SHORTER CONTRIBUTION

SOUTHERN OCEAN SEA-AIR ENERGY EXCHANGE

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1. INTRODUCTION

A co-operative meteorological program between the U.S. Weather Bureau and the Australian Bureau of Meteorology commenced in August 1968 with the attachment of one of us (W. R. J. D.) to the U. S. A. R. P. oceanic research vessel "Eltanin" for Cruise No. 35 and subsequent cruises in waters south of Australia. In addition to the routine ship-board observational program, hourly measurements of a number of parameters are being made for selected periods as part of a study of the energy budget of the Southern Ocean. The object of this study is to determine the latent and sensible heat energy supplied to the cold polar air masses by the waters of the Southern Ocean on both climatological and synoptic time scales, so as to assess, more accurately than hitherto possible, the energy conservation constraints imposed upon the general atmospheric circulation in the Southern Hemisphere and to examine the energetics of individual synoptic systems. This note outlines the present phase of the investigation, which utilises data from Eltanin Cruises 35 and 36 and indicates some preliminary results.

2. COMPUTATION OF SEA-AIR TRANSFER OF SENSIBLE HEAT AND WATER VAPOUR

Processing of the data to determine the vertical turbulent fluxes of enthalpy (sensible heat) and water vapour is being carried out on the Bureau's IBM 360/65 computer. The bulk aerodynamic method forms the basis for the evaluations, the fluxes of sensible heat (H) and water vapour (E) being related to the sea and to air (subscripts 's' and 'a' respectively) differences of potential temperature (θ) and specific humidity (q), and anemometer level wind speed (u) by expressions of the form

\[ H = \rho \cdot C_p \cdot C_H \cdot (\bar{\theta}_s - \bar{\theta}_a) \cdot \bar{u}_a \]

\[ E = \rho \cdot C_E \cdot (\bar{q}_s - \bar{q}_a) \cdot \bar{u}_a \]

where \( \rho \) is air density and \( C_p \) the specific heat of air at constant pressure. Standard meteorological formulae and numerical values are used for air density and specific heat. Potential temperature differences are approximated by temperature differences, and specific humidity of the air is derived via the psychrometric equation and Tettens formula (Dilley, 1968) from readings of ventilated dry and wet bulb temperatures (approximately 6 metres above sea level). Wind speed at a height near 18 metres is available directly from a cup rotor and Bendix impeller type anemometer.
$C_H$ and $C_E$, the sensible heat and water vapour bulk transfer coefficients, are complex functions of atmospheric stability, aerodynamic roughness of the sea surface, and measurement heights for potential temperature, specific humidity and wind speed. In this investigation the heat and water vapour fluxes are first computed assuming neutral stratification, with corresponding neutral coefficients implied by an empirical drag-coefficient-wind-speed relationship due to Deacon and Webb (1962), along with the evaporation theory of Sheppard (1958). Until recently no satisfactory method for incorporating the effect of stability was available; however, Deardorff (1968) has offered a method whereby the 'neutral' fluxes, computed as described above, are multiplied by a correction factor determined via recent diabatic profile formulae from a bulk Richardson number. The data of Cruises 35 and 36 have been processed in this way.

The evaporative water loss (E) by the sea involves an oceanic internal energy expenditure of $LE$, where $L$ is the latent heat of evaporation, and this is frequently treated as a latent heat flux into the atmosphere. This convention is adopted here, and the variation of the sensible (H) and latent (LE) heat fluxes from the Southern Ocean to the air above is indicated for two interesting cases:

(i) an approximately east-west cross section through a moderately intense atmospheric frontal system south of Australia,

(ii) the latitudinal variation of energy exchange across a sharp oceanic frontal zone in the vicinity of the Antarctic Convergence averaged over the 8 meridional traverses of Cruises 35 and 36.

3. CROSS SECTION THROUGH A FRONTAL SYSTEM NEAR 40°S

By making slight corrections for the vessel's northward progress and assuming the cyclone structure changes only slowly with time over a 36-hour period as it moves at near constant speed along its known trajectory, the time variation of heat exchange computed from hourly measurements on board the "Eltanin" may be regarded as equivalent to a profile through the northern edge of the storm. In Fig. 1(a) a conventional meteorological analysis (supported by "Eltanin" data) is superimposed on an ESSA 6 photograph of the frontal band and associated cloud vortex which moved ESE at approximately 30 kt to the south of the Great Australian Bight during 3 and 4 September 1968. Fig. 1(b) illustrates the variation of the heat fluxes $H$ and $LE$ along the curved line A B C which represents the "Eltanin's" trajectory relative to the storm. The principal feature of interest is the steady decrease in both sensible and latent heat fluxes into the atmosphere as the front is approached from the east; the 300 mile wide band of 20 to 30 knot northerly winds ahead of the front is actually warming the sea, though slight evaporation and corresponding latent heat flux to the atmosphere continues. Westward of the front as winds swing to the northwest and west the sea is giving up heat, the total loss reaching a maximum of 300-350 watts metre$^{-2}$ in the strong cold stream which becomes established several hundred miles to the rear of the front.

4. SEA-AIR ENERGY EXCHANGE NEAR THE ANTARCTIC CONVERGENCE

During Cruises 35 and 36 the "Eltanin" crossed a marked oceanic frontal zone, just north of the so-called Antarctic Convergence, eight times at latitudes from $49^\circ$ to $56^\circ$S (see Fig. 2(a)). Fig. 2(b) shows the north-south variation of the sensible and latent heat fluxes, corresponding means of sea-air temperature and water vapour pressure differences, and wind speed averaged with respect to the middle of
Fig. 1(a) Surface pressure field at 00 GMT Sept 4 1968 superimposed on an ESSA 6 satellite photo mosaic south of Australia (grid adjusted slightly to position systems correctly at 00 GMT) showing vortical cloud pattern, frontal band and an extensive area of convective cloud behind the front. The curved line ABC represents the trajectory of the Eltanin relative to the moving cyclone.
Fig. 10(b)

Variation of sea-to-air heat fluxes H and LE along relative trajectory ABC of Fig. 1(a) based on hourly series of measurements on board the Eltanin.
Fig. 2(a) Tracks of Eiltanin cruises 35 and 36 showing location and width of the zone of large sea surface temperature gradient for each north-south traverse. The single short lines crossing the tracks within the oceanic frontal zone indicate the latitude taken as its 'middle'. The mean position of the Antarctic convergence as given by Mercer (1967) is shown as a broken line.
Fig. 2(b) Variation of heat fluxes LE and H (top) wind speed (centre) and sea-to-air differences of vapour pressure and temperature (bottom) averaged with respect to the middle of the zone of very large sea surface temperature gradient over the 8 north-south traverses of cruises 35 and 36. The horizontal scale is in degrees of latitude from the middle of the frontal zone.
the zone of large sea temperature gradient. Significant features are the large maximum of both evaporation (latent heat flux) and sensible heat transfer to the atmosphere in a belt 2 to 3 degrees of latitude wide, on the northern edge of the oceanic frontal zone, with the minima just southward. A somewhat similar pattern was noted on crossing the Agulhas Current south of Africa (Zillman and Bell, 1968).

5. CONCLUSION

As data from further cruises are processed it should be possible to specify the sea surface energy sources for the atmospheric circulation systems over the Southern Ocean with greater precision than at present. The additional measurement of radiative heat fluxes on forthcoming cruises will provide further detail on the distribution of energy transfers, conversions and storages over the Southern Ocean.

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REFERENCES


