A comprehensive survey of atmospheric quasi 3-day planetary-scale waves and their impacts on the day-to-day variations of the equatorial ionosphere

Guiping Liu, Scott L. England, Thomas J. Immel, Harald U. Frey, *UC Berkeley*
Anthony J. Mannucci, *JPL*
and Nicholas J. Mitchell, *U. Bath*

This research work was supported by the National Aeronautics and Space Administration (NASA) Heliophysics Research program through Award NNX12AD48G.

Ultra-Fast Kelvin Waves

The Good:

- Long vertical wavelength.
- High phase-speed.
- Moderately-high amplitude wind, temperature perturbations.
- Global-scale – easily sampled from ground & space.
- Latitudinal symmetry – efficient at driving dynamo currents.
- Interact with tides.
- Seen to induce ionospheric perturbations – some great case-studies & simulations exist.

The Bad:

- No fixed period (~2.5-4.5 days).
- Not always large amplitude.
- Sporadic occurrence (last ~10-30 days) – can't used long averages.
- More than 1 wavenumber exists.
- Do not always produce ionospheric perturbations.

Specific Questions

- We know we have seen ionospheric perturbations that are coincident in time with large amplitude UFKWs. Do these occur regularly enough to rule-out a coincidence?
- What about for smaller/ more normal amplitude UFKWs?
- Are these ionospheric perturbations large enough to care about for prediction / modeling of the ionosphere? If so, at what level?
- UFKWs are not all created equal – they vary in wavenumber (1,2,3), wavelength, amplitude, season – do any of these impact whether or not we see an ionospheric response?

General approach

- Develop a database of all of the UKFW seen in the mesosphere and all signatures in the ionosphere over an extended period of time (11 years of SABER data used here).
- For each, we will determine its basic properties – wavelength, amplitude, duration etc.
- Then do the same for ionospheric signatures – including ones with no apparent ionospheric counterpart and ionospheric signatures that do not appear to be connected with UFKW – it is important to know how often these occur (11 years of TEC data used here as it is the only global dataset to cover this time-period).
- Look for temporal coincidence of these events as a guide to which ones are connected.
- Note – this approach is incredibly time-consuming.

- First we must identify the periods when UFKW are present.
- A simple 2D FFT helps to identify time-periods when the amplitude in the 3-day wavenumber 1-3 is large.
- We search for 2.5-4.5 day periods, wavenumbers 1-3.
- Then we need some criteria for determining if a clear UFKW is present.
- This is done in 2-steps. First, we require the amplitude found in the 2D FFT to be at least 4K.

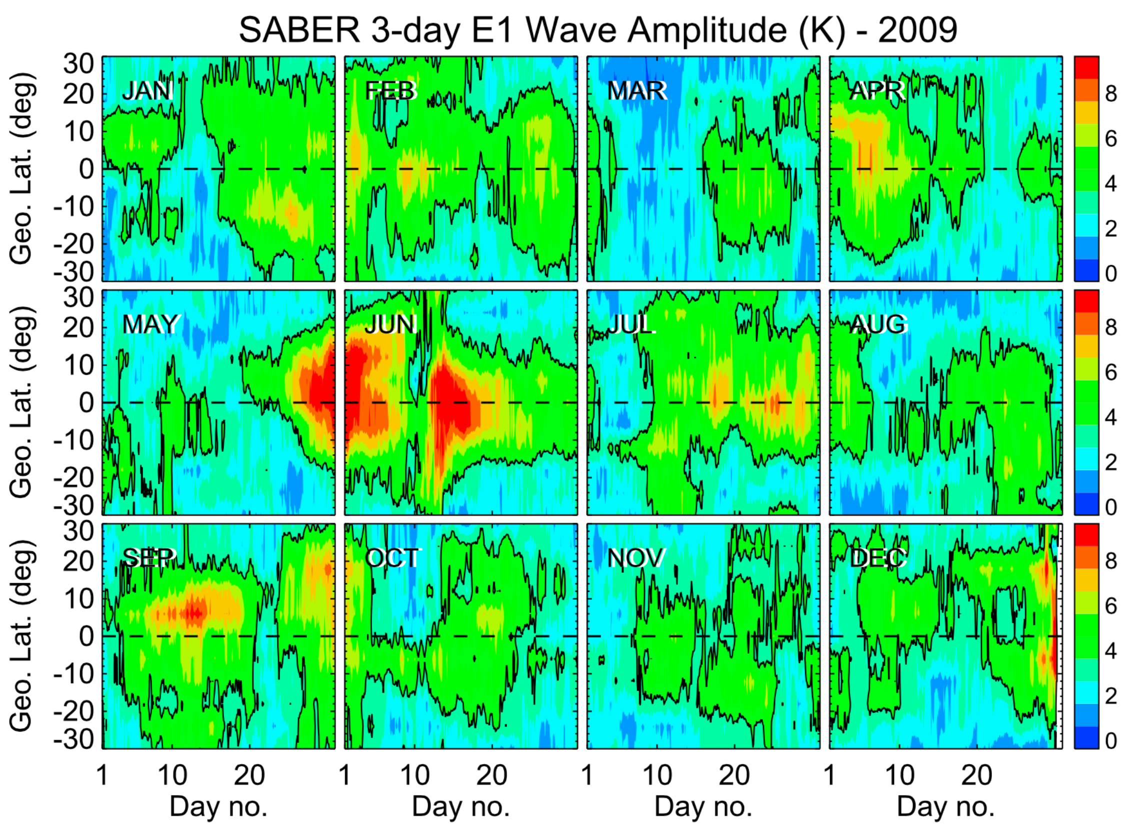


Figure 1. Amplitudes of the 3 day waves for the eastward propagating zonal wave number 1 (*E*1) component as determined from the SABER temperature observations at 98 km altitude during 2009. The contour lines on the plot mark the level of 4 K in temperature.

- For every event identified from 2002-2012 in the 2D FFT, we then look in more detail at the propagation & wavelength of the wave to determine if this is really a wave.
- This also lets us determine other properties like the vertical wavelength.

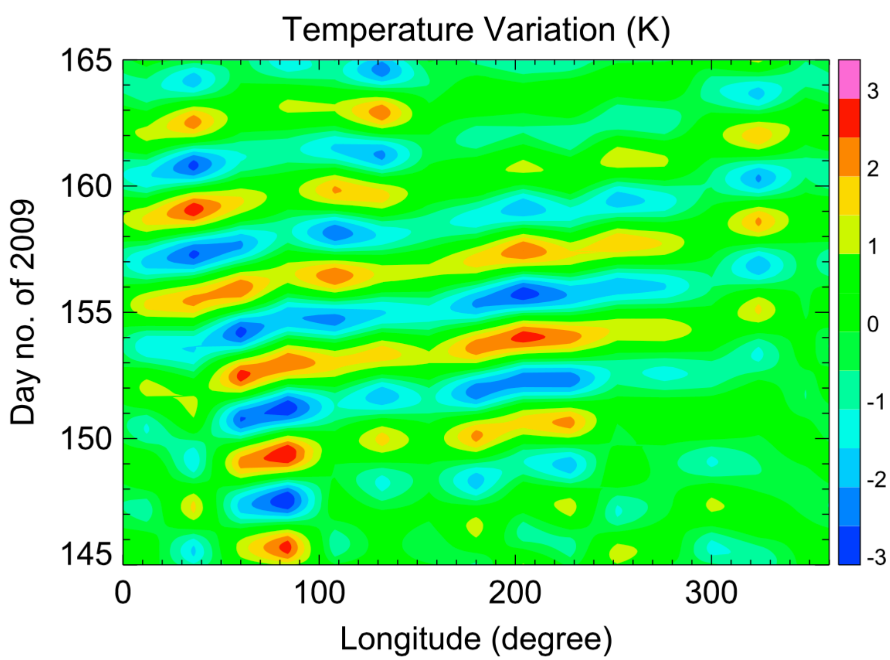


Figure 4. Longitude-time reconstruction of the 3 day wave from the SABER temperatures measured over ±10° latitude at 98 km altitude through days 145–165 of 2009 (25 May to 14 June). Over days 150–160, the eastward propagation of this wave as a function of time is seen. At a single point of time, the wave appears to have a zonal wave number of 1.

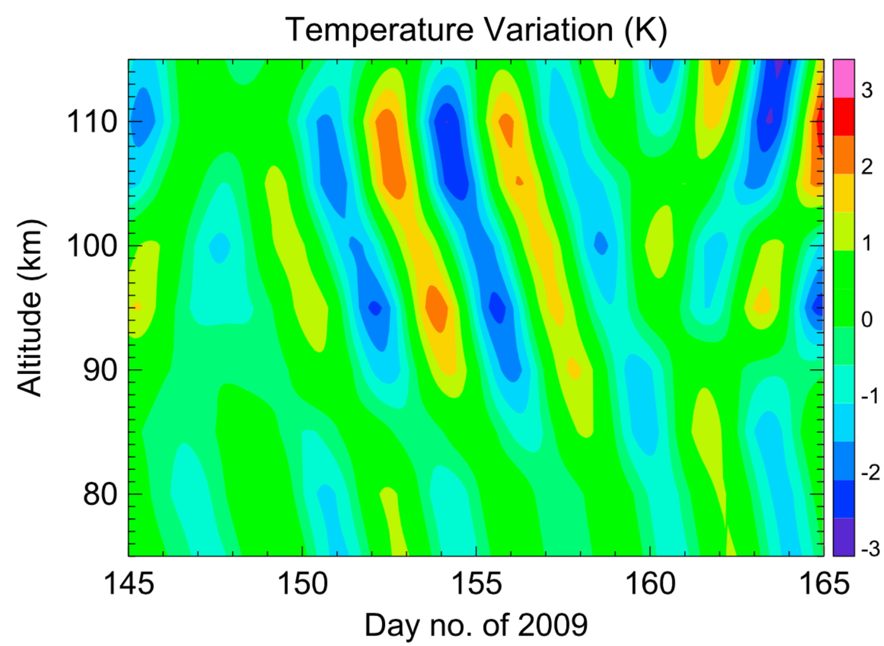


Figure 5. Altitude-time reconstruction of the 3 day wave from the SABER temperature measurements over ±10° latitude throughout days 145–165 of 2009 (25 May to 14 June). The downward phase between days 150 and 160 suggests the upward propagation of this wave. Using the phase propagation, the vertical wavelength of the wave is estimated to be 31–41 km.

- This is the tally of waves observed by wavenumber and year.
- Generally, we see E1 the most frequently, but we see plenty of E2 and E3 as well.
- This may be an artifact of our 4K criterion, but there is a limit to what we can identify.
- In total, we see 300 wave events – all of which are included in this study.

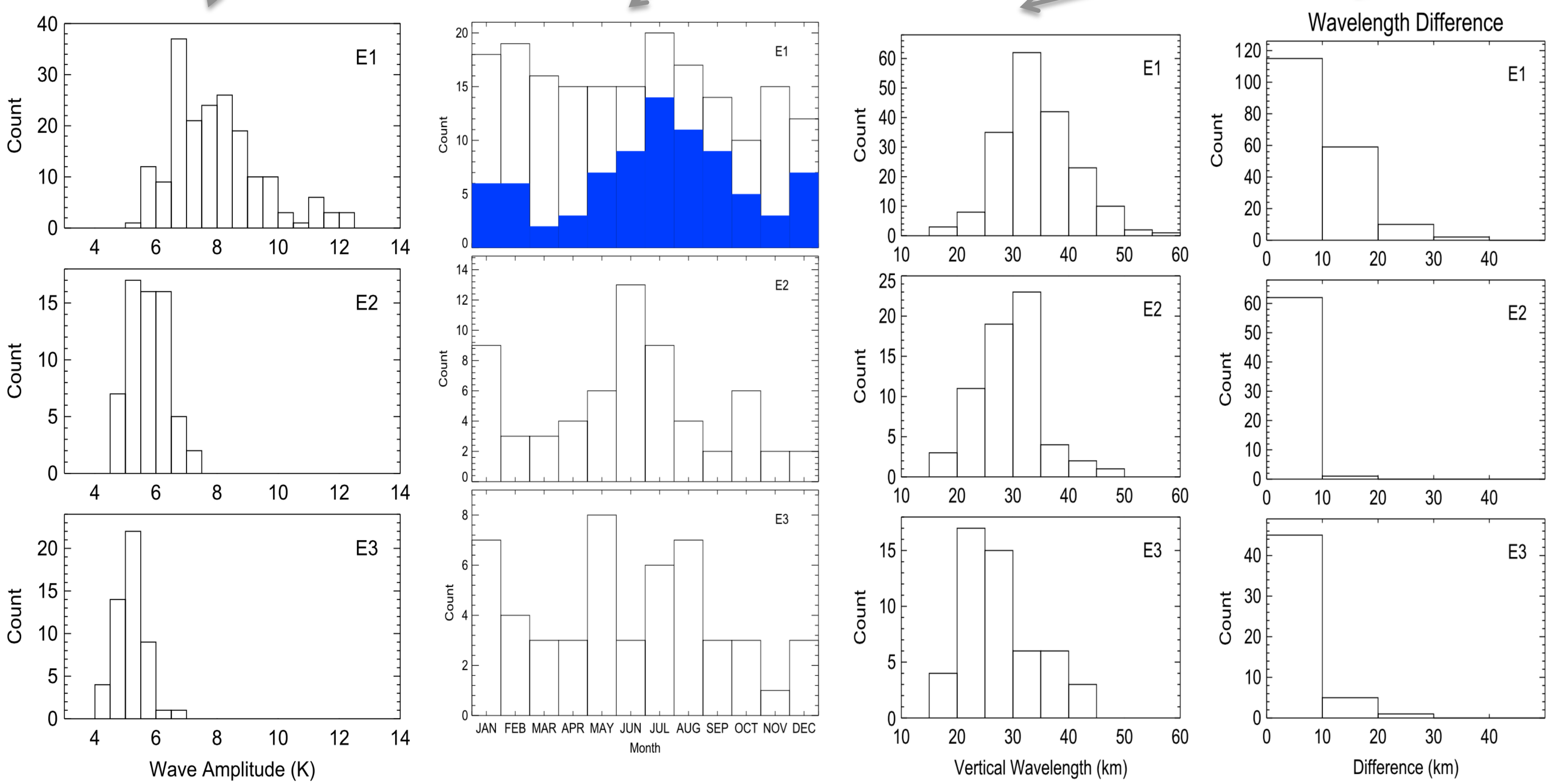
Table 1. Total Events of 3 Day Waves Identified From the SABER Temperature Observations at 98 km Altitude for Three Wave numbers Over 2002–2012

Year	Wave Number 1 (*E*1)	Wave Number 2 (*E*2)	Wave Number 3 (*E*3)	Total
2002	17	7	3	27
2003	20	3	3	26
2004	16	3	5	24
2005	15	5	8	28
2006	16	5	4	25
2007	18	10	9	37
2008	16	4	3	23
2009	20	6	5	31
2010	11	4	4	19
2011	16	6	3	25
2012	21	10	4	35
Total	186	63	51	300

Clear E1 population.
4K cut-off for E2/E3?

Seasonal signal in amplitude, not occurrence for E1.

Vertical wavelengths behave themselves as per disp. rel.



- We use the same 2D FFT to find wavenumber-1 to 3, 2.5-4.5 day TEC variations.
- For our threshold, we use 2 approaches – either 90th percentile or 4.2% amplitude.
- We require the signal either north or south of the mag. eq.

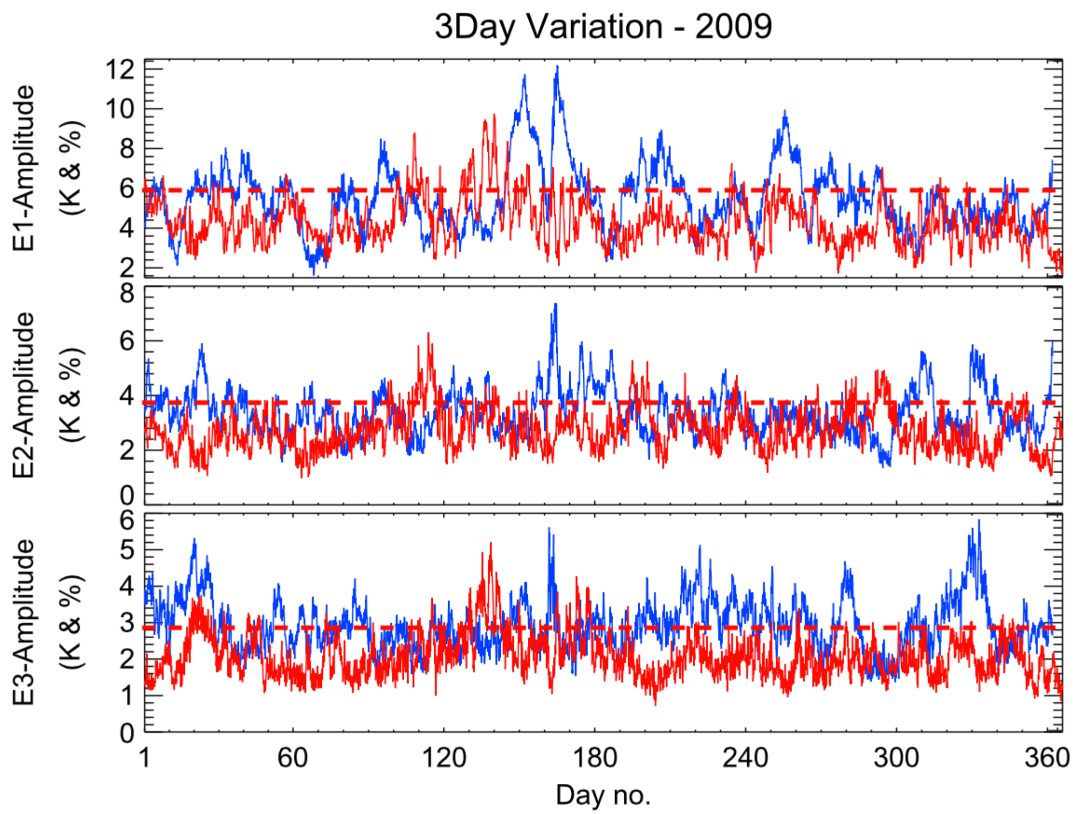


Figure 7. Normalized 3 day variations in TECs (% relative to the mean values), presented in the red color for the zonal wave number 1 (*E*1), zonal wave number 2 (*E*2), and zonal wave number 3 (*E*3) during 2009. The red dashed lines denote the 90th percentiles of these TEC variations. The 3 day wave amplitudes in temperatures are presented in the blue color.

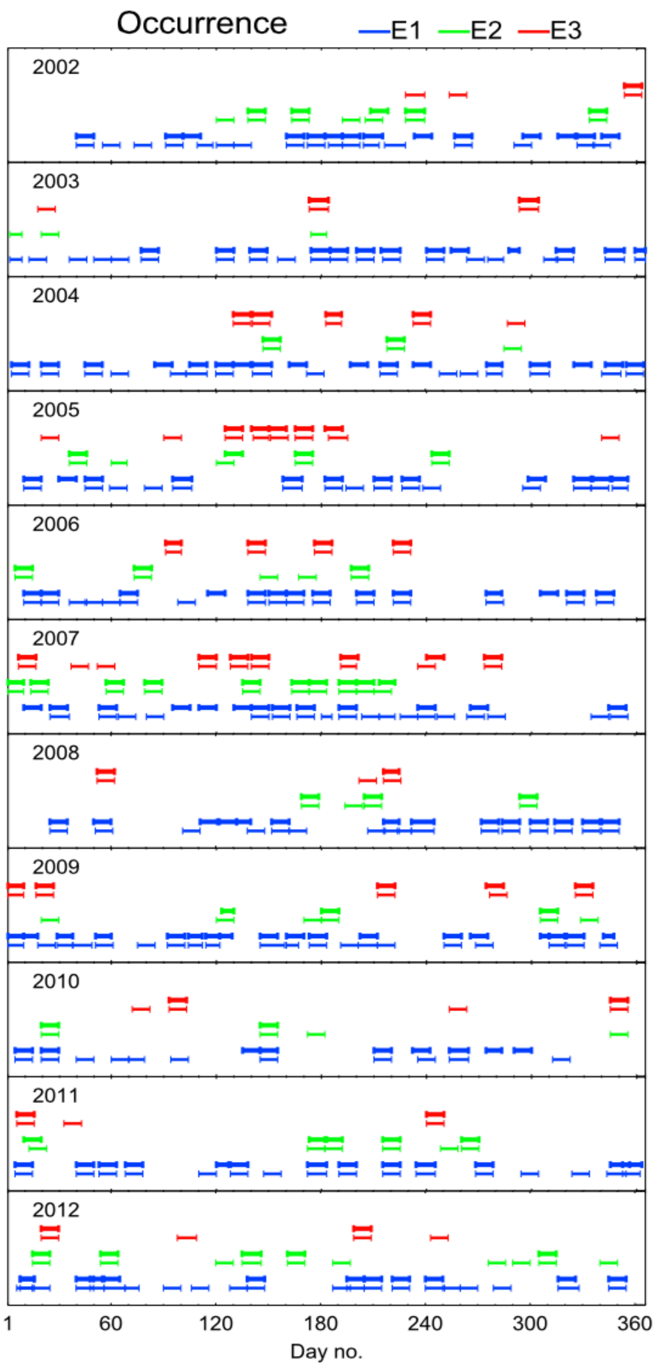


Table 2. Total Numbers of 3 Day Waves That Have Corresponding Variations in TECs (Above 90th Percentiles) Throughout 2002–2012

Year	Wave Number 1 (*E*1)	Wave Number 2 (*E*2)	Wave Number 3 (*E*3)	Total
2002	11	5	1	17
2003	11	0	2	13
2004	11	2	4	17
2005	11	4	5	20
2006	12	3	4	19
2007	9	10	7	26
2008	11	3	2	16
2009	15	3	5	23
2010	6	2	2	10
2011	12	5	2	19
2012	12	5	2	19
Total	121 (65%)	42 (67%)	36 (71%)	199 (66%)

- The figure & table show the summary of all UFKW and TEC events seen, and their coincidence, or not.
- There is some difficulty in linking E2 with TEC2, and E3 with TEC3 for a couple of reasons:
  1. E1 can generate TEC2 (at a weaker amplitude).
  2. We think we are cutting off the E2 and E3 spectrum (see histograms).
- For this reason, we'll only look further at E1 and TEC1.

- For simplicity, I'm only showing the 4.2% TEC variation data.
- For E1 & TEC1, only ~20% of TEC1 appear to have no E1.
- Here we see the larger amplitude TEC1 events are often associated with E1 (about 2/3 of the time).
- The longer wavelengths appear more efficient at generating TEC1.
- The larger amplitude UFKW produce larger amplitude TEC1.
- No preference is seen with season or solar cycle – a large UFKW can impact the ionosphere anytime.

Table 4. Total Numbers of 3 Day Waves and the Numbers (Percentages) of Corresponding TEC Variations Through 2002–2012 for Various Categorizes of the Waves[a]

Category	Waves	TEC Variations
Long vertical wavelength (>35 km)	81	63 (78%)
Normal vertical wavelength (25–35 km)	173	121 (70%)
Short vertical wavelength (<25 km)	46	13 (28%)
Large wave amplitude (>8 K)	75	68 (91%)
Normal wave amplitude (6–8 K)	123	96 (78%)
Small wave amplitude (<6 K)	102	33 (32%)
Equinoxes	124	79 (64%)
Solstices	183	121 (66%)
Solar maximum	53	33 (62%)
Solar minimum	73	47 (64%)

[a]The TEC variations are for the level of 4.2% change.

Liu, G., S. L. England, T. J. Immel, H. U. Frey, A. J. Mannucci, and N. J. Mitchell (2015), A comprehensive survey of atmospheric quasi 3 day planetary-scale waves and their impacts on the day-to-day variations of the equatorial ionosphere, J. Geophys. Res. Space Physics, 120, 2979–2992, doi:10.1002/2014JA020805.