Space Weather Division

Progress towards mitigating space weather effects in aviation

NTSB August 26, 2015

W. Kent Tobiska President and Chief Scientist Space Environment Technologies http://spacewx.com

Tobiska

http://spacewx.com

Space Weather Division

Space weather is moving beyond <u>understanding</u> (2000) into <u>tailored risk management</u> (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)

NTSB and Space Weather

-60

VPL

R

Space Weather Division



Space Weather Division

Example 1: Aviation radiation environment specification

NTSB and Space Weather

Space Weather Division

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
- W Crew, frequent flyers, fetuses in first trimester are the most at-risk populations
 - o 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

NTSB and Space Weather

Space Weather Division

Steps towards aviation radiation management What can be done about it?

- **W** 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)

Tobiska

NTSB and Space Weather

Space Weather Division

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
- w ICAO can set standards and guidelines for event identification
- w 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

NTSB and Space Weather

Space Weather Division

Steps towards aviation radiation management

- What is currently being done?

- **w** 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

NTSB and Space Weather

Space Weather Division

Real-time global aviation radiation climatology

Real-time local aviation radiation measurements





Tobiska

http://spacewx.com



Space Weather Division

Real-time measurement demonstrations





ARMAS Phase II

• 60+ FM1 DC-8 flights 2013-2015

Tobiska

http://spacewx.com



Tobiska

http://spacewx.com



Space Weather Division

Typical FM1 flight profile (flight 18)

Elbert Dose Rates 20130828 0257 UT



NTSB and Space Weather

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



NTSB and Space Weather

Space Weather Division

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







Tobiska

http://spacewx.com

NTSB and Space Weather

Space Weather Division





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

Tobiska

SPACE Environment Technologies

-

Space Weather Division



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

NTSB and Space Weather

Space Weather Division

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)



RMAS T

NTSB and Space Weather

Space Weather Division

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

		+ 3 sol.spacenvi	ironment.net/~AF	RMAS/index.html		C	Reader
🗋 🎹 Bonjou	r 🔻 SET OPS	SpaceWx Alert System	LAPS hasdm1a	LAPS hasdm1b	LAPS hasdm2a	LAPS has	dm2b >>
SpaceWx	Wells Far	hasdm1a	hasdm1b	ARMAS	ARMA	s »	+ 100
	ý	Automated Radiat	ARMA	S ents for Aviat	ion Safety		İ
Home							
Overview	ARMAS						
Overview NAIRAS	ARMAS The Automated a low-cost dosi	d Radiation Measureme imeter sensor to enhan	nts for Aviation Sa ice Earth science r	afety (ARMAS) pro	ject uses an innov ove aviation safety	ative appro	ach with S team
Overview NAIRAS Gallery	ARMAS The Automated a low-cost dosi will deploy and real-time, dow	d Radiation Measureme imeter sensor to enhan d obtain data from dosi inlinked to the ground,	nts for Aviation Sa the Earth science r meters to be flowr and used in the va	afety (ARMAS) pro esearch and impro n on commercial ai alidated Nowcast c	ject uses an innov ove aviation safety ircraft. These data of Atmospheric Ion	ative appro The ARMA will be retr izing Radiat	ach with S team ieved in tion for
Overview NAIRAS Gallery Movies	ARMAS The Automated a low-cost dosi will deploy and real-time, dow Aviation Safety and dose rates	d Radiation Measureme imeter sensor to enhan d obtain data from dosii nilinked to the ground, y (NAIRAS) modeled ra a along flight tracks. In	nts for Aviation Sa ice Earth science r meters to be flowr and used in the v diation environme doing so, the ARM	afety (ARMAS) pro- esearch and impro- o on commercial ai alidated Nowcast co nt. The result will IAS project has ma	ject uses an innov ove aviation safety ircraft. These data of Atmospheric Ion be improved accur ade a significant co	ative appro The ARMA will be retr izing Radiat racy of radia ontribution	ach with S team ieved in tion for ation dose toward
Overview NAIRAS Gallery Movies Instruments	ARMAS The Automated a low-cost dosi will deploy and real-time, dow Aviation Safety and dose rates improving U.S. system that ca	d Radiation Measureme imeter sensor to enhan d obtain data from dosi nilniked to the ground, y (NAIRAS) modeled ra a along flight tracks. In and international avia n monitor the natural g	ints for Aviation Sa ice Earth science r meters to be flowr and used in the va diation environme doing so, the ARM tion safety by layi galactic and solar	afety (ARMAS) pro- essearch and impro- n on commercial ai alidated Nowcast of nt. The result will IAS project has ma- ng the groundworf- radiation environm	ject uses an innov proraft. These data of Atmospheric Ion be improved accur ade a significant co k for an automatee nent at commercial	ative appro The ARMA will be retr izing Radia particular ontribution d, reliable o I aviation fli	ach with S team ieved in tion for ation dose toward perational ight
Overview NAIRAS Gallery Movies Instruments Data	ARMAS The Automated a low-cost dosi will deploy and real-time, dow Aviation Safety and dose rates improving U.S. system that ca levels.	d Radiation Measureme imeter sensor to enhan d obtain data from dosi inlinked to the ground, y (NAIRAS) modeled ra s along flight tracks. In . and international avia an monitor the natural g	nts for Aviation Sa cce Earth science r meters to be flowr and used in the v diation environme doing so, the ARM tion safety by layi galactic and solar	afety (ARMAS) pro esearch and impro o no commercial ai alidated Nowcast c nt. The result will IAS project has ma ng the groundwork radiation environm	ject uses an innov ove aviation safety ircraft. These data of Atmospheric Ion be improved accur ade a significant co k for an automated ent at commercial	ative appro . The ARMA will be retr izing Radiat racy of radia ontribution d, reliable o I aviation fli	ach with S team ieved in tion for ation dose toward perational ight

1. Acquires dose rate and GPS data on board.

- 2. Forms Iridium data packets that are sent in real-time.
- 3. Captures the real-time aircraft and NAIRAS most recent run data on servers at SET.
- 4. Pre-processes the data for differences from NAIRAS climatology at USU SWC.
 - 5. Stores those results in an operational database.
 - 6. Provides those results to NASA LaRC for generating accumulated dose rates over flight paths.
 - 7. Delivery of dose rate jpegs to web sites and smart phones with ~15 minutes latency from original measurement.



NTSB and Space Weather

Space Weather Division

Example 2: Radio communication disruption management

NTSB and Space Weather

Space Weather Division

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

<u>ionosphere</u>

- 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



Space Weather Division

Flight Plan Communications

HF NAT route communication example

4 strongs station-frequencies

01/20/	2012	01:00	OUTC		NEW_YORK_P	A_05598	NEW_YOR	K_E_06628	GA	NDER_D_046	75 GANDER_A_05598	
01/20/	2012	02:00	OUTC		NEW_YORK_P	A_05598	NEW_YOR	K_A_03000	NEW_	YORK_E_066	28 NEW_YORK_A_13306	
01/20/3	2012	03:00	OUTC		NEW_YORK_A_0300		NEW_YORK_A_05598		NEW_YORK_A_08906		06 GANDER_D_04675	
01/20/	2012	04:00	OUTC		NEW_YORK_A_03000		GANDER_F_03476		NEW_YORK_A_05598		98 GANDER_A_03016	
01/20/	2012	05:00	OUTC		NEW_YORK_P	A_03000	GANDER_A_03016		GANDER_F_0347		76 GANDER_D_04675	
01/20/3	2012	06:00	OUTC		GANDER_A_05598		ICELAND_D_04675		GANDER_A_0301		16 GANDER_F_03476	
01/20/3	2012	07:00	OUTC		ICELAND_B_02899 SHANWICK_F_03476		SHANWICK_A_03016		<pre>16 SHANWICK_D_04675</pre>			
01/20/	2012	08:00	OUTC		ICELAND_F	3_02899	ICELAN	D_D_04675	SHANWICK A 03		SHANWICK_F_03476	
01/20/3	2012	09:00	OUTC		SHANWICK I	03476	SHANWIC	K_D_04675	SHANWICK A 030		16 ICELAND_D_04675	
01/20/3	2012	10:00	OUTC		SHANWICK #	05598	SHANWIC	K_F_06622	SHAN	WICK A 089	06 SANTA MARIA A 13306	
Ti	me oi	f Calo	culati	ion:	01/20/2012	2 21:00UTC						
											Enter Flight Plan	
											#Latitude,Longitude,Date (MM/DD/YYYY),Time (24:00)	
2012	1	20	1	0	-118.20	34.00	-88.	-88.	-90.	-90.	41.5,-111.0,01/20/2012,01:00 41.5,-111.0,01/20/2012,02:00	
2012	1	20	2	0	-111.00	41.50	-86.	-87.	-88.	-88.	46.8,-100.0,01/20/2012,03:00 51.1,-86.0,01/20/2012,04:00	
2012	1	20	3	0	-100.00	46.80	-82.	-83.	-84.	-85.	55.1,-72.4,01/20/2012,05:00 61.1,-47.7,01/20/2012,06:00	
2012	1	20	4	0	-86.00	51.10	-79.	-83.	-83.	-84.	64.0,-21.8,01/20/2012,07:00 62.0,-6.9,01/20/2012,08:00	
2012	1	20	5	0	-72.40	55.10	-78.	-79.	-79.	-81.	51.3,-0.6,01/20/2012,09:00 41.7,12.5,01/20/2012,10:00	
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												
9/	/4/20	15				Tobiska	http://	SpaceWx.co	om	21	Submit	
2.		-						1		-		

NTSB and Space Weather

Space Weather Division

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)



Space Weather Division

How you can access realtime space weather SpaceWeather app for iPhone, iPad and SpaceWx app for Android



Credit: USU SWC & SET

http://spacewx.com