1. Classification *INPE-COM.10/PE* *C.D.U.: 551.501:551.46(815.32)*	2. Period	4. Distribution Criterion internal [ ] external [X]
3. Key Words (selected by the author) *AIR-SEA INTERACTION* *MARINE METEOROLOGY - CABO FRIO*		
5. Report Nº *INPE-1105-PE/079*	6. Date *August, 1977*	7. Revised by *Antônio Divino Moura*
8. Title and Sub-title *AIR-SEA INTERACTION STUDIES AT CABO-FRIO, BRAZIL*		9. Authorized by *Nelson de Jesus Parada* *Director*
10. Sector *DME*	Code	11. Nº of Copies *25*
12. Authorship *Nandamudi Jagan Mohana Rao* *Mascarenhas Jr., A.S.* *Yoshihiro Yamazaki*		14. Nº of Pages *18*
13. Signature of the responsible		15. Price $ 16,00

16. Summary/Notes

Observed sea surface meteorological parameters are used in the transfer formulas to compute the main heat exchange co-efficients, the sensible heat exchange and the latent heat exchange, also the values of eddy shearing stress of the wind on the sea surface, Bowen's ratio and dissipation of kinectic energy are computed. The computations involved are for the periods July 2 to July 10, 1969, and September 9 to September 21, 1972, at station Cabo Frio (lat 23°S, long 42°W) occupied by the Naval Ship R/V "Almirante Saldanha", which took regular observations at three hourly intervals. The variations in the computed values are studied, in relation to surface synoptic situations, and the results are presented, especially the effect of the presence and displacemente of Tropical Maritime Anticyclone.

17. Remarks *Work to be submitted to "Seminário Internacional sobre Climatologia do Hemisfério Sul". This work was partially supported by the "Fundo Nacional de Desenvolvimento Científico e Tecnológico - FNDCT" under contract number FINEP - 271/CT.*

AIR-SEA INTEPACTION STUDIES AT CABO FRIO, BRAZIL*

by

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ABSTRACT

Observed sea surface meteorological parameters are used in the transfer formulas to compute the main heat exchange co-efficients, the sensible heat exchange and the latent heat exchange; also the values of eddy shearing stress of the wind on the sea surface, Bowen's ratio and dissipation of kinectic energy are computed. The computations involved are for the periods July 2 to July 10, 1969, and September 9 to September 21, 1972, at station Cabo Frio (lat 23^{o}S, long 42^{o}W) occupied by the Naval Ship R/V "Almirante Saldanha", which took regular observations at three hourly intervals. The variations in the computed values are studied, in relation to surface synoptic situations, and the results are presented, especially the effect of the presence and displacement of Tropical Maritime Anticyclone.

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* *This work was partially supported by the "Fundo Nacional de Desenvolvimento Científico e Tecnológico - FNDCT" under contract number FINEP - 271/CT.*

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INTRODUCTION

The energy exchanges between the ocean and atmosphere have been studied by Pyke (1965), Wyrtki (1966), Brocks et al (1970) and Chandrakant (1974) who related the air-sea exchange to the synoptic changes in weather. These exchange properties, especially the exchange of sensible heat and latent heat from the ocean to the atmosphere, can be computed by utilizing the routinely measured meteorological parameters and substituting them in the transfer formulas (Malkus, 1962).

The present authors attempted to associate the air-sea exchanges, using the data of Cabo Frio (Fig. 1) ($23^{o}S$, $42^{o}W$), the measurements taken by R/V "Almirante Saldanha". Three hourly observations are used for the periods July 2 to July 10, 1969 and from September 9 to September 21, 1972. Added to the exchange properties, also are computed the values of kinetic energy, Bowen's ratio and wind stress. The variations are described and presented, associating them with synoptic sequences (for 1969 data) and the upwelling and downwelling phenomena (for 1972 data) at the region. Cabo Frio region is noted for its upwelling which has a great biological importance in the production and variation of sardine, which is fished commercially for food, in the country (Silva, 1971).

COMPUTATIONAL PROCEDURE

The transfer formulas method has been used to compute transfer of latent heat (Q_e) and sensible heat (Q_s), between ocean and atmosphere, from the knowledge of routinely observed meteorological parameters. The formulas essentially consider the rate of transfer of water vapour and sensible heat from above the ocean surface through the process of turbulence. The form and accuracy of these formulas have been a subject of controversy, the formulas appear in various forms and there is no general agreement to which forms of equations are most useful.

In this study the so called Transfer/Exchange/Bulk aerodynamic formulas as listed by Malkus (1962) are used

$$Q_e = \rho L_e E = L_e C_D (q_s - q_a) V$$

$$Q_s = \rho\ C_p C_D (T_s - T_a) V$$

The notation and dimensions used are:

Q_e = Latent heat transfer between ocean and atmosphere in Cal cm^{-2} day^{-1};

Q_s = Sensible heat transfer between ocean and atmosphere in Cal cm^{-2} day^{-1};

L_e = Latent heat of evaporation at sea surface in Cal gm^{-1}

$$(L_e = 596.73 - 0.601 T_s)$$

T_a = Temperature of the air in ^oC;

T_s = Temperature of sea surface in ^oC;

C_D = Drag coefficient (dimensionless);

V = Scalar wind speed in knots;

C_p = Specific heat of air at constant pressure in Cal g^{-1} $^oC^{-1}$;

q_s = Mixing ratio of the air at anemometer level (dimensionless);

q_a = Mixing ratio of the air at sea surface (dimensionless);

ρ = Density in g cm^{-3}

The values of density and mixing ration are computed for each observation. The following coefficients have been taken as constant.

$$C_D = 2 \times 10^{-3} \text{ (dimensionless)}$$

$$C_p = 0.240 \text{ Cal g}^{-1}\ {}^{o}C^{-1}$$

The kinetic energy (K), wind stress (W_s) and Bowen's ratio (B_o) are also computed using the following expressions (in MKS units)

$$K = \frac{1}{2} V^2$$

$$W_s = 12.85\ C_D . V^2$$

$$B_o = \frac{Q_s}{Q_e}$$

METEOROLOGICAL ASPECTS OF THE REGION

Weather in the region is subjected to variation by the presence of tropical maritime anticyclone to east of Rio with easterly winds blowing on the coast (Figure 2). The cold polar anticyclone in Argentina, by its presence, pushes the tropical maritime high, and the winds back to Northeast, North and finally northwest on the approach of the cold front. Then the winds back to southwest, southeast, as the cold front advances northeastwards. This cycle repeats itself as the cold polar anticyclone, already in low latitudes, degenerates into tropical maritime anticyclone. During July to December the cycle is rapid, and slows down during January to June since the cold airmass is not strong enough to push the tropical anticyclone into the ocean.

ANALYSIS AND DUSCUSSION

July 1969

Table 1 presents the air-sea exchange values that are plotted in Figure 3. The figure shows the variations in the air-sea exchange values for the period July 2 to 10.

From the surface synoptic maps (though not shown here) during the period, one can notice that the tropical maritime high during the beginning of the period is located at southeast of Cabo Frio, then south of it, then east and finally northeast and away northeast. It is observed from the figure that air-sea exchange values increased when the winds are strong northeasterlies. This situation creates a classical situation for upwelling in the region. During the period of 02 July 1969, 03 GMT to 09 July 1969, 19 GMT, the pressure ranged between 1025 mb and 1013 mb, sea surface temperature is generally lower than the air temperature. Analysis of the temperature and salinity distribution, at 10 m depth, shows a surface anomaly of cold and less saline waters indicating upwelling (Mascarenhas, 1971). At the beginning of the period, though the winds are between west and north, probably due to the presence of the cold front, afterwards the conditions became stable from 03. July 1969, 00GMT, with winds from northeast, east rarely changing to southeasterlies, till 09 July 1969, 19 GMT. T_s being less than T_a, a negative increase in $(T_s - T_a)$ and increase of windspeed at the station resulted in the increase of Q_e values. For a decrease of pressure and winds blowing from northeast, the exchange values especially, Q_e, Bowen's ratio, wind stress and kinetic energy increased. The values of Q_s are mostly negative and low. Comparing the values of Pyke (1965) and Malkus (1962), as shown in the following Table 2, one can notice large exchanges for Q_e at Cabo Frio.

TABLE 1

AIR SEA EXCHANGE VALUES FOR JULY 1969 - CABO FRIO

DAY ↑	MONTH ↑	YEAR ↑	HOUR ↑	PRESS mb ↑	T_s °C ↑	T_a °C ↑	T_{hum} °C ↑	RH% ↑	Vm/s ↑	$T_s - T_a$ ↑	$q_s\ (T_s)$ ↑	$q_a\ (T_A)$ ↑	Q_s ↑	Q_e ↑	BR ↑	KE ↑	τ ↑
2	7	69	3	1025.0	21.8	21.0	20.0	91.2	2.0	0.8	0.016	0.001	7.737	349.833	0.022	2.000	0.103
2	7	69	6	1024.0	21.7	20.0	19.5	95.5	2.0	1.7	0.016	0.001	16.483	349.216	0.047	2.000	0.103
2	7	69	9	1024.0	21.7	20.2	19.5	93.7	2.0	1.5	0.016	0.001	14.534	349.176	0.042	2.000	0.103
2	7	69	12	1025.5	21.8	22.2	21.0	89.8	0.0	-0.4	0.016	0.001	0.000	0.000	0.000	0.000	0.000
2	7	69	15	1024.8	22.0	23.2	21.0	82.1	0.0	-1.2	0.016	0.001	0.000	0.000	0.000	0.000	0.000
2	7	69	18	1023.4	22.3	23.8	21.8	83.9	2.0	-1.5	0.017	0.002	-14.347	355.454	-0.040	2.000	0.103
2	7	69	21	1024.0	22.0	21.5	20.5	91.3	2.0	0.5	0.016	0.001	4.823	352.926	0.014	2.000	0.103
3	7	69	0	1025.0	21.9	21.6	20.2	88.0	2.0	0.3	0.016	0.001	2.896	351.457	0.008	2.000	0.103
3	7	69	4	1024.4	21.8	22.0	20.2	84.8	1.0	-0.2	0.016	0.001	-0.963	174.511	-0.006	0.500	0.026
3	7	69	7	1023.5	21.8	21.4	20.0	87.9	1.0	0.4	0.016	0.001	1.929	174.883	0.011	0.500	0.026
3	7	69	10	1024.6	21.6	21.5	20.0	87.1	1.0	0.1	0.016	0.001	0.483	172.525	0.003	0.500	0.026
3	7	69	13	1026.5	21.9	22.1	20.2	84.0	0.0	-0.2	0.016	0.001	0.000	0.000	0.000	0.000	0.000
3	7	69	16	1025.0	22.1	23.0	20.4	78.9	5.0	-0.9	0.017	0.001	-21.614	888.229	-0.024	12.500	0.643
3	7	69	19	1024.1	21.9	22.2	21.2	91.5	5.0	-0.3	0.016	0.001	-7.217	870.469	-0.008	12.500	0.643
3	7	69	22	1024.6	21.9	22.0	20.5	87.3	4.0	-0.1	0.016	0.001	-1.927	700.888	-0.003	8.000	0.411
4	7	69	1	1025.0	21.9	21.4	20.0	87.9	5.0	0.5	0.016	0.001	12.073	880.292	0.014	12.500	0.643
4	7	69	5	1024.3	21.6	21.6	20.2	88.0	5.0	-0.0	0.016	0.001	-0.000	861.041	-0.000	12.500	0.643
3	7	69	8	1024.0	21.4	21.4	19.8	86.3	5.0	0.0	0.016	0.001	0.000	852.627	0.000	12.500	0.643
4	7	69	11	1024.9	21.4	-21.6	19.6	83.0	7.0	-0.2	0.016	0.001	-6.756	1195.667	-0.006	24.500	1.259
4	7	69	14	1025.5	21.9	22.0	20.0	83.2	4.0	-0.1	0.016	0.001	-1.929	703.977	-0.003	8.000	0.411
4	7	69	17	1023.0	22.1	22.0	19.1	76.1	5.0	0.1	0.017	0.001	2.405	898.706	0.003	12.500	0.643
4	7	69	20	1022.1	22.0	22.0	19.0	75.3	4.0	0.0	0.017	0.001	0.000	714.800	0.000	8.000	0.411
4	7	69	23	1022.4	22.3	22.0	19.4	78.4	7.0	0.3	0.017	0.001	10.096	1271.902	0.008	24.500	1.259
5	7	69	2	1022.7	21.6	21.0	18.0	74.7	5.0	0.6	0.016	0.001	14.477	877.748	0.016	12.500	0.643
5	7	69	6	1020.5	21.4	21.0	17.4	70.0	4.0	0.4	0.016	0.001	7.705	696.334	0.011	8.000	0.411
5	7	69	6	1020.5	21.4	21.0	17.4	70.0	4.0	0.4	0.016	0.001	7.705	696.334	0.011	8.000	0.411
5	7	69	9	1020.0	21.4	20.4	17.2	72.7	4.0	1.0	0.016	0.001	19.292	697.699	0.028	8.000	0.411
5	7	69	12	1021.1	21.3	21.6	17.2	64.3	5.0	-0.3	0.016	0.001	-7.213	865.758	-0.008	12.500	0.643
5	7	69	15	1019.8	21.6	21.8	18.2	70.5	6.0	-0.2	0.016	0.001	-5.759	1051.132	-0.005	18.000	0.925
5	7	69	18	1017.5	21.7	21.5	17.5	67.3	7.0	0.2	0.016	0.001	6.710	1241.715	0.005	24.500	1.259
5	7	69	21	1017.1	21.3	21.0	17.4	70.0	6.0	0.3	0.016	0.001	8.639	1037.652	0.008	18.000	0.925
6	7	69	0	1018.4	21.1	21.0	18.0	74.7	6.0	0.1	0.016	0.001	2.883	1018.844	0.003	18.000	0.925
6	7	69	3	1017.7	20.7	21.0	17.8	73.1	7.0	-0.3	0.015	0.001	-10.084	1159.220	-0.009	24.500	1.259

TABLE 1 - CONT.

6 769 7	1016.7	20.7	20.5	18.0	78.5	7.0	0.2	0.015	0.001	6.728	1157.498	0.006	24.500	1.259
6 76910	1016.1	20.5	20.2	18.0	80.8	6.0	0.3	0.015	0.001	8.654	978.995	0.009	18.000	0.925
6 76913	1017.1	20.4	21.6	18.6	75.1	7.0	-1.2	0.015	0.001	-40.229	1127.807	-0.036	24.500	1.259
6 76916	1014.5	20.8	21.6	19.2	79.9	6.0	-0.8	0.015	0.001	-22.929	987.881	-0.023	18.000	0.925
6 76922	1014.1	20.5	21.5	20.0	87.2	4.0	-1.0	0.015	0.001	-19.105	640.511	-0.030	8.000	0.411
7 769 1	1014.8	20.4	21.0	19.0	82.8	6.0	-0.6	0.015	0.001	-17.237	963.405	-0.018	18.000	0.925
7 769 5	1013.4	20.4	21.0	19.8	89.6	5.0	-0.6	0.015	0.001	-14.344	796.844	-0.018	12.500	0.643
7 769 8	1013.2	20.4	21.0	20.0	91.3	2.0	-0.6	0.015	0.001	-5.736	318.126	-0.018	2.000	0.103
7 76911	1015.0	20.2	21.0	20.0	91.3	2.0	-0.8	0.015	0.001	-7.662	313.768	-0.024	2.000	0.103
7 76914	1015.5	20.4	22.0	20.2	84.9	2.0	-1.6	0.015	0.001	-15.279	317.394	-0.048	2.000	0.103
7 76917	1014.6	20.7	23.0	20.0	75.9	5.0	-2.3	0.015	0.001	-54.676	811.197	-0.067	12.500	0.643
7 76920	1016.2	20.4	21.0	20.2	93.0	5.0	-0.6	0.015	0.001	-14.383	793.716	-0.018	12.500	0.643
7 76923	1018.0	19.7	21.5	20.0	87.2	5.0	-1.8	0.014	0.001	-43.152	757.685	-0.057	12.500	0.643
8 769 2	1019.0	20.1	21.3	20.3	91.3	4.0	-1.2	0.015	0.001	-23.052	621.271	-0.037	8.000	0.411
8 769 6	1017.9	20.8	21.4	20.0	88.0	2.0	-0.6	0.015	0.001	-5.755	326.876	-0.018	2.000	0.103
8 769 9	1018.3	21.1	21.4	20.4	91.3	1.0	-0.3	0.016	0.001	-1.439	166.190	-0.009	0.500	0.026
8 76912	1017.2	21.3	22.0	20.8	89.8	0.0	-0.7	0.016	0.001	0.000	0.000	0.000	0.000	0.000
8 76915	1017.8	21.9	22.5	21.0	87.5	2.0	-0.6	0.016	0.001	-5.733	348.820	-0.016	2.000	0.103
8 76918	1015.0	22.0	22.3	21.1	89.9	2.0	-0.3	0.017	0.001	-2.860	350.936	-0.008	2.000	0.103
8 76921	1017.0	21.2	21.6	21.0	94.8	2.0	-0.4	0.016	0.001	-3.830	332.742	-0.012	2.000	0.103
9 769 0	1017.3	21.0	21.4	20.6	93.0	5.0	-0.4	0.016	0.001	-9.586	823.751	-0.012	12.500	0.643
9 769 3	1016.5	20.4	21.5	20.5	91.4	8.0	-1.1	0.015	0.001	-42.130	1266.004	-0.033	32.000	1.645
9 769 7	1016.1	20.0	20.4	19.4	91.1	1.0	-0.4	0.015	0.001	-1.922	155.669	-0.012	0.500	0.026
9 76910	1017.2	20.0	19.0	18.0	90.8	1.0	1.0	0.015	0.001	4.833	157.788	0.031	0.500	0.026
9 76913	1018.8	20.4	20.6	19.8	92.9	0.0	-0.2	0.015	0.001	0.000	0.000	0.000	0.000	0.000
9 76916	1017.1	19.9	22.6	20.4	81.9	6.0	-2.7	0.015	0.001	-77.314	917.986	-0.084	18.000	0.925
9 76919	1017.1	20.2	21.6	19.4	81.5	4.0	-1.4	0.015	0.001	-26.818	631.055	-0.042	8.000	0.411
9 76922	1018.6	20.1	20.0	19.0	91.0	1.0	0.1	0.015	0.001	0.482	157.350	0.003	0.500	0.026
10 769 1	1020.0	20.1	20.2	19.0	89.3	2.0	-0.1	0.015	0.001	-0.965	314.674	-0.003	2.000	0.103
10 769 5	1019.0	20.0	19.0	13.5	95.4	7.0	1.0	0.015	0.001	33.887	1099.385	0.031	24.500	1.259
10 769 8	1019.0	20.0	19.0	18.1	91.7	4.0	1.0	0.015	0.001	19.364	630.551	0.031	8.000	0.411
10 76911	1018.1	19.9	18.1	17.1	90.6	5.0	1.8	0.015	0.001	43.668	790.150	0.055	12.500	0.643
10 76914	1020.8	19.9	19.4	17.0	78.7	5.0	0.5	0.014	0.001	12.108	790.504	0.015	12.500	0.643
10 76917	1018.9	20.0	19.6	17.6	82.2	5.0	0.4	0.015	0.001	9.662	791.629	0.012	12.500	0.643
10 76920	1019.9	20.0	17.5	15.5	90.4	7.0	2.5	0.015	0.001	85.238	1119.729	0.076	24.500	1.259
10 76923	1020.1	20.1	18.4	16.1	79.0	4.0	1.7	0.015	0.001	33.026	646.143	0.051	8.000	0.411

TABLE 2

COMPARISON OF EXCHANGE VALUES - JULY/69

AUTHOR	Q_e cal cm^{-2} per sec	Q_s cal cm^{-2} per sec
MALKUS	70	20 to 30
PYKE	50 to 400	30 to 200
PRESENT STUDY	170 to 1270	-55 to +85

September 1972

Table 3 presents the air-sea exchanges, that are plotted in Figure 4. The figure shows the variations in exchange values for the period September 11 to 21.

During this period, T_s is always less than air temperature throughout. Gama et al (1974) reported intense upwelling throughout. Winds are moderate to strong northeasterlies and southeasterlies. Q_s is mainly from atmosphere to sea and latent heat transfer is from sea to atmosphere. Large exchange values for Q_e are observed throughout the period. When the wind direction is southwest the exchange values are less (11 September 1972, 21 hours to 13 GMT) though the upwelling continues. T_s range is found to be between 16.5 and 21.5 whereas for T_a, it is between 21.0 and 28.5. Table 4 shows the comparison of between values.

TABLE 3

AIR-SEA EXCHANGE VALUES FOR SEPTEMBER 1972 - CABO FRIO

↑ DAY	↑ MONTH ↑ YEAR ↑ HOUR	↑ PRESS mb	↑ T_s °C	↑ T_a °C	↑ T_{hum} °C	↑ R.H.%	↑ $V_{m/s}$	↑ $T_s - T_A$	↑ q_s (T_s) Mix. Ratio	↑ q_a (T_A) Mix. Ratio	↑ Q_s	↑ Q_e	↑ BR	↑ KE	↑ τ
9	97219	1012.3	16.5	26.0	21.5	67.1	9.0	-9.5	0.012	0.001	-401.466	1069.794	-0.375	40.500	2.082
9	97221	1012.5	14.9	24.0	20.6	73.5	12.0	-9.1	0.011	0.001	-516.340	1282.197	-0.403	72.000	3.701
10	972 1	1012.8	20.6	22.5	20.5	83.5	14.0	-1.9	0.015	0.001	-126.453	2245.616	-0.056	98.000	5.037
10	972 5	1011.7	19.9	22.0	20.5	87.3	13.0	-2.1	0.015	0.001	-129.860	1987.372	-0.065	84.500	4.343
10	972 8	1010.5	19.6	22.5	19.7	77.2	12.0	-2.9	0.014	0.001	-165.067	1811.362	-0.091	72.000	3.701
10	97211	1011.6	19.6	24.3	19.3	62.4	8.0	-4.7	0.014	0.001	-177.465	1211.990	-0.146	32.000	1.645
10	97214	1010.0	19.8	28.0	20.5	50.2	7.0	-8.2	0.015	0.001	-267.142	1061.660	-0.252	24.500	1.259
10	97217	1008.1	20.2	28.5	20.5	48.0	7.0	-8.3	0.015	0.001	-269.443	1090.734	-0.247	24.500	1.259
10	97220	1008.0	20.0	24.3	20.7	72.3	9.0	-4.3	0.015	0.001	-181.990	1382.006	-0.132	40.500	2.082
10	97223	1009.0	19.9	25.0	21.0	69.9	9.0	-5.1	0.015	0.001	-215.550	1368.095	-0.158	40.500	2.082
11	972 2	1008.8	20.0	23.5	21.0	80.0	11.0	-3.5	0.015	0.001	-181.679	1684.204	-0.108	60.500	3.110
11	972 6	1009.5	20.2	22.0	20.5	87.3	6.0	-1.8	0.015	0.001	-51.261	936.509	-0.055	18.000	0.925
11	972 9	1010.7	20.4	22.0	20.8	89.8	5.0	-1.6	0.015	0.001	-38.016	788.877	-0.048	12.500	0.643
11	97212	1012.0	21.3	23.0	21.5	87.6	3.0	-1.7	0.016	0.002	-24.183	499.867	-0.048	4.500	0.231
11	97215	1011.0	21.6	24.5	21.5	76.7	0.0	-2.9	0.016	0.001	0.000	0.000	0.000	0.000	0.000
11	97218	1009.8	21.9	23.3	21.0	81.4	0.0	-1.4	0.017	0.001	0.000	0.000	0.000	0.000	0.000
11	97221	1011.6	21.1	23.0	21.6	88.4	2.0	-1.9	0.016	0.002	-18.011	328.386	-0.055	2.000	0.103
12	972 0	1013.6	21.0	22.3	21.3	91.5	2.0	-1.3	0.016	0.002	-12.378	327.181	-0.038	2.000	0.103
12	972 4	1012.2	21.5	22.5	21.5	91.6	2.0	-1.0	0.016	0.002	-9.502	337.916	-0.028	2.000	0.103
12	972 7	1012.6	21.5	22.0	21.0	91.5	2.0	-0.5	0.016	0.001	-4.761	339.604	-0.014	2.000	0.103
12	97210	1015.0	21.5	22.0	21.2	93.1	2.0	-0.5	0.016	0.002	-4.772	338.945	-0.014	2.000	0.103
12	97213	1016.3	21.6	23.3	21.8	87.7	3.0	-1.7	0.016	0.002	-24.261	508.629	-0.048	4.500	0.231
12	97216	1014.8	21.6	23.5	22.0	87.7	2.0	-1.9	0.016	0.002	-18.037	338.408	-0.053	2.000	0.103
12	97219	1014.3	21.6	22.5	21.5	91.6	3.0	-0.9	0.016	0.002	-12.854	510.324	-0.025	4.500	0.231
12	97222	1015.8	21.6	22.0	21.0	91.5	3.0	-0.4	0.016	0.001	-5.731	512.848	-0.011	4.500	0.231
13	972 1	1017.8	21.7	21.8	20.6	89.7	2.0	-0.1	0.016	0.001	-0.958	345.519	-0.003	2.000	0.103
13	972 5	1017.1	21.6	21.5	20.0	87.2	3.0	0.1	0.016	0.001	1.437	517.664	0.003	4.500	0.231
13	972 8	1018.0	21.4	21.5	19.8	85.5	2.0	-0.1	0.016	0.001	-0.959	341.078	-0.003	2.000	0.103
13	97211	1020.5	21.5	22.0	19.7	80.8	3.0	-0.5	0.016	0.001	-7.198	515.376	-0.014	4.500	0.231
13	97214	1021.0	21.5	24.0	20.4	72.0	3.0	-2.5	0.016	0.001	-35.761	511.622	-0.070	4.500	0.231
13	97217	1020.3	21.6	24.5	21.2	74.5	3.0	-2.9	0.016	0.001	-41.383	511.186	-0.081	4.500	0.231
13	97220	1020.1	21.3	22.5	17.5	75.6	3.0	-1.2	0.016	0.001	-17.238	509.258	-0.034	4.500	0.231
13	97223	1021.0	21.4	21.5	19.2	80.6	5.0	-0.1	0.016	0.001	-2.405	857.169	-0.003	12.500	0.643

TABLE 3 - CONT.

14	972 2	1022.0	21.4	21.5	18.0	71.1	5.0	-0.1	0.016	0.001	-2.407	865.912	-0.003	12.500	0.643
14	972 6	1021.2	21.3	21.2	21.0	98.2	5.0	0.1	0.016	0.002	2.407	837.633	0.003	12.500	0.643
14	972 9	1021.2	21.1	21.0	18.0	74.7	4.0	0.1	0.016	0.001	1.927	679.196	0.003	8.000	0.411
14	97212	1023.5	21.3	22.5	19.0	71.7	3.0	-1.2	0.016	0.001	-17.296	511.465	-0.034	4.500	0.231
14	97215	1023.7	21.5	24.5	19.5	62.5	4.0	-3.0	0.016	0.001	-57.276	687.437	-0.083	8.000	0.411
14	97218	1021.3	21.5	22.7	19.5	74.2	7.0	-1.2	0.016	0.001	-40.243	1204.193	-0.033	24.500	1.259
14	97221	1022.6	20.8	23.0	19.0	68.4	6.0	-2.2	0.015	0.001	-63.257	988.959	-0.064	18.000	0.925
15	972 0	1023.5	20.3	21.8	18.5	72.8	7.0	-1.5	0.015	0.001	-50.569	1121.038	-0.045	24.500	1.259
15	972 4	1023.8	20.2	21.5	18.0	71.1	6.0	-1.3	0.015	0.001	-37.616	958.820	-0.039	18.000	0.925
15	972 7	1022.0	20.6	21.5	18.3	73.4	5.0	-0.9	0.015	0.001	-21.663	818.679	-0.026	12.500	0.643
15	97210	1023.2	19.4	21.5	18.0	71.1	7.0	-2.1	0.014	0.001	-70.850	1059.612	-0.067	24.500	1.259
15	97213	1024.2	20.1	22.7	19.0	70.4	6.0	-2.6	0.015	0.001	-74.952	943.341	-0.079	18.000	0.925
15	97216	1022.3	19.6	24.0	19.0	62.1	5.0	-4.4	0.014	0.001	-105.043	759.678	-0.138	12.500	0.643
15	97219	1021.4	20.6	21.0	19.3	85.3	10.0	-0.4	0.015	0.001	-19.276	1622.953	-0.012	50.000	2.570
15	97222	1022.2	20.0	21.0	18.2	76.3	6.0	-1.0	0.015	0.001	-28.939	944.384	-0.031	18.000	0.925
16	972 1	1022.7	19.6	21.5	18.0	71.1	7.0	-1.9	0.014	0.001	-64.071	1074.127	-0.060	24.500	1.259
16	972 5	1020.5	19.0	21.0	18.5	78.7	7.0	-2.0	0.014	0.001	-67.411	1026.079	-0.066	24.500	1.259
16	972 8	1020.2	19.4	21.3	18.5	76.5	6.0	-1.9	0.014	0.001	-54.820	903.969	-0.061	18.000	0.925
16	97211	1022.0	19.2	22.2	18.7	71.6	6.0	-3.0	0.014	0.001	-86.445	889.828	-0.097	18.000	0.925
16	97214	1022.0	19.5	23.0	20.0	75.8	5.0	-3.5	0.014	0.001	-83.810	747.102	-0.112	12.500	0.643
16	97217	1019.9	20.7	24.5	19.5	62.5	6.0	-3.8	0.015	0.001	-108.421	977.354	-0.111	18.000	0.925
16	97220	1018.0	20.7	23.0	19.0	68.4	7.0	-2.3	0.015	0.001	-76.807	1146.117	-0.067	24.500	1.259
16	97223	1020.5	20.9	22.0	19.0	75.3	7.0	-1.1	0.015	0.001	-36.949	1162.101	-0.032	24.500	1.259
17	972 2	1020.4	21.0	21.8	18.5	72.8	8.0	-0.8	0.016	0.001	-30.730	1343.079	-0.023	32.000	1.645
17	972 6	1019.2	21.1	21.7	18.5	73.6	7.0	-0.6	0.016	0.001	-20.149	1183.178	-0.017	24.500	1.259
17	972 9	1021.1	21.1	21.5	18.5	75.0	7.0	-0.4	0.016	0.001	-13.467	1183.255	-0.011	24.500	1.259
17	97212	1022.0	21.0	23.0	18.5	64.8	7.0	-2.0	0.016	0.001	-67.054	1174.516	-0.057	24.500	1.259
17	97215	1020.5	21.0	24.0	19.0	62.1	7.0	-3.0	0.016	0.001	-100.092	1168.908	-0.086	24.500	1.259
17	97218	1019.3	20.9	24.3	19.3	62.4	8.0	-3.4	0.015	0.001	-129.357	1323.289	-0.098	32.000	1.645
17	97221	1019.5	20.6	23.0	19.5	72.1	9.0	-2.4	0.015	0.001	-103.195	1456.958	-0.071	40.500	2.082
18	972 0	1020.5	20.9	22.0	20.5	87.3	5.0	-1.1	0.015	0.001	-26.390	818.660	-0.032	12.500	0.643
18	972 4	1018.5	20.6	21.5	19.5	83.0	9.0	-0.9	0.015	0.001	-38.857	1457.767	-0.027	40.500	2.082

TABLE 3 - CONT.

18	972 7	1019.1	20.9	21.5	20.0	87.2	9.0	-0.6	0.015	0.001	-25.919	1480.908	-0.018	40.500	2.082
19	97210	1021.0	20.8	22.0	20.0	83.2	7.0	-1.2	0.015	0.001	-40.326	1143.728	-0.035	24.500	1.259
18	97213	1020.7	20.9	24.0	20.7	74.2	7.0	-3.1	0.015	0.001	-103.437	1143.058	-0.090	24.500	1.259
18	97216	1020.4	20.7	25.5	21.5	70.1	8.0	-4.8	0.015	0.001	-182.056	1277.916	-0.142	32.000	1.645
18	97219	1019.2	20.2	23.0	20.0	75.9	10.0	-2.8	0.015	0.001	-133.728	1567.889	-0.085	50.000	2.570
18	97222	1021.0	20.7	22.0	19.5	79.2	7.0	-1.3	0.015	0.001	-43.687	1141.287	-0.038	24.500	1.259
19	972 1	1022.4	20.9	22.5	19.5	75.6	9.0	-1.6	0.015	0.001	-69.109	1487.054	-0.046	40.500	2.082
19	972 1	1022.4	20.9	22.5	19.5	75.6	9.0	-1.6	0.015	0.001	-69.109	1487.054	-0.046	40.500	2.082
19	972 5	1020.3	20.8	21.8	19.2	78.3	9.0	-1.0	0.015	0.001	-43.208	1481.541	-0.029	40.500	2.082
19	972 8	1021.5	20.8	21.7	19.0	77.5	6.0	-0.9	0.015	0.001	-25.964	989.497	-0.026	18.000	0.925
19	97211	1023.0	20.8	22.5	20.3	81.8	7.0	-1.7	0.015	0.001	-57.142	1140.230	-0.050	24.500	1.259
19	97214	1023.8	20.5	24.0	20.0	69.1	9.0	-3.5	0.015	0.001	-150.614	1439.759	-0.105	40.500	2.082
19	97217	1020.1	20.4	23.5	19.2	66.6	8.0	-3.1	0.015	0.001	-118.355	1280.994	-0.092	32.000	1.645
19	97220	1022.7	20.2	22.7	18.5	66.7	8.0	-2.5	0.015	0.001	-95.954	1272.228	-0.075	32.000	1.645
19	97223	1021.2	20.1	22.0	19.0	75.3	10.0	-1.9	0.015	0.001	-91.236	1572.583	-0.058	50.000	2.570
20	972 2	1021.8	19.1	21.4	18.5	75.7	9.0	-2.3	0.014	0.001	-99.663	1328.302	-0.075	40.500	2.082
20	972 6	1018.7	17.7	21.0	18.0	74.7	6.0	-3.3	0.013	0.001	-95.173	807.919	-0.118	18.000	0.925
20	972 9	1019.3	17.2	21.5	18.0	71.1	8.0	-4.3	0.012	0.001	-165.167	1040.423	-0.159	32.000	1.645
20	97212	1021.0	17.1	22.6	19.0	71.1	10.0	-5.5	0.012	0.001	-263.516	1277.518	-0.206	50.000	2.570
20	97215	1019.3	17.5	23.0	19.5	72.1	10.0	-5.5	0.012	0.001	-262.713	1306.759	-0.201	50.000	2.570
20	97218	1017.0	17.1	23.0	19.0	68.4	7.0	-5.9	0.012	0.001	-196.834	894.451	-0.220	24.500	1.259
20	97221	1017.5	18.6	22.0	19.0	75.3	9.0	-3.4	0.013	0.001	-146.405	1276.829	-0.115	40.500	2.082
21	972 0	1020.0	18.3	21.5	19.0	79.0	10.0	-3.2	0.013	0.001	-153.741	1389.284	-0.111	50.000	2.570
21	972 4	1019.0	17.5	21.0	19.0	82.8	10.0	-3.5	0.012	0.001	-168.275	1313.274	-0.128	50.000	2.570
21	972 7	1018.0	17.3	21.0	18.0	74.7	10.0	-3.7	0.012	0.001	-177.726	1309.434	-0.136	50.000	2.570
21	97210	1019.1	18.0	21.5	18.4	74.2	11.0	-3.5	0.013	0.001	-184.812	1506.207	-0.123	60.500	3.110
21	97213	1021.2	19.4	22.5	19.0	71.8	8.0	-3.1	0.014	0.001	-118.885	1199.239	-0.099	32.000	1.645
21	97216	1019.9	20.2	26.0	20.5	60.5	3.0	-5.8	0.015	0.001	-82.322	467.718	-0.176	4.500	0.231
21	97219	1019.5	19.7	24.5	21.0	73.0	3.0	-4.8	0.014	0.001	-68.443	449.748	-0.152	4.500	0.231

TABLE 4

COMPARISON OF EXCHANGE VALUES - SEPTEMBER/72

AUTHOR	Q_e cal cm^{-2} per sec	Q_s cal cm^{-2} per sec
MALKUS	70	20 to 30
PYKE	50 to 400	30 to 200
PRESENT STUDY	300 to 2000	-500 to -1

CONCLUSIONS

July 1969

1. The variations in air-sea exchange values reveal that the latent heat transfer is from sea to atmosphere at Cabo Frio and large amounts take place in the region, whereas sensible heat transfer is either from sea to atmosphere or vice-versa. During this period Q_s values are less. +ve values of Q_s are observed when the cold air passes the region;

2. Negative air-sea temperature difference and positive air-sea temperature difference are observed during the period. The former is found to be due to upwelling while the latter due to passage of cold air;

3. Whether upwelling or downwelling the exchange values showed higher values, especially Q_e.

September 1972

1. Large exchanges of latent heat transfer from sea to atmosphere are observed during this period at Cabo Frio. Higher values for

Q_e and more negative values for Q_s are noticed in this period as compared to July'69;

2. Due to strong upwelling throughout the period (Gama et al 1974), the negative temperature difference is noticed in all the observations;

3. During upwelling, the exchange values increased;

4. To have large exchanges, specially latent heat transfer, the winds from Northeast blowing on to Cabo Frio create condition for upwelling in the region. The direction of wind does not effect the exchange values directly, but the velocity of winds due to presence of anticyclone and its displacement, which enhances upwelling at Cabo Frio, is also the one affecting Q_e values.

ACKNOWLEDGEMENTS

The authors place on record their grateful thanks to Dr. Luiz Gylvan Meira Filho, Dr. Antonio Divino Moura and personnel of N/oc 'Almirante Saldanha'.

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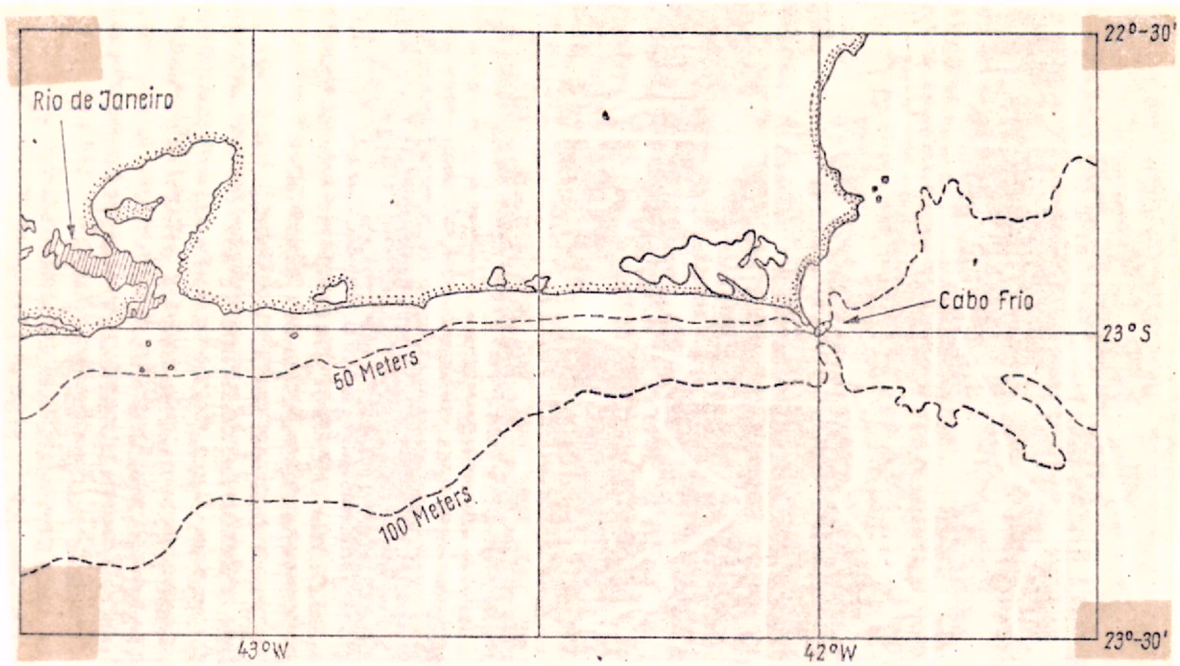

Fig. 1 - The coast between Guanabara Bay and Cabo Frio (Mascarenhas et al, 1971)

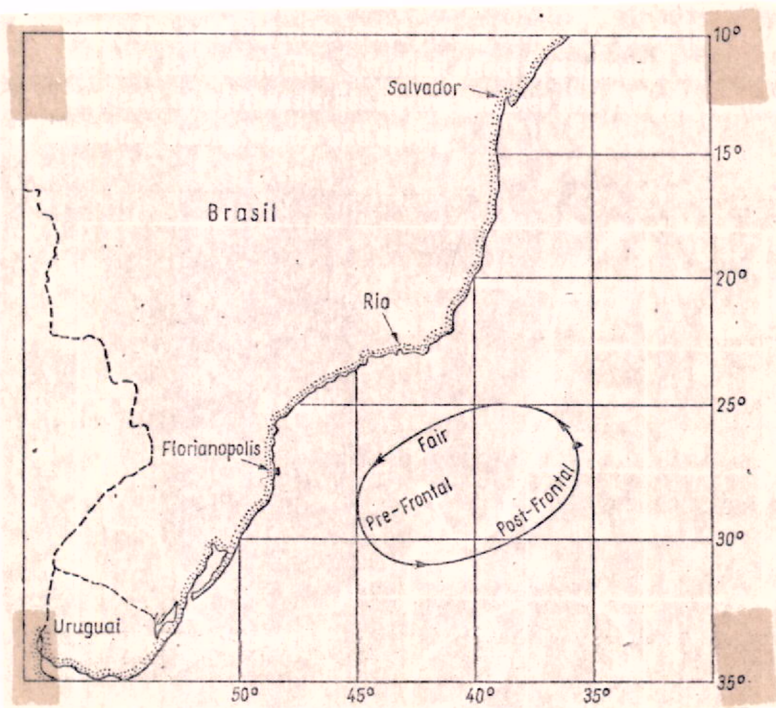

Fig. 2 - Weather cycle in Southern Brazil, showing the succession of weather types and winds (Silva, 1971)

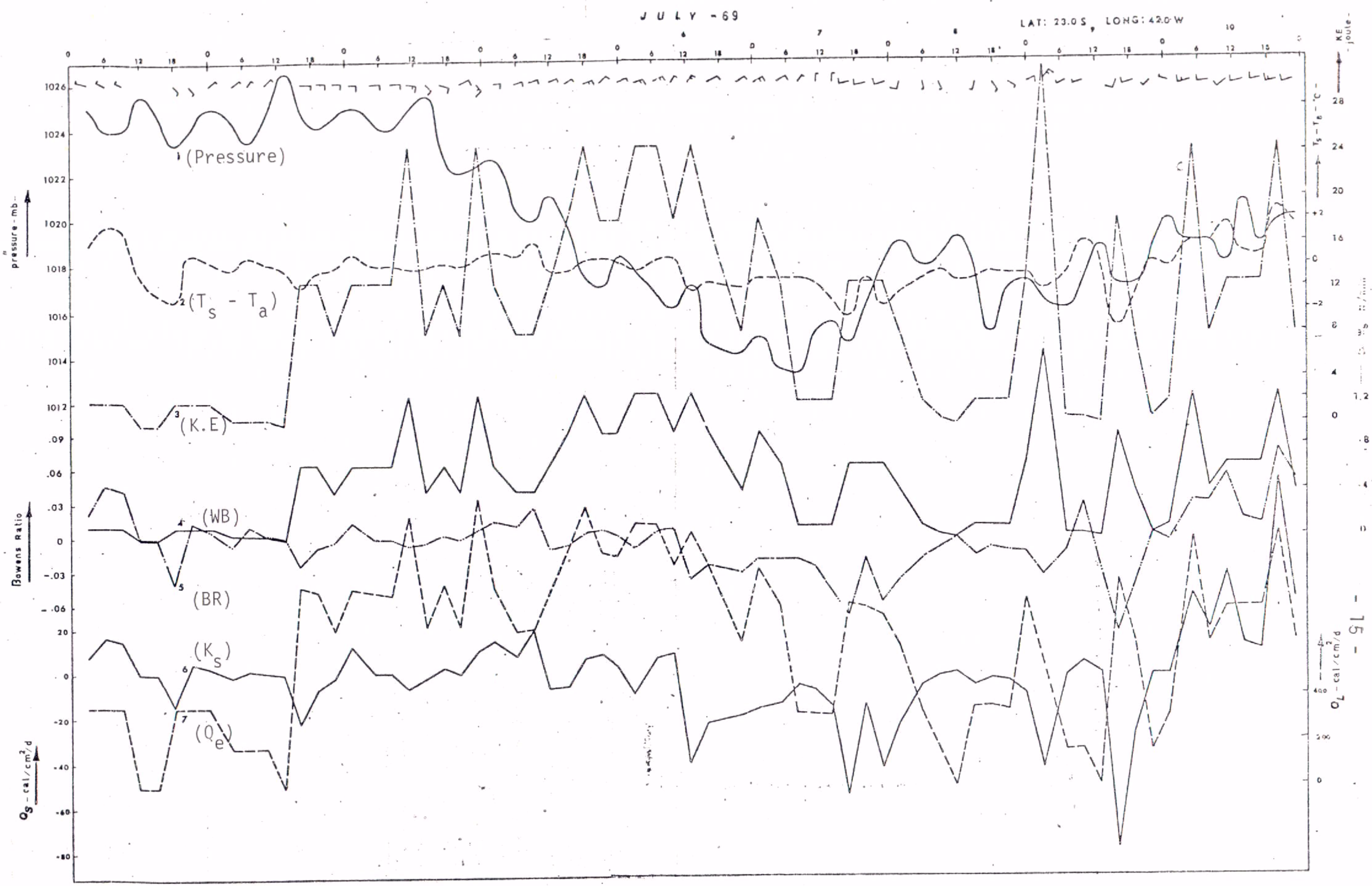

Fig. 3 - Variations of Air-sea Exchanges at Cabo-Frio - July'69

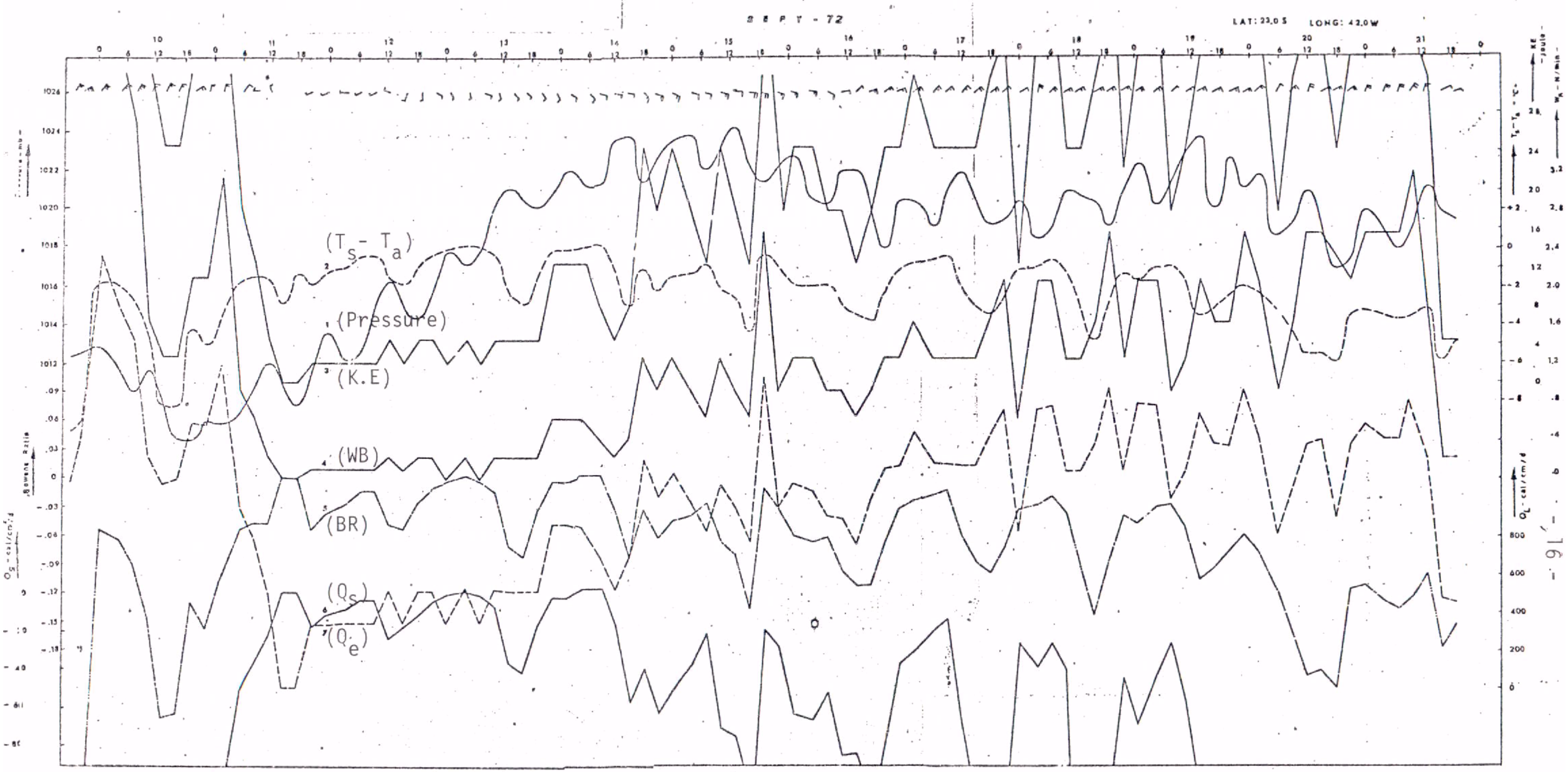

Fig. 4 - Variations of Air - Sea Exchanges at Cabo-Frio - September'72