Using TUV for inline photolysis in CESM

C. Bardeen, D. Kinnison, M. Mills, F. Vitt, S. Walters, S. Madronich
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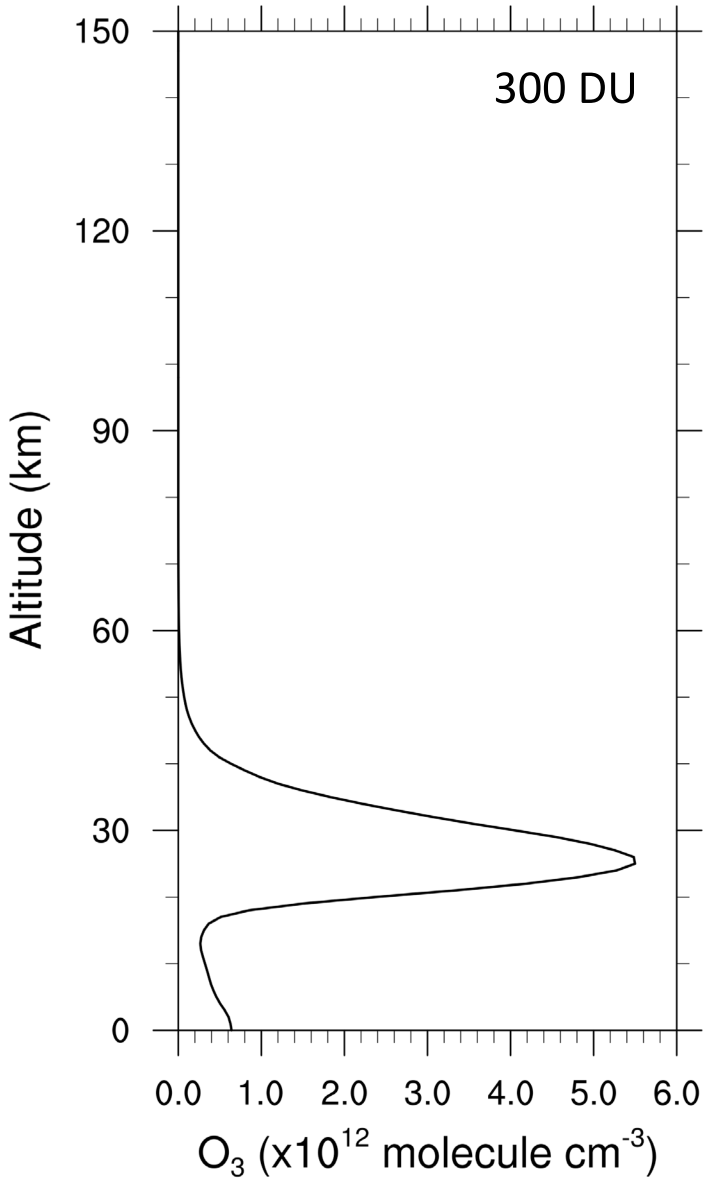
Current Photolysis Algorithm in CESM2

- Provides photolysis rates and chemical heating rates
- Uses 100 wavelength bands from 121-750 nm
- Two methods for actinic flux:
  - jshort (121-200 nm, 33 bands)
    - Calculates actinic flux as O_2 and O_3 transmission
  - jlong (201-750 nm, 67 bands)
    - Calculates actinic flux using a lookup table
- Calculates photolysis rates using a table of cross-sections and quantum yields compiled by Doug Kinnison
- Clouds: effective albedo (clouds below) and transmission factor (clouds above) based upon cloud fraction and cloud water content

Actinic Flux Lookup Table

- Calculated off-line using TUV
  - 4-stream calculation
  - Fixed O_3 profile that scales with column amount
  - No aerosols, NO_2, or SO_2
- /glade/p/cesmdata/cseg/inputdata/atm/waccm/phot/RSF_GT200nm_v3.0_c080811.nc

Dimension	Count	Minimum Value	Maximum Value
Albedo	6	0.05	1.0
Column O_3	20	30 DU	600 DU
Solar Zenith Angle	24	0˚	97˚
Altitude	151	0 km	150 km
Wavelength	67	201 nm	725 nm



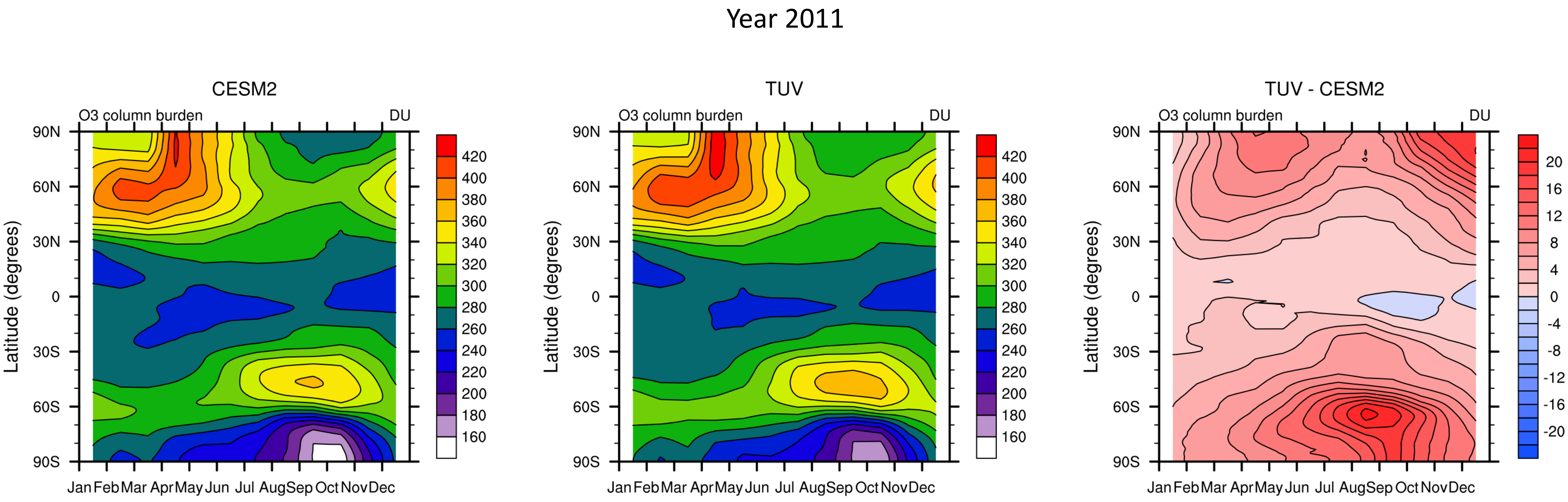
Tropospheric Ultraviolet and Visible (TUV) Radiation Model

- Calculates the following in the UV and visible:
  - actinic flux
  - photolysis rates
  - action spectra
- Has its own set of cross-sections and quantum yields
- Stand-alone version created by Sacha Madronich (Madronich & Flocke, 1997; Lee-Taylor & Madronich, 2007)
- Available for download: https://www2.acom.ucar.edu/modeling/tropospheric-ultraviolet-and-visible-tuv-radiation-model
- Ported to WRF by Stacy Walters
- Ported to CESM & MICM by Francis Vitt

New CESM/TUV inline implementation

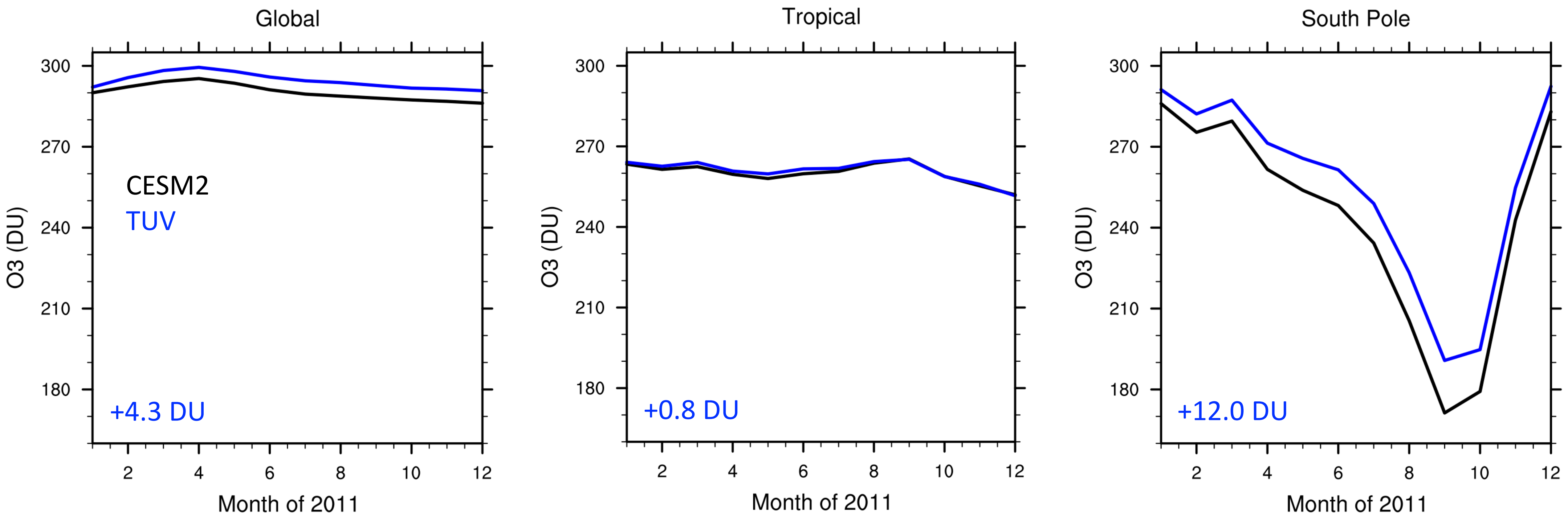
- Inline TUV currently only used for the actinic flux calculation
  - 2-stream calculation
  - Uses CESM wavelength grid (100 bands from 121-750 nm)
  - Uses actual gas profiles (O_2, O_3, NO_2, and SO_2)
  - Includes combined aerosol profile
    - optics interpolated from optical properties calculated for RRTMG
  - Clouds can be handled in TUV following Liao et al. (1999) or in chemistry as we do now
  - Provides output for actinic flux and some spectral integrals
- Uses cross-sections and quantum yields from CESM2 (Kinnison)
- Used for photolysis and heating rate calculations

SD-WACCM: CESM2 & TUV give similar O_3

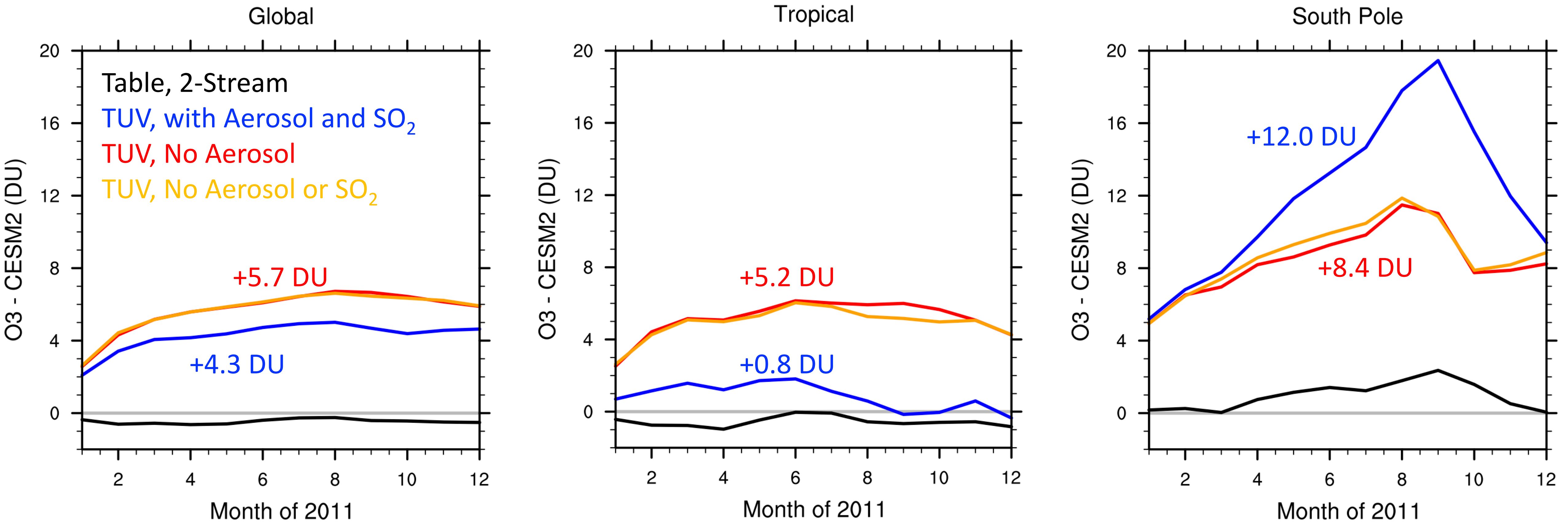


But TUV up to 22 DU (~7%) higher in some regions

Using TUV Increases Ozone column



Aerosols reduce tropical O_3, increase polar O_3



Perhaps removing the fixed O_3 profile affects high latitude?

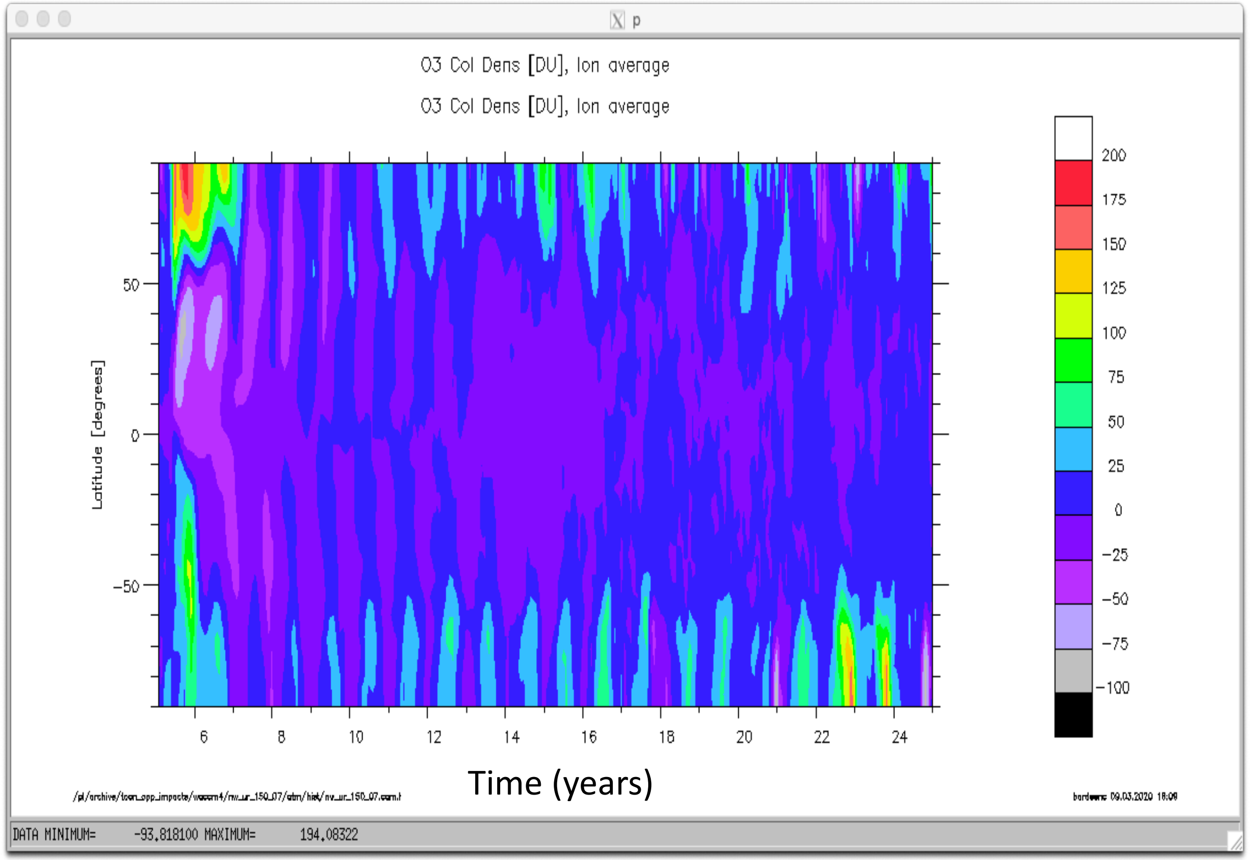
Nuclear weapons ignite mass fires injecting smoke into upper troposphere/stratosphere

- Flash with thermal pulse
- Followed by blast wave
- Can ignite fires in large area and generate secondary ignition
- Firestorms may develop which modify local meteorology and inject smoke into the upper troposphere
- Area burned scales with weapon yield
- Hiroshima
    - 15 kt weapon
    - 13 km^2 burn area

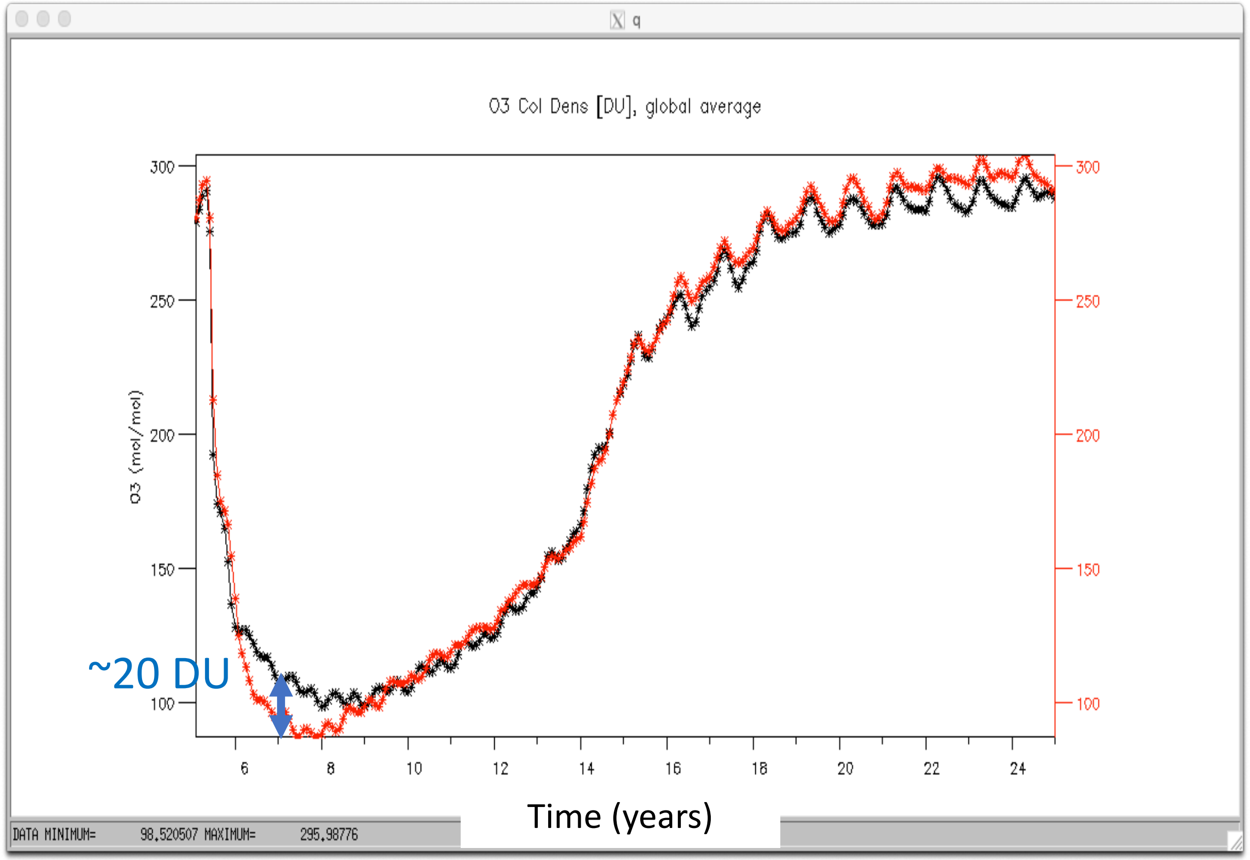
Hiroshima after blast and fires

WACCM 150 Tg Smoke: CESM vs. TUV
US/Russia Global Nuclear War

O_3 Column: TUV – Table

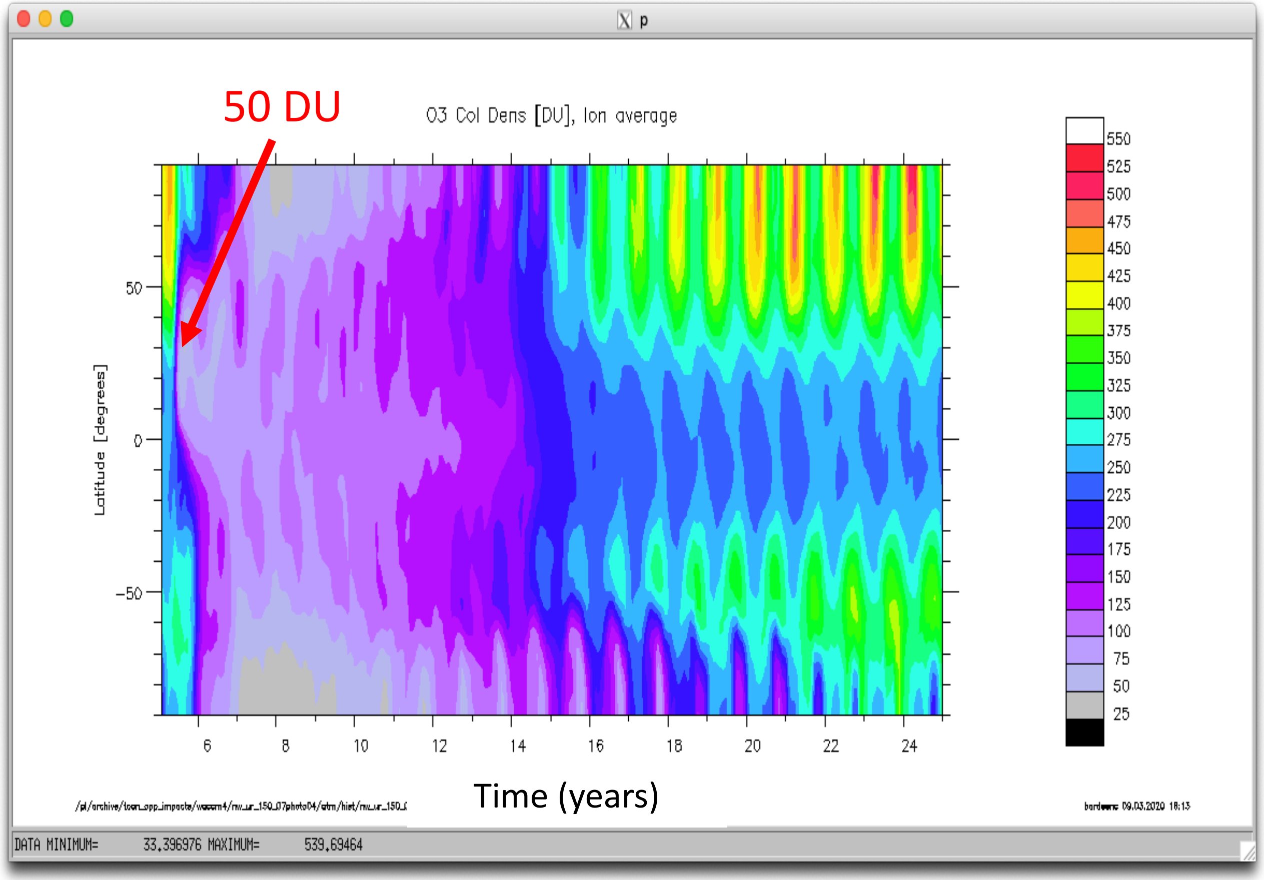


O_3 Column: TUV   Table

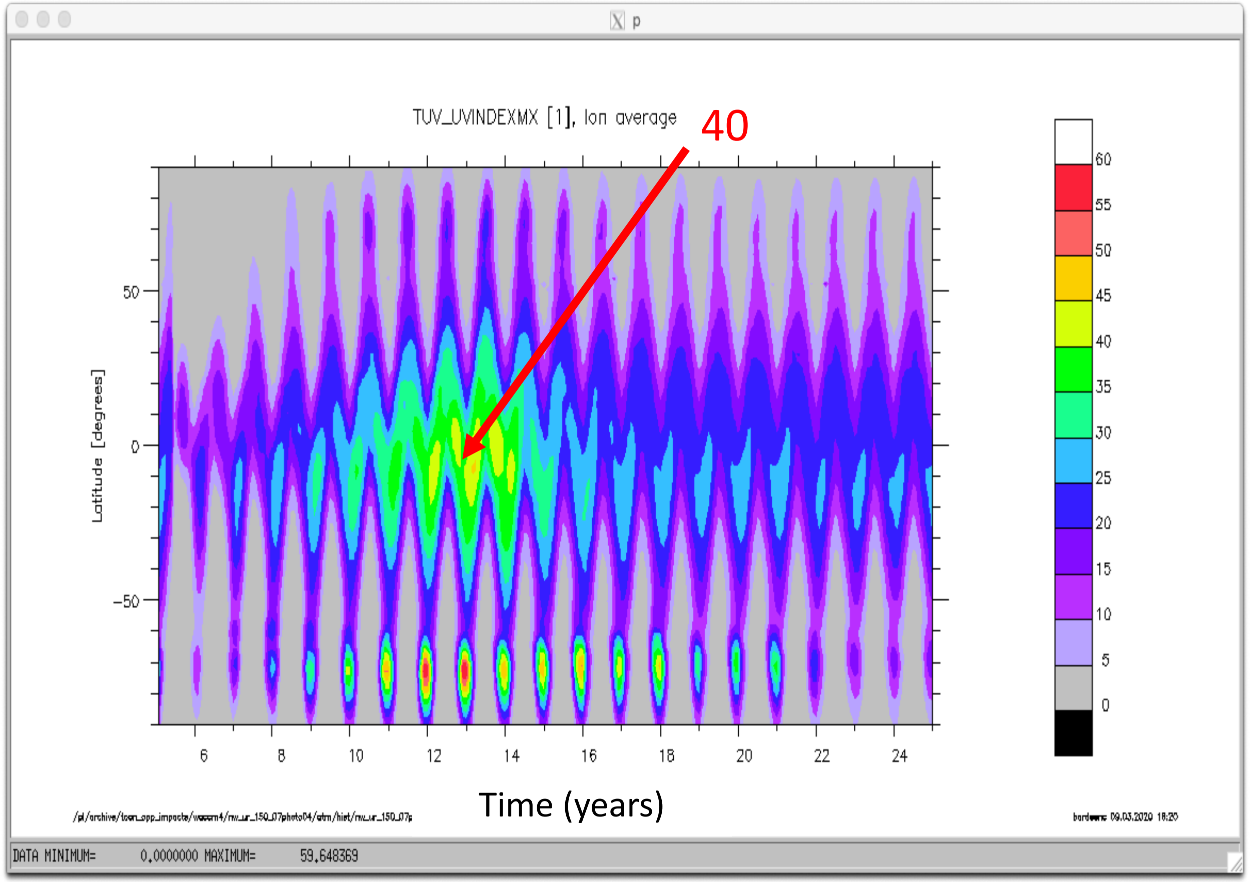


WACCM 150 Tg Smoke: Ozone and UV Index US/Russia Global Nuclear War

O_3 Column: TUV



max(UV Index): TUV



Can now get this from CESM, no postprocessing!

Raikoke

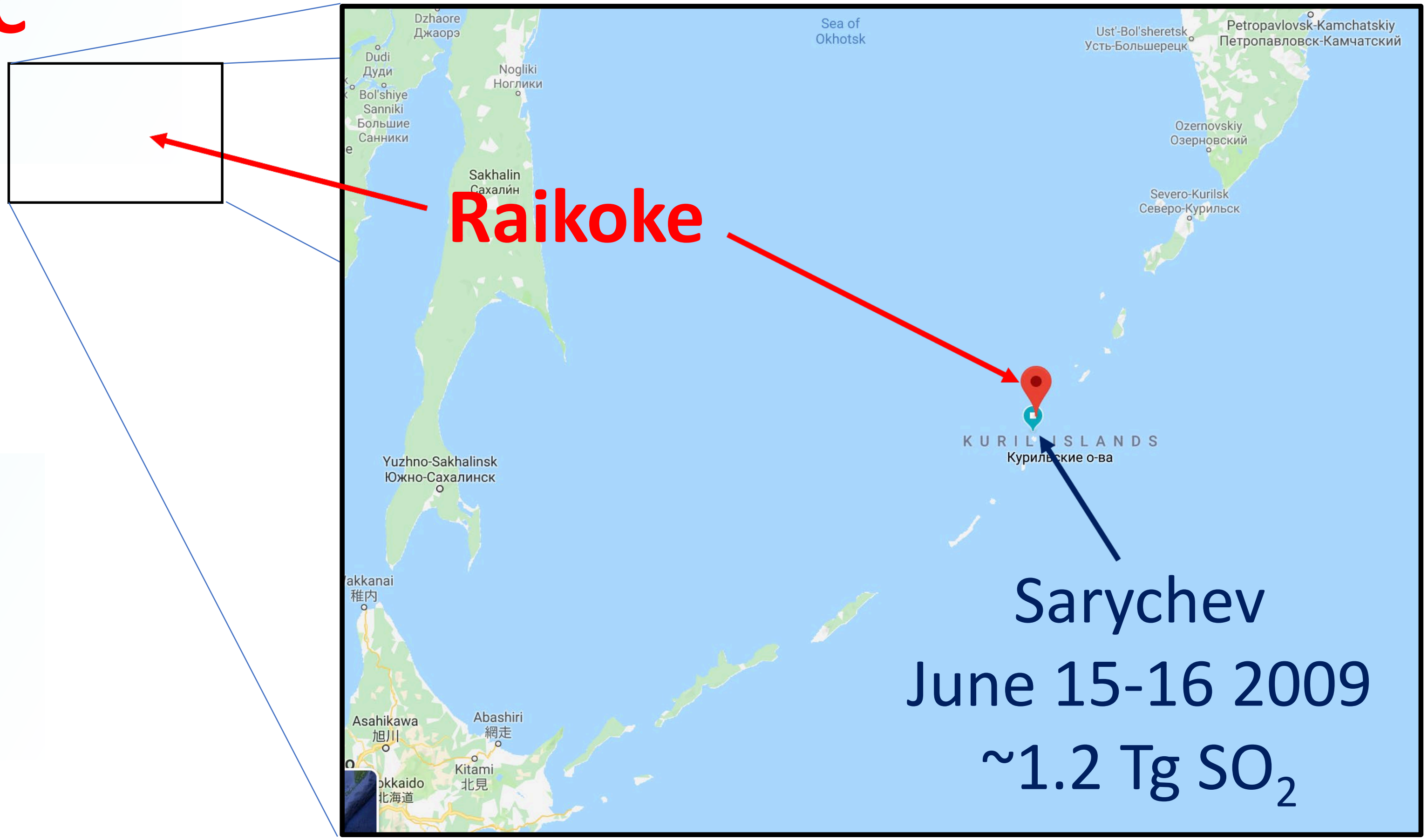
circular 2.5 x 2.0 km island

153.24°E, 48.29°N

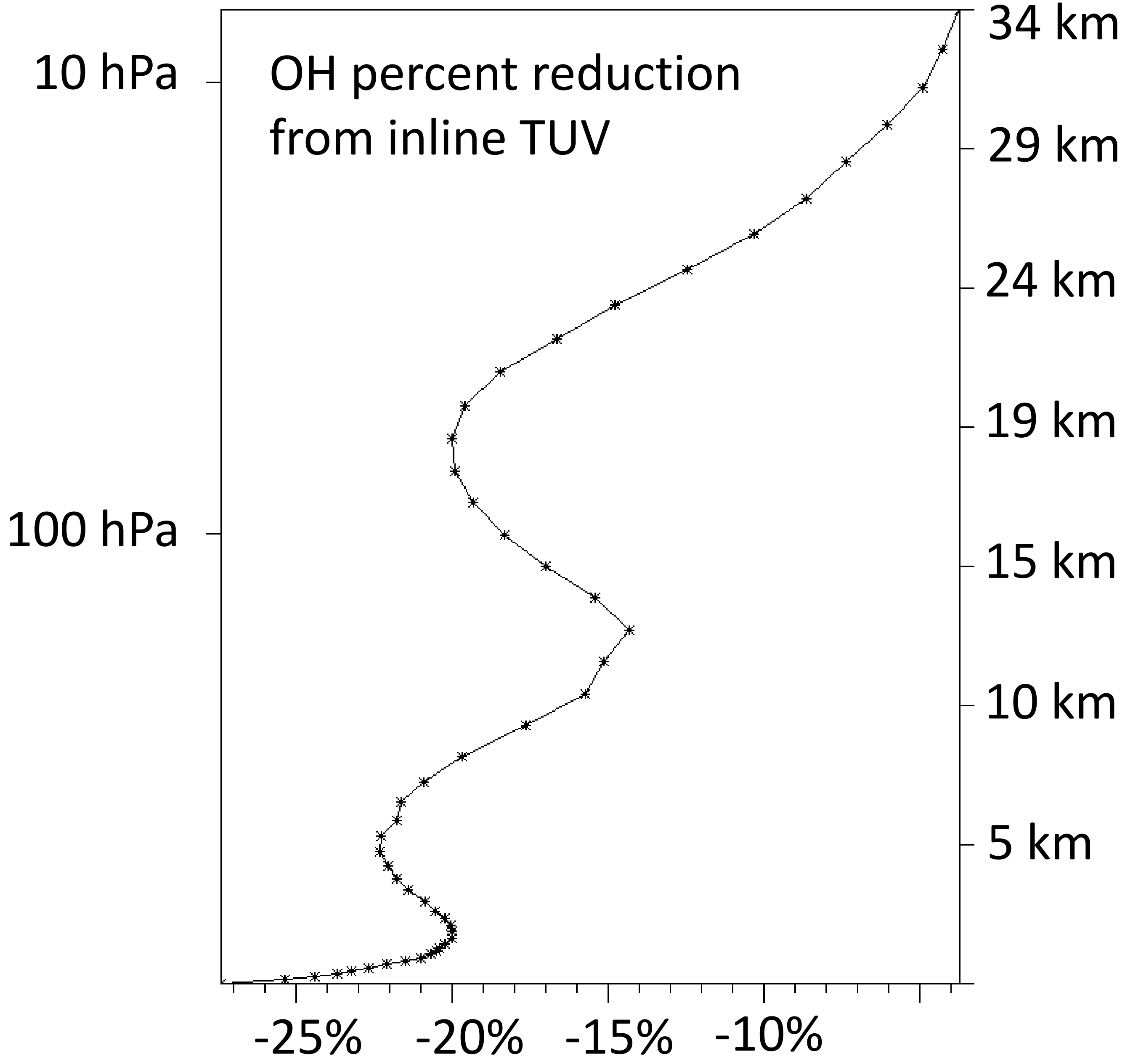
Begin: 21 June 2019 18UTC

End: 22 June 2019 3UTC

1.5 ± 0.2 Tg SO_2



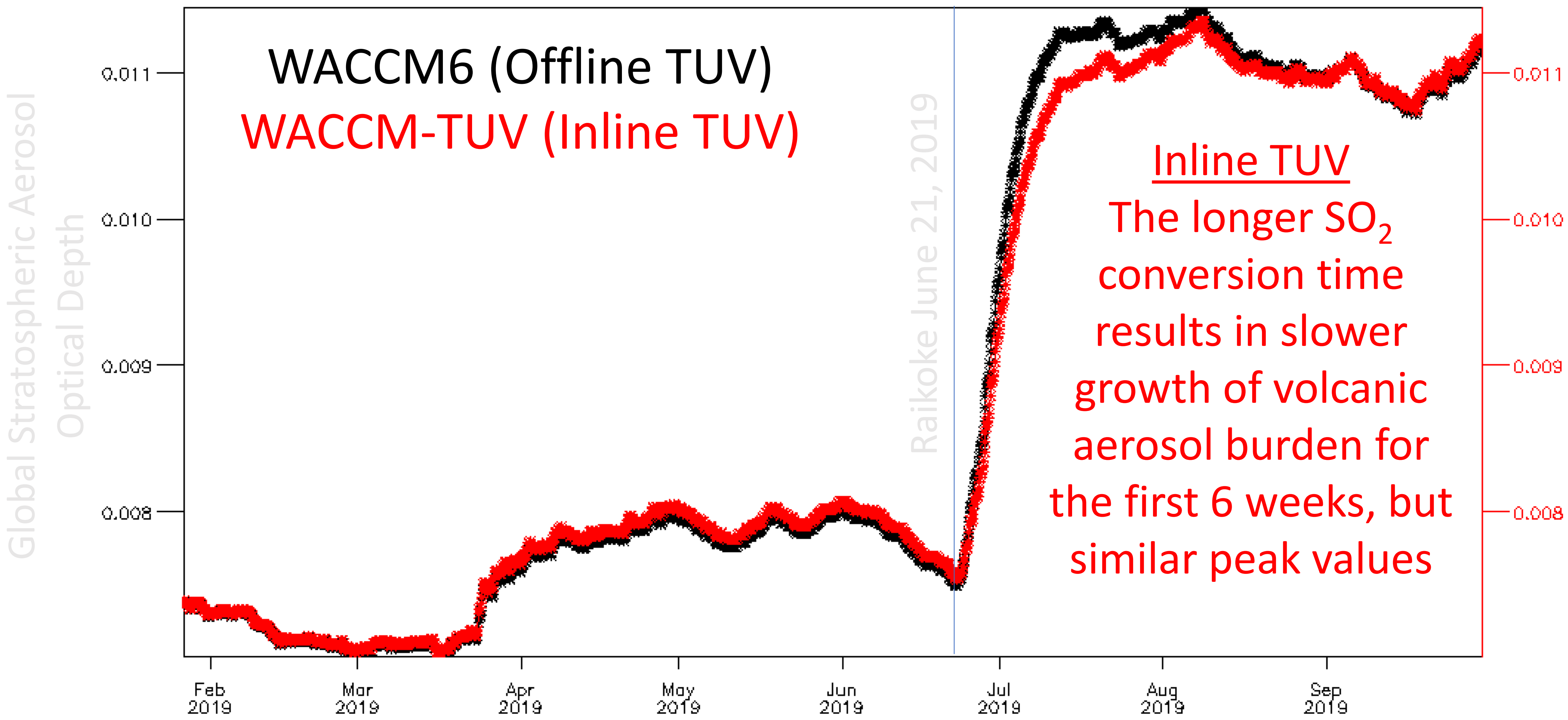
Largest SO_2 emission since the 2011 Nabro eruption.



5-25% reductions are seen in calculated OH when inline TUV is included in WACCM calculations.

OH oxidizes SO_2.

Reduced OH leads to longer SO_2 lifetimes.


WACCM6 (Offline TUV)
WACCM-TUV (Inline TUV)
Global Stratospheric Aerosol Optical Depth
Raikoke June 21, 2019
Inline TUV
The longer SO_2 conversion time results in slower growth of volcanic aerosol burden for the first 6 weeks, but similar peak values
0.011
0.010
0.009
0.008
Feb 2019
Mar 2019
Apr 2019
May 2019
Jun 2019
Jul 2019
Aug 2019
Sep 2019

Summary

- Inline calculations using TUV allow for more precise calculations of photolysis rates including the effects of actual profiles of O_3, SO_2, NO_2, aerosols, and clouds.
- ~1.6% change in model throughput in WACCM
- Allows new output fields:
  - Action Spectra: UV-A, UV-B, UV-B*, PAR, UV Index, max(UV Index)
  - Profiles of actinic flux: Lyman alpha (121 nm), Schuman Runge Bands (180 nm), O3 Hartley Band (210, 240, 308 nm), Chappuis Bands (400, 600 nm)

Questions/Discussion

- Still using existing lookup table for cross-sections and quantum yields, will want to unify values from Kinnison, TUV (Madronich), and other sources (e.g. HARP, Hall)
- How do we want to handle cloud effects (cloud fraction, cloud overlap, …)? We currently have 2 different approaches.
- TUV 4-stream (discrete ordinate) code will also be ported to WRF, CESM and MICM as an option. It will be more expensive (maybe 2.25x the cost of 2-stream), but perhaps not too expensive.
- Are there other photolysis reactions that people are concerned about that should be evaluated?
- Do we want any other output? Other action spectra?
- Rare computational errors resulting in high max(UV Index) values require further investigation.
- We are planning to port FastJ. Are there any other approaches people would like to see?