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Scientific note

A study on the Arctic upper-atmospheric tide by EISCAT radar —Recent results and prospects—

Takehiko Aso

Arctic Environment Research Center, National Institute of Polar Research,
Kaga 1-chome, Itabashi-ku, Tokyo 173-8515 (aso@nipr.ac.jp)

Abstract: The polar middle and upper atmospheric tide can be affected by both electromagnetic disturbances from above due to ion drag or Juole coupling and by the various interactions due to polar vortex and wave dynamics in the denser lower atmosphere. The EISCAT radar system now includes mono-static UHF radar in Svalbard (ESR, 78°N) in the polar cap region, which complements the mainland KST system of both tri-static UHF and mono-static VHF radars in the auroral region of northern Scandinavia (67–69°N). It is expected that this radar system will play more important role in studying the Arctic upper and middle atmosphere dynamics. Here, a brief description of recent EISCAT tidal observations by the new ESR (EISCAT Svalbard Radar) is given.

1. Introduction

Four years have elapsed since the National Institute of Polar Research, Japan joined the EISCAT Scientific Association. During this period, research activities in the Arctic upper atmosphere have widely expanded in the vast disciplines of the solar-terrestrial environment from the mesosphere to the thermosphere, ionosphere, and magnetosphere. Especially, conjunctive and global multi-instrumental observations with satellites, ground-based radar and optical platforms are intensive by on-going and planned. EISCAT mainland radar comprises two radars, a tri-static UHF (931 MHz) system in Tromsø (69 °N, Norway), Sodankyla (67°N, Finland) and Kiruna (68°N, Sweden), and a VHF (224 MHz) mono-static radar in Tromsø. In 1997, a new EISCAT UHF (500 MHz) radar system was built in Svalbard, (78°N, referred to as EISCAT Svalbard Radar ESR) which can explore the polar cap ionosphere where solar wind flows directly into the earth's upper atmosphere through the cusp/cleft region. In autumn 1999, a fixed Cassegrain antenna was added to the ESR system, and observation of higher temporal and spatial resolutions has become possible.

We are working on the observation of polar upper-atmospheric dynamics by the EISCAT radar and associated radars and optics to study the dynamical coupling of the polar middle atmosphere and lower thermosphere. Specifically, observations of atmospheric tides have ever been done in Tromsø. The ESR radar further north is expected to reveal latitudinal differences in tidal signatures and also involved dynamical features influenced from above via particles and fields driven by geomagnetic disturbances, and from below via wave and mean flow coupling in the polar middle atmosphere. Here emphasis is placed on the recent results and prospect of a study on atmospheric tides by the EISCAT radar.

2. Observations

In August 1998, ground clutter, which precludes the lower altitude sounding without going to low antenna elevation was fairly well eliminated by adopting the appropriate gup3 coding (Turunen, 1999), and the ESR radar detected echo returns from ranges down to 90 km in the field-aligned beam pointing direction. It must be added that Röttger *et al.* (1998) had also previously done a *D*-region sounding experiment with the ESR by using a complementary code. Collaborative data analysis of the first ESR upper-mesosphere-lower thermosphere dynamics test run on August 11–14 and the following CP (common program) run on August 17–19, 1998, have been reported by Van Eyken *et al.* (2000) and Aso *et al.* (1999). Then, the ionosphere *D* and *E* layer observation on October 5, 1998 (interrupted by the power failure) and 2-component (zonal/meridional) phase quadrature observation on March 17–18, 1999 were carried out by us in collaboration with the University of Tromsø. The March run was a 24 hr short observation by switching the antenna beam direction between south and west at elevation angle 45°. Hence, the neutral wind inference is limited to the lower altitudes in this run. In July 1999, a fairly long period of observation of tides and gravity waves was proposed by UK scientists and participated in by all the associated countries. Radar runs were carried out in CP2 mode by KST radar (99/07/01 1500–99/07/03 0000 and 99/07/03 1200–99/07/09 1500) and in gup3 mode by ESR (99/07/01 0900–99/07/09 1500) over 9 days in July 1999 with some interruptions. A series of these observations is planned to study problems of the arctic polar atmospheric tide, including climatology of the diurnal tidal component, penetration of non-migrating tide to polar latitudes, the erratic appearance and temporal variabilities of zonal wavenumber 1 semidiurnal component which was first detected by the meteor radar observation at the South Pole (Forbes *et al.*, 1995; Portnyagin *et al.*, 1998), other tidal variabilities associated with mode coupling and non-linear coupling with planetary and gravity waves (*e.g.*, Beard *et al.*, 1999), behavior and variabilities of the ter-diurnal component, the effect of hydromagnetic tides and ionosphere-magnetosphere disturbances from above and the effect of wave and mean flow interactions in the lower atmosphere (Aso *et al.*, 1987). EISCAT Tromsø data in summer 1998 show enhanced equatorward flow of ions associated with strong particle precipitation above 120 km. Moreover, the energy dissipation rate of the gravity wave in the high latitude region has been estimated from spectrum analysis of wind-velocity data down to 85 km based on our October observation (Hall and Aso, 1999). In the next section, a brief description on the tidal analysis of recent EISCAT observations and comparison with the ATM2 modeling (Aso *et al.*, 1987) is given.

3. Results and discussion

Figure 1 shows the results of analysis of the diurnal component of magnetically northward (almost meridional) wind for the radar runs mentioned above. Amplitudes (solid lines) are converted from the measured field-aligned to horizontal velocities by multiplying with 1/sin 8°=7.2 for ESR and 1/sin 12°=4.8 for Tromsø where 8° and 12°

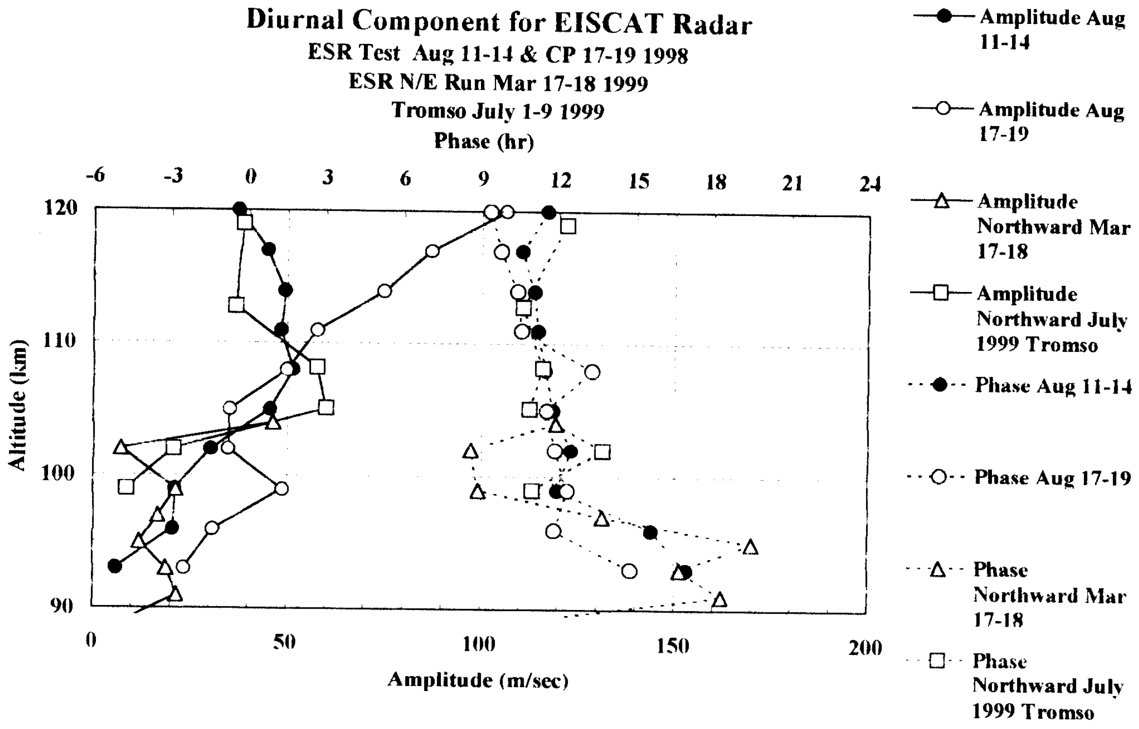

Fig. 1. Amplitude and phase of diurnal component observed by EISCAT radar.

are the magnetic field inclination, respectively. Phase (dashed lines) refers to the time of northward maximum in UT (local time − 1 hour). Solid and open circles refer to ESR runs in August 1998, triangles to observations by ESR on March 17, 1999, and squares to the Tromsø long run in July. The March run was only for 24 hr, and data quantity at night was low. A study of possible ion-drag induced neutral instability has also been made based on this experiment (Hall and Aso, 2000). For summer-time observations latitudinal difference is not obvious.

Horizontal amplitude lies between 20–70 m/s and is larger than is obtained from the ATM2 model without thermospheric *in-situ* forcing (Aso *et al.*, 1987). Amplitude increase and constant phase above 100 km might suggest *in-situ* forcing in this altitude region and above (Miyahara and Miyoshi, 1997). Phase is consistent with the dominating evanescent (1, −2) mode at high latitudes with its phase staying around 1100 UT. Furthermore, superposition of some phase gradient or propagating characteristic is envisaged. In winter-time, penetration of a non-migrating diurnal component to higher latitude is indicated by ATM2 modeling (Ekanayake *et al.*, 1997; Aso, 2000). The electron density in winter is fairly low, and observation at this altitude around 100 km is not easy. A meteor radar, if it exists, can complement this high-powered incoherent scatter radar in its continuous operation. Williams *et al.* (1994) have given the Tromsø tidal result averaged over 11 days during August to October in 1987 to 1988. Amplitude and phase there are, by and large, consistent with the present results.

Altitude profiles of amplitude and phase for the semidiurnal component are shown in Fig. 2. Details are the same as in Fig. 1. Also, ATM2 modeling profiles of the northerly

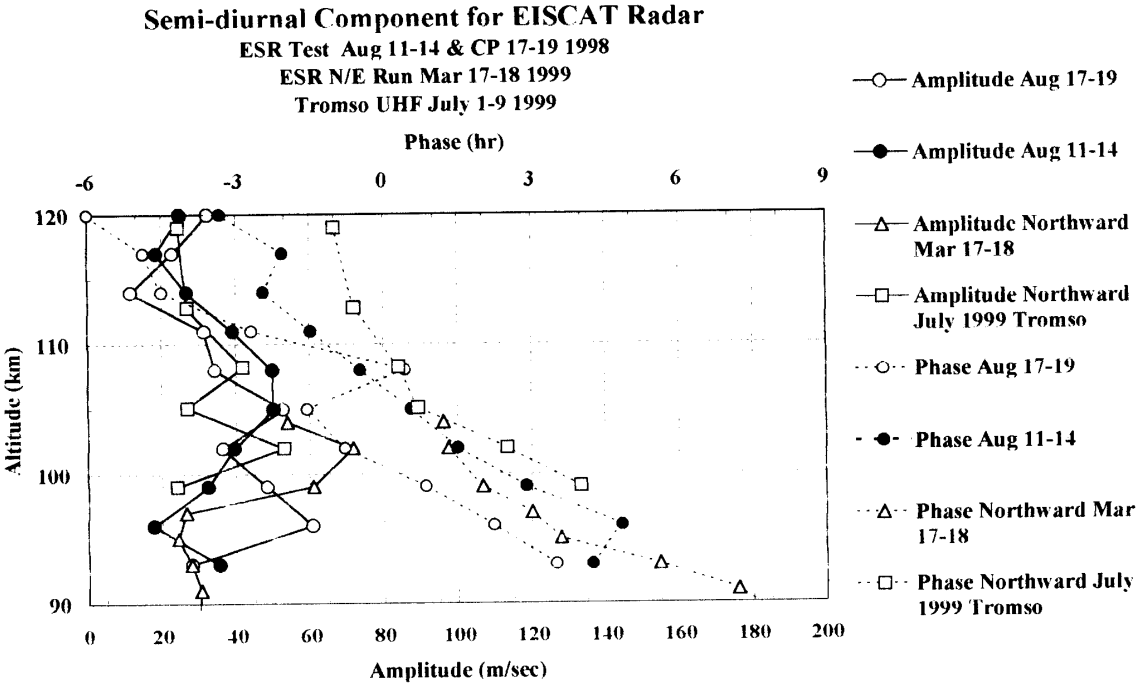

Fig. 2. Amplitude and phase of semi-diurnal component observed by EISCAT radar.

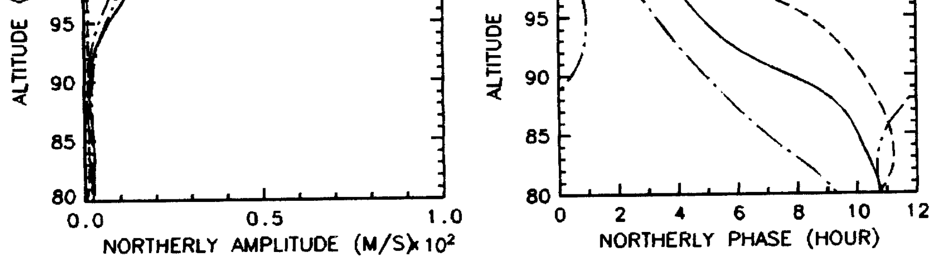

Fig. 3. Numerical profiles of the northerly amplitude (left) and phase (right) of the semi-diurnal tides at 80° N for August (solid), October (dashed-dot), November (dashed-double-dot) and equinox (dashed) wind conditions by the ATM2 modeling.

amplitude (left) and phase (right) of the semi-diurnal tide at 80°N are indicated in Fig. 3 for August (solid), October (dashed-dot), November (dashed-double-dot) and equinox (dashed) background wind conditions. The amplitude of the semidiurnal tide in Fig. 2 lies around 40–70 m/s; the ATM2 modeling result is by and large smaller. This might be due to the possible mixture of non-migrating $s=1$ semidiurnal component also at summer polar mesosphere and to *in-situ* forcing or caused by an influence of $E\times B$ ion drift above 110 km. The slope of a phase is steep corresponding to both prevailing higher order modes at high latitudes and the non-migrating mode (not shown here), and vertical wavelength is about 30 km, consistent with the ATM2 model calculation at high latitudes. The observed phase is $-2\sim0$ UT 110 km, 0–3 at 100 km, 5–7 at 90 km and a deviation is seen with the ATM2 model. Apart from a small phase lag, the result by Williams *et al.* (1994) shows similar features to those in Fig. 2. The result of the GSWM (Global Scale Wave Model) model based on the formulation by Forbes (1982) is also similar to our ATM2 result. In doing observations and analyzing the semidiurnal component data, we must take into account the diminishing migrating component at the pole, dominant summer time zonal wavenumber 1 component, and other complications such as inertial oscillations and pseudo-tide observed in temperature variations (Walterscheid *et al.*, 1986). At present, numerical modeling by Miyahara (Personal communication, 2000) suggests that the wavenumber 1 semidiurnal component is evidently dominating the migrating component at higher latitudes and might presumably be due to the nonlinear interaction of semidiurnal tide and zonal wavenumber 1 stationary planetary waves in the lower atmosphere, as suggested by Forbes *et al.* (1995). Our ATM2 modeling assuming hypothetical forcing in the winter strato-mesosphere also supports the dominance of nonmigrating semidiurnal tide in the opposite hemisphere. In addition, the 3-hour phase difference of semidiurnal component is clearly found in the beam-switching experiment between south and west in March.

Strong $E\times B$ ion drift is imparted to the neutral motion daring the disturbed condition. Comparison of magnetogram and ion drift suggests that this hydromagnetic effect is less obvious below ~110 km. Though some works have dealt with this issue (*e.g.*, Johnson and Luhmann, 1985), this should, however, still be pursued from both theoretical and observational points of view by relying on the vectorially derived EISCAT radar velocity data.

4. Conclusion

Analyses of the EISCAT 9 days continuous observations in July 1999 are now on-going. In order to clarify the tidal climatology in the polar region, long-term and global observations with respect to longitude, latitude and conjugate chain are essential. To this end, we are planning to install a meteor radar and the airglow spectrometer in Longyearbyen, Svalbard to participate in the comprehensive analysis with radar and optical instruments such as the SOUSY radar which detects PMSE echo, Esrad in Kiruna, MF radars in Tromsø and Poker Flat, a meteor radar in Dixon Island, and also the MF/meteor radar in Antarctica.

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