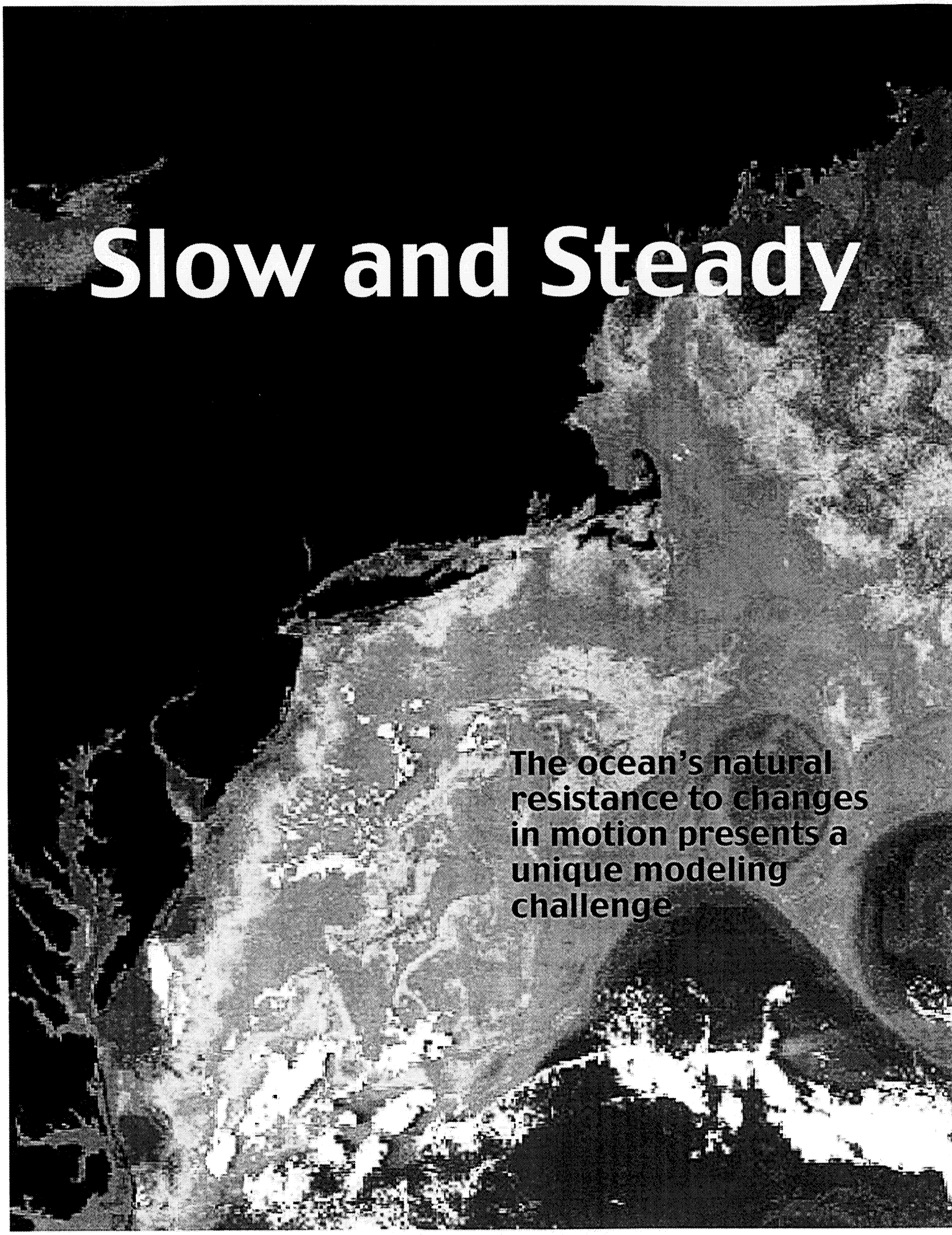
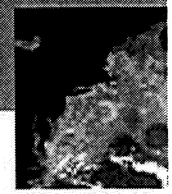
Slow and Steady



The ocean's natural resistance to changes in motion presents a unique modeling challenge

Ocean Circulation



The study of ocean circulation is vital to understanding how our climate works. The movement of the ocean is closely linked to the progression of atmospheric motion. Winds close to sea level add momentum to ocean surface currents. At the same time, heat that is stored and transported by the ocean warms the atmosphere above and alters air pressure distribution. Therefore, any attempt to model climate variation accurately must include reliable calculations of ocean circulation.

Unlike movement of the atmosphere, movement of the ocean's waters takes place mostly near the surface. The major patterns of surface circulation form gigantic circular cells known as *gyres*. They are categorized according to their general location—equatorial, subtropical, subpolar, and polar—and may run across an entire ocean. The smaller-scale cell of ocean circulation is known as an *eddy*. Eddies are much more common than gyres and much more difficult to track in computer simulations of ocean currents.

What moves the ocean?

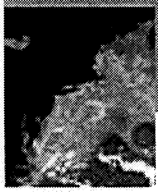
As mentioned earlier, atmospheric circulation and ocean circulation are closely linked. Both are governed by the distribution of momentum, heat, and moisture. For example, just as differences in air pressure push atmospheric circulation, differences in ocean density move water currents. Low temperatures and high *salinity* (the amount of salt in the water) increase the density of a body of water, making cold, salty water sink below warmer water. Movement that is driven by density is called *thermohaline circulation*.

Despite some basic similarities in atmosphere and ocean movement, ocean circulation generally changes much more slowly than atmospheric circulation. Because water has a higher density than air, beginning or altering a current takes more momentum. Furthermore, the effect of heat lasts longer in ocean circulation than in atmospheric movement because water can contain far more thermal energy than air. In effect, the ocean has a longer "memory" of the climate's influence on circulation than air does.

Modeling the ocean

Because observational data of ocean circulation is scarce, developing accurate ocean general circulation models (OGCMs) is important. Unfortunately, the scarcity of measurements that can be assimilated into a model is a challenge to ocean modeling. Most measurements are limited to the surface and the Northern Hemisphere.

The complex characteristics of ocean flow present other modeling challenges as well. First, the small size of eddy currents makes their effect difficult to capture. In addition, an OGCM must incorporate salinity in its calculations. Furthermore, an OGCM must account for the slower rate of temperature changes in the deep ocean. One way to adjust a model for this phenomenon



Sea Surface Height

Another important aspect of ocean movement is sea surface height (SSH). SSH is a measure of the deviation of the vertical position of the sea surface relative to a known reference surface. Tracking the height of the ocean can provide an early warning of dramatic climate changes, such as the melting of polar ice sheets. Moreover, measuring SSH helps track other ocean characteristics, such as current velocity, because violently strong ocean currents create waves that change SSH.

Causes of sea-level variation include the following:

- Barotropic response to wind stress
- Changes as a result of heating and cooling (water expands when heated)
- Internal fluctuations of water density as a result of ocean currents
- Variations in geostrophic velocities caused by the Earth's rotation
- Melting ice from the polar caps

Satellite altimeters can make measurements of SSH. These measurements are compared to a reference surface such as the *oceanic geoid*, the shape of the Earth's surface under normal conditions.

is to alter the time step numerically for deep ocean calculations.

References

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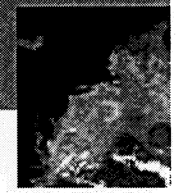
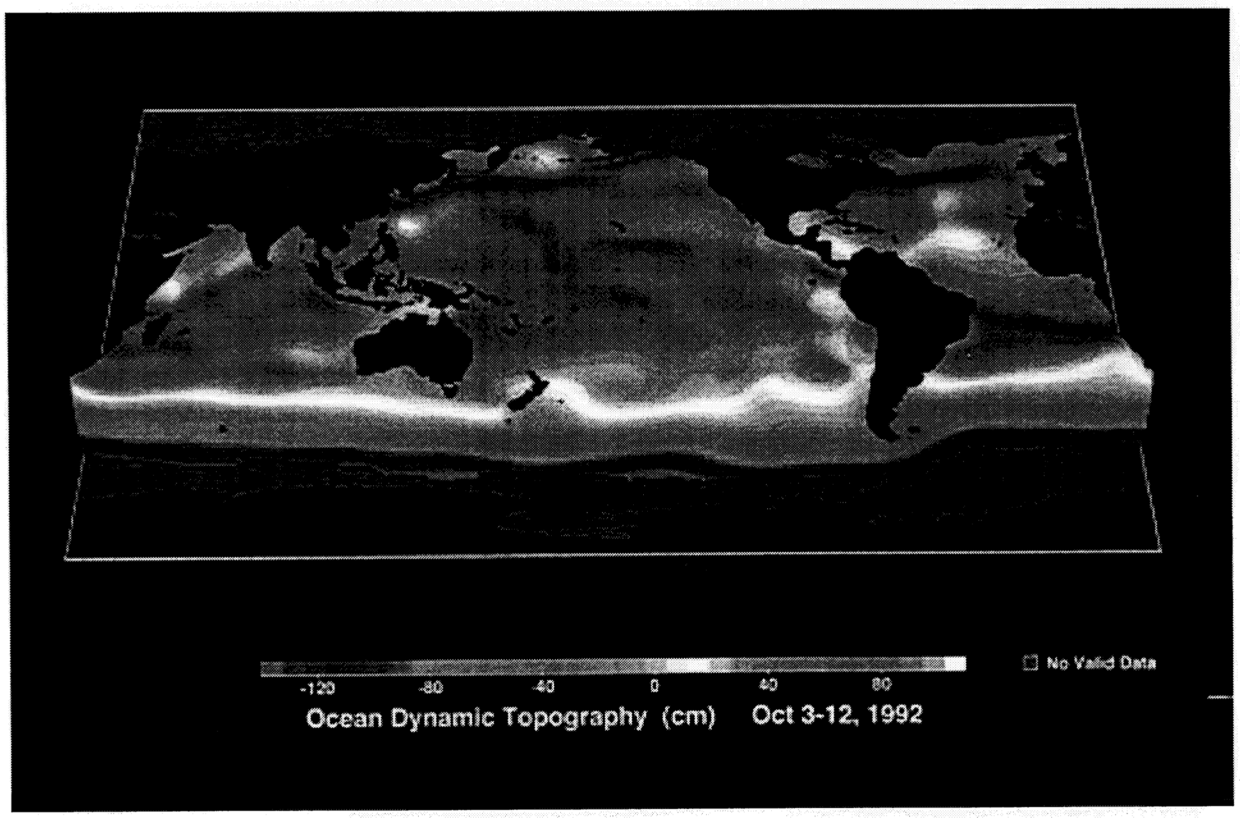
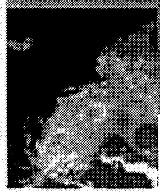




Ocean topography data from satellite recordings can provide information on ocean circulation. *Image credit: NASA Jet Propulsion Laboratory*



Research Profile: The Influence of Sea Surface Height on Ocean Currents

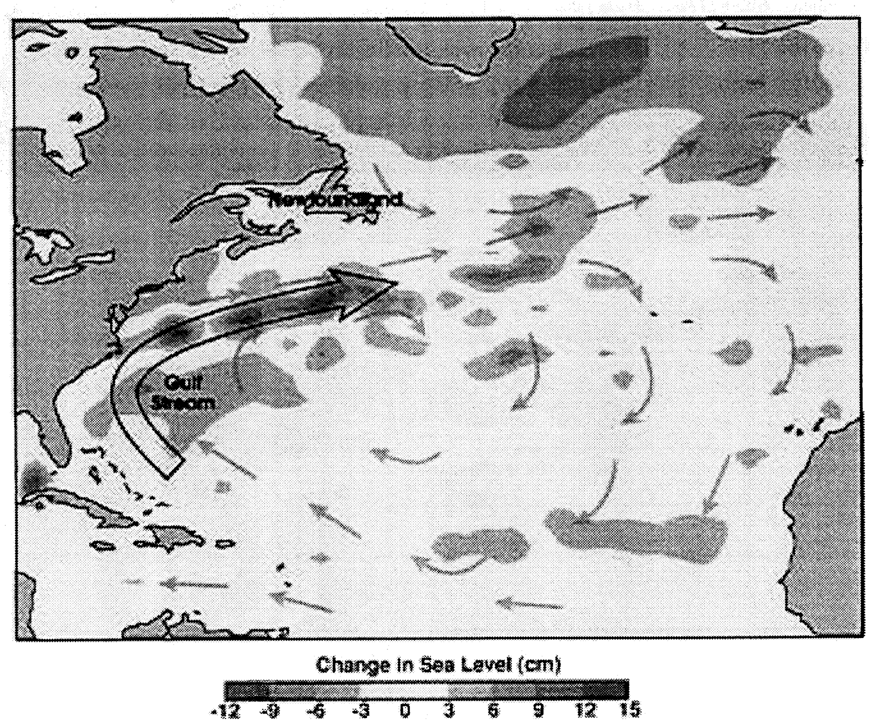
Investigator:
Sirpa Häkkinen, NASA Goddard Space Flight Center, Oceans and Ice Branch

Häkkinen used the computing resources of the NCCS to study the connection between SSH and ocean circulation in the North Atlantic. She sought to determine which held the greater influence on SSH: basin-scale temperature changes or wind-driven currents.

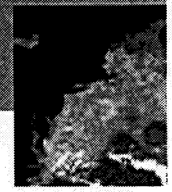
In this research project, Häkkinen ran three simulations of SSH variation between the years 1951 and 1993 and one simulation between 1958 and 2000. The numerical grid covered the Arctic and North Atlantic oceans, with a resolution of 0.7 by 0.9 degrees and 20 different coordinate levels.

"Clearly, simulation of 50 years...is not exactly nontrivial," says Häkkinen. "Also, the (data) storage requirements are rather large because the analysis of this data has to be on-line always."

The model computed the movement of heat through the oceans based on sea surface temperatures (SSTs), saturation humidity, air



Sirpa Häkkinen, a scientist at NASA Goddard Space Flight Center, ran computer models of SSH variation on an NCCS supercomputer. The results revealed a close association between SSH and the strength of overturning currents in the North Atlantic. The models also recorded a 12-centimeter drop in SSH between the winters of 1995 and 1996. "People have not wanted to believe that you can have these kinds of changes over a decadal time scale"said Häkkinen, "But in fact, very large changes can occur over decadal time scales."



temperatures, and atmospheric humidity. Monthly climatology averages estimated the amount of cloud cover that influenced SST, as well as the effects of precipitation, evaporation, and river runoff on ocean height.

Each simulation assimilated different sets of actual SSH recordings to study the effects of dif ferent anomalies:

- Experiment 1 used anomalies in wind speed and temperature, as recorded by the Comprehensive Ocean Atmosphere Data Set (COADS).
- Experiment 2 used only the temperature anomalies from COADS.
- Experiment 3 used only the wind speed anomalies from COADS.
- Experiment 4 used anomalies in wind speed and temperature, as recorded by the National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) Reanalysis data set.

Removing a type of anomaly from an experiment run and replacing it with monthly climatological averages enables the experimenter to observe closely the influence of the remaining anomaly type. Complete removal of an anomaly's effect is not possible, but the relative strength of one compared to the other is still evident.

Häkkinen performed an empirical orthogonal function (EOF) analysis on the results of these SSH simulations. The EOF analysis organized the vast calculations of SSH change into recognizable trends, or orthogonal modes. Most of the simulated variation occurred along the Gulf Stream and North Atlantic Current. The main orthogonal mode also contained an opposing variation in SSH along the U.S. eastern seaboard and in the subpolar gyre.

According to the EOF analysis, the main cause of decadal variation in SSH and gyre circulation in the North Atlantic was basin-scale temperature changes rather than wind currents. The results from Experiment 2, in which only thermal recording anomalies were included in calculations, showed the strongest evidence of a decadal pattern of variation. The two orthogonal modes from Experiment 2, which was influenced by anomalies in ocean temperature, also had the most correlation when compared to the other simulation runs.

Next, this research effort determined the effect of meridional overturning. Meridional overturning is a major circulation pattern in which water flows either north or south away from the Equator, sinks when it cools, returns to the equatorial region, and then rises back to the ocean surface. This project determined whether meridional overturning in the Atlantic followed the same decadal pattern attached to the temperature variation in the Gulf Stream. In fact, heat changes in the Gulf Stream follow within 2 years of current speed changes in the meridional overturning at a latitude of 25° N.