# Tracking CFCs in a Global Eddying Ocean Model

*Ocean ventilation provides clues to climate change*

"The entire ocean is affected by a pebble," said Blaise Pascal, the 17th century scientist. "The least movement is of importance to all nature." Pascal, a mystic at heart, may have overstated the case. However, researchers today increasingly recognize the important, but largely unknown, influence of oceanic activity on climate change. They want to know how the ocean is coping with vast deposits of chemical pollutants, how it moves them about, stores them over long periods of time, and ultimately exchanges them at the surface with the air. Using the powerful computers now available, they are building simulations to assess with greater precision the long-term effect of this oceanic housekeeping on global climate.

Oceans play a critical role in the earth's balance of heat, water, and chemicals such as carbon dioxide (CO2) and chlorofluorocarbons (CFCs). After absorbing chemicals from the atmosphere at the surface, the ocean can store substances for hundreds to thousands of years, circulating them through the 319 million cubic miles of water around the globe. This process, called ventilation, influences climate in multiple, still-to-be-determined ways. It is very difficult to measure directly, but it can be inferred from observations of dissolved chemical compounds, or tracers. One particularly useful class of chemical tracers for seeing how chemicals are moved through the ocean is CFCs, which human activity has introduced into the atmosphere.

Using Jaguar, the Cray XT system at Oak Ridge National Laboratory, Synte Peacock and Frank Bryan at the National Center for Atmospheric Research (NCAR) and Mathew Maltrud at Los Alamos National Laboratory (LANL) have for the first time carried out a global eddying ocean simulation that has run a 100-year model. The model carried not only CFCs but also a host of other tracers that yielded valuable information about ocean ventilation pathways and timescales. To date, this team has been able to refine and successfully reassess earlier estimates linking changes in pollutant concentrations to climate change.

CFCs are an ideal tool for tracing what paths chemicals follow as they move through the ocean and how long they stay in one place. CFCs were first used in the 1930s but are now being phased out. Researchers know at what temperature CFCs become soluble in water, and they know that they become inert (don't react with anything else) once in the water. By comparing the measured CFC concentration at a point deep in the ocean to the surface concentration, scientists can estimate how long it has been since that water parcel was last at the surface (giving the ventilation age of the water). However, CFCs have been in the atmosphere for only tens of years, not thousands, so this metric has an inherent bias. To properly understand the ventilation process, researchers also need accurate information about how the water was transported to the observed location. This is where Ocean General Circulation Models can play an important role by providing insight into transport processes.

Because of the limits of computational power, most previous studies of CFC distributions using ocean models have been done using fairly coarse resolutions (grid spacing greater than 100 kilometers), for which some important transport activities are either poorly resolved or poorly estimated. To begin to resolve features such as narrow currents and mesoscale eddies (circular loop-like features with a diameter of less than 200 kilometers), researchers need a model with a finer grid resolution—one of kilometers to tens of kilometers.

Thanks to powerful supercomputers such as Jaguar, it has been possible to perform studies of the ocean uptake of CFCs and other trace gases using global fine-resolution (eddying) models. The NCAR/LANL model is one of the most realistic global eddying models ever run, Maltrud said, and the only one to simulate such a large set of tracer distributions. A standard way to assess the accuracy of the model's eddy strength is to compare model sea-surface height changes with measurements from satellite altimeters (signals bounced off the sea surface to detect local changes in the height of the water). The close agreement between altimeter readings and this model on the size of the eddies and their patterns is unprecedented in this type of ocean model.

## Using simulated CFCs to assess internal ocean turbulence

Observations of CFCs in the ocean can be done only from research ships, so they are sparse and widely distributed in time and space. The ocean is full of eddies, and concentrations of chemicals vary across them, so a sample taken at a given time and place may give very different results from one taken at the same place a week or a month later. How representative are such measurements of average concentrations throughout the entire global ocean? Oceanographers frequently use changes in concentrations of tracers (typically measured 5 to 10 years apart at the same location) to infer whether there are fundamental shifts in ocean circulation timescales or pathways. But they must know the extent of the variability (e.g., in heat and cold, salt and CFC concentrations) in different parts of the eddy to assess whether these changes are significant compared with background ocean turbulence.

Earlier studies have noted apparent changes in the CFC concentrations in various parts of the world ocean and attributed these to changing ocean circulation driven by changing climate. But do these conclusions hold water? The NCAR and LANL researchers were able to investigate this question with five CFC simulations, each one giving a sample of the possible oceanic CFC distribution. Using their eddy-resolving CFC simulation to quantify measurement uncertainty, the researchers found that in a number of places where concentrations had been measured, the observed CFC age differences were only marginally significant and most of the change was attributable to eddy variability deep beneath the surface. These results, the first of their kind, will be very useful in the future for both comparing model output with actual measurements and helping scientists interpret the observational record.

Understanding the process of ocean ventilation is critical for projecting the oceanic uptake of all atmospheric gases, notably CO2. Jaguar is one of the few computers with enough computing power to allow the researchers to run a 100-year simulation at very high resolution and carrying multiple tracers. Peacock said the increasing availability of observations of transient tracers such as CFCs provides a powerful tool for diagnosing timescales and processes of ocean ventilation, adding that they are also a valuable metric for testing the fidelity of ocean circulation models.

But there is still a great deal to do, Peacock said. While the observational data are as yet too sparse to characterize concentrations of these tracers on space and time scales associated with turbulent eddies, computational modeling is bringing researchers closer to a realistic assessment. Eddy-resolving ocean models are now providing sufficiently realistic proxies of ocean transient tracers, she said, that researchers can begin to use them to give a realistic picture of where and in what concentrations CFCs are found and moved through the ocean. “This will help researchers better understand the role of the ocean in uptake and redistribution of gases such as anthropogenic (man-made) CO2, which will ultimately increase understanding of the role that oceanic activity plays in climate change.”

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