Climate Effects of a Regional Nuclear Conflict

The climate effects of the regional nuclear conflict simulated in this study would last much longer and be much larger than those of the June 15, 1991 Mt. Pinatubo eruption, which followed the smaller June 12 eruption pictured here.

***Alan Robock**, Professor in the Department of Environmental Sciences at Rutgers University, New Jersey, visited the IPRC in August 2006. He gave two seminars, "Climatic Response to High-Latitude Volcanic Eruptions" and "Climatic Effects of Regional Nuclear Conflict." The effects of nuclear explosions described in the second seminar have very grave implications for climate and societies, and we asked Professor Robock to contribute this article based on the seminar.*

The first nuclear war, in which the United States dropped two atomic bombs on Hiroshima and Nagasaki, Japan, in 1945, so shocked the world that in spite of the massive build-up of these weapons since then, they have never been used in war again. In the mid-1980s, research conducted jointly by Western and Soviet scientists discovered that if a third of the then existing nuclear arsenal were exploded, a nuclear winter would result. The climatic consequences and indirect effects of the collapse of society would produce famine for billions of people far from the target zones. This realization helped end the arms race between the United States and the Soviet Union, reducing their arsenals by about two-thirds, but each still retains many thousands of deployed nuclear weapons. In the meantime, the number of nuclear weapon states has grown to nine (Table 1), with 40 more countries possessing enough enriched uranium and/or plutonium to quickly assemble nuclear weapons.

In this context, I have been working with **Brian Toon** and **Charles Bardeen** (University of Colorado), **Richard Turco** (UCLA), **Georgiy Stenchikov** (Rutgers University), and **Luke Oman** (Johns Hopkins University) to examine the effects of a regional nuclear war between new nuclear weap-

Country	No. of Weapons
Russia	10,000
United States	10,000
France	350
China	200
Britain	200
Israel	75–200
India	40–50
Pakistan	<50
North Korea	<15

Table 1. Approximate number of nuclear weapons in the arsenals of different countries. (From Table 2.1 from **International Panel on Fissile Materials**, 2006, with original data from Norris and Kristensen, 2006). The totals for the United States and Russia do not include warheads awaiting dismantlement.

ons states. (Turco, Toon, Stenchikov, and I had been deeply involved in nuclear winter research 20 years ago.)

With support from the National Science Foundation, we studied the following scenario: A nuclear war between two countries in which each country is using 50 Hiroshima-size (15 kilotons) weapons to attack the other's most populated urban areas with populations that could exceed 10 million. These 100 bombs represent less than 0.03% of the explosive power of the current nuclear arsenal worldwide. In our 100-weapon scenario, we estimate that five megatons of smoke would result from urban firestorms rising into the upper troposphere due to pyro-convection. Direct fatalities due to fire and smoke would be comparable to those worldwide in World War II. Furthermore, the megacities exposed to atmospheric fallout of long-lived radionuclides would likely have to be abandoned indefinitely, with severe national and international implications. We also anticipate substantial perturbations of global ozone.

To investigate the climate response to this massive smoke injection, we conducted simulations with a state-of-the-art general circulation model, ModelE from the NASA Goddard Institute for Space Studies, which includes a module to calculate the transport and removal of aerosol particles. Our experience with this model shows it simulates realistically the climate response to large volcanic eruptions.

The atmospheric model is coupled to a full ocean general circulation model that allows the surface-ocean to respond quickly and the deeper ocean on yearly time scales. We ran both models at 4°×5° latitude–longitude resolution, the atmospheric model with 23 vertical layers extending to a height of 80 km, and the ocean model with 13 layers.

We conducted a 30-year control run with no smoke aerosols and three 10-year simulations in which we injected five megatons of black carbon on May 15 into a column of grid boxes at 30°N, 70°E, and placed the black carbon in the model-layers that correspond to the upper troposphere (300–150 mb). Compared to the control run, the three ensemble members differed little in their response to the smoke injection, ensuring us that natural, chaotic weather variability is not responsible for the effects we see.

In the model, the black carbon particles in the aerosol layer are heated by absorption of shortwave radiation. This heating induces vertical motions and the aerosols are lofted close to the top of the stratosphere, much higher than is typical of weakly absorbing volcanic sulfate aerosols. As a result, the carbon aerosols have a very long residence time and continue to affect surface climate for more than a decade. The mass e-folding time for the smoke is six years; for typical volcanic eruptions, one year; and for tropospheric aerosols, one week.

The global-average surface shortwave radiation in response to the aerosols decreases by up to 15 W/m^2 (Figure 1). Five years after the initial smoke injection, the global-average perturbation is still at –7 W/m^2. This exceeds the maximum global-average surface cooling of –4 W/m^2 following the 1991 Mt. Pinatubo volcanic eruption, the largest of the 20th century. The cooling is also greater than the global average increase of 1.5 W/m^2 at the surface or 4 W/m^2 at the tropopause for a doubling of atmospheric CO_2.

The smoke cloud lowers surface temperature significantly (Figure 1). (Stratospheric temperatures are also severely perturbed.) A global average surface cooling of –1.25°C persists for years. After a decade, the cooling is still –0.5°C (Figure 1). The temperature changes are largest over land. A map of the temperature change for the Northern Hemisphere summer one year after the smoke injection is shown in Figure 3. Large areas of North America and Eurasia, including

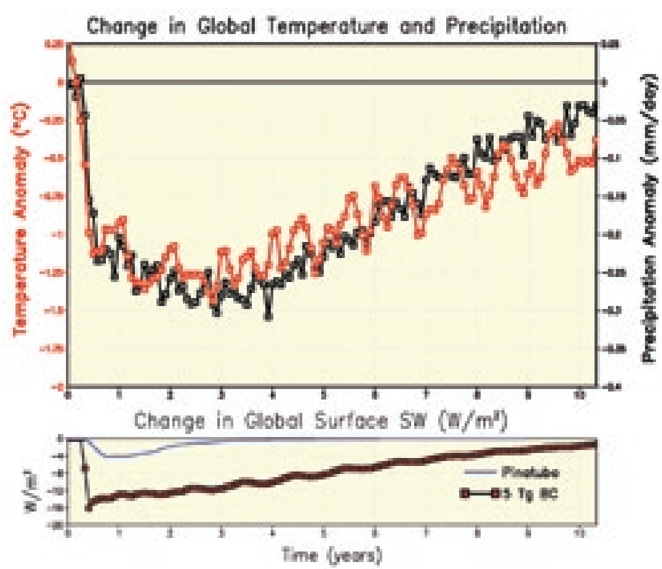

Figure 1. Time variation of global average net surface shortwave radiation, surface air temperature, and precipitation changes for the five megaton standard case. The global average precipitation in the control case is 3.0 mm/day, so the changes in years 2 to 4 represent a 9% global average reduction in precipitation. Precipitation recovers faster than temperature, but both lag the forcing. For comparison, the global average net surface-shortwave forcing from a model simulation of the 1991 Mt. Pinatubo eruption is shown.

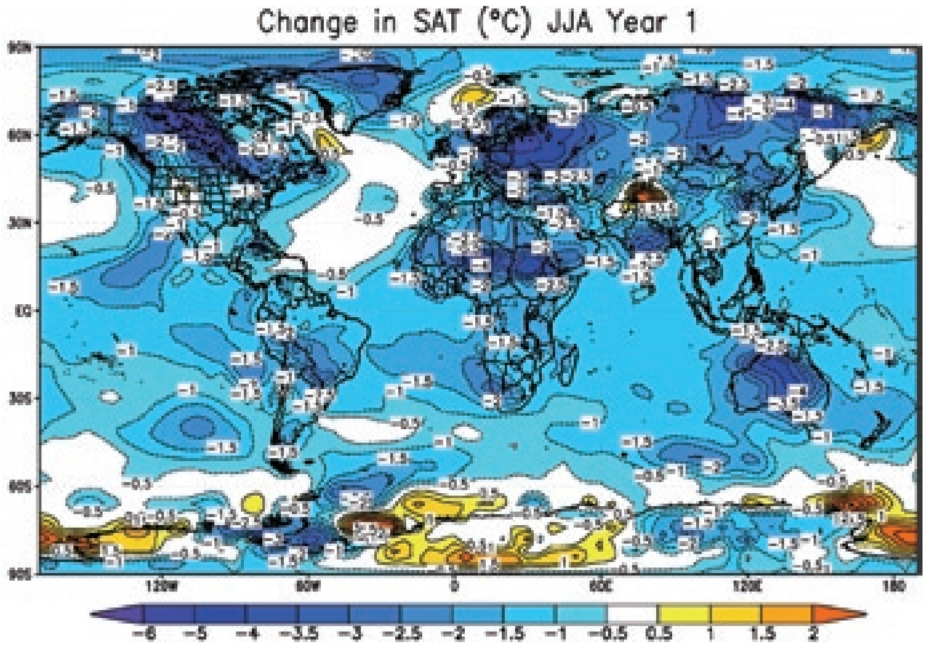

Figure 2. Surface air temperature changes for the five-megaton standard case averaged for June–August of the first year following the smoke injection. Effects are largest over land, but there is substantial cooling over tropical oceans, too. The warming over a small area of Antarctica is part of normal winter interannual variability and is not significant.

most of the grain-growing regions, are several degrees cooler. As in the case with the earlier nuclear winter calculations, large climatic effects are felt in regions far removed from the countries involved in the conflict.

As a result of Earth's surface cooling, evapotranspiration slows and the global hydrological cycle is weakened, with global precipitation reduced by about 10% (Figure 1). Although rainfall decreases mostly in the Intertropical Convergence Zone, as observed after the 1991 Pinatubo eruption, large areas on the continents are also affected, including the Asian summer monsoon.

The temperature, precipitation, and insolation changes would affect agriculture greatly. For example, the growing season in some regions of North America and Europe are shortened by 10 to 20 days. Such a reduction in growing season may completely eliminate crops that have insufficient time to reach maturity. And these reductions continue for several years.

To put the results in a larger historical context, the greatest volcanic eruption of the past 500 years, the 1815 Tambora eruption in Indonesia, resulted in a "Year Without a Summer" in 1816 in the Northern Hemisphere. Killing frosts disrupted agriculture throughout the summer in New England and led to significant emigration. In Europe, the wet cold summer caused a widespread harvest failure, resulting in famines and economic collapse. That climatic disruption only lasted one year. Because the black carbon aerosols in the current nuclear simulation are lofted into the upper stratosphere where their residence time is close to a decade, the climatic effects of the five-megaton case are significantly greater and more persistent than those following the Tambora eruption. Moreover, the cooling in the decade following our five-megaton injection is almost twice as large as the global warming of the past century (about 0.7°C) and would lead to temperatures cooler than the pre-industrial Little Ice Age.

The calculations presented here are the first ever of the effects of black carbon from nuclear conflicts as simulated in a coupled air–sea general circulation model, presumably the most complete and accurate representation of our understanding of the climate system. (Detailed results are found in Toon et al., *Atm. Chem. Phys. Disc.*, 2006, and Robock et al., *Atm. Chem. Phys. Disc.*, 2006.) The results may differ with finer model resolution and models that include smoke other than black carbon rising from burning cities, coagulation of black carbon particles, and photochemical processing in the stratosphere.

In our scenario, the estimated quantities of smoke generated by the detonation of one megaton of nuclear explosives could lead to global climate anomalies exceeding any changes experienced in recorded history. The current global arsenal is about 5,000 megatons!

The results in this paper need to be tested with other climate models, and the detailed consequences on agriculture, water supply, global trade, communications, travel, air pollution, and many more potential human impacts need further study. Each of these potential hazards, however, already now deserves careful analysis by governments, advised by a broad section of the scientific community.

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