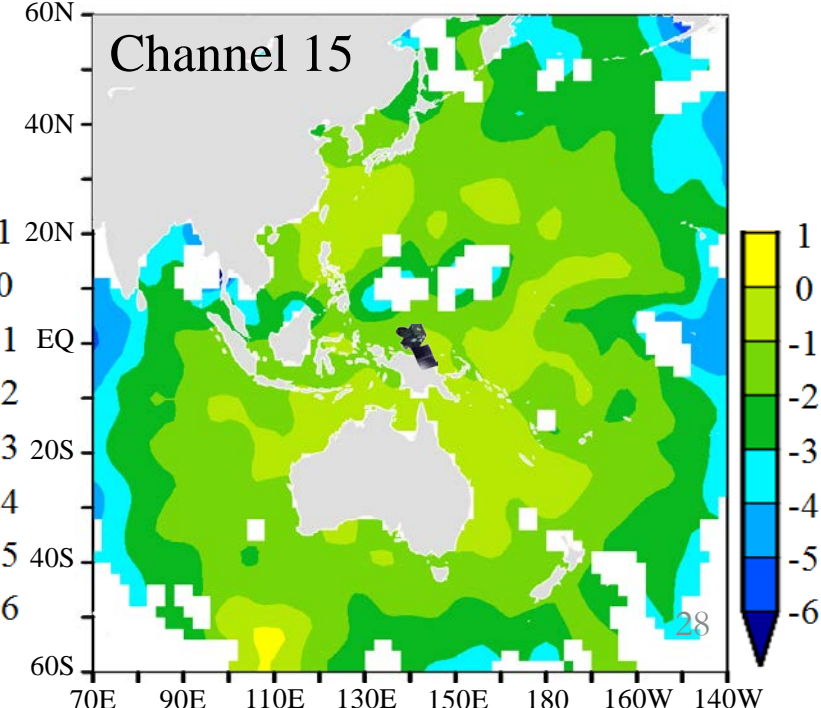
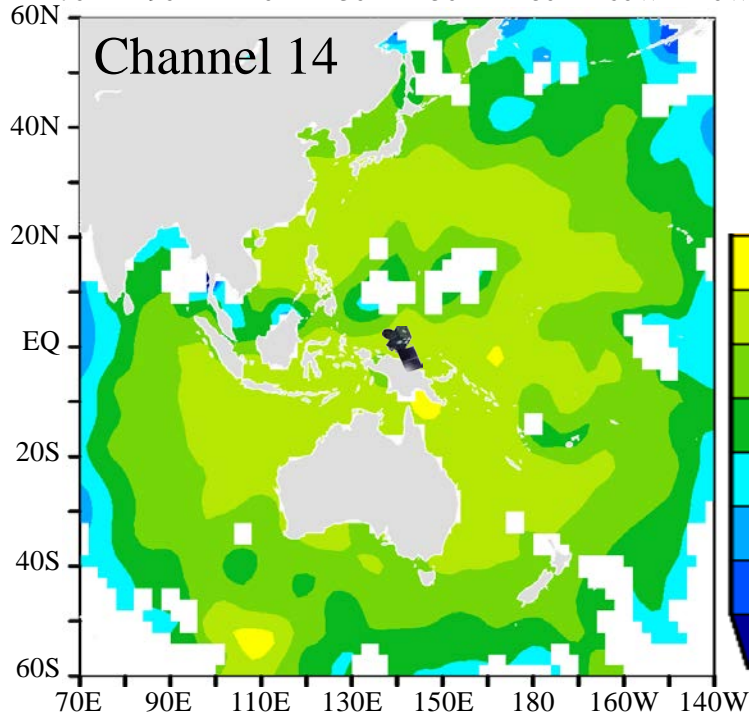
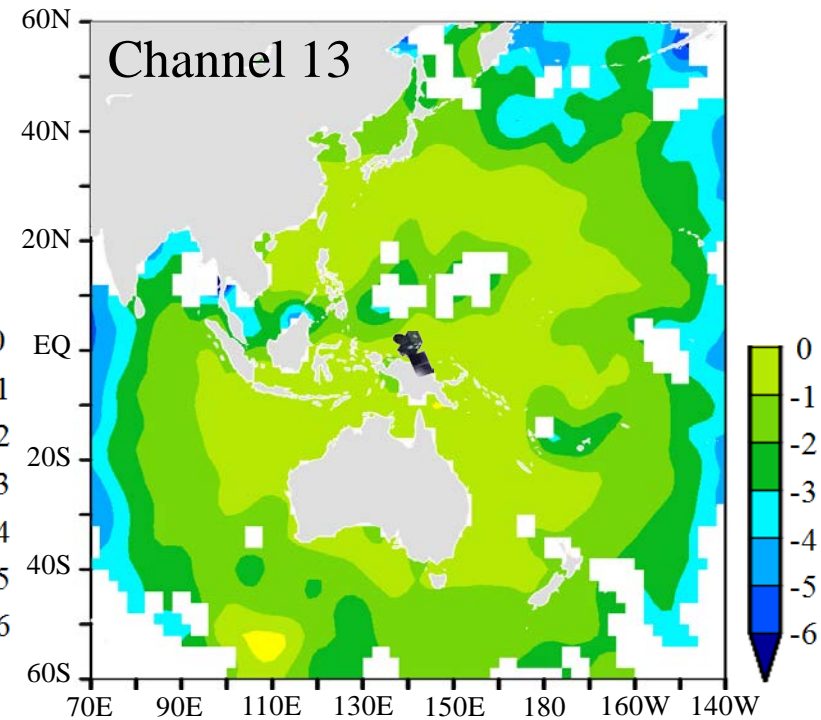
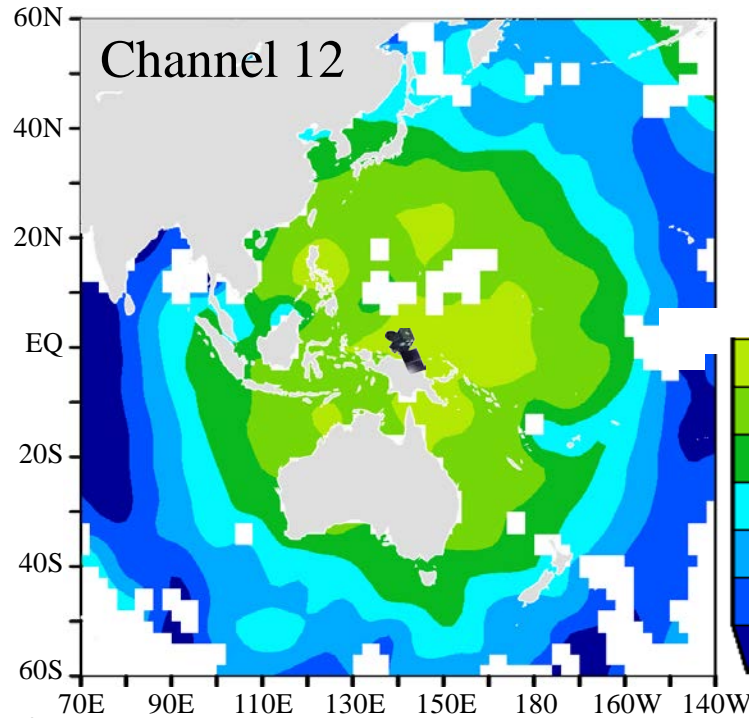
- The AHI O-B bias increases with satellite zenith angle
- The O-B bias of AHI channel 16 increases from zero to about 6 K when the satellite zenith angle changes from zero to more than 70°

All clear-sky data over ocean on August 4, 2015 at half hour interval.

**O-B
Biases
of AHI
Channel
8-11**

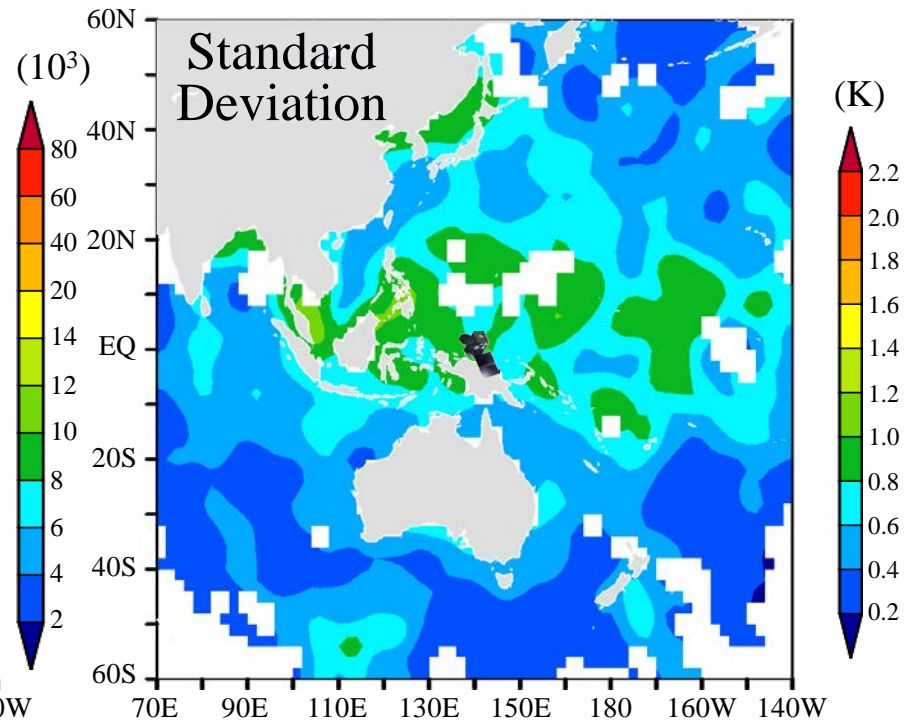
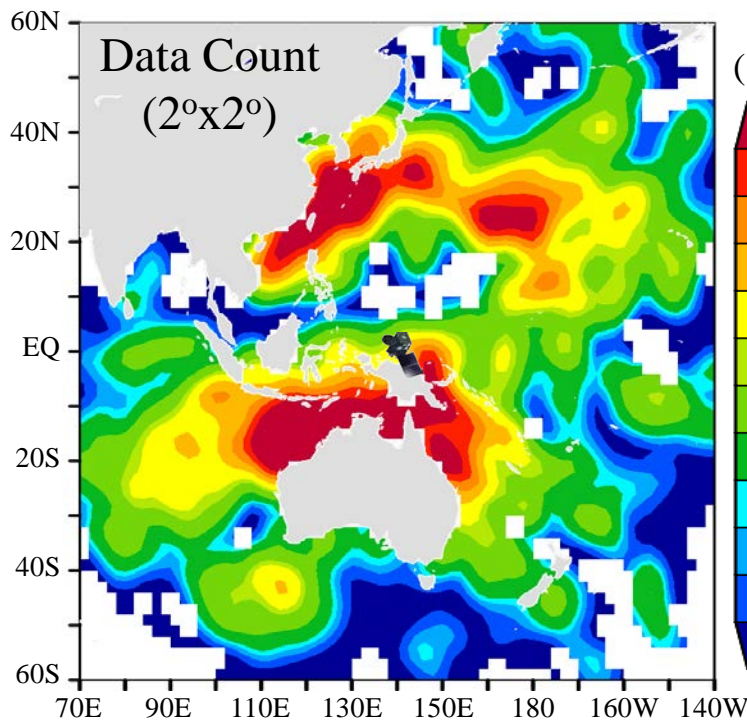
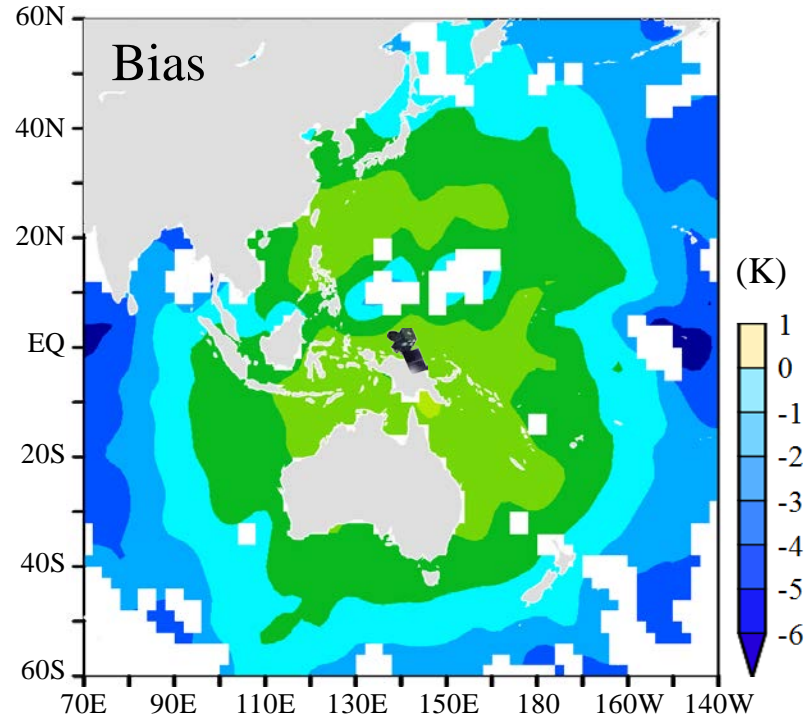


**O-B
Biases
of AHI
Channel
12-15**



Spatial Distribution of AHI O-B Bias and Standard Deviation of Channel 16

- Zenith dependent bias is independent of data count distributions
 - Standard deviation is usually larger when data counts are smaller
- All clear-sky data over ocean on August 4, 2015 at half hour interval.



Summary and Conclusions

- Assimilation of GOES imager radiance in HWRF resulted in improvements in hurricane track and intensity forecasts and coastal QPFs
- GOES-R AWG cloud mask algorithm is fully vetted in the baseline HWRF/DA system for quality control of clear-sky radiance assimilation
- The bias of AHI radiance data is evaluated with respect to the ECMWF forecast fields. In clear-sky conditions, O-B bias is dependent on scan angle
- Future AHI data assessment will be extended to cloudy conditions and O-B bias features will be separately characterized according to different cloudy types and surface conditions.