*Atmósfera (1995)*, 8, *pp. 23-34*

# Recent experiments on monthly weather prediction with the Adem Thermodynamic Climate Model, with especial emphasis in Mexico

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(Manuscript received July 7, 1994; accepted in final form Sept. 6, 1994)

RESUMEN

Una versión revisada del Modelo Termodinámico de Adem se usa para hacer predicciones de las anomalías de temperatura y precipitación en el Hemisferio Norte. Los datos de inicialización son la temperatura de la superficie del océano y la temperatura del aire en el nivel de los 700 milibarios, en el mes anterior.

Se llevaron a cabo predicciones para el periodo diciembre 1981 a noviembre 1983 y fueron verificadas sobre la República Mexicana. Los resultados muestran cierta habilidad en la predicción de las anomalías de temperatura y precipitación.

Los experimentos muestran que la temperatura de los océanos tiene un papel importante en las predicciones y sugieren que la existencia de temperaturas más altas que las normales en el Golfo de México y en las regiones cercanas del Océano Pacífico pueden producir en México, precipitaciones abajo de las normales, y posiblemente favorecer una situación de sequía.

Experimentos de sensibiblidad sobre el cambio de albedo de superficie debido a los cambios de la vegetación muestran que hay importantes variaciones regionales en la temperatura y la precipitación, y por consiguiente, se sugiere la necesidad de su incorporación en el modelo de predicción climática mensual en esta región.

ABSTRACT

A revised version of the Adem Thermodynamic Model is used to make mean monthly predictions of temperature and precipitation anomalies in the Northern Hemisphere. The initialization data are the sea surface and 700 mb temperatures in the previous month.

Predictions for the period December 1981 to November 1983 were carried out and verified over the Mexican Republic. The results show some skill in the prediction of temperature and precipitation anomalies.

The experiments show that the ocean temperatures play an important role in the predictions, and it may be suggested that above normal temperatures in the near Pacific Ocean regions and in the Gulf of Mexico may produce below normal precipitation anomalies in Mexico and possibly favour a drought situation.

Sensitivity experiments on the change of surface albedo due to changes in vegetation, show important regional variations in temperature and precipitation and therefore, suggest the necessity of its incorporation in the model for monthly climate prediction in this region.

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## Introduction

The first energy balance model in which the large scale horizontal turbulent transport was parameterized by the use of a Defant (1921) type "austausch" coefficient, was developed by Adem (1962, 1963). This model was adapted to carry out monthly predictions of temperature in the Northern Hemisphere, while the senior author was in the Extended Forecast Division of the National Meteorological Center (NMC), which was headed by J. Namias. The sea surface temperature anomalies and the snow and ice conditions, which were used subjectively in the preparation of the monthly outlook, were incorporated in the model together with the 700 mb temperature anomalies as initial conditions for the predictions. The first results of the model verified over the contiguous United States were encouraging (Adem 1964a, 1964b, 1965, 1970; Adem and Jacob, 1968).

In the eighties, experiments were carried out in the Lamont Geological Observatory to improve the skill of the model in the contiguous US (Adem and Donn, 1981; Donn, *et al.*, 1986). Furthermore, in the former Soviet Union, Mamedov (1986, 1989), also developed and applied thermodynamic models for temperature prediction with some success.

In the original Adem model, the Northern Hemisphere NMC grid abridged to 512 points, with a grid distance of 817 km, was used. This grid is not adequate to carry out experiments on a regional basis in such countries as Mexico, where more spatial resolution is required. For this reason a model with the full NMC grid with a grid distance of 408.5 km and 1977 points, has been developed and applied in the numerical experiments described in this paper on the monthly prediction of 700 mb and surface temperatures, and precipitation in Mexico ( Ruiz-Barradas, 1991).

## Brief description of the model

The model is described in a recent review article (Adem, 1991). It consists of an atmospheric layer of about 9 km thickness, including a cloud layer, an oceanic layer of 60 m in depth, and a continental layer of negligible depth. It also includes a variable layer of ice and snow over the continents and oceans.

The conservation of thermal energy is applied to the atmospheric layer and to the ocean (or continental layer), yielding two predicting equations that contain the mean atmospheric temperature, the surface temperature, and the heating and transport terms as variables.

The other conservation laws are used diagnostically, together with semi–empirical relations, to parameterize the heating and transport terms. These parameterizations, described by Adem (1979), provide additional equations, which are combined with the thermal energy equations to yield a system of simultaneous equations. These are solved with an implicit integration method that gives the surface ocean and continental ground temperature, the 700 mb temperature, the heating by short– and long–wave radiation, and the horizontal heat transports by mean wind and transient eddies. The model also includes as variables computed internally: the anomalies of evaporation at the surface, sensible heat given off from the surface to the atmosphere, heat gained by condensation of water vapor in the clouds, and the horizontal extent of cloudiness.

The surface albedo can also be carried out as variable by adjusting the boundary of snow and ice so that it coincides with a surface isotherm (currently 0°C). This has been done in long–term integrations (Adem, 1991). The horizontal transport of heat by mean winds is parameterized in the way described by Adem (1970). The heat gained by condensation of water vapor at the clouds is parameterized with the empirical formulas of Clapp *et al.* (1965), which express the anomaly of the heat gained by the condensation of water vapor in the clouds as a linear function of the anomalies of the mid–tropospheric temperature and its horizontal derivatives.

The coefficients of this linear function depend on the season and on the geographic position. The precipitation anomalies are predicted in the model assuming that they are proportional to the anomalies of heat gained by condensation of water vapor in the clouds, which are computed internally in the model, and therefore interact with the temperature field.

The variables in the equations are averaged over a month, so that the transient eddies horizontal transport of heat in the atmosphere can be parameterized using an austausch coefficient equal to 3 to $5 \times 10^{10}$ cm$^2$ sec$^{-1}$. According to Defant (1921), these values correspond to the scale of migratory cyclones and anticyclones of the middle latitudes.

The procedure used in the predictions is to first compute the normal values for a particular month with the use of the observed normal (long term average) values for the previous month; then the prediction of actual values for the month is made from the observed values of the previous month as initial conditions. The predicted anomalies then are obtained by subtracting the normals computed for the given month from the actual computed values.

The initialization variables are:

a) The ocean surface temperature in the previous month.

b) The 700 mb temperature in the previous month.

c) The albedo based on snow and ice distribution in the last week of the previous month.

We use the surface ocean and 700 mb temperatures prepared by the NMC and the snow and ice data prepared by NESS–NOAA. For these data, normal albedo maps adequate for use in the model have been prepared (Donn and Adem, 1981).

## Numerical experiments

Figure 1 shows the region of integration and the position of the grid points. In the experiments reported here, the anomalies of snow and ice albedo of the previous month are neglected.

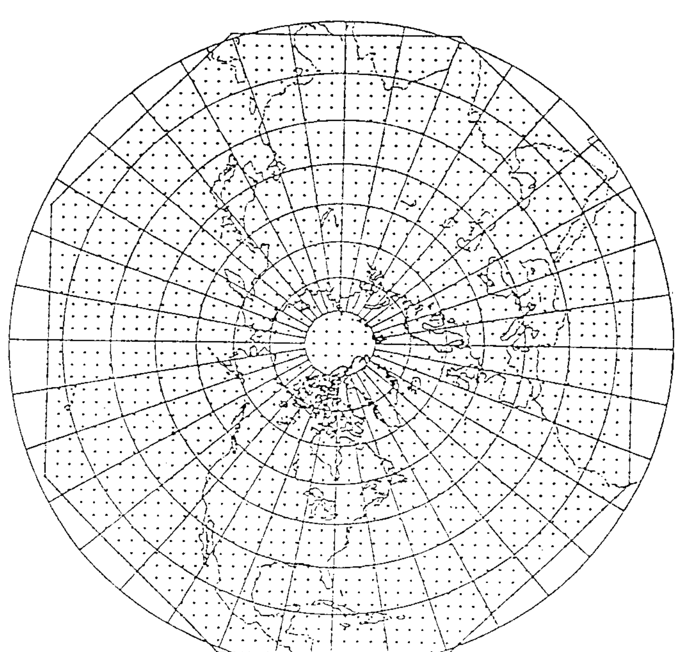

Fig. 1. The region of integration and the grid points used in the model.

As an illustration we show in Figure 2 surface temperature anomalies predicted for December 1983, in tenths of Celsius degrees, for the quarter of the integration region which includes Mexico. It is interesting to notice that the positive temperature anomalies of the Pacific and Atlantic Oceans in the previous month (November 1983), not shown, are associated to important positive anomalies in the Mexican Republic. Figure 3 shows the predicted anomalies of precipitation for the same month which are negative over Mexico and over the adjacent parts of the ocean.

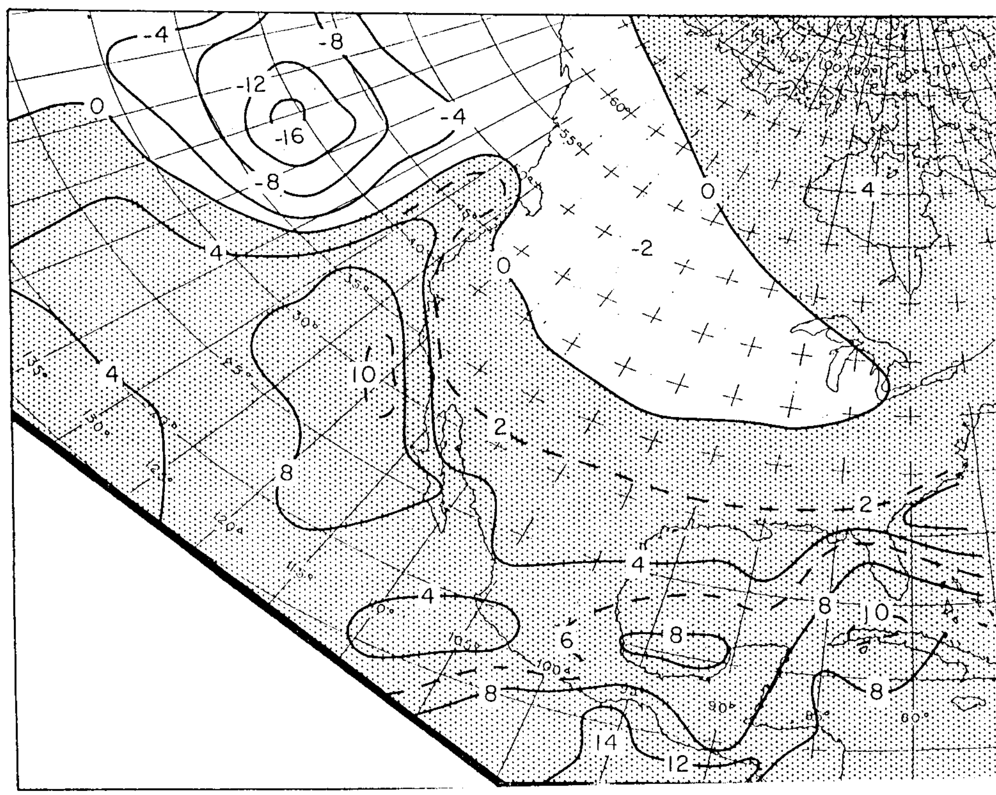

Fig. 2. Predicted surface ocean and continental ground temperature anomalies for December 1983, in tenths of Celsius degrees. In all of the figures, shaded areas indicate above normal and unshaded, below.

The results for June 1982 are in the next three figures. Figure 4 shows in part A the predicted anomalies of surface ground temperature and in part B the observed surface air temperature. Figure 5 shows the 700 mb temperature anomalies predicted by the model (part A), and observed (part B). And Figure 6 shows the sign of the precipitation anomalies computed (part A) and observed (part B).

From Figures 4, 5 and 6 we see, for June 1982, that the sign of the predicted anomalies is predominantly positive for the temperature, and negative for the precipitation; and in this particular case the signs have been correctly predicted, as can be seen by comparison of parts A with parts B.

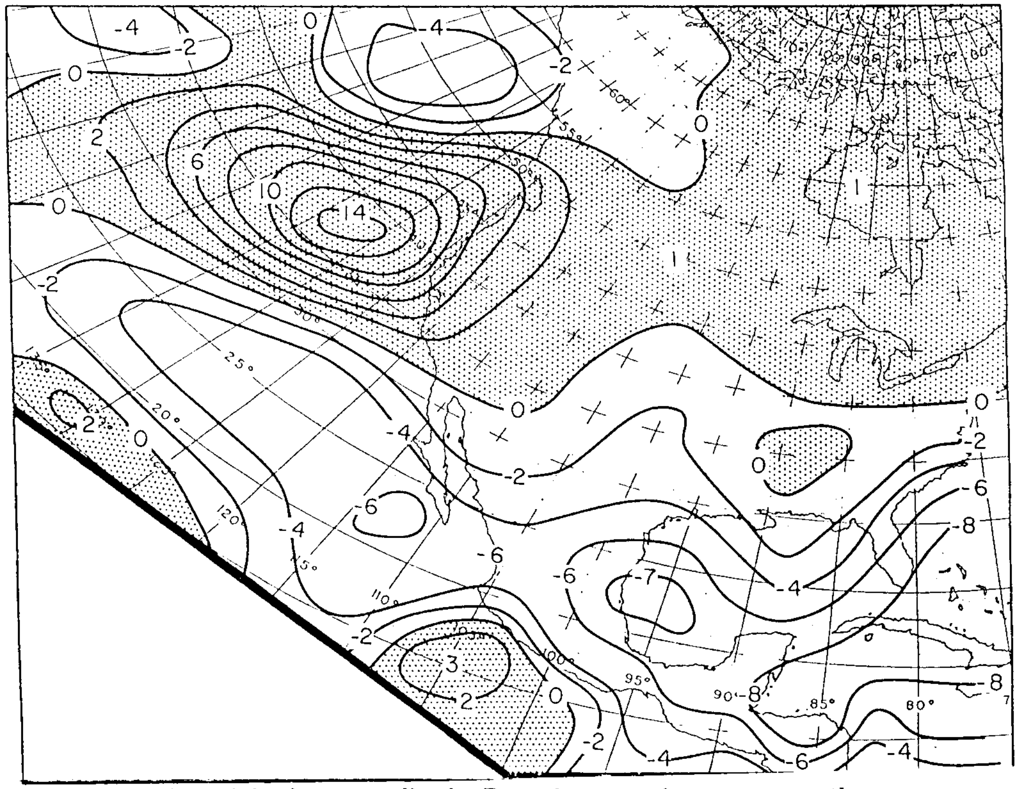

Fig. 3. Predicted precipitation anomalies for December 1983, in mm per month.

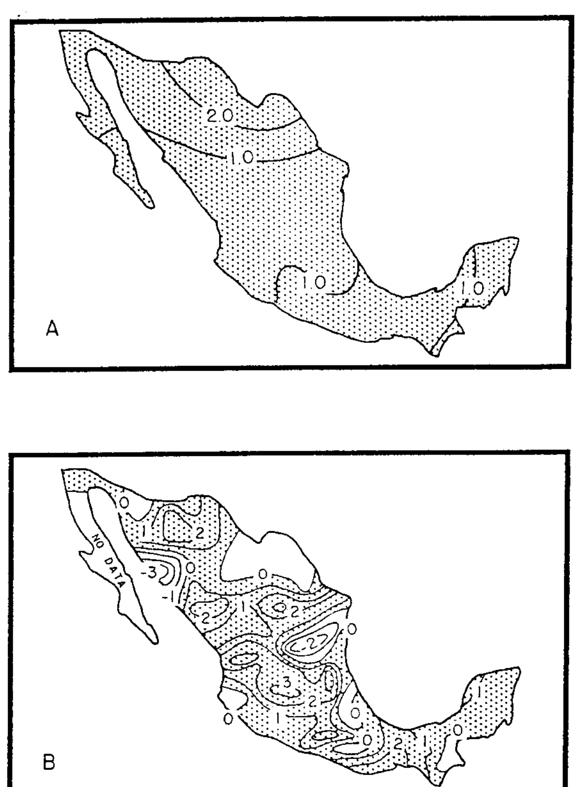


Fig. 4. Surface temperature anomalies (°C) for June 1982: A) predicted by the model; B) observed.

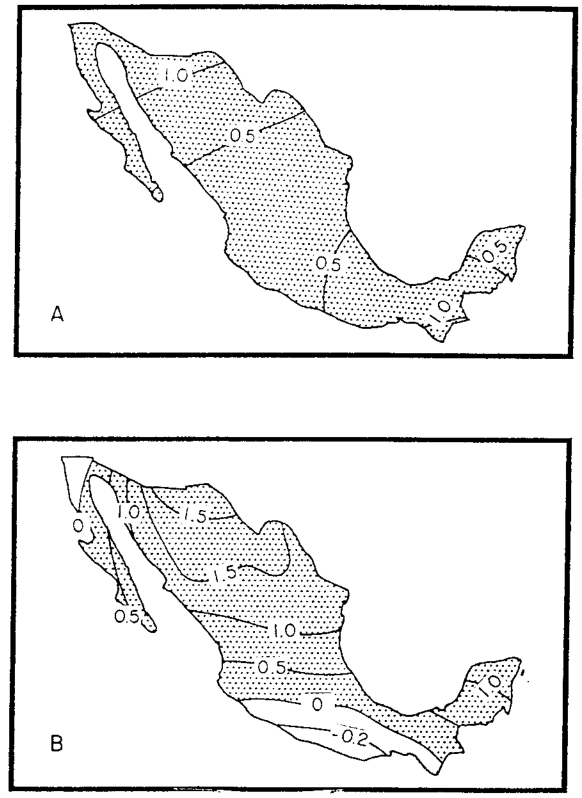


Fig. 5. The 700 mb temperature anomalies (°C) for June 1982: A) predicted by the model; B) observed.

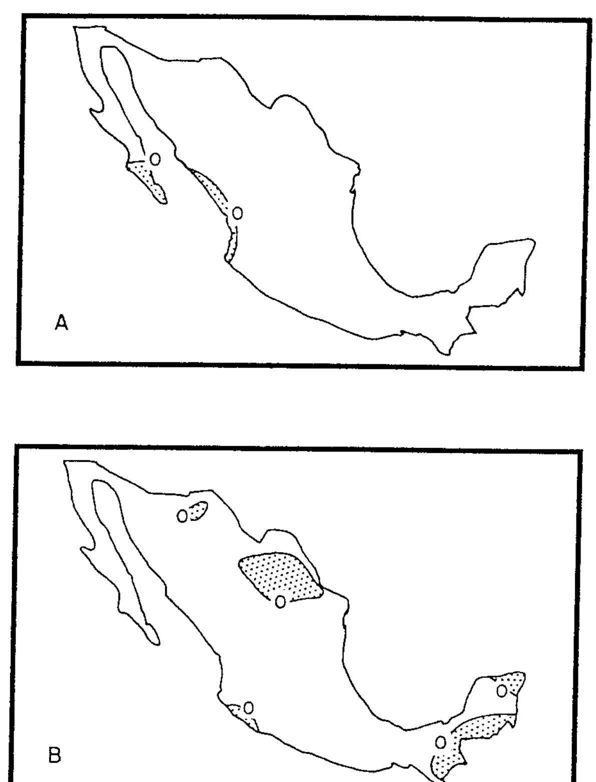


Fig. 6. The sign of the anomalies of precipitation for June 1982: A) predicted by the model; B) observed.

Table 1 shows the percentage of signs correctly predicted of the 700 mb temperature anomalies for the 24–month period from December 1981 to November 1983 in the Mexican Republic, where the initial conditions were the surface ocean and 700 mb temperature anomalies, and the normal surface albedo. This table shows that for the whole period, the model predicts correctly 73.4% of the signs, while persistence, which is the control prediction used, predicts correctly only 68.3%. Therefore the predictions with the model exceed persistence by 5.1%. Table 1 shows that the worst predictions of the model occur during winter when persistence exceeds the model by 8.0 percent.

Table 1. Percentage of signs correctly predicted by the persistence and by the model, and its difference, of the 700 mb temperature anomalies, for the 24–month period December 1981 to November 1983 in the Mexican Republic.

| Season | Persistence | Model | Difference |
|---|---|---|---|
| Winter | 74.7 | 66.7 | -8.0 |
| Spring | 68.9 | 73.3 | 4.4 |
| Summer | 67.4 | 67.4 | 0.0 |
| Fall | 62.3 | 86.2 | 23.9 |
| Annual | 68.3 | 73.4 | 5.1 |

Table 2 shows the percentage of signs correctly predicted of the precipitation anomalies for the same 24–month period from December 1981 to November 1983 and with the same initial conditions than those used to produce the results given in Table 1. For the whole period, the model predicts 53.8% of the signs of the anomalies of precipitation, which is 1.5% smaller than the prediction by persistence. However, for the summer, the model predicts correctly 61.6% of the signs of the anomalies which is 15.2% larger than the percentage correctly predicted by persistence. This result shows that the model has some good skill for predicting the precipitation anomalies in the rainy season.

Table 2. Percentage of signs correctly predicted by the persistence and by the model, and its difference, of the precipitation anomalies for the 24–month period December 1981 to November 1983 in the Mexican Republic.

| Season | Persistence | Model | Difference |
|---|---|---|---|
| Winter | 56.5 | 49.9 | -6.6 |
| Spring | 60.9 | 51.5 | -9.4 |
| Summer | 46.4 | 61.6 | 15.2 |
| Fall | 57.2 | 52.1 | -5.1 |
| Annual | 55.3 | 53.8 | -1.5 |

### 1. Effect of the surface ocean temperature anomalies in the predictions

Table 3 is as Table 1 except that in this case only the sea surface temperature anomaly is used as initial condition for the predictions. In this case the model is capable of predicting 72.7% of the signs of the 700 mb temperature anomalies, which is 4.4% higher than the control prediction, and 0.7% smaller than the case when the 700 mb temperature anomalies are also included as initial data. This result shows that the ocean temperature anomalies play the most important role in the predictions, possibly due to the narrowness of the Mexican territory.

Table 3. Percentage of signs correctly predicted by the persistence and by the model, and its difference, of the 700 mb temperature anomalies for the 24-month period December 1981 to November 1983 in the Mexican Republic, when only the sea surface temperature anomaly is used as initial condition.

| Season | Persistence | Model | Difference |
|---|---|---|---|
| Winter | 74.7 | 66.7 | -8.0 |
| Spring | 68.9 | 71.8 | 2.9 |
| Summer | 67.4 | 66.0 | -1.4 |
| Fall | 62.3 | 86.2 | 23.9 |
| Annual | 68.3 | 72.7 | 4.4 |

## 2. Effect of the surface albedo due to changes in the vegetation

In previous applications the surface albedo has influenced the predictions through the variations in snow and ice, and in this way important anomalies have been predicted in middle latitudes as has been verified over the contiguous US (Adem, 1965, Adem and Donn, 1981). It is evident that the influence of the snow and ice effect decreases towards the lower latitudes, and in the experiments described in this paper, we have neglected such effect.

In order to evaluate the importance of the changes in surface albedo due to the variations in vegetation, we have carried out experiments in which two surface albedos over the Mexican Republic are used: one corresponding to the dry season and the other to the wet season.

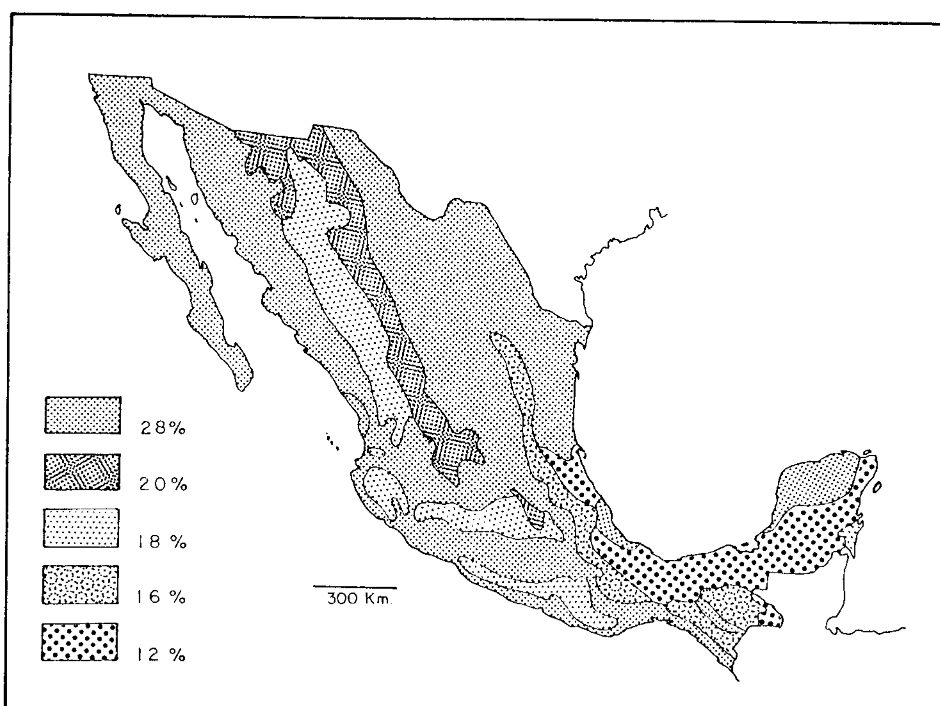


Fig. 7. Albedo for the dry season in Mexico, in percent.

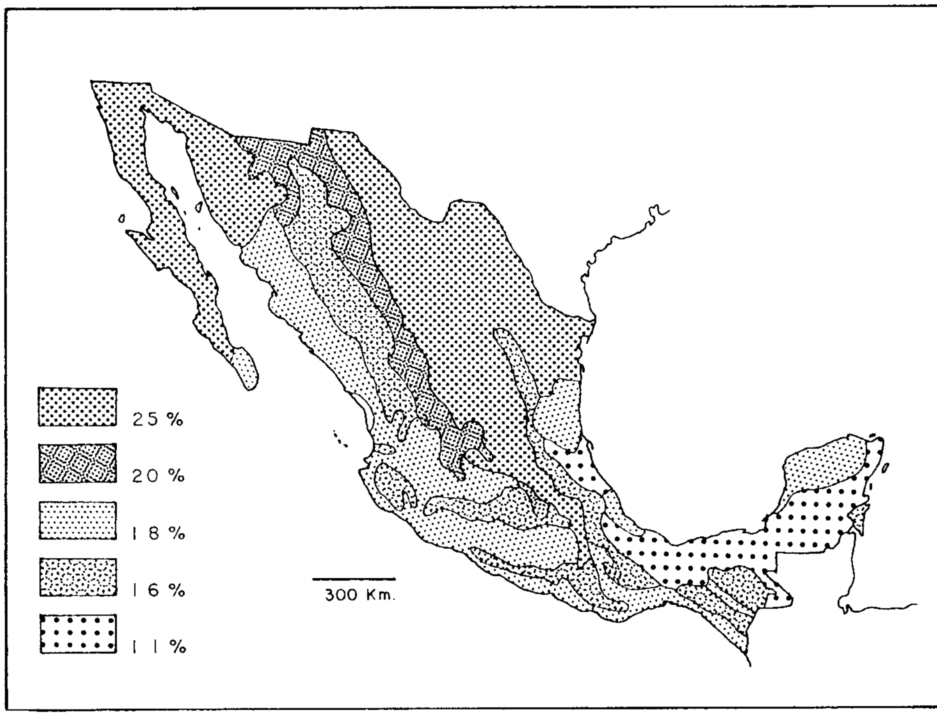


Fig. 8. Albedo for the wet season in Mexico, in percent.

The charts of albedo for the dry and the wet seasons are shown in Figures 7 and 8, respectively. They were prepared by Barradas (1990), based on the distribution of natural vegetation determined by Rzedowski (1981).

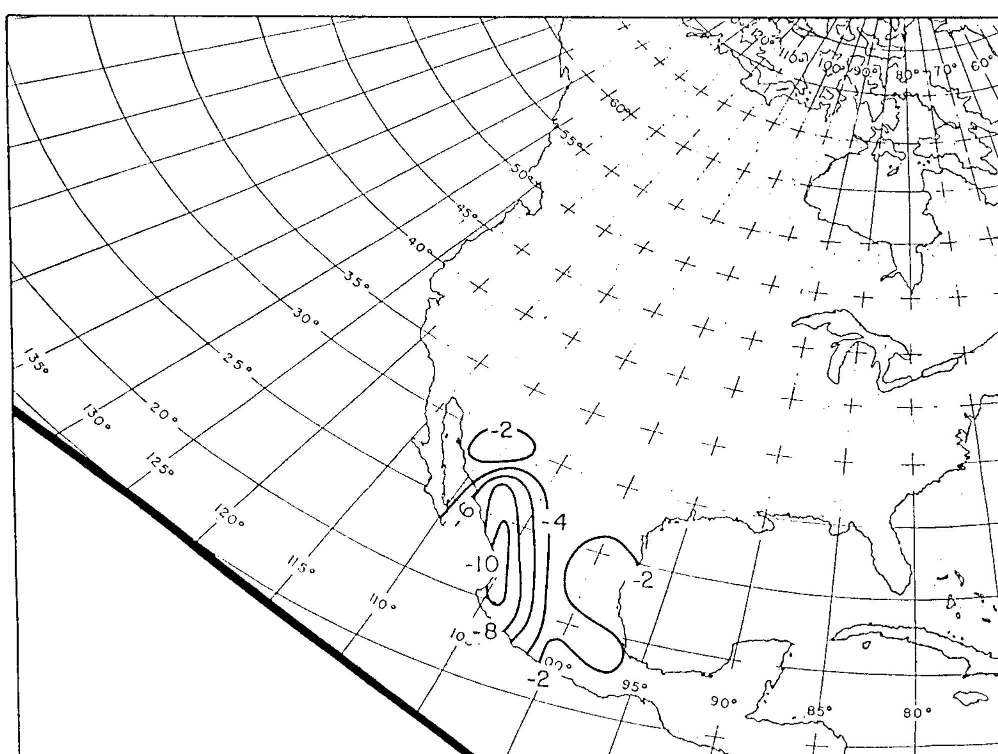


Fig. 9. Albedo for the wet season minus albedo for the dry season in Mexico, in percent.

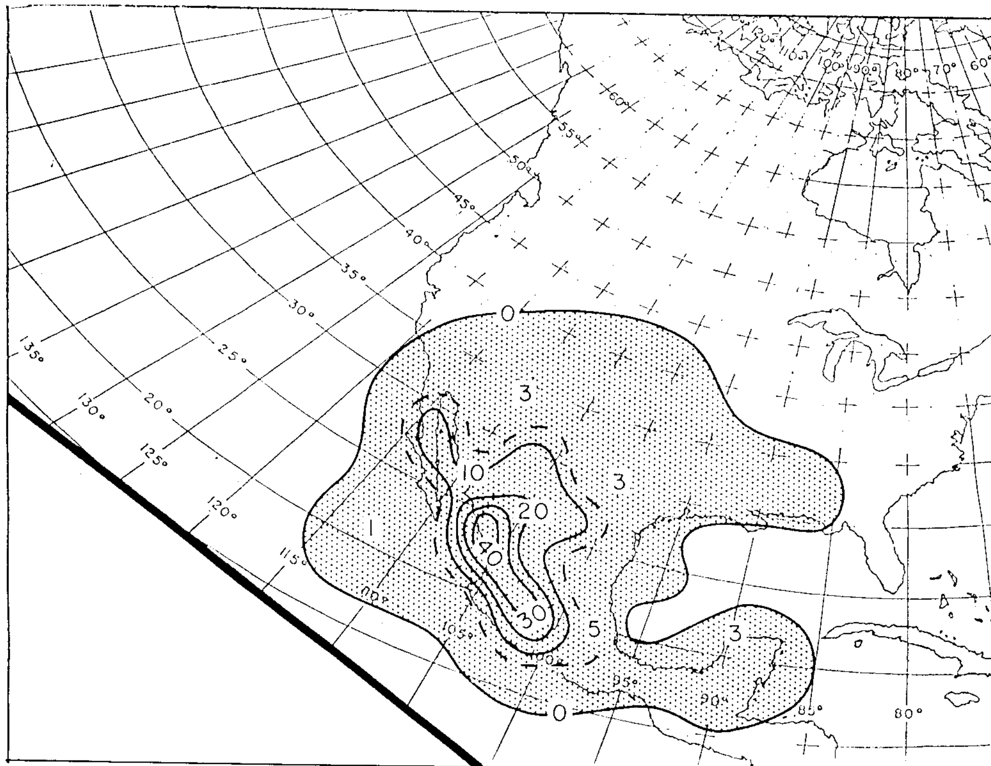

Fig. 10. Increase of surface temperature for June, in tenths of Celsius degrees, due to the change in surface albedo associated with the change of vegetation from the dry season to the wet season.

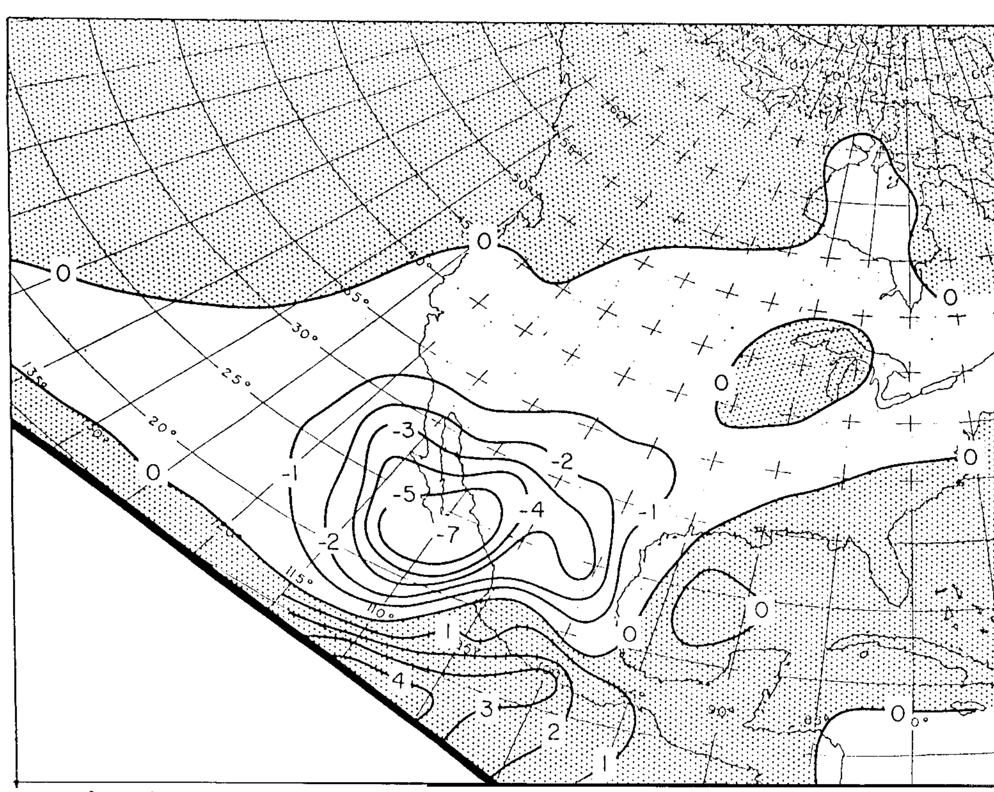

Fig. 11. Increase of precipitation for June due to the change in surface albedo associated with the change of vegetation from the dry season to the wet season, in mm per month.

In the numerical experiments we use the surface normal albedo of Posey and Clapp (1964), except in the Mexican Republic where Barradas (1990) values of dry and wet albedos are used. In the runs the dry albedo is used for the run of the normal case, and the wet one for the abnormal, so that the anomalies are negative, as shown in Figure 9. In this experiment we use normal initial conditions both for the normal and the abnormal cases except for the albedo, which is introduced as the only forcing as described above.

The surface temperature and precipitation anomalies generated by the model for June are shown in Figures 10 and 11, respectively. Both anomalies are significant, and this sensitivity experiment shows that the surface albedo variations due to changes in vegetation could possibly add a new initial condition for the monthly climate prediction.

## Final remarks and conclusions

1. The experiments for 24 predictions verified over Mexico show good skill in the percentage of signs correctly predicted in the 700 mb temperature anomalies. The worst predictions occur in winter. The predictions of 700 mb temperature using only the ocean temperatures as initial values also yield good skill, showing their importance in the predictions.
2. The best skill for precipitation prediction is obtained in summer (the rainy season), when the Mexican monsoon dominates the weather, and the influence of the Gulf of Mexico is of the utmost importance. The experiments suggest that warm temperatures in the Gulf of Mexico and in the Pacific Ocean regions contiguous to Mexico, could possibly produce a drought situation with the possibility of predicting it with the model. However, we cannot generalize this conclusion, because we are dealing with a small number of cases, which are included in a period of strong "El Niño" and Southern Oscillation. Therefore more experiments for other ENSO and non-ENSO years are needed to generalize this suggestion.
3. Sensitivity experiments show that the change of vegetation from the dry to the wet season produces anomalies of surface temperature, due to the change of surface albedo as large as $1^\circ$ to $3^\circ$C in a considerable part of Mexico, showing the importance of incorporating this factor in the predictions.
4. The improvement in the treatment of the dynamics in the Adem climate thermodynamic model by the use of the vorticity equation has yielded preliminary results, which seems to increase the skill of the predictions, specially in winter (Mendoza, 1993).

## Acknowledgements

We are indebted to Jorge Zintzún and Alejandro Aguilar for the computational technical support, to Ma. Esther Grijalva and Thelma del Cid for their help in the preparation of the manuscript, and to Rodolfo Meza for his help in the preparation of the figures.

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