

Accelerating Climate Prediction

In the past two decades, the growth of greenhouse gas emissions has generated concern that unrestrained future emissions of greenhouse gases may precipitate a potentially disruptive change of the earth's climate. Computer simulation is central to building the scientific basis for predicting climate change and characterizing its effects on the nation. Computer simulation is, in fact, the only tool available to answer the questions posed by the increases in greenhouse gases in the atmosphere. Experiencing the effect of greenhouse gas build-up in the atmosphere is not an experiment we wish to perform.

Particular economic sectors, such as energy, agriculture, and transportation have large stakes in any change in national policy designed to stabilize atmospheric greenhouse gas concentrations. Identifying an acceptable equilibrium level of greenhouse gas concentrations and evaluating the effect of changes in the climate along the path to stabilization requires a detailed understanding and quantitative estimation of climatic effects at both global and regional scales. Further, these predictions must be reliable over decades to centuries, which will require that ever more complete models of the climate system be continuously developed, evalu-

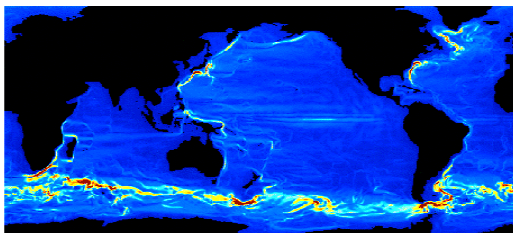
ated and employed in order to make informed judgments and policies.

Computer simulation models are the means for integrating our knowledge about the workings of the climate system and developing scenarios for possible future climates. Climate is an extraordinarily complex process and accurately predicting the effects of greenhouse gas emissions involves a series of very demanding calculations. For climate simulations to contribute to the establishment of technically sound energy and environmental policies, they must provide:

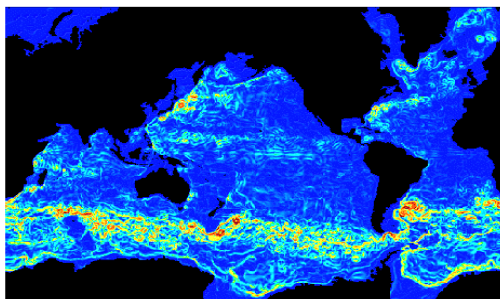
- greater certainty in climate models at both global and regional levels, and
- detailed information about the effects of climate change.

This can only be achieved if there is a dramatic reduction in the time required to complete model simulations, and if the models are capable of including all of the relevant physical, chemical, and biological processes at the necessary level of detail.

Breakthroughs in climate simulation will result from the development of new climate models



1992 - 20 Mile x 35 Mile Resolution



1995 - 10 Mile x 10 Mile Resolution

These two simulations illustrate the impact of increased resolution on the features that can be resolved in climate simulations. Increased resolution is one of the keys to improving the accuracy of climate predictions. Terascale computers will be required to extend such calculations to encompass the entire world.

that can take advantage of the increased computing power of terascale computers—computers capable of trillions of arithmetic calculations per second—which will become available early in the 21st century. The complexity of the new computer systems, the complexity of the climate modeling problem, and the enormous amount of data that will be produced demand a multi-year commitment of teams of scientists from a wide range of backgrounds—from physics and chemistry through meteorology to applied mathematics and computer science—to generate the needed simulations.

Full climate models are built by coupling separate component models of the global ocean, the atmosphere, sea ice, and the land surface. Both the atmosphere and ocean are simulated with three-dimensional general circulation models that describe the fluid motion of the air and water. In these models, the atmosphere and ocean are divided into many small fluid volumes, and the changing forces and properties of the fluid in each volume are mathematically calculated as a function of time. Within each of these component models are sub-models describing important physical, chemical, and biological processes that influence the properties and composition of the fluids. The submodels describe the effects of vegetation, precipitation, glaciers, atmospheric radiative transfer, clouds, etc.

Coupling the component models introduces mathematical problems related to the mismatches between their inherent time and space scales. For example, the atmosphere responds relatively rapidly to changes, on a time scale of a few weeks. On the other hand, changes in the ocean circulation encompasses time scales that range up to hundreds of years for the deep, slow moving ocean abysses. The interactions among these disparate time scales make climate projection a complex exercise in computer simulation. Small, but systematic errors in the models and submodels can dramatically influence projections of any scenario associated with changes in greenhouse gas concen-

trations.

Despite the complexity of a climate model for the earth, the steady advances in successful weather prediction as well as recent successes in predicting short-term climate effects such as the El Niño phenomenon, provide optimism for progress in developing accurate long-term climate prediction models. Within the next several years, computational models operating at the needed resolution and complexity will become possible using computer systems capable of sustaining ten to forty trillion mathematical calculations per second—a thousand times faster than today's computers. The models will help assess the impact of any mitigation proposals, and provide accurate projections of future climate changes at different stabilization levels. The models will not only be able to estimate the direct effects of greenhouse gases on large-scale climate but also a number of contributing problems, for example, the impact of increases in plankton in the ocean resulting from run-off of phosphates and other fertilizers.

This information generated by these simulations will only be useful if it is disseminated to the broad and diverse user base that is concerned with assessing the impacts of climate change. The projections will be used to estimate a wide range of important climate parameters, including many that are not now possible, such as the increase in tropical storm frequency, number of days of heavy rainfall, and other possible climatic changes that may accompany an increase in greenhouse gas concentrations. To disseminate this information as broadly as possible, new data management and presentation tools and technologies will be developed for the Internet.

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