PRELIMINARY RESULTS OF THE GLOBAL THERMODYNAMIC MODEL

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RESUMEN

Con el propósito de saber qué influencia tiene el gradiente térmico sobre los cambios de la energía térmica en el sistema Troposfera-Océano-Continente, se usaron los principios básicos del Modelo Termodinámico Hemisférico de Adem (1962), además se desarrolló un Modelo Global para calcular las temperaturas del océano, continente y troposfera, en base a las siguientes hipótesis:

1) El gradiente térmico es una función de la longitud, latitud y el tiempo.
2) La altura troposférica es constante.

También se consideraron las siguientes hipótesis del Modelo de Adem: se supone que la superficie de la Tierra está formada únicamente por océanos o continentes y se considera un coeficiente de intercambio constante para el transporte horizontal turbulento de energía térmica.

Las temperaturas resultantes con estas condiciones fueron comparadas con los resultados obtenidos para un gradiente térmico constante y una altura troposférica variable, como en el Modelo inicial de Adem (1963). Cuando se consideró una tierra oceánica, los resultados obtenidos para la superficie del océano y la troposfera media, son similares a los resultados de Adem, pero para una tierra continental se encontraron diferencias.

ABSTRACT

With the purpose to know the influence of the lapse rate in the changes of thermal energy in the troposphere-ocean-continent system, we have used the basic principles

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of the hemispheric thermodynamic Adem's Model (1962), in order to develop a global model to calculate the temperatures, of the ocean, continent and troposphere, using the next hypothesis

1) The lapse rate is a function of longitude, latitude and time.
2) The tropospheric height is constant.

Some of the hypothesis from Adem's Model are also considered here: assume that the earth surface is formed only by oceans or continents and use a constant exchange coefficient for the horizontal turbulent transport of thermal energy.

The temperatures results from our considerations were compared with the results obtained for a constant lapse rate and a variable tropospheric height, as the initial Model of Adem (1963). When we assumed an oceanic earth the results for the surface ocean and mid-troposphere, are similar to the Adem's results, but for a continental earth we found differences.

INTRODUCTION

Adem's model (1962, 1964, 1968) is used to forecast anomalies on the climatic variables for periods of a month or a season, and it's recently used too in paleoclimatology studies (Adem, J., 1974, Saw, D. M. & Donn, W. L., 1971); as the model simulate quite accurately the atmospheric phenomena in the troposphere-ocean-continent system, we utilized the model on this paper for a global system using a zonally averaged technique in order to know the influence of the changes of thermal energy, in the temperatures fields system, due to variation of lapse rate.

On this model we have six unknown variables, the superficial temperatures of the ocean (T'_s) and the continent (T'_c), the mid-tropospheric temperatures (T'_m), the lapse rate (β'), the excess of radiation on the earth surface (E_s), and in the troposphere (E_T), which are functions of: the storage energy of the ocean, the loss of thermal energy by vertical turbulent transport of sensible heat and evaporation by latent heat, the incoming and outgoing short and long wave radiation, the albedo, the cloudiness, the horizontal turbulent transport in the troposphere and the gain of thermal energy by condensation of the water vapor.

BRIEF DESCRIPTION OF THE MODEL

Adem's model is described by the autor in several papers (1962, 1963, 1968, 1974), therefore only a brief description will be given here.

The principle of conservation of thermal energy (first law of thermodynamics) is applied to the incoming and outgoing short and long wave radiation and the gain or loss of thermal energy by latent heat (evaporation or condensation) in the troposphere-ocean-continent system with the next dimensions, for a tropospheric height of 11 km, an oceanic depth down about 50 to 100 m and the continental layer with negligible depth.

We make for the atmosphere in the Adem's model two options:

OPTION A, with the following assumptions

$$\begin{aligned} P^* &= P^* (\psi, \varphi, z, t) \\ T^* &= T^* (\psi, \varphi, z, t) \\ H &= H (\psi, \varphi, t) \\ \beta &= \text{constant}, \end{aligned}$$

where P^* is the pressure, T^* the tropospheric temperature, H the height of the troposphere, β the lapse rate, ψ the longitude, φ the latitude, z the altitude, and t the time.

OPTION B, with

$$\begin{aligned} P^* &= P^* (\psi, \varphi, z, t) \\ T^* &= T^* (\psi, \varphi, z, t) \\ \beta &= \beta (\psi, \varphi, t) \\ H &= \text{constant}. \end{aligned}$$

For both options in order to obtain the daily mean conditions over the latitude, we applied the average operator

$$\frac{1}{2\pi\tau}\int_{t}^{t+\tau}\int_{0}^{2\pi}\left[\quad\right] d\psi\, dt$$

to the equations of conservation of thermal energy obtained by Adem (1968) for the troposphere-ocean-continent system. For the option A neglecting according with Adem (1963) the changes of thermal energy by advection and by horizontal turbulent transport of second order, we obtain the next expression for the troposphere.

$$K F_{65} \frac{d^2 T'_m}{d\varphi^2} = E_T + G_2 + G_5 \qquad (1)$$

where T'_m is a departure of the mid-tropospheric temperature T_{m_0}, with $T'_m = T_m - T_{m_0}$, and $T'_m \ll T_{m_0}$; $K = 5 \times 10^{10}$ cm^2 seg^{-1} is the exchange coefficient, F_{65} is a constant given in Adem (1968), $K F_{65} \frac{d^2 T'_m}{d \varphi^2}$ represent the changes of thermal energy due to horizontal turbulent transport by the migratory cyclones and anticyclones, G_2 and G_5 represent the gain of thermal energy by vertical turbulent transport of sensible heat and by condensation of the water vapor, E_T is the excess radiation in the troposphere given by

$$E_T = F_8 + \in F'_8 + F_9 T'_m + (F_{10} + \in F'_{10}) T'_s + \\ + \left(\beta \frac{F_{11}}{H} - \beta \frac{F_9}{2} \right) H' + \in b_3 I + a_2 I \tag{2}$$

where $\in$ is the fractional cloudiness, I is the solar radiation in the upper troposphere, a_2 and b_3 are the absorption coefficients in short wave for the troposphere and the clouds, respectively, T'_s is a departure of earth surface temperature T_{so} with $T'_s = T_s - T_{so}$ and $T'_s \ll T_{so}$; H' is a departure troposphere height from the constant H_o with $H' = H - H_o$ and $H' \ll H_o$, finally the coefficients F_8, F'_8, F_9, F_{10}, F'_{10}, F_{11} and $H' = A T'_m$ are given by Adem (1963, 1968).

Using the equation (2) in (1) we obtain

$$K F_{65} \frac{d^2 T'_m}{d \varphi^2} - F_{66} T'_m = F_{67} (\varphi) \tag{3}$$

where

$$F_{67}(\varphi) = -\Big\{ F_8 + \in F'_8 + (F_{10} + \in F'_{10}) T'_s + \in b_3 I + \\ + G_2 + G_5 + (F_2)_o \left(1 + \frac{\beta A}{2} \right) \frac{(T'_m)_i}{\Delta t}$$

where A and $(F_2)_o$ are given in earlier studies (Adem, J., 1962, 1963) and T'_s is the surface temperature, obtained applying the principle of conservation of energy to the earth surface layer, being the ocean temperature for the case assuming an oceanic earth, or the continent temperature for a continental earth assumption.

The principle of conservation of energy (First law of thermodynamics) applied to the ocean layer and neglecting the changes of thermal energy by horizontal turbulent transport, and by advection due to mean ocean currents and by upwelling effects according with Adem (1963, 1964) take the form

$$\frac{h_s \rho_s c_{vs}}{2} \frac{\partial T_s'}{\partial t} = E_s - G_2 - G_3 \qquad (4)$$

where h_s is the depth considered, ρ_s the density, c_{vs} the specific heat of the ocean, E_s is the excess radiation, G_2 and G_3 are the loss of thermal energy by vertical turbulent transport of sensible heat and by evaporation, respectively.

The excess radiation of the ocean, E_s, is given by

$$E_s = F_{12} + \in F_{12}' + F_{13} T_m' + \frac{F_{13}}{2} \beta H' +$$

$$+ F_{14} T_s' + (Q + q)_0 \left[1 - (1 - \delta) \in \right] (1 - \alpha) \qquad (5)$$

where $(Q + q)_0$ represent the possible radiation received on the surface with clear sky, α is the surface albedo, δ is the regression coefficient given by Budyko (1963) and F_{12}, F_{12}, F_{13}, F_{14} are constants given by Adem (1968).

Using (5) on the equation (4) we obtain

$$T_s' = \frac{1}{D_s - F_{14}} \left\{ D_s (T_s')_1 + F_{12} + \in F_{12}' + (Q+q)_0 \left[1 - (1 - \delta) \in \right] (1 - \alpha) - \right.$$

$$\left. - G_2 - G_3 \right\} + \left(\frac{\beta F_{13} A'}{2(D_s - F_{14})} + \frac{F_{13}}{D_s - F_{14}} \right) T_m' \qquad (6)$$

where $(T_s')_1$ is the ocean surface temperature in the previous month.

For the continental layer we have a negligible storage energy, and the thermal energy conservation principle is reduced to

$$E_s - G_2 - G_3 = 0 \qquad (7)$$

For option B, we have the same considerations used in option A, except now the height, H of the troposphere is a constant and the lapse rate, β is a variable with $\beta = \beta_0 + \beta'$ and $\beta' \ll \beta_0$ is a departure of the lapse rate (β_o) and as first approximation is given according with Adem (1968) by

$$\beta = \frac{(T_a - T)}{H} \qquad (8)$$

where T_a and T represents the troposphere temperatures in $z = 0$ and $z = H$, respectively. On this option we applied the same zonally averaged technique to the equations of thermal energy conservation already obtained by Adem (1968), taking for the troposphere the next form

$$K \frac{d^2 T_m'}{d \varphi^2} + F_{25} T_m' = F_{32}(\varphi) \qquad (9)$$

where

$$F_{32}(\varphi) = \frac{1}{F_{23}} \Big\{ F_s + \in F_8' + (F_{10} + \in F_{10}') T_s' + Ib_3 \in +$$

$$+ a_2 I + G_2 + G_5 + \left(\frac{2}{\Delta t}\right) \Big[(F_5)_0 - (F_5)_0/H \Big] (T_m')i +$$

$$+ \left(2 \frac{F_{11}}{H} - F_9 - \left(\frac{1}{\Delta t}\right) \Big[(F_5)_0 \frac{2}{H} - (F_2)_0 \Big] \right) T_s' +$$

$$+ \left(\frac{1}{\Delta t}\right) \Big[(F_5)_0 \frac{2}{H} - (F_2)_0 \Big] (T_s')i - KF_{24} \frac{\alpha^2 \bar{T}_s}{\alpha^2}$$

For the earth surface we have now

$$T_s' = \frac{1}{(D_s - F_{13} - F_{14})} \Big\{ D_s (T_s)_i + F_{12} + \in F_{12} - G_2 - \qquad (10)$$

$$- G_3 + (1 - \alpha)(Q + q)_0 [1 - (1 - \delta) \in] \Big\}$$

where all the coefficients of the Eqs. (9) and (10) are given in earlier studies of Adem (1968). In this last option the surface temperature is not function of mid-tropospheric temperature, Eq. (10), because we have assumed that the ocean surface temperature is equal to tropospheric temperature in $z = 0$, and the lapse rate can be obtained from the next approximation, Adem (1968)

$$\beta' = \frac{2 (T_s' - T_m')}{H}$$

The solutions of the equations (1) and (9) are of the same form, and are given for the following expression:

$$T'_m = \frac{e^{D\varphi}}{2KD}\int_{-\frac{\pi}{2}}^{\varphi} e^{-D\varphi}\,F(\varphi)\,d\varphi - \frac{e^{-D\varphi}}{2KD}\int_{-\frac{\pi}{2}}^{\varphi} e^{D\varphi}\,F(\varphi)\,d\varphi +$$

$$+ K_1\,e^{D\varphi} + K_2\,e^{-D\varphi}$$

where in the option A, $D = (F_{66}/K\,F_{65})^{1/2}$ and $F(\varphi) = F_{67}(\varphi)$. In the option B, $D = (-F_{25}/K)^{1/2}$ and $F(\varphi) = F_{32}(\varphi)$. In both cases the arbitrary constants K_1 and K_2 are determined from the boundary conditions

$$\left.\frac{d\,T'_m}{d\,\varphi}\right|_{-\frac{\pi}{2}} = \left.\frac{d\,T'_m}{d\,\varphi}\right|_{+\frac{\pi}{2}} = 0$$

and represents physically that the zonal wind is zero at the poles (shown as a good approximation by Adem (1962, 1964, 1965)).

RESULTS AND CONCLUSIONS

The prescribed variables of this preliminary model were taken from different sources: the sensible heat by vertical turbulent transport G_2 and the loss of thermal energy by evaporation from the surface G_3 from Jacobs (1951) for the Northern Hemisphere and from Privett (1960) for the Southern Hemisphere. The observed temperatures for the troposphere T_m (at 500 mb) and the sea surface T_s, from the U. S. Navy Marine Climatic Atlas of the World, Vol. VIII, the surface albedo $\propto$ from Possey and Clapp (1964), the cloudiness $\in$ from Landsberg (1945), the possible radiation and the regression coefficient δ from Budyko (1963) and the short wave absorption coefficients, a_2 for the troposphere and b_3 for the clouds from London (1957).

The solutions of the mid-tropospheric temperature from the equation (11) for the model A and B are represented in the figures 1a, 1b, 1c and 1d, for the periods of March-April-May, June-July-August, September-October-November, and December-January-February, respectively. In each figure the observed temperature at 500 mb, is represented by dashed line. The computed mid-tropospheric temperature for option A, when we assumed an oceanic earth is represented by dotted line, and in a continental earth by cross-wise line. For the option B, the computated mid-tropospheric temperature for an oceanic earth is represented by the continuous line and for the continental case by dotted-dashed line.

For both hemispheres we use the same constant exchange coefficient, similar to Adem's Hemispheric Model (1963), even when this hypothesis is not quite convenient and it should be considered a variable, in the same way the term of advection of the thermal energy, due to the mean wind should be incorporated on the equations. On this paper as a first approach and observing that the calculated mid-tropospheric temperature and the ocean temperatures give good approximations to the observed values, will be kept it for our purpose on the same form and left to a next paper the improvement of this considerations.

For option A and for all the seasons, as was expected, we obtain similar solutions to the Adem's results (1963). For the summer hemispheres (figures 1b, 1d) the computed temperature of the troposphere in a continental earth is warmer than under a consideration of an oceanic earth, due that the continents are warmer and give off greater amounts of thermal energy to the troposphere. For the winter hemispheres assuming an oceanic earth we obtain warmer tropospheric temperatures than for a continental earth because the oceans are warmer than the continents and increase the flux of thermal energy from the ocean to the troposphere.

In all the figures (1a, 1b, 1c and 1d) we can observe that our solutions give a good simulation of the observed temperatures, but in special the option A is a better approximation to the real case. The greater differences between the observed and the calculated temperature were found for the continental case in option B, obtaining colder solutions than option A due to the assumption $T_a' = T_s'$ wich produce a greater tropospheric loss of thermal energy by long wave radiation, than the real case.

In the figures 2a, 2b, 2c and 2d are shown the observed ocean surface temperature (dashed line), the computed temperatures of the ocean surface for the options A and B (continuous line), the computed surface continental temperatures for the option A (cross-wise line), for the option B (dotted and dashed line).

The computed ocean surface temperatures for both options give similar results due that the storage energy plays a more important rule that the others factors considered, and for this reason give the best approximation to the observed temperature, obtaining also similar values to Adem's

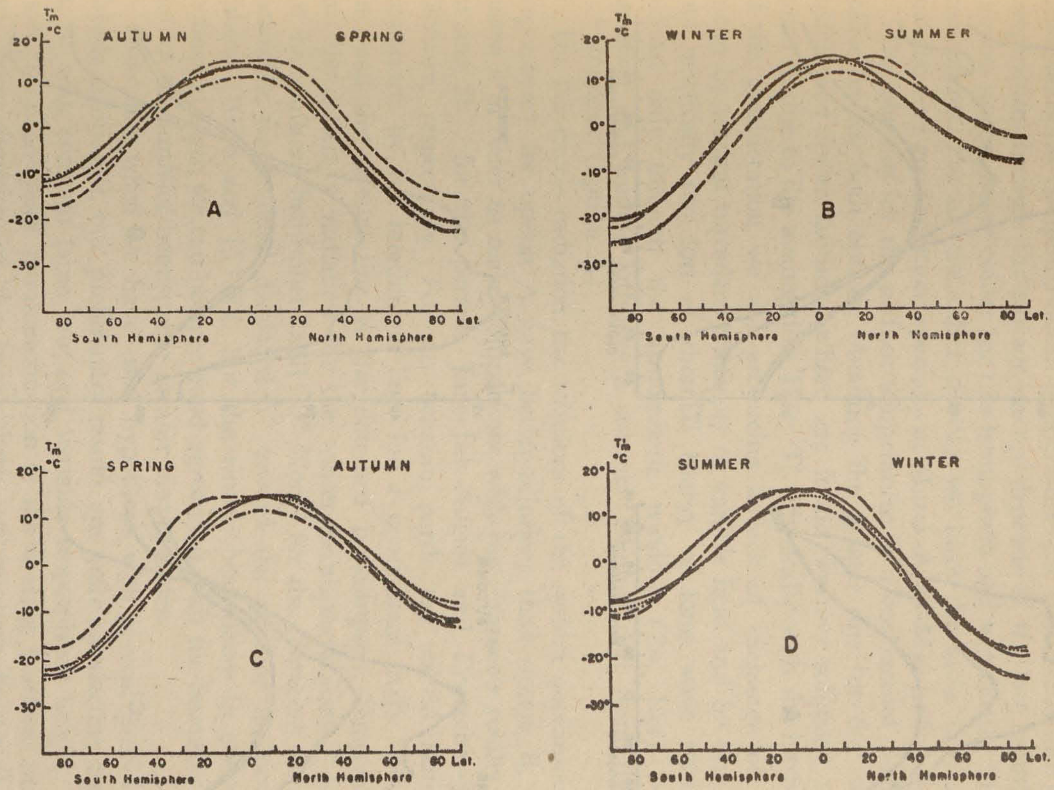

Fig. 1. The computed quarterly mid-tropospheric temperatures. For option A the dotted line and cross wise line and for option B the continuos line and dotted dashed line represents respectively the temperatures in an oceanic and continental earth assumption. The observed temperature at 500 mb is represented by the dashed line.

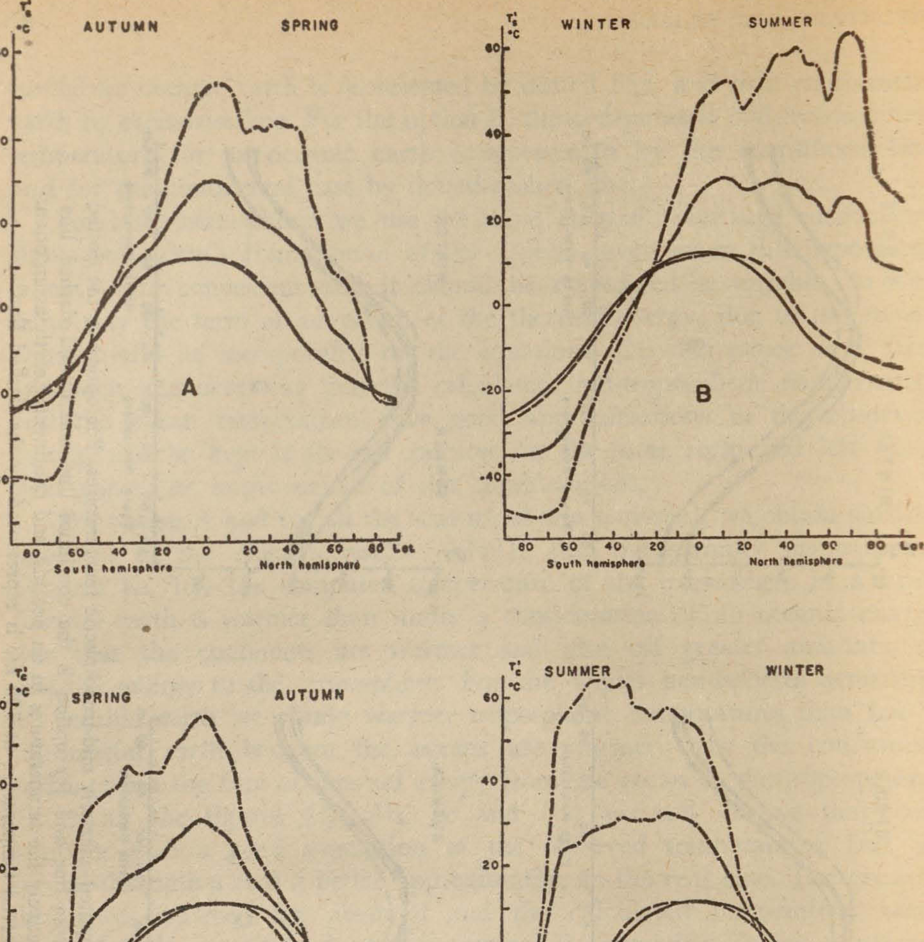

Fig. 2. The computed quarterly surface temperatures. The continuous line represents for both options the oceanic temperatures. For option A the cross wise line and for option B the dotted and dashed line represents the temperatures in an oceanic and continental assumption. The dashed line is the observed ocean temperature.

hemispheric results. If we observe the figures 2b and 2d for the summer hemispheres the computed ocean temperatures are colder than the observed temperatures because the storage energy depends of the last month of the previous season, being colder for this hemisphere and warmer for the winter hemispheres. For all the other seasons we have the same considerations and also very good solutions specially in March-April-May period figure 2a.

The solutions for the surface temperature in a continental earth shown differences for both options, obtaining the greater one for the case B in middle and lower latitudes where are found warmer solutions than for option A, due to the assumption $T'_a = T'_s$. Physically with the introduction of this consideration we are producing a lack of exchange of thermal energy by vertical turbulent transport of sensible heat and by evaporation, and practically the loss of thermal energy of long wave radiation is realized only through the atmospheric window (8μ, 13μ) obtaining for lower and middle latitudes a warmer solution that form the model β = constant (option A).

For the excess radiation the solutions of the system (ocean-continent-troposphere) for option A gave better solutions than option B, and we choose it in order to make comparisons with the Simpson's results (figures 3a and 3b), for the periods June-July-August and December-January-February, respectively. For an oceanic earth the excess radiation is represented by the continuous line, for a continental earth with dotted line, and the dashed line is the obtained by Simpson. Simpson found that the deficit of radiation for the winter hemisphere started 15°South for the Southern hemisphere and 20° North for the Northern hemisphere meanwhile we founded displaced 5° toward the equator for both hemispheres (10° S and 15° N). For the winter hemisphere in oceanic and continental earth we can observe good agreement with the Simpson's values and for the summer hemisphere greater discrepancies.

Even that when we have used hypothesis with several possible errors already mentioned, our preliminary results are quite satisfactory for model A, i.e. with constant lapse rate and variable tropospheric height. For the model B an adequate parameterization of the heating functions are necessary, being function of the tropospheric temperature in $z = 0$ or the temperature near the surface, with the object to disappear the effect introduce by the hypothesis $T'_a = T'_s$ mainly for the continental model. The changes in thermal energy due to variations in the lapse rate for the troposphere and oceans are practically negligible, because the variations in a long term of the lapse rate are very slow and don't produce big

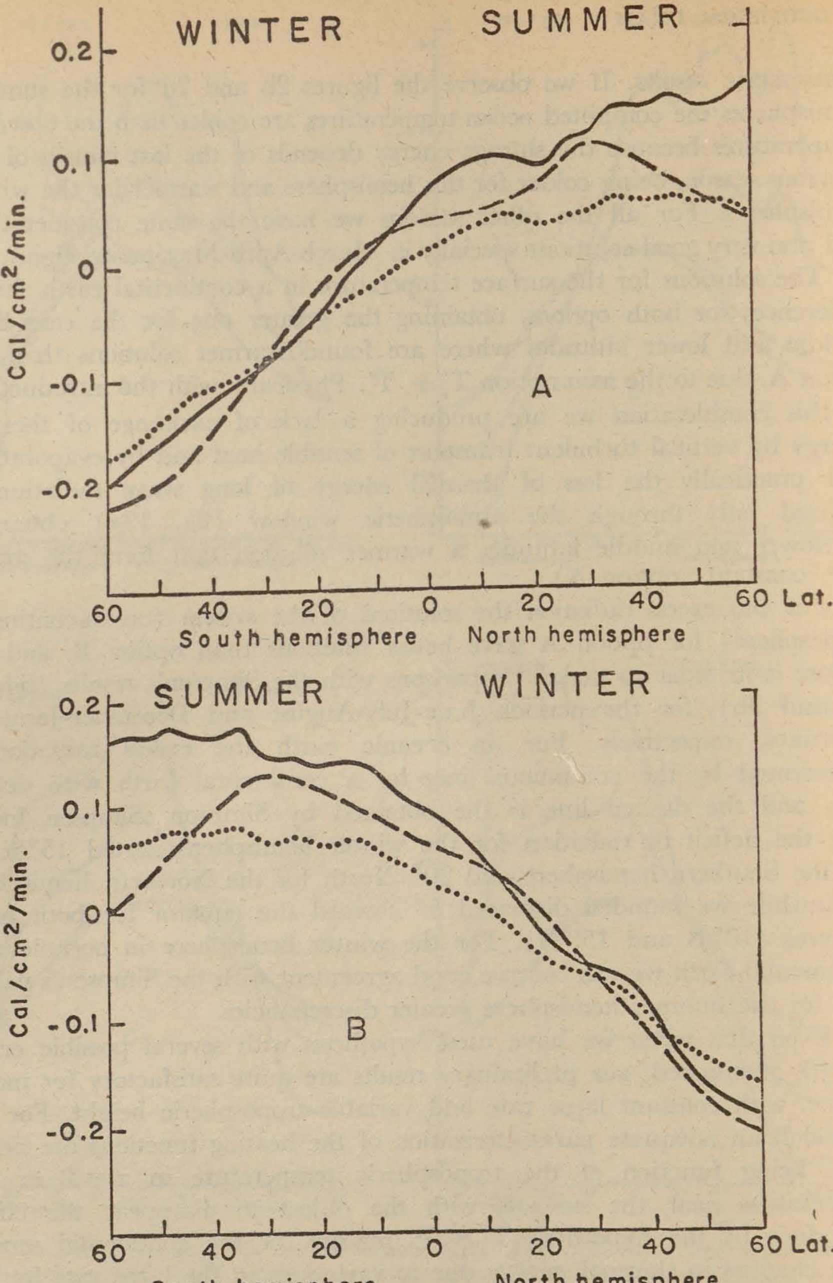

Fig. 3. The computed excess radiation for June-July-August and December-January-February periods. The continuos and dotted line represents the excess radiation in an oceanic and continental earth respectively. The dashed line is the excess radiation as given by Simpson.

changes on the temperature fields of the ocean and troposphere such as we can observe in the figures.

We think that the discrepancies between the temperatures calculated and the observed will reduce with the incorporation of the factors mentioned and be able to obtain a more realistic results.

ACKNOWLEDGEMENT

The authors wish to express their appreciation to Dr. J. Adem, for his teaching's and helpful suggestions. The numerical work was carried out at Centro de Servicio de Cómputo of the Universidad Nacional Autónoma de México.

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