Ozone, dust, smoke and humidity in nuclear winter

SIR—We wish to comment on recent correspondence on nuclear winter. Brown[1] draws attention to the Tunguska meteor explosion of 1908, which was estimated through aerodynamic calculations to have generated up to 30 million tons of NO, similar to the amount generated by about 6,000 megatons of nuclear explosives[2]. But there are several reasons why the Tunguska event may not be useful in calibrating the effects of a major nuclear exchange. Recent ice core analyses of NO, deposition from 1908–11 suggest that the NO production by the Tunguska meteor was equivalent only to 600 megatons or less of explosives[3]. Although ozone variations deduced from solar observations during the same period range as high as 20 to 30%, the ozone effect is uncertain because of statistical noise in the data base[2], so that a significant cause/effect relationship cannot be established.

Brown[1] and Peczkis[4] both confuse the relationship between the optical depth of an aerosol cloud, the composition of the cloud, and its effect on sunlight intensity and climate. Volcanic clouds are composed of dust-like aerosols that scatter light efficiently but absorb very little. The recent eruption of the El Chichôn volcano (Mexico, April 1982) produced a hemispheric cloud with a measured optical depth of about 0.3 at its zenith; although the cloud reduced the direct solar beam by about 25%, the forward-scattered light made up for most of this with a net loss of intensity of only 2 to 3%[5]. Smoke aerosol, by contrast, efficiently absorbs light, so that the same optical depth of smoke (0.3) may reduce the intensity of sunlight by a full 25% at high noon (and by more than 25% at other times of the day). It follows that smoke injected at high altitudes can be much more efficient than dust (per unit optical depth, or unit mass) at inducing climatic change[6].

Peczkis[4] has misinterpreted Stothers' data on the Tambora eruption of 1815[7], confusing scattering with absorption, and thus calculating a 90% depletion of solar insolation. The volcanic cloud may have reduced the direct solar intensity by that amount, but the net solar intensity would have been reduced by less than 5 to 10%. In fact, Stothers' estimate of the volcanic aerosol optical depth, which is larger than previous estimates, implies an average global temperature decrease of about 2°C (see ref.8), while the records show a roughly 1°C decline[6]. Even so, the year following the Tambora eruption became famous as the "year without a summer", illustrating the potential climatic significance of even small average temperature fluctuations.

Historical fires would provide useful calibration points for nuclear winter calculations if sufficient data were available. In most cases, there are difficulties in determining the quantity of material burned and the height of injection of the smoke. While German and Japanese cities were extensively burned during the Second World War, scientific record keeping was scanty and little can now be deduced quantitatively. And, although natural wildfires often burn for weeks or months affecting 10,000 km^2 or more[9], this situation differs markedly from the aftermath of a nuclear war, when hundreds of thousands of square kilometres of wildlands and hundreds of cities might burn in a matter of days.

Many of Peczkis' incidental statements about fires and smoke require qualification. For example, cooling is not expected beneath thin low-level smoke palls generated by persistent smouldering wildfires[10], although significant cooling has been observed below high-level smoke clouds[11], supporting the prediction of possible quick cooling and freezing under thick nuclear clouds, at least on a regional scale[12]. Moreover, smoke does not have to be injected into the stratosphere to cause a nuclear winter[13]; injection into the middle and upper troposphere is sufficient[14].

Almost all observations point to rapid geographical dispersion of smoke plumes from large fires[15], which is why Peczkis' speculation that such dispersal may not occur in nuclear fires is puzzling. Moreover, his estimates of smoke emissions in past forest fires are too high; typical forest fuel loadings are $\simeq 2\ \mathrm{g\,cm^{-2}}$, and one-third or less of this fuel generally burns in intense fires[10,16], so that less than 5 million tons of smoke should have been generated by even the largest historical fire complexes. The strongest effects of such fires would be expected to be limited to nearby regions[17], but even so, further analysis of meteorological and geographical records may be warranted.

Katz[18] is wrong in stating that water condensation and smoke scavenging processes have been ignored in published nuclear winter calculations; both prompt and delayed washout of smoke have been included[10,13,16]. Katz is most concerned with the moisture drawn into a fire by the convective winds established over the heat source. Excess humidity may be efficiently wrung from a humid smoke column in the form of local precipitation, as in the "black rain" which fell on Hiroshima on 6 August 1945[19], although smoke is apparently much less efficiently removed[10,20]. The condensed water that does not precipitate from the fire column disperses with the smoke clouds and soon evaporates — as do cumulonimbus anvils — releasing any smoke previously scavenged.

The temperatures of stabilized smoke clouds are sub-freezing when the altitudes attained are greater than a few kilometres. The water content of the clouds should also be rather modest because of the dehydrating effect of the "cold trap" over the smoke column, through which most of the smoky air must initially pass. Hence, a smoke cloud downwind of a fire is not likely to precipitate spontaneously, even if cooled further. The humidity of such a cloud is soon dominated by the humidity of the background air which dilutes the cloud, and by the absorption of solar radiation, which can heat and stabilize the smoke layers against convective penetration and washout[10,12–14,16].

Water condensing in the chilled slabs of air beneath a dense cloud of smoke may form a fog on any smoke particles that happen to be present, but this effect is of minor importance for a variety of reasons: (1) significant temperature reductions must first occur to trigger the effect; (2) the smoke at such low altitudes does not have a major role in nuclear winter climate effects; (3) the condensation is essentially a one-time process whose smoke removal efficiency may not be as high as Katz implies[10,20].

Idso's comments[21] on the nuclear winter concept are muddled. Physical scientists certainly should favour partially calibrated models over uncalibrated ones in analysing potential threats to the global environment. If a grand experiment has not been done, or cannot be done, prognostication with the best models available is a necessity. Studies of volcanic explosions, meteor impacts and dust storms provide fundamental insights into the responses of the Earth's climate system to heavy aerosol loading, and contribute to a clearer understanding of the nuclear winter phenomenon. The martian atmosphere is not such a pure vacuum as to preclude wind-driven dust storms there of global scale, which provide a unique opportunity to investigate planet-wide anomalies in atmospheric dynamics and climate triggered by clouds of soil particles.

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