MEDITERRANEAN AND GLOBAL OCEAN AND CLIMATE DYNAMICS

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Mediterranean and Global Ocean and Climate Dynamics

The Mediterranean is a mid-latitude semi-enclosed sea, or almost an isolated oceanic system. Rapid progress has been made in recent years in describing the physical structure of its currents and circulation and in identifying associated space-time variabilities. Definitive dynamical studies are now possible in order to understand processes and mechanisms of the Mediterranean general circulation and its influences, regionally and globally. Many processes that are fundamental to the general circulation of the world ocean also occur within the Mediterranean, either identically or analogously. But the relatively small size of the Mediterranean facilitates research logistics and minimizes resources required for experimental modeling and field research.

A week-long workshop was held in August 1992 in Venice, Italy, in which twenty participants discussed Mediterranean processes and global ocean climate dynamics. The meeting was sponsored by the International Institute for Earth, Environmental and Marine Sciences and Technologies, which is an institute under the International Centre for Science and High Technology of the United Nations Industrial Development Organization.

The Mediterranean provides a laboratory basin for general circulation research both as a site for process and methodological studies and as a test-bed for a complete and comprehensive basin-wide general circulation case study. Similar considerations extend to applied research on modern methods and systems for marine operations and ocean management. The Mediterranean provides an ideal location to develop and assess (coupled) observational monitoring systems and operational forecast models. The Mediterranean Sea exchanges water, salt, heat, and other properties with the north Atlantic Ocean. The north Atlantic is now known to play a singularly important role in the global thermohaline circulation, as the major site of deep and bottom water formation (NADW) for the global thermohaline cell (conveyor belt) that encompasses the Atlantic, Southern, Indian, and Pacific oceans. The salty water of Mediterranean origin may affect NADW formation processes [*Reid*, 1979] and variabilities and even the stability of the global thermohaline equilibrium state. Relevant research is necessary to understand the possible role of the Mediterranean in the Earth's climate system and in global change.

The Mediterranean Sea, connected to the Atlantic by the shallow and narrow Straits of Gibraltar, is composed of two basins nearly equal in size, the western basin and the eastern basin, which are connected by the narrow and shallow Straits of Sicily. Additionally, the narrow Adriatic, which is a few hundred meters deep in the south but very shallow in the north, extends northward between Italy and the Balkans, exchanging water with the eastern Mediterranean basin through the Straits of Otranto. A larger shelf sea, the Agean, lies between Greece and Turkey connected to the eastern basin through the several straits of the Grecian Island arc. The Mediterranean circulation is forced by water exchange through the Straits of Gibraltar (and Sicily, etc.), by wind-stress and buoyancy flux at the surface from fresh water and heat fluxes [*Garrett*, 1993]. The new picture of the circulation that is emerging is complex and composed of multiple interacting scales including basin-scale, subbasin scale, and mesoscale structures [*Malanotte-Rizzoli and Robinson*, 1991; *POEM-Group*, 1992]. Complexity and scales arise from the multiple driving forces, strong topographic and coastal influences, and internal dynamic processes. There are free and boundary currents and jets which bifurcate, meander, and grow and shed ring vortices; permanent and recurrent subbasin scale cyclonic and anticyclonic gyres; and small but energetic mesoscale eddies. Evidence exists for seasonal, interannual, and multiannual variabilities and their relative importance is not yet established. A definite warming trend in the otherwise stable deep water temperature (0.05°C/20 yrs) has been detected [*B'ethoux*, 1990], most likely due to anthropomorphic reduction of river water flux into the eastern basin [*Leaman and Schott*, 1991]. Geological records may provide the basis for long-time scale climate change studies.

Surface and intermediate waters of the Atlantic Ocean are significantly saltier than those of the Pacific Ocean, and NADW forms when salty intermediate waters in the Iceland/Greenland and Labrador seas get entrained upwards and cooled by winter storms and then undergo deep convection. A positive feedback mechanism for the maintenance of the global conveyor belt is the increased salinity provided by the evaporation that occurs when water is returned to the northern north Atlantic through tropical and subtropical latitudes in the upper branch of the global thermohaline cell. Salinity anomalies occur (for example, in the 1960s and 1970s) that appear to be able to stop or diminish NADW deep water formation. It is speculated that such processes can produce significant climate change, such as the Younger Dryas.

The Mediterranean basins are evaporation basins (lagoons) with fresh water flux from the Atlantic through the Gibraltar Straits and into the western Mediterranean through the Sicily Straits. Relatively fresh waters of Atlantic origin circulating in the Mediterranean increase in density because evaporation exceeds precipitation (advective salinity preconditioning). These fresh waters then form new water masses via convection events driven by intense local cooling from winter storms. Bottom water is produced. For the western basin (WMDW), it is produced in the Gulf of Lions; and for the eastern basin in the southern Adriatic (EMDW), which plunges down through the Otranto Straits. Recent observations also indicate deep water formation in the northeastern Levantine basin during exceptionally cold winters, where intermediate water (LIW) is regularly formed seasonally. The LIW is an important water mass that circulates through both the eastern and western basins and contributes predominantly to the efflux from Gibraltar to the Atlantic, mixed with some EMDW and together with WMDW. Also, intermediate and deep (but not bottom) waters formed in the Aegean are provided to the eastern basin through its straits. Important research questions relate to the preconditioning, formation, spreading, dispersion, and mixing of these water masses. These include sources of forced and internal variabilities; the spectrum and relative amounts of water types formed, recirculating within the Mediterranean basins, and fluxing through the straits.

Internal thermohaline cells with interesting similarities and differences to each other and to the global thermohaline circulation exist in both the western and eastern Mediterranean. The eastern basin thermohaline circulation is now known to consist of a single cell encompassing both the Ionian and Levantine basins with a deep renewal time of 125 years. More research is needed to define the western basin cell. The NADW formed in the Labrador and Iceland/Greenland seas is the source of deep water for the entire global conveyor belt that extends through the Southern Ocean to the Indian and Pacific oceans with an estimated turnover time of ~1000 years. All the cells involve advective salinity preconditioned deep water formation processes. The global cell is known from modeling studies (supported by some geological evidence) to have multiple equilibria, including the modes in which the NADW ceases to be formed. Do multiple equilibria exist for the Mediterranean thermohaline circulation(s)? The eastern basin is a lagoon for the western, and the Mediterranean Sea is a lagoon for the north Atlantic. Can there be switches to estuarine behavior? Could this affect NADW formation and the stability of the global thermohaline cell?

Research on ocean general and thermohaline circulations and their variabilities, and the identification and quantification of critical processes relevant to climate dynamics involves complex issues. Conceptual, methodological, technical, and scientific issues include the formulation of multiscale (for example, basin, subbasin, mesoscale)

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interactive nonlinear dynamical models; the representation of convection and boundary conditions in general circulation models; the parameterization of air-sea interactions and fluxes; and the determination of specific regional processes of water formation and transformations. A nonlinear ocean system is involved whose components are circulation elements and structures, air-sea interactions, and water mass formations and transformations. The Mediterranean Sea provides a unique opportunity to gain experience and knowledge across the range of relevant issues and problems involved in researching such a system. It is a constrained basin for which accurate budgets of heat, salt, and water can be obtained feasibly. Its internal thermohaline cell is relatively fast, which facilitates hypothesis testing and model verification, and it has a climatic change signal through manmade reduction of freshwater inflow. The relatively small size and workable climate of the Mediterranean suggest relative ease of logistics. It should be possible to obtain an understanding of the Mediterranean general circulation, to validate dynamical and numerical models, and to design and implement a coupled observational monitoring network and operational model system with fewer resources and in a much shorter time than required for the global general circulation. Valuable insights and transferable technology and methodology that should accelerate research progress for the global ocean will result.—*A. R. Robinson, Harvard University, Cambridge, Mass.; C. J. Garrett, University of Victoria, British Columbia, Canada; P. Malanotte-Rizzoli, Massachusetts Institute of Technology, Cambridge; S. Manabe and S. G. Philander, Princeton University, NJ.; N. Pinardi, IMGA/CNR, Modena, Italy; W. Roether, University of Bremen, Germany; F. A. Schott, University of Kiel, Germany; and J. Shukla, University of Maryland, College Park*

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