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A preliminary comparison of Na lidar and meteor radar zonal winds during geomagnetic quiet and disturbed conditions

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ABSTRACT

We investigate the possibility that sufficiently large electric fields and/or ionization during geomagnetic disturbed conditions may invalidate the assumptions applied in the retrieval of neutral horizontal winds from meteor and/or lidar measurements. As per our knowledge, the possible errors in the wind estimation have never been reported. In the present case study, we have been using co-located meteor radar and sodium resonance lidar zonal wind measurements over Andenes (69.27°N, 16.04°E) during intense substorms in the declining phase of the January 2005 solar proton event (21–22 January 2005). In total, 14 h of measurements are available for the comparison, which covers both quiet and disturbed conditions. For comparison, the lidar zonal wind measurements are averaged over the same time and altitude as the meteor radar wind measurements. High cross correlations (~0.8) are found in all height regions. The discrepancies can be explained in light of differences in the observational volumes of the two instruments. Further, we extended the comparison to address the electric field and/or ionization impact on the neutral wind estimation. For the periods of low ionization, the neutral winds estimated with both instruments are quite consistent with each other. During periods of elevated ionization, comparatively large differences are noticed at the highermost altitude, which might be due to the electric field and/or ionization impact on the wind estimation. At present, one event is not sufficient to make any firm conclusion. Further study with more co-located measurements are needed to test the statistical significance of the result.

1. Introduction

Investigations of energetic particle precipitation (EPP) impact on the middle atmosphere have a long history, which starts in the late 1960s. Such studies have gained particularly strong attention in the last few decades. Energetic particles (protons, electrons, heavier ions) precipitate from different sources: directly from the Sun in large solar particle events (SPEs), from the plasma sheet and the radiation belts during geomagnetic storms and substorms, or from outside the solar system. The particles from different sources have different energy spectra and hence affect different altitudes and geographic locations (Sinnhuber et al., 2012). The EPP events can last up to a few days and lead to polar atmospheric changes through ionization, dissociation, dissociative ionization, and excitation processes. They are known to cause significant changes in chemical constituents such as HO_x (H, OH, HO_2), NO_x (N, NO, NO_2), and ozone, which in turn may cause changes in the associated heating and cooling rates. Changes in the temperature will impact the middle atmosphere residual circulation. The chemical changes during EPP events are evident even in small geomagnetic storms (Zawedde et al., 2016), while the subsequent potential dynamical changes are poorly understood. Detailed information on middle atmospheric chemical changes during EPP can be found in Sinnhuber et al. (2012). Very few observations have, however, reported the dynamical changes associated with EPP in the mesosphere lower thermosphere (MLT) (e.g., Pancheva et al., 2007; Singer et al., 2013; Trifonov et al., 2016).

The MLT is characterized as an ocean of dynamical changes ranging from short time scales, such as gravity waves, to large time scales, such as quasi-biennial oscillation, and their impact varies from regional response to global circulation changes. Both ground-based and space-based instruments are used to understand the MLT region. Although satellites provide global coverage, the coverage over polar latitudes is less complete. Ground-based observations such as MF radar (e.g., Manson and

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Meek, 1991; Kishore Kumar et al., 2014a), Meteor radar (e.g., Hocking, 2001; Pancheva and Mitchell, 2004; Pancheva et al., 2007; Singer et al., 2013; Kishore Kumar et al., 2014a, b) and lidar (She and Yu, 1994) are powerful tools and have been widely operated over different latitudes and longitudes. They provide a wealth of information about MLT dynamics. Each of these instruments has its own spatial and temporal coverage accompanied by advantages and disadvantages. The MF radar technique makes use of the ionized component of the atmosphere as a tracer for the neutral motions in the altitude region 50–110 km and provide neutral winds with a good time resolution. However, it has a limitation during strong ionization events such as EPP, which saturate the MF radar system and make it inefficient in resolving the neutral motions. The meteor radar technique, when implemented properly, can provide both wind and temperature information. It is based on the ionized column (meteor trail) created by meteor ablations. These ionized columns can strongly backscatter radar pulses in a direction at right angles to the long axis of the ionized column. By measuring the Doppler shift resulting from the motion of the meteor trail, a pulsed Doppler radar can be used to profile the neutral winds in the meteor region with one-hour time resolution generally considered optimal. Traditionally, the lidars are meant for a middle atmosphere thermal structure with high time and height resolution. Multiple frequency probing provides wind information with good time and height resolution (She and Yu, 1994). Unlike the MF and Meteor radars, however, lidars seldom provide a long, continuous data record as they are dependent on weather conditions and often require continuous supervision.

As the EPP influence is regional, mainly at auroral latitudes, and with short time scales of up to a few days, ground-based observations are of great importance in studying the dynamical changes. The meteor radars do a good job although the meteor counts are reduced due to ionization (e.g., Pancheva et al., 2007). The meteor radar method for measuring wind assumes that collision frequencies are sufficiently large that the ionized meteor trails assume a bulk motion equal to that of the ambient neutral wind. Kaiser et al. (1969) showed in their theoretical studies that in large electric fields meteor trail can be divided into motions of both the plasma and the ambient neutral atmosphere. High electric fields such as those that occur during geomagnetic disturbances might decouple the meteor trail from the neutral medium (Reid, 1983; Prikryl et al., 1986), leading to erroneous measurements of the neutral wind during sufficiently disturbed conditions. Hocking (2004) reported that there is an anisotropy in the rate of expansion of trails formed above 93 km altitude with a distinct diurnal variation. It has been suggested that this diurnal variation is due to external electric fields that are tidally driven. It is worth noting that both the lidar and meteor wind analyses assume that the vertical wind is zero, which might be violated during strong Joule heating events (Banks, 1977; Price and Jacka, 1991). As the neutral wind impact during these events is of fundamental interest in itself it is, hence, very important to quantify the errors in the winds due to the geomagnetic disturbances. This can be achieved by comparing the meteor radar winds with different remote sensing measurements, such as those of the lidars.

Co-located lidar and meteor wind measurements especially during high ionization periods are rather sparse at auroral latitudes. We were able to inter compare co-located measurements during the declining phase of an SPE (Nesse Tyssøy et al., 2008). Although the meteor radar observations are available during the entire month, the lidar measurements are limited, as only 14 h of measurements during 21–22 January 2005 are available. In this paper, we will investigate the correlation between the two wind measurements in the MLT region. We will assess the correlation between the different zonal wind measurements, as well as discuss potential sources of errors associated with geomagnetic disturbed periods.

This paper is organized as follows: Section 2 describes details of meteor radar and lidar and riometer data, along with a description of the methodology used in this study. Section 3 describes the results from different statistical comparisons between radar and lidar wind measurements and possible reasons for the observed biases and their consequences. Section 4 deals with discussion about the results and section 5 lists the conclusions drawn from the present study.

2. Database and analysis

The complementary instrumentation at and near Andøya offers an opportunity to investigate the compatibility of wind measurements based on meteor radar and lidar measurements during different geomagnetic conditions. Both the Skiymet meteor radar and the ALOMAR Weber Na lidar estimate winds in the altitude region 80–100 km. In addition, we will use the cosmic radio noise absorption in selected beams measured by the Imaging Riometer for Ionsopheric Studies (IRIS) as a proxy for the electron density variation above Andøya associated with disturbed geomagnetic conditions. A brief description of each technique and its measuring principle is given below.

2.1. Observational techniques

2.1.1. Meteor radar

The meteor radar used in this study is located at Andenes (69.27°N, 16.04°E). It is a commercially produced Skiymet radar (Hocking et al., 2001a) designed for all sky real time meteor detection. The meteor radar operates at a frequency of 32.55 MHz with a peak power of 12 kW and transmits radio pulses with a length of 13.3 μs that corresponds to typical sampling resolution of 2 km. At lower elevation angles (less than about 60° (30° from zenith)), the resolution is further degraded due to angular effects - an accuracy in locating the meteor of 1° leads to an additional height error of 1 km or so, so the overall resolution is more than 2 km. The meteor radar system transmits short electromagnetic pulses with a broad polar diagram using one vertically directed three-element Yagi antenna. If the meteor ionization trail is aligned perpendicular to the direction of line of sight from the radar to the meteor, it reflects the transmission signal backwards. The backscattered signal is received by the reception system, which consists of five crossed two element Yagi antennas. The five receiving antennas are arranged in the form of an asymmetric cross, with two perpendicular arms having lengths of 2λ, and the other pair of perpendicular arms having lengths of 2.5λ. Meteor locations are determined from the phase information recorded at the receiving antennas using an interferometric technique with an accuracy of better than ± 1.5-2° (Jones et al., 1998). The meteor detection and discrimination is done through regressive detection algorithms and a detailed description of the detection process can found in Hocking et al. (2001a).

From each specular meteor echo, the radial velocity of the meteor trail due to the projected background wind is estimated. To estimate the horizontal winds, an all-sky least squares fit is applied to the radial velocities of meteors detected within a specific altitude-time window, typically covering a height region of 3–4 km and a time duration of about 1.5 h. The analysis assumes a uniform wind u = (u, v, w) and minimizes the quantity $\sum_i (\{u.r_i^u\} - v_{ri})^2$, where i refers to the meteor number in a specified altitude-time window. The vector r_i^u is a unit vector pointing from the radar to the ith meteor trail. The value v_{ri} is the measured radial velocity, and $u.r_i^u$ is a dot-product. In general, the vertical velocities are assumed to be zero. If the difference between measured radial velocity and observed radial velocity is greater than 30 m/s, then the particular meteor is rejected as an outlier. The analysis will be repeated with the meteors that pass the threshold test. The altitude-time window is stepped at time steps of 1 h and height steps of 3 km. In general, the meteors detected at zenith angles between 10° and 60° are used for the horizontal wind estimation in order to avoid overhead reflections and to avoid range ambiguity at higher zenith angles. The horizontal winds are estimated in six height range bins 80.5–83.5, 83.5–86.5, 86.5–89.5, 89.5–92.5, 92.5–95.5, and 95.5–99.5 km and are assigned to 82 km, 85 km, 88 km, 91 km, 94 km and 98 km, respectively.

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