Exploring the Limitations of Observing the ETA

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Motivation

- The Equatorial Thermosphere Anomaly (ETA) is a prominent and persistent feature that is highly coupled with the ionosphere, yet there is not a strong consensus on the theory of its formation
- The discrepancy lies in the lack of simultaneous measurements of various parameters, limited instrument capabilities, and different interpretations of measurements
- Neutral density/wind structures are indicators of momentum-driven forces that can explain how the ETA forms, but many flux-measuring satellite sensors have a density-wind ambiguity
- This poster focuses on addressing the density-wind ambiguity using CHAMP's STAR accelerometer measurements, ICON's MIGHTI wind data, and outputs from TIEGCM

Target Region: ETA

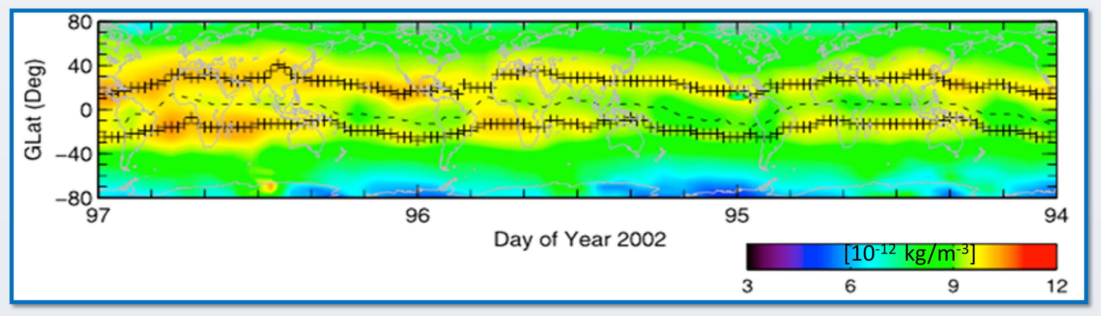

Figure 1: Neutral Density at 400 km from the CHAMP mission [1]

The ETA is a dayside, equatorial feature with two crests at ±20-30° in magnetic latitude and a trough near the magnetic equator as shown in Fig. 1. Although the ETA is a neutral feature, it is magnetically aligned, indicating strong ion-neutral coupling.

- **Altitude Range:** 250-550 km
- **Geographic Latitude Range:** ± 60°
- **Local Time Range:** 09:00-16:00

Approach

Accelerometer Data

- Data from satellite missions using highly sensitive accelerometers have been utilized to derive neutral atmospheric density
- After subtracting solar/Earth radiation pressure and co-rotating winds, the remaining drag acceleration is expressed as:

$$\vec{a_d} = -\frac{A_{ref} C_d}{2m} \rho (\vec{V}_{s/c} - \vec{w})^2$$

Equation 1: Acceleration Due to Drag

- The coefficient of drag (**C_d**), reference area (**A**), mass (**m**), and spacecraft velocity (**$V_{s/c}$**) are known
- Density (**ρ**) and winds (**w**) are the two unknowns for this equation creating an ambiguity between density and winds

Ascending/Descending Analysis

- To address this ambiguity, the underlying wind structure can be better interpreted by analyzing accelerometer measurements from a satellite as it traverses the target region from south-north (ascending) and north-south (descending) as shown in Fig. 2.
  - The first approach is to attribute all in-track winds to density and observe differences in the ascending/descending orbit paths for various wind structures
  - The second approach is to assume a constant density and attribute any changes in the accelerometer data as a wind feature in the ascending/descending orbit paths

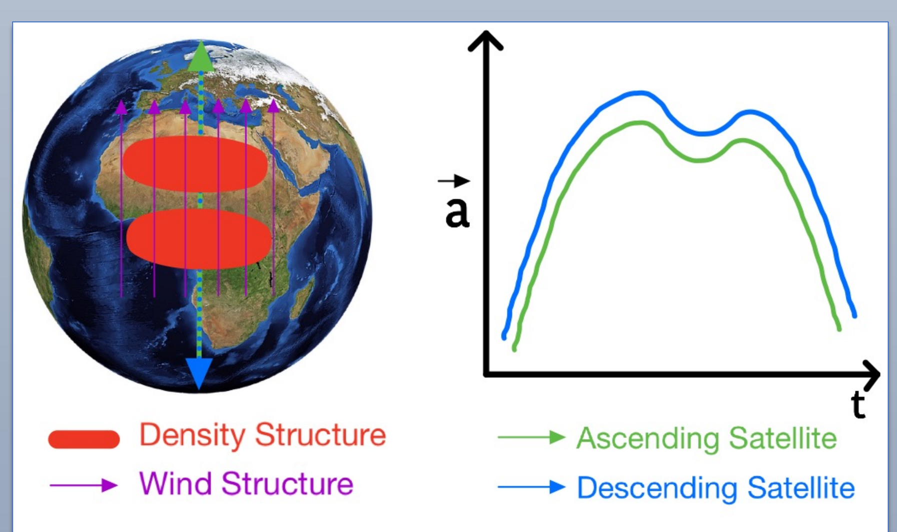

Figure 2: Diagram Depicting Descending/Ascending Orbits with their Concomitant Accelerometer Measurements in the Presence of a Northward Wind

Method

- This trade study utilizes 3 data sets
  - TIEGCM: Density and Wind Outputs
    - Has demonstrated the capability to reproduce the ETA [2]
  - CHAMP: STAR Accelerometer Density Measurements
  - ICON: MIGHTI Wind measurements

Exploring the Density-Wind with TIEGCM

- Figure 3 shows the representative acceleration curve with the assumption that there are no winds, and the drag acceleration is only dependent on density
  - For both ascending and descending paths in this case, the acceleration curve is the same
- Figure 4 shows how introducing various wind structures and attributing them to density reveal differences between ascending and descending orbits
- Figure 5 shows how maintaining a constant density and attributing density changes to velocity affect the extracted wind structure

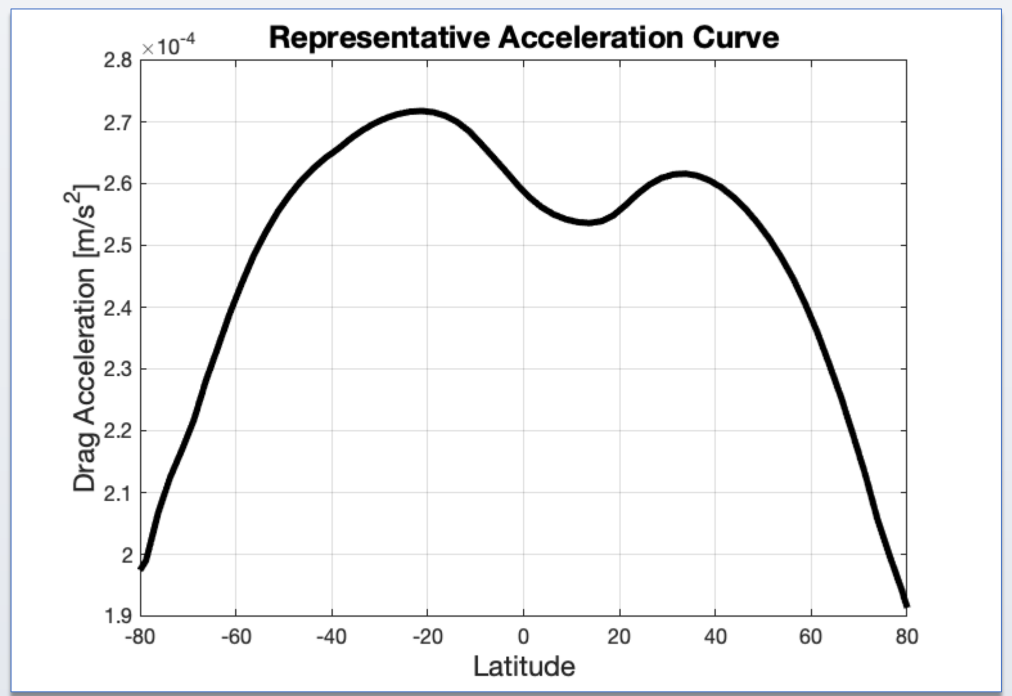

Figure 3: Representative Acceleration Curve Using Density from TIEGCM for a High Inclination Orbit at a KP of 2, F10.7 of 150

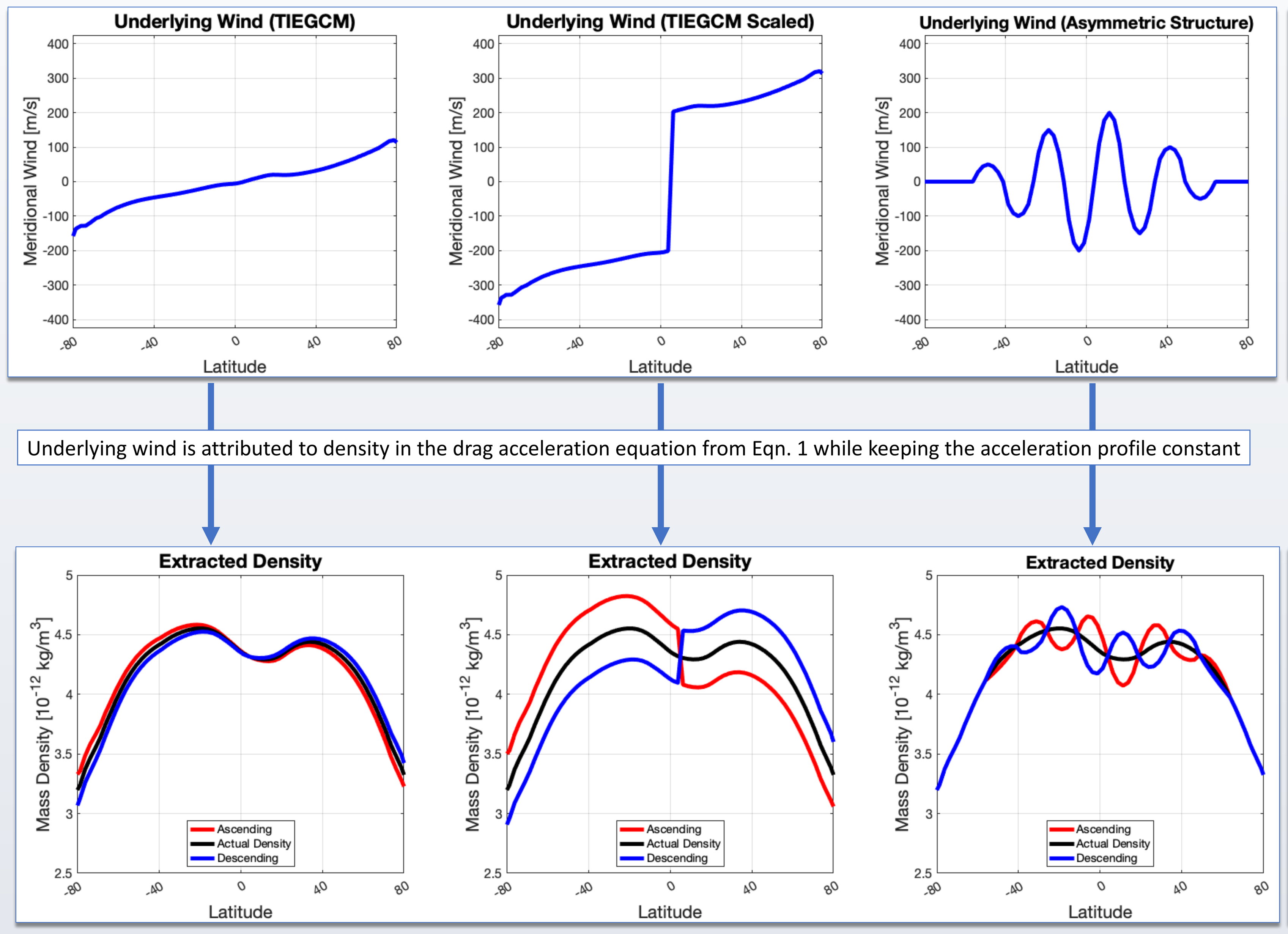

Figure 4: Accelerometer-Extracted Density from Ascending/Descending Orbits

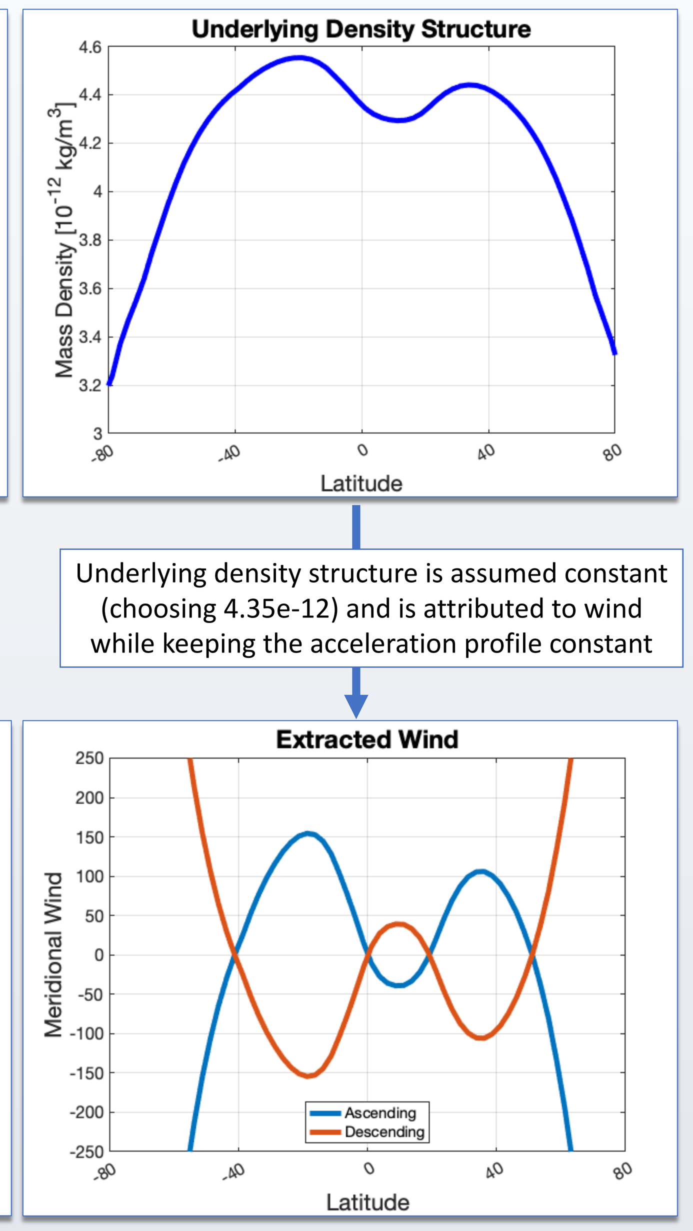

Figure 5: Accelerometer-Extracted Wind from Ascending/Descending Orbits

CHAMP - STAR Accelerometer Coverage

- Figures 6 and 7 display density extracted from CHAMP's STAR accelerometer, normalized to 400 km, as it ascends the target region in 2003 and descends the target region in 2004 [4]
  - 2003 and 2004 were observed because the local times captured fall under similar seasons
- This analysis assumed the winds are negligible and attributed all accelerometer changes to the density, similar to Fig. 4
  - The underlying meridional wind structure is accounted for in the uncertainty using HWM-93

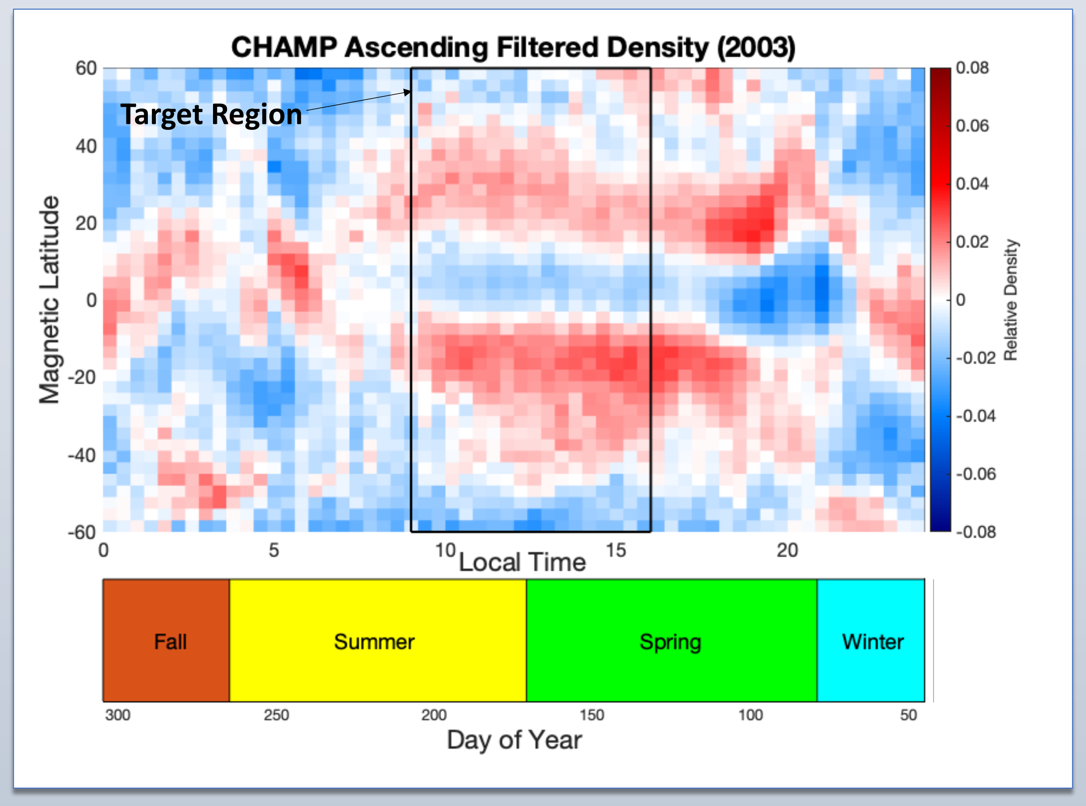

Figure 6: Magnetic Latitude vs Local Time of CHAMP's Relative Density Measurements in 2003 (Ascending)

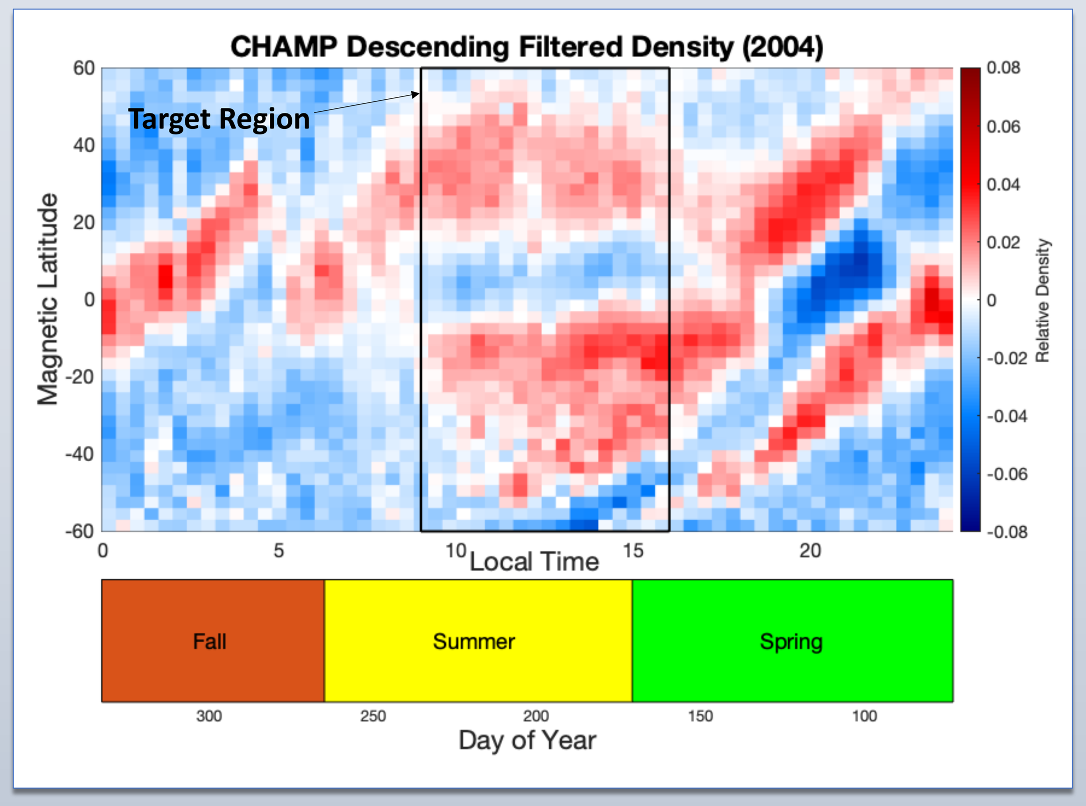

Figure 7: Magnetic Latitude vs Local Time of CHAMP's Relative Density Measurements in 2004 (Descending)

ICON - MIGHTI Coverage

- Figure 8 shows the dayside meridional wind extracted from ICON's MIGHTI instrument [3] during solar minimum near the summer solstice at 301 km
  - The TIEGCM meridional wind at LT = 14 is overlaid for comparison

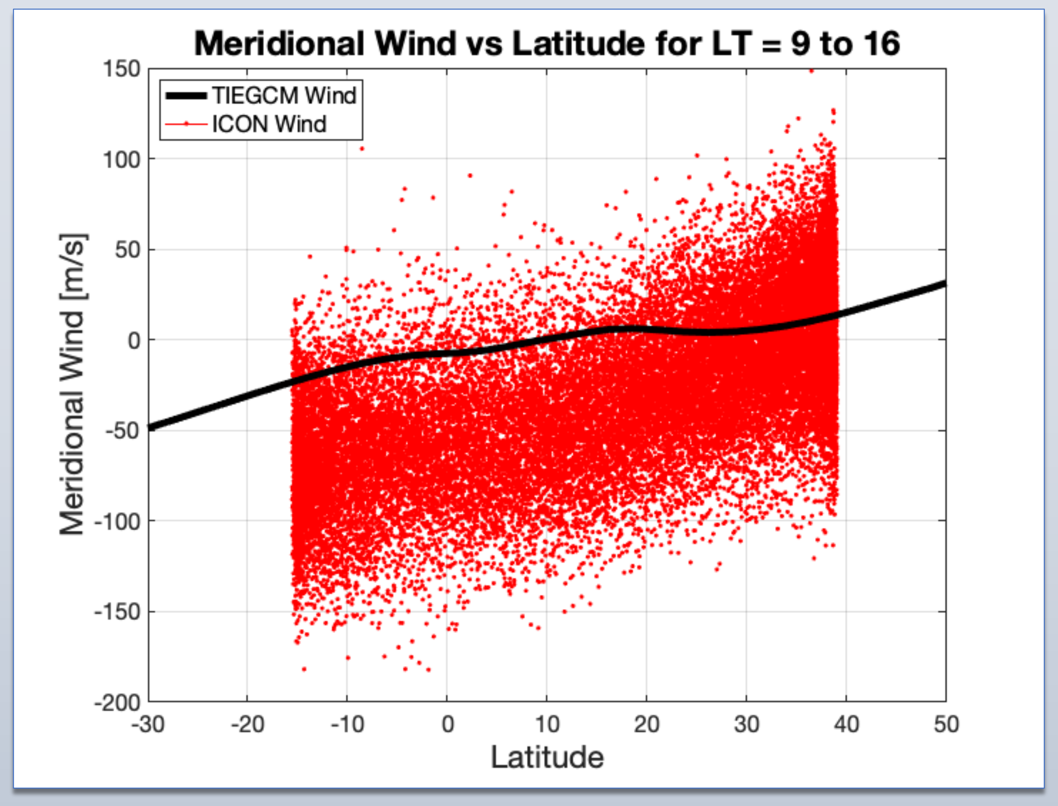

Figure 8: ICON's MIGHTI Meridional Wind Structure

Conclusion/Interpretation

TIEGCM Analysis

- Density-wind ambiguity in flux-measuring instruments can be better understood by observing ascending/descending measurements of a target region
  - Attributing the TIEGCM wind structure to density creates an amplitude bias of <1% in the ascending/descending orbits
  - Attributing the scaled TIEGCM wind structure (>200 m/s) to density creates an amplitude bias of 6% in the ascending/descending orbits
  - Attributing an asymmetric wind structure to density reveals shifts in the underlying density feature
  - Attributing the TIEGCM density structure, assuming a constant density, reveals wind structures that are equal in magnitude, but opposite directions

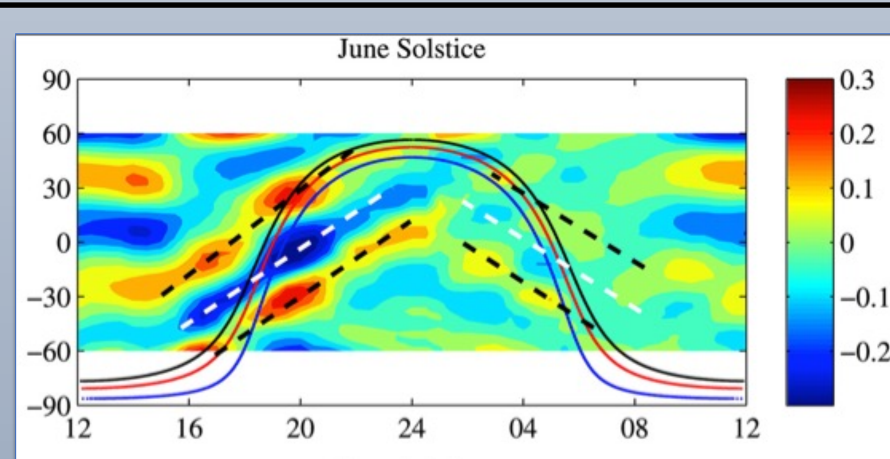

Figure 9: Latitude vs Local Time of the Residual Density at 400 km Showing Terminator Wave Signatures [from Liu H., et al [2017]

CHAMP Analysis

- CHAMP did not reveal noticeable magnitude changes between ascending/descending that could indicate large wind structures (>200 m/s)
- CHAMP did not see noticeable shifts in the trough that would indicate strong alternating winds
- CHAMP also revealed signatures of terminator waves registered as density increases near LT = 6 and LT = 17, resembling the terminator analysis shown in Fig. 9

ICON Analysis

- ICON measurements show wind speeds <200 m/s, which resemble the TIEGCM wind structure and magnitude

Overall Considerations

- Evidence to support that the ETA is a persistent density structure (LT = 9-16), with winds only causing <1% density difference, which is not enough to obscure the ETA trough

Next Steps

- Perform statistical analyses on CHAMP's ascending/descending accelerometer data using 10 years' worth of data
  - Considering solar cycle, local time, and seasonal variations
- Explore terminator wave signatures from CHAMP data with a similar approach as the density-wind analysis
- Revisit the ETA formation theory with more restrictive assumptions based on the density-wind analysis
- Capture more properties with instrument sensitive enough to capture small-scale gradients simultaneously with varying orbit configurations
  - GDC Mission
    - Will have a large coverage area with a long mission duration
    - Will capture both ionospheric and neutral properties
    - Will be able to resolving the wind/density ambiguity

References

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