Modelling the Earth system without greenhouse gasses

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Abstract

Keywords: Climate; Is; Where; The; Keywords; Go.

1 Introduction

When modelling the climate system, climatologists always omit certain physical/chemical/biological processes. These modelled processes are mainly limited by available computational power, our understanding of the Earth system and historical records [IPCC 2021]. As shown in Figure 1, global General circulation models (GCMs) originally modelled atmospheric and oceanic circulation, radiative transfer, land physics and sea ice, while the newest GCMs also describe chemistry and biogeochemistry on land and in the oceans, land cover and clouds.

While GCMs are the most well known kind of climatic models, climatologists also use other kinds of models, which are generally divided into three groups: Energy Balance Models (EBMs) predict sea-level temperatures as a function of energy balance, Radiative-Convective (RC) models are used for computing vertical temperature profiles by modelling radiation and convection processes and Statistical-Dynamical (SD) models operating in zonal latitude averages [Rose and Scott-Brown 2021].

My goal with is to learn to combine parts of climate models, which we have developed during the semester into a single model, while understanding the effects of various underlying processes. Model results may be useful to determine biggest shortfalls and most significant processes omitted in the model.

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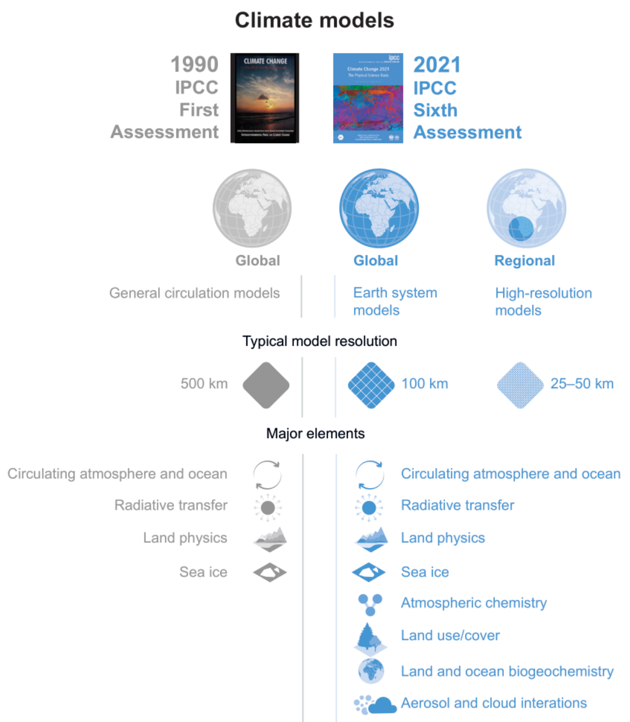

Figure 1: Comparison of climate models used in the first and sixth IPCC assessment reports, including major modelled processes. [IPCC 2021]

1.1 Physical processes

Climatic models integrate temperature, moisture and other parameters from differncial

1.1.1 *Atmosphere*

In our model developed during the semester, temperature at the surface was set

1.1.2 *Soil*

Soil temperature is mostly influenced by solar irradiance, water content, slope aspect, vegetation cover, ... Soil temperature varies seasonally and daily - In medium latitudes, the annual amplitude for grass-covered soil is around 17°C at 0.5m and 9°C at 2m below ground [Novák and Hlaváčiková 2019].

1.1.3 *Surface*

optimisation

1.2 Model goals

2 Methods

The model is developed as two-dimensional (2D), representing height and length. First experiments don't however include any variability in the "length" domain for the time being. This variability can be represented in several ways, for instance the model could be used for comparing and modelling interactions between surfaces with different albedos.

2.1 Model components

The presented model contains several components, each modelling a different sphere - atmospheric boundary layer, heat equation in the soil and surface energy balance.

2.1.1 *Surface balance*

Surface energy balance is computed based on the ... equation (). Incoming shortwave radiation changes over time as described in Section 2.2.

The surface temperature is optimised numerically, using the Limited-memory BFGS-B algorithm.

2.1.2 *Boundary layer*

This module computes atmospheric temperature and moisture, while also being equipped

2.1.3 *Heat equation*

This module computes soil temperature based on a forward time difference and central spatial difference of the heat conductivity equation (Equation 1)

$$T_i^{n+1} = T_i^n + V_g \frac{\Delta t}{\Delta z^2}(T_{i+1}^n - 2T_i^n + T_{i-1}^n) \tag{1}$$

Boundary conditions for soil temperature are set at the surface and lowest modelled point (2m below ground). The surface temperature is defined by a Dirichlet boundary condition - temperature computed in the Surface balance module. Temperature in the lowest modelled point is on the other hand defined as the same as in the second lowest point (Neumann condition).

2.2 Model parameterisation

The model uses incoming shortwave radiation computed based on the solar constant and solar altitude angle, derived from spherical trigonometry according to Equation 2.

$$sin(\alpha) = sin(\Phi)sin(\delta) + cos(\Phi)cos(\delta)cos(h) \tag{2}$$

Φ represents local latitude (50°N for this model), δ solar declination and h the hour angle. the resulting solar altitude angle (α) then serves as input into Equation 3, where α is multiplied by the solar constant ($1366 W/m^2$) and negative incoming radiation values are set to 0.

$$Irradiance = max(0, 1366 * sin(\alpha)) \tag{3}$$

The computed solar irradiance changes with both the time of day and the season, as shown in Figure 2 and Figure 3. These values serve as input for the surface balance module of the model.

Time period modelled - processing time considerations - workstation specs

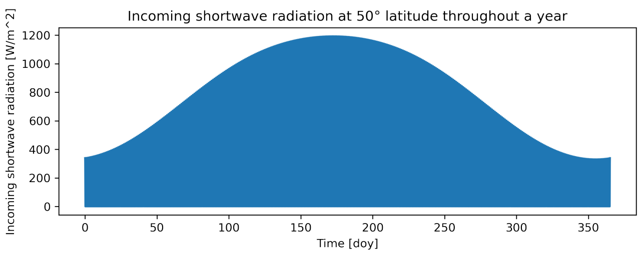

Figure 2: Seasonal change in incoming shortwave radiation throughout one year represented by maximum irradiance during a day.

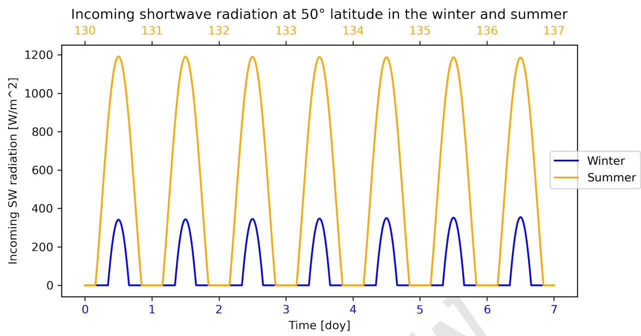

Figure 3: Daily change in incoming shortwave radiation throughout two periods during a year - blue line shows the first week of January, orange line shows days 180-187 during a year (beginning of July).

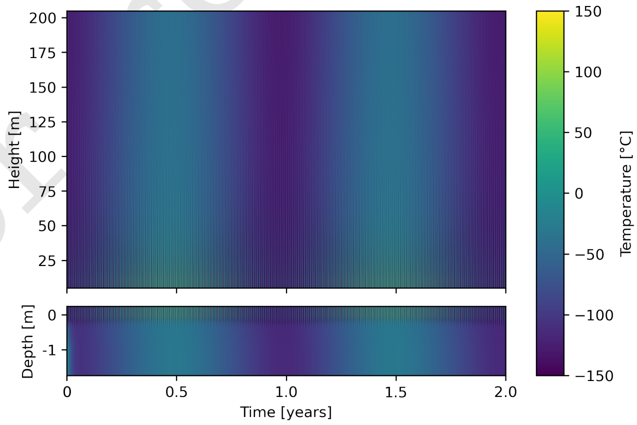

Figure 4: Modelled temperatures over a two-year period.

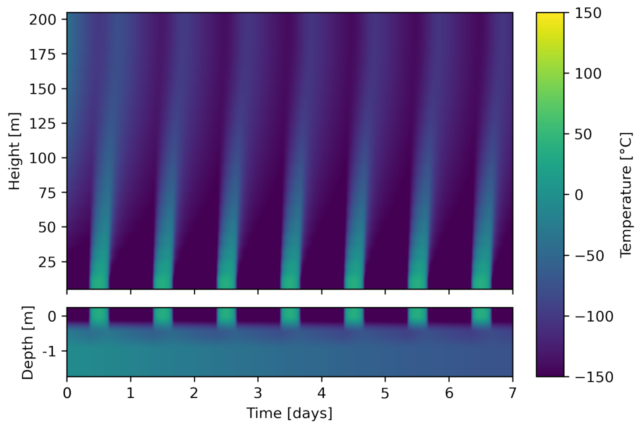

Figure 5: Modelled temperatures over a week in the winter (1st week of January)

3 Results

4 Discussion

5 Conclusions

Data Availability

Code for creating and running the model is available on github - `https://github.com/YesPrimeMinister/HU-ClimateModeling`

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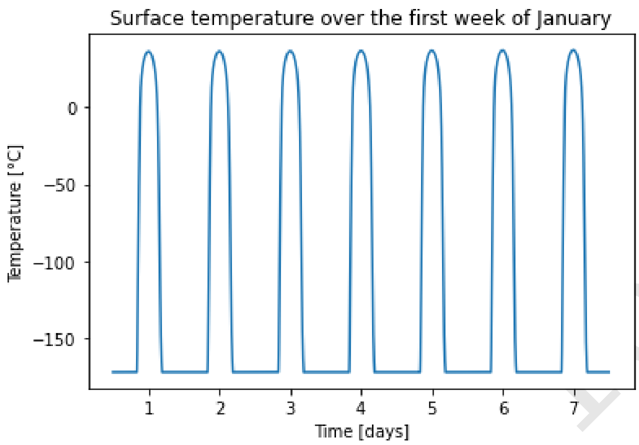

Figure 6: Modelled surface temperatures over a week in the winter (1st week of January)

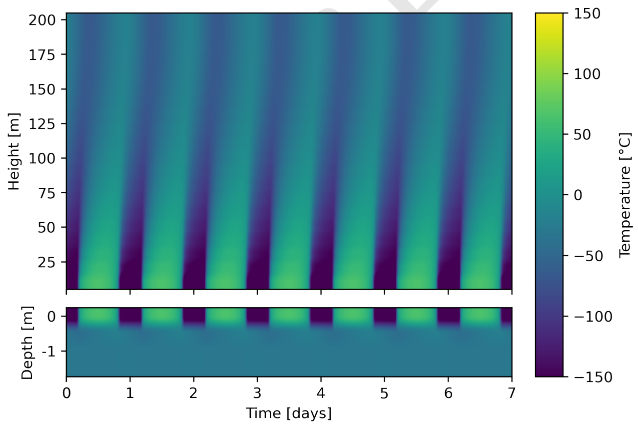

Figure 7: Modelled temperatures over a week in the summer (1st week of June)

References

IPCC (2021). "Climate Change 2021: The Physical Science Basis", page 2409. DOI: 10.1017/9781009157896.

Novák, V. and H. Hlaváčiková (2019). "Soil Temperature