The Role of Atmosphere Feedbacks During El Niño

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1. Motivation

General Circulation Models (GCMs) still have trouble simulating the observed frequency, structure and amplitude of the El Niño-Southern Oscillation (ENSO) phenomenon.

Recent work *(Guilyardi et al., 2004, 2008)* suggests that the atmosphere plays a dominant role in determining the properties of ENSO. The work described here builds on this by analyzing the two main ENSO-relevant ocean-atmosphere feedbacks in the WCRP CMIP3 multimodel dataset. Can differences in the modelled feedbacks help explain the diverse ENSO simulation in models?

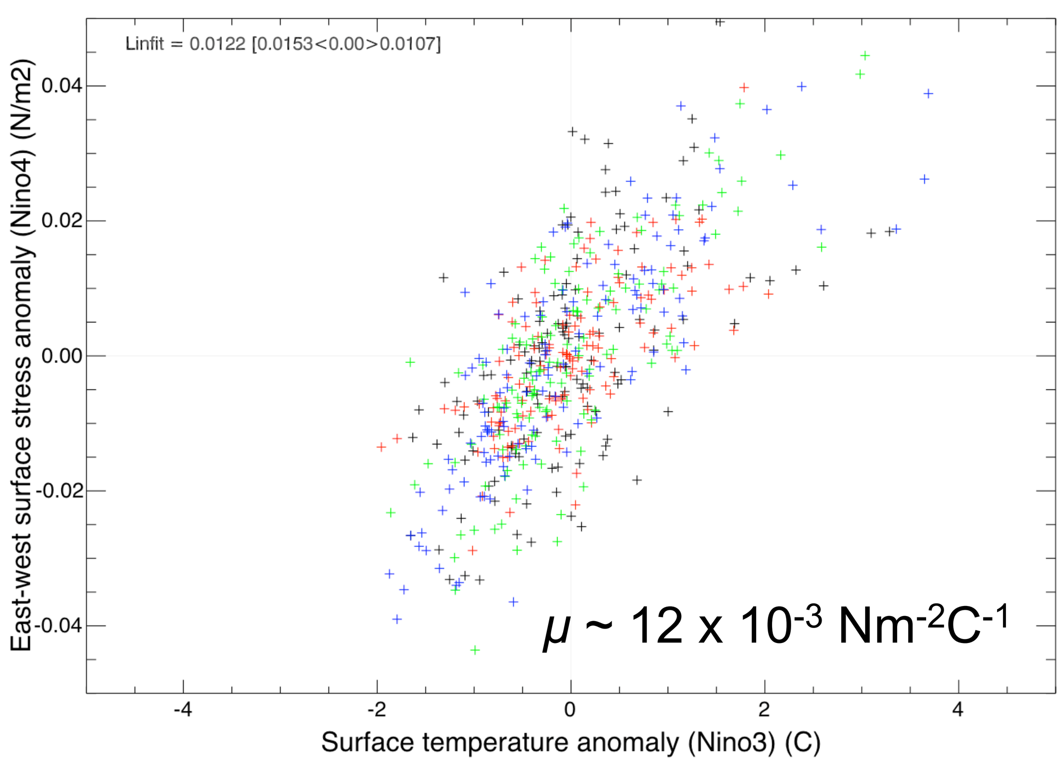
2. ENSO Ocean-Atmosphere Feedbacks

There are two main ocean-atmosphere feedbacks relevant to ENSO:

- **Dynamical (Bjerknes) feedback: $\tau_x A = \mu SSTA$**
  Positive feedback (μ) linking zonal wind stress ($\tau_x A$) and SST anomalies ($SSTA$).
- **Thermodynamical feedback: $QA = \alpha SSTA$**
  Negative feedback (α) linking total surface heat flux (QA) and SST anomalies.

These feedbacks are diagnosed in GCMs by linearly regressing the relevant variables:

(a)



(b)

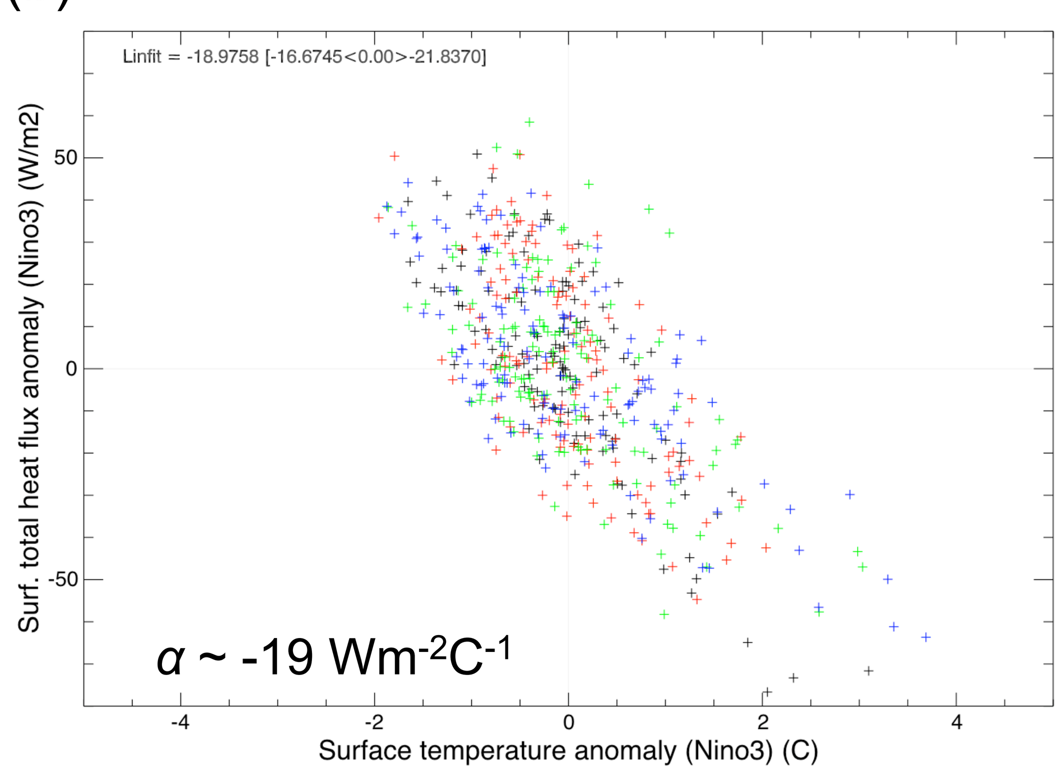


Figure 1. The two ocean-atmosphere feedbacks in ERA40: (a) Zonal surface stress anomaly (Niño4) against SST anomaly (Niño3). The linear fit gives a value for μ (b) Surface total heat flux anomaly (Niño3) against SST anomaly (Niño3). The linear fit gives a value for α. Each point represents one monthly average.
Niño4 = 160E-150W, 5N-5S (West Pacific)
Niño3 = 150W-90W, 5N-5S (East Pacific)

3. The Feedbacks in the GCMs

a) Annual averages of μ and α

Both feedbacks are generally underestimated in the models compared to the ERA40 and OAFlux (α only) reanalysis data. The zonal wind stress coupling with an East Pacific SST change is too weak, as is the heat flux damping response. There is thus an error compensation between the two feedbacks.

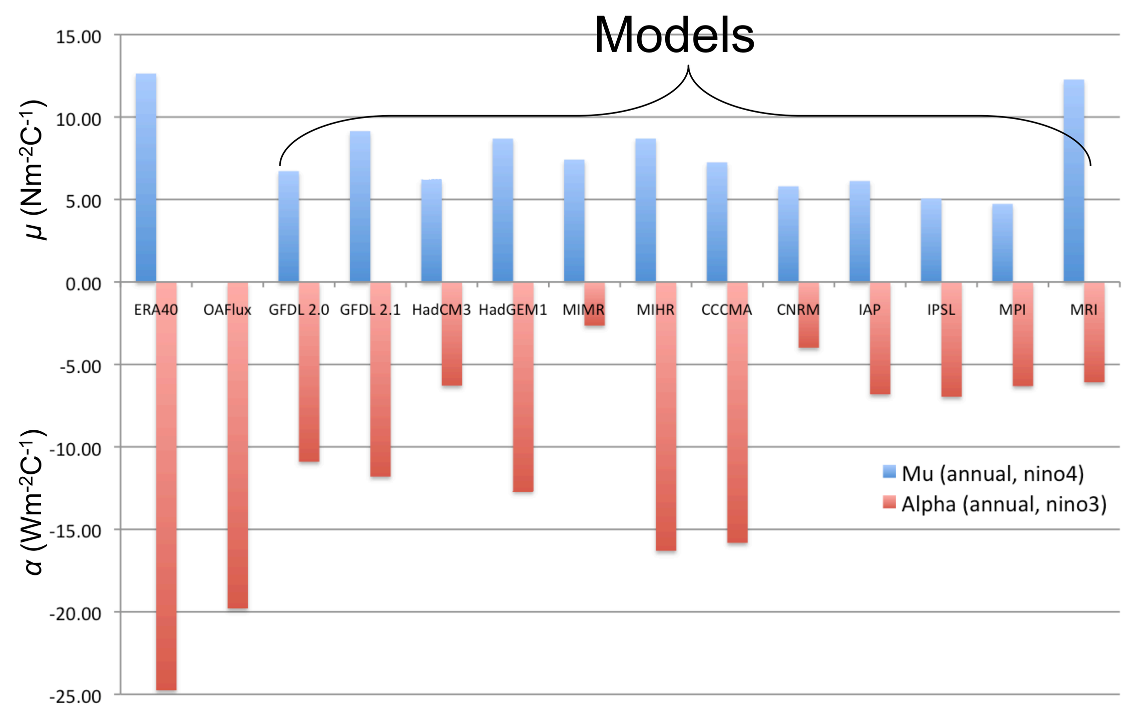


Figure 2. Average annual Niño 4 μ (blue bars) and Niño 3 α (red bars) for ERA40, OAFlux (α only) and 12 CMIP3 models.

b) Relationship to ENSO strength

The relationship of α to the ENSO strength (measured by the SST Niño 3 standard deviation) shows that the models with strongest damping have the weakest ENSO, whereas those with the weakest damping generally exhibit a stronger ENSO.
However, the corresponding μ graph (not shown) shows the opposite result to expected - this will need to be investigated.

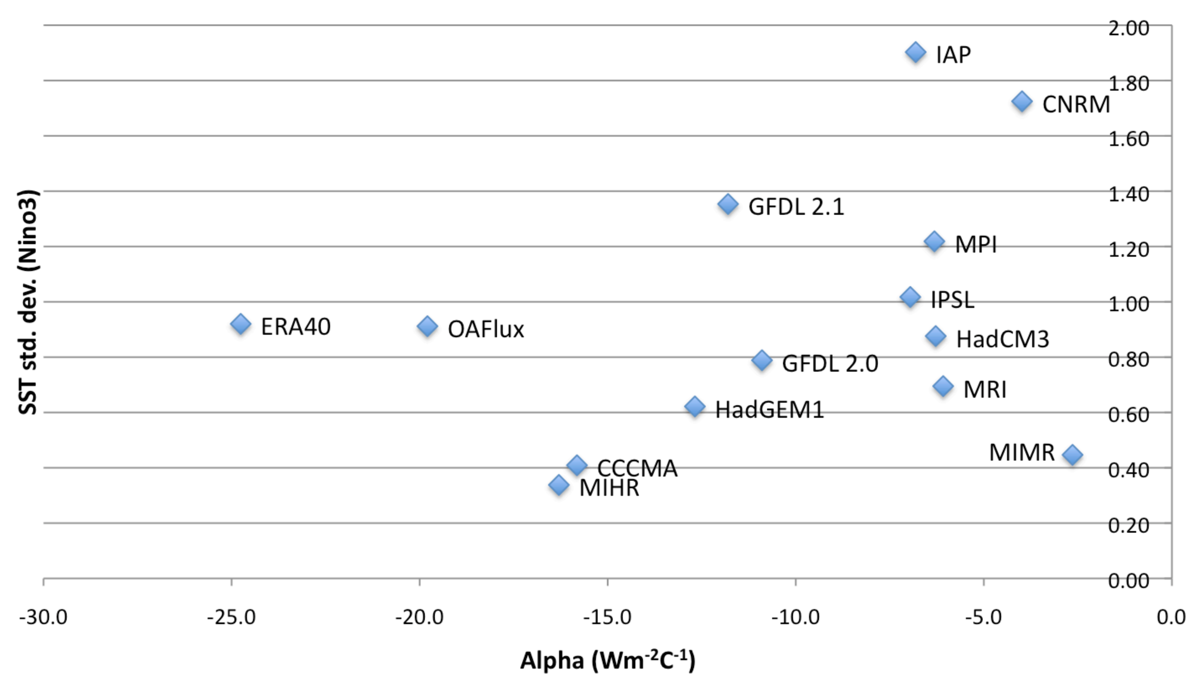


Figure 3. ENSO amplitude against α feedback for ERA40, OAFlux and 12 CMIP3 models.

4. Understanding the α Feedback

a) Splitting up the net feedback

The total heat flux can be separated into four components: shortwave radiation (SW), longwave radiation (LW), latent heat flux (LH) and sensible heat flux (SH). The individual feedbacks are calculated for each of these in the Niño 3 region:

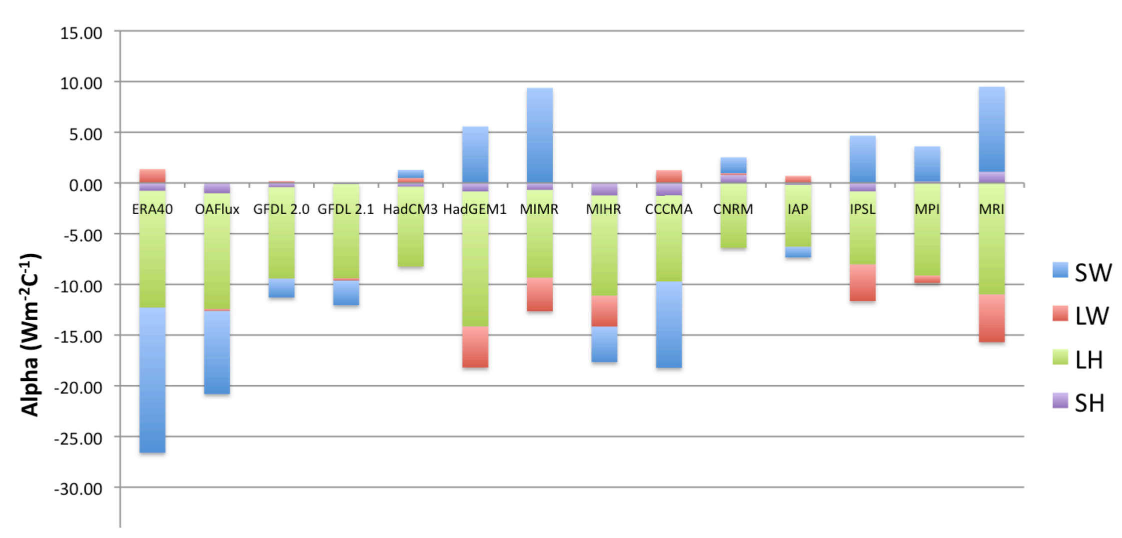


Figure 4. Average annual α feedback components in Niño 3 for ERA40, OAFlux and 12 CMIP3 models.

The latent heat and shortwave feedback components dominate, but it is the shortwave component, α_{SW}, which exhibits the most variation between models.

b) The SW component, α_{SW}

In the East Pacific the sign of α_{SW} depends on the large-scale circulation, with a negative feedback in areas of ascent and a positive feedback in subsident regimes. (R & C, 1991; Philander et al., 1996)
By binning the vertical velocity at 500hPa (w_{500}) according to SST we have calculated the Niño 3 'ascent threshold' for each model, the average SST above the mean state at which ascent occurs.

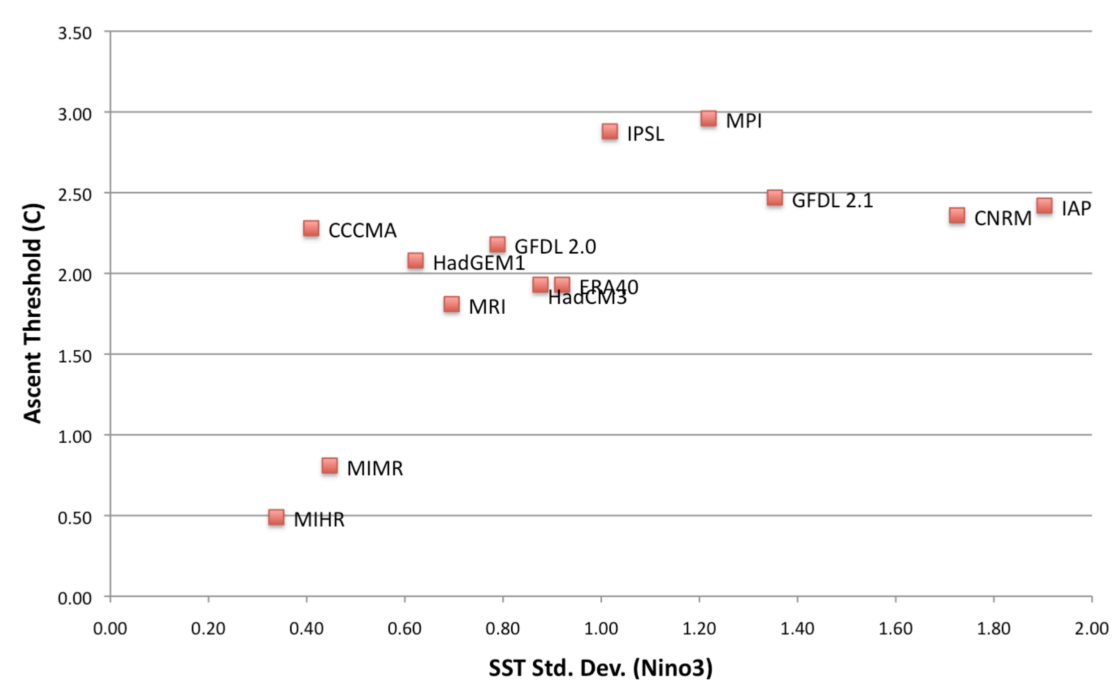


Figure 5. Ascent threshold vs. ENSO amplitude.

The models with the higher ascent thresholds tend to have larger ENSO amplitudes and vice-versa. This could be explained by considering the positive (growing) and negative (damping) α_{SW} regimes below and above the threshold respectively.

5. Conclusions

- The heat flux feedback, α, can be related to the ENSO amplitude in the models.
- The SW component could help explain the model diversity in both overall α and ENSO amplitude.

Next steps:

- Look for links between the feedbacks and the mean state biases in the models.
- Understand the dynamical μ feedback, especially the relationship with ENSO amplitude.

6. References

- Guilyardi, E., Wittenberg, A., Fedorov, A., et al., 2004. *J.Climate*, 17, 4623-4629
- Guilyardi, E., Braconnot, P., Jin, F.-F., et al., 2008. *J. Climate* (submitted)
- Philander, G., Gu, D., Halpern, D., et al., 1996. *J. Climate*, 9, 2958-2972
- Ramanathan, V. and Collins, W., 1991. *Nature*, 351, 27-32