Microphysics Parameterization Changes Based on Observational Studies

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Motivation

• New observational, theoretical and laboratory studies are leading to new parameterization formulas in bulk microphysics schemes
  – Heymsfield, Schmitt, Bansemer and Twohy: Improved representation of ice particle masses based on observations in natural clouds (JAS, 2010)
  – Heymsfield and Westbrook: Advancements in the estimation of ice particle fall speeds using laboratory and field measurements (JAS, 2010)
Mass-Diameter Relation

Heymsfield et al. (2010) use data from 6 field programs

– Tropical/convective: CRYSTAL-FACE (Florida), NAMMA (Africa), TC4 (Costa Rica)

– Mid-latitude/stratiform: ARM SGP 2000, AIRS-2 (Canada), C3VP (Canada)
Mass-Diameter Relation

• Particle Size Distribution (PSD) derived from observations is a temperature dependent gamma distribution of the form
  \[ N = N_0 D^\mu \exp(-\lambda D) \]
  where \( \mu \) is a cubic fit to \( \lambda \), and \( \lambda \) is an exponential function of temperature.

• Note that this PSD is only a function of \( T \) not ice water content (IWC).
Gamma PSD for different T

log N

T warmer

D (cm)
Mass-Diameter Relation

• Fitting IWC measurements to probe size data using this PSD yields a fit over a range of median-mass diameters and temperatures from 0ºC to -60ºC. For the complete dataset, the following function is optimal

\[ m_g = 0.00528D_{cm}^{2.1} \]
Fallspeed-Diameter Relation

• Heymsfield and Westbrook (2010)
  – Use drag coefficient ($C_d$) that accounts for attached boundary layer ($D+\delta$) as a function of Reynolds number (Re)
  – Introduce a new form of Best number ($X* \equiv C_d * Re^2$) that has lab-derived effect of particle sub-circular cross-sectional area factor ($A_r$) on drag
  – These allow derivation of a new $Re(X^*)$ and hence
    \[ v_t = Re \ \eta / \ \rho_{air} \ D \]
  – Note that the $v_t(D)$ relation is not of the form $aD^b$
Log-log $V_t$ versus D for various T
Mass-Weighted Fallspeed

• In microphysics parameterization the mass-weighted fall speed ($V_t$) is required
  – Mass-weighted particle $v_t(D)$ is integrated numerically over the particle size distribution for each temperature
  – $A_r$ also taken to be function of $D$ from field data
• $V_t$ is fitted as a quadratic function of $T$ separately for the tropical/convective and mid-latitude/stratiform datasets
• Since the PSD is self-similar for different IWC at a given $T$, a unique feature of this scheme is that $V_t$ is not a function of IWC, only $T$
Mass-Weighted Fallspeed

Convective (solid)
Stratiform (dashed)
Temperature versus Fallspeed

- Observations seem to support this relation, but there is some spread
- Is this due to neglecting IWC?
Temperature versus Fallspeed

- Different IWC (lines) show no trend
- Fallspeed seems not to be correlated with IWC (also from separate scatter plot, not shown)
- This supports idea of temperature-only function
Initial Implementation in WRF

- Fall speed (convective formula) added to WSM6 microphysics option (not yet other aspects of size distribution)
- Replaces mass-weighted fall speeds from exponential distribution for snow and mass-diameter relation for mean ice crystal diameter
- Since it is independent of IWC, we can just treat ice and snow fall speeds independently
- Tests on hi-res 1 km 22-23 Jan 2006 TWP-ICE case
22/12Z-23/18Z precip rate 3 km domain

QuickTime™ and a BMP decompressor are needed to see this picture.
Comparison: Domain-mean vapor and snow versus time

old

new
Comparison: Domain-mean ice and graupel versus time

old

new
Comparison: Domain-mean rain and cloud water versus time

old

new
Comparison OLR

old

new
Domain-averaged OLR versus time
Comparison 12-hr Precipitation

old

new
Domain-averaged precip accumulation and rate versus time
Summary and Further Work

• Need to evaluate differences against observations

• New fall speeds differ with height leading to
  – Less mean hydrometeor mass suspended
  – Small effect on rainfall
  – Increased OLR effect despite lower ice mass

• Further implementation
  – Apply PSD for microphysical processes that generally depend on particle sizes and fallspeeds
  – Radiation scheme should also be unified to use the same PSD and ice particle properties
Suitability for GCMs

• By being a unified scheme for addressing the PSD and fallspeeds of all non-rimed ice, this can be the basis of a relatively cheap single-moment bulk scheme in climate models with non-rimed ice and snow particles represented by a single array

• It has been derived from observation-based size distributions combined with lab and theoretically-based particle fallspeeds