State of WACCM

A. Gettelman, L. M. Polvani, M. Mills
+ “WACCM Team”

WACCM4/5 Highlights

- CCMI Simulations (Kinnison)
- WACCM Last Millennium Run
- GEOMIP Experiments (Mills)

WACCM6 Current Plans/Progress

- Updated Chemistry (From CCMI): Kinnison
- Updated Gravity Wave Schemes: Garcia
- Inertial Gravity Waves: Smith
- Internally Generated QBO: Richter
- Prognostic Stratospheric Aerosols: Mills
- WACCM-X Ionospheric Electrodynamics: Liu, Solomon
- WACCM5.5: Santos, Gettelman

Status of WACCM CCMI Simulations

Base CCMI simulations (REFC1, REFC1SD, and several REFC2)

- Simulations were completed last year. Unfortunately, the necessary improvement in the cold pole bias in these simulations was not scientifically justifiable.
- Anne Smith and Rolando Garcia have recently settled on a new approach that is acceptable for finishing these simulations (see Anne Smith's talk today).
- Simulations were started yesterday!

Evaluation of polar chemical processes (in SD)

- Examination of polar processes using the SD-WACCM / MERRA simulation has been conducted. This work has been submitted to JGR (Solomon et al., 2015).
- Agreement between model constituents and Aura MLS, OMI observations are excellent. The importance of accurate temperatures and sulfate SADs distributions are highlighted (See Doug Kinnison talk today).

Tropospheric processes in preliminary CCMI simulations.

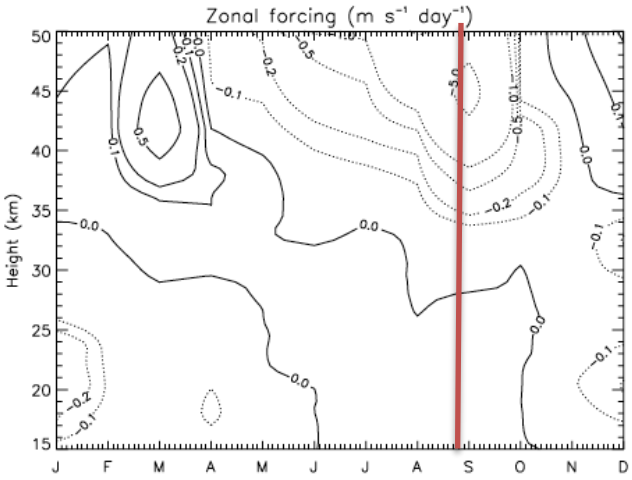
- Examination of constituent distributions in CAM-Chem and WACCM simulations have show good agreement in the troposphere. This is encouraging since CMIP6 simulations will include the full tropospheric chemistry using the high top configuration. See Simone Tilmes talk on Thursday (CCWK).

CCMI annual meeting will be held 7-9 October 2015, in Frascati/Rome (Italy)

Inertial Gravity Waves & GW Tuning

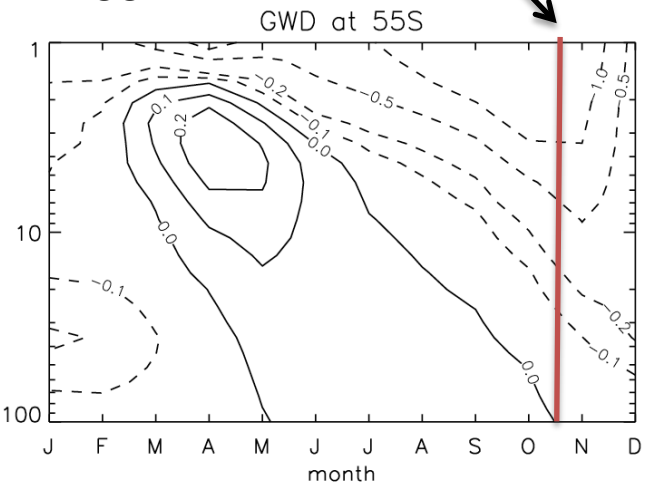
A. K. Smith

momentum forcing derived from radiosondes at 55°S from Zink and Vincent, JGR, 2001

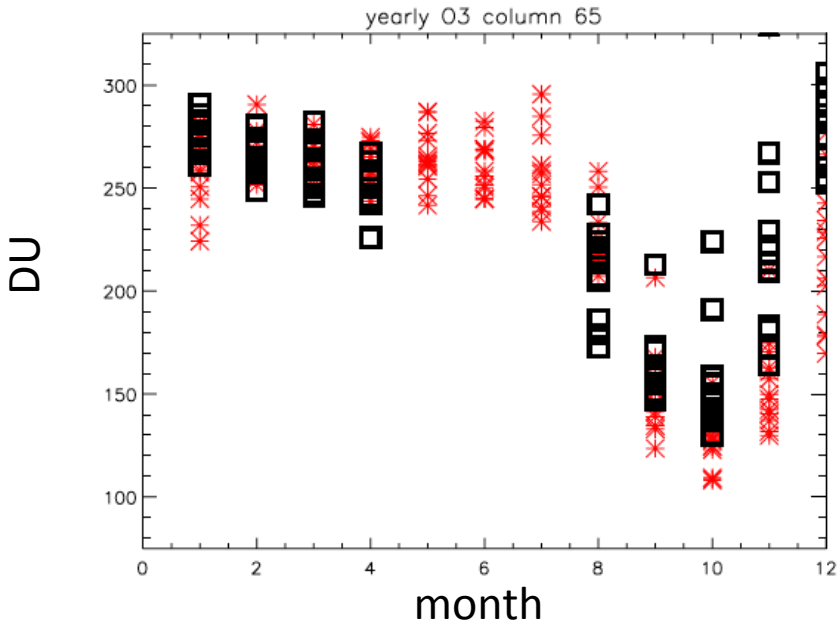


delay

WACCM



WACCM column O_3 (red stars) and Halley obs (black squares) 1995-2007



COMPROMISE

- GW forcing in SH is realistic except delayed by more than a month
- ozone hole development is OK but column amount is a bit low

Quasi Biennial Oscillation (QBO) in CESM-WACCM5

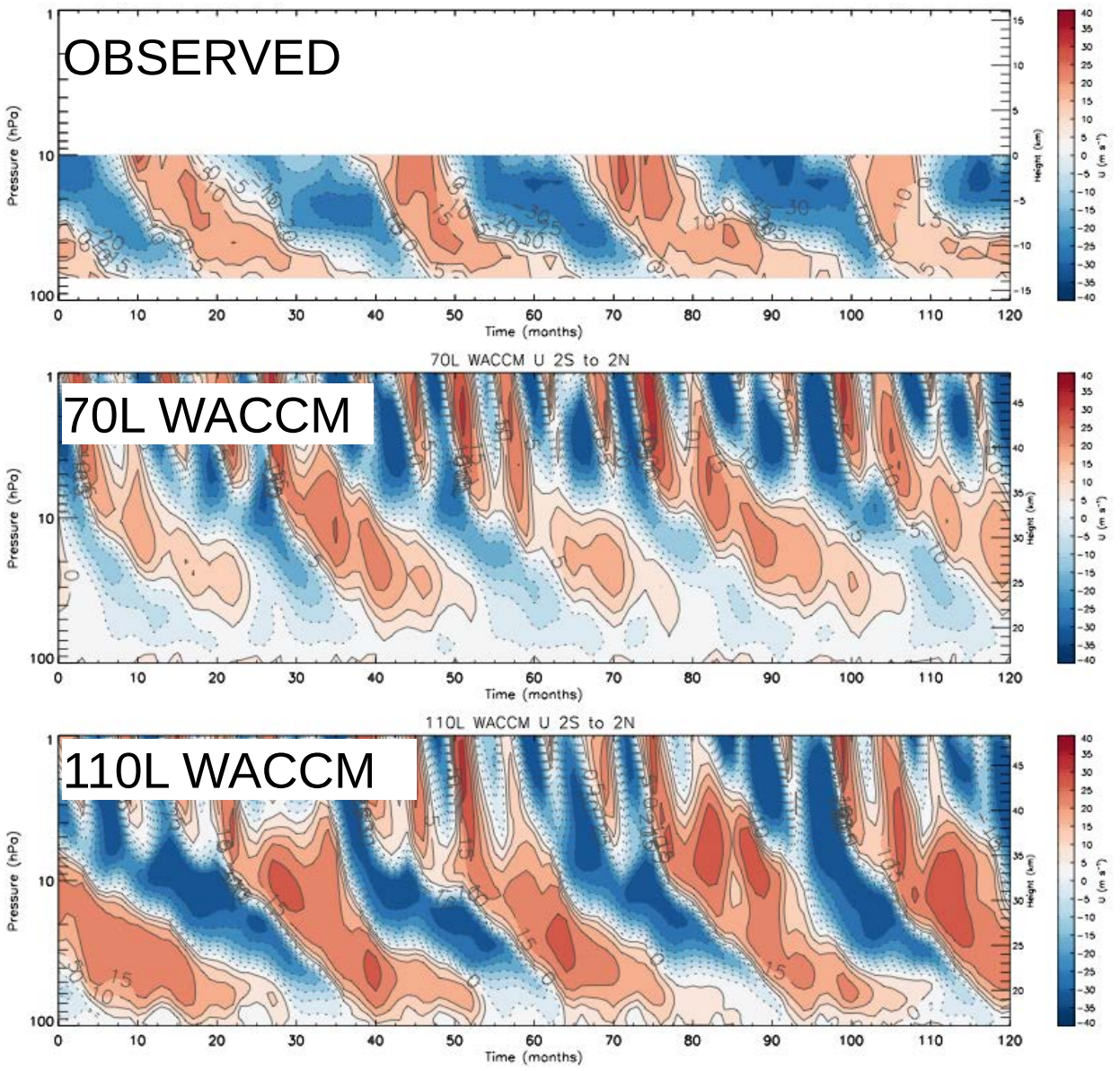
- CESM-WACCM5 can simulate the QBO
- Expect to have a version of WACCM6 with a QBO

70L (standard WACCM5.3)
Looks 'okay'

110L 'Ideal'

From J. Richter

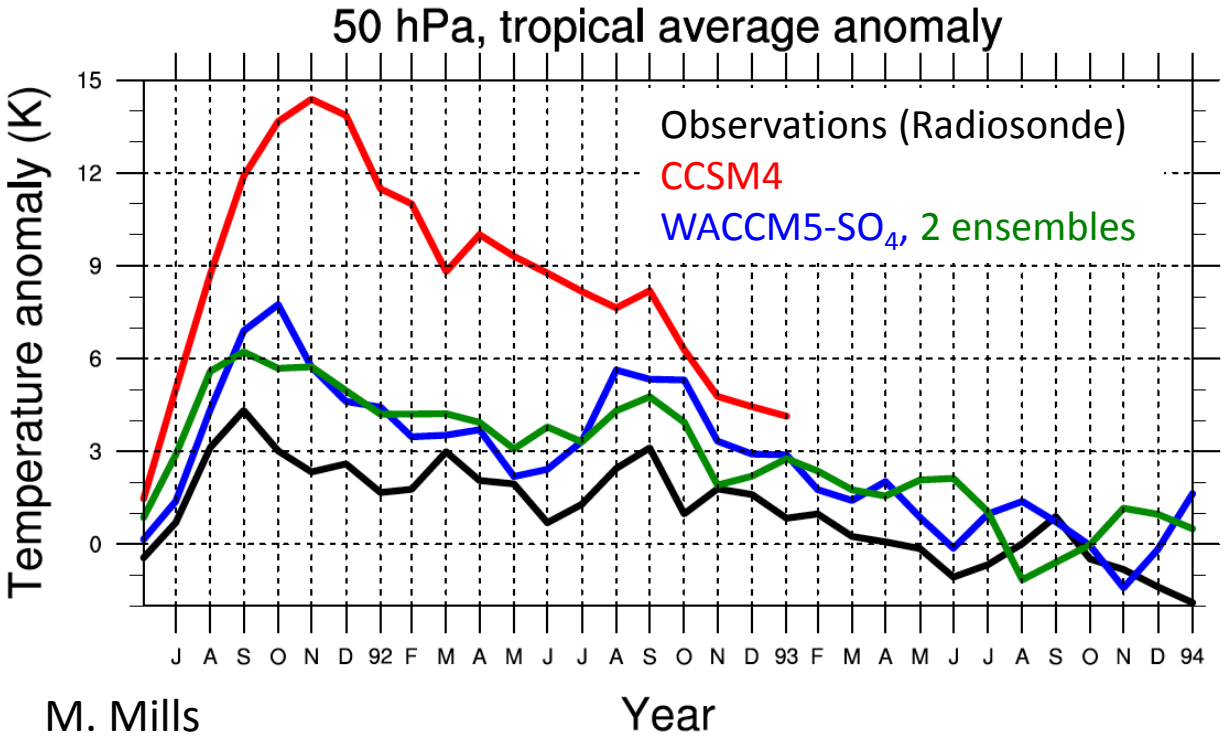
Equatorial Zonal Wind (U)



Prognostic Stratospheric Sulfur (Volcanoes)

- Modal Aerosol Model (MAM) modified to simulate stratospheric sulfur
- Input: specified emissions of SO_2/SO_4 : also working on a community dataset
- For WACCM, but can be used by all versions of CESM2
- Better representation of volcanic effects on climate (see below)

Uses: Historical Runs, Paleoclimate Volcanoes, Geo-engineering, Recent Attribution



M. Mills

Temperature anomaly after the Mt. Pinatubo eruption (June 1991).

Stratospheric Sulfur WACCM5 (1,2) better reproduces radiosonde observed temperature anomalies than CCSM4.

Next Steps….more volcanoes

Old Database with 13 Volcanoes from 2000 to 2010

Volcano	Eruption Date	SO_2 Injected (Tg)	Max. Injection Height (km)	VEI
Ulawun (Ul)	2000.74	0.05 [Deshler et al., 2006]	15	4
Ruang (Ru)	2002.73	0.055 [Prata and Bernardo, 2007]	20 [Prata and Bernardo, 2007] 16* [Tupper et al., 2007]	4
Reventador (Ra)	2002.83	0.096 [Carn et al., 2009]	17	4
Anatahan (At)	2004.28	0.065 [Prata and Bernardo, 2007]	15 [Prata and Bernardo, 2007]	3
Manam (Ma)	2005.07	0.18 [Prata and Bernardo, 2007]	19 [Kamei et al., 2006]	4
Sierra Negra (Si)	2005.81	0.36 [Thomas et al., 2009]	15 [Thomas et al., 2009; Geist et al., 2007]	3
Soufrière Hills (So)	2006.38	0.2 [Prata and Bernardo, 2007]	20 [Prata and Bernardo, 2007]	3
Tavurvur (Ta)	2006.76	0.125 [Prata and Bernardo, 2007]	17 [Prata and Bernardo, 2007]	4
Jebel at Tair (Jb)	2007.75	0.08 [Carn et al., 2009]	16 [Carn et al., 2009]	3
Chaiten (Ch)	2008.34	0.01 [Carn et al., 2009]	19* [Carn et al., 2009]	4
Okmok (Ok)	2008.53	0.122 [Prata et al., 2010]	16 [Arnoult et al., 2010]	4
Kasatochi (Ka)	2008.60	1.7 [Corradini et al., 2010]	14-18 [Waythomas et al., 2010] 18* [Bitar et al., 2010]	4
Sarychev (Sa)	2009.44	1.4 [O'Neill et al., 2012]	17 [O'Neill et al., 2012]	4

Neely et al. GRL 2013

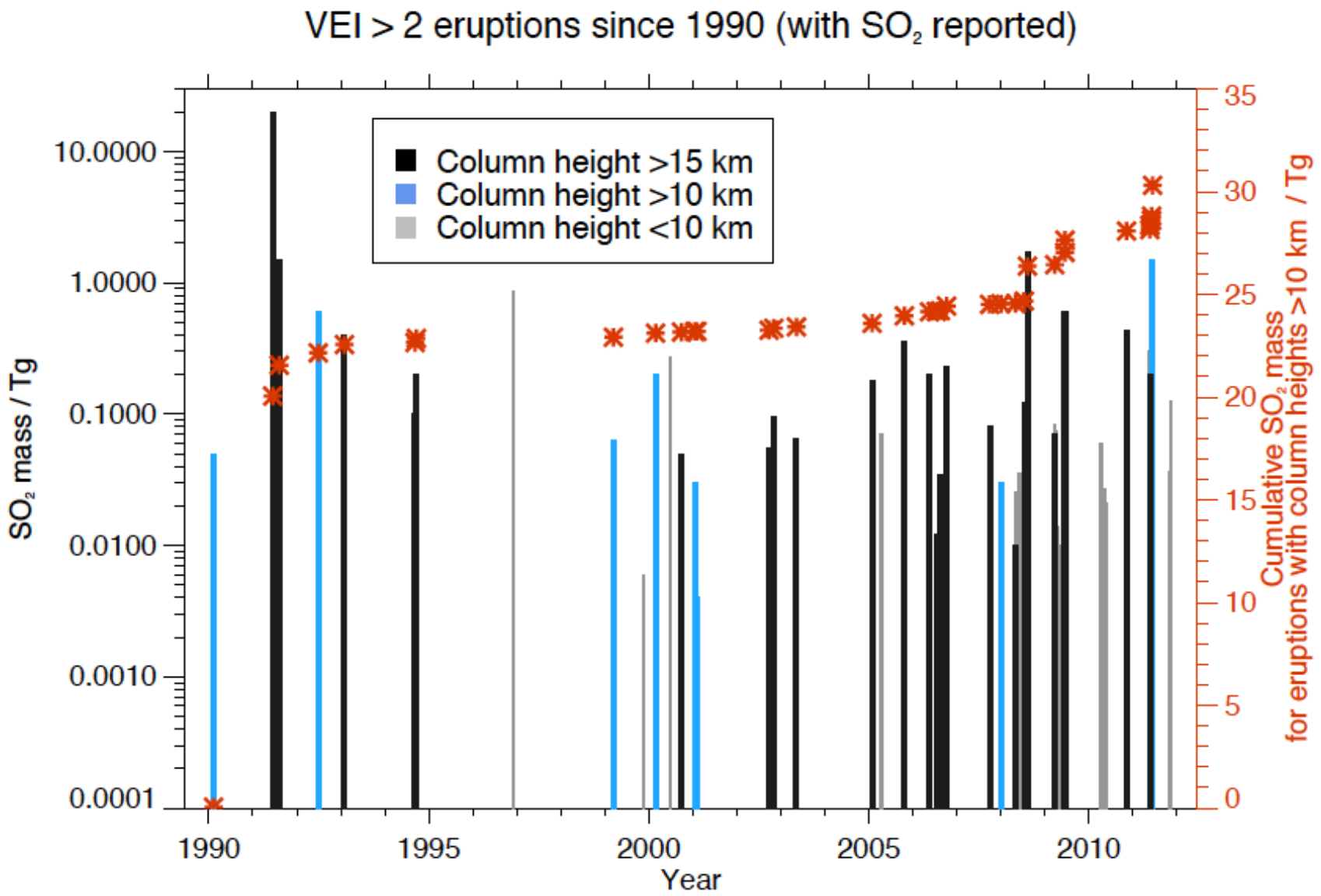
Current Database with 110 Volcanoes from 1990 to 2012

Volcano	VEI	Year	SO_2	Height
Kelut	4	1990	0.09000	32.0
Pinatubo	6	1991	20.00000	29.0
Hudson_Cerro	5	1991	1.80000	28.0
Spurr	4	1992	0.40000	24.0
Lascar	4	1993	0.40000	20.0
Klyuchevskoi	3	1994	0.10000	20.0
Rabaul	4	1994	0.20000	20.0
Nyamuragira	3	1998	0.80000	8.8
Shishaldin	3	1999	0.06000	10.7
Tungurahua	3	1999	0.03000	6.5
Hekla	3	2000	0.20000	11.0
Miyake_Jima	3	2000	0.27000	2.0
Ulawun	4	2000	0.09000	19.0
Ulawun	3	2001	0.09000	14.0
Cleveland	3	2001	0.03000	11.0
Ruang	4	2002	0.09000	20.0
Reventador	4	2002	0.09000	16.8
Anatahan	3	2003	0.06000	19.0
Manam	4	2005	0.18000	19.0
Anatahan	3	2005	0.07000	10.0
Negra_Sierra	3	2005	0.36000	19.0
Soufriere_Hills	3	2006	0.20000	20.0
Tungurahua	3	2006	0.01200	
Tungurahua	3	2006	0.03600	
Rabaul	4	2006	0.29000	18.0
Jebel_At_Tair	3	2007	0.08000	16.0
Llaima	3	2008	0.09000	12.0
Cerro_Azul_Galapagos	1	2008	0.02682	8.0
Cerro_Azul_Galapagos	1	2008	0.00972	8.0
Chaiten	4	2008	0.01000	21.0
Cerro_Azul_Galapagos	1	2008	0.00179	8.0
Cerro_Azul_Galapagos	1	2008	0.00277	8.0
Cerro_Azul_Galapagos	1	2008	0.01603	8.0
Cerro_Azul_Galapagos	1	2008	0.01886	8.0
Cerro_Azul_Galapagos	1	2008	0.02828	8.0
Cerro_Azul_Galapagos	1	2008	0.01799	8.0
Cerro_Azul_Galapagos	1	2008	0.00717	8.0
Cerro_Azul_Galapagos	1	2008	0.00303	8.0
Cerro_Azul_Galapagos	1	2008	0.01103	8.0
Cerro_Azul_Galapagos	1	2008	0.03668	8.0
Okmok	4	2008	0.12200	19.0
Kasatochi	4	2008	1.70000	18.0
Redoubt	3	2009	0.07000	18.0
Redoubt	3	2009	0.08400	10.0
Redoubt	3	2009	0.02760	6.0
Redoubt	3	2009	0.01680	9.0
Redoubt	3	2009	0.07920	8.0
Redoubt	3	2009	0.01770	7.0
Redoubt	3	2009	0.03960	8.8
Redoubt	3	2009	0.01400	7.0
Redoubt	3	2009	0.01260	8.0
Redoubt	3	2009	0.01260	6.0

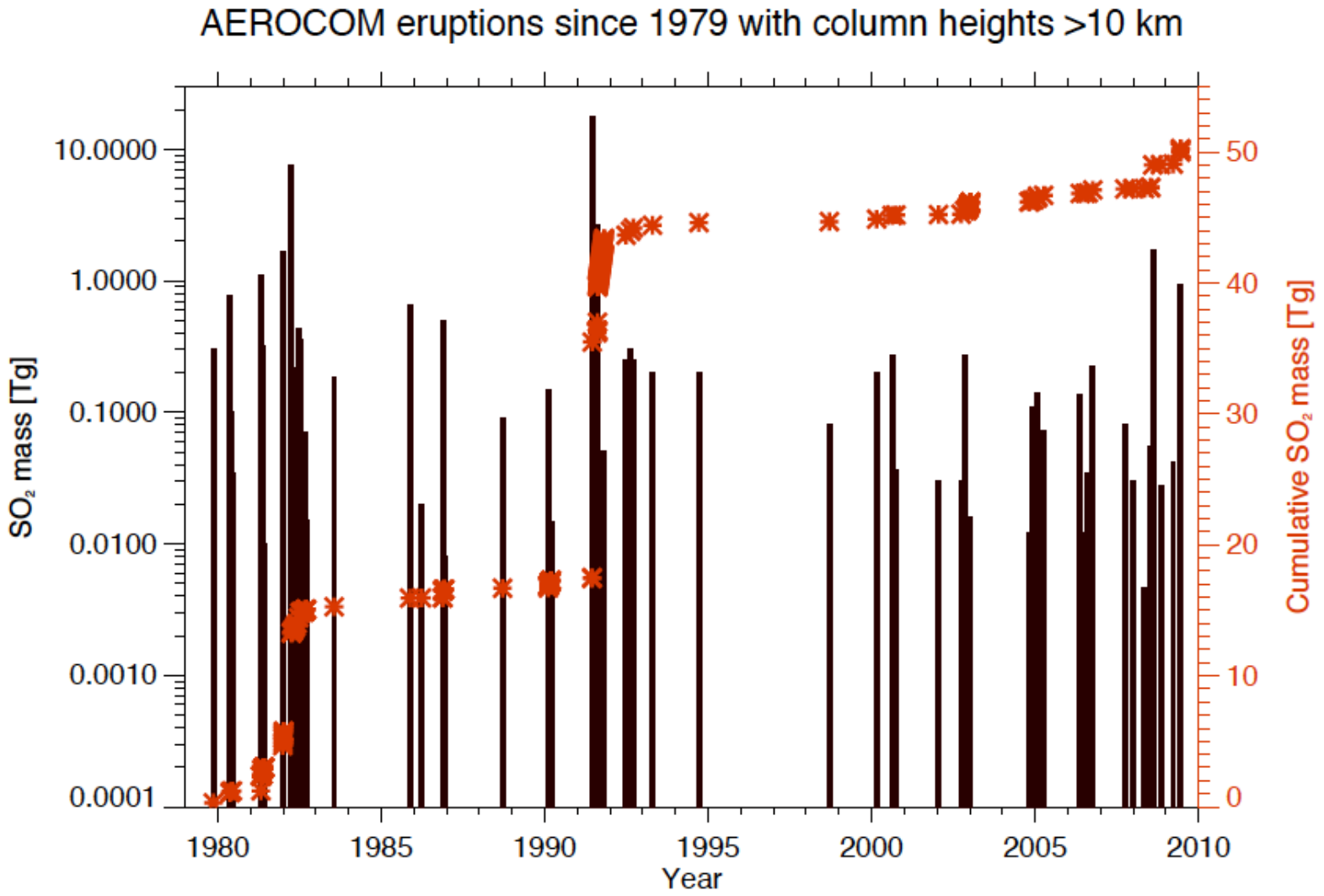
New Database with ??? Volcanoes from 1850 to 2012

Volcanic Eruptions

A. Schmidt



Volcanic Eruptions (since 1980)



Volcanic Emissions

Neely, Schmidt (Leeds), Mills

- Next Steps: Develop a database of volcanic SO2 emissions.
  - Push this all the way back to 1783 (Laki)
  - Includes 1850-present ‘CMIP’ period
- Working with CMIP6 group, focusing on spreadsheet of emissions we can turn into a netCDF file.

WACCM/CARMA Update

- Improved Aerosols
  - Added support for fractal particles (Wolf, Bardeen)
  - Cleaned up sulfates (Mills, Bardeen)
    - Added Lyman-alpha photolysis
    - Added quantum yields to visible photolysis
    - Added Kelvin effect for water
    - Corrected wet deposition (no removal on ice, corrected rates)
    - Corrected heterogeneous chemistry rate calculations
    - Added support for neutralization
- Projects
  - Polar Stratospheric Clouds (Zhu)
  - Internally Mixed Aerosols (Yu)
  - Meteor Smoke (Bardeen, Feng, Brooke)
  - Meteor Smoke & Sulfates (Bardeen, Brooke)
  - Volcanic Aerosols (Jegou)
  - Meteor Impact (Bardeen)
  - Polar Mesospheric Clouds (Bardeen)

WACCM-SE NE120NP4/L209

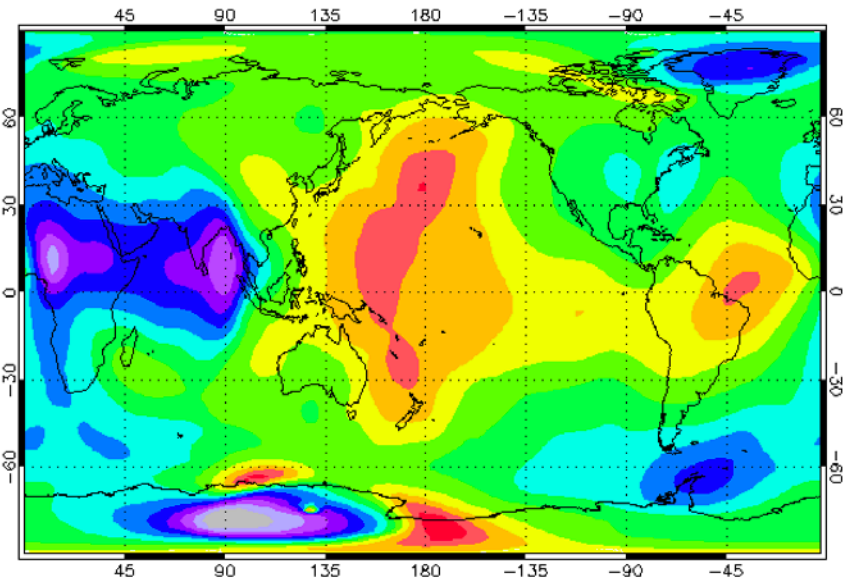
Liu

- Hi-Resolution (horiz & vert) WACCM
  - SE dy-core
- Finished 1.5 model-year simulation.
- Spatial structure and seasonal variation of resolved gravity wave energy density and absolute momentum fluxes in good agreement with SABER analysis.

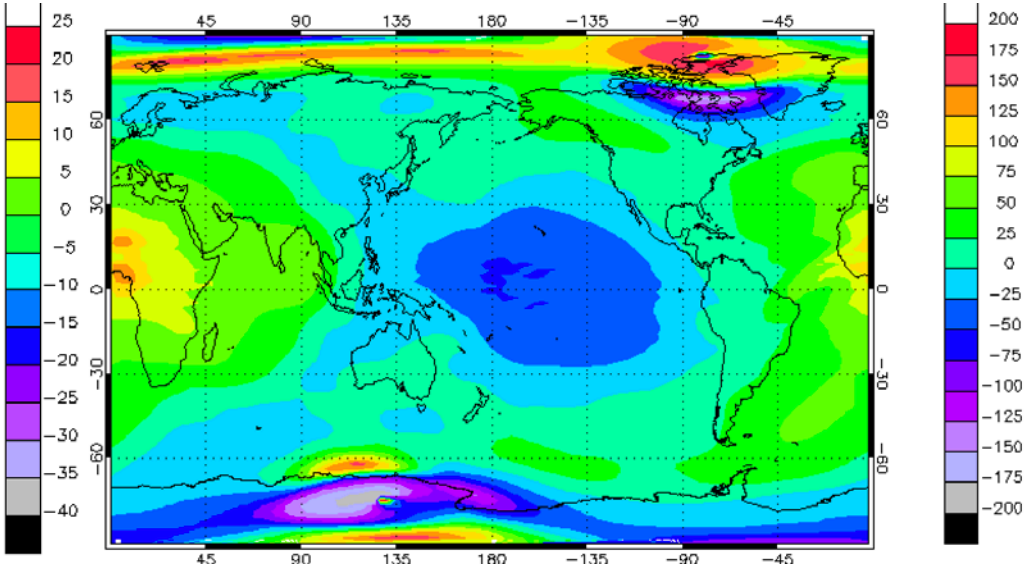
WACCM-X: Vertical and Zonal Drifts

Liu

Vertical



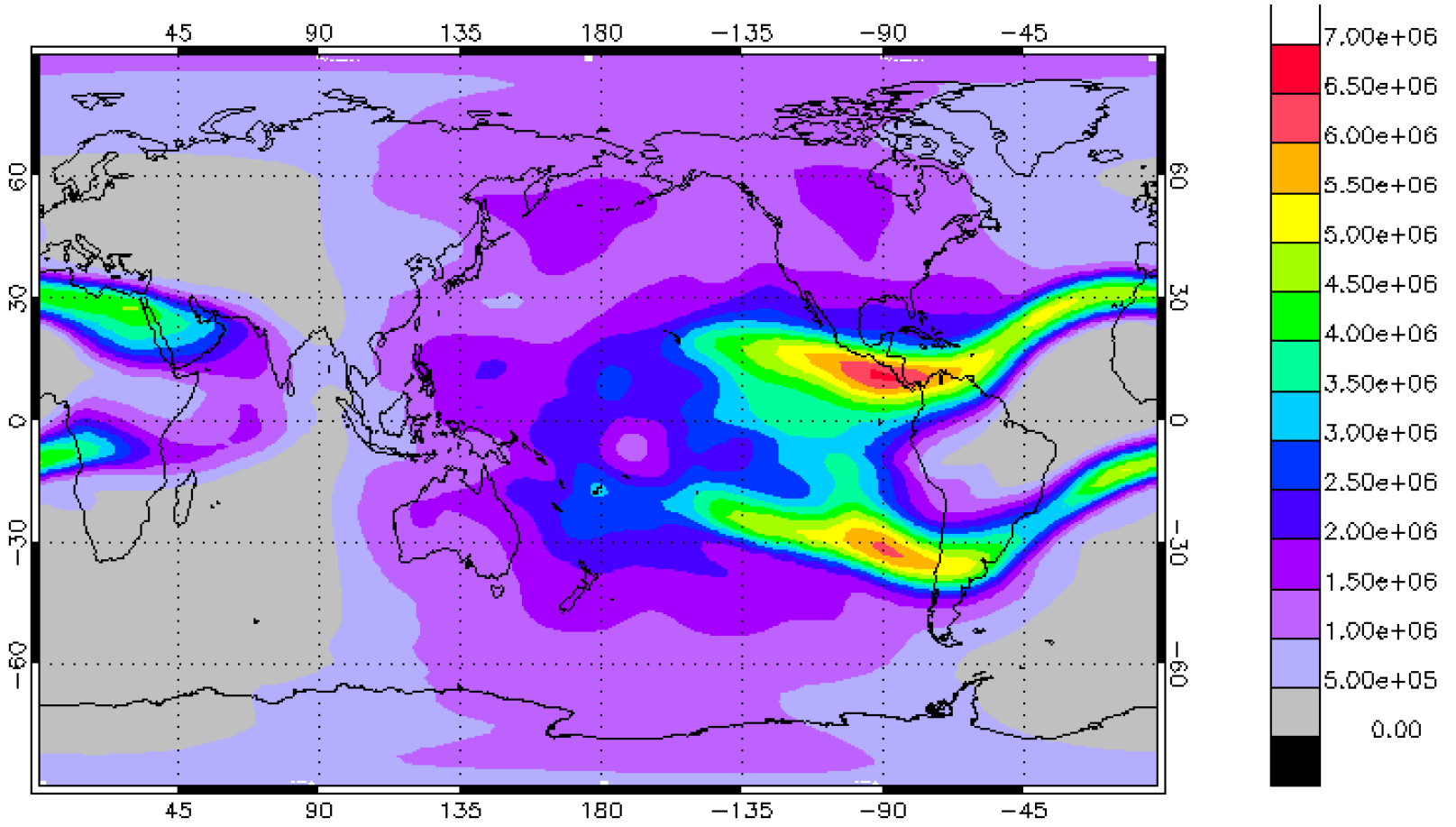
Zonal



- Interactive ionospheric electric wind dynamo has been implemented.
- Vertical and horizontal plasma drift in good agreement with climatology: upward during day downward at night, and a clear pre-reversal enhancement.

F-region O+ Density

Liu



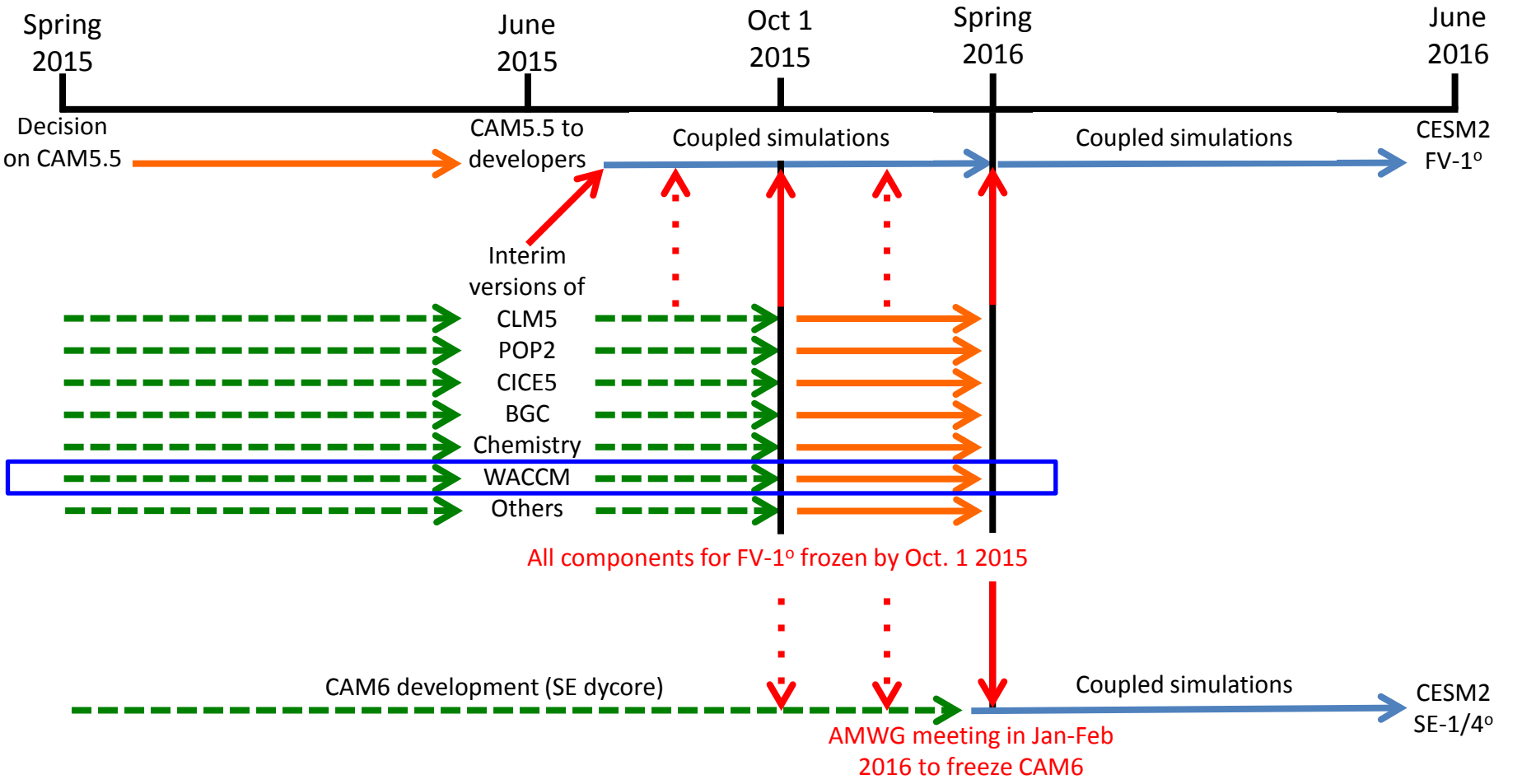
- O+ transport has been implemented: ambi-polar diffusion, and field-aligned transport.
- A well defined equatorial ionospheric anomaly (EIA) is produced by the model.

Current Ionospheric Development

Liu, Solomon, HAO Team

- Further test WACCM-X with ionosphere modules.
- Raise WACCM-X further to 4.5×10^{-10}hPa (from 3.3×10^{-9}hPa) and increase vertical resolution to quarter-scale height to better resolve ionosphere F-region region (especially under solar maximum conditions).

Timeline for CESM2



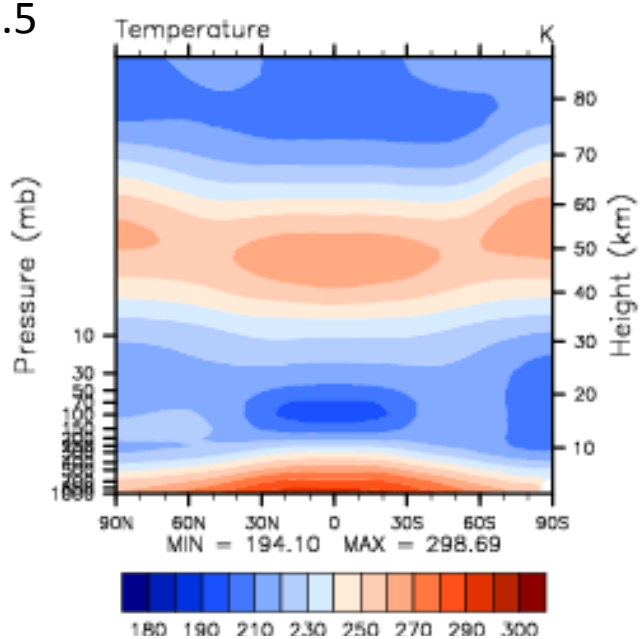
WACCM5.5

Gettelman, Santos, Richter

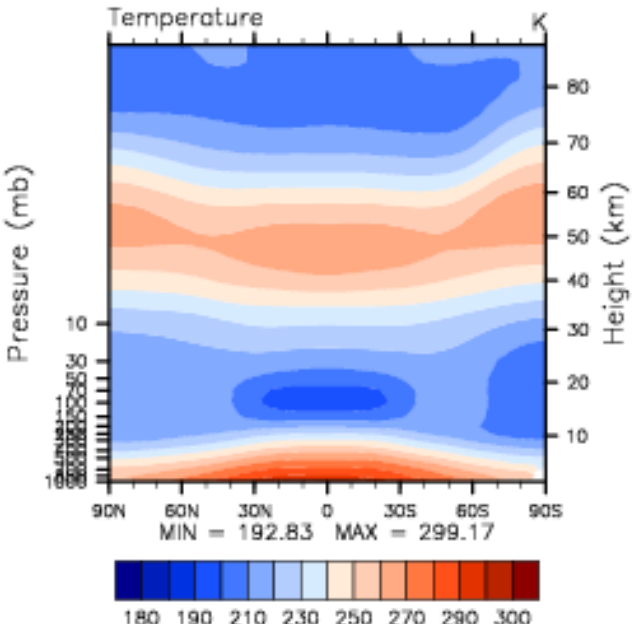
- WACCM5.5 (CAM5.4+CLUBB) running
  - Thanks to hard work by Sean Santos
- Decent climatology (see next slides)
- QBO exists with CAM5.3 (no CLUBB). Better with with SE dycore
- WACCM5.5=Worse QBO with the default version of CLUBB (not enough planetary waves)
- WACCM5.5v2=CLUBB with ZM relaxation time scale of 1800 is doing as well as the 70L 5.3 without CLUBB - which is a good sign.

WACCM5.5: Temp

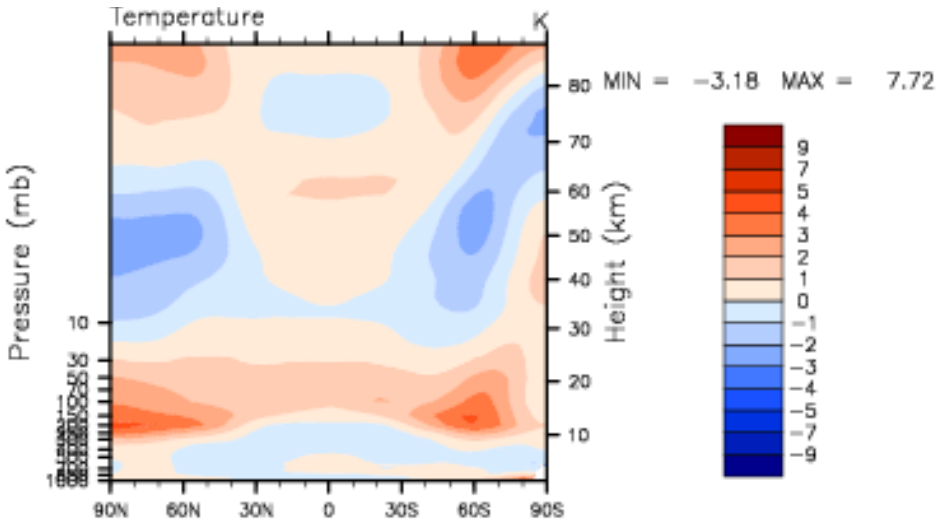
WACCM5.5



WACCM5.3



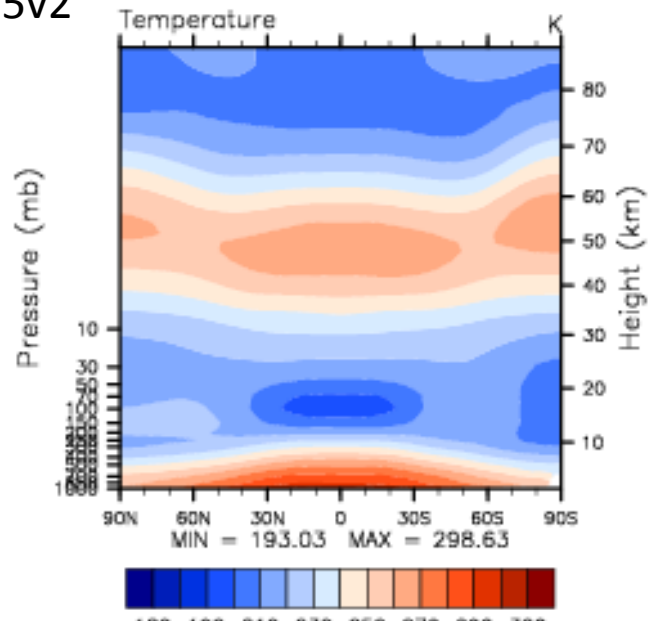
WACCM5.5-WACCM5.3



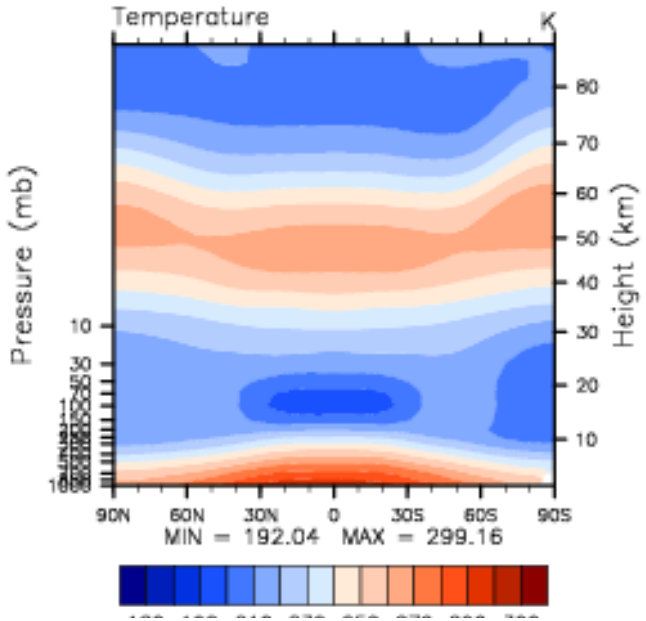
WACCM5.5 looks ‘reasonable’
Note reduction of LS cold pole

WACCM5.5v2: Temp

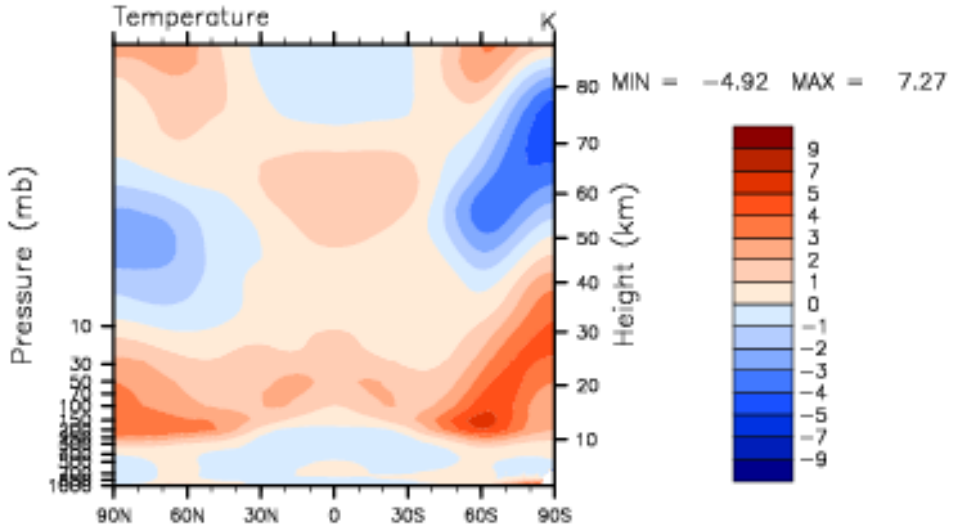
WACCM5.5v2



WACCM5.3



WACCM5.5v2-WACCM5.3

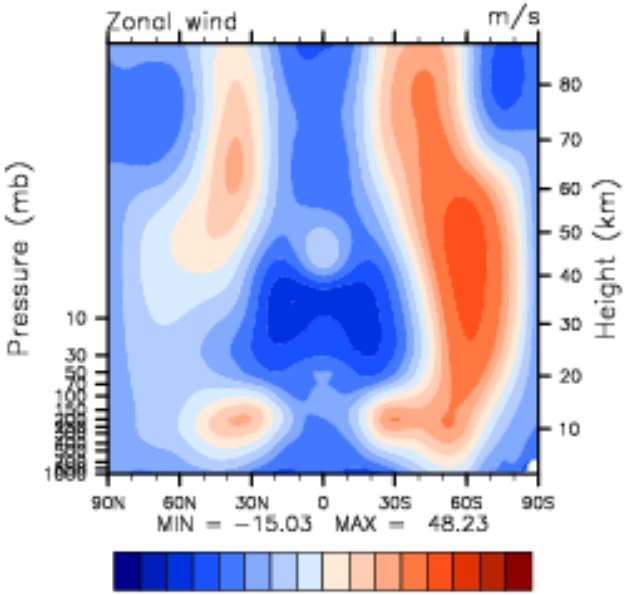


WACCM5.5v2= different convective tuning (shorter timescale of ZM deep convection, better Kelvin waves)

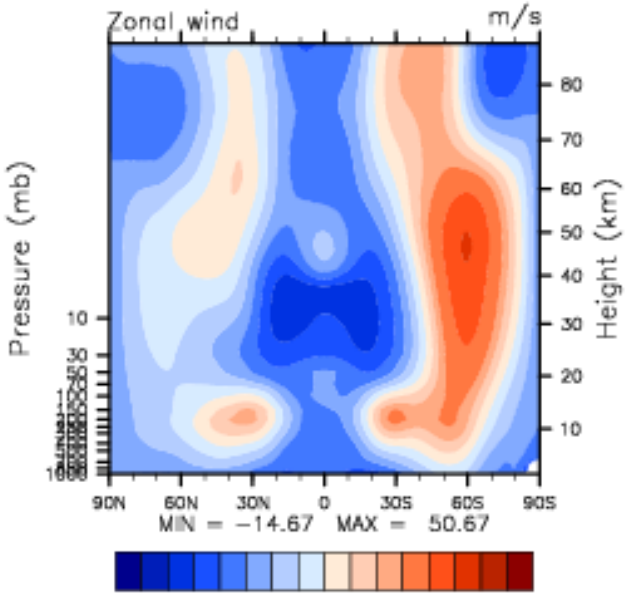
More reduction of cold pole

WACCM5.5: U

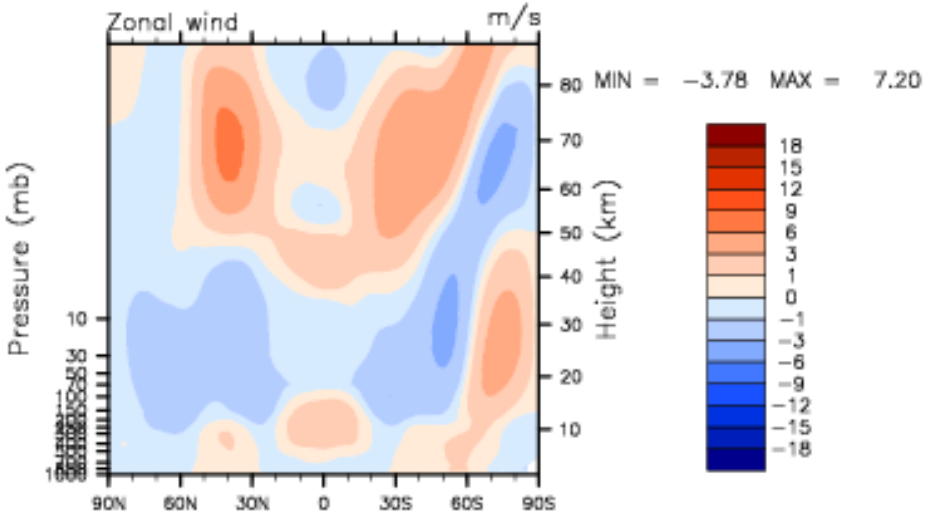
WACCM5.5



WACCM5.3



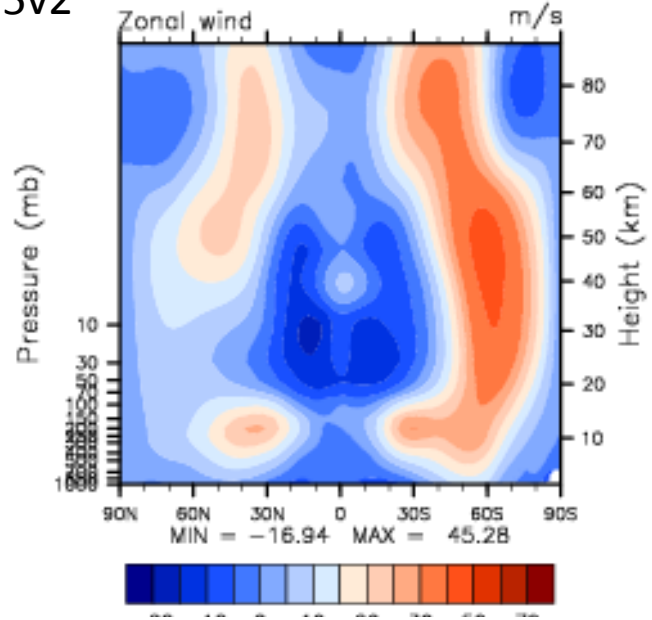
WACCM5.5-WACCM5.3



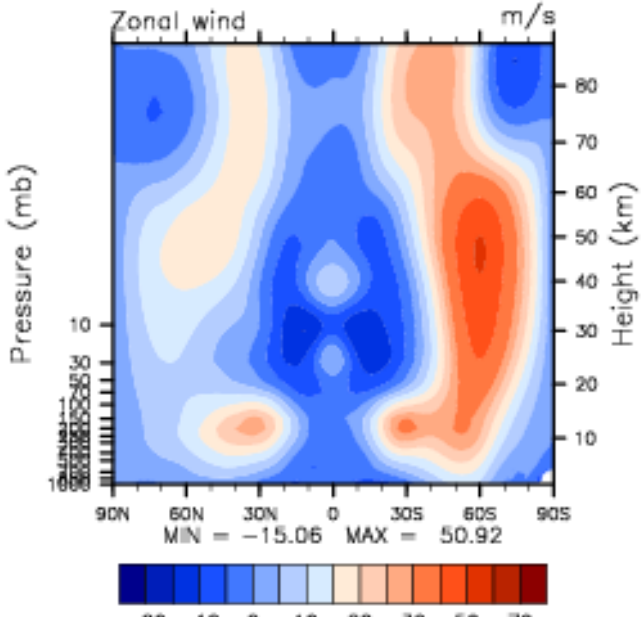
WACCM5.5 looks ‘reasonable’

WACCM5.5v2: U

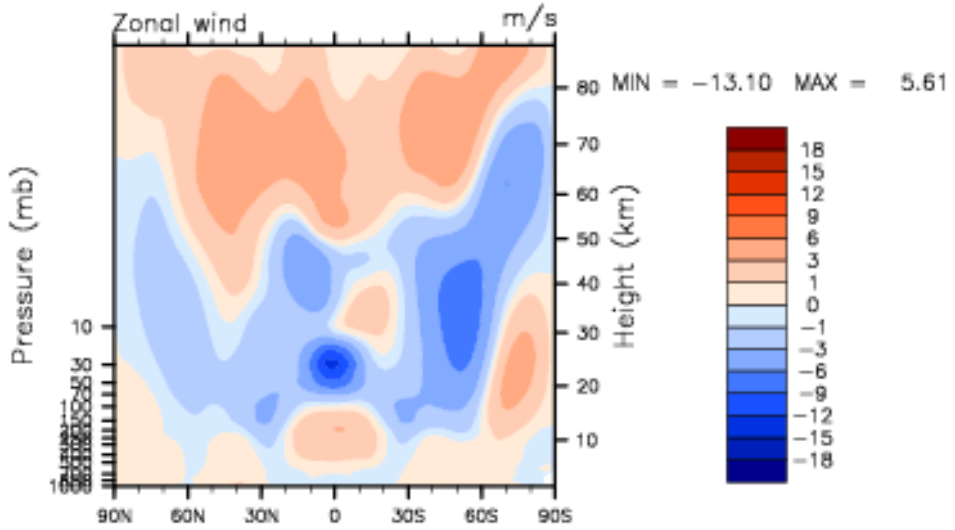
WACCM5.5v2



WACCM5.3



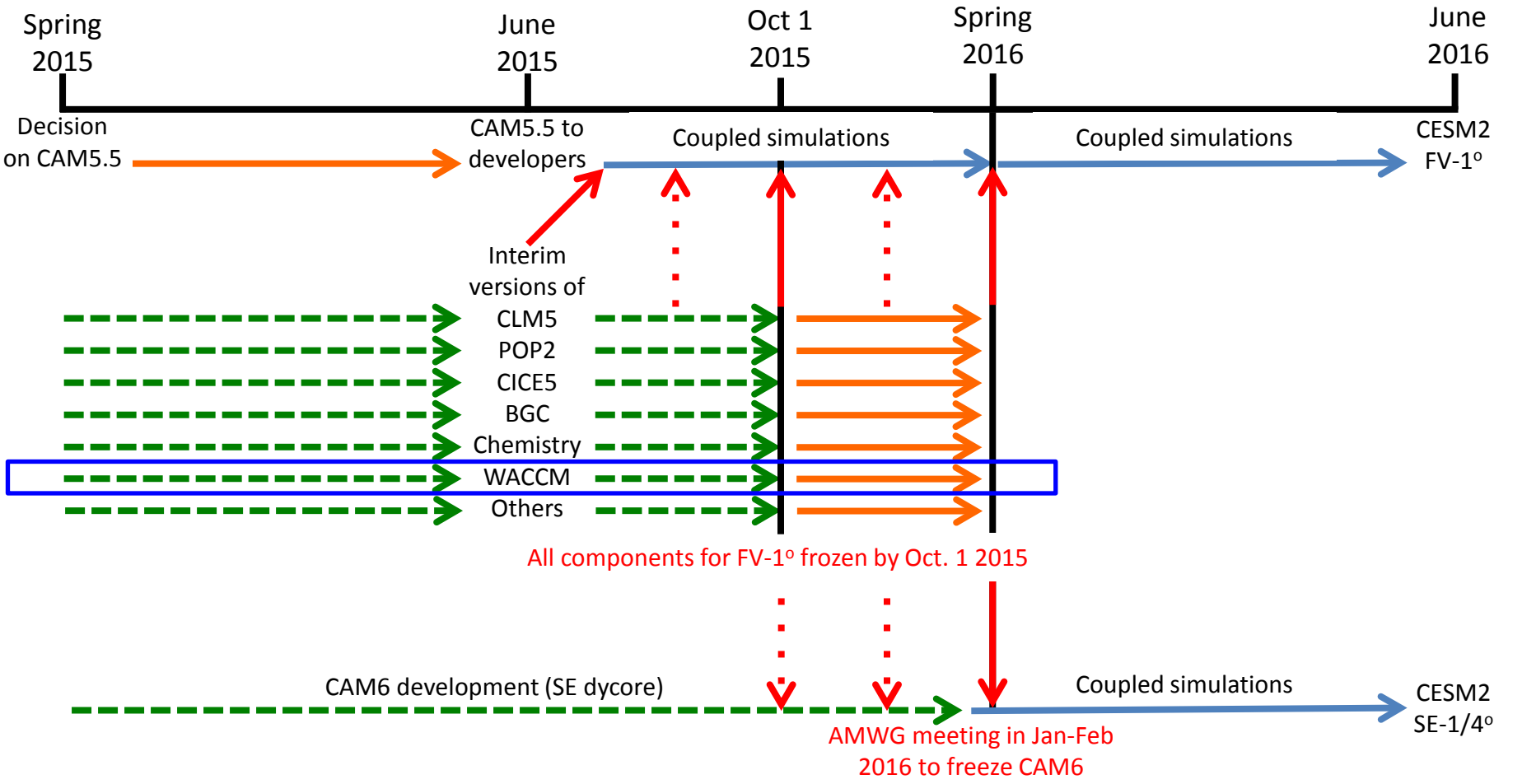
WACCM5.5v2-WACCM5.3



WACCM6: To CESM2 and beyond

A. Gettelman, L. M. Polvani, M. Mills
+ “WACCM Team”

Timeline for CESM2



WACCM6 Development: Current

- Prognostic Sulfur in CAM5.4
  - Add volcanic database
- GW schemes in same code base
  - Not active with CAM5.5
- WACCM6 prototypes
  - WACCM5.5
  - Discussion of GW and effects with AMWG
  - Convection may be an issue

WACCM Plans for CESM2

Planned Baseline Versions (full support)

- WACCM6 (1° FV TSMLT)
  - Base model WACCM
  - TSMLT chemistry
  - Will be used to develop CESM2 forcing
  - Means an early date for WACCM6 readiness
    - Early Spring 2016
- WACCM6-SC
  - Specified Chemistry version, also 1° FV

WACCM Plans for CESM2

Community versions (may not have full support)

- WACCM-X
  - Full functionality of ionospheric physics/dynamics
  - May not be fully tested
- WACCM6-V
  - Higher vertical resolution in middle atmosphere
  - Higher tropospheric resolution too (pace CAM6-V)
  - Goal: Better internally generated QBO
  - CAM6 physics: 1° FV likely (TBD)
- Others?

WACCM-WG Strategy

- What science covered by WACCM, WACCM-X?
  - Stratospheric Chemistry, Dynamics
  - UTLS: Strat-Trop Coupling, Polar
  - Upper atmosphere, space weather
  - Aerosols & volcanoes (Geoengineering)
- What science is missing in WACCM?
  - Where does WACCM go next, how does it evolve?
  - Have some directions, but what else?