Global Climate Modelling

1. Introduction

Global climate models (GCMs) use mathematical equations to describe the behavior of factors of the Earth system that impact climate. These factors include dynamics of the atmosphere, oceans, land surface, living things, and ice, plus energy from the Sun. Sophisticated climate models are increasingly able to include details such as clouds, rainfall, evaporation, and sea ice. Thousands of climate researchers use global climate models to better understand the long-term effects of global changes such as increasing greenhouses gases or decreasing Arctic sea ice. The models are used to simulate conditions over hundreds of years, so that we can predict how our planet's climate will likely change.

1.1.Spatial Resolution

Although we know that traits like temperature vary continuously over the surface of the Earth, calculating such properties for the entire globe is beyond the reach of even the fastest supercomputers. Instead, a climate model places "virtual weather stations" at intervals around the modeled Earth and reports the calculated properties at each station. Models use grids of "cells" to establish the locations of the "virtual weather stations." A typical climate model might have grid cells with a size of about 100 km (62 miles) on a side. The "virtual weather stations" are located at the corners of the grid cells. Models can be generated with higher or lower resolutions. The grid cells could be reduced in size to 50 km. This would mean that more cells cover Earth's surface, increasing spatial resolution. Or the grid cells could be enlarged to 200 km. This would mean fewer grid cells and decreased spatial resolution. More, smaller cells increases the amount of computing time because there are more "virtual weather stations" at which atmospheric variables must be calculated. Higher resolution models provide much more detailed information, but take lots more computing time. As a general rule, increasing the resolution of a model by a factor of **two** means about **ten times** as much computing power will be needed (or that the model will take ten times as long to run on the same computer).

Model grids for atmospheric (including climate) models are three dimensional, extending upward through our atmosphere. Early climate models typically had about 10 layers vertically; more recent ones often have about 30 layers. Because the atmosphere is so thin compared to the vast size of our planet, vertical layers are much closer together as compared to the horizontal dimensions of grid cells. Vertical layers might be spaced at 11 km intervals as compared to the 100 km intervals for horizontal spacing.

1.2.Temporal resolutions

Just as modelers must decide how close together in space to put the "virtual weather stations" at grid intersections, they must also decide how close together in time (that is, "virtual" or "model world" time) to make their calculations. As is the case with spatial resolution, computing-time increases as temporal resolution increases, so if conditions in the model world are calculated too frequently, the model takes a very long time to run. However, if too much "model world" time passes between calculations, the model becomes inaccurate.

Climate models are typically run with time steps of about 30 minutes. A climate model run for a century might, therefore, involve 1,753,152 (the number of half-hours in a century) time steps. All model parameters (temperature, wind speed, humidity, etc.) would be calculated at each of the thousands to millions of grid points in the model at each of those time steps. That's a lot of calculating... sounds like a job for a supercomputer!

A model is often run for several "model years" before the time frame of interest to allow the modeled system to become stable before scientists introduce conditions that alter the system, such as increased levels of carbon dioxide.

2. IPCC and CMIP5

2.1. IPCC scenarios

There are four different scenarios used by climate models described in IPCC reports. The main scenario groups are named A1, A2, B1, and B2. (There are also a few subdivisions of the A1 scenario.) Are you lost in this alphabet soup yet? Below are some illustrative (but not comprehensive) descriptions of the assumptions made by the major scenarios. The scenarios are pretty complex, so this is just a broad overview.

- **A1 scenarios:** assume rapid economic and technological growth, a low rate of population growth, and a very high level of energy use. Disparities between "rich" and "poor" countries narrow.
  - The **A1FI** scenario is based on high levels of fossil fuel use for energy.
  - The **A1T** scenario assumes non-fossil energy sources will predominate.
  - The **A1B** scenario presumes that a balance of fossil and non-fossil fuels will be used for energy.
- **A2 scenario:** assumes high population growth, that technological change and economic growth will be slower and more disparate (between countries and regions) than in other scenarios, and that energy use will be high.
- **B1 scenario:** assumes a high level of environmental and social consciousness which leads to sustainable development, low population growth, high economic and technological

advancement, and low energy use. Area devoted to crops and grasslands decreases, while reforestation efforts expand forests.

- **B2 scenario:** similar assumptions to the B1 scenario in that it also assumes a more sustainable and environmentally conscious world economy and society. However, there are more disparities between industrialized and developing nations in this scenario. Technological and economic growth is slower than in B1, and population growth is greater (though still less than in A2). Energy use is midway between B1 and A2. Changes in land use are also less dramatic than in B1.

2.2. CMIP5 Scenario

CMIP5 promotes a standard set of model simulations in order to: evaluate how realistic the models are in simulating the recent past, provide projections of future climate change on two time scales, near term (out to about 2035) and long term (out to 2100 and beyond), and understand some of the factors responsible for differences in model projections, including quantifying some key feedbacks such as those involving clouds and the carbon cycle. The CMIP5 (CMIP Phase 5) experiment design has been finalized with the following suites of experiments:

I. Decadal Hindcasts and Predictions simulations,

II. "long-term"simulations,

III. "atmosphere-only" (prescribed SST) simulations for especially computationally-demanding models.

3. Cryosphere Climate interactions

Feedback refers to the modification of a process by changes resulting from the process itself. Positive feedbacks accelerate the process, while negative feedbacks slow it down. Part of the uncertainty around future climates relates to important feedbacks between different parts of the climate system: air temperatures, ice and snow albedo (reflection of the sun's rays), and clouds. An important positive feedback is the ice and snow albedo feedback. Sea ice and snow have high albedo. This means that they reflect most of the solar radiation. With warmer polar temperatures, the area of sea ice and snow cover decreases, exposing new expanses of ocean and land surfaces that absorb an increased amount of solar radiation. This increase of total absorbed solar radiation contributes to continued and accelerated warming. Many IPCC climate models suggest a major loss in sea ice cover by the mid 21st century caused by albedo feedback from shrinking snow cover and increased open water areas in summer.