A final comment. It was disappointing to find no real mention of Bayesian methods in this report. There is some irony here, since a number of commonly used methods (kriging, for example) have a strong Bayesian flavor. In any case, whatever their predilections, statisticians must recognize that there have been enormous advances in practical Bayesian methods. Some of us actually use them!

Comment

Hans von Storch

1. GENERAL

Being in the process of preparing a monograph on "statistical analysis in climate research," I was intrigued by the title of the report of the National Research Council on the present use and future need of statistics in physical oceanography. But after having gone through it I became rather disappointed—apparently these people had a "physical oceanography" in mind which had hardly any overlap with the type of problems which I meet in my own research. Relevant topics were not mentioned, such as the variability of the thermohaline circulation (note that the deep ocean was excluded in Figure 2.1 of the report) and its implications for the global climate. Influential names, such as Frankignoul, did not appear. Fundamental papers, such as that of Hasselmann (1976) on stochastic climate models, were not cited. The data assimilation issue related to preoperational predictions of the oceans were not sufficiently taken into account (see Derber and Rosati, 1989, or Mellor and Ezer, 1991). I could not even identify the members of the committee who supposedly represent the community of physical oceanographers.

The solution to this inconsistency is likely that neither the committee nor I—and my colleagues whom I have contacted in this matter—represent the full spectrum of statistical thinking in what is called physical oceanography. I have to admit that I am in touch with only a narrow window of the spectrum, namely, that part with relevance for the dynamics of climate and for the concept of climate change. In the following I will go through a number of examples of statistical thinking in our field. These examples have been encountered by the Climate Dynamics and Oceanography division of the Max-Planck-Institut für Meteorologie in Hamburg, in the past.

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2. THE IDENTIFICATION OF DYNAMICAL SUBSYSTEMS

The dynamics of the ocean operate on a large phase space with spatial and temporal scales spanning a wide range. The sheer amount of information, representing the state of the ocean during any well-documented interval of time, inhibits any complete description of the oceanic dynamics—independently if we work with observed or simulated data. Therefore it is advisable, or even required, to split the full phase space into a "signal" subspace and a "noise" subspace. The definition of the two subspaces depends, of course, strongly on the considered problem: The physically significant part of the dynamics span the "signal" subspace whereas the "noise" subspace comprises those processes which contribute to the dynamics only through their overall statistics and not through their details. The identification of such dynamical subsystems represents a major challenge for ocean sciences.

2.1 Stochastic Climate Models

In the "stochastic climate model" approach (Hasselmann, 1976) the separation into signal and noise subspaces is done by means of time scales. The "high-frequency" part is considered as "noise" whereas the "low-frequency" part is understood as being the dynamical response to the "noise." To keep the system stationary, negative feedback must prevail in the "signal" subspace.

This concept has been applied to modeling the dynamics of sea-ice variability (Lemke, 1977) and of sea-surface temperature variability (Frankignoul and Hasselmann, 1977; Ortiz Bévia and Ruiz de Elvira, 1985; Herterich and Hasselmann, 1987). More recently the concept has been used in a "stochastically forced" ocean general circulation model experiment (Mikolajewciz and Maier-Reimer, 1990). In this run the ocean model was forced with climatological conditions without any temporal vari-