Using convoluted probability distributions to estimate average auroral intensity

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1. A new technique to estimate average auroral intensities during sunlit conditions

Aurora during sunlit conditions

Introduction

Sunlight makes it difficult to measure the aurora. We use data obtained by the Special Sensor Ultraviolet Spectrographic Imager (SSUSI) onboard the Defense Meteorological Satellite Program's (DMSP) F16-19 satellites to quantify the auroral intensities during sunlit conditions. We use Environmental Disk Radiance (EDR) Aurora data product from the SSUSI-team, where the dayglow is already subtracted. The error in the dayglow-subtraction is proportional to the strength of the dayglow and represents an uncertainty in the observations. We characterize the auroral intensity and the dayglow part of the signal by combining multiple observations during similar solar illumination, and magnetic local time/latitude. By fitting convolutions of symmetric (dayglow-error) and fat-tailed distributions (aurora) on data from many years, it might be possible to separate the auroral signal from the dayglow residual.

We bin the SSUSI-irradiance data using an equal area grid based on its Magnetic Local Time (MLT) and Magnetic Apex latitude (MLAT) coordinates. The grid is shown in Figure 1 and is oriented in bands of equal MLAT, separated by 1 degree, and a similar distance in the zonal direction. The method developed here builds on interpreting the distributions of SSUSI-irradiances in these bins. Figure 2 shows three of these bins, and the bins are highlighted in Figure 1.

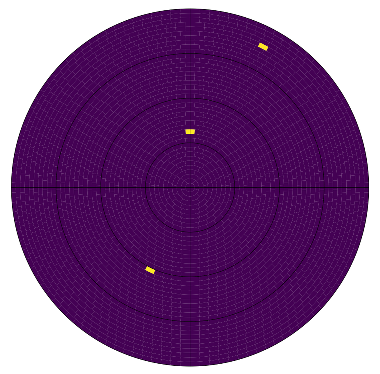

Figure 1: A representation of the grid.

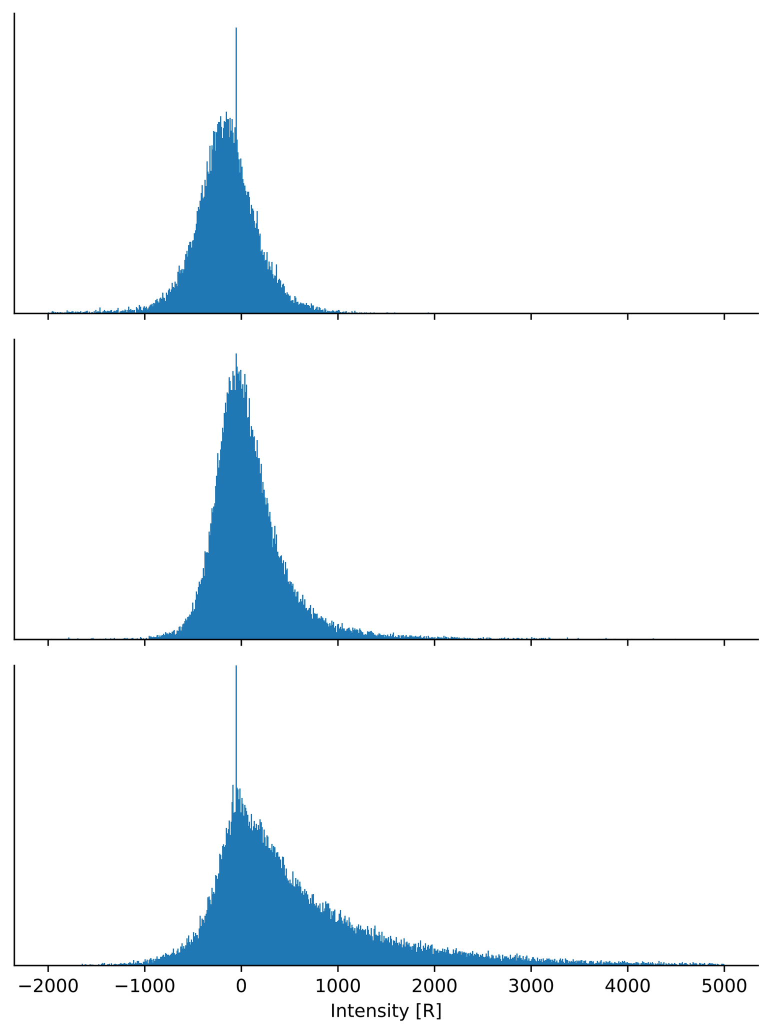

Figure 2: A: Histograms of a typical bin without aurora, a typical bin with weak aurora and a typical bin with strong aurora. The first is symmetrically distributed, the second has a weak tail and the third is dominated by the aurora.

- We use data from 2005 to 2021 containing 200 000 satellite passes per hemisphere, so the dataset is large conatining over 14e9 observations. Because of this we use a python-package called Vaex used to handle out-of-core dataframes. In the analysis we have only looked at the Lyman-Birge-Hopfield short wavelengths.

Fitting the convoluted distribution function to the data.

Developing the method

- By assuming that the dayglow error is normally distributed, and that the signal from the aurora is Moyal-distributed, we can assume that the total signal is a composition of the dayglow-residual and the aurora. And that this total signal can be represented as the convolution of the normal and Moyal-distributions.
- The reasoning behind choosing the Moyal distribution is two-fold. It is used to describe the energy loss of relativistic charged particles due to ionization of the medium, and that it fits the signal from the aurora.
- The convolution is done by performing the convolution integral on the distribution functions. Due to a limitation in determining both position parameters it makes sense to find a suitable value for the location of the normal distribution. This was done by plotting the distribution where there was no aurora, and finding the most common center value. This turns out to be -150 R, and we use this value as the location of the normal distribution in the integral.
- Using this assumption and result, we can fit this convoluted distribution function to the data, and extract the parameters used to obtain the best fit. This allows us to reconstruct the Moyal-component of the signal, and then estimate a value for the auroral intensity only, with the contribution from the dayglow-residual removed.

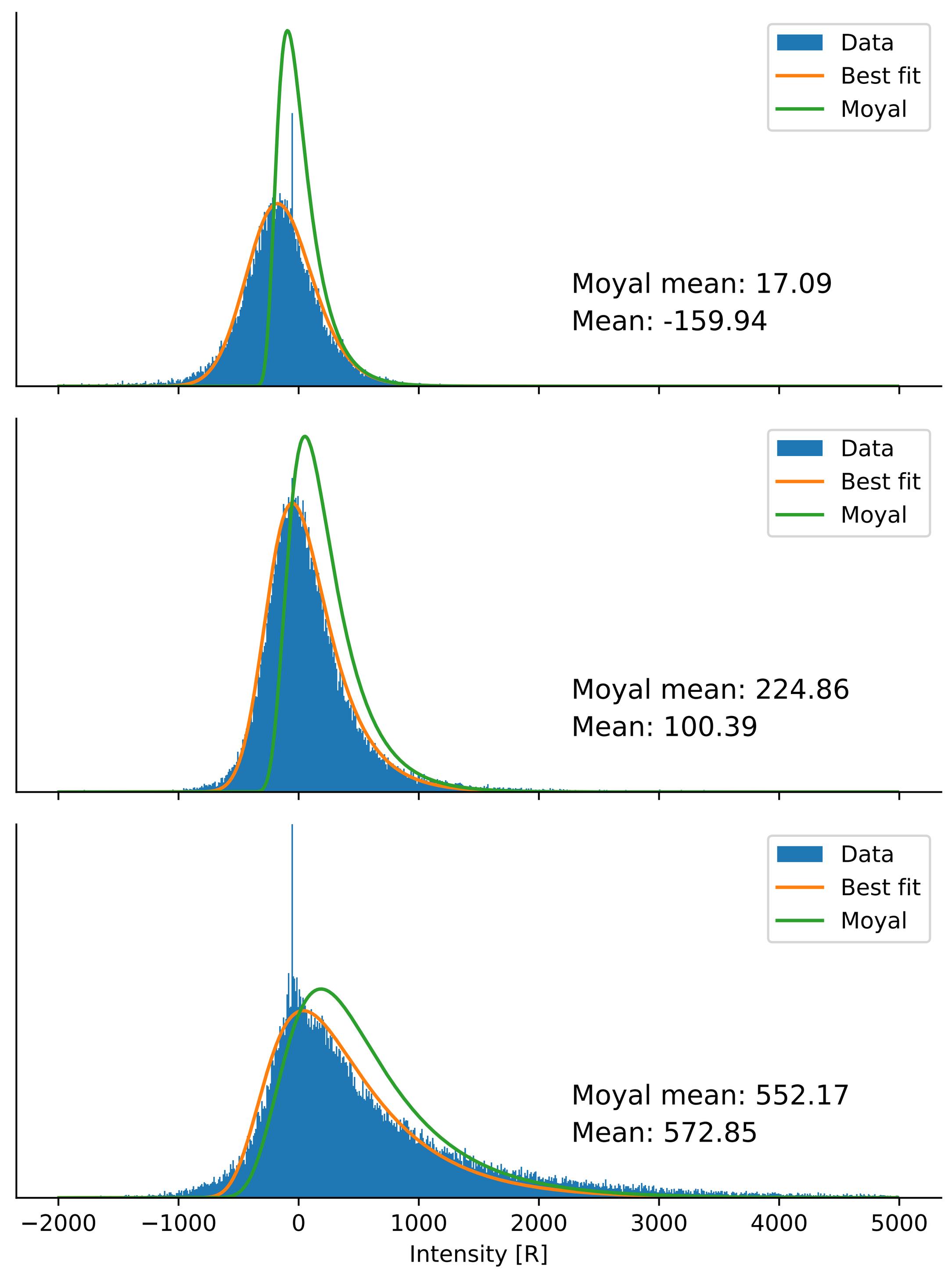

Figure 3: Histograms with fitted probability distribution functions. Here the line labeled as best fit is the convolved normal and Moyal-distribution, and the line labeled as Moyal is plotted from the parameters used to obtain the best fit. Here we can see that the best fit approaches the Moyal distribution with stronger aurora.

Evaluating the fits

- Here we can see that the bins with more contribution from the aurora return a much wider total distribution. This is as expected.
- The Moyal mean has a larger value than the total mean, except for where there is strong aurora where the values converge.

2. Results and possible applications of the method

Plotting maps of auroral intensity

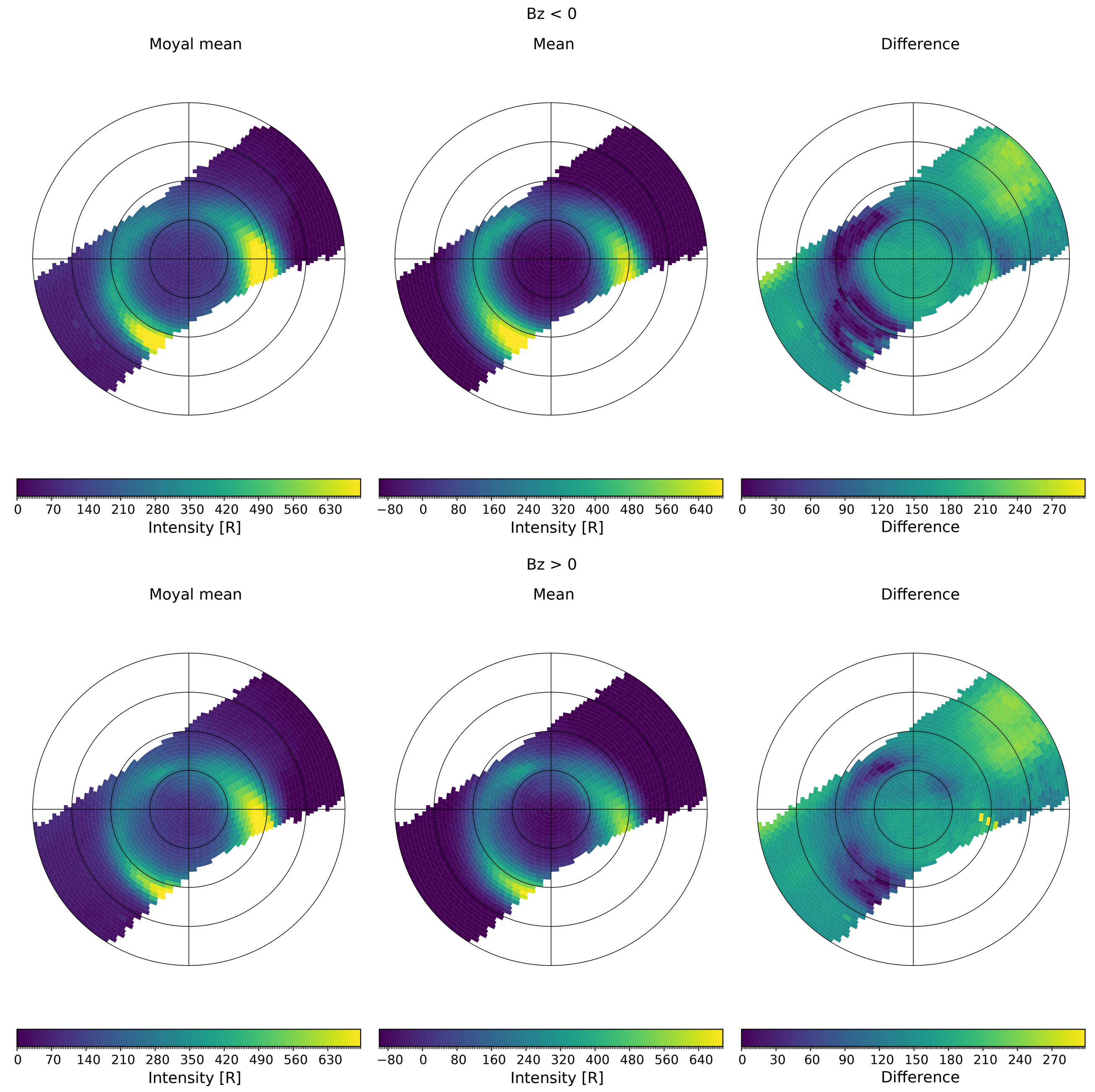

Figure 4: Maps of Moyal mean, mean and the difference between the values of each bin. In these plots the fitting method is applied to each bin. The rows have been sorted in negative and positive Bz respectively. These plots use data from April 2005 to September 2005, and from April 2006 to September 2006

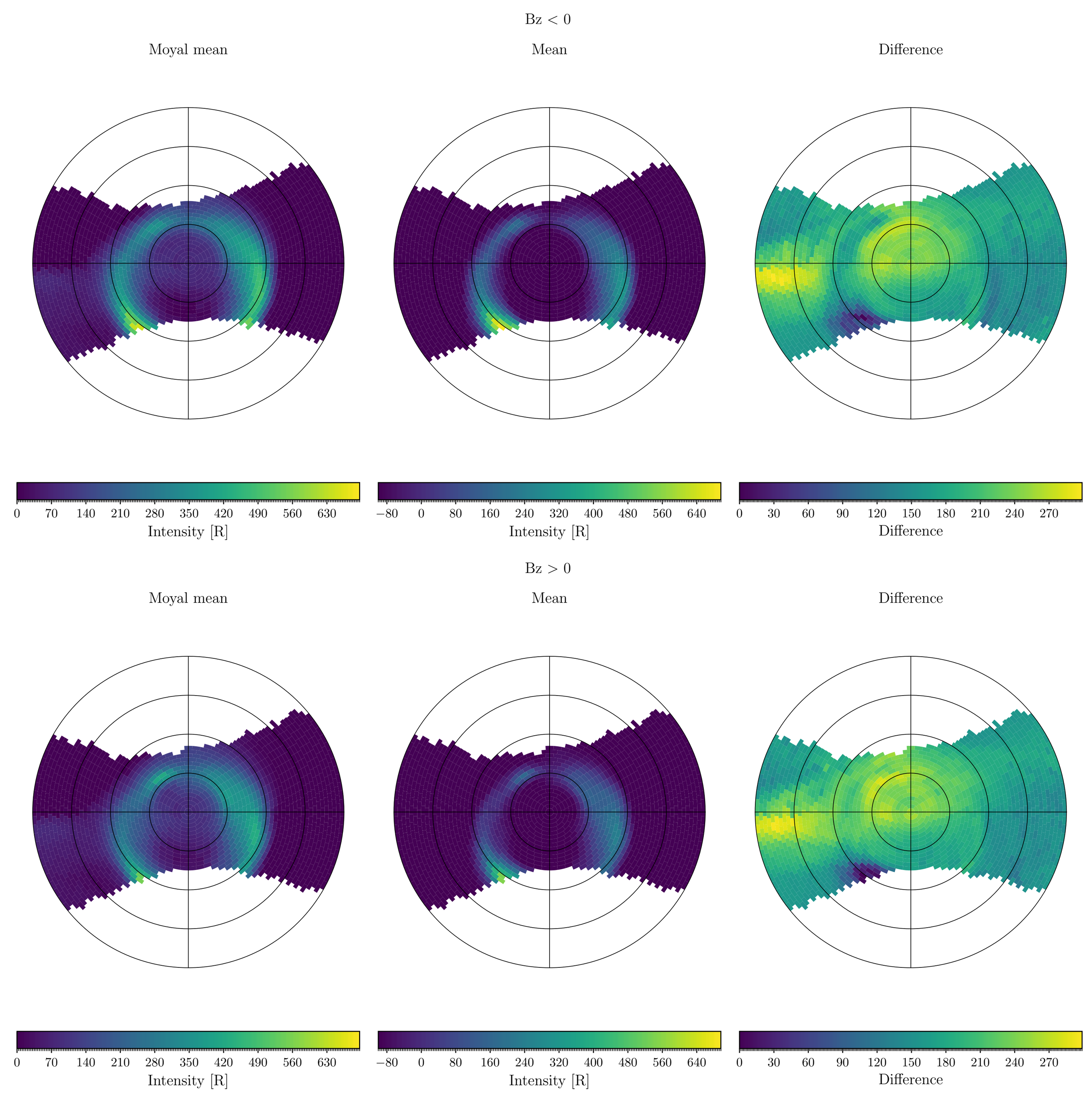

Figure 5: Maps of Moyal mean, mean and the difference between the values of each bin. In these plots the fitting method is applied to each bin. The rows have been sorted in negative and positive Bz respectively. These plots use data from April 2009 to September 2009

Results

Evaluating the plots

- In the difference plots we see that where the aurora is strongest there is much less difference, this is as expected from the results from the histograms.
- The method returns higher values in the dayside and in the polar cap compared to the mean. The oval appears to be wider in the dayside as well.
- During moderate aurora it seems that the method return greater values than the mean. This can be seen in the difference-plots between Figure 4 and Figure 5.

Discussion and future work

Discussion

- The method is relevant in the quantification of auroral intensities during sunlit conditions. This method suggests stronger aurora during sunlit conditions than found before. [3]
- The method may provide new insights into the importance of mechanisms producing emissions in the summer polar cap (HiLDA), due to the higher values obtained during sunlit conditions. [2]

Future work

- In the future we will look at periods dominated by IMF By, HiLDA. We expect that our new method will lead to increased average intensities compared to previous analyses, e.g. the Carter et al analysis [1].
- We will explore how the IMF By affects the boundary of the aurora (polar and equatorial boundaries), and how this may be different in summer and winter.

Acknowledgements and references

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