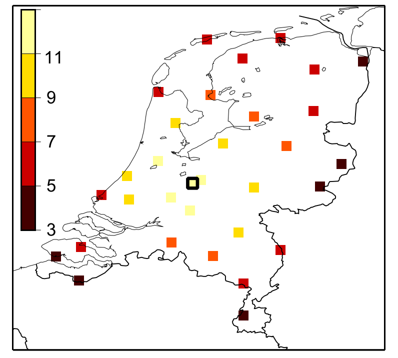
Using a dew point temperature scaling framework to interpret changes in hourly extremes from convection-permitting model simulations

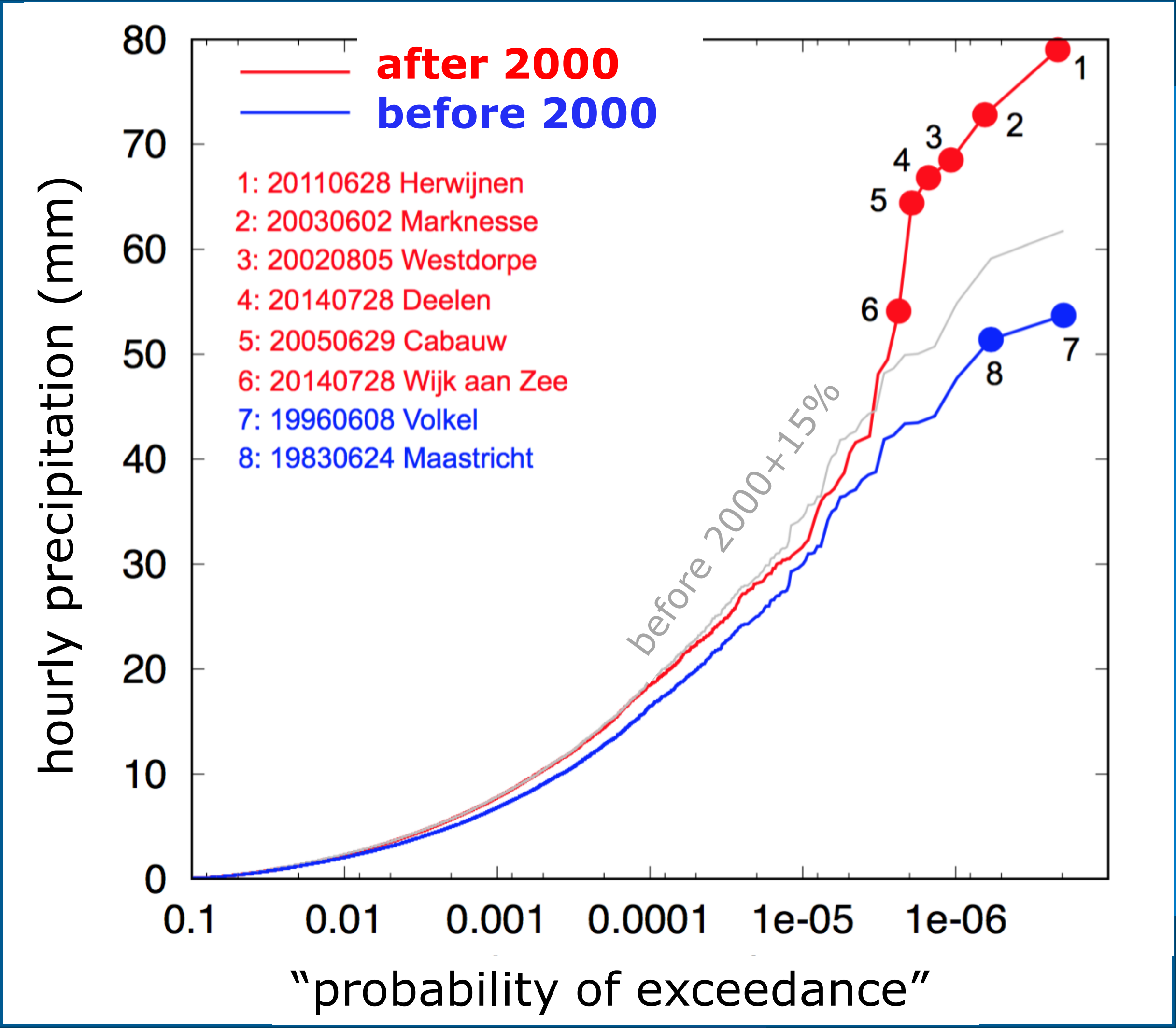
Geert Lenderink (KNMI, TUD)

Erik van Meijgaard, Hylke de Vries, Bert van Ulft, Renaud Barbero, Hayley Fowler & Kai Lochbihler

Hourly precipitation extremes measured at KNMI stations: before and after 2000



Number of stations not constant over time, but total number of observations before and after 2000 are ~ equal



1. Until 25 mm/hour change +15 % in amounts
2. Five unprecedented high values after 2000 (> 60 mm/hour)

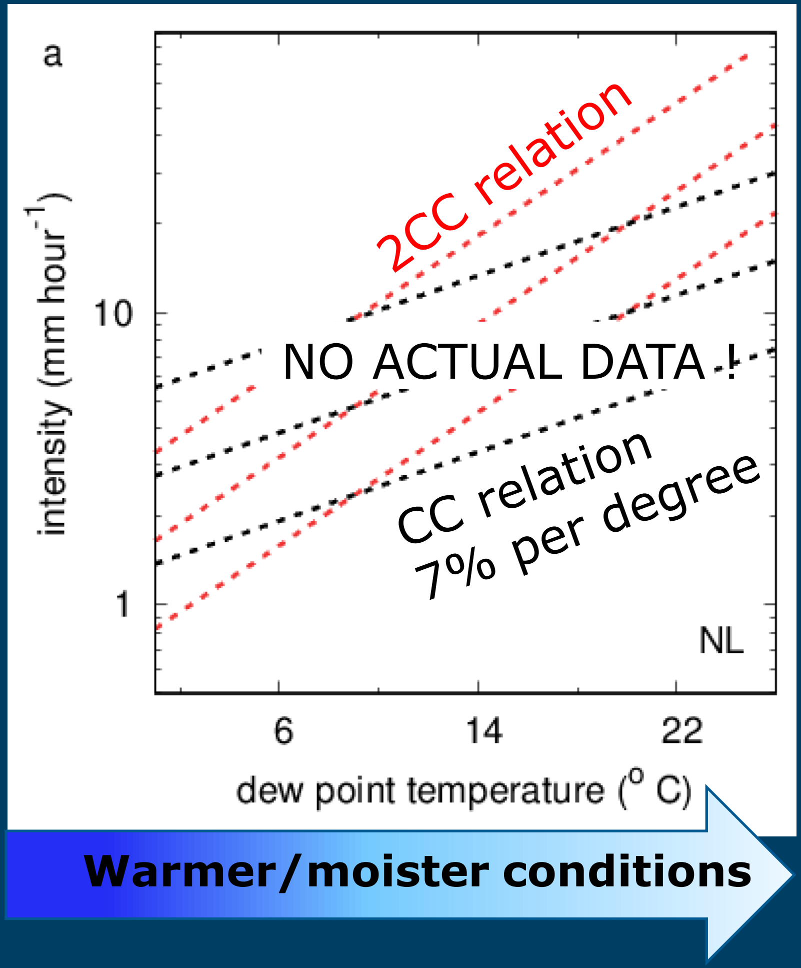
(note, given station inhomogeneities the statistical interpretation is non-trivial)

A short course in atmospheric thermodynamics

- **Dew point temperature**:
  - Temperature at which the air reaches saturation when cooled
  - Measure of the amount of atmospheric water vapor (**absolute humidity**)
  - 1-degree warming equals 6-7% more water vapor **(Clausius-Clapeyron relation)**
  - Typical range summer: 8-22 ^{o}C (>22 ^{o}C tropical)
- Relative humidity:
  - Ratio between saturation water vapor at a temperature and the actual amount of water vapor
  - **At constant relative humidity: 1-degree temperature rise implies a ~1-degree dew point temperature rise**

Scaling
precipitation extremes on (dew point) temperature

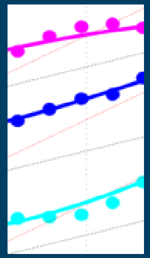
- Pair hourly precipitation with near surface (dew point) temperature
- Pool data based on dew point temperature into bins, typically 2 degrees wide
- From binned pooled data compute percentiles hourly precipitation e.g. 99th percentile ± highest 1% precipitation (usually taking only wet events)



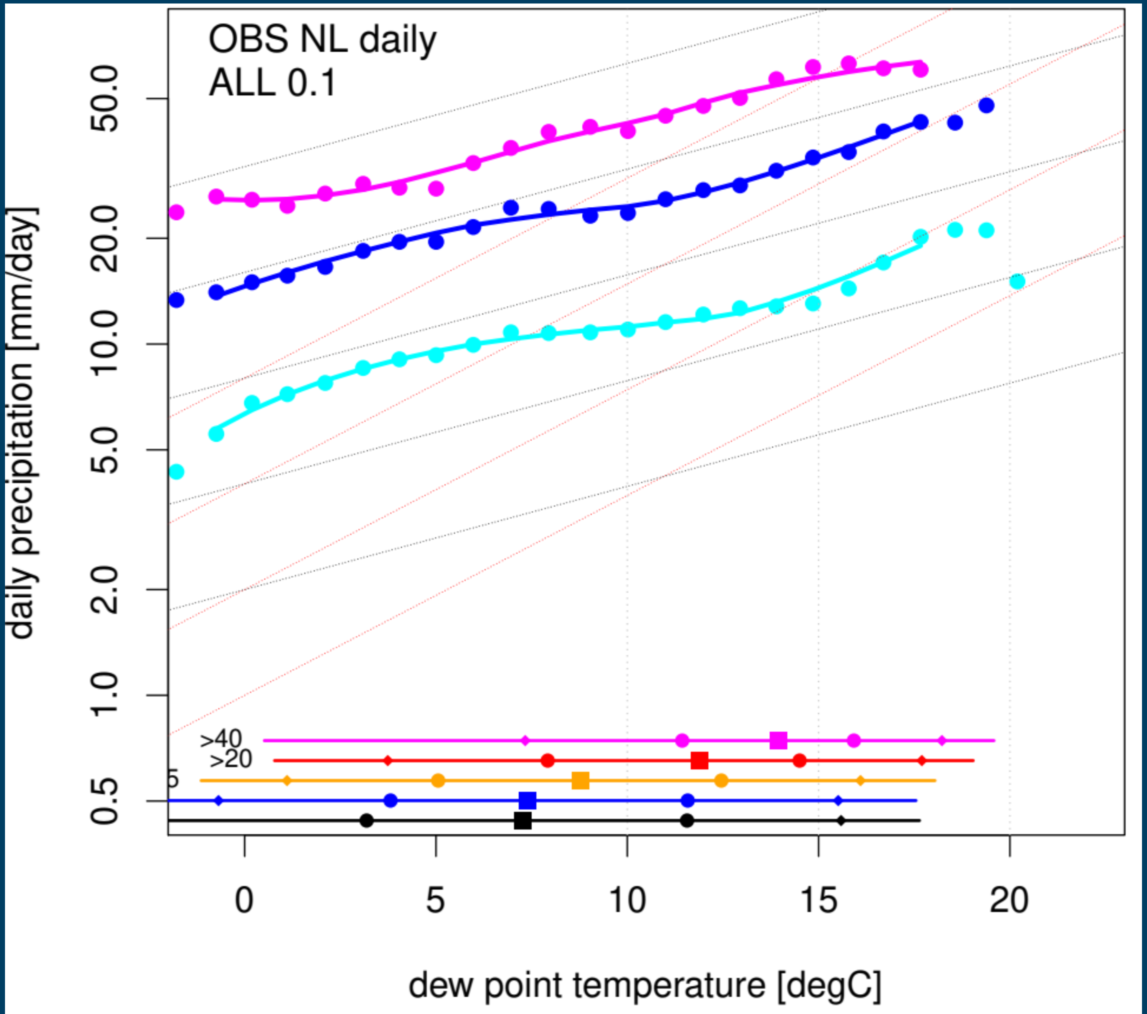
logarithmic y-axis

Scaling of daily precipitation extremes

Once every

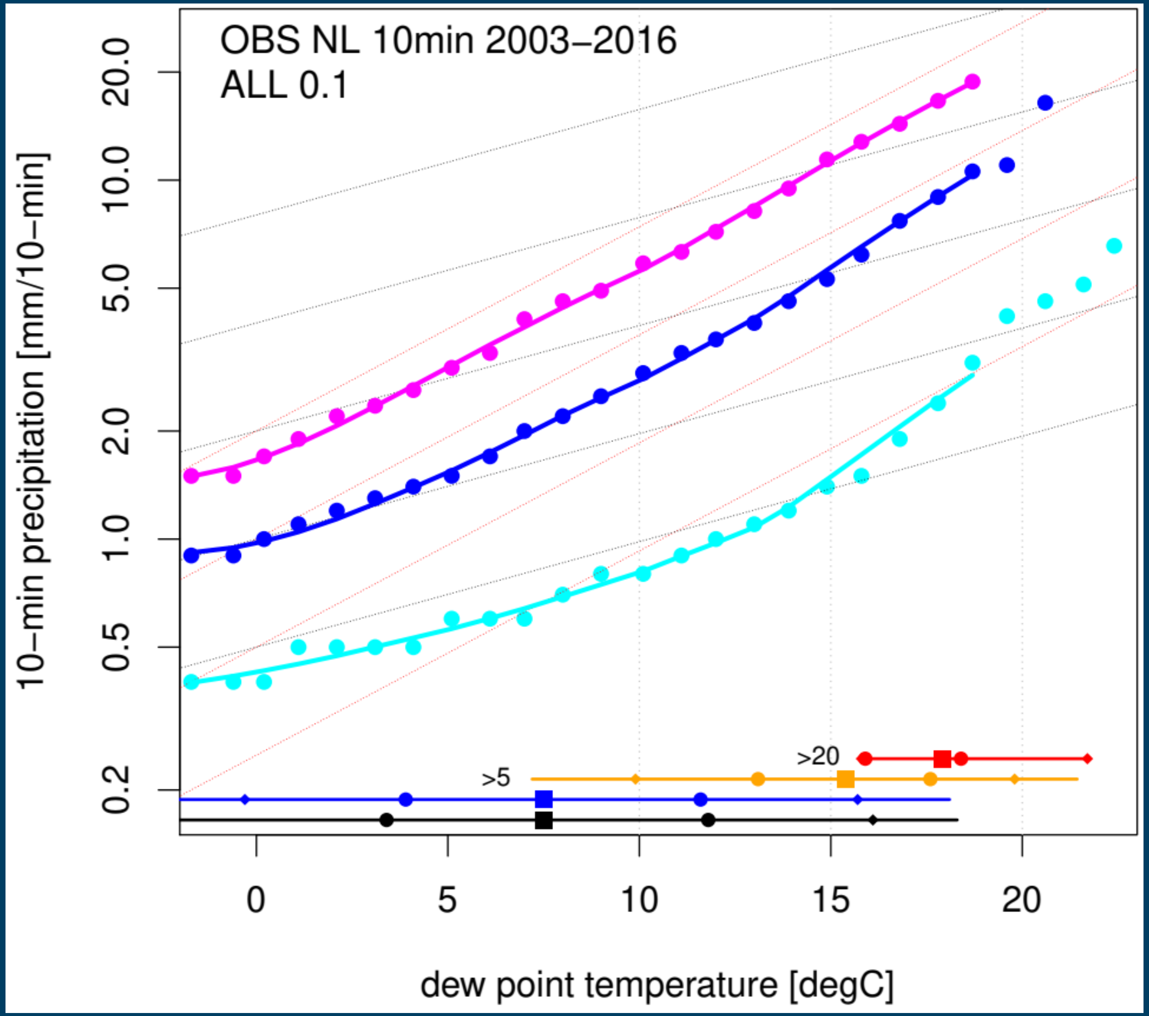


days (hours) with rain



- No surprises
- Extremes follow approximately the Clausius-Clapeyron prediction:
  - each degree of warming in dew point is equivalent to 6-7% more moisture and results in 6-7% more rainfall
- fit is not very good for daily rainfall

Scaling of **10-min** precipitation extremes



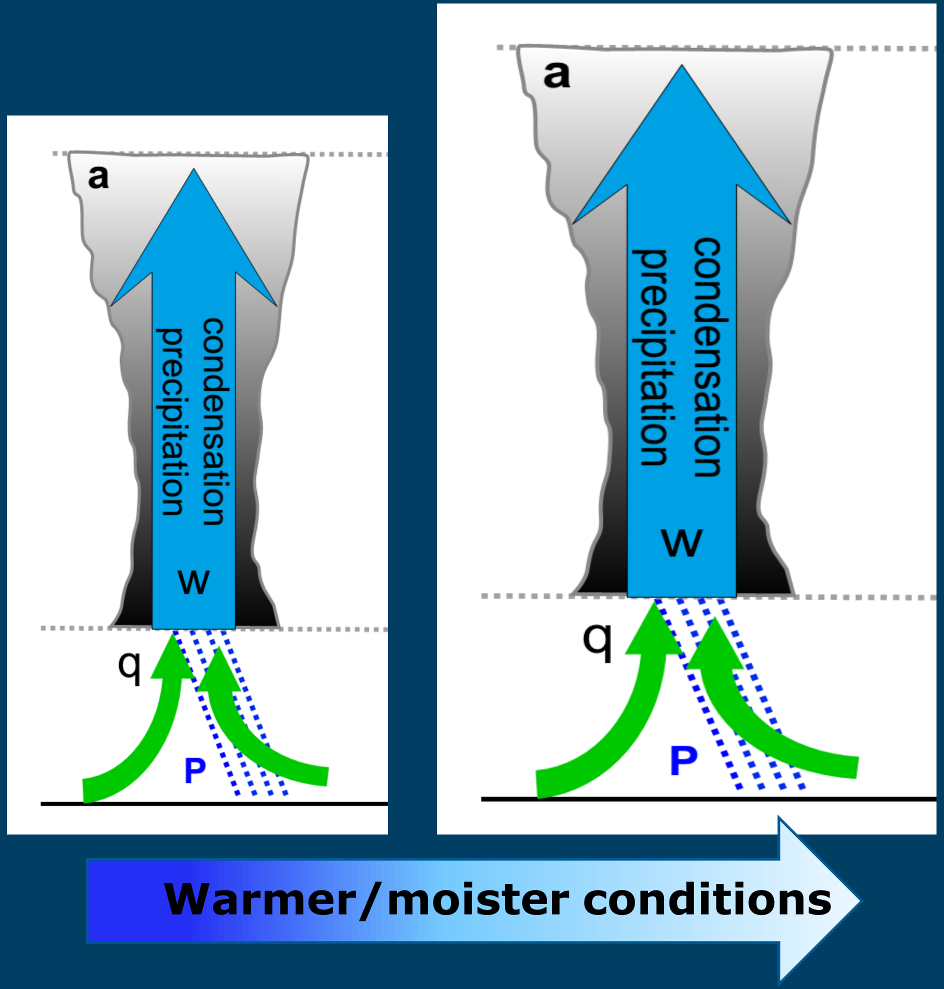
- A big difference, much stronger dependencies on dew point temperature
- Extremes follow approximately the 2 times the Clausius-Clapeyron prediction, 2CC:
  - each degree of warming in dew point is equivalent to 6-7% more moisture, **but** results in 12-14 % more rainfall
- Note the more regular behaviour

How is super-CC (>7% per degree) scaling possible?

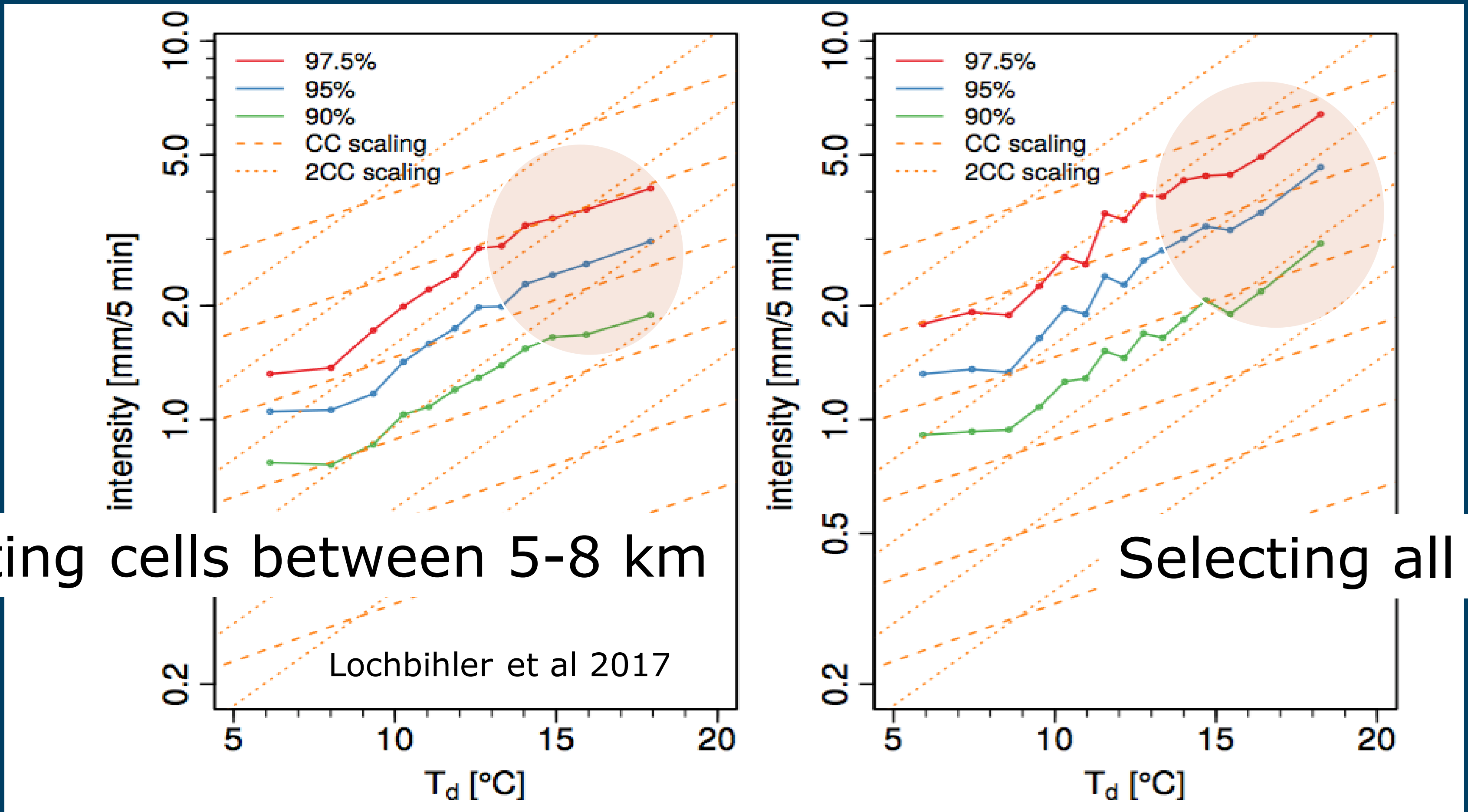
Hypothesis:
Latent heat produced by condensation can feedback on to cloud dynamics, and lead to stronger/bigger clouds under warmer conditions

the same rate as the moisture increase, namely 7% K^{-1} with warming. In fact the rate of increase can even exceed this because the additional latent heat released feeds back and invigorates the storm that causes the rain in the first place, further enhancing convergence of moisture.'

Trenberth et al. 2003, BAMS



Can we see evidence for this mechanism? statistics from tracking rain cells in rain radar (NL)

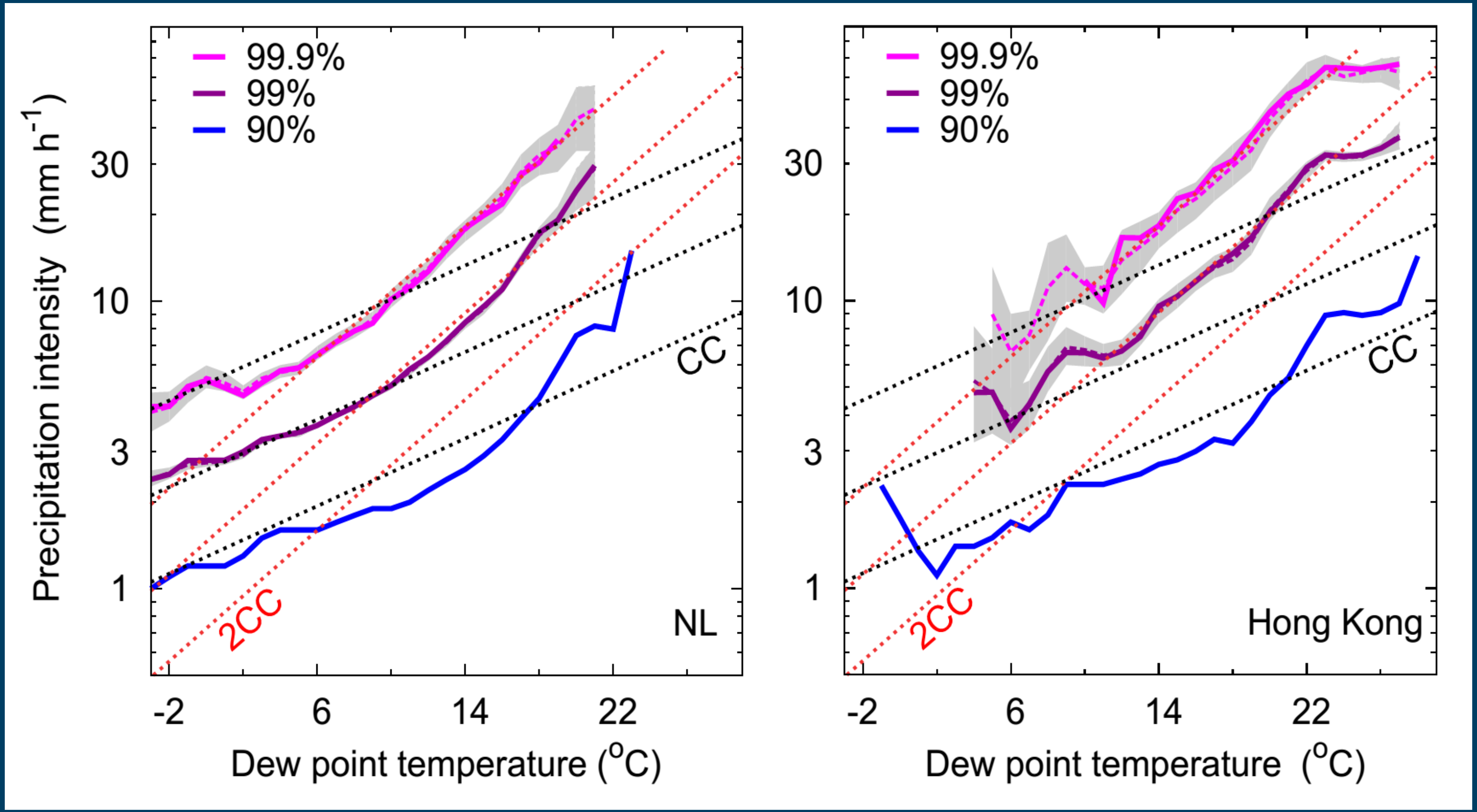


Sub-selecting cells between 5-8 km

Selecting all cells >5 km

Lochbihler et al 2017

Some degree of universality in scaling hourly rainfall in The Netherlands and Hong Kong



Note:

- Only found using *dew point* temperature
- Both are moist climate zones (close to ocean)
- Different relations found (less steep) for more continental areas
- Decrease/No sensitivity above 22 ^{o}C

A “heated” debate on scaling

nature geoscience
PERSPECTIVE
PUBLISHED ONLINE: 27 MARCH 2017 | DOI: 10.1038/NGEO2911

Complexity in estimating past and future extreme short-duration rainfall

Xuebin Zhang[1]*, Francis W. Zwiers[2], Guilong Li[1], Hui Wan[1] and Alex J. Cannon[3]

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RMetS Royal Meteorological Society

Short Communication

Temperature-extreme precipitation scaling: a two-way causality?

R. Barbero,[a,b]* S. Westra,[c] G. Lenderink[d] and H. J. Fowler[a]

LETTERS
PUBLISHED ONLINE: 16 JANUARY 2017 | DOI: 10.1038/NCLIMATE3201
nature climate change

Future increases in extreme precipitation exceed observed scaling rates

Jiawei Bao*, Steven C. Sherwood*, Lisa V. Alexander and Jason P. Evans

SHORT COMMUNICATION

Comments on “temperature-extreme precipitation scaling: A two-way causality?”

Jiawei Bao, Steven C. Sherwood, Lisa V. Alexander, Jason P. Evans

Received: 2 May 2018 | Revised: 4 July 2018 | Accepted: 8 July 2018
DOI: 10.1002/joc.5799
International Journal of Climatology RMetS

SHORT COMMUNICATION

Reply to comments on “Temperature-extreme precipitation scaling: a two-way causality?”

Geert Lenderink[1] | Renaud Barbero[2] | Seth Westra[3] | Hayley J. Fowler[4]

Does scaling relate to climate change?


LETTERS

Increase in hourly precipitation extremes beyond expectations from temperature changes

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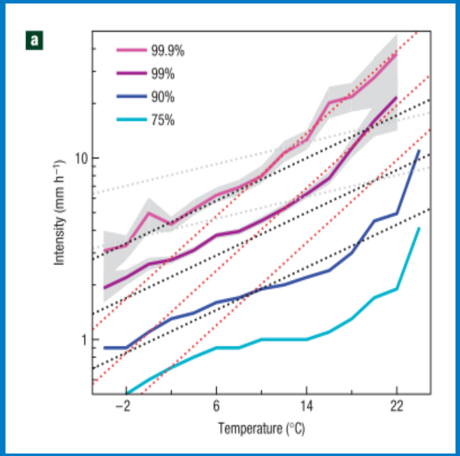
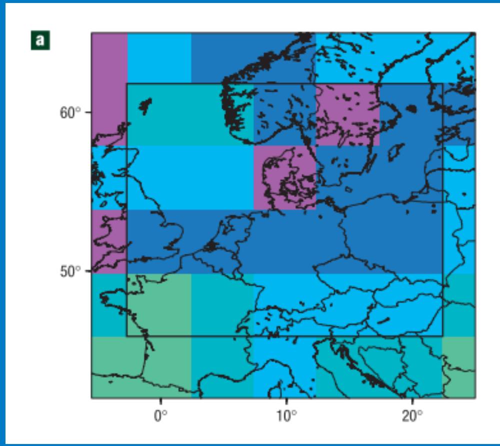
Nature geoscience **2008**



14% per degree as a predictor of the response of extremes to climate change?



Observations mostly affected by present-day climate variability

Long term climate change response in a (at that time start-of-art) climate model, 25 km resolution)

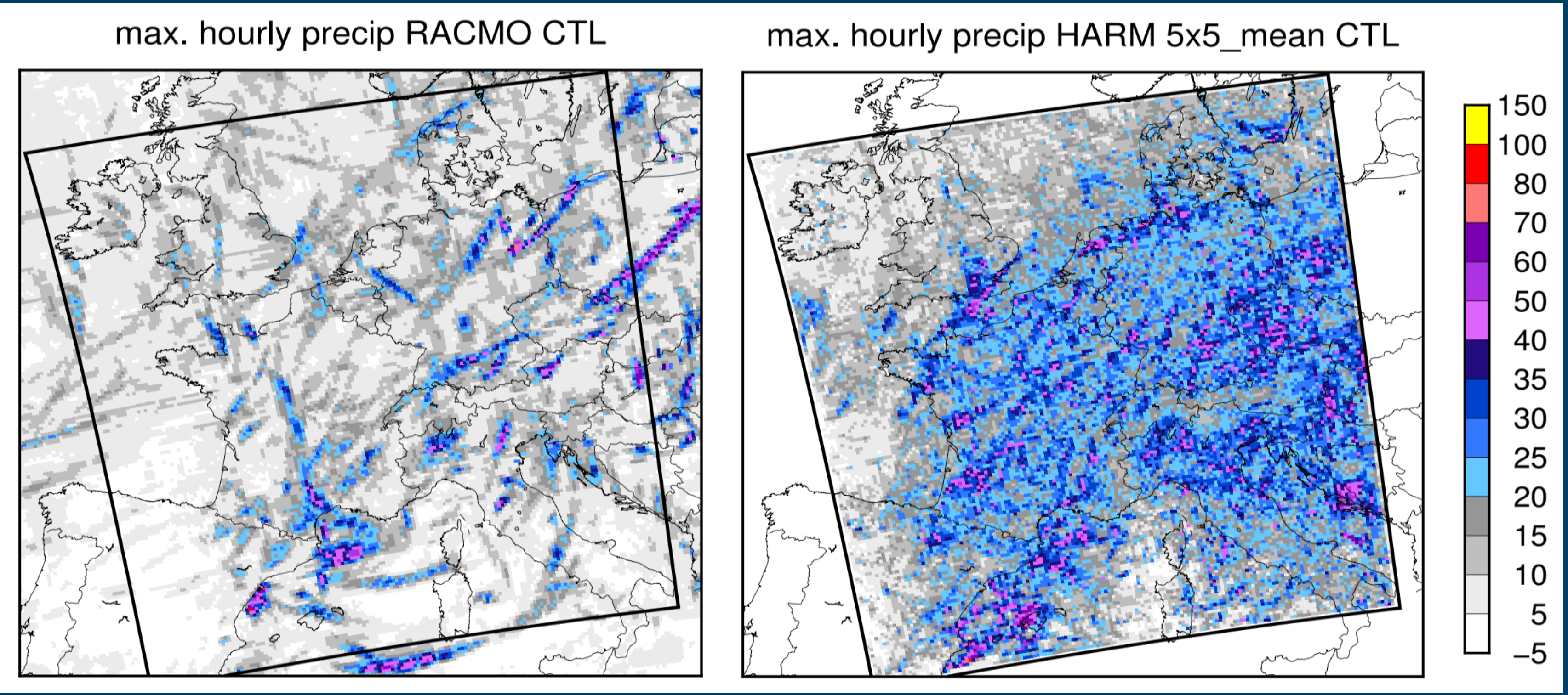
We know in **2020**

- Temperature is not the appropriate variable -> use of dew point temperature
- **The hydrostatic model used in 2008 is likely not good enough to look at hourly extremes**
- **Dependencies derived from present-day climate variability may be different from long-term response**

Hydrostatic (old generation, 12km) versus convection-permitting (new generation, 2.5 km) model

Max. hourly precipitation over 10 summer months (both @ 12x12km2 scale)

Hydrostatic model:
- Generally too low intensities
- Very few, very intense and very organized showers



Convection permitting model:
- Generally higher intensities
- More evenly distributed
- Much more realistic

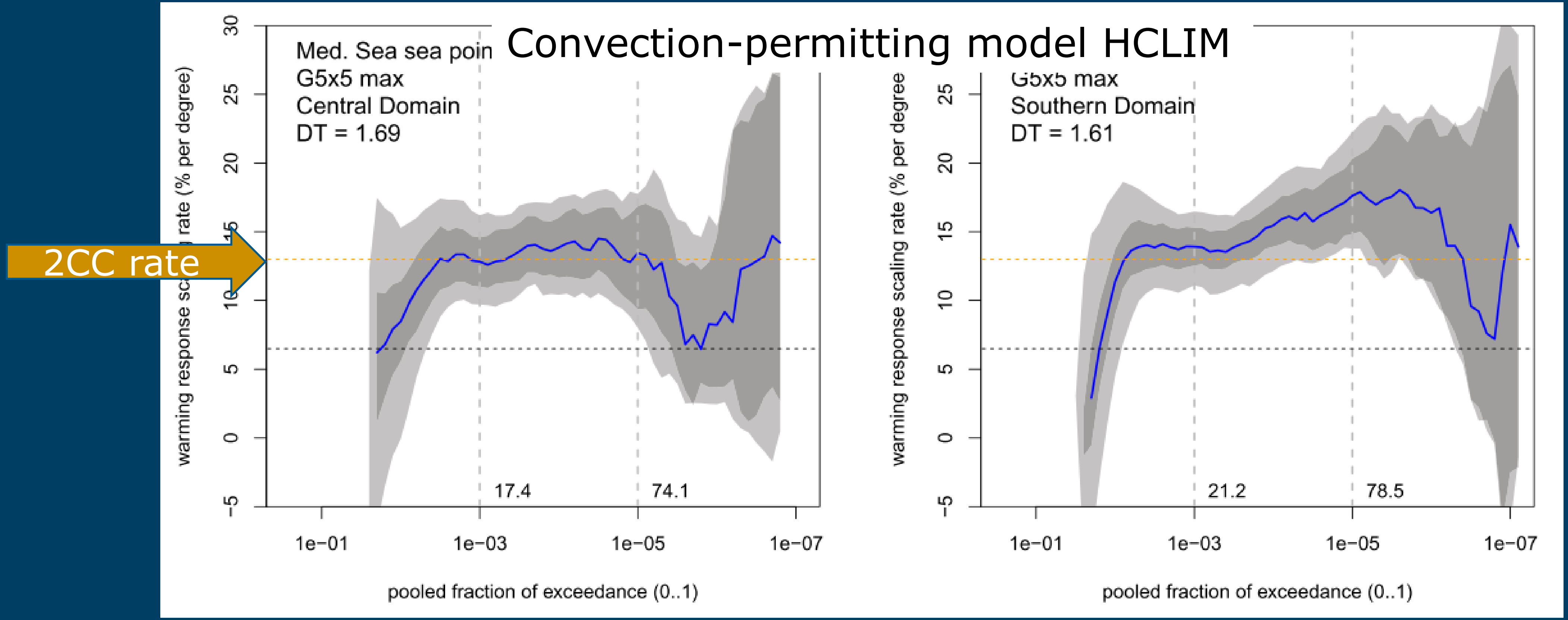
Scaling is not necessarily a good indicator for the climate change response in precipitation extremes

- Scaling is "assumed" to represent predominantly the *thermodynamic* response: the humidity influence, including direct cloud feedbacks, on precipitation extremes (amount/intensity)[1].
- Yet, other effects may play a role as well, at least in a climate change context:
  - large-scale circulation changes
  - atmospheric stability changes, changes in relative humidity
  - changes in the frequency of rain
- **How much does this matter?**

[1] Lenderink et al. J. Climate 2017

A simple warming experiment to estimate the thermodynamic response; response in hourly extremes over Mediterranean sea

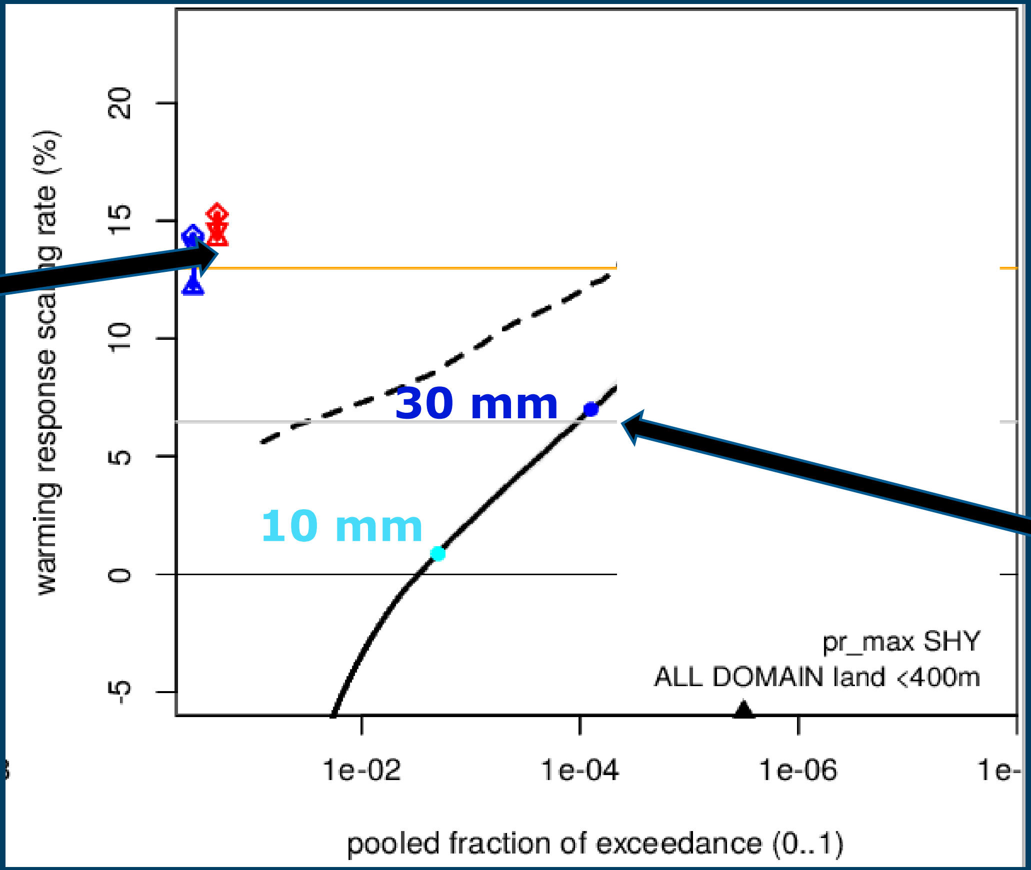
10 summer months | 10 autumn months



Lenderink et al. ERL 2019

A full (GCM driven) climate change experiment response in hourly extremes over western EU continent

Present-day modelled derived “apparent” scaling ~14 % per degree (consistent with observations)



Harmonie-climate (HCLIM) @ 2.5 km resolution

2089-2099 vs. 1996-2005

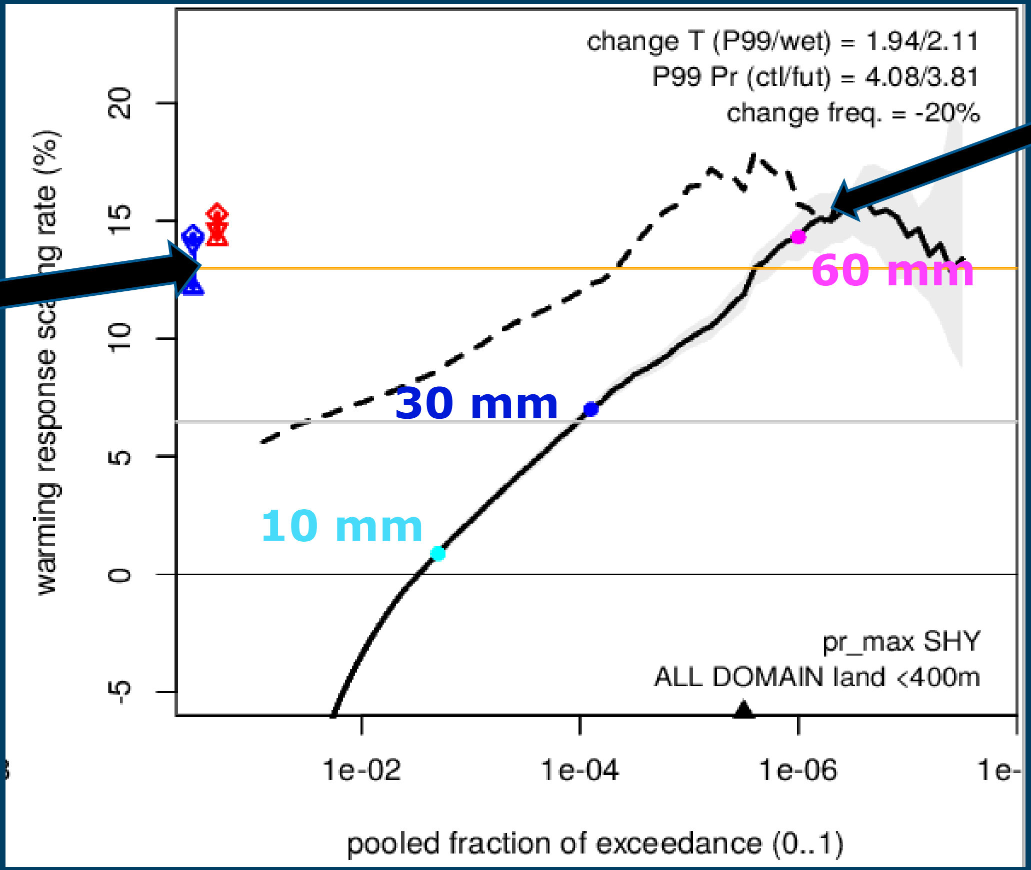
Boundaries: ECEARTH global climate model

Response normal extremes (~30 mm/hour in control climate) approximately 7 % per degree (CC rate)

Lenderink et al. 2020, in draft

A full (GCM driven) climate change experiment response in hourly extremes over western EU continent

Present-day derived “apparent” scaling ~14 % per degree



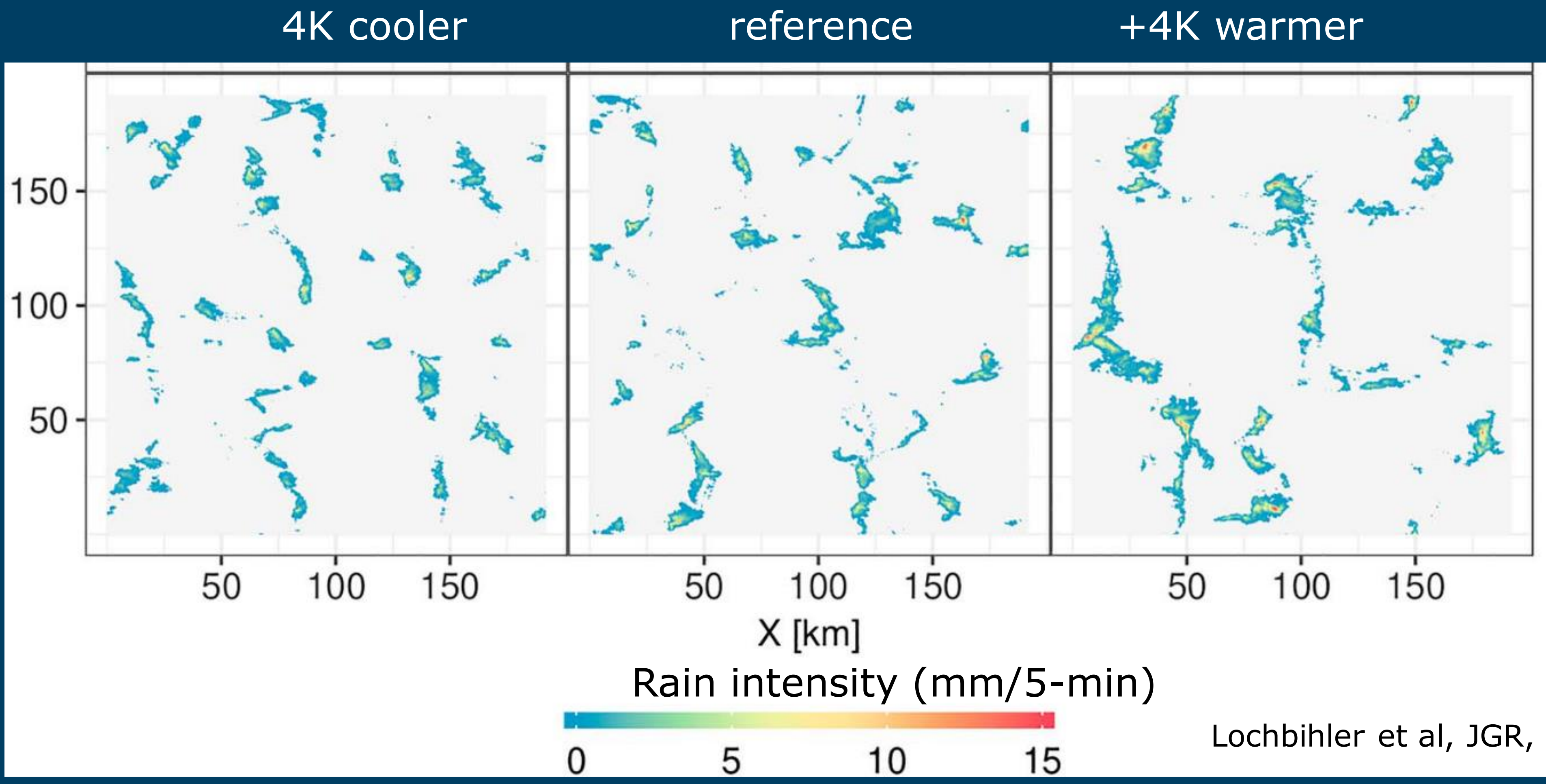
Response strongest extremes (~60 mm/hour in control climate) approximately 14 % per degree (2CC rate)

Similar behaviour is found a different 10-year experiment with HCLIM

Yet, others appear to find contradictory results

Lenderink et al. Philosophical Transactions A, INTENSE special issue (in prep.)

Learning from even higher resolution models
Large eddy simulation @200m resolution to study cloud dynamics



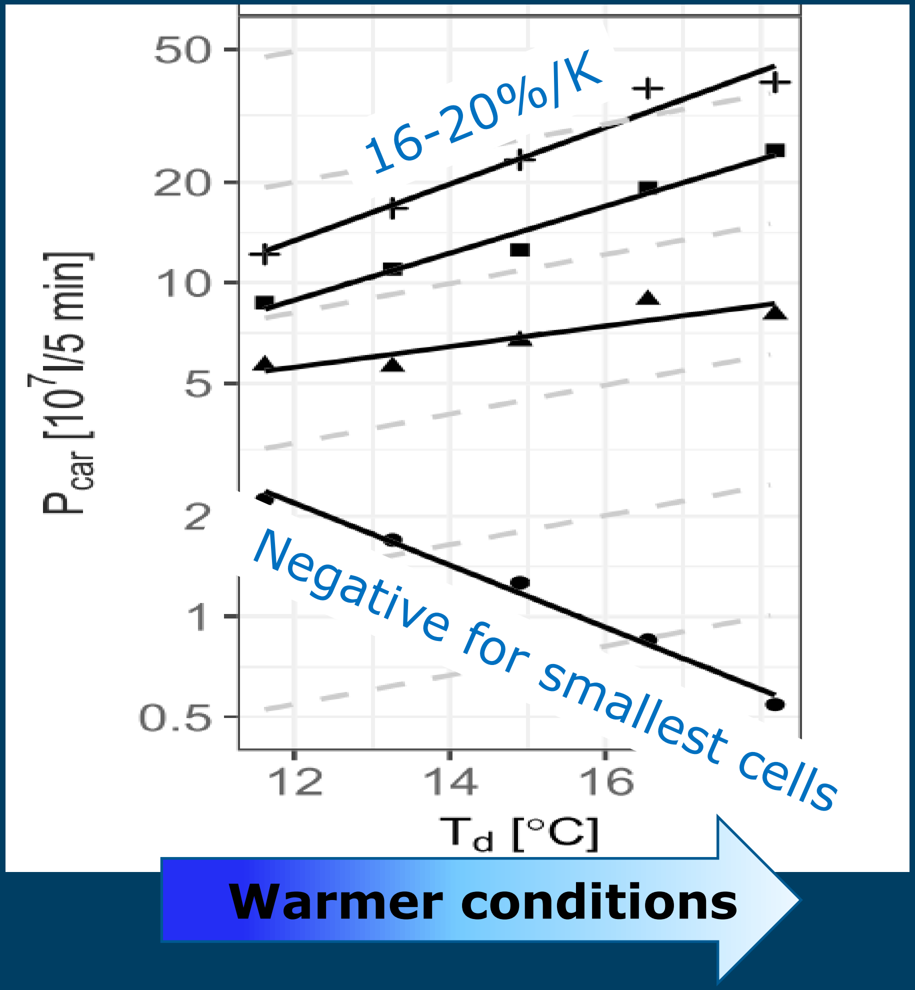
LES idealized case of one heavy convective day (composited forcing from observations)

Domain: 200x200 km2

Idealized warming/cooling experiment

Lochbihler et al, JGR, 2019

Under warmer conditions bigger cell tend to produce much more rain



Statistic:
Rain rate aggregated over rain-cell area

Lessons from LES.

Warmer conditions lead stronger cloud dynamics:

- Faster growth of rain cells
- Bigger, more intense cells at the expense of smaller cells: redistribution of rain cell sizes
- More organization

But, limiting effects by moisture availability are apparent too

Lochbihler et al, JGR, 2019; Lochbihler et al. 2020 (in prep)

Summary

- Dew point temperature scaling provide surprising insights in the behaviour of precipitation extremes
- Dependencies beyond the Clausius-Clapeyron (CC) rate (6-7% per degree) are possible – super Clausius-Clapeyron scaling – even up to a 2CC rate
- Evidence points to strong relations between super-CC behaviour and cloud size/organization (bigger clouds at warm conditions)
- To degree to which present-day derived scaling rates are reflected in the climate change response of precipitation extremes is strongly debated
- But, some evidence exists that the heaviest extremes respond close to the rate predicted by scaling