Regional Cooperation for
Limited Area Modeling in Central Europe

LACE
nwp central europe

The shallow convection closure

Radmila Brožková, Ivan Bašták- Ďurán, Ján Mašek

DHMZ

ZAMG

ROMANIA ANM

Main choices in ALARO

- Shallow convection should be called more precisely non-precipitating convection;
- In ALARO the scheme is on the side (or part) of the turbulence scheme TOUCANS;
- It is NOT on the side of the deep convection scheme 3MT due to choices made for 3MT:
  - 2D closure;
  - Prognostic mass-flux scheme;
  - To avoid arbitrary thresholds what is "shallow" and "deep".
- The "shallow convection" scheme in ALARO is a direct parameterization of the **moist** buoyancy flux $<w'.\rho'>$.

Problem of water phase changes

- “**Dry**” case means there is no condensation of water vapor and/or evaporation of cloud water;
- “**Moist**” case means there are phase changes =>
  - Release/consumption of latent heat - change of density and static stability => complex difficulties.
- In a dry case, potential temperature can play the role of a conservative variable and also of a particle comparison, but not in the moist case.

Classical turbulence interpretations (in a fully dry case)

The prognostic TKE equation

$$\frac{\partial E}{\partial t} = A_{dv}(E) + \frac{1}{\rho}\frac{\partial}{\partial z}\rho K_E \frac{\partial E}{\partial z} + K_m\left[\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2\right] - \frac{g}{\theta}K_h\frac{\partial \theta}{\partial z} - \frac{C_\varepsilon E^{3/2}}{L}$$

Development of the terms of shear production and of production/destruction by buoyancy (conversion term)

$$K_m\left[\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2\right] - \frac{g}{\theta}K_h\frac{\partial \theta}{\partial z} \approx K_m S^2\left[1 - \frac{K_h}{K_m}\frac{g}{\theta}\frac{\partial \theta}{\partial z} / S^2\right]$$

$$= K_m S^2\left[1 - \frac{K_h}{K_m}(N^2 / S^2)\right] = K_m S^2\left[1 - \frac{K_h}{K_m}R_i\right] = K_m S^2(1 - R_{if})$$

One thus establishes a direct link between the Richardson number, the Richardson-flux number, the conversion term (<w'. ρ'>) and the static stability (i.e. the squared BVF N^2). Should all this be reproduced identically in the ***moist*** *case? One has to realise that the above fully relies on a dual role of θ: conserved quantity AND stability parameter.*

Previous solution to account for phase changes

- Modification of the Richardson number: R_i => R_i^*

$$R_i^* = R_i^{dry} + \frac{Lmin(0, \partial(q_t - q_s)/\partial z)}{S^2}$$

- Use of the modified Richardson number allows to follow the same strategy in p-TKE and full TKE schemes;
- Anti-fibrillation treatment accounting moisture is incorporated:

$$K^{'} = \frac{K}{1 + (\beta - 1)K\Delta t}$$

$$K^{'}(R_i, R_i^*) = K(R_i) + \frac{K(R_i^*) - K(R_i)}{1 + (\beta - 1)\left(K(R_i^*) - K(R_i)\right)\Delta t} \xrightarrow{yields} K^{'}(R_i^{'})$$

New solution in ALARO-1

direct buoyancy parameterization via moist BVF

Main igredients

- Recent works on thermodynamics (Marquet 2011 and Marquet Geleyn 2013):
  - formulations of moist entropy, moist entropy potential temperature and moist Brunt Vaisalla Frequency for unsaturated and fully saturated cases;
  - General BVF expression with a cloudiness-type parameter for a partly saturated case;
- Parameterizing the cloudiness-type parameter (LL04):
  - Using profiles of a moist static energy equivalent and total water;
  - Using a fit to LES data.

Lapse rate

Non-saturated and fully saturated case

$$\Gamma_{ns} = \left(-\frac{\partial T}{\partial z}\right)|_{s,q_v} = \frac{g}{c_p}$$

Lapse rate – temperature gradient at constant moist entropy s and water content (in non saturated case water vapor)

$$\Gamma_{fs} = \frac{g}{c_p} \frac{1 + \left(\frac{L_v(T) r_{sat}}{R_d T}\right)}{1 + \left(\frac{R}{c_p}\right)\left(\frac{L_v T}{R_d T}\right)\left(\frac{L_v T r_{sat}}{R_d T}\right)}$$

Lapse rate in the fully saturated case is far more simple using the M11 and MG13. If no condensation is present, it naturally collapses to the non saturated case.

Lapse rate
comparison with other results

$$\Gamma_{sw} = \left(g(1+r_t)/c_{pd}\right)\frac{1+\left[\frac{L_v(T).r_{sw}}{R_d.T}\right]}{1+\frac{c_{pv}.r_{sw}+c_l.r_l}{c_{pd}}+\left(\frac{R(1+r_t)}{c_{pd}}\right)\left(\frac{L_v(T)}{R_v.T}\right)\left[\frac{L_v(T).r_{sw}}{R_d.T}\right]} \quad \text{(DK82)}$$

Durran and Klemp 1982 (colored terms are additional to MG13)

$$\Gamma_{sw} = \left(g(1+r_t)/(c_{pd}+c_{pv}.r_{sw})\right)\frac{1+\left[\frac{L_v(T).r_{sw}}{R_d.T}\right]}{1+\frac{c_l.r_l}{c_{pd}+c_{pv}.r_{sw}}+\left(\frac{R(1+r_t)}{c_{pd}+c_{pv}.r_{sw}}\right)\left(\frac{L_v(T)}{R_v.T}\right)\left[\frac{L_v(T).r_{sw}}{R_d.T}\right]} \quad \text{(E94)}$$

Emmanuel 1994 form. These expressions do no find back the simple non saturated form when there is no condensation.

Transition
to a partly cloudy general case

$$F(C) = 1 + C\left[\frac{L_v(T)}{c_p T}\frac{R}{R_v} - 1\right]$$

The function *F(C)* reflects the impact of the ratio of total water transport on the buoyancy flux between cloudy and clear-sky conditions. We introduce a "geometry-type" factor *M(C)* as Function of *F(C)* and Clausius-Clapeyron relationship so that:

$$\Gamma(C) = \left(\frac{g}{c_p}\right)M(C)$$

Moist BVF

in a partly cloudy general case

$$\frac{N^2(C)}{gM(C)} = \left(\frac{c_{pd}}{c_p}\right)\frac{\partial ln\theta_l}{\partial z}$$

$$+\left\{\frac{R_v - R_d}{R} + \boldsymbol{C}\left[\frac{L_v(T)}{c_p T}\frac{R}{R_v} - 1\right]\left[\frac{R_v - R_d}{R} + \frac{1}{1-q_t}\frac{1}{1+D_C}\right]\right\}\frac{\partial q_t}{\partial z}$$

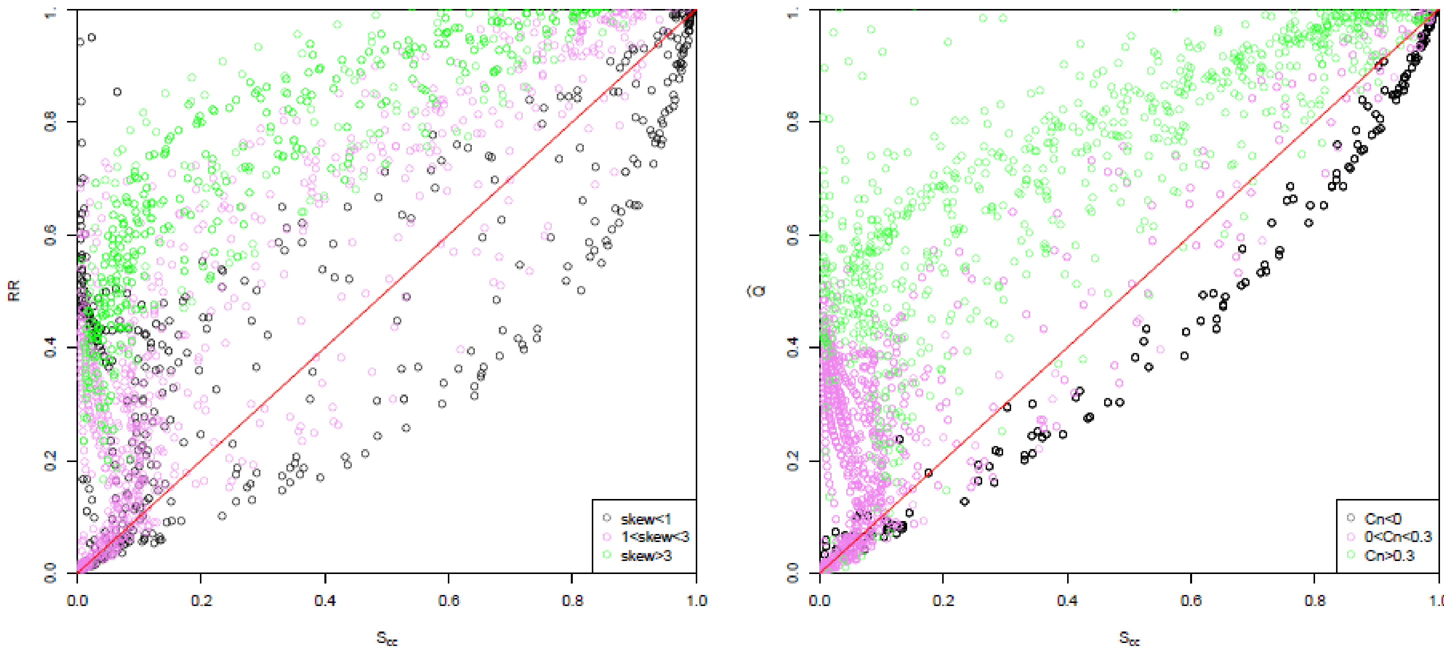
The factor C here is not a mean partial cloud fraction but a function of it to "interpolate" between clear sky and fully cloudy situations. We shall denote this function as $\hat{Q}$ and it depends on both partial cloud cover and "partial cloud cover at neutrality", which gives a measure of skewness.

$$\hat{Q}(C, C_n)$$

Modelling $\hat{Q}$

- The function $\hat{Q}$ is in a way similar to the one of $\hat{R}$ introduced by LL04 as also an interpolation factor to determine buoyancy flux in partly cloudy conditions – i.e. between "dry" and "wet" cases;
- Moreover, the LL04 approach determines $\hat{R}$ simply from vertical profiles of first order quantities, using a mass flux type approach;
- LL04 proposal is verified w.r.t a large set of LES results;
- Yet, the relation between $\hat{R}$ and partial cloud cover is not one to one;
- TOUCANS proposal for $\hat{Q}(C, C_n)$ leads to a better fit of the same LES data than it is the case for $\hat{R}$.

$\hat{Q}$ vs $\hat{R}$ proposal



LL04 propose to use mass-flux type computations for getting the best relationship between shallow convective cloudiness (*Scc*) and effectiveness of buoyancy flux ($\hat{R}$). Vertical velocity skewness, colored in the left diagram, is the linking parameter.

We modify LL04 ($\hat{R}$=>$\hat{Q}$) by using a specific moist entropy approach (Marquet and Geleyn, 2013) and by replacing skewness by an internal parameter *Cn* of the $\hat{Q}$ computation. On the right, see progress in three aspects: 1) less dispersion; 2) clearer extreme borders;
3) more continuous effect of the new linking parameter. *Cn* is computed from the profile.

Practical implementation in TOUCANS (1)

- **Option 1**: use of the modified (moist) Richardson number R_i^* (LCOEFK_RIS=.TRUE.), including the moist anti-fibrilation treatment;
- Using wind shear S^2, moist BVF N^2 is computed out of R_i^*;
- As the next step, one computes the cloudiness parameter C from the relationship for $N^2(C)$;
- In case we use the option LCOEFK_SCQ=.TRUE., we employ the full $\hat{Q}\ (C, C_n)$ relationship. Value of C_n ;is diagnosed (partial cloud fraction at neutrality) and used as skewness. Equation for $\hat{Q}$ is iterated to get its final value as well as the one of the partial shallow convection cloudiness parameter C; Otherwise $\hat{Q} = C$;
- Compute the final value of moist Brunt-Vaisalla Frequency as well as the source terms for turbulence – conversion between TKE and TTE.

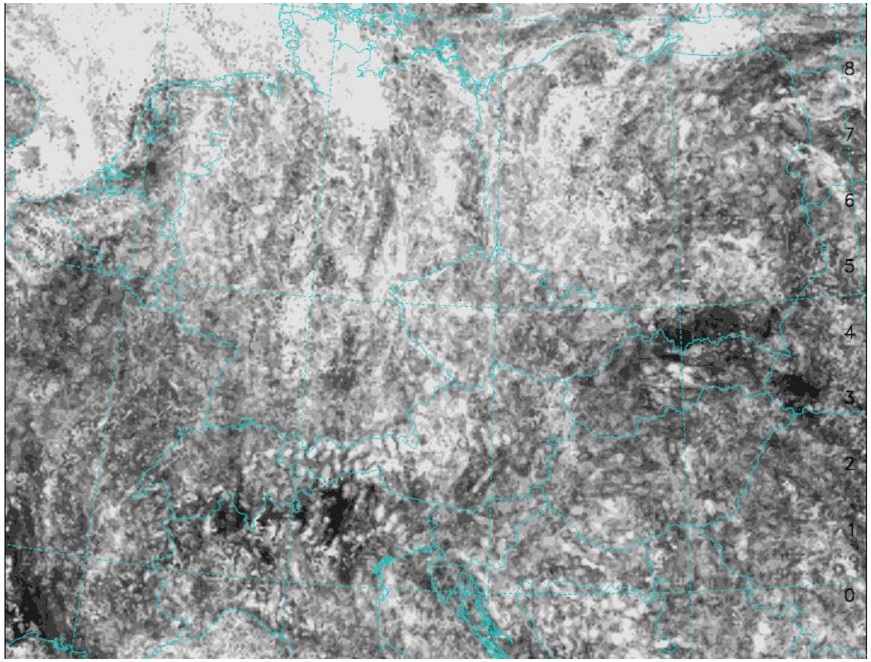
Practical implementation in TOUCANS (2)

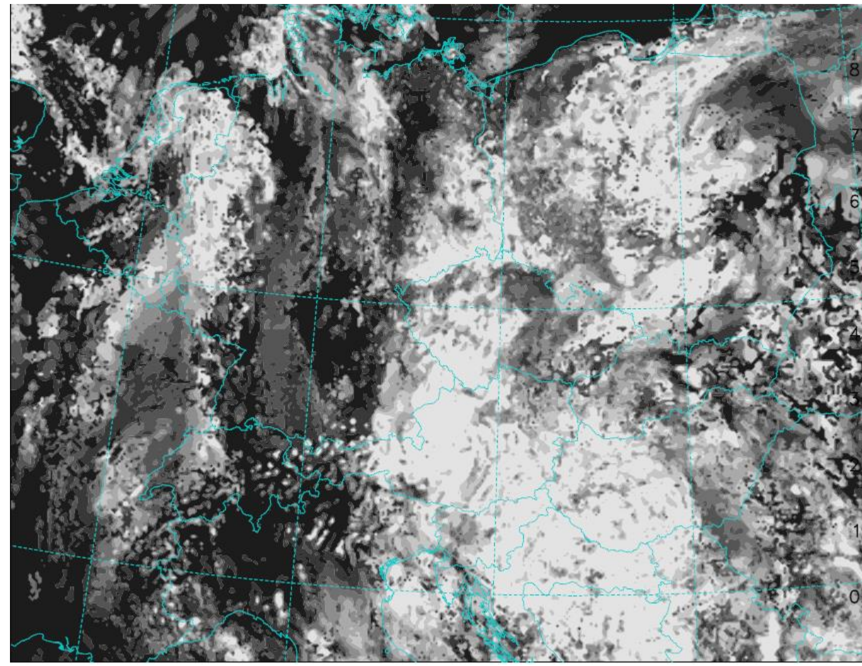
- **Option II**: use of the **mass-flux approach** (LCOEFK_MSC=.TRUE.) proposed by Lewellen&Lewellen 2004;
- A profile of a particle is constructed to determine a ratio between unsaturated (no cloud) and fully saturated (solid cloud) and moist BVF N^2 is computed between its dry and saturated limits accordingly;
- As the next step, one computes the first guess of $\hat{Q}$ to start the iteration; this is equal to the "dry-saturated" ratio given by the profile;
- The option LCOEFK_SCQ=.TRUE., is used, i.e. we employ the full $\hat{Q}\ (C, C_n)$ relationship. Value of C_n ;is diagnosed (partial cloud fraction at neutrality) and used as skewness. Equation for $\hat{Q}$ is iterated to get its final value as well as the one of the partial shallow convection cloudiness parameter C;
- Compute the final value of moist Brunt-Vaisalla Frequency as well as the source terms for turbulence – conversion between TKE and TTE.

mass-flux approach considerations

- The profile:
  - a very crude approach seems sufficient – construction of the moist adiabatic ascent;
  - There is no need to introduce entrainment – it can be used to prevent starting a cloud above a thick enough stable layer;
  - Cloud is aborted when there is no buoyancy (other considered conditions, like weak turbulence reveals to be quite subtle – strong negative feedback).
- Shallow Convective Cloudiness (SCC) thresholds:
  - There is no SCC under stable conditions …. i.e. when saturated BVF gives stable conditions, otherwise no restrictions;
- Shallow Convective Cloudiness use:
  - A bit problematic due to staggering (half-levels) and whether one could put equality between the "cloudiness parameter ***C***" and cloud cover.

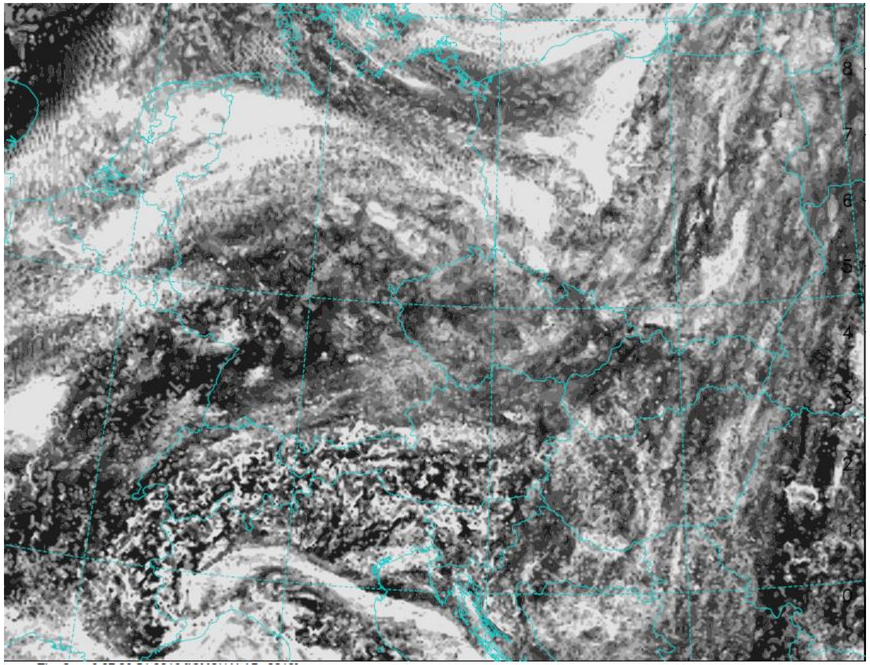
Comparison of the C parameter scene (1)

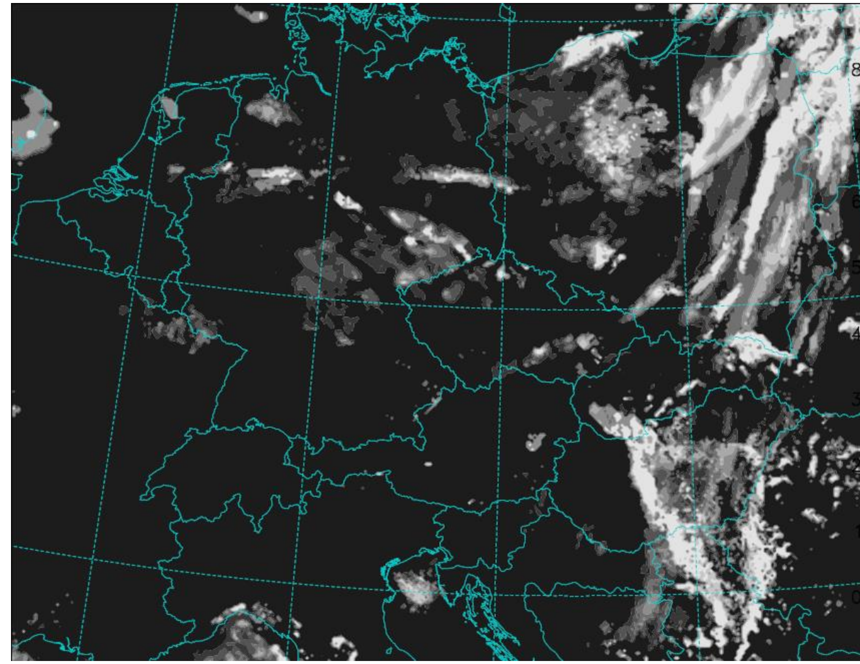




We see a 2D picture of a 3D field (maximum-random overlap);
Left – method I using Ri* computation;
Right – method II using the “mass-flux type” approach.
It is a summer day morning., forecast range +9h starting from 0h UTC.

Comparison of the C parameter scene (2)

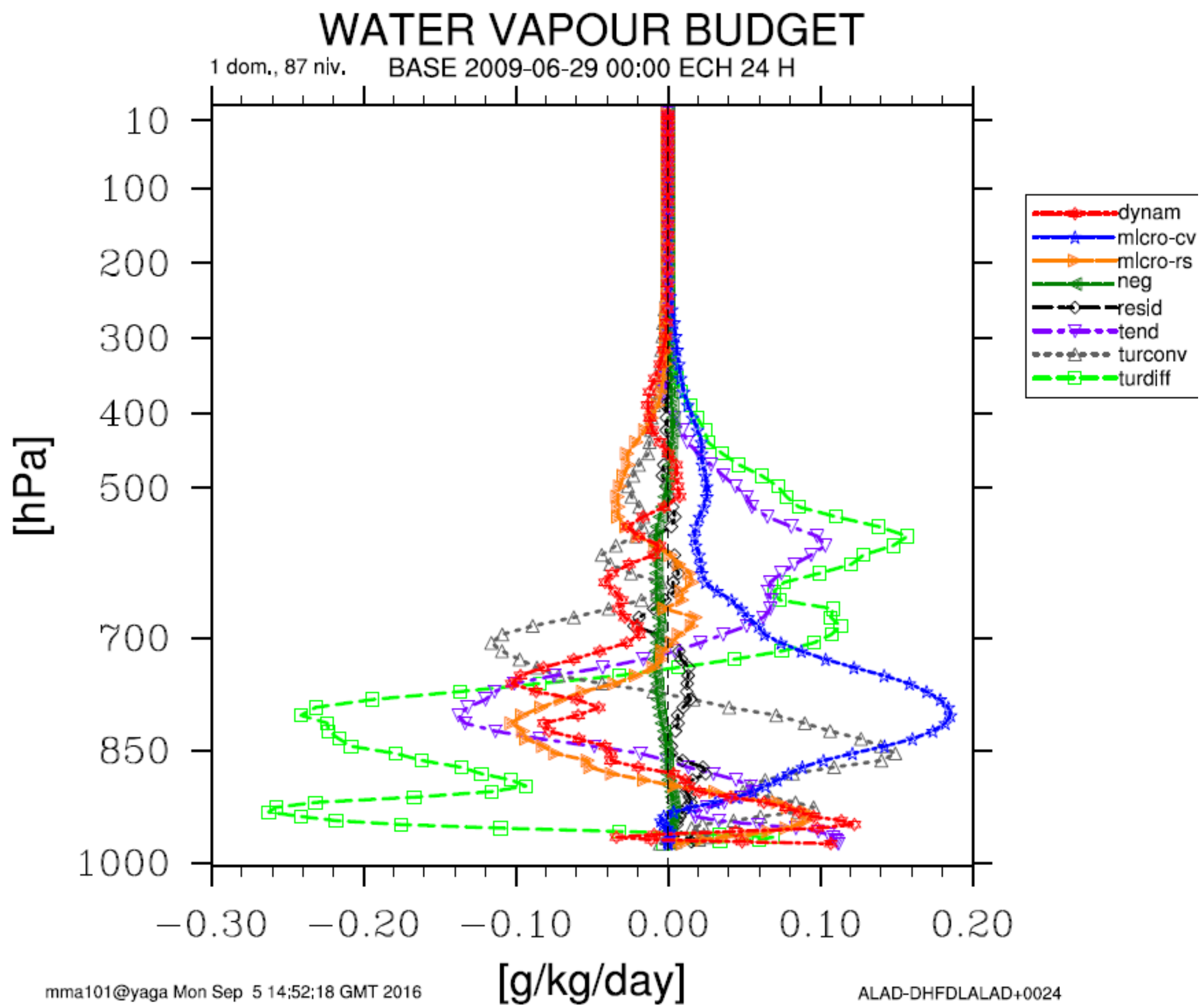




We see a 2D picture of a 3D field (maximum-random overlap);
Left – method I using Ri* computation;
Right – method II using the "mass-flux type" approach.
It is a winter midday., forecast range +12h starting from 0h UTC.

Moisture transport

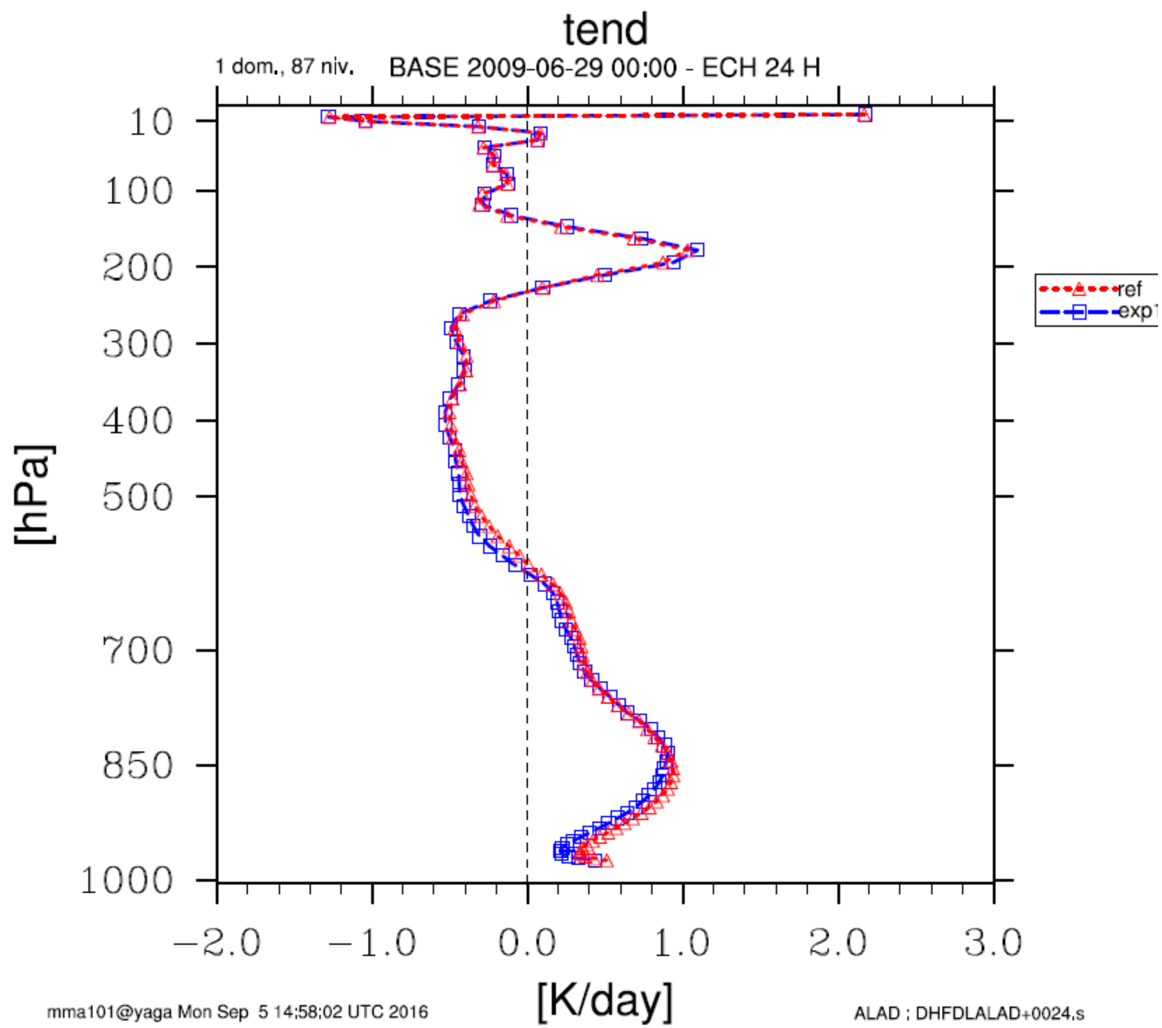
Multi-budget difference of the MSC experiment w.r.t. Ri* reference.
It shows the major impact on the turbulent transport of water vapor driving the resulting tendency of qv.
In summer, moisture is brought from PBL higher.



Heat transport

Impact on temperature (total tendency) is less obvious due to various feed-backs at place.

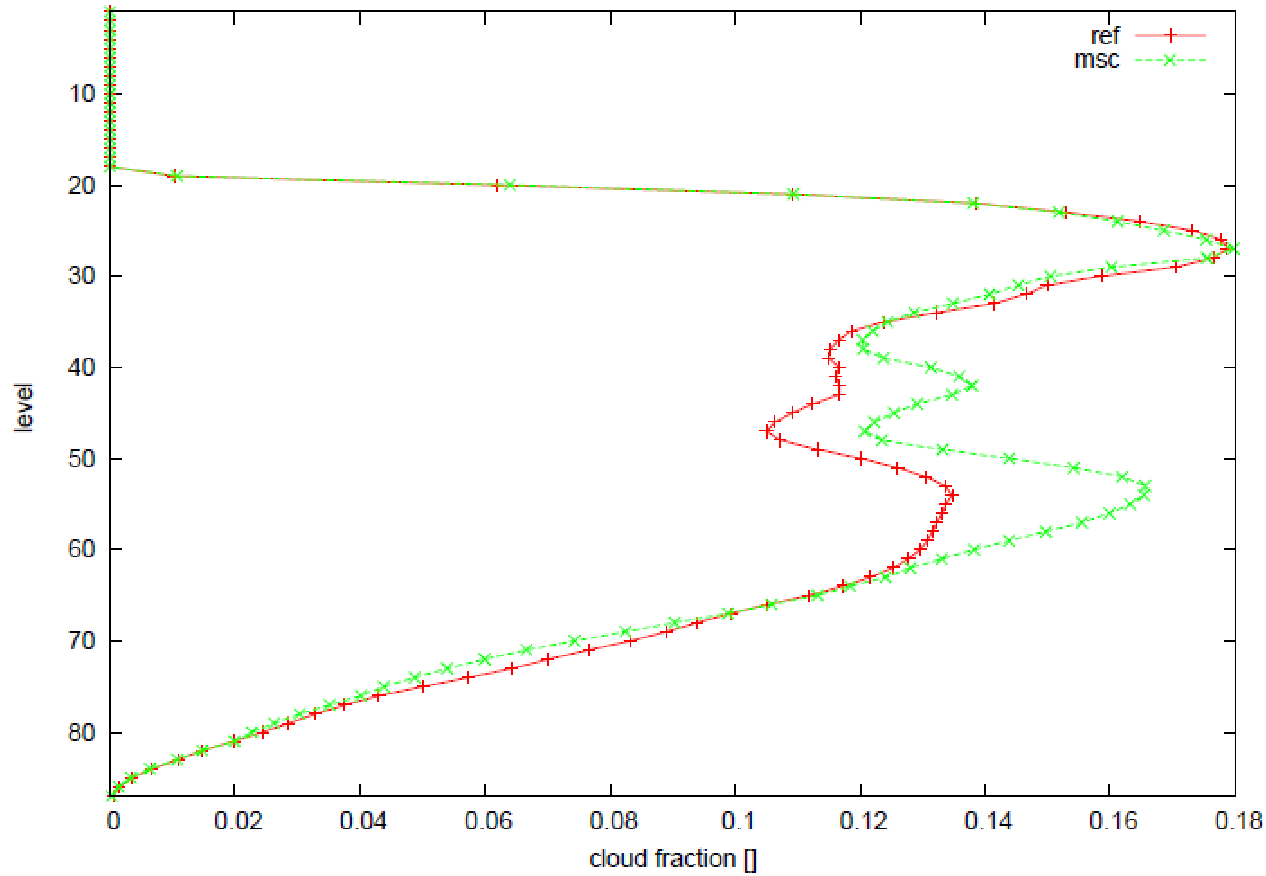
There is a cooling, too exaggerated at the surface, but not coming from the turbulence transport.



Impact on the radiative cloudiness

Due to the change in the humidity distribution, there is more cloudiness with a peak around PBL top – here on the picture we have summer afternoon peak around 2000m.

It is an average profile in the center of the domain.



Conclusions and Outlook

- New shallow convection closure namely modifies the total water transport – more realistic C parameter, better structures;
- Moist anti-fibrillation scheme is not necessary any more;
- Effect is larger in summer when atmosphere water content is high – interaction with moist deep precipitating convection;
- Feedbacks with radiation (via the cloudiness reacting to modified humidity structure) and consequently deep convection are important and therefore a retuning of the radiative cloudiness becomes necessary.
- Tuning approach is explained in another talk.