Papers

Characterictics of turbulent horizontal heat exchange in subsurface layers of the Southern Ocean Part II. Indian Ocean and Pacific*

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Heat exchange
Turbulent diffusion
Horizontal diffusion
Southern Ocean
Indian Ocean
Pacific

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Abstract

This paper is part two of study already published [4], dealing with the coefficients and scales of turbulent horizontal heat exchange in the subsurface layer of the Southern Ocean. These characteristics were based on an atlas of surface currents [1, 2] and maps of isolines of mean climatic temperature values in the subsurface ocean layer, prepared by the Marine Environmental Data Service in Ottawa [3] from the data recorded by floating oceanographic buoys and satellite techniques during the First GARP Global Experiment (FGGE), carried out between December 28, 1978 and December 21, 1979. The above-mentioned study [4] presents basic equations, assumptions, and empirical data which form the basis of the method chosen by the authors for determining the turbulent horizontal heat exchange coefficients in the subsurface ocean layer and linear horizontal dimensions (scales) of thermal eddy structures occurring in this layer. In addition, the study also presents the characteristics of turbulent heat exchange for the southern hemisphere of the Atlantic Ocean.

1. Objects, aims and scope of the paper

The aim of this paper is the same as in the case of previous paper [4]: to extend the scope of oceanographical description of thermal non-homogeneities by discussing additional elements of interactions between the ocean and atmosphere in the southern hemisphere, which have been the main goal of the FGGE.

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2. Turbulent horizontal heat diffusion coefficients for macro- and mesoscale exchange processes

As stated in section 2 of paper [4], the basis for the determination of turbulent heat diffusion coefficients is a formula which takes into account the influence of macro- and mesoscale horizontal circulation of water masses on heat exchange processes in the subsurface ocean layer [4]:

$$K_l = \frac{\bar{u}\dfrac{\partial\overline{(T')^2}}{\partial x} + \bar{v}\dfrac{\partial\overline{(T')^2}}{\partial y}}{2\left[\left(\dfrac{\partial\bar{T}}{\partial x}\right)^2 + \left(\dfrac{\partial\bar{T}}{\partial y}\right)^2\right]}, \tag{1}$$

where: K_l – horizontal heat diffusion coefficient, $\bar{u}$ and $\bar{v}$ – latitudinal and meridional components of mean velocity of water mass flow,
$\bar{T}$ and T' – mean and pulsatory (deviation from the mean) values of subsurface water layer temperature on a standard horizon.

The scale of a thermal eddy structure corresponding to coefficient K_l is given [4] by the formula:

$$l = \left\{\frac{\bar{u}\dfrac{\partial\overline{(T')^2}}{\partial x} + \bar{v}\dfrac{\partial\overline{(T')^2}}{\partial y}}{2\beta\left[\left(\dfrac{\partial\bar{T}}{\partial x}\right)^2 + \left(\dfrac{\partial\bar{T}}{\partial y}\right)^2\right]}\right\}^{3/4}, \tag{2}$$

where: $\beta = 6.81 \cdot 10^4\ \mathrm{m}^{2/3} \cdot \mathrm{s}^{-1}$.

The discrete quantization step of a random function $T(x_i, t)$, describing the climatic temperature field of the subsurface ocean layer, on a standard horizon, in time t and space x_i is given by the following parameters:

– time quantization: $\Delta t = 120$ hours, with the averaging time assumed to be 120 hours (5 days),

– linear quantization along the parallel: $2.7 \cdot 10^5\ \mathrm{m} \leqslant \Delta x \leqslant 4.2 \cdot 10^5\ \mathrm{m}$,

– linear quantization along the meridian: $\Delta y = 5.56 \cdot 10^5\ \mathrm{m} = \mathrm{const}$,

– thickness of subsurface layer for which coefficients K_l and scales l were determined: $\Delta z = D = 1\ \mathrm{m} = \mathrm{const}$.

The values of coefficients $K_l \left[\frac{\mathrm{m}^2}{\mathrm{s}}\right]$ were computed for four seasonal periods in the southern hemisphere:

December 28, 1978 – March 22, 1979 (summer) (Figs. 1 and 6),

March 23, 1979 – June 25, 1979 (autumn) (Figs. 2 and 7),

June 26, 1979 – September 23, 1979 (winter) (Figs. 3 and 8),

September, 24, 1979 – December 21, 1979 (spring) (Figs. 4 and 9), as well as for the annual period:

December 28, 1978 – December 21, 1979 (Figs. 5 and 10).

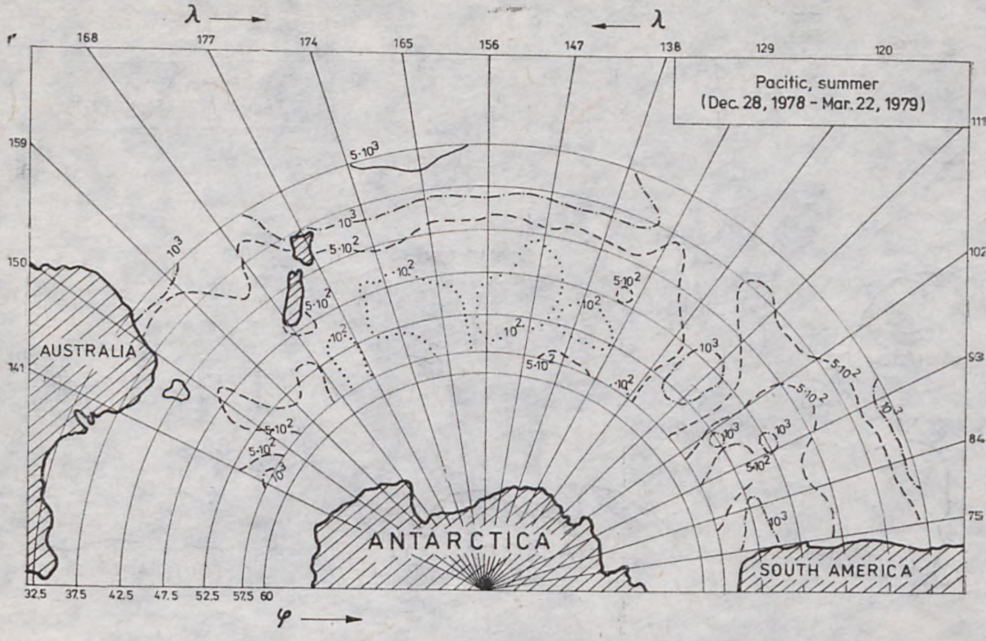
Pacific, summer
(Dec. 28, 1978 - Mar. 22, 1979)
AUSTRALIA
ANTARCTICA
SOUTH AMERICA

Fig. 1

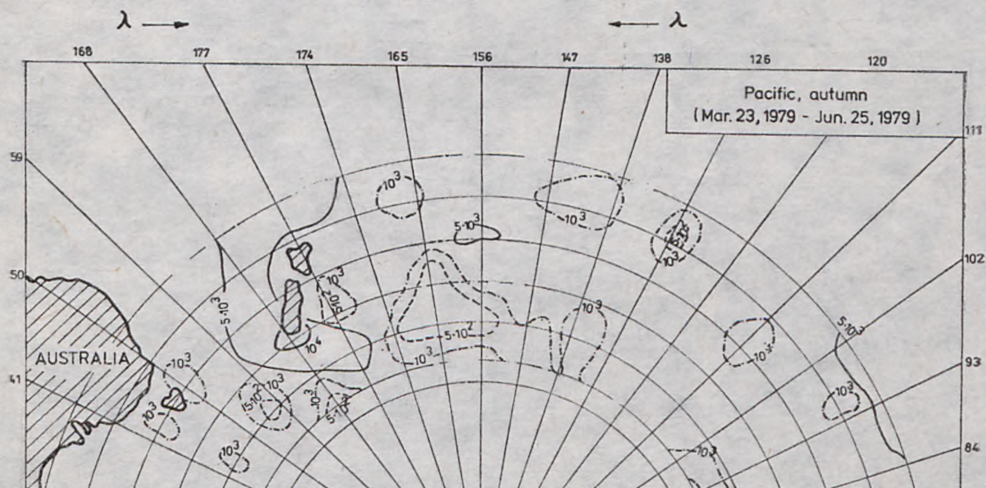
Pacific, autumn
(Mar. 23, 1979 - Jun. 25, 1979)
AUSTRALIA
ANTARCTICA
SOUTH AMERICA

Fig. 2

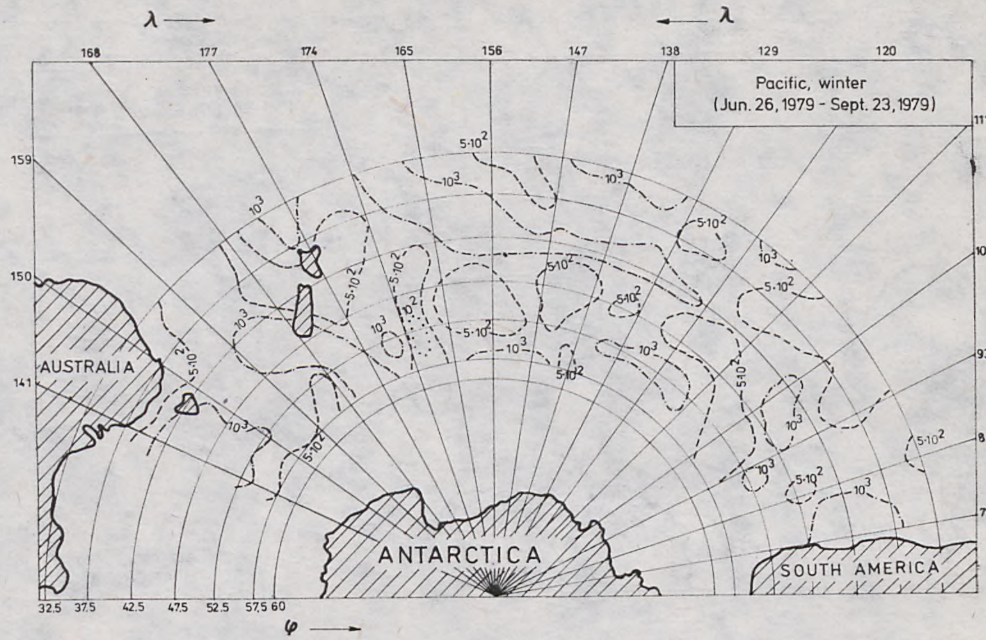
λ
λ
168
177
174
165
156
147
138
129
120
Pacific, winter
(Jun. 26, 1979 - Sept. 23, 1979)
111
159
102
150
93
141
84
75
AUSTRALIA
ANTARCTICA
SOUTH AMERICA
32.5
37.5
42.5
47.5
52.5
57.5
60
φ

Fig. 3

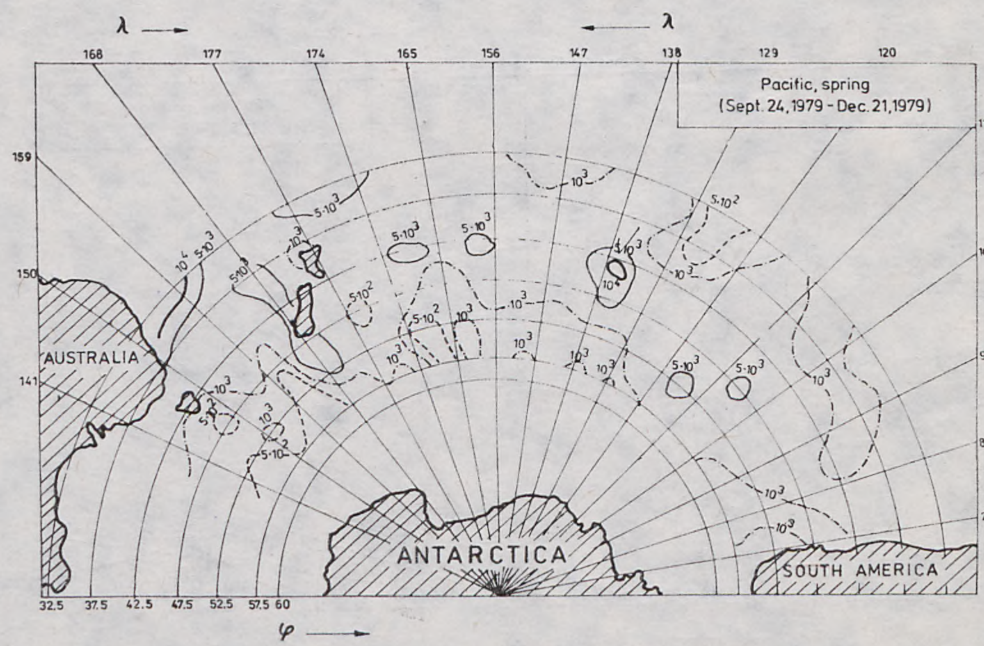
λ
λ
168
177
174
165
156
147
138
129
120
Pacific, spring
(Sept. 24, 1979 - Dec. 21, 1979)
111
159
102
150
93
141
84
75
AUSTRALIA
ANTARCTICA
SOUTH AMERICA
32.5
37.5
42.5
47.5
52.5
57.5
60
φ

Fig. 4

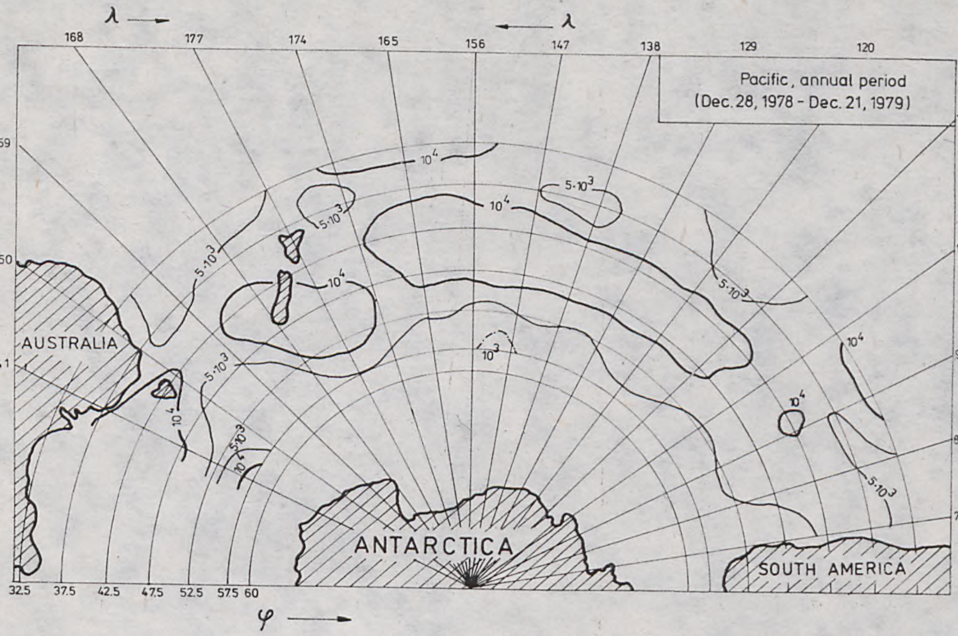
λ
λ
168
177
174
165
156
147
138
129
120
Pacific, annual period
(Dec. 28, 1978 - Dec. 21, 1979)
159
150
141
111
102
95
84
75
AUSTRALIA
ANTARCTICA
SOUTH AMERICA
32.5
37.5
42.5
47.5
52.5
57.5
60
φ

Fig. 5

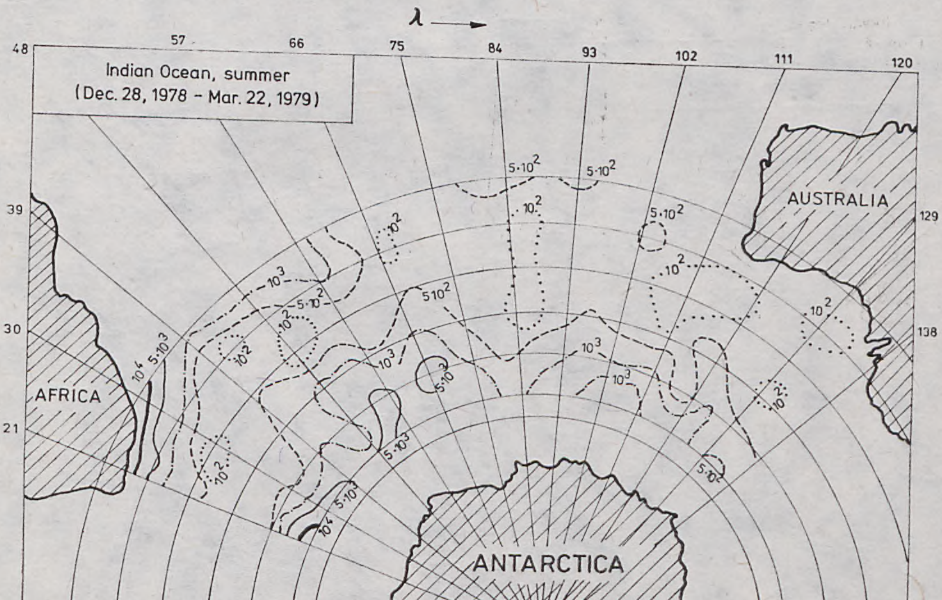
λ
48
57
66
75
84
93
102
111
120
Indian Ocean, summer
(Dec. 28, 1978 - Mar. 22, 1979)
39
30
21
129
138
AFRICA
AUSTRALIA
ANTARCTICA
32.5
37.5
42.5
47.5
52.5
57.5
60
φ

Fig. 6

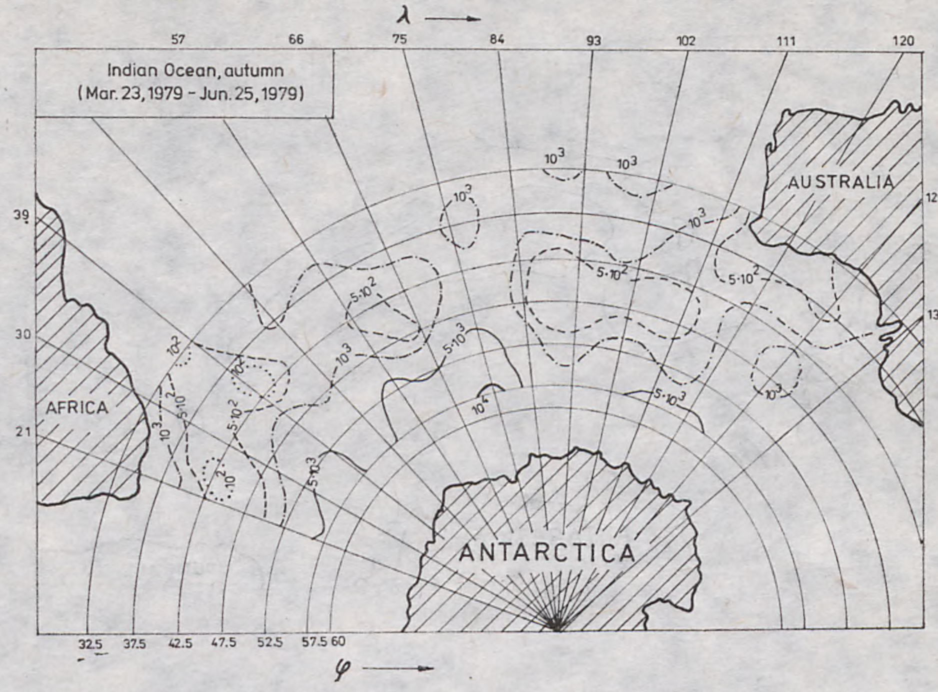
λ
Indian Ocean, autumn
(Mar. 23, 1979 - Jun. 25, 1979)
AUSTRALIA
AFRICA
ANTARCTICA
φ

Fig. 7

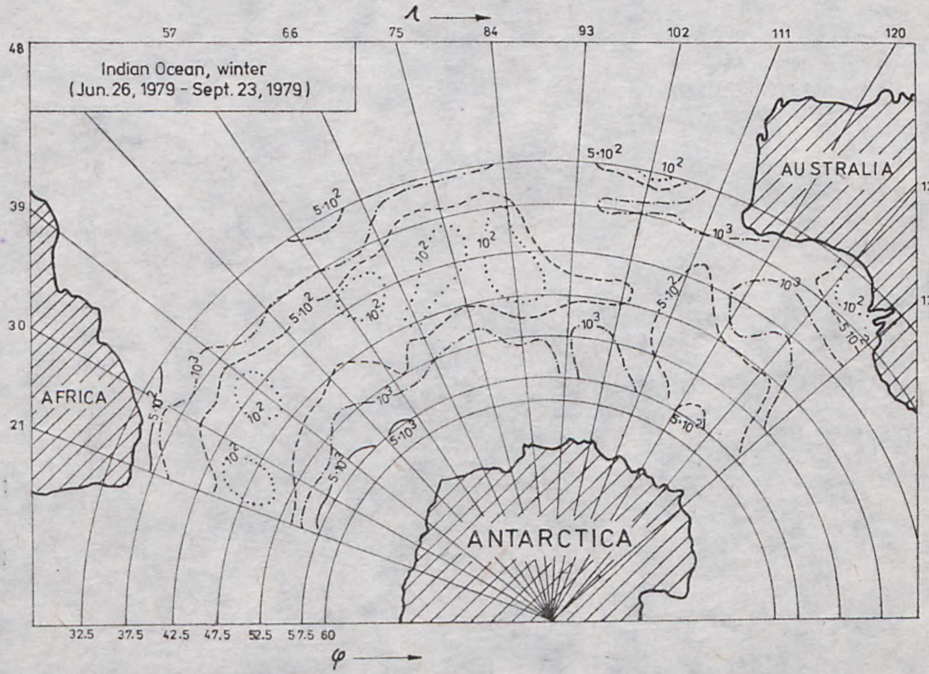
λ
Indian Ocean, winter
(Jun. 26, 1979 - Sept. 23, 1979)
AUSTRALIA
AFRICA
ANTARCTICA
φ

Fig. 8

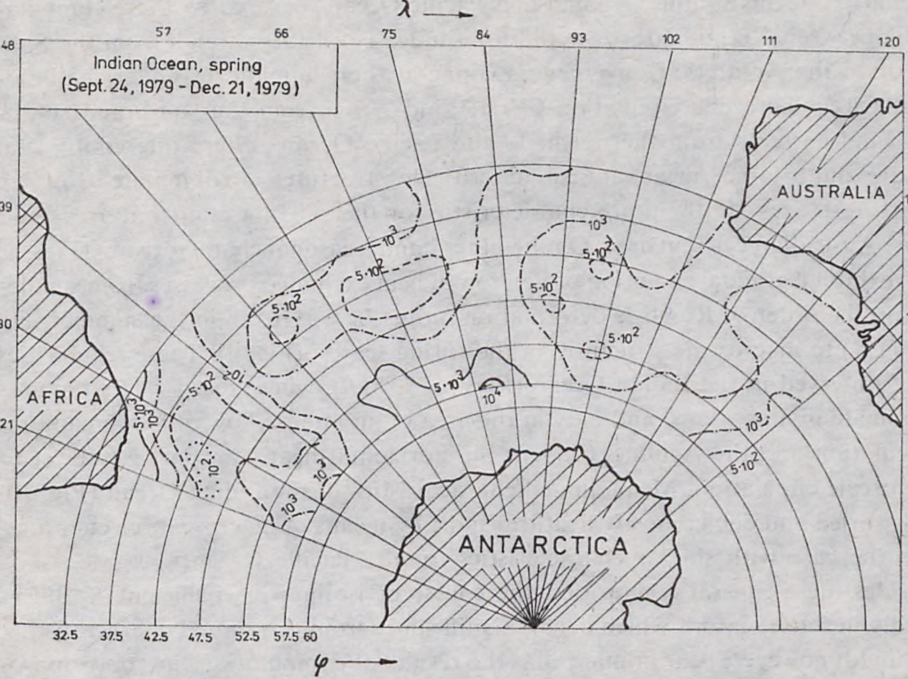
λ →
Indian Ocean, spring
(Sept. 24, 1979 - Dec. 21, 1979)
AFRICA
AUSTRALIA
ANTARCTICA
φ →

Fig. 9

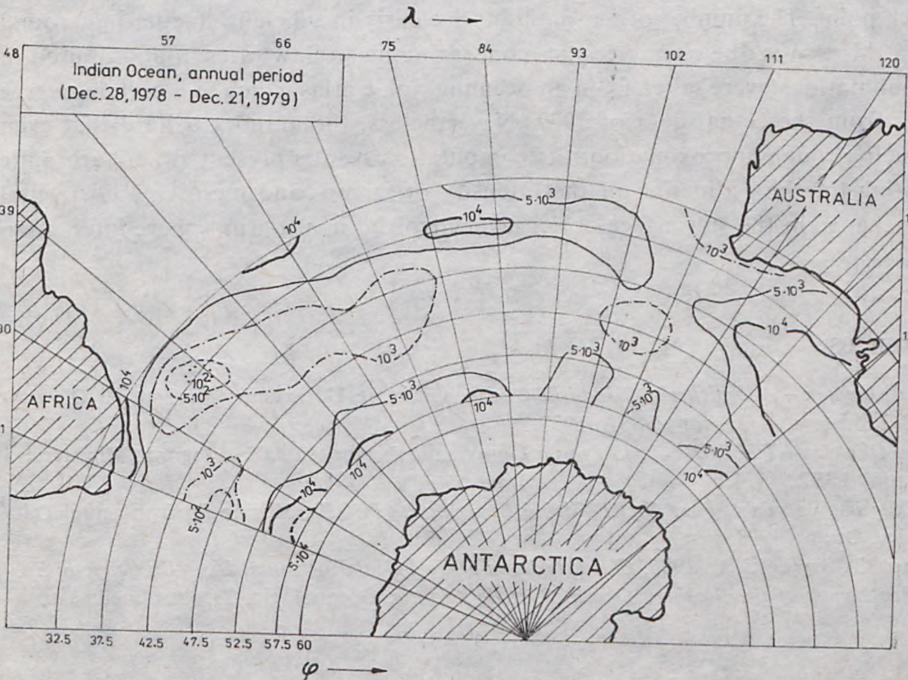
λ →
Indian Ocean, annual period
(Dec. 28, 1978 - Dec. 21, 1979)
AFRICA
AUSTRALIA
ANTARCTICA
φ →

Fig. 10

The areas of the Southern Indian and Pacific Oceans covered by these computations lie between 30° and 60° of southern latitude. Thus, they stretch from the Subantarctic to the Antarctic Convergence, falling at their boundaries under the influence of Circumantarctic circulation (West Wind Drift) from the south and south-trade wind currents from the north. In the Pacific Ocean, where intercontinental areas are quite large, mean annual macroscale structures predominate (Fig. 5); their greatest sizes $l \approx 10^6$ m are characteristic for the subantarctic front areas and the East Australian Current area. On the other hand, seasonal characteristics (Figs. 1, 2, 3, 4) exhibit a gradual evolution of horizontal heat exchange processes from smaller scales on the order of Rossby's deformation radius $L_R \approx 5 \cdot 10^4$ m in the summer season (Fig. 1) to macroscale structures in the spring season (Fig. 4). These regularities are not observed in the Indian Ocean (Figs. 6, 7, 8, 9), where mesoscale structures predominate in all seasons, and only in the area of an intense flow of Circumantarctic circulation and the Agulhas Current the horizontal heat transport is subject to a macroscale circulation. Mean annual characteristics of the Indian Ocean (Fig. 10) are less varied and depict mostly heat transport by means of macroscale circulations, as was the case with similar characteristics for the Pacific Ocean.

Besides these general regularities, the course of isolines of coefficient K_l differs markedly in those seasons which depart significantly from the annual characteristics. One should, however, bear in mind that the results of computations are only approximate, not only as a result of simplifications of the method, but also due to the varying representativeness of statistical sets, among which only the annual set contains a considerable number of 73 temperature values from five-day averaging periods for each point. The number of seasonal sets is clearly insufficient, fluctuating around 18 data. Moreover, the characteristics concerning mean flow rates, $\bar{u}$ and $\bar{v}$, used in the computations, were taken from an oceanographic atlas which to a certain degree departs from the actual data of 1979. Nevertheless, the authors believe that even with such a rough approximation, the computation results presented here are quite interesting for the estimation of the intensity of macro- and mesoscale horizontal heat exchange in the subsurface ocean layer involved in sea-atmosphere interaction processes.

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