Dissecting Tropical Biases in the NCAR CAM3 and CCSM3

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INTRODUCTION

During El Nino, deep convection and associated massive cloud systems in the western Pacific warm pool region move eastward to the central and eastern Pacific. The vast cloud cover in the region leads to much stronger cloud cloud radiative forcing than normally observed. In general, current state-of-the-art GCMs simulate atmospheric circulation and hydrological responses to El Nino reasonably well, given the sea surface temperature conditions [Sun et al. 2006]. However, the simulation of the cloud radiative forcing response is less successful. For example, in the National Center for Atmospheric Research (NCAR) Community Atmosphere Model CAM3 at T42 resolution the cloud radiative forcing fields show a much weaker response to ENSO than observed, particularly in shortwave.

Another serious tropical bias in GCMs is the double ITCZ problem. The appearance of a spurious Inter-Tropical Convergence Zone precipitation band south of the equator in the central and eastern Pacific is common in coupled atmosphere-ocean global climate models (CGCM), including the NCAR Community Climate System Model CCSM3.

Since tropical cloud and precipitation systems in warm SST regions are mainly associated with convection, we examine in the this study, by contrasting two types of simulations using both CAM3 and CCSM3, the physical factors that affect the simulation of the SWCF response to El Nino and the ITCZ precipitation. One type uses the standard model configuration, and the other uses a revised Zhang-McFarlane convection scheme. It is my hope that this will provide more insight into understanding and improving the simulation of tropical climate in the NCAR models.

SIMULATION EXPERIMENTS

Two sets of model simulations are carried out, one using CAM3 and another using CCSM3. The CAM3 simulations focus on the shortwave cloud radiative forcing response to El Nino. The CCSM3 simulations focus on the double ITCZ problem. Although double ITCZ appears in CAM3 as well, it is much worse in CCSM3 due to amplification from the coupled air-sea interaction. Table 1 lists the experiment specifics.

The data used are: ERBE: April 1985 to Feb. 1989. ISCCP: July 1983 to Oct. 2001. SSMI: July 1987 to Oct. 2001

Table 1: List of Experiments

Model	Experiments	Convection Scheme	Simulation Length
CAM3	CAM3 Ctrl	Zhang-McFarlane (1995)	1979 to 1995
	CAM3 Exp	Revised Z-M (Zhang 2002)	1979 to 1995
CCSM3	CCSM Ctrl	Z-M	10 years
	CCSM Exp	Revised Z-M	10 years
	C2E	Revised Z-M	10 years, starting from end of Ctrl
	E2C	Z-M	10 years, starting from end of Exp

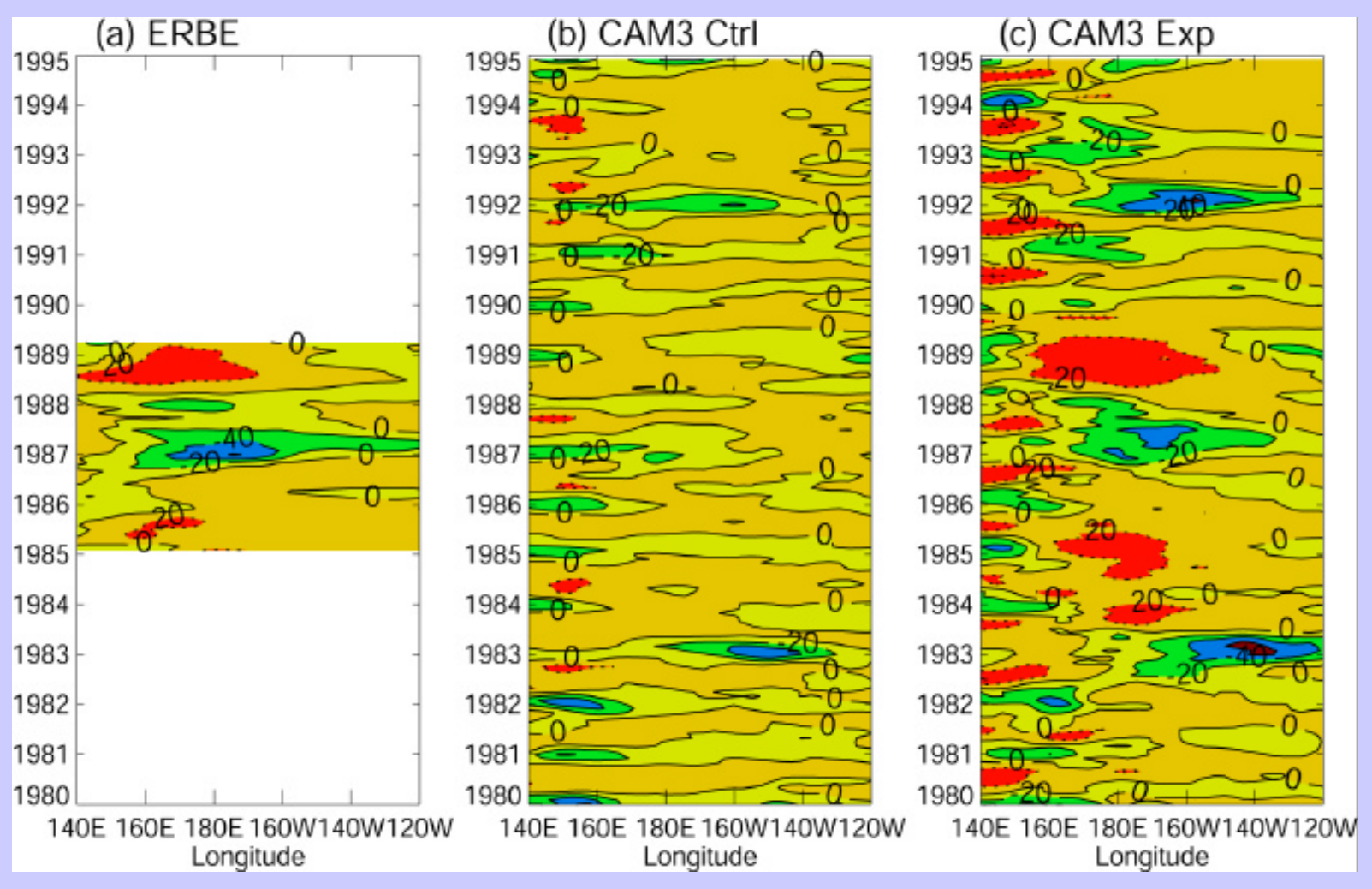

Fig. 1: SWCF anomalies from ERBE observations and CAM3 simulations. The anomalies are obtained by subtracting the mean SWCF at each longitude over the period of interest, which is from February 1985 to April 1989 for ERBE and from January 1980 to December 1994 for CAM3.

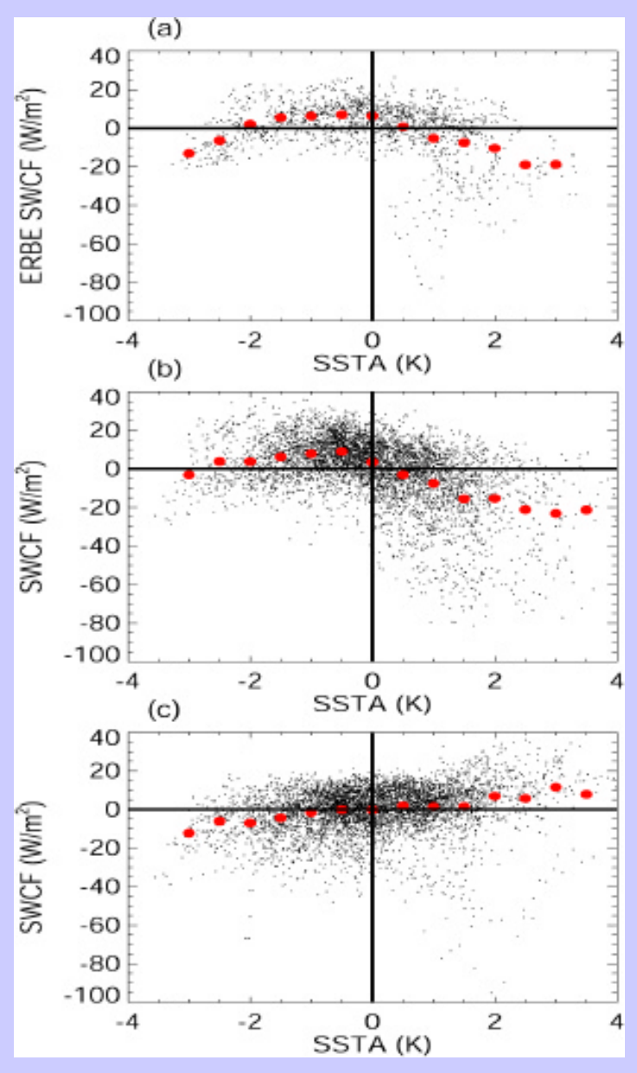

Fig. 2: Scatter plots of SWCF anomaly versus SST anomaly from (a) ERBE data, (b) CAM3 Exp and (c) CAM3 Ctrl over the central and eastern equatorial Pacific (180-100W, 5S-5N). Each point represents a monthly mean value over a CAM3 grid point. The red dots are averages within each 0.5 K SSTA bin.

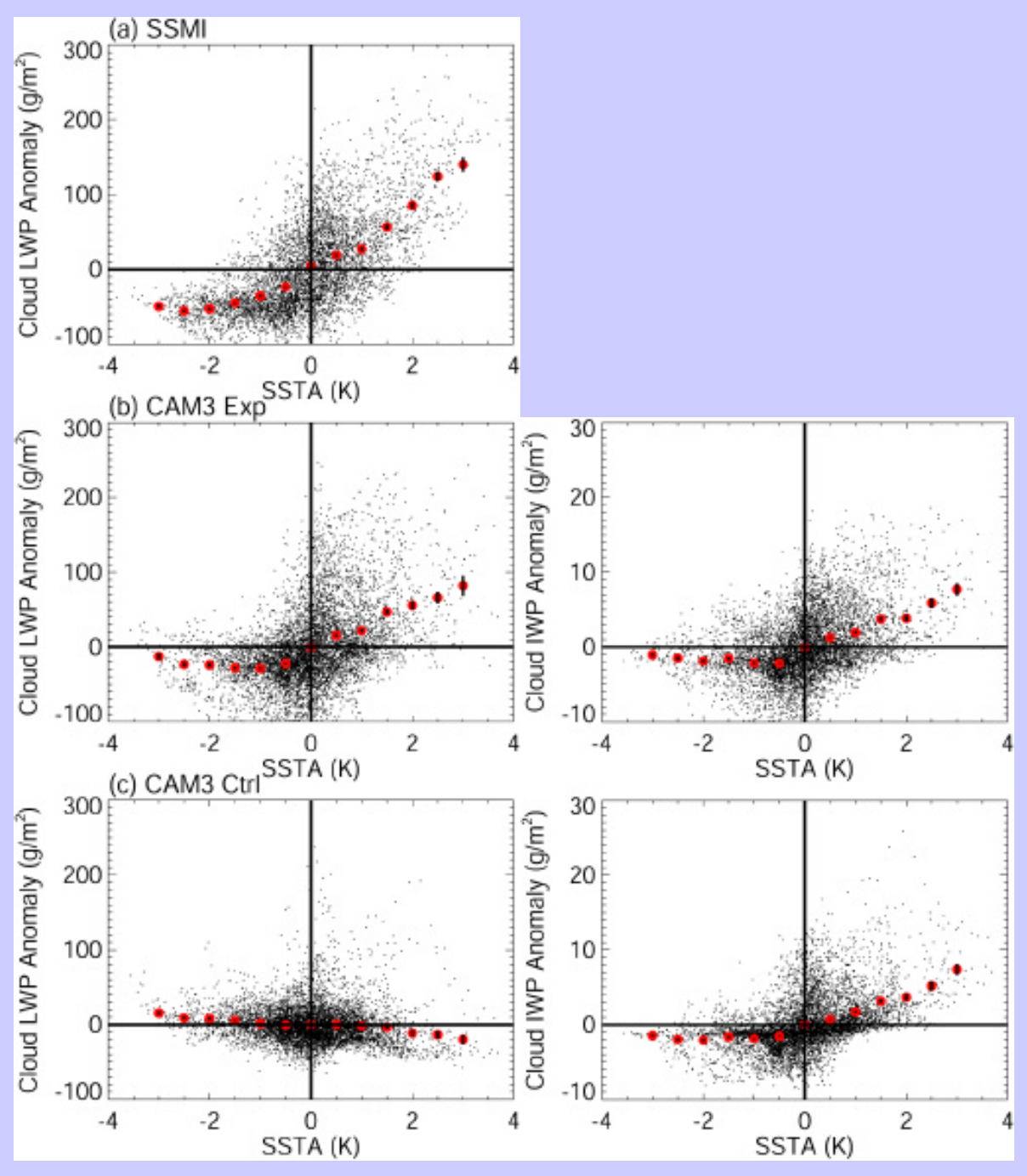

Fig. 3: Same as Fig. 2 but for LWP (left) and IWP (right) for CAM3 Exp and CAM3 Ctrl. Observations for LWP are from ISCCP.

RESULTS

- Shortwave cloud forcing (SWCF) response to ENSO is weak in CAM3 Ctrl, but realistic in CAM3 Exp (Fig. 1). In fact, at GCM grid point resolution, SWCF variation with SST anomaly even has the wrong sign in CAM3 Ctrl (Fig. 2).
- Both liquid water path (LWP) and ice water path (IWP) anomalies increase with SST anomalies in CAM3 Exp, while LWP anomalies decrease with SST anomalies in CAM3 Ctrl. Clearly, decrease of LWP anomaly with SST anomaly is largely responsible for the wrong SWCF in CAM3 Ctrl (Fig. 3).
- Variation of high, middle and low cloud amount anomalies with SST anomalies in central equatorial Pacific in CAM3 Exp is closer to that of ISCCP than CAM3 Ctrl is, particularly for low clouds (Fig. 4).
- LWP correlates well with middle and high cloud amount in observations. This is well simulated in CAM3 Exp, but not in CAM3 Ctrl. For cold SST anomalies, both Exp and Ctrl produce more low clouds, which offset less high clouds to give small LWP anomalies. For warm SST anomalies, more middle and high clouds in CAM3 Ctrl do not give more LWP most of the time (Fig. 5).

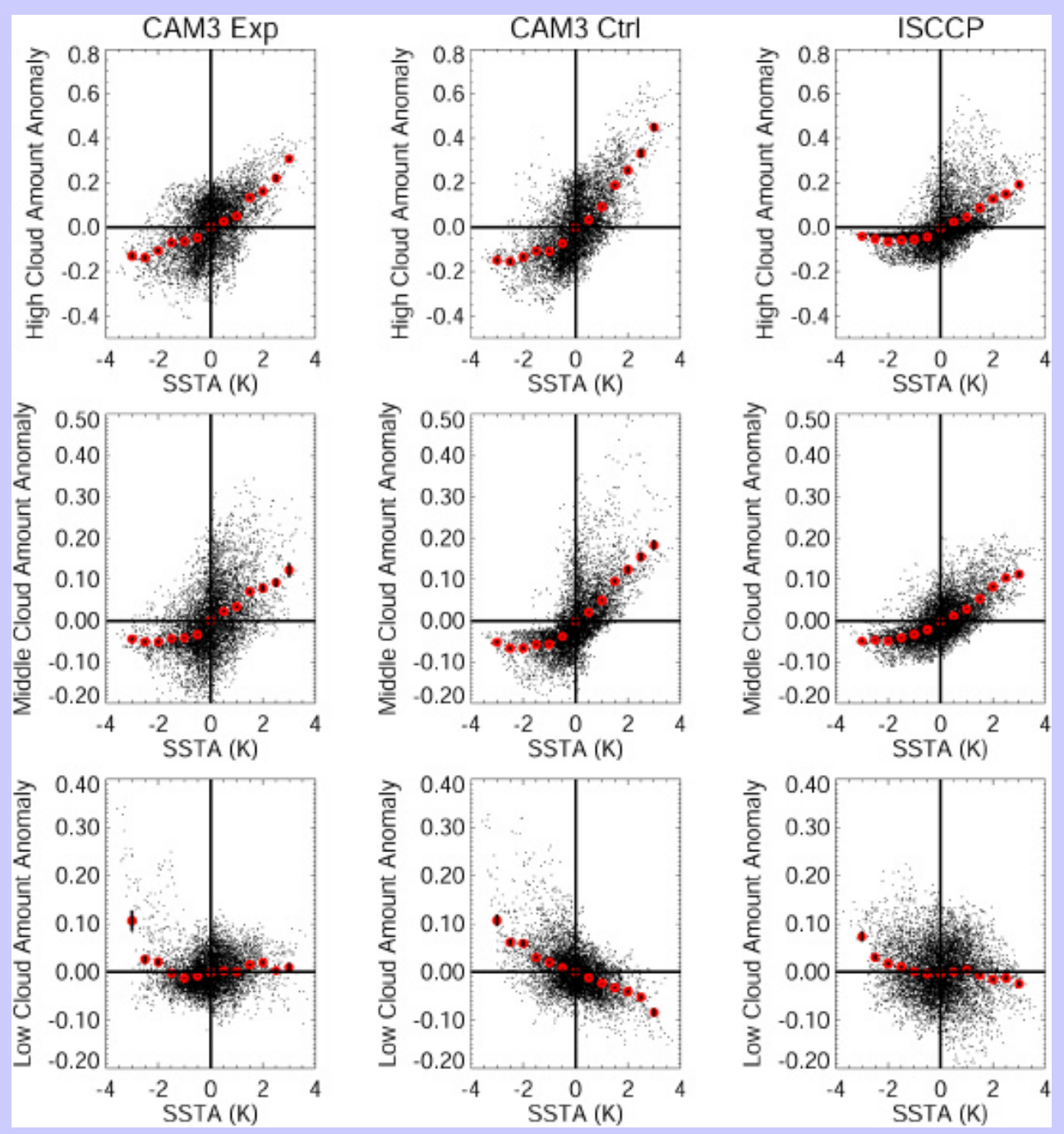

Fig. 4: Scatter plots of variation of high-, middle- and low-level cloud amount anomalies with SST anomalies in the central equatorial Pacific (150E-110W, 5S-5N) for CAM3 Exp (left), CAM3 Ctrl (middle) and ISCCP (right).

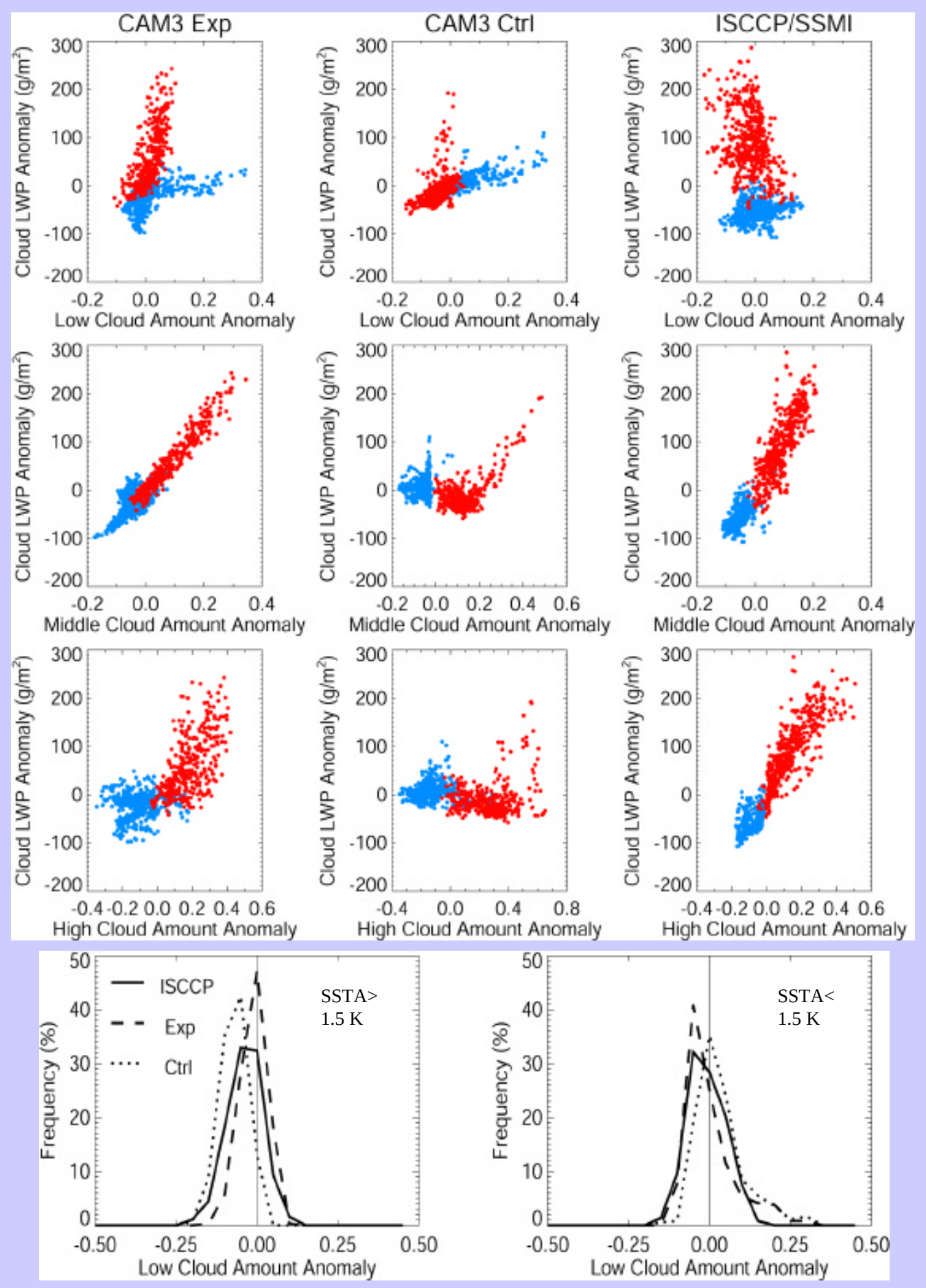

Fig. 5: Scatter plots of cloud LWP anomaly vs. cloud amount anomaly for CAM3 Exp(left), CAM3 Ctrl (middle) and ISCCP/SSMI (right) for SSTA > 1.5 C (red) and SSTA < -1.5 C (blue), and histogram of low cloud anomalies (b/w plots at the bottom) for SSTA> 1.5 C (left) and SSTA < -1.5 C (right). For Exp, LWP anomalies are highly correlated with middle cloud anomalies for both cold and warm SST events. For Ctrl, LWP anomalies are largely correlated with low-cloud anomalies, although for large LWP anomalies middle and large cloud become important. For observations with cloud amount from ISCCP and LWP from SSMI, LWP is correlated with middle and high clouds.

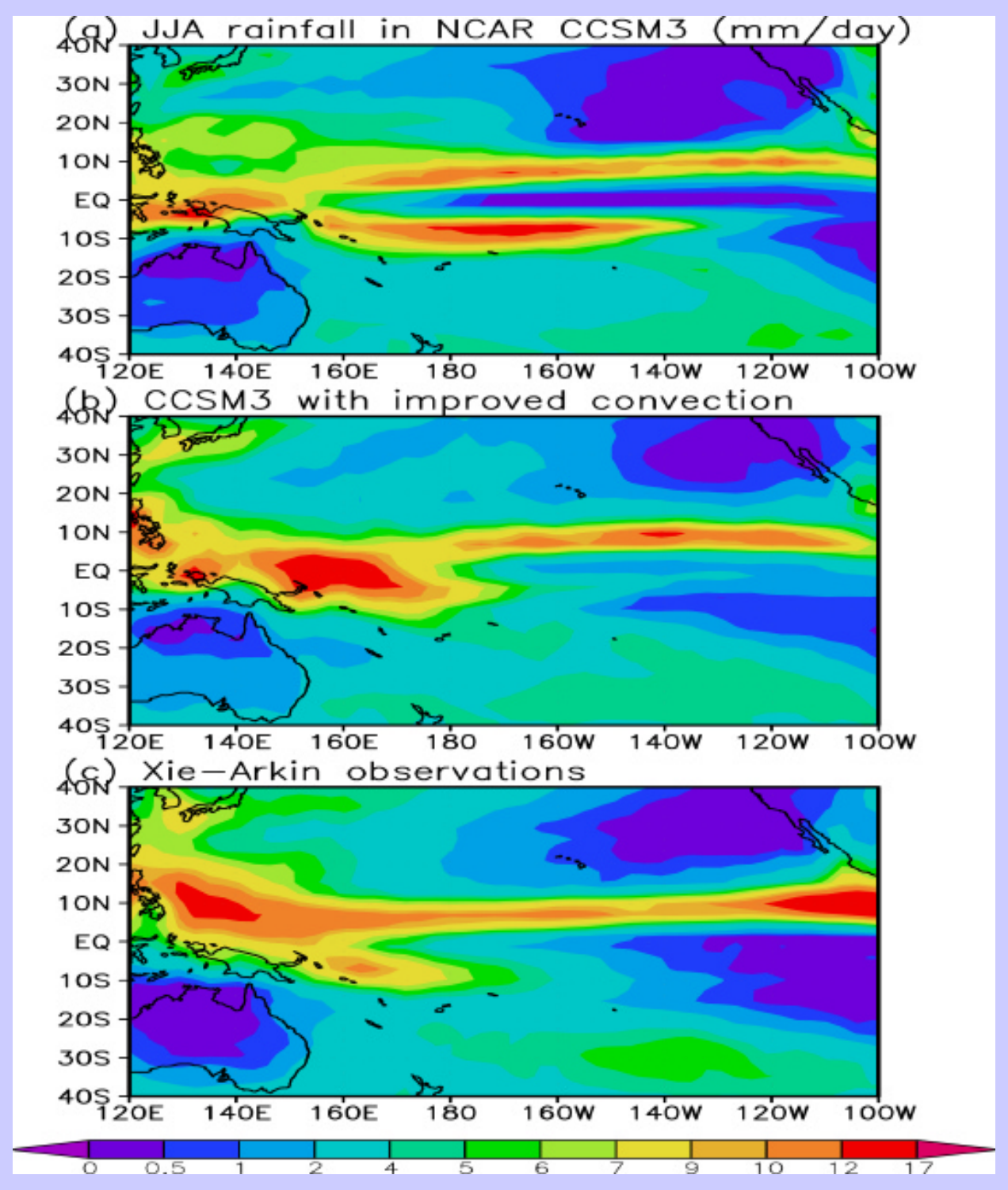

Fig. 6: Precipitation distribution for JJA from standard CCSM3 (Ctrl run, top), the CCSM3 with revised Zhang-McFarlane convection scheme (Exp run, middle) and Xie-Arkin observations (bottom).

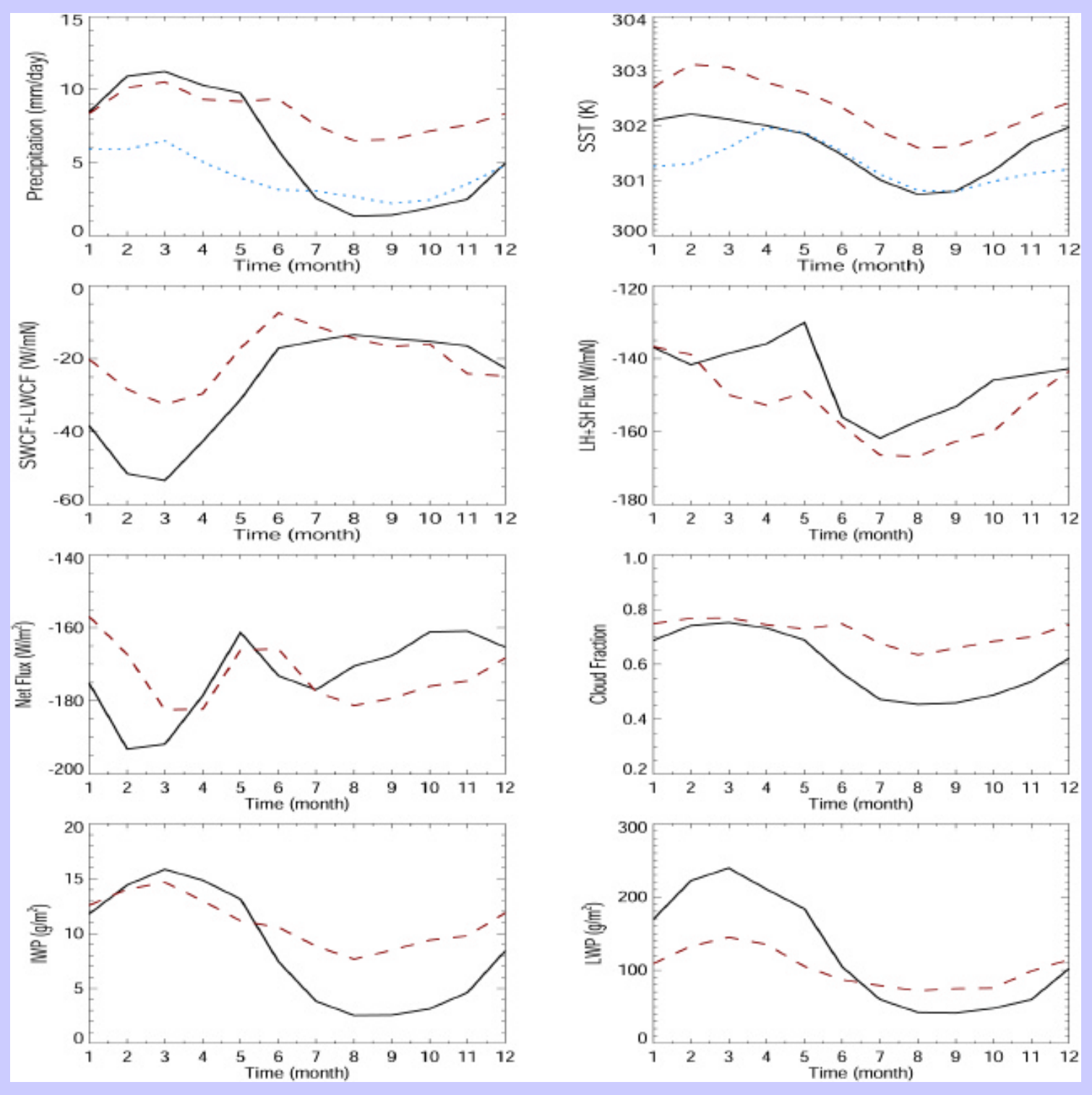

Fig. 8: Annual cycle averaged over the 10-yr simulation period and over the southern ITCZ region of relevant fields. Red dashed line is for CCSM3 Ctrl, black solid line is for CCSM3 Exp. Blue line is from observations. 'Net Flux" is the sum of SWCF, LWCF, latent and sensible heat fluxes, respectively.

RESULTS (Cont'd)

- The coupled model CCSM3 in the standard configuration (Ctrl run) shows a clear double ITCZ precipitation distribution for JJA. The revised Zhang-McFarlane convection scheme (Exp run) eliminates the fictitious southern ITCZ, leading to better agreement with the observed precipitation distribution (Fig. 6)
- Double or single ITCZ, depending on the convection scheme, develops within the first year of the model integration. It is independent of the initial condition (Fig. 7).
- Ocean surface energy budget averaged over the southern ITCZ region (180E-130W, 10S-5S) shows that strong cloud radiative forcing in boreal winter and spring in the Exp helps to cool the SST, thus suppress convection in JJA. The opposite holds for Ctrl (Fig. 8).
- The Ctrl run, by design of convection scheme, shows high correlation between precipitation and CAPE (convective available potential energy). This is not true for the Exp. Precipitation and SWCF in the Exp run are better correlated with 500 mb vertical velocity. They also respond more strongly to the dynamics than in the Ctrl run (Fig. 9).

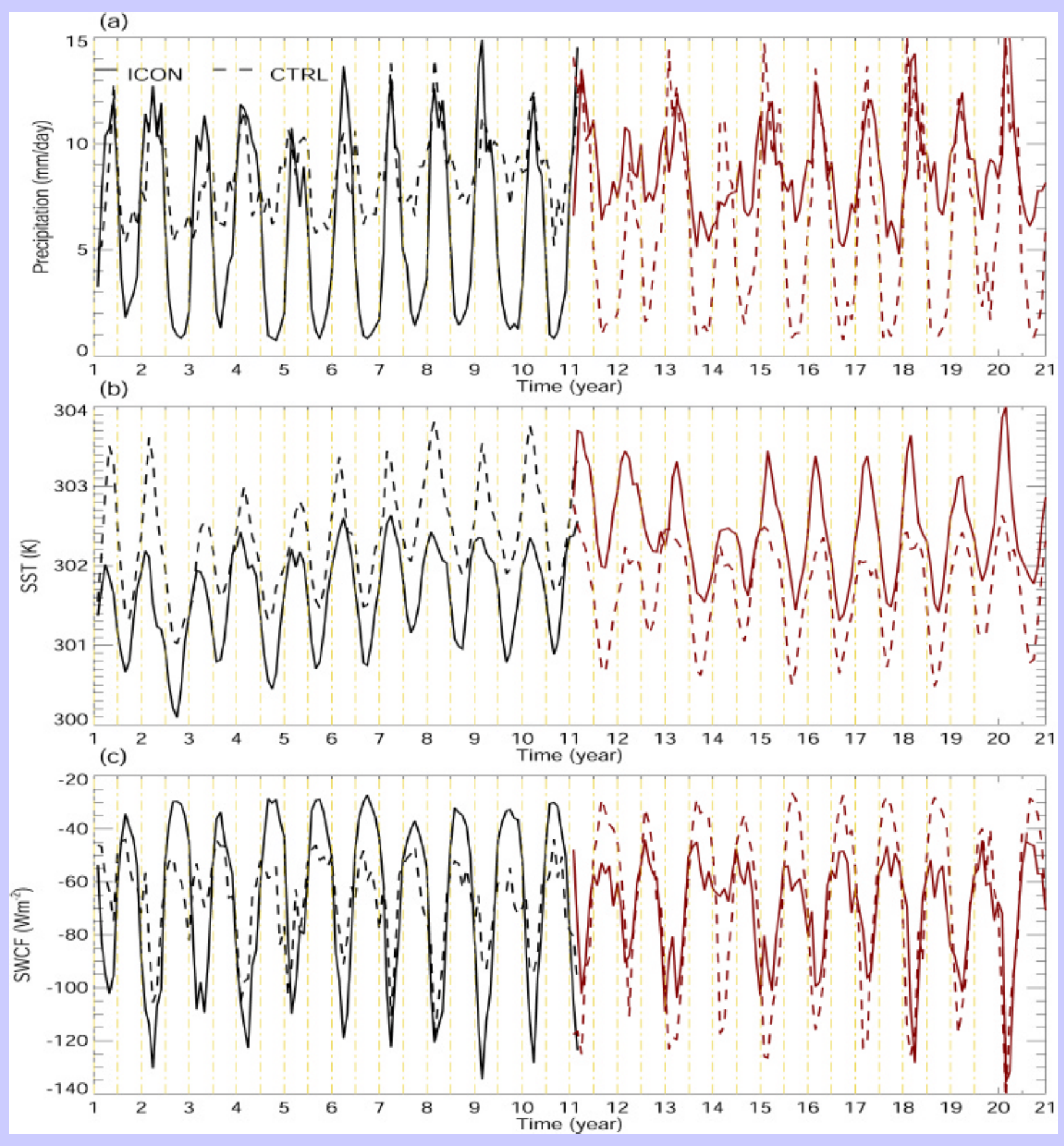

Fig. 7: Time series of precipitation, SST and SWCF from Ctrl (black dashed) and Exp (black solid), C2E (red dashed) and E2C (red solid). Simulations C2E and E2C are to show that differences in simulation characteristics resulting from changing convection scheme are independent of initial conditions. See Table 1 for specifics of the runs.

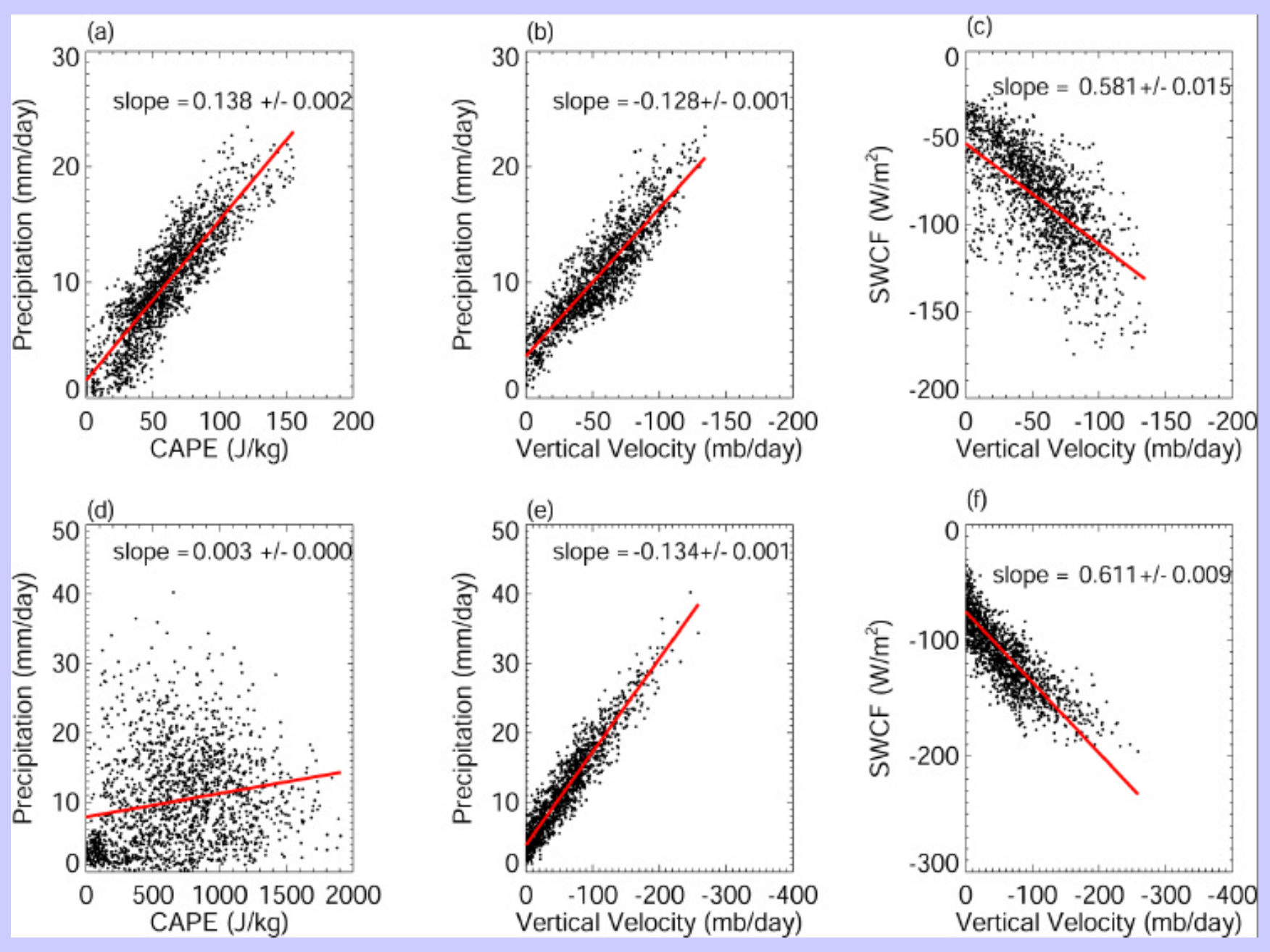

Fig. 9: Scatter plots of precipitation versus CAPE, and precipitation, SWCF versus 500 mb vertical velocity for CCSM3 Ctrl (top, a-c) and Exp (bottom, d-f) for Jan-Feb-March.

CONCLUSIONS:

- This study examined two major tropical biases in the NCAR models: weak SWCF response to ENSO in CAM3 and double ITCZ in CCSM3. By contrasting two sets of simulations, one with the standard configuration and one with a revised convection scheme, we find that:
- The revised Zhang-McFarlane scheme significantly alleviates the tropical biases in the NCAR CAM3 and CCSM3.
- Lack of high LWP and insufficient low-level cloud, which can be traced to decreased shallow convection, are responsible for the weak SWCF during El Nino in the CAM3. This points to the importance of the interaction between deep and shallow convection in climate simulation.
- The weak cloud radiative forcing in boreal winter and spring leads to high SST and double ITCZ in summer in CCSM3.