Reply

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ABSTRACT

Penny et al. recently showed that the midwinter suppression in storminess over the western and central Pacific Ocean is due to a reduction in the number and amplitude of ''seed'' disturbances entering the Pacific storm track from midlatitude Asia. In this reply, the authors strengthen the conclusions that were originally put forth and show that the apparent departure from this behavior presented in a recent comment originates in the commenters having undersampled the full dataset of interannual variability. It is shown that when the Pacific storm track is only weakly ''seeded'' by an upstream source, as is common during winter and uncommon during fall and spring, it is likely to be weaker than average, and this reduction is highly statistically significant and the amplitude compares well with the midwinter suppression.

1. Introduction

Penny et al. (2010, hereafter PRB10) diagnosed that the midwinter suppression in Pacific storm track activity is due to a pronounced reduction in the number and amplitude of ''seed'' disturbances entering the Pacific storm track from midlatitude Asia. We used a feature tracking algorithm (Hodges 1994) to identify individual cyclonic and anticyclonic disturbances and analyzed what aspects of their cumulative behavior could give rise to the midwinter suppression. Our results show that the reduction in the number and amplitude of cyclonic disturbances that enter the Pacific storm track from midlatitude Asia is more than sufficient to account for the midwinter suppression. Our results also show that the growth rate, speed, and areal extent of cyclonic features that propagate within the Pacific storm track cannot account for the midwinter suppression, and there is no wintertime minimum in the number or amplitude of anticyclonic features. The research and comments in Chang and Guo (2011, hereafter CG11) do not challenge any of the above statements nor do CG11 question our methods. Instead, CG11 present new research to challenge our interpretation that the observed reduction in upstream seeding *causes* the observed reduction in storminess downstream. In this reply we show that a seeming inconsistency between the results of PRB10 and CG11 arises because CG11 draw conclusions about the climatology based on an analysis that only includes a subset of the data. When the entire record is considered there is no inconsistency. In our opinion, CG11's results do not challenge the interpretations put forward by PRB10 in any way.

2. Data and results

To determine how upstream seeding impacts the Pacific storm track on interannual time scales, we analyze the relationship between the strength of the storm track and the strength of upstream seeding during the months of November, January, February, and April in the 40-yr

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European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA-40) dataset (Uppala et al. 2005) for all years between 1959 and 2001, shown in Fig. 1. As in PRB10, we temporally filter the data with a 2–10-day bandpass filter. In Fig. 1 each dot corresponds to the monthly averaged meridional wind variance within an upstream (35°–65°N, 90°–120°E, as in CG11) and a downstream (20°–70°N, 160°E–160°W, as in CG11) region. Results are essentially unchanged if we restrict the analysis to only include data from the satellite era (1979–2001, as in CG11), if we consider all cold-season months (October–April), if we make modest changes to the location of the two regions, if we consider geopotential height instead of meridional wind, or if we consider feature tracking statistics instead of variance. The results presented here are chosen to parallel CG11 as closely as possible.

The results in Fig. 1 highlight several interesting relationships between the upstream and downstream regions, and we focus here on three. First, consistent with PRB10, there is a visually obvious and statistically significant correlation between storminess in the upstream and downstream regions ($r = 0.38$ when all four months are considered, >99% significance determined from a Student's t test). It is also clear that the midwinter minimum, though very definitely a real phenomenon, emerges from a great deal of scatter, making it important to sample all the available data.

Second, also consistent with PRB10, the data for January and February are generally clustered in the lower left of the figure, whereas the data for November and April are not. This observation can be shown quantitatively; the mean and 95% bounds (determined from a Student's t test) for January and February (denoted with a plus sign) and November and April (denoted with a times sign) are indicated in Fig. 1a. In this climatological average, January and February upstream seeding is 14% weaker, and the Pacific storm track is 10% weaker, than in November and April. This latter number is consistent with the magnitude of the midwinter minimum reported from other studies (e.g., Nakamura 1992) and emphasizes that, on grounds of parsimony, the correlation with upstream seeding is all that is needed to account for the phenomenon in the climatology.

Finally, it is clear that the upstream source during January and February is *nearly always small* compared to November and April. There are only 5 months—out of 86 possible—in which storminess in the upstream region during winter exceeds the mean for fall and spring. There are no months in which storminess in the upstream region during winter is one standard deviation above the mean for fall and spring (not shown). These results alone do not prove that seeding causes the midwinter suppression, as correlations are not causal. However, when taken together with the results presented in PRB10, these new results strengthen the conclusions that we originally put forward.

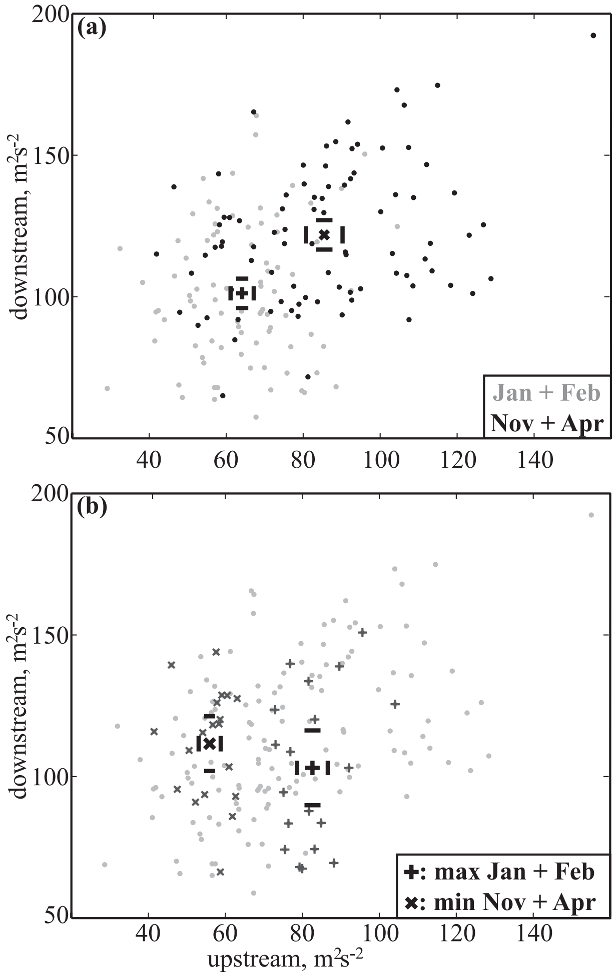

FIG. 1. Scatterplots that compare the strength of upstream seeding to the strength of the Pacific storm track. Results are presented for variance in upper-level (300 hPa) meridional wind for the months of November, January, February, and April. (a) January and February (gray dots) and November and April (black dots) along with the means and 95% confidence for January and February (plus signs) and November and April (times signs). (b) Strongest seeding months in January and February (plus signs), weakest seeding months for November and April (times signs), and data for all four cold-season months (gray dots).

We now move on to reconcile our results with CG11, shown in Fig. 1b. CG11 identify the January and February months with the strongest upstream seeding (hereafter $\mathrm{JF}_{\mathrm{max}}$), which we indicate by a gray plus sign in Fig. 1b, and the November and April months with the weakest upstream seeding (hereafter $\mathrm{NA}_{\mathrm{min}}$), indicated by a gray times sign in Fig. 1b.[1] The mean and 95% confidence bounds (determined from a Student's *t* test) for these two subsets are shown in black. CG11 correctly point out that the $\mathrm{JF_{max}}$ months are characterized by stronger upstream seeding than the $\mathrm{NA_{min}}$ months. CG11 also correctly point out that, although not statistically significant, the $\mathrm{JF_{max}}$ months have a weaker storm track. When viewed together with the data from all years, however, it is clear that this observation is not representative of the climatology. Given the considerable scatter in the data, it is not clear from our analysis if this observation of CG11 is an artifact of undersampling the available data, or if it represents a true nonlinearity in the tails of the distributions. However, it is clear from our analysis that the aforementioned tendency for January and February months to cluster in a different region of the graph than November and April months is entirely consistent with the conclusions put forth in PRB10.

3. Discussion and conclusions

In this reply, we have strengthened the conclusions originally put forth in PRB10. When the Pacific storm track is only weakly ''seeded'' by an upstream source, as is common during winter and uncommon during fall and spring, it is likely to be weaker than average, and this reduction is both highly statistically significant and the amplitude compares well with the midwinter suppression.

The research presented in CG11 addresses the question of whether strongly anomalous wintertime seeding (which is not very strong relative to fall and spring anomalies) produces anomalously strong storminess downstream, not the question of how seeding relates to downstream storminess on average. Therefore CG11 and PRB10 are seeking to understand two different phenomena, and it is not surprising that they arrive at different results.

In their abstract, CG11 state as their primary argument that ''during midwinter months when upstream seeding is as strong as that in spring/fall, the Pacific storm track is not significantly stronger than average and is still much weaker than that in spring/fall, suggesting that the strength of upstream seeding cannot be the primary cause of the midwinter suppression of Pacific storm-track activity.'' While the first half of this statement is true, we have shown that the interpretation that winters with anomalously strong upstream seeding are representative of the climatology is not true. CG11 have drawn conclusions based on the data highlighted in boldface in Fig. 1b. We argue that they should have drawn conclusions based on all of the data in Fig. 1.

The new results presented in this reply highlight some interesting phenomena—tangential to both CG11 and PRB10 and not emphasized here—that we will investigate in more detail in the future. PRB10 discuss on several occasions that there is a clear discrepancy between observed growth rates and baroclinicity within the wintertime Pacific storm track. Understanding how nonlinear interactions in the atmosphere give rise to these discrepancies is certainly a central component of understanding midlatitude storm-track dynamics, and the research presented here and in PRB10 does not negate this in any way. However, our results show that these nonlinear processes do not give rise to the midwinter suppression. The comments of CG11 do not modify this conclusion.

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[1] There are small cosmetic differences in data between CG11 and this reply that do not affect any physical interpretation but that should be mentioned. First, we have used different temporal filters. Second, CG11 identified the 10 ''strong winter seeding'' and 10 ''weak fall/spring seeding'' months in the 23-yr ERA-40 dataset, 1979–2001. In this reply we show results from the same dataset but include 43 years, 1959–2001. To represent the same fraction of the data, we identify 19 strong winter seeding and 19 weak fall/spring seeding months, instead of 10, in Fig. 1b.