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THE IMPORTANCE OF LOCAL MESOSCALE FACTORS IN ANY ASSESSMENT OF THE NUCLEAR WINTER SCENARIO

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The possibility that severe climate changes would follow a major nuclear war (the so called "nuclear winter") due to the injection of large amounts of smoke into the atmosphere has been the subject of much recent speculation.[1,2,3,4,5] In all these considerations assumptions have been made about the amount of smoke generated, its carbon content, the size of the constituent particles and so the associated optical properties. Furthermore, given these assumptions, the calculations of the subsequent cooling of the surface air temperature are based on either One Dimensional Models[1] or versions of coarse Three Dimensional[3,4] global atmospheric circulation models originally designed to further understanding of climate variability on the global scale. A widespread uniform smoke distribution is an essential assumption for 1-D models. The 3-D models used to date have a resolution of not better than about 5^{o} latitude which also does not allow mesoscale processes to be adequately represented. Related assumptions have also to be made about the rate at which the smoke is scavenged from the atmosphere.

It may be that these latter assumptions take a great deal of meteorology for granted. The sources of the smoke are fairly widely distributed in most of the scenarios that have been suggested. This means that, in the early stages of a nuclear conflagration, there would be a number of discrete smoke plumes. The calculations to date all ignore this initial stage and assume that meaningful calculations can be made with the starting point at some time later when these plumes have merged into a general and more extensive pall.

Given the local nature of these initial intrusions of smoke, and the strong temperature gradients that their radiative characteristics would create, it is reasonable to suppose that mesoscale atmospheric circulations would be set up, especially near the edges of the plumes. This is quite separate from any circulations that might be expected locally at the source of the smoke due to heat and moisture which inevitably must be associated with the smoke generation. If such mesoscale circulations produce cloud it would be expected to increase either the scavenging rate or the rate at which the smoke particles coagulate to larger sizes. For a given mass of smoke the radiative effects decrease significantly as the size of the particles increases.[6]

To test the possibility that such mesoscale circulations might be set up, a case study has been completed using a numerical mesoscale model currently under development in the Meteorological Office for improving short period weather forecasting. Briefly it is a non-hydrostatic, compressible model using a semi-implicit time-stepping scheme to ensure numerical stability.[7] The vertical co-ordinate is height above orography[8] and in the study 16 levels were used with 5 of them in the lowest km of the atmosphere and the highest at 12 km. The model has an explicit representation of grid scale clouds[9] and uses a 1-D steady state cloud model to parametrize deep convection. A $1\frac{1}{2}$ order closure diffusion scheme models sub grid-scale turbulence. In normal use radiative effects are calculated using input to a surface heat balance equation. However for the purposes of this study the absorption due to smoke was modelled as an internal heat source in addition to its effect on the surface radiation. The domain for the case study was the British Isles and a 15 km grid mesh was used.

In the study a steady state source was inserted in a column of radius 75 km near the middle of the model grid. The vertical profile of the smoke was chosen to be consistent with published data and to have a concentration of 6.1×10^{-4} kg m^{-2} over the model depth and a peak at 9 km of 1.1×10^{-7} kg m^{-3}. The model winds transported the smoke across the grid. No effect on the smoke concentration of other variables was permitted, and the only effects of the smoke on other variables were via the internal radiative heating and the heat balance at the ground. Using the absorption coefficient calculated by Slingo and Goldsmith[6] (1.5 m^{2}g^{-1}) gave an optical depth of 0.91 for the source region of smoke at normal incidence. With a solar elevation of 53^{o} about 20% of the short wave radiation reached the ground. This depletion of the solar beam implies modest smoke concentrations compared with previous studies.

The day chosen for the study was 15 June 1984 when an anticyclone covered England and Wales and skies were generally clear. Initial actual data for 0600 GMT were used. A weak northwesterly wind at upper levels resulted in the main plume spreading to cover much of northern England, the East Midlands and East Anglia (see Fig 1) by 1800 GMT. Solar absorption early in the forecast period quickly resulted in a 5°C temperature excess at about 300 mb near the centre of the plume compared with the control run which was for the same occasion but without the smoke plume. This excess produced a vertical circulation of air with maximum upward motion of 0.2 ms^{-1} in the smoke cloud and weaker subsidence around it. One effect of this circulation was to limit the temperature rise and, after sunset to remove it. Another was to increase the humidity as illustrated in Fig 2, where the air blowing through the source region has been lifted with the result that its associated water vapour condensed to produce cloud. This cloud was absent in the control run and has a water content such that some precipitation would be expected which in turn would evaporate before reaching the ground in the low humidities below cloud base. The relationship of this cloud to the smoke is shown in the cross-section (Fig 3) along the line A-B of Fig 1. Associated with the thickest smoke, upward motion has been much enhanced and in the indicated regions, cloud has formed. The model does not attempt to represent the physics of the interaction between water and smoke; however the results confirm that mesoscale circulations, capable of producing cloud formations that otherwise would not occur, can be set up by the local smoke plume.

The results described above demonstrate that smoke plumes associated with individual nuclear targets could have fairly immediate consequences on the local meteorology which may result in the characteristics of the smoke being modified before it has had time to be diffused to become part of the near hemispheric smoke pall which is the starting point of the "nuclear winter" calculations used to date.

In the case described, fairly dry anticyclonic conditions prevailed. This case was chosen not because it was typical but because, if a more representative mobile moist westerly situation had been used, the smoke plume would have moved outside the area of the mesoscale model domain too quickly for its effect to be ascertained. The fact that significant circulations were set up in this simulation leading to cloud formation is perhaps indicative that in more common situations, where the air is initially moister and less stable, extensive clouds with precipitation could be the normal short term consequence of plumes of smoke generated as postulated in the "nuclear winter" scenarios. Such short term effects have not been included in the 'nuclear winter' models to date.

In conclusion we would emphasise that the work reported in this paper points to a major weakness in the arguments put forward to date which support the contention that catastrophic climate consequences would follow a major nuclear war. Other major weaknesses already recognised include assumptions about the smoke production rate,[5] the optical properties[6] of the particles and the scavenging rate. It is undoubtedly so that if enough black smoke were to become widely and uniformly dispersed throughout a large part of one hemisphere of the global atmosphere severe climatic consequences would result. However there is much uncertainty about the quantities of smoke that might be generated in any nuclear conflagration and now in addition the question must be posed whether mesoscale meteorological influences associated with the initial plumes would ameliorate the situation by increased scavenging or particle growth to such a degree as to make assumptions implicit in current 1-D and the 3-D global simulations of the effects of the smoke pall untenable.

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CAPTIONS

Fig. 1. Smoke concentration in $kg\text{-}kg^{-1}$ at 9 km altitude ($\sim$ 300 mb) after 12 hours integration. The stippled area shows the source region.

Fig. 2. Air flow and relative humidity (%) at $10\frac{1}{2}$ km altitude near the smoke plume after 12 hours integration.

Fig. 3. Schematic representation of the development of a vertical circulation about the smoke cloud and the subsequent formation of cloud seen in the cross-section marked A-B in Fig. 1.

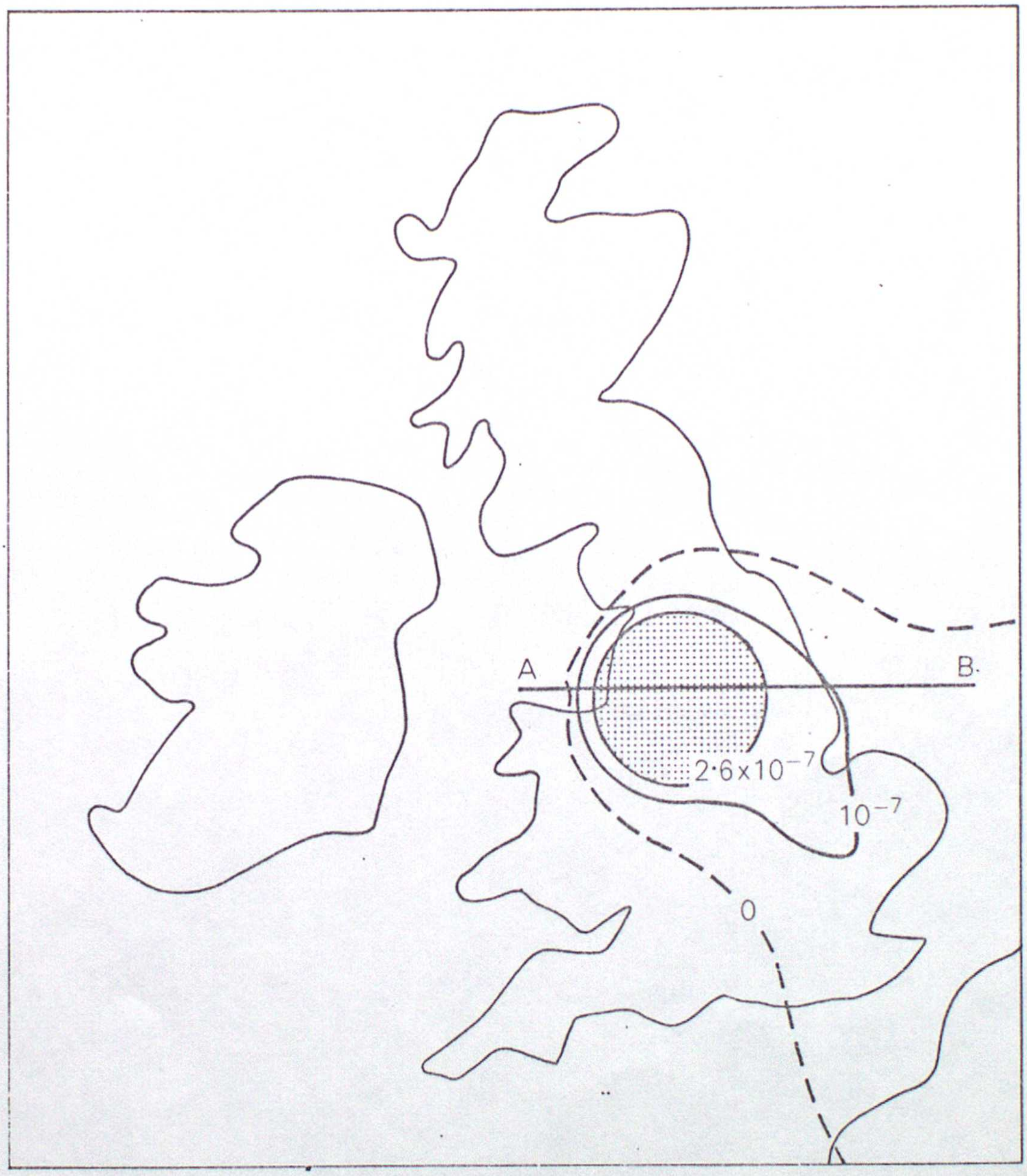
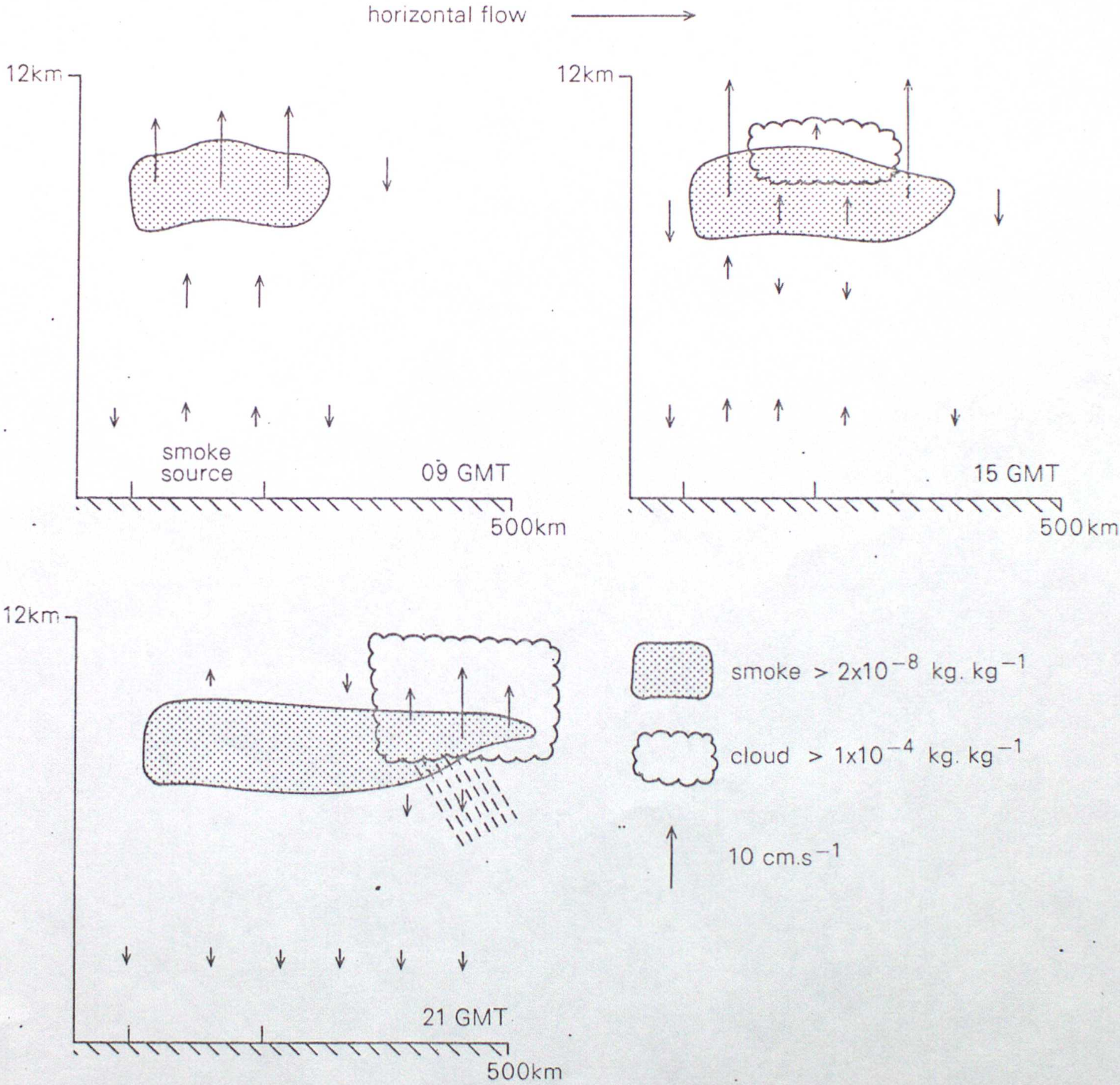


Fig. 1

Fig. 2



horizontal flow
12km
smoke
source
09 GMT
500km
12km
15 GMT
500km
12km
21 GMT
500km
smoke > 2x10^{-8} kg. kg^{-1}
cloud > 1x10^{-4} kg. kg^{-1}
10 cm.s^{-1}

Fig. 3