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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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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

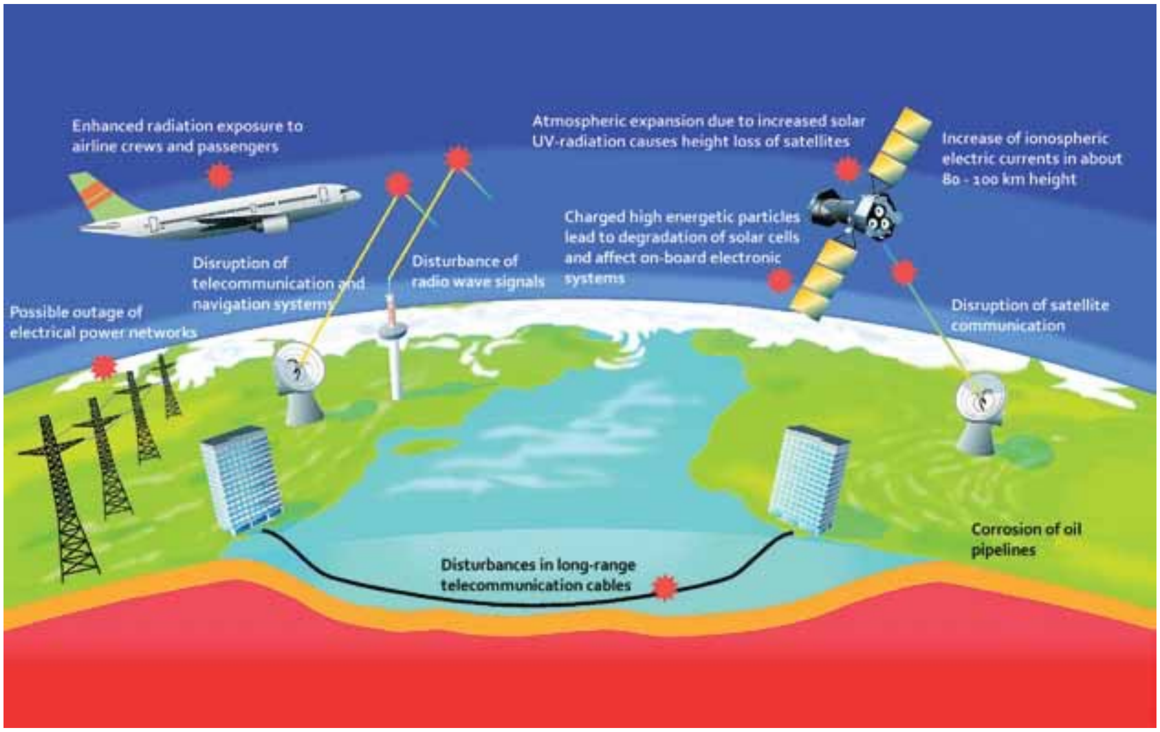

Fig. 1. Space weather affects technological infrastructures. (Graphic by R. Michaelis, A. Grosse, V. Bothmer, reproduced courtesy of the *Hamburger Abendblatt.)*

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).

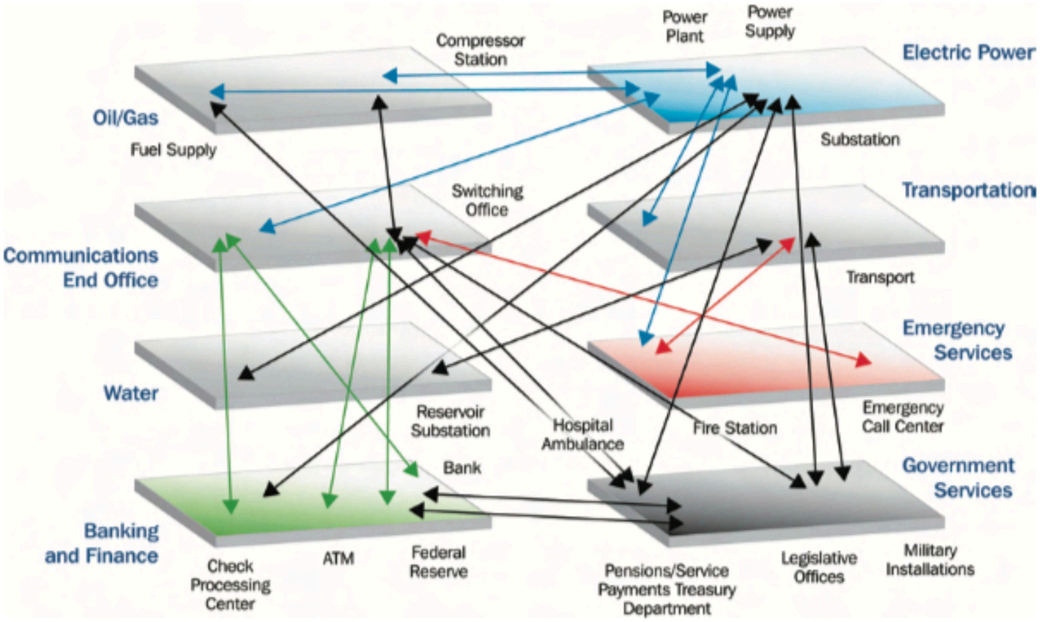

Fig. 2. Connections and interdependencies across the economy. Schematic showing the interconnected infrastructures and their qualitative dependencies and interdependencies. SOURCE: Department of Homeland Security, National Infrastructure Protection Plan, available at http://www.dhs.gov/xprevprot/programs/editorial_0827.shtm.

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 h[1]. 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.

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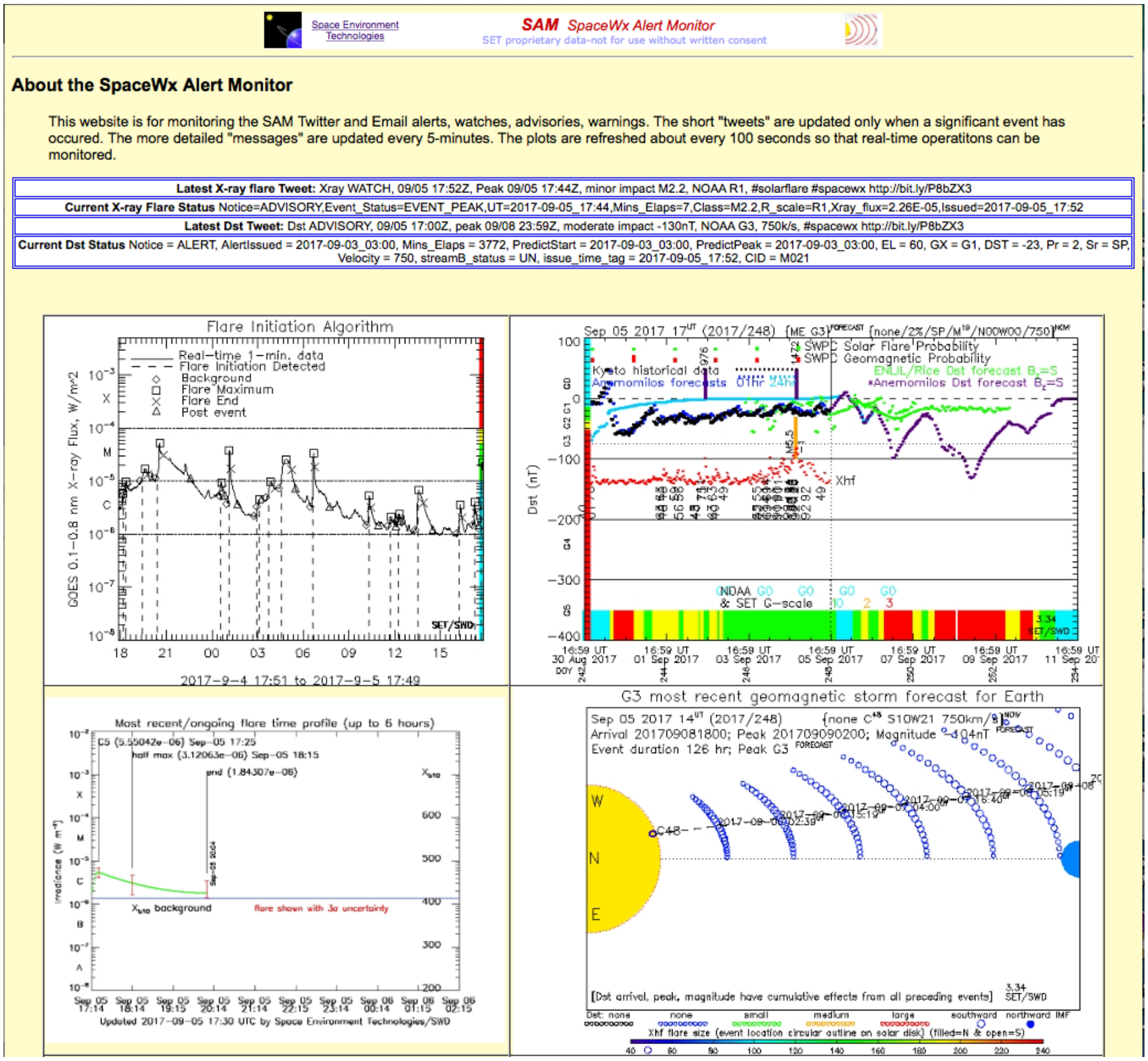
[1] MacAlester, M. H. and W. Murtagh (2014), Extreme Space Weather Impact: An Emergency Management Perspective*, Space Weather, 12,* 530–537, doi:10.1002/2014SW001095.

[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 2012[3]. SET's Dst is often used for days-ahead qualitative estimates of coming geomagnetic disturbances.



About the SpaceWx Alert Monitor

This website is for monitoring the SAM Twitter and Email alerts, watches, advisories, warnings. The short "tweets" are updated only when a significant event has occured. The more detailed "messages" are updated every 5-minutes. The plots are refreshed about every 100 seconds so that real-time operatitons can be monitored.

Latest X-ray flare Tweet: Xray WATCH, 09/05 17:52Z, Peak 09/05 17:44Z, minor impact M2.2, NOAA R1, #solarflare #spacewx http://bit.ly/P8bZX3

Current X-ray Flare Status Notice=ADVISORY,Event_Status=EVENT_PEAK,UT=2017-09-05_17:44,Mins_Elaps=7,Class=M2.2,R_scale=R1,Xray_flux=2.26E-05,Issued=2017-09-05_17:52

Latest Dst Tweet: Dst ADVISORY, 09/05 17:00Z, peak 09/08 23:59Z, moderate impact -130nT, NOAA G3, 750k/s, #spacewx http://bit.ly/P8bZX3

Current Dst Status Notice = ALERT, AlertIssued = 2017-09-03_03:00, Mins_Elaps = 3772, PredictStart = 2017-09-03_03:00, PredictPeak = 2017-09-03_03:00, EL = 60, GX = G1, DST = -23, Pr = 2, Sr = SP, Velocity = 750, streamB_status = UN, issue_time_tag = 2017-09-05_17:52, CID = M021

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.

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[3] The SET Dst current epoch specification and forecast can be viewed at https://sol.spacenvironment.net/~sam_ops/index.html? with the reference of Tobiska, W. K., D. Knipp, W. J. Burke, D. Bouwer, J. Bailey, D. Odstrcil, M. P. Hagan, J. Gannon, and B. R. Bowman (2013), The Anemomilos prediction methodology for Dst, *Space Weather,* 11, 490–508, doi:10.1002/swe.20094.

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 altitudes[4] (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 belts[5]. 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 pilots[6] (Figure 5). ARMAS has been mapping the global aviation radiation environment since 2013 (Figure 6). It has now achieved a rudimentary

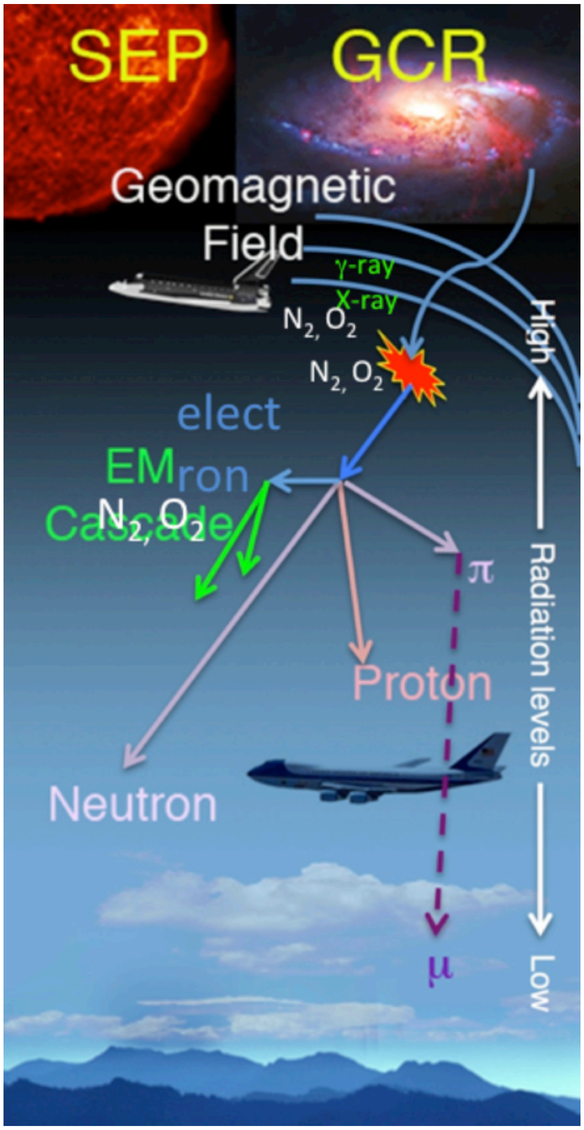

Fig. 4. The complex radiation environment at and above commercial aviation altitudes due to GCRs and SEPs.

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[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).

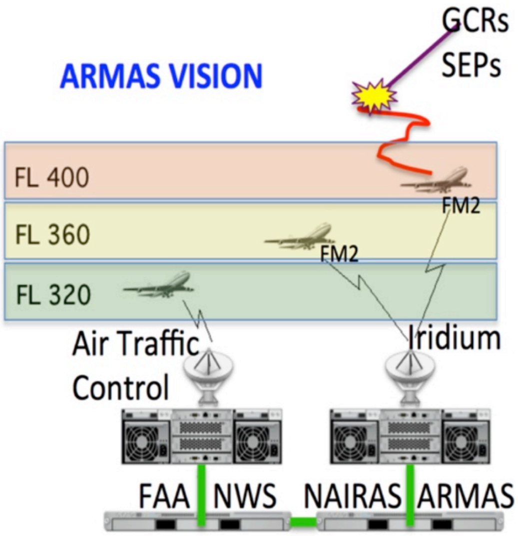

Fig. 5. ARMAS vision integrating real-time dose rate measurements into operational aerospace/space traffic management systems.

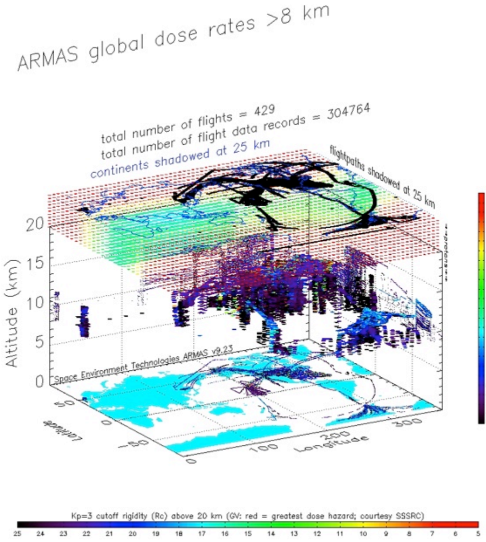

Fig. 6. Global ARMAS measurements since 2013 and on 429 flights above 8 km.

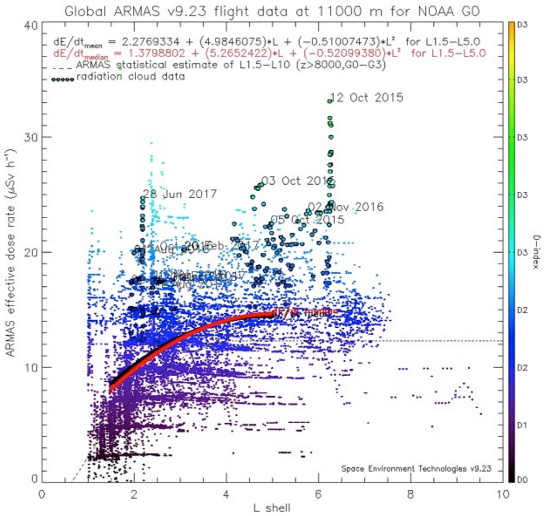

Fig. 7. RADIAN statistical forecast algorithm for effective dose rate (red line and equation) for all magnetic latitudes (specified by L-shell), with a NOAA G0 geomagnetic activity level (quiet), and at an altitude of 11 km. The light black dashed line is for the NAIRAS climatological forecast only,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

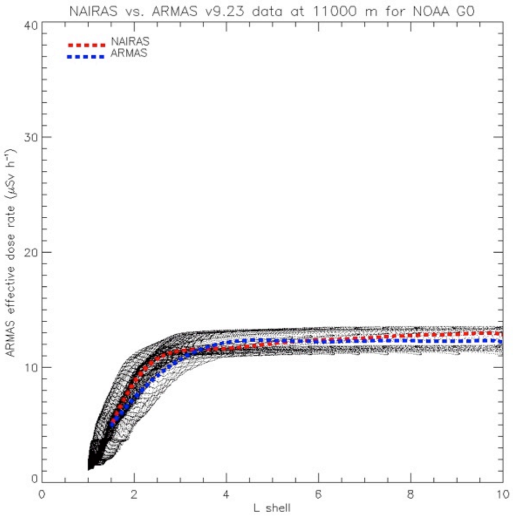

Fig. 8. RADIAN climatological forecast algorithm (red line is climatological NAIRAS and blue line is statistical ARMAS) for all magnetic latitudes (specified by L-shell), with a NOAA G0 geomagnetic activity level (quiet), and at an altitude of 11 km. The light black dashed lines are for the NAIRAS climatological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

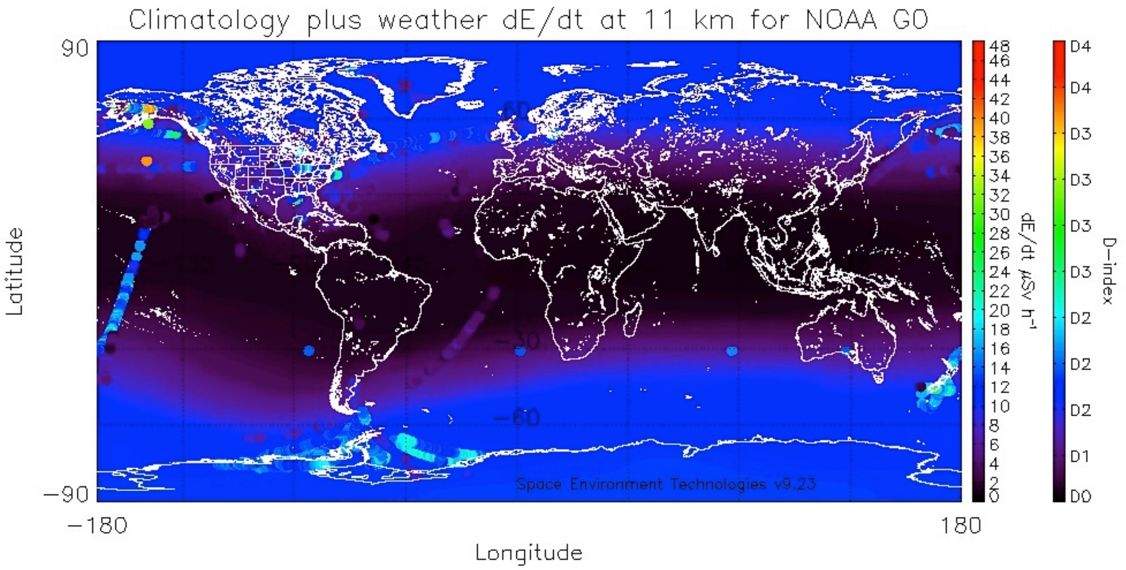

Fig. 9. Global climatology and weather representation of effective dose rates (dE/dt) at 11 km altitude for NOAA geomagnetic conditions of G0 (quiet). Colored dots are ARMAS data for assimilation into NAIRAS that can upgrade the radiation weather along a flight track.

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 hurricane 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.

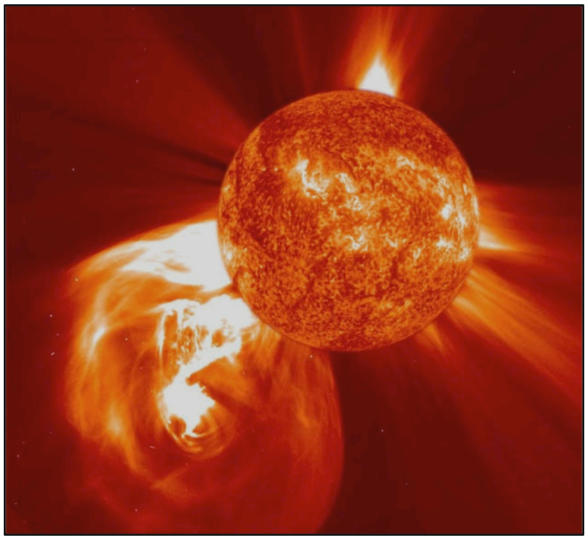

Fig. 11. The 4th largest solar flare recorded, an X17, erupts on the Sun 07 September 2005.

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.

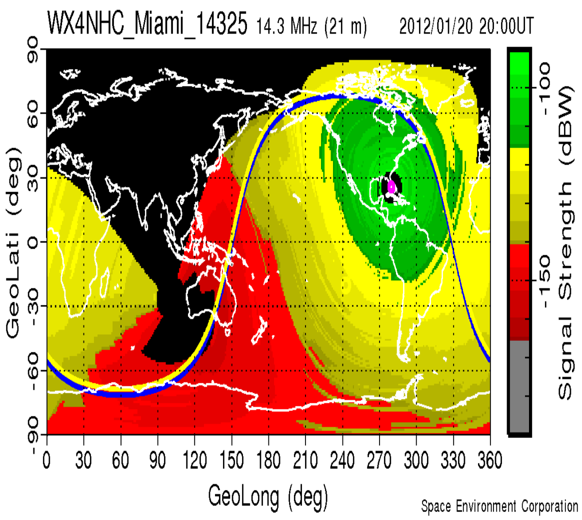

Fig. 12. Global HF availability forecasts showing an example of signal strength from Miami.

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 smartphones[7] (Figure 13).

Impacts of Space Weather – Upper Atmosphere Density Increases Supplement

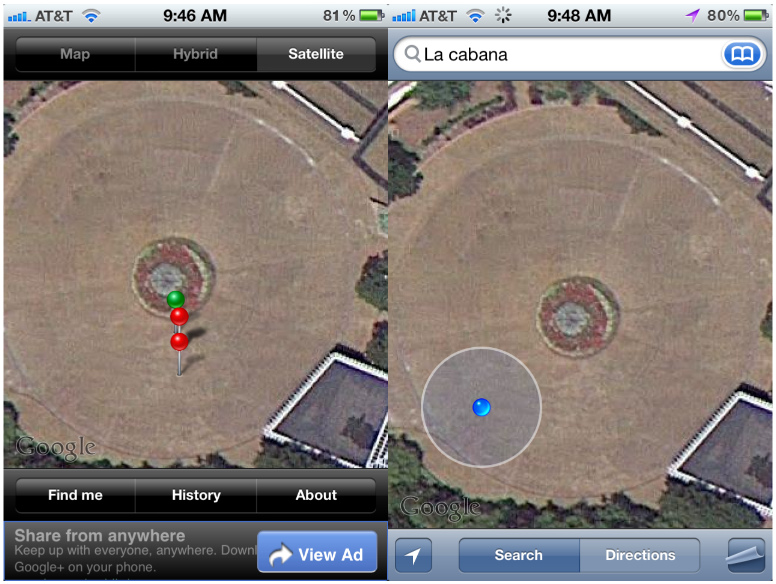

Fig. 13. (left) Corrected GPS position using GAIM-GM and SpoT-On concept (green dot is final position 2 m from center of traffic circle flower garden and (right) uncorrected position (blue dot) using an iPhone native GPS location.

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 released[8] – it was the single largest improvement for reducing LEO atmospheric density uncertainties since the 1960s. Space Command has operationally

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

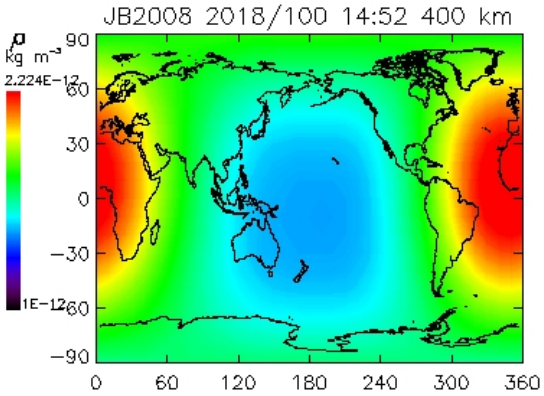

Fig. 14. The JB2008 thermosphere density at 400 km.

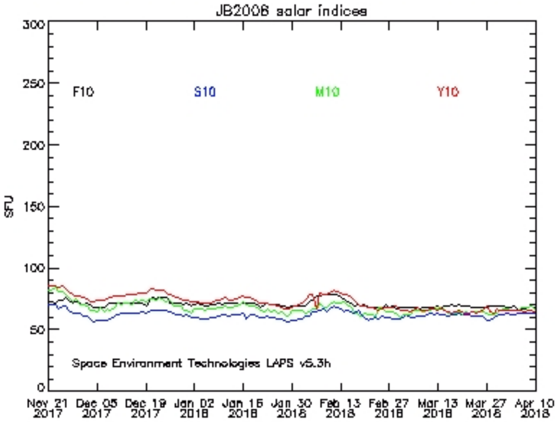

Fig. 15. Solar indices used by JB2008.

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 standard[9].

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.

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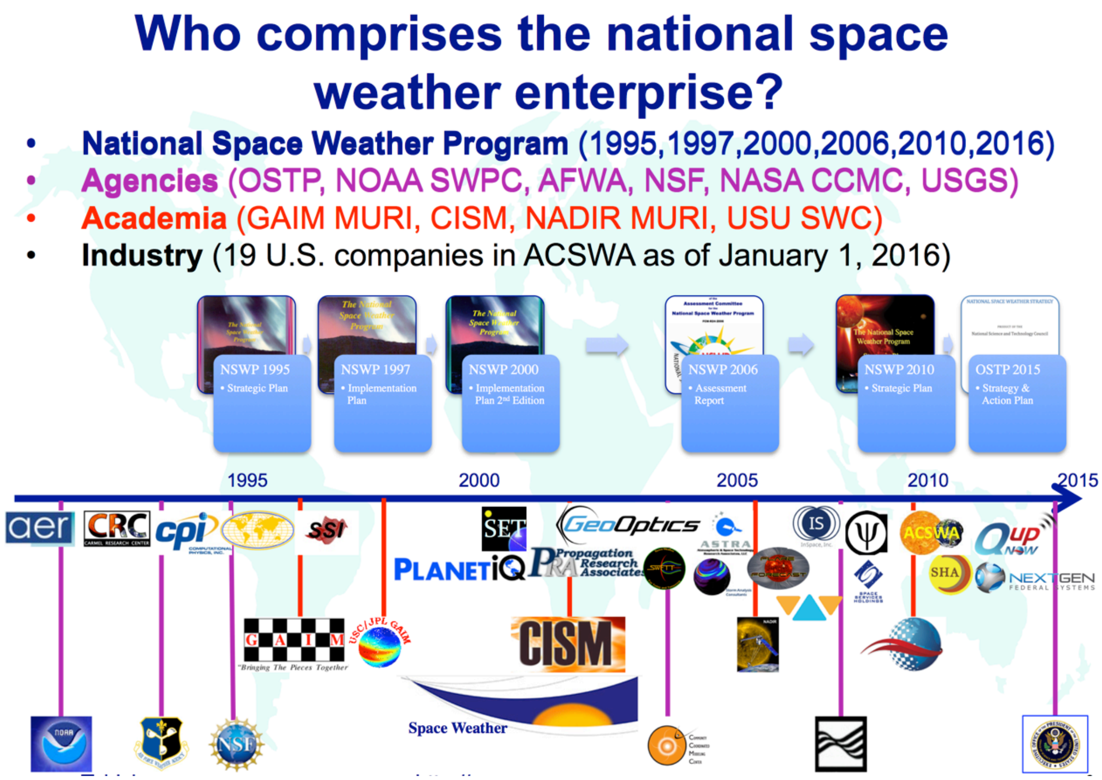
[8] Bowman, B. R., W. K. Tobiska, F. A. Marcos, C. Y. Huang, C. S. Lin, and W. J. Burke (2008), A New Empirical Thermospheric Density Model JB2008 Using New Solar and Geomagnetic Indices, *AIAA/AAS Astrodynamics Specialist Conference,* AIAA 2008-6438.

[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 benchmarks[11]. Both

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

i. 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;
ii. SET letter of concern to the U.S. House of Representatives for the *U.S. Government Shutdown*, 07 October 2013;
iii. 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;
iv. ACSWA Response to the NOAA *Commercial Space Policy Draft*, 30 September 2015;
v. ACSWA Response to the OSTP *Space Weather Action Plan*, 11 July 2016;
vi. ACSWA Comments to NOAA on *Improving Space Weather Forecasting R2O-O2R Capability*, 20 March 2017;
vii. 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;
viii. 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;
ix. 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;
x. 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 organizations[12], 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 RADIAN 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.

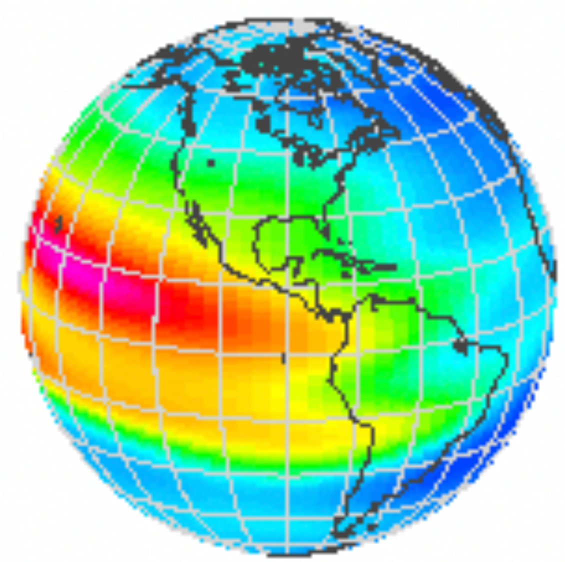

Fig. 17. USU's GAIM global ionosphere model for specification and prediction. This model is used by the USAF Weather Agency for an operational ionosphere as well as by the USU and SET team for Q-Up and Spot-On derivative products.

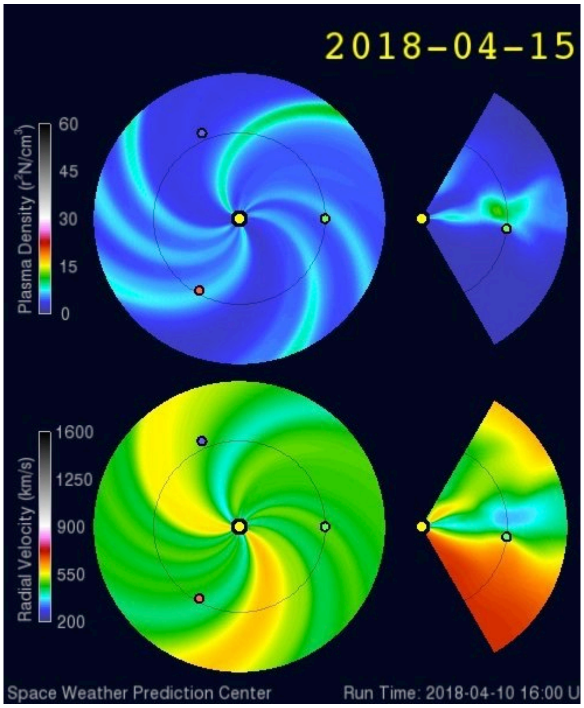

Fig. 18. NOAA's WSA/ENLIL/CONE solar wind model for specification and prediction.

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[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.

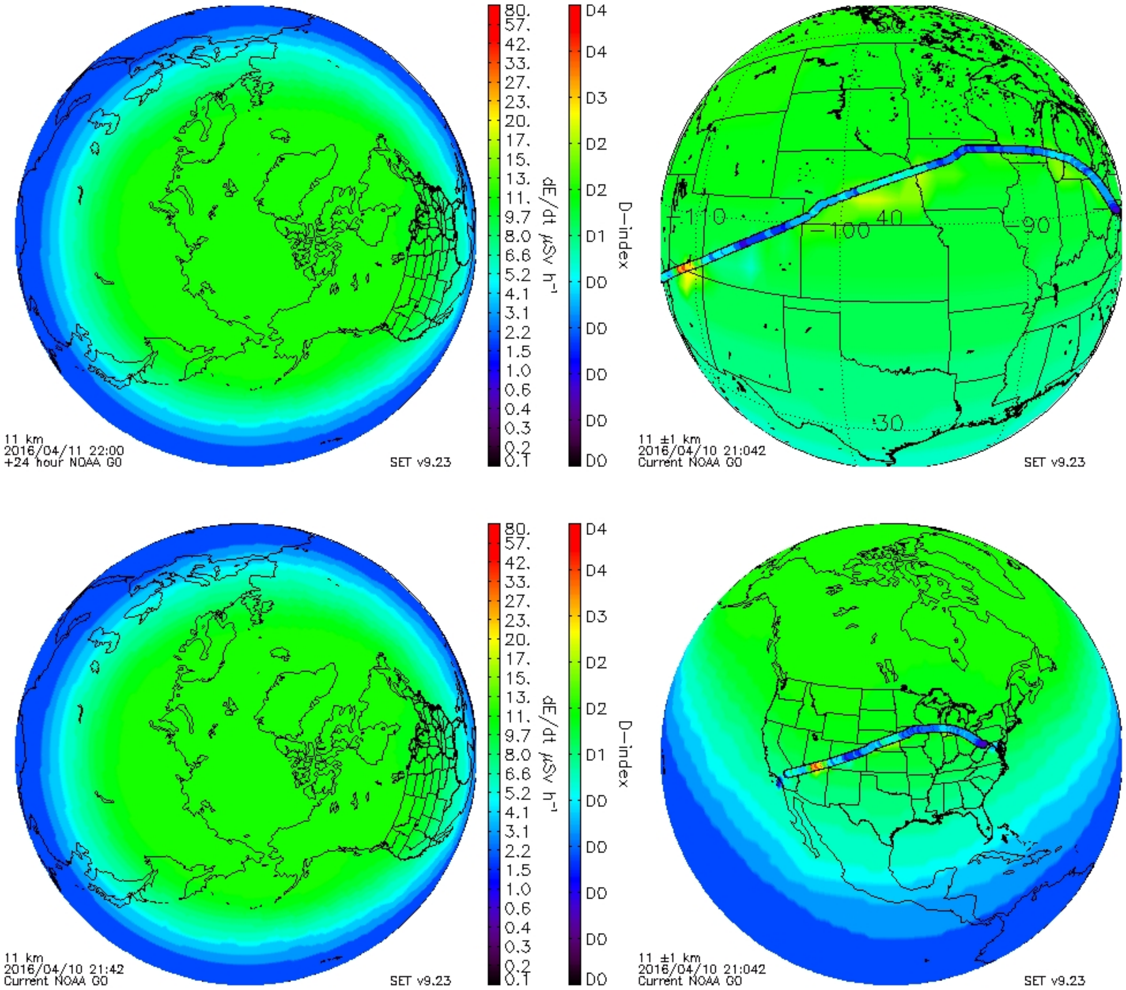


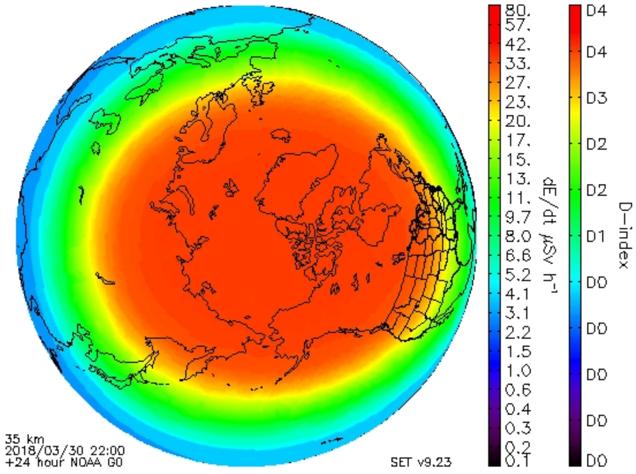
Fig. 19. SET's RADIAN global radiation model for specification and prediction showing the 24 h northern hemisphere forecast (top left), the current epoch (bottom left), the regional flight track of a LA–DC flight (top right), and the hemispheric view of the LA–DC flight (bottom right).

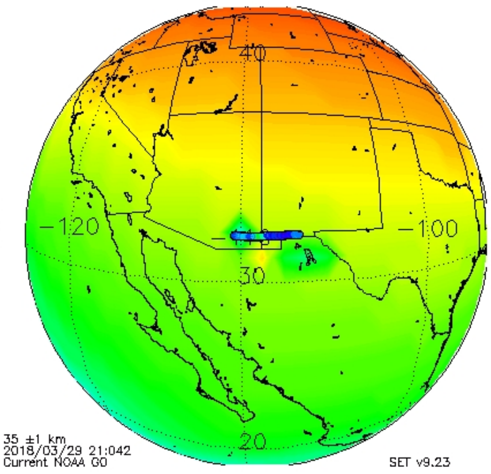
TOBISKA SHORT BIOGRAPHY

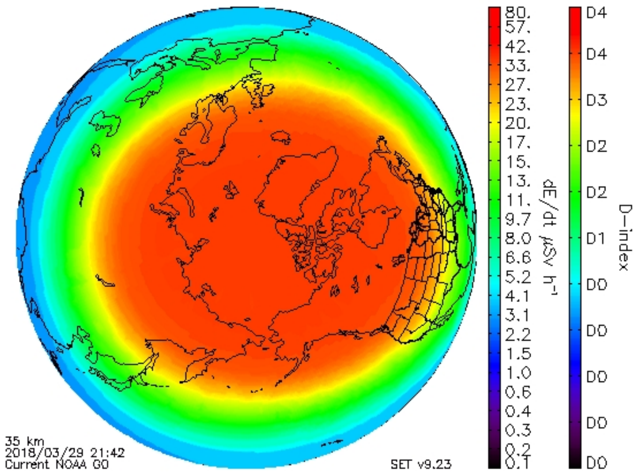
Dr. Tobiska is the President and Chief Scientist of Space Environment Technologies, LLC (SET). He is also the director of the Utah State University Space Weather Center and President of Q-Up, LLC. He invented the world's first operational computer code for solar irradiance forecasting and extended this 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.

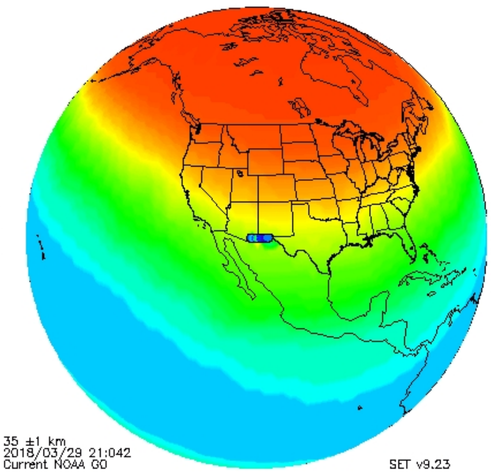
ARMAS

Automated Radiation Measurements for Aviation Safety









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