“A Unified Convection Scheme: ‘UNICON’

CCSM Meeting. Breckenridge. CO.
June. 21. 2011

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“The Unicorn is the only fabulous beast that does not seem to have been conceived out of human fears. He is fierce yet good, selfless yet solitary, but always mysteriously beautiful. He could be captured only by unfair means, and his single horn was said to neutralize poison.” From the ‘The Unicorn and the Lake’ by Marianna Mayer.
# Evolutions of CAM-CESM1

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<td>CAM5 (L30)</td>
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<td>Modal Aerosol Model (MAM)</td>
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<td>Ocean</td>
<td>POP2 (L40)</td>
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A Strategic Plan for Next Generation CAM6

Organized Plumes

Non-Steady Plumes

CAM5 Physics Core

Shallow Convection (CIN Closure) + Deep Convection (CAPE Closure)

CAM6 Physics Core

Unified Convection
Major Remaining Issues in the Parameterization of Convection

I. Unified Treatment of *Shallow* and *Deep* Convection

II. Unified Treatment of *Dry* and *Moist* Convection

III. Unified Treatment of *Forced* and *Free* Convection

IV. Treatment of *Downdraft Dynamics*

I. Parameterization of *Lateral Mixing*

II. Formulation of *Self-Consistent Closure*

I. *Cloud Overlap* for Microphysics, Radiation, and Aerosol Wet Deposition

II. *Microphysics* interacting with *Aerosols*

III. Convection across the *Scale Barrier*
• Some important ‘features’ (possibly) associated with convection scheme

  – Precipitation Climatology: Double ITCZ, Monsoon, Precipitation over Land, Precipitation FQ, Ratio of Convective to Stratiform Precipitation
  – Lack or weak Diurnal Cycle of Precipitation
  – Lack or weak Madden-Julian Oscillation
  – Too rapid transition from stratocumulus to cumulus along the subtropical transect
  – ENSO characteristics
  – Climate sensitivity of cirrus clouds
  – Global teleconnection
  – Biases of water vapor & clear sky LW radiation (?)
  – Too strong subtropical high in summer (?)
  – Too strong hydrological cycle (?)
  – Many other features since ‘convection’ is the ‘pump’ of the atmospheric circulation
I. Brief Description on the UNICON

II. SCAM5 Simulation:
   • Dry Convection (DCBL)
   • Stratocumulus-Topped Convection (DYCOMS)
   • Stratocumulus to Cumulus Transition (STCU)
   • Shallow Convection (BOMEX)
   • Deep Convection (ARM95, ARM97, GATEIII, TOGAI)

III. CAM5 Simulation
   • Precipitation Climatology
   • Diurnal Cycle of Precipitation
   • Madden-Julian Oscillation
   • Stratocumulus to Cumulus Transition

IV. SUMMARY
Overview of UNICON

I. A completely new vertical transport scheme by asymmetric turbulences designed for addressing the major issues associated with the parameterization of convection:

• Intensive debugging and consistency check: Nov. 2009 ~ Nov. 2010.
• Testing and consistency check: Nov. 2010 ~ Present.
• Code: ~ 10,000 Lines, Computation time: ~ CAM5 shallow convection scheme when n=1.

II. Some of unique aspects of UNICON are

• Consistent closure for all scalars (q_t, \theta_c, u, v, w, A_m, A_#) controlled by the surface fluxes
• Updraft plume mixing rate as a function of plume radius R
• Launch correlated multiple plumes with different thermodynamic properties and R
• Generic treatments of ‘convective downdraft’ and ‘detrainment’
• Treatment of vertical tilting of updraft plume: ‘cumulus-precipitation overlap’ and associated ‘evaporation of convective precipitation’
• No CIN/CAPE closures: Fully dynamic plume model without any equilibrium assumptions
• Unified treatment of ‘shallow/deep’, ‘dry/moist’, and ‘forced/free’ convections
• Explicit treatment of convective organization
• Well-harmonized with the CAM5 symmetric turbulence scheme (i.e., moist PBL scheme)
Forced Convection

Downdraft-1

\[ \alpha = \frac{\theta(\alpha) - \bar{\theta}(0)}{\sigma_\theta} \], \quad \theta = q_t, \theta_v, w, u, v, A_m, A_h, R

\[ N \cdot \int \pi \cdot R^2 \cdot P_n(\alpha) \cdot d\alpha \geq a \leq 1 \]
UNICON
No CIN/CAPE
Unified Shallow-Deep
Unified Forced-Free
R-based Lateral Mixing
Downdraft Dynamics
Self-Consistent Closure
Convective Tilting

EDMF – ECMWF. 07.
Unified Dry-Moist Convection

Arakawa and Schubert 74
Zhang and McFarlane 95
Deep Convective Plumes

Raymond and Blyth 86
Emanuel 91
Downdraft Buoyancy Sorting

Super-Param. 03.
No Scale Barrier

Kane and Fritsch 90
Updraft Buoyancy Sorting

Park and Bretherton 09
Updraft Plume Dynamics
SCAM5 Simulation

Many thanks to John Truesdale for running SCAM training simulations

DCBL  DYCOMS  STCU  BOMEX

ARM95, ARM97, GATEIII, TOGAII

Stable PBL ➔ Dry Conv. ➔ Sc. Conv. ➔ Sc to Shallow Cu ➔ Shallow Cu ➔ Deep Cu

CAM5 Moist Turbulence (Symmetric Turbulent Transport Scheme)

CAM5 Shallow Convection

CAM5 Deep Convection

UNICON

UNICON (Asymmetric Turbulent Transport Scheme)
Dry Convection Case. DCBL
Stratocumulus-Topped Convection
Shallow Moist Convection. BOMEX
Deep Moist Convection. ARM97.

Precipitation Rate at Surface

Convective Organization. UNICON

Updraft Radius at Surface. UNICON
Bias against Observation. ARM97.

ΔT

ΔQ_v

CAM5

UNICON
SCAM comparison of **UNICON** and **CAM5**

**TAYLOR SCORE** = \( \frac{\text{rmse (CAM5,OBS)}}{\text{rmse (UNICON,OBS)}} \) ([T, Q_v])

<table>
<thead>
<tr>
<th>CASES</th>
<th>TAYLOR SCORE OF <strong>UNICON</strong> RELATIVE TO <strong>CAM5</strong></th>
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<tbody>
<tr>
<td></td>
<td><strong>L30. Δt = 1200 [sec]</strong></td>
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<tr>
<td>DCBL</td>
<td>0.89</td>
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<td>DYCOMS</td>
<td>0.99</td>
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<td>STCU</td>
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<td>GATEIII</td>
<td>0.95</td>
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<td>TOGAII</td>
<td>0.71</td>
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<td>Average</td>
<td>0.82</td>
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Global CAM5 Simulation

Precipitation Climatology

Diurnal Cycle of Precipitation

Madden-Julian Oscillation

Stratocumulus to Cumulus Transition

Thanks to Rich Neale and Dani Coleman for providing plotting package of diurnal cycle of precipitation and MJO
Precipitation Climatology. JJA.
Precipitation Climatology: DJF.
Convective (PRECC) vs Stratiform (PRECL) Precipitation. JJA.

CAM5

UNICON

PRECC

PRECL
Diurnal Cycle of Precipitation. JJA.
Convection is forced to be weaker.
Stratocumulus to Cumulus Transition. SON.

CAM5

UNICON
SUMMARY

• **UNICON** (Unified Convection Scheme or more precisely, sub-grid vertical transport scheme by asymmetric turbulences) was finally found after 5 years of intensive search. With CAM5 sub-grid vertical transport scheme by symmetric turbulences (i.e., PBL scheme), UNICON can simulate all sub-grid vertical transports without any missing or double-counting. Similar to CAM5 symmetric turbulence transport scheme, UNICON can be seamlessly applied across any GCM grid size as long as GCM horizontal grid size is larger than the maximum plume radius assumed in the UNICON (~ 1 km).

• In most of the SCAM tests, UNICON showed improved performances both in L30 and L80 with less sensitivity to vertical resolution. Non-local transport and penetrative entrainment are generically simulated by UNICON.

• Global simulation shows that UNICON well captures observed precipitation climatology, MJO and Sc-to-Cu transition. But diurnal cycle of precipitation needs to be further improved. UNICON can be served as an excellent tool to understand the dynamics of MJO and diurnal cycle of convection.

• UNICON is continuously growing. For mature UNICON, I need to provide the following ingredients: I. Objective and through training-tuning using reliable observation-LES test cases spanning a wide range of regimes and processes (e.g., diurnal cycle); II. implementation of detailed aerosol activation and microphysics.