RAMS RADIATION PARAMETERIZATION SCHEMES
A Brief Overview

Christopher Castro
Mesoscale Modeling

RAMS has three radiation parameterization options, each of increasing complexity:

- Mahrer and Pielke (1978)
- Chen and Cotton (1983)
- Harrington (1997)

Focus on the Mahrer and Pielke scheme, since it is the most basic and easy to understand (and many of the empirical equations used in the parameterization are included in Chapter 9). The boxed equations feed back to terms in level one equations.

Principal assumptions in Maher and Pielke scheme:

1. **No liquid water! Effect of condensate and clouds neglected in short and long wave**
2. **Molecular scattering in short wave by water vapor, ozone, and carbon dioxide.**
3. **Accounts for absorption, emission of water vapor and carbon dioxide**

Point out the highlights of the Chen and Cotton scheme in a qualitative discussion.

The Harrington scheme is omitted in this discussion (because I didn't have time to thoroughly research the documentation on it). The primary reference, though, is Jerry Harrington's 1997 thesis entitled *The Effects of Radiative and Microphysical Processes on Simulated Warm and Transition Season Arctic Stratus.* (CSU Atmospheric Science Paper #637)

Mahrer and Pielke Scheme: Shortwave Radiation

The diurnal variation of the solar flux at the top of the atmosphere is computed as:

$$S = S_o \cos Z \tag{1}$$

$$\cos Z = \sin\phi \sin\delta + \cos\phi \cos\delta \cos\psi \tag{2}$$

ϕ = latitude
δ = solar declination
ψ = solar hour angle

At the surface, the solar radiation is obtained by using two empirical transmission functions

I. Kondratyev (1969) and Atwater and Brown (1974) function → G

- Based on observed data from the Soviet Union
- Includes molecular scattering and absorption by permanent gases such as oxygen, ozone, and carbon dioxide,
- Accounts for forward Rayleigh scattering.

$$G = 0.485 + 0.515\left[1.041 - 0.16\left(\frac{0.00949p + 0.051}{\cos Z}\right)^{\frac{1}{2}}\right] \tag{3}$$

p = pressure in mb

II. McDonald (1960) function → a_w

- Accounts for the absorptivity of water vapor. Curve fit to water vapor absorption observations of Fowle (1915).

$$a_w = 0.77\left[\frac{r(z)}{\cos Z}\right]^{0.3} \tag{4}$$

Where r is the optical path length of water vapor above the layer z (in cm).

$$r(z) = \int_{z}^{top} \rho q dz \tag{5}$$

According to McDonald, the values of a_w are accurate to within 10% from a range of r = 0.1 cm to r = 8 cm.

The net short wave radiative flux at the surface is (for cos Z > 0):

$$R_s = S_o \cos Z (1 - A)(G - a_w) \tag{6}$$

Where A = albedo

The reflected short wave radiation from the surface is assumed to escape to space.

Rs = 0 for cos Z < 0

Solar radiative heating in the atmosphere is computed for the absorption of short wave energy by water vapor only:

$$\left(\frac{\partial T_A}{\partial t}\right)_{SW} = 0.231 \frac{S_o \cos Z}{\rho c_p} \left[\frac{r(z)}{\cos Z}\right]^{-0.7} \frac{dr}{dz} \tag{7}$$

Maher and Pielke Scheme: Longwave Radiation

We want to parameterize the broadband emissivity across several discrete wavelength intervals (equation 8.34):

$$\in^{s}(u,T) = \sum_{i=1}^{I} \pi B_{\bar{\lambda}_i}(T)\left[1 - \Gamma^{s}_{\bar{\lambda}_i}(u)\right]\frac{\Delta_i \lambda}{\sigma T^4} \tag{8}$$

In the longwave scheme:

- Atmospheric heating due to flux divergence calculated for each time step.
- Considered as emitters of long wave radiation are carbon dioxide and water vapor.

Path length for water vapor (Δr_j) is computed for each layer from the surface to the top of the model by:

$$\Delta r_j = -\frac{(p_{j+1} - p_j)}{g} q_j \tag{9}$$

q_j = water vapor mixing ratio

The path length for carbon dioxide (Delta c_j) is:

$$\Delta c_j = 0.0004148239(p_{j+1} - p_j) \tag{10}$$

Where p is pressure in mb.

After these increments are obtained, they are summed up from the first level to the *i*th level to give the total path length:

$$r_i = \sum_{j=1}^{i} \Delta r_j \tag{11}$$

$$c_i = \sum_{j=1}^{i} \Delta c_j \tag{12}$$

Emissivity for water vapor derived from data of Kuhn (1963)

$$\epsilon_r(ij) = \begin{cases} 0.11288 \log_{10}(1 + 12.63\,\overline{r}) & \text{for } \log_{10}\overline{r} < -4 \\ 0.104 \log_{10}\overline{r} + 0.440 & \text{for } \log_{10}\overline{r} < -3 \\ 0.121 \log_{10}\overline{r} + 0.491 & \text{for } \log_{10}\overline{r} < -1.5 \\ 0.146 \log_{10}\overline{r} + 0.527 & \text{for } \log_{10}\overline{r} < -1 \\ 0.161 \log_{10}\overline{r} + 0.542 & \text{for } \log_{10}\overline{r} < 0 \\ 0.136 \log_{10}\overline{r} + 0.542 & \text{for } \log_{10}\overline{r} > 0 \end{cases} \qquad (13)$$

where $\overline{r} = |r_i - r_j|$ is the optical path length between the ith and jth levels.

Kondratyev's (1969) emissivity function for carbon dioxide in the form:

$$\epsilon_{CO_2}(i,j) = 0.185\left[1 - \exp\left(-0.3919|c_i - c_j|^{0.4}\right)\right] \qquad (14)$$

With the path length of carbon dioxide in centimeters.

The emissivity at each level is given as the sum of the water vapor + carbon dioxide contributions:

$$\epsilon(i,j) = \epsilon_r(i,j) + \epsilon_{CO_2}(i,j) \qquad (15)$$

Using the emissivity functions, get solutions for the downward and upward long wave radiative fluxes at a level N. Here, *emissivity is the only component sensitive to empirical specification.*

Downward flux:

$$R_d(N) = \sum_{j=N}^{top-1} \frac{\sigma}{2}\left(T_{j+1}^4 + T_j^4\right)\left[\in(N,j+1) - \in(N,j)\right] + \sigma T_{top}^4\left(1 - \in(N,top)\right) \tag{16}$$

Upward flux:

$$R_u(N) = \sum_{j=N}^{N-1} \frac{\sigma}{2}\left(T_{j+1}^4 + T_j^4\right)\left[\in(N,j) - \in(N,j+1)\right] + \sigma T_g^4\left(1 - \in(N,0)\right) \tag{17}$$

The radiative cooling at each layer is computed as the difference between upward and downward fluxes between level N and N+1:

$$\left(\frac{\partial T}{\partial t}\right)_N = \frac{1}{\rho c_p}\frac{\left(R_u(N+1) - R_u(N) + R_d(N) - R_d(N+1)\right)}{z(N+1) - z(N)} \tag{18}$$

Since the above procedure consumes a large amount of computation time, assume the whole atmosphere has a temperature of the level at which flux divergence calculated (Sasamori, 1972):

$$\boxed{\left(\frac{\partial T}{\partial t}\right)_N = \frac{1}{\rho c_p}\frac{\left[\left(\sigma T_N^4 - \sigma T_G^4\right)\left(\in(N+1,0) - \in(N,0)\right) + \left(\sigma T_{top}^4 - \sigma T_N^4\right)\left(\in(N+1,top) - \in(N,top)\right)\right]}{z(N+1) - z(N)}}$$

(19)

Chen and Cotton Scheme Highlights

Long Wave model

Full solution of the radiative transfer equation using an emissivity approach

For clear atmosphere, the emissivity of water vapor parameterized using empirical schemes of Rogers (1967) and Stephens and Webster (1979) as function of water vapor optical path length. No explicit parameterization for the effect of carbon dioxide.

For cloudy atmosphere, emissivity function of liquid water optical path length based on an empirical formula from Stephens (1978). No differentiation between liquid water and ice.

For mixed clear and cloudy atmosphere, a "mixed" emissivity based on fractional coverage of cloudiness.

Short Wave Model

Calculates the reflectance, absorptance, and transmittance for each layer, then uses a two stream radiative transfer model

Clear Atmosphere

- Yamamoto's (1962) parameterization of absorptance of water vapor, function of water vapor optical path length
- Stephen's parameterization for Rayleigh scattering as a function of pressure and zenith angle.
- Absorption by ozone as a function of the optical path length of ozone at the top of the model

Cloudy Atmosphere (Stephens, 1978)

- Two bands considered (wavelength for the line of demarcation is 0.75 um). Different expressions for absorption, transmission, and reflectance in each two bands.
- Absorption by cloud droplets in the ultraviolet and visual region ignored.
- Reflectance, transmittance, and absortance function of cloud optical thickness, droplet single-scattering albedo, backward scattering fraction and zenith angle.

Mixed Clear-Cloudy Atmosphere

- Tranmittance and Absorptance a summation of three empirically derived exponential functions (Stephens, 1977).
- If clouds present in layer, transmittance and absorptance calculated by the cloudy atmosphere parameterization
- Total transmittance in a column depends on the fractional coverage of cloudiness.