Reconciling backlogged Cloud Cover Data over the Pierre Auger Observatory Using GOES Satellite Data

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1 Introduction

The Pierre Auger Observatory is a cosmic ray observatory located near Malargue Argentina. It has two main detection methods a surface detector (SD) and a fluorescence detector (FD) [**?**]. The fluorescence detectors operate during the night hours, detecting the UV light emitted from secondary particles interacting with the nitrogen in the atmosphere. This paper will focus entirely on the FDs. A cloud detection method was developed previous that used infrared capabilities of the GOES class satellites [2]. However it has been some time since the published database has been updated. For collaborators to verify that there work is valid an update is necessary. Having a robust cloud detection method is imperative for the integrity of any science done with the FD because clouds can obscure the UV light emissions from reaching the FD detectors. The images that the FDs produce when cloud cover is present can mimic interesting cosmic ray shower events. An effort was made to make the database modern and updated. All backed up data has been processed and updated through December 2017. During the month of December 2017 the GOES-13 satellite has been put into retirement and the new GOES-16 satellite has taken over its duties. The old method may need some revision to process the new GOES-16 image data. We are confident that the update using the old methods is correct. We independently verified using two methods that the new data being made available is of good quality. The first method used GOES-13's visible waveband to check against our infrared method. We also used a data intense method that checked a pixels yearly normal color distribution versus the total distribution of a years' worth of data for all pixels.

2 Visible light method

Although the FD detectors operate at night and the IR method of cloud detection is not normally used during day time hours we thought it would be worth hbp [width = 0.85]CldMap.png

Figure 1: A sample cloud probability map on the left. A grey scale is used to display how likely a cloud is occupying the area in the pixel. The Auger array outline is seen in red. The FD are the colored fans.

hbp [width = 0.85]BadPixLocations2016.png, BadPixLocations2017.png

Figure 2: On the left a is a graph of all two and three sigma count pixels for the year 2016. On the right is 2017's two and three sigma count pixels. You can see some reoccurring patterns between the years like the feature from pixels 15-19 and pixel 359. Pixels with counts greater than 2 sigma but less than 3 are seen in yellow. Pixels with counts greater than 3 sigma are seen in orange.

seeing if our method closely resembled what is seen during the day. We used GOES-13 visible light capabilities and our infrared algorithm and compared them side by side.

(insert image)

Figure 1. On the left: A visible light spectrum image from the GOES-13 satellite. On the right: An image made using our IR algorithm of the exact same time. From inspection you can see pretty good agreement despite the visible image being 4 times the resolution.

Based on these images we concluded that our IR-method was successfully processing day-time cloud cover. Some adjustment had to be made in the algorithm for the IR-images to work during the day. However We don't recommend the use of this IR method during the day. Several dozens of the images were produced as seen in figure 1.

3 Pixel Color Distribution

To determine if the images had any sort of pattern or if the cloud distribution across the images were truly random a pixel analysis was done. The first step was to determine the average number of occurrences of a given color the pixel could be. Each pixel has up to 5 colors corresponding to how probable a cloud is in the pixel. We chose to use a grey scale for displaying the probability chances 1. Once the average was found for each color a normal distribution was assumed and a standard deviation of number of occurrences was calculated.

Pixels behaving poorly were identified as having above or below a two sigma count number from the average. These pixels were plotted on a map of the observatory. After seeing some coincidental pixels behaving poorly through consecutive years of cloud data we decided to investigate the topography of the area 2.

A new map was generated with the misbehaving pixel array overlayed on a topographic map. Some features were identified as possible candidates for elevation causes such as the foothills near Malargue, and the line of inactive hbp [width = 0.85]BadPixLocations2009, BadPixElevations09.png

Figure 3: On the left: a graph showing each pixels ID number. The pixels that have a two sigma count number are filled in yellow, the three sigma in orange. The Auger array is outlined in salmon. On the right is the same data plotted on an elevation map. Red and purple were chosen for the two and three sigma count numbers for easier reading. You can see some elevation features that may be the cause of these larger problems like on the bottom right the old volcano and the bottom left the mountain foothills.

volcanoes that appear on the bottom right of the area surveyed 3.

However not all geographical reasons for misbehaving pixels could be claimed. A program was written that determined how likely two numerically sequential pixels could have 2 or 3 sigma deviations from the average. It was found that for a given year there was between an 80-90 percent chance that at least one 2 sigma or 3 sigma pixel's neighbor could also be misbehaving. Considering that each of our graphs contains 5 different distributions (one for each color the pixel can be) the likelihood of two or more pixels having behavior that deviated from the average is nearly guaranteed. So the "clumping" behaviors we see in these graphs could be considered random and not an artifact of our algorithm behaving inappropriately.

4 Conclusion

Taking everything into consideration we are happy to give our blessing to the last of GOES-13's data and have updated the cloud database for our collaborators to use. The work that remains is transitioning the cloud detection method into a new phase of its life working with the GOES-16 satellite. We are excited to see how it improves the spacial resolution of our IR observation technique.

5 Citations