Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Assessing the sensitivity of moist convection to climate change within an idealized cloud-resolving modeling framework

WCRP conference,

Denver

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The diurnal cycle of moist convection over land

- impact on water and energy balance
- numerical modeling difficult, smaller than grid spacing of most current climate models
- difficulties of parameterizations to reproduce current climate (e.g. Bechtold et al., 2004, Brockhaus et al., 2008)
- large uncertainty in future projections of regional precipitation changes, large spread between different simulations of summer precipitation (e.g. Frei et al., 2006)

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⇒idealized cloud-resolving model (CRM)

- explicit resolution of deep, organized convection

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.

Model set-up

COSMO_CLM (CCLM) 4.0

- grid-spacing $0.02^{\circ} \triangleq 2.2km$
- 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

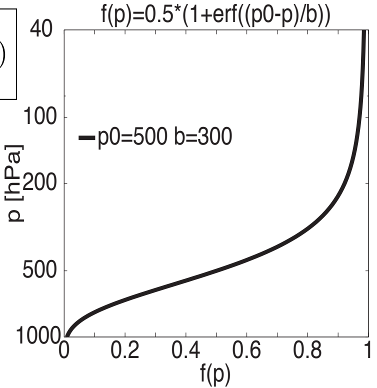
$$\left(\frac{\partial X}{\partial t}\right)_{relax} = -\frac{\overline{X} - X_{ref}}{\tau} \cdot f(p)$$

$X : T, Qv, U, V$

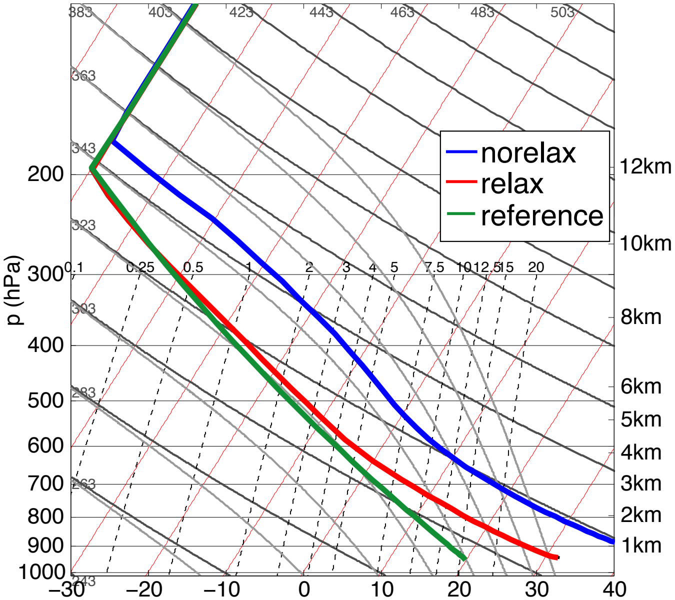
X_{ref}: reference profile

$\overline{X}$: spatial mean value

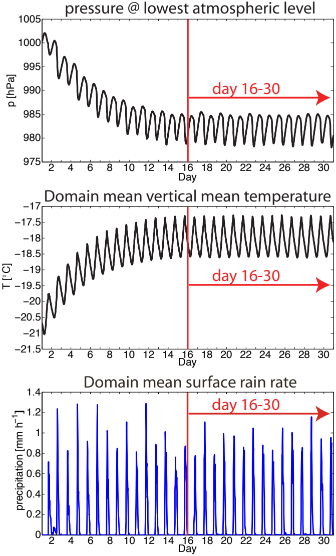
$\tau = 24h$



skewT mean @ 12UTC



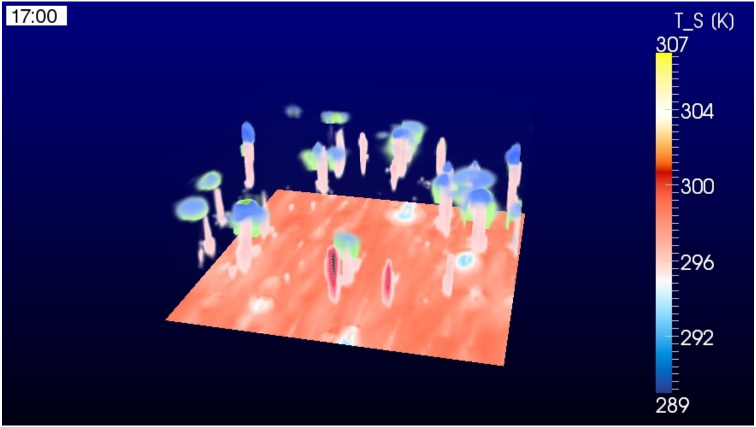
State of diurnal equilibrium



integration time 30d

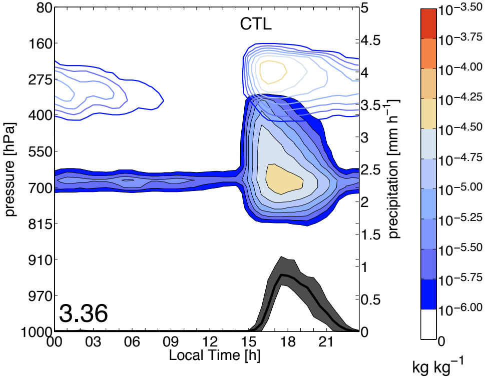
day 16-30 used for evaluation

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


17:00
T_S (K)
307
304
300
296
292
289

Cloud water, cloud ice and precipitation

Control simulation



Mean diurnal cycle of domain mean quantities

Schlemmer et al., (2011a), J. Atmos. Sci. 68, 5, 1041-1057.
Schlemmer et al., (2011b), Revised for Quart. J. Roy. Meteorol. Soc.

Projected anthropogenic climate changes

Intensification of the hydrological cycle

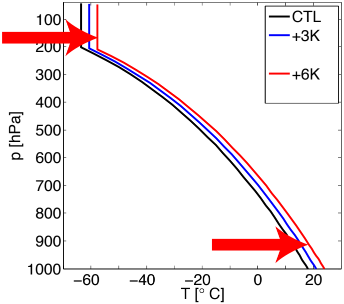
Precipitation

- increase of precipitation extremes that is greater than changes in mean precipitation (Kharin and Zwiers, 2005)
- mid-latitude land areas in summertime: both decrease of mean precipitation (droughts) and increase of precipitation extremes (e.g. Christensen and Christensen, 2003, Frei et al., 2006)
- Hourly precipitation extremes can even exceed expected increases from the Clausius Clapeyron equation for daily mean surface temperatures above 12°C (Lenderink and van Meijgaard, 2008, Allan et al., 2010)

Simulation strategy

CTL simulation

+ Homogeneous warming over the whole atmosphere (3 K, 6 K)

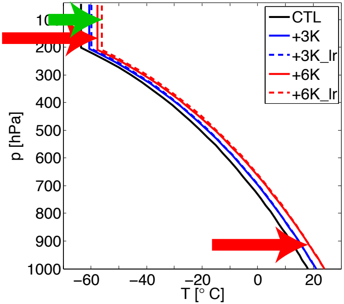


relative humidity constant for all simulations ⇒increased specific humidity for the warmer climates

Simulation strategy

CTL simulation

+ Homogeneous warming over the whole atmosphere (3 K, 6 K)
+ Inhomogeneous warming: Stabilization of the atmosphere

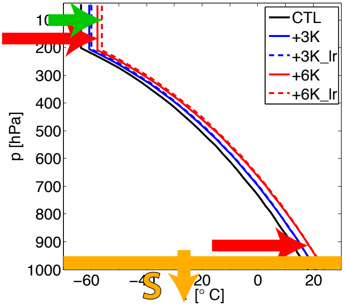


relative humidity constant for all simulations ⇒increased specific humidity for the warmer climates

Simulation strategy

CTL simulation

+ Homogeneous warming over the whole atmosphere (3 K, 6 K)
+ Inhomogeneous warming: Stabilization of the atmosphere
+ Drying of the soil during summertime, reduction of soil moisture saturation by 10%



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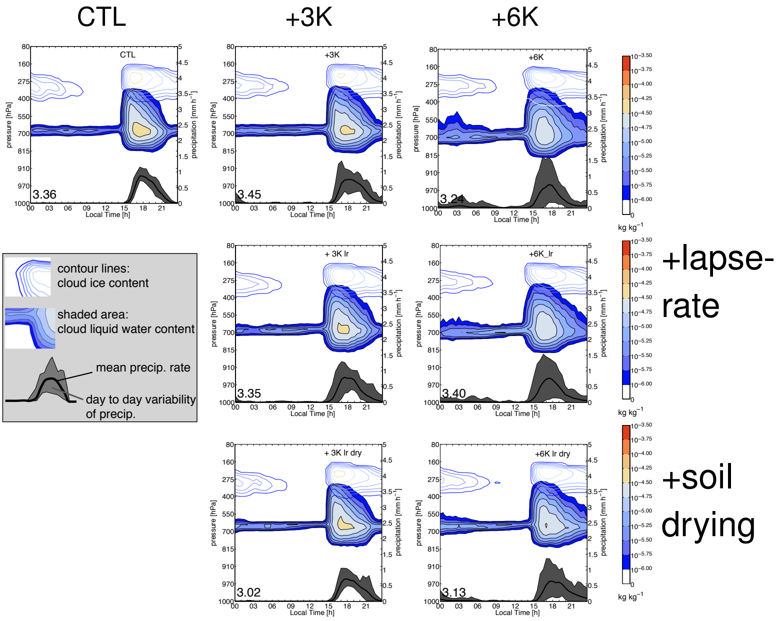
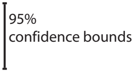
Simulations: Mean diurnal cycle of clouds



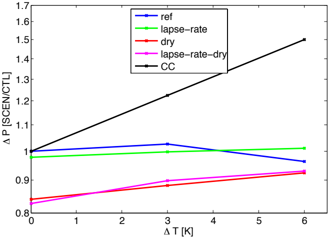
Precipitation extremes

Generalized extreme value distribution (Maximum likelihood fit)

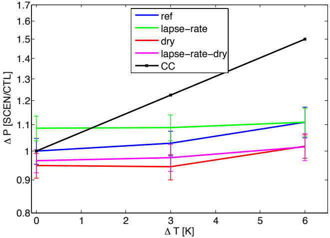
Maximum hourly precipitation sum in the domain at each day used as block maxima



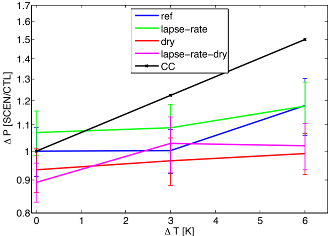
Mean values



10-day return levels



100-day return levels



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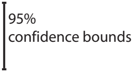
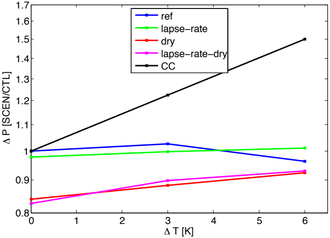
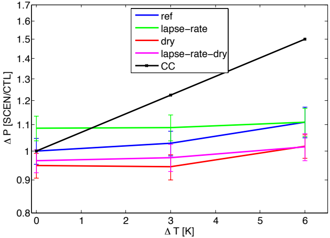


Mean values

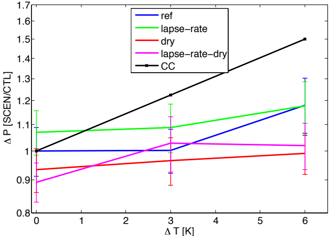


Increases in precipitation extremes smaller than expected from Clausius-Clapeyron Scaling

10-day return levels

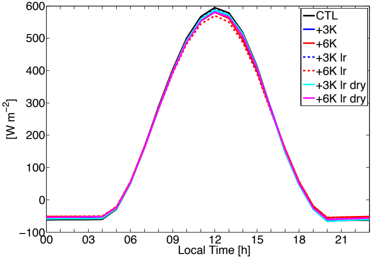


100-day return levels

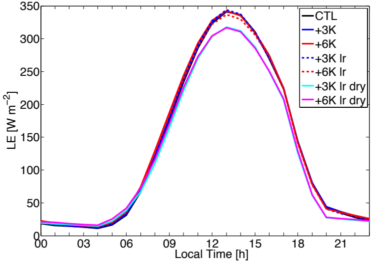


Evaporative control on precipitation

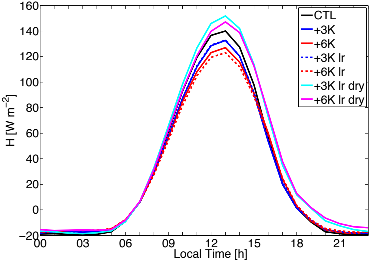
available energy (SW+LW)



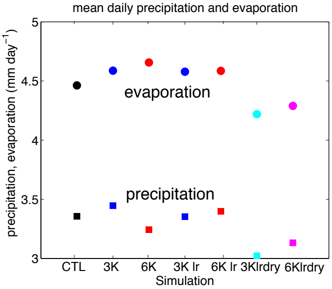
latent heat



sensible heat



evaporation, precipitation

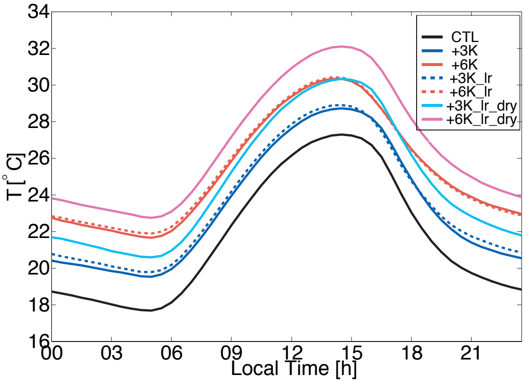


Summary

- Cloud water content increases with moderate warming but decreases for extreme warming
- Mean precipitation: small changes of both signs
- Extremes: increase with warming, especially in conjunction with stabilization
- Increases smaller than expected from Clausius-Clapeyron scaling (in contrast to previous studies)
- No large-scale moisture convergence in our setup (precipitation largely determined by surface evapotranspiration)
- Increases at the extremes due to larger day-to-day variability
- A drying of the soil decreases precipitation over all intensities

Near-surface temperatures

mean diurnal cycle of 2m temperatures



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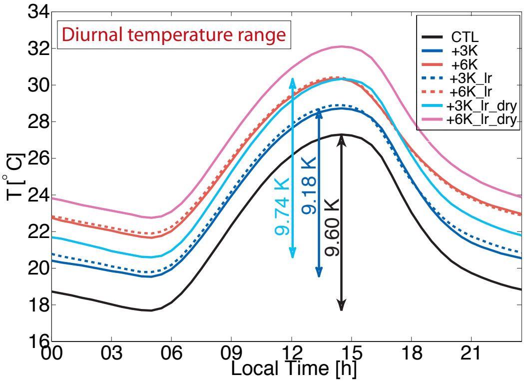


Decrease of the diurnal temperature range for warmer climates, increased diurnal temperature range over drier soils

Return level for maximum daily hourly precipitation sums

Simulation	mean mm/h	10 day mm/h	ΔP %	100 day mm/h	ΔP %
CTL	0.14	28.83±0.94		37.64±2.34	
3K	0.14	29.66±0.90	103	37.72±1.80	100
6K	0.13	31.75±1.18	110	40.63±2.31	108
CTL lr	0.14	31.30±0.97	109	40.28±2.06	107
3K lr	0.14	31.94±1.04	111	40.99±2.56	109
6K lr	0.14	32.00±1.26	111	44.30±3.00	118
CTL dry	0.12	27.36±0.81	94.9	35.17±1.74	93.4
3K dry	0.12	27.22±0.88	94.4	36.36±2.13	96.6
6K dry	0.13	24.51±0.78	85.0	29.57±1.51	78.6
CTL lr dry	0.12	27.83±0.70	96.5	33.65±1.15	89.4
3K lr dry	0.13	28.15±1.05	97.6	38.73±3.03	103
6K lr dry	0.13	29.28±1.06	102	38.42±2.15	102

CAPE

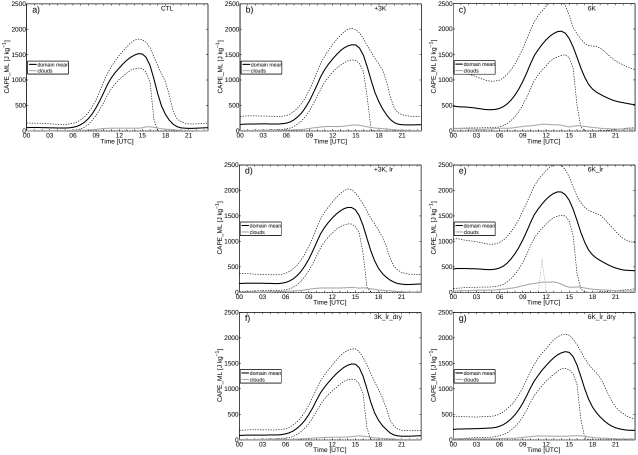


Figure 4.4: *Mean diurnal cycle of CAPE ($J\,kg^{-1}$) with domain mean values in black and cloudy points in grey for (a) CTL, (b) 3K, (c) 6K, (d) 3K_lr, (e) 6K_lr, (f) 3K_lr_dry and (g) 6K_lr_dry. Mean values are shown by the solid lines while the 10th and 90th percentile are shown by the dashed lines. The 10th and 90th percentile were calculated by considering all grid points on all 15 days.*

Convective mass flux

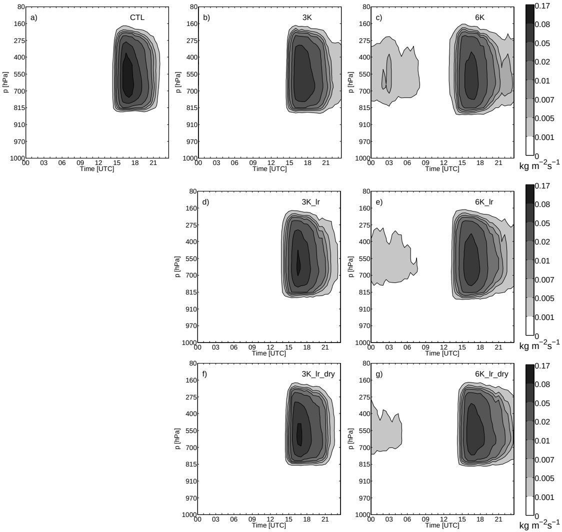
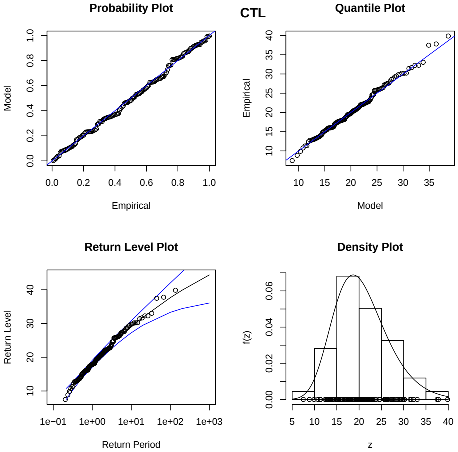
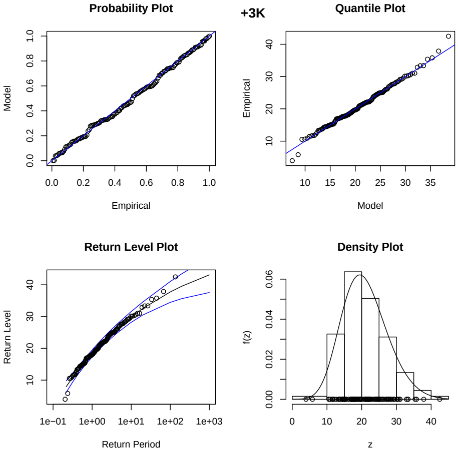
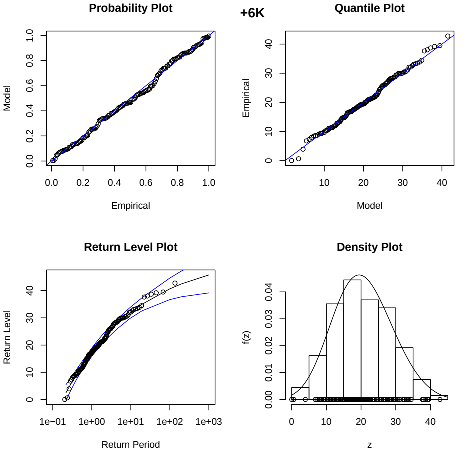
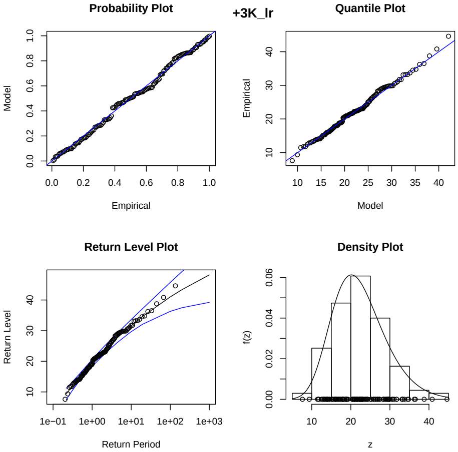


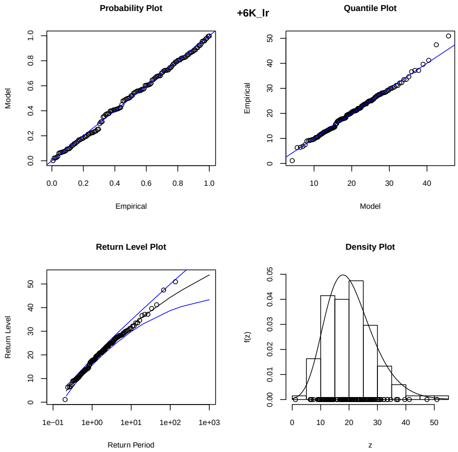
Figure 4.5: *Mean diurnal cycle of convective mass-flux (kg m^{-2} s^{-1}) for the set of simulations.*

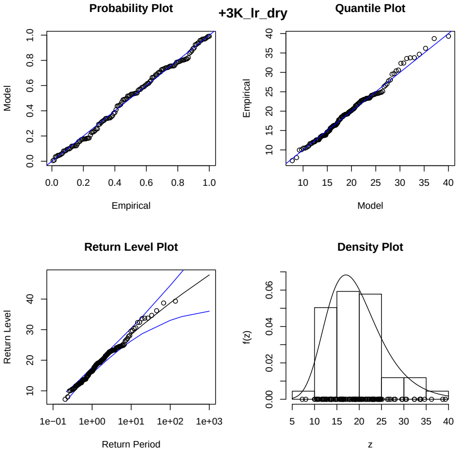

CTL
Probability Plot
Model
Empirical
0.0
0.2
0.4
0.6
0.8
1.0
Quantile Plot
Empirical
Model
10
15
20
25
30
35
40
Return Level Plot
Return Level
Return Period
1e−01
1e+00
1e+01
1e+02
1e+03
Density Plot
f(z)
z
0.00
0.02
0.04
0.06
5
10
15
20
25
30
35
40

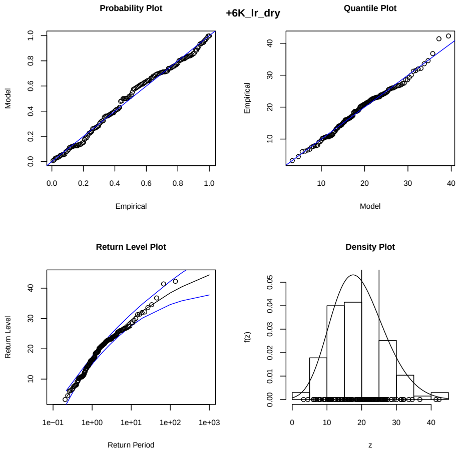

+3K
Probability Plot
Model
Empirical
0.0
0.2
0.4
0.6
0.8
1.0
Quantile Plot
Empirical
Model
10
15
20
25
30
35
40
Return Level Plot
Return Level
Return Period
1e−01
1e+00
1e+01
1e+02
1e+03
Density Plot
f(z)
z
0.00
0.02
0.04
0.06
0
10
20
30
40


+6K
Probability Plot
Model
Empirical
0.0
0.2
0.4
0.6
0.8
1.0
Quantile Plot
Empirical
Model
0
10
20
30
40
Return Level Plot
Return Level
Return Period
1e−01
1e+00
1e+01
1e+02
1e+03
Density Plot
f(z)
z
0.00
0.01
0.02
0.03
0.04


+3K_lr
Probability Plot
Model
Empirical
0.0
0.2
0.4
0.6
0.8
1.0
Quantile Plot
Empirical
Model
10
15
20
25
30
35
40
Return Level Plot
Return Level
Return Period
1e−01
1e+00
1e+01
1e+02
1e+03
Density Plot
f(z)
z
0.00
0.02
0.04
0.06


+6K_lr
Probability Plot
Model
Empirical
0.0
0.2
0.4
0.6
0.8
1.0
Quantile Plot
Empirical
Model
0
10
20
30
40
50
Return Level Plot
Return Level
Return Period
1e−01
1e+00
1e+01
1e+02
1e+03
Density Plot
f(z)
z
0.00
0.01
0.02
0.03
0.04
0.05


+3K_lr_dry
Probability Plot
Model
Empirical
0.0
0.2
0.4
0.6
0.8
1.0
Quantile Plot
Empirical
Model
10
15
20
25
30
35
40
Return Level Plot
Return Level
Return Period
1e−01
1e+00
1e+01
1e+02
1e+03
Density Plot
f(z)
z
0.00
0.02
0.04
0.06
5


+6K_lr_dry
Probability Plot
Model
Empirical
Quantile Plot
Empirical
Model
Return Level Plot
Return Level
Return Period
Density Plot
f(z)
z