***R**egional **C**ooperation for*
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New shallow convection parameterization in ALARO-1

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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 $<w'.\rho'>$.

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^*

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

- 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
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

$$\frac{N^2(C)}{gM(C)} = \left(\frac{c_{pd}}{c_p}\right)\frac{\partial ln\theta_l}{\partial z}$$
$$+\left\{\frac{R_v - R_d}{R} + C\left[\frac{L_v(T)}{c_p T}\frac{R}{R_v} - 1\right]\left[\frac{R_v - R_d}{R} + \frac{1}{1-q_t}\frac{1}{1+D_C}\right]\right\}\frac{\partial q_t}{\partial z}$$

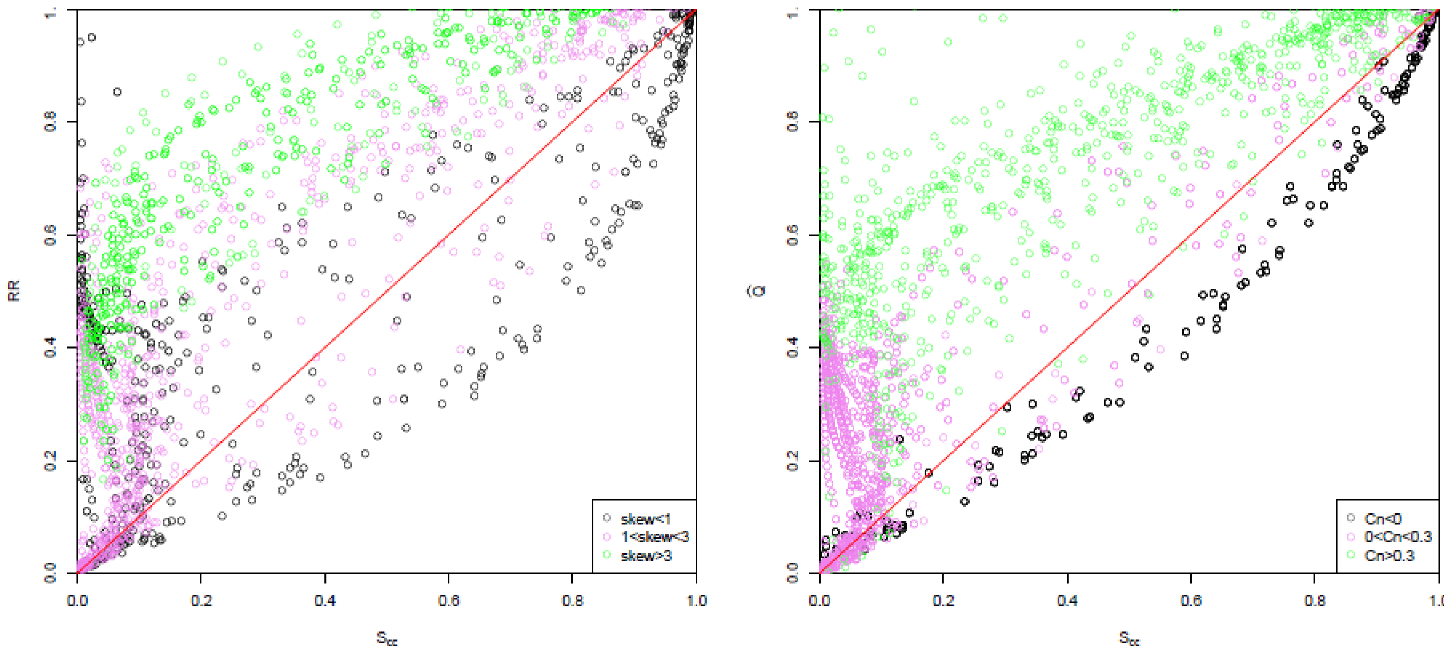
The factor C here is not a mean partial cloud fraction but a function of it to "interpolate" between clear sky and fully cloudy situations. We shall denote this function as $\hat{Q}$ and it depends on both partial cloud cover and "partial cloud cover at neutrality", which gives a measure of skewness.

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

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;
- Our 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



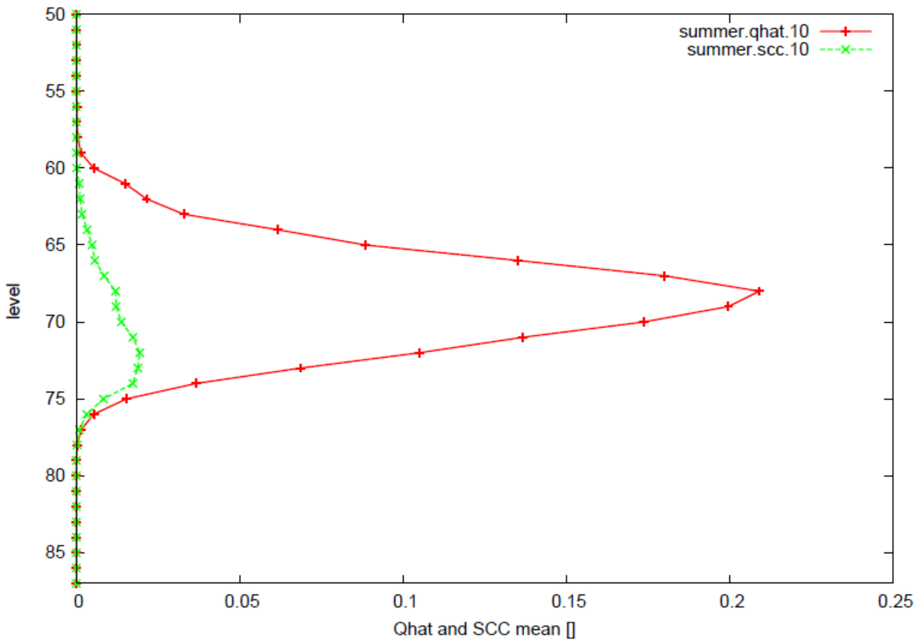
LL04 propose to use mass-flux type computations for getting the best relationship between shallow convective cloudiness (*Scc*) and effectiveness of buoyancy flux ($\hat{R}$). Vertical velocity skewness, colored in the left diagram, is the linking parameter.

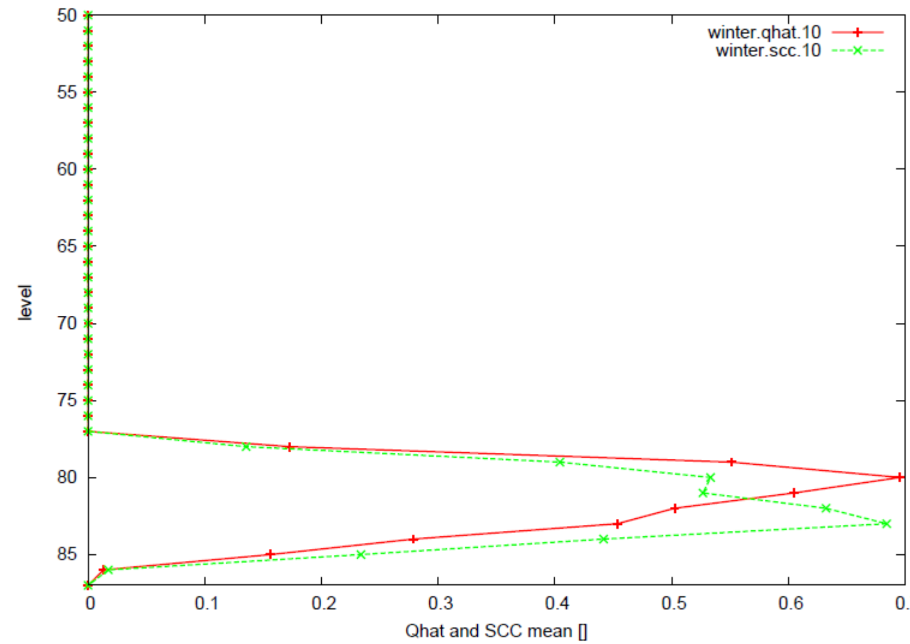
We modify LL04 ($\hat{R}$=>$\hat{Q}$) by using a specific moist entropy approach (Marquet and Geleyn, 2013) and by replacing skewness by an internal parameter *Cn* of the $\hat{Q}$ computation. On the right, see progress in three aspects: 1) less dispersion; 2) clearer extreme borders;
3) more continuous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

Practical implementation

- Mass-flux type of computation to get the profile;
  - In general, a very crude approach is sufficient. There is no need to introduce entrainment; although it can be done to refine the resulting profile.
- Get a first estimate of $\hat{Q}$ from the profile, as well as the value of C_n;
- Iterate the equation for $\hat{Q}$ to get its final value as well as the one of partial shallow convection cloudiness;
- Compute the final value of moist Brunt-Vaisalla Frequency as well as the source terms for turbulence – conversion between TKE and TTE.

Preliminary results

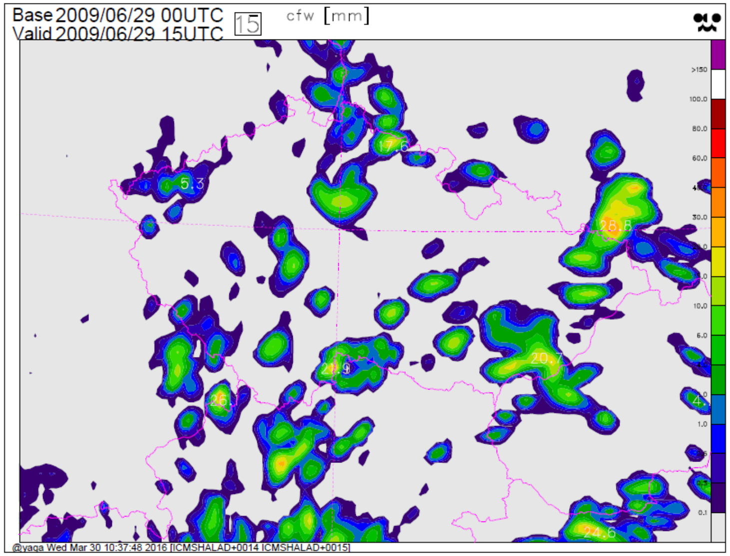


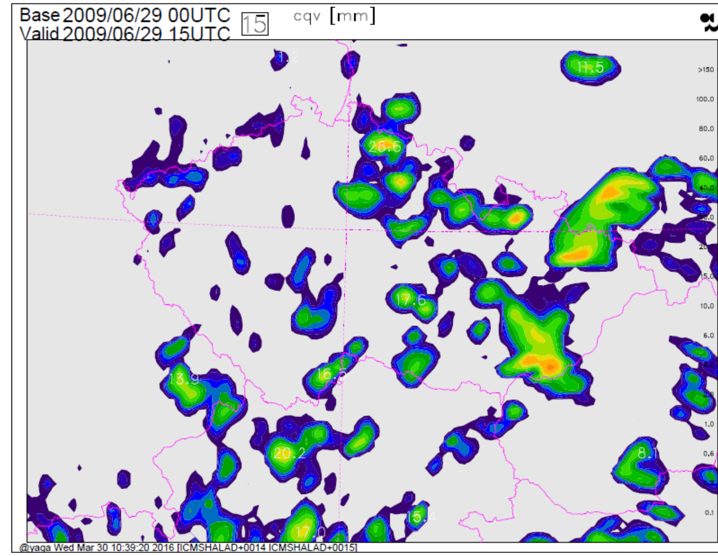


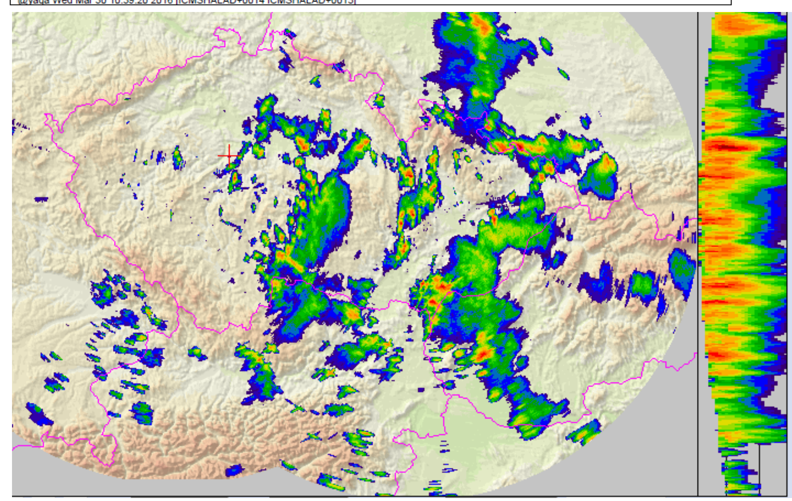
Mean profiles of $\hat{Q}$ and partial shallow convection cloudiness SCC for summer with deep convection developing (left) and winter with a low level stratocumulus and inversion conditions (right).

These patterns come from 3D real complex experiments.

Preliminary results







Summer convection:
Left – reference scheme;
Right – new scheme and radar picture

In summer, new parameterization of shallow convection helps to organize better the deep one.

Conclusions and Outlook

- In short, our new proposal for parameterizing buoyancy flux is based on the following postulate:

"Moist turbulence seems to try homogenizing moist entropy potential temperature and thus delegating a maximum of the buoyancy flux to the process of total water transport."

- Tests of the new scheme are now going on in the full 3D model in order to replace the modified Richardson number approach.