The Roles of Clouds in Climate Sensitivity

AMWG Meeting

Feb. 11. 2010

Sungsu Park and many other people

AMP. CGD. NCAR

Aerosol Indirect Effect

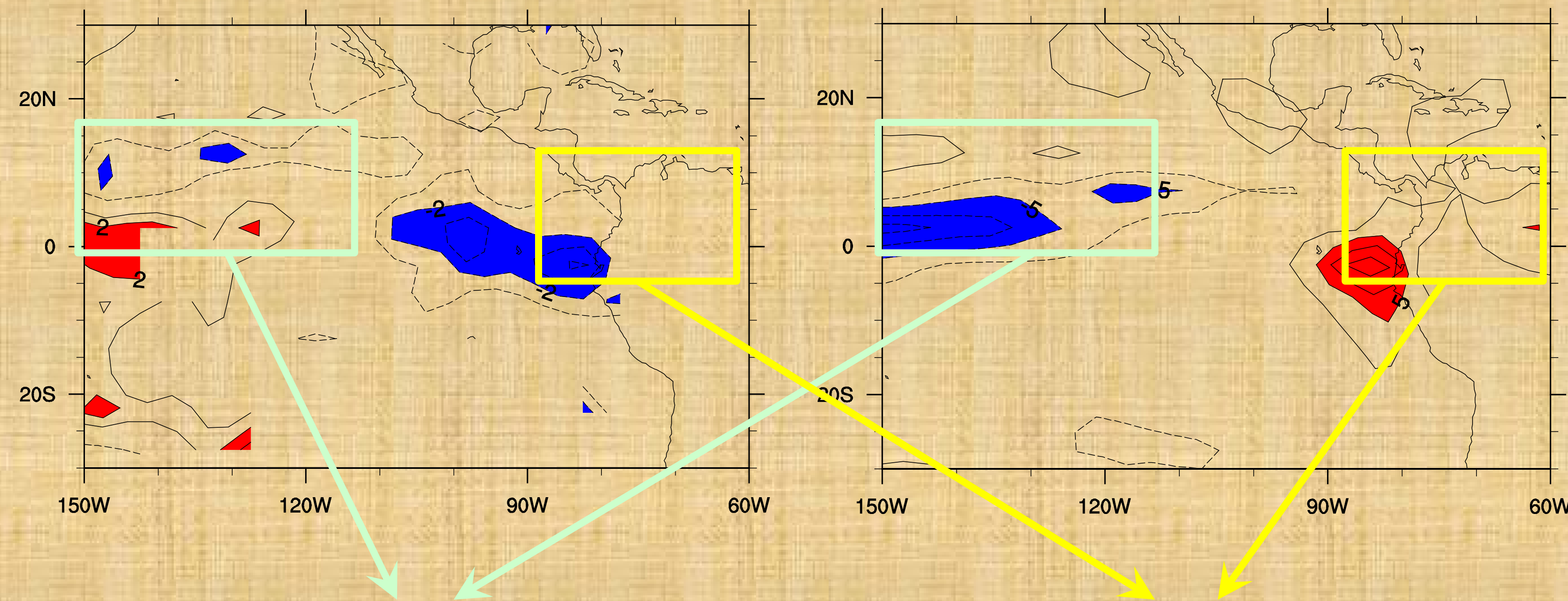
Ship Track

[MODIS Satellite Visible Image. May. 11th. 2005]

ENSO regression anomalies during Jul-Aug-Sep

Total Cloud Fraction
(1956-1995)

Net Downward Radiation at Surface
(1984-2000)



Deep Convective Cloud (Cirrus)
: Negative Feedback to SST

Marine Stratiform Cloud (MSC)
: Positive Feedback to SST

The Roles of Clouds in Climate Sensitivity

MSC SST

SST

Cirrus SST

CO_2 SST H_2O

MSC SST

Stabilities

Cirrus SST

$$S_{LTS} \equiv \theta_v(700) - \theta_v(1000)$$

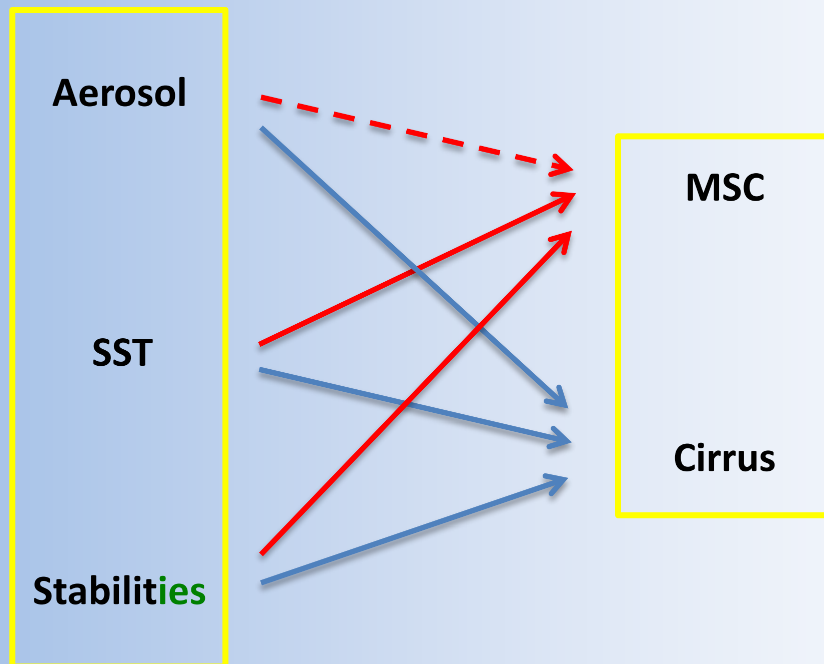
$$S_{MTS} \equiv \theta_v(500) - \theta_v(1000)$$

$$S_{SFC} \equiv T_{s,air} - SST$$

SST

Aerosol MSC SST

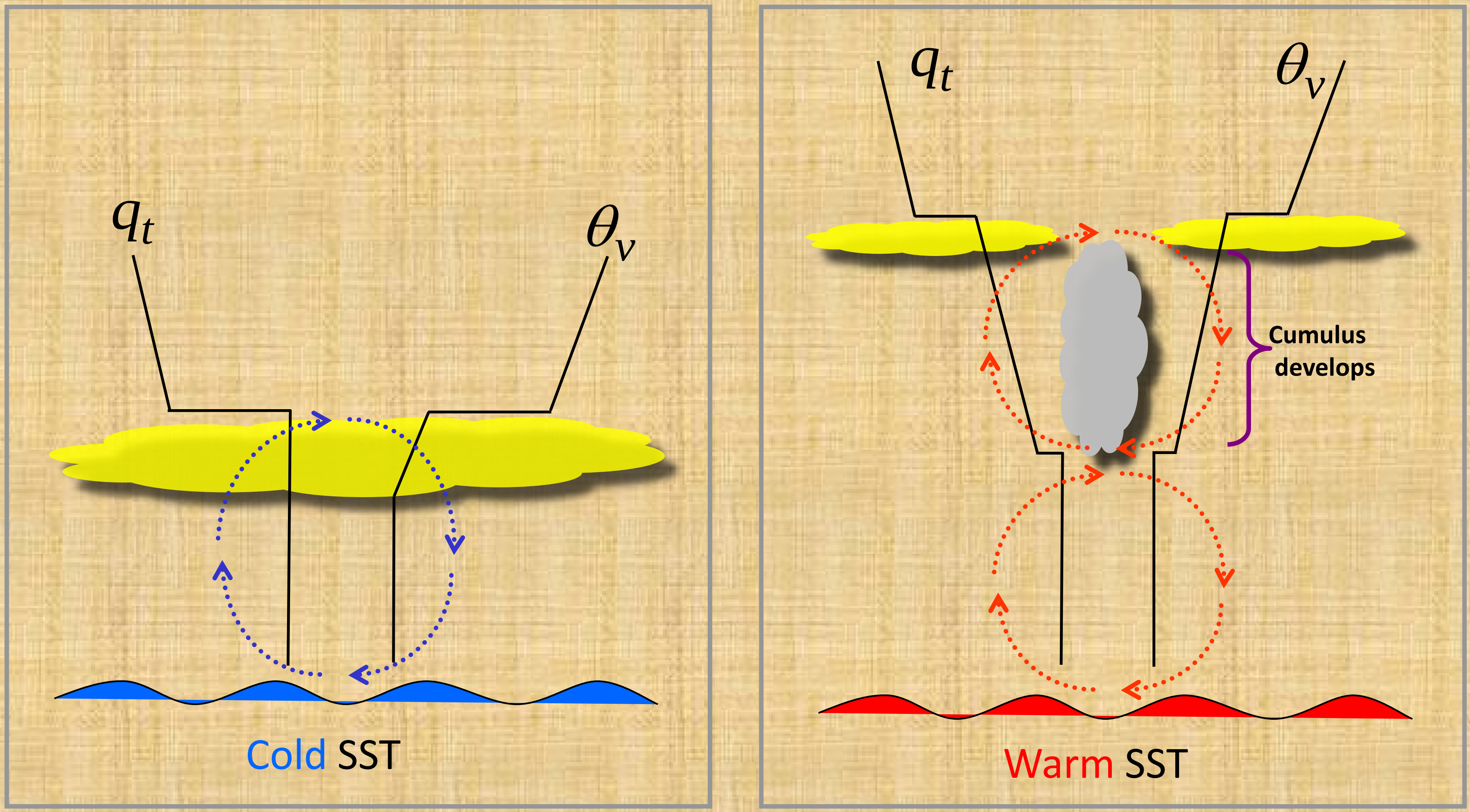
Cirrus SST



Q1. How does the cloud system respond to these 3 forcings *in nature* ?

Q2. Does the CAM reproduce the observed cloud sensitivities ?

Deepening-Decoupling-Dissipation of Stratocumulus



Simulation Results:
Observation vs CAM4 vs CAM5

Observation : 42-yrs (1956-1997) EECRA ship-observations, NCEP/NCAR Reanalysis
17-yrs (1984-200) ISCCP satellite-derived radiation at surface

CAM4 : 92-yrs coupled simulation using pre-industrial GHG and aerosols

CAM5 : 69-yrs coupled simulation using pre-industrial GHG and aerosols

Lower Tropospheric Stability → MSC

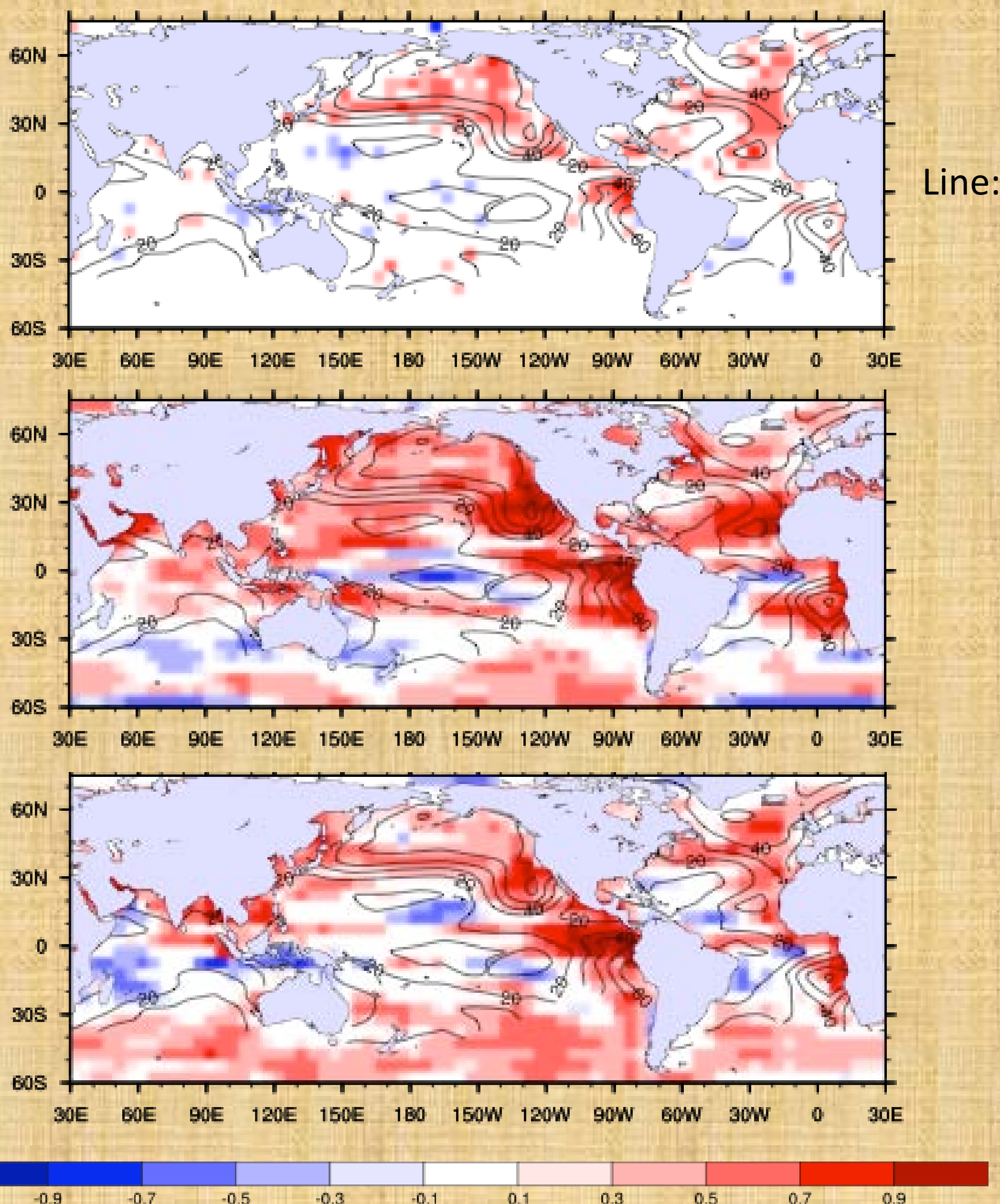
Interannual Correlation between $S \equiv \theta_v(700) - \theta_v(1000)$ and Low Cloud Amount. JJA.

Observation

CAM4

CAM5

Line: Ship-observed LCA



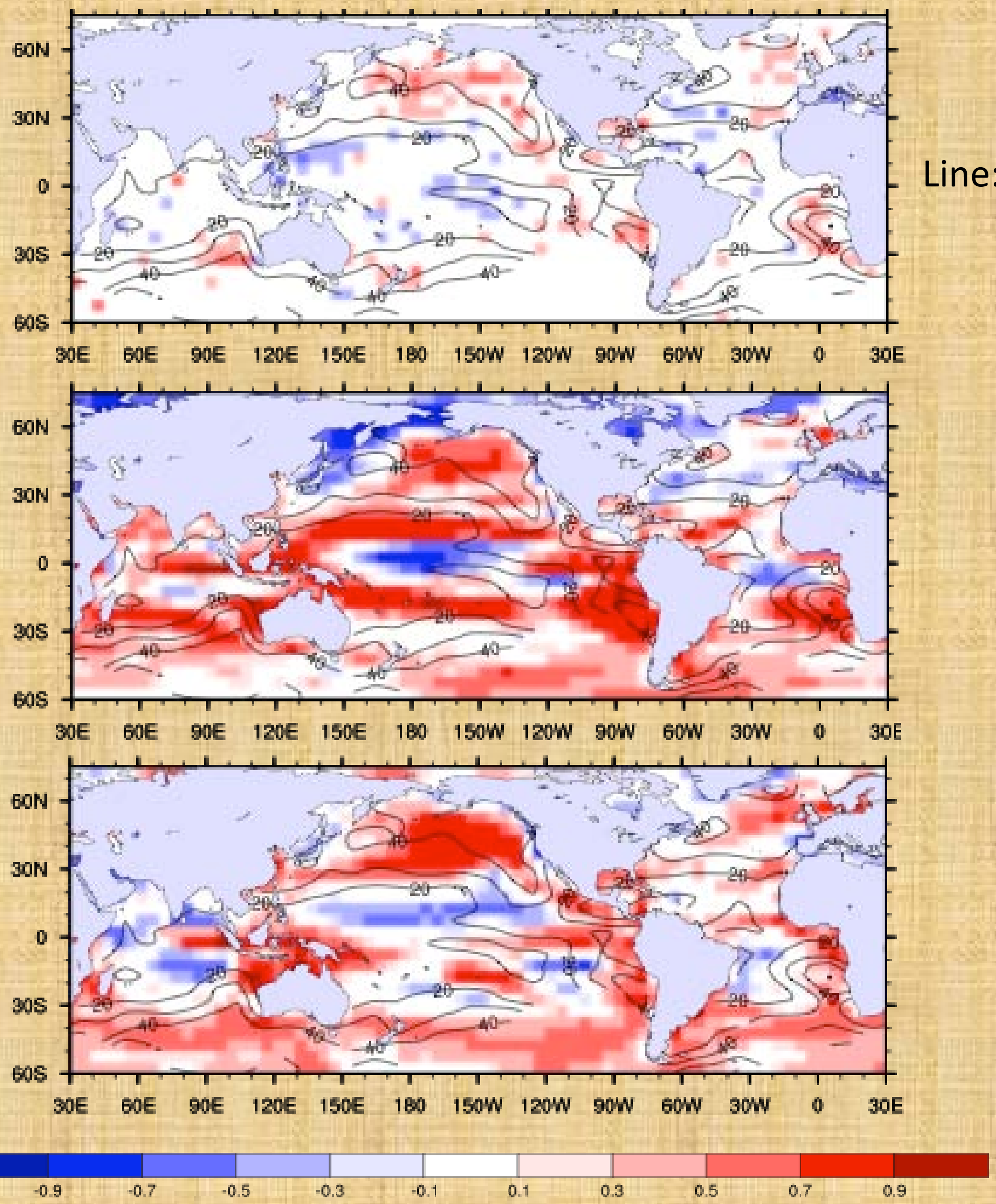
Interannual Correlation between $S \equiv \theta_v(700) - \theta_v(1000)$ and Low Cloud Amount. DJF.

Observation

CAM4

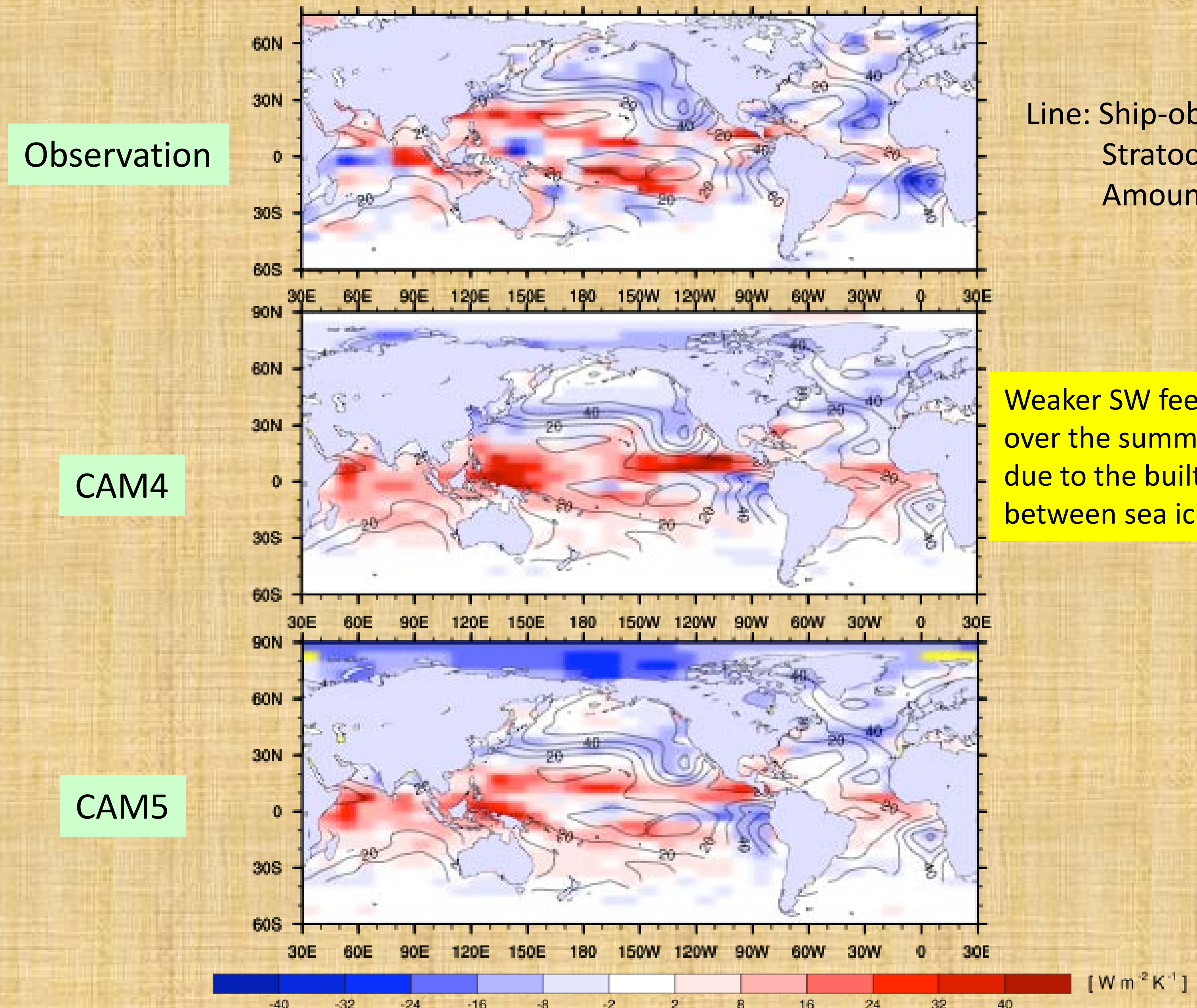
CAM5

Line: Ship-observed LCA



SST → MSC

SW Surface Heat Flux Feedback $\lambda_{SW} \equiv -\partial Q_{SW}^{\downarrow} / \partial SST$. JJA.



Line: Ship-observed Stratocumulus Amount

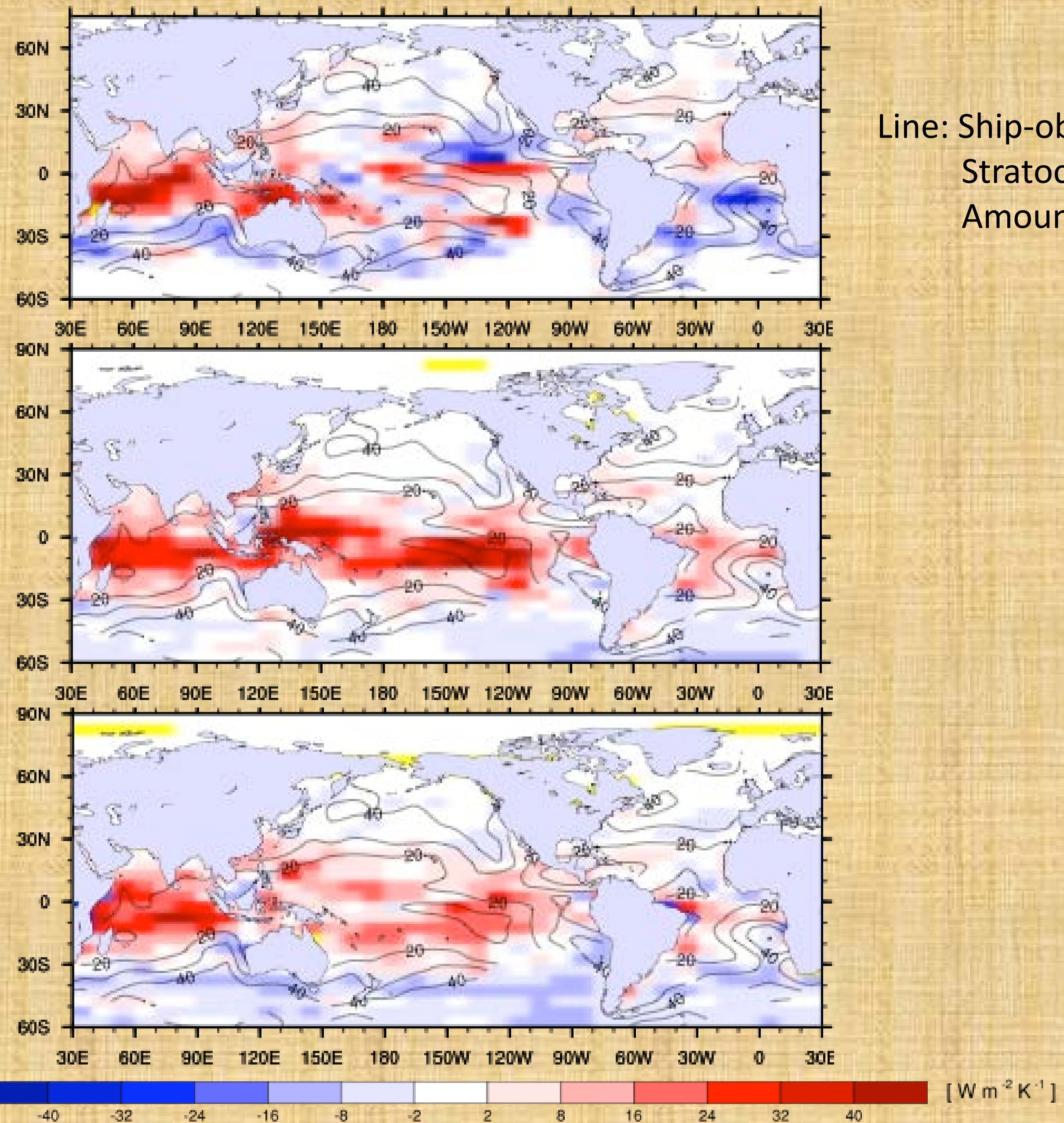
Weaker SW feedback in CAM4 over the summer Arctic is likely due to the built-in negative feedback between sea ice and stratus fraction.

SW Surface Heat Flux Feedback $\lambda_{SW} \equiv -\partial Q_{SW}^{\downarrow} / \partial SST$. DJF.

Observation

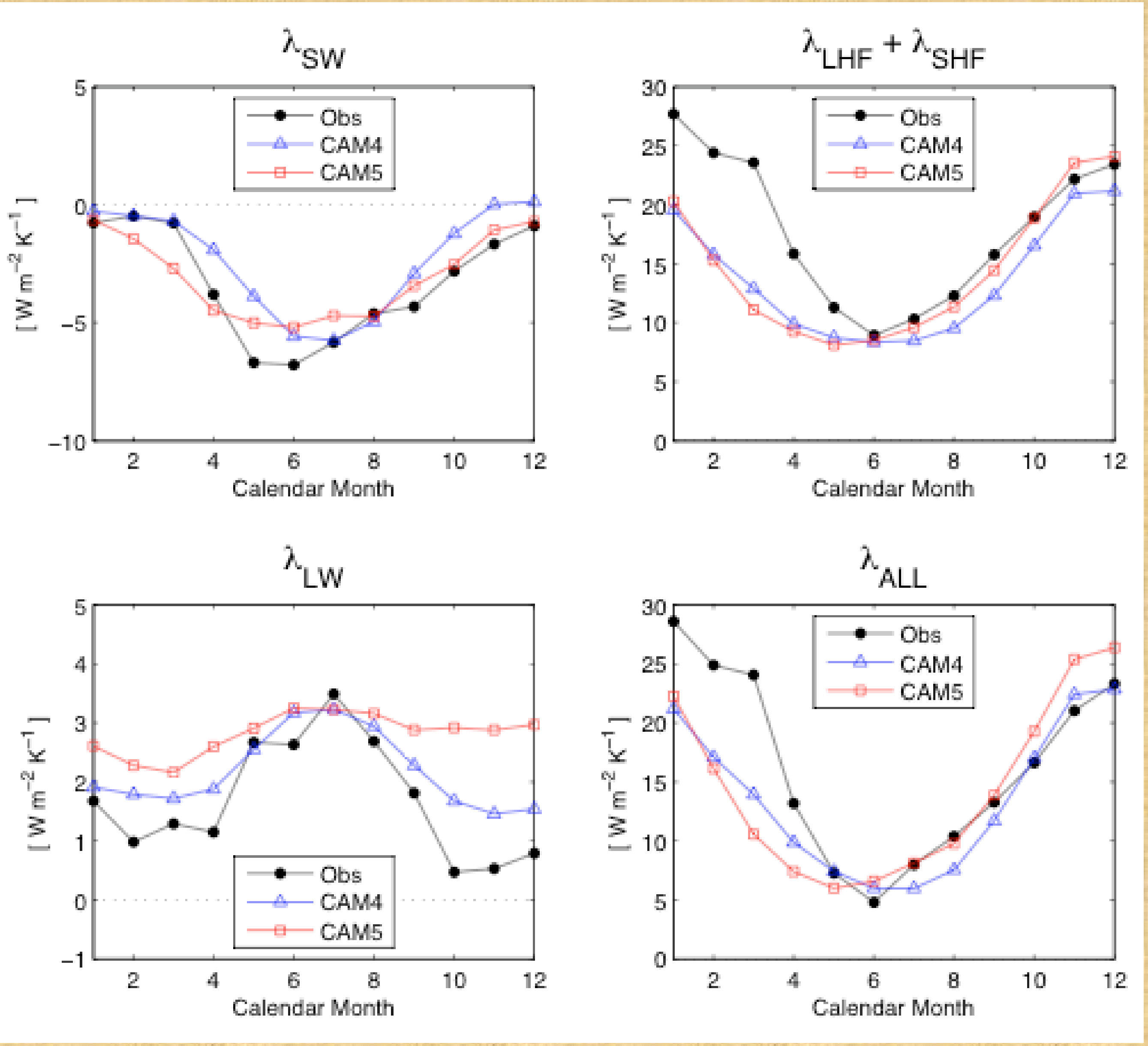
CAM4

CAM5



Line: Ship-observed Stratocumulus Amount

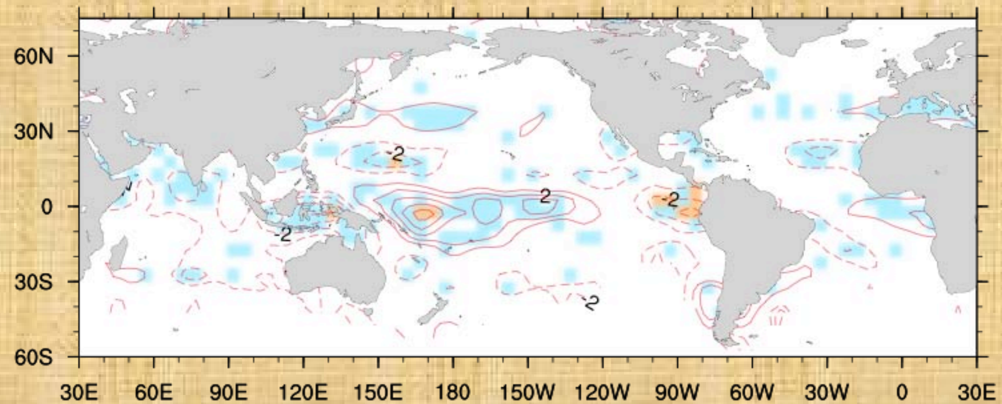
Surface Heat Flux Feedback over the North Pacific Ocean



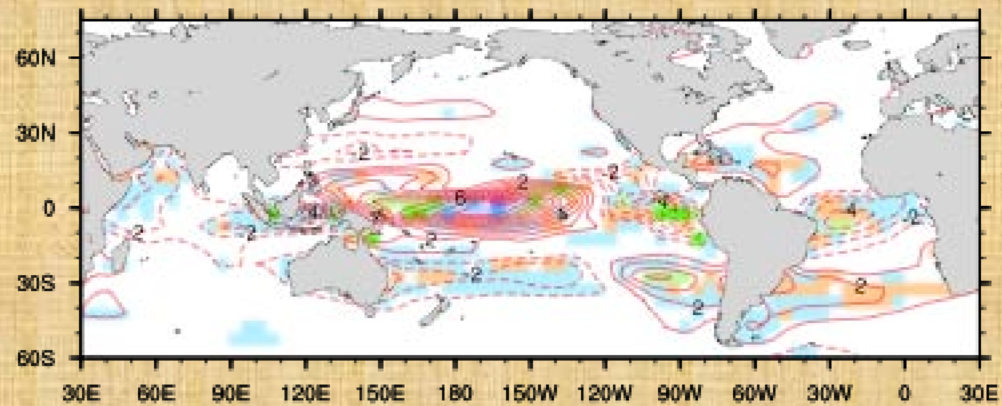
ENSO → TCA

ENSO Regression Anomalies of Total Cloud Amount [%]. JAS.

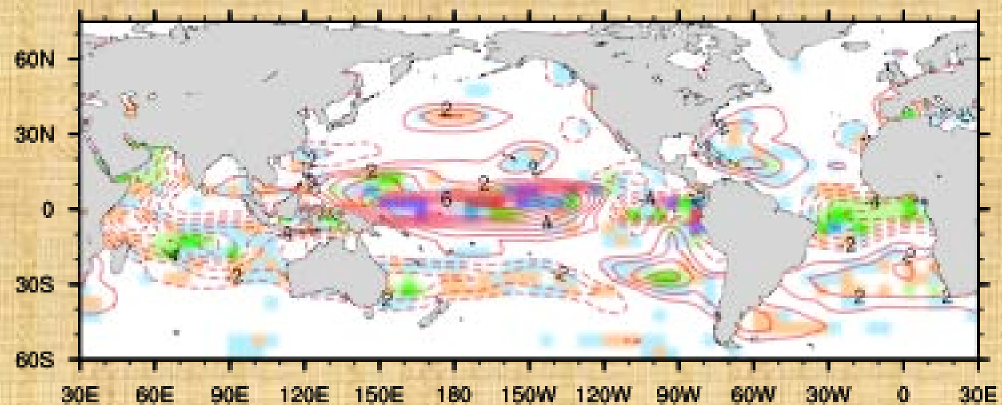
Observation



CAM4

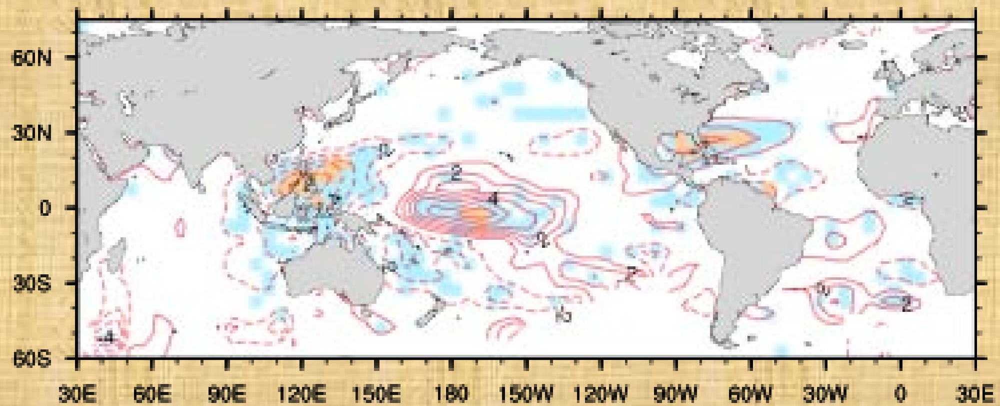


CAM5

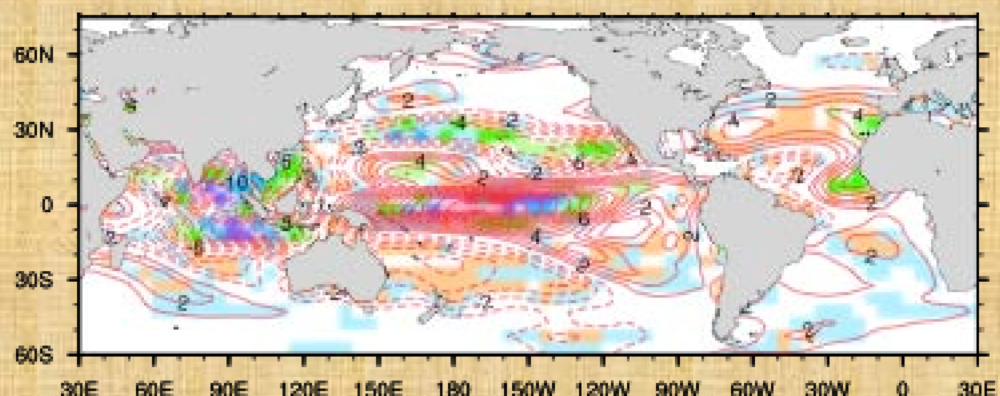


ENSO Regression Anomalies of Total Cloud Amount [%]. DJF.

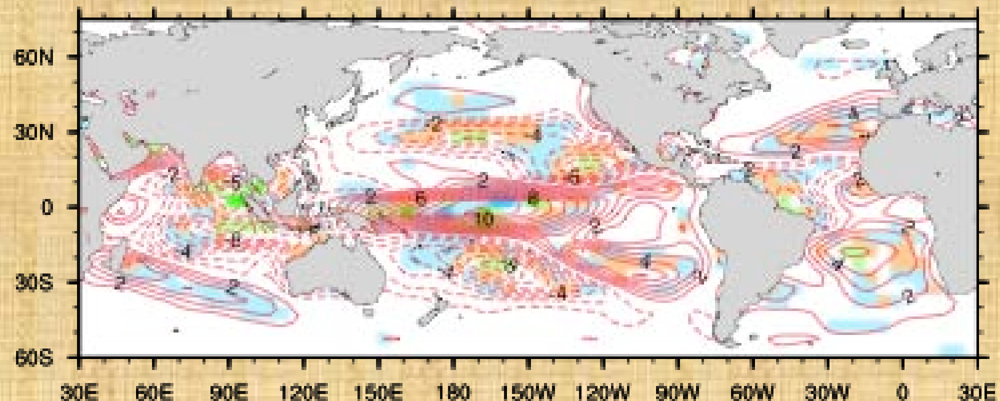
Observation



CAM4



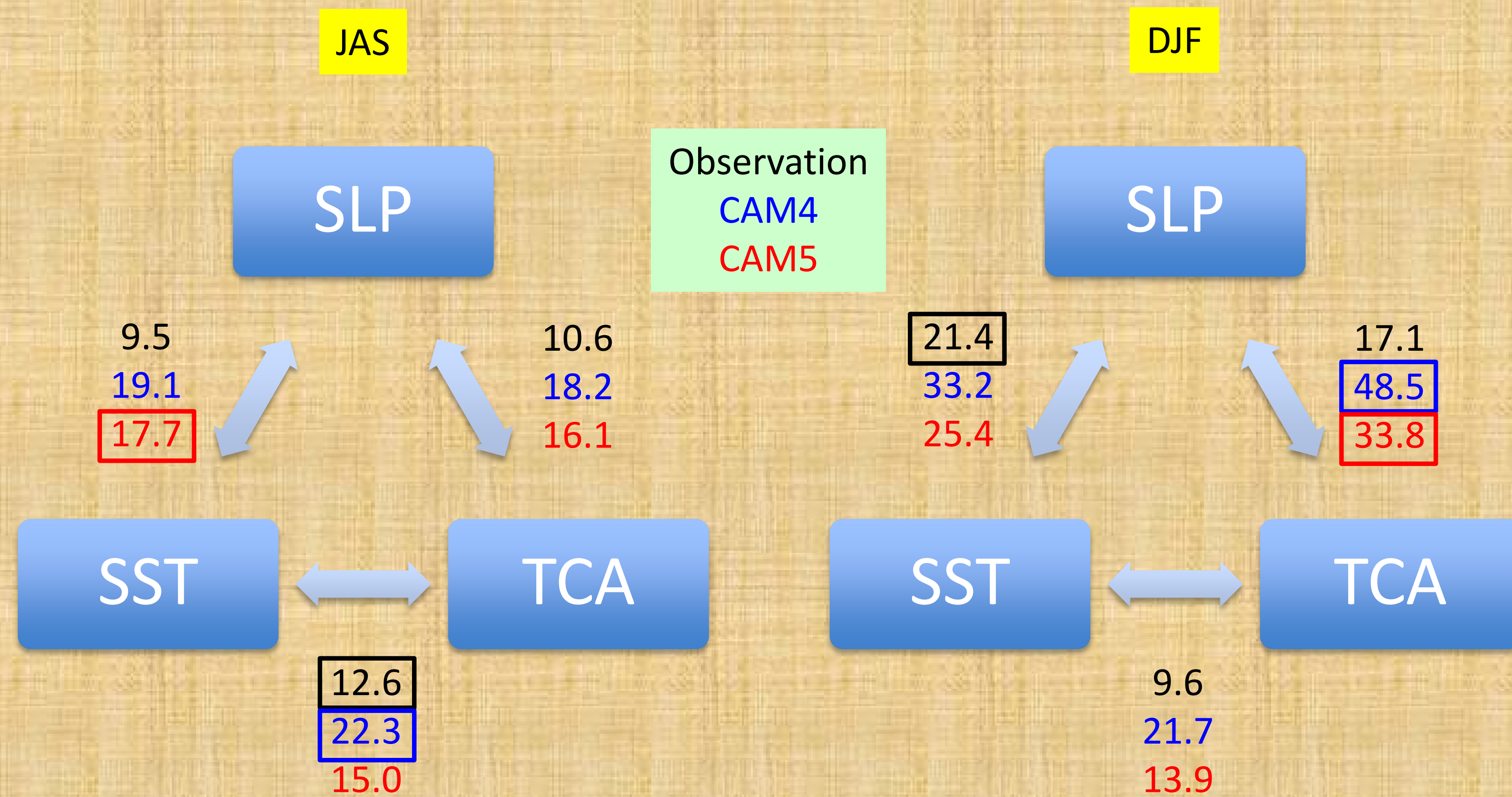
CAM5



SUMMARY

- The response of MSC to SST and stability is similar to the observations both in CAM4 and CAM5.
- However, CAM5 shows more stronger positive feedback over the Arctic and southern hemisphere oceans during boreal summer than CAM4.
- The ENSO teleconnection of TCA in CAM5 is not better than CAM4 especially in DJF.
- This analysis indicates that the success of CAM5’s simulation of 20th century climate change is likely to be determined by its ability to simulate the observed AIE associated with MSC and Cirrus.

Normalized Covariance of the 1st Coupled Mode from the SVD Analysis over the North Pacific



Remaining Issues and Future Plans :
Moist Turbulence Scheme

- Diffuse moist conservative scalars instead of non-conservative scalars. From this, extract the tendency of condensate mass. Couple of different ways are possible in this extraction procedure. Similar procedures should be used for convection scheme.

- Consistent treatment of vertical diffusion of condensate mass and number concentration. We should use the predicted effective droplet radius of cloud water and ice. Similar approach may need to be used for aerosol mass and number concentration.

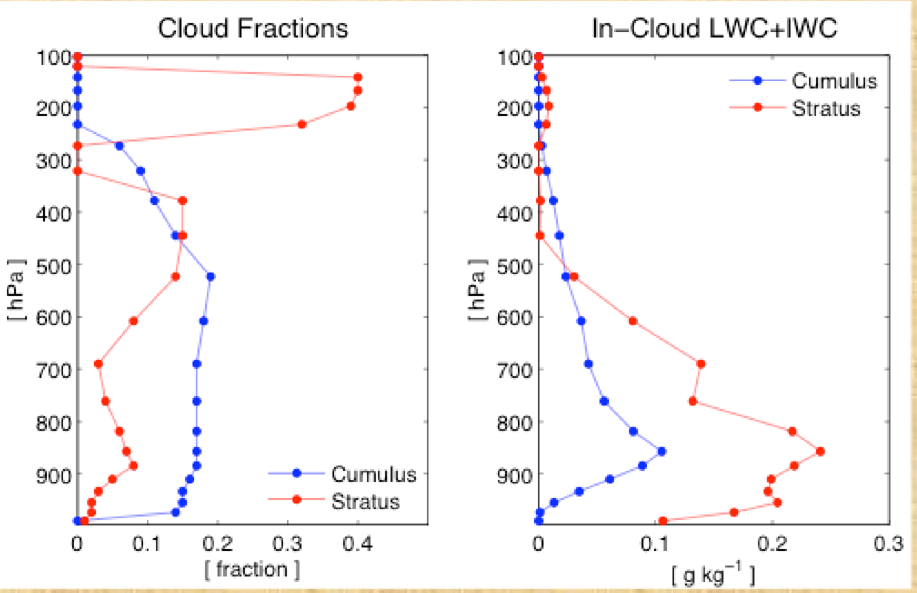
- Reduce the sensitivity to the vertical resolution (e.g., the thickness of the radiative buoyancy production layer, merging criteria).

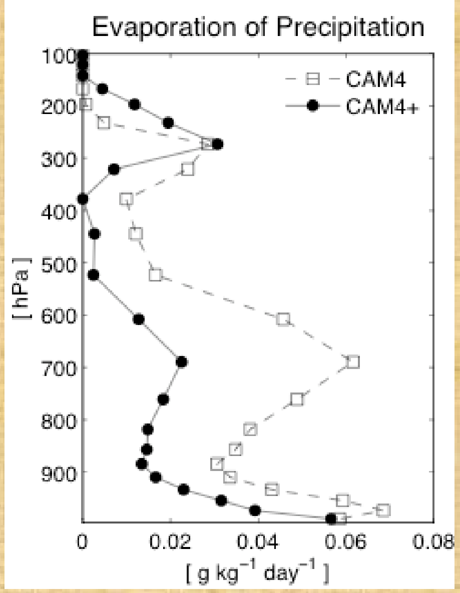
Remaining Issues and Future Plans : Convection Scheme

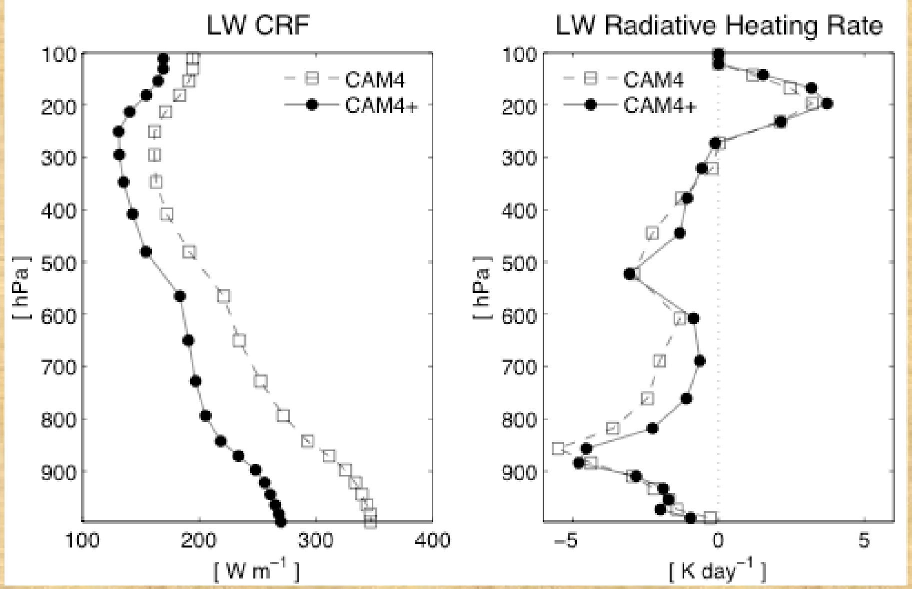
- When cumulus condensate is detrained into the environment, detrainment of number concentration should be correctly taken. Convective tendency of cloud droplet number should not be treated as conservative scalars.

- Consistent treatment of vertical diffusion of condensate mass and number concentration. We should use the predicted effective droplet radius of cloud water and ice. Similar approach may need to be used for aerosol mass and number concentration.

- Reduce the sensitivity to the vertical resolution (e.g., the thickness of the radiative buoyancy production layer, merging criteria).


Cloud Fractions
Cumulus
Stratus
[hPa]
[fraction]
In−Cloud LWC+IWC
Cumulus
Stratus
[hPa]
[g kg^{-1}]

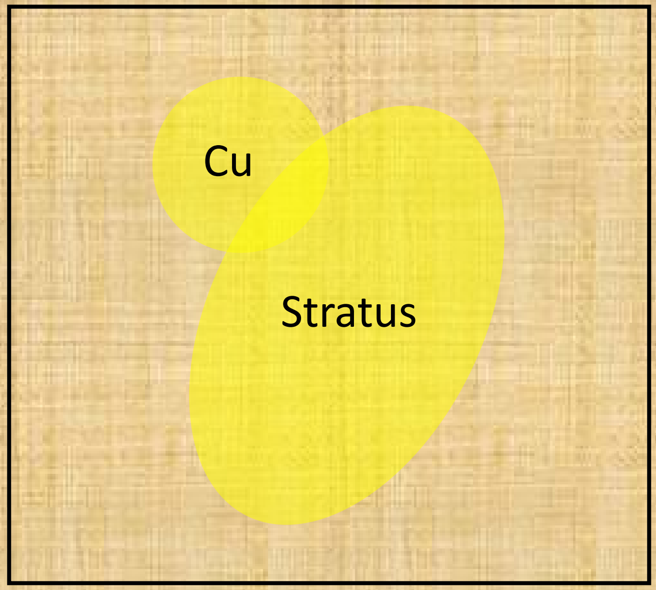

Evaporation of Precipitation
CAM4
CAM4+
[hPa]
[g kg^{-1} day^{-1}]


LW CRF
CAM4
CAM4+
[hPa]
[W m^{-1}]
LW Radiative Heating Rate
CAM4
CAM4+
[hPa]
[K day^{-1}]

Macrophysics Scheme in CAM4

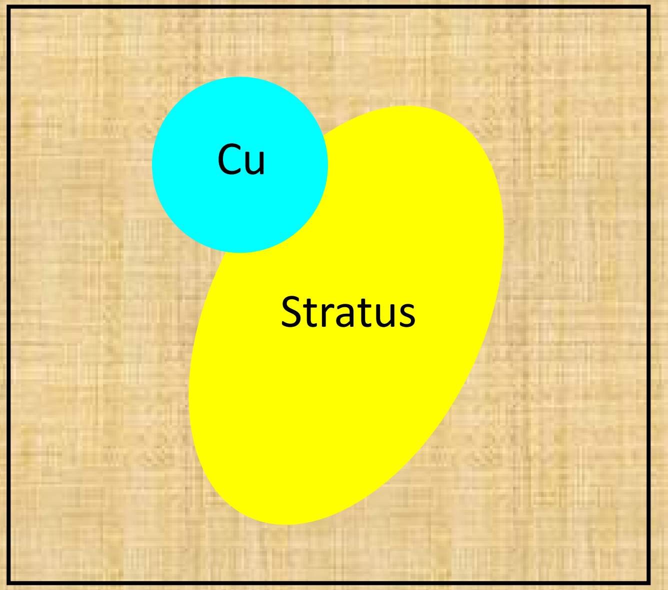
- Uses a single equilibrium cloud fraction at each time step.
- Condensation formulation based on conservative scalars
- Remove 'empty' ($a>0$, $q_{l,cloud}=0$) and 'dense'($a=0$, $q_{l,cloud}>0$) stratus
- Explicit treatment of in-cumulus LWC

CAM3 Macrophysics



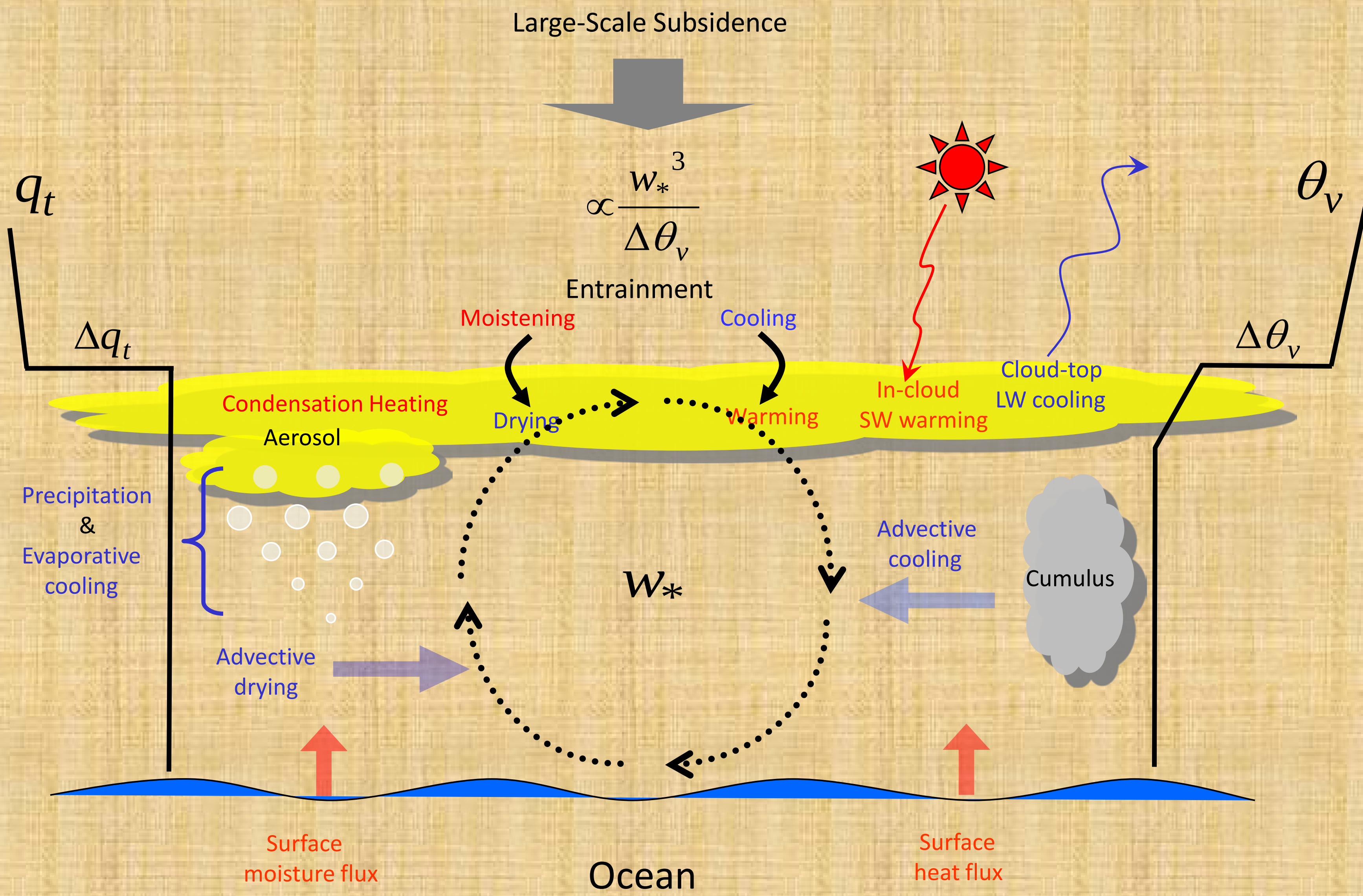
- Overlap
- In-cumulus LWC = In-stratus LWC

Revised Macrophysics



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

Interplay among Various Processes in Stratocumulus



3 Cloud Types in CAM3.5

- Cumulus

$$a_c = f(M) \quad , \quad M: \text{Convective Updraft Mass Flux}$$

- RH (Relative Humidity) Stratus

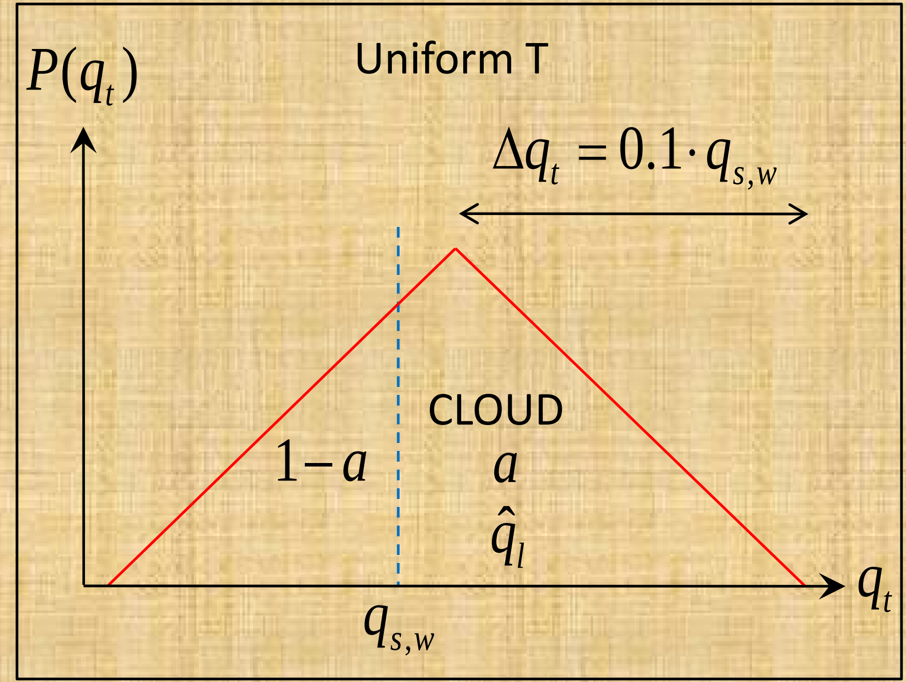
$$a_{s,RH} = f(\overline{RH}) \quad , \quad \overline{RH}: \text{Grid-Mean Relative Humidity}$$

- KH (Klein-Hartmann) Stratus

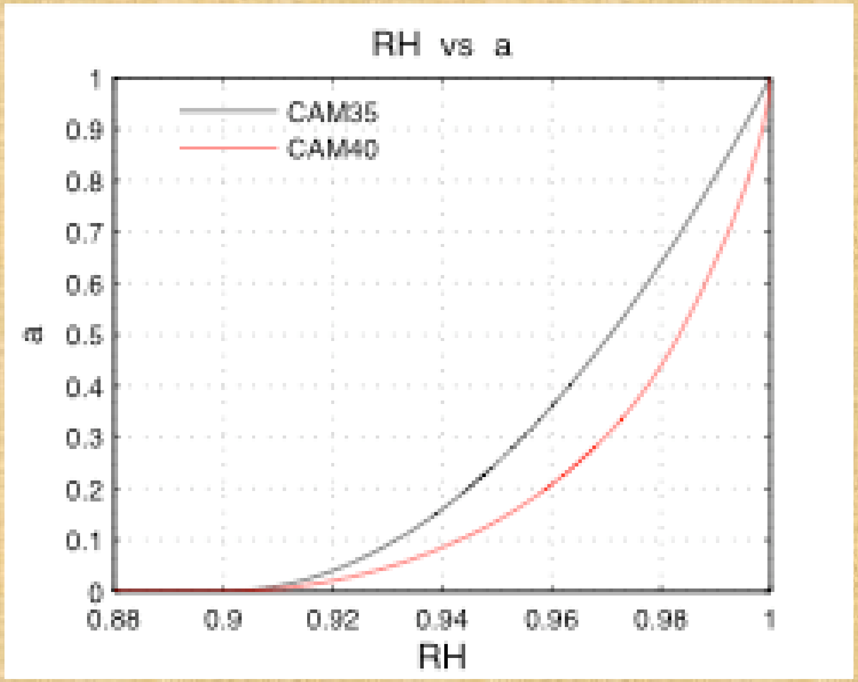
$$a_{s,KH} = f(S) \quad , \quad S \equiv \theta_v(700) - \theta_v(1000)$$

Computation of Liquid Stratus Fraction

PDF of q_t for liquid cloud only



Stratus Fraction as a function of RH



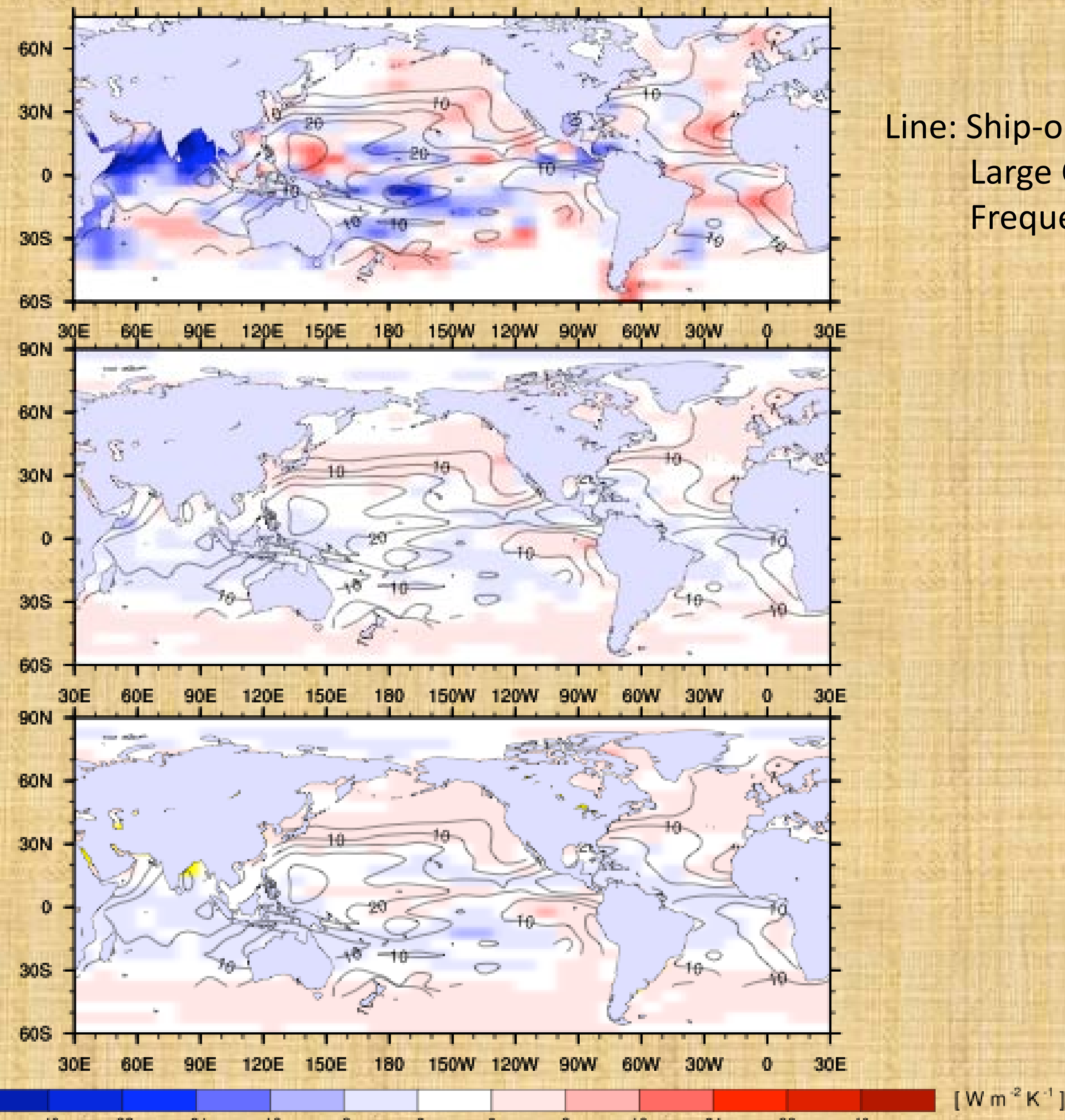
LW Surface Heat Flux Feedback $\lambda_{LW} \equiv -\partial Q_{LW}^{\downarrow} / \partial SST$. JJA.

Line: Ship-observed Large Cumulus Frequency

Observation

CAM35

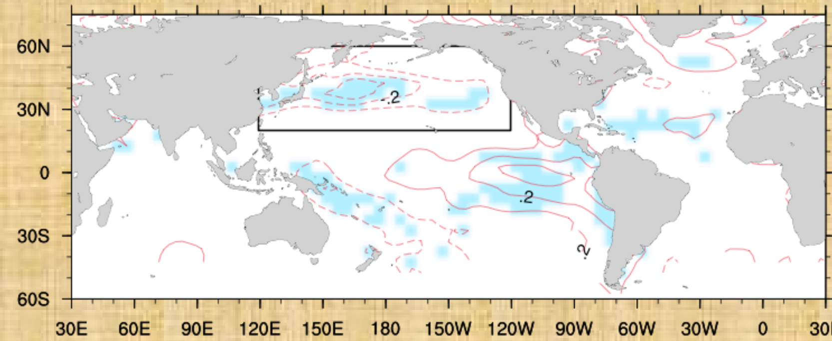
CAM4



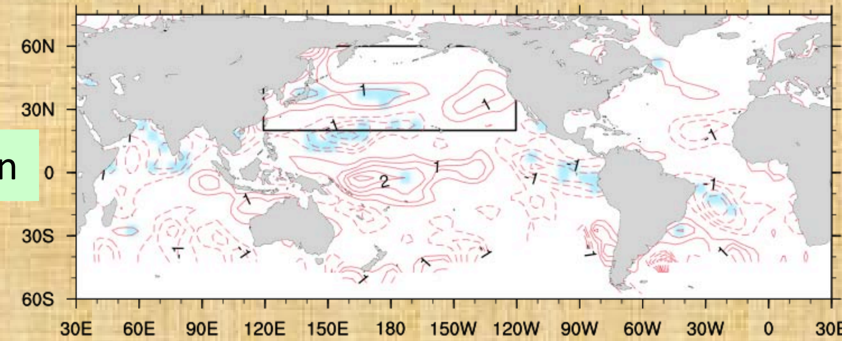
SVD Heterogeneous Map. SST vs TCA. JAS.

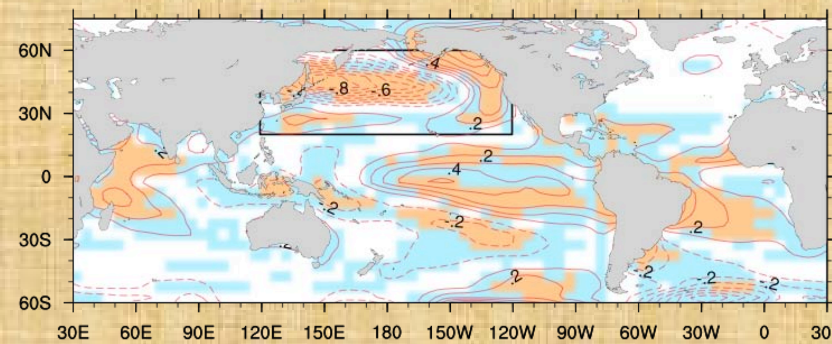
SST

TCA

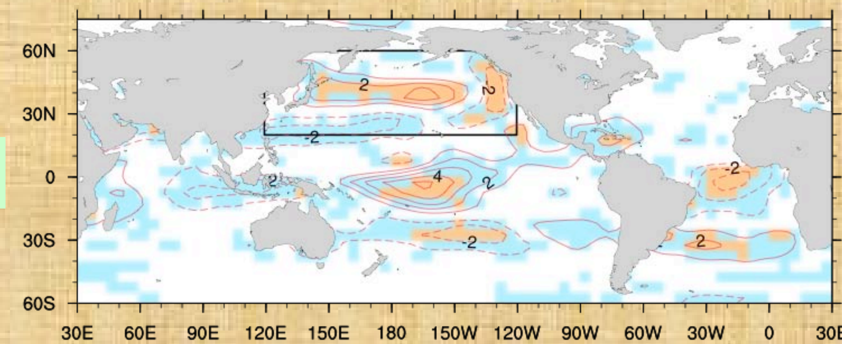


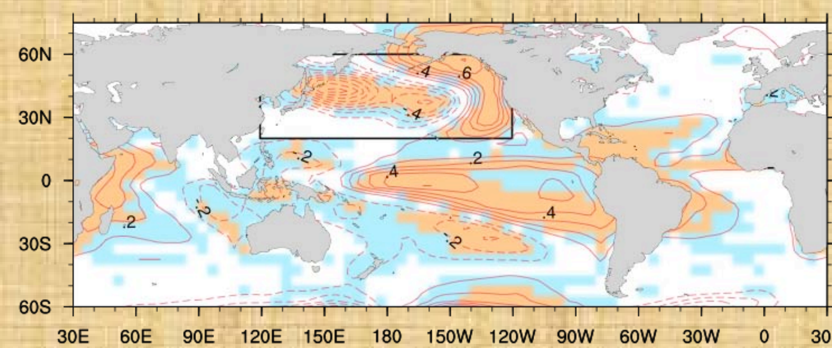
Observation



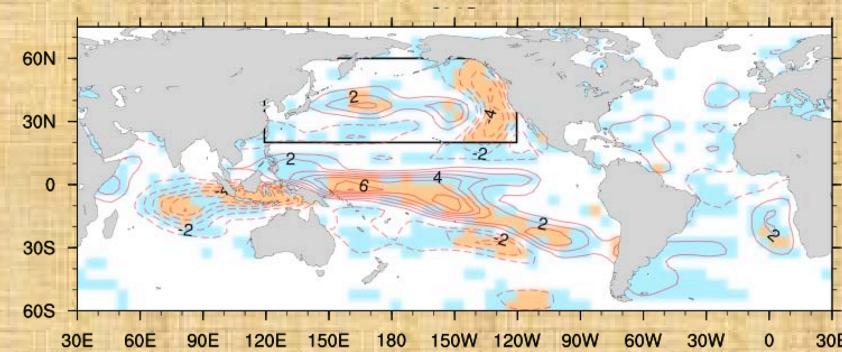


CAM3.5





CAM4

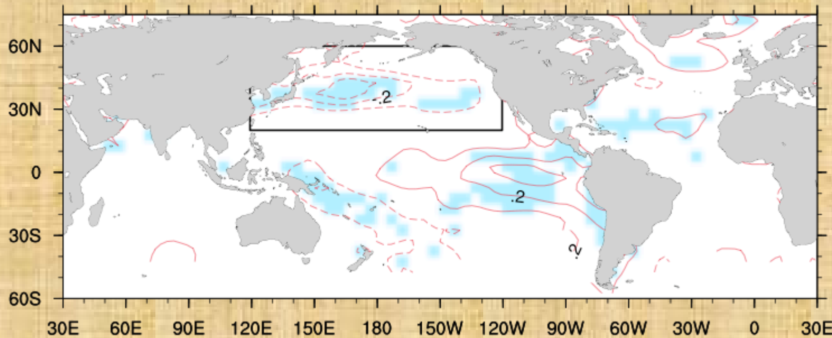


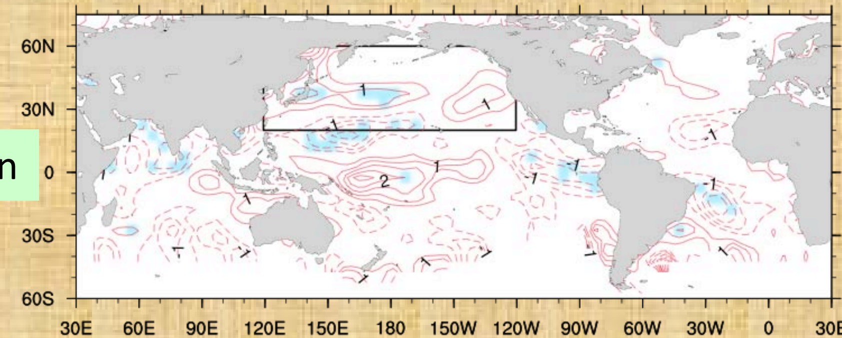
SVD Heterogeneous Map. SLP vs TCA. DJF.

SLP

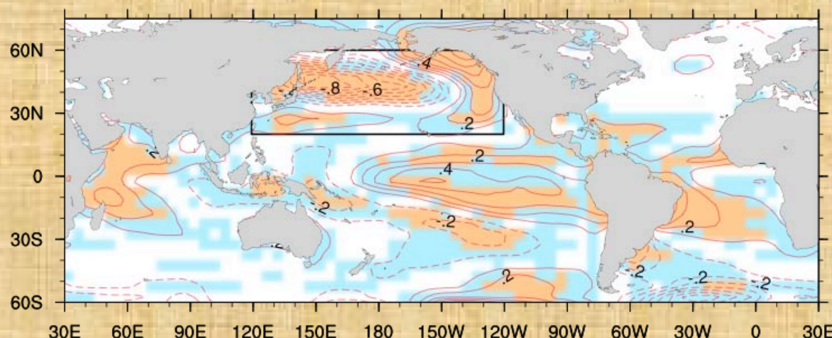
TCA

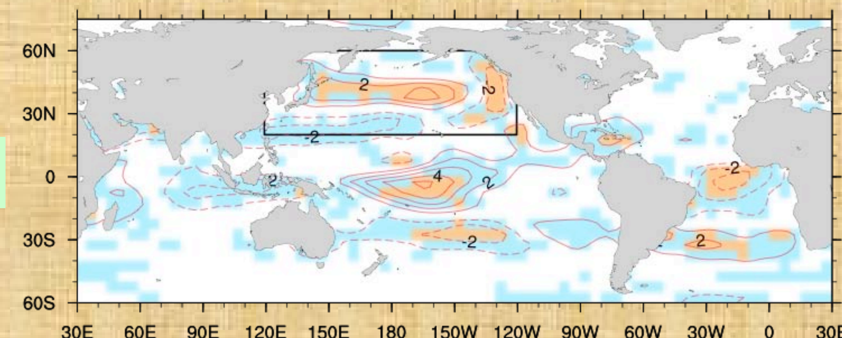
Observation



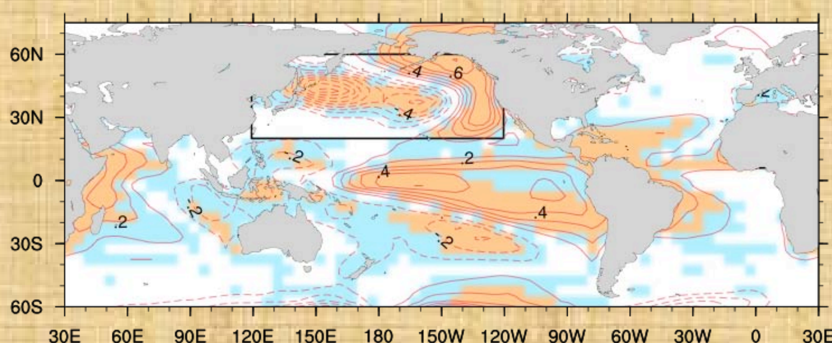


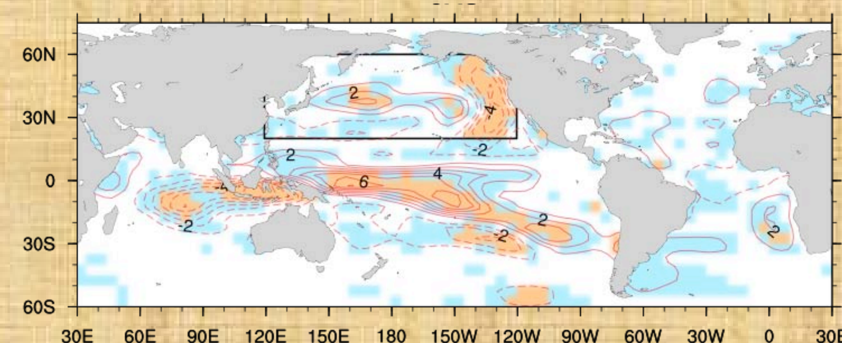
CAM3.5



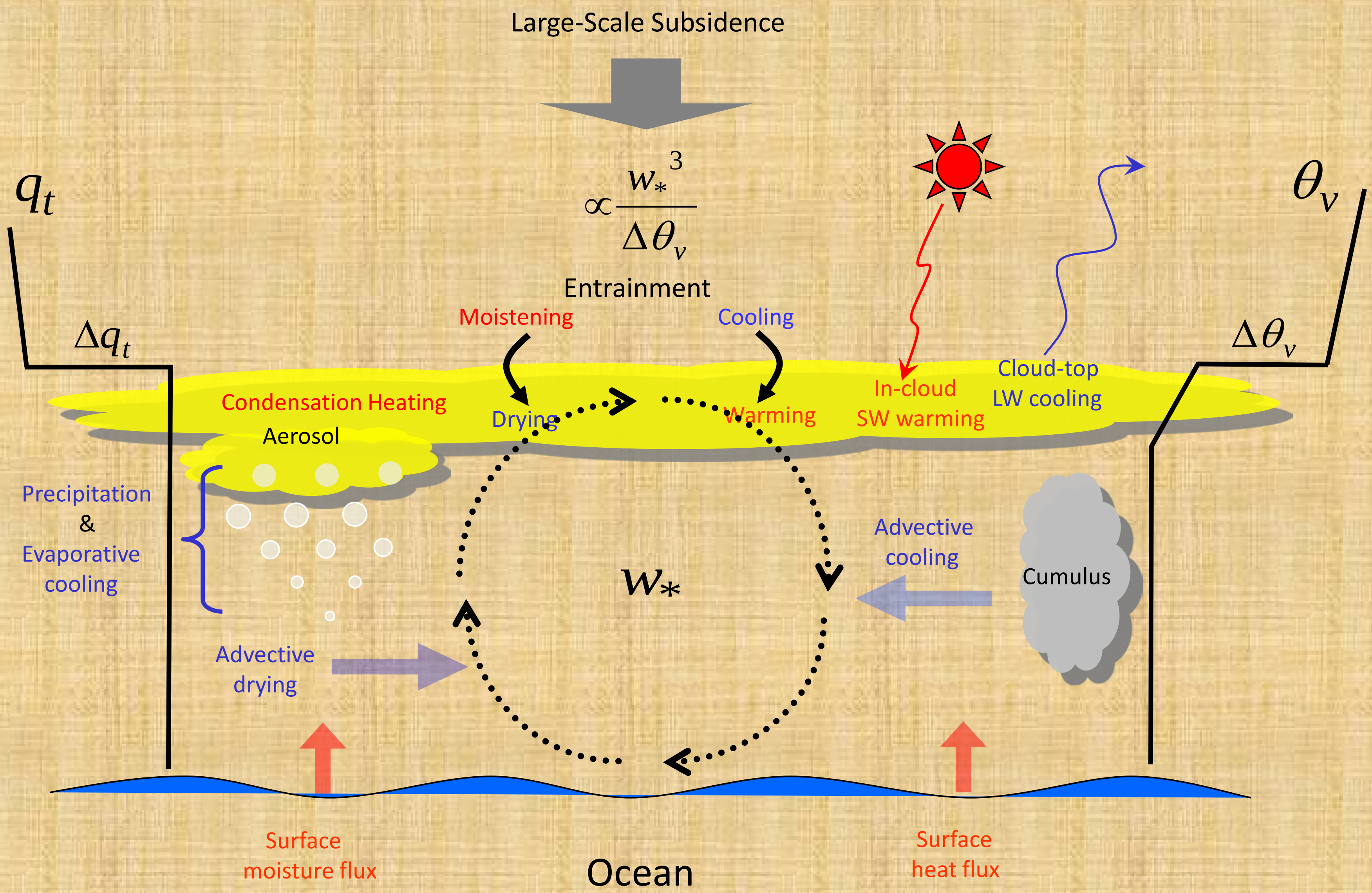


CAM4

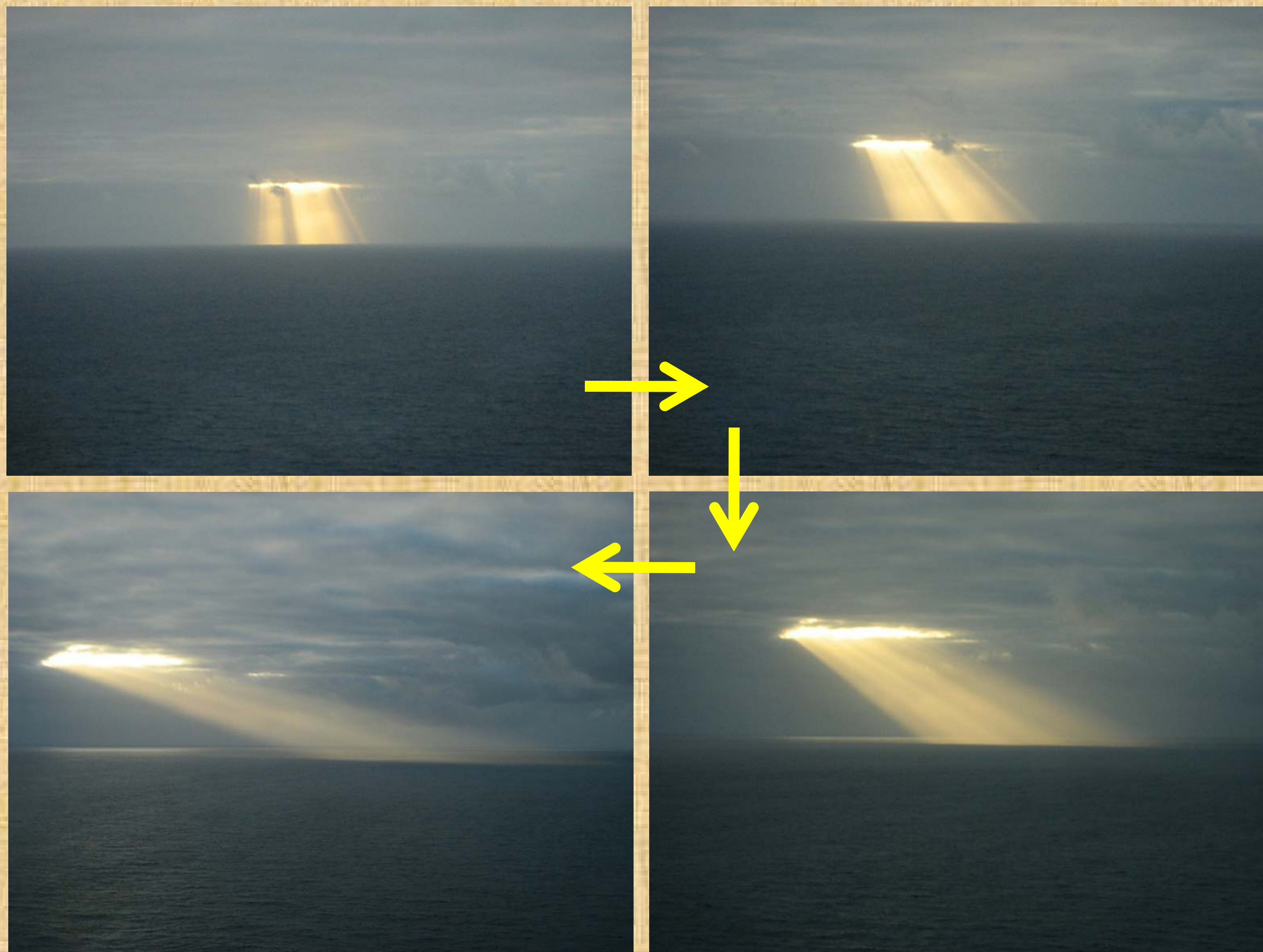




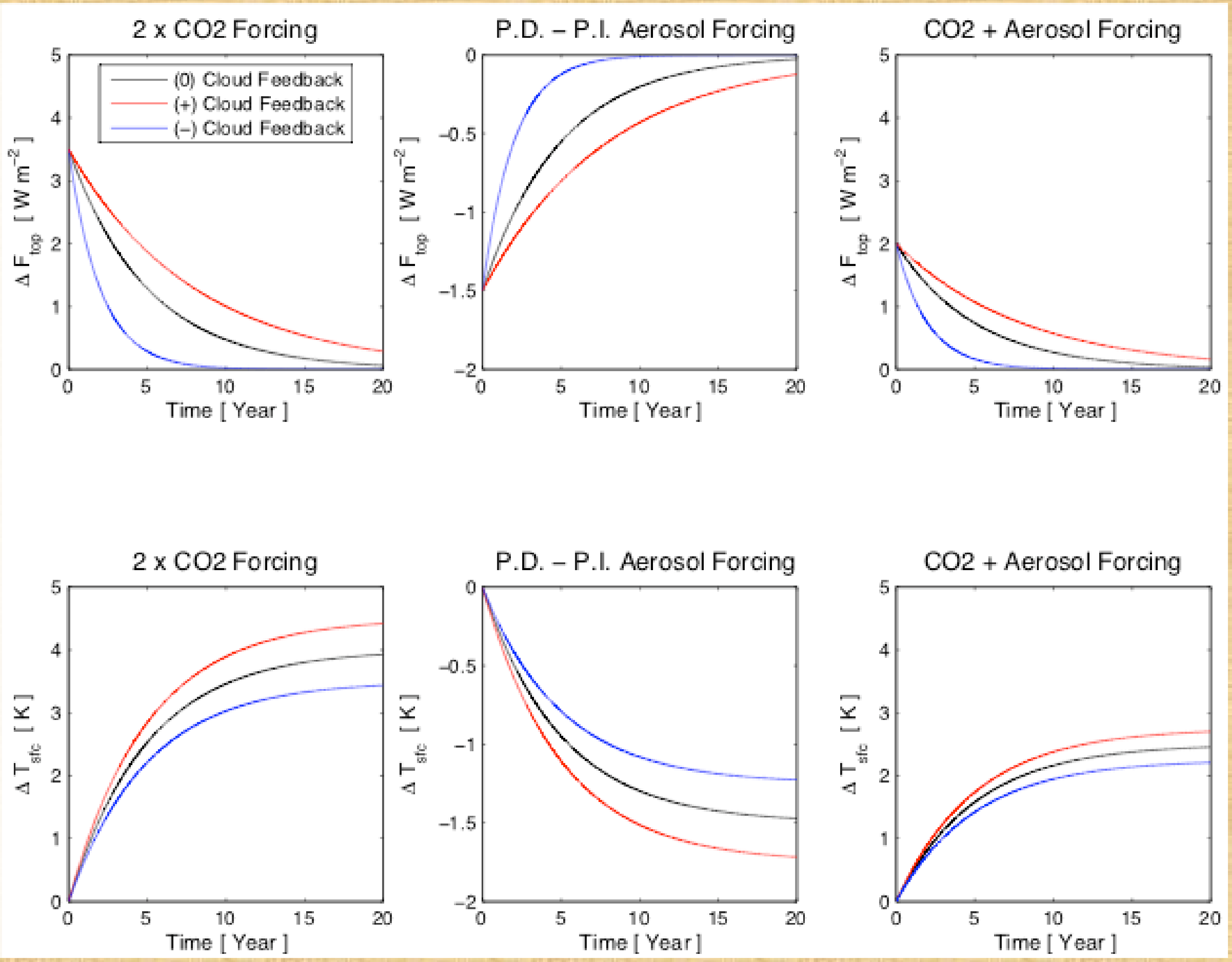
Interplay among Various Processes in Stratocumulus



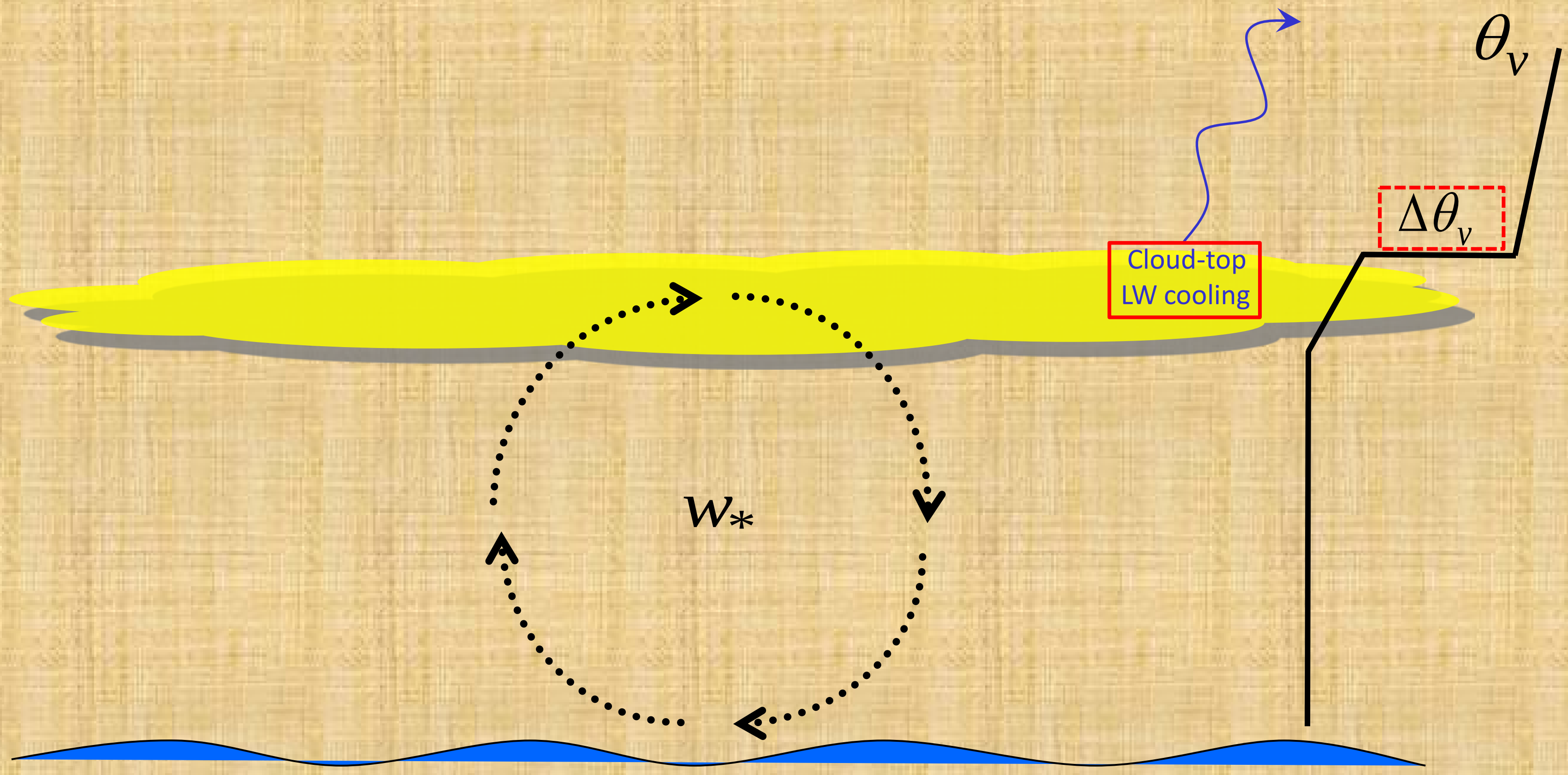
Stratocumulus – SW Radiation



VOCAL. Oct. 2008. Crepuscular ray sequence

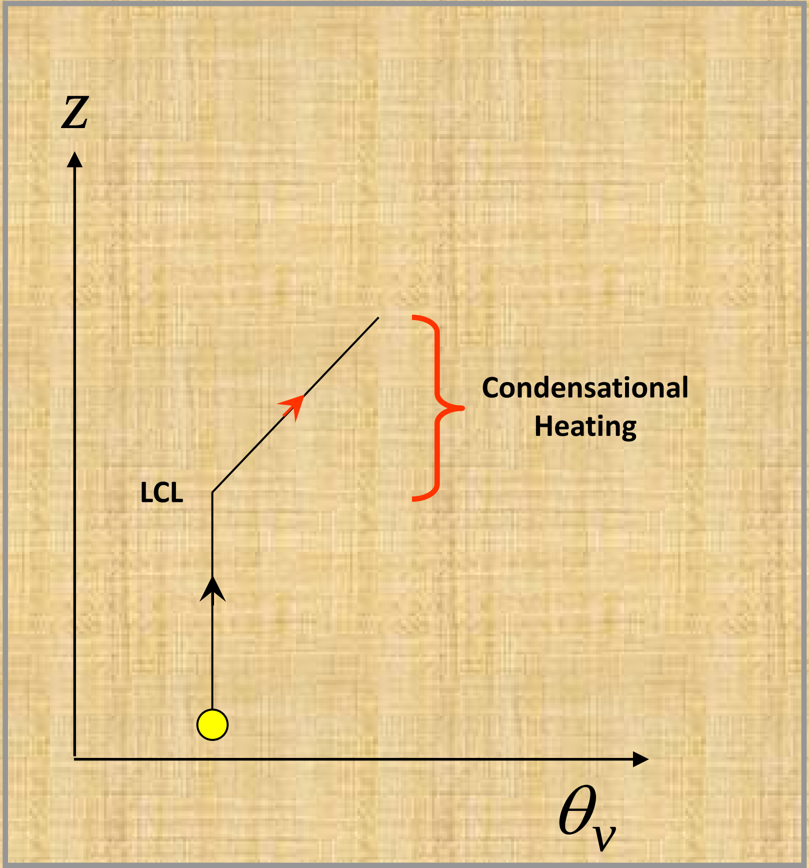

2 x CO2 Forcing
P.D. – P.I. Aerosol Forcing
CO2 + Aerosol Forcing
(0) Cloud Feedback
(+) Cloud Feedback
(–) Cloud Feedback
Δ F_top [W m^-2]
Δ T_sfc [K]
Time [Year]

Interplay among Various Processes in Stratocumulus

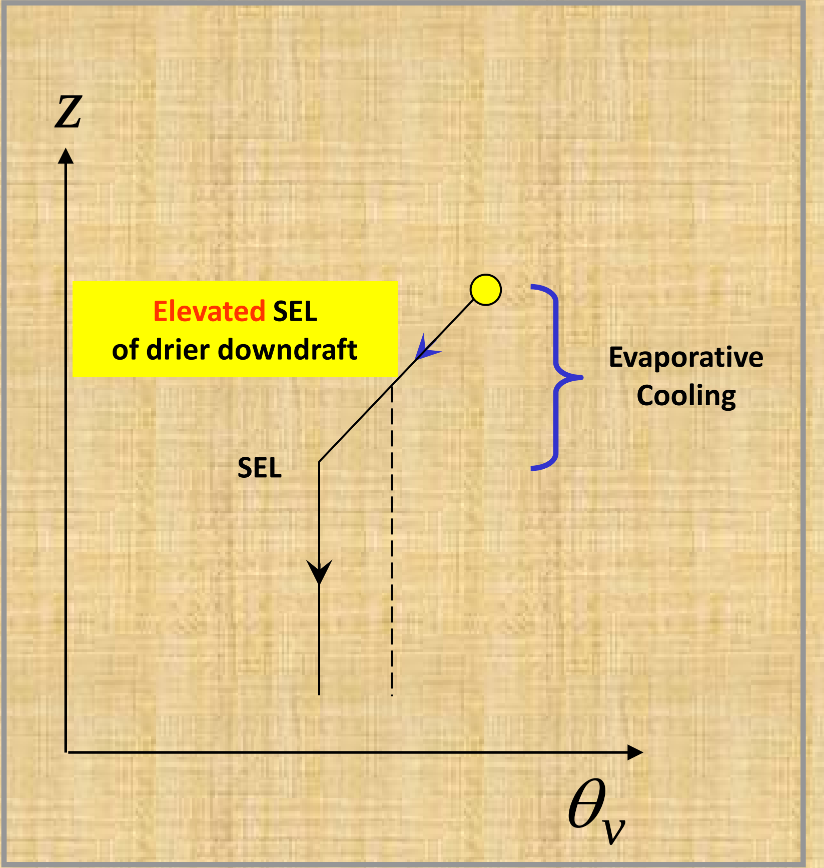


Thermodynamic Levels

LCL : Lifting Condensation Level



SEL : Sinking Evaporation Level



Response of MSC to increasing SST