The Role of Non-Convective Condensation Processes in Response of Shortwave Cloud Radiative Forcing to El Niño Warming

Lijuan Li*   Bin Wang, Guang J. Zhang

ljli@mail.iap.ac.cn, July 9, 2014

***LASG, Institute of Atmospheric Physics, China**

Motivation

Method & Data

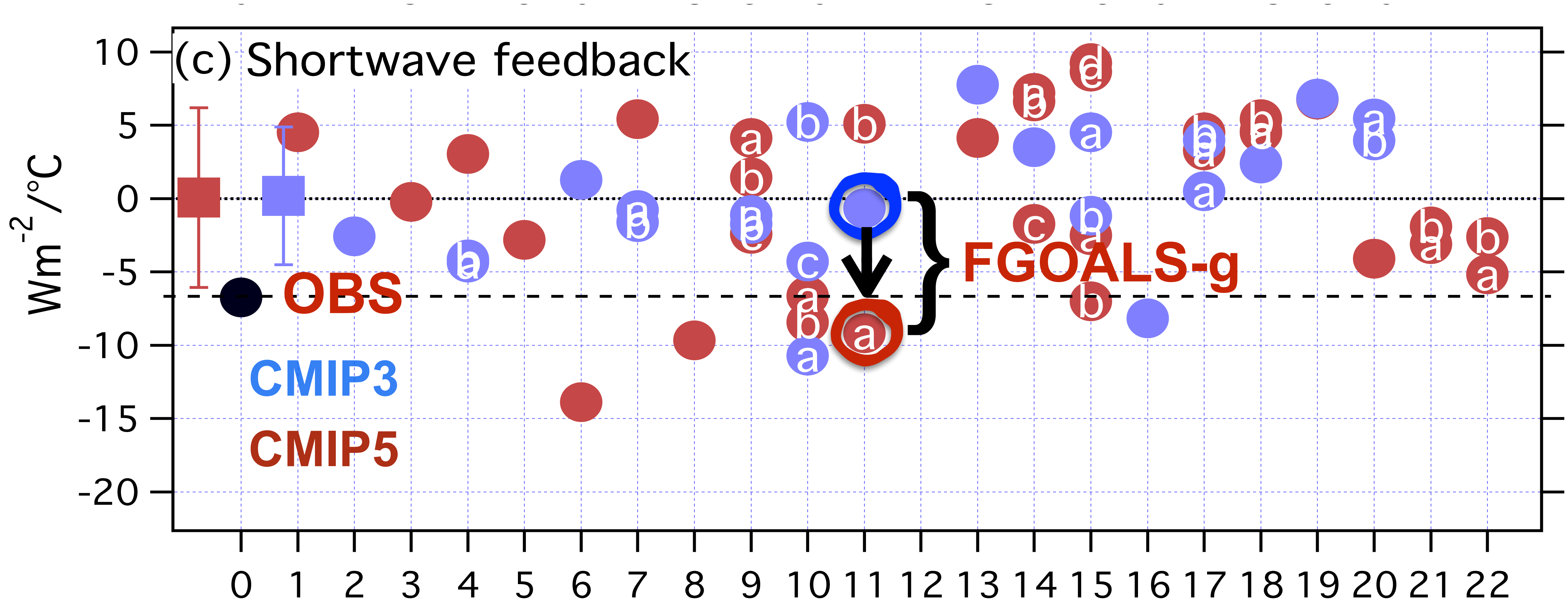
Result Analysis

Summary

Li et al., 2014, J. Clim., in press

Motivation

The shortwave cloud radiatvie forcing (SWCF) feedback in the Equatorial Pacific is one of the dominant components of negative heat flux feedbacks that drive the El Niño-Southern Oscillation (ENSO) evolution.



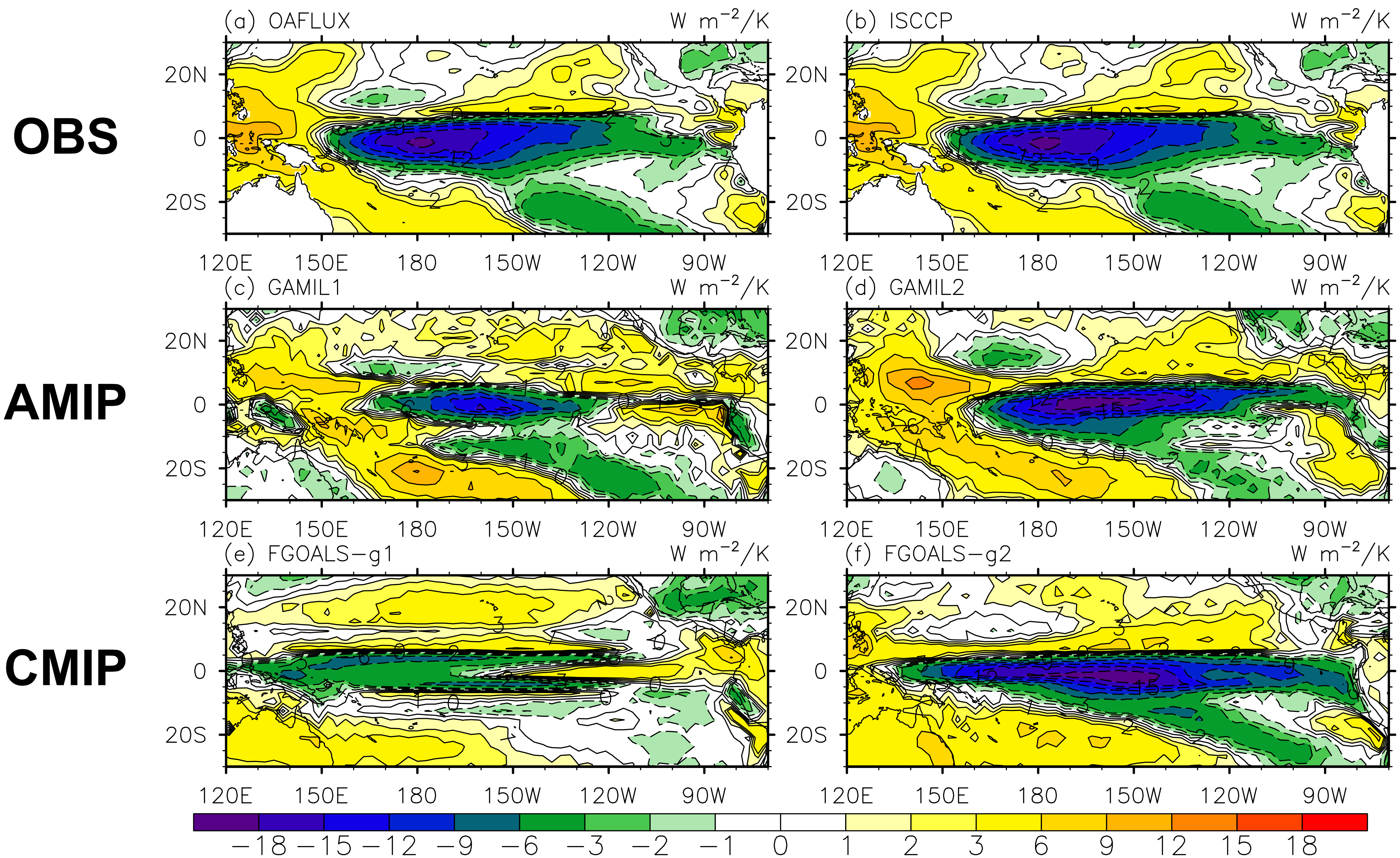
Bellenger et al., 2013, Clim. Dyn.

Most CMIP models underestimate the SWCF feedback

What causes the improvement in the CMIP5 version of FGOALS-g?

Motivation

——SWCF feedback



FGOALS-g1(CMIP3) **FGOALS-g2(CMIP5)**

The SWCF feedback improvement in the FGOALS-g2 is mainly from its atmospheric component.

Motivation

$$\frac{dSWCF}{dSST} = \frac{\partial SWCF}{\partial CLD}\frac{dCLD}{dSST} + \frac{\partial SWCF}{\partial LWP}\frac{dLWP}{dSST} = \frac{\partial SWCF}{\partial CLD}\left(\frac{\partial CLD}{\partial \omega_{500}}\frac{d\omega_{500}}{dSST} + \frac{\partial CLD}{\partial SST}\right) + \frac{\partial SWCF}{\partial LWP}\frac{dLWP}{dSST}$$

SWCF feedback | cloud fraction feedback | liquid water path feedback | dynamical feedback

(i) more emphases on the convection scheme and its individual processes, such as closure assumption and momentum transport (Wu et al., 2007;Kim et al., 2008; Li and Zhang, 2008; Neale et al., 2008; Guilyardi et al., 2009a etc.)

(ii)the uncertain parameters in AGCMs and the different horizontal resolutions (Toniazzo et al., 2008; Zhang and Sun 2008; Philip et al., 2010; Kim et al., 2011; Watanabe et al., 2011)

However, the importance of non-convective condensation processes, e.g. cloud micro- and macro-physical processes, has not received enough attention.

Method & data

The response of an atmospheric variable F to El Niño (or feedback) is measured by the linear regression coefficient

$$FA = \alpha \langle SSTA \rangle$$

Nino 3 Index

cloud radiation fluxes:

ISCCP (Jul 1983-Dec 2002)

liquid water path and cloud cover :

SSM/I (Jul 1987-Dec 2002); ISCCP (Jul 1983-Dec 2002)

Precipitation:

CMAP (1979-2002); GPCP (1979-2002)

Circulation variables:

ECMWF-interim (1979-2002); NCEP Reanalysis II (1979-2002)

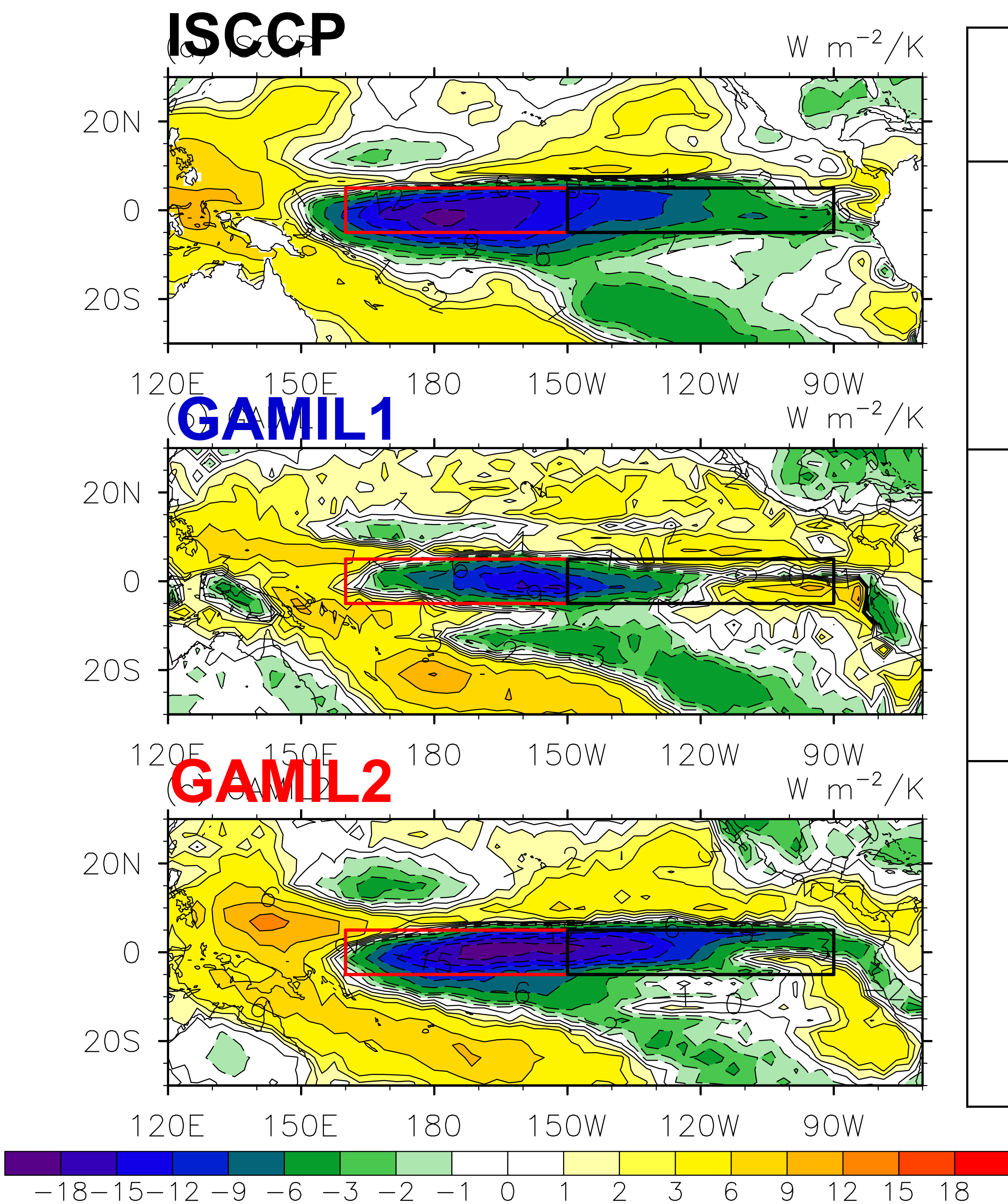
Model Description

	GAMIL1(AR4)	GAMIL2(AR5)
Horizontal Resolution	2.8°X2.8°	2.8°X2.8°/1°X1°/ 0.5°X0.5°/0.25°X0.25°
Vertical Resolution	26 levels	26 levels
Dynamical scheme	Wang et al. (2004)/Yu (1994)	Wang et al. (2004)/Yu (1994) /Wang (2009)
Convective Scheme	Zhang and McFarlane (1995)/Hack(1994)	Zhang and Mu (2005)/ Hack(1994)
Cloud microphysical	Rasch and Kristjansson (1998)	Morrison and Gettelman (2008)/Shi et al. (2013)
Convective cloud fraction	Rasch and Kristjansson (1998)	Xu and and Krueger (1991)

14 uncertain parameters were reset in GAMIL2.0 (Li et al., 2013, AAS)

AMIP experiment: Jan 1979 - Dec 2002 (24yr), monthly mean output

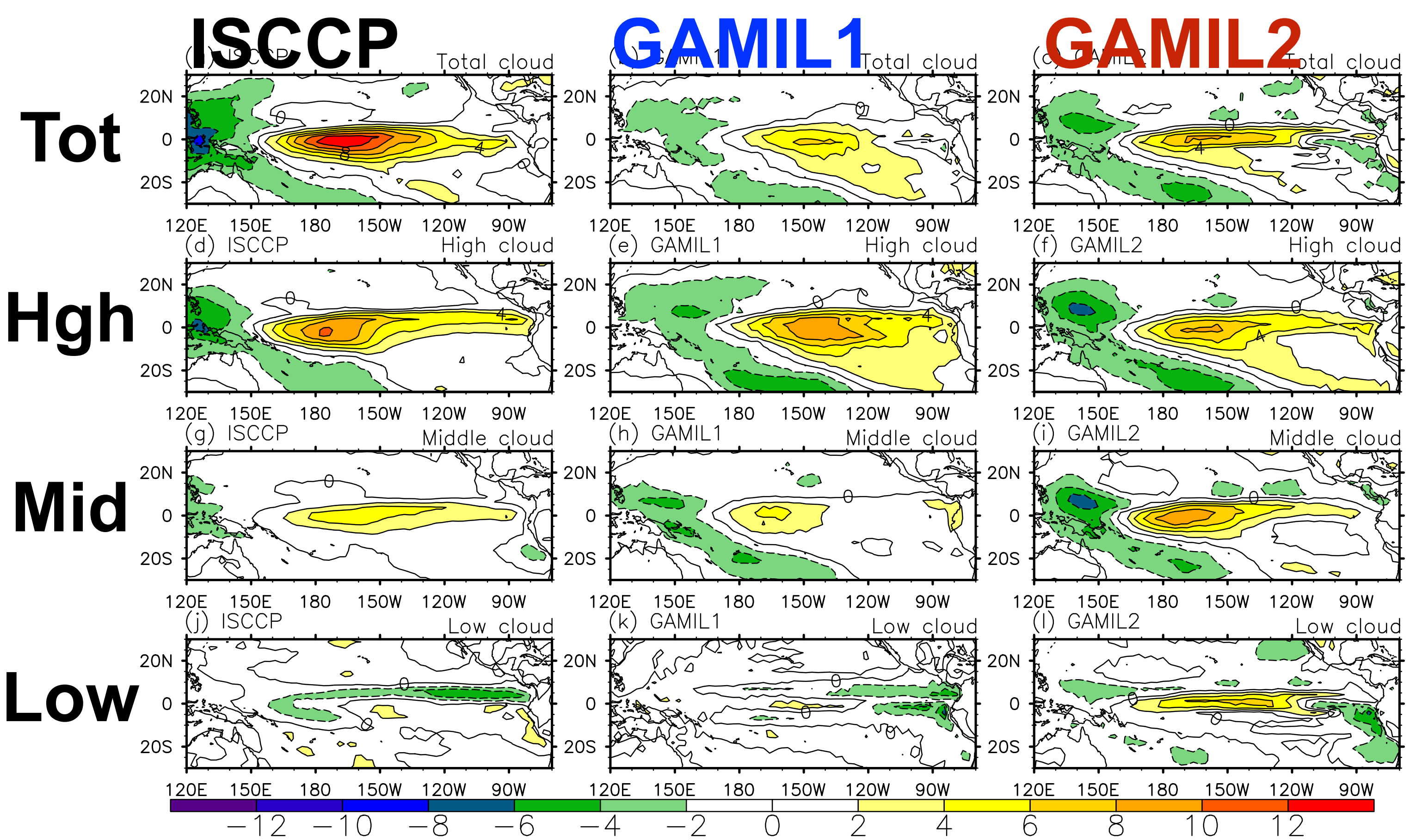
SWCF response to El Niño



Niño 4	Niño 3
-13.6	-6.4
-5.2	-0.41
-10.3	-7.1

GAMIL2 produces a more reasonable negative/positive SWCF response

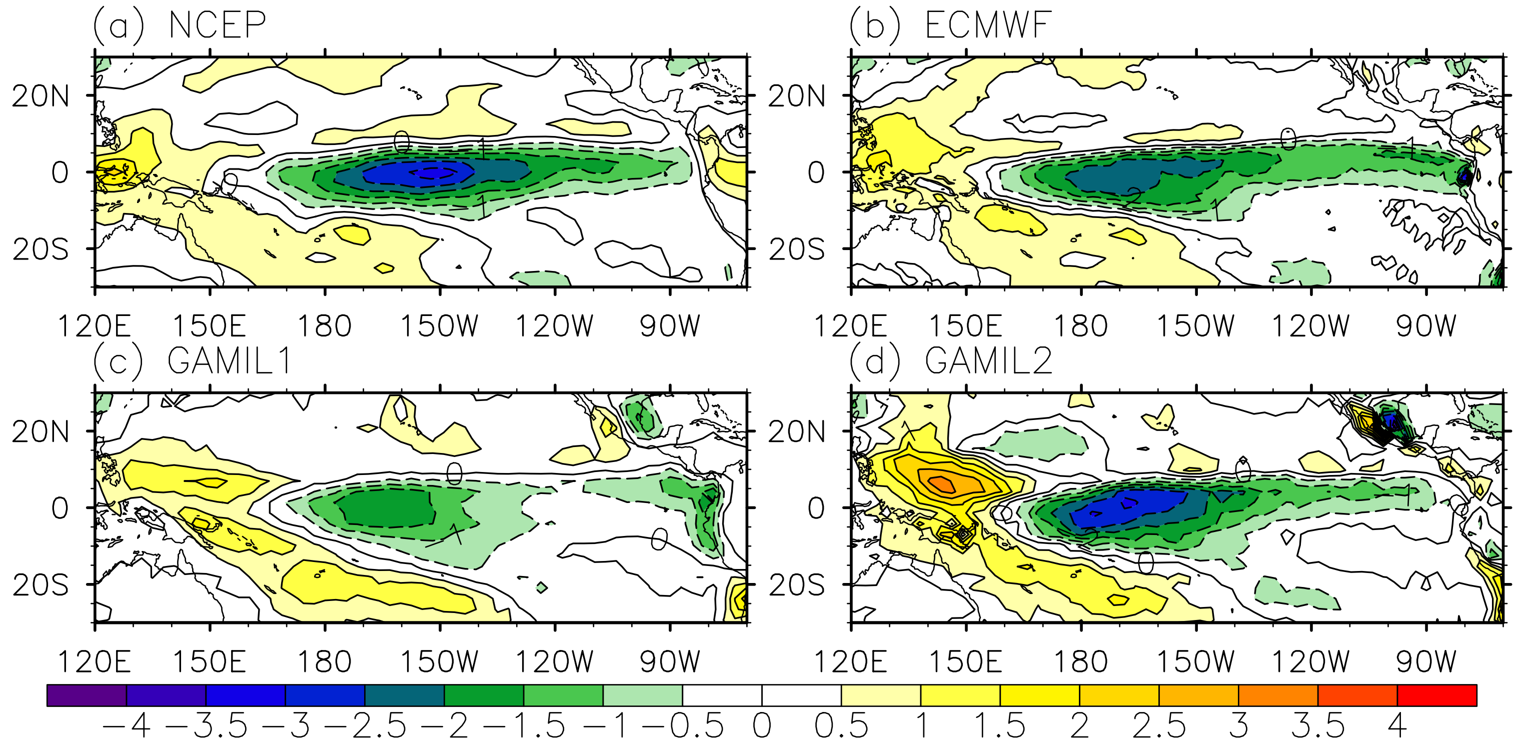
Cloud fraction response to El Niño



	ISCCP N4/N3	GAMIL1 N4/N3	GAMIL2 N4/N3
Tot	8.8/5.2	1.7/2.8	4.0/2.6
Hgh	7.5/3.9	2.8/6.6	4.3/4.1
Mid	3.4/3.0	2.0/1.3	5.6/2.6
Low	-1.2/-0.4	0.46/-1.4	2.3/2.0

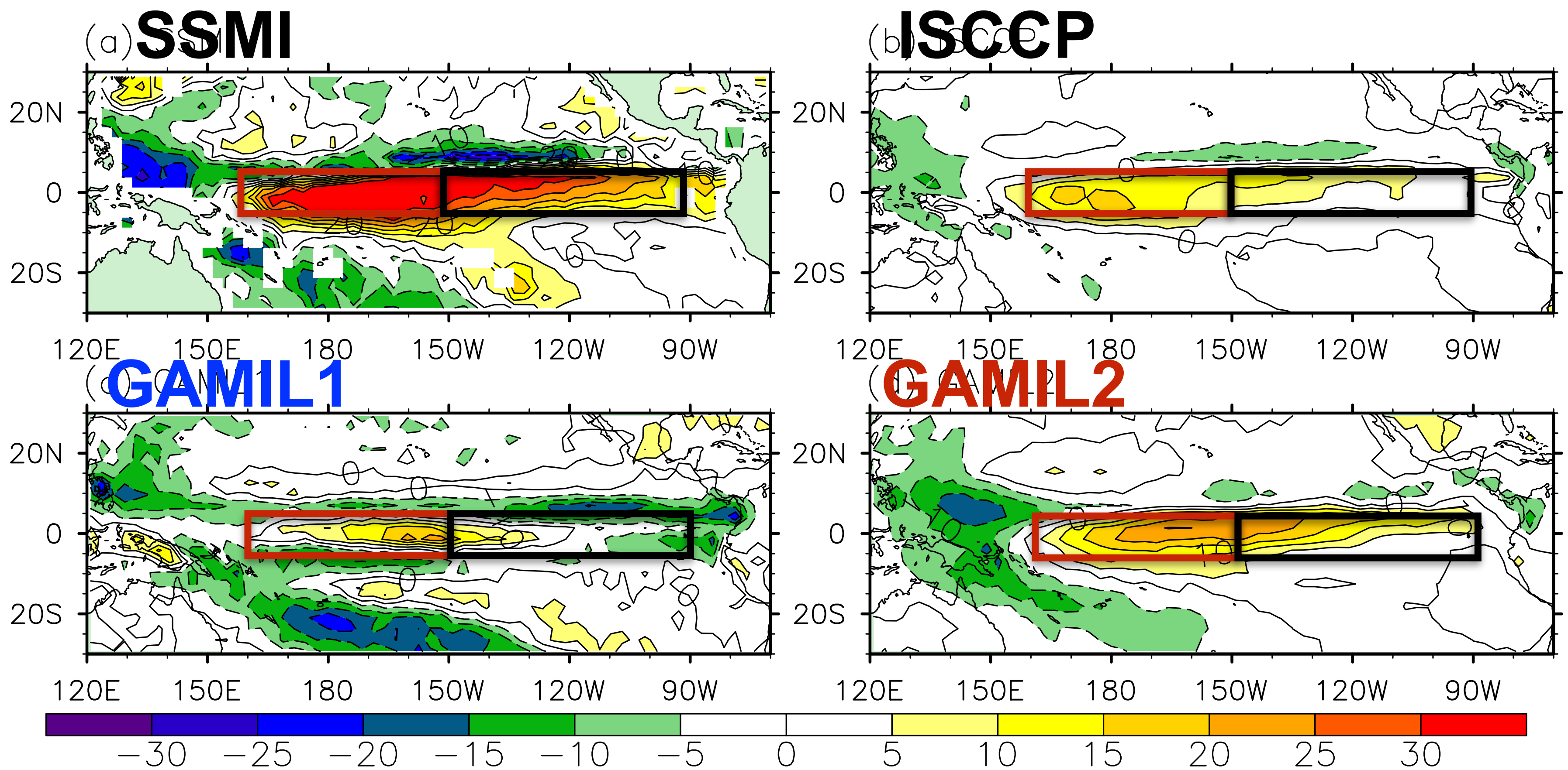
- In Nino 4 region, both models underestimate the total and high cloud response and overestimate the low cloud response compared to ISCCP.
- In Nino 3 region, the negative low-cloud response in GAMIL1 agree well with its positive SWCF response east of 120W.

500hPa vertical velocity response



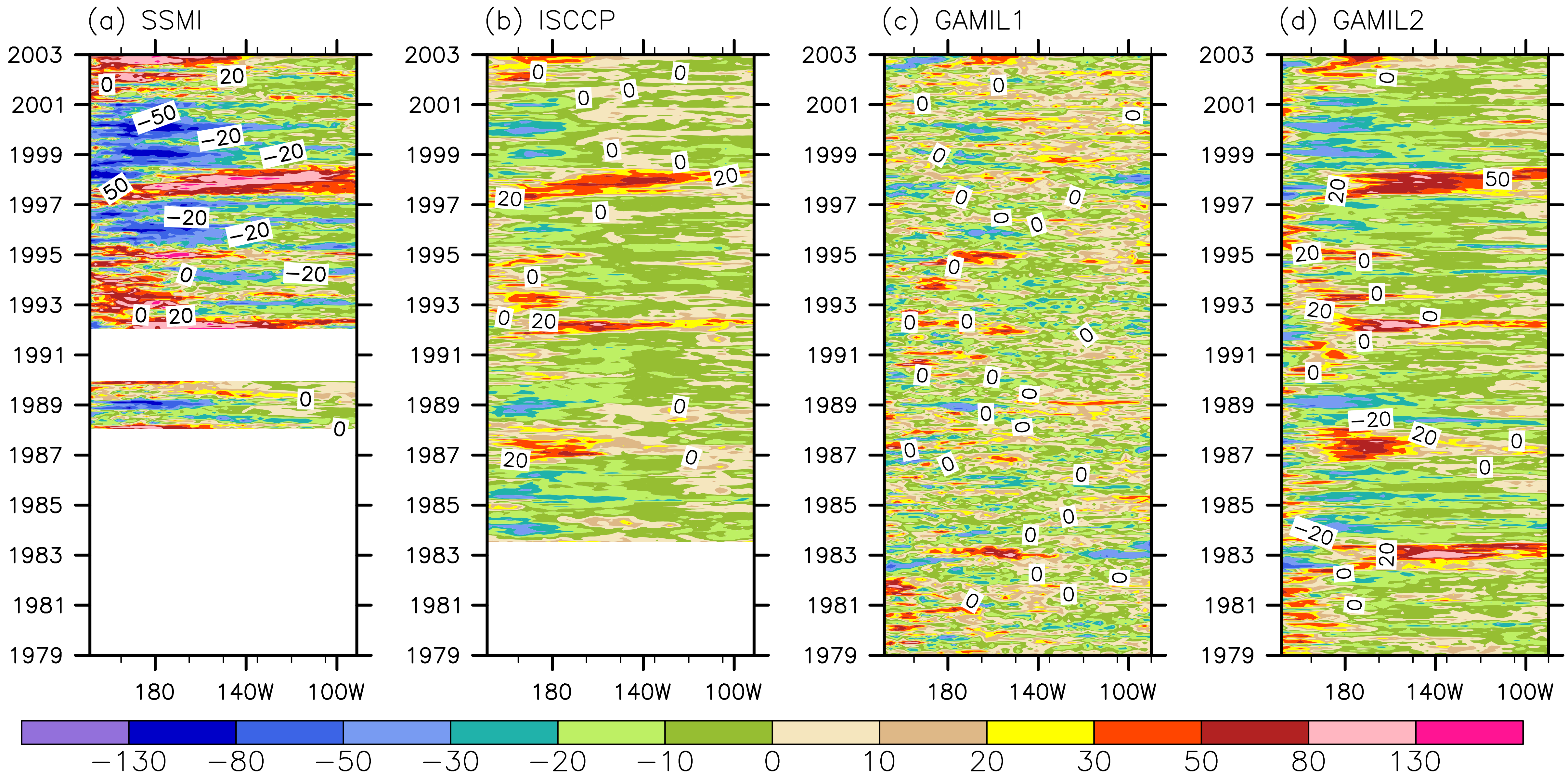
	Niño 4	Niño 3
OBS	-1.4[NCEP] -1.6[ECMWF]	-1.5[NCEP] -1.2[ECMWF]
GAMIL1	-0.97	-0.6
GAMIL2	-1.8	-1.0

Total liquid water path response



	Niño 4	Niño 3
OBS	29.5[SSMI] 11.8[ISCCP]	22.4[SSMI] 5.0[ISCCP]
GAMIL1	3.1	-3.3
GAMIL2	12.9	10.8

Hovmöller plots of total liquid water path anomalies

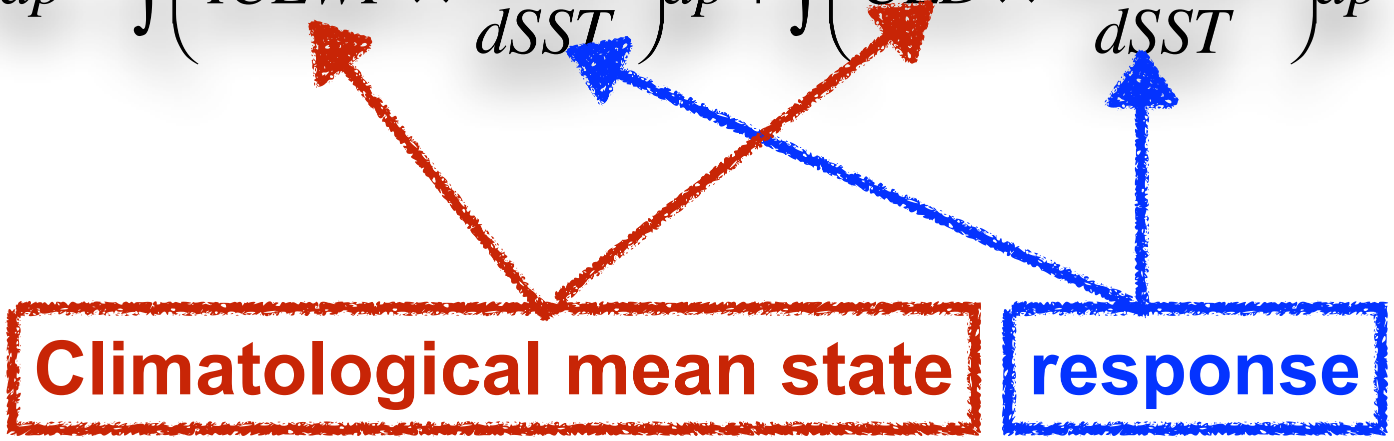


- ☑ the magnitude of positive LWP anomalies during strong El Niño (such as 1986, 1991, 1997) is larger than that of negative LWP anomalies during strong La Niña (1988/1989 and 1999/2000).
- ☑ the non-linearity between weak and strong ENSO events exists in the eastern equatorial Pacific.

Division of total LWP response

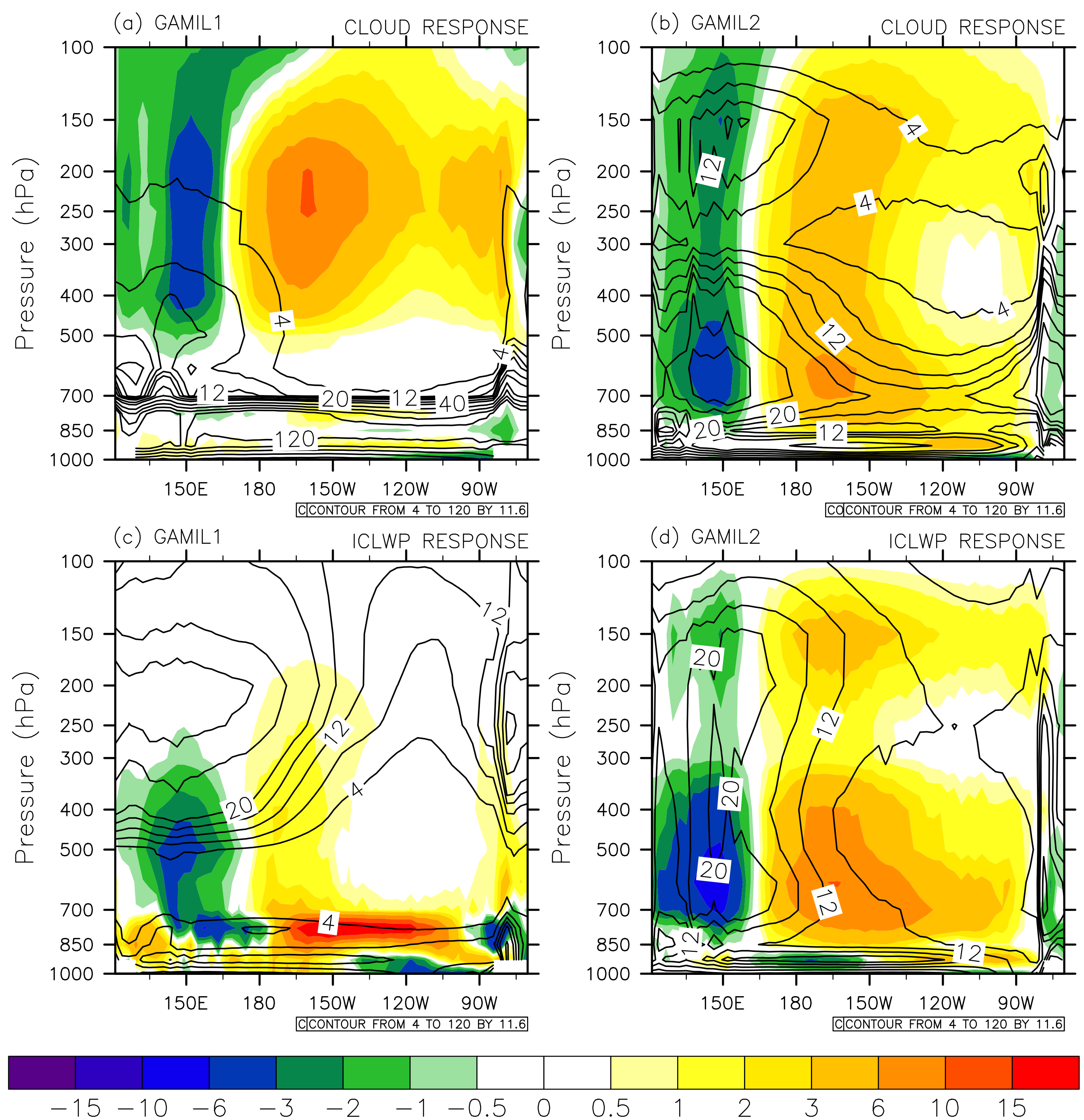
Since LWP is the vertical integral of the product of cloud fraction and in-cloud LWP (ICLWP), the LWP response can be roughly divided into two parts(the term related to the response of column-integrated pressure is neglected):

$$\alpha_{lwp} \approx \int \frac{d(CLD \times ICLWP)}{dSST} dp = \int \left(ICLWP \times \frac{dCLD}{dSST} \right) dp + \int \left(CLD \times \frac{dICLWP}{dSST} \right) dp$$

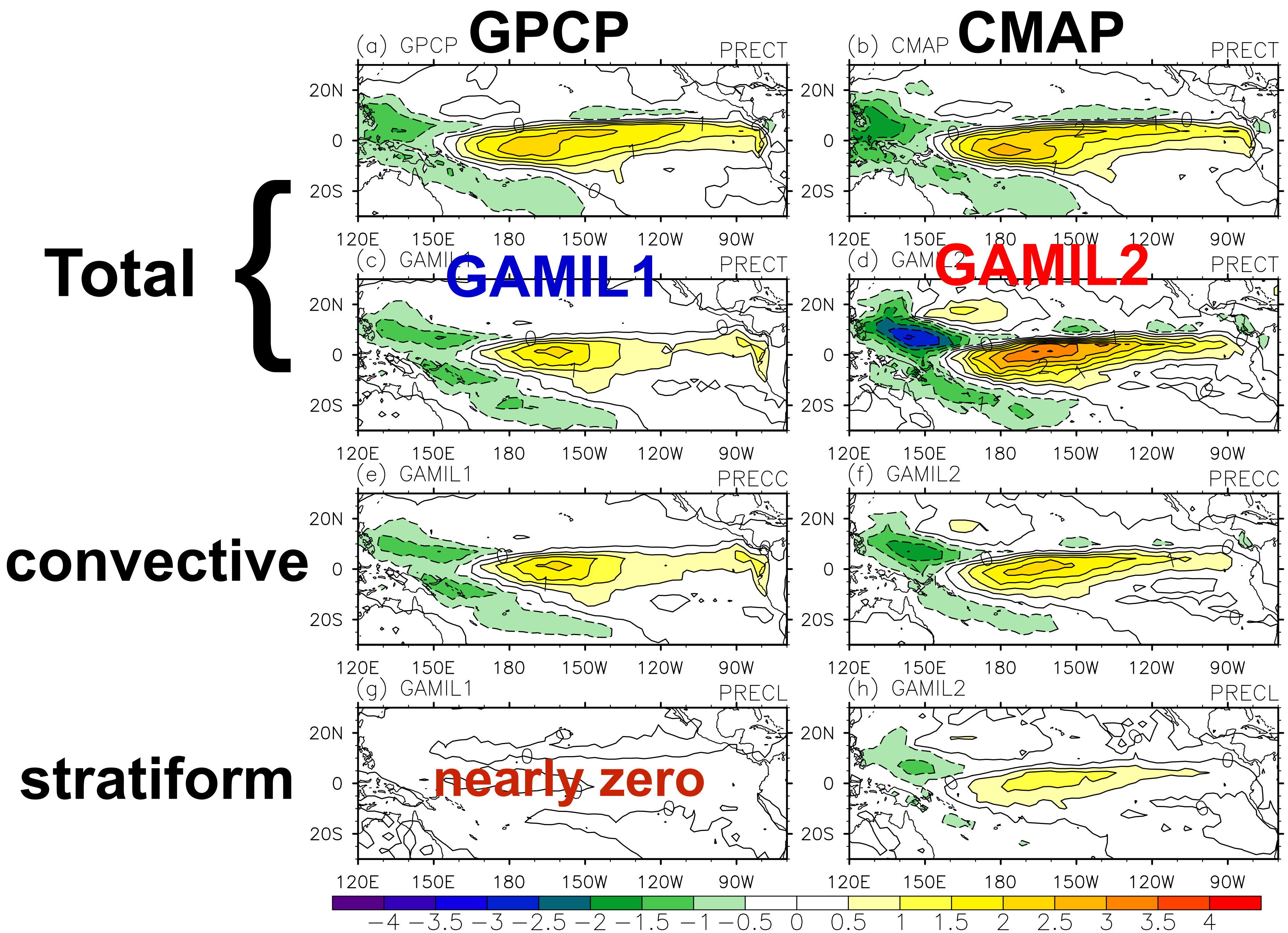


ICLWP and CF response(color)& annual mean ICLWP and CF (cont)

- There are two distinct features of this vertical mismatch in GAMIL1, contributing to its weak total LWP response. First, large (small) ICLWP response approximately coincides with small (large) mean cloud amount values. Similarly, large (small) cloud response approximately coincides with small (large) ICLWP. Both contribute to small integrands on the rhs of eq. above. Second, the positive/negative cloud amount and ICLWP anomalies above/in the boundary layer offset each other in the eastern equatorial Pacific.
- On the other hand, the large positive ICLWP and cloud anomalies match well with their climatological mean distributions in GAMIL2. Thus, when vertically integrated the product of cloud amount response (mean state) and ICLWP mean state (response) is much smaller in GAMIL1 than in GAMIL2.

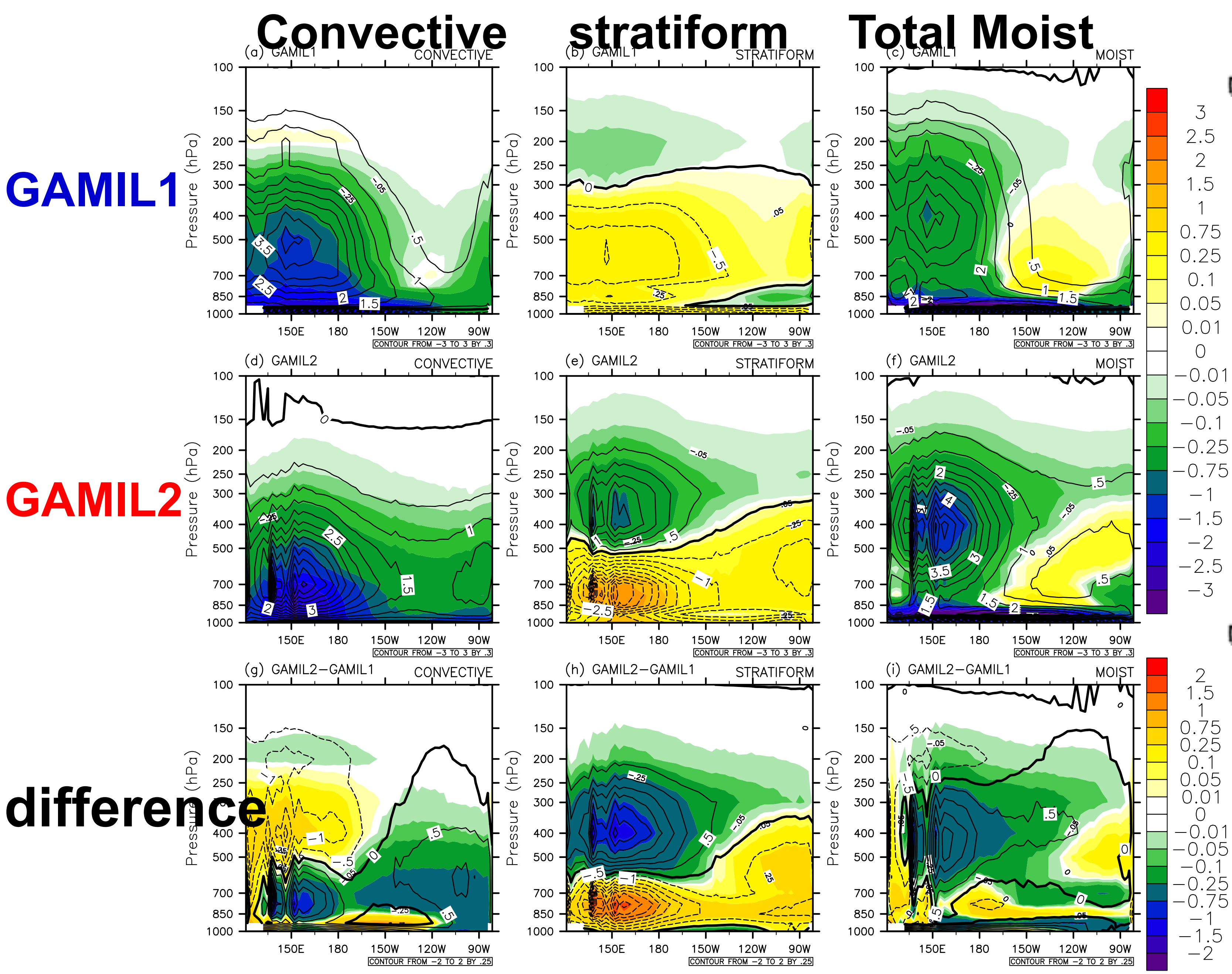


Total,convective and stratiform rainfall response



- The significantly different regression values between the two models are due to contributions from both convective and stratiform precipitation.
- Particularly, GAMIL1 predicts very small (nearly zero) stratiform/ grid-scale precipitation response in the equatorial Pacific.

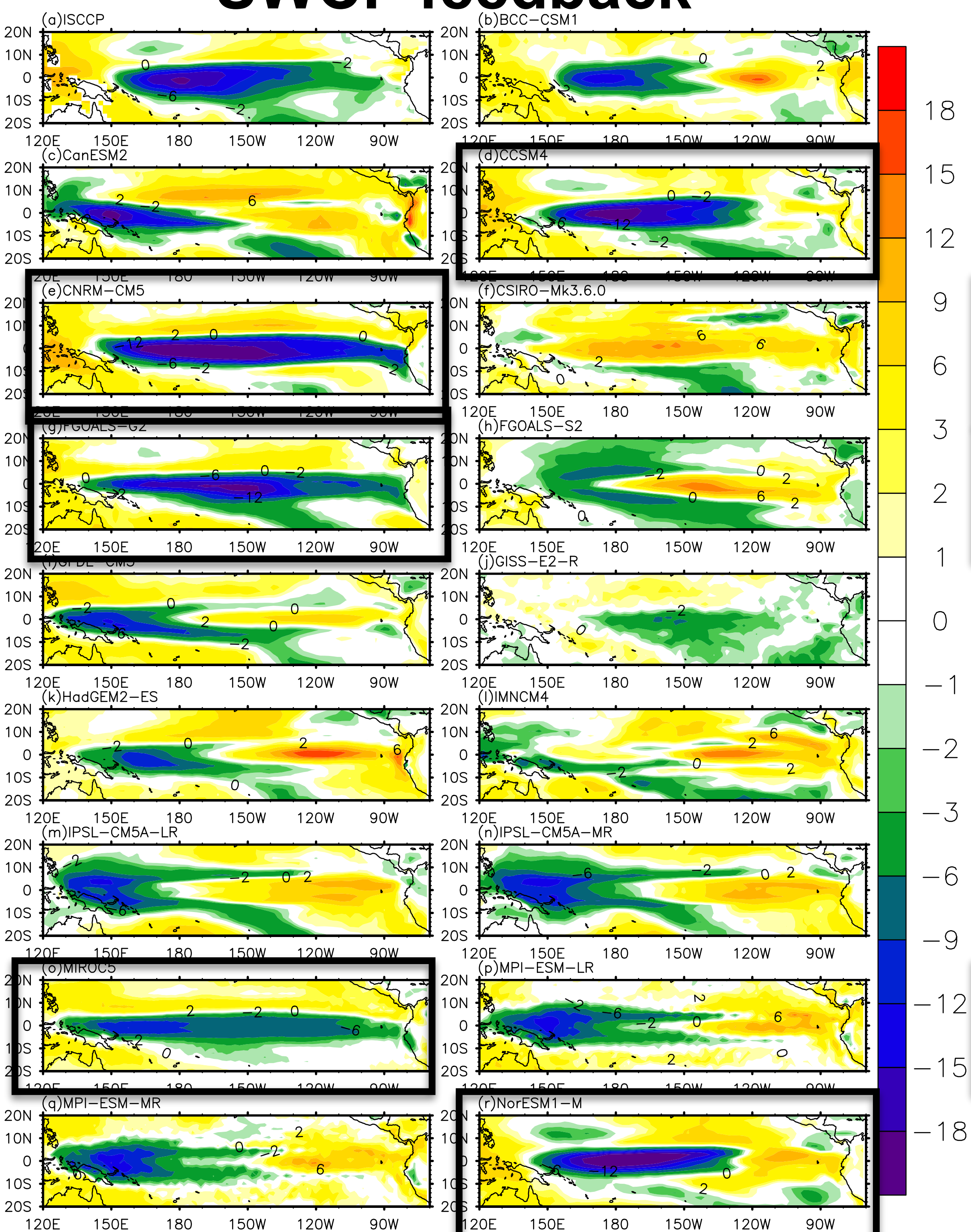
heating rate(cont)& moistening rate (color)



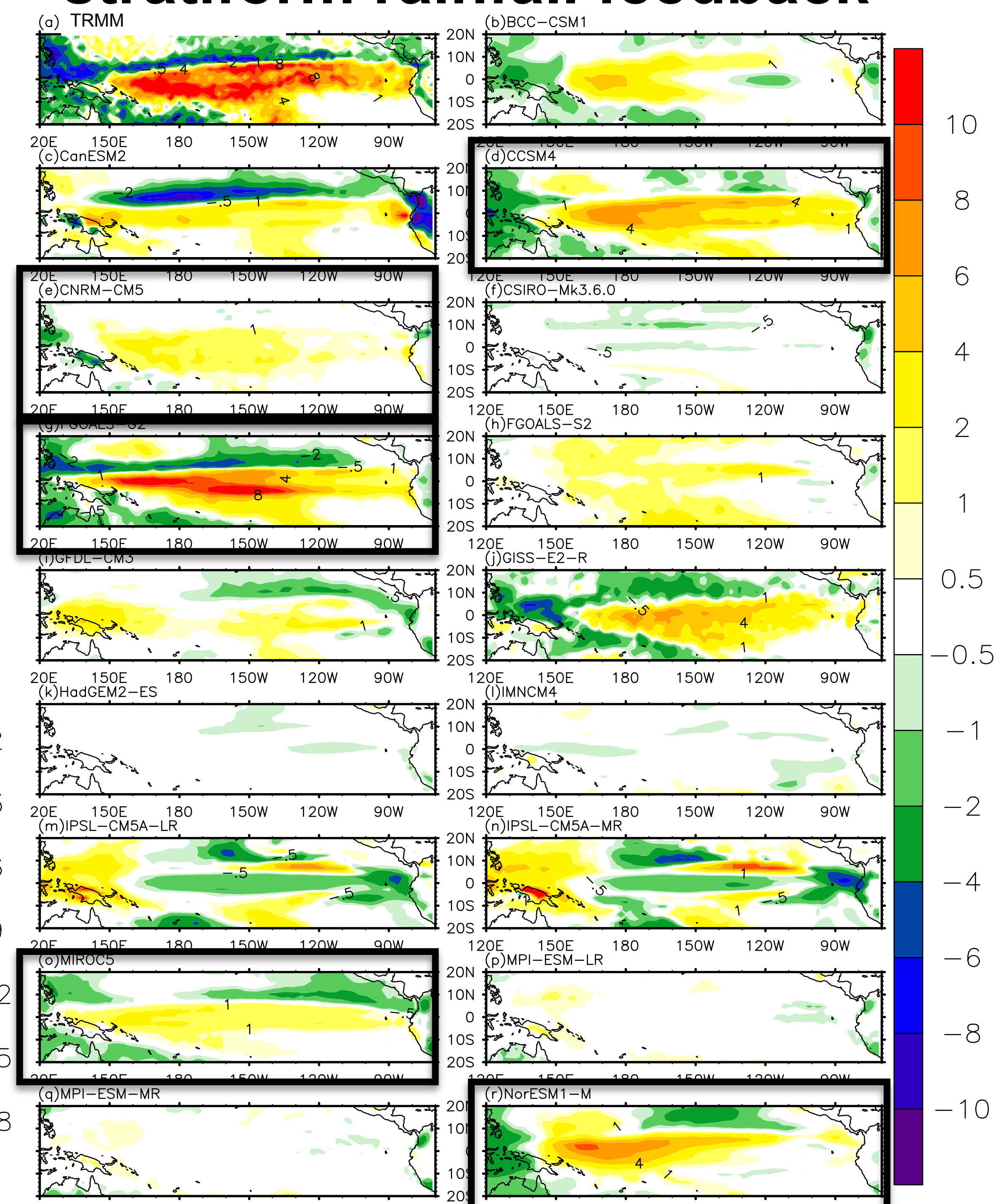
- The weak condensation process in the upper levels contributes to its wet bias (affecting high cloud), though this bias is also attributed to the deficiency of too frequent convection occurrence (Dai and Trenberth, 2004; Zhang and Sun, 2006).
- Both the weak evaporation in the stratifrom cloud process and the small stratiform precipitation lead to too much water content (or LWP) in the lower levels.

CMIP5 models

SWCF feedback



stratiform rainfall feedback



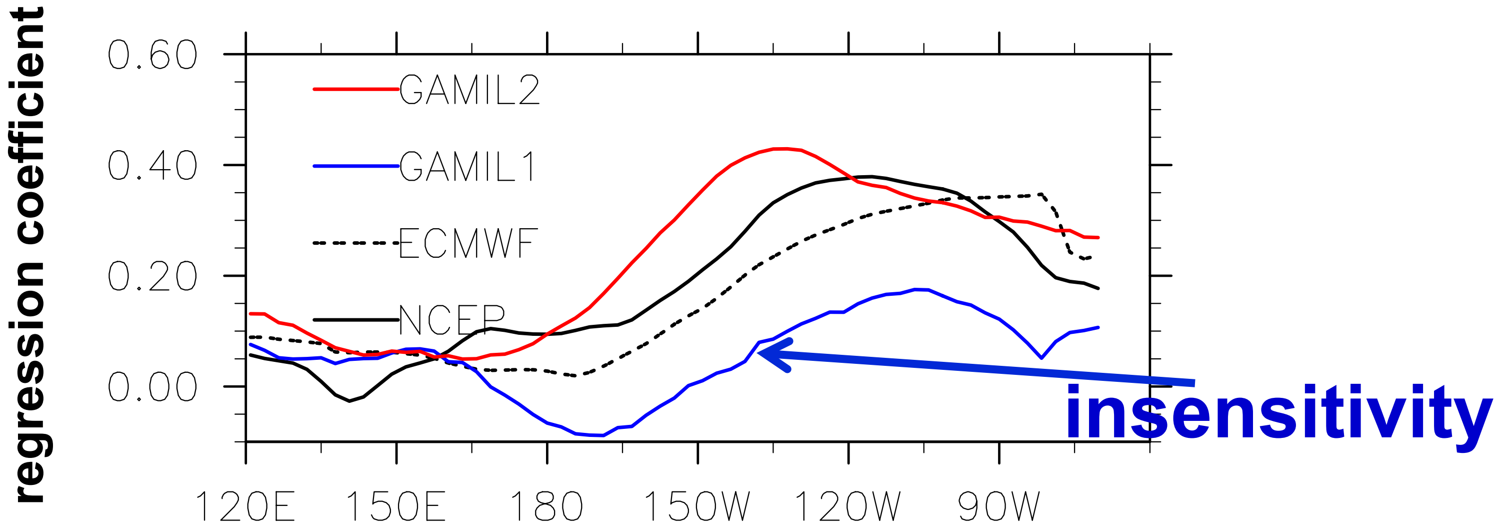
ongoing work

Summary

- **All of the improved dynamical (vertical velocity at 500hPa), cloud amount and total liquid water path (LWP) responses contribute to the SWCF response improvement in GAMIL2.**
- **The enhanced stratiform condensation and evaporation in GAMIL2 play an important role in improving the simulations of multi-year annual mean water vapor (or relative humidity), cloud fraction and in-cloud liquid water path (ICLWP) and hence in reducing the bias of the SWCF and rainfall response.**

Thank you for your attention!

700-hPa temperature response



The less sensitivity means that under colder surface conditions, the lower troposphere is more stable, resulting in more boundary layer clouds and excessive low-cloud response in GAMIL1.

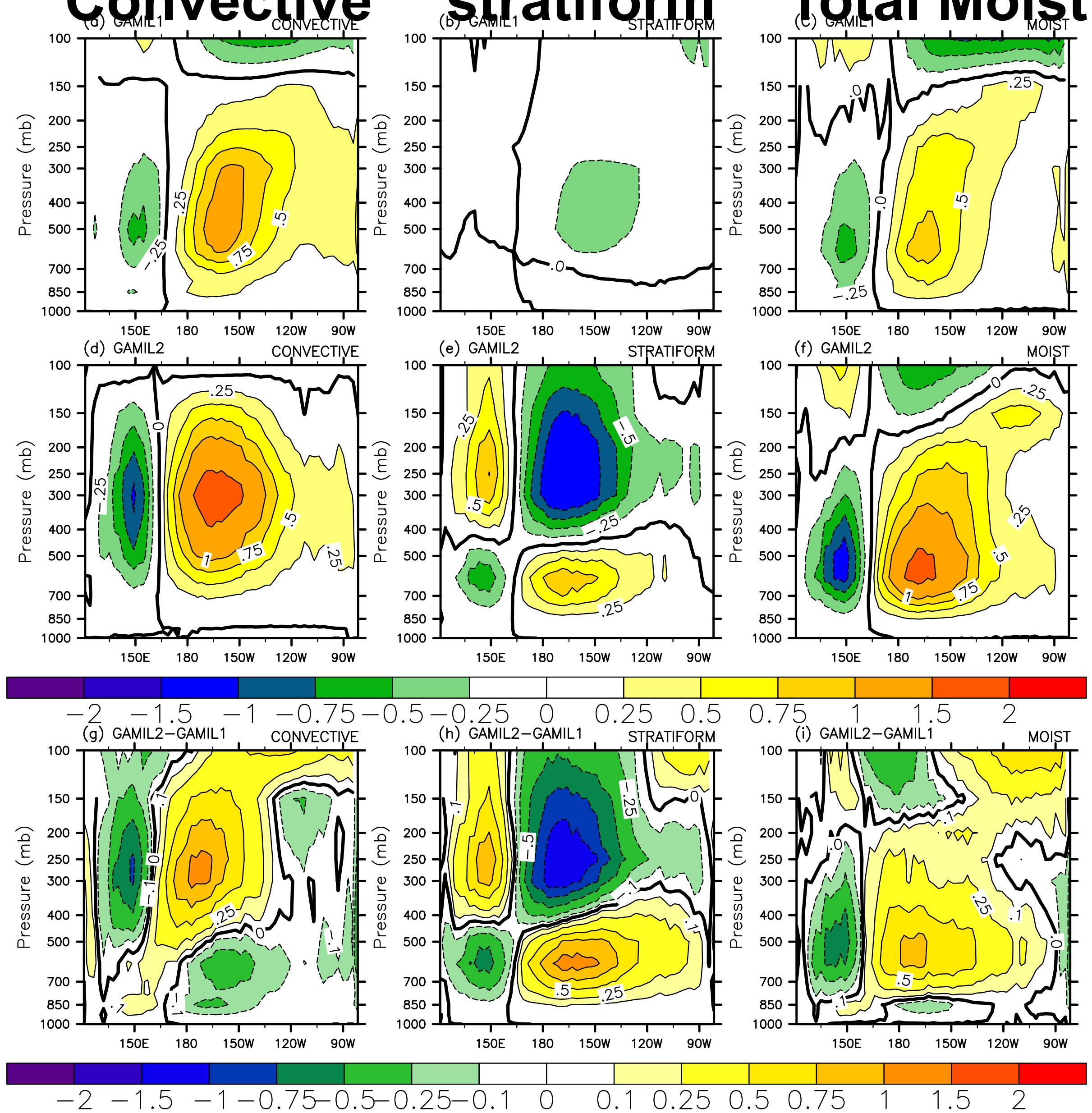
heating rate response to El Niño warming

Convective **stratiform** **Total Moist**

GAMIL1

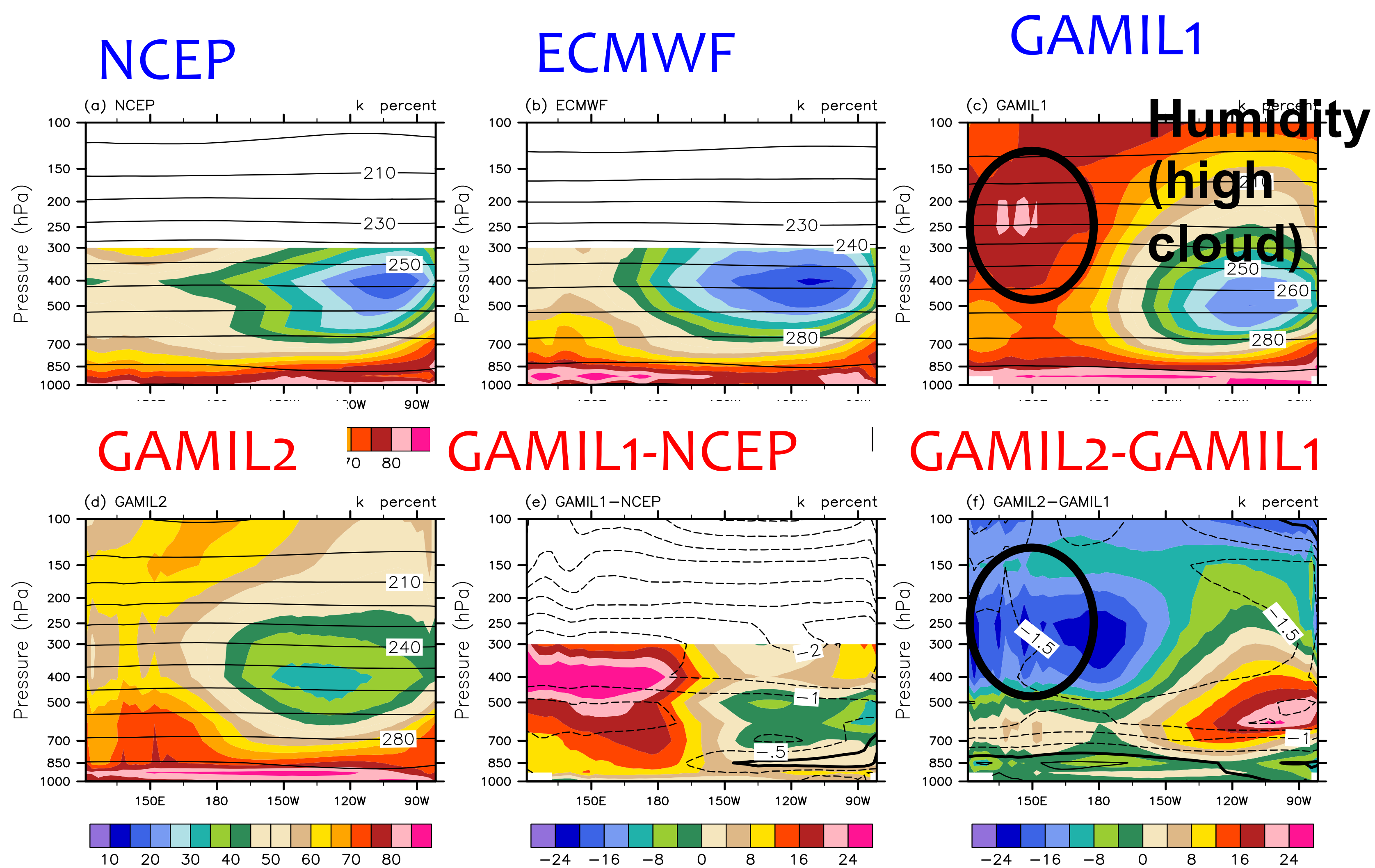
GAMIL2

Difference



The different responses of the stratiform heating in two models contribute to their differences of 700-hPa temperature response, SWCF and rainfall responses.

Vertical Profile of temperature (cont) &relative humidity (color)



Regression coefficients in Niño 3 under SSTA>0 and SSTA<0

	Observation (SSTA>0/SSTA<0)	GAMIL1 (SSTA>0/SSTA<0)	GAMIL2 (SSTA>0/SSTA<0)
α_{swcf}	**-8.9/0.899**[ISCCP]	**-2.6/2.3**	**-10.4/-0.77**
α_{pr}	**1.72/0.17**[GPCP] **1.51/0.16**[CMAP]	**0.91/0.17**	**1.82/0.07**
α_{prc}	——	**0.95/0.21**	**1.17/0.05**
α_{prl}	——	**-0.04/-0.04**	**0.64/0.01**
α_{lwp}	**24.1/5.5**[SSMI] **7.3/-1.3**[ISCCP]	**0.07/-0.97**	**14.5/1.2**
$\alpha_{\omega 500}$	**-1.9/-0.6**[NCEP] **-1.6/-0.17**[ECMWF]	**-0.76/-0.01**	**-1.4/-0.1**
α_{cldtot}	**6.56/-0.16**[ISCCP]	**3.0/0.77**	**3.9/0.16**
α_{cldhgh}	**5.2/0.33** [ISCCP]	**6.4/3.2**	**5.2/1.7**
α_{cldmid}	**3.6/0.7** [ISCCP]	**1.6/0.18**	**4.2/-0.05**
α_{cldlow}	**-0.87/0.26** [ISCCP]	**-0.87/-1.53**	**2.7/0.21**