10. Weather and Climate Modelling

Numerical weather prediction models

A numerical weather prediction (NWP) model is a computer model developed to simulate the behaviour of the atmosphere. It solves a complex system of mathematical equations based on physical laws to predict the future state of the atmosphere from specified initial conditions. The mathematical equations are more complete and complex forms of the dynamical and thermodynamical equations for the wind, pressure and temperature that have been used in this course. In addition physical processes, such as radiation, clouds and precipitation, and surface exchanges are represented in the models using parameterisation schemes.

The model divides the planet into a number of vertical layers representing levels in the atmosphere, and divides the surface of the planet into a grid of horizontal boxes separated by lines similar to latitudes and longitudes. In this way, the planet is covered by a three-dimensional grid of boxes, as shown in Fig. 10.1. The typical size of these boxes in a global NWP model is about 150 km in the east-west direction and 100 km in the north-south direction, with 20 to 40 levels in the vertical. This means that the atmosphere is represented by about one million or more individual boxes. In each of these boxes, the wind components, temperature, pressure and moisture are predicted. The model will typically use a time step of about 10 minutes of simulated time to make forecasts for up to 5 to 10 days ahead. The size of the models and the number of calculations required for the forecast means that these forecasts can be made only on the largest and fastest computers.

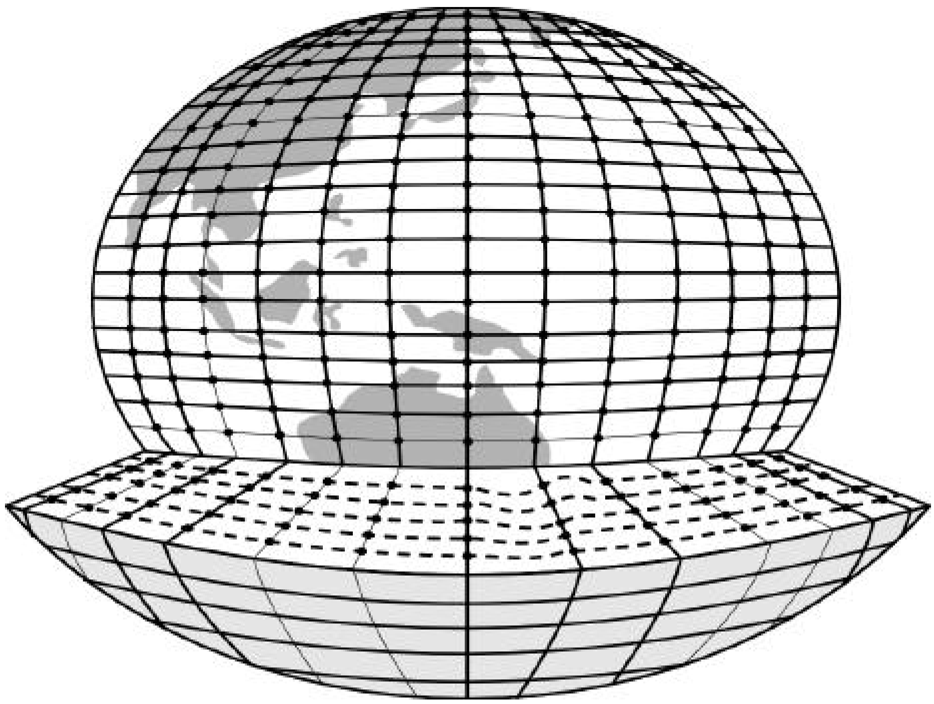

Figure 10.1. Schematic representation of the grid of boxes covering the Earth's surface and atmosphere in a typical global atmospheric model.

To make a weather prediction, the model starts from initial conditions based on the observed state of the atmosphere at the initial time. The model equations are integrated forward in time to predict the simulated state of the atmosphere at the future time. As the equations are non-linear, small errors in the initial conditions amplify as the model simulation progresses, so that the difference between the predicted atmospheric conditions and the true conditions grow over time in the forecast. These errors grow to such an extent that reliable NWP model forecasts can be made for only up to about 7-10 days. This behaviour of the atmosphere is an example of a non-linear chaotic system.

The size and speed of high performance computers limit the resolution that is possible in global NWP models. However, more accurate predictions can be made if higher resolution models (with smaller size boxes subdividing the atmosphere) are used. Hence, regional or limited-area NWP models are used with higher resolution over a smaller domain, such as over Australia. Such regional NWP models use horizontal boxes of size about 50km. As the resolution improves, smaller scale processes, such as individual thunderstorms or coastal sea breezes, can be explicitly simulated in high resolution NWP models.

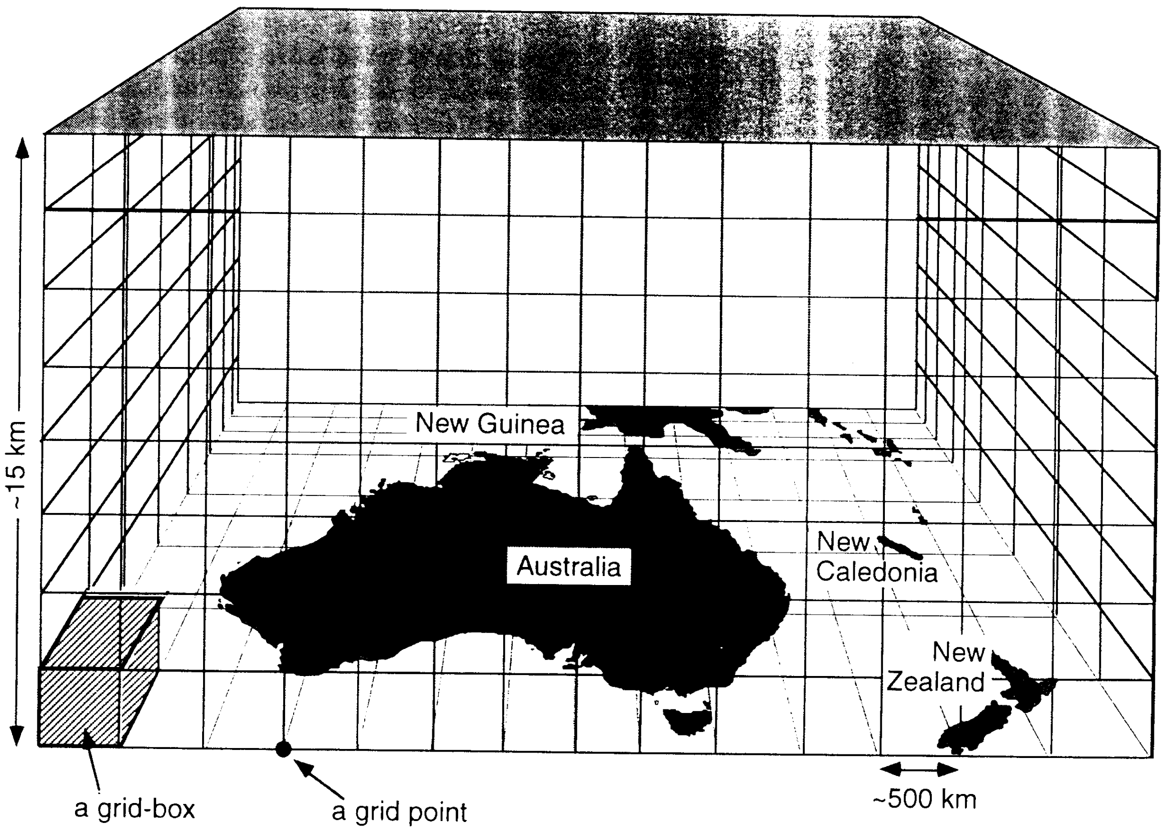

Figure 10.2. Schematic representation of a limited-area NWP model in the Australian region. While the grid box size shown here is of order 500 km, most current models use higher spatial resolution, with grid box size of order 50km.

Global climate models

A global climate model (GCM) is a computer model representing the atmosphere, oceans, land and icecaps. They use the same mathematical formulation for the atmosphere as NWP models, but also have to represent the other systems that are important for climate, such as exchanges with the ocean, land surface, and ice caps. These interactions are illustrated in Fig. 10.3.

In practice, the major difference between a GCM and an NWP model is that the climate model is used to predict the average behaviour of the atmosphere (its climate) and not to make a deterministic prediction of the exact weather at a specific time. The unpredictable, chaotic nature of the atmosphere means that deterministic predictions are not possible. However, it is possible to predict changes in climate due to changes in boundary conditions, such as exchanges with the ocean or the land surface, or changes in external forcing factors, such as changes in solar radiation or in the amount of greenhouse gases is the atmosphere. Climate models are usually integrated for much longer periods, to perform simulations on time scales from seasons to more than one hundred years.

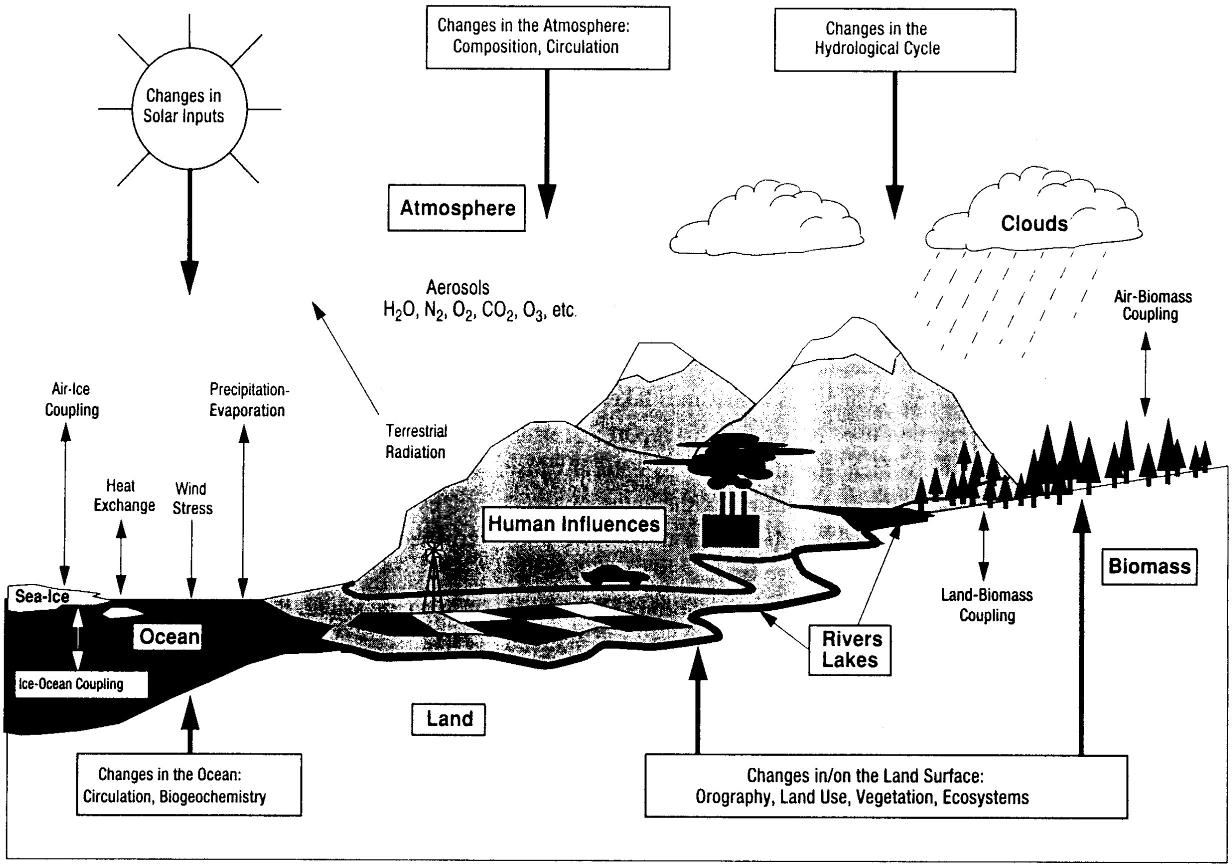

Figure 10.3. Schematic view of the components of the global climate system (bold face), their processes and interactions (thin arrows), and some aspects that may change (thick arrows). Reproduced from *Climate Change 1995: The Science of Climate Change*, Eds. J. T. Houghton et al. (1996).

To allow the GCMs to be run for these long-period simulations, they generally use lower resolution than NWP models. The horizontal size of a typical grid box in the CSIRO GCM is about 500 km by 300 km, limited largely by computer power. Inside each grid box, the mathematical equations are solved at model time-steps of about twenty minutes for many model-decades until a picture of the Earth's climate is built up. Global climate models capture large-scale climate features like the deserts and tropics very well, but have difficulty capturing smaller features like cyclones and thunderstorms because they occur at scales much smaller than the grid boxes.

Coupled ocean-atmosphere GCMs employ models of the full ocean (including the deep ocean). They can simulate the uptake of surface warming by the deep ocean and changes in ocean circulation, and the consequent effect this has on regional climate. Some features of climate variability associated with the El Niño-Southern Oscillation (ENSO) are also captured by coupled models.

Typical problems that can be investigated using GCMs include the seasonal rainfall variations over Australia associated with sea surface temperature anomalies due to El Niño (where the model is forced by specifying the changed sea surface temperatures as a lower boundary condition) or simulations of future climate change due to increasing greenhouse gases in the atmosphere (where the concentration of carbon dioxide in the model atmosphere is increased). GCMs are also used to simulate climate changes like ice ages associated with changes in solar radiation or just to simulate the natural internal variability of the coupled ocean-atmosphere climate system.