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# Local versus non-local atmospheric weather noise and the North Pacific SST variability

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[1] The interactive ensemble coupling strategy has been developed specifically to determine how noise impacts climate variability within context of coupled general circulation model (CGCM). This study examines the impacts of local versus non-local noise on the North Pacific sea surface temperature anomaly (SSTA) variability using three CGCM simulations. The control run uses the standard coupling strategy. In the first experiment, the interactive ensemble strategy is applied globally thereby reducing the noise at the air-sea interface at each grid point. In the second experiment, the interactive ensemble strategy is applied locally in the extra-tropics only. Perhaps as expected, our analysis indicates that the impact of local noise on the North Pacific SSTA variability is much larger than that of non-local noise. However, non-local noise can not be neglected; for example, non-local noise influences decadal SSTA variability in the central North Pacific. The hypothesis put forward here is that the noise due to enhanced tropical internal atmospheric variability causes the modulation of El Niño and Southern Oscillation, which in turn affects the North Pacific SSTA variability through the atmospheric bridge. **Citation:** Yeh, S.-W., B. P. Kirtman, and S.-I. An (2007), Local versus non-local atmospheric weather noise and the North Pacific SST variability, *Geophys. Res. Lett.*, *34*, L14706, doi:10.1029/2007GL030206.

## 1. Introduction

[2] North Pacific sea surface temperature (SST) variability affects physical and biological conditions in the North Pacific Ocean. The potential mechanisms for the North Pacific SST variability can be separated into three broad categories, i.e., (1) variability that is driven by atmosphere stochastic forcing (i.e., noise) [*Hasselmann*, 1976], (2) ocean-atmosphere coupled feedbacks in the North Pacific [*Latif and Barnett*, 1994], and (3) remote forcing from other regions of the globe (i.e., the tropical Pacific) [*Alexander et al.*, 2002; *Deser et al.*, 2004]. Within these three broad categories there are a number of competing hypotheses and no clear consensus for the mechanisms of North Pacific variability.

[3] The potential importance of atmospheric stochastic forcing was addressed in some detail by *Yeh and Kirtman* [2004] (hereinafter referred to as YK04). YK04 used the so-called interactive ensemble coupling strategy [*Kirtman and Shukla*, 2002] to isolate the SST variability in the North Pacific in a coupled general circulation model (CGCM) that was specifically associated with atmospheric noise. YK04 focused on local SSTA variance ratios (i.e., with and without interactive ensemble coupling in a CGCM) and argued that by far the bulk of the North Pacific SSTA variability was due to the atmospheric stochastic forcing. Coupled feedbacks, at best, played only a minor role. A potential problem with the YK04 results was that the atmospheric stochastic forcing was reduced globally, so that they could not determine how changes in other modes of variability (e.g., ENSO, NAO…) due to the application of the interactive ensemble coupling might influence the results through reduced interactions with the North Pacific. In other words, did a "noisier" ENSO lead to more remote forcing in the North Pacific? In this paper, this issue is addressed by applying the interactive ensemble strategy regionally. By comparing the regional interactive ensemble with global interactive ensemble we can isolate the role of local North Pacific atmospheric noise, independent of remote changes in, say, tropical Pacific variability. The manuscript is outlined as follows. The description of model is given in the section 2. The primarily results based on the model analysis are described in the section 3. We provide our summary in the section 4.

## 2. Model and Methodology

[4] The interactive ensemble strategy is to couple ensemble average atmospheric fields from multiple AGCM realizations to a single OGCM. The goal in this approach is to minimize internal atmospheric variability that is unrelated to the OGCM's SSTA fields. The atmospheric component is the Center for Ocean-Land-Atmosphere Studies (COLA) global spectral AGCM with a horizontal resolution of T42 and 18 unevenly spaced vertical $\sigma$ levels [*Kinter et al.*, 1997]. The ocean component is version 3 of the Geophysical Fluid Dynamics Laboratory (GFDL) Modular Ocean Model (MOM3) [*Pacanowski and Griffies*, 1998].

[5] In order to isolate local noise we conduct an idealized interactive ensemble experiment (hereafter, RegIE). The RegIE has six realizations of the AGCM coupled to an OGCM in the midlatitudes, but only a single AGCM realization is coupled into an OGCM in the tropics. Figure 1 shows a schematic representation of an application of the RegIE experiment. The number of AGCMs coupled to an OGCM linearly increases from the tropics to the midlatitudes where the fluxes experienced by the ocean model are the ensemble average of six atmospheric realizations.

[6] The control run uses the standard coupling strategy (i.e., one single AGCM is coupled to a single OGCM,

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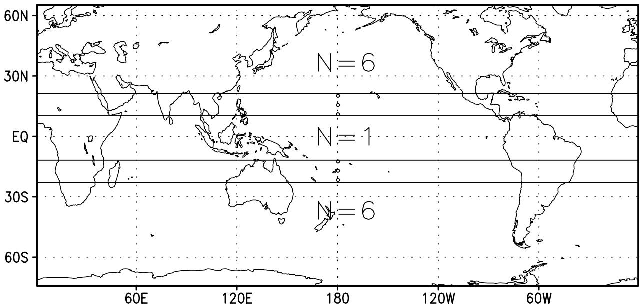


**Figure 1.** Schematic of an idealized interactive ensemble model. N indicates the number of AGCM realizations coupled to a single OGCM.

hereafter, CON) for the simulation period of 400 years. The first experiment, in which the interactive ensemble strategy is applied globally, consists of six AGCMs coupled to a single OGCM within the globe (hereafter, IE). In the second experiment, the interactive ensemble strategy is applied locally in the midlatitude only (i.e., RegIE). The main difference between the IE and RegIE simulation is the amplitude of internal atmospheric variability felt by the ocean component at the air-sea surface *in the tropics*. We will focus on the North Pacific SST variability by comparing the RegIE simulation and IE simulation with the CON. The analyzed period of the IE simulation is 500 years. The RegIE simulation is integrated for 117 years and the last 100 years are analyzed in this study.

## 3. Analysis

[7] We first show the total variance of monthly SSTAs simulated in the RegIE (Figure 2a). The SSTA is defined by the deviation from the climatological annual cycle over the entire analyzed period. The North Pacific SSTA variability simulated in the RegIE has two distinct centers of action. One is a zonally extended structure centered near 43°N in the western and central North Pacific, which is coincident with the simulated Kuroshio-Oyashio extension in the model. The other corresponds to the structure oriented from the northeast to southwest in the central North Pacific, which is associated with the variability of the subtropical gyre. The dominant structure of North Pacific SSTA variability simulated in the RegIE is broadly consistent with that of the previous results in both the observations and coupled model simulations [*Nakamura et al.*, 1997; *Miller et al.*, 1998]. Figure 2b shows the difference of total SSTA variance between the RegIE and IE simulation and Figure 2c is the same as in Figure 2b except the ratio. Note that shading indicates regions above 90% confidence level by an *F*-test. The simulated SSTA variance in the RegIE increases overall in the North Pacific Ocean basin compared to that in the IE simulation. Significant maximum differences are located in the western part of the North Pacific including the Kuroshio-Oyashio extension. The SSTA variance associated with the subtropical gyre, which is oriented from the northeast to southwest in the central North Pacific, is also slightly increased within some significant regions. Simply put, this suggests that there are some parts of the North Pacific where ''non-local'' noise impacts the SSTA variability, perhaps by increasing the ENSO amplitude associated with the increasing tropical 'noise' [*Eisenman et al.*, 2005] and thus the remote North Pacific. In other words, enhanced internal atmospheric variability over the tropics contributes to force the North Pacific SSTA variability.

[8] For comparison, we provide the difference of total SSTA variance between the CON and IE simulation with the ratio (Figures 3a and 3b). Similar to Figure 2b, there is a marked difference in two regions of the North Pacific, i.e., a zonally extended band in the western part of the North Pacific and the central North Pacific. Note that the results in Figure 3a could be considered as the impact of both local and non-local noise on the North Pacific SSTA variability. The differences and ratios of SSTA variance between the CON and IE (Figures 3a and 3b) are much larger than that between the RegIE and IE (Figures 2b and 2c) in both the western North Pacific and the central North Pacific. Note that the North Pacific region is almost above 90% confidence level by an *F*-test in Figure 3b. By directly comparing

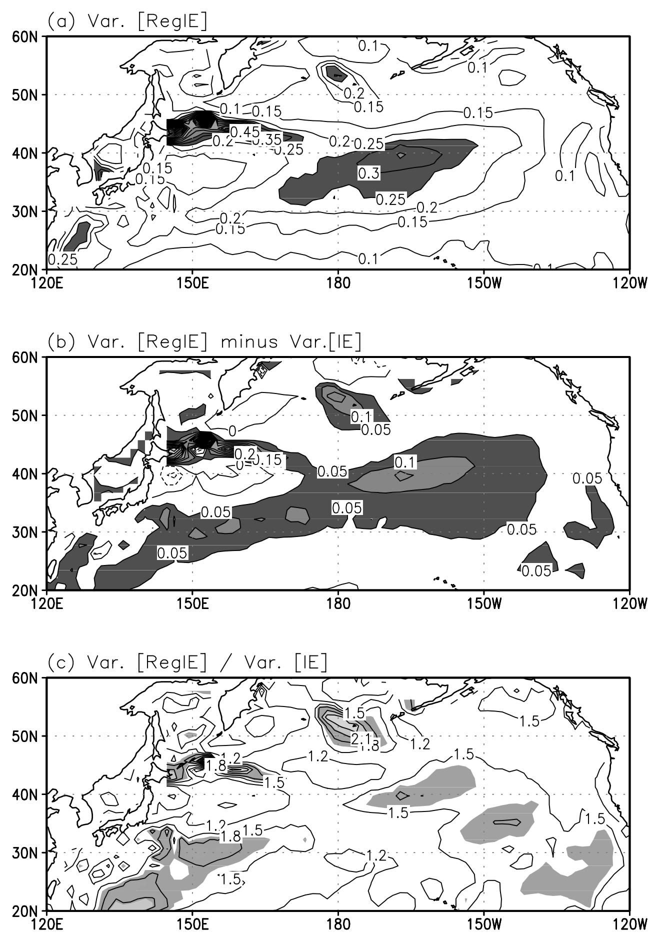


**Figure 2.** (a) Variance of monthly mean SSTAs simulated in the RegIE for the entire analyzed period. Contour interval is 0.05°C and shading is above 0.25[°C]$^2$. (b) The difference of SSTA variance between the RegIE and IE simulation. Shading indicates regions above 0.05[°C]$^2$. (c) The ratio of SSTA variance between the RegIE and IE simulation. Shading indicates regions above 90% confidence level by an *F*-test.

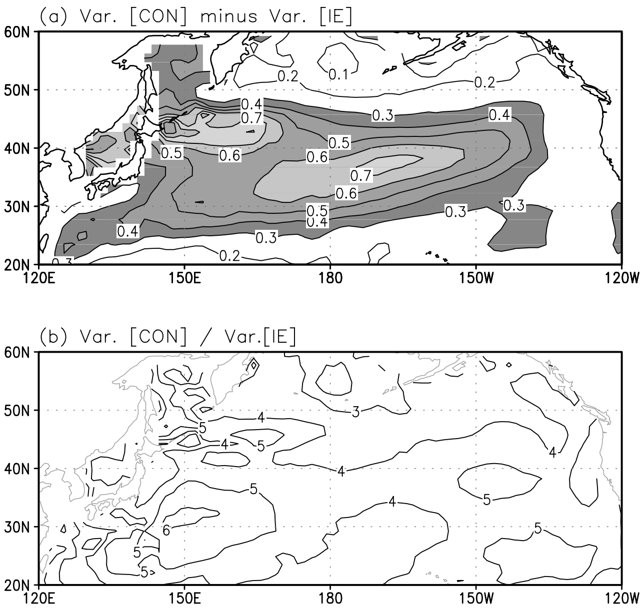


**Figure 3.** (a) The difference of variance for SSTA in the CON and the IE calculated for the entire analyzed period. Values greater than 0.4 [°C]$^2$ are shaded. (b) Same as for Figure 3a except for the variance ratio between the CON and the IE.

Figures 3a and 3b with Figures 2b and 2c we conclude that the impact of local noise on the North Pacific SSTA variability clearly dominates.

[9] For more detail comparison we define the western North Pacific and the central North Pacific SST index simulated in the RegIE, IE and CON, respectively. The western and central North Pacific SST index is defined by the time series of the SSTA variability averaged over 38°N ~ 47°N, 145°E ~ 170°E and 30°N ~ 40°N, 180°E ~ 150°W, respectively. Table 1 summarizes the variance for the western North Pacific and central North Pacific SST index with its ratios in the RegIE, IE and CON, respectively. Again, larger variance ratios of $\frac{CON}{IE}$ (i.e., 4.5 and 3.9) than $\frac{\mathrm{Re}\, gIE}{IE}$ (i.e., 1.3 and 1.5) in the western North Pacific and central North Pacific SST indices, respectively, indicate that local noise is the dominant forcing for the North Pacific SSTA variability. On the other hand, an increase in variance ratio from $\frac{\mathrm{Re}\, gIE}{IE}$ to $\frac{CON}{IE}$ in the western North Pacific SST index is larger than that in the central North Pacific SST index, indicating that local noise is more effective in forcing the SSTA variability in the western part of the North Pacific than that associated with the subtropical gyre in the central North Pacific [e.g., *An and Wang*, 2005].

[10] We also calculated the power spectrum of the western and central North Pacific SST index in the IE (Figures 4a and 4b) and the RegIE (Figures 4c and 4d) simulation and compared this to the CON (Figures 4e and 4f) simulation. The western North Pacific SST index has strong low frequency variability on decadal timescales in the IE, RegIE and CON simulation. Despite an increase of variance due to non-local and local noise on decadal timescales (Figures 4c and 4e), the power spectrum is not significantly different from red-noise (dashed curve in Figure 4). The central North Pacific SST index simulated in the IE simulation is dominated by interannual timescales with periods around 24 months (Figure 4b). On the other hand, the spectral density of the central North Pacific SST index simulated in the RegIE (Figure 4d) and CON (Figure 4f) on decadal timescales is relatively large compared with that in the IE simulation. Non-local noise effects seem to influence the decadal SSTA variability in the central North Pacific, however, the spectral density is not significantly different from a random red noise process.

[11] Here we briefly described how this non-local noise effects can influence the North Pacific SSTA variability in the RegIE simulation. The tropical Pacific variability is larger in the RegIE simulation (Variance of NINO3.4 SST index = 0.30°C$^2$) than the IE simulation (Variance of NINO3.4 SST index = 0.18°C$^2$) which then leads to change the North Pacific SSTA variability due to atmospheric bridge. In other words, noise over the tropics due to enhanced internal atmospheric variability causes the modulation of ENSO [*Eisenman et al.*, 2005; *Vecchi et al.*, 2006], which in turn affects the North Pacific SSTA variability. The NINO3.4 SST index is defined by the time series of the SSTA averaged over the NINO3.4 region (170°E–240°E, 5°N–5°S). Figures 5a, 5b, and 5c are the same as in Figure 4 except for the NINO3.4 SST index. The most striking difference is that the spectral density of the NINO3.4 SST index simulated in the RegIE (Figure 5b) is largely dominated on interannual-to-decadal timescales, which is similar to the results in simulated in the CON (Figure 5c), compared to that in the IE on biennial timescale (Figure 5a). When noise is reduced in both the North Pacific and the tropical Pacific (i.e., the IE), the variability of central North Pacific SST index coincides with the ENSO variability on biennial timescales (Figure 4b and Figure 5a). This is because the signal from the tropics directly influences the SSTA variability in the central North Pacific region in the presence of reduced noise (YK04). However, when internal atmospheric variability is enhanced over the tropics (i.e., RegIE and CON), the ENSO variability on interannual-to-decadal timescales is enhanced, resulting in changes in the North Pacific SSTA variability.

[12] To support this argument, we compare the coherence square between the central North Pacific SST index and the NINO3.4 SST index on biennial timescales (i.e., 1.5 ~ 3 years) versus on interannual-to-decadal timescales (i.e., 4 ~ 25 years) in the RegIE and IE simulation, respectively.

**Table 1.** The Variance for the Western North Pacific and Central North Pacific SST Index With Its Ratios in the RegIE, IE, and CON, Respectively

| | Model | Western North Pacific SST Index | Central North Pacific SST Index |
|---|---|---|---|
| Variance [°C$^2$] | RegIE | 0.13 | 0.15 |
| | IE | 0.10 | 0.10 |
| | CON | 0.45 | 0.39 |
| Variance ratio | $\frac{\mathrm{Re}\, gIE}{IE}$ | 1.3 | 1.5 |
| | $\frac{CON}{IE}$ | 4.5 | 3.9 |

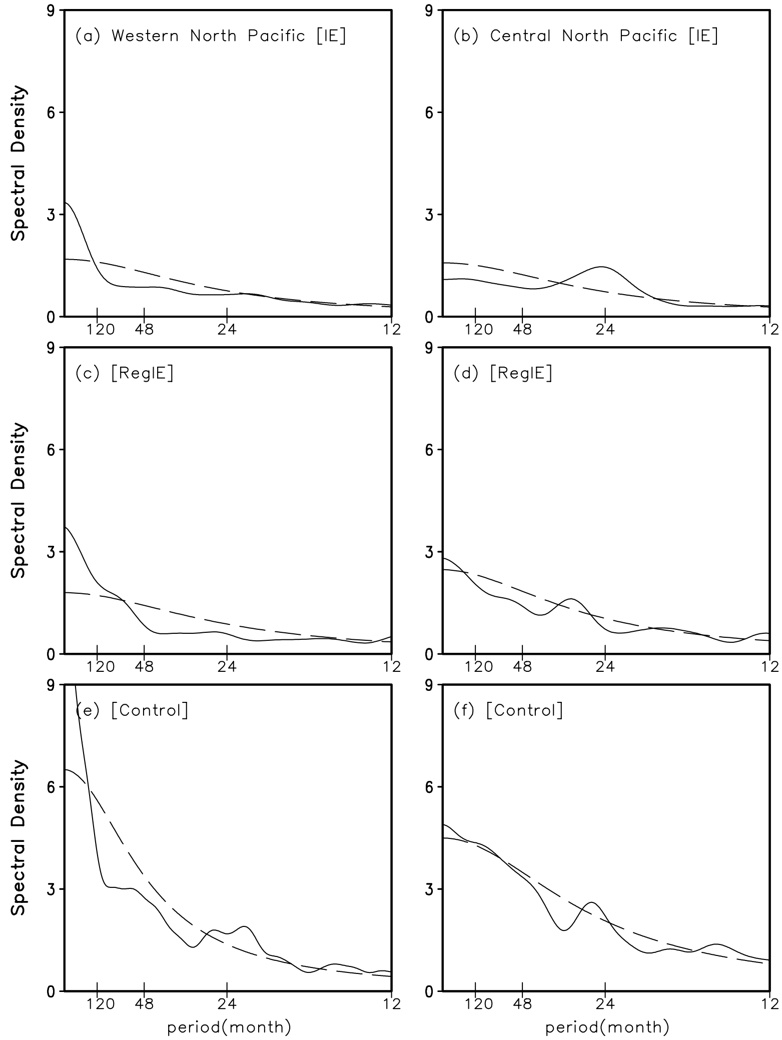


**Figure 4.** Power spectral density of (a) the western North Pacific and (b) central North Pacific SST index in the IE, (c, d) the RegIE, and (e, f) the CON simulation, respectively. The solid curve shows the power spectral and the dashed curve shows the power spectra for red noise.

The coherence on biennial timescales is 0.45 and 0.66 in the RegIE and IE simulation, respectively, which is generally consistent with the results in Figure 4b and Figure 5a. On the other hand, those on interannual-to-decadal timescales are 0.53 and 0.45 in the RegIE and IE simulation, respectively. This indicates that the fraction of central North Pacific SST index associated with ENSO in the RegIE simulation is larger than that in the IE simulation on interannual-to-decadal timescales.

## 4. Summary

[13] To identify the impacts of local versus non-local noise on the North Pacific SSTA variability we examined three CGCM integrations, i.e., the IE, RegIE, and CON simulation. The IE consists of the ensemble average of six AGCMs coupled to one OGCM globally. The RegIE has the ensemble average of six AGCMs coupled to one OGCM in the midlatitudes and a single AGCM is coupled into one OGCM in the tropics. One single AGCM is coupled to a single OGCM in the CON globally. Our analysis indicates that there are some parts of the North Pacific where the non-local effects play a role to force the SSTA variability. However, the impact of local noise on the North Pacific SSTA variability is much larger than that of non-local noise. In particular, local noise is more effective to force the SSTA variability in the western part of the North Pacific including the Kuroshio-Oyashio extension than that associated with the subtropical gyre in the central North Pacific. Nevertheless, our results also showed that non-local noise can influence the SSTA variability in the western North Pacific and central North Pacific region. For instance, the non-local effects contribute to the decadal SSTA variability in the central North Pacific region enhancing the redness of the power spectrum. A recent result [*Newman*, 2007] also argued that the Pacific decadal oscillation may represent the sum of several phenomena, each of which represents a different red noise process.

[14] We argue that the non-local effect is to enhance tropical internal atmospheric variability, which modulates ENSO, which in turn affects the North Pacific SSTA variability through the atmospheric bridge. The spectral density of the NINO3.4 SST index simulated in the RegIE is largely dominated on interannual-to-decadal timescales

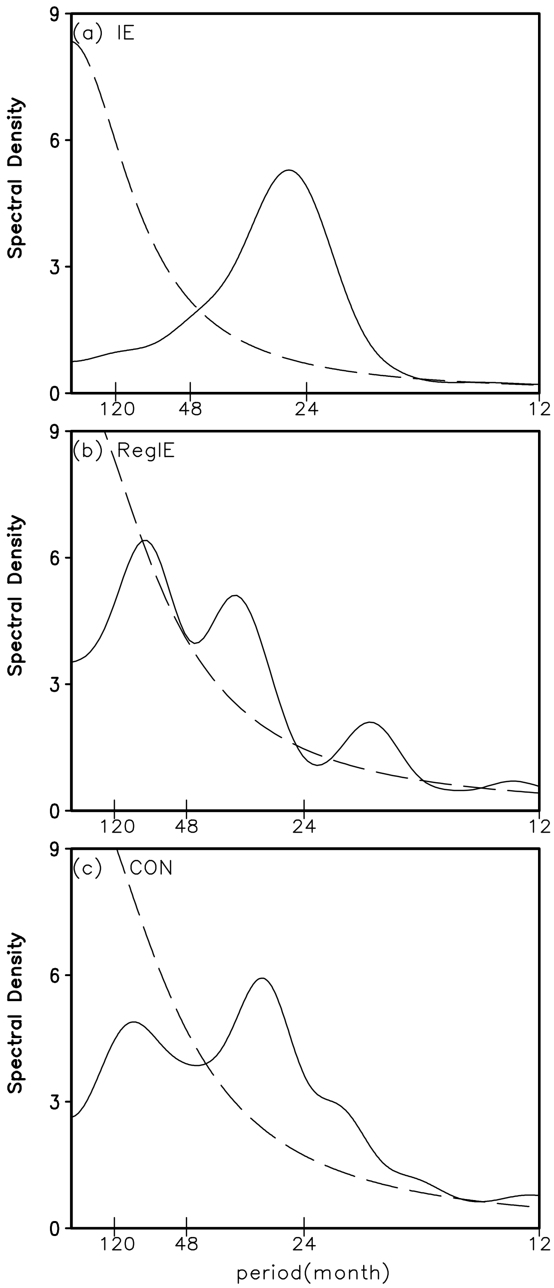


**Figure 5.** Same as for Figure 4 except for the NINO3.4 SST index in (a) the IE, (b) the RegIE, and (c) the CON simulation.

compared to that in the IE on biennial timescales. The coherence analysis indicates that the fraction of central North Pacific SST index due to ENSO in the RegIE simulation is larger than that in the IE simulation on interannual-to-decadal timescales. The ENSO simulated in the RegIE is similar to that simulated in the CON simulation in terms of amplitude and frequency. Simply put, this result indicates that *tropical* internal atmospheric variability is effective to strengthen and broaden interannual-to-decadal timescales of tropical Pacific SSTA variability. In other words, the noise in tropics more efficiently projects onto those timescales of SSTA variability. This issue on the changes in ENSO variability due to the noise changes in tropics is our ongoing work.

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