Research topics at KNMI

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The role of entrainment and updraft velocity in an EDMF[1)] scheme

Wim de Rooy, Geert Lenderink, Pier Siebesma, Roel Neggers and Stephan de Roode*

A dual mass flux[2)] Eddy Diffusivity/Mass Flux (EDMF) scheme, distinguishes two types of updrafts: Dry updrafts that never reach lifting condensation level, and moist updrafts that condense and become cumulus clouds. In such a scheme the fractional entrainment (ε) and the formulation of the vertical velocity eq. play a crucial role. However, it is yet unclear which vertical velocity equation(s) is(are) adequate for the different updrafts in sub cloud and cloudy layer. Here a simple robust parameterization for ε is proposed, that is much less sensitive to the vertical velocity formulation. In combination with a detrainment (δ) coefficient according to [3)] good results are obtained for the complex ARM shallow convection case.

1. Introduction

At the Royal Netherlands Meteorological Institute (KNMI) a dual mass flux EDMF scheme is for the first time combined with a TKE turbulence scheme and applied in a regional climate as well as a meso-scale NWP model. Unfortunately, an earlier version (referred to as "REF") of this scheme, showed important deficiencies.

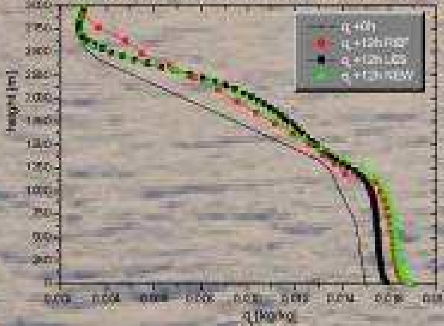

Figure 1. Total specific humidity profiles for the ARM case

2. Problem formulation

Comparing LES humidity profiles for the ARM case with REF results, reveal the too aggressive and too deep mixing (see Fig.1). This is dominantly caused by the applied combination of ε and vertical velocity equation.

i. Vertical velocity equation

The vertical velocity eq. usually has the following form:

$$\frac{1}{2}\frac{\partial w_u^2}{\partial z} = -\alpha\cdot\varepsilon w_u^2 + \beta\cdot B \qquad (1)$$

Where w_u is the updraft vertical velocity, B is the buoyancy, and α and β are constant values, varying e.g. for β from 1/3 (tuned for the cloudy layer) up to 10/7 (derived for the dry convective layer). The above mentioned uncertainty in α and β has considerable impact on the vertical velocity. Nevertheless, it is yet unclear which coefficients are adequate for the different updrafts in the sub cloud and cloudy layer. In REF relatively small α and large β are used, both leading to high w_u values.

ii. The entrainment formulation

In REF we use: $\varepsilon = (w_u \tau)^{-1}$ (2)

Where τ is the adjustment time scale. Although physically appealing, this formulation is very sensitive for the vertical velocity eq.. For example if (1) leads to too high w_u, ε with (2) will be very small, leading to less dilution of the updraft and consequently even higher w_u values. This mechanism explains the too deep and aggressive mixing in REF.

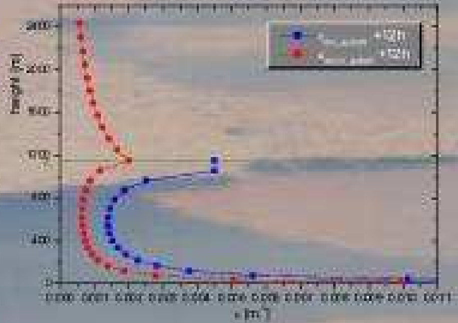

Figure 2. Fractional entrainment rate profiles for the dry and moist updraft using (3) and (4) for the ARM case at +12h.

3. New entrainment formulation

For the dry updraft we adopt the ε formulation of [1)] for the dry convective boundary layer (see Fig 2):

$$\varepsilon_{dry\,updr} = 0.4\left(\frac{1}{z} + \frac{1}{z_i - z}\right) \qquad (3)$$

Where z_i is the inversion height. Eq. (3) reflects the increasing ε when w_u goes to zero at z_i. However, for the moist updraft w_u decreases but does not reach zero at the top of the sub cloud. In contrast with LES results, (1) with small α and large β, in combination with (2) hardly slows down, and consequently hardly dilutes, the updraft near cloud base. Therefore, the following formulation is proposed:

$$\text{sub cloud: } \varepsilon_{moist\,updr} = 0.3\left(\frac{1}{z} + \frac{1}{z_i - z + \frac{z}{0.01 z_i - 1}}\right) \qquad (4a)$$

$$\text{cloudy layer: } \varepsilon_{moist\,updr} = \frac{1}{z - z_i + 500} \qquad (4b)$$

Where (4a) has a similar shape as (3) but leads to smaller values (corresponding with stronger updrafts) and now goes to $2\cdot10^{-3}$ [m⁻¹] at the top of the sub cloud layer (see Fig. 2). From there (4b) starts from $2\cdot10^{-3}$ at cloud base and then decreases with z^{-1}, roughly in accordance with LES. Eqs. (4a) and (4b) are much less sensitive to the chosen vertical velocity equation. By ensuring substantial dilution near cloud base the excess at cloud base is small, in accordance with observations and LES. Finally to close our scheme δ according to [3)] can be easily adapted to (4b), resulting in accurate mass flux and thermodynamic profiles for the ARM case (see Fig. 1, NEW).

4. Conclusion

A fractional entrainment rate inversely proportional to the vertical updraft velocity is very sensitive to the exact formulation of the initial excess and the vertical velocity equation, while on the latter much uncertainty exists in literature. Here we propose a simple and more robust parameterization of ε. In combination with a detrainment formulation according to [1)] good results are obtained for a complex shallow convection case.

References

[1] Siebesma et al., 2007: *A combined Eddy-Diffusivity Mass-Flux Approach for the Convective Boundary Layer.*, J. Atmos. Sci., **64**, 1230-1248.
[2] Neggers et al., 2007: *A dual mass flux framework for boundary layer convection. Part I: Transport.* ECMWF/ARM report series No. 2.
[3] de Rooy, W.C., and A.P. Siebesma, 2008: *A simple parameterization for detrainment in shallow cumulus.* Mon. Wea. Rev., 136, 560-576.

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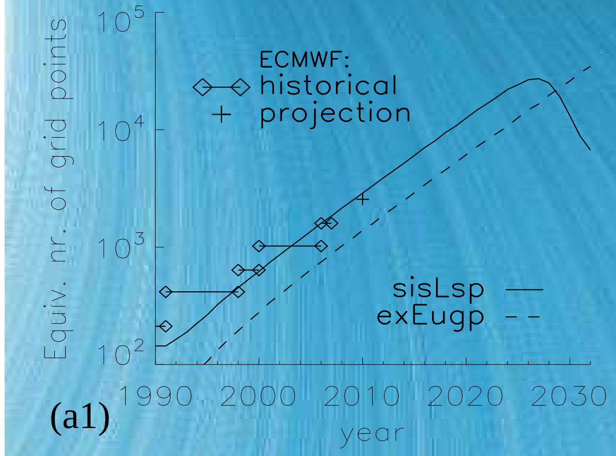
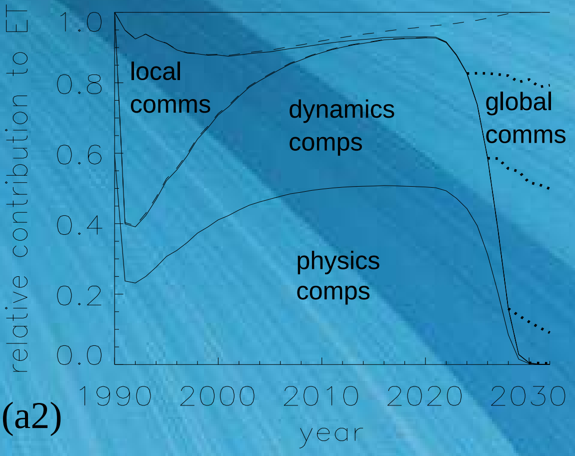
24 more years of NWP

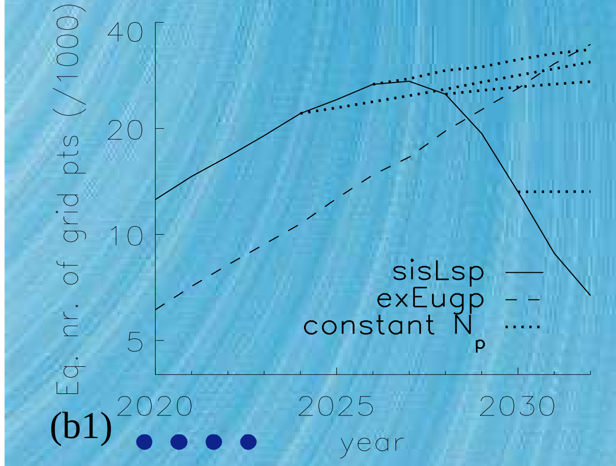
Gerard Cats



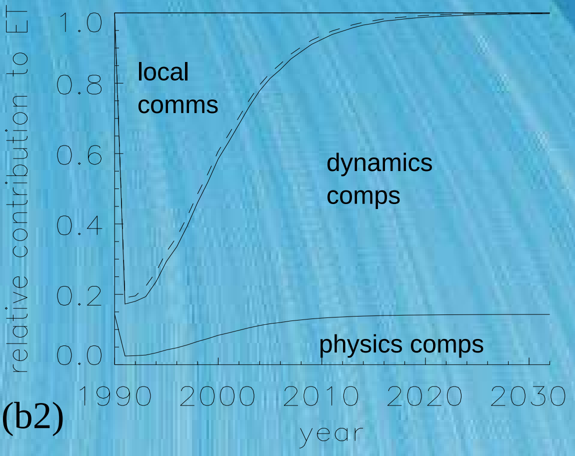
(a1)



(a2)

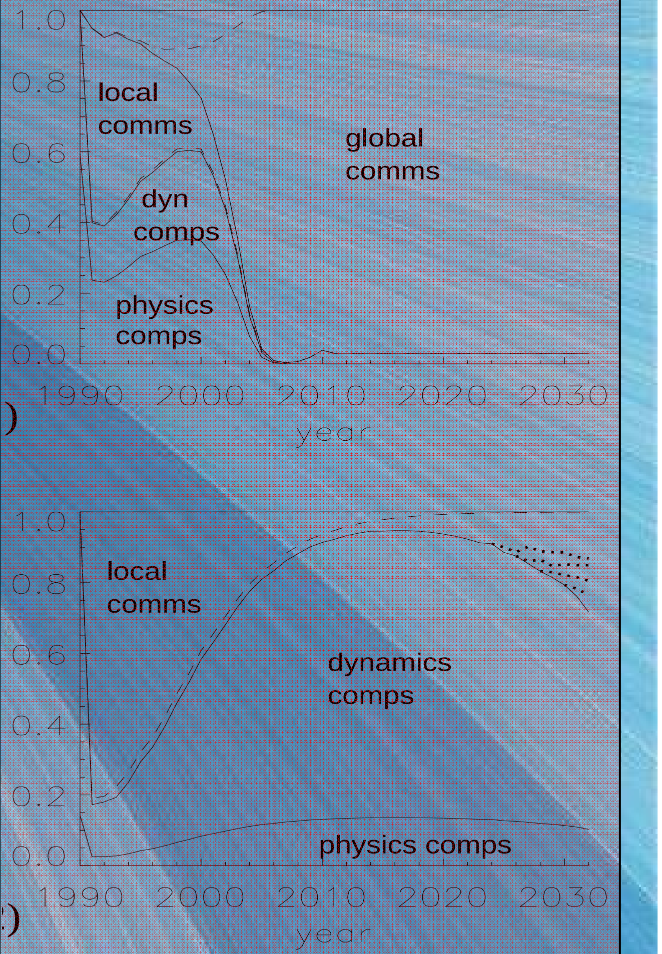


(b1)



(b2)

Grid computer



Hirlam CAPE singular vectors

Roel Stappers[1] and Jan Barkmeijer

Background

The main application for the HIRLAM system is the production of general weather forecasts, with particular emphasis on detection and forecasting of severe weather. Results are presented for SVs specifically designed to trigger one type of high impact weather namely, deep convective systems. This is achieved by looking for perturbations that maximize convective available potential energy (CAPE) instead of total energy.

Theory

The time evolution of small perturbations $\epsilon(0)$ of the initial condition $x(0)$ over a certain time T is given by

$$\epsilon(T) = \mathbf{M}(0,T)\epsilon(0) \tag{1}$$

Here M is the tangent linear propagator. The leading singular vector is the vector $\epsilon(0)$ that maximizes the ratio

$$\frac{||\epsilon(T)||^2_{\mathbf{C}_1}}{||\epsilon(0)||^2_{\mathbf{C}_0}} \tag{2}$$

for given norms $||\cdot||_{\mathbf{C}_1}$ and $||\cdot||_{\mathbf{C}_0}$.
Let $\mathcal{C}(x)$ be a function that computes CAPE. Taylor expansion of $\mathcal{C}(x)$ around a reference profile x^* gives

$$\mathcal{C}(x) - \mathcal{C}(x^*) = \left.\frac{\partial \mathcal{C}}{\partial x}\right|_{x^*} \epsilon = \mathbf{C}\epsilon \tag{3}$$

Where $\epsilon = x - x^*$. The leading CAPE-SV is the vector $\epsilon(0)$ that maximizes the ratio

$$\frac{||\mathbf{C}\epsilon(T)||^2}{||\epsilon(0)||^2_{\mathbf{C}_0}} \tag{4}$$

Case study

In the morning of August 22nd 2007 a thunderstorm hit Finland which the operational FMI-model failed to predict in any of the cycles verifying at the same time. The predictability is investigated using TE and CAPE-SVs. Total energy and CAPE singular vectors where calculated for the period 2007-08-15 00UTC until 2007-08-30 12 UTC at 6 hour intervals with an optimization time of 12 hours using a dry total energy norm at initial time (no specific humidity perturbations).
Figure 1 shows the leading singular value as function of the start of the SV-calculation using the TE-norm and CAPE-norm There is a daily pattern in the singular values with the CAPE-norm with higher values during the windows 12–00 UTC and 18–06UTC. Both runs show higher values around August 22nd indicating that the atmosphere was sensitive to small analysis perturbations in the period when the FMI-model failed. In figure 2 the vertical energy distribution of the leading 10 TE-SVs and 10 CAPE-SVs at initial and final time are given for August 21 at 18 UTC.

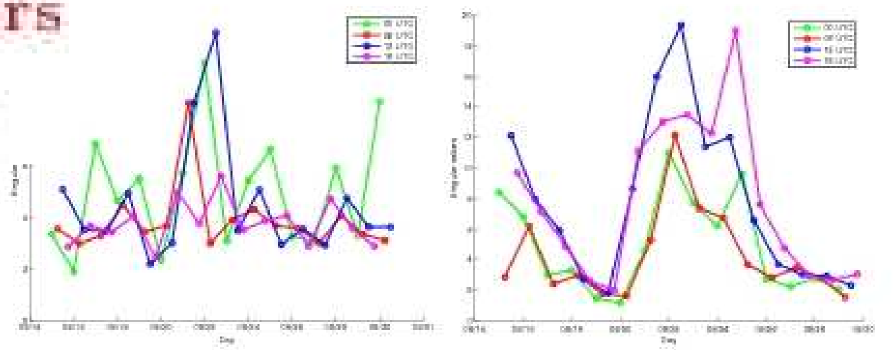


Figure 1: Leading singular value as function of start of SV-calculation with TE-norm (left) and CAPE-norm (right)

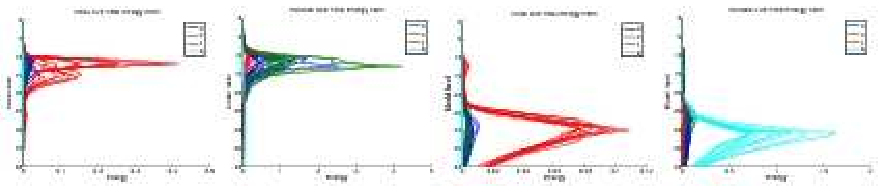


Figure 2: Vertical energy distribution of the leading 10 SVs, from left to right: Initial TE-SV, evolved TE-SV, initial CAPE-SVs, evolved CAPE-SVs

For comparison the temperature, wind and moisture fields are converted to units of energy using the total energy norm. For the TE-SVs most perturbation energy is initially in the temperature field which is converted to kinetic energy at final time. Because the TE-SVs are located high in the troposphere while CAPE is determined by the stability in the lower troposphere we do not expect that these TE-SV have a large impact on CAPE. The CAPE-SVs are located below 500 hPa at initial and final time and they mainly influence the moisture distribution in the lower troposhere at final time. Both the evolved TE-SVs and CAPE-SVs are located close to the active region (not shown).
At evolved time the RMS of CAPE for the TE-SV and CAPE-SVs are 9.7 and 289.4 respectively showing that the CAPE-SVs are almost 30 times more effective in triggering CAPE.

Conclusions

The CAPE-norm has been presented and the SV experiments with the Finnish case have shown that the final time norm may have a large impact on the structure of the SVs. The CAPE-SVs are considerably more effective in perturbing CAPE than TE-SVs. Both TE-SVs and CAPE-SVs suggest that the failed FMI forecast might be a result of errors in the analysis.

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