Using Power Spectral Density and a Self-Organizing-Map to Detect Precipitation Bands Observed by SAMPEX

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Abstract

Precipitation bands are a form of relativistic electron precipitation in the outer Van Allen radiation belt. They contribute significantly to the rapid loss of electrons from the outer belt, yet their origin is still unclear. In this study, we develop an algorithm to automatically detect precipitation bands observed by the Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX) satellite (1992-2012) using an unsupervised machine learning technique called a Self-Organizing-Map (SOM).

1) Introduction

- Incoming electrons from the solar wind become trapped by the Earth’s magnetic field.
- They spiral along the field lines, making up the Van Allen radiation belts.
- Relativistic electron precipitation (REP) occurs when these trapped electrons fall to the Earth’s atmosphere. This often interferes with communications, spacecraft, and is regularly linked to ozone depletion.
- "Precipitation bands" are one form of REP, typically observed by SAMPEX as increases in count rates lasting tens of seconds.
- Microbursts are a shorter form of REP, typically observed lasting less than a second.
- Previous studies have not been able to consistently identify precipitation bands.
- They contribute significantly to the loss of electrons from the outer belt, yet their origins are unclear.

2) SAMPEX Data

- SAMPEX stands for Solar, Anomalous, and Magnetospheric Particle Explorer.
- It traveled in a low Earth orbit from 1992 to 2012. It used it’s HILT instrument to measure the counts of relativistic electrons with energies greater than 1 MeV.
- Precipitation bands, which are typically on the order of tens of seconds, can be visually identified within the count data.
- A visual study of such a large dataset is unrealistic as it would be biased and incredibly time consuming. Instead, we are a machine learning technique to detect precipitation bands.

3) Self-Organizing-Map

- A SOM, or Kohonen map, is an unsupervised machine learning technique.
- This artificial neural network utilizes "competitive learning."
- It classifies inputs by putting them into bins based on their similarity to one another. If two different inputs look like each other, they are likely to be placed into the same bin.
- It does this by using weight vectors and Euclidean distance in order to determine a best matching unit.

4) Methods

1. Filtering the data
   In order to properly analyze the data, we need to filter it. First, we separate it into ten-minute intervals. Then, we detrend it and remove the moving mean, NaNs, and gaps in the data.

2. Power Spectral Density
   To use the SOM, we take the power spectral density of each filtered ten-minute interval using Welch’s method. The power spectral density of a ten-minute interval containing a precipitation band contains a distinct peak in the lower frequencies while the power spectral density of noise/microbursts does not.

3. Self-organizing-map
   Once exporting the count data and power spectral density for each ten-minute interval into new files, we can feed it into the SOM. For this run of the SOM, we use one month of data, or around 4400 intervals. The SOM analyzes the normalized power spectral density data for each interval and puts them into bins based on their similarity. We use the normalized power because this allows the SOM to classify the data based on the frequency dispersion and not just peak intensity.

5) Results

- The result of the SOM is a 5x5 grid of folders.
- Each of these folders contains files of data. Combined, they contain all the data from the run.
- Some folders contain almost only precipitation bands, some contain only noise, some contain almost only low quality data, and some contain a mix.
- Precipitation bands, along with their time stamps and power spectral densities, are now available in specific folders.
- Low quality data and noise are successfully classified into their own folders as well.

6) Conclusion/Future Work

With this algorithm, we accomplished the goal of identifying precipitation bands based on their power spectral densities. While this algorithm worked very well to filter out low quality data and noise from the precipitation bands, it can still be improved. There are a few cases where folders contain more than one classification. For this study, we decided to keep the microbursts in the data. However, there are multiple files where a precipitation band occurs within the same interval as microbursts, leading to the file being misclassified. In order to further separate the precipitation bands from the rest of the data, the SOM can be run again, but with the microbursts filtered out and only taking in the folders containing precipitation bands. It can also be run for a larger amount of data, possibly taking in a year of data instead of a month. With this larger and better filtered set of data, the SOM will be able to more reliably classify precipitation bands.