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Inter-calibration of VAP-HOPE particle detectors to obtain the anisotropy of electron Pitch Angle Distribution

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Abstract

Whistler mode chorus waves play a key-role in the formation of prompt changes in outer radiation belts. Despite of that, the generation mechanism of chorus emissions is still a subject of debate. Many theories aim at explaining the results of empirical studies on wave-particle interaction. Validation requires a thorough investigation based on precise datasets. EMFISIS, HOPE and MagEIS on the Van Allen Probes provide excellent measurements of electromagnetic waves and particles for such studies. In this summary paper we present the reliability and efficiency of HOPE instrument from this point of view. The 5 polar pixels of HOPE have not been inter-calibrated yet, leading to inaccuracies in angular measurements and in pitch angle distribution (PAD) data also. A preliminary investigation of HOPE L1 data's count rates is presented, in the aim of using count ratios of neighboring pixels with overlapping pitch angle intervals. A list of cross-calibration data was produced for the entire mission. Finally, a case study on 14 November 2012 is presented to represent the efficiency of the corrected dataset, as defining isotropy or anisotropy in PADs. To calculate anisotropy of PADs is essential to determine times and energies of an electron population which presumably interacting/generating chorus wave emissions.

1. Introduction

Recent years' NASA missions, such as the Time History of Events and Macroscale Interactions during Substorms (THEMIS), Van Allen Probes (RBSP) and Magnetospheric Multiscale (MMS) missions, provide valuable data sets for radiation belt models: useful for model validation, also indispensable for setting boundary conditions and other key parameter inputs. Unfortunately, such missions are barely capable for long-term, real-time and global monitoring of those necessary input parameters. Our goal is to replace/complement satellite observations with ground-based measurements. A well-known effort is the Automatic Whistler Detector and Analyzer Network (AWDANet) (Lichtenberger et al. [2008, 2010]), which is a global VLF receiver network consisting of 28 stations. These station's locations cover a wide range of longitudes and latitudes, where whistler waves are detected and analyzed automatically. Therefore AWDANet is able to provide a quasi real-time monitoring of plasmaspheric electron density.

A current research of the AWDANet Team aims to open a new direction. Namely, using whistler-mode chorus waves, recorded at AWDANet stations at higher latitudes (L>4) to obtain information about the interaction between chorus waves and low energy particles, which is known to have a key role in radiation belt's acceleration processes. One way is to estimate the density and energy range of the source population (few keV - 100 keV electron population injected to the equatorial region from the plasma sheet during magnetic storms), employing the non-linear generation mechanism theory of Omura et al. [2008, 2009, 2011]. Another possibility is to directly compare intensities of chorus waves recorded in-situ and on the ground. Both tasks require an in-depth analysis of simultaneous measurements of particles and waves, that are available from Van Allen Probes and THEMIS missions. In this paper, we will present the first results on this new approach.

2. Inter-calibration of VAP A HOPE detectors

Besides low count rates, the different gains of pixel detectors can cause uncertainties in pitch angle resolved data. From Level 1 pitch angle tagged electron Count data we created a time-energy-pitch angle dependent counts product, using only mode 0 (the main science mode data). Assuming that count rates change relatively slow, we can use total count rates of the common pitch angle areas of neighboring detectors to compare detector gains. Selecting only PADs where the total electron count is higher than 100, a list of detector ratios are computed (Figure 1). Further investigation showed that the calibration coefficients depends on time, particle energy (Figure 2). These ratios vary between 0.7-1.6 differently in time and energy for all detectors, tough we can concluded that below ~100 eV detectors do not measure reliably. Also, previous study of Juhasz et al. [2016] showed that detector gain ratios are Dst dependendent.

Taking into account these observations, we were able to correct the PADs of Level 1 data.

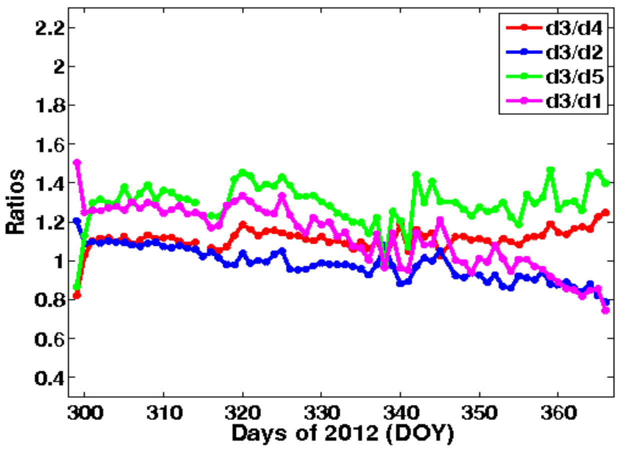

Figure 1: Ratios of counts referring to the middle detector of Van Allen Probes HOPE-A instrument from 2012.

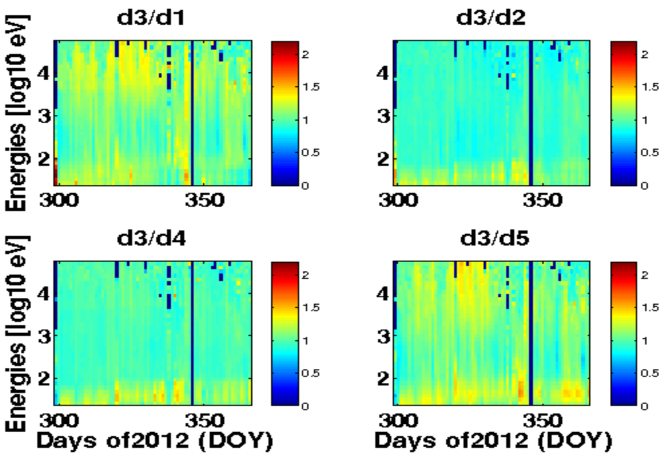

Figure 2: Ratios of counts referring to the middle detector of Van Allen Probes HOPE-A instrument from 2012, ratios are varying between 0.7-1.6.

Comparing the raw data of Counts Level 1 (Figure 3. left column) to the corrected dataset (Figure 3. left column) it is clearly visible, that the out-liner points of the raw dataset (red dots) fit in a more definite pitch angle distribution function after the correction. To demonstrate the effectiveness of our calibration, we chose the time period of 14th of November 2012 between 09:00-16:30 to compare the raw Count Level 1 data of to our corrected dataset at the same time in the following way: fit the PADs of the selected periods of measurements to the functional form (Figure 3. green lines)

$$f(\alpha_0) = c_1 \sin^n \alpha_0 + c_0 \qquad (1)$$

where α_0 is the equatorial pitch angle, c_0, c_1, and n are constants, which can describe basic types of PADs (90°-peaked, flattop and pancake). To compare the goodness of the fits the root mean square deviation normalized by the mean value of the measurements of each PAD has been calculated:

$$NRMSD = \sqrt{\left(\frac{\sum_t (\hat{y}_t - y_t)^2}{n}\right)} / \overline{y_t} \qquad (2)$$

where $\hat{y}$ is the measured count and y is the fitting result. On the top and bottom panel of Figure 5., NRMSD of the raw and corrected dataset are shown. The comparison of the two shows that the corrected data's NRMSD decrease ~0.2 on average, which improvement is agreement with the examples of Figure 3.

The time period of 14th of November 2012 between 09:00-16:30 is a geomagnetically disturb phase. During that time plasma injections can be recognized on the particle data (Figure 4. middle panel), also upper-band and lower-band chorus waves appear on wave data measured by the EMFISIS instrument on-board the Van Allen Probes (Figure 6). Therefore we expected to observe a wide range of PAD types, which were necessary for our numerical validation. In the next section, we present a physical verification of the corrected dataset through a case study on 14th of November 2012 between 09:00-16:30.

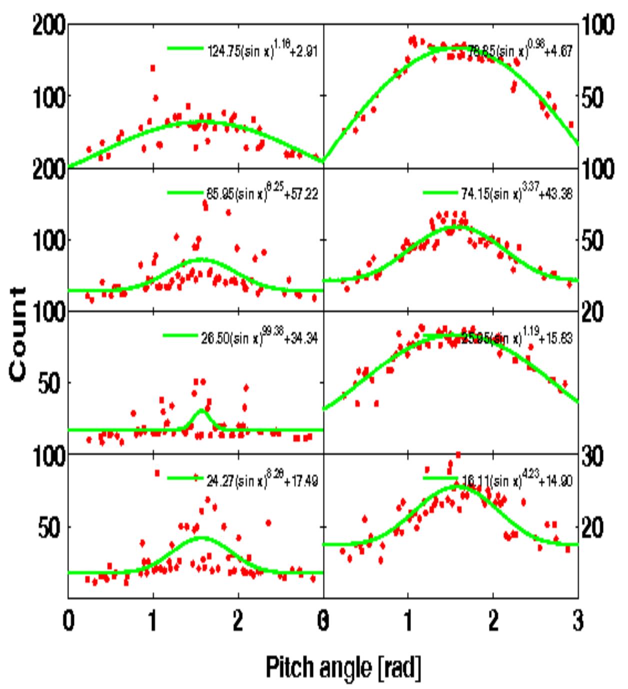

Figure 3: PADs (red dots) and the fitted anisotropy function (green line) at energies [192,968,2837.9,8318,7] eV from top to bottom without correction (left side) and with correction right side) at 14:20:22.433 on 14 November 2012.

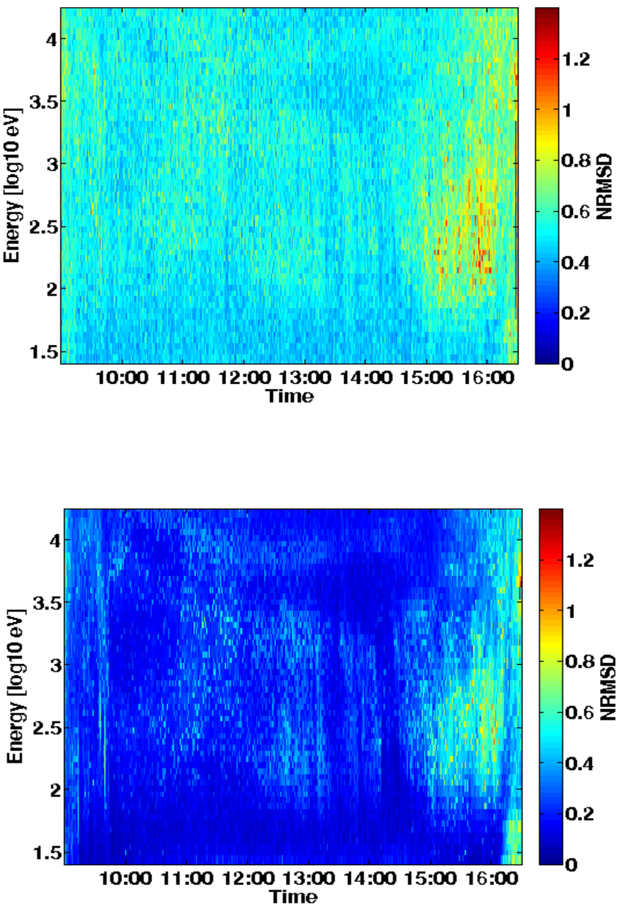

Figure 4: Normalized root mean square deviation (NRMSD) of original dataset (top panel) and of corrected data (bottom panel) on 14th November 2012.

3. Anisotropy of electron PADs

Anisotropic PADs can be the signature of freshly injected energetic particles, which assumed to be the free energy source of whistler mode waves. Wave-particle interactions can be identified in particle dataset as isotropic PADs, formed after pitch angle scattering. Because HOPE PADs have missing data, we used the functional form of Eq. (1) for fitting, then we calculate anisotropy based on Chen et al. [1999], using fits to obtain an anisotropy function in closed form,

$$A=\frac{n}{2}\left[1+\frac{4c_0\Gamma((n+5)/2)}{3\sqrt{\pi}c_1\Gamma((n+2)/2)}\right]^{-1} \quad (3)$$

where Γ is the gamma function. On the bottom panel of Figure 5. anisotropy values are shown as a function of time and energy. A=0 represents pitch angle isotropy, A>0 indicates maximum peak, A<0 corresponds to minimum peak at 90° in PADs. Without an in-depth examination of this time period, we only want to draw attention to the coincidence of wave and particle data: the initially high anisotropies disappear after chorus emission enhancement and appear again when chorus waves no longer visible. The white lines on each panels of Figure 6. show the typical lower and upper ban chorus wave ranges as well as the gap between them, 0.2 f_{ce}, 0.8 f_{ce} and 0.5 f_{ce}, respectively. These frequencies were used to calculate the minimum electron energies for relativistic resonance with chorus waves, see red (0.2 f_{ce}), black (0.5 f_{ce}) and blue (0.8 f_{ce}) dots on bottom panel of Figure 5. The small increase of anisotropy during 10:00-15:00 between 1-3 keV forms a line and moves parallel with the minimum resonance energy of 0.5 f_{ce} .

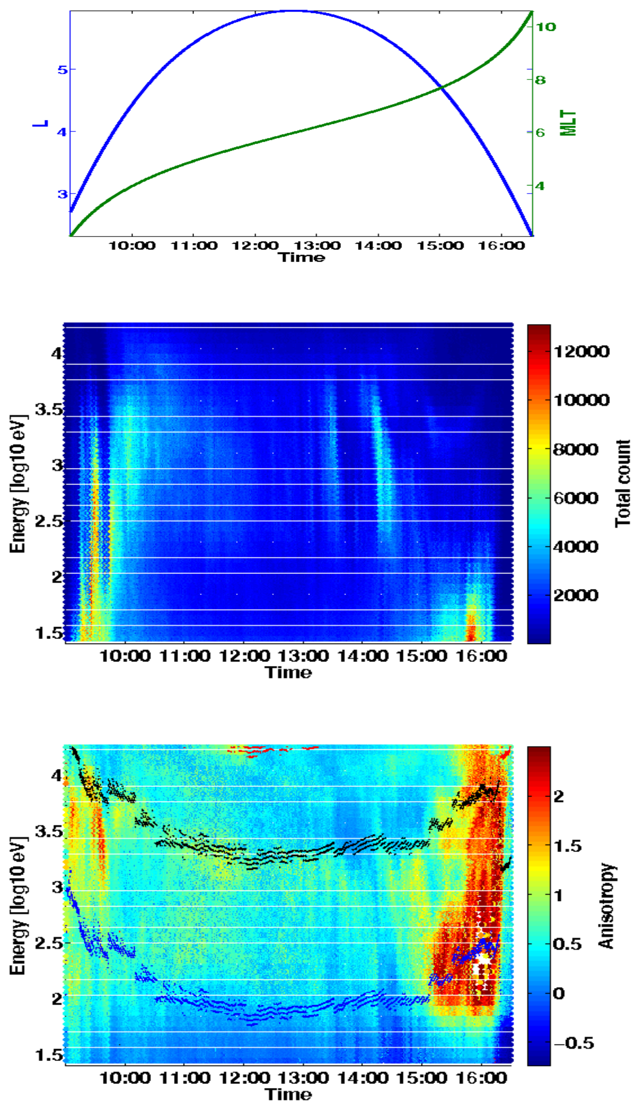

Figure 5: *(top panel)* L and MLT value *(middle panel)* Total electron count *(bottom panel)* Anisotropy of PADs and the minimum electron energy of relativistic resonance with chorus waves of various frequencies (blue: 0.8 f_{ce}, black: 0.5 f_{ce}, red: 0.2 f_{ce})va of on 14th November 2012

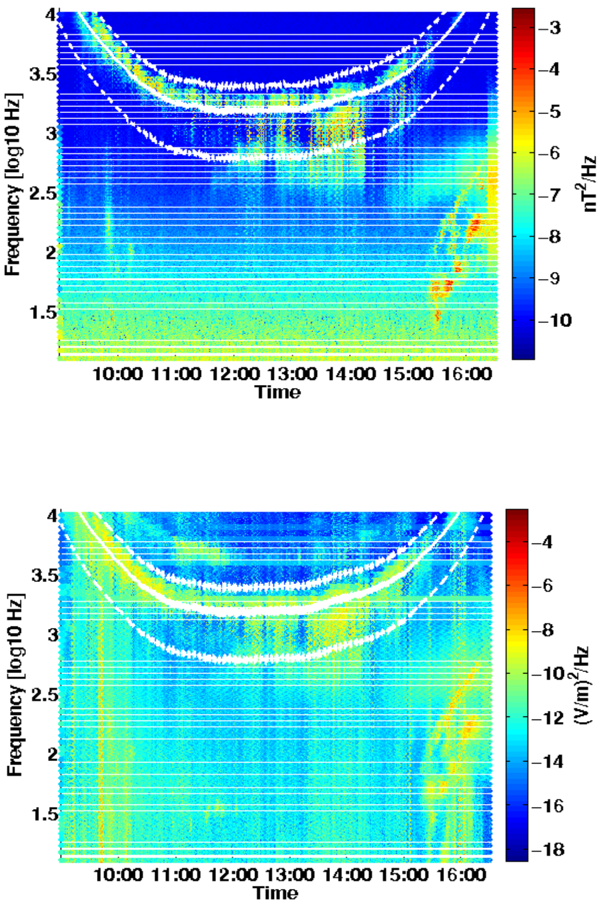

Figure 6: VAP-A EMFISIS EuEu *(bottom panel)* and BuBu *(top panel)* component on 14th of November 2012 , white lines represent 0.8 f_{ce}, 0.5 f_{ce} and 0.2 f_{ce}

4. Conclusion

Our first task, namely to create calibration coefficients for the five independent detector of HOPE instrument, was successful: we revealed that there are significant differences among the calibration coefficients, both in time and energy. Though this study does not explain differences in gain response, we found that the ratios clearly vary with Dst indices (Juhasz et al. [2016]). Daily variation of the calibration coefficients (not shown) also imply that detectors close to perigee respond differently, our future plan is to create a statistical study of this dependency.

The goal of the inter-calibration was to correct the electron PADs to be able to use them for isotropy-anisotropy identification. With the original dataset, only a rough estimation of isotropic PADs was possible (Juhasz et al. [2016]). The next step is to utilize the corrected particle dataset and produce a robust, empirical model of wave-particle interaction based on the theoretical study of Omura, therefore provide a basic model for chorus inversion processes.

5. Acknowledgements

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7. References

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