SENSITIVITY STUDIES OF THE 'G.C.M.' SIMULATIONS TO CLOUDINESS SPECIFICATION

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1. INTRODUCTION

The cloud generation schemes presently used in general circulation models were originally designed in order to predict the release of latent heat in the atmosphere, as well as the transport of sensible heat, water vapour and momentum, associated with convection. But cloudiness also modifies the energetics of the atmosphere because it changes the solar and infrared radiative fluxes. To take the problem into account, most GCMS now try to predict in a simple way the percentage cover of cloudiness, either as a function of large scale variables (such as relative humidity, vertical velocity or vertical stability) or in relating the occurrence of cloudiness to the occurrence of precipitation. (Somerville et al., 1974 ; Gates and Schlesinger, 1977 ; Washington and Williamson, 1977 ; Wetherald and Manabe, 1980 ; Slingo, 1980 ; Geleyn, 1980). Although some progress has been made, especially in the prediction of stratus, stratocumulus, and low convective clouds (e.g. Moeng and Arakawa, 1980 ; Wakefield and Schubert, 1981 ; Ramanathan and Dickinson, 1980) and in the direction of predicting the cloud liquid water content and the cloud optical properties (Sasamori, 1975 ; Sundquist, 1980), the problem of predicting accurately in GCM the cloudiness percentage cover, as well as the cloud vertical distribution or the cloud optical properties, remains largely unsolved. This is especially true for the deep convective clouds, where the cloud fraction predicted by convective schemes (such as Kuo-scheme) corresponds only to the entraining clouds and considerably underestimates the actual cloud fraction.

As a result of this complexity, most general circulation sensitivity studies have focused on the problem as to whether or not it was important to have a good description of the cloud cover in GCM, and whether it was necessary to predict rather than to prescribe it. This has been done in a climate perspective, in order to see whether cloudiness could enhance or diminish the climate variations due to a modification of external boudnary conditions such as the solar constant (Wetherald and Manabe, 1980), the CO_2 concentration (Manabe and Wetherald, 1980) or the sea surface Schneider et al., 1974). More specifically a number of studies have also tried to analyse the role of a given change in cloudiness on the general circulation.

Different comparisons have been made :

- zonal prescribed cloudiness versus transparent atmosphere (Hunt, 1978) ;
- zonal climatology versus "geographical" distribution of cloudiness (Meleshko and Wetherald, 1981) ;
- fixed cloudiness (in time) versus predicted cloudiness (Schukla and Sud, 1981) ;
- reference cloudiness versus cloudiness transparent in the infrared or the solar range (Herman et al., 1980) ;
- variations of the cloud base height or of the cloud optical properties (Hunt, 1982) ;
- zonal climatological cloudiness versus predicted cloudiness (Le Treut and Laval, 1983) ;
- removal of convective clouds (Tiedtke,1983).

All these experiments are different in their nature, and have been made with different models. Therefore their results are difficult to compare, and many more studies are needed to assess the role of cloud-radiation interaction. We will present here some new experiments we have done with the L.M.D. GCM.

2. THE MODEL ; THE EXPERIMENT

A detailed description of the L.M.D. GCM may be found in Laval, Le Treut and Sadourny (1981) and in its companion paper Laval, Sadourny and Serafini (1981). But, unlike in those papers, we have used here a global version of the model with realistic orography and a finer resolution (64 points in longitude, 50 points in latitude, and 11 levels).

The reference version for our experiments has been described in Le Treut and Laval (1983) (and referenced there as well as hereafter as IC experiment).

The experiment starts from the 12th of June 1979 and is carried out for 50 days, with the boundary conditions of a July climate. Throughout the integration the cloud fraction is predicted over three fixed levels. The occurrence of cloudiness is linked to the occurrence of precipitation. Whenever supersaturation occurs, we predict 100 % cloudiness. For Kuo-type convection we use the fractional area of active cumulus predicted by the scheme. Cloudiness is then split over the three fixed levels and a simple spatial smoothing is done. The cloudiness climatology for the last 30 days of the experiments is displayed in Fig. 1.

From the same initial state, we have carried out two other 50 day integrations :

- For the first one (hereafter referenced as FGC experiment), we have used the fixed geographical cloudiness distribution averaged for the last 30 days of the reference run.

- For the second one (hereafter referenced as FZC experiment), we have used a zonal average of this climatology.

As we have not yet achieved a precise study of the variability of the reference integration, we will use here, in order to estimate the significance of our results, two integrations very similar to the IC experiments (but with some modification of the albedo over the Sahel).

In what follows, they will be referred to as IC2 and IC3. All the analysis we show correspond to the last 30 days of the various integrations.

3 RESULTS

3.1 Precipitations

A first measure of the feedback effects due to the cloud-radiation interaction will be given by the precipitation distribution. We have displayed in Figure 2 the precipitation distributions for the IC, FGC and FZC experiments, in the Tropics. In both integrations where cloudiness was prescribed rather than predicted, the convective regions over the oceans have diminished, especially over the Atlantic. On the contrary, the precipitation has increased over the Central Africa. These results are in accordance with those of Slingo (1980) or Herman (1980). The largest differences in the precipitation distributions are found in South East Asia. Their significance is difficult to assess due to the large variability of the precipitations in that region.

3.2 Temperatures

We have displayed in Figure 3.a the map of the differences of ambient temperature between the IC and FGC experiments. Although the mean solar flux distributions are almost the same, we may see that large differences of temperature occur. Over Central Africa, the diminution of temperature in the FGC experiment seems to be linked to an increase of evaporation (not shown here), which results from the increase of precipitation mentioned earlier. At mid latitudes and high latitudes, the significance of the large differences of temperature is difficult to assess due to the large variability in those regions. Yet the fact that we obtain mainly negative anomalies should indicate that they are the results of the non-linearities due to a time-varying radiative forcing rather than a time-averaged radiative forcing.

3.3 Wind potentials at 200 mb

The wind potentials at 200 mb for the three experiments IC, FGC and FZC are displayed in Figure 4. The ascending branch of the Hadley circulation is displaced eastward from its position in experiment FZC to that in experiment FGC and in Experiment IC (and experiments IC2 and IC3 as well, although they are not shown here). This displacement may be partly responsible for the changes of precipitation in South-East Asia mentioned in paragraph 3.1, and is an important element in our results.

3.4 Sea level pressures

We show in Figure 5.a the mean distribution of sea level pressure for the IC experiment, as well as the differences between the IC and FGC experiments (Figure 5.b), and between the IC and FZC experiments (Figure 5.c). The characteristics of the IC integration are responsible for the striking features Figure 5.b and Figure 5.c have in common. In particular, the IC integration presents in the Southern Hemisphere deeper lows situated further South, which seems more realistic. Also the high pressures over Northern Atlantic extend more over Europe and Western Asia in the IC experiments than in the two other experiments. The difference between the IC and FGC experiments may be compared to the results of Shukla and Sud (1981), who have made a similar experiment. Our results show a more important response of the sea-level pressure to a radiative forcing varying in time ; the sign of the difference is the same around 40°S but there are disagreements at higher latitudes.

3.5 Cyclone statistics

More insight in the dynamical response of the model to cloud-radiation interaction is given by the cyclonic center statistics. The method used to compute those statistics is described in Le Treut and Kalnay (1983) : it consists in retaining the cyclone centers more than 4mb lower than an average pressure around them. The results for the IC, FGC and FZC experiments are displayed in Figure 6. Unlike the other statistics shown, these analyses have been made using the whole 50 days integration, with one analyse every 12 hours.

The most striking differences are to be found in the Northern Hemisphere. In the IC experiment over North America cyclones form more in the North and then spread eastward over the Atlantic, and there is also more cyclonic activity over Eastern Siberia. In the Southern Hemisphere, the structures we get are much more zonal and difficult to intercompare.

3.6 Energy cycle

We have displayed in Figure 7 the diagram of the energy cycle for the IC, FGC and FZC experiment, separately for both hemispheres. In the Northern Hemisphere, there is some decrease of the eddy energetics in the FZC experiment as compared to the IC experiment and some increase in the eddy available potential energy in the FGC experiment. This last result is in accordance with the results of Shukla and Sud. But unlike in their results we don't find any increase in the zonal kinetic energy of experiment FCG (compared to experiment IC). In the Southern Hemisphere, we find a clear decrease of the eddy energetics in the experiment FZC when compared to FGC, and FGC when compared to IC. Again these results are not in agreement with those of Shukla and Sud.

To get more information on the nature and significance of these changes, we have displayed in Table 1 the transient and stationary energies for the various integrations we have studied. Two results come out very clearly :

- The model with zonal clouds has less stationary eddy available potential energy and less stationary eddy kinetic energy in the Southern Hemisphere.
- The models with fixed clouds have less transient eddy available potential energy in the Southern Hemisphere and also perhaps in the Northern one. But the transient eddy kinetic energy is not affected.

4 CONCLUSION

The experiments described here help clarify the role cloud-radiation interaction may play in the maintenance of the general circulations :

- determination of the convection in the tropics, with a tendency to decrease it over land and enhance it over ocean ;
- determination of the position of the ascending branch of the Hadley cell ;
- modification of cyclogenesis regions ;
- enhancement of stationary waves ...

Yet one must keep in mind that these results may be largely model dependent. In particular we have made the assumption of cloudiness occurring at fixed levels. Thus, the best way to confirm those results would be to do these experiments again with other G.C.M.

REFERENCES

GATES, W.L. and M.E. SCHLESINGER, 1977: Numerical simulation of the January and July global climate with a two-level atmospheric model, J.Atmos.Sci., 34, 36-76.

GELEYN, J.F., 1980: Some diagnotics of the cloud/radiation interaction in ECMWF forecasting model, Report of the Workshop on Radiation and Cloud/radiation interaction held at ECMWF, 15-17 October 1980.

HERMAN, G.F., 1980: Cloud radiation experiments conducted with the GLAS general circulation models, Report of the Workshop on Radiation and Cloud/radiation held at ECMWF, 15-17 October 1980.

HERMAN, G.F., M.L.WU and W.T. JOHNSON, 1980: The effect of clouds on the earth's solar and infrared radiation, J.Atmos., Sci., 37, 1251-1261.

HUNT, B.G., 1978: On the general circulation of the atmosphere without clouds, Quart. J.R.Met.Soc., 104, 91-102.

HUNT, G.E., 1982: On the sensitivity of a general circulation model climatology to changes in cloud structure and radiative properties, Tellus, 34, 29-38.

LAVAL, K., H.LE TREUT and R.SADOURNY, 1981: Effect of cumulus parameterization on dynamics of a general circulation model, Geophys.Astrophys.Fluid Dynamics, 17, 113-127.

LAVAL, K., R.SADOURNY and Y.SERAFINI, 1981: Land surface processes in a simplified GCM, Geophys.Astrophys. Fluid Dynamics, 17, 129-150.

LE TREUT, H. and E.KALNAY, 1983: Comparison of observed and simulated cyclone frequencies as determined by an objective method, Volume of extended abstracts, IAMAP-WMO Symposium held in Paris, August 29-September 2, 1983.

LE TREUT, H. and K.LAVAL, 1983: The importance of cloud radiation interaction for the simulation of climate, to be published in New Perspectives in Climate Modeling, Elsevier Publishing Company.

MANABE, S. and R.T.WETHERALD, 1980: ON the distribution of climate change resulting from an increase in CO_2 content of the atmosphere, J.Atmos.Sci., 37, 99-118

MELESHKO, V.P. and R.T.WETHERALD, 1981: Cloud distribution: model climate effect, J. Geophys.res., 86, C12, 11995-12014.

MOENG, C.H. and A.ARAKAWA, 1980: A numerical study of a marine subtropical stratus cloud layer and its stability, J.Atmos.Sci., 37, 2661-2676.

RAMANATHAN, V. and R.E. DICKINSON, 1980: A scheme for forming non precipitatig low level clouds in GCMs, in Cloud and Climate: Modeling and Satellite Observationnal Studies, Report of the Workshop held at NASA/GISS, New-York, October 29-31 1980.

SASAMORI, T., 1975: A statistical model for stationnary atmospheric cloudiness, Liquid water content, and rate of precitation, Mon.Wea.Rev., 103, 1037-1049.

SCNEIDER, S.H., W.M.WASHINGTON and R.M.CHERVIN: Cloudiness as a global climate feedback mechanism : Effects on cloud amount of global and regional surface temperature changes in the NCAR GCM , J.Atmos.Sci., 35, 2207-2221.

SHUKLA, J. and Y.SUD, 1981: Effect of cloud-radiation feedback on the climate of a general circulation model, J.Atmos.Sci.;38;2337-2353.

SLINGO, J., 1980: A cloud parameterization scheme derived from GATE data for use with a numerical model, Quart.J.R.Met.Soc., 106, 747-770.

SOMERVILLE, R.C., J.P.STONE, M.HALEM, J.E.HANSEN, J.S.HOGAN, L.M.DRAYAN, G.RUSSEL, A.A.LACIS, W.J.QUIRK and J.TENENBAUM, 1974: The GISS model of the global atmosphere , J.Atmos.Sci., 31, 84-117.

SUNDQUIST, H., 1978: A parameterization scheme for non convective condensation including prediction of cloud water content, Quart.J.R.Met.Soc., 37, 677-690.

TIEDTKE, M., 1983: Cloud-interaction studies with the ECMWF model, presented at the Symposium on Interdependence of clouds, radiation and climate, Hamburg, 15-27 August 1983.

WAKEFIELD, J.S. and W.H.SCHUBERT, 1981: Mixed layer model simulation of Eastern North Pacific stratocumulus, Mon.Wea.Rev., 109, 1952-1968.

WETHERALD, R.T. and S.MANABE, 1980: Cloud cover and climate sentivity, J.Atmos.Sci., 37, 1485-1510.

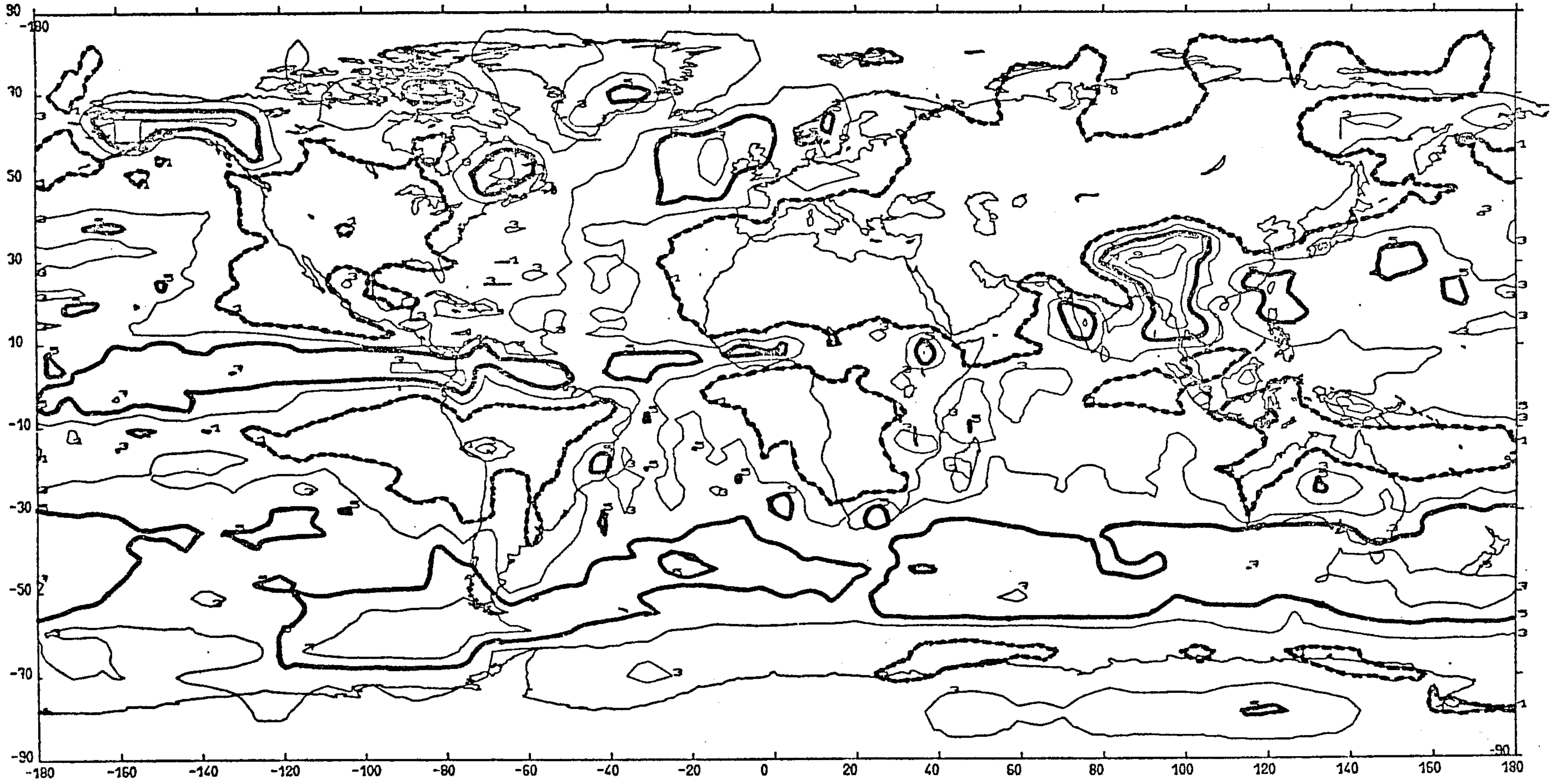


Figure 1.a : Low cloudiness simulated in the IC experiment, mean values over 30 days. The broad lines are 0.5, the dotted lines are 0.1.

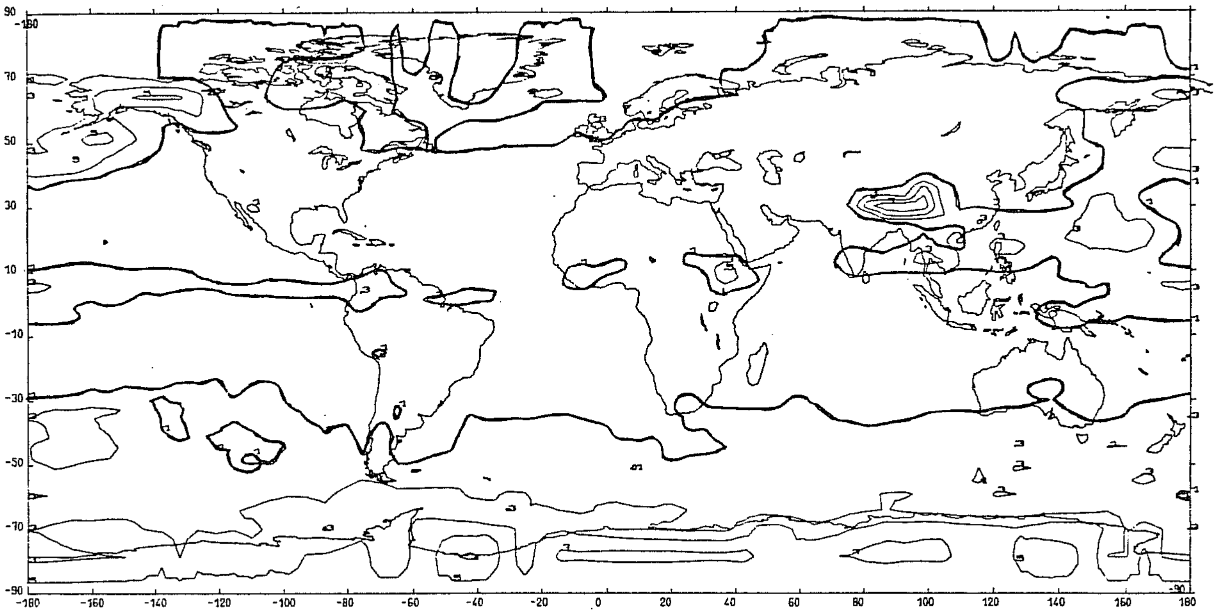


Figure 1.b: Middle level cloudiness simulated in the IC experiment. Mean values over 30 days. The broad lines are 0.1.

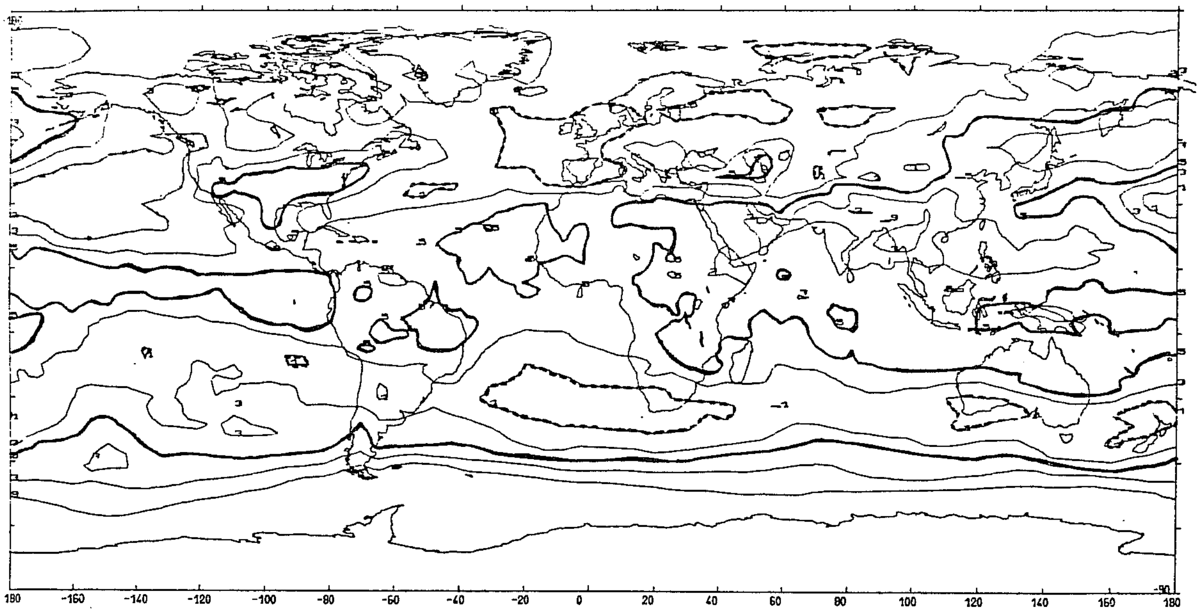


Figure 1.c: High cloudiness simulated in the IC experiment. Mean values over 30 days. The broad lines are 0.5, the dotted lines are 0.1.

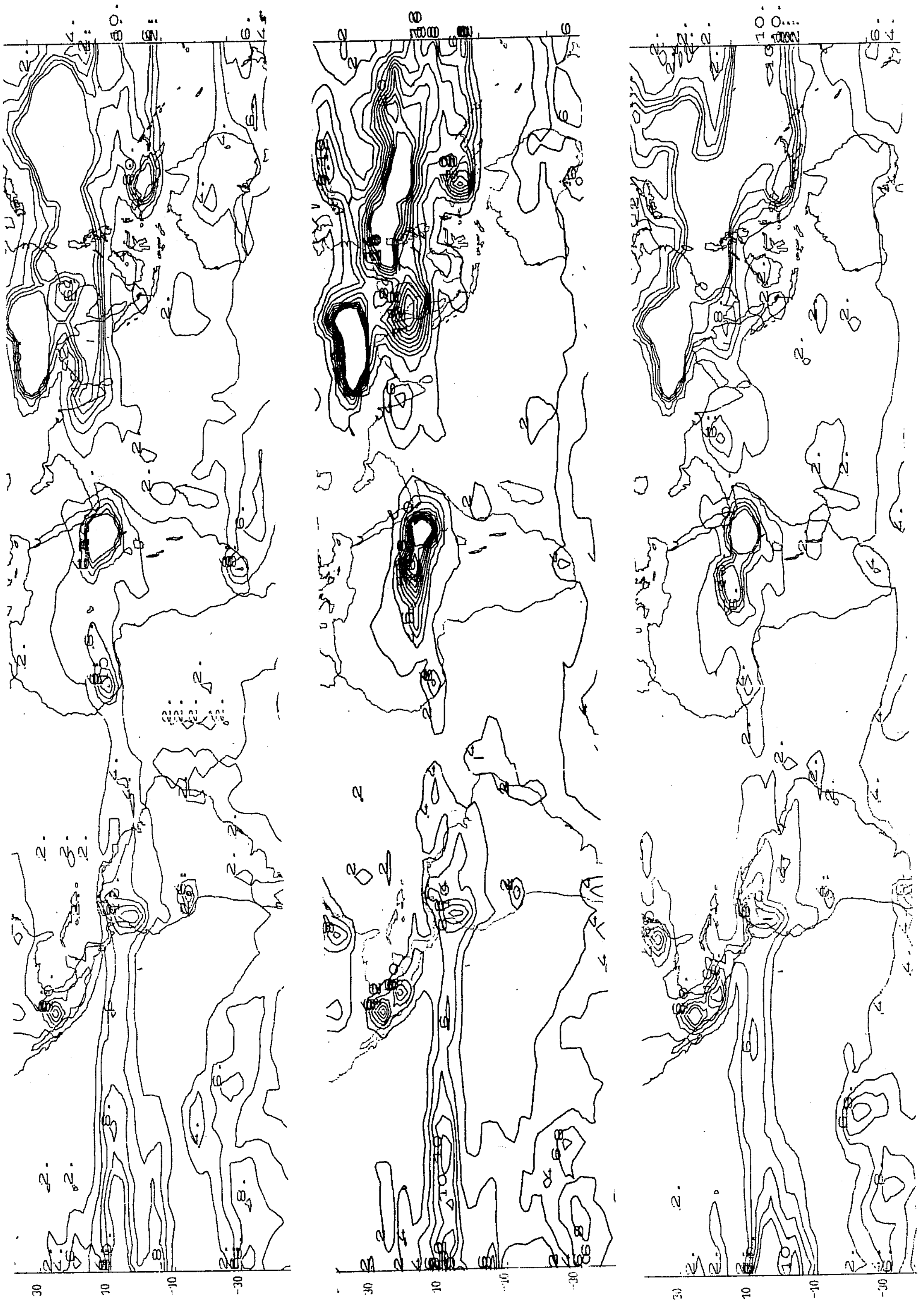


Figure 2 : Distribution of precipitation for the experiments IC, FGC, FZC, from left to right. Mean values for 30 days. Units are in mm/day.

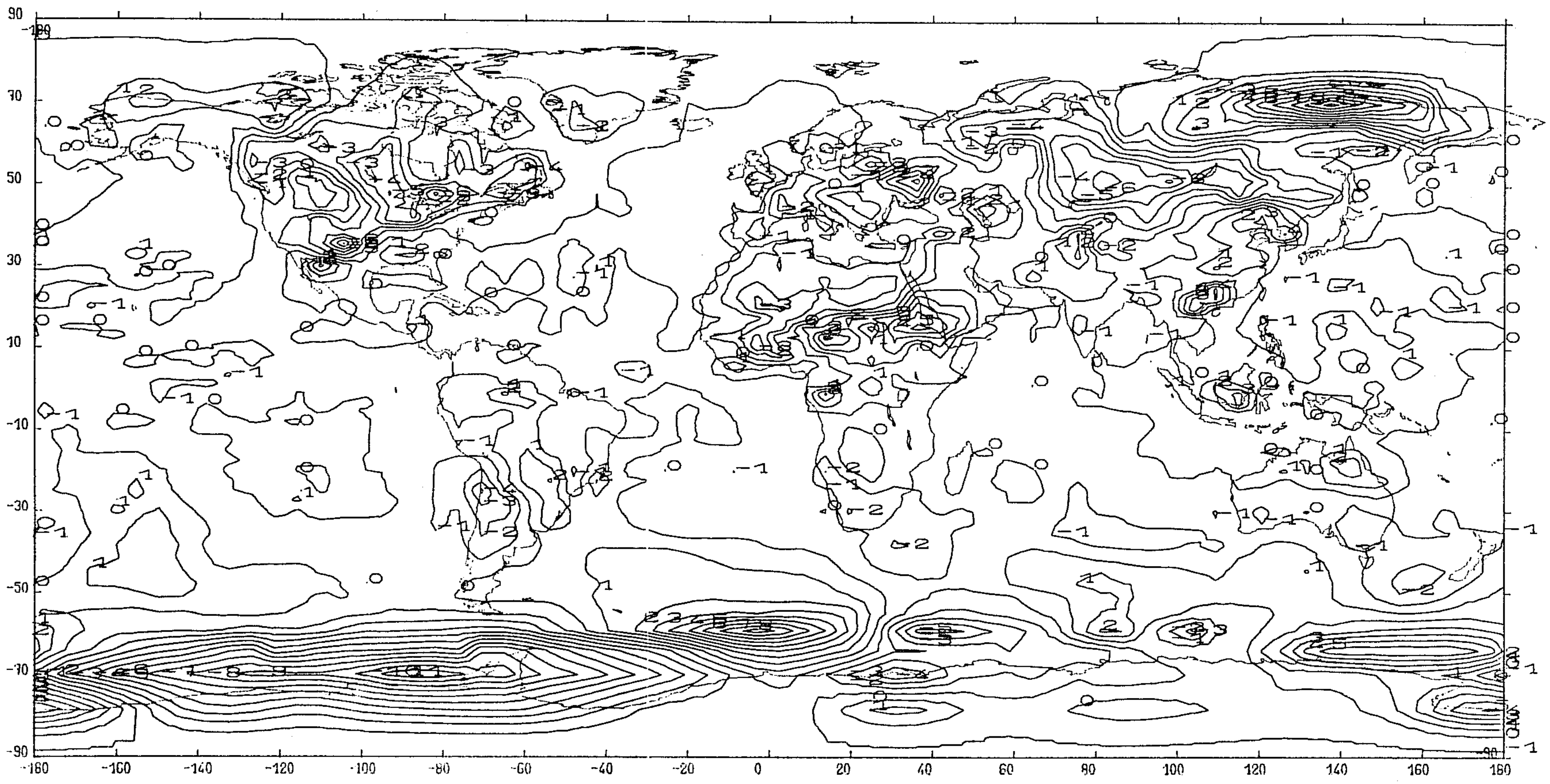


Figure 3: Difference of ambiant temperatue beetween the experiments IC and FGC.

Mean values over 30 days.Units are in °C.

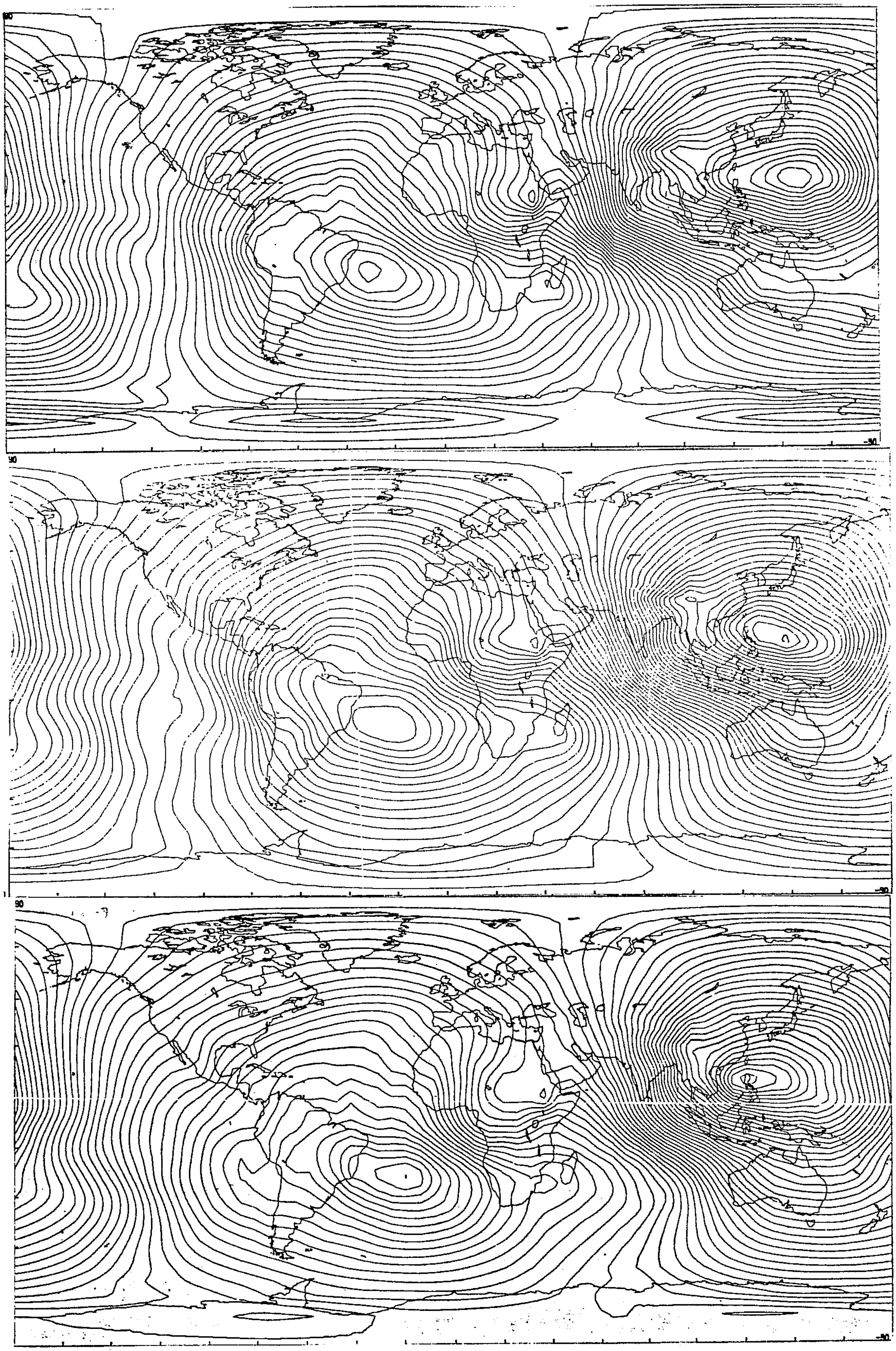


Figure 4: Wind potential at 200 mb for experiments IC, FGC, FZC (from top to bottom). Units are 10^6 m²/s.

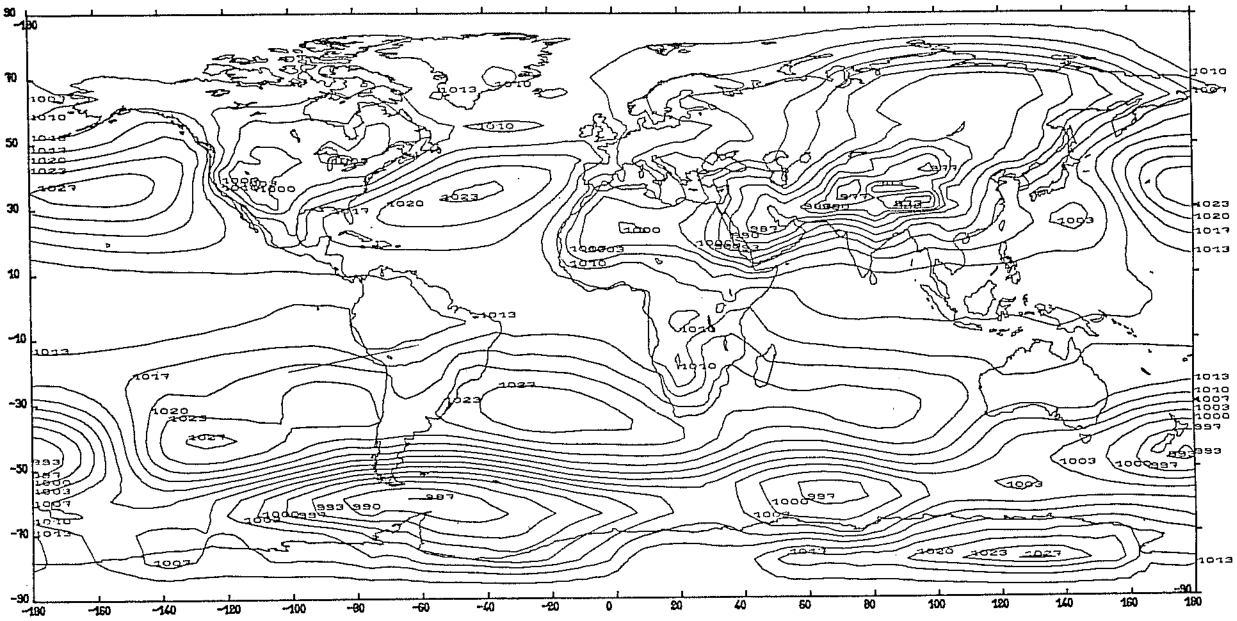


Figure 5.a: Sea-level pressure for the IC experiment (in mb)

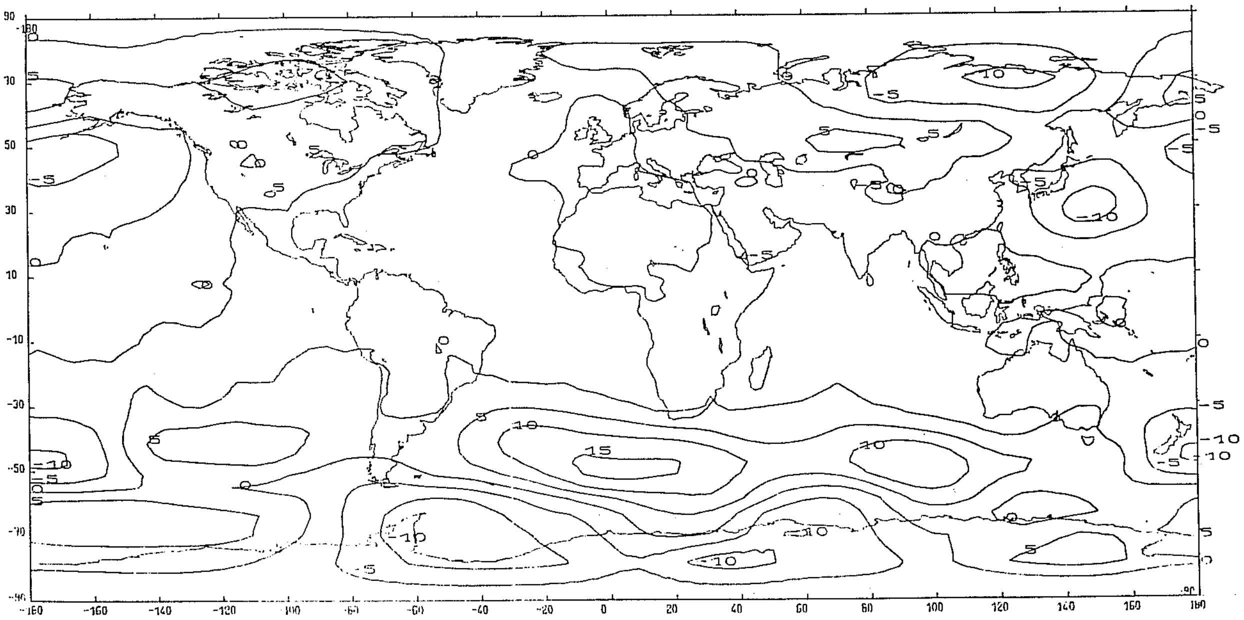


Figure 5.b: Difference of sea-level pressure beetween the experiments IC and FGC (in mb)

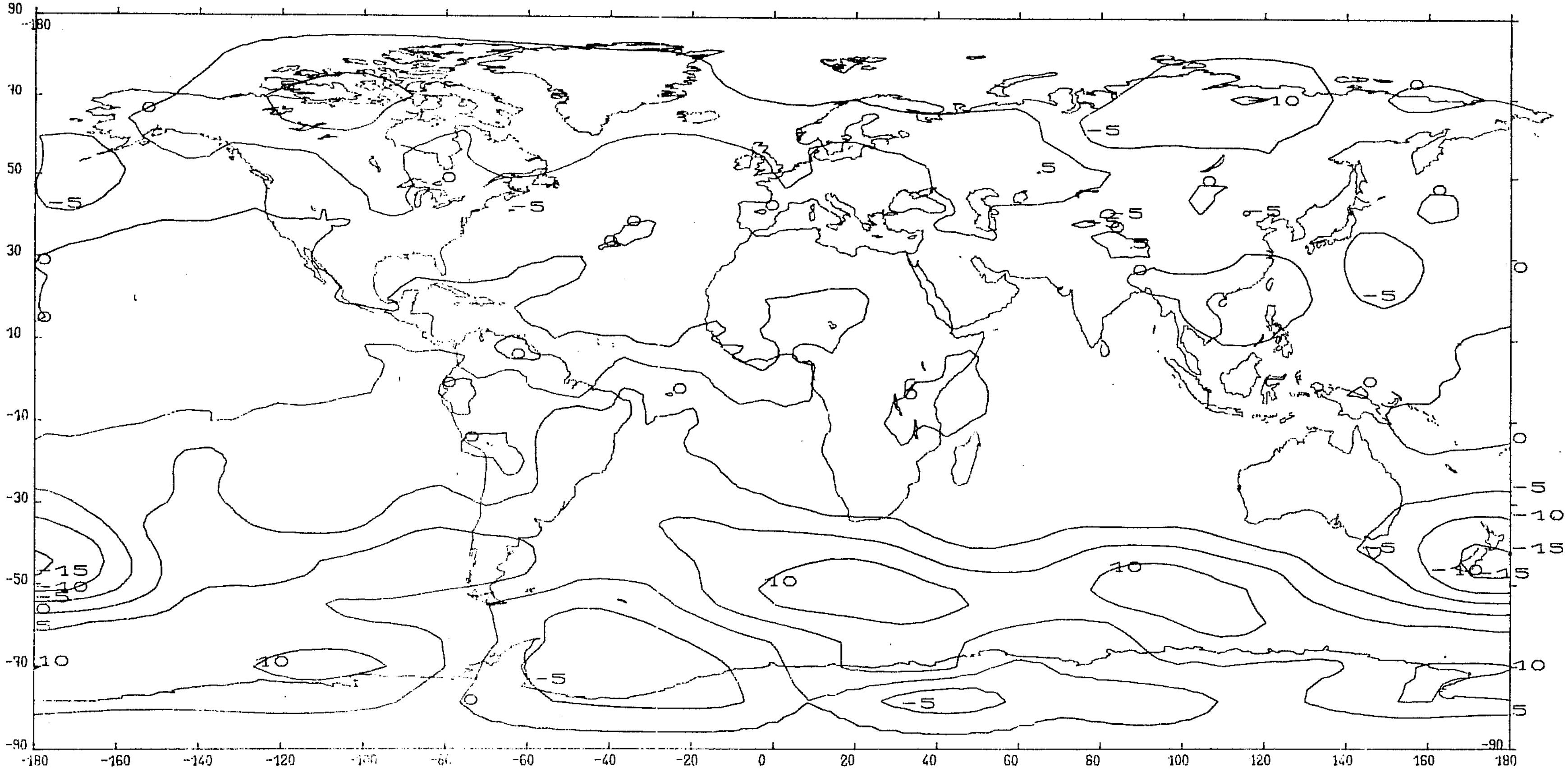


Figure 5.c: Difference of sea-level pressure beetween the experiments IC and FZÇ (in mb)

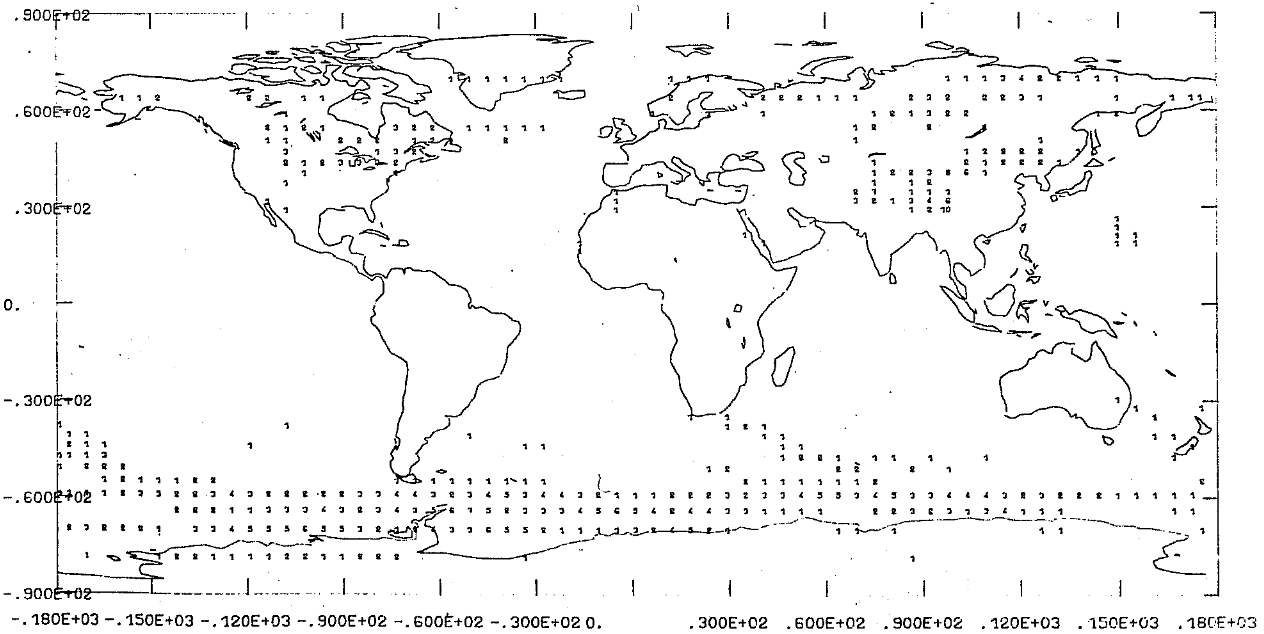


Figure 6.a: Number of cyclonic events for 50 days with 2 analyses per day. Experiment IC

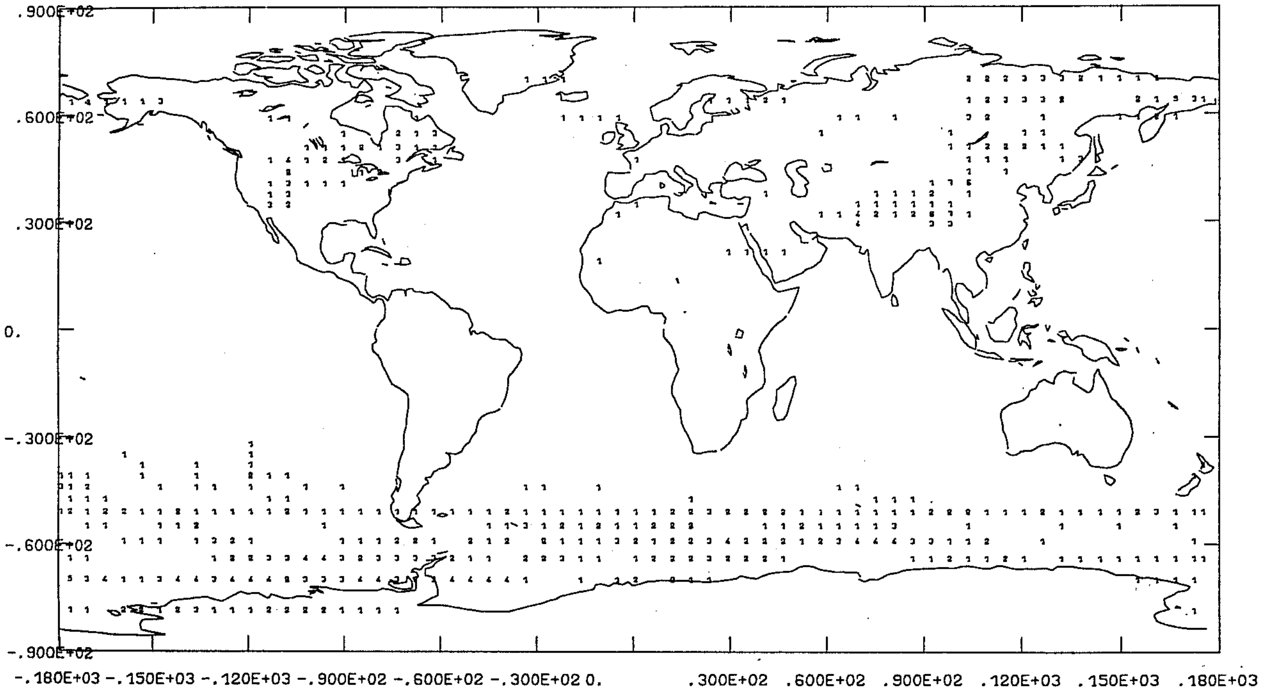


Figure 6.b: Same as Figure 6.a but for FGC experiment.

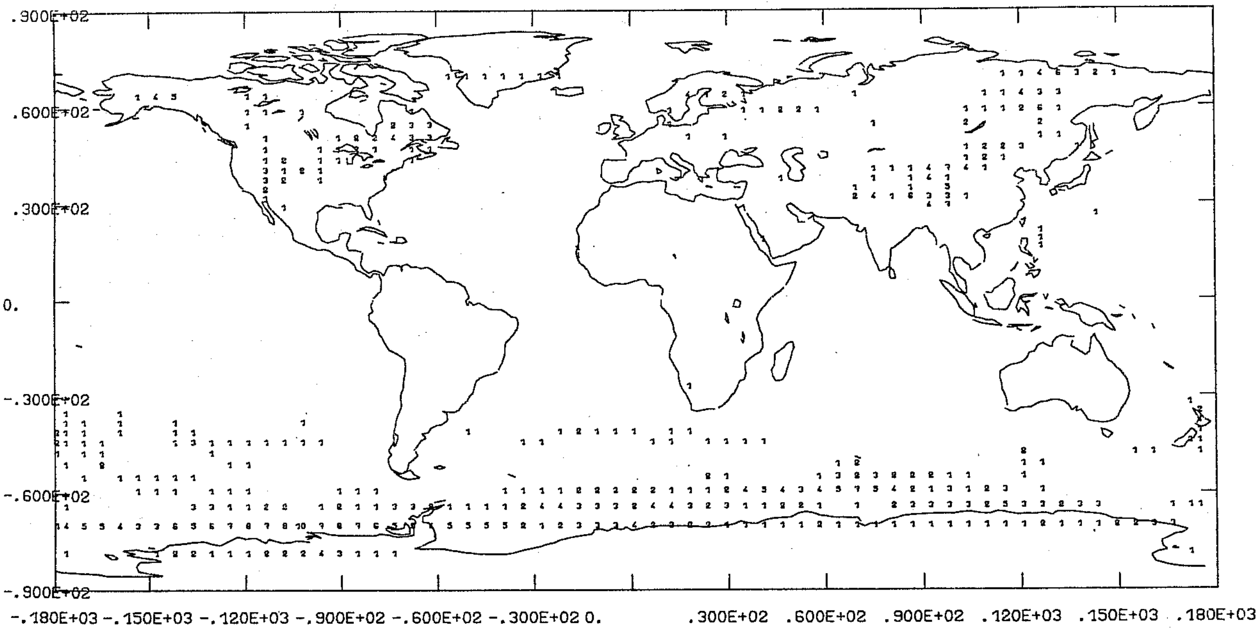
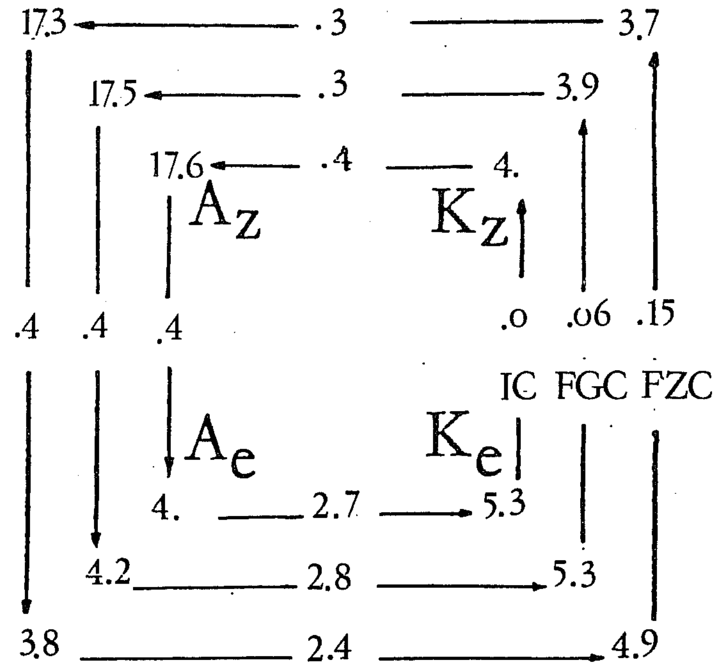


Figure 6.c: Same as Figure 6.a but for FZC experiment.

	stationary				transient			
	kinetic energy		available potential energy		kinetic energy		available potential energy	
	NH	SH	NH	SH	NH	SH	NH	SH
IC	2.52	3.77	3.18	2.50	2.85	5.82	0.85	2.06
IC^2	2.45	3.54	2.94	2.66				
IC^3	2.47	3.61	3.16	2.56				
FGC	2.58	3.23	3.15	2.39	2.71	5.86	0.79	1.79
FZC	2.25	2.53	3.08	1.91	2.66	5.64	0.74	1.76

Table 1 Stationary and transient eddy energies for the various integrations (in 10^5 J/m^2).



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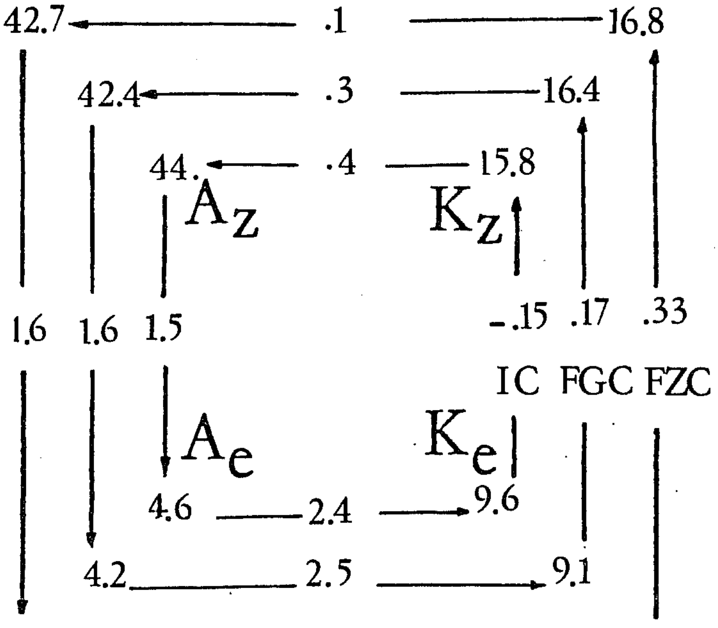

S.H.

Figure 7: Energy cycle for the experiments IC, FGC, FZC, for the two hemispheres separatly. Units are 10^5 J/m² for the energies and W/m² for the conversion terms.