The Purdue Lin Microphysics Scheme in WRF

Russ Schumacher

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Overview

- Introduction to microphysics schemes
- Introduction to the Purdue Lin scheme
- Tunable coefficients, inputs & outputs
- Sensitivity to the input coefficients
- LUT feasibility

Explicit microphysics schemes

- These schemes are used to parameterize the various forms of water substance at a grid point in a numerical model
  - Vapor
  - Cloud Water
  - Cloud Ice
  - Rain
  - Snow
  - Hail
- Some schemes include all of these species, others neglect some of them
- Most schemes are “bulk” schemes, meaning that a particle size distribution is assumed and mass-weighted mean terminal velocities are used

Schemes available in WRF

Scheme	Number of Variables	Ice-Phase Processes	Mixed-Phase Processes
Kessler	3	N	N
Purdue Lin	6	Y	Y
WSM3	3	Y	N
WSM5	5	Y	N
WSM6	6	Y	Y
Eta GCP	2	Y	Y
Thompson	7	Y	Y

- WRF recommendation: for $\Delta x < 10$ km, a scheme including mixed-phase processes should be used, otherwise it is not worth the added expense
- Most of these schemes are "single-moment" schemes, meaning that only the total mixing ratio is predicted
- Double-moment (prediction of number concentration) and triple-moment (prediction of mean diameter) schemes are gaining favor

The Purdue Lin Scheme

- 2-D microphysics scheme introduced by Lin et al. (1983), and Rutledge and Hobbs (1984)
- Was one of the first schemes to parameterize snow, graupel, and mixed-phase processes (such as the Bergeron process and hail growth by riming)
- Has been used extensively in research studies and in mesoscale NWP
- The version used in WRF has been modified slightly from the original formulation; it was taken from the Purdue cloud model and is documented in Chen and Sun (2002)
- In WRF, microphysics is integrated outside of the RK3 scheme, so that saturation remains correct

- Mixing ratios of cloud water, cloud ice, non-precipitable water, rain, snow, and graupel are predicted at each grid point based on advection, production, and fallout

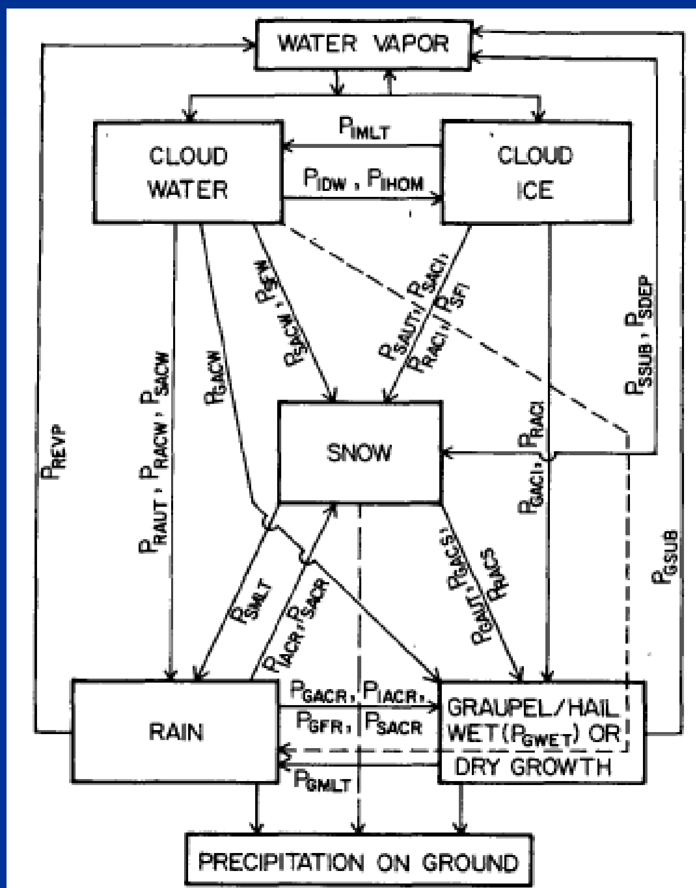


TABLE 1. Key to Fig. 1

Symbol	Meaning
P_{IMLT}	Melting of cloud ice to form cloud water, $T \geq T_0$.
P_{IDW}	Depositional growth of cloud ice at expense of cloud water.
P_{IHOM}	Homogeneous freezing of cloud water to form cloud ice.
P_{IACR}	Accretion of rain by cloud ice; produces snow or graupel depending on the amount of rain.
P_{RACI}	Accretion of cloud ice by rain; produces snow or graupel depending on the amount of rain.
P_{RAUT}	Autoconversion of cloud water to form rain.
P_{RACW}	Accretion of cloud water by rain.
P_{REVP}	Evaporation of rain.
P_{RACS}	Accretion of snow by rain; produces graupel if rain or snow exceeds threshold and $T < T_0$.
P_{SACW}	Accretion of cloud water by snow; produces snow if $T < T_0$ or rain if $T \geq T_0$. Also enhances snow melting for $T \geq T_0$.
P_{SACR}	Accretion of rain by snow. For $T < T_0$, produces graupel if rain or snow exceeds threshold; if not, produces snow. For $T \geq T_0$, the accreted water enhances snow melting.
P_{SACI}	Accretion of cloud ice by snow.
P_{SAUT}	Autoconversion (aggregation) of cloud ice to form snow.
P_{SFW}	Bergeron process (deposition and riming)—transfer of cloud water to form snow.
P_{SFI}	Transfer rate of cloud ice to snow through growth of Bergeron process embryos.
P_{SDEP}	Depositional growth of snow.
P_{SSUB}	Sublimation of snow.
P_{SMLT}	Melting of snow to form rain, $T \geq T_0$.
P_{GAUT}	Autoconversion (aggregation) of snow to form graupel.
P_{GFR}	Probabilistic freezing of rain to form graupel.
P_{GACW}	Accretion of cloud water by graupel.
P_{GACI}	Accretion of cloud ice by graupel.
P_{GACR}	Accretion of rain by graupel.
P_{GACS}	Accretion of snow by graupel.
P_{GSUB}	Sublimation of graupel.
P_{GMLT}	Melting of graupel to form rain, $T \geq T_0$. (In this regime, P_{GACW} is assumed to be shed as rain.)
P_{GWET}	Wet growth of graupel; may involve P_{GACS} and P_{GACI} and must include P_{GACW} or P_{GACR}, or both. The amount of P_{GACW} which is not able to freeze is shed to rain.

Particle Size Distributions

$$n_R(D) = n_{0R} \exp(-\lambda_R D_R),$$
$$n_S(D) = n_{0S} \exp(-\lambda_S D_S),$$
$$n_G(D) = n_{0G} \exp(-\lambda_G D_G),$$

- Intercept parameters:
  - $n_{0R} = 8 \times 10^6$ m^{-4} (Marshall and Palmer 1948)
  - $n_{0S} = 3 \times 10^6$ m^{-4} (Gunn and Marshall 1958)
  - $n_{0G} = 4 \times 10^4$ m^{-4} (Federer and Waldvogel 1975) OR $n_{0G} = 4 \times 10^6$ m^{-4} (Houze et al. 1979; WRF default)

- Slope parameters:

$$\lambda_R = \left(\frac{\pi \rho_W n_{0R}}{\rho l_R}\right)^{0.25},$$
$$\lambda_S = \left(\frac{\pi \rho_S n_{0S}}{\rho l_S}\right)^{0.25},$$
$$\lambda_G = \left(\frac{\pi \rho_G n_{0G}}{\rho l_G}\right)^{0.25},$$

  - $\rho_W = 1000$ kg/m^3
  - $\rho_S = 100$ kg/m^3
  - $\rho_G = 917$ (Lin et al.) OR 400 (Rutledge and Hobbs) kg/m^3

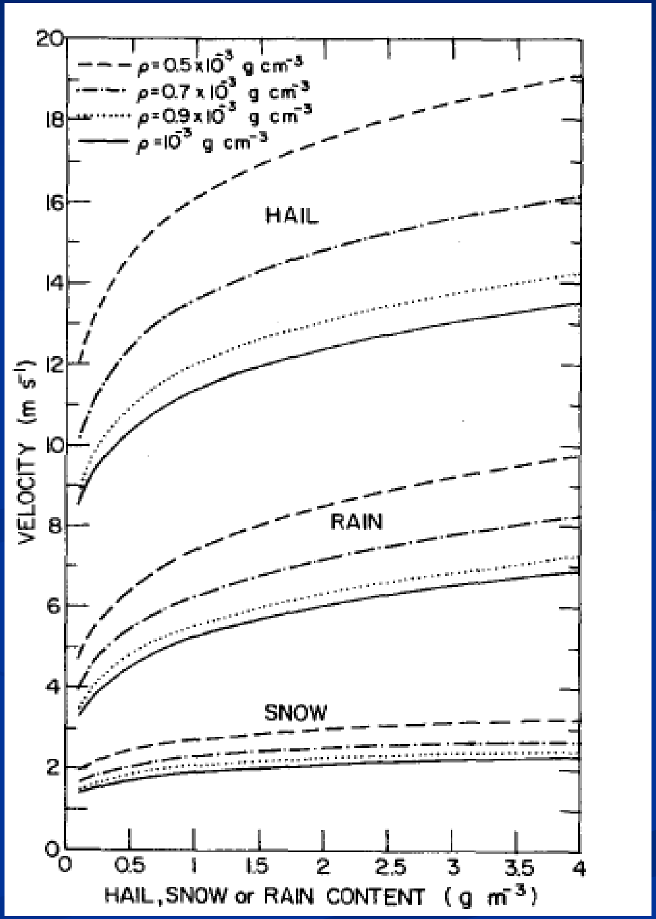
Terminal Velocities

- Terminal velocity of each species is dependent on particle diameter

$$U_{DR} = aD_R^b\left(\frac{\rho_0}{\rho}\right)^{1/2},$$

$$U_{DS} = cD_S^d\left(\frac{\rho_0}{\rho}\right)^{1/2},$$

$$U_{DG} = \left(\frac{4g\rho_G}{3C_D\rho}\right)^{1/2} D_G^{1/2}.$$



- a, b, c, d, C_D are prescribed constants
- These are integrated to get mass-weighted mean terminal velocities:

$$U_R = \frac{a\Gamma(4+b)}{6\lambda_R^b}\left(\frac{\rho_0}{\rho}\right)^{1/2},$$

$$U_S = \frac{c\Gamma(4+d)}{6\lambda_S^d}\left(\frac{\rho_0}{\rho}\right)^{1/2},$$

$$U_G = \frac{\Gamma(4,5)}{6\lambda_G^{0.5}}\left(\frac{4g\rho_G}{3C_D\rho}\right)^{1/2}.$$

Production terms

- An example for rain production:

If T>273.15 K,

Production = autoconversion + accretion of cloud water + melting of graupel + melting of snow – evaporation of rainwater

- Autoconversion (collision-coalescence):

$$P_{\mathrm{RAUT}} = \rho(l_{CW} - l_{W0})^2[1.2 \times 10^{-4} + \{1.569 \times 10^{-12} N_1/[D_0(l_{CW} - l_{W0})]\}]^{-1},$$

- Accretion:

$$P_{\mathrm{RACW}} = \frac{\pi E_{RW} n_{0R} a l_{CW} \Gamma(3+b)}{4\lambda_R^{3+b}} \left(\frac{\rho_0}{\rho}\right)^{1/2},$$

- Evaporation:

$$P_{\mathrm{REVP}} = 2\pi(S-1) n_{0R}\left[0.78\lambda_R^{-2} + 0.31 S_c^{1/3} \Gamma[(b+5)/2] a^{1/2} \nu^{-1/2} \left(\frac{\rho_0}{\rho}\right)^{1/4} \lambda_R^{-[(b+5)/2]}\right] \times \left(\frac{1}{\rho}\right)\left(\frac{L_v^2}{K_a R_w T^2} + \frac{1}{\rho r_s \psi}\right)^{-1},$$

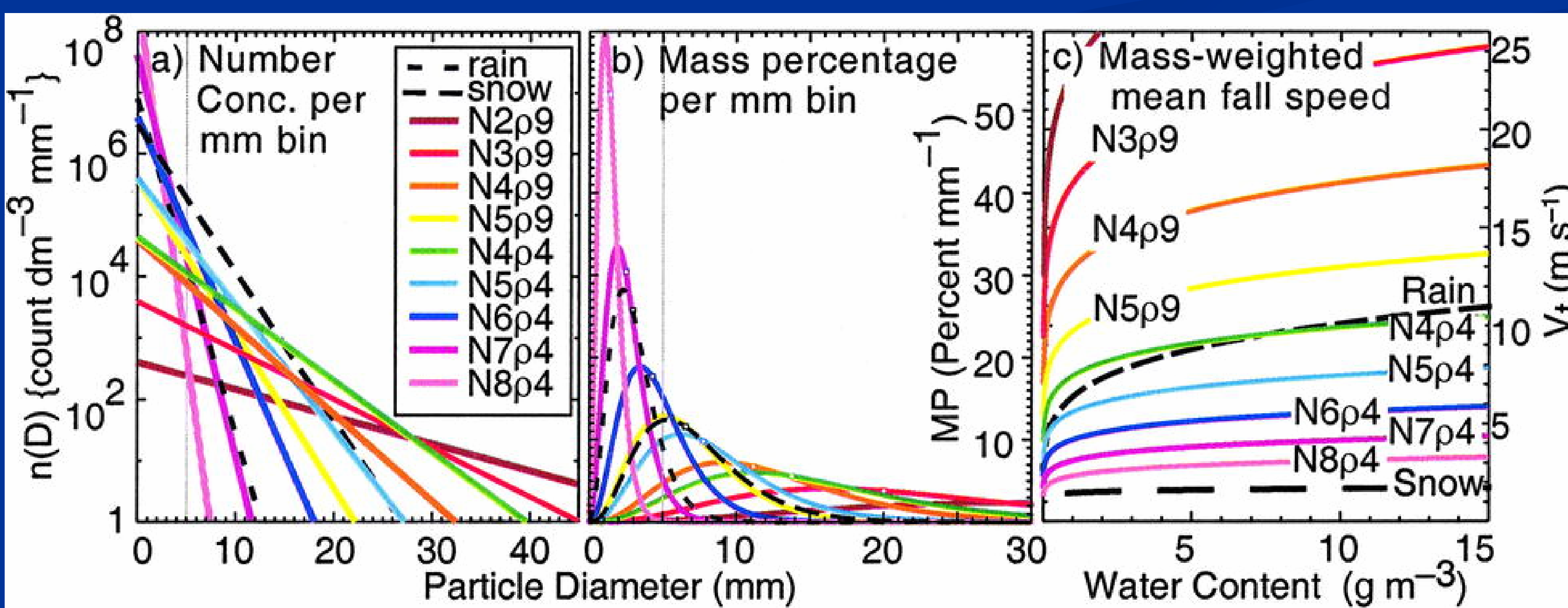
Sensitivity to prescribed constants

- Gilmore et al. (2004) examined sensitivity to changes in n_{0G} (hail size distribution) and ρ_G (hail density)

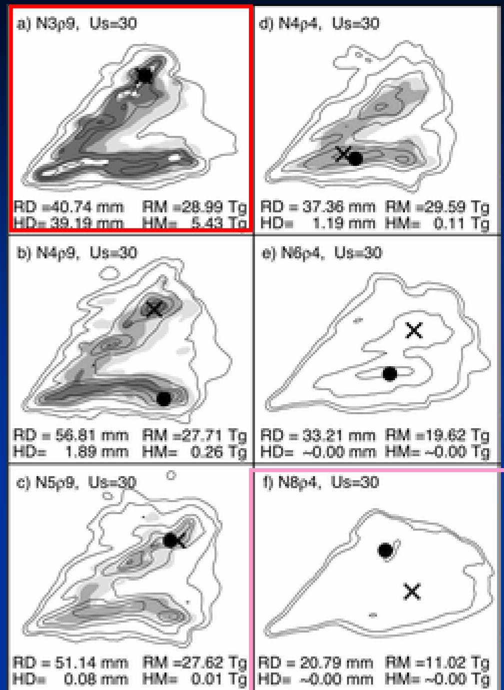
Case name	n_{oh} (m^{-4})	ρ_h (kg m^{-3})	Color key
Warm rain	N/a	N/a	Black
N2ρ9	4×10^2	900	Brown
N3ρ9	4×10^3	900	Red
N4ρ9	4×10^4	900	Orange
N5ρ9	4×10^5	900	Yellow
N4ρ4	4×10^4	400	Green
N5ρ4	4×10^5	400	Light blue
N6ρ4	4×10^6	400	Dark blue
N7ρ4	4×10^7	400	Violet
N8ρ4	4×10^8	400	Pink

Large hail → N3ρ9

Small graupel → N8ρ4



Large hail



Small graupel

Gilmore et al. (2004)

- Simulations biased toward large hail produce stronger cold pools and the most accumulation of hail at the surface; rainfall is maximized in between
- They suggest that single-moment schemes not be used for real-time, cloud-resolving QPF: uncertainties in microphysics are too great
- Can be suitable for research use, however, since researchers can “tune” the parameters to their particular application
- Van den Heever and Cotton (2004) found generally similar results with the RAMS microphysics scheme

Feasibility of LUT approach

- A LUT could be created and used relatively easily for the terminal velocities of rain, snow, and graupel:
  - U_R depends only on density of air and rainwater mixing ratio (similar for U_G and U_S)
  - Recall figures from previous slides: these LUTs have essentially already been created, but in WRF the terminal velocities are still computed each timestep
  - The computational savings from this would be relatively minor

Feasibility of LUT approach

- The creation of a LUT would be more daunting for the rest of the scheme, but could produce substantial computational savings if achieved:
  - 27 production terms; each of which would require its own LUT
  - Some of these terms have only one or two independent variables, but most have 4 (T, ρ, and mixing ratio of two forms, plus several prescribed constants)
  - Fortunately, these variables all have a relatively limited range of possible values
  - To get the final result, almost all of the production terms involve addition, so errors would not grow exponentially