Relationship between tropical Pacific SST and large−scale climate indices in coupled models
Proposal for CMIP2+

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1. Background

Tropical Pacific sea surface temperature (SST) plays a key role in regulating global climate variability and change on intraseasonal to centennial time scales. The relationship between tropical Pacific SST and global climate can often be concisely represented by a simple sensitivity parameter, $S = \Delta CI/\Delta SST$, where ΔCI is a global or large−scale climate index and ΔSST the SST anomaly averaged over a box in the tropical Pacific ocean. Figure 1 illustrates such a relationship, using the observed monthly mean anomalies of global relative angular momentum (ΔAAM) and NINO3.4 index (as ΔSST) (adapted from Huang et al. 2002). Here, the sensitivity $S_1 = \Delta AAM/\Delta SST$ is on the order of 1 angular momentum unit (AMU; 1 AMU = 10^{25} kg m^2 s^{-1}) per ^oC on interannual time scale. In the context of global warming, $S_1 \approx$ 0.75 AMU/^oC in a set of coupled model (the CCCma CGCM1) simulations following an IPCC scenario (Fig. 2, modified from Huang et al. 2001). Räisänen (2003) shows that this parameter depends on the model used for the global warming simulation.

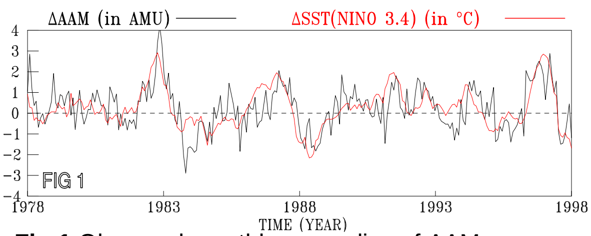

Fig.1 Observed monthly anomalies of AAM (black) and SST(red)

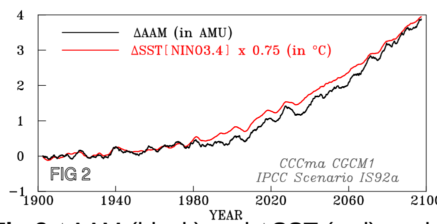

Fig.2 ΔAAM (black) and ΔSST (red) as departure from control in CGCM global warming simulation.

Given the complicated structures in the SST and zonal wind (whose weighted global integral is AAM) and other dynamical fields, simple climate indices illustrated by Figs 1 and 2 are especially useful for the purpose of model intercomparison. This is recognized by previous researchers as the global ΔAAM has been used to compare the performances of atmospheric models in AMIP (Hide et al. 1997) and coupled models in CMIP (de Viron et al. 2002). Both studies found a wide range of GCM−simulated ΔAAM for intraseasonal−to−interannual variability (the former) and global warming (the latter). At the same time, the CMIP models also produce significant disparity in the standard deviation of ΔSST in the El Niño region (AchutaRao and Sperber 2002). With this background, it is timely to consider an additional intercomparison for sensitivity parameters such as $S_1 = \Delta AAM/\Delta SST$. By focusing on the ratio of two indices, we are concerned with not just the variability in each of them, but the strength of the dynamical process that links the two together. This distinguishes our proposed work from previous studies that focus on the variability or change in the climate indices themselves (e.g., Karoly and Braganza, 2001).

Because AAM adjusts to tropical SST on a short time scale (< 1 month), for monthly or seasonal mean ΔAAM and ΔSST can be regarded as occuring simultaneously. The sensitivity S_1 does not depend on time lag. Two other types of dependence exist between a large−scale climate index and ΔSST. First is a time−lagged, yet mostly deterministic, dependence, examplified by $S_2(\tau) = \Delta T_{AIR}(t+\tau)/\Delta SST(t)$, where ΔT_{AIR} is the anomaly of the global mean mid−tropospheric air temperature. The observed $S_2(\tau)$ has a maximum slightly greater than 0.5 that occurs at a time lag τ = 2 seasons (e.g., Angell 2000). The last, and most complicated, type of sensitivity arises from the case when the dependence of a climate index on ΔSST is partially stochastic. An important example is the relationship between the Pacific Decadal Oscillation (PDO) index and the ΔSST of El Niño. As shown by Newman et al. (2002), the former is an integrator of the latter but with a random component in the integrand. A trapezoidalized version of this integrator model, which reads $PDO(t) = \alpha PDO(t-\Delta t)+\beta\Delta SST(t)+$*noise*, successfully hindcasts the observed PDO series (Newman et al. 2002). This discrete model contains only two parameters α and β, the former reflecting the memory of PDO while the latter quantifying the contribution from the ΔSST of El Niño. The simplicity of this framework makes it especially useful for the intercomparison of the behavior of year−to−year memory and decadal variability in the coupled models.

2. Proposed objectives and additional remarks

The expanded archive of CMIP2+ provides exciting opportunities to analyze the sensitivity parameters discussed in Sec. 1 for a wide range of time scales from intraseasonal to centennial. To focus on clearly defined goals, we narrow the proposed objectives to three groups, corresponding to the sensitivity parameters S_1, $S_2(\tau)$, and (α, β).

(1) Evaluate ΔAAM and ΔSST (NINO3.4 and/or NINO3) for the control runs and compare the ratio S_1 = ΔAAM/ΔSST associated with El Niño and decadal/interdecadal variability. Evaluate S_1 for the global warming runs (similar to Huang et al. 2001). Compare S_1 among different models in different stages of global warming. Lastly, evaluate S_1 as a function of time scale (for the whole range from monthly to centennial based on filtering of AAM and SST series) for each GCM for intercomparison. Since ΔAAM of atmospheric models (with fixed ΔSST) have been analyzed in AMIP (Hide et al.1997), the outcome of this project can be compared with AMIP to determine the effect of coupling on the sensitivity of atmospheric zonal wind response to tropical Pacific SST.

(2) Evaluate ΔT_{AIR} (850mb−300mb, global/hemispheric means) and ΔSST (NINO3.4 and/or NINO3) for the control runs and compare the sensitivity $S_2(\tau) = \Delta T_{AIR}(t+\tau)/\Delta SST(t)$ as a function of time lag. The analysis will focus on both the time lag and the maximum value of S_2. The former has implications for seasonal prediction while the latter can potentially be used to extract ENSO signal from the apparent global warming trend (at least for tropospheric temperature, but also possibly for surface temperature, Angell 2000). For the latter purpose, the difference in $S_2(\tau)$ between the control and global warming runs will also be investigated.

(3) Extract the ENSO−like and PDO−like signals from control runs. Construct a simple stochastic model with the PDO index as an integrator of the El Niño index (Newman et al. 2002). In this process, a pair of parameters (α, β) are obtained for each GCM for intercomparison. This forms a useful test for the "memory" (and the extent to which it is affected by noise) of the coupled models in the context of decadal variability. This analysis can be extended to the southern hemisphere counterpart of PDO (related to the so−called Inter−decadal Pacific Oscillation, e.g., Power et al. 1999). Another related approach to this investigation is linear inverse modeling for the pair ($\Delta\Phi$, ΔSST), where $\Delta\Phi$ represnts the height anomalies at 200 and 850 mb (Alexander et al. 2002, Newman et al. 2000). These analyses will also be repeated for the CO_2 doubling runs to examine whether the sensitivity is affected by the changing base state due to global warming.

The analyses in (1) and (2) will use monthly and/or seasonal means of zonal mean zonal wind and temperature (latitude−height cross sections), and the corresponding SST (2−D field). Since the tropical Pacific SST anomaly influences the atmosphere through convective heating, additional outputs of heating rate (or, at least, precipitation rate) from the coupled models will be useful for our analysis. In addition, the investigation related to PDO in (3) requires the monthly mean 200 mb and 850 mb height fields or their equivalents. The parameter α in (3) can be determined directly from the oceanic mixed layer (Deser et al. 2003) using the outputs (temperature fields of the upper ocean) of the coupled models. If these data are available with monthly resolution, we also plan to perform the direct calculation for α to compare with its empirically derived counterpart described in (3).

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