Reply

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We thank Chang and Lin for their thoughtful and constructive comments on our study (Park et al. 2010). In Park et al. (2010), we did not explicitly state that the topography-forced stationary waves are the direct cause for the reduced downstream transient eddy kinetic energy (EKE). The response of stationary waves to topography may saturate even with a relatively small mountain (Cook and Held 1992); furthermore, their magnitudes are much smaller than thermally forced stationary waves (Chang 2009; Held et al. 2002). Instead, we suggest that quasi-stationary waves generated by the central Asian mountains may strongly affect North Pacific storminess by changing the year-to-year variability of westerly winds over the eastern Eurasian continent. Observational analyses indicate that the midwinter suppression of North Pacific storminess does not occur every year. Some years experience stronger and more meridionally confined zonal winds over the western North Pacific, leading to stronger midwinter suppression (Harnik and Chang 2004; Nakamura and Sampe 2002).

In our atmospheric general circulation model (AGCM) analyses, the interannual variability of westerly winds and storminess over the North Pacific decrease substantially in the absence of the central Asian mountains; a year with strong midwinter suppression over the North Pacific occurs rarely in this simulation. Moreover, it is still unclear why the presence of the central Asian mountains strengthens the interannual variability of westerly jets and storminess over the western North Pacific. We believe understanding the cause of this strong interannual variability is key to understanding the mechanisms for the midwinter suppression. Indeed, fundamental questions still remain with regard to the dynamics of quasi-stationary waves, such as how mountains affect the diabatic heating field (Held et al. 2002) and the convergence of eddy momentum fluxes (Chang 2009).

We share the concern of Chang and Lin (2011) that the AGCM integration time (18 yr in our study) may be insufficient to accurately capture the quantitative response of downstream storminess. Also, we agree with Chang and Lin (2011) that a multimodel ensemble approach will be required to better quantify the impact of the mountains on downstream storminess. Along these lines, we tested the robustness of our results using the global atmospheric model, version 2.1 (AM2.1), developed at the Geophysical Fluid Dynamics Laboratory (GFDL; Anderson et al. 2004). This version of AM2.1 uses a finite-volume dynamical core (Lin 2004) with $2.5° \times 2.0°$ horizontal resolution (M45) and 24 vertical levels (L24). Seasonally varying insolation and climatological sea surface temperatures (SSTs) are prescribed in the model. The SSTs are from 50 yr of monthly mean Reynolds reconstructed historical SST analysis, spanning from 1950 to 2000 (Smith et al. 1996). We ran the model for 60 yr, and the last 54 yr are used for the analysis, tripling the integration period of our previous work. Unlike the previous paper, for which an 8-day high-pass filter was used, we used a 10-day high-pass filter to define transient eddies. This method slightly reduces uncertainty by increasing the spectral band by 2 days and is widely used for defining synoptic-scale transients. Overall results are virtually identical with those from the 8-day high-pass filtering method used in Park et al. (2010).

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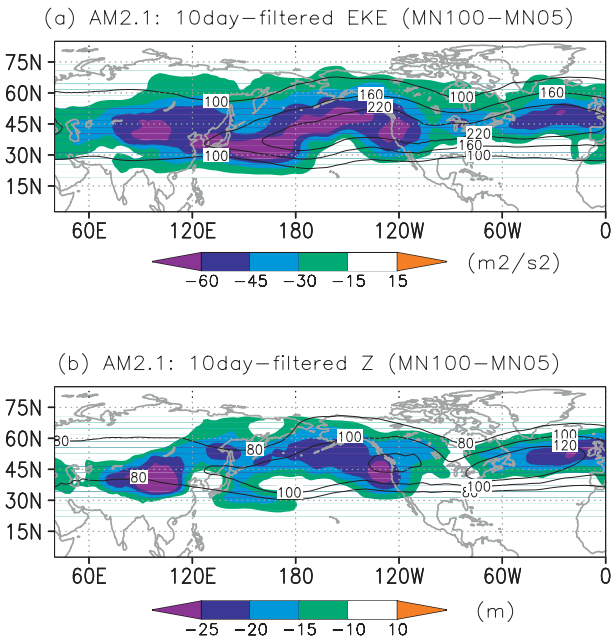

FIG. 1. Anomalous (a) 10-day high-pass filtered transient EKE (shading, $m^2\ s^{-2}$) at 300 hPa, calculated from the differences between MN100 and MN05 (MN100 − MN05). The contour lines indicate the climatological mean transient EKE. (b) As in (a), but for geopotential height.

We found that the sensitivity of downstream storminess to the presence of the central Asian mountains in AM2.1 is slightly weaker than what we found in Community Climate Model 3.10 (CCM3; Kiehl et al. 1998). In CCM3, the removal of the Altai-Sayan Mountains and the northern part of the Tibetan Plateau [i.e., the M50 experiment in Park et al. (2010)] increased downstream storminess by 20%–30%. On the other hand, we had to remove the entire central Asian mountains (hereafter referred to as the MN05 experiment) to get a comparable response of downstream storminess in AM2.1. However, the response of downstream storminess in AM2.1 is still substantially stronger than what Chang and Lin (2011) suggest.

Figure 1a shows the difference in the 10-day high-pass filtered EKE between the MN100 and MN05 experiments (MN100 minus MN05) during midwinter (from 15 December to 14 February). Transient EKE is reduced over a wide range of midlatitudes in the presence of the central Asian mountains. In general, the magnitude of the EKE reduction over the North Pacific is around 20%, which is a little bit smaller than what Park et al. (2010) found, but it reaches up to 30% in some areas sporadically. Consistent with a transient EKE response, the standard deviation of the 10-day high-pass filtered geopotential height $\sqrt{\overline{Z'^2}}$ decreases over a wide range of midlatitudes (Fig. 1b). The magnitude of the response is around 15%–25%, which can substantially deepen the midwinter suppression signal.

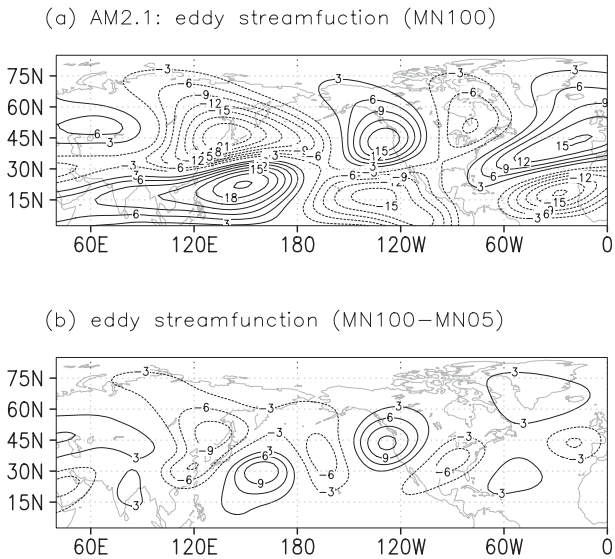

FIG. 2. (a) The 300-hPa eddy streamfunction for MN100. (b) Anomalous eddy streamfunction calculated from the differences between MN100 and MN05. The contour interval is $3 \times 10^6\ m^2\ s^{-1}$.

Figure 2a shows the wintertime stationary waves, defined by the 300-hPa eddy streamfunction, simulated by AM2.1. The climatological mean amplitude of stationary waves simulated by AM2.1 is about 10% weaker than what CCM3 simulates. The anomalously strong stationary waves over the North Atlantic Ocean, appearing in CCM3 (Park et al. 2010) and in an old version of the GFDL model (Held et al. 2002), appear muted in AM2.1. In particular, strong positive and negative dipoles near 50°N over North America, which appear in CCM3 (Park et al. 2010) and in the previous version of the GFDL model (Held et al. 2002), are substantially weakened. Figure 2b shows stationary waves forced by the central Asian mountains, calculated by the difference between MN100 and MN05. Overall, the magnitude of the response is smaller than what CCM3 simulated in Park et al. (2010), but larger than what Chang and Lin (2011) found.

As we mentioned earlier, midwinter suppression does not occur every year. Thus, the climatologically averaged impact of the central Asian mountains on downstream storminess can substantially vary depending on the model used and integration period chosen. We plan to further analyze our AM2.1 simulations to better understand why the central Asian mountains enhance the interannual variability of North Pacific storminess in the context of quasi-stationary waves.

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