Solar Variability and Anthropogenic Change in the Upper Atmosphere

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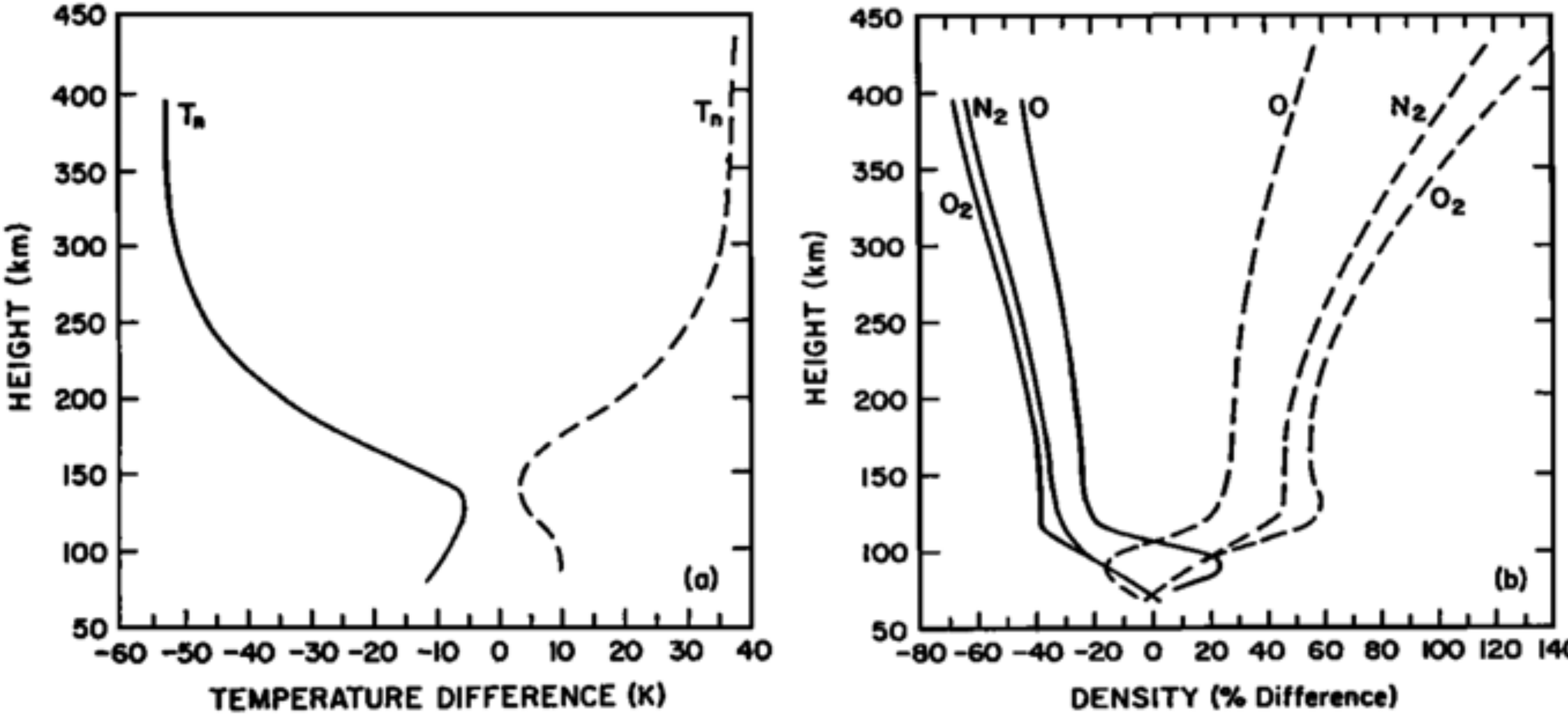
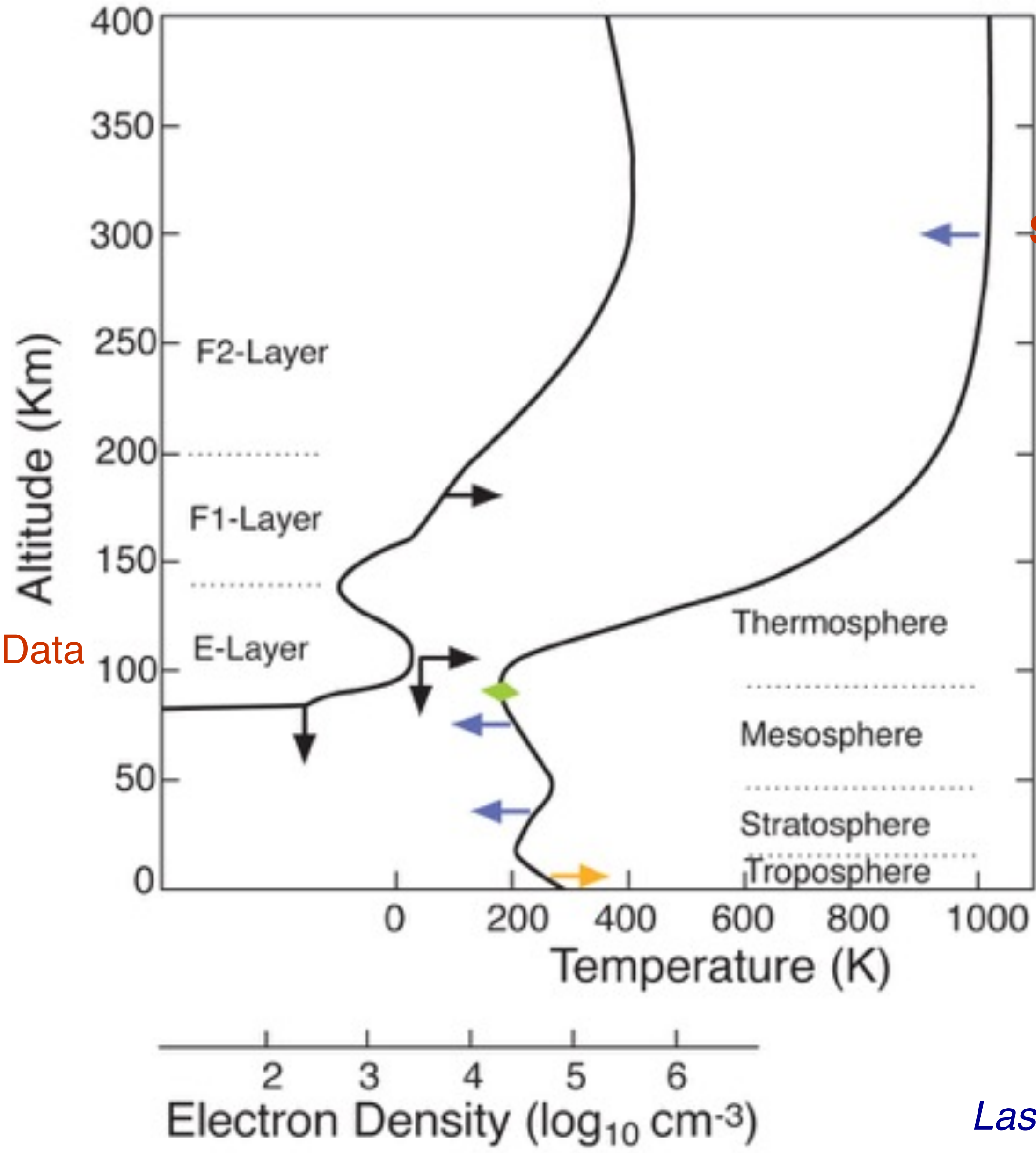
Model Prediction of Global Change in the Thermosphere

Roble & Dickinson [1989]



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

Observed / Inferred Global Change Scenario



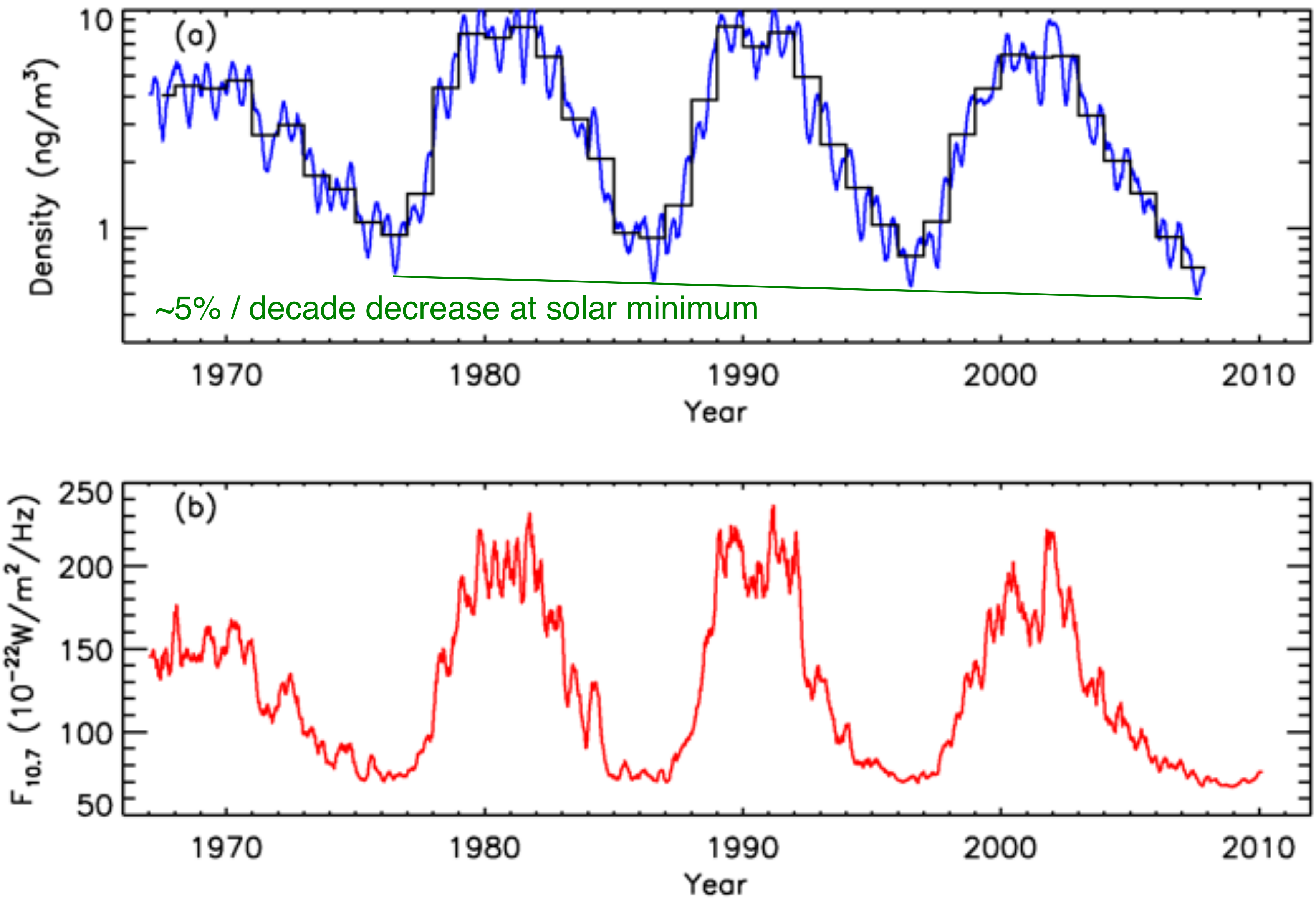
Satellite Drag Data

Ionosonde Data

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

Lastovicka et al., 2006

Strongest Evidence for Upper-Atmosphere Global Change



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)

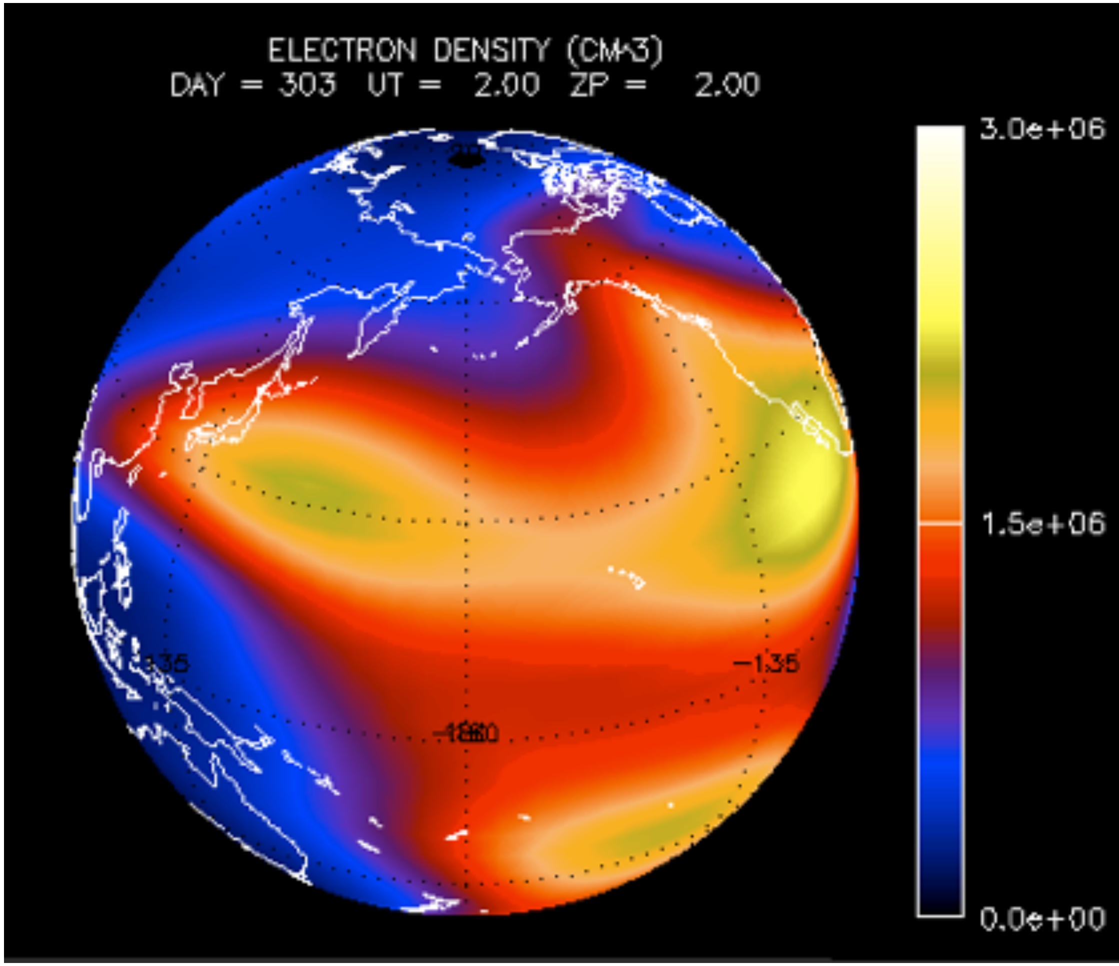
The NCAR Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM)

- Original development by Ray Roble, Bob Dickinson, Art Richmond, et al.

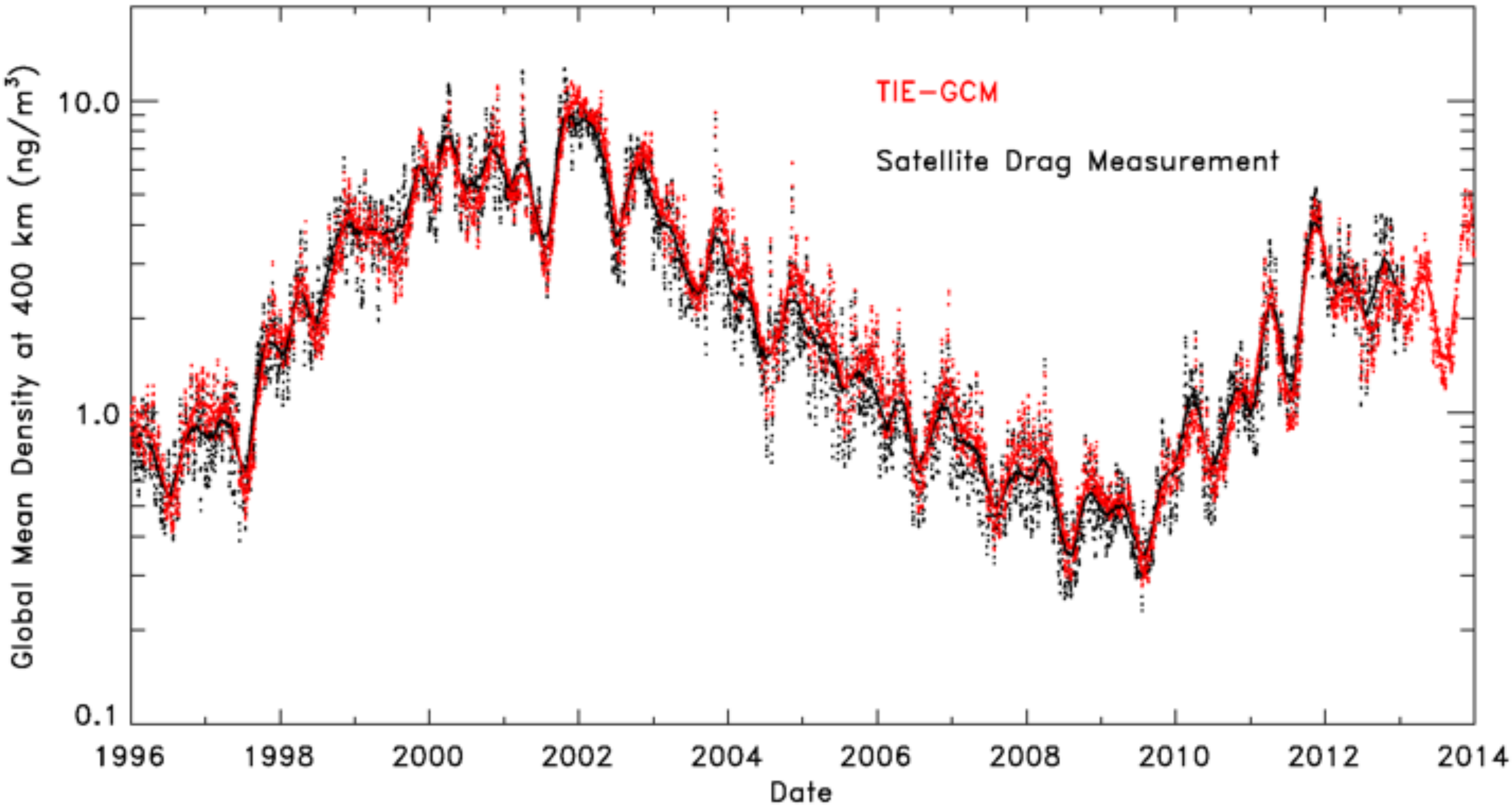
- The atmosphere/ionosphere element of the Coupled Magnetosphere-Ionosphere-Thermosphere (CMIT) model

- Open source community release, available for runs-on-request at CCMC

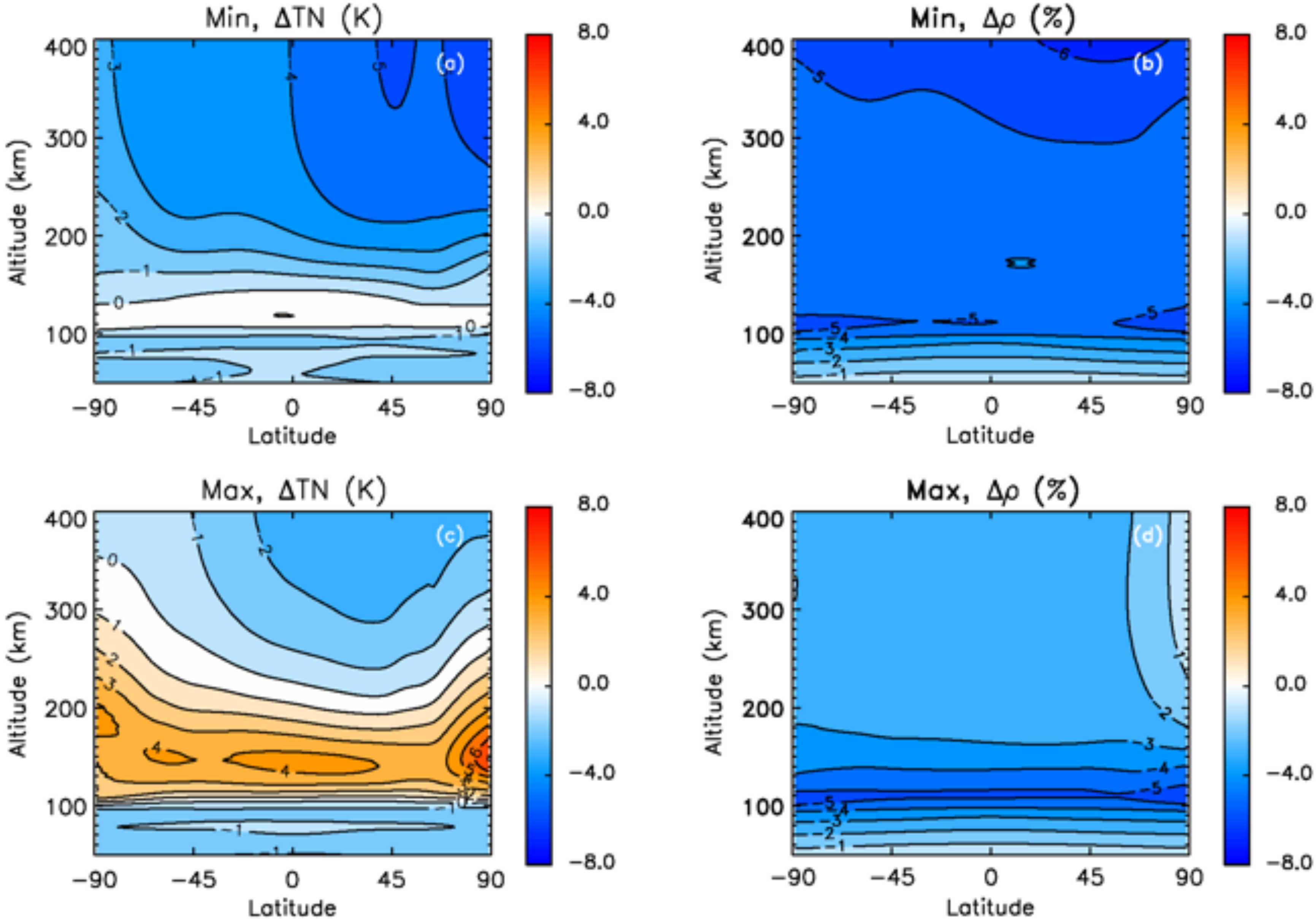
- Can be run using high-latitude inputs from IMF and solar wind, using the Weimer potential model



Measurement & Model of Thermosphere Solar Cycle Variation

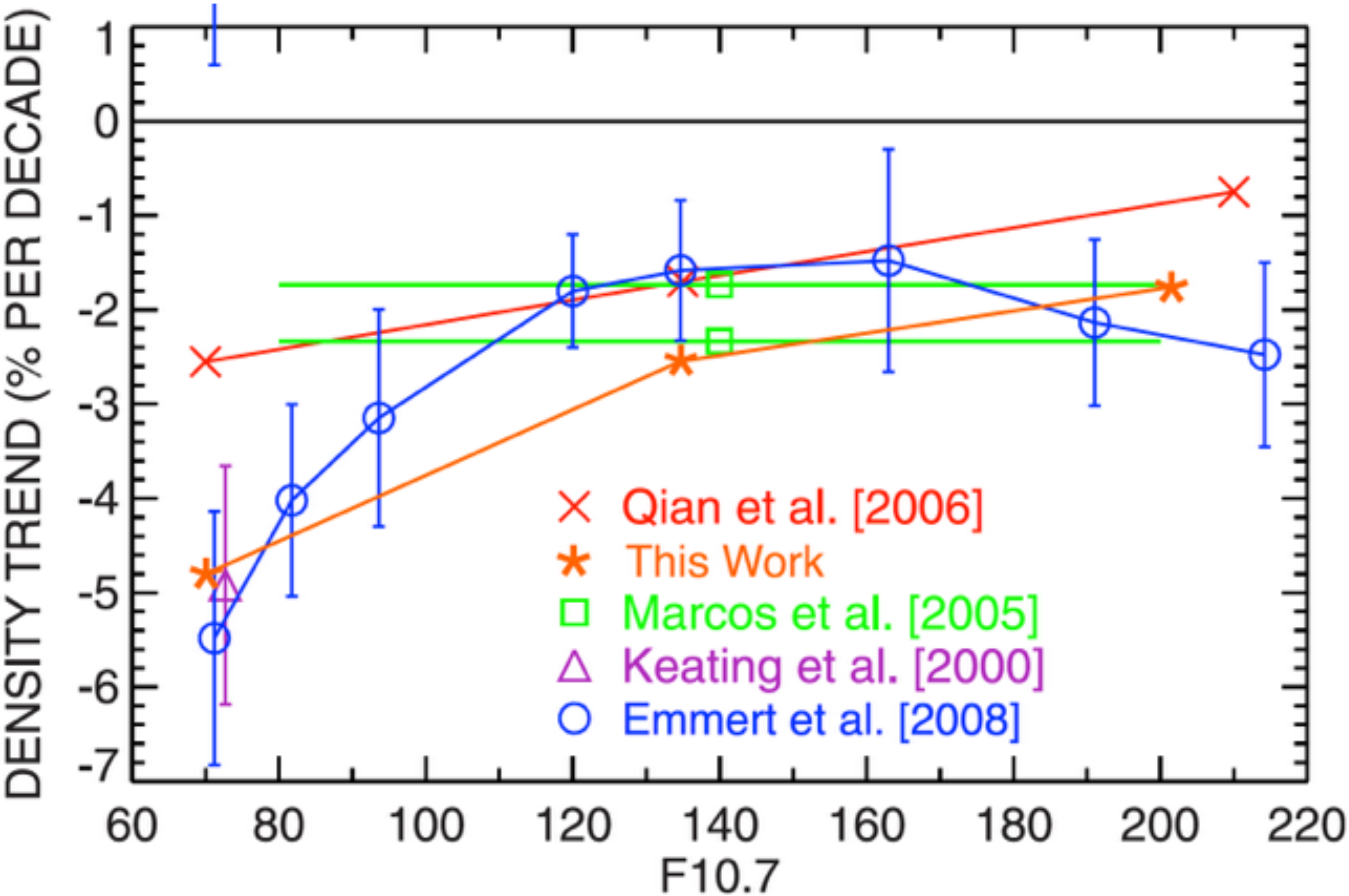


TIME-GCM Simulations of Solar Cycle Effects on Trends



Anthropogenic change in upper atmosphere temperature and density over 11 years

Satellite Drag Trend Measurements Compared to Models



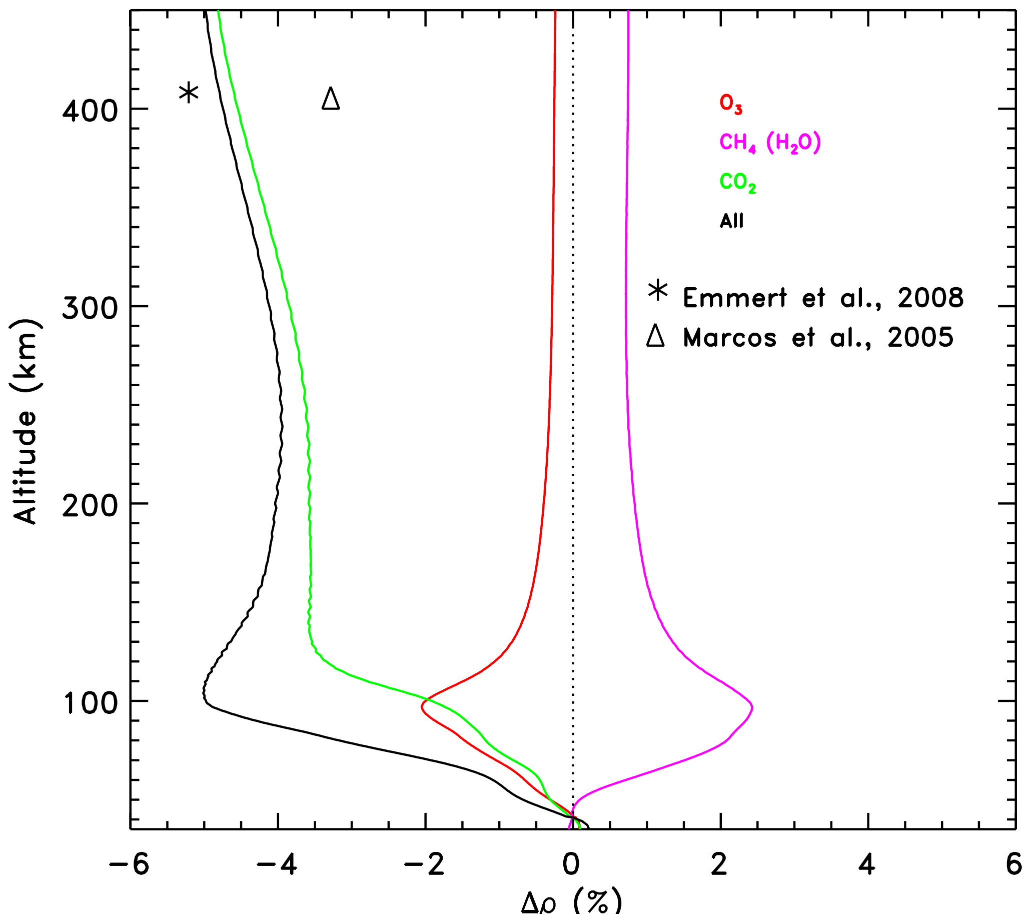
Density trends at 400 km altitude, presented at the TREND-2014 workshop

comparison plot after *Emmert et al.*, 2008

Are There Sources of Thermospheric Trends Other than CO_2?

O_3, CH_4, H_2O:

Significant effect on mesosphere, but much smaller than CO_2 in thermosphere [*Qian et al.*, *JGR*, 2013].



Changes in magnetic field:

Effects ionospheric morphology, but no significant effect on global mean thermosphere [*Cnossen and Richmond*, 2008; 2013]

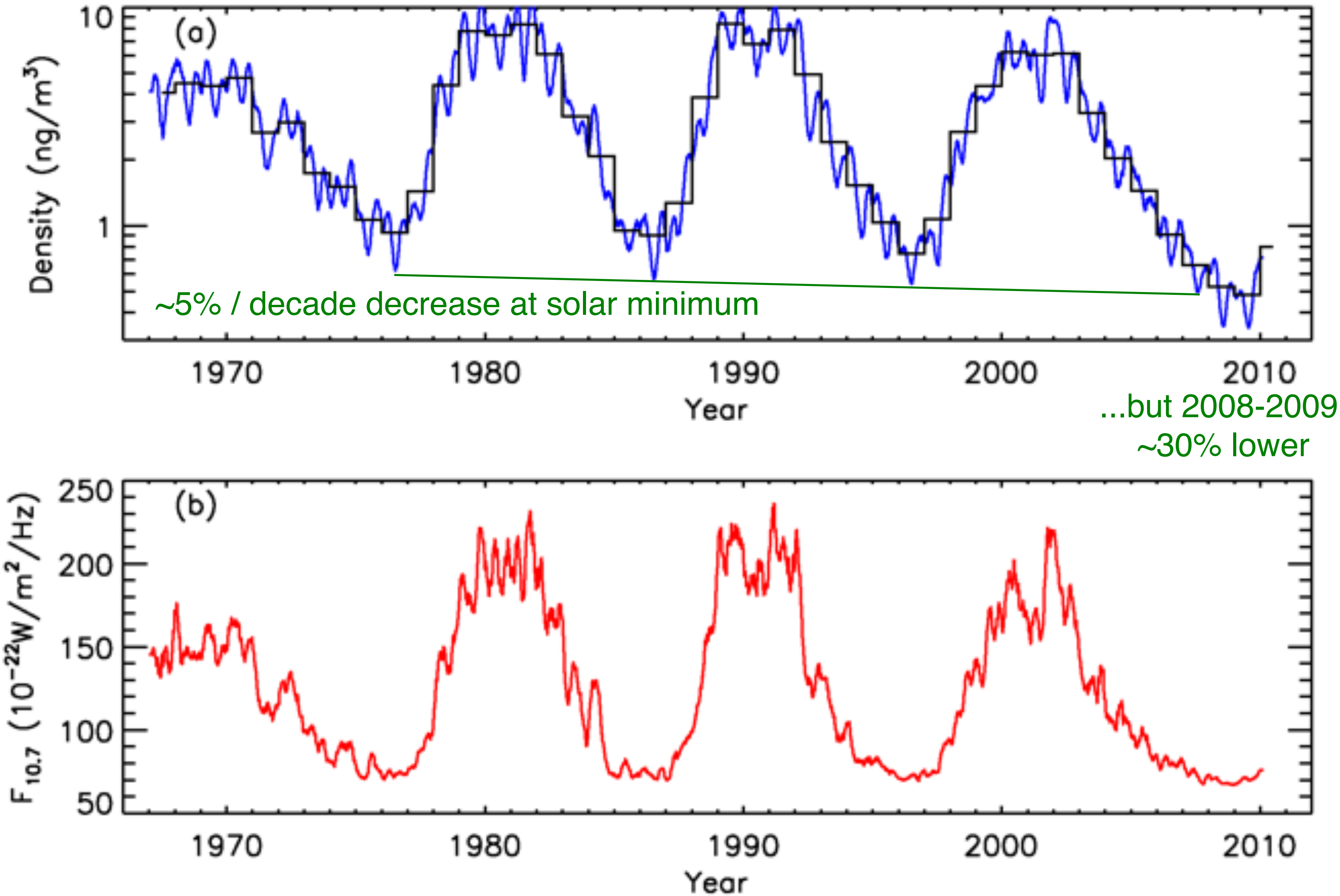
Changes in dynamical processes:

Speculative, except...

Turbopause region mixing has been suggested as a possible reason that observations of the CO_2 profile show increasing trend with increasing altitude [*Emmert et al.*, *Nature*, 2012; *Yue et al.*, *GRL*, submitted.]

Changes in the solar cycle...

Long-Term Satellite Drag Data, Updated

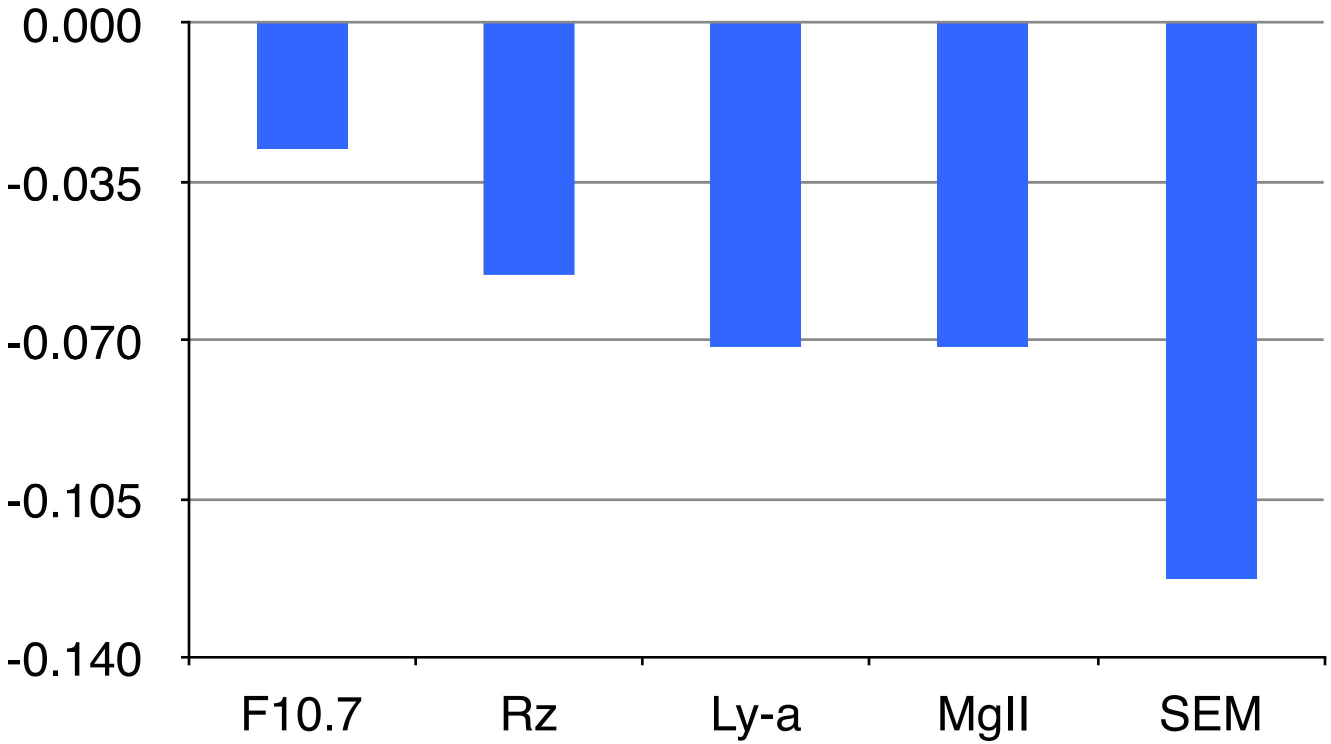


Top: Global average neutral density at 400 km, 81-day average and annual average

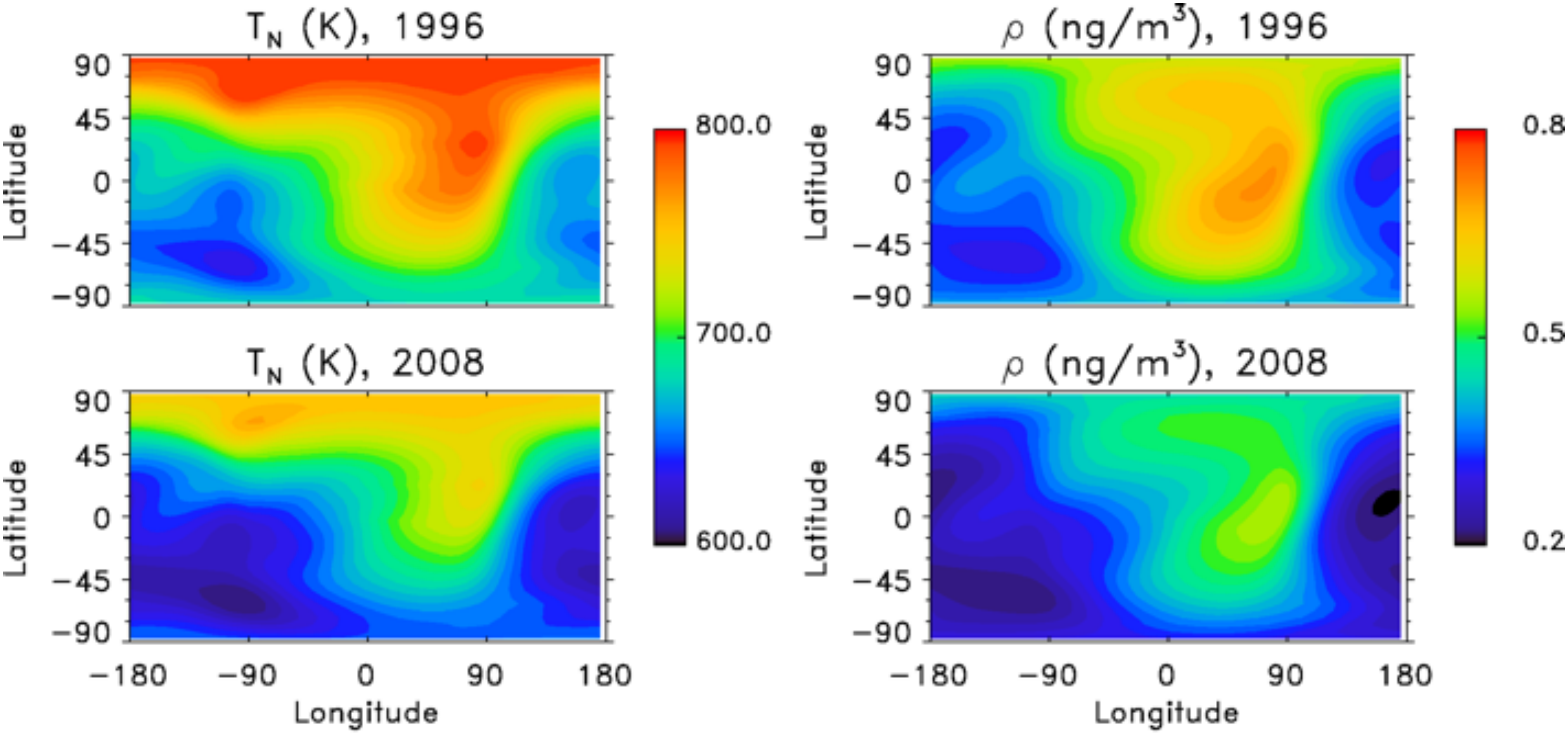
Change in Various Solar Indices and Measurements

Values normalized to solar cycle range:

$$R = (I_{2008} - I_{1996}) / (I_{2001} - I_{1996})$$



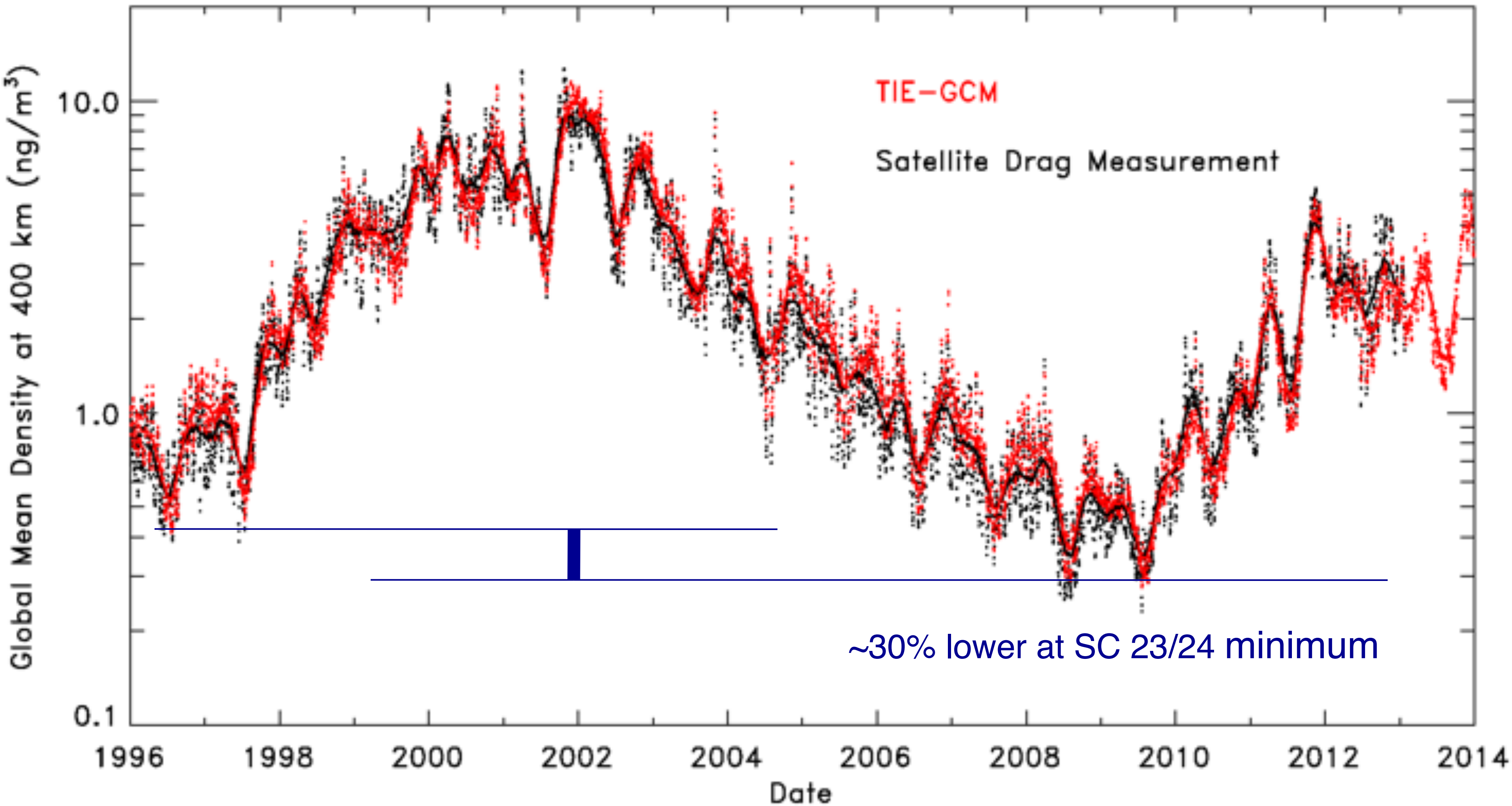
Thermospheric Density Simulations using Mg II c/w Index



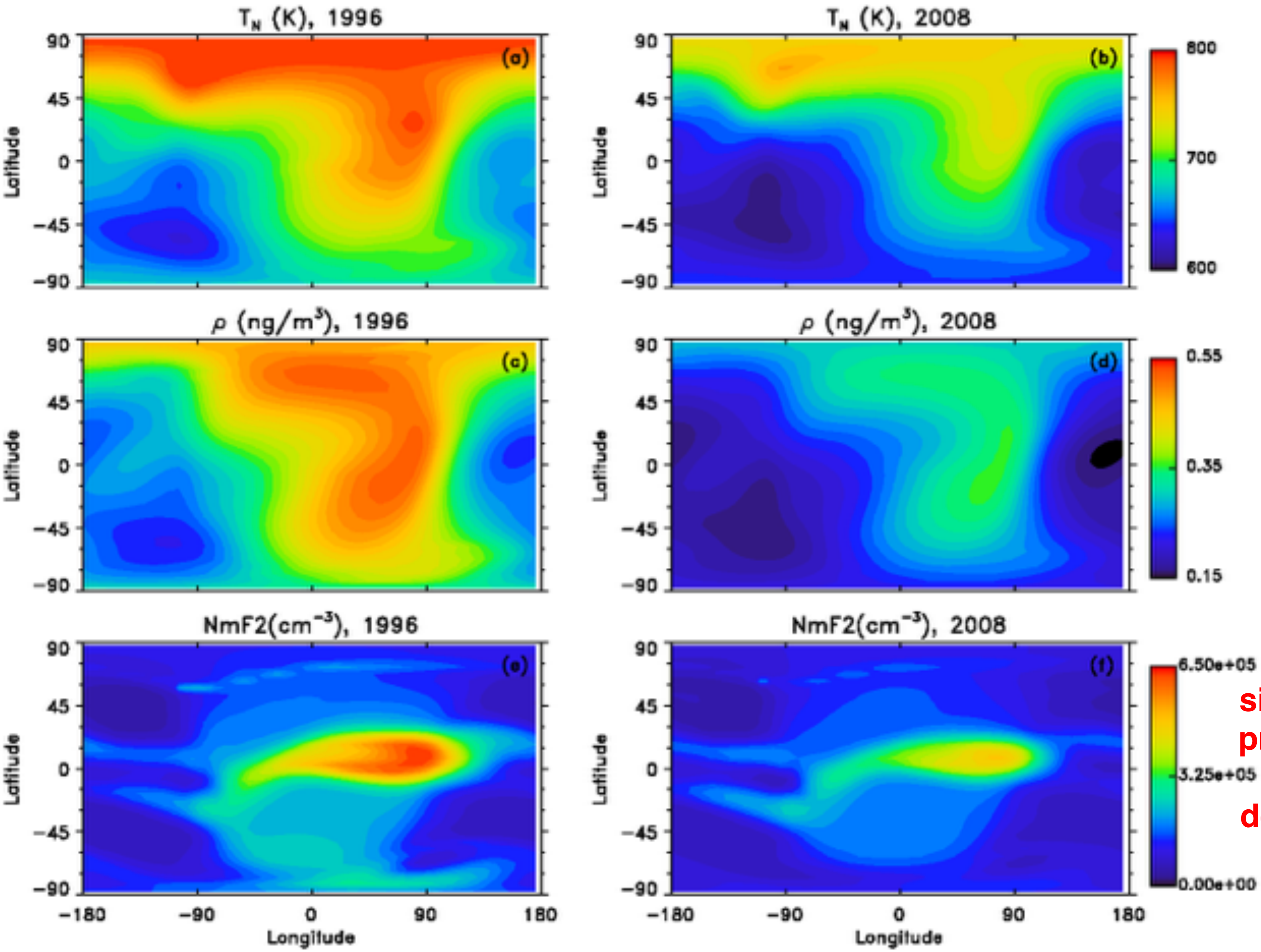
NCAR Thermosphere-Ionosphere-Electrodynamics General Circulation Model
Temperature and Density simulations at 400 km
Simulations include combined effects of:

- Solar EUV decrease
- Geomagnetic activity changes
- CO_2 increase

Comparison of Density Simulation to Satellite Drag Data

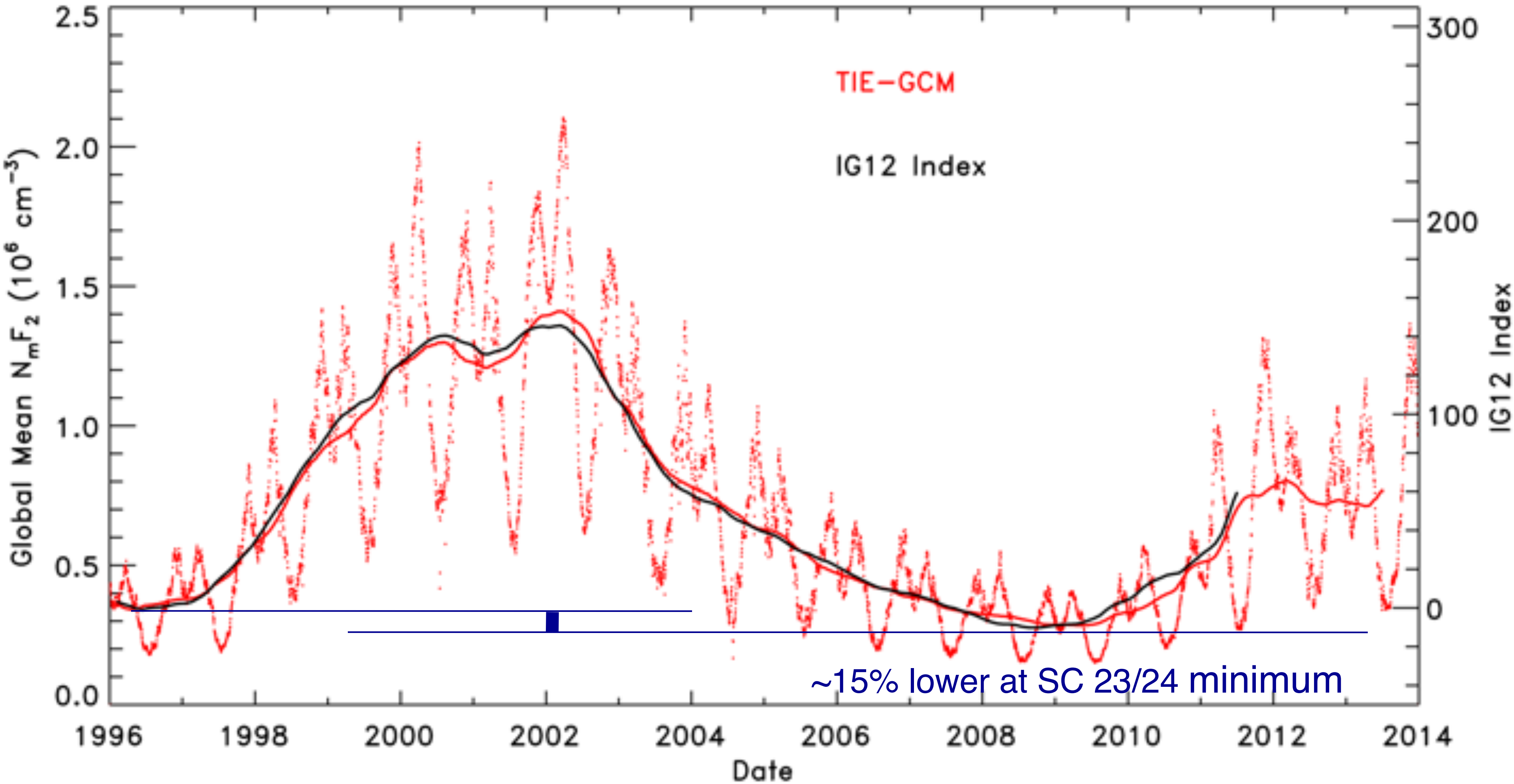


What about the Ionosphere?



TIE-GCM simulations predict 14% average decrease in N_mF_2

Global Mean N_mF_2 Compared to the IG12 Index



IG12 index derived from multiple-station ionosonde measurements at noon.

The IG12 index is used as input to the empirical International Reference Ionosphere model.

Conclusions of Solar Minimum Studies

• The thermosphere/ionosphere system was indeed cooler, less dense, and lower, during the minimum of solar cycle 23/24 than during a "typical" solar minimum.

• The primary cause of this was lower than "usual" solar EUV irradiance.

• Mg II core-to-wing ratio and Ly-α variations are consistent with these observations.

• Lower geomagnetic activity makes a smaller but significant contribution.

• Secular change due to increasing CO_2 also makes a small but significant contribution.

• Future investigation of upper atmosphere climate change will be complicated by the fact that the concept of a "typical" solar minimum is no longer tenable.

• *Solomon et al.* (2010), *Geophys. Res. Lett., 37*, L16103, doi:10.1029/2010GL044468.
• *Solomon et al.* (2011), *J. Geophys Res., 116*, A00H07, doi:10.1029/2011JA016508.
• *Solomon et al.* (2013), *J. Geophys. Res., 118*, 6524, doi:10.1002/jgra.50561.
• *Solomon et al.* (2015), *J. Geophys. Res., 120*, 2183, doi:10.1002/2014JA020886.

Who Cares about Climate Change in the Upper Atmosphere?

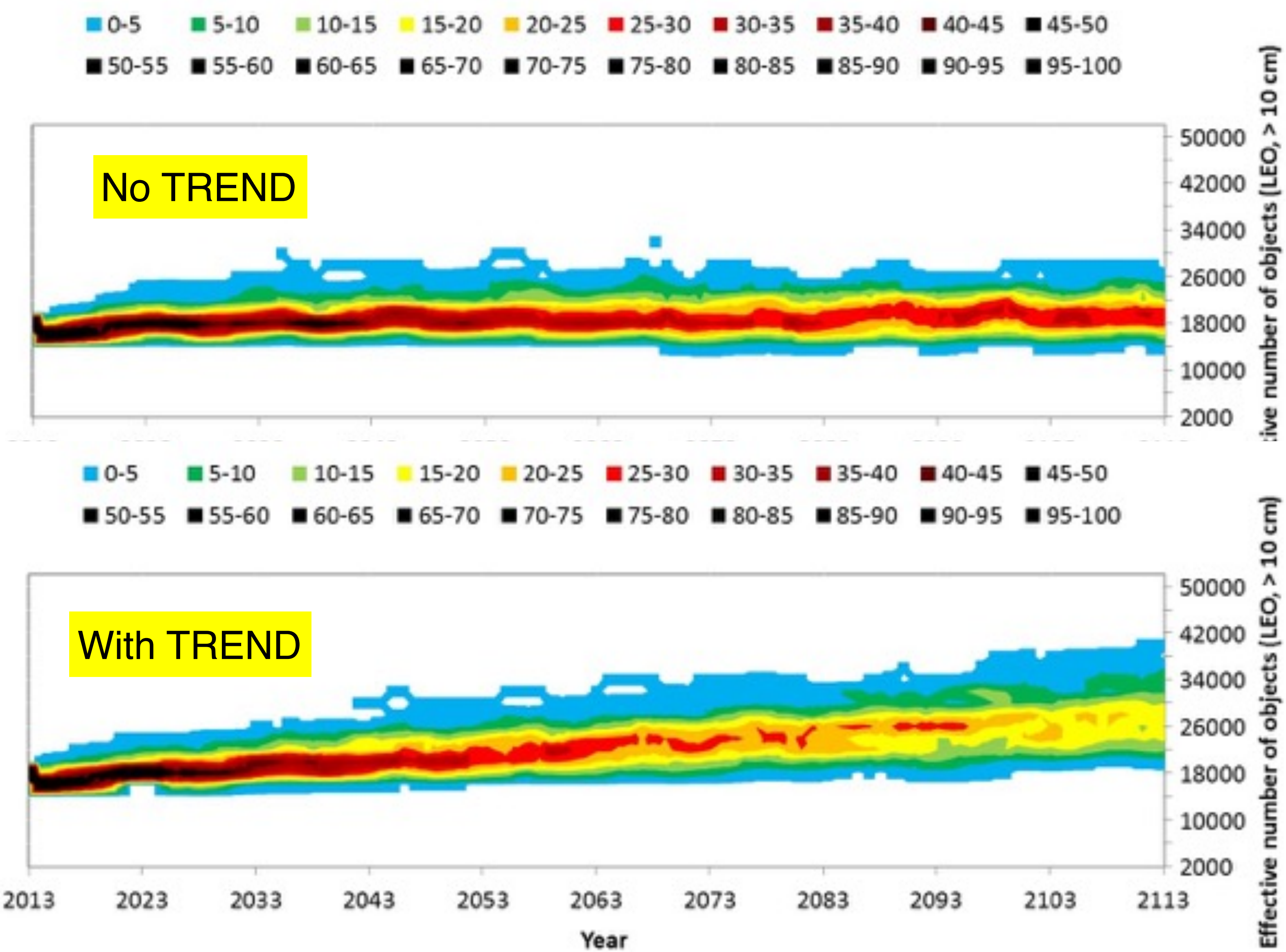
- Important element in demonstrating comprehensive understanding of climate change.

- “Warm down, cool up”

- Satellite tracking

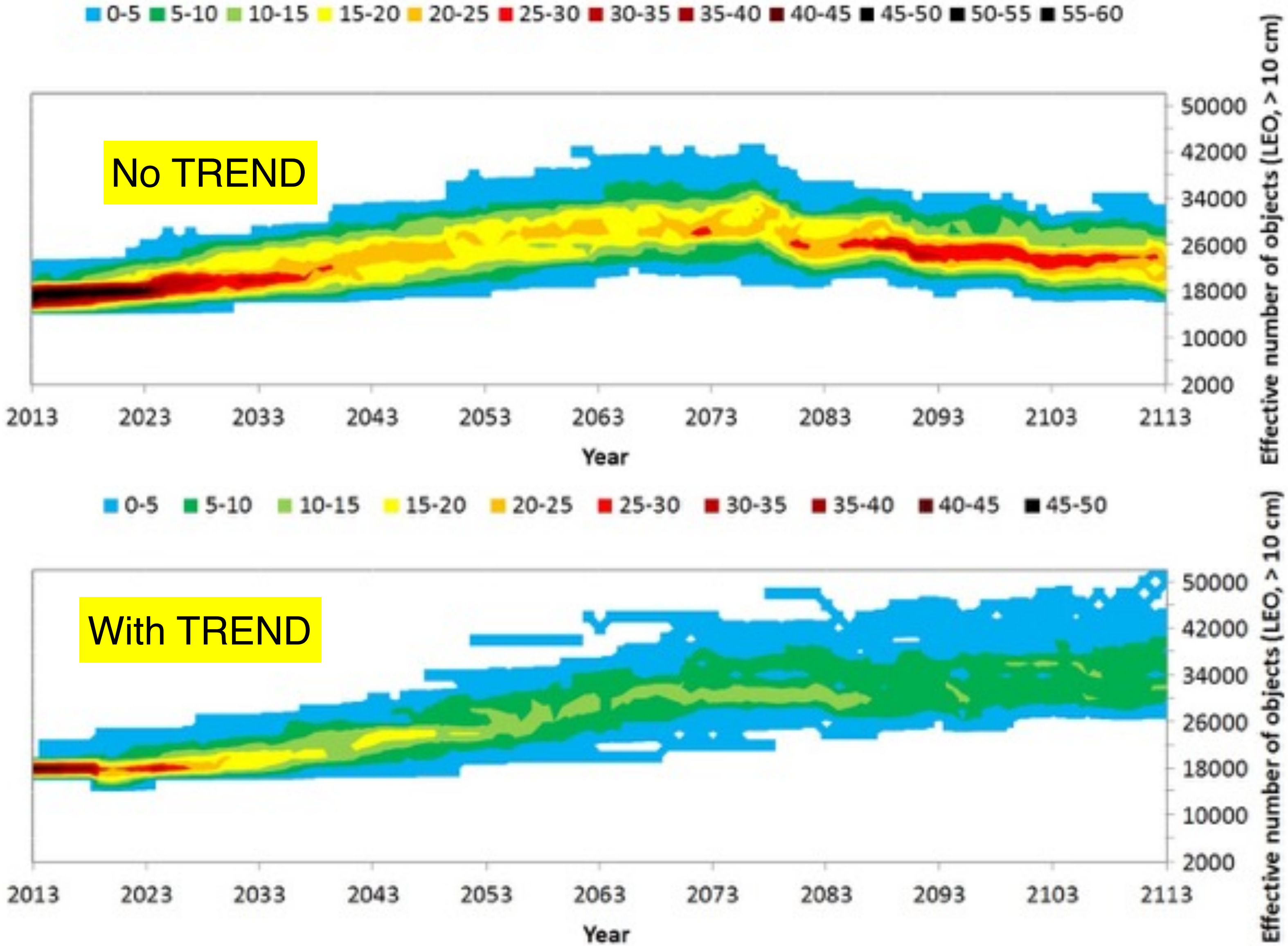
- Orbital debris (a.k.a. “space junk”)

Orbital Debris Numerical Model Predictions



Courtesy Hugh Lewis, University of Southampton (presented at TREND-2014 workshop)

Orbital Debris Numerical Model Predictions Including Long-Term Solar Activity Decline



Courtesy Hugh Lewis, University of Southampton (presented at TREND-2014 workshop)

Discussion

• The minimum between solar cycles 23 and 24 was the longest in a century.

— Was it also the "deepest?"

• Solar cycle 24 appears to be the weakest in a century.

— Will the next solar minimum be even lower?

• Published in *JGR*, 2013:

"SC #24 has been weak as well as late, and may already be in its declining phase. This has fueled speculation that the Sun is entering something resembling the Dalton Minimum of the early 1800's, or even a new Maunder Minimum [Eddy, 1976]. How the solar spectrum changes on decadal or centurion time scales is a central question for upper atmospheric science, and perhaps for atmospheric science in general. The difficulties and controversies surrounding the endeavor to compare solar and geospace parameters between 1996 and 2008-2009 have been instructive. We now have comprehensive, well-calibrated measurements for 2008-2009. Will we have the vision to prepare for 2020?"