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Fluxes through the air–sea interface

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10.1 INTRODUCTION

Considering the World Ocean as a continuous body of water, oceanographers are mainly concerned with the internal processes that control the distribution of its physical and chemical properties. However, there are two regions in which the conditions determining the characteristics and behavior of this water mass are distinctly different from the rest. These are its boundaries with the solid earth below and with the atmosphere above. It is here that liquid ocean waters meet either solid or gas, giving rise to a range of processes not encountered in other parts of the ocean. This chapter is concerned with the interface between the ocean and the atmosphere, the ways in which fluxes from one medium to the other can be measured, and how satellite-derived ocean data can be used with the goal of improving the geographical reach and accuracy of air–sea flux estimates.

From a remote-sensing perspective, the air–sea interface is the part of the ocean most accessible to sensors in space. For electromagnetic waves in those parts of the spectrum that can pass through the atmosphere with little attenuation, the sea surface is the principal encounter point which determines what a satellite remote-sensing instrument observes. While for many oceanographic applications it might be preferable to look through this barrier to see into the deep ocean, for those wishing to study processes centered around the air–sea interface, remote sensing appears to be an ideal tool. Using satellites we can measure or deduce a number of the ocean parameters that influence air–sea fluxes. Unfortunately it is not so straightforward for atmospheric remote-sensing methods to measure air properties close to the sea surface at the bottom of the atmospheric boundary layer (ABL). This creates serious challenges for estimating fluxes on the basis of satellite data alone.

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Now that global warming and climate change are recognized as issues of considerable public interest, there has been a substantial increase in the perceived importance of research to understand the interactions and exchanges between the atmosphere and the ocean, mediated by fluxes across the air–sea interface. The study of only one side of the interface—ocean or atmosphere—cannot offer a complete answer to questions relating to development of the Earth’s climate. Coupled ocean–atmosphere models which aim to provide an accurate description and prediction of these developments depend on parameterizations of processes at the air–sea boundary and of fluxes between the two media. Gases such as oxygen \((\text{O}_2)\) and carbon dioxide \((\text{CO}_2)\) as well as heat, momentum, and humidity (water vapor) are quantities that are exchanged between the ocean and the atmosphere at all times, driven by gradients across the interface. Characteristic properties of the interface itself play an important role in determining the magnitude of this exchange and thus they affect the speed of equilibration following a change of gas concentration or physical quantity in the ocean, the atmosphere, or both.

Characterizing a moving interface between two media at small spatial scales representative of the governing molecular processes is a difficult problem on its own. Add to this the vast horizontal extent of the sea surface, its inaccessibility, and the difficulties of measuring from a ship or buoy, which itself is a moving platform, and it becomes obvious why studying the air–sea interaction poses a complex challenge to classical oceanography. In comparison, the advantages of remote sensing in terms of spatial and temporal coverage and ease of access have a lot to offer. Indeed it is difficult to envisage a system for monitoring air–sea fluxes with global coverage, spatial resolution at the oceanic mesoscale, and time-sampling every few days which does not make extensive use of satellite remote sensing. However, since the air–sea flux of the properties of interest cannot be measured directly from space, the ongoing scientific task for 20 years has been to develop suitable parameterizations that link those quantities that are measurable by satellite sensors to the air–sea fluxes we wish to estimate.

Outlining the progress made in this task forms the content of this chapter, which discusses the air–sea fluxes of heat and gases and how they can be measured from space. Although the flux of momentum is mentioned—because it provides a basis for understanding other fluxes—it is not developed here. In fact the impact of momentum exchange crops up in many other parts of this book, wherever wind stress is implicated in driving an oceanic process such as upwelling (Chapter 5), surface waves (Chapter 8), and wherever wind mixing of the upper ocean is mentioned. The next section explains some of the basic principles underlying parameterization of air–sea exchange processes, and is followed by a review of the remote-sensing methods used to determine the important parameters required for flux estimation. Section 10.4 outlines the current state of the art concerning the global mapping of gas and heat fluxes using satellite data. The final section reflects on what more needs to be done before the benefits of satellite data are fully exploited in global systems for routine monitoring of air–sea fluxes that can supply valuable knowledge about short-term climate change.