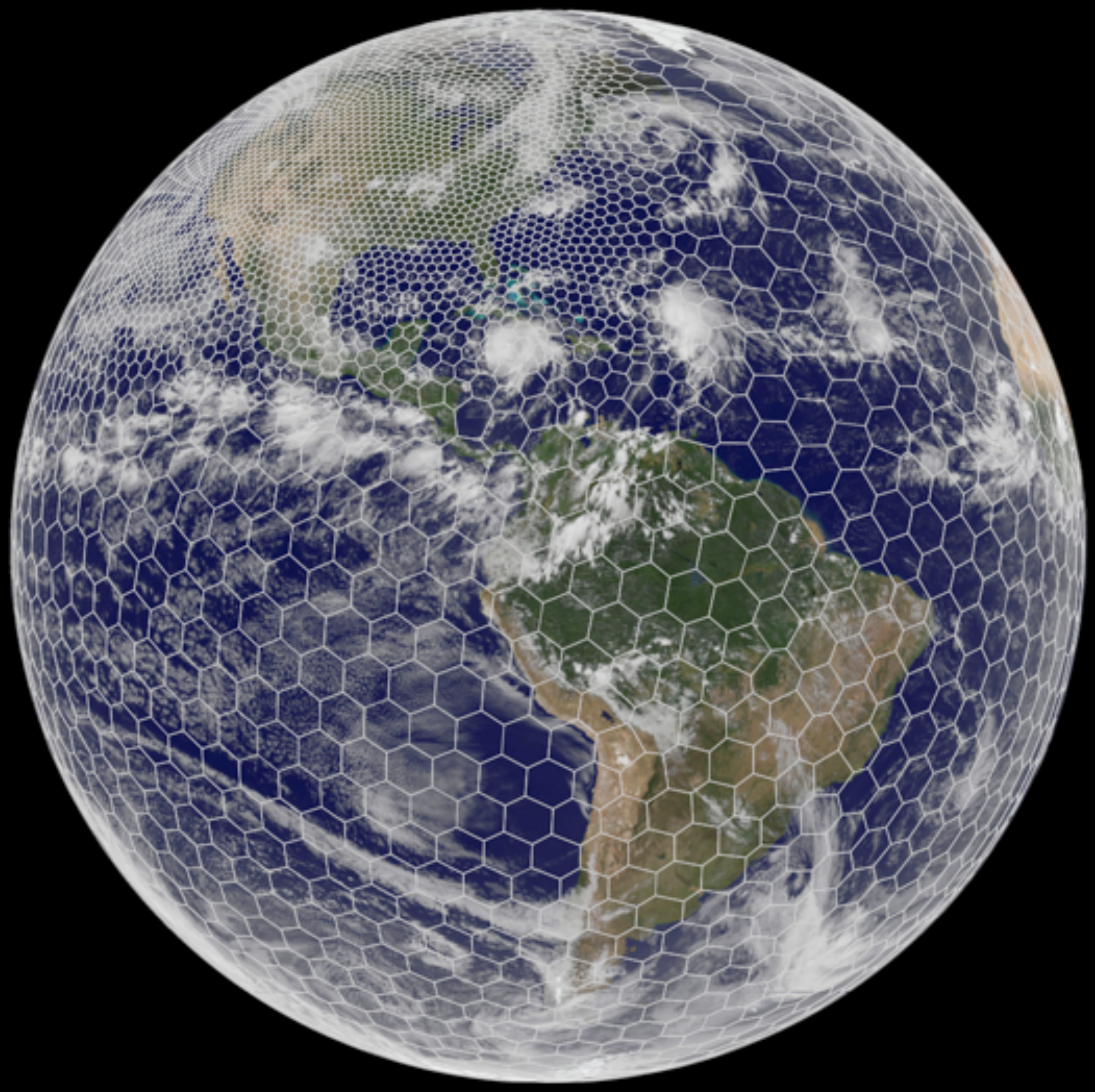

CESM: A platform for atmospheric prediction from the surface to geospace

Dan Marsh,

NCAR & University of Leeds

Whole Atmosphere Modelling Workshop

Deimos, Tres Cantos, Spain

13-15 June, 2018

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Outline

- NCAR Community Earth System Model (CESM) description
  - New release
  - WACCM-X
  - WACCM
- Concluding remarks

CESM2.0 released June 8, 2018

- CESM2.0 includes substantial new scientific additions to all model components, a new wave component, an advanced, interactive ice sheet model and powerful new infrastructure capabilities. A summary of these new features is described at: http://www.cesm.ucar.edu/models/cesm2/whatsnew.html

- To download the model, please reference the Quick Start Guide at https://escomp.github.io/cesm/release-cesm2/

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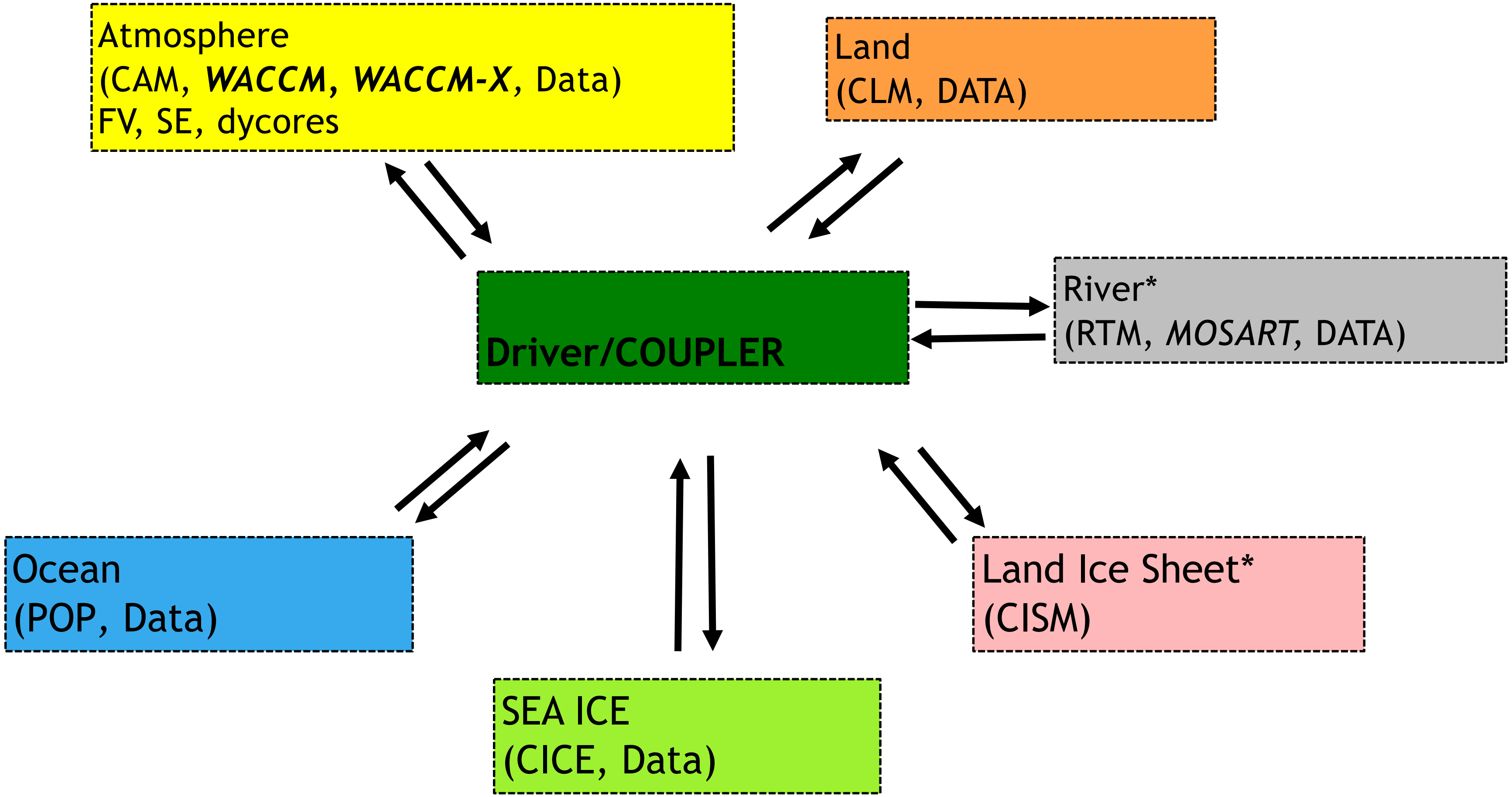
A new model infrastructure

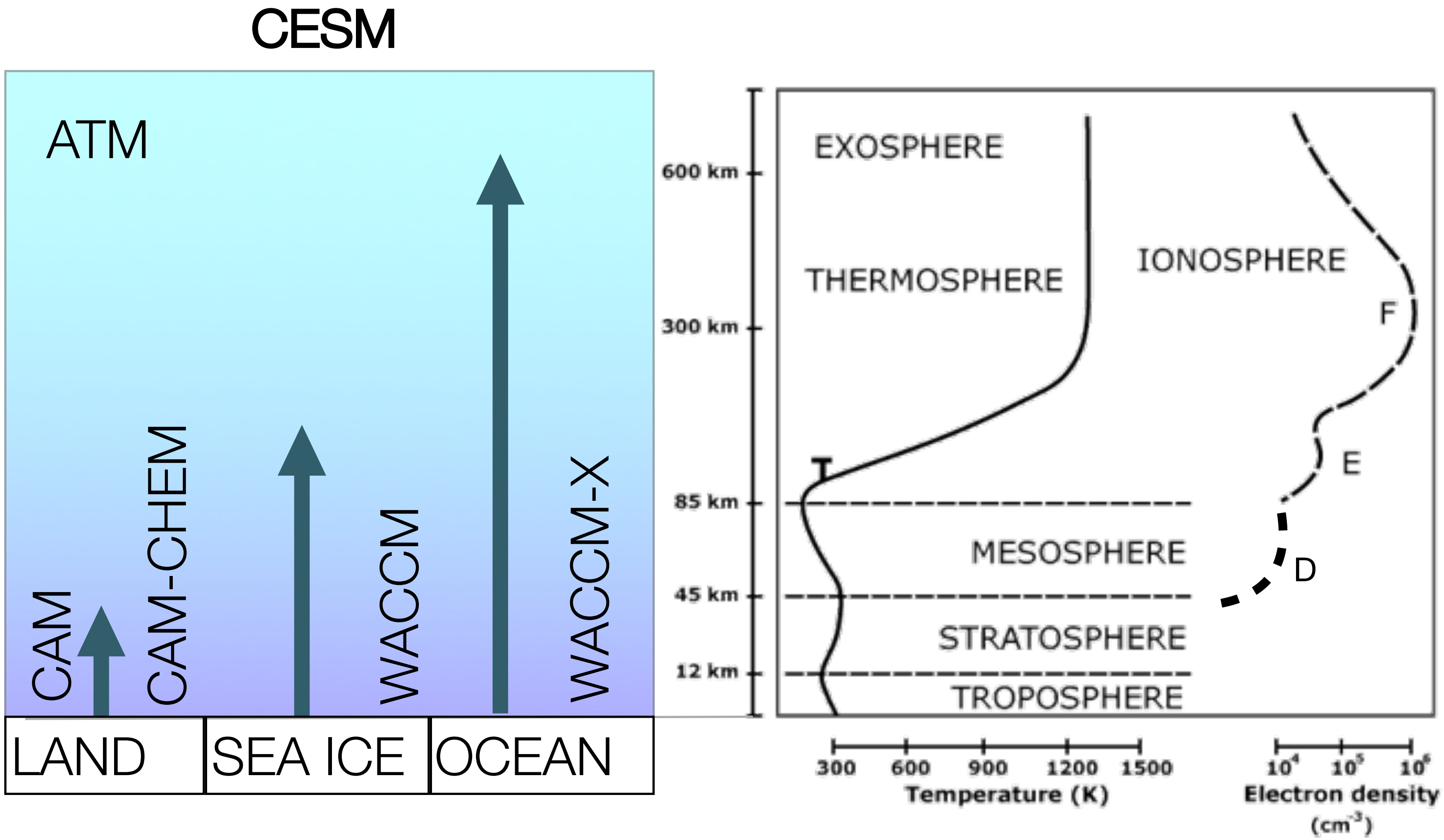
- The coupling infrastructure, scripting utilities and data models are now in **CIME:** Common Infrastructure for Modeling the Earth
- Available via a separate and open-source repository: http://github.com/ESMCI/cime
- CIME provides a Case Control System for configuring, compiling and executing Earth system models.
  - a new object-oriented set of python utilities that aims to provide easier portability, case generation and user customization, testing functionality, and greatly increased robustness and flexibility.

Community Earth System Model



*not currently used in WACCM

CESM Atmospheric Components



WACCM vs WACCM-X

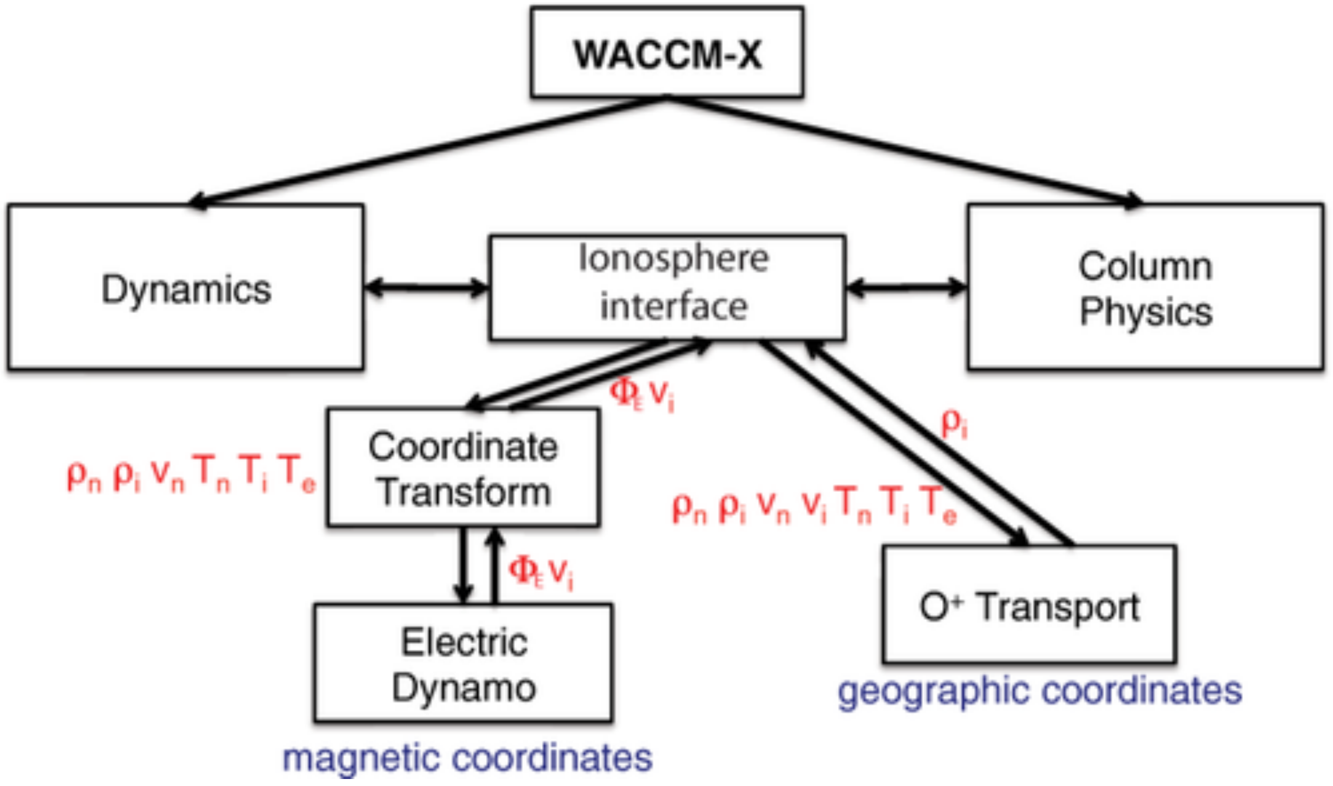
	WACCM	WACCM-X
Levels	70-88	125-145
Model Top	$6x10^{-6}$ hPa (~140 km)	$4x10^{-10}$ hPa (~600 km)
Horizontal Resolution	0.9˚x1.25˚	1.9˚x2.5˚
Time Step	30 min	5 min
Specified Dynamics	X	X
Data Assimilation	DART	DART
Chemistry	TSMLT, MA	MA,$O^+(^2D)$ and $O^+(^2P)$
Non-orographic GW	X	X
Molecular Diffusion	minor	minor and major
Auroral Physics	X	X
Ions	E-region or E&D-region	E-region
Ion Transport		X
Electric Dynamo		X

WACCM extensions to physics

- Parameterized non-orographic gravity waves (based on Lindzen) triggered by convection and fronts [Richter et al., 2010]
- Upper atmosphere LW cooling calculated with non-LTE radiation transfer
- Forced with daily varying spectral irradiance, Kp index (aurora), and solar proton fluxes
- Molecular diffusion following Banks and Kockarts [1973]
- Auroral processes:
    - Ion drag and joule heating
- WACCM electric field based on a composite of two empirical models:
- WACCM-X adds an electrodynamo and O+ transport

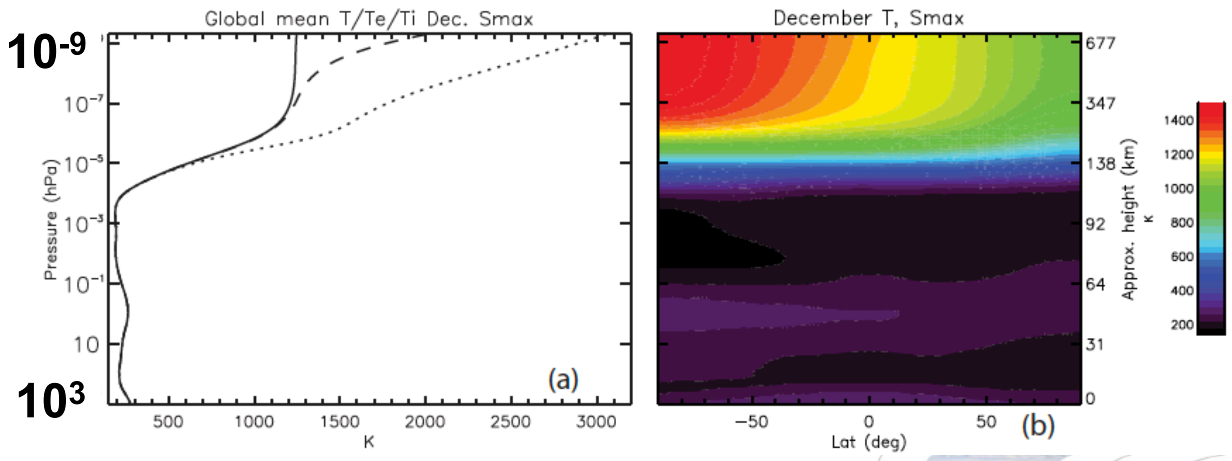
Ionospheric interface

- Ionospheric wind dynamo are solved using geomagnetic coordinates
- O^+ transport in the F-region solved in geographic coordinates
- ESMF used to transform fields between the geographic and geomagnetic grids



Liu et al., 2018, Development and Validation of the Whole Atmosphere Community Climate Model With Thermosphere and Ionosphere Extension (WACCM-X 2.0), DOI: 10.1002/2017MS001232

WACCM-X 2.0 included in CESM2.0 release



Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE
10.1002/2017MS001232

Key Points:
- The Whole Atmosphere Community Climate Model has been extended to include ionospheric electrodynamics
- WACCM-X simulates the interaction of lower atmosphere and solar influences in the ionosphere
- Preliminary validation demonstrates agreement with observations

Development and Validation of the Whole Atmosphere Community Climate Model With Thermosphere and Ionosphere Extension (WACCM-X 2.0)

Han-Li Liu[1], Charles G. Bardeen[2], Benjamin T. Foster[1], Peter Lauritzen[3], Jing Liu[1], Gang Lu[1], Daniel R. Marsh[1,2], Astrid Maute[1], Joseph M. McInerney[1], Nicholas M. Pedatella[1], Liying Qian[1], Arthur D. Richmond[1], Raymond G. Roble[1], Stanley C. Solomon[1], Francis M. Vitt[1,2], and Wenbin Wang[1]

Journal of Geophysical Research: Space Physics

RESEARCH ARTICLE
10.1002/2017JA025010

Key Points:
- First evaluation of WACCM-X during deep solar minimum year was carried out
- Data-model comparisons illustrate the high fidelity of WACCM-X

First Results From the Ionospheric Extension of WACCM-X During the Deep Solar Minimum Year of 2008

Jing Liu[1], Hanli Liu[1], Wenbin Wang[1], Alan G. Burns[1], Qian Wu[1], Quan Gan[2], Stanley C. Solomon[1], Daniel R. Marsh[1], Liying Qian[1], Gang Lu[1], Nicholas M. Pedatella[1], Joe M. McInerney[1], James M. Russell III[3], and William S. Schreiner[4]

[1]High Altitude Observatory, National Center for Atmospheric Research, Boulder, CO, USA, [2]Department of Physics and Astronomy, Clemson University, Clemson, SC, USA, [3]Center for Atmospheric Sciences, Hampton University, Hampton, VA, USA, [4]COSMIC Program Office, University Corporation for Atmospheric Research, Boulder, CO, USA

Journal of Geophysical Research: Space Physics

RESEARCH ARTICLE
10.1002/2017JA024998

Key Points:
- In the mesopause, hydrogen density is higher in summer than in winter, and higher at solar minimum than at solar maximum
- MSIS exhibits reverse seasonal variation than WACCM and SABER do in the mesopause region

Temporal Variability of Atomic Hydrogen From the Mesopause to the Upper Thermosphere

Liying Qian[1], Alan G. Burns[1], Stan S. Solomon[1], Anne K. Smith[2], Joseph M. McInerney[1], Linda A. Hunt[3], Daniel R. Marsh[1,2], Hanli Liu[1], Martin G. Mlynczak[3], and Francis M. Vitt[1,2]

[1]High Altitude Observatory, National Center for Atmospheric Research, Boulder, CO, USA, [2]Atmospheric Chemistry Observations and Modeling Laboratory, National Center for Atmospheric Research, Boulder, CO, USA, [3]NASA Langley Research Center, Hampton, VA, USA

Geophysical Research Letters

RESEARCH LETTER
10.1002/2017GL076950

Key Points:
- We have performed the first comprehensive whole-atmosphere climate change simulations, including the thermosphere and ionosphere

Whole Atmosphere Simulation of Anthropogenic Climate Change

Stanley C. Solomon[1], Han-Li Liu[1], Daniel R. Marsh[1], Joseph M. McInerney[1], Liying Qian[1], and Francis M. Vitt[1]

[1]High Altitude Observatory, National Center for Atmospheric Research, Boulder, CO, USA

Geophysical Research Letters

RESEARCH LETTER
10.1029/2018GL077723

Special Section:
New understanding of the solar eclipse effects on geospace: The 21 August 2017 Solar Eclipse

Simulation of the 21 August 2017 Solar Eclipse Using the Whole Atmosphere Community Climate Model-eXtended

Joseph M. McInerney[1], Daniel R. Marsh[1,2], Han-Li Liu[1], Stanley C. Solomon[1], Andrew J. Conley[2], and Douglas P. Drob[3]

Whole atmosphere climate change 1972-1976 to 2001-2005

Geophysical Research Letters

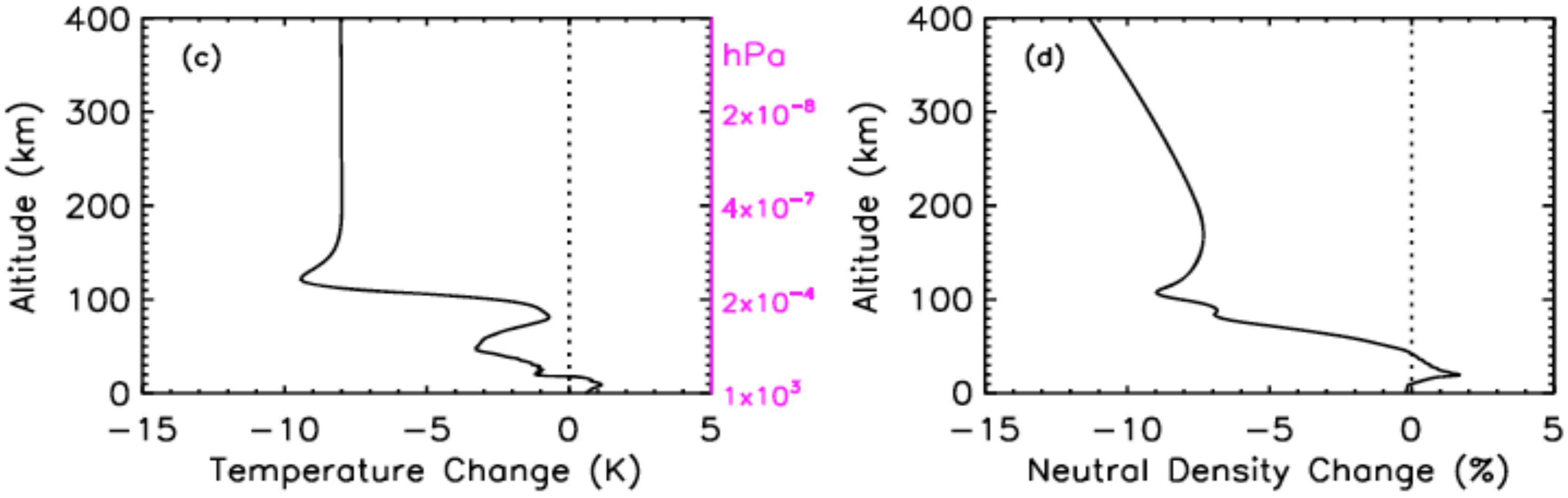
RESEARCH LETTER
10.1002/2017GL076950

Key Points:
- We have performed the first comprehensive whole-atmosphere climate change simulations, including the thermosphere and ionosphere

Whole Atmosphere Simulation of Anthropogenic Climate Change

Stanley C. Solomon[1], Han-Li Liu[1], Daniel R. Marsh[1], Joseph M. McInerney[1], Liying Qian[1], and Francis M. Vitt[1]

Inputs	1972–1976	2001–2005	Change per decade
<CO_2> at surface	330 ppmv	375 ppmv	+16 ppmv
<CH_4> at surface	1.44 ppmv	1.74 ppmv	+0.1 ppmv
<CFC11 + CFC12> at surface	0.29 ppbv	0.79 ppbv	+0.2 ppbv



WACCM-X Simulation of the 2017 Solar Eclipse

Geophysical Research Letters

RESEARCH LETTER
10.1029/2018GL077723

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Simulation of the 21 August 2017 Solar Eclipse Using the Whole Atmosphere Community Climate Model-eXtended

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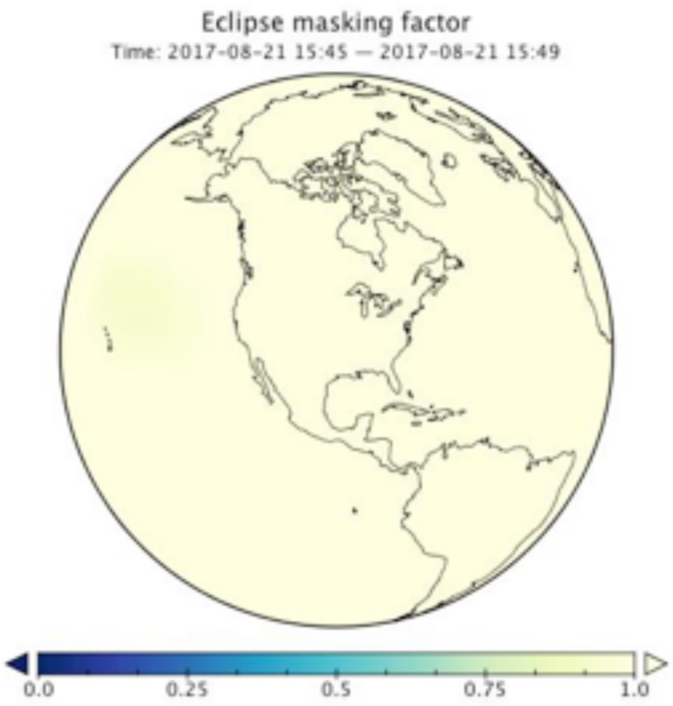
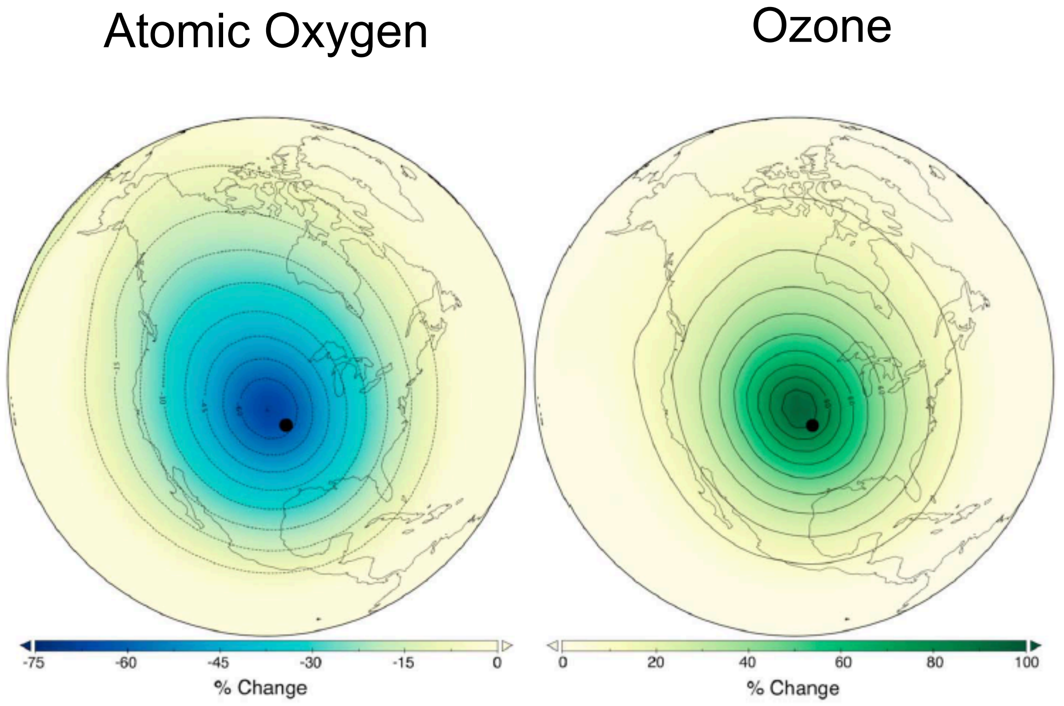
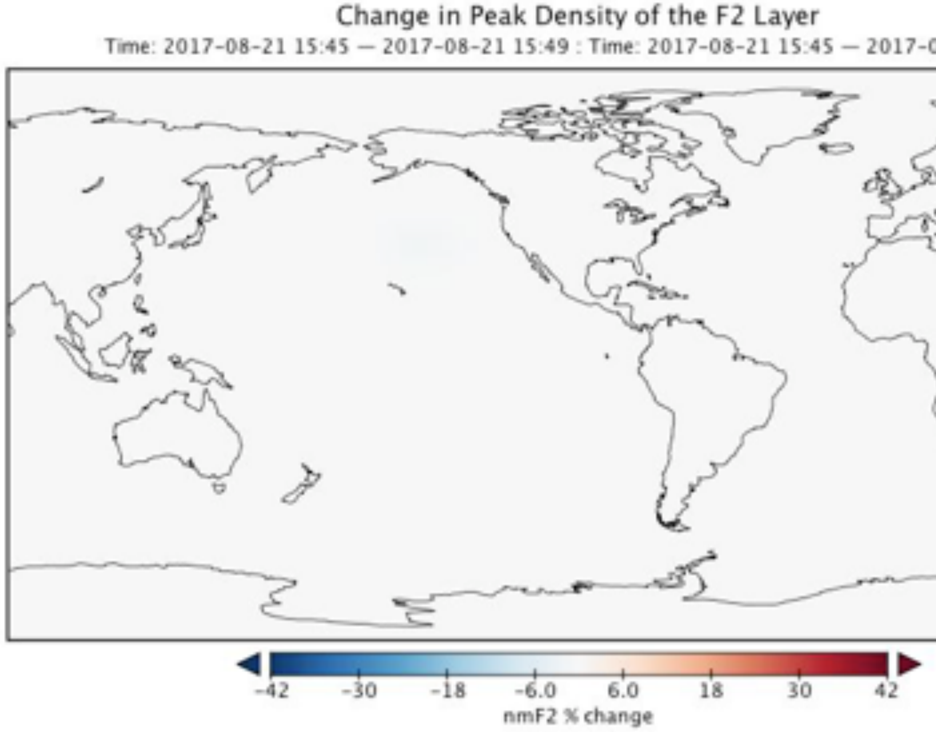




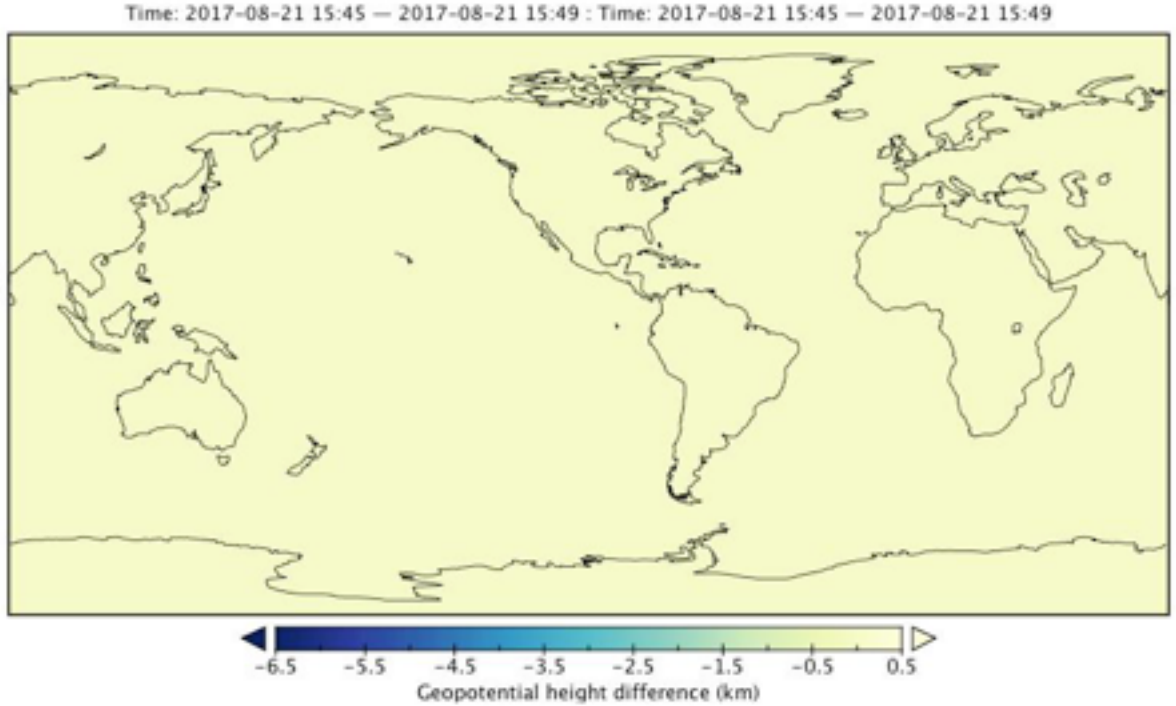
18UT % change at 65 km

Thermospheric response

% change in electron max density



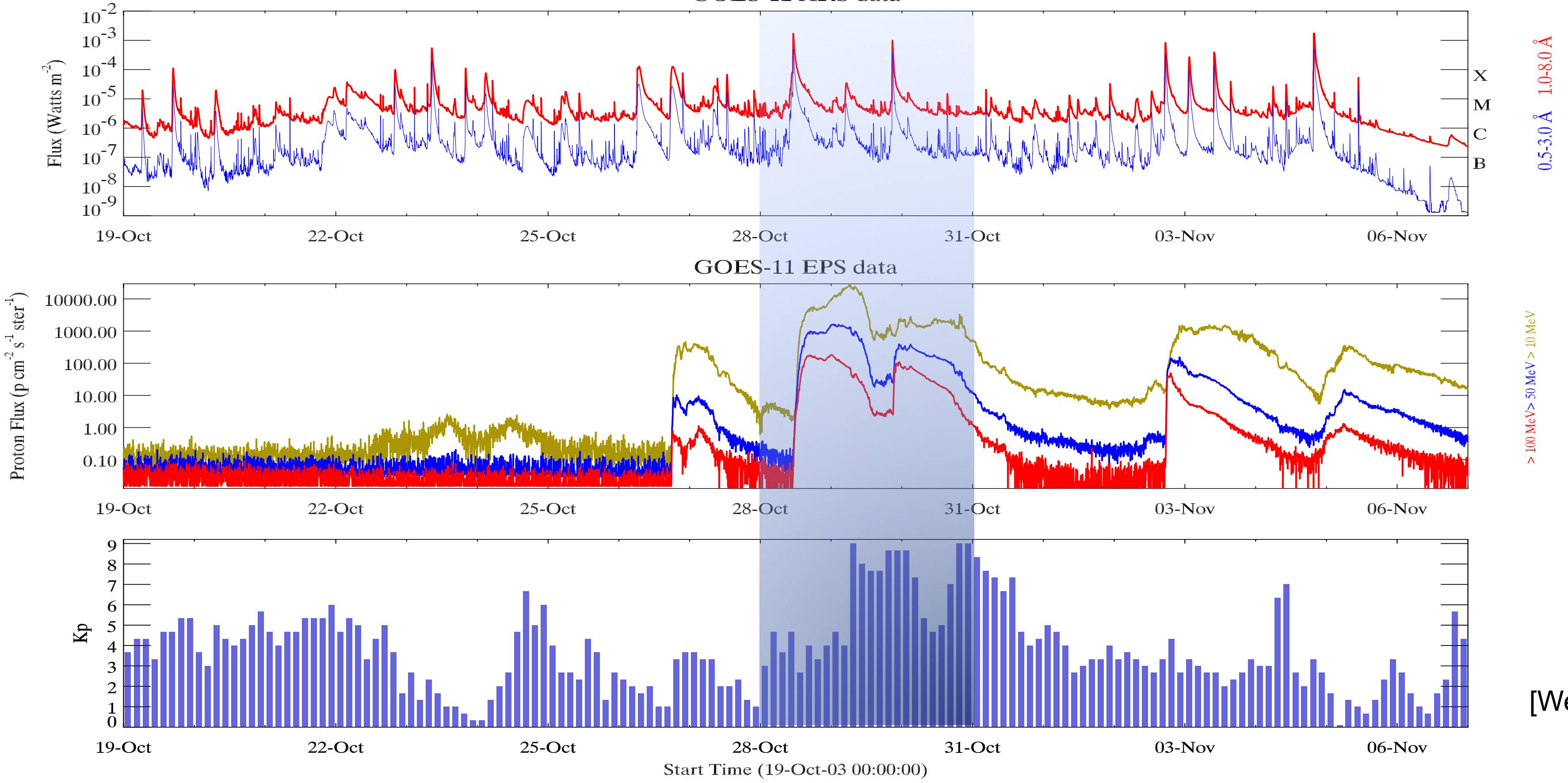
change in geopotential at 250 km



2003 “Halloween” Storm

- Study led by Chuck Bardeen
- Flares: X28 (Nov. 4), X17 (Oct. 28), X10 (Oct. 29)

19 Oct 7 Nov

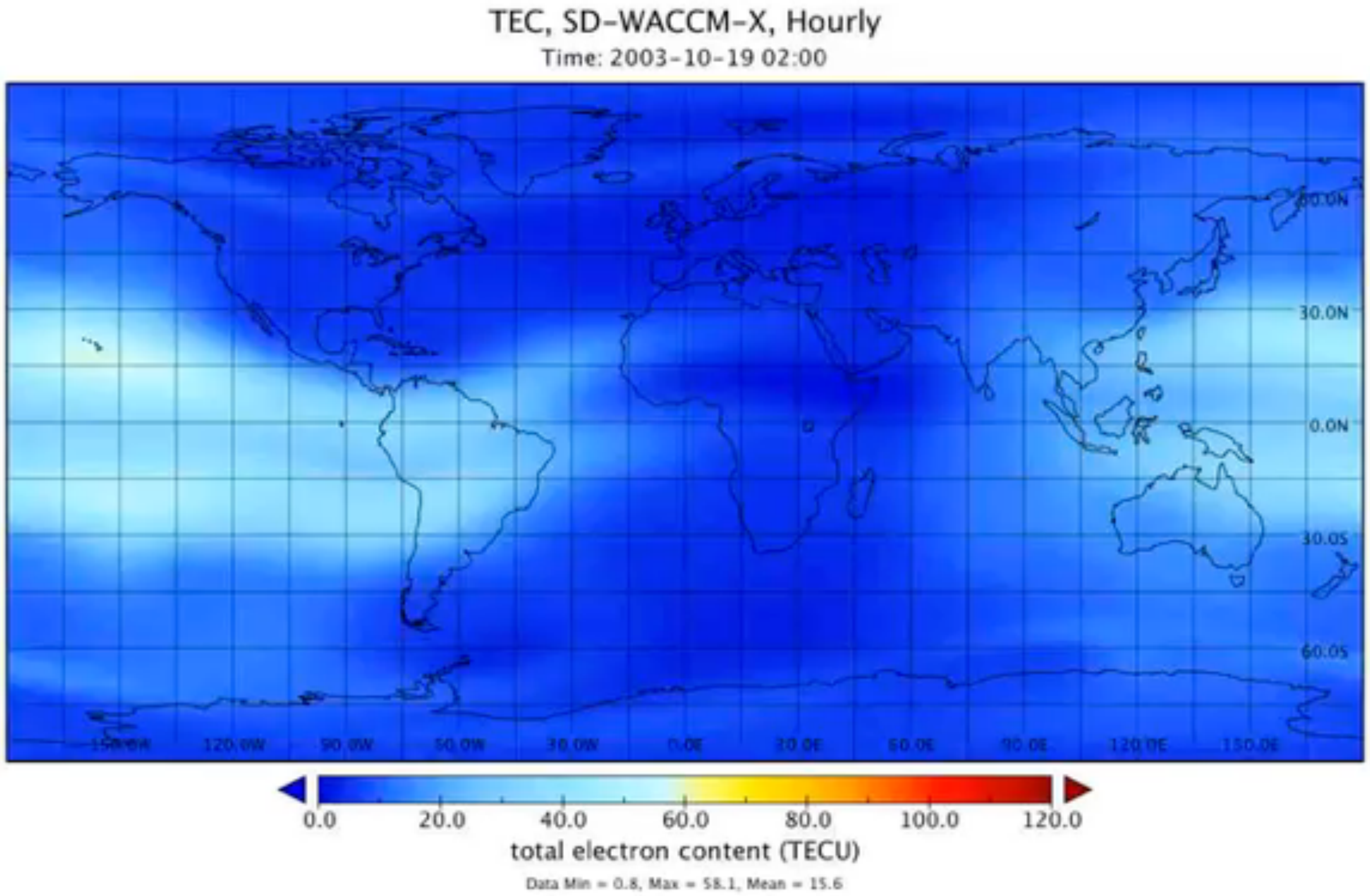


[Weaver et al., 2004]

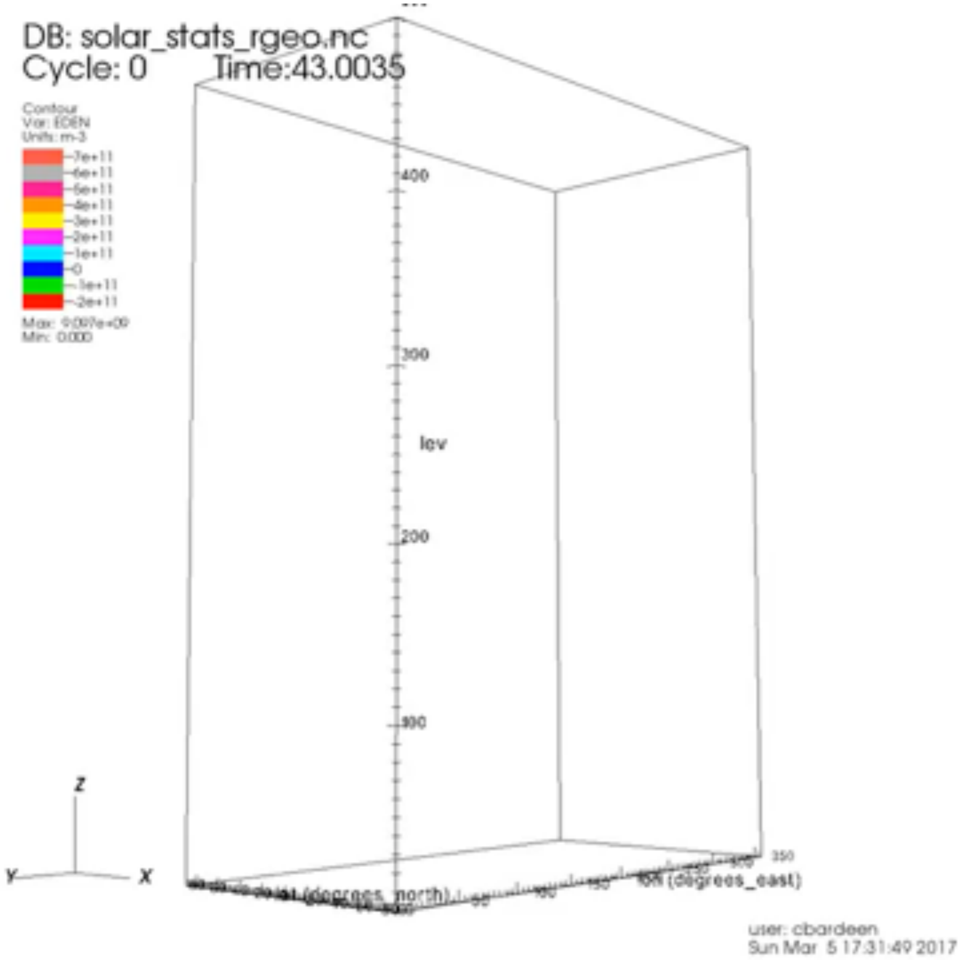
Model forcing

- 3 hour auroral (Kp, Ap)
- Daily f10.7
- 5 minute solar EUV based on Flare Irradiance Spectral Model (FISM, Chamberlain et al., 2008)
- hourly solar proton ionisation rates

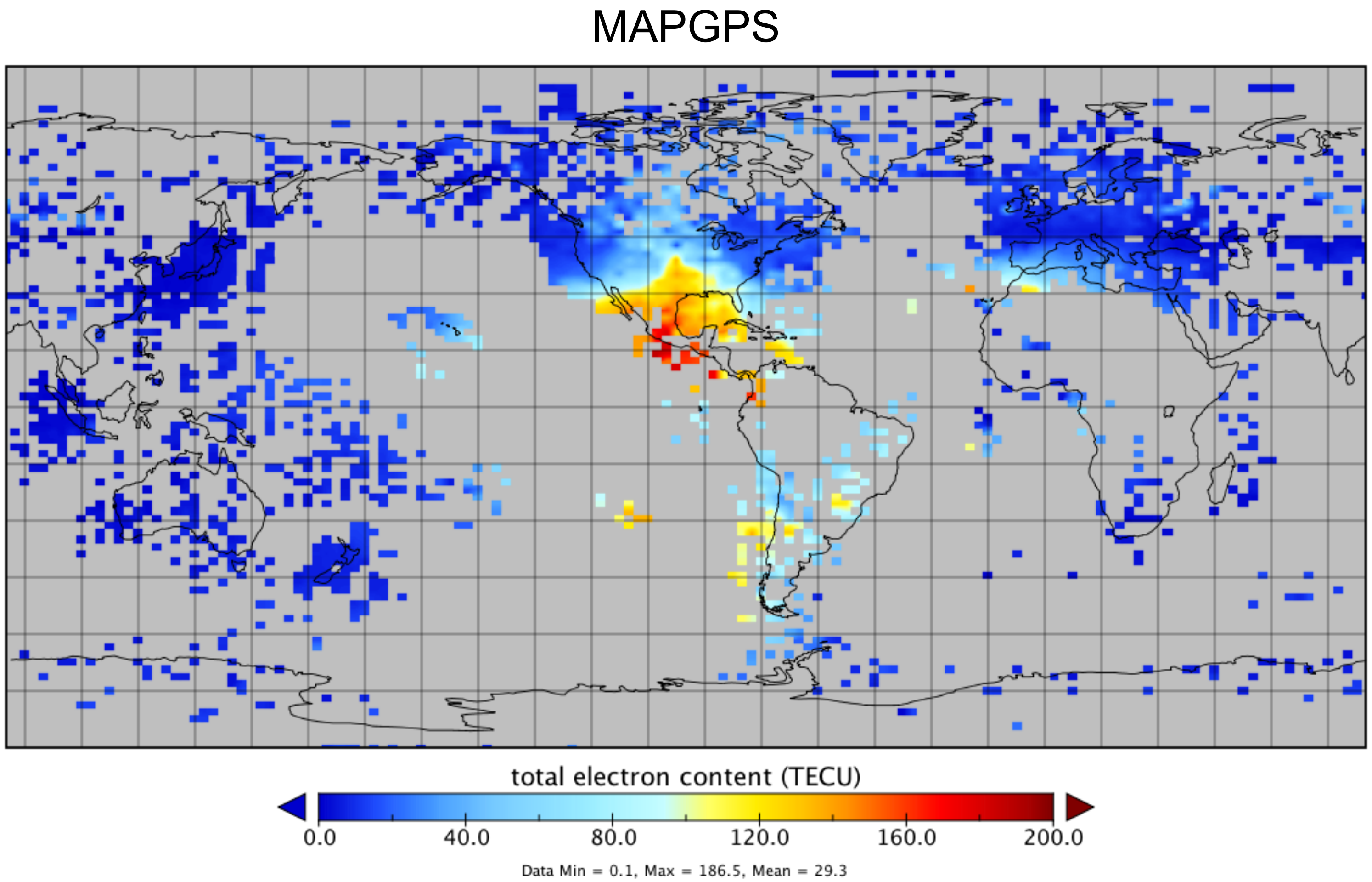
TEC: 19 Oct – 7 Nov



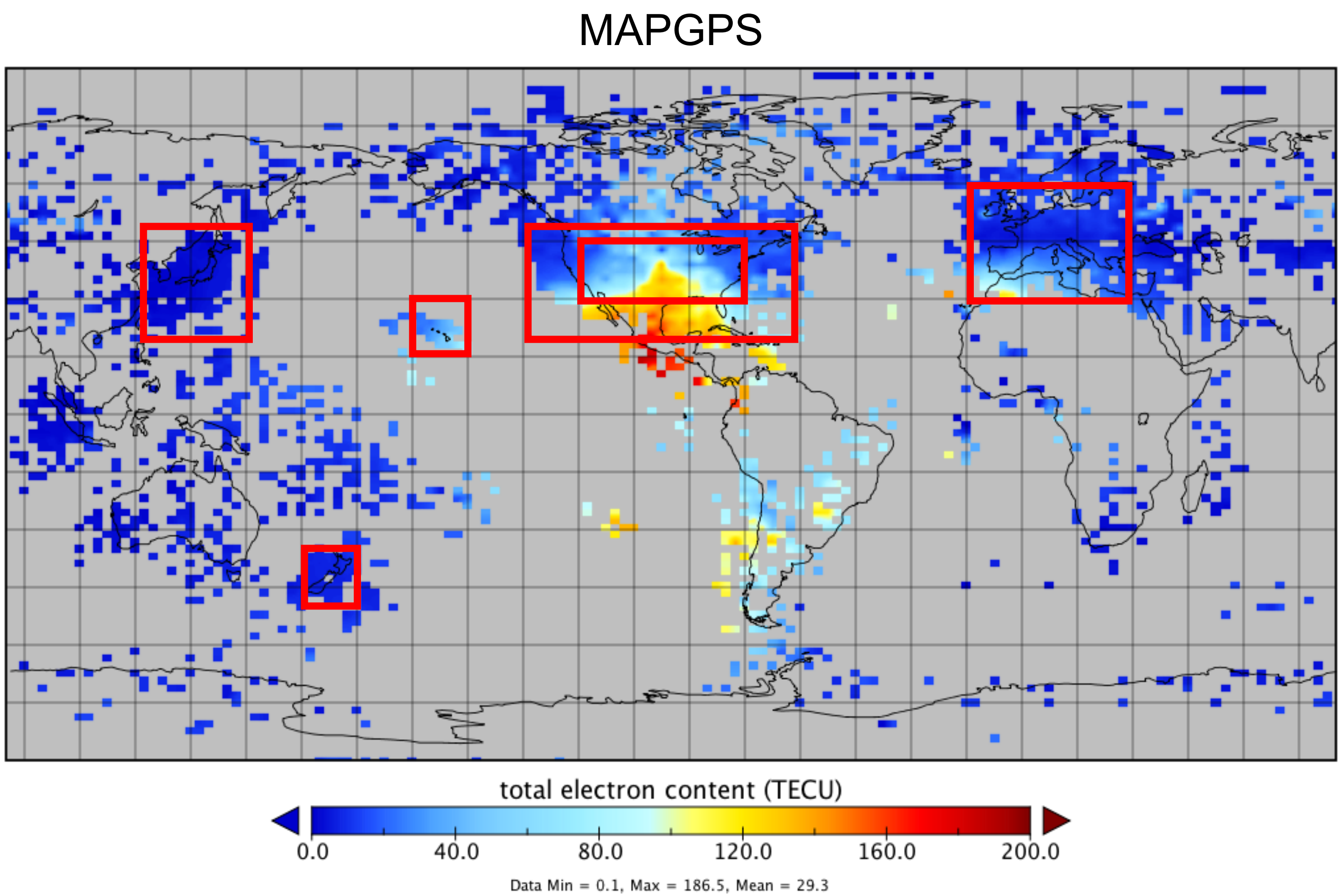
Electron Density : All – Flare



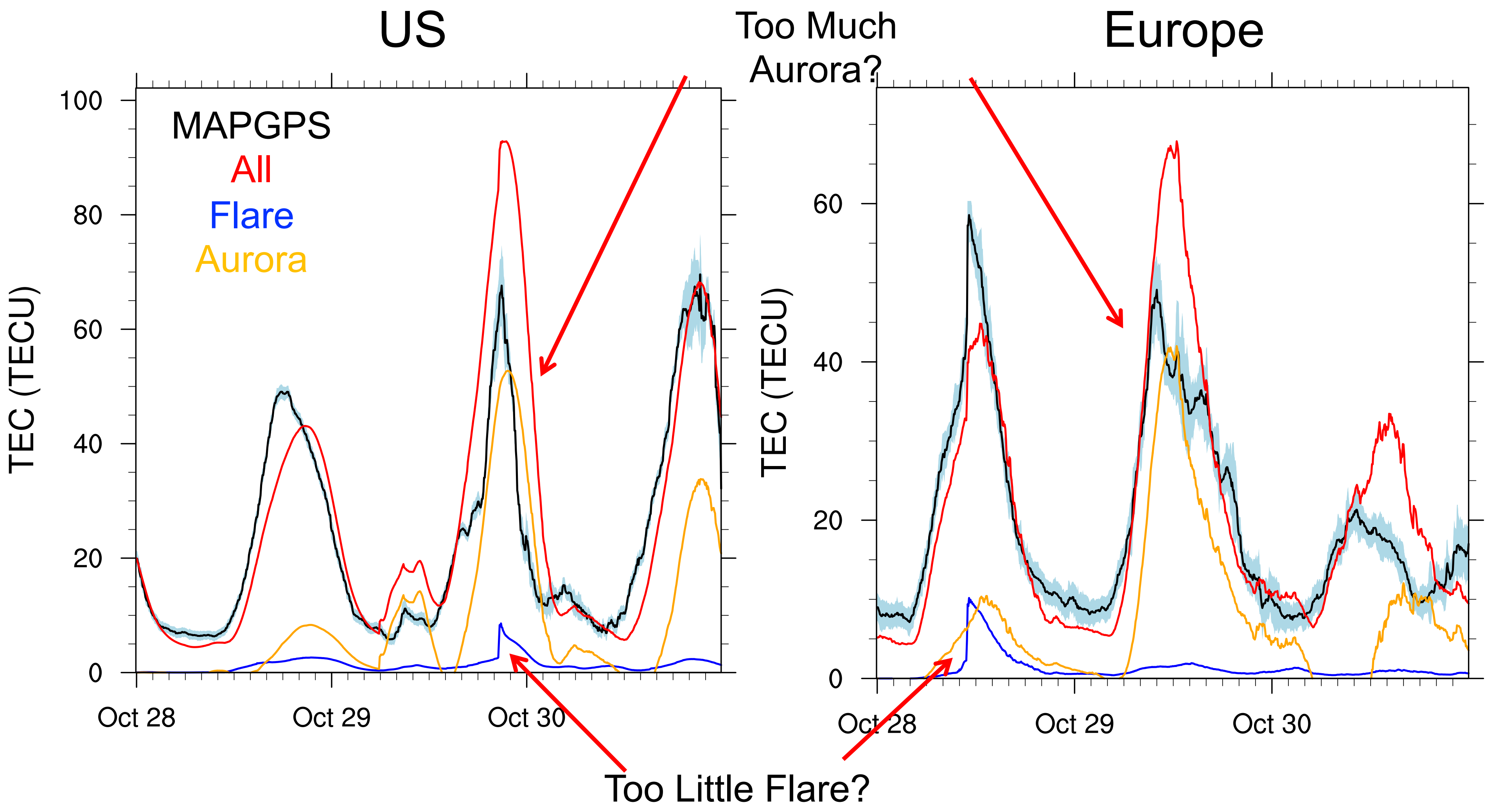
TEC : MAPGPS, 29 Oct @ 20:15



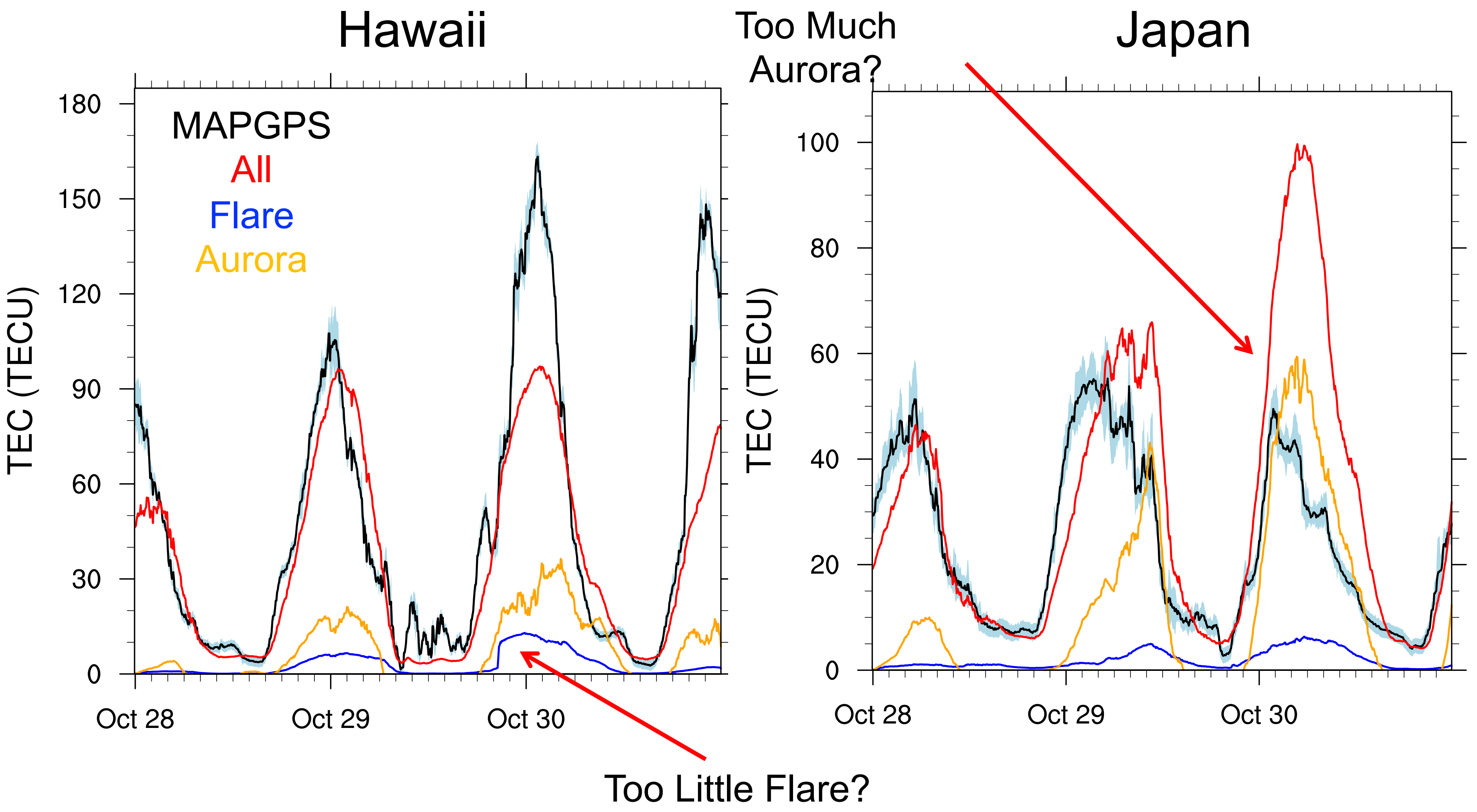
Regional Time Series



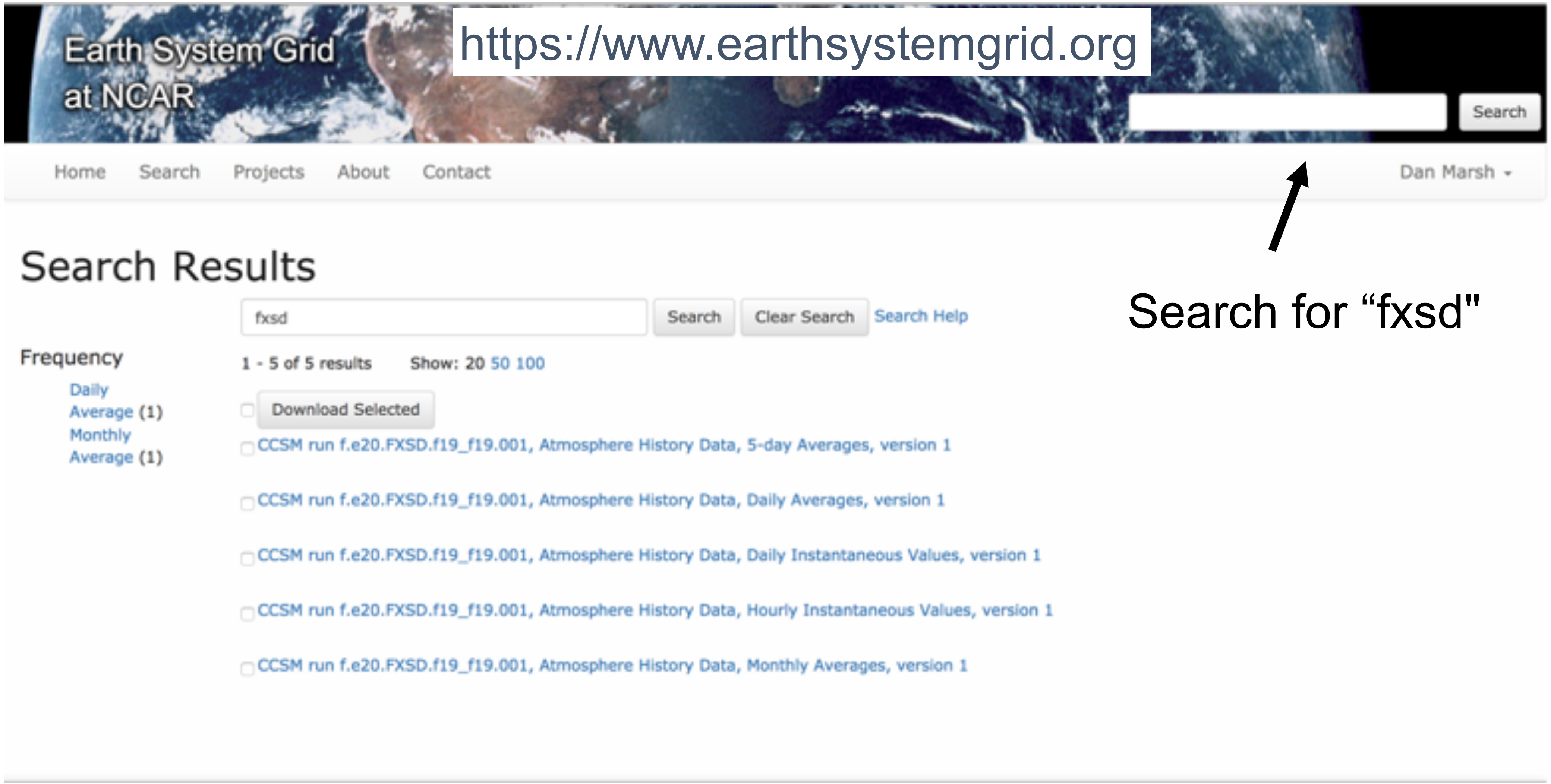
28-30 Oct : US and Europe



28-30 Oct : Hawaii and Japan



SD-WACCMX output is available to download



Search for “fxsd"

WACCM-X output

- **netCDF:** self-describing binary data format used for primary CESM output
- **History files:** WACCM-X output is written to several output streams, each with a particular frequency and averaging characteristic
  - **h0:** monthly averages
    - f.e20.FXSD.f19_f19.001.cam.h0.2000-01.nc (January 2000)
    - f.e20.FXSD.f19_f19.001.cam.h0.2000-02.nc (February 2000)
  - **h1:** hourly instantaneous
    - f.e20.FXSD.f19_f19.001.cam.h1.2000-01-01-00000.nc (January 1, 2000)
    - f.e20.FXSD.f19_f19.001.cam.h1.2000-01-01-00000.nc (January 2, 2000)
  - **h2:** daily instantaneous
  - **h3:** daily averages
  - **h4:** 5-day averages
  - **h5:** daily averages, zonal mean circulation diagnostics

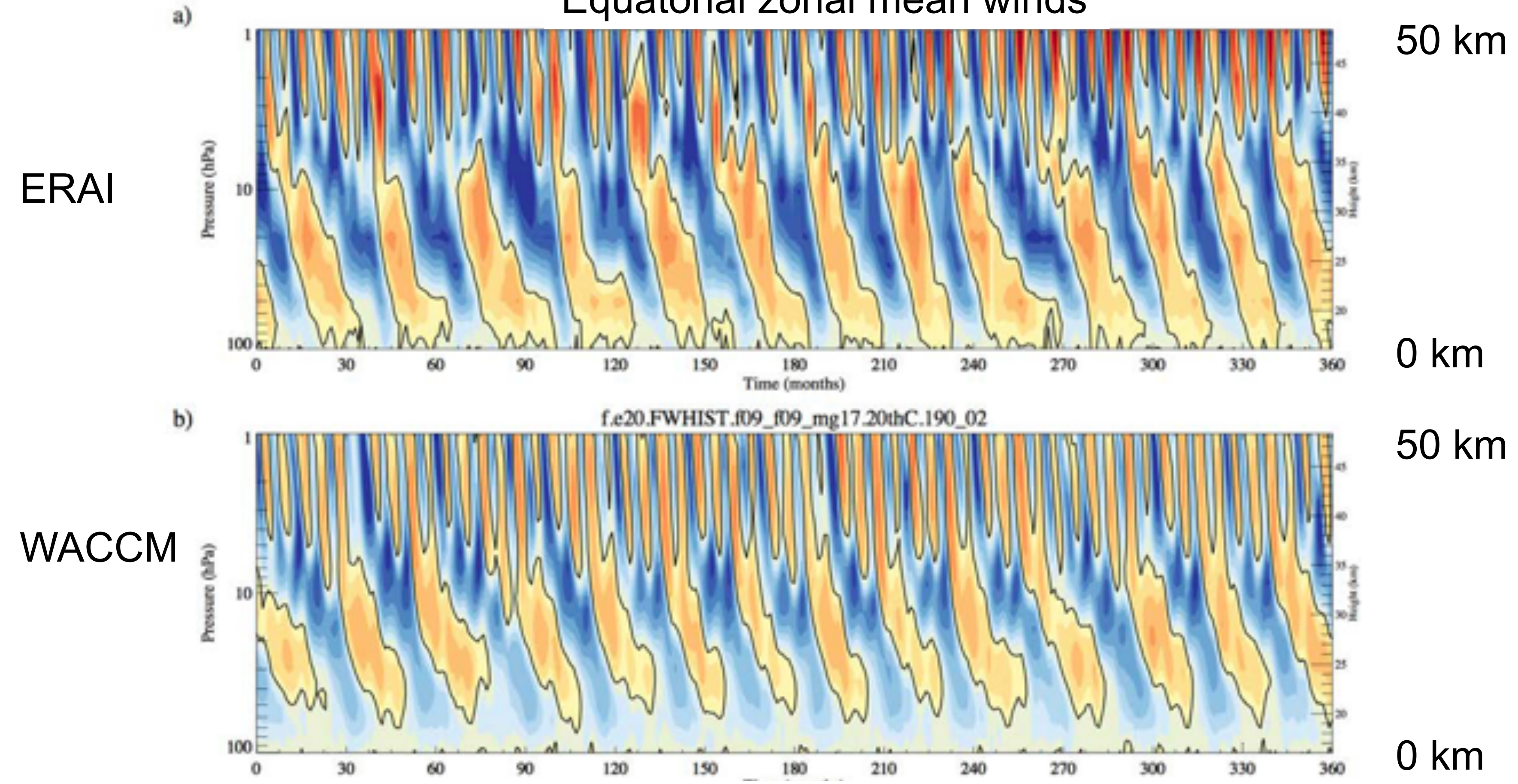
CESM2.0 will include a new version of WACCM

CESM2.0 (WACCM)			
Horizontal resolution	0.95˚x1.25˚	No. Species	228
Vertical layers	70 or 88 (0-140 km)	Kinetic rates	JPL-15
Boundary Layer	CLUBB	Sulfate SAD	Interactive with MAM
Microphysics	MG2.0	ICE SAD	MG2.0
Radiation	RRTMG	Solar Irradiance	SOLARIS-CMIP6
Aerosols	MAM-4	GHG / Halogens	Meinshausen, 2016

DECK simulations for CMIP6 will begin this month

WACCM now produces an internally generated QBO

Equatorial zonal mean winds



Months

J. Richter, AMWG meeting, NCAR, 2018

Quantifying the energetic particle precipitation influences on the budgets of stratospheric NOy and ozone using a new ‘tagging’ scheme in WACCM

EGU2018-3534
Session AS3.20
X5.198

Daniel Marsh[1], Doug Kinnison[1] , Louisa Emmons[1], and Jean-François Lamarque[1]
EGU General Assembly, Vienna, April 2018

[1] Atmospheric Chemistry Observations and Modeling
National Center for Atmospheric Research, Boulder, USA
Contact email: marsh@ucar.edu

Tagging Scheme

- 33 inert tagged tracers added to chemical mechanism
- oxidant levels and non-tagged species are unchanged
- tagged species are operated on by wet and dry deposition at the same rate as their non-tagged counterpart
- tagged species also undergo heterogeneous reactions in both the troposphere and stratosphere
- polar stratospheric cloud formation of nitric acid hydrate is included, with settling of condensed phase tagged HNO_3

Symbol	Composition	Symbol	Composition
XN	N	XPAN	$CH_3CO_3NO_2$
XN2D	N(^{2}D)	XMPAN	$CH_2CCH_3CO_3NO_2$
XNO	NO	XONITR	$C_4H_7NO_4$
XNO2	NO_2	XHONITR	$C_4H_9NO_4$
XNO3	NO_3	XNOA	$CH_3COCH_2ONO_2$
XHNO3	HNO_3	XNTERPO2	$C_{10}H_{16}NO_5$
XNO2NO	N_2O_5	XNTERPOO	$C_{10}H_{17}NO_5$
XNO3NO	N_2O_5	XPBZNIT	$C_7H_5O_3NO_2$
XHO2NO	HO_2NO_2	XTERPNIT	$C_{10}H_{17}NO_4$
XHNO3	HNO_3	XNC4CH2O	$C_5H_9NO_4$
		XNC4CHO	$C_5H_7NO_4$
XBRONO	$BrONO_2$	XNC4CHO	$C_5H_7NO_4$
XCLONO	$ClONO_2$	XALKNIT	$C_5H_{11}ONO_2$
		XISOPNITA	$C_5H_9NO_4$
XO	O	XISOPNITB	$C_5H_9NO_4$
XO3	O_3	XISOPNO3	$C_5H_8NO_5$
XO1D	O(^{1}D)	XISOPNOO	$C_5H_9NO_5$
		XNC4CH2O	$C_5H_9NO_4$

Table 2: Tagged species.

EPP NOx tagging is not the only application for this scheme

Polar descent of EPP NOy

Tagging scheme used to track all NOy originating from EPP as XNOy= {all species in Table 2 except XO, XO3, XO1D}.

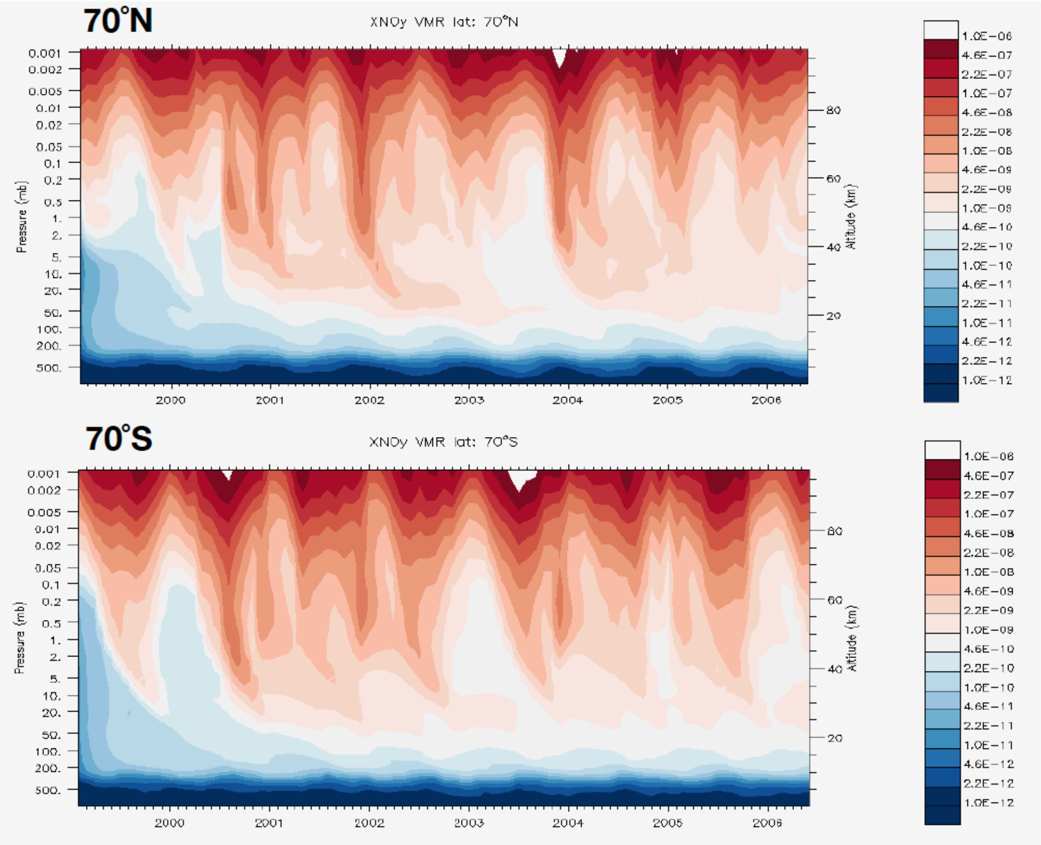
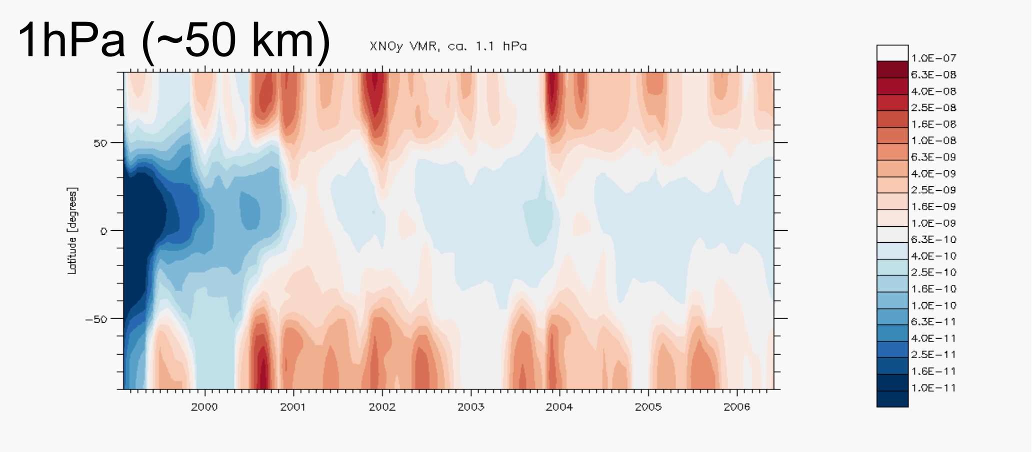
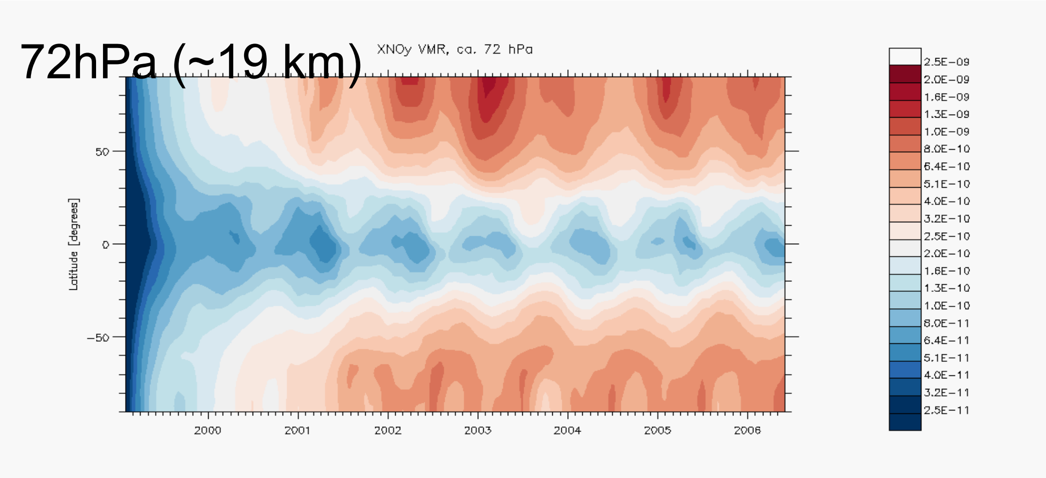
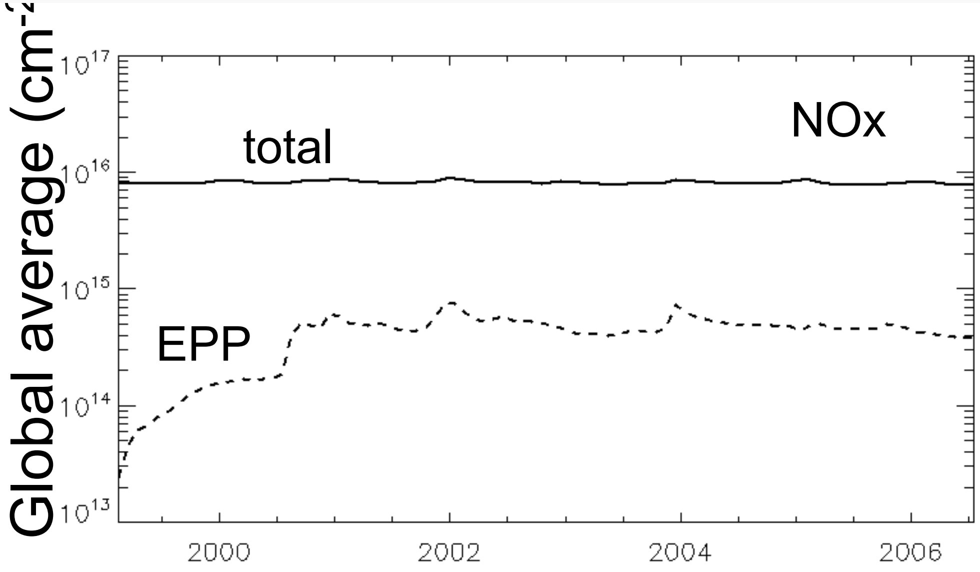


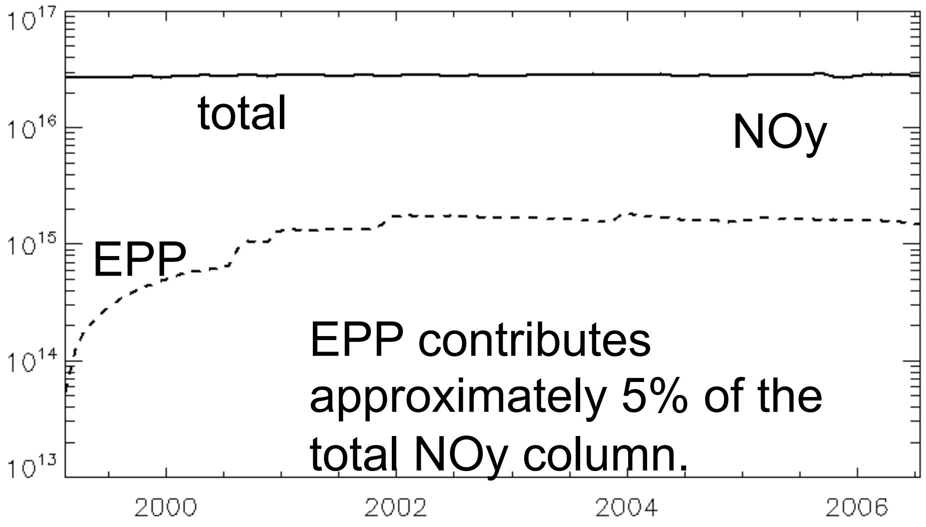
Figure 1: Monthly mean XNOy volume mixing ratio at 70°N (top) and 70°S (bottom) between March1999 and June 2006.

Global average (molecules cm^{-2}) NOx and NOy column, and contribution from EPP

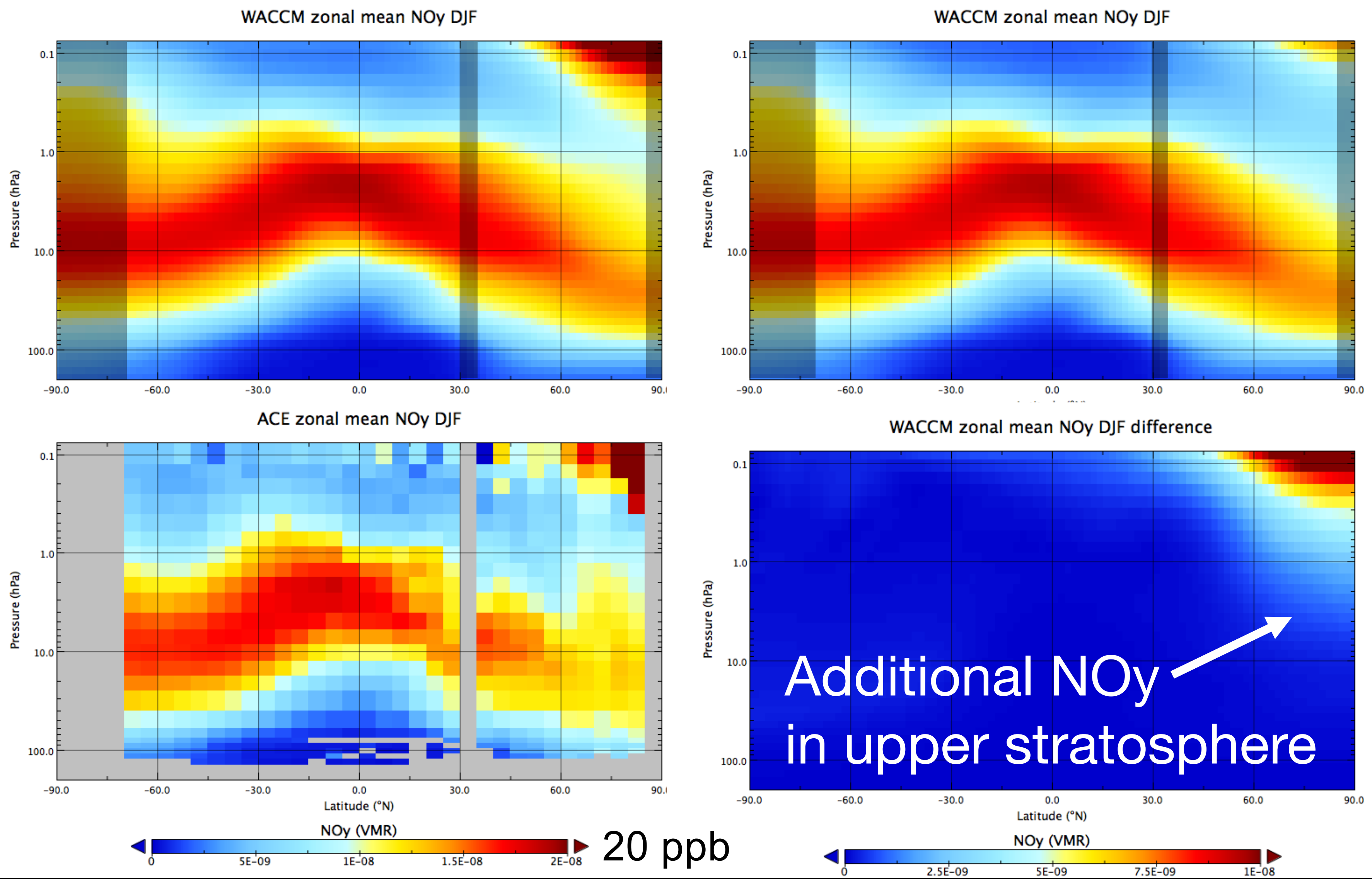




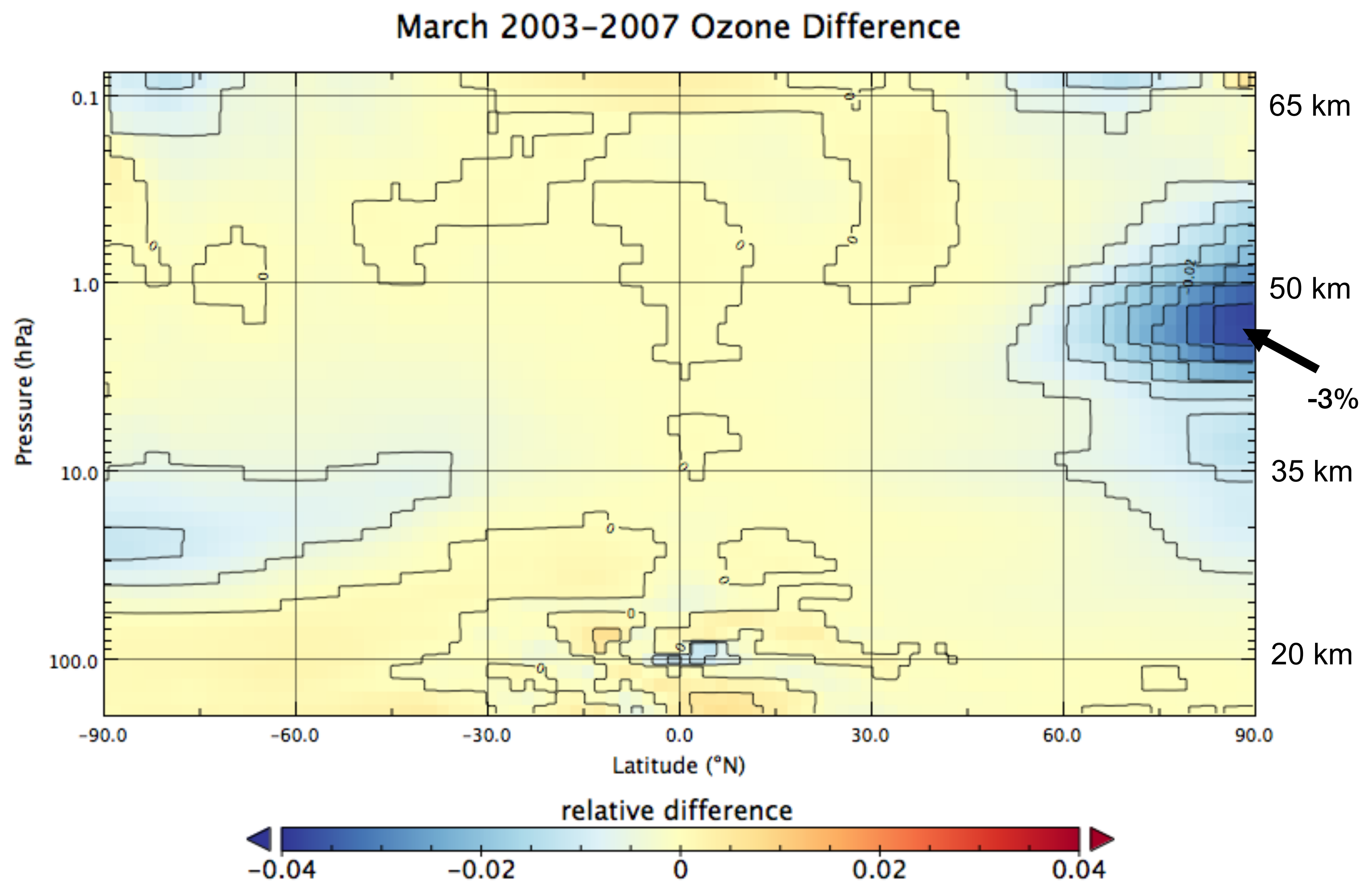




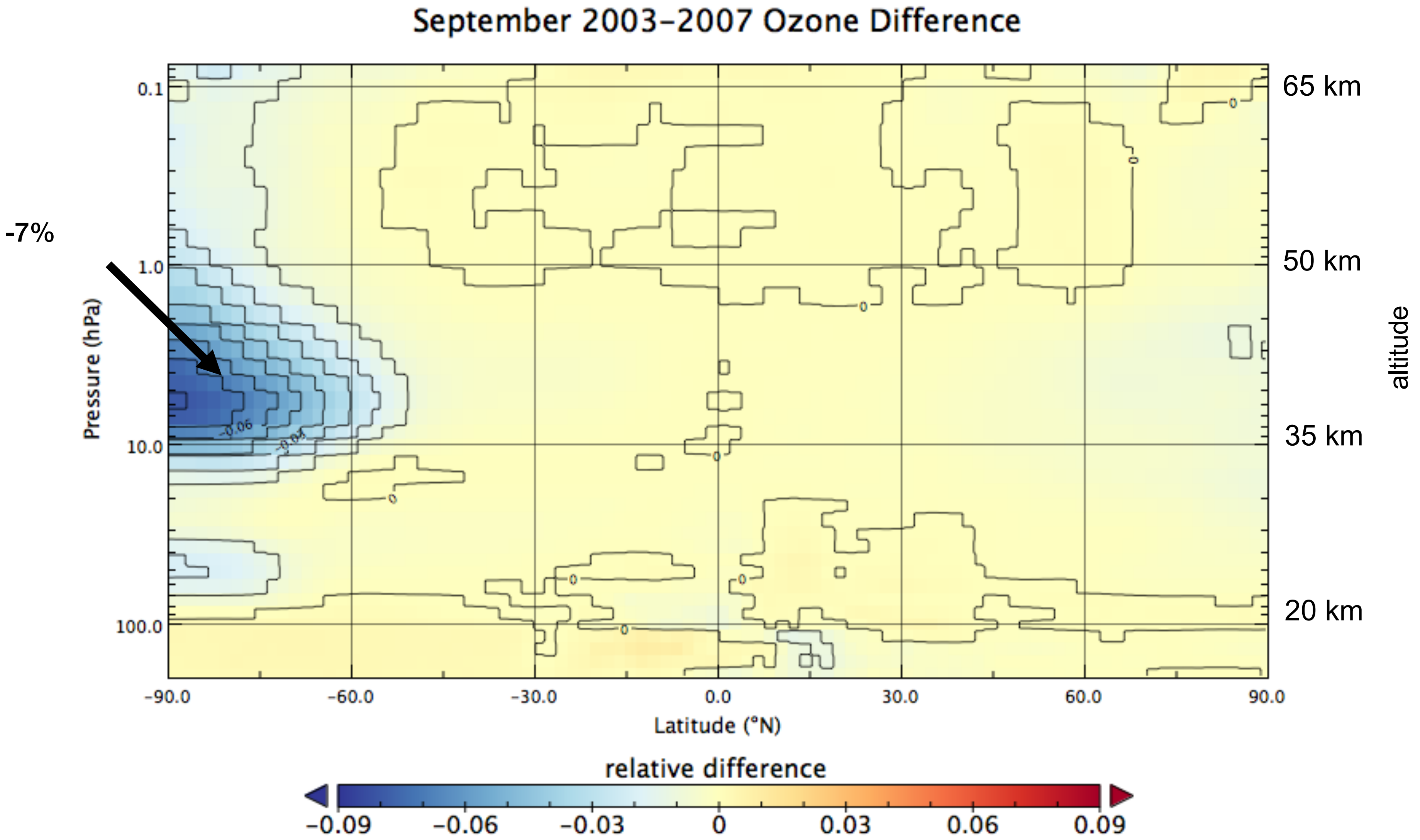
Improving NOy with better EPP



Zonal Mean Ozone Difference March 2003-2007 (control-EPP)/control



Effect is larger in Southern Hemisphere
Zonal Mean Ozone Difference September 2003-2007

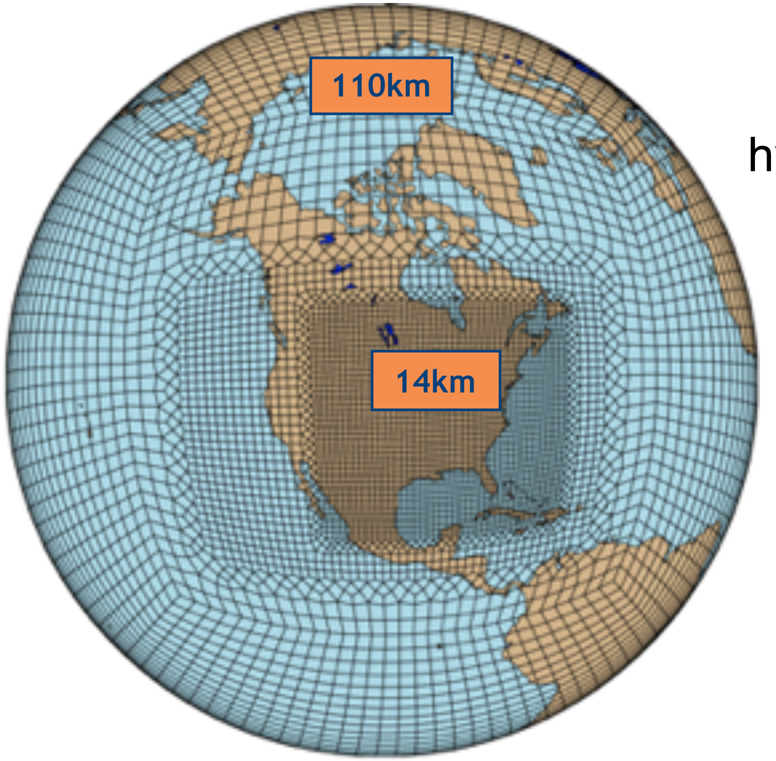


Future directions

- The next steps in atmospheric modeling at NCAR: bridging weather and climate (focus on S2S)
- NCAR will unify its weather, climate, space weather and air quality models
- New unified chemistry model is named *MUSICA: MUlti-Scale Infrastructure for Chemistry and Aerosols*
- Development will begin early 2019 aiming to provide and improve on the functionality of WRF-CHEM, CAM-CHEM, and WACCM

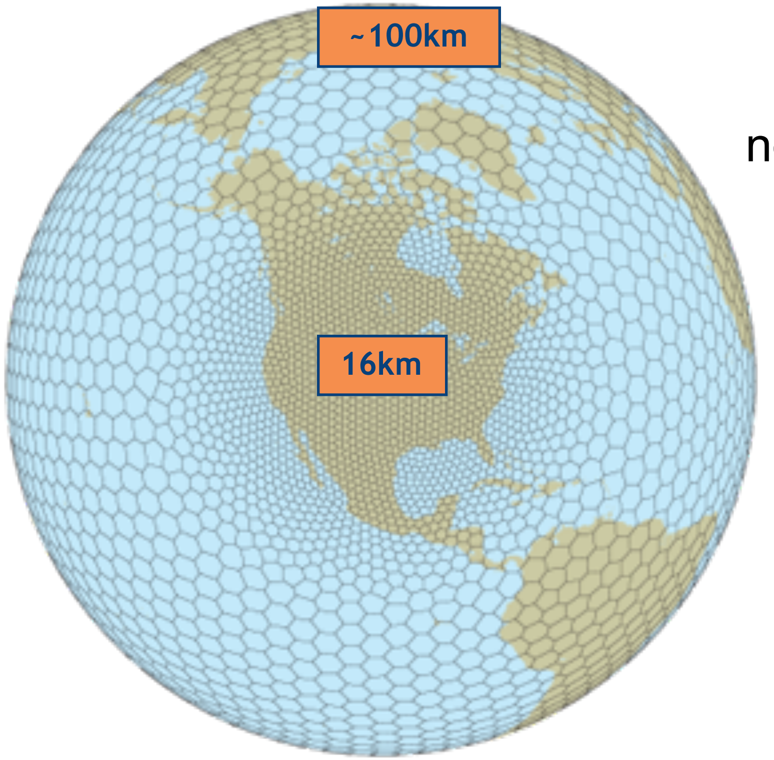
New ‘regionally refined’ options for CESM

- Advantages
  - Numerically less expensive than running globally at high resolution
  - No boundary conditions
  - Non-local teleconnections



hydrostatic

Spectral **E**lement dynamical core (CAM-SE)

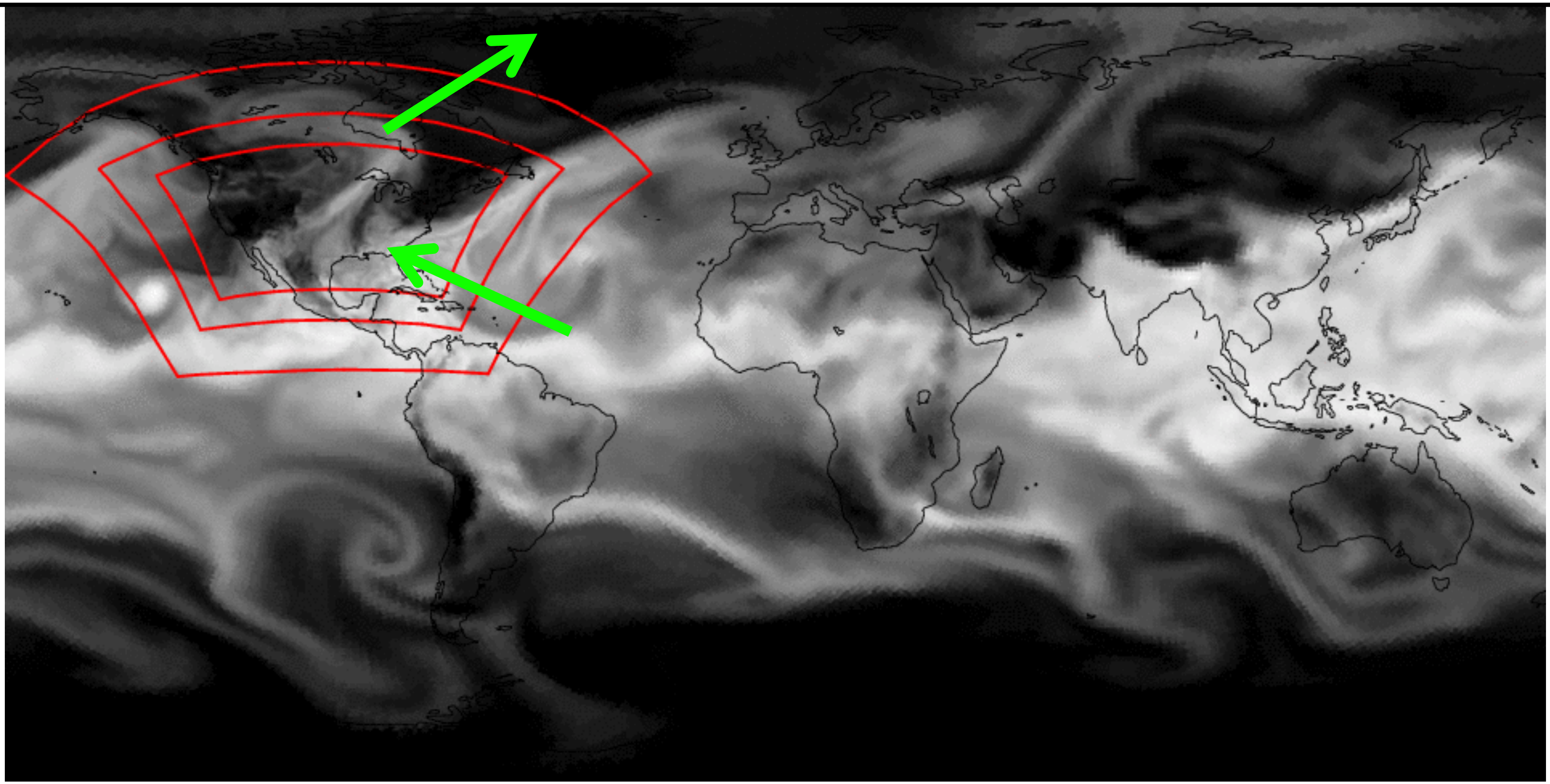


non-hydrostatic

Courtesy Colin Zarzycki

Model for **P**rediction **A**cross **S**cales (CAM-MPAS (v4))

Multi-resolution global simulation

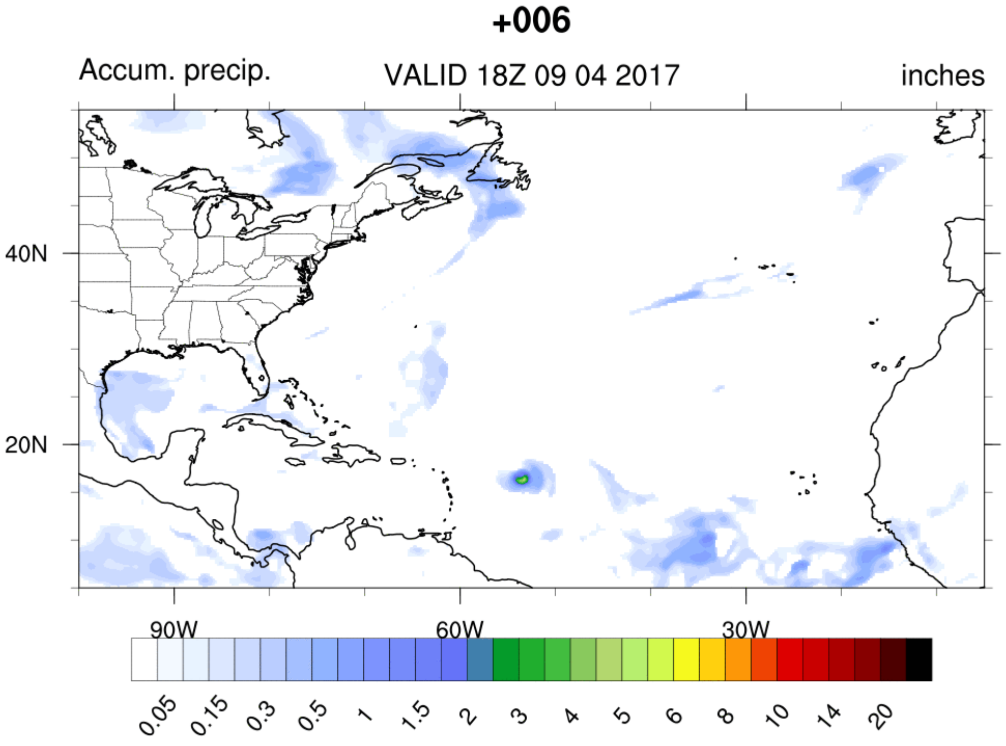


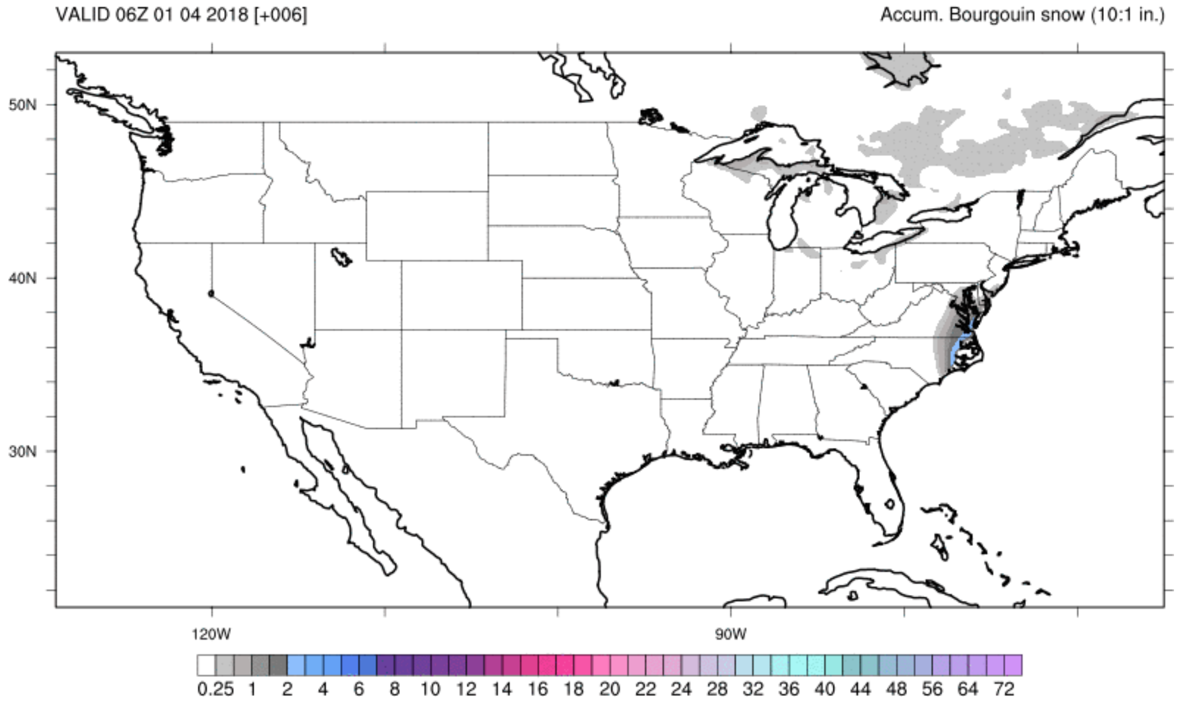
Precipitable water, Sept 23-Oct 3, 111km->14km CAM-SE mesh

Courtesy Colin Zarzycki

CESM "betacasts"

- If you ever wondered what a climate model looks like when you cram a forecast analysis into it in real-time…
- http://www.colinzarzycki.com





Summary

- CESM 2.0 offers significant improvements in our ability to model the atmosphere from the surface to the thermosphere.
  - WACCM-X is vastly improved and suitable for science studies of the Ionosphere-Thermosphere-Mesosphere system
  - WACCM has a 2x improvement in resolution and adds aerosol-cloud feedbacks
  - Future development will aim to bridge the divide between weather and climate
- Timescales to be explored vary from minutes to centuries
- We welcome participation at all levels from using the model output, to running “out of box” simulations and active component development – the C is for community!

Acknowledgements

- Charles G. Bardeen, Benjamin T. Foster, Rolando Garcia, Doug Kinnison, Jean-Francois Lamarqe, Peter Lauritzen, Han-Li Liu, Jing Liu, Gang Lu, Astrid Maute, Joseph M. McInerney, Mike Mills, Nicholas M. Pedatella, Liying Qian, Arthur D. Richmond, Yaga Richter, Raymond G. Roble, Anne K. Smith, Stanley C. Solomon, Francis M. Vitt, and Wenbin Wang, CESM team especially software engineering group.
- This work is in part supported by NSF grants AGS-1135432 and AGS- 1135446, NASA grants NNX14AE06G, NNX14AF20G, NNX14AH54G, NNX15AB83G, NNX16AB82G, and NNX17AI42G, and AFOSR grant FA9550-16-1–0050.
- The National Center for Atmospheric Research is sponsored by the National Science Foundation.