Terdiurnal Atmospheric Tides seen with ICON at E-region Altitudes

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Abstract: Global-scale waves known as atmospheric tides and planetary waves are commonly observed at altitudes just below the ionosphere. Until recently, routine observations of the winds across a wide range of altitudes was scarce at ionospheric altitudes. Recent wind observations from ICON that span the E- and F-regions offer an opportunity to examine the global scale waves that are present, and ultimately determine their impacts on the ionosphere. This work utilizes these wind observations at E-region ionospheric altitudes to identify which tides are present. Specifically, this work will examine the terdiurnal tides that are present and compare these to the better-studied diurnal and semidiurnal tides. Changes with season, altitude will be presented.

1. Introduction

Atmospheric tides and planetary waves represent the dominant dynamical component of 80-120 km height; MLT (mesosphere-lower thermosphere)

Categories of tides:

Diurnal: wavenumber, n = 1; phase: 0-360°

Semidiurnal: wavenumber, n = 2; phase: 0-180°

Terdiurnal: wavenumber, n = 3; phase: 0-120°

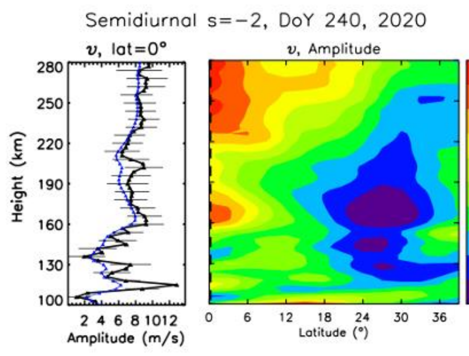


Fig. 1: Amplitude of the SE2 tide from ICON for day 240 in 2020, after Forbes et al., 2022.

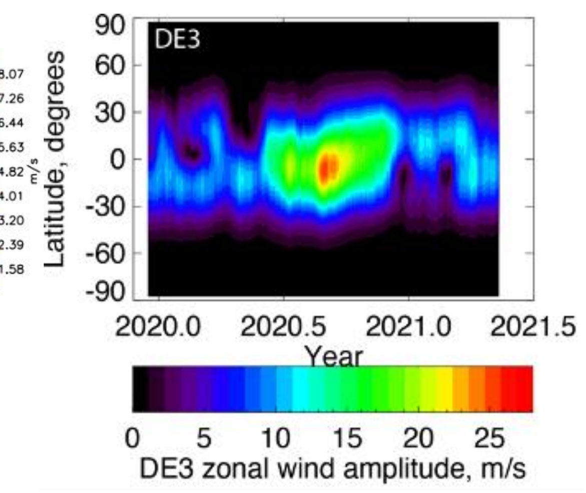


Fig. 2: Amplitude of the DE3 tide vs latitude and time of year at 100 km using ICON-MIGHTI.

2. Instrumentation

Ionospheric Connection, ICON, explorer has an instrument on board - Michelson Interferometer for Global High-resolution Thermospheric Imaging, MIGHTI. This provides winds & temperatures.

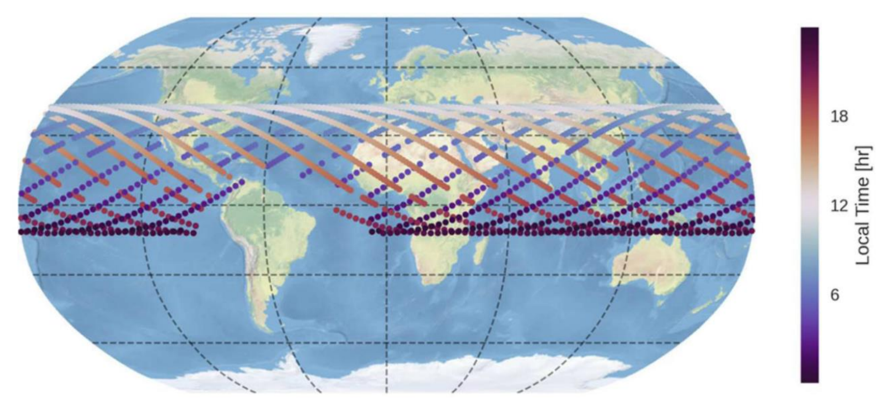


Fig. 3: Geographic coverage of MIGHTI observations, after Englert et al. 2017a; Harding et al. 2017a.

- ❖Nearly circular orbit; Altitude ~ 600 km; 27° inclination; Latitudes 12° South - 42° North
- ❖MIGHTI A and B's phase of observed interference fringes, factored by oxygen red (λ=630 nm) and green line (λ=557.7 nm) emission.
- ❖Vertical profiles of horizontal thermospheric winds are measured
- ❖Red line phase change: 1.8 μrad for every 1 m/s wind speed
- ❖Green line phase change: 2.10 μrad for every 1 m/s wind speed

4. Results: Peak amplitudes and their variations

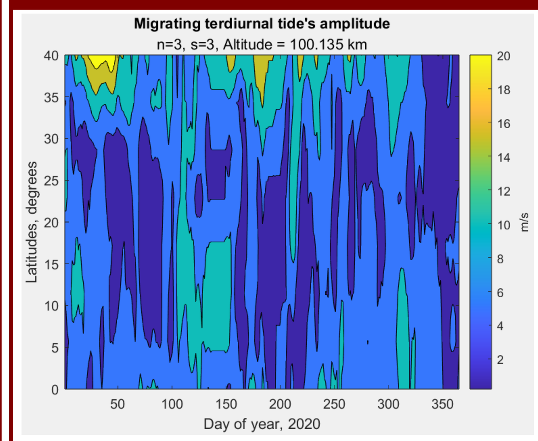


Fig. 8: Tide is generally largest in amplitude at the mid latitudes (30-40 north). Couple of peaks –Jan-Feb, May-Aug. Secondary peaks near 5-15 north, seen when mid latitude peak disappears. This is consistent with this being made up of 2 Hough modes.

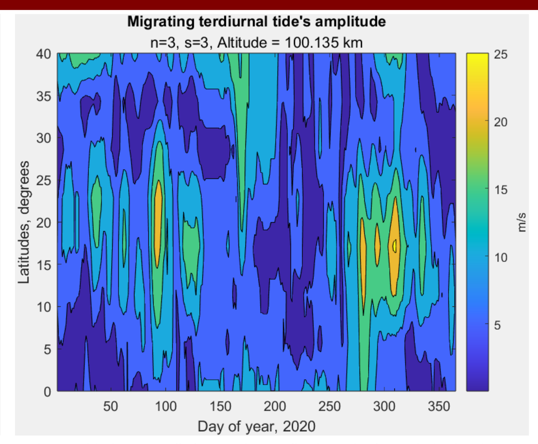


Fig. 9: Tide is generally largest in amplitude at the lower latitudes (10-25 north). Couple of peaks –Apr-May, Oct-Nov. Secondary peaks near 25-40 north, seen when low latitude peak disappears. This is consistent with this being made up of 2 Hough modes.

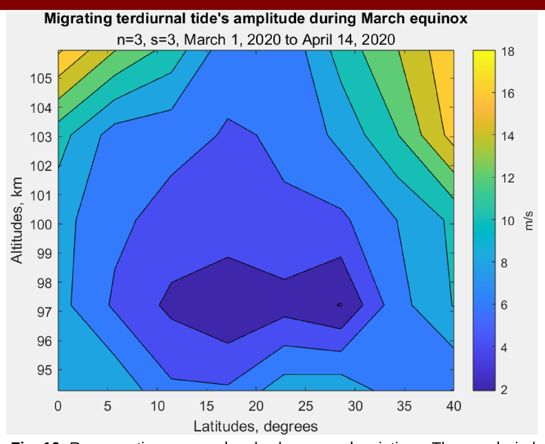


Fig. 10: Representing seasonal and sub seasonal variations. The zonal wind amplitude peaks at extremes of latitude. Generally, amplitude increases with altitude everywhere, as would be expected for an upward propagating wind.

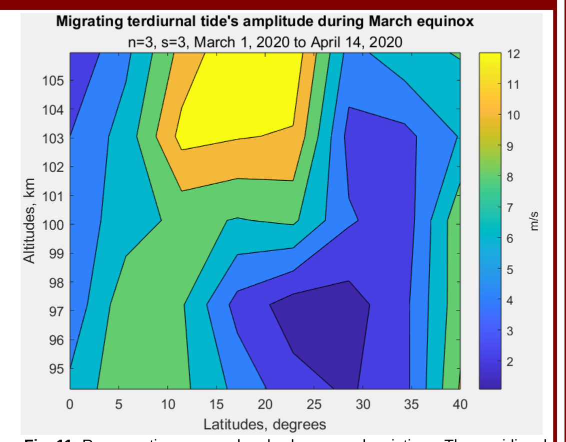


Fig. 11: Representing seasonal and sub seasonal variations. The meridional wind amplitude peaks at middle latitudes. Generally, amplitude increases with altitude everywhere, as would be expected for an upward propagating wind.

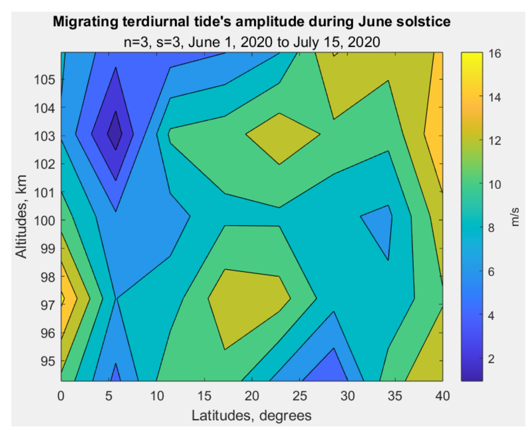


Fig. 12: Peak in amplitude values seen at mid latitudes. The activity near the equator is seen only at lower latitudes and dimities. This gain may be associated with the second Hough model.

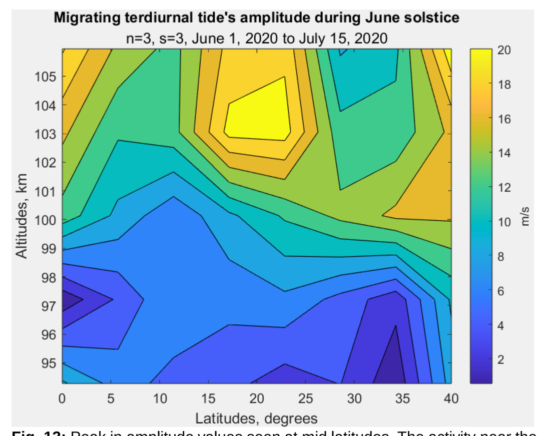


Fig. 13: Peak in amplitude values seen at mid latitudes. The activity near the equator is seen only at lower latitudes and dimities. This gain may be associated with the second Hough model. Notably, all the peaks are at higher altitudes (above 100 km).

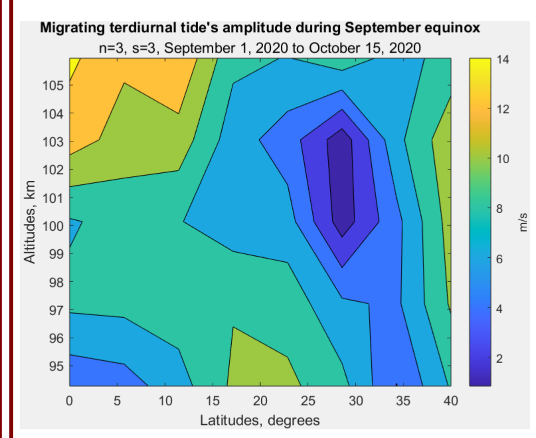


Fig. 14: September reveals a dominance of the lower latitude peak, and generally everything increases with altitude.

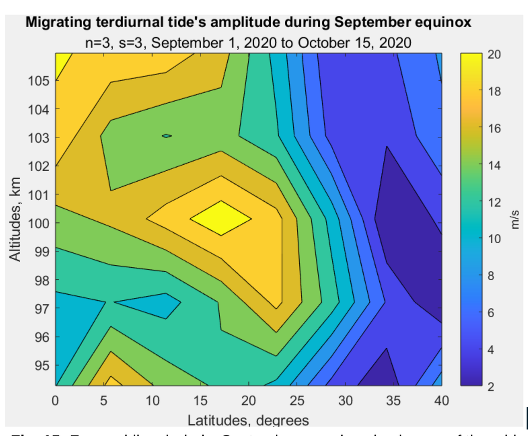


Fig. 15: For meridional winds, September reveals a dominance of the mid latitude peak, and generally the increase is visible with altitude.

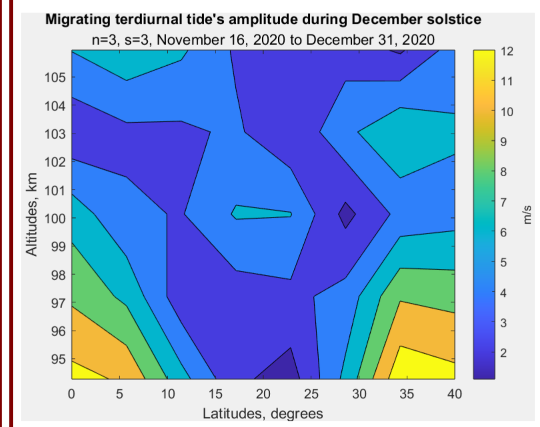


Fig. 16: December is an odd one out, where the tide appears to reach high amplitude at low latitude, then dissipates at altitudes above this.

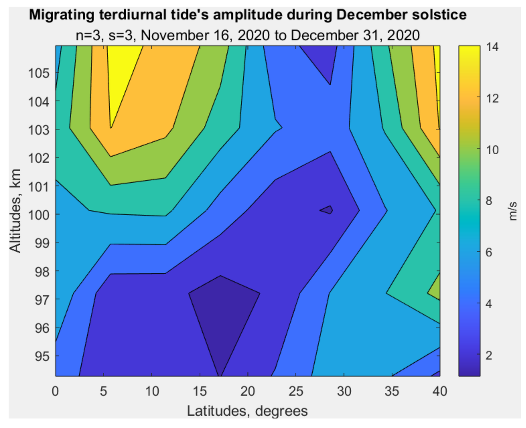


Fig. 17: Meridional wind amplitudes peak in December at higher altitudes and dissipating at altitudes below this.

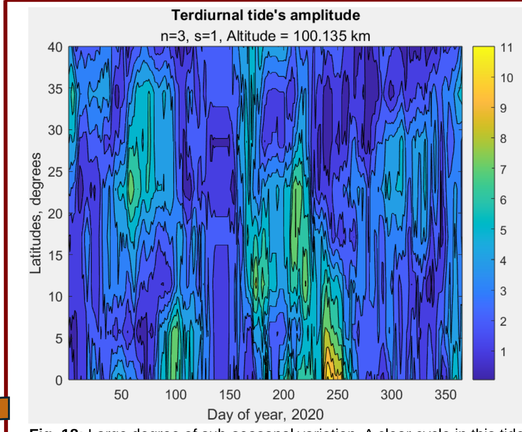


Fig. 18: Large degree of sub-seasonal variation. A clear cycle in this tide is visible – peaking at the equator near DOY 80-110, 200-250, and 350-360, whereas peaking at 15-25 north region at days 50-90, 160-220, and 300-330.

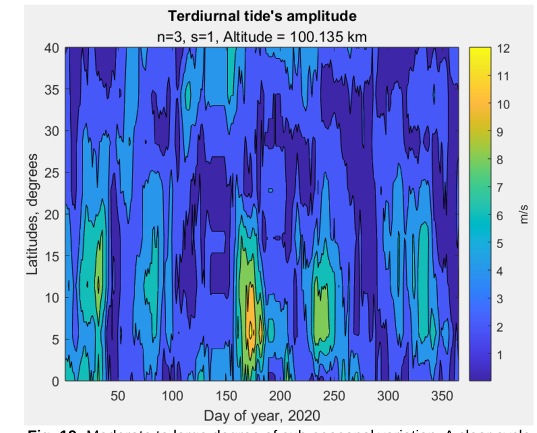


Fig. 19: Moderate to large degree of sub-seasonal variation. A clear cycle in this tide is also visible – peaking at the low latitudes near DOY 30-40, 60-70, 160-180, 230-250, and 330-350. Another tiny peak is visible at 34-40 north at days 155-160.

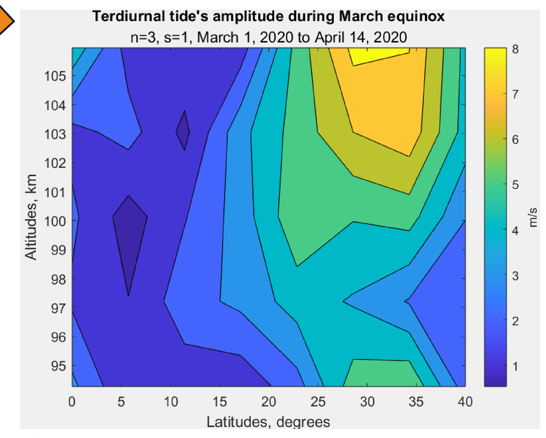


Fig. 20: During Mar-Apr, with s = 1, the zonal wind amplitudes peak in the high latitudes. When s=0, this pattern was not observed, the peaks were at low and high latitudes.

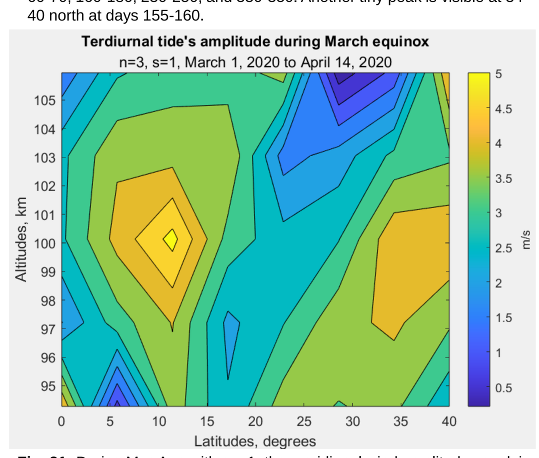


Fig. 21: During Mar-Apr, with s = 1, the meridional wind amplitudes peak in the low-mid latitudes and high latitudes. Also, the peaks are visible between 97-102 km.

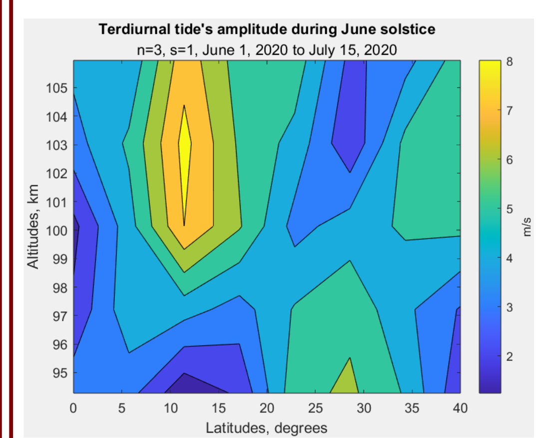


Fig. 22: During June-July, with s = 1, the zonal wind amplitudes peak in the low-mid latitudes. There is no peaks near the equator. When s=0, this pattern was not observed.

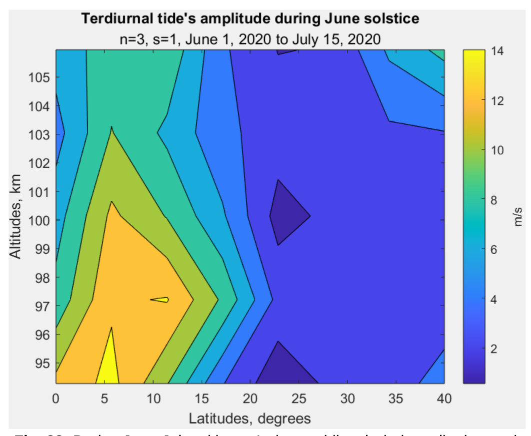


Fig. 23: During June-July, with s = 1, the meridional wind amplitudes peak in the low latitudes (near equator). When s=0, this pattern was not observed, the peaks were at high altitudes.

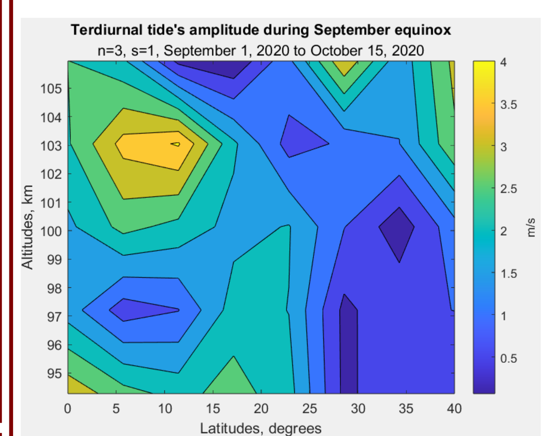


Fig. 24: Four occurrences of peaks are visible. When the latitudes are lower, peaks show on high and low altitudes. When latitudes are higher, the altitude is also high.

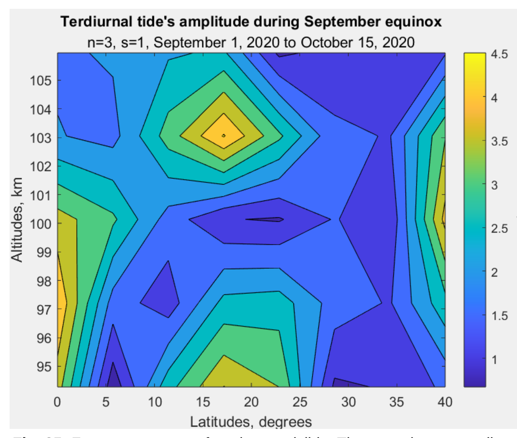


Fig. 25: Four occurrences of peaks are visible. These peaks are on all those spaces where zonal winds did not have a peak.

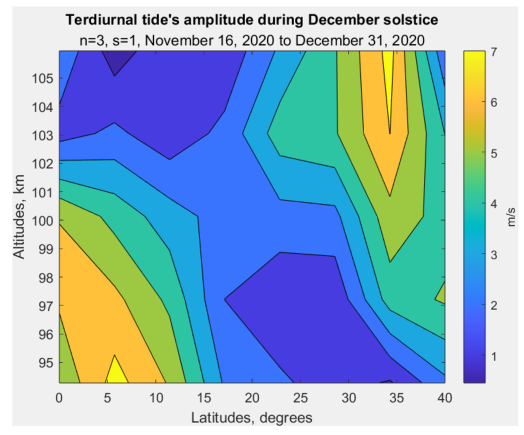


Fig. 26: Two occurrences of peaks are visible. These peaks are on low latitudes and altitudes and on high latitudes and altitudes.

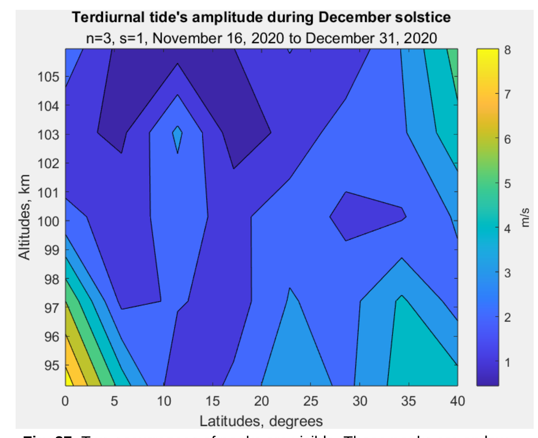


Fig. 27: Two occurrences of peaks are visible. These peaks are on low latitudes and altitudes and on high latitudes and altitudes. These wind amplitude values are more cornered than the zonal wind amplitudes.

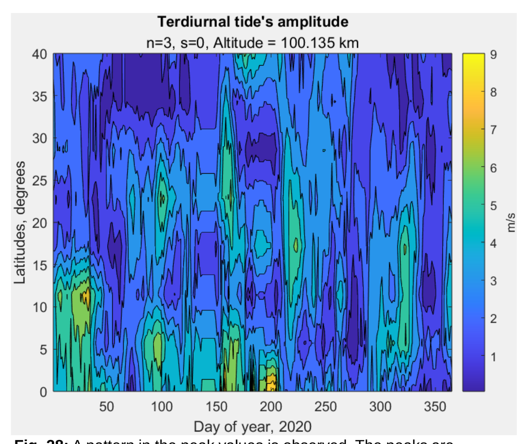


Fig. 28: A pattern in the peak values is observed. The peaks are reached periodically until the first half of the year every 75 days in lower latitudes and also on 75 day intervals from the 100th day at mid latitudes.

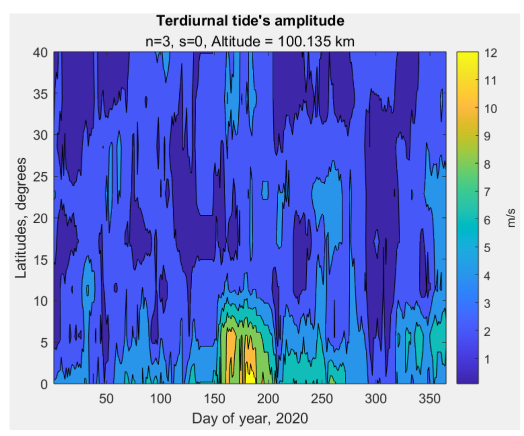


Fig. 29: A pattern might be forming in the peak value occurrences, but a clearly visible peak is between DOYs 150-200 near equator.

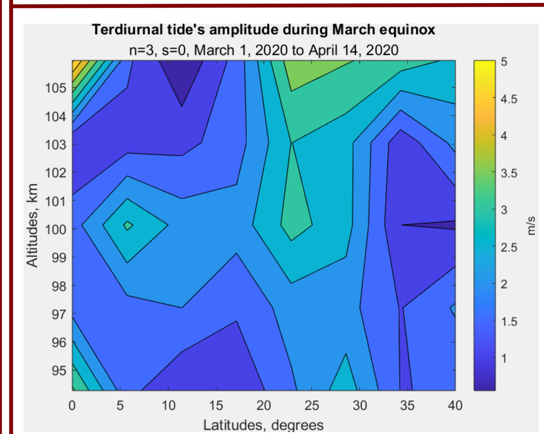


Fig. 30: One clearly visible peak in the zonal wind amplitudes in Mar-Apr is at the equator at higher altitude values.

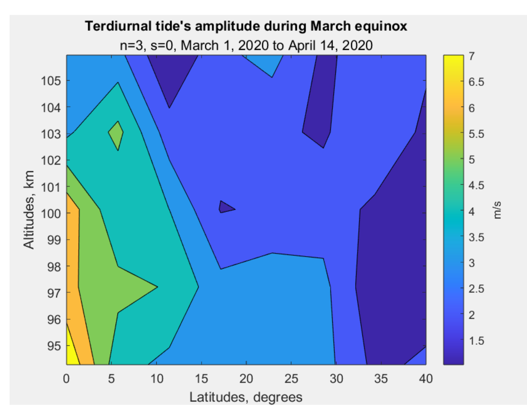


Fig. 31: The values in meridional winds peak at the equator too, but the altitudes are lower.

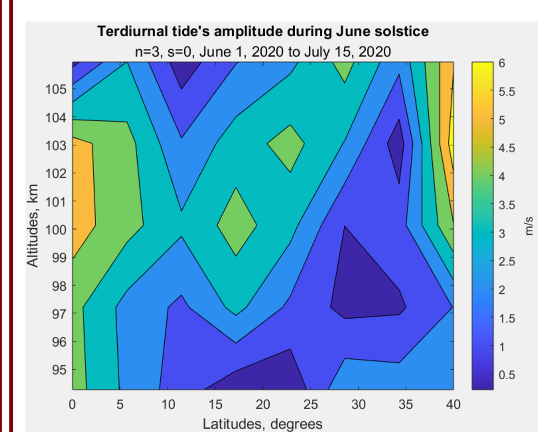


Fig. 32: Tides are largest in the extremes of the latitude range and are visible only mid to high altitudes. Secondary peaks span across the middle latitude values and across the same altitude range.

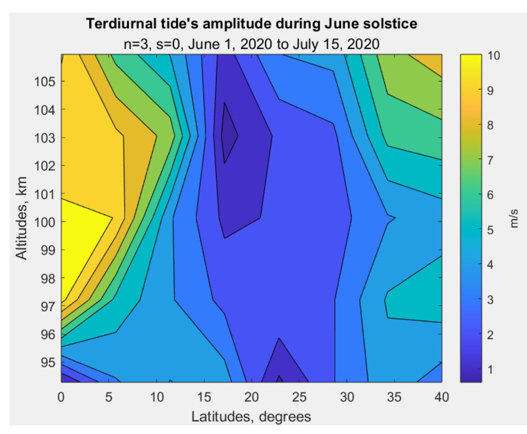


Fig. 33: Tides are largest in the lower latitudes and higher latitudes. Fairly most of the altitude range is showing the peak values.

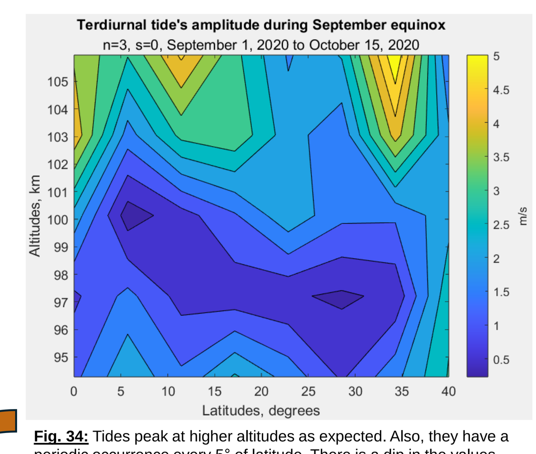


Fig. 34: Tides peak at higher altitudes as expected. Also, they have a periodic occurrence every 5° of latitude. There is a dip in the values between first two peaks around 5-10° latitude at 103-105 km. Looks like an upward triangle.

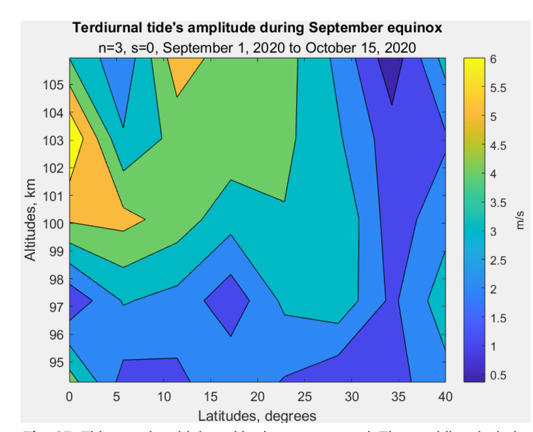


Fig. 35: Tides peak at higher altitudes as expected. The meridional winds have an opposite dip in the values. Looks like a downward triangle. The latitude range of this dip is also 5-10° north and the altitude for this is too 103-105 km.

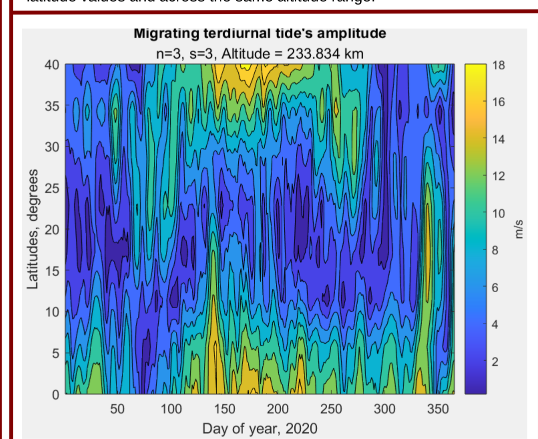


Fig. 38: Redline data; Large degrees of sub seasonal variations. Continuous and simultaneous peaks at 0-10° north and 33-40° north through the span of middle of the year. Significantly more strong tides when compared to Greenline data.

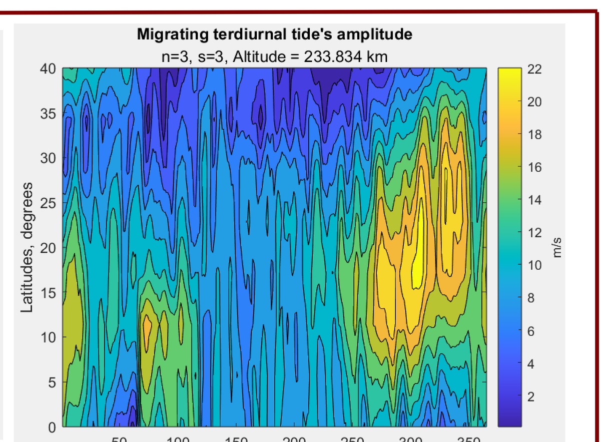


Fig. 39: Significantly high tidal variations. Redline data has more seasonal changes as compared to Greenline data. High amplitudes, are from Oct-Dec in mid latitudes.

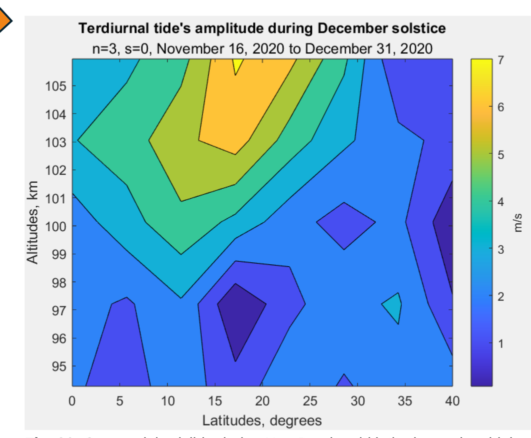


Fig. 36: One peak is visible during Nov-Dec in mid latitudes and on higher altitudes (103-105 km).

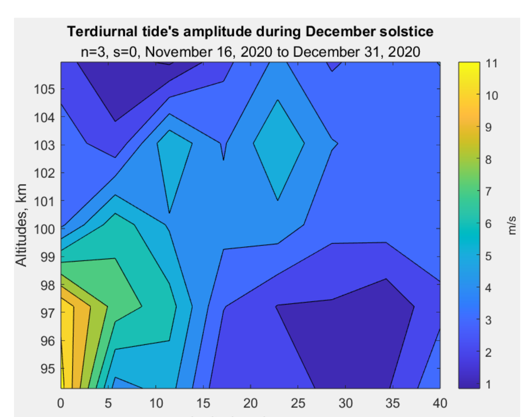


Fig. 37: One peak is visible during Nov-Dec near equator and on lower altitudes (95-98 km).

3. Methodology

Data Model

Obtained raw values of zonal and meridional wind data, along with corresponding space and time dimensions. Initial processing outputs:

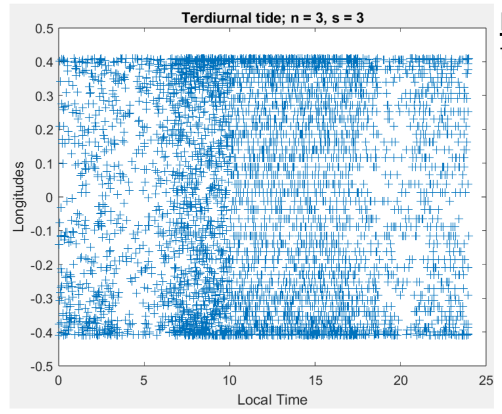
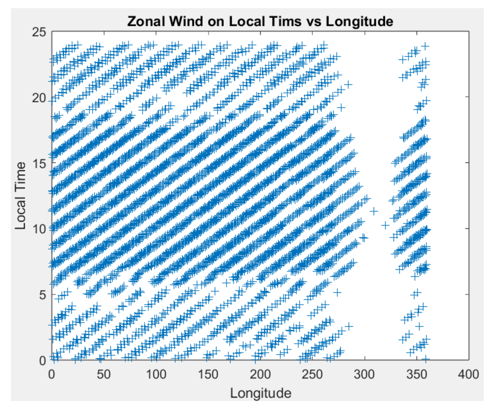


Fig. 4: Migrating terdiurnal tide on Local time vs Longitude; s = 3

- ❖ This is the plot of zonal wind data which spans across 45 days and is plotted over 24 hours.
- ❖ Latitude is limited to 0-5 degrees north.
- ❖ Altitude is 91.33 km.
- ❖ When plotted against Local time and Longitude, the daytime amplitudes are denser as compared to the nighttime.
- ❖ Verifies the MIGHTI data collection process – nighttime has lesser tides because of decreased photoionization.

Fig. 5: Zonal wind on Local time vs Longitude

- ❖ This is the plot of zonal wind data which spans across 45 days and is plotted over 24 hours.
- ❖ Latitude is limited to 0-5 degrees north.
- ❖ Altitude is 91.33 km.
- ❖ When plotted against Local time and Longitude, an upward propagating wind structure is visible.
- ❖ Again, the daytime values are higher than the nighttime values.
- ❖ Verifies the MIGHTI data collection process – nighttime has lesser tides because of decreased photoionization.



Data Processing

A wave model was designed to fit the zonal and meridional wind data into the configurations of the desired tides to be observed:

$$A0 + A\cos\left(nt\frac{2*pi}{24} + (s-n)\lambda\frac{2*pi}{360} - \phi\right)$$

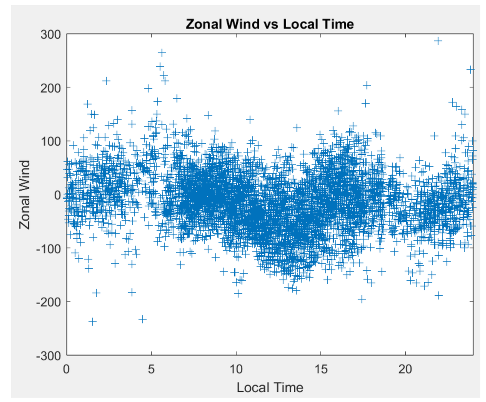
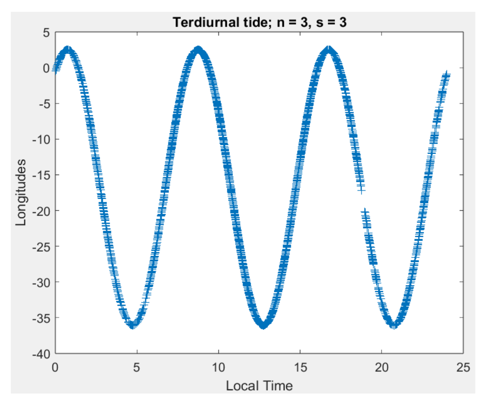


Fig. 6: Raw data of zonal wind plotted against local time

- ❖This is the plot of zonal wind data which spans across 45 days and is plotted over 24 hours.
- ❖Latitude is limited to 0-5 degrees north.
- ❖Altitude is 91.33 km.
- ❖Wave-like structure is visible through the means of individual points.
- ❖Contains all types of tides.

Fig. 7: Zonal wind data fitted and plotted for the migrating terdiurnal tide.

- ❖Latitude is limited to 0-5 degrees north.
- ❖Altitude is 91.33 km.
- ❖3 crests and 3 troughs in a span of 24 hours represent the 8-hour time period.
- ❖**The fit works, therefore, confirms the wave model is appropriate**



5. Conclusions

- ❖ We have examined a year's worth of data from MIGHTI in the form of migrating and non-migrating tides. With our focus on the lesser-known terdiurnal tides, these still seems to have significant amplitudes in the lower thermosphere.
- ❖ Tides with n, s = 3 show seasonal variations
- ❖ Tides with n = 3, s = 1, show a lot of variations in shorter time scales.
- ❖ Tides with n = 3, s = 0, also show a lot of variations in shorter time scales, but the peaks are at lower altitudes than s = 1.
- ❖ Tides in the meridional winds have peaks in the regions where there are no peaks in the corresponding zonal wind tides.

6. Future Work

- ❖ Study more years' data to interpret annual patterns in the tides. Data from 2021 and 2022 can be used.
- ❖ Incorporate red line data in the analysis to examine tides at higher altitude.
- ❖ Analyze phase and temperature values for more holistic pictures of tides.