Duration of wave disturbances generated by solar terminator in magneto-conjugate areas

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Abstract

We consider a possible explanation of long duration of travelling wave packets (TWPs) generated by solar terminator (ST). We suggest a hypothesis about consecutive detecting of MHD-nature disturbances, generated by ST in magneto-conjugate area first and in observation area next. Registration beginning time depends on latitude. In summer in Japan TWP registration starts with ST arriving in magneto-conjugate region– about 2-3 hours depending on latitude before ST arrives to the observation point. Dynamic spectra show clearly additive character of registered disturbances. ST appearance over the registration point accompanies amplitude increment on TWP frequencies in spectrum.

1. Introduction

Ionospheric and atmospheric effects generated by solar terminator (ST) have been investigated for a long time. Solar terminator is a natural source of disturbances; its geometry and parameters are well-known. Registration of a media response to such a source as ST provides an image of actual medium state. On the other hand, it may give a better insight into the nature of geosphere interaction.

The development of GPS satellite systems promotes investigations into ionospheric variations and disturbances, including ST-generated disturbances. The accuracy of phase measurements allows detecting ionospheric disturbances with the amplitude of about 10^{-4} of the background level. Dense GPS networks provide data with spatial resolution of about 18 km. This resolution used to be available only for optical systems.

Research subject of this paper is travelling wave packets (TWP), generated by solar terminator, found in the past [1]. It also was suggested that these disturbances have magneto hydrodynamic (MHD) nature [2]. Data from Japan and Californian dense networks have been employed to detect travelling wave packets. It was found that their appearance synchronized with ST passage. Ensuing works [1, 2] revealed that the TWP generation may precede the ST arrival at an observation point. Meanwhile, the registration synchronizes with the ST arrival at the magneto-conjugate (MC) region. This yields a hypothesis about the magneto hydrodynamic (MHD) nature of TWP.

There are several questions on TWP. One of them is concerned with the long TWP duration. The slow magnetic sound model [3], for one, declares the TWP duration of about several hours. But experimental results show that they may last up to 8 hours. It is also necessary to ascertain whether TWPs of MHD nature appear in both hemispheres or they can be registered only at a magneto-conjugate point. Finally, we should understand whether all registered TWPs are generated by ST-MHD mechanism or part of them is connected with acoustic-gravity waves as it was suggested before.

2. Travelling wave packets duration

Unexpected duration of TWPs registration can be explained by additive character of that duration: it sums up of two parts. Figure 1 presents geometry of sunset terminator movement of winter (a) and at summer (b). At winter ST firstly appears in Northern hemisphere and after time ΔT it will appears in Southern hemisphere. In Northern hemisphere ST induces wave disturbance generation on the magnetic field line. This disturbance propagating in magneto-conjugate area in Southern hemisphere and is registered as TWP here. In a ΔT time solar terminator appears over the observation point and generates MHD wave disturbance again, but now it is registered in generation point directly. Thereby, TWPs would be registered for long time enough and total duration of registration sums up. In summer one can see reversed situation. As deduced from figure 1, it is possible to carry out researches of ST effects in magneto-conjugated areas in America, and in Japan and Australia.

It also should be taken into account other explanation of long TWPs duration. In assumption that only part of registered TWPs have MHD nature and other part connected with acoustic-gravity waves, we obtain following picture. ST passage in MC region induces TWPs and it registered within 2-3 hours for several hours before ST passage over the observation point. ST arriving in observation point will generate acoustic-gravity wave in neutral atmosphere, which give arise TWP-like disturbances in ionosphere.

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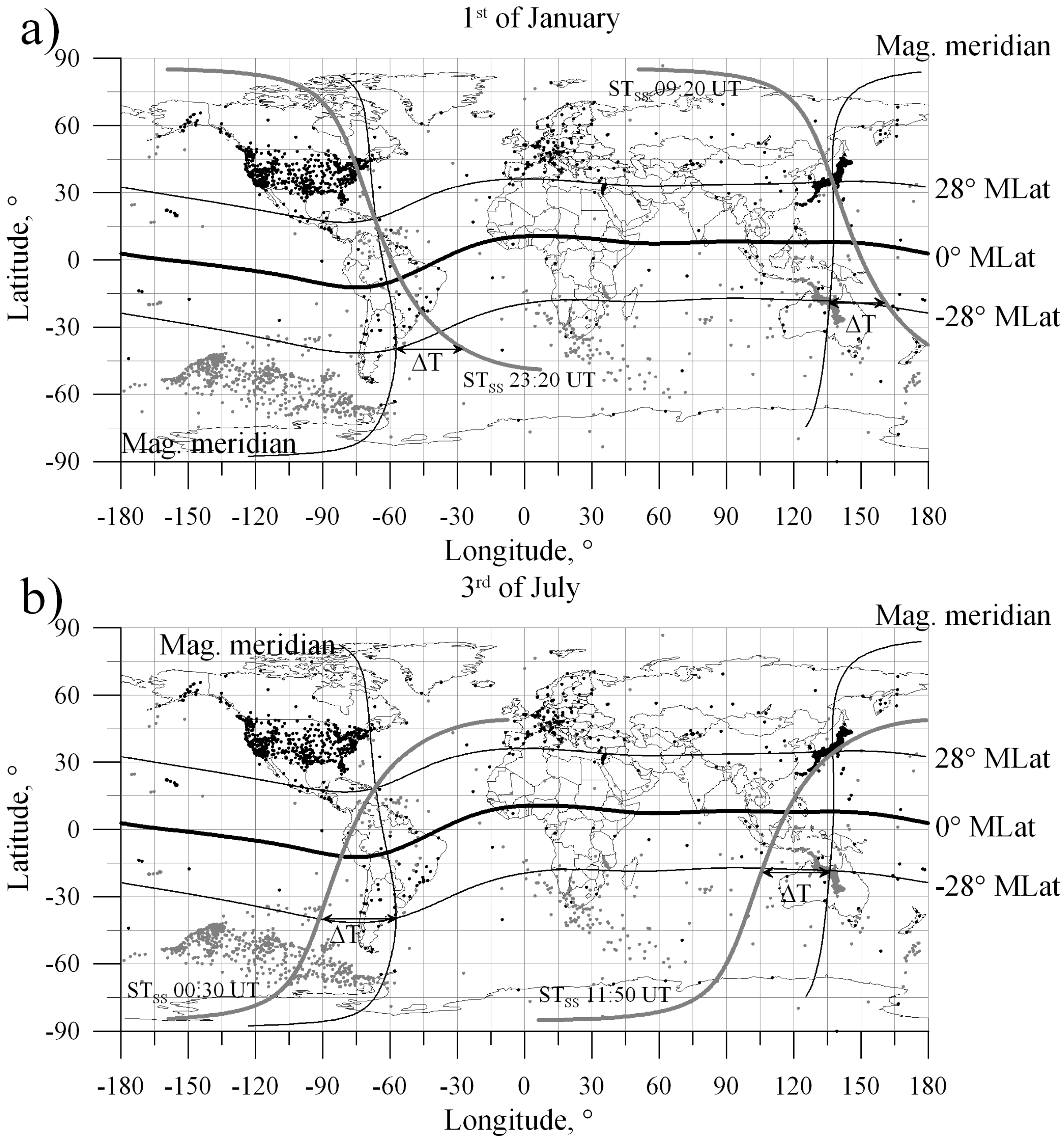

Figure 1. Geometry of sunset ST passage over MC areas in winter (a) and summer (b). Geomagnetic parallels, meridians and geomagnetic equator are presented by black lines; sunset ST line (for the UT time presented nearby) is gray thick line. Black dots are GPS sites in IGS and GEONET networks and gray dots are MC points for each site.

We analyzed difference ΔT between ST arrival time at observation point and in MC area for several regions in Japan, Australia (figure 2. a-c) and America (figure 2 d-f). Dashed line at figures 2a and 2d presents meridian used for calculations, gray dots mark GPS sites location. Dependence of time ΔT versus latitude presented on panels (b-c) and (e-f), for Japan-Australia regions and America, respectively. Positive ΔT value indicates ST arriving to observation point first and to MC region then. Data for the 1st of January presented on figures 2b and 2e and on figures 2c and 2e for the 3rd of July. Figures 2 (b-c) show variations for sunrise ST, figures 2 (e-f) show variations for sunset ST.

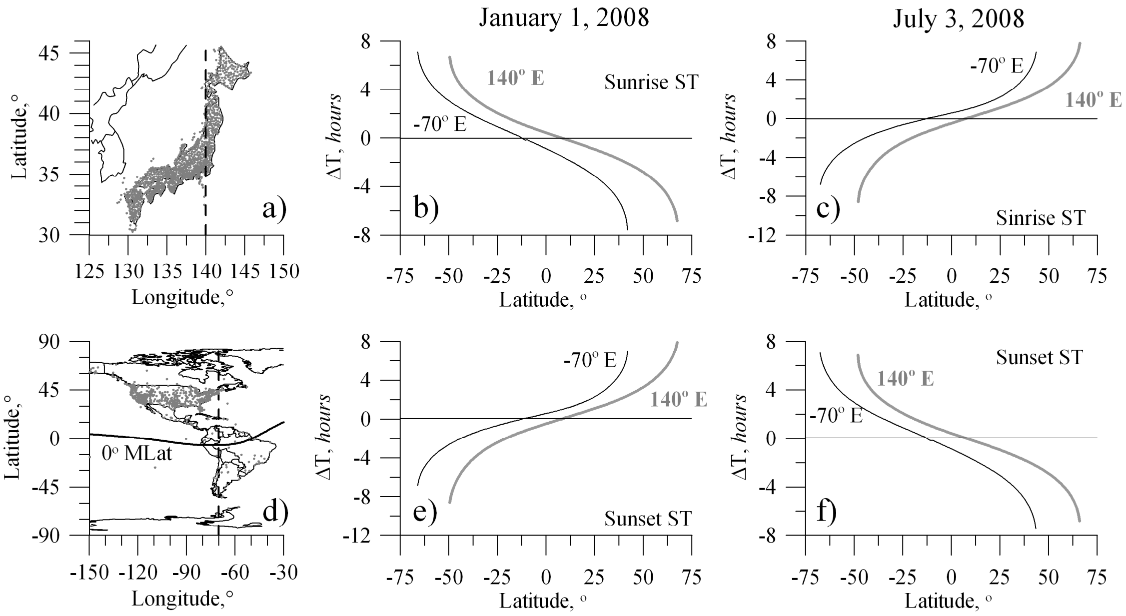

Figure 2. Difference ΔT between ST arrival time in current region and in MC area versus latitude for Japan-Australia (a) and America (d): in sunrise (b-c) and sunset (e-f). Middle column presents data for the January 1 (b, e) and right column – for the July 3. Gray line at (b, c, e, f) is ST difference ΔT on 140°E meridian and black line – on a -70°E meridian.

Northern hemisphere difference between arrival ST times in observation point and in MC point may achieve 7 hours for America longitudes. Meanwhile for Japan longitudes this difference is about 2 hours. Winter dependence for the sunset ST looks similar to summer dependence for the sunrise ST as well as winter-sunrise and summer-sunset dependences. All these dependences are monotone. The big time difference ΔT validate suggested hypothesis.

3. Dependence of dynamic spectra variations on latitude

Connection between wave packets generation and ST appearing presents most obvious in the terminator local time (TLT) system: $dT = t_{obs} - t_{st}$, where t_{obs} is the time in data point, and t_{st} is the time of ST appearing at the altitude H over this point [4]. In other words, we make a transformation of latitude and longitude of the point to a time of the terminator appearing over this point and then we define difference between the terminator appearing time and time in the data point. Distinctive feature of this approach is in excluding of the point coordinates and considering data of each point in the solar terminator context only.

Hypothesis about dependence of ΔT on latitude was tested with help of TEC variations dynamic spectra, calculated by data from dense GPS sites network in Japan – GEONET. Dynamic spectrum collected in TLT with single spectra, calculated for each line of sight to satellite in current region and time period by fast Fourier transforms method [4]. Time axis step was 5 min.

To analyze latitudinal variation of dynamic spectra we choose two regions in Japan: 30-35°N, 130-140°E and 38-45°N, 138-145°, with 465 and 286 sites, respectively. Figures 4a and 4b presents dynamic spectra in TLT for three summer days (July 2-4) of 2008 in those two regions. Green line marks ST arrival time in magneto-conjugate region, blue dashed line marks ST appearance at 300 km over the observation point.

Difference between ST arrival time in observation point and in magneto-conjugate point is about 2 hours for region (a) and is about 3 hours for region (b). Observed difference between ST arrival time and TWP registration start point is in good correspondence with those values (figure 3). It is interesting to see that generation going in two steps: the first one begins when ST arriving in MC region and the second one – in observation point.

4. Conclusion

We consider one of possible explanations of ST-generated TWP long duration and suggest a hypothesis about consecutive detecting of MHD-nature disturbances, generated by solar terminator in magneto-conjugate area first and in observation area next. According to this hypothesis, registration beginning time depends on latitude and it should grow with latitude in middle latitudes, particularly.

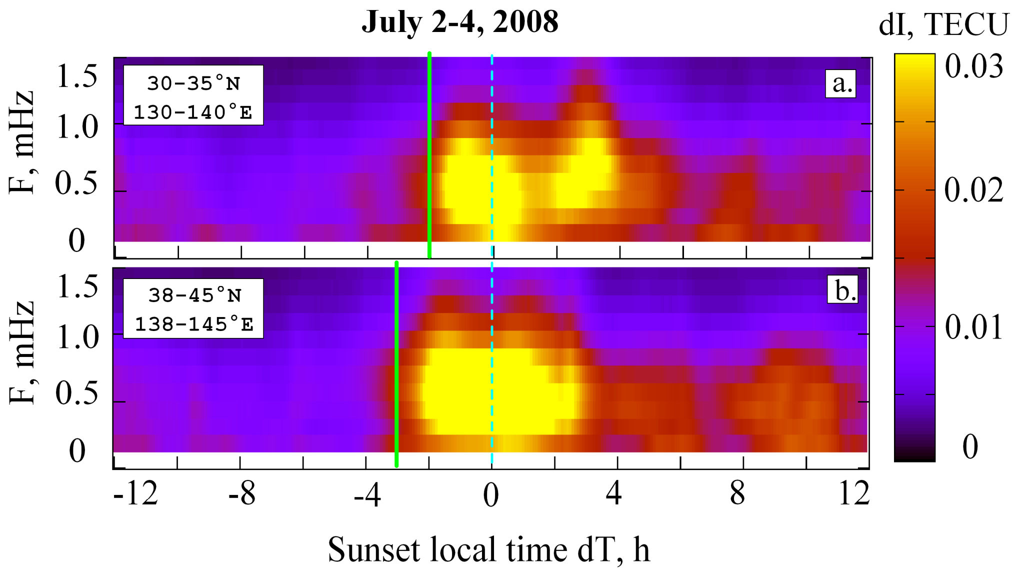

Figure 3. Dynamic spectra of TEC variations in sunset TLT for July 2-4, 2008 over Japan: (a) 30-35°N, 130-140°E and (b) 38-45°N, 138-145°E. Green line marks ST arrival time in MC region, blue dashed line – in observation point.

Dynamic spectra of TEC variations over Japan provide validity evidence for this hypothesis. In summer in Northern hemisphere TWP registration begins with sunset ST arriving in magneto-conjugate region– about 2-3 hours depending on latitude before ST arrives to the observation point. For latitude of 42°N time difference between TWP registration beginning and ST arrival time in observation point is about 3 hours, for 32°N it is about 2 hours.

Dynamic spectra show clearly additive character of registered disturbances. TWP registration begins with ST arriving in magneto-conjugate. When the solar terminator appears over the registration point one can see amplitude increment on frequencies corresponding to the TWPs (2.5-1.0 mHz) in spectral picture.

Seasonal variations of the time difference between registration beginning time and ST arrival time are quite interesting theme. In winter in Japan, for instance, this difference could exceed 7 hours. We also analyzed data for December 29-31, 2008 and found that these days' spectra significantly differ from summer those. There are no peculiarities in spectra when ST arrives in observation point. These problems are subject of further investigations.

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