Federal Aviation Administration

DOT/FAA/AM-18/6
Office of Aerospace Medicine
Washington, DC 20591

MIRA 2017: A CARI-7 Based Solar Radiation Alert System

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July 2018

Final Report

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AM-18/6		

4. Title and Subtitle	5. Report Date
MIRA 2017: A CARI-7 Based Solar Radiation Alert System	July 2018
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Copeland K	

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
FAA Civil Aerospace Medical Institute P.O. Box 25082 Oklahoma City, OK 73125	11. Contract or Grant No.

12. Sponsoring Agency name and Address	13. Type of Report and Period Covered
Office of Aerospace Medicine Federal Aviation Administration 800 Independence Ave., S.W. Washington, DC 20591	14. Sponsoring Agency Code

15. Supplemental Notes

16. Abstract

The Federal Aviation Administration's Civil Aerospace Medical Institute Aeromedical Research Division has operated an advisory Solar Radiation Alert System (SRAS) since 2002. This report describes the third and latest significant upgrade of the system software, known as Maps of Ionizing Radiation in the Atmosphere or MIRA. While retaining all the expected standard outputs from SRAS and its most recent successor, the Enhanced SRAS (ESRAS), the revisions include a complete conversion to using CARI-7 for calculations of solar and galactic cosmic radiation dose rates, an extension of standard output to a vertical cutoff rigidity of 15 GV, and the development of a new capability to automate e-mailing of alert messages and related files to potential users.

17. Key Words	18. Distribution Statement
Solar Radiation Alert System, CARI-7, MIRA, ionizing radiation, in-flight exposure, space weather	Document is available to the public through the Internet: http://www.faa.gov/go/oamtechreports/

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	13	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGMENTS

The author would like to give special thanks to Marc Davidson of the CAMI Knowledge Management Research Team and Ron Keller of the CAMI Numerical Sciences Research Team for writing Python and PowerShell scripts used in MIRA.

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INTRODUCTION

The National Oceanic and Atmospheric Administration's (NOAA) National Weather Service provides data based on high-energy proton flux measurements made with instruments on board its Geostationary Operational Environment Satellites (GOES). The instrument suite for these measurements has changed very little since GOES-5 began providing data in the mid 1980s. The NOAA's Space Weather Prediction Center in Boulder, Colorado, provides proton flux data in near-real-time (ftp://ftp.swpc.noaa.gov/pub/lists/). Alpha particle flux data are made available later. The new GOES-R series has a much-expanded particle flux instrument suite and will be capable of providing energetic particle flux data for many more ions. These new data will create an opportunity for a more complete analysis of the solar cosmic radiation (and possibly also the galactic cosmic radiation) environment at geostationary orbits.

Studies of atmospheric dose rates during large solar proton events indicate the possibility of doses exceeding limits recommended for pregnant crewmembers for a single flight at altitudes commonly used by commercial carriers (Dyer et al., 2003; Copeland et al., 2008). FAA regulations currently require those operating flights at high latitudes to have a plan of action in place in the event of extreme space weather, such as a large solar proton event (CFR, 2017). The Solar Radiation Alert system (SRAS) was developed at the Federal Aviation Administration's Civil Aerospace Medical Institute by the Radiobiology Research Team (since merged into the Numerical Sciences Research Team) and provides advisory information on dose rates at altitudes as high as 70000 ft. due to incident solar particles during these extreme space weather events (Copeland et al., 2005). The SRAS was updated in 2008 and capability to provide map layer data was added in 2014 (Copeland et al., 2009; Copeland, 2016). The solar spectrum evaluation routine used in SRAS and ESRAS will be inadequate for the new GOES data stream, as it uses only proton data as an input stream.

Also, several years of feedback suggests some improvements beyond ESRAS would be well received by users:

a) Global dose rate calculations that incorporate both galactic and solar cosmic radiation contributions,
b) Provision of alternative means of sending the data to users besides via the NOAA NWWS,
c) Incorporation of global anisotropy of particle flux incidence via neutron monitor data analysis,
d) Expansion of analysis of primary solar particles to more than just energetic protons,
e) A more intuitive/interactive visual display of the data than was provided by ESRAS,
f) Use of the most modern methods for spectrum to dose conversions, and
g) More extensive use of space weather scales.

The Maps of Ionizing Radiation in the Atmosphere (MIRA) update to ESRAS as described below follows the plan previously presented in (Copeland, 2012). It directly addresses items *a*, *b*, *f*, and *g*, while holding the capability to immediately incorporate solutions to items *d* and *e*. Item *c* and another improvement, the inclusion of Forbush effects in the galactic cosmic radiation dose rates, require reliable sources of real-time neutron monitor data streams to solve by existing methods and will likely be addressed together in a future update to MIRA when such data becomes available.

DESCRIPTION

Summary

MIRA provides a global picture of the current cosmic radiation levels in the atmosphere at altitudes from 20000 ft. up 70000 ft. MIRA operates on a workstation running the Microsoft Windows 7 ™ operating system. The process for issuing solar radiation alert messages remains the same as SRAS (Figure 1) (Copeland et al, 2009). MIRA is a collection of Microsoft PowerShell ™ and DOS batch scripts, along with compiled Fortran95 programs. Communications with NOAA to retrieve GOES data and send alerts is handled by the scripts. The main compiled elements are *MIRA2017* and *CARI-7 (*a reduced option version of *CARI-7A*) (Copeland, 2017). There are also some compiled utility programs. These are all controlled by a master script, *RunMIRA.BAT* (see Appendix A).

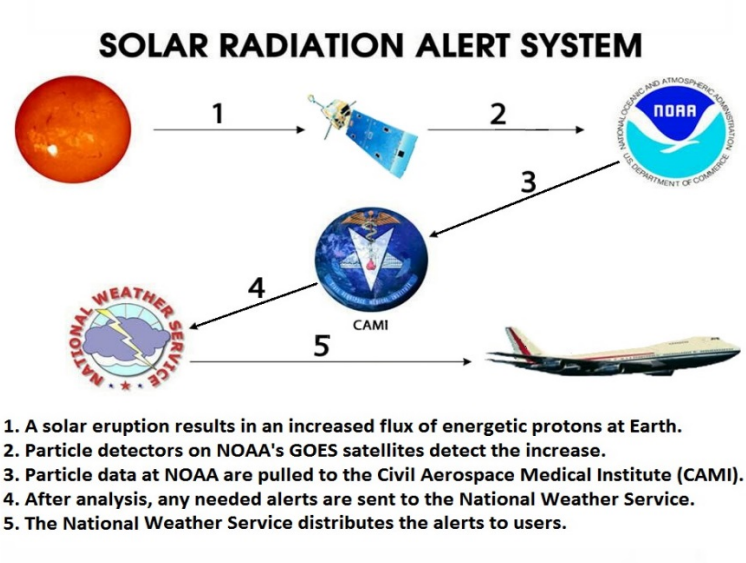

Figure 1. The Solar Radiation Alert system

NOAA Weather Wire Service Messages

Messages sent to the NOAA Weather Wire Service are unchanged from the prevision versions, i.e., an alert is issued if the alert trigger condition for solar particle dose rate is exceeded during 3 consecutive 5-minute periods and cancelled when the trigger condition is unmet for 6 consecutive 5-minute periods. The trigger condition is a estimated solar cosmic radiation dose rate at a location

with no geomagnetic shielding of 20 microsieverts per hour at an atmospheric depth of 73.13 g/cm^2 (equivalent to altitude of 60000 ft.).

Dose Rate Calculations

For each of the 6 most recent 5-minute periods in the GOES data, the solar particle spectrum is calculated from the GOES data using *MIRA2017*, then *CARI-7* is used to calculate dose rates from both solar and galactic cosmic radiation (Copeland, 2014; 2017; FAA**,** 2017). The solar spectrum and all solar calculation results are then archived. The galactic cosmic radiation calculations use the International Standards Organization (ISO) primary galactic cosmic radiation spectrum, ISO 15390:2004, modulated by the most recent monthly average heliocentric potential (ISO, 2004; O'Brien et al., 2003). Text files are then created from the dose rate output files which can then be used to build custom map layers, including D indices (Meier and Matthiä, 2014). The archived files for each 5-min period are identified by the naming convention *G*XX*on*YYYMMDD*at*ZULU.ZZZ where XX indicates which satellite (11 for primary, 10 for secondary), YYYY is the year, MM the month, DD the day of the month, ZULU is the hour and minute in coordinated universal time (UTC), and ZZZ designates which kind of data is in the file:

ZZZ = *sep* is an archive of the solar energetic particle spectrum
ZZZ = *csv* is a solar dose rates on a world grid, with D index
ZZZ = *sdf* is an archive of solar cosmic radiation dose rates calculated by CARI-7
ZZZ = *gdf* is an archive of galactic cosmic radiation dose rates calculated by CARI-7
ZZZ = *cdf* is a table of which combines the solar and galactic cosmic radiation dose rates, with D index, organized by altitude and vertical cutoff rigidity.

Table 1 shows solar particle dose rates calculated by the original version of ESRAS, a revised ESRAS using exactly the same fluence-to-effective dose conversion coefficients as the latest release of CARI-7 and a corrected solar particle spectrum generator, and *CARI-7* as implemented in MIRA using the same spectrum generator. The same GOES data sets and galactic cosmic ray background particle fluxes are used for each method. Dose rates are shown for some periods during the solar proton event of 11 September 2017 and for normal solar activity conditions (i.e., a solar proton event was not in progress) two weeks later, along with the galactic cosmic radiation dose rate calculated using *CARI-7*. Solar cosmic radiation dose rates calculated by MIRA are very similar to those calculated by the current version ESRAS, except at the lowest cutoff rigidity.

Table 1. Effective dose rates from cosmic rays during and 10 days after the solar proton event of 11 Sept. 2017, at locations of 0 GV, 1 GV, and 2 GV effective cutoff rigidity.

Date and time	Altitude, ft. x 1000	Original ESRAS Solar, μSv/h	Revised ESRAS Solar, μSv/h	MIRA Solar, μSv/h	CARI-7 Galactic, μSv/h
			0 GV		
	60	1.92E+01	3.71E+00	6.60E+00	1.82E+01
2017 09 11 at 1700 UT	40	2.29E+00	5.52E-01	8.07E-01	8.25E+00
	20	1.17E-01	3.11E-02	5.23E-02	1.46E+00
	60	1.57E+01	3.32E+00	5.60E+00	1.82E+01
2017 09 11 at 2000 UT	40	1.96E+00	5.82E-01	7.44E-01	8.25E+00
	20	1.02E-01	3.32E-02	4.76E-02	1.46E+00
	60	1.11E+01	1.89E+00	3.65E+00	1.82E+01
2017 09 11 at 2300 UT	40	1.23E+00	2.18E-01	3.67E-01	8.25E+00
	20	5.95E-02	8.84E-03	2.01E-02	1.46E+00
	60	1.48E-01	4.02E-02	4.31E-02	1.82E+01
2017 09 25 at 2300 UT	40	2.30E-02	1.20E-02	1.12E-02	8.25E+00
	20	1.38E-03	8.62E-04	8.86E-04	1.46E+00
			1 GV		
	60	1.63E+01	1.24E+00	1.23E+00	1.78E+01
2017 09 11 at 1700 UT	40	1.96E+00	2.55E-01	2.75E-01	8.15E+00
	20	1.08E-01	2.08E-02	2.39E-02	1.44E+00
	60	1.33E+01	1.32E+00	1.27E+00	1.78E+01
2017 09 11 at 2000 UT	40	1.69E+00	3.45E-01	3.17E-01	8.15E+00
	20	9.50E-02	2.50E-02	2.49E-02	1.44E+00
	60	9.31E+00	3.99E-01	4.21E-01	1.78E+01
2017 09 11 at 2300 UT	40	1.03E+00	4.12E-02	5.16E-02	8.15E+00
	20	5.40E-02	2.74E-03	3.40E-03	1.44E+00
	60	1.43E-01	3.57E-02	3.26E-02	1.78E+01
2017 09 25 at 2300 UT	40	2.24E-02	1.14E-02	1.01E-02	8.15E+00
	20	1.35E-03	8.37E-04	8.13E-04	1.44E+00
			2 GV		
	60	3.40E-01	2.34E-01	2.43E-01	1.58E+01
2017 09 11 at 1700 UT	40	1.32E-01	1.09E-01	1.08E-01	7.61E+00
	20	1.17E-02	1.10E-02	1.24E-02	1.39E+00
	60	4.29E-01	3.70E-01	3.21E-01	1.58E+01
2017 09 11 at 2000 UT	40	1.76E-01	1.65E-01	1.23E-01	7.61E+00
	20	1.40E-02	1.29E-02	1.10E-02	1.39E+00
	60	0.00E+00*	1.94E-03	2.03E-03	1.58E+01
2017 09 11 at 2300 UT	40	0.00E+00*	8.61E-04	8.02E-04	7.61E+00
	20	0.00E+00*	7.13E-05	7.57E-05	1.39E+00
	60	1.25E-02	1.35E-02	1.18E-02	1.58E+01
2017 09 25 at 2300 UT	40	5.12E-03	6.02E-03	4.51E-03	7.61E+00
	20	4.07E-04	4.72E-04	4.04E-04	1.39E+00

[A] Uncorrected SRAS proton spectrum has no >2 GV solar fluence for this 5-minute period.

E-mail Send Option for Alert Messages

To handle sending e-mail versions of the text alert messages generated by the system, a PowerShell ™ script is started simultaneously with the main script. Message files placed into its target directory are sent to a list of subscribers and copied to an archive of sent files.

DISCUSSION

The SRAS disseminates information to the public through the NOAA Weather Wire Service (NWWS) as text files (Copeland et al., 2005; 2009) and has operated almost continuously since its inception. This will continue through MIRA. The publishing of up-to-date maps available to the public envisioned for ESRAS has proven difficult to keep operational from a research facility inside the FAA's secure computing firewall, due to evolving security requirements. Efforts are underway to resolve these issues through an interagency agreement with NOAA related to the nation's Space Weather Operations, Research, and Mitigation (SWORM) activities (http://SWORM.GOV). When the agreement is enacted, this may result in system operation moving to a server at the Space Weather Prediction Center, resulting in the system being integrated into their product set much more fully than it can be now, via only the NWWS and e-mail list.

While both solar and galactic cosmic radiation exposures should be considered in crewmember exposure assessments, alerts are issued based on the solar cosmic radiation because of its potential for extreme variability. Effective dose rates from galactic cosmic radiation can normally exceed the threshold of 20 microsieverts per hour (μSv/h) at high latitudes and altitudes for years at a time during solar minimum (Table 2). Including the galactic radiation in the alert trigger would result in prolonged alert conditions at those altitudes for some regions due to normal radiation exposure conditions present.

Table 2. Effective dose rates calculated for selected altitudes from galactic cosmic radiation with CARI-7 for the three most recent solar minima (maximum monthly average galactic dose rates during the last three solar cycles).

Altitude,	Effective dose rate, μSv/h		
ft. x 1000	March 1987	March 1997	October 2009
70	24.6	22.9	26.4
60	18.6	17.4	19.8
50	13.0	12.3	13.7

As expected, solar cosmic radiation is much less penetrating than is galactic, dose rates increase much faster as altitude increases and are much more sensitive to geomagnetic shielding. When MIRA's solar dose rates are compared with those from older SRA systems, dose rates are not the same (Table 1). The small differences between MIRA and the current ESRAS are the result of differences in spectral interpolation and binning. The reason for the large differences between dose rates calculated by the older and current versions of ESRAS was a bug in ESRAS found and corrected during the development of the multi-particle capable spectrum generator for MIRA. The bug did not influence dose rate calculations during solar proton events with count rates increased

above pre-event backgrounds measured in all channels. However, as seen in Table 1, it could significantly influence dose rates during a solar proton event coincident with a Forbush decrease, as was the case on September 11. The bug usually increased the total dose rate but sometimes decreased it, depending on the most affected channels.

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APPENDIX A: MAIN SCRIPT

The main script, *RunMIRA.BAT*, is shown below. The programs and subscripts called are briefly explained in the comments of the script.

RunMIRA.BAT

```
echo off
rem Except as noted, all programs written by Kyle Copeland
rem This bat file runs the FAA Solar Radiation Alert system.
rem echo off
:LOOP
rem cls
rem If this is the backup machine the latest serial number
rem and conditions are in alert.txt from the CAMI ftp site
rem copy c:\alert\alert.txt
echo off
rem Clean up old outgoing files to NWWS.
rem echo
del prodswxaltpav.txt
del g11pch.txt
del g10pch.txt
del g11par.txt
del g10par.txt
rem Get the proton data files from the SWPC via ftp
rem ftp_script.txt has ftp data and commands to run DOS ftp
call ftp -s:ftp_script.txt
echo off
rem current SWPC proton data source designations are:
rem PRIMARY data are in Gp*.txt: current satellite GOES-13
rem SECONDARY data are in Gs*.txt: current satellite GOES-15
rem
rem Default designations in MIRA/ESRAS/SRAS are:
rem PRIMARY is GOES-11, SECONDARY is GOES-10
rem
rem A rewrite of MIRA spectral analysis will be needed when
rem NOAA switches to GOES-R series instruments as they have
rem a different particle instrument suite and include multiple ions.
echo
ren Gs_pchan_5m.txt g10pch.txt
ren Gp_pchan_5m.txt g11pch.txt
ren Gs_part_5m.txt g10par.txt
ren Gp_part_5m.txt g11par.txt
rem
rem Files must be converted to read them correctly
rem They come in Unix format
rem This unix2dos is part of dos2unix v 7.1.1 and is used under the
rem a FreeBSD style license
rem See http://www.freebsd.org/copyright/freebsd-license.html
unix2dos g11pch.txt
unix2dos g10pch.txt
unix2dos g11par.txt
unix2dos g10par.txt
rem echo off
rem
rem "fixalert" creates a new alert.txt if the file on the CAMI
rem server site is destroyed, which for unknown reasons,
```

```
rem sometimes happens.
rem echo
fixalert64
rem echo off
rem The following copy statements are needed only if data
rem from only 1 GOES satellite is available from SWPC
rem for long term use (e.g., instrument failure, no backup
rem source).
rem
rem copy g11par.txt g10par.txt
rem copy g11pch.txt g10pch.txt
rem
rem MIRA analyses the proton data files and writes any
rem alert messages. It must have good copies of the file
rem alert.txt and the 4 g*.txt files to run.
echo
rem “NEWLOC” updates MIRA.LOC data file for CARI with
rem current time and date NOAA files
NEWLOC
rem Update gcr Forbush factor when neutron monitor data are obtainable
rem (unfortunately not now)
rem FORBUSH
rem Calculate current galactic cosmic radiation using CARI-7
CARI7
move /Y MIRA.ANS MIRA_GCR.ANS
rem Now use the solar data
MIRA2017
rem MIRA loads and runs CARI-7s 12 times, which can take while
rem CARI-7s is a reduced version of CARI-7 that should only be
rem used for solar particle spectra and locations lists, not flights!
rem (MIRA takes about 1 min on the SRAS primary workstation)
rem
rem Label and Show results from Primary satellite output
dir alert11.txt
type alert11.txt
rem
rem Label Show results from Secondary satellite output
dir alert10.txt
type alert10.txt
rem
rem Show MIRA output
type alert.txt
echo off
rem
rem Check if daily test message is sent
rem Program "runtest64" handles the daily test message.
rem A good copy of alert.txt must be present or it will hang the loop.
echo
runtest64
rem Copy ALERT.TXT to local drive as primary copy
copy alert.txt c:\alert\alert.txt
rem COPY ALERT.TXT to CAMI AAM network drive common space for backup
copy alert.txt o:\radiobio\web_up~1\alert.txt
echo off
rem A separate ps script (written by Ron Keller) running
rem concurrently will email any outgoing message to the user list
REM De-REM loop and last four lines to run the system
```

```
rem Solarpush.py (written by Marc Davidson) will SFTP-push messages
rem via NOAA Weather Wire Service gateway and then
rem wait a few minutes for NOAA SWPC to get new GOES data
c:\python27\python solarpush.py
if errorlevel 4 goto DONE
goto LOOP
:DONE
```