Parameterizations of Ice Particle Size Distributions and Bulk Microphysical Properties for Cirrus and Stratiform Ice cloud Layers

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andy, for your talk in hawaii can you include some constructive but hard-hitting criticism of the deficiencies of ice microphysics in "bulk" microphysics schemes, such as the ones currently used in most cloud-resolving models?
Outline

• PSD Parameterization Issues
  – Examine data sets

• Develop an Approach
  – Again examine data

• Results

• Summary and Conclusions
Issues (1)

• **Species**, especially ice/snow distinction

• **Ice Particle Densities**
  – Snow, 0.1 g/m$^3$
  – Graupel, 0.3 to 0.4 g/m$^3$
  – Hail, 0.9 g/m$^3$

• **Terminal Velocities**
  – Pressure dependence, “spread”
Issue 2: PSD Parameterization

• **Representation of snow PSDs**
  how do we parameterization the PSDs using one moment schemes in operational forecast models
  strong sensitivity of diffusion growth to the PSD
  terminal velocity affects cloud bulk properties to a minor extent
• **Representation of graupel/hail PSDs**
  terminal velocity crucial (affects riming/LW depletion rates)
  particle density is also crucial
• **Two moment schemes to represent the PSDs**
  predict the total number concentration by species and ice mixing ratio. Are there other, better variables?
PSD Parameterization Issues

• Representation of Snow PSDs

----- Exponentials

\[ N = N_0 e^{-\frac{D}{l}} \]

For Marshall Palmer,
\[ N_0 = 0.08 \text{ (cgs)}, \quad l = 41R^{-0.21} \]

--- For Ice PSDs, \( R \sim V_t \times IWC \sim 100 \text{ IWC} \)

Therefore, \( N_0 \) should be constant, \( IWC^{-p} \)
$N_0$ for ice PSDs is therefore not constant
is loosely related to IWC
$N_0$ is reasonably well correlated with temperature
Typical Citation Spiral  Descent
Spectral Parameters vs Temperature

$A: \lambda$ vs Temperature

\begin{align*}
\lambda \text{ (cm}^{-1}\text{)} \\
\text{Temperature (°C)}
\end{align*}

Interesting
CRYSTAL, ARM DATA SETS

Convective

Stratiform
Parameterization Development

- \( N = N_0 e^{-\Gamma D} \)
- \( \Gamma = 12.2 \times 10^{-0.0245T} \) (after Ryan) stratiform
  - separate for close to convection
- \( \text{IWC} = \left( \frac{\Gamma}{6} \right) N_0 \Pi(D) D^3 e^{-\Gamma D} dD = f(\Gamma/\bar{\Gamma}) \)
- \( R = \left( \frac{\Gamma}{6} \right) N_0 \Pi(D) V_t(D) D^3 e^{-\Gamma D} dD \)
- \( V_t(D) \) from Mitchell (1996), Heymsfield et al. (2001)
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>IWC ( \left[ \frac{g}{m^3} \right] )</td>
<td>( \frac{5.3 \times 10^5 N_0 r \Gamma(3.4+\mu)}{\lambda r^{(3.4+\mu)}} )</td>
</tr>
<tr>
<td>Z ( \left[ \frac{mm^6}{m^3} \right] )</td>
<td>( 1.02 N_0 r \times 10^6 \Gamma(5.7+\mu) )</td>
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<tr>
<td>( D_{mm} ) ( [cm] )</td>
<td>( 3.035 + \mu )</td>
</tr>
<tr>
<td>( dB Z_e ) ( ^1 )</td>
<td>( 10 \log_{10} Z - 7.2 )</td>
</tr>
<tr>
<td>( V_m ) ( \left[ \frac{cm}{s} \right] )</td>
<td>( \frac{303 \Gamma(3.9+\mu) \lambda r^{-0.5 \gamma}}{\Gamma(3.4+\mu)} )</td>
</tr>
<tr>
<td>( V_Z ) ( \left[ \frac{cm}{s} \right] )</td>
<td>( \frac{244 \Gamma(6.3+\mu) \lambda r^{-0.5 \gamma}}{\Gamma(5.7+\mu)} )</td>
</tr>
<tr>
<td>( R ) ( [mm/hr] )</td>
<td>( \frac{5.78 \times 10^4 N_0 r \Gamma(3.9+\mu)}{\lambda r^{(3.9+\mu)}} )</td>
</tr>
<tr>
<td>( A_c ) ( \left[ \frac{cm^2}{m^3} \right] )</td>
<td>( \frac{5.3 \times 10^3 N_0 r \Gamma(2.9+\mu)}{\lambda r^{(2.9+\mu)}} )</td>
</tr>
<tr>
<td>( \varepsilon ) ( [km^{-1}] )</td>
<td>( 0.2 A_c )</td>
</tr>
<tr>
<td>( r_\varepsilon ) ( [\mu m] )</td>
<td>( \frac{107 \Gamma(3.4+\mu)}{\Gamma(2.9+\mu) \lambda r^{0.4 \varepsilon}} )</td>
</tr>
</tbody>
</table>
Median $V_\text{e}$ vs. Spectral Parameters

A: Mass–Weighted Diameter

- TRMM
- FIRE(1), ARM
- FIRE(II)

$V_\text{e}$ (cm s$^{-1}$) vs. $D_m$ (cm)

B: Spectral Slope

$V_\text{e}$ (cm s$^{-1}$) vs. $\lambda$ (cm$^{-1}$)

- Fit (All)
- Param. (TRMM)
- Param. (Midlat.)
$V_{[P]} / V_{[1000]}$ vs. $V_{[1000hPa]}$, cm s$^{-1}$

250 hPa
$\text{Ratio} = 1 + 0.041V_m^{0.61}$

400 hPa
$\text{Ratio} = 1 + 0.034V_m^{0.54}$

500 hPa
$\text{Ratio} = 1 + 0.029V_m^{0.51}$

750 hPa
$\text{Ratio} = 1 + 0.014V_m^{0.46}$

1000 hPa
Summary and Conclusions

- Issues related to parameterizations of ice particle size distributions were examined.
- Representations of PSDs properties in terms of temperature seem promising, especially if convective situations are separated from stratiform regions.
- The slope of the PSDs, $l$, offer the most promise for parameterization.
- Once $l$ is known, IWC yields the intercept parameter (two moment schemes), or a $l$ versus $N_0$ relationship (one moment) can be used to specify IWC.
- Given $l$ and $N_0$, many microphysical, radiative, and radar-related parameters can be derived.
- Eliminate ice/snow species distinction, consider spread of fall velocities and pressure dependence reliably.