The long-term trends in thermospheric mass density and ionospherie total electron content

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Abstract

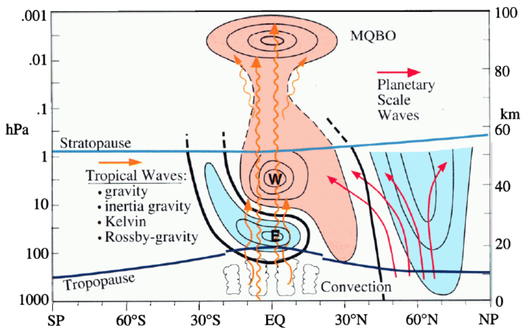
In this research, we present spectral analysis of the daily thermospheric total mass density derived from ~5000 near-Earth space objects from 1967 to 2012 [Emmert et al., 2004; Emmert et al., 2008; Emmert et al., 2009], as well as GPS total electron content from 1999 - 2012. In our analysis, we consider the roles played by solar, as well as possible coupling to the stratospheric quasi-biennial oscillation (QBO), the El Nino Southern Oscillation (ENSO), and the manifestation of possible ionosphere / thermosphere coupling.

Thermospheric Total Mass Density:

- Thermospheric total mass density is a key parameter for near-Earth space operations, and is also very useful for scientific studies of upper atmospheric behavior. [Emmert et al., 2009]

Quasi-biennial Oscillation:

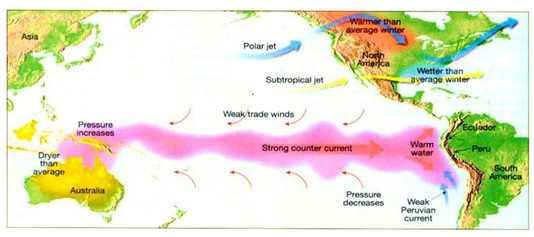
- Quasi-biennial oscillation (QBO) is a climatological oscillation that is most easily to seen in the tropical stratosphere.



- The easterly and westerly zonal-mean wind regimes of the QBO propagate downward in turn in the equatorial stratosphere (16-50 km) and have 28-34 months period.

El Nino Southern Oscillation:

- El Niño–Southern Oscillation (ENSO) is an irregularly periodical variation in winds and sea surface temperatures over the tropical eastern Pacific Ocean, affecting much of the tropics and subtropics.



- Upon the advent of an ENSO event, the pressure over the eastern and western Pacific flip-flops. This cause the trade winds to diminish, lead to an eastward movement of warm water along the equator. As a result, the surface waters of the central and eastern Pacific warm, with far-reaching consequences to weather patterns.

Total Electron Content:

- Total electron content (TEC) is an important descriptive quantity for the ionosphere of the Earth which is the total number of electrons integrated between two points, along a tube of one meter squared cross section.

Motivations & Questions

- How do the possible parameters affect to the variation of thermospheric total mass density and the global TEC? What is the mechanism behind?

- What is the thermosphere-ionosphere coupling response to other possible parameters?

Summary & Conclusions

We performed a set of spectral analysis, using CWT, HHT, and WTC, to separate possible thermospheric total mass density and TEC variations modulated by the solar activity, the stratospheric QBO, and the ENSO index.

- The main driver of both variations is the solar cycle, included 11-year, one-year, half-year, and 27-days period. And the Stratospheric QBO shows a unexpected one-year period response in both thermosphere and ionosphere.

- The thermosphere-ionosphere WTC result shows a set of irregularly periodical high correlation with nearly 6-48 day. And has in phase high correlation in long period higher then ~4-month. However, abnormal region during 2005-2011 has been found. And the phase lag can be changed as high as 90º in these region.

References

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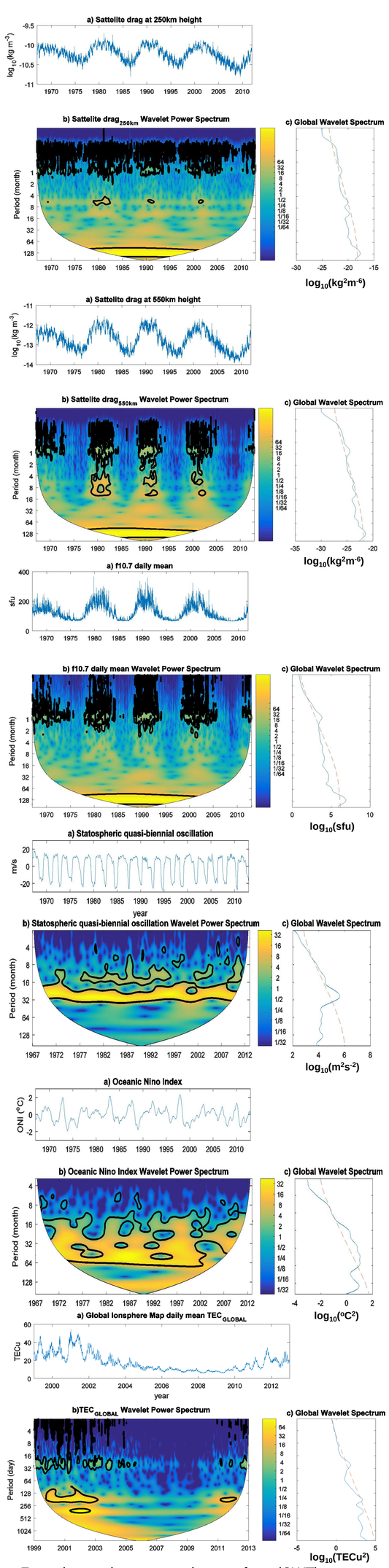
Continuous Wavelet Transform:



- From the continuous wavelet transform (CWT) we can simply find out the frequency of the signals and the time associated to those frequencies.

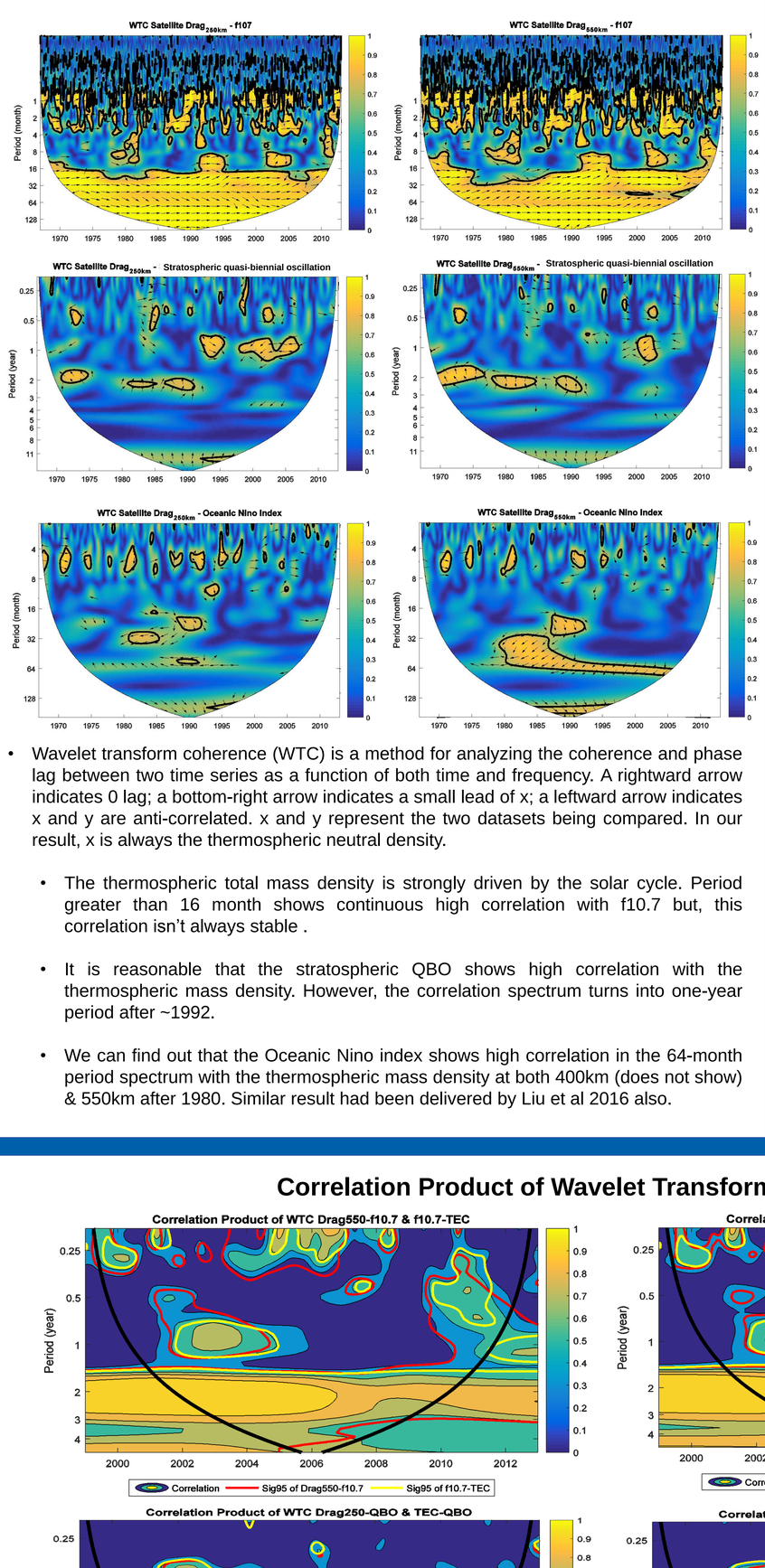
  - The result of thermospheric total mass densty in 250, 400 and 550km have near the same significant period in ~27-day, half-year, one-year and 11-year. These may be associated to the solar cycle.

  - Stratospheric quasi-biennial oscillation has a ~2-year period as we known. However, ~one-year period also appear in some time region.

  - The Oceanic Nino Index (ONI) result shows a set of instable period between ~12 to 64 month.

  - It is obviously that the total electron content (TEC) be driven by the solar cycle, and have ~27-day, half-year and one-year period as the thermospheric total mass density.

Wavelet Transform Coherent Method:



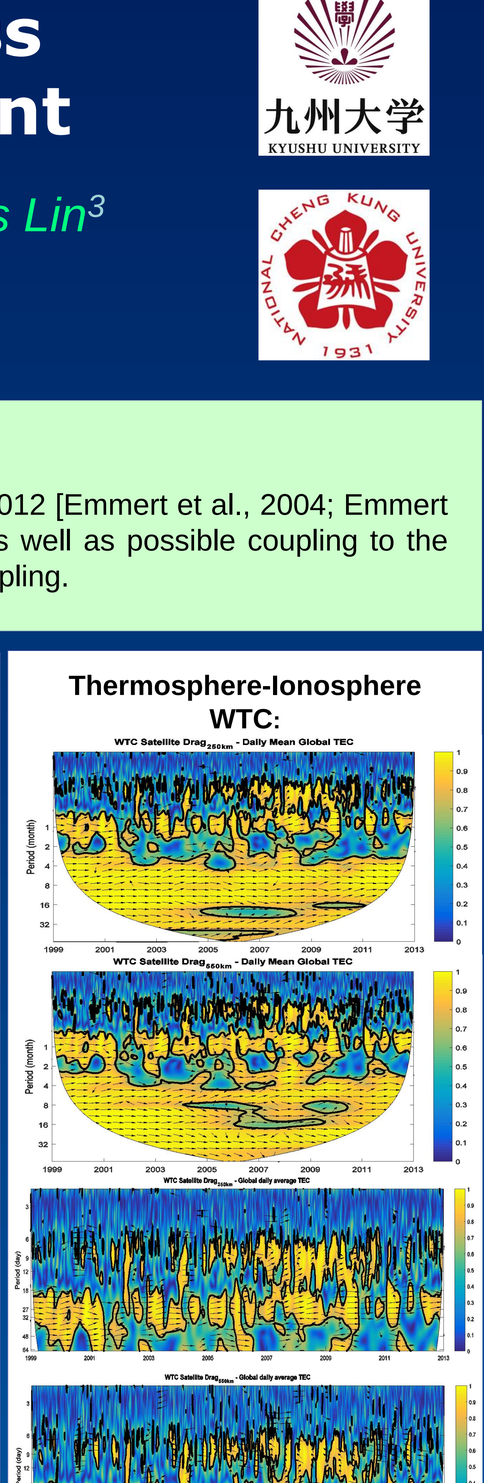
- Wavelet transform coherence (WTC) is a method for analyzing the coherence and phase lag between two time series as a function of both time and frequency. A rightward arrow indicates 0 lag; a bottom-right arrow indicates a small lead of x; a leftward arrow indicates x and y are anti-correlated. x and y represent the two datasets being compared. In our result, x is always the thermospheric neutral density.

- The thermospheric total mass density is strongly driven by the solar cycle. Period greater than 16 month shows continuous high correlation with f10.7 but, this correlation isn't always stable .

- It is reasonable that the stratospheric QBO shows high correlation with the thermospheric mass density. However, the correlation spectrum turns into one-year period after ~1992.

- We can find out that the Oceanic Nino index shows high correlation in the 64-month period spectrum with the thermospheric mass density at both 400km (does not show) & 550km after 1980. Similar result had been delivered by Liu et al 2016 also.

Thermosphere-Ionosphere WTC:

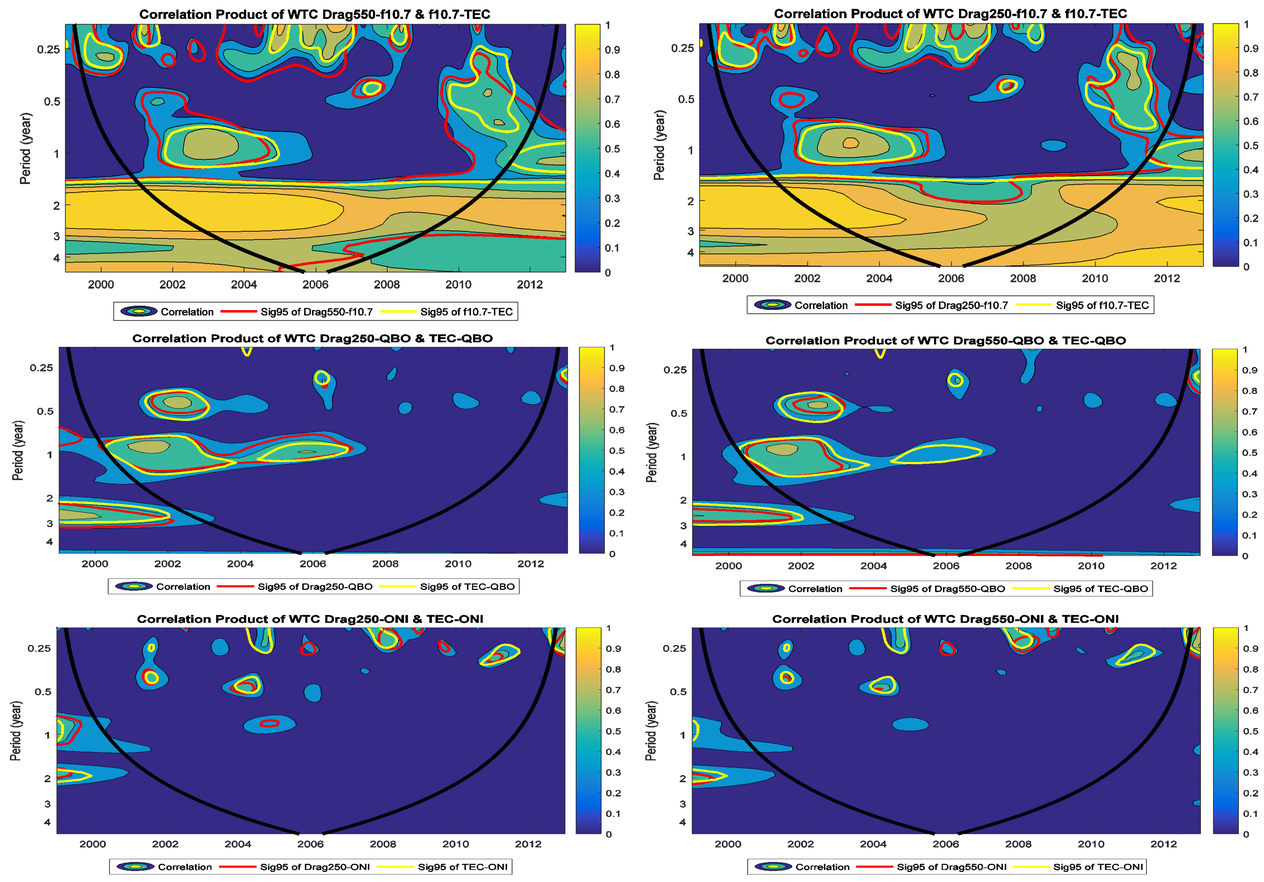


- We also test the thermosphere-ionosphere coupling by using the WTC method.

  - In the result of thermospheric total mass density at each altitude [250,400,550 km] shows an in phase high correlation with period greater then ~4-month. Otherwise, a set of coherent periodicities with ~6-12 day, 18-48 day can also be found.

  - However, coherence become lower in 8-32 month period during 2005-2011. The phase lag shows a 90º change from ~0º to ~90º. In contrast, the short-term period in ~6-18 day band becomes stronger in nearly the same region and the phase lag changes from ~180º to ~90º .

Correlation Product of Wavelet Transform Coherence:



- We test the thermosphere-ionosphere coupling by two correlation coefficient R^2 of WTC result. It shows the response of thermosphere and the ionosphere to such as f10.7 index, QBO index and ONI.

  - The first row represent the spectrum of thermospheric total mass density and the daily average global TEC shows simultaneously high correlation with f10.7. It seems like both the mass density and the TEC modulated by the solar activity in the solar maximum with a nearly one-year period. And the long-term period is modulated by the sun.

  - The stratospheric QBO shows up a one-year period in the result and no response after 2007. It is different to the 28-34 month period.

  - Due to the short time range of the data, we cannot compare the 64-month period which has high correlation with the total mass density in WTC result.