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SHORT CONTRIBUTIONS

Computations of heat flux through the ocean surface as a function of temperature

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1. Introduction

In Walin (1982) a theoretical framework is presented for the description of the thermal state and circulation in the ocean.

In this context the thermal forcing of the ocean is described by a function $\bar{Q}(T)$ defined below. In this note we present some computations of the function $\bar{Q}(T)$. Heat flux data have been obtained from A. F. Bunker (personal communication) and Budyko (1963). For further discussion see Walin (1982).

2. Computations of $\bar{Q}(T)$ for the ocean

The function $Q(T, t)$ is defined as the heat supply to those parts of the ocean surface where the temperature is less than T. We thus have

$$Q(T, t) = \int_{A(T,t)} q(\mathbf{r}, t)\,\mathrm{d}A \tag{1}$$

where $A(T, t)$ is that part of the whole surface A_0 on which the temperature $T_0(\mathbf{r}, t) < T$ at time t. $T_0(\mathbf{r}, t)$ is the temperature at the position $\mathbf{r}$ at time t and $q(\mathbf{r}, t)$ is the heat flux per unit area at the same point and time.

Equation (1) may be written

$$Q(T, t) = \int_{A_0} q(\mathbf{r}, t)\cdot\Gamma(T - T_0(\mathbf{r}, t))\,\mathrm{d}A \tag{2a}$$

where

$$\Gamma(x) = \begin{cases} 1 & \text{when } x > 0 \\ 0 & \text{when } x < 0 \end{cases} . \tag{2b}$$

With this expression for $Q(T, t)$ we can take mean values in time under the integral sign, i.e.

$$\overline{Q(T, t)} = \int_{A_0} \overline{q(\mathbf{r}, t)\,\Gamma(T - T_0(\mathbf{r}, t))}\,\mathrm{d}A \tag{3}$$

where the overbar denotes a mean value over a certain period of time.

Equation (3) may be approximated by

$$\overline{Q(T, t)} = \sum_{\mu} \frac{1}{N_\mu} \sum_{\nu}^{N_\mu} q_\mu^\nu\,\Gamma(T - T_{0\mu}^\nu)\,\Delta A_\mu, \tag{4}$$

where q_μ^ν and $T_{0\mu}^\nu$ are one of N_μ samples of $q(\mathbf{r}, t)$ and $T_0(\mathbf{r}, t)$ in the area element ΔA_μ. The accuracy of (4) depends on the resolution in space and the number of observations N_μ in each element ΔA_μ. It is required that the samples are distributed evenly over the time-period in question. In particular, different periods of the annual cycle must be equally well represented.

Ideally we should compute q_μ^ν from individual ship observations and combine with the temperature $T_{0\mu}^\nu$ at the same place and time. This has not yet been possible. Instead we have been forced to base our calculations on monthly mean values taken separately for q_μ^ν and $T_{0\mu}^\nu$.

Equation (4) has thus been replaced by

$$\bar{Q}(T) = \frac{1}{12} \sum_{1}^{12} \bar{Q}^m(\bar{T}) \tag{5a}$$

$$\bar{Q}^m(T) = \sum_{\mu} \bar{q}_\mu^m\,\Gamma(T - \bar{T}_{0\mu}^m)\,\Delta A_\mu \tag{5b}$$

where $(\bar{q}_\mu^m, \bar{T}_{0\mu}^m)$ represent the mean value of all observations obtained during a particular month from the surface element ΔA_μ.

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In eq. (5) we take mean values of q_μ and $T_{0\mu}$ before we form the product $q_\mu \cdot \Gamma(T - T_{0\mu})$. We thereby introduce an error which depends on the correlation between q_μ and $T_{0\mu}$, i.e. which does not decrease when the number of samples increases. This error would have been even larger if we had computed separate annual mean values of q_μ and $T_{0\mu}$ instead of monthly mean values. Presently we have no estimate of the magnitude of the error introduced when we use eq. (5) instead of (4).

Data on $\bar{q}_\mu^m$ and $\bar{T}_{0\mu}^m$ have been obtained in two ways.

(i) Data for the North Atlantic has kindly been put at our disposal by A. F. Bunker. He has made energy flux computations directly on every individual ship observation over 32 years, and calculated monthly mean values for q_μ and $T_{0\mu}$. The size of his spatial elements is about 3° × 3°.

(ii) Monthly mean values of q_μ and $T_{0\mu}$ have been read directly out of Budyko's atlas which allows a spatial resolution of order 5–10°.

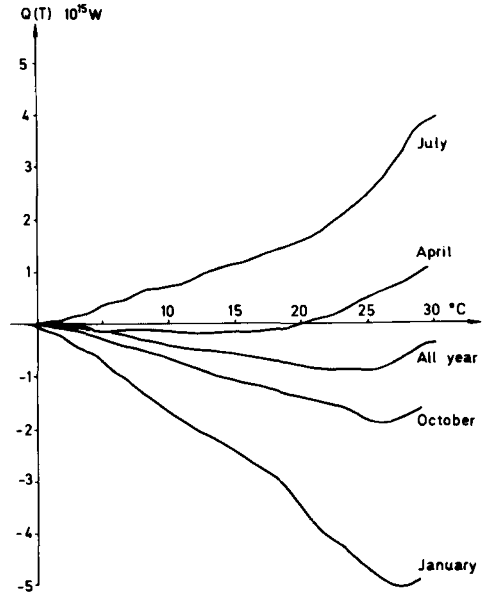

Fig. 2. Monthly mean value of $Q(T, t)$ for certain months for the north Atlantic as obtained from Bunker's data.

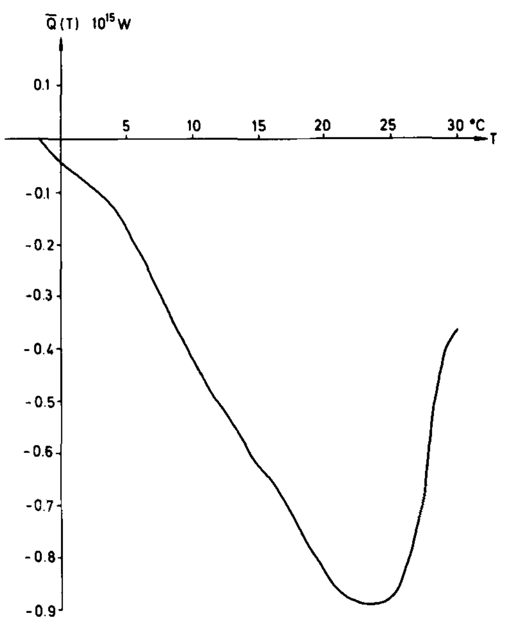

Fig. 1. All year mean value of $Q(T, t)$ for the north Atlantic as obtained from Bunker's data.

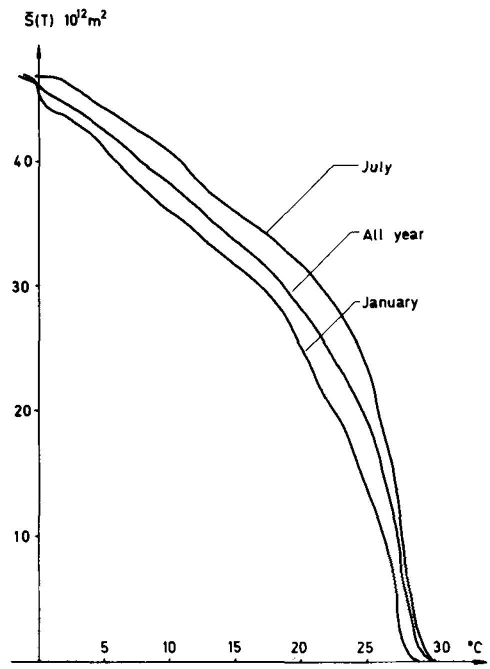

Fig. 3. Monthly mean value for July and January and all year mean value of the area function $S(T, t)$ for the north Atlantic from Bunker's data.

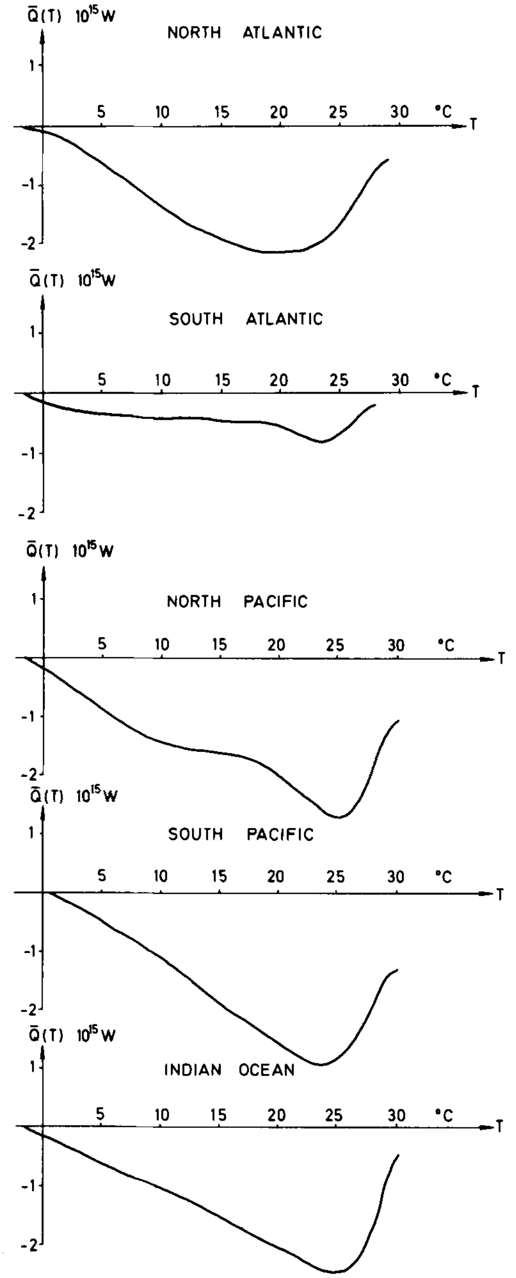

Fig. 4. $\bar{Q}(T)$ for different parts of the ocean as obtained from data taken from Budyko's atlas.

3. Results

Figs. 1 and 2 show our results for $\bar{Q}(T)$ based on Bunker's data. Note the different scale used in Figs. 1 and 2.

The result shown in Fig. 1 is also shown in Fig. 2 for comparison with the monthly mean function for January, April, July and October. We note the very large seasonal variation in $Q(T, t)$ compared with the annual mean. During July the ocean surface is heated at all temperature levels while in January heat is being lost in the whole range except the very highest temperatures.

Fig. 3 shows the annual mean and monthly mean for January and July of the area function $S(T, t)$, defined as the area of the isothermal surface with temperature $>T$.

Figs. 4a–e show our results for the main ocean basins excluding the Arctic basin and the area south of 65° latitude south. These results, based on data from Budyko's atlas, are less reliable than the results for the Atlantic shown in Fig. 1. For some reason which we do not know, the results from Budyko's atlas seem to underestimate the heat supply to the ocean (or overestimate the heat loss). In particular we note that the result for the North Atlantic in Fig. 4a deviates very much from the results shown in Fig. 1.

A striking feature of all our results is that the shape of the curve $\bar{Q}(T)$ for different basins tends to be similar. In particular the temperature level T_m, where $\bar{Q}(T)$ is a minimum, is found in a relatively narrow temperature interval around 24 °C.

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