Intra-Seasonal Variability in Thermospheric Density and Mesospheric Winds: Possible Influences from Tropical Tropospheric Convection

F. Gasperini[1] and A. Maute[2]

(1) Orion Space Solutions (federico.gasperini@orionspace.com)
(2) High Altitude Observatory, National Center for Atmospheric Research

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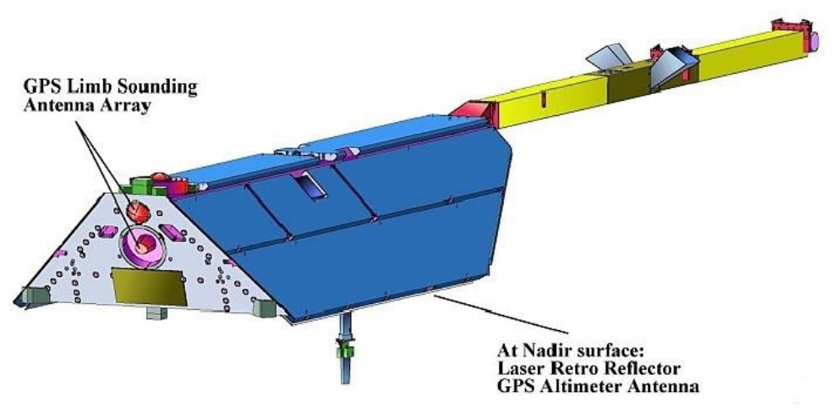
INTRODUCTION

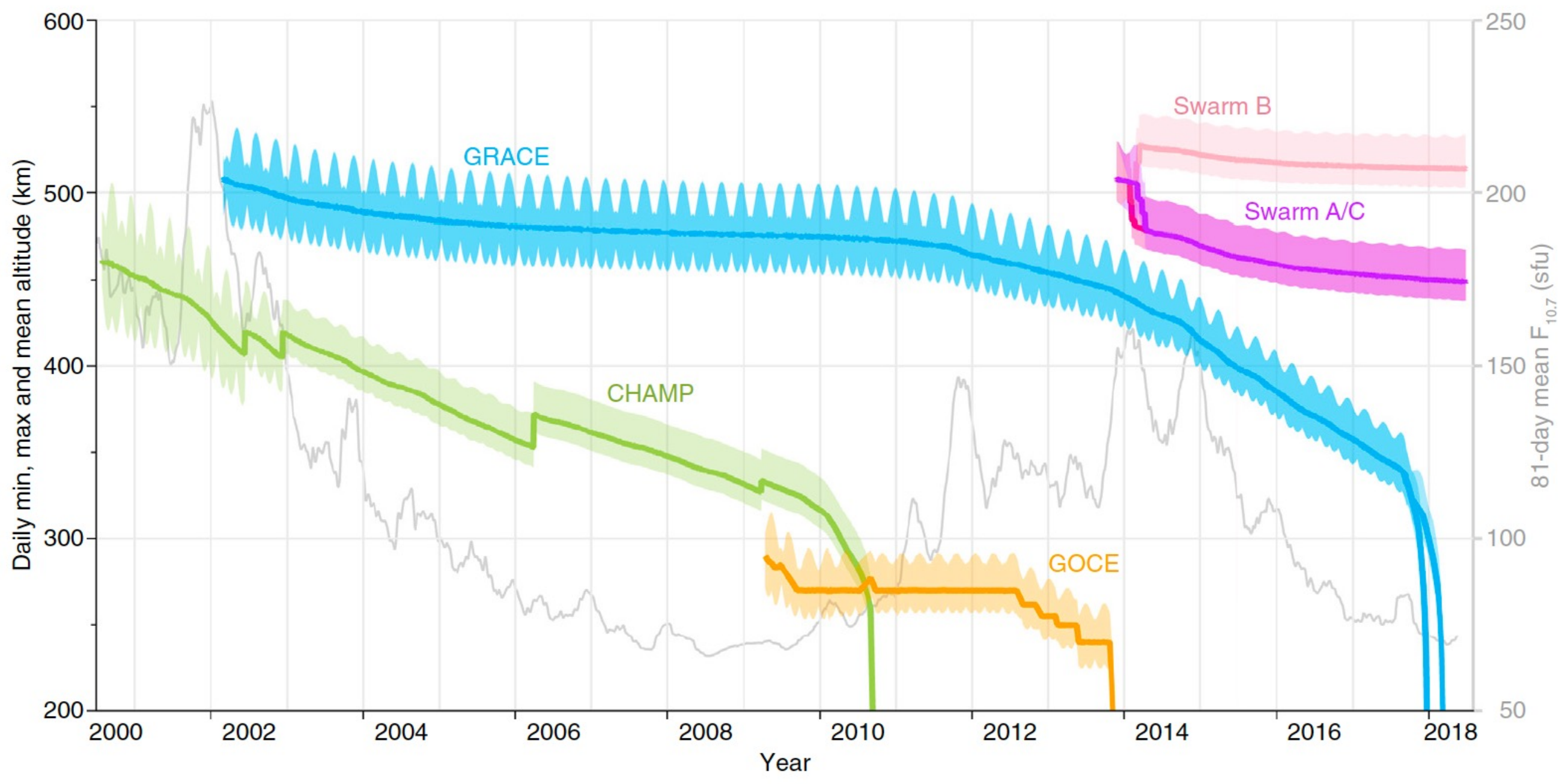
Abstract

The extent to which the thermosphere (ca., 100-500 km) is influenced by the lower (~0-20 km) and middle (~20-100 km) atmosphere from daily to monthly time scales is an important area of research that has escalated during the last two decades. Attaining a better understanding and characterization of intra-seasonal (IS, ~30-90 days) modes of variability in the thermosphere is increasingly recognized as a potential new source of whole atmosphere predictability[1]. Recent observational and modeling-based studies*(2)-(7)* suggest that a spectrum of upward propagating waves, including tides, gravity waves (GWs), and ultra-fast Kelvin waves (UFKWs), excited by deep convection in the tropical troposphere may be a leading driver of thermospheric IS variability. Tropospheric convection associated with the Madden-Julian Oscillation (MJO) is the dominant mode of IS variability in tropical convection and circulation and has been shown to modulate the intensity of upward-propagating tides, GWs and UFKW. In this work, spectral and temporal analyses of 20 years of combined Challenging Minisatellite Payload (CHAMP), Gravity Field and Steady-State Ocean Circulation Explorer (GOCE), and Swarm-C observations reveal prominent, persistent, and global-scale IS variability in middle thermospheric (~260-400 km) density and wind. Correlation analyses between these thermospheric IS variations and IS variability in tropical tropospheric convection (as proxied by Outgoing Longwave Radiation, OLR) demonstrate at least nine large correlative events during 2000-2020. Nearly 15 years of continuous ground-based medium-frequency radar (MFR) zonal and meridional neutral wind measurements from Buckland Park, Adelaide are then used to investigate these IS variations in the ~70-100 km mesosphere-lower-thermosphere (MLT) region. Potential connections to wave driving and the MJO are discussed.

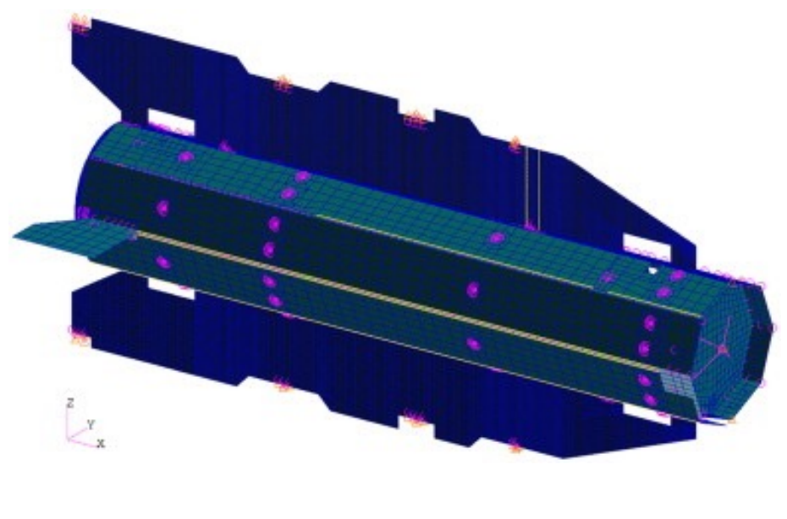
Satellite Data



CHAMP (GFZ)
2000-2010



CHAMP, GRACE, GOCE, and Swarm data availability and evolution[8]



GOCE (ESA)
2009-2013

Swarm-C (ESA)
2013-current

Methods

- Spectral/correlation methods, e.g., FFTs, S-transform wavelets, and Pearson correlations.
- Satellite 'diurnal mean' zonal winds from ascending/descending node averages (~12-hr LT separation).
- Ap>20 days removed (12% of data).
- F10.7/ap effects minimized using linear regression fits in 15d running windows.

Ground-Based Data

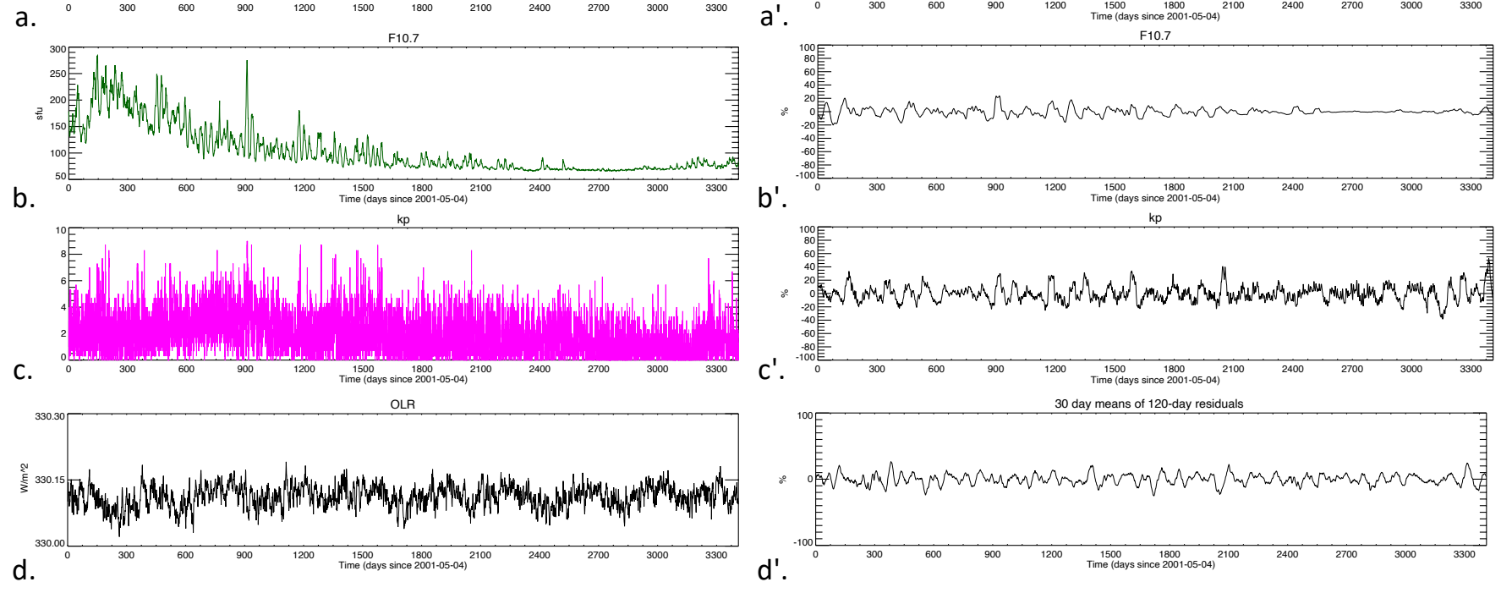
- The Adelaide, Australia Buckland Park (BP) MF radar has operated since 1983.
- The data employed consists of hourly zonal and meridional winds during 2000-2014.
- The height coverage is ~50-98 km during the day and ~70-98 km during the night, with a vertical resolution of ~2 km.

Buckland Park MF Radar (Adelaide Univ.): *2013-current*

RESULTS

IS Variability in Satellite Observations near 380 km

Time Series – CHAMP density



Wavelets & Correlations – CHAMP density

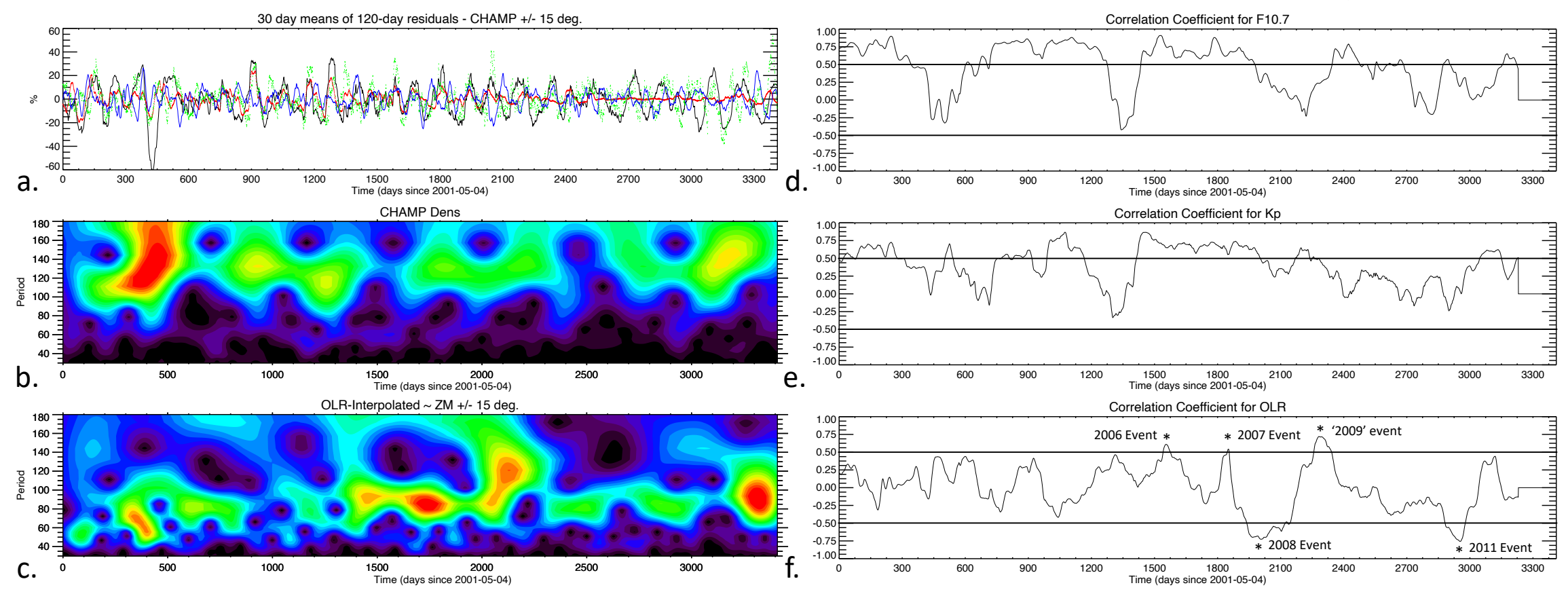


Figure 1 *(a) Time series of CHAMP total mass density averaged 15°S-15°N latitude during 2000-2010 for the ascending (blue line) and descending (red line) nodes. (a') 30-day running means of 120-day residuals of ascending/descending node averages (i.e., proxy for zonal means). (b)-(d) Time series of daily F10.7, 3-hourly Kp, and daily OLR during 2000-2010. (b')-(d') 30-day means of 120-day residuals of (b)-(d).*

Figure 2 *(a) Time series of 30-day running means of 120-day residuals of 15°S-15°N latitude averaged CHAMP mass density (black line), F10.7 (red line), Kp (green line), and OLR (blue line) during 2000-2010. (b)-(c) Morlet wavelets (30-180 days) of 15°S-15°N latitude averaged CHAMP density and OLR, respectively. (d)-(f) Pearson correlation coefficients calculated on 120-day moving windows between the 15°S-15°N latitude averaged CHAMP density residuals and F10.7, Kp, and OLR, respectively. The black horizontal lines in panels d-f denote correlation coefficients r=0.5 and r=-0.5. Five periods of significant (|r|>0.5) correlation are identified in (f).*

IS Variability in MF Radar Zonal Winds in the MLT

Time Series – BP winds

Wavelets – BP winds

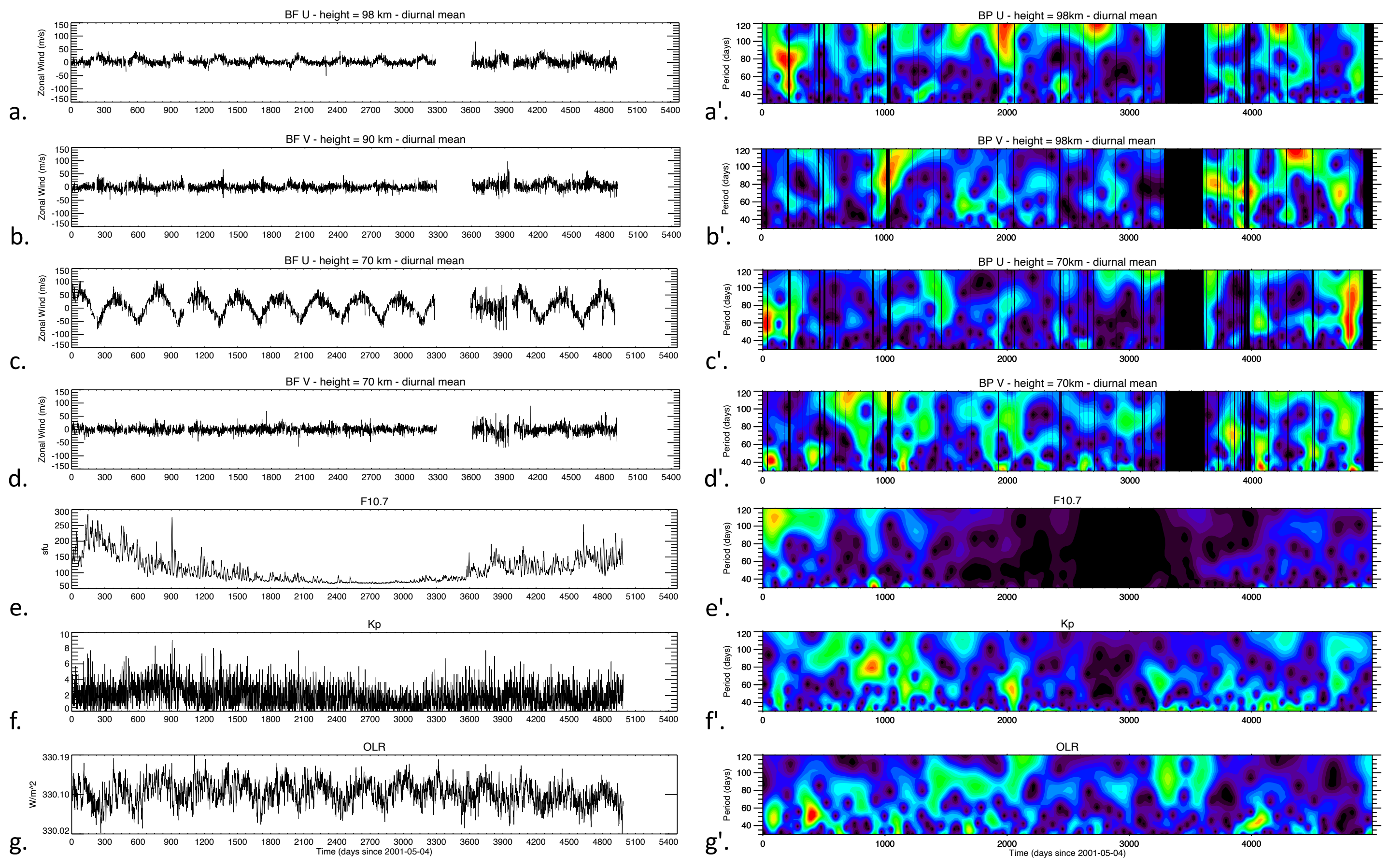


Figure 3 *Time series of BF zonal (a, c) and meridional (b, d) winds near 98 km and 70 km, respectively. Time series of F10.7 (e) , Kp (f) , and OLR (g; zonal mean, averaged 15°S-15°N latitude). (a')-(g') show the Morlet wavelets (30-120 day periods) of (a)-(g). Prominent IS is observed in the winds, with potential connections to contemporaneous OLR IS variations.*

- CHAMP, GOCE, and Swarm-C densities are processed and curated (e.g., poor quality data are removed), and surveying of 20+ years of combined data over ranges of 30-100 days is completed.
- Figure 1 shows an example of the data processing techniques applied to CHAMP density.
- First, the aim is to identify potential connections between the middle thermospheric IS variations and OLR (a proxy for tropical tropospheric convection).
- ***Nine*** periods of prominent IS variability in thermospheric density correlated with prevailing contemporaneous tropospheric OLR variations are identified.
- Five 'events' with |r|>0.5 are found during 2000-2010 (see Figure 2f) - in addition to the known*(2)* large 2009 'event', *two* other correlative 'events' are found in 2006 and 2007.
- Interestingly, *two* strong *anti-correlation* 'events' are found during 2008 and 2011 – possible explanations for these anti-correlations will be part of future work.
- Backland Park (35°S, 138°E) MF (BPMF) radar zonal ($\widehat{U}$) and meridional ($\widehat{V}$) mean winds reveal prominent IS variability from 70-90 km not connected to solar/magnetic effects.
- Wavelets of BPMF radar mesopheric (~70 km) $\widehat{U}$ and $\widehat{V}$ and OLR reveal similar IS variations. These potential connections are not as clear in the lower thermospheric (~98 km) $\widehat{U}$ and $\widehat{V}$. Detailed correlations of BPMF radar winds and OLR, along with physics-based modeling efforts in support of satellite diagnostics, may facilitate interpretation.

SUMMARY & UPCOMING WORK

- Tropospheric convection associated with the MJO generates a whole spectrum of global-scale waves, and modulates stratospheric GW, GW drag, and mean winds.
- Previous work showed MJO-modulation of GWs up to ~15% to extend up to 100 km and into the extra-tropics (45° latitude)*(4)*, with salient MJO signals in MERRA-2 resolved GWs and parameterized GW drag at high northern latitudes during winter*(5)*.
- The MJO can modulate DE3 (DW1) MLT temperature tides by ~25% (~10%)*(6)*, with modulation of tidal heating likely more important than modulation of background winds*(7)*.
- MJO effects on middle thermospheric nonmigrating tides (e.g., DE3) and UFKWs have also been demonstrated*(3)* with mean wind modulations*(2)* up to ±20 m/s.
- Here, satellite and ground-based wind diagnostics reveal *nine* periods of strong correlation between IS in OLR and thermospheric winds.
- Upcoming work plans to: *(1)* examine MERRA-2 ZM fields, SABER temperatures, other ground-based winds, and model output to assess whether/how these IS oscillations co-evolve from ~30-100 km; *(2)* establish whether there are IS longitudinal variations during periods when the ZM data exhibit this temporal variability; *(3)* perform correlation analyses between the band-pass filtered thermospheric IS variations and the ENSO and QBO indices to determine whether tropospheric inter-annual variability might modulate the thermospheric IS variations; *(4)* generate spectra and perform least-squares fitting of the satellite data to determine what large-scale tropical waves (e.g., DE3, UFKW) may be at play in coupling IS variability from the lower to the upper atmosphere.

References

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