

First Steps toward the Verification of Models for the Assessment of the Radiation Exposure at Aviation Altitudes during Quiet Space Weather Conditions

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Abstract:

Space weather is an important driver of the exposure of aircrew and passengers to cosmic rays at flight altitudes. The assessment of the corresponding radiation doses can be realized by measurements or model calculations that cover the whole range of the radiation field in terms of geomagnetic shielding, atmospheric shielding, and the effects of space weather. Since the radiation field at aviation altitudes is very complex in terms of particle composition and energy distribution, the accurate experimental determination of doses at aviation altitudes is still a challenging task. Accordingly, the amount of data with comparatively small uncertainties is scarce. The Community Coordinated Modeling Center invited the Federal Aviation Administration, the German Aerospace Center, and the National Aeronautics and Space Administration to make their radiation models for aviation CARI-7A, PANDOCA, and NAIRAS available for interested users via the Community Coordinated Modeling Center web site. A concomitant comparison of model calculations with measuring data provided information on the predicting capabilities and the uncertainties of the current versions of these models under quiet space weather conditions.

Goal:

Investigation of measuring data from several publications in order to identify reliable high-quality dose rate measurements meeting strict criteria for a first comparison with CARI-7A (FAA), PANDOCA (DLR), and NAIRAS (NASA) model calculations.

Method

The comparison of model calculations d^{model} and measuring values d^{meas} was based on the relative deviation Δ of the investigated dose quantities:

$$\Delta_i = \frac{d_i^{model} - d_i^{meas}}{d_i^{meas}}$$

The index i indicates a particular data point as subset of the complete set of data points, i.e.

$$\Delta_{i,H*(10)} = \frac{d_{i,H*(10)}^{model} - d_{i,H*(10)}^{meas}}{d_{i,H*(10)}^{meas}} \text{ for the rate of the ambient dose equivalent } d_{H*(10)} = dH*(10)/dt \text{ and}$$

$$\Delta_{i,DSi} = \frac{d_{i,DSi}^{model} - d_{i,DSi}^{meas}}{d_{i,DSi}^{meas}} \text{ for the rate of the absorbed dose in silicon } d_{DSi} = dD_S/dt, \text{ respectively.}$$

Δ is positive, if the calculated model value is greater than the measuring value and vice versa.

$\bar{\Delta}$ is a more generalized assessment of the deviation between model calculations and measurements:

$$\bar{\Delta} = \frac{\sum_{i=0}^n |\Delta_i|}{n}$$

The corresponding quantities $\overline{\Delta_{H*(10)}}$ and $\overline{\Delta_{DSi}}$ were used for the evaluation of the models.

Measuring Data Selection Criteria

- Calibration:** the sources used to calibrate the instruments are traceable to a national standard.
- Operations:** the instruments were operated by the scientists themselves during the flights.
- Space Weather:** SEPs were not present and the Kp-index was not greater than 3 during the period when the data were taken, which is indicative of a virtually undisturbed magnetosphere.
- Independence:** measuring data were taken by at least two independent institutes during a flight for each selected data point.
- Deviation:** the individual measuring values did not deviate more than 5% from the average of all instruments for the ambient dose equivalent rate $dH*(10)/dt$ and not more than 10% for the rate of the absorbed dose in Silicon dD_S/dt .

Sources of Measuring Data

- CARMEL flight campaign (2007, close to solar minimum):
Wissmann, F., S. Burmeister, E. Dönsdorf, B. Heber, M. Hubiak, T. Klages, F. Langner, T. Möller, and M. Meier (2010), Field Calibration of Dosimeters Used for Routine Measurements at Flight Altitudes *Rad. Prot. Dosim.* **140** No. 4 pp. 319–325, doi:10.1093/rpd/ncq12810.1093/rpd/ncq128
- CONCORD flight campaign (2013, close to solar maximum):
Meier, M. M., F. Trompeter, I. Ambrozova, J. Kubancak, D. Matthiä, O. Ploc, N. Santen, and M. Wirtz (2016) CONCORD: Comparison of Cosmic Radiation Detectors in the Radiation Field at Aviation Altitudes *J. Space Weather Space Clim.* **6**, doi:10.1051/swsc/2016017

Models

CARI-7A (Civil Aeromedical Research Institute)

Copeland, K. (2017), CARI-7A: Development and Validation. *Rad. Prot. Dosim.* **178**(4): 419–431, doi:10.1093/rpd/ncw369

PANDOCA 2.0.0 (Professional Aviation DOse Calculator)

Matthiä, D., M. M. Meier, and G. Reitz (2014), Numerical calculation of the radiation exposure from galactic cosmic rays at aviation altitudes with the PANDOCA core model. *Space Weather* **12** 161–171, doi:10.1002/2013SW001022

NAIRAS 2.0 (Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS))

Mertens, C. J., M. M. Meier, S. Brown, R. B. Norman, and X. Xu (2013), NAIRAS aircraft radiation model development, dose climatology, and initial validation, *Space Weather* **11** 603–635, DOI:10.1002/swe.20100

Results

The numerical results of the comparison of the three models with the selected measuring data in terms of the relative deviation Δ are given in Table 1 for the ambient dose equivalent rate $dH*(10)/dt$ and in Table 2 for the absorbed dose rate in silicon dD_S/dt . The uncertainties of the measuring values are assumed to be on the order of 5% for the ambient dose equivalent rate $dH*(10)/dt$ and on the order of 10% for the rate of the absorbed dose in Silicon dD_S/dt , respectively. Furthermore, the relative deviation Δ between model calculations and measuring data is depicted in Figure 1 for the ambient dose equivalent rate $dH*(10)/dt$ and in Figure 2 for the absorbed dose rate in silicon dD_S/dt . The uncertainties of the measurements are indicated by the shaded areas. The comparison of the model calculations with the selected dose rate measurements indicates that the upper limit of the uncertainties of the model calculations is on the order of some 20% over the range of the investigated part of the atmosphere for all models. This can be inferred from the general agreement between the measuring values and the model calculations within the overlap of the assumed uncertainties. The mean deviations $\overline{\Delta_{H*(10)}}$ and $\overline{\Delta_{DSi}}$ between measuring data and model calculations are given in Table 3.

Table 1: Comparison of the average ambient dose equivalent rates $dH*(10)/dt$ in $\mu\text{Sv/h}$

i	$dH*(10)/dt$ measured	$\Delta_{\text{CARI-7A}}$	Δ_{PANDOCA}	Δ_{NAIRAS}
1	4.3 ± 0.4	-8%	-3%	15%
2	4.9 ± 0.4	6%	14%	52%
3	9.0 ± 0.6	-3%	2%	8%
4	5.8 ± 0.3	-6%	-6%	-21%
5	4.2 ± 0.3	5%	12%	27%
6	7.7 ± 0.5	-6%	-3%	-14%

Table 2: Comparison of the average absorbed dose rates in silicon dD_S/dt in $\mu\text{Gy/h}$

i	dD_S/dt measured	$\Delta_{\text{CARI-7A}}$	Δ_{PANDOCA}	Δ_{NAIRAS}
7	2.4 ± 0.1	0%	-11%	-12%
8	1.2 ± 0.1	10%	5%	33%
9	2.0 ± 0.1	11%	-1%	-13%
10	1.3 ± 0.1	11%	9%	35%

Table 3: Mean deviations $\overline{\Delta_{H*(10)}}$ and $\overline{\Delta_{DSi}}$ between measuring data and model calculations

Model	$\overline{\Delta_{H*(10)}}$	$\overline{\Delta_{DSi}}$
CARI-7A	6%	8%
PANDOCA	7%	7%
NAIRAS	23%	23%

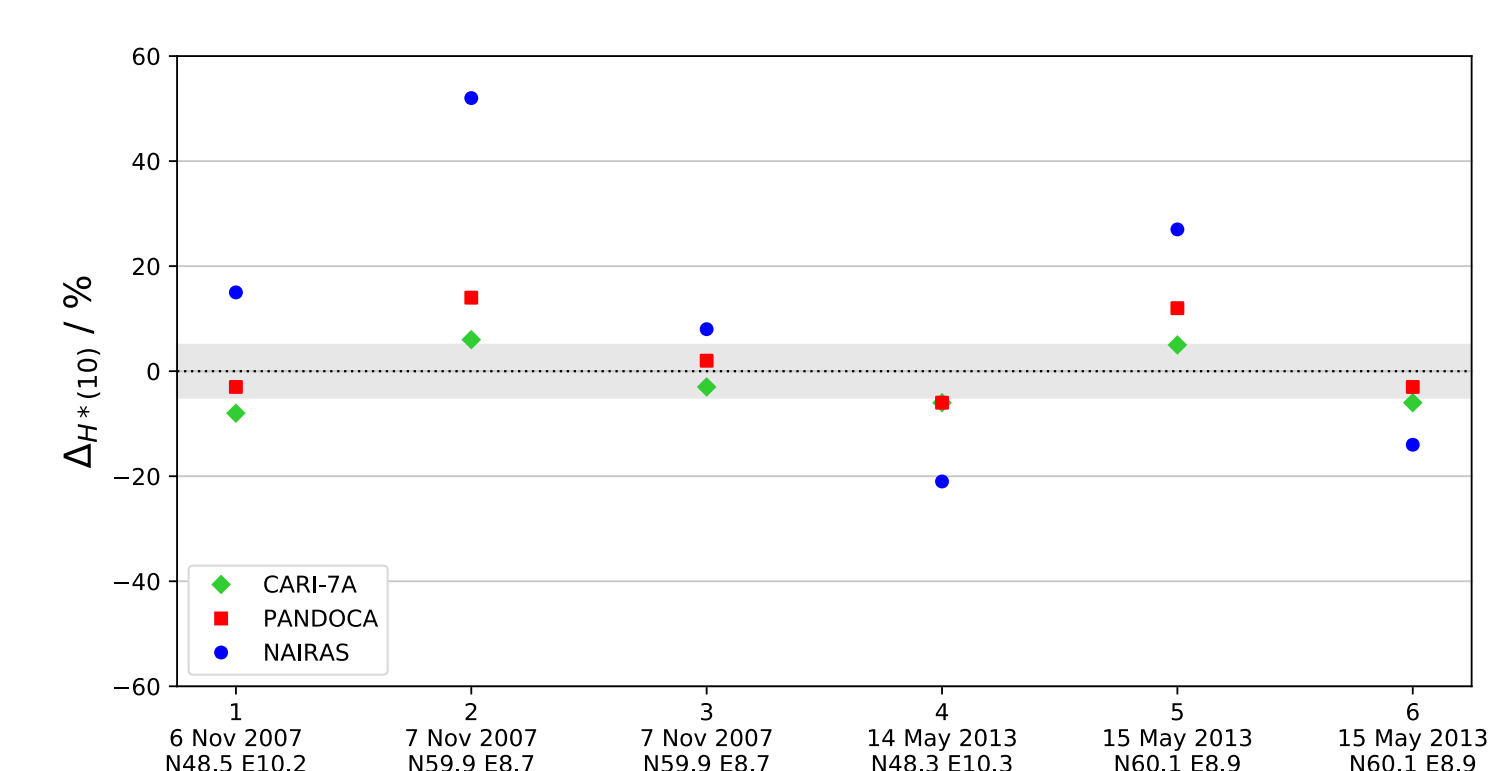


Figure 1: Relative deviation Δ between the model calculations and the measuring data for the ambient dose equivalent rate $dH*(10)/dt$.

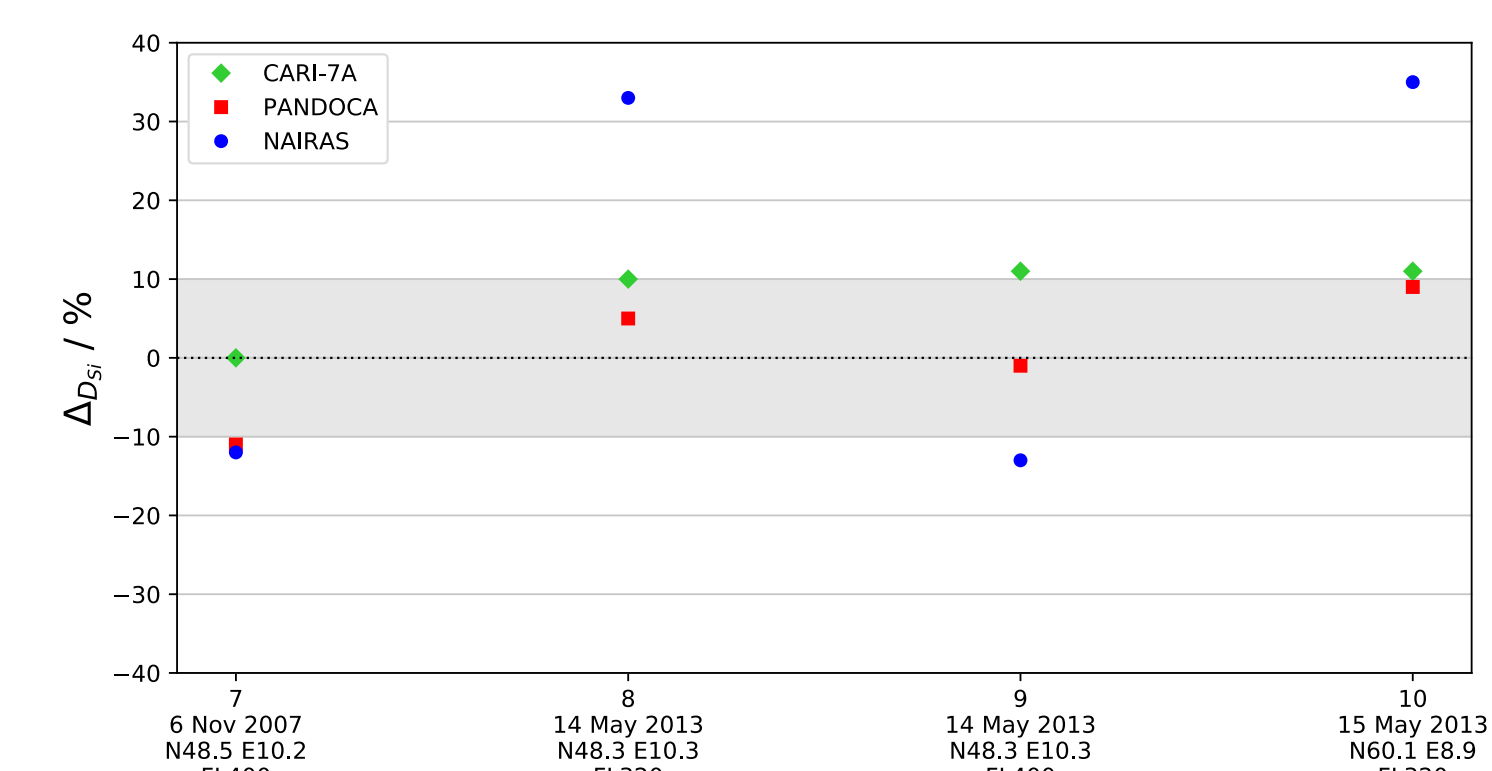


Figure 2: Relative deviation Δ between the model calculations and the measuring data for the absorbed dose rate in silicon dD_S/dt .

Conclusion

The first comparison of models that are designated to be implemented into the CCMC's web page, namely CARI-7, PANDOCA, and NAIRAS, with reliable dose rate measurements was based on data acquired during dedicated flight missions that were available from the literature and analyzed for compliance with strict quality criteria. The application of the chosen criteria for the selection of data revealed that only few data points could be identified for the comparison. All models show agreement with the measuring data within the uncertainties, the upper limit of which could be inferred from the comparison to be on the order of some 20% over the range of the investigated area of the atmosphere. This encouraging result will promote further cooperation between the participating organizations and help improve their models. Furthermore, the analysis of published measurements has underlined the need for high-quality measuring data, acquired under standardized conditions in terms of height, position, and space weather, covering the complete airspace of civil aviation.

Reference



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Key Points:
• CCMC, DLR, FAA, and NASA compare the performance of the radiation models CARI-7A, PANDOCA, and NAIRAS for the assessment of the radiation exposure at aviation altitudes.

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