Coupled DA Workshop, Oct. 18th, 2016, Toulouse, France

Development of a Coupled Atmosphere-Ocean Data Assimilation System in JMA/MRI

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Outline

1. History of CDA System Development in JMA/MRI
2. Experience of developing the quasi-coupled DA system
   -negative feedback between SST and precipitation-
3. Coupled DA System in JMA/MRI -Some early results-
4. Concluding Remarks

1. History of CDA System Development in JMA/MRI

☆ History of CDA System Development in JMA/MRI

CDA System

Sep.2016: Reanalysis experiment
NWP experiment

Mar. 2016: Prototype of CDA system was build up

Quasi-CDA System

2014: Development of weakly coupled DA system was started

2012: ECMWF started CDA system development

2009, 2011: Papers on the negative feedback of SST and precipitation in the quasi-CDA system

2006: Development of a quasi-coupled DA system was started.
(Only ocean data are assimilated into a CGCM.)

2002-2007: Coupled 4DVAR System had been developed in JAMSTEC for the 1st generation of Earth Simulator.

2. Experience of developing the quasi-coupled DA system

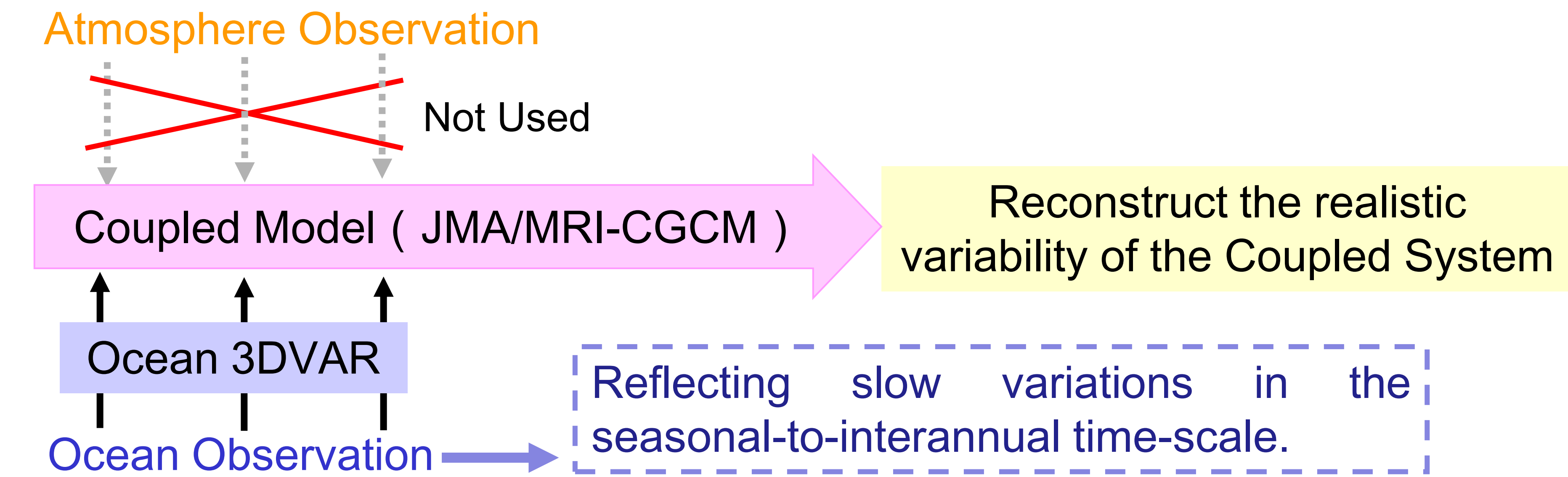
-negative feedback
between SST and precipitation-

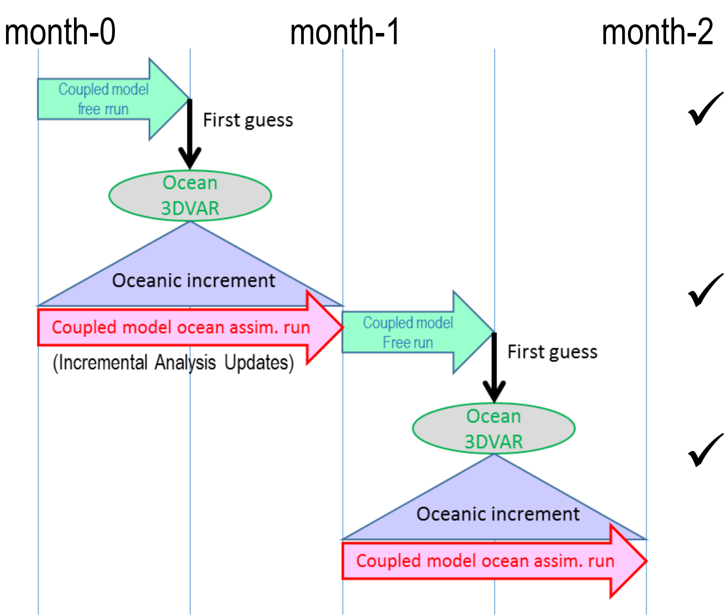
Fujii et al. 2009, J. Clim, http://dx.doi.org/10.1175/2009JCLI2814.1

Fujii et al. 2011, "Climate Variability", InTech, http://dx.doi.org/10.5772/30330

☆ "Quasi-Coupled" Data Assimilation System

A weakly coupled DA system assimilating only ocean data





- ✓ The system was developed as a prototype of a coupled DA system in JMA/MRI.
- ✓ Incremental Analysis Updates (IAU) with an analysis interval of 1 month.
- ✓ Short time-scale variabilities like the weather modes are not constrained in the system.

We compared the result of the quasi-coupled data assimilation (quasi-CDA) system with an AMIP run.

The AMIP run is the simulation of the **uncoupled atmospheric model** using the observation-based daily SST mapping.

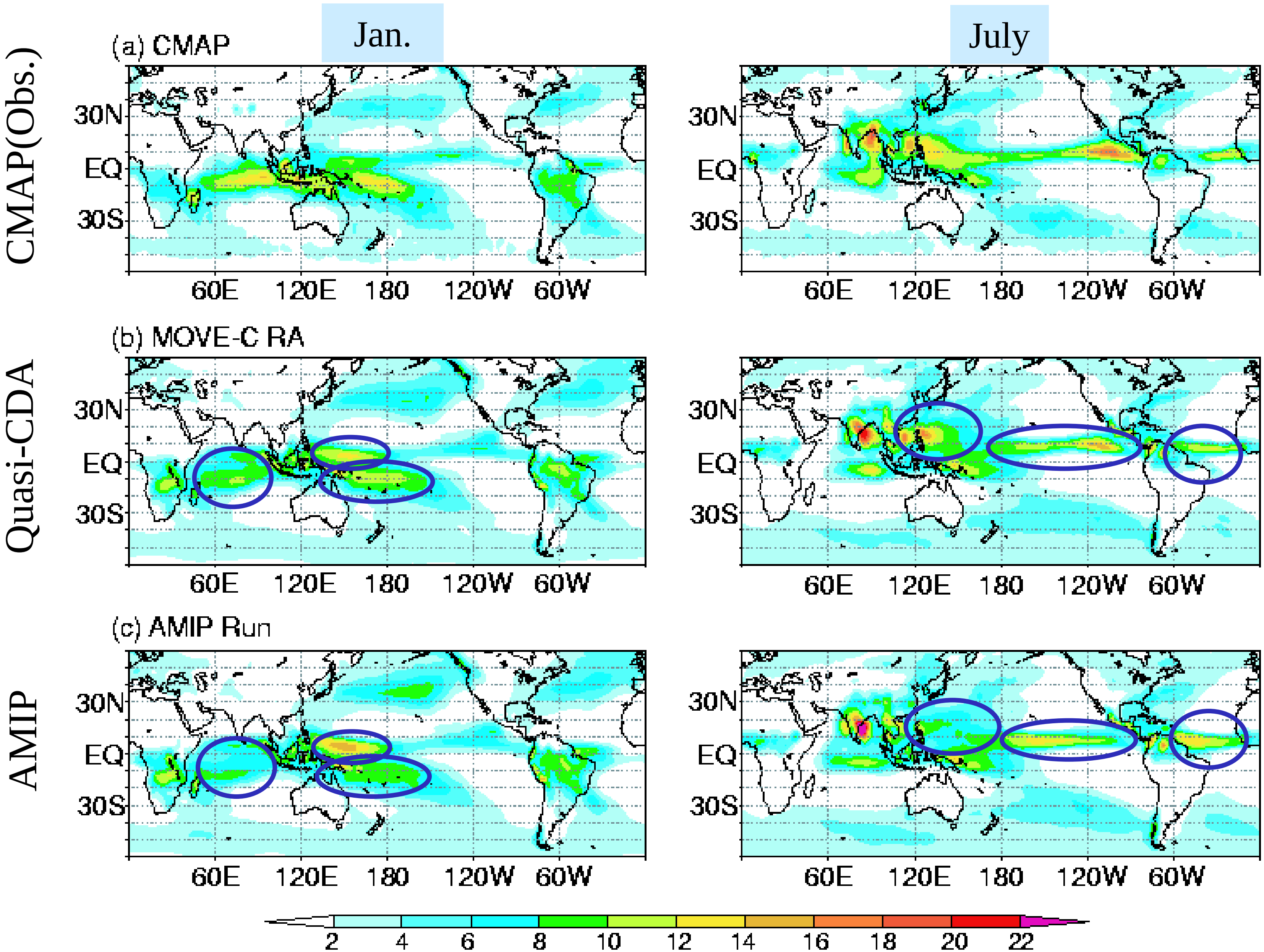
In the AMIP run, the atmosphere is forced by the **observed SST itself**.

In contrast, the SST field in the quasi-CDA system has some **deviations from the observed SST.**

Therefore, it is natural that the atmospheric field in the AMIP run **is better than** that in the quasi-CDA system.

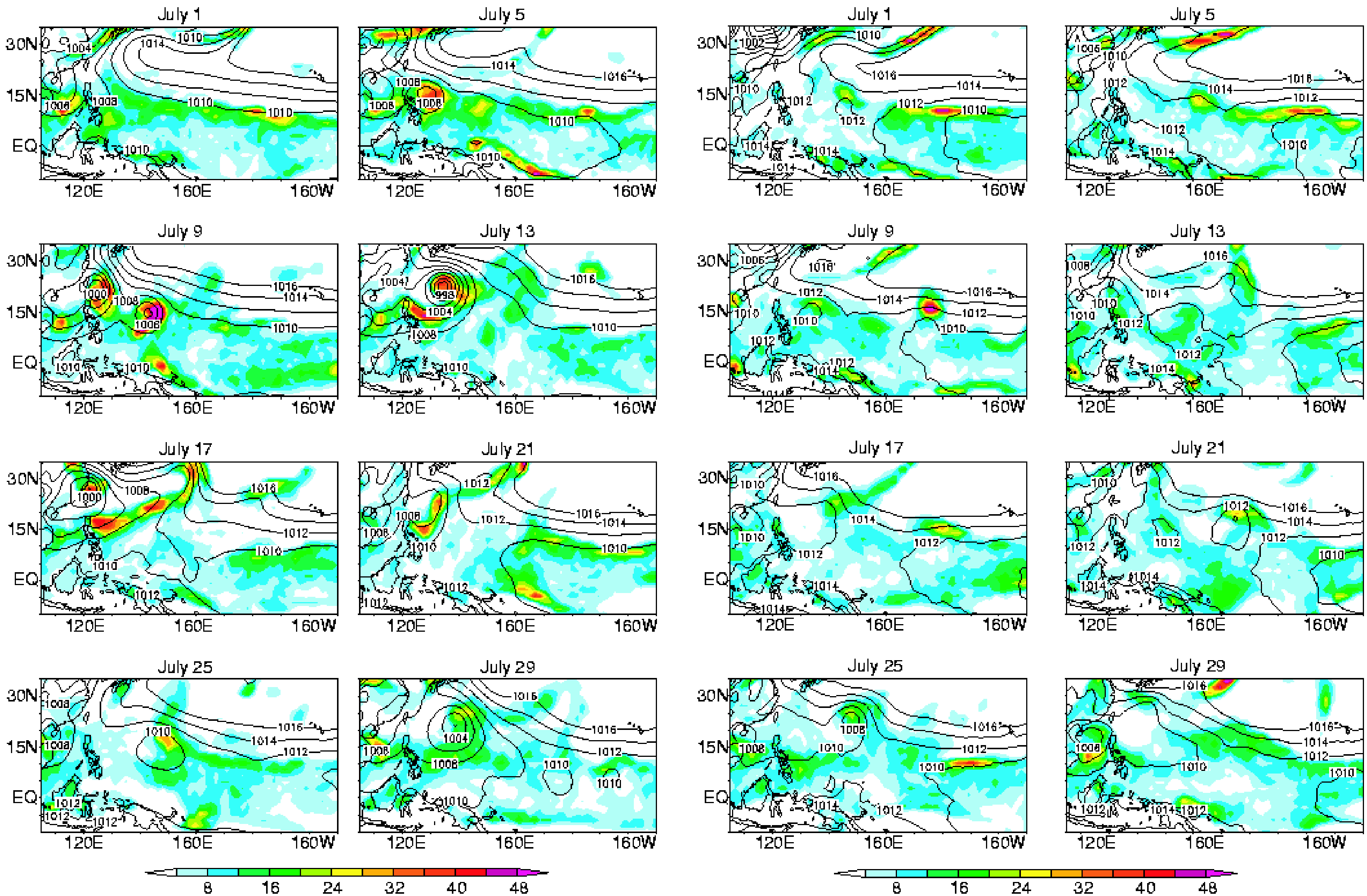
However ...

★ Monthly Climatology of Precipitation



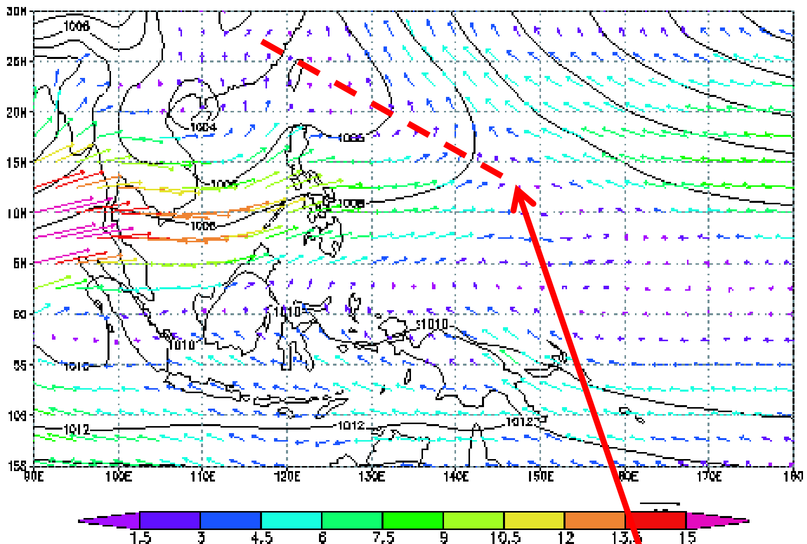
★ Time series of SLP and PRC (July, 1997)

QCDA System　　　　AMIP Run

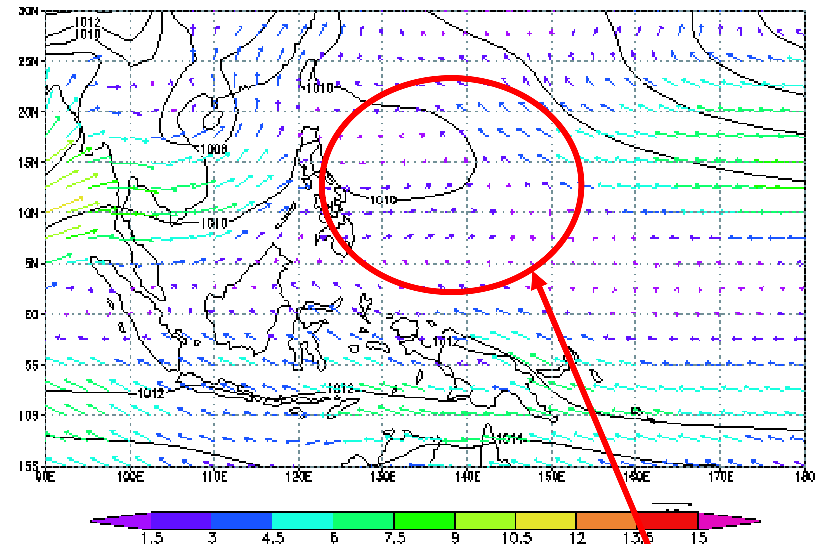


★ SLP and wind at 850hPa (Jun-Aug, 1997)

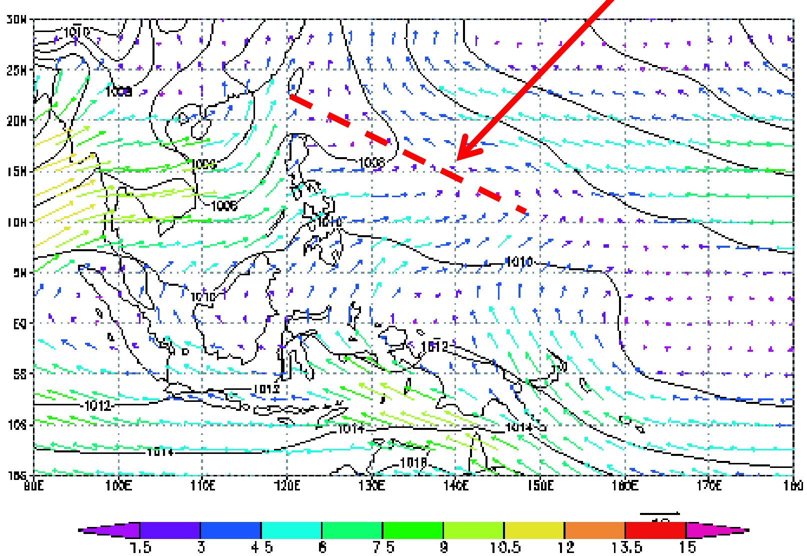
QCDA System



AMIP Run



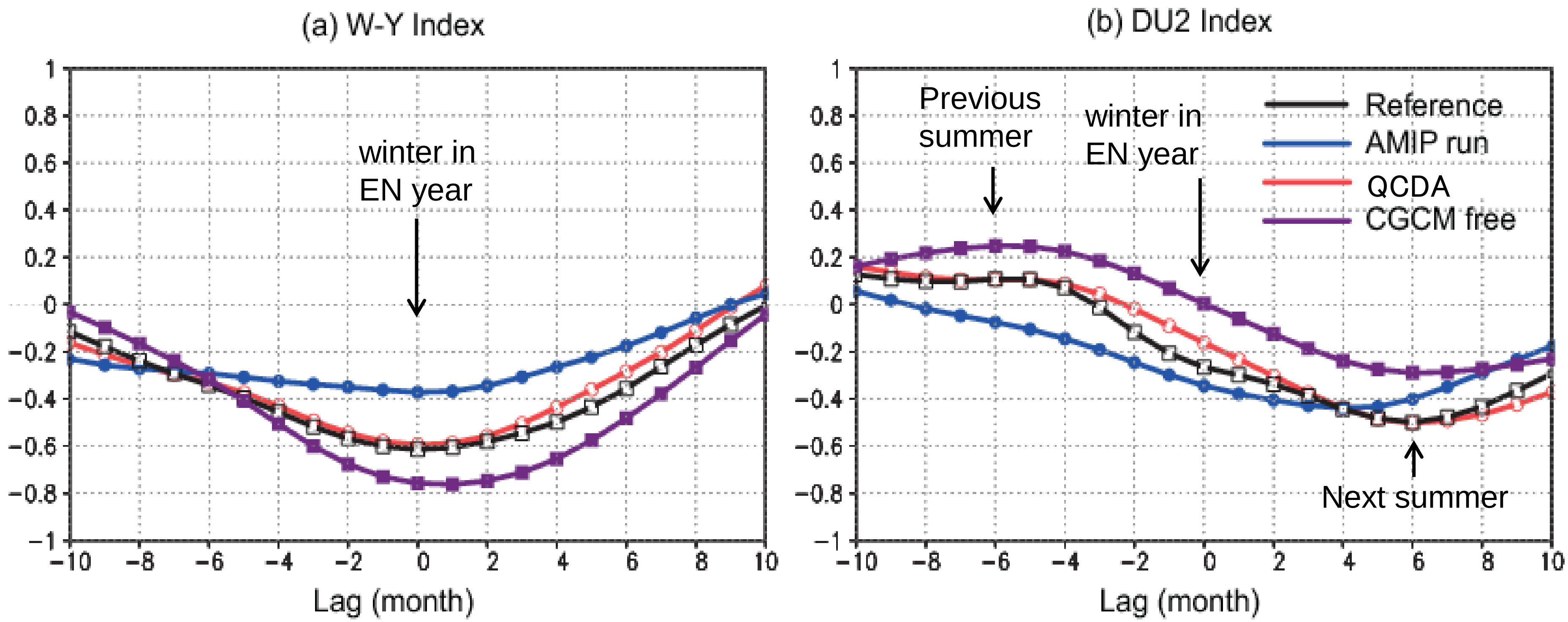
JRA-25 (Obs.)



The monsoon trough can be seen with cyclonic wind and dense SLP contours in JRA-25 and QCDA.

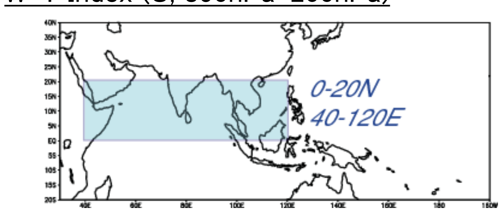
However, it is not clesar and the cyclonic wind is weak in AMIP Run.

★Relation between NINO3 and W-Y/DU2 indices

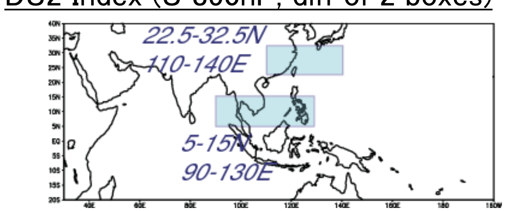


Plots of the correlation coefficients of (a) W-Y index (for the variation of the monsoon trough), (b) DU2 index (for the variation of the Walker Circulation), with the NINO3 index against the lag (month) of the W-Y or DU2 indices for JRA-25 (black), AMIP run (Blue), QCDA (Red), and CGCM Free run (purple). The correlation coefficients averaged for ensemble members are adopted for the QCDA and AMIP runs.

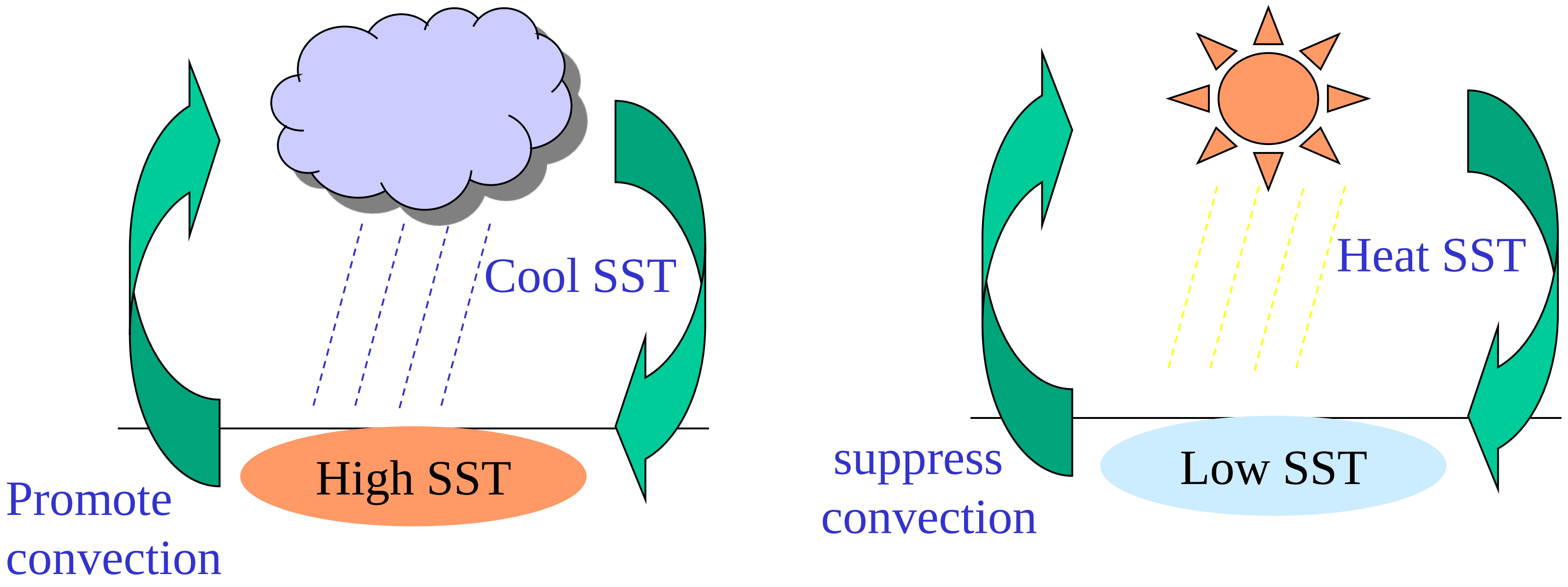
W−Y Index (U, 850hPa−200hPa)



DU2 Index (U 850hP, diff of 2 boxes)



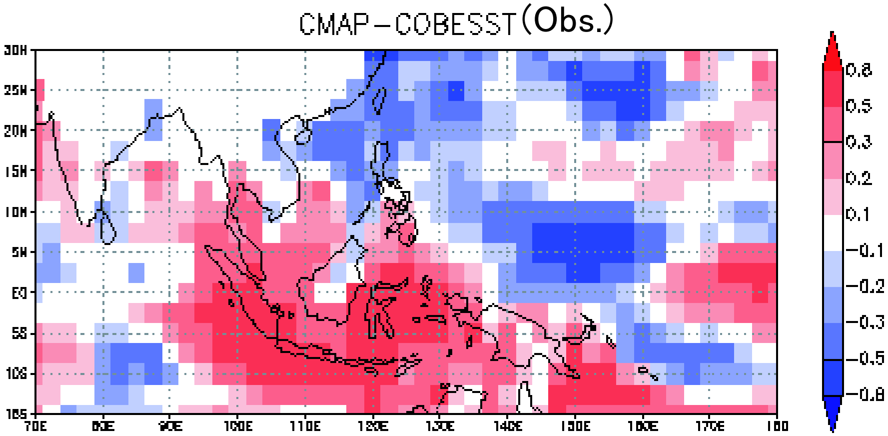
☆ Negative Feedback between SST and Precipitation

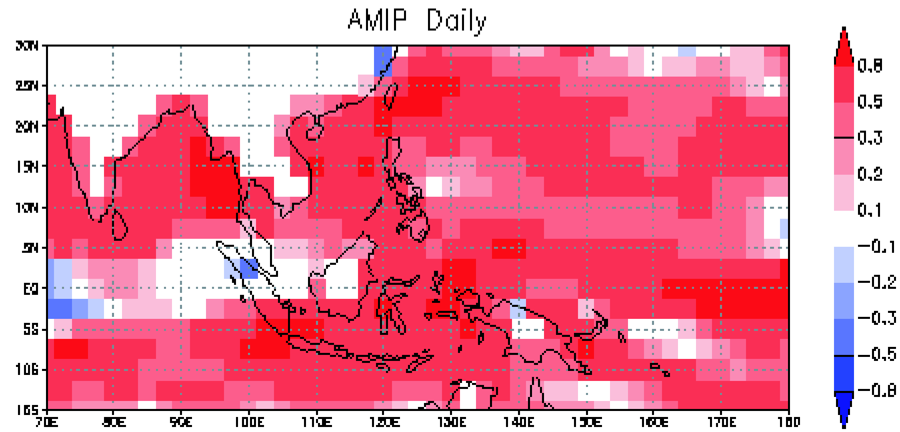


・This negative feedback has a role of adjusting the precipitation, that is, it avoids the continuous rainfall over high SST regions.

・However, this negative feedback does not work in uncoupled atmosphere models (and in the AMIP Run) !!

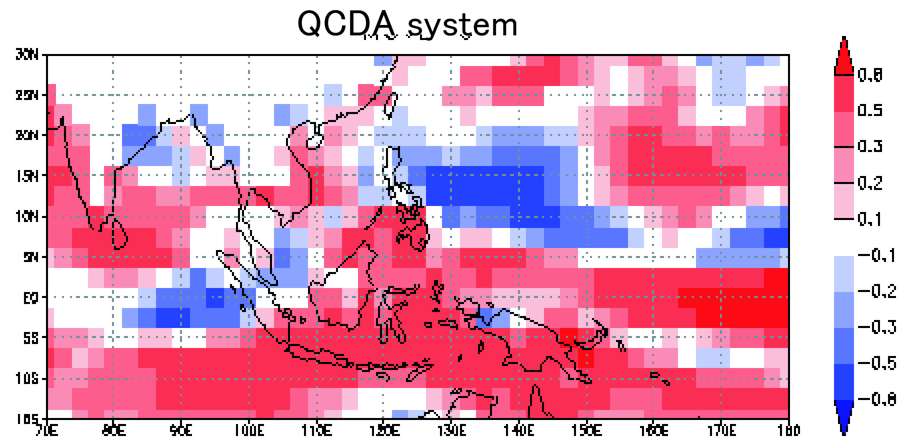
★Correlation between SST and PRC in Jun.-Aug.





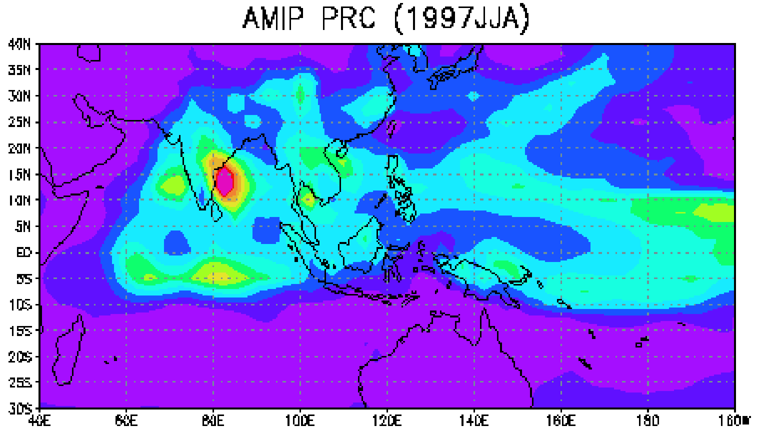
AMIP Run: PRC is strongly coupled with SST.

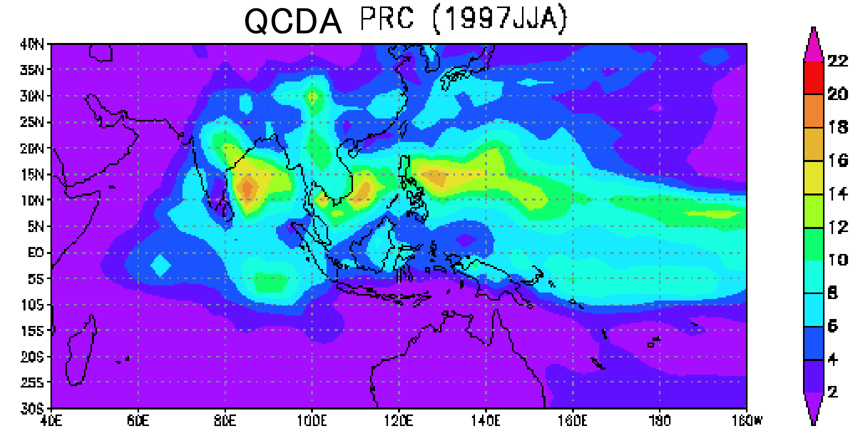
Real World (CMAP-COBESST): The coupling is not so strong because the negative feedback decouples them.

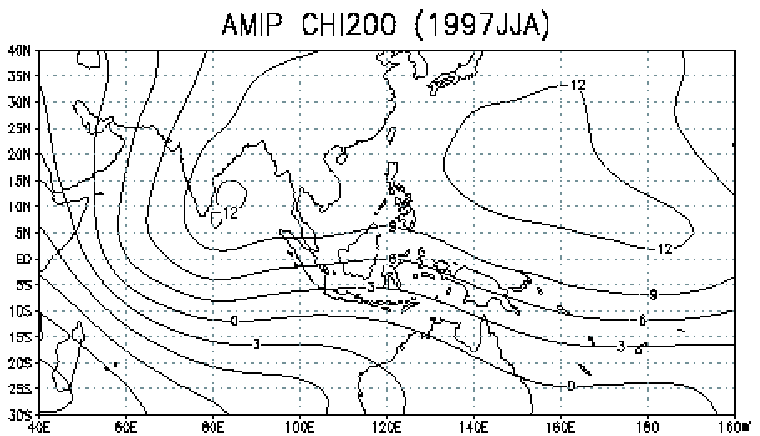


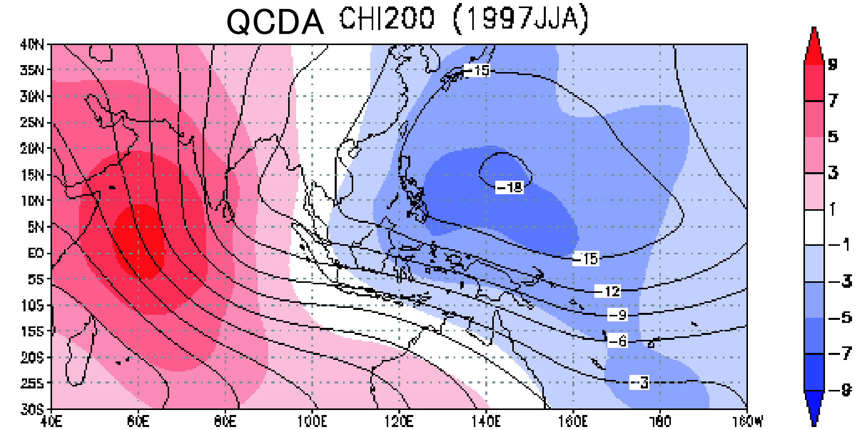
QCDA: The feature above is better estimated in Quasi-CDA because the negative feedback is reproduced. The low correlation in the western tropical Pacific and Bay of Bengal are represented.

★ PRC and Velocity Potential at 200hPa(Jun-Aug, 97)









Color: Difference (QCDA – AMIP)

Although PRC is overestimated at the east of India in the AMIP Run, the negative feedback suppresses it in QCDA. It allows the convection and divergence over the western tropical Pacific.

★ Experience of the quasi-CDA system

- ✓ The negative feedback between SST and PRC is not represented in the AMIP Run, but adequately reproduced in the quasi-CDA system.
- ✓ The negative feedback improves the distribution of the summer precipitation. It suppresses the excess rainfall in the east of India, and allows to increase the convection in the western tropical Pacific.
- ✓ This also improves the climatological state and variability of the monsoon trough and zonal Walker Circulation in summer.

Reference:

Fujii et al. 2009, http://dx.doi.org/10.1175/2009JCLI2814.1

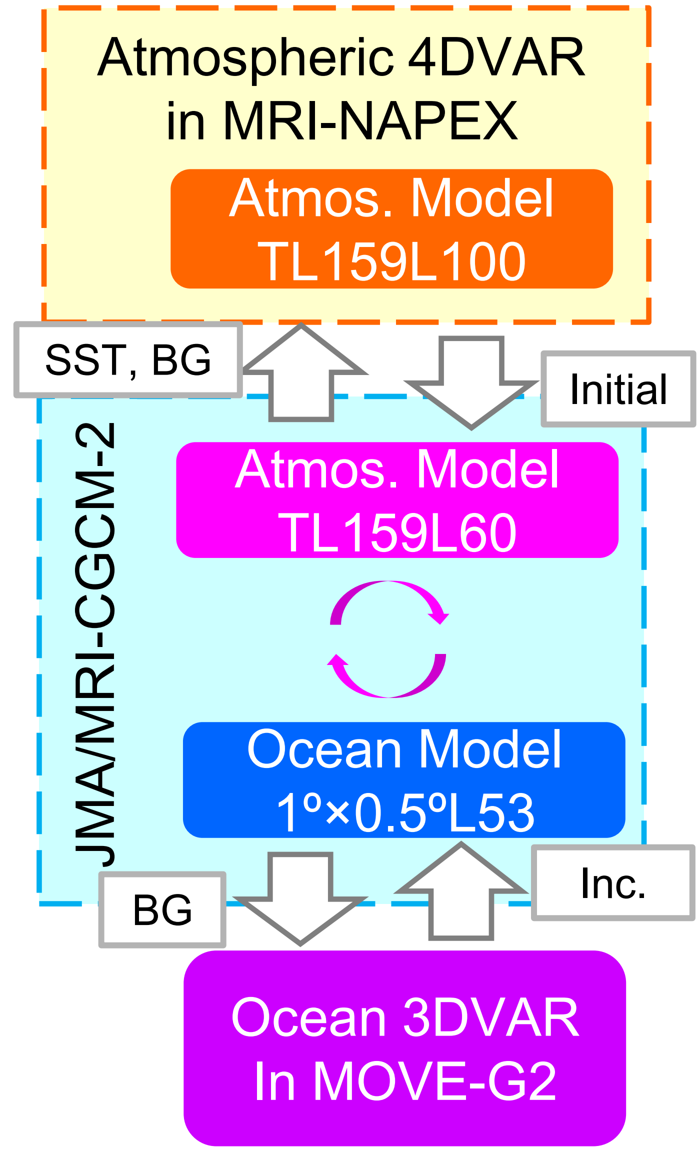
Fujii et al. 2011, http://dx.doi.org/10.5772/30330

3. Coupled DA System in JMA/MRI

-Some early results-

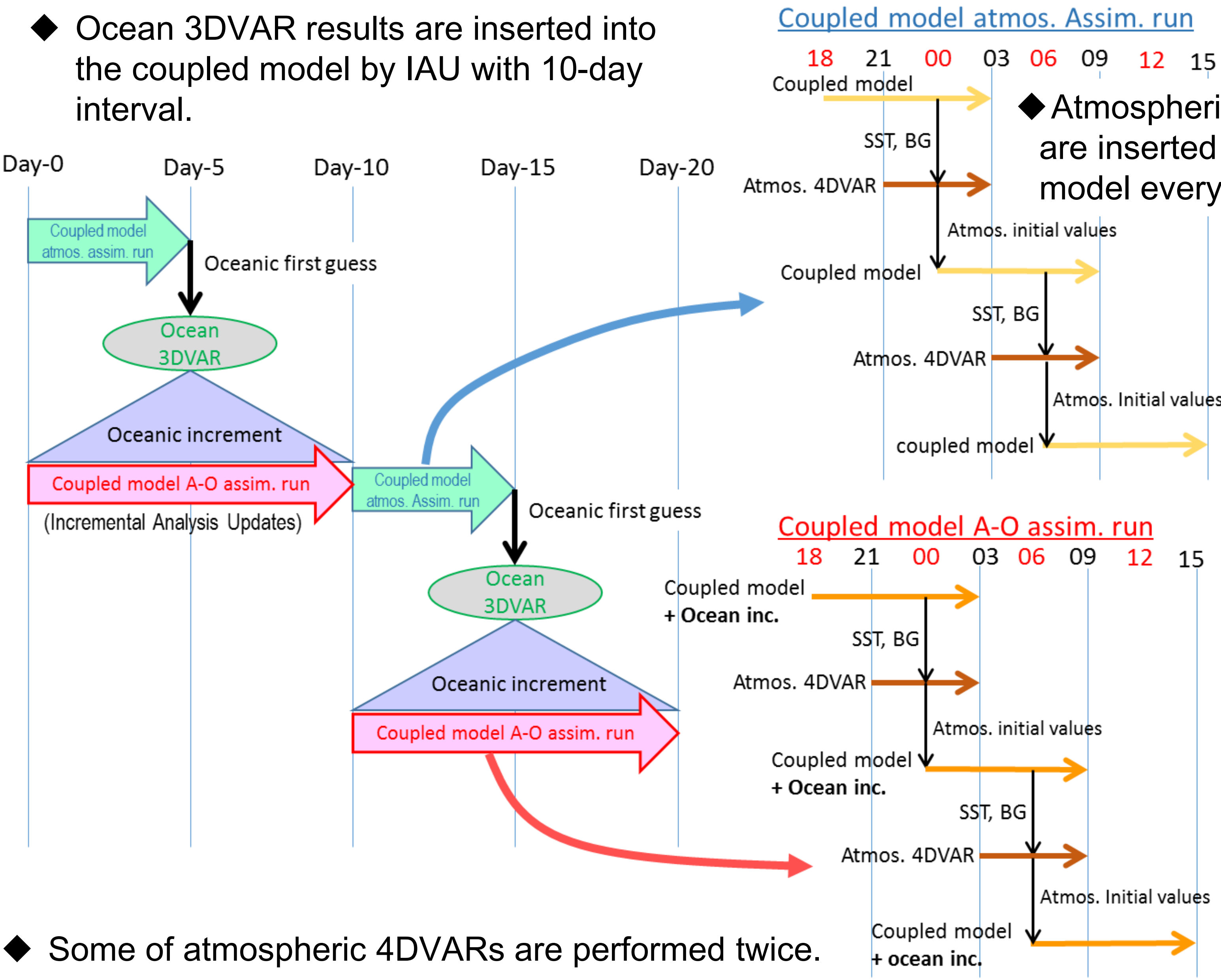
★Configuration of the Coupled DA System in MRI

- ✓ Weekly coupled DA system
- ✓ Based on the operational atmosphere and ocean DA systems (NAPEX and MOVE-G2) and the operational coupled model (JMA/MRI-CGCM2).
- ✓ The coupled model is used as the outer model for atmospheric 4DVAR.
- ✓ The atmosphere model in the coupled model is different from the model in NAPEX (adjusted for seasonal forecasts.)
- ✓ Considering the experience of the quasi-CDA system, we decided to use different intervals for data assimilation cycles of the atmosphere (6 hours) and ocean (10 days.)



★System Flow of the Coupled DA System

- Ocean 3DVAR results are inserted into the coupled model by IAU with 10-day interval.
- Atmospheric 4DVAR results are inserted into the coupled model every 6 hours.



- Some of atmospheric 4DVARs are performed twice.

★ Experimental CDA Reanalysis and References

Reanalysis Period: 28 October 2013 to 06 July 2015

- Separated to 4 streams
  (Oct2013-Feb2014, Feb-Aug2014, Aug2014-Jan2015, Jan-Jul2015)

Reference Data for the Validation

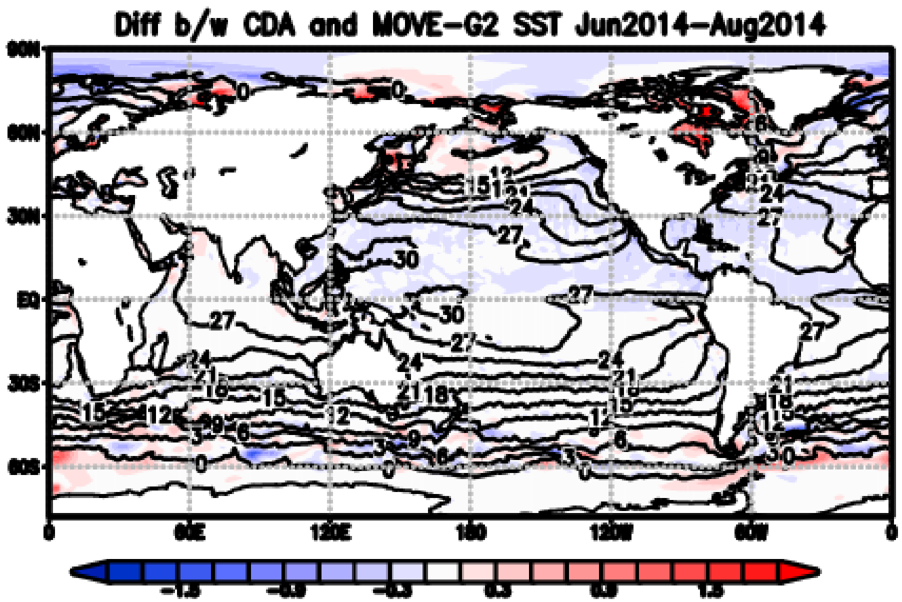
- JRA-55 (pronounced as *jra go go* !)
  - JMA's Atmospheric Reanalysis Data by 4DVAR
  - Outer Model: TL319H60, Inner Model: T106L40
  - The models and 4DVAR scheme are different from those in the CDA
  - In particular, the bulk formula is different from that in the CGCM.

- Operational Analysis of MOVE-G2
  - The ocean model and 3DVAR routine are the same as in the CDA
  - Atmospheric forcing is calculated from JRA-55 through CORE2 bulk formula, which is different from that in CGCM.

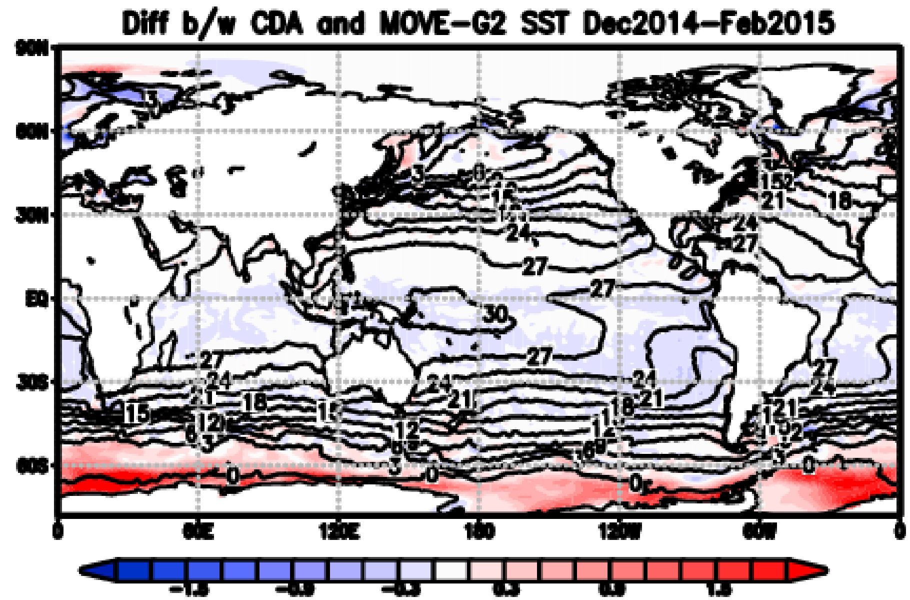
- Observation-based precipitation data
  CMAP (monthly, pentad), GPCP (Monthly)

☆ SST Difference between CDA and MOVE-G2

Jun2014-Aug2014

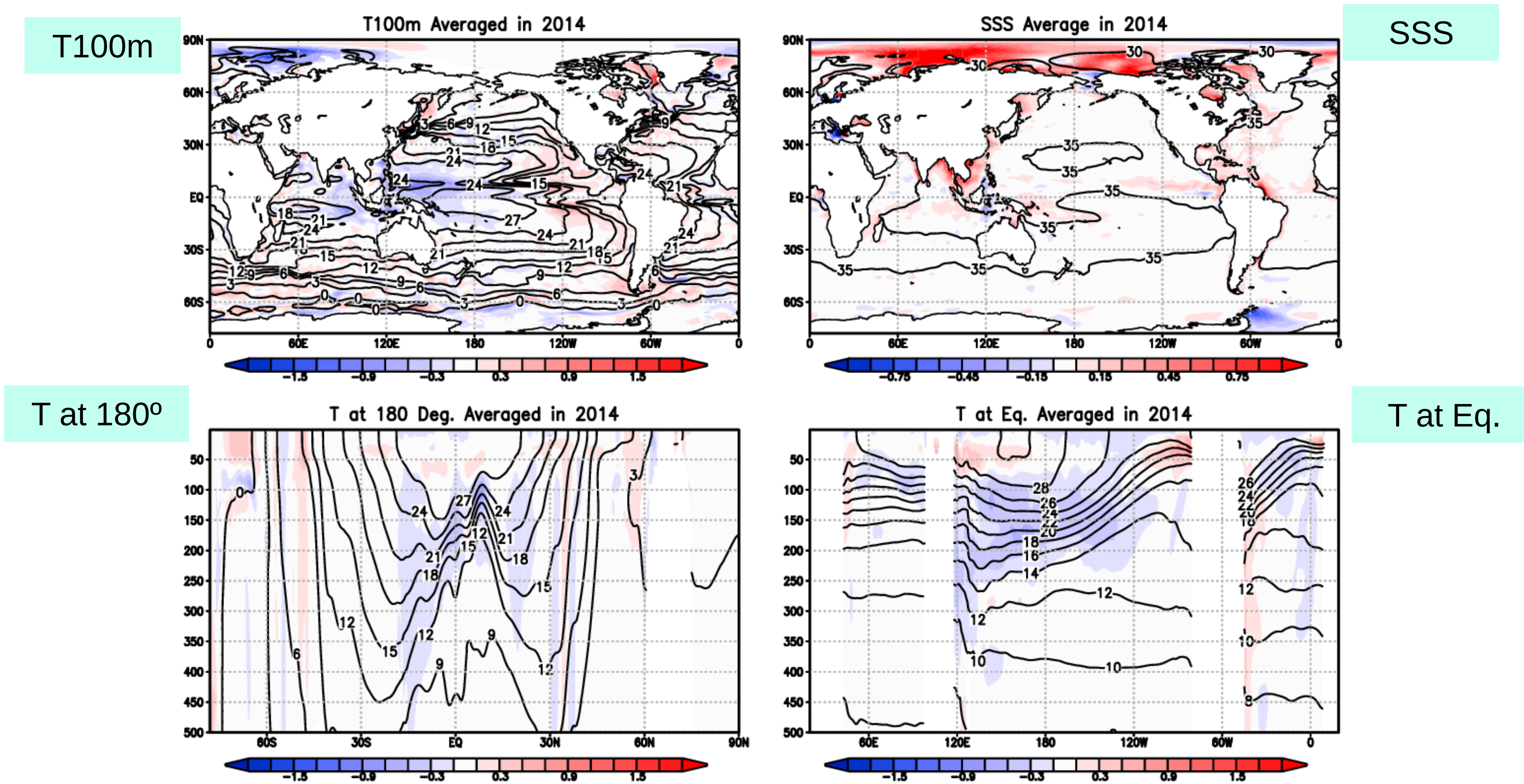


Dec2014-Feb2015



- ✓ The difference is less than 0.3°C in the most area because SST is well constrained by data assimilation.
- ✓ They are also close to observation-based analyses.
- ✓ SST is more than 1°C larger in the Southern Ocean in the austral summer. It may suppress generation of dense water and affect oceanic meridional overturning circulations

☆ T&SSS diff. b/w CDA and MOVE-G2 in 2014



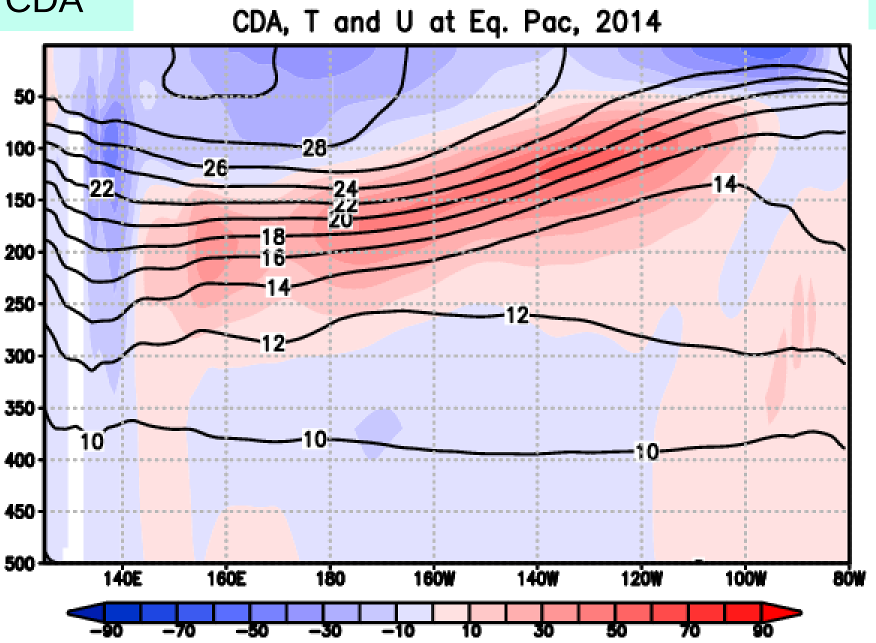
✓ Difference in the temperature field is small.

✓ The thermocline is lifted in the western and central Eq. Pac.

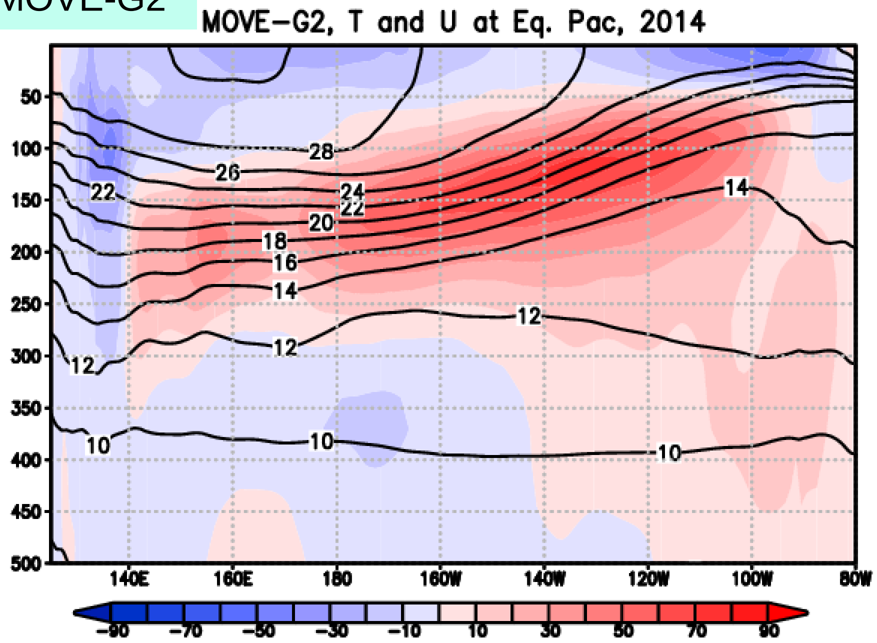
✓ Large difference is found where large run-off is expected.

☆ Difference of EUC between CDA and MOVE-G2

CDA



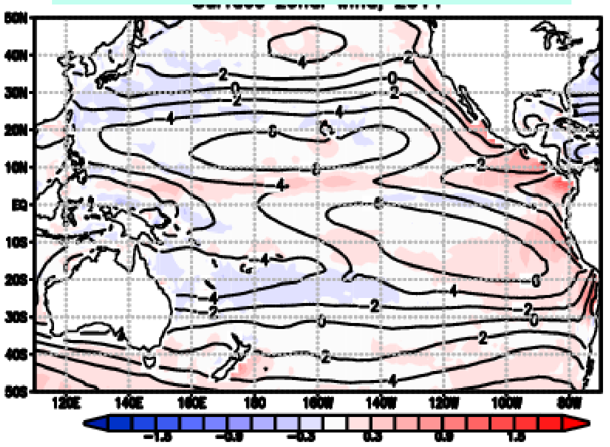
MOVE-G2



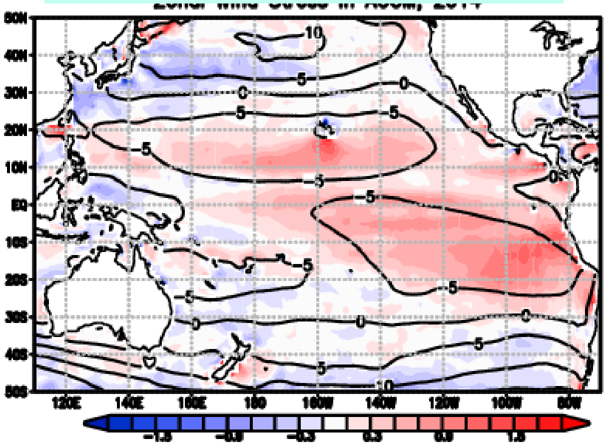
- ✓ Although TS fields are well constrained by data assimilation in the equatorial Pacific, current fields has relatively large difference from MOVE-G2 there.
- ✓ EUC is weakened and SEC is intensified in CDA.
- ✓ In order to examine the cause of this difference, zonal surface wind and wind stress fields are examined in the next slide.

★ Difference of surface zonal winds and wind stress

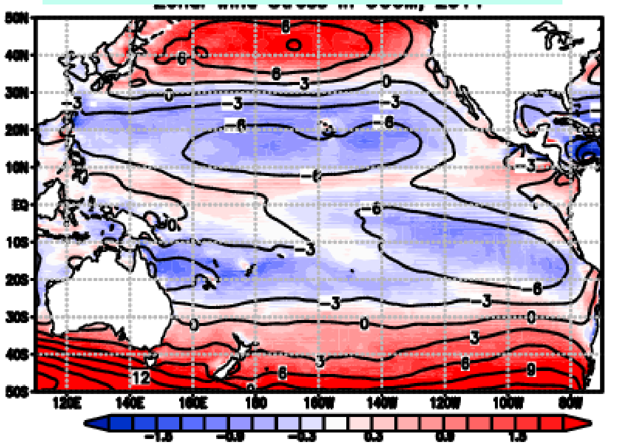
Diff .of U Surf. b/w CDA and JRA-55



Diff .of Zonal Stress b/w CDA and JRA-55

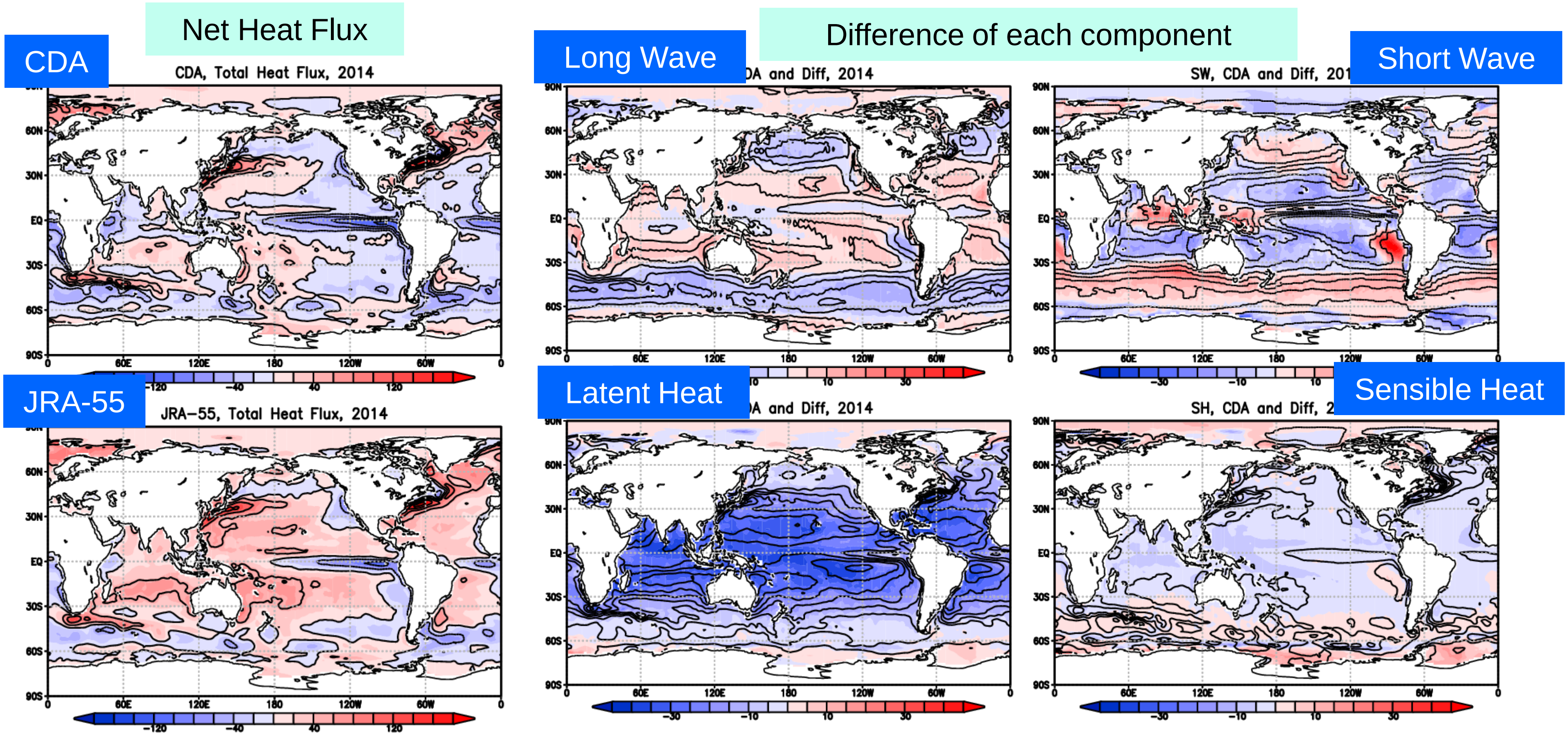


Diff .of Zonal Stress b/w CDA and MOVE-G2



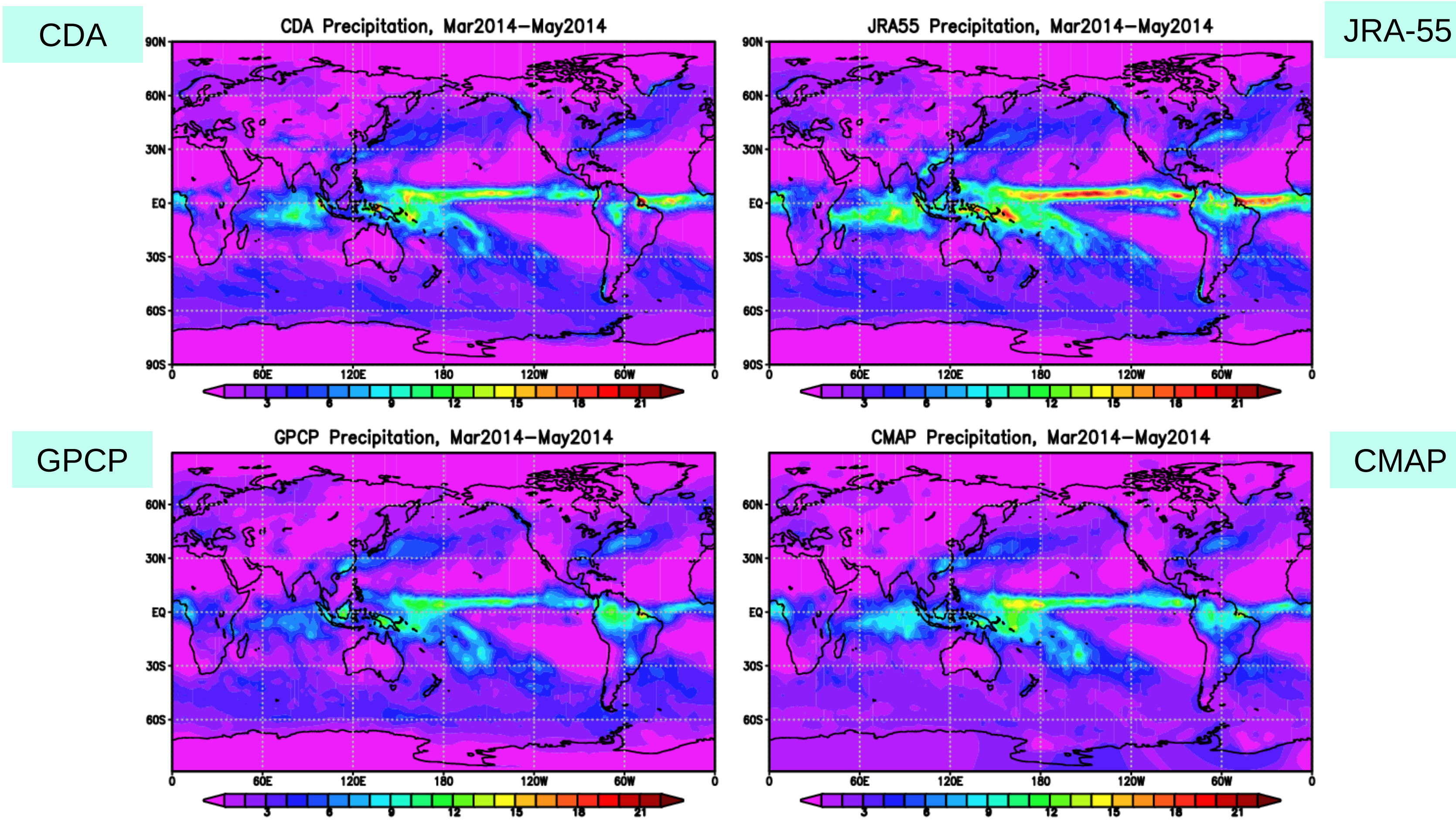
- ✓ Surface zonal winds in CDA is close to those in JRA−55
- ✓ Zonal wind stress in CDA has westerly bias against JRA−55 in the tropical Pacific.
- ✓ However, zonal wind stress in CDA has easterly bias against that used in MOVE−G2.
- ✓ Wind stress in MOVE−G2 is calculated from the surface zonal wind in JRA−55 <u>through the different bulk formula</u>.

★ Difference of Sea Surface Flux b/w CDA and JRA-55



- ✓ Excess latent heat flux in JRA55 is suppressed in CDA mainly due to modification of the bulk formula in the coupled model.
- ✓ Consequently, the oceanic heat budget is much improved.

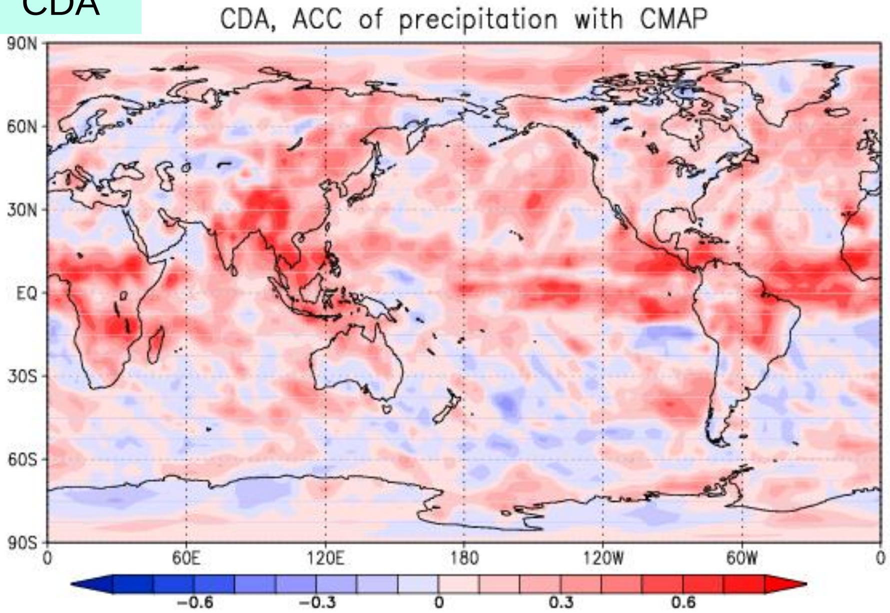
★ Comparison of precipitation (Mar.-May 2014)



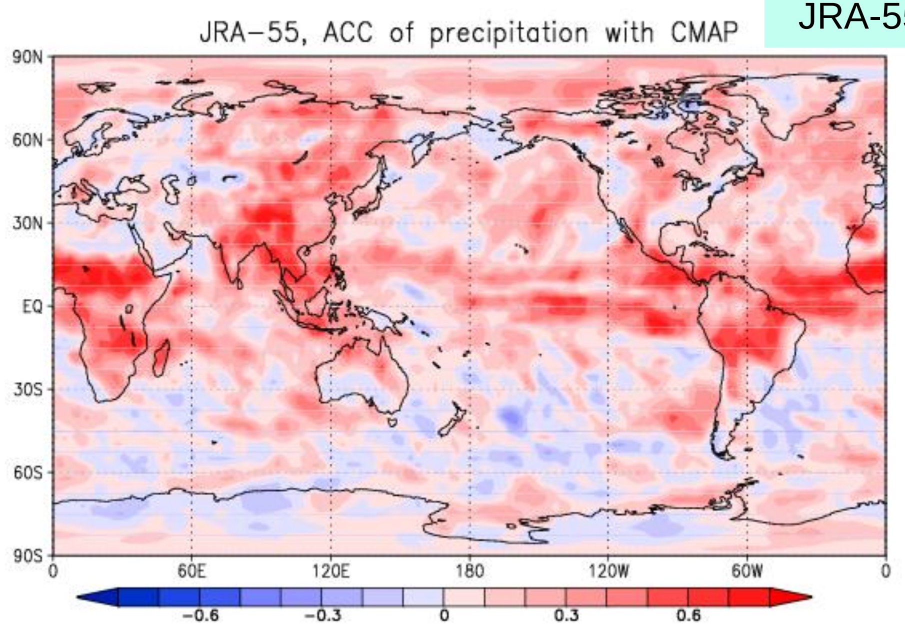
- ✓ Excess precipitation in the tropics in JRA–55 is suppressed in CDA. This tendency is also clear in other seasons.
- ✓ Double–ITCZ structure is weakened in CDA.

★ ACC Score of Pentad Precipitation against CMAP

CDA



JRA-55

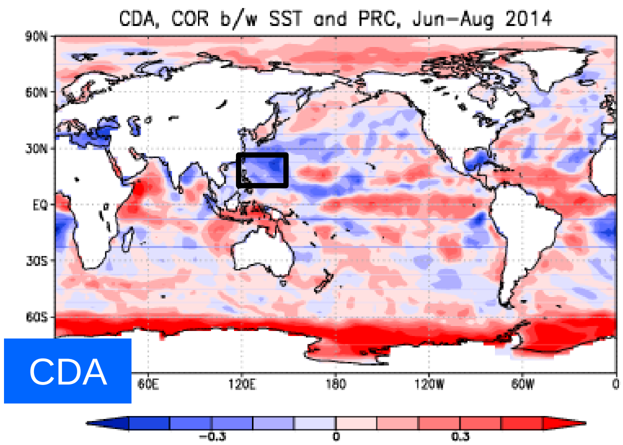


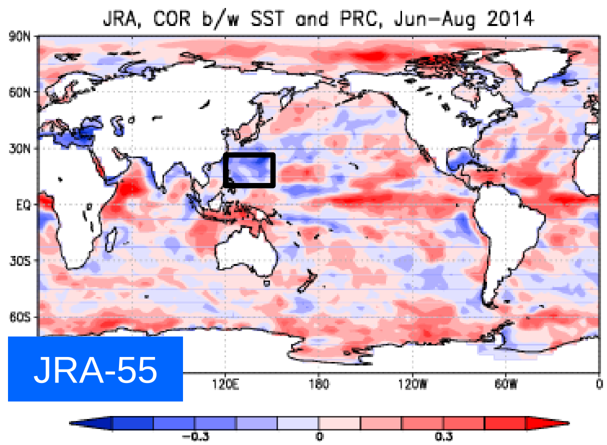
- ✓ ACC score in CDA is very close to the score in JRA-55.
- ✓ But the score is degraded in CDA in some areas (e.g., the tropical region in Africa, south of the NINO3 region.)

  ⇒ The variation of the precipitation may be slightly degraded.

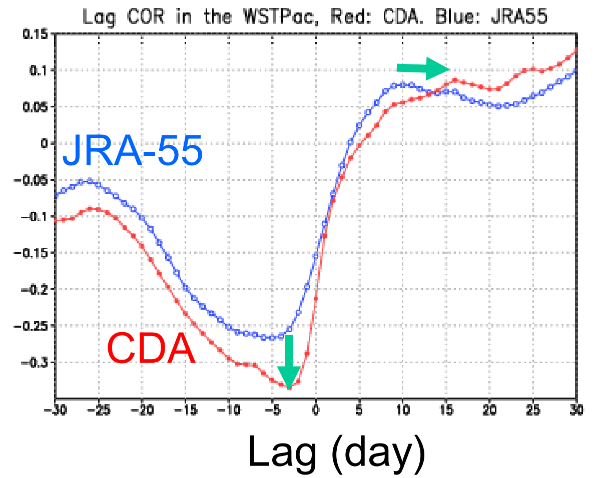
★ Correlation b/w daily precip. and SST (Jun-Aug 2014)

Correlation b/w daily SST and precipitation (Lag 0 day)





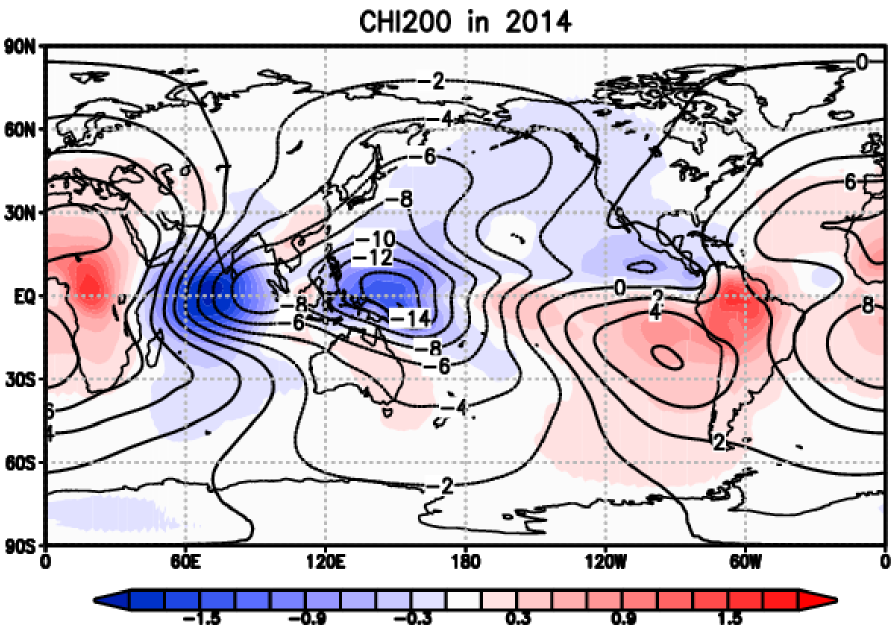
Correlation in the W. Trop. N. Pac.

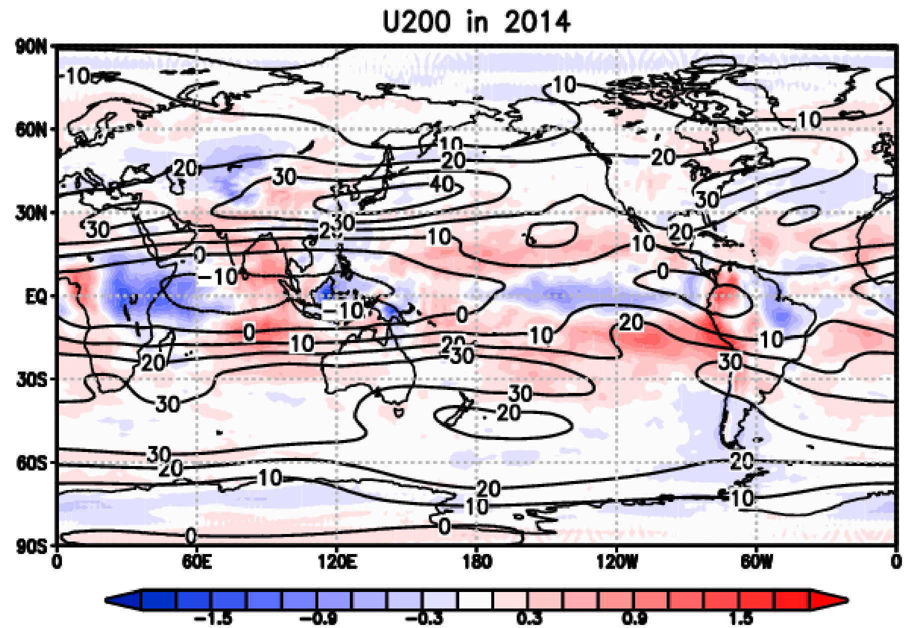


W. Trop. N. Pac.: 10-25°N, 120-150°E

- ✓ The correlation map of CDA is similar to that of JRA–55.
- ✓ The negative correlation in the western tropical North Pacific is intensified.
- ✓ The time lag between SST and precipitation changes is likely to become longer due to the negative feedback between SST and precipitation in the CDA system.

☆ Difference in CHI200 and U200 (CDA - JRA55)





- ✓ Divergence in the upper troposphere is intensified over the western tropical Pacific as in the quasi-CDA system.
- ✓ But the divergence over western Indian ocean is also increased.
- ✓ The walker circulation is intensified over the maritime continent but the difference is small (around 1 m/sec.) basically because wind fields are well constrained.

☆ NWP experiments using CDA analysis

Common Configuration

- 5-day prediction runs every 6 hours
- Model: NAPEX outer model (TL319L100). Uncoupled.
- Period: 01-31 August 2014

CDA experiments

- CDA analysis (result of atmospheric 4DVAR) is used for the initial values of prediction

Control experiments

- The Initial values are taken from successive analysis cycles of the original MRI-NAPEX (outer model: TL319L100, inner model: TL159L100）

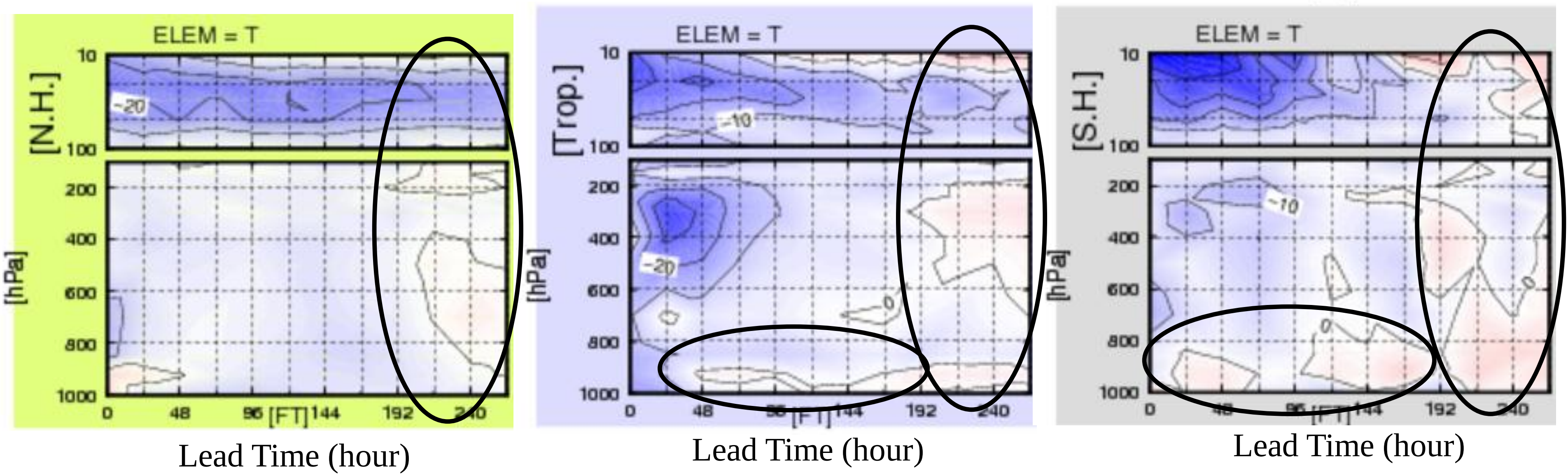
It should be noted that the outer model in MRI-NAPEX has a higher resolution than the coupled model (the outer model in CDA).

CDA	(JMA/MRI-CGCM)	⇒	TL159L60
Control	(MRI-NAPEX)	⇒	TL319L100

★ Validation of forecasted T against Sonde data

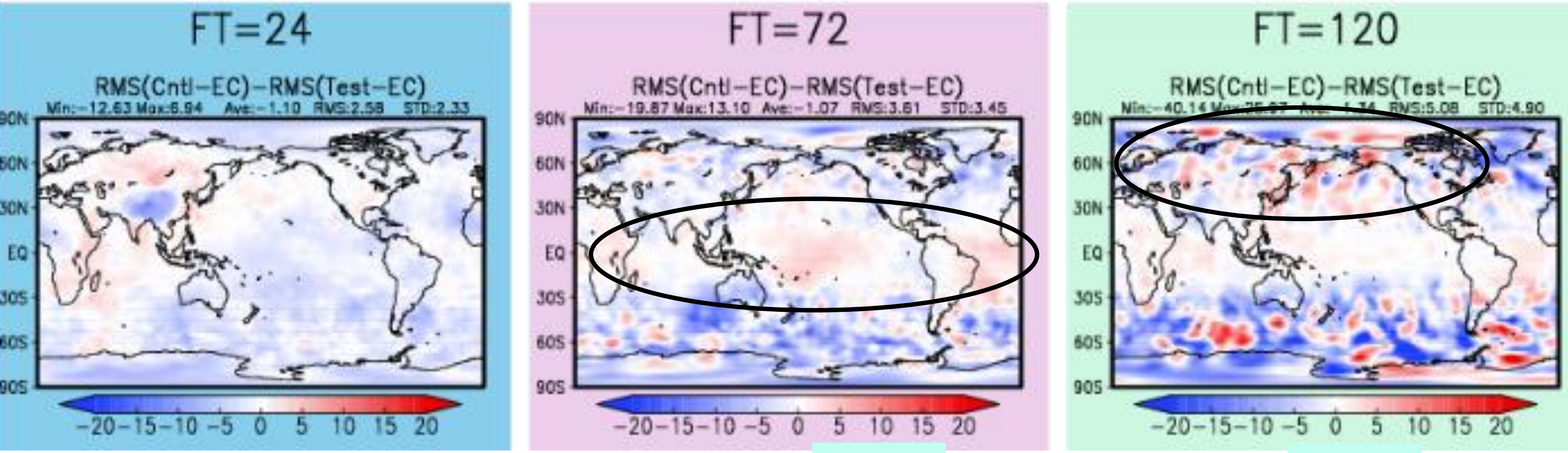
Reduction Ratio of RMSE of forecasted temperature profiles

Red : Improved
Blue : Degraded

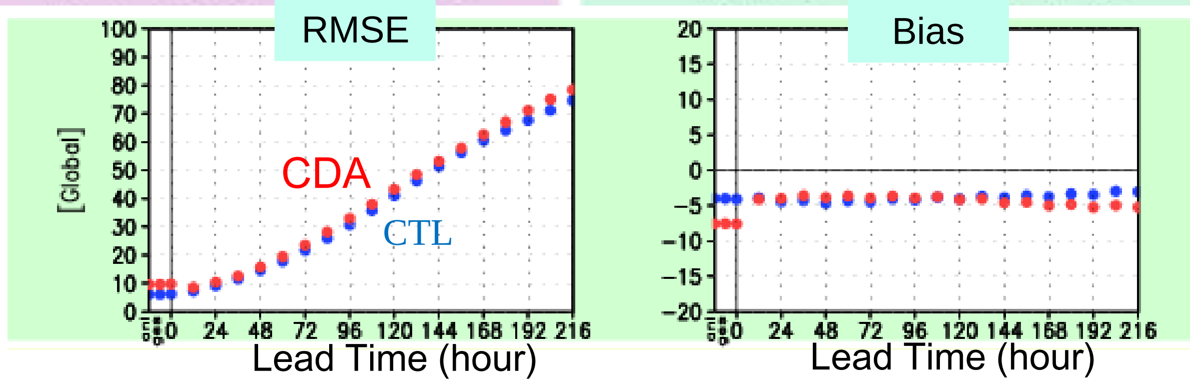


- ✓ Although RMSEs are generally increased partly due to the lower resolution of the outer model, it is reduced in the lower layers in the tropics and the Southern Hemisphere, and for the long lead-time forecasts.
- ✓ Due to the better sea surface flux, better representation of convection, or better physical balance in the initial values from CDA?

☆ Validation of Z500 against ECMWF Analysis

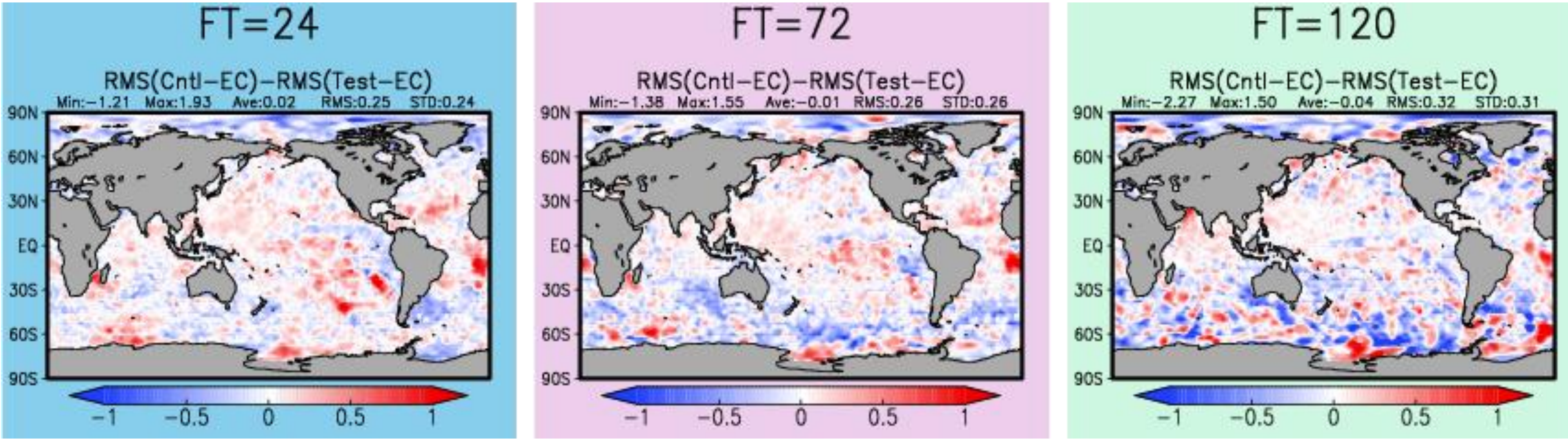


Red： Improved by CDA
Blue：Degraded by CDA

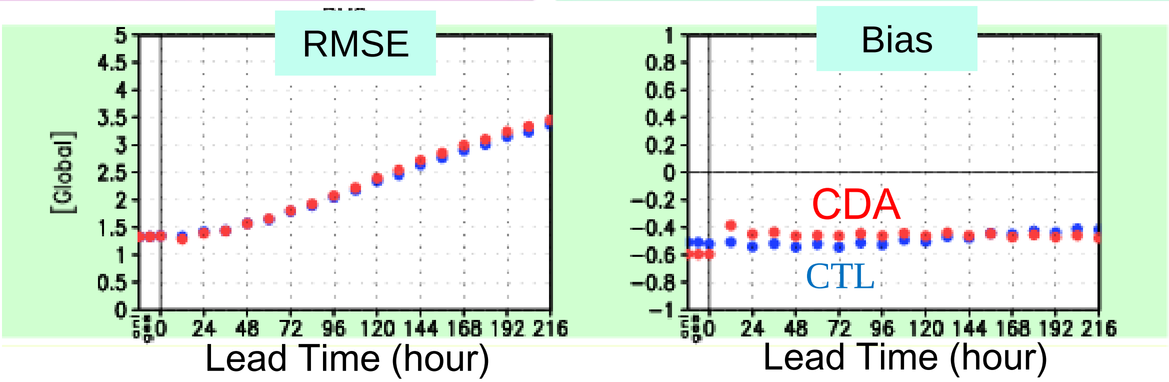


- ✓ There are gaps between initial and forecasted values due to the model difference.
- ✓ Reduction of RMSEs can be seen in the tropical band for 3-day lead-time forecasts and around the North Pacific for 5-day lead-time forecasts.

★ Validation of T850 against ECMWF Analysis



Red : Improved by CDA
Blue : Degraded by CDA



- ✓ RMS difference of T850 is reduced in broad area when CDA results are used for the initial values.
- ✓ Biases are also reduced particularly in tropics for shorter forecasts.

4. Concluding Remarks

★ Major Results

- ✓ Although ocean TS fields are well constrained in CDA, the current fields has notable difference from MOVE-G2 due to the discrepancy of the bulk formula for wind stress.
- ✓ Excess latent heat flux found in JRA-55 is suppressed in CDA mainly due to the modification of the bulk formula.
- ✓ Excess rainfall in the tropics in JRA-55 is also suppressed in CDA. It may partly due to the improvement above, and partly due to reconstruction of the negative feedback between SST and precipitation.
- ✓ Forecast skills are at least not critically degraded by using CDA as the initial of NWP. Skills for the lower layers and for longer (4-5 days) forecasts can be improved.

★ Future Direction

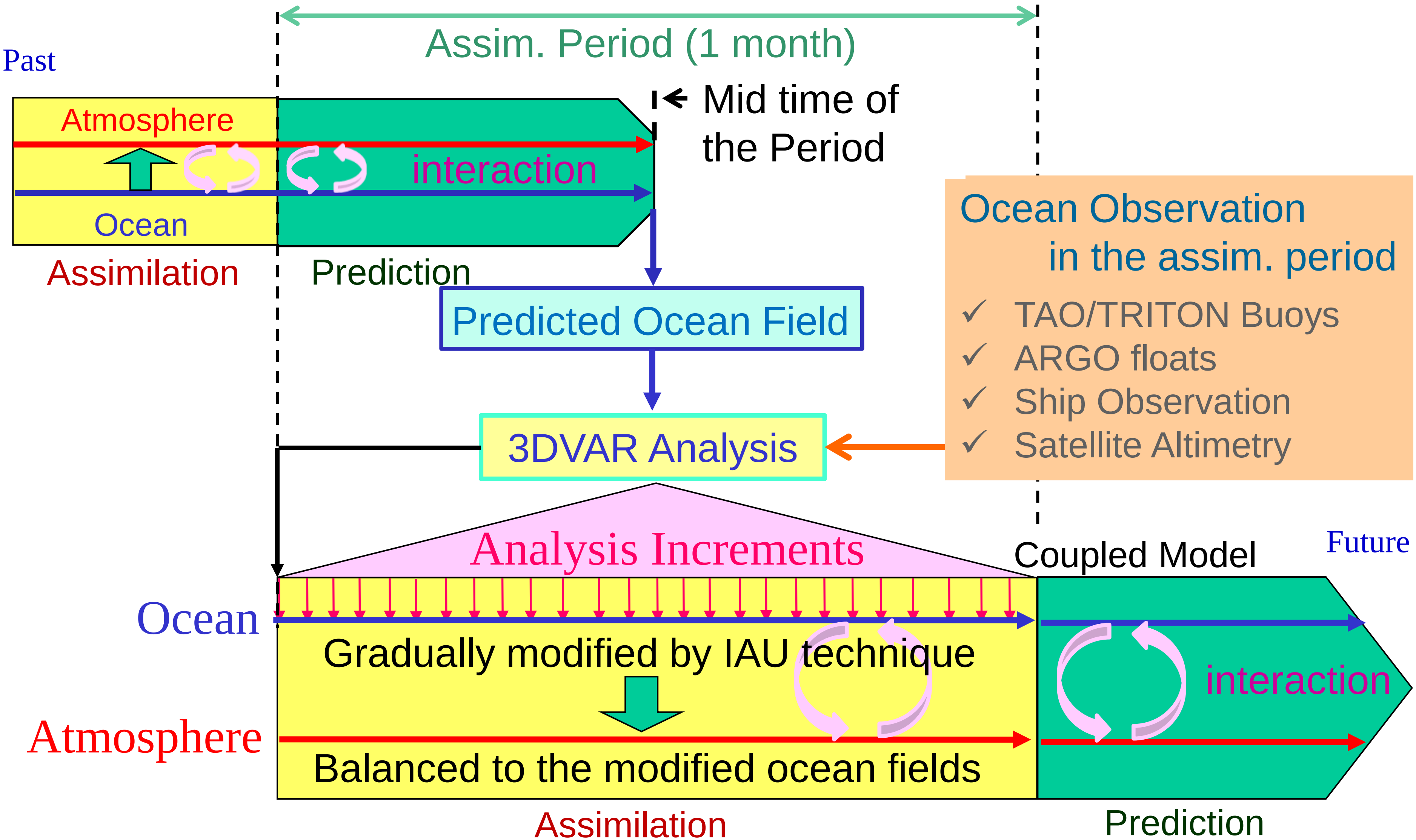
- ✓ Performing NWP and seasonal forecasting experiments using the coupled model. (Will the skills be improved by CDA?)
- ✓ It is better to use the common bulk formula or common atmospheric model. (Improving representation of surface fluxes is a key of improving CDA.)
- ✓ Sea ice data assimilation, and oceanic 4DVAR will be incorporated. Higher resolution models will be also used.

We are still not sure how we start to use CDA in operation.

- From seasonal forecast? -People may think operating both reanalysis and CDA is redundant.
- From reanalysis? -People may think "Re"analysis should be done with the operational NWP system.
- From NWP? -It is not easy to outperform the current NWP system by using a coupled model.

Thank you!!

☆ "Quasi-Coupled" Data Assimilation System



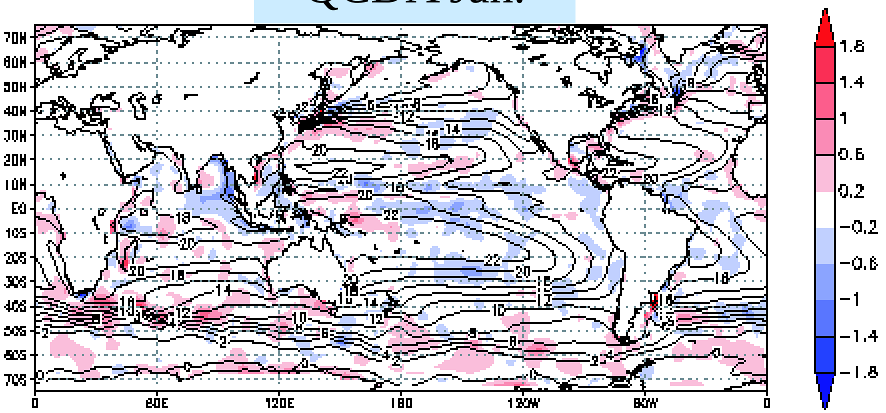
- Short time-scale variabilities like the weather modes are not constrained in the assimilation scheme.

☆ Comparison of the specs

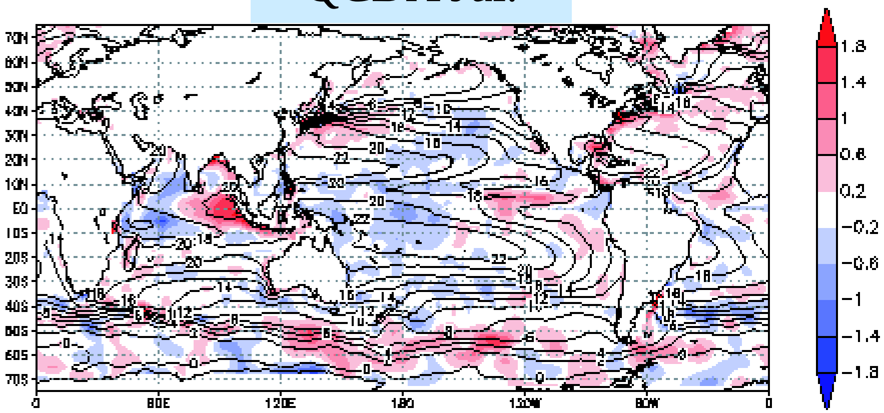
	JMA/MRI-CGCM1	JMA/MRI-CGCM2 (2015.06-)
Atmospheric Part **JMA AGCM** (JMA 2013)	Horizontal resolution: **TL95L40** (~180km) Model Top Level: **0.4hPa**	Horizontal Resolution: **TL159L60** (~110km) Model Top Level: **0.1hPa** **Stochastic physics** **Variation of Greenhouse Gases**
Oceanic Part **(MRI.COM)** (Tsujino et al 2010)	1.0° (zonal) x **0.3-1°** (meridional), **50 Layers** **Domain: 75°S-75°N** Sea Ice: **Climatology**	1.0° (zonal) x **0.3-0.5°** (meridional) **L53** **Domain: Global (Tri-Polar Coordinates)** Sea Ice: **Multi-category EVP model**
Coupler **(Scup)** (Yoshimura and Yukimoto 2008)	Interact every hour **Flux Correction** **(momentum·heat)**	Interact every hour **No Flux Correction** **Effects of ocean currents**
Initial Condition	Atmosphere: **JRA-25** Land: **Clim. Forced by ERA15** Ocean: **MOVE/MRI.COM-G** T, S & SSH Sea Ice: **Climatology**	Atmosphere: **JRA-55** Land: **JRA-55** Ocean: **MOVE/MRI.COM-G2** T, S & SSH Sea Ice: **MOVE/MRI.COM-G2**
Number of ensemble members	51 (**9** BGMs, **6** days with 5-day LAF)	51 (**13** BGMs, **4** days with 5-day LAF)

★Monthly Climatology of 0-300m Averaged T (OHC)

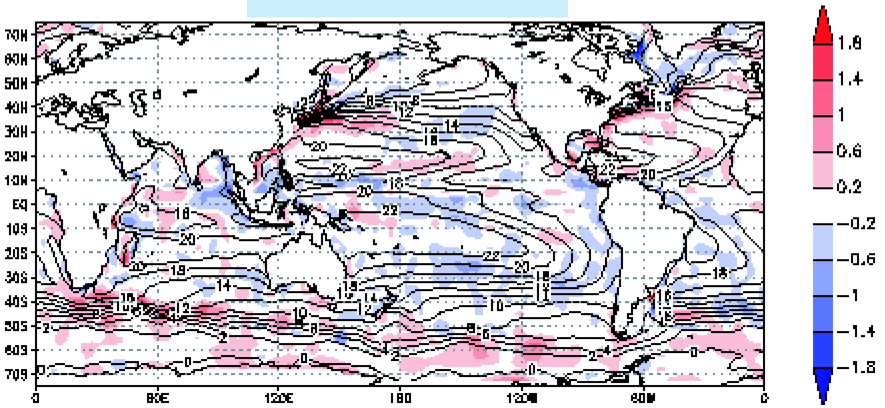
QCDA Jan.



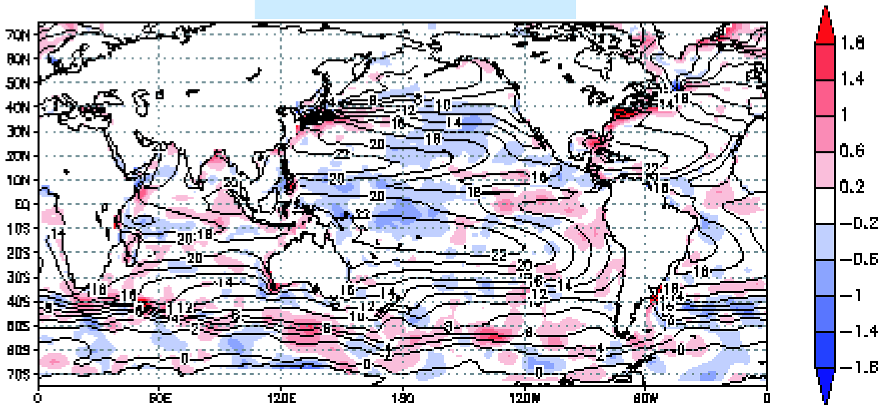
QCDA Jul.



MOVE-G Jan.

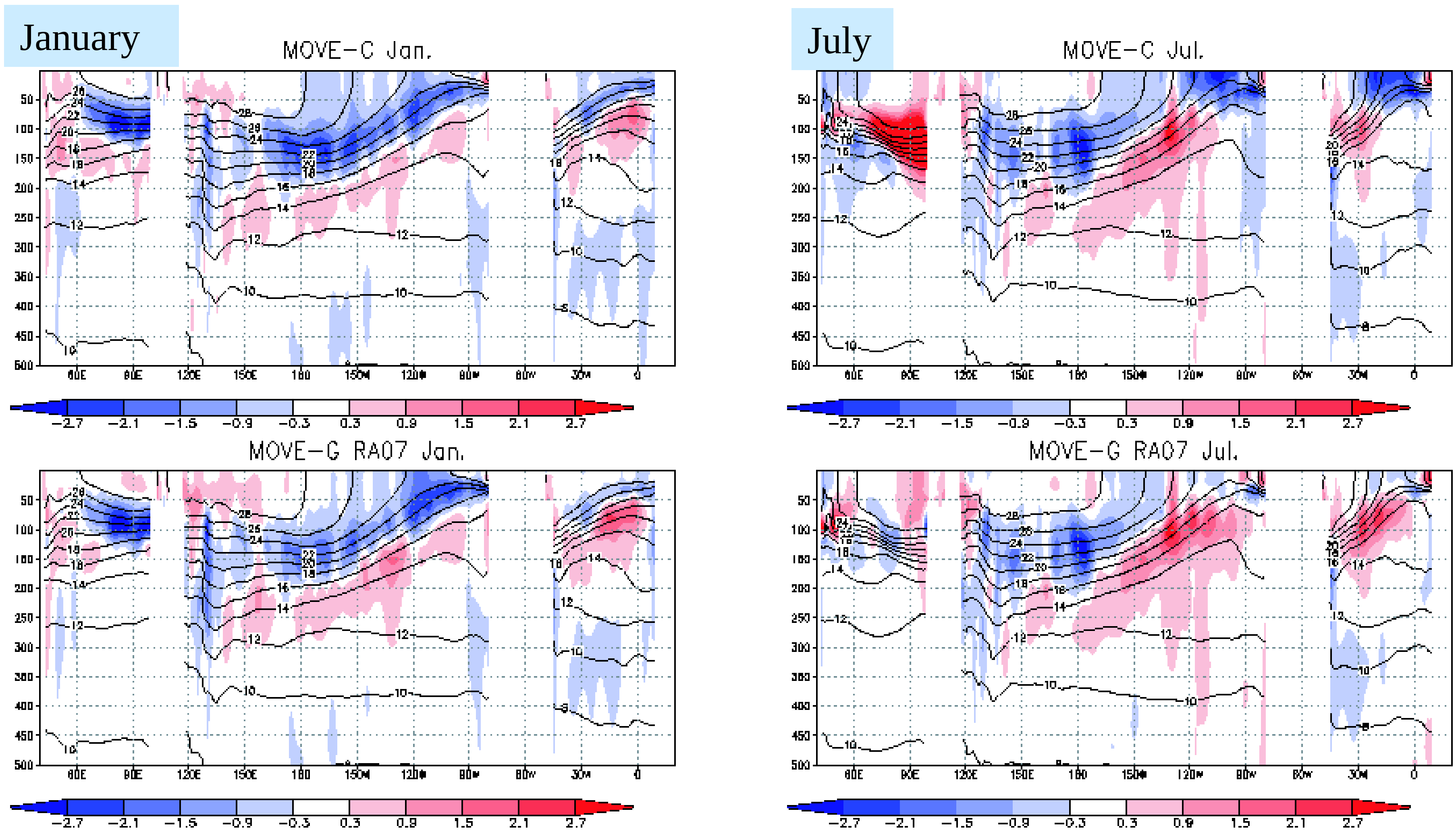


MOVE-G Jul.



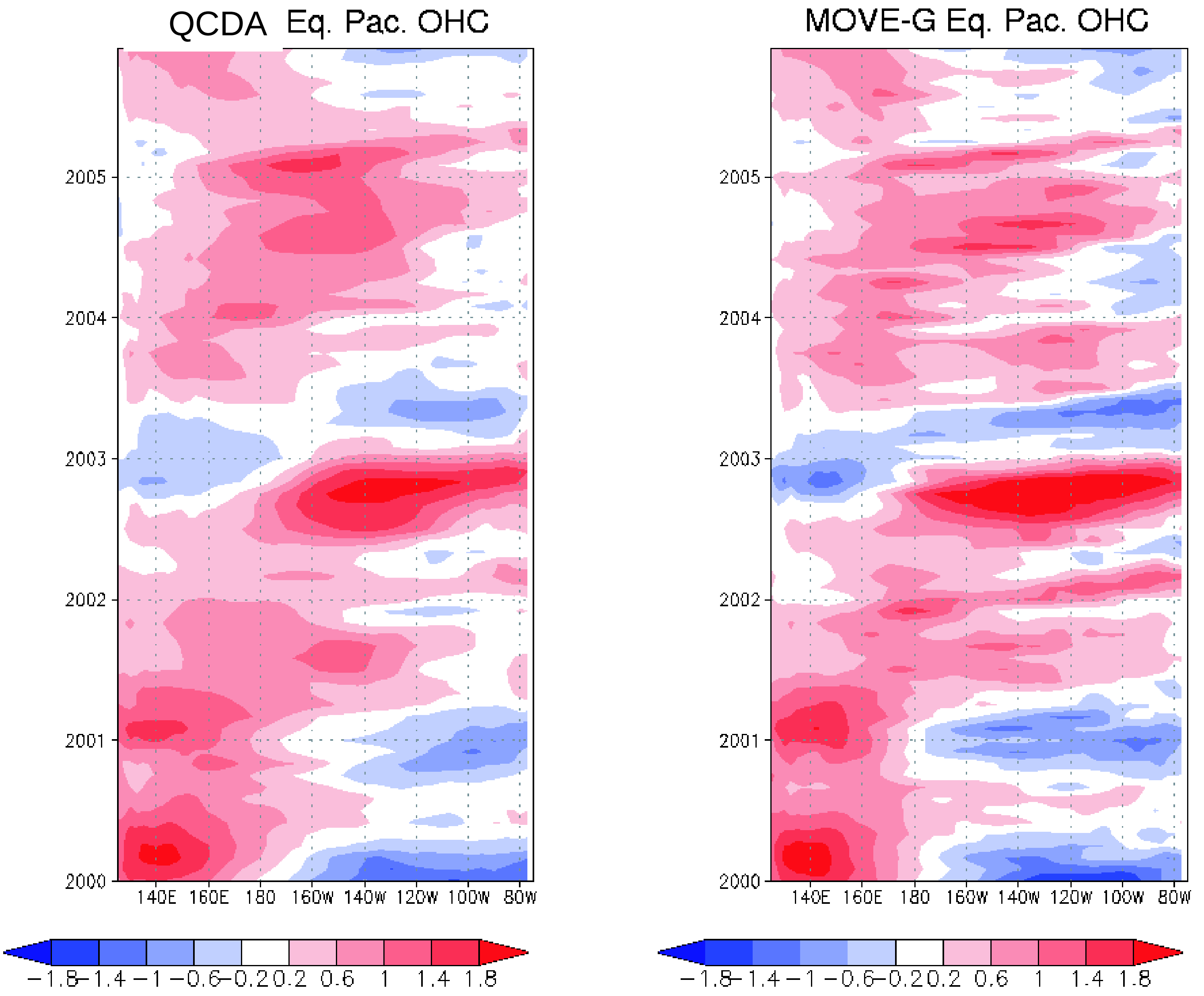
Contour: climatology, Color shading: deviation from WOA2005.

☆ Monthly Climatology of T at the equatorial section.



Contour: climatology, Color shading: deviation from WOA2005.

☆ Longitude-time Section of OHC at Eq. in Pacific

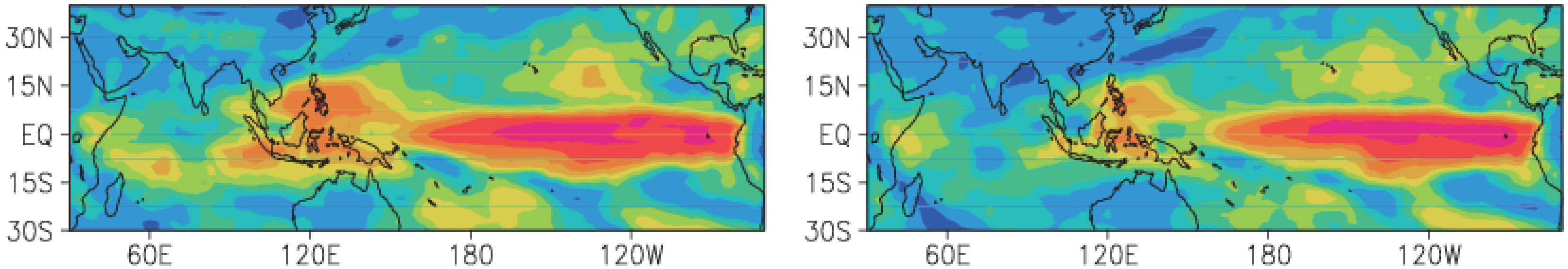


★ Improvement of ACC score over the AMIP run

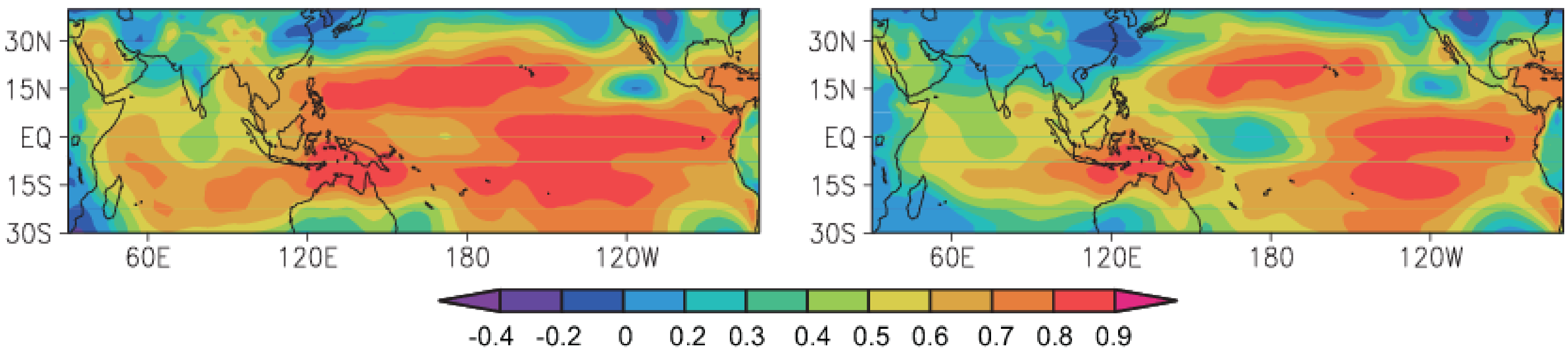
QCDA

AMIP Run

ACC of OLR for all season (reference: NOAA-OLR)



ACC of SLP for Jun.-Aug. (reference: JRA-25)

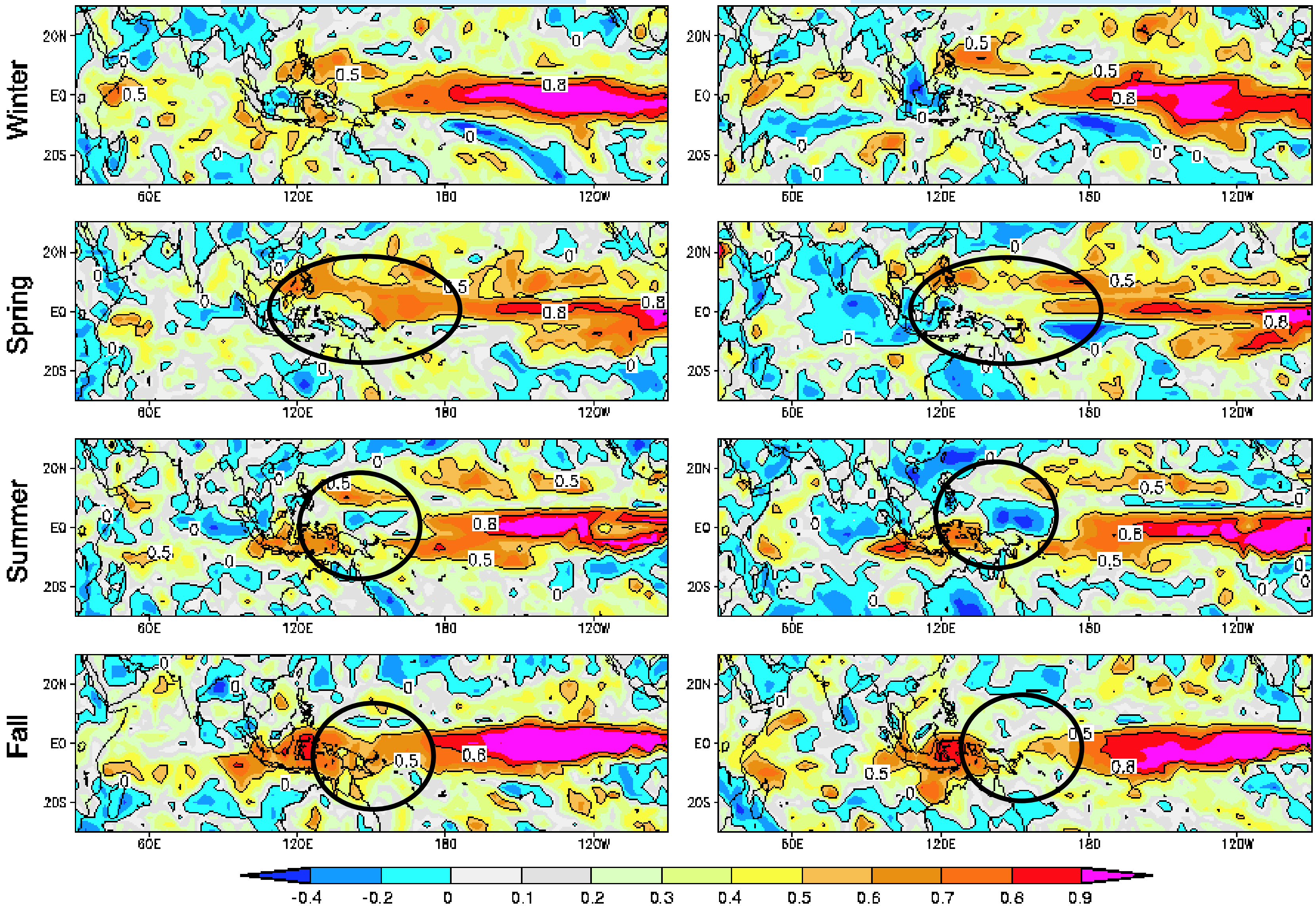


The variability of OLR (outgoing long wave: proxy of precipitation) and SLP (sea level pressure) in the QCDA system is improved around the central and western tropical Pacific, the Philippine Sea, the maritime continent, and the Indian Ocean, over the AMIP run.

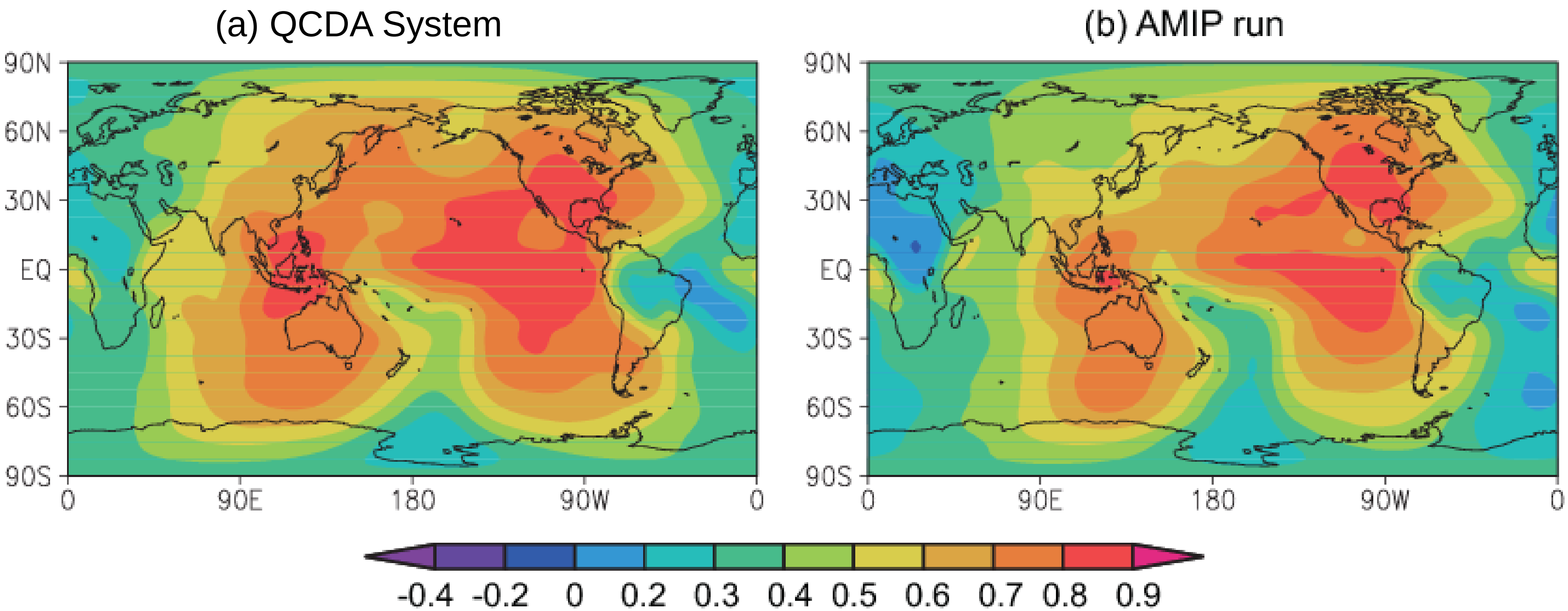
ACC: Anomaly Correlation Coefficient

★ ACC score for the monthly average precipitation

MOVE-C | AMIP-Run



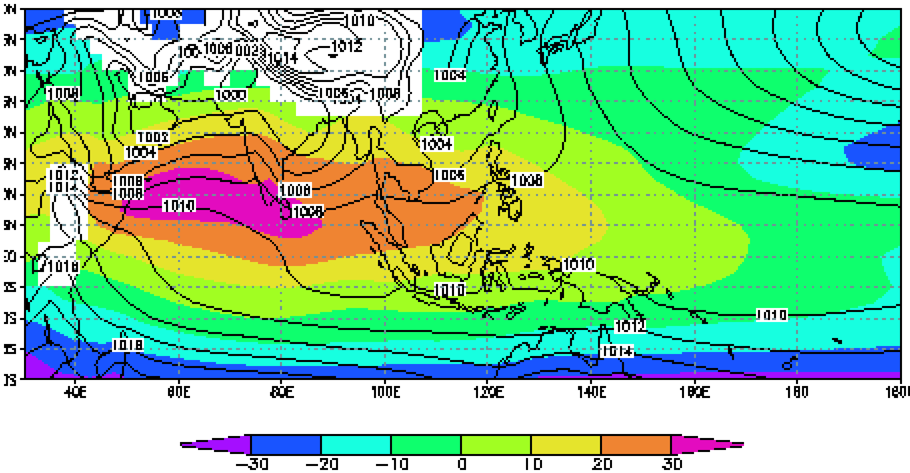
☆ ACC score for Velocity Potential at 200hPa



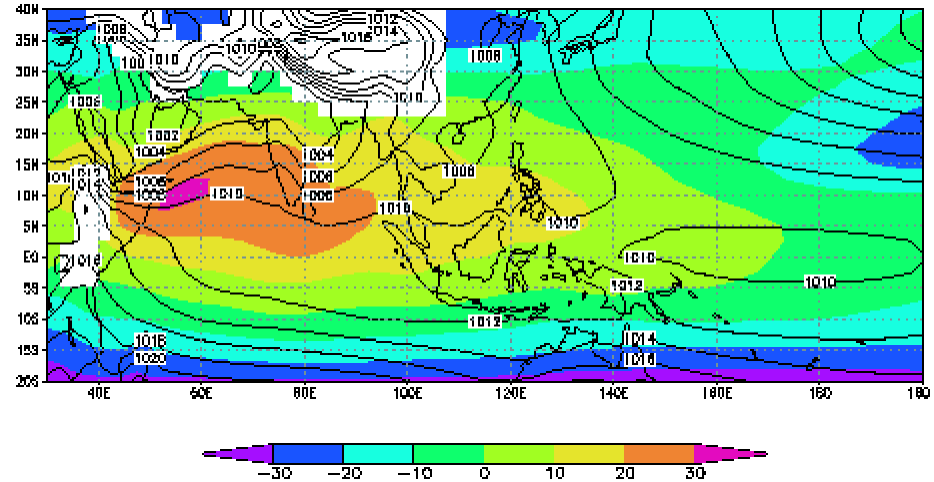
The Variability of the divergence fields at the upper troposphere is improved especially over the maritime continent, east Asia, and western Indian Ocean probably due to the improvement of the precipitation fields.

☆ SLP, Vertical sheer of zonal winds (Jun.-Aug. Clim.)

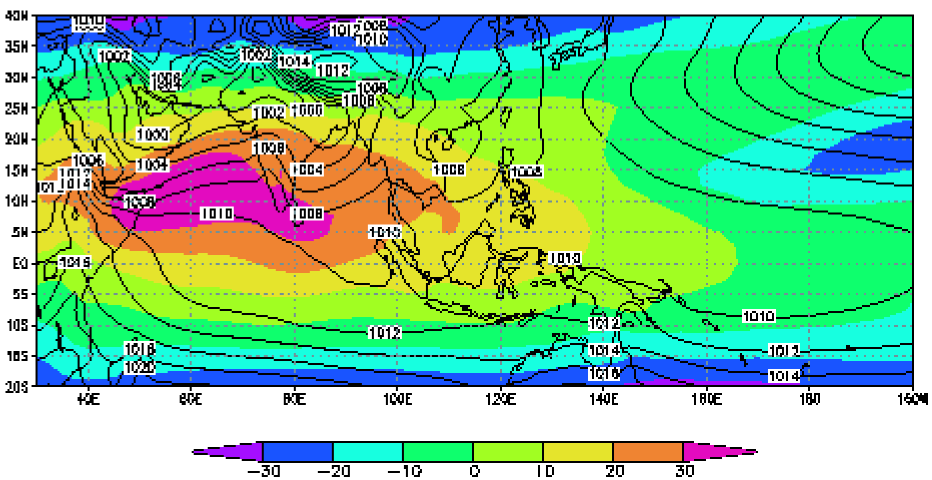
QCDA System



AMIP Run



JRA−25 (Obs.)

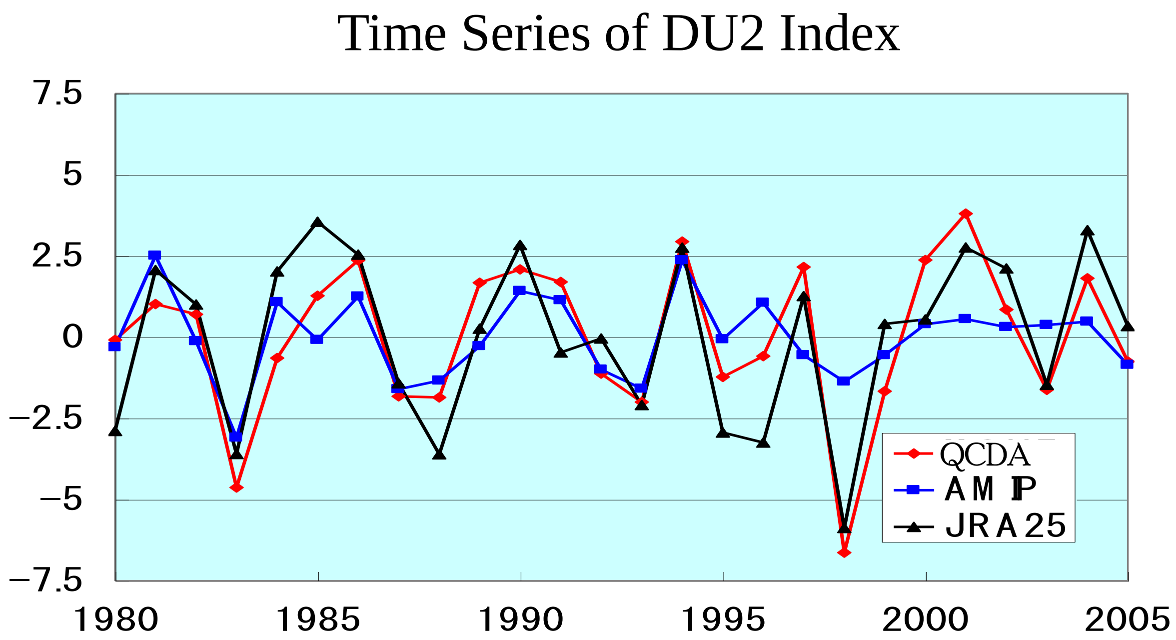


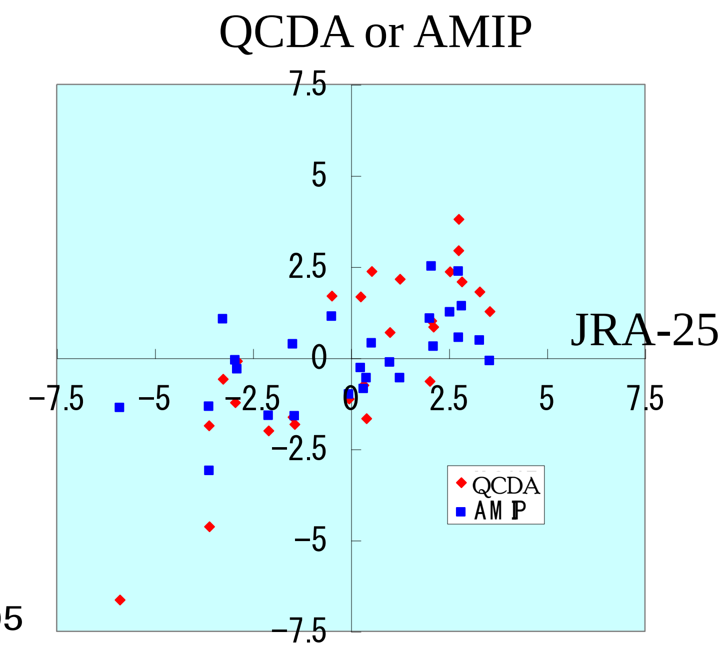
Isobars shows the monsoon trough is not developed in AMIP compared with QCDA and JRA-25.

The small sheer in AMIP imply the weak walker circulation, which is improved in QCDA.

Vertical Sheer of zonal Winds : U(850hPa)-U(200hPa)

★Variation of the monsoon trough in Jun-Aug.

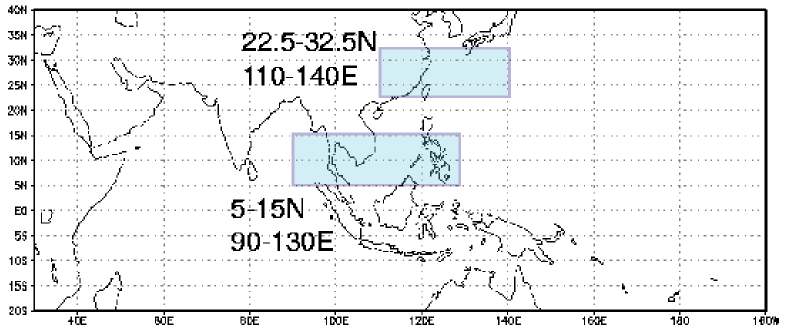




Correlation Coefficient： QCDA 0.81 AMIP 0.60

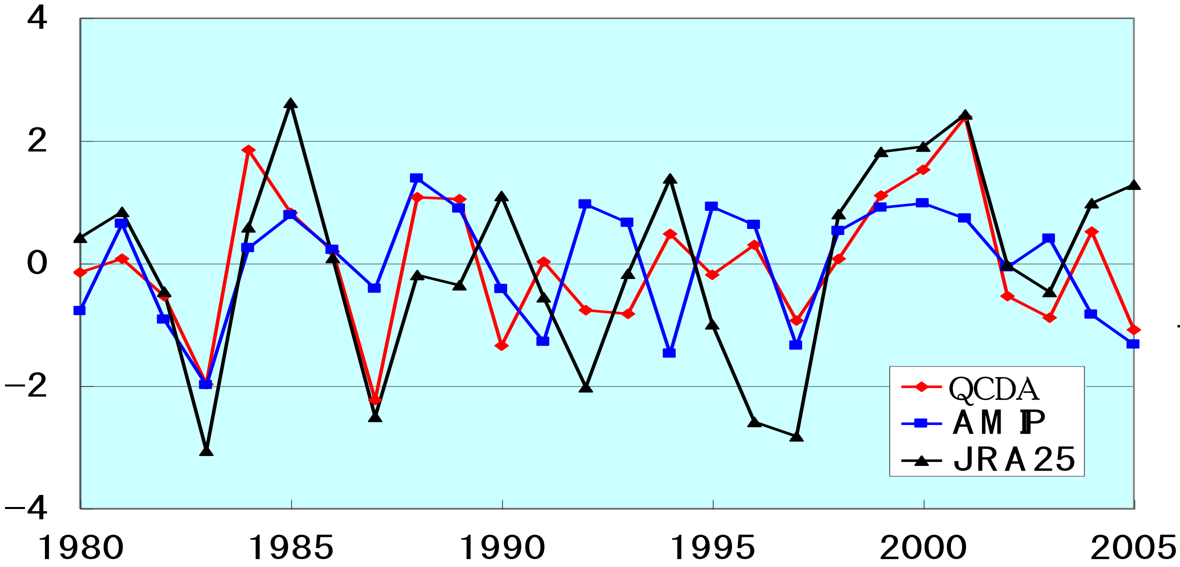
DU2 Index (Wang and Fan, 1999):

representing the strength of the monsoon in summer. U850hPa(5-15N, 90-130E) - U850hpa(22.5-32.5N, 110-140E).

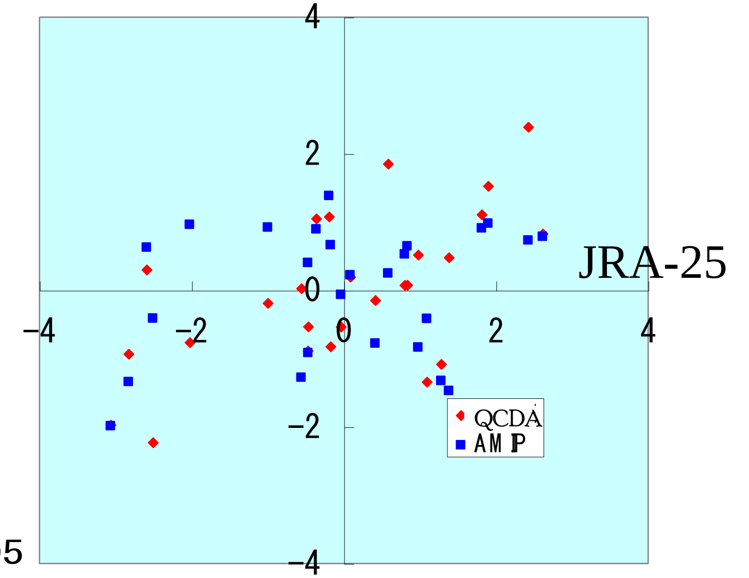


★ Variation of the Walker Circulation in (Jun-Aug)

Time Series of W-Y Index

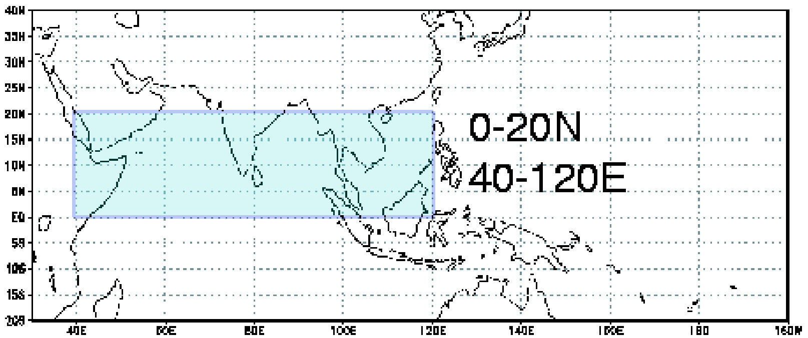


QCDA or AMIP



Correlation Coefficient： QCDA 0.62 AMIP 0.26

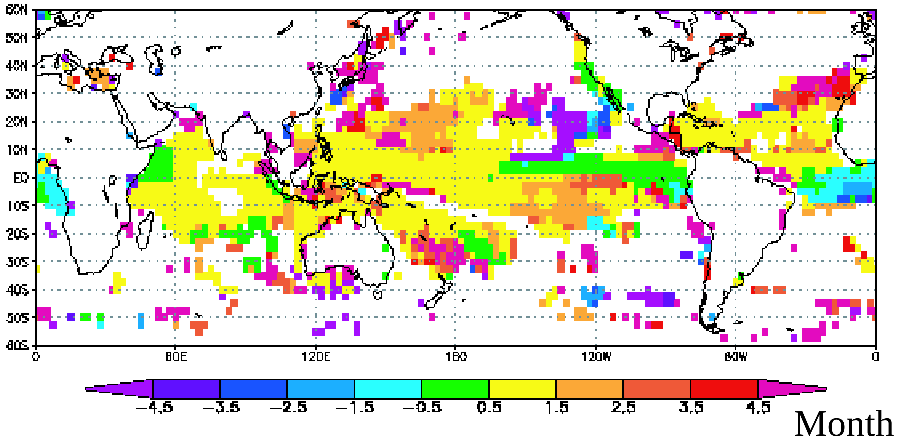
W-Y Index (Webster and Yang, 1992): representing the strength of zonal Walker Circulation in summer. Zonal wind sheer of U850hPa - U200hPa averaged in 0-20N, 40-120E.



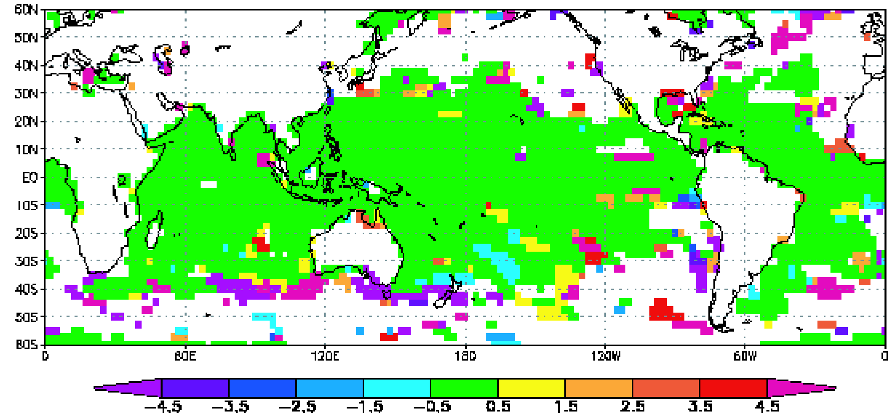
★ Time Lag between SST and PRC

(Evidence of the negative feedback)

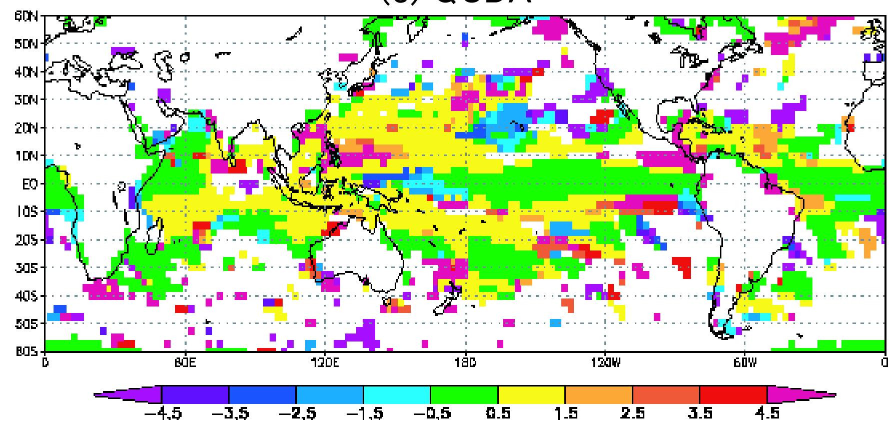
(c) CMAP and COBESST (Obs.)



(a) AMIP Run



(c) QCDA



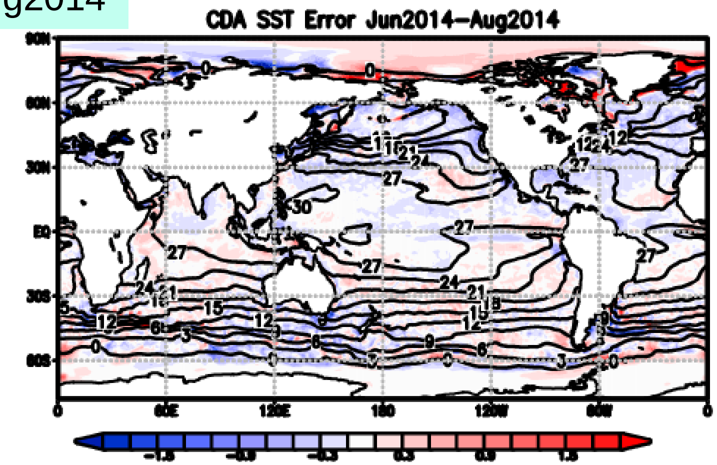
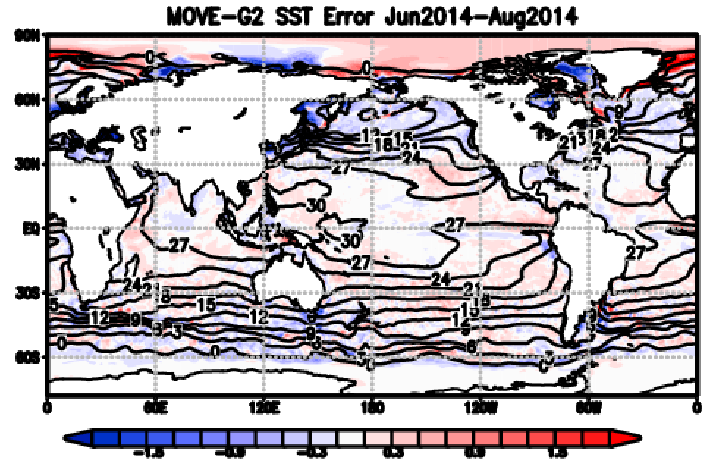
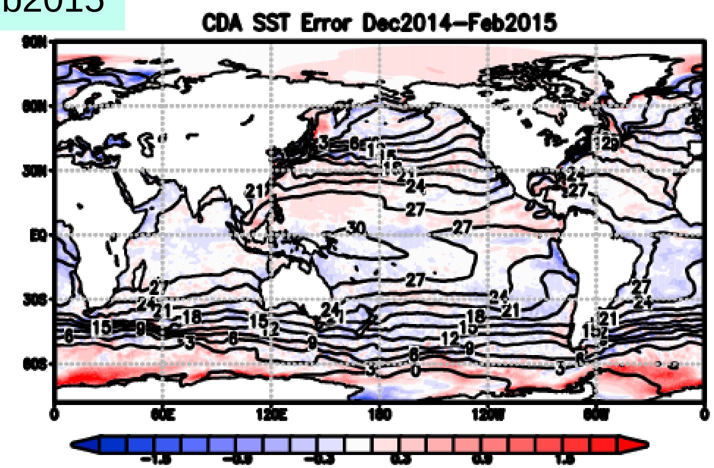
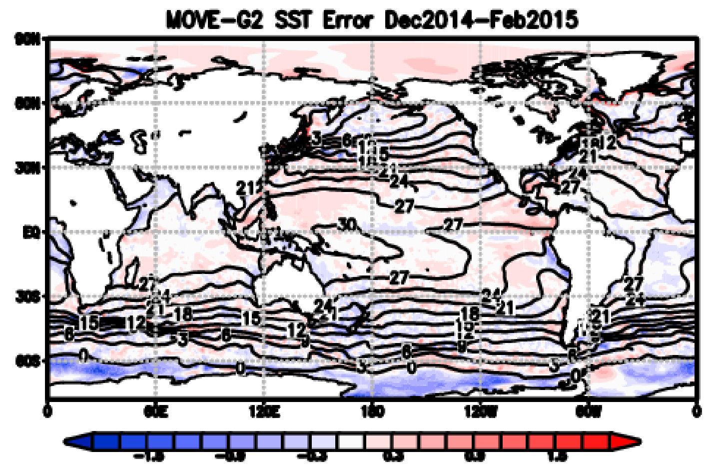
Yellow: One month Time Lag

Green: No time Lag

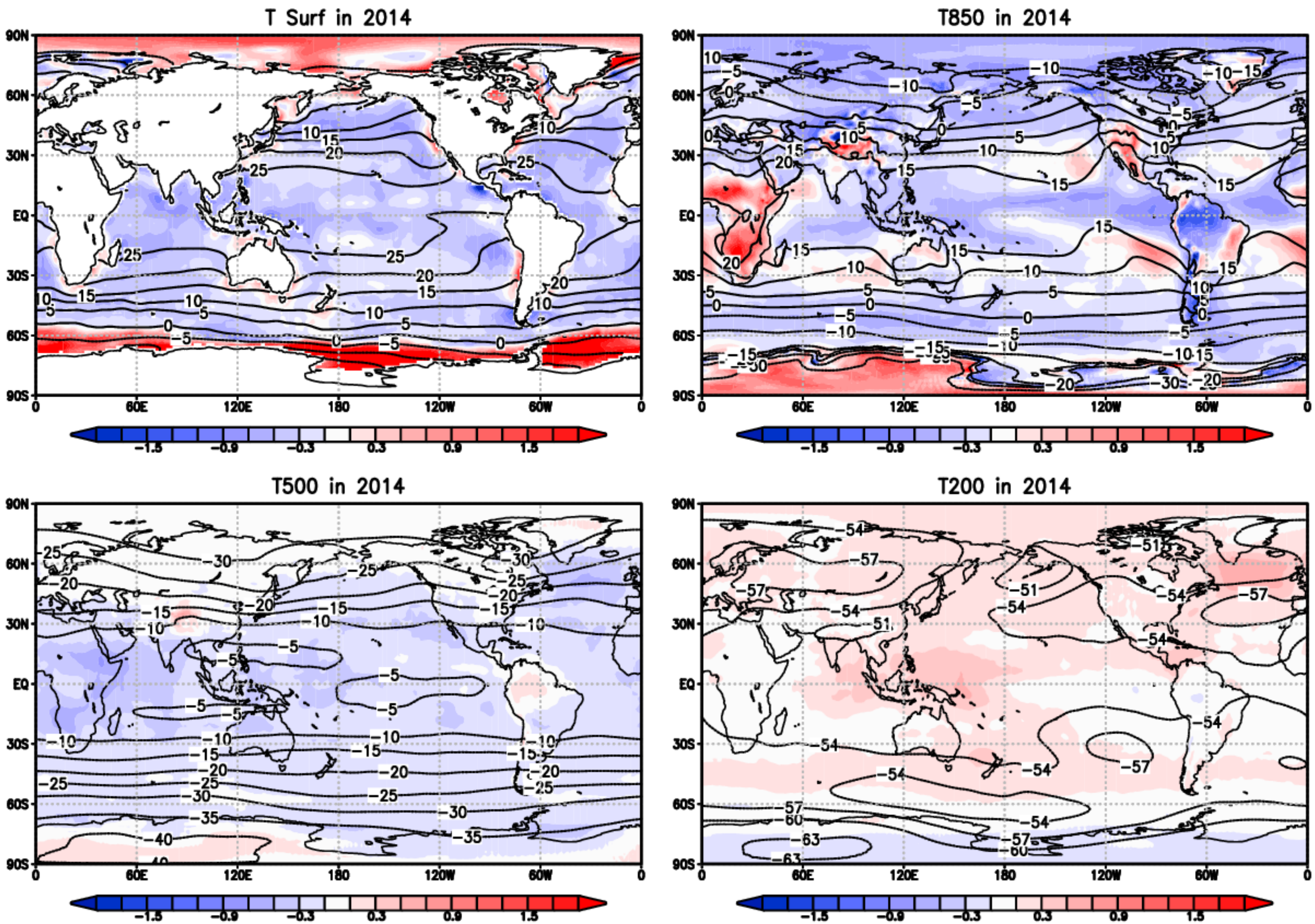
Significance > 99%

CMAP and COBESST: Negative feedback → One month Time Lag
AMIP Run : No negative feedback → No Lag
QCDA : Similar to CMAP and COBESST → Negative Feedback

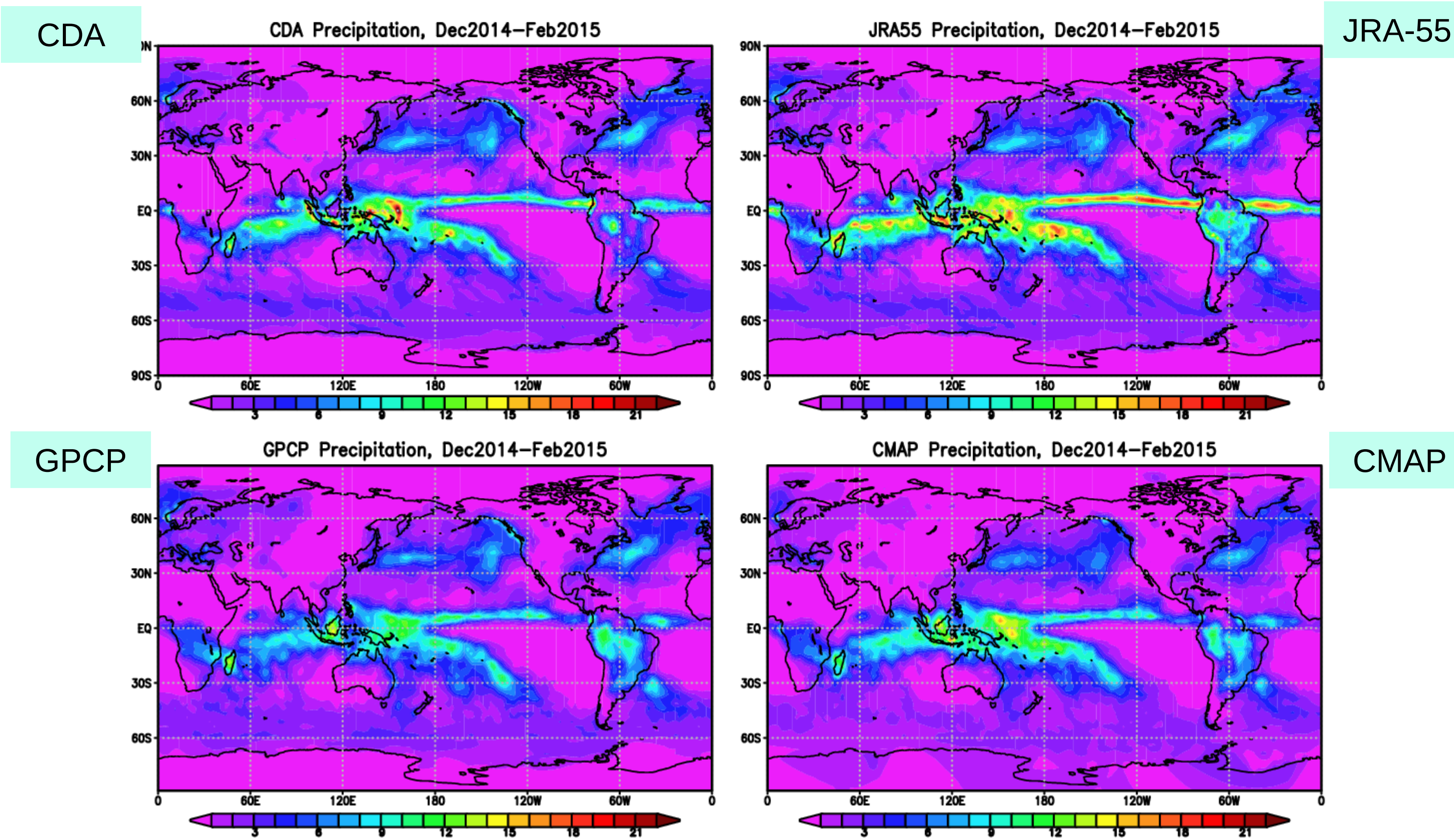
★ SST Bias against Satellite Data

	CDA	MOVE-G2
Jun2014-Aug2014		
Dec2014-Feb2015		

★ Difference of Atmos. Temp. (CDA – JRA55)

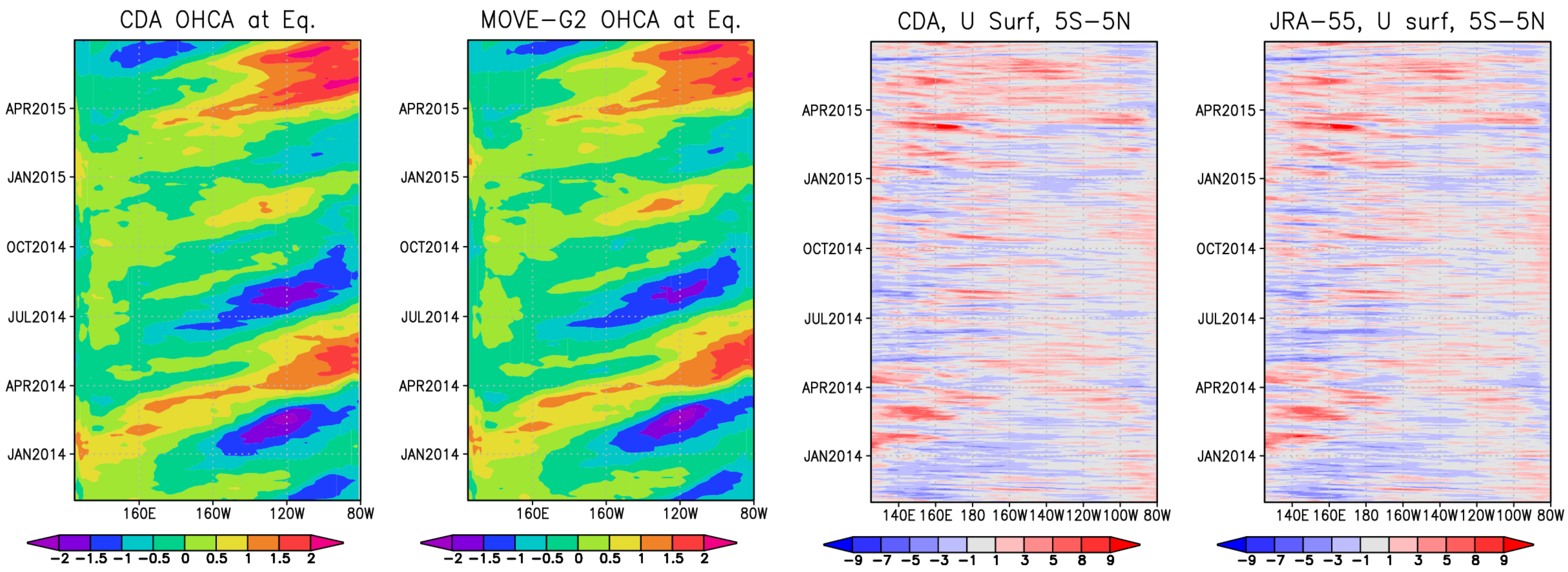


★ Comparison of precipitation (Mar.-May 2014)

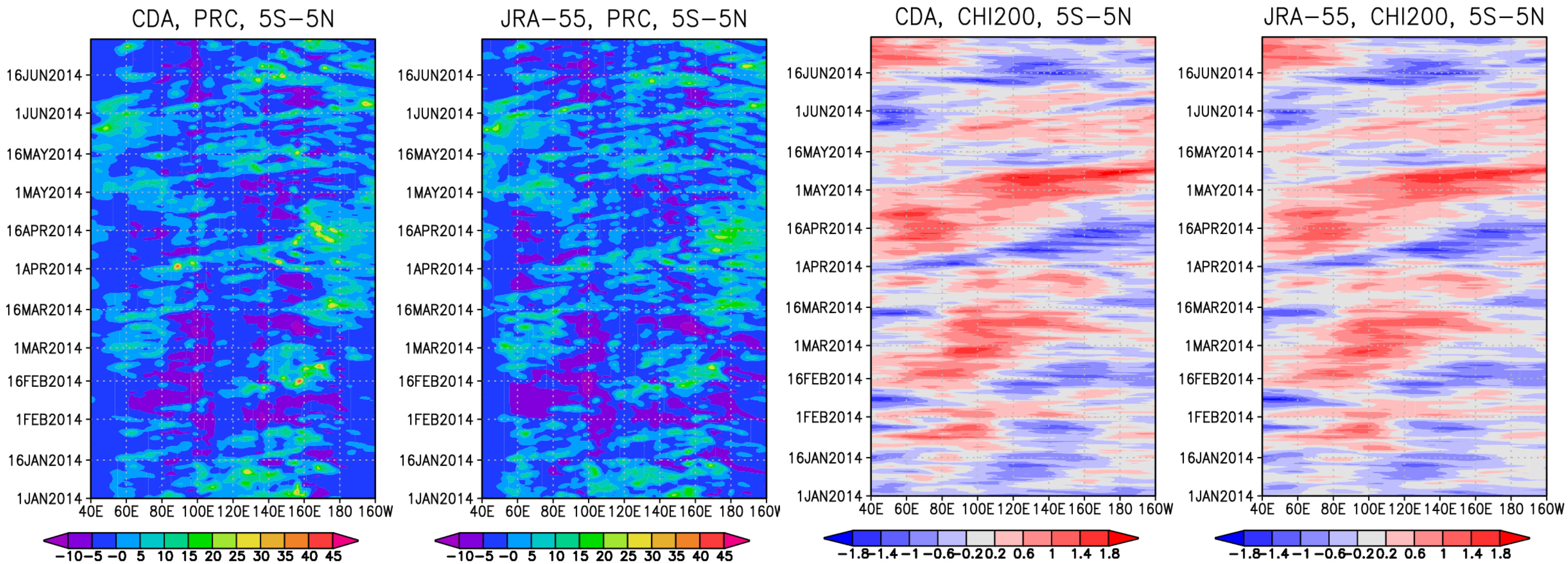


✓ Excess precipitation in the tropics in JRA−55 is suppressed in CDA. The tendency is also clear in other seasons.

★ Hovmöller Diagram of OHCA and U surf at Eq. Pac.

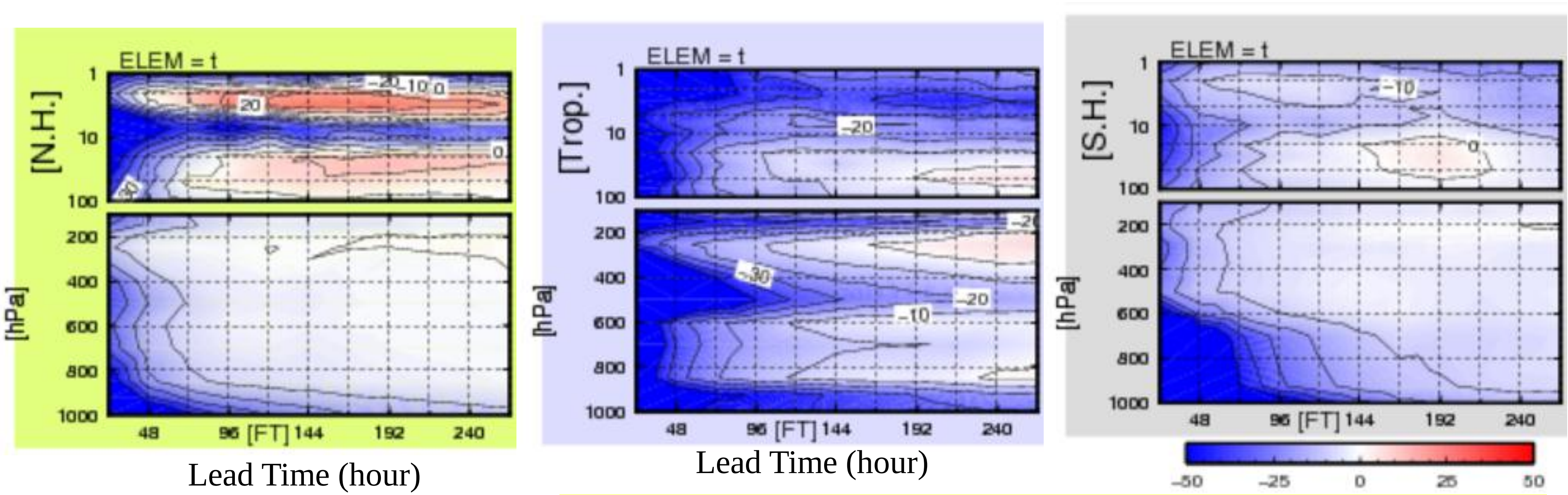


☆ Hovmöller of PRC and CHI200 at Eq. (MJO)



☆ Validation against the analysis used for the initial values

Reduction Ratio of RMSE of forecasted temperature profiles



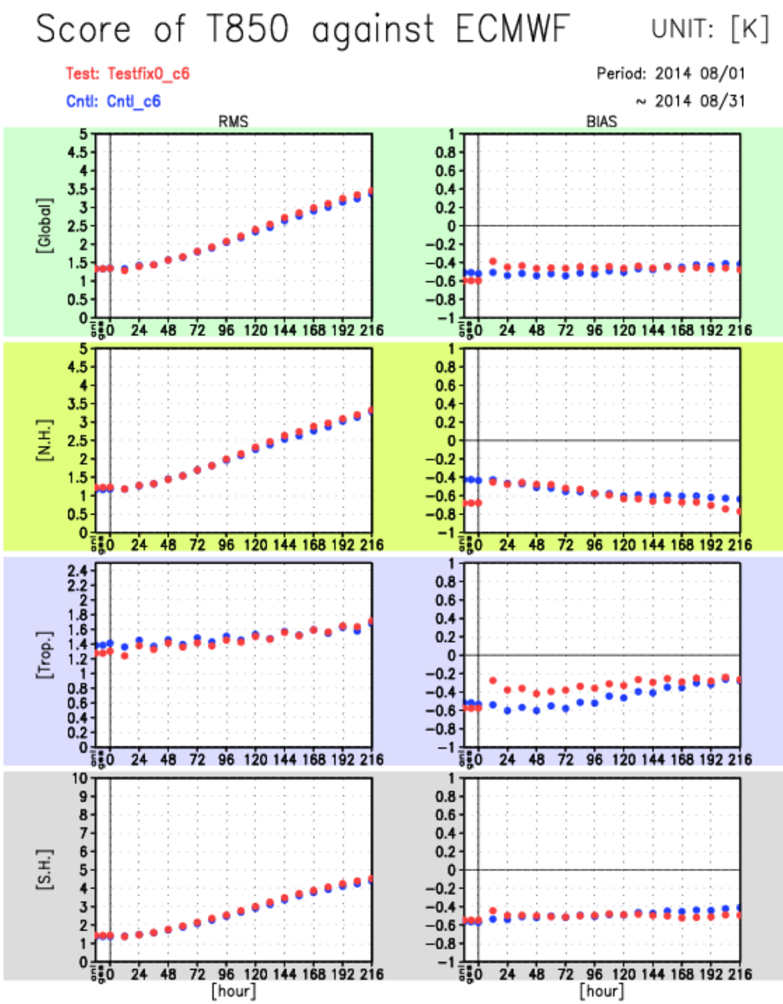
Red : Improved by CDA
Blue : Degraded by CDA

The analyses used for the initial values are also used for the reference data for calculating RMSE.

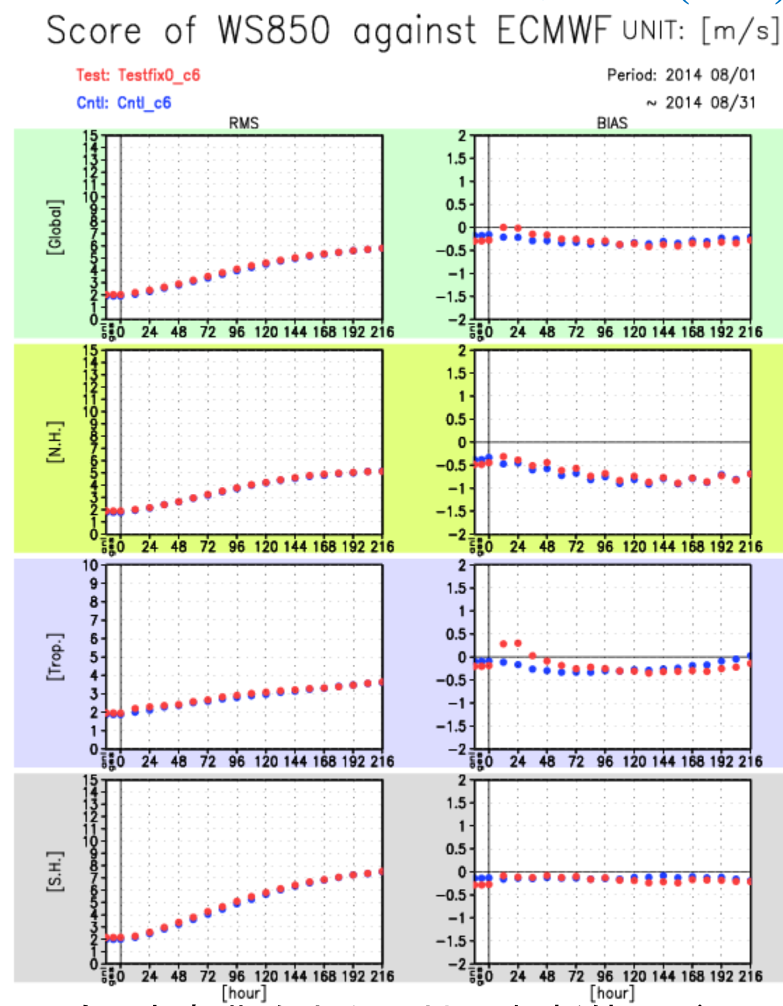
- ✓ The RMSEs are generally increased for CDA.
- ✓ Partly due to the shock occurred when the initial values from the coupled model are given to the higher-resolution NWP model.
- ✓ Partly due to the resolution of the coupled model. (Initial values of the control case are generated by the NWP model itself.)

★ECMWFの全球解析値を真値とした精度評価

赤：結合同化初期値からの予報



青：気象庁現業全球モデルの低解像度モデル(60km)の予報



熱帯のT850では対EC解析値の精度は良い

バイアスは前半やや改善後半やや改悪の傾向

WS850も予報初期を中心に対EC解析値のバイアスは減少傾向

後半は負バイアスがやや増加。

RMSEは中立～若干増大

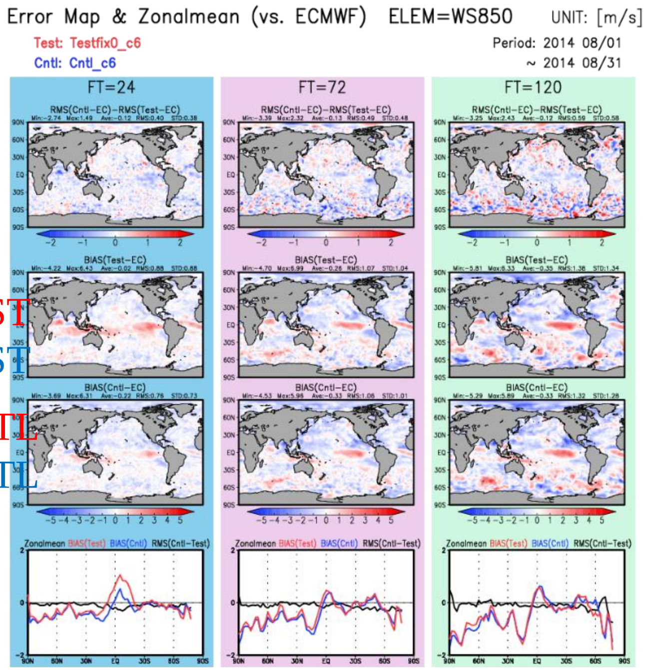
ECMWF解析値に対するBIAS、RMS、Zonal mean

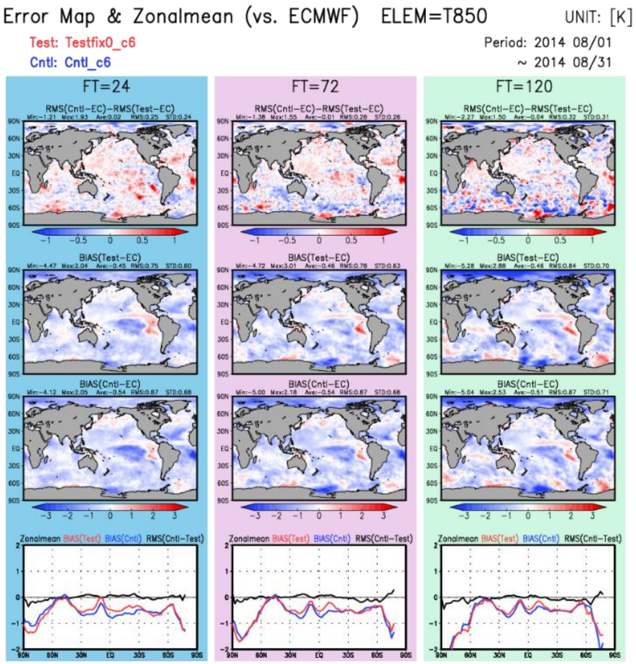
赤：改善
青：改悪

赤：EC<TEST
青：EC>TEST

赤：EC<CNTL
青：EC>CNTL

Zonal mean

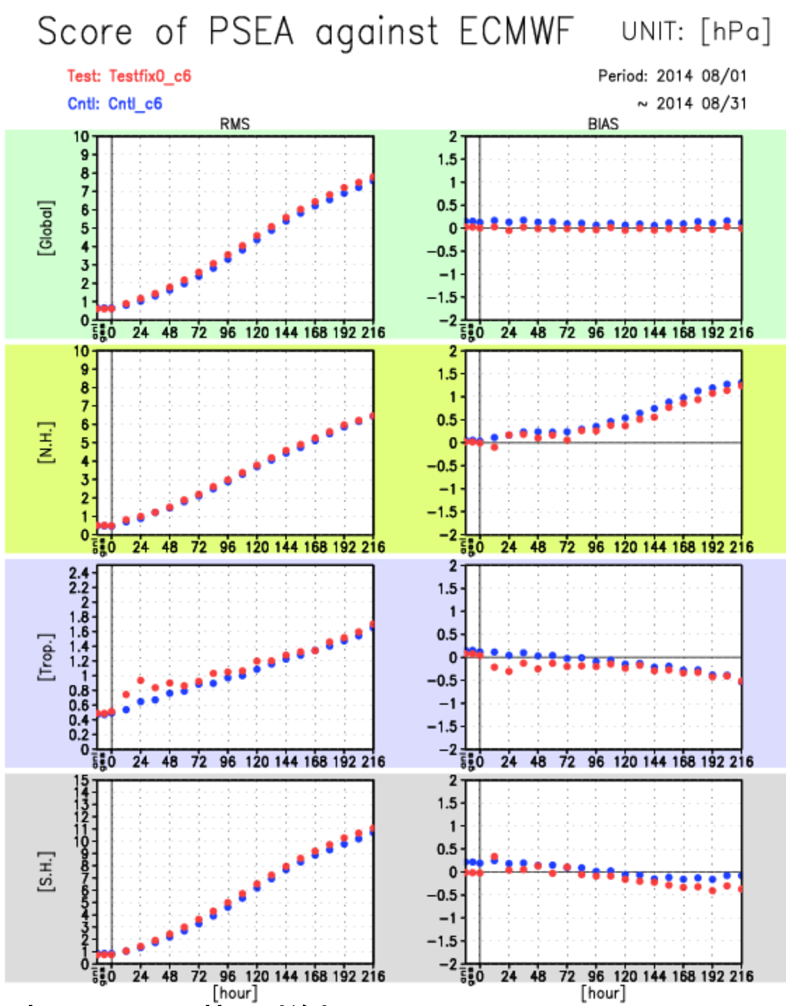


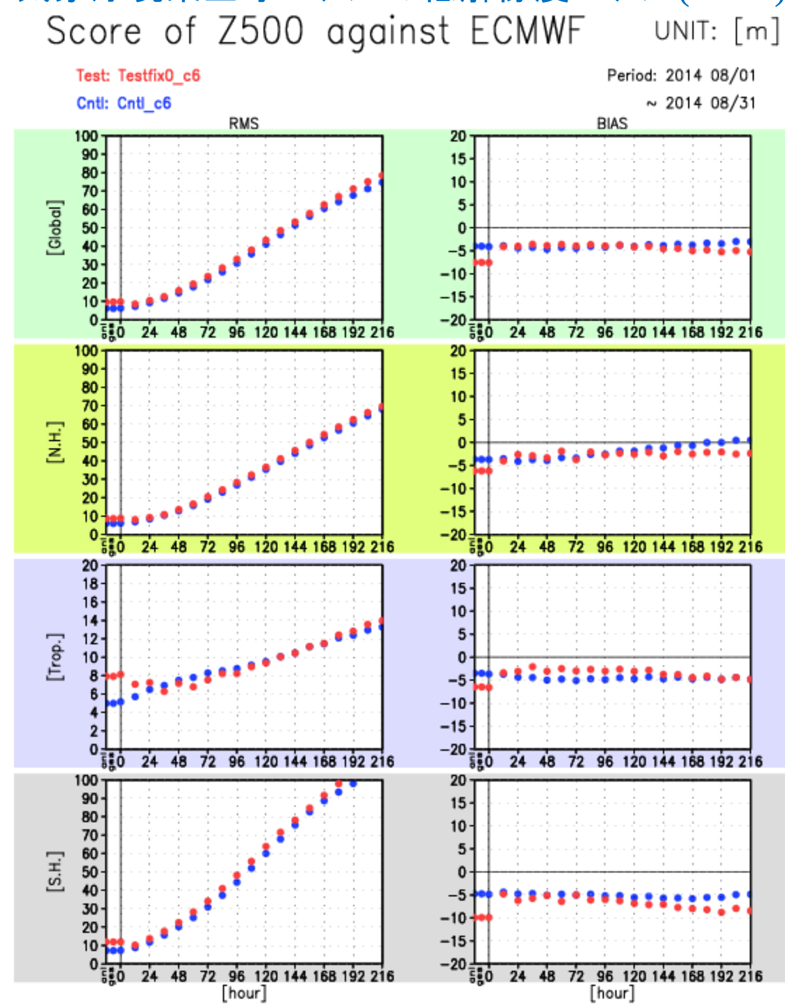


★ECMWFの全球解析値を真値とした精度評価

赤：結合同化初期値からの予報

青：気象庁現業全球モデルの低解像度モデル(60km)の予報





全球RMSEは若干増加

若干予報初期でギャップが見られる
全球バイアスは減少

熱帯では初期値は結合同化はECの解析値との剥離があるが、その後のバイアスは減っている。

ECMWF解析値に対するBIAS、RMS、Zonal mean

赤：改善
青：改悪

赤：EC<TEST
青：EC>TEST

赤：EC<CNTL
青：EC>CNTL

Zonal mean