Impact of all-sky microwave radiance assimilation on analysis and prediction of tropical cyclone in the JMA's global 4D-Var DA system

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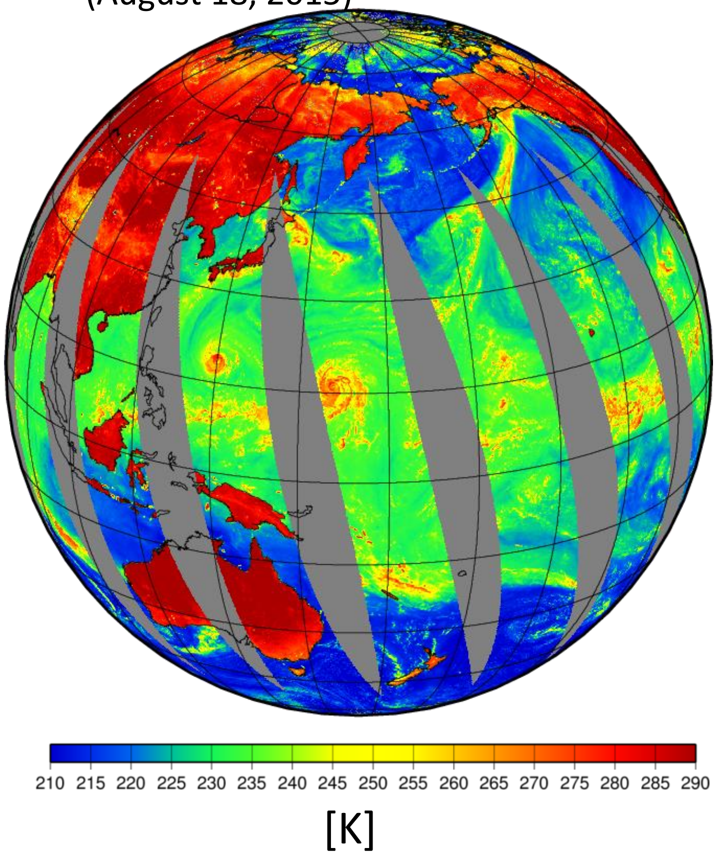
Contents

ECMWF/ESA Workshop: Tropical modelling, observations and assimilation, 7 – 10 November, 2016 ECMWF

Introduction

Microwave Imager observations contain various information on geophysical parameters, e.g., **atmospheric water vapor**, **cloud water**, **precipitation**, **surface wind** and **surface temperature** over ocean.

GCOM-W/AMSR2 37GHz V-pol.
Brightness Temperature (Tb)
(August 18, 2015)



However, present microwave imager Tb data assimilation (DA) focuses on **atmospheric water vapor** information. Because,
cloud and rain affected Tb data are not assimilated in operational JMA global DA system.

Research Objective
Obtain temperature and water vapor information in **cloudy areas**.

Cloudy areas are sensitive to accuracy of severe weather event forecasting (e.g., heavy precipitation, tropical cyclone, mid-latitude cyclone associated with convective storms)

Improvements of analysis in the cloudy areas must bring **better precipitation and tropical cyclone predictions**

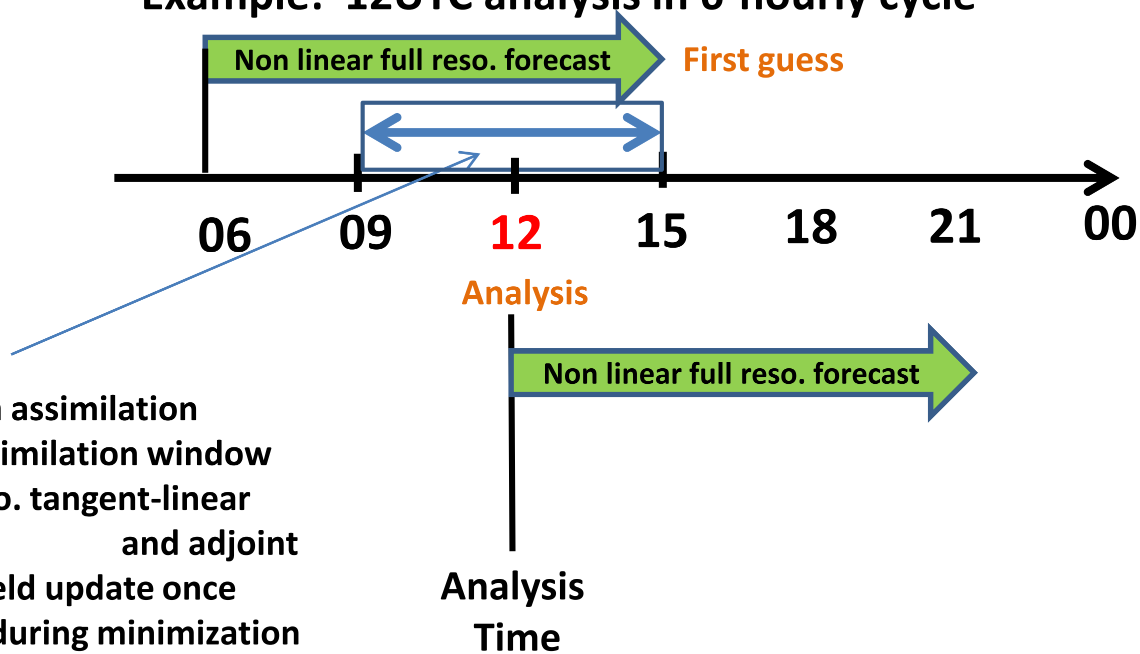
Methodology

Components of all-sky MW radiance assimilation

1. **Cloud and precipitation radiative transfer**
   RTTOV_SCATT developed by NWP-SAF in EUMETSAT
2. **Cloud and precipitation-capable forecast model**
   JMA global model, GSM (TL959L100), as of March 2016
3. **Radiance observations**
   MW-Imagers, i.e., AMSR2, SSMIS, GMI.
4. **Data assimilation methods**
   4D-Var data assimilation

Hydrometeors profiles (**cloud liquid water, cloud ice water, cloud cover, rain, snow**) are obtained from full-resolution GSM for all-sky MW RT calculation.

Example: 12UTC analysis in 6-hourly cycle



4D-Var data assimilation
- **6-hr assimilation window**
- **low reso. tangent-linear and adjoint**
- **Basic field update once during minimization**

Methodology

all-sky observation error setting (Geer and Bauer 2011)

All-sky observation error is defined based on a symmetric predictor $\overline{C_{37}}$ sensitive to CLW in 37GHz observed and simulated radiance.

Averaged Cloud amount

$$\boxed{\overline{C_{37}} \equiv \frac{C_{37}^{b} + C_{37}^{o}}{2}}$$

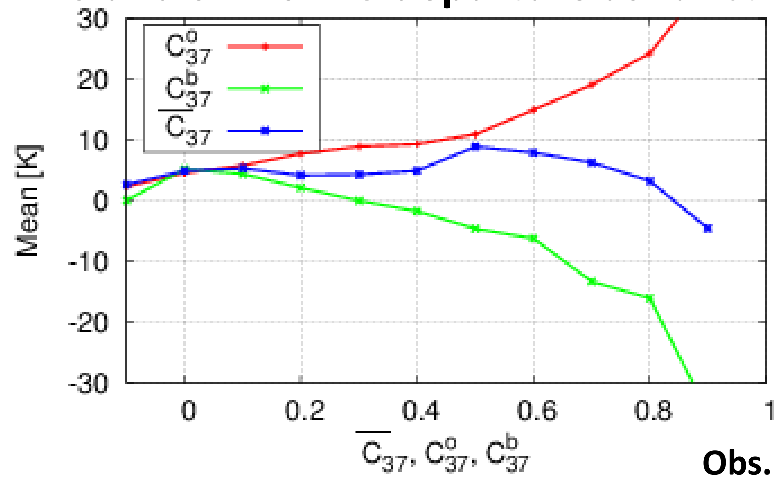
$$C_{37} = 1 - P_{37},$$

$$P_{37} \equiv \frac{T^{v} - T^{h}}{T_{CLR}^{v} - T_{CLR}^{h}} \approx \tau_{CLD}^{2}$$

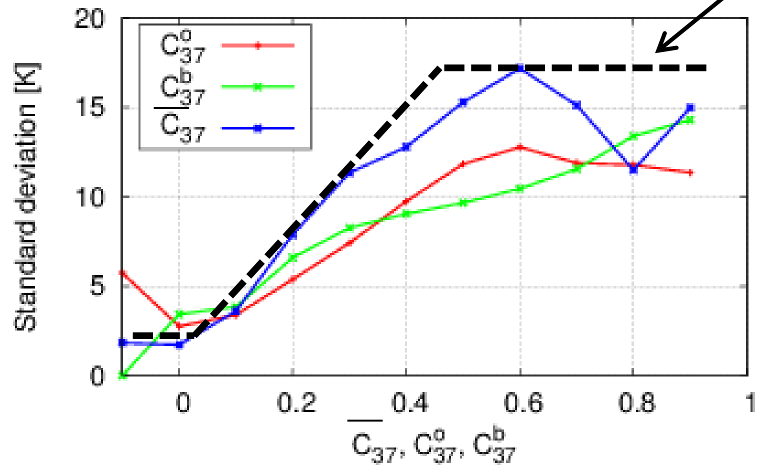
If the observation and forecast model are unbiased each other as assumed in variational DA, the statistics should be symmetric. **Blue line (bias measured by the symmetric predictor) should be flat.**

AMSR-2 19GHz V

BIAS and STD of FG departure as function of $\overline{C_{37}}$



Obs. Error Setting



Data assimilation experiment

CNTL run

Clear sky MW radiance assimilation

- RTM
  - RTTOV-10 (**rttov_direct**)
  - Input profile
    - Temperature, Water vapor
- Data thinning
  - **200 km grid-box thinning**
- Used MW imager
  - AMSR2, SSMIS (F16, F17, F18), GMI 19GHzV, 23GHzV, 37GHzV, **89 GHzV**
- **Constant observation error**

TEST run

All-sky MW radiance assimilation

- RTM
  - RTTOV-10 (**rttov_scatt**)
  - Input profile
    - Temperature, Water vapor, **cloud liquid water, cloud ice water, cloud fraction, rain, snow**
- Data thinning
  - **Averaging with inner model grid** and 200 km distance thinning
- Used MW imager
  - AMSR2, SSMIS (F16,17,18), GMI 19GHzV, 23GHzV, 37GHzV
- **Symmetric observation error depending on symmetric cloud amount**

Data assimilation experiment

DA system: JMA global 4D-Var DA system

Resolution:

Outer model: TL959L100, horizontal reso. 20km, top 0.01 hPa

Inner model: TL319L100, horizontal reso. 55 km, top 0.01 hPa

6-hr assimilation window, and cycling

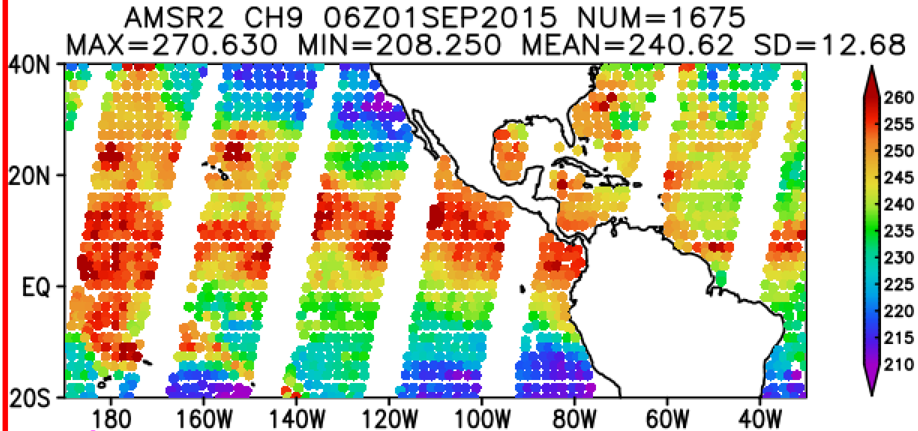
Period: From 10 June to 11 October, 2015

Forecast from 00, 06, 12, 18UTC initial every day

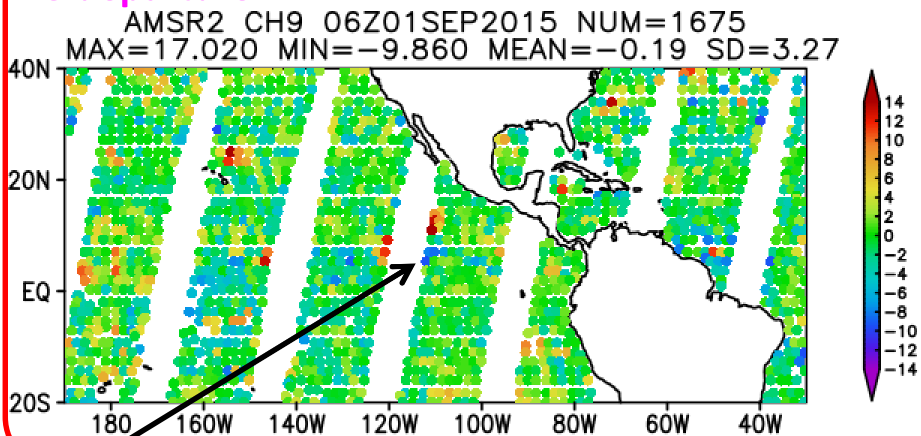
Comparison of assimilated MW imager Tb data

All-sky assimilation

Observation

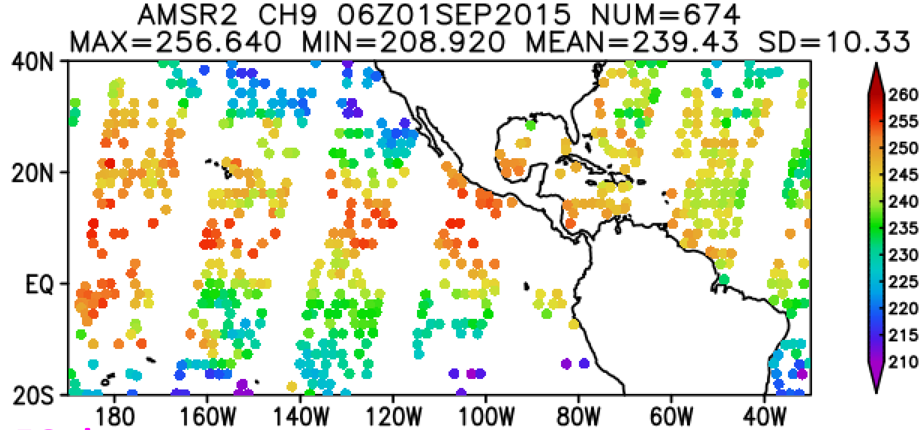


FG departure

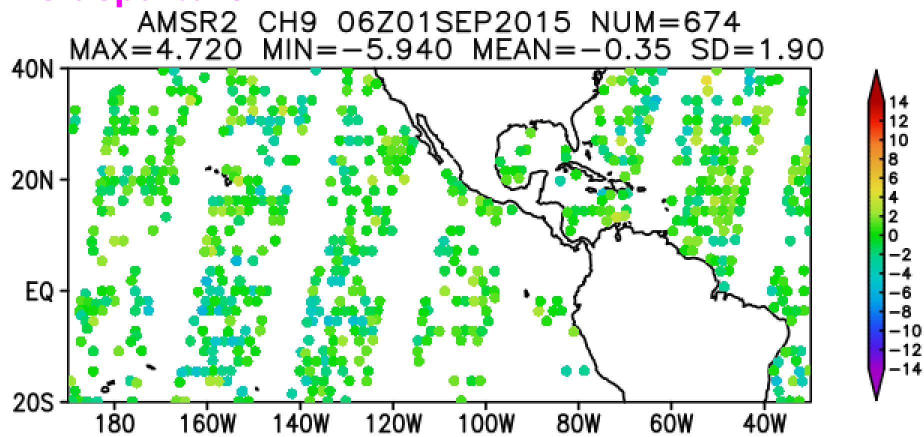


Clear-sky assimilation

Observation



FG departure

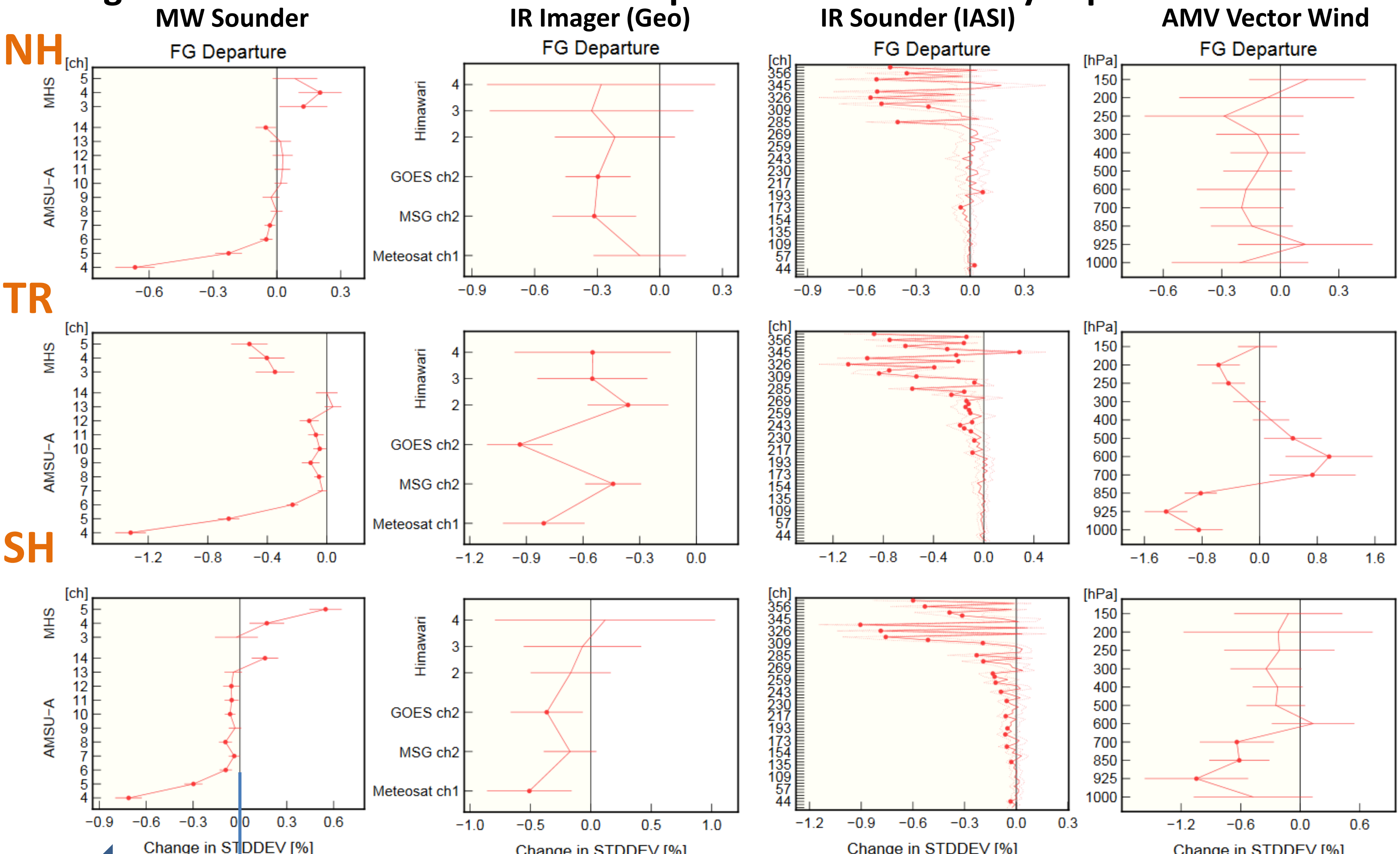


Increase of assimilated data
Large FG departure in cloudy and rainy areas
(paired (positive, negative) FG departure distribution. i.e., **information on mislocation**)

Small FG departure in clear-sky areas

FG fit to observations

Changes of standard deviation of FG departure from clear-sky exp.



Negative value indicates improvements

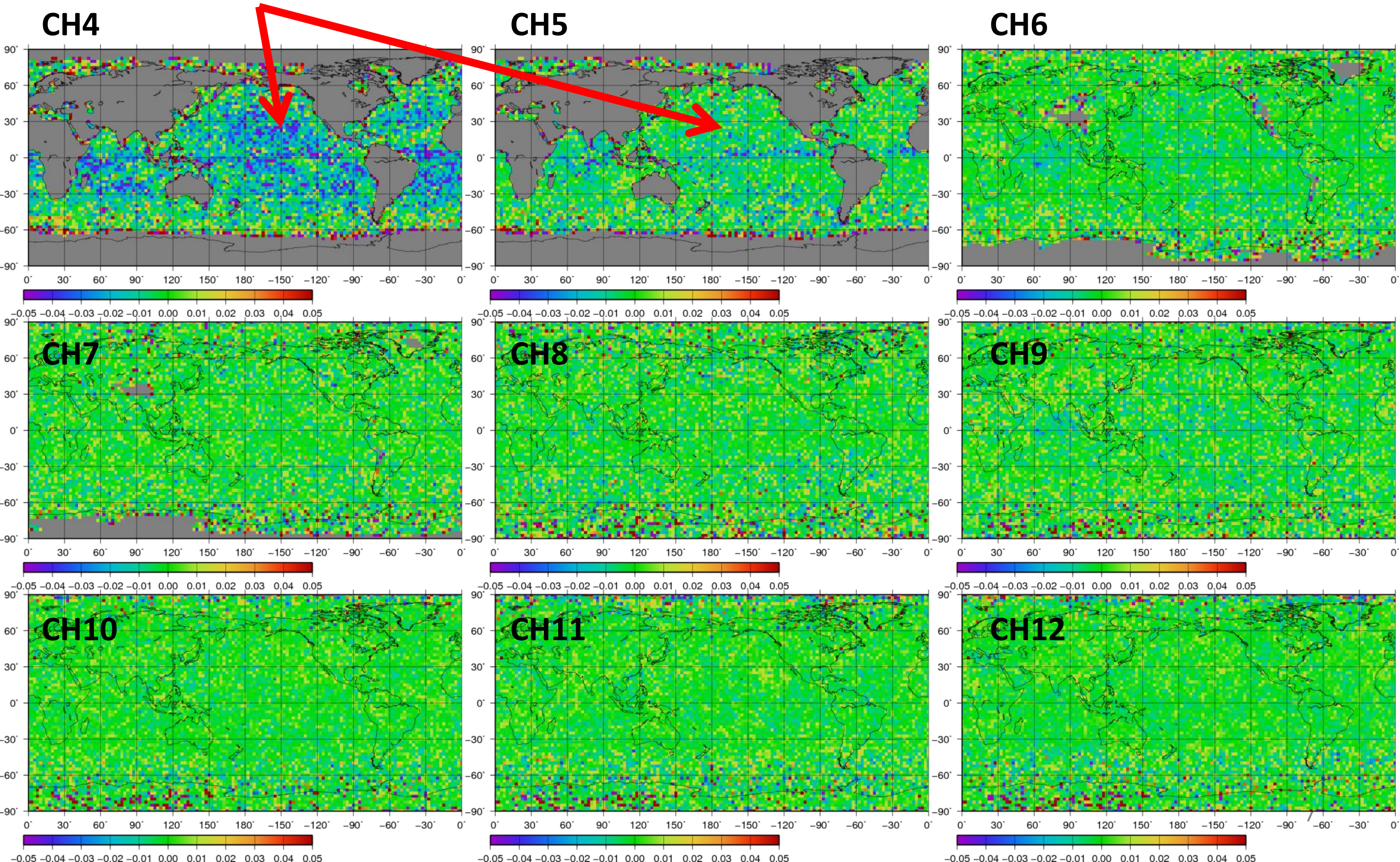
Generally, large positive impacts on temperature, water vapor in the Tropics.

Negative: Water vapor in mid-latitudes, wind in the Tropics.

Changes of standard deviation of AMSUA FG departure

Blue color indicates improvement

Improvement of lower tropospheric temperature over ocean



Change in RMSE of zonal wind forecast

RMSE is against own analysis

(CNTL-TEST)/CNTL

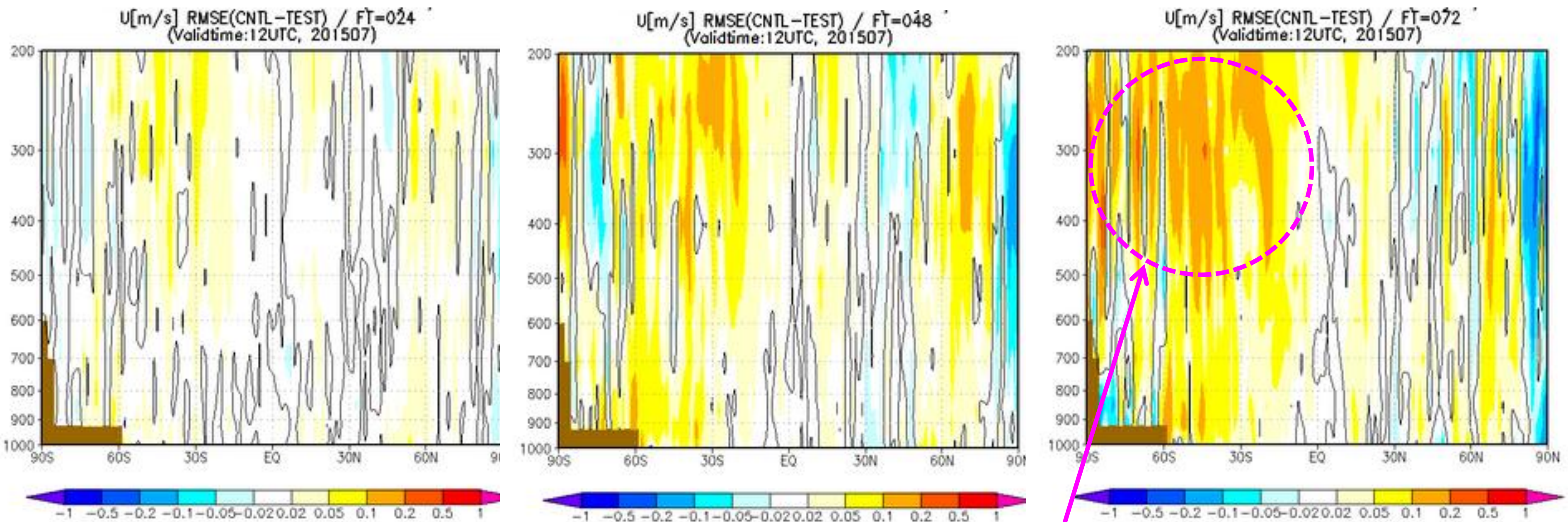
TEST: all-sky assimilation

CNTL: clear-sky assimilation

Warm colors : improvement

Cold colors: degradation

FT=24 FT=48 FT=72



Improvement in upper troposphere wind forecast in the Southern Hemisphere

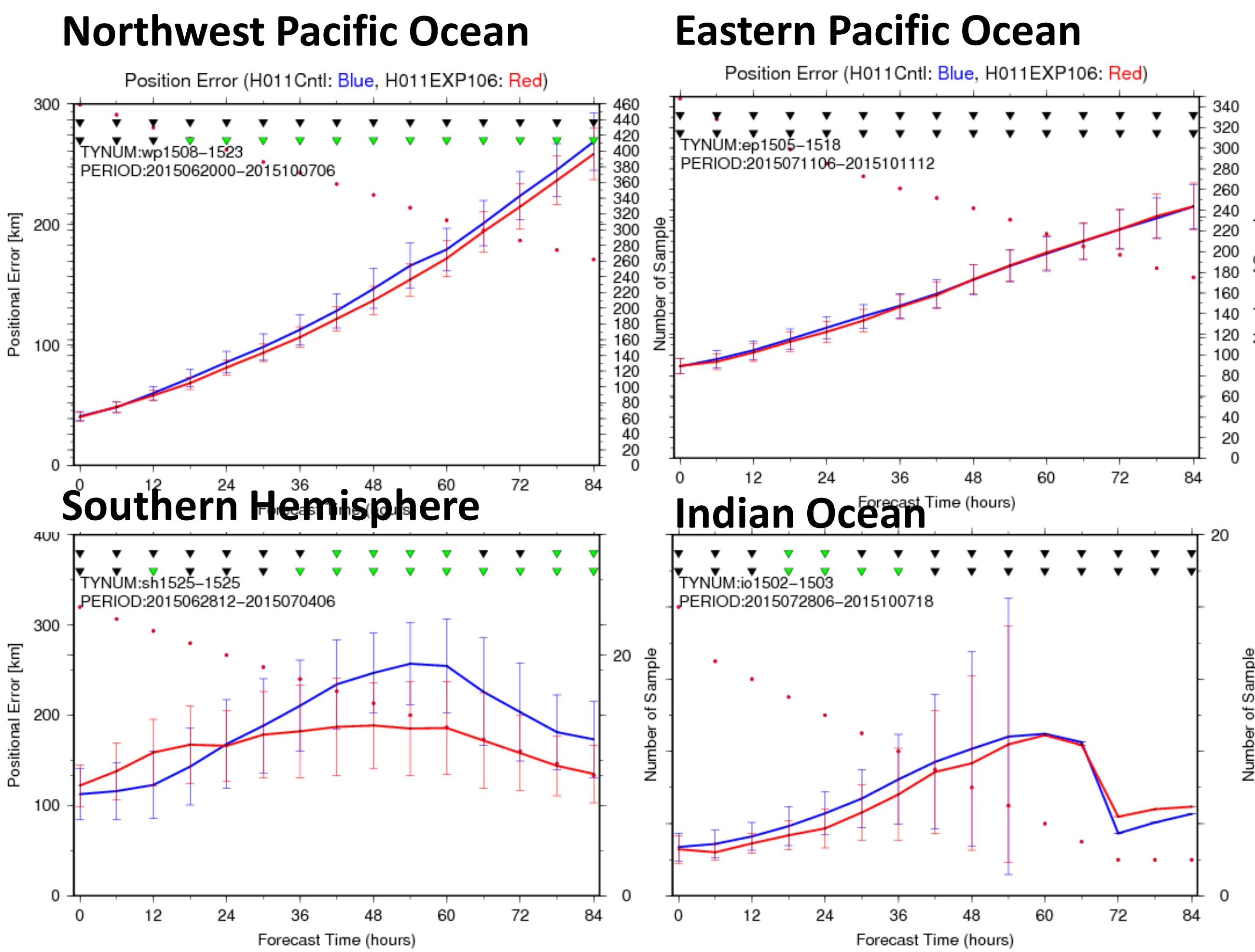
Comparisons: Positioning error of TC track predictions

Red: All-sky assimilation

Blue: Clear-sky assimilation

Truth data: NOAA TC best track

Period: June 20 to Oct. 11, 2015

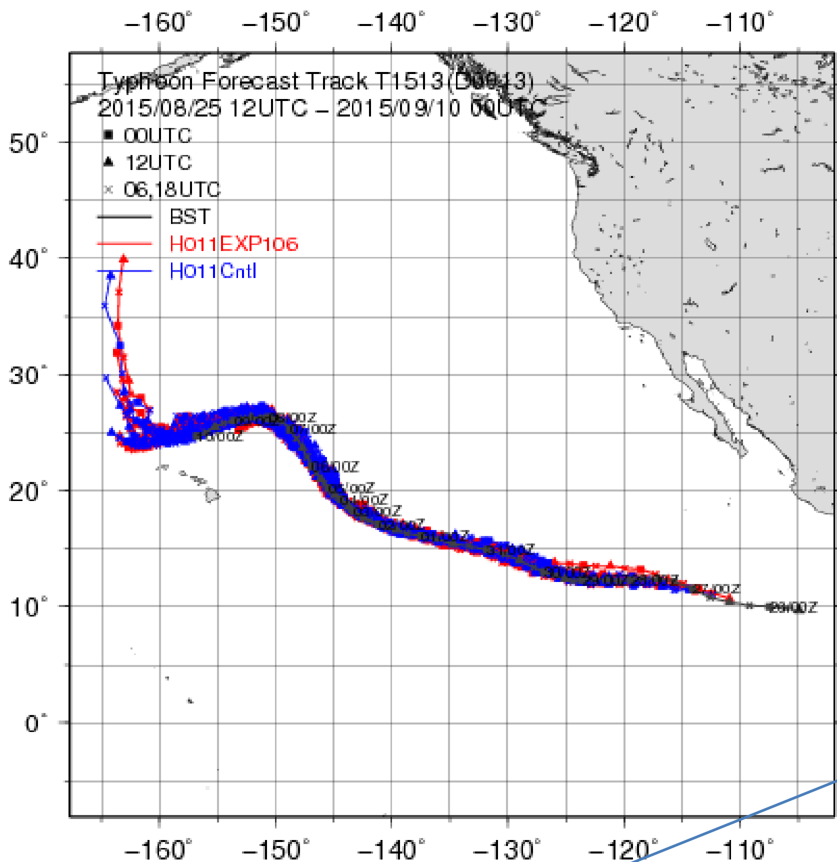


Generally, TC center prediction errors were reduced, except Atlantic Ocean.

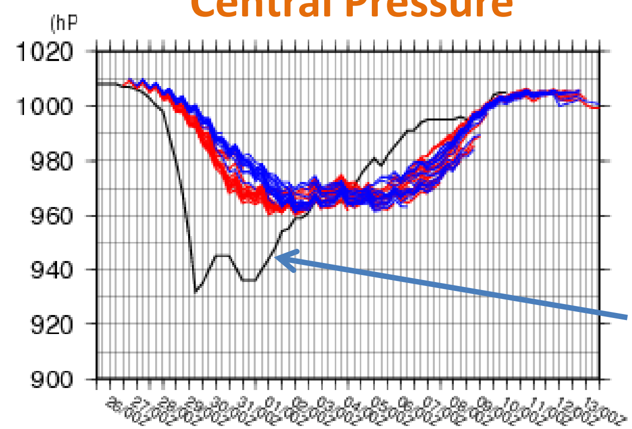
Impact on Tropical cyclone track, intensity and max. surface wind speed forecasting

Red: TEST (all-sky)
Blue: CNTL (clear-sky)

Black: Best track from NOAA
Period: From Aug. 24 to Sep. 10 2015

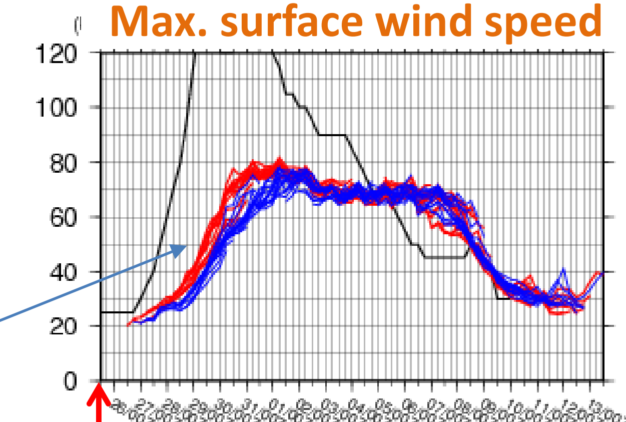


Central Pressure



Black line: NOAA Best track

Max. surface wind speed



Realistic TC predictions in the developing stage.

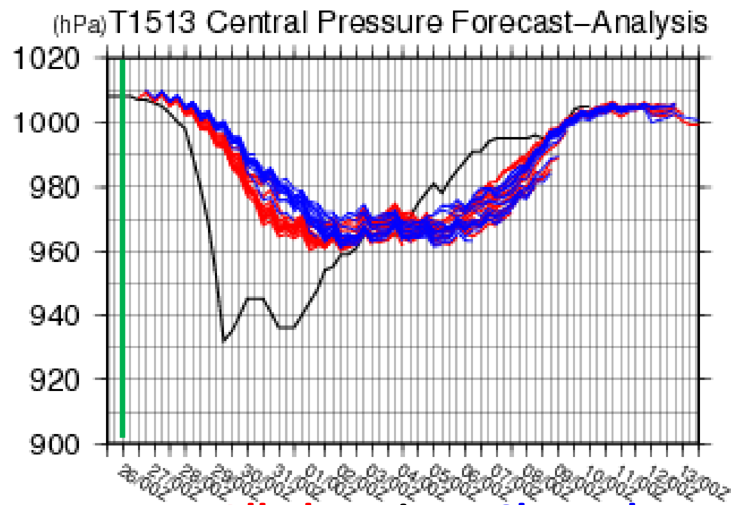
Start time of TC analysis by NOAA (12 UTC 25 Aug.)

Change of water vapor field in TC

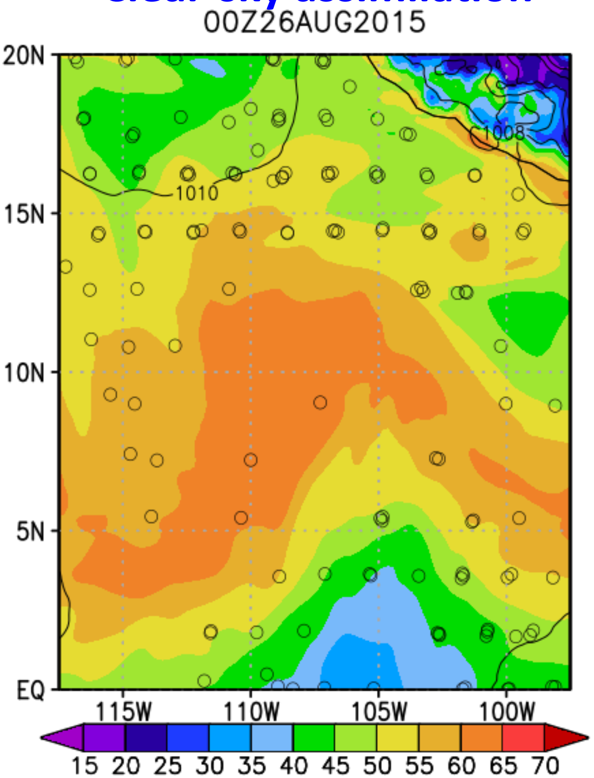
TC formation stage

TPW concentration around TC center

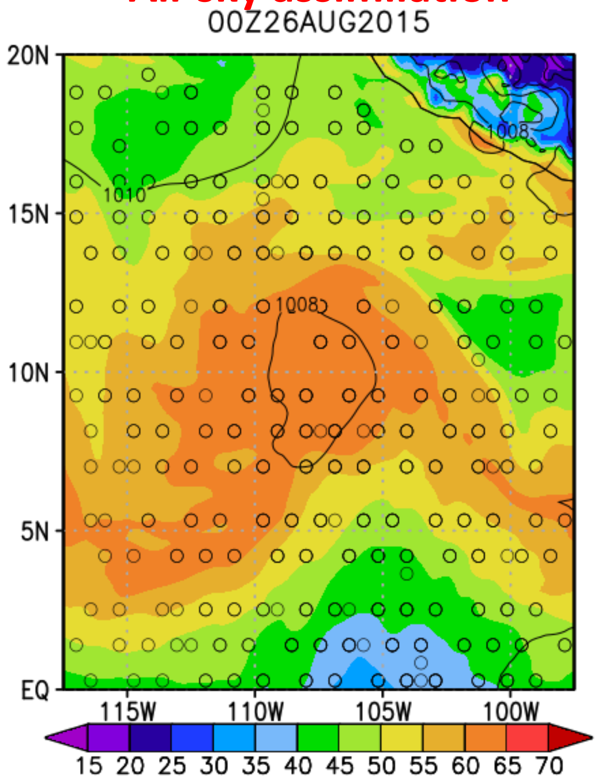
Color : Total column water vapor (mm)
Contour: Sea level pressure (hPa)
Black circle: location of assimilated MW imager radiance



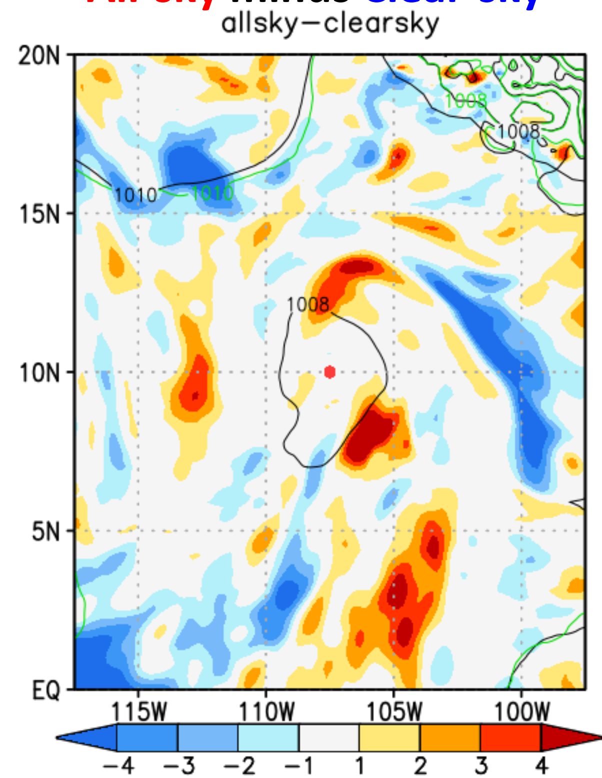
Clear-sky assimilation



All-sky assimilation

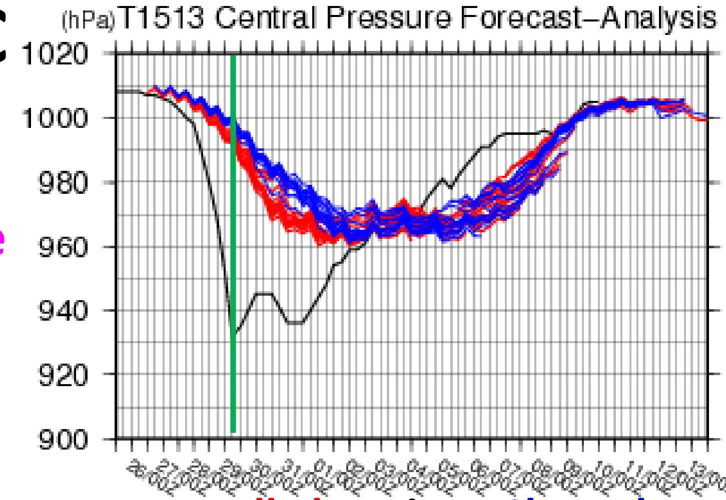


All-sky minus Clear-sky



Increase of assimilated MW imager radiance in all-sky assimilation

Change of water vapor field in TC

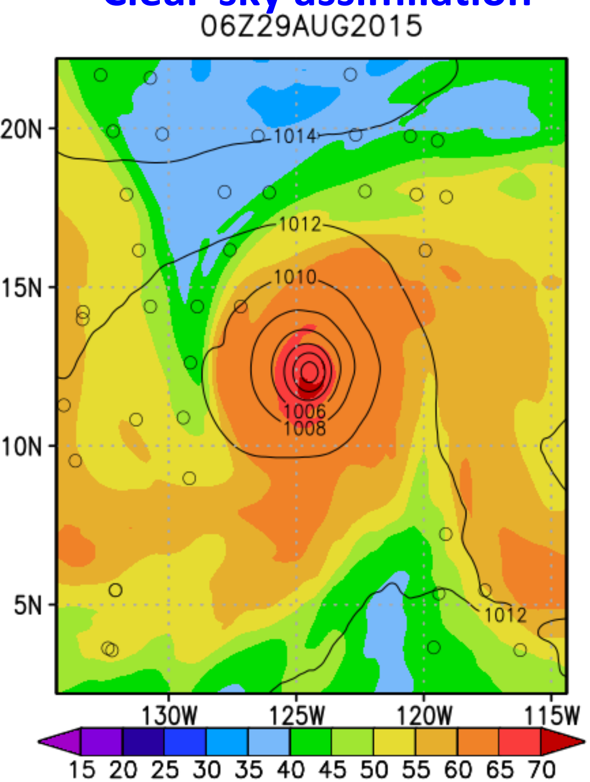


TC developing stage

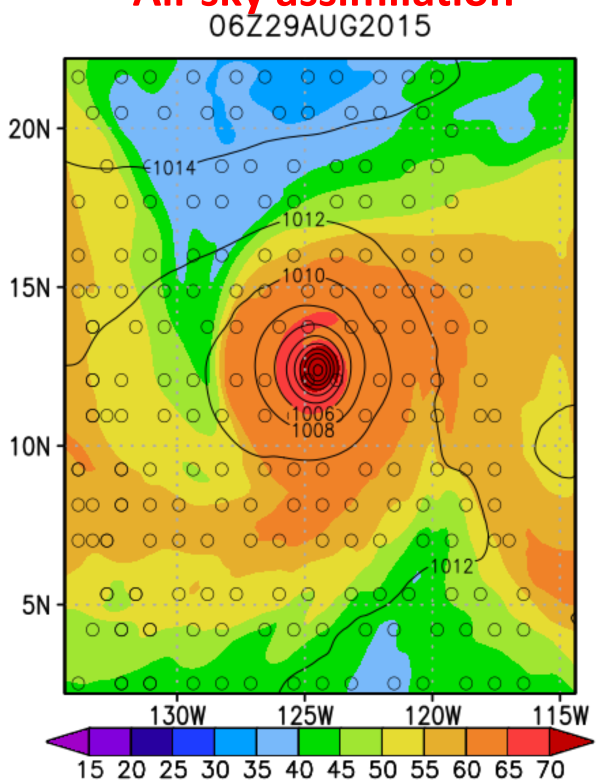
TPW concentration and deep central pressure

Color : Total column water vapor (mm)
Contour: Sea level pressure (hPa)
Black circle: location of assimilated MW imager radiance

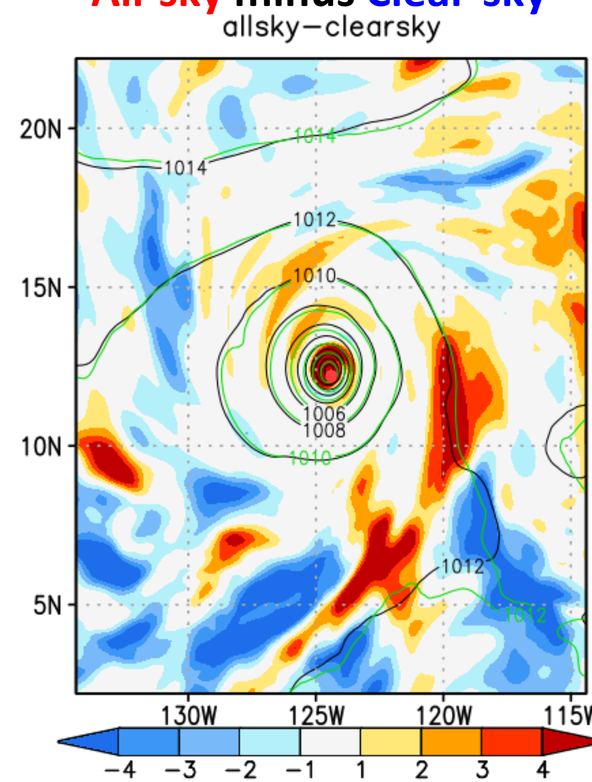
Clear-sky assimilation



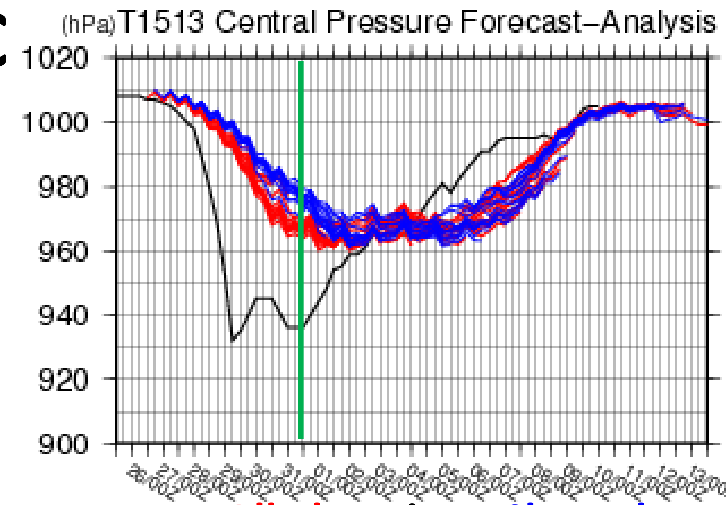
All-sky assimilation



All-sky minus Clear-sky



Change of water vapor field in TC

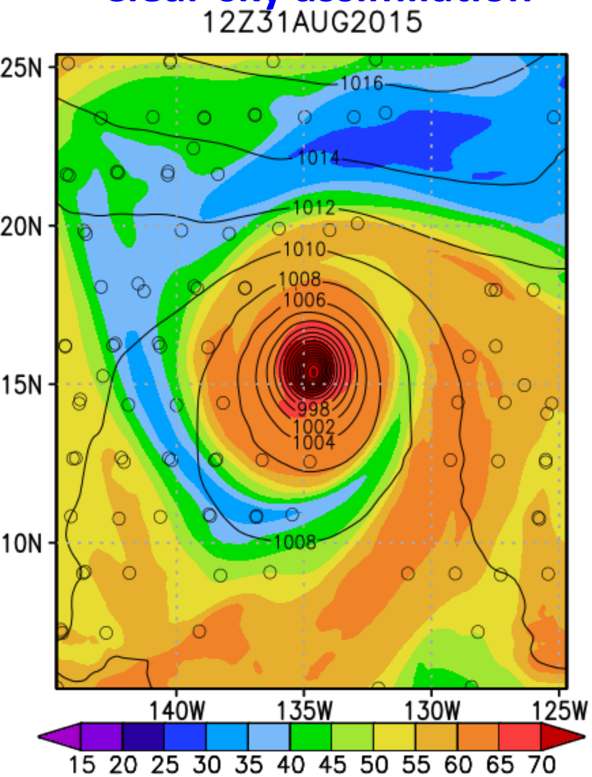


TC developing maximum stage

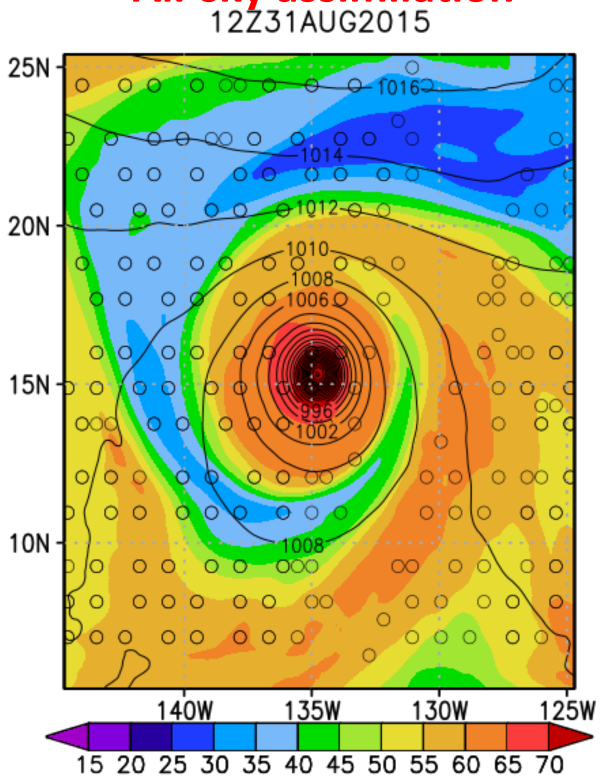
Dry air flow toward TC center

Color : Total column water vapor (mm)
Contour: Sea level pressure (hPa)
Black circle: location of assimilated MW imager radiance

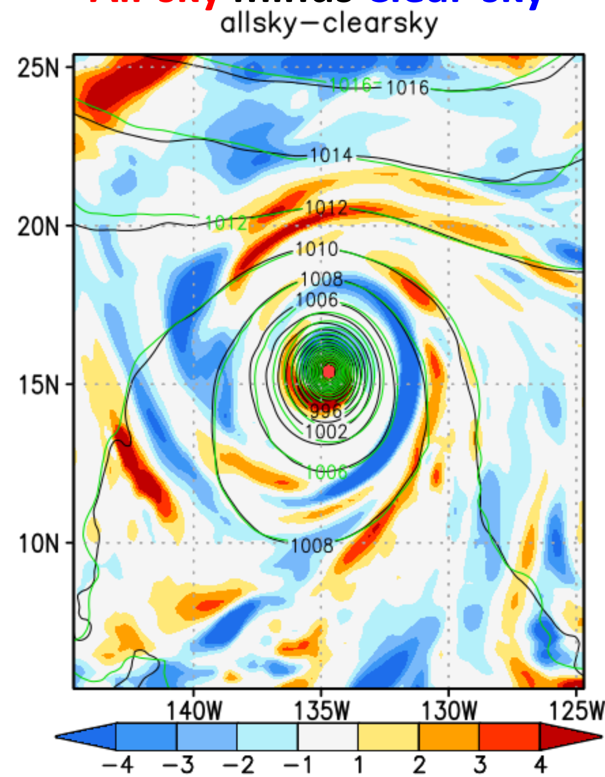
Clear-sky assimilation



All-sky assimilation



All-sky minus Clear-sky

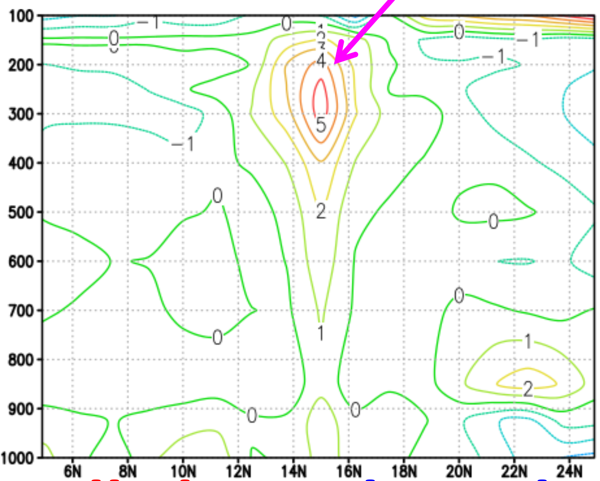


Temperature deviation in vertical cross section at TC center

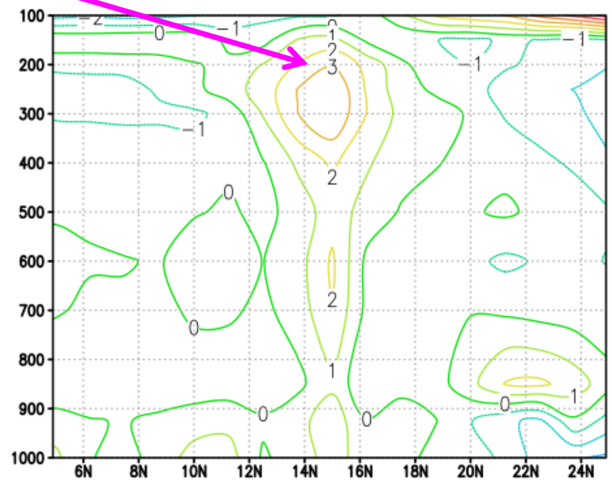
TC developing stage

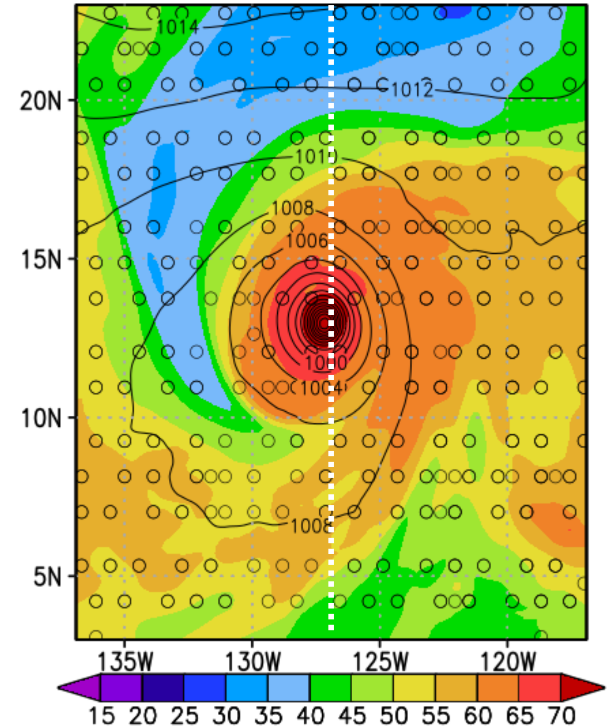
Warm Core

All-sky

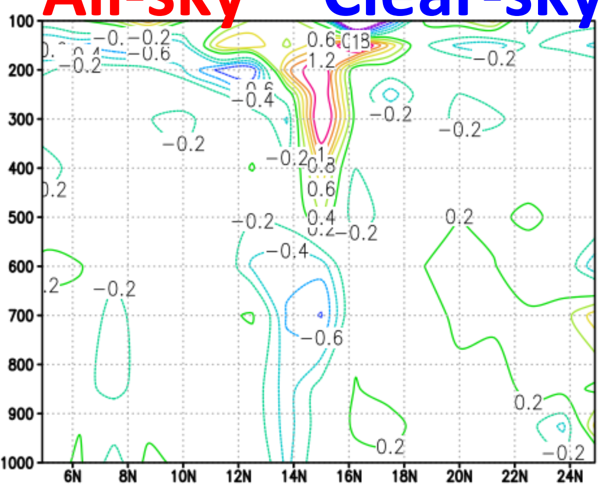


Clear-sky

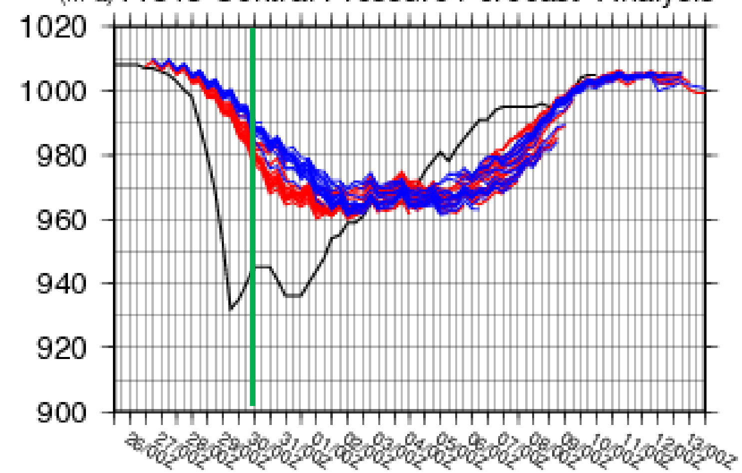




All-sky − Clear-sky



Large difference

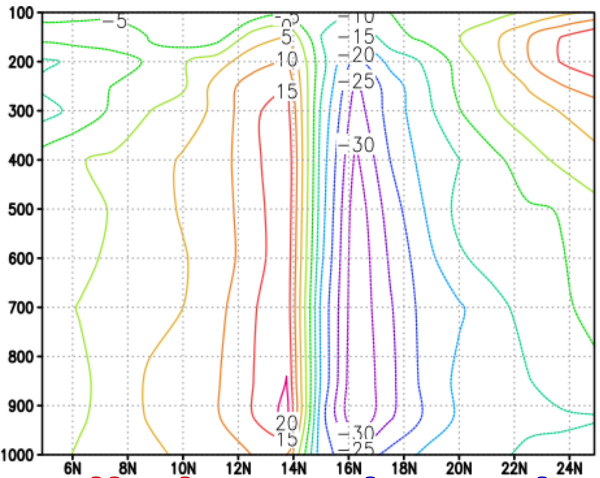


00UTC 30 August 2015
Analyzed Temperature field

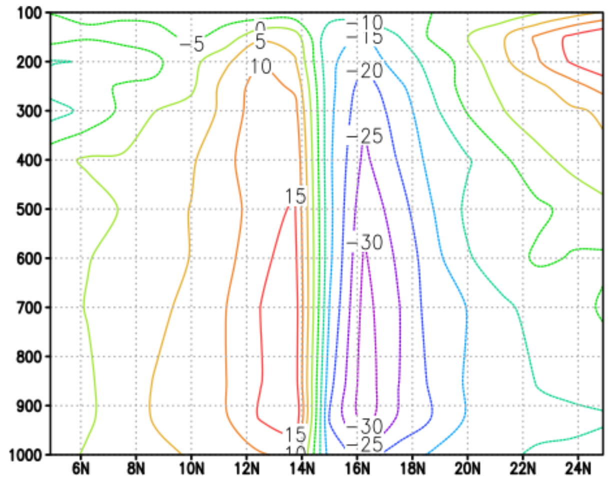
Zonal wind in vertical cross section at TC center

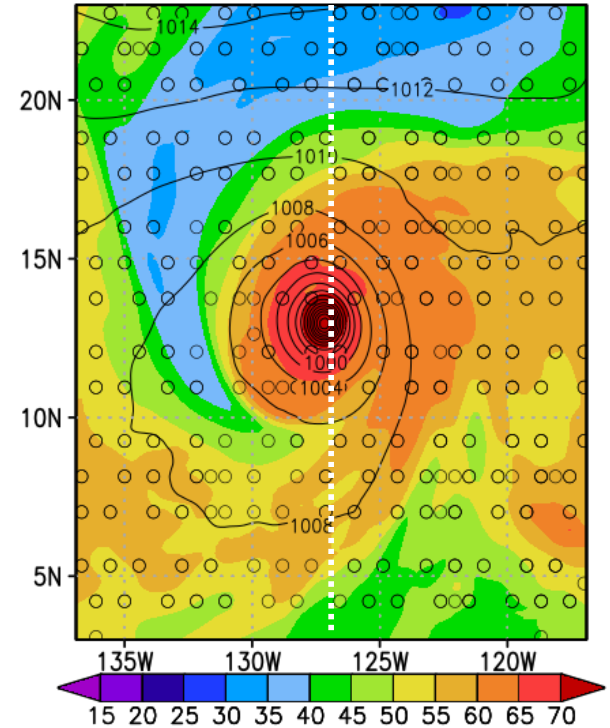
TC developing stage

All-sky

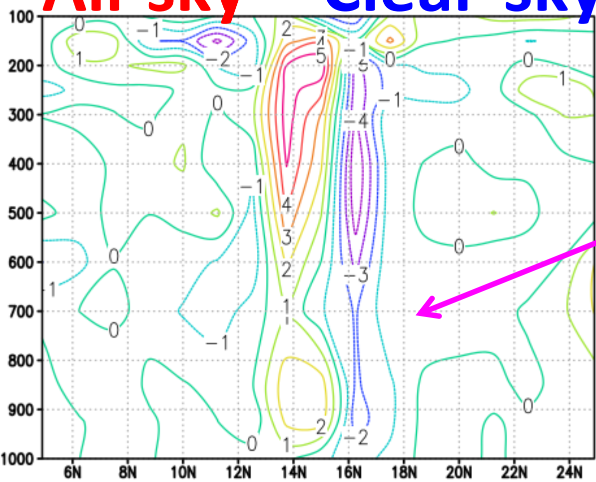


Clear-sky

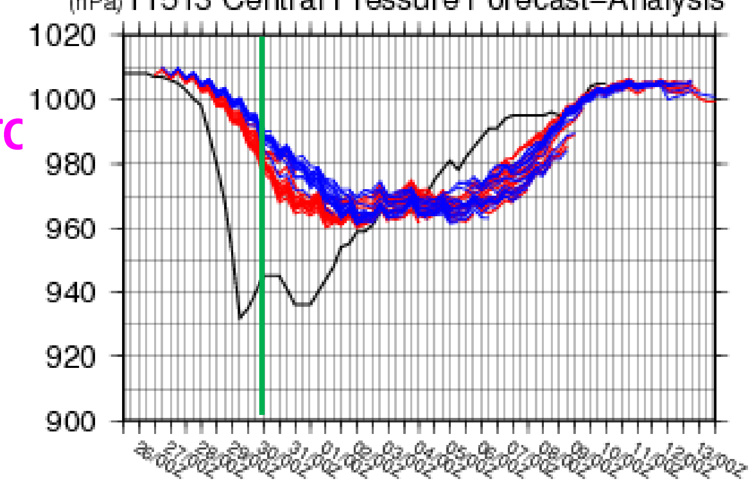




All-sky − Clear-sky

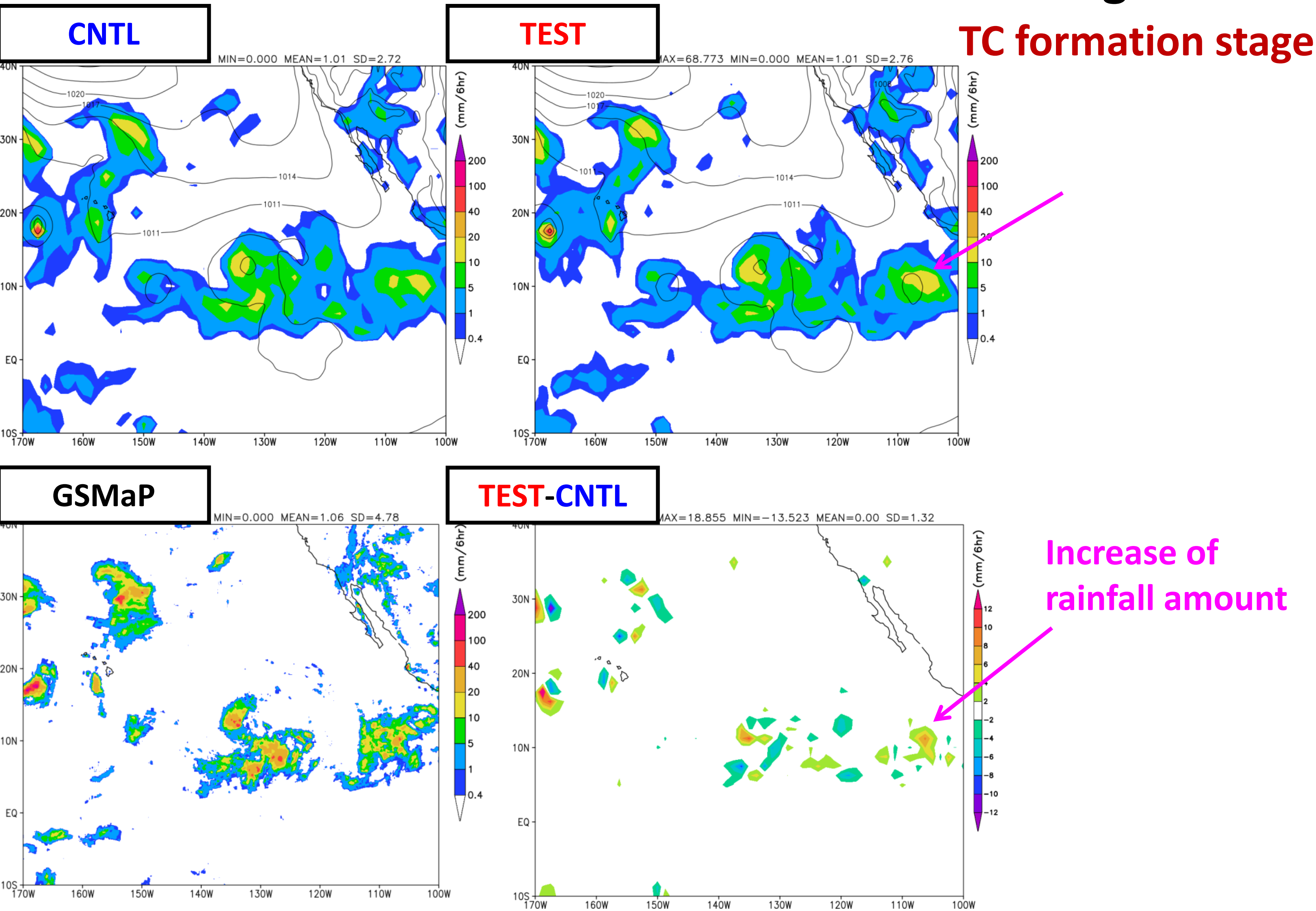


From surface to troposphere, strong wind and vortex is analyzed in TC center.

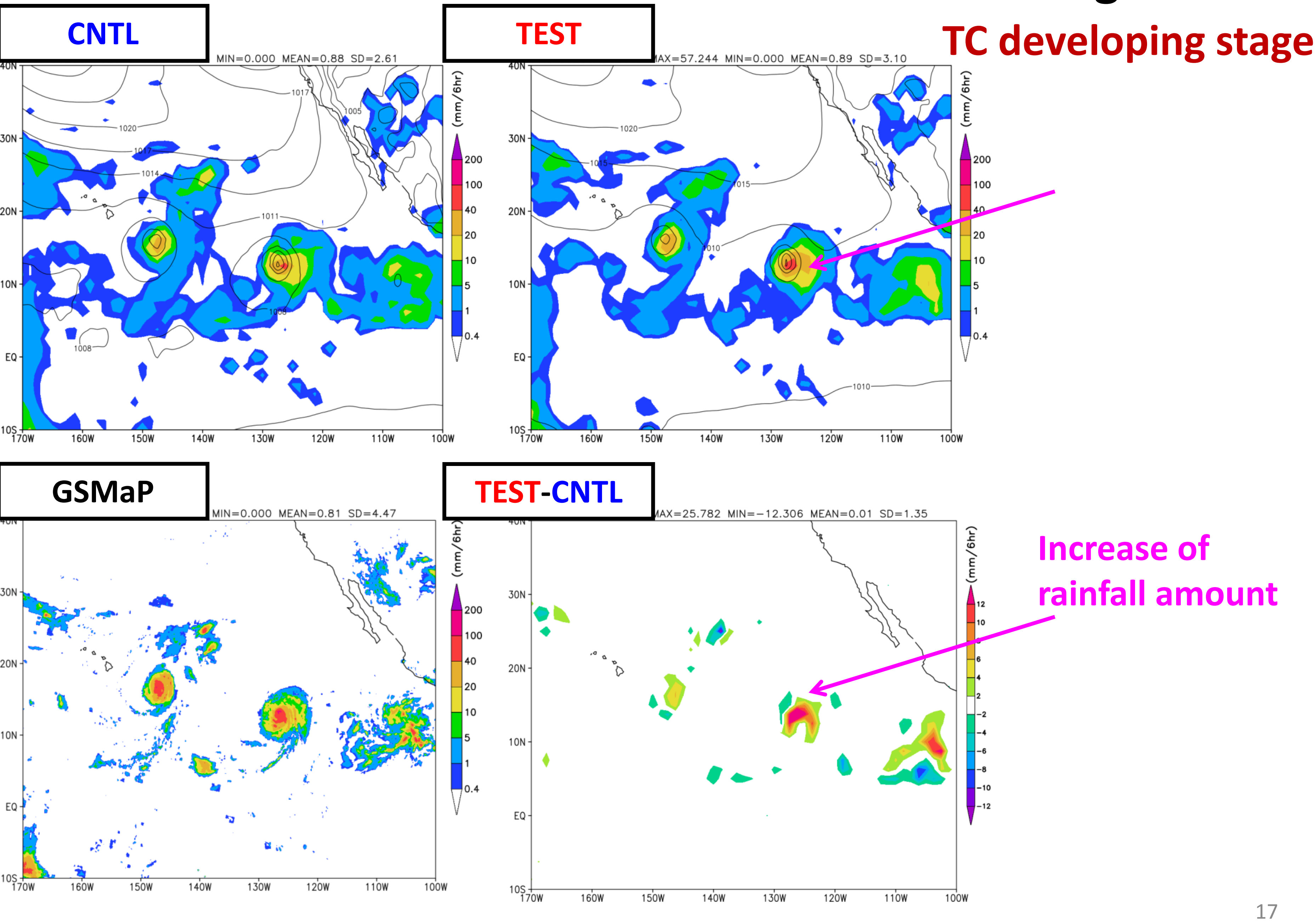


00UTC 30 August 2015
Analyzed zonal wind field

6-hr accumulated rainfall forecast 00 UTC 26 August 2015

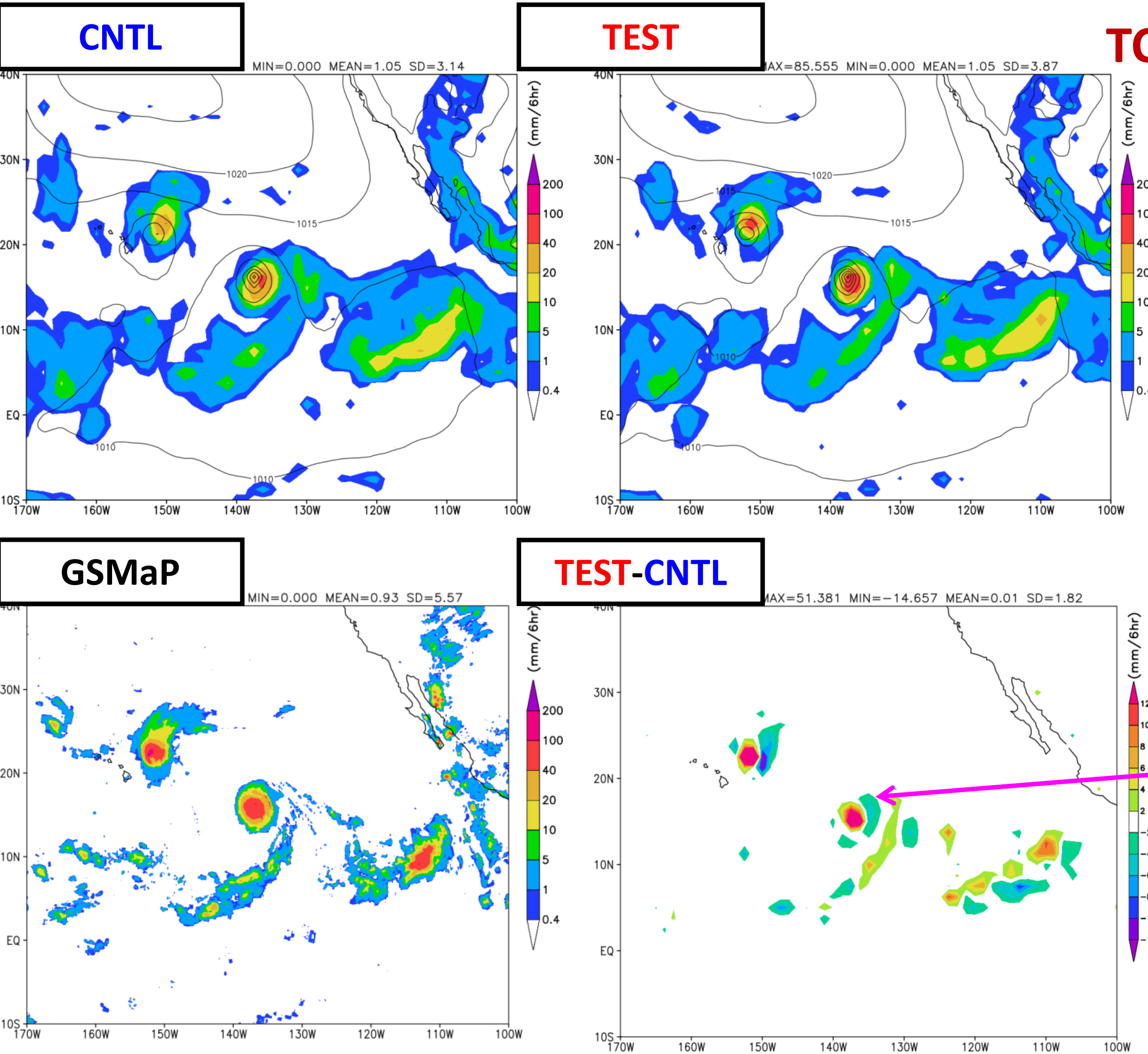


6-hr accumulated rainfall forecast 00 UTC 30 August 2015



6-hr accumulated rainfall forecast 00 UTC 1 September 2015

TC developed stage

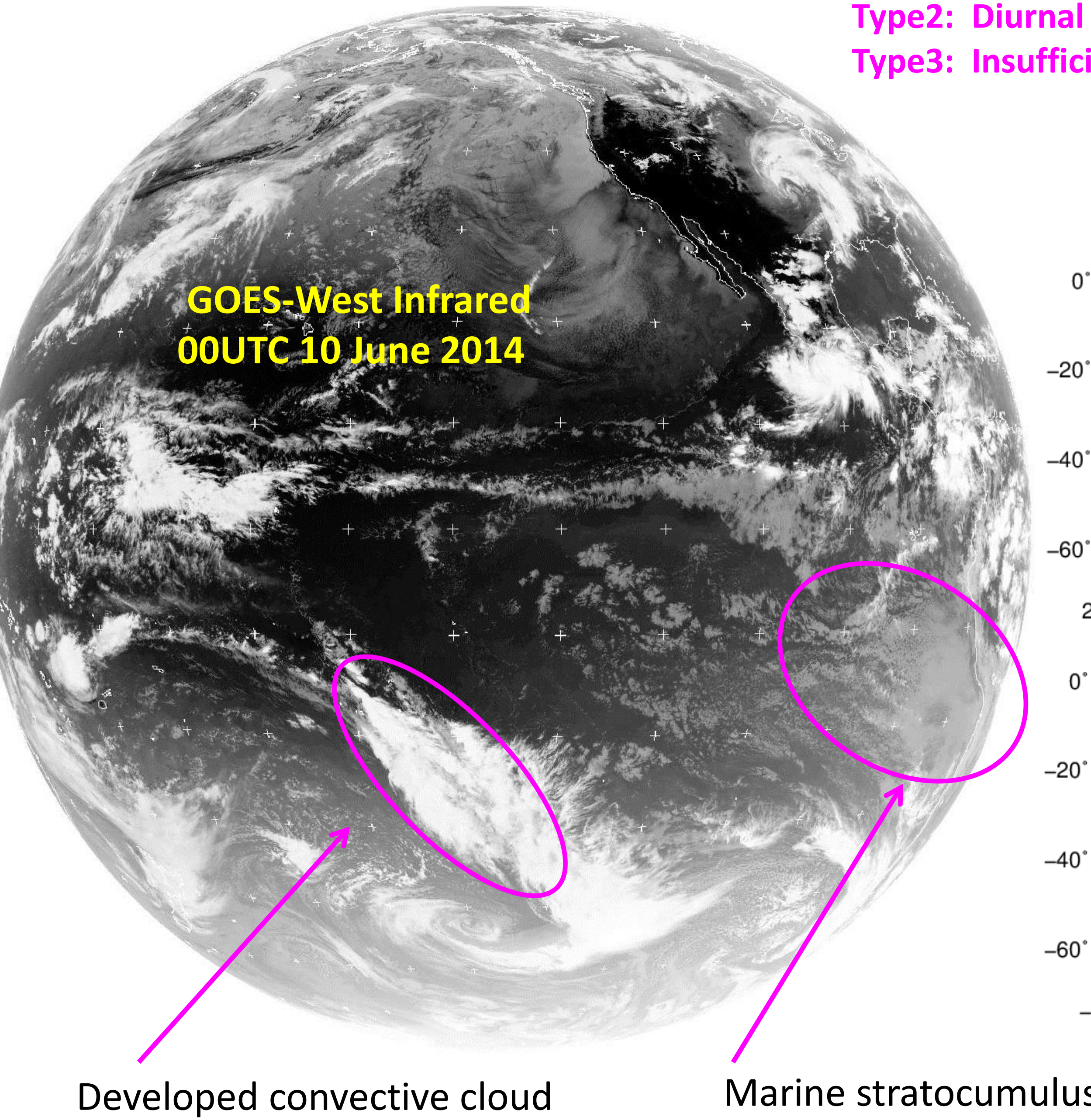


Increase and degrease of rainfall amount

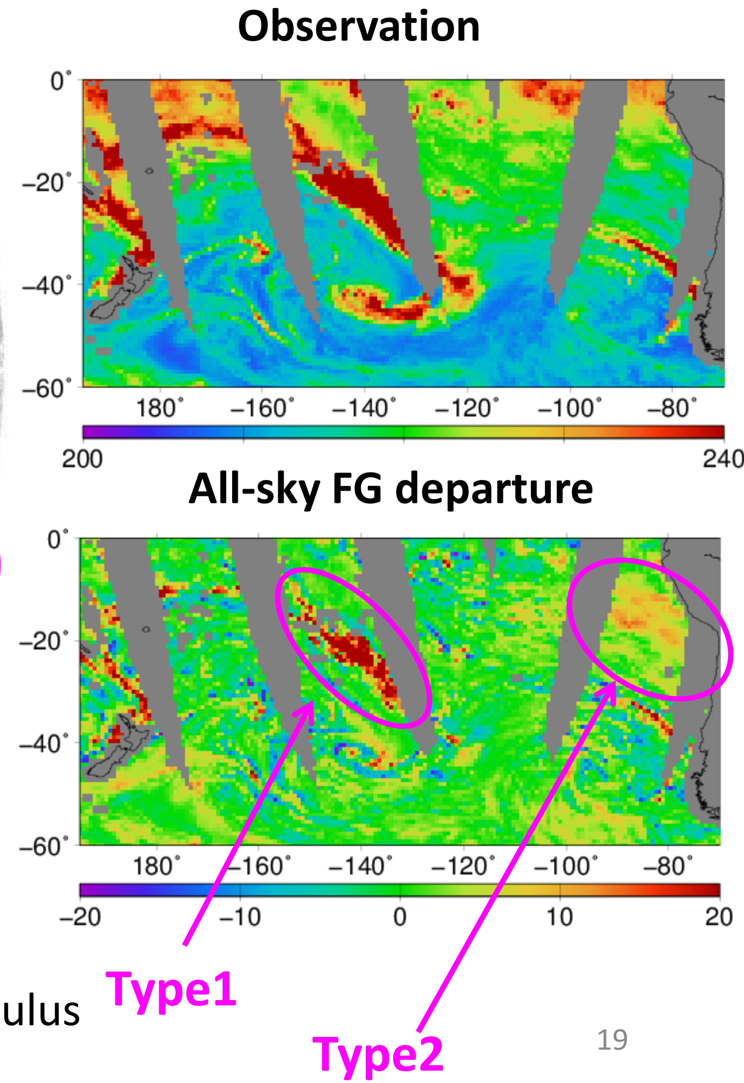
Correction of mislocation

Model bias issues

Type1: Insufficient CLW in deep convective cloud
Type2: Diurnal variation in marine stratocumulus
Type3: Insufficient CLW in cold-air outbreaks



AMSR2 37V 10 June 2014
Southern Hemisphere

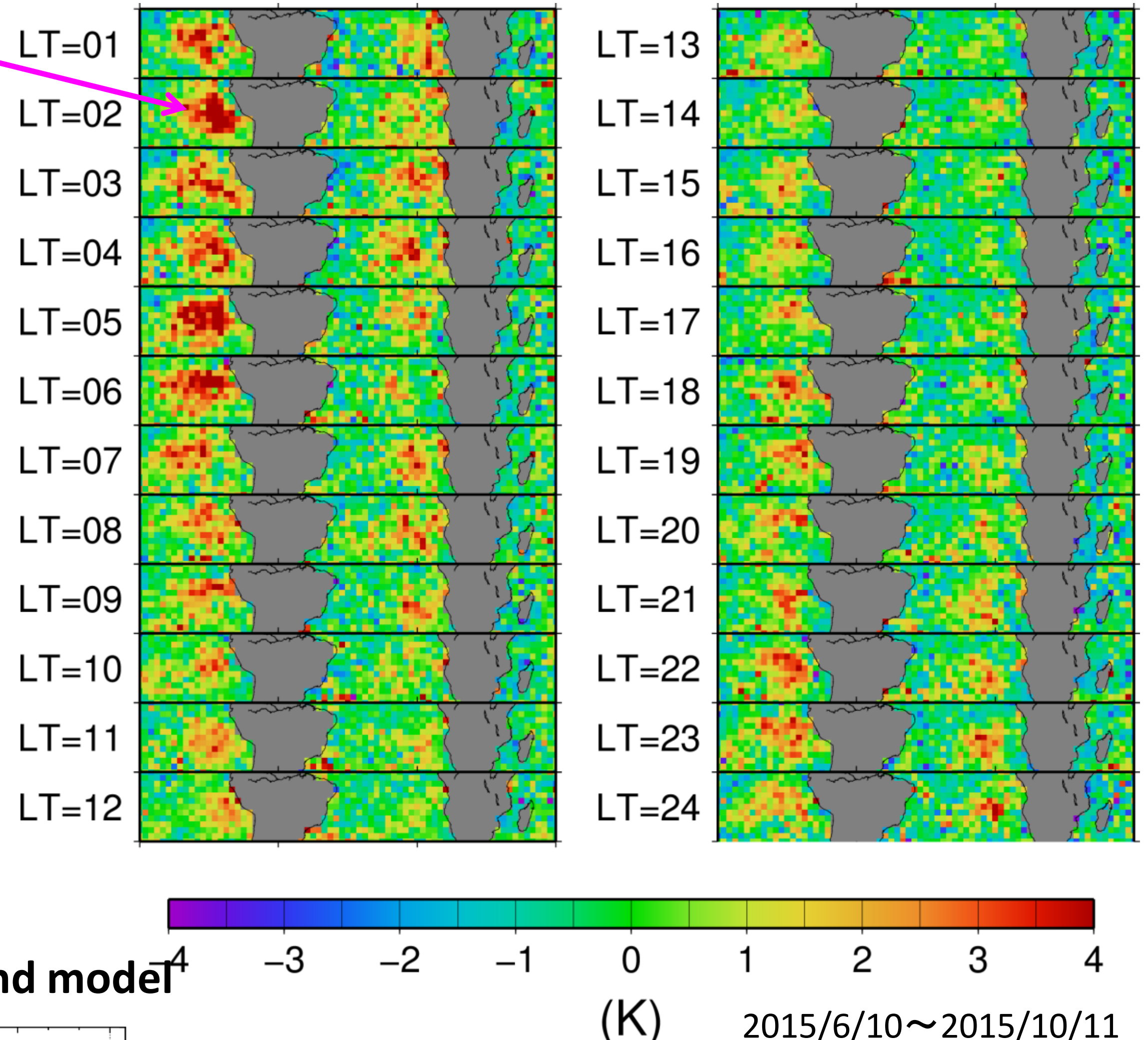


GMI 37GHz V-pol.

Local time dependency of FG departure bias

Type2

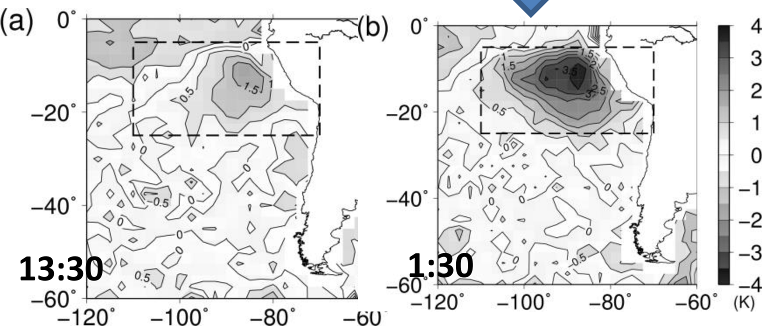
Large biases in nighttime and early morning



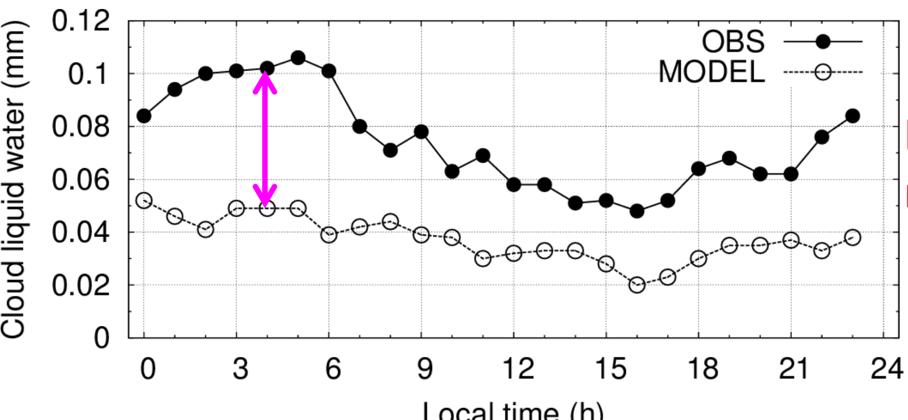
AMSR2 37GHz V-pol.

(a)ascending, (b)descending

FG departure biases



CLW comparison between observed and model

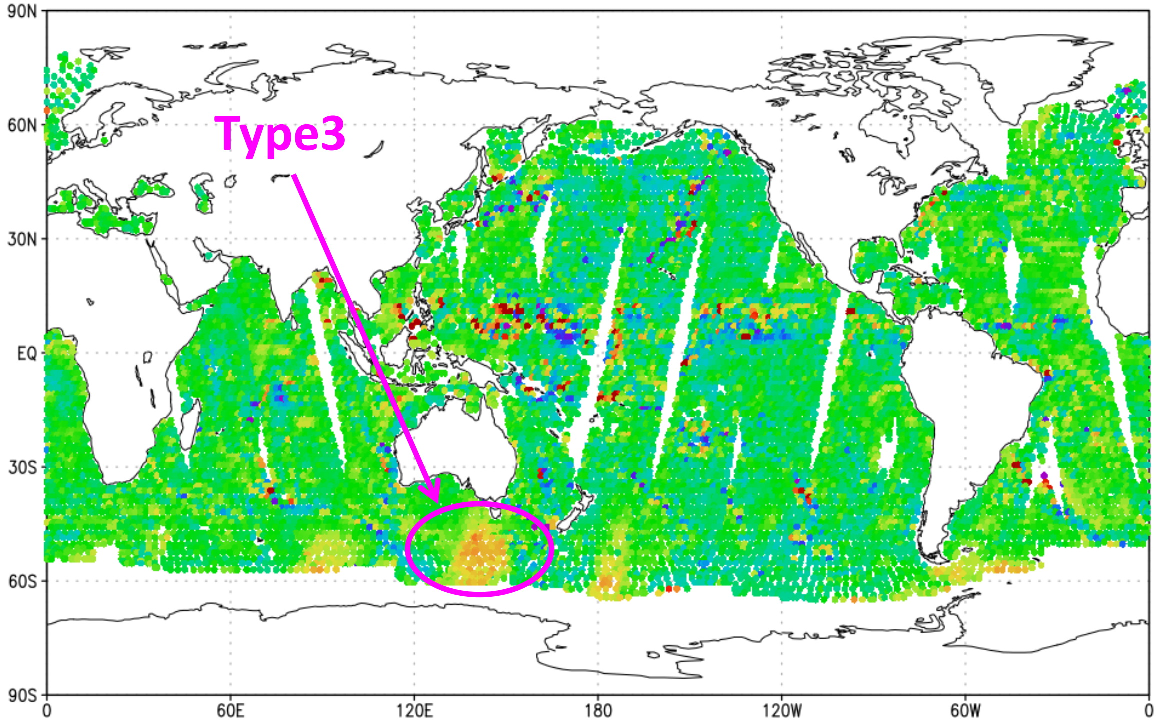


Insufficient diurnal variation of CLW amount in marine stratocumulus in the west of the continent

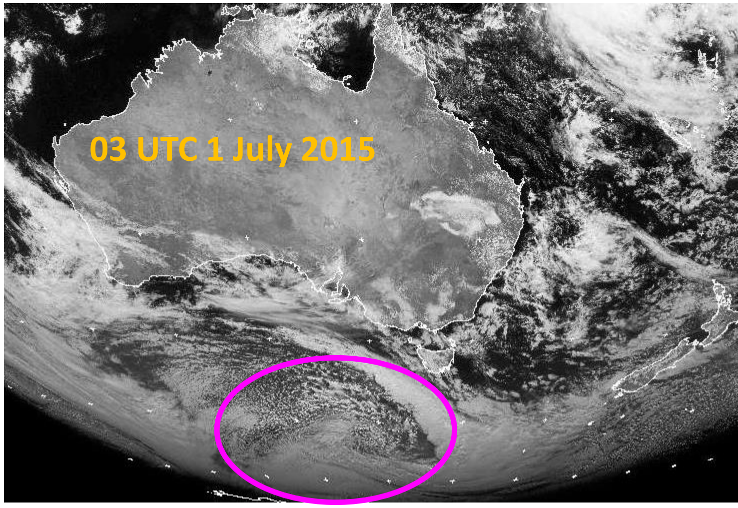
Obs. CLW from Remote Sensing Systems

Model bias issues

Type1: Insufficient CLW in deep convective cloud
Type2: Diurnal variation in marine stratocumulus
Type3: Insufficient CLW in cold-air outbreaks



1 July, 2015
SSMIS 19V
All-sky FG departure



Positive biases in cold-air out breaks.

The cause is insufficient cloud liquid water in JMA global model. The model produces cloud ice, but in reality, super cooled liquid water exists and contribute to microwave radiation.

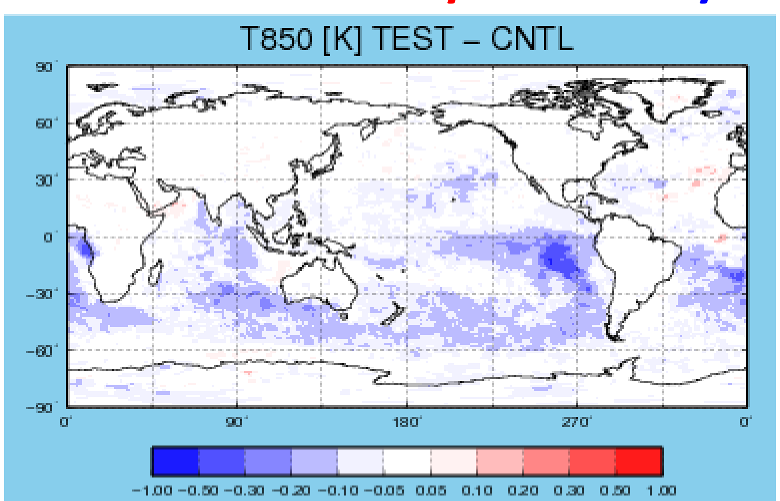
Model bias issues for analysis

- **Decrease of temperature at 850 hPa**
  - JMA global model has biases in cloud liquid water (Type1, 2, and 3).
    The model tends to decrease the temperature at 850hPa. Cloud water signals in MW radiances may not be properly assimilated in the analysis.
- **Decrease of total column water vapor**
  - The all-sky assimilation try to fit FG precipitation to the observed signals in MW radiances. It results in reducing water vapor amount because of weakly broad precipitation pattern of JMA global model's forecast.
- Temperature biases and excessive rainfalls in FG produced **undesired feedback** in the data assimilation.

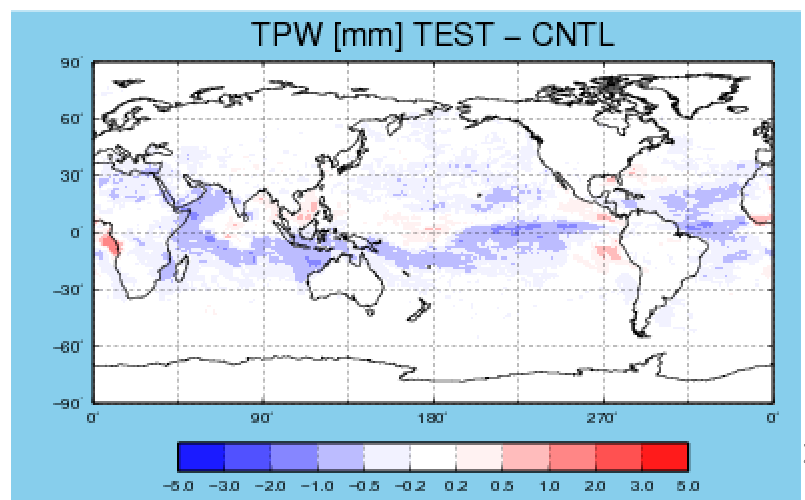
Period: 20 June – 30 Sep. 2015

Mean Analysis difference

T850 diff: All-sky – Clear-sky



TCWV diff: All-sky – Clear-sky

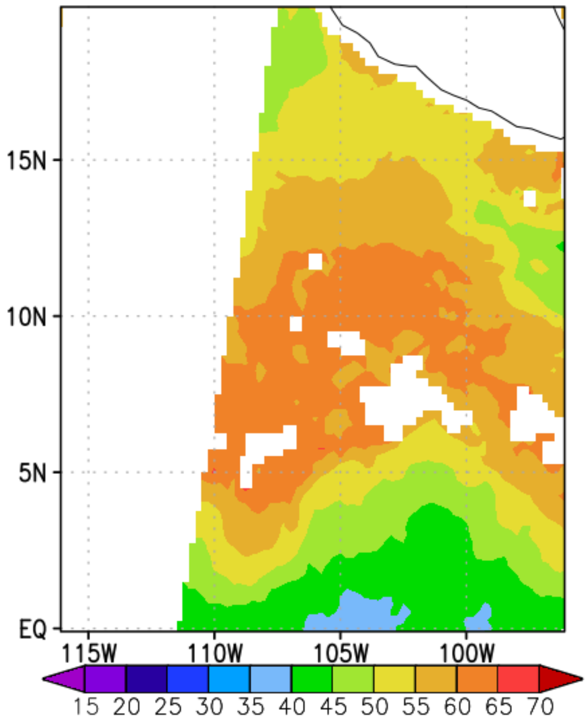


Summary

- **Assimilation experiment of all-sky MW imager Tb in JMA global DA system**
  - **Positive results**
    - Improved analysis and FG water vapor, temperature, wind in the troposphere, especially cloudy and rainy areas
    - **Improved TC analysis and prediction** (realistic intensification and associated precipitation forecast)
  - **Negative impacts**
    - Decrease of mean temperature in a specific level (850 hPa)
    - Decrease of total column water vapor in stratocumulus areas

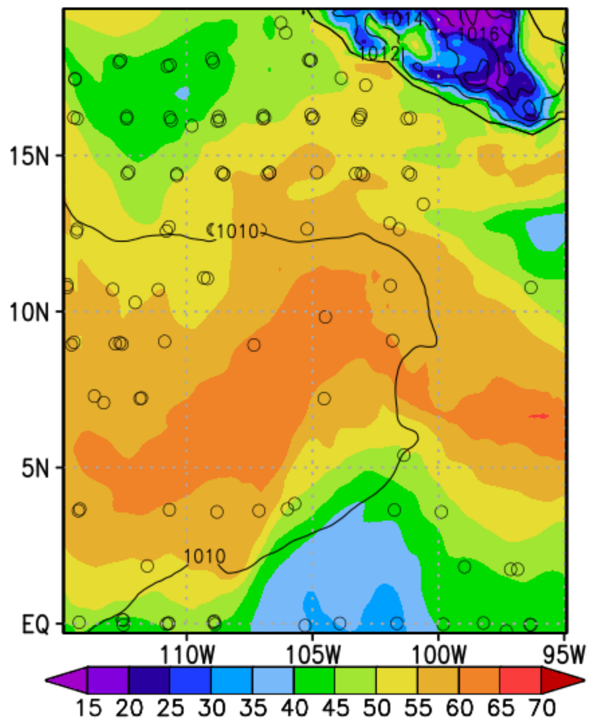
- **All-sky radiance assimilation relies on accuracy of FG cloud and precipitation**
  - Model biases in cloud physics and/or convective scheme would cause spurious increment in the analysis
  - To obtain T & Q information from the observation, and make consistent change among physical variables (T, Q, and cloud, rain), the forecast model biases in cloudy areas should be reduced.

AMSR2 TPW
from Remote Sensing Systems



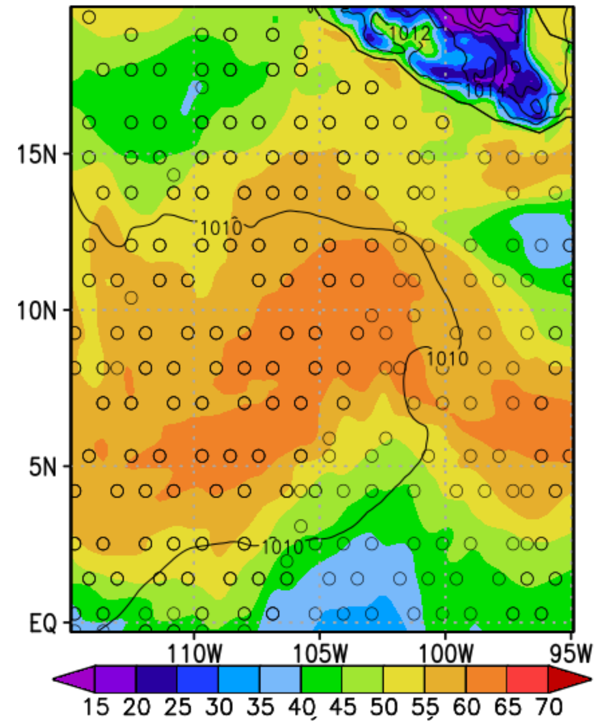
Clear-sky TPW

12Z25AUG2015

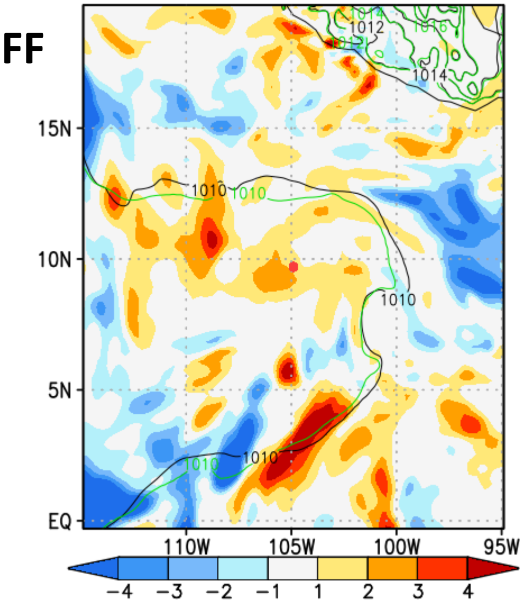


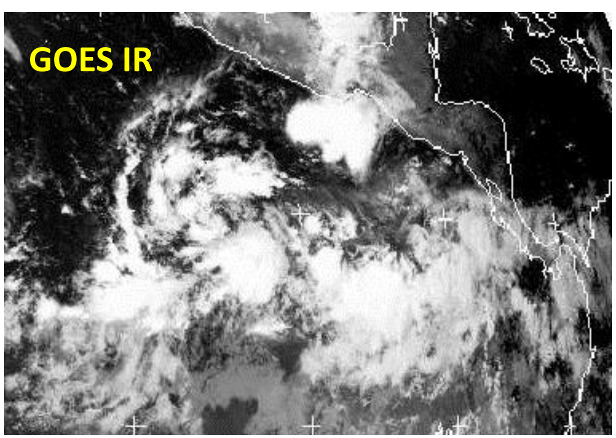
All-sky TPW

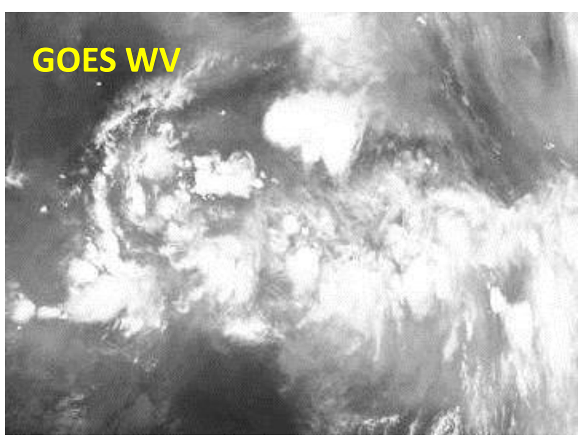
12Z25AUG2015



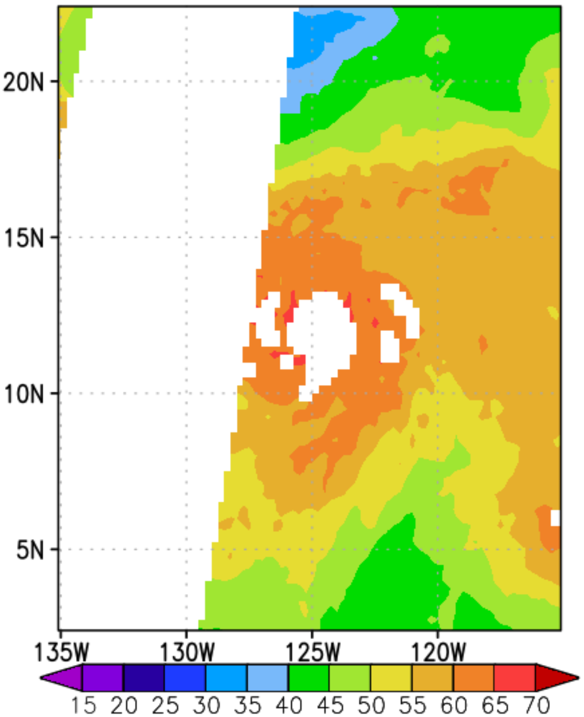
DIFF





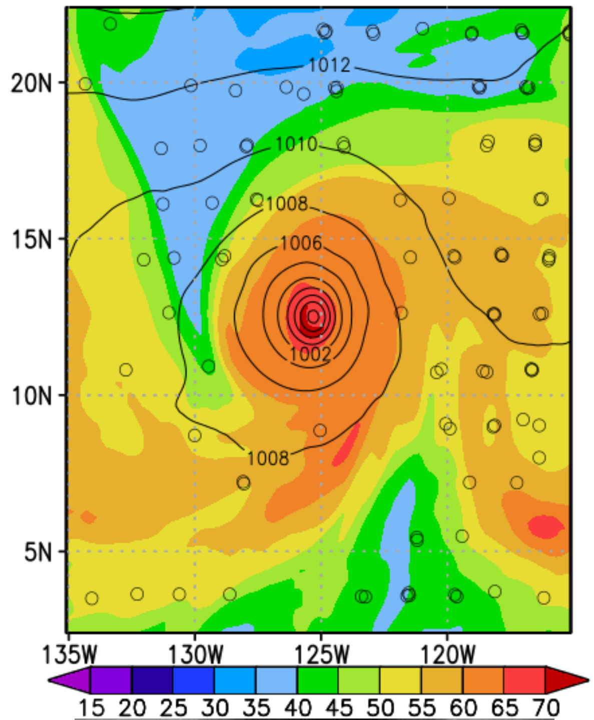


AMSR2 TPW
from Remote Sensing Systems



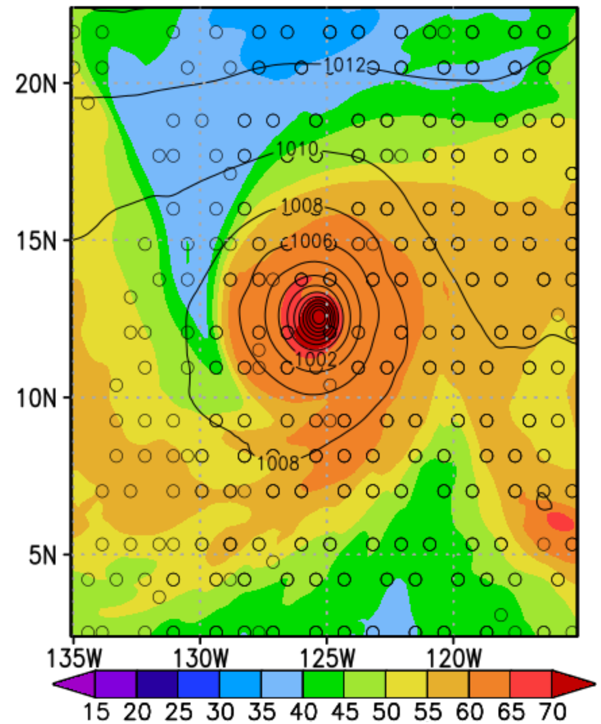
Clear-sky TPW

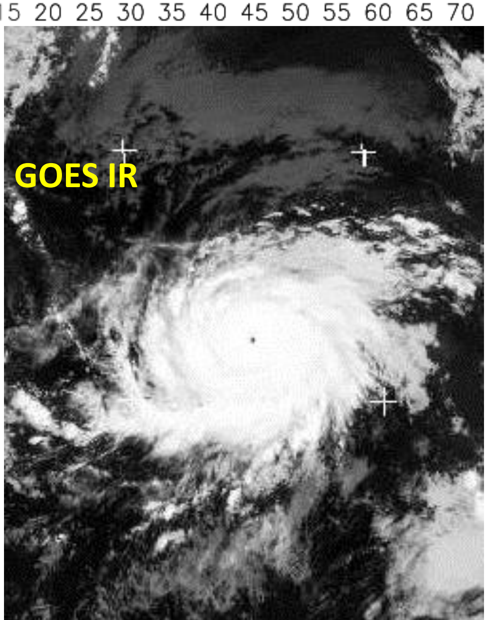
12Z29AUG2015

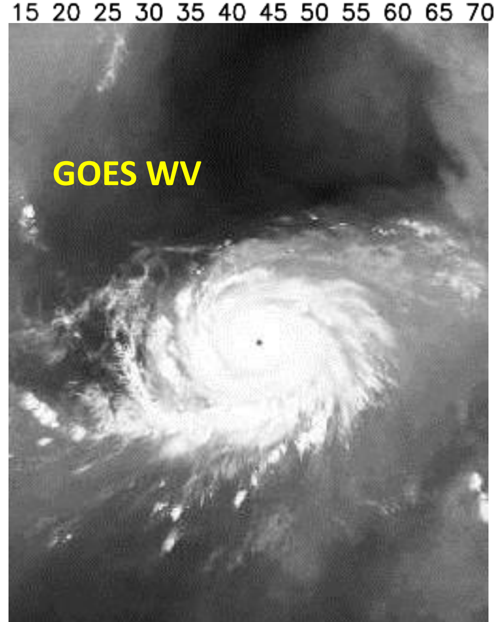


All-sky TPW

12Z29AUG2015







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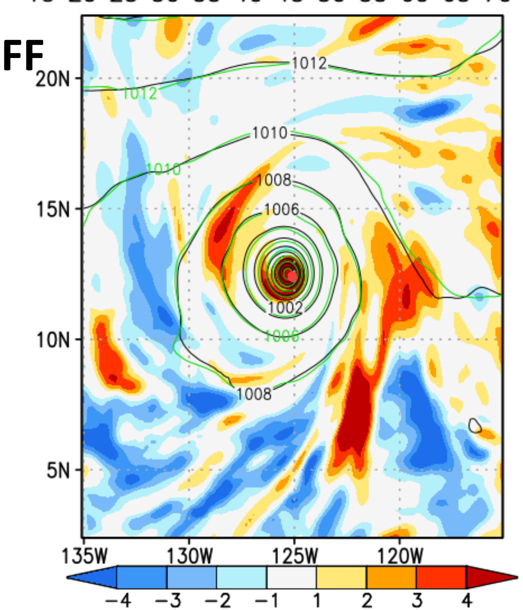
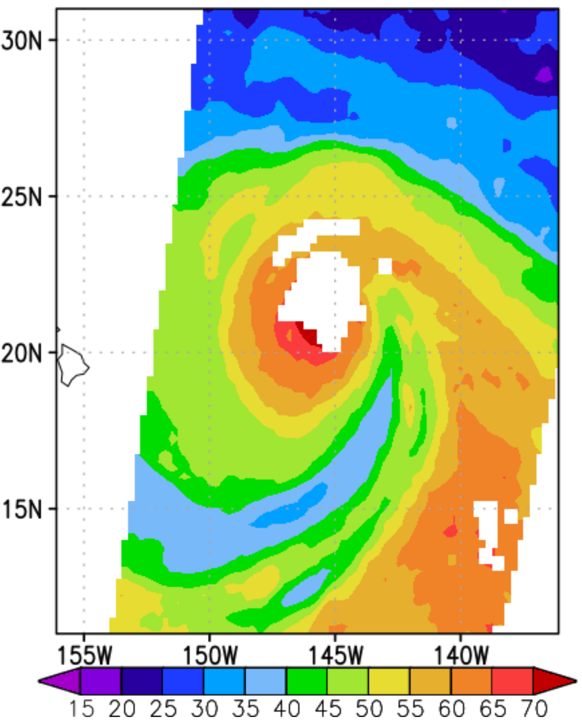
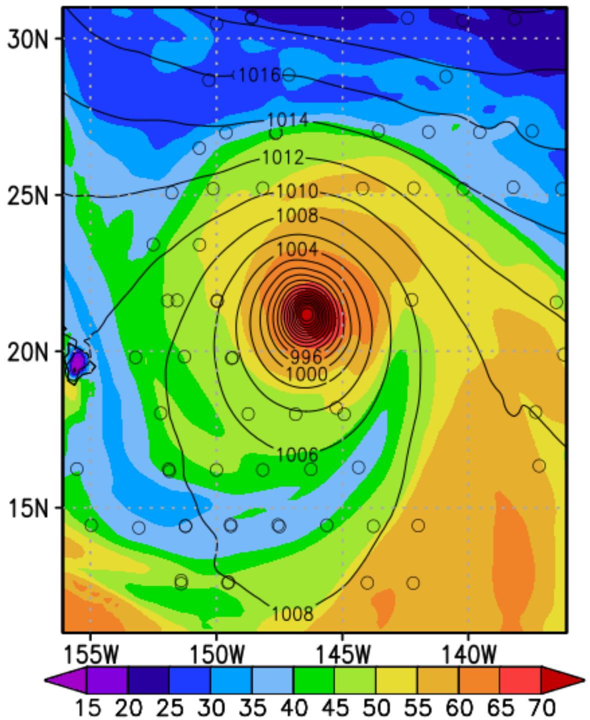


AMSR2 TPW
from Remote Sensing Systems



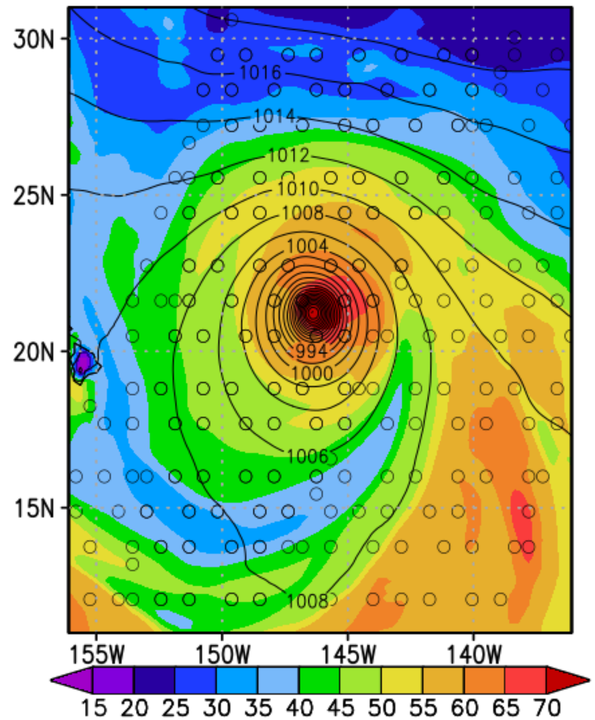
Clear-sky TPW

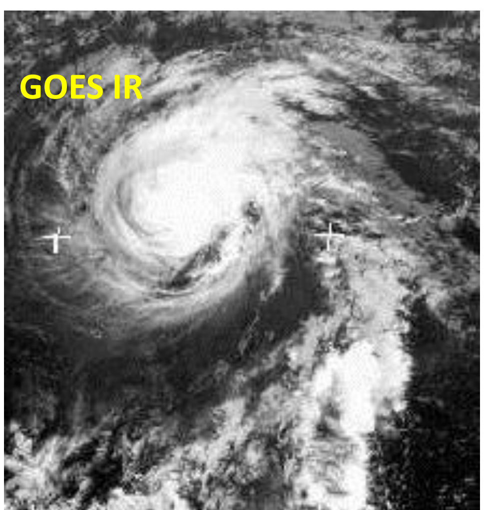
12Z05SEP2015

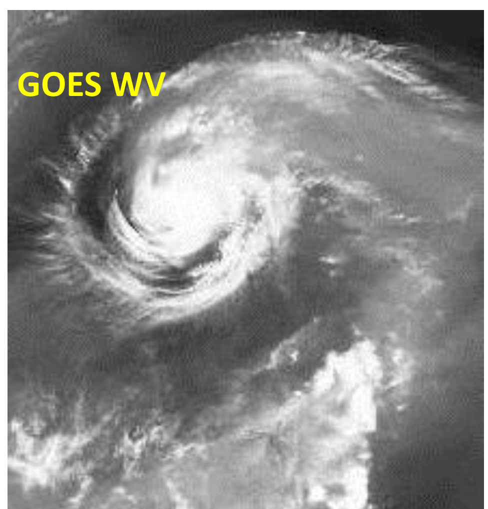


All-sky TPW

12Z05SEP2015







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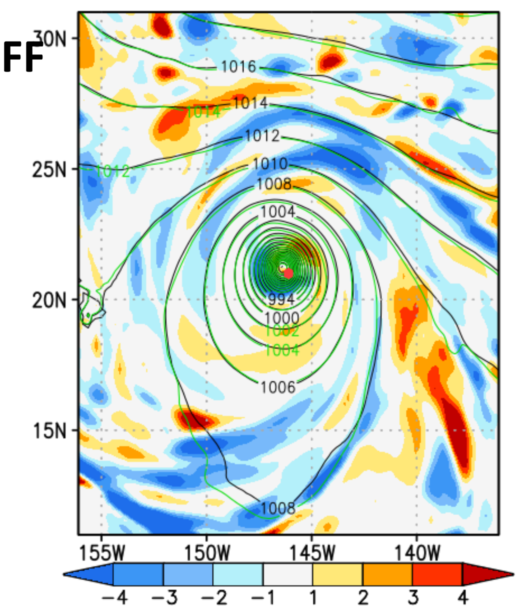

Summary

- **Impacts of all-sky assimilation on Tropical Cyclone (TC) prediction**
  - **Genesis and developing stages**
    - Increase TPW and make water vapor concentration under cloudy situation
    - more realistic rapid intensification through data assimilation cycle

    Direct benefits: Improvement of TC intensity analysis and prediction
  - **Steady and decaying stages**
    - Small impacts. Large-scale synoptic feature dominates transition from TC to extratropical cyclone.
    - Clouds in the tropical cyclone are disappearing. MW imager data in clear-sky have already assimilated.
    - But, improvement in mid-latitude atmospheric circulation (trough and ridge) by all-sky assimilation can bring better TC track prediction

    Indirect benefits: Improvement of TC track prediction in medium-range forecasts

Thank you for your attention.