J. Fluid Mech. (1973), *vol.* 59, *part* 2, *ppl* 414–416
Printed in Great Britain

REVIEW

Atmosphere–Ocean Interaction. By E. B. KRAUS. Oxford University Press, 1972. 275 pp. £7.50.

This book is somewhat broader than we expect, if we translate the title to 'air–sea interaction'. Yet it will introduce the reader to the current levels of understanding and areas of active research. The chapters are entitled: "Basic concepts", "The state of matter near the interface", "Radiation", "Surface waves", "Turbulent transfer near the interface", "The planetary boundary layer" and "Three-dimensional interactions".

At the smallest scales the subject is convincing. The chemistry of sea water and moist air, and local equations of radiative heating seem to be well-enough understood. When locally examined, the surface appears imbedded in molecular sublayers through which matter and momentum pass by diffusion, yet not so efficiently that adjacent air and water are always in chemical equilibrium (CO_2, for example, has difficulty in passing through the surface).

As the scale of interest increases, however, the simplicity vanishes. The surface breaks and reconnects sporadically, transferring mass in bubbles and spray; some 10^9 tons of salt annually reaches the atmosphere when the spray evaporates. Turbulent eddies dominate above and below. The treatment of these transports of matter and momentum vertically is apologetic. Taking the events to be statistically steady, we use dimensional analysis to relate, say, stress to wind speed. This works well when the air is unstratified, since the scatter of drag coefficients (the proportionality constant for these formulae) measured at sea is only $\pm 15\%$ (though apparently the scatter is sufficient to bury any systematic variation of drag coefficient with wind speed). But the elaboration of such arguments to determine more subtle quantities like profile shapes, curvature and roughness lengths, and to include a wider range of descriptive parameters, particularly the gravitational stability of the air, is not impressive to the bystander: the observational scatter (say, of roughness length versus wind speed) can be enormous.

The lack of persuasiveness in this section is not surprising, for the topic seems barren of simple, successful ideas. But if the statistically steady 'constant-flux' layer is difficult to refine, why not explore the alternatives? Neither the physics of intermittent, violent transports (and their observational basis), nor the direct stimulation by computer of the turbulent layer, nor the role of laboratory experiments, is very seriously discussed.

If we hasten on to larger scales, models of the flows could take on a physical, rather than statistical, character. Thus a description of Taylor's early studies of cold continental air, warming as it passes over the sea, might make better reading than do attempts at determining locally the transports across the surface. So would laboratory experiments, such as the penetration of a convecting 'mixed' layer into stable fluid lying either above or below experiments, for example, Deardorff, Willis & Lilly's or Turner's turbulent mixing experiment, or Townsend's experiments in which convective turbulence excites internal waves in the adjacent quiet fluid. These references may seem obtuse, but they are pieces of the puzzle that now have an identity, even though their final importance is not yet clear. Alternatively, more use could have been made of observations (there is about one observational figure per ten pages of text), if only to expose areas where there are few (for instance, small-scale turbulence and orbital motions just below the sea surface).

A section on "mixed layers, inversions, and thermoclines" is satisfying in this way, for some pleasant model studies are included. That of Kraus & Turner, for instance, shows simply how seasonal cycles of surface heating and wind stirring combine to give a gradual deepening of the uppermost, warm layer in summer, yet catastrophic deepening with the arrival of autumnal cooling. It is unfortunate that there is a lack of detail about assumptions crucial to close the analysis, for instance that the wind-stirring energy is partitioned in a particular way between potential and kinetic energies of the water. The justification becomes less clear at each retelling, as does the usefulness of statements (common to the literature) such as "the work of the stress at the interface and the dissipation are both proportional to $\rho_s u_*^3$", ρ_s being the water density and $\rho_s u_*^2$ the wind stress. Like newspaper poetry, they have a bit of truth, but defy improvement

The role of surface waves as intermediaries between wind and currents is not stressed (appeal is made to the questionable presence of a 'fully developed sea'). Yet waves are included for their own sake. Orbital velocities dominate the motion below the surface, whereas turbulence dominates in the air. There are recent advances in the general theory that are preferable to some of the special examples given here. The conservation of 'wave-action' (energy/relative frequency) in wave packets moving through varying currents, for example, is of more use than a sketchy description of radiation stress. Some material may be *too* recent to have been included; the "maser" mechanism, given as the finalé of the discussion of wind waves, has attracted serious objections which warn us against the verbal balancing of second-order effects.

The final chapter deals with large-scale dynamics, at first sight out of place in a book on air–sea interaction, but rather refreshing, for the theories tend to be clear and linear (whether or not they prove to be valid). Important ideas of global dynamics are recounted, like the western intensification of eddies by Rossby wave propagation, and the great vigour of equatorial baroclinic waves (compared with those at mid-latitudes).

The book is (and was intended to be) less mathematical than that of Phillips, yet less dependent on observations than that of Roll. It succeeds as an introduction to the subject, and to these monographs, but at times the descriptions lack the detail to be followed by themselves. The verbal approach may not always satisfy the theoretician: "Localized geostrophic currents can always be interpreted as packets of Rossby waves" (p. 218); "Wave-like processes...are characterized usually by a conservative, rhythmic oscillation between two different kinds of energy;...inertial waves...with the energy of rotation and translation" (p. 34), nor the experimentalist (*re* the turbulent air layer): "Miyake *et al.* (1970*b*) found considerably more energy in the downstream spectrum than in that of vertical velocity even at high frequencies" (p. 158), just after we have read that "the coincidence of these spectra at high frequencies demonstrates the corresponding 'local isotrophy'" (p. 153). But I must scale my criticism against the frightening difficulty of the subject, to which Dr Kraus has given us a useful introduction.

P. B. RHINES