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Climate Models for General Public Understanding

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Abstract: This article presents some important concepts of climate models without any mathematical jargon. The purpose is to provide a broad idea on how climate models work. Background information on climate system and natural climate variation is also included.

1. Introduction

At present, climate change stimulates widespread application of climate models. However, to better utilize these models, it should be beneficial to understand the concept of the models so that their principles and limitations are well aware. This article presents essential concept of climate models for general users, without mathematical or meteorological details. In order to understand the concept of climate models, it is necessary to know about the climate system and natural climate variations as explained in Sections 2 and 3 (World Meteorological Organization, 2015), respectively. Section 4 is about climate models and Section 5 presents ensemble forecast which is a technique to improve accuracy of climate model forecasts.

2. Climate System

The components of the climate system are the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere. Solar radiation is the main source of energy for the climate system. All climate elements (rain, temperature, wind, etc.) are driven by transfer and transformation of energy among all the spheres of the climate system.

In the tropics where the incoming solar radiation is more than the outgoing terrestrial radiation, the temperature is high. While in the higher latitudes where the solar radiation is less than the terrestrial radiation, the temperature is low. This difference in temperature results in large-scale atmospheric circulation that moves warm air from the tropics to the higher latitudes and cold air from the higher latitude to the tropics. Over the tropics, high surface temperature causes warm moist air to ascent and a belt of heavy rain is formed around the globe. This is called as the intertropical convergence zone (ITCZ). The position of ITCZ which moves according to the position of the maximum solar radiation at the earth surface, determines the seasons in the tropics. At the top of the ITCZ (12-18 km) where the air is dry because most of the moisture is condensed as rain, the air spreads out and descended back to the surface, creates the belt of dry and hot air around 30 degree latitudes of both hemisphere. The trade winds then flow back from these dry zones toward the ITCZ and complete the circulation.

In analogous to the atmospheric circulation, the ocean circulation also transports energy. The ocean circulation is in the form of basin-wide circulations called gyres. The ocean currents associated with the gyres carry warm water to higher latitudes and cold water toward the equator. In addition, there are also vertical motion associated with these ocean circulations. Because of the high heat capacity of the ocean, interactions between the rapidly changing atmosphere and the slowly changing ocean are the main causes of the climatic variations. The oceans are also the most important reservoir for carbon dioxide produced by human action.

Beside the ocean, interactions between the atmosphere and the land surface also play important roles. For the part of the atmosphere within the first few tens of meters above the ground (boundary layer) there are many complex physical processes at work, and the understanding about these processes are still inadequate. Land use changes by human activities have led to changes in the amount of solar radiation absorbed by the ground, evaporation and evapotranspiration, and soil moisture.

3. Natural Climate Variations

Climate is not a consistent phenomenon, there are various variations due to natural causes. Most of the climate variations are related to oceanic phenomena. Examples of these phenomena are the El Niño Southern Oscillation (ENSO), Madden-Julian Oscillations (MJO), South Pacific Convergence Zone, Intertropical Convergence Zone (ITCZ), North Atlantic Oscillation (NAO), Interdecadal Pacific Oscillation (IPO), Antarctic Oscillation (AAO) and Indian Ocean Dipole (IOD). Some of these phenomena are briefly explained as follows.

The ENSO oscillates between warm (El Niño) and cold (La Niña) periods of the ocean surface across the eastern and central equatorial Pacific. The impact of ENSO on global climate is complex, however some impacts could be identified.

The MJO is referred to a cycle of heavy rain and relatively quiet periods over the tropics with a time scale of 30-60 days. Tropical cyclones could also formed during the active period. In addition, the MJO could also enhance the development of ENSO. The mechanisms of MJO is not well understood.

The IPO is an inter-decadal fluctuation in atmospheric pressure. When the IPO is low, cooler than average sea surface temperatures occur over the central North Pacific, and vice versa. These changes extend over the entire Pacific Basin.

The IOD is a phenomenon in the Indian Ocean, characterized by cooling of the sea surface in the southeastern equatorial Indian Ocean and warming of the sea surface in the western equatorial Indian Ocean. When this happens, the heavy rain over the eastern Indian Ocean shifts to the west and brings heavy rain over east Africa and severe droughts over the Indonesian region.

It should be noted that all the phenomena mentioned above are not independent from each other. The influence of one phenomenon could enhance or suppress the influences of the others. Thus, climate at any specific space and time is determined not by a single phenomenon but the combination of all phenomenon in all time and space scales. This makes climate prediction a very complicated task.

4. Climate Model

A climate model represents the climate system by a set of mathematical equations based on related physical, biological and chemical processes. This set of equations is so complex that no one is able to find the exact solution. However, an approximate solution can be obtained using numerical computation by a computer. In the numerical methods for climate models, the earth, ocean and atmosphere are divided into grids, both in the horizontal and vertical directions.

All future values of the climate variables are computed at each grid point. The distance between two adjacent grid points (grid space) in a model is related to the spatial resolution of that model. The variables at each grid point are repeatedly predicted for a short time interval (time step) into the immediate future until the pre-determined forecast time is reached. The length of time step depends on the grid space. The smaller the grid space, the shorter the time step. Thus, for the same forecast length, high resolution climate models require longer time to run than low resolution models.

Climate models try to incorporate all the component of the climate system. The success of climate models depends on how realistic the interactions among all components of the climate system are represented. Because of the complexity of the climate system, several simplifying assumptions have to be made.

There are physical processes in the climate system that are smaller than the grid space of climate models and/or too complicate to be explicitly represented in the models, such as clouds, turbulence and heat transfer. However, these processes are essential for climate prediction and have to be included in climate models. To include these physical processes, a technique called parametrization is used to relate these processes to the variables that can be resolved by the models such as temperature, wind and humidity. However, there is no single standard parameterization method for each of these physical processes. As a result, many parametrization options for the same process are usually included in any climate model. It is up to the users of the model to select parameterization methods that are appropriate for their application.

In general, climate models have to cover the whole globe to take into account all processes and areas that determine the development of climate. This results in huge amount of data that are required to run climate models. As a consequence, a large number of calculations are involved. In order for the climate forecasts to be of practical use, large grid space and time steps are applied so that the forecasts can be available in time. Thus, the outputs from global climate models (GCMs) do not have spatial resolutions that are appropriate for smaller scale application for regional climate forecast. In order to utilize the output from a global climate model for any region, a downscaling method to increase the spatial resolution of the output from the global climate model has to be applied.

One method of downscaling is to run a limited area climate model that covers only the area of interest with a higher resolution than the global model. This regional climate model (RCM) uses the output from the global model as driving forces. Regional climate models require less computer resources than global models, but a high performance computer is still necessary for running the model. This approach is called dynamical downscaling. Another method is statistical downscaling, in which the relationship between the output from the global model and the regional climatology is used to increase accuracy of the forecast. This approach can be carried out using a small computer. There are advantages and disadvantages for each method, a combination of dynamical and statistical methods (hybrid method) is believed to further enhance the accuracy of climate forecasts for regional scale. It is imperative that information of the regional scale has to be included in the downscaling process, otherwise it is just only an interpolation.

5. Ensemble Forecast

There are various possible errors in climate models forecast such as formulation of the model equations, numerical approximation, initial condition (observation) and parameterization. That is, a climate forecast from a climate model is just one of many possible realizations. It has been demonstrated by Lorenz (1963) that climate is a chaotic system, small different in the initial conditions could result in widely diverging forecasts. Lorenz summarized chaos as: when the present determines the future, but the approximate present does not approximately determine the future (Wikipedia, 2015). The concept of ensemble forecasts is to run a climate model several times with slightly different initial conditions to create a set of possible states of future climate. These states are then used to determine the most likely climate of the future. Ensemble forecast can also be created from different models with the same initial condition. Performing an ensemble forecast requires huge computer resources, but a significant improve in the forecast accuracy makes it worthwhile.

6. Epilogue

Accuracy of climate forecasts depend on capability of climate models to realistically represent all natural variations (Section 3) and human impacts. At present, only some of natural variations could be forecasted and man-made influences are not well understood. This results in an incomplete picture of the climate change.

Developing a global climate model requires not only a large investment in computer capability but also on education and training in various fields. It is inevitable that developing countries have to rely on developed countries to provide outputs from global climate models for regional climate downscaling. As computer technology advances at an exponential rate, the resolution of global climate forecasts are also increase very rapidly. There will soon come a day when developed countries are able to forecast climate for any area in the world with more accuracy than the countries who govern that area. With adverse effects of climate change, accurate climate forecasts could result in advantages for developed countries and disadvantages for developing countries. However, with strong cooperation among developing countries and assistance from developed countries, all people of the world can together prepare for the impacts of climate change.

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