atmosphere, making interactions between waves and currents less important in the ocean. None the less, it does seem likely that there are some locations in the ocean where internal wave breaking should drive mean flows. One possible location is the continental slope; internal waves generated as lee waves at one location may propagate shoreward, break on the slope, and drive an along-slope current, much as ocean swell incident at an angle to a beach may drive longshore currents inside the breaker zone.

The role of internal waves in other situations may also have been somewhat unrecognized so far. One is their effect on surface mixed layer deepening. The waves alternately shallow and deepen the layer, making the shear across the mixed layer base more destablizing during the shallow phase and enhancing the overall mixing. This is an effect that has been excluded from models of the surface layer, and may be a partial reason why these models sometimes need to include ad hoc extra mixing just below the base of the layer.

Conclusions

Internal waves are both an unavoidable nuisance and a key ingredient of the behavior of the ocean; perhaps they are like the clouds in the atmosphere. The analogy is certainly a good one when one thinks of modeling the large-scale circulation of the two media for applications such as climate prediction. Numerical models fail by several orders of magnitude to have sufficient resolution to treat them explicitly, so their effects must be parameterized. This requires not just an understanding of their role in present conditions, but also a submodel that will predict their characteristics and effects in a changing mean state. A model for internal waves will need to account for the whole awkward mix of generation, propagation, wave–wave interactions, interactions with the mean state, and reflection and scattering from the rough seafloor. We have a partial understanding of many of the pieces but are a long way from putting them all together.

See also

Breaking Waves and Near-surface Turbulence. Internal Tidal Mixing. Internal Tides. Surface, Gravity and Capillary Waves. Wave Generation by Wind.

Further Reading

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INTERNATIONAL ORGANIZATIONS

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Introduction

This article is limited to a description of the most important organizations related to Ocean Sciences, rather than exhaustively cataloging perhaps hundreds of entities which may cross one or more national borders. I have classified the major international organizations into governmental (or more accurately intergovernmental) and nongovernmental organizations, and within those groupings, global and regional organizations. With the proliferation of the world wide web, much information can be readily accessed from each organization's web page, some of which I have edited and utilized.

Intergovernmental Organizations (Global)

The overarching global intergovernmental organization is the United Nations (UN). Within it, the Intergovernmental Oceanographic Commission (IOC) has the main responsibility for the coastal and deep oceans. Organizationally, the IOC is a component commission of the United Nations Educational, Scientific and Cultural Organization (UNESCO).

The World Meteorological Organization (WMO), a UN specialized agency, has strong interactions with the ocean interests, by virtue of the coupling of weather and climate with the circulation of the oceans and its other properties. The Fisheries and Agricultural Organization of the UN also has strong ties to the oceans through its work in marine fisheries.

Intergovernmental Oceanographic Commission (IOC)

The work of the IOC, founded in 1960, has focused on promoting marine scientific investigations and related ocean services, with a view to learning more about the nature and resources of the oceans. The IOC focuses on four major themes: (1) facilitation of international oceanographic research programs; (2) establishment and coordination of an operational global ocean observing system; (3) education and training programs and technical assistance; and (4) ensuring that ocean data and information are made widely available.

The IOC is currently composed of 126 Member States, an Assembly, an Executive Council and a Secretariat. The Secretariat is based in Paris, France. Additionally the IOC has a number of Subsidiary Bodies. Each Member State has one seat in the Assembly, which meets once every two years. The Assembly is the principal organ of the Commission which makes all decisions to accomplish the objectives of the IOC. The Secretariat is the executive arm of the organization. It is headed by an Executive Secretary who is elected by the Assembly and appointed by the Director-General of UNESCO. Countries contribute dues to support the work of the IOC.

Scientific/technical subsidiary bodies of IOC include Ocean Science In Relation To Living Resources, Ocean Science In Relation to Non-Living Resources, Ocean Mapping (OM), Marine Pollution Research and Monitoring, Integrated Global Ocean Services System, Global Ocean Observing System, and International Oceanographic Data And Information Exchange. There are various subprograms attached to most of these including the Global Coral Reef Monitoring Network.

IOC also has regional subsidiary bodies with responsibilities for carrying out region-specific programs voted by the Assembly. These are the Subcommission for the Caribbean and Adjacent Regions, Regional Committee for the Southern Ocean, Regional Committee for the Western Pacific, Regional Committee for the Cooperative Investigation in the North and Central Western Indian Ocean, Regional Committee for the Central Indian Ocean, Regional Committee for the Central Eastern Atlantic and Regional Committee for the Black Sea.

The work of the Secretariat is accomplished by a small permanent staff and a larger number of scientists usually funded by institutions or agencies in their own countries, who have interest in a specific aspect of the activities of the IOC. The funds provided to do this are in addition to country dues. This mechanism to focus staff support on such areas of interest is good, and helps to counterbalance the opposite tendency of the General Assembly, meeting every two years, to direct the General Secretary to undertake new activities. Because such activities must usually be funded out of the existing budget, the tendency inevitably dilutes existing activities, sometimes to a subcritical level.

World Meteorological Organization (WMO)

The World Climate Program (WCP) is the main activity of WMO related to the oceans. Established in 1979, the WCP includes the World Climate Research Program (WCRP), of which the Global Climate Observing System, encompassing all components of the climate system, atmosphere, biosphere, cryosphere, and oceans, is a component. WMO and its WCRP are treated fully elsewhere and only a brief summary is provided here, relating to oceans.

The World Meteorological Convention, by which the World Meteorological Organization was created, was adopted in 1947, and in 1951 was established as a specialized agency of the United Nations. There at least 185 member countries and territories. The World Meteorological Congress, which is the supreme body of WMO, meets every four years. In order to assess available information on the science, impacts and the cross-cutting economic and other issues related to climate change, in particular possible global warming induced by human activities, WMO and the United Nations Environment Program (UNEP) established the Intergovernmental Panel on Climate Change in 1988.

In the early years of their development, WCRP incorporated the Tropical Ocean – Global Atmosphere Study initiated by the Scientific Committee on Oceanic Research (SCOR) (see below), and the World Ocean Circulation Experiment (WOCE). The former was successfully completed and the latter is in its later stages of analysis and synthesis, the major field programs including the WOCE Hydrographic Survey, having been completed. Both programs have been very successful, to the point that

an offspring is beginning to be implemented – the Climate Variability and Predictability Study. This 15-year program to observe the atmosphere and oceans will incorporate new technologies developed as a result of the predecessor programs, and rapidly increasing sophistication of computer hardware and software to develop new coupled models. Past climates will also be reconstructed.

Related to this effort is the Global Ocean Data Assimilation Experiment which is planned for the first half of this decade. This program was a product of the joint IOC/WCRP Ocean Observations Panel for Climate.

In 1999 the governing bodies of WMO and IOC agreed to set up a Joint Technical Commission for Oceanography and Marine Meteorology to act as a coordinating mechanism for the full range of WMO and IOC existing and future operational marine program activities, including the coordinating and managing the implementation of an operational Global Ocean Observing System.

The World Bank

The Global Environmental Facility (GEF) of the World Bank was launched in 1991 as an experimental facility and evolved 'to serve the environmental interests of people in all parts of the world'. By 2000, more than 36 nations pledged $2.75 billion in support of GEF's mission to protect the global environment and promote sustainable development. This has been complemented by $5 billion in co-financing from GEF partners, which include the UN Development Program and the UN Environment Program, as well as host countries. GEF funds projects in four areas: biodiversity, climate change, international waters, and ozone. Up to 1999 the GEF had allocated over $155 million to international waters initiatives. The term 'international' refers to fresh as well as ocean waters, and the projects seek to reverse the degradation of bodies of water controlled by a mosaic of regional and international water agreements.

A list of currently funded projects is available from the GEF web site. Examples include Black Sea Environmental Management, Gulf of Guinea Large Marine Ecosystem and various coral reef rehabilitation and projection projects. The GEF Secretariat is located within the World Bank in Washington DC, USA.

Intergovernmental Organizations (Regional)

Besides regional activities of global intergovernmental organizations referred to above, there are two main regional intergovernmental organizations. The first, the International Council for the Exploration of the Sea (ICES) (for the North Atlantic), and the second is the North Pacific Marine Science Organization.

International Council for the Exploration of the Sea (ICES)

Oceanographic investigations form an integral part of the ICES program of multidisciplinary work aimed at understanding the features and dynamics of water masses and their ecological processes. In many instances emphasis is placed on the influence of changes in hydrography (e.g., temperature and salinity) and current flow on the distribution, abundance, and population dynamics of finfish and shellfish stocks. These investigations are also relevant to marine pollution studies because physical oceanographic conditions affect the distribution and transport of contaminants in the marine environment. ICES promotes the development and calibration of oceanographic equipment and the maintenance of appropriate standards of quality and comparability of oceanographic data.

ICES is the oldest intergovernmental organization in the world concerned with marine and fisheries science. Since its establishment in Copenhagen in 1902, ICES has been a leading scientific forum for the exchange of information and ideas on the sea and its living resources, and for the promotion and coordination of marine research by scientists within its member countries. Each year, ICES holds more than 100 meetings of its various working groups, study groups, workshops, and committees. These activities culminate each September when ICES holds its Annual Science Conference, which attracts 500–1000 government, academic, and other participants. Proceedings of these meetings, and other related activities are published by ICES.

Membership has increased from the original eight countries in 1902 to the present 19 countries which come from both sides of the Atlantic and include Canada, the USA and all European coastal states except the Mediterranean countries from Italy eastward. Each country has a vote in the governance, through two delegates, all of whom come together annually at the 'statutory meeting' held at the time of the science conference. The Council elects a President at three year intervals from its members, as well as a small executive group (the Bureau) to conduct business intercessionally.

The ICES Secretariat in Denmark maintains three databanks, the Oceanographic databank, the Fisheries databank, and the Environmental (marine contaminants) databank. Since the 1970s, a major area

of ICES work as an intergovernmental marine science organization has been to provide information and advice to member country governments and international regulatory commissions (including the European Commission) for the protection of the marine environment and for fisheries conservation. This advice is peer-reviewed by the Advisory Committee on Fishery Management and the Advisory Committee on the Marine Environment before being passed on.

The structure and operation of ICES has continuously evolved, to meet current needs of the advice-seeking member nations and the oceanographic community. In earlier years it focused mostly on the relationship of oceanography to fisheries, but over the past 15 years, the need has arisen increasingly for advice over the broad range of environmental issues from marine contaminants to effects of fishing activities on the environment, particularly the seafloor ecosystems. The annual meeting, which was traditionally a business occasion where standing committees reviewed the activities of working groups and passed recommendations on to the Council, has evolved into a major north Atlantic science meeting on oceanography and its application to regional societal problems.

ICES has tried to capture its past century of achievements through special lectures, a History Symposium and a soon to be published written history volume. Its future is mapped through the development of its first strategic plan, and ongoing organizational evolution.

North Pacific Marine Science Organization (PICES)

PICES held its first Annual Meeting in October 1992, in Victoria, British Columbia. From the beginning, the PICES approach has been multidisciplinary, with standing committees concerned with biological oceanography, fishery science, physical oceanography and climate, and marine environmental quality. There has been growing interaction among these specialties, with joint scientific sessions, interdisciplinary symposia, and a broad study of climate change and carrying capacity (the CCCC program) in the region. Most recently, PICES has taken the lead in joining forces with other international organizations to organize an intersessional Conference under the title of El Niño and Beyond (March 2000). Although PICES is an infant compared with its prototype, ICES, it has already become a major focus for international cooperation in marine science in the northern North Pacific.

PICES is an intergovernmental scientific organization. Its present members are Canada, People's Republic of China, Japan, Republic of Korea, Russian Federation, and the USA. The purposes of the organization are: to promote and coordinate marine research in the northern North Pacific and adjacent seas especially northward of 30°N; advance scientific knowledge about the ocean environment, global weather and climate change, living resources and their ecosystems, and the impacts of human activities; and promote the collection and rapid exchange of scientific information on these issues.

PICES annual meetings, symposia and workshops provide fora at which marine scientists interested in the North Pacific can exchange latest results, data, and ideas and plan joint research. These meetings have been effective in stimulating and accumulating the interest of the scientific community in member countries to coordinate marine science on the basin scale. PICES has been successful at bringing oceanographers from a number of Pacific Rim countries and disciplines (physical, chemical, and biological) together talking and working with fisheries scientists to understand and eventually forecasts temporal variability of ocean ecosystems, and their key species. It has also encouraged and facilitated collaborative marine scientific research in the North Pacific. International collaboration in this region is essential since the open North Pacific is too large for any one country to study adequately on its own, and oceanic circulation and biological species do not recognize international boundaries. Comparisons of similar species and ocean environments on the eastern and western sides of the Pacific will be much more revealing about the large-scale processes affecting ecosystem and fish dynamics than isolated studies in national waters alone.

PICES was established, in large measure, by the tireless efforts of Warren Wooster, of the University of Washington, USA. He had long been active in ICES, including as its President, and had become convinced that there was a great need for a similar organization focused on the North Pacific.

Other Regional Commissions

Throughout the world, governments have formed regional organizations to protect the environment and regulate activities. Two European examples of these are the Helsinki Commission, otherwise known as the Baltic Marine Environment Protection Commission, and OSPAR Commission for the Protection of the Marine environment of the north-east Atlantic. Their members comprise the countries bordering these specific marine environments. There are also several such commissions organized to protect and regulate specific fisheries and/or fishery regions (e.g., the North Atlantic Salmon Commission),

listings and explanations of which go beyond the scope of this article.

Nongovernmental Organizations (Global)

International Council for Science (ICSU)

Formerly known as the International Council of Scientific Unions, ICSU is a nongovernmental organization, founded in 1931 to bring together natural scientists in international scientific endeavor. It comprises 95 multidisciplinary National Scientific Members (scientific research councils or science academies) and 25 international, single-discipline Scientific Unions to provide a wide spectrum of scientific expertise enabling members to address major international, interdisciplinary issues which none could handle alone. ICSU also has 28 Scientific Associates.

The Council seeks to break the barriers of specialization by initiating and coordinating major international interdisciplinary programs and by creating interdisciplinary bodies which undertake activities and research programs of interest to several members. It acts as a focus for the exchange of ideas and information and the development of standards. Hundreds of congresses, symposia and other scientific meetings are organized each year around the world, and a wide range of newsletters, handbooks, and journals is published.

The principal source of finance for the ICSU is the contributions it receives from its members. Other sources of income are grants and contracts from UN bodies, foundations, and agencies, which are used solely to support the scientific activities of the ICSU Unions and interdisciplinary bodies. ICSU has a three-tier system of governance. They are the General Assembly (the highest organ), the Executive Board, and the Officers. These are assisted by a Secretariat responsible for the day-to-day work of the Council.

Interdisciplinary ICSU bodies are created by the General Assembly as the need for these arises in cooperative projects. Two of these, the International Geosphere-Biosphere Program (IGBP) and SCOR, are currently of particular interest to the ocean sciences community.

IGBP, planning for the International Geosphere-Biosphere Program: A Study of Global Change, was begun in 1986. The IGBP is a research program with the objective to describe and understand the interactive physical, chemical, and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human actions. The program is focused on acquiring basic scientific knowledge about the interactive processes of biology and chemistry of the earth as they relate to global change. Priority is placed on those areas in each of the fields involved that deal with key interactions and significant changes on timescales of decades to centuries, that most affect the biosphere, that are most susceptible to human perturbations, and that will most likely lead to a practical, predictive capability.

SCOR, the Scientific Committee on Oceanic Research, established in 1957, is the oldest of ICSU's interdisciplinary bodies. The recognition that the scientific problems of the oceans required a truly interdisciplinary approach was embodied in plans for the International Geophysical Year. Accordingly, SCOR's first major effort was to plan a coordinated, international attack on the least-studied ocean basin of all, the Indian Ocean. The International Indian Ocean Experiment of the early 1960s was the result.

For the next 30 years, the reputation of SCOR was largely based on the successes of its scientific working groups. These small international groups of not more than ten members are established in response to proposals from national committees for SCOR, other scientific organizations, or previous working groups. In general, they are designed to address fairly narrowly defined topics (often new, 'hot' topics in the field) which can benefit from international attention.

Although SCOR does not have the resources to fund research directly, many of its scientific groups have organized international meetings and produced important publications in the scientific literature. Others have proposed and planned large international collaborative efforts such as the Joint Global Ocean Flux Study and Global Ocean Ecosystem Dynamics. Scientists from the 39 SCOR member countries participate in its working groups and steering committees for the larger programs. SCOR often works in association with intergovernmental organizations such as IOC and ICES. The work of SCOR falls into two major categories. The first of these is the traditional mechanism of the SCOR working group, addressing topics which range from the ecology of sea ice to the role of wave breaking on upper ocean dynamics and from coastal modeling to the biogeochemistry of iron in sea water and the responses of coral reefs to global change. For longer-term, complex activities, such as the planning and implementation of large-scale programs SCOR establishes scientific committees.

Over the past 15 years there has been a growing awareness of the influence of the ocean in large-scale climate patterns and in moderating global change. By the early 1980s the promise of increased computing capabilities and new satellite instruments for remote sensing of the global ocean permitted oceanographers to conceive of large-scale, internationally planned and implemented experiments of the sort never before possible.

The first two of these were the World Ocean Circulation Experiment (WOCE) and the Tropical Ocean–Global Atmosphere Study (TOGA, 1985–1995). Both grew out of SCOR's former Committee on Climatic Changes and the Ocean which was also cosponsored by the IOC. A few years ago WOCE was incorporated into the World Climate Research program; its field program is now complete and WOCE is now embarking upon the critical phase of analysis, interpretation, modeling and synthesis.

Since the late 1980s SCOR has played a major role in fostering the development of two newer global change programs, both of which now form part of the IGBP effort. These are the Joint Global Ocean Flux Study and Global Ocean Ecosystem Dynamics.

SCOR consists of its 'members' – the national committees for oceanic research of its 39 member countries, each of which is represented by three individual oceanographers. The biennial general meetings elect an executive committee, which also includes *ex officio* members from allied disciplinary organizations, namely, the International Association for Physical Sciences of the Ocean, the International Association for Biological Oceanography, and the International Association for Meteorological and Atmospheric Sciences.

The Ocean Drilling Program (ODP)

The ODP is an international partnership of scientists and research institutions organized to explore the evolution and structure of the earth. It uses drilling and data from drill holes to improve fundamental understanding of the role of physical, chemical, and biological processes in the geological history, structure, and evolution of the oceanic portion of the earth's crust. The ODP provides researchers around the world access to a vast repository of geological and environmental information recorded far below the ocean surface in seafloor sediments and rocks.

The National Science Foundation (US Federal Government) supports approximately 60% of the total international effort. Other partners (Germany, France, Japan, the UK, the Australia/Canada/Chinese Taipei/Korea consortium, European Science Foundation consortium, and the People's Republic of China), comprising 20 other countries, provide 40% of the program costs.

Currently, specific studies include documenting the history of volcanic plumes in the western Pacific, examining the formation of mineral deposits near west Pacific island arcs, instrumentation of boreholes to study seismicity of the north-west Pacific, and recovery of gas hydrate deposits to examine their formation along the Oregon margin. Support will also be provided for new scientific and operational developments to extend capabilities for deep biosphere investigations for ocean biocomplexity studies.

Other Nongovernmental Organizations (Global and Regional)

Within this category there are many scientific unions and societies, as well as other organizations, which are either explicitly ocean-oriented or have ocean components. Several, as noted above are related to ICSU. Others include the American Society of Limnology and Oceanography and the American Geophysical Union (both primarily north American, but with a substantial international membership), the European Geophysical Society, the Oceanography and Challenger Societies, and many others.

Acknowledgment

I wish to gratefully acknowledge the assistance of my colleague Kandace Binkley in the preparation of this article.

Memorial

I dedicate this article as a small memorial for my friend and colleague Dr. George Grice, whose untimely death occurred in March 2001. A former Associate Director of the Wood's Hole Oceanographic Institution and Deputy Director of the Northeast Fisheries Science Center in Wood's Hole, George was involved with international organizations all his professional life, particularly ICES and IOC. He was serving the latter institution at the time of his death as Senior Science Advisor to the Executive Secretary, Dr. Patricio Bernal.

Links to International Organizations

American Society of Limnology and Oceanography (ASLO) – http://aslo.org
American Geophysical Union (AGU) – http://www.agu.org
Challenger Society for Marine Science

– http://www.soc.soton.ac.uk/OTHERS/CSMS
European Geophysical Society (EGS)
– http://www.mpae.gwdg.de/EGS/EGS.html
Global Ocean Ecosystem Dynamics (GLOBEC)
– http://www1.npm.ac.uk/globec
International Association for Meteorology and Atmospheric Sciences (IAMAS) – http://iamas.org
International Association for the Physical Sciences of the Oceans (IAPSO)
– http://www.olympus.net/IAPSO
International Council for the Exploration of the Sea (ICES) – http://www.ices.dk
International Council for Science (ICSU)
– http://www.icsu.org
International Geosphere-Biosphere Program (IGBP)
– http://www.igbp.kva.se
Intergovernmental Oceanographic Commission (IOC) – http://ioc.unesco.org/iocweb
Joint Global Ocean Flux (JGOFS)
– http://ads.smr.uib.no/jgofs/jgofs.htm
Baltic Marine Environment Protection Commission (HELCOM) – http://www.helcom.fi/oldhc.html
North Pacific Marine Science Organization (PICES)
– http://pices.ios.bc.ca
Ocean Drilling Program (ODP)
– http://www-odp.tamu.edu
OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic
– http://www.ospar.org
Scientific Committee on Antarctic Research (SCAR)
– http://www.scar.org
Scientific Committee on Oceanic Research (SCOR)
– http://www.jhu.edu/ ~ scor
The Oceanography Society (TOS)
- http://tos.org
Tropical Ocean – Global Atmosphere Coupled Ocean/Atmosphere Response Experiment (TOGA)
– http://trmm.gsfc.nasa.gov/trmm_office/field_campaigns/toga_coare/toga_coare.html
United Nations (UN) – http://www.un.org
United Nations Environment Program (UNEP)
– http://www.unep.ch/index.html
United Nations Educational, Scientific and Cultural Organization (UNESCO)
– http://www.unesco.org
World Bank, Global Environmental Facility (GEF)
– http://www.gefweb.org
World Meteorological Organization (WMO)
– http://www.wmo.ch
World Ocean Circulation Experiment (WOCE)
– http://www.soc.soton.ac.uk/OTHERS/woceipo/ipo.html

INTERTIDAL FISHES

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Introduction and Classification of Intertidal Fishes

The intertidal zone is the most temporally and spatially variable of all marine habitats. It ranges from sand and mud flats to rocky reefs and allows the development of a wide variety of plant and animal communities. The members of these communities are subject to the many and frequent changes imposed by wave action and the ebb and flow of the tide. Consequently, animals living permanently in the intertidal zone have evolved a variety of anatomical, physiological and behavioral adaptations that enable them to survive in this challenging habitat. The greater motility of fishes compared with most other intertidal animals allows them greater flexibility in combating these stresses and they adopt one of two basic strategies. The first is to remain in the zone at low tide. This strategy used by the 'residents', requires the availability of some form of shelter to alleviate the dangers of exposure to air and to predators. 'Visitors' or 'transients', that is species not adapted to cope with large changes in environmental conditions, only enter the intertidal zone when it is submerged and leave as the tide ebbs. The extent to which particular species employ either of these strategies varies widely. Many species found in the intertidal zone spend most of their lives there and are integral parts of the intertidal ecosystem. At the other extreme, others simply use the intertidal zone at high tide as an extension of their normal subtidal living space. In between these extremes are species that spend seasons of the year or parts of their life history in the intertidal zone and use it principally as a nursery or spawning ground. The different behavior patterns used by residents and visitors mean that few fishes are accidentally stranded by the outgoing tide.

Habitats, Abundance and Systematics

Fishes can be found in almost all intertidal habitats and in all nonpolar regions. Most shelter is found