

Stratospheric Forcing Needed for Dynamical Seasonal Prediction



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ABSTRACT

While tropical sea surface temperatures certainly influence the atmosphere; winter circulation, temperature, and precipitation over Northern Hemisphere continents are also influenced by circulation patterns related to the stratosphere. In particular, large tropical volcanic eruptions produce winter warming patterns over Northern Hemisphere continents because of a dynamical effect forced by gradients of radiative heating from sulfate aerosols in the lower stratosphere. These effects must be included for accurate dynamical seasonal predictions of Northern Hemisphere winter temperature over both North America and Eurasia.

1. Volcanic patterns

Groisman (1992) and Robock and Mao (1992, 1995), using surface air temperature observations, found a consistent pattern of warming over the continents and cooling over the oceans and Middle East following every large tropical eruption of the past century. Both Perlwitz and Graf (1995) and Kodera et al. (1996) examined the observations of Northern Hemisphere (NH) winter stratospheric and tropospheric circulation for the past 40 yr and found that the dominant mode of circulation of the stratosphere is a strong polar vortex (polar night jet), which occurs simultaneously with a 500-mb pattern with a low anomaly over Greenland and high anomalies over North America, Europe, and east Asia during NH winter. The associated surface air temperature pattern is exactly the same as the observed winter warming pattern found by Robock and Mao (1992, 1995) fol-

lowing tropical eruptions. Perlwitz and Graf called this pattern the “baroclinic mode.” The same pattern had previously been identified as the North Atlantic oscillation (Hurrell 1995, and references therein), and is now also called the Arctic oscillation (AO; Thompson and Wallace 1998, 2000; Thompson et al. 2000). This stratospheric control of tropospheric climate was clearly summarized by Robock (1996, 2000). Perlwitz and Graf (2001) have presented the most recent understanding of these processes.

General circulation model (GCM) experiments have supported the theory of volcanic forcing of winter circulation. Graf et al. (1993) used the ECHAM2 model in a perpetual January mode with forcing based on the 1982 El Chichón eruption to produce a winter warming temperature pattern over NH continents. Kirchner et al. (1999), using an improved forcing dataset based on the 1991 Pinatubo eruption (Stenchikov et al. 1998) and improved GCM that was run through a seasonal cycle, ECHAM4, were able to simulate the surface temperature patterns observed over both North America and Eurasia in the winter of 1991/92. Recent experiments with the SKYHI model (Ramachandran et al. 2000) have obtained similar results. Success in such a simulation requires a GCM with a reasonable simulation of the strength of the polar night jet.

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2. Dynamical seasonal prediction

Surface air temperature patterns and circulation over North America are affected somewhat by Pacific tropical sea surface temperatures (SSTs), as summarized by Shukla et al. (2000). Because of the limited memory of the atmospheric circulation (2–3 weeks), any predictability beyond this range must come from boundary forcing that has a longer timescale. The lower boundary of the atmosphere can provide such forcing both from the ocean and the land. As Shukla et al. have shown, the ocean provides one such potential source of forcing, and it can be predicted out to several months. The land surface also has a memory of about two months in the midlatitudes (Vinnikov et al. 1996; Entin et al. 2000). It is not possible at this time, however, to initialize a model with soil moisture observations due to limitations of land surface models, soil moisture remote sensing, and data assimilation techniques, although progress is being made in this direction (Mitchell et al. 2000).

In addition to the lower boundary, the upper boundary of the troposphere, the stratosphere, can provide a forcing to the system when it is controlled by a long-term process. As discussed above, the positive AO pattern forced by tropical volcanic eruptions is another important boundary forcing in the winters following such eruptions.

3. Separation of volcanic and ENSO patterns

The pattern of surface air temperature over North America produced by an El Niño event is similar to the AO pattern. It is difficult to separate such patterns using observations, as there have been few recent large volcanic eruptions for which good data exist, and they occurred simultaneously with El Niño events. Nevertheless, Robock and Mao (1995), using a linear regression approach during nonvolcanic ENSO events, identified the ENSO pattern and removed it from the data, showing that the winter warming over North America in the winters following the largest tropical volcanic eruptions of the past century, Krakatau (1883), Santa Maria (1902), Agung (1963), El Chichón (1982), and Pinatubo (1991), remained even after the ENSO signal was removed. They attributed them to the influence of these eruptions on the circulation. Yang and Schlesinger (2001),

using a more sophisticated singular value decomposition technique, removed the SST signal from observations and showed that the ENSO signal was weak over North America in the winter of 1991/92, and a large warming signal remained after it was removed.

Mao and Robock (1998) used a model-based approach to separate these signals. Using the output from 29 GCMs participating in the Atmospheric Model Intercomparison Project (AMIP; Gates 1992), they examined the surface air temperature patterns produced over North America following the two large El Niño events during the 1979–88 period of AMIP, the winters of 1982/83 and 1986/87. In AMIP the GCMs were run for this 10-yr period forced only by observed SST and sea ice, with no volcanic aerosols. For the GCMs that had the best El Niño simulations, the pattern of warming produced for both winters was similar, with warming over western Canada of 1°–2°C, but the observations for these winters were different (Fig. 1). While the observed pattern for the nonvolcanic winter of 1986/87 had the same shape as the average of the model simulations (but of higher amplitude), for the 1982/83 winter following the El Chichón eruption, there was a negative correlation of the model simulations with the observed pattern. The observed pattern matches the AO pattern forced by volcanic aerosols in the stratosphere.

4. Discussion

Shukla et al. (2000) conducted dynamical seasonal prediction experiments with six GCMs forced by observed SSTs and evaluated the resulting 500-mb patterns over what they called the Pacific–North America region (15°–70°N, 180°–60°W), which includes North America. They did not include volcanic aerosol forcing. Of the 19 yr considered, the three best results included the winters of 1982/83 and 1991/92. They attribute the predictability they found to the influence of SSTs. While the response over North America in the winter to an El Niño event and a tropical volcanic eruption are similar, both producing warming, the warming produced by the volcanic eruptions is at least as large as that from El Niño events, and the patterns are not identical. For successful dynamical seasonal prediction over the entire Northern Hemisphere, the effects of tropical volcanic eruptions must be considered in addition to effects from the planet's surface.

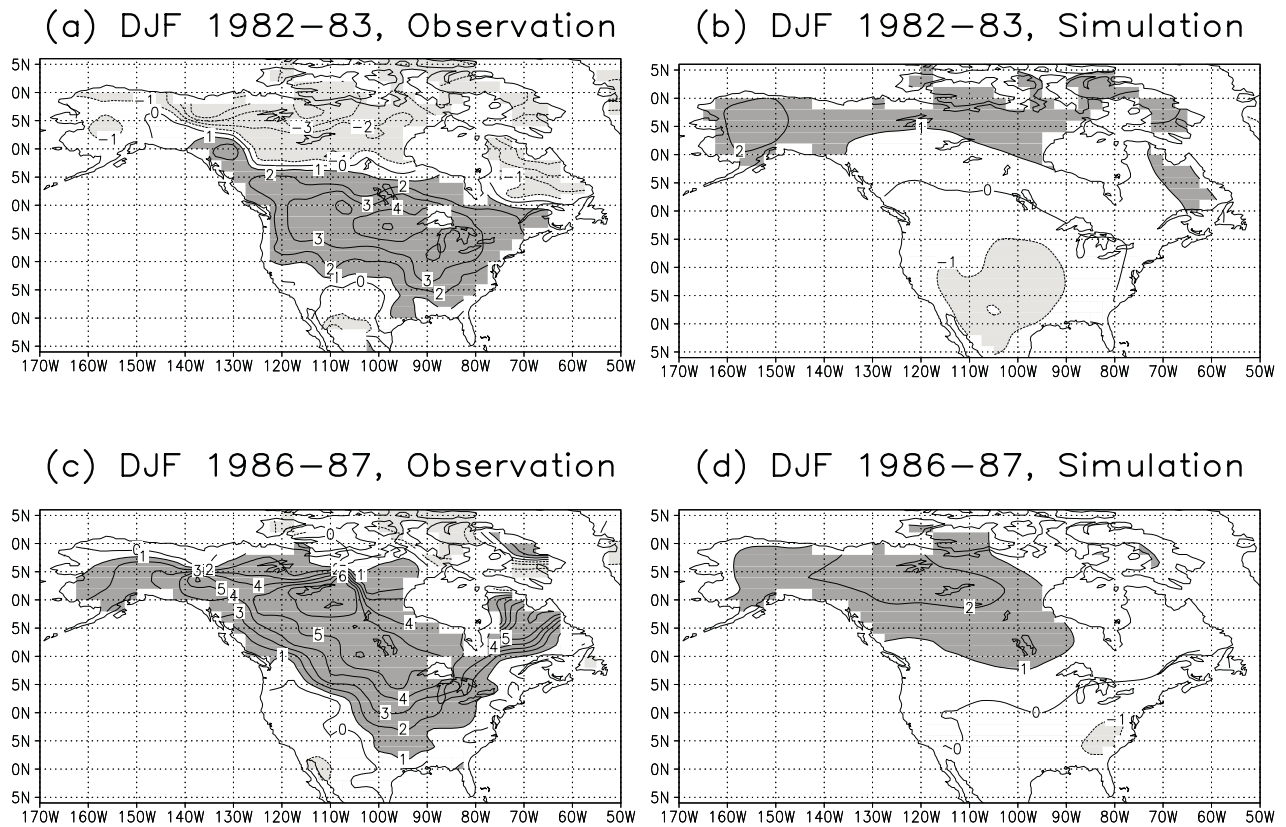


Fig. 1. Surface air temperature anomalies ($^{\circ}\text{C}$) over North America for the winters of 1982/83 and 1986/87. The observations are obtained from Schemm et al. (1992), and the simulations are the average of the eight best AMIP simulations for the ENSO signal (Mao and Robock 1998, their Fig. 12).

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