



Documentation on Regional Integrated Environmental Model System (RIEMS)

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1, Introduction

Global change is significantly affecting human society. To reach the goal of accurately projecting the regional climate change so that potential impacts can be adequately assessed, the researches on regional estimate, analysis and impact assessment of global change have become a great challenge in coming decades. The current assessments under global warming scenarios have shown that there may be significant changes in Asia in terms of climate, water resources, agriculture and so on by about middle of next century. Such research results should form an integral component in policy making by the governments of the region. However the current impact assessments are mainly based on scenarios simulated by global climate models (GCMs) and confidence is low in their ability to project regional climate.

One of the most promising approaches to improve the simulation of regional climate is the development of regional climate models (RCMs) which can better capture both the regional forcing and the large scale forcing through nesting with the GCMs.

The climate in Asia is characterized by a typical monsoon climate. Research has shown that climate and ecosystem are coupled with each other strongly in Asia in two way interactions. On one hand, the high rate monsoon climate changes serve as the strong driving force for the variation of the ecosystems. On the other hand, changes in the terrestrial ecosystem should have significant feedback on the monsoon climate. Therefore there is a need to introduce the biological component to couple with the physical monsoon climate. Further, since Asia is the habitat for nearly 57.2% of the world population and is undergoing rapid economic growth and continuing population increase, the anthropogenic modification of the monsoon system by industrial emission, land use/cover change and urbanization are very likely. Therefore, there is a need to introduce the human component to couple with the natural monsoon system. When the above anthropogenic forcing is taken into account, the chemical processes also involve the monsoon system. Hence there is also a need to introduce the chemical component to couple with the physical monsoon climate. It is anticipated that from the point view of earth system science, a more complete monsoon system should thus be a physical/biological/ chemical/ social coupled system. This is what can be called “ the General Monsoon System”.

Since current regional climate model are not able to describe these major processes of the Asian monsoon system, the development of an Regional Integrated Environmental System Model was began to undertake in early 1991 in a Chinese

national project at the title of “ Predictive Understanding of Living Environmental Change in China in next 20-50 years”. Later on, a proposal on Regional Modeling of the Changes of the “ General Monsoon System” of Asia Under Anthropogenic Forcing was first approved by the START Regional Committee for Temperate East Asia (TEACOM) and it was then submitted to START and APN for funding support. This project is now being implemented under the multiple funding sources from several national projects of the TEACOM region as well as the support from START and APN. One of the major components of this project is to develop a coupled climate/biosphere/ hydrology/chemical/aerosol model which can describe the General Monsoon System of Asia.

This document presents the first version of Regional Integrated Environmental Model for Asia (RIEM tea) developed by a research team in START Regional Center for Temperate East Asia in Beijing, China. The document consists of 3 sections: The model dynamic structure and physical parameterization will be introduced in Part 2 and Part 3 respectively. The appendix is a simple user’s guide to on-line RIEMS (Regional Integrated Environmental Modeling System) which can be reached through world wide web.

This is a draft simplified version of model document for temporal use only in this course.

2, Dynamic Structure

In this part we will mainly introduce the basic aspects of the dynamical structure of the model. It will focus on the following two parts:

- 1) Governing equations and numerical algorithms
- 2) The mesh refinement scheme

All materials are based on the technical report of the fifth-generation Penn State/NCAR Mesoscale Model (MM5). A few of the extensive changes and increases in options will also be presented here.

2.1 Governing equations and numerical algorithms

MM5 has both hydrostatic and non-hydrostatic choices. Its vertical coordinate is defined as terrain following.

$$\sigma = \frac{p - p_t}{p_s - p_t}$$

The hydrostatic model equations consist of horizontal momentum, temperature, surface pressure tendency, and hydrostatic equations.

$$\frac{\partial p^* u}{\partial t} = -m2 \left[\frac{\partial p^* uu / m}{\partial x} + \frac{\partial p^* vu / m}{\partial y} \right] - \frac{\partial p^* u}{\partial \sigma} - mp^* \left[\frac{\sigma}{p} \frac{\partial p^*}{\partial x} + \frac{\partial \phi}{\partial x} \right] + p^* fv + Du$$

$$\frac{\partial p^* v}{\partial t} = -m2 \left[\frac{\partial p^* vu / m}{\partial x} + \frac{\partial p^* vv / m}{\partial y} \right] - \frac{\partial p^* v}{\partial \sigma} - mp^* \left[\frac{\sigma}{p} \frac{\partial p^*}{\partial y} + \frac{\partial \phi}{\partial y} \right] - p^* fu + Dv$$

$$\frac{\partial p^* T}{\partial t} = -m2 \left[\frac{\partial p^* uT / m}{\partial x} + \frac{\partial p^* vT / m}{\partial y} \right] - \frac{\partial p^* T}{\partial \sigma} \dot{\sigma} + p^* \frac{w}{\rho C_p} + p^* \frac{\dot{Q}}{C_p} + D_T$$

The vertical velocity is:

$$\frac{\partial p^*}{\partial t} = -m \left[\frac{\partial p^* u / m}{\partial x} + \frac{\partial p^* v / m}{\partial y} \right] - \frac{\partial p^* \dot{\sigma}}{\partial \sigma}$$

$$\dot{\sigma} = -\frac{1}{p^*} \int_0^\sigma \left[\frac{\partial p^*}{\partial t} + m^2 \left(\frac{\partial p^* u / m}{\partial x} + \frac{\partial p^* v / m}{\partial y} \right) \right] d\sigma$$

$$\frac{\partial \phi}{\partial \ln(\sigma + pt / p^*)} = -RT_v \left[1 + \frac{q_c + q_r}{1 + q_v} \right]^{-1}$$

The hydrostatic equation is used to compute the geopotential heights:

For the nonhydrostatic model a constant reference state and perturbations are defined as follows:

$$P(x, y, z, t) = p_0(z) + p'(x, y, z, t)$$

$$T(x, y, z, t) = T_0(z) + T'(x, y, z, t)$$

$$\rho(x,y,z,t) = \rho_0(z) + \rho'(x,y,z,t)$$

The model equations are then given by following:

$$\frac{\partial p^* u}{\partial t} = -m2 \left[\frac{\partial p^* uu/m}{\partial x} + \frac{\partial p^* vu/m}{\partial y} \right] - \frac{\partial p^* u}{\partial \sigma} + uDIV - \frac{mp^*}{\rho} \left[\frac{\partial p'}{\partial x} - \frac{\sigma}{p^*} \frac{\partial p'}{\partial x} \frac{\partial p'}{\partial \sigma} \right] + p^* fv + Du$$

$$\frac{\partial p^* v}{\partial t} = -m2 \left[\frac{\partial p^* uv/m}{\partial x} + \frac{\partial p^* vv/m}{\partial y} \right] - \frac{\partial p^* v}{\partial \sigma} + vDIV - \frac{mp^*}{\rho} \left[\frac{\partial p'}{\partial y} - \frac{\sigma}{p^*} \frac{\partial p'}{\partial y} \frac{\partial p'}{\partial \sigma} \right] - p^* fu + Dv$$

$$\frac{\partial p^* T}{\partial t} = -m2 \left[\frac{\partial p^* uT/m}{\partial x} + \frac{\partial p^* vT/m}{\partial y} \right] - \frac{\partial p^* T}{\partial \sigma} + TDIV +$$

$$\frac{1}{\rho C_p} \left[p^* \frac{Dp'}{Dt} - \rho_0 g p^* w - Dp' \right] + p^* \frac{\dot{Q}}{C_p} + D_T$$

$$\frac{\partial p^* w}{\partial t} = -m2 \left[\frac{\partial p^* uw/m}{\partial x} + \frac{\partial p^* vw/m}{\partial y} \right] - \frac{\partial p^* w}{\partial \sigma} + wDIV +$$

$$p^* g \frac{\rho_0}{\rho} \left[\frac{1}{p^*} \frac{\partial p'}{\partial \sigma} + \frac{Tv'}{T} - \frac{T_0 p'}{T p_0} \right] - p^* g [(qr + qc)] + Dw$$

$$DIV = -m2 \left[\frac{\partial p^* u/m}{\partial x} + \frac{\partial p^* v/m}{\partial y} \right] + \frac{\partial p^* \dot{\sigma}}{\partial \sigma}$$

The B-grid staggering of horizontal velocity variables is used for Non-hydrostatic finite difference algorithms. Vertical velocity is staggered vertically. The spatial differencing of the terms in the horizontal momentum prediction equations are performed in the staggered points.

The hydrostatic finite differencing of advection, coriolos and heating follows the same way as the non-hydrostatic equations except without the mass divergence term.

It is noted that potential height is required on the velocity levels, it has to be first integrated between surface and the lowest half level with just the lowest level values. At all other levels use vertical averaging between two levels.

The temporal differencing in the hydrostatic and non-hydrostatic models consists of leapfrog steps with an Asselin filter. With this filter splitting of the solution often associated with the leapfrog scheme is avoided.

In both hydrostatic and non-hydrostatic numeric scheme, a time splitting scheme is applied to increase efficiency. Because the nonhydrostatic equations are fully compressible, they permit sound waves. These are fast and require a short time step for numerical stability. For the hydrostatic equations fast moving external gravity waves are the limiting factor. The techniques to split these fast moving waves from the rest of the solution are used.

For the non-hydrostatic equations it is possible to separate terms involved with acoustic waves from comparatively slowly varying terms, and to handle the former with shorter time steps while updating the slow terms less frequently. The method of solution follows the semi-implicit scheme of Klemp and Wilhelmson for the short time step. Temperature and moisture are predicted using the normal leapfrog step, because they have no high-frequency terms contributing to acoustic waves. The slow terms for momentum and pressure are also evaluated on these leapfrog steps. When numerically solving the hydrostatic equations of motion, the stability criterion is severely limited by external gravity waves. These are very fast moving gravity waves that are small in amplitude and contain only a small fraction of the total energy. Because of this, splitting methods have been developed to split these fast waves from solution. The method developed by Madala was chosen in this model as a time splitting methods.

Two boundary conditions are set: sponge boundary conditions and nudging boundary conditions. For the moisture variables, cloud water, rain water, snow, and ice are considered zero on inflow and zero gradient on outflow. There is an option to specify the boundary values in the sane way as for the other variables. An option in the nonhydrostatic model is the upper radiative boundary condition. Klemp and Durran have developed an upper boundary condition that allows wave energy to

pass through unreflectedly. The upper boundary condition is combined with the implicit pressure/vertical momentum calculation.

2.2 The mesh refinement scheme

The 2-way interactive mesh refinement scheme is designed to allow for an arbitrary number of overlapping and translating rectangular grids with an arbitrary number of refinement levels. The grid is required to be aligned with the model coordinates, and the mesh refinement ratio of the temporal and spatial grid increments is common for all meshes. Interpolation is used on initialization of new nests as well as for defining the boundaries of the fine meshes. An accurate and efficient interpolation procedure is very important for mesh refinement scheme. Flux corrected transport (FCT) scheme is used in this model. It uses the high order accurate constant grid flux dissipative algorithms developed by Tremback. The interested reader is referred to Tremback, etc(1987).

The mesh refinement scheme allows for overlapping grids on the same nest level. To ensure the numerical stability the solution in the overlap region has to be identical. To accomplish this, after each time step of the grids in question, the boundary conditions in the overlap regions are provided by the overlapping mesh. It is very important that this procedure be performed at every time step. Nests can also be moved at any time in the forecast. This can be done many times and for any distance. The user may also move the nests automatically if he supplies an algorithm to do so. Upon a move a new nest initialization is performed first. Then all high-resolution information from the previous location of the mesh is used to overwrite the fields of a newly initialized mesh. Therefore, to ensure best use of the high resolution information, it is better to move a nest more often and for a smaller distance.

In order to keep the solution in 2-way interaction from diverging, the meteorological fields have to be fed back from the higher resolution mesh to its coarse grids. This is done at every large time step for the coarse grids. Naturally when this is done without smoothing or averaging, the solution of the coarse grids will show somewhat noisy. To avoid numerical instability, the following methods are supported to remove noise from the coarse grids. Note that these smoothers are only applied over an interior area that is completely determined by the higher resolution domain. It is important that input into the nest and feedback back to the coarse grids doesn't overlap. Thus the smoother defined by Shapiro was used in this model system.

3, Model Physics

The tendency physics include the parameterization of cloud amount, the evaluation of radiative fluxes and atmospheric heating rates; the evaluation of surface fluxes; update land surface properties; evaluation of free atmosphere vertical diffusivities, diagnosis of the PBL height, PBL diffusivities and non-local transport term followed by the vertical diffusion solution et al.. Following we mainly introduce the cloud, aerosol and radiation parameterizations and land surface process, respectively.

3.1 Land surface process

Biosphere and Atmosphere Transfer Scheme (BATS) developed by Dickinson et. Al is used as land surface scheme of this model.

3.1.1 Introduction

The biosphere atmosphere transfer scheme is used to describe the role of vegetation in modifying the surface moisture and energy budgets. The earth surface receives and emits various kind of energy. The most important of these from the point view of physical processes include the solar radiation absorbed after undergoing atmospheric absorption and reflection, the infrared radiation emitted from surface, the sensible heat fluxes and the latent heat fluxes.

The presence of vegetation has a strong control over both diurnal and mean fluxes of energy and water. Th physical characteristics of vegetation most important are its absorption of solar radiation and consequent shading of the ground, exchange of latent and sensible heat fluxes with atmosphere and the presence of canopy surface moisture.

The present document is intended to explain the physics of BATS.

3.1.2 Data and interface requirements for BATS coupled to RIEMS

To integrate BATS with the RIEMS, a number of data fields must be supplied and other fields must be exchanged between BATS and RCM at each model time step.

The data set of land points includes the elevation, sea ice, ocean surface temperature, vegetation cover, soil texture, soil color, soil moisture, snow cover and snow age. At present we have 18 vegetation and land cover types:

- 1 crop/mixed farming
- 2 short grass
- 3 evergreen needleleaf tree
- 4 deciduous needleleaf tree
- 5 deciduous broadleaf tree
- 6 evergreen broadleaf tree
- 7 tall grass
- 8 desert
- 9 tundra
- 10 irrigated crop
- 11 semi desert
- 12 ice cap/glacier
- 13 bog or marsh
- 14 inland water
- 15 ocean
- 16 evergreen shrub
- 17 deciduous shrub
- 18 mixed woodland

For soil map of the world is used as a data source to classify the soil color, texture and drainage. Soil property is associated with the texture. Its albedo in two wavelength regions is associated with the soil color.

3.1.3 Soil temperature

The basis of soil temperature model adopts the force restore method of Deardorff (1978). Soil thermal diffusivity and heat capacity depend on soil moisture and texture.

The surface soil temperature is calculated from the surface energy balance equation. In the presence of snow, snow melt is considered. For the soil moisture -- snow cover specification, the earth's surface is divided into two regions: the oceanic region and the continental region with and without snow cover. For the oceanic regions the surface temperature is prescribed from observational data in the standard model. For other region the computation depends on the current

conditions of snow cover, soil moisture, type of surface and the temperature of the first layer of the atmosphere.

Subsurface temperature is identified with the annual temperature wave in calculating from force-restore corresponding to temperature at a depth of roughly 1m.

3.1.4 Soil moisture and snow cover

Moisture incident on the ground either infiltrate the soil or is lost to surface runoff. For calculating soil water the soil is represented by several layers, all having a top surface at the soil air interface but with lower surface at increasing depth. We consider three parameters to represent the soil moisture:

Surface soil water representing the water in the upper layer

Water in the rooting zone depth of soil

Total water in the soil depth

In calculating soil water budgets, the upper soil water, the rooting zone soil water and the total soil water all gain the same amount of water rainfall and lose the same amount from evaporation and surface runoff, since these fluxes occur at the soil surface.

In principle, each grid square should have a distribution of soil type as established by its climate, vegetation and geology, etc. At present we assume that each grid square has only one soil type.

The evaporative term and the transfer between the upper soil layer and below are difficult to parameterize with sufficient generality. The current expressions are based on the behavior of a soil column that is initially at field capacity and dried by diurnally varying potential evaporation applied at the surface.

During period of heavy rainfall or snowmelt and high soil moisture, much of the water incident on the natural surface doesn't penetrate to the ground---water reservoirs but rather flows immediately into streams and rivers. Surface runoff is now described as occurring primarily over the fraction of a grid square where the soil has become saturated due to a high water table or to the impermeable surface soil. Due to the complex nature of surface runoff process, it is not possible to simulate surface runoff in detail. Thus the surface runoff is usually inferred as a

function of the rainfall history over a basin by analyzing the flood peaks in stream and river hydrographs.

There is no detailed model of snow energy balance and melt processes. In this model, only the snow-surface processes are explicitly modeled. The water on the snow surface is put directly into the soil, whereas real melt or rain water has to percolate through the snow pack and may refreeze. This may lead to some conceptual errors during time of snow melt or rainfall on the snowpack. The melting in the bottom of the snow pack due to heat conducted from the ground is also neglected unless the heat reaches the top of the snow surface.

3.1.5 Drag coefficient and flux over bare soil

Drag coefficients over land are variable. In this scheme it is calculated as a function of bulk Richardson number in the surface and the drag coefficient at neutral stability. The neutral stability drag coefficient is calculated from mixed layer theory.

For the leaf area temperature calculation, drag coefficients are determined as above except that a lower limit is imposed and drag coefficient derivatives with respect to temperature are obtained in the same way.

Over vegetated grid squares, the neutral drag coefficient is estimated by linear combination of drag coefficients for vegetation, for bare soil, or over snow.

The sensible and latent heat fluxes over water, sea ice, or bare soil surface are obtained using the above defined surface drag coefficients.

3.1.6 Energy fluxes with vegetation

The surface area of vegetation per unit area of ground consists of transpiring surface specified by a leaf area index and non-transpiring surfaces specified by a stem area index and the bare soil.

The stem area index is a constant for each land type, whereas the leaf area index has a seasonal variation.

When it rains, the surfaces of vegetation become covered with a film of water before drip through and stem flow carry water to the ground. This water can then

re-evaporate to the air but at the same time transpiration is suppressed over wet green leaves. Similarly the formation of nighttime dew can keep foliage cool in the morning and suppress re-transpiration. Typical values for reevaporation of intercepted rainfall are in the range of 10 to 50 percent of the rainfall, depending primarily on rainfall intensity. The suppression of transpiration by wet leaves has been less studied but is also significant. Snowfall is also intercepted by foliage, and frost formation on foliage often occurs. These are of somewhat less significance for the water budget because of the lower evaporation rates at low temperature. Hence it is reasonable to assume that vegetation storage of solid water is the same as liquid water.

The water fluxes from wet foliage are function of saturation water vapor specific humidity at temperature of the foliage and the water vapor specific humidity ratio of air within the canopy and the aerodynamic resistance to moisture and heat flux of the foliage molecular boundary layer. The water fluxes from dry foliage is the same as that from wet foliage but the resistance to water flux by stomata needs consideration.

The stomatal resistance refers to total mechanical resistance encountered by diffusion from inside a leaf to outside. Water vapor inside leaves is maintained at or very near its saturated value. The stomata are pores which when open are the main conduits for transpired water. Hence the net resistance to water passing from the inside to the outside of the leaf depends largely on the size, distribution, and degree of opening of these stomata. In general the opening of the stomata and hence the resistance changes with various environmental parameters including inability of roots to supply adequately the transpiration demand.

3.1.7 Summary

The above comprehensive model of land surface processes has been used for describe properly the role of vegetation in modifying the surface moisture and energy budgets. The results of these have been incorporated into boundary package. Some important processes are:

- assignment of land type and soil information to each model grid square
- calculation of soil snow and sea ice surface temperature in response to the net surface heating
- calculation of soil moisture evaporation and surface and ground water runoff
- specification of vegetation cover I terms of fractional ground shading and relative areas of transpiring and non-transpiring plant surface for different types of land use

- surface albedo in terms of soil moisture, vegetation cover and snow cover
- plant water budget
- surface drag coefficients as a function of bulk Richards number and vegetation cover

In order to better establish the importance of various aspects of land surface processes for climate and climate changes, large amounts of scientific work still needs to do.

3.2 Cloud Parameterization

Cloud amount (or cloud fraction), and the associated optical properties, are evaluated via a diagnostic method in the model. Although the basic approach is similar to what was employed in the CCM, the specific techniques represent some of the more significant changes to the collection of model physics. The diagnosis of cloud fraction represents a generalization of the scheme introduced by Slingo (1987), and depends on relative humidity, vertical velocity, atmospheric stability et al., Two types of cloud are diagnosed by the scheme: convective cloud and large scale layer cloud. Some of the major changes from Slingo (1987) are: clouds are allowed to form in any model layer, except two layers nearest the surface and layers over 750hPa. The relative humidity thresholds clouds formation are functions of elevation, and convective cloud amount is related with the layer amount where convective cloud occurs and the model resolution. The minimum convective cloud fraction requirement of 20% still employed in the model.

3.2.1 Cloud amount

The cloud is divided in to two types: large scale layer cloud and convective cloud. They are diagnosed in different subroutines of the model, respectively. There are two schemes for cloud amount parameterization. First scheme is same as used in NCAR RegCM2 and second one is new.

1. NCAR RegCM2 scheme

Convective cloud

We suppose the convective cloud friction (a_{frac}) is equal to 1.0 when grid length is 10km, maximum cloud friction (a_{frac1}) 0.3 when grid length 200km. So we can

initially estimate the convective cloud amount (*clfrcv*) when grid length is *dx*.

$$clfrcv = afrac1 + (afrac3 - afrac1) \left[\frac{(dl \text{ arg } c - dx)}{(dl \text{ arg } c - dsmalc)} \right]^2$$

Where the *afrac3*=1.0, *dsmalc*=10km, *afrac1*=0.2, *dlargc*=200km.

Then the cloud friction is made correction after considering the layer number where there are convective clouds.

$$cldfra = 1.0 - (1.0 - clfrcv)^{1/kclth}$$

Where *kclth* is the layer number where convective cloud occurs.

Large scale cloud

The large scale cloud friction is fixed to be 0.6 when the relative humidity in this layer is larger than a threshold of relative humidity which is constant in all layers.

$$exfra = 0.6$$

And the total cloud amount (*cldfra*) is the maximum between large scale and convective clouds

$$cldfra = \max(cldfra, exfra)$$

2. New scheme

Convective cloud

Parameterization scheme for convective cloud is same as used in NCAR RegCM2.

Large scale cloud

We improved the parameterization scheme for large scale cloud that is over simplified in NCAR RegCM2. We determine the cloud amount according to following process:

$$exfra = \begin{cases} 0. & r_k \leq RH_k \\ \left(\frac{r_k - RH_k}{1.0 - RH_k} \right)^{1.5} & r_k > RH_k \end{cases}$$

Where r_k is relative humidity in k^{th} model layer, RH_k is threshold of relative

humidity when large scale cloud occurs and is the function of height(or model layer).

Then the cloud friction is made correction by the vertical motion and atmospheric stratification.

$$exfra = \begin{cases} 0. & \omega > \omega_c \\ exfra\left(\frac{\omega_c - \omega}{\omega_c}\right) & 0.0 \leq \omega \leq \omega_c \\ exfra & \omega < 0.0 \end{cases}$$

Where ω_c is 50hPa/day.

3.2.2 Cloud water path

As in the CCM3, cloud optical properties here are accounted for using the Slingo (1989) parameterization for liquid water droplet clouds. This scheme relates the extinction optical depth, the single-scattering albedo, and the asymmetry parameter to the cloud liquid water path and cloud drop effective radius. The latter two microphysical cloud properties were statically specified in the CCM3. In particular, in-cloud liquid water paths were evaluated from a prescribed, meridionally and height varying, but time independent, cloud liquid water density profile, $\rho_l(z)$, which was analytically determined on the basis of a meridionally specified liquid water scale height (e.g., see Kiehl et al., 1994; Kiehl, 1991). The cloud drop effective radius was simply specified to be 10 μ m for all clouds if no anthropogenic aerosols act as CCN. Our model employs the same exponentially decaying vertical profile for in-cloud water concentration like CCM3 does,

$$\rho_l = \rho_l^0 e^{-(z/h_l)}$$

where the reference value ρ_l^0 is equal to 0.21 g m⁻³. Instead of specifying a zonally symmetric meridional dependence for the cloud water scale height, h_l , it is locally

$$h_l = 700 \ln\left(1.0 + \frac{1}{g} \int_{p_T}^{p_S} q dp\right)$$

diagnosed as a function of the vertically integrated water vapor (precipitable water) The cloud water path is then determined by integrating the liquid water concentration using

$$CWP = \int \rho_l dz$$

which can be analytically evaluated for an arbitrary layer k as,

$$CWP(k) = \rho_l^0 h_l [e^{-z_{k+1/2}/h_l} - e^{-z_{k-1/2}/h_l}]$$

where $z_{k+1/2}$ and $z_{k-1/2}$ are the heights of the k^{th} layer interfaces.

Observational studies have shown a distinct difference between maritime and continental effective cloud drop size, r_e , for warm clouds. For this reason, the model differentiates between the cloud drop effective radius for clouds diagnosed over maritime and continental regimes (Kiehl, 1994). Over the ocean, the cloud drop effective radius for liquid water clouds, r_{el} , is specified to be $10 \mu\text{m}$ if no more anthropogenic aerosols, a , as in the CCM3. Over land masses r_{el} is determined using

$$r_{el} = \begin{cases} 5 \mu\text{m} & T > -10^0 C \\ 5 - 5\left(\frac{T+10}{20}\right) \mu\text{m} & -30^0 C \leq T \leq -10^0 C \\ r_{ei} & T < -30^0 C \end{cases}$$

An ice particle effective radius, r_{ei} , is also diagnosed by model, which at the moment amounts to a specification of ice radius as a function of normalized pressure

$$r_{ei} = \begin{cases} 10 \mu\text{m} & p/p_s > p_I^{\text{high}} \\ r_{ei}^{\text{max}} - (r_{ei}^{\text{max}} - r_{ei}^{\text{min}}) \left[\frac{(p/p_s) - p_I^{\text{high}}}{p_I^{\text{high}} - p_I^{\text{low}}} \right] \mu\text{m} & p/p_s \leq p_I^{\text{high}} \end{cases}$$

where $r_{ei}^{\text{max}} = 30 \mu\text{m}$, $r_{ei}^{\text{min}} = 10 \mu\text{m}$, $p_I^{\text{high}} = 0.4$, and $p_I^{\text{low}} = 0.0$. The fraction of the total cloud water in the form of ice particles is then determined using

$$f_{ic} = \begin{cases} 0 & T > -10^0 C \\ -0.05(T+10) & -30^0 C \leq T \leq -10^0 C \\ 1 & T < -30^0 C \end{cases}$$

3.3 Parameterization of Radiation

The scheme of radiation parameterization is based on CCM3 radiation package. Comparing with CCM2 scheme, there are following improvements in CCM3: Changes to the clear-sky radiation formalism include the incorporation of minor CO₂ bands trace gases (CH₄, N₂O, CFC11, CFC12) in the longwave parameterization, and the incorporation of aerosol in the shortwave parameterization. All-sky changes include improvements to the way in which cloud optical properties are diagnosed, the incorporation of the radiative properties of ice clouds, and a number of minor modification to the diagnosis of convective and large scale cloud amount.

The δ - Eddington approximation of Joseph, Wiscombe, and Weinman (1976) and also Coakley, Cess and Yurevich, (1983) has been adopted and is described in Briegleb (1992). This approximation has been shown to simulate quite well the effects of multiple scattering.

The solar spectrum is divided into 18 discrete spectral intervals (7 for O₃ , 1 for the visible, 7 for H₂O, and 3 for CO₂). The model atmosphere consists of a discrete vertical set of horizontally homogeneous layers within which radiative heating rates are to be specified. Each of these layers is considered to be a homogeneous combination of several radiatively active constituents. Solar irradiance, as well as surface reflectivity for direct and diffuse radiation in each spectral interval, are specified, as well as the cosine of the solar zenith angle.

The δ - Eddington method involves evaluating the δ - Eddington solution for the reflectivity and transmissivity for each layer in the vertical. The layers are then combined together, accounting for multiple scattering between layers, which allows evaluation of upward and downward spectral fluxes at each interface boundary between layers. This procedure is repeated for all spectral intervals to accumulate broad band fluxes, from which the heating rate can be evaluated from flux differences across each layer.

Molecular scattering and cloud water droplet scattering/absorption are included. A summary of the spectral intervals and the absorption/scattering data used in the formulation is given in Briegleb (1992).

For cloud scattering and absorption, the radiative parameterization of Slingo [1989] for liquid water droplet clouds is employed. In this parameterization, the

optical properties of the cloud droplets are represented in terms of the prescribed liquid water path (LWP in units of kg m^{-2}) and effective radius, $r_e = \int r^3 n(r) / \int r^2 n(r) dr$, where $n(r)$ is the cloud drop size distribution over radius r ; The quantity τ_c is the cloud extinction optical depth (0 to ∞), ω is the particle single scattering albedo (0 to 1), g is the asymmetry parameter (-1 to +1), and $a...f$ are positive constant coefficients for 4 spectral ranges: (.25-.69 μm , .69-1.19 μm , 1.19-2.38 μm , and 2.38-4.00 μm). These parametric expressions represent the basic physical dependencies of the optical properties on effective radius r_e : larger effective radius for fixed LWP means fewer droplets and smaller effective cross section, hence, smaller τ_c . Larger droplets mean more absorption of radiation transmitted through the droplets, hence, smaller ω ; larger droplets mean more forward scattering and

$$\tau_c = LWP \left(a + \frac{b}{r_e} \right)$$

$$\omega = 1 - c - d r_e$$

$$g = e + f r_e$$

hence, larger g .

For some diagnostic purposes, such as estimating cloud radiative forcing (Kiehl and Ramanathan, 1990) a clear-sky absorbed solar flux is required. A diagnostic calculation is included to give an estimate of clear-sky column absorbed and surface absorbed flux. For computational efficiency, the clear sky top of atmosphere and surface fluxes are evaluated assuming two homogeneous atmospheric layers. The top layer contains only O_3 , while the lower layer contains all other absorbers/scatterers except clouds. The actual surface albedos are employed.

The model atmosphere is divided into $K+1$ layers in the vertical; an extra top layer (beyond the K layers specified by model) is added. This extra layer prevents excessive heating in the top layer when the top pressure is not very low; also, as CCM3 does not specify absorber properties above its top layer, the optical properties of the top layer must be used for the extra layer. Layers are assumed to be horizontally and vertically homogeneous for each model gridpoint and are bounded vertically by layer interfaces. For each spectral band, upward and downward fluxes are computed on the layer interfaces (which include the surface and top interface). The spectral fluxes are summed and differenced across layers to

evaluate the solar heating rate. The following discussion refers to each of the spectral intervals.

In general, several constituents absorb and/or scatter in each homogeneous layer. Every constituent is defined in terms of a layer extinction optical depth τ , single scattering albedo ω , asymmetry parameter g , and the forward scattering fraction f . The forward scattering fraction is the fraction of radiation scattered into the strong forward peak and is taken as g^2 (see Briegleb, 1992). To define bulk layer properties, the combination formulas of Cess [1985] are used:

$$\begin{aligned}\tau &= \sum_i \tau_i \\ \omega &= \frac{\sum_i \omega_i \tau_i}{\tau} \\ g &= \frac{\sum_i g_i \omega_i \tau_i}{\omega \tau} \\ f &= \frac{\sum_i f_i \omega_i \tau_i}{\omega \tau}\end{aligned}$$

where the sums are over all constituents.

The δ - Eddington solution for each layer requires scaled properties for τ , ω , g , given by the expressions:

$$\begin{aligned}\tau^* &= \tau(1 - \omega f) \\ \omega^* &= \omega \left(\frac{1 - f}{1 - \omega f} \right) \\ g^* &= \frac{g - f}{1 - f}\end{aligned}$$

The details of solution can be found in Briegleb, 1992.

3.4 Representation of aerosol effects

3.4.1 Direct effects

At present the aerosol in the model only refer to anthropogenic sulfate aerosol. The radiation calculation scheme for the sulfate aerosol is the model component that provides the interactive coupling between aerosol and climate model. The calculation of direct effects of the sulfate aerosol is based on the CCM3

radiative transfer scheme (Kiehl et al. 1996). The solar spectrum is divided into eighteen spectral intervals, spanning the range of 0.2 to 5.0 μm and a delta-Eddington approximation is used to calculate the solar fluxes(see 4.2).

The radiative properties of the aerosol are described in terms of three optical properties, the specific extinction, ψ_e , the single scattering albedo, ω_o , and the asymmetry parameter, g . The values of these parameters are primarily taken from the observed aerosols data of Adarsh and Hermann (1983). Then it's re-divided according to spectral intervals in the model(see Tab. 4.1). We suppose the sulfate is made up of H_2SO_4 that concentration is 75% and number density of particles is 9088 cm^{-3} . In addition, the aerosol specific extinction depends on the environmental relative humidity, RH, whereby increased RH results in larger particles which scatter more radiation. This effect is described by multiplying ψ_e by an empirical polynomial function of RH (Kiehl and Briegleb, 1993).

As mentioned, the indirect effects of the sulfate aerosol consist of altering the distribution and concentration of CCN and hence the number density, size distribution and radiative properties of cloud droplets. In the CCM3 radiation package, cloud radiation is calculated in terms of two quantities, the cloud liquid water and ice content, $L\text{ (g m}^{-3}\text{)}$, and the

Tab.4.1 Optical properties of 75% H_2SO_4 during 0.2 – 5.0 μm

Wave length (μm)	ψ_e (km^{-1})	Scattering (km^{-1})	Absorption (km^{-1})	ω_o	g
.200	1.49E+00	1.49E+00	2.05E-07	1.000	.680
.250	1.55E+00	1.55E+00	1.62E-07	1.000	.693
.300	1.55E+00	1.55E+00	1.26E-07	1.000	.713
.337	1.52E+00	1.52E+00	1.10E-07	1.000	.725
.400	1.38E+00	1.38E+00	8.77E-08	1.000	.739
.488	1.15E+00	1.15E+00	6.86E-08	1.000	.736

.515	1.09E+00	1.09E+00	6.43E-08	1.000	.732
.550	1.00E+00	1.00E+00	5.92E-08	1.000	.726
.633	8.22E-01	8.22E-01	7.29E-08	1.000	.709
.694	7.06E-01	7.06E-01	8.78E-08	1.000	.694
.860	4.69E-01	4.69E-01	5.93E-07	1.000	.650
1.060	2.89E-01	2.89E-01	3.70E-06	1.000	.592
1.300	1.64E-01	1.64E-01	1.85E-05	1.000	.518
1.536	9.99E-02	9.97E-02	1.99E-04	.998	.447
1.800	5.88E-02	5.82E-02	6.44E-04	.989	.372
2.000	4.18E-02	4.06E-02	1.28E-03	.969	.332
2.250	2.73E-02	2.57E-02	1.57E-03	.942	.269
2.500	1.85E-02	1.56E-02	2.89E-03	.844	.223
2.700	1.33E-02	9.31E-03	4.03E-03	.698	.192
3.000	6.51E-02	6.32E-03	5.88E-02	.097	.153
3.200	8.27E-02	6.00E-03	7.67E-02	.073	.142
3.392	8.93E-02	6.27E-03	8.30E-02	.070	.130
3.500	8.54E-02	6.23E-03	7.92E-02	.073	.124
3.750	6.53E-02	5.10E-03	6.02E-02	.078	.111
4.000	5.79E-02	4.03E-03	5.39E-02	.070	.098
4.500	4.76E-02	2.42E-03	4.52E-02	.051	.078
5.000	4.28E-02	1.45E-03	4.13E-02	.034	.063

effective cloud droplet radius r_e . The cloud water content is calculated by the model's explicit and cumulus cloud parameterizations as described in section 4.1.

3.4.2 Indirect effects

Aerosol indirect effects are parameterized via a two-step approach (Jones and Slingo 1996): in the first, a relationship is developed between the mass concentration of the sulfate aerosol and the number concentration of cloud droplets, N_c ; the second step consists of a relationship between the average droplet effective radius r_e and N_c . The first step is more difficult to quantify and it is the one that primarily contributes to the uncertainty in describing aerosol indirect effects. Jones and Slingo (1996) reviewed and compared three methods for obtaining N_c from the sulfate concentration, i.e. those of Jones et al. (1994), Hegg(1994) and Boucher and Lohmann (1995). These methods derive from different measurements and observed data and they all have advantages and disadvantages. We selected the method of Hegg (1994) in which N_c is obtained as a function of simulated sulfate mass mixing ratio via the formula

$$N_c = 90.7 (\rho_a \times x)^{0.45} + 23. \quad (*)$$

where ρ_a is the density of dry air and x is the sulfate mass mixing ratio. The advantage of this method is that it does not assume that all the atmospheric aerosol is sulfate, i.e. that a background non-sulfate aerosol is also present. In fact, from Eq. (*), if the sulfate mixing ratio is 0, N_c is still different from 0. note that in Eq. (*) we use the aerosol mixing ratio at the first cloud-free layer below a given cloud layer. This is done in order to avoid using in the computation of N_c sulfate mixing ratio values depleted through removal processes.

Once N_c is calculated from Eq. (5), the cloud water effective radius is calculated as a function of N_c and the cloud water content L via the relationship (Martin et al. 1994).

$$r_e = \left(\frac{3L}{4\pi\rho_w k N_c} \right)^{1/3}$$

where ρ_w is the density of water and k is the cube of the ratio of the mean volume radius and the effective radius of the cloud-droplet spectrum, which is assumed to be equal to 0.67 over continent and 0.80 over ocean (Martin et al. 1994).

3.4.3 Sulfate aerosol distribution

East Asia, including China, Japan and Korea et al., has been one of the most rapidly developing areas of the world for the past decades, which has lead to a rapid increase in emissions of SO_2 . It is hypothesized that the aerosol forcing can modulate the climate response to increased greenhouse gas concentration. So for obtaining the real scenarios of climate change in future, we should incorporate not only greenhouse gases but also sulfate aerosol into the global or regional climate models.

We have three different approaches to set up the distribution of sulfate aerosol according to different needs of research. The simplest way is supposing the distribution of sulfate is even over model domain. In every grid point we set up an equal optical thickness of aerosol, like 0.14, which is used in CCM3. The second way is that we firstly run a chemical transport model, in which the sulfate is included as one of the species, to get the distribution and seasonal variation of sulfate aerosol. There are many simulation works over East Asia using Eulerian model in which the source, transport, transformation and deposition of sulfur materials are included. Then we input the concentration simulated and optical parameters given before to drive the climate model. The third and also most advanced way is interactively coupling the chemical transport model with climate model (Qian et al., 1998) and on-line running two models simultaneously. So the concentration and distribution of sulfate aerosol are changing in every time step due to the feedback of climate fields. We can get the information of both sulfate aerosol and climate change and can investigate the interaction between aerosol and climate change.

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Appendix

A User's Guide to On-line RIEMS (Regional Integrated Environmental Modeling System)

**START Regional Research Center for Temperate East Asia
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1. Introduction

On-line RIEMS is a web-based platform to operate the first version of RIEMS interactively. The whole system consists of four steps. The first two steps are preprocessor to generate initial and lateral boundary fields, and make corresponding plots. These programs are developed from NCAR MM5 preprocessors. The third step is the most important component of the whole system. The main model integration is completed in this step. The last step is postprocessor to make plots of model outputs. This program is developed based on NCAR RegCM postprocessor. The order of the programs and their primary functions are shown in this table:

Step	Purpose
1	Choose the model geographical domain(s) and get corresponding topographical, land-use data.
2a	Retrieve gridded pressure-level analyses of SST, snow, and traditional surface and upper-level fields.
2b	Retrieve observed data and perform an objective analysis on that data
2c	Interpolate 2a or 2b output onto sigma levels and writes out initial, time-dependent lateral boundary condition data.
3	Run RIEMS on your case.
4	Plot/study the results.

The whole system can be reached through <http://ultra2-3d.tea.ac.cn/rcm>, or <http://riems.tea.ac.cn/>

2. Preprocessor

The preprocessor includes two Step 1 and Step 2.

Step 1

Purpose

This program horizontally interpolates (or analyzes) the latitude-longitude interval terrain elevation and land use categories onto the chosen mesoscale domains.

Main Features

- 1) Five types of terrain height source data are available: 1-degree, 30-, 10-, 5-minute and 30-second; and three types of land-use data are available: 1-degree, 30- and 10-minute.
- 2) Multiple-nest domains.
- 3) If the nest type is one-way, users can select any nest ratio. If the nest type is two-way, then the ratio has to be 3:1.

Input parameters

PHIC: Central latitude of the coarse domain in degree.

XLONC: Central longitude of the coarse domain in degree.

MAXNES: Maximum number of domains. This program allows the maximum number of domains less than or equal to 5.

NESTIX: The I(y)-direction dimensions for each of the domains.

NESTJX: The J(x)-direction dimensions for each of the domains.

DIS: The grid size for each of the domain.

NESTI: The I location in its model domain of the nest domain's low-left corner --- point (1,1).

NESTJ: The J location in its model domain of the nest domain's low-left corner --- point (1,1).

RID: The radius of influence in unit of grid points used for Cressman type objective analysis.

NTYPE: The source terrain height and land-use data type for each of the domains:

1---1-degree global terrain and land-use

2---30-minutes global terrain and land-use

3---10-minutes global terrain and land-use

4---5-minute global terrain and 10-minute global land-use

5---30-second regional terrain (contains 48 states in the USA and part of Canada) and 10 minute global land-use.

IFILL: Plots are color filled (True) or not (False).

Step 2

Step 2 has three sub-steps.

Step 2a

Purpose

- 1) Access archived low-resolution meteorological analyses:
 - Latitude-longitude grids.
 - NMC: Global Analyses (2.5°X2.5°).
 - TOGA: Basics Level III data sets (2.5°X2.5°).
- 2) Horizontally interpolate these analyses to the model grid.
- 3) Write the interpolated analyses for input to steps 2b or 2c.
- 4) The fields created by this program are used:
 - To create model input fields directly (Step 2c)
 - As first-guess fields for subsequent objective analysis (Step 2b)

Multiple Domains

This program can process more than one domain in a single submittal, but only if the TERRAIN file is supplied for each domain: Step 2a will process each domain for which it finds a TERRAIN file. In normal use, only the coarse grid to be processed.

Input Files

- 1) Supply terrain and land-use data.
- 2) Files of low-resolution latitude/longitude analyses: NMC or TOGA.

Input parameters

Analysis: Type of input data files to acquire: NMC or TOGA.

SST: Source of Sea-surface Temperatures: NMC or NAVY.

InAnly: Filename(s) of NMC or TOGA analyses.

InSST: Filename(s) for NCEP or NAVY SST.

IFILES: Number of times to process.

NUMDOM: Number of domains to process.

PTOP: Pressure level (hPa) defining model top (usually 100)

ISTRDAY: Starting time (YYMMDDHH, 8 digits).

ITIMINT: Time interval (hours; generally 12).

Output from Step 2a

The data for each domain is written to a separate file (domain 1 → datagrid.out.1; domain 2 → datagrid.out.2, etc).

Each file contains the data at every time period for one domain.

For each time period, the file contains:

- A header record describing the output.

- 5 3-d arrays (Surface, 1000 hPa, 850 hPa, 700 hPa, ..., P_{TOP}):

- 1) Temperature (K) (cross)
- 2) U-wind (rotated to the grid) (ms^{-1}) (dot)
- 3) V-wind (rotated to the grid) (ms^{-1}) (dot)
- 4) Geopotential height (m) (dot)
- 5) Relative humidity (%) (cross)

- 13 2-d arrays:

- 6) Terrain height (m) (cross)
- 7) Land-use category (category) (cross)
- 8) Map-scale factor (non-dimensional) (cross)
- 9) Map-scale factor (non-dimensional) (dot)
- 10) Coriolis parameter (s^{-1}) (dot)
- 11) Latitude ($^{\circ}\text{N}$) (cross)
- 12) Longitude ($^{\circ}\text{N}$) (cross)
- 13) Latitude ($^{\circ}\text{N}$) (dot)
- 14) Longitude ($^{\circ}\text{N}$) (dot)
- 15) Snow-cover flag (non-dimensional) (cross)
- 16) Sea-level pressure (hPa) (dot)
- 17) Sea-level pressure (hPa) (cross)
- 18) Sea-surface temperature (K) (cross)

Step 2b

Purpose

Improve meteorological analyses (the first-guess) on the mesoscale grid by objective analysis of surface and upper-air observations. The analyses input to this program as the first-guess are generally the low-resolution analysis output from Step 2a.

Step 2b capabilities include:

- 1) Various tests to screen the data for suspect observations
- 2) Additional levels: this program can interpolate from mandatory pressure levels to additional levels you specify for an analysis with higher vertical resolution.

Step 2b output used to:

- 1) Provide fields for Initial and Boundary conditions (through Step 2c).
- 2) Provide 3-d fields for analysis-nudging FDDA (through Step 2c).
- 3) Provide surface fields for surface-analysis-nudging FDDA.

Input parameters

InRaobs: Filename(s) for the archived RAOBS data.
InSfc6h: Filename(s) for the archived 6-hrly surface data and ship data.
InSfc3h: Filename(s) for the archived 3-hrly surface data.
IMX: I dimension of the domain being processed.
JMX: J dimension of the domain being processed.
NNEWPL: Number of new pressure levels to interpolate to.
GNLVL: The pressures at the new levels (bottom to top, hPa).

Step 2c

Purpose

This program handles the data transformation required to go from the analysis programs to the mesoscale model. This can entail vertical and horizontal interpolation, diagnostic computation, and simple data reformatting.

Procedures

- 1) input from Step 2a or Step 2b.
- 2) Pressure level Q_v for Psfc.
- 3) Interpolate variables from pressure coordinates to hydrostatic σ .
- 4) U, V, RH: linear in pressure.
- 5) Theta: linear in \ln pressure.
- 6) Remove integrated mean divergence.
- 7) Compute base state.
- 8) Compute w .
- 9) Re-interpolate u, v, t, Q_v .
- 10) Compute perturbation pressure.
- 11) Save current data for boundary file.
- 12) Output interpolated data for initial and boundary conditions.

Input parameters

MAXNES: Total number of domains being processed.
NLNES: Maximum depth of domain nesting.
IMAX, JMAX: Maximum horizontal domain size (grid points) where the first node is defined as (1,1), IMAX refers to I-direction (y-axis) and JMAX refers to the J-direction (x-axis).
KXS: Number of half- σ layers (same as vertical dimension in model), this is one less than the number of full- σ .
KXP: Number of pressure levels.
NSPGD: Number of layers in buffer zone.
NEWCOORD: A bottom-up array of full σ -levels (starting with 1.0 and ending with 0.0).
INHVD: Hydrostatic or Nonhydrostatic.
BEGTIME: Starting time.

ENDTIME: ending time.

TIMINT: Time period in minutes specifying increment between analysis times.

NESTIX: The I(y)-direction dimensions for each of the domains.

NESTJX: The J(x)-direction dimensions for each of the domains.

NESTI: The I location in its model domain of the nest domain's low-left corner --- point (1,1).

NESTJ: The J location in its model domain of the nest domain's low-left corner --- point (1,1).

InData: Input analysis file from Step 2a or Step 2c.

3 Run the model---Numerical prediction part of the modeling system

Input files

Files from Step 2c:

- 1) Model input files(s).
- 2) Boundary conditions for coarse mesh.

Files from this step:

Model restart file(s)

Files from Step 2b:

FDDA surface analysis

Files generated by user:

FDDS 4D obs file(s)

Input parameters

NHYDRO: Hydrostatic run or Nonhydrostatic run.

MAXNES: Maximum number of domains in simulation.

MIX,MJX,MKX: Maximum number of grid points in I,J, and K.

IMPHYS: Options for explicit schemes:

- =1, dry;
- =2, removal of super-saturation;
- =3, warm rain (Hsie);
- =4, simple ice (Dudhia);
- =5, mixed phase (Reisner);
- =6, mixed phase with graupel (Goddard);
- =7, mixed phase with graupel (Reisner);

ICUPA: Options for cumulus parameterization:

- =1, none;
- =2, Anthes-Kuo;
- =3, Grell;
- =4, Arakawa-Schubert;
- =5, Fritsch-Chappell;
- =6, Kain-Fritsch;

=7, Betts-Miller.

IBLTYP: Options for planetary boundary layer schemes:

=0, no PBL;
=1, bulk-aerodynamic with BATS
=2, Holtslag;
=3, Burk-Thompson;
=5, MRF PBL.

FRAD: Options for atmospheric radiation scheme:

=0, none;
=1, simple cooling;
=2, cloud (Dudhia);
=3, CCM3.

IFREST: =True, for restart, =False, for initialization.

IFSAVE: =True, saving data for restart, =False, for no restart output.

IXTIMR: Restart time in minutes.

SAVFRQ: Frequency of restart output in minutes.

IFTAPE: =1, for main model output, =0, no main model output.

TAPFRQ: Frequency of main model output in minutes.

RADISP: Time interval for disposing radiation output in hours.

BATFRQ: Time interval for disposing BATS output in hours.

IBOUDY: Boundary condition options:

=0, fixed;
=1, relaxation;
=2, time-dependent;
=3, inflow/outflow;
=4, sponge.

ICLOUD:

=1, consider cloud effects on surface radiation when FRAD=0,1; consider both surface and atmospheric radiation when FRAD=2.
=0, do not consider cloud effect on radiation.

NESTIX: The I(y)-direction dimensions for each of the domains.

NESTJX: The J(x)-direction dimensions for each of the domains.

NESTI: The I location in its model domain of the nest domain's low-left corner --- point (1,1).

NESTJ: The J location in its model domain of the nest domain's low-left corner --- point (1,1).

TIMAX: forecast length in minutes.

TISTEP: time step in seconds for the coarsest domain (recommend 3*dx(km))

STARTsw:

=NoReStart, start model run at hour zero (initialize);
=ReStart, restart model run.

HYDROsw:

=Hydro, hydrostatic input files;
=NonHydro, nonhydrostatic input files.

Output from this step

A number of files are written out during the model integration. These are

- **History files**(Fortran units 40's), if IFTAPE=1,and the output frequency is set by TAPFRQ.
- **Restart files**(Fortran units 50's),if IFSAVE=.TRUE.,and the output frequency is set by SAVEFRQ.

For each time period the model history output include:

A header record describing the output

3D forecast arrays dimensioned(IX,JX,KX) for that domain (half levels unless specified) -note that the variables are coupled(i.e.,multiplied by Pstar)

- | | | |
|--|-------------------|--|
| 1) U-wind (kPa m/s) | coupled dot | |
| 2) V-wind (kPa m/s) | coupled dot | |
| 3) Temperature (kPa K) | coupled cross | |
| 4) Water vapor mixing ratio (kPa kg/kg) | coupled cross | |
| (if IMPHYS \geq 2) | | |
| 5) Cloud water mixing ratio (kPa kg/kg) | coupled cross | |
| (if IMPHYS \geq 3) | | |
| 6) Rain water mixing ratio (kPa kg/kg) | coupled cross | |
| (if IMPHYS \geq 3) | | |
| 7) Ice cloud mixing ratio (kPa kg/kg) | coupled cross | |
| (if IMPHYS \geq 5) | | |
| 8) Snow mixing ratio (kPa kg/kg) | coupled cross | |
| (if IMPHYS \geq 5) | | |
| 9) Graupel (kPa kg/kg) | coupled cross | |
| (if IMPHYS 6) | | |
| 10) Number concentration of ice | coupled cross | |
| (if IMPHYS 6) | | |
| 11) Turbulent k.e. (J/kg) | not coupled cross | |
| (if IBLTYP=3) | | |
| 12) Atmospheric radiation tendency (K/day) | not coupled cross | |
| (if FRAD \geq 2) | | |
| 13) Vertical velocity (kPa m/s) | coupled cross | |
| full levels (if INHYD=1) | | |
| 14) Perturbation pressure (kPa Pa) | coupled cross | |
| (if INHYD=1) | | |

2D forecast arrays dimensioned (IX, JX)

- | | |
|------------------------------------|-------|
| 1) Pstar(cb) | cross |
| 2) Ground temperature (K) | cross |
| 3) Accum. convective rainfall (cm) | cross |
| 4) Accum. nonconv. rainfall (cm) | cross |
| 5) PBL height (m) | cross |
| 6) PBL regime (category, 1-4) | cross |

7) Surface sensible heat flux (W/m^2)	cross
8) Surface latent heat flux (W/m^2)	cross
9) Frictional velocity (m/s)	cross
10) Surface downward shortwave radiation (W/m^2)	cross
11) Surface downward longwave radiation (w/m^2)	cross
12) Soil temperature in layers 1-6 (K)	cross

2D constant arrays dimensioned(IX, JX)

13) Terrain elevation (m)	cross
14) Map scale factor	dot
15) Map scale factor	dot
16) coriolis parameter(/s)	cross
17) Substrate temperature (K)	cross
18) Latitude (deg)	cross
19) Longitude (deg)	cross
20) Land-use category	cross
21) Snow cover	cross

BATS file

The following BATS surface fields are written to fort.54 in this order:

- 1) Anemometer west wind(m/s)
- 2) Anemometer south wind(m/s)
- 3) Drag-surface stress (si)
- 4) Ground temperature (deg K)
- 5) Temperature of air within foliage (deg K)
- 6) Temperature of foliage (deg K)
- 7) Anemometer temperature (deg K)
- 8) Ground specific humidity (g/kg)
- 9) Anemom specific humidity (g/kg)
- 10) Upper layer soil water (mm H2O)
- 11) Root zone soil water (mm H2O)
- 12) Accumulated precipitation (mm/hr)
- 13) Accumulated evaporation (mm/hr)
- 14) Accumulated surface runoff (mm/hr)
- 15) Snow depth (mm H2O)
- 16) Accumulated sensible heat (watts/m**2/hr)
- 17) Accumulated net infrared radiation (watts/m**2/hr)
- 18) Accumulated net solar absorbed radiation (watts/m**2/hr)
- 19) Accumulated solar absorbed by vegetation (watts/m**2/hr)
- 20) Accumulated solar incident at surface (watts/m**2/hr)

Radiation files

The following variables are written to fort.56 in this order:

- 1) Ozone mixing ratio (ppmv)
- 2) H2O mixing ratio (g/kg)
- 3) Cloud fraction cover (none)
- 4) Cloud liquid water path (g/m**2)
- 5) Solar heating rate (deg K/s)
- 6) Longwave cooling rate (deg K/s)
- 7) Surface absorbed solar flux (watts/m**2)
- 8) Longwave cooling of surface (watts/m**2)(up-down flux)
- 9) Clear sky total column absorbed solar flux (watts/m**2)
- 10) Clear sky surface absorbed solar flux (watts/m**2)
- 11) Clear sky net up flux top of model(up-down flux) (watts/m**2)
- 12) Clear sky cooling of surface(up-down flux) (watts/m**2)

4 Postprocessor-----Step 4

Purpose

This program interpolates the main model output from sigma level to pressure level. It can plot maps in either sigma or pressure level.

Input parameters

IY: Number of model grid points in the Y-direction.
JX: Number of model grid points in the X-direction.
KZ: Number of vertical levels in the model.
CLATGRD: Central latitude of model grid.
CLONGRD: Central longitude of model grid.
FILELAB: 8 characters for plot title(s).
DX: Model grid spacing in meters.
PTOP: Top of model in hPa
IDATE0: Date run started (in YYMMDDHH)
IDATE1: First date to plot (in YYMMDDHH)
IDATE2: Last date to plot (in YYMMDDHH)
INCHR: Plot increment in hours.
FILTYPE: Input file type.
ICONT: =0, solid continental outlines; =1, dotted.
ILAB: =0, do not label contour lines; =1, label.
SIGMA: Plots on sigma level or not.
PRES: Plots on pressure level or not.

MEAN: Snapshots or mean from IDATE1 to IDATE2.

Reference

PSU/NCAR Mesoscal Modeling System Tutorial Class Notes and Users' Guide (MM5 Modeling System Verson 2) by Jimy Dudhia, Dave Gill, Yong-Run Guo, Dan Hansen, Kevin Manning, and Wei Wang, June, 1998.

NCAR REGCM2 User Documentation by Christine Shields, Charles A. D'Ambra and Starley L. Thompson, 1994.