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The effect of the parameterization model on a regional forecast

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RESUMEN

En el presente trabajo se describen los efectos de las parametrizaciones en el modelo NWP/CIMA. Este modelo, en ecuaciones primitivas, incluye entre los procesos físicos parametrizados a: la capa límite planetaria, el ciclo diurno de temperatura, la simulación de la convección y la condensación en gran escala.

Se estudia la influencia de dichas parametrizaciones en una serie de situaciones sinópticas típicas que afectan a la región sur sudamericana. De los casos estudiados se ha seleccionado, como ejemplo de los resultados obtenidos, una ciclogénesis sobre Buenos Aires que evoluciona en un dipolo de alta - baja presión sobre el océano Atlántico. Los resultados muestran que la difusión vertical es la principal responsable de los cambios producidos en la temperatura, las alturas geopotenciales y la precipitación. Las primeras dos variables también son afectadas por la condensación en gran escala.

ABSTRACT

This paper describes the effect of parameterization on the NWP/CIMA model. The main features of the model are that it is formulated in terms of the primitive equations and that physical processes such as surface fluxes of momentum, heat and moisture, large scale and convective precipitation, and a surface temperature diurnal cycle have been included.

The parameterizations used in the model were tested on a wide variety of case studies for the southern region of South America. An example a cyclogenesis over Buenos Aires that developed into a dipole of high - low pressure is described here. The results show that vertical diffusion is the main responsible for the changes in temperature, geopotential heights and precipitation. The first two variables are also affected by large scale condensation.

1. Introduction

In order to forecast the weather in the short term, synoptic scale and mid-latitudes, the parameterization of physical processes such as surface friction and fluxes of heat and moisture are, in general, second rate processes. However, they may be important factors to determine the intensity of a system and therefore it is necessary to implement said processes; in doing so the problem of their representation on a regional mesh will arise.

This paper shows the numerical weather prediction model implemented operationally by the Weather Bureau of New Zealand (Nuñez *et al.*, 1994), adapted to the southerly area of South America. The aim is to analyse the influence of the model parameterizations on typical meteorological situations of this region.

A set of experiments were carried out to test the sensitivity of the model to parameterizations of the vertical diffusion of fluxes of momentum and heat, of radiation and of large scale and convective adjustment. The differences obtained in fields such as geopotential heights, temperature and precipitation are shown for 24 hour forecasts, for the case which took place from January 4th to January 7th, 1992.

2. Features of the model

The model is expressed in primitive equations, in the sigma coordenate system considering motion, mass, moisture and thermodynamic equations. In order to represent the weather phenomena properly, the model includes physical processes, such as surface boundary layer, temperature diurnal cycle, simulation of convection and large scale condensation.

The fluxes of momentum, heat and moisture are calculated in a similar way to the ones of the European Centre for Medium Range Weather Forecasting (ECMWF) model (Louis *et al.*, 1981). Turbulent fluxes are computed from eddy diffusivities, which are functions of the stability of the layer. The theory of Monin and Obukhov (1954) is used in the surface layer in order to suggest the form of the functional dependency on stability, whereas, above the surface layer, the mixing length theory is applied (Blackadar, 1962). To ensure continuity with the surface fluxes, the dependency of the eddy diffusivity with stability is the same as for the surface fluxes.

In order to predict precipitation, two adjustments are used: a cumulus convection scheme based on the modified version of Kuo (1965), and a large - scale saturation adjustment, whenever the mixing ratio exceeds 95 per cent of the saturation ratio at any level of the model, large scale condensation occurs. Water excess precipitates and the mixing ratio is reduced to its saturated value. Concerning cumulus convection, it should be pointed out that Kuo's scheme has been modified according to Hammarstrand (1977), thus increasing the low levels of precipitation of the original scheme.

Radiation is parameterized with a very simple scheme of surface radiative balance (Paltridge and Platt, 1976).

Before starting the forecast, the model is initialized using a scheme of non-lineal vertical modes, according to Bourke and McGregor (1983).

The model is integrated on a grid located on a polar stereographic projection tangent in 60°S where the horizontal resolution is 150 km and it has 10 levels in the vertical. The time lapse calculated by the CFL criterion (Courant *et al.*, 1928) amounts to 15 minutes.

3. Case study and forecast

As mentioned in the introduction, this study was carried out on special cases. The situation, which occurred from January 4th to January 7th, was chosen to describe the effect of including the parameterization, since it contains the results obtained in the set of cases studied. This situation is cyclogenesis over the coast of the province of Buenos Aires, which developed into a system of high - low pressure and at higher levels the air flow splitted into two branches.

The data used are the reanalysis from the National Meteorological Center (NMC) interpolated to grid points, in the horizontal, by means of a bilinear function.

Since the surface variables were not available at the time of this experiment, it was necessary to calculate them from the 1000 hPa level. The surface pressure and temperature were obtained by considering the standard thermal gradient. The humidity of the lowest pressure level (1000 hPa) was the value given to the humidity on the surface.

The precipitation rate of the NMC accumulated every 24 hours is compared with the forecasted precipitation produced by the model. It must be noted that, the analyses of precipitation do not include direct observations, therefore the Forecast Center considers it as a variable class "C" (Kalnay *et al.*, 1996).

3.1. Description of the meteorological case

At 00 UTC 4 January, two systems were observed: a low pressure system in the center of the continent and a high pressure system over the Atlantic Ocean, in front of the Argentine coast. In the 1000/500 field, an intense baroclinic zone appears in the Atlantic Ocean, to the east of the high pressure system, and a less important one in the South Pacific Ocean. In the 500 hPa level, there is a long wave in the southern part of the forecast region, which presents a deeper trough in the Atlantic Ocean than in the Pacific Ocean. There is a short wave at about 40°S, over the continent.

On the 5th, at 00 UTC, (Fig. 1a) in the 1000 hPa level there is a closed low pressure center of 0 mgp over the province of Buenos Aires, so the Atlantic anticyclon is displaced to the south. The entire field is baroclinic. In the graph of precipitation accumulated in 24 hr, Figure 1b, there are two maxima, the most important one of 70 mm over the province of Buenos Aires and the nearby sea, and the other in the mid west of the continent.

In the 500 hPa level (Fig. 1c) the axis of the short wave trough has moved to the east from its position over the continent 24 hr earlier, and has deepened. At this same place, the thermal pattern is delayed with respect to the geopotential pattern and a splitting of the flow can be observed as was suggested the day before. According to Illari (1984) this case might have the characteristics of a block system.

The following day (January 6th) the cyclonic center in the 1000 hPa level moved to the southeast with slightly increasing intensity, allowing the anticyclonic system (dipole) to enter from the South. The area of precipitation moves with the system. Notice that there is a specific humidity maximum in the 850 hPa level coinciding with the low pressure center. In higher levels, the trough moved to the east locating itself over the surface system.

On January 7th, the dipole reaches its greatest extension on the 1000 hPa surface (Fig. 2a) and the precipitation associated to this system has a maximum of 35 mm (Fig. 2b). At higher levels, Figure 2c, the trough axes has a northwest - southeast direction. According to Crum and Duane (1988), this case has several features similar to the so called blocking situation but it does not remain quasi-stationary during a couple of weeks (Illari, 1984) since, on 8 January, the system is not affecting the region any longer.

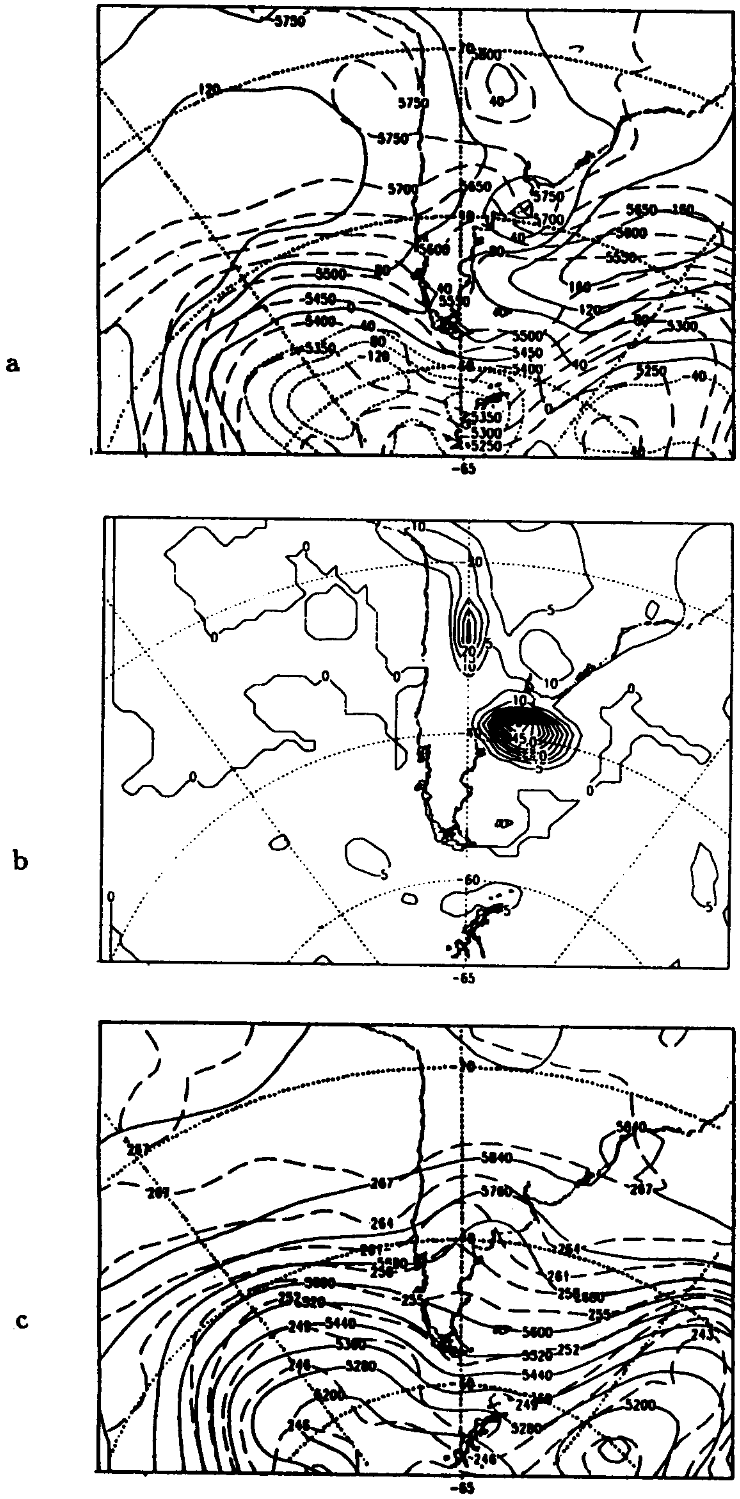

Fig. 1. NMC analyses at 00 UTC January 5th. a) 1000 hPa geopotential height (—) and 1000/500 thickness (- - -). b) 24 hr accumulated precipitation. c) 500 hPa geopotential height (—) and temperature of 500 hPa (- - -).

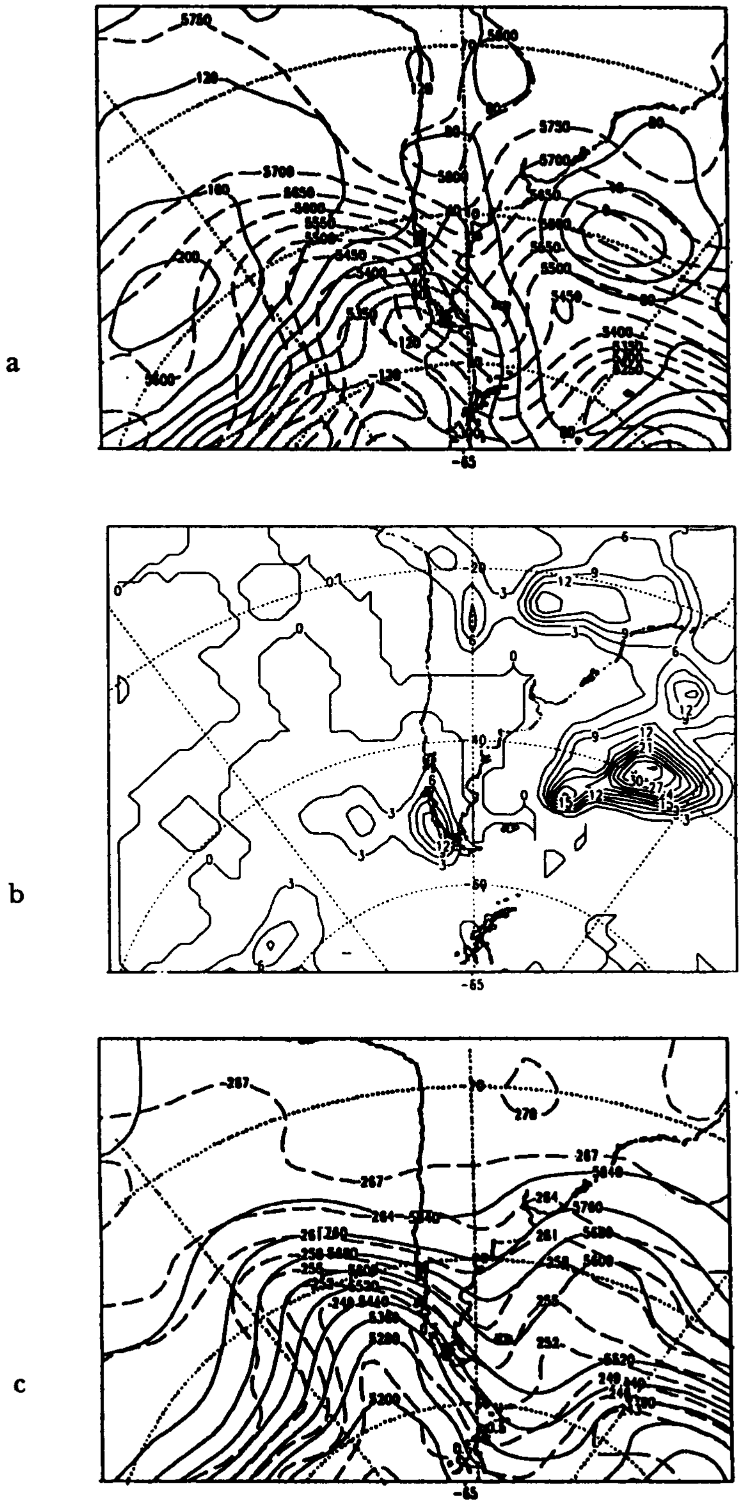

Fig. 2. NMC analyses of 00 UTC January 7th. a) 1000 hPa geopotential height (—) and 1000/500 thickness (- - -). b) 24h hr accumulated precipitation. c) 500 hPa geopotential height (—) and temperature of 500 hPa (- - -).

3.2 Description of the forecast obtained by the model

Figure 3 shows the 24 hr forecast for January 5th with and without topography. The centers of low and high pressure shown in this forecast agree with the analysis of NMC and so do the baroclinicity of the fields. But the intensity of the cyclonic system over the coast of Buenos Aires (Figs. 3a and 3b) was lower than those obtained by the analysis of the 1000 hPa level. The precipitation is also underestimated by both forecasts, giving 35 mm (Fig. 3c) and 45 mm (Fig. 3d) over the cyclogenesis and less than 5 mm in the rest of the continental areas having rainfall. At the 500 hPa level, Figures 3e and 3f, the forecasted trough is delayed some degrees of latitude from the analyzed trough and therefore the bifurcation of the flow is less noticeable. The results of the model with topography show a small improvement in the location of the trough in consideration.

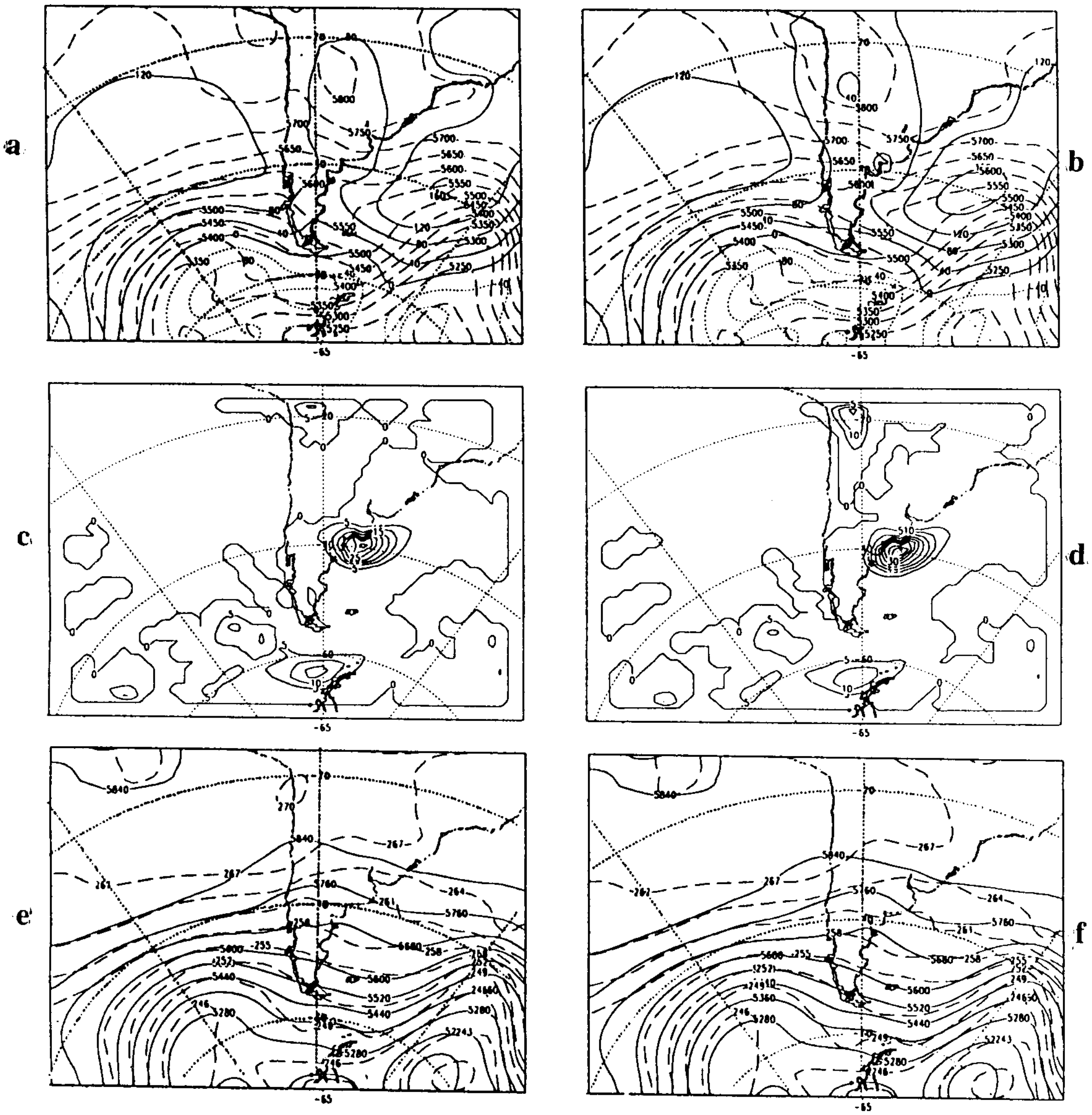

Fig. 3. 24 hr forecasts valid at 00 UTC January 5th. a) geopotential height of 1000 hPa (—) and 1000/500 thickness (- - -) with orography. b) geopotential height of 1000 hPa (—) and 1000/500 thickness (- - -) without orography. c) 24 hr accumulated precipitation with orography. d) 24 hr accumulated precipitation without orography. e) 500 hPa geopotential height (—) and temperature (- - -) with orography. f) 500 hPa geopotential height (—) and temperature (- - -) without orography.

The 24 hr forecasts for the level of 1000 hPa for the 6th (not shown) and 7th of January (Figs. 4a and 4b, with and without topography respectively) reproduce the dipole (intensity as well as location). The same thing occurs with the precipitation over the Atlantic Ocean. Again the amount of rain accumulated is underestimated over the continent (Figs. 4c and 4d). At higher levels, the model forecasts the splitting of the flow as pointed out by the NMC analysis, shown in Figures 4e and 4f.

The differences between the forecasted fields with and without orography are not so significant. They are attributed to the estimation of the surface variables, since as mentioned before, they are not included in the initial data set.

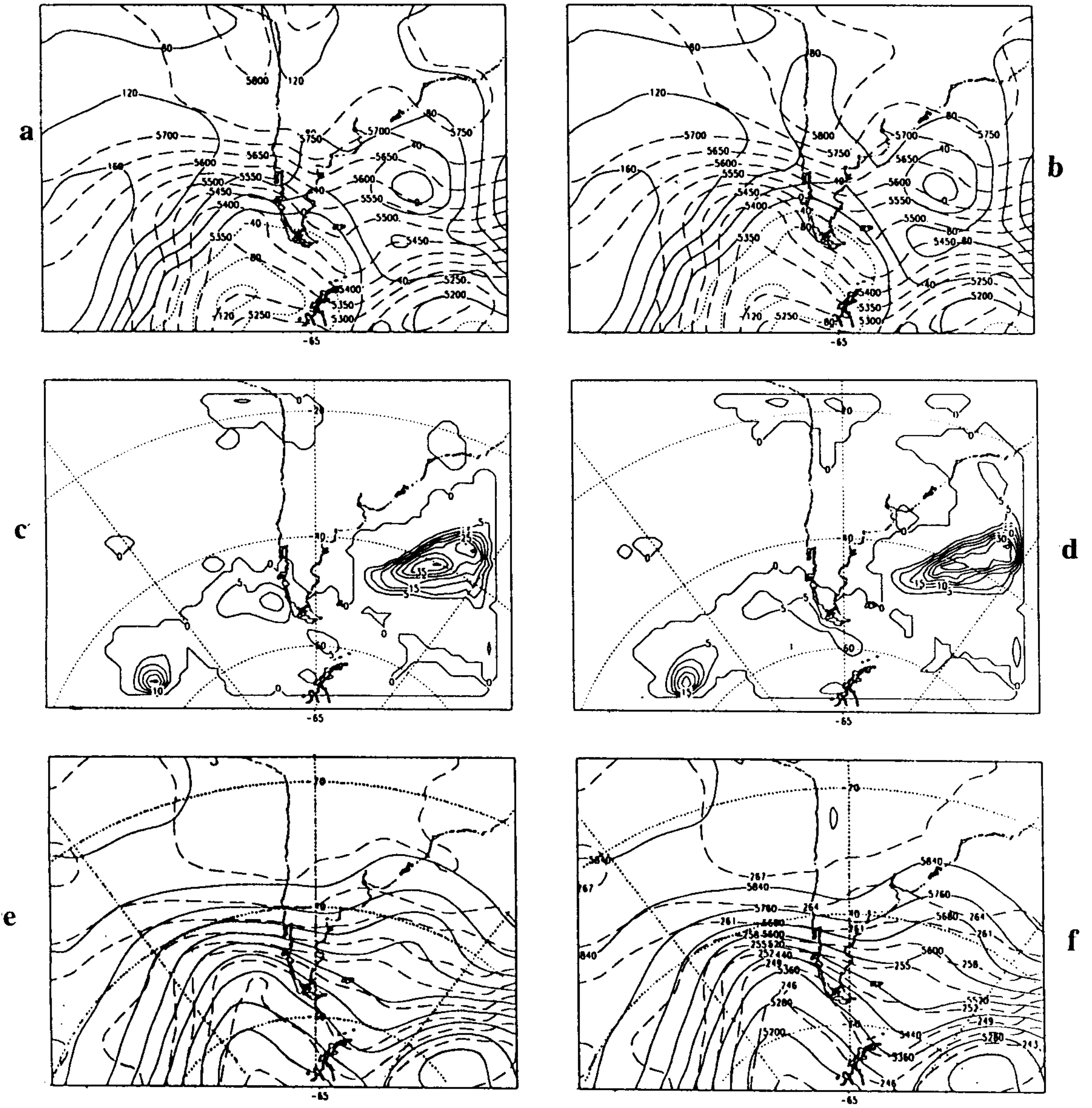

Fig. 4. 24 hr forecasts valid at 00 UTC January 7th. a) 1000 hPa geopotential height (—) and 1000/500 thickness (- - -) with orography. b) 1000 hPa geopotential height (—) and 1000/500 thickness (- - -) without orography. c) 24 hr accumulated precipitation with orography. d) 24 hr accumulated precipitation without orography. e) 500 hPa geopotential height (—) and temperature (- - -) with orography. f) 500 hPa geopotential height (—) and temperature (- - -) without orography.

4. Experiments

The authors' aim is to analyse the parameterization free from numerical effects brought about by topography and from the interpretation of the model products in mountain regions (Jarraud *et al.*, 1986); and taking into account the results discussed in the previous section, the simulations to study the sensitivity of the model to the parameterizations, do not include the representation of the Andes Mountain Range.

The Earth - water distrubution in the area is considered in the experiments carried out, since it is essential in the balance of radiation and it indirectly affects the other parameterizations.

The model results without orography are used as reference or control (CTL) forecasts.

Two different types of experiments were designed to evaluate if the representation of the vertical diffusion of the momentum and heat flows, of the radiation and the convective and great scale adjustments affect the results significantly. The first experiment consisted in forecasting a situation without any parameterization to estimate the importance of the change produced in the results. Later, to study the relative weight of the different physical process, each is canceled individually. The parameterizations included in each experiment are given in Table I.

Table I. Parameterizations included in control forecasts and in each experiment.

Experiment	Vertical diffusion	Large scale adjustment	Convective adjustment	Radiation balance
CTL	Yes	Yes	Yes	Yes
EX1	--	--	--	--
EX2	--	Yes	Yes	Yes
EX3	Yes	--	Yes	Yes
EX4	Yes	Yes	--	Yes
EX5	Yes	Yes	Yes	--

The differences between the forecasts with and without parameterizations are calculated in objective and subjective ways, to evaluate the variations produced by experiment EX1 in: geopotential heights, temperature and precipitation.

An objective verification corresponding to geopotential heights, on January 5th, is included as an example for comparing analyses to forecasts with and without parameterization. The selected region to be verified is where the changes are observed. It includes the continent and the Atlantic Ocean. Table II shows the results of the mean error (A), standard deviation (B), mean error of the persistence (C), persistence (D), correlation of observed and forecasted changes (E), relative error of observed and forecasted changes (F), signs correlation (G), (E + F + G)/2 (H), skill-score of Teweles (H) and skill-score of the persistence (I) for the forecasted geopotential heights at 1000, 850 and 700 hPa with all the parameterizations. Table III shows the same statistics parameters for the forecasted geopotential heights without all the parameterizations.

Table II. Verification parameters for geopotential heights at 1000, 850 and 700 hPa levels. Model with parameterizations (CTL). A = Mean error (m), B = Standard deviation, C = Mean error of the persistence (m), D = Persistence, E = Correlation of observed and forecasted changes, F = Relative error of observed and forecasted changes, G = Signs correlation, H = (E + F = G/2, I = Skill-score of Teweles and J = Skill-score of the persistence.

Levels	A	B	C	D	E	F	G	H	I	J
1000	-1,2	23,6	19,4	38,5	0,89	0,5	0,56	0,98	37	9
850	7,1	20,1	15,1	35,9	0,91	0,47	0,64	1,01	40	7
700	7,8	21,5	9,1	43,1	0,93	0,46	0,65	1,02	39	25

Table III. Idem Table II but model without parameterization (EX1).

Levels	A	B	C	D	E	F	G	H	I	J
1000	12,2	27,3	19,4	38,5	0,85	0,66	0,40	0,96	59	9
850	15,2	24,2	15,1	35,9	0,87	0,65	0,48	1,00	53	7
700	14,0	25,1	9,1	43,1	0,90	0,57	0,46	0,97	43	25

Comparing A and C, it can be seen that the reference forecast (CTL) always shows lower mean error than the persistence, but in the forecast without parameterizations, A is notable higher than the same statistic parameter in CTL. Furthermore, it is over C at 850 hPa. The verification parameter B is always under D in these two simulations, but in EX1 the difference is weaker than in CTL. The correlation of changes (E) are near to 1 in both tables but becoming worse in Table III. The values of the relative error of changes (F) and the signs correlation (G) tests are not so good, but they are always better in the forecast with parameterizations than in the forecast without it. This could be caused, as it has been mentioned before, by the estimation of the surface variables; these parameters improve notably with height, their values in both simulations are about 0,22 for the relative error of changes and 0,90 for the signs correlation at 300 hPa (not shown in Table II and III). Parameter H is always close to 1. Skill-score (I) is better than the skill-score of the persistence (H), and the values of I from the reference forecast are lower than its values from the forecast without parameterizations. January 7th registers similar behavior.

When discarding all physical processes, the greatest variations were produced at the lower levels of the model. For January 7th, Figure 5 shows the vertical and longitudinal cross section for temperature and geopotential centered in 52°S. Significant variations are not observed above the level of 800 hPa (4° in temperature of 500 hPa and 35 mgp in heights of 800 hPa), therefore only the results of level 1000 hPa will be shown in the figures because it has registered the greatest changes.

In the 24 hr forecast for January 5th (Fig. 6) there are differences of up to 30 mgp over the low pressure system, produced not only by the location of the system but also by its intensity. Similar to what was observed on previous days, Figure 7a (January 7th) shows variations in the differences of geopotential heights over the low pressure center of 45 mgp due to movements in the system and changes in their depth. (Compare with Figs. 3b and 4b, respectively).

Regarding temperature, the greatest observed changes are over the continent. In Figure 7b for January 7th, it can be seen that this experiment underestimated the temperature up to 9° coinciding with a geopotential height increase of 20 mgp (Fig. 7a).

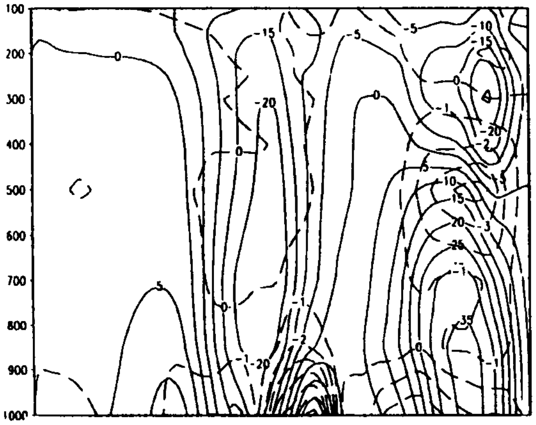

Fig. 5. Zonal vertical cross section at 52°S of the differences between EX1 and CTL (geopotential height (—) and temperature (- - -)). Simulations valid at 00 UTC January 7th.

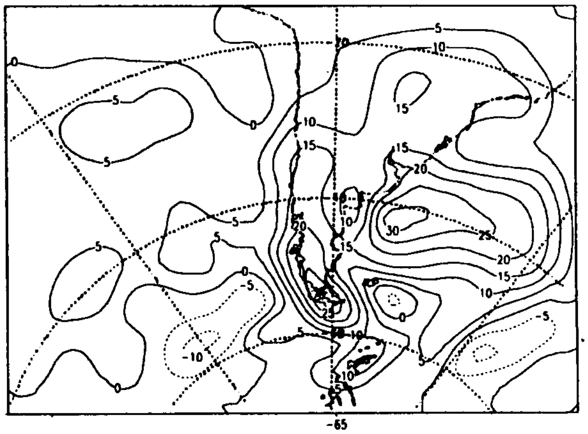

Fig. 6. Differences of geopotential height between EX1 and CTL. Simulations valid at 00 UTC January 5th.

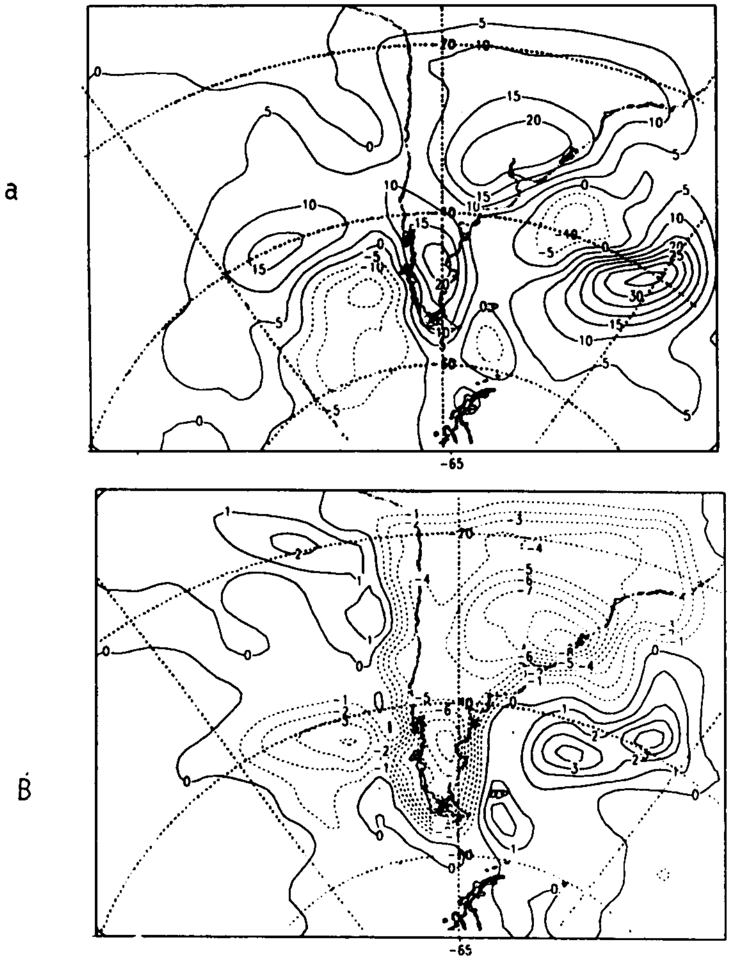

Fig. 7. Differences between EX1 and CTL. a) geopotential height. b) temperature. Simulations valid at 00 UTC January 7th.

Due to the importance of the changes produced by not considering any of the physical processes, experiments are designed in which the parameterizations are eliminated one by one. The differences between the forecasts of each experiment and the control are assessed.

In EX2 the vertical diffusion is discarded, the intensity of the pressure systems is increased up to 20 mgp on the day of the cyclogenesis, Figure 8a, and 25 mgp on January 7th (not shown). The differences in temperature show a cooling of 8° over the continent and 5° over the Atlantic Ocean. This is a consequence of displacement and intensification of the thermal systems as seen on Figure 8b (January 5th).

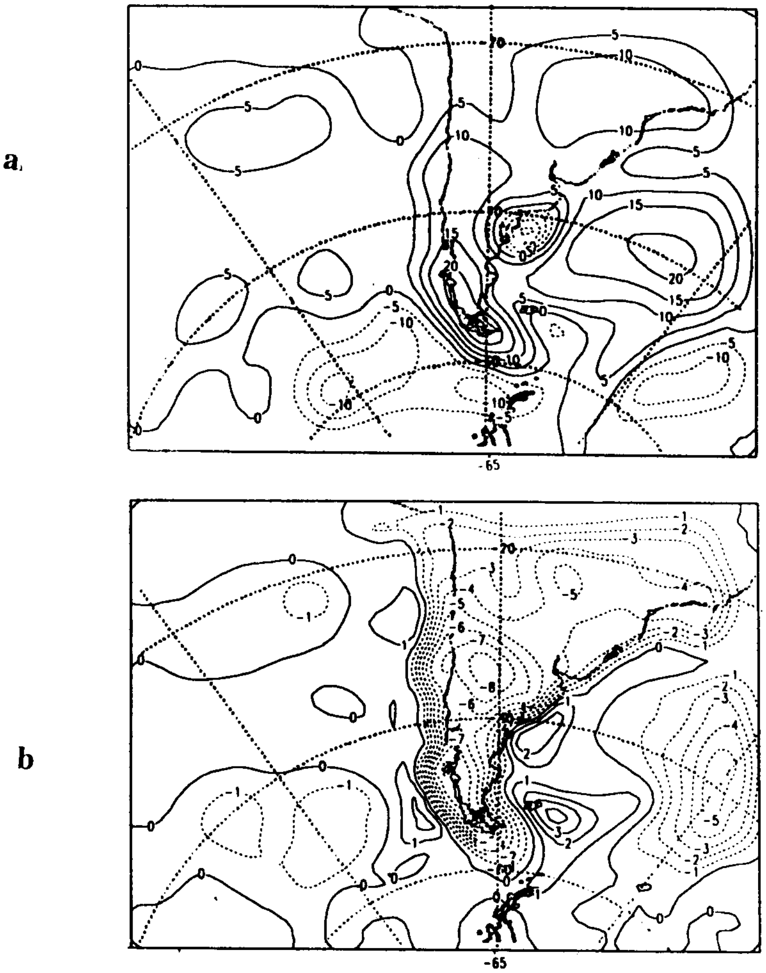

Fig. 8. Differences between EX2 and CTL. a) geopotential height. b) temperature. Simulation valid at 00 UTC January 5th.

On the day of cyclogenesis, the control experiment recorded 45 mm of total precipitation while this experiment 70 mm. This difference is due to the increase of precipitation produced by the large scale adjustment and the existence of 14 mm of convective precipitation in the cyclogenetic area where the control experiment does not forecast this type of rainfall (Fig. 9). For January 7th, on the system of the Atlantic Ocean (Fig. 10), the result of this experiment is a total rainfall of 60 mm while the control registered 35 mm. In this case, the experiment overestimates precipitation due to both adjustments. It is important to note that as on the previous day, the convective adjustment without vertical diffusion produces a spurious precipitation of 35 mm.

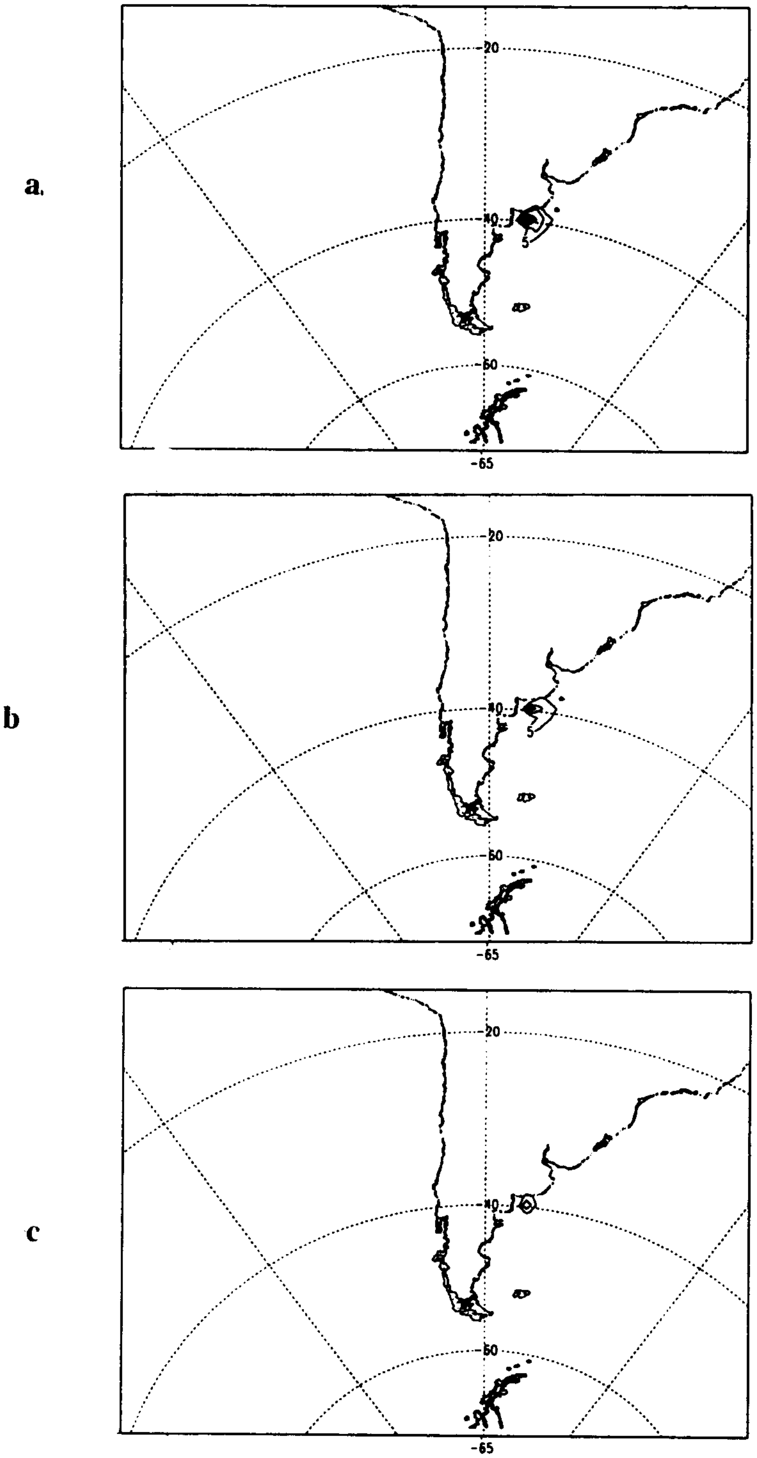

Fig. 9. Differences of precipitation between EX2 and CTL. a) total precipitation. b) large scale precipitation. c) convective precipitation. Simulation valid at 00 UTC January 5th.

Large surface temperature anomalies in experiments EX1 and EX2 are observed when the parameterization of the vertical diffusion is removed. Thus the surface layer is decoupled from the interior layer and the effect of the boundary layer is only felt in the surface layer. As a consequence, the possibility of the diffusion of water vapor would be screened. When vertical diffusion is not considered, instabilities are resolved by both convective and large scale adjustment. Therefore large scale and convective precipitation are increased.

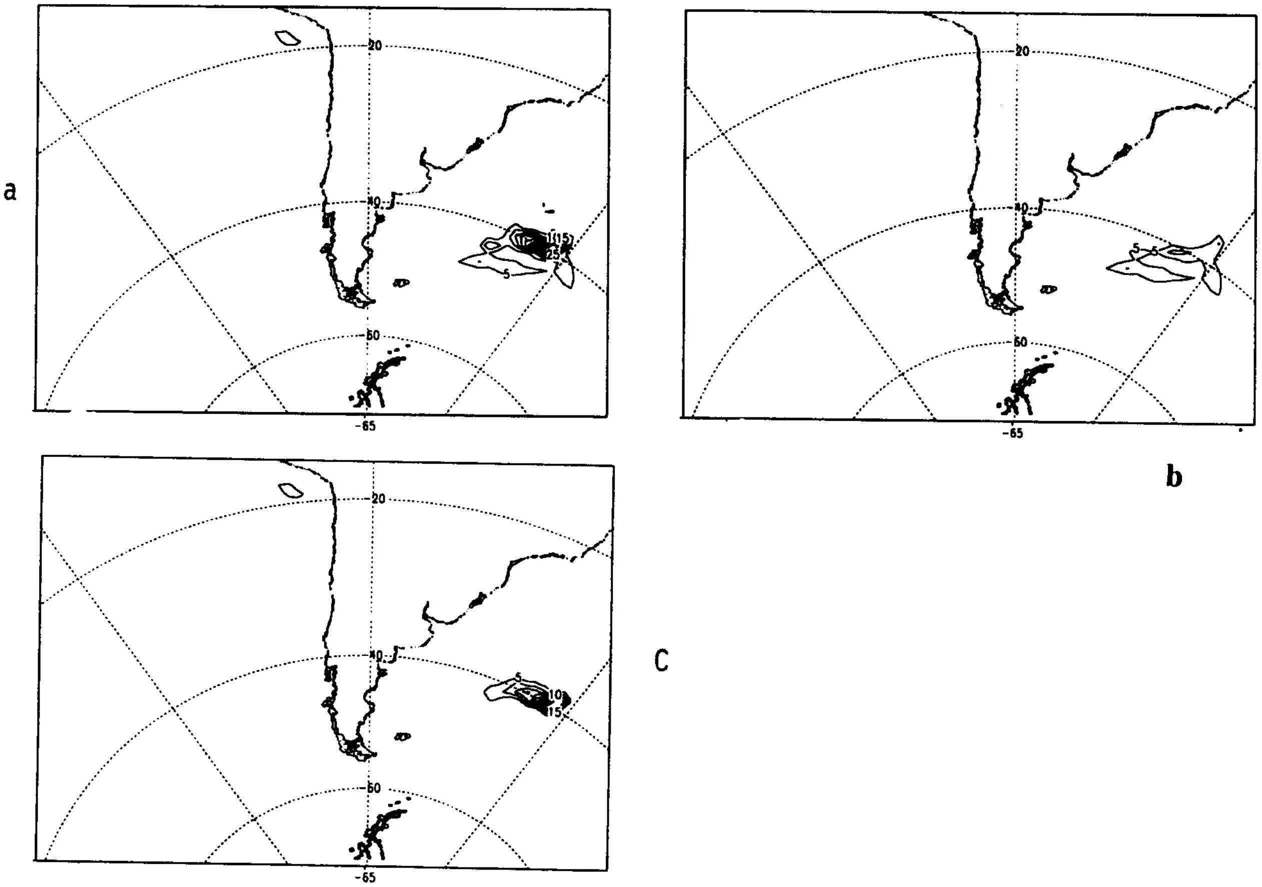

Fig. 10. Differences of precipitation between EX2 and CTL. a) total precipitation. b) large scale precipitation. c) convective precipitation. Simulation valid at 00 UTC January 7th.

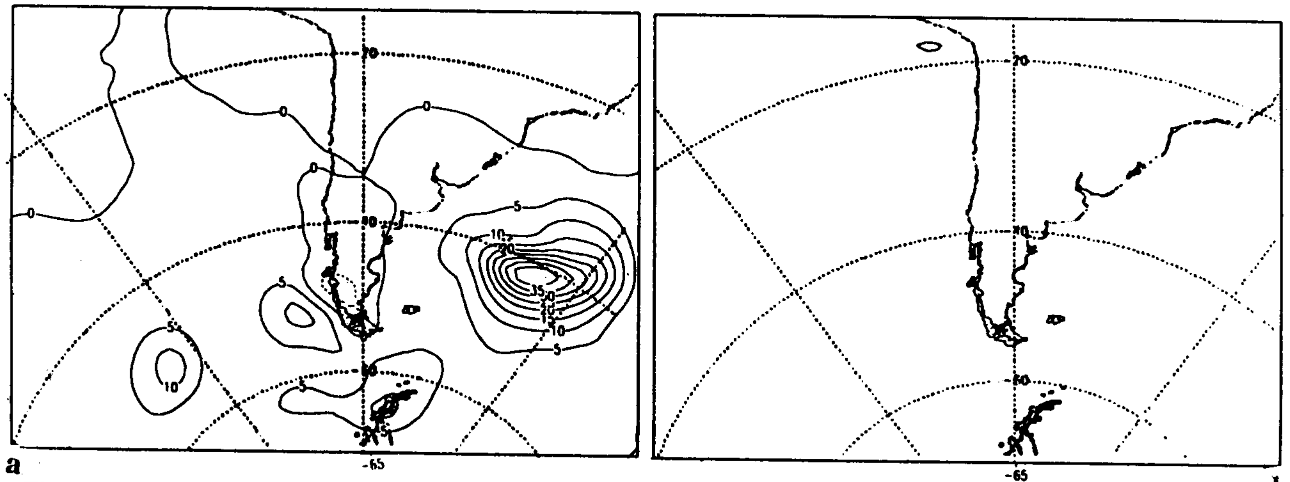

Fig. 11 Differences between EX3 and CTL. a) geopotential height. b) total precipitation. Simulations valid at 00 UTC January 7th.

Figure 11a shows the veriations in the results produced by EX3 on January 7th for geopotential heights. The dipole low pressure center does not reach the same intensity as in the CTL, and is displaced 5° to the east; this synoptic situation recorded smaller changes, for the rest of the days. Large scale adjustment produces little changes in the temperature field which are not higher than 2,5°. For this case CTL does not register convective precipitation, then this experiment shows that the precipitation is resolved by the large scale adjustment (Fig. 11b).

Changes in geopotential and temperature are not so significant on account of the parameterization of the convective adjustment (EX4), the maximum values are 10 mgp and 2° (Figs. not shown). These changes are due to the fact that instabilities are solved by vertical diffusion and the large scale adjustment. Then, precipitation was incremented about 20 mm (Fig. 12).

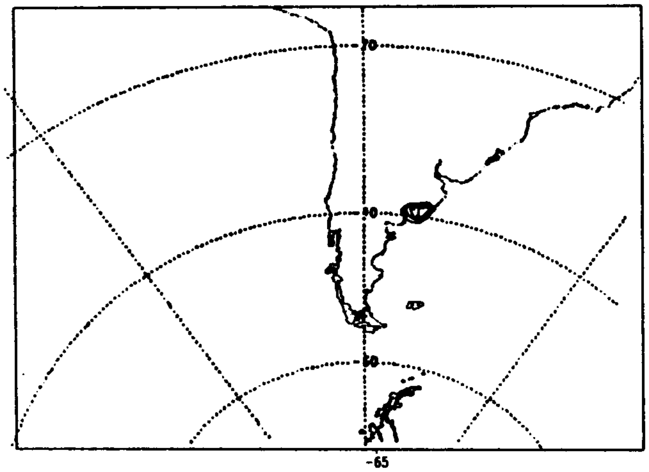

Fig. 12. Differences between EX4 and CTL, total precipitation. Simulations valid at 00 UTC January 5th.

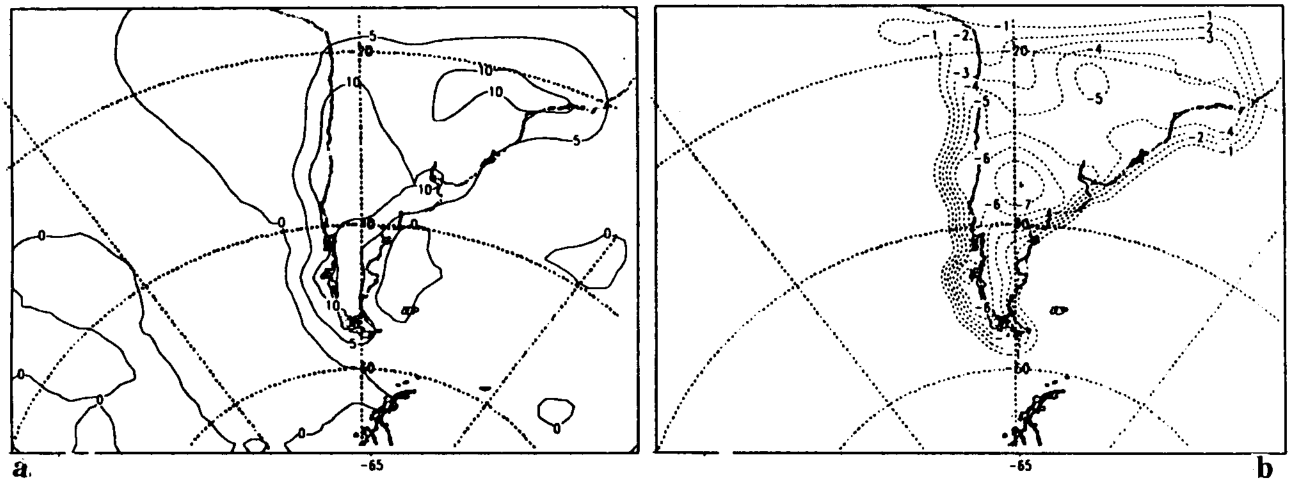

Fig. 13. Differences between EX5 and CTL. a) geopotential height. b) temperature. Simulations valid at 00 UTC January 5th.

The differences of the last experiment (EX5) for January 5th are seen in Figure 13. As expected, the parameterization of the radiation balance is important over the continental region, mainly affecting the temperature. There were coolings of up to 7°, while the geopotential heights increased only 12 mg. On the 7th, the intensity of the variations registered was similar to the ones mentioned before. Large scale and convective precipitation show no significant changes.

5. Conclusions

This model is sensitive to parameterizations in low levels. Its impact is evaluated using subjective and objective methods. Both analyses show a significant improvement in the model forecast with the whole of the parameterizations.

The large scale adjustment and the vertical diffusion of fluxes are the parameterizations, which affect geopotential heights the most. Even though they have opposite sign, they cause variations of up to 40 mgp. ·Considering the selected case, the vertical fluxes were more important than the large scale adjustment over the cyclogeneses, but on the 7th the opposite occurred.

The experiments in which the parameterization of the vertical fluxes and radiation were canceled, showed that these are the principal reason for the changes in temperature when all physical processes are neglected, producing a decrease in temperature of up to 8°.

Vertical diffusion proved to be essential in the precipitation calculated by convective adjustment. There was a great increase of precipitation in forecasts without the mentioned parameterization. Large scale precipitation was also greatly affected by the vertical diffusion, reaching differences of up to 40 percent in the cases studied.

The importance of including the vertical diffusion is related with the couple of the surface and the interior layers, if it is removed the effect of the boundary layer is only felt in the surface layer resulting large temperatures and precipitation.

Convective adjustment is of little importance in temperature and geopotential.

The differences analyzed here correspond to 24 hr forecasts, they intensify for 36 hr forecasts.

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