

Time variations of oxygen emission lines and solar wind dynamic parameters in low latitude region

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Abstract. Aurora phenomenon is an effect of collision between precipitating particles with gyromotion along Earth's magnetic field and Earth's ionospheric atoms or molecules. The particles' precipitation occurs normally around polar regions. However, some auroral particles can reach lower latitude regions when they are highly energetic. A clear emission from Earth's aurora is mostly from atomic oxygen. Moreover, the sun's activities can influence the occurrence of the aurora as well. This work studies time variations of oxygen emission lines and solar wind parameters, simultaneously. The emission's spectral lines were observed by Medium Resolution Echelle Spectrograph (MRES) along with 2.4 meters diameter telescope at Thai National Observatory, Intanon Mountain, Chiang Mai, Thailand. Oxygen (OI) emission lines were calibrated by Dech-Fits spectra processing program and Dech95 2D image processing program. The correlations between oxygen emission lines and solar wind dynamics will be analyzed. This result could be an evidence of the aurora in low latitude region.

1. Introduction

Earth's aurora, which associates with the Earth's geomagnetic activities, is a consequence of interaction between auroral particles, which are solar wind particles gyrating along the Earth's magnetic field lines, and atmospheric ions or neutrals in Earth's ionosphere. Solar wind, a major influence of Earth's aurora, is a high speed plasma carrying solar magnetic field far from solar atmosphere and permeating into interplanetary space. The solar magnetic field that spreads into interplanetary space is called Interplanetary Magnetic Field (IMF). The solar wind has regularly supersonic speed and contains low-density plasma. However, solar wind properties can vary depending on solar magnetic activities [1]. When the solar wind and the IMF reach the Earth's magnetic field, the Earth's magnetic field configuration appears to be compressed at day side, which is called dayside magnetosphere, and to be extended at night side, which is called magnetotail. In the case that the southward IMF and Earth's magnetic field are in opposite direction, they will merge toward each other. This process is called magnetic reconnection. Later, the open magnetic field lines sweep to the night side and reconnect to Earth's magnetic field once again at the magnetotail [2]. After reconnection process, the plasmas from day and night sides will then precipitate into the Earth's ionosphere. These plasmas collide with

ionospheric ions and neutrals and excite their bounded electrons. As the results, the excited electrons decrease their energy by going back to lower states and release photons in various frequencies creating the aurora at high latitude regions as an oval shape around Earth's magnetic poles. The aurora has spectral range of frequency in different colors relying on heights, and type of ionospheric atoms or molecules e.g. nitrogen and oxygen [3]. Generally, Earth's aurora is frequently seen at nighttime in bright green color from oxygen (OI) 5577 Å emissions at 100-150 km altitude. On the other hand, daytime aurora in red color at higher altitude than 150 km is originated from oxygen (OI) 6300 Å and 6363 Å emissions that can be seen at nighttime as well but with faint emissions [4]. In this work, the observations were operated during nighttime. Therefore, the nighttime aurora is our target.

Spectroscopy, one of the great observational technique, is applied to study a spectrum of the atmosphere from celestial objects including Earth's atmospheric emission lines [5,6]. For this case, the oxygen (OI) emission lines could be a trace of the Earth's aurora. We propose that the variation intensity from oxygen emission lines at polar region can be measured from every region including low latitude regions. Moreover, it is believed that from the results of solar wind dynamics, if the nightside particles are highly energetic, they could probably reach to lower latitude region.

2. Observations and data analysis

For ground-based observations, a 2.4 meters diameter telescope with Medium Resolution Echelle Spectrograph (MRES) at Thai National Observatory, Intanon Mountain, Chiang Mai, Thailand, was used to observe spectroscopic data, i.e. flat, bias, Thorium–Argon (Th–Ar) calibration spectrum, 5 frames dark sky for each night, and referent stars during 18:00–22:00 UT on 5–6 February 2017 (01:00–05:00 LT on 6–7 February 2017). Spectra of oxygen emission lines are studied via the spectrum of the dark sky, in order to search for the trace of auroral lines. A data reduction technique and peak intensity identification are discussed in the following sessions.

2.1. Data reduction

For spectroscopic data analysis, there were 3 programs including: 1) Total Commander program, 2) Dech95 – 2D image processing program, and 3) Dech–Fits – spectra processing program. All dark sky frames had to be cleaned from noise signals by data reduction to be ready for analysis. The clearest frame was used for extraction, a production of spectrum lines of a referent star, which was a B–type star. For extraction, Dech95 – 2D image processing program was used for creating a mask. The mask had to be ensured that it can fit every order of spectral image. Accordingly, the mask was used to extract every spectral image. After acquiring spectral lines, master flat frame, which had unsaturated intensity, was normalized before divided by using Dech–Fits – spectra processing program. The last part of data reduction is wavelength calibration, to convert position of pixel to wavelength. The spectrum of Th–Ar lamp, a calibrated light, was used to identify the exact wavelengths from database, and was finally applied to line profile of dark sky frames.

2.2. Spectral line intensity

The emission lines of specific element or compound can be identified by comparing the wavelengths from database. The absorption line database is mostly from the sun's atmosphere, while the emission line database is from Earth's atmosphere. Consequently, peak intensity of the oxygen emission lines can be determined in unit of Analog to Digital Unit (ADU) counts [5].

2.3. Solar wind data

The hourly-averaged solar wind data were obtained from the Low Resolution OMNI (Operating Missions as Nodes on the Internet) or LRO data set at OMNI website

(<http://omniweb.gsfc.nasa.gov/>). Solar wind and IMF data were observed by WIND spacecraft. WIND spacecraft which orbits around L1 point (~ 1.45 km from Earth aligning to sun) can detect the data around 1 hour depending on solar wind speed before reaching to Earth. Consequently, the auroral spectrum should correspond to the solar wind observation detected by WIND spacecraft approximately 1 hour earlier. The solar wind parameters that are chosen to compare with peak intensity of the oxygen emission lines are interplanetary magnetic field magnitude ($|B_{IMF}|$) including IMF in RTN coordinate (B_R , B_T , and B_N), solar wind ion density (ρ), solar wind plasma flow pressure (P), solar wind plasma flow speed (v), and Kp-index, which ranges from 0-9 for the aurora to be visible [7].

2.4. Correlations between space-based and ground-based data

Refer to aurora forecast from National Oceanic and Atmospheric Administration (NOAA) (<http://www.swpc.noaa.gov/products/aurora-30-minute-forecast>), solar wind data were used to predict the aurora because of connection between the solar wind and auroral characteristics. According to possibility of aurora occurring in low latitude regions, if there are highly energetic solar wind particles, we thus notice the correlations between solar wind parameters and intensity of oxygen emissions. The methods for calculating correlations in this study are linear Pearson correlation and Spearman correlation [8]. The linear Pearson correlation coefficient, r_P , shows linear relationship of two variables (x and y). The correlation can be calculated by the equation (1):

$$r_P = \frac{\sum_{i=1}^N (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^N (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^N (y_i - \bar{y})^2}}, \quad (1)$$

where N = number of all values, and \bar{x} and \bar{y} = averaged values of x_i and y_i , respectively.

For the Spearman or rank correlation method, the ranks of two variables instead of ordinary values are used to determine the monotonic relationship. The Spearman correlation coefficient, ρ_S , can be calculated by the equation (2):

$$\rho_S = 1 - \frac{6 \sum_{i=1}^n d_i^2}{n^3 - n}, \quad (2)$$

where n = number of all ranks, and d_i = difference between rank of x_i and y_i .

3. Results and discussions

There are 5 points of oxygen's emission intensity in each day (the x axis of plots in Figure 1.). The correlation coefficient between oxygen's emission intensity and each parameter of solar wind data, which were measured ~ 30 to ~ 50 minutes earlier depending on solar wind speed, was calculated (Table 1.). On 5 February 2017, the solar wind data and oxygen emission line intensity are negatively correlated excepting B_N and $|B_{IMF}|$ which are positively correlated. For the second day of our observation, the results show negative correlations as well, excepting B_N , ρ and P which are uncorrelated (Figure 1.).

4. Conclusions

The correlations between the solar wind, based on space-based observation, and low latitude emission of oxygen lines, based on ground-based observation, tends to be negative. The results suggest that the intensity of oxygen emissions might vary with solar wind in opposite

Table 1. Correlation coefficients between the solar wind dynamic parameters and the intensity of oxygen emissions.

Date	Correlation coefficients	Solar wind dynamic parameters						
		B_R (nT)	B_T (nT)	B_N (nT)	$ B_{IMF} $ (nT)	v (km/s)	ρ (N/cm ³)	P (nPa)
5 Feb 2017	Pearson	-0.617	-0.543	0.352	0.707	-0.837	-0.504	-0.650
	Spearman	-0.700	-0.100	0.100	0.667	-0.700	-0.300	-0.300
6 Feb 2017	Pearson	-0.689	-0.737	-0.224	-0.410	-0.638	-0.088	-0.169
	Spearman	-0.800	-0.821	0.000	-0.447	-0.600	0.000	0.000

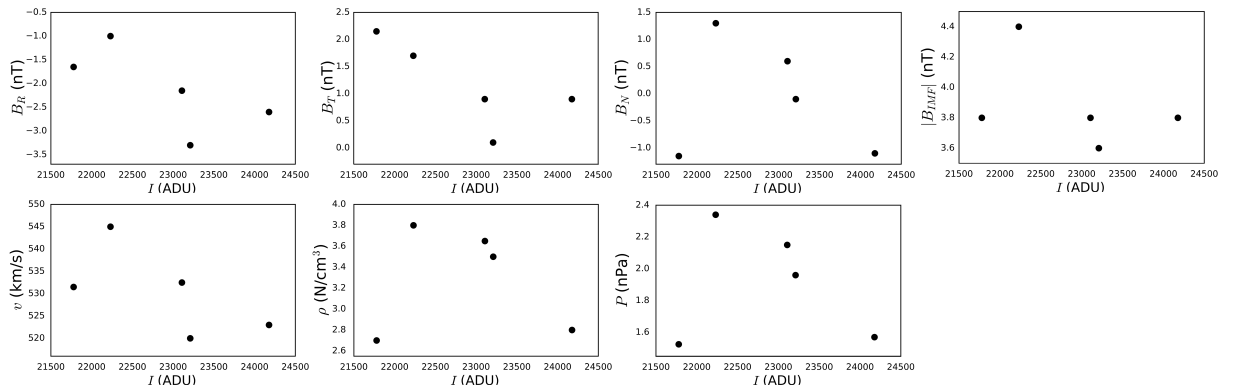


Figure 1. shows the solar wind dynamic parameters (B_R , B_T , B_N , $|B_{IMF}|$, v , ρ , and P) as a function of the intensity of oxygen emissions (I) on 6 February 2017.

direction. Oxygen emissions could be originated from the aurora under the influence of solar wind. However, there are chances that oxygen in atmosphere could collide with energetic particles from other sources outside the solar system, i.e. galactic cosmic rays. In addition, any other conditions are needed to be considered, for example, the corresponding times between space-based and ground-based observations. The other sources of oxygen emissions, and other processes that drive the auroral particles before reaching low latitude regions should be taken into consideration as well. In addition, detail study about the connection between solar wind activity and substorm event, including with the variability of oxygen emissions in low latitude region should be considered for future work.

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