

# **Energy Transfer from the Solar Wind to the Solid Earth**

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## **Geospace as a stellar-planetary system supporting life**

It is often said that we live in the presence of an average and unremarkable star. Following this logic, it must be concluded that the geospace system within which we have evolved is not singular in the universe. Indeed, the recent discovery of an Earth-like extra-solar planet suggests that hard observational evidence is on the horizon. How habitable environments arise in the universe must be considered among the most important and intellectually stimulating questions for mankind. As we begin to amass data on stellar-planetary systems in other parts of the universe, understanding our own solar-terrestrial system takes on renewed relevance and timeliness.

This general motivation can be used to frame a great many detailed science investigations relevant to this survey. This white paper emphasizes one area of investigation—solar wind-solid Earth coupling—and one particularly important approach—coupling of distributed measurements from the ground and from space through first-principles modeling.

## **Force transfer from the solar wind to the solid Earth**

The interaction between the solar wind and the Earth's magnetosphere is analogous to a blunt object standing in a high Reynolds number flow. The net drag exerted by the solar wind is between 10 million and 100 million Newtons. This force must act on some mass, but it is not immediately obvious whether it is the mass that belongs to the magnetosphere or the mass that, by gravitational attachment, belongs to the Earth. A quick calculation makes apparent that it is not the magnetospheric plasma that stands off the solar wind for, if it did, it would be quickly blown away, contrary to experience. The only object within geospace massive enough to balance the drag exerted by the solar wind on the magnetopause is the Earth itself, and its gravitationally bound ionosphere/thermosphere.

The interaction of the solar wind with our magnetic planet produces a broad range of distributed responses. These are, in turn, measured by humans through an equally broad range of instruments and diagnostic strategies. Because of this observational accessibility, it has also become meaningful to develop detailed predictive models of the system. Despite all this, hard quantitative comparisons among theory, modeling, and observation has been sporadic, selective, and guided by the focused interests of individual communities (e.g., CEDAR, GEM, SHINE, USGS).

To break out of this balkanized approach, a paradigm shift is needed. We must view the solar wind, magnetosphere, ionosphere, thermosphere, and geomagnetic field as a coherently integrated system, tightly coupled from the bow shock to the Earth's dipole. We must forge collaborations among theorists and experimentalists, the latter must include investigators focusing on both space-based and ground-based observations of the geospace system. Any new initiative of this type must be ambitiously quantitative, assimilating distributed measurements from ground and from space through first-principles local and global-scale modeling.

## The thermospheric response: an enduring missing piece

Observations of the geospace system have understandably focused on effects that are easy to “see”. These generally involve plasma related processes: electric and magnetic fields, and plasma particle populations. Of equal importance, but presenting a considerably greater observational challenge, is the heating and mechanical response of the Earth’s thermosphere.

Observations have firmly established that the solar wind drives winds in the high-latitude thermosphere and, indirectly, at all latitudes during geomagnetic storms. Theory and modeling predicts that the force on the thermosphere is an order of magnitude bigger than the force that the solar wind exerts on the terrestrial system, the difference being made up by a force between the thermosphere and Earth’s dipole moment mediated by the region 1 current system [Vasyliūnas, 2007; Siscoe, 2009]. This force amplification has been termed the magnetospheric mechanical advantage. This rather surprising prediction can be tested by measuring, separately, the force exerted by the solar wind on the thermosphere, and the force on the geomagnetic dipole during a time when solar wind conditions are steady and the IMF is southward.

Evaluating this global force balance is within the grasp of current observational and modeling capabilities. Essentially, three global forces must be established:

- **Force exerted by the solar wind.** This is determined with global numerical MHD simulation using measured solar wind parameters as input and integrating the computed total stress tensor over a surface containing the terrestrial system.
- **Force on the thermosphere.** This requires measuring the acceleration of thermospheric winds over the area where the force is applied. For large disturbances, this means primarily the polar cap, where NSF has invested in new ionospheric and thermospheric diagnostic capabilities (RISR-N, RISR-C, PFISR, imaging Fabry-Perot interferometers).
- **Force on the Earth dipole.** This is measured by integrating the magnetic stress tensor over the Earth using globally distributed ground magnetometer data.

In the process of pursuing such an objective and the associated technical challenges, much serendipitous science, fundamental in its own right, will emerge. Issues such as thermospheric expansion, ion outflow, plasma convection, are expected to all be advanced by this project, in addition to diagnostic strategies, such as radar signal processing, statistical estimation, and multi-sensor fusion.

## Societal implications

In addition to intellectual motivations, this initiative also has direct societal implications. Our understanding of the effects of space weather on geospace and its inhabitants is remarkably incomplete. Although the forces involved are negligible compared to forces associated with tropospheric weather and geological dynamics, the magnetic nature of these forces makes them highly consequential. Currents induced in transcontinental pipelines need to be accurately predicted for active mitigation of pipeline decay [Gummow and Eng, 2002]. Spacecraft communications may be interrupted as a result of ensuing ionospheric instabilities [Lanzerotti, 2009]. Astronauts and even airline crews can be harmed by extreme space weather events [Getley, 2004]. The effects of space weather are not all deleterious. Impulsive disturbances also provide a high-power, low frequency, signal for geological exploration via magnetotellurics [Berdichevsky et al., 2010]. In a similar way, auroral displays produced by these disturbances provide a remote sensing diagnostic of distant magnetospheric dynamics [Paschmann et al., 2003]. Each of these topics benefits significantly from a complete

understanding of solar wind-terrestrial coupling. The proposed coalescence of theory, modeling, and observation defines a path towards a deeper understanding of this universal cosmic interaction and its immediate impacts on society and technology.

## **Is a dense network of ground-based sensors truly expensive?**

The approach advocated in this proposal involves a close coupling of distributed observations from ground and from space. It is important to consider the differing cost paradigms associated with the two agencies that would typically fund instrumentation in these two domains of observation: NASA and NSF.

A NASA Explorer-class mission costs \$200 Million. A single imaging Fabry-Perot Interferometer, capable of observing the line-of-sight neutral wind field, currently costs about \$200,000, so 1000 times less. If a large network of such sensors are produced, the costs drops precipitously owing to volume purchasing of parts. If the budget of a typical monolithic satellite mission were used, instead, for ground-based instrumentation, a global scale network of geospace sensors could be produced that easily rivals the scientific efficacy of a NASA satellite mission.

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