COASTAL OCEANOGRAPHY

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Summary

The coastal ocean links the continents and the open (deep) ocean; as such, it overlies the continental margin that consists of the shallow continental shelf, steep continental slope, and the deep continental rise. These strong variations in water depth, and associated geomorphological anomalies (for example, submarine canyons and capes and submarine banks and basins), together with earth rotation, exert controls on the direction of coastal ocean circulation. Density stratification, friction, and transience mediate these constraints. Thus, coastal oceanic processes account for the ultimate cross-shore transport of materials from the continents to the open ocean, but which is often delayed and extended through circuitous alongshore displacements influenced by topographic controls.

The coastal ocean is very responsive to atmospheric forcing associated with the "weather cycle" and serves as a coastal wave guide providing teleconnections that

propagate disturbances hundreds or even thousands of kilometers alongshore. It is also under the influence of forcing from the tides, river runoff, meandering oceanic jets, and mesoscale eddies. Consequently, the coastal ocean is highly variable and, not coincidentally, ecologically productive, supporting most of the major fisheries of the world.

Fortuitously, the scientific understanding, and supporting technologies, needed to address coastal ocean processes and regional-scale analyses are emerging just as the societal demand has risen for a higher level of coastal environmental and ecological information services to meet the need for integrated coastal zone management (ICZM) and numerous other applications.

1. Introduction

1.1. Definition

"Coastal oceanography" embraces the study of the physics, chemistry, ecology, and geology of the "coastal ocean." The "coastal ocean" basically encompasses the 200 nautical miles (NM) wide Exclusive Economic Zone (EEZ), a political concept introduced through the United Nations Law of the Sea Treaty (UNLOS) that has practical consequences for ocean resource management, both for exploitation and conservation. It also has consequences for the sponsorship of basic and applied research, and the development and implementation of operational observing and modeling systems. Furthermore, utilization of the EEZ as a defining principle for the coastal ocean is useful scientifically because it more or less coincides (not by chance) with the continental margin; that is, the continental shelf, continental slope, and continental rise that serve to structure the dynamics of the coastal ocean. Usually the estuaries, coastal lagoons, Great Lakes, and inland seas are also included in the definition of the coastal ocean. The marginal and semi-enclosed seas are special cases of the coastal ocean, and are thus treated as well. Here, the topical coverage is focused on the physics of the coastal ocean, with some references to implications for ecology, chemistry, and geology where most appropriate.

1.2. General Nature

The coastal ocean is where the continents meet the open ocean; hence, it serves as a "bridge" for transporting organic and inorganic, natural and anthropogenic materials between the land and sea. More accurately, it functions as a turbulent boundary layer that joins the land and the sea under the influence of forces and their responses (involving a variety of phenomena and processes) on a large range of time and space scales. As a beginning example, the coastal ocean is impacted by El Niños (with time scales of several months and space scales of a few megameters), as well as surface gravity waves (with time scales of several seconds and space scales of a few hundred meters). Similarly, the coastal ocean circulation is driven by a variety of (often competing) forces: winds, atmospheric pressure, solar and atmospheric heating/cooling, evaporation/precipitation, freezing/melting, buoyant river discharge, tides, and offshore currents and their meandering jets with associated mesoscale eddies and fronts. Some of the forcing is hourly; other forcing is seasonal or even interannual, interdecadal, or

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longer. The response of the coastal ocean to the various forcing functions depends upon the joint effects of the earth's rotation (that is, the Coriolis parameter), variable bottom topography, and density stratification, and it is manifested in various processes and phenomena. In addition to the forced responses noted above, the circulation of the coastal ocean can be controlled by its intrinsic variability because of dynamical instabilities of the currents. Hence, the coastal ocean is generally characterized as being highly variable in space and time. Indeed, in some circles several decades ago, the coastal ocean was thought to be too complicated (due to its intense variability over a broad range of time and space scales) to be amenable for study. As a result of modern instrumentation, theoretical and observational advances in process understanding, and developments in numerical simulation, a degree of order has been brought to the investigation of coastal ocean regimes that had been previously thought perhaps overwhelmingly chaotic, and that had been approached with hopelessly naive methods, deficiently idealized concepts, and grossly under-sampled observations.

1.3. Importance

Historically, knowledge of the coastal ocean has been essential to the safe and efficient conduct of maritime trade, and for the defense of coastal nations and attacks by maritime powers. Interest in tides, storm surges, tsunamis, and long-term coastal sea level variations has been motivated over recent centuries by concerns for coastal flooding, safe navigation, and safety of coastal populations and infrastructure. Coastal marine ecosystems are rich and diverse, supporting much of the commercial and recreational fisheries of the world. Rich deposits of oil and gas, other minerals, and sand and gravel underlie many portions of the coastal ocean. In recent decades, coastal tourism has become a significant component of the world economy, but it depends, in part, on the quality of the coastal environment and the abundance of coastal fish. By their very nature, most rivers discharge to the coastal ocean; their discharges include suspended and bedload sediments. With the rise of modern agriculture, their discharges also include fertilizers and pesticides. With the rise of industrial and municipal waste disposal, their discharges include bacteria and viruses; and with the rise of industrialization, their discharges include various hydrocarbons, toxins, and carcinogens. Some of these discharged chemicals accumulate within the coastal ocean and its ecosystems and sediments; others are transferred to the open ocean, sediments on the deep seafloor, or the atmosphere. With the already high and rapidly growing human population densities in the coastal zones of the world, the coastal nations are under increased pressure to balance the conflicting uses of the coastal ocean. Furthermore, the coastal ocean is host to several natural hazards that threaten human coastal populations, both their infrastructure and human health; for example, storm surges and coastal flooding, storm-driven sea and swell, tsunamis, land-falling hurricanes, coastal erosion and deposition, rising sea level due to climate variability and global change, eutrophication and hypoxia (and its end state anoxia), and harmful algal blooms. Only the more developed coastal nations have a modicum of understanding of their coastal resources and risks, let alone a scientific understanding of coastal oceanography. There is also a great shortage of generally available, continuing, real-time, and strategic observations, and supporting modeling activities, for the coastal ocean. Thus, there is a severe lack of information pertaining to the day-to-day state of the coastal ocean. Consequently, awareness and documentation of the onset and evolution of natural and

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anthropogenic events are seriously limited, restricting the efficacy of emergency and environmental managers. Logically, it would therefore seem that there is an urgent global priority to address coastal oceanography in its broadest sense.

In this regard, it is becoming increasingly difficult to place bounds on coastal oceanography. For example, the coastal ocean is so strongly forced dynamically, and even chemically, by the coastal atmosphere that knowledge of coastal meteorology needs to be taken into account. Conversely, the coastal ocean provides thermal, and also chemical, forcing (for instance, out-gassing of dimethylsulfide (DMS) formed by certain plankton that plays a role in marine stratus formation and ejection of salt particles that help form marine aerosols) to the coastal atmosphere. Thus, the coupling of the coastal ocean and atmosphere is increasingly considered, especially as coastal oceanic and atmospheric observing and modeling systems adopt mesoscale resolution. As another example, the coastal ocean is forced dynamically and chemically by surface water runoff from rivers, estuaries, coastal lagoons and so-called “non-point” sources along the coastline, and by groundwater flowing into shelf sedimentary layers and then entering the ocean through seeps or springs. Conversely, seawater invades coastal aquifers and spoils them with its brine, which is an increasing problem as coastal populations draw down the water table, thus facilitating such invasions. The linking of coastal oceanography and coastal hydrology is in its infancy, and it cannot be done well without coastal meteorology. However, it can be anticipated that such linking will occur as coupled coastal oceanic, hydrological, and atmospheric processes and modeling systems are addressed, both scientifically and societally. These initial perspectives provide the basis on which this article is built, and their salient points are revisited at the end.

2. Some Dynamical Factors

2.1. Variable Bottom Topography and Its Effects

The coastal ocean overlies the continental margin that consists of the continental shelf, continental slope, and continental rise. The continental shelf extends from the coastline to the shelf edge or shelfbreak, typically at a depth of 100 to 200 m. The width of the shelf ranges from about 10 km to a few 100 km; thus, the bottom slope of the shelf is typically between 0.001 and 0.01. The continental slope has a typical bottom slope of 0.1 and extends to a depth of a few km, where the continental rise continues to greater depths with a gentle slope of about 0.001. With an idealized smooth, monotonically shoaling continental margin, surface gravity waves propagating from offshore to the coast will begin to “feel” (that is, interact with) the bottom at some depth depending upon the incident wave frequency, and the waves slow (and amplify) because their phase speed equals the square root of the product of gravitational acceleration and water depth. As a consequence, if the waves are obliquely incident, they will refract to align their wavecrests with the coastline, where they break (that is, form surf) and generate mean alongshore jets near shore.

While most surface gravity waves are generated by winds (in the near field, they are called “wind waves,” and in the far field, they are called “swell”), tsunamis are generated by tectonic disturbances on the sea floor, undersea volcanoes, and

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catastrophic mudslides over the continental slope. These relationships underlie many aspects of coastal ocean dynamics, including the trapping of certain classes of surface gravity waves on the shelf, called “edge waves,” that are constrained to alongshore propagation. Here, the scope is not limited to the idealized continental margin and the time scale of seconds to minutes characteristic of surface gravity waves.

The coastal ocean commonly has bottom topographic perturbations that can be categorized as submarine banks or basins, coastal islands or lagoons, submarine canyons or capes, and smaller scale bottom roughness elements associated with sand waves and ripples, rock outcrops, and other geological anomalies. Similarly, coastlines are highly fractal as they are characterized by a series of capes and embayments on all scales; in some regions, they are punctuated by fjords and, in others, they are connected to estuaries or coastal lagoons. Because of its relatively shallow water depth and commonly occurring strong bottom slopes and complex coastline configurations, topographic effects play a prominent role in determining the circulation of the coastal ocean.

For example, the combined effects of variable depth and the earth’s rotation tend to constrain the mean circulation to flow along isobaths, that is, as alongshore flow. This constraint also leads to the general expectation of mean cyclonic circulation around basins and mean anticyclonic circulation around banks. However, the effects of density stratification, wind forcing, bottom friction, and time-dependence can break that constraint. Obviously, the constraint of alongshore flow must be broken, at least episodically in time and/or space, to accommodate the cross-shore flux of materials from the continents to the open ocean that is known to occur, but seldom observed.

As another example, in regions where the tides have relatively large amplitudes, the tidal currents are strong, producing strong turbulent mixing at the bottom and associated bottom friction, especially over shoal areas such as banks. More generally, the bottom roughness elements serve to produce turbulence due to currents and wave motions that in turn damp the flow and waves. Actually, there is often a two-way interaction, depending on sediment grain size and composition, with the currents and waves serving to shape the sedimentary bedforms through erosion, resuspension, advection, and deposition, thus creating or modifying some of the bottom roughness elements.

The irregularities in coastlines cause important effects; for example, an alongshore wind stress typically sets up an alongshore pressure gradient that can only be “supported” in the presence of capes; when the wind stress relaxes, the pressure gradient produces a counter flow as it relaxes. Part of this scenario is the generation of cross-shore “squirts and jets,” that may become connected to the filaments (mentioned below) driven by mesoscale eddies over the continental slope, and together they can transport shelf waters a hundred kilometers or more offshore over the course of several days.

While contemporary studies of coastal ocean circulation generally treat the bottom topography and coastline as time-invariant, the fact that the near shore bottom topography and coastlines vary with the passage of storms on a seasonal basis implies that two-way interactions between currents and sediments will need to be incorporated in future studies, especially in numerical coastal ocean circulation models.

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Biographical Sketch

Professor Christopher N. K. Mooers
Born in Hagerstown, Maryland, USA, in 1935, Prof. Christopher N. K. Mooers and his wife reside in Coconut Grove (Miami), Florida, where he has been a Professor of Applied Marine Physics since 1991. He received a B.S. degree (with distinction) in 1957 from the US Naval Academy (naval science, equivalent to general engineering) and served as an active duty naval officer until 1964. He completed a M.S. (Physics) degree in 1964 from the University of Connecticut, and was awarded a Ph.D. (physical oceanography) degree in 1969 from Oregon State University. After a NATO postdoctoral year at the University of Liverpool, he joined the Faculty of the Rosenstiel School of Marine and Atmospheric Science, University of Miami in 1970. In 1976, he joined he Faculty of the College of Marine Studies, University of Delaware. In 1979, he became the Chairman of the Oceanography Department, Naval

Postgraduate School. In 1986, he became the founding Director of the Institute for Naval Oceanography under the University Corporation of Atmospheric Research. In 1989, he joined the Institute for Earth, Oceans, and Space, University of New Hampshire. In 1991, he returned to the Faculty of the University of Miami.Professor Mooers has served as Secretary, President-Elect, and President, Ocean Sciences Section of the American Geophysical Union. He was a founding Managing Editor of the Springer-Verlag (now American Geophysical Union) monograph series on *Coastal and Estuarine Studies*. He has served as an editor of the *Journal of Physical Oceanography*. He has served as Chair, US National Committee for the International Union of Geodesy and Geophysics. He has also served as Chair, American Meteorological Society, Committee on Meteorology and Oceanography of the Coastal Zone (now Committee on Coastal Environments). He is serving as a Co-Chair, SCOR Working Group 111 (Coupling of Winds, Waves and Currents in Coastal Models).

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