Whole Atmosphere Simulation of Anthropogenic Climate Change

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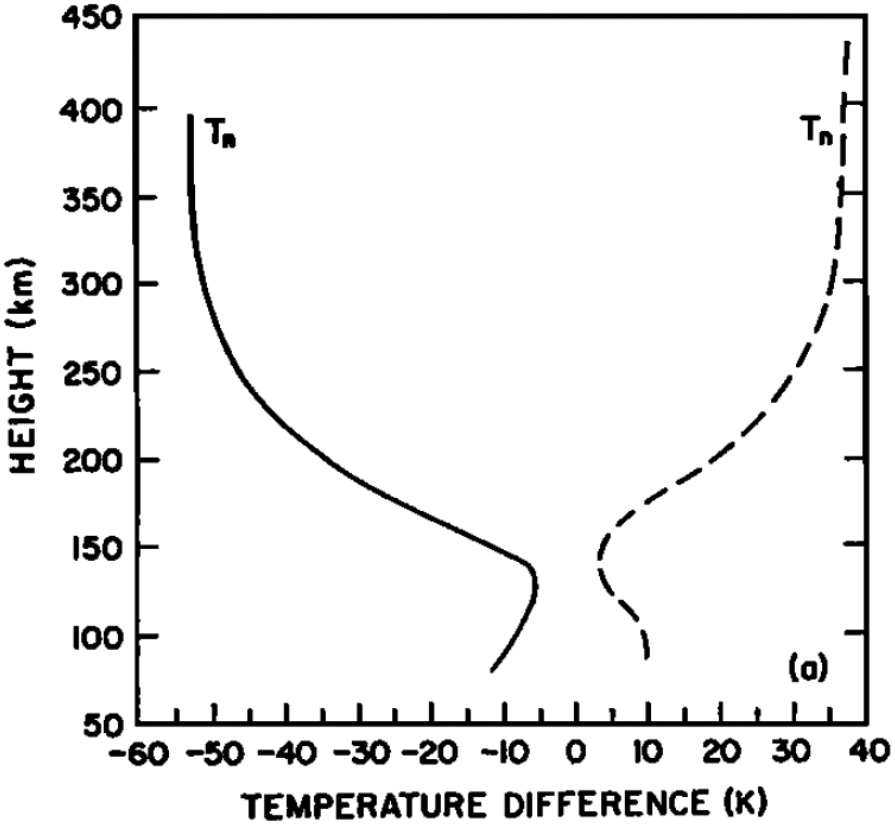
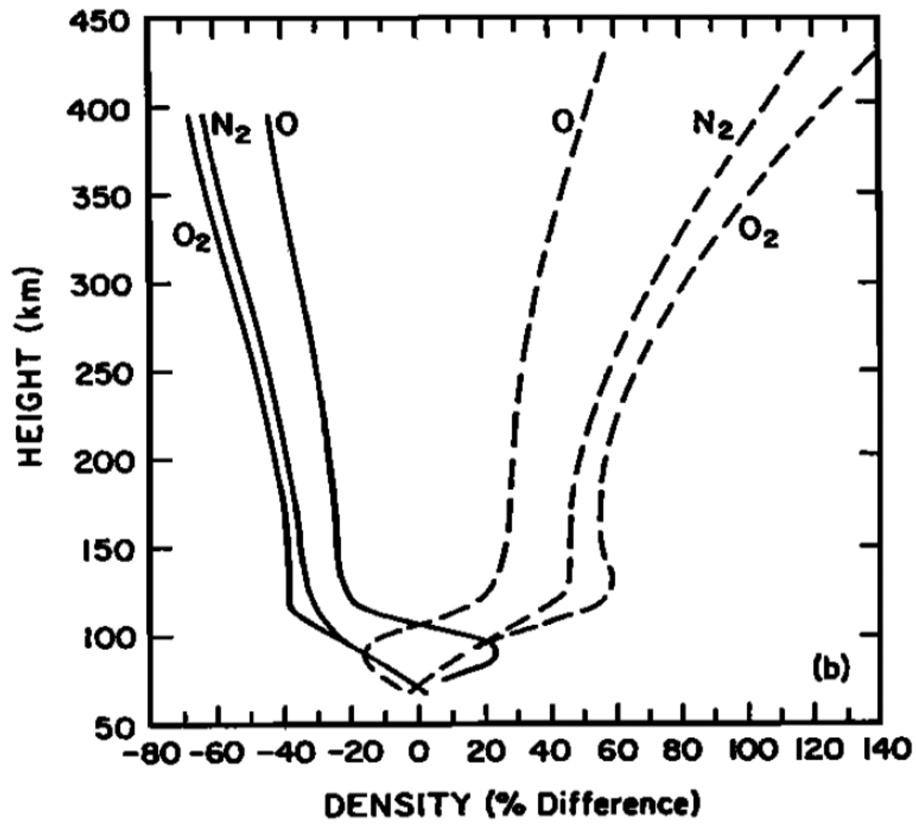
Model Prediction of Global Change in the Thermosphere

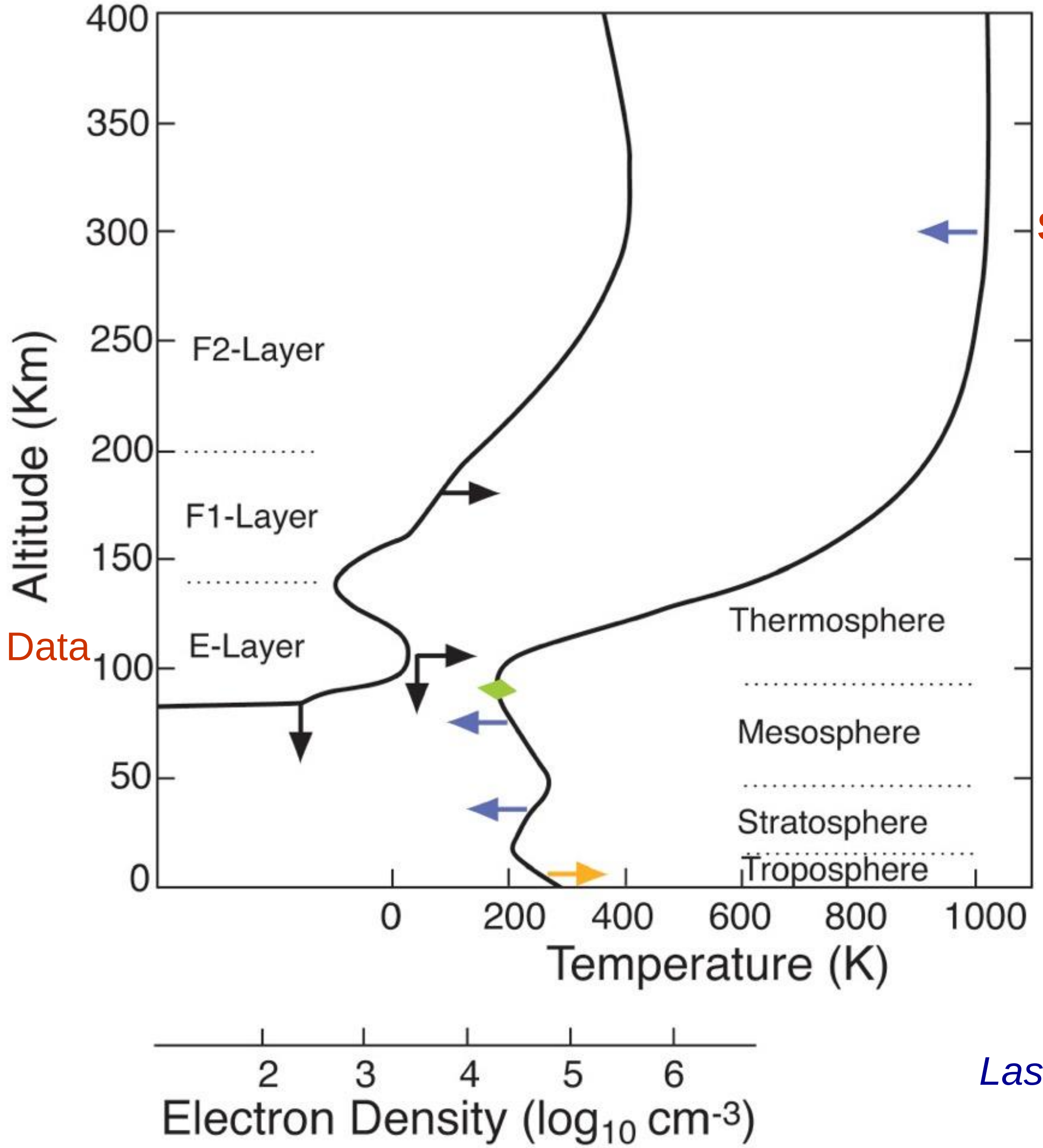
Roble & Dickinson [1989]





Global mean temperature, density, and composition study
for doubled and halved CO_2 and CH_4

Observed / Inferred Global Change Scenario:
"Warm Down, Cool Up"



Ionosonde Data

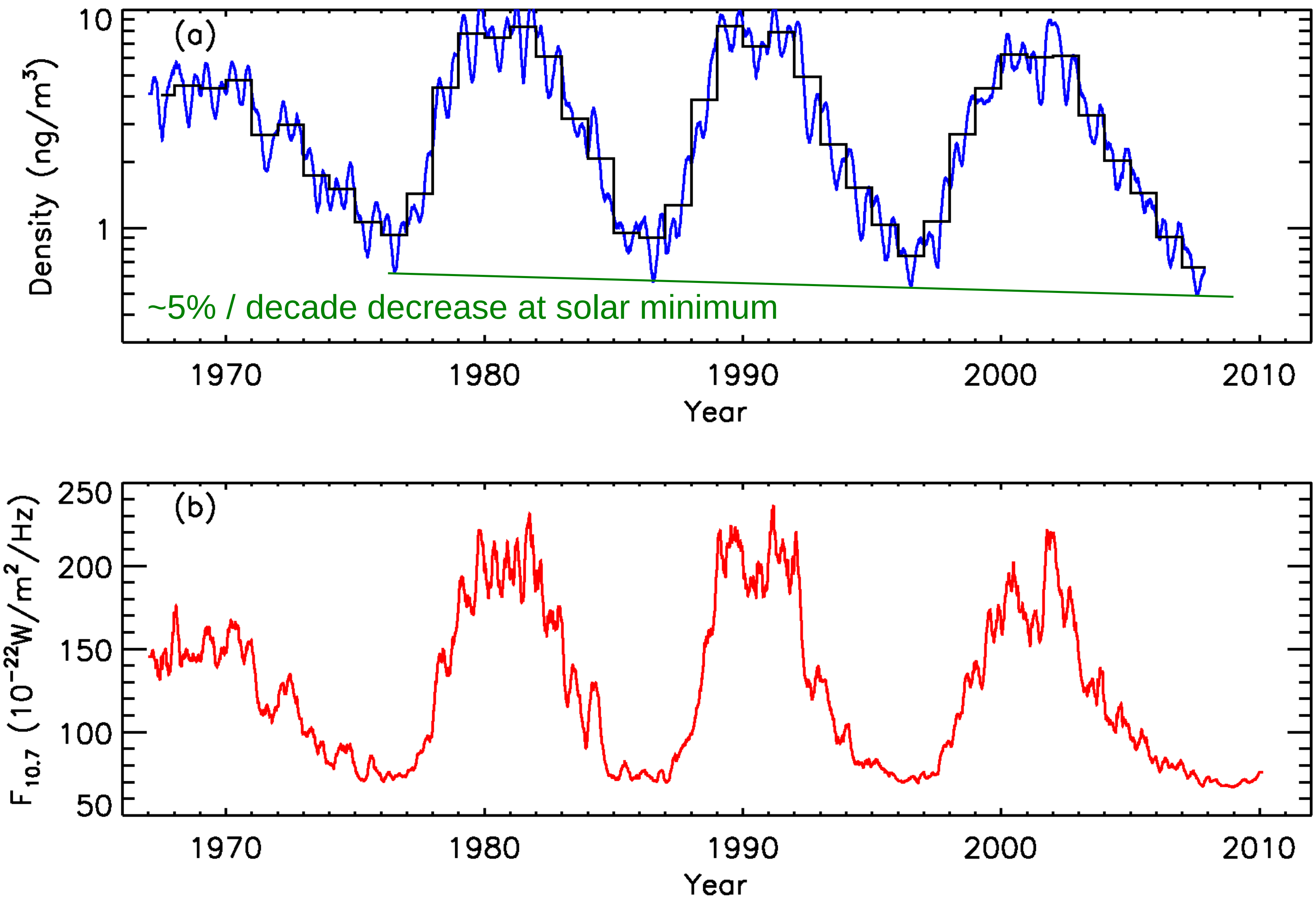
Satellite Drag Data

Radar,
Lidar;
Rocketsonde;
Airglow;
Satellite;
etc.

Lastovicka et al., 2006

Evidence from Satellite Drag for Upper-Atmosphere Global Change

But Modulated by Solar Activity



Top: Global average neutral density at 400 km, 81-day average and annual average

Emmert et al., 2010; (c.f., Keating et al., 2000; Marcos et al., 2005; Saunders et al., 2010)

Whole Atmosphere Community Climate Model – eXtended (WACCM-X)

WACCM-X is WACCM with additional physics and extended vertical range through the thermosphere/ionosphere (~500km)

Whole Atmosphere Community Climate Model (WACCM) is CAM with additional chemistry/physics and extended vertical range into the lower thermosphere (~120km)

Community Atmosphere Model (CAM) is atmospheric component of CESM

NCAR Community Earth System Model (CESM)

Recent Progress on WACCM-X

- Ion and electron energetics implemented:
  — Now calculating T_i and T_e in WACCM-X.

- Equatorial electrodynamo installed:
  — Mostly parallel, ESMF interpolation from geographic to geomagnetic coords.

- Ionospheric dynamics implemented:
  — Vertical diffusion and horizontal transport of O^+ in the upper ionosphere.

- Variable mean molecular mass and heat capacity (C_p) included in dynamical core

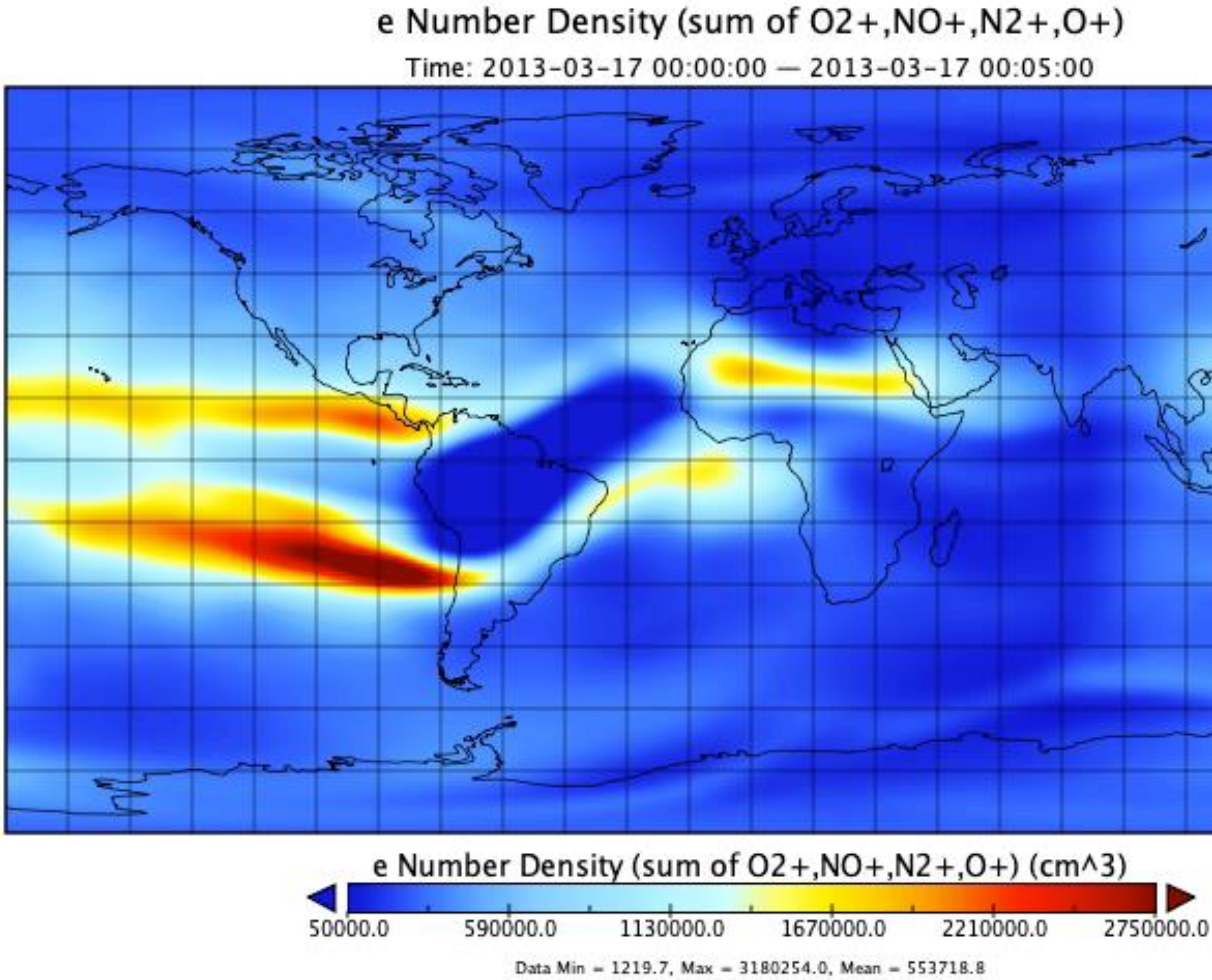
- Capability for using Assimilative Mapping of Ionospheric Electrodynamics (AMIE)

- WACCM-X v. 2.0 released as a component of CESM 2, June 2018
  (but still based on CAM 4 physics)

- WACCM-X v. 2.1 released as a component of CESM 2.1, January 2019

H.-L. Liu et al. (2018), J. Adv. Mod. Earth Sys., doi:10.1002/2017MS001232

WACCM-X Simulation of a Geomagnetic Storm



WACCM-X Global Change Simulation Methodology

- Solar minimum conditions:
  $F_{10.7} = 70$, $K_p = 0.3$

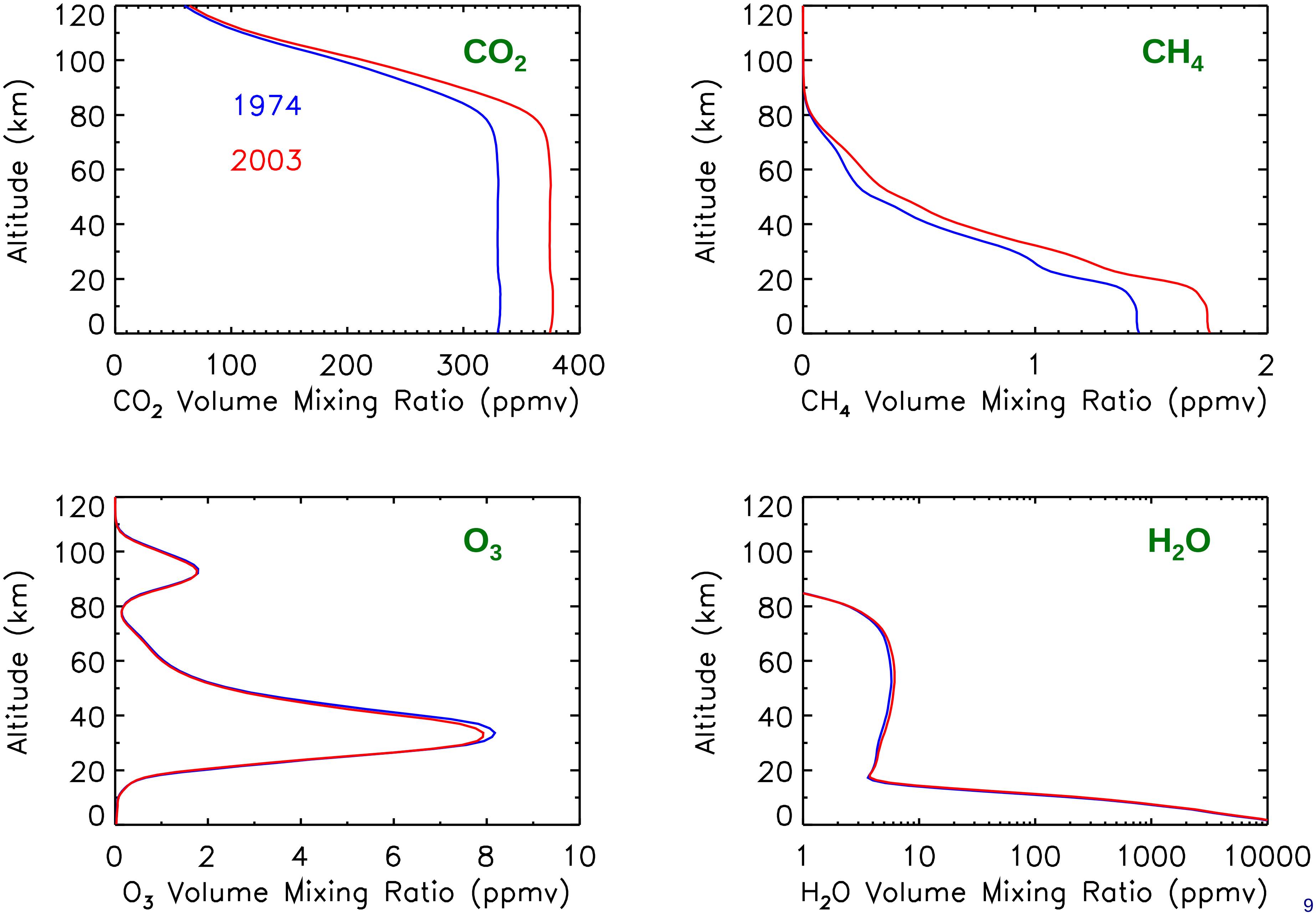
- Solar maximum conditions:
  $F_{10.7} = 200$, $K_p = 0.3$

- Four sets of five-year runs to simulate change in a 29-year interval:
  two with CO_2, CH_4, and CFCs from 1972–1976
  two with CO_2, CH_4, and CFCs from 2001–2005
  secular change of geomagnetic field is included

- Full WACCM-X free-running climate simulations
  but using specified SSTs — no interactive ocean or sea ice, etc.
  2° resolution using FV dycore

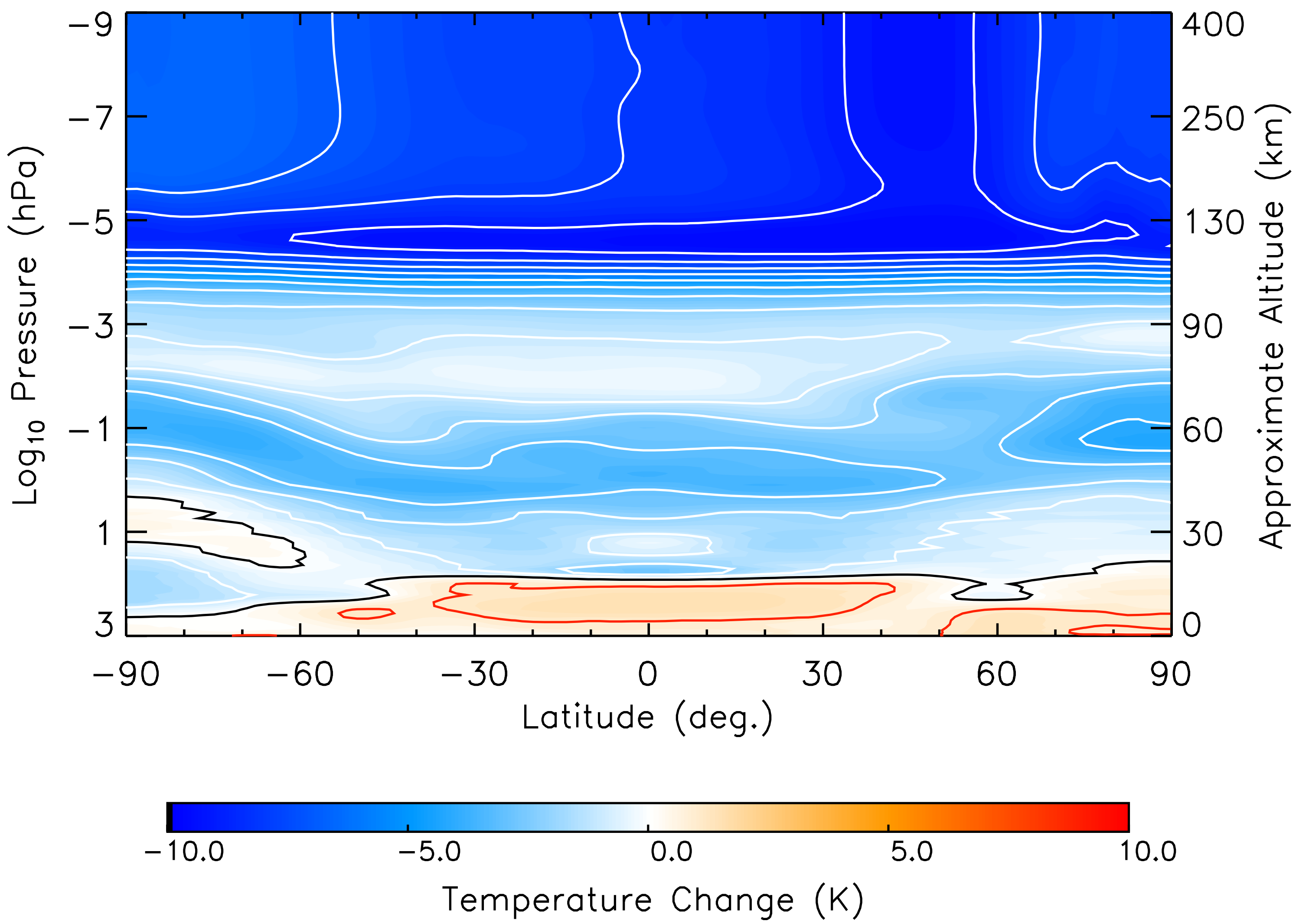
- Decadal change rates estimated by scaling from 29-year interval to 10 years

Anthropogenic Global Change, 1974 to 2003



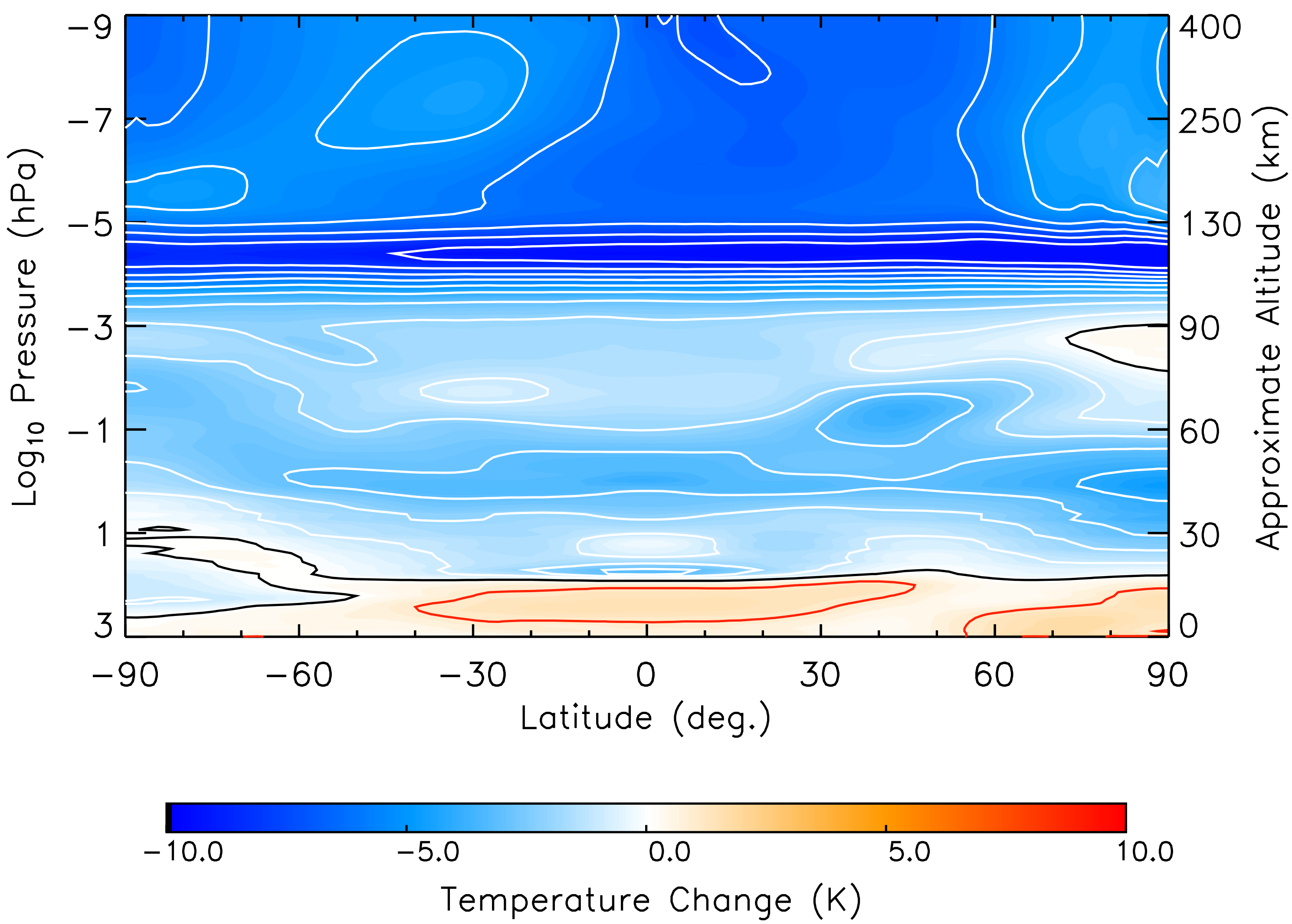
Zonal Mean Temperature Change, 1974 to 2003

Solar Minimum, 5-Year Annual Averages



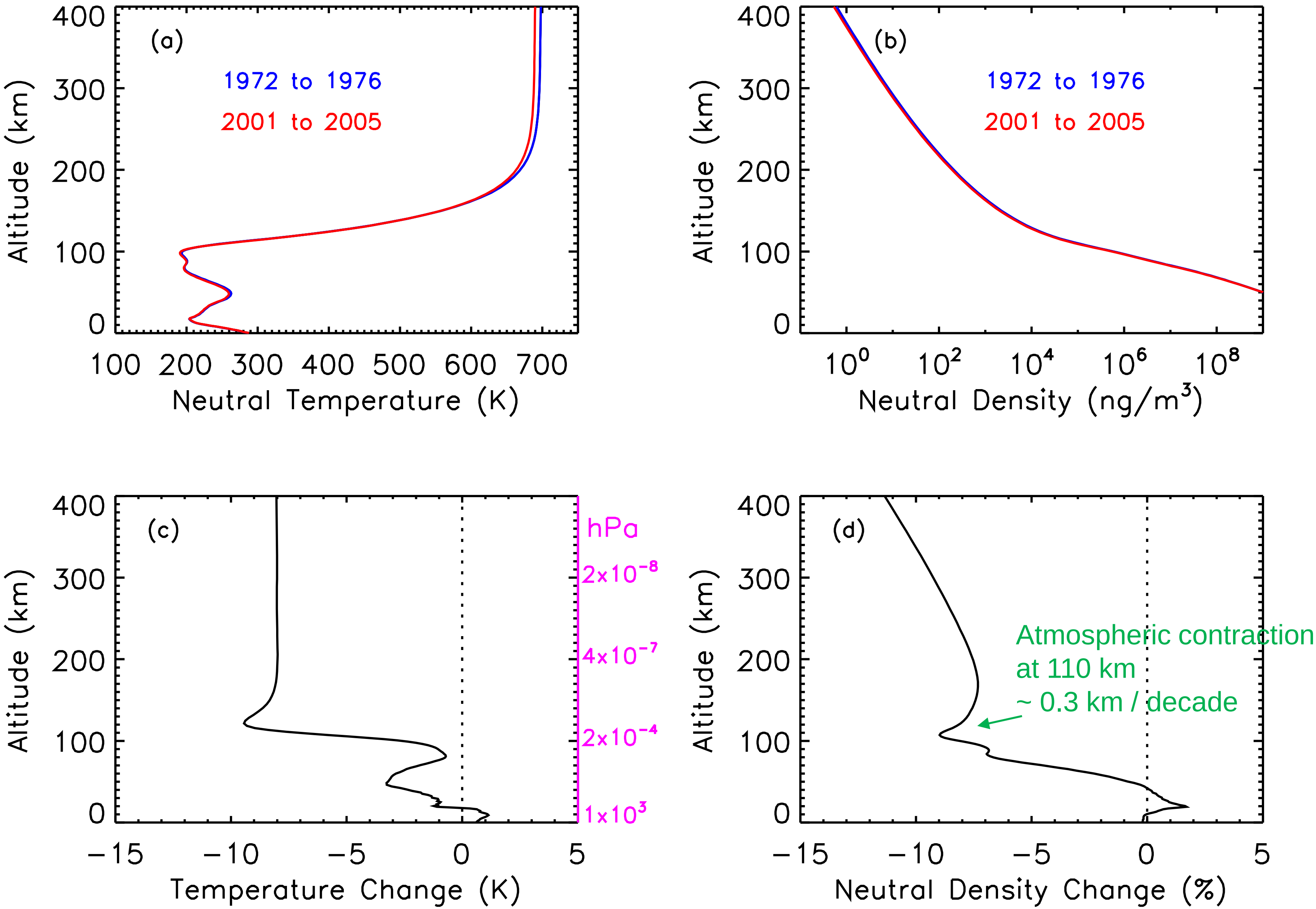
Zonal Mean Temperature Change, 1974 to 2003

Solar Maximum, 5-Year Annual Averages



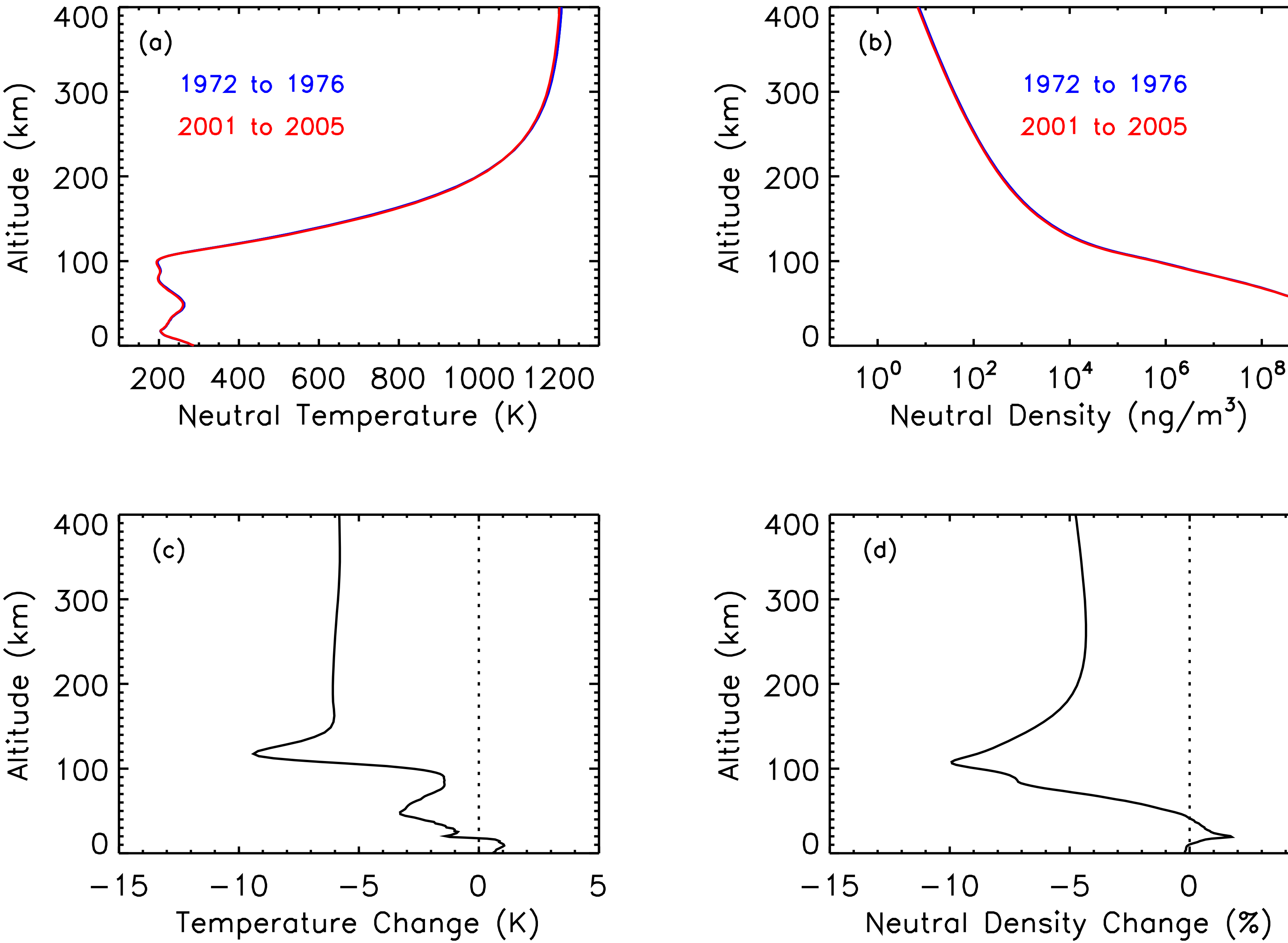
Global Annual Mean Temperature Change, 1974 to 2003

Solar Minimum Conditions

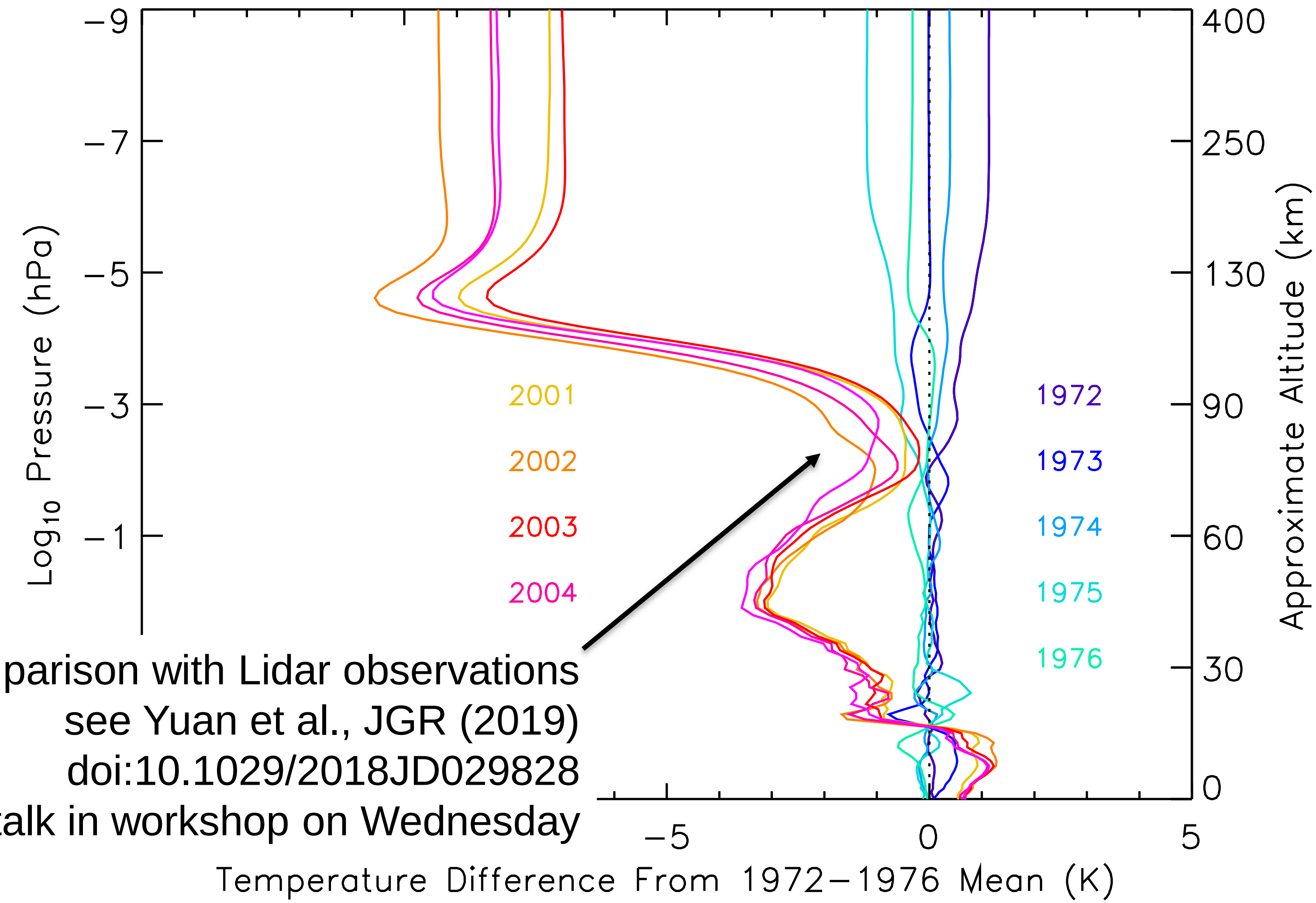


Global Annual Mean Temperature Change, 1974 to 2003

Solar Maximum Conditions



Interannual Variability of Global Mean Temperature
Solar Minimum Conditions



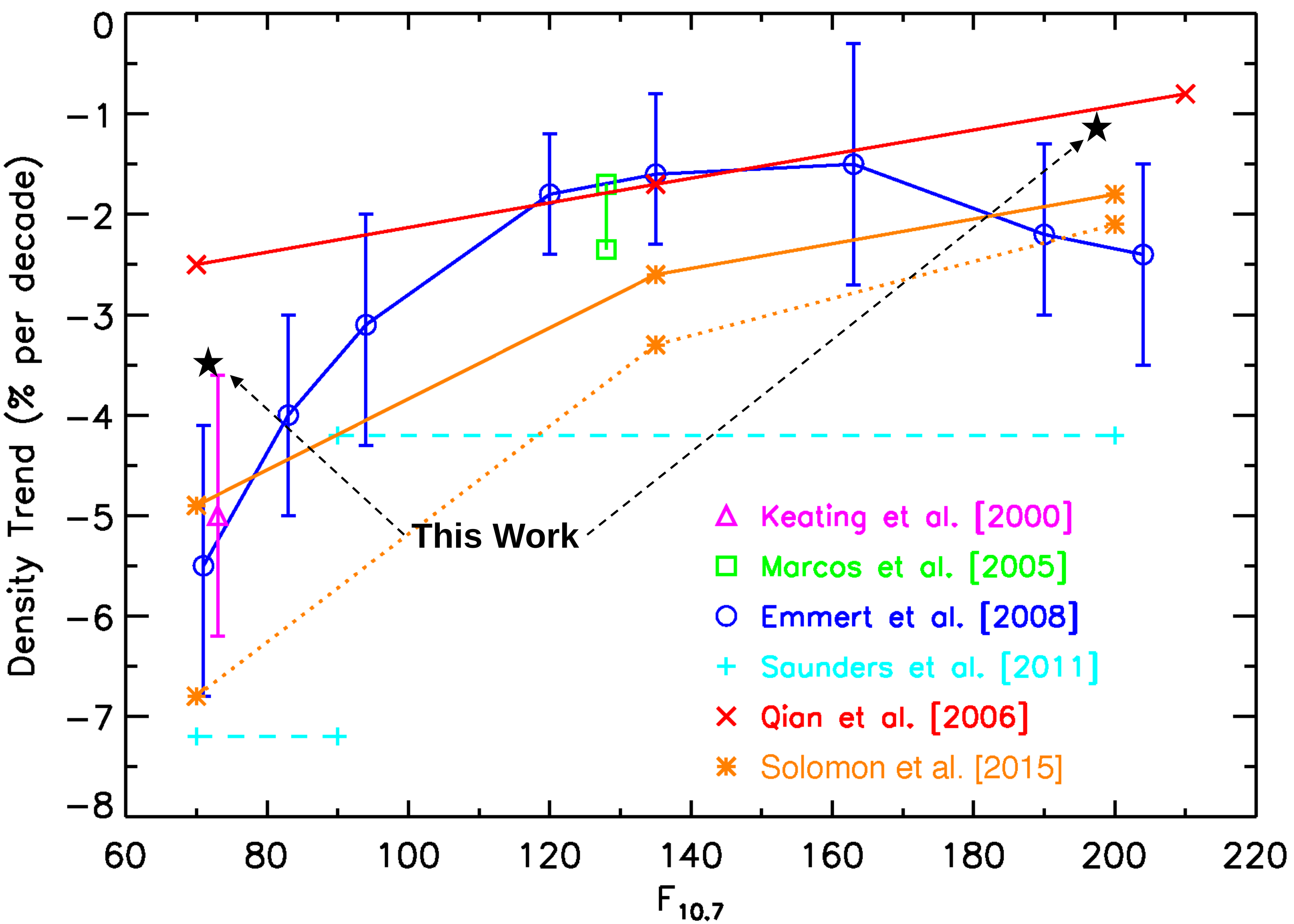
Comparison with Lidar observations
see Yuan et al., JGR (2019)
doi:10.1029/2018JD029828
and talk in workshop on Wednesday

Summary of Results for Thermospheric Density at 400 km
(all in percent per decade)

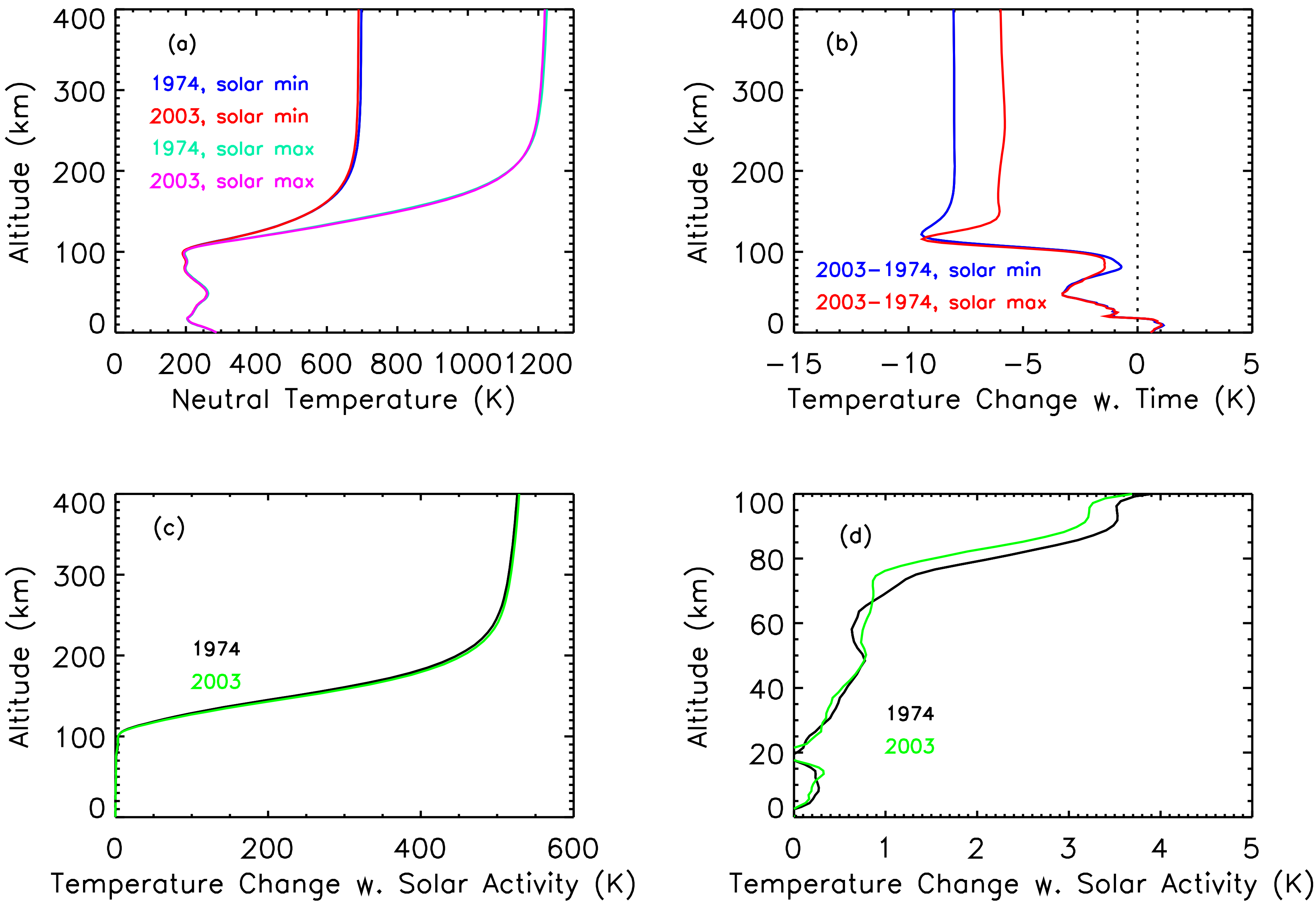
Δ<ρ> *at 400 km Altitude*	*Low Solar Activity*	*Average Solar Activity*	*High Solar Activity*
Observations			
Keating et al. (2000)	-5 %		
Marcos et al. (2005)		-1.7% to -2.4 %	
Emmert et al. (2008)	-5.5 ± 1.4 %		-2 ± 1 %
Saunders et al. (2011)	-7 %		-4 %
Emmert et al. (2015)		-2 ± 0.5 %	
Models			
Roble & Dickinson (1989)		-3 %	
Rishbeth & Roble (1992)		-2 %	
Qian et al. (2006)	-2.5 %	-1.7 %	-0.8 %
Akmaev et al. (2000, 2006)*		-3% to -5 %	-3% to -5 %
Solomon et al. (2015)	-4.9 %		-2.0 %
Solomon et al. (2018a)	-3.9 %		
Solomon et al. (2019b)			-1.7 %

*at 200 km altitude

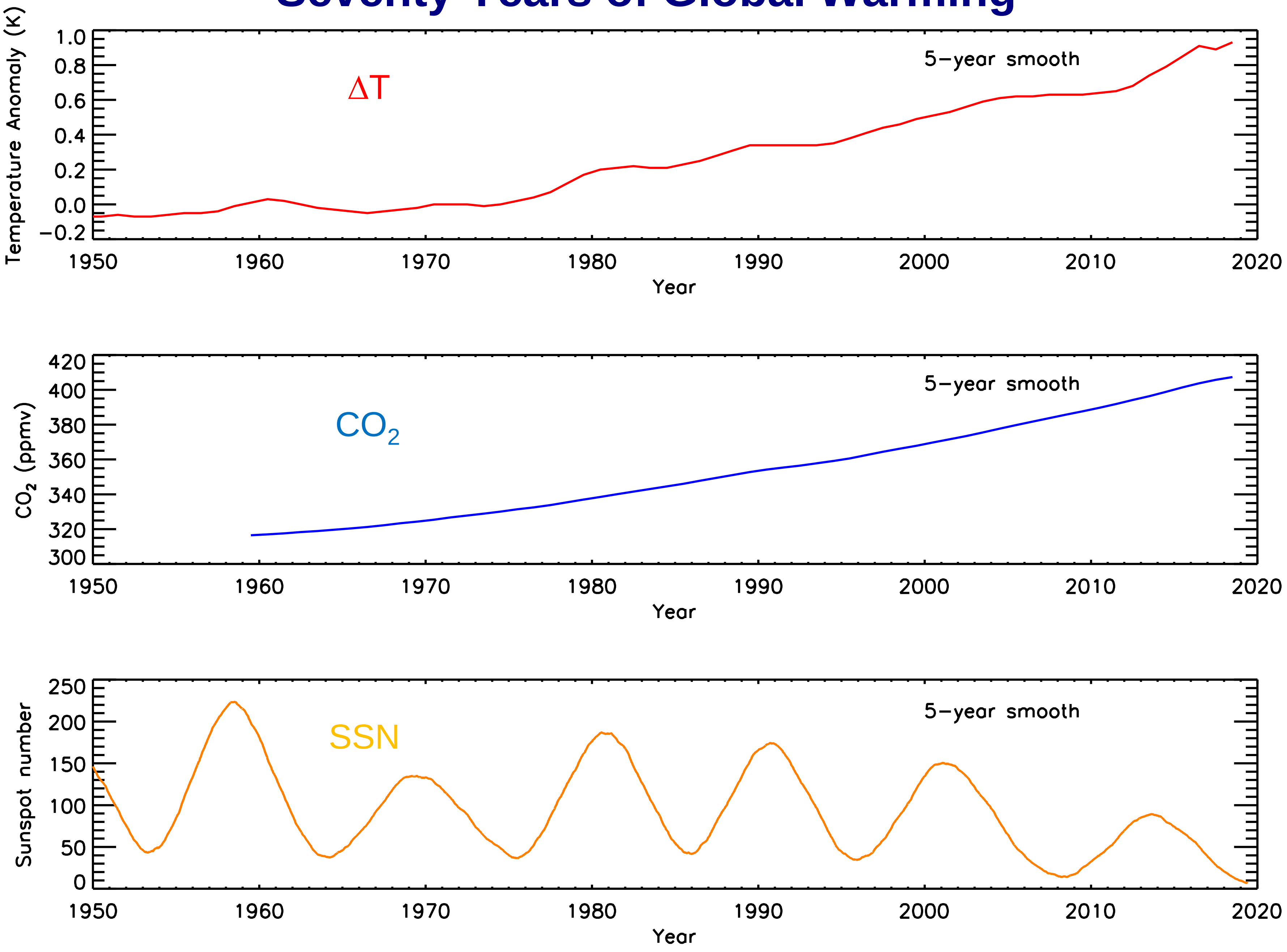
Comparison of Density Trends at 400 km



“Warm Down, Cool Up”



Seventy Years of Global Warming



Summary and Conclusions

• Observations and model simulations demonstrate that the upper atmosphere, particularly the thermosphere/ionosphere, is cooling and contracting in response to anthropogenic change, primarily increases in CO_2.

• There is considerable interannual variability in global mean annual mean temperature change, especially near the mesopause.

• Solar variability makes it challenging to quantify anthropogenic change above the stratopause, and to verify whether our models are calculating it correctly.

• The cooling of the upper atmosphere, while solar activity is decreasing, demonstrates that the warming of the lower atmosphere is not caused by our star, but by ourselves.

For more information, see:

Liu, H.-L., et al. (2018), Development and validation of the Whole Atmosphere Community Climate Model with thermosphere and ionosphere extension (WACCM-X v. 2.0), *J. Adv. Mod. Earth Sys.*, *10*, 381, doi:10.1002/2017MS001232

Solomon, S. C., et al. (2018), Whole atmosphere simulation of anthropogenic climate change, *Geophys. Res. Lett.*, *45*, 1567, doi:10.1002/2017GL076950

Solomon, S. C., et al. (2019), Whole Atmosphere Climate Change: Interaction with Solar Activity, *J. Geophys. Res. Space Physics*, *124*, doi:10.1029/2019JA026678

n.b.: also available from the authors at http://download.hao.ucar.edu/pub/stans/papers

Workshop on Wednesday

CEDAR and Climate Change

10:00 – 12:00

Zia/Eldorado

Workshop Description

The Intergovernmental Panel on Climate Change 1.5 degree report (https://www.ipcc.ch/sr15/) released in October 2018 concluded risks of dire consequences of climate change and that the next decade is critical for transformational change to achieve deep reductions in greenhouse gas emissions to avoid the most serious impacts. This workshop will provide a forum for discussion about ways that the CEDAR community might contribute to global efforts to address climate change. Such efforts could include whole atmosphere studies of climate change processes; identifying aeronomy data sets and techniques that can also provide tropospheric information; continued work to reduce uncertainties in observations to facilitate their use for longer-term comparisons; and ways that the CEDAR community is or could potentially contribute to national and international climate assessment processes. We also welcome presentations relating to communicating climate science to the public.

Links, DOIs, Codes

Solomon et al. (2019), JGR, *124*
doi:10.1029/2019JA026678

Solomon et al. (2018), GRL, *45*
doi:10.1002/2017GL076950

Supporting model output data
doi:10.26024/ypnz-d857

WACCM-X web site
www2.hao.ucar.edu/modeling/waccm-x