MIT Single-Column Model

User's Guide

K. Emanuel, 15 March 2010

The MIT single-column model is a one-dimensional, time-dependent code that solves equations for radiative and convective heat transfer. The model consists mostly of three physics packages: a band-averaged radiative transfer model developed by J. J. Morcrette (1991) for use in the European Centre for Medium Range Weather Forecasts (ECMWF) prediction model, a representation of cumulus convection (Emanuel, 1991, Emanuel and Živkovic-Rothman, 1999), and a parameterization of layer clouds (Bony and Emanuel, 2001). The radiation code handles the entire spectrum of longwave and shortwave radiation, including ultraviolet radiation as it interacts with ozone. The convection scheme represents a spectrum of cumulus clouds, ranging from shallow, non-precipitating cumuli to deep, precipitating cumulonimbus. It also includes a simple dry adiabatic adjustment that also allows water vapor to condense and be precipitated out should a layer undergoing adjustment become saturated. The layer cloud parameterization developed by Sandrine Bony predicts cloud fraction and water content based on a constructed probability distribution of total water concentration whose mean is the predicted specific humidity in the column and whose variance is proportional to the difference between that mean and the total water content inside the cumulus clouds at the level in question.

Radiation interacts with the surface, clouds, water vapor (which varies with altitude and time according to surface evaporation and the physics of the convective scheme), ozone (which is fixed in time but varies with altitude as specified in the input file *sounding.in*), and specified, constant concentrations of carbon dioxide, methane, nitrous oxide, and CFC 11 and 12.

These three principal physics components are supplemented by a computation of the temperature of a simple slab of ocean or land, based on the net fluxes of energy through the surface. These fluxes include the net radiative flux and turbulent fluxes of sensible and latent heat calculated from simple aerodynamic flux formulae with prescribed surface wind speed (but note that the prescribed background wind is augmented by convective gusts produced by the convective scheme). The fraction of ocean versus dry land in the column is represented crudely by multiplying the predicted latent heat flux (assuming a water surface) by a fraction that varies between 0 and 1. Note that there is no representation of boundary layer physics, other than the surface flux scheme and the dry adiabatic adjustment.

The model itself is written in Fortran 77, and the output is in ordinary ascii files. We have also written Matlab scripts to display the output.

The following describes the files necessary for setting up and running the single-column model, as well as the output files and scripts for displaying the output.

Running the model

Be sure that that the main executable together with the files *sounding.in*, *params_verN.in*, and all the *.h* files are present in the working directory (see below for definitions of these files). If using Matlab, then just run the script *run_model*, otherwise first create a subdirectory called **output**, compile the Fortran program rc_verN.f if necessary, and finally run the executable. If successful, several messages are printed on the screen (e.g. "LW clear-sky calling frequency") and the code executes; be aware that execution may take a few minutes. See the *Output* section below to find and interpret the model output.

Files and directories

Model Code: All of the actual model code is contained in a single Fortran file: rc_ver*N*.f, where *N* is the version number. We have successfully compiled this code on unix machines, PCs, and Macs.

Resource Files: There are 9 resource files, ending in the suffix '.h', that supply parameters common to many of the radiation subroutines. These seldom, if ever, need to be altered but must be present in the same directory that the executable is stored in.

Sounding input and output files: *Sounding.in* supplies the initial surface temperature and vertical profiles of temperature, pressure, specific humidity, ozone, large-scale (imposed) pressure velocity, and radiative cooling. (This last is only used in the event that the radiation scheme is turned off.) This file also has the effect of specifying the vertical structure of the model. A file of identical structure, *sounding.out*, is written at the end of the integration both to the user-specified output directory and to the main directory, where it can be read in, alternatively to *sounding.in*, to restart an integration where the previous one left off.

Control file: The model is controlled and many parameters specified through the single ascii file *params_verN.in*, where *N* is the version number. Note that users of the Matlab wrapper for this program will be presented with a menu that allows the parameter values to be changed without having to manually edit the control file. The next section of this guide describes all the parameters in this file.

Output directory: A single subdirectory **output** must be present for the program to write output to. For Matlab users, we provide a wrapper (*run_model.m*) that automatically creates this subdirectory.

Parameters in the control file

The control file, **params_verN.in**, contains parameters that control the numerical integration, output, radiation, convection, surface conditions, greenhouse gas concentrations, and background (prescribed) vertical motion. The model reads parameters from the first column of this file, while the default values are given in the second column. Normally, this is the only file that needs to be altered for experiments with the model.

The definitions of most of the parameters in the file are self-evident, but in some cases more description is desirable:

The first parameter in the file, set to 'y' or 'n' (for 'yes' or 'no') tells the program to use the initial conditions given either in *sounding.in* (if 'n') or in the output of the last simulation as stored in *sounding.out* (if 'y').

The second parameter sets the length of the integration, while the third sets the numerical time step.

The fourth parameter sets the interval of time at the end of the integration over which quantities are averaged to produce the vertical profile output, and the fifth sets the resolution of the time series output.

In the section of parameters dealing with radiation, the first sets whether radiative transfer is calculated. If it is not, the vertical profile of radiative cooling in *sounding.in* is used through the integration. Likewise, if no interactive clouds are specified, then the time-averaged cloud amount in *profile.out*, generated in the last simulation, is used for the whole integration. If the surface temperature is not calculated, the value read from *sounding.in* is used. Other options specify the frequency of calls to the radiation scheme (the radiative fluxes are held constant between these calls), solar constant, starting date and time, and so on. Radiation can be averaged over a day or a year, or can be calculated as a function of time. If an ocean surface is used, then its albedo can be calculated as a function of solar zenith angle within the code; else it is specified in the parameter list.

The next set of parameters specifies the greenhouse gas mass concentrations for the well-mixed species. Note that water vapor is by default calculated interactively, and the vertical profile of ozone is set in the file *sounding.in*. (If interactive water vapor is turned off, then the program uses the water vapor in *sounding.in* and holds it fixed through the integration. In this case, interactive clouds are also switched off.) The last two parameters in this set multiply the ozone and/or water vapor distributions by the specified fraction (which should be between zero and 1) before they are passed to the radiation scheme to allow for experiments on the radiative effects of these gases.

The two parameters under the *convection* heading specify whether dry adiabatic adjustment is used and whether the moist convection scheme is invoked. Note that if moist convection is calculated, then dry adiabatic adjustment is also invoked, even when the dry adjustment parameter is set to 'n', because the moist convection scheme will become numerically unstable if the environmental lapse rate is steeper than dry adiabatic.

Turbulent fluxes may be turned on or off, and if they are on, then the specified parameters set the wind speed used in the aerodynamic flux formulations, and the fraction of latent heat flux over open water that is actually passed to the atmosphere. The depth of the slab of ocean or land is also specified here; note that the density and heat capacity of this slab is that of water.

A cubic vertical profile of background vertical velocity (actually, pressure velocity, in hPa/hour) can be specified. One can specify the peak magnitude of the velocity (remember that negative values denote

upward motion) and the pressure levels at which the velocity peaks and at which it vanishes at the top and bottom of the profile. The whole profile can also vary sinusoidally in time.

It is possible to run the model in "Weak Temperature Gradient" mode. In this case, the temperature of the free troposphere is fixed between a user-specified pressure level (usually best to choose a level near 850 hPa) and the tropopause and the vertical motion is calculated to be that which is needed to insure no temperature tendency in that layer. Convection still moistens the free troposphere and cools and dries the boundary layer.

Output

The model dumps output into the *output* subdirectory in the form of a set of ascii files. Here are brief descriptions of the contents of these files:

- ***time.out:*** Contains time series of, in order, time (days), precipitation rate (mm/day), evaporation rate (mm/day), air temperature (C) at lowest model level, sea (or land) surface temperature (C), 500 hPa temperature (C) and specific humidity (g/Kg), and top-of-the-atmosphere shortwave and longwave radiative fluxes (W/m^2), hurricane potential wind speed (m/s), hurricane potential minimum pressure (hPa), time (days) at the mid-point of the plot interval, and hurricane potential outflow temperature (C).
- ***profile.out***: Contains vertical profiles of various quantities averaged over the specified interval at the end of the integration. The quantities are, in order, pressure (hPa), air temperature (C), specific humidity (g/Kg), buoyancy of air lifted from the lowest model level (C), relative humidity, heating rates by moist convection, radiation, dry convection, and background vertical velocity (C/day), convective mass fluxes: updraft, penetrative downdraft, and unsaturated downdraft (10^{-3} Kg m^2s^{-1}), convective mass entrainment and detrainment (10^{-3} Kg m^2s^{-1}), moist static energy divided by heat capacity (C), and cloud fraction, cloud condensed water content (g/Kg)

The rest of the files are arrays of various quantities as a function of time and pressure. These arrays include:

- ***buoy.out***: Buoyancy of parcel lifted from lowest model level (C)
- ***cldhov.out***: Cloud fraction
- ***thov.out***: Temperature (C)
- ***qhov.out***: Specific humidity (g/Kg)
- ***rhhov.out***: relative humidity (%)
- ***mhov.out***: Convective updraft mass flux (10^{-3} Kg m^2s^{-1})
- ***mdhov.out***: Penetrative downdraft mass flux (10^{-3} Kg m^2s^{-1})
- ***mphov.out***: Unsaturated downdraft mass flux (10^{-3} Kg m^2s^{-1})
- ***omhov.out***: Omega (hPa/hour)

MATLAB routines

We supply a Matlab routine for plotting the output, and a wrapper for ease in controlling the integration. The routine ***rcm.m*** is a menu-driven routine that reads the output files described above and plots the quantities; it is mostly self-explanatory. Note that the actual variable names are displayed at the top of the time series and profile plots in case the user wishes to save them, e.g., for comparison to the output of subsequent simulations. The wrapper ***run_model.m*** provides menu-driven parameter input, runs the model, and then runs the plotting routine. It also allows the user to specify the name of the output directory.

References

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