Using WRF for Parameterization Development: The Making of ECPP in MMF Models

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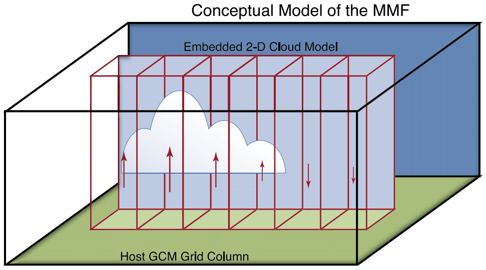
Multiscale Modeling Framework

Conceptual Model of the MMF

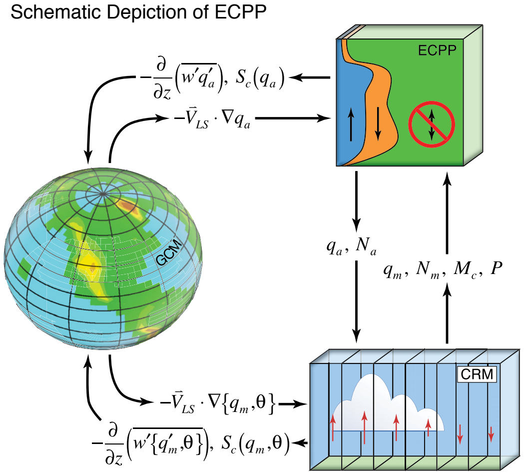


The Multiscale Modeling Framework (MMF) is a modeling technique where the traditional physics parameterizations, e.g. clouds and radiation, are removed from the a global climate model (GCM) and are replaced by embedded cloud-resolving models (CRM) within each grid column.

The ECPP Parameterization

The Explicit-Cloud Parameterized-Pollutant (ECPP) parameterization is a technique to reduce the computational resources necessary to perform aerosol calculations within an MMF model. The chemistry/aerosol species are carried on the coarse, GCM, grid. Information from the embedded CRMs are used to improve the vertical transport of the aerosol, while the aerosol information is used to better represent cloud-aerosol interactions, such as the indirect effects and aqueous chemistry.

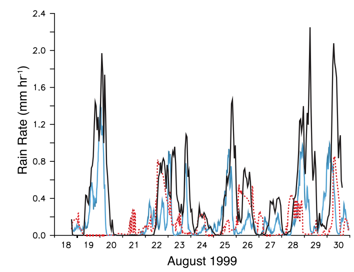
Schematic Depiction of ECPP



Schematic depiction of ECPP showing linkages between ECPP in relation to the host GCM and embedded CRMs in the MMF. Large-scale advective tendencies of tracer species (subscript *a*), moisture species (subscript *m*), and temperature (θ) are provided by the GCM to ECPP and the CRM. ECPP and the CRM exchange information on mass (*q*), number (*N*), cloud mass flux (M_c), and precipitation (*P*), which among other things, are used to determine fractions of area within the GCM column that are assigned to updraft, downdraft, and quiescent draft classes by level. In turn, ECPP and the CRM provide vertical advection and source–sink terms for sub-GCM scales for tracer species (ECPP) and moisture species and temperature (CRM), which are returned to the GCM.

ECPP Proof of Concept

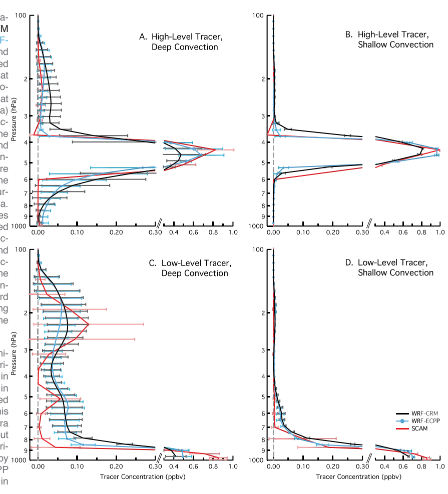
Rain rate time series for University of Washington radar-based observations (blue), WRF-CRM (black), and SCAM (dashed red). Units are mm h^{-1}.



- WRF-Chem as a 3-D doubly-periodic CRM (WRF-CRM)
  - ➢ Represents the CRM embedded within the GCM column in the MMF as well as a proxy for realistic tracer transport and processing
  - ➢ 2-km grid spacing with 122x122x40 grid points to resolve major cloud features
  - ➢ Large-scale forcing tendencies from the Kwajalein Experiment (KWAJEX) in the Republic of the Marshall Islands, 17-31 August 1999
- WRF-Chem as a single column model (SCM) with ECPP (WRF-ECPP)
  - ➢ Represents the GCM column in the MMF
  - ➢ Added ECPP parameterization and removed all other parameterizations
  - ➢ Large-scale forcing tendencies provided by the CRM
- Single Column version of the Community Atmospheric Model (SCAM)
  - ➢ Represents a traditional GCM handling of tracers
  - ➢ Provided the same large-scale KWAJEX tendencies as WRF-CRM

Tracer concentration for WRF-CRM (black), WRF-ECPP (blue), and SCAM (red) based on composites at 12 UTC for profiles initialized at 18 UTC. Panels (a) and (b) are for tracers initialized to one between 400 and 500 hPa, and panels (c) and (d) are initialized to one between the surface and 900 hPa. The composites are further divided by deep convection (a and c) and by shallow convection (b and d). The horizontal bars indicate the standard deviation among the days within the composite.

Note the more uniform vertical distribution of tracer in WRF-ECPP than in SCAM compared to WRF-CRM. This is due to the extra information about cloud height distributions provided by the CRM to ECPP than is available in the SCM.

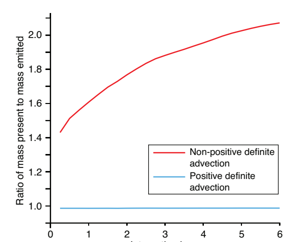


WRF Modifications to Enable ECPP

Changes to WRF were minimal and relatively easy to implement to enable the ECPP proof of concept.

- Changes for WRF-CRM
  - ➢ Implement large-scale forcing tendencies for potential temperature, water vapor, and sea surface temperature using ASCII input files
  - ➢ Add a new chemistry package to handle the inert tracers
  - ➢ Code to reinitialize the tracers at a defined time interval
  - ➢ Output time averaged history output for certain variables, e.g. W
  - ➢ Output domain averaged profiles of some variables for diagnostics
- Offline post-processor for WRF-CRM output
  - ➢ Prepares 3-D WRF-CRM output for use as input to WRF-ECPP
  - ➢ Outputs domain averaged profiles of mass flux masked for predefined categories used by ECPP, e.g. updraft, downdraft, and quiescent regions
- Changes for WRF-ECPP
  - ➢ Code to read input from the post-processor for large-scale forcing tendencies and other necessary ECPP input
  - ➢ The same tracer setup and reinitialization code as in WRF-CRM
  - ➢ Solve_em has been gutted with all 3-D advection and parameterizations calls removed
  - ➢ Dynamical (U, V, & W), state (T & P), and moisture species are set to WRF-CRM horizontal averages
  - ➢ Tendencies for the chem species (currently the tracers) include vertical advection (zero with periodic boundaries) and tendencies from chem_driver, which include the ECPP sub-grid vertical transport and cloud-aerosol interactions

Positive Definite Advection



Ratio of tracer mass present in a test domain to the actual emitted mass for a single point source emitter using the default, non-positive definite advection (red line) and the newer positive definite advection (blue line) schemes.

Using positive definite (PD) advection was critical to the success of this project. Negative mixing ratio values created by numerical errors are replaced with zeros leading to large mass conservation errors without PD advection. The above example shows an error >100% in the worst case scenario.

More Information

Gustafson, W. I., L. K. Berg, R. C. Easter, and S. J. Ghan, 2008: The Explicit-Cloud Parameterized-Pollutant hybrid approach for aerosol-cloud interactions in multiscale modeling framework models: Tracer transport results. *Environ. Res. Lett.*, **3**, doi:10.1088/1748-9326/3/2/025005.

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