Idealized simulations of shallow convection using recent HIRLAM physics

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Motivation

- → the **importance of shallow convection** for describing realistic vertical structures of atmospheric forecast variables in the low troposphere.
- → **new results** with HIRLAM physics
- → some **results** are **much improved** relative to what has previously been published in the context of 1D simulations (e.g. EUROCS shallow cumulus case)
- → the somewhat **uncertain future of HIRLAM physics** might be **an additional reason for presenting the present status.**

Present study described in detail in the report

`Idealized simulations of shallow convection using recent HIRLAM physics´

(contact the author)

OVERVIEW

1) Introduction summarizing setup
2) Essential parts of HIRLAM physics for this study
3) Main results for ASTEX, BOMEX, EUROCS
4) Concluding remarks

(1.1) experimental setup

* In this study shallow convection is defined as convectively unstable conditions with clouds and condensation in the lowest 3 km of the atmosphere.

* 1D-model is run with appropriate forcing specified (fluxes or tendencies from dynamics and from surface)

* Summary for 3 cases : ASTEX , BOMEX , EUROCS

(1.2) specification of cases

Number of levels : 80 , with 17 below 1 km, 33 below 3 km

Time step: 150s, (75s)

ASTEX: (12-13 June 1992)

-Atlantic Stratocumulus Transition EXperiment –

(Bretherton and Pincus 1995), simulation period: 24 h

Forecast length: 24h.

BOMEX :(June 1969)

- Barbados Oceanographic and Meteorological EXperiment-

(Nitta and Esbensen1974), simulation period: 7 hours.

EUROCS (21 June 1997)

shallow cumulus over land - ARM site in Oklahoma-

LES-results: Brown et. al. (2002), 1D-simulation results: Lenderink et al. (2004).

(1.3) HIRLAM physics

Nomenclature of experiments:

Turbulence scheme (HIRLAM version of CBR) based on TKE and a diagnostic length scale

`dry´ turbulence scheme: CBRD

`moist´ variable turbulence scheme: CBRM

`new´ convection scheme (STRACO): CVNEW

(1.4) OUTPUT

OUTPUT

- Vertical profiles at the end of the simulation period.
  For EUROCS time series of cloud base, cloud top, cloud cover and vertical mean TKE below 900 hPa

  Vertical profiles of
  -relative humidity
  -liquid water potential temperature
  -cloud cover
  -wind components
  -turbulent kinetic energy (TKE)

Convection (2.0)

→scheme (STRACO) based on a moisture budget

→separate vertical distribution functions for temperature, humidity and cloud condensates

→effect of `overshooting´ convective eddies parameterized.

→scale dependent parameterizations

→`cloud´ model based on a (new) entrainment formulation but using classical definitions and experiences

→no traditional mass flux computations

Physics: convective cloud cover (2.1)

The statistical fomulation of convective cloud cover is based on the solution of the following 3 equations:

I) The integrated probablility of PDF-boxes for total specific humidity which equals 1

II) An equation for the mean specific humidity of the grid box

III) An equation for the grid box mean specific cloud condensate.

Physics: convective cloud cover (2.2)

$$f_{cv} = 1 - \frac{2\,(q_s(T_c) - \overline{q})}{2q_s(T_c) - \overline{q} - q_*} \qquad (1)$$

In (1) $q_* < \overline{q}$ is the lowest occurring specific humidity which needs to be parameterized from other model variables. Currently the following parameterization is used for q_*

$$q_* = \overline{q}\frac{(1 - K_a\widehat{Q})}{(1 + K_b\frac{q_c}{q_s})} \qquad (2)$$

In (2)

$$\widehat{Q} = min(\frac{\widehat{Q_a}}{Q_{00}}, 1) \qquad (3)$$

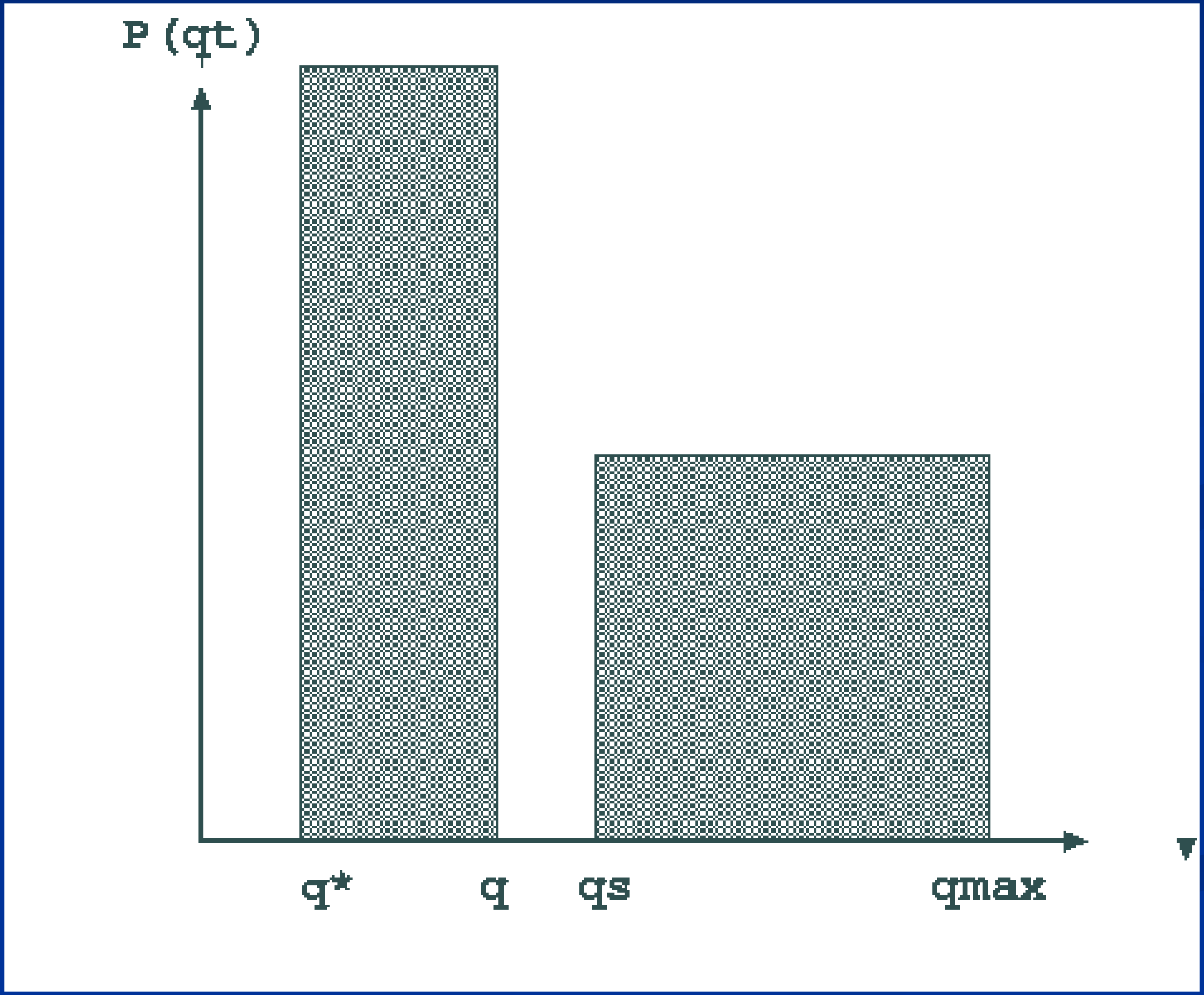
The second term in the nominator of (2) involving K_a tentatively describes a small effect of moisture availability to the convective cloud. $\widehat{Q_a}$, constrained to be non-negative, is the vertical mean moisture supply to the convective cloud ($\mathrm{kg \cdot kg^{-1} \cdot s^{-1}}$) through humidity advection and convergence.

$K_a = 3.0 \cdot 10^{-2}$, $K_b = 6.0$, $Q_{00} = 3.0 \cdot 10^{-8}\mathrm{kg \cdot kg^{-1} \cdot s^{-1}}$

The denominator of (2) expresses a dependency of total specific cloud condensate q_c through the dimensionless parameter $q_c/q_s(T_c)$

The formulation of convective cloud cover expressed by (1) and (2) is well behaved for all values of the parameters since q_* is always less than $\overline{q}$, and $\overline{q}$ is always less than $q_s(T_c)$. Hence the cloud cover will always be non-negative.

Probability function of convective cloud cover (2.3)



Entrainment and moistening (2.4)

The modified entrainment formulation may be written

$$\epsilon_e = (K_{\epsilon 0} + \frac{K_{\epsilon 1}}{Ri_*}) \cdot D_* \cdot Z_*^2 \qquad (1)$$

The first term $K_{\epsilon 0}$ in the brackets of (1) is a basic entrainment parameter. The second term describes an effect of wind shear. Ri_* is Richardson number. Z_* is a dimensionless height defined as

$$Z_* = \frac{z}{K_{\epsilon 2}} \qquad (2)$$

D is the model grid size, and D_* is a dimensionless parameter

$$D_* = \frac{D_{cv}}{D} \qquad (3)$$

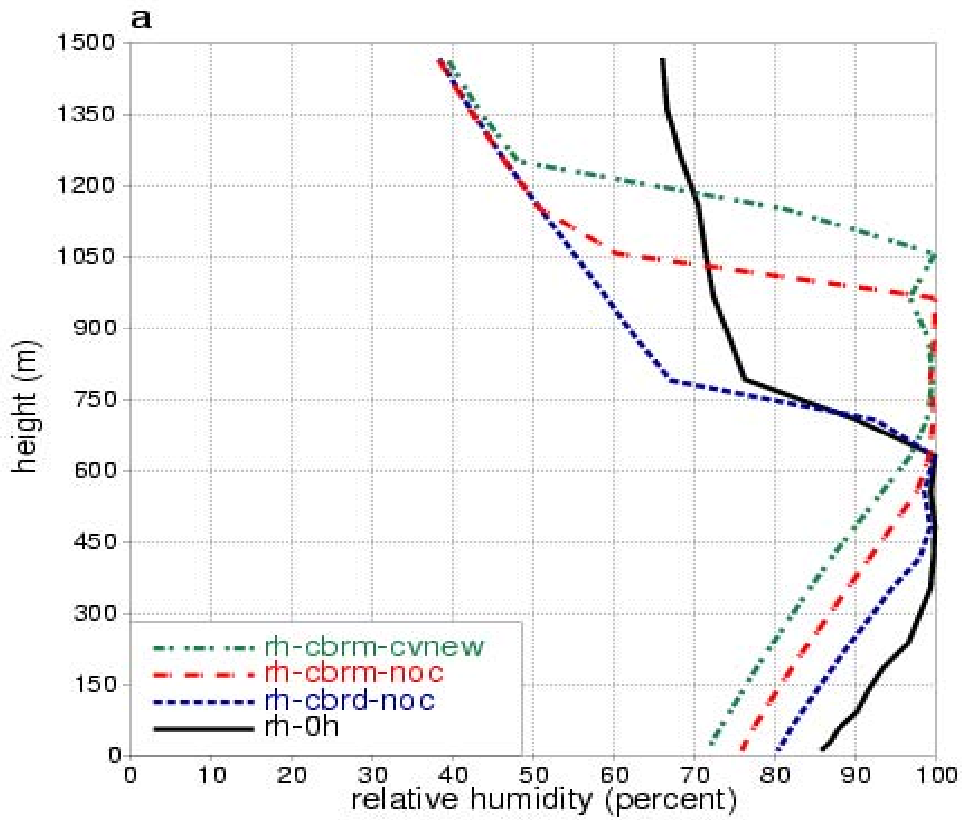
The current values of the constants are $D_{cv} = 4000\text{m}$, $K_{\epsilon 0} = 5.0 \cdot 10^{-4}\text{m}^{-1}$, $K_{\epsilon 1} = 7.5 \cdot 10^{-4}\text{m}^{-1}$ and
$K_{\epsilon 2} = 2400\text{m}$

The moistening parameter β is parameterized according to the following formula

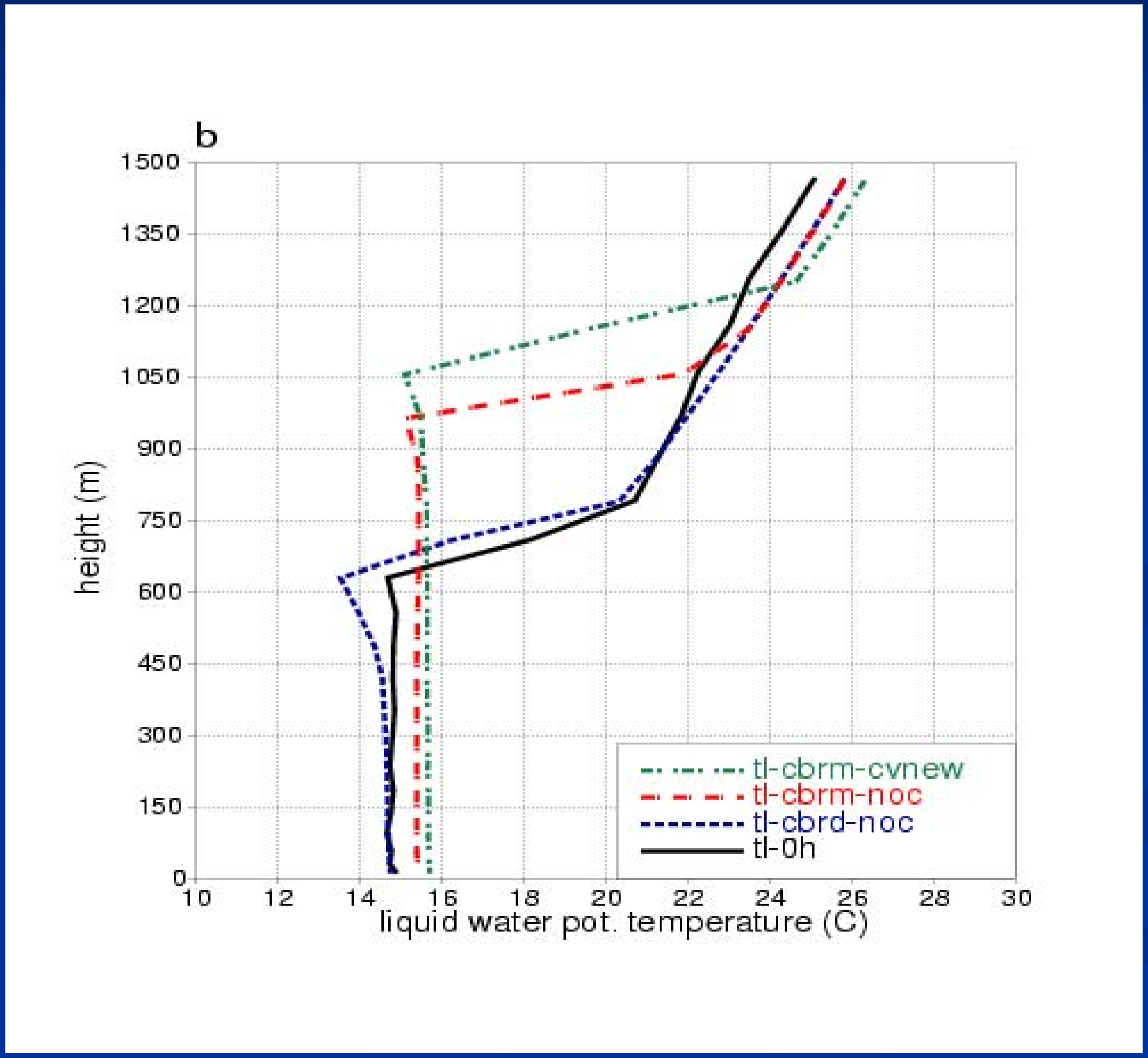
$$\beta = 1 - \frac{1}{1 + \sqrt{\frac{D_{cv}}{D}} \cdot (\frac{q_s(T_c) - q_e}{K_H})} \qquad (4)$$

This parameter expresses the fraction of the converging humidity on grid scale that is transported vertically without condensing. In (4) a dependence of resolution is introduced through the square root of D_{cv}/D. $K_H = 15.0 \cdot 10^{-3}$ Qualitatively such dependency should be expected. $q_s(T_c)$ is the mean specific humidity of cloud parcel, and q_e is specific humidity of the environmental air.

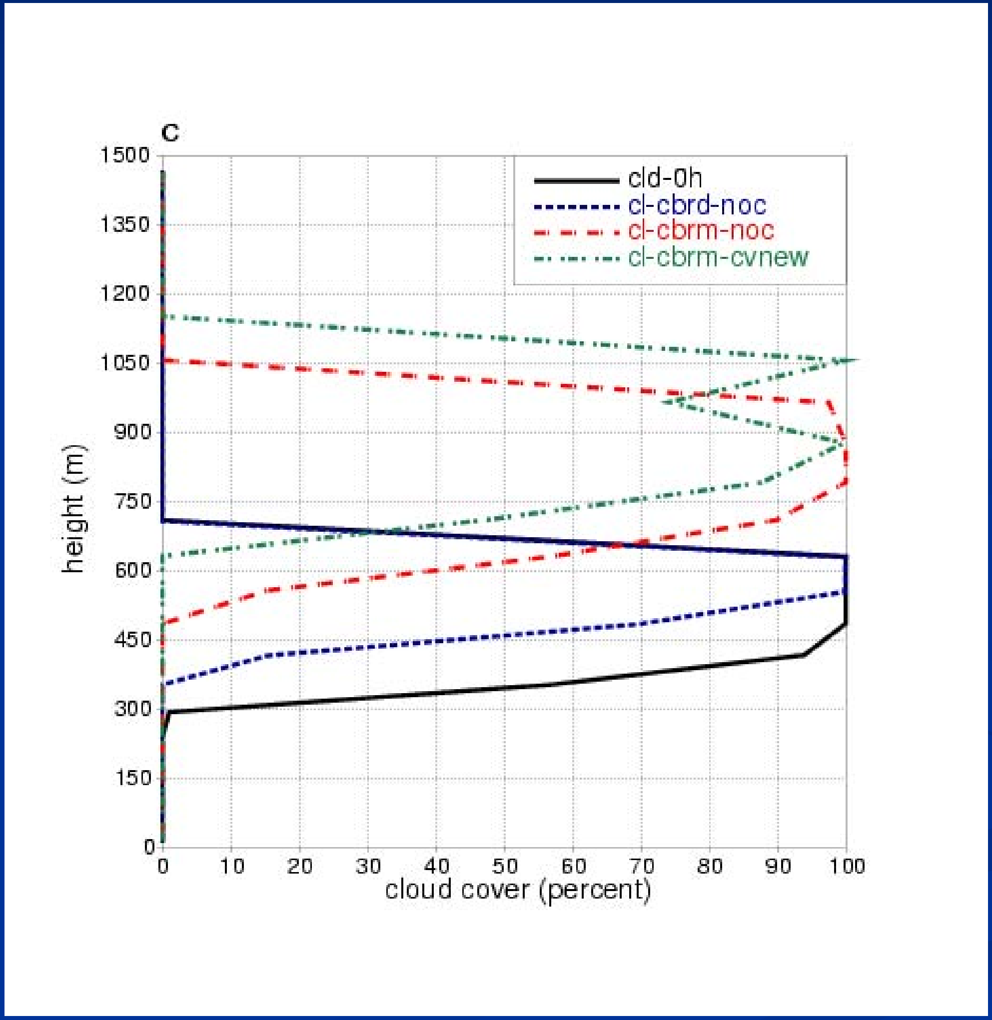
3.1 -ASTEX relative humidity (24h)



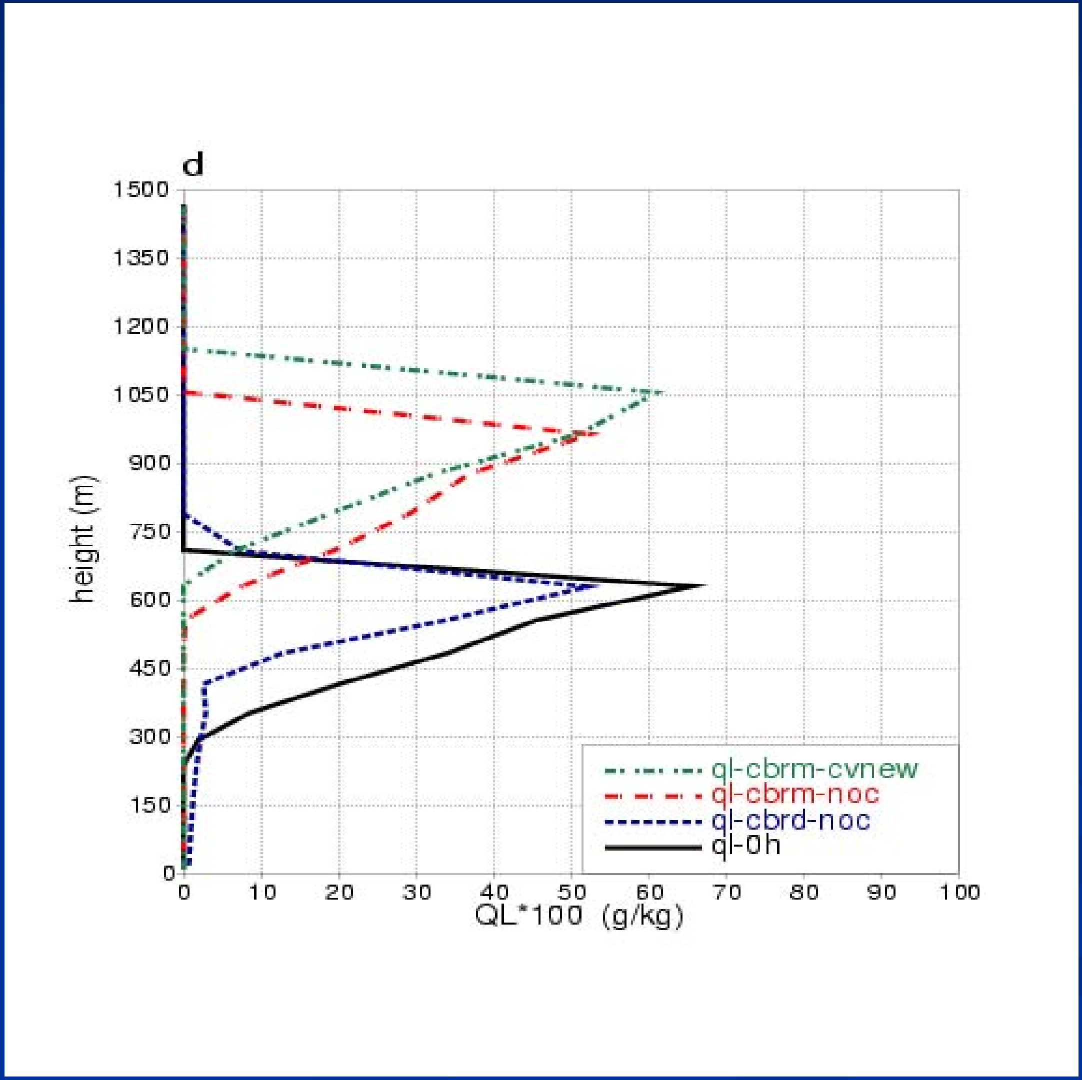
3.2 –ASTEX liquid water pot. temperature (24h)



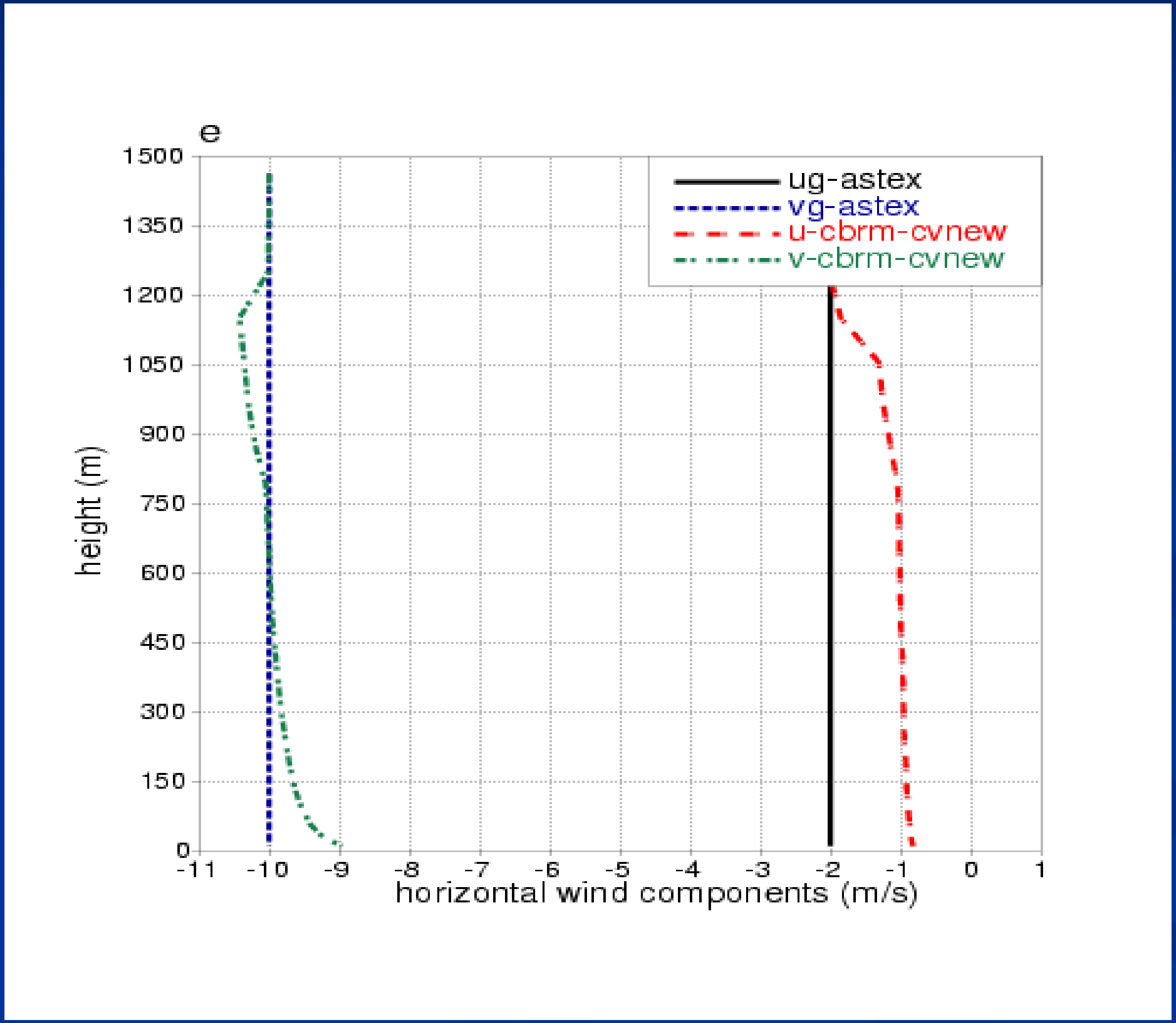
3.3- ASTEX cloud cover (24h)



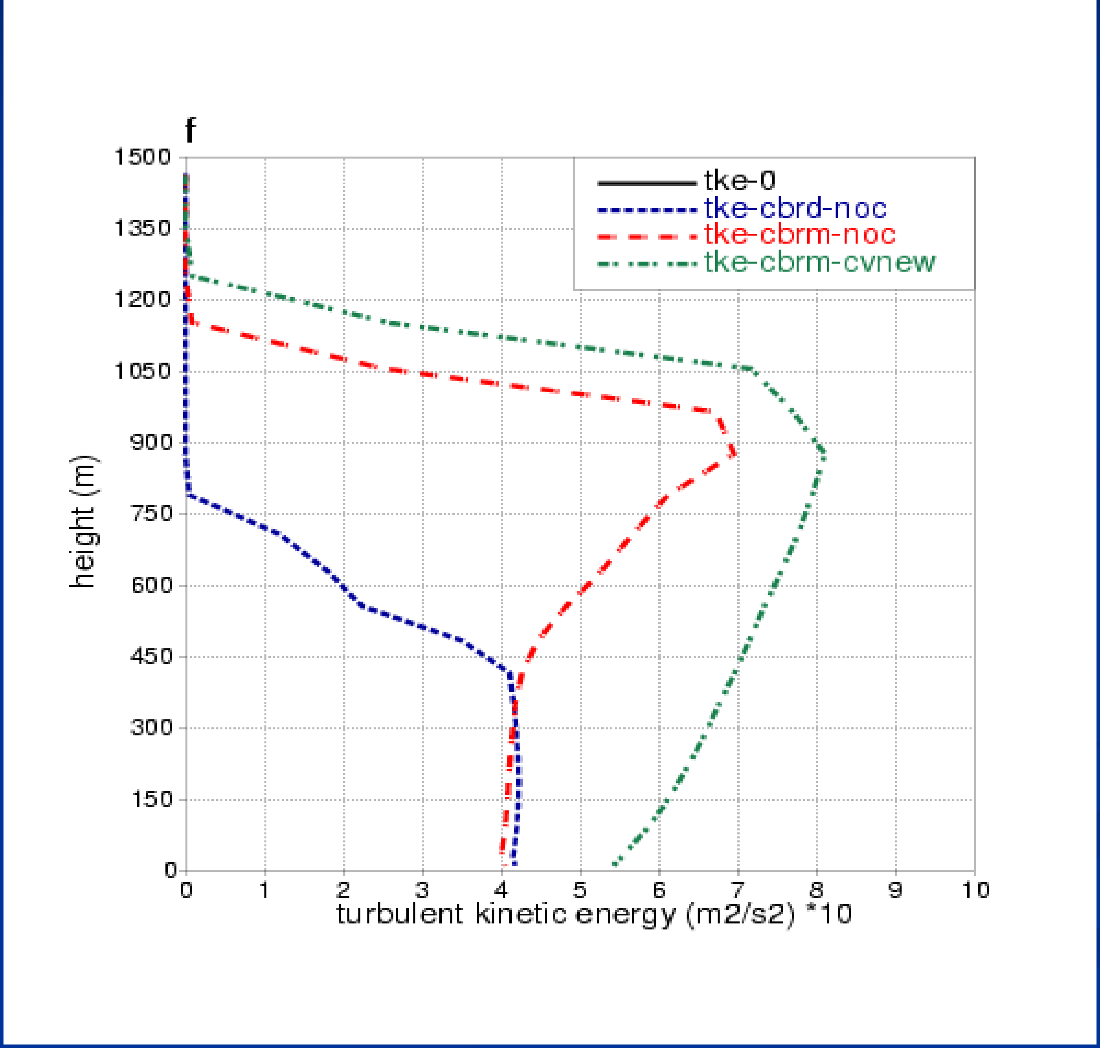
3.4 - ASTEX liquid water (24h)



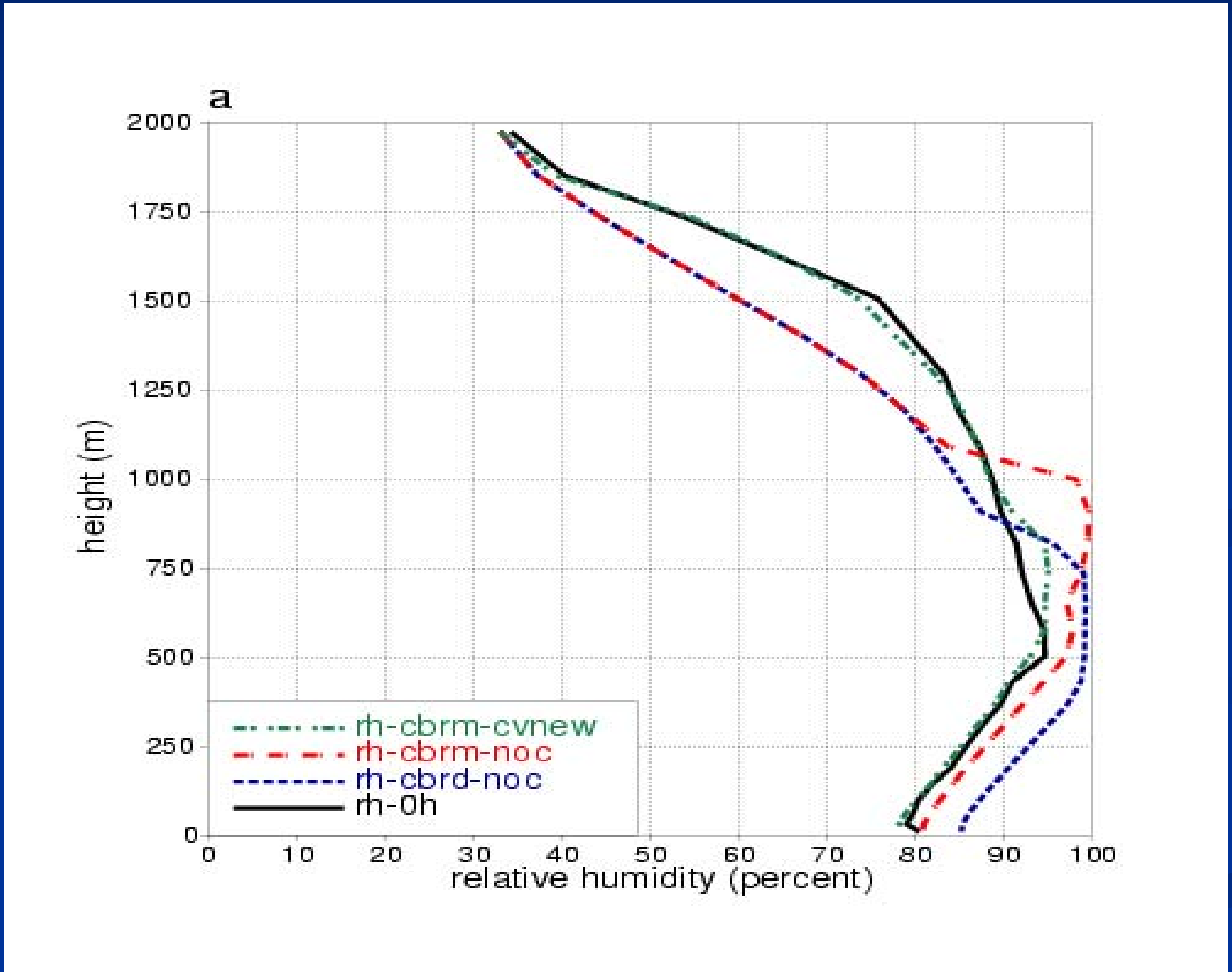
3.5 - ASTEX wind components



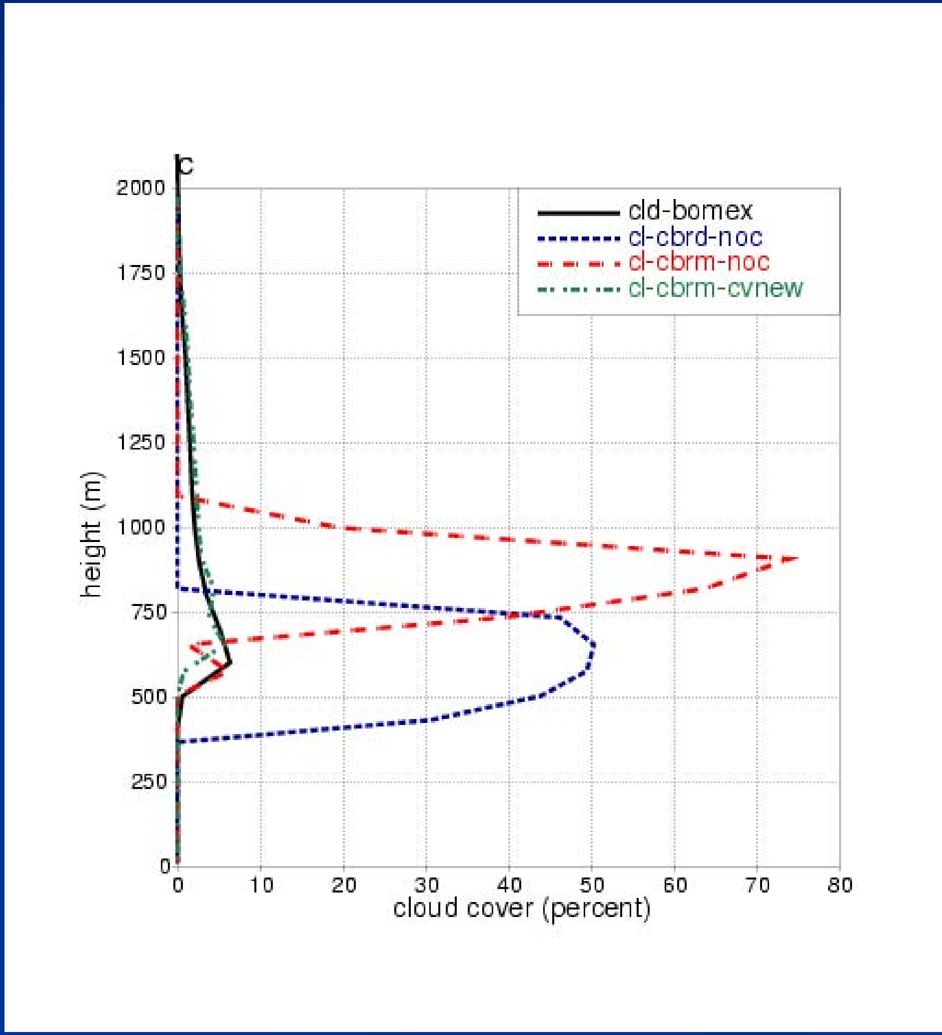
3.6 – ASTEX turbulent kinetic energy (24h)



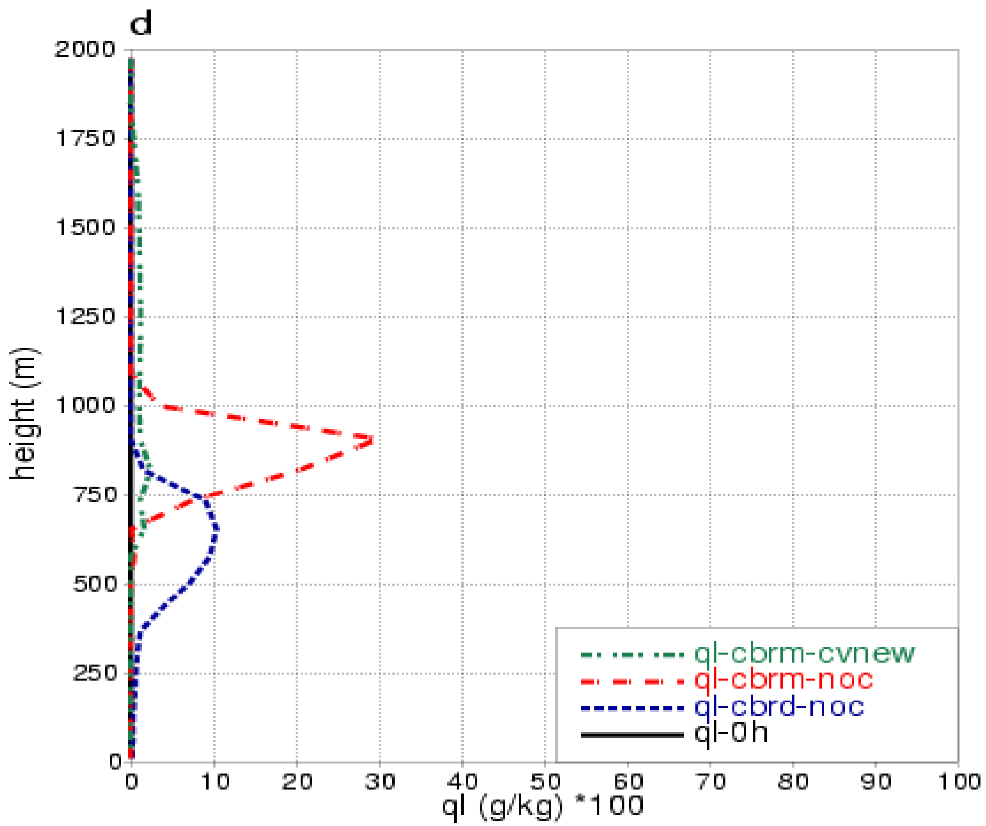
3.8 – BOMEX relative humidity (7h)



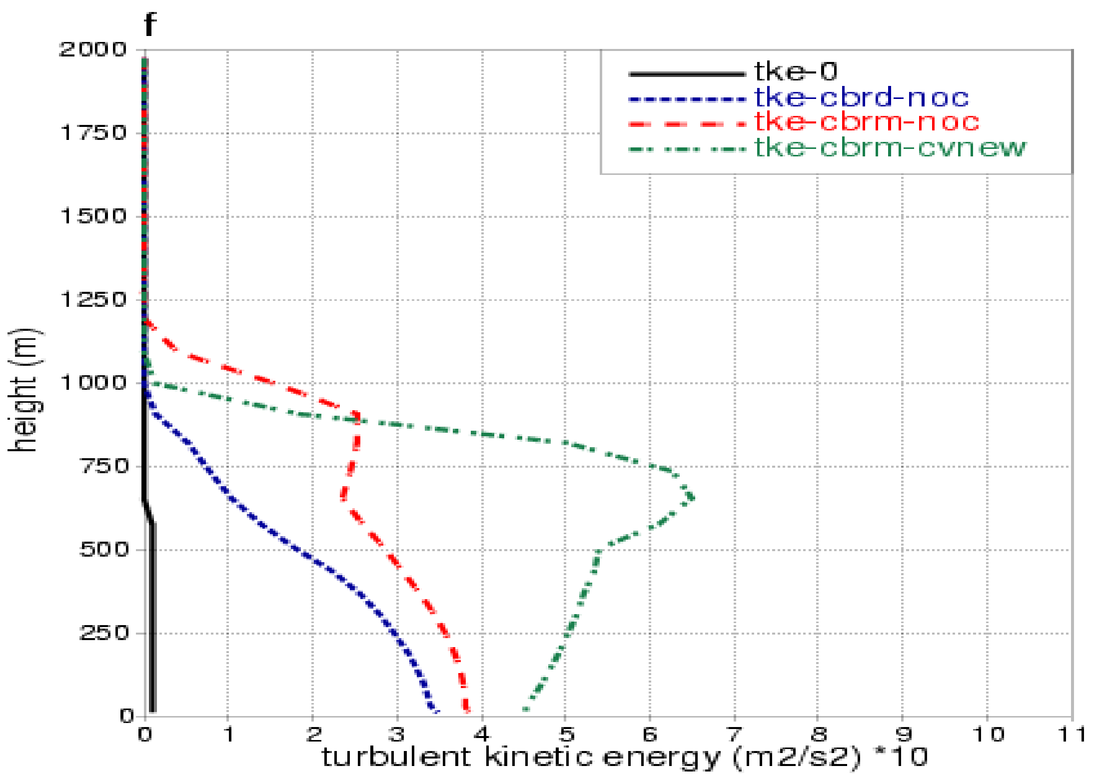
3.10 BOMEXcloud cover (7h)



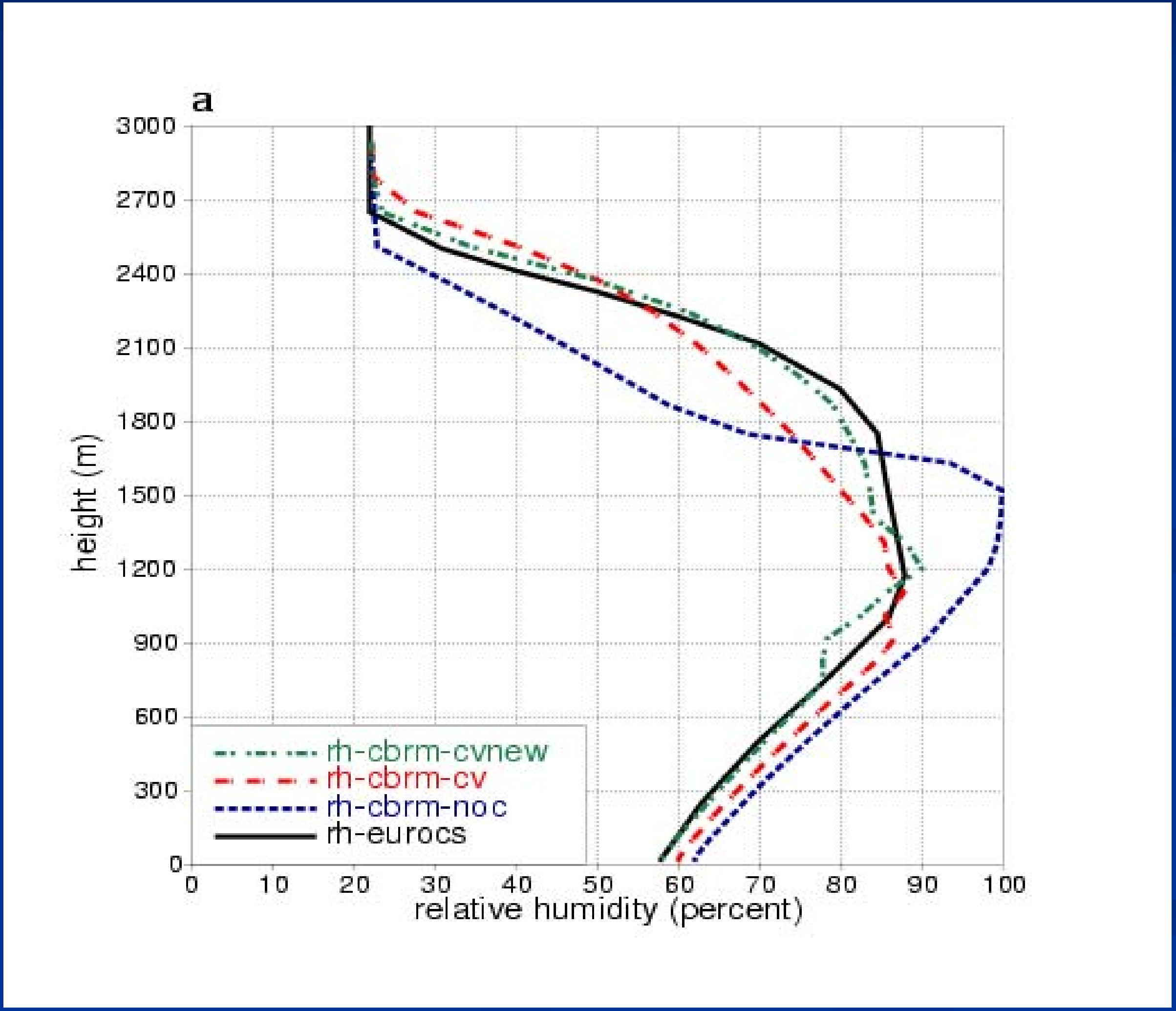
3.12 –BOMEX liquid water (7h)



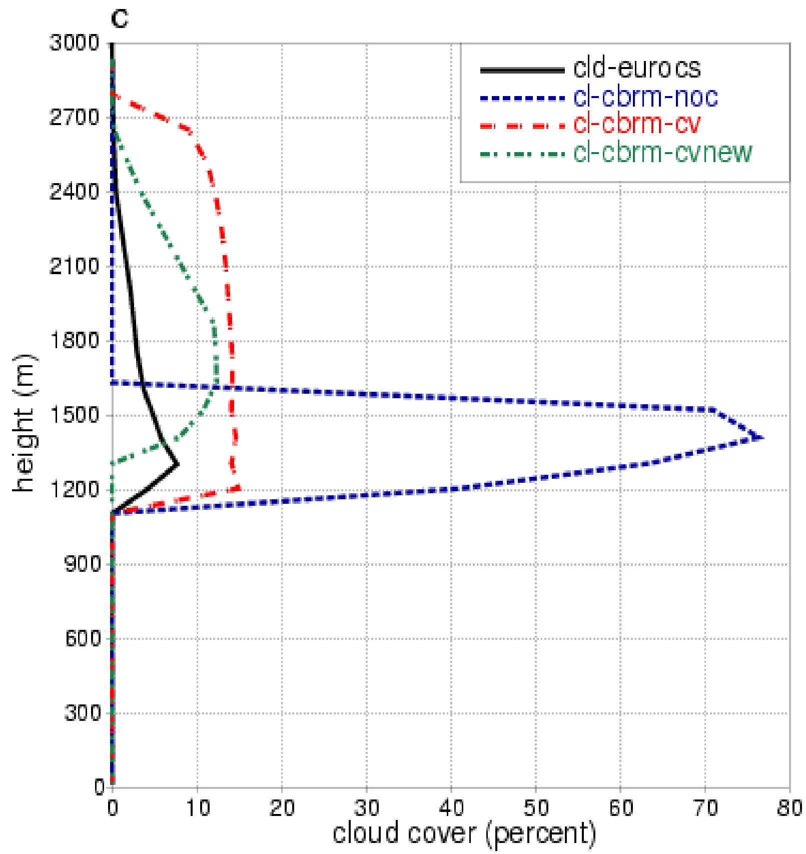
3.13- BOMEX TKE (7h)



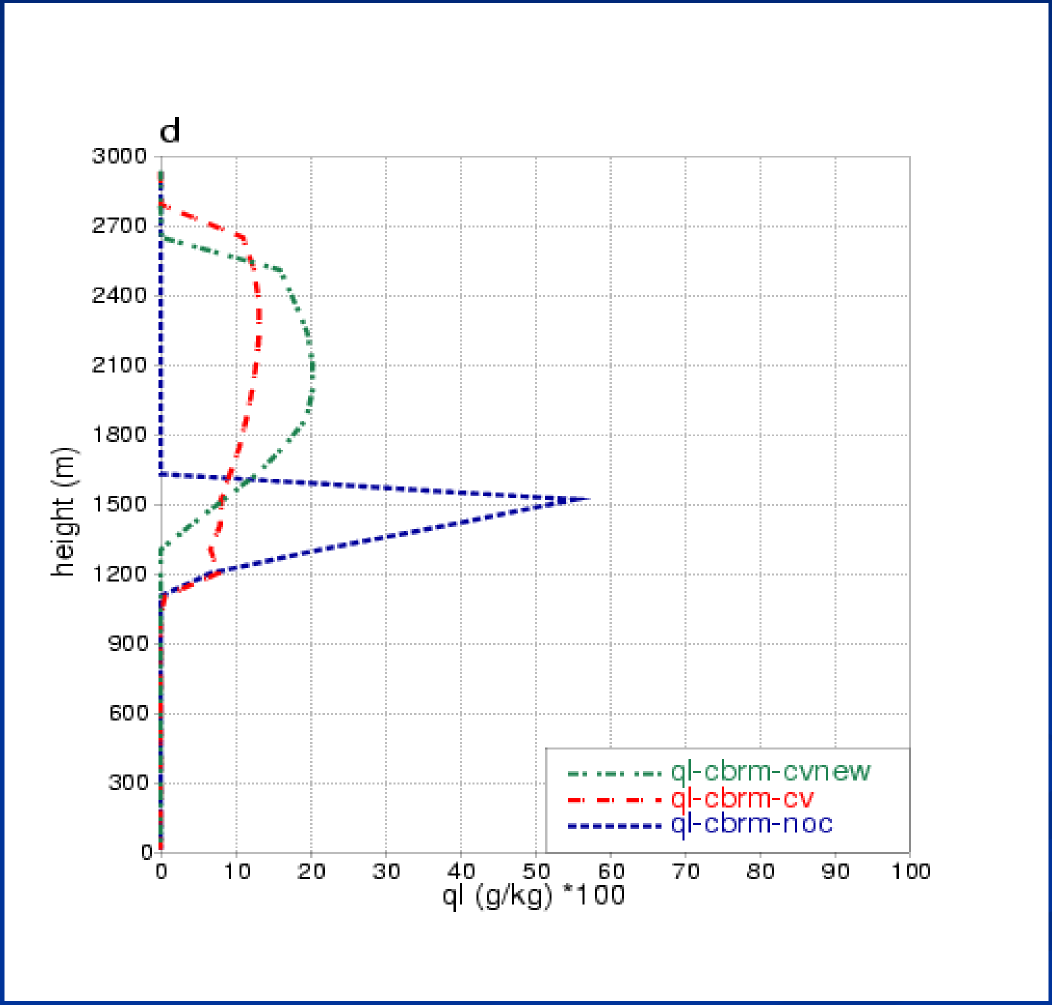
3.14- EUROCS relative humidity (10h)



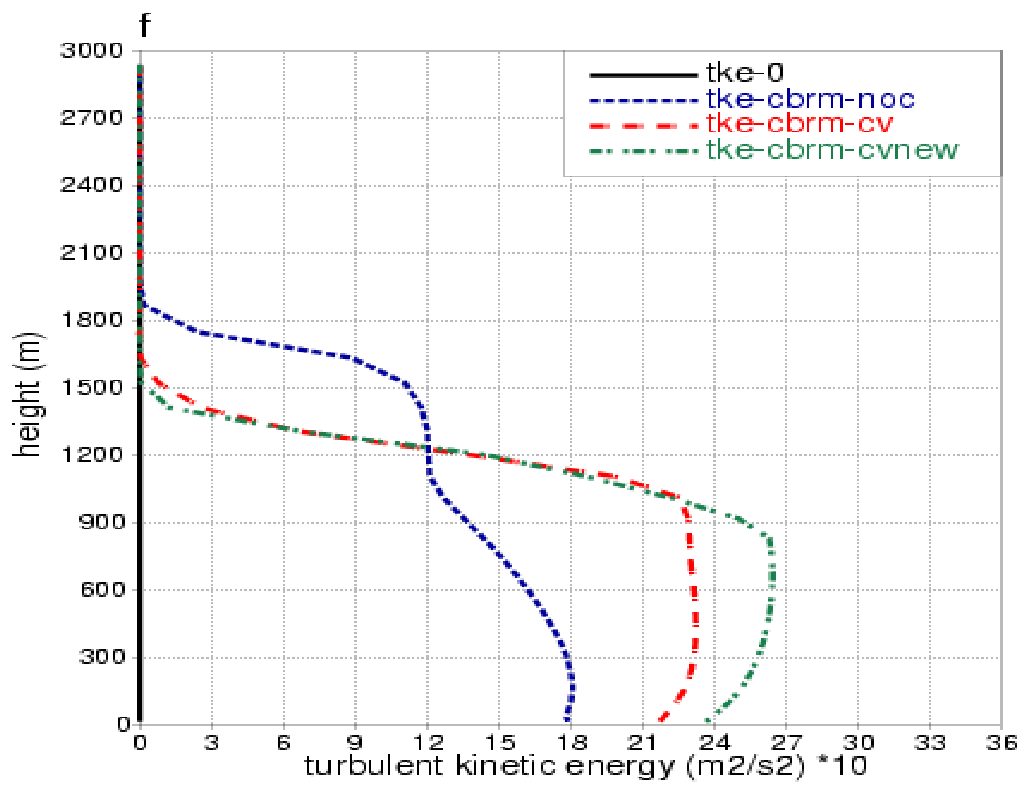
3.14 – EUROCS cloud cover (10h)



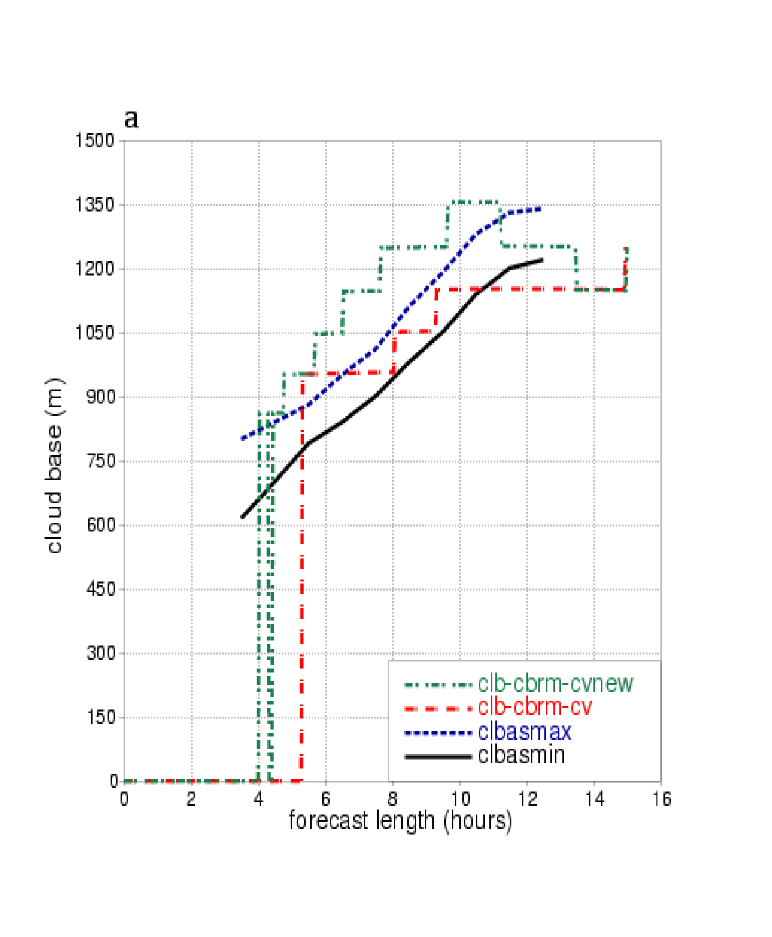
3.15- EUROCS cloud water (10h)

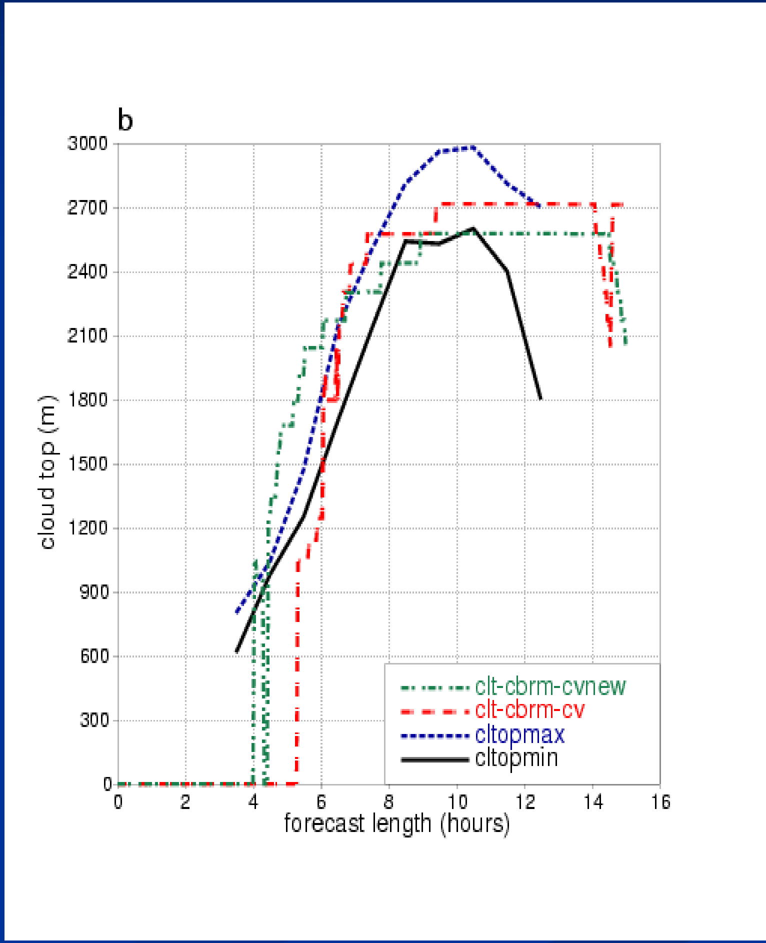


3.16- EUROCS TKE (10h)

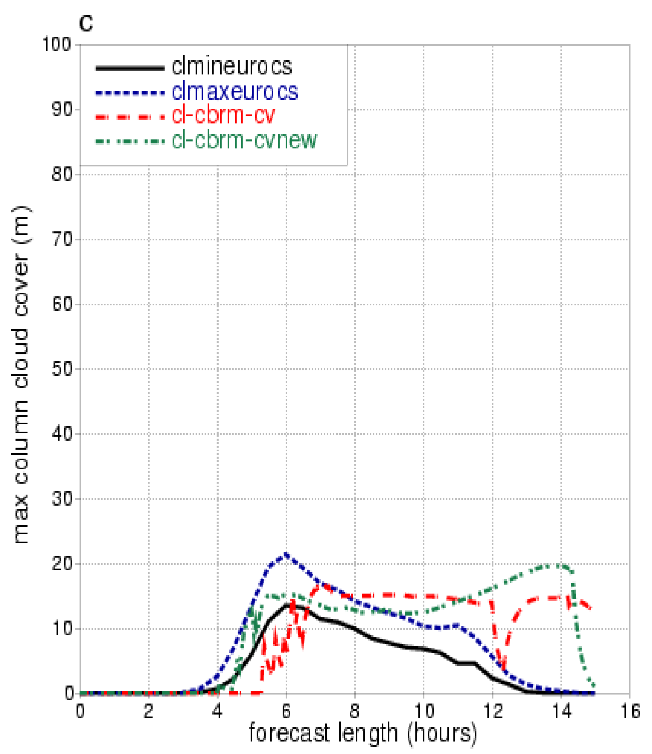


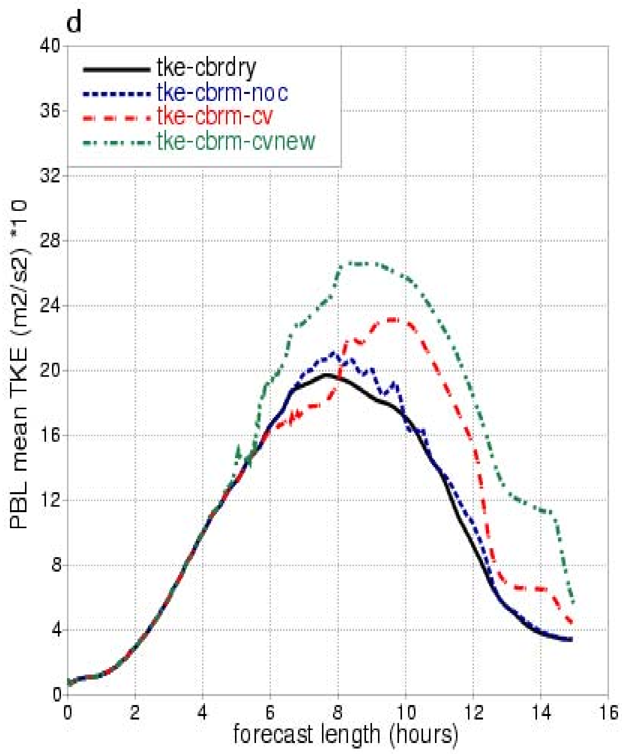
3.17- EUROCS cloud base and top





3.18 – EUROCS cloud cover and TKE





Concluding remarks (4.1)

- Traditional turbulence schemes as currently used in HIRLAM needs a convection scheme in order to describe shallow convection adequately
  Exception: moist stratocumulus cases such as ASTEX handled well by moist turbulence scheme.

- It is difficult to obtain a realistic interaction between turbulence and convection parameterization.

Concluding remarks (4.2)

* The new version of the convection scheme has given improved results for BOMEX compared to previous version (not shown). Also for EUROCS the results are much improved to what has been previously shown with HIRLAM physics and probably competitive to the results of most other schemes for important key parameters, e.g. relative humidity.

Concluding remarks (4.3)

* Specific cloud condensate at +10h of EUROCS is considerably higher in 1D run presented, compared to LES. This result appears to be somewhat sensitive to the assumptions on subgrid scale condensation and the time scale for evaporation of cloud water

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