Surface Heat Flux Response to SST Anomalies:
CCSM3.5+ vs Observation

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OUTLINE

I. Brief overview of CAM4 development focusing on ‘cloud’ package

II. Comparison of Surface Heat Flux Feedbacks from CCSM3.5+ and Obs.

III. Summary

I. Brief Overview of CAM4 Development

Sequence of CAM Development

CAM3.0

- Modified ZM Deep Convection Scheme (Neale and Richter)
    - Updraft lateral mixing & convective momentum transport
    - → Improve ENSO (e.g., 2 yr to 4-5 yr period)
- Modified Macrophysics
    - Update cloud fraction after macrophysics
    - → Reduce high-latitude LCA and land temperature biases in the N.H.
- Revised Gravity Wave Drag and Polar Filtering
    - → Reduce mid-latitude SLP bias in the winter N.H.

Track I (CAM3.5)

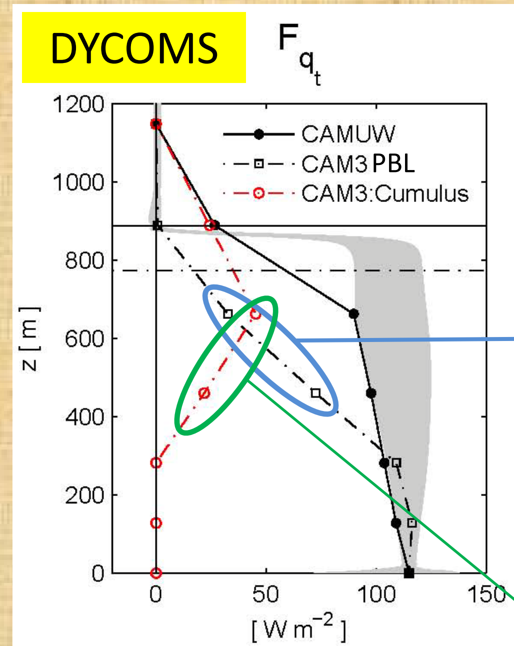
- New Microphysics (Morrison and Gettelman)
    - Simulate 'nl,ni' as well as 'ql,qi'
    - → Allow simulation of AIE, reduce LWP bias

Track II

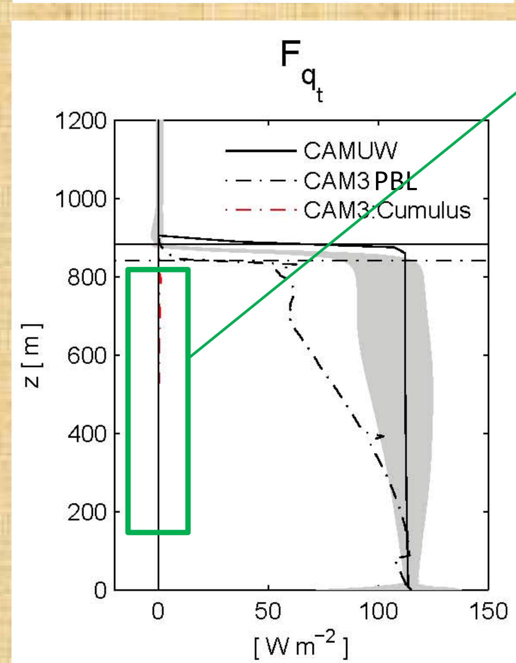
- Revised Radiation Scheme (Collins and Colney) & Cloud Optics (Mitchell, Conley)
- MAM Prognostic Aerosol with a revised droplet activation (Ghan and Liu)
- UW Moist Turbulent (PBL) Scheme (Bretherton and Park)
    - Simulate moist turbulence generated by clouds
    - → Improve marine Sc without a stability-based kludge for MBL cloud fraction
- UW Shallow Convection Scheme (Park and Bretherton)
    - CIN-TKE based mass flux closure with buoyancy sorting and pen. entrainment
    - → Realistic updraft mass flux, w, LWC and cumulus fraction at the right spot
- Revised Macrophysics (Park, Bretherton, Rasch)
    - Use conservative scalars and remove inconsistencies in cloud treatment
    - → Consistent cloud fraction and in-cloud LWC → Improved moist turbulence

Track V

L30



L150



Problem.1

CAM3 PBL is less efficient in vertical mixing of conservative scalars
due to weak turbulence in association with the neglect of LW cooling and condensation heating

Problem.2

CAM3 shallow convection scheme is
1. unrealistically active in the MSC deck
2. very sensitive to vertical resolution.

Problem.3

Even with shallow convective flux, CAM3 often fails to moisten the PBL top.
→ need additional cloud fraction based on the stability in the lower troposphere (KH empirical formula)
→ induce inconsistency in the macrophysics

Eddy Diffusion (PBL) Scheme Comparison

	CAM-UW	CAM-30
K	internally computed (1st order TKE closure)	externally specified (K-profile scheme)
TKE sources / Operation regimes	everywhere	only at surface / only within PBL
Moist process (cloud-radiation-turbulence interactions)	explicitly treated	not treated
Treatment of 3rd aerosol indirect effect	possible	impossible

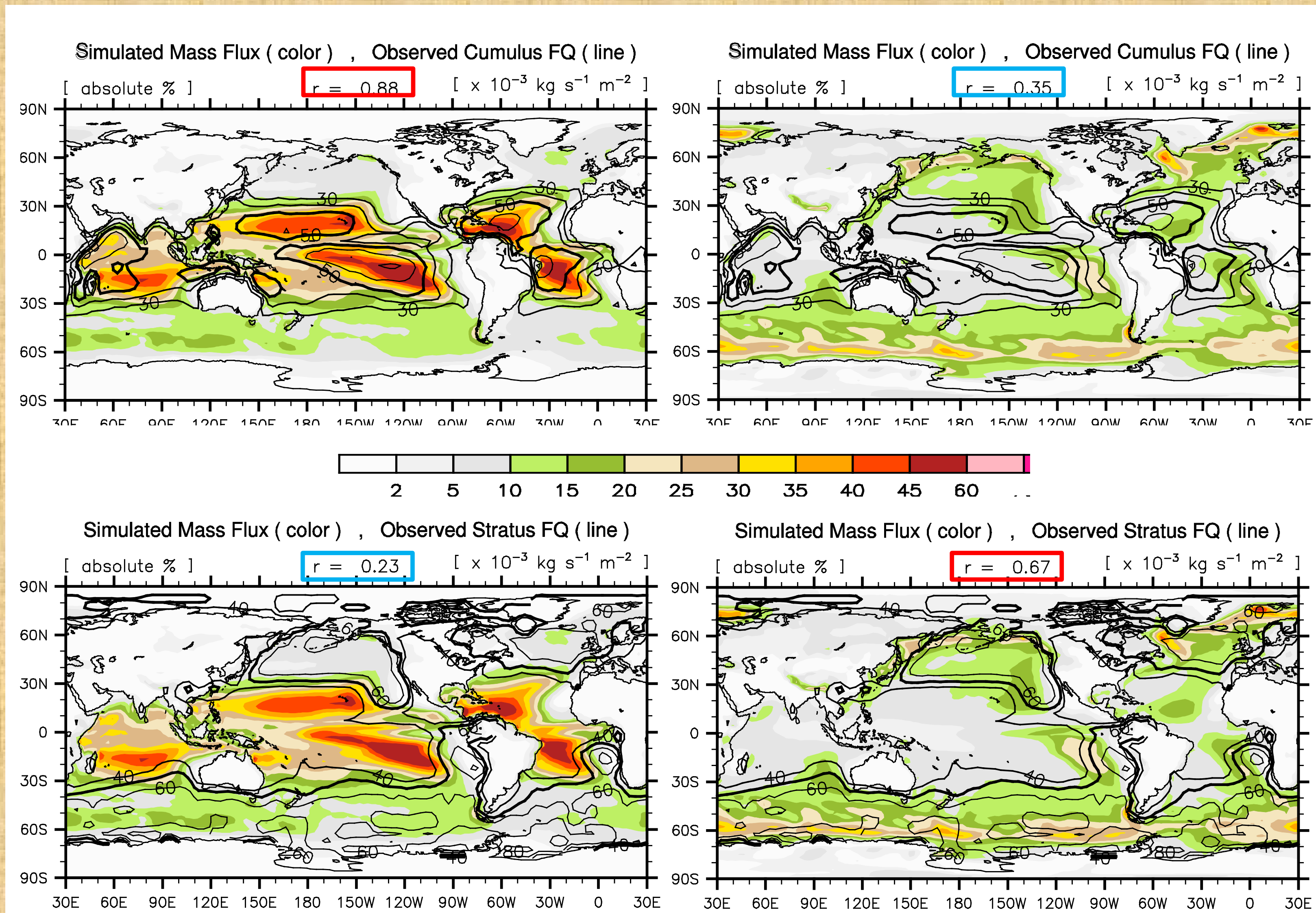
Shallow Convective Mass Flux at Cloud Base. Annual.

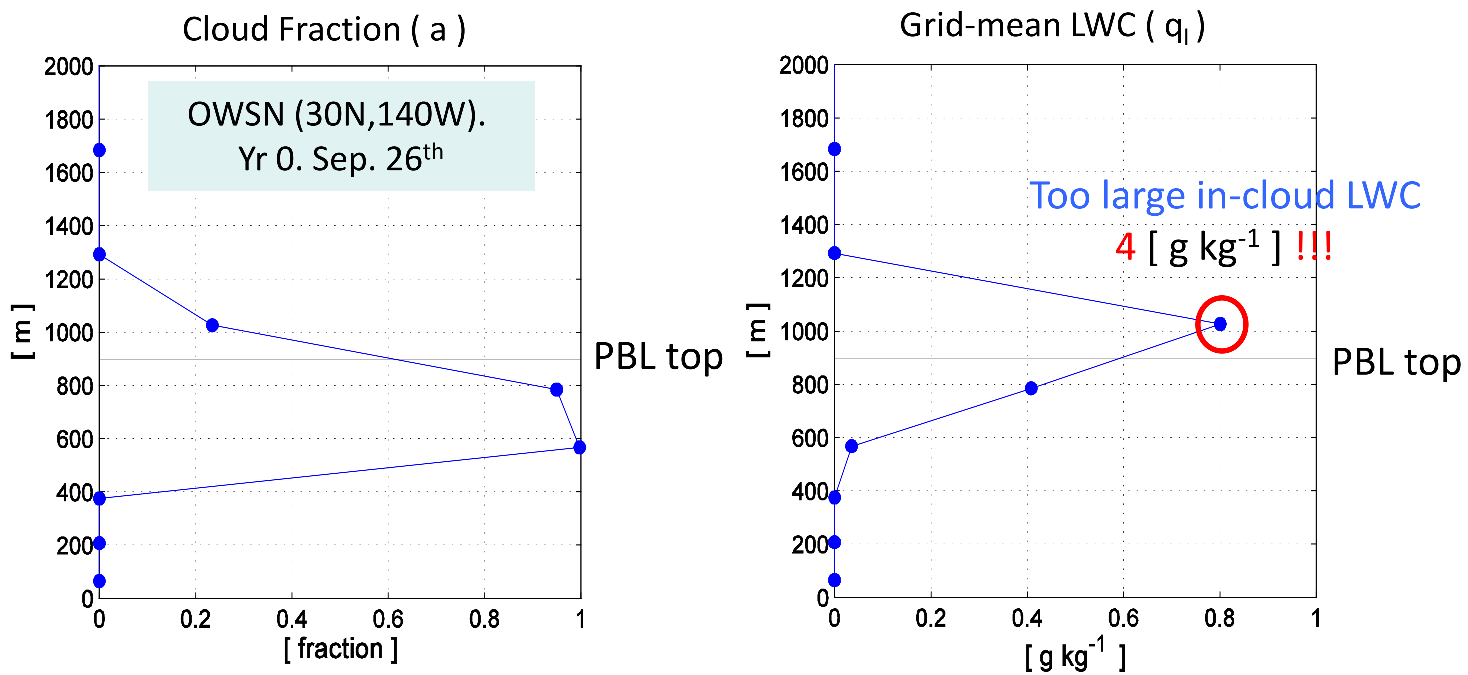
CAMUW

CAM30

Observed Cumulus

Observed Stratus





CAM3 suffers from inconsistency between cloud fraction and in-cloud LWC

→ distorts LW cooling profile

→ too strong inversion at the PBL top

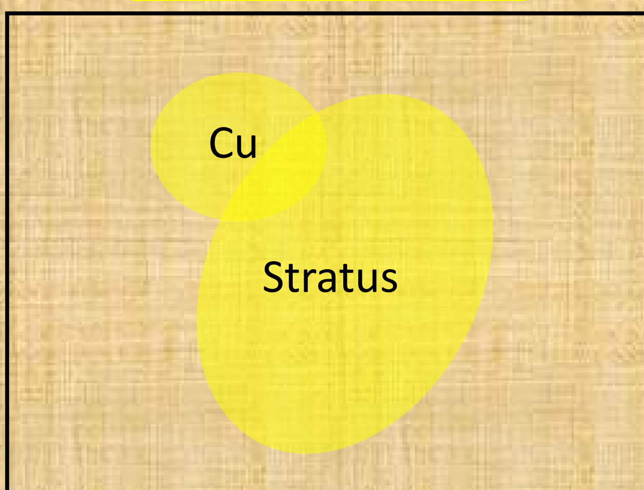
→ too weak entrainment rate

→ too shallow and moist PBL

Revised Macrophysics Scheme

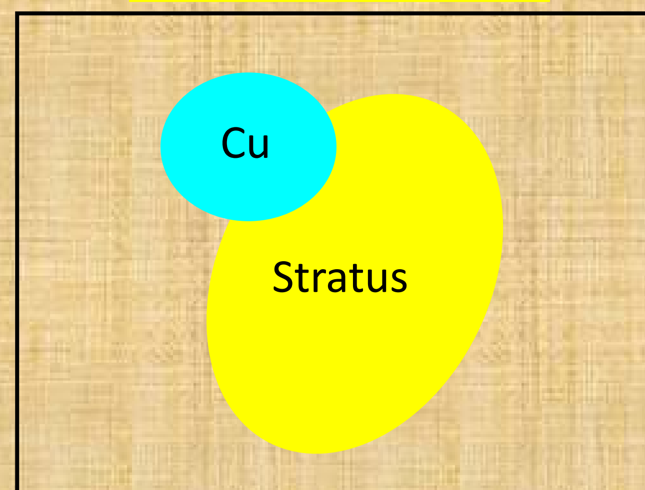
- Uses a single equilibrium cloud fraction at each time step.
- Condensation formulation based on conservative scalars
- Remove 'empty' ($a>0$, $q_{l,cloud}=0$) and 'dense'($a=0$, $q_{l,cloud}>0$) cloud
- Stratus fraction does not use the kludge based on stability
- Liquid stratus fraction = f(RH), Ice stratus fraction = $f(q_i)$
- Explicit treatment of in-cumulus LWC → Radiative active cumulus

CAM3 Macrophysics



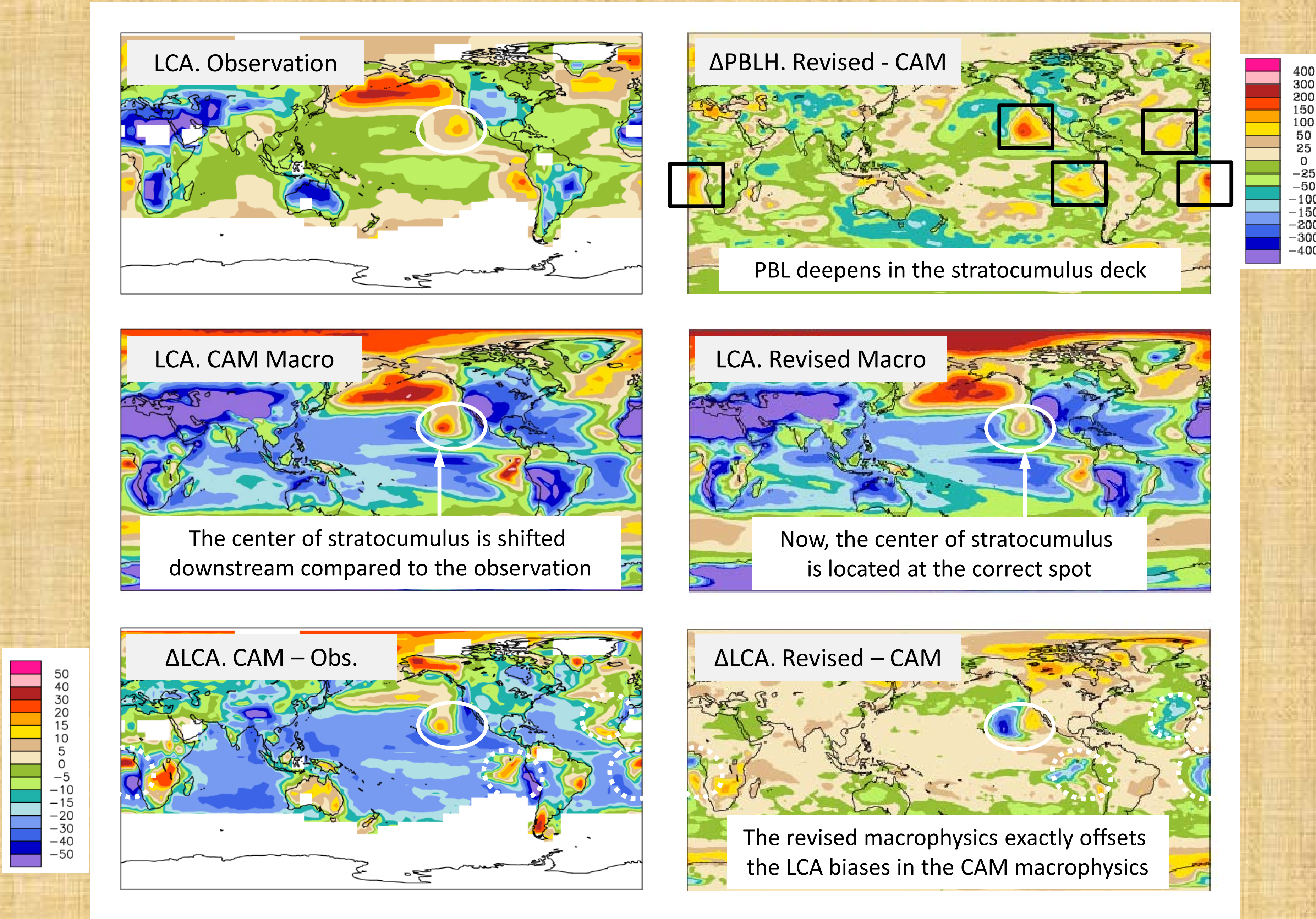
- Overlap
- **In-cumulus LWC = In-stratus LWC**

Revised Macrophysics



- Non-overlap
- **In-cumulus LWC ≠ In-stratus LWC**

SENSITIVITY TO MACROPHYSICS. JJA.



II. Surface Heat Flux Responses to SST Anomaly : Surface Heat Flux Feedback

Surface Heat Flux Feedback

[Frankignoul and Hasselman 1977; Deser et al. 2003; Park et al. 2005]

$$\rho \cdot C_p \cdot \overline{H} \cdot \frac{\partial}{\partial t} SST' = Q' = -\lambda \cdot SST' + q'$$

Q' : Downward surface heat flux anomaly

$$\lambda \equiv -\frac{\partial Q'}{\partial SST'} = -\frac{Cov[\, SST'(-1), Q'(0) \,]}{Cov[\, SST'(-1), SST'(0) \,]}$$

$\lambda < 0$: SST anomaly is amplified → Positive feedback

$$= \lambda_{LHF\ +\ SHF} + \lambda_{(SW\ +\ LW)_{cloud}} + \lambda_{(SW\ +\ LW)_{clear}}$$

PBL turbulence, convection | stratocumulus, anvil cirrus | water vapor, aerosol

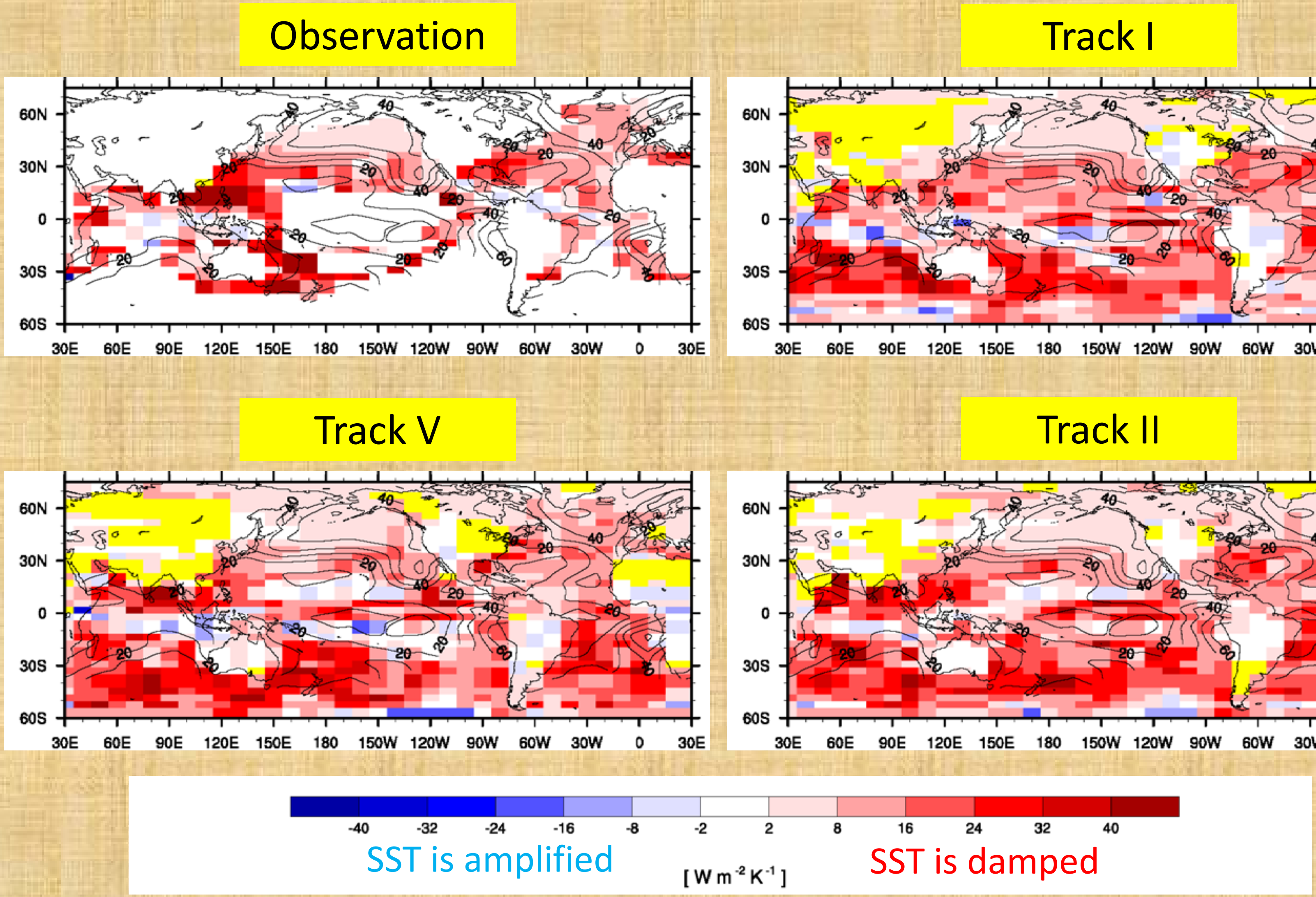
Estimation of Surface Heat Flux Feedback

- Observation (Park, Deser, and Alexander, 2005)
  - LHF and SHF are from the EECRA ship observation during 1956-1995 (40 yrs)
  - SW and LW at the surface are from ISCCP FD during 1984-2000 (17 yrs)

- CCSM coupled simulations after 10-yrs of spin-up period
  - Track I : 40 yrs
  - Track II : 43 yrs
  - Track V : 35 yrs

- Remove ENSO signals, detrend, and compute feedback parameters following PDA2005

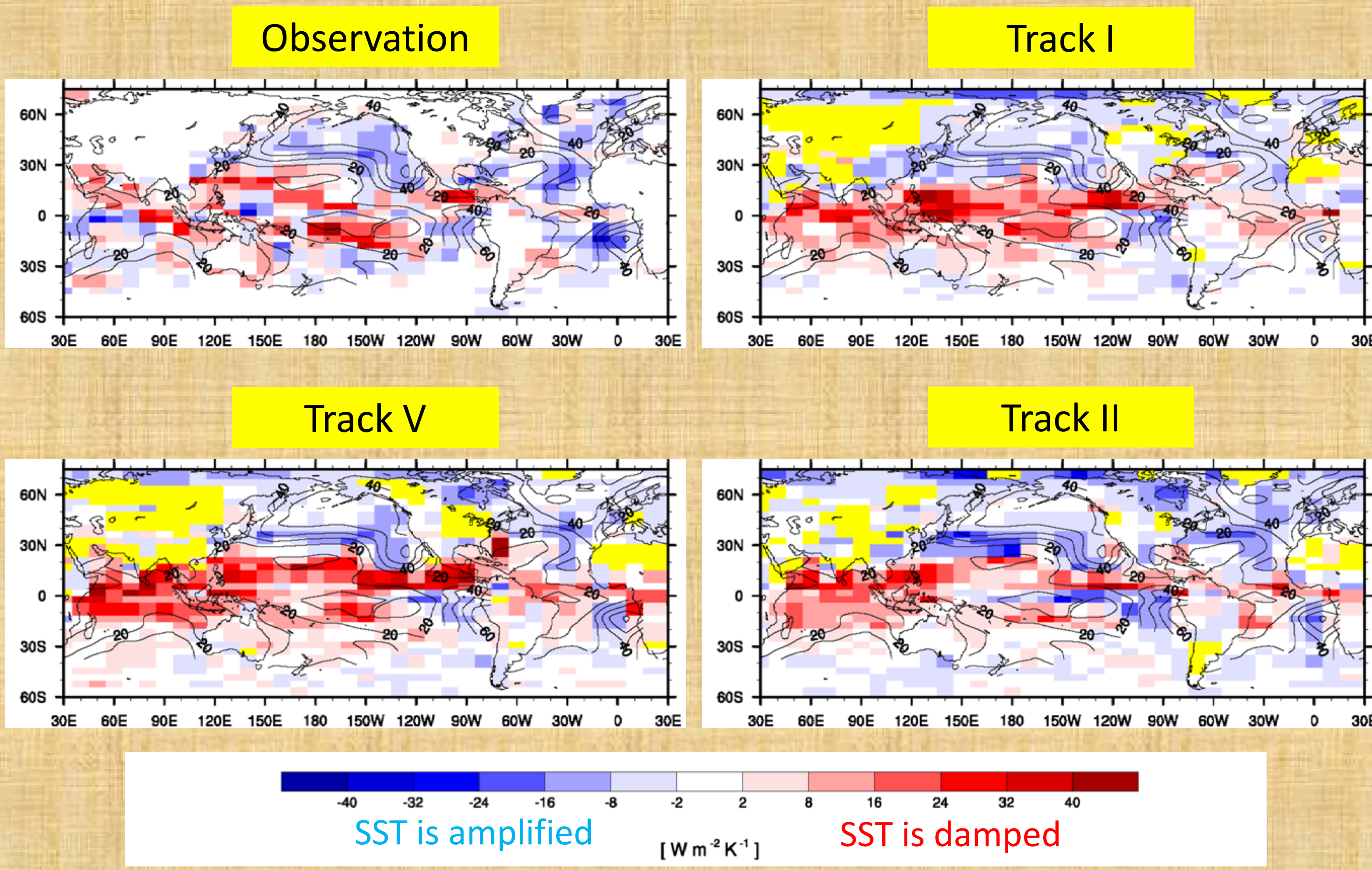
$\lambda_{LHF} + \lambda_{SHF}$, JJA



Solid line : Ship-observed Stratocumulus AMT in '56-'95 (absolute %)

Yellow Color : Non-significant signals at the 95% confidence level from the two-sided t-test

λ_{SW} , JJA



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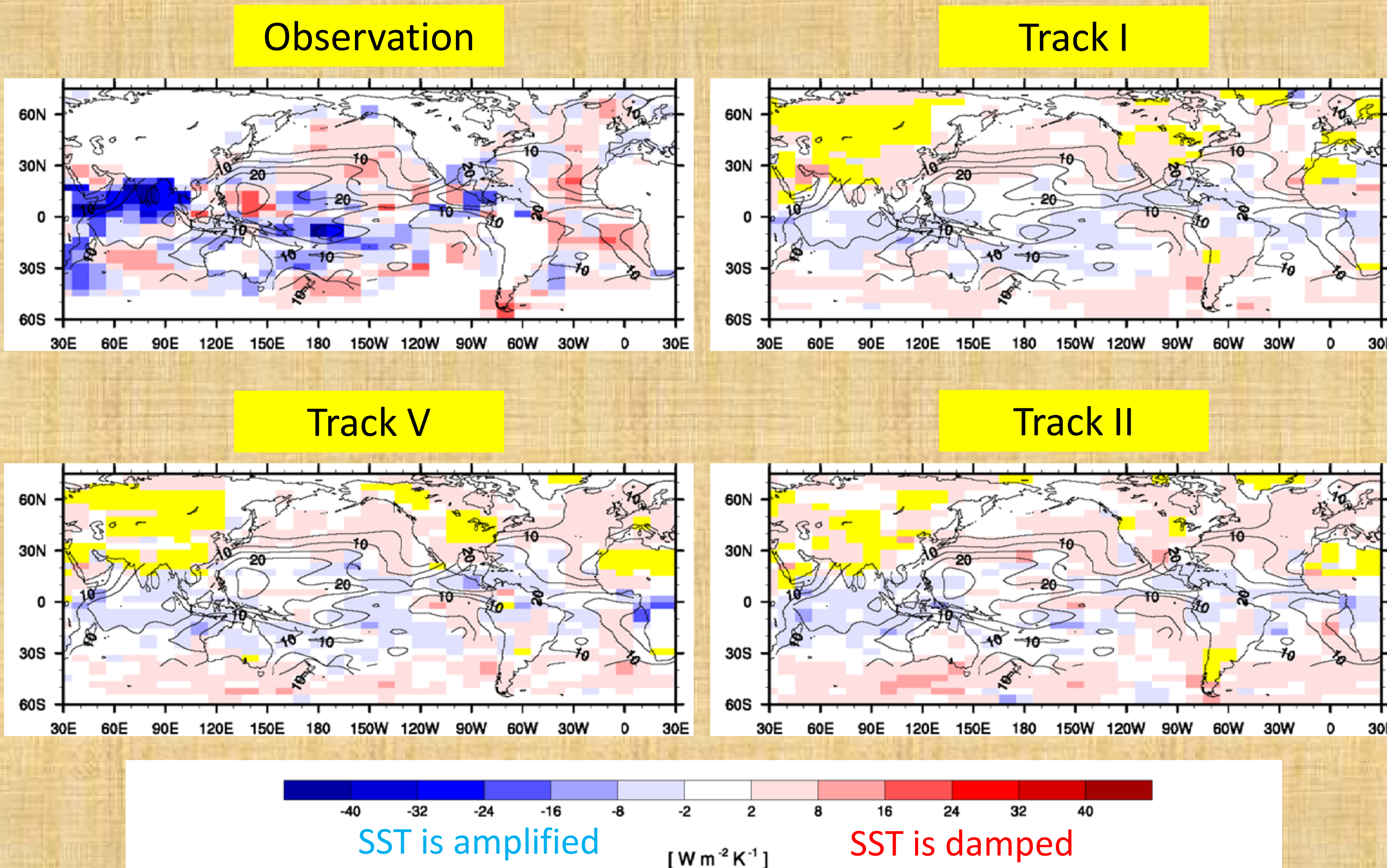
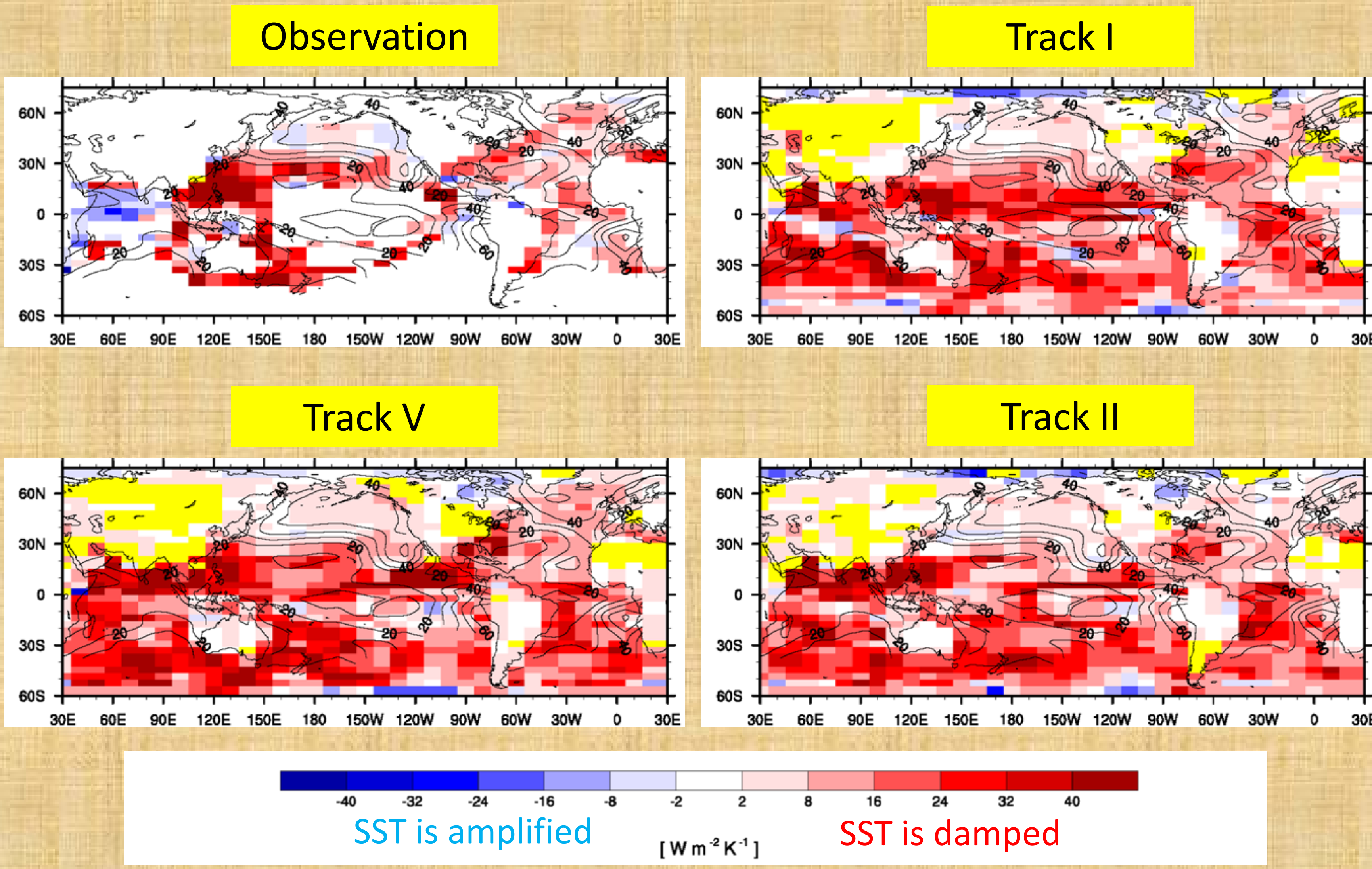
λ_{LW} , JJA



Solid line : Ship-observed Cumulonimbus FQ in ‘56-’95 (absolute %)

Yellow Color : Non-significant signals at the 95% confidence level from the two-sided t-test

$\lambda_{LHF} + \lambda_{SHF} + \lambda_{SW} + \lambda_{LW}$, JJA



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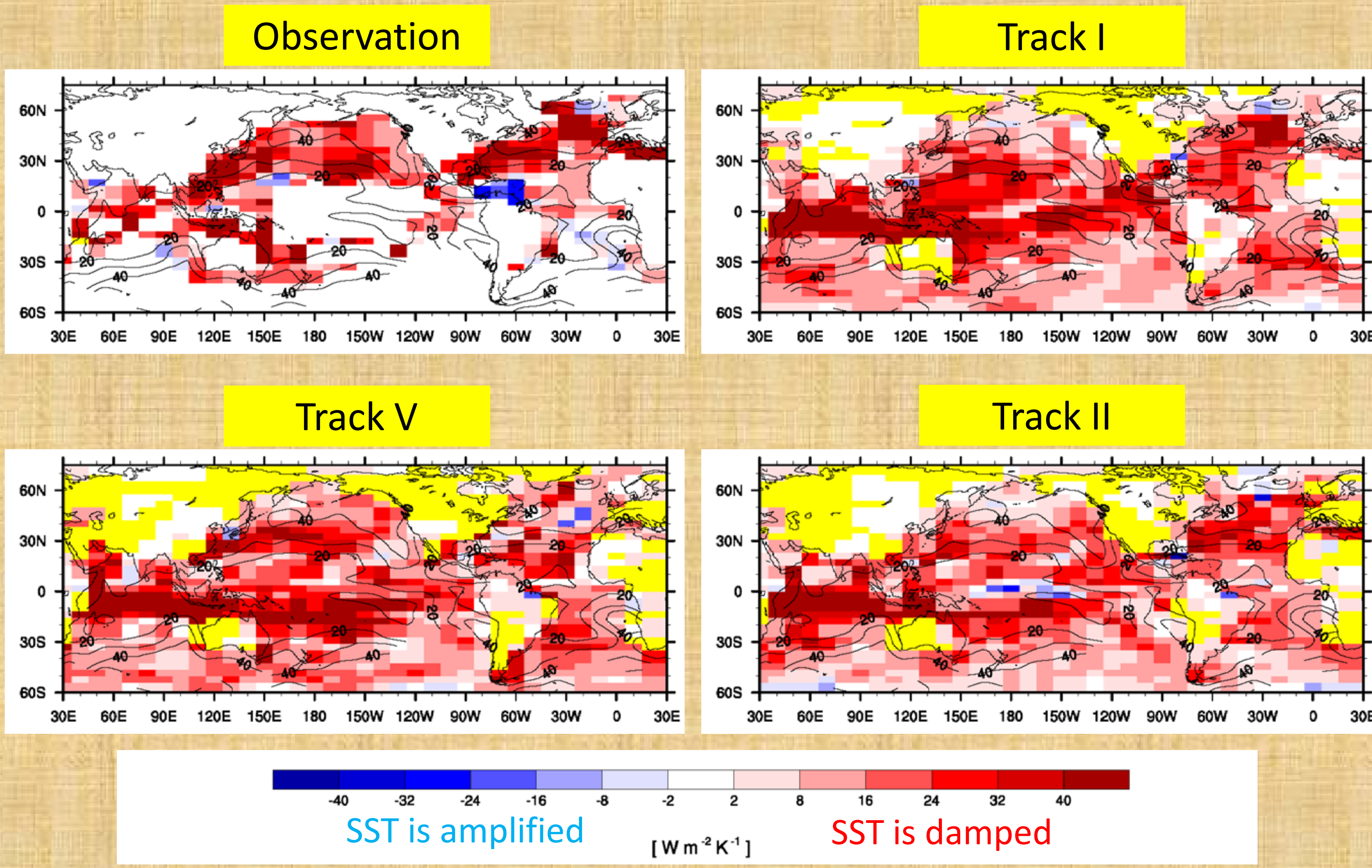
$\lambda_{LHF} + \lambda_{SHF} + \lambda_{SW} + \lambda_{LW}$, DJF



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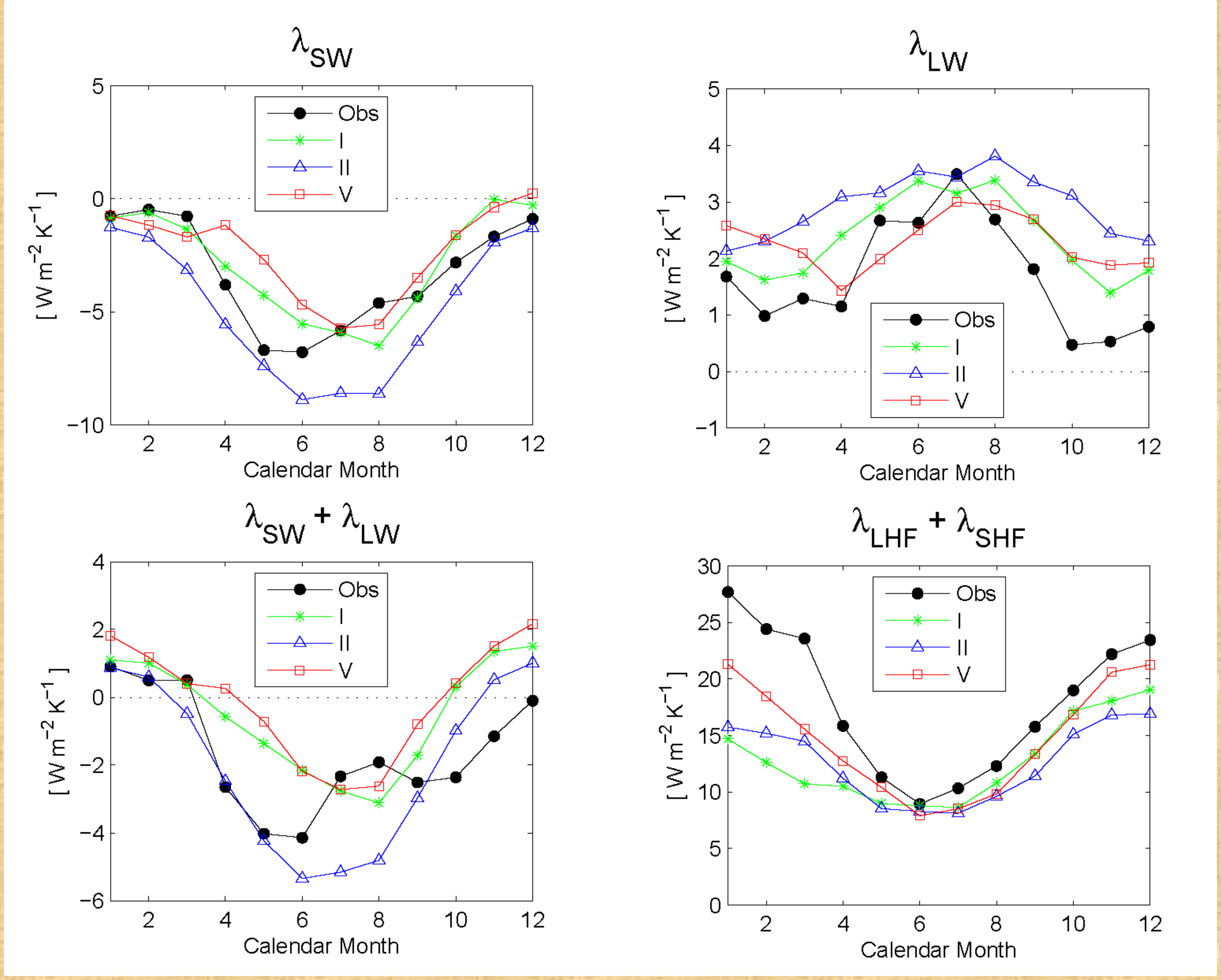
Feedback averaged over the North Pacific (25ºN-55ºN, 140ºE-120ºW)



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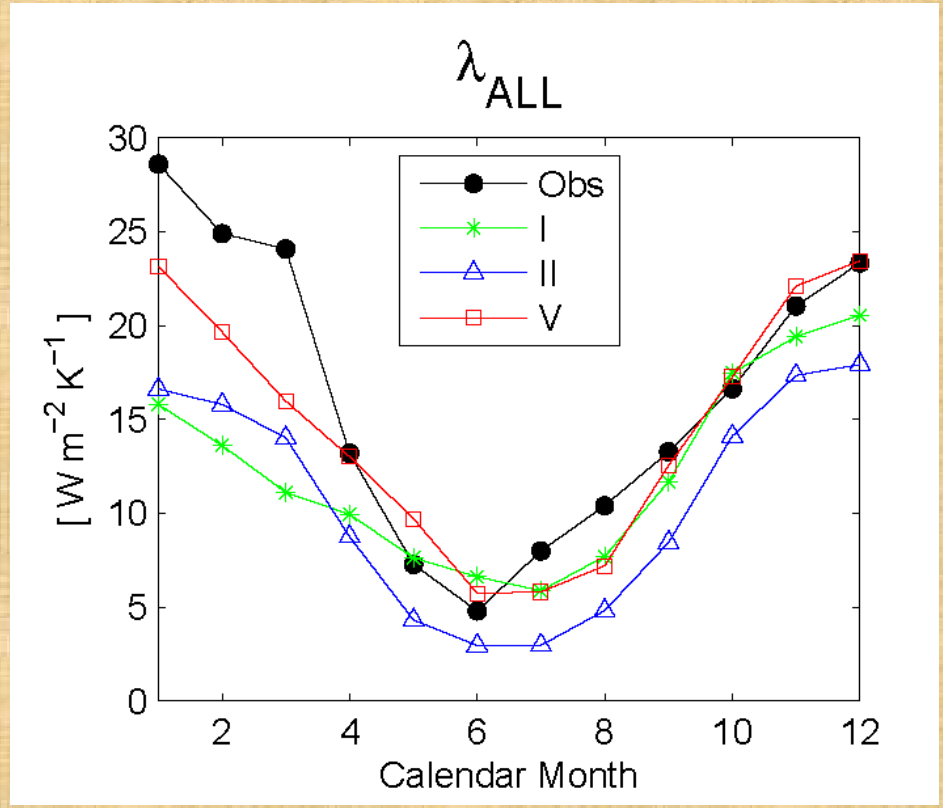


Annual-Mean Feedback

	OBS	I	II	V
LHF+SHF	19.4	12.1	12.5	14.5
SW+LW	-2.4	-0.8	-2.2	0.2
SW	-3.9	-3.4	-5.2	-2.1
LW	1.5	2.6	3.0	2.3
ALL	17.0	11.3	10.3	14.7

SUMMARY

- We have developed a set of moist turbulence, shallow convection, and revised macrophysics schemes and implemented them into CAM. They
  - simulate cloud-radiation-turbulence interactions
  - simulate shallow convective activity at the correct spot
  - impose consistency between cloud fraction and in-cloud LWC

- Overall patterns of surface heat flux feedback in Track I, II, and V are similar to each other and to observation. However, all of them failed to simulate the observed positive feedback over the western tropical Atlantic during DJF and over the Indian Ocean during summer.

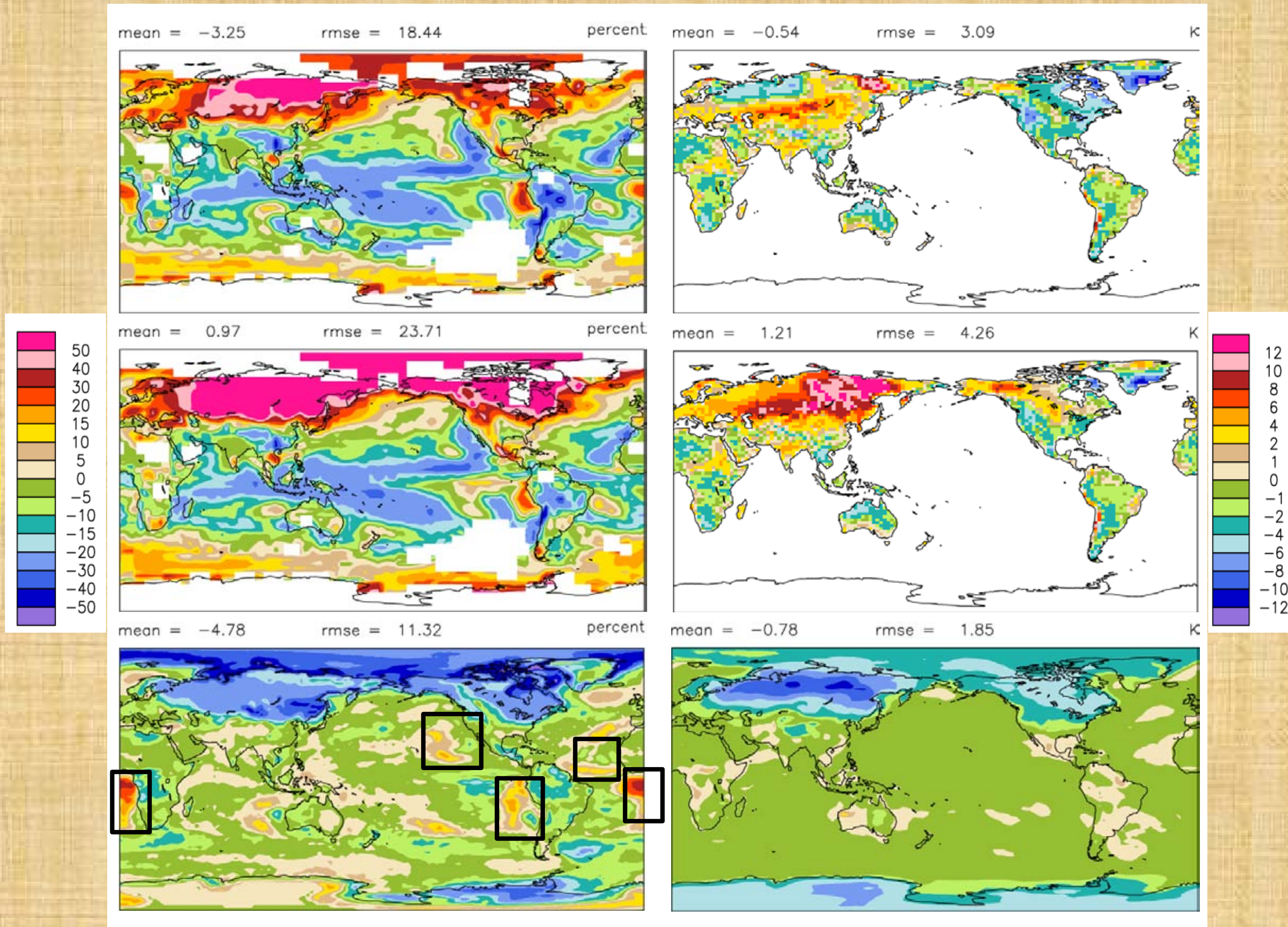
- Without the stability-based cloud fraction kludge, Track V well reproduced the observed SW feedback. Track V simulates the observed net heat flux feedback over the North Pacific better than Track I and II.

ΔLCA. DJF. | ΔT_{2m}. DJF.

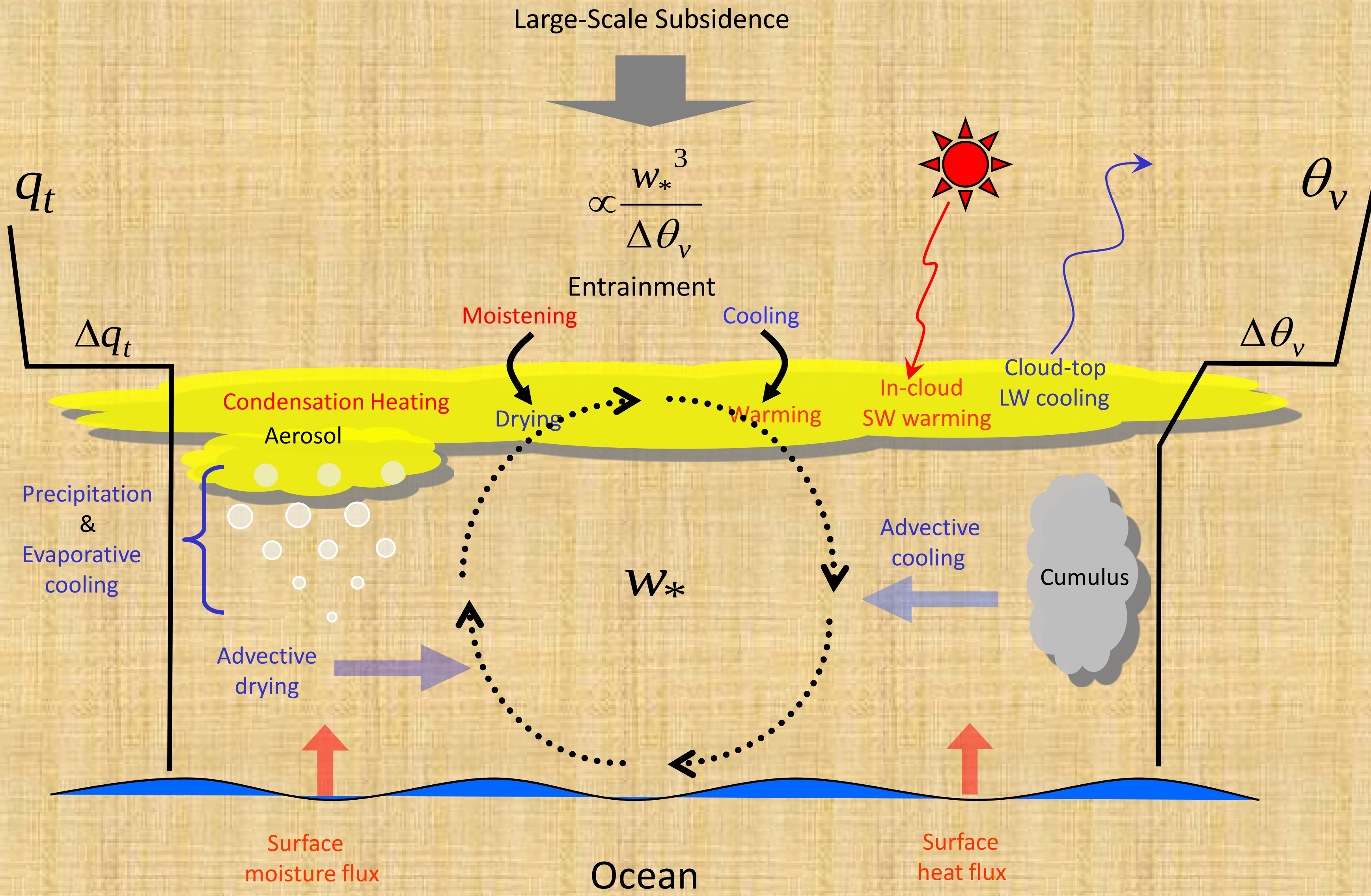
After Mod. CAM.-OBS.

Before Mod. CAM.-OBS.

After Mod- Before Mod

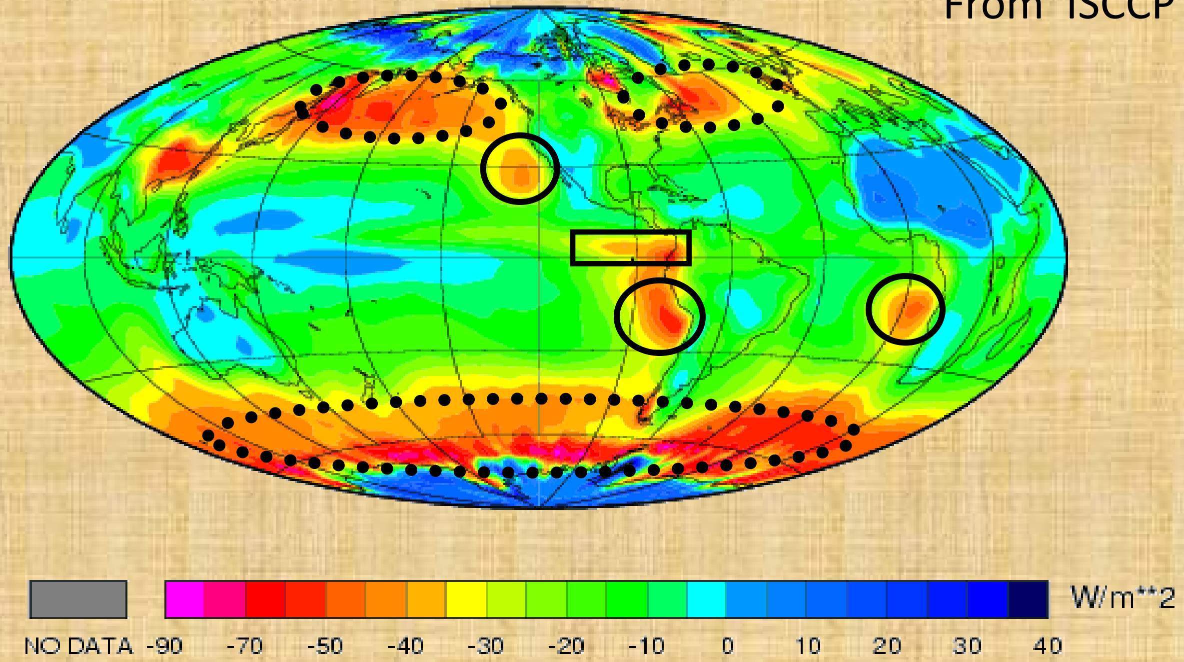


Interplay among various processes in stratocumulus

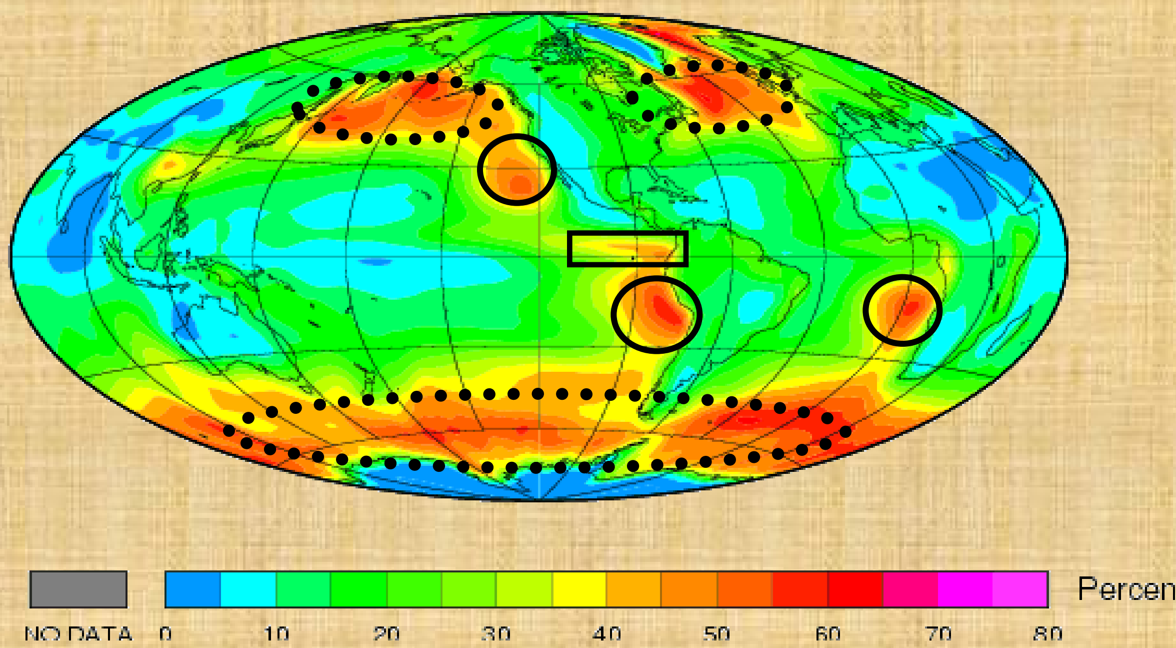


From ISCCP

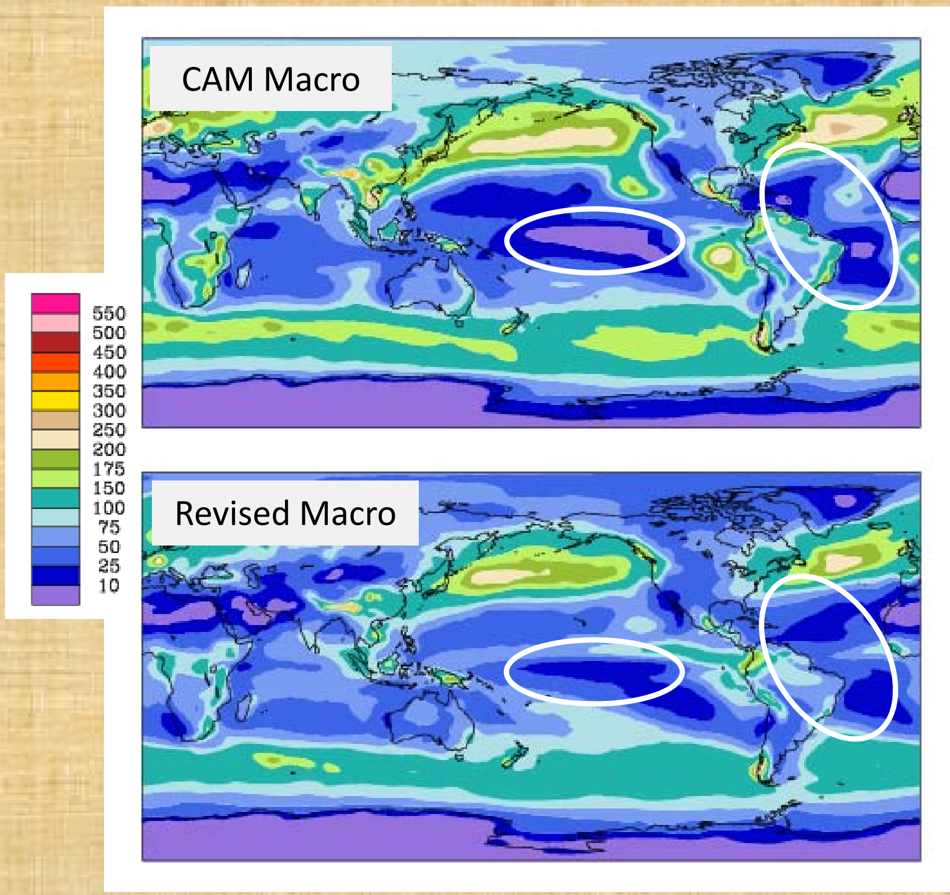
CRF at TOA

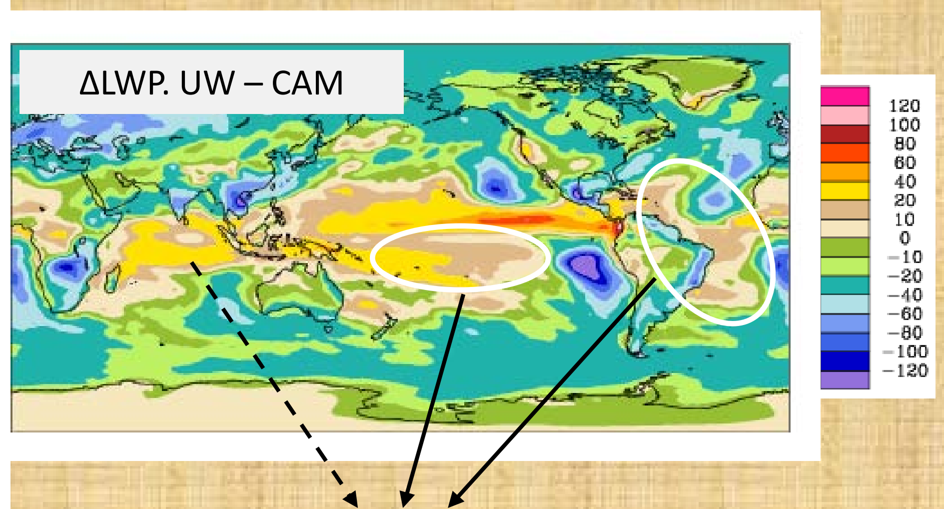


Low Cloud Amount



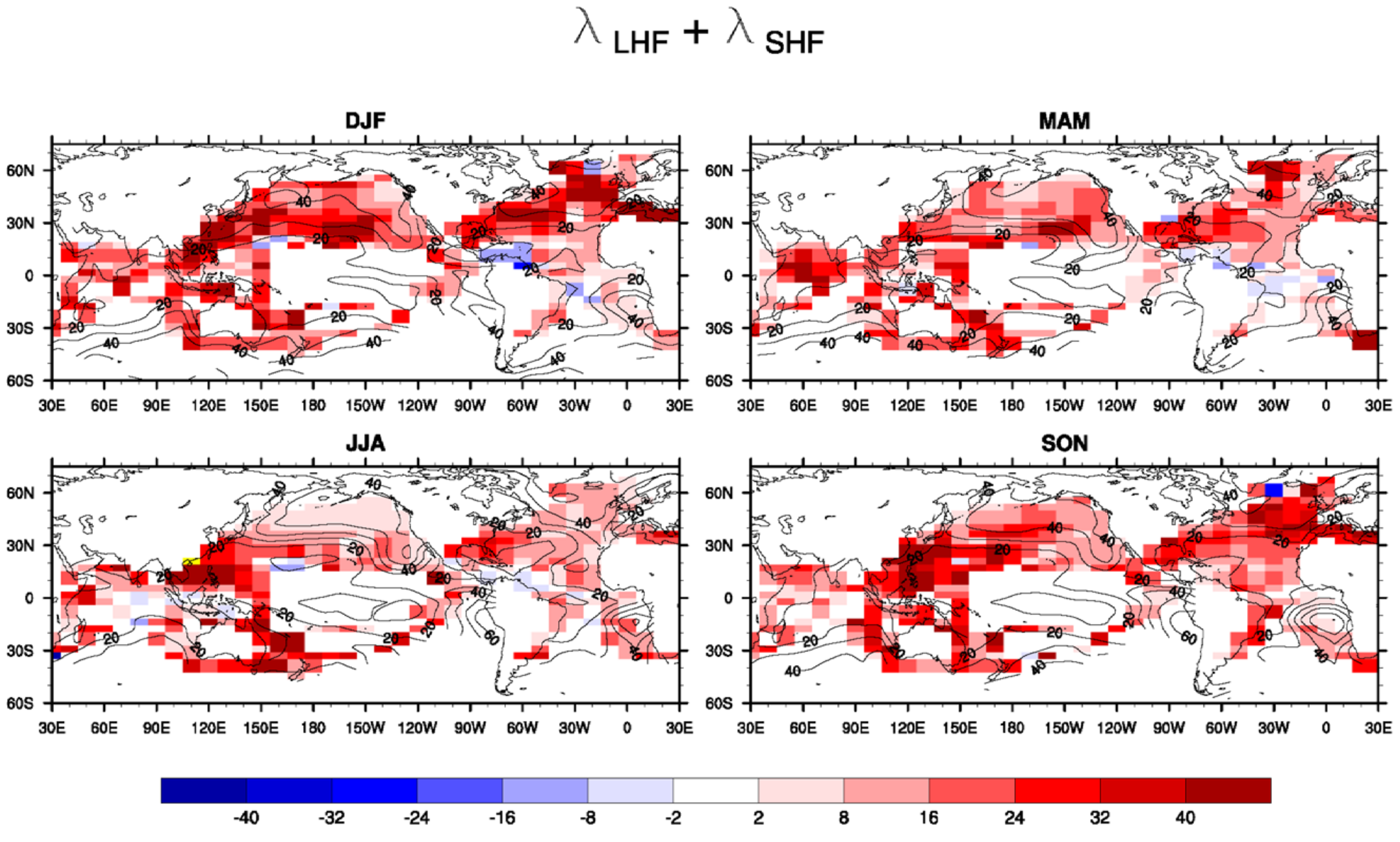
LWP. Annual Mean





Increase of LWP
in the trade cumulus & deep convective areas
due to explicit treatment of in-cumulus LWC

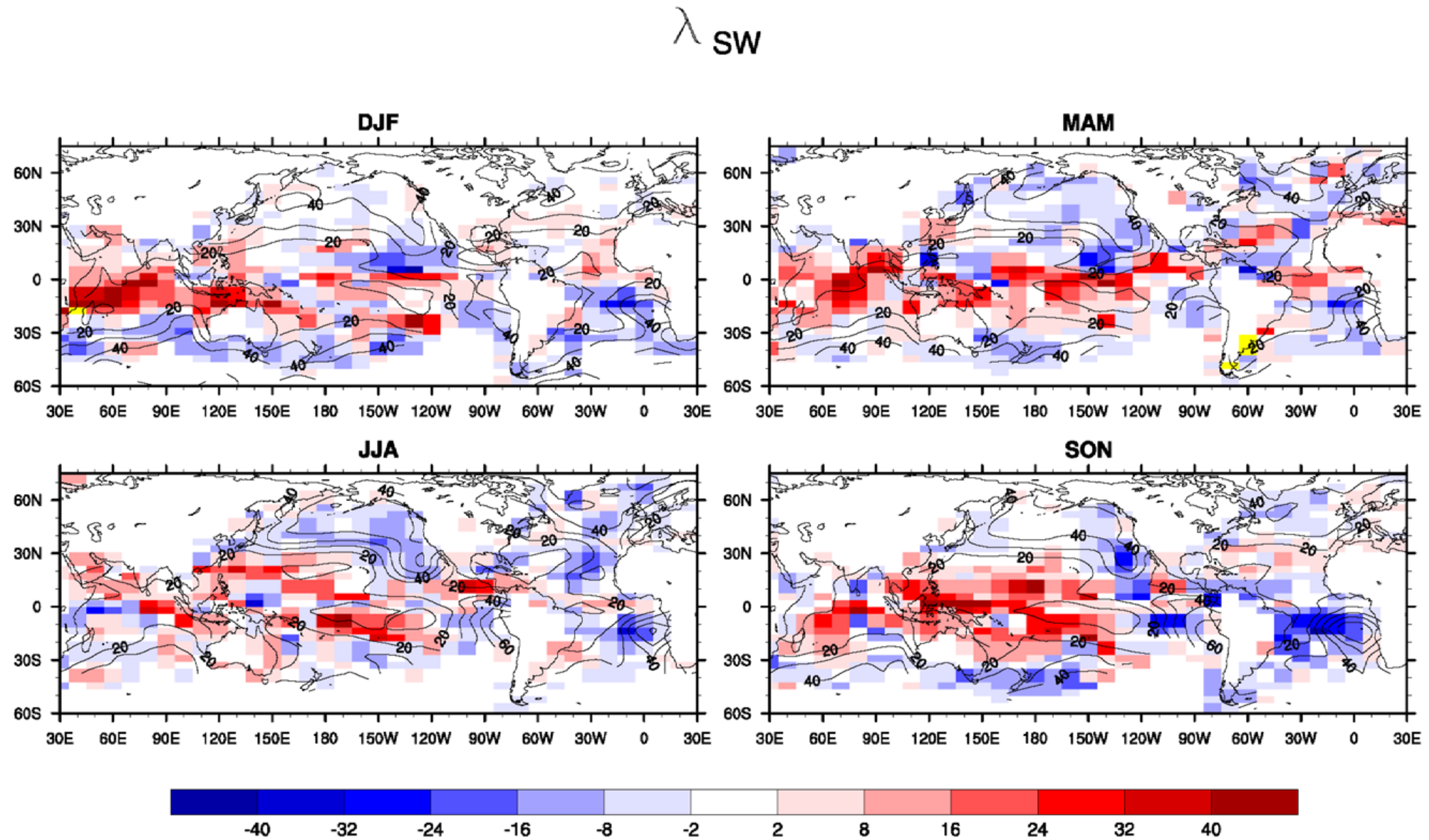
Observation



SST is amplified [W m^-2 K^-1] SST is damped

Solid line : Ship-observed Stratocumulus AMT

Observation



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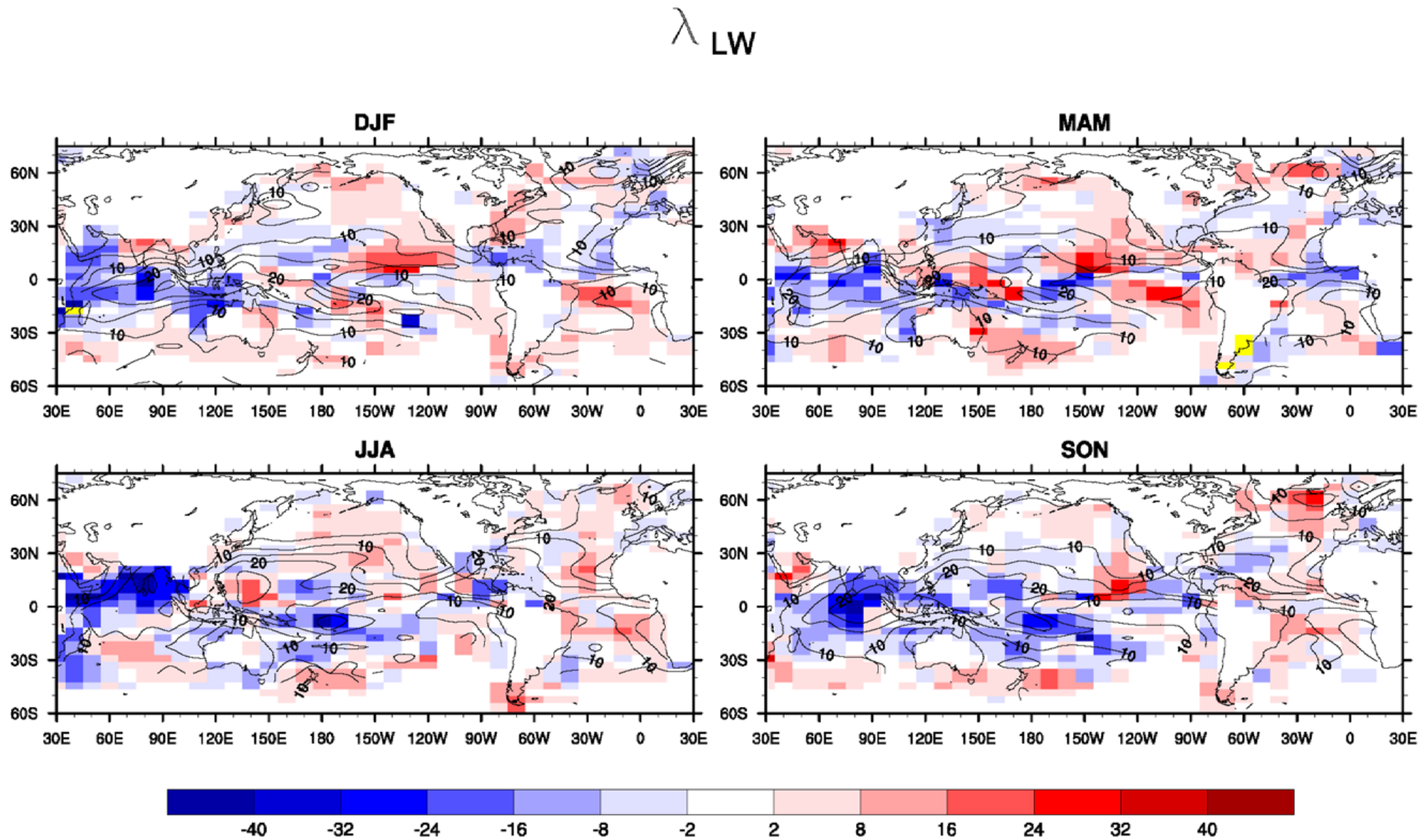

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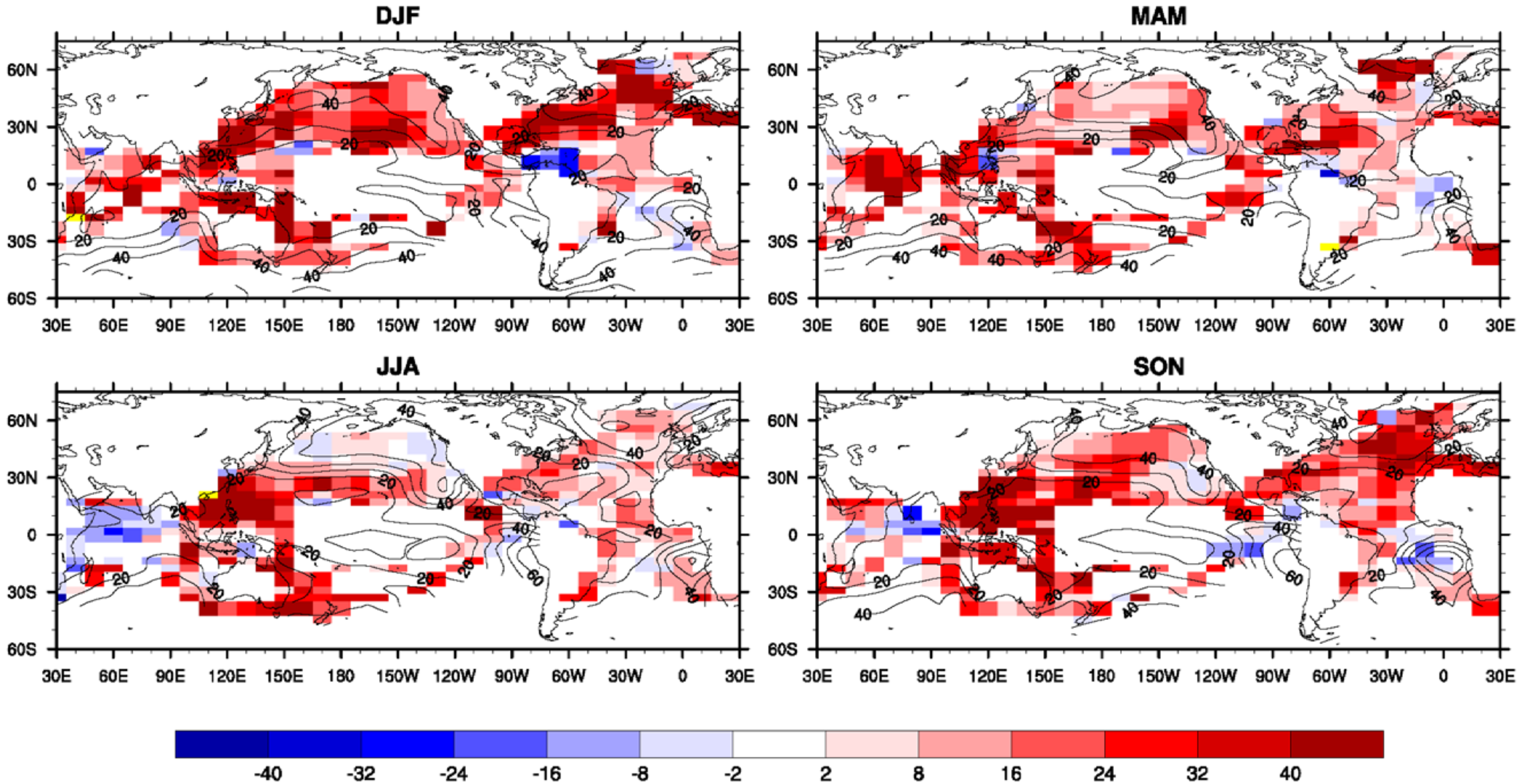
Observation

$$\lambda_{LHF} + \lambda_{SHF} + \lambda_{SW} + \lambda_{LW}$$



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