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Development of weakly coupled atmosphere-ocean data assimilation system and the evaluation of the coupled reanalysis in JMA/MRI

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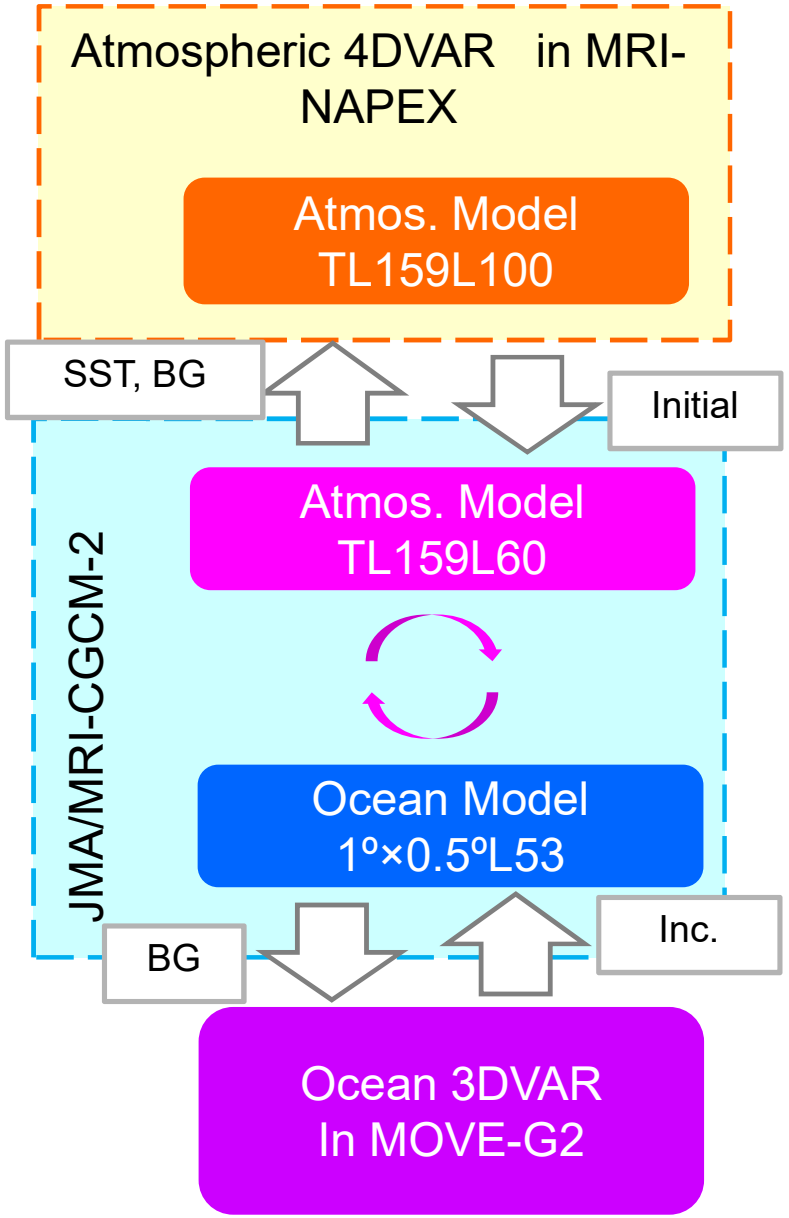
Outline

1. Introduction of the CDA system in JMA/MRI
2. Improvements found in CDA reanalysis over JRA-55
3. Impact of heat coupling
4. Lagged correlation between SST and precipitation in the western tropical Pacific
5. Impact of momentum coupling
6. Summary

1. Introduction of the CDA system in JMA/MRI

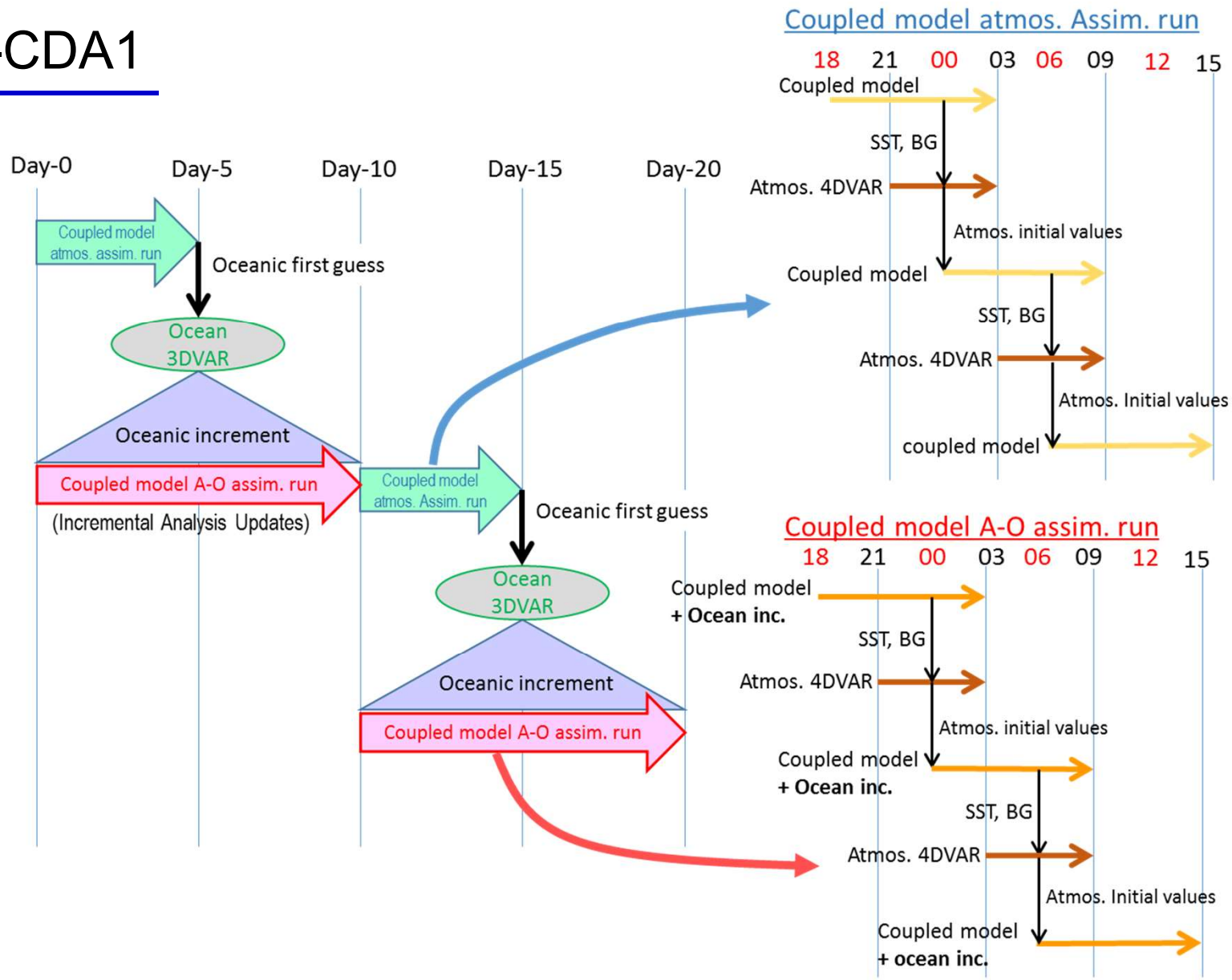
★Configuration of MRI-CDA1

- ✓ Weakly 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 background state required for integration of the adjoint model is generated by the coupled model.) => Outer Loop Coupling
- ✓ The system uses different intervals for data assimilation cycles of the atmosphere (6 hours) and ocean (10 days.)



★System Flow of MRI-CDA1

- Ocean 3DVAR results are inserted into the coupled model by IAU with 10-day interval.
- But the model integrations in the IAU scheme are substituted by alternate integrations of the coupled model and atmospheric 4DVAR.
- Atmospheric 4DVAR results are used as the initial of the coupled model every 6 hours. And the coupled model passes SST and background state data to the 4DVAR system every 6 hours.
- Atmospheric 4DVARs are performed twice from Day-0 and Day-5. This allows atmospheric fields to adjust to the assimilated oceanic fields.



★ Reanalysis Experiments

- Reanalysis experiments are performed for the period from 28 October 2013 to 31 December 2015.
  - CDA: Reanalysis run of the coupled data assimilation system, MRI-CDA1
  - UCPL: All delivery of oceanic data (SST, sea ice, surface current) to the atmospheric model is stopped.
  - NOCU: Only the delivery of the ocean surface current data is stopped.
  - CDA-Conv: Same as CDA but only conventional data are assimilated in the atmospheric data assimilation.
  - UCPL-Conv: Same as UCPL but only conventional data are assimilated in the atmospheric data assimilation.

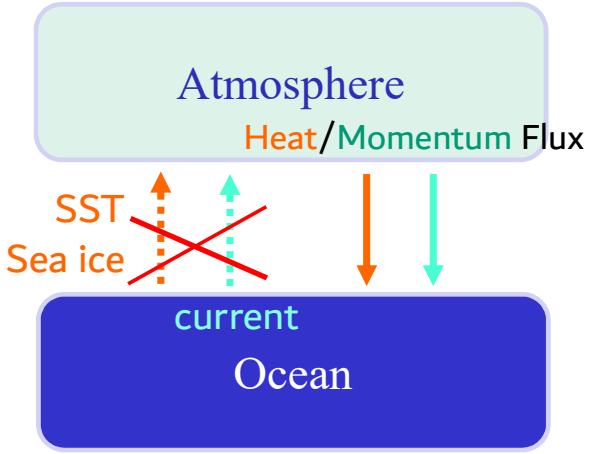
- Reference data

✓ JRA-55: JMA's Atmospheric Reanalysis Data by 4DVAR. The atmospheric model is different from those in MRI-CDA1.

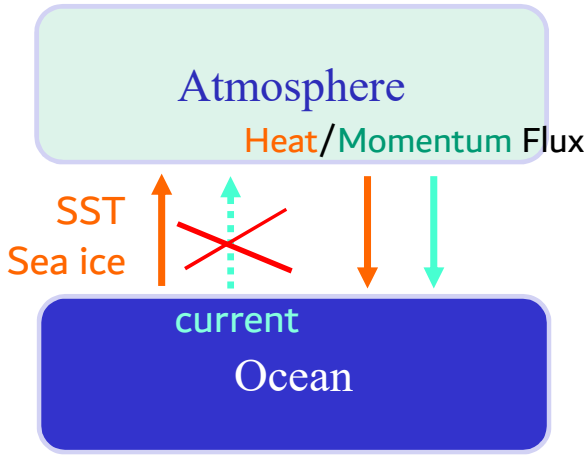
✓ CMAP and GPCP (for precipitation)

✓ COBE-SST TRMM-SST

UCPL



NOCU

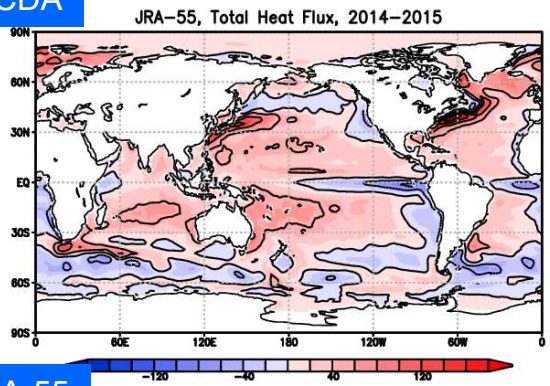


2. Improvements found in CDA reanalysis over JRA-55

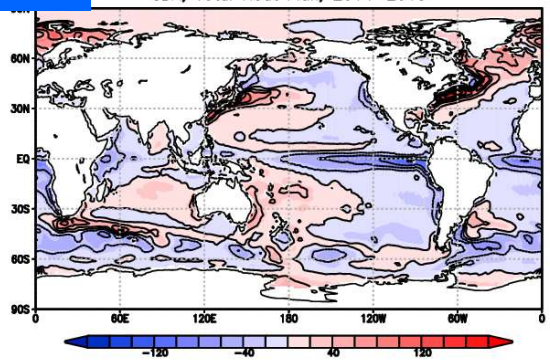
★ Improvement of Sea Surface Heat Flux (Averaged in 2014-2015)

Net Heat Flux

CDA

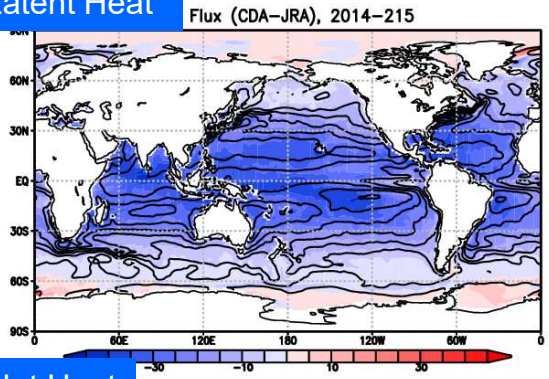


JRA-55

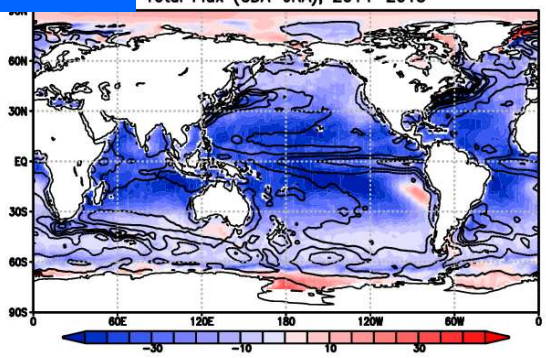


(CDA) - (JRA-55)

Latent Heat

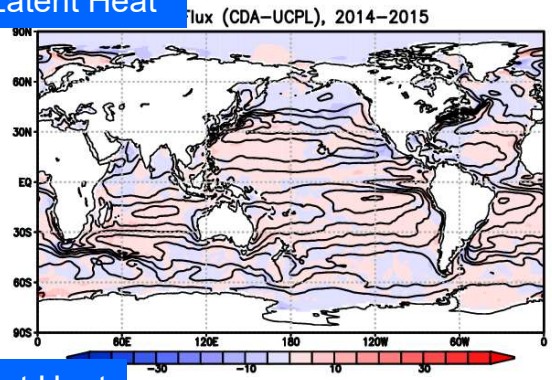


Net Heat

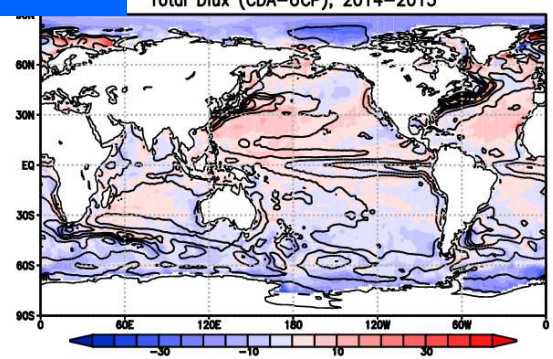


(CDA) – (UCPL)

Latent Heat



Net Heat

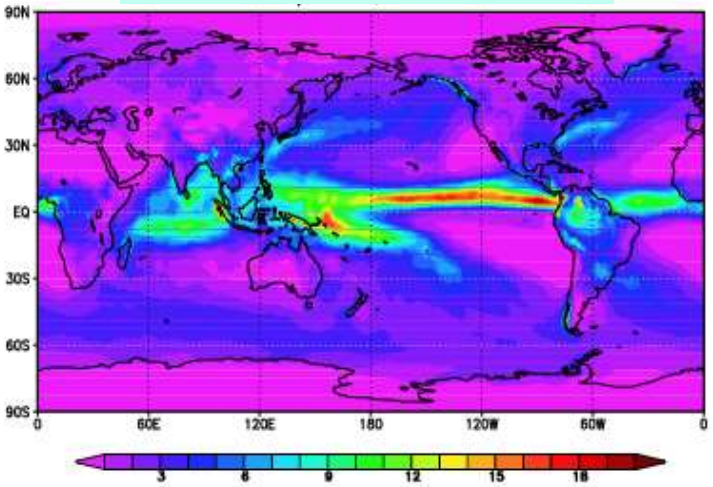


- ✓ JRA-55 has excess latent heat flux as often pointed out.
- ✓ The excess latent heat flux is suppressed in CDA.
- ✓ Consequently, the oceanic heat budget is much improved.

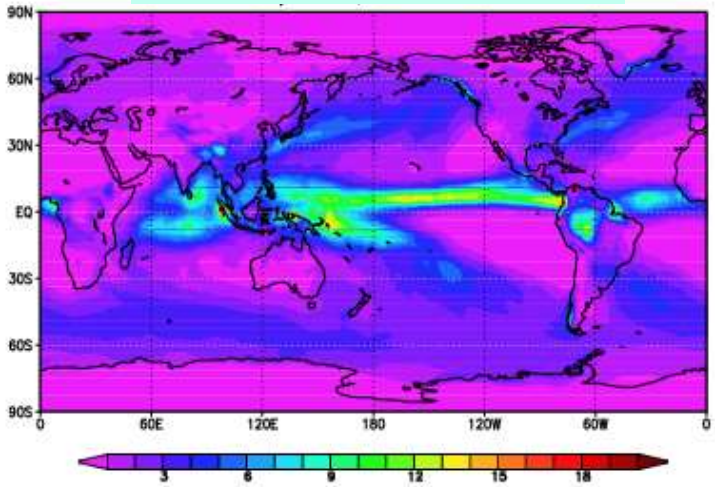
- ✓ The large difference between CDA and JRA-55 is caused by the difference of the atmospheric models.

★ Comparison of Mean Precipitation (2014-2015)

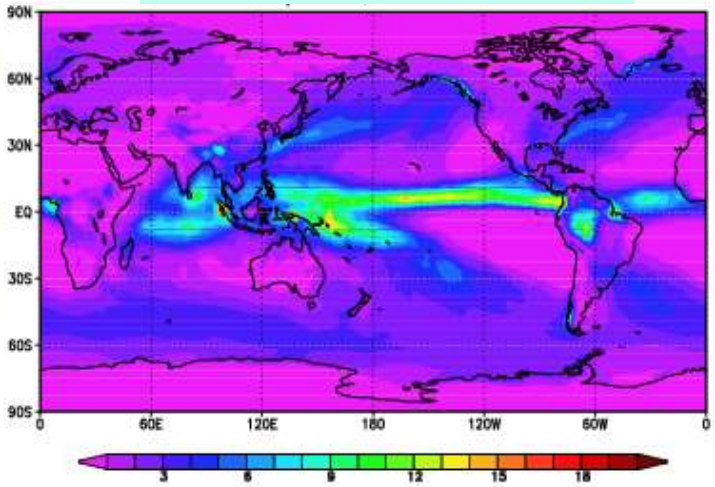
JRA-55



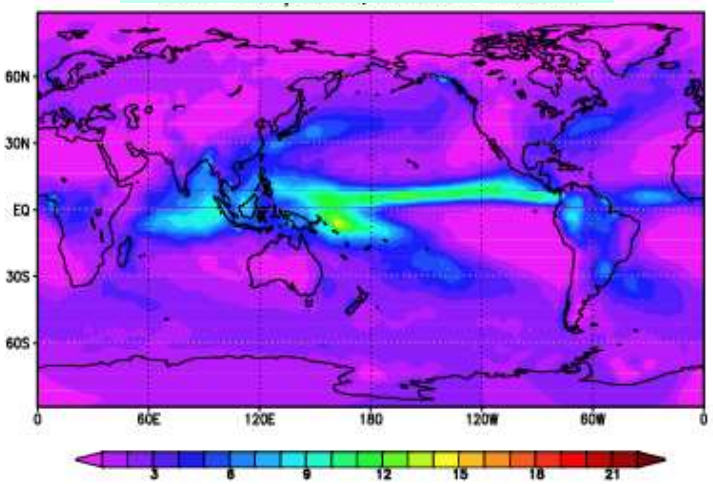
CDA



UCPL



CMAP (Observation)



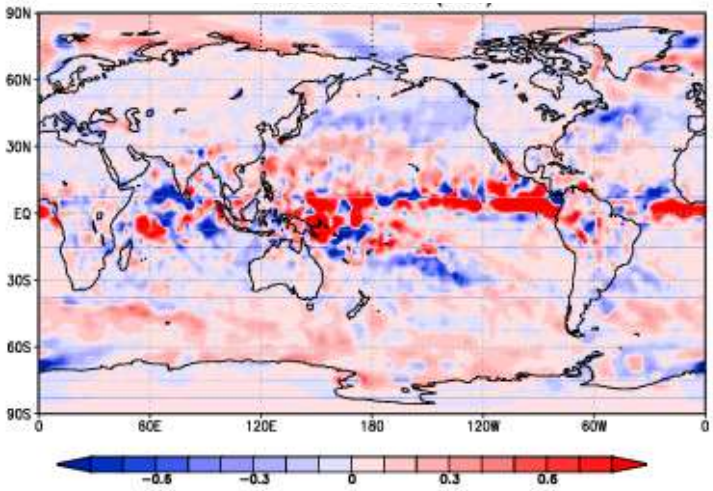
- ✓ Excess precipitation in the tropics in JRA-55 is suppressed in CDA.
- ✓ This improvement also appears in UCPL. Therefore, this improvement is also caused by the difference of the atmospheric models between CDA and JRA-55 systems.

3. Impact of heat coupling

★ Comparison of PRC scores between CDA and UCPL (Dec2013-Nov2015)

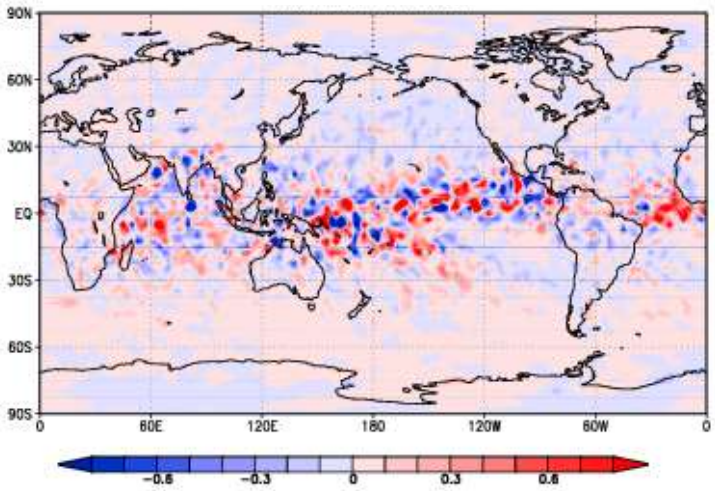
Absolute Bias (UCPL-CDA)

30°S-30°N Average: 0.0758mm/day



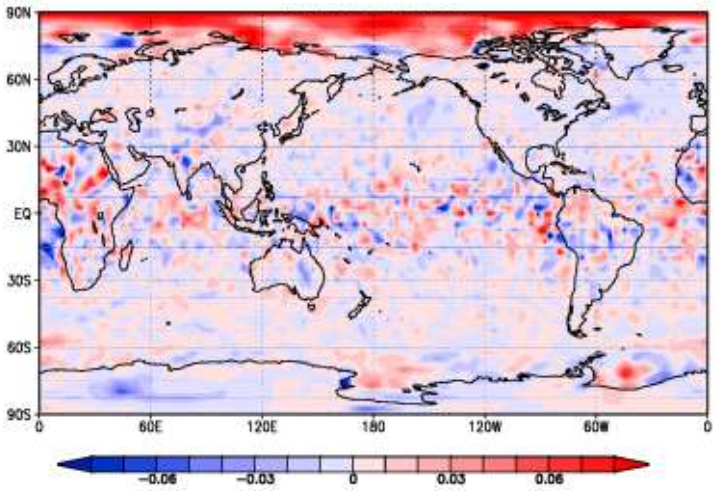
RMSE (UCPL-CDA)

30°S-30°N Average: 0.0146mm/day



ACC (CDA-UCPL)

30°S-30°N Average: 0.0073



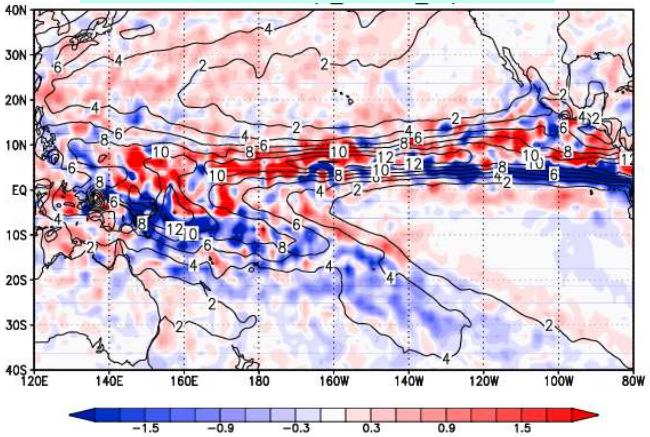
- ✓ Although the difference is smaller than the improvement over JRA-55, CDA reduces the bias and RMSE of the precipitation.
- ✓ CDA reduces the absolute bias averaged over tropics by 0.076 mm/day and RMSE by 0.015 mm/day.
- ✓ ACC averaged over tropics are also slightly increased in CDA.

★ Differences in mean precipitation and meridional velocity (2014-2015)

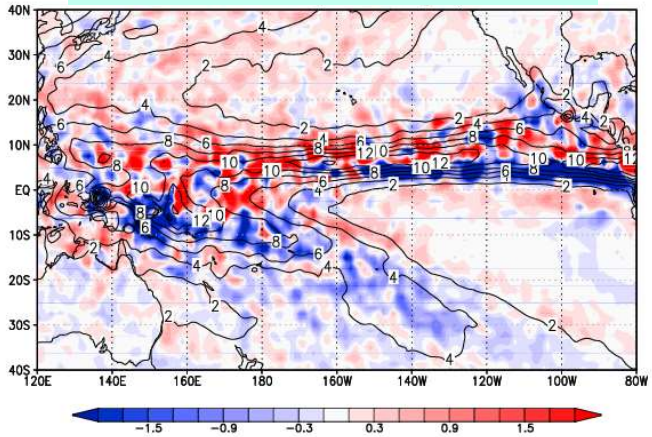
- ✓ The air–sea coupling tends to replace ITCZ northward,
- ✓ This difference remains even if we cut the delivery of the surface ocean current data to the atmosphere in NOCU.
- ✓ Caused by heat–coupling.

Precipitation

(CDA - UCPL) x 5, CDA

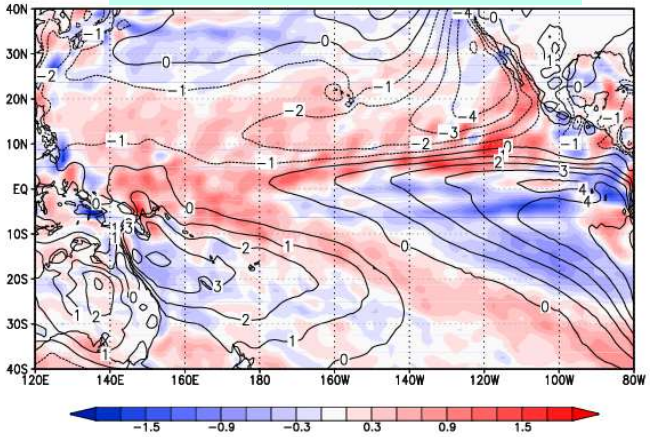


(NOCU – UCPL) x 5, NOCU

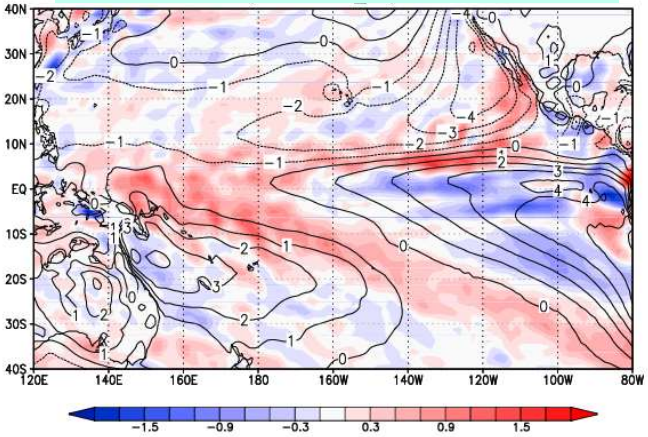


Surface Meridional Velocity

(CDA - UCPL) x 10, CDA

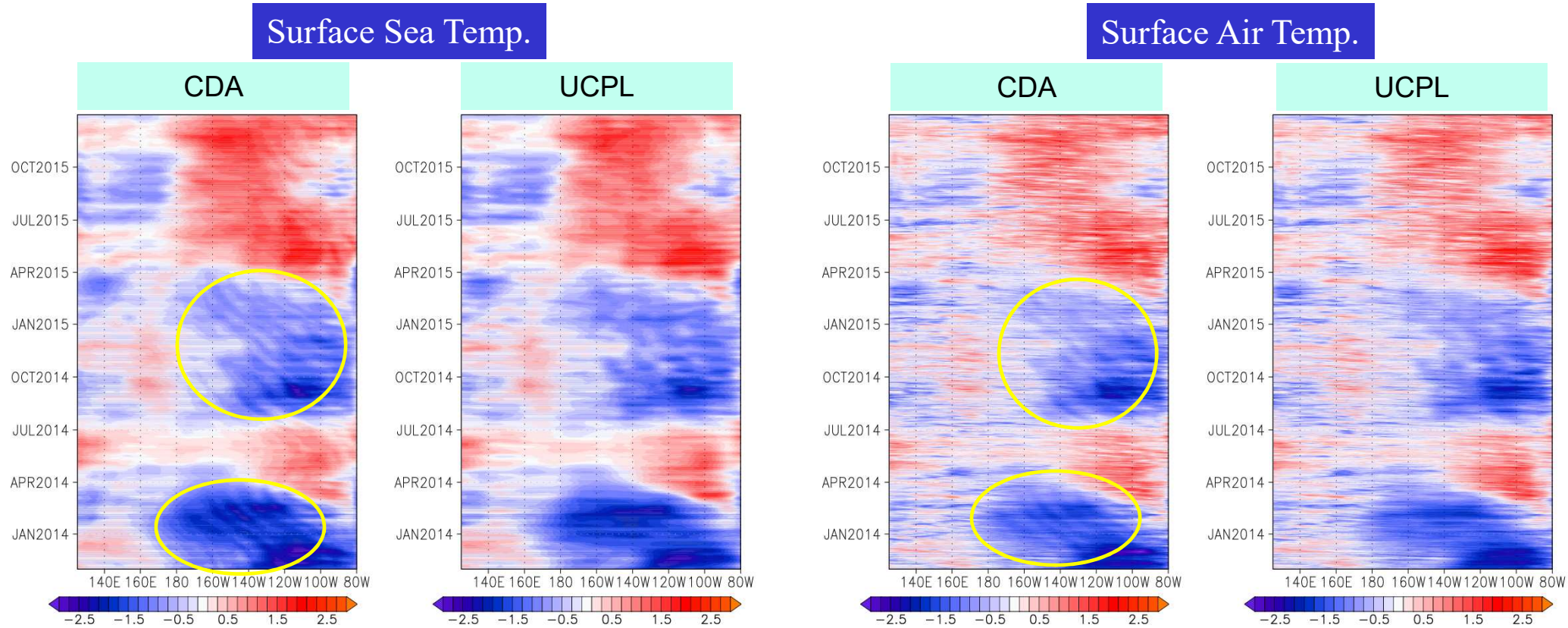


(NOCU - UCPL) x 10, NOCU



- ✓ Southward (northward) surface winds are weakened at the north (south) of ITCZ in CDA.
- ✓ The North Pacific subtropical high is weakened in CDA.
- ✓ This difference also remains in NOCU. Thus, this is also caused by heat coupling.

★ Longitude-time section of SST and SAT averaged in 0-5N.



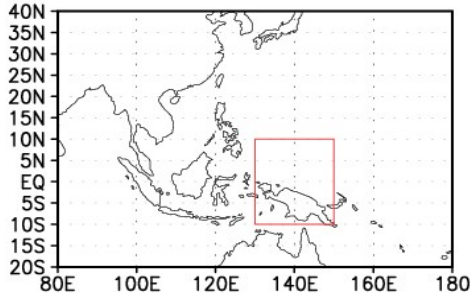
✓ The ocean model generated physically-consistent variation of SST such as those related to Tropical Instability Waves (TIW) in CDA

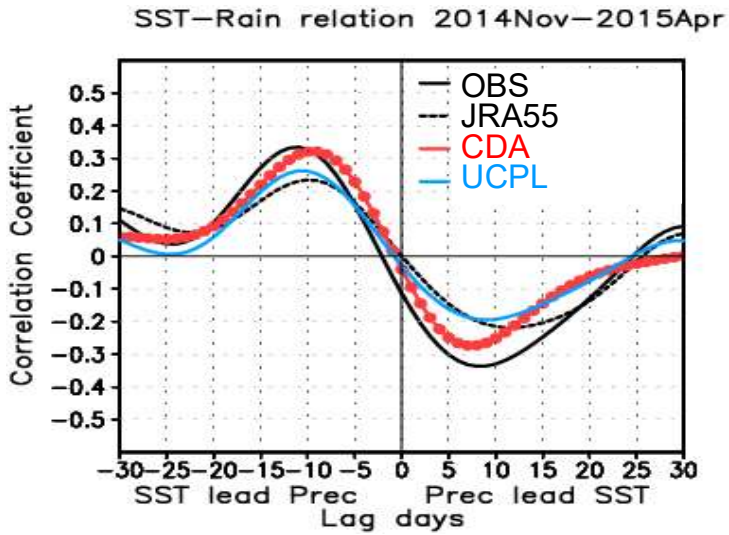
✓ The atmospheric fields (particularly Sea surface Air Temperature, SAT) adjust to the SST variation calculated by the ocean model

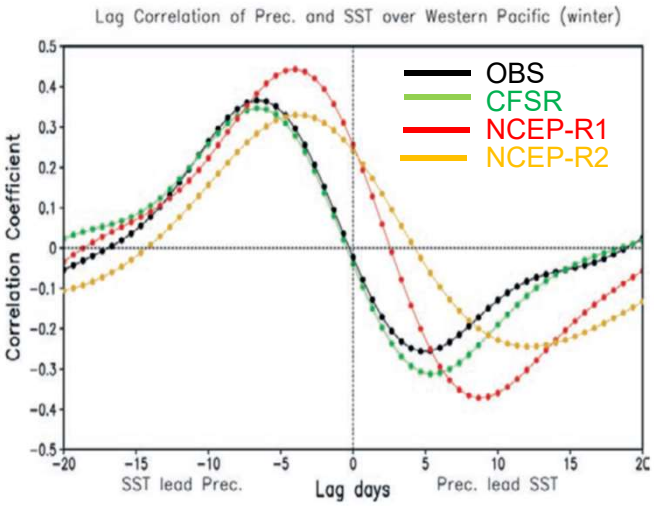
4. Lagged correlation between SST and precipitation in the western tropical Pacific

★ Comparison of the Lagged correlation between SST and precipitation

- ✓ Time series of SST and precipitation averaged in 10ºS-10ºN, 130-150ºE are used.
- ✓ The time series are bandpass-filtered for 20 to 100 days







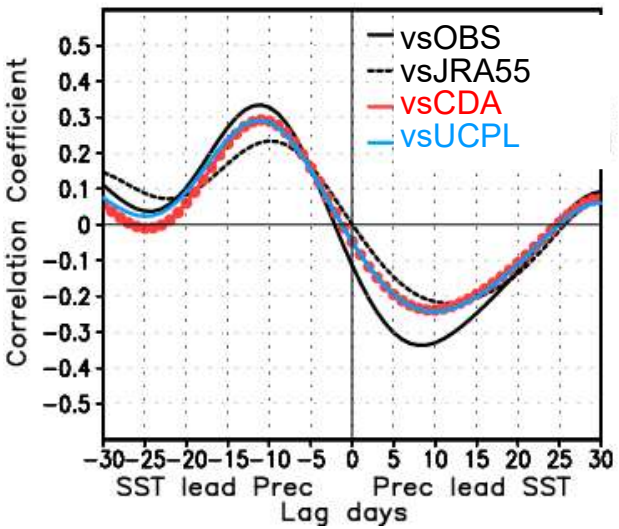
From Saha et al. (2010)

- ✓ CDA reproduces lagged correlation between SST and precipitation (precipitation lags 10 about days behind SST) better than UCPL and JRA-55.
- ✓ A similar result based on NCEP reanalyses is also reported by Saha et al. (2010).

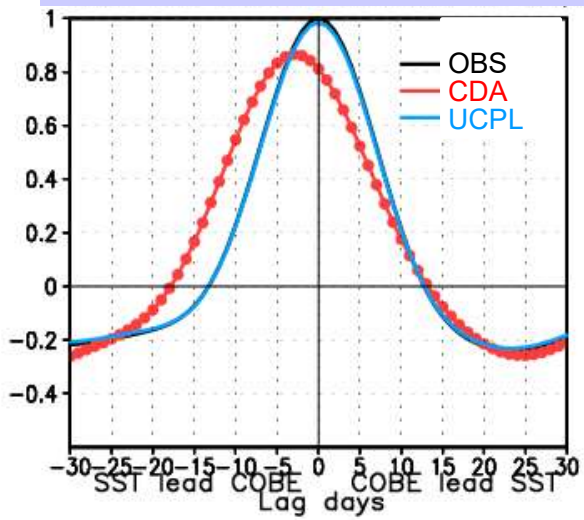
★How the lagged correlation is reproduced?

- ✓ However, time series of precipitation in CDA is almost in phase with UCPL and JRA55. Therefore, if we compare the time series of the precipitation in CDA with that of independent SST, the lag cannot be seen.
- ✓ The same result based on NCEP reanalyses is reported by Kumar et al. (2013).
- ✓ Because constraint of the atmospheric fields by data assimilation is too strong, the precipitation field cannot be adjusted to the SST field.
- ✓ The SST field is adjusted to the atmospheric fields instead.

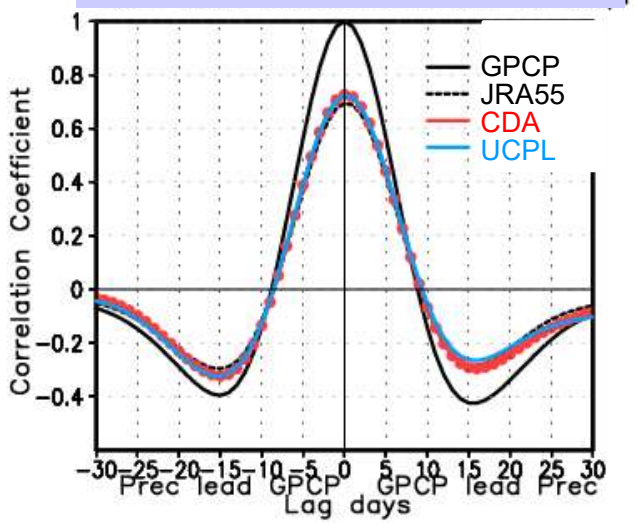
Obs-SST-model-rain relation



Obs-SST-model-SST relation

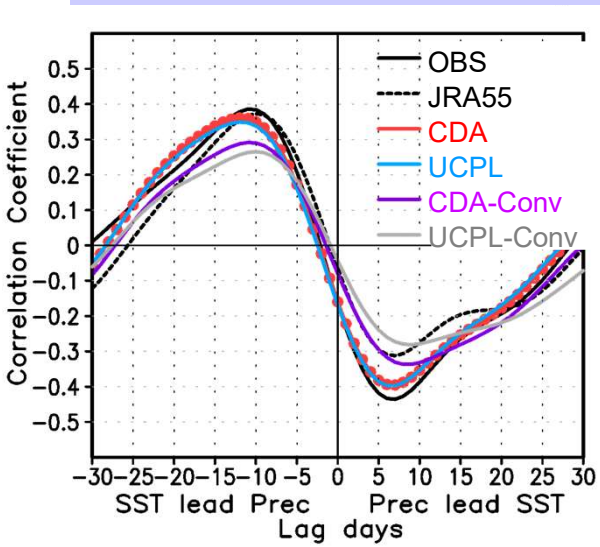


Obs-rain-model-rain relation

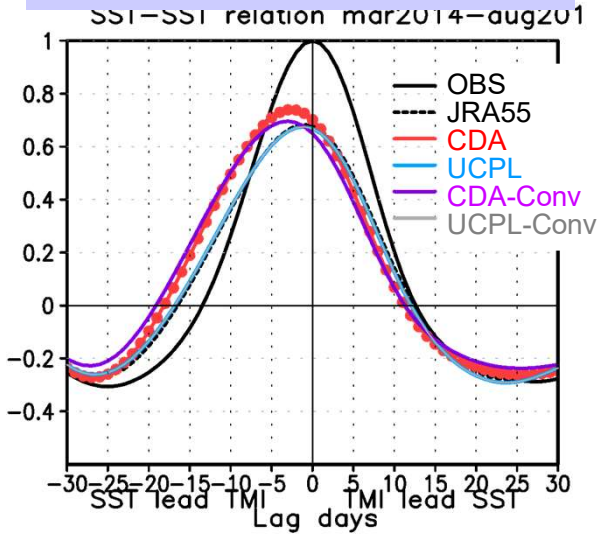


★In the case of assimilating conventional atmospheric data alone

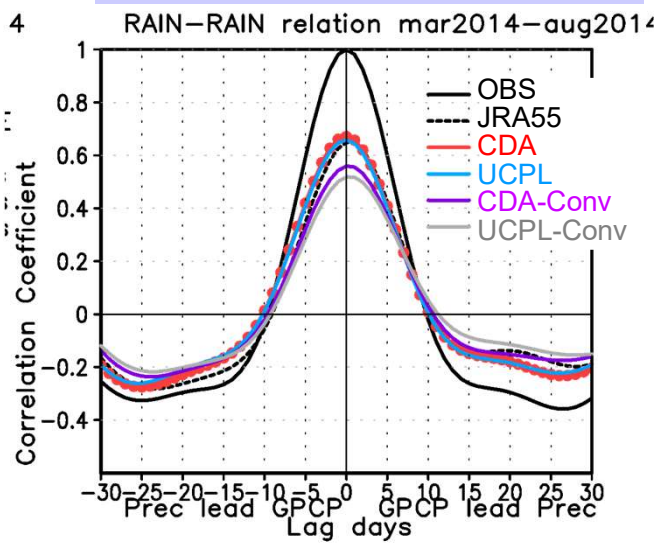
Obs-SST-model-rain relation



Obs-SST-model-SST relation



Obs-rain-model-rain relation



- ✓ In the case of assimilating conventional atmospheric data alone (without assimilating satellite data), the lagged correlation of precipitation with the observed SST is better represented when the coupled data assimilation is performed (comparison between the purple and the red).
- ✓ Correlation of precipitation with observed data is also increased, although assimilation of satellite data improves the precipitation field more effectively.

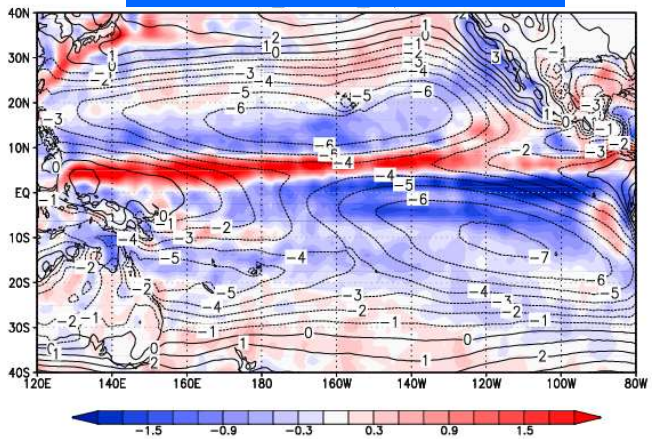
5. Impact of momentum coupling

★ Impact of the momentum coupling

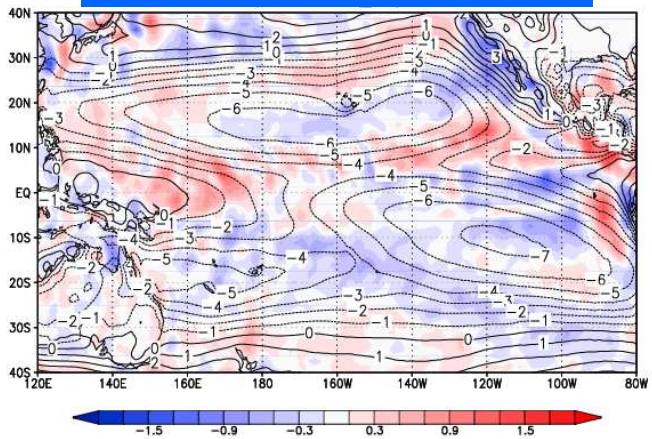
- ✓ The trade winds around the equator (5°N) are intensified (weakened) in CDA.
- ✓ This difference does not appear in the comparison between NOCU and UCPL,
- ✓ Thus, this difference is caused by using surface ocean currents when calculating wind stress.

Surface zonal winds

(CDA – UCPL) x 10 , CDA

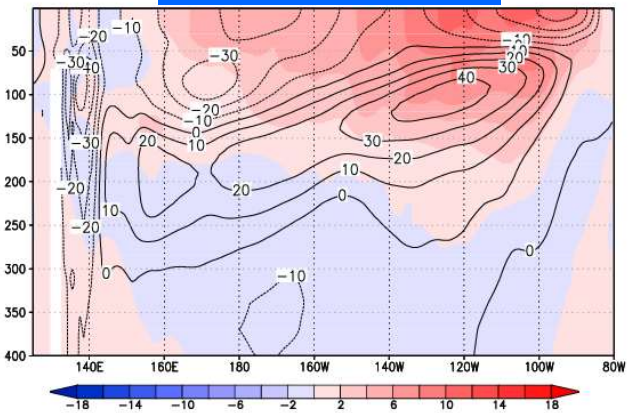


(NOCU– UCPL)x10, NOCU

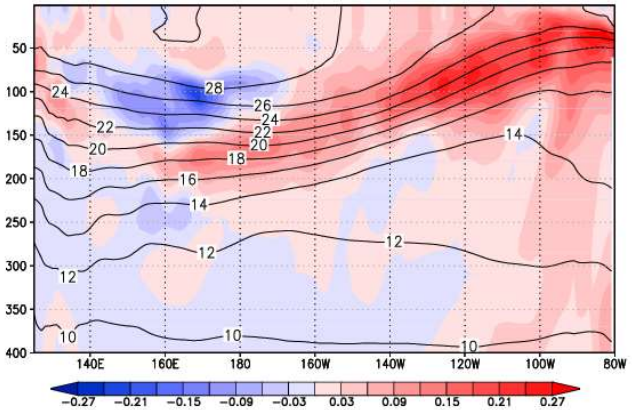


Equatorial Ocean Vertical Section. Contours: CDA, Color: CDA-UCPL

Zonal Current



Temperature



- ✓ In the equatorial vertical section of the ocean, intensification of westward currents are induced due to smaller wind stress.
- ✓ CDA also deepens the thermocline in the eastern and central equatorial Pacific, and makes the slope of the thermocline moderate.
- ✓ This causes the tendency to weaken the cold bias in the eastern equatorial Pacific.

4. Summary

★ Summary

- ✓ Excess latent heat and excess rainfall found in JRA-55 is suppressed in CDA mainly due to the difference of the atmospheric model.
- ✓ Heat coupling (delivering SST data in the ocean model to the atmospheric model) generally improves precipitation fields in the tropics (reduces bias and RMSE). It weakens the North Pacific subtropical high and replaces the ITCZ northward.
- ✓ Lagged correlation between SST and precipitation in the western tropical Pacific is improved in CDA. However, observation-based SST field is modified instead of the atmospheric fields because atmospheric data assimilation constrains it strongly.
- ✓ In CDA, the surface ocean current speed is considered in estimation of the wind stress fields (Momentum coupling). This effect intensifies easterly trade winds and moderate the zonal slope of the thermocline at the equator. It tends to reduce the cold bias in the eastern equatorial Pacific.

Thank you!!