Do We Need Cloud Microphysics Parameterization to Simulate Convection?

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Objectives

• Examine how well WRF microphysics schemes reproduce the observed cloud properties compared to a no-microphysics simulation

• Estimate the large-scale convection from simulation without microphysics
WRF Simulations

• Warm-season heavy precipitation event (27-31 May 2001)

• 8 WRF microphysics scheme simulations compared with a no-microphysics simulation

• Two-way nesting: 9- and 3-km grid spacing with 41 vertical levels
Surface and Upper Air Stations Used for Data Assimilation

- 15 Extended Facility surface observations and 1 Upper air data at SGP Central Facility

- **3DVAR**: data assimilated for 3 hrs from 05-07 UTC for 15 Surface stations (hourly) and 1 upper air observation at 06 UTC

- **4DVAR**: data assimilated from 06-12 UTC -- every 1 hr for 15 surface stations and every 6 hrs for 1 upper air station (at 06/12 UTC)

- **Control Run (CNTRL)**: No data assimilation
Profiles of Equivalent Potential Temperature and CAPE

- Temporal $\theta_e$ (shading) profile well-captured, but overestimated at low levels
- CAPE (contour) was overestimated
Correlations between No Microphysics and Microphysics Simulations (CNTRL)

$\Theta_e(0-16 \text{ km})$

Height (km)

$\text{CAPE (0-4 km)}$

$\text{CIN (0-4 km)}$

Correlation
WSR-88D vs. Simulated Weather Radar Reflectivity (for > 20 dBZ)

WSR-88D (Vance AF Base)

2001-05-27 06:00:00

SIMULATED (CNTRL)

2001-05-27 06:00:00

Variance explained 30%

Variance explained 18%

Score ($\sigma$)

Reflectivity

dbz

Precipitation (mm)

Time (27-31 May 2001)
Contribution of Hydrometeors to Cloud Radar Reflectivity (%)
Precipitable Water Vapor (PWV) Correlations

• Correlations between observed and simulated PWV were evaluated for 9 x 9 (solid) and 35 x 35 (dashed) grid points surrounding SGP CF
• Large observed-simulated PWV correlations
• Water vapor very well-simulated in all microphysics scheme simulations
• Modal correlations exceed +0.88 for most microphysics scheme simulations
• Correlations are highest for 3DVAR and 4DVAR data assimilation simulations
Estimation of Large-scale Convection

WRF Microphysics fallout (precipitation) terms are computed as downward flux of hydrometeor mass at each time step

\[
(f_{r,s,i,g})_k = \sum_{k=\text{top}}^{\text{bottom}} \Delta \left( \rho_a q_{r,i,g,s} V_{r,i,g,s} \right)_k
\]

For No-microphysics simulation “precipitation” is estimated as

\[
R \propto \frac{1}{\rho_w} \sum_{p=900 \text{ hPa}}^{400 \text{ hPa}} [(q_v - q_{sw})\rho_a + (q_v - q_{si})\rho_a] w'
\]

Reflectivity (mm\(^6\) mm\(^{-3}\)) is computed from R(mm hr\(^{-1}\)) using the Z-R relationship

\[
Z = 300 \ R^{1.4}
\]
Estimated Large-scale Convection (Contd.)

WSR-88D (30%)  ESTIMATED (16%)

EOF1

Scores
Key Conclusions

- Thermodynamic structures of 3 consecutive cloud systems over the SGP CF were assessed.
- Role of microphysical processes in the life cycles of these organized cloud systems was examined through cloud stability analysis of simulations with and without microphysical schemes.
- Equivalent potential temperatures from no-microphysics and microphysics-enabled simulations correlate very strongly.
- Misalignment of lower and upper tropospheric convection is one of the reasons for model inability to simulate the first significant convection.
- The no-microphysics estimated large-scale convection reproduced more realistically the first significant convection compared to microphysics-enabled simulation results.
Thank you
WRF Microphysics Used

- Lin et al. scheme (Lin et al.)
  - 6 classes: rain, WV, CW, cloud ice (CI), snow, graupel
- WRF Single-Moment 5-class scheme (WSM5)
  - Predicts WV, rain, snow, CI, and CW allows mixed-phase processes
- Eta Microphysics (Eta)
  - Predicts changes in WV, CW, CI, rain, and precipitation ice (snow/graupel/sleet)
- WRF Single-Moment 6-class scheme (WSM6)
  - Extends WSM5 by including graupel and associated processes
- Goddard Microphysics scheme (Goddard)
  - Allows ice, snow, graupel processes
- Thompson et al. scheme (Thompson)
  - Ice, snow, graupel processes. Predicts rain number concentration
- WRF Double-Moment 5-class scheme (WDM5)
  - Same as WSM5, but has double moment rain, cloud and CCN for warm processes
- WRF Double-Moment 6-class scheme (WDM6)
  - Same as WSM6, but has double-moment rain, cloud and CCN for warm processes

Physics Options

- MM5 5-layer soil temperature Land-Surface Model (LSM)
- The Yonsei University PBL scheme
- Rapid Radiative Transfer Model (RRTM) longwave radiation scheme
- MM5 shortwave radiation scheme
- The Kain–Fritsch cumulus parameterization for the outer 9 km resolution domain
- No convective scheme for the 3-km resolution inner-nested domain
- 6-hrly NCEP’s FNL Reanalysis for initial and lateral boundary conditions
Cloud Stability Parameters (CNTRL, CAPE)

- No-MP
- Mean-MP
- Lin
- WSM5
- Eta
- WSM6
- Goddard
- Thompson
- WDM5
- WDM6

Graph showing CAPE (J kg\(^{-1}\)) and Precipitation (mm) over time (UTC).
Cloud Stability Parameters -- LCL (Data Assimilation)

No-MP (4DVAR)  Mean-MP (CNTRL)  Mean-MP (3DVAR)  Mean-MP (4DVAR)  Rawinsonde
Profiles of Equivalent Potential Temperature and CAPE

- Temporal $\theta_e$ profile well-captured, but overestimated at low levels
- CAPE was over estimated
3D-Var -- Three-Dimensional Variational data assimilation
   -- Method of obtaining “optimal” estimate of the true atmospheric state
     at analysis time through iterative solution of a prescribed
     cost-function (equation attached)
4D-Var -- Four-Dimensional Variational data assimilation
CAM  -- NCAR Community Atmosphere Model
CNTRL – Control Run
Data Assimilation -- A method of combining all available
   information (observations and previous forecasts/background errors)
   on the atmospheric state in a given time-window to produce an
   estimate of atmospheric conditions valid at a prescribed analysis
   time based on laws of physics.
FDDA/Grid Analysis -- Newtonian nudging in which model solutions are
   relaxed towards gridded-reanalysis
FNL -- NCEP Final Analysis System
IWC -- Ice Water Concentration
LWC -- Liquid Water Concentration
MMCR – Millimeter Cloud Radar
OBS-NUD -- Observational Nudging
PBL -- Planetary Boundary Layer
RRTM -- Rapid Radiation Transfer Model
SFDDA -- Surface Analysis Nudging
WDM5 -- WRF Double-Moment 5-class scheme
WDM6 -- WRF Double-Moment 6-class scheme
WSM5 -- WRF Single-Moment 5-class scheme
WSM6 -- WRF Single-Moment 6-class scheme
WRF -- Weather Research and Forecasting Regional Model
Precip
OMEGA from CMBE