OVERVIEW of the
MILBRANDT-YAU GRID-SCALE CONDENSATION SCHEME
in the GEM-LAM-2.5

1. Role of cloud schemes

The Milbrandt-Yau cloud microphysics scheme is one of the grid-scale condensation schemes belonging to the RPN-CMC library of physics subroutines. A "cloud" scheme is a physical parameterization in an atmospheric model and predicts the effects of a set of cloud microphysical processes. Cloud schemes are invoked when a model grid element reaches saturation or when condensate is already present in a grid element. Through the calculation of processes involving phase changes of the water substances, such as condensation or melting, the model dynamics (i.e. temperature, pressure and vertical air velocity) are affected by latent heating and cooling. The dynamics are also affected due to changes in buoyancy from precipitation loading, whereby downward vertical air motion is induced due to the weight of the condensed water/ice. There is also a feedback though the radiation scheme, which uses liquid and ice water contents predicted from the cloud scheme to compute cloud optical properties. The grid-scale condensation scheme also contributes to the total model precipitation at the surface and, depending on the complexity of the scheme, can provide details about the type precipitation.

2. Description of current version

The scheme currently used in the experimental GEM-LAM-2.5 windows (as of March 2008) is the single-moment version of the Milbrandt-Yau multi-moment bulk microphysics scheme. The total hydrometeor spectrum is partitioned into six categories: *cloud* (small, non-precipitating liquid droplets), *rain* (precipitating liquid drops), *ice* (pristine crystals), *snow* (large crystals and aggregates), *graupel* (moderate-density rimed ice), and *hail* (high-density rimed ice and/or frozen drops). In the single-moment version of the scheme, there is one prognostic variable for each particle category x, the mass mixing ratio, q_x, which is the ratio of the total particle mass concentration to the mass of dry air (with units of kg kg^{-1}). Each predictive mixing ratio variable q_x is advected by the model dynamics. These 3D dynamic model variables, listed in Table 1, are available for output.

Category	Variable	Output Name
cloud	q_c	QCT1
rain	q_r	QRT1
ice	q_i	QIT1
snow	q_s	QNT1
graupel	q_g	QGT1
hail	q_h	QHT1

Table 1. Prognostic 3D variables from the singe-moment Milbrandt-Yau scheme.

The rates of growth and decay for specific microphysical processes, listed below, including the sedimentation of all categories (except *cloud*), are computed and summed appropriately within the scheme to obtain the total rates of change for each of the mixing ratio variables. These tendencies are passed back to the model and used to update the final values of the variables at the end of a model time step. Processes that involve phase changes also affect the air temperature tendency. Processes involving diffusional growth (condensation/evaporation and deposition/sublimation) also produce changes to the water vapour mixing ratio.

Source/sink terms

The tendency equations for the mass mixing ratios of the hydrometeors and water vapour and for the air temperature are listed below. Each term represents a microphysical process. The naming convection for each source/sink term is AB_{xy}, where AB denotes the process, listed in Table 2. The subscripts x and y denote water vapour or hydrometeor categories, where $x, y \in \{v, c, r, i, s, g, h\}$ for *vapour*, *cloud*, *rain*, *ice*, *snow*, *graupel*, *hail*, respectively) and the process is a sink for x and a source for y. For example, ML_{sr} is the melting rate of *snow* to rain; it is a source for *rain* (q_r), a sink for *snow* (q_s), and results in decrease in air temperature (T). The tendency equations are:

$$\left.\frac{dq_c}{dt}\right|_S = VD_{vc} - CN_{cr} - CL_{cr} - FZ_{ci} - CL_{ci} - CL_{cs} - CL_{cg} - CL_{ch}$$

$$\left.\frac{dq_r}{dt}\right|_S = \begin{cases} CN_{cr} + CL_{cr} + VD_{vr} + ML_{ir} + ML_{sr} + ML_{gr} + ML_{hr} - CL_{ri} \\ -CL_{rs} - CL_{rg} - CL_{rh} - FZ_{rh} + SEDI_r \end{cases}$$

$$\left.\frac{dq_i}{dt}\right|_S = \begin{cases} NU_{vi} + FZ_{ci} + VD_{vi} + IM_{si} + IM_{gi} + CL_{ci} - CL_{ir} - CL_{is} - CL_{ig} \\ -CL_{ih} - CN_{is} - CN_{ig} - ML_{ir} + SEDI_i \end{cases}$$

$$\left.\frac{dq_s}{dt}\right|_S = \begin{cases} \delta_{srs} \cdot (CL_{rs} + CL_{sr}) + CN_{is} + VD_{vs} + CL_{cs} + CL_{is} - CN_{sg} - CL_{sr} \\ -CL_{sh} - IM_{si} - ML_{sr} + SEDI_s \end{cases}$$

$$\left.\frac{dq_g}{dt}\right|_S = \begin{cases} \delta_{irg} \cdot (CL_{ir} + CL_{ri}) + \delta_{srg} \cdot (CL_{sr} + CL_{rs}) + \delta_{grg} \cdot (CL_{gr} + CL_{rg}) + CN_{ig} \\ +CN_{sg} + CL_{cg} + CL_{ig} - CL_{gr} - CN_{gh} - ML_{gr} - IM_{gi} + SEDI_g \end{cases}$$

$$\left.\frac{dq_h}{dt}\right|_S = \begin{cases} \delta_{irh} \cdot (CL_{ir} + CL_{ri}) + \delta_{srh} \cdot (CL_{sr} + CL_{rs}) + \delta_{grh} \cdot (CL_{gr} + CL_{rg}) \\ +FZ_{rh} + CN_{gh} + CL_{ch} + CL_{rh} + CL_{ih} + CL_{sh} - ML_{hr} + SEDI_h \end{cases}$$

with

$$\left.\frac{dq_v}{dt}\right|_S = -VD_{vc} - VD_{vr} - NU_{vi} - VD_{vi} - VD_{vs} - VD_{vg} - VD_{vh}$$

$$\left.\frac{dT}{dt}\right|_S = \begin{cases} L_f \begin{pmatrix} CL_{ci} + CL_{cs} + CL_{cg} + CL_{ch} + CL_{ri} + CL_{rs} + CL_{rg} \\ +CL_{rh} + FZ_{ci} + FZ_{rh} - ML_{ir} - ML_{sr} - ML_{gr} - ML_{hr} \end{pmatrix}, \\ +L_s (NU_{vi} + VD_{vi} + VD_{vs}) + L_v (VD_{vc} + VD_{vr}) \end{cases}$$

where L_f, L_s, and L_v are the constants for the latent heat of fusion, sublimation vaporization, respectively, and δ_{xyz} is a delta function, where the subscripts x and y are the source categories and z is the destination category (for accretion processes that result in a different type of hydrometeor).

Symbol	Microphysical process
CL	collection (accretion)
CN	conversion
FZ	freezing
NU	nucleation
IM	Ice multiplication
ML	melting
VD	diffusion of vapour
SEDI	sedimentation

Table 2. Microphysical source/sink terms for the prognostic variables affected by the Milbrandt-Yau scheme.

3. Precipitation types

Based on a combination of explicit quantities predicted from the scheme and diagnostic conditions, the hydrometeor sedimentation rates at the surface are used to compute the precipitation rates for several specific types of precipitation. The output variables for the instantaneous rates and accumulated quantities are summarized in Tables 3 and 4, respectively. Note that these variables are computed within the scheme itself; no post-processing is performed outside. Thus, for processes such as the formation of ice pellets, for example, latent heat release due to phase changes is computed and impacts the model state variables.

Precipitation Rate	Output Name	Units
liquid drizzle	RRN1	$m\ s^{-1}$
liquid rain	RRN2	$m\ s^{-1}$
freezing drizzle	RFR1	$m\ s^{-1}$
freezing rain	RFR2	$m\ s^{-1}$
ice crystals	RSN1	$m\ s^{-1}$
snow	RSN2	$m\ s^{-1}$
graupel (snow pellets)	RSN3	$m\ s^{-1}$
ice pellets	RPE1	$m\ s^{-1}$
hail	RPE2	$m\ s^{-1}$
large hail	RPEL	$m\ s^{-1}$
mixed precipitation	RMX	$m\ s^{-1}$

Table 3. Specific precipitation rates available from the Milbrandt-Yau scheme.

Accumulated Quantity	Output Name	Units
liquid drizzle	RN1	m
liquid rain	RN2	m
freezing drizzle	FR1	m
freezing rain	FR2	m
ice crystals	SN1	m
snow	SN2	m
graupel (snow pellets)	SN3	m
ice pellets	PE1	m
hail	PE2	m
large hail	PE2L	m
mixed precipitation	AMX	m

Table 4. Specific accumulated precipitation quantities available from the Milbrandt-Yau scheme.

For backward compatibility with existing systems, each of the precipitation rates and quantities are summed appropriately such that the total rates and quantities are also available. These include: total liquid rain (including drizzle), RN; total freezing rain, FR; total snow (all types), SN; and ice pellets, PE. The contribution of the precipitation variables from the Milbrandt-Yau scheme to these four variables are summarized in Table 5. Note that for the GEM-LAM-2.5, no deep convective parameterization scheme is used, so the contribution to the variables in Table 5 from the convective schemes comes entirely from the precipitating shallow convective scheme, with the application of the Bourgouin diagnostic to determine the precipitation type.

Variable	**Output Name**	**Description**
liquid rain	RN	RN1 + RN2 + portion diagnosed from convective schemes
freezing rain	FR	FR1 + FR2 + portion diagnosed from convective schemes
snow	SN	SN1 + SN2 + SN3 + portion diagnosed from conv. schemes
ice pellets	PE	PE1 + portion diagnosed from convective schemes

Table 5. Other model precipitation variables and their relation with the variables from the Milbrandt-Yau scheme.

Also, there are four output variables for the rates and accumulated quantities of the total liquid and total solid precipitation from the grid-scale condensation scheme only. The four variables, and their relation to the specific variables from the Milbrandt-Yau scheme, are summarized in Table 6.

Variable	**Output Name**	**Description**
total liquid (rate)	P2	RRN1 + RRN2 + RFR1 + RFR2
total solid (rate)	P4	RSN1 + RSN2 + RSN3 + RPE1 + RPE2
total liquid (accumulation)	A2	RN1 + RN2 + FR1 + FR2
total solid (accumulation)	A4	SN1 + SN2 + SN3 + PE1 + PE2

Table 6. Total precipitation rates and accumulated quantities from grid-scale condensation schemes and their relations to the specific variables from the Milbrandt-Yau scheme.

Notes

The rate (accumulation) of *large* hail [i.e PE2L (RPEL)] is a subset of the rate (accumulation) the *total* hail [i.e PE2 (RPE2)], and thus does not appear in any of the other summed quantities. Hail is considered large if the mean-mass diameter of the hail that is precipitating at the lowest prognostic model level is greater than 1 cm. This threshold is tentative and is intended to be adjusted upon feedback from the community regarding the usefulness of this field.

The rate of the *mixed precipitation* type (RMX) is computed as the total precipitation rate from the grid-scale condensation scheme under the condition that both the total liquid and total solid precipitation rates exceed 0.01 mm h^{-1}. The accumulated mixed precipitation quantity (AMX) therefore includes all precipitation which fell when at least a trace amount of both liquid and solid (but any of the specific types) precipitation were occurring. Thus,

$$RMX = \begin{cases} P2 + P4 & \text{if } [(P2 > \text{min\_val}) \text{ and } (P4 > \text{min\_val})] \\ 0 & \text{otherwise} \end{cases},$$

where *min_val* = 2.78×10^{-9} m s^{-1}.

4. Other fields

Several other diagnostic fields computed in the scheme are also available as output variables.

Synthetic radar reflectivity

Based on the mixing ratio values, the size-distributions and the physical characteristics (shape, bulk density and phase) of each hydrometeor category, the equivalent radar reflectivity, ZET (output variable name), from the Milbrandt-Yau scheme is calculated as:

$ZET = Z_r + Z_i + Z_s + Z_g + Z_h$,

where Z_x is the equivalent reflectivity of each category $x \in \{r, i, s, g, h\}$ (for *rain*, *ice*, *snow*, *graupel*, *hail*, respectively). The units of Z_x are m^{3}m^{-6}, but ZET is converted to dBZ for output. The composite (column-maximum) reflectivity is also available as the 2D output variable, ZEC.

Supercooled liquid water content

The total supercooled liquid water content, SLW [units of kg m^{-3}], predicted by the cloud scheme is also available as a 3D output variable. It is defined simply as,

$$SLW = \begin{cases} \rho_a \cdot (q_c + q_r) & \text{if } T \leq 0^\circ\text{C} \\ 0 & \text{if } T > 0^\circ\text{C} \end{cases}$$

where ρ_a is the air density and T is the air temperature.

Visibility

The visibility, *VIS* [units of km], through fog (*cloud* water) is available as a 3D diagnostic output variable. It is computed from the *cloud* mixing ratio as,

$$VIS = 1.13 \cdot (10^{-9} \cdot \rho_a q_c N_c)^{-0.51},$$

where N_c is the total number concentration of *cloud* droplets. In the current (single-moment) version of the Milbrandt-Yau scheme, N_c is specified as either 80 x10^6 m^{-3} or 200 x10^6 m^{-3} for maritime or continental air masses, respectively. The air mass type is currently specified for the entire model domain.

Mean-mass diameter

The mean-mass diameter, D_x, for each hydrometeor category $x \in \{c, r, i, s, g, h\}$ is available for output. The output variable names are DMC, DMR, DMI, DMS, DMG and DMH [units of m]. Note that these variables are used mainly for experimentation purposes. For the daily GEM-LAM-2.5 runs, the variables are not output.