Chemistry in CESM2

Eirik Rolland Enger

Colorado State University

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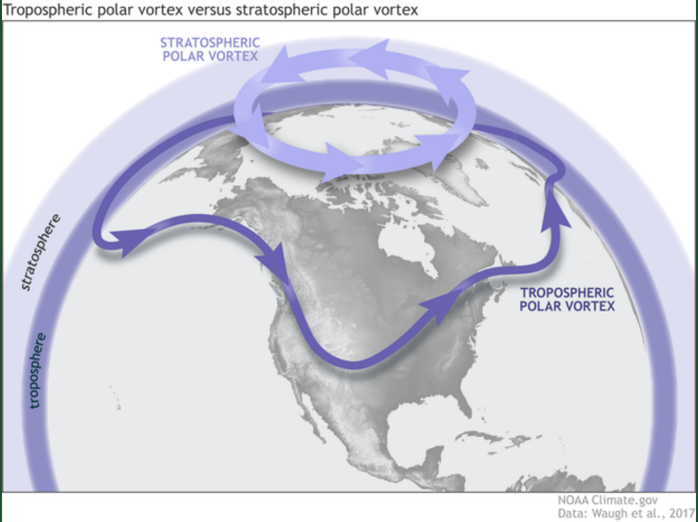
Motivation

Stratospheric Sudden Warmings



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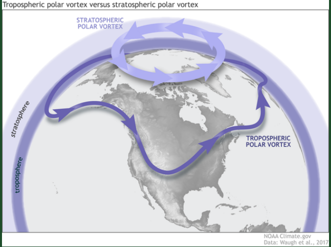
Stratospheric Sudden Warmings



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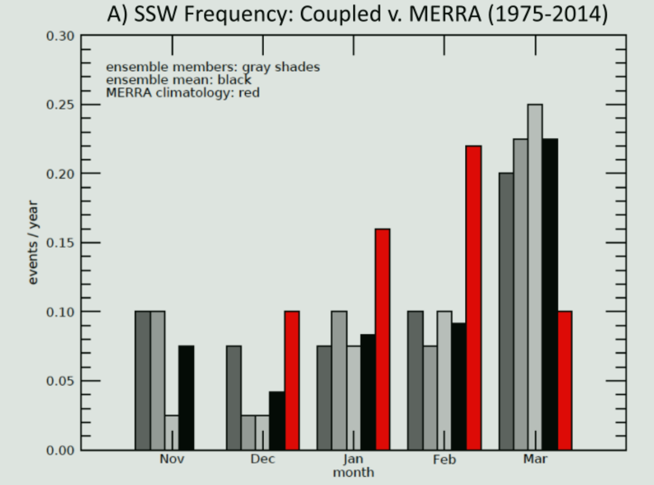
- Defined as a wind reversal (eastward) at 10 hPa ($\sim$ 25 km), 60 °N
- Big improvement from including updated parametrizations of turbulent mountain stress (TMS), surface stress due to unresolved topography
- A lack of stratospheric internal variability without a high-top atmosphere

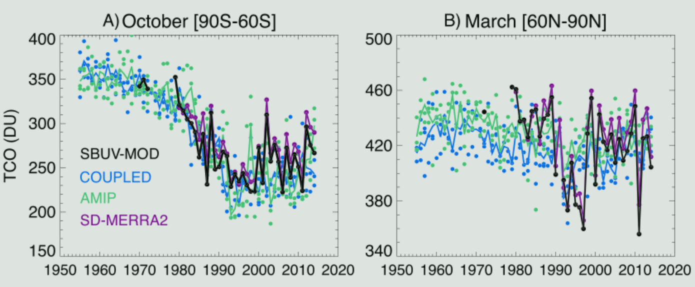
Stratospheric Sudden Warmings



[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

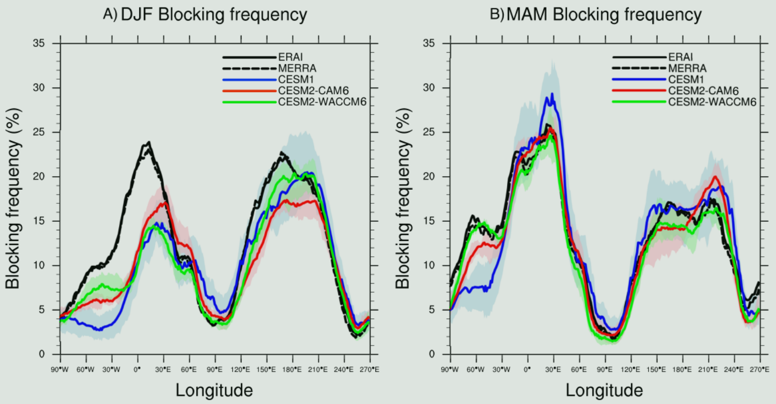
Frequency of the meridional gradient of 500-hPa geopotential height below a threshold of $\mathrm{GHGS} > 0$, $\mathrm{GHGN} < -5\,\mathrm{m/degree}$

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

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

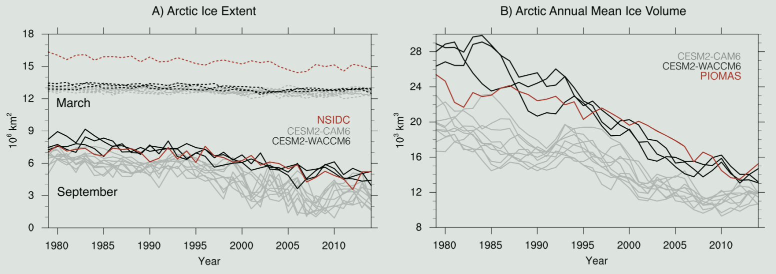
Blocking Frequency



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

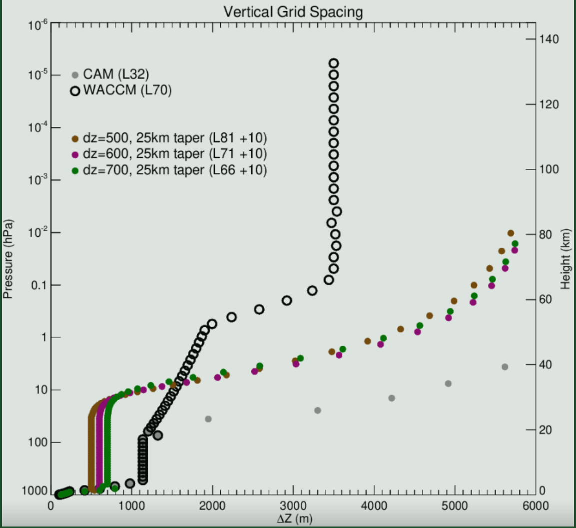
IMPLEMENTATION

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
WACCM5.4	1°, 110 L	MA	20 000
WACCM5.4-SC	1°, 110 L	SC	9000

Spatial



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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

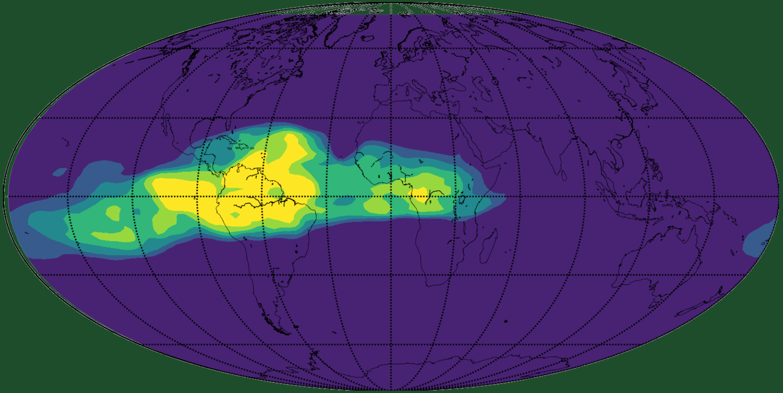
MOZART (*Model for OZone And Related chemical Tracers*)

- 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

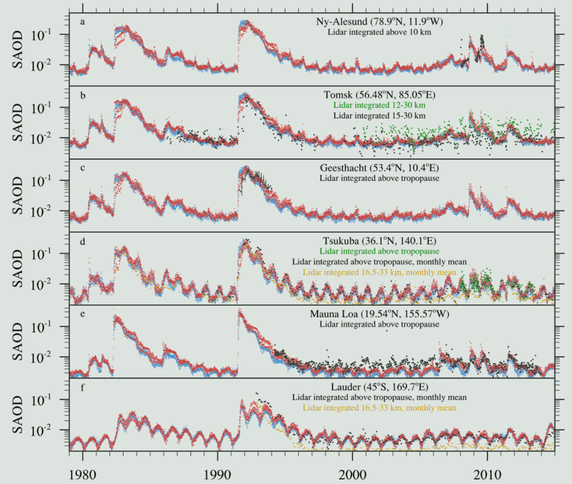
Stratospheric Aerosols

In CAM, stratospheric aerosols are prescribed based on output from previous WACCM simulations



Aerosol optical depth from stratospheric volcanic eruption in WACCM

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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