State of WACCM6
Update: June 2017

Gettelman, Mills, Polvani
& The WACCM ‘Team’
Thanks to:
Kinnison, Smith, Garcia, Richter, Bardeen, Tilmes, Vitt, Liu
Outline

- Logistics
- State of WACCM
- WACCM6 overview
- WACCM6 configurations
- Beyond WACCM6 (discussion)
  - WACCM6 Configurations
  - WACCM6 for CMIP6, MIPS
  - Future plans
Logistics

• Continental Breakfast: 10:00AM break

• Lunch 12-1:30PM
  • $10 sack lunch on the patio Tues, Wed, Thurs (sandwich, chips, whole piece of fruit, cookie, cold beverage)
  • Full cafeteria options at Center Green and Foothills Lab

• Tuesday
  • 8:30AM-12PM: WACCM in the morning
  • 1:30-3PM: Climate Engineering (South Bay)
  • 3:30-5PM: Simpler Models (South Bay)

• Wednesday
  • 1:30-5PM: Atmosphere Model Working Group
  • 5:30-7PM: Happy Hour at Rayback Collective, 2775 Valmont Road

• Thursday
  • 8:30AM-12PM: Chemistry Climate Working Group
  • 12:30-1PM: Concluding discussions
State of WACCM

“Same as it ever was”

- CESM2 (WACCM6)
  - WACCM6 is done
  - Science freeze will occur once CESM2 is finalized
  - SC, SD, and FR climatologies now available
  - Started piControl steps (next slide)
  - Coupled nitrogen deposition to CLM and ocean BGC added to trunk (testing, no issues)
WACCM-generated forcings for CESM2

- **WACCM6 will create forcing for CESM2**
  - 5-day 2D stratospheric ozone and 3-mode stratospheric aerosol for CAM
  - Monthly 3D oxidants (O3, OH, NO₃, HO₂) for CAM
  - Monthly 3D H₂O production from CH₄ oxidation for CAM
  - Monthly nitrogen deposition for CLM and ocean BGC
- **Iterative steps to piControl**
  1. Run FW1850 20 years with SSTs from B1850 coupled run
     [DONE: Waiting on final CESM2 configuration]
  2. Run B1850 100 years with forcings from step 1
  3. Re-run FW1850 for 20 years with SSTs from step 2
  4. B1850 for another 200-300 years with forcings from step 3
  5. BW1850 for 250 years (WACCM6-CMIP6 Control)
WACCM6
WACCM Working Group
WACCM6 major advancements

• Updated (and unified) chemistry
  • Better ozone hole evolution
  • Combined tropospheric and stratospheric chemistry

• Prognostic Stratospheric Aerosols
  • Better prediction of response to volcanic eruptions

• WACCM6 matches CAM6 physical parameterizations
  • Aerosol and Cloud adjustments made to CAM6 for WACCM6

• WACCM-X with interactive thermosphere
  • Simulations of the upper atmosphere

• Improved stratospheric variability
  • Internally generated QBO
  • SSW climatology improved
## Column Physics and Chemistry

<table>
<thead>
<tr>
<th>Process</th>
<th>CESM1 (WACCM4) CCMI</th>
<th>CESM2 (WACCM6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Resolution</td>
<td>1.9°x2.5°</td>
<td>0.95°x1.25°</td>
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<tr>
<td>Vertical Layers</td>
<td>26/66/88</td>
<td>32/70/88</td>
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<tr>
<td>Boundary Layer</td>
<td>HB</td>
<td>CLUBB</td>
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<tr>
<td>Shallow Convection</td>
<td>Hack</td>
<td>CLUBB</td>
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<tr>
<td>Deep Convection</td>
<td>ZM</td>
<td>ZM</td>
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<tr>
<td>Macrophysics</td>
<td>R&amp;K</td>
<td>CLUBB</td>
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<tr>
<td>Microphysics</td>
<td>R&amp;K</td>
<td>MG 2.0</td>
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<td>Radiation</td>
<td>CAMRT</td>
<td>RRTMG</td>
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<tr>
<td>Aerosols</td>
<td>Bulk</td>
<td>MAM4</td>
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<tr>
<td>QBO</td>
<td>Nudged to Observations</td>
<td>Interactive</td>
</tr>
<tr>
<td>Chemical Mechanism</td>
<td>180 species</td>
<td>228 Species</td>
</tr>
<tr>
<td>Chemical rates</td>
<td>JPL-11</td>
<td>JPL-15</td>
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<tr>
<td>Sulfate SAD</td>
<td>Prescribed (CCMI)</td>
<td>Interactive (MAM)</td>
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<td>ICE SAD</td>
<td>Bulk Scheme</td>
<td>MG 2.0</td>
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<tr>
<td>Solar Variability / ETF</td>
<td>NRLSSI v1 (Judith Lean)</td>
<td>CMIP6 (NRLSSI2/SOLSTICE)</td>
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<tr>
<td>GHG abundances</td>
<td>Meinshausen, 2011</td>
<td>Meinshausen, 2016</td>
</tr>
<tr>
<td>Halogens</td>
<td>WMO, 2010</td>
<td>Meinshausen, 2016</td>
</tr>
</tbody>
</table>
Prognostic Stratospheric Aerosol
with VolcanEESM SO$_2$ inventory (Neely and Schmidt)
Prognostic Stratospheric Aerosol compares well to lidar observations

Mills et al. (JGR, 2016)
Prognostic Stratospheric Volcanoes

Prognostic stratospheric aerosol is coupled to radiation and chemistry.

Stratospheric temperature anomalies due to heating from volcanic aerosols are improved with **prognostic treatment** over prescribed treatment in **CCSM4/CESM1**.

Mills et al. (JGR, 2016)
Top-of-atmosphere radiative flux response to Pinatubo eruption agrees well with satellite observations.

Mills et al. (submitted to JGR, 2017)
Prognostic Stratospheric Aerosols:

Global average stratospheric aerosol optical depth compared to CMIP6 prescribed

Excellent agreement with CMIP6 during satellite era (1979-present)
CESM2(chem): Increasing non-volcanic layer due to OCS emissions

CMIP6: constant in non-volcanic periods, based on 1996-2005 levels

CMIP6: 1850-1978 eruptions not consistent with source (Arfeuille et al., 2014)
WACCM-X in CESM2
Now with an ionosphere (750km)

Ionosphere F-region Peak Electron Density Height

- WACCM-X in CESM2 interactive ionosphere
  - Ionospheric electrodynamics, ion transport and ion temp
- Image ionosphere peak electron density height matches COSMIC obs
  - Measure of ionosphere electrodynamics
Ice Microphysics #1: Wet Stratosphere

- CAM4/WACCM4 consistent stratospheric H2O (free running or specified dyn)
- CAM5.5/WACCM5.5 too wet when using specified dyn
- Why? MG too little deydration (using gridbox average RH for growth)
- WACCM6/CAM6: Add subgrid-scale factor for RH based upon cloud fraction
Ice Microphysics #2: Polar Water & Ice

- Ice and H2O in the polar strat affect heterogeneous chemistry and O3
- WACCM5.5: too much dehydration and too little ice surface area v. WACCM4
- Changes to Ice Nucleation, Ice min size & Fall Speed
- The adjustments are also beneficial in the upper troposphere.
WACCM6 Climatologies

• Specified Chemistry simulation for 1975-2014
• Specified Dynamics simulation of year 2011
• Free-Running simulation with data ocean: 1975-2014
Temperature
FR-WACCM6

Tropics: 10°N-10°S
Cold point bias < 2K

SH (60°S-90°S)
Bigger biases in LS (may affect O3)
Tropical LS Water Vapor
Tape Recorder

Tape recorder has only small biases
WACCM6-SC
SH 60°S-90°S Temperatures

Temperatures look ‘OK’ in SH
Note: LS difference snot significant

Thanks to: R. Garcia
WACCM6 O3 v. OBS
MERRA T, MLS O3 (60-90S)

- FR WACCM (a few years F2000)
- Seems to show LS temperature biases
- In the SH Polar LS
- Warmer T → Less O3 loss
- Note: T biases similar in WACCM-SC, LS not significantly different
Ozone Hole Evolution
WACCM SD 2011: Total O3

Comments:

CCMi & WACCM6 compare well to TOZ observations for year 2011.

- Polar NH (60N) Spring maximum: CESM2 is more consistent with OMI.
- Polar SH (60S) Spring maximum: CESM2 is more consistent with OMI.
- Polar, SH Spring: There is more depletion near 1 Oct (day 270) in CCMI.
- Polar, SH, Winter: CESM2 has lower TOZ in May and throughout the winter.

D. Kinnison
Multiple realizations needed to fully assess polar ozone depletion. (1950-2014)
Cold Summer Mesopause

WACCM6, 3 years vs SABER observations 2002-2016

Summer mesopause
- June
  - WACCM warmer than SABER (134K vs 129K)

Other discrepancies:
- WACCM global mesospheric T too warm
- WACCM summer stratopause too cool
- WACCM summer mesopause altitude too low (probably related to overall high mesospheric T)

Thanks to: A. Smith
SAO in equatorial zonal wind

- WACCM has some semiannual variation but much weaker than the observation-based SAO and wrong vertical structure.
- This suggests a need for changes in the momentum forcing by resolved and/or parameterized waves.

Thanks to: A. Smith
WACCM6 QBO
N1 simulation WACCM-SC run

(Garcia Talk)
Sudden Stratospheric Warmings

- Climatology better than WACCM4, seen some variability in frequency
- Latest estimate using a 20 day separation criteria is 18/28 years, or ~0.64/yr. Close to obs (~0.5-0.6/yr)
- Not sure of final results.
- Counts very sensitive to March it seems
WACC M6 Configurations

• ‘Full’ WACC M (WACC M6) 1°
  • 70L, full chemistry, 140km lid
  • FW2000, FWHIST, BWHIST, BW1850

• WACC M6-SC 1°
  • 70L, fixed ozone and oxidants, 140km lid
  • FWHISTSC

• WACC M-X 2.0 (2°)
  • 126L, 750km lid, WACC M4 physics
  • Ionospheric Physics, Transport
  • FWX Comp Set

• Other options (not full scientific support):
  • High vertical resolution: L110 Initial condition
  • Reduced Chemistry: Middle atmosphere mechanism exists
  • Will also have 2° versions
WACCM6 Release Comp Sets

• CESM2.00 Release
  • FWHIST (1950-2015)
  • FW1850
  • FW2010climo
  • BW1850
  • FWscHIST, FWmaHIST (unsupported at release)
  • FX2000climo, FXHIST, FXSD

• CESM2.0.1 Release (CMIP6 configuration)
  • DECK Experiments (BWHIST, BW4xCO2,BW1PCT)
  • WACCM-SC DECK Experiments (FWscHIST, BWHIST, BW4xCO2,BW1PCT)
  • FWSD
Future WACCM Plans

Gettelman, Mills, Polvani

& The WACCM ‘Team’
Discussion Outline

• WACCM6 Configurations Review
• WACCM6 for CMIP6 (MIPs...)
• Beyond WACCM6/CESM2: emerging science
WACCM6 Configurations
What are we missing?

- ‘Full’ WACCM (WACCM6) 1°
  - 70L, full chemistry, 140km lid
  - FW2000, FWHIST, BWHIST, BW1850
- WACCM6-SC 1°
  - 70L, fixed ozone and oxidants, 140km lid
  - FWHISTSC
- WACCM-X 2.0 (2°)
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  - Ionospheric Physics, Transport
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- Other options (not full scientific support):
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WACCM For CMIP6

‘DECK’ Experiments

• **WACCM6 will create forcing for CESM2**
  1. Run FW1850 20 years with SSTs from B1850 coupled run
  2. Run B1850 100 years with forcing
  3. Re-run FW1850 for 20 years
  4. B1850 for another 200-300 years
  5. BW1850 for 250 years (WACCM6-CMIP6 Control)

• **WACCM6 Deck**
  • BW1850 (#5 above)
  • 1%/yr, 4xCO2, AMIP (1979-2014), 20\textsuperscript{th} Century (x3)

• ScenarioMIP: SSP5-8.5, SSP3-7, SSP2-4.5, SSP1-2.6
WACCM6: MIP, MIP, MIP

- QBOi (Richter)
- Solar Variability (Marsh)
- Dyn Var (Marsh, Simpson)
- VolMIP (Mills)
- ISA-MIP (interactive stratospheric aerosols: Mills)
- AerChemMIP (Lamarque/Emmons)
- GeoMIP (Tilmes)
Beyond WACCM6/CESM2

- WACCM-X $\rightarrow$ WACCM6X (merge up to WACCM6)
- Global Electric Circuit
- High vertical resolution (SAO)
- Heterogeneous Chemistry Updates
- FAST-J or TUV
- Other emerging science issues?