Chemistry in CESM2

Eirik Rolland Enger

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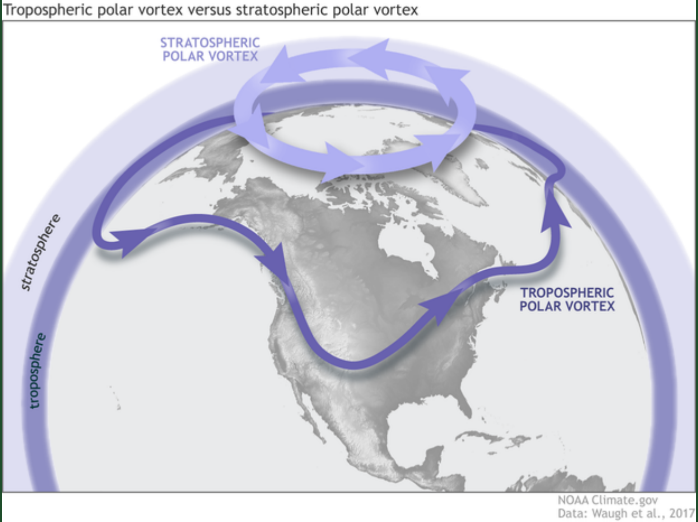
Colorado State University

MOTIVATION

STRATOSPHERIC SUDDEN WARMINGS



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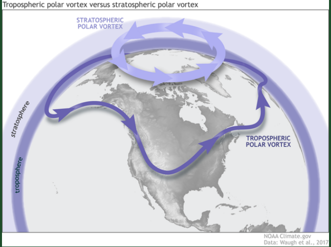
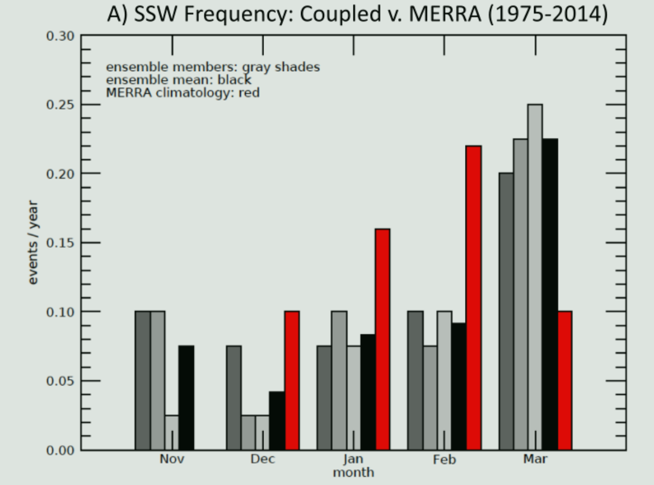
Stratospheric Sudden Warmings



climate.gov

- Defined as a wind reversal (eastward) at 10 hPa ($\sim$ 25 km), 60 °N
- Big improvement from including updated parametrizations of turbulent mountain stress (TMS), surface stress due to unresolved topography
- A lack of stratospheric internal variability without a high-top atmosphere

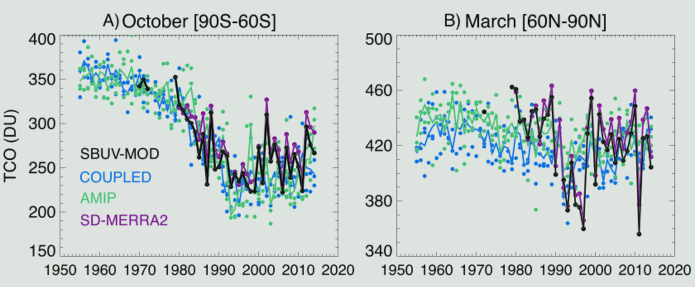
Stratospheric Sudden Warmings



[3] Gettelman et al. “The Whole Atmosphere Community Climate Model Version 6 (WACCM6)”. 2019

Evolution of the Ozone layer

- WACCM6 is able to reproduce the evolution of the ozone layer (also SH polar ozone hole)
- Ozone variability in the tropical stratosphere improves on the inclusion of an internally generated quasi-bilennial oscillation (QBO)



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Atmospheric Blocking

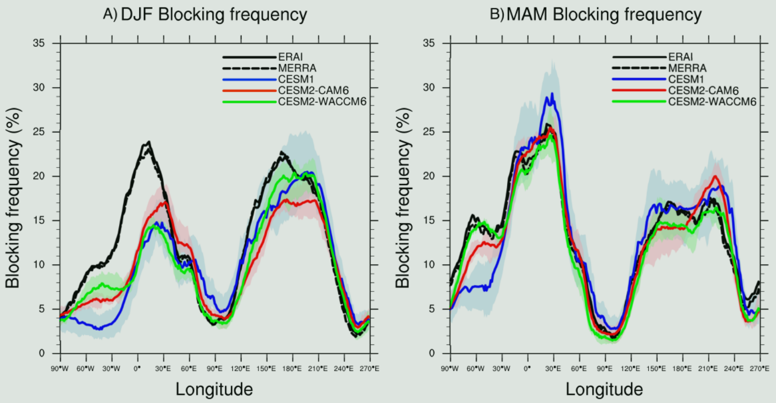
Frequency of the meridional gradient of 500-hPa geopotential height below a threshold of $\mathrm{GHGS} > 0$, $\mathrm{GHGN} < -5\,\mathrm{m/degree}$

$$\mathrm{GHGS} = \frac{Z(\phi_0) - Z(\phi_\mathrm{S})}{\phi_0 - \phi_\mathrm{S}}$$
$$\mathrm{GHGN} = \frac{Z(\phi_\mathrm{N}) - Z(\phi_0)}{\phi_\mathrm{N} - \phi_0}$$

where $\phi_\mathrm{N} = 78.75\,^\circ\mathrm{N} + \Delta$, $\phi_0 = 60\,^\circ\mathrm{N} + \Delta$, $\phi_\mathrm{S} = 41.25\,^\circ\mathrm{N} + \Delta$ and $\Delta = -3.75^\circ, 0^\circ, 3.75^\circ$ [1].

[1] D'Andrea et al. "Northern Hemisphere atmospheric blocking as simulated by 15 atmospheric general circulation models in the period 1979–1988". 1998

Blocking Frequency



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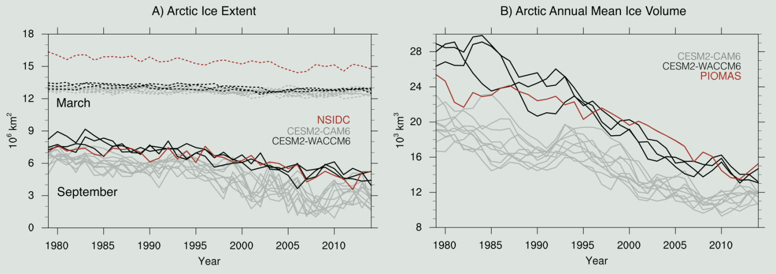
Sea Ice

- The September NH sea ice extent is better in WACCM6 than in CAM6
- Less downward surface SW and LW in WACCM6 due to higher LWP[1] which in turn is due to higher aerosol number.

⇒ Tropospheric aerosol chemistry impacts Arctic sea ice.



[1] liquid water path

[3] Gettelman et al. "The Whole Atmosphere Community Climate Model Version 6 (WACCM6)". 2019

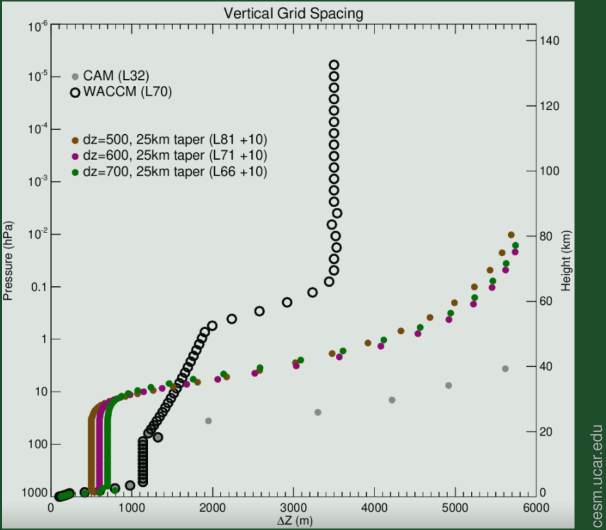
IMPLEMENTATION

COMPUTATIONAL COST

Table 1: Approximate costs of running different atmosphere models (From lecture by Mills)

Configuration	Resolution	Chemistry	Core-hours/simulation years
CAM6	1°, 32 L	CAM	3700
WACCM6	2°, 70 L	MA	5400
WACCM6	1°, 70 L	TSMLT	22 000
WACCM6-SC	1°, 70 L	SC	6000
WACCM6-SD	1°, 88 L	TSMLT	23 000

Spatial


Vertical Grid Spacing
CAM (L32)
WACCM (L70)
dz=500, 25km taper (L81 +10)
dz=600, 25km taper (L71 +10)
dz=700, 25km taper (L66 +10)
Pressure (hPa)
Height (km)
ΔZ (m)
cesm.ucar.edu

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- Additional thermosphere eXtension (WACCM-X)

Chemistry in TSMLT

MAM4 (*Modal Aerosol Model*), also used in CAM6, but WACCM6 adds chemistry.

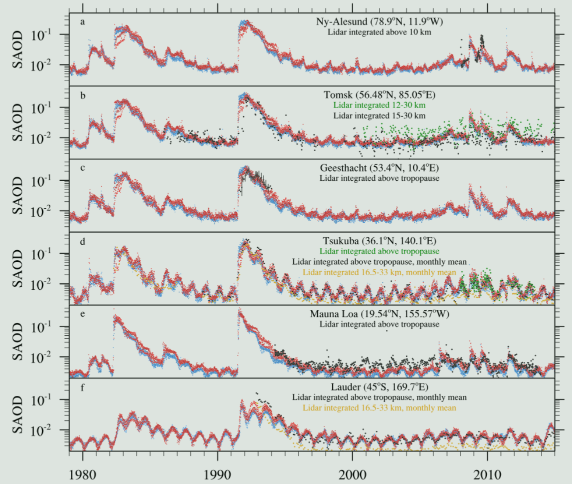
- Includes the chemical families O_x, NO_x, HO_x, ClO_x and BrO_x, as well as CH_4
- Allows growth of sulfate aerosols, so the prognostic stratospheric aerosols can increase in width
- Maximum altitude of 20 km for eruptions outputting more than 3.5 Tg SO_2

MOZART (*Model for OZone And Related chemical Tracers*)

- The chemical mechanism in CESM2, available from WACCM6, but also CAM-chem
- See table 2[2] for a complete list of chemical reactions included in CESM2 when run with the TSMLT (troposphere, stratosphere, mesosphere, lower thermosphere) configuration.

[2] https://agupubs.onlinelibrary.wiley.com/action/downloadSupplement?doi=10.1029%2F2019MS001882&file=jame21103-sup-0003-2019MS001882+Table_SI-S02.pdf

Stratospheric Aerosol Optical Depth



Stratospheric aerosol optical depth at different locations agree well

[3] Gettelman et al. “The Whole Atmosphere Community Climate Model Version 6 (WACCM6)”. 2019

LUMPING

- TSMLT has 231 solution species
- Species are lumped togheter to reduce the computational cost
- Example: $C_{10}H_{16}$ in MOZART-4 turned into five new lumped species, with APIN, BPIN, LIMON, MYRC and BCARY giving the primary degradation rates.

Solar and Geomagnetics

- Photoionization and heating rates uses parametrization of Solomon and Qian (2005), with input from the $F_{10.7}$ index
- Ion-pair production rates are prescribed
- Low energy electrons included by the parametrized auroral oval model by Roble and Ridley (1994)
- Input to the model is HP, hemispheric power, related to the $\mathrm{K_p}$ index:

$$HP = \begin{cases} 16.82\exp(0.32\mathrm{K_p}) - 4.86, & \mathrm{K_p} \leq 7 \\ 153.13 + 73.4(\mathrm{K_p} - 7.0), & \mathrm{K_p} > 7 \end{cases}$$

- Since WACCM3, E region ionosphere is represented with a chemistry consisting of O^+, ${O_2}^+$, N^+, ${N_2}^+$, NO^+

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