Experiments with a scale and aerosol aware convective parameterization

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Motivation/Outline

Coupled weather and chemistry modeling systems on better and better resolutions:
Need for scale and aerosol aware convective parameterization

– Including transport of chemical compounds,
– Including aerosol interactions
– Use stochastic parameterization
Grell-Freitas Convective Param

- Scale-aware/Aerosol-aware (Grell and Freitas, 2014, ACP)
  - Stochastic approach adapted from the Grell-Devenyi scheme
  - Scale awareness through Arakawa approach (2011) or spreading of subsidence
  - Transitions to shallow-cumulus scheme as grid spacing decreases
    - First temperature & moisture tendencies decrease as resolution increases
    - At very high resolution (dx < 3km) parameterized convection becomes much shallower – cloud tops near 800 mb (down from 200-300 mb).
    - Tendencies in general become very small, practically shutting off below 5 km grid spacing.

The scale awareness: Our adaptation of Arakawa’s approach

1. Define fractional coverage (σ)
   
   = area covered by active updraft and downdraft plume

1. Define very simple relationship between σ and entrainment rate (which is related to radius of plume) – but any other approach may easily be used

2. Initial entrainment rate determines when σ is becoming important (when scale awareness kicks in),
   
   1. maximum allowable fractional coverage determines when scheme transforms itself to a shallow convection parameterization
Grey Zone Project to test scale awareness

The Grey Zone Project (headed by UK Met Office) aims to systematically explore convective transport and cloud processes in NWP models at resolutions ranging from 1 to 16 km.

- For each set of the LAM simulations (at grid spacings of 1, 2, 4, 8, 16 km), two permutations were run:
  1. GF deep-cu scheme OFF GF shallow-cu scheme OFF.
  2. GF deep-cu scheme ON GF shallow-cu scheme ON.

- 36 hour simulations are done using ECMWF analyses beginning at 12 UTC 30 Jan 2010, and used every 6h to generate LBCs for the coarsest domains.

- Two set of 1-way nested domains are used:
  - 16-4-1 km grids
  - 8-2 km grids

Final results after some improvements in the PBL (MYNN-Olson) scheme

Aerosol awareness

Change 1: Change constant autoconversion rate to aerosol (CCN) dependent Berry conversion

\[
\left( \frac{\partial r_{\text{rain}}}{\partial t} \right)_{\text{autoconversion Berry, 1998}} = \frac{\rho_r^2}{60 \left( 5 + \frac{0.0366 \text{ CCN}}{\rho_r m} \right)}
\]

Change 2: Modified evaporation of raindrops (Jiang and Feingold) based on empirical relationship

\[
\text{PE} \sim (L_t)^{a_1} \times \text{CCN}^\xi = C_{pr} (L_t)^{a_1} \times \text{CCN}^\xi
\]

Change 2 introduces a proportionality between precipitation efficiency (PE) and total normalized condensate \((L_t)\), requiring determination of the proportionality constant \(C_{pr}\)

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Aerosol awareness

How do we get CCN?

1. Most sophisticated approach:
   - directly from complex model results (WRF-Chem)
2. Simplest approach:
   - from observed Aerosol Optical Thickness (AOT) at 550 nm (global or regional analysis), following Rosenfeld et al. (2008) and Andreae et al (2008), using
   \[
   AOT = 0.0027 \text{ CCN}^{-0.643}
   \]
3. Or anywhere in between – depending on complexity of model setup

The dependency introduced through precipitation efficiency
- can have a strong effect on downdrafts, but is
- limited by other environmental conditions (e.g., if the precipitation efficiency is already very low, it cannot get much lower, and vice versa)
**Example of 1d sounding test (tropical conditions),
Grell and Freitas, ACP 2014**

- **Polluted** (AOD=1.0)
- **Clean** (AOD=0.01)

1d test show that polluted conditions cause:
- much more detrainment of cloud water and ice at cloud top
- less suspended hydrometeors, especially in lower part of parameterized clouds
- stronger downdrafts. Leading to less drying in and just above the boundary layer, but stronger cooling in lowest levels

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**3D: Evaluate and “train” the parameterization with test case selected by the WGNE working group to evaluate aerosol impact on NWP (using WRF-Chem)**

**Case 3: Extreme biomass burning smoke in Brazil – the SAMBBA case**

**Experiment set-up**

- Aerosol effects: forecast with and without interactive aerosols, including direct and indirect effects.
- Ideally four experiments should be performed:

<table>
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<th>Experiment</th>
<th>Direct effect</th>
<th>Indirect effect</th>
<th>Direct + Indirect effect</th>
<th>No aerosol interaction</th>
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- Duration and time period: 10 days, 05-15 September 2012
- Length: minimum of 3 days forecasts from the 00UTC or 1200UTC analysis with and without interactive aerosols.
- Center of the model domain (for limited area models): 60°W, 10°S
- Model configuration should be compatible with the configuration of the operational system used currently for NWP.
- Initial and boundary conditions for meteo fields can be provided upon by ECMWF (eg MACC) for the limited area models.

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Figure 3: 1d: Pollutant location and accumulated for September 2012 (source: http://www.epe-b.de/australas/) Down: Monthly average of aerosol optical depth at 500 nm from MODIS for September 2012 (source: http://disc.sci.gsfc.nasa.gov/astdsc) The dot with the initials R, P, ... denote AERONET site locations.
3D: Evaluate and “train” the parameterization with test case selected by the WGNE working group to evaluate aerosol impact on NWP (using WRF-Chem)

WRF-Chem full domain is shown in following figures:
- $dx=15km$, 41 vertical levels
- RRTMG radiation, MYNN PBL, Noah land surface, Morrison microphysics
- ECMWF initial conditions, MACC chemistry, South American Biomass Burning Analysis (SAMBBA) case (experiment 3)

Initial runs:
1. WRF, meteorology only (MET)
2. WRF-Chem, gas phase chemistry (RADM2) and modal aerosols (MADE/VBS), direct effect turned on, but no indirect effect (DIR)
3. WRF-Chem, as in (2) but with indirect effect in GF scheme (DIR+IND)
4. WRF-Chem using simple GOCART modules only

First simulation starting at 00z 9 September 2012

Modeled AOD at 21UTC, September 9

BOX A, B, and C are used for further analysis. Initial AOD too low, future runs will include spin-up period
T2M difference fields, 10 September 2012, 1200UTC. Positive (red) is warmer compared to MET.

T2M difference fields, September 10, 2100UTC.

WRF simulations, 24hr total precipitation (MET) and difference fields (MET – DIR) and (MET – (DIR+IND)).

Total rainfall, day 2
Difference direct and semi-direct effect
Difference direct, semi-direct, and indirect effect
Effect of aerosol awareness on vertical profiles of cloud water, ice, snow, and rainwater distribution, 10 Sept 2012, 21UTC: DIR+IND - DIR

Results are similar to the 1d test, but with additional cooling (downdrafts) at lowest levels for aerosol aware simulation.

1-year AMIP/CMIP forecasts – FIM w/ GF
Surface Downward Shortwave (W/m²)
Coupled atmosphere/ocean – FIM240km forecast

JJA: Improved stratocu, overall in FIM CMIP than CFSv2.
DJF: Too much cloud for FIM CMIP, too little for CFSv2.
Conclusions

• As implemented, aerosols have significant but plausible effects on how convection will modify the environment. Higher pollution levels lead to:

  • Less efficient conversion of cloud water to rainwater with more aerosols, resulting in upward shift of rainwater concentrations, and more detrainment of cloud water and ice in upper levels
  • Stronger downdrafts through more efficient evaporation: Since this effect depends on other parameters that regulate downdrafts (such as wind shear or sub-cloud humidity), end results is mixed. But pronounced effect in moist tropical regions
  • As implemented, without any “training”, aerosol awareness in convective parameterization has larger impacts than the direct and semi-direct effects

• Results are sensitive to the background AOD which is the basis on determining the proportionality constants

Future work

• Evaluation over longer time periods (complete SAMBBA period, maybe also case 2 from Beijing) with WRF-Chem
• Comparison to cloud-resolving fully interacting WRF-Chem simulations, aqueous phase chemistry, modal or sectional aerosols
• Use model-predicted CCN (wet-scavenging is still a big question mark)
• Compare with very simple approach: GOCART or only observed AOD
• Experiments with different ensembles for stochasticism
  • Experiments with more interesting stochastic approaches (instead of random number generators)
    • L. Bengtsson et al.: Using cellular automata
    • B.Khouider: Stochastic multi-type particle interacting systems on a lattice
• Aerosol awareness will also be tested in FIM global model using observed (analyzed) AOD fields (60km to 10km resolution)
• Scale awareness is currently under investigation in MPAS global model with global unstructured grid, resolution in one run varying from dx=50km to dx=3km