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APPLICATIONS OF THE REGIONAL ATMOSPHERIC MODELING SYSTEM (RAMS) AT THE NOAA AIR RESOURCES LABORATORY

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ABSTRACT. The Regional Atmospheric Modeling System (RAMS) is applied at the NOAA Air Resources Laboratory (ARL) to support air quality research and operational emergency response requirements. This document describes the version of RAMS used at ARL and the enhancements made to run RAMS operationally. The methodology to configure, initialize, and run ARL-RAMS in three dimensions with four-dimensional data assimilation on a UNIX workstation is summarized. The available graphical and statistical packages used at ARL for postprocessing RAMS analyses are also reviewed. A two-dimensional version of the ARL-RAMS package was created to run several simulations concurrently, and this system is also described.

1. INTRODUCTION

The Regional Atmospheric Modeling System, (RAMS), was developed at Colorado State University and is currently used at the Air Resources Laboratory (ARL) to simulate mesoscale atmospheric circulations on a pair of IBM/6000 workstations. This document summarizes the major features of the ARL version of RAMS version 3a and then gives an overview of special software developed at ARL. An expanded description of the RAMS software and name-list parameters that control model configuration can be found in the RAMS user's guide (Walko et al., 1993). Pielke et al. (1992) presented a comprehensive review of all RAMS capabilities. McQueen et al. (1994) summarized RAMS applications to create a mesoscale meteorological forecast for real-time air pollutant emergency response; this version of RAMS was also applied to air quality studies (McQueen et al., 1995).

The software developed at ARL allows the user to set up and initialize RAMS and perform simulations for a domain anywhere in the world using the ARL packed meteorological fields and global land and water surface datasets. This system was designed to be used for operational real-time simulations or research runs. Procedures to set up and run a customized RAMS simulation are summarized. Various ARL graphical tools to visualize RAMS outputs and create pollution dispersion projections are also described.

The enhancements made to RAMS at ARL for operational and research purposes have been transferred to UNIX workstations at several institutions including the U.S. Air Force Tactical Assessment Command (AFTAC) and NASA/Marshall Space Flight Center. Therefore, a detailed technical description on using the ARL enhancements is also given here.

Specifically, the standard RAMS initialization was improved to input National Centers for Environmental Prediction (NCEP) meteorological datasets in ARL packed format in real time for daily operational forecasting. The ARL initialization package is relatively easy to use and contains model blending options not normally available. This same initialization procedure along with the ARL land surface preprocessor can also be applied for research-oriented case studies. These and other modifications were made to support ARL's air quality emergency response and research programs. All these enhancements are reported on, and technical guidelines on using these modification are given for the experienced RAMS user. This manual also shows how to set up and run RAMS in an operational mode using the ARL developments.

A general overview of RAMS and its applications at ARL is given in sections 2-4, and procedures for running RAMS and using special utilities are reviewed in sections 5-7. The two-dimensional version of RAMS is described in section 8, and a summary of ARL code changes is given in section 9. Public access to ARL-RAMS products through the Internet is described in section 10.

2. RAMS DESCRIPTION

2.1 Grid Structure and Basic Equations

RAMS utilizes an Arakawa-C staggered grid of the thermodynamic and momentum variables to reduce finite differencing error. An oblique stereographic horizontal grid coordinate can be specified. This is similar to more familiar polar stereographic coordinates if the "pole" position is defined at the center of the RAMS domain. All grids are true at this pole position. A simple Cartesian coordinate is also available. A two-way, interactive, multiple nested-grid scheme exists so that scale interactions can be incorporated. At ARL, up to five nested grids can be used for one simulation. This nested-grid approach also allows for a finer mesh to resolve local-scale circulations in the area of interest and a coarser mesh outside that area. This approach can be computationally efficient by avoiding a fine-mesh grid on a large area. The nesting option is a modification of the one described by Clark and Farley (1984) for their Midwest thunderstorm simulations. The coarse-grid prediction is advanced in time by first predicting variables on the coarse-grid alone. These predicted fields are then interpolated tri-quadratically to the fine-grid boundary points. Prediction of fine-grid quantities is then carried forward on the interior of the fine grid mesh. Finally, the coarse-grid values in the fine-grid domain are replaced by local averages from the fine grid variables. Two or more nested grids within a coarse mesh may be independent of one another.

The model vertical surfaces are based on a terrain-following height coordinate system, Z^*:

$$Z^* = Z_{agl} / (1 - Z_{terr} / Z_{top}) \qquad \textbf{(1)}$$

where Z_{agl} is the height above ground of the model surface, Z_{terr} is the topographical height at that grid point, and Z_{top} is the height of the model top. This formula ensures that the model top is a geopotential surface and the other levels are a given fraction of the distance between the surface and the top geopotential. Variables are staggered in the vertical such that horizontal momentum (u- and v-wind components), potential temperature (Θ), mixing ratio (r), and pressure, indicated by the exner function (π), are defined at one set of levels, whereas vertical motions (w) are defined at intermediate levels. The first half-level of the model is defined beneath the ground; therefore the first realistic half-level would be defined at level 2. The Appendix lists the vertical half-levels used in a typical operational forecast run. The vertical domain used at ARL usually extends to 15 to 20 km above ground level. Higher levels are included if deep convection is simulated. This coordinate system is much like the sigma surfaces used in other mesoscale models, which are terrain-following, pressure-type surfaces.

The prognostic equations are configured assuming a non-hydrostatic, quasi-compressible fluid and are described in detail by Tripoli and Cotton (1980, 1982). The prognostic equations of motion, neglecting the projection transformation terms, are

$$\frac{\partial u}{\partial t} = ADV(u) - \Theta \frac{\partial \pi'}{\partial x} + fv + TURB(u) \qquad \textbf{(2)}$$

$$\frac{\partial v}{\partial t} = ADV(v) - \Theta \frac{\partial \pi'}{\partial y} - fu + TURB(v) \qquad \textbf{(3)}$$

$$\frac{\partial w}{\partial t} = ADV(w) - \Theta \frac{\partial \pi'}{\partial z} + \frac{g \Theta_v'}{\Theta_0} + TURB(w) \qquad \textbf{(4)}$$

where the primes represent the deviation from the base state variable (denoted as a_0), f is the coriolus force, g is gravity,

θ_v is the virtual potential temperature and θ_0 is the base-state potential temperature. Three-dimensional advection of a quantity is signified by ADV, while turbulent mixing is indicated by TURB; π the Exner function, is a measure of pressure and is defined by

$$\pi = c_p \left(\frac{P}{P_0}\right)^{\kappa} \tag{5}$$

where c_p is the specific heat of dry air (1004 J K^{-1} kg^{-1}), P is the model pressure at the grid point, κ is a constant equal to 0.286 and P_o is a reference pressure equal to 1000 mb.

The prognostic thermodynamic equation is

$$\frac{\partial \theta_{il}}{\partial t} = ADV(\theta_{il}) + TURB(\theta_{il}) + \left(\frac{\partial \theta_{il}}{\partial t}\right)_{rad} + \left(\frac{\partial \theta_{il}}{\partial t}\right)_{con} \tag{6}$$

where θ_{il} is the ice-liquid water potential temperature and the subscript rad denotes the tendency from the radiation parameterization and conv indicates the adjustment to temperature from convection. θ_{il} is used to avoid specifying latent heating tendencies and is defined by

$$\theta = \theta_{il}\left[1 + \frac{L_v r_n}{c_p} T_v\right] \tag{7}$$

where L_v is the latent heat of vaporization and T_v is the virtual temperature. The equation for water-species mixing ratio r_n is

$$\frac{\partial r_n}{\partial t} = ADV(r_n) + TURB(r_n) + \left(\frac{\partial r_n}{\partial t}\right)_{conv} + S_q \tag{8}$$

where S_q represent changes in r_n resulting from freezing, sublimation, and condensation. The compressible, nonhydrostatic mass continuity equation is

$$\frac{\partial \pi'}{\partial t} = -\frac{R\pi_0}{c_v \rho_0 \theta_0}\left(\frac{\partial \rho_0 \theta_0 u}{\partial x} + \frac{\partial \rho_0 \theta_0 v}{\partial y} + \partial \frac{\rho_0 \theta_0 w}{\partial z}\right) \tag{9}$$

where R is the dry gas constant and ρ is the air density. The simpler hydrostatic equation is used instead of the vertical equation of motion and the nonhydrostatic mass continuity equation if the RAMS hydrostatic option is chosen.

2.2 Initialization

2.2.1 Meteorology

The model can be initialized from spatially inhomogeneous meteorological observations; therefore simulations are not limited to synoptically undisturbed cases. A FORTRAN program developed at ARL, **arl2mdl**,is used to ingest ARL packed National Centers for Environmental Prediction (NCEP) model gridded fields into RAMS. The NCEP datasets available for input are summarized in Table 1; they are available in real time a few hours after the 1200 UTC and 0000 UTC analysis cycles. Data from the NCEP Regional Analysis Forecast System (RAFS) over North America, described by Petersen and Stackpole (1989), are used to initialize the Nested Grid Model (NGM). Data from the Global Data Analysis System (GDAS), described by Kanamitsu (1989), are used for the Medium Range Forecast (MRF) or Aviation(AVN) global spectral models. These model datasets in ARL-packed format are described in detail by Draxler (1992). These analysis systems are run twice per day at NCEP. The **arl2mdl** program reads NCEP gridded analyses and forecasts on polar stereographic grids and pressure or σ vertical terrain-following surfaces, and interpolates the momentum (u- and v-wind components), potential temperature(θ), specific humidity (q), pressure (π), and sea surface temperature (SST) to the user-defined RAMS coarsest grid on Z^* surfaces. More than one input NCEP dataset can be used by combining these fields to create a complete input through the troposphere. For example, the NGM archive can provide high-resolution input on σ surfaces through 0.546 sigma, and above that another dataset that extends higher (i.e. MRF) could be used. Likewise input datasets can be blended horizontally if one set does not completely cover the chosen RAMS domain. **arl2mdl** uses the topography interpolated to the RAMS grid. If any nested grids are defined, terrain will be averaged near the fine-grid boundary so that on both grids the topography is similar. The outputs are then read in by RAMS and interpolated to initialize the nested grids.

Alternatively, NCEP model gridded data and surface and rawinsonde data can be objectively analyzed to isentropic surfaces before being interpolated to the model grid using the RAMS isentropic initialization package. Objective analysis is performed by inputting NCEP model data on a 2.5° latitude-longitude horizontal grid and mandatory pressure levels. The isentropic package is more complex to configure than the **arl2mdl** package and cannot easily ingest ARL archived datasets (Table 1). Also, vertical and horizontal grid blending is not available.

Table 1. Available NCEP analyses for RAMS ingest. NX and NY are the number of grid points in the *x*- and *y*- directions, respectively; ΔX is the model grid spacing. Under vertical spacing, σ refers to a terrain-following sigma vertical coordinate system.

Model	**NX**	**NY**	**Freq (h)**	**Vertical spacing**	ΔX **(km)**
Eta	110	103	6	50 mb	90.5
NGM	65	56	1	σ	91.4
NGM Archive	33	28	6	σ	182.
Aviation (AVN) run of MRF	129	129	6	Mandatory P levels	182.
MRF Archive	65	65	6	Mandatory P levels	381.

2.2.2 Ground Surface

The user can choose constant or spatially varying surface variables. These surface variables include soil moisture, soil and vegetation type, canopy temperature and water content, terrain height, land roughness, land percentage, and water surface temperature. Table 2 summarizes the spatially varying surface datasets available at ARL and their coverage. Over the United States, surface data exist at a higher resolution (30 latitude-longitude seconds, or about 1-km resolution) than is available globally (10 latitude-longitude minutes, or about 18-km resolution). The SST dataset is updated weekly whereas the soil moisture dataset is updated each day. Specifically, soil moisture is estimated by computing an Antecedent Precipitation Index (API, Chang and Wetzel, 1991) derived from the last few months of observed or model gridded precipitation archived at ARL. Soil moisture content is now included in the Eta Data Assimilation System outputs now archived at ARL and can be used instead of API derived soil moisture.

Table 2. Summary of surface data available for RAMS.

Type	**Coverage**	**Resolution (°)**	**Increment sizes or range**	**Update**
Topography	Global	10'	10 m	NA
Topography	U.S.	30"	10 m	NA
Sea Surface Temperature	Global	1°	0.1 K	Weekly
Soil type	Global	1°	12 categories	NA
Soil moisture fraction	Global	NCEP model resolution	0-1	Daily
Soil moisture	U.S.	precip. interpolated to 91-km grid	0-1	Daily
Land use	Global	1°	18 categories	NA
Land use	U.S.	30''	18 categories	NA
Roughness	Global	1°	1 cm	NA

2.2.3 Data Assimilation

Four dimensional data assimilation (FDDA) using dynamical Newtonian relaxation (or nudging) developed at Westinghouse, Savannah River Laboratories (Fast, et al., 1995), is currently being used in our version of RAMS. FDDA is applied only with hourly surface winds and therefore directly impacts the lowest model levels. Temperature and moisture can be assimilated, but it is not possible in an unattended, automated, operational environment to maintain a realistic vertical stratification. Observations are analyzed to the RAMS model grid at each observation time using a Kriging interpolation method. A tendency term is then added to the RAMS momentum equation at each model time step and is of the form

$$G\,W(x,y,z)\,\beta(t)\,(\varphi_{obs}-\varphi_{mdl}) \qquad \textbf{(10)}$$

where *G* is a relaxation coefficient, *W(x,y,z)* is a three-dimensional spatial weighting coefficient, φ is either the *u* or *v* momentum component, and β is the temporal weighting coefficient. *W(x,y,z)* is proportional to the estimated variance of the interpolated observations. The variance is determined from the spatial arrangement of the data. *W(x,y,z)* ranges from 0, when a grid point is sufficiently far from an observation, to 1, when a grid point and an observation location are identical. In the horizontal, the spatial weight decreases by a factor of e^{-1} at a user-specified distance from an observation location. In the vertical, *W(x,y,z)* decreases by a factor of e^{-1}, above and below an observation location in order to produce realistic vertical wind shears.

The temporal weighting function, $\beta(t)$, is used to weight the relative contributions of two observation times that cover the current model time step and is given by

$$\begin{array}{lll} \beta(t) = 1 & |t-t_0| < \tau/2 & \\ \quad\; = 0 & |t-t_0| > \tau & \quad \textbf{(11)} \\ \quad\; = (\tau - |t-t_0|)/(\tau/2) & \tau/2 < |t-t_0| < \tau & \end{array}$$

where t_0 is the observation time and τ is the half-period (Stauffer and Seaman, 1990) of the time window over which the observations can influence the model predictions.

2.3 Physics

The RAMS model contains a full set of nonhydrostatic compressible dynamic equations, a thermodynamic equation, and a set of cloud microphysics equations for water- and ice-phase clouds and precipitation. Numerous options exist for the type of parameterization desired to represent the planetary boundary layer (PBL) and cloud and radiation effects. The discussion here concentrates on the options most frequently used and those that have important impacts on air quality studies. As an example, a summary of the configuration used for the ARL operational run is shown in Table 3.

Table 3. RAMS operational run configuration.

Model characteristic	**Option used**
Basic equations	Compressible, nonhydrostatic
Initialization	**arl2mdl** package
Input Meteorology	Eta model analysis and 12- and 24-h forecast (at 0000 and 1200 UTC)
Assimilation	Hourly surface station data
Input surface	30'' terrain, land cover 90-km gridded soil moisture 1° soil type 1° SST data
Physics	
Radiation	Chen and Cotton (1983) longwave and shortwave
Moist processes	Explicit microphysics for rain, snow, ice crystals and aggregates
Cumulus	Modified Kuo scheme
Horizontal diffusion	Deformation K (first-order)
PBL turbulence	Prognostic turbulent kinetic energy equation (level 2.5; Mellor and Yamada, 1982)
Surface layer	Louis (1979)
Surface model	Tremback and Kessler (1985)
Numerics	
Time differencing	Forward-backward time splitting
Space differencing	Second-order flux form
Horizontal coordinates	Oblique stereographic
Vertical coordinates	Terrain-following Z^*
Boundary conditions	
Lateral boundaries	Davies (1983) sponge blending (5 LBC points)
Top boundary	Raleigh friction absorbing layer above 14 km

2.3.1 Surface Model

The surface parameterizations of vertical heat, water vapor, and momentum fluxes are computed as a function of ground surface temperature derived from a surface energy balance (Mahrer and Pielke, 1977). The RAMS surface energy balance equation defined by Tremback and Kessler (1985) is

$$C_s \Delta z_G\, \partial\theta_G/\partial t = \underbrace{R_s\!\downarrow + R_l\!\downarrow - \sigma T^4}_{\text{Net Radiation}} + \underbrace{\rho_a c_p u_* \theta_*}_{\text{Sensible Heat Flux}} + \underbrace{\rho_a L_v u_* q_*}_{\text{Latent Heat Flux}} - \underbrace{C_s \lambda\, \partial\theta/\partial z|_G}_{\text{Soil Flux}} \quad \textbf{(12)}$$

where θ_G is the ground potential temperature; R_s and R_l are the longwave and shortwave radiation; C_s is the volumetric specific heat of the soil; λ is the thermal conductivity; L_v is the latent heat of vaporization; ρ_a is the air density near the ground; σ is the Stefan-Boltzmann constant; u_*, θ_*, and q_* are the surface layer scaling parameters for momentum, heat, and specific humidity, respectively; and Δz_G is the vertical spacing in the soil.

Values of soil temperature and soil moisture are predicted from a prognostic soil model developed by McCumber and Pielke (1981) and modified for RAMS by Tremback and Kessler (1985). The predictive equation for soil moisture is as follows:

$$\partial\eta_G/\partial t = (\rho_a u_* q_* - D_\eta \partial\eta/\partial z - K_\eta) / \Delta z_G \qquad \textbf{(13)}$$

where η is the soil moisture (volume water/volume soil), D_η is the moisture diffusivity and K_η is the hydraulic conductivity which are both a function of η and soil type. RAMS currently supports 12 different soil types from sand to peat (Table 4). The total soil porosity is an indication of the maximum moisture that the soil type can hold. The default soil model layers extend to 30 to 50 cm beneath the ground surface; however the soil layers can be specified by the user.

RAMS uses 18 land-use types(Table 5). Surface-layer variables in each grid cell are computed and weighted for the fraction of each ground surface type in that cell (bare ground, shaded ground, vegetation, and water).

Table 4. Soil textural classes in RAMS

USDA soil textural class	**Number**	**Total porosity, ν**
Sand	1	0.395
Loamy sand	2	0.410
Sandy loam	3	0.435
Silt loam	4	0.485
Loam	5	0.451
Sandy clay loam	6	0.420
Silty clay loam	7	0.477
Clay loam	8	0.476
Sandy clay	9	0.426
Silty clay	10	0.492
Clay	11	0.482
Peat	12	0.863

Table 5. Land-use categories in RAMS.

Land cover type	**Number**	**Albedo**	**Emmis-sivity**	**Rough-ness (m)**
Crop/mixed farming	1	0.20	0.95	0.06
Short grass	2	0.26	0.96	0.02
Evergreen needleleaf tree	3	0.10	0.97	1.0
Deciduous needleleaf tree	4	0.10	0.95	1.0
Deciduous broadleaf tree	5	0.20	0.95	0.80
Evergreen broadleaf tree	6	0.15	0.95	2.0
Tall grass	7	0.16	0.96	0.10
Desert	8	0.30	0.86	0.05
Tundra	9	0.20	0.95	0.04
Irrigated crop	10	0.18	0.95	0.06
Semi-desert	11	0.25	0.96	0.10
Ice cap/glacier	12	0.40	0.82	0.01
Bog or marsh	13	0.12	0.98	0.03
Inland water	14	0.14	0.99	0.0024
Ocean	15	0.14	0.97	0.0024
Evergreen shrub	16	0.10	0.97	0.10
Deciduous shrub	17	0.20	0.97	0.10
Mixed woodland	18	0.18	0.96	0.80

The vegetation parameterization is currently not used for grid points that are partially or wholly covered by inland water or ocean. Therefore, the roughness length is calculated by the Charnock (1955) relationship

$$z_0=0.018u_*^2/g \tag{14}$$

Studies at ARL indicated that the fluxes of heat and moisture over the Chesapeake bay were sensitive to the formulation of Z_0. Following recent studies by Miller et al. (1992), roughness over water in meters was defined by

$$z_{0M} = 0.11\nu/u_* + 0.018u_*^2/g \tag{15}$$

$$z_{0H} = 0.40\nu/u_* + 1.4\text{x}10^{-5} \tag{16}$$

$$z_{0Q} = 0.62\nu/u_* + 1.3\text{x}10^{-4} \tag{17}$$

where Z_{0M}, Z_{0H}, and Z_{0Q} are the roughness length for momentum, heat and moisture respectively and ν is the air kinematic viscosity ($=1.4 \times 10^{-5}$ m^2 s^{-1}). This roughness length formulation is now used at ARL.

2.3.2 Turbulence

The surface-layer scaling parameters for u_*, q_* and θ_* are used to compute the surface fluxes, following Louis(1979):

$$H=\rho c_p u_* \theta_* \tag{18}$$

$$LE=\rho L_v u_* q_* \tag{19}$$

$$\tau=\rho u_*^{\,2} \tag{20}$$

where H is the sensible heat flux, LE is the latent heat flux, and τ is the momentum flux.

The vertical eddy fluxes of momentum and sensible heat are proportional to non-linear functions, F_m and F_h, and are defined, respectively, by

$$\begin{gathered} u_*^2=a^2u^2\ F_m\left(\frac{z}{z_0},Ri_B\right) \\ u_*\theta_*=\frac{a^2}{R}u\Delta\theta\ F_h\left(\frac{z}{z_0},Ri_B\right) \\ \text{where} \\ a^2=k^2/\left(\ln\frac{z}{z_0}\right)^2 \end{gathered} \tag{21}$$

k is Von Karman's Constant (=0.40); R, a dimensionless constant, is the ratio of transfer coefficients of momentum and heat in the neutral limit; and the bulk Richardson number is

$$Ri_B=\frac{gz\Delta\theta}{\bar{\theta}u^2} \tag{22}$$

A constraint is placed on the minimum value of z/z_0 in Equation (21) so that the functions agree with observed data.

A second-order closure scheme where turbulent kinetic energy (TKE) is explicitly predicted and controls boundary layer mixing (Mellor and Yamada, 1982) is normally used at ARL for turbulence above the surface layer. The TKE budget equation in RAMS is dependent upon the following :

- Buoyant production or consumption which is proportional to the heat flux.
- Mechanical or shear production or loss.
- Turbulent transport of TKE.
- A pressure correlation term that mixes TKE by pressure perturbations.
- Viscous dissipation of TKE.

The boundary layer terms are therefore redistributed and mixed vertically depending on the amount of TKE produced.

A Smagorinsky-type vertical eddy viscosity mixing with a Richardson number dependence is sometimes used to mix variables in the boundary layer, instead of the more complex TKE parameterization. This method utilizes a first-order-closure vertical diffusion coefficient profile and is valid for model grid spacings greater than 1-2 km. The diffusion coefficient is proportional to the product of the local fluid deformation rate and the square of the grid spacing.

2.3.3 Moist Processes

The longwave and shortwave radiation parameterizations developed by Chen and Cotton (1983) are used when clouds are included in a model simulation. The longwave technique accounts for the effects of both clear and cloudy air absorption. Within clear air, the effects of both water vapor and carbon dioxide absorption are predicted. The cloud effects on both shortwave and longwave radiation are based on the empirically derived scheme of Stephens (1978 a,b) and account for the radiative effect of liquid water and ice. This scheme is computationally intensive to perform, but when clouds are not present the Mahrer and Pielke (1977) radiation parameterization can be used. This scheme does not include the effects of liquid water and ice.

RAMS includes both an explicit cloud microphysics scheme and a convective cloud parameterization to simulate cloud effects on the atmosphere and precipitation. The explicit scheme includes equations for cloud water, rain water, pristine ice crystals, snow, and graupel as well as warm rain conversion and accretion of cloud water to raindrops, evaporation, and sedimentation. Nucleation of ice crystals, conversion nucleation and accretion of graupel, as well as ice crystal growth, evaporation, melting, and sedimentation, can also be included as an option. The most realistic but computationally intensive option includes the conversion and growth of aggregates, melting, evaporation, and sedimentation, and a prognostic nucleation model. The concentration of activated cloud droplets is specified by the model user as a climatologically derived input parameter. The explicit cloud model is described in detail by Cotton et al. (1982, 1986).

A cloud parameterization based on the modified Kuo approach can be specified instead of the cloud microphysics codes. Convective parameterization is used to vertically redistribute heat and moisture in a grid column when a superadiabatic convectively unstable region develops. This scheme is only valid on coarser grids of 20 km or greater. The explicit cloud microphysics model can be used at resolutions of about 2 km or less. There is currently no satisfactory scheme to simulate convective cloud moist processes for model grid spacings of between 2 and 20 km in RAMS version 3a.

2.4 Numerics

ARL-RAMS normally is used with nonhydrostatic time-split compressible primitive equations in one, two, or three dimensions. Nonhydrostatic physics allows for the high-resolution grid spacings (less than 10 km), which are needed in simulating deep convection or flow over complex terrain. Forward-backward time-split second-order finite time and space differencing is used and is described in detail by Tremback et al. (1987).

The interior lateral boundary conditions (LBC) can be treated by the two-way nested lateral boundary condition or through several one-way nested boundary condition approaches, which allow waves to reach the boundaries with a minimum of wave reflection. The Davies (1983) sponge condition is the ARL default lateral boundary condition on the coarse grid, with NCEP model tendencies blended with the RAMS predictions on the five grid points nearest the boundary. The NCEP model tendencies are normally ingested into RAMS every 6 to 12 h.

The upper boundary condition employed most often with the nonhydrostatic option is an absorbing layer or a simple rigid lid approach. Upward propagating gravity waves are damped by the absorbing layer, which reduces noise reflection from the model top; therefore this scheme is more often used, especially in complex terrain.

3. OPERATIONAL CAPABILITIES

RAMS has recently been used operationally for air quality dispersion forecasts. Lyons et al. (1991) summarized work in forecasting thunderstorm potential over Cape Kennedy using the Pielke model which was a predecessor to RAMS. However, the simulations were hydrostatic and did not account for phase changes of water. The simulations were not applicable when synoptic disturbances were nearby or when moist convection was present. Fast et al. (1995) summarized their operational forecast capabilities for the Savannah River Laboratories area in Aiken, South Carolina, where they produced 36-h forecasts with 26-km grid spacings.

At ARL, RAMS is run operationally in both forecast and hindcast modes. It can be run in one, two or three dimensions. Tables 6 and 7 summarize the current operational configuration. On the IBM 6000/Model 590, RAMS is configured to produce 18 to 24-h forecasts twice per day after the latest Eta model fields are available. On the IBM 6000/Model 560, RAMS is configured in a hindcast mode while also assimilating surface wind data (using four-dimensional data assimilation, FDDA) normally available every hour. The geographical locations of the coarse- and fine-grid operational forecast domains are shown in Figure 1. RAMS outputs are available in real time on a 1-week rotating archive on the ARL workstations. The 15-km hindcast archive is saved to tape and is available from 1993 to the present.

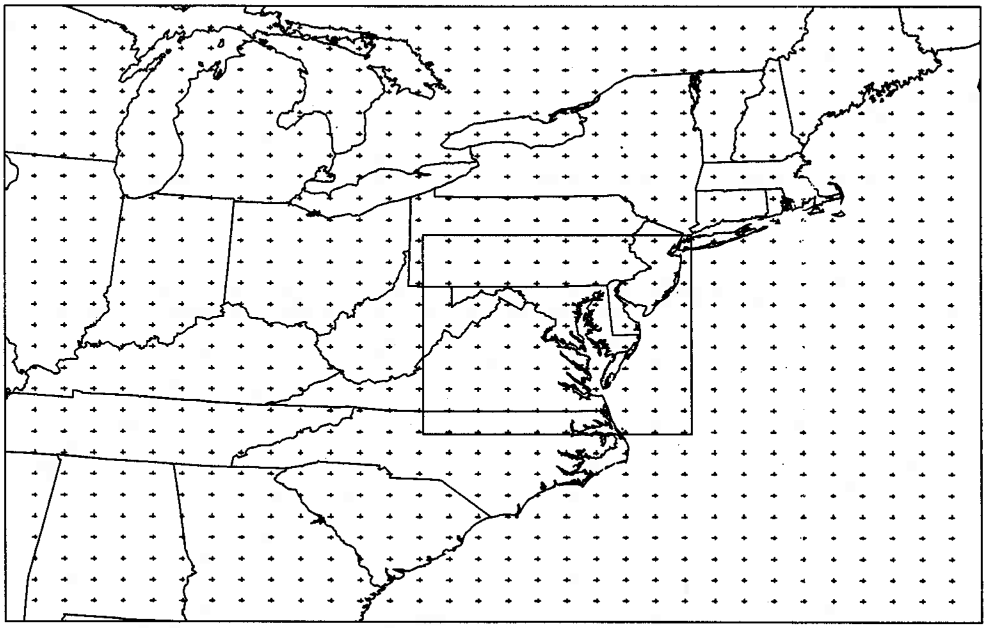

Figure 1 The RAMS coarse- and fine-grid domains and the coarse thermodynamic grid points used over the mid-Atlantic Chesapeake Bay. Momentum points (not shown) are staggered between thermodynamic grid points. The only fine grid-points that are shown above are those coinciding with the coarse-grid points.

RAMS is normally run over the Chesapeake Bay and mid-Atlantic region when it is not required for an emergency, for exercises or to support air quality experiments. The RAMS domain can easily be moved through ARL's Real-time Environmental Applications and Display system (READY; Rolph et al., 1993, 1995; Draxler et al.,1993) by simply specifying the center latitude and longitude of the coarse grid through the READY menu. READY is also used for postprocessing graphics.

Table 6. RAMS operational-run parameters. ΔX is the model grid spacing; Δt is the model time step; NX, NY, and NZ are the number of grid points in the *x*, *y* and *z* direction, respectively; Δz_1 is the depth of the first model layer closest to the ground; Δz Max is the depth of the coarsest model vertical layer; and K_h is the horizontal diffusion coefficient.

Parameter	**Grid 1**	**Grid 2**
ΔX (km)	60	15
Δt (s)	75	25
NX	32	42
NY	30	46
NZ	24	24
Δz_1(m)	100	100
Δz Max(m)	1500	1500
K_h	0.40	0.70

Table 7. RAMS operational configuration.

Workstation	**Mode**	**Location**	**Domain (km)**	**cpu/ wall time**	**ΔX(km)**
IBM 6000/560	12-h hindcast w/ FDDA	mid-Atlantic/ Chesapeake Bay	1920x1800 630x690	0.33	60 and 15
IBM 6000/590	18-h forecast	mid-Atlantic/ Chesapeake Bay	1920x1800 630x690	0.33	60 and 15

Besides the grid structures based for the operational runs, ARL has configured RAMS with several other grid structures, as shown in Table 8. Simulations performed over the Susquehanna

River valley in Pennsylvania employed the finest nested-grid spacings to date (ΔX=2.5 km). RAMS was evaluated there for air quality predictions, and the results were summarized by McQueen et al. (1995). The finest mesh grid spacing used to produce operational 18- to 36-h forecasts over the Chesapeake Bay is 15 km. Grid domains of the finest mesh for various simulations have ranged from 50 to 600 km depending on the grid spacing.

Table 8. RAMS simulations performed at ARL.

Simulation	**Period**	**Grids**	**Mode**
Chesapeake Bay operations	1992-present	60 and 15 km	18-h forecasts 12-h hindcasts with FDDA
Nevada Test Site	1995-present	40 and 10 km	24-h forecasts
Yorktown, VA Federal Radiological Management Assessment Center (FRMAC)	Sept. 95	60 and 15 km	24-h forecasts
Urban Airshed Model Maryland domain	Summer 95	20 and 5 km	24-h hindcasts
Ft.Calhoun,Nebraska FRMAC 93	July 93	80 and 20 km	12-h hindcasts
North Atlantic Regional Experiment (NARE)	Aug. 93	80 and 20 km	24-h forecasts
Susquehanna, PA Nuclear Regulatory Commission (NRC) exercise	Dec. 92	40,10 and 2.5 km	12-h hindcasts
Florida Aerosal Characterization Experiment (ACE)	Nov. 92	40 and 10 km	12-h forecasts
European Tracer experiment(ETEX)	April 92 Oct. 92	80 km	72-h forecasts 12-h hindcasts
Oak Ridge, Tennessee	Summer 92	40 and 10 km	12-h hindcasts
Lake Champlain, Vermont	Dec. 89	40 and 10 km	12-h hindcasts

4. SUMMARY OF RAMS FEATURES FOR AIR QUALITY APPLICATIONS

4.1 Strengths

- RAMS has the ability to provide three-dimensional predicted wind fields on a high-resolution domain, which allows for simulation of horizontal and vertical transport. The model can predict the state of the atmosphere at offshore locations where meteorological towers cannot be placed.

- Nonhydrostatic physics are incorporated to realistically predict the atmosphere over a limited domain at very high spatial resolution. This capability is essential for dispersion studies where grid spacings of 3 km or less are often needed to adequately predict the local-scale flow fields.

- The effects of vegetation and soil variations on atmospheric flows are parameterized in a realistic manner.

- A two-way nested grid capability reduces computational time and required memory.

- Various levels of cloud parameterizations are available as options.

- Realistic horizontally inhomogeneous atmospheric initial conditions can allow for simulations during synoptically disturbed periods by using the ARL or RAMS isentropic initialization.

4.2 Needed Improvements

- Techniques to parameterize cloud water effects for grid spacings of 3-20 km are currently being explored by several researchers. The explicit cloud microphysics scheme, while very sophisticated is too computationally intensive and is not appropriate for the operational grid spacings.

- More accurate techniques for specifying spatially varying soil and vegetation parameters should be explored further. Satellite-derived vegetation parameters have been determined by Chang and Wetzel (1991), and real-time soil moisture values from previous rainfall measurements have also been determined by the Chang and Wetzel. Model simulations with high-resolution surface parameters should be done to evaluate the importance of these fields on the local-scale flow.

5. THREE-DIMENSIONAL RAMS PROGRAMS AND FILE STRUCTURE ON THE ARL WORKSTATIONS

The RAMS programs and UNIX scripts used to create the initial data, run the model, and create graphics are described in this section. The directory and file structure described here can be re-created on a UNIX platform with an installation script that is available from ARL. This system was designed to be used for operational real-time simulations or research runs. Scientists who access ARL datasets for RAMS operational or research simulations have formed an informal users group. The group's objectives are to keep participants informed of recent progress and problems with using RAMS. ARL updates a document of Frequently Asked Questions (FAQ) and maintains member addresses, recent activities and RAMS related publications. The users include scientists from the U.S. Air Force Tactical Applications Center (AFTAC), NASA-Huntsville Research Center, the NOAA/Great Lakes Environmental Research Laboratory (GLERL), NOAA/Atmospheric Turbulence and Diffusion Division (ATTD), GE Savannah River Laboratories (SRL), DOE Pacific Northwest Laboratory (PNL) and the University of Michigan.

5.1 RAMS Directory Structure

The RAMS directory structure is shown in Figure 2. A description of procedures to initiate and run RAMS and produce graphics within the context of this structure follows. Normally, the user need only edit the configuration files in the **cfgfile** directory and then submit the driver script from the **scripts** directory. The RAMS input data are created in the **arl2mdl, sfcbndy, setbase,** and **work** directories. Modifications are not required by the user in these latter directories.

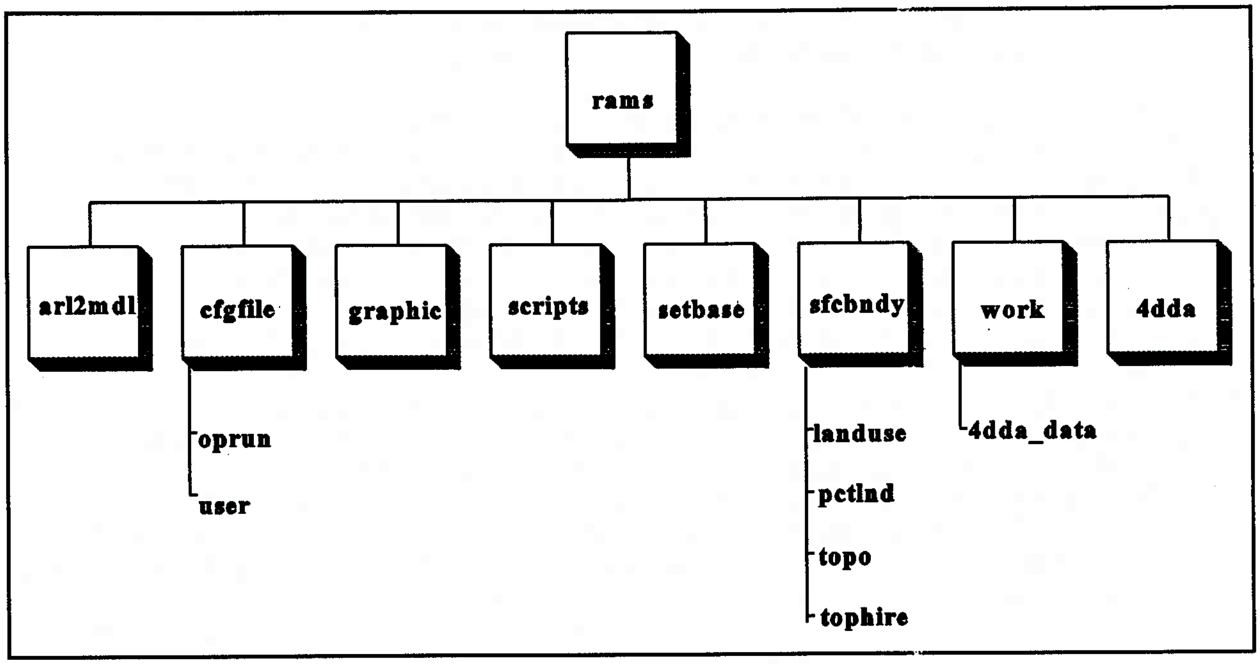

Figure 2. RAMS directory structure on the ARL workstations.

5.2 RAMS UNIX Driver Scripts

The RAMS UNIX driver scripts are found in the **scripts** directory on the RAMS account. These scripts drive the RAMS preprocessing, data initialization, submission, and graphical output. A brief description of these scripts follows:

Script Name	Description
ramsops.scr	Drives the model run. This script can be used directly for research runs without using **autoram.scr**.
ramsplot.scr	Controls the postprocessing of the RAMS output. This includes graphical plotting, updating the running data archives, and updating the ARL internet world wide web (www) page graphics with the latest predictions from operational runs.
autoram.scr	Updates the operational RAMS archive files and calls **ramsops.scr** to begin a batch operational run. This script also checks that the latest NCEP model datasets are available on the ARL workstations. This script is only necessary for repeated batch operational runs.

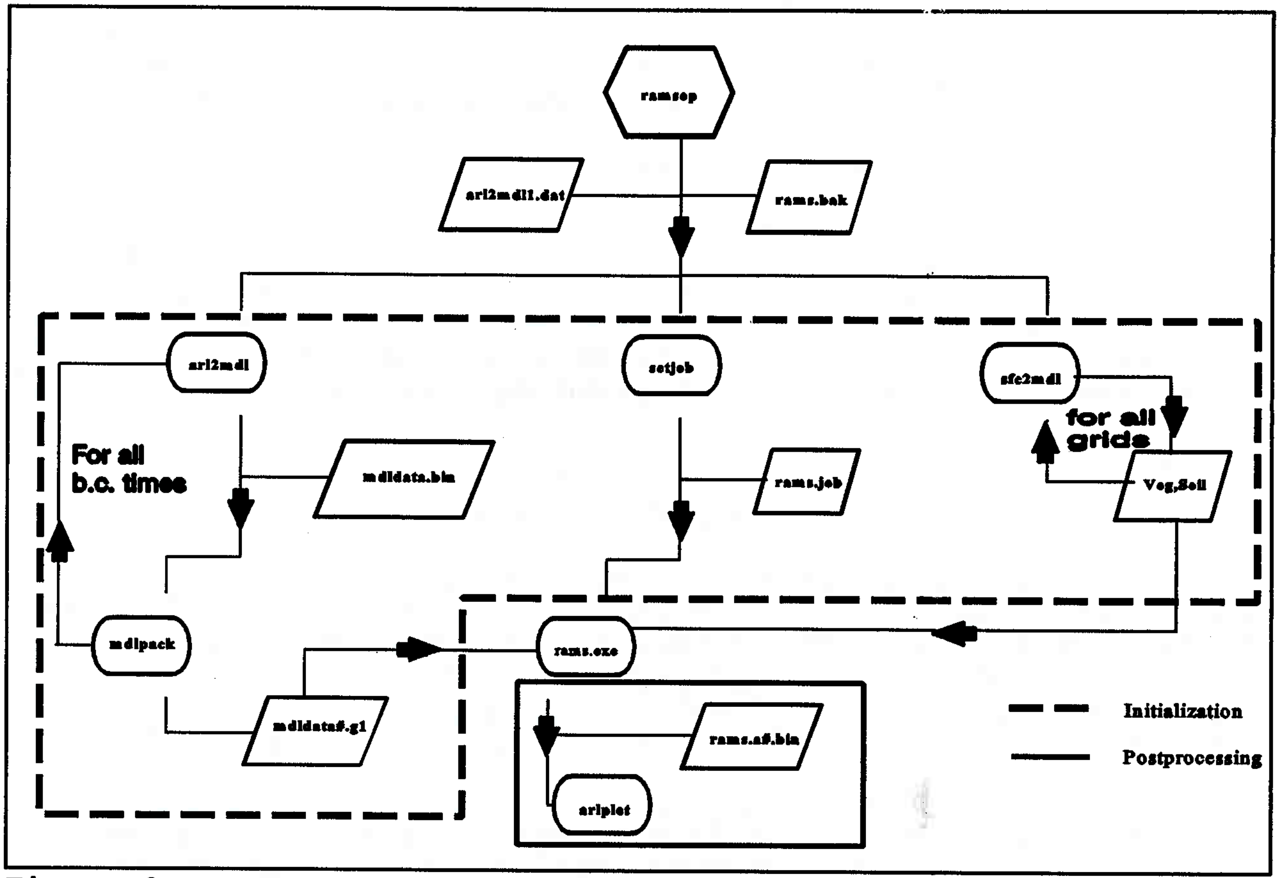

Figure 3. ARL-RAMS flow chart run showing model intitialization, simulation, and postprocessing. Skewed rectangles indicate I/O datasets, while rounded rectangles indicate executable code (programs).

A flow chart of the **ramsops** and **ramsplot** scripts is shown in Figure 3. Input/Output (I/O) data are indicated by the skewed rectangles, while programs are shown in the rounded rectangles.

Specifically, these scripts drive the simulation by

1. Creating the RAMS "mdldata" initialization files from NCEP fields using the **arl2mdl** and **mdlpack** programs.
2. Creating RAMS land surface files from global fields using the **sfc2mdl** program.
3. Configuring RAMS grid parameters in **rams.job** using the **setjob** program.
4. Creating surface files for assimilation if chosen.
5. Submitting the RAMS batch job file by running the

rams.exe executable code for the model.

6. Creating graphics from RAMS output using READY. The **arlplot** program is normally used to plot *x-y* maps.

To submit the driver script, enter

nohup ramsops.scr [*run identifier* **]**

where *run identifier* is the subdirectory where the configuration data files are located (see section 5.3). For automated, operational simulations, the **autoram** script is normally run using the *crontab* UNIX utility for repeated submissions.

5.3 RAMS Preprocessing

The datasets, programs, and scripts needed to create the input RAMS datasets are stored in the directories shown in Figure 2. The **cfgfile, arl2mdl, setbase** and **sfcbndy** preprocessing directories and all the preprocessing programs and scripts are described in sections 5.3.1 and 5.3.2. However, to set up and run the basic RAMS model at ARL, only the following steps need to be performed:

1. Edit the configuration file (**cfgfile** directory, section 5.3.1.1) to set up the model grid definition and important physical parameterizations.

2. Edit the RAMS job file containing the RAMS namelist (**cfgfile** directory, section 5.3.1.2) to change more advanced parameters. This step is optional.

3. Put any special surface datasets (eg: soil moisture, SST) in the **cfgfile** directory (section 5.3.2.3) for use by RAMS.

4. Edit the READY batch graphics configuration files in the **graphic** directory (section 5.5) for use by the **arlplot** program.

5. Submit the RAMS operational script in the **scripts** directory (section 5.2).

5.3.1 Setting the Model Grid and Physical Options (**cfgfile** Directory)

The **cfgfile** directory contains the input configuration files needed to specify a RAMS run. The structure of a typical **cfgfile** directory is shown in Figure 4. Subdirectories off the **cfgfile** directory are created by the user. The subdirectory name is designated during job submission so that configuration files can be read in by the ARL-RAMS system programs. The two files that must be present are **arl2mdl#.dat and rams.bak**. If the user wishes to use variable surface datasets (SST dataset, **SST.ASC** and soil moisture data, **SMI1.12**), these files should also reside in this directory. The two mandatory configuration files are described in sections 5.3.1.1 and 5.3.1.2.

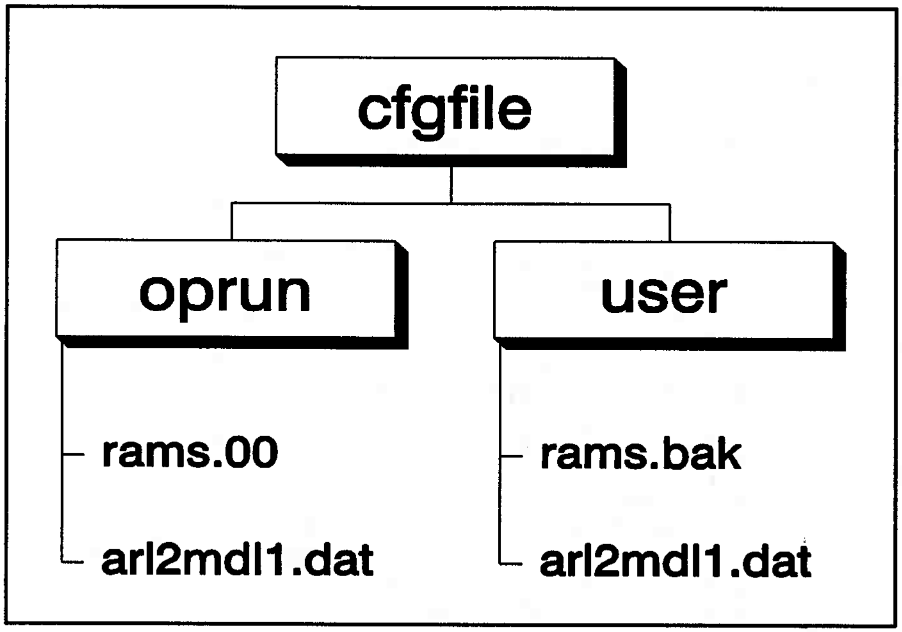

Figure 4. The RAMS **cfgfile** directory containing the configuration files used to setup the RAMS run.

5.3.1.1 **arl2mdl#.dat** file of the configuration parameters (**arl2mdl** Directory)

Parameters in the **arl2mdl#.dat** file specify the input NCEP and surface dataset(s) to be used as well as the parameters needed to define the RAMS domains. The most frequently used parameterization options are also set there. This file is copied to another file, **defgrid.dat**, in the **arl2mdl** directory for use by the **arl2mdl.exe** executable file. The # in this file is an integer that points to the configuration file that will be used for initialization (#=1) and for creating the temporal lateral boundary condition (LBC) fields (#=2-N). For example:

#	Config file name	Description
1	**arl2mdl1.dat**	Used to create coarse-grid RAMS initialization fields.
2-N	**arl2mdl#.dat**	Used to create coarse-grid LBC fields(e.g. +12 forecast hours).

Specifying more than one configuration file is useful if the LBC fields will be created with a different NCEP meteorological dataset than the one used for initialization. Only **arl2mdl1.dat** is needed if the RAMS LBC and initialization fields can be generated from the same NCEP data file. In that case, the script will reuse the options set in **arl2mdl1.dat** to create the LBC files.

An example of the **arl2mdl#.dat** file configured for two RAMS grids is shown in Figure 5. The variables in the **arl2mdl#.dat** configuration file are described below.

```
=============================================================================
# Met file description__________________________________________
1                         # initialization technique (1=arl2mdl,2=isan)
02                        # number of input files
'/auto/avn/AVNFNH'        # input file names with path in single quotes
'/auto/eta/ETAFNH'        # input file names with path in single quotes
0                         # multi-file averaging flag (0:no 1:yes)
24                        # TIMMAX: run time in hours
00                        # offset start time
12                        # lateral boundary condition file frequency
# RAMS grid-independent params__________________________________
60.                       # output grid spacing in km for coarse grid
75.                       # timestep in seconds for coarse grid
O                         # soil wetness flag(O=obs,N=ngm,A=avn,0=none)
0                         # FDDA flag (0:no 1:yes)
2                         # number of rams grids
# Grid definition section_______________________________________
39.0         38.5         # center lat for each grid
-78.5        -77.0        # center lon for each grid
32           38           # number rams grid points in x for each grid
28           38           # number rams grid points in y for each grid
1            4            # nesting ratio for each grid
.4           .7           # horizontal diffusion coefficient
2            3            # moisture complexity  (1=vapor,2=condensed,3=full)
1            0            # cumulus parameterization flag (0:no 1:yes)
# Ground sfc datasets___________________________________________
2            1            # topography (1=U.S.30", 2=10' global, 3=constant)
0.           0.           # silhouette avging wt (SILAVWT)
2.           4.           # topo cutoff wavelength (TOPTWVL)
2            1            # land use    (1=U.S. 30'',2=1° global,3=constant)
2            0            # SST (1=climo, 2=real-time 1°, 3=SST.KON or const)
# Vertical grid structure_______________________________________
24                        # NZ
100.0                     # initial delta-z
1.20                      # delta-z stretch ratio
1200.0                    # maximum delta-z
=================================================================
```

Figure 5. Example of the arl2mdl#.dat file configured for two RAMS grids.

5.3.1.1.1. Variables for the meteorological file description

Initialization: Initialization technique to use. Currently only the **arl2mdl** option is available through the ARL/RAMS processing system.

Number of files: The number of NCEP meteorological data files to use.

File names: The name of each corresponding NCEP local file with its directory path in single quotes. The RAMS input file can be created from more than one input NCEP file (see Table 4) by using this option. When more than one NCEP file is used, the data from the first file are overwritten by data from the second file up to the highest vertical level of the second dataset. Therefore, the first dataset should extend higher than the second file. This option is useful if you want to use a high-resolution data set that does not extend very high (e.g., NGM archive data) to initialize the lower RAMS levels and then another dataset (e.g., AVN or MRF global data) to specify the upper RAMS levels. The higher resolution (NGM) file should be specified after the lower resolution (MRF) files. Therefore, the higher resolution NGM data will replace the lower resolution (MRF) data file where the two files coincide in the vertical.

Some ARL-archived NCEP files saved before 1990 do not have a surface pressure (PRSS) field. In this case, set the number of input files to 3. Then designate the input data files in the following order:

NGMTO12	To initialize all variables including PRSS.
MRFTO72	To fill in upper-level fields. This file will use the PRSS data from the previous file to perform vertical interpolation to the RAMS grid.
NGMTO12	to overwrite fields. This overwrites the low-level MRF fields with the higher resolution NGM data where the two models overlap in the vertical.

Averaging: Specifies multi file averaging in the horizontal. This option is not working properly.

TIMMAX: The total model simulation time in hours.

FILEHRS: The offset hour for the first NCEP meteorological input file. This parameter also indirectly specifies the RAMS starting date and time, by extracting that information from the NCEP data record corresponding to the offset hour indicated.

INTRVL: The interval in hours between NCEP meteorological input lateral boundary condition files.

5.3.1.1.2 Variables for the RAMS grid-independent parameters section

DELTAX: Output coarse grid spacing (km) in the *x* and *y* directions. In the ARL setup, it is assumed that DELTAY will equal DELTAX.

DTLONG: Time step for the coarsest grid. DTLONG is proportional to the grid spacing, and recommended values are given in the AKMIN description in the grid definition section (next).

SOILWET: Variable soil wetness flag to define the soil moisture index (SMI) file type. The available options are

O = Use SMI derived from observed precipitation file covering the U.S.
N = Use SMI derived from the NGM-predicted precipitation.
A = Use SMI derived from the AVN-predicted global precipitation.
0 = Use constant soil wetness; the constant value should be specified by the variable SLMSTR in **rams.bak**.

FDDA: Four dimensional data assimilation flag (0/1). FDDA is described in detail in section 5.6.1

NGRIDS: Number of RAMS grids including the coarsest outer grid.

5.3.1.1.3 Variables for the grid definition section

When nested RAMS grids are desired, all grid-dependent parameters are specified for each grid on the same line. For example, in the **arl2mdl#.dat** file shown in Figure 5, two values are specified in the grid definition section; the first corresponds to the coarse grid's value and the second to the fine grid's value.

CENTLAT: Center latitude in degrees for each grid specified. South latitude is negative.

CENTLON: Center longitude in degrees for each grid specified. West longitude is negative (-180° to 180°).

NXP: The number of grid points in the *x* direction for each grid. Both NXP and NYP should not exceed the maximum value (200) set in the RAMS code.

NYP: The number of grid points in the *y* direction for each grid.

NSTRATX: The grid spacing-ratio in the *x* direction relative to the next coarser grid. In the example in Figure 5, NSTRATX=4 for grid 2, which indicates that the resolution on this grid is 4 times finer than on grid 1 (ΔX=15 km on grid 2 and 60 km on grid 1). It is assumed that the grid spacing ratio in the *y* direction, NSTRATY, will equal NSTRATX. NSTRATX is always 1 for the coarsest grid.

AKMIN: Horizontal diffusion coefficient. AKMIN should be increased with increasing horizontal resolution. These are recommended values for different grid spacings and time steps:

DELTAX	AKMIN	DTLONG
80 km	0.3	75 s
60 km	0.4	60 s
40 km	0.5	30 s
20 km	0.6	20 s
5 km	0.75	7 s
1 km	1.0	2.5 s
250 m	2.0	1 sec

NLEVEL: The level of sophistication for moist processes (0-3). See section 2.3.3 for more details.

0 = Moisture is not predicted. A dry atmosphere is assumed.
1 = Only water vapor is predicted as a passive tracer.
2 = Any excess water vapor (supersaturated moisture) will be condensed and produce clouds and precipitation.
3 = Full explicit condensed microphysics predictive equations. Only the predictive equations for rain, snow, aggregates and ice crystals are used operationally. Full explicit microphysics will produce more realistic precipitation; however, computational requirements will normally increase by 20-30%.

NNQPARM: Cumulus parameterization flag (0/1). As discussed earlier, cumulus parameterization is not recommended at grid spacings finer than 15-20 km. Also, the model top should be fairly high (greater than ≈17 km).

5.3.1.1.4 Variables for the ground surface datasets section (grid dependent)

The ground surface data sets are located in the **sfcbndy** subdirectory and were described in section 2.2.2. RAMS can read in the 30 second resolution topography and vegetation directly. ARL has developed modules to read in all other datasets. These modules are summarized in section 9. The precise directory name of the surface datasets will be automatically set in the **rams.bak** file (section 5.3.1.2) of the **cfgfile** directory (the ITOPTFN and IVEGTFN namelist variables) when using the ARL-RAMS system.

ITOPTFLG: Topography type to use (1-3).

1 = Use 30 second resolution topography. This dataset is available only for over the U.S.
2 = Use 10 minute resolution global topography.
3 = Constant that can be specified in the RAMS **ruser3a.f** Fortran subroutine (section 9).

SILAVWT: The type of topographical smoothing, which can vary between 0 and 1. A value of 0 indicates conventional smoothing while a value of 1 indicates all silhouette averaging. A value between 0 and 1 indicates a weighted average between silhouette and conventional averaging. Conventional smoothing is preferred.

TOPTWVL: The cutoff wavelength for topographical filtering. Topographical smoothing is performed in mesoscale models to avoid strong gradients that may not be properly resolved by the model. TOPTWVL represents the wavelength in grid cell units of the smallest horizontal mode of terrain height data to appear on the final RAMS grid. Typically, TOPTWVL is set to 4 in complex terrain. A value of 2 or less turns off any smoothing.

LANDUSE: Variable vegetation parameterization flag.

1 = Use 30 second resolution U.S. vegetation.
2 = Use 1° resolution global dataset.
3 = Constant, which is set with the **rams.bak** namelist variable NVGCON (see section 5.3.1.2).

At ARL, using coarse-resolution (option 2) landuse or soil-type data on fine RAMS grids has led to unrealistic thermal gradients, and therefore using these datasets is not recommended.

SSTFLG: Sea surface temperature data type.

1 = 1° global monthly climatological SST.
2 = 1° global weekly-updated SST from NOAA/National Environmental Satellite Data Information Service (NESDIS).
3 = use a constant SST over water set with the **rams.bak** namelist variable SEATMP (See section 5.3.1.2).

5.3.1.1.5 Variables for the vertical grid structure section (grid independent)

NZ: Number of vertical levels.

DELTAZ: First model layer depth (typically, 25-100 m).

DZRAT: Z stretching ratio (1-1.2).

DZMAX: Maximum layer depth (1000-1500 m).

A few precautions should be taken when configuring the vertical grid structure, especially over complex terrain. The general rule of thumb for setting up your grid with complex topography is

$$\Delta TOPO <= 5*\Delta Z$$

That is, the change in topography from one grid point to the next should be less than 5 times the first model layer depth. The following three parameters can be adjusted to satisfy this condition:

1. Increase DELTAZ.

2. Decrease DELTAX.

3. Increase TOPTWVL, the topography smoother wavelength coefficient.

Also, increasing the model top height to greater than 18 km helps to reduce model-generated noise over complex terrain. An absorbing layer at the model top is useful to dampen upward-propagating waves that may be reflected (The TNUDTOP and ZNUDTOP in the **rams.bak** file).

In RAMS 3a, an option exists to nest in the vertical. This is not normally used; therefore it is not an option in **arl2mdl#.dat**. To use this option, modify NESTZ in **rams.bak**

5.3.1.2 **rams.bak** file configuration parameters

The **rams.bak** file is a version of the **rams.job** batch file, which will be submitted to run RAMS. This file contains FORTRAN name-lists that specify physical and numerical options used by the run. This file is edited if the user wishes to change more advanced parameters. The more frequently used parameters are set in the **arl2mdl#.dat** file. See Walko et al. (1993) for a complete description of the **rams.job** file.

The **oprun** subdirectory was shown in Figure 4. This subdirectory is used if automatic repeated submissions in real time are desired. For this scenario, the input configuration files should be in the **oprun** subdirectory and the **rams.bak** files should be renamed to **rams.00** and **rams.12,** which are used after the 00:00 UTC and 12:00 UTC NCEP model files have been downloaded to ARL.

The user need not modify the **rams.bak** file if the default physical and numerical settings are to be used. Some of the most frequently changed parameters in this file are the following:

AFILOUT:	The name of the output RAMS binary analysis file.
ISWRTYP,ILWTYP:	Flag to specify radiation parameterization types The default is 1 for the Mahrer and Pielke, 1977 clear-sky parameterization.

ARL special features were added to some parameters in **rams.bak**. A description of these changes follows:

IOUTPUT:	The output type flag. 1 = Write all output files in RAMS packed format. 2 = ARL packed format. 3 = Create two output files, one in each format.
NVGCON:	NVGCON is the numerical value for vegetation type(1-18) if a constant is to be specified. If NVGCON is negative, then the coastlines are initialized with the 30 second high-resolution land use files. However, land use is constant and is specified as the absolute value of NVGCON.
SEATMP:	If the constant value for sea surface temperature, SEATMP, is less than zero then the absolute value (K) will be used to initialize all inland water grid points(land use type 14). The ocean SST values are still initialized with the variable SST data.
CSZ:	CSZ is the coefficient for the amount of vertical PBL mixing. If CSZ is negative and less than -1, then the turbulent kinetic energy tendency term will be multiplied by the absolute value of CSZ to increase vertical mixing.

5.3.2 Details of the ARL-RAMS Preprocessing System for Advanced Users

Sections 5.3.2.1-5.3.2.3 give an overview of the details of the ARL-RAMS system; they are added for advanced users who wish to make more basic changes. These sections can be skipped if the user is interested only in running RAMS without making any changes to the preprocessor.

5.3.2.1 Creating the initial meteorological datasets: (**arl2mdl** directory)

Files and programs used to create the RAMS meteorological initialization files and lateral boundary condition files are found in the **arl2mdl** directory. A description of these files follows.

The **arl2mdl** program reads in ARL packed ETA, NGM, or MRF model fields on either sigma or pressure surfaces and interpolates the momentum and thermodynamic variables to the RAMS coarsest oblique stereographic grid domain on Z surfaces. Global SST data (see Table 2) are also interpolated to the RAMS coarse-grid domain. The program reads in topographical data exactly as used by RAMS and meshes this terrain between nested grids to ensure interpolation is done properly.

The following files are input into **arl2mdl**:

- NCEP meteorological model datasets: The real-time NCEP files are located on the ARL workstation and are used to initialize the RAMS atmospheric variables. To access archived NCEP files, the user would specify the filenames in **arl2mdl1.dat** (see section 5.3.1.1).

- SST data: **arl2mdl.exe** also interpolates SST data to the RAMS grid. If an archived SST data file, **SST.ASC,** is found in the **cfgfile** subdirectory, then **arl2mdl** will ingest this dataset. The archived data is the same weekly averaged 1° dataset used for real-time operational runs. These datasets are archived at ARL and NOAA/NESDIS.

The following files are output by **arl2mdl**:

- **MDLDATA.BIN**: Interpolated RAMS model initial fields (u,v,θ,q,π, and SST)in ARL packed format. For a description of this format see the appendix.

- **SEATEMPS**: The SST data on the RAMS coarsest grid.

After the RAMS model data are created, the **mdlpack** program is run to convert the interpolated meteorological data fields from ARL packed format to RAMS packed format. **MDLDATA.BIN**, the RAMS initial fields in ARL packed format, is input. The following files are output by **mdlpack**:

- **mdldata0,1,2...N**: RAMS model data initialization and LBC files in RAMS packed format. The last digit indicates the LBC file number(e.g. 1 for the first LBC file, 2 for the second; 0 indicates the initialization file).

In addition, a utility program, **mdlprint.exe**, is available to print the RAMS meteorological initialization fields that were written in the **MDLDATA.BIN** file. This program is useful for debugging the initialization process.

5.3.2.2 Configuring the input namelist data (**setbase** directory)

The **setjob** program located in the **setbase** directory sets namelist parameters in the **rams.bak** file by reading options set in **arl2mdl#.dat**. This program creates the **rams.job** file, which sets up and submits the RAMS executable.

5.3.2.3 Creating the input land surface data

The sfc2mdl program located in the **sfcbndy** directory creates land use, soil type, soil wetness and roughness files on the RAMS coarse and fine grids.

The following files are input to **sfc2mdl**:

- Soil moisture files: If the archived Soil Moisture Index (SMI) data file is found on the **cfgfile** directory, the program will use this data from that file as input instead of the operational real-time data. The format of the file name should be: SMI[SMI type]1.[SMI hour] (e.g. SMIO1.12, for observed SMI data valid at 12:00 UTC). These SMI files are created and archived at ARL.
- Land-use files: There are several subdirectories in the **sfcbndy** directory that contain the surface raw data files on a latitude-longitude grid (e.g., topography, land use, soil type, percent land cover, roughness length). These files are either read in directly by RAMS or interpolated by **sfc2mdl** to be input to RAMS. These data files are summarized in Table 2.

The following surface files on each RAMS grid are output by **sfc2mdl**:

- **LANDUSES{n}**
- **SOILWETN{n}**
- **SOILTYPE{n}**
- **ROUGHLEN{n}**

Here **n** indicates the grid number. The utility program, **sfcprint.exe**, will print data in these surface files to the screen.

5.4 RAMS Execution (**work** Directory)

All created initialization files are copied to this directory by the RAMS script and RAMS is run in the **work** directory. The following scripts or executables are located in this directory.

FILE NAME	DESCRIPTION
rams.exe	RAMS model executable file. This represents the results of compiling all the RAMS modules and subroutines and any user-customized code.
rams.a	RAMS model archive file containing all library and object code.
rams.job	RAMS-run script created by **setjob**. This important job file is submitted by the main **ramsops** script. This file submits the RAMS model to the batch processor and contains all the configuration namelists.
cpile.job	Script to recompile RAMS if desired.
mdldata1..n.g1	Initialization and lateral boundary condition files created by **arl2mdl** in RAMS packed format.
LANDUSES1..n,SOILTYPE1..n, **SOILWETN1..n,ROUGHLEN1..n,** **SEATEMP1**	Surface files created by **sfc2mdl** for the RAMS coarse grid and any nested grid.

5.5 RAMS Postprocessing (**graphic** Directory)

The ARL-packed output files for each nested grid will be found in the **archive** directory that is defined in the RAMS script. Once the RAMS simulation is complete, graphics are created using **arlplot** software available in the READY system. **arlplot** is a FORTRAN program that creates *x*-y contour maps using NCAR Graphics routines. The ARL-RAMS packed files are described in the Appendix. When RAMS is output in ARL packed format, all the READY display software under the **mdlplot** submenu can be used (e.g., soundings, meteograms). See Rolph et al. (1995) for a complete description of these programs.

Another package, **VAN**, written by Aster, Inc. is available for quick-look contoured graphics. However, this program reads output data in RAMS packed format. For detailed analysis, the GEMPAK analysis package (Bruehl, 1994) is available for gridded data manipulation and visualization. More information on GEMPAK is given in the advanced applications section 5 6.3.

The following READY programs are available for displaying

RAMS products in ARL format:

5.5.1 arlplot

arlplot produces x-y maps of coarse- and fine-grid model outputs. Figure 6a is an example of RAMS-predicted winds and temperatures on the 15-km domain. Figure 6b is an example of a HY-SPLIT dispersion model (Draxler, 1992) forecast from Washington, D.C., using the RAMS predictions.

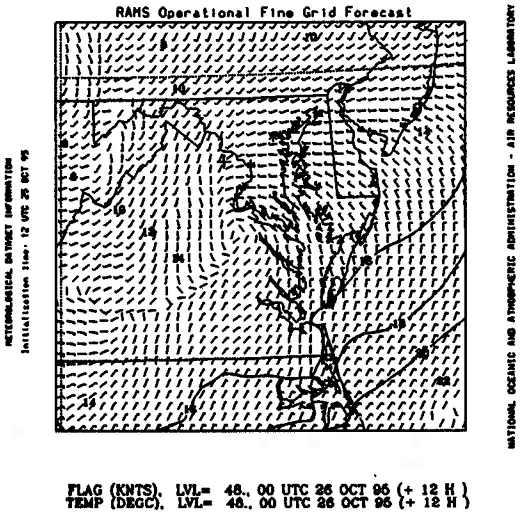

Figure 6a. An example of the RAMS fine-grid (ΔX=15km) 24-h operational winds (barbs) and temperature (°C) forecasts at 48 m AGL.

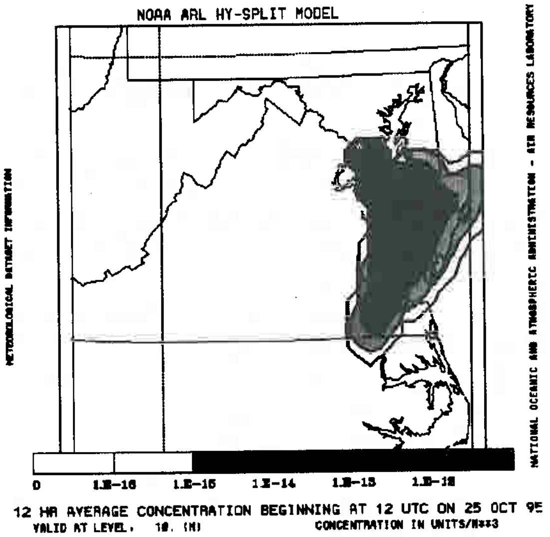

Figure 6b. HY-SPLIT transport and dispersion model forecast using the RAMS fine-grid forecasts.

The **RAMS** operational coarse-grid forecasts using the READY four-panel plotting option are shown in Figure 7.

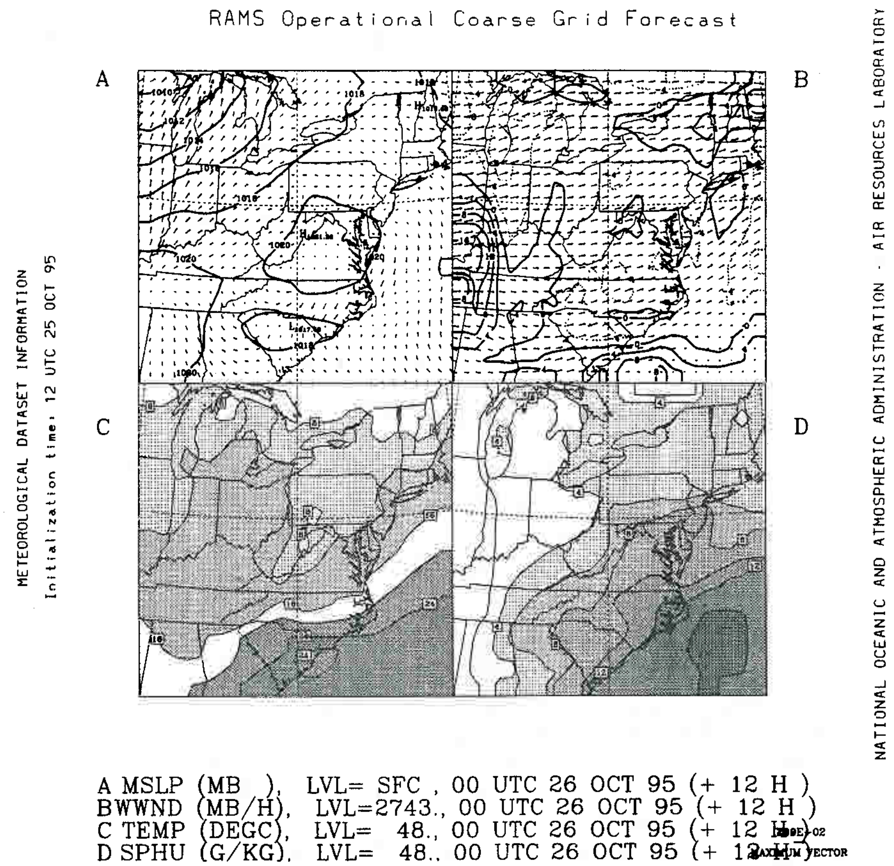

Figure 7. The **RAMS** coarse grid (ΔX=60 km) 12-h forecast using the READY four-panel plot option.

To run **arlplot**, type:

arlplot.scr (0/1)

where 0 indicates interactive and 1 indicates batch mode. In the batch mode the **ramsplot** script calls **arlplot.scr** and uses the **batch{n}.cfg** (where n indicates grid number) graphic configuration files when plotting output from the coarse and fine grid. Therefore these batch files should be customized to plot the desired variables before submitting the **ramsop** script. An example of the **batch.cfg** file is shown in Figure 8:

```
=============================================================================
 RAMS  3A  forecast DelX=15 km      # Title for all plots    (line 1)
/auto/rams/rams.a2.bin                     # Name of data set
4                                          # Number of fields to plot (columns)
00                                         # Month (0's beginning of data set)
00                                         # Day                (line 5)
12                                         # Hour
1                                   # Full grid = 1, Subset grid = 3
  25.00                                    # Lower left latitude
 -100.00                                   # Lower left longitude (West is neg)
  55.00                                    # Upper right latitude
  -70.00                            # Upper right longitude
  -80.00                            # Orientation long. (area of interest)
TEMP FLAG MSLP TPPT                 # Fields (Format : A4,1X)      (line 13)
 1    1    0    0                   # Vertical Level (0 for surface)
06   06   06   00                   # Frequency in hours           (line 15)
02   02   02   01                   # Total number of frequencies
 1    1    1    2                   # 1=contour, 2=fill, 3=shade
 1    0    0    0                   # Overlay option (0/1)
 0    0    0    0                   # 4 panel option (0/1)
=============================================================================
```

Figure 8. Example of the **batch.cfg** file.

A complete description of the **batch.cfg** file and arlplot are found in Rolph et al. (1995). However, a brief description of the **batch.cfg** file (Figure 8) for RAMS follows:

Line 1:	Title to be plotted as a header on each plot.
Line 2:	Complete path name of the ARL packed file.
Line 3:	The number of fields to plot. This parameter corresponds to the number of field columns input by the user starting on line 13.
Line 4-6:	The starting month, day, and hour in UTC to begin plotting. If month and day are set to 0, then the hour will represent the forecast hour of the ARL model file.
Line 7-12:	Latitude and longitude subgrid settings to be used if a subgrid is desired. For RAMS, the whole grid is normally plotted by setting the line 7 parameter to 1. The parameters on lines 8-12 are then ignored.
Line 13:	The model field identifier to plot for each graph. In the example in figure 8, four fields will be plotted (TEMP,FLAG, MSLP, and TPPT) as specified in line 3. The field identifiers for RAMS are described in the Appendix. The parameters on the following lines correspond to settings for each field indicated.
Line 14:	The vertical level number to plot for each field. 0 is specified for a surface field (eg: MSLP - mean sea level pressure). The vertical level number corresponds to the RAMS Z^* level.
Line 15-16:	The frequency in hours and the total number of frequencies for each field to plot beginning with the starting time set in lines 4-6. In the example in figure 8, the TEMP field will be plotted every 6 hours

for a total of two forecast times.

Line 17: The fill pattern option. Set this to 1 for contour lines, 2 for color fill and 3 for gray shade plots.

Line 18: The overlay option. Set this to 1 if the following field name (column) on line 13 is to be overlayed on top of the current field to plot. The example shows that the FLAG (wind barbs) variable will be overlayed on the TEMP variable since the overlay option is set to 1 in the TEMP column.

Line 19 : The 4-panel option. Set this parameter to 1 if the first four fields on line 13 are to be plotted on one page.

The **FLDFILE.CFG** file is also in the **graphic** directory and is used by READY to set the units for each field to be plotted. The format of each line is : [FIELD ID] [UNITS] [SCALE FACTOR].

The **SYMBPLT.DAT** file is also in the **graphic** directory. **arlplot** will read the latitude and longitude data in this file and draw a marker at that location on the map. More than one marker can be drawn.

5.5.2 **meteogram**

A meteogram for a selected point in the RAMS domain may be plotted with the READY meteogram program. An example of a forecast meteogram is shown in Figure 9. The batch version of this program, **autogram**, is run from the **ramsplot.scr** if a file named **STATION.LST** is located on the graphic directory. This file will contain the meteogram title and latitude and longitude of the location to plot.

5.5.3 Vertical profiles

A vertical profile for a selected point in the RAMS forecast domain may be plotted with the READY profile program. No batch version is currently available, but the interactive version is simple to run using READY.

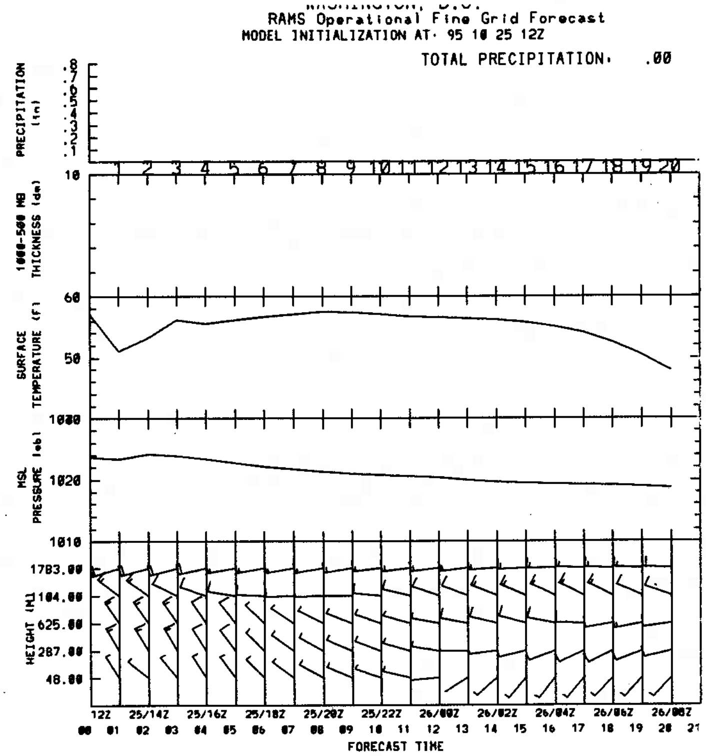

Figure 9. The RAMS fine grid meteogram forecast of precipitation (inches), 1000-500 mb thickness (dm), surface temperature (°F), mean sea level pressure (mb) and wind (barbs, knots) for the first five model levels for Washington, D.C. Fields are plotted every forecast hour to 20 hours.

5.6 Advanced Applications

5.6.1 Four Dimensional Data Assimilation (**4dda** directory)

A general description of the Four Dimensional Data Assimilation (FDDA) used by ARL-RAMS was given in section 2.2.3. The FDDA ingestion programs and scripts are located in the **4dda** directory. The script **mk4dda.scr** controls the creation of the ingestion data and is called by **ramsops.scr** if fdda=1. This script will invoke the FORTRAN program **mk4dda.f** which will create FDDA meteorological data files for ingestion. The following procedure should be followed to run with FDDA.

5.6.1.1 Creating the FDDA configuration file

The FDDA configuration file, **4dda.cfg**, should be created in the **cfgfile** directory. This file contains the nudging weights for FDDA and the Kriging covariance parameters needed for objective analysis of the observed data to the RAMS grids. An example of this file, set for a triple-grid simulation, is shown in Figure 10.

```
==================================================================
60                      # NSTEP:  Frequency (min) of FDDA data files

.001  .001  .002        # GWGT:  FDDA nudging weight for each grid

2     2     2           # NANZP:  number of vert. levels to be influenced

1     1     1           # NGRID:  flag controlling FDDA on each grid(0/1)

100.  50.   30.         # RMAXKRG: Kriging radius of influence (km)

60.   30.   3.8         # EDECAY:  Kriging E-folding decay radius (km)

1600. 800.  200.        # CAZKRG: Kriging vertical weighting (m)
==================================================================
```

Figure 10. Example of the **4dda.cfg** file, set for a triple-grid simulation.

This particular file is used to drive surface data assimilation on the operational archive run (60-km coarse grid, 15-km nested grid, and sometimes a third 3- to 5-km grid). Complete details on these parameters are given in Fast et al. (1995). Tips on setting these parameters are given below:

NSTEP: Frequency in minutes to assimilate the surface data files.

GWGT: Nudging weight to be used for each grid. Values larger than 0.002 are not recommended as determined by Fast et al. (1995).

NANZP: The number of vertical levels to be influenced by FDDA.

NGRID: Flag controlling FDDA on each RAMS grid (0/1). This option allows FDDA to be used only on selected grids. 0= do not use FDDA, 1=use FDDA.

RMAXKRG: Horizontal radius of influence for Kriging interpolation (km), which is proportional to the station and RAMS grid spacing. RMAXKRG should always be larger then EDECAY.

EDECAY: E-folding decay radius (km) for Kriging interpolation. This variable is proportional to the RAMS horizontal grid spacing and the station spacing.

CAZKRG: Covariance vertical weighting parameter (m). This parameter is proportional to the ratio of the RAMS horizontal to vertical grid spacings. A larger value will decrease the effect that observation data will have on nearby RAMS grid points.

The surface meteorological data files should also be available in a user-defined directory. The name of the files and directory location are defined in parameters set in **mk4dda.scr** (see next section).

5.6.1.2 Creating the assimilation datasets

mk4dda.scr will drive programs that read in surface observation files in READY ASCII format (the **OBS.CLN** files, See Rolph et al., 1995) and write out surface temperature, mixing ratios, and winds. The following parameters may have to be changed in the script:

SFCDIR: Directory where the surface data is located.

OPRUN: = 1: For RAMS operational run. Real-time surface data will be decoded and assimilated.
= 0: For a user research run. READY Ascii formatted and archived (.CLN) surface data located in the surface directory [SFCDIR] will be used.

PREFIX: File name prefix for the input surface data (surface data naming convention: PREFIX.HR,e.g., **sfc**.06)

The **mk4dda** script will create the following files that will be read in by RAMS for assimilation:

FDDA data files; These files (**4dda.0m, 4dda.60m,** etc.) are created in the **4dda_data** sub-directory in MKS units. Therefore, speed is in m/s. Temperature(K) and specific humidity (g/kg) are currently not assimilated.

4dda.loc: This file, created in the **work** directory contains the latitude and longitude locations and height AGL of the stations listed in the data files.

An optional file, **special.dat**, will be used if found in the work directory. This file can contain any type of special data (e.g., tower, ship data), which can also be assimilated. The height of the tower must be included. The format of this file is:

Station ID	*Height*	*T*	*q*	*u*	*v*
SSQ	10	302	16	3	-3

where measurement data for the station SSQ, the Susquehanna nuclear power plant, will be assimilated. The measurement was taken at 10 m AGL with temperature in K, specific humidity in g/kg and *u*- and *v*- wind components in m/s.

5.6.2 HY-SPLIT Interface

The Hybrid Single-Particle Lagrangian Integrated Trajectory (HY-SPLIT) model is a pollutant transport and dispersion model used at ARL (Draxler, 1992). HY-SPLIT predictions are driven by NCEP or RAMS meteorological model fields. ARL has written code to output RAMS in ARL packed format (subroutine **arlwrt** in the **ruser3a.f** module). This format can be read in HY-SPLIT. See the HY-SPLIT user's guide (Draxler, 1992) for more information on running HY-SPLIT. HY-SPLIT version 4 is currently used at ARL which allows transport calculations using multiple meteorological grids as input. This is advantageous when inputting several RAMS nested grids into HY-SPLIT.

5.6.3 GEMPAK Interface

GEMPAK (The GEneral Meteorological PAcKage) is a meteorological display and data analysis package originally developed jointly by NASA/Severe Storms Laboratory and NOAA/NCEP AWIPS Transition Division. See Bruehl (1994) for more information on running GEMPAK. GEMPAK has been used at ARL for advanced analysis and visualization of gridded fields (e.g., cross-sections, overlays, profiles, streamlines, time series) and to derive meteorological parameters (e.g., divergence, stability functions, frontogenesis).

RAMS fields can be converted to GEMPAK format by using the ARL GEMPAK interface, **mdl2gem** package. The script **mdltogem.scr** drives the software. The script will ask the user a series of questions and then create a GEMPAK header file using the GEMPAK utility, **GDCFIL**. This program will create a GEMPAK grid file with header information describing the RAMS grid.

The created GEMPAK file, named **model.gem**, can be then used as input to all the GEMPAK gridded analysis programs (e.g., **gdcntr, gdplot, gdstream, gdcross, gdtser, gdinfo,** etc.).

6. SUBMITTING THE RAMS RUN

To submit a RAMS simulation, type the following commands in the **scripts** directory:

```
nohup ramsrun.scr [run name] [narc]
```

where

- **run name** is the name of the run. This is also the name of the subdirectory of the **cfgfile** directory, which contains the configuration files. If run name = 00 or 12, then the configuration files are assumed to be located in the **oprun** subdirectory for repeated submissions at 00 and 12 UTC (see Figure 4).

- **narc (archive type)** determines whether the simulation will be an archive or forecast run. This parameter is set only for real-time simulations. The following options are available :

  1 = Archive mode where **arl2mdl** uses a separate meteorological archive file for initialization and for the boundary condition file.

  0 = Forecast mode; the INTRVL parameter will be used (**arl2mdl#.dat**; see section 5.3.1.1) to advance the start time for boundary condition files.

7. RAMS UTILITIES

hynest is a PC program which helps the user determine the latitudes, longitudes, and starting points of each RAMS grid using a mapping graphical user interface. To run this program

1. Edit **hynest.cfg** to set center latitude,longitude for the coarse grid and number of grids.

2. Run **hynest**.

The following output will be printed, which can then be input into **arl2mdl#.dat** for RAMS initialization:

- The center latitude and longitude for each chosen RAMS grid.
- NX and NY for each grid.
- The southwest corner point of each nest.

A UNIX program, **setrams**, also exists to create plots of the RAMS domains with topography plotted. This program is interactive and will ask the user for the location of all the grids to plot. This program can also be called through the READY system.

8. THE TWO-DIMENSIONAL VERSION OF ARL-RAMS

The two-dimensional (2-D) RAMS system will run the model on an x-z cross-sectional grid. This method can be used to run sensitivity experiments or when gradients in the y direction are constant over the simulation time. The 2-D RAMS was modified at ARL to run several simulations in one batch submission. The system can be initialized with either sounding data from the namelist or data from **arl2mdl**. The RAMS VAN package is normally run to create cross sections and a flux file at a specified grid point. The model can be run for several cases with the use of a special initialization dataset. The procedure to run the 2-D RAMS is summarized below.

8.1 Creating a 2-D Initialization Dataset

The 2-D RAMS can be run from a sounding file created from NCEP gridded fields. This sounding file, created by **arl2mdl,** is an ASCII dataset consisting of u,v,θ,q, and π at the chosen RAMS levels. **arl2mdl** will interpolate the NCEP data to the center latitude and longitude specified in the **arl2mdl1.dat** file. **arl2mdl** interpolates the NCEP fields to a 50x50 km grid. Then, the center point on this grid is written as the initial sounding data. Surface data can also be used for initialization if a file named **sfcwx.dat** is created in the **arl2mdl** directory. **arl2mdl** will also calculate the geostrophic winds for input into the RAMS momentum equations as an additional tendency term (e.g., fu_g and $-fv_g$).

To run **arl2mdl** for 2-D initialization, set NY=1 in the **arl2mdl1.dat** file in the cfgfile directory. Only one grid can be specified for 2-D simulations, with the center of the grid located at the center latitude and longitude set in the configuration file. Otherwise, the configuration parameters are set as described in section 5.3.1.

8.2 Running Multiple Simulations

Multiple 2-D simulations are controlled by running the **rams2d.scr** script after creating a **cases2d.dat** file in the **cfgfile** directory. The **cases** file contains a list of days to run with an on/off switch on whether to run that date. The RAMS 2-D script reads this file and copies the NCEP datasets for input by **arl2mdl** to create the RAMS profile file.

The format of the cases2d.dat file is :

YEAR MONTH DAY HOUR(UTC) RUN_FLAG(0/1) SST (K)

where this line is repeated for each case to run.

The RUN_FLAG controls whether to run the 2-D RAMS for that case. The SST parameter will set SST to a constant value for all water points in the 2-D domain. When **cases2d.dat** and **arl2mdl1.dat** are set, the model can be run by using the nohup batch UNIX command.

8.3 2-D Postprocessing

Output from each run is plotted using a postprocessing script, **ramspl2d.scr**, similar to the 3-D version. This script is called by **rams2d.scr** and it in turn calls the RAMS VAN plotting package. The VAN package is described in detail by Walko et al. (1993). The default **van.job** file located in the **van** subdirectory will plot a cross section of temperature and wind vectors with height.

The packed output files are stored on the **output** subdirectory in RAMS and ARL packed format. After plotting, the data are moved to an archive file and compressed (.Z) with the format **ramsYYMMDD.Z**. This is done for each case specified in **cases2d.dat**.

A **flux** file is also created with the **vanflux.job** script by specifying FLUX in the namelist. Changes were made to the RAMS VAN **rafld3a.f** subroutine to create this file. The flux data are currently written at the center of the 2-D model. The flux file format is as follows, and the data are valid at the first model level above the ground for each hour :

$$MN\ DY\ YR\ HOUR\quad T_{air}\ T_{sfc}\ r_t\ u\ v\ w\quad \tau_u\ \tau_v\ H\ LE\ R_{SW}\ R_{LW}\quad TKE\ u_*$$

All variables have been previously defined except for τ, the surface stress.

Finally the flux data for all cases are averaged by hour and compared with any observed data in a file named **ramsvobs.avg**. The script **stats2d.scr** calls the **mrgdat** and **mkstats** programs in the **stats** directory to create the averaged flux file.

9. MODULE CHANGES FOR ARL-RAMS

The features described above for RAMS involved modifying and adding code to several RAMS subroutines. All changes have been documented in the code with comment lines beginning with *Cjtm*. These changes are available from ARL, and the important modifications are listed below for non-ARL users wishing to obtain the ARL changes.

In the **ruser3a.f** RAMS module, the following subroutines have been modified:

arlwrt:	Routine to output fields in ARL packed format.
force:	The FDDA routine.
srfinit:	The driving routine for ingesting surface data.
sstinit:	ARL SST data ingestor.
surfinit:	ARL roughness length data ingestor.
soilinit:	ARL soil type and wetness data ingestor.
vtypeinit:	ARL vegetation type data ingestor.
veginit:	ARL vegetation characteristics data ingestor.
ugeos:	Routine to compute the geostrophic wind tendencies for the 2-D RAMS.

In the **rhhi3a.f** module, various routines were modified to ingest the 2-D sounding data for horizontally homogeneous initialization.

In the **rvari3a.f** RAMS module:

varmisc: Calls the ingestor modules and removes the restriction that soil moisture be equal to 0.4

In the **rnest3a.f** RAMS module:

geonest: Calls the surface data ingestor modules.
prgintrp: Soil type ingestor.

In the **rsurf3a.f** module, various routines were modified to improve the surface layer parameterizations and to compute deposition velocity and various roughness formulations.

In the **rafld3a.f** VAN module and **rvtab3a.f** module, various subroutines were modified to output flux fields for the 2-D model.

10. ARL-RAMS PUBLIC-ACCESS DATASETS

The RAMS real-time forecasts are available on the World Wibe Web and are updated daily. If you have a World Wide Web browser, the ARL web address is:

http://www.arl.noaa.gov/

RAMS predictions can be viewed and analyzed through the web version of the READY system found at the above web address. The daily RAMS forecast dataset in ARL packed format, the current soil moisture and sea surface temperature data are located on the ARL anonymous ftp. For more information, contact ARL.

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12. REFERENCES

Bruehl, M., 1994: Support of GEMPAK as an education and research tool. 10th Int. Conf. on Interactive Information and Processing Systems for Meteorology, Hydrology, and Oceanography, Jan. 23-28, 1994, Nashville, TN, American Meterological Society, Boston, MA, 297-302.

Chang, J.T., and P.J. Wetzel, 1991: Effects of spatial variations of soil moisture and vegetation on the evolution of a pre-storm environment: A numerical case study. Mon. Wea. Rev. 119:1368-1390.

Charnock, H., 1955: Wind stress on a water surface. Q. J. R. Meteor. Soc. 81:639-640.

Chen, C., and W.R. Cotton, 1983: A one-dimensional simulation of the stratocumulus-capped mixed layer. Boundary-Layer Meteor. 25:289-321.

Clark, T.L., and R.D. Farley, 1984: Severe downslope windstorm calculations in two and three spatial dimensions using anelastic interactive grid nesting: A possible mechanism for gustiness. J. Atmos. Sci. 41:329-350.

Cotton, W.R., M.A. Stephens, T. Nehrkorn, and G.J. Tripoli, 1982: The Colorado State University three-dimensional cloud/mesoscale model-1982. Part II, An ice phase parameterization. J. Rech. Atmos.16:295-320.

Cotton, W.R., G.J. Tripoli, R.M. Rauber, and E.A. Mulvihill, 1986: Numerical simulation of the effects of varying ice crystal nucleation rates and aggregation processes on orographic snowfall. J. Clim. Appl. Meteorol. 25:1658-1680.

Davies, H.C., 1983: Limitations of some common lateral boundary schemes used in regional NWP models. Mon. Wea. Rev., 111:1002-1012.

Draxler, R.R., 1992: Hybrid single-particle Lagrangian integrated trajectories (HY-SPLIT): Version 3.0 -- user's guide and model description. NOAA Technical Memo ERL ARL-195, National Technical Information Service, Springfield VA, 26 pp. + Appendices.

Draxler, R.R., G.D. Rolph, J.T. McQueen, J.L. Heffter, and B.J.B. Stunder, 1993: Capabilities of the NOAA Washington Regional Specialized Meteorological Center for atmospheric transport model products for environmental emergency response. Int. Workshop on Users' Requirements for the Provision of Atmospheric Transport Model Products for Environmental Emergency Response, Dorval, Quebec, Canadian Meteorological Service, Canada.17 pp.

Fast, J.D., B.L. O'Steen, and R.P. Addis, 1995: Advanced atmospheric modeling for emergency response. J. Appl. Meteor. 34:626-649.

Kanamitsu, M., 1989: Description of the NMC global data assimilation and forecast system. Weat. Forecasting 4:335-342.

Louis, J.F., 1979: A parametric model of vertical eddy fluxes in the atmosphere. Bound.-Layer Meteor. 17:187-202.

Lyons, W.A., C.S. Keen, R.A. Pielke, W.R. Cotton, D.A. Moon, and N.R. Lincoln, 1991: A prototype real-time forecasting system for mesoscale dispersion in land/lake breezes. Proc., Third Topical Meeting on Emergency Preparedness and Response, Chicago, IL, American Nuclear Society, La Grange Park, IL, 99-102.

Mahrer, Y., and R.A. Pielke, 1977: A numerical study of the airflow over irregular terrain. Beitr. z. Phys. Atmos. 50:98-113.

McCumber, M.C., and R. A. Pielke, 1981: Simulation of the effects of surface fluxes of heat and moisture in a mesoscale numerical model. Part I Soil layer. J. Geophys. Res. 86:9929-9938.

McQueen, J.T., R.R. Draxler, and G.D. Rolph, 1994: Examining the possibility of real-time mesoscale model forecasts in regions of moderately complex terrain. Preprints, 10th Conf. on Numerical Weather prediction, July 18-22, 1994, Portland, OR, American Meteorological Society, Boston, MA, 412-414.

McQueen, J.T., R.R. Draxler, and G.D. Rolph, 1995: Influence of grid size and terrain resolution on wind field predictions from an operational mesoscale model. J. Appl.Meteor. 34:2166-2181.

Mellor, G.L. and T. Yamada, 1982: Development of a turbulence closure model for geophysical fluid problems. Rev. Geophys. Space Phys. 20:851-875.

Miller, M.J., A.C.M. Beljaars, and T.N. Palmer, 1992: The sensitivity of the ECMWF model to the parameterization of evaporation from the tropical ocean. J. Climate 5:418-434.

Petersen, R.A., and J.D. Stackpole, 1989: Overview of the NMC production suite. Wea. Forecasting 4:313-322.

Pielke, R.A., W.R. Cotton, R.L. Walko, C.J. Tremback, W.A. Lyons, L.D. Grasso, M.E. Nicholls, M.D. Moran, D.A. Wesley, T.J. Lee, and J.H. Copeland, 1992: A comprehensive meteorological modeling system--RAMS. Meteor. Atmos. Phys. 49:69-91.

Rolph, G.D., J.T. McQueen, and R.R. Draxler, 1993: Real-time

Environmental Applications and Display System. Proc., Topical Meeting on Environmental Transport and Dosimetry, Sept. 1-3, 1993, Charleston, SC. American Nuclear Society, La Grange Park, IL, 113-116.

Rolph, G.D., R.R. Draxler, and J.T. McQueen, 1995: Real-time Environmental Applications and Display System (READY) user's guide. NOAA Tech. Memorandum ERL ARL-210, Air Resources Laboratory, Silver Spring, MD, 83 pp.

Stauffer, D.R., and N.L. Seaman, 1990: Use of four-dimensional data assimilation in a limited-area mesoscale model: Part 1, Experiments with synoptic-scale data. Mon. Wea. Rev. 118:1250-1277.

Stephens, G.L., 1978a: Radiation profiles in extended water clouds: I, Webster theory. J. Atmos. Sci. 35:2111-2122.

Stephens, G.L., 1978b: Radiation profiles in extended water clouds. II, Parameterization schemes. J. Atmos. Sci. 35:2123-2132.

Tremback, C.J., and R. Kessler, 1985: A surface temperature and moisture parameterization for use in mesoscale numerical models. In Preprints, 7th AMS Conference on Numerical Weather Prediction, June 17-20,1985. Montreal, Canada. American Meteorological Society, Boston, MA, 355-358.

Tremback, C.J., J. Powell, W.R. Cotton, and R.A. Pielke, 1987: The forward in time upstream advection scheme: Extension to higher orders. Mon. Wea. Rev. 115:540-555.

Tripoli, G.J., and W.R. Cotton, 1980: A numerical investigation of several factors contributing to the observed variable intensity of deep convection over south Florida. J. Appl. Meteor. 19:1037-1063.

Tripoli, G.J., and W.R. Cotton, 1982: The Colorado State University three-dimensional cloud/mesoscale model--1982: Part I, General theoretical framework and sensitivity experiments. J. Rech. Atmos. 16:185-220.

Walko, R.L., C.J. Tremback, and R.F.A. Hertenstein, 1993: RAMS, the Regional Atmospheric Modeling System version 3a User's Guide. ASTeR, Inc., P.O. Box 466, Ft. Collins, CO, 100 pp.

APPENDIX: ARL-RAMS ARCHIVED MESOSCALE MODEL OUTPUT FORMAT

A.1 OVERVIEW

For more information on ARL packed format, see Draxler (1992). The RAMS archived data are formatted as follows:

COMPUTER	IBM 6000 RISC WORKSTATION
FORMAT TYPE	DIRECT ACCESS,BINARY
RECORD LENGTH	NX*NY+50
BLOCK SIZE	NX*NY+50

A.2 FILE ORGANIZATION

Prior to 1995, a RAMS header file, named **rams.a1(2).hdr,** was created for each run. Currently, header information is included at each forecast time as an index record in the binary file. The index record contains information on the model grid definition and data available.

A.2.1. Archive Files

Fields are listed in order as found on the archive files. The following fields are written every time period (usually hourly):

FIELD	**ID**	**UNITS**	**LEVEL**
Index record field	INDX	N/A	N/A
Topography	SHGT	m	sfc
Total accumulated precip	TPPA	m	sfc
Mean sea level pressure	MSLP	mb	sfc
Surface pressure	PRSS	mb	sfc
PBL depth	MXLR *	m	sfc
Surface temperature	TMPS	K	sfc
Friction velocity	USTR	m/s	sfc
Friction theta	TSTR	K	sfc
qstar	QSTR	kg/kg	sfc

There are seven three-dimensional fields for each Z* layer (e.g., U(1),V(1),...,U(n),V(n),...).

FIELD	**ID**	**UNITS**	**LEVEL**
U wind component	UWND	m/s	Z*
V wind component	VWND	m/s	Z*
Vertical velocity(Ω)	WWND	mb/s	Z*
Water vapor mixing ratio	SPHU	kg/kg	Z*
Temperature	TEMP	K	Z*
Pressure	PRES	mb	Z*
Turbulent kinetic energy	TKEN	kg-m^2/s^2	Z*

In addition, descriptive information is written at the beginning of each record giving the following information:

A.2.2. Header Data Format for Each Record

The first 50 characters of each record contain header information regarding the data to follow on that record. The following identifies the header information and its FORTRAN format below each parameter

YEAR	MONTH	DAY	HOUR (UTC)	MODEL HOUR # (0,1,2,.)	FORECAST ID	LEVEL	GRID	FIELD NAME
I2	I2	I2	I2	I2	I2	I2	I2	A4

SCALING EXPONENT	UNPACKED DATA PRECISION	FIRST DATA	UNPACKED VALUE	PACKED VALUE
I4	E14.7	E14.7	NX*NY	binary

A.2.3. Archive Run Output Levels

Every RAMS vertical level is archived up to level 20 :

Archive Level	Z* (m AGL)
1	50
2	155
3	285
4	440
5	625
6	845
7	1105
8	1415
9	1780
10	2220
11	2745
12	3365
13	4105
14	4985
15	6030
16	7280
17	8725
18	10235
19	11735