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

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# outline

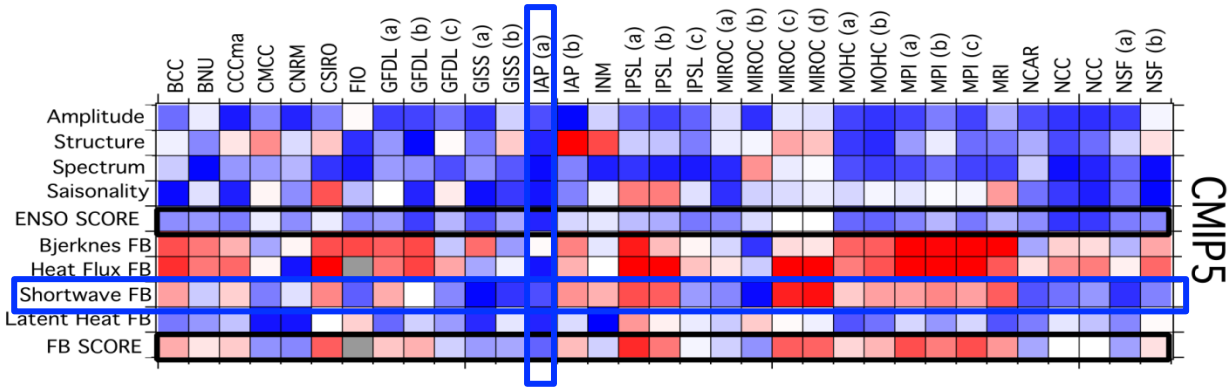
- Background & motivation
- Models, Data & Analysis Method
- Results
- Summary

# Background

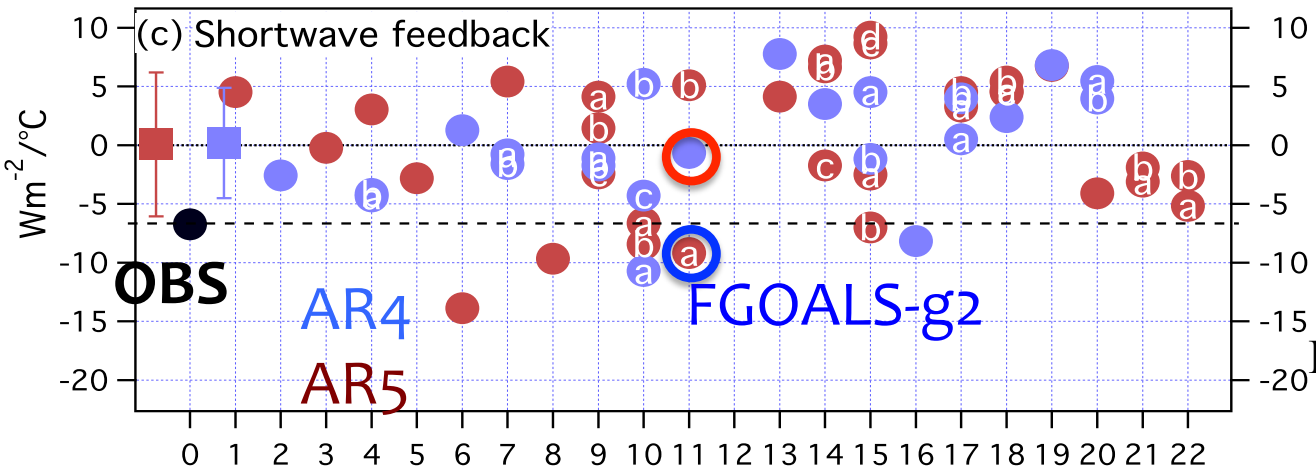
**The shortwave cloud radiatvie forcing (SWCF) feedback in the Equatorial Pacific is one of the dominant components of negative heat flux feedbacks that drive the El Niño-Southern Oscillation (ENSO) evolution (Zebiak and Cane, 1987; Guilyardi et al., 2009b; Lloyd et al., 2011, 2012; Bellenger et al., 2013). It tends to be negative for El Niño warming and positive for La Nina cooling.**

# What causes the SWCF feedback improvement in FGOALS-g2?

# Motivation




FGOALS-g2




Bellenger et al., 2013, Clim. Dyn.

Kim et al., 2013, Clim. Dyn.; Chen et al., 2013, J. Climate

# Motivation

1) Previous studies emphasize 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.)

2)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, have not received enough attention

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# Model Description

| | GAMIL1.0 | GAMIL2.0 |
|---|---|---|
| Horizontal Resolution | 2.8°×2.8° | 2.8°×2.8° |
| 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 scheme | Rasch and Kristjansson (1998) / Zhang et al. (2003） | Morrison and Gettelman (2008) |
| Convective cloud fraction | Rasch and Kristjansson (1998) | Xu and and Krueger, 1991 |

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

# Experiment Design

**Two sets of numerical experiments using GAMIL1 and GAMIL2 are performed following the standard setting for Phase II of the Atmospheric Model Intercomparison Project (AMIP II) with the same forcing recommended by the CMIP5 project. Each experiment runs for 28 years from January 1975 to December 2002, and the last 24 years of the model output (1979 to 2002) are used for analyses and comparisons.**

# Observation Data

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:

ERA-interim (1979-2002); NCEPII (1979-2002)

# Method

**For an atmospheric variable F (such as SWCF, cloud fraction),**

**its response to SST is measured by the linear regression coefficient** $\alpha$

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

**where FA is the anomaly of F after removing the annual cycle, and is the SST anomaly averaged over the Niño 3 (5°S ~5°N, 150°W~90°W) region from the HadISST.**

# Results

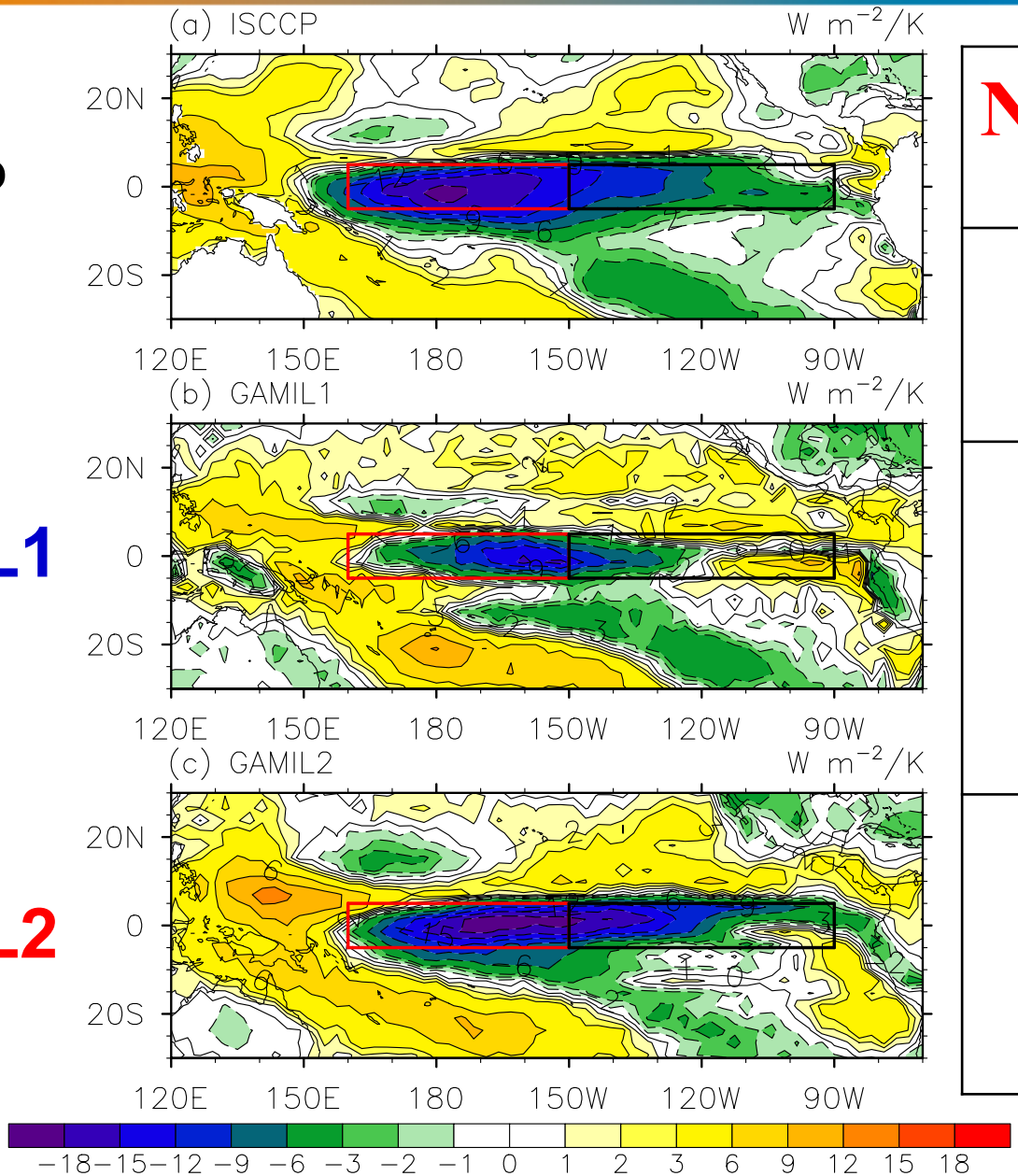
- Response Analysis
  - Strength
  - Nonlinearity
- Climatological mean state

# SWCF response

ISCCP

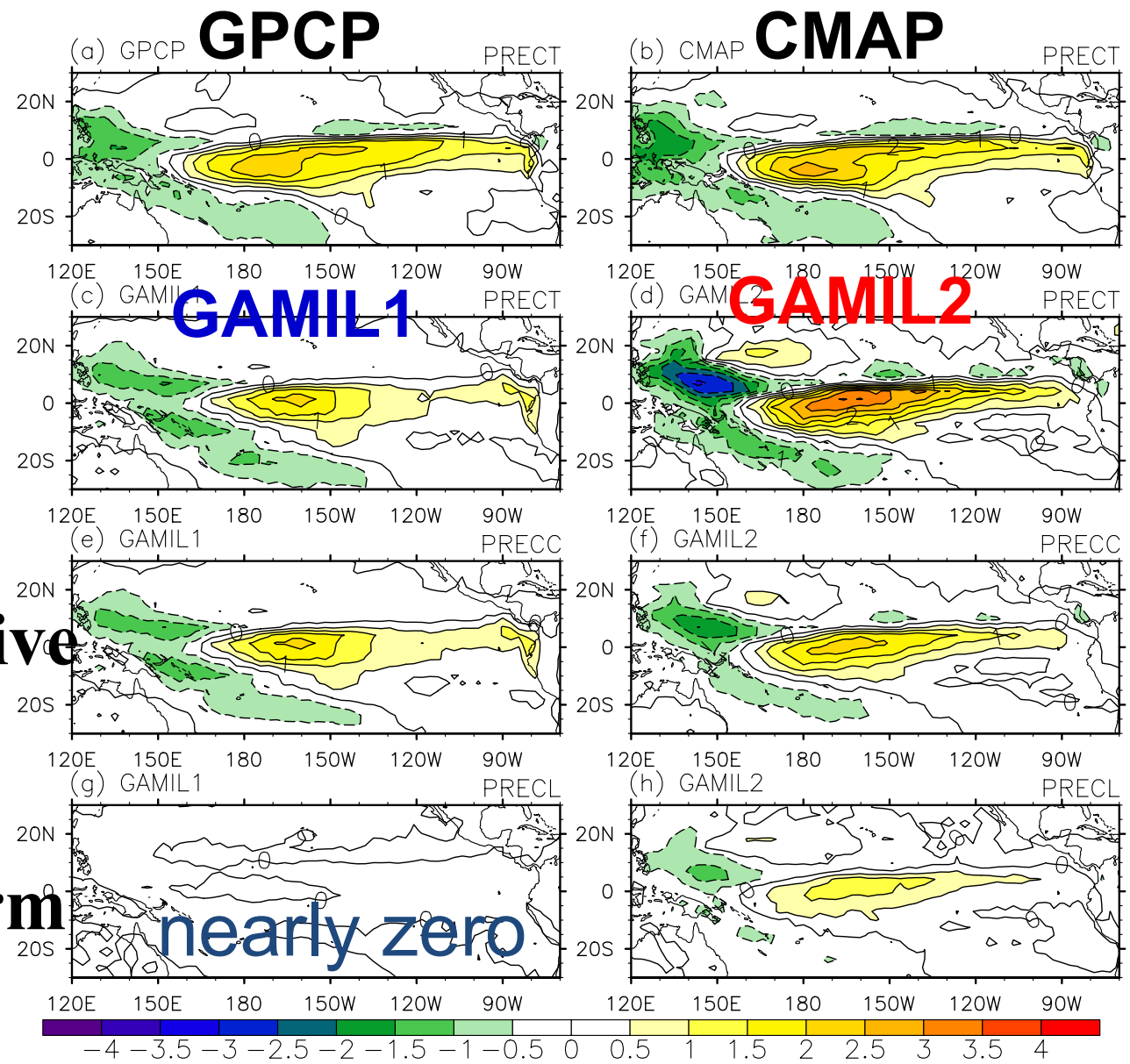
GAMIL1

GAMIL2




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

# Total, convective and stratiform rainfall response




**Total**

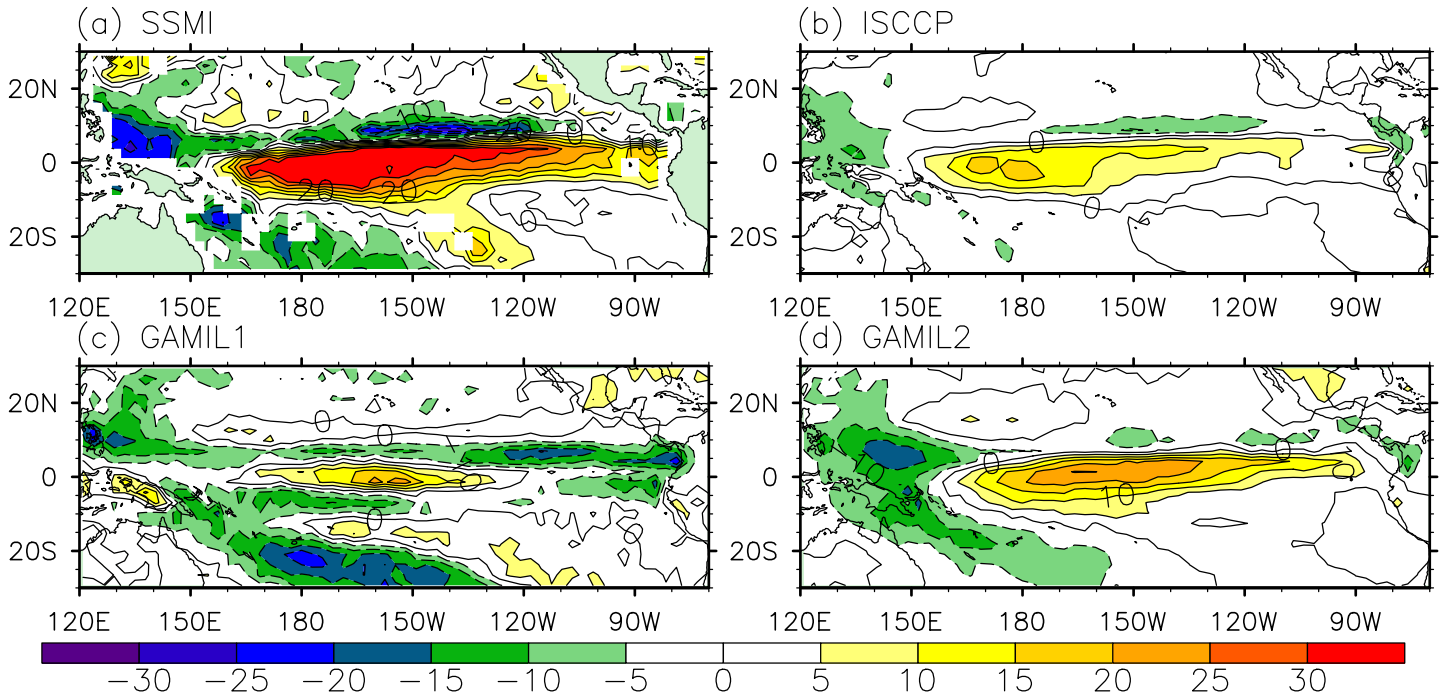
**Convective**

**Stratiform**

nearly zero

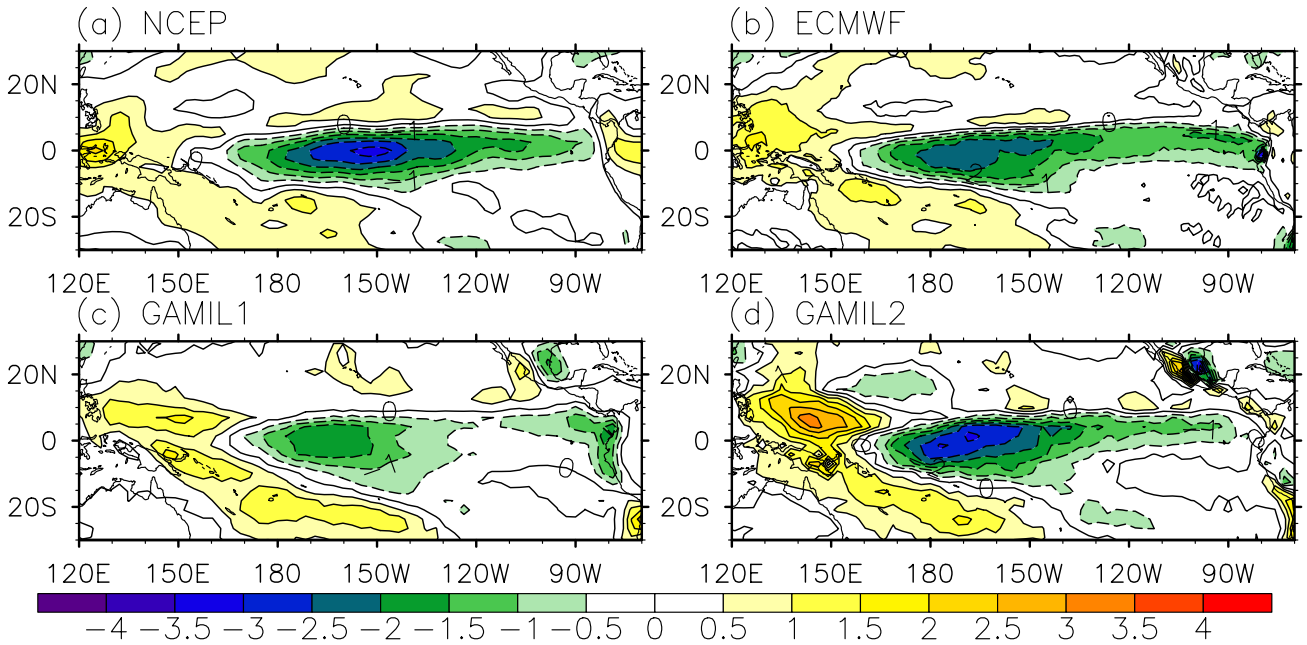
**The significantly different responses between two models are due to the contributions from both convective and stratiform precipitation**

# Total Liquid Water Path response



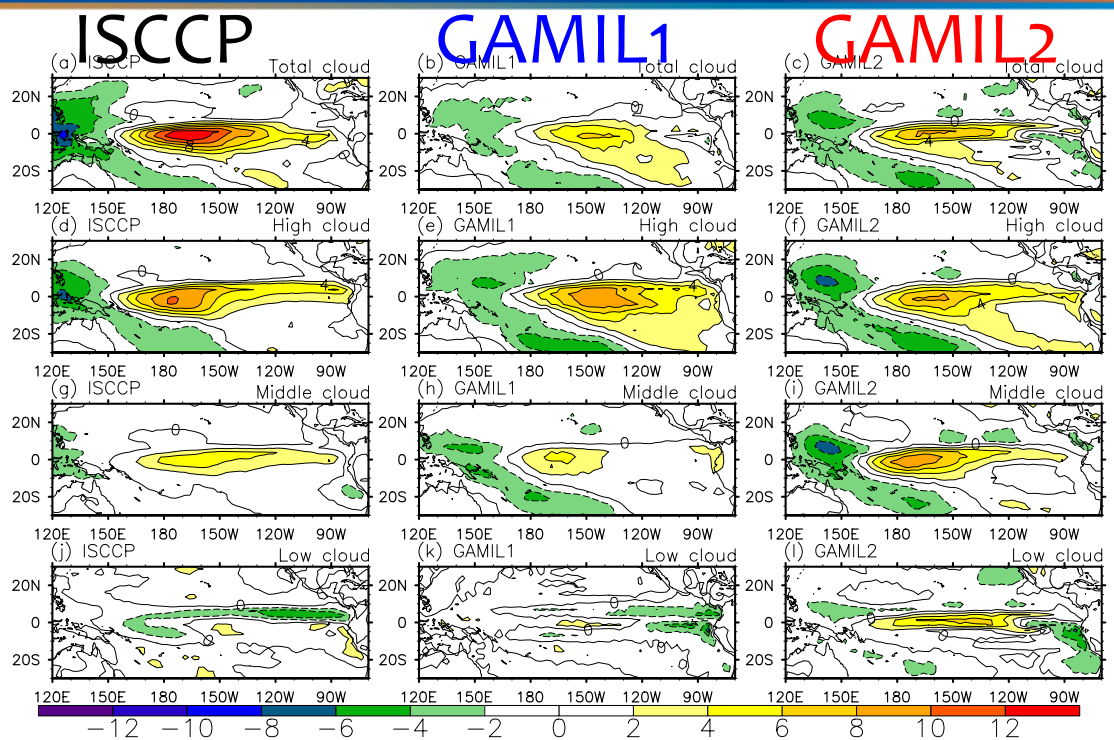

| | Niño 4 | Niño 3 |
|---|---|---|
| OBS | $24.1^{SSMI}$ $7.3^{ISCCP}$ | $5.5^{SSMI}$ $-1.3^{ISCCP}$ |
| GAMIL1 | 0.07 | -0.97 |
| GAMIL2 | 14.5 | 1.2 |

# 500-hPa vertical velocity (dynamical) response




| | Niño 4 | Niño 3 |
|---|---|---|
| OBS | -1.4$^{NCEP}$<br>-1.6$^{ECMWF}$ | -1.5$^{NCEP}$<br>-1.2$^{ECMWF}$ |
| GAMIL1 | -0.97 | -0.6 |
| GAMIL2 | -1.8 | -1.0 |

# Cloud fraction response




| | Observation (Niño 4/ Niño 3) | GAMIL1 (Niño 4/ Niño 3) | GAMIL2 (Niño 4/ Niño 3) |
|---|---|---|---|
| **Total cloud fraction** | **8.8/5.2 ISCCP** | **1.7/2.8** | **4.0/2.6** |
| **High cloud fraction** | **7.5/3.9 ISCCP** | **2.8/6.6** | **4.3/4.1** |
| **Middle cloud fraction** | **3.4/3.0 ISCCP** | **2.0/1.3** | **5.6/2.6** |
| **Low cloud fraction** | **-1.2/-0.44 ISCCP** | **0.46/-1.4** | **2.3/2.0** |

# Division of LWP response

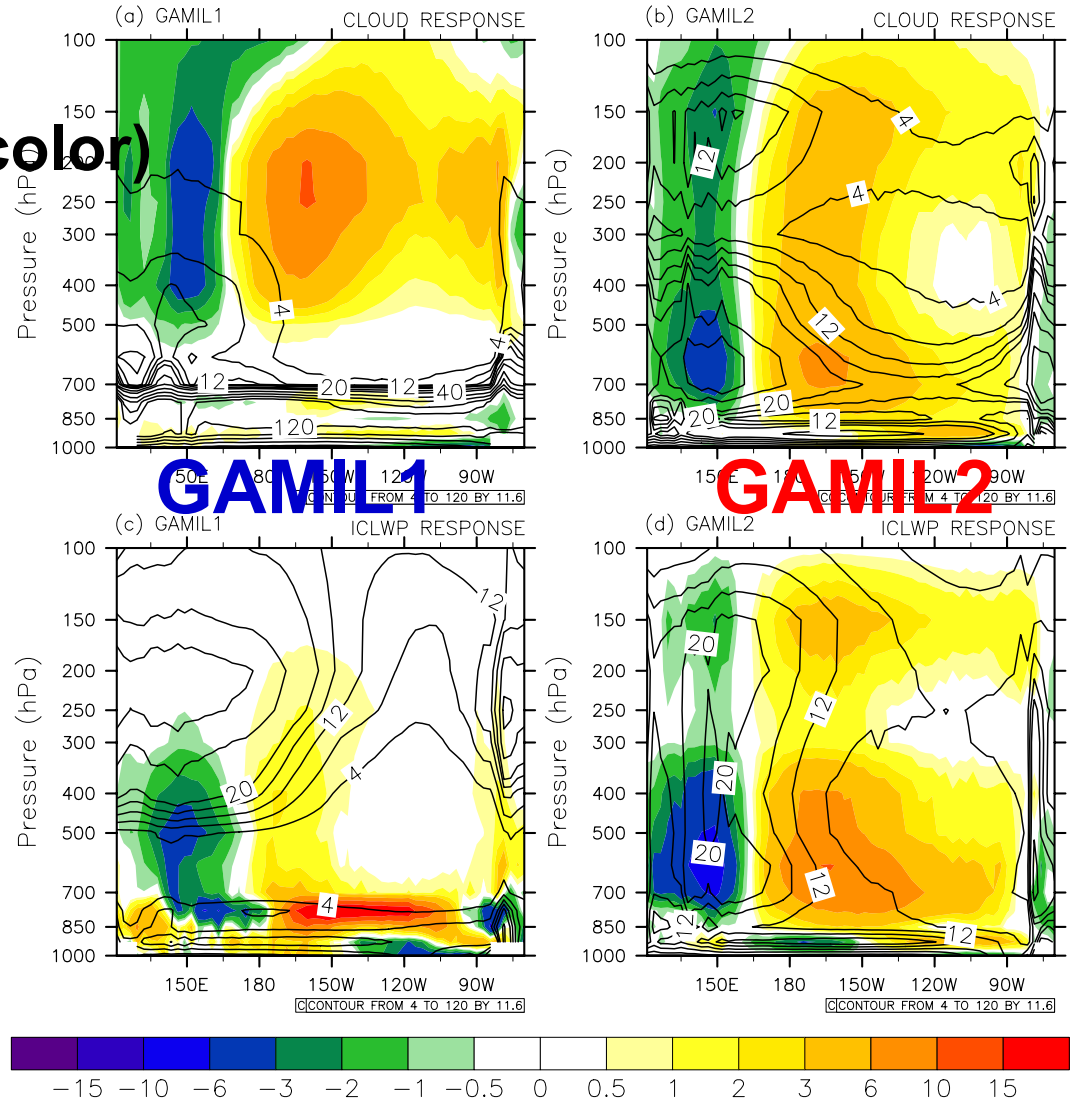
From the above analyses, the LWP is the dominant factor contributing to the large differences in SWCF response between GAMIL1 and GAMIL2. Since LWP is the vertical integral of the product of cloud fraction and in-cloud LWP (ICLWP), the LWP response can be divided into two parts:

$$\alpha_{lwp} = \int \frac{\partial(CLD \times ICLWP)}{\partial SST} dp = \int ICLWP \times \frac{\partial CLD}{\partial SST} dp + \int CLD \times \frac{\partial ICLWP}{\partial SST} dp$$

**Climatological mean state** **Response**

**cloud fraction response(color)**
**& mean ICLWP (contour)**

**ICLWP response(color)**
**& mean Cloud (contour)**



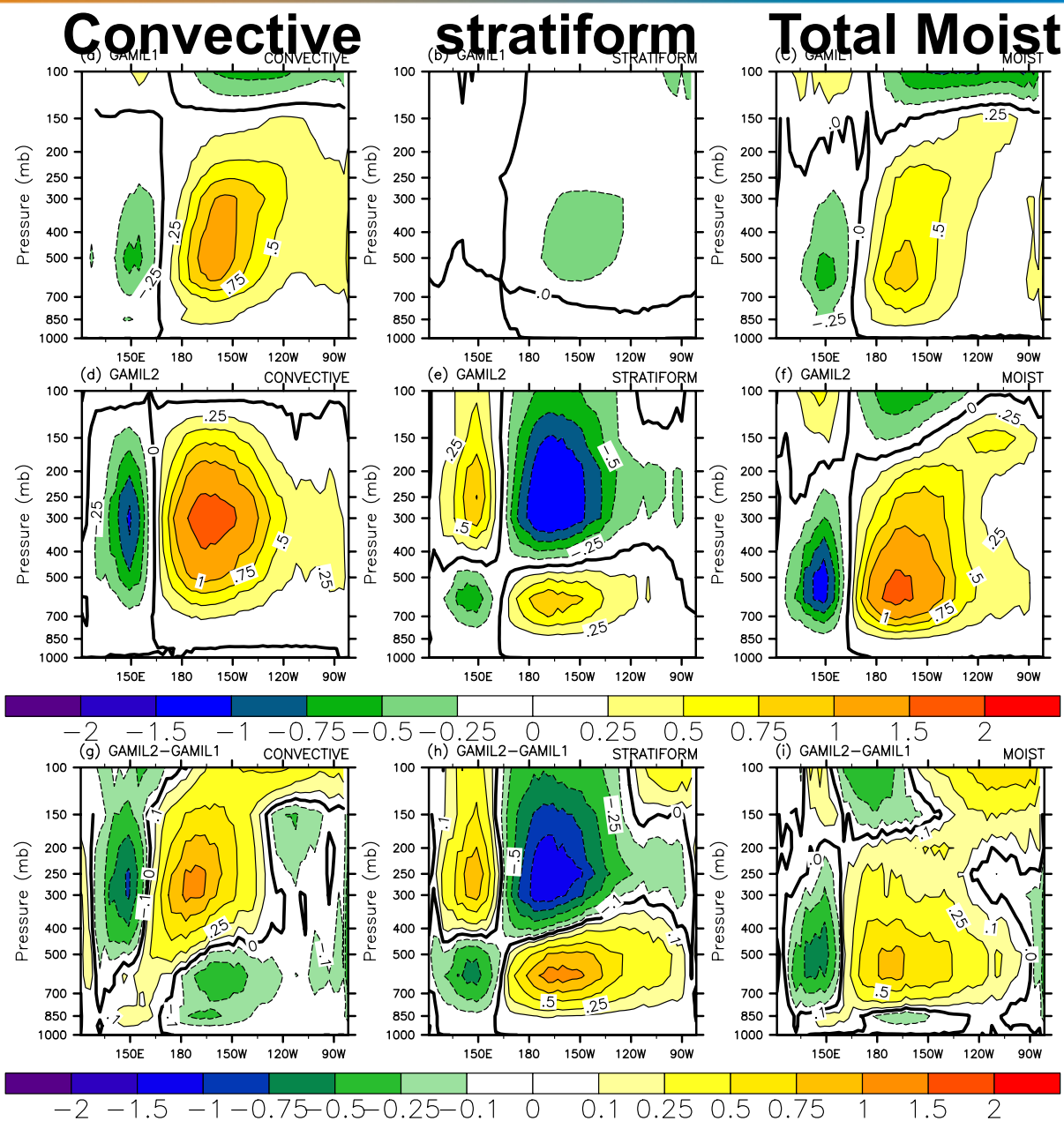
# Regression coefficients in Niño 3 under SSTA>0 and SSTA<0

| | Observation (SSTA>0/SSTA<0) | GAMIL1 (SSTA>0/SSTA<0) | GAMIL2 (SSTA>0/SSTA<0) |
|---|---|---|---|
| $\alpha_{swcf}$ | -8.9/0.899 ISCCP | -2.6/2.3 | -10.4/-0.77 |
| $\alpha$ | 1.72/0.17 GPCP | 0.91/0.17 | 1.82/0.07 |
| $\alpha_{cldlow}$ | -0.87/0.26 ISCCP | -0.87/-1.53 | 2.7/0.21 |

the responses of the atmospheric variables to El Niño are much stronger than those to La Niña in both observations and simulations.

Improvement is seen from GAMIL1 to GAMIL2

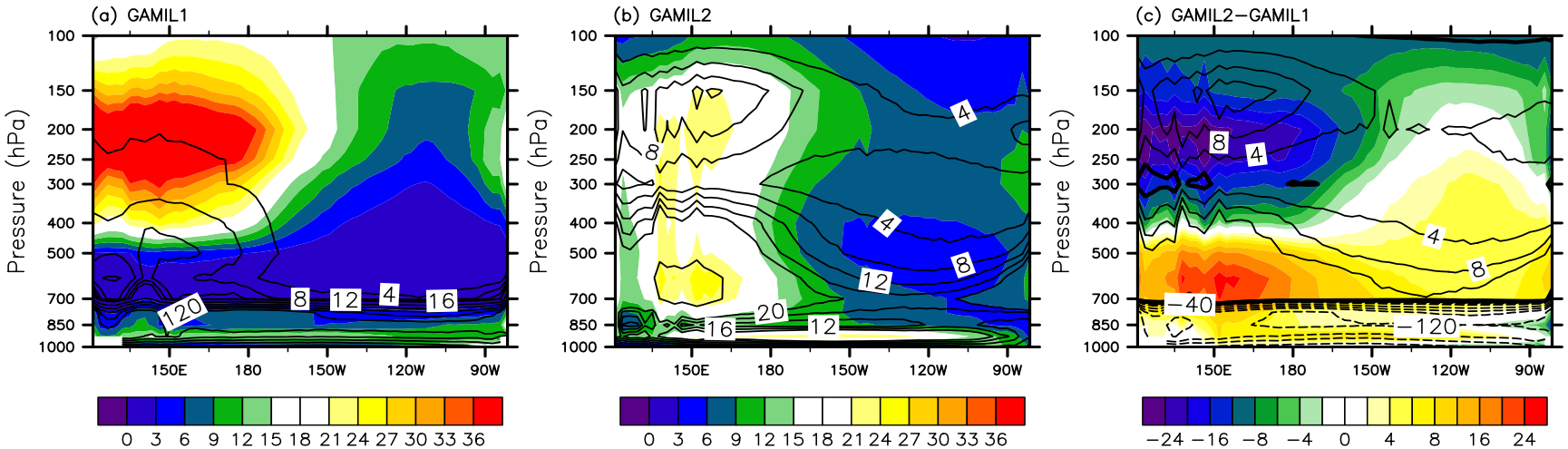
# heating rate response to El Niño warming




The different responses of the stratiform heating in two models contribute to their differences of SWCF and rainfall responses.

# Climate mean cloud fraction (color) and in-cloud liquid water path (contour)

GAMIL1 GAMIL2 GAMIL2-GAMIL1




**The vertically mismatched distribution of cloud and ICLWP in GAMIL1 resembles their response to El Niño, indicating the response errors largely come from the errors in climatological mean state.**

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❶ The enhanced stratiform condensation and evaporation in GAMIL2 play a key 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 biases of SWCF and rainfall responses to El Niño.

❷ The improvement comes from the better dynamical (vertical velocity at 500hPa), cloud amount and total liquid water path (LWP) responses.

❸ The largest contribution to the SWCF response improvement is from LWP in Niño 4 and from low cloud cover and LWP in Niño 3.

❹ As a crucial factor in the low cloud response, the atmospheric stability change in the lower layers is significantly influenced by the non-convective heating variation during La Niña.

# Thank you for your attention!

# Annual mean cloud fraction