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**HEAT TRANSFER FROM OCEAN TO  
ATMOSPHERE IN THE TASMAN SEA AREA**

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## HEAT TRANSFER FROM OCEAN TO ATMOSPHERE IN THE TASMAN SEA AREA

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### Summary

Seasonal mean values of sensible plus latent heat transfer from ocean to atmosphere were calculated for the Tasman Sea area. Data from surface synoptic ship reports collected by the New Zealand Meteorological Service for the period July 1957 to June 1965 were averaged over 5 degree latitude and longitude squares.

The total heat transfer was found to be a maximum in all seasons just off the east coast of Australia and a minimum just to the west of New Zealand. Winter and autumn transfers were greater than those for spring and summer.

Heat transfers for individual seasons were calculated for the latitude belt 35–40°S. Patterns of variation were found which had considerable persistence in space and in time.

### INTRODUCTION

The fluxes of sensible heat and latent heat from the oceans to the atmosphere have been calculated from climatological data by Jacobs (1942), Budyko (1963), Privett (1960) and others.

There are two main techniques used in estimating this energy transfer. Neither is free from uncertainties. In one an energy budget is written down for a column of water extending from the surface to the bottom of the sea. This is simple to do in principle but difficult in practice because data are usually insufficient to estimate, at all accurately, some of the terms involved.

In the second method the turbulent exchange of heat and water vapour is found by means of aerodynamic theory assuming a knowledge of the wind profile in the lowest layers and the turbulent exchange coefficients of heat and water vapour. The physical mechanism of the exchange process at the ocean surface is not yet fully understood. There are inevitably simplifications and empirical elements in the treatment. The aerodynamic method is used here following Swinbank (1965).

The fluxes of sensible heat  $F_H$  and latent heat  $F_W$  can be written:

$$\begin{aligned} F_H &= C_z U_z \rho C_p (T_z - T_o) \\ F_W &= C_z U_z \rho L (q_z - q_o) \end{aligned} \quad (1)$$

where  $U_z$ ,  $T_z$ ,  $q_z$  are respectively the wind speed, temperature and specific humidity at same height  $z$  above the sea surface,  $T_o$  is the sea surface

temperature and  $q_0$  the saturated specific humidity at temperature  $T_0$ .  $C_p$  is specific heat at constant pressure,  $L$  the latent heat of evaporation and  $\rho$  the air density.

$C_z$  the eddy diffusivity is assumed to be the same for sensible heat and for water vapour. If  $z$  is 10 m then Swinbank's treatment gives  $C_z = 1.6 \times 10^{-3}$ . This differs from the values used by Jacobs ( $2.3 \times 10^{-3}$ ) and Privett ( $1.8 \times 10^{-3}$ ). A discussion of the values of  $C_z$  used by different workers is given by Robinson (1966).

Most calculations of heat transfer are made on a hemispheric basis even though over large areas the amount of data is inadequate. The present analysis is for a restricted area and uses ships weather reports made every six hours and collected by the New Zealand Meteorological Service for the Tasman Sea region during the period 1957-1965. The aim was to find the seasonal mean heat transfers in the New Zealand area, and to see whether the data were sufficient to give the year to year variations.

#### COMPUTATION OF HEAT TRANSPORT

The ship reports were sorted by computer into 5 degree squares of latitude and longitude and internal consistency checks were made on each report to remove the gross errors. For each square, seasonal mean values of pressure, wind speed, sea temperature, air-sea temperature difference and wet-bulb depression were found for each year and for the whole period. Until 1959 there were few recorded observations of wet-bulb temperature so that the amount of data available for this important element is much less than for the other elements. The number of observations of wet-bulb temperature for the four seasons is shown in Fig. 1 in each of the squares for which heat transport was calculated.

Using equations (1) the seasonal mean transports of sensible and latent heats were calculated in langleys per day. The results are given in Table 1.

The patterns of autumn and winter heat transports are somewhat similar and the values are higher than those in spring and summer which also have a similar type of distribution.

Between latitudes 30-40°S where the largest number of data is found, seasonal transports are a maximum just off the east coast of Australia and generally a minimum between longitudes 170-175°E. There is a secondary maximum north of the Bay of Plenty.

A comparison between the results found by Privett (1960) from U.K. Meteorological Office ship report files, and those given here is shown in Fig. 2 for the latitude bands 30-35°S and 35-40°S. Results for winter and summer only have been plotted. The considerable differences at some longitudes are due partly to the different values of  $C_z$  used in the flux

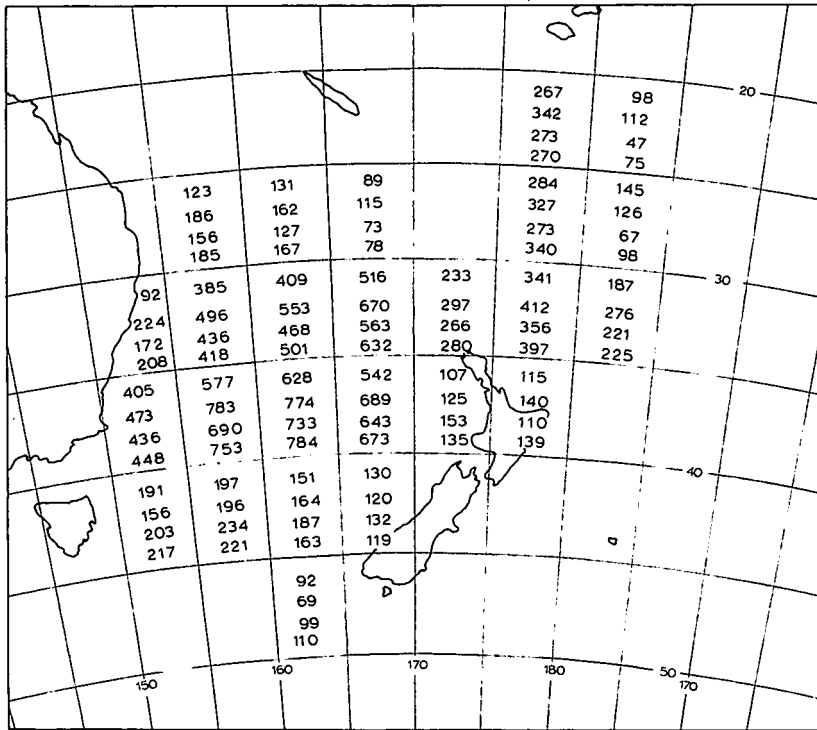


FIG. 1—The number of observations of wet-bulb depression each season in the 5 degree squares for which heat flux was computed. Figures from top to bottom in each square are for summer, autumn, winter and spring.

equations and partly due to the different sets of data used. There is however a general similarity in pattern.

The seasonal mean values of the ratio of the fluxes of sensible and latent heat, the Bowen Ratio, is shown in Table 2. Values are given for 5 degree belts of latitude.

It is seen that with the exception of the summer values there is an increase in the ratios with latitude and also there are seasonal changes. Greatest values are in winter.

#### ERRORS INTRODUCED BY USE OF ROUTINE DATA IN THE AERODYNAMIC METHOD

Besides errors in estimating heat fluxes introduced through uncertainties in the basic theory of the aerodynamic method, errors are also introduced because of deficiencies in the data and the way the data are used. Errors

TABLE 1—Seasonal Mean Heat Transport (Langley/Day) from Sea to Air

		SPRING						
	150°E					180°		
20°S	—	—	—	—	—	290	289	
	—	241	240	224	—	257	259	
	261	251	197	185	167	206	195	
40°S	190	218	204	161	156	183	—	
	216	174	173	148	—	—	—	
			207					
		SUMMER						
	150°E					180°		
20°S	—	—	—	—	—	290	262	
	—	243	259	256	—	287	280	
	277	271	218	187	148	238	166	
40°S	206	206	175	149	133	187	—	
	151	132	154	159	—	—	—	
			145					
		AUTUMN						
	150°E					180°		
20°S	—	—	—	—	—	356	376	
	—	387	404	391	—	344	346	
	341	351	307	261	247	308	274	
40°S	366	258	312	244	228	282	—	
	295	290	254	222	—	—	—	
			273					
		WINTER						
	150°E					180°		
20°S	—	—	—	—	—	331	386	
	—	378	415	437	—	333	366	
	411	356	328	278	253	301	274	
40°S	384	346	294	285	292	306	—	
	252	221	267	227	—	—	—	
			229					

TABLE 2—Seasonal Mean Values of  $F_H/F_W$ —the Bowen Ratio

Latitude	Spring	Summer	Autumn	Winter
25–30°S	0.09	0.06	0.11	0.14
30–35°S	0.09	0.04	0.11	0.16
35–40°S	0.10	0.01	0.14	0.22
40–45°S	0.17	0.07	0.20	0.26

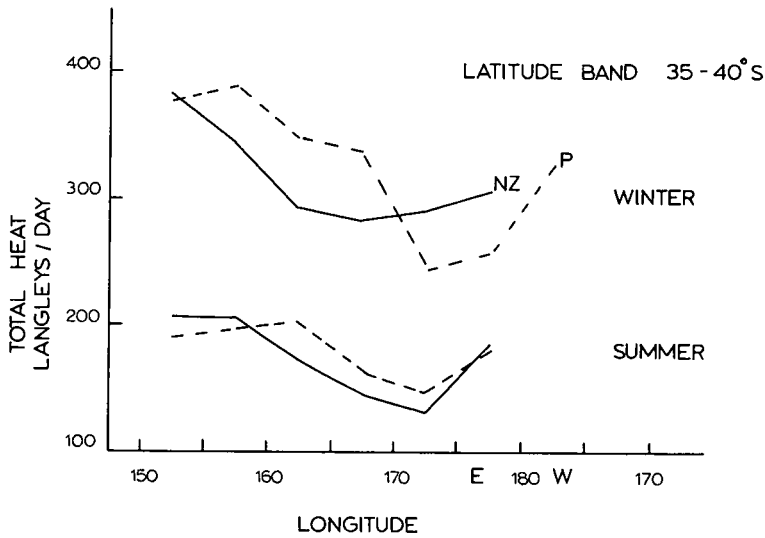
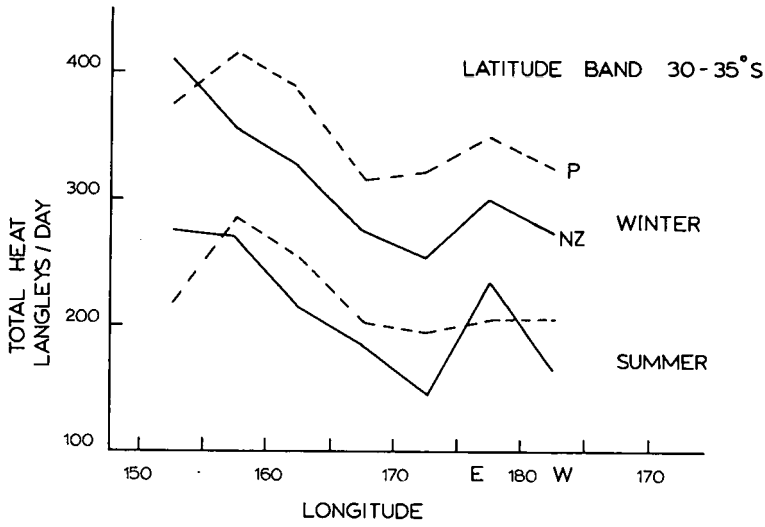


FIG. 2—A comparison of seasonal mean heat flux found by Privett (P) and from the New Zealand data (NZ) along latitude bands 30-35°S and 35-40°S.

are introduced for the following reasons although in most cases their magnitude cannot be determined.

1. Observations are meaned over 5 degree squares in which observations are not scattered at random but usually lie along well defined shipping lanes.
2. Calculations are made using mean values, so that the equations used are of the type:

$$\bar{F}_H = C_z \bar{U}_z \bar{\rho} C_p (\bar{T}_z - \bar{T}_0)$$

where bars denote mean values. This ignores correlations between instantaneous values of the variables. These were shown by Kraus and Morrison (1966) to be small but not insignificant.

3. With high winds evaporation is under-estimated because of the evaporation from spray droplets. It has been estimated (Pisharoty, 1965) that this can make a significant contribution to the total.
4. Air-sea temperature differences are not measured at a standard distance apart.
5. Sea temperatures are not true surface water temperatures but are mostly the temperature of the water at the condenser intake of the ship.

#### YEAR TO YEAR VARIATIONS IN HEAT TRANSPORT

The patterns of seasonal heat fluxes found above are means for the whole data period. Fluctuations about these means were investigated in the attempt to discover:

- (a) whether in any season there were significant changes from year to year;
- (b) whether any changes found were only local (confined to a 5 degree square) or had some larger spatial coherence.

Kraus and Morrison (1966) in a detailed analysis of wind, air, dew-point and sea temperature records from Atlantic weather ships showed that local variations between years were highly significant. They also had a consistent pattern with a scale of more than 500 miles and persistence of several months.

The data here are sufficient in number to study year to year variations only in the 30-40°S latitude belt but are not suitable for any elaborate statistical analysis.

The 35-40°S zone was chosen for analysis as having greater longitudinal extent (20 degrees) than the 30-35°S zone and having of the order of 100 observations per season in each 5 degree square. The heat fluxes for the period 1959-1964 were calculated and are shown for each season in Fig. 3. The maximum and minimum mean daily fluxes in the six-year

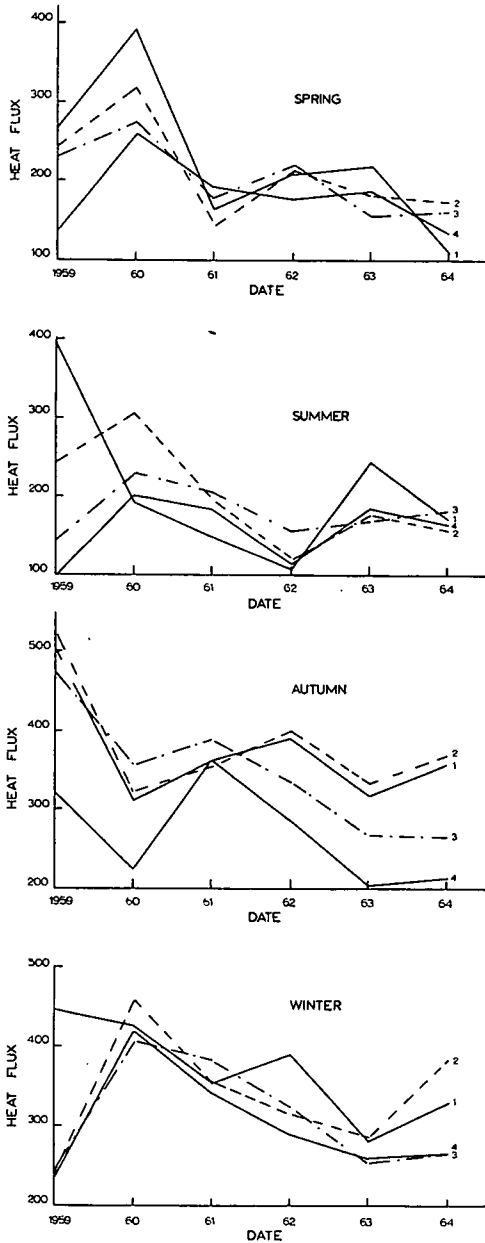


FIG. 3—The mean heat flux (langley/day) each season from 1959–1964 in the latitude band 35–40°S. Square 150–155°E = 1, Square 155–160°E = 2, etc.

period and the years in which they occurred are given in Table 3 for each 5 degree square.

TABLE 3—Extremes of Seasonal Heat Flux in Lat. 35–40°S

(Square 1 = 150–155°E Long.  
Square 2 = 155–160°E Long., etc.)

Square	Spring				Summer			
	Max.	Year	Min.	Year	Max.	Year	Min.	Year
1	391	1960	107	1964	396	1959	107	1962
2	319	1960	141	1961	305	1960	120	1962
3	272	1960	155	1963	229	1960	142	1959
4	259	1960	134	1964	200	1960	97	1959
Square	Autumn				Winter			
	Max.	Year	Min.	Year	Max.	Year	Min.	Year
1	501	1959	310	1960	447	1959	281	1963
2	527	1959	322	1960	461	1960	286	1963
3	483	1959	267	1964	408	1960	253	1963
4	361	1961	201	1963	422	1960	260	1963

It can be seen that:

- (1) Large fluctuations (1–200 langley/day) took place in the year to year values of seasonal mean heat fluxes.
- (2) The maxima in all seasons (with one exception) occurred in 1959–1960.
- (3) There are periods when over the whole 20 degree longitude range, seasonal values have similar deviations from the seasonal mean. Maximum flux conditions in the 3 squares from longitude 155°E–170°E lasted for the winter, spring and summer of 1960.

In order to find the relation between the heat flux changes in the 5 degree squares of the 35–40°S latitude belt, the annual cycle was removed from the series of 1959–1964 seasonal means. The result is shown in Fig. 4. Correlation coefficients calculated between fluxes in neighbouring squares are given in Table 4.

TABLE 4—Correlation Coefficients Between Seasonal Mean Heat Fluxes in the 35–40°S Latitude Belt

Variables	Correlation coefficients
Fluxes in squares (155–160°E) and (160–165°E)	0.49
Fluxes in squares (160–165°E) and (165–170°E)	0.76
Fluxes in squares (165–170°E) and (170–175°E)	0.80

There is thus a similarity in the changes in the seasonal mean daily heat fluxes throughout the year in the central Tasman Sea between

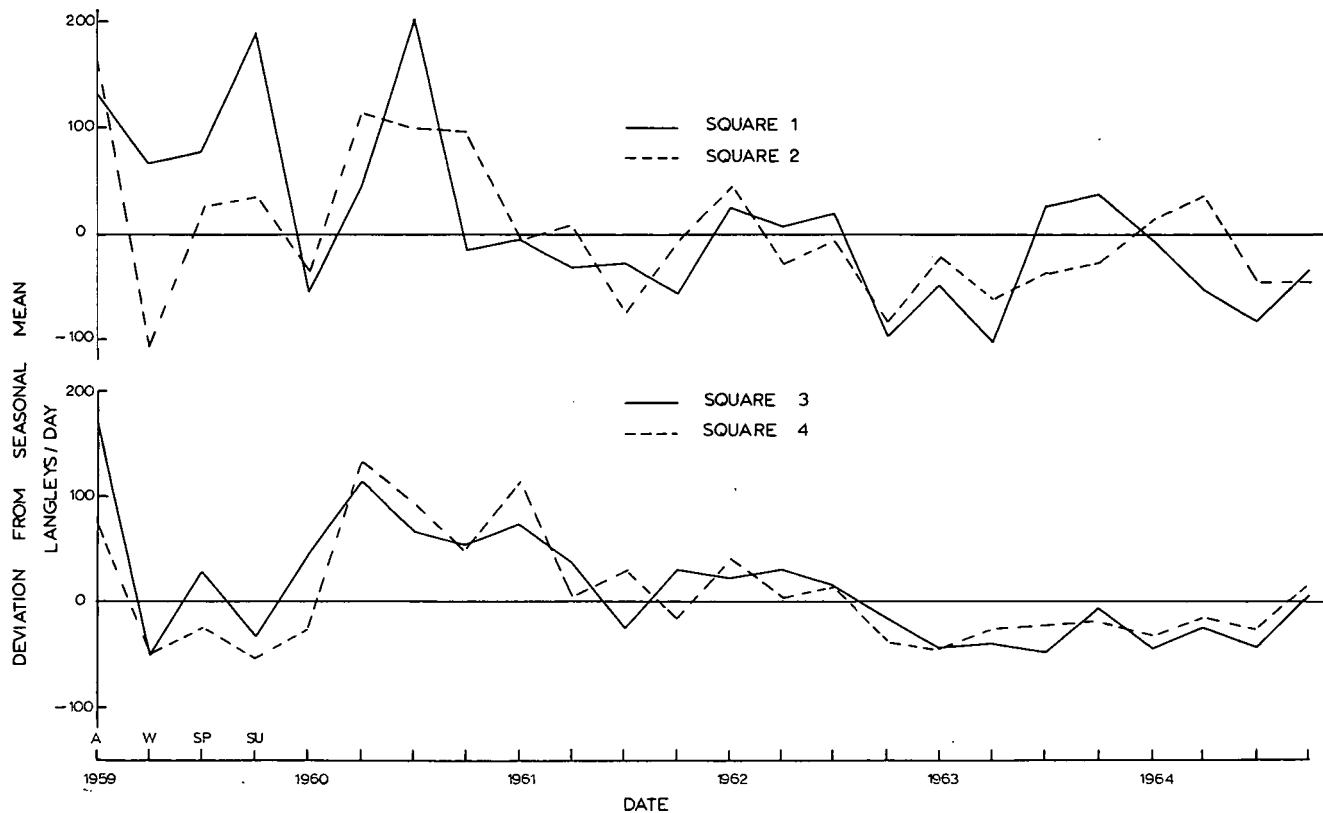


FIG. 4—The deviation from the seasonal mean of the heat flux (langleys/day) each season for the period 1959–1964. Square 1 is from 150–155°E in the 35–40°S band, etc.

latitudes 35–40°S. The relation between the flux patterns in the central Tasman Sea to those in the square contiguous to the Eastern Australian coast is weaker.

The East Australian current flows through this westernmost square. Reed *et al.* (1968) showed that the current was typically a narrow stream near the shore but that its position was variable in space and time and that south of 33°S detached fast moving eddies were common.

Near latitude 40°S, on the average the current turns towards the east. The variability of this eastwards moving branch is much greater than the main current (Marine Division of the Meteorological Office, 1967). The correlations in Table 4 are consistent with these considerations.

#### CONCLUSIONS

From mean total heat fluxes calculated over 5 degree squares in the Tasman Sea area from surface synoptic ship reports it was found that:

- (1) The seasonal means had maxima just off the Australian coast and minima just to the west of New Zealand in all seasons. There was also a secondary maximum north of the Bay of Plenty.
- (2) The seasonal means in winter and autumn were greater than those in spring and summer.
- (3) In individual seasons large variations can occur about the seasonal mean.
- (4) The pattern of variation can be similar on occasions over 20 degrees of longitude in the 35–40°S latitude belt and for three quarters of the year.
- (5) The variations of seasonal heat fluxes from the 3 squares between 160–175°E in the 35–40°S latitude belt are similar. The similarity with the fluxes from the waters bordering eastern Australia in the same latitude belt is much less.

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