A STUDY OF THE "FEED-BACK" ASPECTS OF DIABATIC FORCING IN THE FRENCH LARGE SCALE HEMISPHERIC MODEL "EMERAUDE"

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I - INTRODUCTION

In this study we look at the diabatic forcing in the french large scale hemispheric operational forecasting model "Emeraude" by trying to identify some "chains" of influence between individual atmospheric diabatic processes. We concentrate on a single forecast (87/04/01, 00Z), we choose the range 72 to 96 hours for our study - beyond the "spin-up" period and before climate drift starts to be significant -, and we limit ourselves to zonal mean tendencies, a tool very suitable for the diagnostic of diabatic forcing but incomplete with regards to the energetics of the general circulation.

Despite all these limitations, some of our results are rather clear-cut and we go as far as inferring from them a strategy of design and tuning for "physical parametrization packages" based on a flow-diagram of the major feed-back effects. The zonally averaged thermodynamic/dynamic interaction appears to be the least diabatically controlled aspect in our results and this is independently confirmed by a comparison of operationally averaged zonal mean absolute tendencies between the ECMWF model and "Emeraude".

We shall briefly describe the relevant characteristics of the "Emeraude" model in section II ; the design of the experiment will be presented in section III and its results in section IV ; section V deals with the basic conclusions of the study that are complemented by the ECMWF/"Emeraude" comparison in section VI. Finally section VII indicates potential extensions and further applications of this type of diagnostics.

II - A RAPID SURVEY OF THE FRENCH OPERATIONAL LARGE SCALE FORECASTING MODEL WITH EMPHASIS ON ITS DIABATIC PART

The model is hemispheric, spectral with a triangular truncation at wave number 79 (the associated Gaussian grid on which diabatic processes are calculated has 60 rows of 240 points in the Northern hemisphere). The vertical coordinate is hybrid (Simmons and Burridge, 1981) with 15 levels which are given in Table 1. For more details see Coiffier et al. (1987).

The physical parametrization package consists of the following items :

- a simple radiation scheme is called at every time step ; all effects are taken as zonal means but for clouds, black body functions, solar flux at the top of the atmosphere and surface albedo + emissivity ; only one spectral interval for solar radiation and also only one for thermal radiation ; "two stream" - type calculations, the gaseous optical depths being precomputed in clear sky conditions ; in the thermal case the

Table 1 : Boundary values for the "A" and "B" functions in the "Emeraude" 15 layers hybrid vertical coordinate : $p = A\ p_o + B\ p_s$ (p_o = 1000 hPa ; p_s surface pressure)

	A	B
0	0.	0.
1	0.0500	0.
2	0.0857	0.0271
3	0.1088	0.0773
4	0.1209	0.1465
5	0.1236	0.2307
6	0.1187	0.3257
7	0.1077	0.4275
8	0.0923	0.5321
9	0.0742	0.6354
10	0.0549	0.7333
11	0.0363	0.8218
12	0.0198	0.8967
13	0.0071	0.9541
14	0.	0.9899
15	0.	1.

cooling to space term is computed without approximation and the optical depths for the "monochromatic" approximation to the exchange terms are chosen in order not to overestimate any of these terms,

- the vertical turbulent fluxes are parametrized following the 1983 version of the ECMWF scheme, as described by Louis et al. (1982) : Monin-Obukov type computation for the surface fluxes and mixing length approach for the PBL (and free atmosphere) fluxes ; the influence of stability on the strength of the exchange is parametrized in terms of analytical functions of the bulk Richardson-number,

- the effects of shallow convection are parametrized through a modification of this Richardson number in case of strong humidity gradients (Geleyn, 1987) ; the scheme is self-regulating and requires no additional tuning,

- sub-grid-scale vertical momentum transport has also a gravity wave drag component (Rochas and Geleyn, 1987) : the surface extraction is proportional to the standard deviation of the sub-grid-scale orography (no anisotropic effets yet) and the vertical deposition rate is computed with a continuous version of Lindzen's saturation hypothesis,

- the parametrization of deep convection is based on a mass-flux type scheme controlled by a Kuo-type closure assumption (Bougeault, 1985) ; entrainment and liquid water sustentation are considered in the modelled cloud ascent ; the interaction with PBL fluxes of heat and moisture is total and convective redistribution of horizontal momentum is considered with the mass flux type equations ; the vertical profile of the mass flux is proportional to the square root of the "cloud minus environment" moist static energy excess,

- stratiform precipitations are parametrized using a slightly modified version of the Kessler scheme : no supersaturation is allowed and the sub-cloud evaporation in unsaturated layers is linear in the inverse of pressure for the square root of the precipitation flux,

- the soil treatment follows Deardorff's (1978) force-restore proposals for the temperatures and water amounts. The following constants are used : 1.1 10^{-5} °K/(J/m^2) for the soil surface layer's inertia, 5 for the ratio of the depths of the two layers, 20 and 100 Kg/m^2 for their maximum water contents ; the evapotranspiration is obtained by a linear combination of the relative humidity and Hallstead-Budyko methods, the second weight corresponding to the vegetation covered portion of the grid area (Royer et al. 1981).

The whole of the parametrization ensemble is written in such a way that full consistency between all parametrizations is ensured and that conservation of enthalpy and moisture is total even with the specific heat of the air varying with its moisture content (Geleyn, 1986).

III - DESCRIPTION OF OUR EXPERIMENTS ABOUT FEED-BACK PROCESSES

We consider only the effects of atmospheric parametrizations (radiation, vertical eddy fluxes, shallow convection, gravity wave drag, deep convection and stratiform precipitation) and do not go into the problem of surface fluxes. We are aware that this brings some limitations to our demonstration but, in our mind, there exists no clean way of separating the diverse land surface reponses to atmospheric forcing and the opposition between land and sea effects would anyhow make the use of zonal mean averages very risky in such a case.

The idea behind the study is simple. We run seven forecasts from the operational initialized analysis : a reference run with the complete configuration and six runs, each time with one of the parametrizations switched off. In fact, to comply with our previous remarks, full radiation computations are performed but the resulting surface fluxes are kept constant through the atmosphere, ensuring no heating or cooling of atmospheric layers ; in the case of vertical diffusion we keep the basic computation of surface fluxes and the dry convective adjustment aspect by simply putting the asymptotic mixing length to a small value, rather than switching off the parametrization. Nevertheless one can say that the effects of each of the six parametrizations on the atmospheric layers are taken out successively.

We then study the zonal mean impact of each parametrization by subtracting, in our diagnostics, the results of the perturbed run from that of the reference one. In each case and, when applicable, for each of the four basic variables (temperature, specific humidity, zonal and meridional wind) we look first at the direct effect (in most cases equal to the contribution of the parametrized process in the reference run). We then try to identify the mean compensating process among the five other ones and we estimate the degree of compensation (i.e. minor, partial or nearly full). We then look at the impact on the total diabatic forcing and the total impact (the previous one plus the impact on the adiabatic response). In the case of temperature we also consider the impact on the energy conversion term that gives an idea of the response of the meridional circulation.

Before going further we want to stress that the results that will be presented now may be quite model-dependent and in particular that the hemispheric character of our model casts some uncertainty on our conclusions near the equator.

All results will be presented in the classical zonal mean diagrams : isolines in a rectangular regular grid representing the averages along the model latitude circles for each hybrid level. Thus the representation is neither "true" in the vertical (the thin PBL layers get an exaggerated representation) nor in the North-South direction (we do not have an area weighted representation but something very close to the development of one meridian). The Equator is on the left, the North Pole on the right, the zero isoline is always thickened, positive isolines are continuous, negative ones are dotted, the contouring intervals are the following :

0.5 °K/day for temperature
0.0002 kg/kg/day for specific humidity (the former x Cp/L)
1 m/s/day for wind
roughly the equivalent of the one of temperature for the conversion term.
(No line quotes are given in this representation).

IV - RESULTS

a) the reference run

To get an idea of the parametrized forcings, we first present the absolute results of the reference run. Figure 1 shows several diabatic contributions to the temperature budget, Figure 2 does the same for moisture, Figures 3 and 4 for the two wind components. We thereby note that all subgridscale vertical transports (turbulent fluxes, shallow convection and, for the wind, gravity wave drag) are put together in one single diagram. The first two could anyhow not be separated and for the latter the important effects separate from themselves (in altitude).

A full description of the results of Figures 1 to 4 will not be presented since it is beyond the object of this paper and, further it would not add much on top of several other papers dealing with the same subject. We shall only comment briefly on the total diabatic effects and on the conversion term, all in Figure 5.

The temperature effects (Fig.5a) look very realistic (compare them for instance to the right hand part of Figure 3 from Holopainen, (1988 -same Volume)) and one can easily show that heating areas correspond either to PBL fluxes of sensible heat or to deep convection (in the ITCZ) or to stratiform precipitation (both around 40° N and 75° N). The moisture budget (Fig.5b) is more difficult to assess, owing to uncertainties in the reference measurements and to the fact that it represents a residual between two stronger effects (turbulent moistening and convective drying) ; we can simply say that the picture is coherent with the temperature one, the drying area being connected to condensational heating and the only place of simultaneous heating and moistening being the PBL from 10° N to 75° N. The wind diabatic tendencies (Fig.5c and 5d) give a good indication of the height of the PBL while the meridional stratospheric forcing shows the regions of activity for the gravity wave drag (the uncorrelated effects on the zonal wind in the subtropical upper troposphere correspond to turbulent shear stress around the jet). As one can judge our parametrized convective friction is negligible in that zonal mean context.

Finally the conversion term (Fig.5e) shows well the Hadley and Ferrell cells but also indicates that north of 60° N the circulation is far from text-book-like, this being no surprise for a single case averaged only over 24 hours. This is also the reason why we do not show here the zonally averaged total (diabatic plus adiabatic) tendencies ; while reasonably balanced in the tropics they exhibit patterns that are purely circumstantial from 20 N onwards and it could be misleading to interpret them or to compare them with the impact patterns later on. We simply hope that the impact patterns are more robust and less situation dependent than the absolute tendencies, as it should be, at least in principle.

b) The impact of vertical eddy fluxes

The impacts of strongly reducing the asymptotic mixing length (therefore also reducing shallow convective effects) are shown on Figures 6,7,8 and 9.

The fact that we do not fully switch off the parametrization (especially for the lowest layers) is reflected in the differences between Figures 6a, 7a, 8a, 9a and 1c, 2c, 3c and 4c respectively. But the interesting point is that vertical eddy transfer is taken over by deep convection (the main compensating mechanism in all cases) nearly fully for

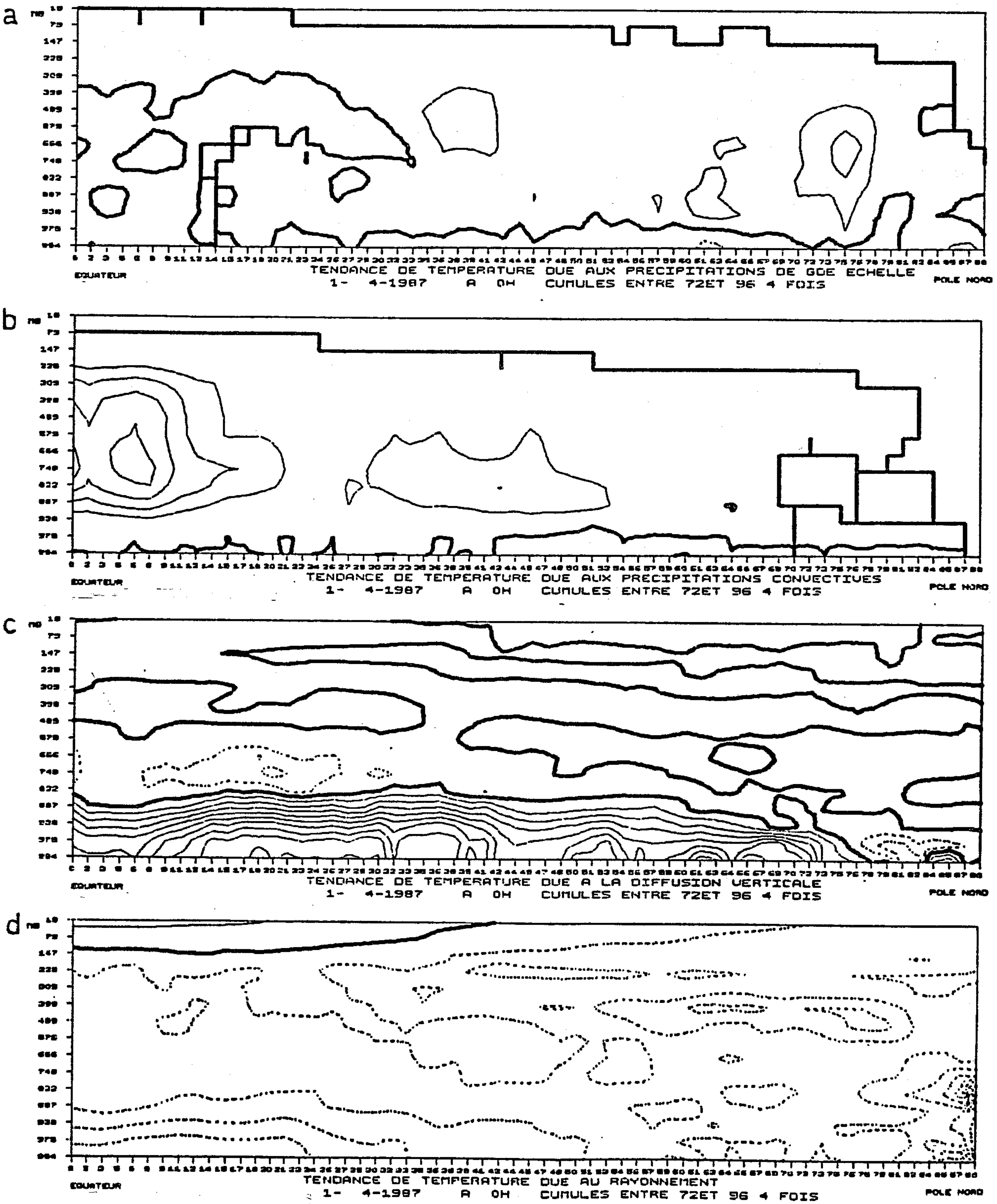


Figure 1 : Zonal mean temperature tendencies in the reference run due to : a) stratiform precipitation ; b) convective precipitation ; c) vertical turbulent fluxes ; d) radiation. Zero line reinforced. Negative isolines dotted. Contouring interval 0.5 K/day. For details see text.

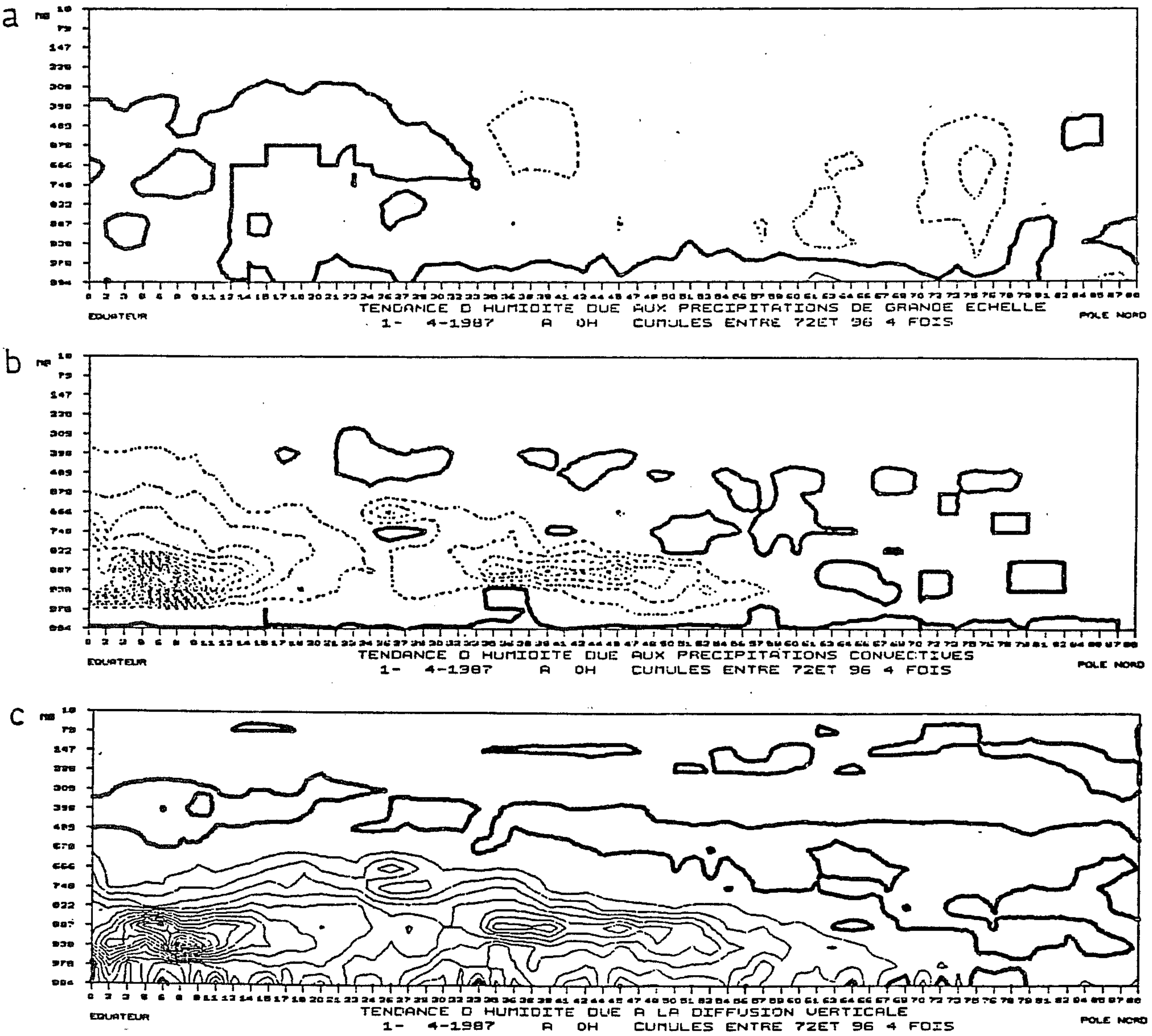


Figure 2 : Same as Figure 1 but for specific humidity. Contouring interval 0.0002 kg/kg/day.

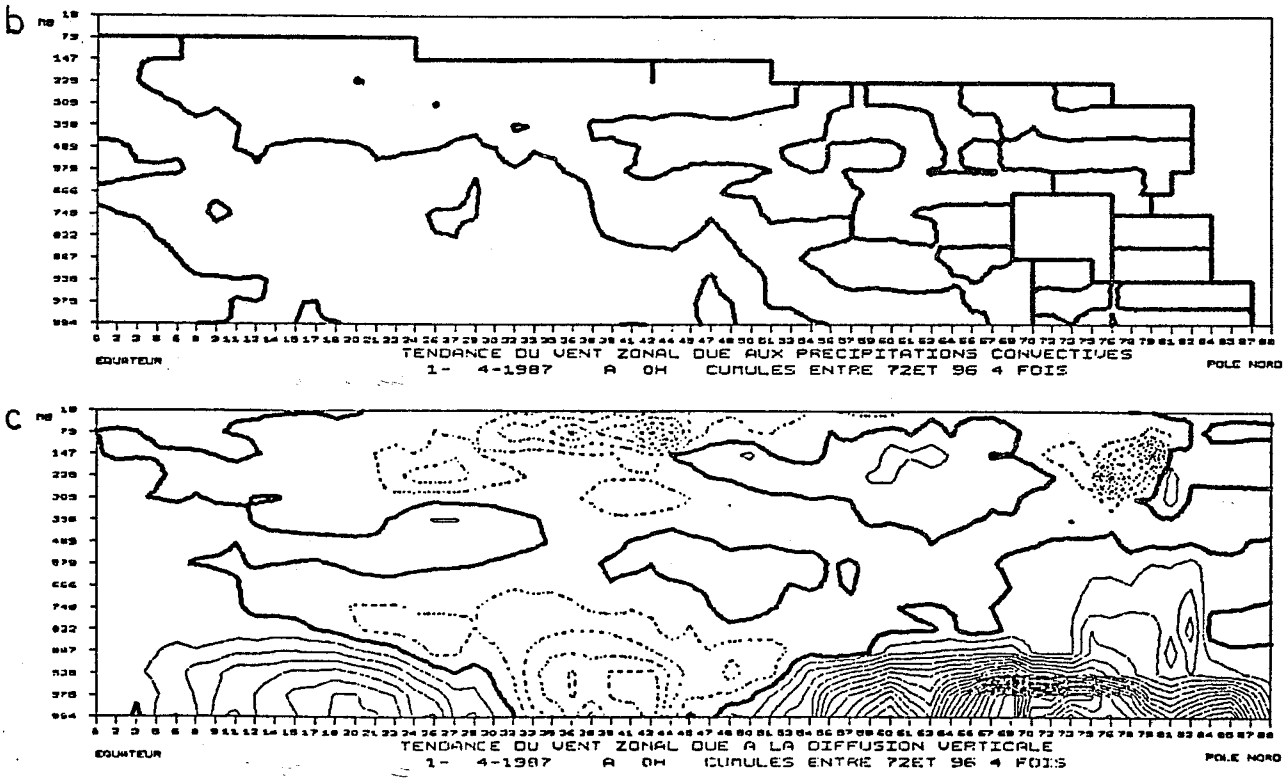


Figure 3 : Same as Figure 1 but for the zonal wind. Contouring interval 1 m/s/day.

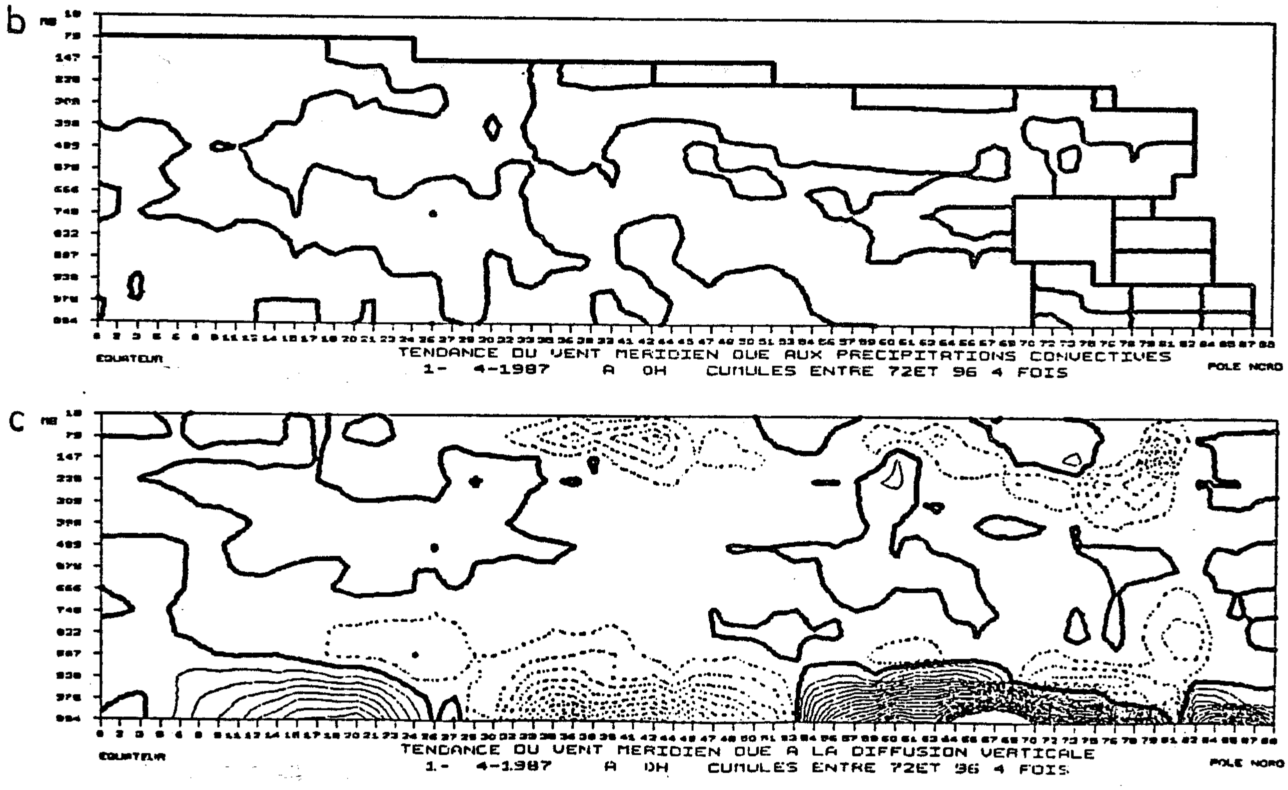
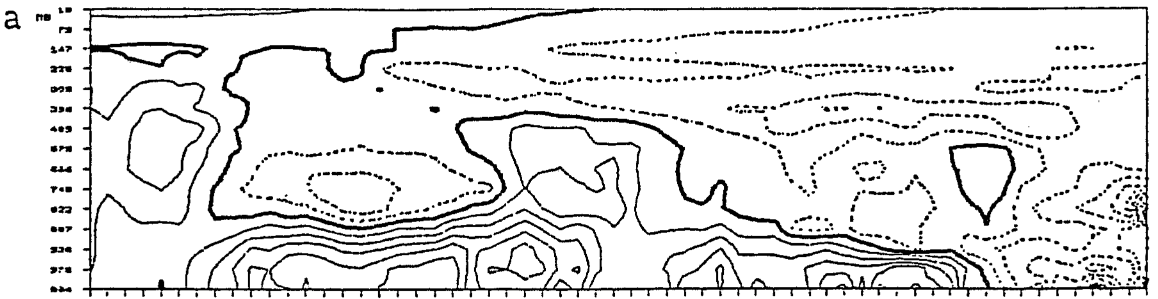


Figure 4 : Same as Figure 1 but for the meridional wind. Contouring interval 1 m/s/day.



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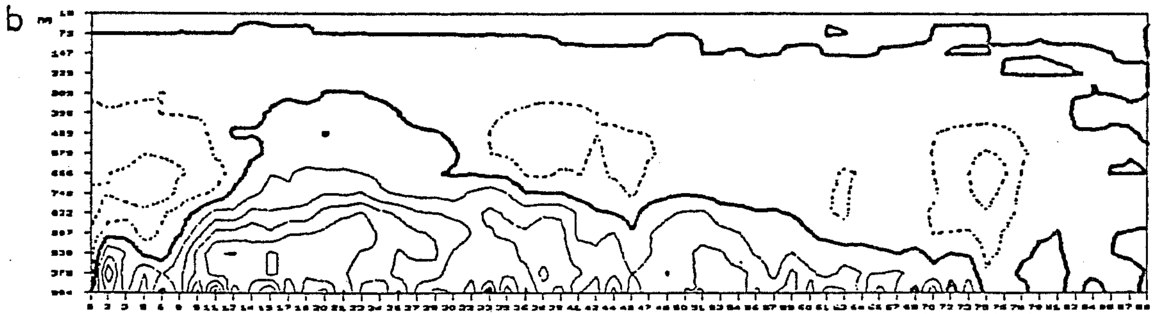

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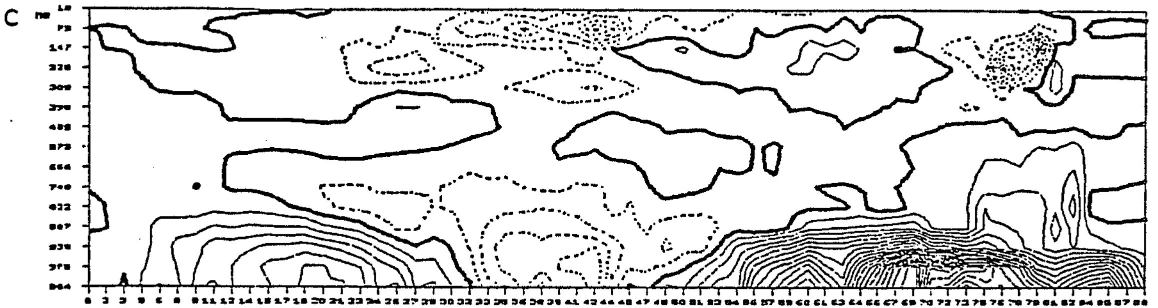

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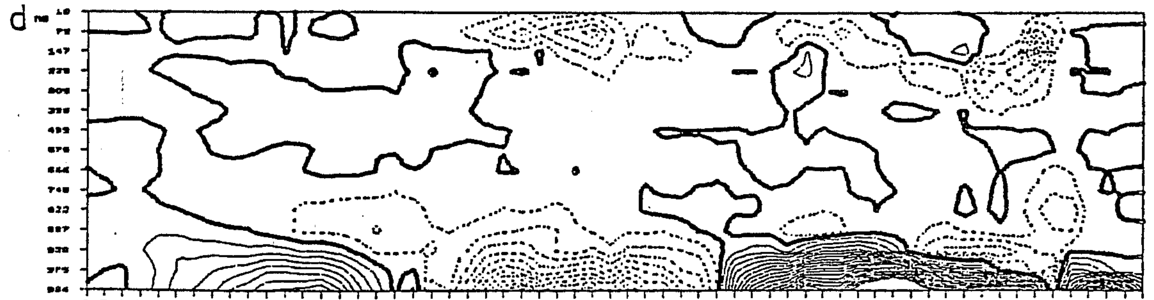

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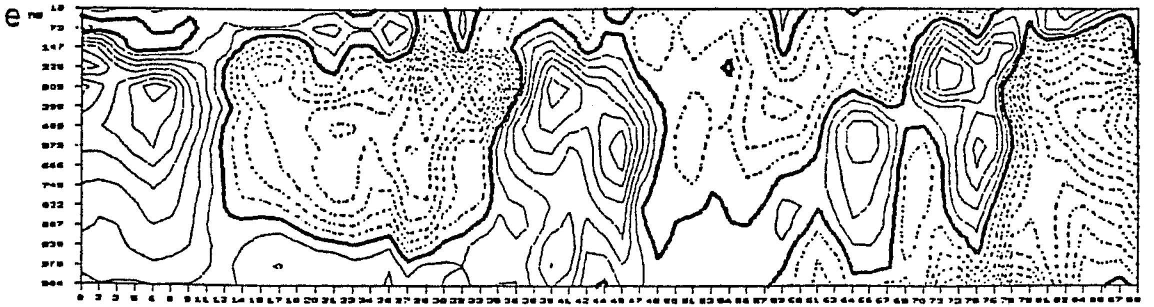

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Figure 5 : Total diabatic tendencies in zonal mean : a) temperature ; b) specific humidity ; c) zonal wind ; d) meridional wind. Same conventions as in Figures 1 to 4. Energy conversion term in 5e) $(\kappa \omega T/p)$: continuous line = upward motion ; dotted line = downward motion. For details see text.

moisture as one could have expected (Fig.7b) but also partially for temperature (Fig.6b) and even locally for wind in mid latitudes (Fig.8b and 9b). A very clear convective signature (deep + shallow) also appears in the thermodynamical net diabatic impact south of 30°N (Fig.6c and 7c), and this independently of the above-mentioned compensating effects : convection needs vertical eddy fluxes of moisture to be efficient. However this convective link is completely absent from the total effect for temperature and nearly so for moisture (Fig.6d and 7d), the adiabatic tendency working exactly in the opposite way (we shall come back to that point later). The situation is quite different north of 35° N where both temperature and zonal wind (Fig.6d and 8d) exhibit impact patterns in the free atmosphere that have little to do with the direct diabatic effets of Figures 6c and 8c. The clue to this surprising behaviour can be found in Figure 6e concerning the conversion term : a rapid comparison with Figure 5e shows a striking similitude between both patterns of ascending and descending motions above 800 hPa. Thus the main role of eddy fluxes appears to be the control of the meridional circulation above the PBL, that is where their magnitude is small and unfortunatly very difficult to correctly assess. In the tropics convective control by eddy moisture feeding compensates the forcing of the meridional circulation by the same eddy fluxes, but this obviously cannot be the case in mid-latitude and polar regions.

These remarks about the importance of small residual turbulent eddy fluxes in the mid-latitude free atmosphere must be put together with the findings of Holopainen (1988, same Volume) and Klinker and Sardeshmukh (1988, same Volume) about the difficulty to verify and tune the free atmospheric momentum diabatic forcing ; they are also probably related to Machenhauer's (1988) experiments on the sensitivity of baroclinic processes to the specification of the asymptotic mixing length in the ECMWF - type PBL parametrization.

c) The radiative impact

Here the picture is very simple : we have only temperature effects to consider ; there is no significant compensating effect (Fig.10b has thus been omitted altogether), the net diabatic effect is indeed very close to the radiative forcing (Fig.10c) and much of it remains in the total impact (Fig. 10d). Finally the dynamical consequences on the meridional circulation are limited to the upper part of the Hadley cell. Radiation reinforces the cell through enhanced sinking in the subtropics and some additional rising effect in clouds at the top of the ITCZ (Fig.10e).

The main interesting result remains however that of Fig.10d : the radiative forcing is neither compensated by other diabatic forcings nor by any adiabatic counter-effect. It goes straight into the thermodynamic structure of the atmosphere but without apparent influence on its dynamics. One can conjecture that the first fact happens because the troposphere is never in radiative equilibrium (while being nearly in convective equilibrium, this explaining the different behaviours with respect to the corresponding forcings) and that the second one simply reflects the relatively small magnitude of the radiative forcing and, more important, of its horizontal and vertical gradients.

This does not mean that radiative forcing is unimportant. In fact the cumulative uncompensated temperature impact will start to play a more and more important role as the forecasting range increases and, on the other hand, our remark about horizontal gradients does not apply when leaving the zonal mean framework,on the contrary (see e.g. Slingo, 1984).

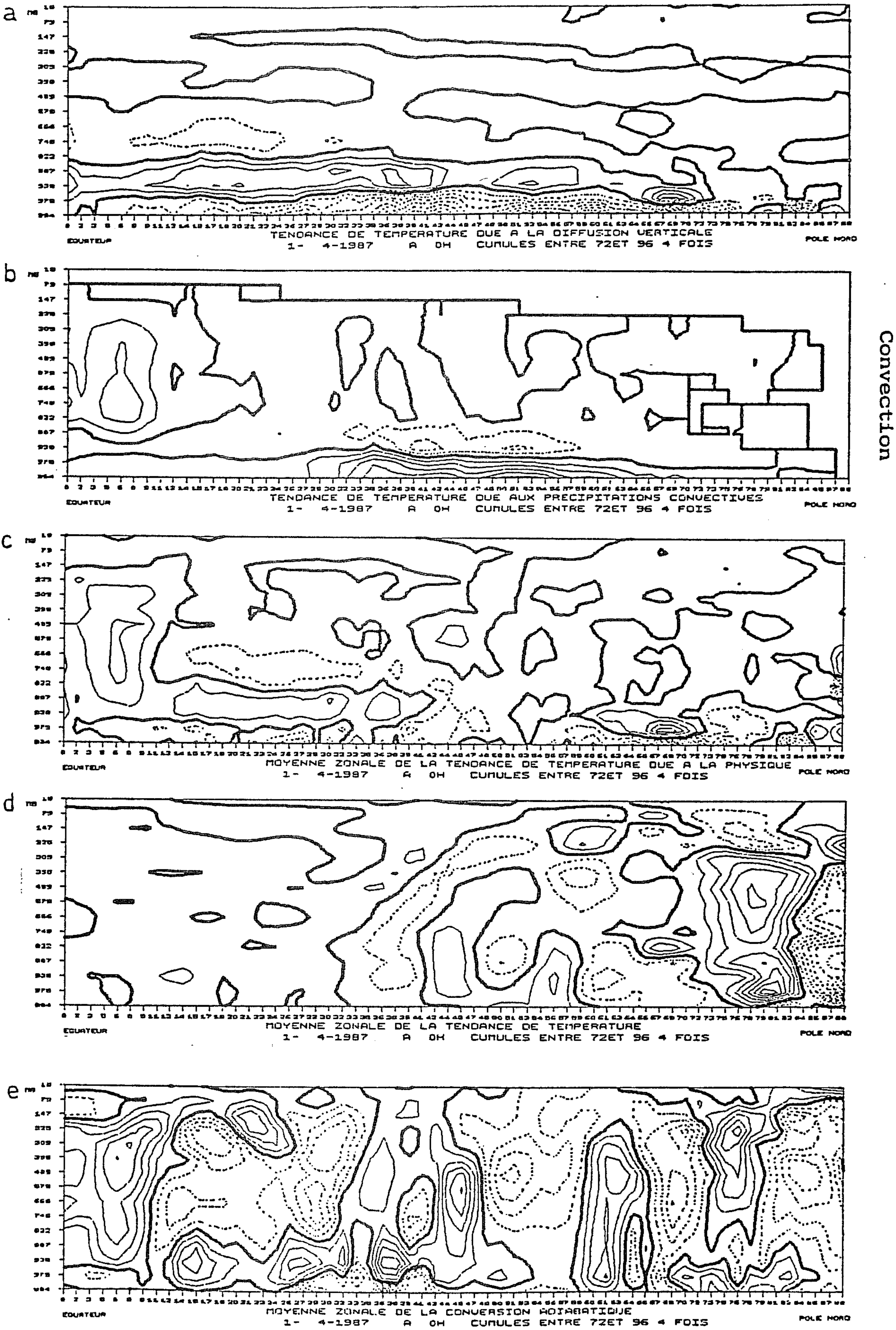


Figure 6 : Impact of the vertical turbulent fluxes on the zonal mean temperature tendencies : a) direct impact ; b) compensating effect by deep convection ; c) total diabatic impact ; d) total impact (diabatic + adiabatic). Impact of the vertical turbulent fluxes on the energy conversion term in 6e). All the contouring conventions are the same as in Figures 1 to 5.

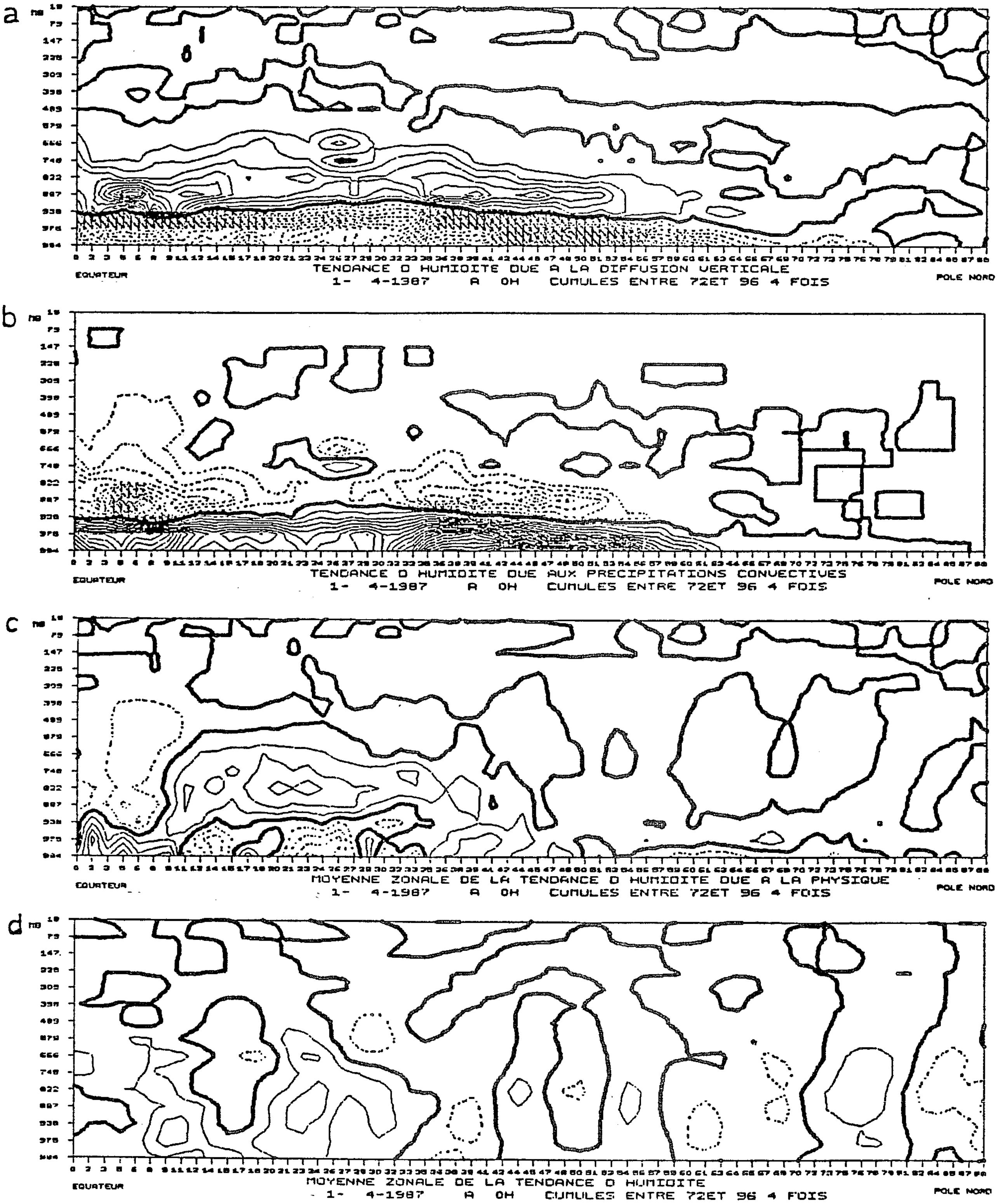
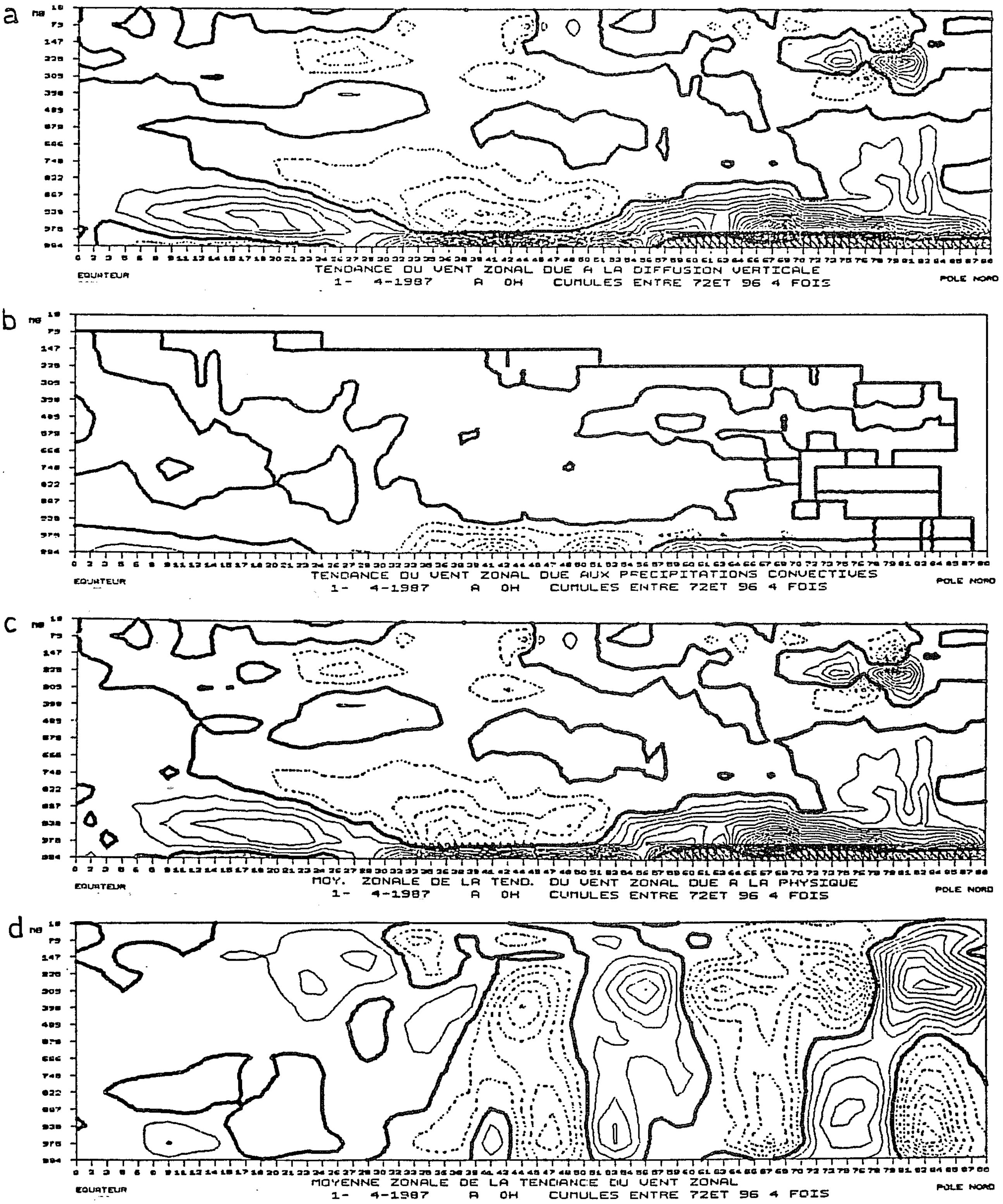


Figure 7 : Same as Figure 6 (a) to d)) but for specific humidity.



Convection

Figure 8 : Same as Figure 6 (a) to d)) but for the zonal wind.

Convection

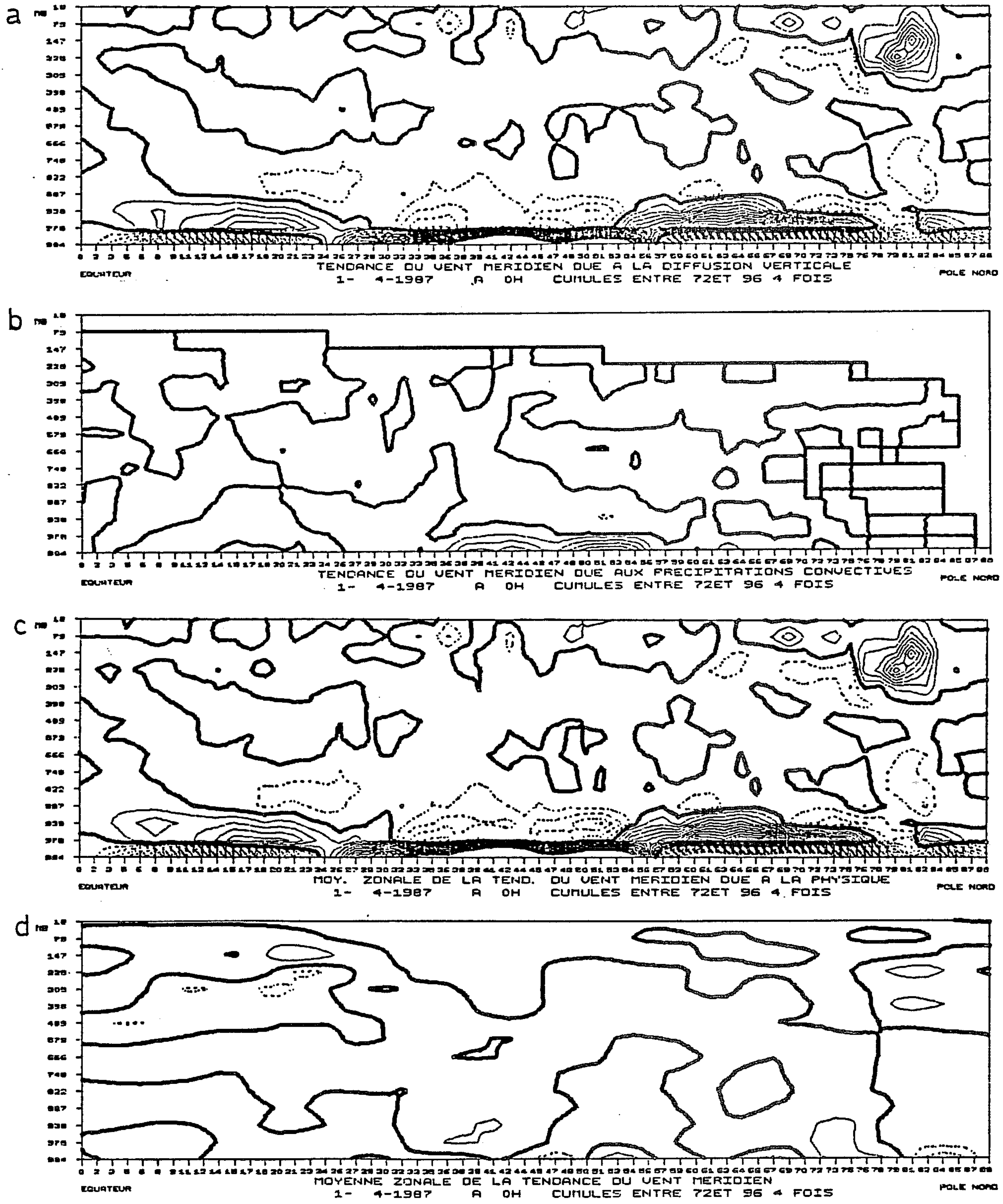


Figure 9 : Same as Figure 6 (a) to d)) but for the meridional wind.

If the compensating mechanisms are also ineffecient in the "eddy-sense" there is a strong case for getting the radiative parametrization right for itself.

A word of caution seems appropriate to conclude this sub-section : our "parametrization package", like all other ones used in NWP (at least to our knowledge) does not have a real interaction between the precipitation and turbulence aspects of cloudiness and cloud-radiative forcing. Whether a future scheme having this new feature would still show the same "independent" behaviour of radiative forcing remains to be seen.

d) The impact of stratiform precipitations

There again the situation is simple, although slightly unexpected. The compensating role is taken by convective rainfall (Fig.11b). In the case of moisture this compensation is so good that we decided to omit the picture of humidity impacts. For temperature the surprise comes from Figure 11c. The total diabatic effect has nothing to do with the direct forcing or its compensation by convective precipitation . Its cirrus-like pattern suggests that it has to do with radiation and Figure 12 (the radiative impact of large scale precipitation , shown as an exception to our rule of presentation) confirms it. Condensation prevents radiatively active high clouds from appearing or growing. If they exist, these clouds will have a net heating effect in the tropics (solar absorption plus thermal exchange with surface) and a top cooling and bottom heating effect (cooling to space gaining more importance) in mid-and polar latitudes. Given what was said in the previous sub-section it is not surprising to find this effect still very apparent in the total temperature impact (remember that there is hardly any moisture total impact !) but the previous remarks about cloud/radiative parametrization are even more meaningful here than before. There is surely an impact via radiation, but whether what we show here is realistic or not in its details is a matter of discussion.

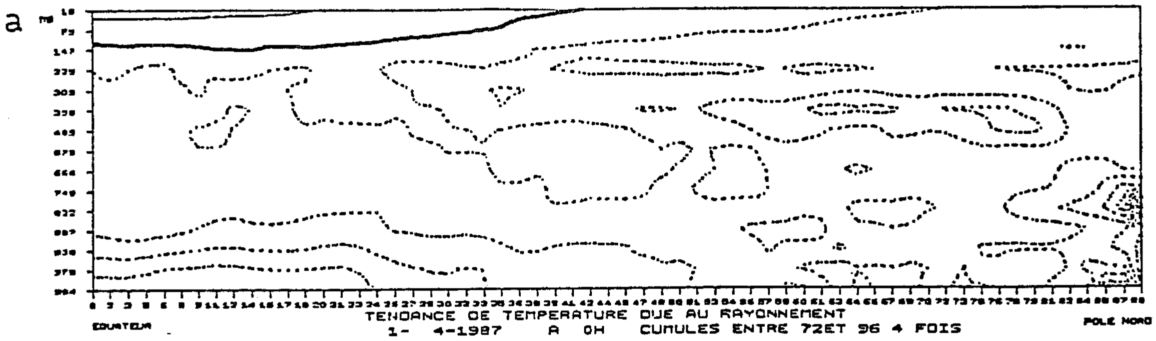
Indeed Figures 11 and 12 show the urgent need for a better link between rainfall parametrizations and cloud radiative forcing in future NWP models. Another point that will later be reinforced by the study of the deep convective impact and that is obvious in Figure 11 is the arbitrariness of the distinction between convective and large scale rainfall in to-day's models.

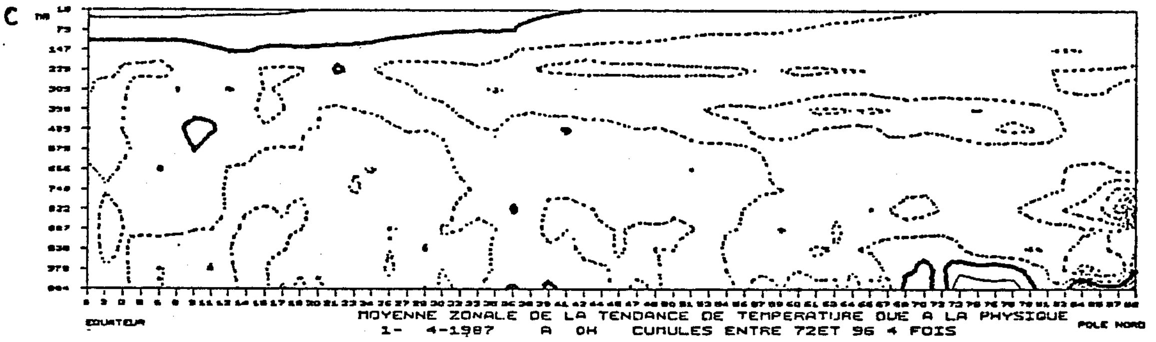
e) The gravity wave drag impact

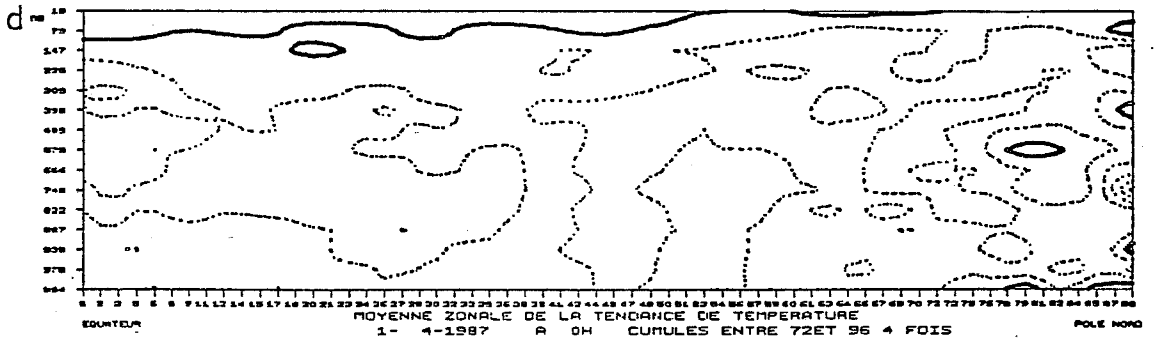
No surprise this time : the direct effect on the wind field exists but does not appear in the total impact on momentum (Fig.14 and 15). In fact the latter exists for the zonal flow only, but it is a consequence of a mass field link (Fig.13d) via a reorganisation of the zonal circulation (Fig.13e). The whole process is apparently confined North of 60°N in our case and shows no apparent interaction with the rest of the diabatic forcing. For a complete discussion of this rather isolated process the reader is referred to Palmer et al (1986).

f) *The deep convective impact*

The wind effects being small and anyhow questionable (what is really cumulus friction ?) we shall show only the thermodynamic effects in Figures 16 and 17. As one could expect the reciprocal of the stratiform case happens. Large scale precipitations are playing the compensating role for any missing deep convective activity (Fig.16b and 17b). But they do it







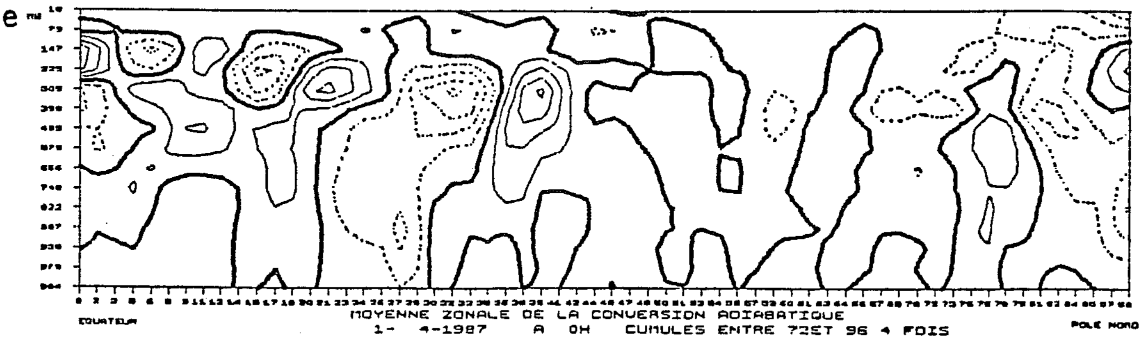


Figure 10 : Same as Figure 6 but for the impact of radiation. No Figure 6b) (no clear compensating effect).

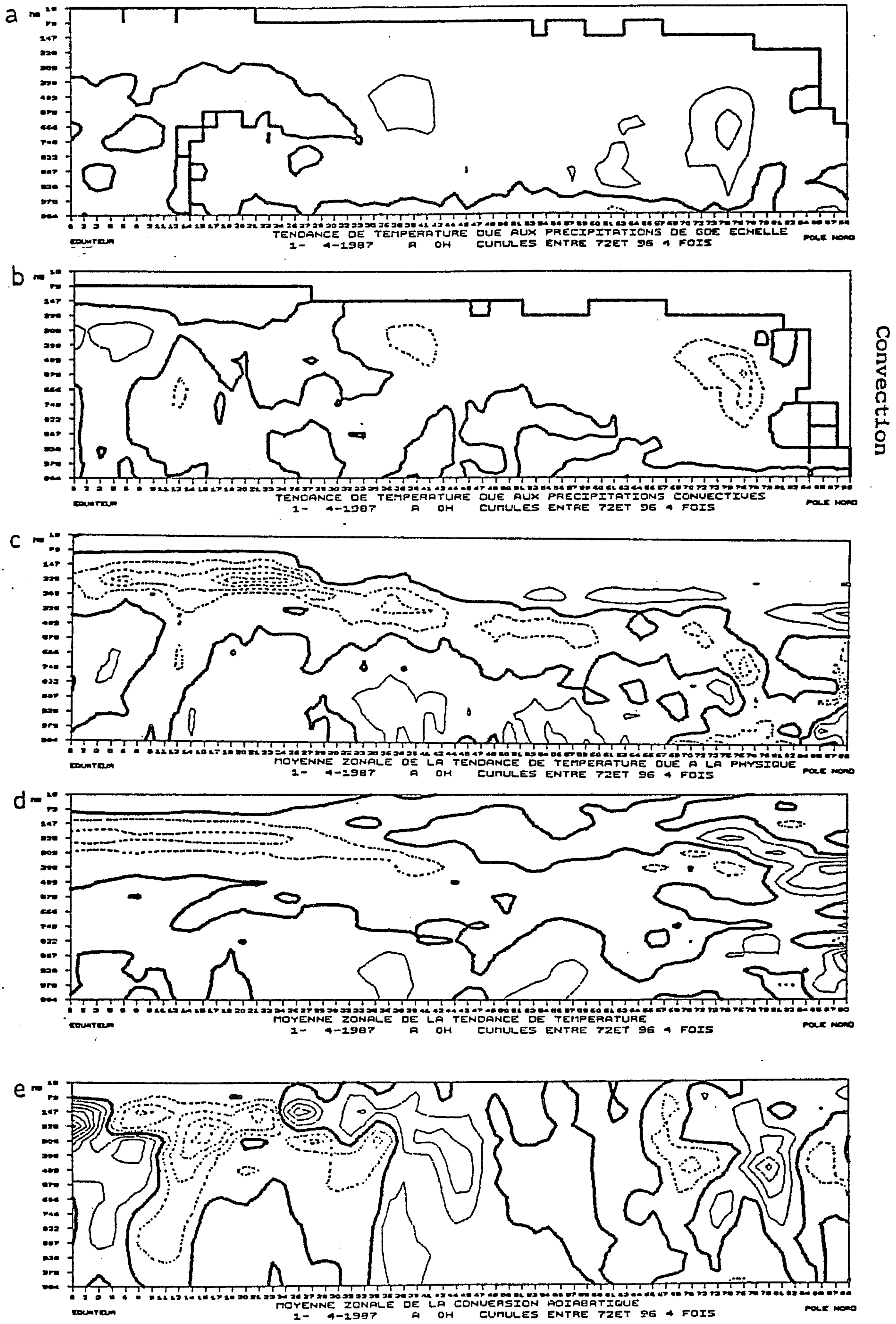


Figure 11 : Same as Figure 6 but for the impact of stratiform precipitation . The compensating effect shown in 11b) is that of deep convection.

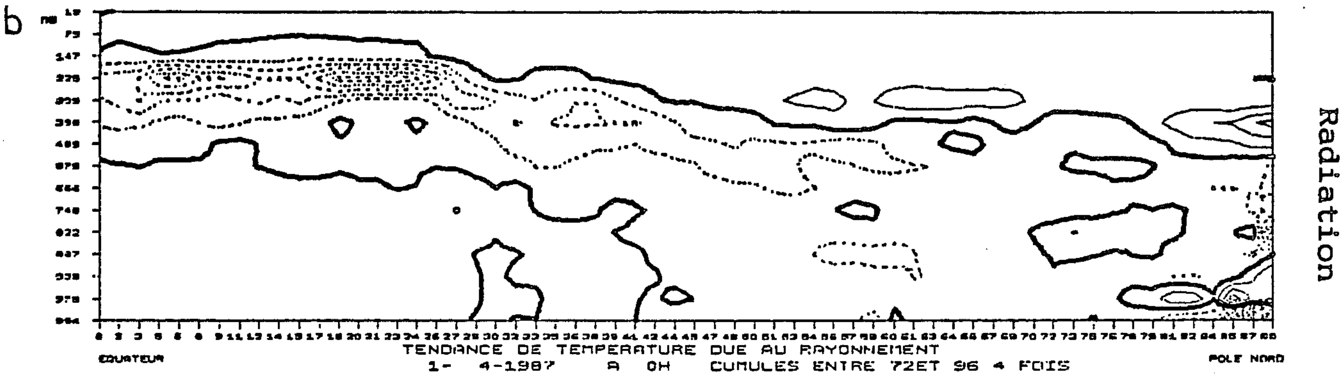


Figure 12 : Impact of stratiform precipitations on the zonal mean radiative temperature tendency (12b)).

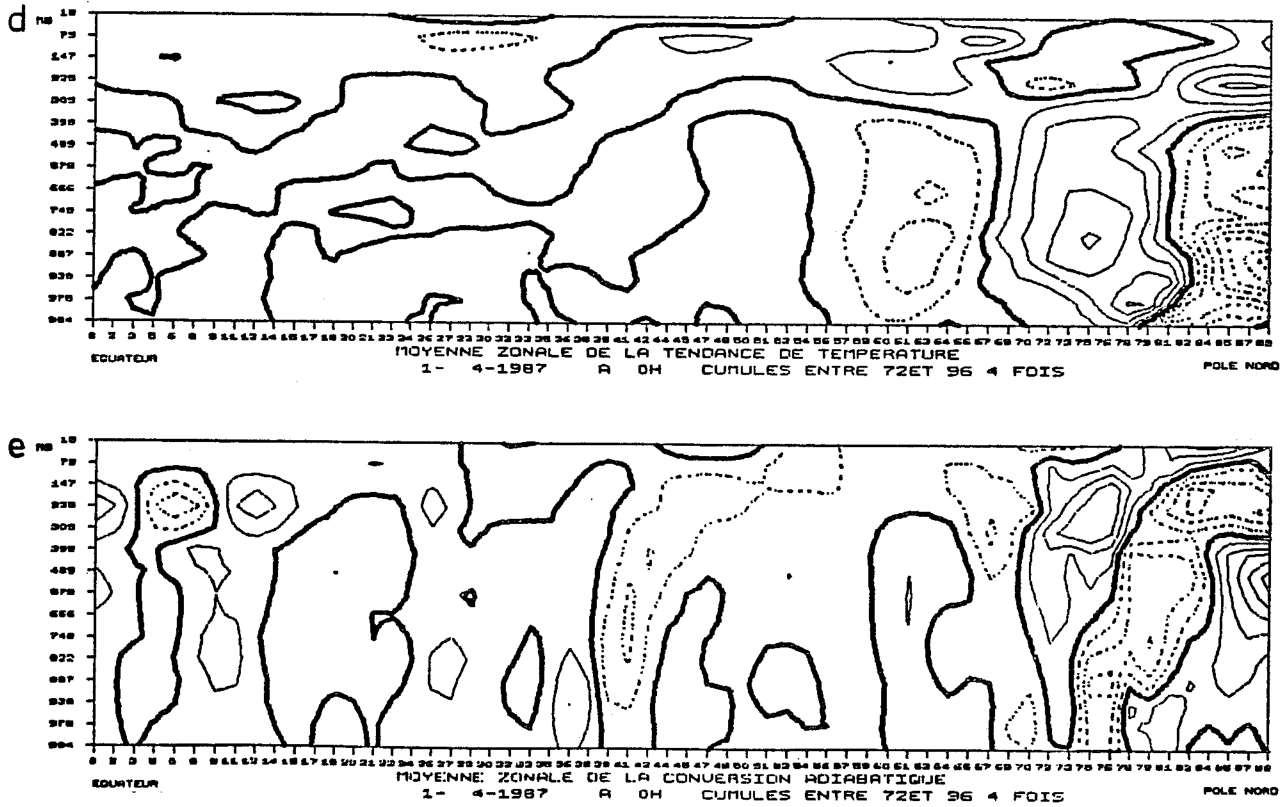
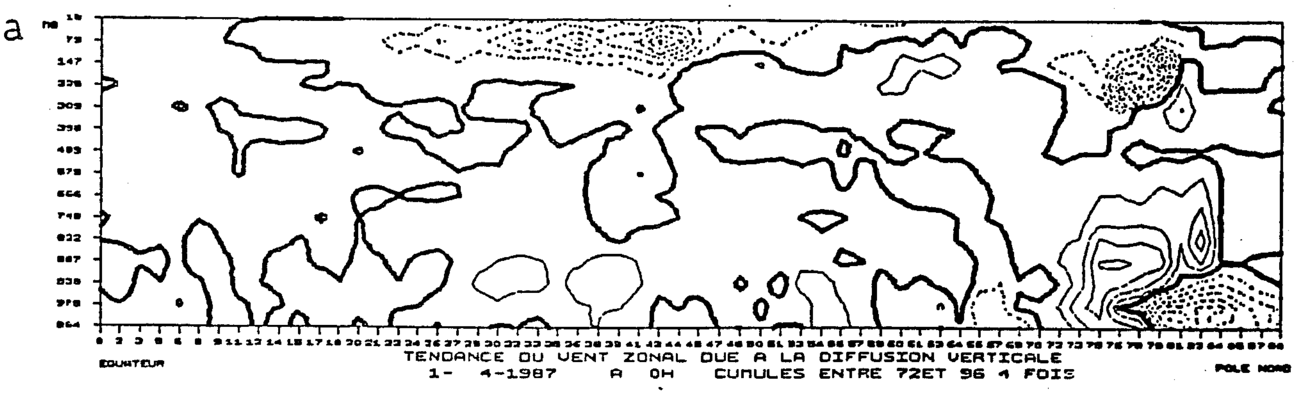
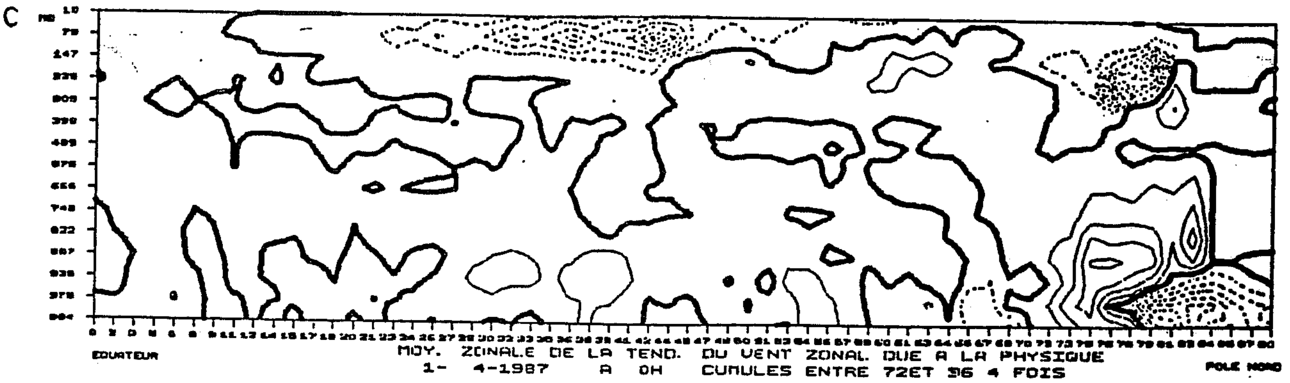


Figure 13 : Same as Figure 6 (d) and e)) but for the impact of the gravity wave drag.





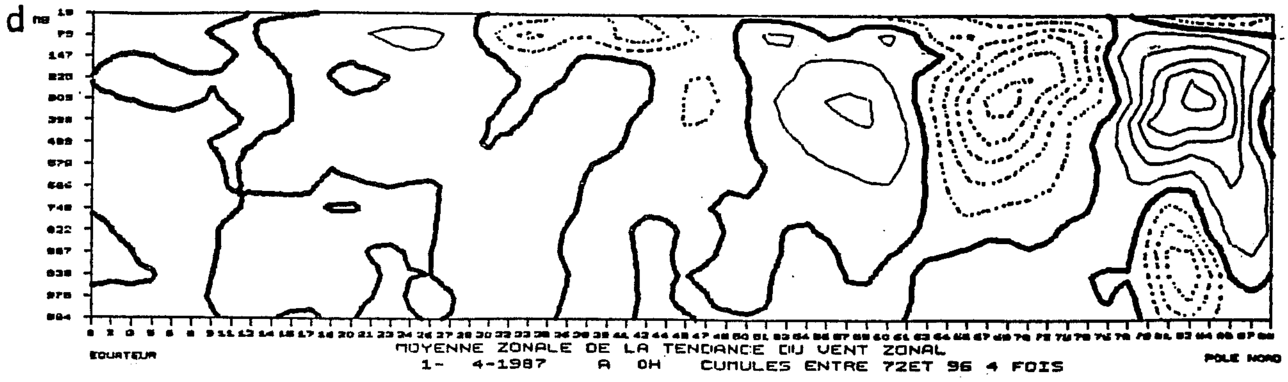
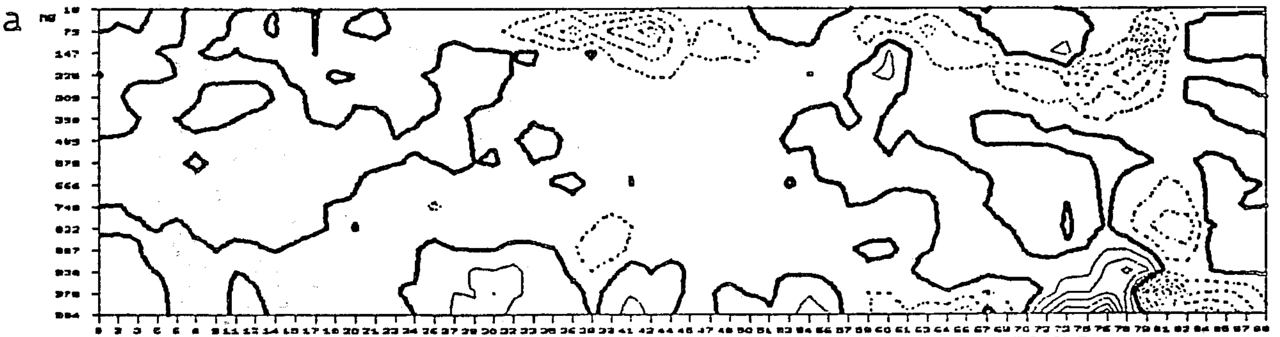


Figure 14 : Same as Figure 8 but for the impact of the gravity wave drag. No Figure 14b).

a



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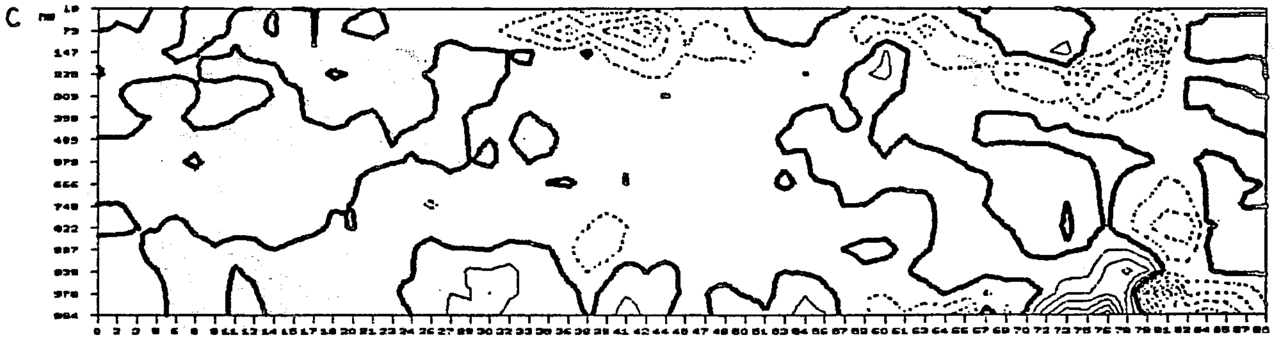

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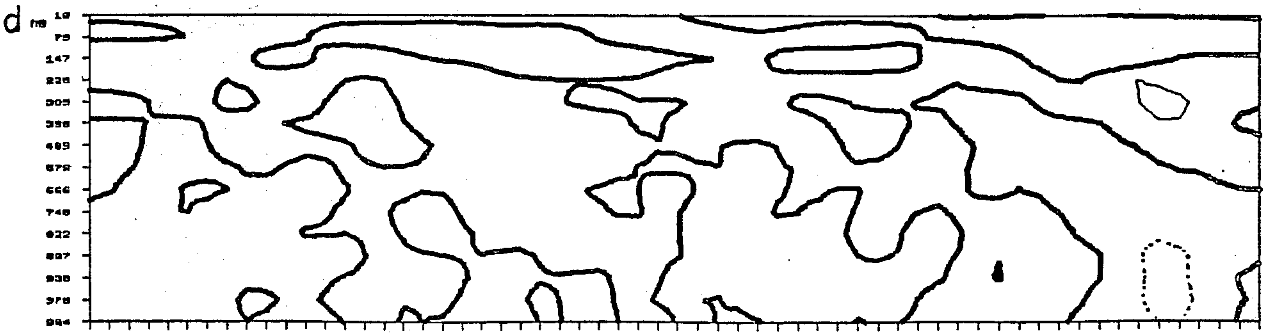

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Figure 15 : Same as Figure 9 but for the impact of the gravity wave drag. No Figure 15b).

with a rather different vertical structure and, as already noticed by many, they tend to over-do it both from the point of view of heating (Fig.16c) than from that of vertical moisture transport and drying (Fig.17c).

But the most striking result lies in Figure 16d (and to a lesser extent 17d).As was already hinted at in the case of convection driven by turbulent fluxes, the thermodynamic diabatic and adiabatic impacts of the deep convection compensate nearly exactly especially for temperature.

One can view that result from at least two different points of view. Either following Bougeault (1985) we state that the whole of the so-called large scale forced ascent in the ITCZ happens only inside convective towers of negligible horizontal extension, the environment remaining basically undisturbed ; or following Emmanuel (1988, same Volume) we say that, like the real atmosphere, our modelled atmosphere is neutral to convection and that only an external forcing can change its thermodynamical vertical structure. The interesting point in this discussion is that, contrary to the case of an adjustment scheme, there is nothing built in the convection scheme used in "Emeraude" that would a priori ensure such a behaviour. In fact our result first seems at odd with Emmanuel's reservation about the Kuo closure assumption. We can explain this paradox in the following way : provided that differential surface evaporation and horizontal non-divergent advective effects tend to get an horizontally homogeneous distribution of specific humidity in the PBL, the moisture convergence by dynamical processes will simply be proportional to the mass convergence ; then the Kuo closure will merely ensure that, in the absence of surface evaporation, convective heating will exactly compensate adiabatic cooling in the areas of dynamical convergence.

One might now ask why we parametrize deep convection at all. The answer lies in Figure 16e. The dynamical impact of convection on the strength of the Hadley cell is everything but negligible. One sees indeed that deep convection tends to slow down the tropical meridional circulation ! This is linked to the potential overshooting effect of the alternative stratiform solution.

Combining our interpretations of Figures 16d and 16e we can give the following image of the tropical/subtropical zonal mean circulation : the tropical free atmosphere behaves like a "porous stone", the moist PBL air that is converged at its basis rises through the thin holes and does not affect its thermodynamical properties, since condensational heating compensates adiabatic cooling ; but this forced channelisation puts a limit on the strength of the circulation and the driving force needed to overcome this breaking effect is provided by local evaporation at the surface and subsequent condensation of that additional moisture in the same towers. Finally the dry air at the top of the "stone" is recycled and rehumidified by high level poleward motion, subtropical dry sinking and PBL convergence towards the ITCZ.

If this is right, the main balance, that a good convective parametrization scheme should correctly ensure in the tropics, is between the moisture loading of the converging circulation (through a surface evaporation increasing with a stronger surface wind)and the "breaking effect" of convection on the same circulation. To our knowledge this test has yet to be done for any parametrization scheme currently used or proposed for NWP.

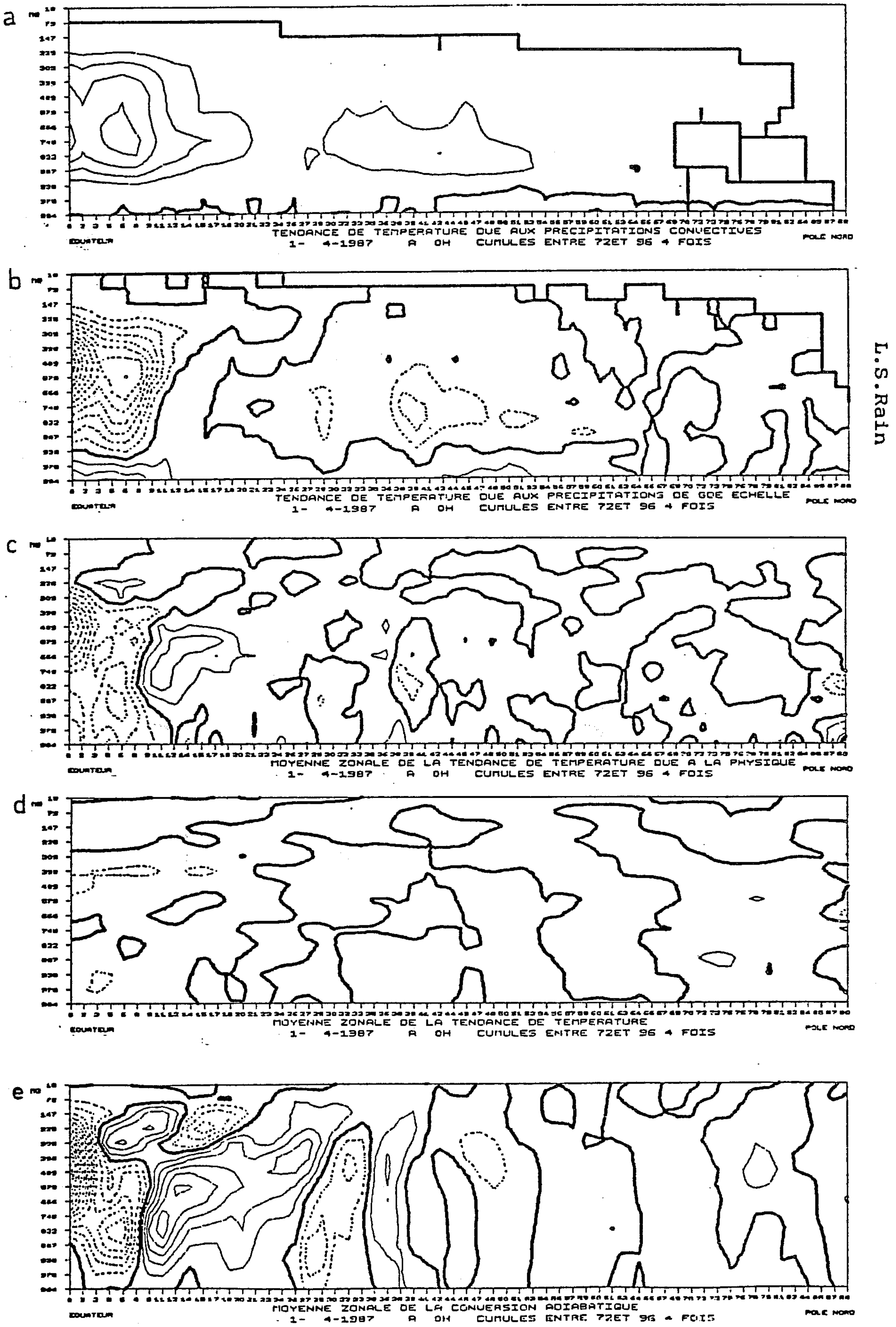
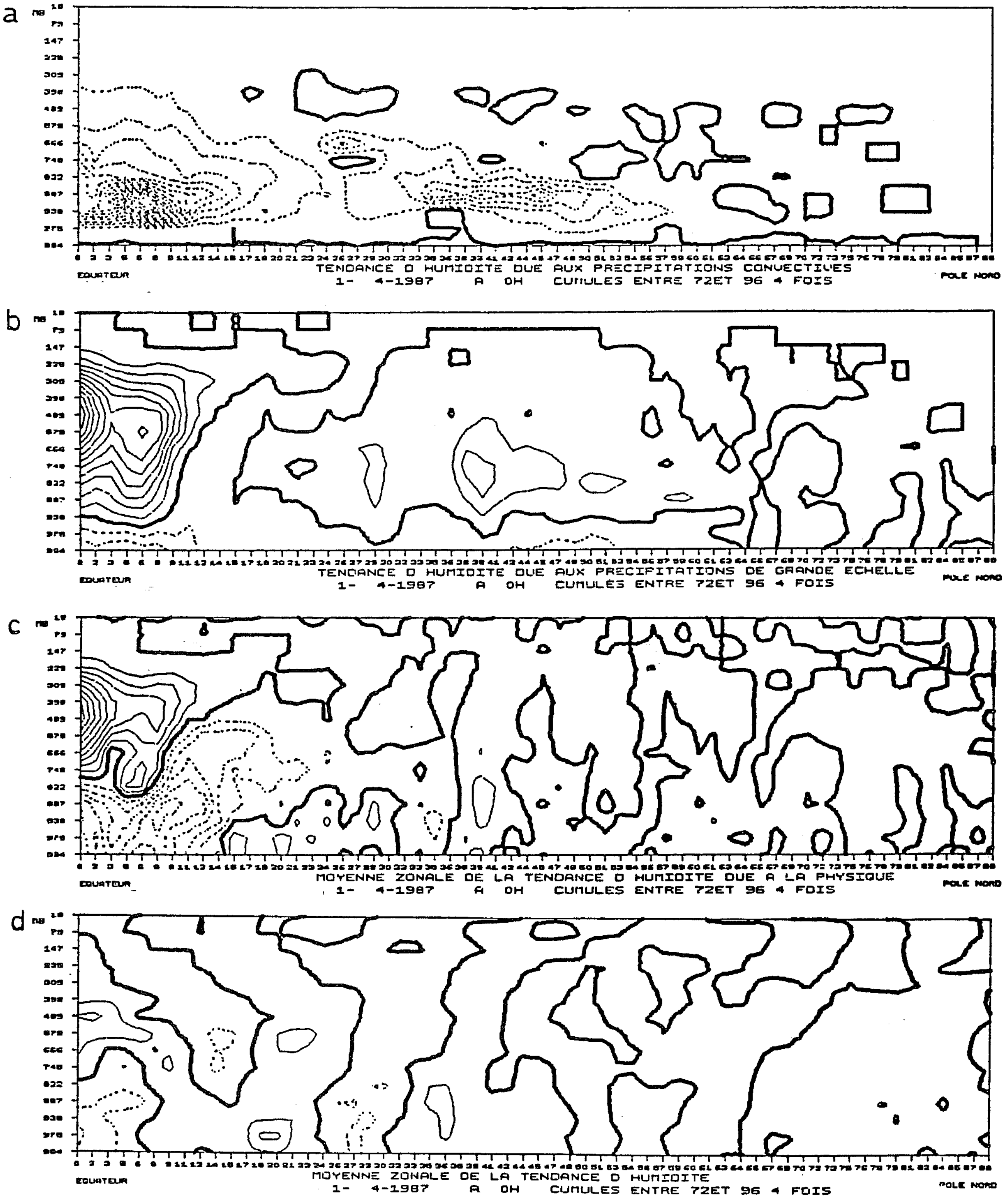


Figure 16 : Same as Figure 6 but for the impact of deep convection. The compensating effect shown in 16b) is that of stratiform precipitation .



L.S.Rain

Figure 17 : Same as Figure 16 (a) to d)) but for specific humidity.

g) The impact of shallow convection

There again the wind effects, despite being less arbitrarily parametrized, are negligible. The compensating effect of shallow convection is partly ensured by deep convection (Fig. 18b and 19b) ; that means that shallow convection is an efficient mean of increasing the deep convection's feeding by local surface evaporation. Thus, according to our previous discussions, shallow convection enhances the strength of the Hadley cell (Fig.18e). In the subtropics some part of the moisture effect is left uncompensated ensuring that the PBL does not get exaggeratedly moist to the expense of the free atmosphere (Geleyn, 1987) (Figures 19c and 19d) while the coupled diabatic temperature effect is dynamically compensated (Fig.18c and 18d).

V - SUMMARY OF THE FEED-BACK STUDY

The flow diagram of Figure 20 sums up the previous findings : large scale rain has a strong two way compensation with deep convection but mainly influences the thermodynamic state of the atmosphere via radiative effects, radiation being the only process to have a direct thermodynamical impact. Vertical diffusion and shallow convection can feed deep convection that has no direct influence on the thermodynamical structure of the atmosphere but has, on the contrary, a very direct link with its dynamics. Finally vertical diffusion and gravity wave drag act on the thermodynamic state of the atmosphere via a modification of the wind tendencies.

One can also mention that the moisture structure is relatively insensitive to all diabatic forcings and that some of these conclusions might be more dependent on the design of the parametrization schemes as one would wish, (convective closure assumption, cloud/radiative forcing and free atmospheric turbulent fluxes in particular). Finally one point where our study quickly reached its limits is the link between thermodynamic and dynamic forcing and reversely. We see some links but we cannot explain them with the relatively simple diagnostic tools used here.

At that point we shall go into a more controversial subject and try to draw conclusions from this study on how one should ideally go about the business of either designing or retuning an ensemble of parametrization schemes. Our choice will obviously be subjective and thus questionable, but we believe that it will at least stimulate a reflection on an area where empiricism is today the only rule.

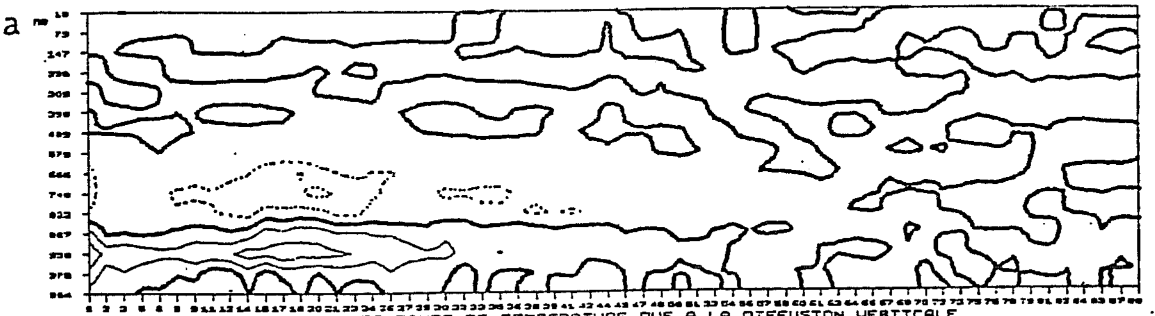
We suggest the following order of work (independently of any scale of values) ; we don't want to do things in increasing or decreasing order of importance but in a "logical way" according to Figure 20.

1) Vertical diffusion : because it has a strong overall effect, that, if wrongly handed, could mask everything else.

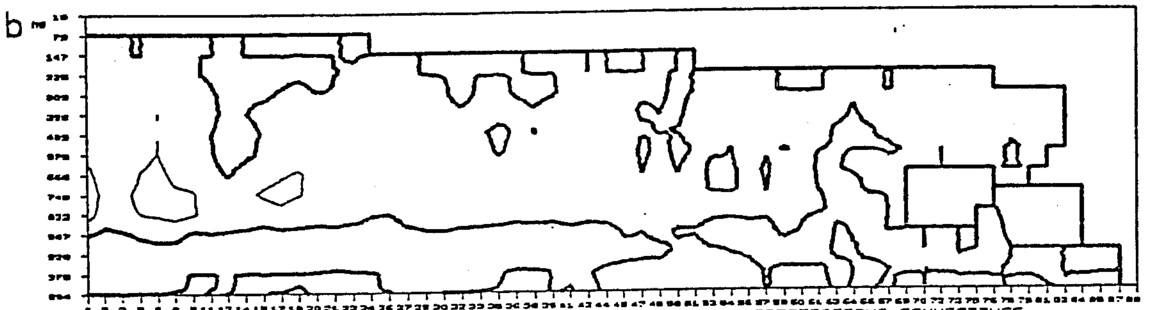
2) Radiation : because its "robust" effect can be viewed as a kind of external constraint and should thus be fixed prior to more sensitive tunings.

3) Gravity wave drag : rather independent but has mostly to balance for the two previous effects in the polar regions.

4) Large scale rain : has to be studied close to deep convection (is there a real threshold between the two ?) but is less crucial.

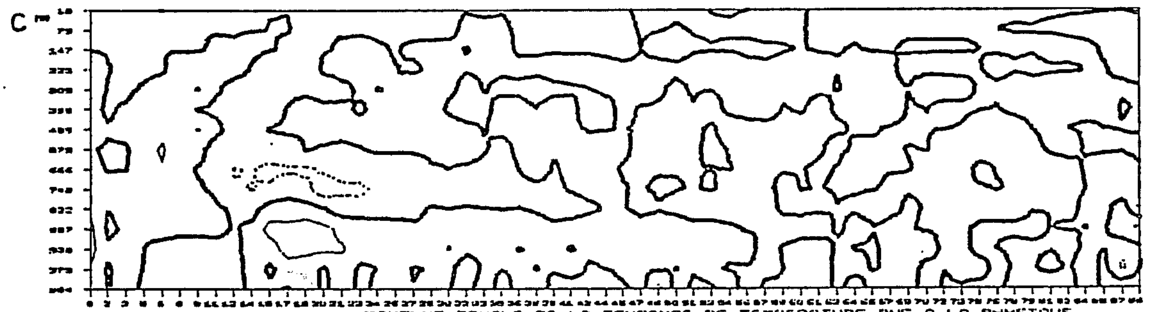


TENDANCE DE TEMPERATURE DUE A LA DIFFUSION VERTICALE
1- 4-1987 A 0H CUMULES ENTRE 72ET 96 4 FOIS

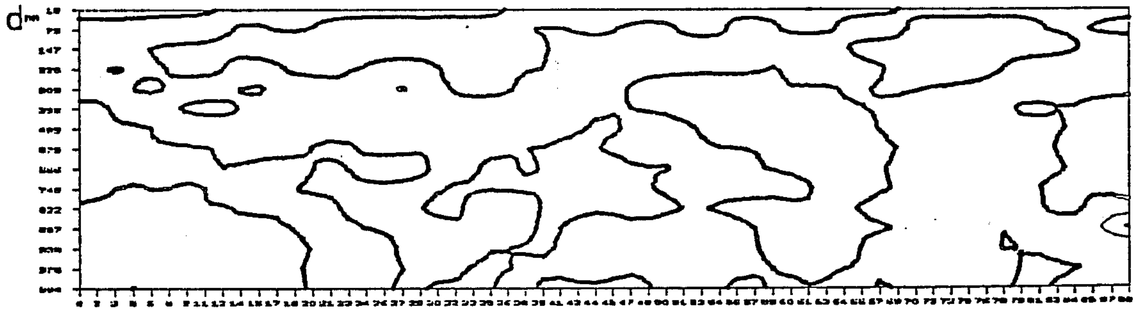


Convection

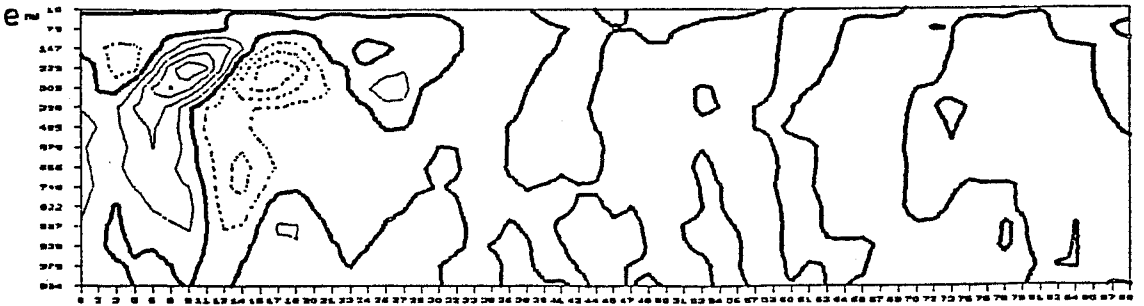
TENDANCE DE TEMPERATURE DUE AUX PRECIPITATIONS CONVECTIVES
1- 4-1987 A 0H CUMULES ENTRE 72ET 96 4 FOIS



MOYENNE ZONALE DE LA TENDANCE DE TEMPERATURE DUE A LA PHYSIQUE
1- 4-1987 A 0H CUMULES ENTRE 72ET 96 4 FOIS

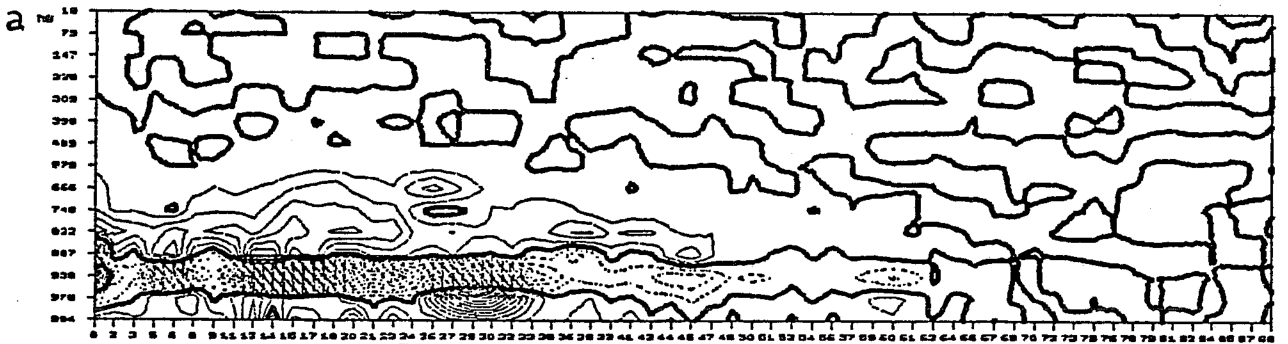


MOYENNE ZONALE DE LA TENDANCE DE TEMPERATURE
1- 4-1987 A 0H CUMULES ENTRE 72ET 96 4 FOIS

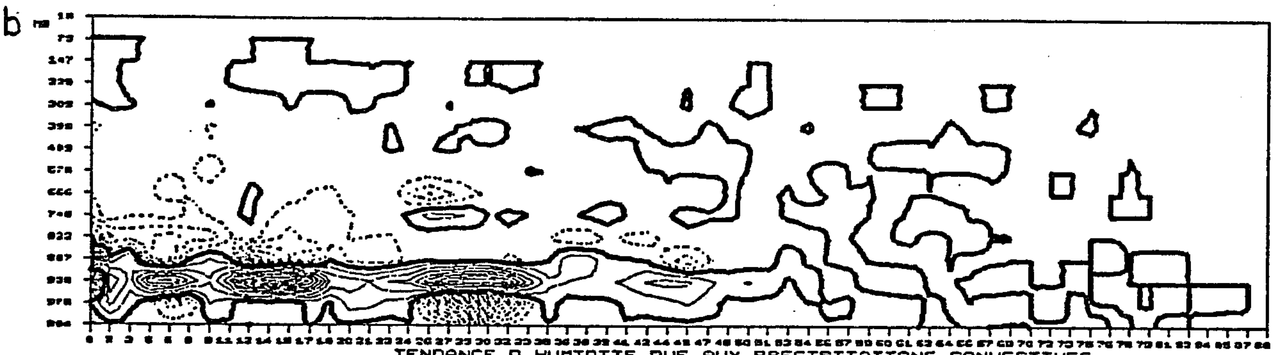


MOYENNE ZONALE DE LA CONVERSION ADIABATIQUE
1- 4-1987 A 0H CUMULES ENTRE 72ET 96 4 FOIS

Figure 18 : Same as Figure 6 but for the impact of shallow convection. The compensating effect shown in 18b) is that of deep convection.



TENDANCE D HUMIDITE DUE A LA DIFFUSION VERTICALE
1- 4-1987 A 0H CUMULES ENTRE 72ET 96 4 FOIS



TENDANCE D HUMIDITE DUE AUX PRECIPITATIONS CONVECTIVES
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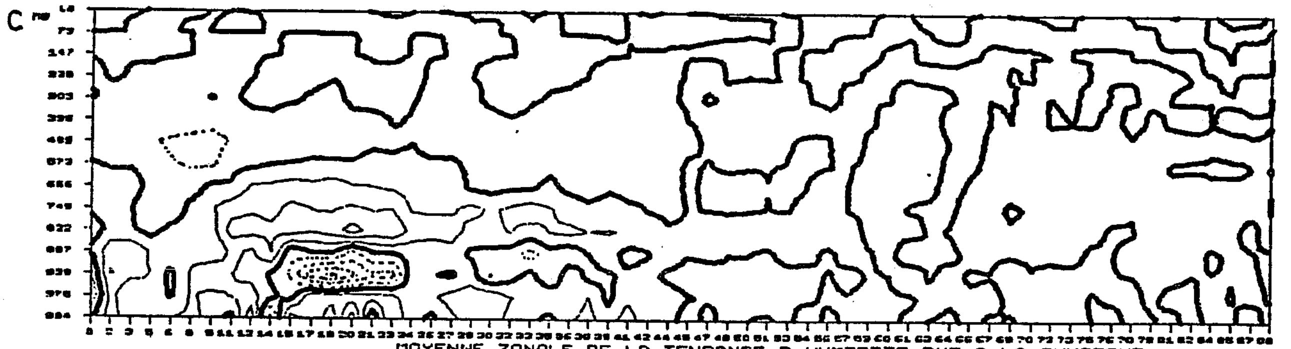
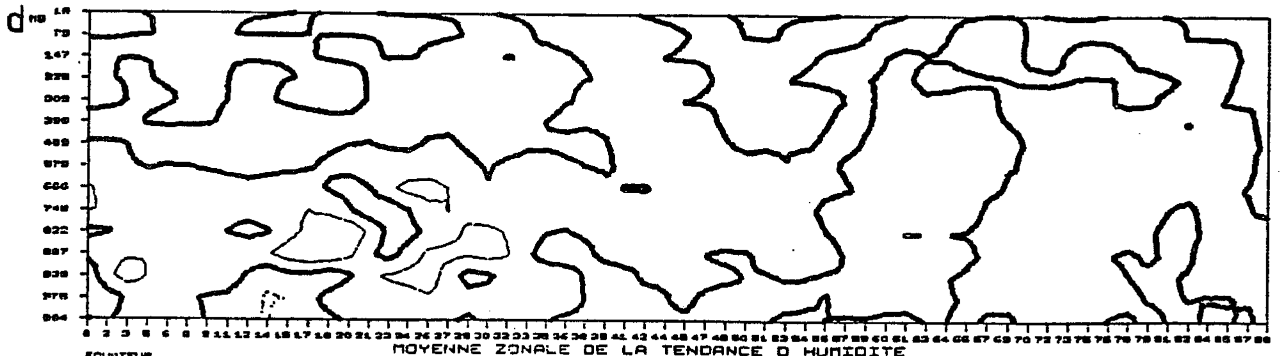


MOYENNE ZONALE DE LA TENDANCE D HUMIDITE DUE A LA PHYSIQUE
1- 4-1987 A 0H CUMULES ENTRE 72ET 96 4 FOIS



MOYENNE ZONALE DE LA TENDANCE D HUMIDITE
1- 4-1987 A 0H CUMULES ENTRE 72ET 96 4 FOIS

Figure 19 : Same as Figure 18 (a) to d)) but for specific humidity.

MAIN CHARACTERISTICS OF THE INTERDEPENDENCIES BETWEEN INDIVIDUAL DIABATIC FORCINGS

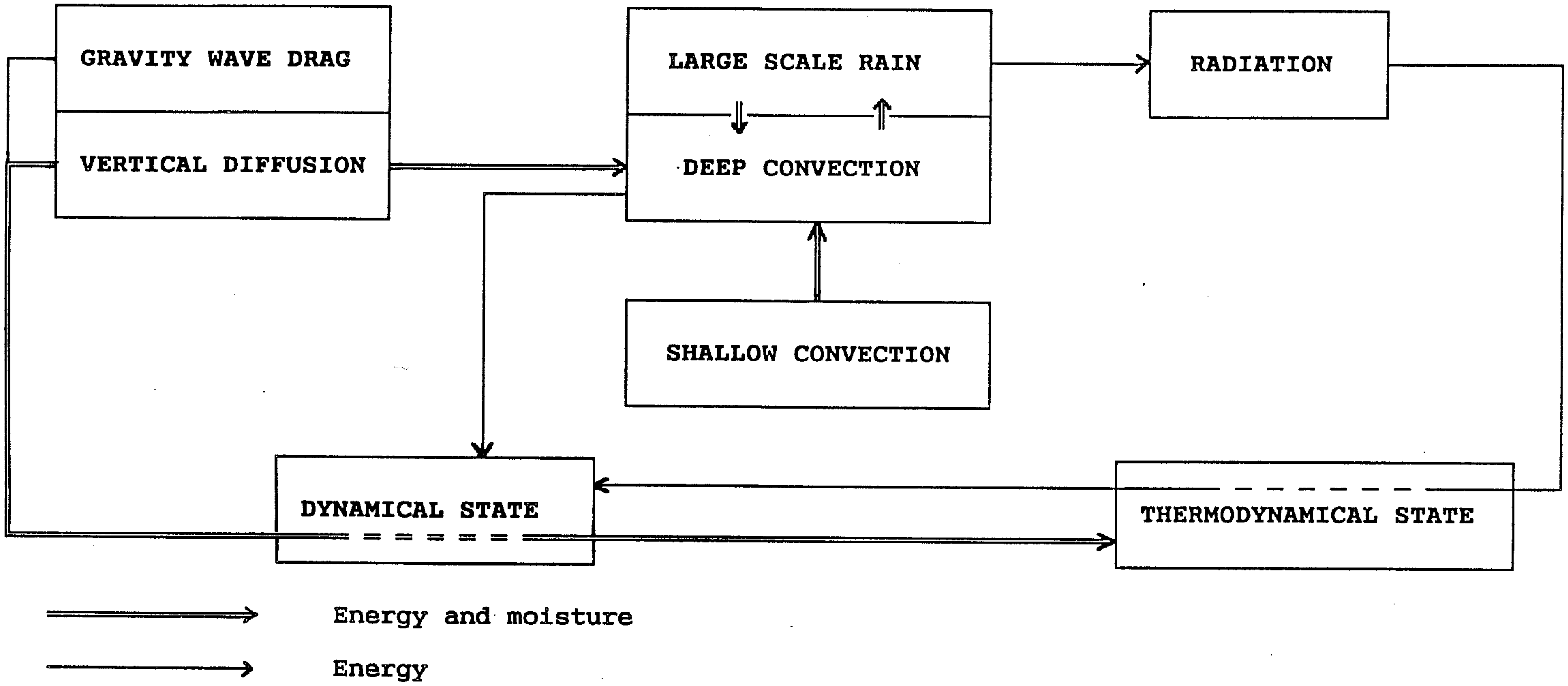


Figure 20

5) Shallow convection : as a specific feeder of the next and last process.

6) Deep convection : because of its special direct link with the dynamical forcing.

This rank of order calls for at least two questions. How much is this choice dependent on the chosen convective closure assumption (the Kuo-one in our case) ? And where would one like to introduce the land surface processes in that picture ? We shall leave them unanswered.

As indicaded in section I we shall now use a different approach (the comparison of total ECMWF and "Emeraude" tendencies) in order to get a second look at the question marks about the humidity control and the link between dynamical and thermodynamical forcings.

VI - A COMPARISON OF TWO NWP OPERATIONAL SETS OF MONTHLY ZONAL MEAN TOTAL TENDENCIES.

Independently of the previously described study a comparison between ECMWF and "Emeraude" was organised for zonally averaged absolute tendencies taken as a mean between all operational runs of a given month in each model. The comparison has obviously to be limited to the Northern hemisphere and we shall show here results for the month of January 87 only (at a time when the gravity wave drag parametrization of "Emeraude" was not correctly tuned and created stratospheric problems). It should also be mentioned that the ECMWF data were collected on p-surfaces while the "Emeraude" ones were accumulated on hybrid model surfaces before being interpolated to p levels for the sake of a clean comparison ; this explains the noisy aspect of the "Emeraude" diagrams. We show the same type of zonal mean representation as before, the two only changes being the use of a regular pressure coordinate in the vertical and the different presentation allowing for a side by side comparison : "Emeraude" on the left, ECMWF on the right. Among several interesting features, two are worth mentioning in relation to the previous sections :

- the spin-up manifestations are, for both systems, essentially apparent in the moisture tendencies (Fig.21 : a) for 0 --> 24 hour ; b) for 24 --> 48 hour) and have very different "signatures" between the two models ; the "Emeraude" spin-up is of the moistening type and lasts less than the ECMWF one, which is rather on the "drying" side,

- despite the fact that the two structures of the 0 --> 96 hour temperature error (in the monthly mean sense : tendency = error) are radically different and even almost symmetrical (Fig.22 a) we get striking similarities between the corresponding zonal wind errors, both linked to the well known systematic jet-shift and associated secondary effects (Fig.22b). Therefore this error seems to be insensitive to the zonal mean thermodynamical forcing, even if its magnitude in "Emeraude" is about 1.5 time that of the ECMWF model.

The second point reinforces our remarks in Section IV about the quite independent character of the modification to the zonally averaged thermodynamical and dynamical structures created by each parametrization (with the exception of gravity wave drag) ; on the other hand, either the spin-up problem has little to do with diabatic forcing, or our conclusions about the relative "freedom" of the moisture structure are linked to our own model, or more probably, to the considered time scale.

Fig : 21a

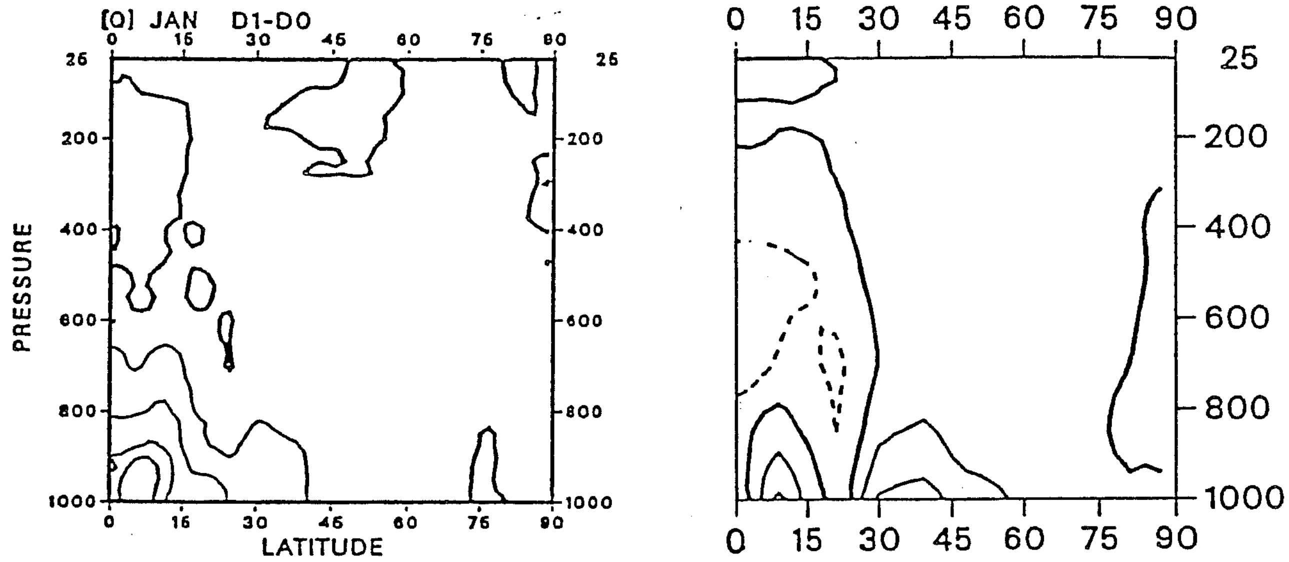


Fig : 21b

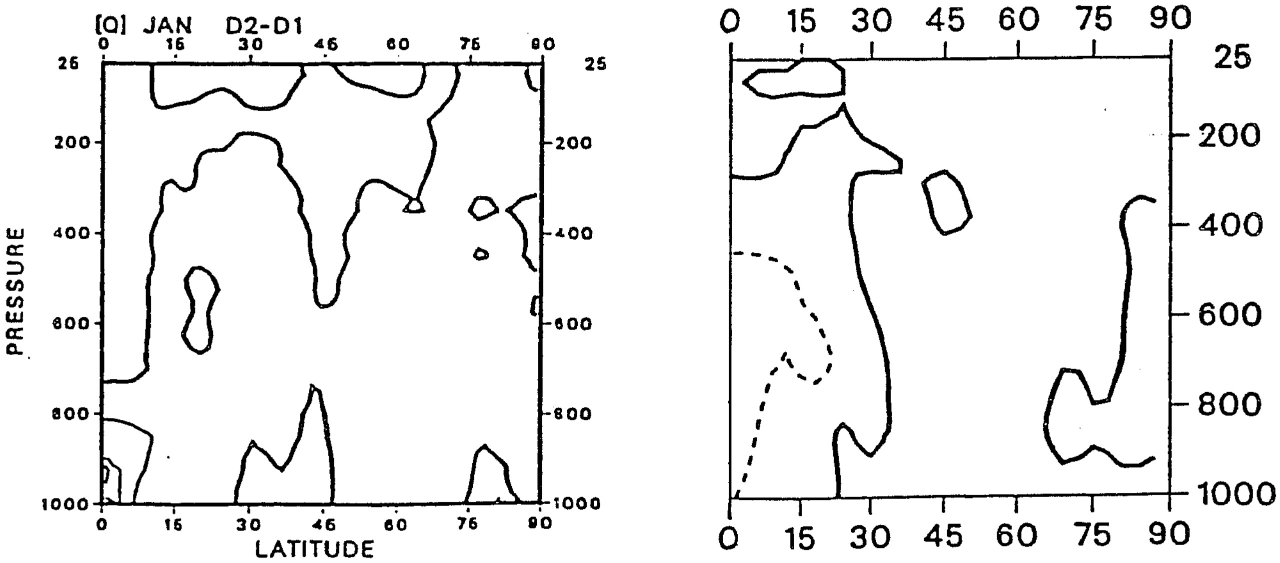


Figure 21 : Zonally averaged specific humidity total tendencies (diabatic plus adiabatic) in operational forecasts during the month of January 87 (ensemble values) : a) "Emeraude" 0 to 24 hour on the left, ECMWF 0 to 24 hour on the right ; b) "Emeraude" 24 to 48 hour on the left, ECMWF 24 to 48 hour on the right. Vertical scale linear in pressure. Horizontal scale linear in latitude. Northern Hemisphere only. Same contouring conventions as previously. For details see text.

Fig : 22a

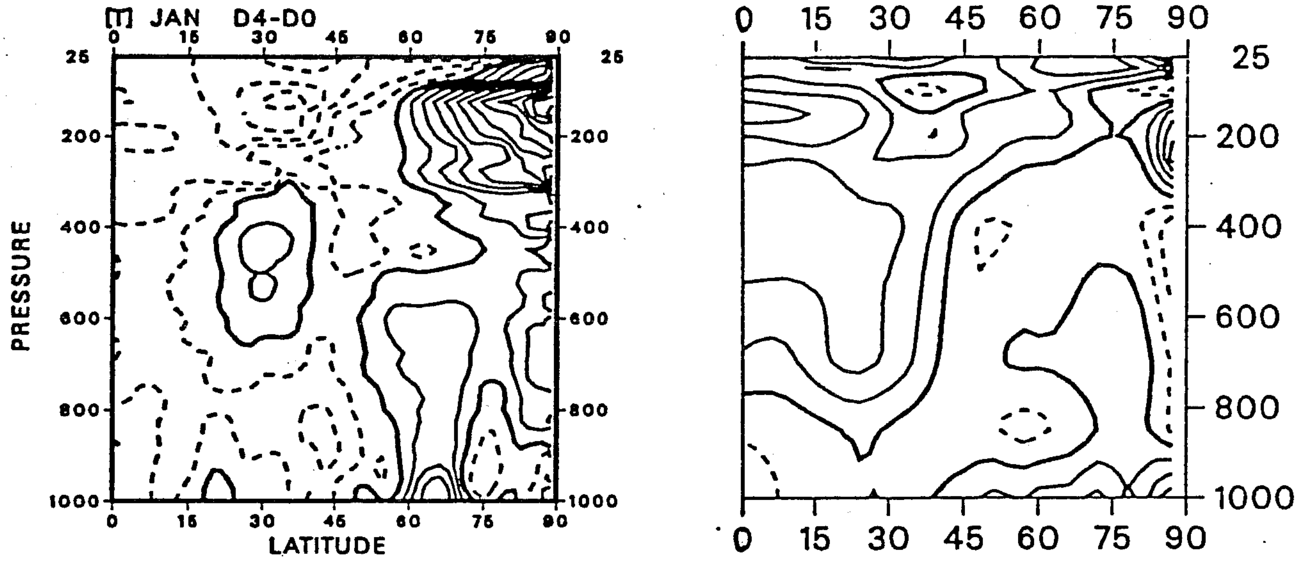


Fig : 22b

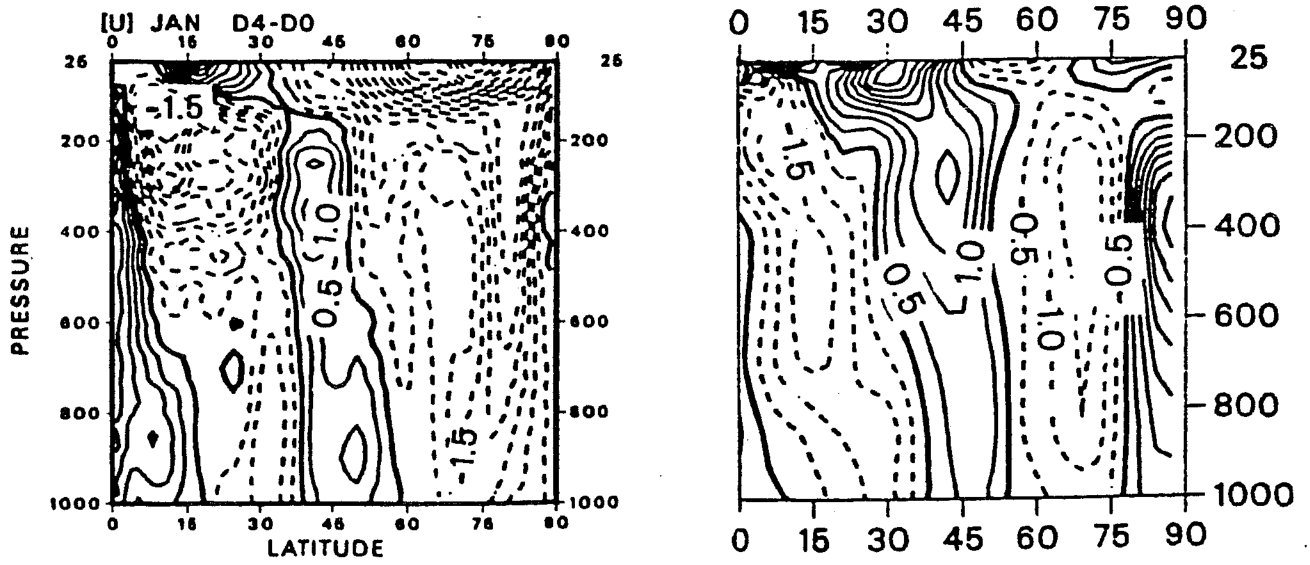


Figure 22 : Same as Figure 21 but 0 to 96 hour and : a) temperature in "Emeraude" on the left, temperature in ECMWF on the right (contouring interval 0.125 °K/day) ; b) zonal wind in "Emeraude" on the left, zonal wind in ECMWF on the right. (contouring interval 0.125 m/s/day).

VII - SUMMARY AND OUTLOOK

We can draw three main conclusions from the combination of these two studies :

- the way in which a given parametrized process creates "diabatic forcing" (whatever this exactly means) is very different from one to the next, radiation and deep convection being the extreme examples ;

- ideally this should have implications on the strategy for design and tuning of "global parametrization packages" ;

- the relationship between thermodynamical and dynamical forcings is surely the most difficult point to regulate even with the help of dedicated diagnostic tools such as those described in this paper.

We would like to add that these ideas ought to be retested in the framework of a global model since the Southern hemisphere might behave differently from the Northern one (hopefully we will be able to do it in 1988 at DMN),that the "switch-off" technique might be applied to study either the spin-up problem or the model's climate drift but with a more difficult interpretation problem than in our case, and that confirmation (or infirmation) of the results presented here with other parametrization packages would be a very valuable information for us.

VIII - ACKNOWLEDGMENTS

The authors are indebted to D. Burridge and C. Brankovic from ECMWF for their help in the comparison described in Section VI. Thanks are also due to all the people that contributed to the development of the "Emeraude" model and its parametrization package and to Mrs R. Eloi for her dedicated typing of the manucript.

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