November 16, 2023

Ms. Peg Luce, Heliophysics Division Acting Director
National Aeronautics and Space Administration
Heliophysics Division
300 E Street, SW
Washington, DC 20546-0001

Dear Ms. Luce:

The Heliophysics Advisory Committee (HPAC), an advisory committee to the Heliophysics Division (HPD) of the Science Mission Directorate (SMD) of the National Aeronautics and Space Administration (NASA), convened on 14-16 November 2023 via a hybrid meeting with some attending in-person and some attending by Webex virtual connection. The undersigned served as Chair for the meeting with the support of Dr. Janet Kozyra, HPAC Designated Federal Officer (DFO) of NASA-HPD.

Jennifer Kearns briefed HPAC about the Government Performance and Results Act - Modernization Act (GPRAMA) process for 2023. The members of HPAC that participated in the GPRAMA review process were:

- Aroh Barjatya (Embry-Riddle Aeronautical University), remote
- Dave Brain (University of Colorado, Boulder), remote
- Paul Cassak (West Virginia University), Chair
- Nicole Duncan (Ball Aerospace), remote
- Christoph Englert (Naval Research Laboratory), Vice Chair
- Matina Gkioulidou (Johns Hopkins University Applied Physics Laboratory)
- Farzad Kamalabadi (University of Illinois, Urbana-Champaign)
- Laura Peticolas (Sonoma State University)
- Barbara Thompson (NASA Goddard Space Flight Center), remote
- Lisa Upton (Southwest Research Institute), remote
- Marco Velli (University of California, Los Angeles), remote
- Jia Yue (Catholic University)
- Eric Zirnstein (Princeton University)

HPAC is tasked to lead the review of two of the SMD performance goals:

P.G. 1.2.1: Demonstrate progress in exploring and advancing understanding of the physical processes and connections of the Sun, space, and planetary environments throughout the Solar System.

P.G. 1.2.6: Demonstrate progress in developing the capability to detect and knowledge to predict extreme conditions in space to protect life and society and to safeguard human and robotic explorers beyond Earth.

Also, within PG 1.2.6, we were requested to assess NASA's performance on this subgoal:

> *Advancing scientific understanding of background solar wind, solar wind structures, and coronal mass ejections, which can be integrated into key models used to predict the arrival time and impact of space storms at Earth.*

Following substantial deliberation, all in attendance voted unanimously for a "green" rating for both of these performance goals and the subgoal (with one abstention due to absence), finding "expectations for the research program fully met in context of resources invested." The specific summary text generated by HPAC for each of the performance goals and the subgoal is included below.

We thank the HPD staff for providing source material with highlights from the NASA-supported missions and research projects. This was most helpful in our assessment of the performance goals for the GPRAMA review. We welcome any requests from NASA Heliophysics Division for clarification or elaboration on our findings.

Sincerely yours,

Paul Cassak

Paul Cassak
Chair, Heliophysics Advisory Committee

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GPRAMA Summary Statement for PG 1.2.1

PG 1.2.1: Demonstrate progress in exploring and advancing understanding of the physical processes and connections of the Sun, space, and planetary environments throughout the Solar System.

The Heliophysics Advisory Committee determined in November, 2023, that NASA has demonstrated progress in its annual performance towards exploring and advancing understanding of the physical processes and connections of the Sun, space, and planetary environments throughout the Solar System. Below are summaries of evidence of this progress reported in FY 2023.

At scales hundreds of times larger than the distance between the Sun and Earth, scientific progress has been made with the help of NASA's Interstellar Boundary Explorer (IBEX) mission. IBEX remotely images the distant "bubble" with a comet-like tail surrounding our solar system called the heliosphere that is inflated by the solar wind. As the heliosphere moves through interstellar space, it distorts the interstellar magnetic field, as the Voyager spacecraft have observed for the past decade. Interpretations of the data as the Voyager satellites move farther from the heliosphere have never been fully reconciled with models. A study this past year provided a solution by finding previously unknown uncertainties with Voyager measurements using models constrained by IBEX data. Not only did this finally create a unified picture of the interstellar magnetic field between observations and models, but also the capability to predict how far out future interstellar missions must travel before the spacecraft sample undisturbed interstellar space.

Just as a raft floating down a river is influenced by water currents and turbulence, particles that follow along Earth's magnetic field are influenced by electric currents and electromagnetic turbulence. Energy from the Sun is transferred to Earth's magnetic field and NASA has made strides in understanding how that energy gets released in a process known as magnetic reconnection, as well as the interplay between turbulence and this energy release. Unlike turbulence in water, the electrically charged particles in space plasmas interact with magnetic fields. This year, satellites from NASA's Magnetospheric Multiscale (MMS) mission obtained data from the space within Earth's invisible magnetic shell which directly confirmed that energy released during magnetic reconnection contributes to the growth of turbulence and that turbulence does not impede the release of energy by magnetic reconnection.

Earth's upper atmosphere is subject to energy and material input from both space and the lower atmosphere. Zodiacal light, also called false dawn, is seen before sunrise as a faint glow of sunlight scattered by interplanetary dust. This dust comes primarily from asteroid collisions or when material from a comet vaporizes, and comprises the bulk of interplanetary material entering Earth's atmosphere. The NASA Wind mission revealed a strong annual variation of this dust when Earth is aligned with the direction of the flow in interstellar space. The dust collected in Earth's atmosphere shows an unexpected 22-year cycle, suggesting it is related to the solar cycle over which the number of sunspots and the amount of solar activity vary. This relationship highlights the complex physics connecting the Sun, Earth, and the interplanetary environment. In addition, NASA's Global Scale Observations of the Limb and Disk (GOLD) and Aeronomy of Ice in the Mesosphere (AIM) missions have added crucial insights into the day-to-day variability of Earth's ionosphere driven by meteorological forcing. GOLD observations revealed how sudden stratospheric temperature warming events strengthen global-scale waves during a time of low

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solar activity, while AIM observations revealed that coupling between the surface and the ionosphere is partially controlled by wind effects due to the stratospheric polar vortex (a large area of cold air surrounding Earth's poles) on vertically propagating buoyancy/gravity waves from the troposphere. Because the stratosphere can be forecasted one week ahead, understanding the connection between the stratosphere and ionosphere would help us to predict the condition of the ionosphere, which is important for radio communication.

The space environment of the Moon changes over the course of its orbit as it moves periodically in and out of regions influenced by Earth's magnetic field (the magnetosphere). One might therefore expect Earth's magnetic field to periodically shield the Moon from energetic particles from the Sun or beyond. However, recent measurements from NASA's Wind and Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun (ARTEMIS) missions show that these outside particles have just as much access to the Moon when it is situated behind Earth, deep in the magnetosphere. This is because particles sneak into Earth's magnetosphere well behind the Earth and Moon, where Earth's magnetic field strength is very low. Guided by Earth's magnetic field, the particles then travel back towards Earth, encountering the Moon. This work has implications for whether strong planetary magnetic fields truly shield planets from energetic events from the Sun.

The committee voted unanimously for a GREEN rating for P.G. 1.2.1, with one abstention due to absence.

GPRAMA Summary Statement for PG 1.2.6

P.G. 1.2.6: Demonstrate progress in developing the capability to detect and knowledge to predict extreme conditions in space to protect life and society and to safeguard human and robotic explorers beyond Earth.

The Heliophysics Advisory Committee determined in November, 2023, that NASA was making progress towards achieving this performance goal. Below are examples of the scientific progress reported in FY 2023. The studies highlighted in the GPRAMA PG 1.2.6 report directly address extreme space weather events.

In February 2022, 38 commercial satellites that were launched into a low Earth orbit in preparation for subsequent orbit-raising maneuvers were lost to premature reentry. This was the result of increased aerodynamic resistance on the satellites caused by an atmospheric density increase resulting from a minor eruption in the Sun's atmosphere. While it was well-known that upper atmospheric densities, and therefore the aerodynamic drag forces on satellites, are highly variable, recent observations by NASA's Global-scale Observations of the Limb and Disk (GOLD) mission shed light on this specific event. The changes in upper atmospheric temperature and composition were studied. Not only did the instrument verify that there was a significant increase in upper atmospheric density for this time period, it provided details on the spatial and temporal response of the upper atmosphere to this specific solar eruption. These studies powerfully demonstrate the necessity to observe the upper atmospheric environment in order to advance the capability to detect and gain quantitative understanding of the space environment's response to external drivers and, ultimately, to develop the capability to create accurate forecasts.

The solar wind, made up of energetic charged particles released into space from the Sun's atmosphere, imparts energy to the near-Earth environment, powering space weather. Just like wind-driven waves drive currents and transfer energy to Earth's oceans, solar wind-driven waves on the outer boundary of Earth's magnetic field (the magnetopause), transfer energy to the region inside the magnetopause (the magnetosphere). These boundary waves, also known as Kelvin-Helmholtz waves, can cause rotational flows called vortices, which sometimes roll-up like steepened waves crashing on a seashore. A new statistical study of magnetopause boundary waves using data from NASA's Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission covering an eleven-year period over which the Sun's magnetic field changes directions (a solar cycle) showed that the rate the waves occur exhibit clear seasonal and daily variations. The variation is identical to reported variations of space weather intensity in Earth's space environment, as determined by ground magnetometers that measure the magnetic field strength at Earth's surface. These results suggest that the boundary waves contribute to space weather activity over solar-cycle periods, and therefore indicate the necessity for models to reconsider aspects of solar wind-magnetosphere energy coupling to predict near-Earth space weather.

The hot plasma (ionized gas) just beneath the Sun's surface moves in complex patterns. These plasma flows are a crucial aspect to the generation of magnetic fields that create sunspots, which in turn are the source of magnetic eruptions that cause extreme space weather events which can impact humans on Earth and in space. The Helioseismic and Magnetic Imager (HMI) on NASA's Solar Dynamics Observatory spacecraft has provided more than thirteen years of high-quality data that has been used to study the properties of the magnetic fields and plasma flows of the Sun. By using HMI data, researchers recently discovered oscillations of the global flows in the Sun's outer layer that were not known before. These oscillations occur in both East-West (zonal) and North-South (meridional) flows and happen over a period of about one solar rotation (which is roughly 27 days). These results are important for determining how plasma flows on the Sun impact the magnetic fields and will help us understand the Sun's magnetic activity cycle. Understanding the origin of these variations is fundamental to the prediction of extreme conditions in space.

The committee voted unanimously for a GREEN rating for P.G. 1.2.6, with one abstention due to absence.

GPRAMA Summary Statement for the Subgoal to PG 1.2.6

Subgoal to P.G. 1.2.6: Advance scientific understanding of background solar wind, solar wind structures, and coronal mass ejections, which can be integrated into key models used to predict the arrival time and impact of space storms at Earth.

The Heliophysics Advisory Committee determined in November, 2023, that NASA was making progress towards achieving this performance subgoal. Below is an example of scientific

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progress reported in FY 2023. The study highlighted here directly addresses understanding the solar wind which will improve predictions of the impact of space storms at Earth.

The mechanism that accelerates the solar wind from the Sun's atmosphere into interplanetary space is a long-standing problem in heliophysics. It has important implications for the prediction of space weather responses on Earth. Recent measurements from NASA's Parker Solar Probe (PSP) mission show evidence that magnetic reconnection, a process that can convert energy to accelerating particles, is a likely candidate for driving the solar wind. The implications of this affect our understanding of the source and properties of the solar wind passing by Earth and can be integrated into space weather modeling to better predict the impact of space weather at Earth.

The committee voted unanimously for a GREEN rating for the subgoal to P.G. 1.2.6, with one abstention due to absence.

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