Effects of Volcanic Eruptions on Large-Scale Atmospheric Circulation

Large explosive volcanic eruptions inject massive amounts of sulfur into the stratosphere. This rapidly forms a significant aerosol layer of sulfuric acid droplets that persists over the next two or three years. In the last decades of the 20th century there were several major explosive eruptions: Mt. Agung, Indonesia, in 1963; El Chichon, Mexico, in 1982; and Mt. Pinatubo, Philippines, in 1991. Following each of these eruptions, the climate in the Northern Hemisphere in the two subsequent years was anomalous. In summer the extratropical surface temperatures were lower than normal, which is an expected consequence of the reduced direct solar heating of the troposphere as more of the solar beam is absorbed in the stratosphere. In winter, however, the situation was more complicated and the most prominent effects observed at the surface were warm anomalies in North America and northern Europe. The observed winter-mean anomalies in the extratropical circulation and surface climate were as large as those that typically accompany the mature phases of large El Niño events. How the volcanic perturbation to the stratospheric aerosol layer is related to the winter extratropical surface anomalies remains uncertain.

Kevin Hamilton, IPRC Theme 4 leader and Professor of Meteorology, has been investigating the atmospheric processes that may be mediating the warming of certain regions of the Northern Hemisphere troposphere by studying the effects of the largest and best-observed of these 20th-century eruptions, that of Mt. Pinatubo in June 1991. He is conducting this work with colleagues **Gera Stenchikov** and **Alan Robock** (Rutgers University), **V. Ramaswamy** and **Dan Schwarzkopf** (NOAA–Geophysical Fluid Dynamics Laboratory). They are applying the SKYHI troposphere-stratosphere-mesosphere general circulation model to simulate the atmospheric effects. Imposing the detailed space-time evolution of the stratospheric aerosol cloud observed by satellite after the Pinatubo eruption in integrations of the model, they are comparing these perturbed runs with results from long control integrations. Figure 4 shows the model simulated stratospheric geopotential anomalies during (a) the first post-Pinatubo winter, and (c) the following winter, and the simulated mid-tropospheric geopotential anomalies during (b) the first post-Pinatubo winter, and (d) the following winter. The model results agree reasonably well with the observed anomalies for the same periods. As in the observations, the simulated tropospheric circulation anomalies are accompanied by significant surface warming over North America and northern Europe.

The connections between the aerosol perturbation and the winter circulation changes may be quite subtle. The aerosol absorbs more solar radiation at stratospheric levels. In the winter-hemisphere stratosphere, this leads to an enhanced equator-to-pole temperature gradient and a stronger polar vortex (hence the negative geopotential anomalies over the pole in Figure 4a and c). But how are the anomalies in the stratosphere transmitted down into the troposphere? Given the realistic simulations of the post-Pinatubo anomalies with the SKYHI model, Hamilton and his collaborators are now applying the model to study the processes that could produce the anomalous surface warming over North America and northern Europe. The tropospheric anomalies could be due to the purely dynamical effects of the changed stratospheric vortex on the propagation of large-scale planetary waves. Alternatively, such anomalies could result from aerosol-related radiative perturbations to the troposphere. Even determining the significant radiative perturbations is complicated, as the aerosols affect both solar and terrestrial radiation directly via absorption and indirectly through their effects on stratospheric ozone chemistry.

Hamilton and his colleagues have completed a number of other experiments with the model in which, for example, the effects of the aerosol on the stratospheric ozone, or the effects of the aerosol on the absorption of the direct solar beam, are suppressed. Analysis of this array of simulations will produce insight concerning the significance of various mechanisms that connect the presence of the volcanic aerosol to perturbations in the surface climate.

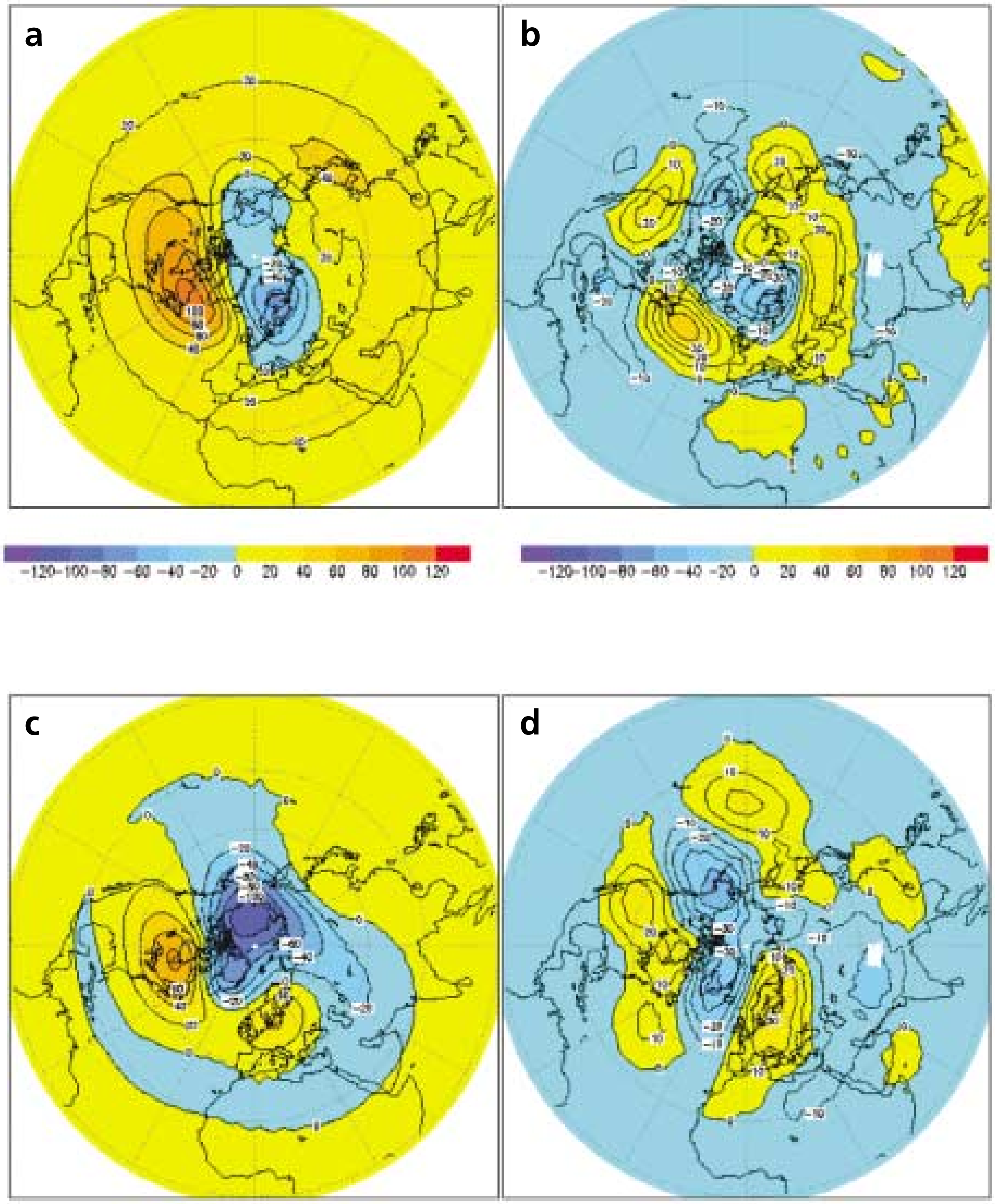

Figure 4. *Aspects of the SKYHI model simulation of aerosol effects from the Pinatubo eruption: (a) 50 hPa and (b) 500 hPa geopotential height anomalies for December to February in the first year after eruption; (c) 50 hPa and (d) 500 hPa geopotential height anomalies for December to February in the second year.*