Reductionism in Meteorology and Climatology[1]

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This paper discusses the science of climate dynamics from a philosophical point of view, with a focus on the issue of reductionism. Several of these words deserve clarification:

- Science can be defined as the search for general statements about reality: statements which are logically sound, conform with empirical observations and are acceptable to peers
- Science philosophy is concerned with the way in which human brains interact with their environment when they do science
- Reductionism is the feasibility to explain all (geoscientific) phenomena with the basic laws of nature and appropriate initial conditions ("my scientific problems can be solved with the help of the laws of physics").

To clarify the words "explain" and "climate dynamics", this paper will report on current developments in climate dynamics, illustrating how far we get in a reductionistic approach, that is, in an approach starting from the basic physical equations.

The climate system consists of the atmosphere/ocean/sea-ice/land-surface system including physical and biochemical processes and feedbacks. Researchers attempt 1. to reconstruct the evolution of the state of this system; 2. to understand the observed variations; and 3. to predict its future state.

Observations

Recently, an increasing number of high-quality observations is becoming available, both from new technology (e.g., earth observation) and paleo reconstructions. Nevertheless, the system cannot be observed in its full complexity due to spatial and temporal limitations and because not all relevant parameters can be monitored. Therefore, climate models are used for interpolation. These so-called General Circulation Models (GCMs) which numerically integrate the basic fluid dynamics equation have their limitations for a variety of reasons: 1. limited resolution due to limited computer capacity; 2. the need to parametrize subgrid scale processes; 3. the need to restrict the model to a subset of relevant variables; and 4. a lack of knowledge of external influence (such as solar variations) and initial conditions. Nevertheless it has been possible to validate GCMs by comparing their performance with observations. Weather prediction is a case in point. Weather models have improvement significantly over the last few decades. A similar trend

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occurred in climate models which have been validated against observations. In addition, model intercomparisons shed light on model uncertainty.

Prediction

Climate models predict a warming of the globe due to anthropogenic effects. To what extent can we believe the predictions of these models, given the limited predictability due to unresolved external influence and uncertainty in initial condition and model uncertainty? A number of examples will be given, from medium range weather prediction (where there has been a steady improvement in the skill, because of better observations and better models), seasonal prediction (El Nino) and longer-term natural and anthropogenic climate change. The bottom line is this: the quality of predictions is increasing, but there will always be uncertainty. Therefore, much energy is now going into quantification of this uncertainty.

Understanding

Some believe that understanding is even more difficult then prediction. We will illustrate this with a number of examples, such as understanding ocean waves near a beach, and the issue of attribution in climate change. The bottom line here is that understanding is probably limited in complex systems, by nonlinear behaviour and by complex feedbacks.

In summary, one may argue that there is no indication that the earth system is not governed by the basic equations of physics, but also that there is limited understandability and predictability in the system. In dealing with the climate system most scientists therefore follow a pragmatic reductionistic approach, i.e. they try and see how far they get, starting from the basic laws of nature. An interesting new development is the attempt of quantifying uncertainty on the basis of these very laws.