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Diabatic forcing in fully compressible model III

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Contents

1 Introduction

The aim of this stay was to continue an investigation of diabatic forcing in the fully compressible model ALADIN. Former 2D and 3D academic experiments with instantaneous heating performed at one time-step in the dry atmosphere indicated that the solutions using an hydrostatic adjustment parameterization, equation (1) and (2)

$$\frac{dT}{dt} = -\frac{RT}{c_v}D_3 + \frac{Q}{c_p} \tag{1}$$

$$\frac{dp}{dt} = -\frac{c_p p}{c_v}D_3 \tag{2}$$

and an exact treatment of diabatic terms as in equations (3) and (4)

$$\frac{dT}{dt} = -\frac{RT}{c_v}D_3 + \frac{Q}{c_v} \tag{3}$$

$$\frac{dp}{dt} = -\frac{c_p p}{c_v}D_3 + \frac{Qp}{c_v T} \tag{4}$$

converge after a very short period (Trojakova (2004)).

Further research of diabatic forcing is dedicated to the real case study, where is necessary to take into account the effects of moist processes. Considering the second thermodynamics principle for reversible precesses as

$$ds = \frac{dq}{T} \tag{5}$$

and closed heterogeneous system containing m_d kg of dry air, m_t kg of water substance $m_t = m_v + m_w$ where m_v is the mass of water vapor and m_w is the mass of liquid water. The total differential expression of entropy S can be written (Iribarne and Godson (1981)) as follows

$$dS = (m_d c_{pd} + m_v c_{pv} + m_w c_w)\, d\ln T - m_d R_d\, d\ln p_d - m_v R_v\, d\ln e + \frac{l_v}{T} dm_v \tag{6}$$

The combination of equations (5), (6) and definition of $q_i = \frac{m_i}{m_d + \sum m_i}, i = v, w$ one can obtain

$$dq = (c_{pd} + (c_{pv} - c_{pd})q_v + (c_w - c_{pd})q_w)dT - (R_d(1 - q_v - q_w) + R_v q_v)T\frac{dp}{p} + l_v dq_v \tag{7}$$

The previous equation can be rewritten for $c_p = c_p(q_i)$ and $R = R(q_i)$ as

$$dq = c_p dT - RT\frac{dp}{p} + l_v dq_v \tag{8}$$

After combination with following formulation of continuity equation

$$\frac{1}{p}\frac{dp}{dt} + \frac{1}{\alpha}\frac{d\alpha}{dt} = \frac{1}{p}\frac{dp}{dt} + D_3 = \frac{1}{R}\frac{dR}{dt} + \frac{1}{T}\frac{dT}{dt} \tag{9}$$

where R is the same as the $R(q_i)$ defined in (8), the prognostic equations for the temperature and pressure follow:

$$\frac{dT}{dt} = -\frac{RT}{c_v}D_3 + \frac{1}{c_v}\frac{dq}{dt} + \frac{T}{c_v}\frac{dR}{dt} - \frac{l_v}{c_v}\frac{dq_v}{dt} = -\frac{RT}{c_v}D_3 + \frac{Q}{c_v} \tag{10}$$

$$\frac{dp}{dt} = -\frac{c_p}{c_v}pD_3 + p\left(\frac{1}{Tc_v}\frac{dq}{dt} + \frac{c_p}{c_v R}\frac{dR}{dt} - \frac{l_v}{Tc_v}\frac{dq_v}{dt}\right) = -\frac{c_p}{c_v}pD_3 + p\left(\frac{Q}{c_v T} + \frac{1}{R}\frac{dR}{dt}\right) \tag{11}$$

As the pressure is not a prognostic variable, the equation (11) will become for non-hydrostatic pressure departure variable $\hat{q} = ln(\frac{p}{\pi})$

$$\frac{d\hat{q}}{dt} = \frac{1}{p}\frac{dp}{dt} - \frac{\dot{\pi}}{\pi} = -\frac{c_p}{c_v}D_3 - \frac{\dot{\pi}}{\pi} + \left(\frac{Q}{c_v T} + \frac{1}{R}\frac{dR}{dt}\right) \tag{12}$$

Prognostic equations (10) and (12) represent the exact treatment of diabatic terms with moist processes included and hydrostatic adjustment parameterization assume rescaling $\frac{c_v}{c_p}$ of diabatic term in temperature equation and an omission of diabatic terms in pressure equation. The equation (10) and (12) then become:

$$\frac{dT}{dt} = -\frac{RT}{c_v}D_3 + \frac{Q}{c_p} \tag{13}$$

$$\frac{d\hat{q}}{dt} = \frac{1}{p}\frac{dp}{dt} - \frac{\dot{\pi}}{\pi} = -\frac{c_p}{c_v}D_3 - \frac{\dot{\pi}}{\pi} \tag{14}$$

2 GARD case study

On 8 and 9 September 2002 the department of the Gard (in the south of France) was subjected to exceptionally violent storms which caused a flood. The case was studied with AROME prototype, based on ALADIN dynamics and the physical package imported from the Méso-NH model (Seity et al.(2004)). In AROME prototype the output of physical package are directly the tendencies of prognostic variables (the temperature, wind components, contents of water vapor, liquid water, ice crystal, rain, snow, graupels and turbulent kinetic energy) and the current code concerning the diabatic terms in AROME prototype follows as:

$$T^+ = T^+ + \Delta t. \left.\frac{\partial T}{\partial t}\right|_{phys} \tag{15}$$

$$d^+ = d^+ + \Delta t. \left.\frac{\partial d}{\partial t}\right|_{phys} \tag{16}$$

where for NH pseudo-vertical divergence $d = d_3 = -g\frac{p}{mR_dT}.\frac{\partial w}{\partial \eta}$ the physical tendency has form

$$\left.\frac{\partial d}{\partial t}\right|_{phys} = -g\frac{p}{mR_dT^+}.\frac{\partial}{\partial \eta}(\left.\frac{\partial w}{\partial t}\right|_{phys}) \tag{17}$$

Thus the temperature equation (15) is modified by the physical tendency (as corresponds to the hydrostatic parameterization adjustment, e.i. Q/c_p) and for NH case a conversion of vertical velocity tendency $\left.\frac{\partial w}{\partial t}\right|_{phys}$ via relation (17) into NH pseudo-vertical divergence tendency in the equation (16) is used. In current code no diabatic tendency is used for pressure derived NH variable pressure departure.

To obtain exact forcing, following modification were introduced. For temperature the scaling factor $\frac{c_p}{c_v}$ of temperature tendency is needed, so the equation (15) has the form

$$T^+ = T^+ + \Delta t.\frac{c_p}{c_v}\left.\frac{\partial T}{\partial t}\right|_{phys} \tag{18}$$

and relation for the NH pressure departure $\hat{q} = ln(\frac{p}{\pi}))$ was added

$$\hat{q}^+ = \hat{q}^+ + \Delta t.(\frac{1}{T}\left.\frac{\partial T}{\partial t}\right|_{phys} + \frac{1}{R}\frac{dR}{dt}) \tag{19}$$

where $R = R_d(1 - q - q_l - q_i - q_r - q_s - q_g) + R_v q$ and
$\frac{dR}{dt} = R_v \left.\frac{\partial q}{\partial t}\right|_{phys} - R_d(\left.\frac{\partial q}{\partial t}\right|_{phys} + \left.\frac{\partial q_l}{\partial t}\right|_{phys} + \left.\frac{\partial q_i}{\partial t}\right|_{phys} + \left.\frac{\partial q_r}{\partial t}\right|_{phys} + \left.\frac{\partial q_s}{\partial t}\right|_{phys} + \left.\frac{\partial q_q}{\partial t}\right|_{phys})$
and $\left.\frac{\partial q_j}{\partial t}\right|_{phys}, j = l, i, r, s, g$ are the physical tendencies coming form physical parameterization package.

2.1 Setup of experiment

The real case test was performed with AROME prototype with above mentioned modification for the exact treatment of diabatic terms and following experimental setup: 2TL SL SI scheme was used (also 2TL ICI scheme was tested with similar results) with 15s time step. The horizontal resolution 2.5 km, the size of the domain 180x180 grid points. The beginning of the forecast on 8th of September 2002 at 12 UTC and the length of forecast is 12 hours.

2.2 Results

As the reference the Méso-NH model forecast can be used (Fig. 1). On Fig. 2 is the based forecast of AROME prototype without any modification, thus corresponds to usage of hydrostatic adjustment parameterization. The pressure departure tendency can be divided in two parts for the exact treatment of diabatic terms

$$\left.\frac{\partial \hat{q}}{\partial t}\right|_{phys} = \frac{1}{T}\left.\frac{\partial T}{\partial t}\right|_{phys} + \frac{1}{R}\frac{dR}{dt}$$

let's call the first RHS term Q-term and the second R-term. The impact of just the Q-term included is on Fig. 3 and the influence of both terms is on Fig. 4.

The use of Q-term only results in small changes in the structure of precipitation field and a little increase of the precipitation maximum to 268 mm/12 hours. For both terms included the maximum 301 mm/12 hours is much higher than Méso-NH reference with 246 mm/12 hours and also than based reference AROME of 246 mm/12 hours. Although the R-term is much smaller than Q-term, the diagnostic of the maximum for the both terms in all domain, you can see on the next figure, and in this case the average of maximum R-term values is around 5% of the Q-term values. The results of the sensitivity test with 10% higher Q-term only included is showed similar sensitiveness on small change of physical tendencies (Fig. 5.) with maximum of 323 mm/12 hours. The last figure include the cumulated rainfall for hydrostatic integration with the maximum of 419 mm/12 hours.

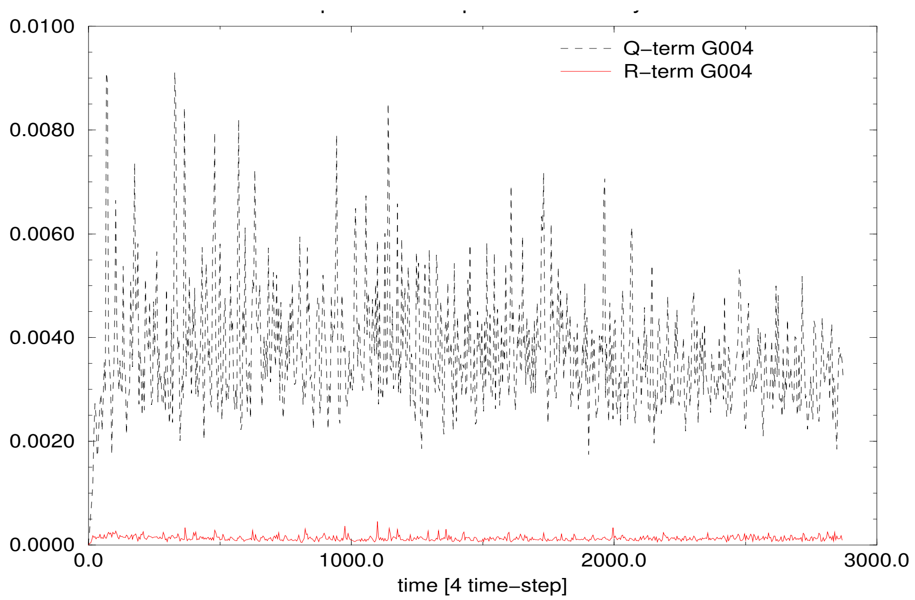

Fig. 0: Diagnostic of the maximum of Q-term and R-term in all the domain every 4 time step.

Not to make conclusion from different model simulation only, also the comparison with the real observations was used for validation. For this purpose it was necessary to modify an initial condition with help of mesoscale surface data reanalysis and a microphysical adjustment (Seity personal communication). Cumulated 10 hours rainfall from Nimes radar are on Fig.7 with maximum more than 300 mm/10h. On Fig.8. and Fig.9. are AROME simulation using hydrostatic adjustment and exact treatment of diabatic terms. The differences are mainly in the structure of precipitation and the maximum of 298mm/10h . for the exact treatment is closer to observed than the based reference with 250 mm/10h.

3 Conclusion

It is very difficult to make some outstanding conclusions from the only one real case study. The results of performed experiments showed that exact treatment of diabatic tendencies is sensitive to small perturbation in physical tendencies. The exact treatment has the impact on the structure of precipitation and an increase of maximum which better corresponds to the observation. In general this approach if not improved the forecast at least not deteriorate it. In case of the high resolution simulation the exact treatment of mutual adjustment of the temperature and pressure fields plays important role and an accurate account of the adjustment process is highly desirable, thus the abandon of use the hydrostatic adjustment parameterization can help to obtain results not only consistent with model dynamics but mainly more physical.

References

J.V.Iribarne and W.:.Godson, 1981: Atmospheric Thermodynamics *Geophysics and astrophysics monographs; v. 6* D.Reidel Publishing Company, Dordrecht, Holland, pp 259

Alena Trojáková, 2004: Diabatic forcing in fully compressible model II *report from stay*

Yann Seity, Sylvie Malardel and Gwenaelle Hello, 2004:The AROME/ALARO prototype: Technical documentation *http://www.cnrm.meteo.fr/aladin/aladin2/prototypeAROME_ALARO.pdf*

Cumulated 12 hour rainfall

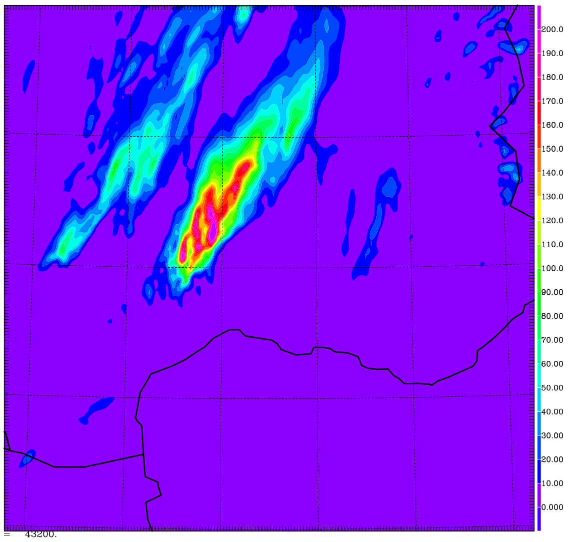

Fig. 1: Méso-NH reference. (max = 246 mm).

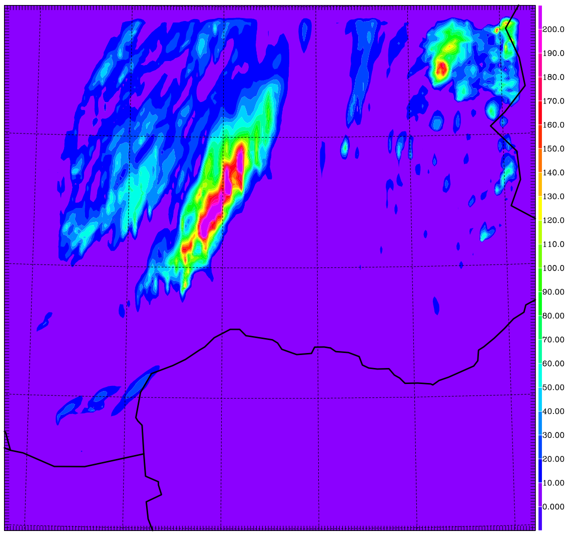

Fig. 2: AROME - reference. (max = 264 mm)

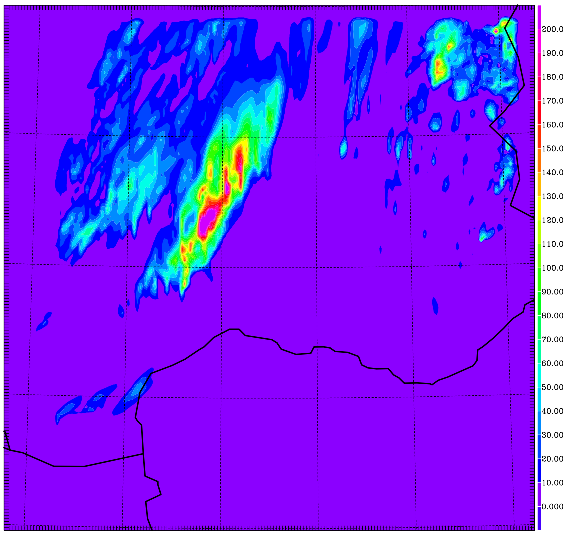

Fig. 3: Q-term included only. (max = 268 mm)

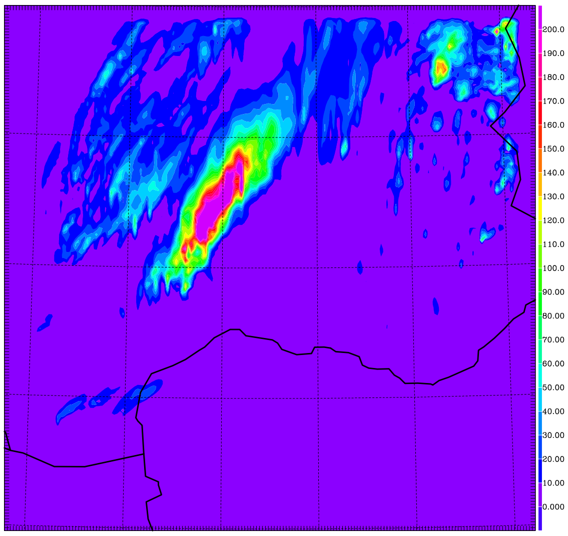

Fig. 4: Q-term and R-term included. (max = 301 mm)

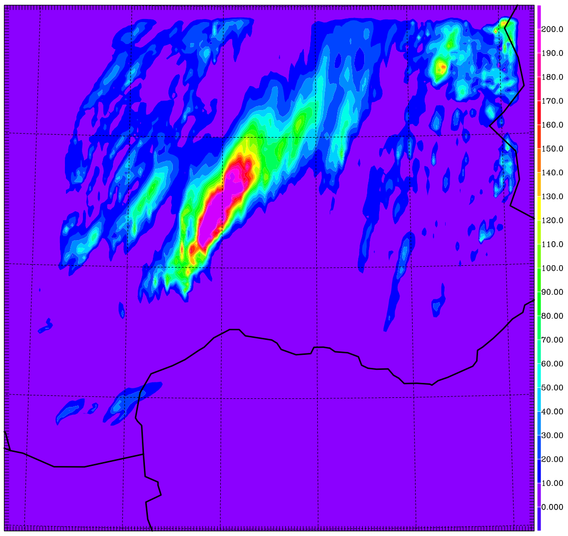

Fig. 5: 1.1 Q-term test (max = 323 mm)

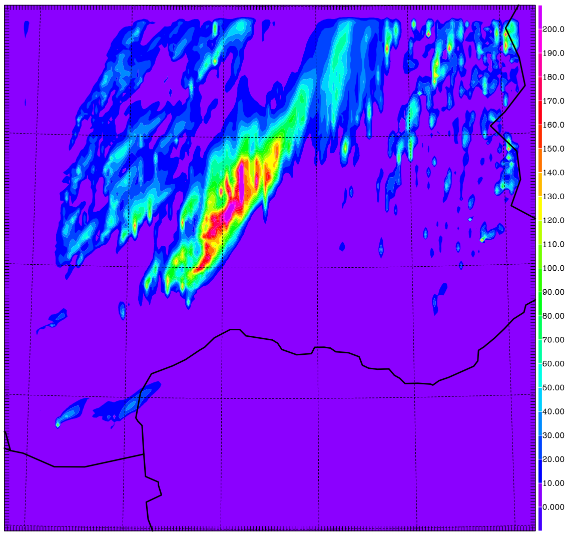

Fig. 6: Hydrostatic run (max = 419 mm)

Appendix

A List of Symbols

g	...	gravity acceleration
p	...	true pressure
π	...	hydrostatic pressure
T	...	temperature
R_d	...	gas constant of dry air
R_v	...	gas constant of moist air
c_p	...	specific heat of air at constant pressure
c_v	...	specific heat of air at constant volume
w	...	vertical velocity $(w \equiv \dot{z})$
d	...	common symbol for NH pseudo-vertical divergence $\hat{d}, d_1, d_2, d_3$
D_3	...	3D divergence
m	...	$\dfrac{\partial \pi}{\partial \eta}$ (η is a terrain following coordinate)
X_l	...	value of X on full level l
$X_{\tilde{l}}$	...	value of X on half level $\tilde{l}$
X^*	...	value of X related to semi-implicit background
q	...	specific humidity
q_l	...	liquid water
q_s	...	snow
q_r	...	rain
q_i	...	ice crystals
q_g	...	graupels
q_c	...	cloud droplets

B Source code modification

The modifications were done on cycle CY26T1_cy27 upon Yann Seity prototype ClearCase branches mrpm637_CY26T1_PROTOTYPE and mrpm637_AL26T1_AROME

All modification are in branch arp_mrpe694_CY26T1_diabPROTOTYPE with following cc_list
adiab/cpg.F90
adiab/cpg_pt.F90
adiab/cputqy_arome.F90
module/gmv_subs.F90
module/type_gmvs.F90
module/yomdiab.F90
namelist/namdiab.h
phys_dmn/mf_phys.F90
setup/su0phy.F90

The content of GMKPACK directory src/local, genesis and ics_aladin are on tora
/u/gp/mrpe/mrpe694/source_pack/AROME

Executables are stored on delage /cnrm2_a/mrpe/mrpe694/2004/G/bin
AA.ref - reference binary with no modification
AA.diab - diabatic forcing without ICI scheme (cputqy_arome.F90,mf_phys.F90,su0phy.F90 namdiab.h,yomdiab.F90)
AA.diab.test1.1 - sensitivity test 1.1$*Q$-term
AA.diab.PC - additional modif for ICI scheme (cpg.F90,cpg_pt.F90,gmv_subs.F90,type_gmvs.F90)
AA.diab.PC.test1.05 - sensitivity test 1.05$*Q$-term

Scripts with namelist and listings are stored on /cnrm2_a/mrpe/mrpe694/2004/G/GARD.tar.

Cumulated10 hours rainfall

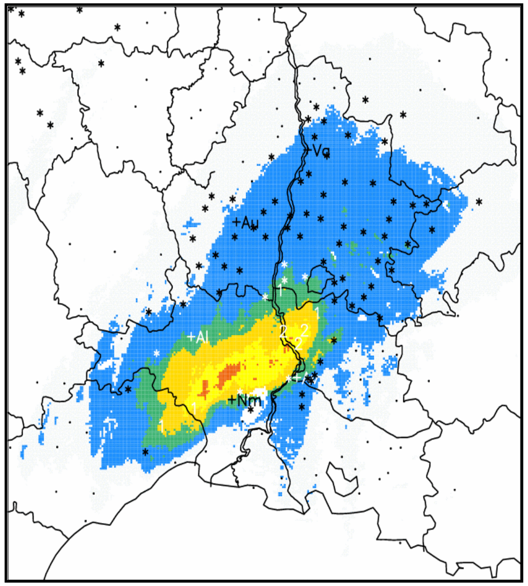

Fig.7: Nimes radar (12-22UT)

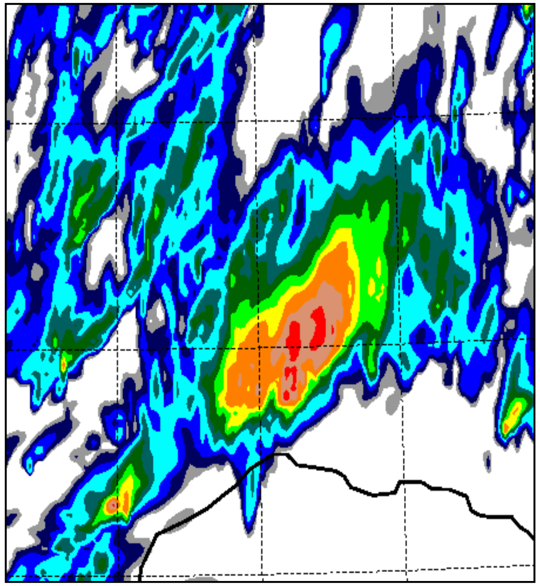

Fig.8: AROME hydrostatic adjustment

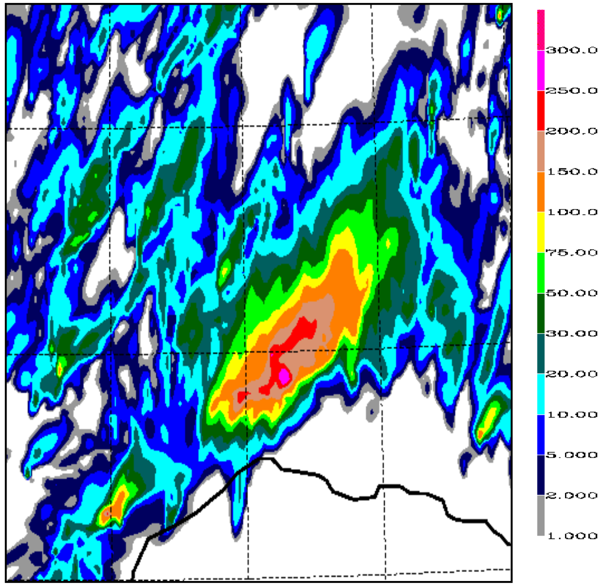

Fig.9: AROME exact treatment

ERROR: invalidrestore
OFFENDING COMMAND: restore

STACK:

-savelevel-
-savelevel-