4.9 Interocean and Interbasin Exchanges

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Summary

(This summary is mostly based on the introduction to the chapter. Related references and figures are given in the original chapter of the book.)

Interbasin exchanges within and between the global oceans, as well as exchanges between selected adjacent seas and through deep passages, are part of the meridional overturning circulation. Dense water overflows across the sills of the Greenland-Scotland ridge and mixes with salty surface waters that have cooled to sink in the North Atlantic and form North Atlantic Deep Water that penetrates southward along the western boundary and crosses the equator. Part of this deep water mixes with Antarctic Bottom Water that sinks at specific sites around the continental margin of Antarctic. The mixing can occur either directly at depth or nearer the surface with North Atlantic Deep Water that has upwelled within the Antarctic divergence zone. The resulting bottom water spreads northward over deep passages to fill the abyssal basins of the Atlantic (via the Romanche Fracture Zone, Vema and Hunter Channels), the Pacific (via Samoan and Wake Island Passages) and the Indian (via the Southwest Indian Ridge and Amirante Passage) Oceans and forms the lower limb of the overturning circulation. The remainder of the southward flowing deep water shoals through diapycnal mixing in the Southern Ocean and is converted by air-sea fluxes into intermediate and mode waters that also spread northward into the major ocean basins to form the upper overturning cell. In the Pacific, this upper limb eventually exits as a warm, relatively fresh current through the Indonesian seas into the Indian Ocean and then returns via the Agulhas leakage south of Africa back to the North Atlantic sinking regions.

Marginal seas play an important role in the meridional overturning circulation, either as regions where water mass formation directly forces the circulation like the Nordic Sea north of the Greenland-Scotland Ridge and the Labrador Sea, or as regions where water masses are formed which modify and mark the water masses in the meridional overturning circulation. These latter regions include the Mediterranean and Carribean Seas adjacent to the North Atlantic, along with several seas that border the eastern boundary of Asia, of which the Okhotsk Sea is particularly important for water mass formation in the North Pacific. Because all these adjacent seas are semi-enclosed and mostly of relatively small size, they are

frequently sites of intense air-sea exchange. Intra-basin exchanges with marginal seas therefore provide contrasting thermohaline fluxes that can potentially affect the strength, stability and meridional distribution of the overturning circulation.

While the meridional circulation is thought to be the primary mechanism for the spreading of heat, salt, carbon and other biogeochemical properties, at subtropical and sub-polar latitudes the distribution is further enhanced by the basin-wide horizontal gyre circulations and their strong western boundary currents. In the Southern Ocean, the Antarctic Circumpolar Current plays a critical role in the transportation of oceanic properties between the major ocean basins. Together, the meridional and vertical currents within the overturning circulation and the strong horizontal flows of the gyres, the Antarctic Circumpolar Current and the inter-basin exchanges provide a unifying concept of the three-dimensional, interconnected global ocean circulation.

The multiple streams and components, along with the complex physical processes that actively transform water masses and their properties along the various pathways, can make it difficult to quantitatively measure and understand the variability within the global circulation system. While there has been a recent concerted effort to establish trans-basin arrays to monitor the meridional overturning circulation, particularly in the North Atlantic, the vast zonal width of the major ocean basins has historically made this logistically challenging. For this reason, narrower “choke-points” at key locations where there is inter-ocean and/or inter-basin exchange, have provided natural geographical constraints for more convenient monitoring of climate variability. In the Southern Ocean, Drake Passage and the Agulhas leakage around southern Africa are particularly attractive locations since they fully constrain the meridional width of the Antarctic Circumpolar Current and provide direct linkages for the inter-ocean exchange of the Pacific and Indian Oceans, respectively, with the Atlantic Ocean. Furthermore, the Drake Passage lies in the Southern Ocean along the “cold-water route” for the overturning pathway to the Atlantic, while the “warm-water route” follows the tropical Indonesian Throughflow and returns via the Agulhas leakage. However the relative contribution of each route, their variability and distribution with depth, has not as yet been adequately quantitatively observed and described. In the tropical oceans, the Indonesian seas provide the only low latitude pathway for surface to intermediate waters to pass from the Pacific to Indian Oceans. Although the Indonesian archipelago is the largest in the world consisting of islands, sills and basins of various widths and depths, recent observations suggest that much of the Indonesian Throughflow variability in mass, heat and freshwater can be captured by measurements within the two main inflow passages and three relatively narrow passages that provide the main exit pathways into the southeast Indian Ocean. Semi-enclosed marginal seas similarly encompass a highly complex geometry where water masses are exchanged with the open ocean through a number of interconnected straits and sills (e.g. Okhotsk Sea) or through a single restricted channel or strait (e.g. Mediterranean Sea). In the lower limb of the overturning circulation, it is thought that roughly equivalent volumes of dense water sink as deep water in the North Atlantic and as bottom water around Antarctica. However since only limited long-term direct velocity measurements exist in a few select deep passage choke points, the fate of the deep flows are poorly resolved once they circulate into the basin interiors.

The complex bathymetry and many unique dynamical processes associated with inter-ocean and inter-basin exchanges at the passages and choke-points provide challenges for observations and models alike. A complicated system of currents may be driven by winds, buoyancy forcing through air-sea exchange, and by mixing due to winds, tides and eddies. The pressure gradient force set-up within the water column between two interconnected basins can drive the water above sill depth out through the passage into another basin. Deep inter-basin exchanges occur through passages in ridges that are often narrow and shallow, which are favorable conditions for a hydraulic control of the flow.

In this chapter, the present knowledge of inter-ocean exchange through the high-latitude Drake Passage and Agulhas system in the Southern Ocean and the low-latitude Indonesian seas are discussed. Examples of inter-basin exchange from marginal seas illustrate their importance as source regions for the forcing of the circulation, or as regions where water masses are formed that modify and mark the variability in the global climate system. Finally, deep passage overflows that permit the exchange of deep and bottom waters between neighboring ocean basins, their characteristics and dynamics are reviewed.