Development of an all-sky assimilation of microwave imager and sounder radiances for the Japan Meteorological Agency global numerical weather prediction system

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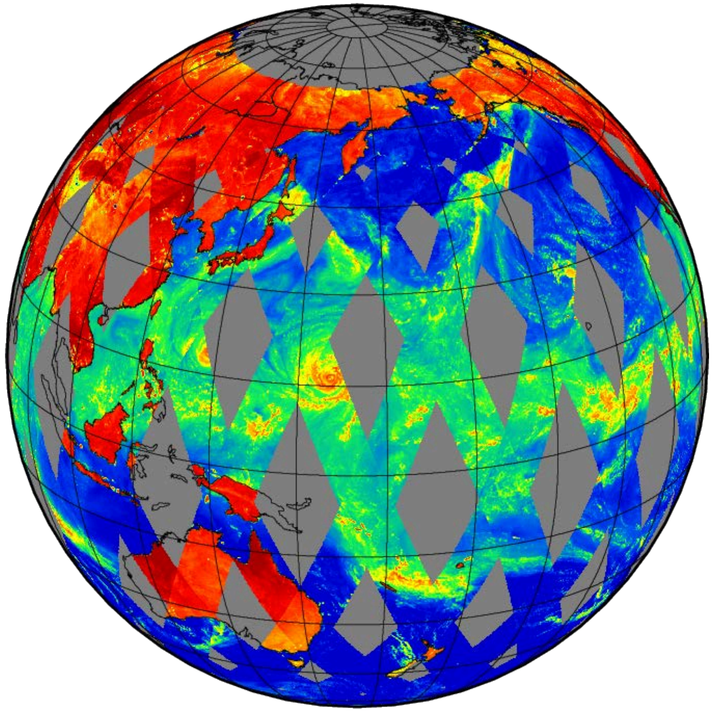
Introduction

Microwave radiance observations have various information on geophysical parameters, e.g., **atmospheric temperature, water vapor, clouds, precipitation and** surface conditions.

GPM/GMI 37GHz V-pol. Brightness Temperature (Tb) [K]
(August 18, 2015)



However, present microwave Tb data assimilation (DA) is a clear-sky assimilation in the JMA global NWP system. Cloud and rain affected Tb data are not assimilated in the operational system.

Objective
Obtain water vapor information in **cloudy areas** from all-sky assimilation

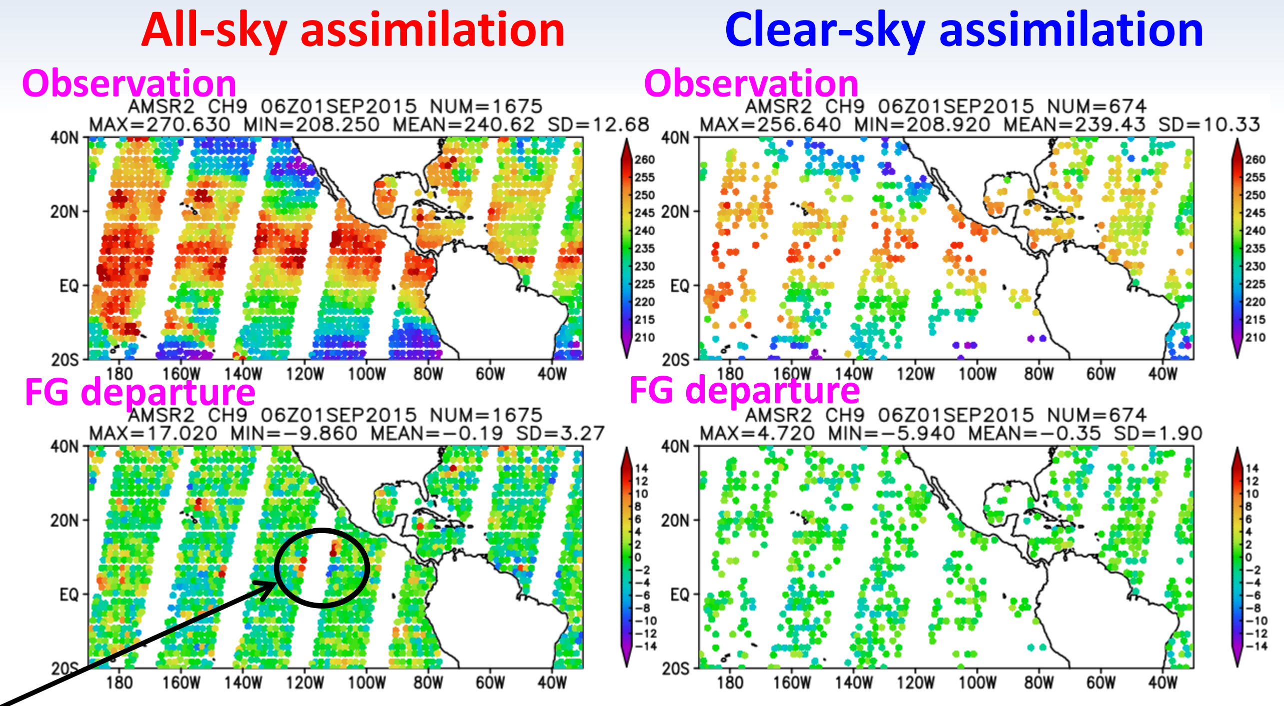
Cloudy areas are sensitive to accuracy of severe weather forecasting (e.g., heavy precipitation, tropical cyclone, mid-latitude cyclone associated with convective storms)

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

All-sky MW radiance assimilation

Key components of all-sky MW radiance assimilation

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



Cloud formation & Precipitation are non-linear phenomena.

Outer-loop iterations (trajectory updates) in the minimization of 4D-Var cost function can help to include the non-linear processes. The updates can increase QC-passed data.

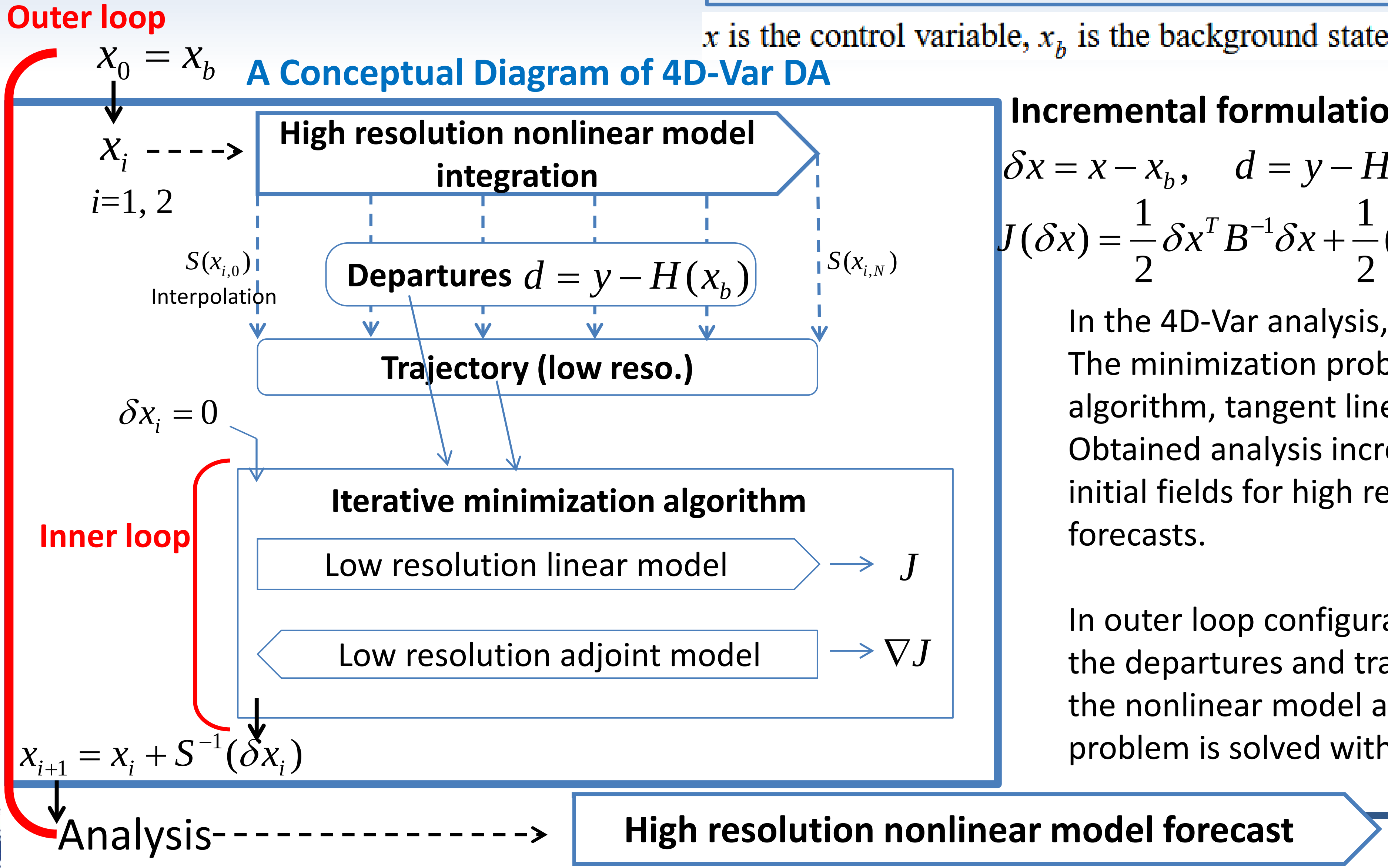
Incremental 4D-Var and outer-loop

4D-Var cost function:

Assimilation = Finding the minimum of J

$$J(x)=\frac{1}{2}(x-x_b)^T B^{-1}(x-x_b)+\frac{1}{2}(H(x)-y)^T R^{-1}(H(x)-y)+J_c$$

x is the control variable, x_b is the background state, y is the vector of observations



Incremental formulation

$$\delta x = x - x_b, \quad d = y - H(x_b)$$

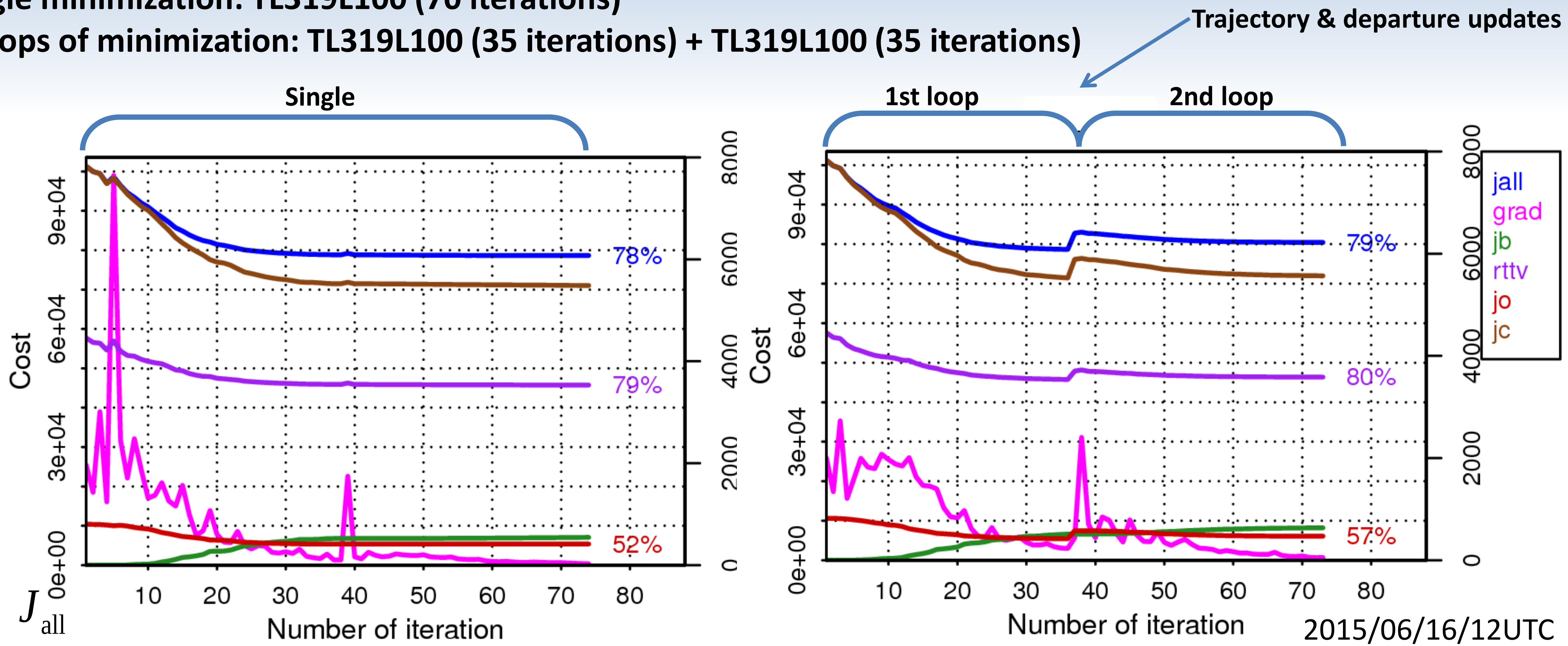
$$J(\delta x)=\frac{1}{2}\delta x^T B^{-1}\delta x+\frac{1}{2}(\mathrm{H}\delta x-d)^T R^{-1}(\mathrm{H}\delta x-d)+J_c$$

In the 4D-Var analysis, cost function J is minimized. The minimization problem is solved with an iterative algorithm, tangent linear and adjoint models. Obtained analysis increments are used to make initial fields for high resolution nonlinear model forecasts.

In outer loop configuration, after the minimization, the departures and trajectory are re-computed with the nonlinear model and again new minimization problem is solved with updated QC-passed data.

Changes of the cost function in the minimization

Single minimization: TL319L100 (70 iterations)
2 loops of minimization: TL319L100 (35 iterations) + TL319L100 (35 iterations)



Blue: J_{all}
Pink: ∇J
Green: J_{b}
Red: J_{o}

Non-linear effects are considered from the addition of the outer-loop.
Comparable convergence of the cost function was obtained at the end of the minimization.

Data assimilation experiments

CNTL: Clear-sky MW imager and sounder assimilation same as JMA operational system
TEST1: **All-sky MW imager + sounder** assimilation
TEST2: **CNTL** + outer-loop
TEST3: **All-sky MW imager + sounder** assimilation + outer-loop

Period: 10 June – 11 October 2015

All-sky MW imager + sounder
AMSR2, GMI, SSMIS F17, F18 (19V, 23V, 37V)
GMI, MHS (NOAA, Metop) (183 GHz)

JMA global NWP system:
JMA global model (JMA-GSM) as of Nov. 2016
4D-Var DA system
Outer model: TL969L100, 20 km horizontal resolution, 100 layers, the model top 0.01 hPa
Inner model: TL319L100, 55 km horizontal resolution, 100 layers, the model top 0.01 hPa
6-hr assimilation window, Static background error covariance matrix (NMC method)

Input atmospheric profiles for RTM : T, Qv, O3, Clw, Ciw, Rain and Snow from JMA-GSM
Obs. Error Setting: Symmetric cloud index C37 (MW-Imager) and SI (MW-Sounder) (Geer and Bauer 2011, Geer et al. 2014)
QC: Gross error check. Ocean data selection for MW imager and ocean & land for MW-sounder

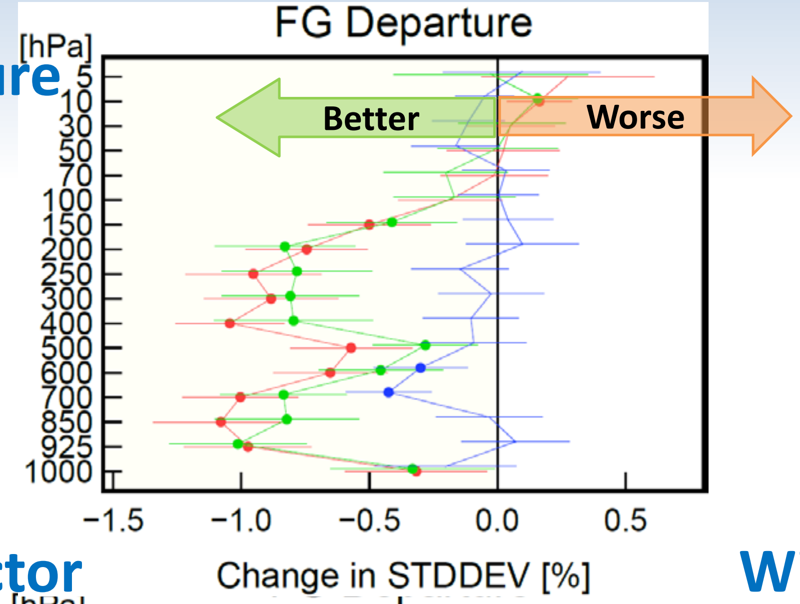
Change of STD of FG departure from CNTL

CNTL:
TEST1:
all-sky MW imager+sounder
TEST2: CNTL + outer-loop
TEST3:
all-sky MW imager+sounder
+ outer-loop

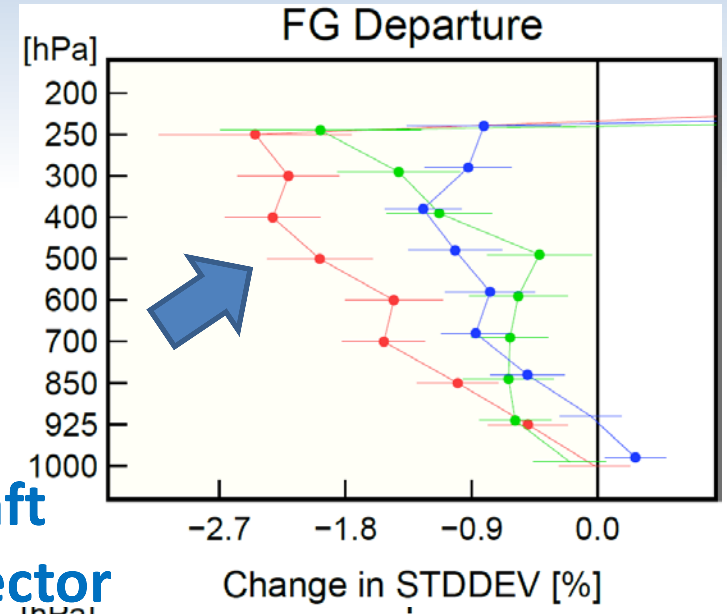
FG (First-Guess) fields (FT=3～9) of T, RH, WV were improved.

Improvements of lower level wind and upper level humidity were obtained from all-sky assimilation of MW images and sounders, respectively.

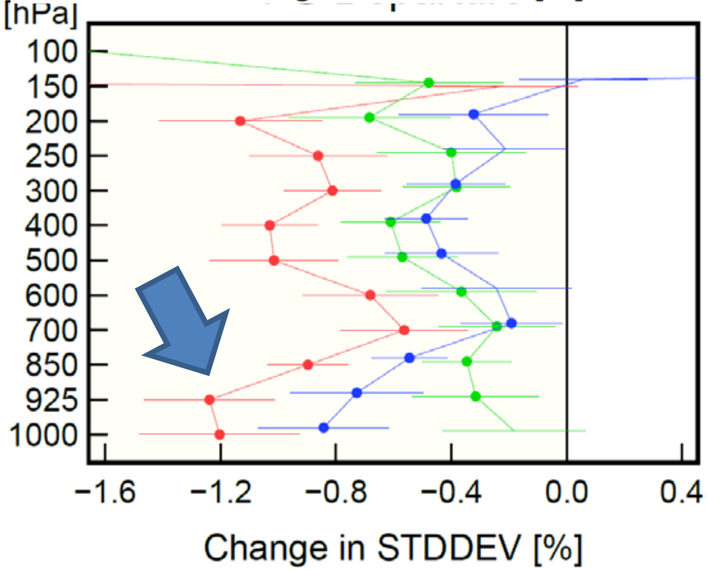
RAOB Temperature



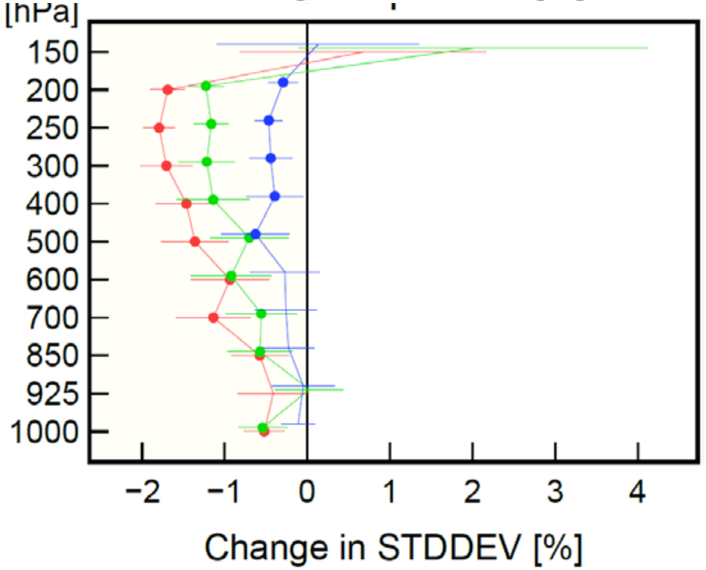
RAOB RH



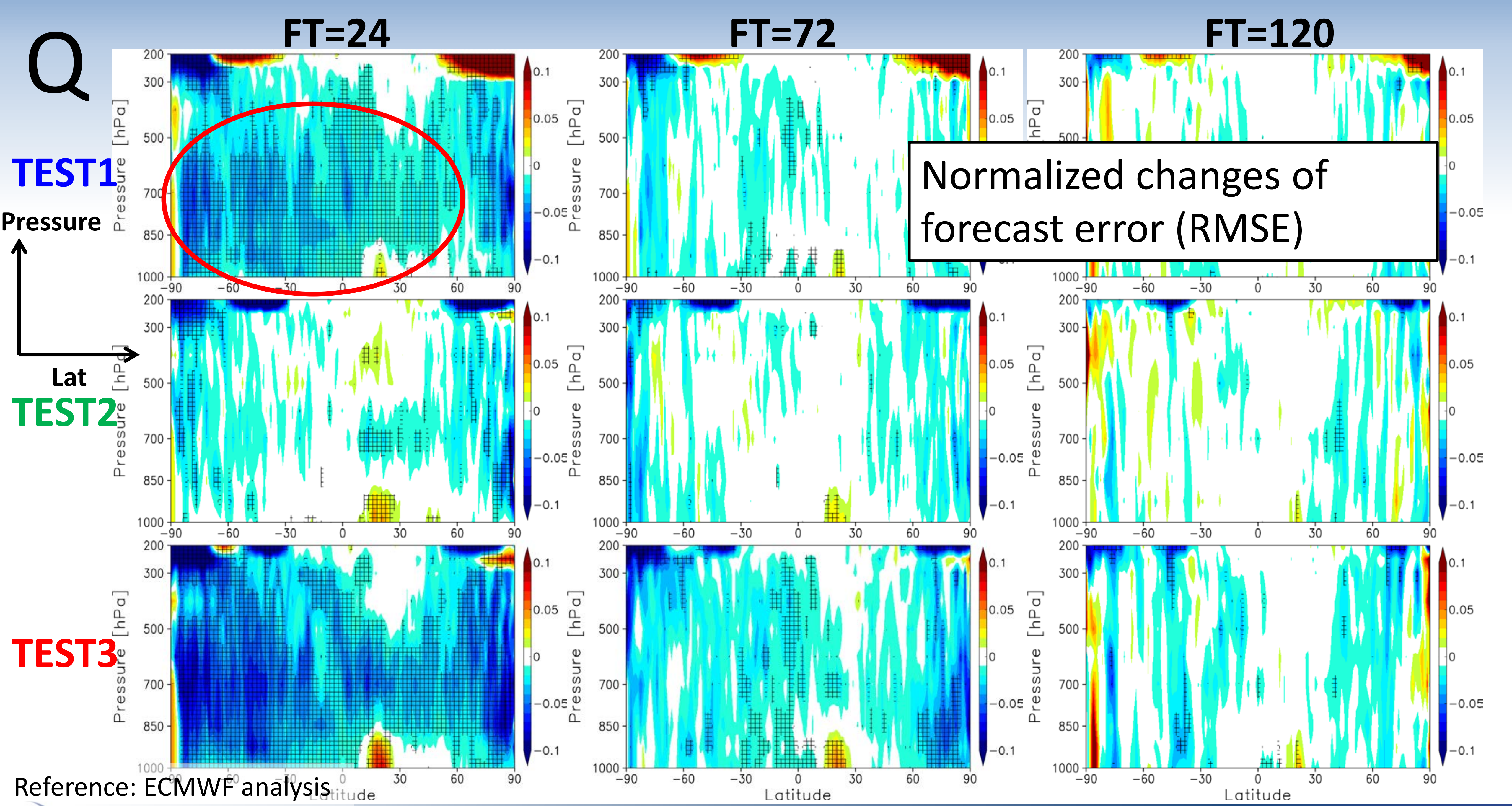
AMV Wind Vector



Aircraft Wind Vector



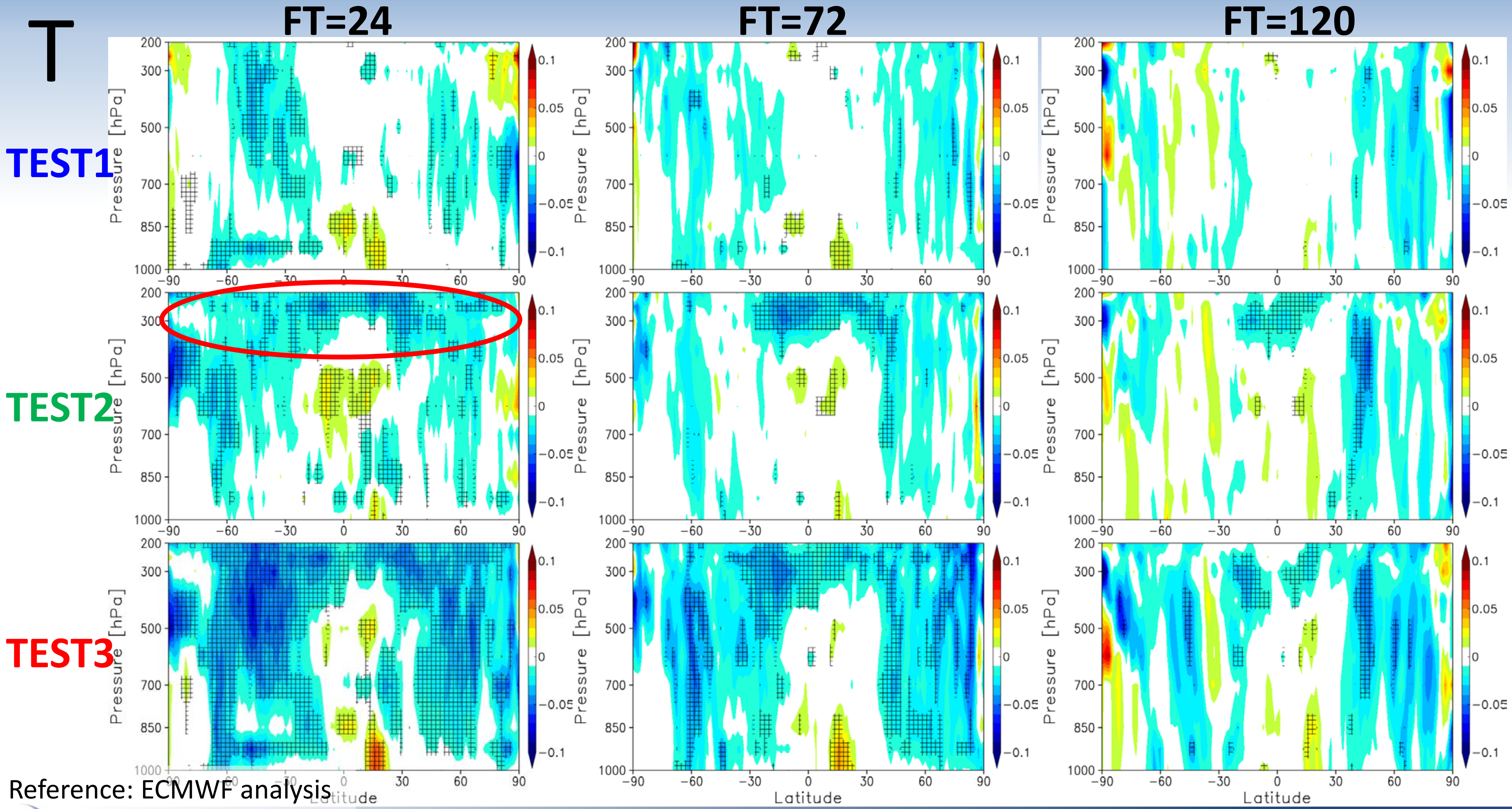
Q



Reference: ECMWF analysis

Blue color indicates reduction of forecast errors.

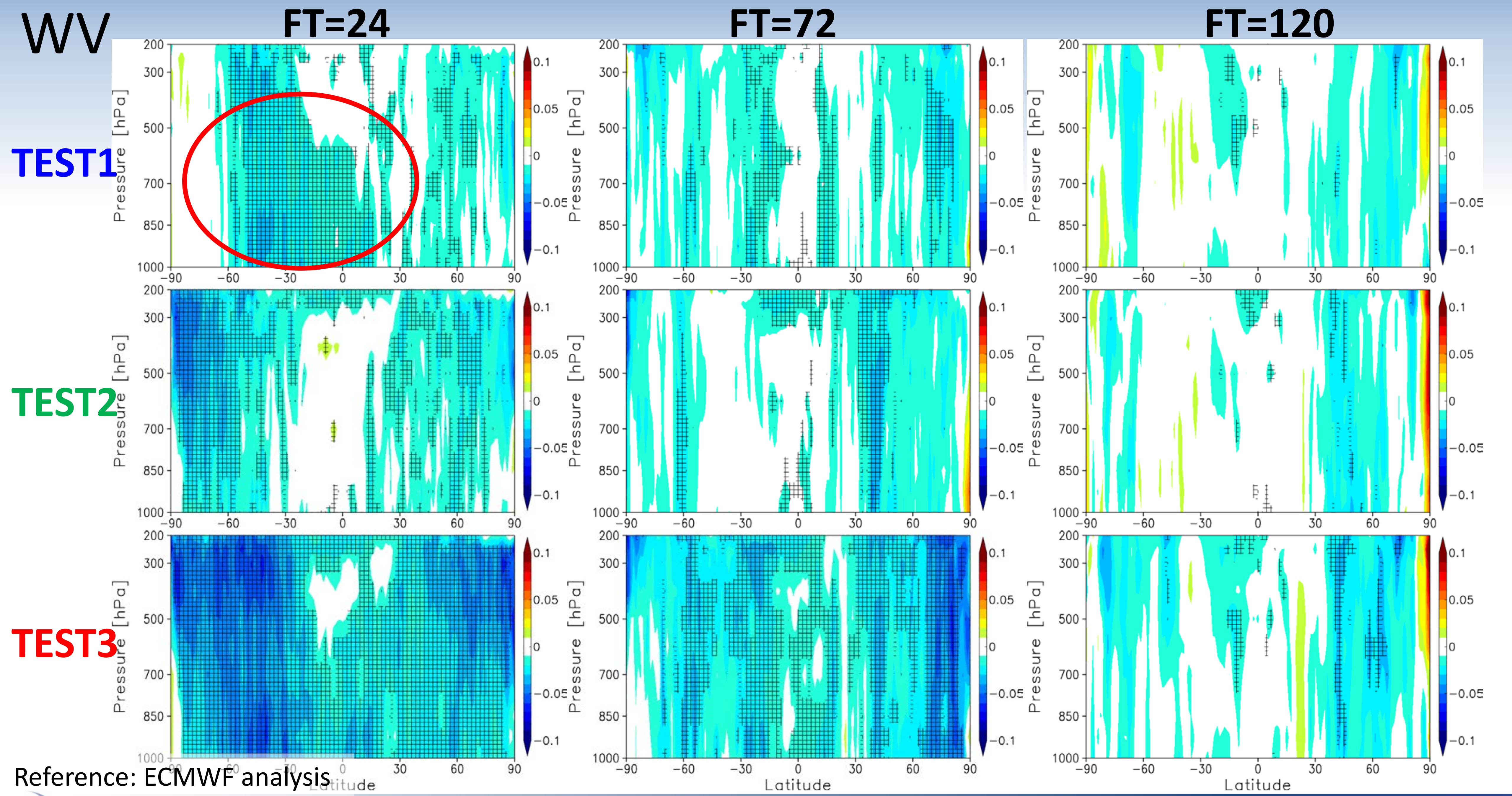
T



Reference: ECMWF analysis

Blue color indicates reduction of forecast errors.

WV



Reference: ECMWF analysis

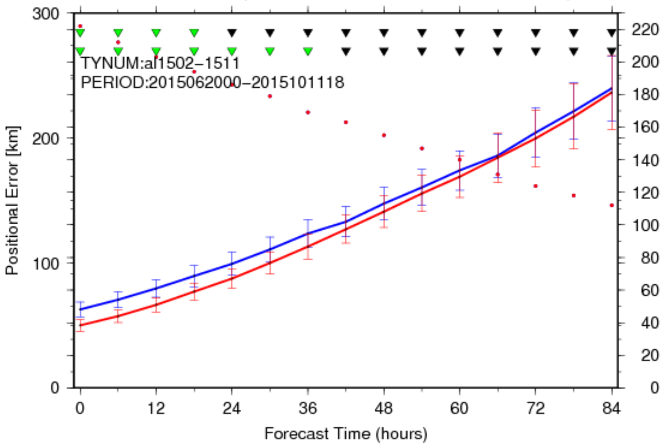
Blue color indicates reduction of forecast errors.

Impacts on TC track predictions

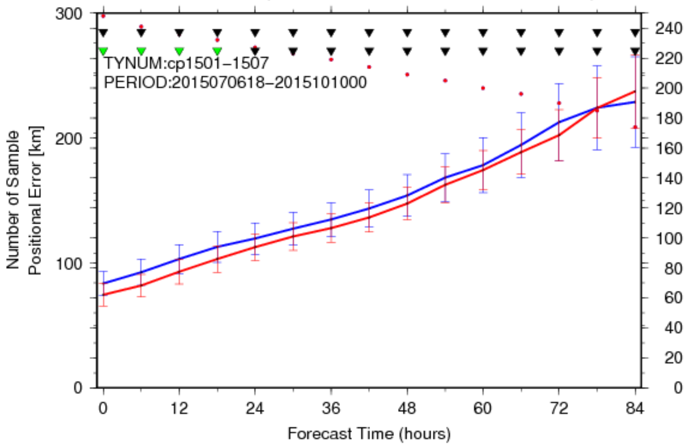
TEST3
All-sky MW imager+sounder +OUTER

CNTL

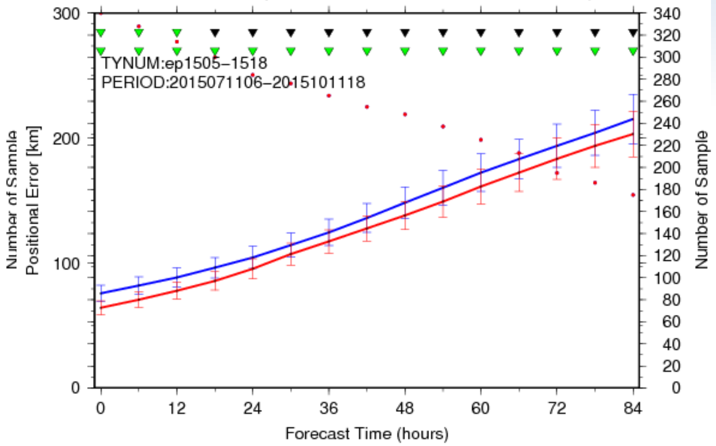
Atlantic Ocean



Middle Pacific Ocean

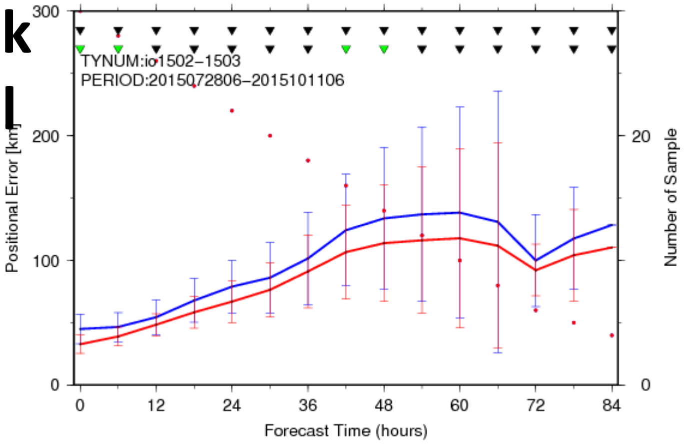


Eastern Pacific Ocean

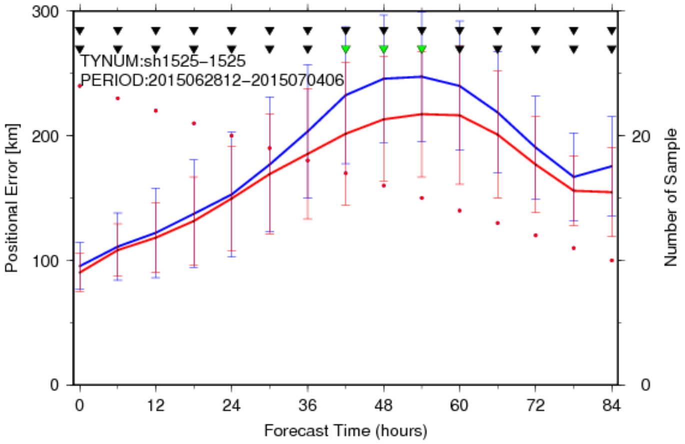


All-sky assimilation improved TC track predictions for all ocean areas.

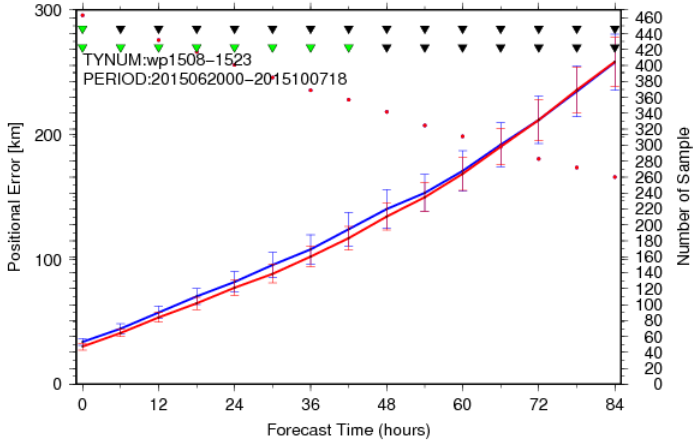
Indian Ocean



Southern Hemisphere



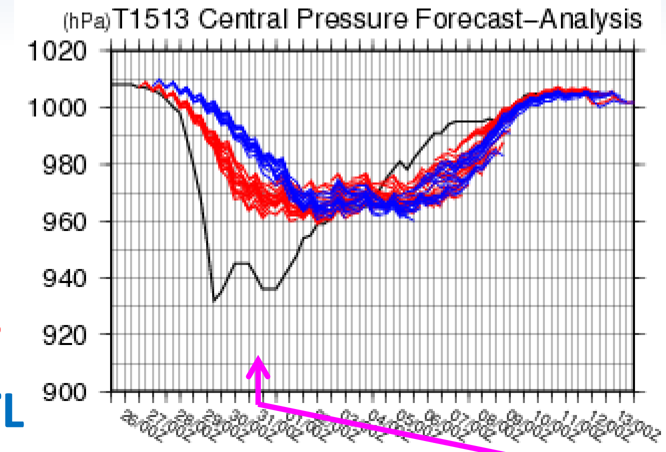
North-Western Pacific



Impacts on TC intensity predictions

TC central pressure prediction

TEST3



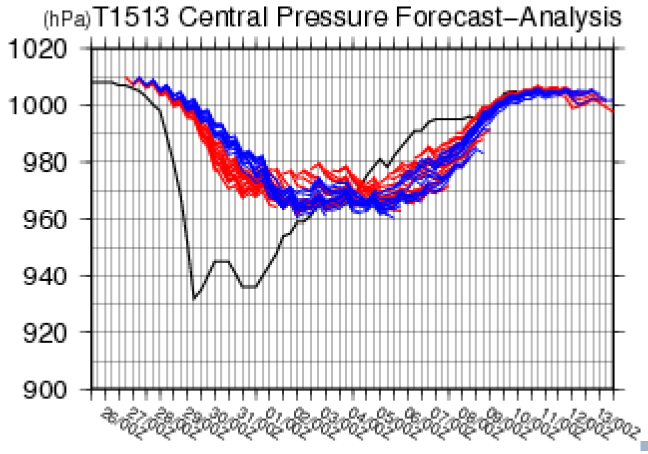
Red : TEST

Blue : CNTL

Black : NOAA Best track data

00UTC 31 Aug. 2015
Maximum stage

TEST2



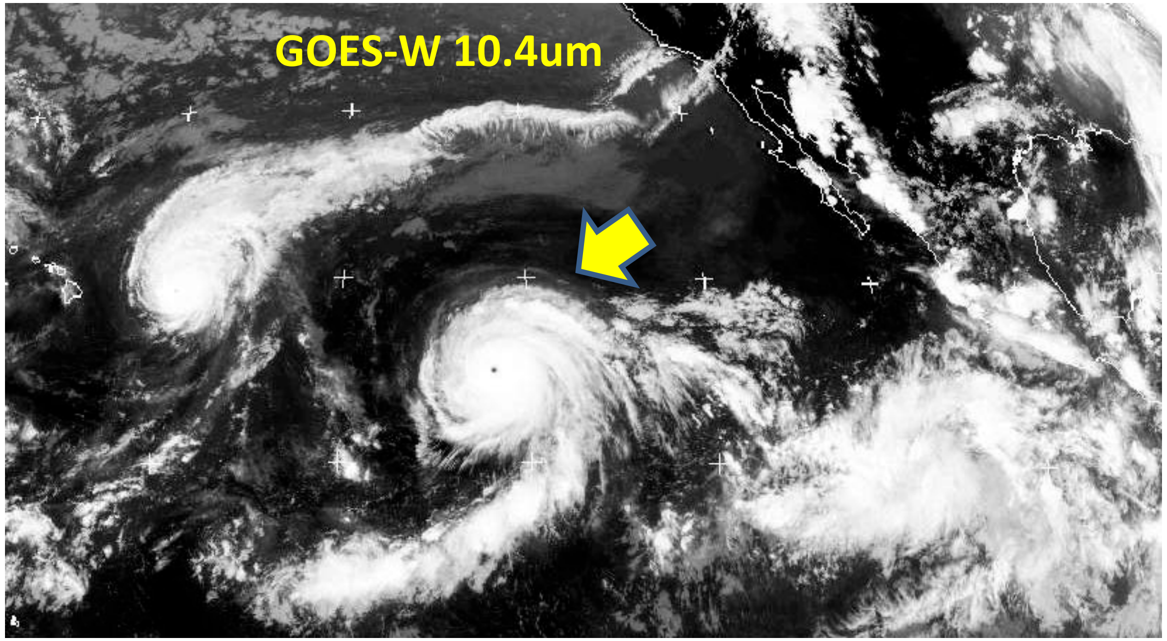
Improved prediction at TC developing stages

The heat release from water vapor condensation is a source of TC development.

Rapid Intensification* of TC was predicted in the all-sky assimilation experiment.

Water vapor analysis in cloudy conditions would be improved.

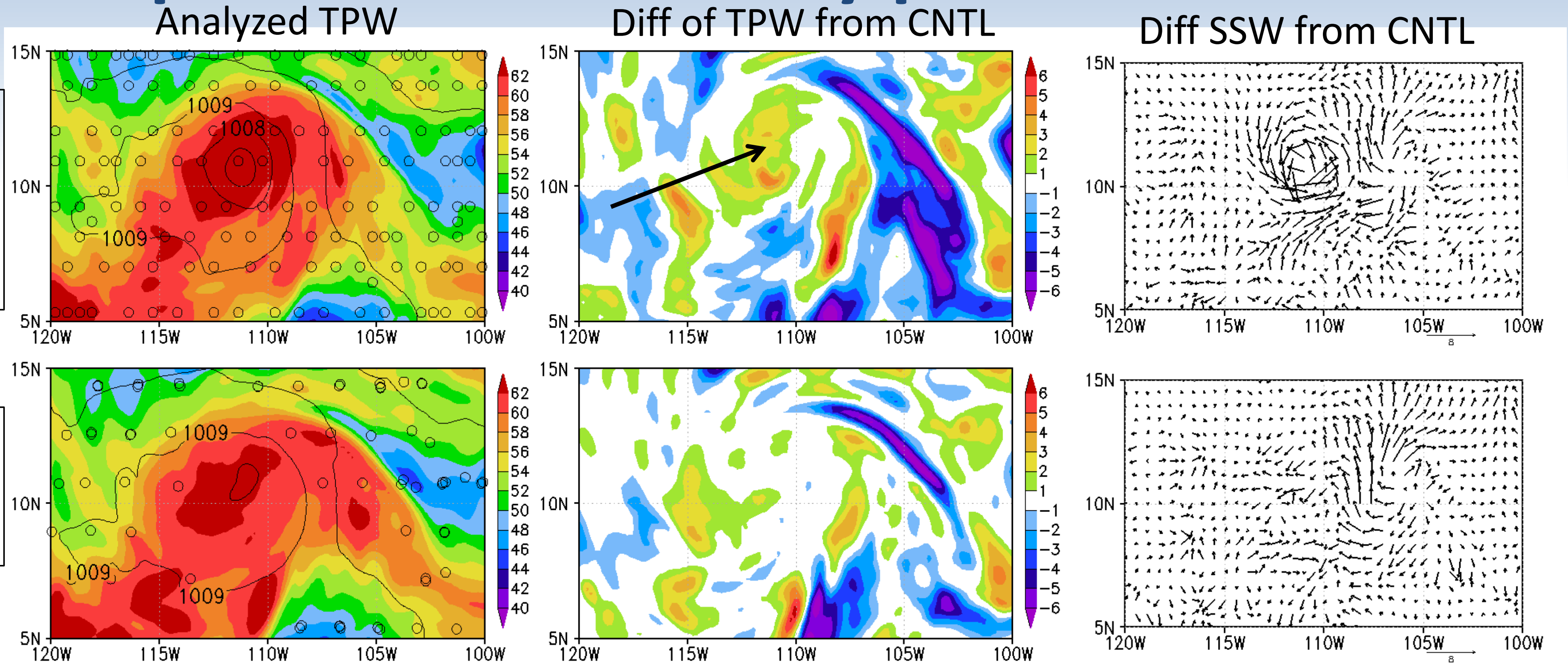
* Decrease in the central pressure of TC at least 30 hPa in a 24-hour period.



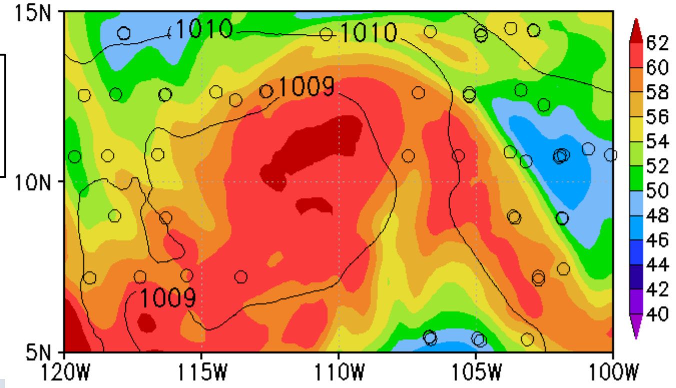
Impacts on TC intensity predictions

TEST3
All-sky + OUTER

TEST2
CNTL+OUTER



CNTL



Black circle: MW radiance observation

TC developing stage 12 UTC 26 August 2015

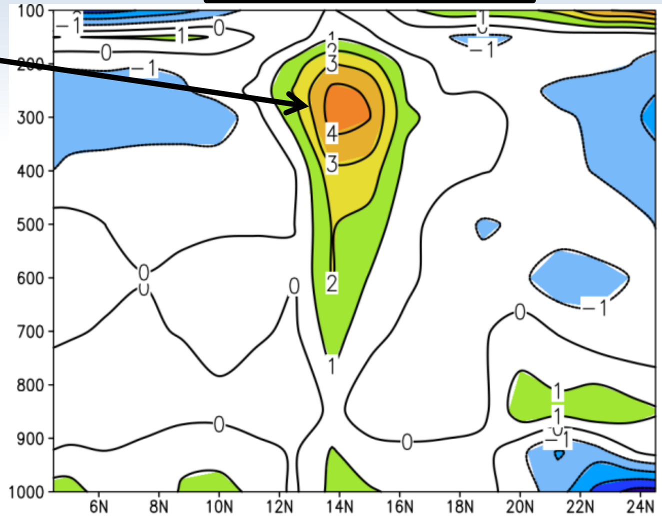
Enhanced water vapor contrast is analyzed.
Increase of water vapor amount and strengthened vortex in the center of TC.

Temperature anomaly in the vertical cross section at the center of TC

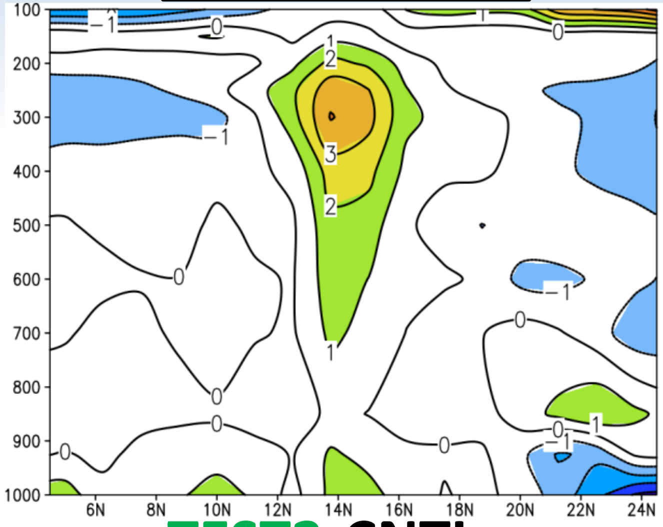
Warm Core

(hPa)

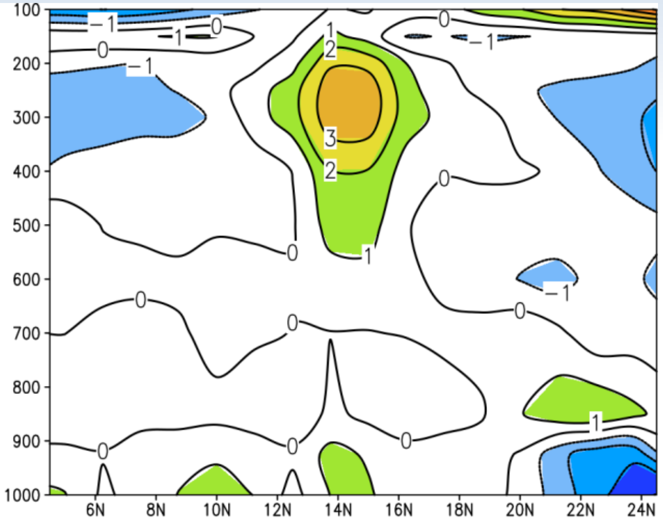
TEST3



TEST2



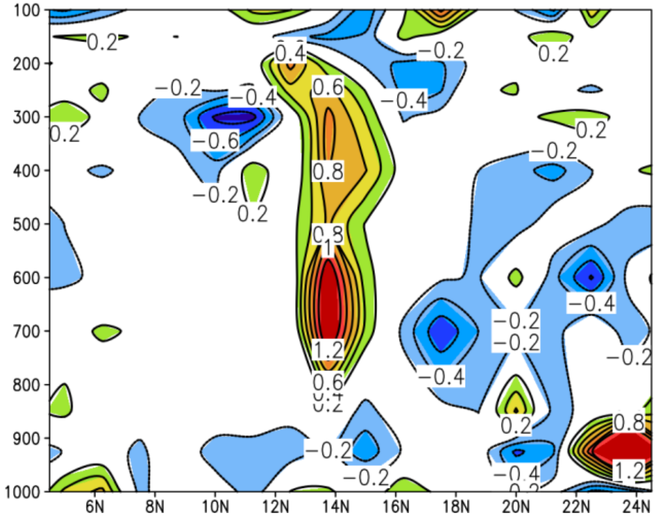
CNTL



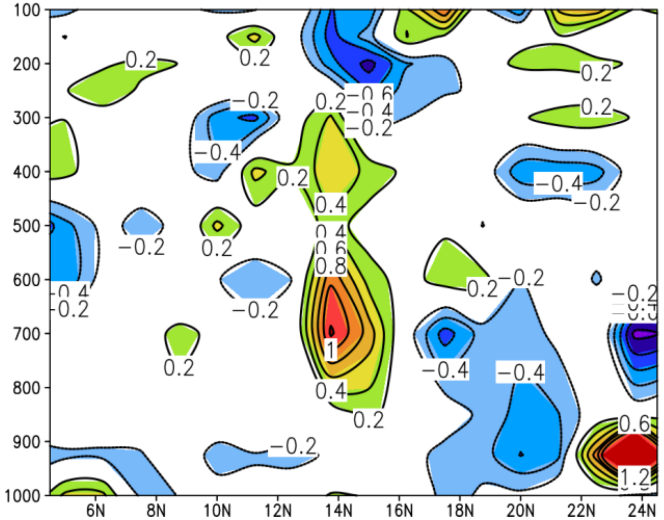
Enhanced Warm Core was analyzed in all-sky assimilation

(hPa)

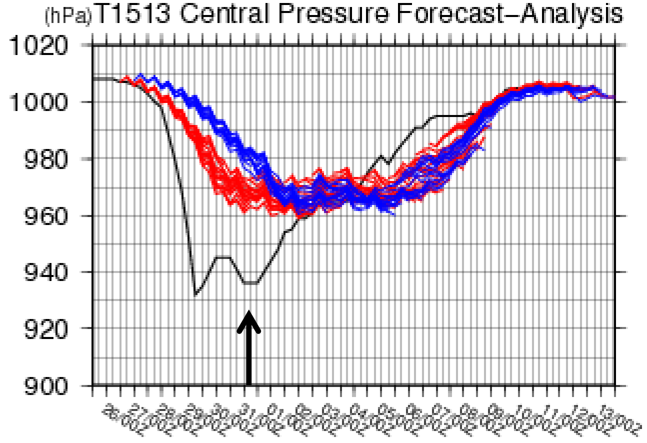
TEST3-CNTL



TEST2-CNTL



Analyzed Temperature field. 18 UTC 30 August 2015



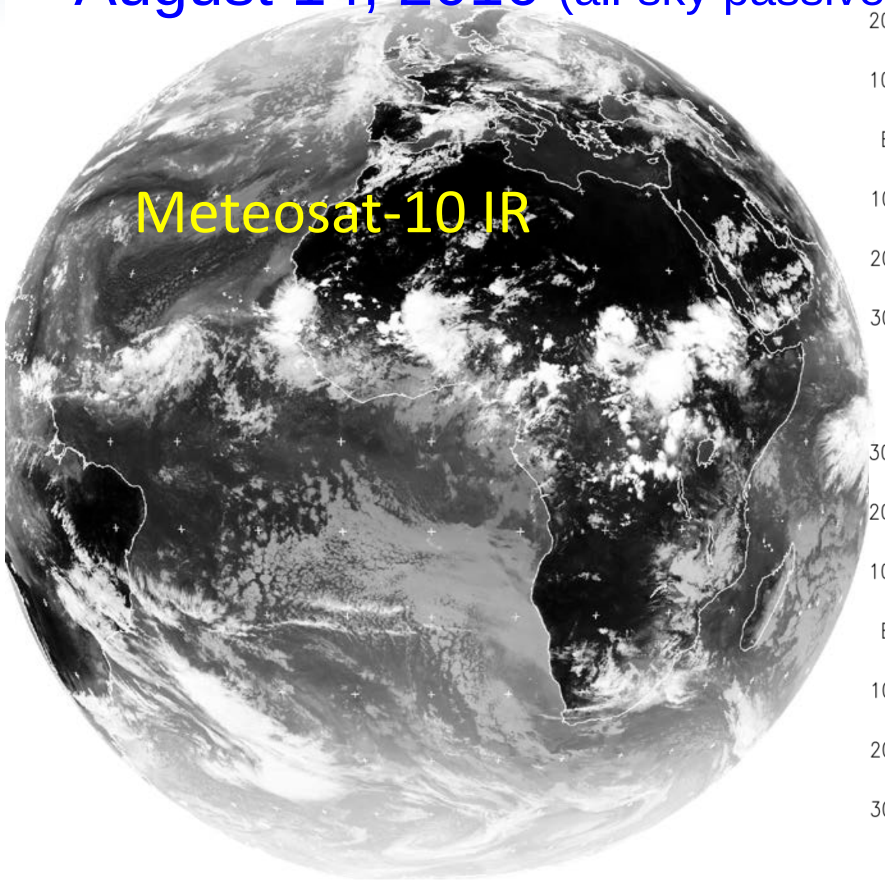
Maximum stage

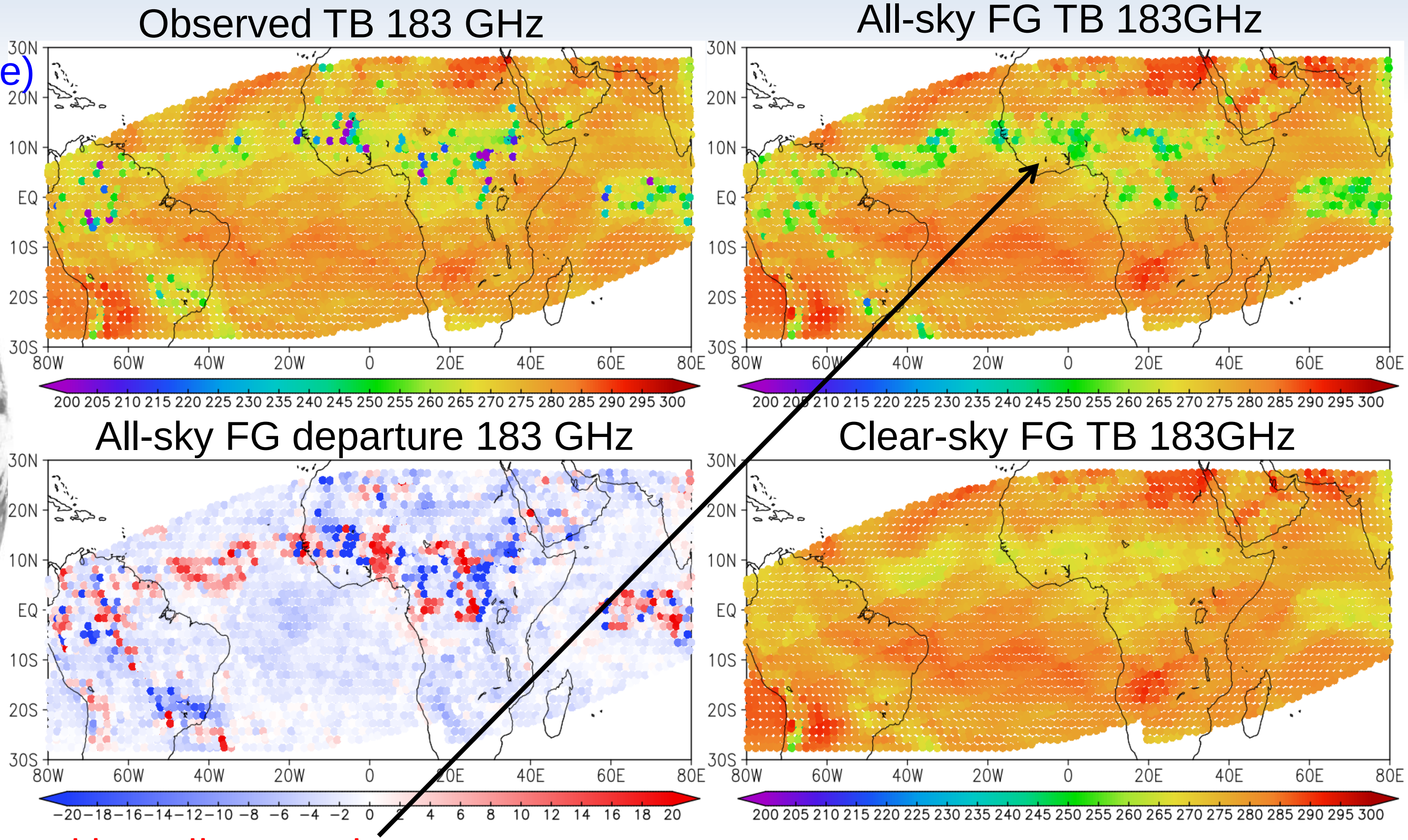
Forecast model bias issues in all-sky MW DA

- **Underestimation of strong convective clouds in the JMA global model?**

SAPHIR 183.31+6.8 GHz

August 14, 2016 (all-sky passive)





Model's convective clouds are weak and broadly spread.

Model's precipitation representation is crucial for all-sky 183 GHz humidity sounding radiance assimilation.

Summary

- Development of **all-sky MW imager and sounder radiance assimilation** using JMA global DA system in progress
- Experiments of all-sky assimilation + outer-loop using JMA global DA system
  – Large positive improvements from outer loop introduction for Q, T, WV forecast fields.
  – Better fits of FG field to various observations.
  – All-sky assimilation enhanced water vapor contrast under cloudy conditions.
    - Improved TC track forecasts
    - Realistic deepening (Rapid Intensification) of TC central pressure and strong wind fields
    - Well-formed warm-core structures in the TC maximum strength stage
- Realistic water vapor analysis in cloudy areas can produce realistic TC intensification, especially in the development stages. Outer-loop introduction enhanced the trend.
- **Forecast model's performances for convective clouds are crucial for all-sky 183 GHz humidity sounding radiance assimilation.**

Thank you for your attention.