Creating an Online Space Weather Forecasting System

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Purpose:

Importance:

❖ **With current forecasting capabilities, a major solar storm could result in over $2 trillion of damages.**

In September of 1859, a particularly strong Coronal Mass Ejection (CME) caused auroras to be seen all over the world and telegraphs to go haywire. This type of event in the modern world would destroy most satellites and cause severe damage to power utilities on the ground. Most of this damage can be prevented or mitigated by turning vulnerable equipment off, however this requires reliable warning.

Goals:

❖ **Model-based Predictions – An improvement over current heuristic forecasting:**

This project is intended as a first step in creating a model based space weather forecasting system. There are currently experience-based systems available, however these use very little of our theoretical understanding of the solar wind and magnetosphere. As a result, these forecasts provide little detail and lack point-to-point predictions. Using the *Open Geospace General Circulation Model* (OpenGGCM) , it is hoped that eventually more accurate predictions of the local space weather will be possible.

❖ **Outreach – Education and raising interest:**

In addition to its utilitarian goals, this project aims to stimulate interest and educate the general population about solar wind phenomena and why space weather prediction is so important and difficult. As part of this outreach, it is important to supply some applicability to the general public, so the site will also provide a graphical prediction of the Auroras in the Northern Hemisphere.

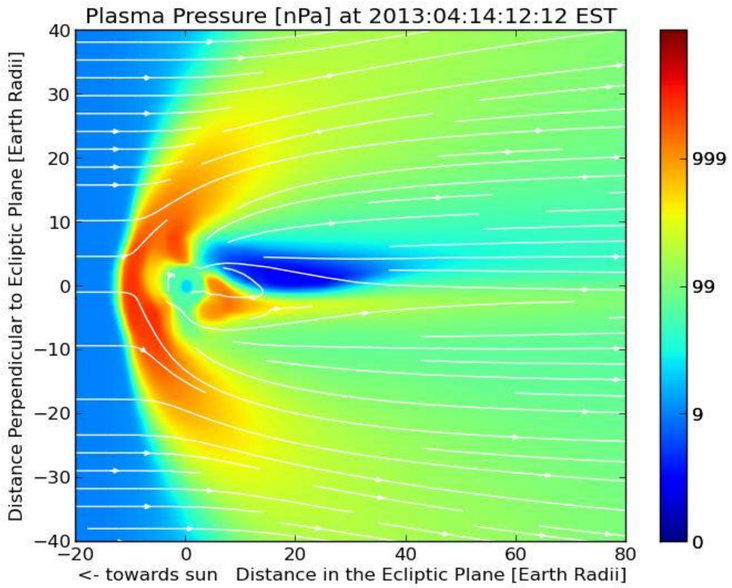

Figure 1: This is a sample of the output of the simulation as it appears on the website. There are currently two outputs available to display: one of plasma pressure with velocity stream lines (shown above), and the other of plasma density with magnetic field lines (not shown). Both the plasma density and plasma pressure use a log scale in the display.

Background:

The Physics:

❖ **The Solar Wind:**

The solar wind is a fast moving soup of negatively charged electrons and positively charged protons separated in the Sun's photosphere and constantly cast off in all directions.

❖ **Solar Flare and CMEs:**

The Sun's magnetic field is a jumble of tangled lines constantly changing, breaking and reconnecting. This can cause hot-spots that are bright in the ultraviolet range to occur, called solar flares. These solar flares are often followed by a Coronal Mass Ejection (CME), where a massive part of the Sun's corona is flung off into space.

❖ **The Magnetosphere and Ionosphere:**

The Earth is like a giant permanent magnet, with a north and south pole. Between 85 km and 600 km above the surface is the ionosphere, where the thin atmosphere is ionized by the solar wind. Beyond this is the magnetosphere, where the flow of the solar wind is dominated by the Earth's magnetic field.

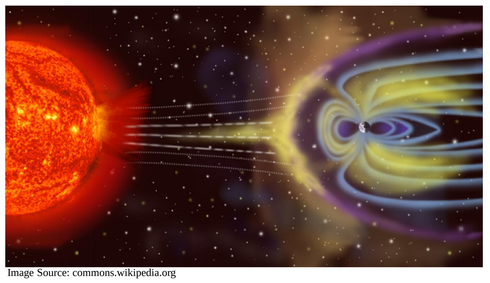

Image Source: commons.wikipedia.org

Figure 2: This is an artists rendition of the solar wind emanating from the Sun and flowing towards the Earth. Distances and sizes are not to scale.

The Model:

❖ **Challenges in Modeling Solar Wind in the Magnetosphere:**

The solar wind is a very low-density compressible fluid with the added complication that the fluid is made up of charged particles. Moving charges have magnetic interactions that are important to accurately model plasmas. The complexity is such that approximations are necessary for a practical model.

❖ **The MHD approximation:**

The basic magnetohydrodynamic (MHD) approximation for plasma flows is dependant on two assumptions:

1.) The speed of the plasma is very small compared to the speed of light
2.) The resistivity of the plasma is negligible.

The simulation uses a variation of this model called resistive MHD that allows for small but non-negligible resistivity.

❖ **Open Geospace General Circulation Model (OpenGGCM):**

OpenGGCM is two models running in parallel, one for the magnetosphere, and one for the ionosphere. The magnetosphere model uses resistive MHD to model the behavior of the solar wind in the Earth's magnetic field. The simulation then maps these result into the ionosphere using a variety of algorithms. One of the major advantages to this approach is the ability to use multiprocessing, which greatly improves the resolution to time ratio.

Acknowledgements:

❖ The data used to run the simulation comes from ACE real-time solar wind data (http://www.swpc.noaa.gov/ace/)
❖ The html and javascript currently used is an adaptation of that used by WSA-enlil (http://www.swpc.noaa.gov/wsa-enlil/)
❖ This work was supported by NSF grant AGS-1056898
❖ Thanks of course to my advisor, Kai Germaschewski

My Work:

Progress To Date:

❖ **Background Tasks:**

The bulk of the work done so far has been in creating the code to automatically run the simulation and convert the data-file outputs into jpegs that are read on the website. Thus far, the simulations have been run using data from the ACE satellite available online.

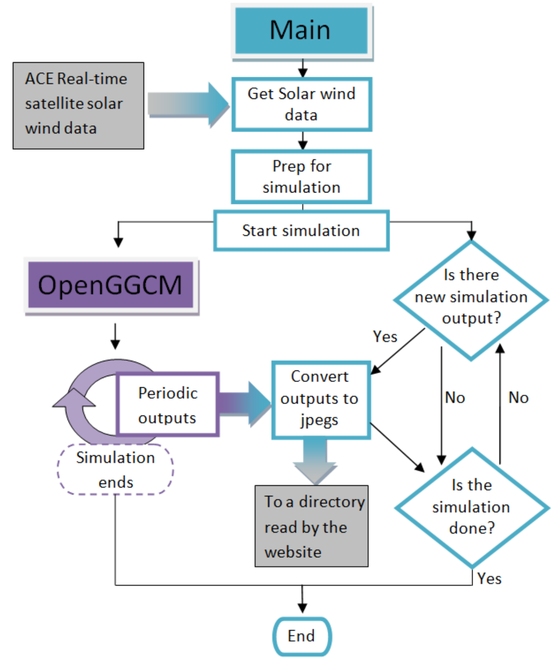

Figure 3: A chart illustrating the basic code flow, with purple representing a separate thread that runs the simulation in a virtual terminal, blue representing the main body of code, and grey representing locations outside of the code.

❖ **The Website:**

There is currently a website up and running, with a home page and two separate animated displays of the simulation output. The html and java-scripts used for the website are adaptations of the code used for the WSA-Enlil site.

Future work:

❖ **Improvements of the Website:**

There is a new site in development, and will offer a greatly improved user interface. Other possible extensions of the website capabilities may include point predictions of space weather, where a user can enter coordinates and get predicted values for any of the modeled quantities.

❖ **Aurora Predictions:**

Towards the goal of outreach, we will be adding a feature that predicts the Auroras. The predictions will be presented as an overlay of the expected light show on a map of the northern hemisphere.

❖ **Solar Wind Predictions – Using forecast input data:**

The simulation, which require solar wind data as input, is currently running from ACE solar wind data, which means the simulation could get an hour or two ahead of the start time at best, and as it is currently running, it only gives information about what has already happened. There are models such as WSA-Enlil that make predictions of the solar wind up to a week in advance. We plan to coordinate with this team to use their forecast data as input to our simulation.