The atmosphere after a nuclear war

We easily dismiss the horror of nuclear war as beyond our imaginings. It's not easy to come to grips with the fact that we have created an arsenal of nuclear weapons that is poised to deliver world-wide death and destruction.

Yet ignoring it won't make this nightmare go away. We have to 'think the unthinkable' if we are to see a way out of our predicament.

At a conference held at the Australian National University last May, more than 400 people confronted the issue of what the consequences of a major nuclear war might be. Nobody was left in much doubt that these would be so terrible that such a war could not serve any rational purpose, even for the 'winning' side.

Most discussion of the effects of nuclear conflict has concentrated on the death and destruction caused directly by the unimaginably powerful explosions and by the radiation released by the bombs. Estimates such as the United States National Security Council's prediction that 140 million Americans and 113 million Soviet citizens would die from the immediate effects of a major nuclear 'exchange' have been bandied about. But what about the broad environmental effect, the impact of a nuclear war on the earth's capacity to support life?

So far, we have only sketchy knowledge of what this would be. The question is a vitally important and a scientifically demanding one. A small group of scien-

tists at the CSIRO Division of Atmospheric Research have devoted time to it, and their initial findings were presented in two papers delivered to the conference. Dr Barrie Pittock reviewed the general physical nature of the global impact, and Mr Ian Galbally (and co-workers in West Germany and Sweden) concentrated on quantifying the effects, particularly on Australia. Some aspects of their studies drew on work by Divisional colleagues Dr Peter Manins and Dr Ian Enting.

Two scenarios

A great deal depends, of course, on the nature of the hypothetical war. Dr Pittock referred to two war scenarios, both considered reasonable at the time they were proposed, which differ considerably.

One was the basis of a 1975 report by the United States National Academy of Sciences. In that scenario 10 000 million tonnes of TNT equivalent are exploded in the Northern Hemisphere, with half the warheads large enough — half a megatonne or more — to place half their debris or more in the upper atmosphere. That study largely neglected the effect of dust and smoke, and instead concentrated on the effects of the oxides of nitrogen that would be produced by the high temperatures and shock waves associated with the nuclear fireballs.

Every megatonne of explosive yield is estimated to produce about 5000 tonnes of nitric oxide. The Academy report concluded that the nitric oxide produced by the explosion of 10 000 megatonnes of TNT equivalent would cause a large percentage of the ozone shield in the upper atmosphere to be destroyed (up to 70% in mid northern latitudes), leading to increases in skin cancer, crop damage, and other little-understood (but potentially serious) biological effects. These effects would last up to 2 years and, despite all the nuclear explosions being assumed to take place north of the equator, would affect the Southern Hemisphere, although to a lesser extent.

Part of the huge black cloud produced in the Northern Hemisphere would spread south.

A more recent (1982) scenario, prepared as the basis of studies sponsored by the Swedish Academy of Sciences' environmental journal *Ambio*, envisages the near-surface detonation of 14 740 warheads mostly of sizes ranging from 100 kilotonnes to a megatonne. The total explosive yield would be 5742 megatonnes, all but 3% of it in the Northern Hemisphere. There would be far fewer warheads large enough to inject debris directly into the stratosphere than in the other scenario, so far less serious destruction of the ozone layer would result from such direct injection.

The *Ambio* report suggested that more serious effects could result from the large quantities of dust and smoke generated by the nuclear explosions and the fires they would ignite. Besides the production of nitrogen oxides, nuclear explosions generate radioactive material, dust, and vaporized solids, including an estimated 1–10 000 tonnes of sub-micron-diameter particles per megatonne of explosive yield.

Mr Galbally calculates that the pollution load in the southern atmosphere from the *Ambio* scenario explosions south of the equator might not differ much from that resulting from the volcanic eruption of Krakatoa in 1883. While the aerosol from nuclear explosions would probably absorb sunlight more readily than that from volcanoes, the climatic effects of the two events would probably be of comparable magnitude. Although undesirable, these effects appear insignificant compared with the direct effects of a nuclear war.

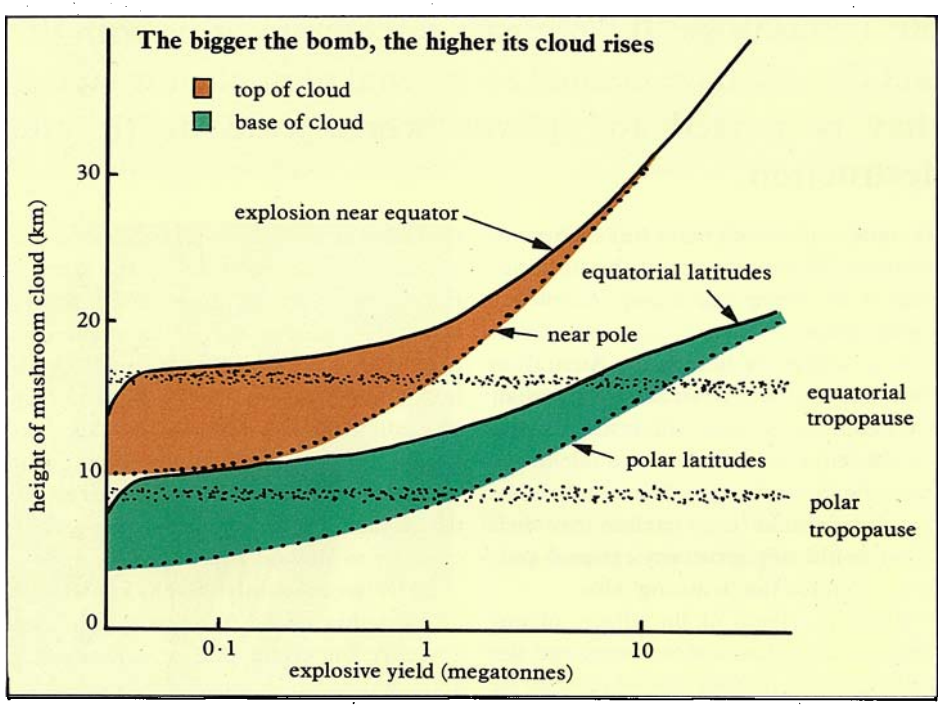
However, part of the huge black cloud produced in the Northern Hemisphere would spread south. The scientists find it difficult to calculate how much would do so — there are many uncertainties — but it would pose a grave risk to us. Undoubtedly some of it would reach the stratosphere and spread globally. The cloud would also create world-wide climatic disturbances that might well increase air flow across the equator at lower altitudes, bringing more of the debris south.

Predicting the effect of a nuclear war is something like forecasting the weather on another planet. Our description can only be framed in the most broad terms and be based on factors we have already recognized.

Estimates based on knowledge of the normal atmospheric circulation on the earth could greatly underestimate the effects of a Northern Hemisphere war on the atmosphere south of the equator. Nevertheless, short of doing expensive and elaborate calculations with huge computer models of the atmosphere, this is the only practical approach. It should give us a notion, at least, as to how our atmospheric mantle would respond if we were to vent our collective anger in a nuclear war.

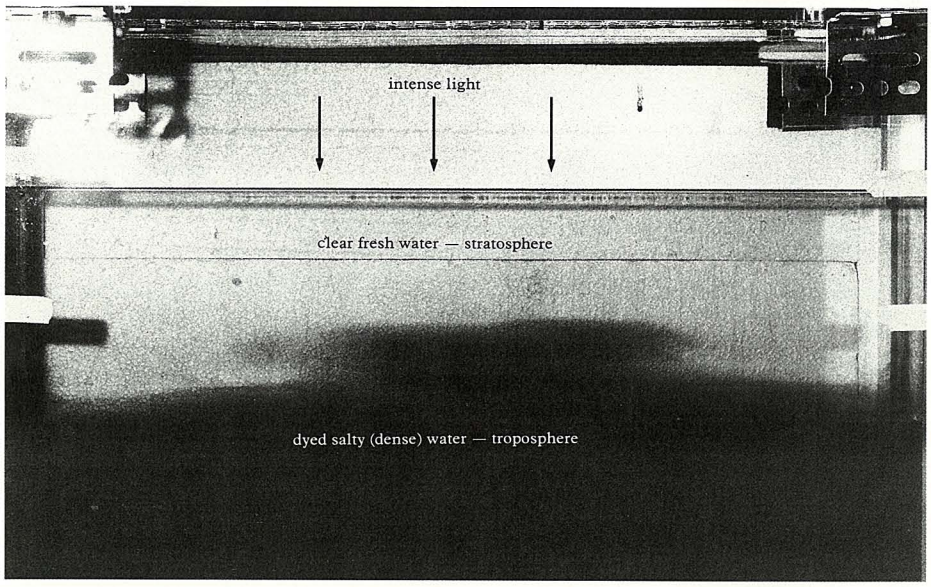
Twilight at noon

The lower atmosphere (below 10–15 km) is called the troposphere. Here, temperature decreases with altitude, and convection, cloud formation, and rain occur. Most



More bomb debris gets into the stratosphere (above the tropopause) from larger explosions. Bombs detonated near the equator rise higher than ones near the poles; however, the stratosphere is also higher near the equator. The net result is that, for the same size bomb, more debris reaches the stratosphere at polar latitudes.

A water-tank model of a smoke-filled troposphere. When strong light (resembling sunlight) shines down on the murk, the light is absorbed and the top layer heats up; the resulting convection takes dark material upwards. In the same way, smoke may enter the stratosphere.



of the contaminants in this well-mixed region will normally be removed in days or, at most, weeks.

Above the troposphere lies the stratosphere, where the temperature profile is such as to inhibit mixing. It has few clouds and almost no precipitation; introduced material, if too fine to settle out rapidly, will stay there for periods ranging from 6 months to several years.

Under normal conditions it takes about a year for air in one hemisphere to mix with that from the other. So nuclear debris finding its way into the northern troposphere would nearly all settle out north of the equator; however, a substantial proportion of stratosphere-borne material would inevitably find its way south.

This contamination would add to that from the 173 megatonnes exploded, in the *Ambio* scenario, in our hemisphere. The critical question is how much debris might be injected into the northern stratosphere.

It is conceivable that nuclear armaments may be detonated in the upper atmosphere either through interception of ballistic missiles or in explosions designed to burn out electrical circuits over a wide area (from their intense electromagnetic pulse). The scientists have not yet modelled such an event.

More significantly, the fateful mushroom cloud of a nuclear bomb is the sign of a hot, rising fireball. The bigger the blast, the higher that fireball will rise.

Evidence to date indicates that weapons greater than about half a megatonne can launch at least half their debris into the stratosphere if exploded at latitudes greater than 30°, where the lower boundary of the stratosphere is at a height of about 10 km;

The reference scenario

The starting point for the CSIRO scientists' work was a hypothetical nuclear war described in the Swedish environmental journal *Ambio* in 1982.

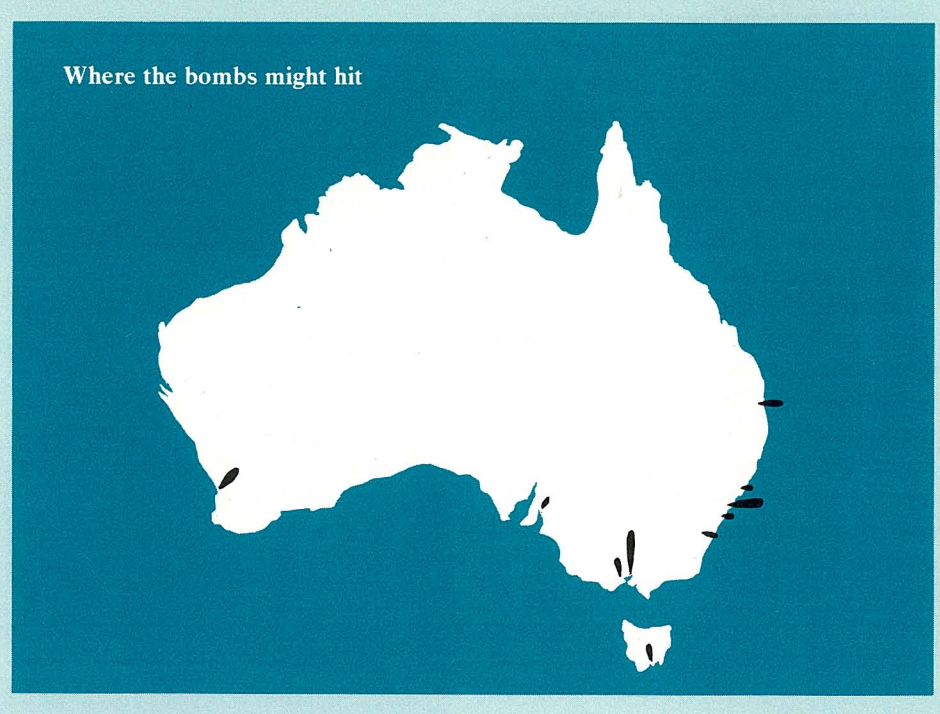
This war begins on June 10, 1985. The nuclear arsenals of the United States and Russia at that time are calculated to total about 12 000 megatonnes, deployed in 55–60 000 tactical and strategic warheads.

North America, Europe, and the USSR are assumed to be the main targets, and both sides fire their weapons in rapid succession. In all, less than half the arsenal is expended, amounting to 14 741 warheads and 5742 megatonnes.

Only 173 megatonnes is exploded in the Southern Hemisphere, including 33 in Australia. Sydney receives 10 megatonnes, Melbourne and Brisbane each receive 3 megatonnes, and other cities with more than 100 000 people receive 1 megatonne.

The fall-out plumes over Australia are shown on the map, using the winds prevailing 5 years earlier as the guide. The plumes are drawn to show areas that would receive at least 450 rad, a dose that would kill about half the population still alive within a month.

It should be added that this scenario, especially the number of bombs targeted on Australia, is controversial. Dr Des Ball, of the Institute of Strategic Studies at the Australian National University, believes that only the three main joint U.S.–Australian bases at North West Cape, Pine Gap, and Narrungar, and possibly Cockburn Sound, are likely targets.



The *Ambio* scenario sees cities with more than 100 000 people hit. The fall-out plumes are drawn according to the wind on 10 June 1980.

A smoke plume from a bushfire. The bigger the fire, the higher the plume reaches. Dr Manins calculates that plumes from burning cities could rise into the stratosphere.

at lower latitudes the boundary rises to 16 km, and here a 1-megatonne explosion is needed to achieve the same result.

Significantly, over recent years military strategy has shifted from reliance on large warheads to the use of smaller, more accurately targeted ones. This is reflected in the reference scenario, which sees only seven 10-megatonne devices exploded. Nevertheless, this event would lead to at least 10% of the total explosive yield reaching the stratosphere.

Burning cities

An equally important source of stratospheric contamination would be the buoyant plumes rising from intense fires ignited by the nuclear devices. The 12-kilotonne bomb dropped on Hiroshima resulted in a fire that consumed 50 000 buildings. We are considering the outcome of detonating nearly 15 000 weapons with yields ten to one hundred times larger.

Large cities contain huge quantities of combustible materials. Typically, 3 months' supply of oil and gas is held in storage, amounting to 1·5 thousand million tonnes world wide, and other burning materials might add half as much again.

Dr Manins calculates that the largest cities would burn with intensities of around 30 million MW, creating smoke plumes that would rise to 18 km (8 km into the stratosphere at latitudes greater than about 30°). At low latitudes he estimates that stratospheric heights would not be reached. We have had an example of such a smoke plume — from the firestorm in Hamburg caused by Allied bombing in 1944. This plume is reported to have reached 13 km. Forest fires would also add smoke to the troposphere, but plumes from them would not be big enough to reach the stratosphere.

On Dr Manins' reckoning, about 200 cities (all in the Northern Hemisphere) would burn strongly enough to inject debris into the stratosphere.

The debris from fires would contain large quantities of ash and sooty material, estimated from combustion and fire safety studies to comprise, at their source, 20 g of particulates per kg of fuel burnt. In addition, hydrocarbons and oxides of nitrogen would emanate from incomplete combustion and damaged or burning oil and gas wells.

The critical question is how much debris might be injected into the northern stratosphere.

The total sub-micron-sized aerosol production might be about 10 million tonnes in the Southern Hemisphere and 200 million tonnes in the Northern, Dr Galbally estimates. Again, stratospheric injection would be confined mainly to the Northern Hemisphere.

Acting on the stratosphere, the effect of this debris would be to destroy ozone, with a resulting rise in the amount of strong ultraviolet rays let through. Scientists are currently unable to quantify the amount because of the operation of several subsidiary factors.

Firstly, the black cloud in the troposphere underneath would act as a screen for the ultraviolet radiation, preventing it reaching the surface. Moreover, in the Northern Hemisphere the clouds would, for a while, be so thick (more than 100 times the normal thickness of the atmospheric dust loading, or 10 times that produced from Krakatoa) that very little sunlight would reach the surface.

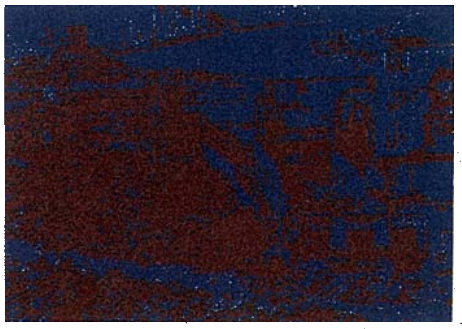
And then, all the sun's energy would be absorbed in the top kilometre of the cloud, heating it, and making it rise rapidly into the stratosphere. Dr Manins has modelled this phenomenon in a water tank, and the result of the experiment is shown in the photograph. He is unable to say, however, what fraction of the tropospheric cloud would be drawn into the stratosphere in this way.

Mr Galbally calculates that if 50% of the aerosol emitted in the Northern Hemisphere (possibly 100 million tonnes) were uniformly suspended around the globe in this way, sunlight reaching the earth would be reduced to 20% of its former strength for months — a climatic disaster.

The material that remained in the troposphere would have the potential to form a dense photochemical (ozone) smog. The scientists are unsure whether the sunlight penetrating would be strong enough to produce such a smog from the particulates, nitrogen oxides, and hydrocarbons. If it were, the ozone deficit in the stratosphere would be partly compensated for by an ozone excess lower down. In this way, ultraviolet damage might be ameliorated, but the ozone would damage plants. And the stratospheric ozone reduction would persist much longer than the tropospheric increase. Deposition of soot would also be likely to inhibit plant growth.

From studies of the fate of radioactive material from atomic tests, and the dispersion and settling out of atmospheric particles, Mr Galbally estimates that if the circulation did not change (which is unlikely) the tropospheric cloud should decline to 30% of its original bulk within 2 weeks to a month. More probably, the cloud would last longer.

Particles in the stratosphere are liable to stay there for many months, and spread over the globe. Mr Galbally believes extended computer modelling of all the factors at work is necessary to define the fate of the cloud more precisely, and, in particular, to give us an indication of the probable climatic effects, especially those that might result from major changes to the normal atmospheric circulation.



In summary, the immediate effects that a nuclear war conforming to the *Ambio* scenario would exert on the Southern Hemisphere atmosphere would be small in comparison with the direct effects — destruction of cities and local radioactive fall-out. The smoke and dust clouds produced south of the equator would only cover a tiny percentage of the surface (although beneath them sunlight might briefly be greatly reduced). They would disperse in a few days.

Long-term effects would be dominated by what happened in the Northern Hemisphere. A pall would be cast over the entire Hemisphere, which would undoubtedly upset the world's climate, although in unknown ways.

Apart from this, the most vital question is how much smoke, radioactivity, and nitrogen oxides could enter the northern stratosphere. For whatever amount did would inevitably be shared 'down under'.

Science to help

Scientists have a role to clarify the issues and narrow the uncertainties. It is encouraging that nuclear war is now being looked at in a scientific light. The United States National Academy of Sciences and the Australian Institute of Physics have issued statements on its dangers.

The Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions has begun an international project on the environmental effects of nuclear war. The central theme of the project is the chances of humans and the environment surviving, and recovering from, a nuclear war.

Andrew Bell

More about the topic

The atmospheric effects of nuclear war: an introductory survey. A.B. Pittock. Some changes in the atmosphere over Australia that may occur due to a nuclear war. I.E. Galbally, P.J. Crutzen, and H. Rodhe. In 'The Consequences of Nuclear War for Australia and Its Region', ed. M.A. Denborough. (Croom Held Australia: Canberra 1983.)

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Nuclear explosions and the atmosphere. A.B. Pittock. *The Australian Physicist*, 1982, **19**, 189–92.

'Report of the Committee on the Atmospheric Effects of Nuclear Explosions.' United States National Research Council. (National Academy Press: Washington 1983.)