

Lessons From Aviation: Linking Space Weather Science to Decision Making

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Linking scientific knowledge to decision making is a challenge for both the science and policy communities. Policy makers work in a fast-paced environment where they apply readily available solutions to today's problems. Scientists, on the other hand, focus on increasing scientific knowledge, which gradually builds the foundation for solutions. However, scientific information is seldom communicated effectively to decision makers. This gap is prevalent in most science disciplines to varying degrees, and the field of space weather is no exception.

Both natural changes and technological advances are increasing society's vulnerability to space weather. Because technology has evolved and our reliance on electrical and satellite-based systems has increased significantly, as solar maximum approaches, humankind will face challenges that did not exist during the last solar cycle. For example, industries and individuals are more dependent on the Global Positioning System (GPS), wireless technology, and satellites than ever before, and any disruption or inaccuracy can result in severe economic impacts. Thus, it is highly important to link science with policy decision making.

But how do you stress that a given topic should be important to decision makers? To help answer this, a group of social science researchers developed a framework through which scientists can effectively link information to decision making. Their research shows that information requires three attributes—salience, credibility, and legitimacy—to cross boundaries [see *Cash et al.*, 2002]. Salient information is relevant to the needs of decision makers. Credible information presents well-reasoned scientific and technical evidence and arguments. Legitimate information reflects the "fairness" of an information-producing process and whether that process considers the values and beliefs of different stakeholders.

Without overtly intending to follow this framework, one area of space weather research has already successfully interfaced with decision making: the use of forecasts for aviation operations. As cross-polar traffic increases, the aviation industry is becoming more aware of how adverse space weather can hinder operations during high-latitude ($>50^{\circ}\text{N}$) and polar operations ($>78^{\circ}\text{N}$): Adverse space weather can disrupt high-frequency communications, introduce satellite navigation system errors, increase radiation hazards to humans, and damage avionics. Because scientists successfully made space weather research and products salient, credible, and legitimate, more airlines are using them. A closer look at the steps the space weather community followed to make research important to the aviation industry will help scientists apply this framework to other research avenues important to space weather.

Meeting Space Weather's Unique Challenges

Although all science fields struggle with linking research to decision making, the field of space weather faces unique challenges. For example, many decision makers might not know that space has weather and that this weather poses hazards to our economy, in part because only recently has technology blossomed to the point where adverse space weather actually poses problems for society. Compounding this, in an era of limited funds for scientific research, hazards posed by other natural disasters such as flooding and earthquakes are by contrast well known to policy makers, further making the importance of space weather research and monitoring a tough sell.

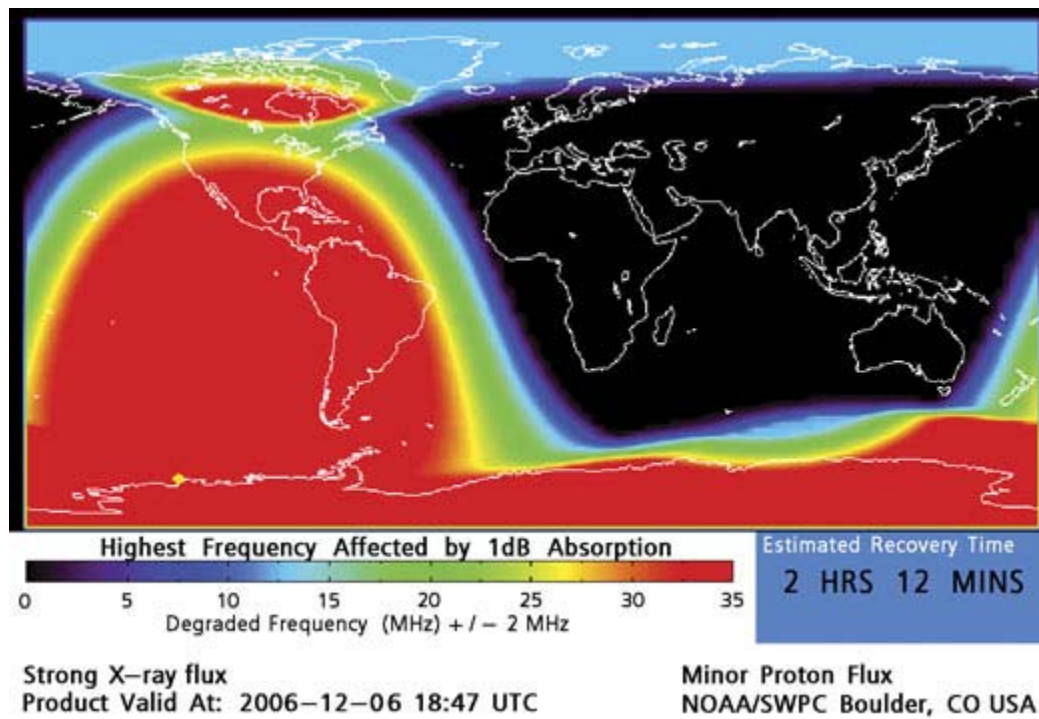
Facing these challenges requires that the space weather community work doubly hard to tie research to decision making. Although some decision makers are considering space weather information to help reduce risk and maximize operations [*National Research Council*, 2008], more work is needed to stress how adverse space weather can wreak havoc on daily lives and the economy.

Past successes, such as the interaction between the space weather and aviation communities, serve as useful guides for future progress. Yet exactly how did scientists effectively overcome barriers between research and policy making in their interaction with the aviation industry? The answer is found through careful examination of the framework's components.

Is the Information Salient?

Salient information answers meaningful questions and can be put to use by various stakeholders. To achieve saliency, research must be relevant outside the scientific community and have a bearing on real-world situations in order to shape decisions. For example, just providing the flux level of a solar radiation storm will not likely be salient to a satellite or airline operator, both of whom are likely more concerned with how space weather phenomena will affect operations.

To produce salient information, NOAA's Space Weather Prediction Center (SWPC) and commercial service providers work closely with users of space weather information to make sure that forecasts are useful to decision making processes. In particular, conditions of the space environment, including solar radiation storms and radio blackouts, are highly salient to an airline dispatcher who uses forecasts to determine whether to reroute an aircraft (see Figure 1). Some operators alter operations based on the NOAA space weather scales—if an alert is issued for a solar radiation storm of level 4 (S4) or higher, operations managers may request that a flight avoid the polar regions because the likely loss of high-frequency communication will prevent aircraft from sending updates to and receiving reports from air traffic control systems, jeopardizing passengers and crew. In fact, U.S. Federal Aviation Administration (FAA) rulings require that the need to maintain two-way communications be considered before flight paths are set.



NOAA Space Weather Prediction Center

Figure 1. In December 2006, Earth was hit by a series of intense solar eruptions. This map, similar to those currently produced and distributed by NOAA's Space Weather Prediction Center, shows that signals in frequency ranges up to 35 megahertz (MHz) were weakened by at least 1 decibel (dB) over polar regions and much of the Western Hemisphere. Ultraviolet and X-ray emissions bombarded Earth, affecting lower and middle latitudes on the daylit side, while energetic protons penetrated high latitudes, affecting polar operations. Because high-frequency signals are critical for communications in remote areas, which include over-ocean flights and large portions of polar routes, products like these help to make space weather salient to aviation operators.

Meetings that bring together scientists and airline representatives, such as the annual NOAA Space Weather Workshop and the recent American Meteorological Society (AMS)/SolarMetrics workshop [AMS, 2007; Fisher and Jones, 2007], are held specifically to improve saliency by incorporating users' perspectives in generating space weather forecasts and products. At the AMS/SolarMetrics workshop, the participants decided that the Cross Polar Working Group (CPWG)—an ad hoc group of international aviation representatives involved in polar operations—should develop a set of user needs to be submitted to the FAA and the International Civil Aviation Organization (ICAO). As a result of this process, space weather researchers will gain an improved understanding of the values and priorities of the airline industry, which will help them to provide salient information in the future.

Is the Information Credible?

Credibility is established through the scientific and peer-review processes. For information to be credible, research must appear trustworthy to decision makers, and decision makers must understand data and forecasting

limitations.

For example, to ensure credibility, airline dispatchers and meteorologists attend space weather meetings to hear firsthand from scientists about the quality of the data and forecasts. The data, methods, and analysis are presented and explained at such meetings, allowing researchers and decision makers to become familiar with each other's operational language.

Once trust has been established in the data and the forecasts, dispatchers review the SWPC's forecasts when planning their operations and modify flight plans accordingly. To reinforce this trust, NOAA makes an effort to communicate the forecasts effectively by using terminology and channels familiar to the industry. Additionally, space weather training and education materials provide the aviation industry a foundation for making decisions.

Is the Information Legitimate?

Legitimacy—the idea that information is unbiased and balanced—is judged based on who participated in the research and how information is produced, vetted, and disseminated. Developing legitimate information requires listening to decision makers' perspectives and incorporating feedback into end products. Regardless of how salient or credible information is, if the process of producing and dispersing information is not seen as legitimate, there is a high probability the information will not be used.

Many processes are in place to ensure that information is balanced. For example, the National Space Weather Program (<http://www.nswp.gov>), an interagency initiative to provide timely and accurate space weather observations and warnings, promotes legitimacy through fostering cooperation to help different agencies meet common needs. This involves ensuring that the interests of each agency are addressed.

Specifically for the aviation industry, the meetings that bring together scientists and airline representatives are held with the intent of incorporating users' perspectives and priorities in the development of products. In addition, science community participation in aviation meetings organized by the CPWG, International Air Transport Association (IATA), and ICAO assists in the defining of user needs and requirements, creating information that is legitimate.

Making Space Weather Relevant

Space weather information has tremendous potential for being linked to policy decision making, and anyone interested in connecting research with policy should consider using this framework as a guide. Efforts to connect researchers with the aviation industry are working, and similar strong partnerships could be formed with decision makers in the electric power and GPS industries.

The key to connecting research to decision making is to ensure that the information strikes all three targets—salience, credibility, and legitimacy—while being communicated effectively. To achieve this, scientists need to understand the decision makers' perspectives, including their language and culture, and respect that their needs may evolve with time. This, coupled with future technological advances, creates a necessity for continuous communication between scientists and decision makers.

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