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Geomagnetic Storms and Space Weather: Current Status of Understanding, Modeling and Future Developments

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Space weather is an old branch of space physics that is currently experiencing explosive growth, because its effects on human technologies have become increasingly diverse [1]. The field of space weather concerns the variability of solar processes that cause interplanetary, magnetospheric, ionospheric, atmospheric and ground level effects [2]. Geomagnetic storms are one of the most important space weather phenomena, as many effects and impacts are closely related to the occurrence of geomagnetic storms. During geomagnetic storms, plasma populations from the solar wind and from the ionosphere (including oxygen ions) are energized up to a few hundred keV and form a torus-shape current flowing around the Earth. This current is called the 'ring current'. The diamagnetic disturbance from the ring current detected by the ground-based magnetometers signals the appearance of a geomagnetic storms. In order to understand the dynamics of the geomagnetic storms and the ring current plasma, we need to simulate the global response of the Earth's magnetosphere to external driving conditions. This is a nontrivial task, since the near-Earth plasma environment is a mixture of different plasmas in different regimes, from highly collisional ionospheric plasma to collisionless magnetospheric plasma. All these populations are coupled; therefore, a complex solution is required which allows the coupling of different plasma models. We review approaches to simulate geomagnetic storms and the ring current plasma, including bounce-averaged kinetic models, coupled global MHD-bounce-averaged codes, and hybrid global codes. An important question is how to verify global model results. We present the imaging of the ring current in Energetic Neutral Atoms (ENA) as a technique to diagnose the global plasma dynamics in the Earth's magnetosphere. Published work demonstrates that ENA imaging allows to restore the underlying plasma population of the ring current, its pitch-angle distributions and 3D dynamics. Figure 1 shows an example from NASA IMAGE mission, as well as model results. It is anticipated that future ENA detectors with better resolution and sensitivity will be able to resolve plasma dynamics in the near-Earth tail region. Finally, we describe space weather effects related to geomagnetic storms and outline the challenges of modeling and predicting these effects with global models. In conclusion, we review future developments, showing examples of data assimilation, tomography and machine learning techniques to study magnetospheric plasmas, and the ring current region in particular. This work was supported by NASA grant 80NSSC19K0085.

References

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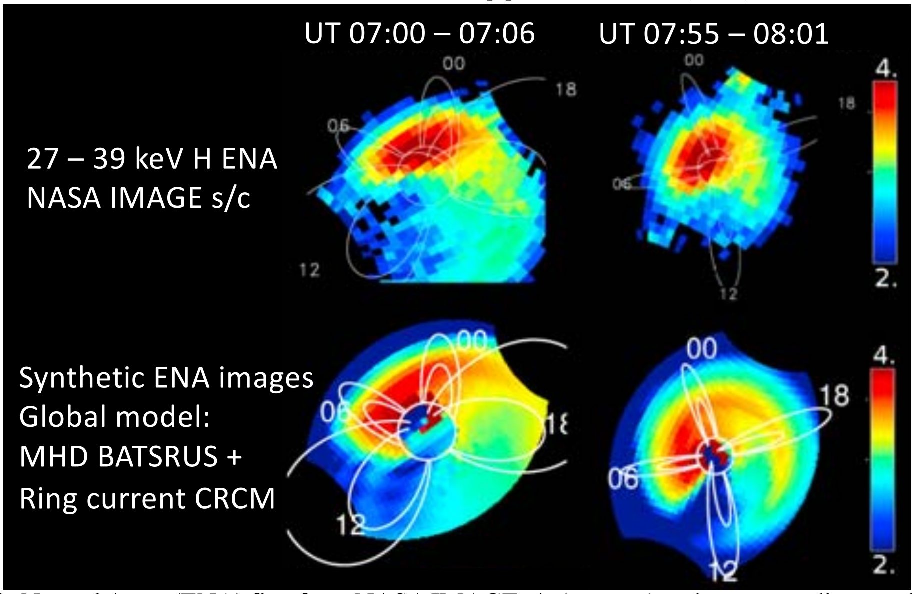

Figure 1. Energetic Neutral Atom (ENA) flux from NASA IMAGE s/c (top row) and corresponding synthetic ENA images generated with 3D MHD BATSRUS model coupled with the ring current model (bottom row). ENA images are taken during the main phase of a large geomagnetic storm of August 12, 2000. Thin white lines show dipole magnetic lines drawn for 4 different local time sectors, midnight (00 h), noon (12 h), dawn (06 h), and dusk (18 h). Note a strong asymmetry in ENA emissions indicating a strong asymmetry in the underlying plasma distribution. This asymmetry has important implications for the dynamics of the Earth's magnetosphere. Modified from Figure 11 in [3].