NUCLEAR WAR: ILLUSTRATIVE EFFECTS OF ATMOSPHERIC SMOKE
AND DUST UPON SOLAR RADIATION

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Abstract. It has recently been suggested that following a nuclear exchange there might be a significant reduction in surface temperature over land areas, due to the impact upon the radiation budget of the surface-atmosphere system of smoke produced by fires and of dust injected into the stratosphere by ground bursts. The present study addresses several aspects of this possible radiative perturbation, such as the unusual nature of the climate response to the perturbation, a description of differences which are inherent within existing model studies, an evaluation of radiative transfer assumptions which have been employed in existing model studies, and illustrative latitudinal and diurnal variability of the smoke-dust impact upon solar radiation.

1. Introduction

Recently four studies have appeared which consider the climate impact of a large-scale nuclear war (Turco et al., 1983; MacCracken, 1983; Aleksandrov and Stenchikov, 1983; Covey et al., 1984). These studies followed an earlier suggestion by Crutzen and Birks (1982) that fires resulting from a nuclear exchange could produce large quantities of atmospheric smoke, thus significantly reducing the amount of solar radiation reaching the earth's surface.

Turco et al. (1983) subsequently pointed out that, in addition to smoke, ground bursts in the vicinity of missile silos could inject substantial quantities of dust directly into the stratosphere. They then employed a one-dimensional radiative-convective climate model to estimate, for a number of different scenarios, that the ground temperature for mid-continental regions might be significantly suppressed, by perhaps several tens of degrees Celsius, for a period of several months following the exchange. Comparable results were obtained in the three other studies. MacCracken (1983) employed both a one-dimensional radiative-convective model and a two-dimensional statistical-dynamical model. The remaining two investigations utilized general circulation models; an annual-average model by Aleksandrov and Stenchikov (1983) [see also Thompson et al. (1984)], and a seasonal model with fixed sea-surface temperature by Covey et al. (1984) who showed changes in atmospheric circulation for winter, spring and summer simulations, but presented surface temperatures only for the summer.

Because of the significantly different nature of the models, as well as their differing smoke-dust solar forcing as will be illustrated in following sections, a comparison of the model results would not be particularly meaningful. But it is important to understand why, in somewhat differing manners, the models all produced strong surface cooling, even though in three of the models the smoke-dust addition produced increased solar absorp-
tion by the surface-atmosphere system. One intent of the present paper is to provide such an understanding.

A second and primary purpose of this paper is to study one aspect of the climate forcing; the impact of atmospheric smoke and dust upon the absorption of solar radiation by the surface-atmosphere system. This includes an appraisal of radiative transfer approximations which have been utilized in certain of the climate impact studies, in addition to illustrating the smoke-dust impact upon both latitudinal and diurnal variability of the solar radiation budget of the surface atmosphere system.

2. Climate Response to a Forcing

As a prelude to understanding nuclear-war induced climate change as predicted by the current model efforts, it is instructive to subdivide climate change into a two-stage process. The first stage pertains to the direct (or initial) radiative forcing which induces the change, such as infrared radiative forcing due to an increase in atmospheric CO₂, or solar radiative forcing resulting from a change of the solar constant, to cite two often studied examples. The second stage is the climate response to that forcing, and it is here that climate feedback processes play a role. As discussed by Dickinson (1982), for example, the change in global-mean surface temperature, as induced by a radiative forcing \( G \), may be expressed by

\[
\Delta T_s = \frac{G}{\lambda}
\]  

where \( \lambda \) is a responsive function which incorporates relevant feedback processes.

What is germane to the present discussion is the radiative forcing \( G \), which refers to the net radiative forcing of the surface-troposphere system. In other words, and as summarized by Potter and Cess (1984), it is not the direct radiative forcing of either the surface or the troposphere which is important, but rather the forcing of the surface-troposphere system. This is due to the fact, at least within the models which have been used to arrive at this conclusion, that small-scale convective mixing within the troposphere essentially couples the surface and troposphere so that they act as a single thermodynamic system. But the restriction here is to small radiative perturbations.

Quite a different conclusion applies to the nuclear war studies, and this is due mainly to the large magnitude of the smoke-dust radiative forcing. To illustrate this, it is convenient to first consider the general circulation model results of Covey et al. (1984), for which the sea surface temperature was held fixed, since the large heat capacity of the oceans would preclude their changing significantly over the 20 day simulation which was considered.

Covey et al. (1984) included only smoke and assumed that this was purely absorbing at solar wavelengths and had a negligible infrared opacity. In a later section it will be shown that their neglect of scattering of solar radiation by smoke is reasonable, while except possibly for very large optical depths the infrared opacity of smoke is unimportant (J. T. Kiehl,