1. Introduction

Recognition that earth's climate and biogeophysical conditions are likely changing due to human activities has led to a heightened awareness of the need for improved long-term global monitoring. The present long-term measurement efforts tend to be spotty in space, inadequately calibrated in time, and internally inconsistent with respect to other instruments and measured quantities. In some cases, such as most of the biosphere, most chemicals, and much of the ocean, even a minimal monitoring program is not available. Monitoring is defined here as long-term measurements of key climate variables with continuous coverage in time, maintenance of required instrument calibration accuracy, and empowered by careful diagnostic analysis of the data.

Recently, it has become evident that emerging global change issues demand information and insights that the present global monitoring system simply cannot supply. This is because a monitoring system must provide much more than a statement of change at a given level of statistical confidence. It must describe changes in diverse parts of the entire earth system on regional to global scales. It must be able to provide enough information to allow an integrated physical characterization of the changes that have occurred. Most importantly, it must allow a separation of the observed changes into their natural and anthropogenic parts. This separation can only be accomplished by combining theoretical and modeling insights with reality, as obtained from the monitoring data. The enormous policy significance of global change virtually guarantees an unprecedented level of scrutiny of the changes in the earth system and why they are happening.

These pressures create a number of emerging challenges and opportunities. For example, they will require a growing partnership between the observational programs and the theory/modeling community. Without this partnership, the scientific community will likely fall short in the monitoring effort.

The monitoring challenge before us is not to solve the problem now, but rather to set appropriate actions in motion so as to create the required framework for solution. Each individual instrument system needs to establish its role in the large problem and how the required interactions are to take place. Below, we emphasize...
some of the needs and opportunities that could and should be addressed through participation by theoreticians and modelers in the global change monitoring effort.

2. Requirements for Theory/Modeling Support for Monitoring

CONTEXT

All observing systems are incomplete in the sense that they will never be able to measure everything, everywhere, all of the time with perfect accuracy and sustained calibrations. Moreover, even if this impossible goal could be achieved, the changes recorded by the ‘perfect’ measurements would still need to be interpreted in the context of previous predictions and to be explained scientifically. Thus, the challenge before us is to seek the mechanisms by which models and theoretical analysis can be used in cooperation with observational systems to yield the maximum information and to produce the required synthesis.

INFORMATION CONTENT OF OBSERVATIONAL NETWORKS

One of the most straightforward ways to utilize models in a monitoring context is in the evaluation of existing or hypothetical networks. For the atmosphere, successful studies conducted at GFDL have included evaluations of the global radiosonde network (Oort, 1978), the Dobson total ozone network (Moxim and Mahlman, 1980), and satellite temperature soundings (Graves, 1986). In such approaches, time-dependent, three-dimensional model output statistics are sampled in ways identical or similar to that of a given network. The advantage of using the model is that the ‘right’ answers in this context are readily available for comparison against the answers inferred from the network subsample. Such research has revealed a number of significant deficiencies in the existing networks, as well as in the models used in the evaluations.

A frequent objection to using models for research in this context is that the models are seriously incomplete depictions of reality. True enough. However, models do have the virtue of constituting a self-consistent global dataset. Moreover, models produce only a restricted version of the much richer spatial and temporal structure found in nature. Thus, model diagnoses of network information tend to err on the conservative side; problems identified in networks through use of models are likely to be even worse in the real world.

EVALUATION OF MODELS FROM SPARSE OBSERVATIONAL DATA

The other side of the coin is that even the current monitoring networks can be very powerful tools for evaluating strengths and weaknesses of models. Surprisingly, this is still true even for seriously undersampled quantities such as tropospheric ozone or oceanic salinity. It is a common misconception that 3-D global models