14.2.2.2 Balancing the need for finer scales and the need for ensembles

There is a natural tendency to produce models at finer spatial scales that include both a wider array of processes and more refined descriptions. Higher resolution can lead to better simulations of atmospheric dynamics and hydrology (Chapter 8, Section 8.9.1), less diffusive oceanic simulations, and improved representation of topography. In the atmosphere, fine-scale topography is particularly important for resolving small-scale precipitation patterns (see Chapter 8, Section 8.9.1). In the ocean, bottom topography is very important for the various boundary flows (see Chapter 7, Section 7.3.4). The use of higher oceanic resolution also improves the simulation of internal variability such as ENSO (see Chapter 8, Section 8.7.1). However, in spite of the use of higher resolution, important climatic processes are still not resolved by the model's grid, necessitating the continued use of sub-grid scale parametrizations.

It is anticipated that the grids used in the ocean sub-components of the coupled climate models will begin to resolve eddies by the next report. As the oceanic eddies become resolved by the grid, the need for large diffusion coefficients and various mixing schemes should be reduced (see Chapter 8, Section 8.9.3; see also, however, the discussion in Section 8.9.2). In addition, the amount of diapycnal mixing, which is used for numerical stability in this class of ocean models, will also be reduced as the grid spacing becomes smaller. This reduction in the sub-grid scale oceanic mixing should reduce the uncertainty associated with the mixing schemes and coefficients currently being used.

Underlying this issue of scale and detail is an important tension. As the spatial and process detail in a model is increased, the required computing resources increase, often significantly; models with less detail may miss important non-linear dynamics and feedbacks that affect model results significantly, and yet simpler models may be more appropriate to generating the needed statistics. The issue of spatial detail is intertwined with the representation of the physical (and other) processes, and hence the need for a balance between level of process detail and spatial detail. These tensions must be recognised forthrightly, and strategies must be devised to use the available computing resources wisely. Analyses to determine the benefits of finer scale and increased resolution need to be carefully considered. These considerations must also recognise that the potential predictive capability will be unavoidably statistical, and hence it must be produced with statistically relevant information. This implies that a variety of integrations (and models) must be used to produce an ensemble of climate states. Climate states are defined in terms of averages and statistical quantities applying over a period typically of decades (see Chapter 7, Section 7.1.3 and Chapter 9, Section 9.2.2).

Fortunately, many groups have performed ensemble integrations, that is, multiple integrations with a single model using identical radiative forcing scenarios but different initial conditions. Ensemble integrations yield estimates of the variability of the response for a given model. They are also useful in determining to what extent the initial conditions affect the magnitude and pattern of the response. Furthermore, many groups have now performed model integrations using similar radiative forcings. This allows ensembles of model results to be constructed (see Chapter 9, Section 9.3; see also the end of Chapter 7, Section 7.1.3 for an interesting question about ensemble formation).

In sum, a strategy must recognise what is possible. In climate research and modelling, we should recognise that we are dealing with a coupled non-linear chaotic system, and therefore that the long-term prediction of future climate states is not possible. The most we can expect to achieve is the prediction of the probability distribution of the system's future possible states by the generation of ensembles of model solutions. This reduces climate change to the discernment of significant differences in the statistics of such ensembles. The generation of such model ensembles will require the dedication of greatly increased computer resources and the application of new methods of model diagnosis. Addressing adequately the statistical nature of climate is computationally intensive, but such statistical information is essential.

14.2.2.3 Extreme events

Extreme events are, almost by definition, of particular importance to human society. Consequently, the importance of understanding potential extreme events is first order. The evidence is mixed, and data continue to be lacking to make conclusive cases. Chapter 9, Sections 9.3.5 and 9.3.6 consider projections of changes in patterns of variability (discussed in the next section) and changes in extreme events (see also Chapters 2 and 10). Though the conclusions are mixed in both of these topical areas, certain results begin to appear robust. There appear to be some consistent patterns with increased CO_2 with respect to changes in variability: (a) the Pacific climate base state could be a more El Niño-like state and (b) an enhanced variability in the daily precipitation in the Asian summer monsoon with increased precipitation intensity (Chapter 9, Section 9.3.5). More generally, the intensification of the hydrological cycle with increased CO_2 is a robust conclusion. For possible changes in extreme weather and climate events, the most robust conclusions appear to be: (a) an increased probability of extreme warm days and decreased probability of extreme cold days and (b) an increased chance of drought for mid-continental areas during summer with increasing CO_2 (see Chapter 9, Section 9.3.6).

The evaluation of many types of extreme events is made difficult because of issues of scale. Damaging extreme events are often at small temporal and spatial scales. Intense, short-duration events are not well-represented (or not represented at all) in model-simulated climates. In addition, there is often a basic mismatch between the scales resolved in models and those of the validating data. A promising approach is to use multi-fractal models of rainfall events in that they naturally generate extreme events. Reanalysis has also helped in this regard, but reanalysis *per se* is not the sole answer because the models used for reanalysis rely on sub-grid scale parametrizations almost as heavily as climate models do.

One area that is possibly ripe for a direct attack on improving the modelling of extreme events is tropical cyclones (see Section Chapter 2, 2.7.3.1; Chapter 8, Section 8.8.4; Chapter 9, Section 9.3.6.4, and Chapter 10, Box 10.2). Also, there is the potential for