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GEOS 215: Earth System Data Science
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The Sun Is A Deadly Laser

A GEOS 215 Project Prospectus to Assess the Accuracy of the One-Dimensional Single-Layer Atmosphere Model Using a Data Science Approach

Proposed Title:

We propose to call our project the following:

"The Sun is a Deadly Laser: Assessing the Accuracy of the One-Dimensional Single-Layer Atmosphere Model Using a Data Science Approach"

List of group members and description of roles/responsibilities:

For the majority of the project, we (Leafia and Jocelyn) plan to equally split the coding and literature review responsibilities necessary to compute the global single-layer atmosphere model and compare the computed temperature results with the observed temperature records. After computing the general model, we will formulate new discussion questions based on our comparisons. After formulating these discussion questions, we will each choose the discussion questions that we are most interested in and pursue answering those questions individually. When we present these findings and discussions, the author in charge of a discussion question will be in charge of presenting their results specific to their discussion question, including writing, research, coding, and figure creation.

Research questions:

The Earth's climate system is an extremely dynamic system that is controlled by a large variety of variables, from the albedo of the Earth's surface to the solar flux of the Sun. Although the solar flux is usually considered to be a constant, the Sun's solar flux varies slightly from year to year. Since the Earth's surface temperature is, in large part, dependent on the solar flux of the Sun, it can be assumed that changes in the solar flux affect the Earth's surface temperature.

Global Climate Models (GCM's) have been used in recent years to more accurately model the Earth's surface temperature. However, these models, despite their relative accuracy, require a dramatic amount of computing power. Meanwhile, simpler, one-dimensional models of Earth's climate system can approximate the Earth's temperature and be easily modeled on a standard personal computer.

For this GEOS 215 Term Project, we propose to use solar irradiance data from the Global Solar Atlas in a one-dimensional single layer atmosphere model to roughly model the change in surface temperature due to variations in the solar flux of the Sun. We will then compare these results with observed temperature data from the Global Solar Atlas, the Global

Historical Climatology Network (GHCN), and the Goddard Institute for Space Studies' (GISS) Surface Temperature Analysis data in order to assess the accuracy of the single-layer atmospheric model compared to observed temperatures, as well as to assess the impact of modified solar flux on observed global surface temperatures. We are also interested in understanding where on Earth the single-layer atmospheric model is most accurate, and where this model is the least accurate. We are also interested in the degree that variations in solar irradiance effect the the temperature system versus other variables like surface albedo.

Hypotheses:

We predict that the modeled temperatures from the single-layer atmospheric model will dramatically differ from the observed temperatures, especially in coastal regions and regions North and South of the tropics. We predict that the region near the equator would have temperatures closest to the single-layer atmospheric model because the Sun's irradiance is most direct there, while regions farther North or South would have differing temperatures because the angle of incidence is different, and thereby less intense, than that of the equator. We also predict that regions with albedo closest to the Earth's average surface albedo will have the most similar observed and modeled temperatures.

Sources of data:

We will acquire the majority of our solar irradiance data from the Global Solar Atlas, which is a database that houses solar data relevant to solar energy applications for international users. The Global Solar Atlas was prepared by the SolarGIS group under a contract to The World Bank, and the database is based on a solar resource database that SolarGIS already owns and maintains. This database was created for the purpose of providing quick and easy access to solar resource data to users around the world. The Atlas provides long-term averages of solar resource data in the form of Global Horizontal Irradiation (GHI), Diffuse Horizontal Radiation (DHI), and Direct Normal Irradiation (DNI) from the mid-1990's to 2015. The Atlas also provides air temperature data at 2 m above the surface, and these data sets begin at different times depending on location (i.e. 1994, 1999, or 2007) and end in 2015. All data sets are measured within the latitude range of 60°N and 45°S; all land areas outside of those ranges are not measured. These data sets are at a resolution of 30 arcseconds per pixel and are free to download in the GIS GeoTIFF file format on The Global Solar Atlas website[1]. MATLAB comes with the ability to read GeoTIFF files using the geotiffread() function, so these datasets can be easily used and analyzed in MATLAB.

We will also compare the temperature data provided by the Global Solar Atlas with two other data sets: the Version 3 Historical Mean Temperature Data from the Global Historical Climatology Network (GHCN)[2], managed by the National Oceanic and Atmospheric Administration (NOAA), and the Goddard Institute for Space Studies (GISS) Surface

[1] https://globalsolaratlas.info/downloads/world
[2] https://www.ncdc.noaa.gov/ghcnm/

Temperature Analysis Data[3], managed by the National Aeronautics and Space Administration (NASA). The GHCN is a temperature dataset that was first developed in the early 1990's, and since May 2011, NOAA has published three versions of this dataset. The GISS's Surface Temperature Analysis Data is homogenized via the inclusion of homogeneity corrections for non-climatic discontinuities, meaning that variations due to collection are minimized in the dataset. We have previously used the GHCN data in Data Lab 1, so we know that these data work with MATLAB, and the GISS Surface Temperature Analysis data comes in a easily-readable comma-separated variable file format.

For constants related to using this single-column atmospheric model, such as albedo, we will use the average albedo for the Earth's surface α, which is about 0.3 (Goode et al., 2001). If we have time, we may also use the NASA Earth Radiation Budget Experiment (ERBE) spatial distribution of albedo data from 1986 to 1987[4]. We will also consult other sources in the literature to find constants for the average specific heat capacity, the thermal conductivity, and thermal diffusivity of the Earth's surface, as well as constants for the temperature of the Sun and its emissivity. We will also consult the literature to find the Sun-Earth distance, the radius of the Earth, and the radius of the Sun.

Proposed methods:

This should include types of calculations/analyses you will perform with the datasets you are using and the types of visualizations you expect you will be able to create, which you can illustrate using mock-ups of graphs.

We plan to use the 1D radiative transfer model for a single-layer atmosphere to approximate the surface temperature of the Earth using solar irradiance data from the Global Solar Atlas. This model relies on the energy flux from a star's surface, q_s, to calculate the total energy flux from the star, q_s':

$$q_s' = q_s\left(\frac{r_s}{R_p}\right)^2$$

Where r_s is the radius of the Sun and R_p is Sun-Earth distance. Using this, we can compute the total power intercepted by the planet, Q_p:

$$Q_p = \pi r_p^2 q_s'$$

Where r_p is the Earth's radius. The average flux incident on the planet, q_p, is:

$$q_p = \frac{Q_p}{(4\pi r_p^2)}$$

The incident flux, q_{in}, that is then absorbed on the planet's surface is:

[3] https://data.giss.nasa.gov/gistemp/stdata/
[4] https://iridl.ldeo.columbia.edu/SOURCES/.NASA/.ERBE/.ALL/.total/.albedo/index.html

$$q_{in} = (1 - \alpha)q_p = \frac{q_s'(1-\alpha)}{4}$$

Assuming the incident energy flux q_{in} is equal to the re-emitted energy flux in infrared light from the surface, q_{out}, and that:

$$q_{out} = \varepsilon\sigma T_p^{\ 4}$$

Where ε is the emissivity of the surface, σ is the Stefan-Boltzmann constant, and T_p is the temperature of the planet, therefore, when q_{in} is equal to q_{out}, T_p for a no-atmosphere model is:

$$T_{p,\ barerock} = \left(\frac{q_s'(1-\alpha)}{4\sigma}\left(\frac{r_s}{R_p}\right)^2\right)^{1/4}$$

For the single-layer atmosphere model, $T_{p,barerock}$ is also equal to the so-called "skin-temperature", which is the temperature of the outermost layer of the model. Therefore, for a single-layer atmosphere model, the temperature of the atmosphere, T_a, is equal to $T_{p,\ barerock}$, and the temperature of the ground, T_g, is expressed by the relationship:

$$T_g = 2^{1/4} T_a$$

For this project, the total energy flux from the star q_s is equal to the solar irradiance data from the Global Solar Atlas. We plan to compute the temperature at any given 30 arcsecond pixel in the dataset using the above equations for a given pixel's solar irradiance. We plan to use a constant albedo of 0.3 for our calculation. After computing the temperatures at each pixel, we will compare our calculated temperatures from our observed temperatures by taking the difference between our temperature $T_{modeled}$ and the observed temperature T_{obs}. We will perform this calculation for all three temperature datasets.

References:

Goode, P.R., Qiu, J., Yurchyshyn, V., Hickey, J., Chu, M.-C., Kolbe, E., Brown, C.T., Koonin, S.E. (2001). Earthshine observations of the Earth's reflectance. *Geophysical Research Letters, 28* (9), 1671-1674.