New insights found from coalescence of the ionospheric and thermospheric measurements at auroral latitudes

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Understanding the flow of energy and mass throughout the magnetosphere-ionosphere-thermosphere coupled system is a fundamental goal of solar-terrestrial physics. Since substantial energy accumulated in the substorm growth phase in the magnetospheric tail flows into the polar ionosphere immediately after the substorm onset, investigating the energy dissipation process at high latitudes around the time of substorm onset can contribute significantly to achieving that objective. Sudden commencement of the poleward expansion of the auroral arc is one of the typical features in the first stage of the substorm expansion phase. Upward field-aligned current (FAC) induced by the inverted-V type potential pattern in the acceleration region of the magnetosphere is spatially encompassed by the converging electric field, $\mathbf{E}_{\perp}$, perpendicular to the local magnetic field, **B**, or the arc at ionospheric heights. The perpendicular electric field accelerates ionospheric ions in the $\mathbf{E}_{\perp}\times\mathbf{B}$ direction, which in turn transfers the ion momentum to the neutral particles via collisions. That is the fundamental mechanism of the Lorentz force. The curl-free current or the principal ionospheric closure current near but outside of the arc results in an exchange of energy from the kinetic energy of the ionospheric ions to the thermal energy of the thermospheric particles, according to Ohm's Law. This is the Joule heating process. Lorentz force and Joule heating are the two major processes capable of modulating the dynamics of the thermosphere.

Lower thermospheric wind fluctuations in the vicinity of an auroral arc immediately before and after a substorm onset were examined by analyzing data from a ground-based green line Fabry-Perot interferometer (FPI) at Tromsø, Norway, and in situ measurements from a trimethyl aluminum (TMA) trail released from a sounding rocket launched during the Dynamics and Energetics of the Lower Thermosphere in Aurora 2 (DELTA-2) campaign on 26 January 2009. Soon after the rocket launch but before disappearance of the TMA trail, a substorm onset occurred. The DELTA-2 TMA experiment appears to be the first case in which the substorm onset occurred during the TMA wind measurement. It is known that energy dissipation induced by the ionospheric closure current is compacted at the poleward side of the discrete arc in the ionospheric morning cell. Both FPI and TMA measurements were made at the poleward side, but the FPI measured winds nearer to the poleward edge of the arc than the TMA by 110–130 km. The FPI winds at distance of 53–74 km relative to the arc edge showed clear fluctuations immediately after the substorm onset, but there was no obvious similar fluctuation in the TMA-measured winds.

This result suggests that magnetospheric plasma energies dissipated adjacent to the breakup arc flow into a moderately narrow area of the ionosphere, but are large enough in magnitude to modulate the lower thermosphere within a few minutes. The response time is surprisingly quicker than we expect. Some related studies implied significance of the advection in the lower thermosphere, by contrast localized torrential energy dissipations and sequential confinement of the wind modulations seen in the DELTA-2 result lack in logical consistency. To go beyond our present understanding, we should refine on the theory of particle collisional process embedded in the partially ionized space retrieving evidences from measurements. Our understanding is now confronted by necessity of more precise measurements, requiring a paradigm shift by new methodologies such as in-situ ion/neutral particle measurements with ionospheric satellites but in spatiotemporally perfect simultaneousness and volumetric measurements of the ionosphere and thermosphere with high resolutions in time and range. This presentation will discuss future researching activities, in particular regarding application of EISCAT_3D, Scanning Doppler Imagers (SDIs) and the FACTORS satellite.

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