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Advancing Space Weather Services Through International Coordination

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Growth in Service Demand

The space weather service enterprise is growing around the globe. This growth is being driven by the increasing need to mitigate the impacts of space weather, which affect our economic and security infrastructures both in space and on the ground. Many countries are initiating new programs to deliver space weather services, while others are expanding their efforts. Within the United States, the number of both domestic and foreign customers of NOAA's space weather products has been rising steadily (Figure 1). The subscription service for NOAA's space weather alerts and warnings was initiated in 2005, and today roughly 25% of its subscribers are outside the United States.

With this growth come both opportunities for improvement and the need for coordination. Providing the space weather services demanded today and in the future requires a worldwide network of strong partners. International partnerships are a critical component of all aspects of space weather, including the integrated system of space-based and ground-based observations, accurate numerical prediction models, and the delivery of comprehensive services. As more and more nations become involved, the participants in this network must act collectively to foster collaboration and interconnect the diverse components needed for an effective, global space weather service enterprise.

Space weather has a long history of international cooperation. The first daily broadcasts of solar and geophysical events were made from Paris, from the Eiffel Tower, in 1928 [*Simon*, 1981]. By 1981, a coordinated global service consisting of hundreds of observation sites and 9 regional warning centers had been established. These warning centers operated as the International URSIgram and World Days Service, which in 1996 became the International Space Environment Service (ISES; see www.ises-spaceweather.org). With the addition of a center in South Korea this past November, ISES now has a total of 14 regional warning centers (Figure 2).

While progress has been made, the level of services available today still lags the expanding demand. For example, uncertainty about the onset and magnitude of geomagnetic storms still limits the ability of customers to take action. Existing numerical prediction models are not well constrained by available measurements, and there are significant gaps in the geographic coverage of real-time data. Fortunately, efforts to expand and improve space weather services are occurring

Figure 1. *Growth in the number of international (non-U.S.) and U.S. customers subscribing to NOAA's space weather alerts and warnings. Both customer groups have steadily increased, with roughly 25% of total customers today registered as non-U.S.*

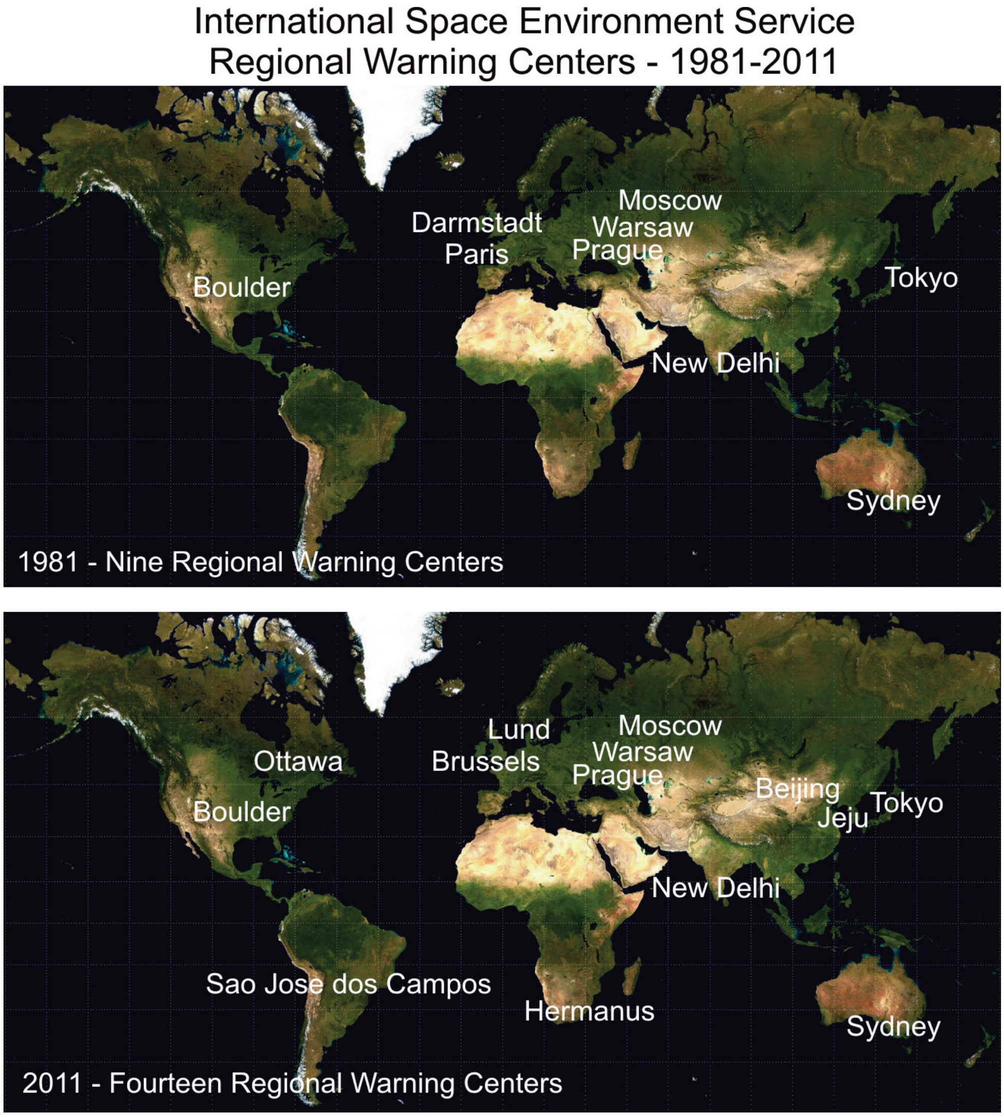

Figure 2. Change in international space environment service regional warning centers, 1981–2011. Today the International Space Environment Service also includes a collaborative expert center at the European Space Agency, Noordwijk, Netherlands, and an associate warning center in Toulouse, France.

at national, regional, and global levels. This increased participation will spur the long-term improvement of our observing and modeling capabilities and raise the quality of services and access to them.

An Integrated Observation Network

The comprehensive observing network needed for space weather services can be realized only with the participation of countries around the world. Many key observations are currently obtained from research satellites that may not be replaced after reaching end of life. Various other ground-based and space-based observations being made today either are not available in real time or have not yet been integrated into a dissemination network. Few space weather observations have thus far been incorporated into data-assimilation models.

For the purposes of international coordination, the physical parameters to be measured belong to one of two broad categories: external drivers of Earth's space weather (e.g., the Sun, coronal mass ejections, and the solar wind) or geographically localized conditions that affect specific infrastructure components, such as the electric power grid and GPS navigation systems (e.g., ground magnetic field, ionospheric scintillation, and total electron content). An important distinction between these two categories is that measurements of the parameters driving planetary-scale conditions can be obtained by a limited number of countries and shared, while measurements of local conditions usually must be made by individual nations.

Both categories of observation are required to provide the full suite of space weather services. Measurements of the large-scale drivers of space weather enable long-lead-time forecasts of solar eruptions and the detection of disturbances in the solar wind upstream of Earth. These data identify conditions that can have planetary-scale impacts. Measurements of local conditions are needed to issue warnings of hazardous conditions at or near specific locations as well as for data-assimilation models.

The core observations for determining the large-scale drivers of space weather are obtained primarily from space-based instruments. Many countries today are sharing data from their space-based assets, and many are exploring new instruments. There is uncertainty, however, as to which instruments may be flown by other countries, how long existing research satellites will be able to support operational services, and which new instruments and which satellite orbits will best complement the current and planned configuration of instruments.

A cost-effective, shared approach to obtaining the minimum set of space-based measurements should be defined and updated regularly. This could be done under the auspices of international organizations that benefit from the participation of national space weather service-providers and national space agencies. Planning future missions is complicated by economic uncertainties, and each nation must balance contributing to a shared, interdependent, international system against developing its own autonomous space weather capabilities. Nonetheless, prioritizing the core set of requisite observations and discussing opportunities for collaboration will increase the probability that critical measurements will be continuously available at an affordable cost.

Maintaining a comprehensive, global network of local or regional data will require measurements from countries around the world. How can contributions of such local space weather measurements be sustained? The situation will be different in every country, but the provision of services to its own national customers will likely be necessary for a government to support its domestic instruments and infrastructure for continuous, real-time data. Therefore, the most effective condition under which a country will be able to contribute space weather data will be for it to be responsible for the products and services needed nationally. Consequently, a priority for countries that already have strong space weather programs should be to foster the establishment of service-providing programs in nations with evident interest. By sharing data, numerical prediction models, and services, countries with existing programs will lay the foundation for other countries to initiate their own programs and thereby add new resources to the global network.

Research, Modeling, and Service Delivery

Space weather service providers will need state-of-the-art numerical models. At present, few physics-based numerical models are used for space weather services. With scientific progress and greater access to real-time data, numerical prediction models and data-assimilation techniques will improve. As models mature and accuracy increases, participating countries will need to identify ways to share these assets. As with high-resolution, global meteorology models, only a handful of countries will have the capacity to run the most sophisticated space weather models, yet many countries will be able to benefit from them. In addition, access to models that can be run on standard computer systems will also be important. Without the independent ability to use numerical models, services may be difficult to sustain politically, particularly when compared to those of countries with more advanced capabilities. In order to maintain space weather programs around the globe, approaches must be found that will allow countries to generate products for their national customers using numerical models run on their own computers as well as output from the more computer-intensive models executed elsewhere.

Partnerships between research institutions and service organizations will also be essential to improving space weather services. Encouraged by programs such as the U.N.-sponsored International Space Weather Initiative, universities and national laboratories around the world are initiating new programs in space science and space weather. New instrument arrays are being deployed, and programs are being created to expand space science research and education. These efforts will yield well-trained young scientists and valuable local measurements over large regions. Because the infrastructure and the institutional resources may not exist in many locations to support real-time dissemination of quality-controlled data, it is important to coordinate science and education activities with the efforts of space weather service providers. If strong partnerships can be formed between research and service organizations, then local talent and data will inevitably lead to better space weather services.

An important element of space weather services is the coordination of information on the global and regional scales. Solar eruptions can drive space weather activity over the entire Earth, yet specific disturbances can be fundamentally different from location to location. For example, X-rays and energetic particles from solar eruptions affect large regions of the ionosphere with important consequences for commercial and military aircraft. Steep gradients and small-scale irregularities in the ionosphere also affect airlines and air traffic management in limited areas. All service providers will seek to obtain accurate and consistent information about large-scale conditions, which may be issued by one or a small number of organizations, and they will have to integrate this into their local information to support their direct customers.

How can individual countries best contribute to the global effort while benefiting from existing services and information from sources around the world? One example of a nation actively addressing this question is South Korea, which is rapidly developing the research, observations, and services needed to meet the urgent demand for space weather information [*Ahn*, 2011]. A combination of partnerships among domestic agencies and research institutions as well as partnerships with foreign organizations is being used to strengthen the capabilities necessary to protect South Korea's national assets and to strengthen its involvement in monitoring space weather. The European Space Agency's Space Situational Awareness Preparatory Programme is exploring the idea of coordinating data and services produced by individual countries through an international center [*Kumar*, 2010]. In this way, services will provide broad support for the program's overall objectives while its activities remain distributed throughout Europe.

Mechanisms for Coordination

Mechanisms to improve our coordination of space weather services currently include regional, national, and international entities such as the ISES (www.ises-spaceweather.org), the World Meteorological Organization (www.wmo.int/sat), the International Civil Aviation Organization (www2.icao.int), the United Nations Office for Outer Space Affairs (www.oosa.unvienna.org), the recently formed Asia-Oceania Space Weather Alliance (aoswa.nict.go.jp), and the United States National Space Weather Program (www.nswp.gov). These organizations prioritize and coordinate transnational efforts, guaranteeing a strong, global space weather enterprise. As more countries become engaged in space weather services, access to data will improve and new research will be undertaken, which will ultimately result in better products and more reliable forecasting.

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