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RESEARCH ON THE CLIMATIC EFFECTS OF NUCLEAR WAR

FINAL REPORT

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Contents:

RESEARCH ON THE CLIMATIC EFFECTS OF NUCLEAR WAR

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SUMMARY:

The major thrust of this work has been to investigate the surface climatic effects of a thin layer of smoke thought likely to move over Australia following a major nuclear war in the Northern Hemisphere. Detailed calculations performed at the Los Alamos National Laboratory in the United States suggest that a layer of smoke sufficient to absorb some 20% of the incident sunlight could pass overhead within a few weeks of a nuclear war, and similar amounts could remain overhead for 6-12 months. We have investigated the likely effects of such a smoke layer on surface temperature and rainfall, and made an estimate of the likely effect on Australian food production.

We find that daily average surface coolings would be in the range of 2-4°C, but that daily maximum temperatures could cool by 5°C or more over large areas of Australia, especially in the dry season. Overnight minimum temperatures would be less affected. Coolings are less over wet soil, and in some cases where smoke cover greatly reduces rainfall, leading to drier soil, local warmings can occur.

The most important effect over Australia is a large reduction in summer monsoonal and convective rainfall, even assuming sea surface

temperatures remain unchanged. In separate calculations we have estimated that sea surface temperatures could be lowered by several °C over a full 12 months, which could lead to reduced rainfall over all parts of Australia.

On the basis of an assumed halving of Australian rainfall, and a surface cooling by 5°C, we estimate that crop production would drop by some 30%. This by itself would not be sufficient to cause food shortages in Australia since we normally have a large surplus of production over domestic consumption. However, various other factors, notably increases in ultra-violet radiation due to destruction of ozone, and loss of various human inputs to agriculture due to loss of imports, could significantly increase the loss of crop productivity. Other socio-economic factors could also add to the problem.

A separate investigation was made of the possibility that nuclear explosions could lift large quantities of unburnt carbon from fuel dumps and other high carbon targets directly into the upper atmosphere within the nuclear fireball, thus adding to the smoke problem. A satisfactory computer model of the rising fireball was constructed. Simulations with this model lead to the conclusion that it is most unlikely that carbon would survive unburnt within a nuclear fireball, because of large quantities of oxygen which would be entrained into the fireball.

The fireball model has potential usefulness in calculating the lofting of other material, including oxides of nitrogen and radioactivity, into the upper atmosphere. Further studies with the model suggest that some past estimates of nitrogen oxide injections into the upper atmosphere from near-surface nuclear explosions may be overestimated. The environmental consequences of this have not been examined, but it does imply a reduction in the estimated depletion of ozone following a nuclear war.

Recommendations are made that a wider study be undertaken, which would take into account increases in ultraviolet radiation due to ozone depletion, and various socio-economic factors such as loss of vital imports, loss of economic incentives for farmers, and a possible controlled or uncontrolled influx of refugees. Such a study has been carried out in preliminary fashion in New Zealand. There is an interest in New Zealand in a follow-up study which would include Australia, in view of the close economic links between the two countries. Such a study would also have relevance to estimating the potential stresses on crop production and world trade brought about by the greenhouse effect and ozone depletion due to chlorofluorocarbons. A series of coordinated international studies of this nature is already underway.

Results of the present study should be made known to all relevant government agencies.

INTRODUCTION:

The probability of severe global scale climatic effects from a major nuclear war in the Northern Hemisphere has been repeatedly confirmed by numerous studies since the first such suggestion by Crutzen and Birks in 1982. These effects would arise essentially from the large quantities of smoke which would be generated by large area fires ignited by nuclear explosions, especially those occurring over urban and industrial areas where high fuel loadings exist. The SCOPE report, issued in 1986, and of which one of the present investigators (Pittock) was a principal author, documented this at length. Since then a number of new studies, including those financed under the IYP grant and reported here, have tended to confirm the effects, although modifying our understanding of them somewhat [see for example the recent review by Turco and Golitsyn (1988), and the statements issued by Warner et al (1987) and the Myrdal Conference (1988)].

Following the early suggestions that surface coolings over land in the mid-latitudes of the Northern Hemisphere could be as large as 30-40^{o}C, but would only last a few weeks, more recent investigations have led to smaller estimates of the initial cooling, of the order of 15-20^{o}C, but with longer lasting "chronic" coolings of the order of 5^{o}C, and significant reductions in precipitation especially in the tropics and monsoon regions. Significant chronic climatic effects are now thought possible for as long as one or two years after a major nuclear war. In terms of effects on agriculture and food supplies, the reduced acute-phase coolings are still sufficient to cause massive losses leading to widespread starvation, at least in the Northern Hemisphere, while the significant chronic effects would also lead to significant crop losses, and these would extend into the Southern Hemisphere.

The United Nations report issued on 5 May 1988 has again confirmed the reality and seriousness of these potential environmental effects. Our research has contributed significantly to a number of these reports and conclusions, especially in regard to chronic effects and effects in the Southern Hemisphere.

Central to our investigations has been concern as to the potential effects in the Southern Hemisphere of an elevated layer of smoke which the climatic models predict would pass across the equator into our hemisphere. The major thrust of our research has been to investigate the potential surface climatic effects resulting from such a layer of smoke. We have also investigated another possible mechanism which could possibly have lofted large extra quantities of absorbing material into the upper atmosphere, viz. the lofting within the nuclear fireball of unburnt carbon from fuel storages and other high fuel-density targets. If this were a significant additional source of absorbing material in the upper atmosphere it would significantly increase the severity of effects expected at our latitudes because the normal loss and delay mechanisms in the sequence from surface mass fires to soot in the upper atmosphere would be short circuited.

NUCLEAR FIREBALL MODELLING:

Surface nuclear explosions are capable of lofting large amounts of solid material into the upper atmosphere. American tests showed that between 30 and 300 thousand tonnes of surface material could be lofted per megaton of explosive yield. In the present study we have examined the possibility that surface nuclear explosions over fuel dumps, coal fields or regions of peaty soils might carry vast quantities of soot into the upper atmosphere, adding to the climatic effect from smoke plumes from mass fires. This mechanism, if effective, would be of particular importance to effects in the Southern Hemisphere because the normal loss and delay mechanisms operating on smoke plumes would be avoided, so that there would be greatly increased soot amounts in the upper atmosphere, with enhanced climatic effects in our latitudes.

A numerical model of the late "ascending" stage of a nuclear fireball was developed. The model is based on five equations covering the conservation of mass and entrainment, buoyancy, radiative loss of heat, the energy balance of the fireball and the velocity-distance relationship. The ideal gas law is used to relate pressure, volume and temperature, and a free energy minimization scheme is used to calculate the molecular composition and enthalpy of the fireball air. The model simulations compare favourably with available data from mid-latitude explosions (Galbally, 1987).

A chemical scheme for the uptake of carbon and combustion of soot particles in the fireball (based on the work reviewed by Wagner, 1981) has been developed and incorporated into the model.

Both standard runs with the model and sensitivity studies for a range of conditions indicate that all the soot particles within the fireball burn up as the hot fireball ascends in the air, and no soot is released into the upper atmosphere. It thus appears that this mechanism will not contribute extra soot to the upper atmosphere after a nuclear war. Estimates of the climatic effects should therefore be based on soot production from fires, carried into the upper atmosphere by smoke plumes, and to a lesser extent on non-sooty dust particles carried aloft by the fireballs. This work is being prepared for publication, and completes the original project.

Further work has been carried out with the fireball model, funded by CSIRO, to examine the question as to the rate of injection of nitrogen oxides into the upper atmosphere from the fireballs. Preliminary findings indicate that the rate calculated from this model is substantially less than that estimated by previous workers (Goldsmith et al, 1973). Thus depletion of ozone in the upper atmosphere due to nitrogen oxides from the nuclear explosions may be less than previously thought. However, no quantitative calculations of ozone depletion using these new injection rates for nitrogen oxides has been undertaken as yet (and it should be noted that there are other processes involved in the potential destruction of ozone following a nuclear war).

CLIMATIC EFFECTS OVER AUSTRALIA:

We took as our starting point in these calculations the results of global climate model simulations by Malone et al (1986) and Malone (personal communications), which indicated that some 2 to 3 months after a major nuclear war in the Northern Hemisphere a fairly uniform layer of smoke capable of absorbing some 20% or so of the incident sunlight (an absorption optical depth, or AOD, of 0.2) would be present at an altitude of 10-20 km over the mid-latitudes of the Southern Hemisphere. It was also noted that recent work indicates that the lifetime of this smoke in the upper atmosphere is of the order of a year or more (Stephens, Calvert and Birks, in press; Turco and Golitsyn, 1988). Thus we took a fixed uniform elevated smoke layer of AOD = 0.2 as our baseline case for use in the global climate model simulations, although in other models we did explore the effect of different smoke amounts.

Three different approaches have been used. The first used a coupled one-dimensional model of the atmosphere and the upper layers of the ocean (Walsh and Pittock, in press) to study the sensitivity of the sea surface temperature to variations in the absorption and reflectivity (albedo) of an elevated smoke layer. Results of this work are summarised in figure 1, which shows the cooling of the sea surface relative to normal, at 30 S latitude, for various smoke layer thicknesses (AOD) and albedos, 12 months after the smoke layer was inserted in the model.

The most probable range of AODs over Australia is around 0.15-0.3, and of albedos around 0.1-0.2. These give sea surface coolings of the order of 2-3^{o}C after one year. These coolings are slightly greater in summer than in winter, and greater at low latitudes than at high latitudes. These results indicate the effect of neglecting changes in sea surface temperatures, which was done for simplicity in the later climate modelling work.

The second approach was to use a mesoscale model (one with a horizontal scale of a few km, and high resolution in the vertical, especially near the Earth's surface) to study surface temperature effects, sea breezes, and cold drainage winds, in inland and coastal zones. This model has much more detailed representation of surface and near-surface processes, including soil properties, and variations in atmospheric stability near the ground, than most global scale climate models. We were also able to explore in this model the importance of smoke infrared emission and absorption, which we neglected in the global climate modelling (Pittock et al, in press; Garratt, Pittock and Walsh, in preparation).

Results from the mesoscale model simulations highlighted the importance of soil moisture, which largely determines the evaporative heat losses from the surface, and of the daily temperature cycle. Coolings due to smoke were found to be considerably greater during the day than at night, and over dry soil than over wet. Smoke infrared emission and absorption was found to make an almost negligible contribution to the heat balance during the day, but to significantly reduce the surface coolings at night.

In general, the presence of a smoke layer of about the thickness expected to occur over Australia (AOD of 0.2) led to soil surface coolings of 3-6^{o}C during the day, but in the range 0-2^{o}C at night, depending on soil wetness and other factors.

In coastal zones the smoke led to a weakening of the sea breezes, and to an increase in cold drainage winds towards the coast over sloping terrain. For large smoke thicknesses, such as might be expected in the Northern Hemisphere, the latter could produce shallow but very cold drainage winds, similar to the "katabatic" winds often experienced around the coast of Antarctica. Such cold drainage flows could negate the moderating effect of proximity to the oceans in some coastal zones.

No allowance was made in these mesoscale model calculations for water cloud or fog effects.

The third approach was to use a three-dimensional global climate model in which the effect of an elevated uniform layer of purely absorbing smoke of AOD 0.2 was simulated. Full details of the model, including assumptions and caveats, will be found in Pittock et al (in press) and Pittock, Walsh and Frederiksen (in preparation). In particular, the model predicts temperature and rainfall, but assumes fixed average climatological cloud cover in determining the radiation balance, and fixed climatic average sea surface temperatures. It also neglects downward infrared emission from the smoke, and smoke albedo. These limitations must be borne in mind, and their implications are discussed in the detailed papers. We do not believe these limitations have any radical effect on the validity of our conclusions.

Figures 2 a and b show the differences in daily average soil surface temperature due to the smoke, averaged around each circle of latitude, for the first ten days after smoke was introduced in July and January. Coolings of the order of 2-4^{o}C are evident in both seasons at all latitudes with substantial land surfaces, except in the regions of the polar night. Coolings remained similar throughout the 105 days of the simulations.

30-day average precipitation rates (mm/day) averaged over land around each circle of latitude are shown in figure 3 a for July and in figure 3 b for January. Note the decreases in precipitation in the runs with smoke (the "perturbed" runs) of the order of 50% in the tropics and in the subtropical regions influenced by the monsoons. Decreases occur essentially in areas of predominantly convective or monsoon activity. It should be noted that if cooling of the oceans were to be taken into account this might lead to decreased rainfall at higher latitudes also.

Runs with a daily temperature cycle showed that daily maximum temperatures at the soil surface and in the lowest layer of the atmosphere generally cooled by up to 5 or 6°C, especially in the dry season. However some areas of local warming occurred during the wet season, which were attributable to reduced rainfall leading in the perturbed case to much drier soil and reduced evaporative cooling. At night coolings were generally in the range 1-3°C.

Taking into account the effects of variable cloudiness, neglect of smoke albedo and infrared emission, and changes in sea surface temperature, we conclude that a reasonable temperature scenario is to consider that average surface air temperatures might drop by about 5°C over most of Australia, and rainfall might decrease by about 50%.

More elaborate climate model simulations, including variable cloudiness, smoke infrared emissions, and reduced sea surface temperatures, could now be carried out. Similarly the climate perturbations could be coupled with more sophisticated crop simulation models. However, given the uncertainties in the war scenarios themselves (eg., targeting, fuel densities, initial weather conditions, season), we are not sure that such more rigorous simulations would greatly improve the reliability of the results.

IMPACTS ON AUSTRALIA:

Besides the reductions in rainfall and surface temperature, it should be noted that there would also be reductions in the effective length of day by an amount which depends on how length-of-day is defined, and in the intensity of the noonday solar radiation at the surface of the order of 20-30%. Another possible stress which might contribute to a substantial loss of crop productivity is a several-fold increase in biologically damaging ultraviolet radiation (UV-B), but this is not yet accurately quantifiable. Radioactive fallout over Australia is considered to be negligible as far as the impact on crop production is concerned, unless there were nuclear detonations at or near the surface in Australia.

We have made a preliminary estimate of the effect of the reductions in temperature and rainfall only, on crop productivity (Pittock, in preparation). This is based on a crude relationship between net primary productivity (NPP) and annual rainfall and annual average temperature, known as the Miami Model, and applied earlier to a greenhouse warming scenario by Pittock and Nix (1986). This is necessarily rather crude, but we think it is consistent with the degree of uncertainty in the climatic scenario at this time. We believe the results provide a conservative estimate of the loss of crop productivity to be expected after a nuclear war.

The Miami Model was applied to some 18 stations around Australia, mostly in the wheat belt. Results indicated an average loss of production of some 30%, with nearly all of this loss being due to reduced rainfall.

Given the normal large surplus of production over domestic consumption in Australia, a decrease in production of this order of magnitude would not by itself lead to serious food shortages in Australia. Indeed, it is comparable to the impact of the 1982-83 drought, which caused significant economic hardship in rural areas, but no food shortages (Allan and Heathcote, 1987).

However, the situation might be considerably worse when other stresses are taken into account, including reduced length of day (which affects the dates at which some plants begin certain stages of growth) and reduced amounts of sunlight. Perhaps most importantly, if preliminary estimates of possible reductions in ozone are correct, then large increases in UV-B radiation could greatly increase crop losses.

Besides loss of productivity due to climatic effects, the effect of loss of some human subsidies to agriculture, including fertilisers, pesticides, and the use of some machinery, could be significant in

Australia due to loss of trade with supplier countries (Harwell and Hutchinson, 1985; Green, Cairns and Wright, 1987; Pittock, 1987). Any direct targeting of Australian cities would of course cause serious disruption to agricultural production and food distribution (Coombs, 1983; Pittock, 1987), and high altitude nuclear explosions could cause disruption to electronic communication and control equipment and electrical supply systems, due to the electro-magnetic pulse (EMP) effect (Pittock et al, 1986). Arrival of refugees from non-combatant countries in the Northern Hemisphere and tropics (Pittock, 1987) could also add to food shortages. Any breakdown in plant, animal or human disease quarantine could also seriously affect food production.

It should be added that the sort of climatic effects found here for Australia would apply in the tropics and Northern Hemisphere either in the first or second growing season after a spring or summer war in the Northern Hemisphere. The implications for food production and ensuing mass starvation are far more severe for those countries which do not normally have large food surpluses than for Australia. This could rebound on Australia in terms of an increased refugee problem from non-combatant countries in the South-East Asian region.

RECOMMENDATIONS:

We have concluded that the temperature and rainfall reductions found here would not by themselves lead to mass starvation in Australia. However, taken in the context of other possible stresses and socio-economic impacts, notably increases in UV-B radiation, loss of trade, and a possible controlled or uncontrolled influx of refugees, these climatic stresses could contribute to a serious food shortage and other problems in Australia.

We would therefore recommend that a wider study be undertaken, which would take all these factors into account, perhaps along the lines of the study conducted in New Zealand by the New Zealand Planning Council (Green, Cairns and Wright, 1987; Green, 1988). It is probable that New Zealand will undertake a follow-up study in which they would need to consider impacts on Australia, since New Zealand would be largely reliant on trade and the sharing of resources with Australia in the aftermath of a nuclear war.

Factors to be considered include food storage and distribution, availability of fertilisers, pesticides, veterinary supplies, vaccines, special lublicants, machine parts, electronic components, etc., all of which may be threatened by loss of imports. (The socio-economic impacts of loss of export markets and incentives, and of the arrival of refugees, may also be important.)

Interest in such a study has been expressed in Australia by Prof. Henry Nix, Director of the Centre for Resource and Environmental Studies, Australian National University, and Dr. Rod Simpson, School of Australian Environmental Studies, Griffith University. It also has support in principle from the national Committee for the Environment of the Australian Academy of Science.

Some further refinement of the climatic scenario could be carried out within the CSIRO Division of Atmospheric Research by the climate modelling group, while atmospheric chemists at the Division could work on the ozone/UV-B problem, but both groups would need external funding in order to undertake such work.

There is a close connection between the present work and that necessary to anticipate the effects of the greenhouse gases, which could also have significant agricultural and socio-economic effects on Australia and other countries (Pittock, 1988). Indeed, there is international interest in a series of national case studies, which are being coordinated by Dr. Mark Harwell, Director of the Global Environment Program at Cornell University in the United Sates, and which are to address the possible impacts of both nuclear war and the greenhouse effect. Case studies are to be carried out in China, Japan, India, Venezuela, and sub-Saharan Africa. Such studies clearly relate to questions of world trade, and international aid and development, as well as to future Australian policy.

Finally, we recommend that the relevant results of the present study be brought to the attention of all relevant Australian Government departments and organisations, including most obviously the Natural Disasters Organisation and the Department of Primary Industries and Energy.

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FINANCES:

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The original grant amount of $140,000 was increased by $18,562 by interest up to 31 August 1988. Major expenses have been for computing operations ($79,095) and for salaries ($59,031) as anticipated. A sum of $4,901 was spent on travel, most of which went to bring Dr. R. C. Malone of Los Alamos National Laboratory to visit during February 1987, when he presented unpublished results and gave advice regarding our climate modelling effort. Small amounts were spent to top up travel funds for Dr. Pittock to present results at a meeting of the International Geophysical Union in Vancouver in August 1987 and a meeting of the International Association for Impact Assessment in Brisbane in July 1988. Some $14,358 was spent on computing supplies and equipment, and $1413 to date on reprints of publications. The current balance is slightly negative, and additional reprint costs are expected. On the other hand a small amount of additional interest is expected before the account is closed. The Division of Atmospheric Research will absorb any cost in excess of funds available under the grant.

A short financial statement follows:

Income:

grant	$140,000
interest to 31/8/88	18,562
total	158,562

Expenditure:

computing operations	$79,095
computing supplies and equipment	14,358
salaries	59,031
travel	4,901
reprints	1,413
total	158,798

Balance as at 15 September 1988: -236

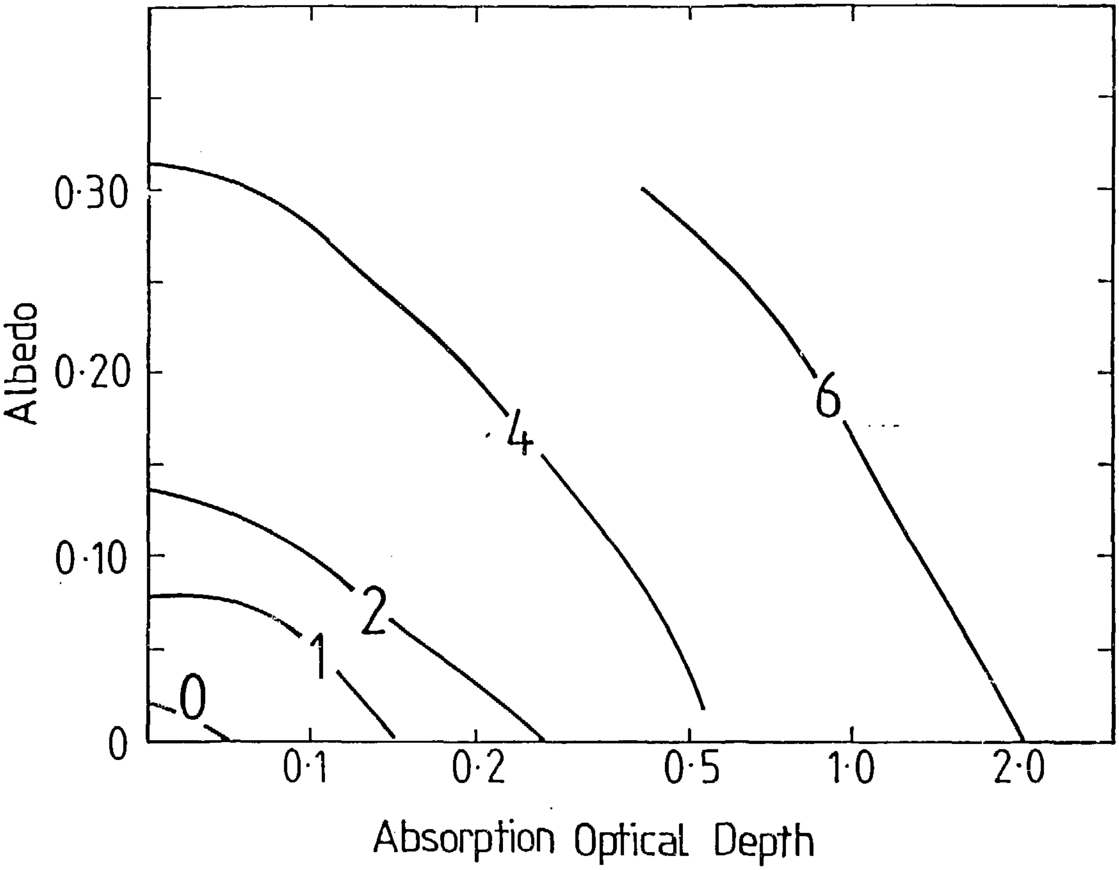

Figure 1. Sea surface temperature coolings relative to the climatological cloud run for 30 S, for varying absorption optical depth and albedo of a simulated smoke layer, after 12 months of model simulation.

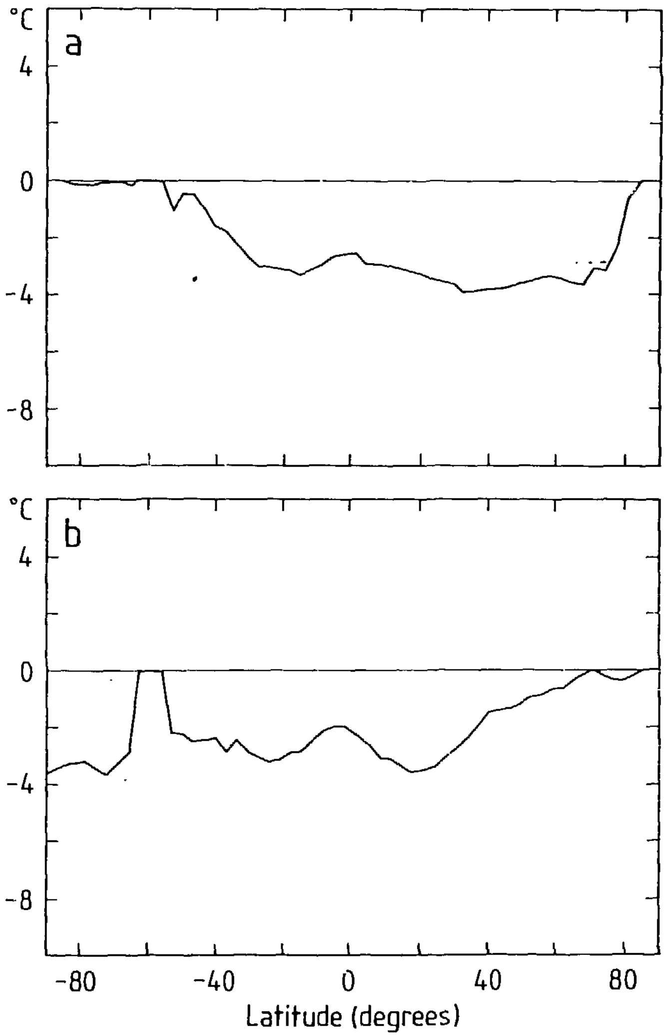

Figure 2. Zonally-averaged daily mean soil surface temperature differences, with smoke minus without smoke, for the first ten days after uniform smoke of AOD = 0.2 was introduced in (a) July, and (b) January. Smoke of AOD = 0.2 is what is expected over Australia in the first 6 to 12 months after a major nuclear war in the Northern Hemisphere. Note the coolings due to smoke averaging 2-4°C over all land areas outside the polar night.

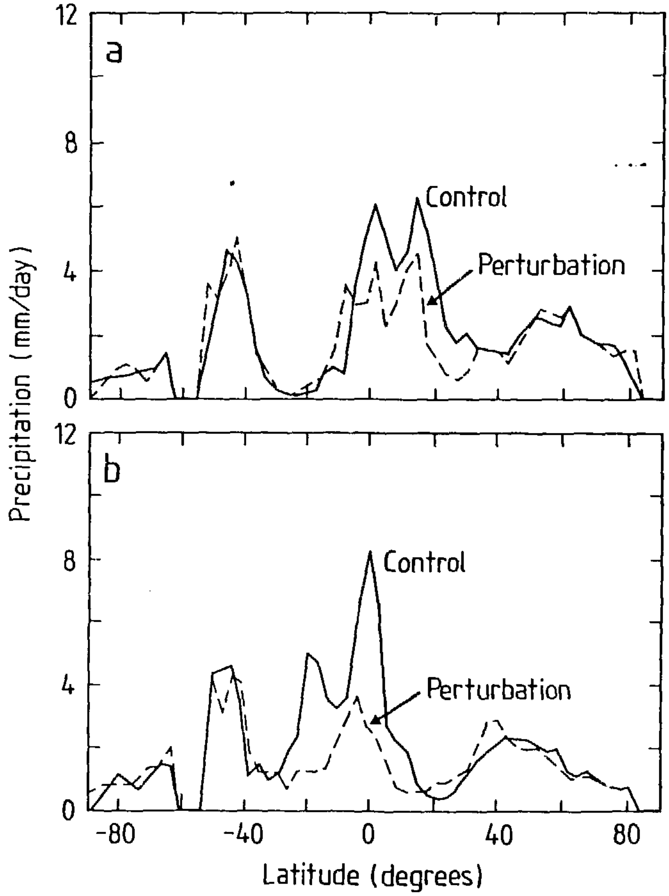

Figure 3. Zonally-averaged 30-day mean rainfall rates (mm/day) over land for (a) July, and (b) January. Control (no smoke) simulations are indicated by the full lines, and perturbed (globally uniform smoke of AOD = 0.2) simulations by the dashed lines. Note the major reductions in rainfall, due to the smoke, in the tropics and monsoon regions.