# Study on dynamics in the mesosphere, thermosphere and ionosphere with optical observations from the International Space Station

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**Abstract**

Mesospheric airglow structures and global $He^+$ distribution in the ionosphere were investigated based on optical observations from the International Space Station (ISS). The International Space Station - the Ionosphere, Mesosphere, upper Atmosphere, and Plasmasphere mapping (ISS-IMAP) mission and the Astronaut-Ionosphere, Mesosphere, upper Atmosphere, and Plasmasphere mapping (A-IMAP) campaign were carried out onboard the ISS from 2012 to 2015. New data obtained in these missions enable us to investigate phenomena in the Earth's upper atmosphere from a new point of view.

In chapter 1, the dynamics of the Earth's upper atmosphere is briefly introduced. I also introduce the outlines of the ISS-IMAP and A-IMAP mission.

In chapter 2, calibration technique of space-borne photography is described. In A-IMAP campaign, airglow on the limb of the Earth captured with a digital single-lens reflex camera from the ISS by astronauts. To utilize the photographs as scientific data, sensitivity calibration of the camera was carried out, and new geometry calibration technique was developed. The result of sensitivity calibration indicated that the DSLR cameras have a sensitivity for airglows in the Mesosphere and $F$-region ionosphere, such as OI 557.7 nm and 630 nm emissions, NaD, OH and $O_2$ emissions. Matching the apparent city light positions on a photograph with the actual city light positions derived from the DMSP-OLS stable night light map in the pinhole camera model, the imaging parameters, such as the angle of view, exact position, and orientation of the camera, can be determined. I applied the calibration method to the photographs taken by astronauts on the ISS on August 26, 2014, and evaluated the precision and stability of the calibration. The precision of the derived time lag for the camera clock was 0.3 second and that of the camera orientation was 0.08°. The precision of the FOV was 0.12° for the pixel with a distance of 1,500 pixels from the center of the image. The EIA structure captured in the

red channel of the space-borne photographs is mapped to geographic coordinate, and compared with IMAP/VISI observation. The comparison shows good agreement and supports the validity of the calibration method. With the technique described in this chapter, consecutive airglow photographs taken from the ISS can be utilized as a scientific data of airglow in the Earth's upper atmosphere.

In chapter 3, I present the vertical and horizontal structures of the mesospheric airglows, that were successfully obtained from a series of photographs taken by astronauts from the ISS with front-viewing field-of-view. A large-scale wave structure was identified at mid-latitudes, where the intensity and layer heights of the airglows were modulated. The wave front was extended to 2,000 km in the zonal direction, and the horizontal wavelength was $820 \pm 60$ km. The wave structures in the green (OI) and the red (NaD, OH) airglows were in the opposite phase, indicating that the vertical wavelength was $8 \pm 4$ km. It is interpreted that the imaging succeeded in capturing the three-dimensional image of mesospheric large-scale gravity wave for the first time, while previous ground-based measurements partially detected such a large-scale wave as a temporal variation.

In Chapter 4, the global distribution of $He^+$ in the topside ionosphere was presented using data of the $He^+$ resonant scattering emission at 30.4 nm obtained by the Extreme Ultra Violet Imager (EUVI) onboard the International Space Station. The optical observation by EUVI from the low-Earth orbit provides $He^+$ column density data above the altitude of 400 km, presenting a unique opportunity to study the $He^+$ distribution with a different perspective from that of past studies using data from *in-situ* measurements. We analyzed data taken in 2013 and elucidated, for the first time, the seasonal, longitudinal, and latitudinal variation of the $He^+$ column density in the dusk sector. It was found that the $He^+$ column density in the winter hemisphere was about twice that in the summer hemisphere. In the December solstice season, the magnitude of this hemispheric asymmetry was large (small) in the longitudinal sector where the geomagnetic declination is eastward (westward). In the June solstice season, this relationship between the $He^+$ distribution and the geomagnetic declination is reversed. In the equinox seasons, the $He^+$ column densities in the two hemispheres are comparable at most longitudes. The seasonal and longitudinal dependence of the hemispheric asymmetry of the $He^+$ distribution was attributed to the geomagnetic meridional neutral wind in the $F$-region ionosphere. The neutral wind effect on the $He^+$ distribution was examined with an empirical neutral wind model, and it was confirmed that the transport of ions in the topside ionosphere is predominantly affected by the $F$-region neutral wind and the geomagnetic configuration.

Chapter 5 summarizes the new results obtained from the optical observations from the ISS.