Microphysics

Improving QPF and much more …

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Outline

Background

Tests

Results

Applications

Future

Conclusions
NCAR-RAL microphysics research

Goals:
- Improve forecasts of water phase at surface (QPF) and aloft (aircraft icing)
- Incorporate observations from field programs
- Transition to operations (RUC, WRF-RR)

Sponsor:
FAA – Aviation Weather Research Program

Participants:
NCAR: Greg Thompson, Roy Rasmussen, Trude Eidhammer

Collaborators:
John Brown (NOAA-ESRL), Hugh Morrison (NCAR-MMM), Yi Jin (NRL), Istvan Geresdi (Univ of Pecs, Hungary)
Major deficiencies of bulk micro

Autoconversion
- extremely threshold dependent
droplet number concentration issue

Ice nucleation
- vapor deposition (at 100% RH_i)
- Hallet-Mossop
- contact/immersion

Collision/Collection
- efficiencies typically 1.0
- Wisner or Mizuno approximations

Species choices
- habit – snow: constant density spheres
- graupel vs. hail
- assumed number distribution
- constant intercept parameter

Graupel source terms
- most prolific resulting from nearly all water freezing processes:
  - snow riming
  - ice collisions with drops
  - depositional growth

Sedimentation
- melting snow/graupel
- excessive artificial size sorting (2-moment)

Lin, Farley, Orville (1983)
Rutledge & Hobbs (1984)
Ferrier (1993)
Meyers et al (1997)
Seifert & Beheng (2001)
Hong et al (2004)
Morrison et al (2005)
Milbrandt & Yau (2005)
## Microphysics improvements

<table>
<thead>
<tr>
<th>Property or Source/Sink</th>
<th>Deficiency in prior schemes</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cloud water</td>
<td>Monodisperse or exponential distribution</td>
<td>Generalized gamma with variable shape parameter.</td>
</tr>
<tr>
<td>Rain</td>
<td>Single-moment assumes exponential distrib with constant y-intercept</td>
<td>Double-moment (warm-rain vs. melted snow/graupel); proper size-sorting sedimentation.</td>
</tr>
<tr>
<td>Snow</td>
<td>Constant density, spherical snow assumes exponential distrib with constant y-intercept</td>
<td>Variable density (based on size) and assumes sum of 2 gamma distributions based on 9000 observations from mid-latitude storm systems</td>
</tr>
<tr>
<td>Graupel/hail</td>
<td>Exponential with constant intercept parameter</td>
<td>Variable y-intercept parameter attempts to mimic graupel and hail.</td>
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<tr>
<td>Autoconversion</td>
<td>Simple threshold</td>
<td>Follows results of bin model; depends on characteristic diameters that vary according to clean vs. polluted air.</td>
</tr>
<tr>
<td>Collision/collection</td>
<td>Oversimplified with 100% collection efficiency and improper mathematical simplification of true double-integral</td>
<td>Explicit size-dependent collection efficiency and explicit bin-model solution of collection equation double-integral.</td>
</tr>
<tr>
<td>Graupel production</td>
<td>Snow riming threshold to create all graupel</td>
<td>Snow riming to form graupel is less abrupt, more continuous.</td>
</tr>
<tr>
<td>Sedimentation of melting snow/graupel</td>
<td>Mathematically correct not physically correct!</td>
<td>Snow/graupel fall faster as they melt, not slower.</td>
</tr>
</tbody>
</table>
Example: cloud water distribution

Affects “autoconversion”
3 characteristic diameters considered when converting cloud water to rain

Affects accretion
due to changes in MVD

Affects droplet freezing
larger drops more likely to freeze than small drops

Liquid water content = 0.25 g m$^{-3}$

Continental
more drops
smaller mean size

Maritime
fewer drops
larger mean size
Example: snow density and size distribution
Example: snow sedimenting
Example: graupel sedimenting
# Benchmark testing with “ideal” cases

<table>
<thead>
<tr>
<th>Test case</th>
<th>WRF ideal experiment name</th>
<th>Primary purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple 2-D bell-shaped hill</td>
<td>em_hill2d_x</td>
<td>Simple and FAST! No complex dynamics. Test all aspects of microphysics sensitivity.</td>
</tr>
</tbody>
</table>
Benchmark testing with “real” cases

<table>
<thead>
<tr>
<th>Case study</th>
<th>Primary purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990Feb13</td>
<td>WISP – front range winter upslope event with freezing drizzle and snow and seeder-feeder.</td>
</tr>
<tr>
<td>1998Jan30</td>
<td>Shallow stratus cloud, supercooled liquid (no drizzle) observed by NASA Twin Otter.</td>
</tr>
<tr>
<td>1998Feb04</td>
<td>Classic “Nor’Easter” with typical freezing rain; observed by NASA Twin Otter.</td>
</tr>
<tr>
<td>2001Feb01</td>
<td>Strong Pacific-Northwest, fully occluded low pressure observed during IMPROVE-1. Low liquid water content, lots of ice/snow instead.</td>
</tr>
<tr>
<td>2001Nov28</td>
<td>Two strong Pac-Northwest storms interacting with Oregon Cascades, well observed during IMPROVE-2.</td>
</tr>
<tr>
<td>2001Dec13</td>
<td>Two cases of WY wave clouds studied for ICE-L campaign; good tests of ice initiation scheme.</td>
</tr>
<tr>
<td>2002Jun12</td>
<td>Three rather typical squall lines starting in northwest OK, first one part of IHOP experiment; other two cases have disdrometer and dual-pol radar data.</td>
</tr>
<tr>
<td>2005May12</td>
<td></td>
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<tr>
<td>2007Jun12</td>
<td></td>
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<tr>
<td>2007Nov16</td>
<td></td>
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<tr>
<td>2007Nov18</td>
<td></td>
</tr>
</tbody>
</table>
Example: “ideal” bell-hill (2D)

Maritime (25 cm$^{-3}$)

Continental (300 cm$^{-3}$)

HFIP physics workshop, 10 Aug 2011
CO Headwaters: microphysics sensitivities

References:
Ikeda et al, 2010
Rasmussen et al, 2011
Liu et al, 2011 (MWR, in press)
Applications: aircraft/ground icing
The next frontier: “aerosol awareness”

☑️ **Crawl:**
  Constant cloud droplet number that influences precipitation

☐ **Walk:**
  Creating ice and droplet number based on simple, but realistic aerosols

☐ **Run:**
  Full integration with WRF-Chem and multiple aerosol species

HFIP physics workshop, 10 Aug 2011
Input aerosols: sulfates, sea salts and dust

GOCART $2.5^\circ$ (lon) x $2.0^\circ$ (lat) global monthly avg data, 20 sigma levels

Sulfates (all bins) at $k = 0$

Sea salt (all bins) at $k = 0$
Aerosol test: clean vs. polluted airmasses
Aerosol test: clean vs. polluted airmasses

Maritime
fewer drops
much larger mean size
less liquid water content
more drizzle/light rain

Continental
more drops
much smaller mean size
more liquid water content
delayed drizzle/rain
alters upper cloud
Dust (> 1μm) as primary ice nuclei

- **Primary ice nucleation:**
  1) Depends on dust concentration
  2) Based on DeMott et al (2010)
  3) Homogeneous freezing of deliquesced aerosols (T<−30°C)

- **Droplet freezing also depends on :**
  1) Dust concentration
  2) Temperature and droplet size

- **Secondary ice nucleation remains**
Biggest challenges ahead

- Ice initiation
- Input aerosol data
- Grid-spacing_RESOLUTION dependence
- Data assimilation
- PBL issues
Biggest challenges ahead

Ice initiation – how many small ice?
Observations of ice in tropical versus mid-lat clouds
Validation of microphysics, especially tropical systems
Diagnostic products for comparison purposes

Physics interactions:
  • radiation and microphysics
  • PBL and microphysics
  • Cumulus and microphysics

Fractional cloudiness?
Operational vs. research, considerations of CPU time/resources
Cloud modeling workshop case with TC? Including idealized setup
Future: aerosols -> Saharan dust, CCN, IN
Bulk scheme tunings from higher order/complex schemes
Recommendations for “reference configurations”