

**Changes in the  
distribution of rain  
frequency and intensity  
in response to warming**

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# Changes in the distribution of rain

## 1. Introduction

- Why the distribution would change

## 2. Theory

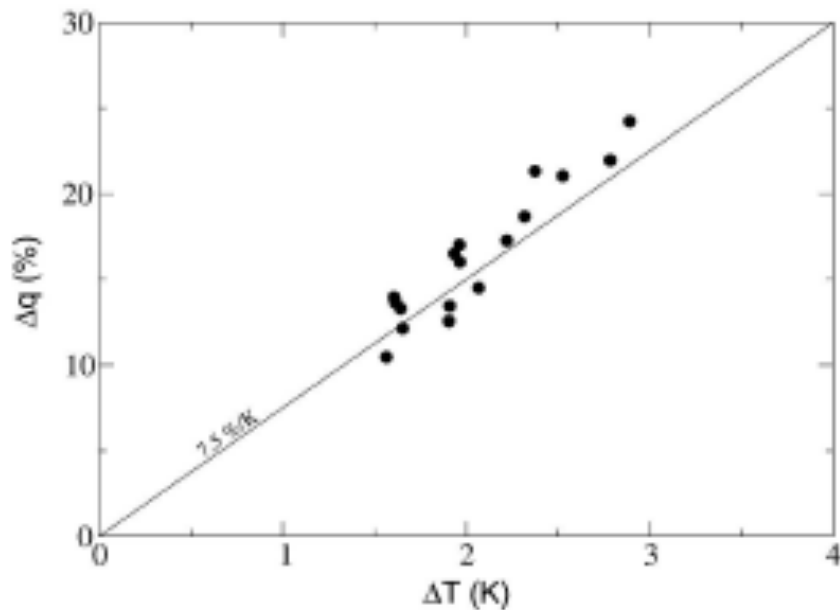
- **Shift** and **increase modes** of change

## 3. Response to CO<sub>2</sub> increase in CMIP5 models

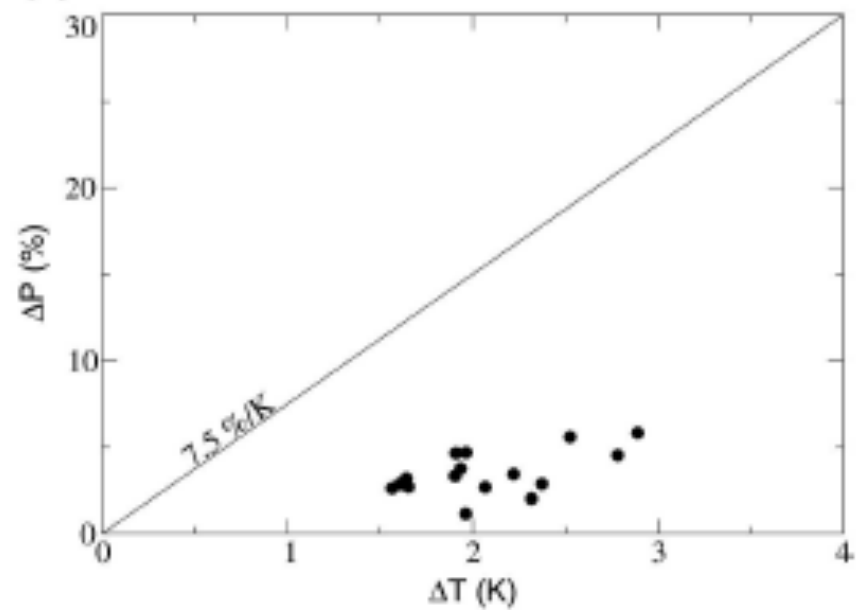
- Shift + Increase modes
- Extreme mode

# Moisture increases, Precipitation increases less

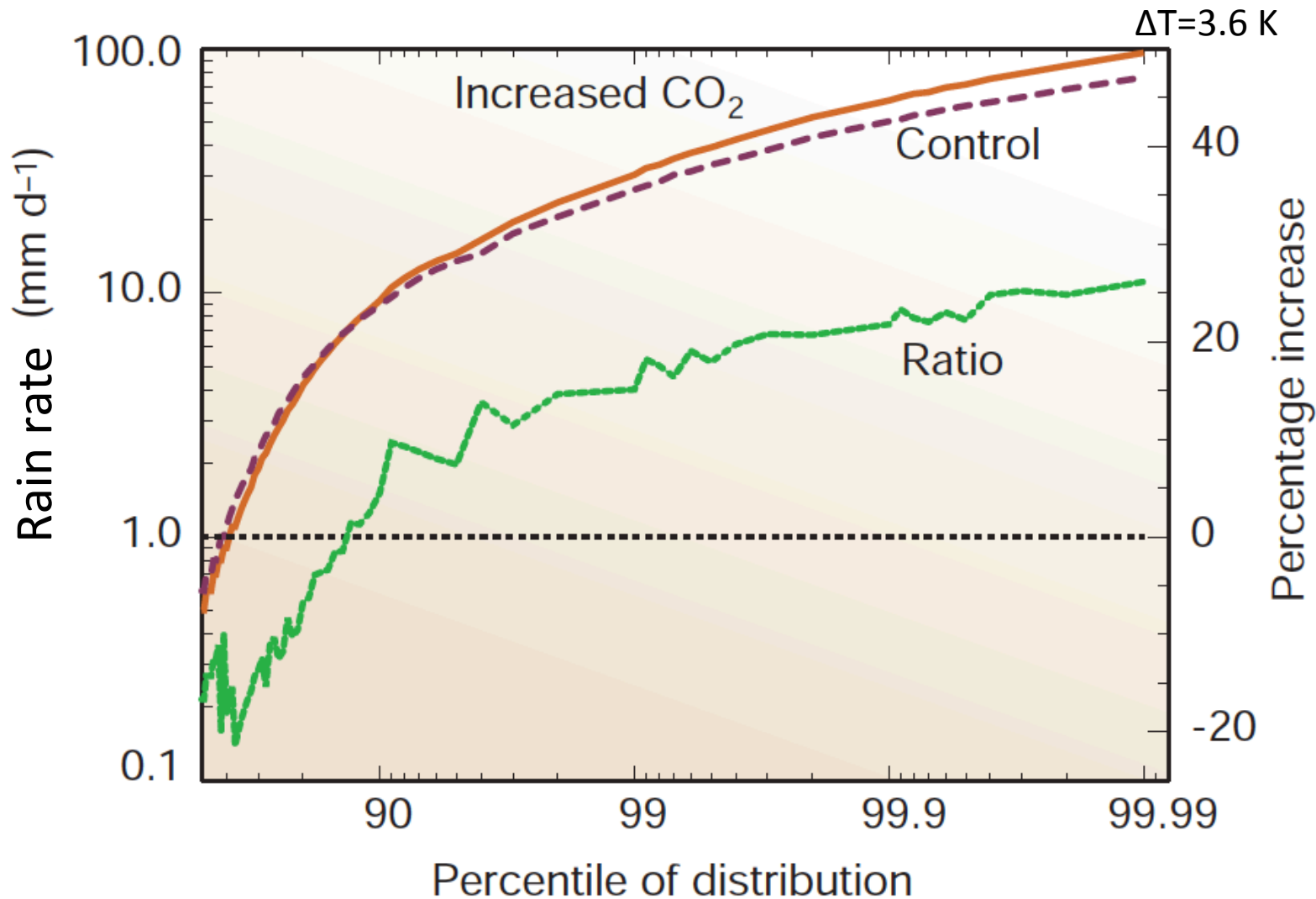
Moisture increases at 7%/K



Precipitation increases at 1-3%/K



# Extreme precipitation increases with moisture



# Rain distribution should change shape

- Global-mean rainfall increases by 2 %K<sup>-1</sup>
- Extreme rain rate increases by around 7 %K<sup>-1</sup>
- The distribution must change
  - Less frequent, more intense rainfall

How can we quantify the relationships among changes in  
**global-mean** rainfall,  
**extreme rain** rate,  
and the rest of the **distribution** of rain?

# Daily precipitation data

- Rain rate in mm/day
- Climate model simulations
  - CMIP5 Carbon dioxide increase (1pctCO2)
  - 22 models
- Observations
  - Global Precipitation Climatology Project (GPCP) 1 Degree Daily
  - 1997-2012

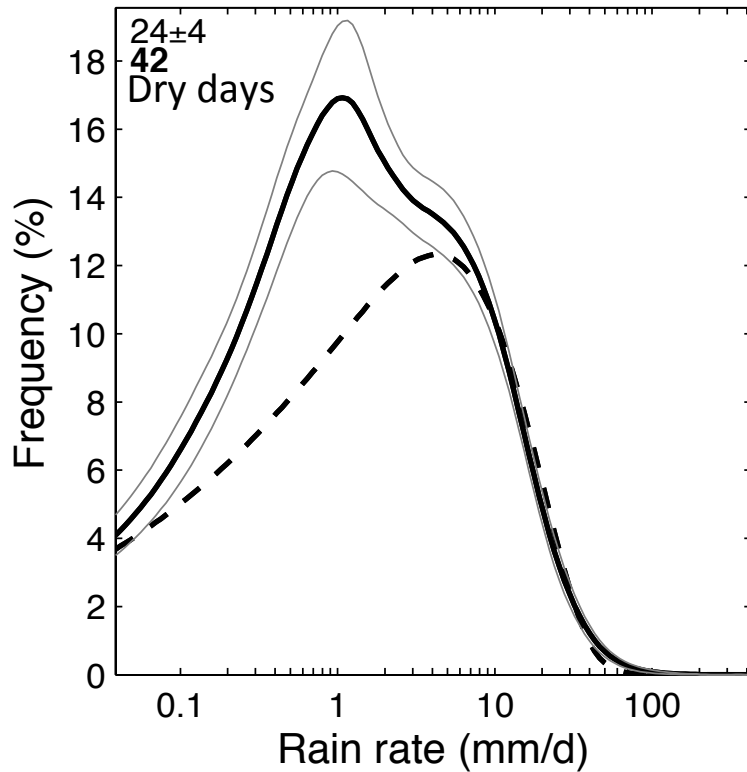
# Methodology

- Calculate both rain frequency and rain amount distributions
- Average globally
- Dry threshold of less than 0.1 mm/d
- Logarithmic rain rate axis

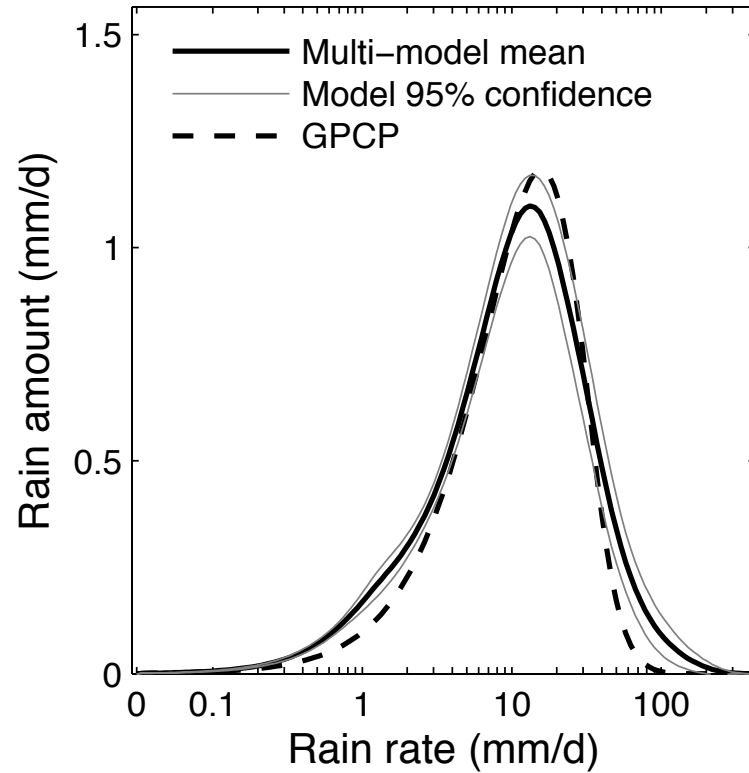


# Rain distribution

## Rain frequency



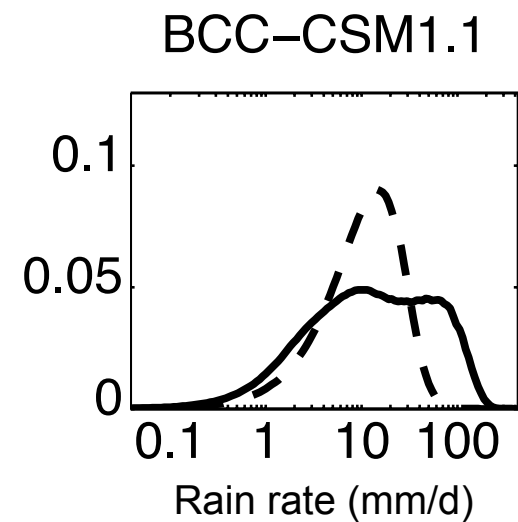
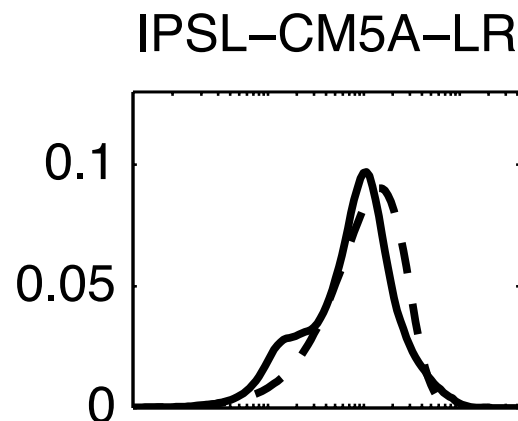
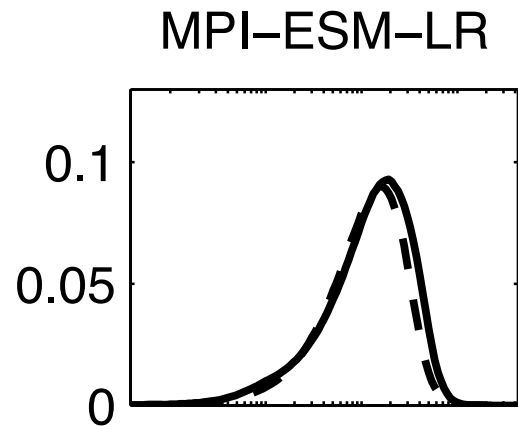
## Rain amount



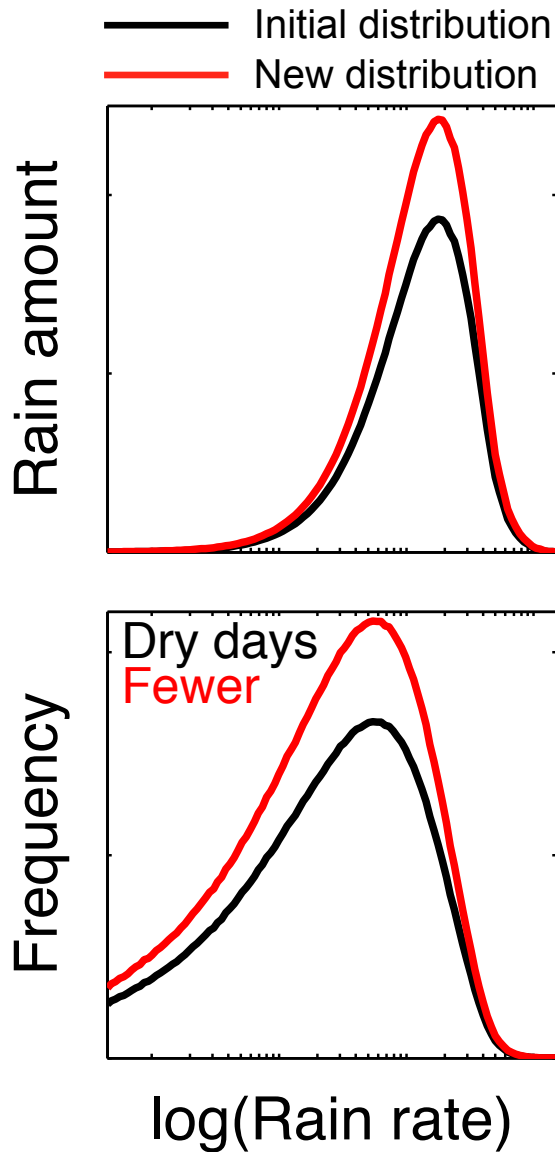
$$p(\ln r) = r f(\ln r)$$

# Models vary in their fidelity to observations

Rain amount



# How could the distribution of precipitation change?



- It could rain **more** often (and be dry **less** often)

## Increase mode

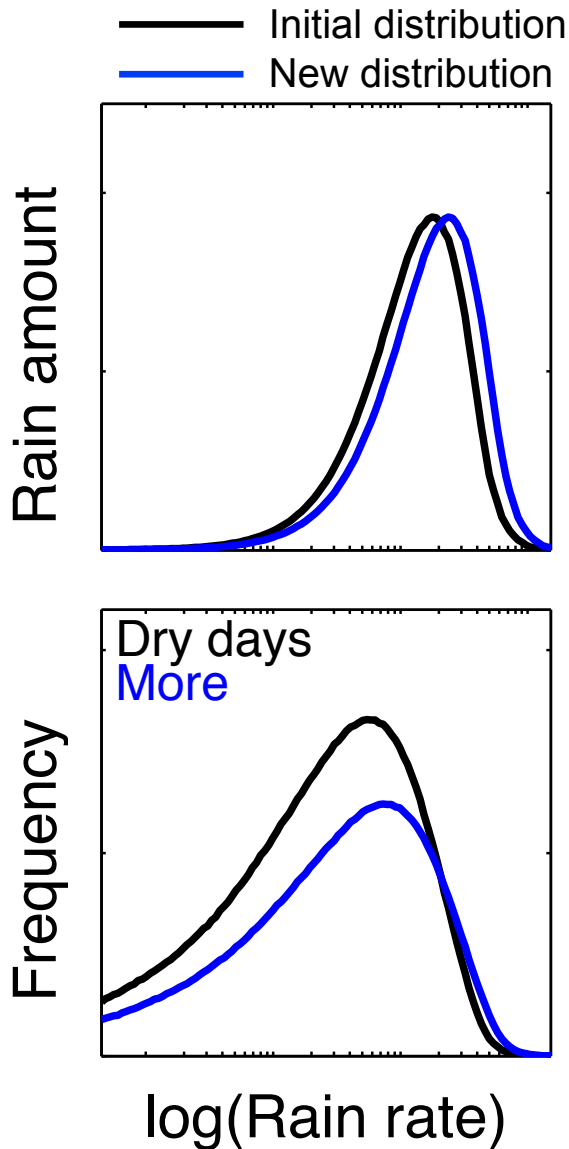
- Rain frequency and amount increase by the same fraction at all rain rates

$$p'(\ln r) = (1 + a)p(\ln r)$$

$$f'(\ln r) = (1 + a)f(\ln r)$$

- Total rain increases

# How else could the distribution of precipitation change?



- It could rain harder

## Shift mode

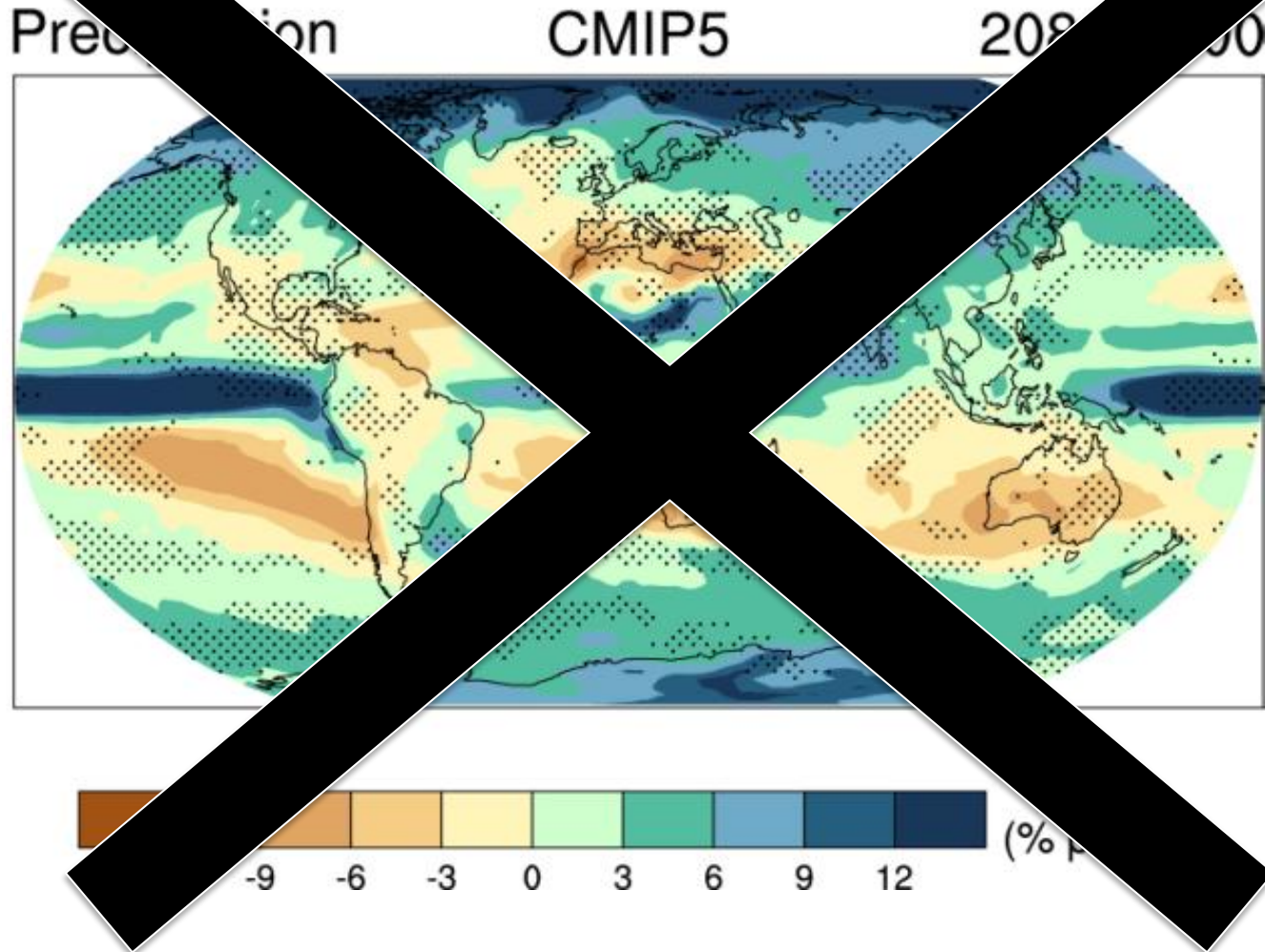
- The same amount of rain falls at higher rain rates

$$p'(\ln r) = p(\ln r - b)$$

$$f'(\ln r) = e^{-b} f(\ln r - b)$$

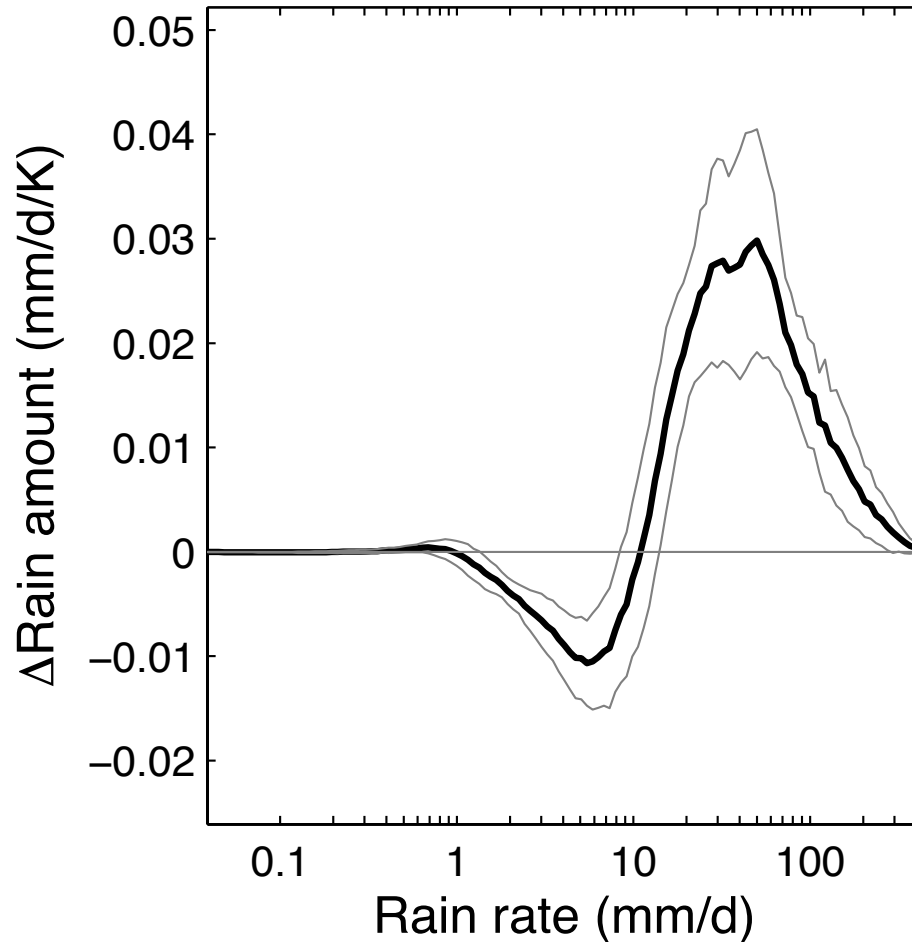
- Total rain **does not** change

# Shifts in space

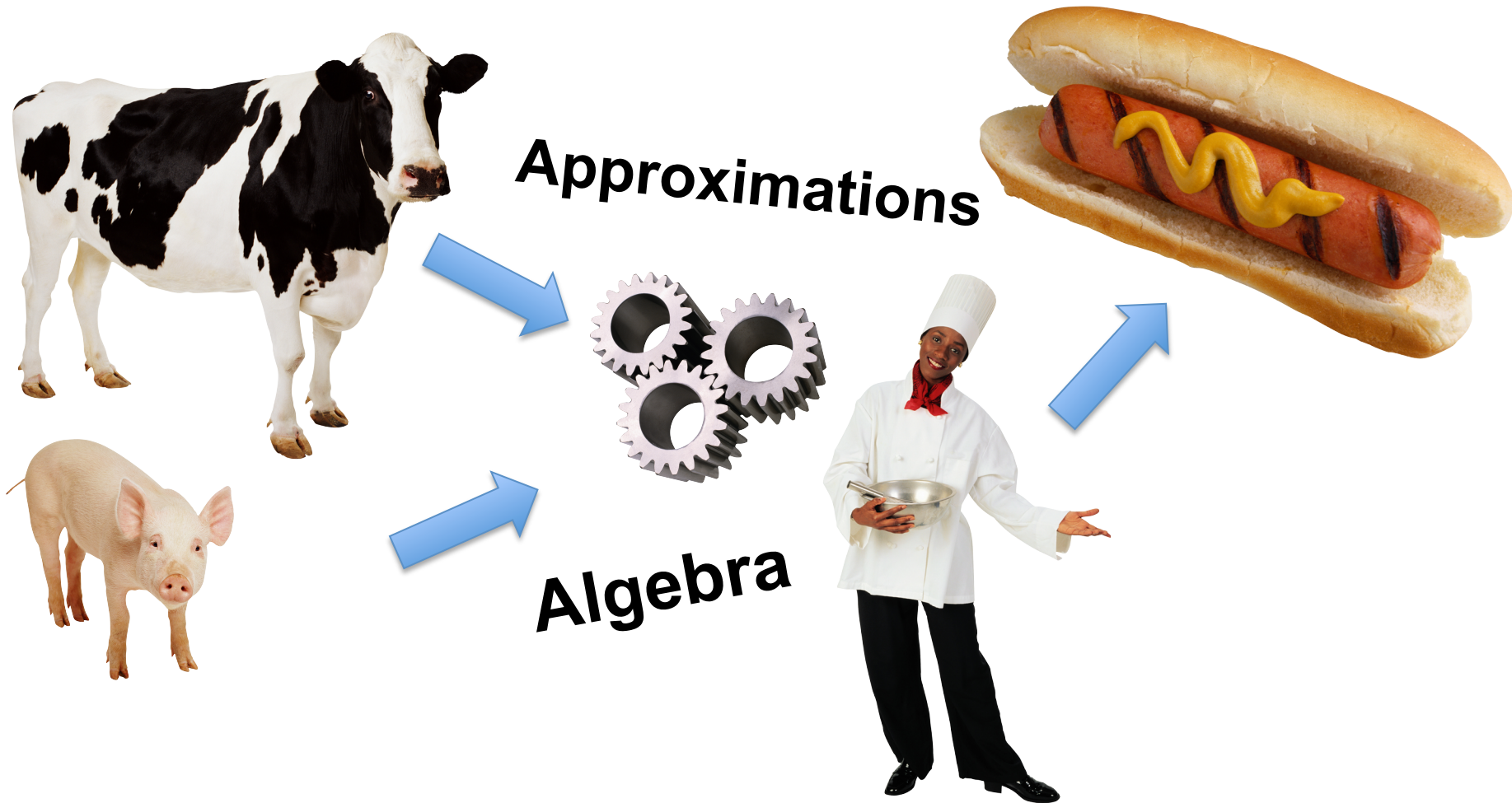


# Multi-model mean rain distribution response to CO<sub>2</sub> increase

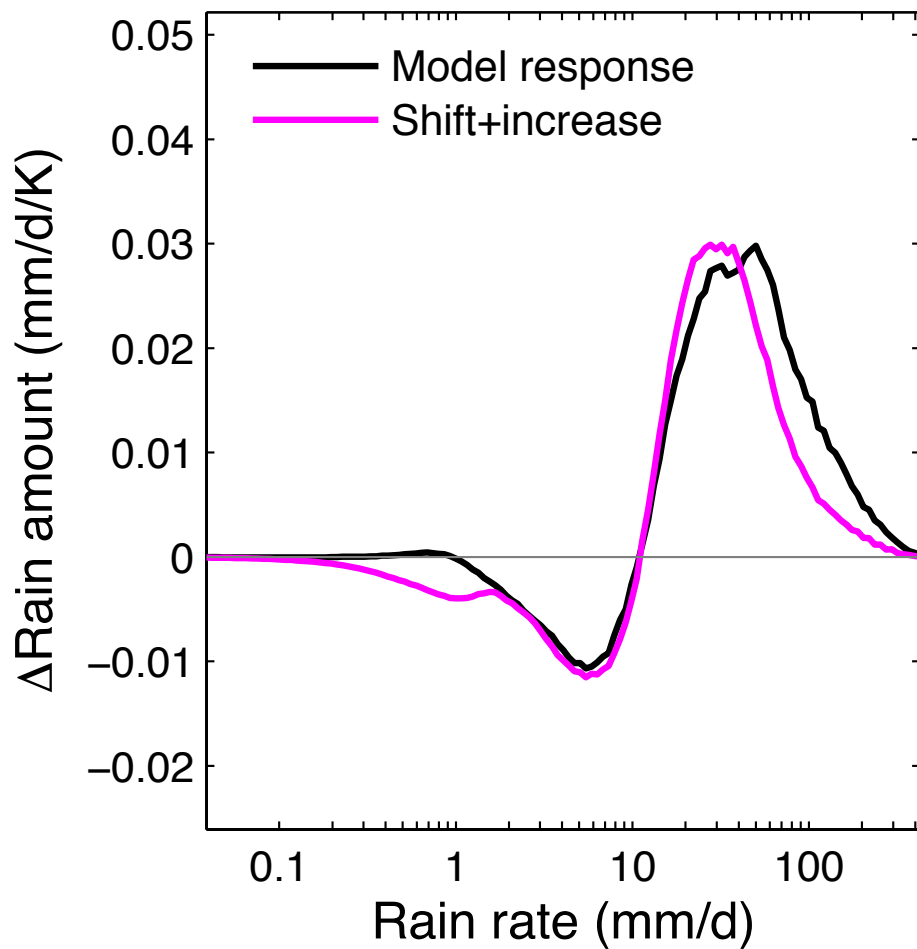
## Rain amount



# Fit the shift and increase modes



# Best fit shift-plus-increase



*a* Increase: 0.9 %K<sup>-1</sup>

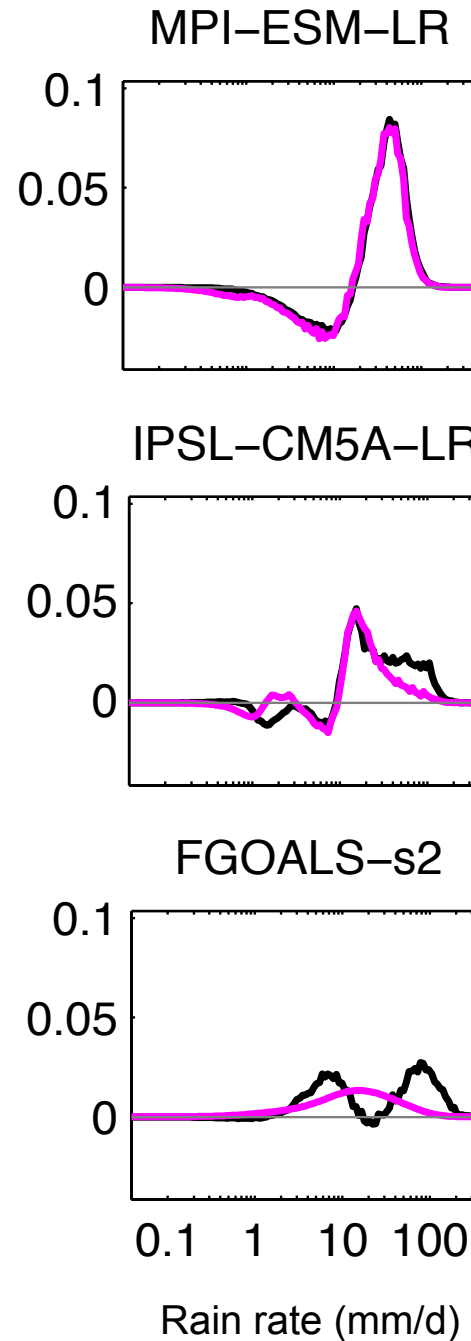
*b* Shift: 3.3 %K<sup>-1</sup>



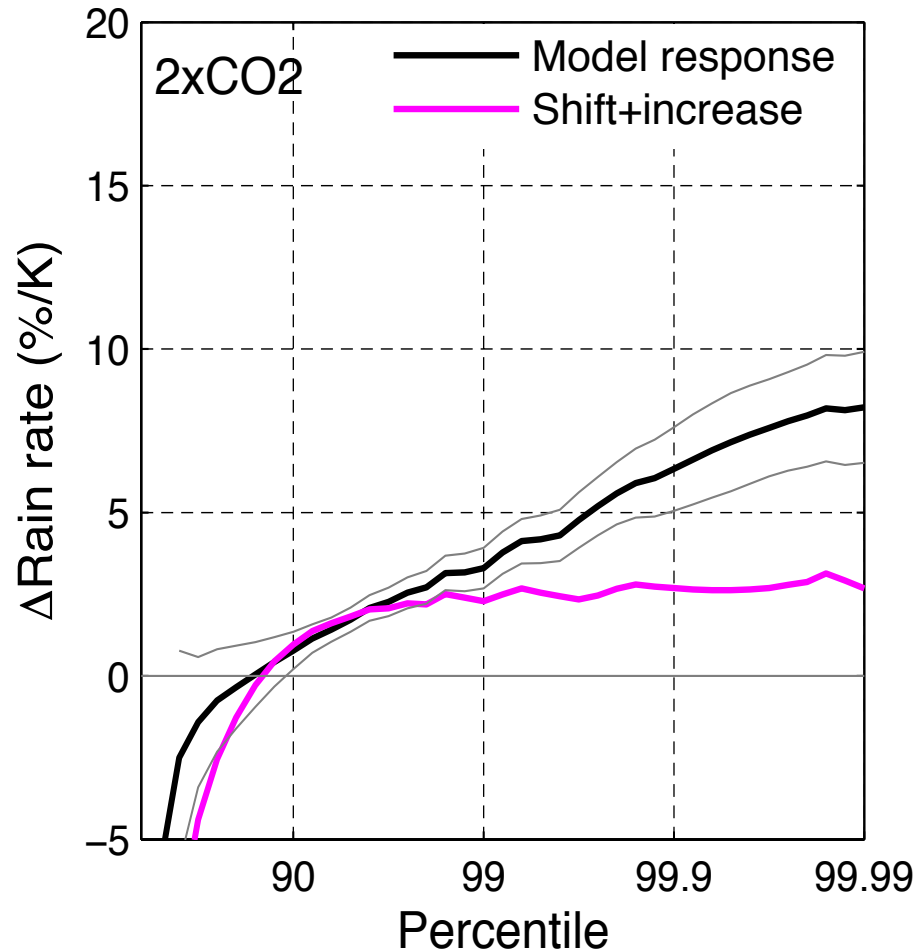
## Repeat for every model

Average of models

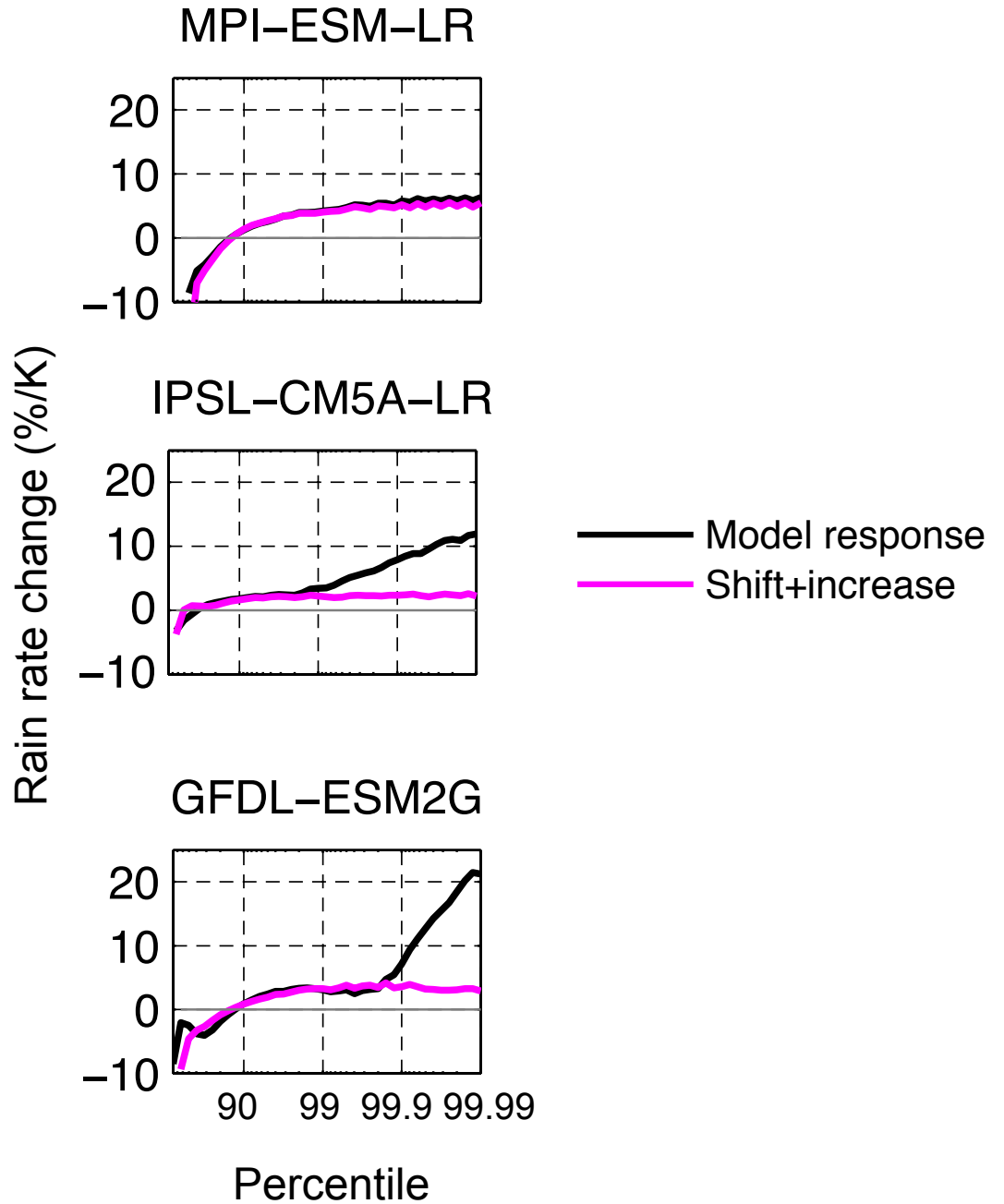
- Shift 3.3 %K<sup>-1</sup>
- Increase 1.1 %K<sup>-1</sup>



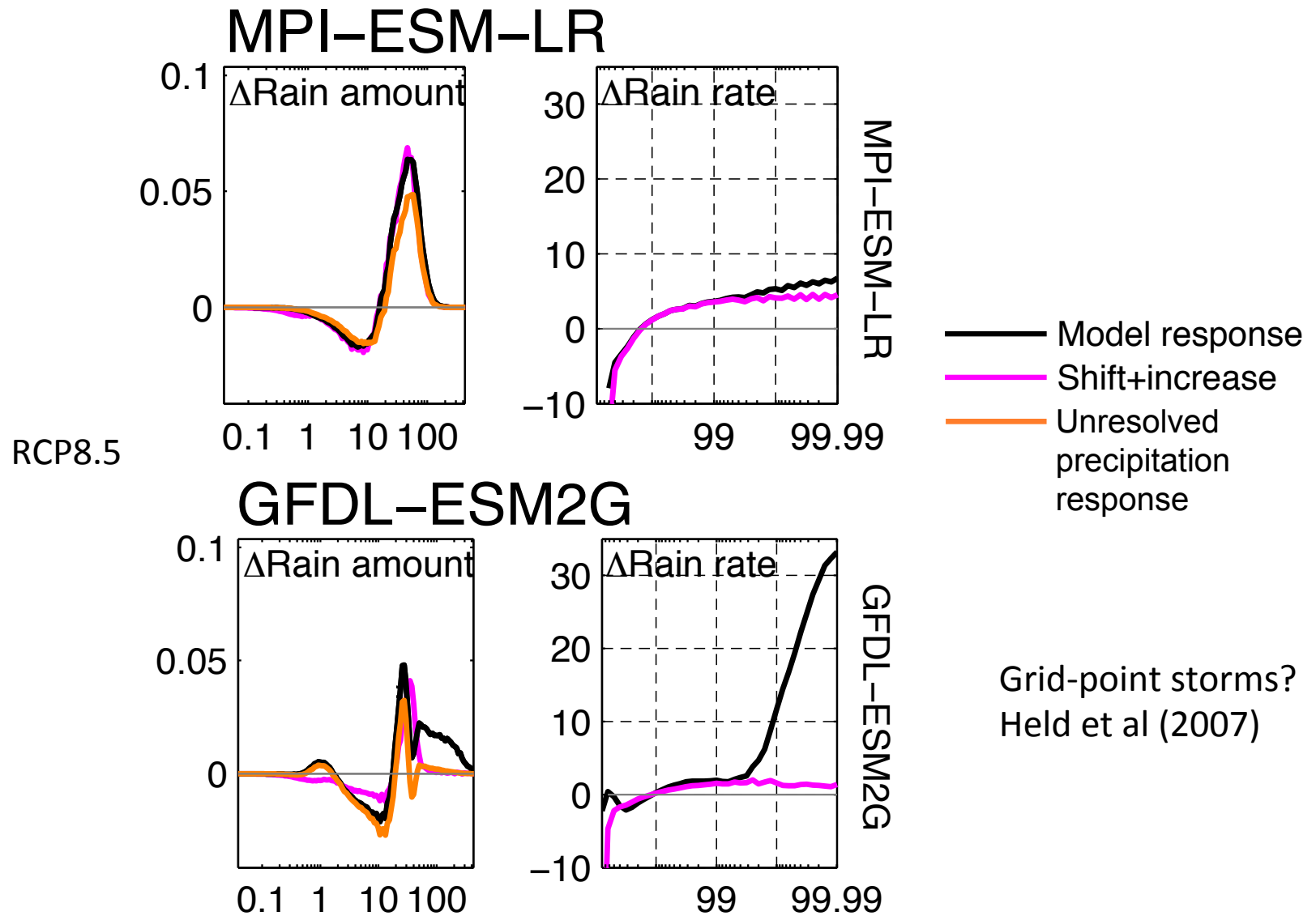
# Change in extreme rain: Multi-model mean response to CO<sub>2</sub> increase



# Models have different responses



# Extreme mode falls as resolved precipitation



# Conclusions

- Most of the increase in total rainfall in response to global warming comes as the **increase mode** – a uniform increase at all rain rates.
  - Some of the rest comes from the **extreme mode**, which occurs in only some models.
- The increase in extreme rain occurs as a **shift** of the distribution to higher rain rates in some models
  - In other models it occurs as an **extreme mode**.

Read more:

- Submitted to *Journal of Climate*
  - Drafts at [www.atmos.washington.edu/~angie](http://www.atmos.washington.edu/~angie)

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