Regional Cooperation for
Limited Area Modeling in Central Europe

LACE
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Shallow convection closure using mass-flux type approach

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ALARO shallow convection - recall

- In ALARO the shallow convection scheme is on the side of the turbulence scheme TOUCANS;
- Prognostic equation for TKE:

$$\frac{dE_k}{dt} = -g\frac{\partial}{\partial p}\left(\rho K_{E_k}\frac{\partial E_k}{\partial z}\right) + I + II_m - \frac{2E_k}{\tau_k}$$

- To compute buoyancy term II_m requires to parameterize moist BVF in a general case of partly saturated grid box.

Buoyancy term

- In TOUCANS we express the buoyancy term II_m as follows, i.e. as weighted turbulent fluxes of moist conservative variable s and total water q_t:

$$II_m = E_s \overline{w's'} + E_{q_t} \overline{w'q_t'}$$

- With the link to the moist BFV:

$$N_m^2 = E_s \frac{\partial s}{\partial z} + E_{q_t} \frac{\partial q_t}{\partial z}$$

- Computation of "weights" E_s and E_{qt} comes from the work on thermodynamics – see the next slide.

Moist BVF

in a partly cloudy general case

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

$$+\left\{\frac{R_v - R_d}{R} + \hat{Q}\left[\frac{L_v(T)}{c_pT}\frac{R}{R_v} - 1\right]\left[\frac{R_v - R_d}{R} + \frac{1}{1-q_t}\frac{1}{1+D_C}\right]\right\}\frac{\partial q_t}{\partial z}$$

The function $\hat{Q}$ is a kind of an "interpolator" between non-saturated and fully saturated cases. It depends on both partial cloud cover and "partial cloud cover at neutrality", which gives a measure of skewness:

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

$\hat{Q}$ and $\hat{R}$ parameters

- The idea of an interpolating function between non-saturated and saturated BVF was proposed in work of Lewellen and Lewellen (LL04). They denoted it as $\hat{R}$:

$$N_m^2 = \left(1 - \hat{R}\right) N_{dry}^2 + \hat{R} N_{sat}^2$$

- LL04 further proposed to compute $\hat{R}$ by a mass-flux type method in a rather simple way and they have shown a relationship between $\hat{R}$ and cloud cover *C* derived from LES data
- In TOUCANS this approach is enhanced: $\hat{R}$ is replaced by $\hat{Q}$ (based on the work of thermodynamics) and its dependence on the "skewness" parameter C_n (*C* in case of neutrality) is introduced. Fit to LES data is better than in the case of $\hat{R}$.

$\hat{Q}$ - practical computation

- There is a relationship between $\hat{Q}$ and C, while C_n can be determined diagnostically. When getting either $\hat{Q}$ or C, the relationship can be iterated to obtain final values;
- Getting C would require to employ some scheme to get shallow convection cloudiness (danger to break the consistency with other assumptions made so far);
- Instead, in TOUCANS we decide to obtain *the first estimate of* $\hat{Q}$ from the mass-flux type computation proposed by LL04 to get $\hat{R}$.

Idea of mass flux (1)

- According to LL04, the parameter $\hat{R}$ can be expressed as a ratio of condensed water flux and of the flux of difference between total water and saturation vapor (saturation deficit):

$d_{sat} = q_t - q_{sat}$:

$$\hat{R} = \frac{w'q_l'}{w'd_{sat}'}$$

- Here we can borrow the convective mass flux expression, which for a general quantity ψ reads:

$$w'\psi' = \alpha M_c(\psi^u - \bar{\psi})$$

- Where α represents entrainment, M_c is mass flux, subscript u denotes updraft and bar denotes mean grid-box value

Idea of mass flux (2)

- Since we have ratio of fluxes, we may omit both entrainment rates and mass fluxes to write directly the expression for $\hat{R}$:

$$\hat{R} = \frac{max(0, q_t^u - q_w^u\ ) \ - max(0, \overline{q}_t - \overline{q_{sat}})}{(q_t^u - q_w^u) \ - (\overline{q}_t - \overline{q_{sat}})}$$

- Where our quantity ψ is deficit to saturation, computed in updraft and as a mean grid box value.

Updraft parameterization (1)

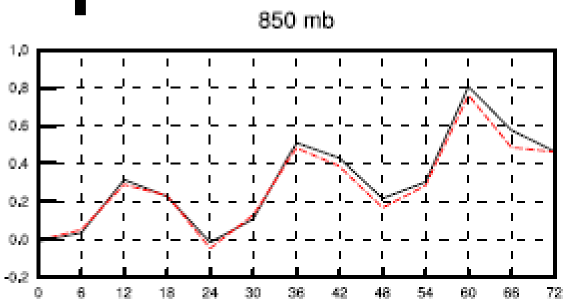
- We construct moist adiabatic cloud profile like in case of moist deep convection => simplified computation taken from ACCVUD;
- Questions on entrainment
  - Thanks to the ratio of fluxes it is not needed by principle;
  - We use it to prevent starting new cloud above a thick enough stable layer:
    - We determine N_{sat} and compute the first model level starting from the ground topping 2500m thick layer of a stable N_{sat} stratification;
    - From that model level we apply a relatively strong entrainment rate of the order 10^{-3}, relaxing the profile to the environment.
  - This constraint is a relatively weak one.

Updraft parameterization (2)

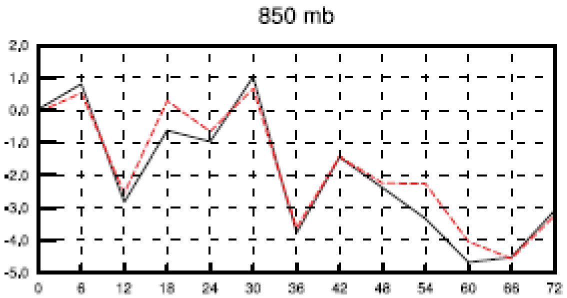
- When to abort cloud
  - Previously we had a condition on turbulence activity measured by TKE and TBE values => cloud aborted when these were enough small.
    - Problem of a feedback, since buoyancy is source/sink of turbulence, and by doing so we could reverse the causality at work;
    - Problem to determine the TKE/TBE thresholds – too arbitrary.
    - This approach was abandoned.
  - Test on net condensate in updraft
    - When not positive => return to zero buoyancy (before clipped to zero)
  - Test on buoyancy
    - When negative, return to the mean grid-box values of blue point and cloud condensate

Impact on results

T



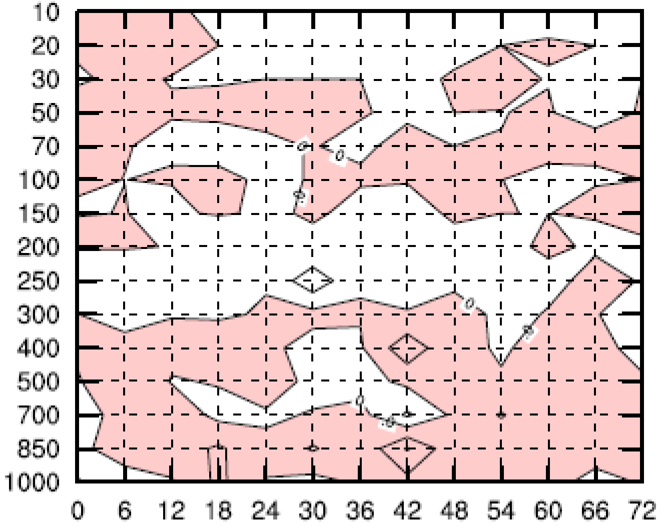
RH



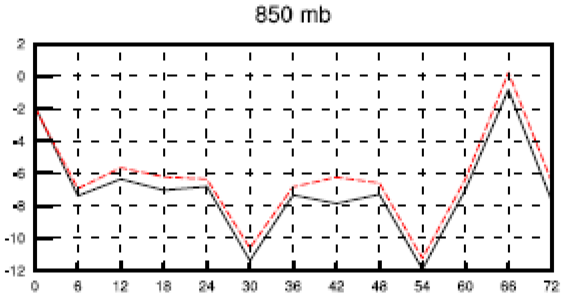
REF
TEST

Summer e-suite; scores from 22/06 to 10/07/2017. Improved SCC reduces warm and dry bias at the PBL top. RMSE scores within PBL are also slightly improved.

RH – RMSE diff



RH - bias



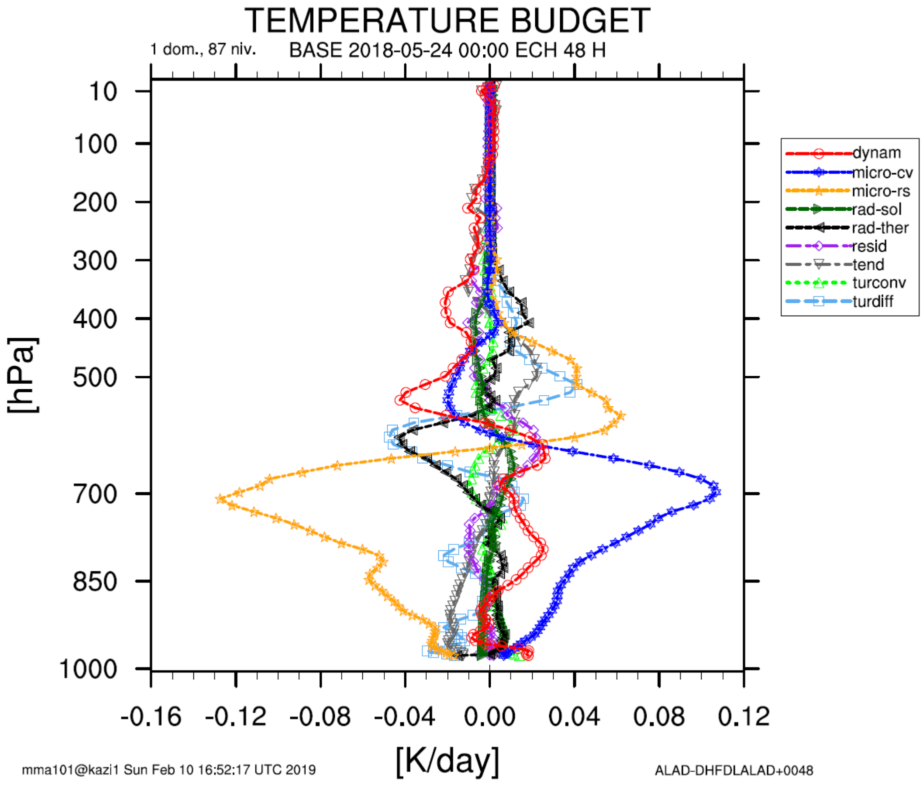
Winter e-suite from 10/01 to 20/01/2017. Better humidity scores.

Impact on results -discussion

- In general, the recent modifications enhanced turbulent transport within PBL;
- Especially in summer we see the "resolved" condensation gets more importance than the one in convective updrafts;
- In this way, turbulence (shallow convection) plays an important role on the activity of respective condensation schemes (thermodynamic adjustment vs unresolved updrafts);
- We do not have arbitrary thresholds in the cloud profile computation, except one: the 2500m thickness of the stable layer to forbid starting a cloud. What is the sensitivity to it?

Some additional tests

- Pushing the limit of thickness of a stable layer from 2500m lower? To which thickness?
- In case the stable layer starts from the ground, it may prevent to start a cloud base higher than this limit;
- Again, the role of this limitation is more visible in summer, i.e. what is taken by resolved vs unresolved condensation.
- Temperature multi-budget difference of 1500m vs 2500m limit. Push toward more unresolved condensation is clearly seen.



Case of 24 May 2018, dx=2.3km

Conclusions and Outlook

- New shallow convection closure based on the mass-flux approach works much better than the previous approach based on the moist Richardson number R_i^*;
- Moist anti-fibrillation scheme is not necessary any more as it had to be the case when using R_i^*;
- Is there still something to open?
  - Cloud profile computation seems to be well consolidated;
  - There is the "enough thick stable layer" of 2500m, which does not have a big impact but still ….
  - The real question is to open again the shallow convective cloudiness result as input to the radiation in order to replace the current "QSSC" trick.