Separating neutrino events by source using the IceCube Neutrino Observatory's IC86 data

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ABSTRACT

The IceCube Neutrino Observatory, located at the South Pole, is a cubic-kilometer particle detector made of Antarctic ice. Cherenkov light, which is the end result of the interaction of neutrinos with the ice, is detected by 5,610 optical modules that are suspended on a set of 86 strings with a depth of up to 2,500 meters. IceCube's primary purpose is to detect neutrinos produced by astrophysical sources; the characteristics of these neutrinos tell us something about the nature of their sources (supernovas, black holes, pulsars, active galactic nuclei and other extreme extragalactic phenomena). Competing with the astrophysical neutrino detector events are those generated by atmospheric neutrinos that are produced in cosmic rays showers. The atmospheric neutrinos are also of scientific interest, but a method is needed to distinguish the two event types. Some degree of separation can be achieved by performing a sort of IceCube data by neutrino energy and zenith angle. In this study, I will use the data processing ability of MATLAB paired with algorithms to sort over 138,000 neutrino events by energy. These events were recorded by IceCube from March 2011 to 2012, and were released in the IC86 data set. A complete separation of astrophysical and atmospheric neutrino events is a complex and model-dependent process, and therefore it is not the expected outcome for this project. Instead, this work will assist in creating a new research capability in my department that can continue to be used to analyze the results of future IceCube data releases.

THE ICECUBE OBSERVATORY

The IceCube Observatory is a facility located in Antarctica near the Amundsen-Scott South Pole Station. Using the Cherenkov radiation emitted by the weak interactions of neutrinos passing through the ice, IceCube is able to detect a neutrino flux. This is achieved by using a combined 5,160 digital optical modules (DOMs) across 86 "strings". These strings are spaced 125 meters apart and each string suspends 60 DOMs frozen into bored holes in the polar ice. The DOMs are arrayed over a cubic kilometer, with a depth from 1,450 to 2,450 meters. The polar ice in Antarctica is ideal for this detector because Cherenkov light is best detected in a clear medium. Polar ice, being some of the clearest water on the planet, provides a large enough area to accommodate the size and scope desired. These data collected by the DOMs are transmitted to the surface IceCube Laboratory (ICL), where it can be distributed and analyzed by scientists.

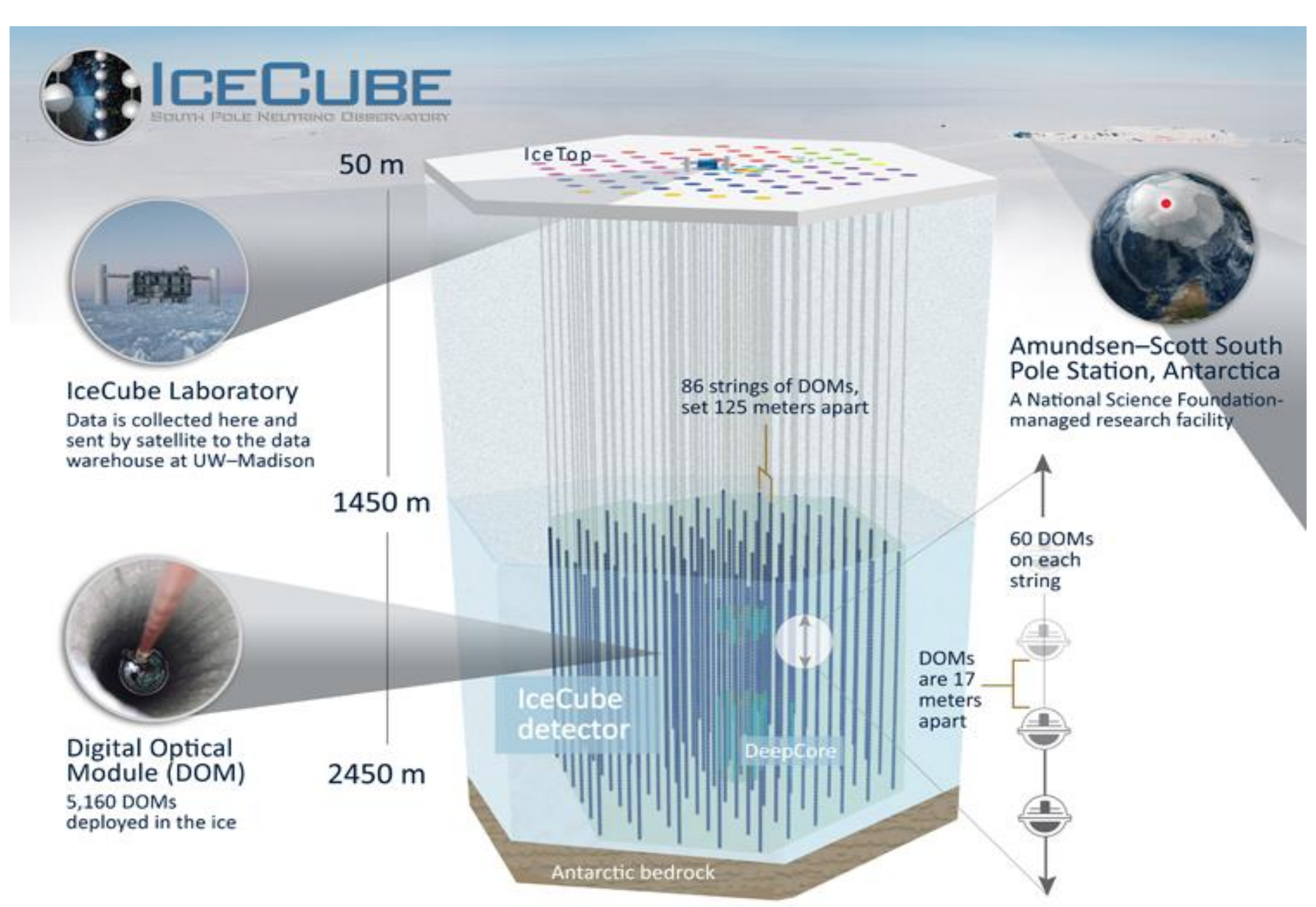

Figure 1. Schematic of the IceCube Observatory showing the geographical location, the depth, and orientation of the DOM strings. Pictured is the full 86-string configuration. (Source: icecube.wisc.edu)

METHOD

IceCube Observatory provides public access to data releases on the site https://icecube.wisc.edu/science/data. This site has all of the data releases from the observatory. The one used in this research is titled "Search for point sources with first year of IC86 data (released 1 Nov 2016)". This page will contain a link for the accompanying journal article, a link to download a .zip folder, and descriptions of the data files contained therein.

Once downloaded and unzipped, the folder contains .pdf figures and .txt files of tabulated data. The text files can be imported into an Excel workbook with the File/Import function. This will make working with the data easier. MATLAB was used to sort and examine the data by neutrino energy and declination angle. To import the data into MATLAB, the xlsread function was used.

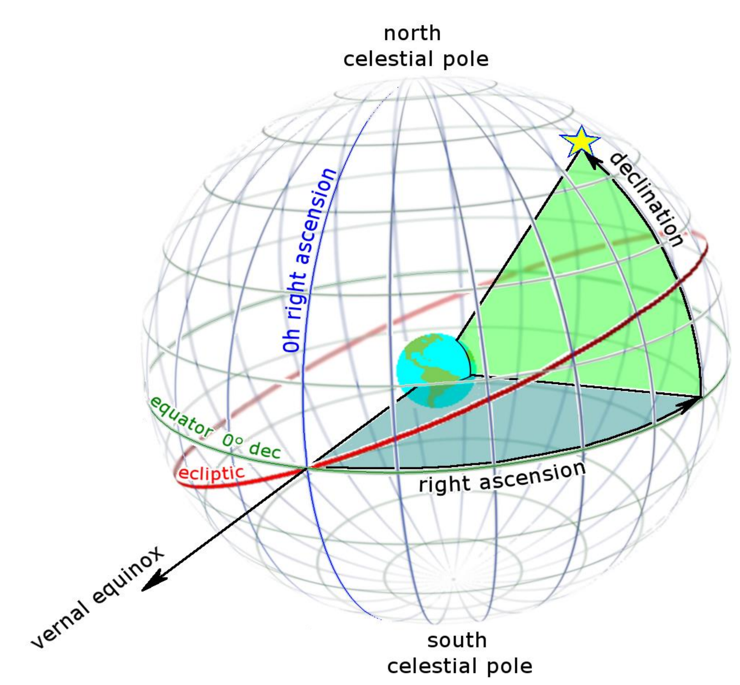

Figure 2. Source: wikimedia.org

The data release gives us right ascension and declination (Figure 2). Declination uses the equator as a reference point. IceCube is located at the south pole so the observation point is located at $-90°\left(\frac{-\pi}{2}\right)$. This means that Earth is filtering out the neutrinos from atmospheric sources from $0° - 90°\left(0 - \frac{\pi}{2}\right)$. This is called an "up-going" event perspective.

RESULTS

As stated above, Earth filters out atmospheric neutrinos. The neutrinos most likely to pass through Earth are astrophysical. The plots in Figure 3 show evidence of the filtering. Log(E) is the base 10 logarithm of the detected energy in the DOMs. This energy is that of the Cherenkov photons, which can be related back to the neutrino energy. The plots include the full range of detected energies. As the declination is raised in 15° intervals, more and more of Earth's mass will serve as a filter. As you can see, the density of the data points decreases as the declination increases. This means that at larger declinations the neutrinos detected are more probable to be astrophysical because they are more energetic and more likely to pass through Earth.

We are also able to sort the data by energy range. In Figure 4 below, we show events with energies ranging from 630 eV to 1000 eV. The plot as you can see is generally isotropic. However, this type of plot could be used to identify point sources of astrophysical neutrinos by identifying clusters of events.

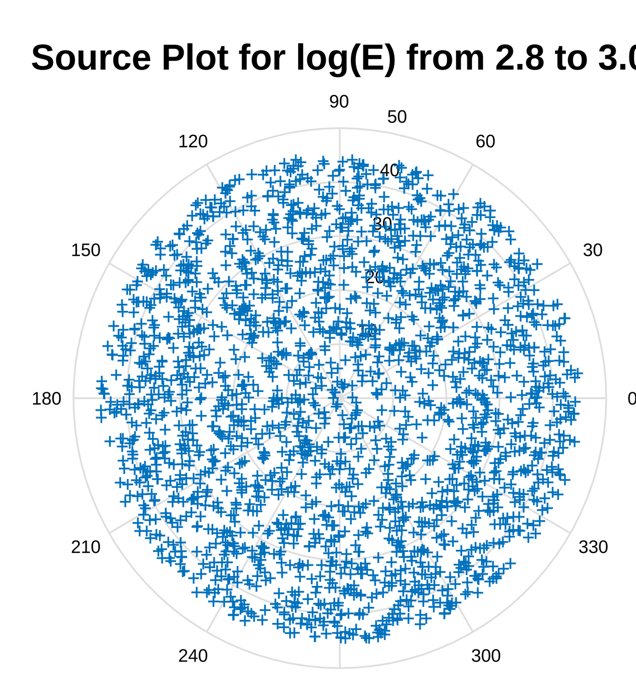

Figure 4. A plot of IceCube data events in the declination range of 45° to 90° and the log(E) range of 2.8 to 3. This energy range represents the detection energies from approximately 630 eV to 1000 eV.

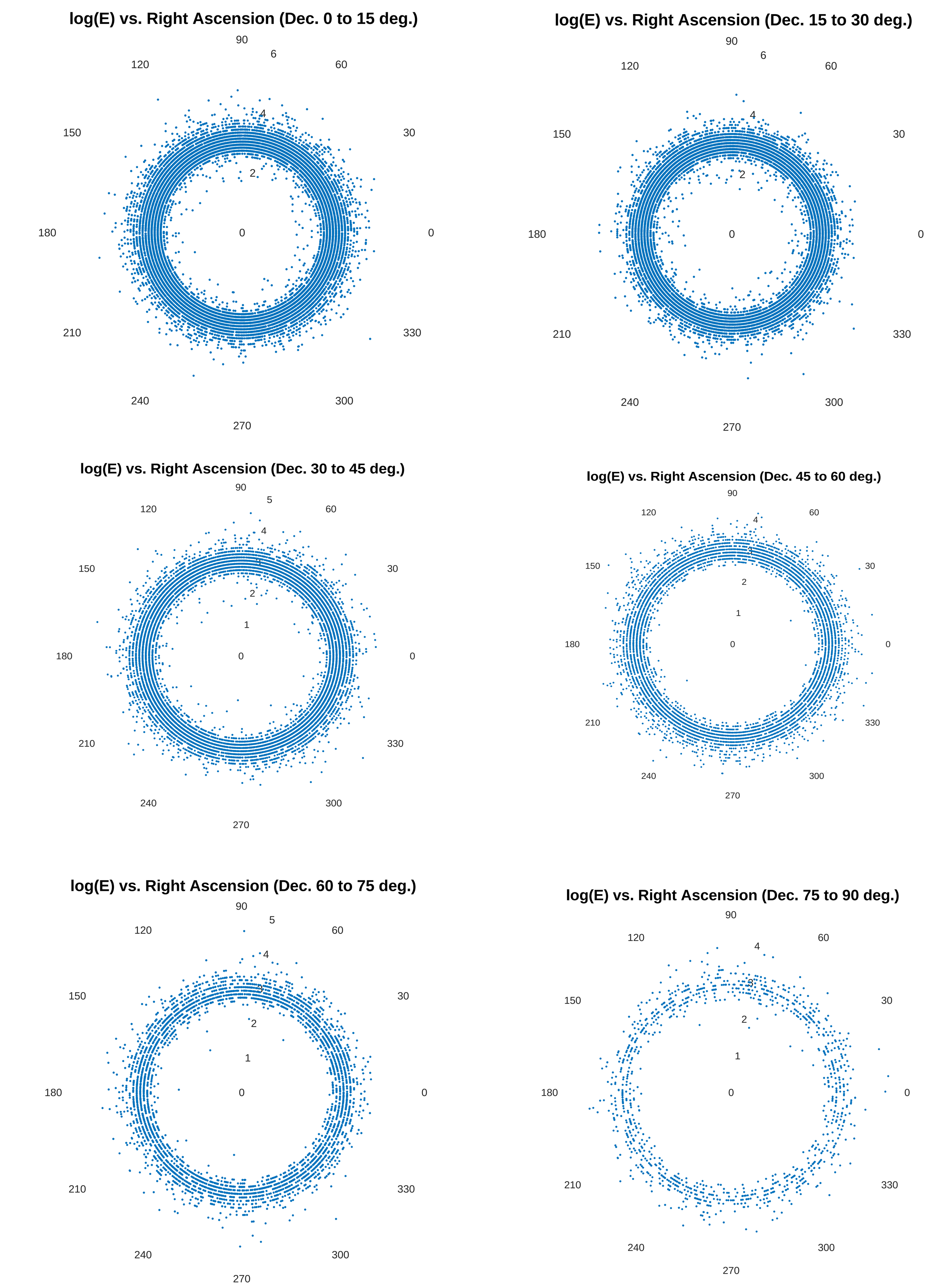

Figure 3. Shown above are polar plots of six 15° declination angle intervals depicting the log(E) radially and the right ascension angle circumferentially.

CONCLUSION

While it is possible to do some simple sorting of the data set by declination angle and detected energy, the actual separation of astrophysical from atmospheric neutrinos is rather complex. For example, researchers have used models of atmospheric neutrino energy, such as the Honda Model, to subtract the contribution of high energy atmospheric neutrinos from astrophysical candidates. Questions that can be pursued with the tools available to us are: 1. What is the distribution of the Cherenkov photon energies within the certain declination ranges? 2. Is there evidence of clustering of events for specific angular ranges? This research is preliminary in nature and is part of an effort to develop a possible new research focus. This is achieved, in part, by carefully documenting steps taken and resources used in accessing and analyzing the IceCube data.

ACKNOWLEDGMENTS

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Sources:

"Searches for Extended and Point-like Neutrino Sources with Four Years of IceCube Data," IceCube Collaboration: M.G. Aartsen et al. Published in *The Astrophysical Journal 796 (2014) 109*, doi: 10.1088/0004-637X/796/2/109

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