Making a LUT of the Mahrer-Pielke Radiation Parameterization in RAMS

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Where am I going today?

1. Introduction/Motivation
2. Mahrer-Pielke SW Parameterization
3. Mahrer-Pielke LW Parameterization
4. The LUT Structure
   a) Hierarchical directory structure
   b) Populating the LUT
   c) The Shortwave LUT
   d) The Longwave LUT
5. Time Testing
6. Future work

1. Introduction/Motivation

- Parameterizations are engineering code:
  - Why worry about exact answers?
  - Just treat them as a black box, as long as they are accurately reproduced.
- Mahrer-Pielke is a simple rad. scheme
  - Good only for clear sky conditions
  - If we can achieve time gains here, more complicated schemes could (and should) yield greater results!
- Operational forecasters could use faster models…ensemble forecasting, solution convergence.

2. SW Parameterization

- Rayleigh scattering (O_2, O_3, CO_2):

$$G = 0.485 + 0.515\left[1.041 - 0.16\left(\frac{0.000949p + 0.051}{\cos Z}\right)^{\frac{1}{2}}\right],$$

- Absorptivity of water vapor:

$$a_w = 0.077\left[\frac{r(z)}{\cos Z}\right]^{0.3},$$

- Heating rates:

$$\left(\frac{\partial T}{\partial t}\right)_S = 0.0231\frac{S_0 \cos Z}{\rho c_p}\left[\frac{r(z)}{\cos Z}\right]^{-0.7}\frac{dr}{dz}.$$

2. SW Parameterization

- Inputs (107 total points):
  - Column variables (35 vertical points):
    - Water vapor content (r_v), density (ρ), air pressure (Π)
  - Single valued variables:
    - Cosine solar zenith angle, albedo
- Outputs (36 total points):
  - Column heating rate
  - Surface absorbed shortwave radiation

3. LW Parameterization

- CO_2 (Δc_j) and H_2O (Δr_j) only constituents to emit in longwave (path lengths):

$$\Delta c_j = -0.4148239(p_{j+1} - p_j).$$

$$\Delta r_j = -\frac{(P_{j+1} - P_j)}{g} q_j.$$

- Emissivity of water:

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

3. LW Parameterization

- Emissivity of carbon dioxide:

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

- Heating rate:

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

3. LW Parameterization

- Inputs (140 total points):
  - Column variables:
    - Temperature (θ)
    - Water vapor content (r_v)
    - Air density (ρ)
    - Air pressure (Π)
- Outputs (36 total points):
  - Column heating rate
  - Surface absorbed longwave radiation

4. A) Directory Structure

- Data in the LUT is stored in a hierarchical directory structure, based on input data:
  - Example: 274/269/261/…/data.dat
    - To match air temperatures
    - data.dat would contain the heating rates and the surface-bound radiation
  - Example: 3223/2232/2112/…/data.dat -or- 3/2/2/3/2/2/3/2/2/1/1/2/…/data.dat
    - If matching bins…first directory would be for 3rd, 2nd, 2nd and 3rd bins
    - data.dat is as above…storing the heating rates and surface-bound radiation.

4. B) Populating the LUT

- Real sounding data used
  - Sea-level sites, from various climate zones (Barrow, Albany, Keflavik, Hong Kong, etc.)
  - Must contain temperature, height and dew point at the 10 lowest mandatory levels (1000mb up to 150mb)
  - At each point, temperature and dew point must be separated by at least 1˚C to remove chance of cloudy layers.
  - 24,150 profiles used
- Sounding profiles then run through the parameterization, and data saved at end of corresponding directory

4. C) SW LUT Design

- How do we deal with 107 inputs, and 36 outputs?
- Using scaling arguments density and pressure effects on shortwave heating can be ignored:
  - "Average" values of these variables are used.
- LUT is only a function of water vapor profile, cos(Z) and albedo
  - Input space therefore reduced by 70, down to 37 inputs.

4. C) SW LUT Design

- "Brute Force" Method:
  - At each vertical level, water vapor content given value of 1, 2 or 3.
    - 3^{35} possible combinations (5×10^{16})
    - Constrained such that not all combinations are possible
  - Matching directories from model top, down
  - Each file at end of directory contained info for varying cos(Z) (0.1 resolution)
  - Surface bound shortwave modified by albedo
  - Values returned to RAMS

4. C) SW LUT Design

- "Elegant" Method:
  - Determined r_v at mandatory sounding levels (10 in total)
    - Changed values to integers in 100ths g/kg (i.e., 18.31g/kg = 1831)
  - Matched directories from top down
  - Each file at end of directory contained info for varying cos(Z) (0.1 resolution)
  - Surface bound shortwave modified by albedo
  - Values returned to RAMS

4. D) LW LUT Design

- This time starting with 140 inputs:
  - Using scale arguments, air pressure and density variations can be ignored
  - Temperature and water vapor content are interpolated to 10 mandatory sounding levels each
- We end up using 20 inputs
- But since we are using linear searching methods, need to determine an order for matching…

4. D) LW LUT Design

- Used multiple linear regression to get regression/correlation coefficients for each input/output combination:
  - For each input value…an average correlation coefficient was found…
  - Order determined by highest average correlation value (only used first 10 to match)
    - Water vapor at levels 2, 1 and 3 (lowest 2km)
    - Temperatures at levels 4, 3, 5, 6, 2, 7 and 1.

5. Time Testing (SW)

	Time (sec.)	Normalized
Original	1.191	1.00
Brute Force LUT	2.919	2.45
Elegant LUT	8.328	6.99

- Both LUTs take longer than the original parameterization.
- Elegant LUT has smaller errors than Brute Force LUT
- Moving on to LW version…

5. Time Testing (LW)

- Most recent test shows a 4% ***decrease*** in time when LUT used (after table has been loaded into hard drive buffer):
  - 7% - Converting to 10 points, and converting integers to characters
  - 30% - Determining location of data
  - 41% - Reading data from LUT (gains here?)
  - 22% - Choosing correct data (gains here?)
- Accuracy still not very good
  - Need to check if adding more data to LUT will help (could cause speed decrease)

6. Future Work

- Continue with ideas for time reduction on current paradigm:
  - Check for inefficiencies in code
  - Increase LUT size (accuracy check)
- Place LUT in RAMS to check how accuracy of LUT effects model outputs
- Begin investigation into how neural networking can help with determining the outputs.
- Other parameterizations (turbulence, other radiation schemes)