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OF SCIENCE AND TECHNOLOGY (ENGLAND) DEPT OF PHYSICS
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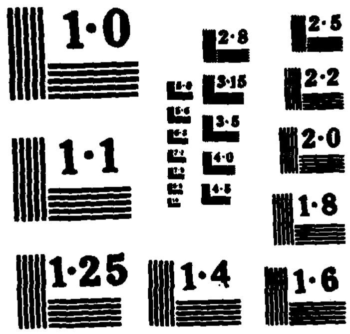

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RADIATION FOG MODELING

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The radiation fog model is being developed in an attempt to predict the initiation, development and characteristics of these fogs. The model is primarily based upon three important processes which interact to determine whether a fog will form in preference to haze development and what characteristics and fluctuations are likely to occur if a fog does form. These processes are:

1. Radiative exchanges
2. Droplet growth and CCN spectra
3. Turbulence characteristics.

The exact nature of these interactions is poorly understood and consequently have not yet been fully included in existing models. To date, therefore, accurate simulation of all fog characteristics on various temporal and spatial scales has not been achieved.

Data from recent field studies, especially Meppen, have produced results which will enable not only the model to be fully tested, but also greatly assist in the understanding of radiation fog, which will in turn allow more accurate and detailed models to be developed.

MODEL FORMULATION

The model, at present, utilises the following equations to describe the changes in temperature, supersaturation, and liquid water content, in addition to explicitely calculating droplet growth.

Droplet growth

$$\frac{\delta r_{ij}}{\delta t} = \left(\frac{1}{A}\right)\left[\frac{S}{r_{ij}} - \frac{B}{r_{ij}^{2}} + \frac{CM_j}{r_{ij}^{4}} - DFQ_a(r)\right] \tag{1}$$

where the coefficients are

$$A = \frac{L_H \rho_L}{kt}\left(\frac{L_H M}{R_G T} - 1\right) + \frac{\rho_L R_G T}{D_f M e_s(T)}$$

$$B = \frac{2\sigma M}{\rho_L R_G T}$$

$$C = 6.9246 \times 10^{-5} m^3 kg^{-1}$$

$$D = \frac{1}{kT}\left(\frac{L_H M}{R_G T} - 1\right)$$

Temperature

$$\frac{\delta T}{\delta t} = -\frac{1}{\rho_a C_p}\frac{\delta R_N}{\delta Z} + \frac{\delta}{\delta Z}\left(k\frac{\delta \theta}{\delta Z}\right) + \frac{L_H C_N}{C_p} \tag{2}$$

Supersaturation

$$\frac{\delta S}{\delta t} = \frac{1}{M_{RS}}\frac{\delta M_R}{\delta t} - \frac{L_H M}{R_G T^2}\frac{\delta T}{\delta t} \tag{3}$$

Liquid Water Content

$$\frac{\delta W}{\delta t} = \frac{4}{3}\pi \rho_W \frac{\delta}{\delta t}\sum_i \sum_j N_{ij} r_{ij}^{3} \tag{4}$$

Condensation rate

$$C_N = \frac{\delta W}{\delta t} - \frac{\delta G}{\delta Z} - \frac{\delta}{\delta Z}\left(K\frac{\delta w}{\delta Z}\right) \tag{5}$$

Mixing ratio

$$M_R = (1 + S)\, M_{RS}$$

T = dry bulb temperature

ρ_L = density of water

k = thermal conductivity of air

M = molecular weight of water

R_G = universal gas constant

D_f = diffusivity of water vapour in air

σ = surface tension of water vapour

ρ_a = density of air

R_N = net radiative flux

K = turbulent exchange coefficient

θ = potential temperature

L_H = latent head of vaporization

C_N = condensation rate

C_p = specific heat of air at constant pressure

M_{RS} = saturation mixing ratio

M_R = mixing ratio

r_{ij} = droplet radius class i

m_j = nucleus mass

N_{ij} = concentration of drops in class i

F = radiative exchange function for droplet growth

$$= \tfrac{1}{2}(F\uparrow + F\downarrow) - {}_{SBC}T^4$$

$Q_a(r)$ = absorption efficiency of water droplets

$$= 1.18(1 - \exp(-0.28r_{ij}))$$

W = liquid water content

G = gravitational sedimentation

SBC = Stefan-Boltzmann constant

γ = function of terminal velocity of drops

The droplet growth is determined by Eq.1, which in addition to the usual terms, contains a term derived by Roach (1976) which allows for net radiative loss from the droplet. Eq. 2 describes the time rate of change of temperature which is determined by the divergence of net radiation, the eddy diffusion of heat, and the release of heat through condensation. The change of supersaturation, eq. 3, is a result of changes in temperature and removal by condensation.

In addition to these equations, changes in droplet concentration, determined by eddy diffusion and gravitational sedimentation, are also included.

Number concentration

$$\frac{\delta N_{ij}}{\delta t} = \gamma\, r_{ij}^{2} \frac{\delta N_{ij}}{\delta Z} + \frac{\delta}{\delta Z}\left(K \frac{\delta N_{ij}}{\delta Z}\right)$$

Gravitational sedimentation

$$\frac{\delta G}{\delta Z} = \frac{4}{3} \pi \rho W \left[V(r_{ij}) \frac{\delta N_{ij}}{\delta Z} + \frac{\delta}{\delta Z}\left(K \frac{\delta N_{ij}}{\delta Z}\right)\right]$$

Although these terms are included in the model their formulation (and to a large extent that of other terms) depend on the trubulence characteristics of fogs which are not well known. It is believed that the value of K, the turbulent exchange coefficient, and its method of derivation, are critically important in determining the precise nature of fluctuations in the fog, interactions between the properties of the fog top and the fog structure below, and interactions between the fog and the ground. The exact nature of these interactions are being closely examined.

INPUT PARAMETERS

The input parameters for the model are as follows:

1. Mixing ratio - assumed constant with height. In addition to temperature determines initial relative humidity.
2. Isothermal atmosphere up to 400m - the ground temperature is specified.
3. Turbulent exchange coefficient - this can be varied as an input parameter but also can be re-calculated according to variations in stability.
4. Soil temperature.
5. Net radiative flux - appropriate values can be input or calculated from a parameterization scheme.
6. CCN spectra - the number concentration of nucleus sizes are input, but the model assumes them to be soluble ammonium sulphate ($(NH_4)_2SO_4$). *However, the chemical composition*

of the CCN can be varied as required. The aerosol concentration is in the form of a Junge distribution

$$\frac{dN}{d \log R} = C r^{-v}$$

where v = 3 and C = 1.

MODEL PROCEDURE

Droplet growth (a brief synopsis)

At first, while relative humidity is low, the model is run with a 4 sec time step, although this can be changed as necessary. A shorter time step would be desirable, but computation time would be much greater with little improvement in accuracy in the present model.

At first droplets are set at their equilibrium radii, which are determined by nucleus mass, chemical composition, and relative humidity, and are calculated in a subroutine of the program. The initial stage of the model can be used therefore to describe reasonably well the development of haze droplets before fog initiation.

At each time step in the model the equilibrium radii are calculated, so as allowing an upper limit to growth to be initially specified. Small droplets, with a 4 sec time step, reach equilibrium radius within that time step, but as relative humidity and drop size increase, so the larger drops fail to attain their equilibrium size.

When the relative humidity in the lower layers has exceeded 99.98%, then the time step is reduced to 1 sec for more sensitive computation. The droplets continue to grow in response to the increase in relative humidity and finally supersaturation. The radiative loss term in the droplet growth equation allows some drops to be activated before 100% relative humidity, by lowering their critical supersaturation. Essentially this radiation term describes the reduction of droplet temperature in relation to environmental temperature, and allows some drops to continue to grow in an undersaturated atmosphere.

The procedure for calculating the other parameters required for fog development will be set out fully in the program documentation as explanation in the context of this report is difficult without referring extensively to a program description. A more detailed description of droplet growth will also be provided with the program documentation.

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