Effects of atmospheric oscillations on the field-aligned ion motions in the polar $F$-region

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Abstract. The field-aligned neutral oscillations in the $F$-region (altitudes between 165 and 275 km) were compared using data obtained simultaneously with two independent instruments: the European Incoherent Scatter (EISCAT) UHF radar and a scanning Fabry-Perot interferometer (FPI). During the night of February 8, 1997, simultaneous observations with these instruments were conducted at Tromsø, Norway. Theoretically, the field-aligned neutral wind velocity can be obtained from the field-aligned ion velocity and by diffusion and ambipolar diffusion velocities. We thus derived field-aligned neutral wind velocities from the plasma velocities in EISCAT radar data. They were compared with those observed with the FPI ($\lambda = 630.0$ nm), which are assumed to be weighted height averages of the actual neutral wind. The weighting function is the normalized height dependent emission rate. We used two model weighting functions to derive the neutral wind from EISCAT data. One was that the neutral wind velocity observed with the FPI is velocity integrated over the entire emission layer and multiplied by the theoretical normalized emission rate. The other was that the neutral wind velocity observed with the FPI corresponds to the velocity only around an altitude where the emission rate has a peak. Differences between the two methods were identified, but not completely clarified. However, the neutral wind velocities from both instruments had peak-to-peak correspondences at oscillation periods of about 10–40 min, shorter than that for the momentum transfer from ions to neutrals, but longer than from neutrals to ions. The synchronizing motions in the neutral wind velocities suggest that the momentum transfer from neutrals to ions was thought to be dominant for the observed field-aligned oscillations rather than the transfer from ions to neutrals. It is concluded that during the observation, the plasma oscillations observed with the EISCAT radar at different altitudes in the $F$-region are thought to be due to the motion of neutrals.

Key words: Ionosphere (Ionosphere–atmosphere interactions) – Meteorology and atmospheric dynamics (thermospheric dynamics; waves and tides)

1 Introduction

Oscillations of plasma and neutral atmosphere in the ionosphere were studied theoretically by Hines (1960). Following his pioneer work, the field-aligned ion-neutral interaction along with the effects of the ambipolar diffusion were formulated theoretically by Hooke (1968) and Testut and Francois (1971). Experimental evidence that agrees with previous theories has been reported, it was based on observations of neutral oscillations with all-sky imagers, photometers, and mass spectrometers on board satellites (e.g. Hedin and Mayr, 1987; Taylor and Edwards, 1991; Hines, 1993; Forbes et al., 1995) and on observations of plasma oscillations with incoherent scatter (IS) radars, HF and MF radars, ionosondes, and total electron contents when it was assumed that the plasma acts a passive tracer to display motions of the neutral atmosphere (e.g. Titheridge, 1968; Hajkowicz and Hunsucker, 1987; Rice et al., 1988; Hajkowicz, 1991; Williams et al., 1993; Manson et al., 1997). The observations also indicated that the propagation of traveling ionospheric disturbances is associated with atmospheric gravity waves (AGWs).

Modeling studies have suggested that the generation of AGWs at high latitudes is a direct response of the atmosphere to ionospheric disturbances at high latitudes (Richmond and Matsushita, 1975; Millward et al., 1993a, b). Ionospheric disturbances are associated with the electric field and electron precipitation in the auroral region, which enhance the thermal energy in the atmosphere through Joule/frictional heating and the

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heating due to the direct impact of incoming electrons with neutral particles. The thermal energy tends to expand the neutral atmosphere, producing pressure gradients that drive divergent flows vertically and/or horizontally. Generally, upward flows are generated during enhancement of the electric field and electron precipitation. When the enhancement relaxes, the heat source ceases to be effective, which stops the thermal expansion. The parcel then moves downward because the gravitational force overcomes the buoyancy one. Enhancement of the electric field and electron precipitation thus can result in vertical motion of the neutrals.

The dispersion relation of internal gravity waves (Hines, 1960) reveals that the period of neutral atmospheric waves must be longer than the Brunt-Väisälä period. The Brunt-Väisälä period is proportional to the ratio of the neutral temperature to the mean neutral mass. While the mean mass gradually decreases with height, the neutral temperature, as a first approximation, increases gradually with height in the F-region. The Brunt-Väisälä period thus normally increases with height. For example, in the auroral ionosphere, it is estimated to be about 11 min at 230 km and 13 min at 300 km. The increase in the Brunt-Väisälä period with height indicates that the oscillation period of the neutrals also increases with height. Because the waves and oscillations have height-dependent features, incoherent scatter radars with good altitude resolution (20–50 km in the F-region) are an appropriate tool for studying gravity waves.

Interactions between plasmas and neutrals can be described by coupled nonlinear partial differential equations such as the momentum equation, the energy equation, and the continuity equation, all of which must be solved together in order to estimate thermospheric motions, temperatures, and densities. Understanding the atmospheric motions in the thermosphere is difficult because the plasma affects the neutrals through frictional heating and momentum exchange. The plasma is, in turn, affected by the neutral motions through collisions. Hence, simultaneous observations of ion and neutral motions must be the basis for more sophisticated modeling efforts.

Simultaneous observations with IS radars and interferometers have been conducted in the auroral region (Nagy et al., 1974; Rees et al., 1984; Thuillier et al., 1990; Lilensten et al., 1992; Lathuille et al., 1997). In the F-region, meridional neutral winds derived from European Incoherent Scatter (EISCAT) radar data showed relatively good agreement with the winds observed with the Michelson Interferometer for Coordinated Auroral Doppler Observations (MICADO interferometer) with a few discrepancies (Thuillier et al., 1990). These discrepancies were related to the assumption of negligible vertical neutral wind velocity in the derivation of the meridional wind velocity using EISCAT radar data. In addition, the meridional wind velocity derived from EISCAT radar data depends on the ion-neutral collision frequency, which has to be derived from a model. Lilensten et al. (1992) derived the meridional neutral wind velocity from EISCAT radar data considering the vertical neutral wind velocity, which was calculated from the MICADO interferometer temperature. They concluded that a vertical neutral wind velocity usually has a stronger effect on the derivation of the meridional wind velocity than ambipolar diffusion velocity.

Altitude profiles of the neutral wind velocity and the emission rate should be considered when estimating the effective height range of Fabry-Perot interferometer (FPI) measurements. A wind shear in the polar F-region has been observed using rockets that released a trimethyl aluminum chemical trail (Mikkelsen et al., 1981). The results suggest that the Lorentz force and Joule/frictional heating have a strong influence on the wind shear. Rees and Roble (1986) calculated the altitude at which the auroral red-line emission rate has a peak, and found that it is a function of the characteristic energy of the incident Maxwellian electron-energy spectra. The altitude decreases as the characteristic energy increases, from 240 km at 0.1 keV to 180 km at 2.0 keV. The height-profile of the emission rate also depends on the neutral wind velocity due to local transport of neutral parcels (Hays and Atrey, 1971; Sica et al., 1986). To estimate the effects of the variation in the altitude of the peak emission rate and of the wind shear as well as the neutral temperature gradient, McCormac et al. (1987) simulated the neutral wind velocity that would be observed with an FPI at a wavelength of 630.0 nm. They found a discrepancy between the simulated neutral wind velocity and the exospheric velocity, which was caused by large vertical gradients of the neutral wind velocity.

This work describes the ionosphere-thermosphere interactions, focusing especially on a comparison of the field-aligned oscillations of neutrals in the F-region for periods from 14 to 55 min derived independently with the EISCAT UHF radar and with a scanning FPI at Tromsø, Norway (69.6°N, 19.2°E). Section 2 describes the instrumentation and data. Section 3 describes the method we used to estimate the neutral wind velocity derived from EISCAT radar data, the model we used to calculate the 630.0 nm emission rate, and the two methods we used to interpret the neutral wind velocity. Section 4 describes the observation results. The momentum transfer processes between ions and neutrals are discussed in Sect. 5.

2 Instrumentation and data

For the observation campaign from January 11 to February 13, 1997, two FPIs of the Communications Research Laboratory (CRL), Japan, were installed at the EISCAT radar site in Tromsø (Ishii et al., 1997). One was an all-sky-type FPI, and the other was a scanning-type FPI. In this work, the neutral wind velocity observed with the scanning FPI was used, because the scanning FPI had a full-view angle of 1.4°, which was almost the same as the full-power beam width of the EISCAT UHF antenna, about 1.2°. The scanning FPI was fixed to look along the geomagnetic field line.