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Exploratory Applications of High Frequency Atmospheric Electrical Discharges

by

Alison Kate Rudzinski

An Honors Capstone

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to

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10-Nov-19

Date
Exploratory Applications of High Frequency Atmospheric Electrical Discharges

Project Included Coordination with the following people:

❖ UAH/Themis Chronis
❖ NASA/Geoffrey Stano
❖ UAH/George Priftis
❖ UAH/Ming Sun
❖ KSU/Joshua Chatham
❖ NASA/Sherry Harrison
❖ NASA/Lamar Hawkins

Methods and Procedures

To begin the project, a specific list of dates was gathered from the USGS (United States Geological Survey) that shows quake data (day, time, location) necessary for extraction and data analysis. The pool of data was narrowed down by limitations due to LMA data restrictions of dates in action.

Once in contact with NASA/Geoffrey Stano and NASA/Sherry Harrison, these dates were coordinated with the USGS dates. LMA data was then provided by these personnel. Once LMA data was received, we began reading files and organizing the data. The LMA data has the following specific format arranged by columns, respectively:

i. The time in seconds since the start of the day in UTC time.
ii. Latitude of the observed source.
iii. Longitude of the observed source.
iv. Altitude of the observed source in meters.
v. Reduced chi squared – This is generally a quality control value. Generally, various flash algorithms will use this to determine if an observed source is "trustworthy" enough to use.
vi. Power of the observed source in decibel watts – A measure of the signal strength for the source.
vii. A hexadecimal mask to identify which LMA sensors observed a particular source.
   a. For example, the hexadecimal value may be 0176. To know what sensors observed this source, we first convert this number to binary.
   b. This gives a binary value of 0000 0001 0111 0110.
   c. Each "1" indicates one NALMA station, so for this source 6 stations observed this source.
   d. We can expand on this by using the Station mask order: NMLKJHI GFEDCBA. (Note: This can change from file to file and network to network depending on the number of available sensors.)
   e. We read the binary from right to left and each "1" corresponds to one of the letters in the mask order. Our mask includes stations B, C, E, F, G, and I.
   f. Using the Station information section of the header, this gives us: Ardmore, Boeing, Green, Hospital, Keel, and Owen.
   g. Overall, we deal with this when we are intentionally pulling sources with a certain minimum number of stations.

After analysis and coordination with Dr. Chronis, we decided on which columns we considered pertinent for this data extraction/organization for research purposes. For our USGS data, we began with working with the following column headers:

i. Date/Time
ii. Latitude
iii. Longitude
iv. Depth
v. Magnitude

For our LMA data, we began working with the following column headers:

i. Date/Time
ii. Latitude
iii. Longitude
iv. Altitude
After analysis of pertinent columns, we began creating a python script that completes data consolidation for the LMA data of one singular day. The python script extracts the data from the LMA data from NASA/Geoffrey Stano and consolidates it into a text file with the entire day of data line-by-line. This procedure was then completed for all the other dates from the USGS pre-selected date pool.

To begin the process of understanding the data, a python program was created to explore what the LMA data could visualize and provide. This program was created to explore possible future scenarios and/or freshen up on previous knowledge in a safe practice space. The program accomplished the following tasks:

i. Opening files.
ii. Printing any specific line of a called text file.
iii. Printing the number of lines of data in a called text file.
iv. Two-dimensional plotting with various variables.
v. Identifying additional points on plots with a colored dot.

A python program was then created to plot LMA data from one day of data by latitude and longitude. These LMA sources were then compared to the USGS latitude and longitude of that same day. The first day explored is 2011-03-19. Other days were explored further, with the emphasis on plotting latitude and longitude of LMA data against latitude and longitude of USGS data.

We then created a GUI (Graphical User Interface) for the python program that eases the usability of the program and allows the user to pull a specific date, plot the USGS data, adjust the size of the plotting points, adjust the zoom, and save the plotted graph. Relationships were explored for LMA latitude/longitude and USGS latitude/longitude. After fixing (or shall I say editing) the program for better usage, graphs were compiled for each USGS day to plot the LMA data for the entire day against the USGS location. Dot size is 0.5 for reference in the program. Here are the graphs in result of the observations (format for the date is YYMMDD):
In essence of working towards future goals, several goals were created to enhance the production of data explored. The following are the next steps of research:

i. Fetching Altitude: We will take a look at altitude of LMA sources for each day versus the time in the day that it appears. We will look at the days and be able to narrow down some of our points, to get rid of points from our GUI plots and make the plots more refined. I would like the graph to compare the first column of data (time) with the fourth column of data (altitude) for any specific day I choose.

ii. Three-Dimensional Perspective: I think it would be valuable to have a three-dimensional plot of an entire day's LMA data with a focus of plotting latitude(x), longitude(y), and altitude(z). I would like the graph to compare the second column of data(latitude) with the third column of data(longitude), and the fourth column of data(altitude) for any specific day I choose.
iii. Radial Reference: I would like to narrow down our LMA sources (latitude vs. longitude) with a radial distance from the USGS source. This will get a little tricky, since the earth is indeed a globe, thus making the conversion from lat/long to meters is going to be difficult.

iv. Tornado!!!: Another interesting idea that I want to jump towards is observing the development of LMA sources in tornadic regions.

We then jumped ahead and created a program to analyze the altitude versus time for LMA data of a single day. This will shine light on frequency of sources at varying altitudes. The following are the graphs of each altitude versus time for each of our observing days:
In observing each of these plots, we gathered a notion, a slight notion, of altitudes that would be appropriate to eliminate from our USGS/LMA data. This way, when plotting the latitude versus longitude, we can filter out unnecessary altitudes for analysis. All plots eliminate LMA sources over 100 kilometers. The reasoning behind this choice is that at 100 kilometers (62 miles), the Kármán line,
or 1.57% of Earth's radius, is often used as the border between the atmosphere and outer space. As an extra point of observation, I have added the ability to see when the USGS tremor/quake occurred (indicated by the red line). The following plots were generated for each of our observation days:

![LMA data for 080602](image1)

![LMA data for 080718](image2)

![LMA data for 080802](image3)

![LMA data for 090503](image4)

![LMA data for 100118](image5)

![LMA data for 110319](image6)
Through observing the latitude and longitude plots again, I then began to realize that these ranges do not coincide with a specific radial distance per day. Each are different, and thus, difficult to compare. I then worked towards eliminating points from the plots by both a 5-kilometer distance and a 10-kilometer distance. These plots are limited by the 100km altitude constraint. The following are the plots with a radial distance limitation of 10 kilometers:
LMA data for 080602

LMA data for 080718

LMA data for 080802

LMA data for 090503

LMA data for 100118

LMA data for 110319
Included are also the following plots with a radial distance limitation of 5 kilometers.
To explore possible correlations between LMA data and USGS data, a neural network architecture is being developed. This includes Recurrent Neural Network (RNN), which essentially allows the network to remember the previous data points, while making the next prediction. It will also have a layer aimed at outputting a relevancy scalar, with inputs from the power, chi squared, and altitude, and output going into an RNN. Other inputs will include latitude and longitude to hopefully give the network the ability to predict a guess location. The overall output will be a prediction of time and location, with a confidence score. This program was continuous throughout this semester and is continuing on through the summer.

i. The initial goal is not to have an accurate predictor of earthquakes, but rather to see if this approach can shine light on possible correlations between seismic and LMA data.

ii. The architecture of this will likely change as we progress.

The process of analyzing these plots of LMA data led me from assuming a high correlation between tremors and LMA sources to assuming a low correlation between tremors and LMA sources. Dr. Chronis and I pushed for exploring this correlation: perhaps we are looking in the wrong area. After doing some research on possible related articles, I found only one article covering the topic. Two scientists located on the island of Crete published an article stating the following in their abstract:

i. "On the basis of our analysis of a number of continuous observations made by the monitoring network on Crete, we assume that electrically active clouds are produced in an atmosphere above the sea on the eve of earthquake. These electrically active clouds, which occur at heights of 0.1-10 km, create the conditions for electrical discharges in an atmosphere that may
be the source of the very high frequency (VHF) radio-emissions registered on Crete. We further suggest possible mechanisms of thunder electricity generation. We present the model of convection transport in which the first condition in the generation of thunder electricity is an atmosphere with a horizontal gradient of temperature. Base on this model, the occurrence of electrical charges on the surface of the sea and their transportation further upwards to heights of up to 10km is due to pollution energy allocated within the bottom of the sea as gases and heat injection. The average flux density and power estimations of the VHF precursors were made for the Crete net situation to compare with published VHF data and radio star sources.”

Aside from being motivated again, the further reading of this article led me to understand that indeed, I may have been narrowing my search too far. It turns out, the information I could be looking for, according to this article, may have some specific restrictions. In distance, altitude, and period before the tremor, we then retrieved new constraints to work in and hopefully support the hypothesis. I plan on analyzing (as well as training the RNN) on the following constraints (supported by the above-mentioned article):

i. Distance from the source: not stated
ii. Altitude of LMA sources: 0.1-10km
iii. Time before tremor/quake: observed 1-3 days prior to event
iv. Length of sources: several hours to a day

As a step to further the exploration of LMA data and climate related topics, I looked towards creating a Hovmoeller diagram for a single tornadic event touchdown. In the thirty minutes preceding the touchdown, we can observe minute-by-minute chunks of time versus altitude plot. For each minute and every 100 meters, the number of LMA sources in a narrow radius of 2 or 3 kilometers (centered around the touchdown) is noted and represented in the Hovmoeller diagram.

viii. The first day observed was May 3rd, 2009. The following constraints were applied:
    a. Tornado touchdown occurred at 17:00:00.
    b. Touchdown location was (34.6059,-86.4397)
    c. Altitude constraints maxing out at 10 kilometers.
    d. Observing a 2 kilometer radius from the touchdown.
If you notice the plot is entirely teal, as well as the scale is centered on zero with minimal variation. This is because there are no LMA points that fit these criteria for this day. There are zero LMA points following the constraints. The good thing is that we have nine more days of data we tested. With that, more days have been observed, including days that contain more than one tornado. The following constraints were applied:

i. Altitude constraints maxing out at 10 kilometers.
ii. Observing a 2-kilometer radius from the touchdown.
iii. Observing every 60 seconds from T-30 minutes.
In observing the tornadic data, we have concluded that perhaps we have been looking at the USGS with the wrong altitude constraints. To observe the USGS/LMA data with this realization, the plots have been regenerated as follows: The first set of plots are mapping out the USGS location (red dot) about all of the LMA source points we have for the whole day, with an altitude restriction of 20 kilometers.
The second set of plots maps out the altitude versus time of the day's events, maxed out at an altitude of 20 kilometers. The red line indicates when in the day the quake occurred.
The third set of plots measures each full day of events with a radial constraint around the quake location of 10 kilometers. Altitude restrictions are still in place at 20 kilometers high.
LMA data for 080602

LMA data for 080718

LMA data for 100118

LMA data for 110323

LMA data for 110319

LMA data for 110323
We then decided to observe solar data, specifically GLE (Ground Level Enhancement) events. Ground level enhancement (GLE) events, typically in the GeV energy range, are the most energetic of solar energetic particle (SEP) events with the protons penetrating Earth's neutral atmosphere. During solar cycle 23, sixteen GLE events were observed with excellent data coverage of associated solar eruptions. The source of these GLE particles has been examined in this paper using white light observations of coronal mass ejections, type II radio bursts, and soft X-ray flares. It has been shown that the GLE events are consistent with shock acceleration in every single case. While the possibility of the presence of a flare component during GLE events cannot be ruled out, it can be definitely said that a shock component is present in all the GLE events.

For the specific days that GLE events occurred, we began to observe the LMA data associated, starting with an altitude constraint of up to 20 kilometers and days without any severe weather. Observations were made by creating Hovmoeller plots of the entire day, with no radial restriction. It was pertinent that we observed as much area coverage as possible. The bin size for the python program was every 30 minutes for time, and every 250 meters for altitude. The following four plots were observed.
When I first 'plotted'/filled in these diagrams, I was surprised to see how vertical the outputs were, as if there were 'waves' of sources. I began looking into the times that these waves of sources appeared, with the various times that they did appear. Other than the oddly scattered plot of 031028, it appeared a correlation, if found, would be represented in those waves occurring at different times.

When looking at the times, there were ranges of 2.75 hours to 0.7 hours to about 5 hours from the time that the GLE event occurred to the time a wave of LMA sources appeared. The 'waves' occurred within the time range of 30 minutes after the event to 5 hours after the event. As a side note, there is also a trend of higher density of sources between 5km and 15km.

In the growing elementary knowledge that I do have about GLE events, I say this is a significant display of data of possible correlation. Whether or not these 'waves' of LMA sources are correlated to the GLE events, I believe that we can create plots/diagrams of days that we know GLE events didn't occur (for an open day of clear weather) and compare to see if these 'waves' are causal or unrelated.

This specific section of the project has been handed over to graduate student UAH/George Priftis, where he will continue to explore and possibly note a correlation between GLE events and LMA sources apparent in the North Alabama region. As for the rest of the project, Dr. Chronis and I will continue to explore each of these topics, with an emphasis on continuing to build upon the repertoire and data analysis that we have created thus far. I look forward to furthering my research in the three fields of observing seismic, tornadic, and solar data against LMA data.