The Sun is a Deadly Laser

Assessing the Accuracy of the One-Dimensional Single-Layer Atmosphere Model

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Motivation and Design of SLGCM

The Earth’s climate is frequently modeled **using general circulation models (GCM’s)**. These models **require a massive amount of supercomputing power.** From an educational perspective, these models’ computing demands make GCM’s inaccessible to interested undergraduates that want to practice global climate modeling in the classroom on personal computers.

Luckily, another, computationally simpler climate model exists: the **one-dimensional single-layer atmosphere model (1D SLAM)**. The 1D SLAM assumes that Earth’s surface is a blackbody (emissivity = 1) and that the atmosphere is a single column of non-circulating air. The temperature of the Earth’s surface using the 1D SLAM model, T_g, is equal to:

$$T_g = \left[2\left(\frac{(1-\alpha)q_p}{\sigma}\right)\right]^{1/4}$$

Where α is the albedo of the surface [dimensionless], σ is the Stefan-Boltzmann constant, defined as 5.67 x 10^{-8} W m^{-2} K^{-4} (Blevin and Brown, 1971), and q_p is the incident radiation on the surface of the planet [W/m^2]. This model can be expanded into a **single-layer global climate model (SLGCM)** by dividing the Earth’s surface into a grid and defining each grid space as a non-circulating column of air that has no lateral heat transport between columns (Figure 1).

The simplicity of the SLGCM comes with its own drawbacks. Most notably, the model is known to be an extremely inaccurate predictor of actual Earth surface temperatures. This observation begs the question: **How accurately does the SLGCM predict surface temperatures? Are there regions on Earth where the predictions are more/less accurate? How do these predictions vary seasonally?**

This study compares the SLGCM ground temperatures with observed surface and sea surface temperatures from the HadCRUT4 dataset in order to **assess the degree of the model’s predictive accuracy.**

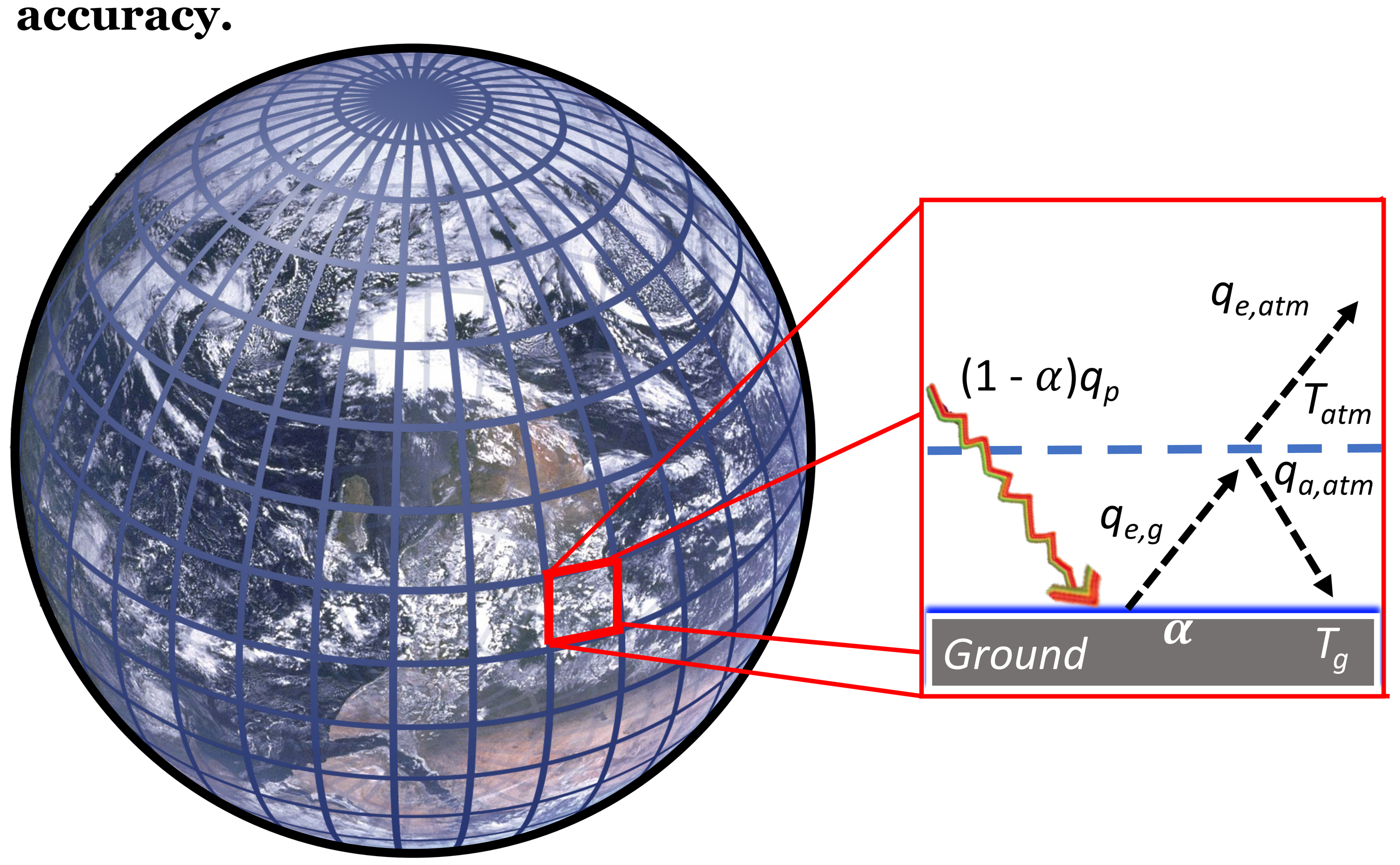

Figure 1. Model of the single-layer global climate model (SLGCM) used in this study. Each grid space is approximated as a single column of noncirculating air that has no lateral transport of heat between grid spaces. The Earth’s surface in each grid space is assumed to be a perfect blackbody (emissivity = 1). $q_{e,g}$ is the emitted infrared radiation from the ground, $q_{e,atm}$ is the emitted infrared radiation from the atmosphere, and $q_{a,atm}$ is the infrared radiation from the ground that is reabsorbed by the atmosphere.

Difference Between SLGCM and Observed Temp.

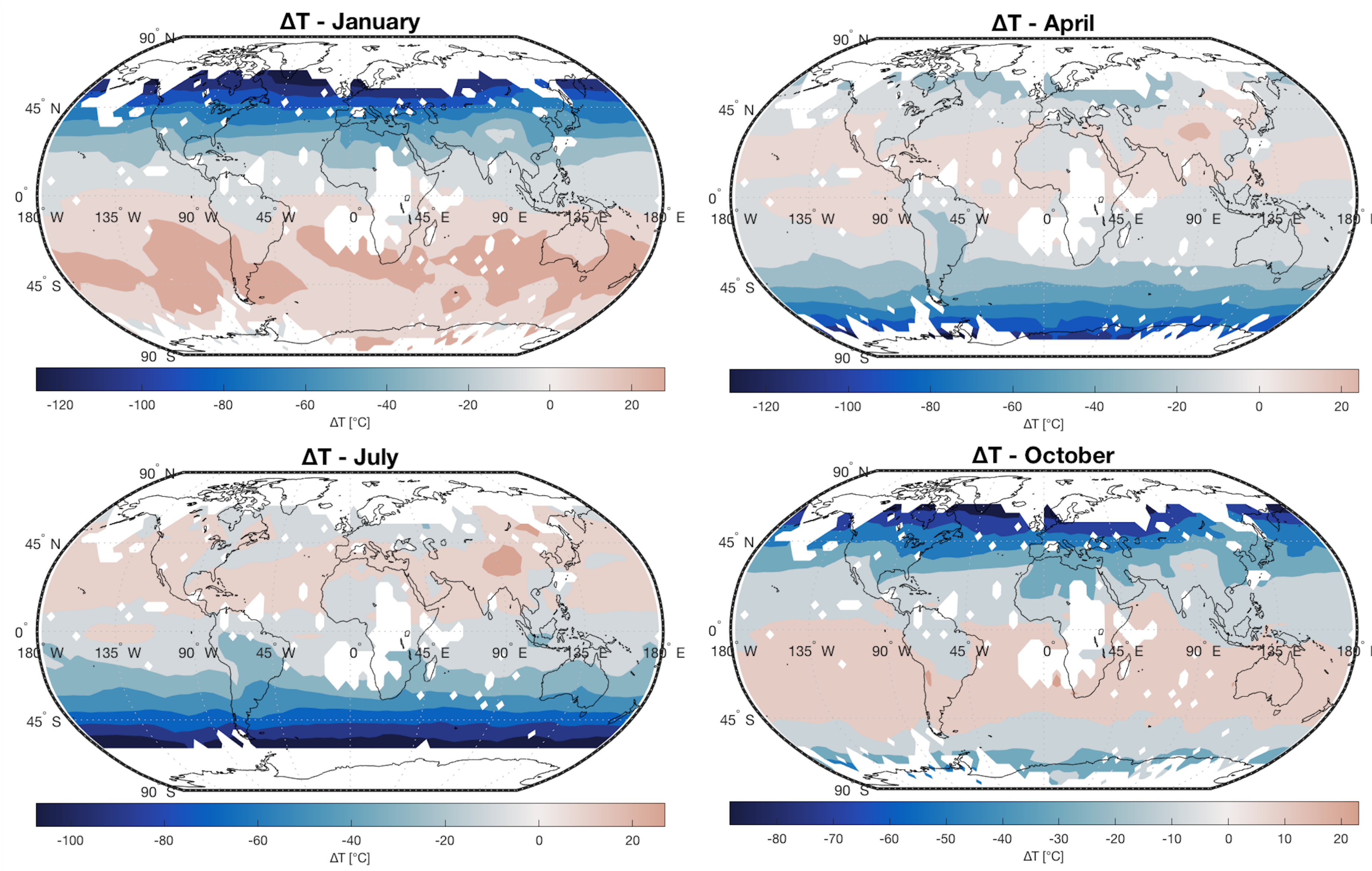

Figure 2. Plots of the temperature difference ΔT between the modeled SLGCM temperatures and the observed HadCRUT4 temperatures for A) January (Northern Hemisphere (NH) Winter, Southern Hemisphere (SH) Summer); B) April (NH Spring, SH Fall); C) July (NH Summer, SH Winter); and D) October (NH Fall, SH Spring). Bright white regions on the plots are regions with no data. Redder regions are where the modeled temperatures are warmer than observed; bluer regions indicate colder predictions.

CLARA-A2, ERBE, and HadCRUT4 Datasets

CLARA-A2 Solar Irradiation - q_p

- The surface downwelling longwave radiation measurements from the CLARA-A2 dataset (assuming clear-sky conditions) (Karlsson et al., 2015) were used to represent the **incident solar irradiation q_p** for the SLGCM.
- Solar irradiance shows seasonal variation (Figure 3 A-D)

Earth Radiation Budget Experiment (ERBE) Mean Albedo 1986-1987 - α

- NASA’s Earth Radiation Budget Experiment (ERBE) mean albedo between 1986-1987 (Barkstrom and Smith, 1986; Barkstrom et al., 1990) were used to represent the **albedo α** of the Earth’s surface for the SLGCM (Figure 3 E).

HadCRUT4 Observed Temperatures

- Originally presented as temperature anomalies calculated relative to the mean temperature over a 1961-1990 reference period in a 5°x5° grid (Morice et al., 2012).
- 1961-1990 reference mean temperature used was calculated from mean monthly temperatures between 1961-1990 in a 5°x5° grid (Jones et al., 1990).
- Observed temperatures used in this study were equal to the temperature anomalies plus the mean temperature between 1961-1990 (Figure 3 F).

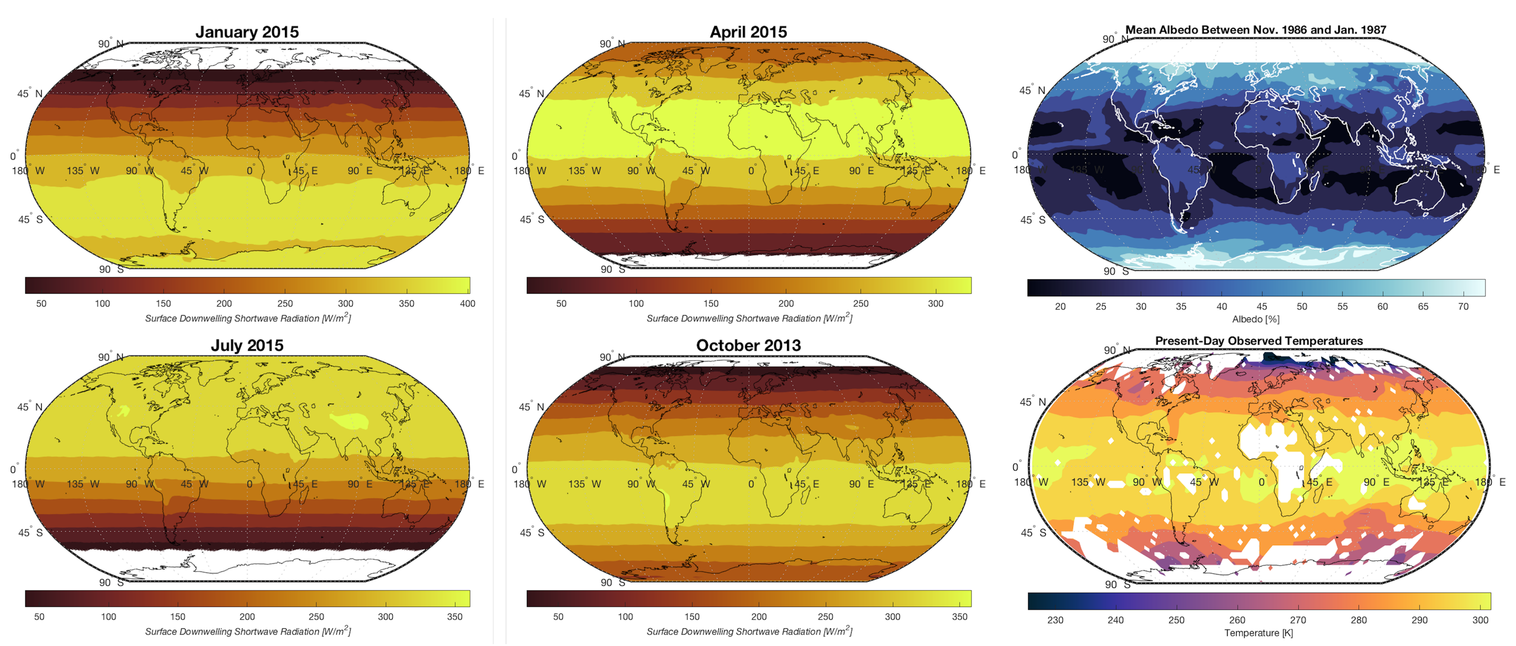

Figure 3. A)-D) CLARA-A2 surface downwelling longwave radiation measurements in A) January 2015; B) April 2015; C) July 2015; and D) October 2013. Units are in watts per square meter. E) ERBE mean albedo between November 1986 and January 1987. F) HadCRUT4 present-day observed temperatures. Observed temperatures are equal to the HadCRUT4 temperature anomalies plus the mean temperature of the reference period between 1961-1990. Temperatures are presented here in units of Kelvin.

Methodology

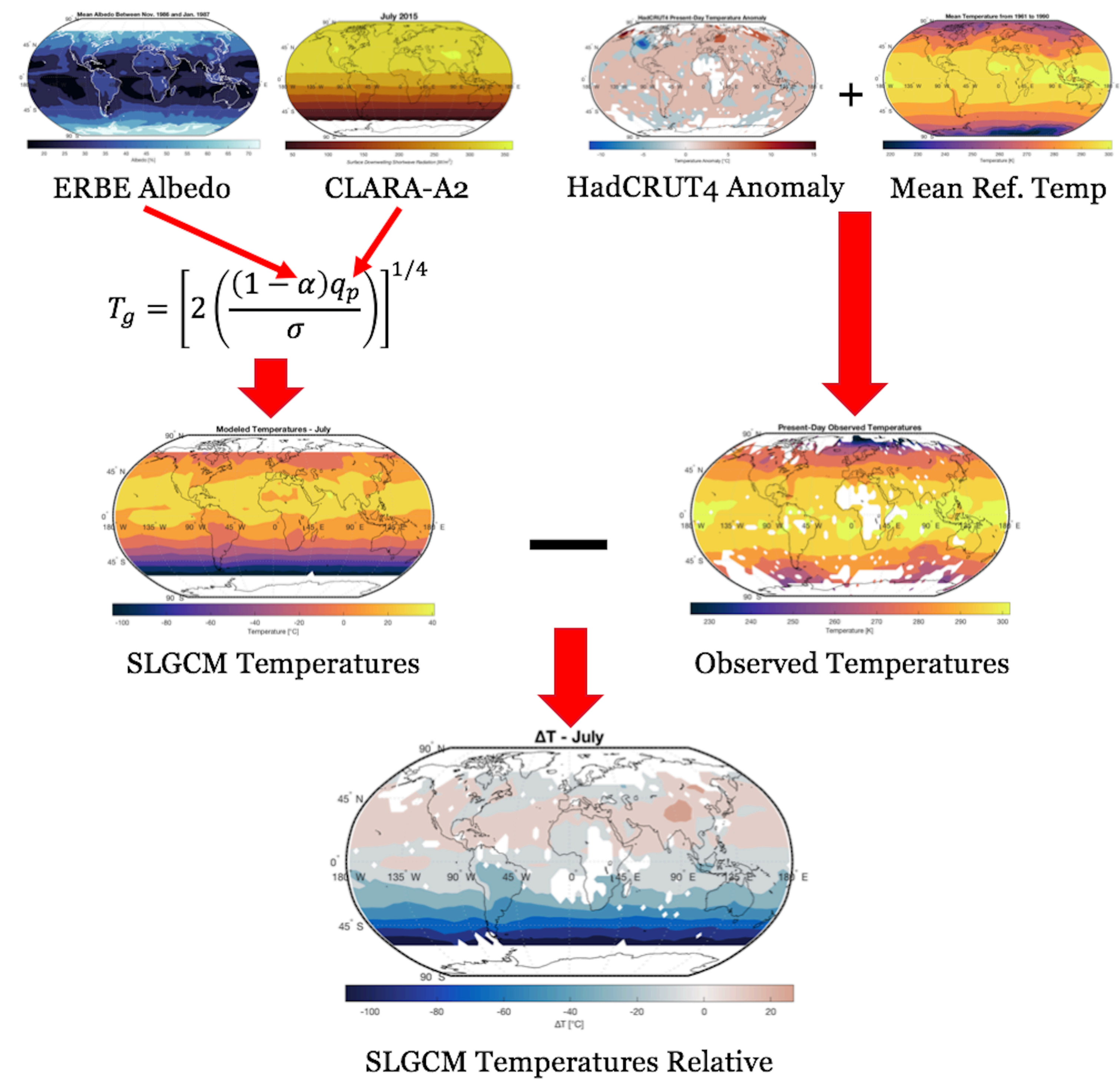

Figure 4. Flowchart depicting the SLGCM comparison methodology. On the left, the modeled SLGCM ground temperatures T_g are calculated using the mean albedo from the ERBE and the solar radiation from CLARA-A2. On the right, the observed temperatures are derived from the raw HadCRUT4 temperature anomaly data set by adding a mean reference temperature with the anomalies. The SLGCM temperatures are then subtracted from the observed temperatures to compare the SLGCM temperatures.

Interpretations and Future Work

- The SLGCM is much less accurate than the observed temperatures, often 10^2 to 10^3 orders of magnitude off the real value.
- The SLGCM is least accurate for polar regions, i.e. areas that receive little incident sunlight, especially during local winters.
- High elevation areas (e.g. Himalayas, Andes) in local summers and springs seem to have a slightly more positive ΔT then the surrounding, lower elevation topography.
- ΔT over oceans in high-intensity solar irradiation bands are notably warmer in the SLGCM than the surrounding topography. This might be due to the lower albedo measurements for oceans in the ERBE dataset.
- Future work would involve directly comparing the results of a more sophisticated general circulation model with that of the SLGCM.

Acknowledgements

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