POYNTING FLUX AND KINETIC ENERGY FLUX DERIVED FROM THE FAST SATELLITE

A Major Qualifying Project submitted to the Faculty of Worcester Polytechnic Institute

In partial fulfillment of the requirements for the Degree of Bachelor of Science

by

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Project sponsored by SRI International

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1. EXECUTIVE SUMMARY

This report outlines the 2010 Silicon Valley Electrical and Computer Engineering (ECE) Major Qualifying Project (MQP). The 2010 MQP is part 1 (year-1) of a larger, four-year, project proposed by Doctor Russell Cosgrove of SRI International and approved by the National Science Foundation (NSF). The main goal of the NSF project is to get a better understanding of energy contributions to the Earth's atmosphere. Specifically, the NSF project lays out a plan to the study and quantify the interaction between solar wind, made primarily of electromagnetic waves and charged particles called space plasma, and the Earth's own geomagnetic field. By the end of the NSF project, Dr. Cosgrove wishes to create a number of models that describe this complex interaction which will, in turn, be used as inputs in larger-scale models. These larger-scale models, typically referred to as Global (General) Circulation Models (GCM's), are used to describe and predict properties of the atmosphere like density, temperature, and circulations patterns.

The primary tool of use for the NSF project is the Fast Auroral SnapshoT (FAST) Explorer Satellite. The FAST satellite was launched on August 21, 1996 by NASA. NASA's plan was to study the Earth's oval-shaped auroral regions located at the poles (high latitudes). Although scientific theories had already been established on some of the causes and effects of the auroras before FAST, based on new data, some of those theories have been revised. In the simplest terms, the Earth's aurora is caused by the transfer of kinetic energy (collision) between solar wind particles with particles that make up the lower-altitude portion of the Earth's atmosphere. One of the questions that NASA hopes that FAST will answer is how electrons and ions are accelerated in space to create the aurora. The effects of the auroras have been poorly quantified, but the main effect that the NSF project and thus this MQP is concerned with is the heating of the ionosphere. The ionosphere refers to a region of altitude in the Earth's atmosphere between about 300 km and 1000km and the outer edge of the atmosphere. The ionosphere is named such because the many billions and trillions of collisions between molecules in the ionosphere and other particles cause electrons to be knocked off causing the molecules to become ionized. The ionosphere's interaction with solar wind, ionospheric heating, and all subsequent effects are the main topics explored in the NSF project.

As mentioned previously, Dr. Russell Cosgrove of SRI international was the proposer of the NSF project, thus he became the Principal Investigator (PI). Cosgrove chose SRI colleague Dr. Hasan Bahcivan as CoPI because of his expertise in the field and interest in the project. The project was to be performed and is to be completed at SRI international in Menlo Park, California. This makes SRI International the corporate sponsor of the 2010 MQP. Because Cosgrove slated the first three parts (three years) of the project to be performed by WPI students as part of their MQP's, SRI International will also be a corporate sponsor for the 2011 and 2012 MQP's. SRI International is a contract-based research company with innovations in a multitude of fields including engineering, education, political policy, national defense, robotics, space physics and many others. The students of the 2010-2012 MQP's will be working at the Center for Geospace Studies (CGS) in the Engineering and Systems Division (ESD) of SRI.

The final deliverables for year-1 of the NSF project, and thus the final deliverables for the 2010 MQP, included the development and documentation of methods for the computation of Poynting flux and kinetic energy flux from data measured by the FAST satellite. The Poynting flux is the amount of energy carried by an electromagnetic wave going through an area. Poynting flux is calculated by finding the cross product of the electric field and the magnetic field intensity, which results in the Poynting vector, and multiplying by the desired area. Units of Poynting flux are measured in watts per square meter (W/m^2) or joules per square meter-seconds ($J/m^2 *s$). The kinetic energy flux is the amount of energy carried by particles through an area. Kinetic energy flux is calculated by summing the kinetic energy of all incoming particles through a certain area. Units of kinetic energy flux are also measured in watts per square meter (W/m^2) or joules per square meter-seconds ($J/m^2 *s$).

Once the students were able to develop the methods for calculating the Poynting flux and kinetic energy flux, the students were asked to use their methods to process a limited number of FAST orbits that contained interesting and representative samples. As a starting point, the students needed to understand why the research was being done. They found that similar research projects studying the energy inputs due to auroral processes had already been conducted, but because electric field measurements in previous projects were calculated using electric field models instead of being taken directly. Because deriving electric field data from models has a probabilistic nature, there is an error or variance included in the electric field data, which carried over to calculations of the Poynting flux. The NSF project seeks to rectify the problem of electric field variability by using electric field measurement values taken directly instead of deriving values from models.

After the students learned the basic theory behind the project, they were able to begin creating methods for calculating Poynting flux and kinetic energy flux. The first step was to view and obtain data from the FAST satellite. To view FAST data, the students had two options: they could view plots of measurements using the Satellite Data Tool (SDT) which connects directly to FAST data banks or they could navigate to the University of California Berkeley FAST website and view summary plots online. The summary plots contain partially processed data taken from FAST. The processing of data includes de-spinning electric and magnetic field measurements, subtracting the geomagnetic field from the magnetic field measurements in order to find the perturbations, transforming data into another coordinate system, and a number of other techniques. The students used both methods to view and become familiar with FAST data. The next step was to obtain the actual data. The students also had two options for this: they could download data they view on SDT or they could download summary files, which correspond to summary plots, from the Berkeley website. Because the summary files available on the Berkeley website were already partially processed, the students chose to obtain data that way. If the students wanted to obtain data the other way by using SDT, they would have to process the raw data from scratch using a combination of SDT and Interactive Data Language (IDL) routines written by Berkeley researchers. This would have been the ideal situation because the students would have been able to control exactly how data was processed instead of relying on already partially processed data. In practice however, the students were not able to make use of the IDL routines because of software debugging problems. At this point in the project, the students had an understanding of what the data looks like and how to obtain partially processed data online. The next step was to process the data for Poynting and kinetic energy flux.

The summary data was provided by Berkeley researchers and posted online in Common Data Format (CDF). Because there were so many instruments on FAST, there were actually a couple of versions of the CDF files, but the students only needed 4 of the 6 available versions: the DC fields data, the electron energy spectrum data, the ion energy spectrum data, and the orbit-ephemeris (positional) data. Once all the data was obtained for a particular orbit, they needed to align the fields and particle data with the positional data in time. The aligning of the fields, particle, and positional data is done using a simple MATLAB interpolation function. Once all of the data was aligned in time, the students needed to transform the positional data from a non-earth-fixed coordinate system (Geocentric Equatorial Inertial, GEI) to an earth-fixed coordinate system (Geocentric Geographic, GEO). This allowed the students and mentors to describe the position of events with respect to the Earth. Once the positional data was transformed from GEI to GEO, the students found values for the geomagnetic field using the IGRF-1995 model. Geomagnetic field models were required to transform the electric and magnetic fields data from the Berkeley Data Coordinate System (DCS) to GEO which was the next step of data processing. Once all of the available field and position data was transformed into GEO, the final step was to find the cross product of the electric field and magnetic field intensity, H (found by multiplying the magnetic field by the permeability of free space). The resulting Poynting vector could be multiplied by an area to find the Poynting flux. Luckily for the students, the kinetic energy flux was already calculated by Berkeley researchers and posted in the summary files. The students simply multiplied by a scalar to obtain the desired units.

The final step in the project was for the students to plot and interpret the results. The students plotted using MATLAB and presented to Cosgrove and Bachivan. Because a thorough understanding of the results by the students is outside the scope of this project, the students could not readily verify their results, but upon initial inspection, were told by Cosgrove and Bachivan that their results were reasonable. Specifically, the values of the Poynting and kinetic energy flux were within the expected range and the directions were as expected as well.

In wrapping up the project, the students wrote this report and documented all of their efforts through video and supplemental text documents. The students also created a website as a resource for future students and advisers.

THE SUBMISSION OF REMAINDER OF THIS REPORT WILL BE POSTPONED UNTIL THE COMPLETION OF A FINAL VERSION

The final version of this report will be completed and turned in by Nicole Cahill by the last day of classes during D-term 2010.