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Key Points:
- The shut down significantly affected U.S. aviation radiation monitoring
- During radiation event, 20 people likely received lifetime fatal cancer doses
- Active radiation environment operational monitoring is needed

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U.S. Government shutdown degrades aviation radiation monitoring during solar radiation storm

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Abstract The U.S. Government shutdown from 1 to 17 October 2013 significantly affected U.S. and global aviation radiation monitoring. The closure occurred just as a S2 radiation storm was in progress with an average dose rate of 20 μSv h^{-1}. We estimate that during the radiation event period, one-half million passengers were flying in the affected zone and, of this population, four would have received sufficient dose to contract fatal cancer in their lifetimes. The radiation environment can be treated like any other risk-prone weather event, e.g., rain, snow, icing, clear air turbulence, convective weather, or volcanic ash, and should be made available to flight crews in a timely way across the entire air traffic management system. The shutdown highlighted the need for active operational monitoring of the global radiation environment. Aviation radiation risk mitigation steps are simple and straightforward, i.e., fly at a lower altitude and/or use a more equatorward route. Public tools and media methods are also needed from the space weather scientific and operational communities to provide this information in a timely and accessible manner to the flying public.

1. Background

On Monday evening 30 September 2013, the U.S. Government began to close numerous facilities as a result of the lack of federal budget funding. Included in this shutdown was the computer system that runs the *Nowcast of Atmospheric Ionizing Radiation System* (NAIRAS: http://sol.spacenvironment.net/~nairas/index.html) [*Mertens et al*., 2009, 2010, 2012, 2013] at NASA's Langley Research Center (LaRC). This system provides real-time data driven climatology of the aviation radiation environment as shown in Figure 1, which is the last report before the shutdown. The source radiation in this figure is from both Galactic Cosmic Rays (GCRs) and Solar Energetic Particles (SEPs).

Regrettably, the shutdown occurred just as a moderate solar radiation storm was peaking. A day earlier, on 29 September, a small X-ray solar flare occurred around 21:45 UT. Coincident with the flare was a large spatial eruption in the NW quadrant of the solar disk. A 35 degree long north-south filament eruption, centered near N15W40, led to the injection of fast plasma into the interplanetary medium. NOAA Space Weather Prediction Center (SWPC) reported that the charged particles arrived at Earth approximately 17 h later on 30 September 2013 14:20 UT and were correlated with the GOES satellite measurements of >10 MeV protons having a maximum flux of 182 protons cm^{-2} s^{-1}. These SEPs coupled with the Earth's magnetosphere to produce a moderate S2 radiation storm (http://www.swpc. noaa.gov/NOAAscales) with a peak at 20:05 UT on 30 September and continuing for 27 h until 1 October at 17:15 UT. Figure 2 shows this radiation event observed by GOES-13. High-energy particle measurements (>100 MeV) are a better indicator of radiation risk to passenger and crews but have not yet been studied for this event. The geomagnetic storm associated with this event combined with a high-speed stream (HSS), which had a minimum Dst value of −54 nT at 12 UT on 2 October. The non-HSS, slower particles than those creating the S2 radiation storm produced a later G2 geomagnetic storm event with a −43 nT minimum Dst value near 2 UT on 3 October. The combined events relaxed to background Dst (0 nT) near 21 UT on 4 October 2013.

2. Radiation Risk Analysis

The question naturally arises: *what risks were there for passengers and crew on commercial aircraft flights during the 30 September to 1 October 2013 S2 radiation event?* In this type of radiation storm, passengers and crew in aircraft flying at high latitudes or high altitudes can be exposed to elevated radiation risk; pregnant women are particularly susceptible.

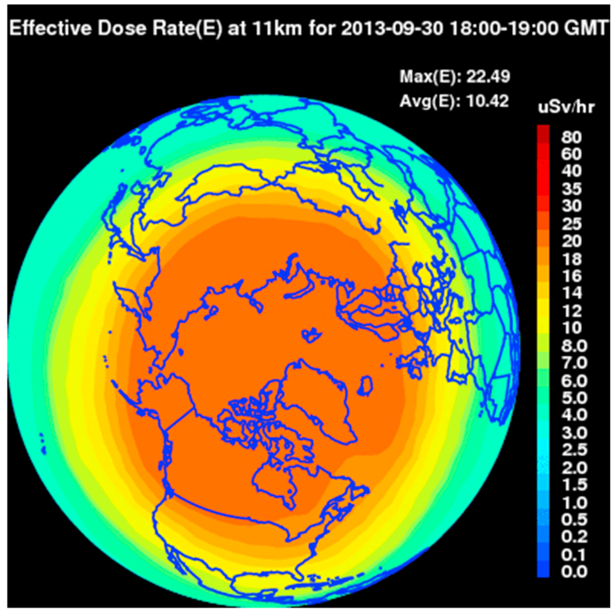

Figure 1. NAIRAS effective dose rate at the time of the U.S. Government shutdown of NASA LaRC computers and prior to the 20:05 UT peak of the radiation storm on 30 September 2013.

To answer this question, we must understand two things. First, what was the peak effective dose rate at commercial aviation altitudes during the radiation event? Second, what statistical guidelines can we use to estimate those radiation risks?

2.1. What Was the Radiation Event Effective Dose Rate?

The NAIRAS system, which provides data-driven climatology for the aviation radiation environment, showed an effective radiation dose rate for this event peaking around 21 μSv h^{-1}, and averaging around 15 μSv h^{-1}, at the typical 11 km (36,000 ft. or Flight Level (FL) 360) commercial aviation flight altitude for latitudes higher than 20°N (Figure 1). Military and private jets flying at 15 km (49,000 ft.) likely experienced 50% higher effective dose rates. Aircraft at latitudes greater than 60° N also experienced about 30% higher dose rates. Unfortunately, due to the U.S. Government shutdown, data were not reported at the radiation event peak or during its decay back to nonevent levels on 1 October 2013.

There have been previous successful efforts to capture and map dose rates from aviation altitudes [*Getley et al*., 2005, 2010; *Stassinopoulos et al*., 2003]. The *Automated Radiation Measurements for Aviation Safety* system (ARMAS),

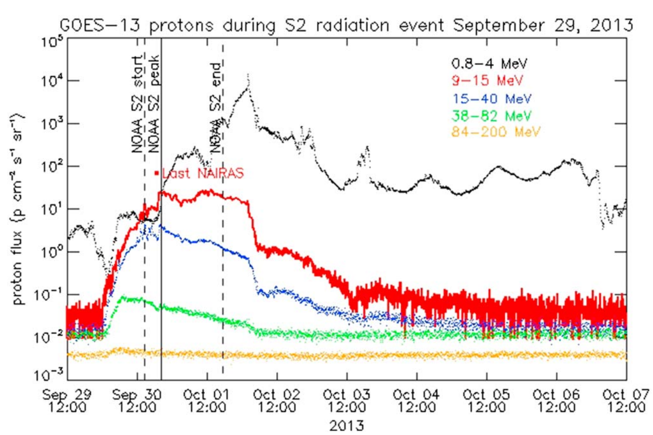

Figure 2. GOES-13 proton flux during the radiation event as reported by NOAA SWPC. The SWPC S2 event is reported on the red >10 MeV protons. The last NAIRAS run (Figure 1) is the red dot.

Figure 3. World 24 h air traffic pattern (individual planes as yellow dots) from the website http://www.flixxy.com/scheduled-airline-flights-worldwide.htm.

where information is provided in real time at http://sol.spacenvironment.net/~ARMAS/index.html, measured and reported a week before the event comparable rates of 1–2 μGy h^{-1}. These values were consistent with GCR radiation source results identified by *Stassinopoulos et al.* [2003].

The effective dose rates for the S2 event were considerably higher than those measured by ARMAS just a week earlier at similar latitudes and altitudes. ARMAS had just completed its summer season of 29 successful flights on a NASA Dryden Flight Research Center (Palmdale) DC-8 on 23 September.

In addition, ground-based experiments using particle accelerators to simulate components of the aerospace radiation environment were conducted on the ARMAS micro dosimeter in August and September 2013. These experiments were to characterize the ARMAS micro dosimeter and cross-calibrate the instrument with "gold standard" radiation micro dosimeters for human tissue and silicon (relevant to aircraft instrumentation). As part of these experiments, a model aircraft shield consisting of 5.3 g cm^{-2} Al with 3 g cm^{-2} HDPE was used to simulate an aircraft hull and interior at both the Loma Linda University Medical Center (LLUMC) 175 MeV proton beam and the Los Alamos Neutron Science Center (LANSCE) 1-800 MeV neutron beam. Preliminary data from these experiments indicate that the aircraft hull tends to complicate the data in ways that are still under study. In any event, the laboratory experiments indicated that the ARMAS micro dosimeter system appears to be an effective instrument for real-time measurements on aircraft.

Given these considerations for the $>$24 h radiation event, an effective dose rate of 20 μSv h^{-1} was used for the 24 h period distributed asymmetrically around 30 September 2013 20 UT.

2.2. How Many People Were Flying in the Affected Radiation Zone During This Period?

This number is nearly impossible to determine so we use a heuristic approach to make an estimate. Taking the U.S. case alone, the U.S. Bureau of Transportation Statistics (BTS) reports that 744 million passengers traveled on U.S. domestic and international flights between July 2012 and June 2013. This yearly passenger rate, assumed to be valid for 30 September to 1 October, 2013, becomes 2 million passengers flying during the radiation event; this represents a maximum population sample for U.S. origin-destination flights only.

This number must be reduced because only longer-distance flights of more than 1 h duration are near FL 360 for any considerable length of time. This excludes many regional flights that are below FL 280, i.e., the radiation detection threshold altitude for ARMAS. We also further limit flights to those that are at high enough magnetic latitudes to be affected. Thus, one can consider that only a limited number of international North America-Europe-Asia flights were most at-risk for the 30 September radiation storm. The world air traffic pattern (Figure 3) supports this consideration, further showing that the North American-European routes dominate the system.

As an example, a typical San Francisco-Frankfurt flight takes around 11 h and, eliminating take off and landing, 10 h can be used as a canonical long distance international flight time that would be at FL 360 or higher. The United Star Alliance has 5600 flights a day to 374 destinations throughout the Americas, Europe, and Asia according to their marketing literature. Assuming that 10% of these may be on the North America-Europe route,

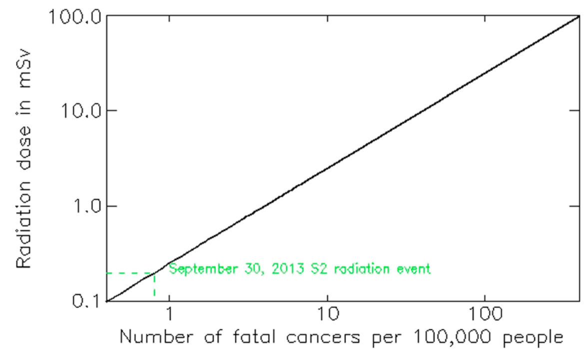

Figure 4. Linear model of radiation dose vs. number of fatal cancers per 100,000 people (cf. *Barish*, 1996; *Valentin*, 2005).

then 560 flights a day would be a reasonable assumption for the number of affected flights from that airline alliance. This is tangentially supported by the fact that United Air Lines flies 500 flights a day alone from Chicago O'Hare, which is a hub for many international flights. If we assume 560 flights a day for the Star Alliance, and make similar conclusions for the smaller Sky Team and Oneworld airline alliances, then approximately 1200 flights a day can be considered for the North America-Europe route. *Executive Travel* magazine reported in December 2009 that there were 1164 aircraft crossings on this route each day.

A common aircraft used for long distance international flights is the Boeing 777 long-range wide body, which has a typical seating capacity of 314 to 451 passengers. Using an estimate of 350 passengers per flight, considering the U.S. BTS passenger load factor for June 2013 of 86%, then 420,000 passengers could be affected. This estimate ignores routes out of the North America-Europe corridor, both U.S. domestic and international, such as to Asia. In addition, as Figure 2 demonstrates, the radiation event lasted considerably longer than the NOAA S2 event designation. Thus, we reasonably round up the total affected passengers to 500,000, which provides a population number for those that were in the affected radiation area during the 30 September 2013 event.

Using the figure that ½ million affected passengers received 20 μSv h^{-1} during their 10 h flights at FL 360 or above, individuals in this population then received up to a total dose of 0.2 mSv from the combined background GCR neutrons and the 30 September 2013 SEP protons; the latter were the dominant radiation source.

2.3. What Is the Risk to These Passengers From This Radiation Event?

It is generally agreed in the scientific community that accurately estimating the risks from radiation exposure below 100 mSv is not possible; the 0.2 mSv dose from this event is considered a low level dose. The risk from this level of exposure is primarily from contracting fatal cancer at some later point in life. For the entire at-risk population on these flights, their whole body (including sensitive organs) was subjected to the exposure. Thus, to estimate the risk, both the *National Council of Radiation Protection and Measurements* (NCRP — a U.S. committee of experts) and *International Commission on Radiological Protection* (ICRP — an international expert committee) use a linear model of dose vs. effects [*Valentin*, 2005]. As *Barish* [1996] notes, "This model predicts that there is a possibility of harm associated with any exposure to radiation, no matter how small, and that the harm from low doses of radiation can be predicted by scaling down the known risk levels for high-dose exposures. This is a conservative approach that, if anything, errs on the side of public safety." The Federal Aviation Agency (FAA), through its Civil Aerospace Medical Institute (CAMI) program, also provides a similar radiation exposure risk assessment [*Staedter*, 2006].

Recognizing the uncertainties associated with the linear model, which extrapolates abundant data from high dose exposure populations to minimal data low dose exposure populations, this is the currently accepted methodology for estimating low exposure risks of cancer in human populations. Using the linear model with its unknown uncertainties at low doses, one calculates that a 0.2 mSv dose would likely cause about 1 cancer death in a population of 100,000 (Figure 4). Thus, for the half million at-risk passengers and crew flying within the 30 September 2013 radiation zone, up to four eventual cancer deaths would likely occur from this single event. This conservative number uses effective dose rate values from NAIRAS that did not report the peak of the event or the actual (longer) duration because of the U.S. Government shutdown of the monitoring computers.

The shutdown highlights the need for active operational monitoring of the global radiation environment. This topic has been widely discussed over the past decade through a number of forums [*Fisher and Jones*, 2007; *Tobiska*, 2008, 2009; *Fisher*, 2009; *Kataoka et al.*, 2011] that have identified policy, communication of information, standardization, prediction techniques, and education/training for aviation radiation exposure risks.

3. Conclusions

Given the uncertainty in modeling this event using a heuristic approach, one can only conclude that improved modeling, measurements, and public reporting tools of the radiation environment inside commercial aircraft are needed so that air traffic control (ATC), crew, and passengers can assess more accurately their risks. The U.S. Government shutdown severely inhibited this radiation monitoring capability.

The shutdown highlighted the need for active operational monitoring, rather than only scientific modeling, of the global radiation environment. NOAA SWPC and its National Weather Service computers would be an ideal platform for hosting this operational capability. The use of the information by the FAA for air traffic control and management is also an important consideration. The radiation environment can be treated like any other risk-prone weather event, e.g., rain, snow, icing, clear air turbulence, convective weather, or volcanic ash, and should be made available to flight crews in a timely way across the entire air traffic management system.

In events such as this, the radiation risk mitigation steps are simple and straightforward — fly at a lower altitude and/or use a more equatorward route. Real-time radiation monitoring data from instrument systems like ARMAS aboard a fleet of global aircraft would provide the needed information to improve global systems such as NAIRAS by enabling them to operate in a data assimilative mode for real-time specification and near-term (hours) forecasting.

Individuals such as frequent flyers, pregnant mothers, and crew members reaching their monthly radiation exposure threshold also need and deserve tools to manage their radiation exposure risk, if they so desire. Public tools and media methods are needed from the space weather scientific and operational communities to provide this information in a timely and accessible manner. With such information, individuals may be able to decide how to manage their own risks, including the option to fly at other times or on other routes during solar radiation storms, assuming they are not already in flight.

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