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World Ocean Circulation Experiment

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Introduction

The oceans are an equal partner with the atmosphere in the global climate system. The World Ocean Circulation Experiment is presently being implemented to improve ocean models that are useful for climate prediction both by encouraging more model development but more importantly by providing quality data sets that can be used to force or to validate such models. WOCE is the first oceanographic experiment that plans to generate and to use multiparameter global ocean data sets. In order for WOCE to succeed, oceanographers must establish and learn to use more effective methods of assembling, quality controlling, manipulating and distributing oceanographic data.

Oceans Role in the Climate System

Major Part of Hydrological Cycle

It is not always recognized that water vapour plays a dominant role among the greenhouse gases in creating a climate on earth in which life could be developed and sustained. The oceans provide the source for the majority of the evaporation by which water vapour enters the atmosphere. There is also some evidence that salt crystals and sulphur compounds that enter the atmosphere through sea spray also supply condensation nuclei that result in clouds and precipitation. Both these processes are important parts of the atmospheric weather systems; clouds also play important roles in the global radiation balance.

Heat Storage

The ocean has a much greater heat capacity than the atmosphere. The ocean surface layers have the ability to absorb many days of solar heating during the spring and summer spring and summer and only warm by a few degrees each week. Only under conditions of low wind speed and shallow and strong stratification in the upper levels can one observe diurnal variations of temperature in the ocean of a degree or more. In contrast, day / night temperature differences of 10 degrees are relatively common in surface soil and air conditions at interior meteorological stations.

This effect is also seen in the seasonal cycle at moderate to high latitudes. Spring warming is delayed by several weeks at coastal stations relative to stations a few hundred kilometres inland. On the other hand, air temperatures remain higher in the fall months.

Within the climate system, the ocean is believed to serve as one of the principal mechanisms by which a climatic variation is sustained over periods of seasons and longer. The interactions between sea surface temperature anomalies in the tropical Pacific and anomalous wether around the globe have moved from research journals to the nightly weather broadcasts. Mid and high latitude temperature and sea ice anomalies have been linked with anomalies in atmospheric circulations, especially over northern Europe; however, these studies have not been universally accepted by either oceanographers or meteorologists.

At even longer time scales, simulations of the transient response of climate to changing atmospheric gas concentrations has suggested that the oceanic heat capacity slows down the expected global rise intemperature by several decades.

Heat transport

Oceanic processes transport as much heat across meridional circles at mid latitudes (20-30 degrees) as does the atmosphere. A large part of this transport arises through the thermohaline overturning of the ocean. Colder waters flow equatorward in the deeper layers of the ocean and are replaced at high latitudes by warmer surface waters flowing poleward. This overturning is driven by convective processes presently centred on a few high latitude regions in the North Atlantic and its marginal seas as well as in the Southern Ocean.

Oceanic heat transport also arises in the wind driven gyre circulations. In the sub tropical gyres, strong western boundary currents move warm water poleward where it releases its heat to the atmosphere and cools. The cooled waters return equatorward in the ocean interior. The difference in temperature between the poleward flowing boundary current waters and the equatorward flowing waters of the interior result in a net poleward heat flux.Finally, in some regions of the ocean, heat may be transported poleward through eddy motions. This is a dominant mechanism for atmospheric meridional heat transport; however, it appears to be of only second order importance in the ocean with the possible exception of within the Antarctic Circumpolar Current system.

Reservoir for Radiatively Active Gases (RAG's)

The ocean has a great storage capacity for many of the radiatively active gases and thus oceanic processes must be considered when developing models of how the atmospheric concentrations of these gases may have changed over recent historical or geological time. Ocean processes will advect, store and release these gases much as they deal with heat. In addition, biological processes in the ocean will also play roles for gases such as Carbon Dioxide.

The Goals of WOCE

Goal 1

To develop models useful for predicting climate change and to collect the data necessary to test them.

Within Goal 1, the specific objectives are:

To determine and understand on a global basis the following aspects of the world ocean circulation and their relation to climate:
1. The large-scale fluxes of heat and fresh water, their divergences over 5 years and their annual and interannual variability.
2. The dynamic balance of the world ocean circulation and its response to changing surface fluxes.
3. Components of ocean variability on months to years, megametres to global scale, and the statistics of smaller scales.
4. The rates and nature of formation, ventilation and circulation of water masses that influence the climate system on time scales of ten to one hundred years.

Goal 2:

To determine the representativeness of the specific WOCE data sets for the long-term behaviour of the ocean and to find methods for determining long-term changes in the ocean circulation.

Within Goal 2, the specific objectives are:
1. To determine the representativeness of the specific WOCE data sets.
2. To identify those oceanographic parameters, indices and fields that are essential for continuing measurements in a climate observing system on decadal time scales.
3. To develop cost effective techniques suitable for deployment in an on-going climate observing system.

The Upper Ocean

Constraining Air Sea Fluxes

Ocean models can only be validated against observations when one has precise and accurate air-sea flux fields to drive those models. While estimates of all these fields are presently available from climatological surface meteorological data, little is known about the accuracy of these estimates. A WOCE strategy is to use the ocean observations themselves to provide a large scale constraint on these estimates. For example, the transport of the Florida Current is broadly consistent with estimates of the wind stress distributions over the sub tropical gyre of the North Atlantic.

The North Atlantic has a great wealth of surface meteorological data stretching way back into the previous century. Oceanographers have also measured the oceanic heat flux across several latitudes in this ocean. One cannot find any parameterization of the surface meteorological observations that will result in estimates of the air-sea fluxes which are consistent with consistent with the changes in oceanic heat flux estimates from the equator to mid latitudes.

Recently, atmospheric boundary layers have been added to long range forecast models; hence these models should be providing reasonable regular estimates of wind stress and air sea fluxes of heat and fresh water. These models are also assimilating scatterometer data which should also provide better estimates of wind stress directly and the other flux terms indirectly. WOCE has specified a network of XBT sections designed to allow the heat content of the upper ocean to be computed at least bimonthly at a 500 to 1000 km scale. The upper ocean velocity field is also being planned to be measured on the same spatial scales using satellite tracked drifters. Changes in heat content over periods of a few months corrected for the upper ocean circulation will be used to check estimates of air-sea fluxes produced by the various techniques and forecast models.

Upper Ocean Circulation

Most of what is known about ocean circulation has been learned using techniques or data sets that emphasize larger space and time scales. The WOCE/TOGA Surface Velocity Programme is using surface drifters to map the time dependent Lagrangian surface current field throughout the major ocean basins. This program is well underway in the Pacific Ocean and beginning to build in the Atlantic. Satellite altimeters (ERS-1 and TOPEX-Poseidon) will map the sea surface elevation field of the globe every two weeks to a month. Combining the altimetric and drifter data will permit a mapping of some of the mesoscale features of the upper ocean circulation field over the WOCE period.

From estimates of the surface winds through advanced forecast models and scatterometer measurements, measurements of the lagrangian velocity at 15 metres using an instrument whose direct response to wind forcing is both known and small, estimates of the sea surface slopes from altimetry and estimates of the upper ocean stratification from the XBT program, WOCE hopes to get a better understanding of the role that ageostrophic currents play in the transports of mass, heat and fresh water in the upper ocean.

The Full Depth Ocean

Wind Driven Gyre Circulation

The wind driven gyre circulation of the global ocean is the dominant mechanism by which mass, heat, salt and tracers are transported both meridionally and zonally within the ocean. The basic balances of these circulations have been understood for the past 40-50 years and good estimates of the strengths of the western boundary components of many of the principal gyres have been made over the past two decades. Eddy resolving ocean circulation models have demonstrated how the eddy field associated with these strong western boundary currents can generate both deep and upper ocean recirculation gyres resulting in western boundary transports much larger than those implied by simple sverdrup integrations of the wind stress across the gyre. There is still difficulty reconciling what we know about the seasonal variation of the wind forcing over a gyre and the few sparse observations of the seasonal variability of the western boundary transports.

The WOCE implementation plan is designed to obtain a global description of the three dimensional distribution of a 'mean' oceanic velocity field that can be used to validation ocean general circulation models. This estimate will be made from high quality eddy resolving full depth hydrographic sections crossing every major ocean basin and gyre both zonally and meridionally, a global deep float release, mooring arrays across every major western boundary current and global satellite altimeter coverage. It is hoped that the hydrographic sections in each ocean basin can be completed in as short a time as possible, ideally over periods less than 5 years, so that long term variations in water mass structure don't complication the dynamical interpretation of the data. In regions where seasonal variability is known to be large, repeat sections in particular seasons are specified. The deep floats will provide an estimate of the lagrangian velocity at a depth of the order of 1500 metres. Averaged over five years and spatial scales of 500 km, this velocity should be accurate to 0.01m/s. The mooring arrays will be set of periods of 1-2 years and will be designed to provide estimates of the mean transports of these boundary currents with an accuracy of the order of 10%.

There is a certain amount of redundancy in the measurements. The strategy is to use inverse methods to arrive at circulations which best fit the ensemble of all the ocean and wind stress data available for the particular ocean or gyre that is being investigated. The WOCE challenge is to ensure that the various individual data sets are assembled, quality controlled, documented and made available to scientists who have not used such data in the past. We are looking to the data management community to develop new convenient ways to encourage this process.

Thermohaline Circulation

The thermohaline circulation is responsible for a significant part of the meridional transport of heat and salt which is so important to the global climate system. Mooring arrays will be set to measure the deep western boundary currents which carry the deep waters away from their high latitude formation regions towards the rest of the global ocean. For the deep and bottom waters, the ocean appears like a series of connected basins. Mooring arrays have been placed in the gaps between these basins to measure the interbasin transports. Finally the global hydrographic survey described in the previous section will also map the distribution of a variety of tracers.

Our strategy is to again use inversion models starting with the large scale velocity fields estimated for the wind driven circulation and adding information from the tracer distributions, western boundary undercurrent transports, flows through gaps and estimates of the rates of formation of these water masses to gain a better understanding of the roles that advection and mixing might play in the thermohaline circulation

Oceanic Eddies

Through most of the world ocean, WOCE's principal concern with ocean eddies is to design a measurement programme that remove the effects of eddies from estimates of larger scale oceanic phenomena. In eddy resolving ocean models, the eddy dynamics are an important mechanism through which energy and momentum is transferred between the various components of the circulation. How well a model describes its eddy field will be an important test of such models.

The satellite altimeters, surface drifters, hydrographic sections, high density XBT sections mooring arrays and RAFOS floats will all resolve some components of individual eddies. These data will all be analyzed to provide a better description of the distribution of eddies in the global ocean. WOCE has collected statistics from all deep sea moorings with more than 9 months data records as part of this mapping exercise. The WOCE Implementation plan also calls for a limited number long term moorings in regions without any such description; these moorings are not considered to be among our highest priorities.

Eddies are believed to be the principal mechanism through which heat and salt are transported across the Antarctic Convergence zone. Here the WOCE implementation plan calls for eddy resolving mooring arrays both in regions where satellite altimetry has indicated a high level of eddy activity and in those where eddy activity appears reduced. We hope to use satellite altimetry to interpolate the results of two or three such eddy arrays around the entire Southern Ocean.

Oceanic Variability

Interannual variability of water mass formation

Scientists working in the North Atlantic have noted significant variability in temperature/salinity characteristics of deep and intermediate water masses close to the regions where they are believed to be formed. This means that historical hydrographic data taken over a long period of time cannot necessarily be combined as a single description of the temperature and salinity distribution of an ocean and then used to estimate such properties as the divergence and convergence of heat and salt transport.

WOCE plans call for repeat hydrographic sections to be occupied across the source regions (or overflow regions) for each of the major intermediate and deep water masses in the northern oceans. These sections are to run at the end of each winter's cooling season and as a second priority in the fall at the start of each cooling season. These data will serve two purposes. First, we will have a record over the 5 or so years of WOCE of any variation of the properties of these deep and intermediate water masses near their source regions. This will permit a bit of time space blending of the WOCE hydrographic data set when creating the mean fields for each ocean basin. Second, it will permit the development and testing of models that will have the potential of integrating the ocean over a winter cooling season and predicting the water mass characteristic that is likely to result. Models useful for climate prediction will need to be validated against known climate variations within both the ocean and the atmosphere.

Gyre scale circulation variability

Whenever oceanographers have looked at the detailed hydrographic and dynamical fields in some part of the gyre circulation over periods of months they have seen a variability that appears to be of lower frequency and longer wavelength that oceanic eddies. People have suggested that such variability may be due to the gyre circulation shifting its position slightly without changing its strength. Others believe that it is more likely to be a local variation in the circulation. As part of WOCE Core Project 3, there are plans to carry out quasi simultaneous hydrographic surveys of several different parts of the North Atlantic circulation. These survey would also include hydrographic sections to link this particular regions with the structure of the entire gyre. The basin wide measurements such as floats, drifters and satellite altimetry will also be used to make this links. At present these studies are much better subscribed in the sub polar gyre of the North Atlantic than in the subtropical gyre.

Conclusions

WOCE is a global, multiparameter oceanographic experiment that will rely on an effective data management system if it is to succeed. WOCE will bring together every class of ocean data presently in use. The principal WOCE scientific results are likely to arise from combining different types of data rather that the older oceanographic pattern of a principalinvestigator making observations in the field and then analyzing those data without the addition of any data collected outside of that particular field part.

Question Period

Q. Several questions on rapid data dissemination

A. WOCE is encourages participants place their hydrographic data in the IGOSS system. They have not insisted that this be done.

Q. WOCE quality standards are very high whereas the last speaker (Leetmaa) indicated that model operators are not terribly concerned about quality. How do you explain this difference?

A. WOCE actually includes both. Woce encourages the use of IGOSS to rapidly disseminate data while some WOCE scientific objectives require a very high degree of quality assurance to meet these goals.

Q. How are WOCE data acquisition being tracked?

A. WOCE uses techniques first developed by the IOC and WMO. It has adapted these and information on what is planned and what has been accomplished is available to all on the OCEANIC system.

Q. How will data be made available?

A. All WOCE data will be placed in the IODE system of World and National Data Centers.