Numerical–thermodynamical prediction of mean monthly ocean temperatures

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ABSTRACT

Results are presented of numerical predictions of month-to-month changes in ocean surface temperature anomalies in the Northern Hemisphere, using a thermodynamic model. For the 73-month period December 1965 to December 1970, and June 1972 to May 1973, statistical evaluation of the predictions (of the sign of the change of anomalies) shows skill substantially higher than that of predictions of a return toward normal. The effect of the different heating and transport components that enter in the predictions is evaluated. It is shown that the horizontal turbulent transport of heat in the oceans corresponding to an exchange coefficient equal to 3×10^8 cm^2 sec^{-1} plays an important role in determining the skill of the predictions. However, a model in which the total horizontal transport of heat is neglected also shows good skill, due to evaporation and vertical turbulent transport of sensible heat from the surface of the oceans. The anomalies in the transport by mean ocean currents due to anomalies in the surface wind are taken into account using Ekman's formulas. However, although they are important for the changes of the temperature anomalies, their contribution in improving the skill of the predictions is not apparent from the limited number of cases in which they were included.

1. Introduction

A thermodynamic approach to predict the mean anomalies of temperature in the Atmosphere–Ocean–Continent System for periods of about a month has been developed and applied in long-range weather prediction (Adem, 1964*a*, 1965*b*, 1970*b*) and in ocean temperature prediction (Adem, 1969, 1970*a*, 1971), as well as in studies of climatic fluctuations (Shaw & Donn, 1968, 1971; Adem, 1974, 1975) and of the ocean effects on weather and climate (Adem, 1973).

The specific purpose of this paper is to present a report on the applications of the model to the prediction of mean monthly anomalies of surface ocean temperature, which can be considered as an extension of previous reports on the same subject (Adem, 1969, 1970*a*, 1971).

2. Brief description of the model

The model used in the numerical predictions of ocean temperature that are reported in this paper is described in detail in several previous papers (Adem, 1962, 1963, 1964*a*, 1964*b*, 1965*a*, 1965*b*, 1970*a*, 1970*b*). Therefore, only a brief description of it will be given here.

The conservation of thermal energy (first law of thermodynamics) is applied to the upper layer of the oceans (down to about 50 to 100 m), the upper layer of the continents (negligible depth), and a vertically integrated one-layer atmosphere (up to about 10 km), which includes a cloud layer.

The conservation of thermal energy for the atmosphere is given by the following equation (Adem, 1965*a*):

$$c_v a_0 \frac{\partial T'_m}{\partial t} + AD_1 - c_v a_0 K \nabla^2 T'_m - c_v K \mathbf{b} \cdot \nabla T'_m = E_T + G_5 + G_2 \quad (1)$$

where ∇ is the two-dimensional horizontal gradient operator; T'_m is the departure of the mean atmospheric temperature from a constant value T_{m_0}, $T_{m_0} \gg T'_m$; c_v is the specific heat of air at constant volume;

$$a_0 = \int_0^H \varrho_0^* dz, \quad AD_1 = c_v \mathbf{M}_a \cdot \nabla T'_m,$$

$$\mathbf{M}_a = \int_0^H \varrho_0^* \mathbf{v}_H^* dz \text{ and } \mathbf{b} = \int_0^H \nabla \varrho^* dz,$$

where H is the constant height of the model atmosphere and ϱ^* is the density given by

$$\varrho^* = \varrho \left(1 + \frac{\beta(H-z)}{T_m - \beta H/2}\right)^{\frac{g}{R\beta}-1}$$

$T_m = T_{m_0} + T'_m$, ϱ is a fixed constant density at $Z = H$, β is the constant lapse rate used in the atmospheric layer, g is the acceleration of gravity, $\mathbf{v}_H^*$ is the horizontal component of the wind, ϱ_0^* is the value of ϱ^* obtained by replacing T_m by T_{m_0}, and K is the horizontal austausch coefficient for the atmosphere.

On the right side of eq. (1), E_T is the rate at which energy is added by radiation, G_2 is the rate at which heat is added by vertical turbulent transport from the surface, and G_5 is the rate at which heat is added by condensation of water vapor in the clouds.

On the left side, $c_v a_0 \partial T'_m/\partial t$ is the local rate of change of thermal energy, and AD_1 and $-c_v a_0 K \nabla^2 T'_m$ are the advections of thermal energy by the mean wind and by horizontal eddies, respectively. The term $c_v K \mathbf{b} \cdot \nabla T'_m$ will be neglected.

The equation for the ocean layer (Adem, 1970a) is:

$$h\left(\frac{\partial T'_s}{\partial t} + \mathbf{v}_{s_T} \cdot \nabla T'_s - K_s \nabla^2 T'_s\right) + W = \frac{1}{\varrho_s c_s}(E_s - G_2 - G_3) \quad (2)$$

where T'_s is the departure of the surface ocean temperature from a constant value T_{s_0}, $T_{s_0} \gg T'_s$, ϱ_s is a constant density and c_s is the specific heat; h is the depth of the layer; $\mathbf{v}_{sT}$ is the horizontal velocity of the ocean currents; W is the vertical transport of heat at the bottom of the layer; K_s is the constant austausch coefficient; E_s is the rate at which the energy is added by radiation; G_2 is the rate at which sensible heat is given off to the atmosphere by vertical turbulent transport; and G_3 is the rate at which the heat is lost by evaporation. The term $h\partial T'_s/\partial t$ is the local rate of change of thermal energy; $h\mathbf{v}_{sT} \cdot \nabla T'_s$ and $-hK_s \nabla^2 T'_s$ are the horizontal rates of transport of thermal energy by mean ocean currents and by turbulent eddies, respectively.

In the continents, eq. (2) reduces to:

$$0 = E_s - G_2 - G_3 \quad (2')$$

In the earlier version of the model, the following assumptions have been made:

(a) In eq. (2), the horizontal transports of heat by the mean ocean currents and by turbulent eddies are neglected.

The vertical transport at the bottom of the layer is also neglected.

(b) In eq. (1), $\partial t'_m/\partial t$ is replaced by $(T'_m - T'_{m_p})/\Delta t$; where T'_{m_p} is the value of T'_m in the previous month and Δt is the time interval taken as a month. Similarly, $\partial T'_s/\partial t$ in eq. (2) is replaced by $(T'_s - T'_{s_p})/\Delta t$ where T'_{s_p} is the value of T'_s in the previous month, and Δt is also taken as a month.

Using parameterizations for E_T, E_s, G_2, G_3, G_5 and AD_1, the different components that appear in eqs. (1) and (2) are expressed as functions of T'_s, T'_m, $\partial T'_m/\partial x$ and $\partial T'_m/\partial y$ (Adem, 1965b, 1970b).

Substituting the parameterized heating functions in eqs. (1) and (2) and using assumptions (a) and (b), we obtain two linear equations to compute T'_m and T'_s. Due to assumption (a), eq. (2) becomes algebraic. Therefore, the problem is reduced to solving a linear second order elliptic differential equation of the type:

$$K\nabla^2 T'_m + F''_1 \frac{\partial T'_m}{\partial x} + F'''_1 \frac{\partial T'_m}{\partial y} + F'_1 T'_m = F'_2 \quad (3)$$

where F'_1, F''_1, F'''_1 and F'_2 are known functions of the map coordinates x and y (Adem, 1970b).

We can remove (a) and still get the same type of integration problem. To introduce the transport by horizontal mean ocean currents and by turbulent mixing, as well as upwelling, a different method of integration is used, which consists in integrating the equation for the ocean layer with forward differences and the equation for the atmosphere with backward differences.

Considering that the term $h\partial T'_s/\partial t$ is of the same order of magnitude or larger than any one of the others in eq. (2), one can attempt to solve eq. (2) with forward or centered differences to obtain the predicted ocean temperature, which is then substituted in eq. (1) in which we still use backward differences. This can be done because in contrast with what happens in the oceans, the storage term in the atmosphere is small compared with the heating functions. The integration problem is therefore reduced again to the solving of an elliptic differential equation for the tropospheric temperature.

For the total ocean current, $\mathbf{v}_{s_T}$, we assume

$$\mathbf{v}_{s_T} = \mathbf{v}_{s_w} + (\mathbf{v}_s - \mathbf{v}_{s_N})$$

where $\mathbf{v}_{s_w}$ is the observed normal seasonal ocean current, $\mathbf{v}_s$ is the pure wind drift current, and $\mathbf{v}_{s_N}$ is the corresponding normal wind drift current.

The components of the vector $\mathbf{v}_s$ are computed from the following formulas:

$$u_s = c_1 \frac{0.0126}{\sqrt{\sin \varphi}} (u_a \cos \theta + v_a \sin \theta) \quad (4)$$

and

$$v_s = c_1 \frac{0.0126}{\sqrt{\sin \varphi}} (v_a \cos \theta - u_a \sin \theta) \quad (5)$$

where the directions of the coordinate axes are arbitrarily chosen, u_s and v_s are respectively the x and y components of the current, u_a and v_a are respectively the x and y components of the surface wind, φ is the latitude, c_1 is a constant parameter, and θ is the angle that measures the direction of the vector surface ocean current to the right of the surface wind direction.

The detailed derivation of eqs. (4) and (5) has been given elsewhere (Adem 1970*a*).

The components of $\mathbf{v}_{s_N}$ are obtained using normal values[1] of the surface wind components in eqs. (4) and (5).

For the upwelling term, we use the same parameterization as in a previous paper (Adem, 1970*a*).

For a more complete information on the equations, the method of solution, the data sources, and the parameterizations used, the reader is referred to the previous papers (Adem, 1964*a*, 1965*a*, 1965*b*, 1970*a*, 1970*b*).

[1] Normal values are defined as long-term monthly means at each geographical point.

The method of prediction is the same as the one used in the above mentioned papers. That is, one makes a prediction for the normal values using normal observed values of the previous month as initial conditions and another prediction for the month considered using the observed values of the previous month as initial conditions. The predicted anomalies are obtained by subtracting from the computed values for the given month, the corresponding computed normal values.

The equation of conservation of thermal energy when only the horizontal turbulent mixing is included is of special importance. In this case, (2) becomes:

$$\frac{\partial T_s}{\partial t} = K_s \nabla^2 T_s \quad (6)$$

The solution of (6) depends only on the temperature for the previous interval and on the exchange coefficient K_s, for which we will use a value of the order 3×10^8 cm^2 sec^{-1}. This value is 100 times smaller than the one used in the atmospheric layer.

The solution of (6), discussed in a previous paper (Adem, 1971), shows a tendency for the anomalies to return to normal, but the rate at which the anomalies return to normal depends on their size, so that the smaller anomalies disappear before the larger ones.

To illustrate this selective return to normal, Fig. 1 shows different sizes of anomalies, labeled with Roman numbers; the side of the smaller one corresponds to the grid distance used in the numerical experiment which is equal to 817 km.

Fig. 2 shows the evolution of the different anomalies with time; the anomaly of size I disappears after 43 days, and the larger anomalies are, the slower they decrease (Adem, 1971).

3. Results of the numerical experiments

Many examples of prediction have been published already by the author (Adem & Jacob, 1968; Adem, 1969, Adem, 1970*a*).

Inspection of particular cases shows that the predictions have some skill. However, to determine the value of the method of prediction, we need to use an objective evaluation applied to a large number of samples.

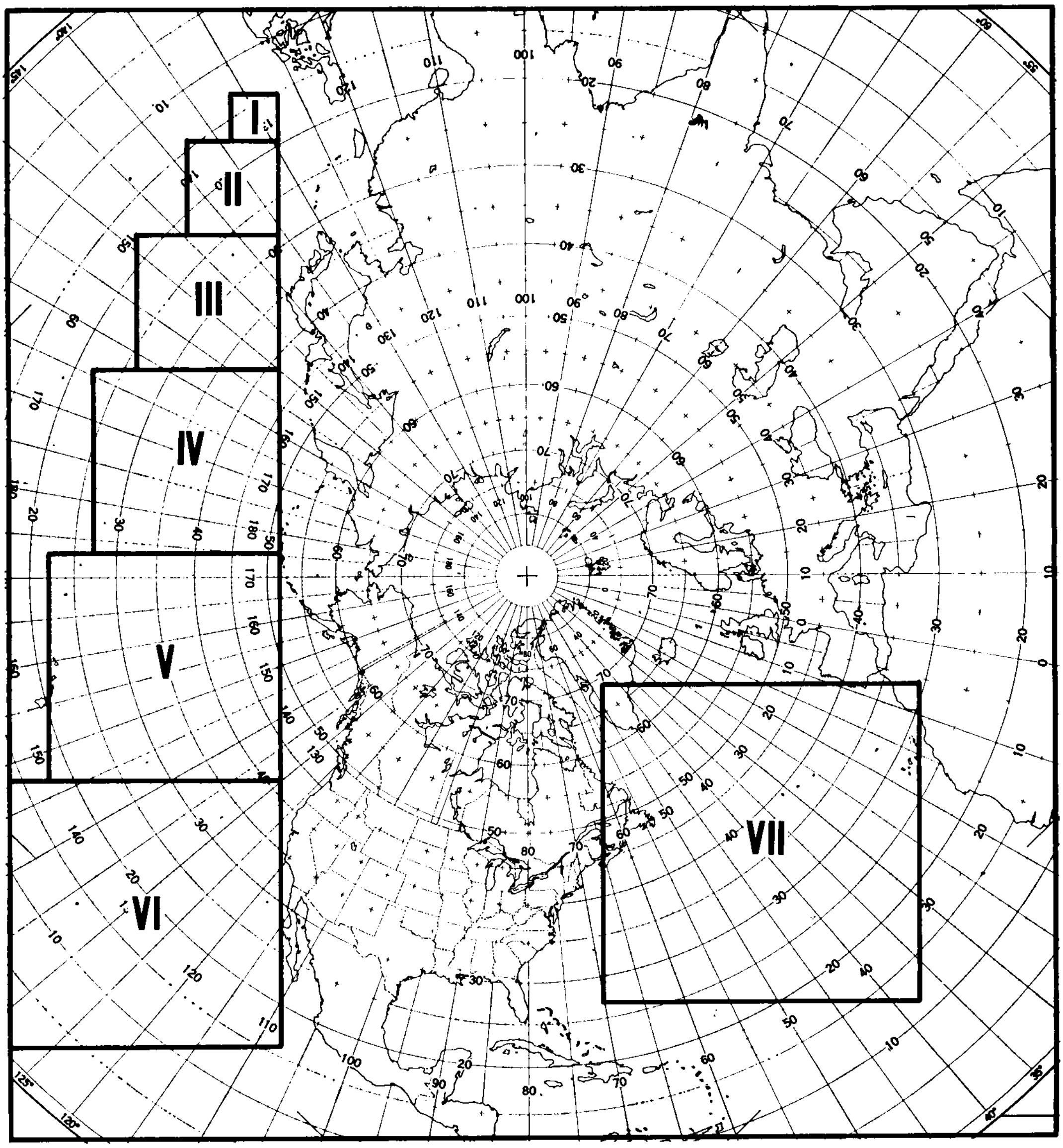

Fig. 1. Different sizes of ocean temperature anomalies. The side of the smaller one is equal to 817 km, which is the grid distance used in the numerical experiments.

We will evaluate the skill of the model in predicting correctly the sign of the month to month change of anomalies and, for that purpose, will compute the percentage of signs correctly predicted. As control, we will use return to normal which is a prediction in which the change of the anomaly is equal to the anomaly of the previous month with opposite sign.

Fig. 3A, which shows the area of the Pacific and the Atlantic Oceans included in the verification, illustrates a typical prediction. It corresponds to the monthly change from August to September, 1972, predicted with a model which includes only horizontal turbulent mixing, and in which time steps of 5 days have been used. Comparison with the corresponding observed

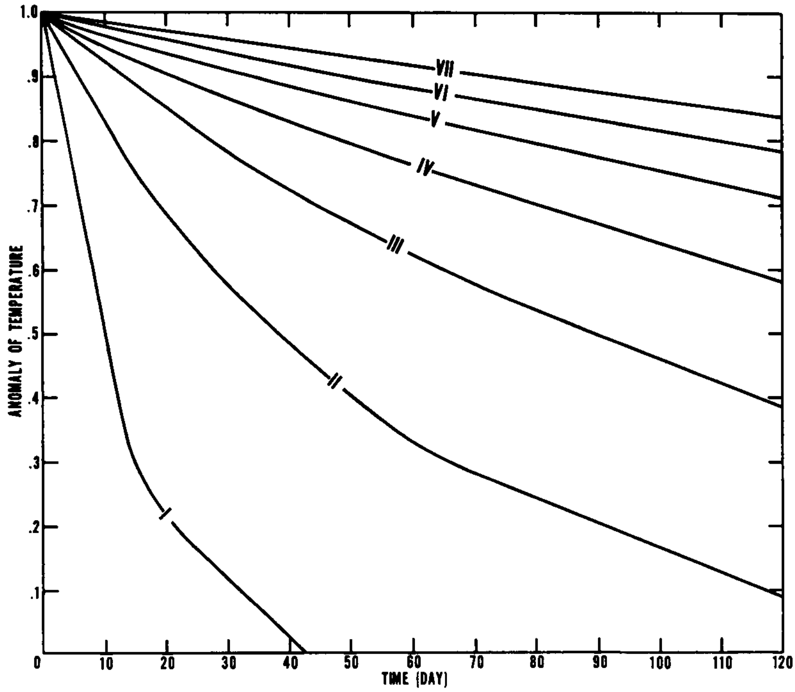

Fig. 2. Evolution with time of the ocean temperature anomalies shown in Fig. 1, in a model in which only horizontal turbulent mixing is included.

changes (Fig. 3B) shows that not only the signs of the changes of anomalies, but also the position of some of the maxima and minima, are well predicted. Furthermore, the predicted change is of the correct order of magnitude, although somewhat smaller than the observed change.

First we will show the results of predictions using the current thermodynamic model in which assumptions (*a*) and (*b*) have been used. These predictions have been carried out since 1965 and we will show the evaluation of 73 cases, from December 1965 to December 1970 and from June 1972 to May 1973.

Table 1 shows the results for each individual case for the model and for return to normal and their difference. From these results, it is evident that the skill of the model is superior to the control prediction. Table 2 shows the average results by seasons and for the whole period of the 73 monthly predictions. From this table, it is evident that the best results are obtained for winter on the Pacific Ocean, for which the model predicted correctly 64.1 % of signs of month to month changes in ocean temperature anomalies, being 6 % higher than the control.

The higher percentage is of 65.1 in the summer over the whole area, but in this case, the excess over the control is only of 3 %. Over the whole period and over both oceans, the total percentage is 63.2 % correctly predicted, with an excess over the control of 3.7, while over the Pacific is of 63.4, with an excess over the control of 4.7.

Table 3 shows the results of 24 predictions from January 1970 to December 1971, and from June 1972 to May 1973, using the model in which only turbulent mixing is considered with time steps of 5 days. Table 4 shows the results by seasons and for the whole 24-months period. In this case, if we consider the two oceans, the best skill is in the fall, with an excess over the control of 11.5 %. However, in the other seasons, the skill is also extremely good and the average for the whole period for both oceans is an excess of 8.1 over the control.

In Table 5, a comparison of the skill using different options of the model is shown using

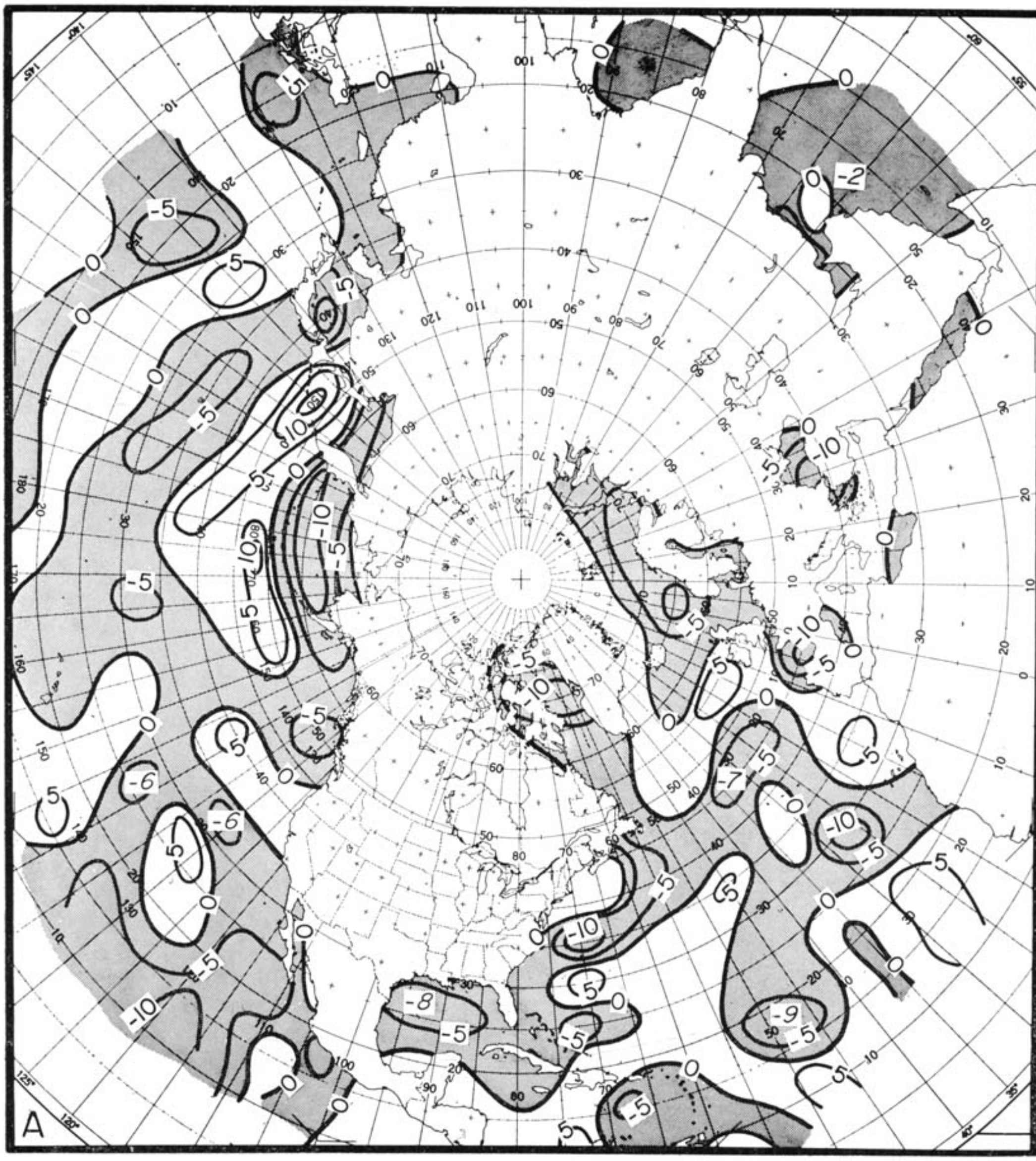

Fig. 3. Changes of surface ocean temperatures, in tenths of Celsius degrees, from August to September 1972: (A) predicted by the model; (B) observed.

the same sample of 24 cases. In the first line are the values for the control, namely return to normal: in the Pacific 58.7, in the Atlantic 57.9 and in both oceans 58.3 correctly predicted. In the second line are shown the excesses over the control, using the current thermodynamic model: in the Pacific 4, in the Atlantic 5.7, and in both oceans 4.8. In the third line the excesses over the control when one uses the model in which there exists only turbulent mixing with forward time steps of 5 days: in the Pacific 6.9, in the Atlantic 9.1, and in both oceans 8.1. Finally, in the last line, using a model in which only turbulent mixing is used, but integrating the equation with one single 30 day time step.

Table 5 shows that the best results are ob-

tained with the model with turbulent mixing alone using time steps of 5 days.

Numerical experiments including the transport by mean ocean currents as well as the complete set of equations have been carried out in a limited number of cases and using time steps of 30 days for atmosphere and ocean. Although the work of Namias (1959) suggests that the advection of heat by ocean currents is important, the skill of these predictions has not been as good as those corresponding to the two simplified models used in the predictions whose results have been shown here. This could be due to the fact that, as was shown in a previous paper (Adem, 1971), in these cases shorter time steps than a month need to be used to avoid large truncation errors that would lower the skill of the predictions.

Furthermore, in this case, the integration is carried out using forward integrations for the

Table 1. *Percentage of signs of the month-to-month changes in ocean temperature anomalies predicted correctly by the thermodynamic model and by return to normal for the 73 months from December 1965 to December 1970, and from June 1972 to May 1973*

Pacific and Atlantic			
Month	Model	Return to normal	Difference
1965			
Dec.	53.5	52.0	1.5
1966			
Jan.	64.4	57.9	6.5
Feb.	64.9	51.5	13.4
Mar.	54.5	43.6	10.9
April	70.3	60.9	9.4
May	68.3	63.3	5.0
June	71.3	69.8	1.5
July	68.8	62.9	5.9
Aug.	58.9	60.9	−2.0
Sept.	58.4	55.4	3.0
Oct.	54.5	52.0	2.5
Nov.	63.9	54.5	9.4
Dec.	61.8	57.0	4.8
1967			
Jan.	64.9	54.5	10.4
Feb.	60.4	55.0	5.4
Mar.	58.4	56.0	2.4
April	64.4	62.4	2.0
May	61.4	57.9	3.5
June	58.4	57.0	1.4
July	67.8	64.9	2.9
Aug.	64.9	61.4	3.5
Sept.	58.4	57.4	1.0
Oct.	62.4	58.4	4.0
Nov.	59.9	54.0	5.9
Dec.	73.3	71.7	1.6
1968			
Jan.	65.4	63.9	1.5
Feb.	62.4	57.9	4.5
Mar.	60.8	56.4	4.4
April	61.8	57.4	4.4
May	64.4	67.8	−3.4
June	53.9	50.9	3.0
July	61.8	59.4	2.4
Aug.	66.3	66.3	0
Sept.	54.5	57.4	−2.9
Oct.	59.4	59.4	0
Nov.	62.3	58.9	3.4
Dec.	65.3	65.3	0

Pacific and Atlantic			
Month	Model	Return to normal	Difference
1969			
Jan.	64.9	59.9	5.0
Feb.	61.4	58.9	2.5
Mar.	66.3	60.4	5.9
April	64.9	65.8	−0.9
May	62.9	58.4	4.5
June	58.9	56.4	2.5
July	70.4	69.3	2.1
Aug.	64.3	64.8	−0.5
Sept.	70.9	71.9	−1.0
Oct.	65.8	65.8	0
Nov.	72.4	69.8	2.6
Dec.	68.8	67.8	1.0
1970			
Jan.	55.9	54.5	1.4
Feb.	63.9	59.9	4.0
Mar.	61.4	55.4	6.0
April	59.9	57.9	2.0
May	68.8	68.3	0.5
June	70.3	61.9	8.4
July	71.8	66.8	5.0
Aug.	62.9	56.4	6.5
Sept.	61.4	56.9	4.5
Oct.	72.3	59.9	12.4
Nov.	59.9	47.5	12.4
Dec.	62.4	60.9	1.5
1972			
June	67.8	62.0	5.0
July	65.4	60.9	4.5
Aug.	67.8	65.3	2.5
Sept.	61.9	57.9	4.0
Oct.	61.4	57.4	4.0
Nov.	54.0	50.0	4.0
Dec.	60.9	54.5	6.4
1973			
Jan.	40.1	38.6	1.5
Feb.	70.8	66.3	4.5
Mar.	71.3	67.8	3.5
April	59.4	52.0	7.4
May	61.4	58.9	2.5

equation in the ocean and an implicit method of integration for the equation in the atmosphere in which backward time differences are used, with a time interval different than the one for the ocean.

The upwelling term can become important locally, as is the case off California, where vertical velocities of the order of 4×10^{-3} cm sec^{-1} exist, as has been shown by Roden (1972). According to computations carried out by the author, such velocities can be of importance in producing non-negligible ocean temperature

Table 2. *Averages for seasons and for the whole period of the percentage of signs of month-to-month changes in ocean temperature anomalies predicted correctly by the thermodynamic model and by return to normal*

	Pacific			Pacific and Atlantic		
Season	Model	Return to normal	Difference	Model	Return to normal	Difference
Winter	64.1	58.1	6.0	62.4	58.3	4.1
Spring	63.3	58.0	5.3	63.3	59.5	3.8
Summer	63.4	59.7	3.7	65.1	62.1	3.0
Fall	62.8	58.9	3.8	61.9	58.0	3.9
Average for whole period	63.4	58.7	4.7	63.2	59.5	3.7

Table 3. *Percentage of signs of the month-to-month changes in ocean temperature anomalies predicted correctly by a model with horizontal turbulent mixing alone and by return to normal for the 24 months from January 1970 to December 1970, and from June 1972 to May 1973*

Pacific and Atlantic				Pacific and Atlantic			
Month	Model	Return to normal	Difference	Month	Model	Return to normal	Difference
1970				1972			
Jan.	64.4	54.5	9.9	June	65.4	62.9	2.5
Feb.	63.9	59.9	4.0	July	63.9	60.9	3.0
Mar.	60.4	55.4	5.0	Aug.	69.8	65.4	4.5
April	65.3	57.9	7.4	Sept.	69.8	57.9	11.9
May	68.8	68.3	0.5	Oct.	62.4	57.4	5.0
June	68.3	61.9	6.4	Nov.	60.9	50.0	10.9
July	76.7	66.8	9.9	Dec.	68.8	54.4	14.4
Aug.	71.8	56.4	15.4	1973			
Sept.	62.4	56.9	5.5	Jan.	60.9	38.6	22.3
Oct.	73.8	59.9	13.9	Feb.	63.3	66.3	−3.0
Nov.	66.3	44.1	22.2	Mar.	69.3	67.8	1.5
Dec.	66.8	60.9	5.9	April	61.9	52.0	9.9
				May	66.8	58.9	7.9

Table 4. *Averages for seasons and for the whole period of the percentage of signs of month-to-month changes in ocean temperature anomalies predicted correctly by a model with horizontal turbulent mixing alone and by return to normal for the 24 months, from January 1970 to December 1970, and from June 1972 to May 1973*

	Pacific			Atlantic			Pacific and Atlantic		
Season	Model	Return to normal	Difference	Model	Return to normal	Difference	Model	Return to normal	Difference
Winter	62.9	56.4	6.5	66.9	55.1	11.8	64.7	55.8	8.9
Spring	65.0	58.9	6.1	66.0	61.5	4.5	65.4	60.1	5.3
Summer	67.9	62.7	5.2	71.0	62.0	9.0	69.3	62.4	11.5
Fall	67.6	56.0	11.6	64.0	52.5	11.5	65.9	54.4	11.5
Average for whole period	65.9	58.5	7.4	67.0	57.8	9.2	66.3	58.2	8.1

Table 5. *Averages for the whole period of 24 months (from January 1970 to December 1970, and from June 1972 to May 1973) of the percentage of signs of month-to-month changes in ocean temperature anomalies predicted correctly*

In the first line are the values of the control prediction (return to normal), in the second line, the excesses over the control obtained when using the current thermodynamic model; in the third and fourth lines are the excesses obtained when using the model in which only horizontal turbulent mixing is included with forward time steps of 5 days, and with one single 30 day time step respectively

Case	Pacific	Atlantic	Both oceans
Return to normal	58.7	57.9	58.3
HE	4.0	5.7	4.8
TU(5)	6.9	9.1	8.1
TU(30)	5.9	7.8	6.8

anomalies (Adem, 1970*a*). However, it is evident from the scale of the horizontal distribution of vertical currents that the distance of the grid points used in this case must be smaller than the one used in the computations presented in this paper.

4. Interpretation of results and conclusions

The above results show that the large scale horizontal turbulent mixing is an important process in producing changes of anomalies of the ocean temperature for periods of a month.

These results depend on the use of an exchange coefficient, which has been taken equal to 3×10^8 cm^2 sec^{-1}. Improvement in the skill of the predictions could possibly be obtained by using a more realistic exchange coefficient dependent of the geographical position.

Evaporation and vertical turbulent transport of sensible heat given off to the atmosphere from the surface are also important. This is, in fact, expected from the findings of several authors among them Clark (1967), Jacob (1967) and Adem (1969). All these processes produce a tendency towards return to normal: the turbulent horizontal mixing is a selective return to normal in which the smaller are the anomalies, the faster they decrease, while evaporation and vertical transport of sensible heat is a somewhat complex return to normal in which the atmospheric conditions interact yielding better predictions than those corresponding to simple return to normal.

The above results show that numerical predictions of ocean temperature with a thermodynamic model for periods of about a month, have skill.

The experiments presented here can be regarded as the initial stage of a series of numerical computations aiming at improving the predictions of ocean temperature by using better parameterizations of the heating and transport terms, better input data and a more complete model.

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ЧИСЛЕННЫЙ ТЕРМОДИНАМИЧЕСКИЙ ПРОГНОЗ СРЕДНЕМЕСЯЧНОЙ ТЕМПЕРАТУРЫ ОКЕАНА

Представлены результаты численного прогноза с помощью термодинамической модели изменений от месяца к месяцу аномалий температуры поверхности океана в северном полушарии. Статистическая оценка прогнозов (знака изменений аномалий) для периода в 73 месяца с декабря 1965 по декабрь 1970 гг. и с июня 1972 по май 1973 гг. показывает их успешность, значительно большую, чем для прогнозов, предсказывающих возвращение к норме. Оценивается влияние различных компонент нагревания и переноса, входящих в модель прогноза. Показано, что горизонтальный турбулентный перенос тепла в океане, соответствующий коэффициенту обмена, равному $3 \cdot 10^4 м^2/с$, играет важную роль в определении успешности прогнозов. Однако модель, в которой пренебрегается полным горизонтальным переносом тепла, также показывает хорошую успешность, что происходит благодаря учету испарения и вертикального турбулентного потока тепла с поверхности океанов. Аномалии в переносе средними течениями в океане, возникающие из-за аномалий в поле ветра у поверхности, учитываются путем использования формул Экмана. Однако, хотя они и важны для изменений аномалий температуры, их вклад в улучшение качества прогнозов не является очевидным из рассмотрения ограниченного числа случаев, в которые они были включены.