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Method for Estimating Neutral Wind Azimuth using 2D TID Propagation Parameters

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Abstract

We test wind-filtering hypothesis based on long-term TIDs observations by the Hokkaido East SuperDARN radar. Method for estimating neutral wind azimuth using 2-dimensional TIDs propagation parameters is developed and tested. Calculated wind azimuth generally corresponds to the HWM2007 model, excepting midnight hours. Differences between estimations and model at midnight most probably caused by the presence of TIDs not corresponding to internal gravity waves (IGW), or by wind behavior features not described by HWM2007. The proposed method is universal and allows estimating neutral wind azimuth from any 2-dimensional TID phase velocity vector distributions. It can be useful for improving neutral wind models and/or for studying the factors not taken into account by wind models.

1 Introduction

Interaction of internal gravity waves (IGW) with a neutral wind has been studied for a long time. In [1, 2, and 3] it was shown that most of the observed traveling ionospheric disturbances (TIDs) propagate in the direction opposite to the neutral wind velocity. This effect was explained by IGW wind-filtering hypothesis in the following way: 1) the amplitudes of downwind propagating IGWs greatly decrease due to dissipation; 2) the amplitudes of upwind propagating IGWs increase [1, 2, 4]. Nicolls et al. [5] concluded that IGWs azimuth distribution anisotropy may be caused by wind-filtering as well as by other factors. In [6] both the Irkutsk incoherent scattering radar and the EKB HF radar data were used to reveal significant anisotropy of TIDs occurrence and average horizontal velocities depending on the propagation direction. Observed effect is well explained by wind filtration. In this paper we test wind-filtering hypothesis by using representative TIDs statistics obtained by the Hokaido East SuperDARN radar during 2007-2014. As mentioned above, the amplitudes of downwind propagating IGWs greatly decrease due to dissipation, and the amplitudes of upwind propagating IGWs increase. Therefore, if most TIDs are manifestation of IGWs, then maxima of TIDs distributions in times of day and azimuth should coincide with directions opposite to the strongest and most frequent wind propagation for a given season and diurnal time.

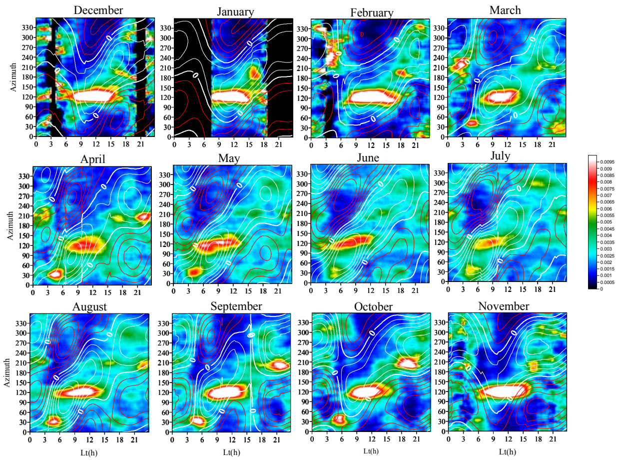

Figure 1. Distribution of TIDs occurrence in time-azimuth plane (by color) and distributions of neutral wind projections (by contours)

Figure 1 shows distribution of TIDs occurrence in time-azimuth plane (by color) and distributions of neutral wind projections (the white contours are the negative wind projections, and red ones are the positive) for different seasons. Neutral wind was calculated using HWM2007 model. Hereinafter, the occurrence is a number of TIDs propagating in a given direction for a given time divided by a full number of TIDs observed for a given time. It should be noted that the radar operates at a frequency of ~11 MHz. This leads to the absence of ground backscatter registration during winter nighttime due to low background electron density. As can be seen from Figure 1, the vast majority of disturbances occur in the region of negative neutral wind projections (white contours). Thus, we can assume that most of the observed TIDs are manifestations of IGWs. In [6–7] the average monthly diurnal neutral winds were obtained by using statistical data of TIDs 3-D propagation parameters and assuming that the Hines dispersion equation is satisfied. The Hokkaido East SuperDARN radar can obtain only TID 2-D propagation parameters (azimuth and apparent horizontal velocity). In this case using dispersion equation is impossible. The question arises whether it is possible to estimate the azimuth of neutral wind from representative statistics of TID 2-D propagation parameters?

2 Method for Estimating Neutral Wind Azimuth

Let's try to solve the problem inverse to testing of wind-filtering hypothesis. For each time moment, for each possible wind azimuth (0°–359°) we will consider how many disturbances occur in the regions of negative wind projection, and how many disturbances occur in the regions of positive wind projection. The optimized function looks like this

$$I(t,\alpha) = -\sum_{\varphi=0}^{\varphi=359} N(t,\varphi)\cos(\widehat{\alpha\varphi}) \rightarrow \max \qquad (1)$$

In (1) N is number of TIDs propagating at time t with azimuth φ, $\alpha\varphi$ is angle between φ and α. The angle α providing the maximum of the function $I(t,\alpha)$ is considered as neutral wind azimuth at time t. Below are the calculations results.

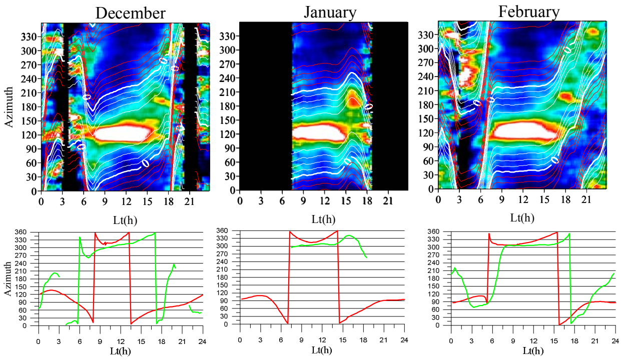

Figure 2. Winter season. The upper row: TIDs distribution (color) and distributions of neutral wind (calculated azimuth) projections (contour). The bottom row: the red line is neutral wind azimuth (HWM2007), and green line is calculated azimuth.

As can be seen from Figure 2, in the daytime the calculated azimuth and HWM2007 model are in good agreement. As noted earlier the nighttime echoes are almost absent during winter season. Nevertheless, in February the calculated azimuth fits the model well even at night.

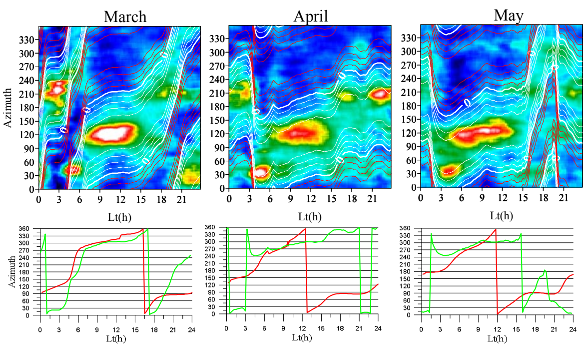

Figure 3. Spring season. The upper row: TIDs distribution (color) and distributions of neutral wind (calculated azimuth) projections (contour). The bottom row: the red line is neutral wind azimuth(HWM2007), and green line is calculated azimuth.

As can be seen from Figure 3, the calculated wind azimuth generally corresponds to the HWM2007 model (especially good in March), except for midnight hours. As can be seen from the TIDs distributions in time and azimuth, there are maxima about 210° in the midnight hours. This maxima leads to obtaining north azimuth instead of the south and east azimuths. Further we discuss the possible causes of such situations.

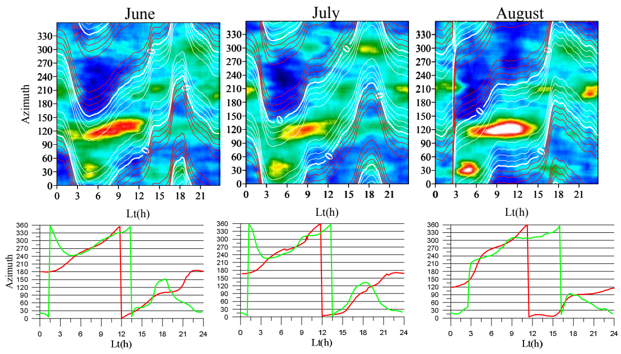

Figure 4. Summer season. The upper row: TIDs distribution (color) and distributions of neutral wind (calculated azimuth) projections (contour). The bottom row: the red line is neutral wind azimuth(HWM2007), and green line is calculated azimuth.

For summer season the calculated azimuth again fits well with the HWM2007 model, except for the midnight hours. As can be seen from Figure 4 there is stable maximum of about 210° around midnight hours for all months.

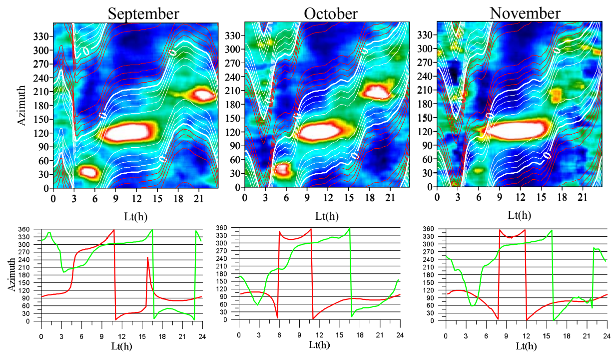

Figure 5. Autumn season. The upper row: TIDs distribution (color) and distributions of neutral wind (calculated azimuth) projections (contour). The bottom row: the red line is neutral wind azimuth(HWM2007), and the green line is calculated azimuth.

As can be seen from Figure 5, the calculated wind azimuth generally corresponds to the HWM2007 model. However, according to the HWM2007 model in October and November, the wind azimuth is already being changed to the winter mode, whereas calculated wind azimuth is similar to the September azimuth. For the first time in October (with the exception of the winter season), we do not observe a maximum of about 210° at midnight and the calculated azimuth corresponds to HWM2007.

3 Discussion

There is a surprisingly stable maximum of about 210° in the TIDs distribution in time and azimuth for all months around midnight (except for October and the winter season). This maximum does not correspond to the wind pattern according to HWM2007. We can assume the following reasons for this phenomenon: some data processing artifact, presence of TIDs not corresponding to IGW (for example, various instabilities), or wind behavior features not described by HWM2007. We can exclude data processing artifact, because of other researches using other techniques also observed such TIDs at these hours. Shiokawa et al. [9] presented a statistical study of TIDs using mid-latitude 630-nm airglow images and reported that most of the observed TIDs propagate southwestward during all seasons. Similar results were obtained from GPS TEC maps [10, 11]. The authors assume that these TIDs are not manifestations of IGWs.

Above we used information about TIDs azimuth distribution. Let try to use information about TIDs horizontal phase velocities. Regardless of the TIDs nature: 1) horizontal phase velocities of downwind propagating TIDs increase; 2) horizontal phase velocities of upwind propagating IGWs decrease. Let calculate the TIDs average horizontal phase velocity for each time and azimuth. It can be expected that maximum of TIDs average horizontal velocities corresponds to positive wind projections, and minimum of TIDs average horizontal velocities corresponds to negative wind projections. (We have great statistics (2007-2014), and can assume that without wind average horizontal velocities will be similar for each direction.)

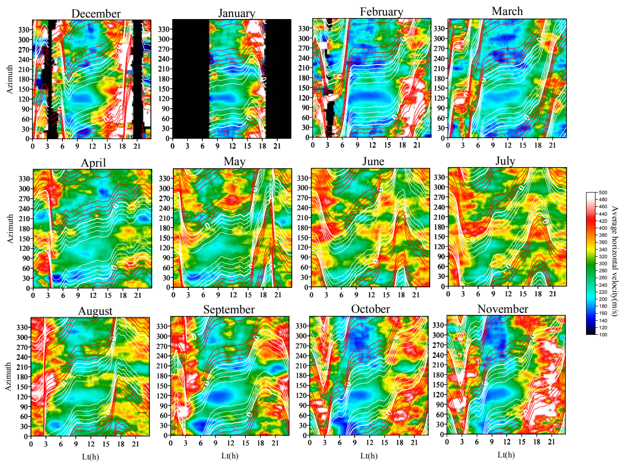

Figure 6. Distribution of TIDs average horizontal phase velocities (by color) and distribution of calculated neutral wind projections (isolines: white negative projection, red positive projection)

As can be seen from Figure 6, the majority of TID average horizontal velocities maxima occur in the regions of positive wind projections (red contours), and the majority of TID average horizontal velocities minima occur in the region of negative wind projections (white circuits). Also it can be seen, that stable southwest (~210°) midnight maxima of TID distribution in azimuths and times always correspond to minima of TID average horizontal velocities distribution. So, it seems like these TIDs propagate upwind. Consequently, it can be assumed that wind is really directed to the northeast (opposite to ~210°). This is the argument for the wind behavior features which are not described by HWM2007. On the other hand it can be assumed that TIDs of not IGWs nature have so slow horizontal phase velocities that even downwind propagation cannot increase its horizontal phase velocities to horizontal phase velocities of IGW manifestations. So, problem of southwest midnight maxima requires further studies.

4 Conclusion

The proposed method is universal and allows estimating neutral wind azimuth by using distributions of 2D TID phase velocity vector obtained regardless the technique. There is a number of techniques allowing to obtain 2D TID phase velocity (as opposed to a 3D phase velocity vector). Therefore, this method might be useful in application to development and improvement of various neutral wind models. The method might be useful for studying the factors not taken into account by HWM model.

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