THE POSSIBLE INFLUENCE OF THE EARTHWARD/TAILWARD PROTON FLUX IN THE EARTH'S MAGNETOTAIL ON THE LUNAR SURFACE.

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Introduction: The Earth's Moon is exposed to a wide range of plasma environments during its 29.5-day orbit period. For about three-quarters of each lunar lunation, the Moon is bombarded by the solar wind. For the remaining 3-5 days, the Moon is shielded from the solar wind bombardment in the Earth's magnetosphere, whereas exposed to ions coming from the ionosphere and upper atmosphere (hereafter called Earth wind). The Earth wind is transported from the ionosphere/upper atmosphere to the lunar orbit along the magnetic field lines and observed by the Kaguya, Geotail, and ARTEMIS spacecrafts [1-5]. Ozima et al. (2005) proposed that most of the nitrogen and some of the other volatile elements in the nearside lunar soils come from the Earth's atmosphere rather than the solar wind [6]. Recently, Wei et al. (2020) suggested that the evolution of the magnetosphere and atmosphere can be inferred by examining the implanted particles in the lunar soil from both the lunar nearside and farside during geological history [7]. Many studies show that solar wind protons implanted in the uppermost surface of lunar mineral grains could produce lunar surface water (e.g. [8-11]). The lunar surface water content has not decreased when the Moon enters the magnetotail, when the solar wind is shielded by Earth's magnetic field [12-13]. Thus, it is important to statistically examine the plasma flow within the Earth's magnetotail around the Moon and to estimate their influences on the lunar surface.

The plasma flows in the Earth's magnetotail have been observed within ~ –66 RE < X GSM < ~ -9 RE including lunar orbit using the Active Magnetospheric Particle Tracer Explorers/ Ion Release Module (AMPTE/IRM), ISEE, Geotail, Cluster, and ARTEMIS observations [14]. Kiehas et al. (2018) showed that there are many fast earthward ions flows emanating from beyond the lunar orbit using five years of ARTEMIS data. They suggested that near-Earth and midtail reconnection are equally probable of occurring on either side of the ARTEMIS downtail distance. In this work, we intend to statistically examine the earthward/tailward flux around the Moon using ARTEMIS observations and study their influence on the lunar surface water using Monte Carlo simulation.

Methods: In this study, we used the ion measurements from the two ARTEMIS probes (ARTEMIS-P1 and ARTEMIS-P2) to find earthward/tailward flow events. Following the selection criteria used in previous statistical studies, the earthward and tailward flow events were selected by Vx > 30 km/s and Vx < -30 km/s, respectively, with durations of at least 1 minute. Figure 1 shows an example of the earthward flux event observed by ARTEMIS-P1.

The ballistic hops of water molecules in the lunar exosphere are simulated using a Monte Carlo method as described in Schörghofer (2014) [15]. Individual water molecules are launched with Gaussian-distributed Cartesian velocity components that amount to a random initial azimuth and thermal speed appropriate for the local surface temperature. Water molecules are lost inflight by photo-destruction.

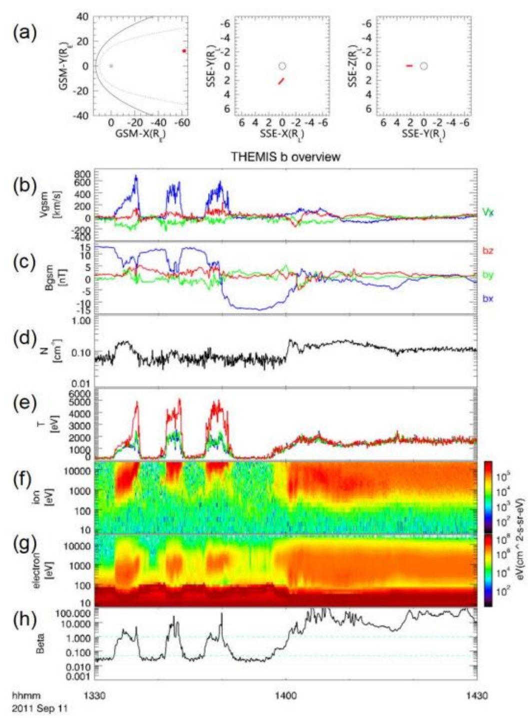

Figure 1. Overview of an earthward flux event observed by ARTEMIS-P1 satellite. From top to bottom are locations of the satellite in the SSE coordinate system, plasma velocity, magnetic field, density, temperature, proton energy spectrum, electron energy spectrum, and plasma beta.

Results and Discussion: As shown in Figure 2, the earthward/tailward flux mainly appears in the plasma sheet and plasma sheet boundary layer. The occurrence rate of tailward flux is higher than that of earthward flux. The occurrence rate of earthward flux is higher on the dawnside and the occurrence rate of tailward flux is higher on the duskside, which are consistent with previous results [14]. Figure 3 shows that the energy flux at 1 keV of earthward/tailward flux is two orders of magnitude lower than that in the solar wind at 1 keV, the earthward/tailward flow has an energy flux two orders lower than the solar wind. However, the energy flux with energies greater than 4 keV is larger in earthward/tailward flow than that in the solar wind.

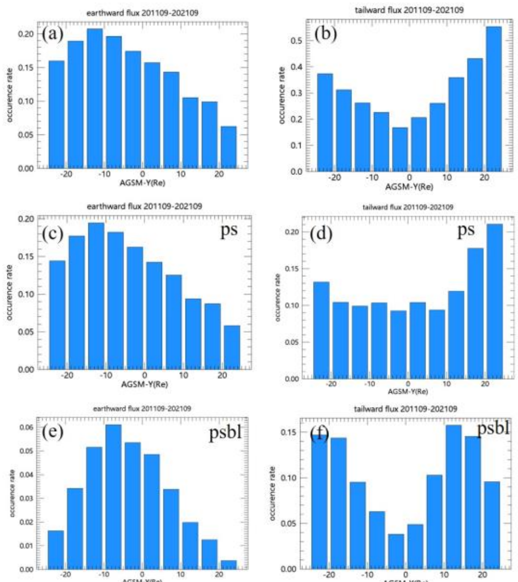

Figure 2. (a-b) Occurrence rates of the earthward and tailward flow events as a function of AGSM-Y. The occurrence rates of the earthward and tailward flow events (c-d) in the plasma sheet and (e-f) in the plasma sheet boundary layer, respectively, as a function of AGSM-Y.

We simulate water molecules produced by earthward flux in Earth wind. Figure 4 shows that the water molecules produced by earthward flux can be preserved in the lunar soil, as the lunar farside is in the nightside and the temperature is lower. Both the earthward ion flow and tailward ion flow in the magnetotail can implant both the lunar farside and nearside, whereas the solar wind only implant into the lunar farside, which could explain the formation of hematite in the both side of the lunar surface. Moreover, the high energy protons and heavy ions in earthward flux could produce more vacancies on the lunar surface, which could effectively promote the water formation process.

The possible formation mechanism for Earth wind-induced water remains unclear due to the fact that the transport of mass, flux, and energy in the Earth's magnetotail is much more complicated and dynamic than that in the solar wind.

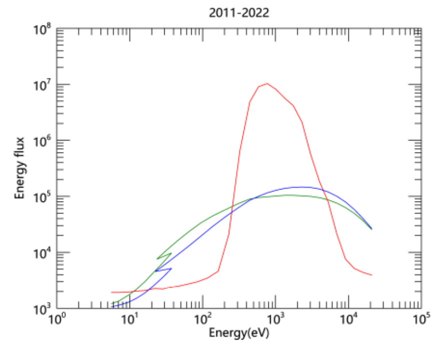

Figure 3. The energy flux of solar wind (red), earthward flux (blue), and tailward flux (green).

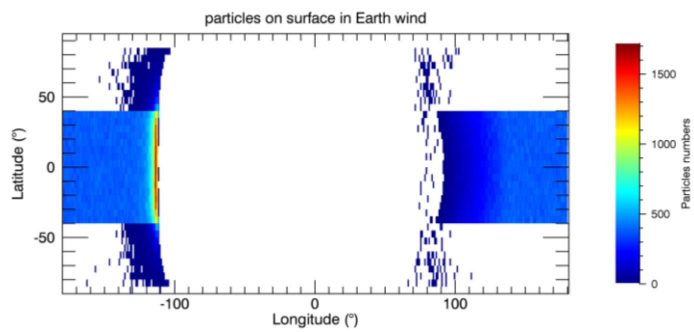

Figure 4. The simulation result of the water molecules produced by earthward flux implanted into the lunar farside surface.

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