

SURVEYING THE SPACE WEATHER LANDSCAPE

JOINT HEARING

BEFORE THE

SUBCOMMITTEE ON ENVIRONMENT &
SUBCOMMITTEE ON SPACE

COMMITTEE ON SCIENCE, SPACE, AND
TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED FIFTEENTH CONGRESS

SECOND SESSION

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SURVEYING THE SPACE WEATHER LANDSCAPE

THURSDAY, APRIL 26, 2018

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENVIRONMENT AND
SUBCOMMITTEE ON SCIENCE,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittees met, pursuant to call, at 10:01 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Andy Biggs [Chairman of the Subcommittee on Environment] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

Congress of the United States
House of Representatives

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

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WASHINGTON, DC 20515-6301

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Surveying the Space Weather Landscape

Thursday, April 26, 2018

10:00 a.m.

2318 Rayburn House Office Building

Witnesses

Dr. Neil Jacobs, Assistant Secretary of Commerce for Environmental
Observation and Prediction, National Oceanic and Atmospheric
Administration

Dr. Jim Spann, Chief Scientist, Heliophysics Division, Science Mission
Directorate, National Aeronautics and Space Administration

Dr. Sarah Gibson, Senior Scientist, High Altitude Observatory, National
Center for Atmospheric Research and Co-Chair, Committee on Solar and
Space Physics, National Academy of Science

Dr. W. Kent Tobiska, President and Chief Scientist, Space Environment
Technologies

**U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY**

HEARING CHARTER

Wednesday, April 25, 2018

TO: Members, Subcommittee on Environment, Subcommittee on Space
FROM: Majority Staff, Committee on Science, Space, and Technology
SUBJECT: Joint Subcommittee Hearing: "Surveying the Space Weather Landscape"

The Subcommittees on Environment and Space will hold a joint hearing *Surveying the Space Weather Landscape* on Thursday, April 26, 2018, at 10:00 a.m. in Room 2318 of the Rayburn House Office Building.

Hearing Purpose:

The purpose of the hearing is to gain a better understanding of the current actions on space weather from the relevant stakeholders involved in these matters.

Witness List

- **Dr. Neil Jacobs**, Assistant Secretary of Commerce for Environmental Observation and Prediction, National Oceanic and Atmospheric Administration
- **Dr. Jim Spann**, Chief Scientist, Heliophysics Division, Science Mission Directorate, National Aeronautics and Space Administration
- **Dr. Sarah Gibson**, Senior Scientist, High Altitude Observatory, National Center for Atmospheric Research and Co-Chair, Committee on Solar and Space Physics, National Academy of Science
- **Dr. W. Kent Tobiska**, President and Chief Scientist, Space Environment Technologies

Staff Contact

For questions related to the hearing, please contact Majority Staff at 202-225-6371.

Chairman BIGGS. The Subcommittee on Environment and Space will come to order. And without objection, the Chair is authorized to declare recesses of the Subcommittee at any time.

Welcome to today's hearing entitled "Surveying the Space Weather Landscape." I now recognize myself for five minutes for an opening statement.

And I welcome you again to this important subcommittee hearing of the Environment Subcommittee and the Space Subcommittee as well entitled "Surveying the Space Weather Landscape." And first, I thank each Member of this panel here today. We have excellent witnesses, and I'm excited to hear their testimony on this important topic.

With an issue as complex and consequential as this one, it is important that we begin a dialogue on where we are and where we are going. There are many exciting developments in space weather, from innovative space weather technologies and the accuracy of space weather forecasting models, to the potential impacts space weather can have on our terrestrial environment.

All of these topics are important and worth addressing, but I think it's crucial that we first lay the groundwork for understanding the current policies, procedures, and major players in both the private and public sectors. And I'm pleased to have key stakeholders from private industry, as well as academia, along with leaders from the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA) with us today. I look forward to hearing from them about not only what their efforts have been in this arena, but also what they think the future holds for the observation, modeling, and forecasting of space weather events.

Just as it is a primary driver of weather on Earth, the Sun is also the largest driver of disturbances in our space environment. Solar winds, whose charge and intensity ebbs and flows with various solar phenomena, interact with Earth's magnetic field in interesting and sometimes highly adverse ways. The result of these interactions are what we refer to as space weather storms. While often relegated to the magnetosphere, these storms can and do have tangible and sometimes highly damaging effects in the upper atmosphere and at the terrestrial level. These can range from issues with the performance and reliability of space-borne and ground-based technological systems, all the way to endangering human life or health.

As with terrestrial weather, without thorough monitoring and accurate modeling, we simply have no good way to predict space weather events and, in turn, no ability to ensure that citizens are kept out of harm's way if severe events arise. In the federal government, NASA and NOAA are tasked with monitoring and issuing forecasts that inform the public. To make these forecasts, countless dollars are spent on observation and data collection, but despite this, space weather science as a discipline is still in its nascent phase.

While I have no doubt that NASA and NOAA play a vital role in monitoring solar phenomena and making space weather forecasts, we need to explore whether it makes sense to rely solely on government for addressing space weather challenges. In the 21st

century, the landscape has changed, and as we can see from our witnesses today, the federal government isn't the only game in town, nor should it be.

Forecasting space weather depends on understanding the fundamental processes that give rise to hazardous events. Particularly important is the study of processes that link the Sun-Earth system and that control the flow of energy toward our planet. Partners in the private sector can and should use their advanced, innovative technologies to help us more thoroughly understand these phenomena and improve our space weather predictions. In the face of space weather challenges, instead of continuing to think inside the "government-only" box, NASA and NOAA need to look to private partners who are ready and willing to help.

Last year, President Trump signed into law the *Weather Research and Forecasting Innovation Act*, a comprehensive bill to increase our weather forecasting capabilities to better protect lives and property. What I like most about this legislation is that it requires personnel within government agencies to innovate by partnering with the growing private sectors in testing and validating its data in order to enhance our nation's forecasting capacity and capabilities. It is my hope that, on the subject of space weather, we will continue to look to the *Weather Research and Forecasting Innovation Act* as a model.

Adverse space weather presents unique challenges, and the consequences of inaction could be far-reaching and catastrophic. However, I believe that through the right combination of government monitoring, private industry innovation, and good old American determination, we will be able to respond to any future challenges that may arise. I look forward to learning more today from our excellent panel of witnesses about this topic, about their efforts to advance understanding in this field, and about the technologies and methods that will lead the way to a better and smarter future.

And with that, I yield back the balance of my time.

[The prepared statement of Chairman Biggs follows:]



COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
 Lamar Smith, Chairman

For Immediate Release
 April 26, 2018

Media Contacts: Thea McDonald, Brandon VerVelde
 (202) 225-6371

Statement by Chairman Andy Biggs (R-Ariz.)

Surveying the Space Weather Landscape

Chairman Biggs: Good morning, and welcome to today's joint Environment and Space Subcommittee hearing, entitled "Surveying the Space Weather Landscape." I would like to first thank our excellent witnesses for being here today and for testifying on this important topic.

With an issue as complex and consequential as this one, it is undeniably important we begin a dialogue on what the status quo is and in what direction momentum is heading. There are many avenues we could explore for this hearing, from innovative space weather technologies and the accuracy of space weather forecasting models, to the potential impacts space weather can have on our terrestrial environment. While all of these topics are important and worth addressing, I think it is crucial that we first lay the groundwork for understanding the current policies, procedures and major players in both the private and public sectors.

I am glad, then, to have key stakeholders from private industry as well as academia, along with leaders from the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA) with us here. I look forward to hearing from them about not only what their efforts have been in this arena, but also what they think the future holds for the observation, modeling and forecasting of space weather events.

Just as it is a primary driver of weather on Earth, the sun is also the largest driver of disturbances in our space environment. Solar winds, whose charge and intensity ebbs and flows with various solar phenomena, interact with Earth's magnetic field or magnetosphere in interesting and sometimes highly adverse ways. The result of these interactions are what we refer to as space weather storms. While often relegated to the magnetosphere, these storms can and do have tangible - and sometimes highly damaging - effects in the upper atmosphere and at the terrestrial level. These can range from issues with the performance and reliability of space-borne and ground-based technological systems, all the way to endangering human life or health.

As with terrestrial weather, without thorough monitoring and accurate modeling, we simply have no good way to predict space weather events and, in turn, no ability to ensure that citizens are kept out of harm's way if severe events arise. In the federal government, NASA and NOAA are tasked with monitoring and issuing forecasts that inform the public. To make these forecasts, countless dollars are spent on observation and data collection, but despite this, space weather science, as a discipline, is still in its nascent phase.

While I certainly have no doubt that NASA and NOAA play a vital role in monitoring solar phenomena and making space weather forecasts, one of the questions we need to explore in this hearing is whether it makes sense to rely on government alone for addressing space weather challenges. In the twenty-first century, the landscape has changed, and as we can see from our witnesses today, the federal government isn't the only game in town - nor, I would argue, should it be.

Forecasting space weather depends on understanding the fundamental processes that give rise to hazardous events. Particularly important is the study of processes that link the Sun-Earth system and that control the flow of energy toward our planet. Partners in the private sector can - and should - use their advanced and innovative technologies to help us more thoroughly understand these phenomena and improve our space weather predictions. In the face of space weather challenges, instead of continuing to think inside the "government-only" box, NASA and NOAA need to look to private partners who are ready and willing to help.

Last year, President Trump signed into law the Weather Research and Forecasting Innovation Act, a comprehensive bill to increase our weather forecasting capabilities to better protect lives and property. What I like most about this legislation is that it compels the government to innovate by partnering with the growing private sector to test and validate its data in order to enhance our nation's forecasting capabilities. It is my hope that, on the subject of space weather, we will continue to look to that law as a model.

Adverse space weather presents unique challenges, and the consequences of inaction could be far-reaching and catastrophic. However, I believe that through the right combination of government monitoring, private industry innovation and good old American determination, we will be able to respond to any future challenges that may arise. I look forward to learning more today from our witnesses about this topic, about their efforts to advance understanding in this field and about the technologies and methods that will lead the way to a better and smarter future.

###

Chairman BIGGS. I now recognize the gentleman from Colorado sitting in for the Ranking Member of the Environment Subcommittee, Mr. Perlmutter, for an opening statement.

Mr. PERLMUTTER. Thank you, Mr. Chairman, and I'd also like to thank Chairman Smith for convening today's hearing. I'd also like to thank each of our witnesses because we have an excellent panel to talk to us today about space weather, and I'd especially like to thank two of my friends, Colorado Buffaloes Dr. Gibson and Dr. Tobiska, for joining us today.

I've been interested in space weather for a number of years. Colorado has some of the best minds, laboratories, and research institutions on space weather in the country. We have institutions like CU Boulder and the National Center for Atmospheric Research, as well as NOAA's Space Weather Prediction Center. That is why Senator Cory Gardner from Colorado worked with Senator Gary Peters from Michigan to pass the Space Weather Research and Forecasting Act in the Senate, and it's why I've been encouraging this committee to support this legislation and be active on the space weather needs of the academic and research community.

We talk frequently about space weather as a catastrophic event, and it can be. A Carrington-level event, which more or less shut down electrical grids and communications all over the place, or the 2012 event, which shut down Québec's power grid, are worthy of our attention. But what I've learned is that space weather is a daily phenomenon which impacts our electrical grid, our airlines flying over the poles, precision agriculture, and much more.

It is clear there is significant economic consequence to our lack of knowledge and prediction of space weather. That's why I've proposed H.R. 3086, the Space Weather Research and Forecasting Act. It will build upon the success of the National Space Weather Strategy and the National Space Weather Action Plan to better incorporate academic, commercial, and international partners into our space weather enterprise.

I look forward to your testimony today and the discussion so that we can educate ourselves and work with the academic and commercial industries to build on the successes of the last several years and remain focused on improving space weather research and forecasting.

[The prepared statement of Mr. Perlmutter follows:]

OPENING STATEMENT

Rep. Ed Perlmutter (D-CO)

House Committee on Science, Space, and Technology
Subcommittee on Environment
Subcommittee on Space
"Surveying the Space Weather Landscape"
April 26, 2018

Thank you, Mr. Chairman, and I'd also like to thank Chairman Smith for convening today's hearing.

I'd also like to thank each of our witnesses because we have an excellent panel to talk to us today about space weather, and I'd especially like to thank two of my friends, Colorado Buffaloes Dr. Gibson and Dr. Tobiska, for joining us today.

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I look forward to your testimony today and the discussion so that we can educate ourselves and work with the academic and commercial industries to build on the successes of the last several years and remain focused on improving space weather research and forecasting.

Mr. PERLMUTTER. And if I might, Mr. Chair, I'd like to introduce the newest member of our committee.

Chairman BIGGS. Please.

Mr. PERLMUTTER. So I'd like to introduce Conor Lamb. You can stand up and take a bow.

Conor was sworn in on April 12—

Mr. LAMB. Twirl around, too—

Mr. PERLMUTTER. No, no, it's—2018 to represent Pennsylvania's 18th Congressional District, which includes parts of Allegheny, Westmoreland, Washington, and Greene Counties in southwestern Pennsylvania. And I took some time to encourage Conor to join this committee because there are places where we have—lots of places where we have common ground and we work together, we collaborate to advance science. There are places where we have spirited disagreements, and so we really do welcome you.

And I should alert my Republican friends that Conor previously served as an Assistant U.S. Attorney in the Justice Department's Pittsburgh office, where he prosecuted violent crimes and drug trafficking and helped establish the office as a national leader in the fight against the heroin epidemic. So we wanted to bring somebody aboard who also could argue if necessary.

Lamb served on active duty in the United States Marine Corps from 2009 to 2013 and continues to serve as a Major in the United States Marine Corps Reserves. Conor lives in Mount Lebanon, where he grew up. He is a graduate of Pittsburgh Central Catholic High School and went to college and law school at the University of Pennsylvania. 2006 is when he graduated undergrad and 2009 from law school.

So I'd like to welcome Conor Lamb to the Committee, and I know the rest of the Committee will welcome him, too.

Chairman BIGGS. Indeed, welcome, Representative Lamb. Glad to have you on the Committee.

Mr. LAMB. Still learning how these work. Thank you very much, Mr. Chairman.

Chairman BIGGS. Thank you.

Mr. LAMB. You're welcome.

Chairman BIGGS. And now, I recognize the Chairman of the Space Subcommittee, the gentleman from Texas, Mr. Babin, for an opening statement.

Mr. BABIN. Yes, sir. Thank you, Mr. Chairman. And I also would like to welcome Mr. Lamb to our committee. We have a great committee here, and we're quite bipartisan on many, many issues, although, as Mr. Perlmutter said, sometimes it does get heated on certain issues. But welcome.

Mr. LAMB. Thank you.

Mr. BABIN. Mr. Chairman, thank you for the opportunity to conduct this joint hearing. I look forward to the testimony of our witnesses. Specifically, I am interested to hear their insights and observations from the recent Space Weather Workshop in Colorado. Understanding and predicting space weather is critical to protecting American infrastructure and human safety both in space and on the ground.

While government agencies have made steady advances in this area, we must now explore ways to expand our capabilities and

begin leveraging the private sector. As we begin preparations for space exploration outside the protection of Earth's magnetosphere, the Space Subcommittee is keenly aware that understanding and predicting space weather is more important than ever for the safety of our astronauts and the achievement of our exploration goals.

Perhaps even more tangible are the effects of space weather here on Earth. And while space weather can give us some of the most beautiful sights on Earth—the aurora borealis, or the northern lights—there are also many negative effects of space weather that often go unseen. Strong space weather events can knock out electrical grids, corrode pipelines and disrupt satellite communications. Many, including the brave men and women serving our country, rely on critical information gathered by in-space infrastructure like GPS and remote sensing. These space-based assets are particularly vulnerable to the effects of space weather.

It is time to develop a plan to protect ourselves from these events. NASA's continued research and development of space weather satellites will provide more advanced American capabilities. That, combined with NOAA's work in data analysis and space weather prediction, comprise a strong government effort. However, the progress does not come without cost, which is why we must look to the private industry moving forward.

The Deep Space Climate Observatory, also known as DSCOVR, is a good example for defining roles and responsibilities. DSCOVR, built by NASA, is NOAA's first operational satellite in deep space, orbiting a million miles from Earth in order to provide early warnings of potentially harmful space weather. This NOAA operational capability for space weather analysis and prediction was established through the technology transition of unique scientific instruments researched and developed by NASA. I contend this model represents the way forward for interagency space weather activities.

As the private sector continues to move into low-Earth orbit, more and more companies will be relying on space weather predictions to protect their assets. Space weather is another area of great commercial opportunity in space, and, as we have in the past, we must continue to encourage and leverage these private endeavors for the benefit of all Americans. The threats posed by space weather events can be mitigated through advanced research and prediction methods. I hope that this hearing today will shed light on our current space weather projects and how we can continue achieving American excellence in such a very critical area.

I want to thank our witnesses for being here today, for their testimony, and I'm looking forward to the discussion and hearing—and shedding some light on this issue.

I yield back. Thank you, Mr. Chairman.

[The prepared statement of Mr. Babin follows:]



COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
April 26, 2018

Media Contacts: Thea McDonald, Brandon VerVelde
(202) 225-6371

Statement by Chairman Brian Babin (R-Texas)

Surveying the Space Weather Landscape

Chairman Babin: Mr. Chairman, thank you for the opportunity to conduct this joint hearing, and I look forward to the testimony of our witnesses. Specifically, I am interested to hear their insights and observations from the recent Space Weather Workshop in Colorado.

Understanding and predicting space weather is critical to protecting American infrastructure and human safety both in space and on the ground. While government agencies have made steady advances in this area, we must now explore ways to expand our capabilities and begin leveraging the private sector.

As we begin preparations for space exploration outside the protection of Earth's magnetosphere, the Space Subcommittee is keenly aware that understanding and predicting space weather is more important than ever for the safety of our astronauts and the achievement of our exploration goals.

Perhaps even more tangible, are the effects of space weather here on Earth. While space weather can give us some of the most beautiful sights on Earth, the aurora borealis, or the northern lights, there are also many negative effects of space weather that often go unseen. Strong space weather events can knock out electrical grids, corrode pipelines and disrupt satellite communications.

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It is time to develop a plan to protect ourselves from these events. NASA's continued research and development of space weather satellites will provide more advanced American capabilities. That, combined with the National Oceanic and Atmospheric Administration's (NOAA) work in data analysis and space weather prediction, comprise a strong government effort. However, progress does not come without cost. Which is why we must look to the private industry moving forward.

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The threats posed by space weather events can be mitigated through advanced research and prediction methods. I hope this hearing today will shed light on our current space weather projects and how we can continue achieving American excellence in such a critical area.

I thank our witnesses today for their testimony and look forward to this discussion.

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Chairman BIGGS. Thank you, Mr. Babin.

I now recognize the Ranking Member of the Space Subcommittee, the gentleman from California, Mr. Bera, for an opening statement.

Mr. BERA. Thank you, Mr. Chairman. And I want to welcome the witnesses and add my welcome to our colleague from Pennsylvania, Mr. Lamb. I think Conor is going to find that this is one of the best committees to be on in the sense of the topics that we're talking about. And I think if there were Neilson ratings for C-SPAN committee viewership, I think we would be at the top of that because the riveting topics that we talk about, habitable planets, how we're going to deep space, as Mr. Perlmutter would say—let me get that out there—how we go to Mars by 2033. And today's topic is no different, you know, the importance of understanding and forecasting space weather.

I mean, as we think about, you know, how dependent—our communications, our electrical ability, our navigational systems are on, you know, on space weather and how vulnerable they are, it becomes increasingly important. And we know NASA's research and observations in solar and space physics has been instrumental in achieving our current capabilities for space weather monitoring and prediction. The Advanced Composition Explorer and the joint European Space Agency/NASA mission, both launched over 20 years ago, along with other NASA spacecrafts such as STEREO and the Solar Dynamics Observatory provide critical information in forecasting solar eruptions and their movement through the heliosphere.

That said, it's also important for us to understand that we're only at the early stages of our ability to predict and forecast space weather. Improving our current capabilities will require investment in basic research, additional observations, models, and the ability to transition models into operational use.

The National Academies 2012 Heliophysics Decadal Survey stated, "Achievement of critical continuity of key space environment parameters, their utilization in advanced models, and application to operations constitute a major endeavor that will require unprecedented cooperation among agencies in the area in which each has specific expertise and unique capabilities."

To that end, Mr. Chairman, the National Space Weather Strategy and Space Weather Action Plan provide goals for federal agencies to organize our research and operational efforts on space weather and responses to extreme space weather events. The Senate passed bill, and the companion House Bill introduced by Mr. Perlmutter would ensure continued interagency coordination and encourage increased involvement with international, academic, and commercial sectors.

Mr. Chairman, the nation's efforts to deal with space weather demonstrate the ways in which our investments in basic research and NASA benefit our society. In the case of space weather, these investments are integral in ensuring the safety and operations of our critical infrastructure on the ground and in space.

I look forward to hearing from our witnesses on what is needed to advance our nation's understanding and our ability to monitor, predict, and forecast space weather.

Thank you, and with that, I yield back.

[The prepared statement of Mr. Bera follows:]

OPENING STATEMENT
Ranking Member Ami Bera (D-CA)
of the Subcommittee on Space

House Committee on Science, Space, and Technology
 Subcommittee on Environment
 Subcommittee on Space
“Surveying the Space Weather Landscape”
 April 26, 2018

Good morning, and welcome to our witnesses. I look forward to your testimony. Thank you, Mr. Chairman, for holding this hearing on *“Surveying the Space Weather Landscape”*.

Severe space weather events pose significant threats to our national security, economy and society. Space weather can affect everything from electric power systems, satellite, aircraft, and spacecraft operations (including human spaceflight operations); and other ground and space-based infrastructure.

NASA’s research and observations in solar and space physics has been instrumental in achieving our current capabilities for space weather monitoring and prediction.

The Advanced Composition Explorer and the joint European Space Agency-NASA mission, both launched over 20 years ago, along with other NASA spacecraft such as STEREO and the Solar Dynamics Observatory, provide critical information in forecasting solar eruptions and their movement through the heliosphere.

That said, it’s important to understand that we are only at the early stages of our ability to predict and forecast space weather. Improving our current capabilities will require investments in basic research, additional observations, models, and the ability to transition models into operational use.

The National Academies 2012 Heliophysics decadal survey stated, *“Achievement of critical continuity of key space environment parameters, their utilization in advanced models, and application to operations constitute a major endeavor that will require unprecedented cooperation among agencies in the areas in which each has specific expertise and unique capabilities.”*

To that end, Mr. Chairman, the National Space Weather Strategy and Space Weather Action Plan provide goals for federal agencies to organize our research and operational efforts on space weather and responses to extreme space weather events.

The Senate-passed bill and the companion House bill introduced by Mr. Perlmutter would ensure continued interagency coordination and encourage increased involvement with international, academic, and commercial sectors.

Mr. Chairman, the nation’s efforts to deal with space weather demonstrate the ways in which our investments in basic research and NASA benefit our society. In the case of space weather, these

investments are integral in ensuring the safety and operations of our critical infrastructure on the ground and in space.

I look forward to hearing from our witnesses on what is needed to advance our nation's understanding and our ability to monitor, predict, and forecast space weather.

Thank you and I yield back.

Chairman BIGGS. Thank you, Mr. Bera.

I now recognize the Chairman of the full Committee, the gentleman from Texas, Mr. Smith, for an opening statement.

Chairman SMITH. Thank you, Mr. Chairman. And thank you and Chairman Babin for holding this hearing.

While we are all familiar with terrestrial or Earth weather, what exactly space weather is and why it deserves our attention is much less widely understood. Broadly speaking, space weather is the way the behavior of the Sun and the nature of Earth's magnetic field and atmosphere interact. At a more detailed level, space weather is as complex of an issue as it is a consequential one.

At the center of space weather, as with terrestrial weather, are storms. The type and intensity of these storms can vary widely, but all space weather storms do have one thing in common and that is they are affected by the Sun. Solar phenomena, like solar flares, send streams of charged particles toward Earth as solar wind. Once solar wind reaches Earth, it interacts in surprising and hugely consequential ways with our magnetic field. The impact of these interactions varies and is dependent upon the intensity of the charge and concentration of particles in the solar wind.

However, disastrous events like GPS disruptions, satellites knocked out of orbit, and permanent damage to large swaths of the electric grid are possible and, over time, even likely. As a general rule, the damage done by space weather events will be proportional to the amount of advanced technology exposed. In our modern, technology-laden world, a large storm could be incredibly costly both in terms of dollars and lives.

Geomagnetic-induced currents that result from space weather can damage oil pipelines, railways, power grids, and complex technology by causing extensive voltage surges. In the case of power grids, these currents have the potential to damage both transmission lines and transformers, which could potentially lead to the collapse of entire distribution networks.

Space weather is also dangerous to human life. Astronauts on the International Space Station and commercial aviation flights and their passengers could be exposed to significantly larger and unsafe amounts of radiation during space weather events. Astronauts do have technologies in place to help protect them. Flights can be rerouted and grounded. But these quick, piecemeal fixes are not sustainable solutions to a potential major solar weather event.

Just as we currently forecast the active elements of terrestrial weather involving water, temperature, and air, so too is there potential to do the same for space weather. In fact, efforts to model solar activity and forecast the active elements of space weather—the concentration of particles, electromagnetic energy, and magnetic field impacts—are already underway at federal agencies and private entities.

The recent White House Office of Science and Technology Policy and the National Oceanic and Atmospheric Administration's request for information about space weather and ways commercial entities can help deserves our support. The efforts the private sector has been taking are promising and we should encourage them.

We are increasingly dependent on advanced technology. The potential for disruption to society, including the possible destruction

of critical infrastructure by space weather events, is alarming. While we have made strides toward better modeling and prediction of solar phenomena, as well as accurately forecasting space weather, there is still significant room for improvement.

I look forward to learning from our witnesses today and hearing their insights and perspectives on this topic. This committee has a bipartisan history of meeting the challenges and advancing U.S. leadership in space, and I am hopeful space weather will be no exception.

Thank you, Mr. Chairman.

[The prepared statement of Chairman Smith follows:]



COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
April 26, 2018

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Statement by Chairman Lamar Smith (R-Texas)

Surveying the Space Weather Landscape

Chairman Smith: Thank you, Chairman Biggs and Chairman Babin, for holding this hearing. While we are all familiar with terrestrial or Earth weather, what exactly space weather is, and why it deserves our attention, is much less widely understood.

Broadly speaking, space weather is the way the behavior of the sun and the nature of Earth's magnetic field and atmosphere interact. At a more detailed level, space weather is as complex of an issue as it is a consequential one.

At the center of space weather, as with terrestrial weather, are storms. The type and intensity of these storms can vary widely but all space weather storms do have one thing in common and that is they are affected by the sun.

Solar phenomena like solar flares send streams of charged particles toward Earth as solar wind. Once solar wind reaches Earth, it interacts in surprising and hugely consequential ways with our magnetic field.

The impact of these interactions varies and is dependent upon the intensity of the charge and concentration of particles in the solar wind.

However, disastrous events like GPS disruptions, satellites knocked out of orbit and permanent damage to large swaths of the electric grid are possible and, over time, likely.

As a general rule, the damage done by space weather events will be proportional to the amount of advanced technology exposed. In our modern, technology-laden world, a large storm could be incredibly costly in dollars and lives.

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Space weather is also dangerous to human life. Astronauts on the International Space Station and commercial aviation flights and their passengers could be exposed to significantly larger, and unsafe, amounts of radiation during space weather events.

Astronauts do have technologies in place to help protect them. Flights can be re-routed and grounded. But these quick, piecemeal fixes are not sustainable solutions to a potential major solar weather event.

Just as we currently forecast the active elements of terrestrial weather involving water, temperature and air, so too is there potential to do the same for space weather. In fact, efforts to model solar activity and forecast the active elements of space weather - the concentration of particles, electromagnetic energy and magnetic field impacts - are already underway at federal agencies and private entities.

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Chairman SMITH. And before I yield back, two things to mention, and that is I regret I'm going to have to shuttle back and forth between this hearing and the Judiciary Committee, but I hope to be back. And second, although I realized he has already been welcomed, I'd like to welcome Conor here for his first Science Committee hearing. Conor, I have a binder here for you of a lot of our activities and a lot of our jurisdiction, which I'll pass on to you after the Ranking Member finishes her statement. But we're glad to have you, and I appreciate Conor Lamb as being a Member of this Committee as well.

Chairman BIGGS. Thank you, Chairman Smith. I now recognize the Ranking Member of the full Committee, the gentlewoman from Texas, Ms. Johnson, for an opening statement.

Ms. JOHNSON. Thank you very much, Mr. Chairman.

And before I do my statement, I too, would like to welcome Mr. Lamb and say that I know he's facing more Texans on this committee than practically any other committee here, but don't let that frighten you. We always look—know that our responsibility on this job is to look out for the future.

We have a young future scientist potential sitting out here watching us this morning. I want to welcome her as well.

Mr. Chairman, I do appreciate the fact that you're having this committee hearing from two committees because space weather is not well understood but has the potential to impact our daily lives in significant ways. It is a field that is ripe for research and innovation to ensure that life and property can be protected from the negative impacts of large-scale space weather storms to which Texas is accustomed.

But also from the daily challenges posed by the space weather events, the need for basic research is clear, as many of the fundamental science and physics questions related to the Sun-Earth system and space weather remain unanswered. I'm pleased that the Chairman is holding this hearing today, as it allows us to assess the current state of space weather research and preparedness.

I look forward to today's discussion. I hope it will allow us to move quickly to markup Mr. Perlmutter's Space Weather Research and Forecasting Act and take it to the full House for a vote. This bill is widely supported by the broad space weather community, which includes federal agencies, academia, and the commercial sector. Today's panels of expert witnesses is well-suited to provide us with an update on the current state of space weather research and development but also to make clear the need for prompt passage of this legislation to prevent backsliding on progress made today.

I am heartened to see that we have witnesses from NASA and NOAA, the two lead federal agencies responsible for collecting the data on modeling and forecasting space weather events to the public to provide the Administration's perspective. Having an academic and a representative from the commercial sector at the table allows for a robust discussion not only on the state of science in space weather but also about current research needs moving forward. At this critical juncture, it is important for Congress to continue the forward momentum for what was set in motion by the National Space Weather Strategy and the National Space Weather Action Plan in 2015.

Space weather research and prediction capabilities are widely considered to be almost 50 years behind the state of terrestrial weather prediction, leaving our society at a disadvantage. Space weather impacts can be far-reaching, with disturbances in the Sun-Earth system potentially leading to disruption of key services such as GPS, the electric grid, and airline communications to name a few.

Despite our current observing assets that are gathering data on space weather phenomenon, we need to be thinking ahead to the next round of needed observational capabilities to ensure a continuation of critical data collection. We cannot sit idly by and take our time to protect our critical investments and society from the persistent damaging impacts of space weather events. Based on the need for additional research and collaboration and the clear and persistent threats posed by space weather phenomenon on our daily lives, there is no better time than now to put forth a legislative framework approach on how this critical issue should be addressed.

I thank you, Mr. Chairman, and yield back.

[The prepared statement of Ms. Johnson follows:]

OPENING STATEMENT

Ranking Member Eddie Bernice Johnson (D-TX)

House Committee on Science, Space, and Technology
 Subcommittee on Environment
 Subcommittee on Space
"Surveying the Space Weather Landscape"
 April 26, 2018

Thank you, Mr. Chairman.

Space weather is not well understood but has the potential to impact our daily lives in significant ways. It is a field that is ripe for research and innovation to ensure that life and property can be protected from the negative impacts of large-scale space weather storms, but also from the daily challenges posed by space weather events. The need for basic research is clear as many of the fundamental science and physics questions related to the Sun-Earth system and space weather remain unanswered.

I am pleased that the Chairman is holding this hearing today as it allows us to assess the current state of space weather research and preparedness. I look forward to today's discussion, and I hope it will allow us to move quickly to markup Mr. Perlmuter's "Space Weather Research and Forecasting Act," and take it to the House floor for a vote. This bill is widely supported by the broad space weather community, which includes federal agencies, academia, and the commercial sector.

Today's panel of expert witnesses is well-suited to provide us with an update on the current state of space weather research and development, but also to make clear the need for prompt passage of this legislation to prevent backsliding on progress made to date. I am heartened to see that we have witnesses from both NASA and NOAA, the two lead federal agencies responsible for collecting data on, modeling, and forecasting space weather events to the public, to provide the Administration's perspective. Having an academic and a representative from the commercial sector at the table allows for a robust discussion not only on the 'state of the science' in space weather, but also about current research needs moving forward. At this critical juncture, it is important for Congress to continue the forward momentum of what was set in motion by the National Space Weather Strategy and the National Space Weather Action Plan in 2015.

Space weather research and prediction capabilities are widely considered to be almost 50 years behind the state of terrestrial weather prediction, leaving our society at a disadvantage. Space weather impacts can be far-reaching with disturbances in the Sun-Earth system potentially leading to disruption of key services such as GPS, the electric grid, and airline communications to name a few. Despite our current observing assets that are gathering data on space weather phenomena, we need to be thinking ahead to the next round of needed observational capabilities to ensure a continuation of critical data collection. We cannot sit idly by and take our time to protect our critical investments and society from the persistent damaging impacts of space weather events.

Based on the need for additional research and collaboration, and the clear and persistent threats posed by space weather phenomenon on our daily lives, there is no better time than now to put forth a legislative framework approach on how this critical issue should be addressed.

Thank you. I yield back.

Chairman BIGGS. Thank you, Ms. Johnson. I appreciate that.

Now, we're going to introduce our wonderful witnesses on this panel. Dr. Neil Jacobs is our first witness today. He is the Assistant Secretary of Commerce for Environmental Observation and Prediction at the National Oceanic and Atmospheric Administration. Prior to his appointment at NOAA, Dr. Jacobs was the Chief Atmospheric Scientist at Panasonic Avionics Corporation where he directed the research and development of both the Aviation Weather Observing Program and the Numerical Forecast Models. He is the Chair of the American Meteorological Society's Forecast Improvement Group and also served on the World Meteorological Organization's Aircraft-Based Observing Systems Expert Team.

Dr. Jacobs holds bachelor of science degrees in mathematics and physics from the University of South Carolina, a master of science in air-sea interaction, and a doctoral degree in numerical modeling from North Carolina State University. Welcome, Dr. Jacobs.

Dr. James Spann is our next witness. He is the Chief Scientist of the Heliophysics Division in the Science Mission Directorate at NASA headquarters. In 1986, Dr. Spann joined the NASA's Marshall Space Flight Center in Huntsville, Alabama, where he has held numerous positions, including Chief Scientist and Manager of the Science Research Office. He led the study and publication of the Heliophysics Science and the Moon and was Co-Chair of the Heliophysics Roadmap: The Solar and Space Physics of a New Era. Dr. Spann was awarded the NASA Outstanding Leadership Medal in 2010 and the NASA Distinguished Service Medal in 2013.

He received his bachelor of science in mathematics and physics from Ouachita Baptist University and his Ph.D. in physics from the University of Arkansas in Fayetteville. He also spent two years as a postdoctoral fellow with the U.S. Department of Energy in Morgantown, West Virginia. Glad to have you, Dr. Spann.

Dr. Sarah Gibson is our third witness, a Senior Scientist in the High Altitude Observatory at the National Center for Atmospheric Research and Co-Chair of the Committee on Solar and Space Physics at the National Academy of Science. Dr. Gibson's research centers on solar drivers of the terrestrial environment from short-term space weather drivers such as coronal mass ejections to long-term solar cycle variation. She was the recipient of the American Astronomical Society's Solar Physics Division 2005 Karen Harvey Prize. She was a scientific editor for the *Astrophysical Journal* and has served on many national and international committees.

Dr. Gibson received her bachelor's degree in physics from Stanford University and her master and doctoral degrees in astrophysics from the University of Colorado. Welcome, Dr. Gibson.

Dr. Kent Tobiska is our final witness. He is President and Chief Scientist of Space Environment Technologies. His career spans work at the NOAA Space Environment Lab, U.S.—excuse me, UC Berkeley Space Sciences Laboratory, Jet Propulsion Laboratory, Northrop Grumman, SET, Utah State University Space Weather Center, and Q-up LLC. Dr. Tobiska invented the world's first operational computer code for solar irradiance forecasting and extended this expertise into the development of operational space weather systems that now produce solar irradiances, geomagnetic indices, and ground-to-space radiation environment dose rates.

Dr. Tobiska received a Ph.D. in aerospace engineering from the University of Colorado. He is a member of the American Geophysical Union, Committee on Space Research, American Meteorological Society, and an associate fellow of the American Institute of Aeronautics. We're happy to have you as well, Dr. Tobiska.

Thank all of you.

And now, I recognize Dr. Jacobs for five minutes to present his testimony, and I think the 5-minute timer's right there in front of you so you can see it clearly. Thanks, Dr. Jacobs.

**TESTIMONY OF DR. NEIL JACOBS,
ASSISTANT SECRETARY OF COMMERCE FOR
ENVIRONMENTAL OBSERVATION AND PREDICTION,
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION**

Dr. JACOBS. Good morning, Chairmen Biggs and Babin, Ranking Members Bonamici and Bera, and Members of the Subcommittees. Thank you for the opportunity to testify at this hearing about space weather.

NOAA is the U.S. government's official source of civilian space weather forecast, warning, and alerts to the public, industry, and government agencies. Through our Space Weather Production Center (SWPC), NOAA delivers space weather products that meet the evolving needs of the nation. SWPC operates 24 hours a day, 7 days a week and provides real-time forecasts and warnings of solar geophysical events. SWPC works closely with our U.S. Air Force partners, who are responsible for all national security needs and space weather information. SWPC efforts are also closely integrated with other agencies including NASA, National Science Foundation, and the U.S. Geological Survey, as well as commercial service providers, private industry, and academia.

NOAA utilizes an array of space- and ground-based observations in our space weather forecast operations and related research. Currently, NOAA relies on two primary observational assets to underpin our forecasts and warning, one satellite instrument for imagery of the Sun's corona and the other for Earthbound solar wind. The solar imagery used by NOAA comes from the joint European Space Agency/NASA's Solar and Heliospheric Observatory, SOHO. SOHO's coronal imagery is critical for NOAA's 1- to 4-day lead time for geomagnetic storm conditions. SOHO is anticipated to run out of power by 2025, and it currently has no backup.

In 2017, NOAA began development of a flight compact coronagraph (CCOR) to obtain imagery, and we will work with the U.S. Naval Research Laboratory to obtain the quickest possible delivery of this instrument. NOAA is currently evaluating an option to host the CCOR on our GOES-U satellite.

The second satellite NOAA uses is the Deep Space Climate Observatory DSCOVR. Stationed at the Earth's Sun Lagrange point L1 a million miles from Earth, DSCOVR is critical for real-time measurements of Earthbound solar winds. These observations play a critical role in our quest to better predict the probability of an eruption of the Sun. When an eruption occurs, forecasters feed the data into computer models and determine the likely duration and intensity of the solar events of Earth's ionosphere and magnetosphere.

NOAA forecasters communicate current and forecasted space weather conditions using a variety of products. Space weather scales, which are similar to hurricane classifications, communicate potential impacts such as radio blackouts from solar flares, solar radiation storms due to solar energetic particles, and geomagnetic storms from coronal mass ejections.

Watches, warnings, and alerts are issued by email via a product subscription service and also telephone notification to critical customers such as power grid operators, FEMA, and DOD. Using these NOAA products, the nation can enhance national preparedness, mitigation, response, and recovery actions to safeguard assets and maintain continuity of operations during space weather activity.

SWPC ensures that all data are made available to the growing private sector service providers. The NOAA private sector partnership plays a vital role in meeting the nation's needs for space weather services. NOAA makes all of its information available and recognizes that a strong public-private partnership is essential to establish observing networks conduct the research, create forecast models, and supply services necessary to support our national security and economic prosperity. NOAA is committed to working towards the growth of the private sector as a national infrastructure demands more space weather services.

Space weather presents a variety of hazards to technical systems and human health. NOAA's space weather products serve major U.S. airlines, satellite companies, and all U.S. electric power companies. These industries are well aware that solar weather can impact their communications, navigation, electrostatic charging, and cause mission interruption.

On April 19, the White House Office of Science and Technology Policy announced a development and update to the National Space Weather Strategy. This strategy, originally published in October of 2015, sets out to unite the U.S. national and homeland security with science and technology enterprise to formulate a cohesive approach to enhance national preparedness for space weather. This important update seeks to improve the government coordination on long-term guidance for federal programs and activities to enhance national preparedness for space weather events.

The revised strategy will align with priorities identified by the Administration in the 2017 National Security Strategy and Space Policy Directive 1. NOAA will continue to work and partner with other federal agencies in this renewed effort to develop and strengthen our activities in space. NOAA recognizes the importance of engaging public and private expertise and the whole-community collaborative approach to enhance the resiliency and security of our nation to space weather storms.

Thank you again for inviting me to participate today. I would be pleased to answer any questions you may have.

[The prepared statement of Dr. Jacobs follows:]

WRITTEN STATEMENT BY
NEIL JACOBS
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

ON
SPACE WEATHER ACTIVITIES IN THE NATIONAL OCEANIC AND ATMOSPHERIC
ADMINISTRATION

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEES ON SPACE AND ENVIRONMENT
U.S. HOUSE OF REPRESENTATIVES
APRIL 26, 2018

Introduction

Good morning Mr. Chairman and Members of the Committee. My name is Neil Jacobs and I am the Assistant Secretary of Commerce for Environmental Observation and Prediction at the National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce. Thank you for the opportunity to testify at this hearing about space weather. NOAA is the U.S. Government official source of civilian space weather forecasts, warnings, and alerts to the general public, industry, and government agencies. The NOAA Space Weather Prediction Center (SWPC), which is one of nine National Centers for Environmental Prediction within the National Weather Service, has a mission to deliver space weather products and services that meet the evolving needs of the Nation. SWPC operates 24 hours a day, 7 days a week, and provides real-time forecasts and warnings of solar and geophysical events. SWPC works closely with its partner-center in the Department of Defense (DOD), the U.S. Air Force (USAF) 557th Weather Wing. The 557th is responsible for all DOD/National Security needs for space weather information. In addition to the DOD, SWPC efforts are closely integrated with other agencies, including NASA, National Science Foundation (NSF), and the U.S. Geological Survey (USGS), as well as commercial service providers, private industry, and academia. It is SWPC's goal to produce accurate and timely space weather products and decision support tools that protect national critical infrastructure. The importance of SWPC's mission is evident as our Nation relies on technologies and human activities that are vulnerable to space weather impacts.

What is space weather?

Space weather refers to variations in the space environment between the sun and Earth (and throughout the solar system) that can affect technologies in space and on Earth. Space weather is primarily driven by solar storm phenomena that include solar flares, solar particle events, and coronal mass ejections (CME). Solar flares are large eruptions of electromagnetic radiation from the Sun lasting from minutes to hours, and the effects are often referred to as solar flare radio blackouts. Solar energetic particles create radiation storms and occur when an eruption on the Sun accelerates charged particles through interplanetary space. A CME is an expulsion of

billions of tons of plasma gas from the Sun with an embedded magnetic field. CMEs can lead to geomagnetic storms, whose outcome can result in a response partially similar to an electromagnetic pulse (EMP) produced from a high-altitude nuclear detonation. These naturally occurring phenomena have the potential to negatively affect critical infrastructure essential to the Nation's security and economic vitality. Space weather has the potential to disrupt human activities in space and technologies such as the Global Positioning System (GPS), satellite and spacecraft operations, telecommunications, aviation, and the electric power grid—simultaneously affecting large areas, potentially impacting the entire Nation or even wider geographic areas. And it is important to recognize that our critical infrastructure is an interconnected, interdependent system of systems in which the failure of one could cascade to another.

How are forecasts developed and disseminated

A space weather forecast begins with a thorough analysis of the Sun. Forecasters use many different types of solar images from space-based and Earth platforms to analyze active solar regions, localized areas that typically contain enhanced magnetic fields and sunspots. Sunspot groups can be several times the size of Earth and contain complex magnetic structures. Following this analysis, forecasters predict the probability of an eruption on the Sun. When an eruption occurs, forecasters feed the data from the data collection platforms and historical data in our archives into computer models to determine the likely effects of solar events on Earth's ionosphere and magnetosphere. These models help forecasters estimate when the effects will begin, how long they will last, and how severe the event will be.

NOAA is working actively with NASA and NSF to tap into their support of research and space weather modeling developed in the academic community to increase forecast skill. Some of these models have already been tested in a real-time mode at the NASA Goddard Space Flight Center, Community Coordinated Modeling Center. Our focus is to accelerate the transition of research to operations to enable SWPC operational forecasts to be based on these sophisticated models. To date, the NWS now runs two operational models: the George Mason University, Air Force Research Lab, Wang-Sheeley-Arge ENLIL heliosphere model; and the University of Michigan Geospace Model.

SWPC forecasters communicate current and forecasted space weather conditions using a variety of products. Many of the products reference the NOAA Space Weather Scales. Just like there are categories to classify hurricanes, there are also Space Weather Scales for communicating the relative severity of space weather storms. Space weather scales separately map to the aforementioned emissions from the sun - Radio Blackouts (solar flares), Solar Radiation Storms (solar energetic particles), and Geomagnetic Storms (coronal mass ejections). The scales list possible impacts for each level and indicate how often such events happen. Watches, warnings, and alerts are issued by email via a product subscription service and by telephone notification to critical customers such as the various power grid operators and the Federal Emergency Management Agency (FEMA) Operations Center. NOAA's space weather alerts and warnings are key for enhancing national preparedness to space weather. Using these products, the Nation can enhance mitigation, response, and recovery actions to safeguard assets and maintain continuity of operations during space-weather activity.

SWPC ensures all data and services are made available to the growing private sector service providers. The NOAA-private sector partnership plays a vital role in meeting the Nation's needs for space weather services. NOAA makes all of its information available and recognizes that a strong public-private partnership is essential to establish the observing networks, conduct the research, create forecast models and supply the services necessary to support our national security and economic prosperity. NOAA is committed to working toward the growth of the private sector as the national infrastructure demands more space weather services.

Who are the consumers and what actions will they take to mitigate impacts

Space weather presents a variety of hazards to technical systems and human health. SWPC serves a growing and diverse customer base covering a broad spectrum of users. SWPC's Product Subscription Service, which began in 2005 with a few hundred subscribers, ballooned to over 53,000 subscribers just a decade later. All major U.S. airlines subscribe to the service, as do all satellite companies, and all electric power companies.

During severe geomagnetic storms, SWPC forecasters use the 24-hour Emergency Hotline to issue warnings to the 16 Reliability Coordinator centers (RC) across the United States and Canada. The RCs in turn redistribute the information to power companies in their areas of responsibility enabling efforts by those companies to take protective actions.

Likewise, during space weather storms, ground receivers can struggle to lock on to GPS satellites, thus timing and position information becomes less accurate or unavailable. NOAA issues space weather warnings to a variety of public and private industry sectors that rely on GPS, such as oil companies that use GPS services worldwide to position oil rigs and survey vessels. These warnings also go to farmers who rely on GPS for improved crop yield through precise application of pesticides, herbicides, and fertilizers while reducing environmental risks and to construction crews who rely on GPS to improve the productivity, efficiency and safety at their job sites. GPS is also relied upon across the transportation systems sector to improve safety, efficiency and to reduce environmental impacts. As market innovations continue to accelerate the development of autonomous transportation, NOAA will provide the critical information to support safe operations during space weather events in this new transportation paradigm.

Over 15,000 commercial flights flew polar routes in 2017. Airline crews receive a space weather briefing before departing on any polar route. Aviation operators use NOAA space weather information to assess potential impacts—such as communication outages, harmful radiation, and navigation errors—to adjust routes and altitudes.

Spacecraft launch operators use radiation products to avoid electronic problems on navigation systems, preventing launch vehicles from going off course and being destroyed. Space weather effects on satellites can vary from minor interruptions to potential mission failure. Satellite operators rely on space weather products to avoid or analyze problems on their spacecraft. NOAA's forecasts and observations are also important input to manned spaceflight operations. Activities onboard the International Space Station are altered to avoid or mitigate effects of radiation storms impacting crew safety and technological systems. Accurate space weather

information will be important when we return Americans to the surface of the Moon and onward to Mars.

Space weather forecasts are also important inputs to support DOD communications, USAF flight operations, U.S. Navy strike forces, and U.S. Army Special Forces. NOAA's Geostationary Operational Environmental Satellites (GOES) provide the basis for classified and unclassified data for the DOD. In fact, 80% of the DOD space weather alerts and warnings rely on GOES data. The National Defense Authorization Act for Fiscal Year 2018 calls for an assessment of the nature, magnitude, and likelihood of potential EMP, both manmade and natural, that could be directed at or affect the United States within the next 20 years.

A growing number of SWPC customers are realizing social and economic benefits from space weather products and services. NOAA is addressing the accelerating growth in our space weather customer base by improving our understanding of customer needs and by defining new services in response to the evolving needs and requirements of a global high-tech economy.

Observation Platforms

NOAA utilizes an array of space-based and ground based observations in our space weather forecast operations and related research. Many of these data sets are available in near real-time, and come from a variety of sources, ranging from solar imaging satellites to ground magnetometer stations. In addition to NOAA operational assets, we have partnerships with other organizations such as NASA, NSF, USAF, and USGS to utilize data from these agencies to complement the NOAA observations.

Currently, NOAA relies on the European Space Agency/NASA's Solar Heliospheric Observatory (SOHO) for CME imagery. The life expectancy of SOHO, which was launched in 1995, is limited by the power produced from its solar arrays. Solar arrays degrade over time and the latest engineering analysis indicates that by 2025, there will be insufficient power for the satellite to operate. At this time, there is no back up for CME imagery. With the eventual power loss, NOAA will lose access to CME imagery. Without CME imagery, the 1- to 4-day lead-time of likely storm conditions will be degraded, thereby affecting the accuracy of geomagnetic storm watches. NOAA started developing a flight compact coronagraph (CCOR) to obtain CME imagery in 2017, and will continue to work with the U.S. Naval Research Laboratory (NRL) to obtain the quickest possible delivery of the CCOR instrument. NOAA is currently evaluating an option to host the CCOR on the GOES-U satellite on its Sun-Pointing Platform (SPP).

NOAA also relies on NSF's Global Oscillations Network Group (GONG), which provides ground-based observations of the solar magnetic field. GONG consists of a network of six stations that provide imaging and magnetograms on a 24/7 basis. GONG is currently undergoing a modernization program to make it operationally ready to provide critical data inputs to SWPC space weather models. NOAA provides partial support for GONG operations through a 5-year interagency agreement with NSF.

Real-time measurements of the highly variable solar winds are vital for assessing space weather conditions in near-Earth space within the atmosphere and on the ground. For solar wind data upstream of Earth, NOAA uses its Deep Space Climate Observatory (DSCOVR) stationed at

Earth-Sun Lagrange point 1 (L1). DSCOVR is a research-grade satellite and is susceptible to mission failure with the loss of any of several single string critical components. For backup, we use the NASA Advanced Composition Explorer (ACE) spacecraft. ACE (launched in 1997) is limited by fuel used for orbit station-keeping and will run out of fuel in 2026. Loss of in-situ monitoring of solar winds without a replacement will cripple NOAA's ability to provide short-term warnings (15-45 minutes) of space weather storms. NOAA is exploring a partnership with NASA to fly a NOAA Space Weather Follow-On (SWFO) spacecraft as a rideshare with the NASA 2024 Interstellar Mapping and Acceleration Probe (IMAP) launch to L1. As a part of this effort, NOAA will conduct assessments on potential instruments for a solar wind mission.

Additionally, NOAA is exploring commercial opportunities for solutions to meet U.S. government requirements for space weather observations. These commercial solutions could include: the availability of space and resources for U.S. government sensors or instruments on commercially manifested satellite missions (i.e., hosted payloads); commercial satellite systems that complement or meet U.S. government observing requirements; and purchasing commercial space weather observations (i.e. data buys).

To obtain continuous data from DSCOVR and ACE, NOAA relies on a network of ground tracking stations located at various sites around the world. Our foreign partners include the National Institute of Information and Communications Technology in Tokyo, Japan; the Korean Radio Research Agency Space Weather Center in Jeju, Korea; and the German Aerospace Center in Neustrelitz, Germany.

The underpinning data used by NOAA to supply the Nation with geomagnetic storm warnings and alerts are the ground-based magnetic field observations provided by the USGS Geomagnetism Program. NOAA's geomagnetic storm alerts and warnings are based on the USGS magnetometers. These observations describe the local intensity of the changes in magnetic fields and allow NOAA to characterize the intensity of the geomagnetic storm.

NOAAs Interagency Coordination with SWORM

In November 2014, the Space Weather Operations, Research, and Mitigation (SWORM) Task Force was established by action of the National Science and Technology Council (NSTC). It was tasked with uniting the national- and homeland-security enterprise with the science and technology enterprise to formulate a cohesive approach to enhance national preparedness for space weather. As a result, the National Space Weather Strategy and associated Action Plan¹ were published in October 2015. Executive Order (EO) 13744 – Coordinating Efforts to Prepare the Nation for Space Weather Events, was signed in October 2016.

These documents together identify 105 actions for Executive departments and agencies to prepare the Nation for space weather storms. To maximize efficiency in our efforts to complete the goals in the National Space Weather Strategy, NOAA is committed to strong public-private partnerships between the Federal Government, industry, and academia. And given the global threat of space weather, and because the United States has key assets across the world, we must

¹https://www.sworm.gov/publications/2015/swap_final__20151028.pdf

also work with international partners to build adaptive capacity and increase resilience to space weather.

On April 19, the Office of Science and Technology Policy announced the development of an update to the National Space Weather Strategy. This important initiative seeks to improve government coordination on long-term guidance for Federal programs and activities to enhance national preparedness to space weather events. The revised strategy will align with priorities identified by the Administration in the 2017 National Security Strategy (NSS), and the Space Policy Directive – 1. The NSS promotes American resilience through improving our ability to withstand and recover rapidly from natural disasters and other threats to our economy and democratic system. It recognizes that in the event of a disaster, Federal, state, and local agencies must perform essential functions and have plans in place to ensure the continuation of government. Space Policy Directive – 1 provides for a U.S.-led, integrated program with private sector partners for a human return to the Moon, followed by missions to Mars and beyond. Outside Earth’s protective magnetic field and atmosphere, the radiation in space will pose a serious risk to astronauts as they travel to the Moon, Mars and beyond. Space weather forecasts will be important for the safety of our astronauts on deep space missions.

On April 20, NOAA released a Request For Information (RFI) seeking input from the public on ways to improve government coordination and on long-term guidance for Federal programs and activities to enhance national preparedness to space weather events. The RFI also includes the opportunity for the private sector to provide information regarding commercial activities associated with space weather prediction, observation, or the transitioning of research to operations. Specifically, NOAA will utilize the input to enable and advance the private sector role for capabilities, forecasting, modeling, mitigation, research, development, and observation in the space weather domain.

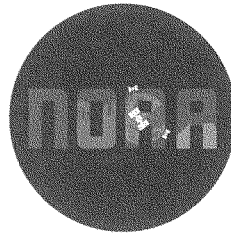
NOAA will continue to work and partner with other Federal agencies in this renewed effort to develop and strengthen our activities in space weather research and forecasting. And we recognize the importance of engaging public and private expertise in a whole community approach, engaging public and private expertise to enhance the resiliency and security of our Nation to space weather storms.

4/24/2018

Dr. Neil Jacobs | National Oceanic and Atmospheric Administration



National Oceanic and Atmospheric
Administration
U.S. Department of Commerce



Dr. Neil Jacobs

Assistant Secretary of Commerce for Environmental Observation and Prediction

Across NOAA | NOAA Leadership

Dr. Jacobs was formerly the Chief Atmospheric Scientist at Panasonic Avionics Corporation, where he directed the research and development of both the aviation weather observing program, as well as the numerical forecast models. He was the Chair of the American Meteorological Society's Forecast Improvement Group, and also served on the World Meteorological Organization's aircraft-based observing systems expert team.

Prior to joining Panasonic (AirDat) in 2005, Dr. Jacobs worked on various analyses and modeling projects including NASA's Earth Systems Science Program, GOES satellite program, and the Department of Energy's Ocean Margins Program. He has bachelor of science degrees in mathematics and physics from the University of South Carolina, and a master of science degree in air-sea interaction, and a doctoral degree in numerical modeling from North Carolina State University.

Chairman BIGGS. Thank you, Dr. Jacobs.
I now recognize Dr. Spann for five minutes for his testimony.

**TESTIMONY OF DR. JIM SPANN,
CHIEF SCIENTIST, HELIOPHYSICS DIVISION,
SCIENCE MISSION DIRECTORATE,
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION**

Dr. SPANN. Thank you. Members of the Subcommittee, as the Heliophysics Chief Scientist for NASA's Science Mission Directorate, I am honored to appear before this Committee to discuss NASA's contribution to understanding space weather phenomenon.

Space weather is complex, involving intricate interactions between the Sun, solar wind, Earth's magnetic field, and Earth's atmosphere. NASA serves as a research organization for our nation's space weather efforts, working with the National Science Foundation to understand space weather. Together, we help operational organizations, NOAA, and the Department of Defense incorporate that understanding into operational models and space weather predictions to better prepare the nation for potential impacts.

Our ability to understand the Sun-Earth system is of growing importance to our nation's economy, national security, and our society as it increasingly depends on technology. While the Sun enables and sustains life here on Earth, it produces radiation and magnetic energy that can have disruptive impacts in space, in air, and on the ground.

Understanding the Sun-Earth system has practical implications for life on Earth. For example, the electric power industry is susceptible to geomagnetically induced currents, which can, without advanced warning, overload unprotected power grids and result in widespread power outages. In the spacecraft industry, intense geomagnetic and radiation storms have the capacity to disrupt normal operations such as satellite communication and television service. Space weather can cause irregularities in signals from GPS satellites, which can adversely affect our warfighters, first responders, truckers, oil drillers, large-scale farmers, and outdoor enthusiasts, pretty much everybody. Finally, the aviation industry is particularly susceptible to space weather events from both an operational and crew/passenger safety perspective.

NASA's heliophysics missions all contribute to understanding the physical processes that drive space weather. With locations throughout the solar system, we observe the Sun-Earth system every day using NASA's Heliophysics Systems Observatory with 18 active missions comprised of 28 spacecraft. At NASA, we're extremely excited to see how our new missions will revolutionize our understanding of the Sun-Earth system and space weather.

The recently launched GOLD mission and an upcoming ICON mission will improve our understanding of what is happening in the ionosphere, the region in the near-Earth space where significant space weather impacts occur. This summer, we'll spend a spacecraft, Parker Solar Probe, closer to the Sun than ever before and dive into the Sun's hot corona to provide the closest ever observations. She will reveal the fundamental science behind what drives the solar wind, which is the constant outpouring of material

from the Sun, and improve forecasts of major eruptions on the Sun, all of which affect space weather near the Earth.

NASA's Heliophysics Division is in the process of selecting its next strategic mission, the Decadal Survey priority IMAP. This mission will observe the boundary of our solar system and investigate acceleration processes critical to understanding space weather. As you've heard, NASA and NOAA are exploring a potential partnership to share IMAP's launch vehicle with NOAA's space weather follow-on mission. These new missions will join our existing fleet to enhance the already vibrant Heliophysics Systems Observatory.

NASA supports world-class research based on data from these missions in order to understand the connections within our Sun-Earth system for science advancement and human safety both on Earth and beyond. This field of research is called heliophysics and provides the foundation upon which predictive models of space weather are built. To help mitigate space weather hazards posed to assets both in space and on the ground, NASA continues to develop and improve predictive models through enhanced fundamental understanding of space weather by funding competed basic research opportunities, which includes topics such as solar variability and ionosphere irregularities.

NASA, in coordination with NOAA and NSF, has developed a cross-agency plan to enhance the transition of research models to operations. NASA has a pilot program to improve space weather products and services for research to operations which will draw on expertise in academia and in industry both in technology and knowledge. This program utilizes the established NASA Community Coordinated Modeling Center, a successful multiagency partnership that provides space science simulations to the research community and support our sister agencies by transitioning space research models to operations.

NASA appreciates the continued support from this committee, which ensures that the United States maintains a superior position in understanding space weather and looks forward to the continued collaboration with our sister agencies, international partners, academia, and industry.

NASA heliophysics has a big year in front of it. The data we receive from upcoming missions and from the existing Heliophysics Systems Observatory will vastly improve our understanding of this challenging phenomenon and enable improved predictive space weather models. Heliophysics research is intrinsically the science of space weather, and NASA is committed to remain the leader in that research.

So I thank you now for the invitation to be here today, and I look forward to answering any questions that you may have.

[The prepared statement of Dr. Spann follows:]

**HOLD FOR RELEASE
UNTIL PRESENTED BY WITNESS
April 26, 2018**

**Statement of
James Spann
Chief Scientist, Heliophysics Division
Science Mission Directorate, NASA
before the
House Subcommittee on the Environment and the
House Subcommittee on Space
Committee on Science, Space and Technology
United States House of Representatives**

Chairmen Biggs and Babin, Ranking Members Bonamici and Bera, and members of the Subcommittees:

As the Heliophysics Chief Scientist for NASA's Science Mission Directorate (SMD), I am honored to appear before this Committee to discuss NASA's contributions to understanding space weather phenomena.

Space weather is complex, involving intricate interactions between the Sun, solar wind, Earth's magnetic field, and Earth's atmosphere. NASA serves as a research organization for our nation's space weather efforts, working with the National Science Foundation to enhance our scientific understanding of space weather. Together, we help the operational organizations of National Oceanic Atmospheric Administration (NOAA) and the Department of Defense (DOD) incorporate that understanding into operational models and space weather predictions to better prepare us for potential impacts.

Our ability to understand the Sun-Earth system is of growing importance to our nation's economy and national security. While the Sun enables and sustains life here on Earth, it produces radiation and magnetic energy that can have disruptive impacts to astronauts and spacecraft in space, airline passengers in the air, communications and positioning devices, and the electrical power grid on Earth. Understanding the Sun-Earth system has practical implications for life on Earth. For example, the electric power industry is susceptible to geomagnetically-induced currents, which can overload unprotected power grids and result in widespread power outages. With warning, power grid operators may be able to adjust operations to counteract such effects. In the spacecraft industry, intense geomagnetic and radiation storms have the capacity to disrupt normal operations such as satellite communication and television service. Space weather can cause irregularities in signals from Global Positioning System satellites, which can adversely affect our warfighters, first responders, long-haul truckers and outdoor enthusiasts. Finally, the aviation industry is particularly susceptible to space weather events from both an operational and safety perspective. Communications between flights taking polar routes and air traffic control could be disrupted due to interference between the radio waves and the effects of space weather

in the ionosphere. In addition, flight routes may be re-routed further south during solar weather events to reduce the radiation exposure to passengers and crew.

NASA's Heliophysics missions all contribute to understanding the physical processes that drive the environment of the connected Sun-Earth system. With locations throughout the solar system, we observe the Sun-Earth system everyday using NASA's Heliophysics System Observatory, with 18 active missions comprised of 28 spacecraft.

At NASA, we are excited to see how new missions will revolutionize our understanding of the Sun-Earth System and space weather. The recently launched Global-scale Observations of the Limb and Disk (GOLD) mission and the upcoming Ionospheric Connection (ICON) mission will improve our understanding of what is happening in the ionosphere. The ionosphere is a little-understood region where the Earth's uppermost atmosphere meets the space that surrounds us — a critical boundary that responds both to terrestrial weather below and space weather above. Placed in different orbits, GOLD and ICON will each get a unique snapshot of the same region in the ionosphere. This overlap will enhance our ability to identify what causes certain changes to the upper atmosphere that cause space weather impacts.

This summer, we will send the Parker Solar Probe closer to the Sun than any human-made object has ever gone, and it will dive into the Sun's hot corona to provide the closest-ever observations. Throughout its seven-year mission, while facing brutal heat and radiation, the mission will reveal the fundamental science behind what drives the solar wind, which is the constant outpouring of material from the Sun that affects space weather near Earth. Parker Solar Probe will explore the Sun's outer atmosphere and make critical observations necessary to improve forecasts of major eruptions on the Sun and the subsequent space weather events that impact our technology dependent lives.

Also launching this summer, the Space Environment Testbed 1 mission, a technology demonstration mission developed in partnership with the Air Force, will improve the engineering approaches to mitigation and accommodations for the effects of solar variability on spacecraft design and operations. The mission will also provide important data to improve hardware performance in the space radiation environment.

NASA's Heliophysics Division is in the process of selecting its next strategic mission, a Decadal Survey priority, the Interstellar Mapping and Acceleration Probe (IMAP). IMAP will observe the boundary of our solar system and investigate acceleration processes critical to understanding space weather. NASA and NOAA are exploring a potential partnership to use the same launch vehicle for IMAP and a NOAA space weather monitoring payload. The partnership would provide NOAA access to the L1 Lagrange point for future space weather monitoring.

These new missions will join our existing fleet to enhance the already vibrant Heliophysics System Observatory, which all contribute to better understanding the physical processes that are driving the space environment around Earth and throughout the solar system. The following missions are particularly focused on improving our understanding of space weather: the Advanced Composition Explorer and NOAA's Deep Space Climate Observatory, which observe the solar wind; the Solar Dynamics Observatory, the Solar and Terrestrial Relations Observatory,

the joint ESA/NASA Solar and Heliospheric Observatory, which can all observe solar eruptions on the Sun; and the Van Allen Probes, which observes the radiation belts around Earth.

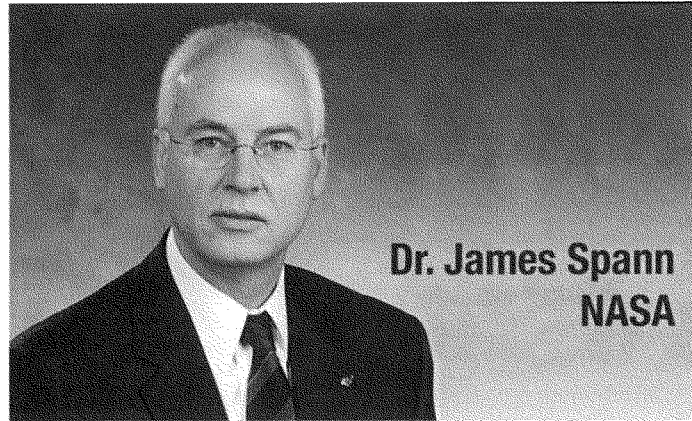
NASA supports world-class research based on these missions and other sources, to understand the connections within the Sun-Earth system, for science and human safety, both on Earth and beyond. Heliophysics research provides a foundation to build predictive models of space weather events, mitigate the hazards posed to assets both in space and on the ground, and understand space weather impacts throughout the solar system. NASA continues to develop and improve predictive models through enhanced fundamental understanding of space weather through funding basic and targeted research opportunities. NASA research opportunities reflect the general and focused science topics that are associated with space weather phenomena, which include understanding solar variability, and how it drives phenomena in the space environment near Earth, where space weather can have its most significant impacts on spacecraft, communications, and positioning devices. NASA, in coordination with NOAA and NSF, has developed a cross-agency plan to enhance the transition of research models to operations and models in operations to researchers.

The NASA Community Coordinated Modeling Center (CCMC), is a successful multi-agency partnership that provides space science simulations to the research community. The CCMC plays a key role in supporting our sister agencies by transitioning space research models to space weather operations. Furthermore, in coordination with NOAA and NSF, we have initiated a pilot program to expand the interagency capability and improve space weather products and services for Research to Operations and Operations to Research (R2O2R).

NASA appreciates the continued support from this committee, which ensures that the United States maintains a superior position in understanding space weather, and looks forward to the continued collaboration with our sister agencies, international partners, academia, and industry.

NASA Heliophysics has a big year in front of it. The data we receive from upcoming NASA's Heliophysics missions and data we already collect from the Heliophysics System Observatory, will vastly improve our understanding of this challenging phenomena. The research these missions enable continues to develop and improve predictive models through enhanced understanding of the science of space weather. Heliophysics research is intrinsically the science of space weather. NASA is committed to remain the leader of that research.

Thank you for the invitation to be here with you today, and I look forward to answering any questions you may have.



Dr. James Spann currently serves as the Chief Scientist of the Heliophysics Division in the Science Mission Directorate at NASA Headquarters. He received his BS degree in Mathematics and Physics from Ouachita Baptist University, and his Ph.D. degree in Physics from the University of Arkansas in Fayetteville. In 1986, Dr. Spann joined NASA Marshall Space Flight Center in Huntsville, Alabama, where he has held numerous positions, including Chief Scientist and Manager of the Science Research Office. Dr. Spann is a native of Fort Worth, Texas.

Chairman BIGGS. Thank you, Dr. Spann.
I now recognize Dr. Gibson for five minutes for her testimony.

**TESTIMONY OF DR. SARAH GIBSON,
SENIOR SCIENTIST, HIGH ALTITUDE OBSERVATORY,
NATIONAL CENTER FOR ATMOSPHERIC
RESEARCH AND CO-CHAIR,
COMMITTEE ON SOLAR AND SPACE PHYSICS,
NATIONAL ACADEMY OF SCIENCE**

Dr. GIBSON. Thank you very much.

My intent is to provide context for your discussion of space weather and to argue for moving forward with legislation as soon as possible.

In brief, the points that I wish to convey today are as follows: First of all, space weather has broad and potentially devastating impacts on the nation; second, there are fundamental scientific questions that are central to space weather that remain unanswered; third, space weather research and operations are observationally starved; fourth, the path forward requires strategic actions that emphasize both efficiency and agility; and finally, space weather legislation is needed now.

First of all, space weather happens all of the time. We're living in the outer atmosphere of our Sun, which is continuously expanding outwards as the solar wind and passing the Earth as an unceasing stream of charged particles. On a regular basis, dense, fast, and strongly magnetized particles are buffeting the Earth and breaking through its magnetic shield.

In the past, this would just mean that we would see auroras, but now, technology has made us vulnerable. As you've heard, geomagnetic activity induces ground currents and impacts power grids. Perturbations of the upper atmosphere disrupt GPS, radiocommunication, and increase the risk of collisions for the International Space Station and for satellites in low-Earth orbit. Radiation storms knock out satellite function, increase the exposure of airplane passenger and crew on polar routes, and are particularly dangerous for our astronauts as they venture forth to the moon and Mars.

Space weather has the potential to be really bad. The Carrington event of 1859 was so big it led to auroras as far south as Cuba and sparked fires along telegraph lines. It's been estimated that a modern superstorm of this size would cost tens of billions of dollars per day, potentially reaching totals in the trillions of dollars from extended power outages and global supply chain disruptions.

Even when it's not a superstorm, space weather is a problem. Analysis of insurance claims associated with power grid disruptions estimated costs on the order of \$10 billion per year for the United States for non-extreme events, and even moderate space weather increases risk for serious hazards, as I have described.

So what do we know? Well, we know that space weather comes from the Sun. Solar flares have an almost immediate effect at the Earth, and then mass and magnetic fields are hurled out into the solar wind, hitting the Earth a day or two later. The devil is in the details. We don't know what triggers the solar eruption. We don't

know how things change from Sun to Earth, and we don't know what exactly to expect when it gets here. There is still much to learn about the fundamental physical processes and the complex interactions from Sun to Earth.

Our best bet for filling the gaps in our understanding are more observations. For tackling basic science problems, this includes higher-quality observations, as well as new types of observations and from new viewpoints. For operational forecasts and monitoring, the requirements are different. There the emphasis is on observations we can analyze quickly and that are consistent and reliable.

The legislation, as presented in the Senate and proposed House bills, provide a good framework for progress. The bills enable research, for example, through multidisciplinary science centers to solve the fundamental problems that will then lead to better forecasting capability. They extend our observational assets, both for filling the science gaps and to protect our baseline for operations. They also lay out the roles and the responsibility for the different government agencies, which leads to more efficient use of national resources and to better protection of our nation.

They promote further efficiency through seeking leveraging opportunities from outside the government, including the international, the commercial, and the academic sectors. An example of this: our prime operational research, the LASCO Coronagraph is on the SOHO satellite, which is a collaboration of NASA and the European Space Agency. Another example, the NASA GOLD mission, was launched on a commercial communications satellite.

And finally, the proposed legislation promotes an agile and necessarily open-ended approach to capitalizing on innovations from and interactions with these nongovernmental groups.

In summary, we are an increasingly technological society, and we cannot afford to ignore space weather. If we delay action, we run multiple risks. We run the risk of being unprepared for a superstorm. We run the risk of failure of our operational assets. LASCO is 23 years old, and that would degrade even our current forecasting capability. And then there's the costs and the risks associated with even moderate space weather. Every day we wait, we waste time and money and we roll the dice on our safety.

[The prepared statement of Dr. Gibson follows:]

Statement of Dr. Sarah E. Gibson

National Center for Atmospheric Research Senior Scientist
 High Altitude Observatory Solar Frontiers Section Head
 Co-chair, Committee on Solar and Space Physics
 Space Studies Board, National Academies of Sciences, Engineering and Medicine

**Before the Joint Subcommittees on Space and Environment
 Committee on Science, Space, and Technology
 U.S. House of Representatives
 April 26, 2018**

Mr. Chairmen, Ranking Minority members, and members of the Subcommittees, I want to thank you for the opportunity to testify today at this hearing on “Surveying the Space Weather Landscape”. My name is Sarah Gibson and I am a Senior Scientist at the National Center for Atmospheric Research and a co-chair of the National Academy of Sciences Committee on Solar and Space Physics. The views presented here are my own, and are based on my professional experience in the field of Heliophysics, the science at the heart of Space Weather.

The particular intent of this testimony is to provide context for your discussion of space weather legislation, and to argue for moving forward with said legislation as soon as possible. I work in Boulder, Colorado, which is a nexus of space-weather research and operations¹. I was pleased to see that my state’s Senator Gardner co-sponsored the Senate space weather bill that passed last year (S.141), along with Senators Booker and Wicker, and that now the House space weather bill (H.R.3086) has been introduced by Colorado’s Mr. Perlmutter, along with Ms. Johnson and Mr. Bridenstine. Space weather is fundamentally an issue of safety and protection of life and property, and as such, it is no surprise that it crosses party lines.

In brief, the points I wish to make today are as follows:

- **Space weather has broad and potentially devastating impacts on the Nation.**
- **Fundamental scientific questions, central to space weather, remain unanswered.**
- **Space-weather research and operations are observationally starved.**
- **The path forward requires strategic actions that emphasize efficiency and agility.**
- **Legislation is needed now.**

¹ Just a few examples of institutes participating in space weather activities in the Boulder area include: NCAR’s [High Altitude Observatory](#), the [Space Weather Prediction Center](#) at NOAA, the [USGS geomagnetism program](#), the [National Solar Observatory](#), the recently formed [Space Weather Technology, Research and Education Center](#) at the University of Colorado, the [Atmospheric and Space Technology Research Associates](#), the Boulder offices of the [Southwest Research Institute](#) and [Northwest Research Associates](#), and aerospace companies including [Ball Aerospace](#) and [Sierra Nevada Corporation](#).

1. Space weather has broad and potentially devastating impacts on the Nation.

We are living inside the atmosphere of our star, the Sun. That atmosphere continually expands outwards as the solar wind, passing the Earth in an unceasing stream of charged particles. It is variable in nature, and, on a regular basis, dense, fast, and strongly magnetized gusts buffet the Earth. Luckily, the Earth's atmosphere and its own magnetic field act as shields that protect us and our technology from direct exposure to this solar wind. However, the Earth's magnetic shield is neither static, rigid, nor indestructible, and the strongest solar wind gusts can and do frequently break through.

When they do, interactions between the magnetic fields in the solar wind and those of the Earth result in one of the most common forms of space weather: geomagnetic activity. Until the last century or so this meant only that humans were treated to the spectacle of beautiful auroras. With the advent of technology, however, new vulnerabilities emerged.

In 1859, Richard Carrington was observing a particularly complicated group of sunspots projected from his telescope onto a screen, when he saw two brilliant spots of white light appear and brighten on top of the otherwise dark sunspots. This was unusual -- only the very brightest solar flares are visible in this manner -- but what made this astronomical observation particularly significant was that Carrington subsequently connected the solar flare to the strong geomagnetic activity observed the following day, when the storm reached the Earth. The storm was so strong that auroras were seen as far equatorward as Cuba and El Salvador, and -- marking the first recorded impact of space weather on our nascent technology -- fires were sparked along telegraph lines.

Now, with our increasingly technological society, our vulnerability to this type of space weather is much higher. Geomagnetic activity induces ground currents that interfere with our power grids (Knipp, 2015). In the event of a "Carrington-level" storm, cascading transformer failures, power outages, and disruptions of global supply chains could cost the U. S. tens of billions of dollars per day (Oughton et al., 2017), with long-term global costs potentially reaching trillions of dollars (Schulte in den Baumen et al., 2014; see also National Research Council, 2008).

Geomagnetically-induced ground currents represent just one of several hazards associated with space weather. A variety of ionospheric disturbances may also occur, affecting global navigation and communications. This introduces wide-ranging costs and risks: a particularly trenchant example occurred in 1967, when space weather disrupted radar and radio communication in a manner that was initially interpreted by the U. S. military as a possibly hostile act by the Soviet Union (Knipp et al., 2016).

Disturbances of the upper atmosphere also pose difficulties for the International Space Station and other satellites in low-altitude orbit (Oliveiros et al., 2017). The atmospheric drag on such assets change in unexpected ways, impacting calculations of satellite trajectories that are critical for avoiding collisions. Radiation storms also often occur with large solar storms, posing a danger to both astronaut health and satellite function. The threat is highest away from the Earth's protective shields, and deep-space missions -- for example to the moon or other planets -- must be prepared for hazardous levels of radiation.

As with terrestrial weather, space weather can range in severity -- from minor squalls occurring multiple times per year, to larger storms that strike once or twice per 11-year solar cycle, to 100-year Carrington-level storms, and, possibly, to storms surpassing anything experienced in modern times (particularly with regards to radiation hazards) (Schrijver and Beer, 2014). There are costs even for the smallest of these events: for example, an assessment of insurance claims attributable to variations in the power grid suggests that the impacts of non-extreme geomagnetic activity may be as large as 10 billion dollars per year for the U.S. alone (Schrijver et al., 2014).

Space weather and associated economic and societal impacts run the gamut from frequent and small (yet still costly) events, to rare (but potentially globally-disastrous) superstorms.

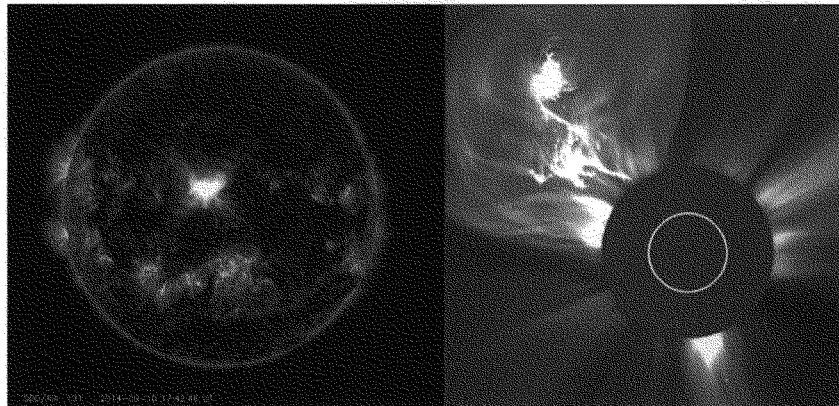


Figure 1. (Left) An X1.6 class solar flare flashes in the middle of the Sun and is observed by the Solar Dynamics Observatory Atmospheric Imaging Assembly (SDO/AIA). (Right) The Solar and Heliospheric Observatory Large Angle and Spectrometric Coronagraph (SOHO/LASCO) observes a coronal mass ejection (CME) as a bright tangled structure exploding out into the solar wind. The white circle indicates the size and position of the solar disk, which is blocked so that the Sun's outer atmosphere, or corona, can be seen (thus, the coronagraph mimics a solar eclipse). (Image credits: NASA/ESA)

2. Fundamental scientific questions, central to space weather, remain unanswered.

The ultimate source of space weather is the Sun. Flares and coronal mass ejections (CMEs) (Figure 1) are both manifestations of a solar eruption. The flare is the flash of light released as the eruption is triggered; it drives radio blackouts at the Earth almost immediately. The CME is the subsequent launch of mass outward into the solar wind; it can lead to geomagnetic activity a day or two later. Both contribute to ionospheric disturbances, satellite tracking problems, and radiation storms.

Ultimately, we would like to be able to predict solar eruptions before they happen. We know that they occur in regions that are magnetically-energized (for example, complex groups of sunspots) and some progress has been made in identifying observational signatures of this energization. However, we still do not know what triggers the eruptions, which significantly limits our capability for prediction.

So, in general, we wait until an eruption occurs, and then hope to provide warning at least in advance of any geomagnetic activity. Unfortunately, we do not know with certainty how severe the space weather impacts at the Earth will be. The likelihood that a CME will break the Earth's magnetic shield depends on the CME's magnetic strength and orientation. To know this, we have to quantify the original 3D magnetic configuration at the Sun, and then understand how it erupts and how the resulting CME interacts with the solar wind as it travels from Sun to Earth. If we get the magnetic orientation backwards, we run the risk of false positives that trigger unnecessary mitigative steps in preparation for an event that turns out to be minor.

Even if we were able to predict the solar storm in advance, and even if we were able to specify the magnetic structure of the CME as it reaches the Earth, we would still be limited in our ability to forecast when, where, and how strongly ground currents, upper atmospheric disturbances, and radiation storms would occur. Fundamental physical processes such as magnetic reconnection and particle acceleration -- both of which are areas of active research -- must be taken into consideration, along with complex interactions between the Earth's upper atmosphere, space environment, and solar wind.

In the words of the recent international Committee on Space Research (COSPAR) Space Weather Road Map (Schrijver et al., 2015), "*The domain of space weather is vast – extending from deep within the Sun to far outside the planetary orbits – and the physics complex – including couplings between various types of physical processes that link scales and domains from the microscopic to large parts of the solar system.*"

Accurately forecasting space weather requires an understanding of all the links in the physical chain from Sun to Earth. At present, there are multiple conceptual gaps along that chain. Many are in fact the very same key science challenges, from Sun to Earth, that were identified in our field's last Decadal Survey (*Solar and Space Physics: A Science for a Technological Society*, National Research Council, 2013). **The gaps in our understanding lie at the bleeding edge of fundamental scientific research in Heliophysics, and represent problems that must be tackled if we wish to advance beyond our current forecasting capability.**

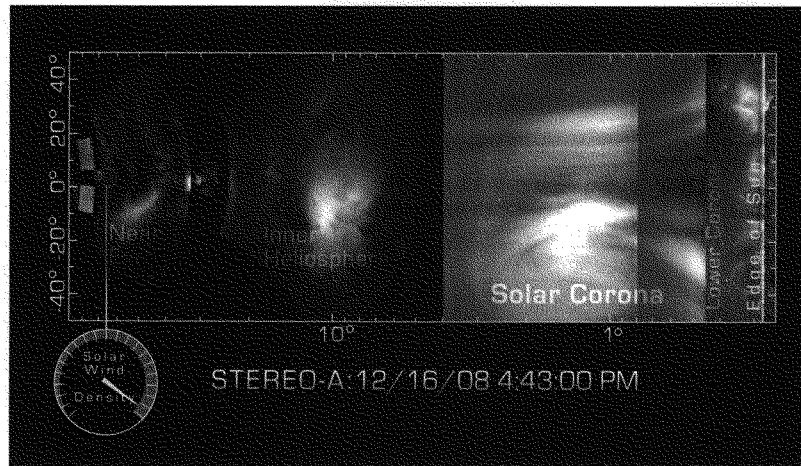


Figure 2. Taking a side view, instruments on board NASA's STEREO-A spacecraft track a CME as it evolves between Sun (on the right of the image) and Earth (the blue dot to the left), and connect image data directly to measurements at Earth at the time of impact. The images at the right are obtained near the Sun and deformed to enable tracking the CME structure through space. The gauge on the left shows solar wind density measured by NASA's WIND spacecraft spiking as the CME passes the Earth. Credit: NASA/Goddard Space Flight Center/SwRI/STEREO/WIND; DeForest et al., 2013; <https://svs.gsfc.nasa.gov/vis/a010000/a010800/a010809/index.html>.

3. Space-weather research and operations are observationally starved.

Our best bet for filling the gaps in our scientific understanding of the space-weather chain is through observations². For example, the question of how the CME changes en route from Sun to Earth is one that could be addressed by directly observing its progress, as shown in Figure 2.

² "If the matter is one that can be settled by observation, make the observation yourself. Aristotle could have avoided the mistake of thinking that women have fewer teeth than men, by the simple device of asking Mrs. Aristotle to keep her mouth open while he counted." -- Bertrand Russell

These observations were taken by one of NASA's two STEREO spacecraft, which precede and follow the Earth in its orbit around the Sun. The views from STEREO are thus complementary to those from the Earth, but are continuously changing. At the time of this event, STEREO had a side-angle view of the Sun-Earth line that was particularly appropriate for space-weather monitoring.

This raises an important point. The observational needs for solving fundamental scientific questions are not necessarily the same as those for day-to-day forecasting (i.e., space-weather operations). If we want to figure out the physical processes acting on a CME as it moves through the solar wind, it does not necessarily matter if the CME we observe is aimed at the Earth, but we do require high-resolution, spatially-continuous observations. If we are making space-weather operational forecasts, we could greatly benefit from the side-angle view of the Sun-Earth line, but we also require near-real-time, consistent and reliable observations. The example shown in Figure 2 is compelling, but offers only a fleeting glimpse of what is needed, and does not fully satisfy either type of needs. Moreover, it represents just one example of the broad range of observations from Sun to Earth required for progress in both space-weather research and operations.

Observations are not only needed to fill gaps in fundamental research, but also in applied research. An example of this is found in the benchmarking activities that are currently being undertaken to quantify the potential severity of space-weather hazards³. Comprehensive observations are needed to make these assessments, which in some cases are not currently available. For example, assessing geo-electric field benchmarks requires characterizing both geomagnetism and ground conductivity, but gaps in observational coverage prevent accurate estimates across much of the continental United States (Love et al., 2016).

In terms of operations, there are a few, critical, measurements that we know we need: for example, the SOHO/LASCO coronagraph observations of CMEs (e.g., Figure 1, right) represent the first definite sign of an approaching storm, and can be used to estimate arrival time and, to some extent, the size of the storm. Measurements just upstream of the Earth, e.g., at the L1 Lagrange point⁴ between the Sun and Earth, act as the “canary in the coal mine” and provide a much more accurate characterization of how big the storm will be, with however only about an hour (or less) of warning. It is no wonder that these two measurements in particular are

³ https://www.ofcm.gov/publications/spacewx/DRAFT_SWx_Phase_1_Benchmarks.pdf

⁴ The Lagrange points referred to here are locations where a spacecraft can maintain its position relative to the Sun and Earth, and so obtain essentially continuous observations from one (reasonably) stable vantage. Of particular interest to space-weather are the L1 point, which lies along the Sun-Earth line and so samples the solar wind in advance of its hitting the Earth; and the L4 and L5 points, which give views from either side of the Sun-Earth line and so enable the imaging of Earth-directed CMEs (similar to the view shown in Figure 2).

emphasized as essential in the Space Weather Action Plan (SWAP)⁵, and that there is concern regarding their future availability. Beyond this, various solar observations (including from ground-based telescopes) along with measurements of the Earth's upper atmosphere and space environment are routinely ingested into space-weather operational models, and ground magnetometer networks and neutron monitors are used for situational awareness of the geomagnetic and radiative environment.

But could we have a better, earlier forecast of storm strength if, for example, we had a continuous side-angle view of CMEs as they move along the Sun-Earth line? Or if we did a better job of measuring the magnetic field of the CME before it left the Sun (Tomczyk et al, 2016)? In truth, it is not yet clear exactly what the optimal set of observations are for forecasting and monitoring space weather.

To summarize: the gaps in our fundamental scientific understanding motivate new, cutting-edge observations of the sort presented in our Decadal Survey. The usefulness of these new observations for operational forecasts can then be assessed through applied research, potentially identifying new targeted observations needed to achieve specific operational goals. This represents one important aspect of a Research-to-Operations/Operations-to-Research (R2O-O2R) feedback loop (a similar argument can be made with regards to the development of the computer models used in space-weather forecasting). **The goal is an operationally relevant, scientifically sound approach to space-weather forecasting; however, currently the observations that support both the research and operations elements of space weather are insufficient and/or at risk.**

4. The path forward requires strategic actions that emphasize efficiency and agility.

A key motivation for the National Space Weather Strategy, stated both in its current form⁶ and in the recent call for its update⁷, is the improvement of government coordination. Laying out roles and responsibility for the different government agencies enables strategic coordination, and through this, a more efficient use of national resources.

Further efficiency comes from leveraging opportunities that arise outside of U.S. government agencies, in particular from the international, commercial, and academic sectors. An example of the benefit of international collaboration specific to the space-weather arena is the LASCO

⁵ Space Weather Action Plan (https://www.sworm.gov/publications/2015_swap_final_20151028.pdf), Section 5.3 "Establish and Sustain a Baseline Observational Capability for Space-Weather Operations"

⁶https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/final_nationalspaceweatherstrategy_20151028.pdf

⁷<https://www.federalregister.gov/documents/2018/04/20/2018-08336/developing-an-update-to-the-national-space-weather-strategy>

coronagraph, so critical to operations. LASCO is an instrument on board the SOHO satellite, a collaboration between NASA and the European Space Agency (ESA). Currently, ESA is considering a mission at the L5 Lagrange point trailing the Earth, which would provide a view of CMEs on the Sun-Earth line, highly complementary to U.S. assets at the Earth and upstream L1 point. Commercial opportunities have similarly benefited space weather activities. An example is NASA's GOLD mission to study the cause of dense, unpredictable bubbles of charged gas that appear over the equator and tropics in the Earth's upper atmosphere, sometimes causing communications breakdowns. GOLD is a hosted payload aboard a commercial communications satellite (SES-14). Ground-based observations relevant to space-weather science are also obtained in collaboration with the international, commercial and academic communities.

These communities have also played, and can continue to play, the absolutely essential role of disruptor. A classic example from the commercial arena is the technological development of small satellites. Both the academic and commercial communities act as an extended work force for the national space-weather enterprise -- analyzing agency observations, helping to build modeling frameworks and operational tools, and playing key roles in R2O/O2R development. International space-weather research and operations is also a growth area around the world, and open exchange of ideas and observations across borders promotes best practices and creative approaches. The sheer diversity of players introduces an organic, unpredictable element to the process. Where will the next good idea emerge? By being open to new ideas, and promoting a broad range of interactions, we maximize the benefit to the Nation.

Space weather affects life and property, so an efficient, coordinated public policy is needed and warranted to ensure that the Nation is safe. Beyond this, we need an agile approach that leverages external opportunities and is open to innovation.

5. Legislation is needed now.

We are an increasingly technological society, and space weather cannot be ignored. Space-weather scientific research and operations is a growing, but still young field -- it is often stated that our current space-weather forecast capabilities are akin to terrestrial-weather forecast capabilities of several decades ago. The problems we face are complex and multidisciplinary, but with coordinated and targeted actions, we stand to make significant progress. I am reminded of the words of the Solar and Space Physics Decadal Survey "DRIVE" initiative: "*Relatively low-cost activities that maximize the scientific return of ongoing projects and enable new ones are both essential and cost-effective.*"⁸

⁸National Research Council (2013); Chapter 4

The various coordinating activities of the Space Weather Operations, Research, and Mitigation (SWORM) Task Force have given us a clear path forward. The actions that have been outlined in the Space Weather Action Plan represent the first steps along that path. To make certain that we continue onwards to where we need to go, we now need legislation. I believe that H.R. 3086 provides a good framework for progress. In particular, it strikes a good balance between promoting coordinated actions of government agencies to act as a bulwark protecting the Nation, and maintaining a (necessarily) open-ended approach to ensure that good ideas and opportunities from outside the government are considered and pursued.

If we delay action, we run multiple risks. The obvious one is that we will be woefully unprepared when a superstorm hits. Another all-too-obvious risk is that LASCO, the sentinel coronagraph monitoring CMEs from the SOHO satellite -- along with related assets sitting at the upstream L1 point -- could fail before they are replaced, leading to substantial backslide in our current monitoring and forecasting skill. Beyond this, the impacts of even moderate space weather are costly, and every day we wait to improve upon our scientific understanding and operational capabilities, we waste time and money.

Finally, I am speaking as an individual, but in preparation for this hearing I have spoken to many people in my field, and attempted to “take the temperature” of the community. The overwhelming impression I gathered from this exercise is that the space-weather community feels that we must keep the momentum going. I personally feel that there is a very real risk of “dropping the ball” if we do not move forward with legislation soon. **Space weather is an urgent national issue, and it is time to take legislative action.**

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SARAH E GIBSON**Professional Preparation**

Stanford University	Physics	BS	1989
University of Colorado	Astrophysics	MS	1993
University of Colorado	Astrophysics	PhD	1995

Thesis Title The large-scale structure of the solar minimum corona

Research Interests Dr. Gibson's research examines solar drivers of the terrestrial environment, from short-term space weather drivers such as coronal mass ejections, to long-term solar cycle variation, with emphasis on the Sun-Earth system at solar minimum.

Appointments

2/01 – Present	Scientist (Senior Scientist/Section Head since 7/12), HAO/NCAR
2/00 – 1/01	Research Assistant Professor in Physics, Catholic University of America
1/99 – 1/00	NSF-NATO Postdoctoral Fellow, University of Cambridge
4/98 – 1/99	Research Assistant Professor in Physics, Catholic University of America
4/96 – 4/98	NRC Associate, NASA Goddard Space Flight Center
10/95 – 4/96	NCAR Postdoctoral Associate HAO/NCAR

Selected Professional Activities

2017-	Co-chair: Committee on Solar and Space Physics (Nat. Acad.)
2017-2018	Project Scientist: PUNCH (NASA SMEX Phase A Study)
2015-2018	IAU Division E (Sun and Heliosphere) Vice President
2018-2020	Chair: Solar Physics Editorial Board (board member since 2016) (Springer)
2013-2019	Member: Space Studies Board (Ex. Com. since 2016; Nat. Acad.)
2017-	Member Daniel K. Inouye Solar Telescope Science Working Group (Nat. Sol. Obs.)
2009-2018.	Graduate Faculty Appointment University of Colorado -- Lecturer
2016-2017	Member: Next Generation Solar Physics Mission Study Team (NASA/JAXA/ESA)
2014-2016	Editor: Frontiers in Astron. and Space Sci. Topical Issue on Coronal Magnetometry
2013-2014	Chair: ISSI international science team on coronal magnetism
2010-2011	Member, Steering Committee of Solar and Space Physics Decadal Survey
2008-2011	Scientific Editor, Astrophysical Journal
2007-2013	Member/Vice-chair, Solar Observatories Council to the AURA Board (NSF)

Professional Affiliations

American Geophysical Union; American Astronomical Society; International Astronomical Union; Committee on Space Research

Honors/Awards

2005	Harvey Prize	American Astronomical Society (Solar Physics Division)
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Selected Educational/Mentoring Activities

2017- Graduate student research advisor: Nathaniel Mathews
 2017-2018 Postdoctoral supervisor: Jie Zhao
 2016-2017 Postdoctoral supervisor: Anna Malanushenko
 2014-2017 Postdoctoral supervisor: Kevin Dalmasse
 2009-2011 Postdoctoral supervisor: Laurel Rachmeler
 2010-2012 Postdoctoral supervisor: Liang Zhao
 2007-2012 Graduate student research advisor: Donald Schmit
 2007/2018 Mentor for multiple undergraduate summer students

Selected Publications

- S. E. Gibson, Kucera, T. A., White, S. M., Dove, J. B., Fan, Y., Forland, B. C., Rachmeler, L. A., Downs, C. and Reeves, K. K., FORWARD: A Toolset for Coronal Magnetometry, Front. Astron. Space Sci., <http://dx.doi.org/10.3389/fspas.2016.00008>, 2016.
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SARAH E. GIBSON

Dr. Sarah Gibson is a Senior Scientist in the High Altitude Observatory (HAO) at the National Center for Atmospheric Research, and Section Head of HAO's Solar Frontiers Section. Dr. Gibson received her Bachelor's Degree in Physics from Stanford University, and her Masters and Doctoral Degrees in Astrophysics from the University of Colorado.

Dr. Gibson's research centers on solar drivers of the terrestrial environment, from short-term space weather drivers such as coronal mass ejections (CMEs), to long-term solar cycle variation.

Dr. Gibson uses theoretical models to understand the magnetic origins of CMEs and related space weather phenomena. Dr. Gibson has led International Space Science Institute (Switzerland) International Teams on the subjects of Prominence Cavities and Coronal Magnetism. She is the primary author of the FORWARD suite of SolarSoft IDL codes for model-data comparison, and is currently coordinating efforts to quantify the magnetic field of the Sun's atmosphere in the form of a Data-Optimized Coronal Field Model (DOCFM).

Dr. Gibson also led the international Whole Sun Month and Whole Heliosphere Interval coordinated observing and modeling efforts to characterize the three-dimensional, interconnected solar-heliospheric-planetary system at solar minimum, and an International Astronomical Union (IAU) Working Group on Comparative Solar Minimum to promote analyses of the degree and nature of variations within and between minima. She is currently involved in project to archive and analyze multi-decadal solar observational records.

Dr. Gibson was the recipient of the American Astronomical Society – Solar Physics Division 2005 Karen Harvey Prize. She was a Scientific Editor for the Astrophysical Journal and has served on many national and international committees. She is currently a member of Executive Committee of the National Academies' Space Studies Board and co-chair of its Committee on Solar and Space Physics, and is Vice President of the IAU Division E (Sun and Heliosphere).

Dr. Gibson is committed to education and public outreach. She gave the first of NCAR's 50th anniversary public lectures, participated in the NOVA episode "Secrets of the Sun" and NBC Learn's "When Nature Strikes: Space Weather" (NSF/TWC), and has written a blog post for the Huffington Post entitled "Living with Space Weather (Baby, It's Charged Outside)".

Chairman BIGGS. Thank you, Dr. Gibson.
I now recognize Dr. Tobiska for five minutes for his testimony.

**TESTIMONY OF DR. W. KENT TOBISKA,
PRESIDENT AND CHIEF SCIENTIST,
SPACE ENVIRONMENT TECHNOLOGIES**

Dr. TOBISKA. Good morning, Chairman Biggs and Babin, Ranking and Committee Members. I'm pleased to testify on the commercial perspective on impacts, monitoring, and forecasting of space weather as President of Space Environment Technologies and also as an Executive Committee member of the American Commercial Space Weather Association.

As you've heard, space weather occurs because energy transfers from the Sun to Earth, causing sudden changes in ground currents, atmospheric radiation, ionosphere, and upper atmosphere densities. From our experience, for example, the power grid is susceptible. As you know, the 1989 Hydro-Québec power collapse, because of a geomagnetic storm, left 9 million customers without power, and imagine the entire Northeastern sector of the United States without power because of a Carrington-class geomagnetic storm. Predicting this without data and observations is impossible.

A common index identifying storm severity is Dst and, in 2011, a company developed the first operational six-day Dst forecast for Air Force Space Command. Now, it is publicly available and used to help estimate coming geomagnetic disturbances.

Turning to radiation, pilots, flight attendants, and frequent flyers can receive excessive dose. Galactic cosmic rays are the main cause, although a solar flare can triple it. Increased exposure leads to greater statistical risk of death from deep-tissue cancer. There's a handy rule of thumb: Every 10 hours at 37,000 feet equals a chest x-ray, and that is one round-trip between DC. and L.A. Until recently, there was no monitoring, so a company started the ARMAS program in 2013 to measure dose on aircraft and immediately send it to the ground for public use.

Next, ionosphere disruptions can lead to lost high-frequency radio signals, as you know. Nine days after Hurricane Katrina, as helicopters lifted people off of rooftops, the fourth largest flare in history occurred. It caused blackouts, affecting disaster recovery HF radio communications. Those are used because Katrina wiped out the telecommunications infrastructure. Coast Guard recovery ships couldn't even communicate with the helicopters. Learning from this event, we saw that no credible HF availability forecast existed, thus, companies worked with Utah State University to develop and distribute a free HF radio 24-hour global forecast.

Finally, from large flares and geomagnetic storms, upper atmosphere density increases, affecting satellite orbits. Now, in 1990, NORAD lost 200 satellites during one storm from its catalog. Based on that experience, Space Command launched a major effort to improve their upper atmosphere forecasts. Within ten years, the HASDM system was deployed, and after 15 years, a new upper atmosphere density model was released. That model was the single largest improvement in upper atmosphere density uncertainties since the 1960s. Companies were the key participants with Space

Command to build that model, and now, the solar geomagnetic activities created cut atmospheric density uncertainties in half.

I use these examples to emphasize that real-time data and observations are vitally important for space weather monitoring. Monitoring cannot succeed until we produce a volume of data that is larger than is currently done by the—all agencies combined. To improve prediction, the use of physics-based data assimilation and ensemble models is our future. The main problem is forecasting the arrival of coronal ejected materials at Earth and knowing the magnitude of its effect. Every important risk management activity depends on solving this problem, and operational data from commercial space weather is a critical part of the solution.

Mr. Chairman, Ranking Members, and Committee Members, thank you for this opportunity to testify, and I welcome any questions.

[The prepared statement of Dr. Tobiska follows:]

DR. W. KENT TOBISKA
SPACE WEATHER EXPERT WITNESS
PRESIDENT, SET
EXECUTIVE COMMITTEE MEMBER, ACSWA

**IMPACTS, MONITORING, AND PREDICTION OF
SPACE WEATHER**

TESTIMONY
TO THE
U.S. HOUSE OF
REPRESENTATIVES

JOINT HEARING
BY THE
COMMITTEE ON SCIENCE,
SPACE, AND TECHNOLOGY

SUBCOMMITTEE ON ENVIRONMENT

AND

SUBCOMMITTEE ON SPACE

SPACE ENVIRONMENT TECHNOLOGIES (SET)
AMERICAN COMMERCIAL SPACE WEATHER ASSOCIATION (ACSWA)

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TESTIMONY SUMMARY

IMPACTS, MONITORING, AND PREDICTION OF SPACE WEATHER

SPACE WEATHER IMPACTS

Energetic charged particles and photons come from the Sun as well as the galaxy and interact with the near-Earth space environment as well as with our technology. The source of these particles and photons comes from solar flares, solar radio bursts, and the galaxy itself. They arrive at Earth and are dynamic in energy, time variability, and numbers of particles or photons. This variability is known as space weather and it can dramatically affect the Earth's magnetic fields and atmosphere causing excessive environmental geo-electric field currents, ionizing radiation, ionospheric disturbances, and upper atmosphere expansion.

Common effects of space weather include:

- Power grid outages resulting from damaged transformers during geo-electric field current surges;
- Radiation effects on astronauts, commercial air crewmembers, as well as frequent fliers from Galactic Cosmic Rays, major solar flares, and even radiation belt particles;
- GPS signal loss and HF radio disruption from ionospheric scintillation during geomagnetic storms and large solar flare events; and
- Low-Earth orbiting satellite losses due to disturbed orbital trajectories resulting from large solar flare events and large geomagnetic storms.

Technologies and industries that are affected by space weather include electric power generation, transportation (space, air, land, sea), national defense, telecommunications (government, commercial and personal), banking and commerce, space operations, and geolocation services.

SPACE WEATHER MONITORING

Since the mid-1990s there has been tremendous progress in monitoring space weather from the ground, air, and space. There are three pillars in American society that contribute to monitoring of space weather: government agencies, universities, and companies. The National Space Weather Implementation Strategy and Plan was developed by this community and has recently evolved into the National Space Weather Action Plan, an activity led by U.S. government agencies with contributions from universities and industry. Agencies such as NOAA, NASA, USAF, USGS, and NSF each provide unique monitoring capabilities for civilian and military users. Major research universities and companies provide distinct monitoring and data production capabilities for the international science community, the public, and commercial customers. Without the contributions from all three pillars, the United States would not have a monitoring capability.

SPACE WEATHER PREDICTION

The current state of predicting space weather is still nascent. Most predictions rely on persistence or recurrence of solar events. Space weather is 50 years behind terrestrial weather forecasting, relying primarily on statistical and climatological datasets or modeling to characterize the current state of the space environment. Using data assimilation into physics-based models and ensemble modeling, we know the direction for success and that includes increasing the sources, types, and quantity of data.

ORAL TESTIMONY: Impacts, Monitoring, and Prediction of Space Weather

Good morning, Chairmen Biggs and Babin, Ranking and Committee Members. I am pleased to testify from the commercial perspective on impacts, monitoring, and prediction of space weather as President of Space Environment Technologies and an Executive Committee member of the American Commercial Space Weather Association.

Sources of Space Weather

Space weather occurs as energy transfers from the Sun to Earth, causing sudden changes in ground currents, atmospheric radiation, the ionosphere, and upper atmosphere densities. From our experience, for example:

Impacts of Space Weather – Power Grid Outages

The power grid is susceptible. In 1989 Hydro-Québec power collapsed because of a geomagnetic storm leaving 9 million customers without power. Imagine the entire northeastern United States without power because of a Carrington-class geomagnetic storm! Predicting this without data is impossible.

A common index identifying storm severity is Dst and, in 2011, a company developed the first operational 6-day Dst forecast for Air Force Space Command. Now it is publicly available and used to estimate coming geomagnetic disturbances.

Impacts of Space Weather – Radiation

Turning to radiation, pilots, flight attendants and frequent fliers can receive excessive dose. Galactic Cosmic Rays are the main cause although a large solar flare can triple it. Increased exposure leads to greater statistical risk of death from deep tissue cancer. There's a handy *rule-of-thumb*: every 10 hours at 37,000 feet equals a chest X-ray – that is one round trip between DC and LA.

Until recently, there was no monitoring so a company started the ARMAS program in 2013 to measure dose in aircraft and immediately send it to the ground for public use.

Impacts of Space Weather – Ionospheric Scintillation

Next, ionosphere disruptions can lead to lost High-Frequency (HF) radio signals. Nine days after Hurricane Katrina, as helicopters lifted people from rooftops, the fourth largest

flare in history occurred. It caused blackouts affecting disaster recovery HF radio communications, used because Katrina wiped out the telecommunications infrastructure. Coast Guard recovery ships couldn't even communicate with helicopters.

Learning from this event, we saw that no credible HF availability forecast existed; companies worked with Utah State University to develop and distribute a free HF radio 24-hour global forecast.

Impacts of Space Weather – Upper Atmosphere Density Increases

Finally, from large flares and geomagnetic storms, upper atmosphere density increases, affecting satellite orbits. In 1990 NORAD lost 200 satellites during one storm. Based on that experience, Space Command launched a major effort to improve upper atmosphere forecasts. Within 10 years, the HASDM system was deployed and, after 15 years, a new upper atmosphere density model was released. That model was the single largest improvement in reducing atmospheric density uncertainties since the 1960s.

Companies were key participants with Space Command to build that model and the solar and geomagnetic indices now created cut atmospheric density uncertainties in half.

Monitoring of Space Weather

I use these examples to emphasize that real-time data is vitally important for space weather monitoring. Commercial organizations know “if it doesn't exist, create it!” Monitoring cannot succeed until we produce a larger volume of data than currently done by all agencies combined. We recommend that HR 3086 explicitly prescribe commercial space weather data production for monitoring space weather hazards.

Prediction of Space Weather

To improve prediction, the use of physics-based data assimilation and ensemble models is our future. The main problem is forecasting the arrival of coronal ejected material at Earth and knowing the magnitude of its effect. Every important risk management activity depends on solving this problem and operational data from commercial space weather is a critical part of the solution.

Thank You

Mr. Chairmen, Ranking Members, and Committee Members, thank you for this opportunity to testify. I welcome any questions.

SUPPLEMENTAL MATERIAL

Sources of Space Weather – Supplement

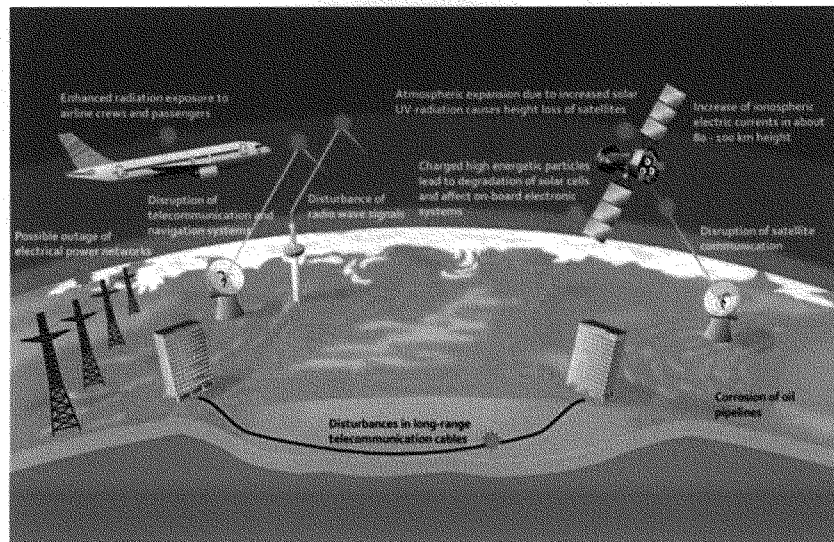


Fig. 1. Space weather affects technological infrastructures. (Graphic by R. Michaelis, A. Grosse, V. Bothmer, reproduced courtesy of the *Hamburger Abendblatt*.)

Space weather is caused by energetic particles and photons that come from large flares on the Sun, from galactic explosive events in supernovae and black holes, and even from disturbances to the Van Allen radiation belts that surround the Earth. As these particles and photons arrived at Earth, they dynamically affect the near-Earth space environment. In particular, there can be sudden changes to the electric currents in the Earth's crust, excessive radiation in the atmosphere at aircraft altitudes and in space, rapidly changes in the ionosphere called scintillation, and even large density increases in the upper atmosphere where the International Space Station and reconnaissance satellites fly (Figure 1).

Impacts of Space Weather – Power Grid Outages Supplement

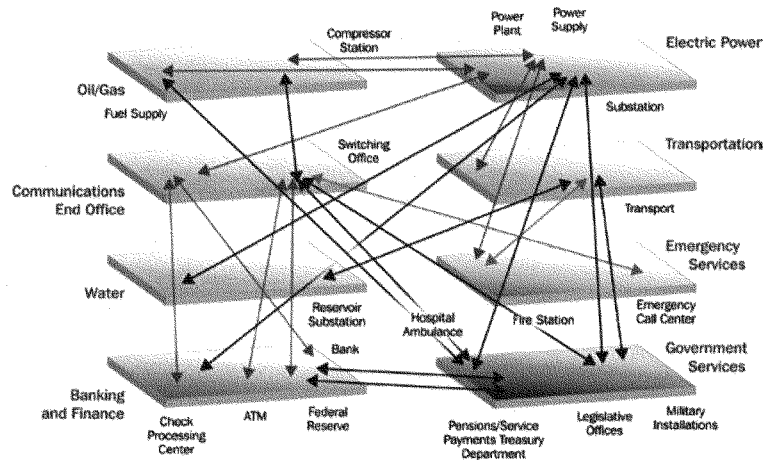


Fig. 2. Connections and interdependencies across the economy. Schematic showing the interconnected infrastructures and their qualitative dependencies and interdependencies. SOURCE: Department of Homeland Security, National Infrastructure Protection Plan, available at http://www.dhs.gov/xprevprot/programs/editorial_0827.shtm.

The impacts from space weather are diverse, broad, and can be substantial (Figure 2). For example, electric power companies can suffer power grid outages when large geomagnetic storms cause surges of the induced electric currents in the Earth's crust. Power transmission lines are easy conduction paths for these currents where rapidly changing currents can overload a system's safety measures, resulting in destruction of large transformers. The most serious example was the 13 March 1989 Hydro-Québec power system collapse caused by increased reactive power consumption, then followed by a safety "tripping" of ancillary power lines with an inability of Hydro-Québec to make up the loss in transmission. Nine million customers in eastern Canada were without power; 83% of the power was restored within 9 h¹. Electric utilities across the northern latitudes of the U.S. also experienced transformer damage, depressed voltages, and the forced tripping of several voltage control devices. The implication of a power outage during a Carrington-class geomagnetic storm is that large swaths of the northeastern United States could be without power for months, affecting the entire national infrastructure (Figure 2)². The 1859 Carrington event was a massive flare on the Sun that led to the largest observed geomagnetic storm in history. Aurora were spotted over Cuba and balls of fire traveled down telegraph lines across the country.

¹ MacAlester, M. H. and W. Murtagh (2014), Extreme Space Weather Impact: An Emergency Management Perspective, *Space Weather*, 12, 530–537, doi:10.1002/2014SW001095.

² *Severe Space Weather Events – Understanding Societal and Economic Impacts Workshop Report*, National Research Council, National Academies Press, Washington, DC, 2008 <http://www.nap.edu/catalog/12507.html>.

A geomagnetic storm's strength depends upon how much the Earth's magnetosphere is disturbed by the solar wind. The Disturbance storm time (Dst) index (Figure 3) shows this disturbance. Space Environment Technologies has been creating and sole-source distributing the current and forecast Dst index to U.S. Air Force Space Command Joint Space Operations Center (formerly called NORAD) since 2012³. SET's Dst is often used for days-ahead qualitative estimates of coming geomagnetic disturbances.

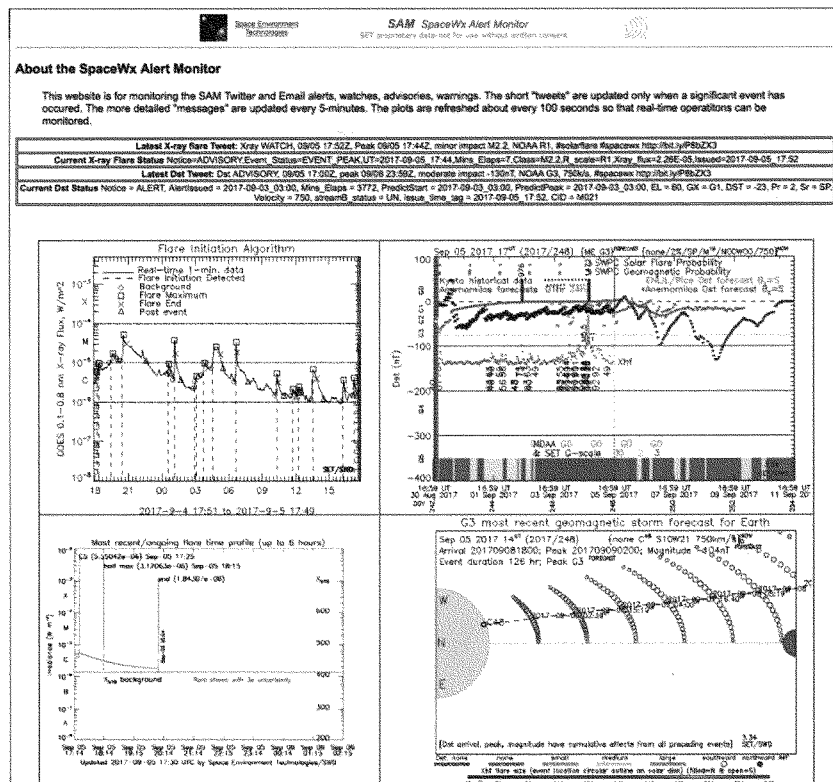


Fig. 3. SET's Dst recent past, current epoch, and 6-day forecast (top right). Black dots are 1 h actual data, vertical line is current epoch, and purple or green dots are forecast Dst by two independent methods. Left panels are solar flare information while the lower right panel is the most recent coronal mass ejection trajectory towards Earth.

³ The SET Dst current epoch specification and forecast can be viewed at [https://sol.spaceenvironment.net/~sam_ops/index.html?with=reference%20of%20Tobiska%2C%20W.%20K.%2C%20D.%20Knipp%2C%20W.%20J.%20Burke%2C%20D.%20Bouwer%2C%20J.%20Bailey%2C%20D.%20Odstrcil%2C%20M.%20P.%20Hagan%2C%20J.%20Gannon%2C%20and%20B.%20R.%20Bowman%20\(2013\)%2C%20The%20Anemomilos%20prediction%20methodology%20for%20Dst%2C%20Space%20Weather%2C%2011%2C%20490-508%2C%20doi%3A10.1002/swe.20094](https://sol.spaceenvironment.net/~sam_ops/index.html?with=reference%20of%20Tobiska%2C%20W.%20K.%2C%20D.%20Knipp%2C%20W.%20J.%20Burke%2C%20D.%20Bouwer%2C%20J.%20Bailey%2C%20D.%20Odstrcil%2C%20M.%20P.%20Hagan%2C%20J.%20Gannon%2C%20and%20B.%20R.%20Bowman%20(2013)%2C%20The%20Anemomilos%20prediction%20methodology%20for%20Dst%2C%20Space%20Weather%2C%2011%2C%20490-508%2C%20doi%3A10.1002/swe.20094)

Impacts of Space Weather – Radiation Supplement

Not only astronauts receive radiation from space weather. A second example is the effect on commercial aircrew members and frequent fliers who can receive excessive radiation doses while flying at commercial aviation altitudes⁴ (above 30,000 feet) (Figure 4). Radiation from Galactic Cosmic Rays (GCRs) is always present at these altitudes. However, when there is a large solar flare with an associated solar energy particle (SEP) event there can be double or triple the dose in the same amount of time. This is especially true for higher latitude air traffic routes across North America, to Europe, and to Asia. There is even new evidence suggesting that there is an additional increase in radiation dose rates in these same regions when no solar flares are occurring but during small geomagnetic storms that disturb the Earth's magnetosphere and radiation belts⁵. The result of increased radiation exposure through time is, of course, an increased statistical risk of death by deep tissue cancer later in life. A rule of thumb is for every 10 hours at 37,000 feet, a person receives the equivalent of one chest X-ray from the GCRs alone.

While NASA and the FAA have done a tremendous job in modeling the commercial aviation radiation environment, there has been no real-time data to actually monitor that environment. As a result, Space Environment Technologies created the Automated Radiation Measurements for Aerospace Safety (ARMAS) program to measure dose rates in aircraft and return that information to the ground in real-time. End users of these data will be air traffic management, aircraft operations, and pilots⁶ (Figure 5). ARMAS has been mapping the global aviation radiation environment since 2013 (Figure 6). It has now achieved a rudimentary

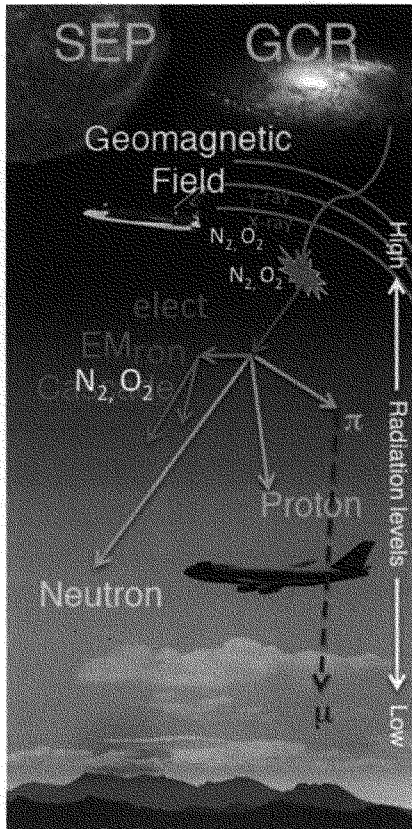


Fig. 4. The complex radiation environment at and above commercial aviation altitudes due to GCRs and SEPs.

⁴ Tobiska, W. K., et al. (2015), Advances in Atmospheric Radiation Measurements and Modeling Needed to Improve Air Safety, *Space Weather*, 13, 202–210, doi:10.1002/2015SW001169.

⁵ Tobiska, W. K., et al. (2016), Global real-time dose measurements using the Automated Radiation Measurements for Aerospace Safety (ARMAS) system, *Space Weather*, 14, doi:10.1002/2016SW001419.

⁶ Tobiska, W. K., et al. (2015), Advances in Atmospheric Radiation Measurements and Modeling Needed to Improve Air Safety, *Space Weather*, 13, 202–210, doi:10.1002/2015SW001169; data can be found at <http://sol.spacenvironment.net/~ARMAS/>.

statistical forecast capability for a combination of the GCR and Van Allen radiation belt particles (Figure 7). A climatological forecast is constructed from NASA's Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS) model (Figure 8), which together with ARMAS, forms the basis for the RADIAN data assimilative modeling system for global aviation radiation (Figure 9).

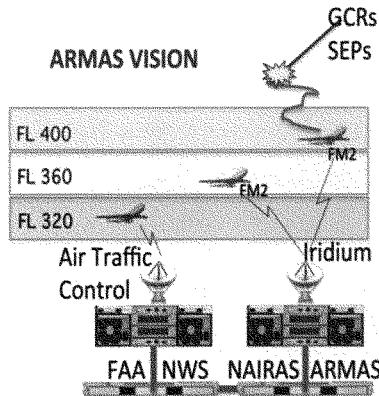


Fig. 5. ARMAS vision integrating real-time dose rate measurements into operational aerospace/space traffic management systems.

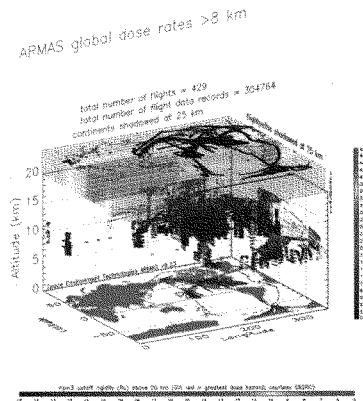


Fig. 6. Global ARMAS measurements since 2013 and on 429 flights above 8 km.

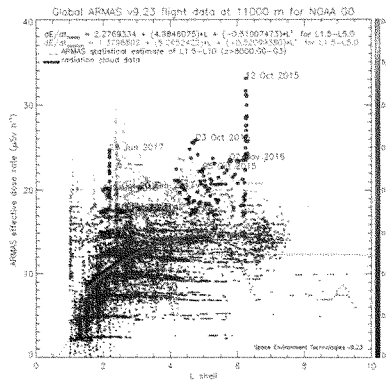


Fig. 7. RADIAN statistical forecast algorithm for effective dose rate (red line and equation) for all magnetic latitudes (specified by L-shell), with a NOAA G0 geomagnetic activity level (quiet), and at an altitude of 11 km. The light black dashed line is for the NAIRAS climatological forecast only, also shown in Figure 8.

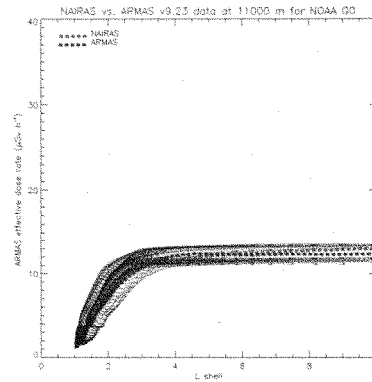


Fig. 8. RADIAN climatological forecast algorithm (red line is climatological NAIRAS and blue line is statistical ARMAS) for all magnetic latitudes (specified by L-shell), with a NOAA G0 geomagnetic activity level (quiet), and at an altitude of 11 km. The light black dashed lines are for the NAIRAS climatological variability across all magnetic longitudes.

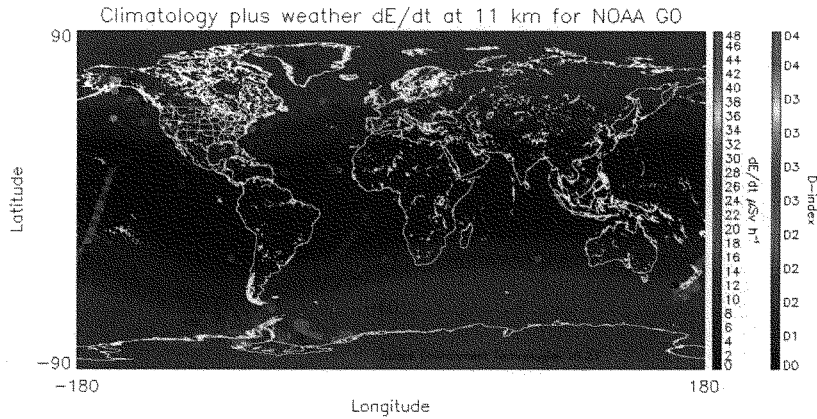


Fig. 9. Global climatology and weather representation of effective dose rates (dE/dt) at 11 km altitude for NOAA geomagnetic conditions of G0 (quiet). Colored dots are ARMAS data for assimilation into NAIRAS that can upgrade the radiation weather along a flight track.

Impacts of Space Weather – Ionospheric Scintillation Supplement

Space weather affects the ionosphere and can lead to the loss of GPS and High-Frequency (HF) radio signals during large solar flares and geomagnetic storms. Nine days after Hurricane Katrina hit New Orleans 29 August 2005 (Figure 10), when we were still watching helicopters airlift people from rooftops, the fourth largest solar flare in recorded history occurred (Figure 11) on 07 September 2005. The X17 flare caused extensive HF radio blackouts on the dayside of the Earth, including across the Gulf of Mexico. Disaster recovery personnel were primarily using HF radio communications because the hurricane wiped out the telecommunications infrastructure in southern Louisiana. The flare caused a telecommunications blackout for several hours and Coast Guard recovery ships in the Gulf could not even communicate with the helicopters that were evacuating people. This showed us that space weather could significantly affect disaster recovery efforts.

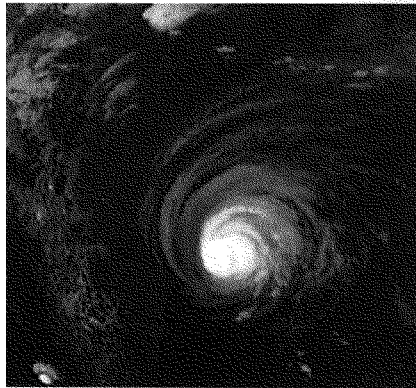


Fig. 10. Hurricane Katrina hits New Orleans on 29 August 2005.

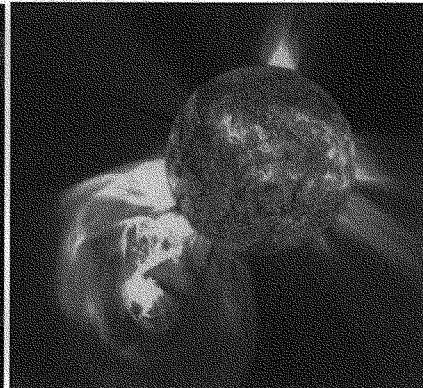


Fig. 11. The 4th largest solar flare recorded, an X17, erupts on the Sun 07 September 2005.

Space Environment Technologies, along with its partners Utah State University and Space Environment Corporation, responded to the need for HF radio frequency availability forecasts. In 2012 the Q-Up system was developed to provide regional and global HF band availability with up to 24 hours notice. Using USU's Global Assimilation of Ionospheric Measurements (GAIM) model, this industry-university partnering began providing much-needed data, products, and services for the public (Figure 12). The USU GAIM model has been used by the U.S. Air Force Weather Agency since 2006 for its operational ionosphere forecasting.

Today's world depends on accurate GPS position as well as timing and without that critical information many sectors are affected. As a derivative of GAIM for GPS improvement, SET and USU have developed the Spot-On system providing 2 m accuracy for any device using single frequency GPS receivers such as smartphones⁷ (Figure 13).

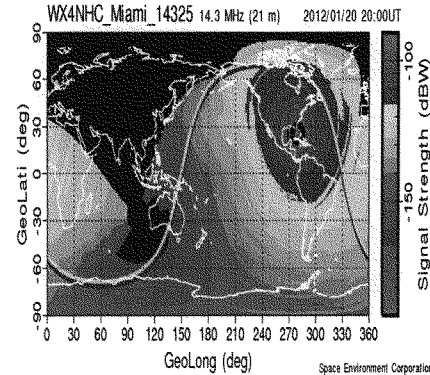


Fig. 12. Global HF availability forecasts showing an example of signal strength from Miami.

Impacts of Space Weather – Upper Atmosphere Density Increases Supplement

Low-Earth Orbit (LEO) space is a critical national defense environment and upper atmosphere density increases during large solar flares and geomagnetic storms can affect satellite assets. In 1990 NORAD, which tracks all objects in space, lost a significant number of satellites during one such solar flare/geomagnetic storm period. Additional tracking efforts were needed to reacquire the missing satellites. Based on that experience, Space Command launched a major effort to improve the forecast of upper atmosphere densities. After 10 years, the High Accuracy Satellite Drag Model (HASDM) was deployed. After 15 years a new thermosphere density model (JB2008) was released⁸ – it was the single largest improvement for reducing LEO atmospheric density uncertainties since the 1960s. Space Command has operationally



Fig. 13. (left) Corrected GPS position using GAIM-GM and SpoT-On concept (green dot is final position 2 m from center of traffic circle flower garden and (right) uncorrected position (blue dot) using an iPhone native GPS location.

⁷ NOAA SBIR Phase I and II contract WC133R17CN0075 to SET starting in 2017.

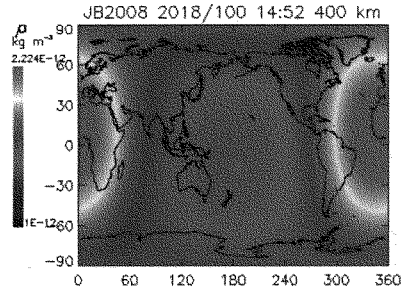


Fig. 14. The JB2008 thermosphere density at 400 km.

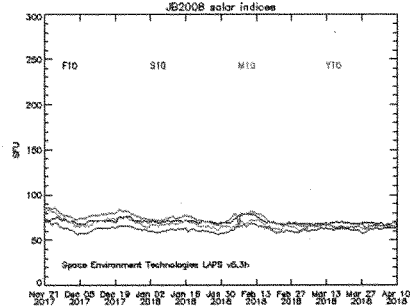


Fig. 15. Solar indices used by JB2008.

used JB2008 since 2012 because satellite orbital track uncertainties are now less than half of what they were in 1990. JB2008 is now an ISO standard⁹.

Space Environment Technologies was a key team member with Space Command in building that new model (Figure 14). The solar and geomagnetic indices used by the model were the main components that helped reduce the uncertainties by half (Figure 15)¹⁰. Since 2012 SET has been operationally producing these indices for space command operators using dedicated, redundant server facilities. The forecast for these indices extends out to six days and Space Command operators retrieve these data several times per day.

Monitoring of Space Weather – Supplement

In 1995 U.S. government agencies organized the National Space Weather Implementation Plan. Universities and companies both contributed to the direction and content of that plan. However by 2013 it became apparent that a more coherent policy was needed to direct U.S. government agencies in the management of risks to the critical national infrastructure. Again the U.S. government agencies consulted with universities and companies and developed the National Space Weather Action Plan (SWAP) under the auspices of the Office of Science and Technology Policy. That plan was published in 2015. During the past two years, both the Senate and House of Representatives have developed bipartisan bills to authorize U.S. government agencies in tasks that manage and mitigate space weather risks to our critical national infrastructure. At the beginning of 2018 this combined Executive and Legislative branch policy collaboration has laid a tremendous foundation for our national ability to monitor space weather. All three pillars (Figure 16) of the national space weather enterprise, including government, academia, and industry, have contributed to building the national asset of space weather strategy and action.

⁸ Bowman, B. R., W. K. Tobiska, F. A. Marcos, C. Y. Huang, C. S. Lin, and W. J. Burke (2008), A New Empirical Thermospheric Density Model JB2008 Using New Solar and Geomagnetic Indices, *AIAA/AAS Astrodynamics Specialist Conference*, AIAA 2008-6438.

⁹ ISO 14222: 2013, *Space environment (natural and artificial) Earth upper atmosphere*, International Standards Organization, Geneva.

¹⁰ Tobiska, W. K., S. D. Bouwer, and B. R. Bowman (2008), The development of new solar indices for use in thermospheric density modeling, *Journal of Atmospheric and Solar Terrestrial Physics*, 70, 803-819.

Who comprises the national space weather enterprise?

- **National Space Weather Program** (1995,1997,2000,2006,2010,2016)
- **Agencies** (OSTP, NOAA SWPC, AFWA, NSF, NASA CCMC, USGS)
- **Academia** (GAIM MURI, CISM, NADIR MURI, USU SWC)
- **Industry** (19 U.S. companies in ACSWA as of January 1, 2016)

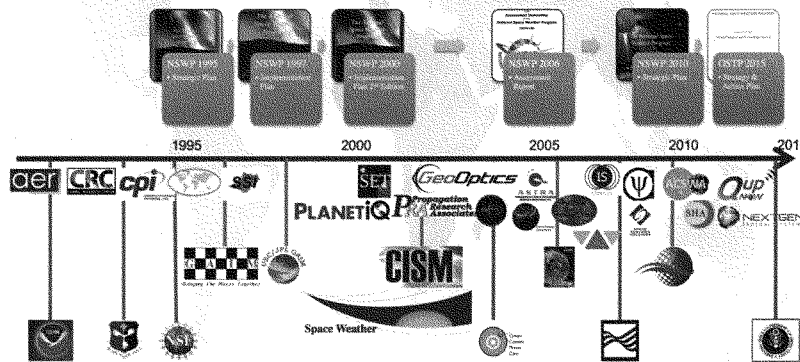


Fig. 16. The three pillars of agencies, academia, and industry form the basis for the U.S. space weather enterprise.

Space Environment Technologies and the American Commercial Space Weather Association have contributed substantial content in this policy conversation during the original concept development and through formal Federal Register comments to the SWAP benchmarks¹¹. Both

¹¹ Listing of ACSWA and SET support documents in the policy debate:

- ACSWA letter of support to the U.S. House of Representatives for the *Weather Forecast Improvement Act of 2013 (H.R. 2413)*, 10 September 2013;
- SET letter of concern to the U.S. House of Representatives for the *U.S. Government Shutdown*, 07 October 2013;
- ACSWA letter of support to the U.S. House of Representatives for the *Weather Forecast and Innovations Act of 2015 (H.R. 1561)*, 15 May 2015;
- ACSWA Response to the NOAA *Commercial Space Policy Draft*, 30 September 2015;
- ACSWA Response to the OSTP *Space Weather Action Plan*, 11 July 2016;
- ACSWA Comments to NOAA on *Improving Space Weather Forecasting R2O-O2R Capability*, 20 March 2017;
- SET letter of support to the U.S. House of Representatives Committee on Space, Science, and Technology for the *American Space Commerce Free Enterprise Act of 2017*, 07 June 2017;
- ACSWA letter of support to the U.S. House of Representatives Committee on Space, Science, and Technology for the *Space Weather Research and Forecasting Act (H.R. 3086)*, 06 July 2017;
- ACSWA recommendations to the U.S. House of Representatives Committee on Space, Science, and Technology for text changes to the *Space Weather Research and Forecasting Act (H.R. 3086)*, 05 October 2017;
- ACSWA recommendations to the National Science Foundation *Request for Information regarding SWORM Goal Priority 5.5.1*, 06 March 2018.

organizations strongly support the passage of HR 3086 and S 2817 so that a coherent national space weather risk management strategy and plan can become the law of the land.

However, monitoring will not be successful until reliable, operational space weather information can be regularly produced on a scale larger than is currently done by NOAA, NASA, and other agencies. We recommend that congressional authorization in these bills emphasizes a national Space Weather Actionable Technology (SWAT) concept where space weather industry provides competitive, cost-effective, and abundant data streams for the next generation of space models and systems. We point to the successful examples of SET's Dst, ARMAS, Q-Up, Spot-On, and JB2008 operational data streams, as well as those from other ACSWA organizations¹², that already provide the information needed to drive advanced space weather models.

Prediction of Space Weather – Supplement

The space weather community sees the use of physics-based models with data assimilation as well as ensemble modeling as the path forward for improving space weather prediction accuracy. To a certain extent, progress has already been made with USU's GAIM model for ionosphere specification and prediction (Figure 17), NOAA's WSA/ENLIL/Cone model for solar wind specification and prediction (Figure 18), and the newly funded SET RADIANT model for eventual aviation radiation specification and prediction (Figure 19). Each of these uses data assimilative techniques. As more models and data streams are developed we anticipate the growth of ensemble modeling that will drastically improved the timing, location, and magnitude of space weather events.

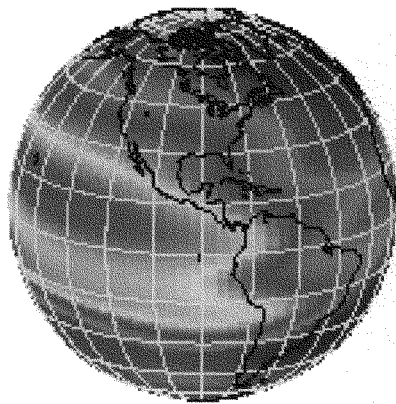


Fig. 17. USU's GAIM global ionosphere model for specification and prediction. This model is used by the USAF Weather Agency for an operational ionosphere as well as by the USU and SET team for Q-Up and Spot-On derivative products.

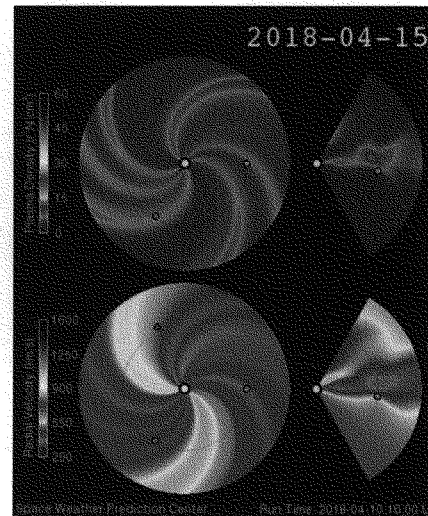


Fig. 18. NOAA's WSA/ENLIL/CONE solar wind model for specification and prediction.

¹² ACSWA capabilities presentation at http://www.acswa.us/Docs/ACSWA_capabilities.pdf.

No progress is possible, however, unless we see an increase in data sources, data types, and data quantity. For example, an outstanding problem of space weather prediction is determining the arrival at Earth of large coronal mass ejections that originate on the Sun. The arrival time is largely dependent on the velocity of the particles that come from the Sun. In addition the directionality of the interplanetary magnetic field is also key factor in determining the how the charged particles couple with the Earth's magnetosphere and result in large or small magnitudes of geomagnetic activity at Earth. All the important risk management activities will depend on understanding these two features of the Sun-Earth connection – and we cannot solve this problem without more global data. Even when global data is available, more real-time dose data in regional areas is needed at aircraft altitudes, for example, to identify higher or lower radiation areas; this would give your traffic management and pilots an ability to avoid higher radiation areas much like they avoid volcanic ash clouds today. Prediction requires data, first and foremost – and with it, we can create the tools and forecasts to protect the critical national infrastructure. U.S. industry stands tall to help with this task.

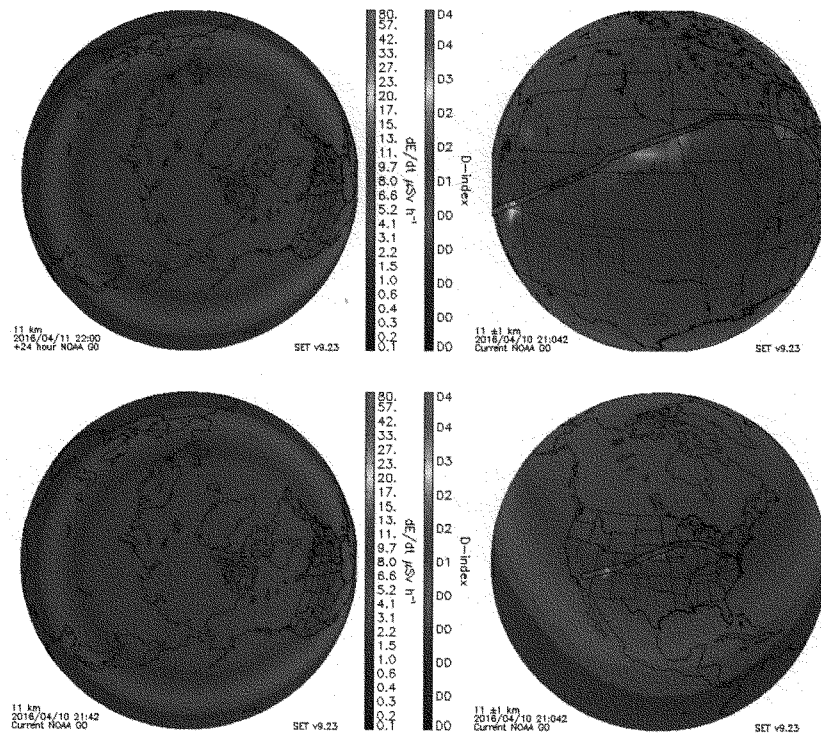
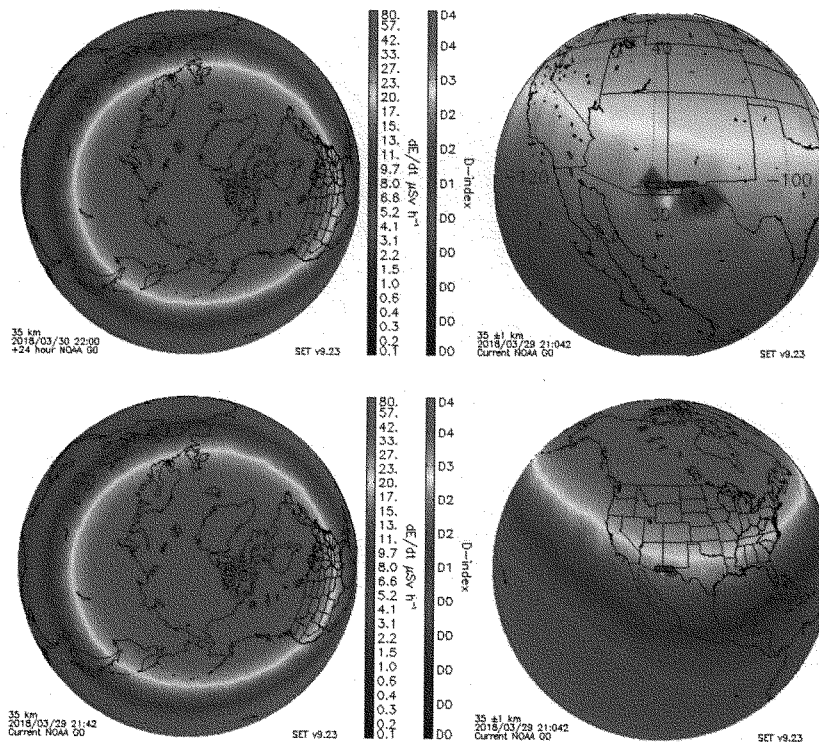
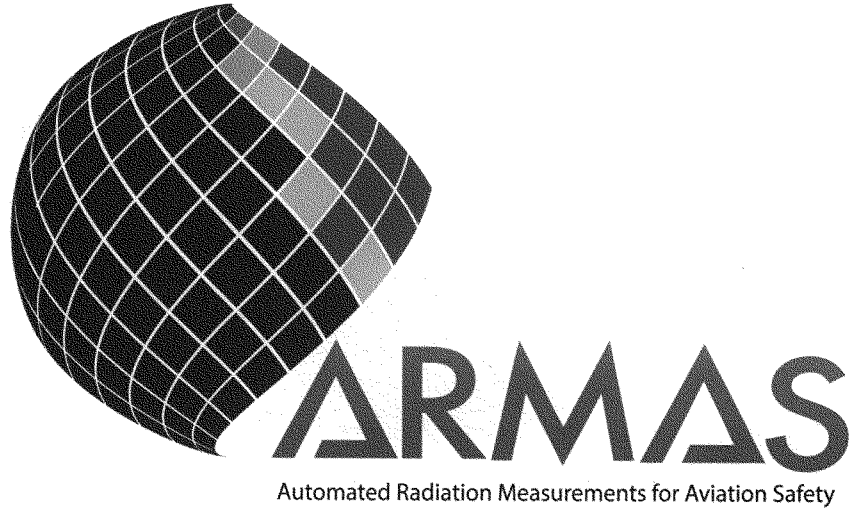


Fig. 19. SET's RADIATION global radiation model for specification and prediction showing the 24 h northern hemisphere forecast (top left), the current epoch (bottom left), the regional flight track of a LA-DC flight (top right), and the hemispheric view of the LA-DC flight (bottom right).



TOBISKA SHORT BIOGRAPHY

Dr. Tobiska is the President and Chief Scientist of Space Environment Technologies, LLC (SET). He is also the director of the Utah State University Space Weather Center and President of Q-Up, LLC. He invented the world's first operational computer code for solar irradiance forecasting and extended this expertise into the development of operational space weather systems that now produce solar irradiances, geomagnetic indices, and ground-to-space radiation environment dose rates. His career spans work at the NOAA Space Environment Laboratory, UC Berkeley Space Sciences Laboratory, Jet Propulsion Laboratory, Northrop Grumman, SET, USU Space Weather Center, and Q-Up. He has been a USAF and a NASA Principal Investigator (PI) and Co-Investigator (Co-I) for over a quarter century. He has been the COSPAR C1 Sub-Commission (Thermosphere & Ionosphere) Chair, the COSPAR International Reference Atmosphere (CIRA) Task Force Chair, and was a Session Organizer for 2002, 2004, 2006, 2008, 2010, 2012, 2014, and 2018 COSPAR scientific sessions. He serves as lead U.S. delegate to the International Standards Organization (ISO) for the space environment and developed the ISO solar irradiance as well as Earth atmosphere density international standards. Dr. Tobiska is an Associate Fellow of the American Institute of Aeronautics and Astronautics and a member of American Geophysical Union, Committee On Space Research, American Meteorological Society, and ISO TC20/SC14 U.S. Technical Advisory Group. He is a founding member, and Executive Committee member, of the American Commercial Space Weather Association (ACSWA). He has authored/co-authored over 165 peer-review scientific papers as well as 10 books and major technical publications.

Chairman BIGGS. Thank you, Dr. Tobiska.

I now recognize myself for five minutes for questions. And before I do so, I just want to make two quick points. Number one, I am in the similar boat as Chairman Lamar Smith as I serve on the Judiciary Committee, and so I will be in and out the balance of this hearing, running down those stairs and back up, which apparently is a better use of my transportation mode than the weekly round-trip from here to Phoenix that I take, so—which makes me very nervous.

Dr. Jacobs, the Department of Commerce recently sent out a request for information seeking public comments on federal space weather policy. Among other things, the RFI seeks input on ways to advance engagement with the private sector in this effort. Can you please give us an idea of how the private sector might enhance the National Space Weather Strategy?

Dr. JACOBS. What we're interested in learning from that is if they have any capabilities, either ground-based, Sun-facing or space-based Sun-facing observing capabilities that could enhance our mission or possibly even forecasting technologies or capabilities.

Chairman BIGGS. Thank you. And, Dr. Tobiska, can you tell me—please tell the Committee how space environment technologies can aid the federal government in improving its National Space Weather Strategy.

Dr. TOBISKA. In particular, the commercial sector first of all sees that it is in partnership with the agencies and academia in helping build this enterprise. The commercial sector has evolved over the last 15 to 20 years, and specifically, there's examples of what the commercial sector can do right now. In the ionosphere for the assimilation side of it, there are companies that are producing high-quality gold-standard simulation monitors that can be used by NOAA for that capability.

For the aircraft radiation environment, companies are building monitoring devices for use on aircraft. In fact, we learn from the tropospheric weather community how to send that data down to the ground via an iridium satellite in real time. There's a lot of good NASA, NOAA, NSF, and FAA research aircraft that are flying those instruments right now, and then even the commercial space transportation sector is starting to buy those kinds of dosimeters.

So the bottom line is that the commercial sector has a lot of capability for instrumentation, for some data production. There's colleagues in the audience here who produce solar energetic particle forecasts, and those kind of activities can actually be transitioned into products and services useful for the agencies so—

Chairman BIGGS. Thank you. And, Dr. Tobiska, can you briefly provide some examples of ways the federal government can improve its coordination with companies like yours? And then I'll ask Dr. Jacobs and Dr. Spann and Dr. Gibson the same question.

Dr. TOBISKA. Sure. That's an excellent question, and I really appreciate you asking it. That was actually a big topic in the sidebar meetings last week at the Space Weather Workshop that was hosted by NOAA and other agencies in Boulder. In particular, the big tentpole that exists right now for this collaboration is not having a common table to sit at, not having a process in place. Over

the years, there has been friction between companies and agencies. It's because in agencies there's researchers, which are good, and they're very enthusiastic about doing activities, but sometimes they don't know what's going on in the commercial sector. And so there's been a competition at different times in the past.

However, I think across the board on the commercial sector we see it extremely important and very possible that the commercial and the academic and the agency guys sit down at some kind of a process rather than we're all being in a swimming pool right now splashing each other. If we could determine a process to determine our swim lanes, that would really help I think ease any friction in the future and enable us to best use our resources where we're having expertise in each area.

Chairman BIGGS. Dr. Jacobs, do you concur? Do you want to expand on that?

Dr. JACOBS. Yes, I do. This is one of the reasons why we released the RFI was because it's hard for us to sort of define swim lanes if we don't know what the other swimmers are doing. So it's of interest to us to learn what's going on in the commercial sector so there's no duplicative efforts in development and also any capabilities that they may have to help us transition research to operational forecasting faster.

Chairman BIGGS. Regrettably, my time is expired.

And now, I'm going to recognize the gentleman from Colorado, Mr. Perlmutter, for five minutes for his questions.

Mr. PERLMUTTER. Thanks, Mr. Chairman. And again, thank you to the panel. This is an excellent discussion.

I've had the chance, and a number of others on this committee, we visited the High Altitude Observatory at Atacama, so the ALMA radio telescopes, and 66 of those telescopes were trained on the Sun as part of observations again through the National Science Foundation. I've had a chance to go to the NOAA lab where the Space Weather Prediction Center is, helping both the Department of Defense, as well as commercial, you know, civilian operations.

And we've got a good system going, but to Dr. Tobiska's point—and I think the purpose of the legislation—is to provide some parameters and some guidelines as to how the commercial, the international, academic, and agency communities work together to avoid, you know, some big problems or at least to know more.

So, Dr. Gibson, let me start with you. You went through about five points as to the importance of understanding space weather. So talk to me—and other members of the panel can jump in—as to what we in Congress can do for all of you to help you understand space weather and its potentialities on the Earth.

Dr. GIBSON. Okay. So, I mean, first and foremost, we need to learn more about these fundamental problems that we don't understand because that's how we're going to do better in our forecasting. And Dr. Tobiska mentioned, for example, the importance of knowing the structure of the coronal mass ejection, knowing what the magnetic fields are when they hit the Earth. That's something which is absolutely key to being able to make progress. And that's something which requires better observations of the magnetic fields back at the Sun, better observations of the coronal mass ejection as it moves from Sun to Earth, and better observations of

the Earth's magnetic field, the space environment, and atmosphere. And so all these observations are needed.

And then we have to bring together the modelers, the theorists, the data scientists who can help us figure out how to improve our understanding and our forecasting using these observations. And so I think that's the first and foremost thing that has to happen.

Mr. PERLMUTTER. Dr. Spann?

Dr. SPANN. Yes, I think I'd concur that having the observations that are fundamental to increase our understanding are critical. And, as I mentioned in my opening statement, we have several missions that not only are doing that now that are coming online to do exactly that where we're studying acceleration processes, we're—both right near the Sun with Parker Probe or with the new IMAP mission, which is focused on not only looking at the boundary of the solar system but also looking at acceleration processes perhaps a little bit closer to the Earth. And then with ICON and GOLD really studying where the rubber meets the road in terms of the impacts of much of our technologies and assets which are in the near Earth environment.

And so as we pursue the decadal priorities in terms of these missions, while we are focused on the fundamental understanding, there is always this aspect that there's an applied component that—where we can work with our sister agencies and academia and industry. Quite frankly, we rely so heavily on academia and industry in terms of providing that knowledge base to really understand these missions.

And so with NASA continuing the strategy with these missions that are ongoing and the ones that are a little bit further out is the way we believe is going to provide the best foundation so that we can have better predictions for space weather.

Mr. PERLMUTTER. All right. So to Drs. Tobiska and Jacobs, are there forums or conferences—is there really—is there any structure or is it really just a swimming pool, you know, and you're not in each other's lanes? What kinds of things are out there to allow the international community, industry, academia, and the agencies to work together in sync and not sort of at cross purposes?

Dr. TOBISKA. I'll take a first stab at that. The—first of all, that's directly on point. I think if you hadn't been a space weather week last week, you certainly would have had a good contribution. The—in particular, the American Meteorological Society is a professional society that has acted as a neutral third-party arbitrator to some extent in maybe a decade or 15 years ago when the commercial weather and NOAA were having issues trying to resolve which swim lanes they were in. As a community, the commercial guys, the academic guys, and the agency folks really do think the AMS can provide that role, and they've actually indicated that they would be interested in that in the future.

So of course there's other meetings and conferences of opportunity, but I would say if there's a neutral third party that would really help organize a table or process for discussion, perhaps some agencies can also help that.

Mr. PERLMUTTER. Thank you, Doctor.

Dr. Jacobs, my time has expired, so I would, if I could, like to introduce into the record, Mr. Chairman, a number of letters that

we have received from the American Astronomical Society; the American Commercial Space Weather Association; the American Geophysical Union; Carmel Research Center; Penn State University; University of Colorado; University of Michigan; University of New Hampshire; and the University Corporation for Atmospheric Research, UCAR. And I ask unanimous consent to enter those.

And just as a parting comment, the purpose of the legislation we're bringing is to help everybody get into those lanes to make the predictions and observations to avoid a lot of pain that might come from some eruption or another. Thank you.

Mr. BABIN. [Presiding] And without objection, those will be entered into the record. Thank you.

[The information follows:]



July 7, 2017

The Honorable Ed Perlmutter
1410 Longworth Office Bldg
Washington D.C. 20515

The Honorable Jim Bridenstine
216 Cannon House Office Bldg
Washington D.C. 20515

The Honorable Eddie Bernice Johnson
2468 Rayburn House Office Bldg
Washington D.C. 20515

Dear Representatives Perlmutter, Bridenstine, and Johnson,

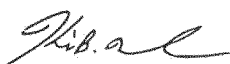
On behalf of the over 7,500 members of the American Astronomical Society (AAS) and its Solar Physics Division (SPD), we write to express our strong support for the Space Weather Research and Forecasting Act (H.R. 3086) and to thank you for your leadership on this important topic. The legislation that you introduced in the House is comprehensive in its scope, addressing key aspects of space weather and its significance for national security, for health, and for human and robotic space operations, including communications, in low Earth orbit and in interplanetary space.

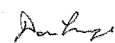
In particular, the AAS and SPD endorse the following components of the bill, all of which are essential to our capability to understand the causes and effects of space weather, as well as to forecast space weather events:

- the need for continued operation of existing space- and ground-based observatories, as well as for complementary new instrumentation to provide timely and systematic observations of the Sun, solar wind, and geospace environment,
- the recognition of the wide impact of space weather and the concomitant call for strong cooperation between stakeholder agencies such as the National Science Foundation, National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, and Departments of the Interior, Homeland Security, Energy, Transportation, and Defense,
- the call for the director of the Office of Science and Technology Policy to establish a space weather interagency working group, with broad representation across these key stakeholders, and for accountability to Congress through the submission of pertinent reports,
- the call for the formation of a space weather government-industry-university roundtable: "to facilitate communication and knowledge transfer among Government participants in the space weather interagency working group..., industry, and academia..."
- the emphasis on basic and applied research, e.g., analysis of data, interpretation of observations, and establishment of clear lines of communication between the multi-disciplinary research community and personnel through the formation of Heliophysics Science Centers, and
- the plan to establish a formal mechanism for the transition of research knowledge to operational capabilities and for communication of operational needs to the research community.

Thank you your attention to this timely and important issue. The membership of the SPD, which includes the nation's foremost experts in many of the areas addressed in this legislation, stands ready to assist in any way it can. If there is anything we can do, please do not hesitate to contact us via Dr. Joel Parriott, the AAS's Director of Public Policy, at (202)-328-2010 or joel.parriott@aaas.org.

Sincerely,


Kevin B. Marvel,
Executive Officer, American Astronomical Society


Dana Longcope
Chair, Solar Physics Division



American Commercial Space Weather Association

July 6, 2017

The Honorable Ed Perlmutter
United States House of Representatives
Washington, DC 20515

Dear Congressman Perlmutter,

On behalf of the American Commercial Space Weather Association (ACSWA), we enthusiastically support the Space Weather Research and Forecasting Act (H.R. 3086, the Space Weather Research and Forecasting Act) that was introduced for consideration in the House of Representatives on June 27, 2017. Given that naturally occurring variations in the space environment between the Sun and Earth, called space weather, can have significant economic, safety, health, and national security implications for our technological society, we must expand our scientific understanding of the Sun – Earth interactions to improve forecasting and mitigate the effects of space weather events. The Space Weather Research and Forecasting Act provides an excellent framework for U.S. Government agencies to coordinate that activity for our societal benefit.

ACSWA is the leading U.S. and [international] commercial space weather industry association dedicated to improving America's competitive edge in space. ACSWA is proud to count 19 U.S. companies in the association with combined annual operating revenue and multi-state job base larger than that of NOAA's Space Weather Prediction Center. ACSWA promotes space weather risk mitigation for critical national infrastructure related to national daily life, economic strength, and national security. In conjunction with its member companies, it has played a vital role in identifying important data and technology gaps that can be filled by *commercial solutions*. Our member companies lead the nation in developing value-added products and services for the benefit of human and property safety and they represent the growing, vibrant commercial sector for the space economy.

Sincerely,
The Executive Committee
American Commercial Space Weather Association (ACSWA)

CC: Rep. Lamar Smith
Rep. Eddie Bernice Johnson
Rep. Andy Biggs
Rep. Suzanne Bonamici
Rep. Brian Babin
Rep. Ami Bera
Rep. Jim Bridenstine

<http://www.acswa.us>



American Commercial Space Weather Association

ACSWA Executive Committee:

Geoff Crowley (Atmospheric and Space Technology Research Associates)
Alec Engell (NextGen)
Devrie Intriligator (Carmel Research Center)
Conrad C. Lautenbacher, Jr., VADM USN (ret.) (GeoOptics)
Bob Robinson (In Space Now)
Bob Schunk (Space Environment Corporation)
W. Kent Tobiska (Space Environment Technologies)

For more information on ACSWA, <http://www.acswa.us>.



American Commercial Space Weather Association

August 31, 2017

The Honorable Ed Perlmutter
United States House of Representatives
Washington, DC 20515

Dear Congressman Perlmutter,

On behalf of the American Commercial Space Weather Association (ACSWA), we reaffirm support for the Space Weather Research and Forecasting Act (H.R. 3086, the Space Weather Research and Forecasting Act) that was introduced for consideration in the House of Representatives on June 27, 2017. From a commercial perspective, we believe that the bill must be strengthened with additions highlighted in **blue** and changes in **red**, respectively. We provide arguments for these changes in sidebar text boxes.

This strengthening is necessary for two reasons: (1) the commercial sector represents the best chance for innovation as well as expansion of space weather risk management for our nation's security and (2) this bill will likely be the only space weather related bill to pass Congress in the next few years and we want to get it right. If this national capability is to grow, it cannot only be through agency or academic efforts. To unleash the additional economic power of business activity, the commercial sector must be given a more prominent role than it has had in the past. A majority of the commercial space weather industry is represented through small business and can cost-effectively contribute to improving space weather risk management.

New concepts for inclusion into the bill include: (1) a FACA to advise the agencies rather than creating and funding any untested, new, costly entity to advise the government; (2) testbed initiatives using industry expertise for R20 and O2R transitions; (3) NOAA and FAA initiatives parallel to NASA's Flight Opportunities program (industry matched funding for space flight) for space weather data production and airborne flight instrumentation development; and (4) specifically require use of existing operational commercial capabilities when appropriate for data and instrument needs to service space weather forecasters.

Thank you for your consideration.

Sincerely,

The ACSWA Executive Committee

Geoff Crowley (Atmospheric and Space Technology Research Associates)
Alec Engell (NextGen)
Devrie Intriligator (Carmel Research Center)
Conrad C. Lautenbacher, Jr., VADM USN (ret.) (GeoOptics)
Bob Robinson (In Space Now)
Bob Schunk (Space Environment Corporation)
W. Kent Tobiska (Space Environment Technologies)



American Commercial Space Weather Association

Additions and changes to HR 3086 to strengthen commercial space weather contributions to the national space weather efforts

§ 60701. Space weather

(f) INTERNATIONAL, COMMERCIAL, AND ACADEMIC COLLABORATION. — Participating Federal agencies in the space weather interagency working group established under subsection (c) shall, to the extent practicable and appropriate, increase engagement and cooperation with the international, commercial, and academic communities on the observational infrastructure, data, and scientific research necessary to advance the characterization, prediction, and mitigation of space weather events. **Under the direction of the space weather interagency working group, at least one participating agency shall be designated as the host of a Federal Advisory Committee Act advisory body to coordinate the increased engagement of said communities.**

Rationale: (NEW) Add FACA sentence as the most direct way, and the least expensive, to bring all parties to the table and enable commercial sector to have a full participation in policy discussions.

§ 60702. Observations and forecasting

(b) INTEGRATED STRATEGY. —

(2) CONSIDERATIONS. — In developing the strategy under paragraph (1), the Director of the Office of Science and Technology Policy shall consider small satellite and microsatellite options, hosted payloads, commercial **ground/ocean/air/space** options, international options, and prize authority.

Rationale: Add phrase for all four domains since commercial sector has capabilities for space weather from ground/ocean-based platforms, from the air, and in space. A space only emphasis eliminates many potential contributions of facilities, including some lower cost options than purely space-based options.



American Commercial Space Weather Association

§ 60702. Observations and forecasting

(e) FOLLOW-ON ~~SPACE-BASED~~ OBSERVATIONS.

(1) PLAN. — The Administrator of the National Oceanic and Atmospheric Administration, in coordination with the Secretary of Defense, shall develop requirements and a plan for follow-on **ground-, ocean-, air- and** space-based observations for operational purposes, in accordance with the integrated ...

(2) RESEARCH NEEDS. — In developing the requirements and plan under paragraph (1), the Administrator of the National Oceanic and Atmospheric Administration shall coordinate with the National Aeronautics and Space Administration and the National Science Foundation regarding the research necessary to improve space weather forecasting and the **ground-, ocean-, air- and** space-based observations that will advance ...

(f) REPORT. — Not later than 180 days after the date of enactment of the Space Weather Research and Forecasting Act, the Director of the Office of Science and Technology Policy shall submit to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives a report on the integrated strategy under subsection (b), including the Plan for follow-on **ground-, ocean-, air- and** space-based observations under subsection (e).

(h) **ADDITIONAL GROUND-BASED OBSERVATIONS.** — The National Science Foundation, the Air Force, and, where practicable in support of the Air Force, the Navy shall each—

(1) maintain and improve, as necessary and advisable, ground-based observations of the ~~Sun~~ **solar, near-space, and terrestrial space weather features** in order to help meet the priorities identified in section 60703(a); and

(2) provide space weather data by means of its set of ground-based facilities, including radars, lidars, magnetometers, radio **and GPS** receivers, aurora and airglow imagers, spectrometers, interferometers, **airborne radiation sensors, neutron monitors**, and solar observatories.

(3) **Buy American products and services, including sensors unless a good reason can be found to do otherwise.**

Rationale: ~~Remove Space-Based~~ since commercial sector has capabilities for space weather measurements from the ground, ocean, air, and in space. Space tends to be an expensive option versus ground-based instruments. NOAA and DoD work in all three domains and eliminating two of them puts small businesses at a disadvantage.

Rationale: ~~Add phrase for all four domains~~ since a space-only emphasis eliminates many potential contributions provided by small business. Ground-based examples include precision GPS stations to measure the ionosphere, magnetic and electric field instruments, and aircraft-based radiation monitoring instruments.

Rationale: ~~Add word ADDITIONAL~~ to complement section (e) title change.

Rationale: ~~Add phrase for all space weather domain elements.~~

Rationale: ~~Add other key technologies~~ that have a mature capability provided by small businesses and that map into operational needs.

Rationale: ~~Add Buy American phrase.~~ Europe is insistent on buying European products, making it difficult to export American products in the space weather arena.



American Commercial Space Weather Association

§ 60703. Research and technology

(b) RESEARCH ACTIVITIES. —

(3) MULTIDISCIPLINARY RESEARCH. —

(C) SENSE OF CONGRESS. — It is the sense of Congress that the Administrator of the National Aeronautics and Space Administration and Director of the National Science Foundation should support competitively awarded Heliophysics Science Centers and **testbed initiatives** that support research to operations and operations to research. **The Administrator of the National Oceanic and Atmospheric Administration and Administrator of the Federal Aviation Administration should support competitively awarded data production and flight opportunity initiatives that support research to operations and operations to research.**

Rationale: (NEW) Add phrases as a way to allow commercial sector to participate in multidisciplinary research. Only large research universities will be able to compete for HSCs while small business and 2nd, 3rd tier universities and colleges can compete for other initiatives. HSCs alone will eliminate nearly all commercial participation.

Commercial organizations are successful at R20, versus universities that focus on 'R' at low Technology Readiness Levels.

NOAA and FAA are included similar to the example of NASA's Flight Opportunities program. Examples might be matching funds programs for NOAA in data production (use of cost-effective commercial data, e.g., GPS scintillation or single frequency improved accuracies from data assimilation models, solar flare and CME forecasts, satellite TEC data). FAA might do a flight opportunity matching fund program (new technologies hosted on aircraft to provide operational data or research data, e.g., temperature, pressure, humidity, radiation sensors) to improve aviation operational capabilities.



American Commercial Space Weather Association

§ 60703. Research and technology

(d) RESEARCH TO OPERATIONS. —

“(3) COMMERCIAL CAPABILITIES. — The Administrator of the National Oceanic and Atmospheric Administration and the Secretary of Defense, in coordination with the Administrator of the National Aeronautics and Space Administration and the Director of the National Science Foundation, shall utilize to the maximum extent possible existing operational data capabilities and instrument facilities of U.S. commercial organizations to fulfill the operational data and instrument needs of space weather forecasters.

Rationale: (NEW) Add new paragraph as a cost-savings method to the government. The commercial sector already has existing commercial space weather operational data streams and instrumentation that provide services to USG agencies at a fraction of the cost that could be duplicated by the government. An example is the commercially-provided space weather indices used by USAF Joint Space Operations Center for satellite tracking and debris-avoidance management. Another example are commercial GPS receivers in Alaska providing forewarning of ionospheric scintillation that affects navigation.



American Commercial Space Weather Association

§ 60704. Space weather data

(c) SPACE WEATHER GOVERNMENT-INDUSTRY-UNIVERSITY ROUNDTABLE. —The Administrator of the National Oceanic and Atmospheric Administration, in collaboration with the Administrator of the National Aeronautics and Space Administration and the Director of the National Science Foundation, shall enter into an arrangement with the National Academies to establish a Space Weather Government-Industry-University Roundtable, **including through the use of a Federal Advisory Committee Act advisory body**, to facilitate communication and knowledge transfer among Government participants in the space weather interagency working group established under section 60701(f), industry, and academia to—

Rationale: Add FACA phrase as the most direct way, and the least expensive, to bring all parties to the table and enable commercial sector to have a full participation in policy discussions. There are suggestions floating in the community to set up (and fund) separate advisory bodies. However, these concepts are not well-formulated and, if funded, would represent an added layer of expense and management, potentially limiting participation by only one sector (agency, academia, industry).

SEC. 6. ENSURING THE SAFETY OF CIVIL AVIATION.

(a) IN GENERAL. —

(2) assess methods, **including commercial options**, to mitigate the safety implications and effects of space weather on aviation communication systems, aircraft navigation systems, satellite and ground-based navigation systems, and potential health effects of radiation exposure **at commercial aviation altitudes**; and

(3) assess options, **including commercial options**, for incorporating space weather into operational training for pilots, cabin crew, dispatchers, air traffic controllers, meteorologists, and engineers.

Rationale: Add phrases to explicitly encourage the FAA Administrator to consider commercial options for lowering costs and reducing time to implementation.



25 April 2018

Dear Congressman Perlmutter:

On behalf of the American Geophysical Union (AGU) and its 60,000 members, I am writing to reaffirm our endorsement of the Space Weather Research and Forecasting Act (H.R. 3086). We're encouraged that the House Science, Space, and Technology Committee is prioritizing this critical issue.

Given the economic and opportunity costs associated with space weather, we support the bill's approach of creating a national, coordinated plan to advance our understanding of the relationship between the sun and Earth and to ensure the development of new technologies and forecasting capabilities to mitigate the threat posed by space weather. The National Research Council estimates that a severe space weather event has the potential to inflict \$1-2 trillion dollars of economic and societal damage in the first year alone and impact more than 130 million people. To recover from such an event could take from 4-10 years.¹ Moreover, space weather fluctuations are not limited to rare catastrophic events but regularly impact our society and economy. It's estimated that the average economic impact of moderate geomagnetic events on the electric power grid in the U.S. is \$7 to \$10 billion per year.² Additionally, a moderate space weather event, if it were to disable the Global Navigation Satellite System (GNSS) for even one hour, would cost end-users, such as our energy and transportation sectors, \$4 to \$8 million in losses.³

We appreciate the bill's recognition that a partnership between industry, academia, and federal agencies is needed to further our understanding and capacity to address the impacts of space weather. As a community dedicated to advancing the understanding of Earth and space science, we applaud the bill's intent to further scientifically-informed action towards disaster preparation, mitigation, response, and recovery.

AGU looks forward to working with you as this legislation advances.

¹ National Research Council (2008) *Severe Space Weather Events: Understanding Societal and Economic Impacts: A Workshop Report*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/12507>.

² Schrijver, C. J. (2015), Socio-Economic Hazards and Impacts of Space Weather: The Important Range Between Mild and Extreme, *Space Weather*, 13, 524–528, doi:[10.1002/2015SW001252](https://doi.org/10.1002/2015SW001252).

³ Abt Associates (2017), Social and Economic Impacts of Space Weather in the United States, Report for NOAA, <https://www.weather.gov/media/news/SpaceWeatherEconomicImpactsReportOct-2017.pdf>.



With best wishes,

A handwritten signature in black ink, appearing to read 'Christine W. McEntee'.

Christine W. McEntee
CEO/Executive Director
American Geophysical Union

CC
Chairman Lamar Smith
Ranking Member Eddie Bernice Johnson



26 July 2017

Dear Congressman Perlmutter:

On behalf of the American Geophysical Union (AGU) and its 60,000 members, I am writing to endorse the Space Weather Research and Forecasting Act (H.R. 3086) and to thank you for crafting this important bill.

Space weather has the potential to inflict trillions of dollars of damage on our economy, weaken our national security, and alter our way of life. We support the bill's approach of creating a national, coordinated plan to advance our understanding of the relationship between the sun and Earth and to ensure the development of new technologies and forecasting capabilities to mitigate the threat posed by space weather. We also appreciate the bill's recognition that a partnership between industry, academia, and federal agencies is needed to further our understanding and capacity to address of space weather.

As a community dedicated to advancing the understanding of Earth and space science, we applaud the bill's intent to further scientifically informed action towards disaster preparation, mitigation, response, and recovery.

AGU looks forward to working with you as this legislation advances.

With best wishes,

Christine W. McEntee
CEO/Executive Director
American Geophysical Union

CC
Chairman Lamar Smith
Ranking Member Eddie Bernice Johnson



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<http://www.carmelresearchcenter.com/>

The Honorable Ed Perlmutter
 United States House of Representatives
 Washington, DC 20515

July 7, 2017

Dear Congressman Perlmutter,

On behalf of Carmel Research Center Inc. (CRC), a member American Commercial Space Weather Association (ACSWA) and as a member of the ACSWA Executive Committee, we enthusiastically support the Space Weather Research and Forecasting Act (H.R. 3086, the Space Weather Research and Forecasting Act) that was introduced for consideration in the House of Representatives on June 27, 2017. Given that naturally occurring variations in the space environment between the Sun and Earth, called spaceweather, can have significant economic, safety, health, and national security implications for our technological society, we must expand our scientific understanding of the Sun – Earth interactions to improve forecasting and mitigate the effects of space weather events. The Space Weather Research and Forecasting Act provides an excellent framework for U.S. Government agencies to coordinate that activity for our societal benefit.

ACSWA is the leading U.S. commercial space weather industry association dedicated to improving America's competitive edge in space. ACSWA has a combined annual operating revenue and multi-state job base larger than that of NOAA's Space Weather Prediction Center. ACSWA promotes space weather risk mitigation for critical national infrastructure related to national daily life, economic strength, and national security. In conjunction with its member companies, it has played a vital role in identifying important data and technology gaps that can be filled by commercial solutions. Carmel Research Center has played a leading role in developing value-added observations, products, and services on space weather for the benefit of human and property safety. They represent the growing, vibrant commercial sector for the space economy.

Sincerely,

A handwritten signature in black ink that reads "Devrie S. Intriligator". The signature is written in a cursive style with a large, stylized "D" at the beginning.

Dr. Devrie S. Intriligator
 Carmel Research Center, Inc. and ACSWA Executive Committee member

CC: Rep. Lamar Smith
 Rep. Eddie Bernice Johnson
 Rep. Andy Biggs
 Rep. Suzanne Bonamici
 Rep. Brian Babin
 Rep. Ami Bera
 Rep. Jim Bridenstine

For more information on ACSWA see: <http://www.acswa.us>.



3665 Discovery Drive
Boulder, CO 80303
Telephone: (303) 492-4509
Email: Daniel.Baker@lasp.colorado.edu

July 14, 2017

The Honorable Ed Perlmutter
U.S. House of Representatives
1410 Longworth House Office Building
Washington, DC 20515

Dear Representative Perlmutter:

On behalf of my colleagues at the Laboratory for Atmospheric and Space Physics (LASP) and the University of Colorado Boulder, I write in support of the Space Weather Research and Forecast Act (H.R.3086). Given the continued threat and vulnerabilities facing our world from solar interactions with the Earth, we applaud the bicameral and bipartisan approach Congress is taking to address the challenges we face with respect to enhancing our nation's space weather forecasting capabilities.

Throughout the Space Age, we have discovered and accumulated a vast knowledge on the governing physical processes of the various regions of both deep space as well as the space surrounding near-Earth. This knowledge has provided an opportunity to expand our reach into the solar system and beyond, as well as increase our Earth observation capabilities. Over time, the increased utilization of satellites continues to have a broad reach across our society, including within the security, public safety and commercial realms. The data we acquire from these satellites is vital in order to protect our national and economic interests, and interruptions stemming from increased solar activity could prove detrimental in carrying out these important functions.

As a result, the call to increase our space weather forecasting and mitigation capabilities was amplified by the National Academies Decadal Survey in Solar and Space Physics in 2012, and again through the Office of Science and Technology Policy's Space Weather Action Plan that was released in October 2015. Through these calls, it has become a national imperative to streamline the mechanisms designed to help develop and maintain a forecasting system that not only help to predict space weather events, but to respond to them. We believe the Space Weather Research and Forecast Act will provide a collaborative framework for the federal government and its agencies to work together alongside academic, international and commercial space communities to advance this critical undertaking.

An important component of space weather research and monitoring is collaboration and cooperation among its many stakeholders. The legislation's call for enhanced interagency coordination as well as its goal for federal agencies to "increase engagement and cooperation with the international, commercial, and academic communities on the observational infrastructure, data, and scientific research necessary to advance the characterization, prediction, and mitigation of space weather events" will be vital in order

to increase our nation's forecasting and responsive capabilities. Furthermore, the establishment of a Space Weather Government-Industry-University Roundtable through the National Academies will ensure the exchange of scientific research and operational needs. Finally, the strong focus on research and operational capacity within this legislation underscores the important role academic institutions will continue to play in addressing the needs of federal agencies. Here at LASP, we take great pride in our expertise in research to operations and operations to research (R2O/O2R) capabilities, and we stand ready to assist in the cooperative model outlined in the H.R.3086 to advance our national space weather forecast and response capabilities

Again, we applaud this legislation and its aim to streamline federal efforts working in conjunction with academic and commercial space partners in order to better understand and predict space weather activities and their impacts on our national interests. Thank you for your outstanding support, and please continue to think of us as resource and partner going forward.

Sincerely,



Dr. Daniel N. Baker
Director, Laboratory for Atmospheric and Space Physics
Distinguished Professor of Planetary and Space Physics
Moog-Broad Reach Endowed Chair of Space Sciences
Professor, Astrophysical and Planetary Sciences
Professor, Department of Physics

Cc: Chairman Lamar Smith
Ranking Member Eddie Bernice Johnson

**PennState**

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April 17, 2018

The Honorable Ed Perlmutter
U.S. House of Representatives
1410 Longworth House Office Building
Washington, DC 20515

Dear Mr. Perlmutter:

I write to express support for H.R.3086, the Space Weather Research and Forecasting Act, and appreciation for your leadership on this legislation that aims to improve efforts for predicting and mitigating space weather events.

By delineating clear roles and responsibilities to federal agencies that study and predict space weather, the legislation would improve resources and make critical measurement data available for the research community to model the frequency and severity of space weather events. This information will be helpful for monitoring space weather events, particularly coronal mass ejections and geomagnetic disturbances that can cause interruptions to the power grid and in satellites, affecting critical infrastructure that is dependent on communications technology and electricity.

With an increase in focus and attention to space weather activities provided by this legislation, researchers with expertise in data assimilation and big data analysis at Penn State and around the nation can conduct risk analysis and plan for responses to space weather events before they occur. Penn State researchers and educators in meteorology, geoinformatics, energy business and engineering, as well as social science, look forward to the data opportunities made available through this legislation.

If I or any of our experts in the College of Earth and Mineral Sciences can be of assistance to you, please feel free to contact my federal relations colleagues Amanda Wintersteen (AWintersteen@psu.edu) and John Latini (JLatini@psu.edu) at 814-865-5431.

Sincerely,

Lee R. Kump
Dean



OFFICE OF THE PRESIDENT

Antonio J. Busalacchi
303-497-1652
tonyb@ucar.edu

April 25, 2018

The Honorable Ed Perlmutter
1410 Longworth House Office Building
Washington, DC 20515

Dear Congressman Perlmutter,

As a research organization committed to better understanding the earth system, including the critical role of the sun in geospace sciences, the University Corporation for Atmospheric Research (UCAR) would like to thank you for proposing HR 3086 – the Space Weather Research and Forecast Act – and voice our strong support. Like S 141, the bill of the same name introduced by Senators Gardner, Peters, and Booker and passed by the Senate last year, HR 3086 will enhance the integration of existing national efforts to understand, predict, prepare for, and mitigate space weather.

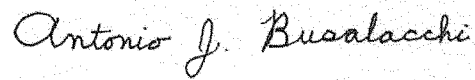
Scientists are just beginning to understand the interactions between our sun and the Earth. Given the growing national importance and reliance on technology, it is critical that we expand our scientific understanding of the interactions between the sun and Earth so that we may improve forecasting and mitigate the effects of space weather events. Coupled with the National Space Weather Strategy and National Space Weather Action Plan, this legislation sets national priorities to increase and improve space weather observations, science, and forecasting abilities.

Most of our understanding of space weather is based on experience and knowledge gained over the last 30 years, though the historical record indicates space weather events of much greater severity have occurred within the last 150 years. Impacting airlines, GPS, and electric utilities, space weather events in recent history resulted in economic consequences in the tens of millions of dollars. Estimates for damage resulting from a repeat of the worst known event of the last 150 years range from \$1 – 2 trillion in the first year alone. Scientists do not know the likelihood of such an event recurring, or even whether such an event is the worst-case scenario.

HR 3086 would provide clear roles and responsibilities to the various federal agencies responsible for understanding, predicting, and forecasting space weather, including the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), and the Department of Defense (DOD). As these are all agencies with which we work regularly, this clarity would enable us to pursue research that will have the best impact on society's ability to predict and respond to space weather events.

Again, thank you for your tireless work supporting the science community in Colorado and across the United States. We appreciate your efforts on this bill and many other endeavors.

Best regards,



Antonio J. Busalacchi
President
University Corporation for Atmospheric Research



S. Jack Hu • Vice President for Research

July 26, 2017

The Honorable Ed Perlmutter
United States House of Representatives
Washington, D.C. 20515

Dear Representative Perlmutter:

On behalf of the University of Michigan, I write to thank you for introducing the Space Weather Research and Forecasting Act (H.R. 3086).

The Space Weather Research and Forecasting Act will help us avoid the significant economic and national security implications that could arise from a large-scale space weather event. This legislation provides critical guidance to federal agencies focused on improving our ability to understand, predict and forecast space weather events.

I greatly appreciate the opportunity this legislation provides for the academic community's participation through the development of a Space Weather Government-Industry-University Roundtable. Such a collaboration will ensure all stakeholders are working together in a coordinated and efficient fashion.

The University of Michigan stands ready to work with the federal government and others in advancing the characterization, prediction, and mitigation of space weather events. We appreciate the Senate's passage of the Space Weather Research and Forecasting Act (S.141) and urge the House Science Committee to consider their version of the legislation expeditiously.

Once again, thank you for championing this important legislation. We greatly appreciate your continued commitment to helping us better understand and predict space weather events.

Sincerely,

A handwritten signature in black ink, appearing to read 'S. Jack Hu'.

S. Jack Hu

CC: Chairman Lamar Smith
Representative Jim Bridenstine



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April 26, 2018

The Honorable Lamar Smith
Chairman
Committee on Science, Space, and Technology
United States House of Representatives
Washington, D.C. 20515

The Honorable Eddie Bernice Johnson
Ranking Member
Committee on Science, Space, and Technology
United States House of Representatives
Washington, D.C. 20515

Dear Chairman Smith and Ranking Member Johnson,

We are writing on behalf of the University of New Hampshire (UNH) to voice our strong support for the *Space Weather Research and Forecasting Act* (H.R. 3086). UNH urges swift passage of this bipartisan legislation critical to ensuring the United States is equipped to predict, mitigate, and respond to the hazards that space weather poses to our national security and economic wellbeing.

Federal support for research and technology development is essential to improving the Nation's space weather readiness. Current space weather monitoring capabilities rely on an observational infrastructure that is incapable of providing the lead time required to undertake proper space weather mitigation measures. H.R. 3086 would support fundamental research into the physical processes behind space weather, enabling more sophisticated prediction capabilities and equipping decision-makers with the information and tools necessary to avert crippling damage to our satellites, electric power grid, and other sensitive assets that underpin our economy and national security apparatus.

UNH is especially supportive of Section 60703 of the bill, which would identify specific research and development activities and outline clear roles and responsibilities of federal research agencies like the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF). Particularly important to UNH and many of its peer institutions is this legislation's commitment to advancing the consensus-based priorities identified by the scientific community and articulated in the National Academies Solar and Space Physics Decadal Survey.

In general, we are pleased this bill promotes the translation of research outcomes to operational capabilities that will make our Nation stronger and safer.

We thank you for your consideration, and we hope that UNH can serve as a resource for you as you continue working to address the pressing issue of space weather.

Sincerely,

Dr. Jan Nisbet
Senior Vice Provost for Research
University of New Hampshire

Dr. Harlan Spence
Director, Institute for the Study of Earth,
Oceans, and Space
University of New Hampshire



July 12, 2017

The Honorable Ed Perlmutter
United States House of Representatives
1410 Longworth House Office Building
Washington, D.C. 20515

Office of the Senior Vice Provost
for Research

107 Thompson Hall
105 Main Street
Durham, NH 03824-3547

V: 603.862.1948
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Dear Representative Perlmutter,

We are writing on behalf of the University of New Hampshire (UNH) to voice our strong support for the *Space Weather Research and Forecasting Act* (H.R. 3086). UNH urges swift passage of this bipartisan legislation critical to ensuring the United States is equipped to predict, mitigate, and respond to the hazards that space weather poses to our national security and economic wellbeing.

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Sincerely,

Dr. Jan Nisbet
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Dr. Harlan Spence
Director, Institute for the Study of Earth,
Oceans, and Space
University of New Hampshire

cc: The Honorable Lamar Smith, Chairman, House Committee on Science, Space, and Technology
The Honorable Eddie Bernice Johnson, Ranking Member, House Committee on Science, Space, and Technology

Mr. BABIN. And in the absence of Chairman Biggs, I'm the Chairman of the Space Subcommittee and will preside until he returns. And I'd like to recognize myself for five minutes for questions.

During the recent 2018 Space Weather Workshop in Colorado, several presentations alluded to the private and academic opportunities within the overall space weather enterprise. These opportunities include the Space Weather Technology Research and Education Center at the University of Colorado in Boulder. Amen. And the possible use of future OneWeb commercial satellites as polar orbit environmental sensors. What other opportunities, especially in forecasting and prediction analytics, are available for the private and academic sectors to help NOAA, the Air Force, and NASA to accomplish space weather goals? Dr. Jacobs, I'd like to direct that to you first.

Dr. JACOBS. The two primary things would be observations and forecasting. So we need observations both to initialize the predictions, as well as to verify the forecasts. So it's impossible to improve a forecast unless you have observations for verification.

The current state of the forecasting is we essentially see an event occurring on the Sun and then we can predict how that will impact the Earth, but there's really no way to predict when these events will occur other than some weak probabilistic guidance, and that I think is where the future of the research needs to focus is actually predicting the onset of these events, not what happens once they occur.

Mr. BABIN. All right. Thank you very much.

And Dr. Spann, could you elaborate on that?

Dr. SPANN. Yes. I think that understanding and being able to predict these events is really tied to the fundamental understanding of what's going on. And as we all try to identify our swim lanes—and I'd like to take that analogy a little further—I think where we want to go is actually synchronized swimming. And so—but right now, we are identifying our swim lanes and understanding what roles each agency plays, and for NASA that is really providing the fundamental understanding. And as we not only launch these new missions, which are really targeted, we also have a new space weather application—science application program that we're rolling out, which will allow competed opportunities very specifically tied toward transitioning the science research to an operational scenario, and that will certainly engage the academic and industry very heavily. And so those are the two areas where I would say—where we can get to the synchronized swimming scenario.

Mr. BABIN. Well, we were just talking about Esther Williams and—so that's a good analogy. And would either of the other two, Dr. Gibson or Dr. Tobiska, would you like to elaborate on that if you would?

Dr. GIBSON. Sure, yes. I would just comment that there's different kinds of observations that are needed, right? I mean, there's the observations we need to make progress in the fundamental science, and this is the real cutting-edge new big telescopes. New measurements, and from different vantages. One of the exciting opportunities is to take observations from a place in the Sun's orbit where you can look back and see a CME moving from the Sun to

the Earth. And this is something that the European Space Agency may actually take on and be an incredible complementary asset to our observations, which are looking right along the Sun-Earth line.

You take that a little farther and you could observe from above the Sun's poles looking down, and you would get that same operational benefit of seeing eruptions go from the Sun to the Earth directed at the Earth, and yet you'd get other scientific benefits as well.

So there's exciting opportunities for moving forward in the fundamental research, and then there's other observations we need to basically have the best possible operational capabilities. And some of these are the ones we know about like the LASCO Coronagraph and the observations of the solar wind just upstream of the Earth. And these we have to maintain so we can keep doing as well as we are now, but there may be new operational assets that, as we move forward in the fundamental science, we identify as observations that can make us actually do better in terms of the operations.

And then finally, the other kind of observations that we need in the benchmarking activity, are related to applied science goals. In the benchmarking activity, one of the things they tried to study was the geomagnetic activity and the ground currents, how extreme they could get. To do that, they needed magnetometers on the ground and also magnetotelluric surveys which tell you about the ground conductivity. And they found that only about half of the United States was really covered by these observations, and this represents another gap that we need. So we just keep finding new things that we need to observe.

Mr. BABIN. Yes, thank you. And Dr. Tobiska?

Dr. TOBISKA. Yes, just one or two comments. I would really like to echo my other colleagues who emphasized the observations needed of the material coming from the Sun to the Earth. Right now, we are really at the point like the tropospheric weather community was 50 years ago. We're just a half-dozen cities making temperature measurements. We can't predict when the snow is going to come over the mountain unless we look out the window.

Now, we need to have the thousands and tens of thousands of measurements in that realm. They don't exist yet. Plus there's other measurements downstream for other technologies, but if we could solve that viewing of what's coming at us from the Sun, knowing the velocity and the directionality of it to get the magnitude, that would be a big deal.

Mr. BABIN. Right. Thank you. And I have about five other questions, but I'm out of time. A lot of them are—I really would like to hear some answers on, especially in regards to national security issues.

But I would like to recognize Dr. Bera, the gentleman from California, for his five minutes.

Mr. BERA. Thank you, Mr. Chairman. As I said in my opening statement, these are fascinating hearings about science. And, you know, for those viewers at home I think it's important—you know, often people say, well, why is Congress talking about space weather? But, you know, I think Dr. Gibson in your opening statement—

I think each of you talk about how these space phenomenon and solar phenomenon can impact every aspect of our lives.

You talked about the electrical grid, you talked about our GPS and navigational systems, and, you know, often the public may just think, you know, GPS is, you know, what I've got on my phone and it helps me get from point A to point B, and if it goes down, well, what's the big deal? I might have an old Thomas Guide in my glove box that I can open up and look in.

But Dr. Gibson, maybe if you want to just expand—I mean, if we're thinking about the future and we're going to have autonomous vehicles, we're going to have, you know, autonomous trucks, that's all going to be reliant on GPS navigational systems. And if you just want to talk about the impact if GPS was knocked down.

Dr. GIBSON. Yes, absolutely. And I think there's a whole continuum there, right? I mean, there's the degrading of GPS where it introduces errors, which can be very significant, maybe not for us if there's a little glitch when we're getting directions, maybe it's not that big of a deal, but for doing mineral surveys or—there's many, many applications where the precision is critical. And then if there's a big event, there's the potential for a true loss, and that's something which hits so many different aspects of peoples in society today.

Mr. BERA. So it's incredibly important for us to better understand this phenomenon as we become increasingly reliant on these new technologies and so forth.

Dr. Spann, you touched on the Parker Solar Probe and, you know, if you could just expand on what the solar probe would allow us to learn and why—you know, it'll go closer to the Sun than I think anything we've ever sent, and if it will help us, you know, with predictable capabilities and what kind of science we're going to learn from—

Dr. SPANN. So Parker Solar Probe is scheduled to be launched, and the window of opportunity opens up at the end of July through August, and that is really focused on two areas. One is trying to understand the acceleration processes. As much as we observe the solar wind, which are the particles emanating from the Sun, we don't understand how they get up to the speeds they get up to. And so a lot of that acceleration process happens very, very close to the Sun, and we've remotely observed the Sun but never really actually gone and touched the Sun, and so Parker is going to be our first opportunity to do that, an incredible technology advance.

So understanding that acceleration process and then also just understanding just kind of fundamentally, you know, parts of the solar atmosphere are hotter even than the surface of the Sun, and we just don't understand that. And so what's going on there? All of that provides us the fundamental understanding about how the Sun works and how it impacts our Earth system, and so Parker is going to provide a significant advancement in those areas.

Mr. BERA. Yes, Dr. Gibson, if I—I'll come back to you. You know, we obviously can try to better understand solar phenomenon and solar flares and things that potentially disrupt and cause space weather. Are there protective things that we can do, you know, here on Earth, you know, understanding that we can't control it, but if we get better at predicting it, you know, what would the

things that we might do to protect some of our systems and, you know—or build redundancy?

Dr. GIBSON. Absolutely. So, I mean, there's a range of things. If we know what's going to happen, for example, the power company can operate in modes that will avoid catastrophic failure, but—and the airlines can potentially change the altitude of their flights. There's various things that can be done. The problem is it's expensive to make these mitigations, and it's critical that we don't give false positives. We have to do better in our forecasting so that they can be taken seriously. And then also we can make use of the benchmarking activity to try to get a sense just how bad things can get can help us harden our assets so that we can prepare for the worst.

Mr. BERA. Okay. Great. And I'm about out of time, but as a Member who represents California who also happens to be a physician, Dr. Tobiska, maybe I should get a lead-lined jacket or something for these flights. So thank you, and with that, I will yield back.

Mr. BABIN. Thank you. I appreciate it, Dr. Bera.

And now the gentleman from California, Mr. Rohrabacher.

Mr. ROHRABACHER. I appreciate this hearing, and I appreciate the guidance that you're trying to give us right now.

How does space weather and a space weather storm—how does that compare to an EMP attack, for example, in terms of the danger that we face? Maybe just start at that end and go to that end.

Dr. TOBISKA. That's an excellent question, and I know that there's been a community. I think the NRC has actually looked at that. In general, the severity of an EMP attack against the United States compared to a Carrington-class event are in the same order of magnitude. If we were to have a Carrington-class event in the United States today that affected, say, the Northeast of the United States, you could potentially have, you know, days to weeks to months of power outages.

And the problem is is that the big transformers that distribute the power grid, when they're hit by this induced current and they blow out, there are not transformers sitting on the shelf to replace them. If each one of these things—the big ones are custom-built. I'm not talking about the telephone pole ones. So building those takes months to do, and they're not sitting around, so that's the problem.

Mr. ROHRABACHER. So a space weather storm could give us that same impact that we've been warned about with EMP. What could—for example, could some space weather storm impact on us to the point that people might wake up one day and not be able to use any of their credit cards or use their cell phone or things like that?

Dr. SPANN. Yes. I think that because we—I mean, just think of in the morning you plug in everything, you know, to an outlet or whatever, so that—you know, anything that requires an outlet now is going to be a problem. And so it does impact a lot of things, all of—you know, we're just so technologically dependent not only on the ground but in space for our communications, so it would, you know should such an event occur, it would impact—

Mr. ROHRABACHER. GPS?

Dr. SPANN. Yes.

Mr. ROHRABACHER. Our GPS——

Dr. SPANN. Yes.

Mr. ROHRABACHER. —system could go down?

Dr. SPANN. Yes. And I would even make a point that, you know, it doesn't take a huge event like that for things to become impactful to us, even with the errors in GPS, even without an EMP or without a major solar storm, just the irregularities in the ionosphere cause issues with communications and GPS signals. And so it was mentioned that space weather happens all the time, and yes, it's punctuated with major storms, but we kind of live through it all the time.

Mr. ROHRABACHER. So we're pretty well—not pretty well but we have a certain degree of protection based on our own atmosphere and—that's around the Earth but—so this means that as we go beyond the atmospheres, especially with satellites, and also deep space missions that this subcommittee oversees, that this is a major—has to be a major consideration if we're expect to have a successful mission beyond that Earth atmosphere?

Dr. SPANN. Yes. And I think the—if I could speak to the deep space aspect, there are really two issues that we can talk about space weather. One is a very strong variability that's driven by the Sun and what's going on, but then there's a constant background radiation is primarily due to the galactic cosmic rays. And this is a place where I think industry can come in and have a major role.

That background radiation, while it may be low-level, that's actually the biggest concern at least for astronauts and humans out in deep space. And so understanding how to protect ourselves and shield ourselves from that, we don't have a good solution for that, and I think this is a place where we could put some emphasis as well.

Mr. ROHRABACHER. Yes. I have always been surprised at the dangers that the world faces that nobody even knows about or cares about, and I've often in this committee tried to draw our attention to the fact that an asteroid could actually be discovered that might hit the Earth that we should be prepared for it. And I think that what we're talking about today is of that magnitude that we need to be aware that this would be an earthshattering—there are potential earthshattering events when it comes to this space weather storms and also the things that we've been talking about.

So thank you, Mr. Chairman, for your leadership in both the Subcommittees, and let's work together to try to—it's our job to make sure we work on things that can bring down the damage that would be done on one of these natural threats. Thank you very much.

Mr. BABIN. Yes, sir. Thank you, Mr. Rohrabacher.

Now, I'd like to recognize the gentlelady from Oregon, Ms. Bonamici.

Ms. BONAMICI. Thank you very much to Chairman Babin, Chairman Biggs, Ranking Member Bera, and thank you to our witnesses.

I apologize I wasn't here during your testimony. I had a conflict with another hearing. But this is a fascinating and important topic, and I'm trying to figure out who's going to be the first person to

use synchronized swimming and swarm task force in the same sentence.

But to each witness, in northwest Oregon and in fact around the country it's essential that our constituents have access to accurate warnings about extreme weather events ahead of time to help vulnerable residents prepare. And last Congress this committee passed—in fact the House passed and the President signed into law bipartisan legislation I worked on with then Representative Bridenstine, now NASA Administrator Bridenstine, to strengthen terrestrial weather forecasting. But unlike terrestrial weather events, space weather has a broader potential to affect our entire planet. The Sun of course and its constant activity present so many risks for significant space weather events, as you have discussed.

Unfortunately, we are decades there, as Dr. Tobiska points out, 50 years behind with the forecast capability of terrestrial weather predictions and are not yet able to prepare ourselves fully before an event occurs. And I know you have described both in your responses and in your testimony the implications of inaction and not moving forward with developing a more robust forecasting capability. And I want to acknowledge the progress, however, that's been made to date.

So I want to ask what data gaps need to be addressed in our current space weather observing infrastructure that would help us better prepare against these threats, and also if you could let us know whether there is additional technology that needs development or is there sufficient technology if we could get the policy through updating? Go ahead, whoever wants to start, and then I do have another question. So, Dr. Spann?

Dr. SPANN. Well, I was just going to mention that just from a fundamental perspective really advancing our models based on the data input and the theories that our folks out in the academia and the industry are providing, that I think provides that foundational—and I'll let others speak to kind of how you implement that, but that is where I see us focusing on. I think we've talked about very large missions but also having distribute missions within the ionosphere with many, many small satellites and other very fascinating things, which again the academia and industry can partner very heavily with government to do that.

Dr. TOBISKA. Yes, I would just add a comment on this. The academic community, some in industry and certainly in the agencies have really begun to take on the lessons from the terrestrial weather community. Fifty years ago, they had the big physics-based models but not much data, so the forecasts weren't very good. Now, our forecasts are really pretty good but they have a lot of data coming in, so it's like knowing the answer—it's like cheating on the exam. You know what's coming at you, but that data assimilation in the physics-based models is critical. And then having several models run simultaneously in ensemble modeling like they do for the hurricane tracks—you have a whole bunch of models that you can see where they're coming—those—the combination of those two kinds of modeling with the data being ingested into them would really make a significant difference. I think the community as a whole really sees that as a path forward, but certainly, as colleagues have said, observations are really critical to feeding that.

Ms. BONAMICI. Terrific. We also had some good discussions in this Committee about the social sciences of message communication, which I think will be critical as well here. Dr. Gibson, can you talk about what the disadvantages or advantages of coordinating or streamlining both nationally and internationally with our efforts to gather space weather data? Is there potential for overlap or redundancy between agencies if there's not a direction on how to proceed?

Dr. GIBSON. There's definitely efficiencies of bringing together so that we're all working towards the same goal with our synchronized swimming. You know, there's also a huge benefit from sharing data between agencies, and, you know, the benchmarking activity is a great example of how having everybody bring their expertise and their knowledge to the table so we can really make progress.

There was a release of data recently I think from the DOD that was part of the executive order which was satellite data of space weather from the DOD and which both introduces important new observations into the scientific analysis of space weather and also provides an opportunity for the DOD to get research done in the direction where they would really care about.

Ms. BONAMICI. And real quickly, how are we doing with international collaboration?

Dr. GIBSON. Fabulous. And this L5 collaboration particularly, which would be the Sun-Earth view from the side, is a wonderful opportunity.

Ms. BONAMICI. Thank you. I see my time is expired. I yield back. Thank you, Mr. Chairman.

Mr. BABIN. Sorry about that. Thank you very much, Ms. Bonamici.

I'd like to recognize the gentleman from Alabama, Mr. Brooks, now for five minutes of questions.

Mr. BROOKS. Thank you, Mr. Chairman.

Dr. Tobiska, you mentioned a Carrington-class storm. What is that and how frequently do they occur?

Dr. TOBISKA. Great question. They occur infrequently. First of all, the name comes from an 1859 event that Dr. Gibson mentioned where they observed it from the ground. They saw big streamers coming off the Sun when the clouds were there in London. That event caused aurora over Cuba. It caused balls of fire going down telegraph lines in the Midwest, and it also caused I think a fire in a telegraph station in Madison Square Garden in New York City.

So this is where there's huge geomagnetic currents set up in the Earth's crust. Those currents have got to go somewhere, and they follow the path of least resistance, so they go down power lines, they go down oil pipelines. Wherever they can go, they'll travel. So that's kind of what a Carrington-class event is.

The occurrence rate are very infrequent, although we had an event on—in July of 2012 where, had the event occurred about four days later when that region on the Sun was facing us, we would have had an extremely large geomagnetic event, maybe not a Carrington but certainly like a G4 level, like a—it'd be like a G4 hurricane. However, it was on the side of the Sun. It had just—the Sun had rotated around and we just missed that one, so those

happen maybe on the order of once every solar cycle or every 10 or 12 years. There's probably moderate-sized storms that happen every year, but that's kind of the frequency of those.

Mr. BROOKS. Was the 1989 Hydro-Québec power collapse caused by a Carrington-class storm?

Dr. TOBISKA. No, it wasn't. It was a smaller storm than the Carrington event, but it just happens that the ground conductivity in that part of the—North America is very susceptible to strong currents, and the Hydro-Québec power grid was not able to trigger off its transmission lines quickly enough.

Mr. BROOKS. And how long was there a power collapse in the 1989 Hydro-Québec?

Dr. TOBISKA. In that one it was for a few hours to a few days in that region, yes.

Mr. BROOKS. Dr. Spann, in your written testimony you state, "For example, the electric power industry is susceptible to geomagnetically induced currents, which can overload unprotected power grids and result in widespread power outages." What has to be done to protect power grids?

Dr. SPANN. Well, I think there are kind of two things that need a look at. One is providing the early warning to those power grids so that they can—and I'm not a power grid operator or an expert necessarily in this field but they can reroute power in ways that the predicted induced currents on their power lines would not damage their transformers, which, as Dr. Tobiska mentioned, that is kind of the failure mode there, so kind of reserivicing how they route their power is one way, but that requires some predictive capability. And so, again, trying to understand how this works and providing that information through the operational agencies so that they can provide that information down to the power companies is—I think is the way to prevent that sort of occurrence.

Mr. BROOKS. I thought when you began you said two ways, so we've got early warning. Is there a second thing that can be done to protect the power grid?

Dr. SPANN. Well, the early warning is kind of the initial step. The second step is that the power grids need to develop a system, and perhaps they already do, where they can reroute their power so that it avoids areas that we think are going to have large currents and being induced, so that would be the second.

Mr. BROOKS. Any judgment on how much cost as necessary in order to provide that kind of early warning with the accuracy and precision that is necessary for the power distributors to be able to properly react and plan and minimize damage?

Dr. SPANN. That's not something that I'm able to provide. I think there may be other people on the panel that could provide that. I would not know what that is.

Mr. BROOKS. Well, my time has expired, but if anyone has a quick answer—the Chairman might indulge us—on how much the cost might be.

Mr. BABIN. Sure.

Dr. GIBSON. I'll make an answer which is that it's not a quick answer because it's a complicated problem. To do what you just asked for, which is to get accurate forecasts of how bad the geomagnetic activity is, we don't have that answer yet, and there's no

one single thing that could be done that would do that, so it would be hard to answer that question.

Mr. BROOKS. All right. Thank you, Mr. Chairman.

Mr. BABIN. Thank you. All interesting and important stuff.

I'd like to recognize the gentleman from Virginia, Mr. Beyer.

Mr. BEYER. Mr. Chairman, thank you very much. And thank all of you. It's a fascinating topic.

Dr. Spann, you wrote about how the Heliophysics Division is in the process of selecting its next strategic mission and decadal survey priority, the IMAP program. The boundary of our solar system and investigating acceleration process is critical to our understanding our space weather. How do you define the boundary of the solar system, and why is that important?

Dr. SPANN. So it's important from the aspect of just understanding how the universe works, how our solar system works. IMAP is the interstellar mapping acceleration probe, and it is really focused on understanding the solar wind, how that solar wind, driven by the Sun, how it expands and basically defines the region of our solar system as it impacts the interstellar space. And so interstellar space is the space between solar systems, and there is a boundary that—upon what's called the heliopause, and understanding how our solar system and the solar wind expands and interacts with that interstellar space, that is that boundary in which, for example, the Voyager spacecraft you all may have seen have now gone beyond that and understanding how that interface operates and what physics occurs there is what IMAP is focused on.

Mr. BEYER. And the heliopause is where—basically where the solar wind peters out?

Dr. SPANN. Basically, it peters out. It buffets up against the interstellar space, and that boundary is a place where actually very interesting physics occurs, including perhaps acceleration of cosmic rays and energetic particles.

Mr. BEYER. That's where it runs into the dark matter.

Dr. SPANN. Yes, well—

Mr. BEYER. Dr. Jacobs, in talking about all the different—the solar flares, particle events, CMEs, et cetera, go back to the 1859 Carrington event, which is the biggest one, and that you think it's 8 minutes and 20 seconds for light to get from the Sun here, and it took 17 hours—17.6 hours for that coronal mass ejection to get here. What can we do in 8 minutes or in 17 hours to get ready for one of these events that we observe?

Dr. JACOBS. Well, the 8 minutes is related to the photons, and the 17 hours to roughly 3 to 4 days is the plasma. And so it's the 1- to 4-day lead time for the coronal mass ejection that's the real problem. And like we've been hearing from the other witnesses today, the big—I think the hardest problem to solve is understanding how to predict the occurrence of those, not what we currently do, which is forecast how they will propagate away from the Sun after the event happens. We need to predict when the event is going to happen on the Sun, and that is cutting-edge basic research.

Mr. BEYER. So we're looking for weeks or months of warning rather than 17 hours? Right.

And, Dr. Gibson, in your testimony you talked about 1967 when space weather disrupted radar and radio communications that was initially interpreted by the U.S. military as a possible hostile act by the Soviet Union.

Dr. GIBSON. Right.

Mr. BEYER. What are the implications for a major event—major space weather event on our nuclear deterrent, launch on warning, space missile, you know, the nuclear shield?

Dr. GIBSON. Yes, I think—I mean, it's clear the military gets space weather, and back in 1967 it was sort of a wake-up call. And it's a good story. It's a story where it was because they had space weather, it was really, really early days but they had people on staff who were looking at the Sun and making observations and were able to say, hey, the fact that those radars are blocked, that's not the Soviet Union, that's the Sun. And it took a while for the information to get around and there were tense moments when there were aircraft ready to take off, but the information did get out and averted some potentially very serious repercussions.

And we talked about the EMPs earlier. I mean, being able to know and recognize space weather for what it is is absolutely critical from the point of view of our military preparedness.

Mr. BEYER. And quickly, do you have confidence that the nuclear powers have a better understanding of this now than they did in 1967?

Dr. GIBSON. Absolutely, definitely have a better understanding than then.

Mr. BEYER. All right. Thank you. Mr. Chair, I yield back.

Mr. BABIN. Yes, sir. Thank you.

I'd like to recognize the gentleman from Florida, Dr. Dunn.

Mr. DUNN. Thank you very much, Mr. Chairman.

Dr. Tobiska, you caught everybody's imagination with the airline trips. Let me just sort of plug that in a little bit more. Was that analysis of the chest x-ray at 37,000 feet, was that just an analysis at that altitude or does that take into account the attenuation of the fuselage of the aircraft?

Dr. TOBISKA. That's a great question. That is—that's—for North America in particular, that's kind of the average dose that you get if you're flying commercially, you know, at 37,000 feet for 10 hours. But that is only from the—as we were just mentioning earlier, from IMAP, that's only from the galactic cosmic rays—

Mr. DUNN. Right, right, so that's cosmic, not the CMEs and what—

Dr. TOBISKA. That's right. If there's a—

Mr. DUNN. So I was going to ask how that's affected by carbon fiber aircraft fuselage now, which are coming into vogue with the big super—

Dr. TOBISKA. Yes. So basically, it's—it doesn't make a difference. The issue is is that the really energetic particles come in. Even if we coated the planes with lead, okay, which the airlines wouldn't want us to do—

Mr. DUNN. Yes. There's a penalty for that.

Dr. TOBISKA. That's right. The more energetic particles would still make it through. They create a spray of lower energy stuff, and it's that soup that we're actually embedded in—

Mr. DUNN. So that goes to the CMEs then. There's no Faraday cage available to us there?

Dr. TOBISKA. That's right.

Mr. DUNN. Okay.

Dr. TOBISKA. Yes.

Mr. DUNN. So also in your testimony you said 1990 NORAD lost 200 satellites. Did they lose them permanently or temporarily?

Dr. TOBISKA. No, but that's a good point. So they—there's a fence, a space surveillance fence, a radar fence that the objects are coming through, and if they don't come through at a certain time, they had to go and look for other objects. Well, as it turns out, 200 of them from the big density changes from that big geomagnetic storm caused the satellites to have their orbits changed such that they didn't come to the fence at the right time. So they had to go off looking for other objects. But now a new object came through. They didn't know if it was a missile or they didn't know if it was an old object that had been delayed in its orbit. So that was a big deal to lose—

Mr. DUNN. They've certainly misplaced these 200.

Dr. TOBISKA. Yes, right, they did find them there, but it took a lot of work on their part.

Mr. DUNN. They just lost track of them right?

Dr. TOBISKA. They lost track of them. Yes.

Mr. DUNN. Thank you for that clarification. I was worried we were going to have to replace every single satellite.

So what steps do we take to harden our satellites these days now that we know this? I guess that's a Dr. Gibson question maybe.

Dr. GIBSON. Practical steps, I think you need to—I would first answer that you need to figure out exactly how bad it could be, and that's this benchmarking activity. To say how bad is it going to be from—if it's a Carrington storm or could be even worse because there's the question of, you know, we've only got 100 or so years of experience with this, and how bad might it be in the future? And there's been studies, for example, looking at other stars, looking at records on the moon, in ice cores to try to get a sense of how bad the radiation could be, and it could even be worse than anything we've experienced or the Carrington storm. So that's the first step is to get that climatology to get that set benchmarking.

And then in terms of the technical hardening, that's outside my wheelhouse. I don't know if Kent wants to—

Dr. SPANN. So I would just respond a little bit from the technical side, as NASA builds its spacecraft, which are science in providing fundamental understanding. Nevertheless, they have to survive in space and have to survive these storms. And so understanding how parts, electronic parts the sit on boards, electronic boards, how they respond to that environment, how different materials degrade over time, all of these things are part of really understanding our space environment and space—

Mr. DUNN. You're actually launching a probe into the Sun.

Dr. SPANN. Absolutely.

Mr. DUNN. Or right near the Sun. So what are you doing to harden that one?

Dr. SPANN. Oh, that is a major accomplishment. That—the big issue there, as you can imagine, is temperature, right? And so

there was a significant effort of—focused on the heatshield that provides—it's going so close to the Sun but yet right behind that heatshield it's a nice warm, you know, 80 degrees Fahrenheit or something like that. It's amazing what they've done.

So that's not—so that's a temperature thing but nevertheless think of the same thing in terms of radiation environment, how to protect those parts, the components—

Mr. DUNN. The charged height—

Dr. SPANN. Yes.

Mr. DUNN. —energetic charged particles—

Dr. SPANN. Right. And—

Mr. DUNN. Can you give me a hint what you're doing on that?

Dr. SPANN. Well, I'm not a parts person, but I just know that they do spot-shield them with some heavier elements, lead and titanium and those sorts of things—

Mr. DUNN. So you're a great time manager. You've cleverly—we've run out of time again. I want to get the answer to that question so—

Dr. SPANN. Sorry about that.

Mr. DUNN. I yield back, Mr. Chairman.

Mr. BABIN. All right. Thank you. Very, very fascinating.

I'd like to recognize the gentleman from Florida—

Mr. CRIST. Thank you, Mr. Chairman.

Mr. BABIN. —Mr. Crist. Yes, sir.

Mr. CRIST. Thank you. And thank you to our witnesses today for being here. We appreciate it.

The district that I represent is Pinellas County, Florida, which is a peninsula. It's surrounded on all three sides by water, and of course you know that Florida is a peninsula as well. So I understand the importance of being able to predict weather. It's pretty important to us in the Sunshine State. And the same certainly holds true for space weather. And it's important that we are sufficiently prepared to predict it and respond to it.

And Dr. Gibson, I had a question. In your testimony you write that "Our best bet for filling gaps in our scientific understanding of the space weather chain is through observations." What kind of new observations would be useful to our understanding of space weather in your view?

Dr. GIBSON. So observations that get at the problem at the source so can define the magnetic field and the eruption at the Sun because if you're going to try to get it at the Earth, you have to first get the input, right? And then observations that show how it may change between the Sun and the Earth so, for example, observations using coronagraphic or heliographic imaging as it moves from Sun to Earth, observations from other vantages where you could look down from the poles, for example, or off from the side to really characterize this.

And then you get to the Earth. You need to get a better sense of our Earth space environment, constellation observations and the tail of the Earth's magnetic field would be really important for that, and then, again, distributed or constellation observations and ground-based observations of the ionosphere and the upper atmosphere.

And I want to say that these are—emphasize again these are both space-based and ground-based observations. A lot of the observations you can do of the Sun, for example, you can do with ground-based telescopes. There's a trade there. The ground-based telescopes can get really, really big because you don't have to launch them, and so you can do very high-resolution observations. The space-based observations take you to places, vantages, viewpoints that you just can't get to from the ground and also let you see wavelengths of light that you can't from the ground, for example.

Mr. CRIST. Thank you. And is it important that we plan our future observing platforms around our research needs?

Dr. GIBSON. Absolutely, and that goes for the fundamental research that we need before we can actually do much better in terms of our forecasting, and it also goes in terms of the applied research that we need to do to determine what the most useful observations are for operations.

Mr. CRIST. Thank you. And I guess to Dr. Jacobs and Dr. Spann, is there a backup plan if any one of our space weather observing systems discontinues working?

Dr. JACOBS. Well, currently, we are single-threaded on a coronagraph through SOHO, which was launched in 1995, and it was a research-grade probe with roughly a three-year lifespan, so it was truly remarkable that it's still reporting data. But we do know that we're expecting the solar rays to start to degrade in their ability to provide power starting in 2020 and be fully out of power roughly by 2025. And we do have a plan to deploy a compact coronagraph. It'll be available roughly 2021 with a deployment around 2024 to 2025.

Mr. CRIST. My next question is directed to all of the witnesses. In your opinions, have there been sufficient advances in our understanding of space weather since the Space Weather Action Plan was released, and if not, why not?

Dr. TOBISKA. I would just like to jump in with one initial comment from the commercial perspective. The—I think across the board all three sectors, the commercial, academic, and agencies really feel that the agencies taking the bull by the horns on that activity really gave us some good guidance.

And I think where we're at at this point is we've recognized that we're all doing some part of this elephant of space weather so that we don't unnecessarily compete with one another or duplicate resources. We need to figure out a process by which we can—between agencies, academia, and industry, begin to talk to one another on a regular basis so that we really coordinate our efforts and don't waste our resources on it.

Dr. GIBSON. And I'll just add that I think we've made great progress but not enough, and we still don't really know what the problem is. We're still defining the problem. And so we've made progress, and we've got all these great activities and we have to keep the momentum going and get a better idea of what is needed.

Dr. SPANN. I would echo both—not that we don't have the problem solved, that we need more fundamental research, but from an observational perspective I think a place where all of us can play together is with some of these distributed space missions that we

really haven't talked very much about, but we've talked a lot about solar imaging and trying to understand and predict with the Sun's going to do but then understanding how the ionosphere and the magnetosphere respond.

And some of the ways that we could observe that to really make great progress is with these small satellite distributed areas. And this is new technology that really I would say industry and the commercial has really taken the lead on. And I think that, as the agencies begin to better understand how to use those very small satellite and those technologies, we can do a much better job in terms of understanding and providing predictive capability that can be transitioned into the operational world.

Mr. CRIST. Thank you, Mr. Chairman. I yield back.

Mr. BABIN. You bet. Thank you very much.

And I'd like to recognize the gentleman from Indiana, Mr. Banks.

Mr. BANKS. Thank you, Mr. Chairman.

First of all, I have a letter from Purdue University that I would like I would like to enter into the record.

Mr. BABIN. Without objection.

[The information follows:]



School of Aeronautics and Astronautics
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April 26, 2018

The Honorable Lamar Smith
Chairman
House Committee on Science, Space, and Technology
2321 Rayburn House Office Building
Washington, D.C. 20515

Dear Chairman Smith:

Thank you for holding this hearing, *Surveying the Space Weather Landscape*, on the current state of space weather science. Purdue University has a long history of studying space, space travel, space communications, and extra-terrestrial objects. Known as the "Cradle of Astronauts," twenty-four Purdue University alumni have been selected for travel to space. But the astronauts are not the only Purdue link to space — many Purdue University professors and their students have been actively involved in research that furthers our reach in space while improving lives on Earth.

One crucial aspect for understanding space weather and its human impact is the prediction of space weather events. Many space weather phenomenon are well understood when measurements are available, after the fact, but predictive capabilities are lacking. This includes short-term prediction of the solar events and collision objects, but also long-term predictions of the phenomena themselves and their effects.

In my current research, I focus on two space weather aspects. First is the effect of space weather, such as geomagnetic storms, on the current space debris population. While solar storms are time-limited, they do cause a secular trend in uncontrolled orbits, changing the population in long term predictions. This means that the effects of geomagnetic storms do not wash out over time, but build up, leading the debris objects to end up in different orbit than without geomagnetic storms. As space debris mitigation measures are based on long-term predictions that is on predictions in which orbits those objects are going to be in 10 or 20 years, necessary corrections need to be made in order to not base mitigation efforts on wrong premises.

An aspect that is currently unsolved in research is the prediction of solar storms and coronal mass ejection. Only reliable predictions allow to implement measures to protect our power grid on earth and failure in GPS connectivity on our satellites. Our reliance on the power grid and satellite navigation is only going to increase in the immediate future. This also results in a new vulnerability towards solar storms and the effects of coronal mass ejections. Systems can be protect shutting them down or making targeted disconnections during the limited time of the solar storm. The damage can be reduced and precaution measures can be taken, but these measures will only be effective when solar phenomena can be reliably predicted with a sufficient warning time.



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Second, on a wider aspect of Space Weather, not focusing solely on solar effects, the United States is ill equipped to accurately predict and respond to hazardous large natural impactors on Earth. Detections based on optical measurements alone lead to significant gaps in detection capabilities, as the meteor that exploded over Chelyabinsk, Russia in 2013 impressively showed. In that case, the meteor was of dark material that is minimally reflective in the optical spectrum, and entered Earth's atmosphere without first being detected. Even when detections are made, astrodynamics modeling is insufficient to quickly and reliably predict the object's orbit and if it is going to hit the earth with certainty. This can only be done when information beyond the state, such as shape, materials, and attitude motion (self-rotation) of the asteroid, can be assessed and correctly modeled, because those parameters effect its trajectory. Having an accurate measure of trajectory allows for sufficient warning time to activate pre-developed and tested engineering measures to deflect or destroy a potential impactor. None of these measures are currently established, leaving us vulnerable. I study the methods to assess parameters and determine a good orbit that allows for certainty if an object is going to impact the earth at a far enough point in the future to give sufficient warning time. Both the predictive capabilities and the engineered solutions benefit from continued research.

Solar origin space weather phenomenon such as coronal mass ejections, solar flares, solar energetic particles and geomagnetic storms have a direct effect on power grid operation on earth, radio navigation frequency transmission to GPS satellites, and the on-board electronic systems. It also alters the earth atmosphere, leading to an altered satellite drag. Satellite drag determines how long a satellite can stay in orbit, and has a direct impact on mission capabilities. Ultimately, there is are still significant advances to be made in our understanding of space weather phenomena, and our ability to predict and mitigate its effects on space exploration and here on Earth.

Sincerely,

A handwritten signature in black ink, appearing to read "C. Frueh".

Dr. Carolin Frueh, Assistant Professor

School of Aeronautics & Astronautics
Purdue University

Mr. BANKS. Thank you.

My first question is for Dr. Jacobs. I understand that NOAA has a number of international partnerships and that in return provides data back and forth. I wonder if that is true for space weather specifically or if there are any other countries that generate space weather data, and does NOAA at all rely on that data from other countries?

Dr. JACOBS. So the relationship we have with the international MetServices is a little bit different than the international space agencies, so it's roughly a five to one on the space-based Earth-directed weather data we collect. We provide roughly 5 times the amount of data that we get in return.

On space weather, it's a little bit different. For the most part, we are the sole provider of this. However, we are in conversations right now with the European Space Agency to potentially share different positions for coronagraph measurements at L1 and L5. Roughly speaking, if ESA is going to deploy at L5, then the thought is we may deploy at L1 and then share data. So having observations from two different vantage points would be very advantageous, but that's just preliminary discussions right now.

Mr. BANKS. Okay. Thank you.

Dr. Tobiska, in your testimony you mentioned that space environment technology has been creating and sole-source distributing the Dst index to the United States Air Force since 2012. Recognizing that we are in an unclassified setting today, can you still give us an indication of the importance of this index for the Air Force mission and operations planning?

Dr. TOBISKA. Absolutely. The product was developed as part of the Small Business Innovative Research (SBIR) program through an Air Force research laboratory activity back in 2010 to 2012 or '13. We coordinated—or we worked with the USGS to help develop this Dst index. They have an excellent index. It's probably the best one in the world now at 1 minute resolution. That data product then goes into the geomagnetic forecast for Space Command as part of this whole effort to understand how these geomagnetic storms affect upper atmosphere density. So we provide operationally to them. Every few hours they get the update from us both for solar as well as these Dst indices.

The one thing about the Dst index is that that particular index itself really helped beat down the uncertainty in atmosphere density because now we are able to get some time resolution on how these big storms are occurring and when they're recovering and to get a better handle on what it's doing to atmosphere densities.

It's not perfect. Our forecasts to be honest with you are pretty bad sometimes, and that's because we simply don't have enough information to know exactly when things are going to arrive or how big they're going to be. But we do make a reduced time granularity product available publicly, yes.

Mr. BANKS. Okay. Along that same note, Dr. Spann, how important is the relationship between the Department of Defense's ability to mitigate space weather risk and operations and planning?

Dr. SPANN. Well, I think it's hugely important. Thank you for bringing that up. I think that the Department of Defense relies heavily, heavily on communications, particularly ground-to-Earth,

Earth-to-ground in very, very different scenarios. There are indicators that operations at times have been impacted by space weather or probable space weather events, and so they are very interested in understanding the fundamental processes that particularly occur in the lower—in the ionosphere that creates scintillation, and those types of very, very applied aspects are some of the areas that the Department of Defense is really focused on. And so, again, providing that fundamental information so that they can develop a better operational environment or tools to help the warfighter or the planning of whatever they're doing is I think a critical place, critical role that space weather plays in that.

Mr. BANKS. I appreciate the feedback. I yield back.

Mr. BABIN. Thank you very much.

And I'd now like to recognize the gentleman from Pennsylvania, Mr. Lamb.

Mr. LAMB. Thank you, Mr. Chairman.

I'm just going to address kind of one wrap-up question to everybody if that's okay. It seems like the common theme uniting each of the issues we talked about, whether it's the effect on DOD, the effect on the grid, and the effect on GPS is your ability to accurately observe, measure, or research about these events. So that tells me that you're looking for more advanced or complicated equipment, personnel. Could you just kind of break down a little more concretely almost what your wish list is or what the needs are in that area?

Maybe start with Dr. Gibson because when we were talking about cost a little bit earlier you kind of interjected at the end that it wasn't a simple answer like you needed one thing. Could you just name a few specific things?

Dr. GIBSON. Yes, I mean the issue is that it's a system, right? It's a system from Sun to Earth. So, for example, I'll start at the Earth since I've talked a lot about the Sun. There are interactions between the Earth's terrestrial atmosphere coming up against the space environment so that the regular terrestrial weather and space weather can interact in ways that are hard to predict. And so understanding that probably requires the kind of constellations that Jim was talking about.

Going back to the Sun because that's my personal love is we have to understand what makes these things erupt in the first place, right? I mean, we would like to get observations and predictions that were more than just after it happens, after the horse has left the barn, right? And so to do that we have to understand the fundamental physical process going on at the Sun, and we need better solar telescopes, bigger solar telescopes. And then, as I've said, trying to track things from Sun to Earth and as it hits the magnetosphere, so it's—think of it as a chain, right, and think of it as there are gaps in our chain and we have to fill them.

Mr. LAMB. And, Dr. Spann, could you address the smaller satellite point that you've touched a couple times?

Dr. SPANN. Sure. I'd love to do that. And I think that we are understanding better how to use these very, very small satellites, and we're talking about something that could fit in—that would be a shoebox size or maybe a couple loaves of bread stuck together. We are understanding how to use that capability, and with more fre-

quent access to space with those very small satellites, they can provide in essence a swarm or a constellation of individual observations spread across—think of a grid, and in that way, just like on a grid where we kind of map topography or something like that, you could map different aspects of the low-Earth environment, geospace as we call it in terms of magnetic field, electric fields, particle populations, the temperature of those populations. All of those sorts of things, the densities, all the sorts of things impact our assets in space.

So developing the capability to use these constellation of small satellites I think would go a long way in terms of providing a lot of the information that's needed for some of the models that are ingested into NOAA and into DOD. And so, you know, a mission that I did not mention, which is the Geospace Dynamic Constellation mission is exactly that. We're getting—that is the mission after IMAP, and so we've got this plan is really focused on providing the fundamental understanding, but it all has a role in terms of the applied component.

Mr. LAMB. Thank you.

Dr. Tobiska, could you follow up on that and just—you mentioned I think at the very beginning about——

Dr. TOBISKA. Yes.

Mr. LAMB. —various businesses providing the instrumentation that some people talked about today. Can you just expand on that, please?

Dr. TOBISKA. Sure. Let's see. If—on a wish list for the aviation radiation side of it, if the U.S. carriers, the major U.S. carriers were carrying the radiation monitoring equipment on their aircraft much like they do the TAMDAR system or the—you know, the—that's where the Pitot tube comes out of the plane and they measure the temperature pressure and humidity, and then that is fed back to the ground via iridium satellite link. That becomes part of the national tropospheric weather.

Just like that, if we had the—that kind of system on the aircraft going over the North Pacific, North Atlantic routes, that would give us an—that would give air traffic management an ability to lower the fleet of aircraft by a couple thousand feet or send it 100 kilometers equatorward to get around major radiation areas. So that would be an example of a wish list.

Mr. LAMB. Thank you, Mr. Chairman. I yield the remainder.

Mr. BABIN. Thank you.

And I know that Dr. Jacobs may have had something to add to that as well. He was kind of looking askance, so I'd like to give you an opportunity.

Dr. JACOBS. Thank you. So I was just—to come back to that question, NOAA is in charge of the operational forecasting, and what's critical to that is having accurate and timely observations. So our concern is not just to have better, more frequent observations from different vantage points but to make sure we don't have a lapse in any observing system capability.

And also to enhance and accelerate the research side so whether it's NASA or the academic universities doing the research to enhance that effort and transition that research faster into operation

so that we can make better use of it sooner would be advantageous to us.

Mr. BABIN. Okay. Thank you very much. And I think this is going to conclude.

Oh, yes, I want to recognize—the gentleman from Colorado wants to—

Mr. PERLMUTTER. Just thank you, panel. This is an excellent discussion. We've been talking about really from the Earth to the Sun and then outwards. There is one other component—and, Dr. Spann, you touched on it a little bit—which is the conductivity of the Earth in these charges.

So the—I promised Mr. Barheim that I would mention the U.S. Geomagnetism Program through the USGS, which also deals with these geomagnetic storms and how the Earth conducts the energy from the Sun and the potential damages that may come from that.

So just thank you to the panel, excellent discussion today.

Mr. BABIN. And I would like to echo that as well, all very great information that is so critical to the advancements of our space program and also our Department of Defense and the warfighting capabilities of our nation and the valuable information that we can impart to our allies around the world.

So I just want to say thank you very much to all four of you witnesses and to the Members for their valuable questions.

The record will remain open for two weeks for additional written comments and written questions from the Members.

So with that, this hearing is adjourned.

[Whereupon, at 12:01 p.m., the Subcommittees were adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

*Responses by Dr. Neil Jacobs***HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY****“Surveying the Space Weather Landscape”**

Dr. Neil Jacobs, Assistant Secretary of Commerce, Environmental Observation and Prediction,
National Oceanic and Atmospheric Administration

Question submitted by Representative Ed Perlmutter, House Committee on Science, Space, and
Technology

- 1. During the Subcommittee testimony numerous comments were directed at power grid vulnerabilities to space weather. What information do we have about space weather vulnerabilities of spacecraft/space hardware/space-based communication infrastructure?**

Space weather effects on satellites depend on the orbit of the satellite, the local environment (highly variable), the satellite exposure time and the “hardness” or shielding of the circuits and components of the satellite. The vulnerabilities of satellite systems to space weather can be roughly divided into the following categories, which are described in further detail below:

- A. Surface charging due to low-energy electrons,
- B. Single event upsets due to high-energy charged particles,
- C. Effects on signal propagation through the ionosphere, and
- D. Effects on satellite orbits.

A. Surface charging due to low-energy electrons

A problem for satellite operators is differential charging, which is the build-up of electrical charges that are not uniformly distributed across the spacecraft. During geomagnetic storms, the number and energy of energetic particles increases, which causes different parts of the spacecraft to be differentially charged. Eventually, this can result in electrical discharges that can arc across spacecraft components, harming and possibly disabling them. Bulk charging (also called deep charging) occurs when energetic particles penetrate the satellite and deposit their charge in its internal parts. If a sufficient charge accumulates in any one component, it may attempt to neutralize by discharging to other components. This discharge is hazardous to the satellite's electronic systems.

B. Single event upsets due to high-energy charged particles

Single event upsets are caused by solar radiation storms where high-energy protons penetrate and hit a sensitive subsystem in a spacecraft, causing temporary or permanent damage. When a high-energy particle travels through semiconductors, the effects can cause undesirable system behavior or even component failure.

C. Effects on signal propagation through the ionosphere

The ionosphere is a region of the upper atmosphere where non-ionized atmospheric gases become ionized by solar and cosmic radiation, producing plasmas. Radio signals propagating to and from a satellite in orbit are affected by the conditions in the ionosphere. The effects on propagating signals are highly variable but space weather can lead to a total loss of

communication due to attenuation and/or severe scintillation when the broadcast signals cross the ionosphere.

D. Effects on orbits due to space-weather induced drag

Space weather conditions can significantly impact the orbital dynamics of satellites in low earth orbit, as changes in the density of particles in the upper atmosphere will impact a satellite's drag. In low earth orbit, the primary forces acting upon a satellite are Earth's gravitational pull and drag from Earth's atmosphere. The drag force increases with solar activity, and during a solar cycle's peak, satellites may have to be maneuvered as often as every two to three weeks to maintain their orbit. Comparatively, during periods of low solar activity, a satellite may only need a few orbit corrections per year to make up for atmospheric drag. Outside of operational costs, variations in atmospheric drag can cause errors in orbit prediction and determination, posing a challenge to maintain space situational awareness.

2. How do industry, civil government agencies, and the Department of Defense monitor and report problems, anomalies and vulnerabilities of their assets to space weather events?

The National Aeronautics and Space Administration (NASA) and the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) support anomaly assessments for civil government satellites, and will typically share information on spacecraft anomalies for public use. On the international level, many civil government agencies are interested in sharing information on satellite anomalies. The Coordination Group for Meteorological Satellites (CGMS) is the entity that globally coordinates meteorological satellite systems. There have been recent efforts by the CGMS to facilitate sharing anomaly data.

Proprietary and classified information are perhaps the most significant obstacles for the development of a centralized and standardized satellite anomaly database. For instance, most commercial satellite owners consider their satellite information proprietary. However, as with other private sector endeavors, NOAA has successfully partnered with commercial vendors to acquire data and services. In addition, many satellite operators for the Department of Defense (DOD) manage classified assets; consequently, the DOD often considers sharing anomaly information an unacceptable risk to national security.

The 2015 National Space Weather Action Plan calls for the Department of Commerce and DOD to create and support a satellite-anomaly database to enable secure collection and analysis of satellite-anomaly data related to space weather. Consequently, NOAA and partner agencies, with help from the private sector, are currently exploring options for a satellite anomaly database that would meet the privacy standards expected by owners of proprietary and classified information.

3. How could an anonymized database for on-orbit spacecraft and communication anomalies provide important information on the routine impacts of space weather events on space-based infrastructure?

A comprehensive satellite anomalies database could be used to efficiently identify and diagnose spacecraft hardware and signaling problems, improve satellite operations, and increase space situational awareness.

For instance, a satellite anomalies database could be used to study and identify trends in the anomalous behavior of different families of satellites. The trends include seasonal groupings, diurnal groupings, as well as identification of anomaly types indicative of certain satellite component types and manufacturers. Information provided by the database can be used in the design phase of spacecraft to prevent the propagation of problems from one spacecraft to the next.

Information from a satellite anomalies database can also be used by operations personnel to anticipate periods of anomalous behavior based on the proven response of an existing spacecraft to environmental conditions. A database would also enable robust statistical analyses of anomaly occurrence to develop statistical models and first-principles models of anomaly phenomena for improved satellite operations.

Finally, a comprehensive database could improve space situational awareness, especially for our national security interests, by helping to determine whether the cause of the anomaly is likely a hardware defect, accidental interference, purposeful attack, or a space weather event.

4. How can the government better leverage next generation observing platforms, such as cubesat constellations, and what types of important measurements can be taken, and at what locations, to best inform space weather forecasting units about the status of the space environment?

NOAA currently utilizes an array of government-owned and operated space-based and ground-based observations in our space weather forecast operations and related research. Many of these data sets are available in near real-time, and come from a variety of sources, ranging from solar imaging satellites to ground magnetometer stations. In addition to NOAA operational assets, we have partnerships with domestic organizations such as the National Aeronautics and Space Administration (NASA), the National Science Foundation, U.S. Air Force, and the U.S. Geological Survey to utilize data from these agencies or their awardees to complement the NOAA observations. NOAA also leverages data from the Space Environment Monitor instrument flying on the MetOp satellite series by the Europeans to augment its space-based data requirements.

Responses by Dr. Jim Spann

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

“Surveying the Space Weather Landscape”

Dr. Jim Spann, Chief Scientist, Heliophysics Division, Science Mission Directorate, NASA

Question submitted by Rep. Ed Perlmutter, Member, House Committee on Science, Space, and Technology

- 1. During the Subcommittee testimony numerous comments were directed at power grid vulnerabilities to space weather. What information do we have about space weather vulnerabilities of spacecraft/space hardware/space-based communication infrastructure?**

The space environment is an important consideration for NASA missions, as spacecraft are susceptible to the radiation in space. For example, during one space weather storm in 2003, satellite anomalies were reported by deep space missions and by satellites in all orbits. The NASA Goddard Space Flight Center Space Science Mission Operation Team indicated that approximately 59 percent of all NASA Earth and space science missions were impacted. Therefore, space weather is factored into the design, launch, and operation of spacecraft missions. For the Chandra mission, with an instrument particularly sensitive to the radiation environment near Earth, the space environment is a critical factor for day-to-day operations. A variety of automated and manual processes are used to assess space weather conditions and to alert the spacecraft and Mission Operations staff during high radiation events.

- 2. How do industry, civil government agencies, and the Department of Defense monitor and report problems, anomalies and vulnerabilities of their assets to space weather events?**

With NASA, standard anomaly investigation practices are followed. The space weather environment at the time of an anomaly is assessed as part of the anomaly investigation process. Specific monitoring and reporting vary from mission to mission. Near and long-term operational impacts are assessed, and adjustments can be made as needed to the mission planning guidelines and to on-console procedures. In addition to the resources available in the operations teams, outside technical experts can also be called upon to support anomaly investigation efforts. When adverse space weather conditions occur or are predicted, measures can be taken, such as activation of the high-radiation response protocol used by the Chandra mission.

- 3. How could an anonymized database for on-orbit spacecraft and communication anomalies provide important information on the routine impacts of space weather events on space-based infrastructure?**

Ongoing research funded by NASA will improve specification and forecast models of the environmental conditions that cause spacecraft anomalies. An improved understanding of when and where anomalies occur, as could be obtained from a database, would benefit researchers developing numerical models by indicating the conditions of highest concern.

Enhanced understanding, through these models, could improve responses to space weather, such as the shutdown of components, changes in operating modes, and the reconfiguration of fault management logic.

4. How can the government better leverage next generation observing platforms, such as cubesat constellations, and what types of important measurements can be taken, and at what locations, to best inform space weather forecasting units about the status of the space environment?

There are several space platforms that can be leveraged to advance the understanding of the space environment variability that will better inform space weather forecasting entities. These platforms include the evolving small satellite capabilities, including CubeSats, and remote sensing solar observing and near-Earth space observing platforms. Constellations of small satellites, particularly in near-Earth region of space, can provide a network of many simultaneous observations of the space environment as they fly through important regions over a broad area. Remote ultraviolet observations of high latitude auroral zones and equatorial emissions could provide key insight into the dynamics of space weather. These observations of the near-earth region would improve the predictive capability of space weather in the regions of space where space weather has its greatest impact, both for spacecraft and ground systems. However, additional observations of the solar wind between the Sun and Earth, and new views of the solar surface before it rotates and faces the Earth, would also have significant impact on the current comprehension of how the observed solar eruptions occur and under what conditions they are more likely to appear.

Effectively incorporating observations into numerical prediction models is another essential aspect of informing space weather forecasts. The distributed measurements obtained from the next generation observing platforms will need to be incorporated into models to maximize specification and forecast accuracy.

Responses by Dr. Sarah Gibson

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

“Surveying the Space Weather Landscape”

Dr. Sarah Gibson, Senior Scientist, High Altitude Observatory, National Center for Atmospheric Research, and Co-Chair, Committee on Solar and Space Physics, National Academy of Sciences

Question submitted by Rep. Eddie Bernice Johnson, Ranking Member, House Committee on Science, Space, and Technology

1. Please describe what would be a preferred mechanism for furthering communication and collaboration between the government, commercial, and academic communities on space weather activities.

The National Academies of Sciences, Engineering and Medicine (hereafter: the Academies) have a forum known as a Roundtable, which is a core and continuing activity that provides a means for representatives of government, industry, private businesses, academia and other stakeholder groups to gather periodically in a neutral setting to identify and discuss issues of mutual concern on a continuing basis.

Such a Roundtable is explicitly called for in H.R. 3086 for the purpose of bringing together government, industry and university community members. I think the Roundtable is an excellent mechanism for this purpose for several reasons.

First- the Academies are known and respected throughout the government, industry, and university communities and are the organizing body behind Decadal Surveys. This lends authority to the Roundtable and increases confidence across these communities that the discussions will be undertaken in a neutral environment and a professional manner. Second- The primary purpose of a Roundtable is to enhance communication and to build collaborative ties across the government, industry and university communities. Academies Roundtables are not advisory in nature, and so are not restricted for example by Section 15 of the Federal Advisory Committee Act. This allows them to bring together a truly broad and representative gathering of the stakeholders.

Third- although Roundtable meetings are open to the public and announced in advance, a meeting, or some portion of it, may be closed to the public if the Office of General Counsel determines that it will disclose matters described in section 552(b) of Title 5, United States code. This means that they enable a “safe space” where privileged/confidential issues may be discussed between government, industry, and academia, thus enabling comprehensive communication and knowledge transfer between these groups.

2. Please provide examples of space weather events that are less hazardous than a coronal mass ejection coming towards earth but still disruptive.

Space weather, like terrestrial weather, ranges from mild to severe. CMEs that are intrinsically weaker or for example hit the Earth with a glancing blow have less of a space-weather manifestation at the Earth than a strong, Earth-directed CME. Recurring streams of fast solar wind may hit the Earth even during periods of low CME activity, increasing geomagnetic/auroral activity and substantially elevating the flux of relativistic electrons in the Earth's outer radiation belt (see, e.g., Gibson et al., 2009, If the sun is so quiet, why is the earth still ringing?, *Journal of Geophysical Research*, <https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2009JA014342>).

Even relatively minor space weather can cause significant impacts (my thanks to Prof. Mike Hapgood, RAL Space, U.K., and Prof. Delores Knipp, Univ. Colorado, for the following examples).

- 1). There is evidence that minor geomagnetic activity can cause small, but economically significant, disturbances in the flow and delivery of electric power. For example:
 - US insurance claims related to problems with industrial electrical equipment have been shown to increase during periods of space weather activity (Schrijver, C. J., R. Dobbins, W. Murtagh, and S. M. Petrinec (2014), Assessing the impact of space weather on the electric power grid based on insurance claims for industrial electrical equipment, *Space Weather*, 12, 487–498, doi: 10.1002/2014SW001066.)
 - Fluctuations in the reliability and market performance of electricity grids appear to be influenced by space weather, e.g. as demonstrated by a recent economic study of the electricity market in England and Wales (Forbes, K. F., & St. Cyr, O. C. (2017). The challenge posed by geomagnetic activity to electric power reliability: Evidence from England and Wales. *Space Weather*, 15, 1413–1430. <https://doi.org/10.1002/2017SW001668>).
- 2). The resource exploration/extraction sector (e.g. oil and gas) is a big customer for everyday space weather services in Europe, especially when working out at sea. They need geomagnetic information, for example information on when geomagnetic variations will challenge control of the orientation of drill heads, as they use magnetometers to determine drill head attitude with respect to the background geomagnetic field. They also need to know about ionospheric effects that will challenge use of Global Navigation Satellite System (GNSS; includes GPS) for precise positioning, e.g. to know when to disconnect the drill on a floating (deep-water) rig.
 - In a study of Low Earth Orbiting satellite data from 2007 to 2011 Yue et al. (2016) found ongoing issues with GNSS signal cycle slip even during mild space weather conditions. The existence of signal cycle slip can significantly influence the data quality and reduce the utility of GNSS in navigation and surveying, such as the GNSS-based real-time kinematic, precise point positioning and calculation of important quantities that assess the state of the ionosphere. (Yue, X., W. S. Schreiner, N. M. Pedatella, and Y-H. Kuo (2016), Characterizing GPS radio

occultation loss of lock due to ionospheric weather, *Space Weather*, 14, 285–299, doi: 10.1002/2015SW001340.)

- The Swarm satellites between December 2013 and November 2015 encountered a range of GNSS signal loss related to mild-to-severe space-weather conditions (Xiong et al., 2016, The Swarm satellite loss of GPS signal and its relation to ionospheric plasma irregularities, *Space Weather*, 14, 563; <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2016SW001439>)

3). Space weather in the form of atmospheric radiation may lead to single event effects (SEEs) that disrupt electronic devices. Examples of the potentially devastating impact of SEEs include:

- In 2008, a control system malfunction caused abrupt changes in the attitude of an Australian aircraft, leading to serious injuries to 11 passengers and one crew member. The precise cause of the malfunction was never established but the official report (reference below) stressed the importance of ensuring that aircraft systems deal robustly with such malfunctions, including SEEs. (Australian Transport Safety Bureau. 2011. In-flight upset, 154 km west of Learmonth, Western Australia, 7 October 2008, VH-QPA, Airbus A330-303. Report AO-2008-070. ISBN 978-1-74251-231-0).
- A spate of problems with solid-state power controller systems on electric trains occurred in the 1990s – interpreted as due to a single event effect whereby one charged particle could trigger a cascade that prematurely destroyed the device. This was fixed by better engineering to prevent cascade, and is a good example of why awareness is needed. (Normand, E. 1997. Neutron-induced single event burnout in high voltage electronics. *IEEE Trans. Nucl. Sci.* 44:2358-2366. doi: 10.1109/23.659062).
- Another example is an error in a voting machine, in Belgium in 2003, where a bit flip added 4096 votes to one candidate (in a local election so a big addition). (PourEVA, 2003. Le Ministre DEWAEL reconnait la faillibilité du vote électronique grâce à un rayon cosmique complice! http://www.poueva.be/article.php3?id_article=36).

4). Lohmeyer et. al (2015) performed a statistical analysis of data (> half a million hours of satellite telemetry) from a geosynchronous communications satellite to determine why high-power amplifiers failed during what seemed like normal operations. The authors also used concurrent space weather data from NOAA satellites to see what was happening in the high-energy electron environment at geosynchronous orbit just before 26 different amplifier anomalies that occurred over 16 years. The authors identified how increased electron fluence, built up over many days, often after the onset of high speed solar wind flows, heightens the likelihood of anomalies. (Lohmeyer, W., A. Carlton, F. Wong, M. Bodeau, A. Kennedy, and K. Cahoy (2015), Response of geostationary communications satellite solid-state power amplifiers to high-energy electron fluence, *Space Weather*, 13, 298–315. doi: 10.1002/2014SW001147.)

5). Recently (November 2015), solar radio interference led to a one to two hour shutdown of air traffic control in Southern Sweden. It is possible that the configuration of the radar systems in Sweden made it vulnerable to solar interference – resulting in the shut-down of Swedish airspace with knock-on effects to other countries with flights crossing Sweden.

3. **The National Space Weather Strategy and Space Weather Action Plan lay out the observations and data necessary to establish a “minimally adequate” observational capability for space weather research and forecasting. However if the nation and the international community are to go beyond a minimally adequate capability, what observational systems would you see as being critical additions or enhancements to the baseline set?**

Clearly it is essential that we do not lose the capability we currently have for forecasting space weather. The examples of the white light coronagraph for observing CMEs as they erupt towards the Earth, and the upstream solar wind measurements providing near-real-time warning represent single-point-failure risks that would devastate this current capability. Thus, establishing a clear baseline level for operational needs is a good and valid goal of the Space Weather Strategy.

However, our current capabilities are simply not good enough, and it is essential that this baseline is not interpreted such that, once achieved, space-weather operational needs are considered fulfilled. A few additional measurements/augmentations are mentioned in the Space Weather Action Plan beyond the coronagraph and up-stream measurements (5.3.3 - 5.3.8 in the Action Plan), however, again these seek to obtain a minimal set based on current operational strategies.

A clearly beneficial addition to this baseline set would be observations off the Sun-Earth line. Measurements of the Sun’s magnetic fields represent a boundary condition on all space-weather operational models. Currently, we only see part of this boundary since we only have one viewing angle on it. Coronagraphic and heliospheric imaging of CMEs as they erupt are also limited by the fact that Earth-directed eruptions are seen “head-on”, so that we miss details of their structure and evolution that would improve forecasts. Observations of solar surface magnetic fields, and from white-light coronagraph and heliospheric imagers from the quadrature, or “L5” point, would provide critical new space-weather operational inputs.

Even more beneficial would be the same measurements obtained from a solar-polar vantage. In this case, a CME could be observed moving from Sun to Earth from above, and interactions between the CME and the solar wind it ploughs through could be uniquely monitored. Moreover, from this vantage space weather could be monitored not just for the Earth, but for all the planets and spacecraft in the heliosphere. This is a key capability for protecting our space exploration assets, including, most importantly, future human travellers to Mars. Note that a single mission (which could be a constellation of satellites with Sun-Earth line ground- and space-based support) could provide both polar and quadrature coverage. (See, e.g., Gibson et al., Solar physics from unconventional viewpoints, Submitted to *Frontiers in Astronomy and Space Sciences*, May, 2018, <https://arxiv.org/abs/1805.09452>)

In addition, the National Space Weather Strategy and Action Plan emphasize the importance of transitioning Research to Operations. For this to move forward effectively, observations designed to answer outstanding research questions must be obtained. For example, fundamental research using recent or near-term assets such as NASA's Van Allen Probes that observe the Earth's radiation belts, or the NSF's Daniel K. Inouye Solar Telescope that will observe the solar magnetic fields with ultra-high resolution, can inform future requirements for operational space-weather observations.

Beyond this, the Decadal Survey provides guidance on the prioritization for future observations -- driven by fundamental research questions but with potential for transformative enhancement to space-weather operational capability. For example, the Geospace Dynamic Connections mission--which is the next NASA mission prioritized after the Interstellar Mapping and Acceleration Probe and which may be undertaken via a constellation of small satellites--would enhance our fundamental understanding of the Earth's space environment. On the ground-based side, the Coronal Solar Magnetic Observatory (COSMO) and Frequency Agile Solar Radio telescope (FASR) represents means of establishing once and for all the magnetic properties of the CME as it leaves the Sun.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

“Surveying the Space Weather Landscape”

Dr. Sarah Gibson, Senior Scientist, High Altitude Observatory, National Center for Atmospheric Research, and Co-Chair, Committee on Solar and Space Physics, National Academy of Sciences

Question submitted by Rep. Ed Perlmutter, Member, House Committee on Science, Space, and Technology

1. During the Subcommittee testimony numerous comments were directed at power grid vulnerabilities to space weather. What information do we have about space weather vulnerabilities of spacecraft/space hardware/space-based communication infrastructure?

We generally have less information about spacecraft vulnerabilities than we have about power grid concerns. Green et al. (2017) note that “...space weather effects on satellites have been well demonstrated by compilations and analysis of previous anomalies” but that, “up-to-date and routine assessments of the most recent anomalies, their relationship to space weather, and impact to the industry are not readily available.”

The situation in space is difficult to assess for several reasons.

First, spacecraft operate in a multitude of environments, including low earth orbit (inside of the Earth’s tenuous upper atmosphere); geosynchronous orbit (above the atmosphere, but inside of Earth protective magnetic field); and interplanetary space (within the Sun’s atmosphere, but beyond Earth’s protection)¹. These different environments present very different operating conditions that can change drastically in only a few seconds during the onset of a solar or geomagnetic storm. While this diversity is well understood by experts, it can sometimes be a challenge to communicate, potentially resulting in oversimplification or even misunderstanding of satellite risks and vulnerabilities by space-weather customers and the general public.

Second, issues with satellite infrastructure relating to defense/security operations are generally not reported in the open literature. Similarly, commercial satellite operators may not wish to publicize every satellite issue for various economic reasons.

Third, there is significant challenge in separating spacecraft hardware vulnerabilities from vulnerabilities associated with communication environment; that is, the radio signals that support satellite telemetry and communication are also subject to space weather effects.

Fourth, solar activity varies over the solar cycle, and solar cycles can be more or less active. The past decade has seen particularly low activity. It is therefore difficult to determine whether decrease in satellite failures arises from improved infrastructure and engineering, or if it is due to the milder space environment of recent years.

¹ A fourth environment is interstellar space, which e.g. the Voyager 1 spacecraft has reached

Finally, rapid development of small- and cubesat constellations is pushing satellite infrastructure into uncharted territory, and in general technology is continuously evolving and increasing in complexity. This makes it unclear how observations gathered to date inform future vulnerabilities.

2. How do industry, civil government agencies, and the Department of Defense monitor and report problems, anomalies and vulnerabilities of their assets to space weather events?

Some information is publicly available, in particular from civil space agencies. For example, as mentioned in my response to Rep. Johnson's Question 2 above, Xiong et al. (2016) analyzed GPS signal losses reported by the European Space Agency's Swarm mission.

Commercial satellite operators do occasionally make data available to individual researchers; for example, Inmarsat made 16 years of proprietary telemetry data available for study (see Lohmeyer and Cahoy (2013), Space weather radiation effects on geostationary satellite solid-state power amplifiers, *Space Weather*, 11, 476–488, doi: 10.1002/swe.20071).

Similarly, some DOD data have been made available: 16 years of GPS particle detector data was made available in 2017 under the terms of the Executive Order for Coordinating Efforts to Prepare the Nation for Space Weather Events (See Morley, S. K., J. P. Sullivan, M. R. Carver, R. M. Kippen, R. H. W. Friedel, G. D. Reeves, and M. G. Henderson (2017), Energetic Particle Data From the Global Positioning System Constellation, *Space Weather*, 15, 283–289, doi: [10.1002/2017SW001604](https://doi.org/10.1002/2017SW001604). Also see Knipp, D. J., and B. L. Giles (2016), Global Positioning System energetic particle data: The next space weather data revolution, *Space Weather*, 14, 526–527, doi: [10.1002/2016SW001483](https://doi.org/10.1002/2016SW001483).)

Anomaly reports and spacecraft position reports relating to satellite drag and collision avoidance are generally not available.

Thus, as Green et al. (2017) state, “Despite the value of shared anomaly informationno public centralized reporting system and database exists. Some anomaly information is tracked in private databases kept by manufacturers or insurance companies such as that of the Atrium Science Consortium database.” Other public databases exist that are, however, decades old. Information has been shared via in-person meetings, but is limited by who agrees to participate.

3. How could an anonymized database for on-orbit spacecraft and communication anomalies provide important information on the routine impacts of space weather events on space-based infrastructure?

The fact is that space-weather observations are grossly under-sampled by the standards of terrestrial weather. This is only compounded by the lack of free access to what observations do exist. An anonymous database could facilitate comprehensive representation of civil, commercial and DOD assets.

Again, quoting Green et al. (2017): “A mechanism is needed to ensure that anomaly occurrences are shared between operators who monitor problems and manufacturers who can feed that information back into better design. While exchanges may take place after significant failures, the information sharing should be extended to include smaller nuisance problems so that all problems are recognized allowing better statistical correlations with space weather.”

- 4. How can the government better leverage next generation observing platforms, such as cubesat constellations, and what types of important measurements can be taken, and at what locations, to best inform space weather forecasting units about the status of the space environment?**

Please see my response to Rep. Johnson’s Question #3.

[My thanks again to Profs. Knipp and Hapgood for assistance with this response. Also please see Green et al., (2017), Impact of space weather on the satellite industry, *Space Weather*, 15, 804–818, doi: 10.1002/2017SW001646.]

Responses by Dr. W. Kent Tobiska

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

“Surveying the Space Weather Landscape”

Dr. W. Kent Tobiska, President and Chief Scientist, Space Environment Technologies

Question submitted by Representative Ed Perlmutter, House Committee on Science, Space, and Technology

1. During the Subcommittee testimony numerous comments were directed at power grid vulnerabilities to space weather. What information do we have about space weather vulnerabilities of spacecraft/space hardware/space-based communication infrastructure?

Typically, communication with spacecraft can occur using a wide range of radio frequency bands. The frequency band depends upon which system is installed by the spacecraft manufacturer. Some frequency bands are susceptible to space weather and others are not. For example, systems using high frequency communications (HF: 3–30 MHz frequency or 10–100 m wavelength) may include cubesats and some suborbital commercial space vehicles (balloons, aircraft-type vehicles); these assets could experience major outages during strong solar flares when the vehicle is in the dayside of Earth (durations of minutes to a few hours) or during major geomagnetic storms at any time day/night (durations up tens of minutes up to a few days) when HF signals are scattered or blocked in the ionosphere.

Systems using ultra high frequency communications (UHF: 300–3000 MHz frequency or 100–1000 mm wavelength) and L-band (0.39–1.55 GHz frequency or 193–769 mm wavelength) may include commanding channels for GEO commercial and DoD communications satellites, GOES weather satellites, LEO (Iridium), deep space vehicles, and all GPS L1 (single frequency) downlink channels; these assets could experience outages or dropped packets during disturbed geomagnetic activity due to scintillation when signals are delayed in the ionosphere.

Higher frequency frequency communications (shorter wavelength) bands (S, K, Ka, Ku, X: >1.55 GHz frequency or <193 mm wavelength) in the microwave bands are typically not susceptible to space weather. Optical communication bands such as infrared (IR: 0.76–1.0 mm wavelength) are not affected by space weather but can be affected by absorption from molecular species in the atmosphere (water, H₂O; carbon dioxide, CO₂; ozone, O₃); these are typically not used for surface-to-space communications.

2. How do industry, civil government agencies, and the Department of Defense monitor and report problems, anomalies and vulnerabilities of their assets to space weather events?

DoD agencies have relied upon The Aerospace Corporation to monitor and track their own spacecraft anomalies; these are usually not disclosed except within the particular agency. However, Aerospace Corporation has published a generalized assessment of spacecraft anomalies from historical missions. Their 1985 studies list the environment as a failure cause in spacecraft electronic subsystems 21% of the time with other significant categories being design, parts, operations, and unknown. Of the environment, surface and internal charging are the dominant anomaly mechanisms.

There is not a readily available listing of satellite anomalies from the commercial sector since competitors could link specific problems to economic impacts. There has been considerable discussion in the NASA Community Coordinated Modeling Center (CCMC) workshops to attempt the construction of such a list using an anonymous satellite database hosted by a trusted third party.

In lieu of anomaly databases, satellite manufacturers and operators typically use well-vetted engineering models to empirically characterize the lessons learned and avoid hazardous processes where possible. In addition, NOAA, NASA, and commercial service providers make available to various industries watches, alert, and warnings of hazardous space weather, ranging from general conditions to specific applications.

3. How could an anonymized database for on-orbit spacecraft and communication anomalies provide important information on the routine impacts of space weather events on space-based infrastructure?

This type of database would be extremely valuable for both satellite manufacturers as well as satellite operators. Manufacturers would have a useful reference database against which to design quality systems using materials and electrical processes that are able to manage the space weather hazard risk. Operational users could manage on-orbit and/or launch systems to avoid outage, quality, or even catastrophic loss hazards from space weather events. Even the research and research-to-operations developers would find such a database highly useful to help guide and optimize the evolution of their products and services.

4. How can the government better leverage next generation observing platforms, such as cubesat constellations, and what types of important measurements can be taken, and at what locations, to best inform space weather forecasting units about the status of the space environment?

Having a monitoring capability in deep space, between the Sun and Earth off of the Sun-Earth line, either in the ecliptic or out of it, is the highest priority for deploying observing platforms as defined by most participants in the national space weather enterprise. This monitoring is needed to capture the evolution of coronal mass ejection (CME) material, including its directionality and its speed. In addition, monitoring from LEO orbits, within neutral atmosphere and ionosphere, as well as from the MEO orbits, within the radiation belts and inner magnetosphere, are on a priority list for obtaining more detailed spatial and temporal observations to characterize and eventually forecast space weather processes and effects. These locations of observations are particularly needed to feed the physics-based, data assimilative models now being developed. This monitoring would lead to significantly improved risk reduction for systems affected by ionospheric scintillation, neutral atmosphere density-related drag, the effects of geomagnetic storms related to the timing and magnitude of power grid susceptibility and the radiation environment at aircraft altitudes. It should be noted that cubesats, while much less expensive to build and operate, often provide a much greater spatial and temporal monitoring capacity. Within the atmosphere, long-term stratospheric balloons, high-altitude, long-duration UAVs, and even instrumented commercial aircraft can be used as inexpensive monitoring platforms for specific domains related space weather. Ground-based systems continue to be important, including neutron monitors that can provide a wealth of information related to galactic cosmic rays and even the state of variability in the magnetosphere for a long-term cost that is negligible compared to the cost of a comparable satellite system.