RAMS

Regional Atmospheric Modeling System

Version 4.3/4.4

INTRODUCTION TO RAMS 4.3/4.4

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RAMS History

RAMS, the Regional Atmospheric Modeling System, is a highly versatile numerical code developed by scientists at Colorado State University and the *ASTER division of Mission Research Corporation for simulating and forecasting meteorological phenomena, and for depicting the results. Its major components are:

(1) an atmospheric model which performs the actual simulations,
(2) a data analysis package which prepares initial data for the atmospheric model from observed meteorological data, and
(3) a post-processing model visualization and analysis package which interfaces the atmospheric model output with a variety of visualization software and other utilities.

RAMS is most often used as a limited area model, and many of its parameterizations have been designed for mesoscale or high resolution cloud scale grids. However, RAMS may also operate as a global scale model for simulating large-scale systems by configuring two hemispheric grids, which use a polar stereographic projection and continually exchange boundary data between them. There is no lower limit to the domain size or to the mesh cell size of the model's finite difference grid; microscale phenomena such as tornadoes and boundary layer eddies, as well as sub-microscale turbulent flow over buildings and in a wind tunnel, have been simulated with this code. Two-way interactive grid nesting in RAMS allows local fine mesh grids to resolve small-scale atmospheric systems such as thunderstorms, while simultaneously modeling the large-scale environment of the systems on a coarser grid.

The atmospheric model is constructed around the full set of nonhydrostatic, compressible equations that atmospheric dynamics and thermodynamics, plus conservation equations for scalar quantities such as water vapor and liquid and ice hydrometeor mixing ratios. These equations are supplemented with a large selection of parameterizations for turbulent diffusion, solar and terrestrial radiation, moist processes including the formation and interaction of clouds and precipitating liquid and ice hydrometeors, kinematic effects of terrain, cumulus convection, and sensible and latent heat exchange between the atmosphere and the surface, which consists of multiple soil layers, vegetation, snow cover, canopy air, and surface water.

RAMS is an outgrowth of two earlier atmospheric modeling programs conducted independently during the 1970's. A cloud model developed under the direction of Dr. William R. Cotton contributed state-of-the-art methods for modeling microscale dynamic systems and microphysical processes. A mesoscale model developed under the direction of Dr. Roger A. Pielke contributed expertise in the modeling of mesoscale systems and the influence of land surface characteristics on the atmosphere. In 1986, the process was begun of combining the capabilities of the two models into a unified multi-purpose modeling system, and thus was born the new RAMS code. In order to introduce a high degree of flexibility and versatility in RAMS, particularly regarding its new grid nesting capability, and to take advantage of the ever-increasing capabilities in computer hardware and software, RAMS was built on an entirely new framework, with the numerical schemes and parameterizations from the earlier models mostly re-written for the new model structure. After two years of concerted effort, the first version of the new RAMS code was in use as a research tool. A major program of continued development has continued to the present day, resulting in many improvements and new capabilities.

The planning, design, and construction of the RAMS code have been conducted primarily by Drs. Craig J. Tremback and Robert L. Walko. This effort has been carried out with a major emphasis given to uniformity of design of the code, and nearly all developments have involved cross-discussion and/or debate which we hope has resulted in the best of our ideas being incorporated. Many valuable ideas and experiences with RAMS have been shared by the students of Drs. Pielke and Cotton and by other users over the years, which has led to significant improvements in RAMS.

RAMS is now primarily supported for execution under the UNIX, Linux, and NT operating systems. The majority of the model code is written in FORTRAN, and now requires FORTRAN 90 for dynamic memory allocation and other code constructs. Some use is made of C code to facilitate I/O procedures. In order to utilize the standard graphics capability of RAMS, the computer installation should have (at least) the GKS Version 3.0 of NCAR Graphics.

This document is the fifth edition of the RAMS User's Guide, and describes Versions 4.3 and 4.4 of RAMS, which were released in 2000 and early 2001, respectively. The first edition of the User's Guide was written for the release of Version 2c of RAMS in April 1991. Code updates to Version 2c were distributed in March 1992 with a brief set of Update Notes. Version 3a of RAMS and the second version of the User's Guide were completed in December 1993. Version 3b of RAMS and the third version of the User's Guide were completed in August 1995.

During the relatively long period (4 years) following the release of RAMS (Version 3b), a large amount of model development took place, resulting in a few additional named versions that were never released nor widely used outside Colorado State University or MRC/*ASTER. Version 3c was developed alongside 3b, with the same improvements, except that it incorporated a new sub-model for soil, hydrology, snowcover, and biophysics called LEAF2. Version 3d followed from 3c with improvements to the bulk microphysics model including full prognosis of cloud water mixing ratio, supersaturation, and number concentration of all other hydrometeor species. Version 4a was developed concurrently with 3b, but with a parallel processing capability. Keeping 3c/3d separate from 4a facilitated the development of each, since major code changes were required for both. In early 1997, once the parallel processing, LEAF2, and new microphysics capabilities were functional and tested, versions 3d and 4a were merged into version 4.1, adopting a new naming convention.

Preparation of version 4.1 for general release was planned, but rapid development of the model continued including the addition of a global modeling capability, fully implicit algorithm for vapor and heat diffusion to hydrometeors, a new radiative transfer model, improvements to the objective analysis of observational data input to RAMS, and modifications for the Linux and NT operating systems. In addition, automatic seasonal variation of vegetation parameters and sea surface temperature, plus easy handling of large sets of observational data files were implemented in order to perform long-term (seasonal, year-long, or longer) climate simulations, functionally similar to methods used in a version of 3b that was modified for climate simulations and was given the name ClimRAMS. The addition of these and other modifications to RAMS resulted in version 4.2, which became the first official released version since all these developments began. Versions 4.3 and 4.4 have followed with a number of added model capabilities.

The RAMS User's Guide is intended as an aid to those who need to install RAMS on a computer system and/or run the model as a tool for studying atmospheric processes. It does not delve into many of the more technical aspects of the code. A separate RAMS Technical Description is available that describes the equations and parameterizations used in the model. A wide range of options is available for the user to select in configuring a model simulation or forecast, many or most of which are inappropriate for a particular application. The main reasons for the availability of options fall into two categories. First, certain options are required for some applications but not for others. For example, the parameterization of cumulus convection is intended for use on coarse grids where convective currents are not resolvable, whereas on fine grids, the model can simulate convection explicitly and cumulus convection should not be parameterized. Second, a variety of options is often made available to allow experimentation and testing of different parameterization schemes or parameter settings, as part of the ongoing research of improving atmospheric models. For research applications, RAMS should not be treated as a black box; as a minimum, it should be used as a ``gray box'', requiring considerable knowledge by the user for proper setting of the model flags and parameters. The primary intent of this documentation is to guide the user in setting up and running a model simulation. We have thus frequently injected our own experiences and advice, particularly in describing how to set values of the atmospheric model namelist variables, but it should be remembered that it is far from possible to cover all avenues in such descriptions. Our experience has been that additional direct consultation is usually required for a user to come up to speed in using RAMS.

The document for versions 4.2 and beyond have changed form also. Rather than write one all-inclusive User's Guide, we are writing and updating smaller documents that will more easily be accessed over the Internet. This document is a general overview of RAMS with summaries of changes made to obtain each new version, beginning with 4.2. Other RAMS documents include or will include the namelist parameter description, installation instructions, data format issues, and customization. These will be available on our web site:

http://www.aster.com

Changes for RAMS Version 4.2

This section summarizes the major changes made to RAMS algorithms and capabilities in its evolution from Version 3b to Version 4.2.

- ***Version 4.2 is Y2K compliant!*** All specifications of years, whether they represent variables in the model code, namelist variables, values on data files, or file names, require 4 digits. The model start time, formerly specified in namelist variable STRTIM, has been replaced by the integer ITIME1 with a syntax of *hhmm*.

- The bulk microphysics package that was the recommended option in version 3b has undergone further development and is now the standard in RAMS. The namelist variables that activate individual hydrometeor species (ICLOUD, IRAIN, IPRIS, ISNOW, IAGGR, IGRAUP, and IHAIL) are no longer grid dependent and therefore have only a single value (for all grids) specified in the RAMSIN file. All of these except for ICLOUD may now be set to 5 to activate prediction of number concentration (two-moment bulk microphysics). Cloud water mixing ratio can now be prognosed instead of diagnosed, so ICLOUD values from 1 to 4 are used. Namelist variables LEVEL (formerly NLEVEL), CPARM, RPARM, PPARM, SPARM, APARM, GPARM, and HPARM are also specified as the same single value for all grids. Aside from prediction of two distribution moments, new features of the bulk microphysics model include:
    - implicit simultaneous computation of heat and vapor diffusion and hydrometeor and air temperature and water content,
    - incorporation of the former iterative computation of potential temperature and cloud water into the implicit diffusion equations, and
    - use of pre-computed lookup tables using detailed bin calculations to improve accuracy and efficiency of several processes including autoconversion and sedimentation.

- Evaporation tables for microphysics are now computed internally during model initialization instead of in a separate program, so there is no longer specification of namelist variable EVAPTFN.

- The two-stream radiative transfer model developed by Jerry Harrington at CSU is activated in RAMS by setting ISWRTYP and ILWRTYP to 3. This model is the most accurate in RAMS, and is the only one to account for the specific optical properties of cloud and rain droplets and ice particles, including number concentrations. Unless the model domain extends up to at least 25 km, the two-stream model includes from 1 to 10 upper atmospheric layers in radiative computations in order to represent a nearly complete atmospheric column.

- Parallel processing designed for distributed memory computer architectures (which also works for shared memory systems) is implemented in RAMS by the method of domain decomposition. Each model grid is decomposed horizontally, in two dimensions, for any number of processors (including prime numbers), and at the end of each timestep for the grid, data at subdomain boundaries are exchanged between compute nodes using MPI. Data for two-way nesting communication are likewise exchanged directly between compute nodes from one grid to another. Dynamic load balancing is available where computational load differs between subdomains of a grid, as when one has active microphysical processes and another does not, or if compute nodes differ in speed, as on a nonhomogeneous cluster of separate computers linked by Ethernet. Parallel algorithms are designed to transfer a minimum of data between compute nodes, with no duplicate computation (on the same grid cell by two different nodes), while achieving identical results in parallel as in sequential computation. This results in very good parallel efficiency, and the model has run 58 times faster in parallel on a 64-processor machine than on a single processor of the same machine. The same set of model code is used for either sequential or parallel computation. The choice between sequential and parallel is made in the makefile that controls the compilation of the model and the optional loading of MPI libraries.

- Several new code files, whose names begin with "mpass", contain model subroutines that are related to message passing for parallel computation.

- Dynamic memory allocation (for the A and B arrays and elsewhere), which formerly used C, now uses FORTRAN, and thus FORTRAN 90 is required. Additional F90 code structures are gradually being introduced to RAMS.

- RAMS is supported under UNIX, Linux, and NT on most platforms in common use today.

- The Land Ecosystem Atmosphere Feedback model, version 2 (LEAF-2) has replaced the soil and vegetation models formerly in RAMS. LEAF-2 represents the storage and vertical exchange of water and energy in multiple soil layers, including effects of freezing and thawing soil, temporary surface water or snowcover, vegetation, and canopy air. Surface grid cells are divided into subgrid patches, each with a different vegetation or land surface type, soil textural class, and/or wetness index to represent natural subgrid variability in surface characteristics. Each patch contains separate prognosed values of energy and moisture in soil, surface water, vegetation, and canopy air, and exchange with the overlying atmosphere weighted by the fractional area of each patch. In order to accommodate the patch structure, all prognostic variables and definition of surface characteristics are stored in 4-D model arrays TGP, WGP, SCHAR, and GSF, which are indexed by (i,j,k,ip), where i and j are horizontal grid indices, ip is patch number, and k may represent either vertical layer as in soil and snowcover or field type for fields that are not multi-layered. A hydrology model based on the Darcy Law for lateral downslope transport, as used in TOPMODEL, exchanges subsurface saturated soil moisture and surface runoff between subgrid patches. LEAF-2 inputs standard landuse datasets in order to define patches and their areas, as well as to obtain biophysical parameters for different vegetation types. Where swamps, bogs, or marshes are indicated in these datasets, soil is initialized as saturated with overlying surface water. LEAF-2 is activated in RAMS by setting namelist variable ISFCL = 1. Variable NZG (formerly NNZG) that specifies the number of soil layers is now a single value for all grids, and NZS specifies the maximum allowed number of layers that snowcover will be divided into (where there is sufficient snowcover). Seasonally-dependent vegetation parameters, such as leaf area index, are updated automatically as a function of time of year and latitude, so namelist variable TSEASN has been removed.

- RAMS can now be run on a global domain. This feature is activated by specifying zero for two of the multiple values of namelist variable NXTNEST, thus stating that two of the model grids have no parent. This automatically makes grid 1 and the other parentless grid hemispheric, and activates communication between them to complete the global domain. Grid nesting up to any number of levels is still available within each or both hemispheric coarse grids, allowing unlimited resolution on nested grids within a global domain.

- Automatic computation of model timestep on all grids, as well as of nesting time ratio values NNDTRAT, acoustic small timestep ratio NACOUST (formerly NRATIO), and sound speed percentage SSPCT, is available by setting certain values in the new namelist variable IDELTAT. The timesteps may be based only on grid spacings and held constant in time, or may also be based on nearness of the model solution to the CFL stability limit and adjusted upward and downward as the solution evolves. This helps to run the model near maximum efficiency for any configuration. (coming in Version 4.3)

- Sea surface temperature values are automatically interpolated in time during a model run, unless the user specifies that they should be held constant in namelist variable IUPDSST. SST files are generated at the beginning of any model run that contain sea surface temperature values interpolated to each grid for each available data time. There is no longer a need to specify a specific month for the file from which the SST data are interpolated. RAMS processes all 12 months worth of climatological, or other time-dependent data for every simulation.

- Surface files, formerly optional in RAMS, are now used for all runs. These contain topography, soil textural class, vegetation class, and fractional area of subgrid patch areas, but no longer include sea surface temperature values which are now stored in the time-dependent SST files.

- Large sets of variable initialization files (varfiles) may be used in a model run with a single specification of a filename prefix (in namelist variable VARFPFX) that all files use. This makes it very easy to run RAMS for long-term climate simulations lasting months or even years, still using a varfile every 6 or 12 hours. Former namelist variables VARFIL and VTIME, which specified each individual varfile name and its time, are no longer used.

- Specification of the year, month, date, and hour of each dataset read into an isentropic analysis (ISAN) run of RAMS is no longer required. Thus, namelist variables IAYEAR, IAMONTH, IADATE, and IAHOUR, and in addition NATIMES are no longer used. Instead, data files to be processed are specified by the starting time and run duration in the $GRIDS namelist and by a time increment in the new variable ISAN_INC.

- All physical and related constants are defined in the rconstants.h include file.

- The ISAN objective analysis package now allows either a gridded pressure level analysis, such as the NCEP reanalysis data, or a RAMS analysis file from a previous run, to be used as a first guess field. Using an analysis file enables the incorporation of observational data into a RAMS simulation in progress, without having to completely begin a new simulation from new observations. The pressure level, rawinsonde, and surface datafiles that are input to ISAN have been slightly modified to a newer format, whimsically called “RALPH2”, that allow easy visual checks for reasonable values. These files are still generated from data archived at NCAR or elsewhere by the separate DPREP program, which has been updated to process NCEP reanalysis data.

- There have been some changes to the directory structure and rearrangement of subroutines in model code files, in addition to several new files written for parallel processing and other added model features.

- The code file rvtab.f, which formerly controlled all selection of array space in the large model "A" array, now reads in a data file called VTABLE that contains all instructions concerning which variables will be included in the "A" array and under which model options, and which variables will be treated as prognostic scalars, and which are to be written to history and analysis files. Modification of VTABLE to change these options or to add a new variable is far easier than in version 3b, where rvtab.f required modification.

- A few former namelist variables have been moved to subroutine ENGPARMS in the code file ruser.f because they should almost never be changed from their standard values. These variables are NTOPSMTH, IZFLAT, SSPCT, IMPL, IADVL, and IADVF.

- REVU, which was already available for version 3b, is now the standard post-processing capability and NCAR graphics driver. REVU includes many new derived fields, and can overlay two contour plots (line contours, color-filled contours, or color-tile plots) plus vectors or wind barbs and a background map in the same frame. Tile plots are especially useful for plotting values of landuse type, temperature, moisture, snowcover, and surface flux values for individual subgrid patches in a frame covering the entire surface area of a grid. In addition, primary fields read from RAMS analysis files and derived fields computed in REVU may be output to secondary files in formats compatible with other graphics packages such as GrADS and Vis5D. REVU also has the capability of interpolating model output fields to specified spatial/temporal locations.

Obsolete features not retained in version 4.2

Some options that had become obsolete because better options existed (or they were rarely used) were removed from RAMS. These include:

- The hydrostatic option and related schemes,
- The strict forward and leapfrog time differencing schemes (hybrid is always used now),
- The old bulk microphysics code, which was the standard version up through model version 3a, and which was included in version 3b,
- The fourth order and Long's filters,
- The gradual spin up of initial winds,
- The "interpolated" horizontal pressure gradient computation method,
- The option to specify input sounding winds at model levels,
- The Galilean transformation of winds.
- The "diagnostic" model run that only computed and output the model memory requirement,
- Changing the frequency of output of the timestep message,
- Choosing not to output a list of namelist variables and specified values,
- The VAN package for plotting RAMS output using NCAR graphics is no longer supported or included in RAMS.

The following namelist variables were removed as a result of these deleted options: IOTYPE, IVWIND, ISTPFL, INPRTFL, ITMDIFF, NONHYD, IBCTOP, TIMSCL, KSPIN, KMSPIN, IPRSPLT, IPGRAD, FILT4, FXLONG, FYLONG, IUSRC, USNDG, VSNDG, KMEAN1, KMEAN2, UMEAN, and VMEAN.

Changes for RAMS Version 4.3

This section summarizes the main changes made to RAMS in its evolution from Version 4.2 to Version 4.3.

- The change with the greatest impact to the model code has been the adoption of FORTRAN 90 free format. From a syntactical aspect, the main impacts of this change are:
    - All source code files now are named with the .f90 extension instead of .f
    - Source code lines generally begin in column 1 unless indented as in a DO loop
    - Lines of source code may run past column 72, although we are not going much past this so that certain editors will not wrap lines around when they are used to look at the code files
    - Continuation lines do not use a special character in column 6, but instead the previous line is terminated with the “&” character
    - All comments in the code are preceded by the “!” character rather than a “C” in column 1
- With Fortran 90 now universally available, we have begun a major revision effort to both standardize the model coding and utilize many new features offered in Fortran 90. This effort will culminate in RAMS version 5, but the first steps have been taken in version 4.3. Most variables in the model are now explicitly declared, and about half of all subroutines begin with the implicit none statement. Also, version 4.3 is the first to use a Fortran 90 module. In version 5, modules will eventually replace all include files. Fortran 90 has also standardized a number of intrinsic functions, and we are replacing old nonstandard ones with these.
- Many subroutines were regrouped in source code files, with a general trend toward using a greater number of smaller files than before. For example, microphysics subroutines that formerly comprised 4 files are now grouped into 7 files, turbulent diffusion subroutines are now in 2 files instead of 1, and grid nesting operations that were formerly grouped into a single file are now in 3.
- The micphys.h common block has been greatly expanded to include all microphysics column scratch arrays and other memory space. This makes for much shorter subroutine calls in many places.
- Prediction of pristine ice number concentration may now optionally be influenced by a variable ice forming nuclei (IFN) concentration field. The IFN concentration may be specified as a constant, a horizontally homogeneous vertical profile, or as a prognostic field.
- Options for writing 3 new types of analysis files have been added, for a total of 4. One new type is the ‘lite’ file, which is intended to include much less information than the standard analysis file so that it may be written much more frequently without filling up excessive disk space. For example, a lite file may contain only surface fields. An ‘averaged’ analysis file is the second type, and this one contains time-averaged fields from RAMS. Any prognostic 3-d or 2-d field in the model may be time averaged, and

additional memory is allocated as needed for those variables selected for averaging. A 'both' file is the third new type of analysis file, and this is simply a lite file that contains time-averaged fields.

- A new, more accurate formula for soil thermal conductivity has replaced the older one in the LEAF-2 submodel.
- RAMS can now assign the long and short (acoustic) timesteps for all grids if you tell it to, and can also adjust these as needed to maintain stability or improve efficiency as a model run progresses.
- The option has been added to automatically delete earlier history files from the current run once later files are successfully written, in order to avoid filling up disk storage.
- The option has been added to overwrite old files from previous runs if the current run should try to write one of the same name.
- Options of envelope topography and reflected envelope topography algorithms have been added to the processing of topographic data for definition on RAMS grids.
- The option of using subgrid-scale topographic data to define surface roughness has been added to the model.
- Processing of observational meteorological data in ISAN now includes the options of polar stereographic projections for input data.
- A horizontal filter may be used in place of standard horizontal turbulent diffusion when steep topography causes numerical instability problems.
- Horizontal turbulent diffusion coefficients for momentum and scalar quantities are now lagged by one timestep, a change which has negligible effect on the model solution but which makes parallel processing much simpler and more efficient. Lagging the K's is already familiar in RAMS and other models whenever a prognostic TKE is used.
- For automated operational runs of RAMS, in which observation or large-scale model data must be acquired over the internet, the model can now be given special instructions on whether to wait for each varfile and for how long.
- ISAN intermediate analyses (isentropic, σ_z , and surface) have been consolidated into a single file. The operation of ISAN has been consolidated into two parts – the data input and analysis and the generating and output of varfiles. A few namelist variables have been eliminated or changed in accordance with these changes.
- The Makefile structure has been changed significantly. While the new structure is somewhat more cryptic than the old, there are many advantages to the new structure.

Changes for RAMS Version 4.4

Relatively few changes have been made in developing version 4.4 from 4.3. They include the following:

- Cloud droplet number concentration may now be prognosed from a specified or predicted CCN concentration field.
- Sedimentation of hydrometeors has been adjusted to limit the fall speeds of the faster hydrometeors representing the largest sizes of the gamma size distribution, since these speeds were unrealistic. Also, the sedimentation speed of any fast hydrometeor is limited somewhat on model grids with very long timesteps to prevent them from falling

too many model levels in one timestep and missing the opportunity to evaporate and warm in those levels. Sedimentation tables were re-constructed as a result.

- Cyclic lateral boundary conditions were adapted to function in parallel processed runs. This instituted a new method of setting up parallel communication tables which will be applied to more parallel processes in the future, particularly for global model communication.
- A major reorganization and partial re-write of the ISAN code was done. This was done as part of changes to the wind analysis. In previous versions, the earth-relative components were analyzed on the RAMS rotated polar-stereographic grid, then rotated to grid relative winds as a final step. This was causing some unexpected results in global simulations. The procedure was changed to first rotate the winds to the polar-stereographic coordinates, then perform the analysis.
- Miscellaneous minor code changes, as always occur in new versions.

Obsolete feature not retained in version 4.4

- The option of plotting of fields directly from ISAN using NCAR graphics has been removed, and NCAR graphics no longer is needed (in either actual or ‘dummy’ form) to compile the model. A near future capability will be implemented where these fields will be written to standard format files (probably GRIB) from which they may be plotted using GraDS or another utility. Several ISAN namelist variables have been removed from the namelist files as a result.