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Space Weather Gets Real—on Smartphones

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True to the saying that "a picture is worth a thousand words," society's affinity for visual images has driven innovative efforts to see space weather as it happens. The newest frontiers of these efforts involve applications, or apps, on cellular phones, allowing space weather researchers, operators, and teachers, as well as other interested parties, to have the ability to monitor conditions in real time with just the touch of a button.

Developing Smartphone Apps

At the start of the 21st century, and only 5 years after articulation of a national strategy for space weather [*National Space Weather Program Council,* 1995], state-of-the-art real-time space weather visualization principally occurred at NOAA's Space Environment Center (SEC; recently renamed the Space Weather Prediction Center, or SWPC). Monitors mounted above NOAA forecasters displayed images of the Sun from the Solar and Heliospheric Observatory (SOHO), jointly sponsored by the European Space Agency (ESA) and NASA, while computer screens showed plots of the X-ray flare data between 0.1 and 0.8 nanometers as the information streamed from satellites at geosynchronous orbit.

Within a few years, space physics research models achieved more maturity and became available for operational space weather users. Discussions at the annual Space Weather Workshops in Boulder, Colo., however, often noted that there were not enough dollars or test beds that would enable models to cross the technology gap from research into operations [*Quinn et al.,* 2009]. At the same time, there were a growing number of applications on the Internet displaying real-time or near–real time space weather. These included the applications on the solar wind/magnetosphere connection, such as the Space Weather Modeling Framework (SWMF [*Tóth et al.,* 2005]), which is hosted by the Community Coordinated Modeling Center (CCMC). In addition, modeled real-time total electron content (TEC) data from the California Institute of Technology's Jet Propulsion Laboratory (JPL) and the real-time solar irradiances generated by SOLAR2000 at Space Environment Technologies (SET) reached operational maturity. Nonetheless, these capabilities did not fully satisfy engineering needs or broader public curiosity for easy, immediate access to real-time space weather information.

With the introduction of coupled systems of data and models in 2008, such as the Communication Alert and Prediction System (CAPS) developed by SET and the Space Environment Corporation, the integrated Space Weather Analysis System (iSWA) developed by CCMC, and the real-time coupling of assimilative mapping of ionospheric electrodynamics (AMIE) and the thermosphere-ionosphere-mesosphere electrodynamics general circulation model (TIME-GCM) at Atmospheric and Space Technology Research Associates (ASTRA), the visualization of space weather took a new turn. The integration of real-time space weather into Web browsers and into Google Earth™ by these systems leveraged the remarkable power of data streaming. In addition, applications on cell phones emerged as a method for satisfying the growing public and commercial interest in how the Sun affects daily life.

By early 2009, the next step in visual innovation occurred. Using smartphone apps, the chain of events from the Sun to a cell phone was demonstrated by the Utah State University Space Weather Center (SWC, funded by the Utah Science Technology and Research initiative, or USTAR). SWC released SpaceWx (weather category, $1.99) for the iPhone. This was followed by releases of other iPhone apps, including Solar Monitor (weather, $1.99, developed by commercial electronics provider Thomas Ebbert), SWx Monitor (weather, free, developed by the South Korean Space Environment Laboratory (SELab)), and 3D Sun (education, free, developed by astronomer Tony Phillips and the members of NASA's Heliophysics Division). For the Android phone, ASTRA developed the SpaceWeather app (free, Google Apps Marketplace™). The Space Weather Laboratory at NASA's Goddard Space Flight Center will soon release an iPhone app, which will include most of the space weather information available at their Web site (http://www.iswa.gsfc.nasa.gov).

Real-time space weather, which was a distant dream in 1995, has come of age in 2010. Visualization progress over the past 15 years is remarkable. For example, circa 1995, lags of months combined with two-dimensional (2-D) plots were the norm when analyzing Upper Atmosphere Research Satellite (UARS) solar irradiances to be ingested into atmosphere models. In 2010, with a couple of finger taps on an iPhone located anywhere in the world, it is possible to retrieve actual solar spectral measurements from the Solar Dynamics Observatory (SDO) Extreme Ultraviolet Variability Experiment (EVE) instrument with a time lag of 60 seconds from spacecraft to smartphone. Furthermore, it is possible to see the energy effects of those solar flare photons upon the real-time global TEC a few minutes later on the same smartphone.

High Utility From Smartphone Apps

The tip of the iceberg of automated systems that can provide immediate data is the mobile smartphone; it permits and even encourages instant understanding of the environment surrounding Earth as it changes dynamically. Some of these smartphone apps depend upon distributed networks [*Tobiska,* 2009] that connect satellite and ground-based data streams with algorithms to quickly process the measurements into geophysical data; incorporate those data into operational space physics models; and generate images, plots, and alerts that can be viewed on smartphones.

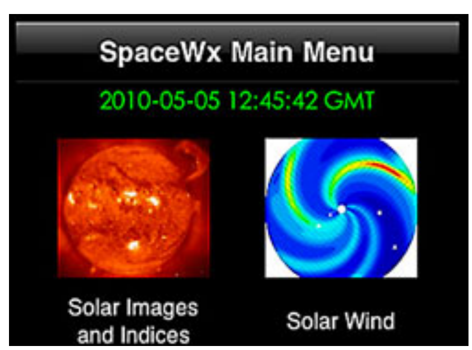
An interesting development from these apps is that institutional teams, which have never before collaborated, now participate in prototyping and operational development processes. In a very real sense, the space weather community is already going through the transition from research models to operations using a methodology that was never anticipated: "proofing" products in real time via smartphones. The resulting smartphone graphics, many of which update continuously, are the undeniable demonstration of this prototyping advancement.

Even though the existing space weather information content on the apps is fairly mature, its application to engineering systems for solving challenges still needs considerable development. The task is one of moving space weather information from raw data sources through automated systems and into final derivative products. A milestone will be reached, for example, when commercial aviation uses space weather data to change flight altitudes. This will result in reducing aircrew radiation dose rates during solar energetic particle events or in air traffic control providing automated backup frequencies during high-frequency radio communications loss at the time of major solar flares. It is even possible that the U.S. Federal Aviation Administration's Next Generation (NextGen) air transportation system may automate system-wide changes of required navigation performance, i.e., the spacing distance between aircraft, due to large Global Positioning System (GPS) uncertainties in geomagnetic storms.

The growing diversity of smartphone apps testifies to the space weather community's applications-oriented innovation; it makes possible broad public education about space weather at the same time as it enables individual science and engineering users to glimpse the effects of a particular space weather event. Smartphone apps that are currently available range from the applications oriented (SpaceWx and SpaceWeather) to the education oriented (SWx Monitor and 3D Sun). These apps continue to evolve, as evidenced by new content and features that are provided in each new release.

SpaceWx

The SpaceWx iPhone app (Figure 1), developed by SWC, is used by scientists and engineers who want specific real-time data updates, amateur radio operators who want to know how space weather is interfering with their communications, and the space-interested public.



For example, say that a flare occurs and a user wants to know its effects at Earth right now. The app uniquely extracts data from real-time, operational systems linking the four major space environment domains (Sun, solar wind, magnetosphere, thermosphere/ionosphere). With a tap of the finger the user sees a detailed chain of energy events including SDO Atmospheric Imaging Assembly (AIA) solar images, the Advanced Composition Explorer (ACE) solar wind calculations, and even the real-time ionospheric TEC, i.e., the entire energy transfer from the Sun to the Earth. Solar index forecasts are provided. The app also serves as a platform upon which 16 diverse organizations collaborate to integrate 123 real-time products using a distributed, operational network.

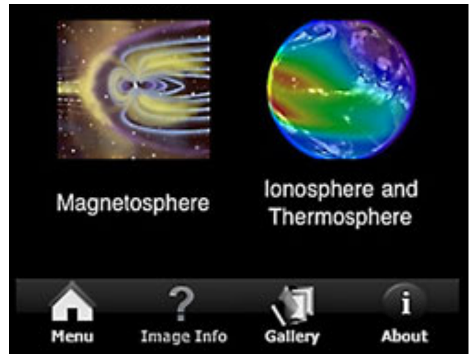


Figure 1. The SpaceWx iPhone app from the Space Weather Center (SWC) shows the four main space weather domains along with the effects of photon and particle energy that is transferred from the Sun to Earth through those domains.

The app is available through Apple's iTunes store and will soon be released for iPad. Other improvements will include expanded data sets of space weather images, alerts, and new information for high-frequency radio users.

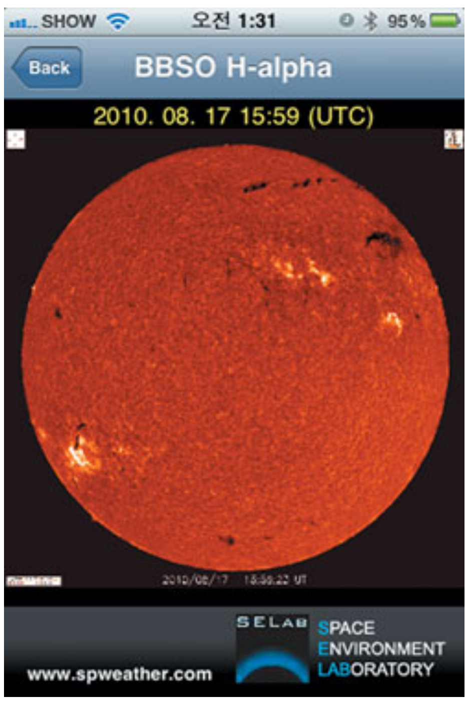


Figure 2. The SWx Monitor iPhone app from the South Korean Space Environment Laboratory (SELab) is aimed at bringing space weather information to the Korean public.

SWx Monitor

SWx Monitor (Figure 2) was developed by SELab in South Korea. It is available through both U.S. and Korean Apple app stores and is available in both English and Korean. Its objective is to increase the level of space situation awareness among potential customers, especially in South Korea.

Currently the app has features showing the primary space weather information from well-known data providers such as SWPC and NASA. It consists of four categories (solar activity, SOHO images, space environment, and alert and forecast) based on data periodically updated from a server.

Not only is SWx Monitor a tool for providing space weather information, but it will also serve as a platform for providing local space weather observations. For example, the regional TEC map in South Korea will be provided in an update. SELab is planning to update the application to report on upcoming space weather data and to develop the same application for other smartphone platforms such as Android and WinCE.

SpaceWeather

SpaceWeather

The SpaceWeather app (Figure 3) was developed for the Android operating system by ASTRA and can be downloaded from the Google Apps Marketplace™.

The app includes solar, magnetosphere, and thermosphere and ionosphere information organized into easy to understand categories for different user types. This comprehensive app provides access to ASTRA's real-time predictions of the global thermosphere and ionosphere as well as high-latitude convection and geomagnetic activity. Because of the phone's GPS capability, users can obtain location-specific vertical profiles of electron density, temperature, and time histories of various parameters from the models. The predictions of magnetic activity about an hour in advance can be used to determine the appropriate time to launch a rocket, and the ionospheric information can be used to select radio frequencies for communications. Real-time TEC maps can be used to assess impacts on GPS. Together with these features, data sets and images provided by NOAA, NASA, and other groups are also included in the app.

ASTRA is currently developing versions of the app for the iPhone and WinCE environment and opening up the Android version to a broader global audience. ASTRA has also been commissioned to develop an Android app for NASA's SDO mission to be released in fall 2010.

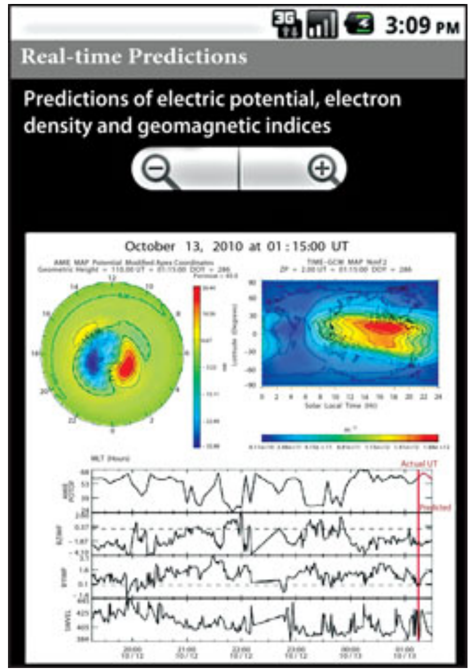


Figure 3. The Atmospheric and Space Technology Research Associates (ASTRA) Android SpaceWeather app includes real-time displays of the high-latitude electrodynamics, global ionospheric parameters such as N_mF_2, and predictions of geomagnetic activity indices approximately an hour ahead of the current time.

Figure 4. The 3D Sun app provides images from Solar Dynamics Observatory (SDO) and Solar Terrestrial Relations Observatory (STEREO) as well as alerts and notifications to inform users of solar events.

3D Sun

The 3D Sun app (Figure 4) was developed for the iPhone and iPad by a team including NASA's Heliophysics Division and Tony Phillips. The target audience is the science-attentive public. A key subset of this audience is teachers, who are using 3D Sun on the iPad for classroom science enrichment.

The core of the app is a fully interactive 3-D model of the Sun assembled in near real time from Solar Terrestrial Relations Observatory (STEREO) imagery. The app's daily news feed highlights images and movies SDO, SOHO, Polar Operational Environmental Satellite (POES), and even amateur sky watchers. A newly added Space Weather Current Conditions panel shows real-time values of solar wind speed, X-ray flux, and geomagnetic indices. Many subscribers say their favorite aspect of the app is the alert capability. The 3D Sun can be set to "ring" when Earth-orbiting satellites detect a solar flare or when geomagnetic storms erupt. Even professional solar physicists are finding this feature useful as a means of keeping abreast of events on the Sun.

Better and Faster Information

As this century's second decade begins, innovation in smartphone apps can be expected to accelerate and will promote prototyping, collaborating, and visualizing as a way of informing about space weather. A common goal of these apps is to transform space weather into a ubiquitous information layer within technology systems from satellite operations to communications, navigation, and defense activities.

But even in the infancy of space weather applications for smartphones, it is clear that these four widely available apps enable professional engineers and scientists, as well as the interested space public, to visualize the real-time changes in space weather as it affects technology. Future efforts will only help to make more accurate information reach users more quickly.

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