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INTERFERENCE OF EXTRATROPICAL SURFACE CLIMATE ANOMALIES INDUCED BY EL NINO AND STRATOSPHERIC SUDDEN WARMINGS

Masakazu Taguchi* & Dennis L. Hartmann
Department of Atmospheric Sciences, University of Washington,
Seattle, Washington

1. INTRODUCTION

Extratropical tropospheric and surface climate variability on seasonal and interannual timescales arises from external forcings as well as from internal processes. It is well known that inherent variability of the atmosphere-ocean coupled system in the tropical Pacific region (ENSO) is the largest source of interannual climate variability around the globe (e.g., Glantz 2001). The global impacts during El Niño conditions include wetter and colder climate of the SE US and northern Mexico during Northern Hemisphere (NH) winter (Ropelewski 1992). Recent studies have suggested that the surface climate is also influenced by the stratosphere, or occurrence of SSWs (Baldwin et al. 2003a; Hartmann et al. 2000). Circulation anomalies following SSWs tend to propagate downward from the stratosphere to the surface, where the climate exhibits sea-level pressure anomalies that resemble the negative phase of the Northern Annular mode (NAM; Baldwin and Dunkerton 1999, 2001).

No study has investigated possible connections between the surface climate impacts of ENSO and SSWs, although both affect planetary-scale flow in NH winter extratropics. The two forcings are also considered separately in applications to weather prediction (Wallace 1994; Baldwin et al. 2003b). Here we explore possible interference of climate anomalies induced by the ENSO and SSWs through both observational analysis and idealized GCM experiments.

2. OBSERVATIONAL ANALYSIS

Our observational analysis makes use of daily NCEP/NCAR reanalysis data of 55 NH DJF winters from 1948/1949 to 2002/2003 (Kalnay et al. 1996). We also used “cold-tongue index (CTI)” of anomalous SSTs in the tropical Pacific averaged over the NH winter season. We divide the sample into four regimes defined by whether ENSO is warm or cold and whether an SSW has occurred or not. For the ENSO state, we classified “El Niño” and “La Niña” winters as those of the 10 highest and lowest values of the CTI,

* Corresponding author address: Masakazu Taguchi, Now at Dept. of Earth Sciences, Aichi University of Education, Kariya 448-8542, JAPAN; e-mail: mtaguchi@auecc.aichi-edu.ac.jp

respectively. We used temperature time series in the polar stratosphere to identify 35 SSWs in the 55 winters, with 6 and 9 in the 10 La Niña and 10 El Niño winters, respectively. We then defined a “post-SSW period” after the peak of the SSWs. We also defined a “quiet-stratosphere period” as days that are well apart from any SSW. The regimes I and II (III and IV) include days in the quiet-stratosphere period (post-SSW period) of the La Niña and El Niño winters, respectively.

The difference, regime II minus regime I, measures the response to the El Niño forcing when the stratosphere is quiescent (Fig. 1A). The response is consistent with previous analyses of ENSO’s impact in mid-latitudes (e.g., Ropelewski 1992) in that it shows colder and wetter climate over the SE US to northern Mexico, accompanied by decline of geopotential height Z300 at an upper tropospheric level 300 hPa above the central and southern US. The climate anomalies change in some regions when the El Niño and SSWs occur together (Fig. 1B, difference IV minus I) compared to the El Niño conditions without SSWs (Fig. 1A). The change is, in principle, equal to the impact of the SSWs during the El Niño winters (Fig. 1C, difference IV minus II). The response to the SSWs alone is similar to the negative phase of the NAM as observed (Limpasuvan et al. 2004).

3. GCM EXPERIMENTS

Our numerical experiments employ the NCAR Whole Atmosphere Community Climate model (WACCM; Sassi et al. 2002).The horizontal resolution is T63, with 66 vertical levels from the surface up to about 110 km. The experiments consist of two runs forced with perpetual January conditions, including prescribed climatological SST and ozone distributions. In one case the SSTs in the eastern tropical Pacific are raised (called WARM), and they are lowered in the other (called COLD) to introduce an ENSO-like SST forcing. The two runs each include 240 months of equilibrated January climate.

We applied a similar four-regime composite analysis to the model data. We populated the four regimes using the WARM and COLD experiments for El Niño and La Niña, and the same definitions for the quiet-stratosphere and post-SSW periods. We identified 21 and 41 SSWs in the runs COLD and WARM, respectively, using the time series of the zonal mean temperature [T] in the polar stratosphere. The modeled responses (Fig. 1D-F) are very consistent with the observations (Fig.1A-C) and show constructive interference over the SE US and northern Mexico much more clearly. Both El Niño and SSWs produce a colder and wetter climate associated with Z300 decline (Fig. 1D,F), and their superposition produces a much amplified response (Fig. 1E). The statistical significance of the modeled constructive interference is obtained at a 95 % level. The synergism also affects probability of extreme weather conditions in the SE US (not shown).

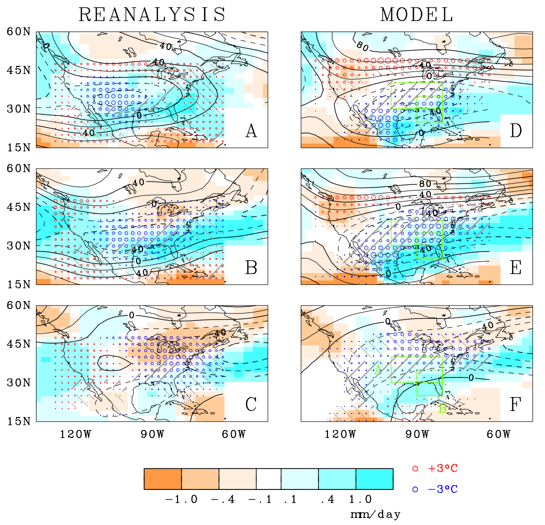

Figure 1: Composite differences for three combinations of the regimes in the observations and GCM experiments. The panels A to C are for the observations; (A) II minus I, impact of ENSO in the quiet-stratosphere period, (B) IV minus I, impacts of ENSO and stratospheric forcings, and (C) IV minus II, impact of the SSWs in the El Niño winters. The panels D, E and F are model counterparts of A, B, and C, respectively. Contours are for geopotential height at 300 hPa, Z300, with a contour interval of 20 m. Red and blue circles are for near-surface temperature, Ts, with red (blue) indicating warming (cooling). Size of the circles is proportional to their magnitude, with examples of ±3ºC given below the panels. Only values over ±0.2 in a region of 60ºW-130ºW and 15ºN-50ºN are plotted. Blue and orange shadings are for precipitation rate, R (mm day^{-1}), with color codes also given below. Gray diagonal lines show that the Z300 impact of the SSWs in the El Niño condition is statistically significant at a confidence level of 75 % for the observations (panel C) and 95 % for the GCM results (panel F). For the statistical test of the observed (modeled) SSWs' impact, Student's t test is applied to 9 (41) values of Z300 in the post-SSW period after the 9 (41) SSWs in the El Niño winters (run WARM) at each gridpoint. Statistical significance of the ENSO's impact (panels A and D) is much higher, as the ENSO forcing persists longer. Diagonal lines toward the bottom-left (bottom-right) show that the Z300 impact of the SSWs is in the same (opposite) sense as that of the ENSO.

4. DISCUSSION

In summary, we examined both observational and modeling results to show significant interference of extratropical surface climate anomalies induced by El Niño and SSWs. The impacts of the El Niño and SSWs each are robust and can basically add to each other. The consistency between the observational and modeling results provides a convincing case that El Niño and SSWs exert synergistic impacts to enhance colder and wetter winter climate over the SE US and northern Mexico.

This work suggests the potential to increase understanding and forecasting of surface climate variability by taking account of both ENSO and SSWs. For example, this interference is of great interest in extended-range weather forecasts, since the impacts of the El Niño and SSWs affect seasonal means and their synergism can increase the frequency of extreme weather conditions. It also seems clear that physical models used to project the response of extratropical climate to tropical SSTs must have a realistic stratosphere and be able to forecast SSWs in order to obtain the correct distribution of the climate anomalies.

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