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Intra-calibration of REACH Dosimeters

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Abstract

The Responsive Environmental Assessment Commercially Hosted (REACH) constellation is a set of 32 payloads hosted on a commercial LEO satellite constellation. This document discusses the intra-calibration activities completed between the individual dosimeters. The median doses measured within 5x5 degree bins within the south Atlantic anomaly (SAA) were determined. The radiation doses within this region are stable and thus provide a unique test bed for intra-calibration activities. It was found that the median dose rate of individual dosimeters for a given flavor were found to consistently be within ~20% of each other. When considering the entire distribution of dose-rates within a given bin is found to be <= 50%. However, this variation is due to the size of the bin and natural differences within that geographic location. Outside of the SAA larger variations are observed. These variations are due to time varying intensities of the LEO radiation environment at high latitude.

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1. Background on REACH

1.1 The REACH Constellation

The Responsive Environmental Assessment Commercially Hosted (REACH) constellation is a set of 32 payloads hosted on a commercial LEO satellite constellation. Each payload (pod) carries two dosimeters which were designed by The Aerospace Corporation and manufactured by Teledyne Microelectronics.

1.2 The Flavors of Dosimeters

There are a total of six unique measurements determined by the physical design of the dosimeter and the inert shielding around the dosimeter detector. We refer to the various measurements with the term "flavor", each of which have a different threshold for electrons and protons. The different flavors are associated with different space-weather hazards: for example, internal charging in the outer radiation belt and Single Event Effects in the inner proton belt or over the polar caps during solar particle events. The flavor designator and characteristics are shown in Table 1.

Table 1. The REACH Dosimeter Flavors, the Nominal Energy Threshold of Electrons and Protons it is Sensitive to, and the Number of Satellites Hosting that Flavor.

Flavor	Mils Mallory	~mils Al	Type	Nominal Electron MeV	Nominal Proton MeV	# of Satellites
Z	0	0	LowLET	0.05	0.2	6
Y	24	183	MedLET	1.6	31	12
X	0	32	MedLET	0.36	12	20
W	0	332	HiLET	-	12	14
V	56	383	MedLET	3.41	47	7
U	80	533	MedLET	4.97	57	5

1.3 Why Orbit Direction Matters

The dosimeters are located on the ram-nadir side of the Iridium-Next host as shown in Figures 1 and 2. The angle between the normal to the detector plane and the ram velocity is approximately 19 degrees. The effect of this is a systematic difference in the observed dose rates in the northern and southern hemispheres when the satellite is either northbound or southbound in latitude. This difference arises from the particle pitch angle response of the dosimeter detector defined in part by the minimum shielding normal to the detector plane. An example of this can be seen in Figure 3. Thus, in order to correctly compare the different satellites, it is important to take into account the orbital effects.

Figure 1. The Iridium satellites prior to launch.The REACH hosted payload is located inside the white hosted payload at the top of the satellite and circled in this figure. [1].

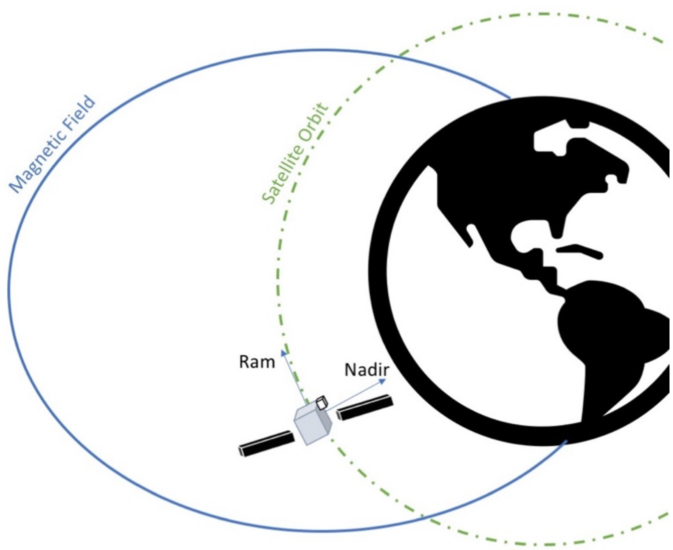


Figure 2. A cartoon of the satellite orbit relative to the field line.Due to the particle trajectories and the change of the field of view of the REACH dosimeters to the magnetic field line (the blue line) with respect to the orbit (green dotted line), REACH samples different pitch angles and portions of the trapped and lost particle populations during different parts of the orbit. This cartoon is not to scale.

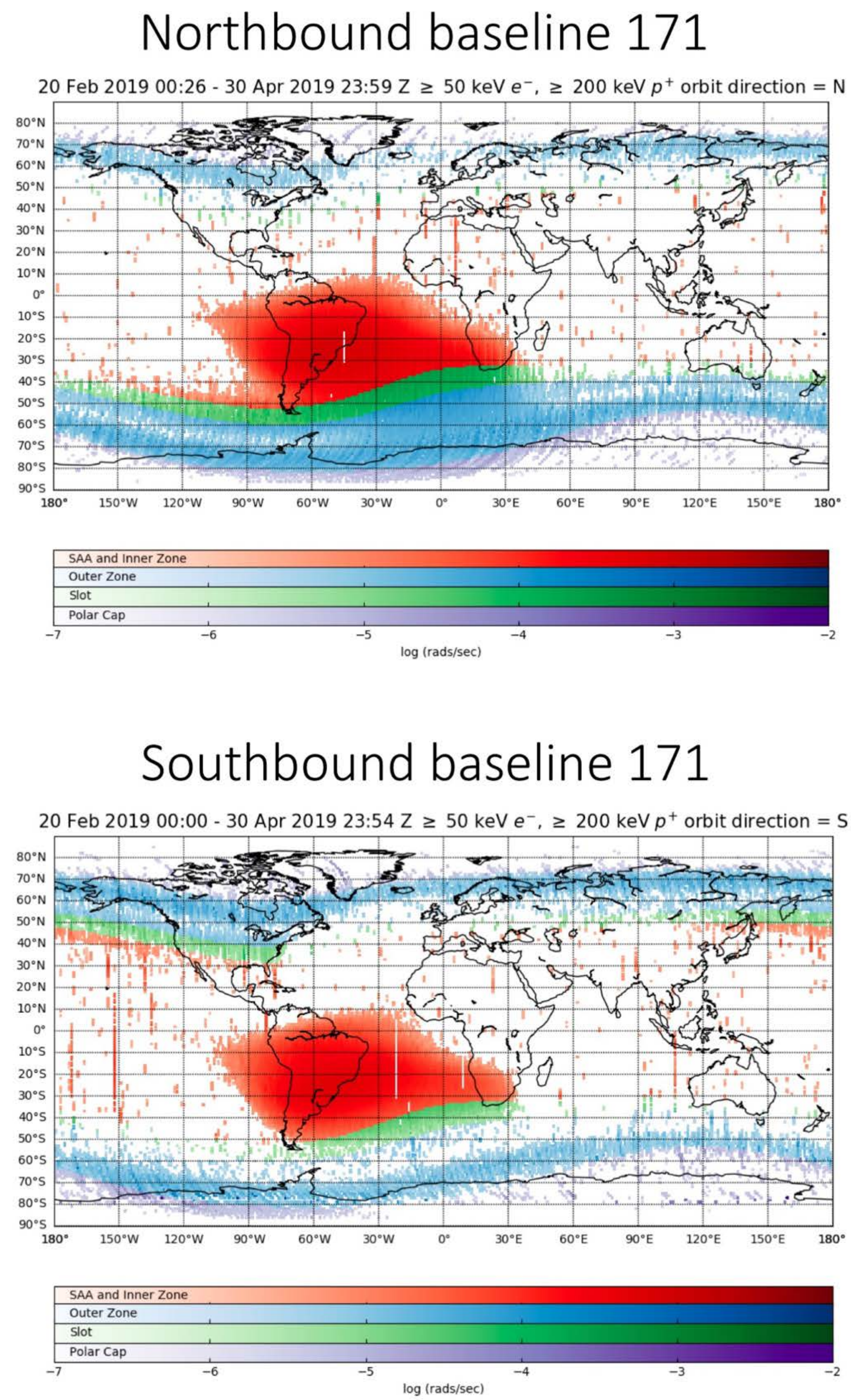


Figure 3. The baseline used for flavor Z with hosted payload number 171.The top panel is when the satellite is moving northwards, and the bottom panel is when the satellite is moving southwards. The values in the title are the nominal thresholds for the dosimeter. The color bars represent the different regions where specific types of space-weather are likely to occur. The red areas are the inner radiation belt and the south Atlantic anomaly (SAA). The green region is the slot, the blue region is the outer radiation belt, and the purple is the polar cap.

2. Creating the Baseline

2.1 The Length of Time Needed

There are both geographical and magnetospheric features which can be captured by the satellites in low Earth orbit (LEO). This includes features such as the SAA and the outer radiation belt. Thus, a significant period of time is necessary in order for the satellite's orbital precession to cover all regions. We use 40 days of near complete time coverage for all 32 satellites which provides ample coverage as shown in Figure 3. The period of February 20th–April 30th, 2019 was chosen as there were no solar energetic particle events and few data gaps during this period. The median for each 1x1 degree latitude/longitude bin is plotted using the color bar for the region which it is in. The inner zone and SAA are plotted using the red color bar, the slot in green, the outer radiation belt in blue, and the polar cap in purple.

2.2 Potential Issues and Plans for Updates to the Baseline

During the period of the baseline there was the expected and standard variability observed in locations such as the radiation belts. Future improvements and changes to the baseline can be determined as the use cases are tested and become better defined. For instance, if a threshold above which satellite anomalies are found to increase, this threshold can be used as the baseline instead of the maps in Figure 3. As the REACH mission continues, quiet days can be found and strung together and used as a baseline in a similar manner to how the Dst index is created [2].

3. Comparison Between Flavors

3.1 Global Comparison

In order to determine how well the dosimeter readings from each satellite compare we first plotted the percent difference between the satellites. For example, in Figure 4 we show the percentage difference between the median doses observed on average during the baseline interval for satellites 171 and 169. Satellite 171 is taken as the norm. Within the very stable SAA there are very little differences between the two satellites. Within the outer radiation belts more variations can be seen. This is due to the satellites observing temporal changes in the radiation environment while dwelling within those bins throughout those 40 days.

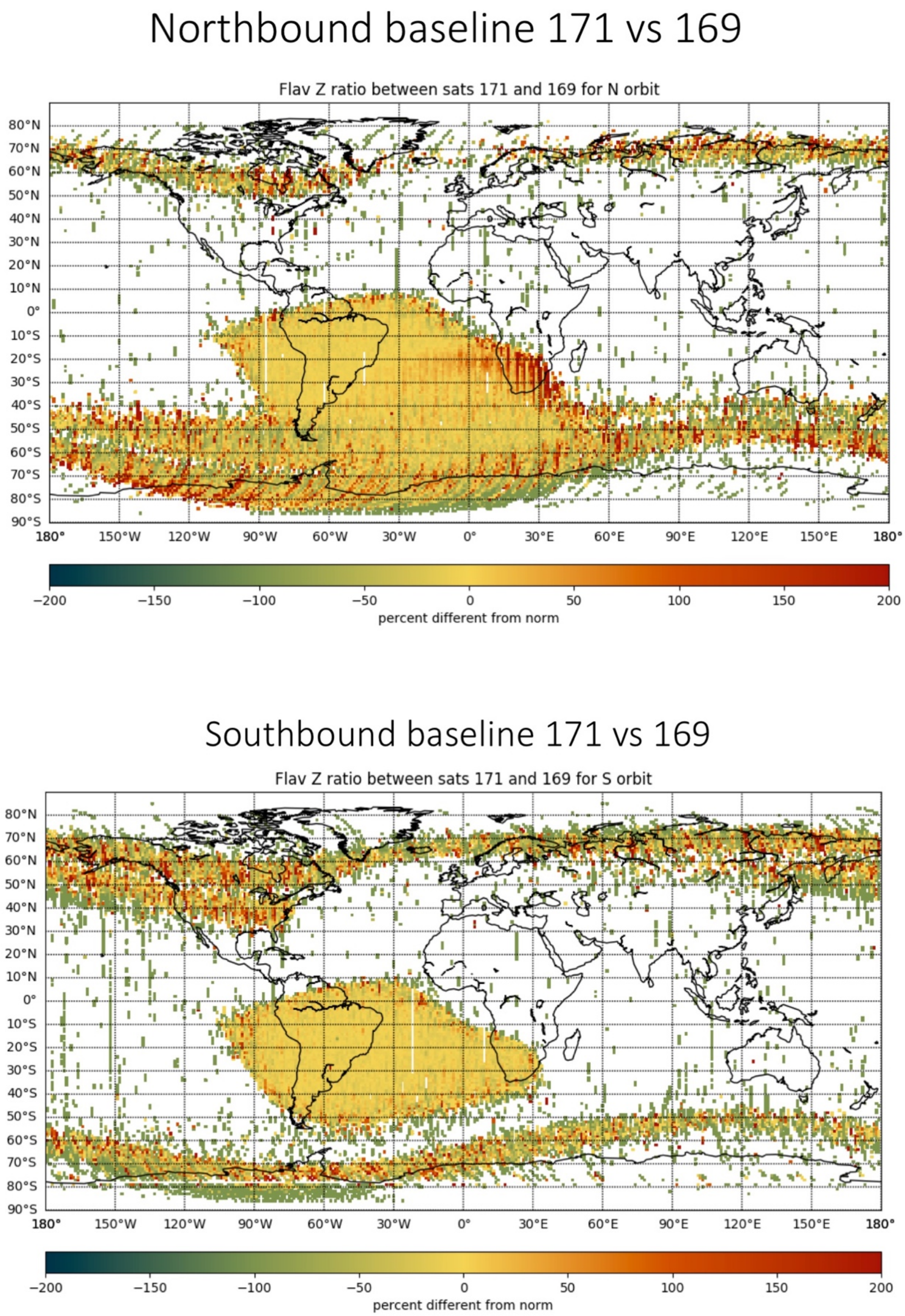


Figure 4. Intra-comparison between satellites 171 and 169 for flavor Z. Top panel shows the northbound orbits and the bottom panel shows the southbound orbits.

A closer look at the SAA in Figure 5 shows that the radiation environment within this region is stable. Figure 5 shows the standard deviation of the natural log of the medians from each flavor Z REACH pod. The white to green color shows where the standard deviation of the natural log is less than 0.2 (or about a 20% error).

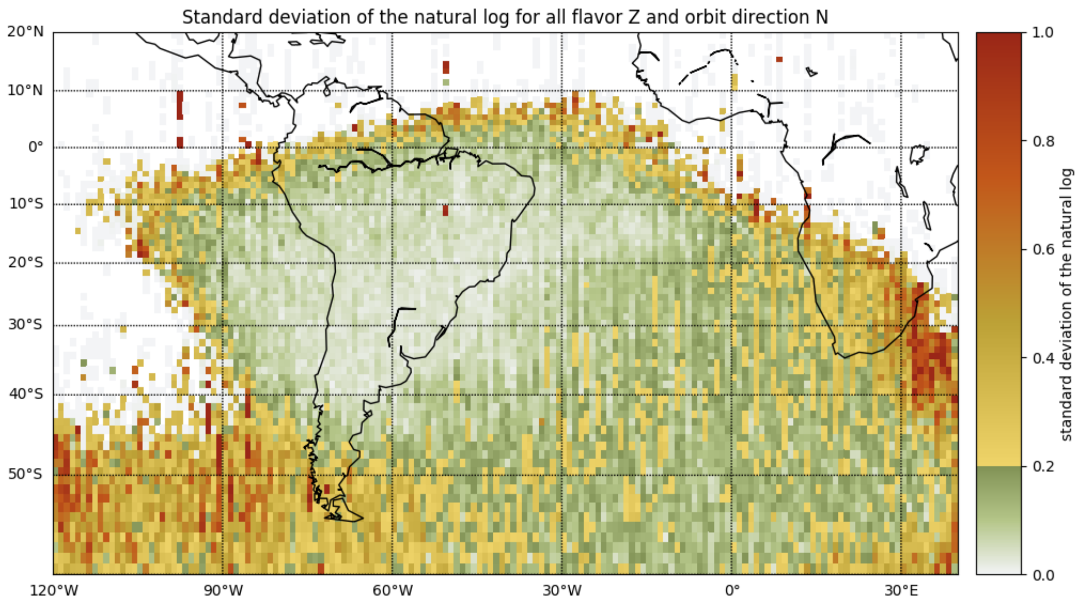


Figure 5. The standard deviation of the natural log of the medians between the Z flavor REACH pods when the orbit is going north.

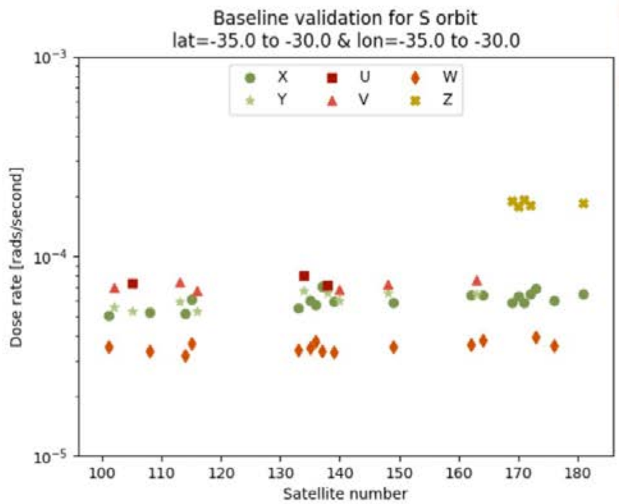
3.2 Individual Bin Comparisons

The maps give us a global quick overview of how the measurements compare. As each satellite visits a specific latitude-longitude bin at different times, it is prudent to look at the most stable bins for the direct inter-comparison. We show here the results from three 5 degree by 5-degree latitude/longitude bins located in the middle of the SAA. Figures 5–7 show, in the bottom right hand corner, a map with the bin considered highlighted in green. The left-hand plot shows the median dose rate in that bin for each satellite and flavor designated with a different symbol. The table included in the upper right-hand side contains the statistics for that bin by flavor. For each bin, the median dose rate for each flavor on each individual satellite is determined. The median dose from the satellite medians for the specified flavor within that bin is calculated (row 1), along with the standard deviation of the natural log for the medians (row 2). This value is not very statistically significant due to the few values used in its determination (e.g., 20 for flavor X). As the statistics are small when looking at the median dose for each flavor, we also consider statistics of all observations within the bin for a given flavor (rows 4 and 5).

As the standard deviation of the natural log of dose rates is small, it is approximately equivalent to the fractional error, for example a standard deviation of the natural log of 0.03 corresponds to an approximately 3% error. Using the standard deviation, however, assumes that the samples come from a normal or symmetric distribution. In order to check that this is true for our sample population, the skewness of the distribution is calculated for both the medians from the satellites (row 3) and for the entire distribution (row 5). A normal or symmetric distribution will have a skewness of 0, a half-normal distribution has a skewness just below 1 and an exponential distribution will have a skewness of 2. The sign of the skewness is related to the direction of the skew. A log-normal distribution, however, will always have a positive value. We see that the majority of flavors have a fairly symmetric distribution.

Thus, we are assured that the standard deviation of the natural log is an appropriate metric to use within the region of the SAA.

	Z	X	Y	U	V	W
Median mrads/sec of Satellites	0. 19	0. 06	0. 06	0. 07	0. 07	0. 03
Median's Stand. Dev. of the natural log	0.03	0.09	0.09	0.04	0.05	0.06
Median's Skewness	0.06	0.22	0.17	1.46	0.32	0.01
Stand. Dev. of the natural log	0.18	0.30	0.29	0.27	0.27	0.26
Skewness	0.38	0.25	0.05	0.35	0.16	0.22



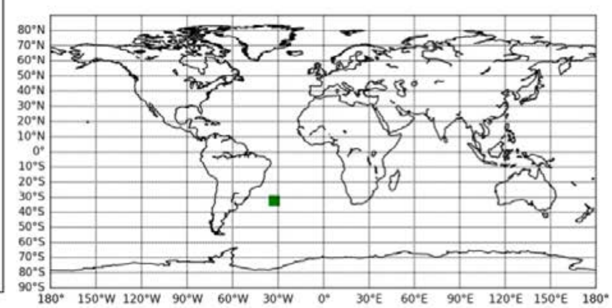
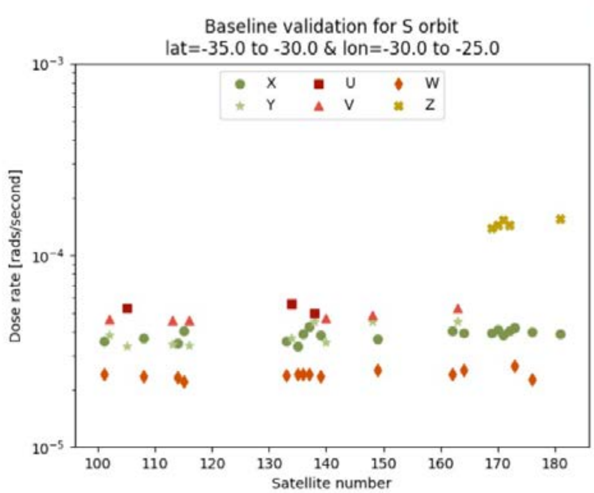


Figure 6. Intra-calibration for all satellites and flavors for the latitude longitude bin of -35 to 30 latitude and -35 to -30 longitude.

	Z	X	Y	U	V	W
Median mrads/sec of Satellites	0. 14	0. 04	0.04	0.05	0. 05	0. 02
Median's Stand. Dev. of the natural log	0.04	0.06	0.12	0.5	0.05	0.05
Median's Skewness	1.15	-0.45	1.00	0.14	1.39	-0.005
Stand. Dev. of the natural log	0.19	0.36	0.40	0.34	0.32	0.28
Skewness	0.21	0.29	0.43	0.08	0.54	0.33



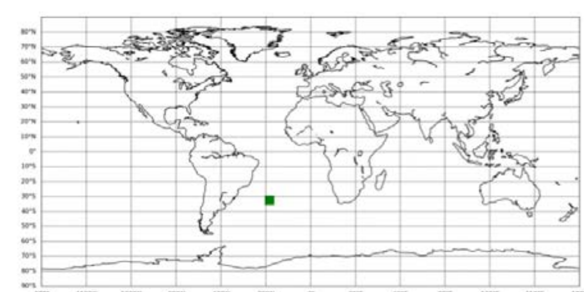
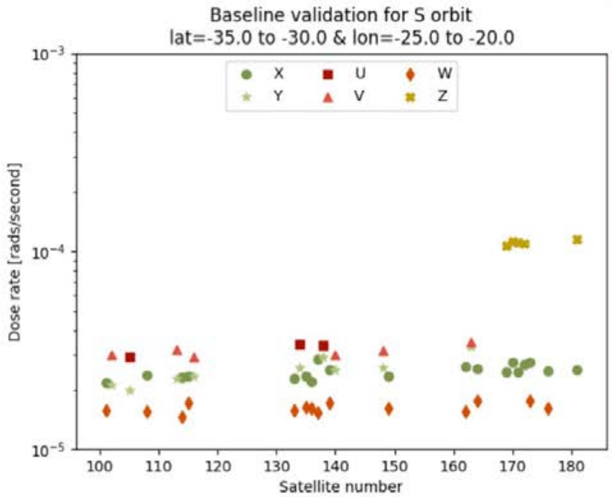


Figure 7. Intra-calibration for all satellites and flavors for the latitude longitude bin of -35- to 30 latitude and -30 to -25 longitude.

	Z	X	Y	U	V	W
Median mrads/sec of Satellites	0.11	0. 02	0. 02	0. 03	0. 03	0. 02
Median's Stand. Dev. of the natural log	0.03	0.08	0.15	0.06	0.06	0.05
Median's Skewness	0.66	0.26	-0.13	-1.8	0.68	0.34
Stand. Dev. of the natural log	0.18	0.37	0.41	0.36	0.36	0.32
Skewness	0.24	0.50	0.31	0.24	0.45	0.35



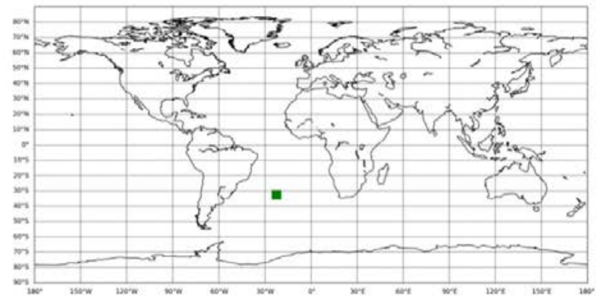


Figure 8. Intra-calibration for all satellites and flavors for the latitude longitude bin of -35 to 30 latitude and -25 to -20 longitude.

4. Conclusions

The median dose rates measured by the individual dosimeters within the SAA for a given flavor were all found to be within ~20% of each other. This agrees with ground-based tests of the individual dosimeters performed prior to flight. We found the entire distribution of dose-rates within a given bin to be <= 50%. This variation likely arises from the physical size of the bin that we used to accumulate the measurements and natural differences in the radiation environment within that geographic location. The variation between the satellites outside of the SAA were found to be larger and due to the space weather observed during the interval studied. As one moves outside of the region of relatively stable protons within the SAA, the standard deviations become larger and the variance becomes dominated by small statistics and space weather, as expected.

5. References

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