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WORKSHOP ON ATMOSPHERIC LIMITED AREA MODELLING
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"Parameterization of Convection"

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Please note: These are preliminary notes intended for internal distribution only.

Lecture Notes for the lecture "Parameterization of Convection" for the workshop on Atmospheric Limited Area Modelling

J-F Geleyn

Part A : Generalities about parameterization

3 goals :
- ensure numerical stability of the model
- simulate correctly the hydrological and energetical cycles
- help the prediction of actual weather

problems : the dynamics only "sees" about 1% of the total energy cycled through the atmosphere between solar radiation input and terrestrial radiation output

errors on each of the energy conversion terms can be far higher than 1% ⇒ the problem looks hopeless

fortunately there are many feed-back loops in the system (definition of a feed-back loop; question of its character : negative, i.e. effects working against causes or positive, i.e. the reverse) and most of them are negative

this helps modelisation but one has to take care to be very carefull with positive feed back modelling and, even more, not to transform natural negative feed-back in positive modelled ones (example)

phenomena to be parametrized :
- limitation to those of energetic importance
- many of them are concerned with cloud processes and we are not yet good at making the different representation of clouds (associated with each of them) coherent or sometimes simply compatible

data problems : Contrary to the adiabatic part a lot of extra information is needed :

* New prognostic variables for land surface processes (5 at least : 2 temperatures, 2 water amounts, 1 snow depth ; and many many more in forthcoming "simple biosphere" model representation)

* Information about the state of the land surface / vegetation : orographic variance, land/sea mask, roughness lengths, proportion of vegetation covered area, albedo, emissivity, soil heat capacity, soil heat conductivity, soil water capacity, soil water conductivity, ... Here also the list will become far longer in coming years

* Physical constants. They can be split into three categories :
- universal ⇒ take the most recent recognized value
- directly measurable ⇒ use laboratory or measurement campaign results
- tunable ⇒ tuning is a very delicate process.

For such constants one should first try to know the order of magnitude through inferences from similar information to that used in the previous category. Then "tuning" (i.e. looking at the best value from the point of view of the overall behaviour of the whole model) can take place. But, as much as possible, the number of tuning constants should be kept low, and one should ensure, through the algorithm's construction that they are physically significant and understandable variety of "control-optimisation" strategies

despite all the above-mentioned difficulties, what makes parametrization work very interesting (if one does not overspecialise) is the variety of approaches (when going from one phenomenon to the next) that one has to use to qualify and improve parametrization schemes. For example:

* in radiation (cloud-free case, of course) the exact answer to a given situation can practically be obtained with a very very expensive algorithm; parametrization becomes then a kind of mathematical exercise to simplify the algorithm while keeping it reasonably accurate until the best compromise efficiency vs. accuracy has been found.

* in cloud microphysics the situation would be even more complicated to describe than in radiation but fortunately some macrophysical experimental evidence (example = Marshall Palmer distribution law) comes to our help.

* in other cases (example convection) measurements are difficult and cannot concentrate on all scales at the same time in a given situation; thus, finer mesh models, "tuned" on a few measured cases must be used to "infer" intermediate scale properties. This does not yet works as well as one would wish

* finally, diagnostic of systematic errors in the behaviour of operational forecasting models can indicate either deficiencies in the behaviour of one given parametrization scheme or the absence of a parametrized (or rather to-be-parametrized) process, like it was the case a few years ago for gravity wave drag.

If a correction in the present status of knowledge seems either impossible or hazardous (like soundings for mountain effects) one has to go back to nature and to mount a measurement campaign (Pyrex as example in the latter case)

In short the ensemble of tools and the "pendulum-type" ~~work~~ work between measurements and models (several types of them as well) does not work too badly in atmospheric science.

2 "extreme" concrete modelisation examples

* one that went well: the tuning of a very simple first version of a gravity wave drag parametrization in the french NWP global model:
- one single tuning parameter
- one optimum in scores averaged over several cases
- meaningful synoptic character of the improvement
- consequences of the practical operational implementation as good as expected

* one that went wrong: why, in two models with very similar parametrization sets, does the maximum of turbulent kinetic energy transfer quits the surface in the french LAM and not in the equivalent global model. Answer: because of the basic differences between the Kuo-type and mass-flux-type convection schemes! Surprise and no way to go further before a mass flux scheme that works better at fine scales than the present one has been redeveloped.

Part B: Special case = convection (especially deep convection)

Why is convection so special

- because no one has yet been successful in proposing a "stand-alone" convective parameterization scheme, i.e. one that works only from a static description of one column (all current schemes also require some description of the so-called large scale forcing, in other words of dynamical tendencies)
- because deep convection is essentially a non-hydrostatic phenomenon that we try to parametrized inside an hydrostatic framework (for most models).
- because the definition itself of "parameterized convection" depends on the model's resolution. A given type of convective behaviour might be resolved with a 10km mesh model and unresolved (→ to be parameterized in a 20km mesh model). This is even more complicated for slantwise and shallow convection where the scale of the actual motion is quite difficult to pin down.
- because, even for the most energetic deep convection, there is still controversy about the basic maintenance process (CISK or no-CISK that is the question!)

In fact, why do we need a parameterization of convection

- 1st (simple) answer: because at to-day's models' scales, most clouds are still subgrid scale (even when evenly distributed in the grid-box) and because, in that case, condensation/evaporation organises its own subgrid scale induced motions
- 2nd (simplistic) answer: because, if one suppresses the parameterization of convection, the condensation/evaporation is taken over by the resolved scale parameterization and the effects are over-done by it.
- 3rd answer: because without an explicit parameterization of convective behaviours the model cannot reproduce the delicate balance between large scale forcing and convective response (or the other way round depending on which theory one favours!)

Controversy about the exact nature of this balance (the two theories)

* CISK (Conditional Instability of the Second Kind)
    - atmosphere permanently unstable in convective regions
    - the convergence at low levels created by the cloud ascents "imports" the moisture needed to maintain (or even sometimes amplify the convective activity)
    - surface evaporation is only a complement to that large scale "humidity convergence"
* CSEI (Convective Surface Evaporation Interaction – invented acronym for the sake of these notes)
    - the atmosphere is at neutrality and stays there
    - the large scale budget of moisture is a closed one (convergence that recirculated dry descending air is not a strong moisture source and can only balance the depletion required by the large scale continuity condition) or nearly so
    - the evaporation at the surface (especially over oceans) created by the converging winds is the extra-source of moisture that creates the driving energy for the convective circulation but it cannot be its primary cause.
* what do the models say about it:
    - at first glance the link between convective heating and drying (not at the same levels) and large scale ascent seems to be a CISK phenomenon; so are also the famous (and unwelcomed) grid-point storms
    - a more careful analysis (in the limited framework of the French large scale global model and its particular mass flux

convection scheme) indicates the opposite for large scale motions: a comparison of two runs with and without parametrization of deep convection shows hardly any impact on zonally averaged values for moisture and temperature but a strong influence on the Hadley circulation: by preventing the exaggerated effects of large-scale parametrization's simulation of convection, the convective effects actually put a break on the Hadley cell. Thus they do not drive it like in a CISK idea

* a better understanding of the CSEI idea: if you are in a lift you are not going up because the counterweight is going down! (Kerry Emanuel's very imaginative way of describing it)

Main aspects of convective motions that a parametrization should treat

* cloud updrafts
* compensating subsidence: needed to close the circulation of the parametrized phenomenon it is in fact not a subsidence. Since the mass-flux is the one required by the continuity equation (at least formally so in the CSEI case but practically also in the CISK case on average) or rather slightly more the environment of the clouds is quasi at rest, or rather slightly sinking (but by an order of magnitude less than the computed "compensating" subsidence that mainly compensates for the already accounted for "large scale ascent", that in fact only takes place in clouds!). Since one can assume that the clouds have little impact on the total thermodynamical budget (remember they are important for the "dynamical budget!) this slight sinking essentially balances radiative cooling.
* cloud water or precipitating water induced downdrafts: very important and even so more as one goes to finer and finer scales of motions. Can be very active in case of tilted cloud ascents (squall

lines for example - cf. numerical example of the French South West coast on 7-6-87). Difficult to represent since their energy source (condensed water that will evaporate to drive the unstable sinking motion) requires some microphysical hypothesis to be assigned a position inside the updraft (unlike the humidity convergence + evaporation from the surface vertically redistributed that could be assumed well known for the updraft problem)
* compensating motion for downdrafts: can be either separated or treated together with the compensating subsidence (both in "dry" environmental air). Same remarks as above - no distinction here -.

Basic constituents of a convective parametrization scheme (deep convection)

* a cloud(s) model: either single (averaged) cloud profile or many possible ascents (like in Arakawa-Schubert). From single adiabatic to complex microphysics and dynamics idea.
* a closure assumption: relates in one way or another the large scale tendencies and the integral convective effects (rainfall to simplify). Kuo, Arakawa-Schubert, relaxation time ... are the most commonly used
. a set of equations (to describe how the effect will be partitioned vertically, i.e. how do the large scale variables "feel" parametrized deep-convection?). 3 categories here: Kuo (lateral mixing), adjustment rules (very close to Kuo in fact), mass-flux-type schemes

A few basic truths about convection schemes

. "Kuo is not Kuo"; or: a convection scheme is not one absolute link between three of the above-mentioned ingredients.

A Kuo closure assumption can very well work with a mass flux type scheme, for example.

- The mass-flux-type scheme is the most general of all three set of equations and should therefore be preferred to the other ones (it can represent more physics)
- A mass flux type scheme might not be complicated at all; or, it has not to be an Arakawa-Schubert scheme to get the mass-flux qualification.

Example : the most simple mass-flux scheme possible

- updrafts only
- one single cloud
- steady cloud
- negligible area of updraft
- all detrained ~~water~~ liquid water evaporates
- no sub-cloud rainfall evaporation

⇒ one set of simple but physically sound and informative equations

Possible extensions of the deep convection parameterization schemes

. to slantwise convection: probably feasible and sound but the distinction between resolved and unresolved processes becomes even more difficult (if that is still possible!)

. to shallow convection: requires the fact that downdraft create a negative mass flux (in absolute terms) near the top of the cloud (top entrainment); possible if the cloud is non-precipitating ⇒ not too deep. Still to be demonstrated that this is technically feasible and produces realistic results. Up to now this kind of convection is usually treated separately.

Main pending problems

- how to soften the jump between parameterization of resolved and unresolved condensation/evaporation processes and how to do it whatever the resolution of the model?
- how to correctly "feed" the downdrafts; through which level of sophistication in the microphysics treatment?
- momentum transport, sources and sinks in convective motions (not mentioned anywhere else in this lecture; so only here for completeness at the end)

GENERALITIES ABOUT PARAMETERIZATION OF PHYSICAL PROCESSES

3 needs (given in historical order)

- ensure numerical stability of the adiabatic "host" model

  Ex: Eckman pumping
  Convective adjustment

- simulate correctly the hydrological and energetical cycles of the atmosphere / land surface system

  1st ex: GFDL end of 60ties

- pay attention to the accurate prediction of actual weather through products of the parameterization schemes

  1st ex: ECMWF end of 70ties

2 main problems

- only about 1% of the energy circulating in the system goes into the dynamics. And the parametrization has got to control the exact value of this small amount. Apparently impossible. Fortunately there are negative feed-back mechanism
- but also positive feed-back mechanism, either real or artificial.

A lot of phenomenae to be parametrised

- Radiation
- * Cloud / Radiation interaction
- Surface exchanges of heat, moisture and momentum
- Vertical redistribution of these fluxes
- Deep convection
- Shallow convection
- Slantwise convection
- Large scale precipitation
- Soil energetic and hydrology on land
- Surface roughness on sea

⟹ the problem of a unique consistent definition of clouds has yet to be solved

Extra data are needed

- Prognostic variables for T_s, T_d, W_s, W_d, S_n
- land surface values of
  - orographic variance
  - roughness length
  - vegetation coverage
  - albedo
  - emissivity
  - .....
- Physical constants used into the schemes
  - universal (ex Karman's constant)
  - measurable (ex $\frac{\partial \varphi}{\partial (z/L)} (z/L \to 0)$ in M.O.'s theory)
  - tunable (ex asymptotic mixing length)

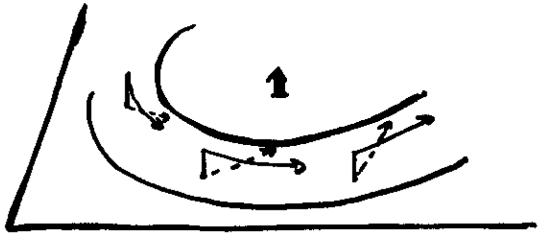
Variety of approaches

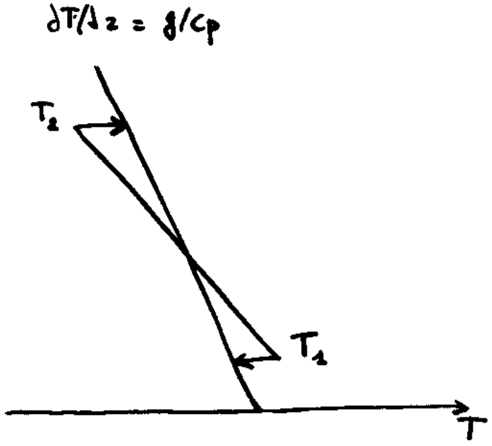
- in radiation we could in princip know the right answer but we have to simplify drastically the algorithms
- in turbulent transport we have to concider the statistical properties of the flow
- in convection studies we are still at the empirical stage and we do not control cleanly the feed back with the dynamical forcing
- in cloud microphysics we have to use simplifyi averaging rules, that, fortunately exist in nature
- in land surface processes we are "guessing"

Thus The problem is
- difficult
- challenging
- interesting to solve in a "constant improvement" mode

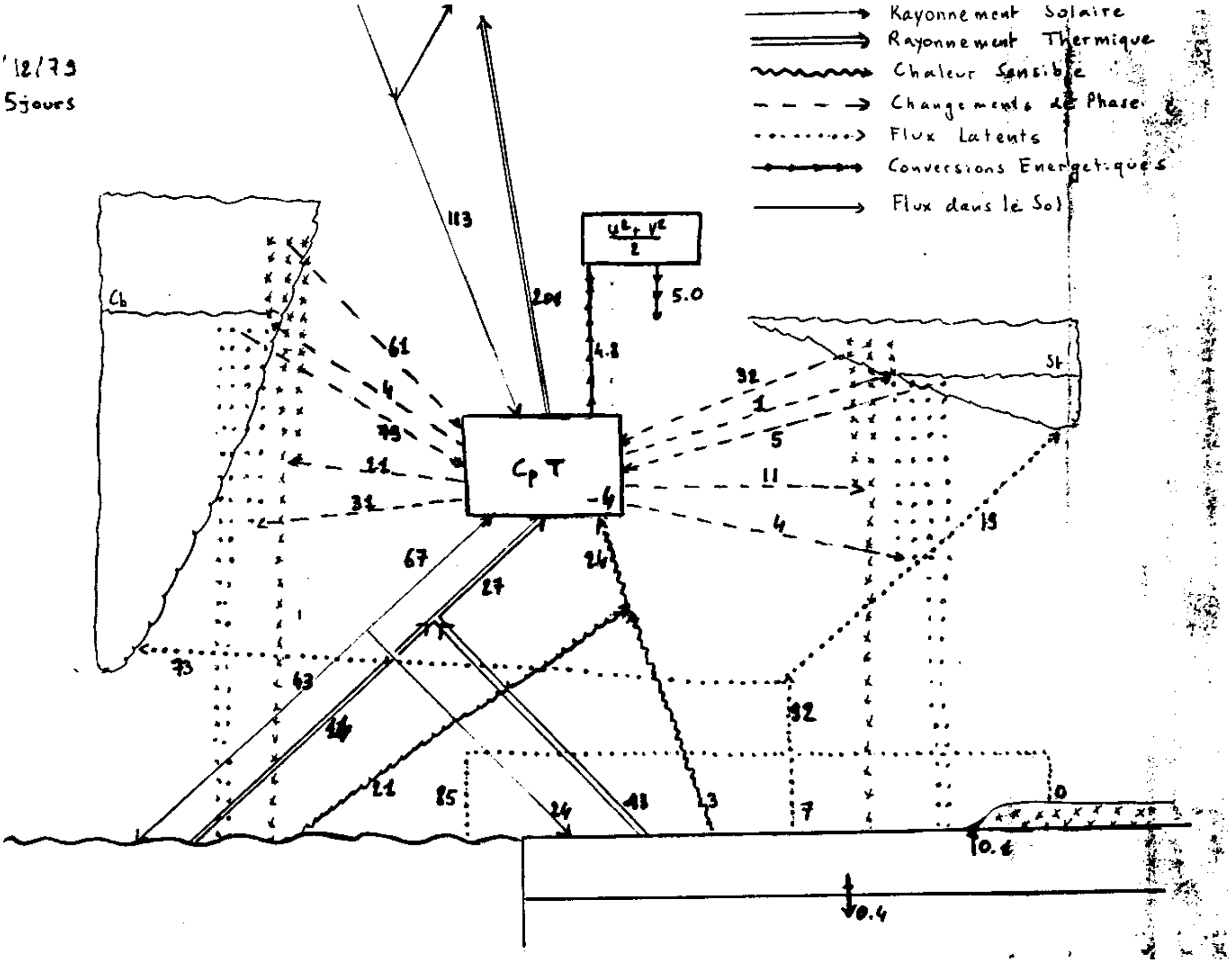
The conditions to work efficiently are
- generality
- consistency
- respect of basic equations

Les "ancêtres" de la parametrisation





13/12/79
Prévi. à 5jours



10³ mm/h

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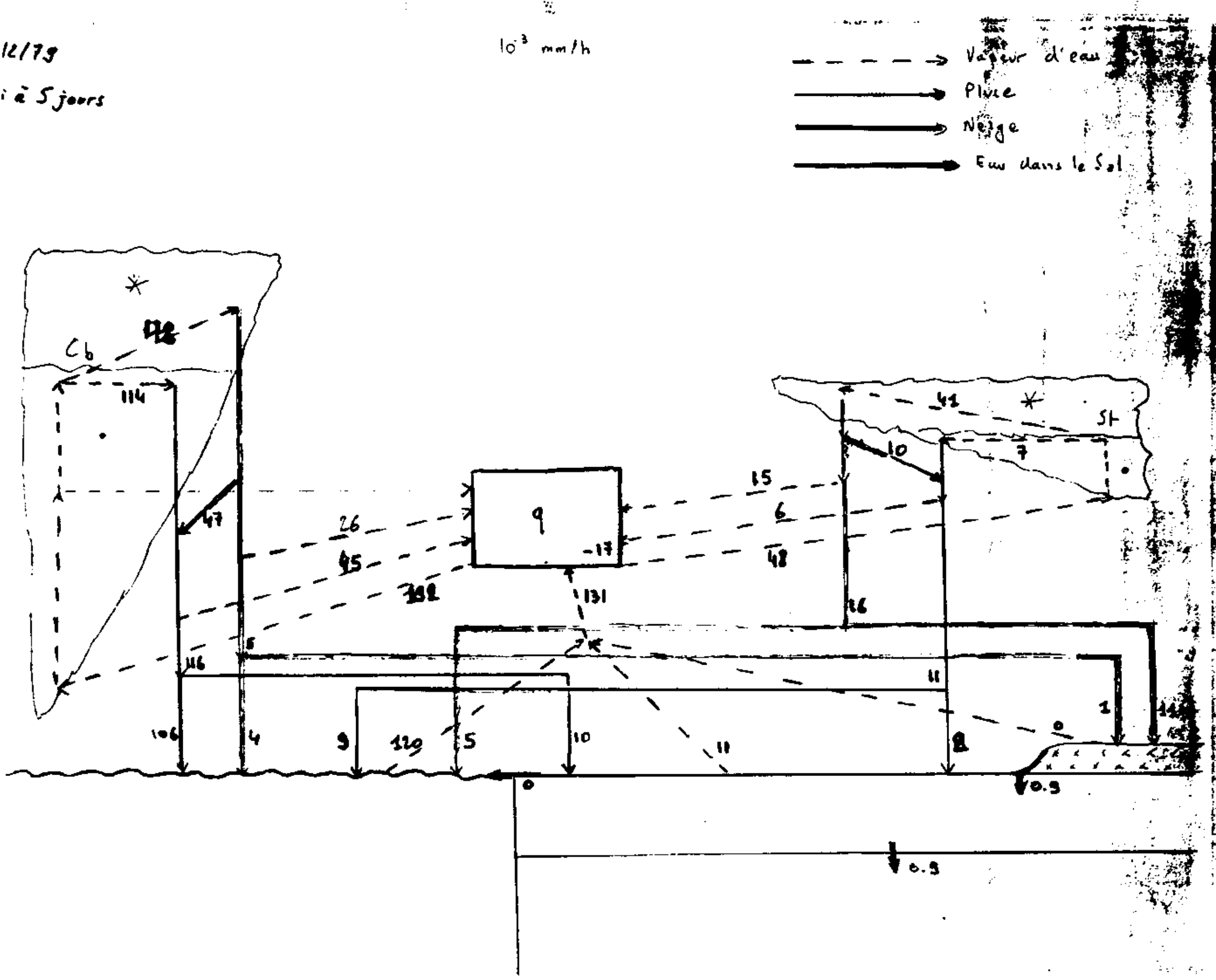
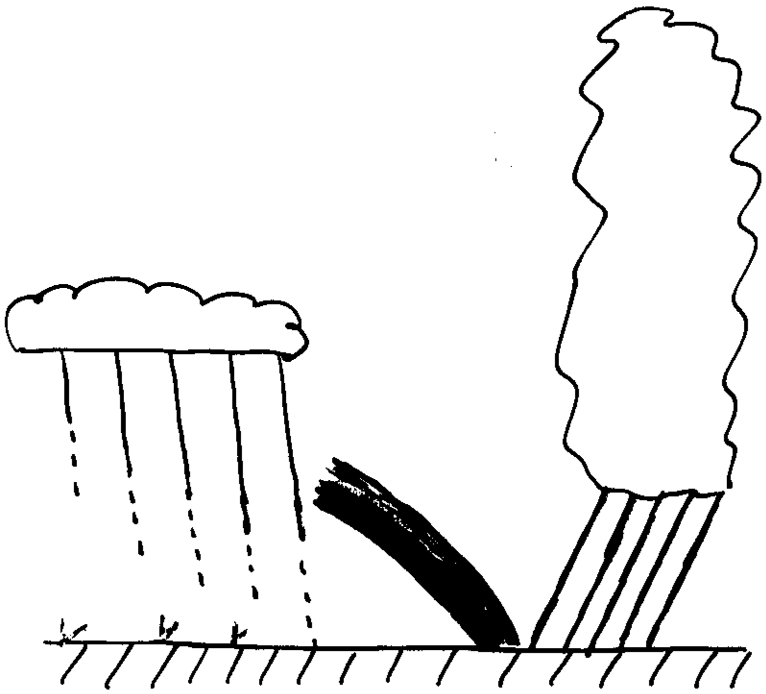
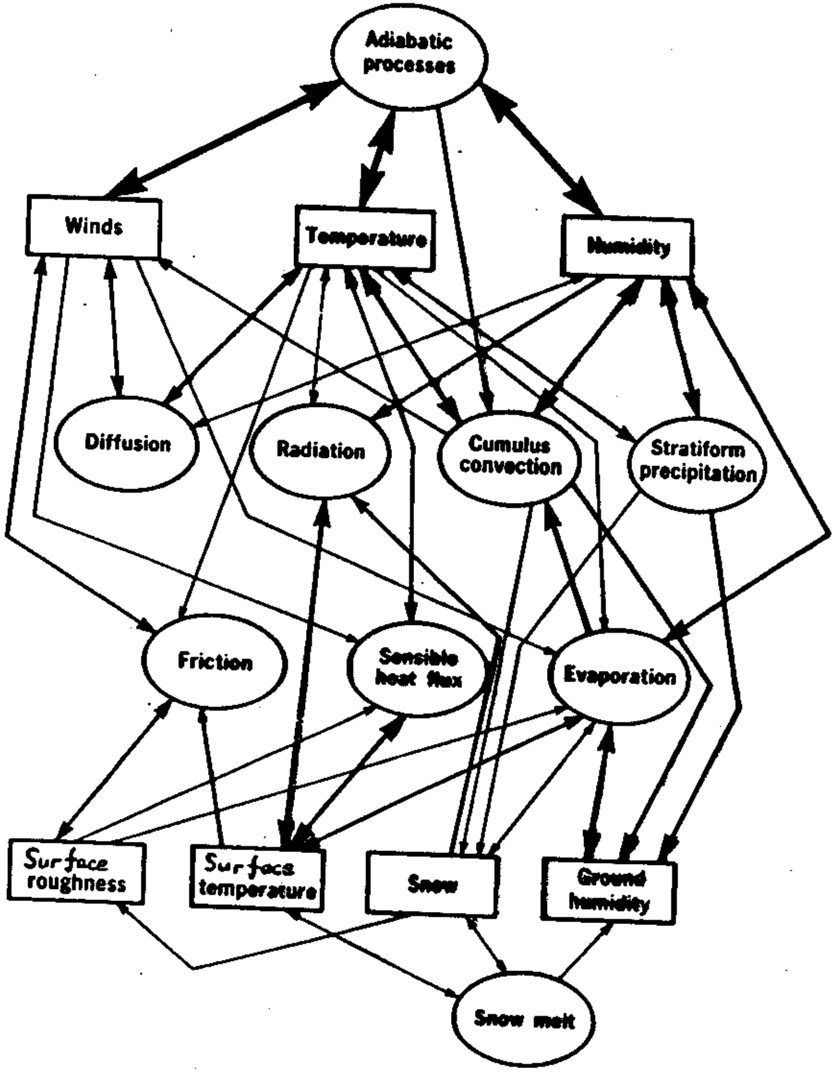
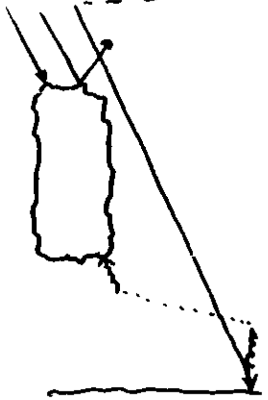


Le Futur ?




Adiabatic processes
Winds
Temperature
Humidity
Diffusion
Radiation
Cumulus convection
Stratiform precipitation
Friction
Sensible heat flux
Evaporation
Surface roughness
Surface temperature
Snow
Ground humidity
Snow melt

Sur terre



+ de nuage

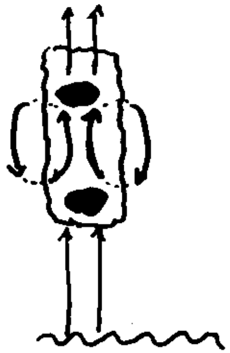
– de rayonnement solaire en surface

– d'évaporation

– de convection

– de nuage

Sur mer



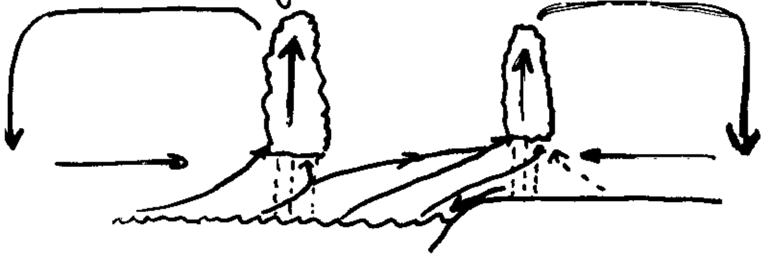
+ de nuage

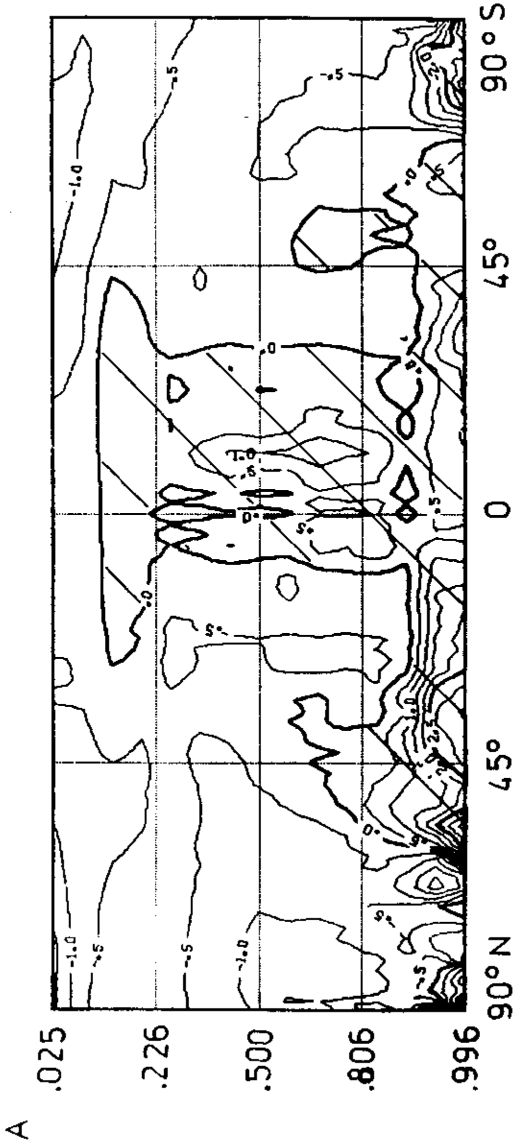
+ de destabilisation par le rayonnement thermique

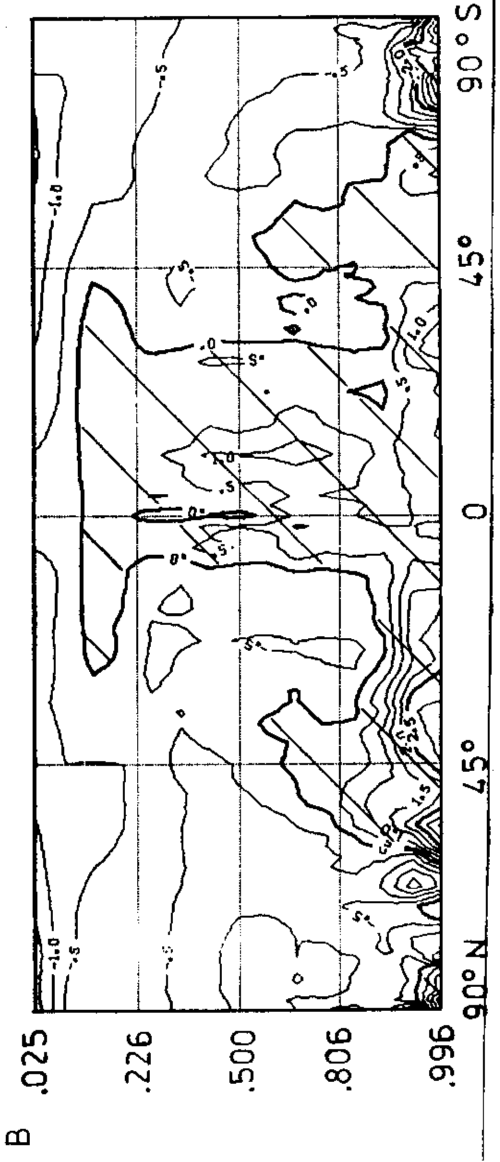
+ de convection

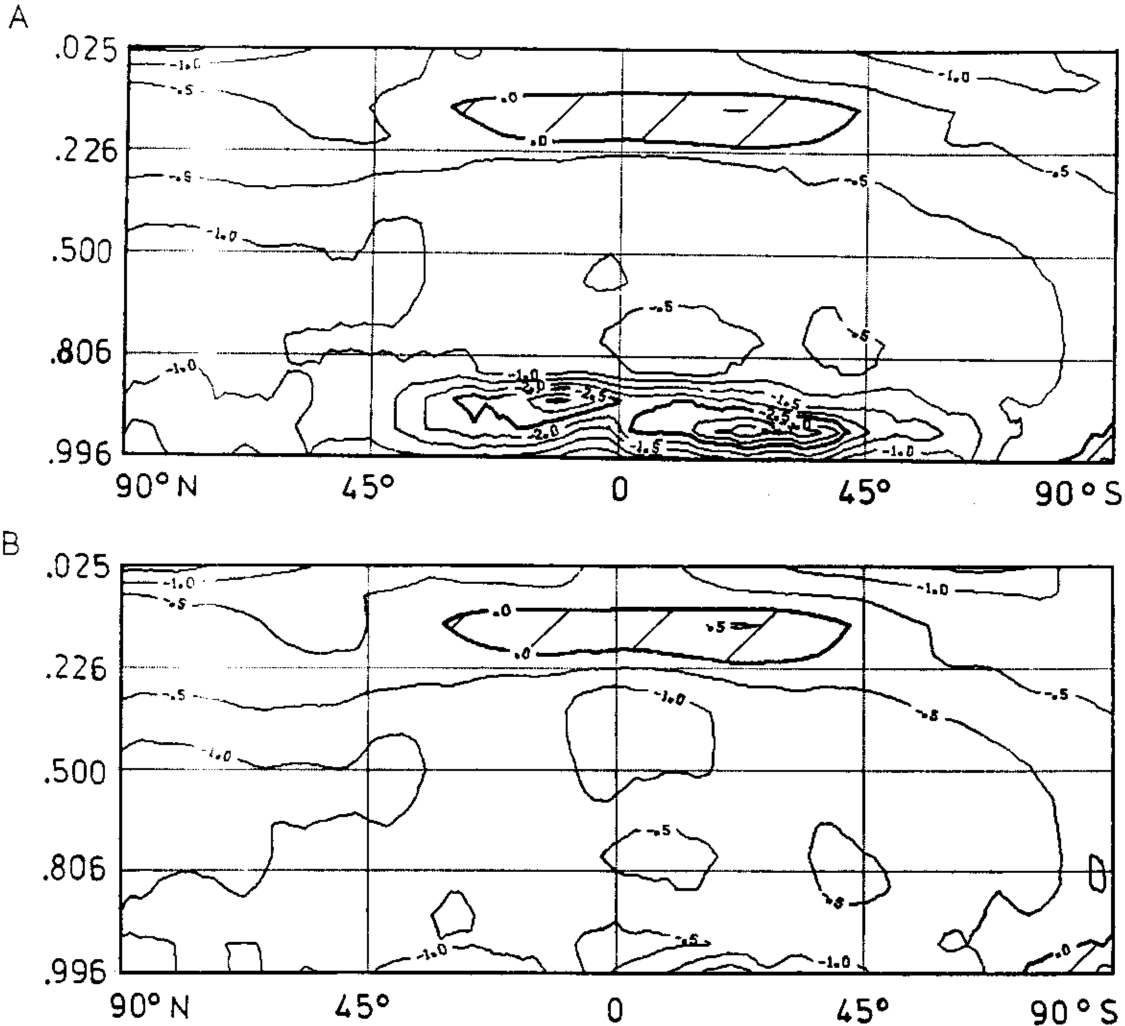
+ de nuage

Contrôle dynamique





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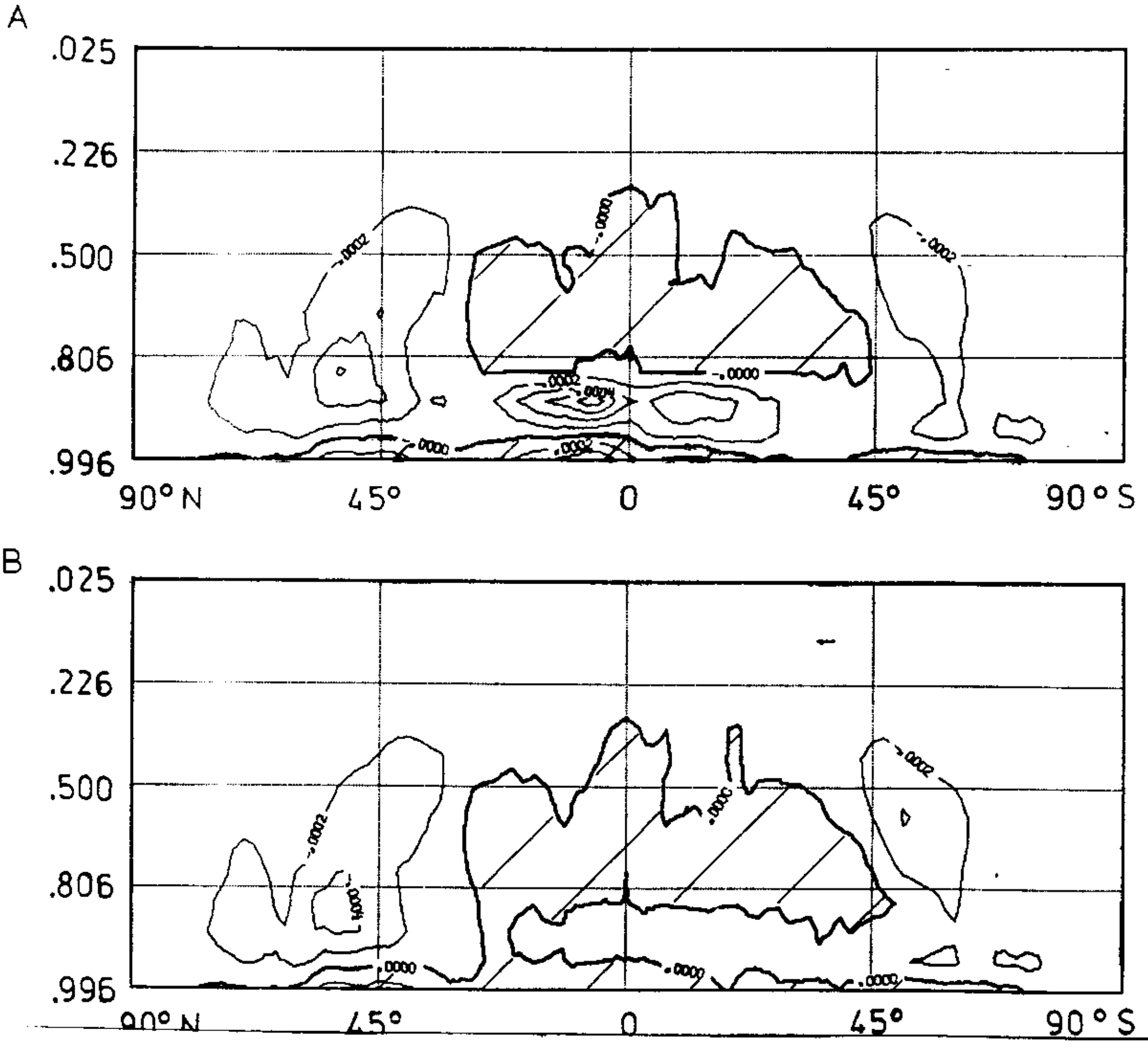
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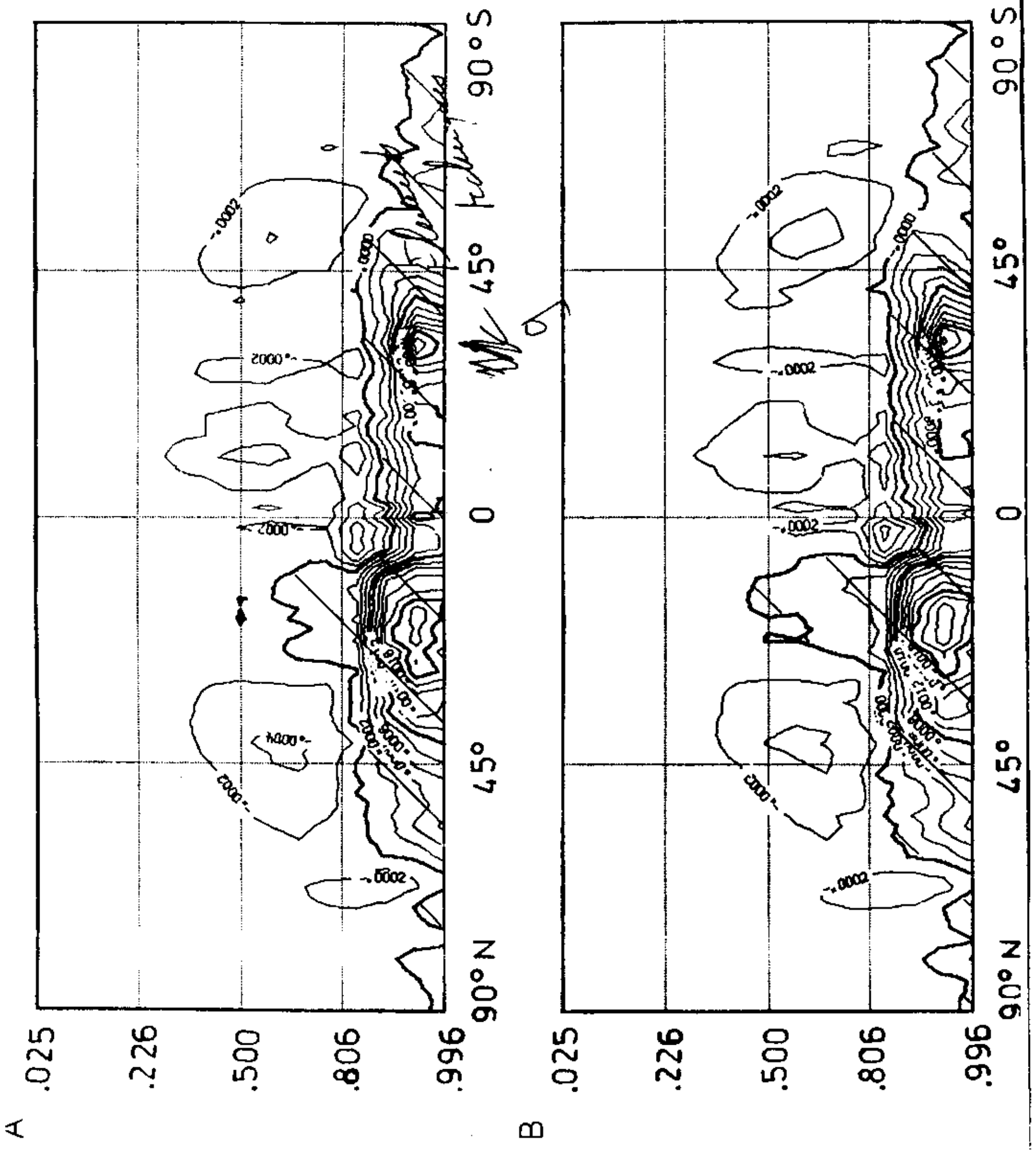


PHYSICAL CONSTANTS

group — **Strategy of use**

Universals

$C_{pa} = 1005.46$ $R_a = 287.05$

$C_{pv} = 1869.46$ $R_v = 461.51$

$L_v = 2500800.$ $L_s = 2834500.$

$g = 9.80665$ .....

To accept "mother nature's" choice !

Measurables (in principle and according to the mathematical framework of a given formulation)

examples

$$\tau_{Rad}(u, v_r) = e^{-\left(\frac{au}{\sqrt{1+bu^2/v_r}} + c\,v_r\right)}$$

$$z_0 = c_x\, u_*^2/g$$

....

To find the best compromise between simple analytical formulae and good fits with in situ and laboratory measurements

Tunables (and to be tuned)

$$l = \frac{\kappa(z+z_0)}{1+\kappa(z+z_0)/\lambda}.$$

$$\frac{\partial(q_v+q_l)}{\partial\phi} = \frac{q_l}{\phi_{crit.}}$$

$$\frac{\partial\sqrt{R}}{\partial(1/f)} = A\,(q_{sat}-q)$$

[illegible] = [illegible] $\vec{V}$ [illegible] $K_{g.w.d.}$

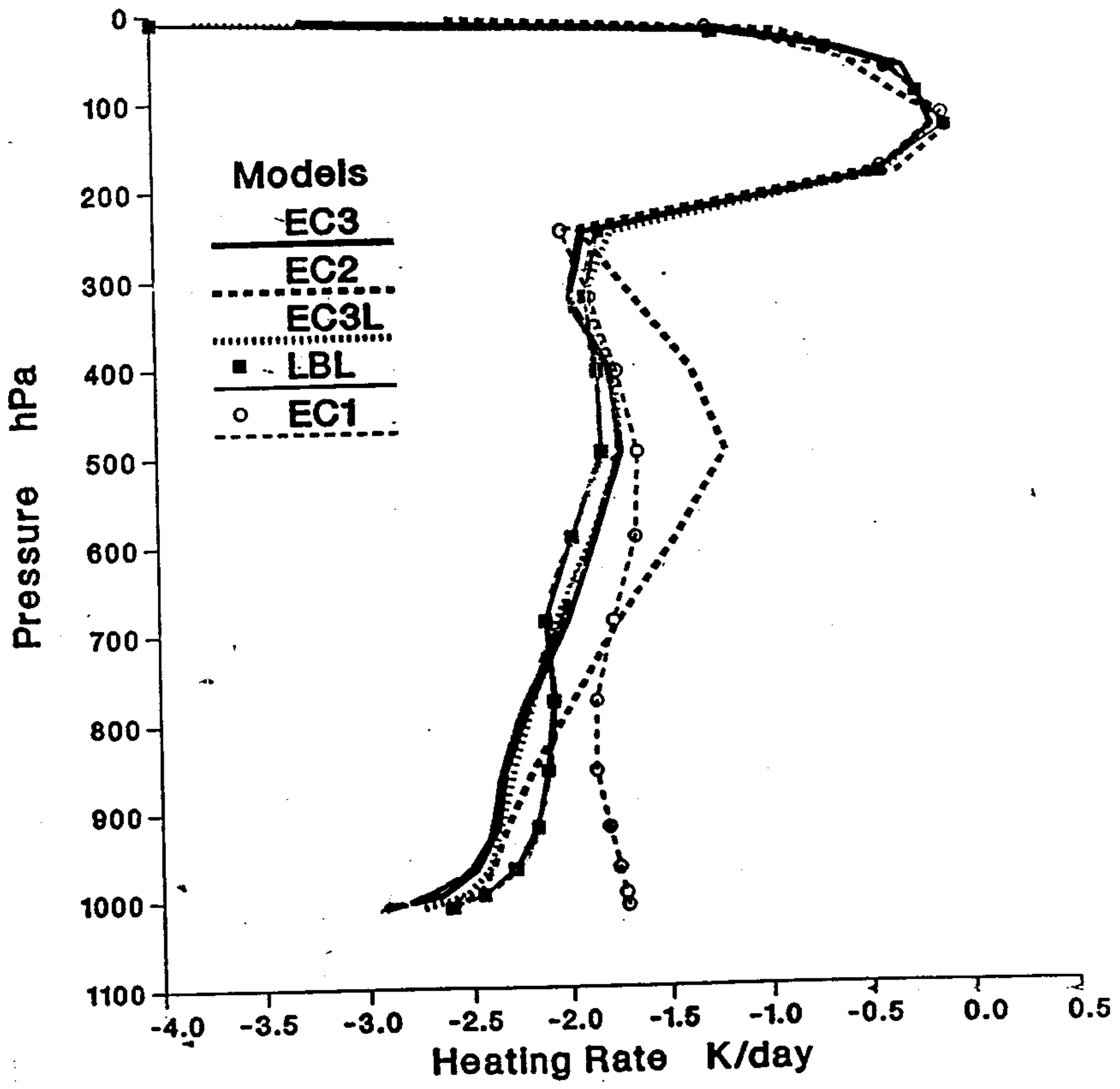
$$C_{la} = \max{}^2\left(0, \frac{HU-HU_c}{1-HU_c}\right)$$

To have as little as possible of them, but, given the choice, to take those that have the most "physical" meaning and are thus central to the behaviour of the scheme.

MORCRETTE (89)

line by line   GFDL   ICRCCM calculations

Longwave Radiation Comparison
MLS   H2O CO2 300ppm O3
Whole Longwave Spectrum



SHORTER CONTRIBUTIONS

THE DISTRIBUTION OF RAINDROPS WITH SIZE

By J. S. Marshall and W. McK. Palmer[1]
McGill University, Montreal

(Manuscript received 26 January 1948)

Measurements of raindrop records on dyed filter papers were made for correlation with radar echoes (Marshall, Langille, and Palmer, 1947). These measurements have been analyzed to give the distribution of drops with size (fig. 1). The distributions are in fair agreement with those of Laws and Parsons (1943).

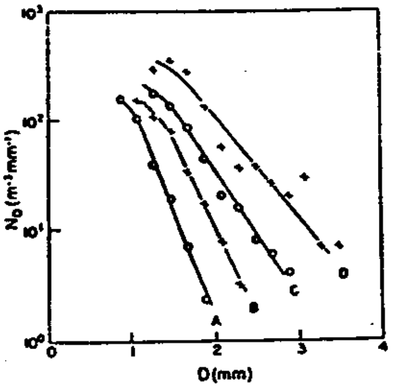


FIG. 1. Distribution of number versus diameter for raindrops recorded at Ottawa, summer 1946. Curve A is for rate of rainfall 1.0 mm hr^{-1}, curves B, C, D, for 2.8, 6.3, 23.0 mm hr^{-1}. $N_D\delta D$ is the number of drops per cubic meter, of diameter between D and $D + \delta D$ mm. Multiplication by 10^{-4} will convert N_D to the units of equation (2).

Except at small diameters, both sets of experimental observations can be fitted (fig. 2) by a general relation,

$$N_D = N_0 e^{-\Lambda D}, \qquad (1)$$

where D is the diameter, $N_D\delta D$ is the number of drops of diameter between D and $D + \delta D$ in unit volume of space, and N_0 is the value of N_D for $D = 0$.

It is found that

$$N_0 = 0.08 \text{ cm}^{-4} \qquad (2)$$

for any intensity of rainfall, and that

$$\Lambda = 41\, R^{-0.21} \text{ cm}^{-1}, \qquad (3)$$

where R is the rate of rainfall in mm hr^{-1}.

For diameters less than about 1.5 mm, both sets of observations fall short of the value for N_D given by equation (1), and they disagree slightly with each other. Laws and Parsons' observations are better in this region, and tend toward a common value of N_0 for all rates of rainfall.

The mass of rain water M per unit volume of space, and the sum Z of sixth powers of drop diameters in unit volume (a radar quantity), can be calculated as functions of Λ from equation (1), and so correlated with the rate of rainfall R by equation (3). It is of interest to compare these correlations with those obtained when M, Z, and R are determined more directly from the experimental records (table 1). The deficit of small drops in the observations, as compared with equation (1), should make the observed value of M, and to a lesser extent that of Z, smaller than those derived from the equations.

TABLE 1. $M = \frac{1}{6}\pi\Sigma N_D D^3\delta D$ and $Z = \Sigma N_D D^6\delta D$ as functions of the rate of rainfall R.

Reference	M mgm m^{-3}	Z mm^6 m^{-3}
Marshall, Langille and Palmer (1947)	80 $R^{0.8?}$ [illegible]	190 $R^{1.72}$
Revision of the above	72 [illegible]	220 $R^{1.60}$
Z/R correlation by Wexler (1947) (data of Laws and Parsons, 1943)	68 [illegible]	320 $R^{1.44}$
From equations (1) and (3)	89 $R^{0.84}$	296 $R^{1.47}$

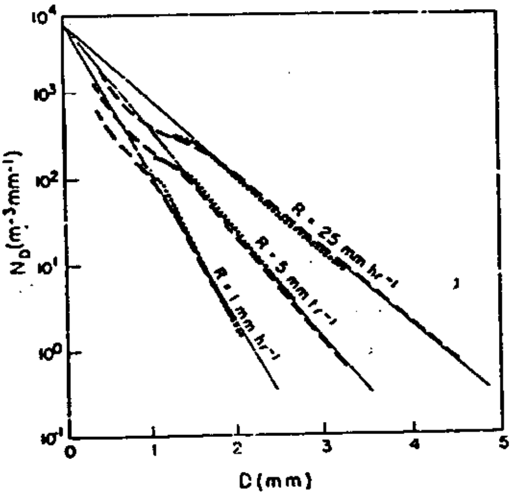


FIG. 2. Distribution function (solid straight lines) compared with results of Laws and Parsons (broken lines) and Ottawa observations (dotted lines).

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[1] Holding a Bursary of the National Research Council of Canada.

The exponential distribution of equation (1) is the type that would obtain if growing drops were in continual danger of disintegrating, the likelihood of disintegration being proportional to the increment in diameter or in distance of fall through cloud. Such behavior might be explained by the random accumulation by each drop of electrical charge as more and more randomly charged cloud drops or smaller raindrops are acquired by coalescence, and the resultant disintegration of overcharged drops. Relevant calculations and experiments on coalescence are in progress.

Part of the work reported here was done during summer employment in the Radar Meteorology Section of the Defence Research Board's Radio Propagation Laboratory at Ottawa.

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Laws, J. O., and D. A. Parsons, 1943: The relation of raindrop-size to intensity. *Trans. Amer. geophys. Union*, 24, part II, 452–460.

Marshall, J. S., R. C. Langille, and W. McK. Palmer, 1947: Measurement of rainfall by radar. *J. Meteor.*, 4, 186–192.

Wexler, R., 1947: Radar detection of a frontal storm 18 June 1946. *J. Meteor.*, 4, 38–44.

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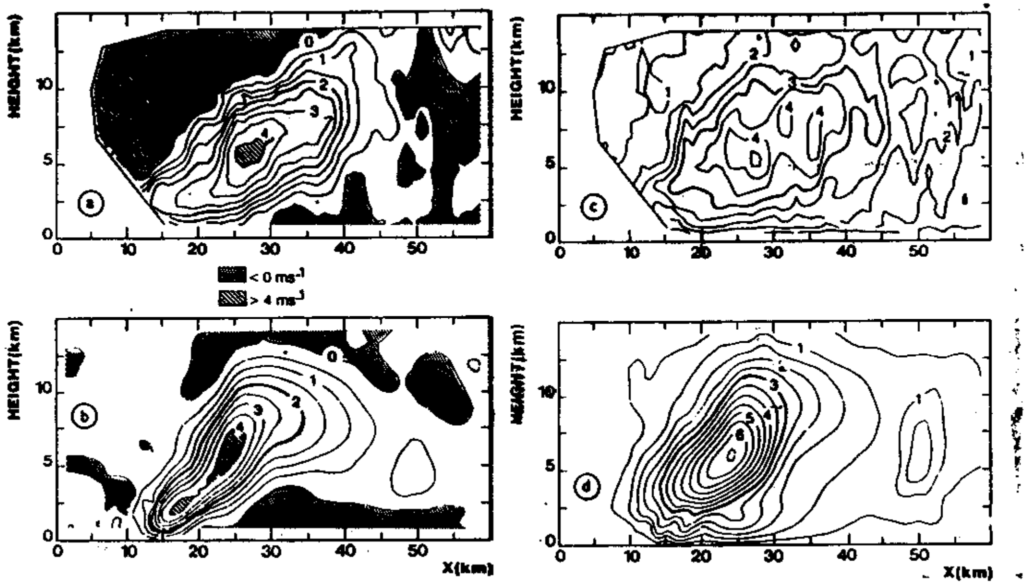


FIGURE 11 : Numerical simulation of a tropical squall line and two-dimensional analysis of the vertical velocity field, from [redacted] :

(a) two-dimensional average for radars. Downdraft areas are dashed, and areas witt values larger than 4 m s^{-1} are heavily dashed. The heavy line represents the 2 m s^{-1} isoline ;

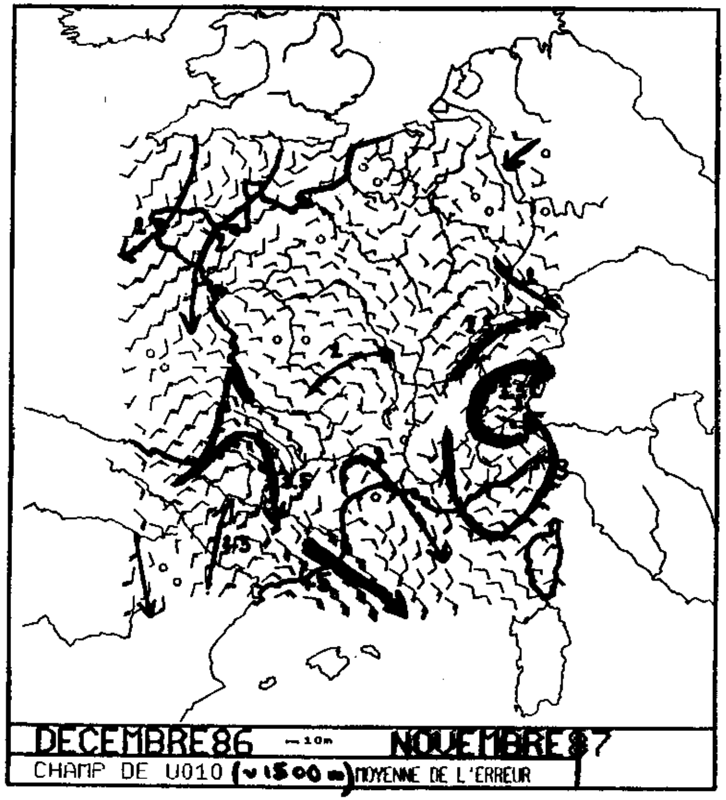
(b) as (a), but for the numerical simulation ;

COPT 81 data

(c) total standard deviation for radars. The heavy line represents the 3 m s^{-1} isoline ;

(d) as (c), but for the numerical simulation. The dotted line represents the crossover zone countour as identified by Redelsperger and Lafore (1988).

Baptistan (88)



σ = 0.864 wind : 24 h. Forecast

– corresponding analysis

1 year mean 00 UTC data

beware : basic arrows are counter oriented !

→ wind Forecast error when over 2 Knots in strength

L : 350 Km

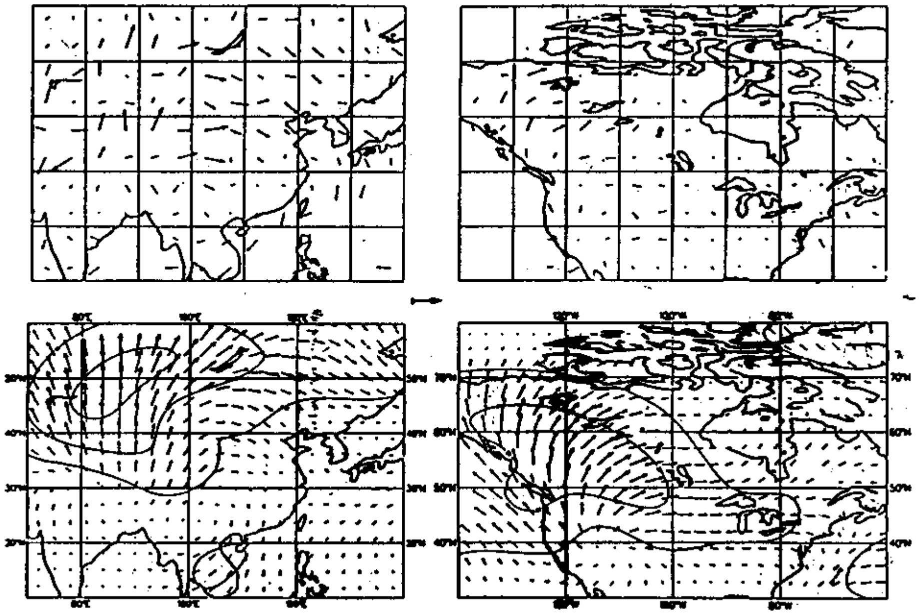
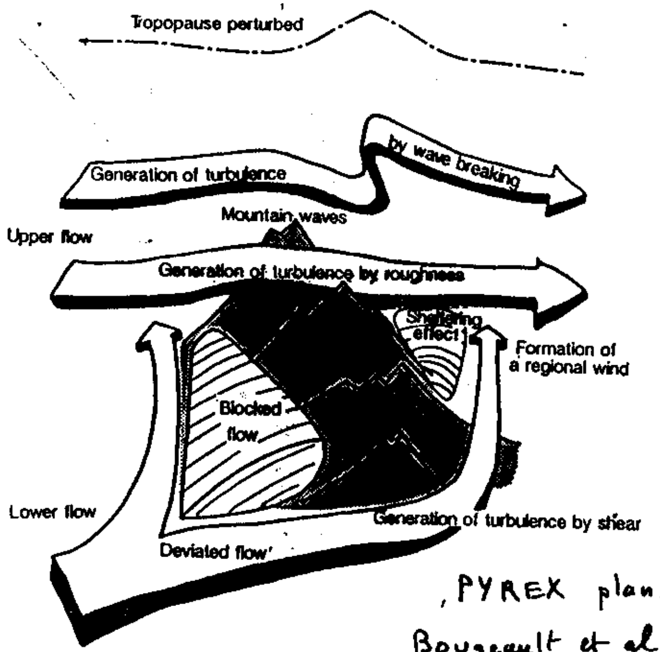


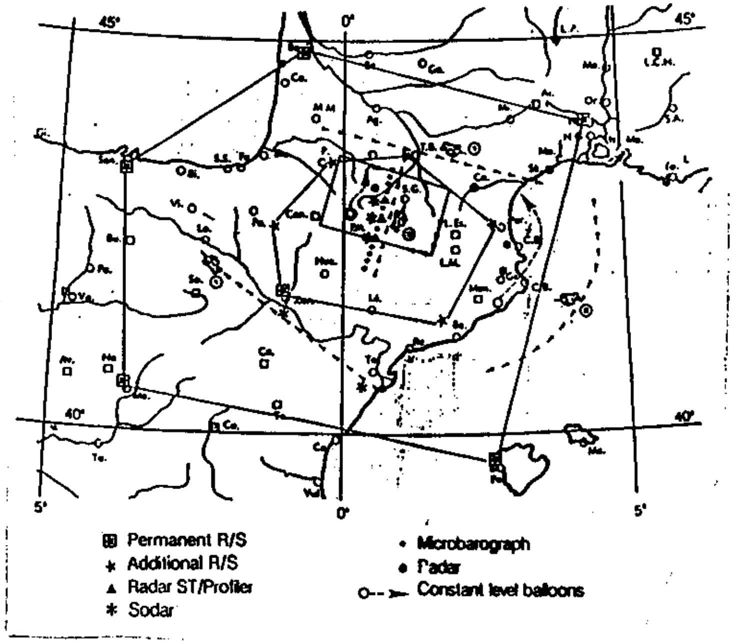
Fig. 6 The top panels show the 6-hour 10 metre wind forecast error verified against actual observations grouped in 5°x5° boxes. The mean initial tendency error at model level 19 is given at the bottom. The arrow in the middle of the figure represents 6 m/s in the top panels and 40 m/s/day in the bottom.

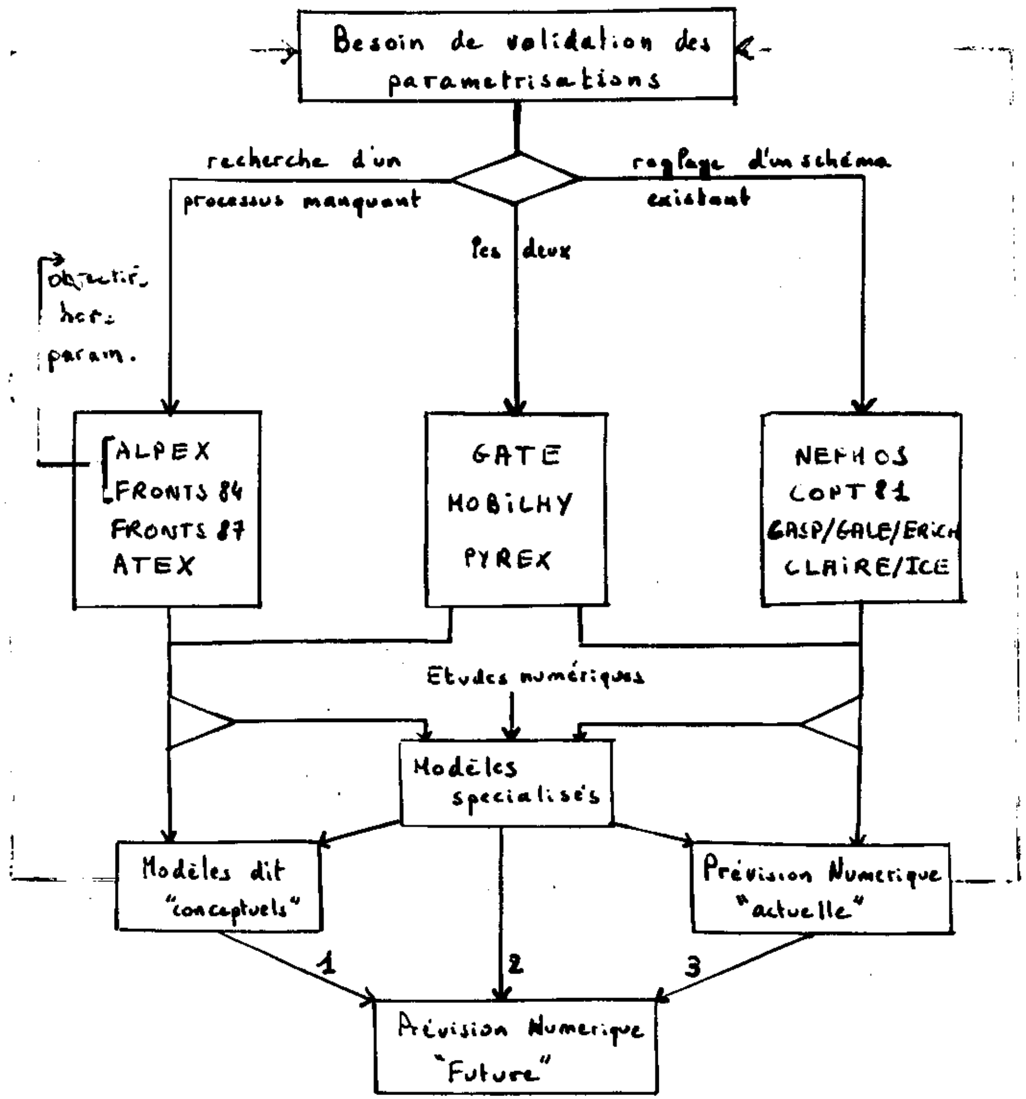
KLINKER and SARDESHMUKH (1987)



PYREX plans

Bougeault et al. (89)





1) ?

2) Le "meilleur" des mondes scientifiques

3) "court circuit"

Formulation

* A la surFace (indice o)

$$\vec{\tau}_0 = -\rho_0 \vec{V}_0 N_0 \underbrace{\left[\frac{E h_0}{l}\right]}_{= k} \sqrt{h_0^2}$$

tension

densité

vent au niveau le + bas

Fréquence de B.V.

écart type de l'orographie non résolue

paramètre adimensionnel de réglage

* ProFil d'absorption atmospherique

F_l nombre de Froude local

$\left(F_l = h_0 \sqrt{\frac{\rho_0 N N_0 U_0}{\rho U^3}} \right)$

$$\tau \sim 1/F_l^2$$

$$\Updownarrow$$

$$N \delta / U = C^{te}$$

Critère de saturation de Lindzen
(δ = deplacement vertical)

$$\Longrightarrow \quad \vec{\tau}_i = -\rho_i \frac{N_0^2}{N_i} \vec{V}_0 \, k \, h_0 \left[\frac{U_i}{U_0}\right]^3 \quad \text{avec} \quad U = \frac{\vec{V} \cdot \vec{V}_0}{\sqrt{\vec{V}_0 \cdot \vec{V}_0}}$$

De plus $\vec{\tau}_i = 0$ si $U_i < 0$

et $\vec{\tau}_i \cdot \vec{\tau}_{i-1}$ si $|\vec{\tau}_i| > |\vec{\tau}_{i-1}|$

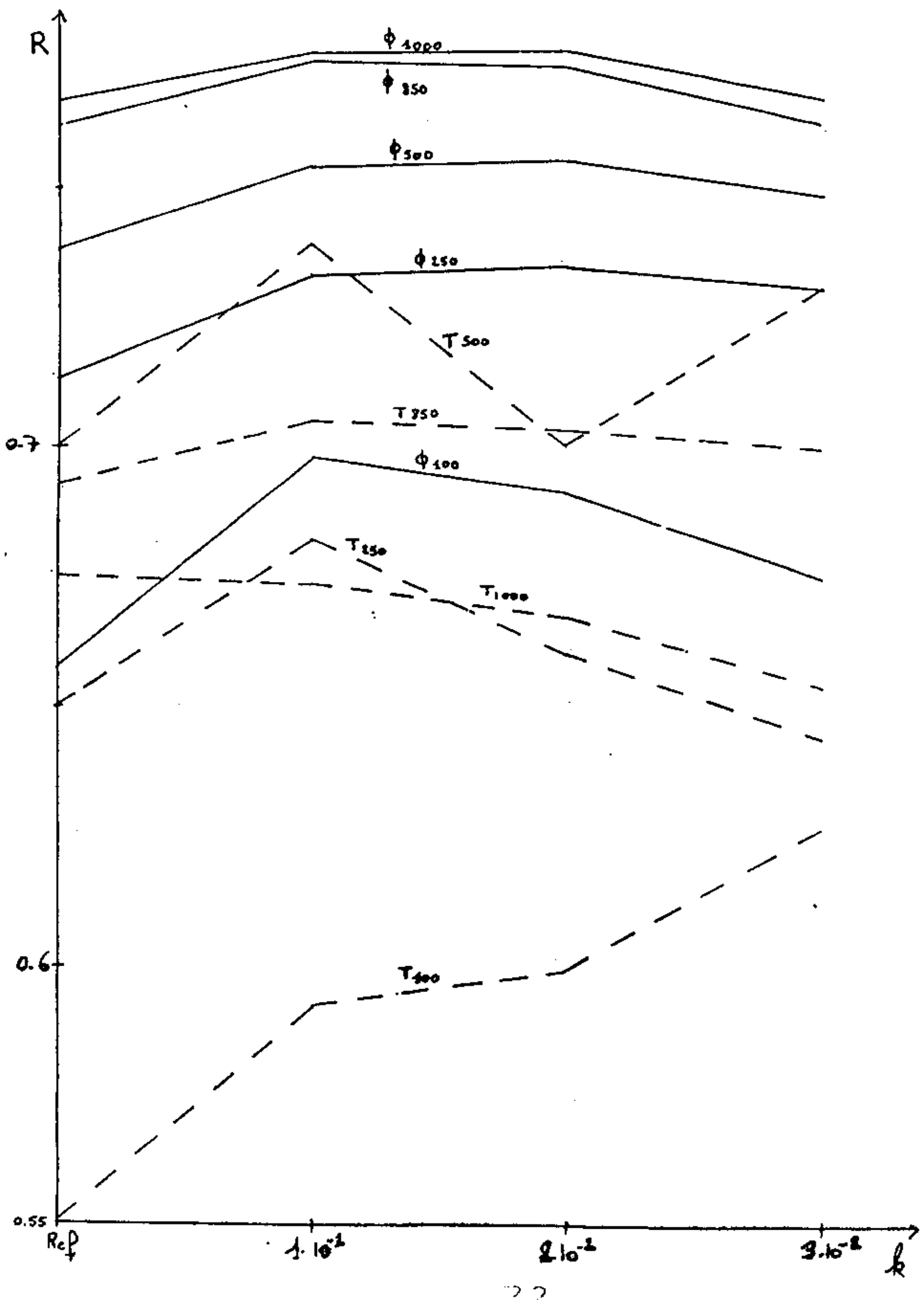
Enfin on discretise $\frac{d\vec{V}}{dt} = +g \frac{\partial \vec{\tau}}{\partial p}$

avec la limitation si $V^+ = V^- + 2\Delta t \frac{d\vec{V}}{dt}$

$$0 < \frac{\vec{V}^+ \cdot \vec{V}_0^-}{\vec{V}^- \cdot \vec{V}_0^-} < 1$$

Figure 1

Variations des coefficients de corrélations sur les tendances
des différentes variables après 96h de prévision
en fonction du paramètre k (Géopotentiel et Température
à 1000, 850, 500, 250 et 100 hPa)



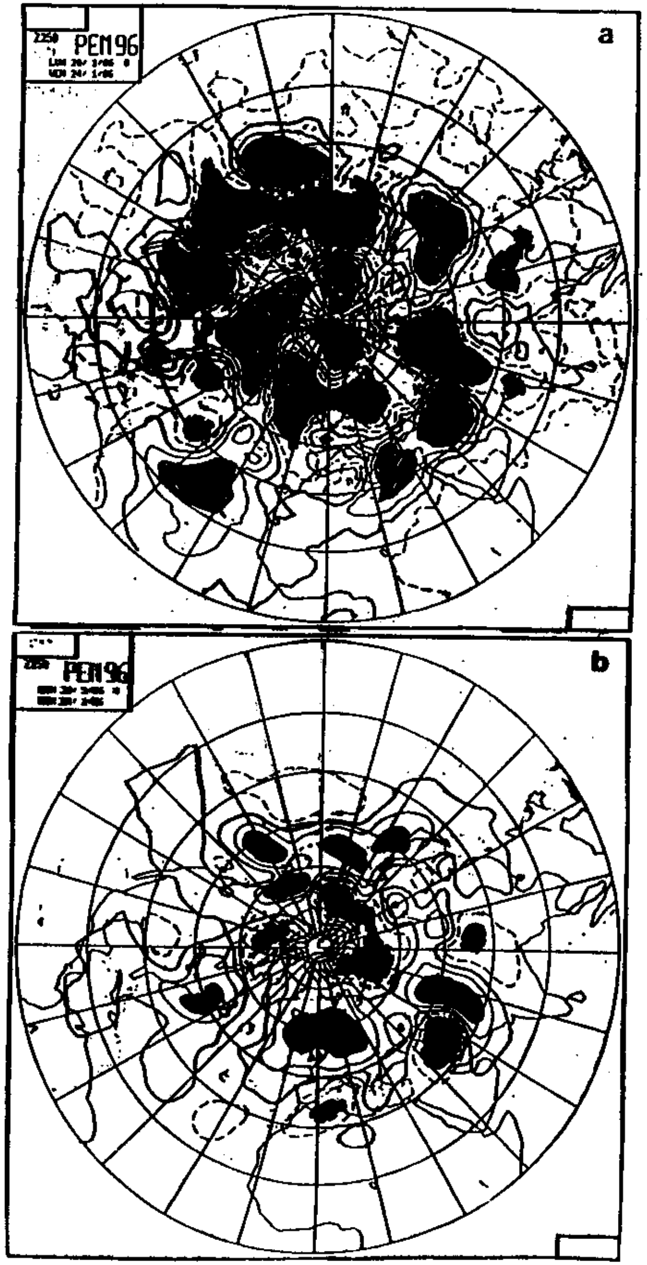


FIGURE 2 : Forecast from 20-1-1986 00Z.
a) 96 hour forecast error map of the 250 hPa height without parameterization of gravity wave drag. Reinforced zero line, negative values dotted, plotting interval 40 m.
b) The same but for the difference between two forecasts : with- minus without g.v.d. parameterization (k = 0.03). One notices the strong negative correlation of the two patterns especially upstream from the Rockies and the Himalaya.

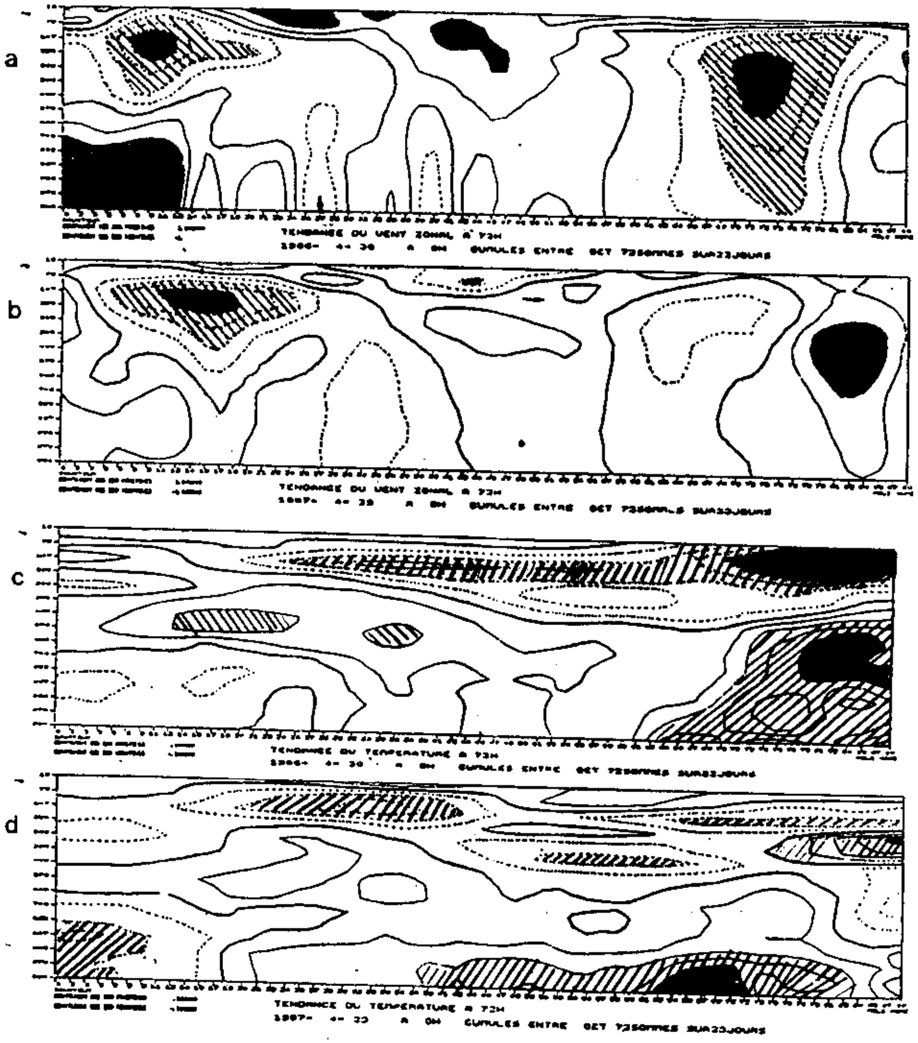
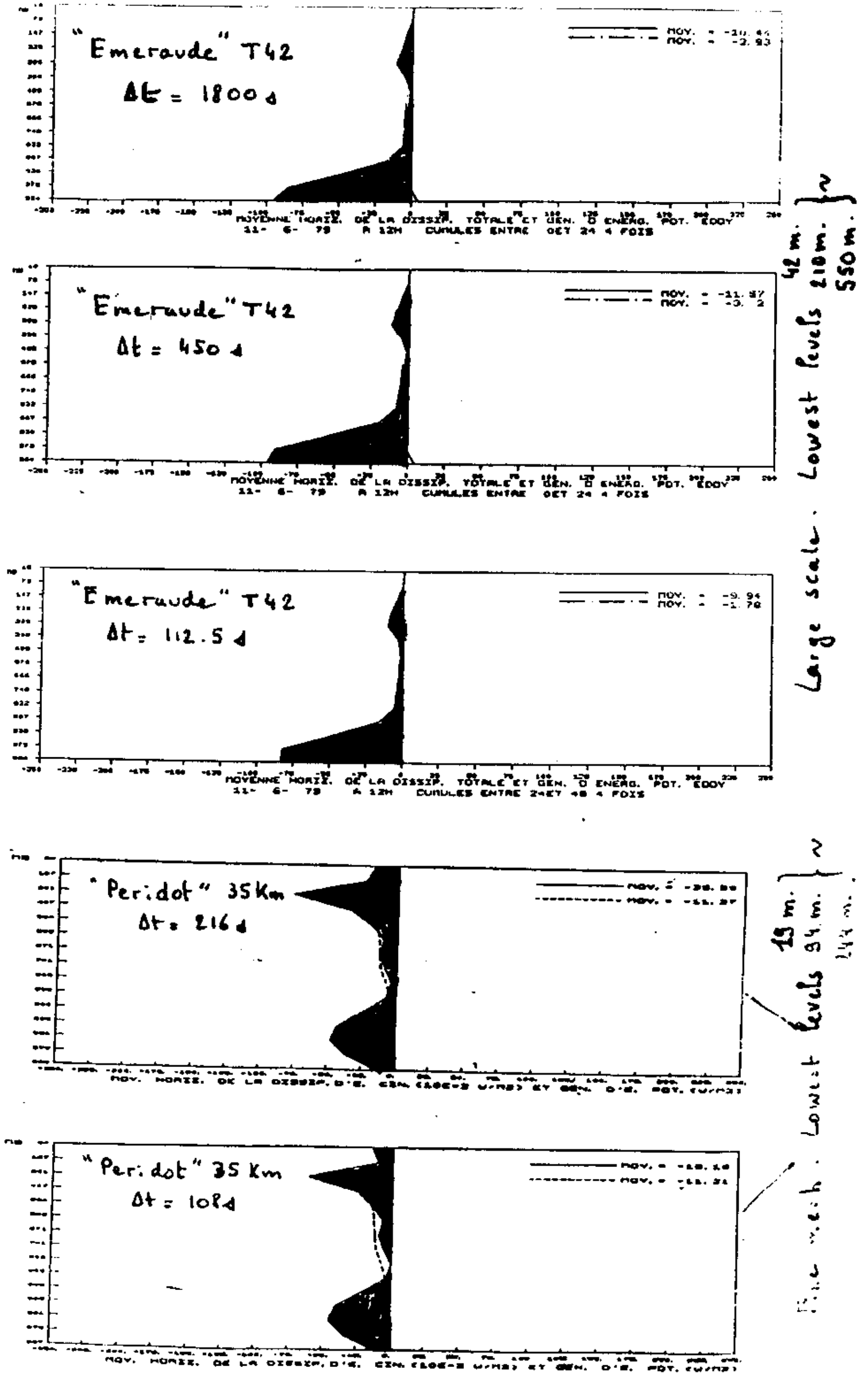


Figure 4 : Moyenne mensuelle de l'erreur zonale moyenne des prévisions opérationnelles.
a) Avril 86 Vent zonal
b) Avril 87 Vent zonal
c) Avril 86 Température
d) Avril 87 Température

DIABATIC DISSIPATION OF KINETIC ENERGY



6 BASIC QUESTIONS

1) What is the best way to verify parametrization schemes ?

2) Can parameterization schemes be built in such a way that they can work at all scales ?

3) Is it possible to eliminate both climate drift and deficiencies in the "transient part" of diabatic Forcing ?

4) Where does the law of diminishing return starts in the search For a better direct weather Forecasting, given the constrainsts of a workable dynamics/physics interFace ?

5) What is more important : exact representation of individual processes or realistically working Feed-back loops ; or, what are the important control parameters and test results ?

) Between the requirements of climate simulation and of improved data assimilation methods is there space For any original, Forecast direcly oriented, specific NWP work in parametrizations ?

WHY DO WE NEED A PARAMETERIZATION OF CONVECTION ?

a) Because most clouds are sub-grid scale

<u>and</u>

b) Because condensation/evaporation <u>organizes</u> sub grid scale motions (non chaotic behaviour)

Parametrization of convection = attempt to mimick what <u>the</u> model is doing when the phenomena are "resolved"

not "any" model !

WHY DO WE SEPARATE THE TWO PARAMETERIZATIONS!

("resolved" and "convective")

Because we (wrongly) believe in a scale separation which :

- is not universal in nature
  (strato cumulus !! slantwise convection !)
- shouldn't exist in a model <u>that imposes its own critical scales</u> to both parametrized and resolved phase changes

WE SHALL STOP DOING IT !

But is it possible consistently and efficiently ??

GENERALITIES

- Clouds without rain ⇒ condensed water may reevaporate in the atmosphere

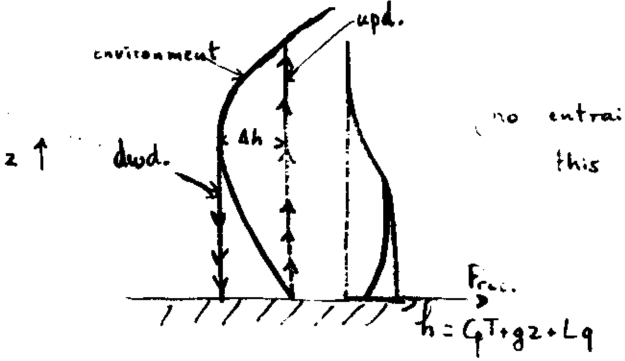
2 cases (for the time being)

- Stable situation : Falling droplets evaporate when crossing non saturated sub-cloud layers

relative evaporation ↗ ⇔ rel. humidity ↘

⇘ rain Flux ↘ (smaller drops)

- Unstable situation
  - ascent : condensation compensates adiabatic cooling
  - descent : evaporation " " heating but only if liquid water is available to evaporate and to maintain the downdraft just at saturation.

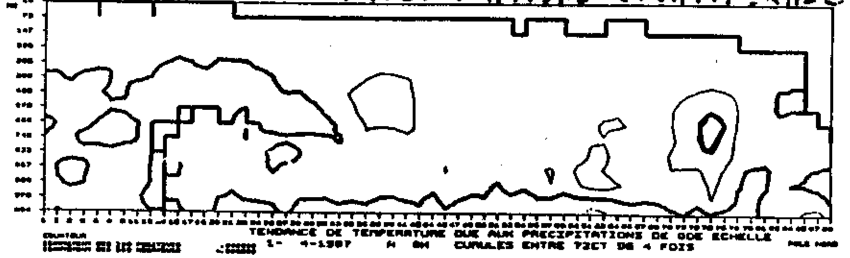


(no entrainment for this simple example)

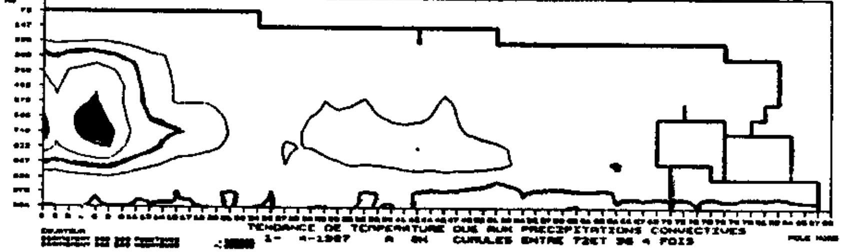
relative evaporation ↗ ⇔ buoyancy excess Δh

(more rain above more unstable layers)

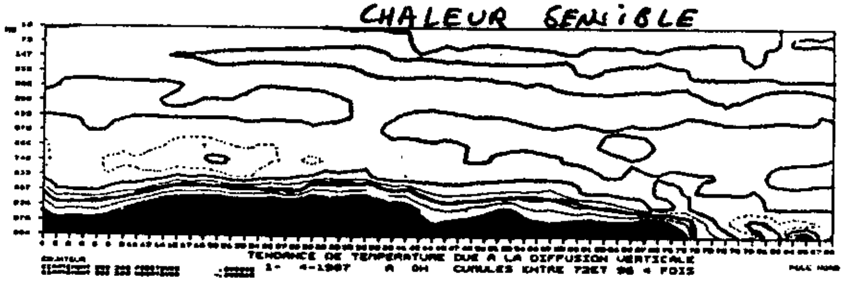
PRÉCIPITATIONS STRATIFORMES



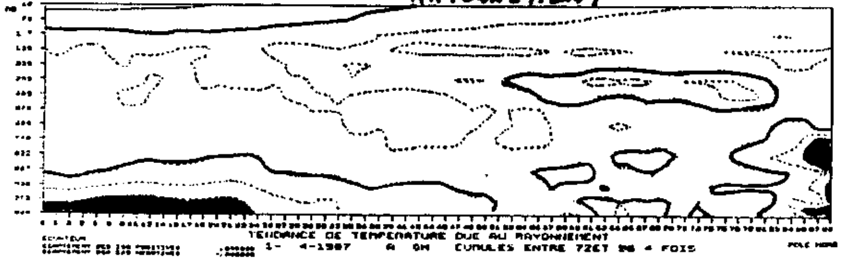
PRÉCIPITATIONS CUMULIFORMES



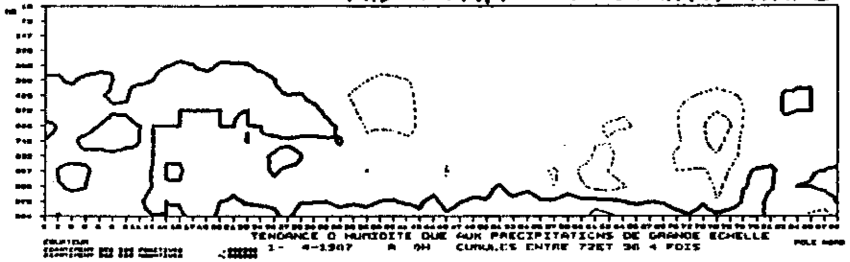
CHALEUR SENSIBLE



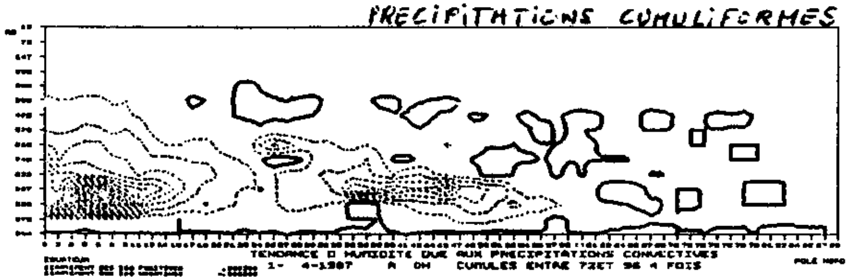
RAYONNEMENT



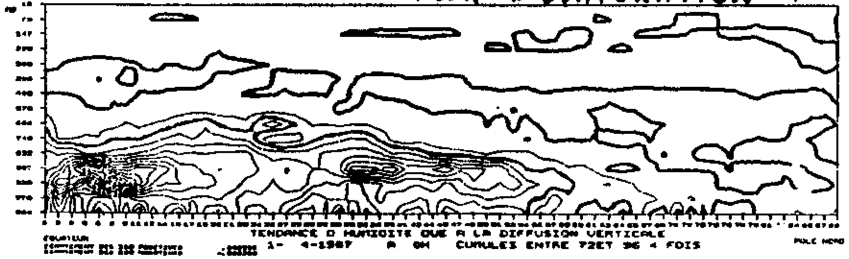
PRECIPITATIONS STRATIFORMES



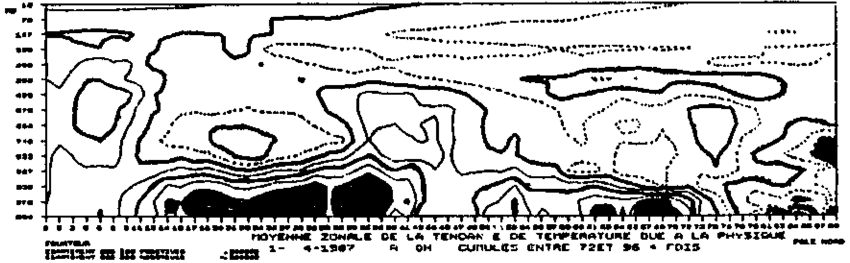
PRECIPITATIONS CUMULIFORMES



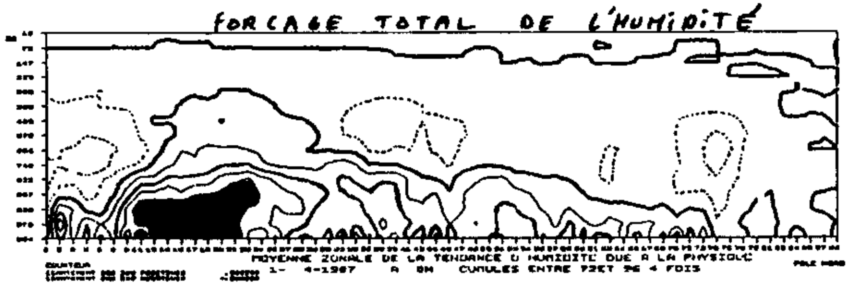
FLUX D'EVAPORATION



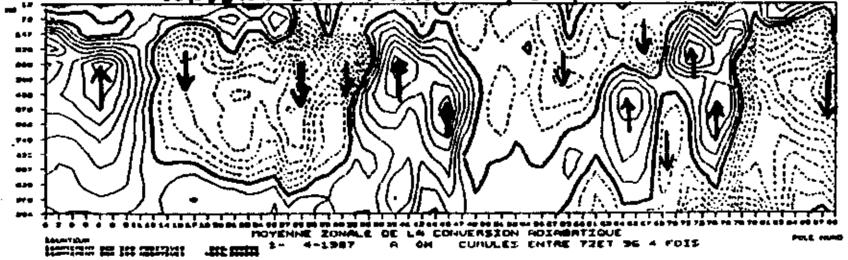
FORCAGE TOTAL DE LA TEMPERATURE



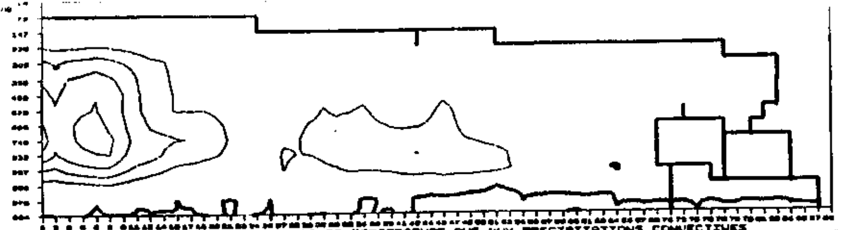
FORCAGE TOTAL DE L'HUMIDITÉ



CONVERSION ENERGÉTIQUE (~ VITESSE VERTICALE)

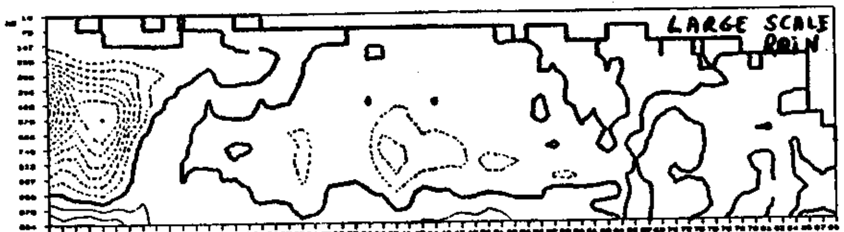


CONVECTION



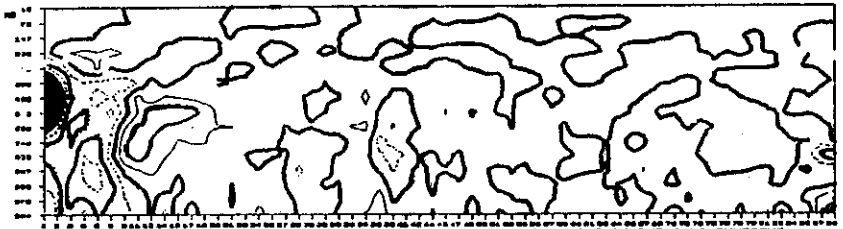
TENDANCE DE TEMPERATURE DUE AUX PRECIPITATIONS CONVECTIVES
1- 4-1987 A 0H CUMULES ENTRE 72ET 96 4 FOIS

a)



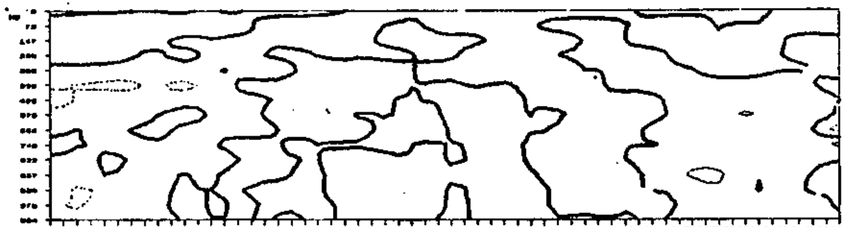
TENDANCE DE TEMPERATURE DUE AUX PRECIPITATIONS DE GDE ECHELLE
1- 4-1987 A 0H CUMULES ENTRE 72ET 96 4 FOIS

b)



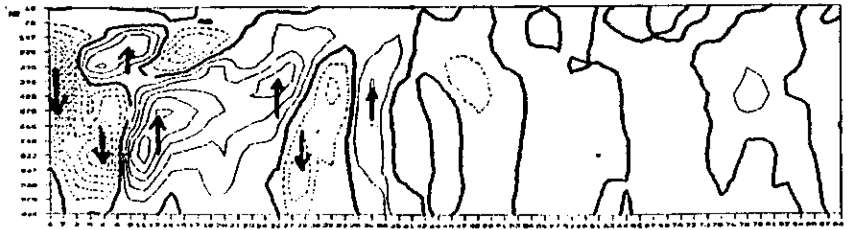
MOYENNE ZONALE DE LA TENDANCE DE TEMPERATURE DUE A LA PHYSIQUE
1- 4-1987 A 0H CUMULES ENTRE 72ET 96 4 FOIS

c)



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

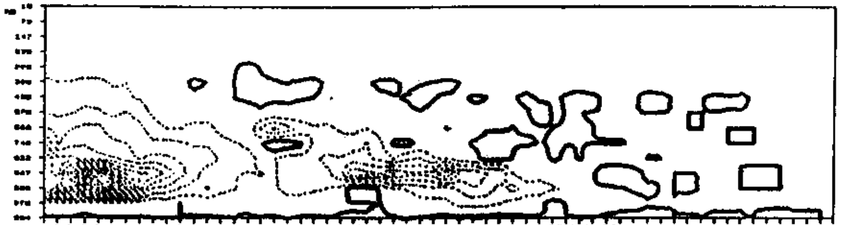
d)



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

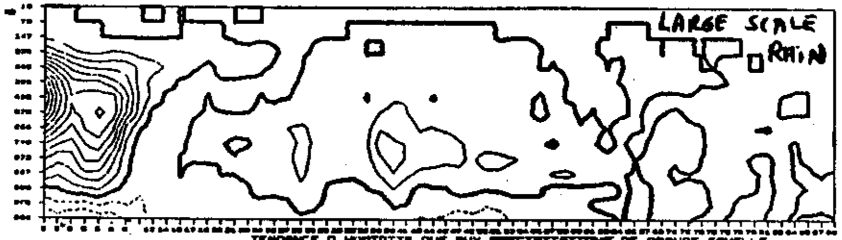
e)

CONVECTION



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

a)

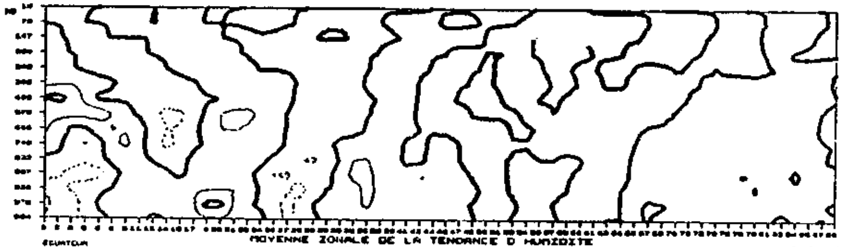


TENDANCE D HUMIDITE DUE AUX PRECIPITATIONS DE GRANDE ECHELLE
1- 4-1987 A 0H CUMULES ENTRE 72ET 96 4 FOIS

b)

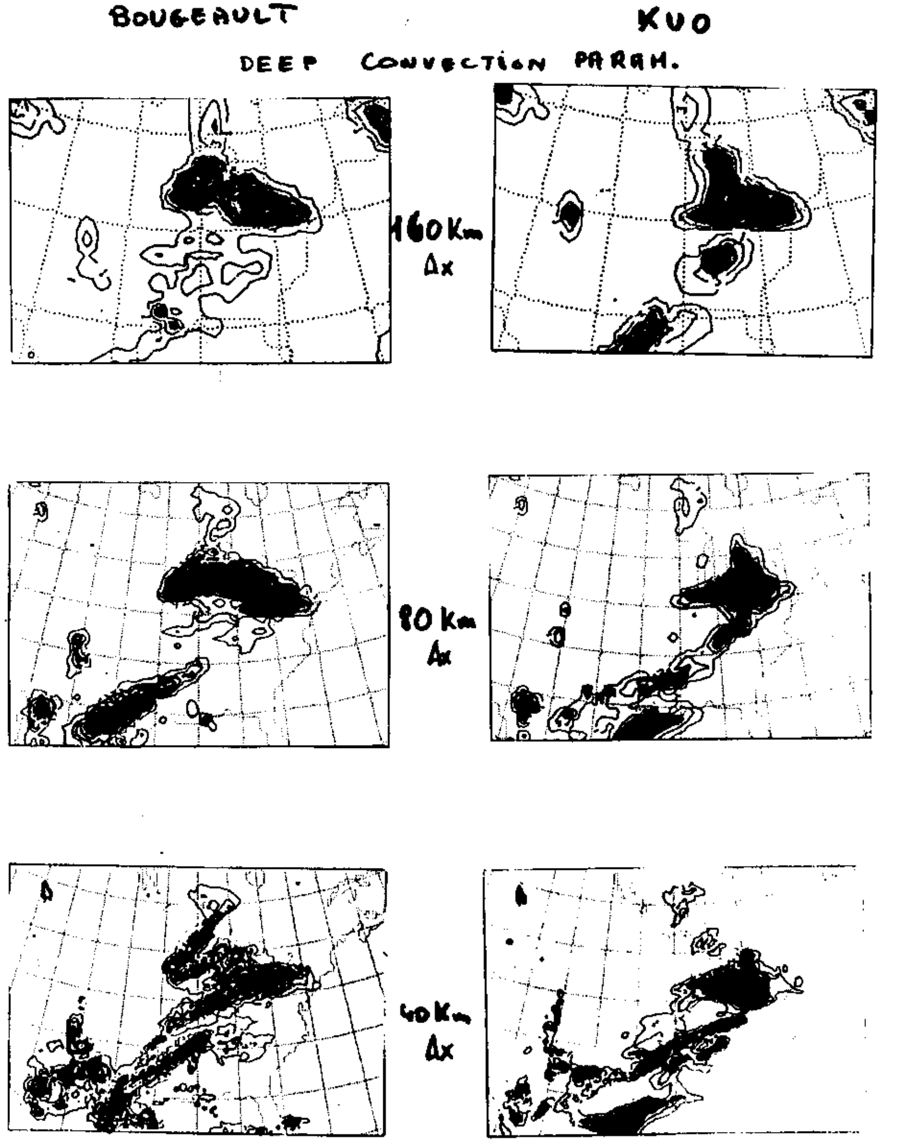
MOYENNE ZONALE DE LA TENDANCE D HUMIDITE DUE A LA PHYSIQUE
1- 4-1987 A 0H CUMULES ENTRE 72ET 96 4 FOIS

c)

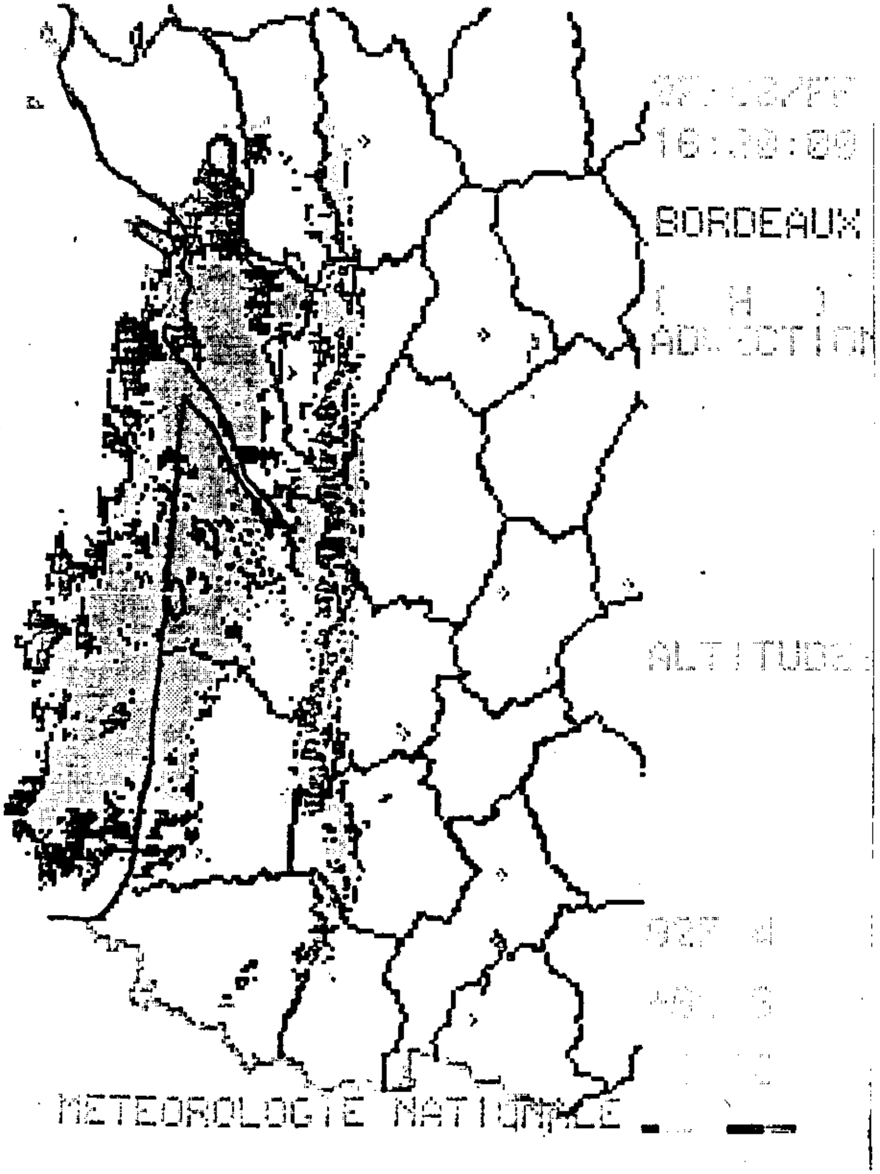


MOYENNE ZONALE DE LA TENDANCE D HUMIDITE
1- 4-1987 A 0H CUMULES ENTRE 72ET 96 4 FOIS

d)



48 hour rainFall Forecast (12h accumulated)



7 JUIN 1987 θ'_W H+6

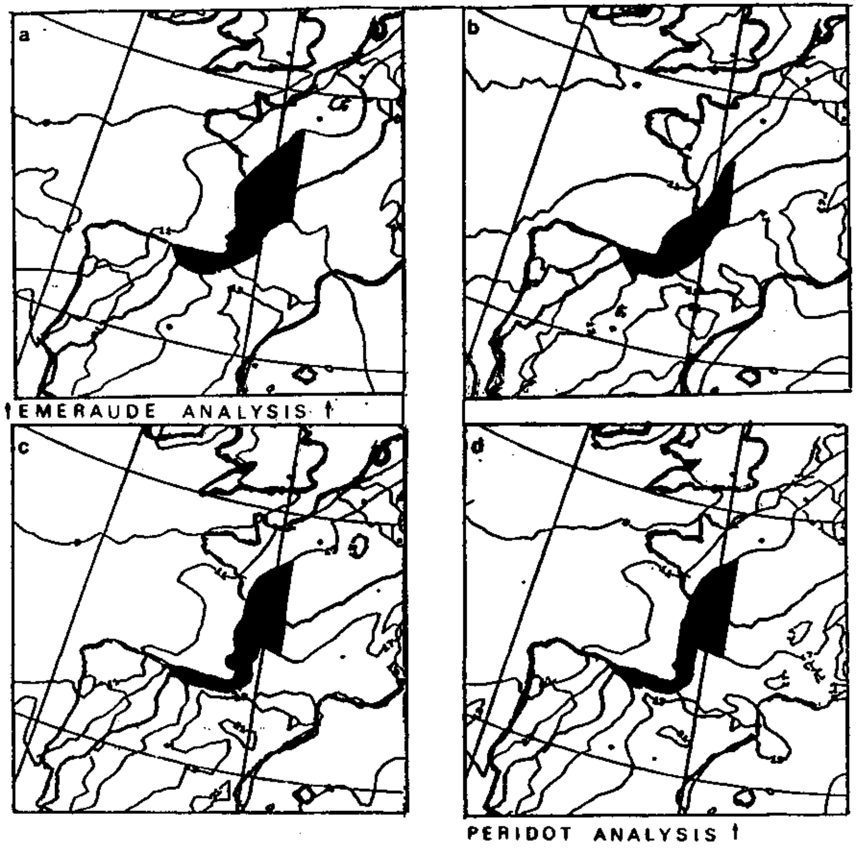
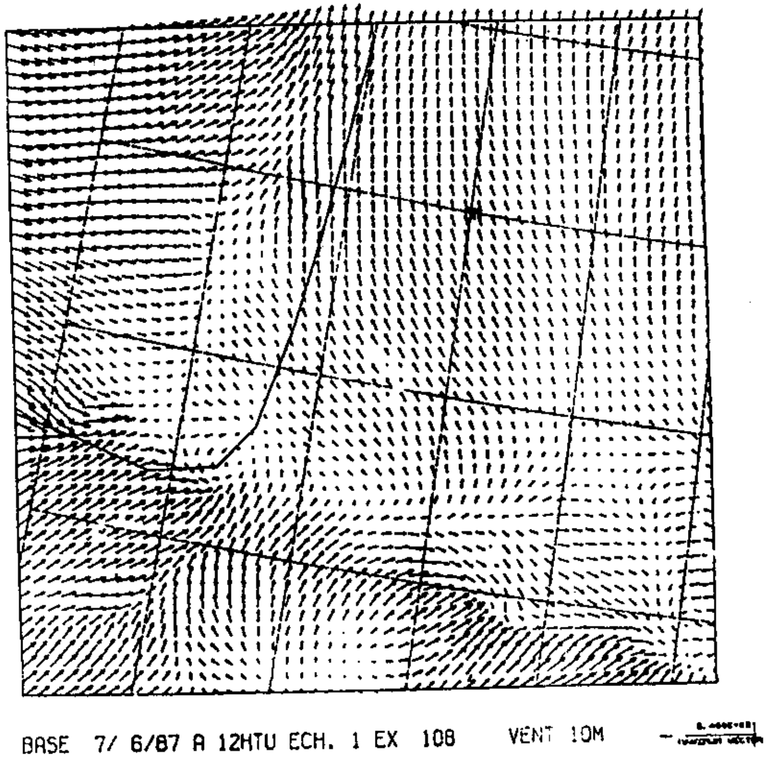


Figure 22 : Maps of 6 hour forecasts of PBL moist equivalent potential temperatures verifying 87-06-07 18Z . The forecasts differ only by their initial states : a) interpolated large scale analysis ; b) fine mesh analysis with large scale forecast as background ; c) fine mesh analysis with fine mesh forecast as background (no satellite data included) ; d) as c) but with satellite data in the fine mesh analysis. Contouring interval 2° (reinforced 15°C isoline). Only part of the 95x95 integration area is shown here.

Integration $\frac{1}{4}$ → grille 4x plus Fine
H+1

→ conditions initiales

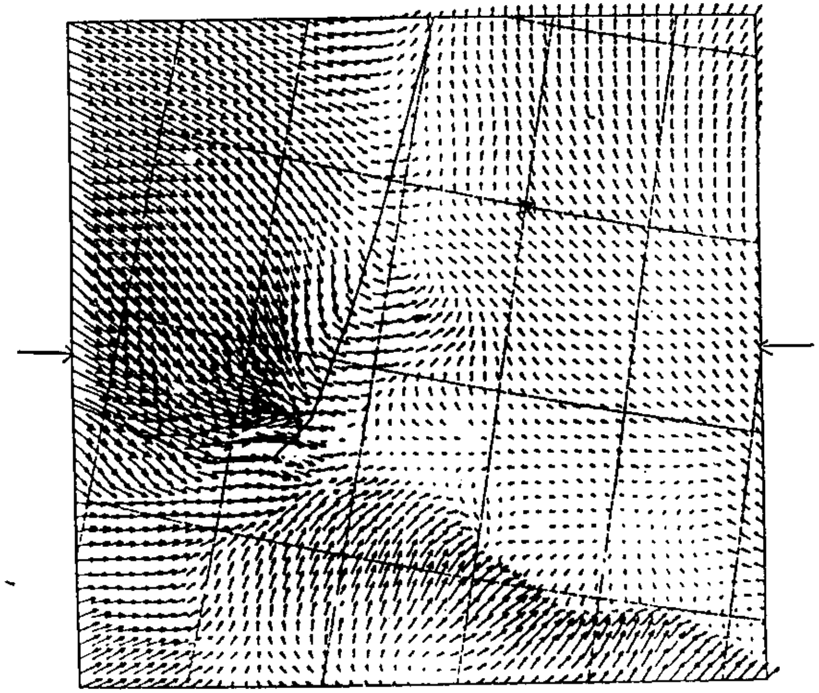
→ conditions aux limites



modèle "identique"

→ ← axe de la coupe

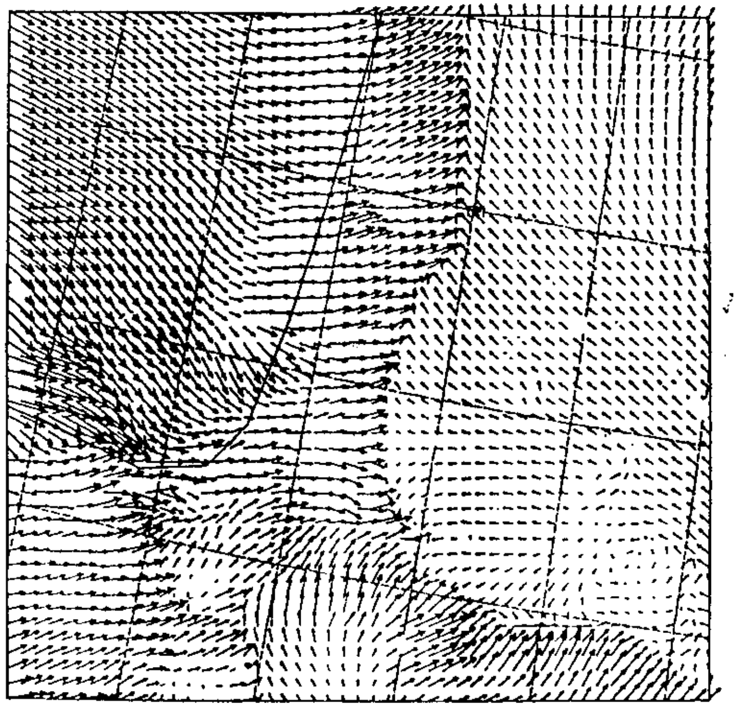
H+3



BASE 7/ 6/87 A 12HTU ECH. 3 EX 108 VENT 10M

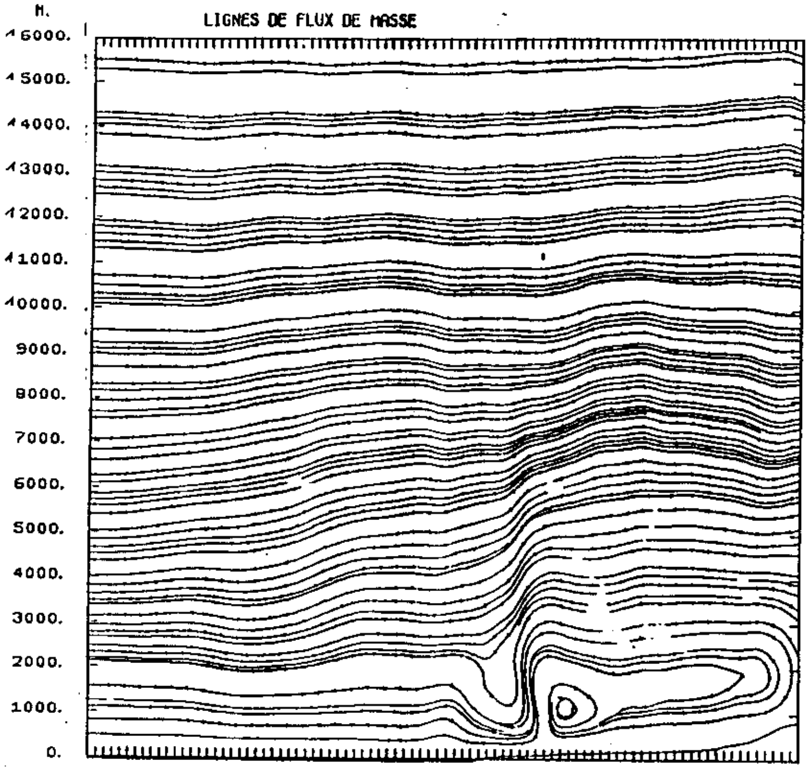
modèle "identique"

H+3

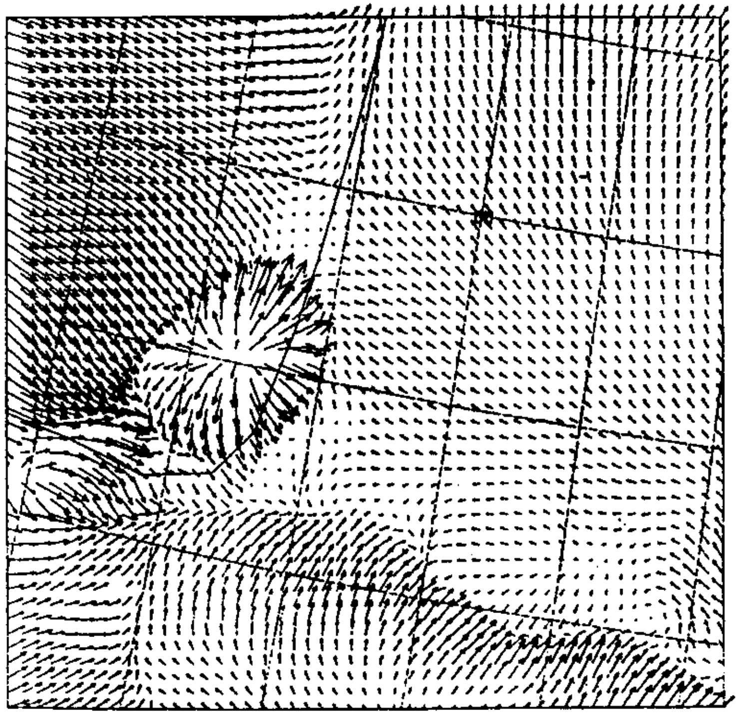


BASE 7/ 6/87 A .2HTU ECH. 3 EX 117 VENT 10M

prise en compte des "courants descendants"



* 7/ 6/87 A 12HTU ECH. 3 EX 117 MØY.SUR 1 PLANS * AXE = (24/14)*(56/94) / 22 DG



BASE 7/ 6/87 A 12HTU ECH. 3 EX 111 VENT 10M

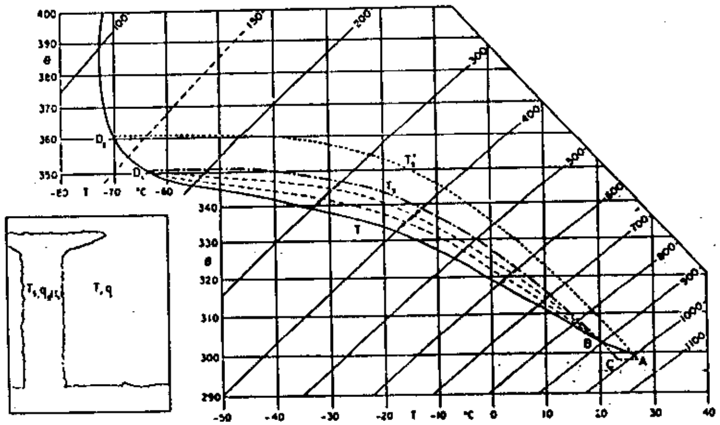


FIG. 1. Distributions of temperature and mixing ratio in the environmental air and inside a deep cumulus cloud. Based on the mean tropical atmosphere for the hurricane season derived by [redacted]

KUO (65)

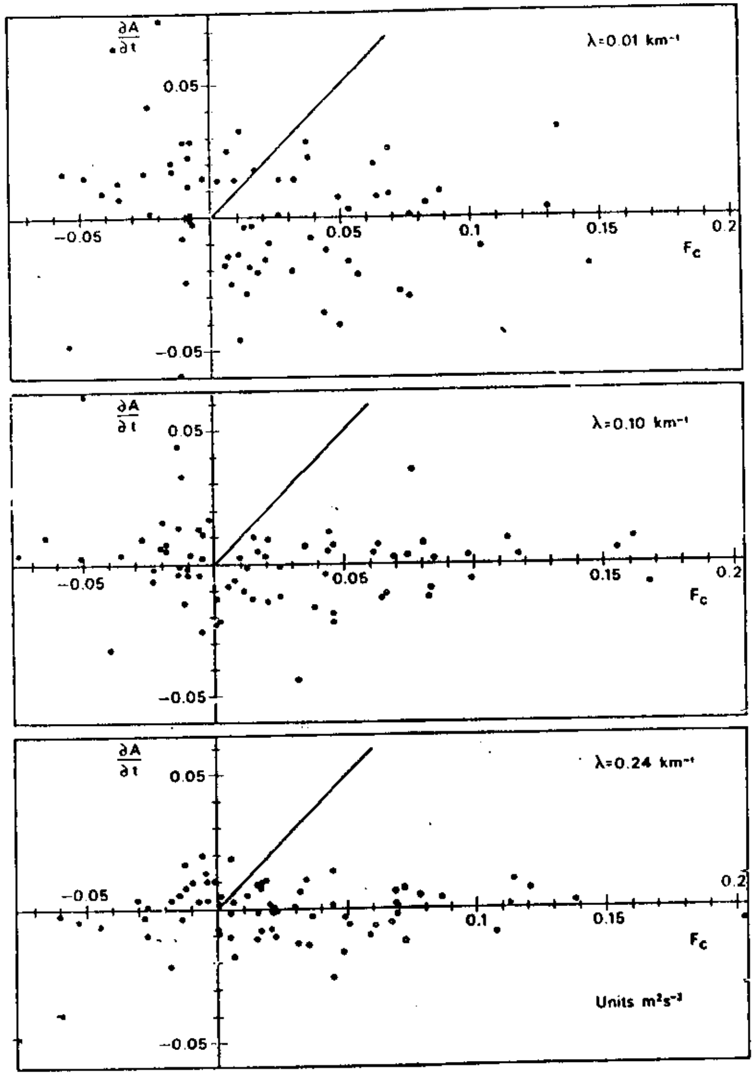
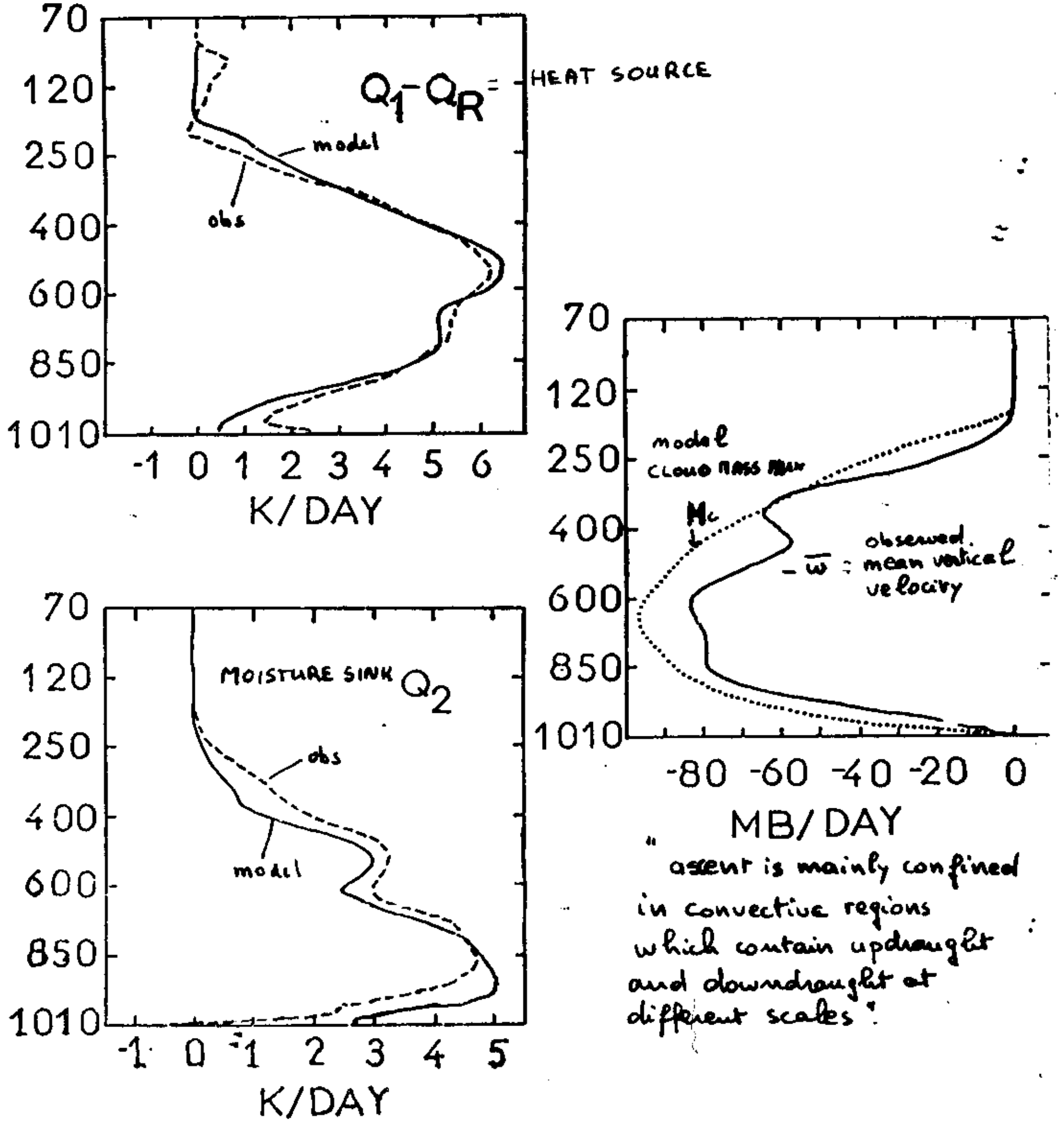


Fig. 6 Large-scale forcing $F_c(\lambda)$ and $\partial A(\lambda)/\partial t$ observed over a 3-hour interval (from König, 1982).

DUMESNIL (83) GATE - data

COMPARISON OF THE CLOUD MASS FLUX SCHEME WITH OBSERVATIONS



" ascent is mainly confined in convective regions which contain updraught and downdraught at different scales ".

BOUGEAULT (83)

GATE data

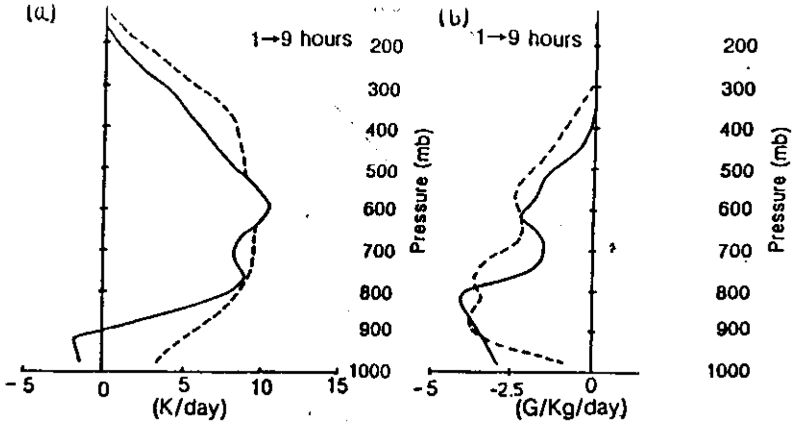


Fig. 4 Vertical distribution of the modelled (————) (a) $Q1_{TOT}$ and (b) $Q2_{TOT}$ compared with observed values (- - - -) for sim A.

GREGORY and MILLER (89)

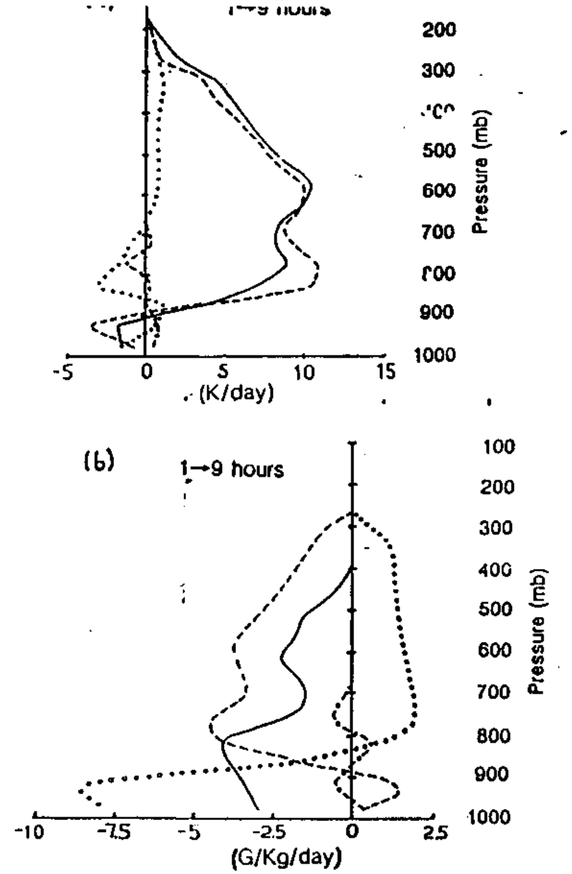


Fig. 5 Contribution of condensational heating/evaporative cooling (- - - -), vertical eddy flux divergence (• • • • • •) and turbulent effects (—•—•—•—) to (a) $Q1_{TOT}$ and (b) $Q2_{TOT}$ (————) for sim A (contribution of boundary layer forcing not shown).

KUO ≠ KUO

It is never "modelling" but always "parameterization"

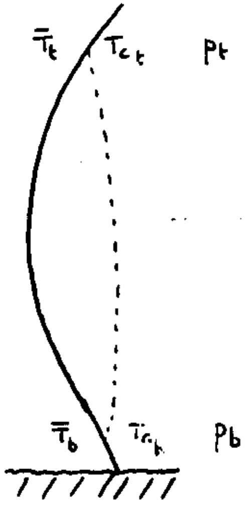
One should only write mass-flux-type schemes

. . . .

closure assumption ≠ convective scheme

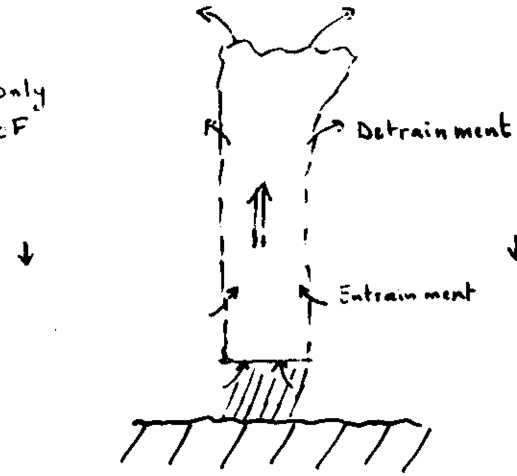
----> there exist mass-flux schemes with a Kuo closure (Bougeault 85)

. . . .



and ϕ ?!

Updrafts only
For the sake of
simplicity



↓ "Compensating" subsidence

M_c = vertical velocity of compensating subsid.

Hypothesis
- steady cloud
- neglegible area of updraft
  $\tilde{\Psi} = \overline{\Psi}$ ~ "environment" — "large-scale"
- all detrained liquid water evaporates
- no subcloud evaporation of rainfall

Equations

$$\frac{\partial \overline{\Psi}}{\partial t} = -\frac{\partial}{\partial p}\left[M_c(\overline{\Psi} - \Psi_c)\right]$$

$$\frac{\partial \overline{q}}{\partial t} = -\frac{\partial}{\partial p}\left[M_c\left(\overline{q} - (q_c + \ell_c)\right)\right] - g\frac{\partial P_r}{\partial p}$$

$$\frac{\partial M_c}{\partial p} = D - E$$

$$M_c \frac{\partial \Psi_c}{\partial p} = E(\Psi_c - \overline{\Psi})$$

$$M_c \frac{\partial (q_c + \ell_c)}{\partial p} = E\left((q_c + \ell_c) - \overline{q}\right) + g\frac{\partial P_r}{\partial p}$$

Choice of $q_c, \ell_c = f(\Psi_c, p, \phi)$
Fixes P_r

Ψ = any thermodynamical [illegible] conserved variable (h, for example)

Mass Flux → Adjustment

$M_c = c^{te}$ and $E \neq 0$ only where $\Psi_c = \overline{\Psi}$
and $q_c + l_c = \overline{q}$

$$\Rightarrow \quad \frac{\partial \overline{\Psi}}{\partial t} = -M_c \frac{\partial}{\partial p}(\overline{\Psi} - \Psi_c) \quad ; \quad \Psi_c = c^{te}$$

$$\frac{\partial \overline{q}}{\partial t} = -M_c \frac{\partial \overline{q}}{\partial p} \quad ; \quad M_c \frac{\partial (q_c + l_c)}{\partial p} = g \frac{\partial P_r}{\partial p}$$

Mass Flux → "KUO" scheme

A bit of rewriting

$$\frac{\partial \overline{\Psi}}{\partial t} = -M_c \frac{\partial \overline{\Psi}}{\partial p} + D\,(\Psi_c - \overline{\Psi})$$

$$\frac{\partial \overline{q}}{\partial t} = -M_c \frac{\partial \overline{q}}{\partial p} + D\,((q_c + l_c) - \overline{q})$$

$$\frac{\partial M_c}{\partial p} = D - E$$

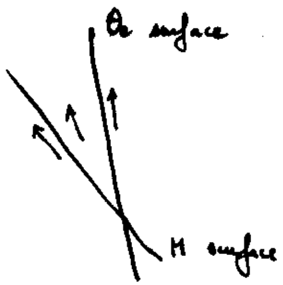
etc ....

$M_c = 0$ but $D = E \neq 0$ ⇒ "KUO-65"

SLANTWISE ASPECTS

Moist instability ⟺ $f . P_e < 0$

- buoyancy → upright convection
- inertial instability (moisture independent)
- so called "symetric instability"



Existing schemes :

"Mixing" of θ_e along M surfaces by modification of the cloud profile (Nordeng)

"Mixing" of M along θ_e surfaces by modification of the cloud profile (proposal Thorpe-Miller)

Proposal : any possible slope (choice to be optimized) by modification of the large scale "environment" of the ascent.

Advantages : - good link with upright convection ; Freedom of choice between different techniques

Problems : - this choice will not be easy (// M // θ_e between !)
- approximations needed

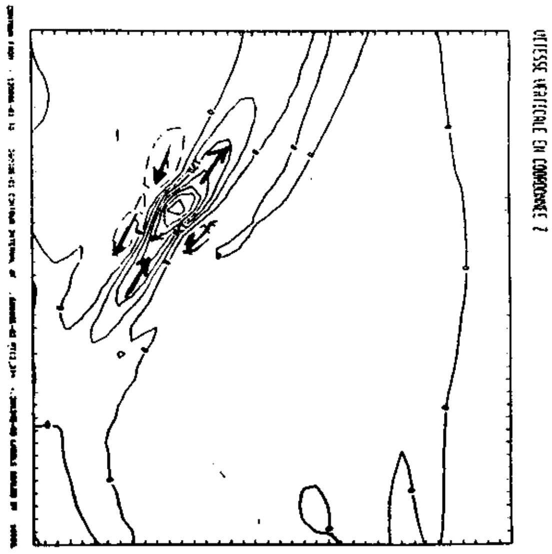


Figure III/23

Vitesses verticales après 18 heures d'intégration de la situation frontale 1.

Perturbation initiale à 105 %

Troposphère saturée.

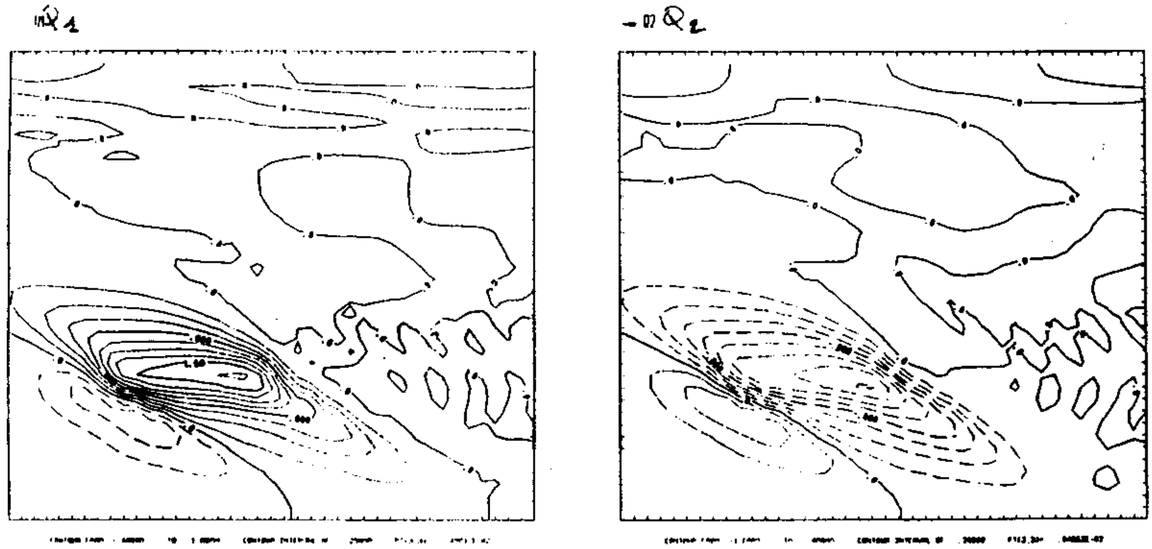


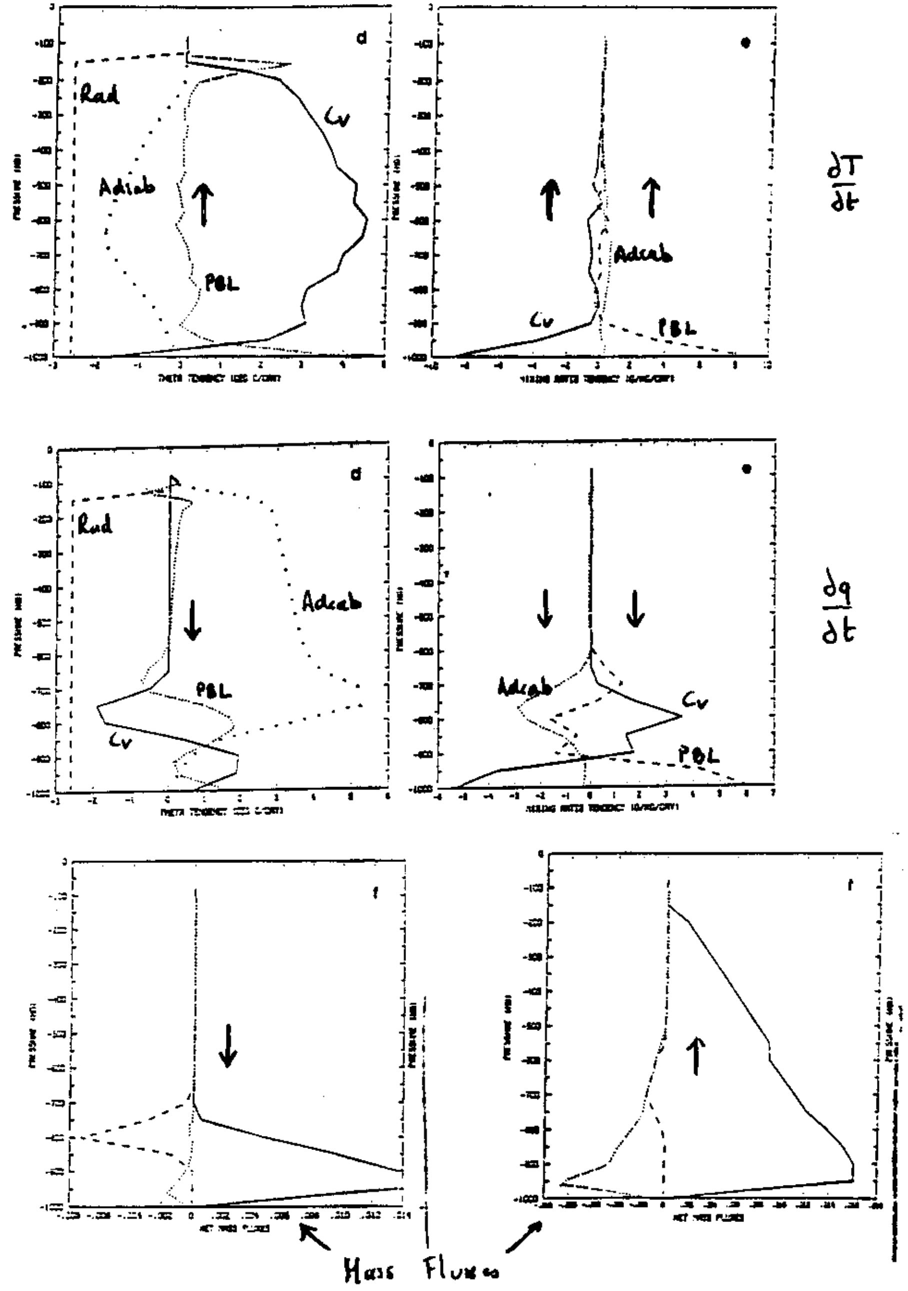
Figure V/1

Q_1 : source de chaleur ; $Q_1 = \rho \frac{d\bar{s}}{dt}$

Q_2 : puit d'humidité ; $-Q_2 = \rho L \frac{d\bar{q}}{dt}$

Après 18 heures d'intégration à partir de la situation frontale 1

Unité : K/jour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∂T/∂t
d
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PBL
Cv
e
Adiab
Cv
PBL
∂q/∂t
f
f
PRESSURE (MB)
THETA TENDENCY (DEG C/DAY)
MIXING RATIO TENDENCY (G/KG/DAY)
NET MASS FLUXES
Mass Fluxes