Interminimum Changes in Global Total Electron Content and Neutral Mass Density

- Global TEC was 19% lower during the 2008 minimum than during the 1996 minimum
- Changes in F10.7 and Kp account for TEC decreases of 9% and 2%, respectively
- Changes are slightly larger in the Southern Hemisphere, at low latitudes, and on the nightside
- TEC and mass density changes are very similar

U.S. NAVAL RESEARCH LABORATORY

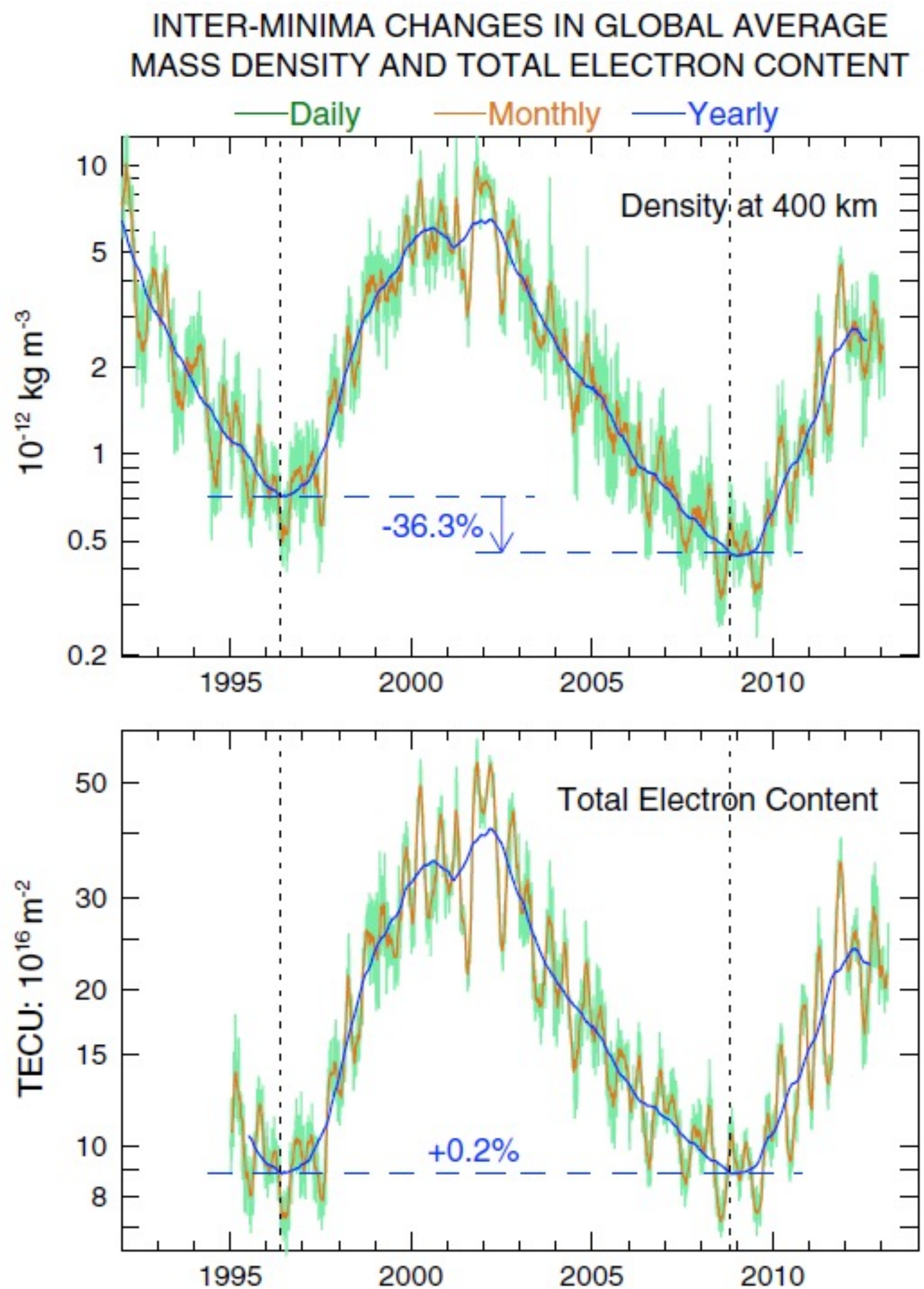
John Emmert, Sarah McDonald
Space Science Division, Naval Research Lab

Anthony Mannucci
Jet Propulsion Laboratory, California Institute of Technology

Acknowledgement: This work was supported by NASA

Introduction

- CODE data was previously the only global TEC data spanning the past two solar minima.
- CODE data show no change in TEC between the past two minima.
- Apparently inconsistent with interminimum decreases in F10.7 solar EUV proxy and geomagnetic activity, both of which contributed to a large decrease in thermospheric mass density.
- Possible causes of discrepancy:
  - Time-dependent bias in data (change in # of GPS receivers?)
  - No actual EUV change
  - Offsetting positive TEC change from another mechanism
- To test the first possibility, we constructed a new series of TEC maps using temporally uniform processing.



Emmert et al., JGR 2014

TEC Observations

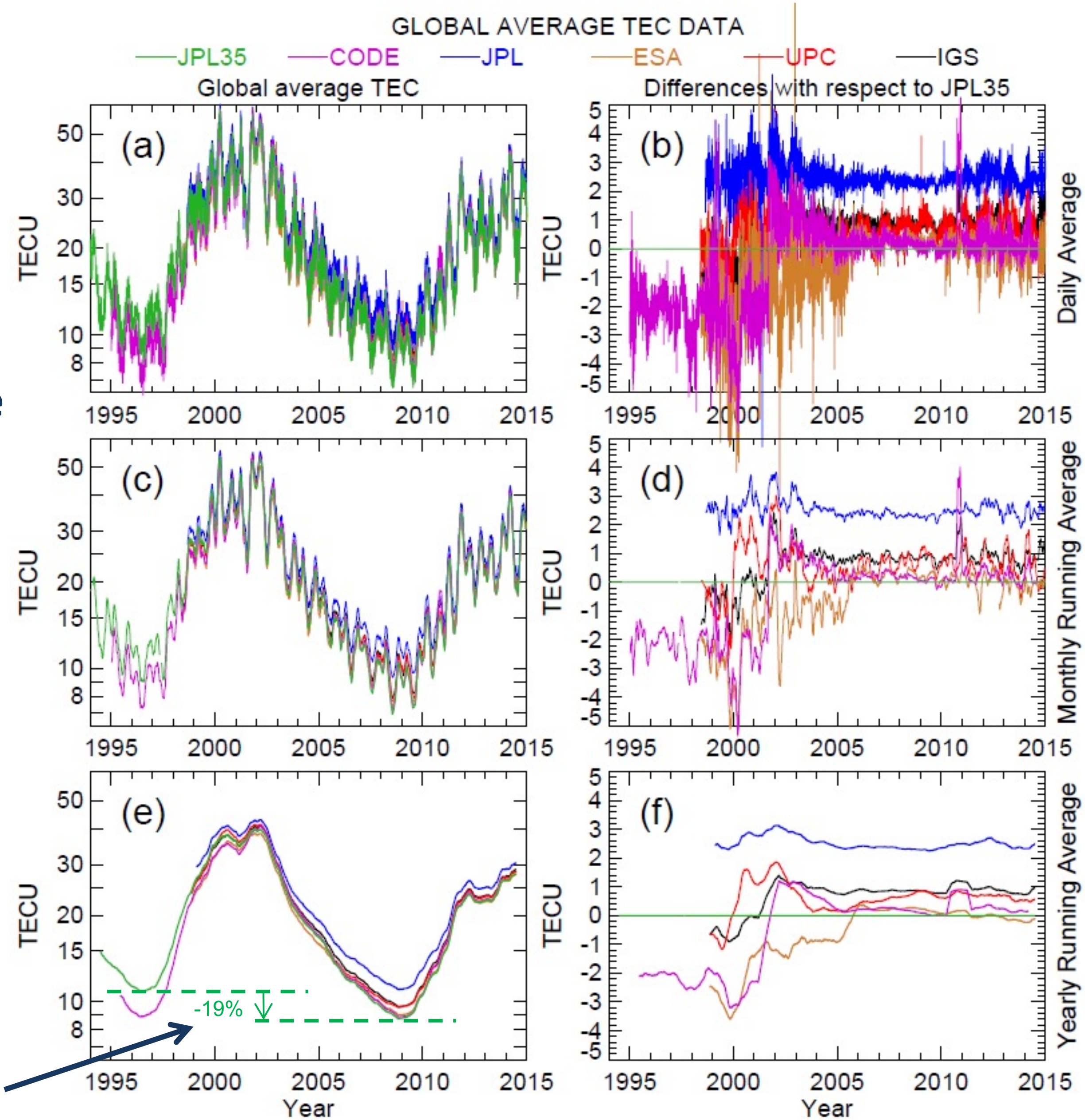
JPL 35-station TEC Maps

- 1994-2014
- Number of GPS receivers held fixed at 35
- Same processing algorithm used throughout

International GNSS Service

- 1998-2014
- Weighted average of maps from four centers (CODE, JPL, ESA, and UPC).

- CODE data have a 3 TECU jump with respect to JPL35 in 2001. This jump projects into IGS average.
- JPL/IGS data has an imposed 2 TECU offset to match altimeter data.
- **JPL 35 data show a -2 TECU (19%) interminimum change.**

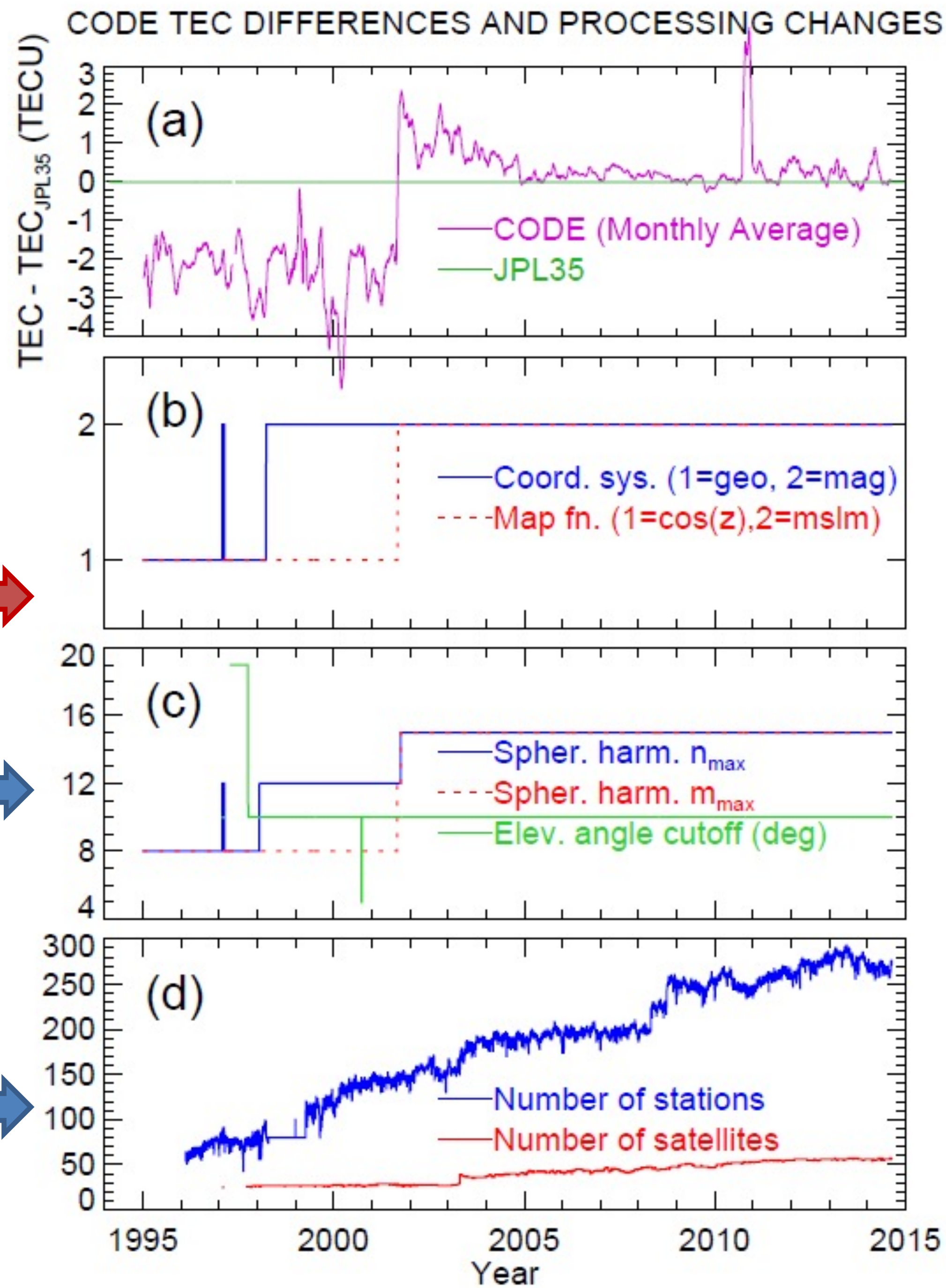


Source of CODE data shift in 2001

Two processing changes occurred at the time of the jump:

- Mapping function to convert slant TEC to vertical TEC
- Spherical harmonic resolution increased from (12,8) to (15,15)

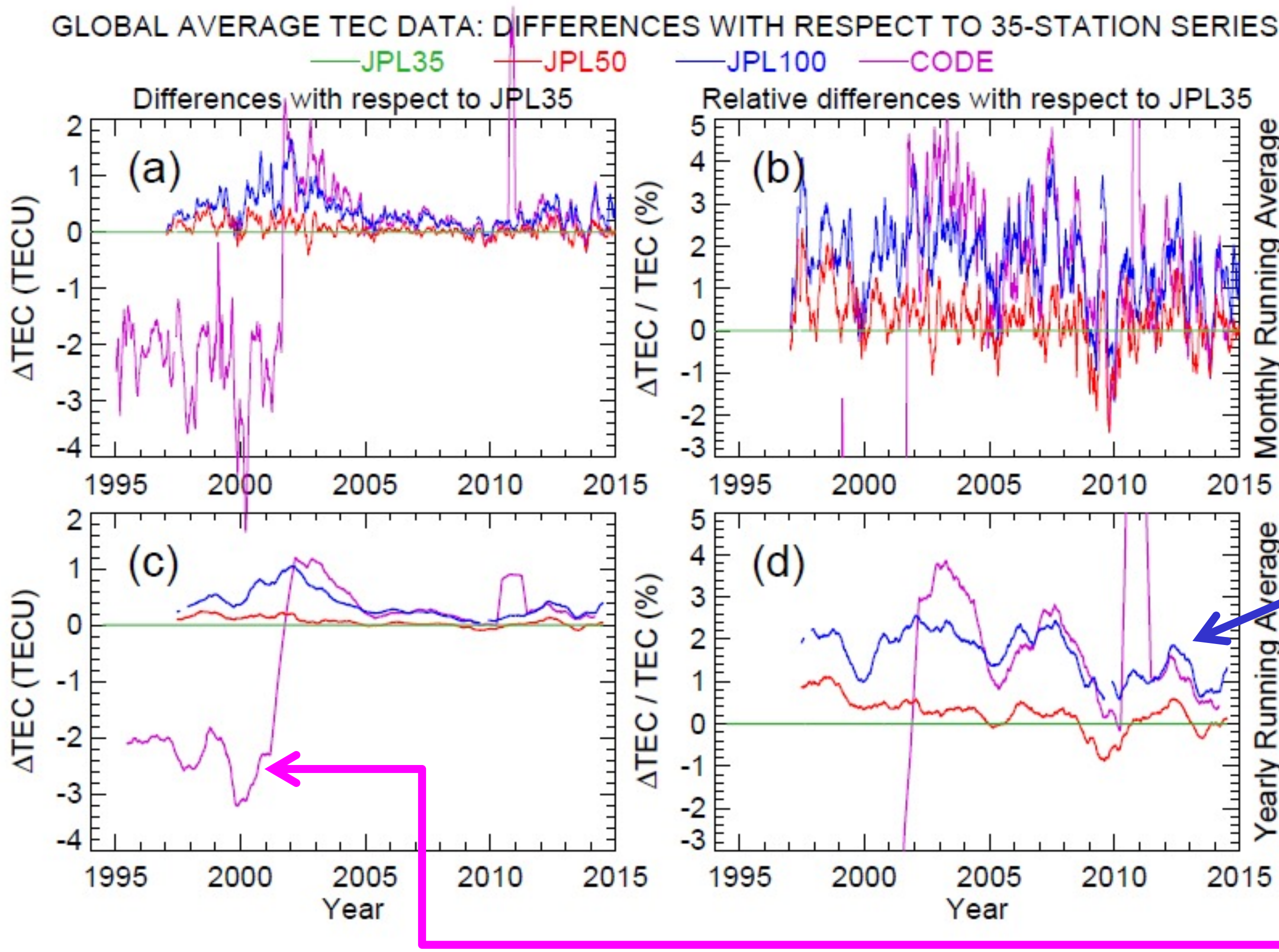
Number of stations has been increasing gradually – cannot account for jump



Global TEC dependence on number of contributing stations

JPL constructed TEC map products using:

- 35 stations (JPL35), 1994-2014
- 50 stations (JPL50), 1997-2014
- 100 stations (JPL100), 1997-2014



Offsets among the JPL TEC products tend to be more constant in a relative sense (up to 2%).

The CODE offset appears to be additive (2-3 TECU).

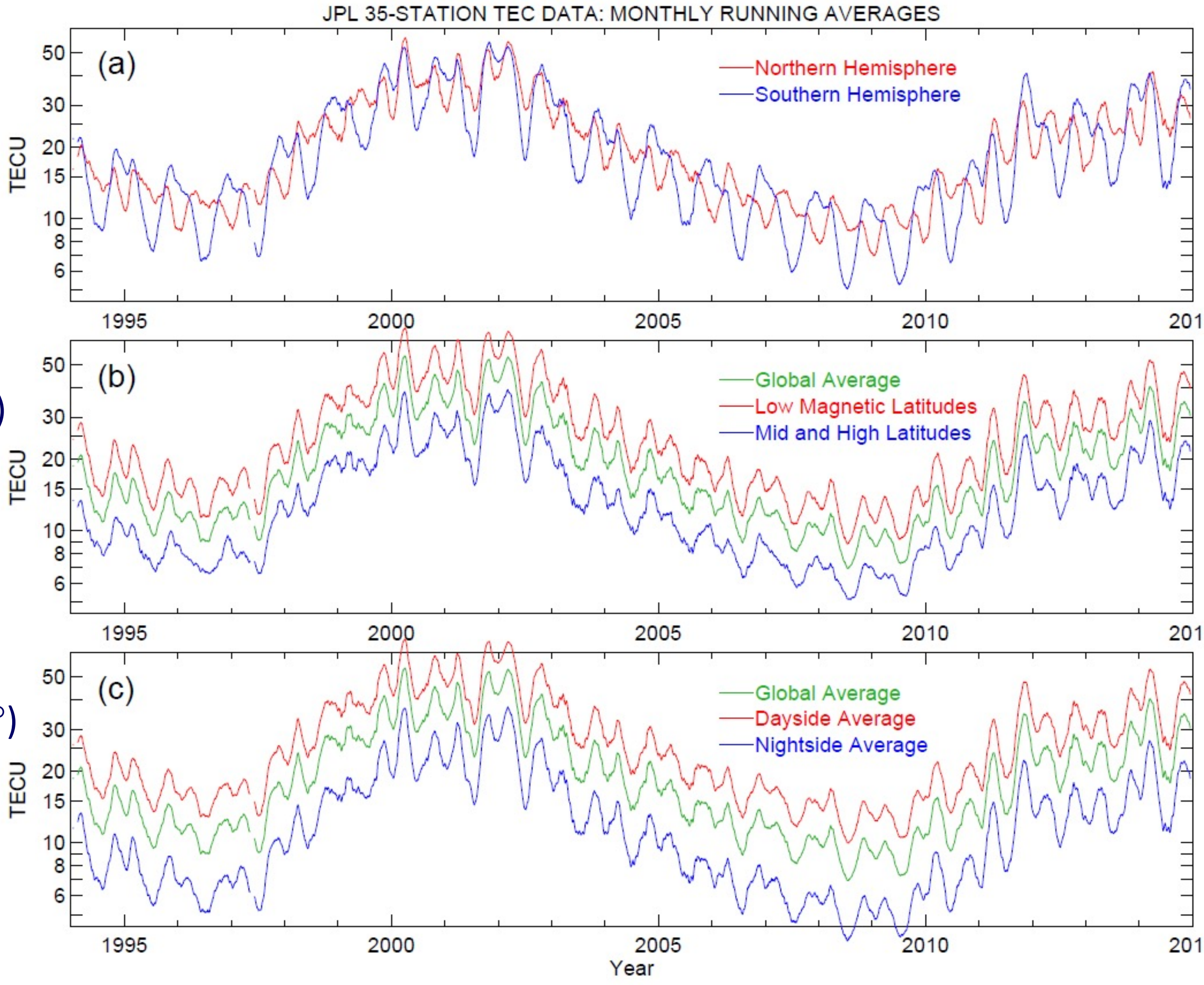
Hemispheric Averages

We divided and averaged the 35-station maps in three ways:

Northern
Southern
hemisphere
(geographic)

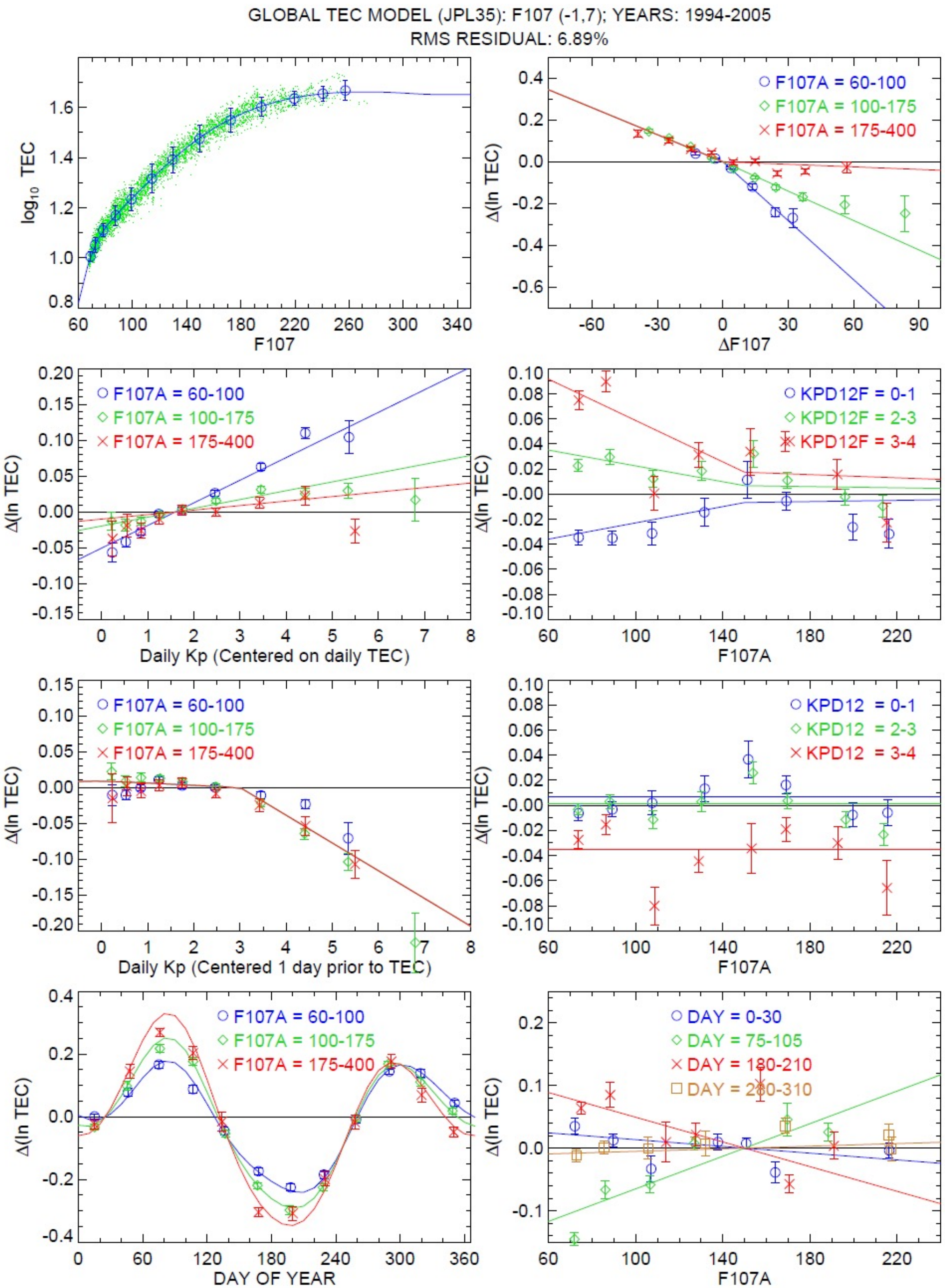
Low (<30°)
Mid/High (>30°)
magnetic
latitude

Day (SZA < 90°)
Night (SZA > 90°)

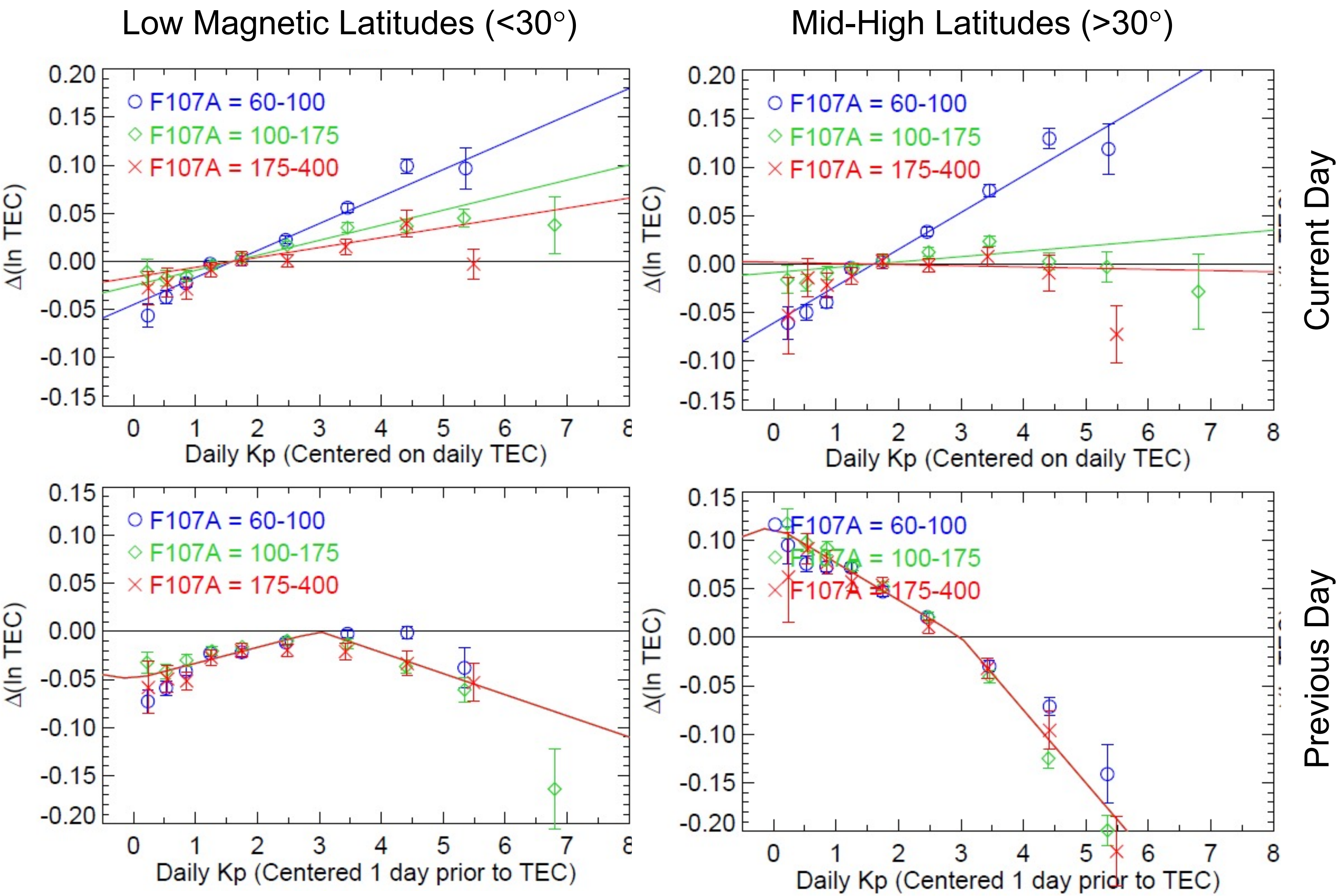


Empirical models

- We fit the global and hemispheric averages as a function of solar EUV irradiance (F10.7 proxy), geomagnetic activity (Kp index), and day of year [following Emmert et al., JGR, 2014].
- Model parameters estimated using 1994-2005 data (i.e., prior to the unusual solar minimum).
- F10.7 dependence is nonlinear and includes short-term (7 days) and long-term (81 days) components.
- Kp and day-of-year dependences modulated by 81-day F10.7.
- Kp dependence includes current day (positive storm effects) and previous day components (negative storm effects).



Empirical Models: Kp dependence at low vs. mid and high magnetic latitudes



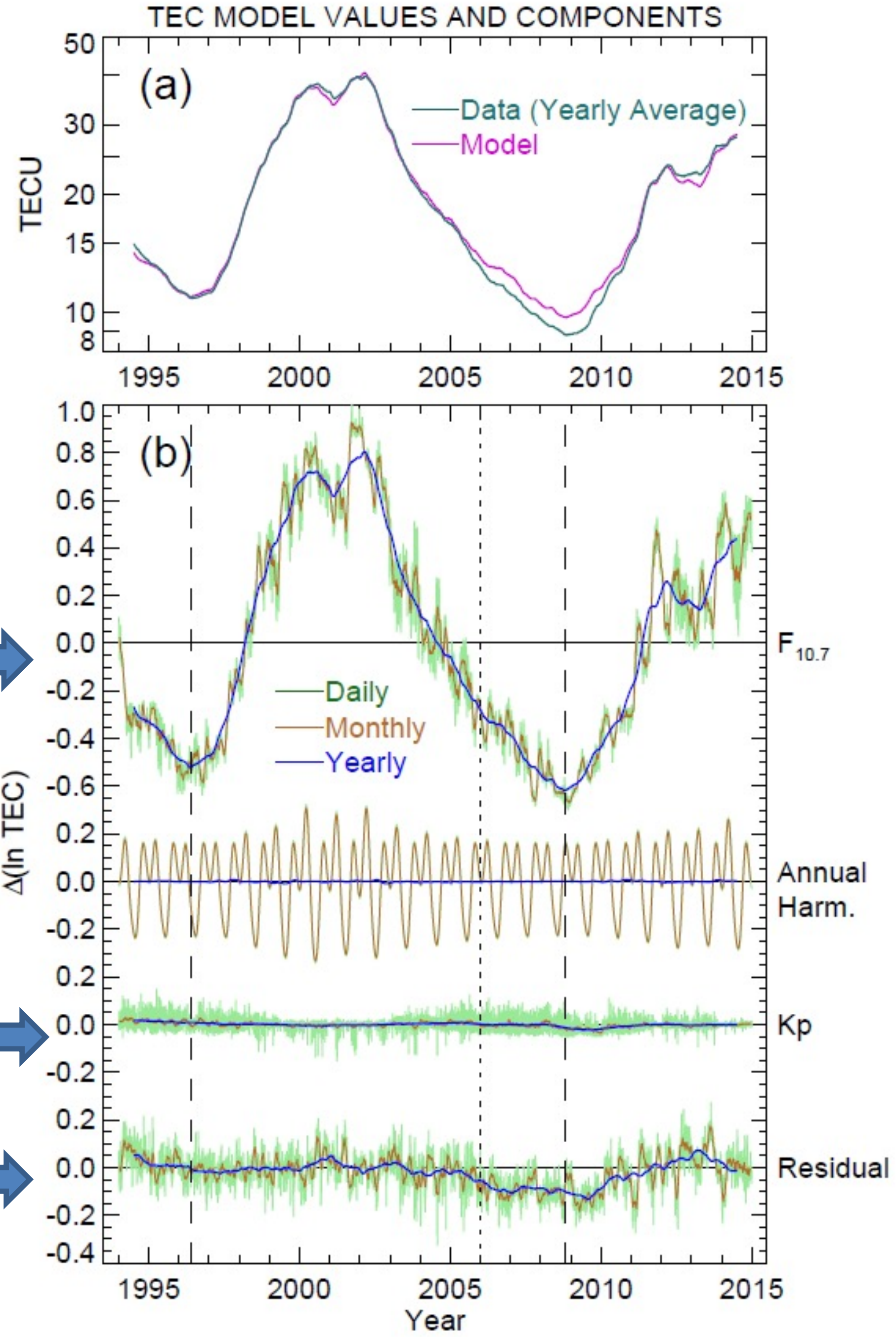
Time Dependence of Model Components (Global Average)

Solar irradiance is largest component of model variation: TEC increases by a factor of 4-5 from solar min to solar max.

Annual and semiannual variations are next largest (±20%).

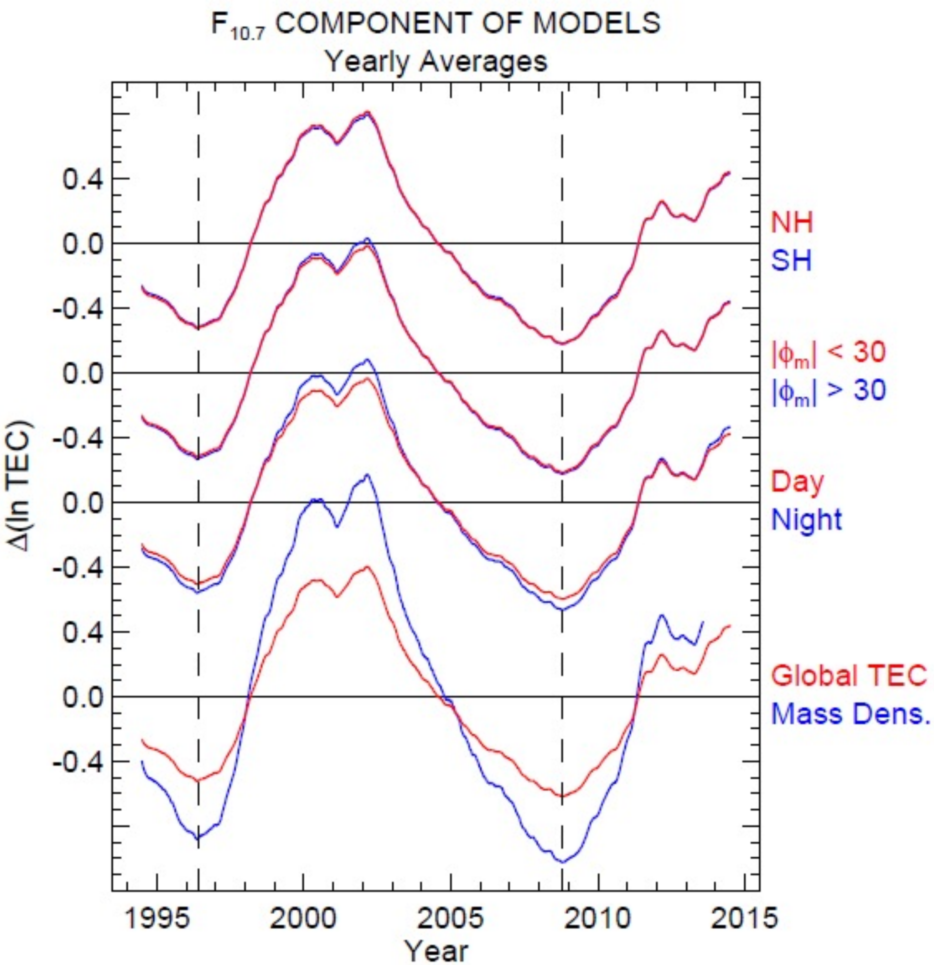
Variation in Kp component is up to 10% in daily averages, up to 2% in annual average.

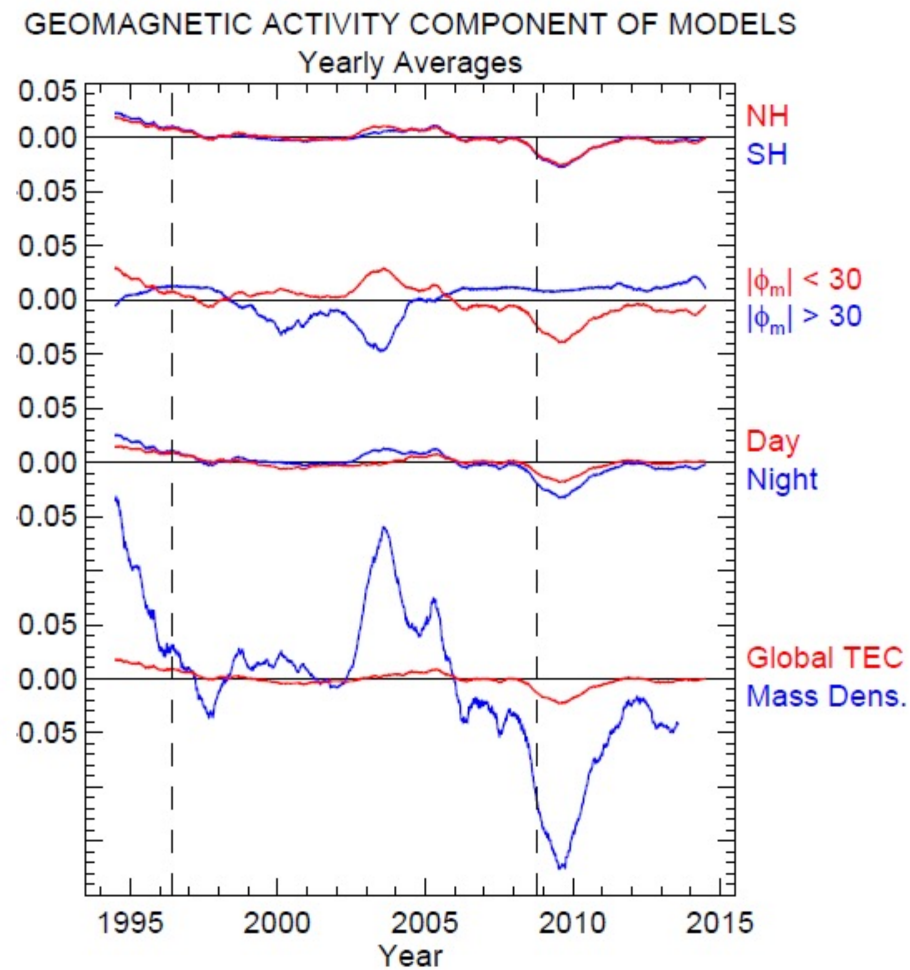
Model does not capture all of the observed interminimum change.



Solar and Geomagnetic Activity Components: Hemispheric Yearly Averages

- Hemispheric solar components are very similar to global model, except that nightside amplitude is slightly larger than dayside.
- Hemispheric geomagnetic components are similar, except that positive storm effects dominate at low latitudes, and negative storm effects dominate at mid and high latitudes.
- Solar component of mass density is comparable to TEC, but geomagnetic activity component is much larger (positive storm effects only).

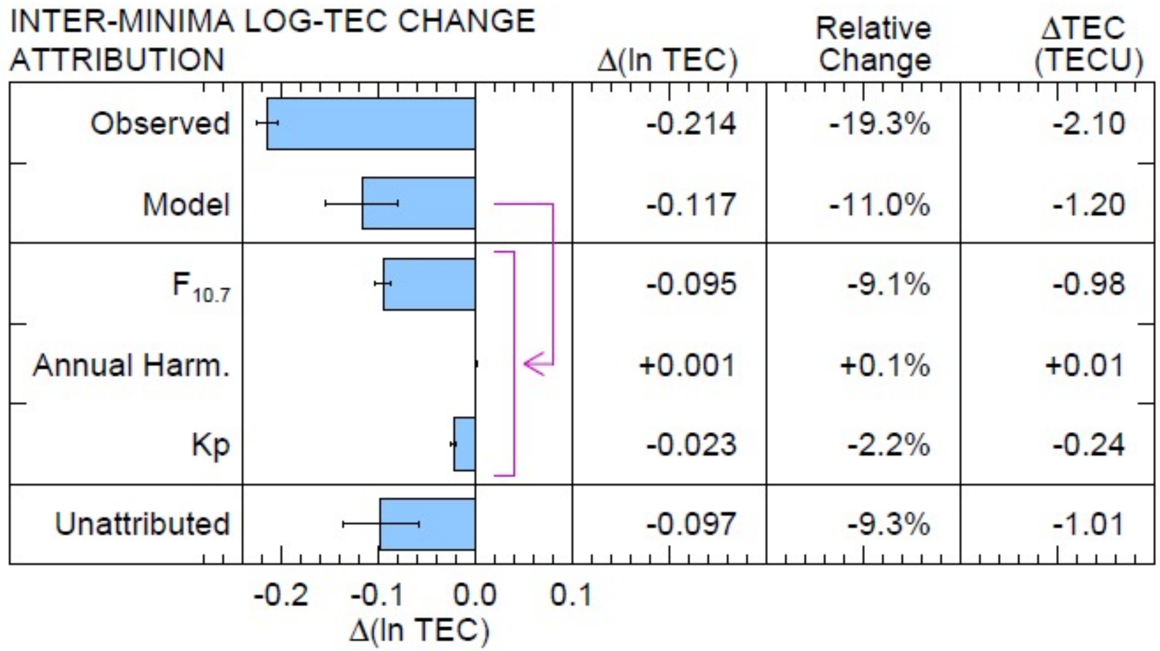




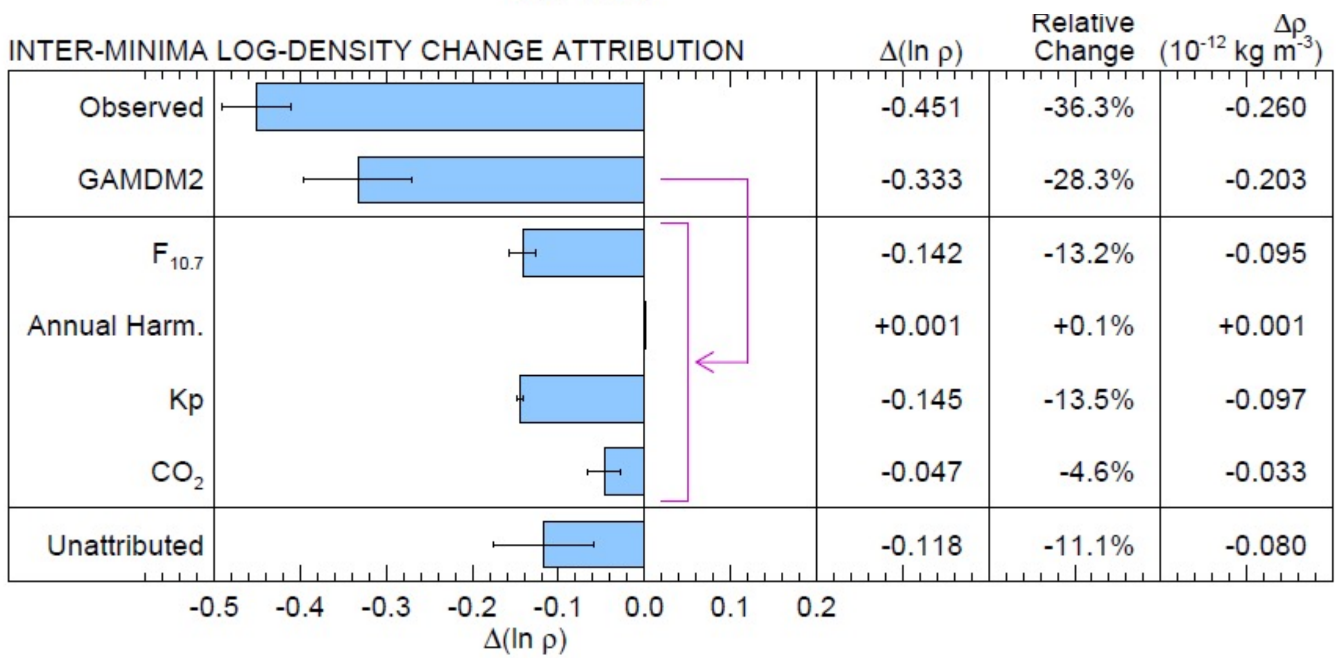
Attribution

- Interminimum change = difference between annual average centered on 1996.4 and 2008.8
- Attribution performed in log space.

TEC

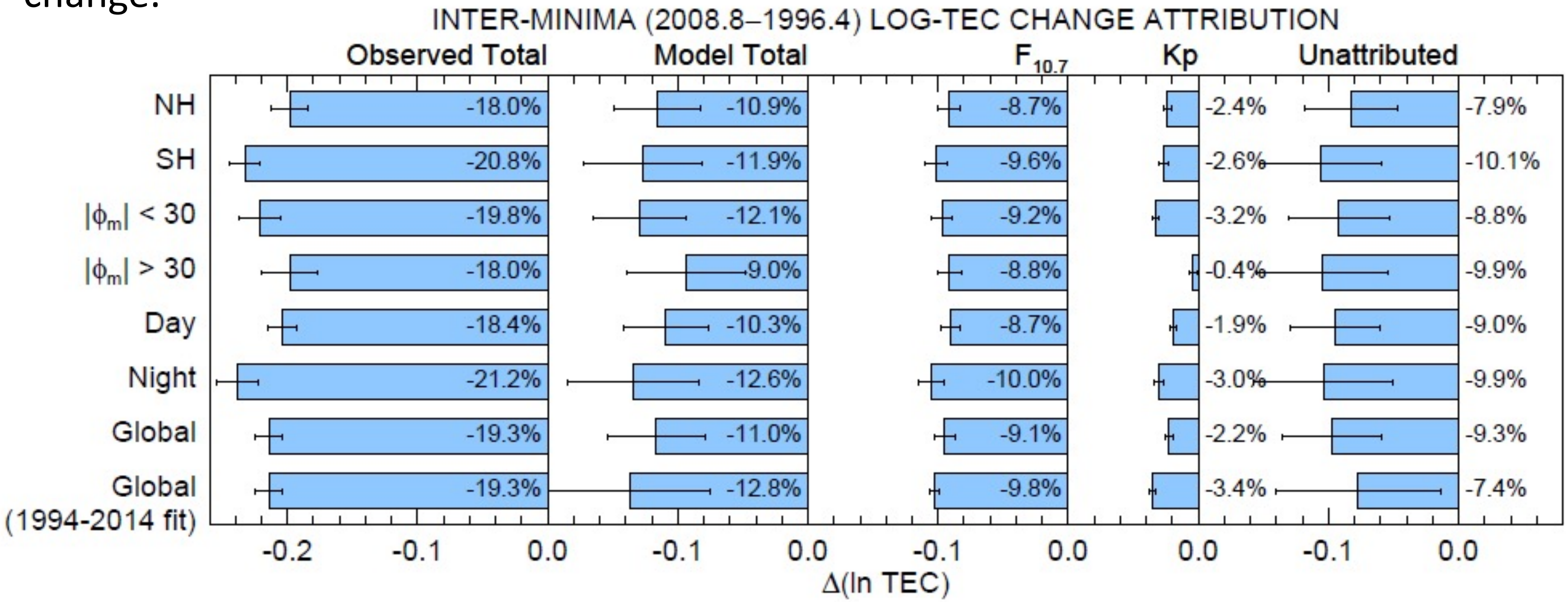


Mass Density (400 km)



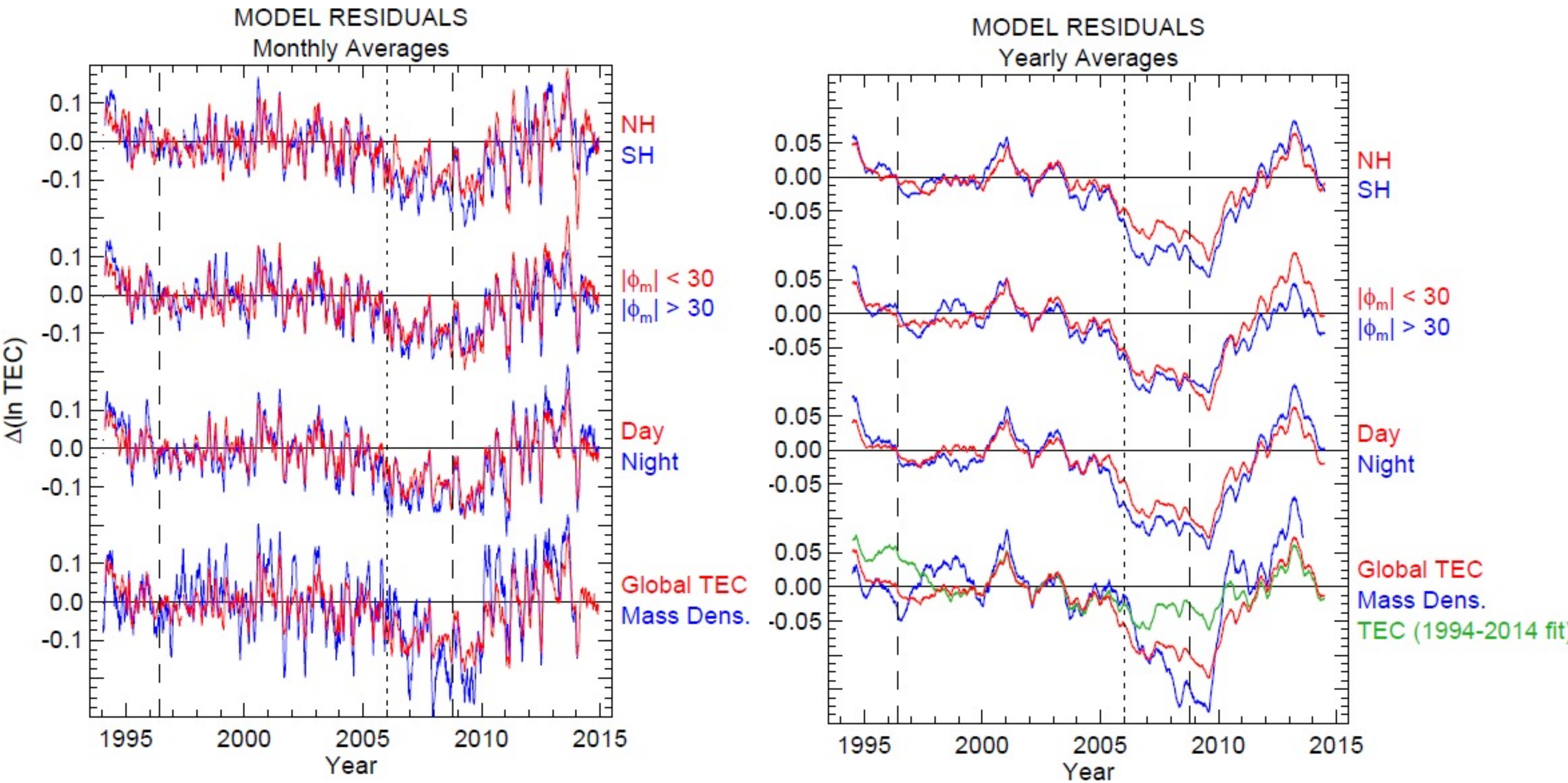
Attribution of Global and Hemispheric Averages

- Interminimum changes and attributions are similar among the selected hemispheric and global averages.
- The change is larger in:
  - The Southern Hemisphere (mainly from a larger F10.7 contribution)
  - Low magnetic latitudes (stronger Kp contribution)
  - The nightside (F10.7 and Kp contributions are both larger than on the dayside)
- The unattributed interminimum change ranges from 8% to 10%.
- Including 2006-2014 data in the fit only slightly increases the modeled intermiminum change.



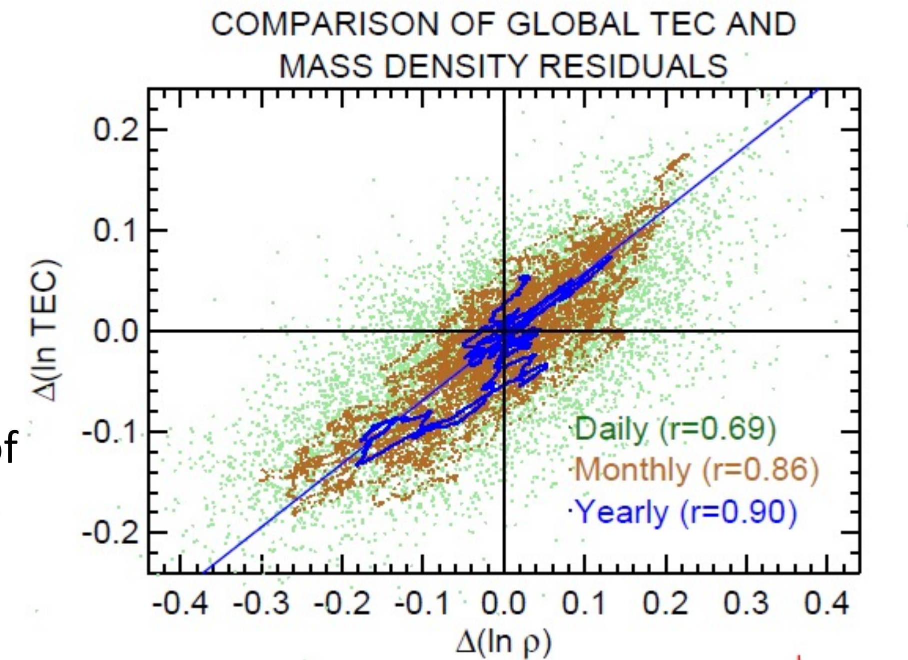
Unattributed variations (data-minus-model residuals)

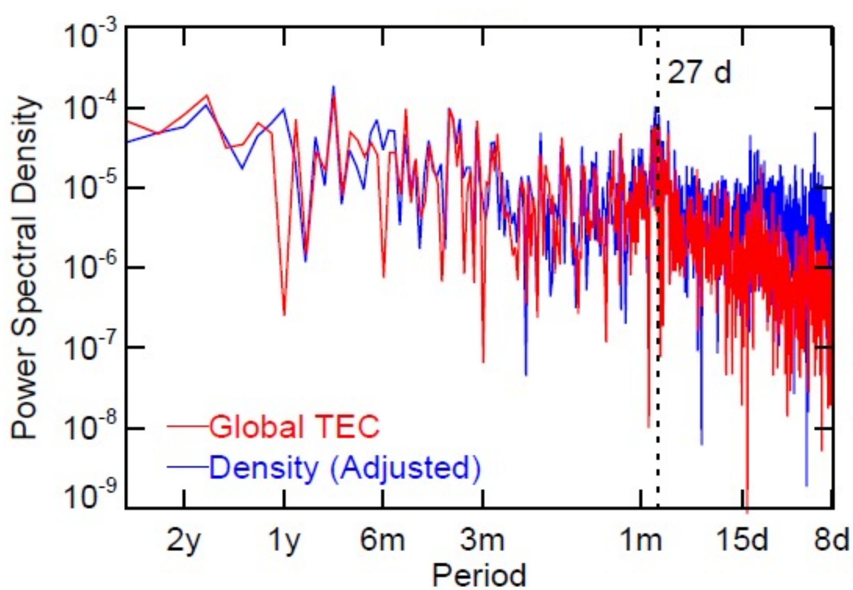
- Global and hemispheric residuals have a common temporal structure.
- Mass density residuals are very similar to TEC residuals.

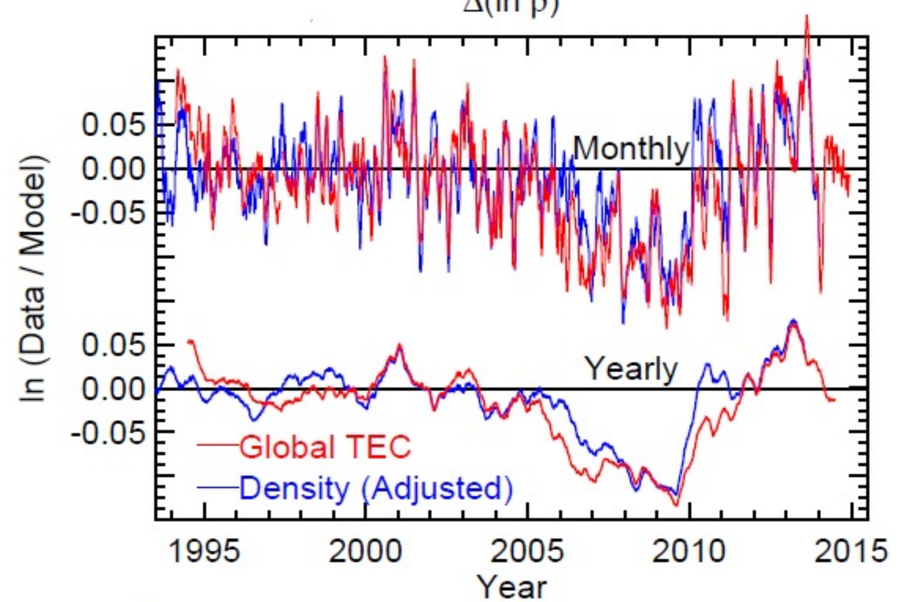


TEC vs. Mass Density Residuals

- Interannual variations of TEC and mass density residuals are highly correlated (r = 0.90)
- No obvious features in power spectra, except at a period of 27 days.
- An additional interminimum change in EUV (beyond F10.7) is a plausible candidate for explaining the TEC and density residuals.
- However, sufficiently accurate measurements of the EUV interminimum change do not exist.
- Another candidate is an unmodeled decrease in thermospheric atomic oxygen.

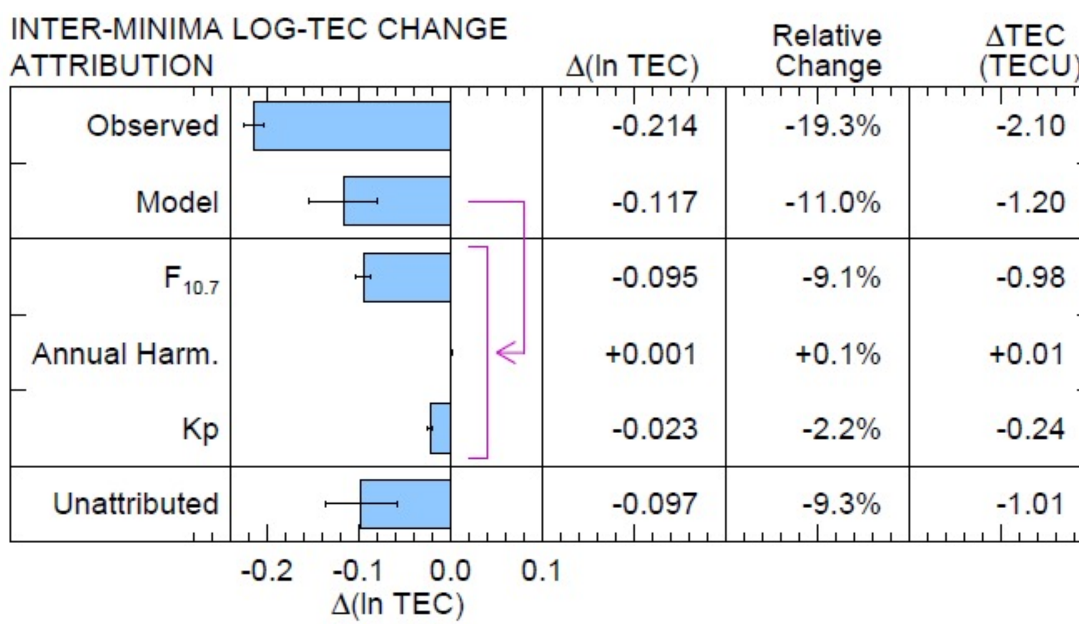






Summary

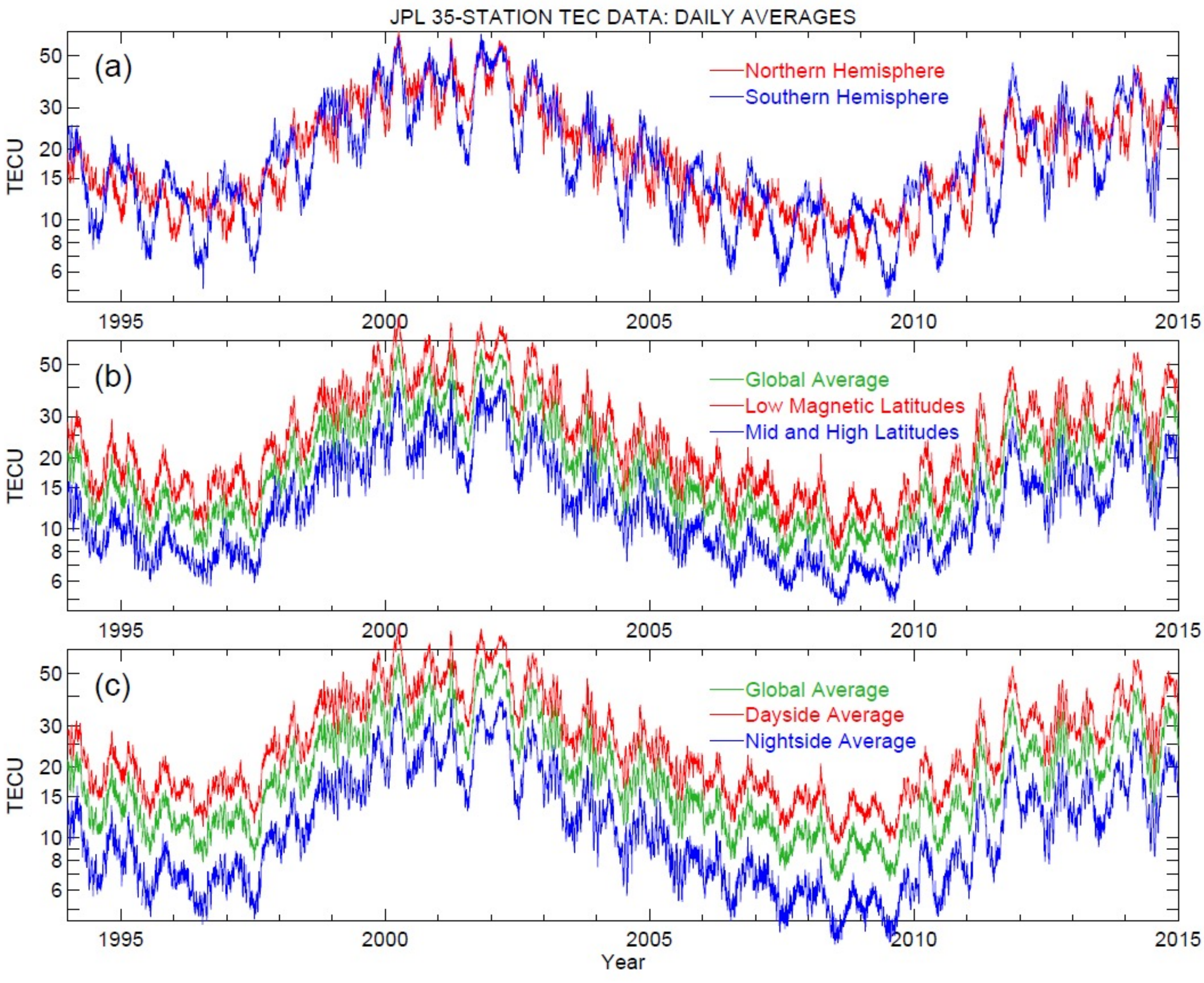
- Global TEC was 19% lower during the 2008 minimum than during the 1996 minimum.
- Changes in F10.7 and Kp account for TEC decreases of 9% and 2%, respectively.
- Changes are slightly larger in the Southern Hemisphere, at low latitudes, and on the nightside.
- TEC and mass density changes are very similar, except that geomagnetic activity contribution is much larger for mass density.
- The TEC and mass density data-minus-model residuals are highly correlated.
- Candidate mechanisms for explaining the TEC and mass density residuals:
  - Additional EUV change
  - Thermospheric composition change



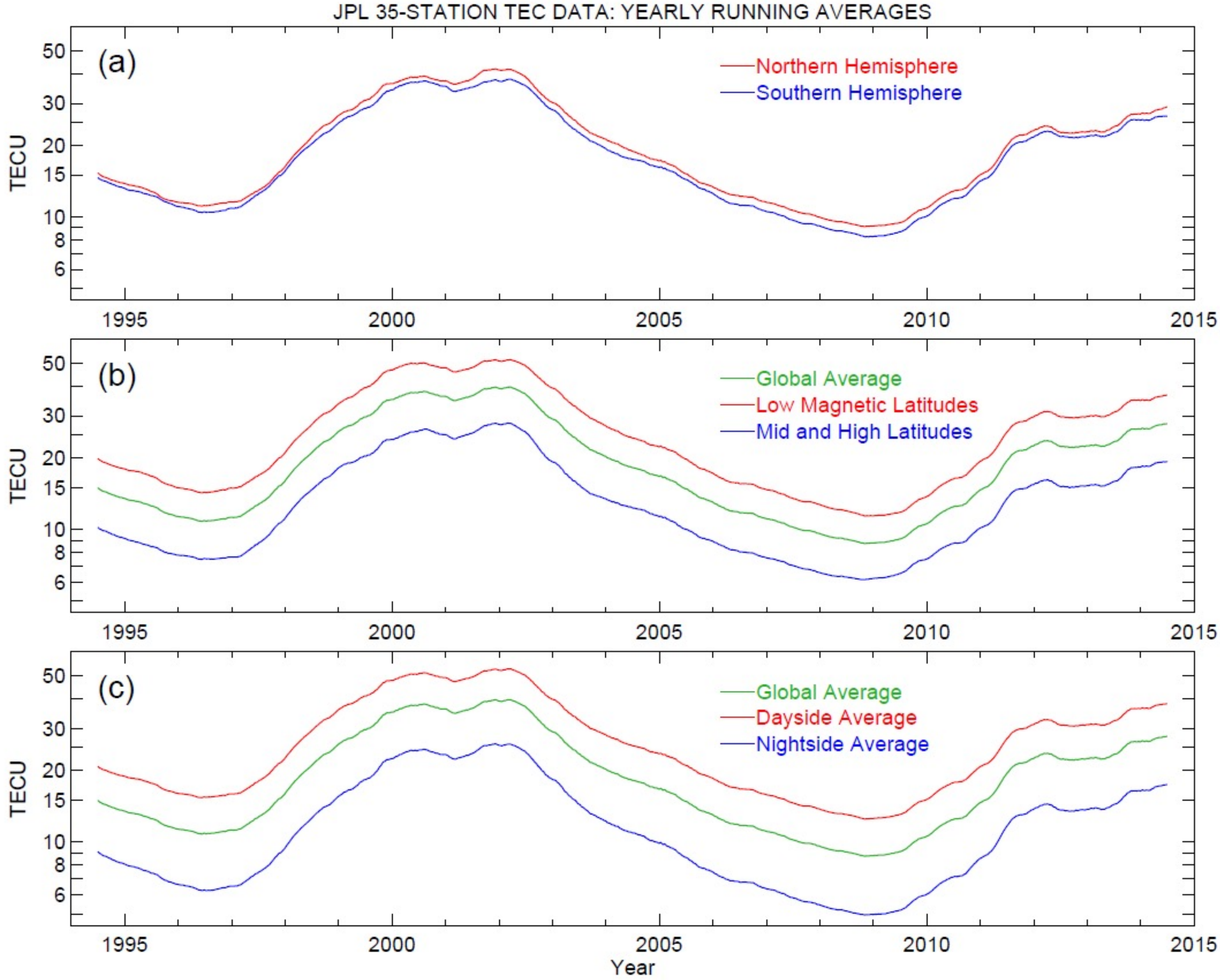
Abstract

Previously, the only available global TEC data spanning the past two solar minima were CODE (Center for Orbit Determination in Europe) global maps derived from ground-based receivers, and nearly global partial TEC measurements from altimeters. Both data sets show no change in TEC between the past two minima. This result is apparently inconsistent with interminimum decreases (between annual averages centered on 2008.8 and 1996.4) in the F10.7 solar EUV proxy and geomagnetic activity, both of which contributed to a large interminimum decrease in thermospheric mass density. One possible cause of the discrepancy is a time-dependent bias in the TEC data, so we constructed a new 1994-2014 series of ground-based TEC maps using temporally uniform processing and a fixed set of 35 GPS receivers. The new data show a 19% interminimum decrease in global TEC, and the resulting attribution is consistent with that of mass density. Changes in F10.7 and Kp account for TEC decreases of 9% and 2%, respectively. Changes are slightly larger in the Southern Hemisphere, at low latitudes, and on the nightside. The TEC and mass density data-minus-model residuals are highly correlated, suggesting that an additional, unaccounted-for interminimum change in EUV is a plausible (but unconfirmed) candidate for explaining the residual TEC and mass density interminimum changes. A unmodeled decrease in thermospheric atomic oxygen is another candidate mechanism that would cause both TEC and mass density decreases.

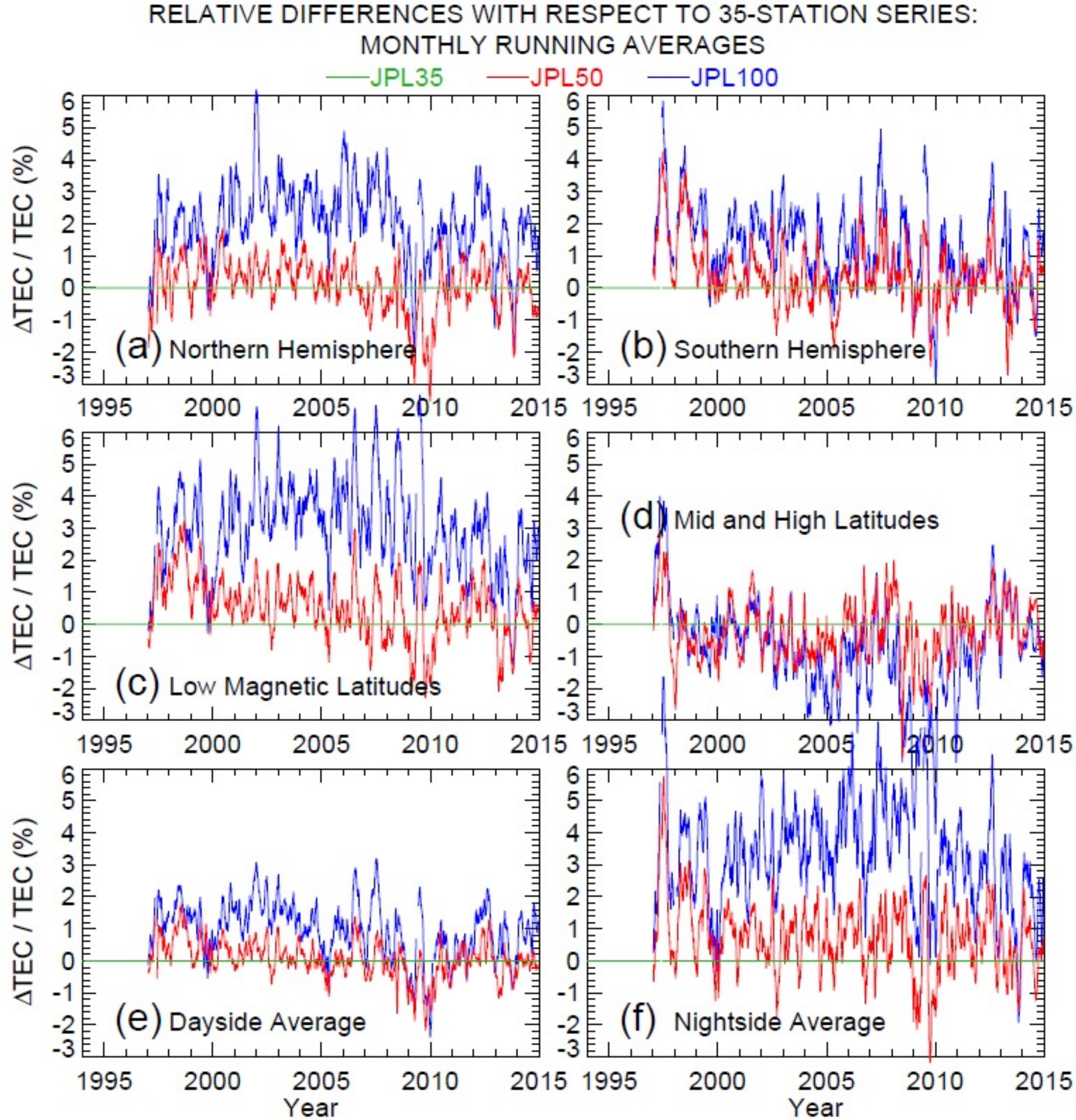
Hemispheric Averages: Daily Averages



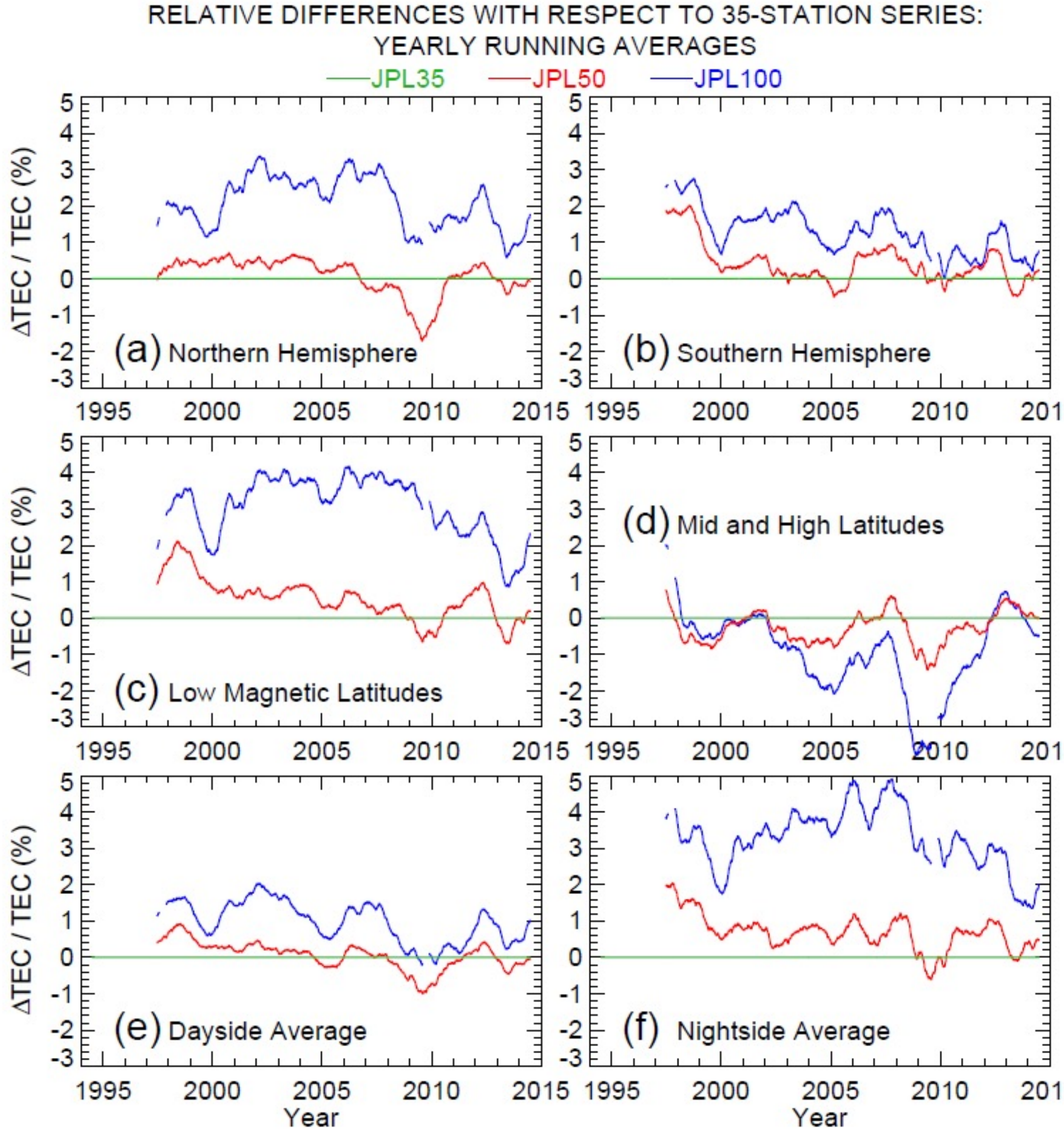
Hemispheric Averages: Yearly Averages



TEC dependence on number of contributing stations: Hemispheric Monthly Averages



TEC dependence on number of contributing stations: Hemispheric Yearly Averages



Solar, Intra-annual and Geomagnetic Activity Components: Hemispheric Monthly Averages