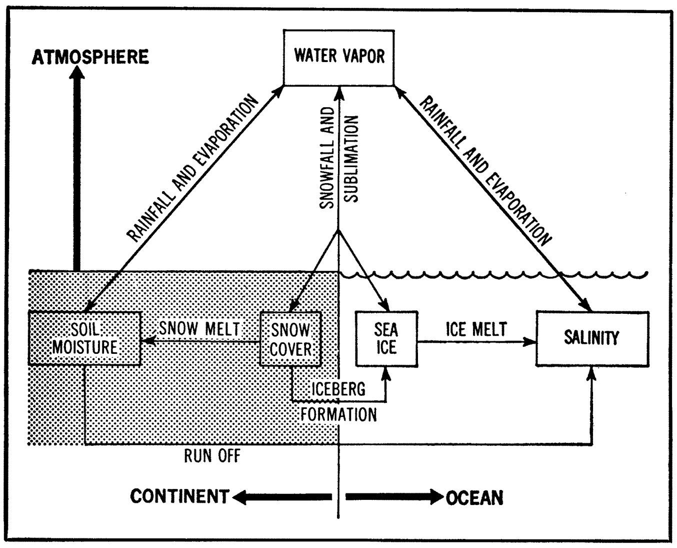
Computing the link between sea and air

Scientists construct realistic mathematical models of joint ocean-atmosphere systems to study the ocean's effects on climate

by Kendrick Frazier



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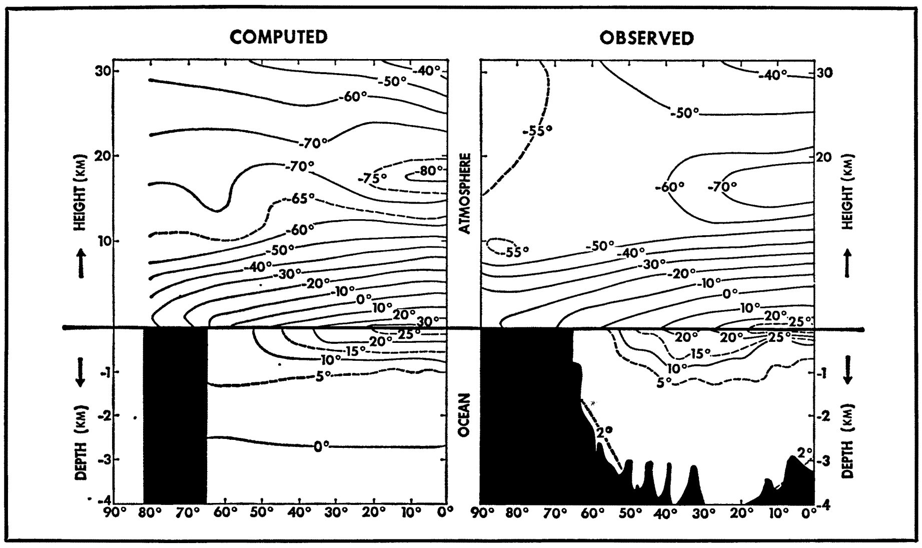
Water exchange: From ocean to air to land and back.



Vertical temperature prediction profile generally matched observations.

The oceans and the atmosphere, geophysicists know, are inextricably linked. The earth's weather and climate are products in part of almost infinitely complex exchanges of heat, moisture and momentum between these two fluid envelopes.

In a loose, qualitative way, the general effect of the oceans on climate has been understood for some time. The oceans store heat during the summer months and release it in the winter, moderating seasonal extremes over much of the world. They also transport heat from the equatorial regions toward the poles, a second moderating process that happens also to be performed by the atmosphere to a considerably greater degree.

But to understand the climate well enough to make some reasonable predictions about its future behavior—a goal gaining increasing importance in recent years—scientists need detailed, quantitative knowledge of all the factors that influence it, especially the interactions between the oceans and the atmosphere. This will require the development and use of sophisticated mathematical techniques.

A pioneering effort to construct a realistic mathematical model of the joint ocean-atmosphere system, and to study the interactions by making a series of controlled numerical experiments is the work of a small group of scientists at the Geophysical Fluid Dynamics Laboratory of the Environmental Science Services Administration in Princeton, N.J.

The eventual goal is to develop models good enough to permit a study of future changes of the environment. If the work continues to progress, the scientists hope someday to be able to tell what the effect will be in a century or two of civilization's increasing release of carbon dioxide into the atmosphere, or of the continuing release by industrial activity of heat into the environment.

The work is also relevant to extension of weather forecasts beyond the atmosphere's two-week limit of predictability. The oceans, with a much greater heat capacity and therefore much slower response time than the atmosphere, have, in effect, a long-term memory that should help scientists preparing long-range forecasts to overcome the rapid forgetfulness of the atmosphere.

"I'm pretty optimistic along these lines," says Dr. Syukuro Manabe, a meteorologist who has been at the forefront of the laboratory's theoretical studies. "I think the model probably will eventually have a number of such applications."

The general circulation model of the joint ocean-atmosphere system now being refined at Princeton is prepared by combining an atmospheric model developed by Dr. Manabe and an ocean model developed by a laboratory colleague, Dr. Kirk Bryan. A mathematical model is a structure of physical conditions and laws, stated mathematically, that describes the behavior of something—in this case the ocean-atmosphere system. There must be a set of equations for each significant factor in the system.

In the joint model, the quantities exchanged between the ocean and atmosphere are momentum, heat and water. Integration of the equations for the atmosphere can give surface wind, net radiation, heat flow, and the rates of snowfall and rainfall, evaporation, runoff and iceberg formation. From the oceanic part, the thickness of ice and the distribution of sea-surface temperature are computed.

To simplify matters, Drs. Manabe and Bryan have described for their model a hypothetical segment of the earth extending about one-third the way around the planet and excluding the north and south polar regions. Within this area is a highly idealized continent and ocean. "It looks like something before continental drift," says Dr. Manabe.

In the Northern Hemisphere the continent looks like an inverted L; the ocean is tucked under the arm of the L. The scientists had to make this simplification in the initial joint model to save computer time. The configuration is roughly representative of North America and the North Atlantic Ocean bordered at the top by Greenland.

Essentially what the scientists then do is describe to the computer starting conditions at points 500 kilometers apart horizontally and at nine levels of the atmosphere and five levels of the ocean. "Since the initial condition represents the state of the atmosphere and ocean without interactions," explains Dr. Manabe, "the change of the state of the joint system should be caused by the interaction between the ocean and the atmosphere."

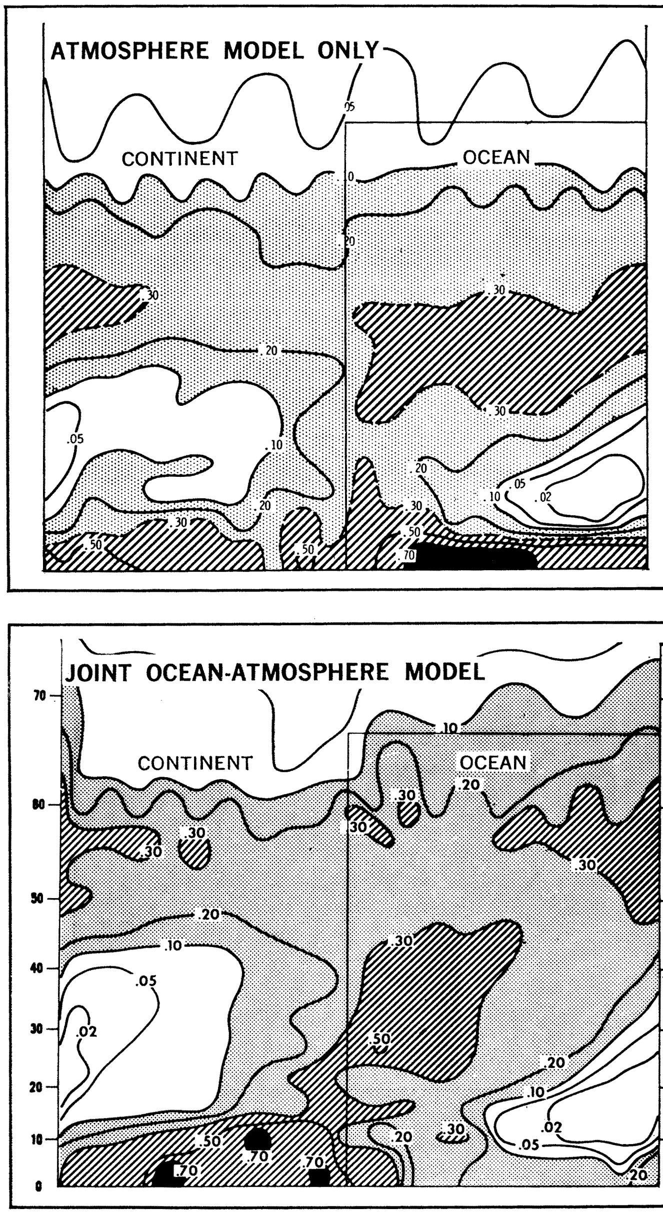
It takes the computer, a UNIVAC 1108, 45 minutes to describe just one day's circulation of the atmosphere; in 300 hours it can describe a year. The ocean changes more slowly; in 800 hours the computer can describe its general pattern for a century.

Using this technique Drs. Manabe and Bryan have obtained encouraging results. Demonstrating the basic realism of the model, the technique has identified more than half a dozen major effects of ocean circulation on the general circulation of the atmosphere. And they seem to correlate closely with conditions as actually observed.

At the equator, for instance, the model shows that upwelling of relatively cold water tends to suppress the intensity of the tropical rainfall over the oceans. The cold water prevents moist convection and also tends to reduce the supply of moisture by lowering the rate of evaporation. Air patterns created by this effect, however, produce more rain over the continental region of the tropics.

In the subtropics, the model shows that precipitation along the east coast of the continent increases significantly because of the ocean current patterns. Because of this effect, the arid region of the subtropical desert is more or less limited to the western half of the continent.

Since this effect was identified by the joint model, Dr. Manabe and his colleagues have been developing a global atmospheric model with a realistic rather than idealized configuration of the continents. He says it has effectively simulated so far the Sahara Desert and the deserts in the western United States and western Australia.



Distribution of rainfall intensity over idealized continent and ocean: Differences between atmosphere model and combined ocean-air model are attributed to the incorporation of ocean's effects.

In middle and high latitudes, the joint model shows that ocean heating of cold continental air tends to enhance the development of cyclones off the east coast of the continent. This seems to correspond, points out Dr. Manabe, with the well-known areas of cyclone development in the Aleutian Archipelago east of the Asian continent and in the vicinity of Iceland east of North America.

Along the west coast of the model continent, the middle-latitude rain belt is shifted poleward due to the effect of the ocean currents.

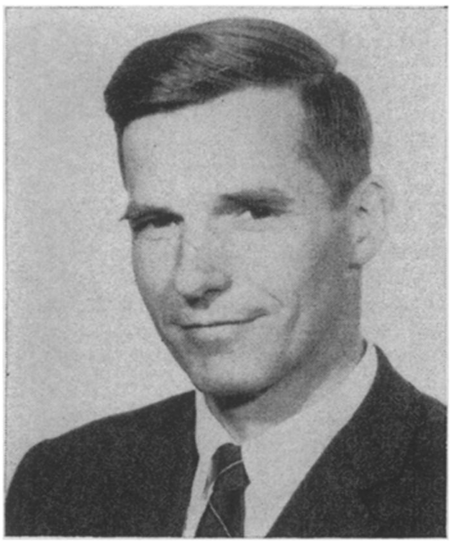
The poleward transport of heat by the ocean circulation, according to the model, decreases the poleward transport of energy in the atmosphere. It also moderates the latitudinal difference in temperatures in the lower atmosphere. This reduces winds and tends to make the atmosphere more stable.

"Despite all of our simplifications, there are very many features of the model that are like the atmosphere," says Dr. Manabe. Most of the work so far has been to refine the model so it can portray accurately the ocean-atmosphere system as it is now understood. "But the model is gradually getting good enough," he says, "to predict features that are not yet observed."

When that capability becomes fully developed, the scientists will then have a tool to begin to foretell what the climate may be like a century or two from now. They certainly would be able to learn more about the natural causes of the ice ages. And they expect to be able to predict man's effects on the climate.

The role of manmade carbon dioxide, for instance, could be identified by using two models, one without any extra input of the gas, one with. After running the equations forward to simulate the passage of a century or so, the

Manabe: Optimistic about predictions.



Bryan: Modeling for next century.

scientists would compare them to see how the carbon dioxide had changed the earth.

Before such an ability is achievable, however, a complete ocean-atmosphere model that uses the realistic continent configurations and that simulates the entire globe, not just a segment of it, will have to be developed. And many more climatic factors would have to be put into the computations.

The big obstacle is the fantastic number of equations the computer will have to handle. For the next step, Dr. Manabe and his colleagues are anticipating the availability, perhaps in three years, of a computer like the ILLIAC IV (SN: 9/6/69, p. 185), designed to be about 100 times as fast as any computers in existence now.

"Then," says Dr. Manabe, "one will be able to discuss the climatology of the earth's atmosphere on a quantitative basis." □