

# Statistical study of the traveling ionospheric disturbances generated by solar terminator based on Dynasonde data

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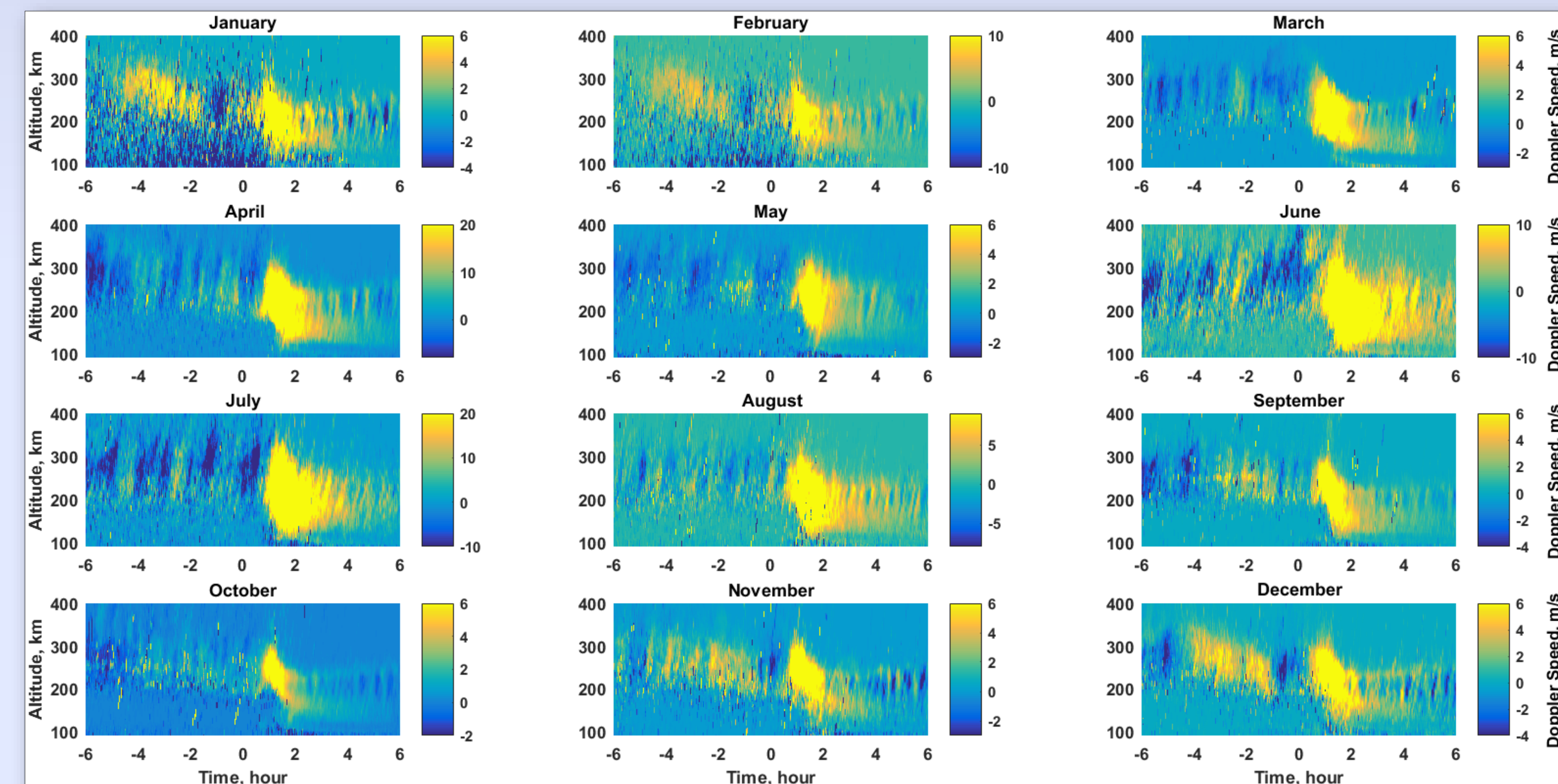
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## Abstract

Solar terminator represents a unique source of atmospheric waves possessing of near-ideal coherent properties: its geometry and magnitude of the impact changes very little from day to day. This feature has been used in [Forbes et al., GRL, 2008] to obtain "snapshots" of terminator waves in the neutral atmosphere at the altitude 400 km by averaging CHAMP accelerometer data over long sequences of the satellite passes. The results were represented in the geographic latitude vs local time coordinates. We apply a similar approach averaging time series of Wallops Island, VA Dynasonde Doppler data to obtain "snapshots" of terminator waves in the ionosphere in the true altitude vs "terminator time" coordinates. The averaging is performed independently for every month of the year-long observation period from May 2013 to April 2014. The altitude range covered is 90 km to 400 km with 1 km resolution, representing the entire bottom-side ionosphere. Individual local time segments

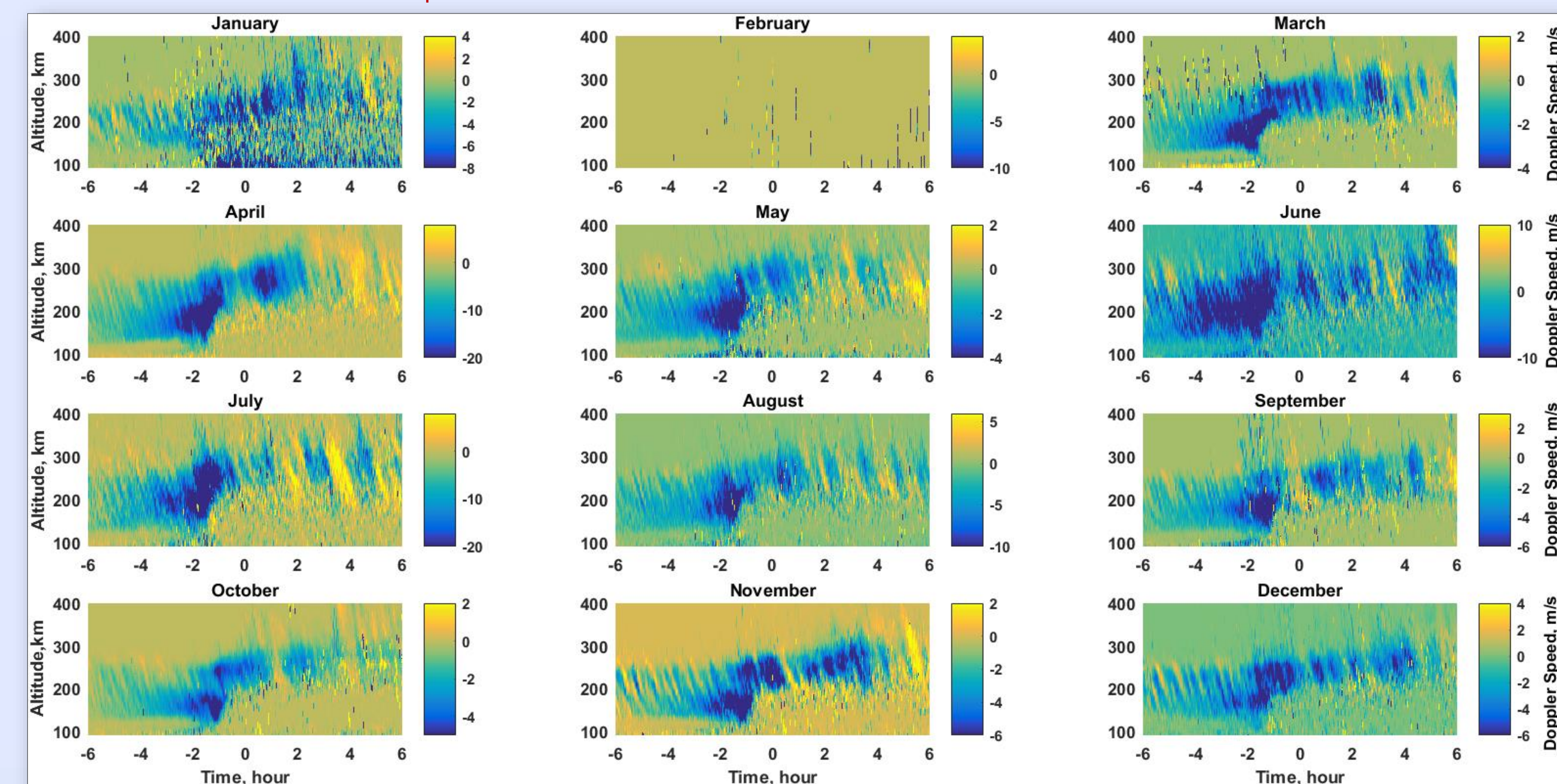
used for the averaging were 12 hours long and all centered on the times of the dawn or dusk terminator passing at every specific altitude. This approach effectively suppresses all kinds of incoherent wave activity and allows one to reveal the perturbation phenomenon mainly caused by the solar terminator. Both dawn and dusk terminator waves can be easily observed in majority of the monthly images. The phase fronts of the dusk terminator wave are propagating downward indicating upward movement of the terminator-related disturbance and of the wave generated by it. The phase fronts of the dawn terminator waves are propagating upward indicating downward movement of the terminator-related disturbance and of the wave generated by it. Spectral analysis of the local time sequences reveals characteristic peaks in the terminator wave activity corresponding to the periods 30-36 min, 1 hour and 2 hours and a continuum component.

Monthly "snapshots" of the **sunrise** terminator waves in the ionosphere over Wallops Island, VA for the period 5/2013-4/2014 in the real altitude vs "terminator time" coordinates.



Phase fronts of the waves are moving upward in this case, what corresponds to downward movement of underlying Gravity Waves. Local downward movement of the sunrise terminator determines the vertical direction of propagation of the waves.

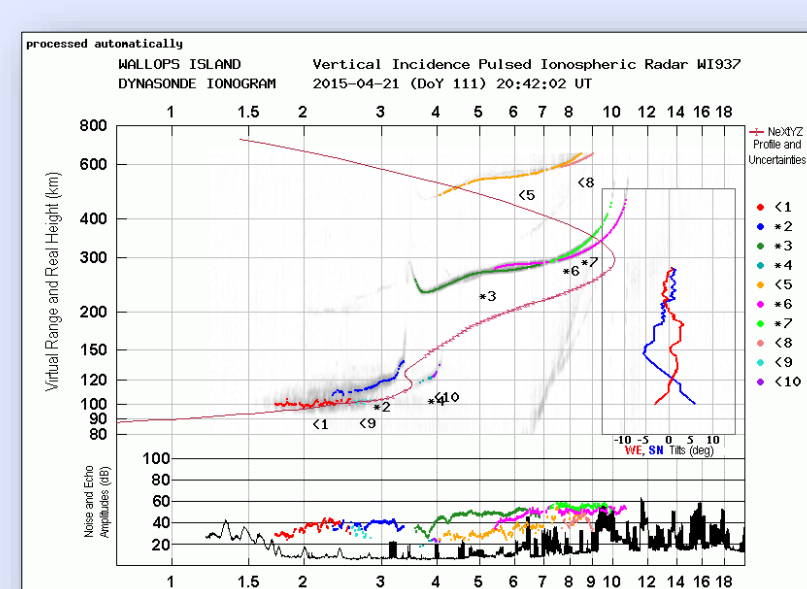
Monthly "snapshots" of the **sunset** terminator waves in the ionosphere over Wallops Island, VA for the period 5/2013-4/2014 in the real altitude vs "terminator time" coordinates.



Phase fronts of the waves are moving downward in this case, what corresponds to upward movement of underlying Gravity Waves. Local upward movement of the sunset terminator determines the vertical direction of propagation of the waves.

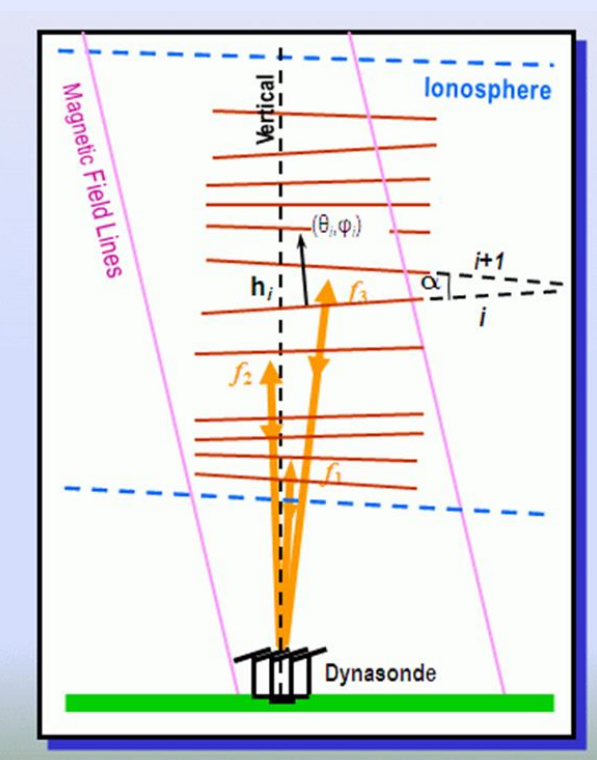
## Distinguishing properties of Dynasonde data analysis

- Comprehensive use of phase information in radio echoes. This is unique to Dynasonde approach to ionospheric radio sounding; in particular this enables processing the list of physical parameters of the echoes instead of traditional amplitude-based image analysis.



- All echoes are useful.

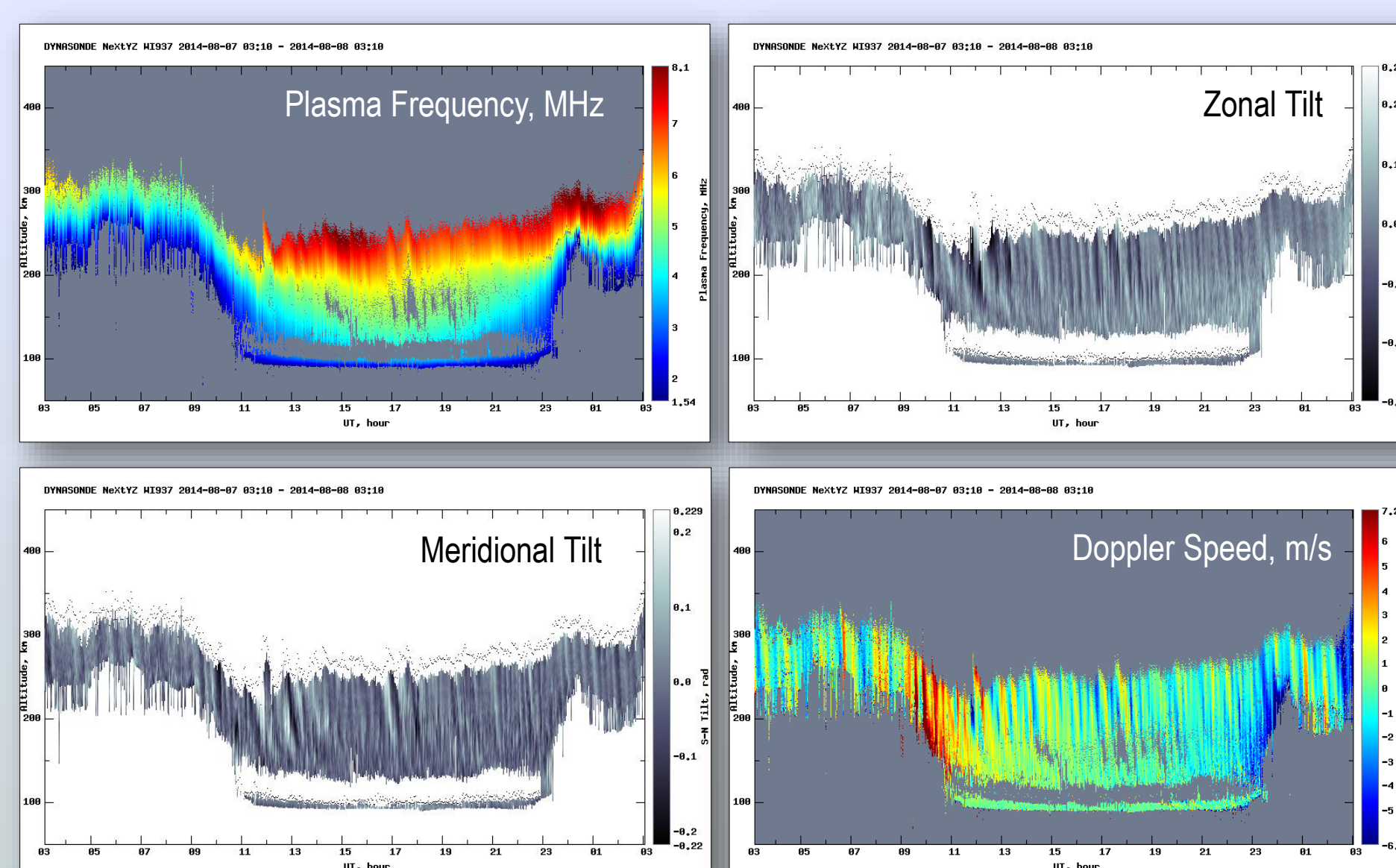
Up to several thousand echoes per ionogram are detected and used. No echo rejection based on range or polarization.



- 3-D structure of ionospheric plasma is accounted for.

No assumption of horizontally stratified ionosphere. NeXTYZ ("Next Wise"), the inversion procedure, uses angles of arrival of all echoes and provides parameters of the Wedge Stratified Ionospheric Model. [Zabotin et al., Radio Sci., 2006]

Standard representation for the time series of NeXTYZ results: Wallops Isl., VA, 7-8 August 2014



An example of the standard output of the Dynasonde analysis: daylong scans of four physical parameters characterizing ionosphere (the zonal and meridional tilts, the plasma frequency, and the vertical Doppler speed). The values are shown by color or by shades of gray as functions of the time of the day (in UT hours) and of the real altitude (in km) for Wallops Island, VA on August 7-8, 2014. The slant structures in the images are caused by downward motion of the phase fronts.

## Approach similar to ours: studying spatial properties of terminator waves averaging satellite accelerometer data over several orbits

[Forbes, Bruinsma, Miyoshi, and Fujiwara (2008), GRL, 35, L14802]

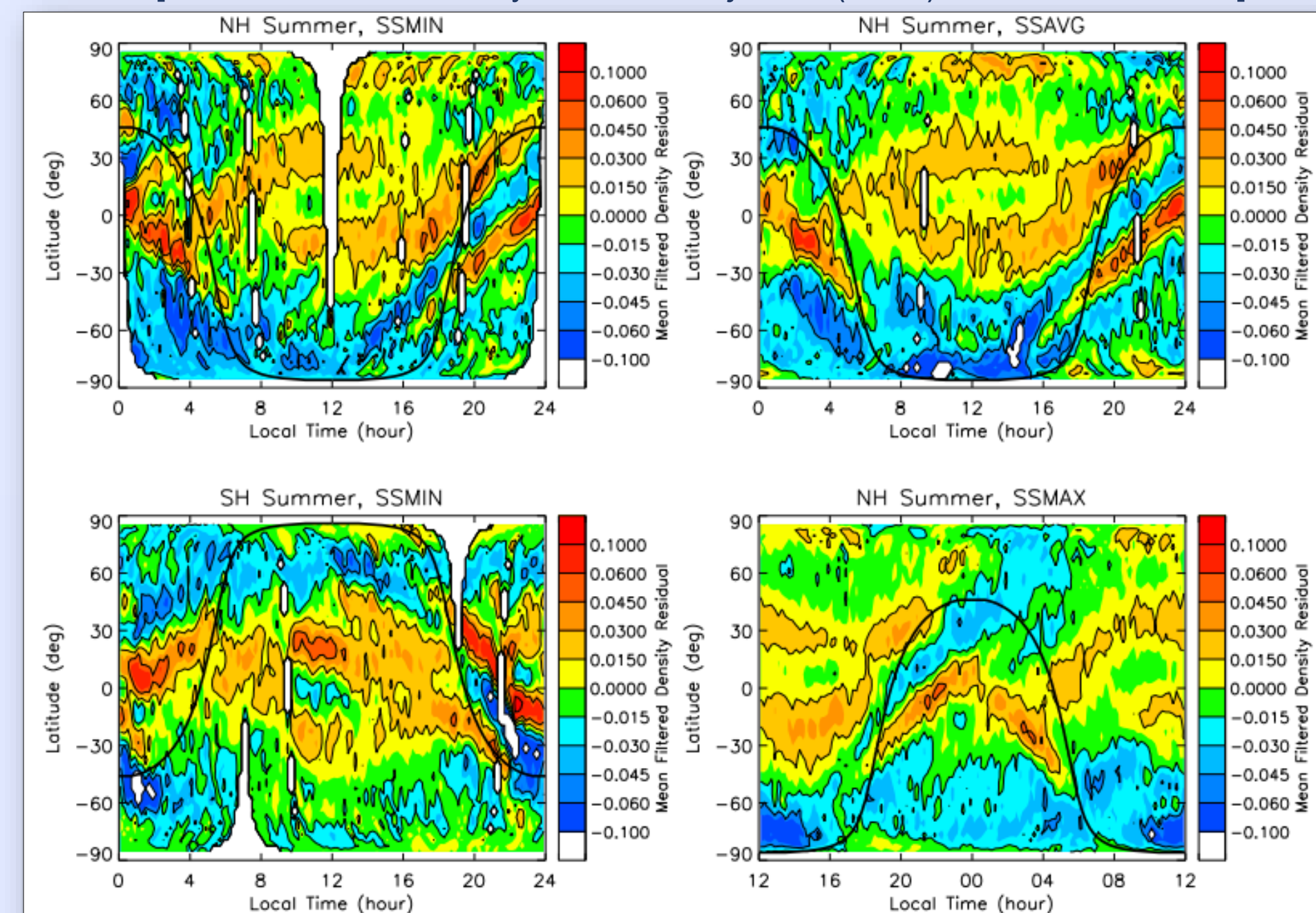
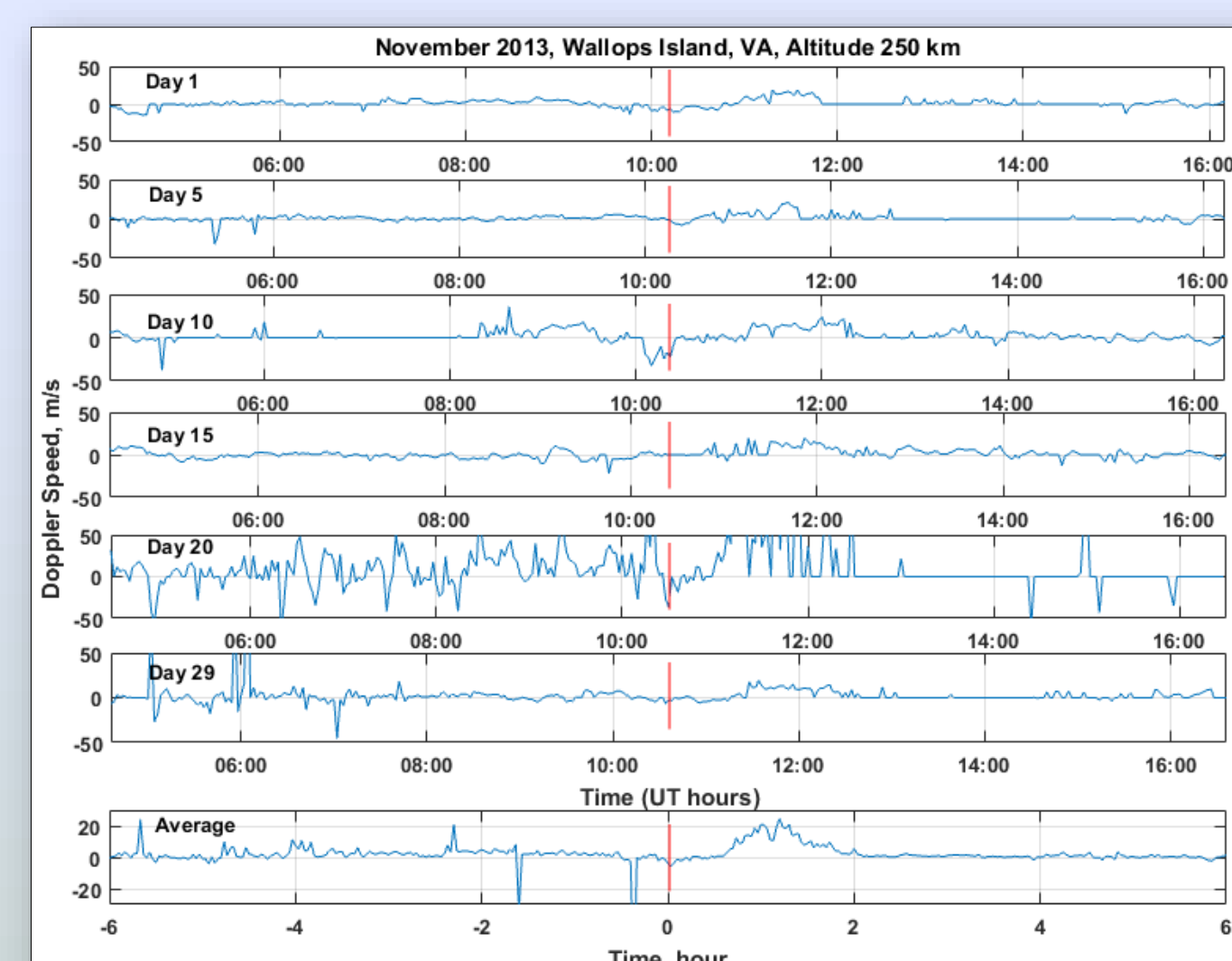


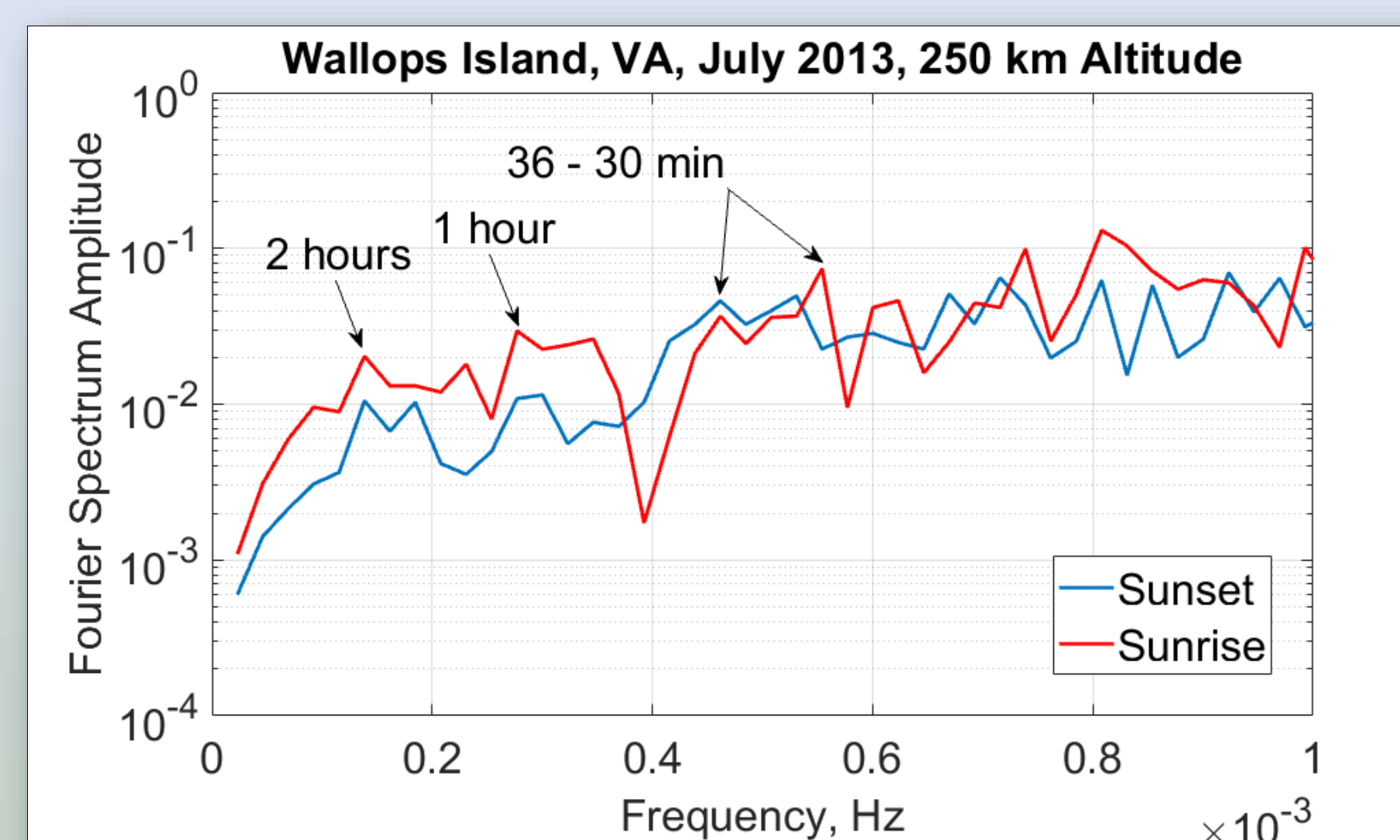
Figure 1. Latitude versus local time depictions of mean relative residual densities during solstice-like conditions various levels of solar activity, as defined in the text. The black solid lines denote the terminator location at 400 km altitude. The grid resolution in constructing these plots is 3° in latitude and 0.2 h in local time (equivalent to 3° in longitude), and only include data for Kp < 3. The SSMIN bins have an average of 96 data points per bin, with a maximum of 398 data points, and 531 empty bins (out of a total of 7139). The corresponding numbers for SSAVG are 180 (avg), 562 (max) and 56 (empty) and for SSMAX are 196 (avg), 610 (max) and 23 (empty). The white regions denote the locations of empty bins.

"Snapshots" of terminator waves in the neutral atmosphere at the altitude 400 km obtained by averaging CHAMP accelerometer data over long sequences of the satellite passes. The results are represented in the geographic latitude vs local time coordinates.

## Illustration for averaging procedure applied to Dynasonde Doppler data to reveal the terminator-related structures



Averaging is performed individually for every altitude (with 1 km resolution) over daily 12-hour long segments of Doppler data within a specific calendar month. The segments are centered at the times of terminator passing (separately for sunrise and sunset). The results are represented in the true altitude vs "terminator time" coordinates.



## Spectral characteristics of the terminator waves

Spectral peaks observed in the terminator-generated waves both during sunrise and during sunset correspond to the periods of 2 hours, 1 hour, and 30-36 min. This is in agreement with previous studies.