Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Diurnal equilibrium convection and land surface atmosphere interactions in an idealized could-resolving model

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Linda Schlemmer[1]
C. Hohenegger[2], J. Schmidli[1], C. Schär[1]

1: Institute for Atmospheric and Climate Science, ETH Zurich
2: Max-Planck-Institut for Meteorology, Hamburg

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Objectives

- We investigate the role of moist convection in the climate system and in climate change with focus on the feedback between the soil and the deep atmosphere from first principles.
- A new framework is introduced using an idealized CRM
- We study the sensitivity of the moist convection to mid- and upper-tropospheric humidity, static stability and soil moisture.

Model set-up

COSMO_CLM (CCLM) 4.0

- grid-spacing $0.02^\circ \hat{=} 2.2km$
- domain of 100x100x50 grid points
- initial condition from sounding (T, QV, U and V)
- full set of physical parameterizations
- no parametrization for convection
- periodic lateral boundary conditions
- no Coriolis force
- no topography

Relaxation

keep simulated profile close to the desired profile

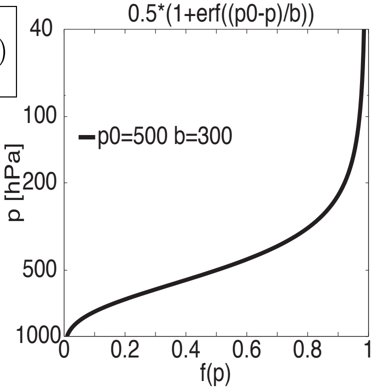
$$\left(\frac{\partial X}{\partial t}\right)_{relax} = -\frac{\overline{X} - X_{ref}}{\tau} \cdot f(p)$$

$X : T, Qv, U, V$

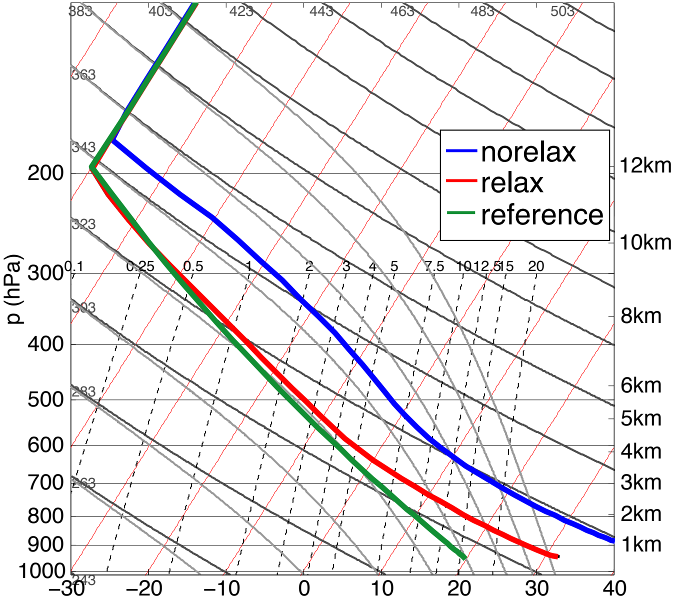
X_{ref}: reference profile

$\overline{X}$: spatial mean value

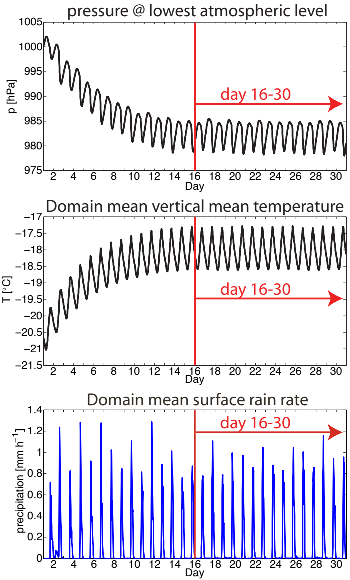
$\tau = 24h$



skewT mean @ 12UTC



State of diurnal equilibrium



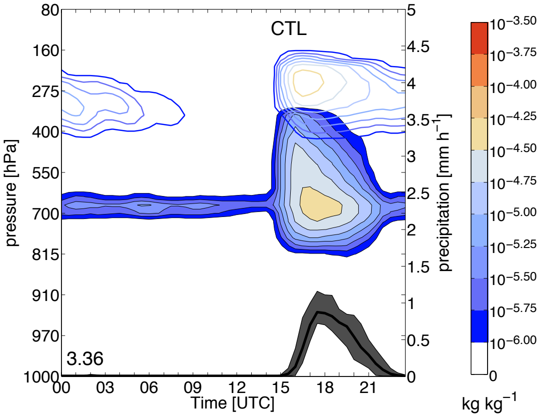
integration time 30d

day 16-30 used for evaluation

Asymptotic limit to flat-pressure gradient synoptic situations (in summertime over mid-Europe 1-2 weeks, e.g. July 2006)

Cloud water, cloud ice and precipitation

Control simulation



Mean diurnal cycle of domain mean quantities

Schlemmer et al. (2011), JAS

Set of simulations

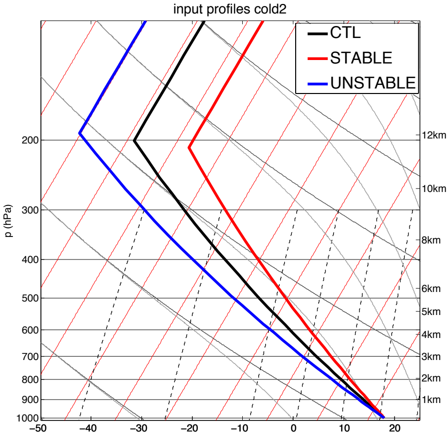
Different atmospheric lapse rates

CTL: $\frac{dT}{dz} = -0.7 \frac{K}{100m}$

STABLE: $\frac{dT}{dz} = -0.6 \frac{K}{100m}$

UNSTABLE: $\frac{dT}{dz} = -0.8 \frac{K}{100m}$

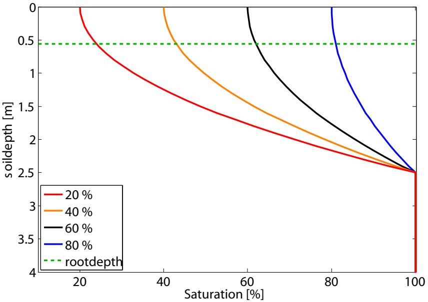
surface: 18°C, 1000 hPa



Set up

Soil moisture saturation close to the surface

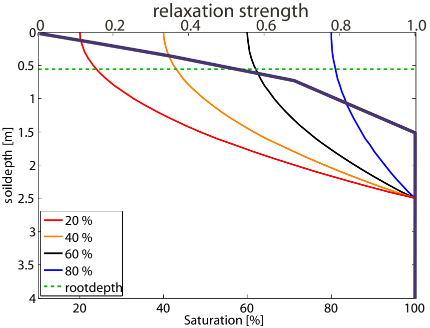
- 20 %
- 40 %
- 60 %
- 80 %



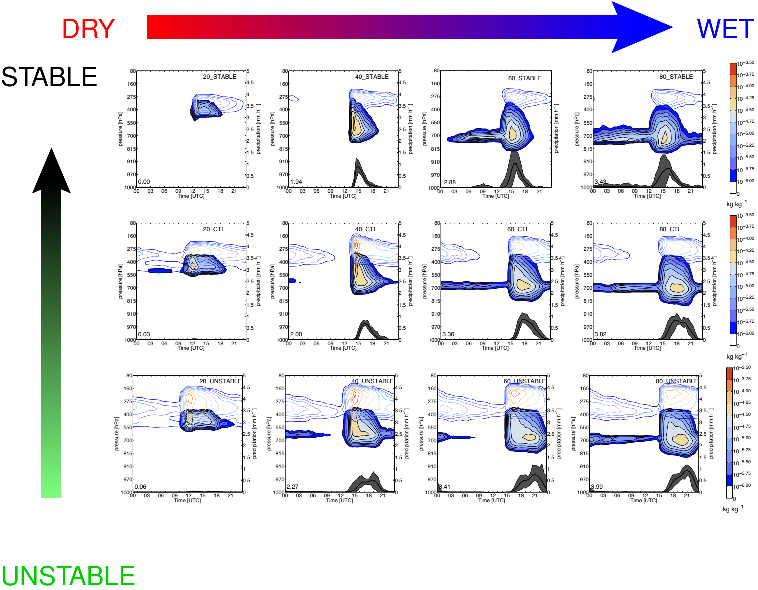
Set up

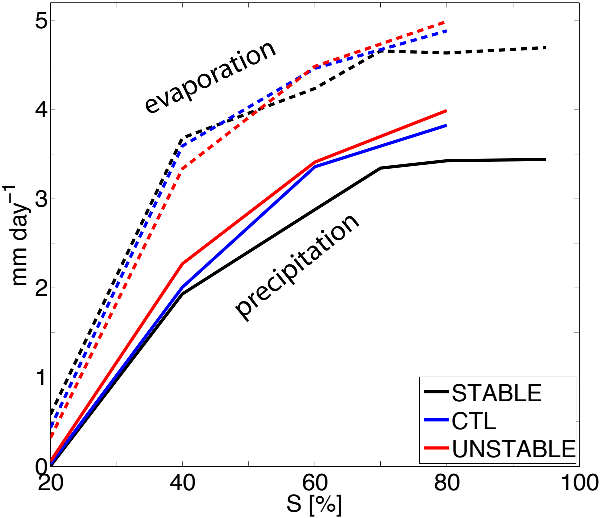
Soil moisture saturation close to the surface

- 20 %
- 40 %
- 60 %
- 80 %



Relaxation, τ_{soil}=1 day

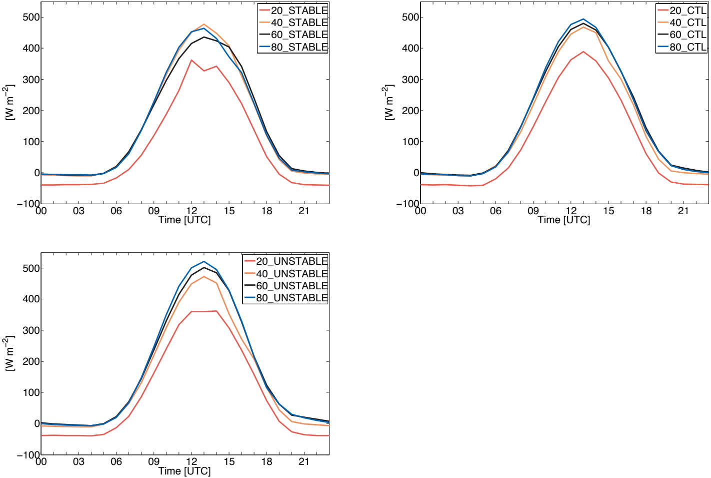

DRY
WET
STABLE
UNSTABLE
20_STABLE
40_STABLE
60_STABLE
80_STABLE
20_CTL
40_CTL
60_CTL
80_CTL
20_UNSTABLE
40_UNSTABLE
60_UNSTABLE
80_UNSTABLE
0.00
1.94
2.88
3.43
0.03
2.00
3.36
3.82
0.06
2.27
3.41
3.99
pressure [hPa]
Time [UTC]
precipitation [mm h^{-1}]
kg kg^{-1}



monotonic increase of evaporation and precipitation with soil moisture

⇒positive soil moisture-precipitation feedback

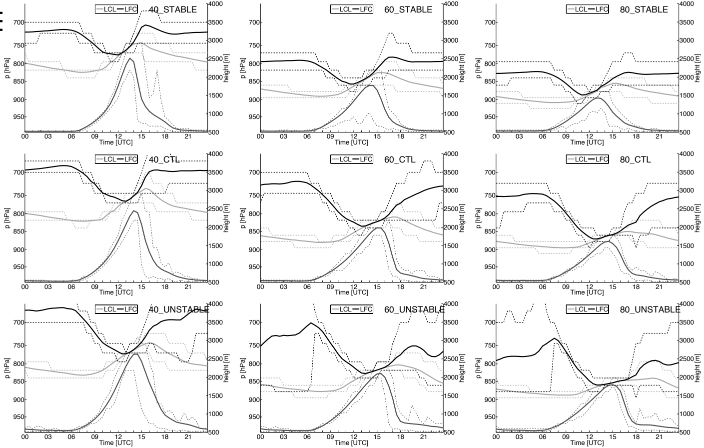
Available energy $Q=R_n$-G



LFC, LCL, PBL height

DRY → WET

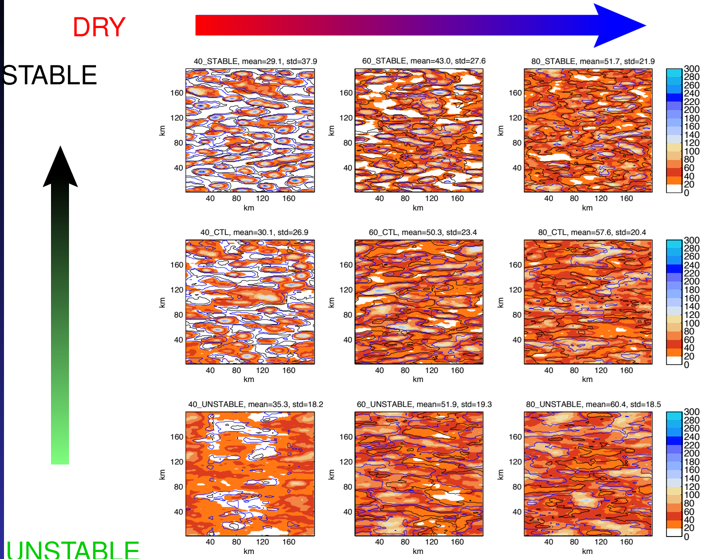
STABLE



UNSTABLE

cf. Findell and Eltahir (2003)

Spatial distribution of accumulated precipitation

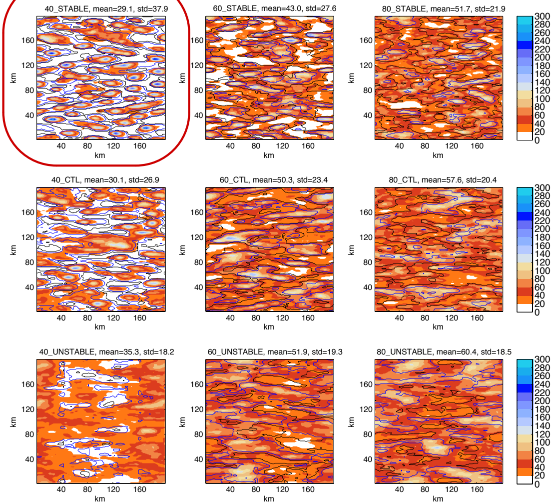


Spatial feedback acting at scales of $O(40\,\text{km})$, strongest for semi-arid regions and stable stratifications

Spatial distribution of accumulated precipitation

DRY → WET

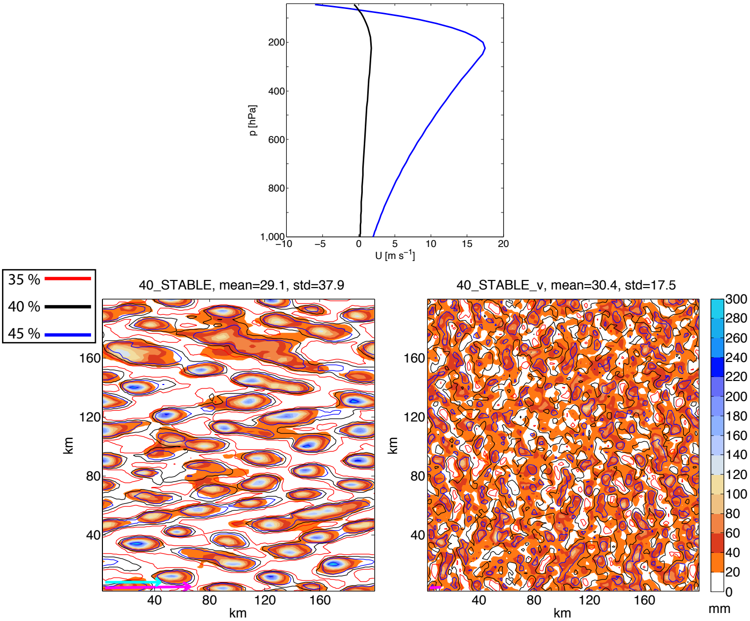
STABLE



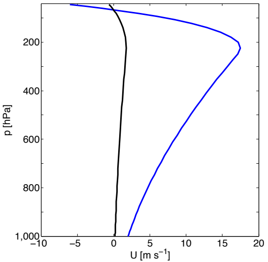
UNSTABLE

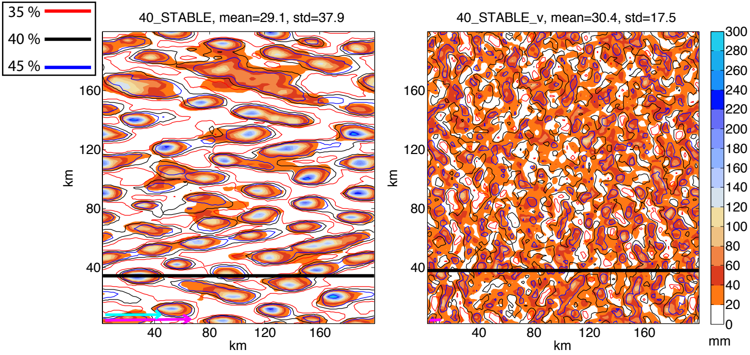
Spatial feedback acting at scales of $O(40\,\mathrm{km})$, strongest for semi-arid regions and stable stratifications

Wind Speed

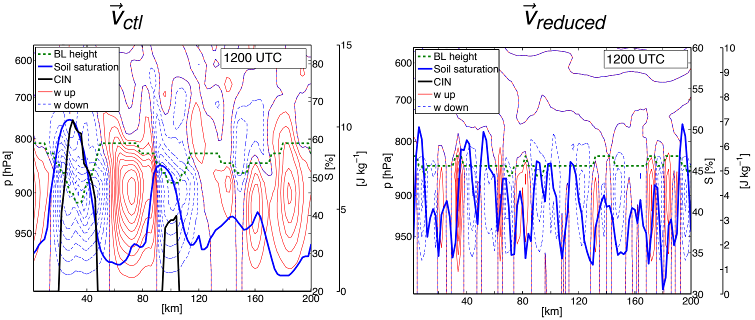

p [hPa]
200
400
600
800
1,000
−10
−5
0
5
10
15
20
U [m s−1]
35 %
40 %
45 %
40_STABLE, mean=29.1, std=37.9
40_STABLE_v, mean=30.4, std=17.5
km
40
80
120
160
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
mm

Wind Speed


p [hPa]
200
400
600
800
1,000
−10
−5
0
5
10
15
20
U [m s−1]


35 %
40 %
45 %
40_STABLE, mean=29.1, std=37.9
40_STABLE_v, mean=30.4, std=17.5
km
160
120
80
40
40
80
120
160
km
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
mm

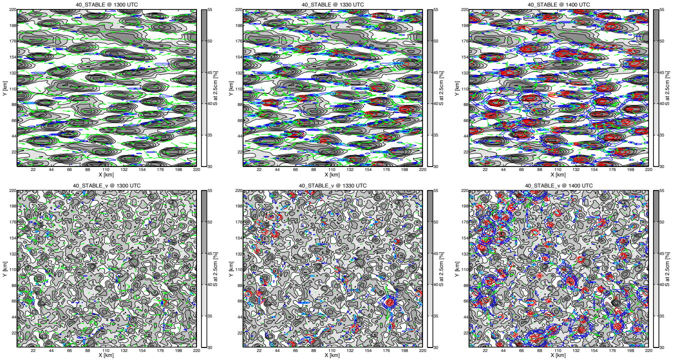
Cross sections



cf. e.g. Clark et al. (2004), Taylor et al. (2005), Taylor et al. (2010)

Triggering of single cells

1300 UTC 1330 UTC 1400 UTC



$\vec{v}_{ctl}$

$\vec{v}_{reduced}$

courtesy Paul Froidevaux

Summary

- Soil moisture has a decisive influence on the diurnal cycle of convection and precipitation amounts
- Unstable atmospheric profile: increase of soil moisture leads to more precipitation
- Stable atmospheric profile: increase of soil moisture leads to more clouds. Incoming shortwave radiation is blocked but outgoing longwave radiation is trapped $\Rightarrow$constant net radiation.
- Different triggering mechanisms for convection are identified (cf. Findell and Eltahir, 2003). The triggered convection transports moisture out of the boundary layer
- Positive feedback acting at spatial scales of $O(40\,\mathrm{km})$

Budget considerations

$$\frac{\partial W_{atm}}{\partial t} = L_v \cdot LE - PR + R \approx 0 \tag{1}$$

$$SW + LW + H + LE + G \approx 0 \tag{2}$$

- dry soil (ET below potential rate): soil cannot meet atmospheric demand, a decrease of soil moisture leads to a decrease of ET

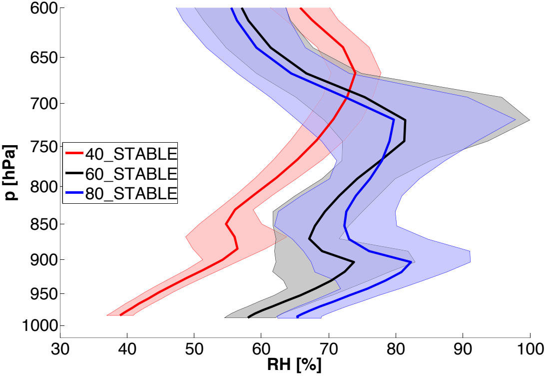
Budget considerations

$$\frac{\partial W_{atm}}{\partial t} = L_v \cdot LE - PR + R \approx 0 \tag{1}$$

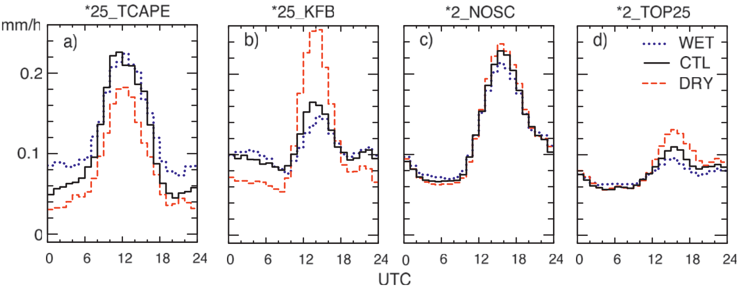
$$SW + LW + H + LE + G \approx 0 \tag{2}$$

- dry soil (ET below potential rate): soil cannot meet atmospheric demand, a decrease of soil moisture leads to a decrease of ET
- wet soil (ET at potential rate): reduction of potential evaporation
  - Reduction of available energy ($SW + LW$)
  - Increase of near-surface humidity (reduction of saturation deficit)

Relative humidity at 1200 UTC

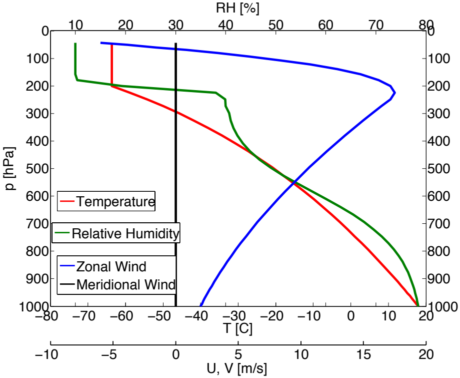


Moisture is transported out of the boundary layer by convection


*25_TCAPE
*25_KFB
*2_NOSC
*2_TOP25
mm/h
a)
b)
c)
d)
0.2
0.1
0
0
6
12
18
24
UTC
WET
CTL
DRY

Input profile = reference profile

constructed profiles: a few parameters to control the vertical structure of the atmosphere



Divergence