Progress towards mitigating space weather effects in aviation

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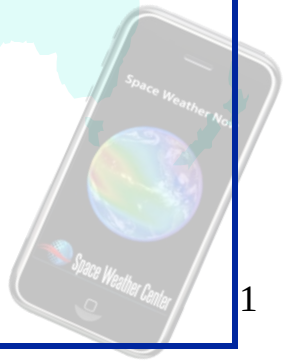
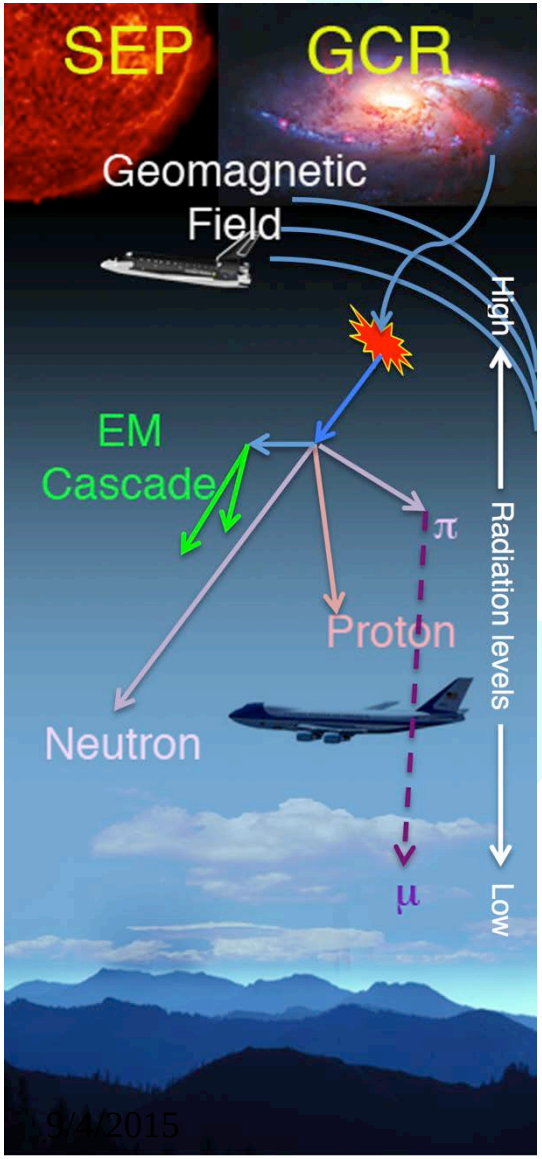


Space weather is moving beyond *understanding (2000)* into *tailored risk management (2015)*

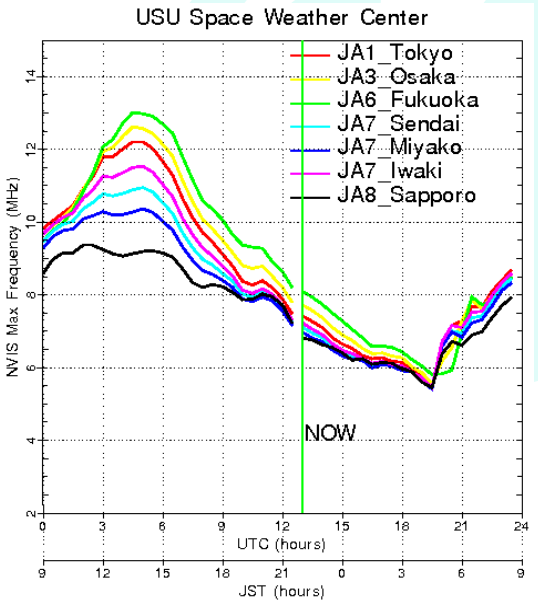
Space weather affects 3 aviation areas

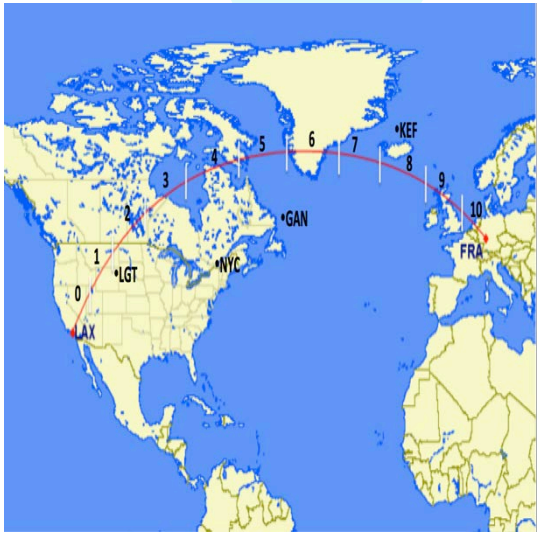
1. **Aviation radiation exposure**
   - GCR background dose (career health)
   - SEP event dose (fleet operations and aircrew/passenger safety)
2. **Ground-to-aircraft radio communication disruption**
   - HF radio communication (transoceanic and polar routes)
   - Scintillation outages for L-band, UHF, HF (satcom, radar, comm)
3. **WAAS GPS Navigation**
   - Increased location uncertainty (during landing and approaches)

Radiation exposure

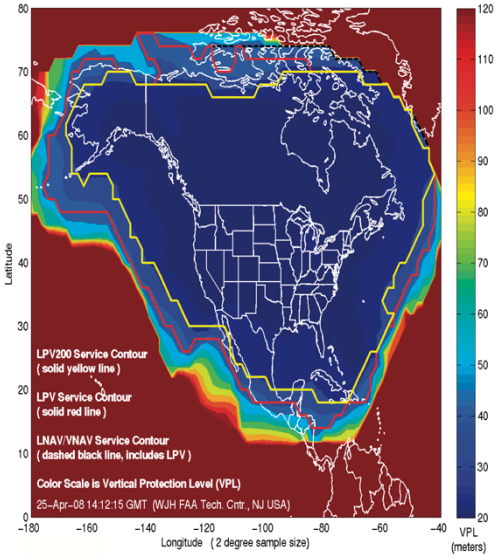


HF communication outages





WAAS navigation error



SpaceWeather app

Example 1: Aviation radiation environment specification

Steps towards aviation radiation management

- **What is the problem?**
  - **Radiation in the aviation environment can lead to elevated cancer rates, producing career limitations or even death**
  - **Crew, frequent flyers, fetuses in first trimester are the most at-risk populations**
    - GCR background can limit careers from long-term statistical exposure
    - SEP solar flare events can constrain crew schedules so they do not exceed monthly, annual dose limits from short-term statistical exposure; rare but historic SEP events can lead to deterministic radiation sickness
    - At 37,000 ft., every 10 hours ≈ 1 chest X-ray in equivalent dose rate
    - Every 6500 ft. higher doubles the dose rate (FL 435 ≈ 2 chest X-rays and FL 500 ≈ 3 chest X-rays)
    - **Every 6500 ft. lower halves the dose rate (FL 305 ≈ ½ chest X-ray)**
    - **100 km equatorward in magnetic latitude may also significantly reduce the dose rate**

Steps towards aviation radiation management

- **What can be done about it?**
  - **Determine the "weather" of the radiation environment**
    - SEP events can be treated like volcanic ash clouds
    - Facilitate background environment monitoring for crew career support
  - **Estimate uncertainties with climatological models in ensemble runs and with data assimilation to move climatology into weather (like with hurricane tracking in tropospheric weather)**
    - Use physics-based models such as NAIRAS (NASA LaRC)
    - Use empirical such as CARI-7 (FAA CAMI)
  - **Build a global system of quality real-time measurements on aircraft supplied to the ground via AMDAR for data assimilation use in radiation "weather" models**
    - Expand systems such as ARMAS (NASA & SET)

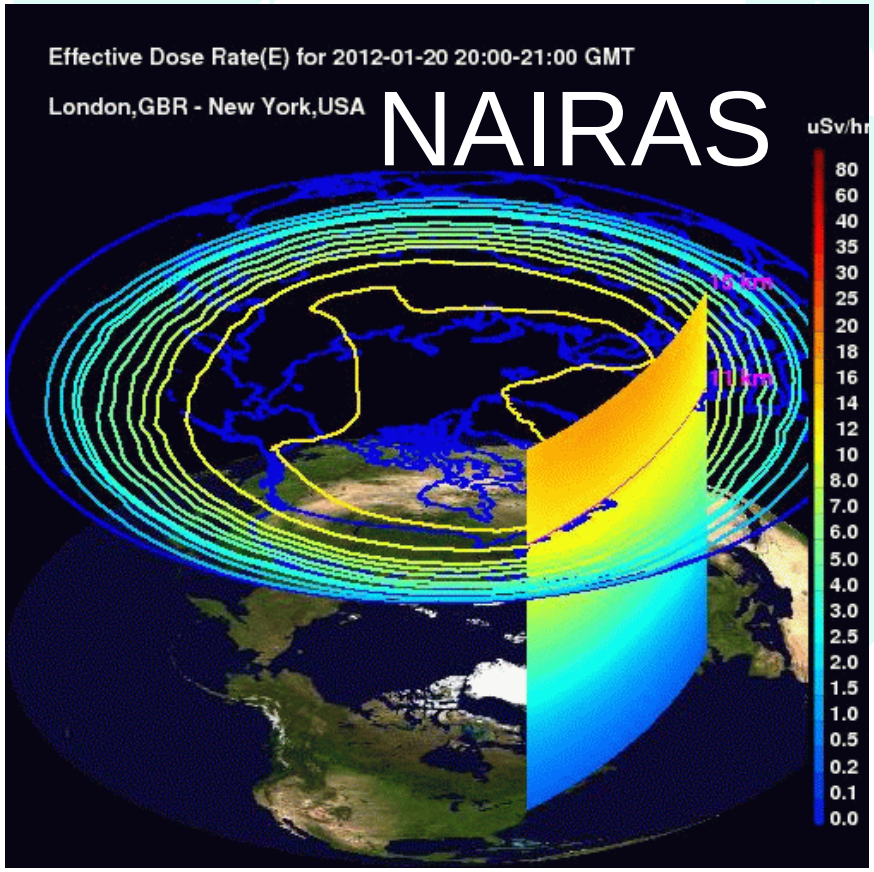
Steps towards aviation radiation management

- **What is the radiation effects management path?**
  - **Non-pilot crew, frequent flyers and fetuses** can only monitor their personal profiles
  - **Pilots** can reroute flight paths during severe radiation events in the same way a regional volcanic ash cloud is avoided
  - **Air Traffic Control** can alter entire regional routes during severe radiation events in the same way a volcanic ash cloud is avoided
  - **ICAO** can set standards and guidelines for event identification
  - **ATC** needs a real-time, forecast data cube to implement tools of
    - **Dropping altitude to lower the dose rate**
    - **Rerouting flight tracks equatorward to reduce the dose rate**

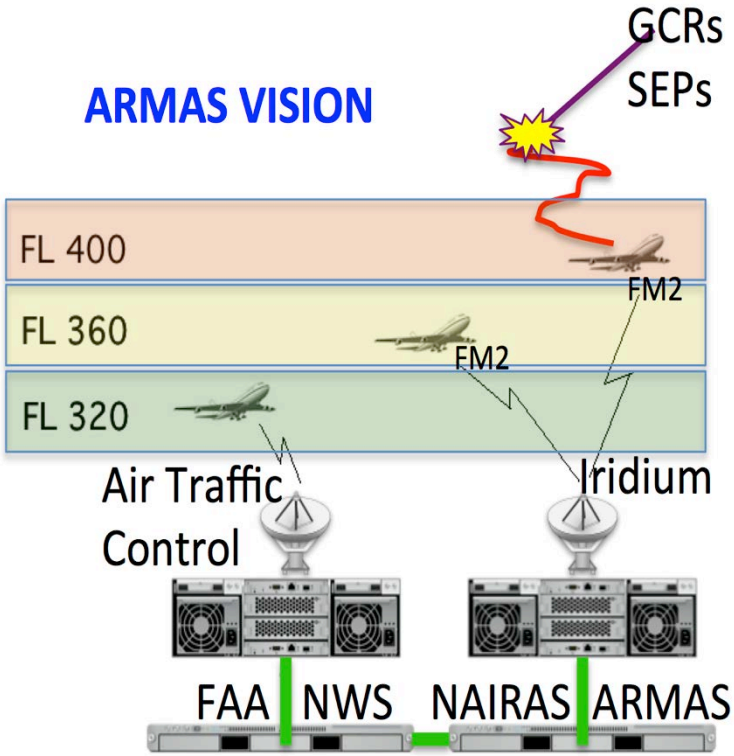
Steps towards aviation radiation management

- **What is currently being done?**
  - **CARI-6 is used for operational guidance**
  - **NAIRAS (Nowcast of Atmospheric Ionizing Radiation System) is going thru operational prototyping development**
  - **ARMAS (Automated Radiation Measurements for Aerospace Safety) system is in early development (4 units in flight)**
    - ARMAS employs airborne micro dosimeters to collect real-time TID (total ionizing dose)
    - ARMAS transmits TID, time, and GPS location to the ground via Iridium satellite link for data comparison (eventual assimilation) with NAIRAS
    - ARMAS TID is calibrated to the “gold-standard” TEPC (tissue equivalent proportional counter) using NSRL, LANSCE, LLUMC, LLNL beam lines
    - ARMAS distributes updated dose rate information with 15-minute latency

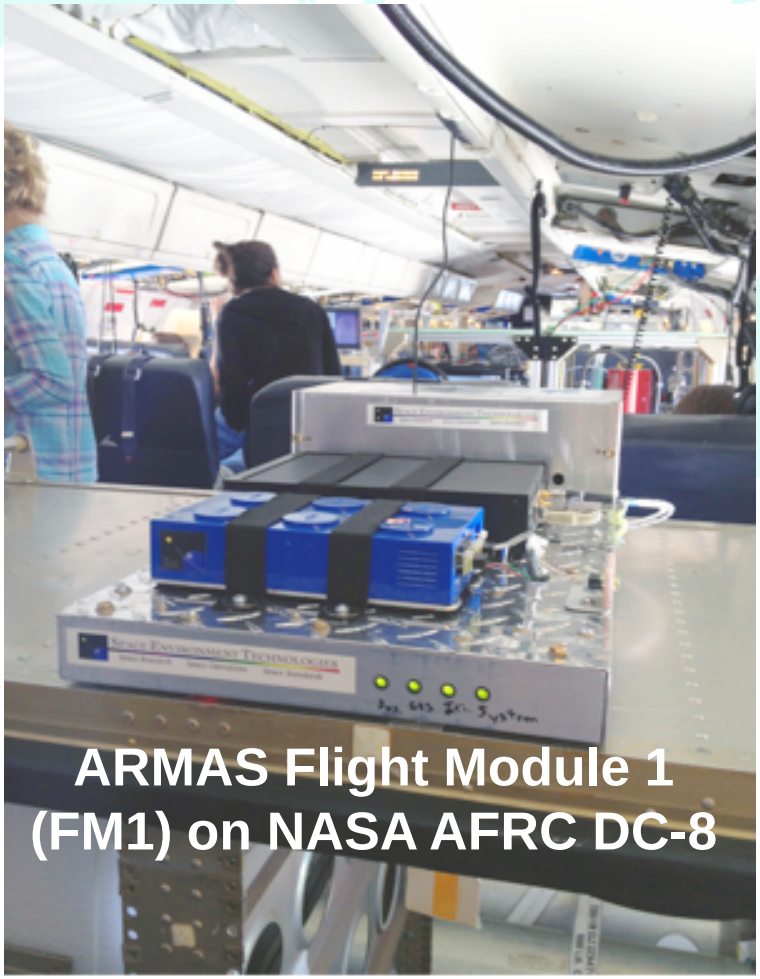
Real-time global aviation radiation climatology



Real-time local aviation radiation measurements

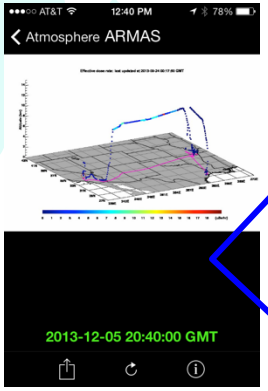


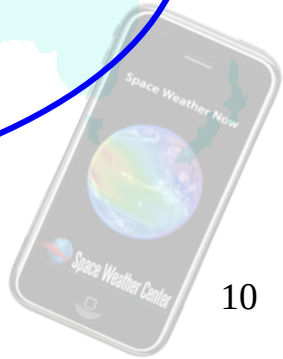
Real-time measurement demonstrations


ARMAS Flight Module 1 (FM1) on NASA AFRC DC-8

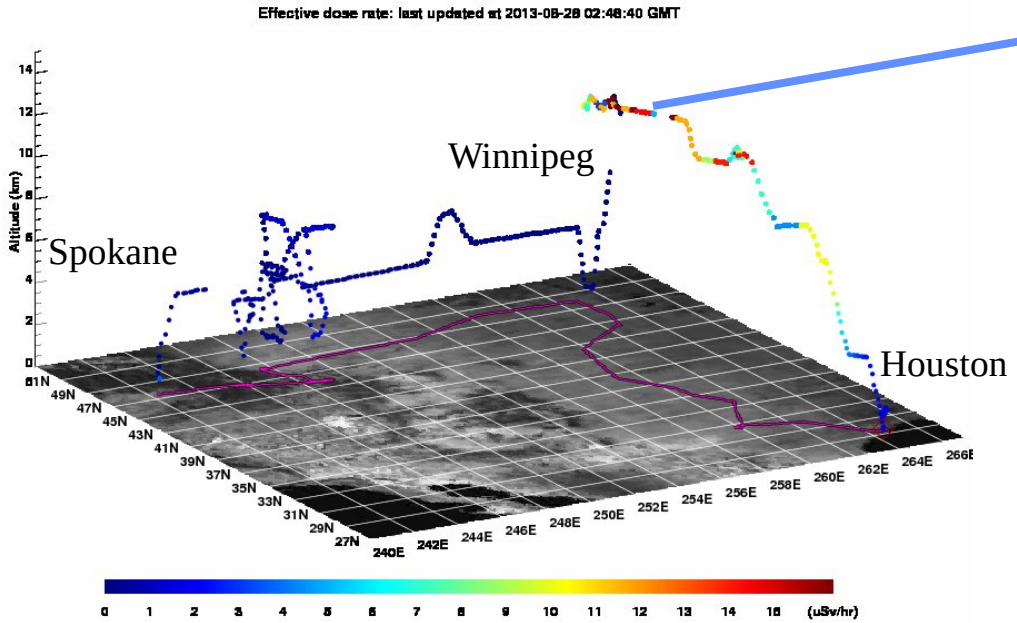
ARMAS Phase II

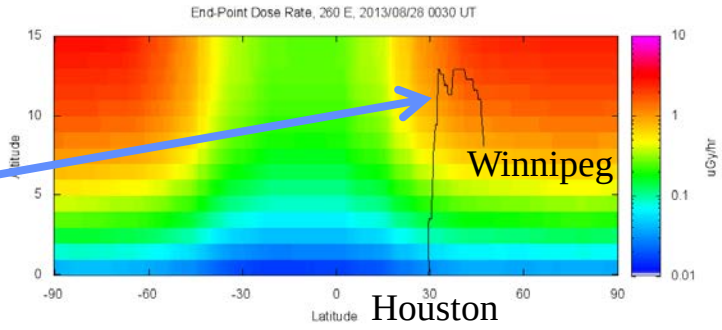
- 60+ FM1 DC-8 flights 2013-2015

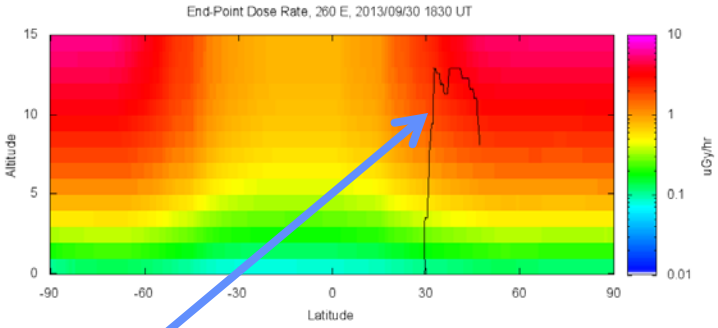


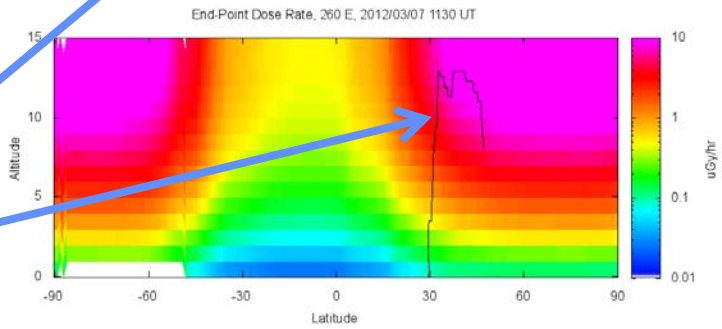


ARMAS FM1 (2013-2015) – flight 18 example



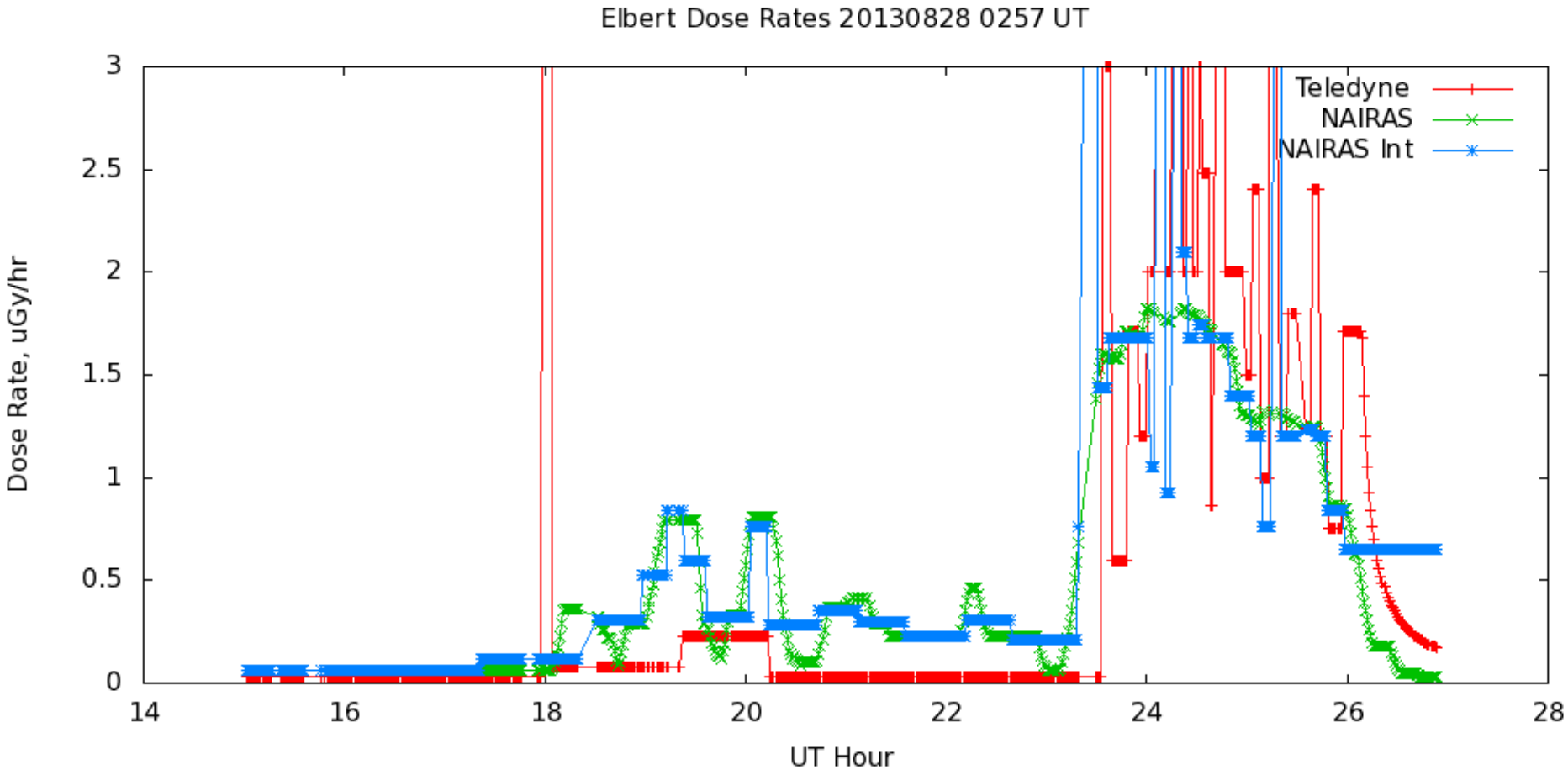






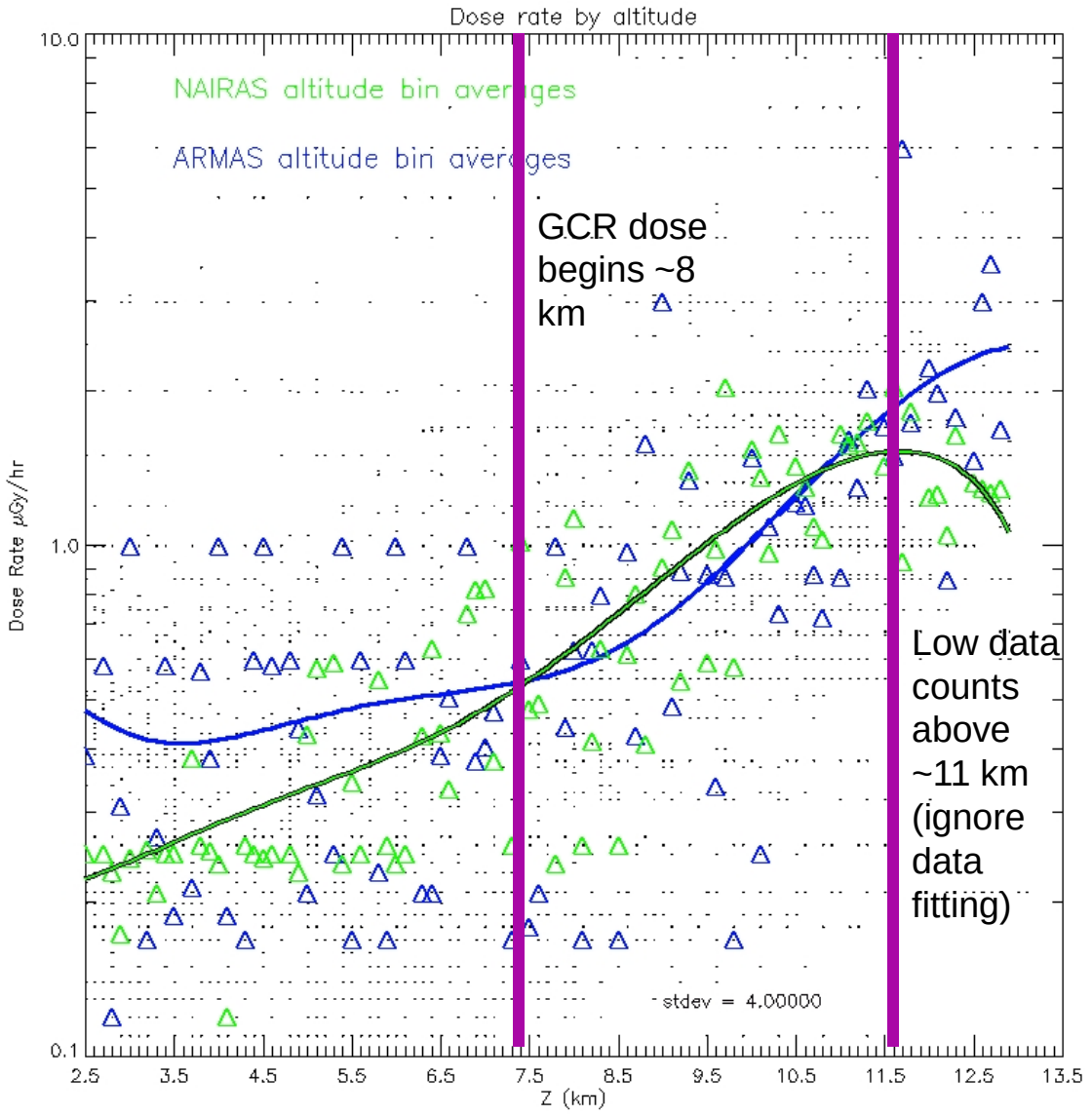
- **Top:** ARMAS flight 18 (August 28, 2013)
- **Middle:** S2 event (September 30, 2013)
- **Bottom:** S3 event (March 7, 2012)

Typical FM1 flight profile (flight 18)



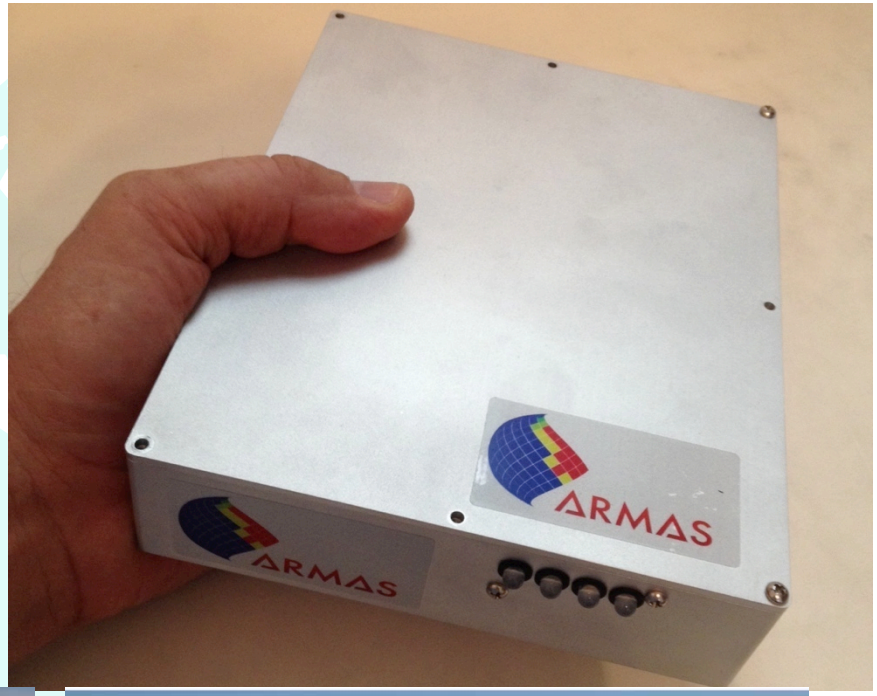
ARMAS FM1 FLIGHT SUMMARY

- 60+ flights during high to moderate solar activity (May 2013 to Aug 2015)
- All data are from GCR radiation with no SEPs
- ARMAS has validated NAIRAS for the FL260 to FL400 range



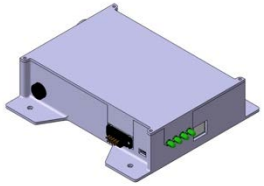
ARMAS FM2 Deployments in 2015

- Korea Space Weather Center purchased two FM2s as part of ARMAS Phase IIE commercialization
- FM2s were deployed to NOAA G4 and NSF G5 in Feb-Mar 2015
- Data became available to the community starting in June 2015 from the NOAA G4



ARMAS FM3 Deployment in 2015

- NASA Armstrong Flight Research Center has acquired one FM3 as part of ARMAS Phase III commercialization
- Deployment on the ER-2 in June 2015
- Data will be available to the community beginning Q3 2015



ARMAS FM4

Deployment

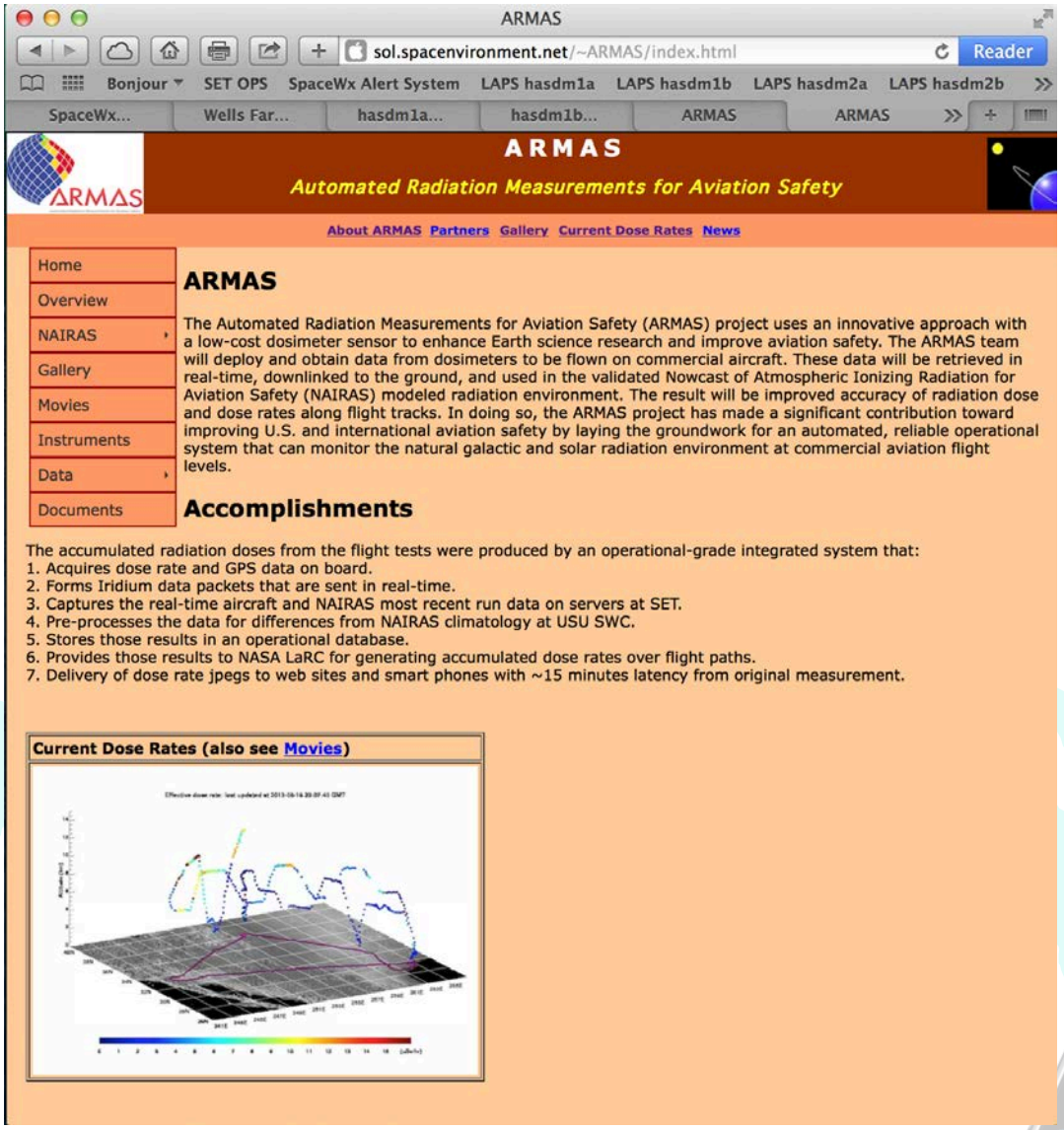
- Stratospheric balloon flights starting in 2016 under MOU between World View and SET
- Data will be extended to ~40 km as a World View pathfinder payload

Credit: World View

ARMAS FM5 on business jets in 2015

- FM5 has micro dosimeter, GPS, Iridium, and Bluetooth in a form factor similar to a smart phone
- altitude range up to 16 km on business jets
- personal dose exposure reported in a global context providing situational awareness
- Provides SEP event flight exposure management options
- FAA compliant (stand-alone unit with no attachment to plane)

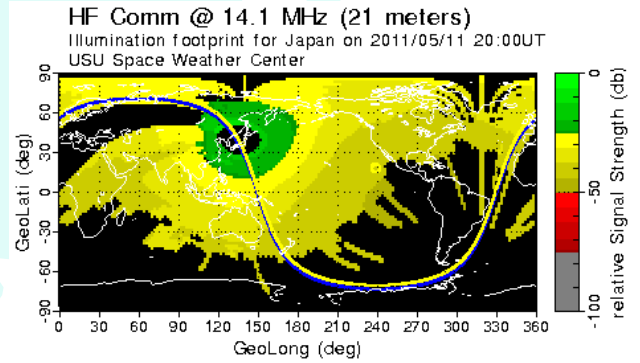
Real-time Automated Radiation Measurements for Aerospace Safety (ARMAS) website

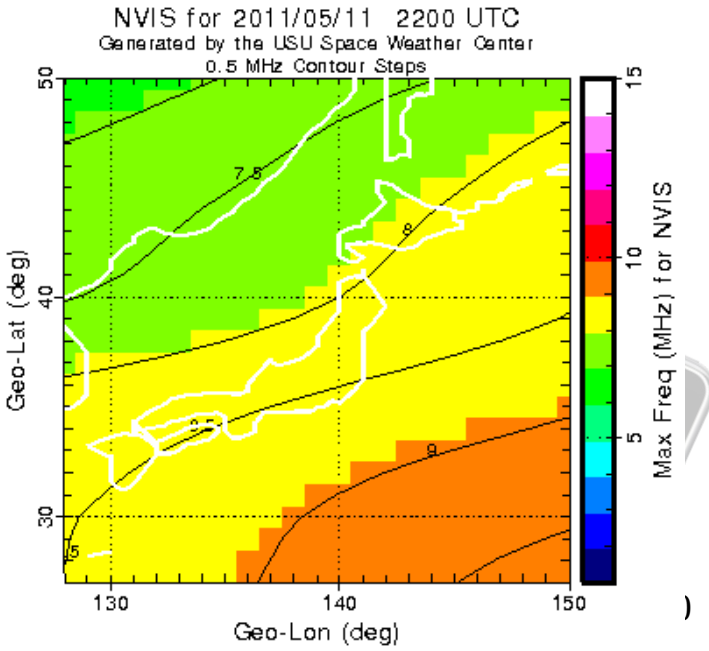


Example 2: Radio communication disruption management

HF communication link frequencies are now accurately calculated using the "real" ionosphere

- Frequencies available to transmit from point-to-point (ground-to-aircraft enroute)
- 3-hour forecasts of available frequencies are provided
- Recommended available frequencies can be used by HF comm operators
- Emergency Conditions available HF frequencies are highlighted





Flight Plan Communications

HF NAT route communication example

4 strongs station-frequencies

01/20/2012 01:00UTC	NEW_YORK_A_05598	NEW_YORK_E_06628	GANDER_D_04675	GANDER_A_05598
01/20/2012 02:00UTC	NEW_YORK_A_05598	NEW_YORK_A_03000	NEW_YORK_E_06628	NEW_YORK_A_13306
01/20/2012 03:00UTC	NEW_YORK_A_03000	NEW_YORK_A_05598	NEW_YORK_A_08906	GANDER_D_04675
01/20/2012 04:00UTC	NEW_YORK_A_03000	GANDER_F_03476	NEW_YORK_A_05598	GANDER_A_03016
01/20/2012 05:00UTC	NEW_YORK_A_03000	GANDER_A_03016	GANDER_F_03476	GANDER_D_04675
01/20/2012 06:00UTC	GANDER_A_05598	ICELAND_D_04675	GANDER_A_03016	GANDER_F_03476
01/20/2012 07:00UTC	ICELAND_B_02899	SHANWICK_F_03476	SHANWICK_A_03016	SHANWICK_D_04675
01/20/2012 08:00UTC	ICELAND_B_02899	ICELAND_D_04675	SHANWICK_A_03016	SHANWICK_F_03476
01/20/2012 09:00UTC	SHANWICK_F_03476	SHANWICK_D_04675	SHANWICK_A_03016	ICELAND_D_04675
01/20/2012 10:00UTC	SHANWICK_A_05598	SHANWICK_F_06622	SHANWICK_A_08906	SANTA_MARIA_A_13306

Time of Calculation: 01/20/2012 21:00UTC

2012	1	20	1	0	-118.20	34.00	-88.	-88.	-90.	-90.
2012	1	20	2	0	-111.00	41.50	-86.	-87.	-88.	-88.
2012	1	20	3	0	-100.00	46.80	-82.	-83.	-84.	-85.
2012	1	20	4	0	-86.00	51.10	-79.	-83.	-83.	-84.
2012	1	20	5	0	-72.40	55.10	-78.	-79.	-79.	-81.
2012	1	20	6	0	-47.70	61.10	-79.	-79.	-80.	-80.
2012	1	20	7	0	-21.80	64.00	-74.	-78.	-79.	-80.
2012	1	20	8	0	-6.90	62.00	-75.	-79.	-79.	-79.
2012	1	20	9	0	-0.60	51.30	-75.	-75.	-78.	-84.
2012	1	20	10	0	12.50	41.70	-81.	-84.	-87.	-91.

-- For Another Run --

Enter Flight Plan

#Latitude,Longitude,Date (MM/DD/YYYY),Time (24:00)
34.0,-118.2,01/20/2012,01:00
41.5,-111.0,01/20/2012,02:00
46.8,-100.0,01/20/2012,03:00
51.1,-86.0,01/20/2012,04:00
55.1,-72.4,01/20/2012,05:00
61.1,-47.7,01/20/2012,06:00
64.0,-21.8,01/20/2012,07:00
62.0,-6.9,01/20/2012,08:00
51.3,-0.6,01/20/2012,09:00
41.7,12.5,01/20/2012,10:00

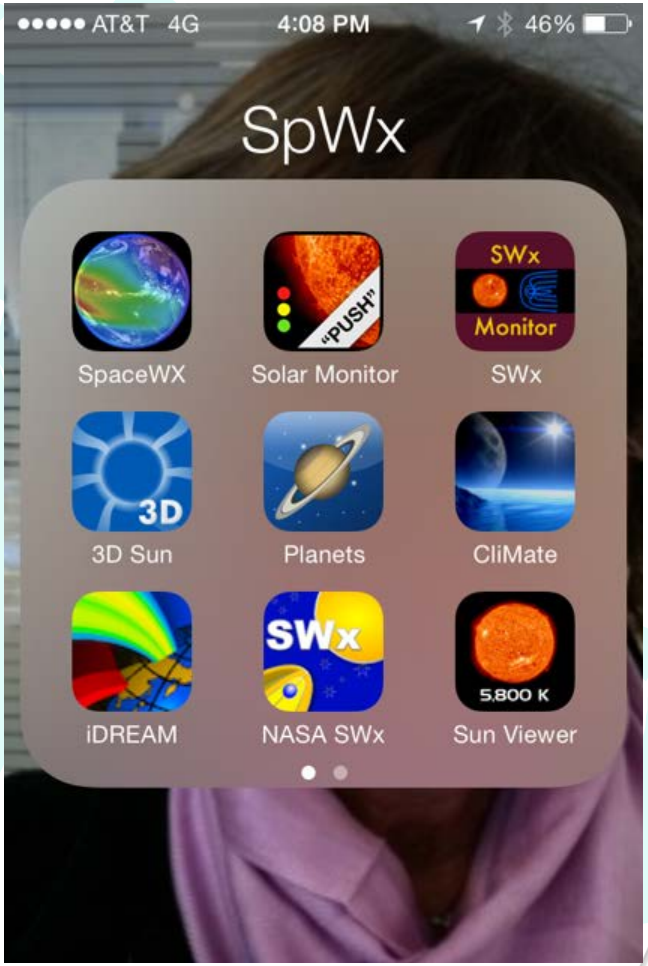
Submit

Milestones Achieved in Operational Space Weather

- All major agencies now have space weather activities
- American Commercial Space Weather Association (ACSWA formed in 2010) now has 20 companies
- ***Space Weather Journal*** is a peer review publication (15 years old)
- OSTP now planning space weather risk mitigation across all agencies
- Space weather support has moved from a purely science activity in 2000 to information and decision tool use by multiple industries in 2015 (aviation, sat ops, power, oil/gas, navigation, communication)

How you can access real-time space weather

SpaceWeather app for iPhone, iPad and *SpaceWx* app for Android



Credit: USU SWC & SET