Community Atmosphere Model (CAM)
CAM4 (Track 1)/CAM5(Track 5)

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NCAR
Phil Rasch, Xiaohong Liu, Steve Ghan

PNNL
# CAM Evolution

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<td>Atmosphere</td>
<td>CAM3 (L26)</td>
<td>CAM3.5 (L26)</td>
<td>CAM4/Track 1 (L26)</td>
<td>CAM5/Track5 (L30)</td>
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<td>Boundary Layer</td>
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<td>Park et al. (09)</td>
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<td>Neale et al. (08), Richter and Rasch mods.</td>
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<td>Park et al. (10)</td>
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<td>Radiation</td>
<td>CAMRT (01)</td>
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<td>RRTMG Iacono et al. (2008)</td>
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<td>Aerosols</td>
<td>Bulk Aerosol Model (BAM)</td>
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<td>Modal Aerosol Model (MAM)</td>
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<td>Ghan et al. (2010)</td>
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<td>Finite Volume (96,04)</td>
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<td>POP2 (L40)</td>
<td>POP2.1 (L60)</td>
<td>POP2.2</td>
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<td>Land</td>
<td>CLM3</td>
<td>CLM3.5</td>
<td>CLM4 - CN</td>
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<td>CSIM4</td>
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<td>CICE</td>
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*References:*
- Hack (94)
- Holtslag and Boville (93)
- Zhang and McFarlane (95)
- Rasch and Kristjansson (98)
- Morrison and Gettelman (08)
- Park et al. (09)
- Iacono et al. (2008)
- Ghan et al. (2010)
Microphysics and modal aerosols permit the study of aerosol indirect effects

CAM4

CAM5
Addressing Forcing Uncertainty

Forcings
- Aerosols (MAM) + radiation (RRTM)
- Aerosols + microphysics (MG, #/c) + clouds (UW) + radiation

Feedbacks
- Clouds -> f(moist PBL, ice #/c)
- Radiation -> f(Water vapor)
Arctic Surface Air Temperature Bias (K) in 1850 - Warren

Track 1 (1 deg) vs Track 5 (2 deg)

JJA

DJF

Community Climate System Model
Arctic Surface Low Cloud Bias (%) in 1850 - Cloudsat

Track 1 (1 deg)  Track 5 (2 deg)

JJA

DJF

✓ Freeze drying
✓ Stability based cloud over ocean
✓ Higher water paths
Summer Surface Shortwave Down Differences (NH-JJA, SH-DJF)

Track 5 (2 deg) minus Track 1 (1 deg)

**Clear Sky**

**All Sky**

Net energy input over arctic ice >50%

Track 5 has snow albedos higher than Track 1

Community Climate System Model
Climate Sensitivity

2xCO$_2$ SOM Climate Sensitivity

- Track 1: 3.4 K
- Track 5: 4.5 K
- Track 5 PD aerosols: 3.5 K
- Track 5 1850 PD aerosols: -2.2 K
- CCSM3: 2.8 K
20th Century All Forcing Coupled Simulations

• 1850-2005 forcing fields
  – CCSM4/Track 1 (1 deg), from year 134
  – CESM1/Track 5 (2 deg), from year 893
  – GHGs, solar, large volcanoes burdens
  – Prescribe aerosol burdens and surface deposition (Track 1)
  – Prescribe aerosol emissions predicted surface deposition (Track 5)

• Global, land, hemispheric timeseries
Surface Temperature Change

Global

Year

TS anomaly (K)

0.908
0.862

1860 1890 1920 1950 1980

Land

Year

TS anomaly (K)

0.925
0.841

1860 1890 1920 1950 1980

Northern Hemisphere

Year

TS anomaly (K)

0.900
0.707

1860 1890 1920 1950 1980

Southern Hemisphere

Year

TS anomaly (K)

0.855
0.897

1860 1890 1920 1950 1980

Tracks:
- Track 5 (2 deg)
- Track 1 (1 deg)
- HadCRU
Surface Temp Change (1990-2004) (K)

Track 1 – 1 deg

mean = 0.91
rmse = 1.13
K
mean = 0.65
rmse = 0.68

Track 5 – 2 deg

mean = 0.49
rmse = 0.68
K
mean = 0.29
rmse = 0.38

Community Climate System Model
Short Wave Cloud Forcing Change

Global

Year
1860 1890 1920 1950 1980
Flux anomaly (Wm^-2)

-2.0 -1.0 0.0 1.0 2.0

Track 5 (2 deg)
Track 1 (1 deg)
HadCRU

Northern Hemisphere

Year
1860 1890 1920 1950 1980
Flux anomaly (Wm^-2)

-2.0 -1.0 0.0 1.0 2.0

Land

Year
1860 1890 1920 1950 1980
Flux anomaly (Wm^-2)

-2.0 -1.0 0.0 1.0 2.0

Southern Hemisphere

Year
1860 1890 1920 1950 1980
Flux anomaly (Wm^-2)

-2.0 -1.0 0.0 1.0 2.0

Community Climate System Model
Aerosol and Cloud Changes (1990-2004) (Track 5)

Aerosol Optical Depth (ANN)

- Mean: 0.03
- RMSE: 0.04
- Dimensionless

Low Cloud Fraction (JJA)

- Mean: 0.03
- RMSE: 1.95
- Percent

Short Wave Cloud Forcing (JJA)

- Mean: -1.02
- RMSE: 4.34
- W/m²

Total Grid Ave. Water Path (JJA)

- Mean: 4.18
- RMSE: 9.56
- g/m²

Community Climate System Model
20th C JJA Arctic Sea Ice Change

1990-2004 1850 control

Track 1 (1 deg)

Track 5 (2 deg)
20thC Sea Ice Change
Arctic

Track 1 (1 deg)
Control
20thC

Track 5 (2 deg)
Control
20thC
20thC Sea Ice Change
Antarctic

Track 1 (1 deg)
Control
20thC

Track 5 (2 deg)
Control
20thC
Summary

- CAM4/Track 1 climate has similar behavior to CAM3.5 climate
- Higher resolution (1 deg) results in decreased short-wave cloud forcing in mid-latitudes
- CAM5/Track 5 includes a significant number of physics enhancements
- Aimed at addressing uncertainty in *indirect effects* and *cloud feedbacks*
- Coupled climate is competitive with Track 1 (1deg/2deg)
- Arctic climate has more low cloud cover, but lower water; increased cold bias in winter
- Arctic sea ice sees a significant summer increase in downwelling shortwave
- Necessary for higher albedos at the present
- Although Track 5 has higher climate sensitivity 20th century response finishes cooler than observed and Track 1
- Different response between hemispheres
  - S. Hem. follows observations and Track 1 well
  - N. Hem. remains cool until mid century followed by strong warming in 1980s (AIE)
- Polar sea-ice volume shows significant decline in late 1990s (< track 1)
- Inclusion of turbulent mountain stress has negative impact in Antarctic sea-ice
CAM3 -> CAM5

Physics Changes

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<tr>
<th>CAM3.5</th>
<th>CAM4</th>
<th>CAM5</th>
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<td>✓ Deep convection dilution and convective</td>
<td>✓ Deep convection dilution and convective</td>
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<td>momentum transports</td>
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<td>*Increase sensitivity to tropical humidity;</td>
<td>*Reduced ice cloud fall speeds at 2</td>
<td>*Land vs. ocean tuning for</td>
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<tr>
<td>improves diurnal cycle, variability and</td>
<td>degree resolution</td>
<td>*autoconversion efficiency</td>
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<td>ENSO</td>
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<td>✓ Freeze drying of cold cloud</td>
<td>*More accurate water transport into</td>
<td>*Implicit representation of the affects of</td>
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<td>stratosphere</td>
<td>aerosols on cloud drop size</td>
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<td>✓ Modal Aerosol Model (MAM3)</td>
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<td>*Accounts for aerosol species interaction;</td>
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<td>*predicts aerosol deposition</td>
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<td>✓ 2 moment microphysics (number + size)</td>
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<td>*Allows for activation of aerosols based</td>
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<td>aerosol number availability</td>
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<td>✓ University of Washington (UW) TKE</td>
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<td>*Accurate representation of stable, moist</td>
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<td>boundary layers</td>
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<td>✓ University of Washington (UW) CIN/TKE</td>
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<td>*Boundary layer turbulence driven shallow</td>
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<td>✓ Rapid Radiative Transfer Model</td>
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<td>*Improved radiative calculation of the</td>
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<td>water vapor continuum</td>
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Surface Temp Change (1960-1979) (K)

Track 1 – 1 deg

mean = 0.31, rmse = 0.46

Track 5 – 2 deg

mean = 0.12, rmse = 0.32

Community Climate System Model
Surface Temp Change
2xCO2 experiments

Global

Land Only