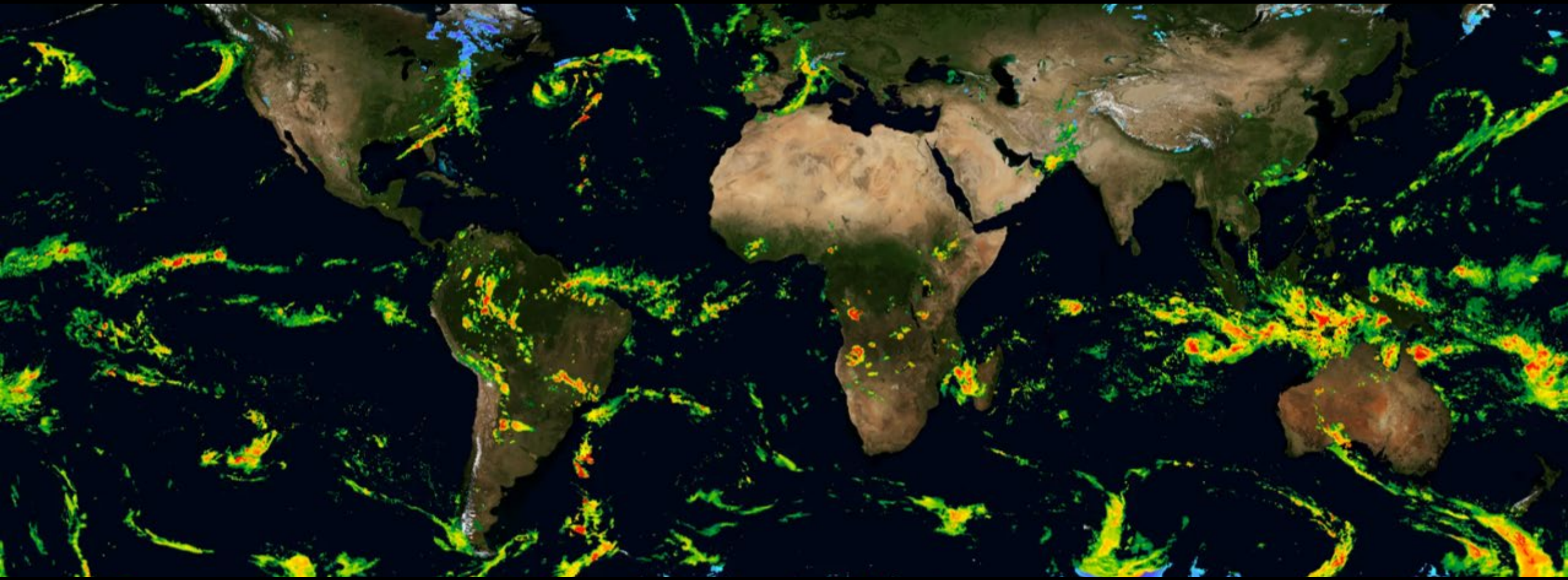
∂³AWN
∂ata-∂riven
Atmospheric & Water
∂yNamics

clim↔act

UNIL Université de Lausanne
Expertise Center for
Climate Extremes (ECCE)

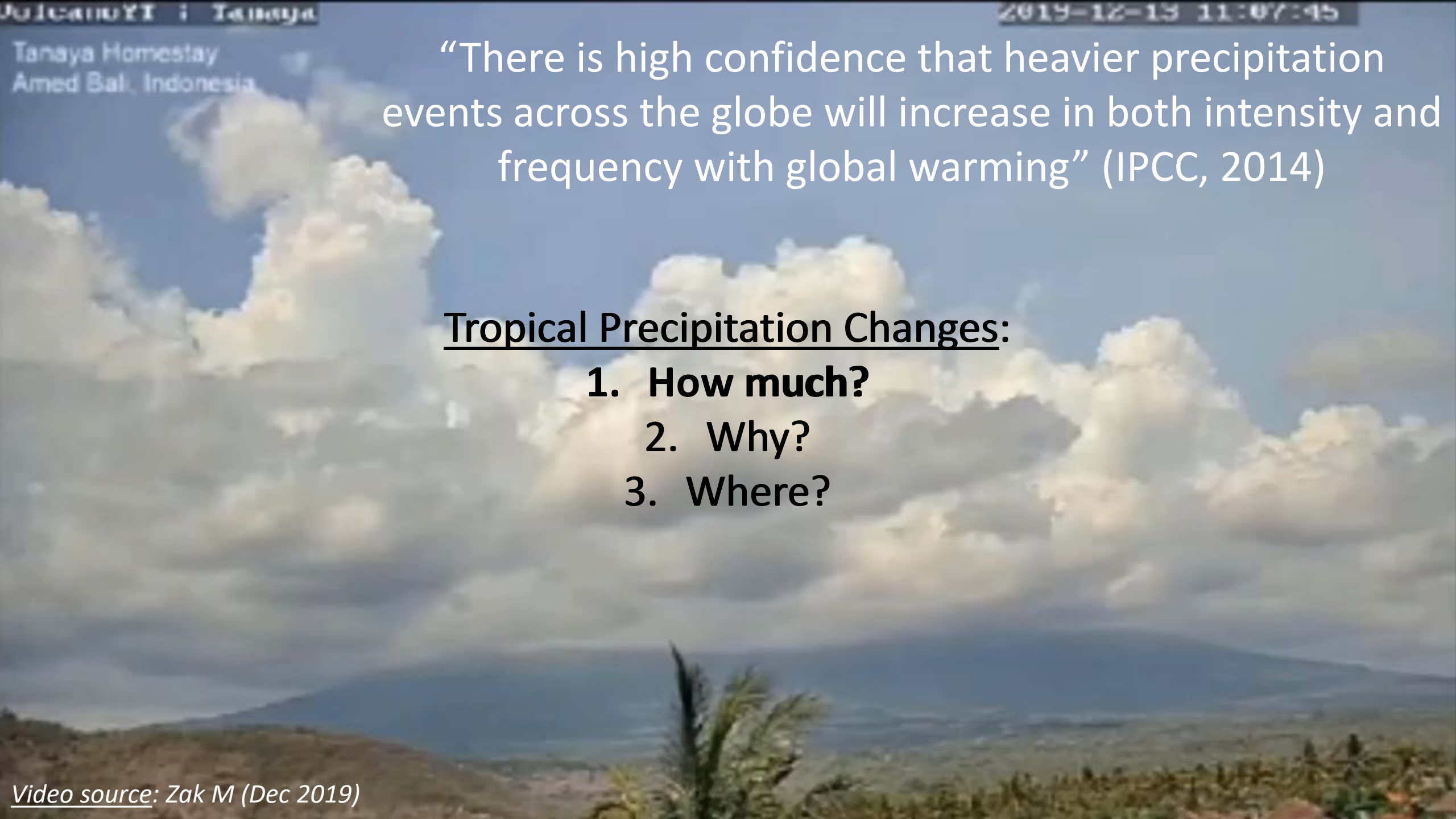
Tropical Precipitation in a Changing Climate



Source: IMERG (NASA)

Presenter: Tom Beucler (UNIL)

Collaborators: G. Mooers (MIT), T. Abbott (NOAA GFDL), M. Pritchard, S. Mandt (UCI), T. Cronin (MIT)



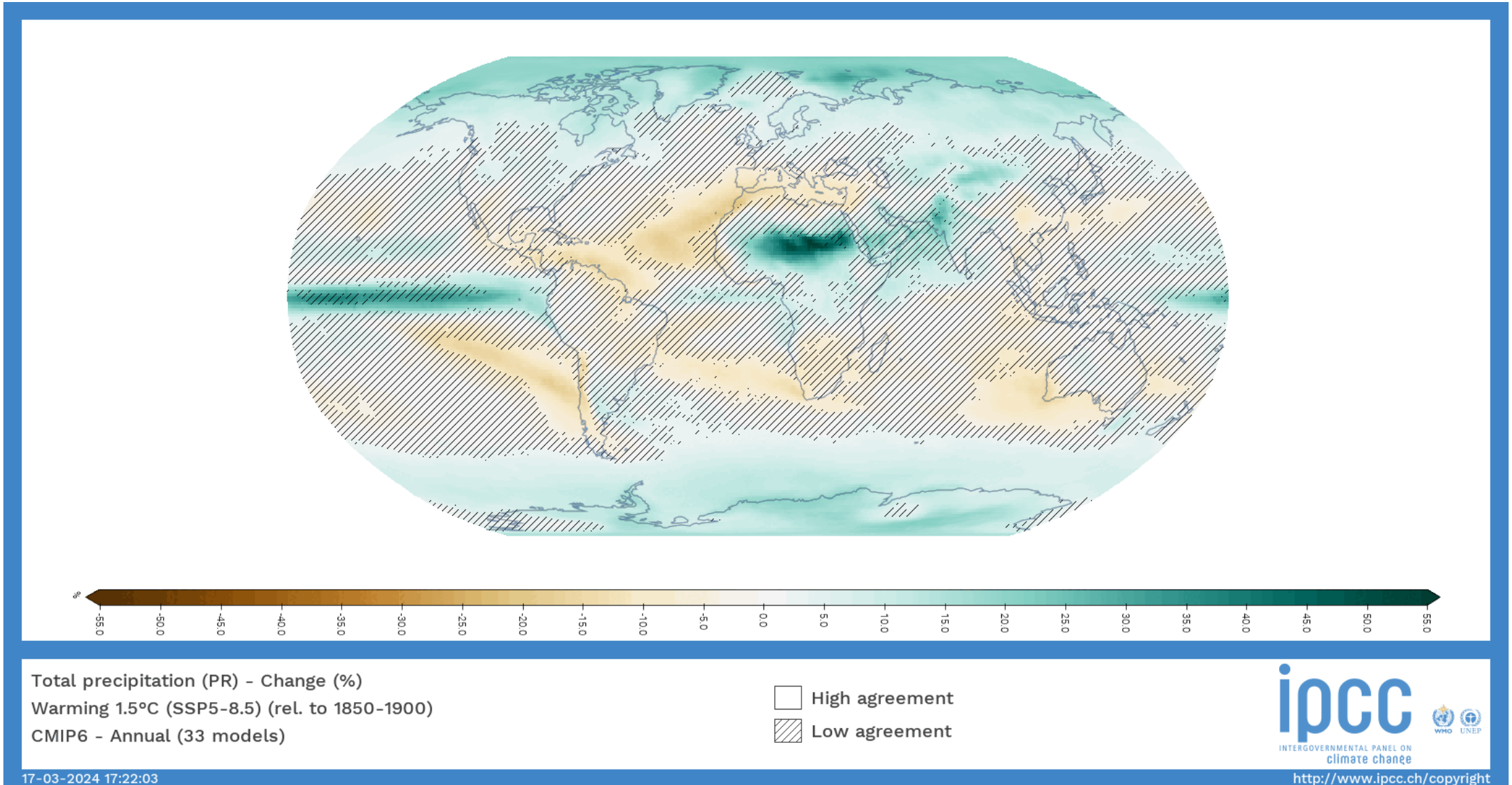
"There is high confidence that heavier precipitation events across the globe will increase in both intensity and frequency with global warming" (IPCC, 2014)

<u>Tropical Precipitation Changes</u>:

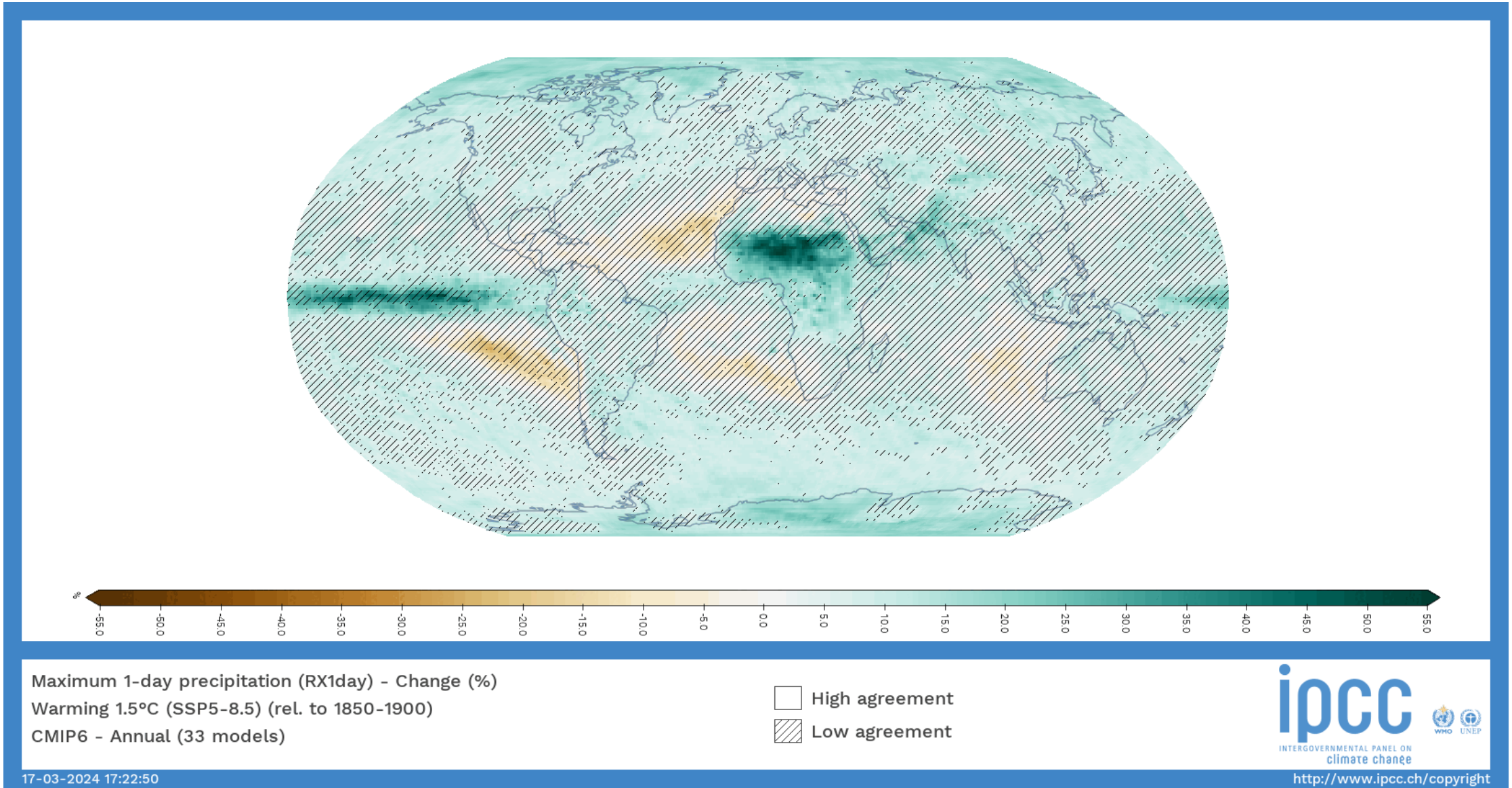
1. **How much?**
2. Why?
3. Where?

<u>Video source</u>: Zak M (Dec 2019)

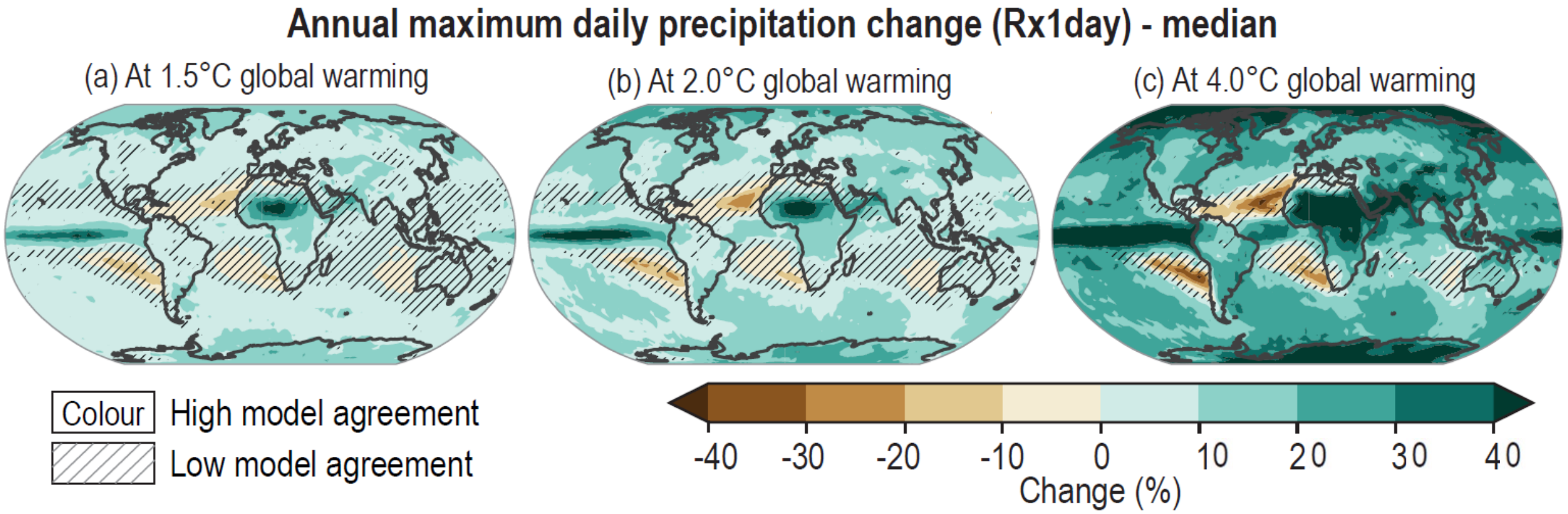
While time-mean precipitation is constrained by the balance of energy in the Earth system…



…extreme precipitation is limited by the amount of water vapor available in the atmosphere



…extreme precipitation is limited by the amount of water vapor available in the atmosphere

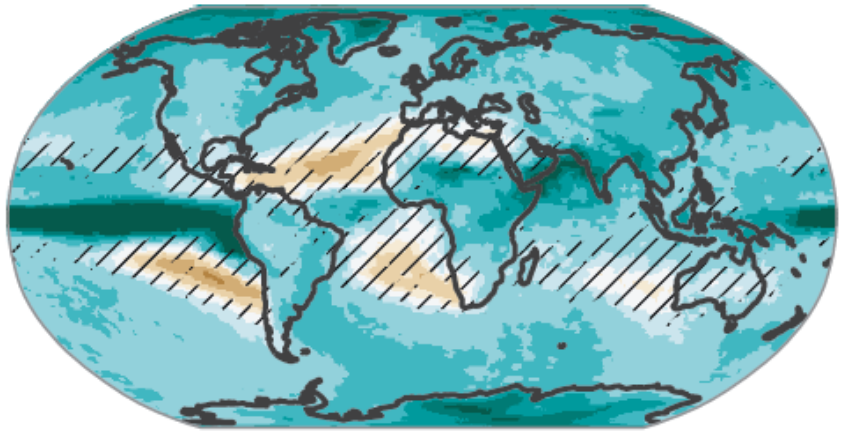


Source: IPCC Chapter 11 – Weather and Climate Extreme Events in a Changing Climate

How to interpret extreme precipitation changes? Thermodynamic vs. dynamic contribution

Change in annual maximum daily precipitation

(a) Total change



Colour High model agreement

Low model agreement

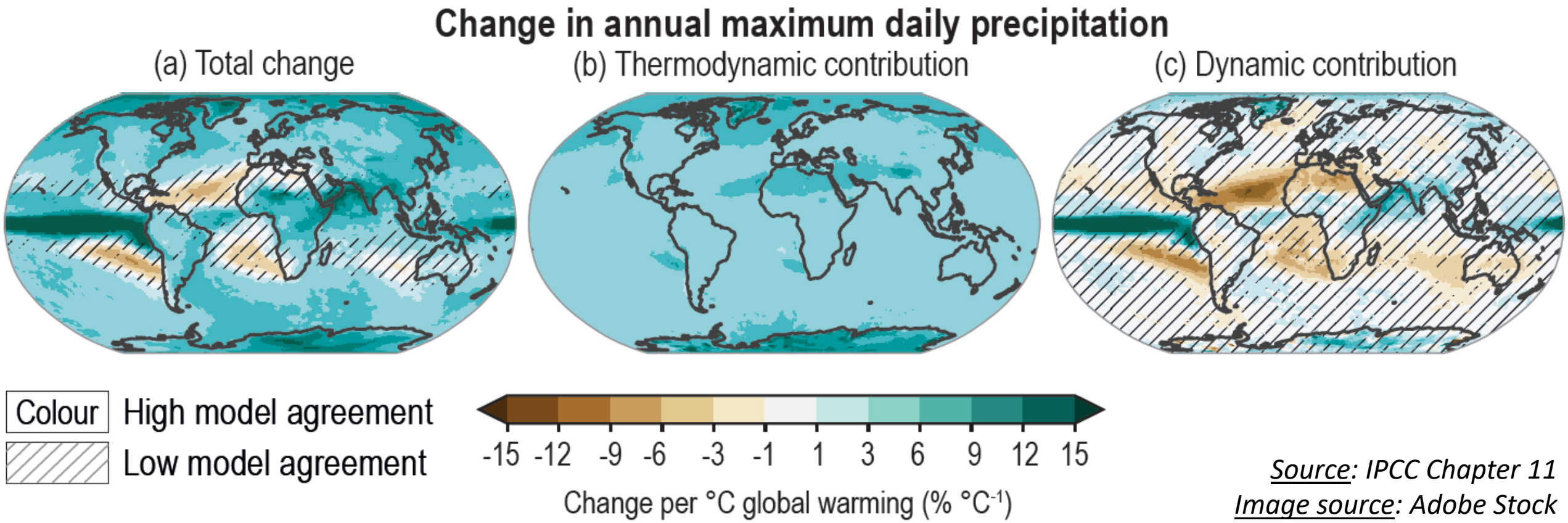
Change per °C global warming (% °C^{-1})

Source: IPCC Chapter 11

Image source: Adobe Stock

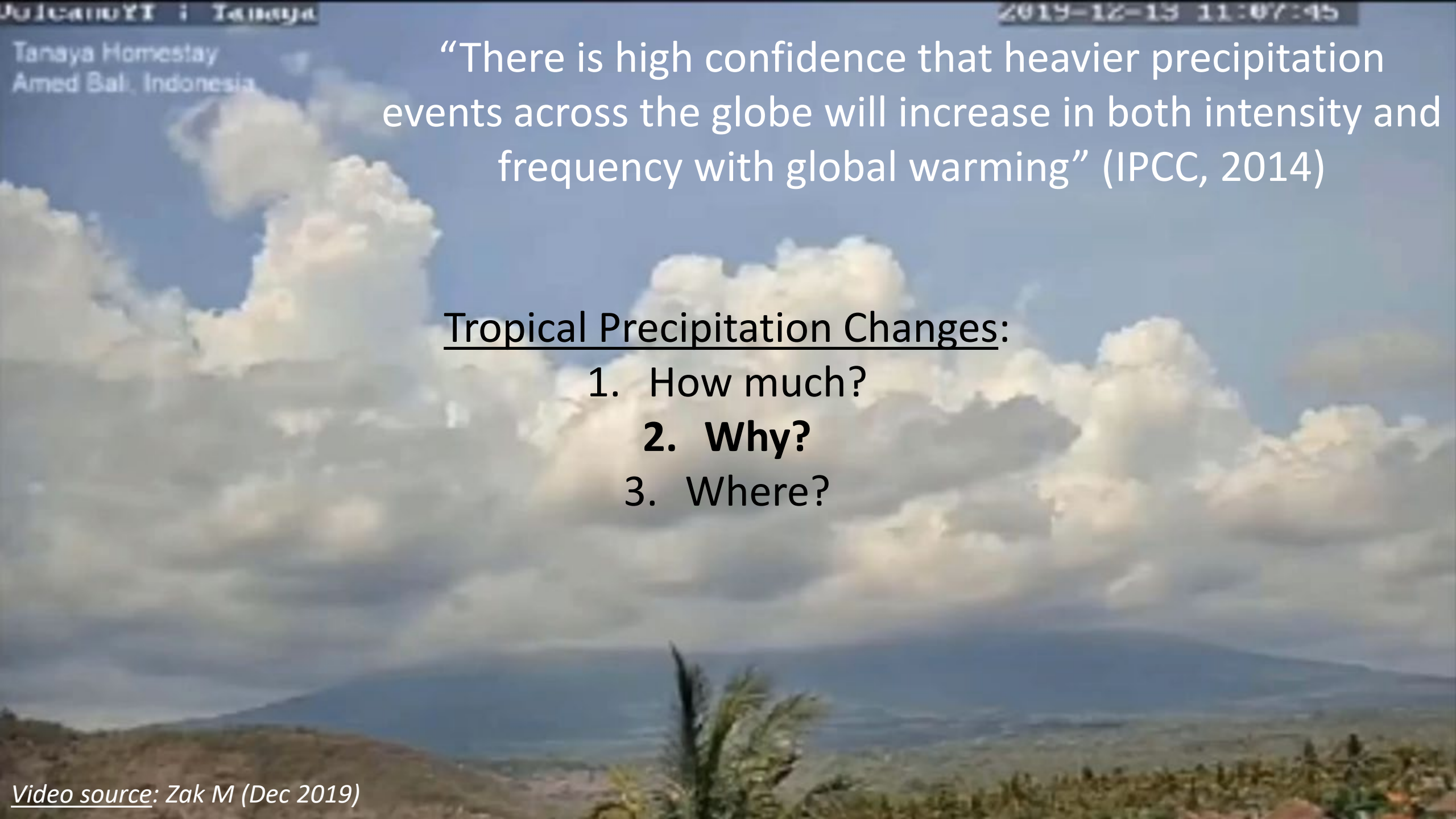
How to interpret extreme precipitation changes? Thermodynamic vs. dynamic contribution

$$\Delta \text{(rain)}\,(\%) \approx \Delta \text{(molecules)}\,(\%) + \Delta \text{(wind)}\,(\%)$$



Source: IPCC Chapter 11

Image source: Adobe Stock



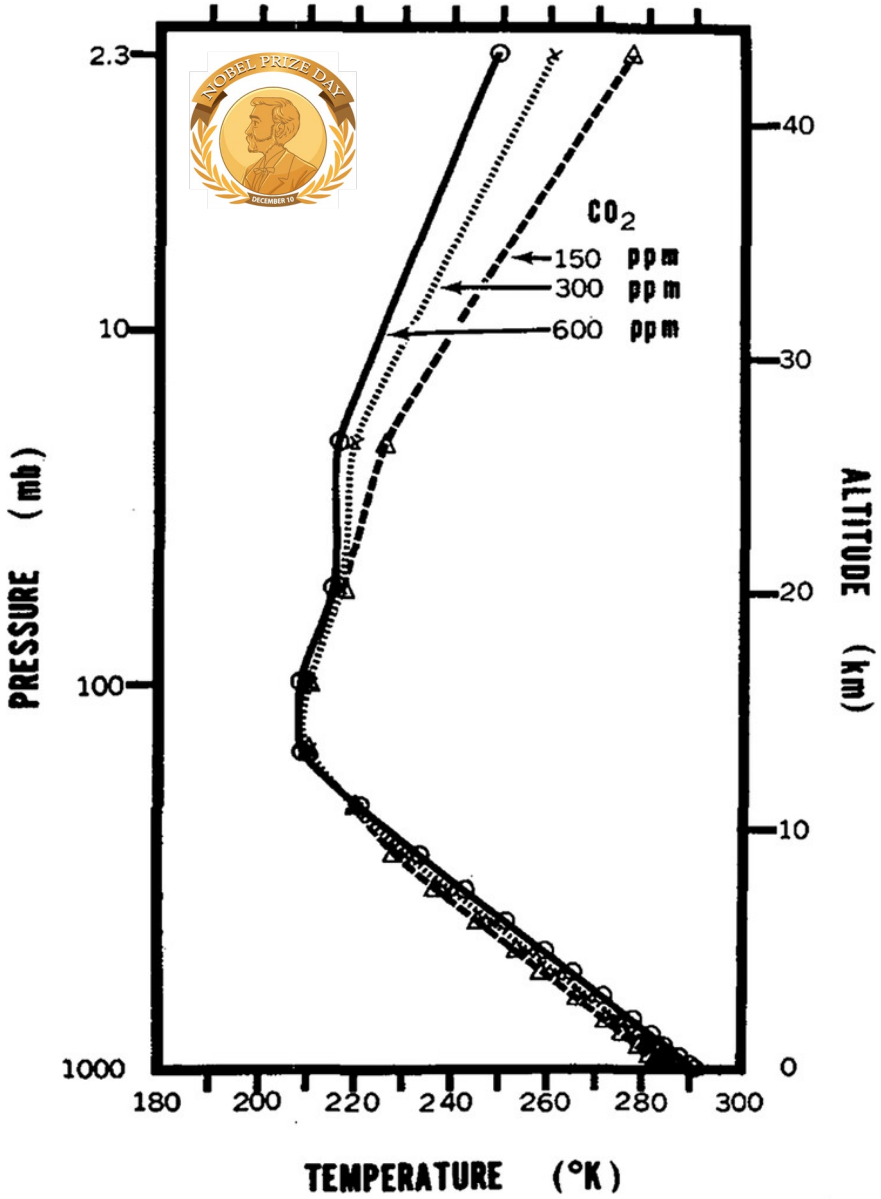
"There is high confidence that heavier precipitation events across the globe will increase in both intensity and frequency with global warming" (IPCC, 2014)

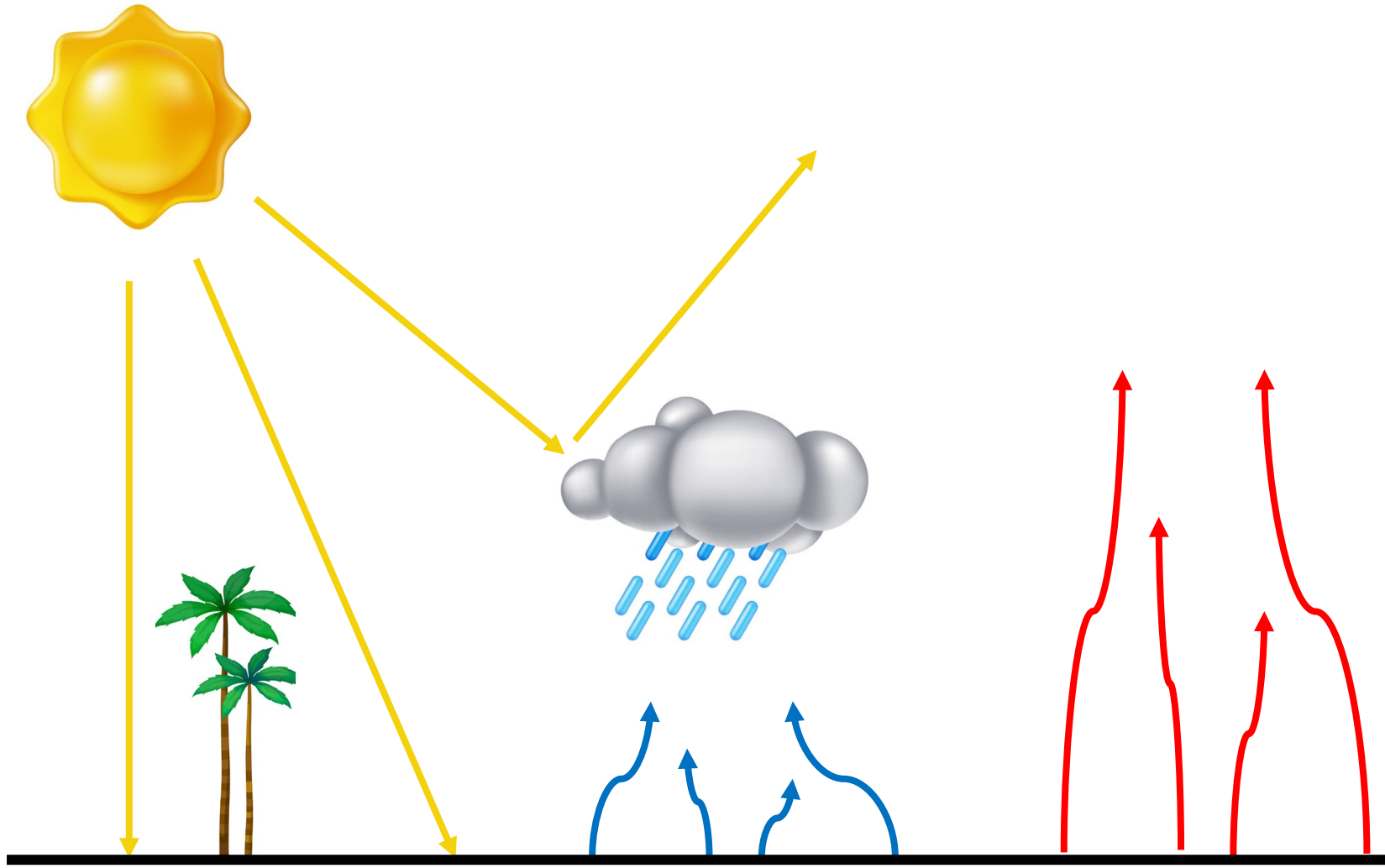
<u>Tropical Precipitation Changes</u>:

1. How much?
2. **Why?**
3. Where?

<u>Video source</u>: Zak M (Dec 2019)

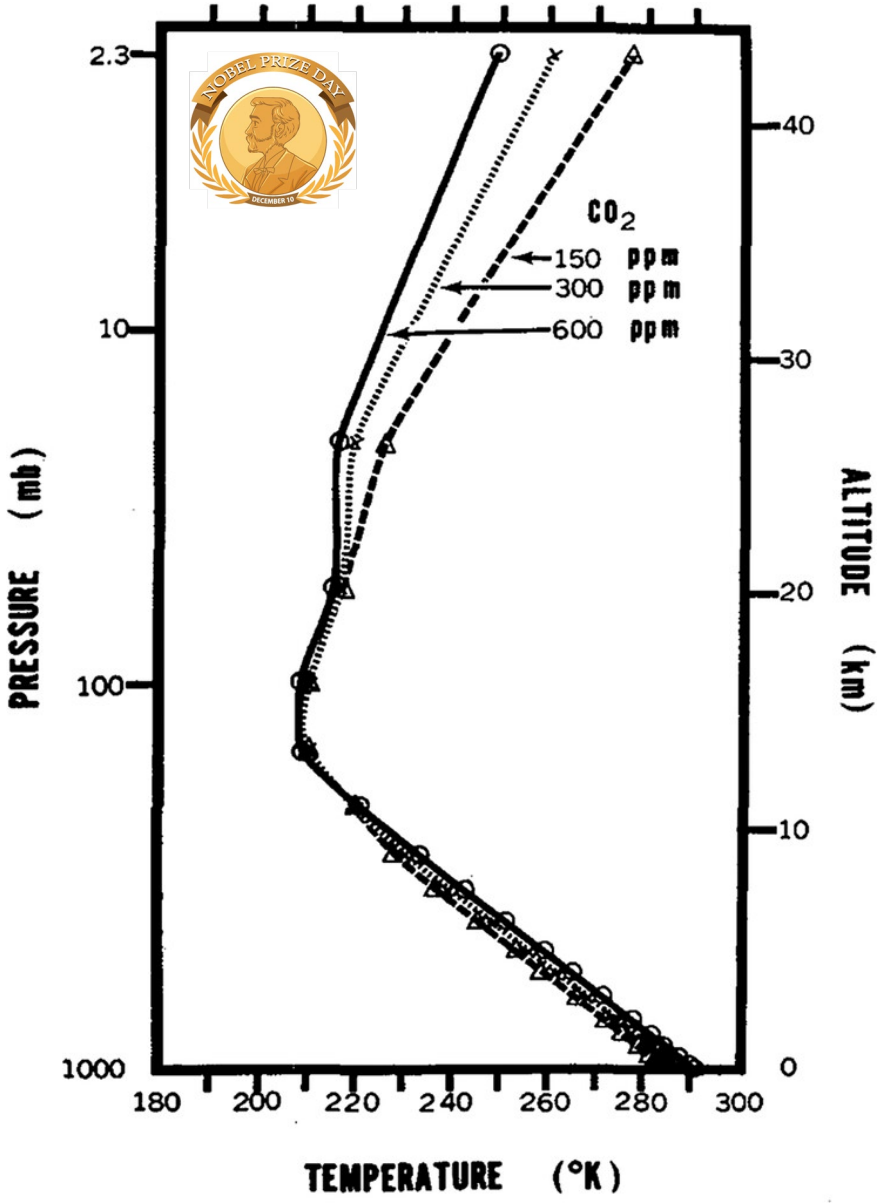
Radiative-Convective Equilibrium is a foundational atmospheric model that can explain vertical temperature profile changes with climate

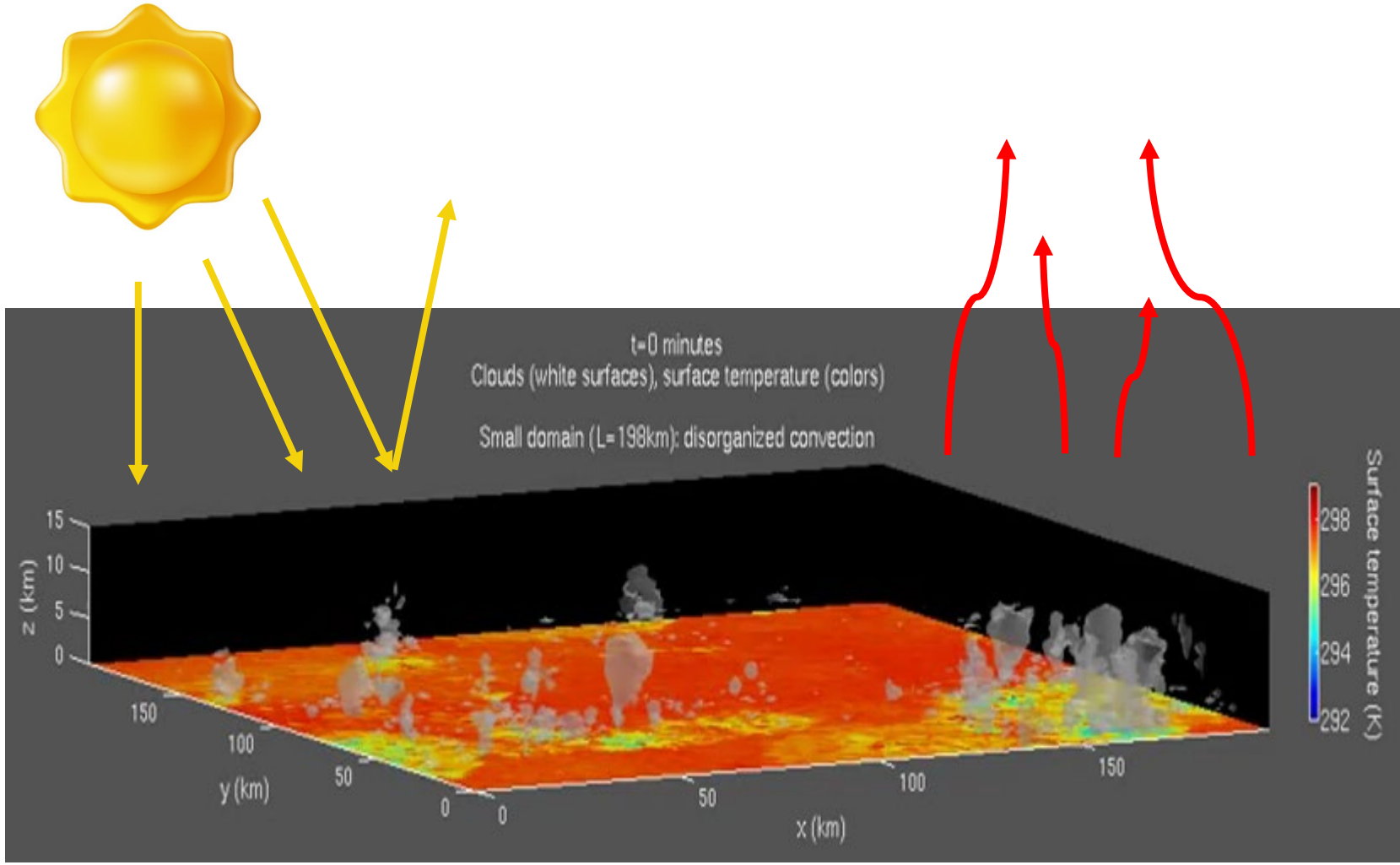




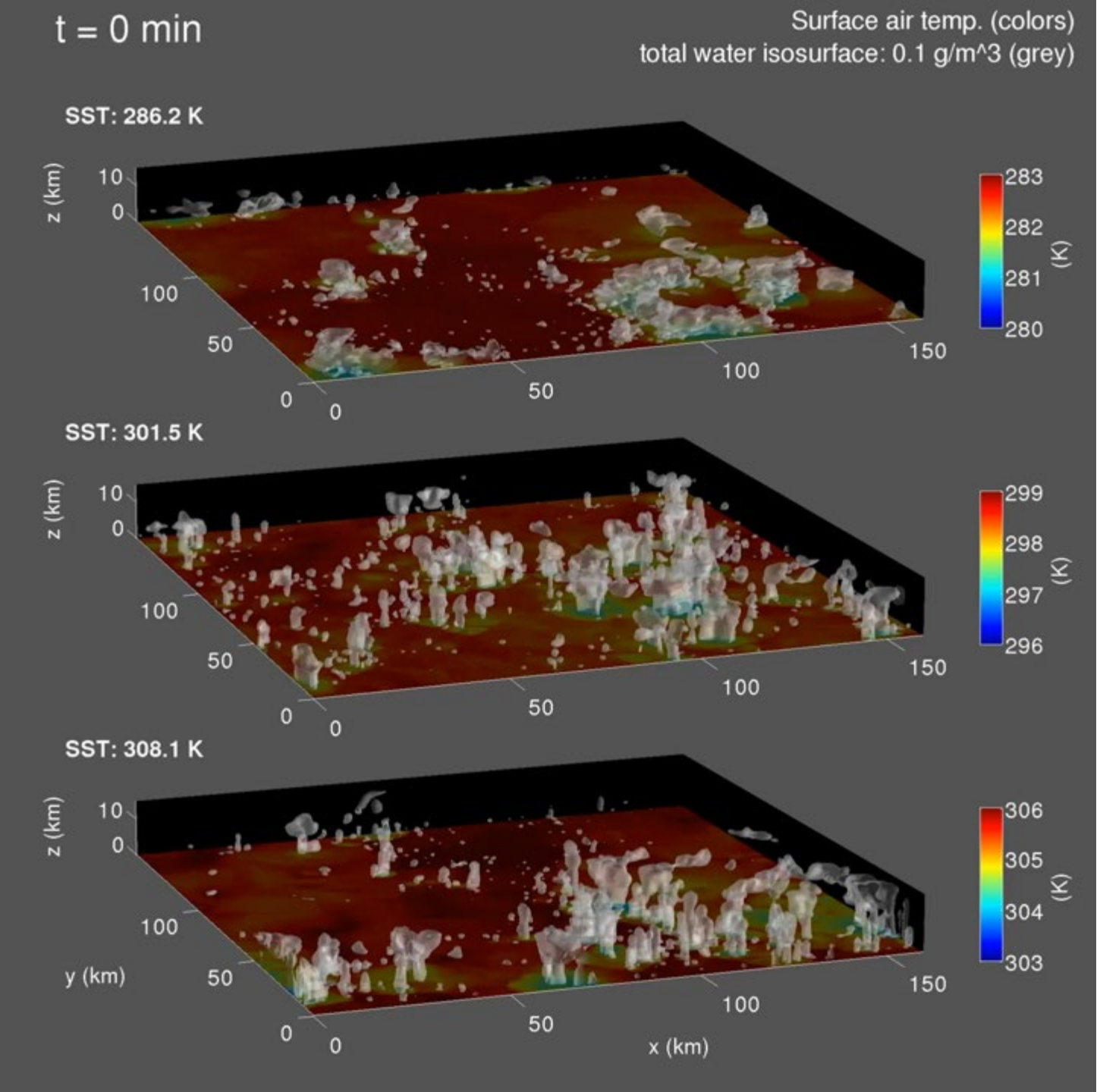
See: Manabe et al. (1961, 1964, 1967, 1975)

Radiative-Convective Equilibrium is a foundational atmospheric model that can explain vertical temperature profile changes with climate





Video Source: C. Müller (2011); See: Wing et al. (2018), Müller et al. (2011), Manabe et al. (1961, 1964, 1967, 1975, etc.)



Precipitation Extremes

286K

301K

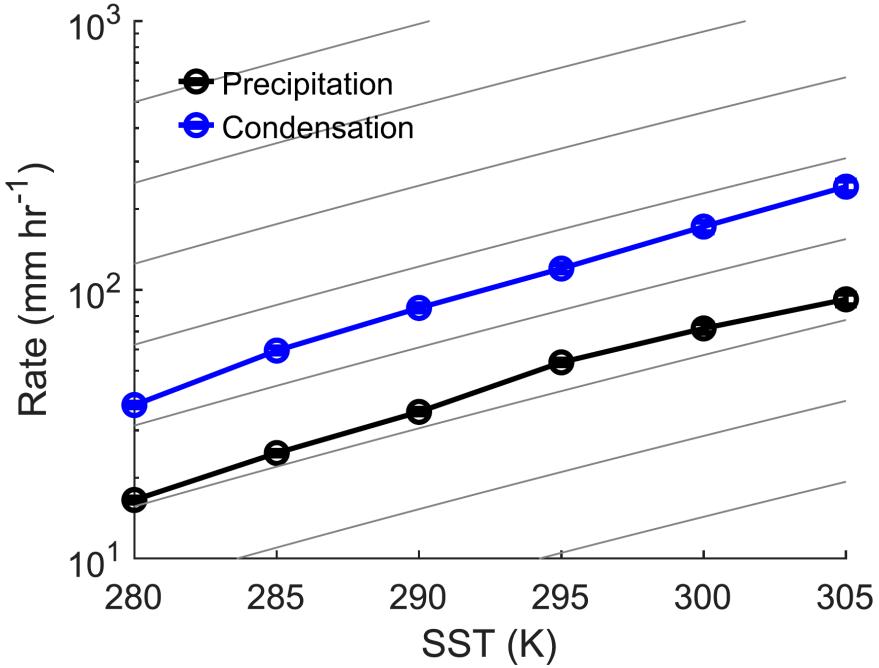
308K

Surface Temperature

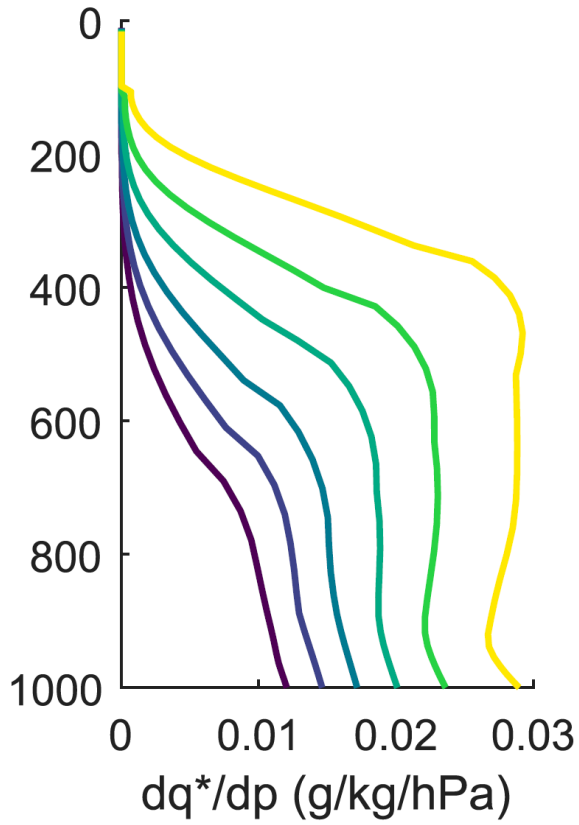
Video Source: mmartimus (Using CM1 Model)

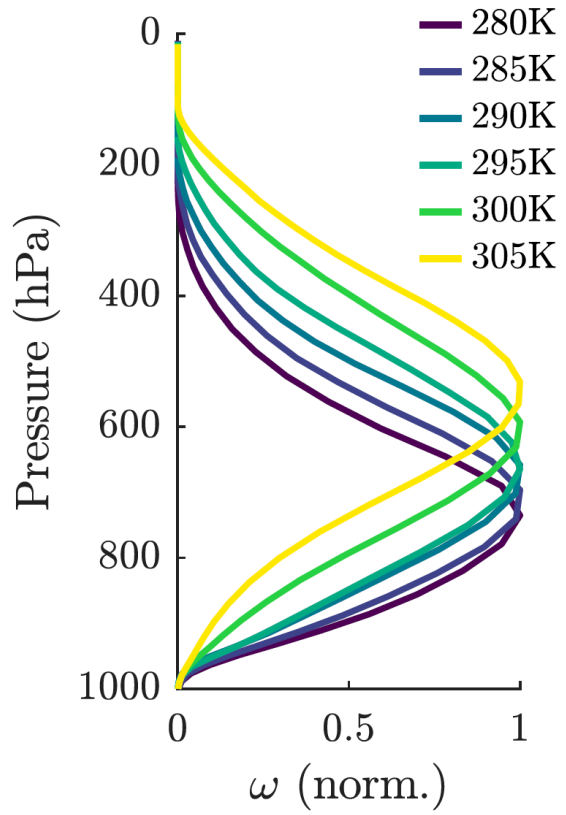
Challenge: Atmosphere's vertical structure changes how much water vapor can be condensed into precipitation!

$$\Delta \text{(rain)}\,(\%) \approx \Delta \text{(water vapor)}\,(\%) + \Delta \text{(wind)}\,(\%)$$



$$\approx 7\%/K$$

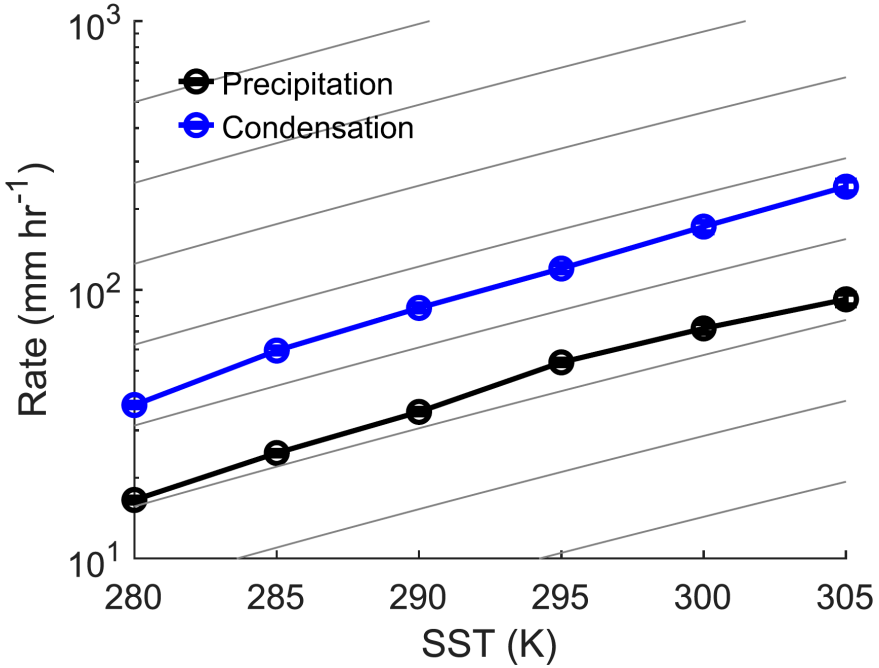




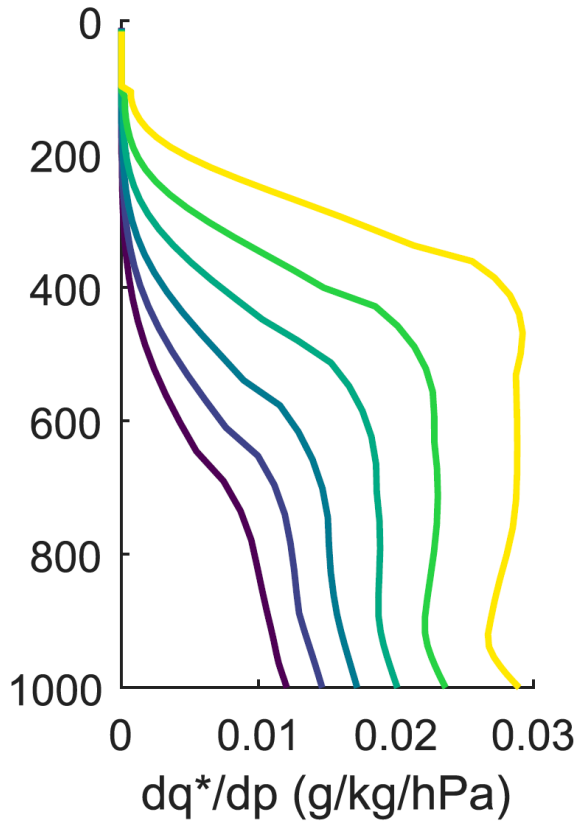
Challenge: The tropopause shifts upwards as the climate warms

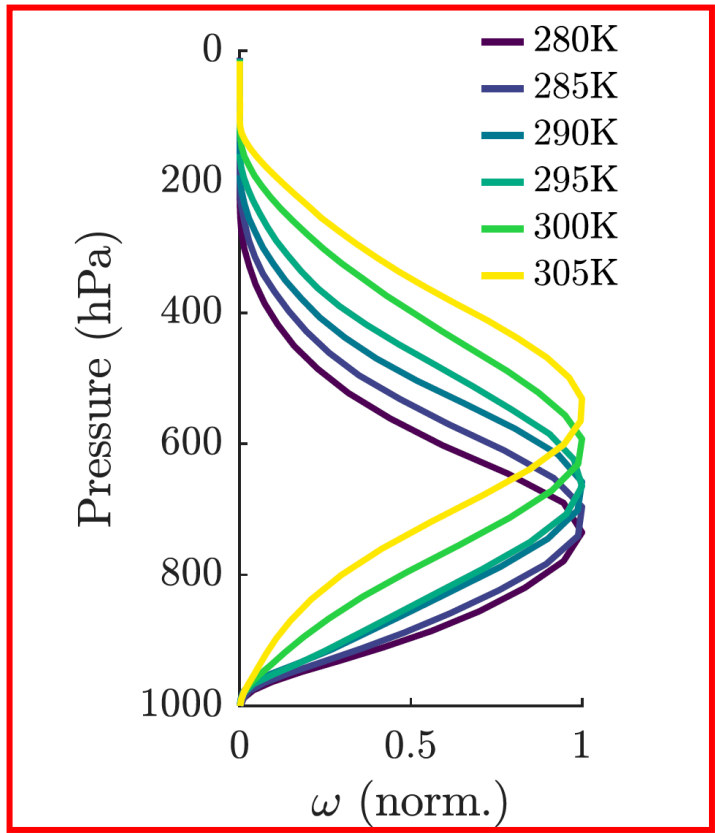
Misleading to assume that the storms' upward air currents do not shift

$$\Delta \text{(rain)}\,(\%) \approx \Delta \text{(water vapor)}\,(\%) + \Delta \text{(updraft)}\,(\%)$$



$$\approx 7\%/K$$

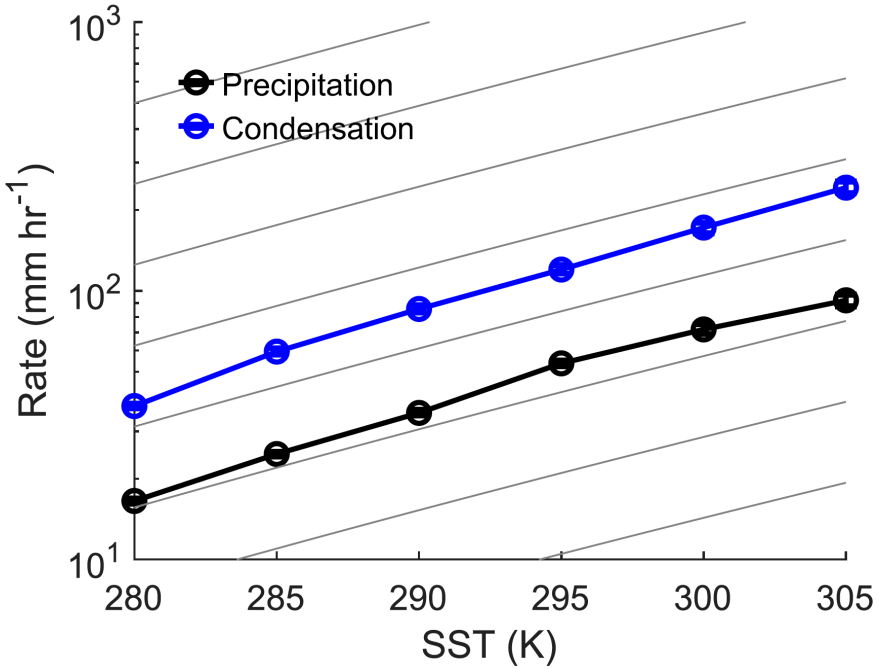




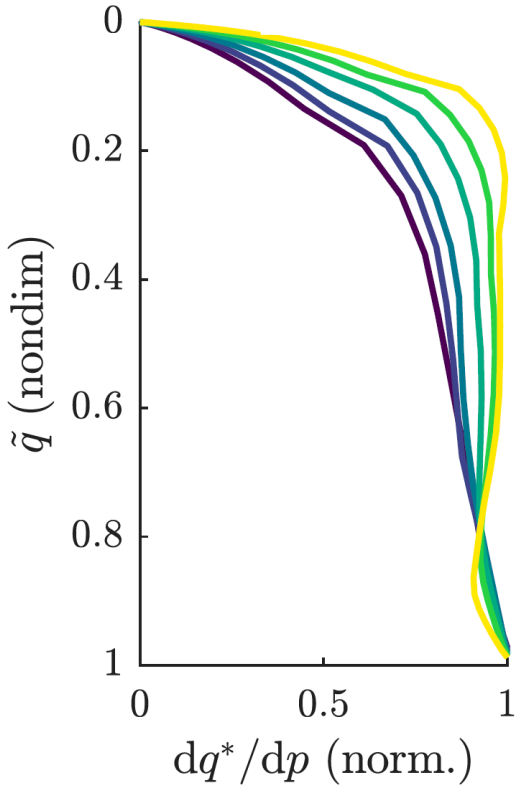
Moisture-Based Coordinate Collapses Upward Air Currents Across Climates

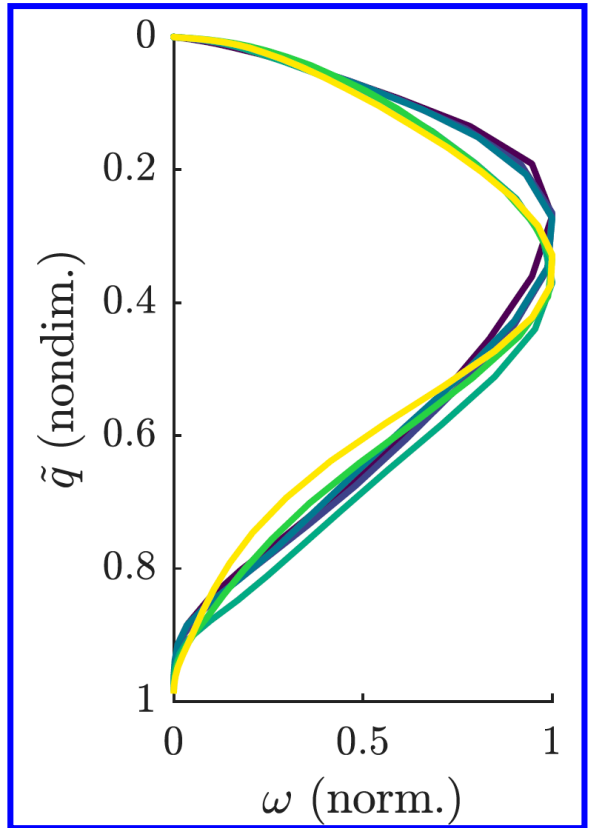
Implication: A simple theory for precipitation extremes changes

$$\Delta \text{(rain)}\,(\%) \approx \Delta \text{(water vapor)}\,(\%) + \Delta \text{(wind)}\,(\%)$$



$$\approx 7\%/K$$





Moisture-Based Coordinate Collapses Upward Air Currents Across Climates

Implication: A simple theory for precipitation extremes changes in RCE

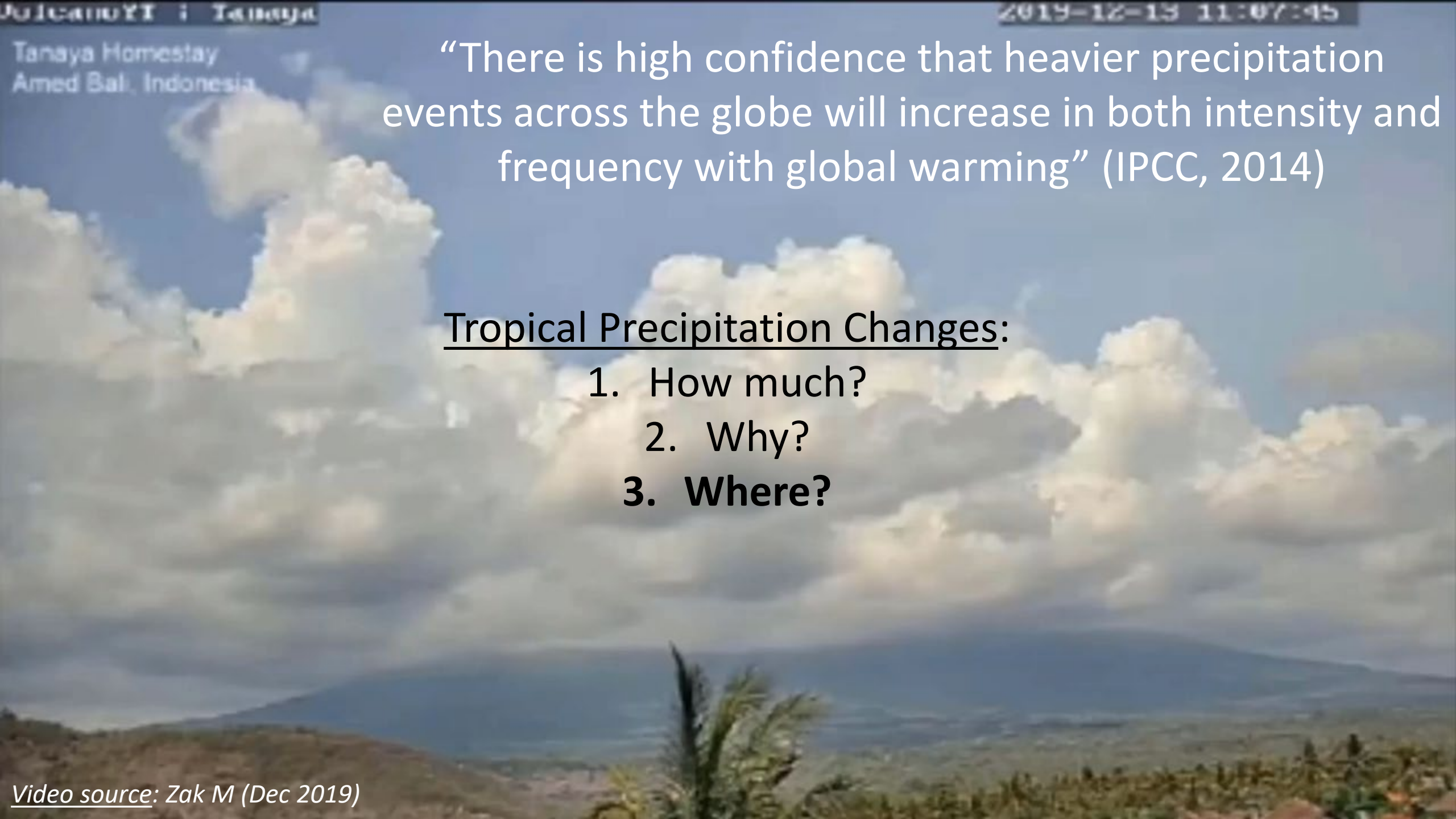
Convective Dynamics and the Response of Precipitation Extremes to Warming in Radiative–Convective Equilibrium

TRISTAN H. ABBOTT AND TIMOTHY W. CRONIN

Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts

TOM BEUCLER

Department of Earth System Science, University of California, Irvine, Irvine, California, and Department of Earth and Environmental Engineering, Columbia University, New York, New York

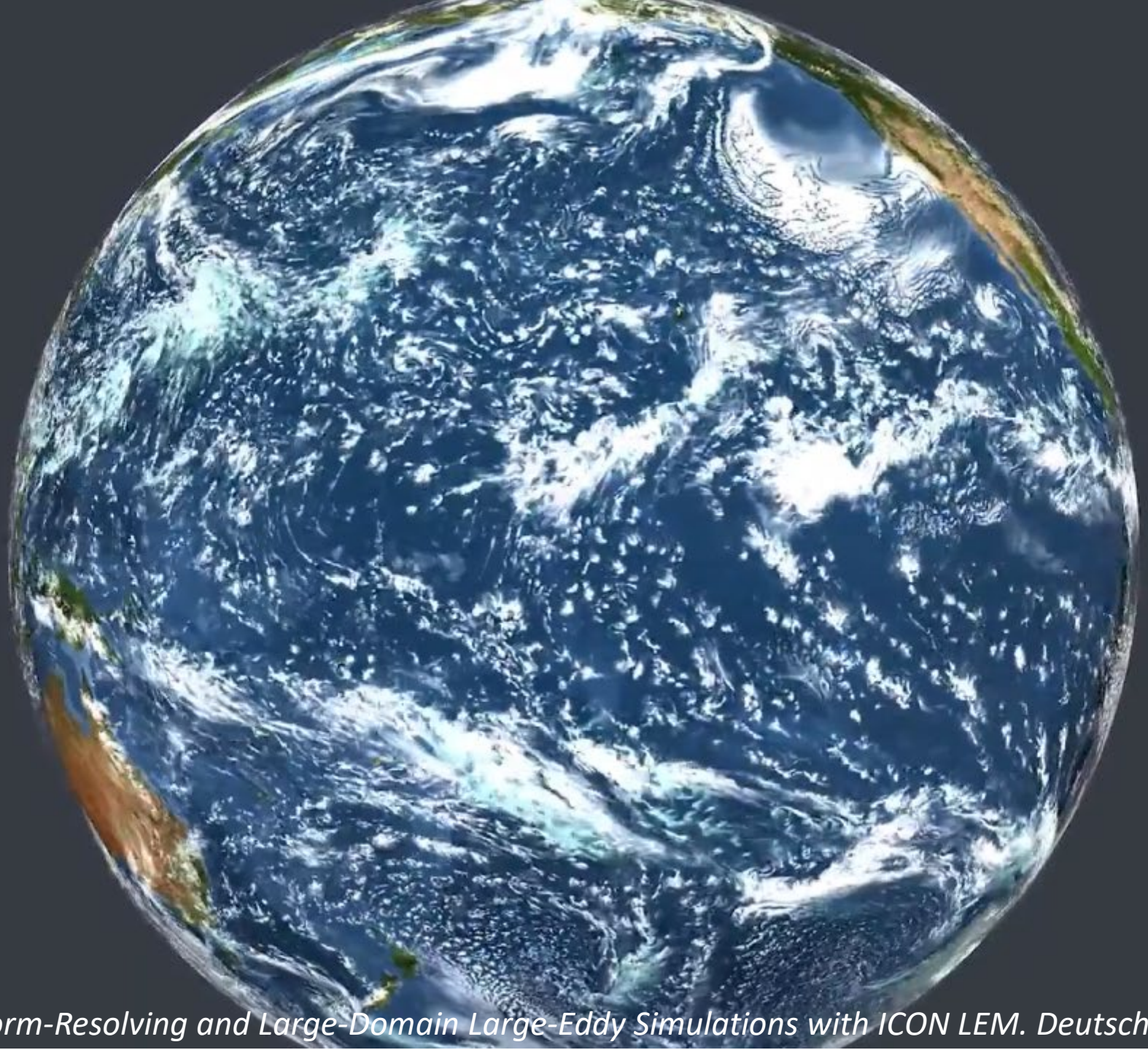


"There is high confidence that heavier precipitation events across the globe will increase in both intensity and frequency with global warming" (IPCC, 2014)

<u>Tropical Precipitation Changes</u>:

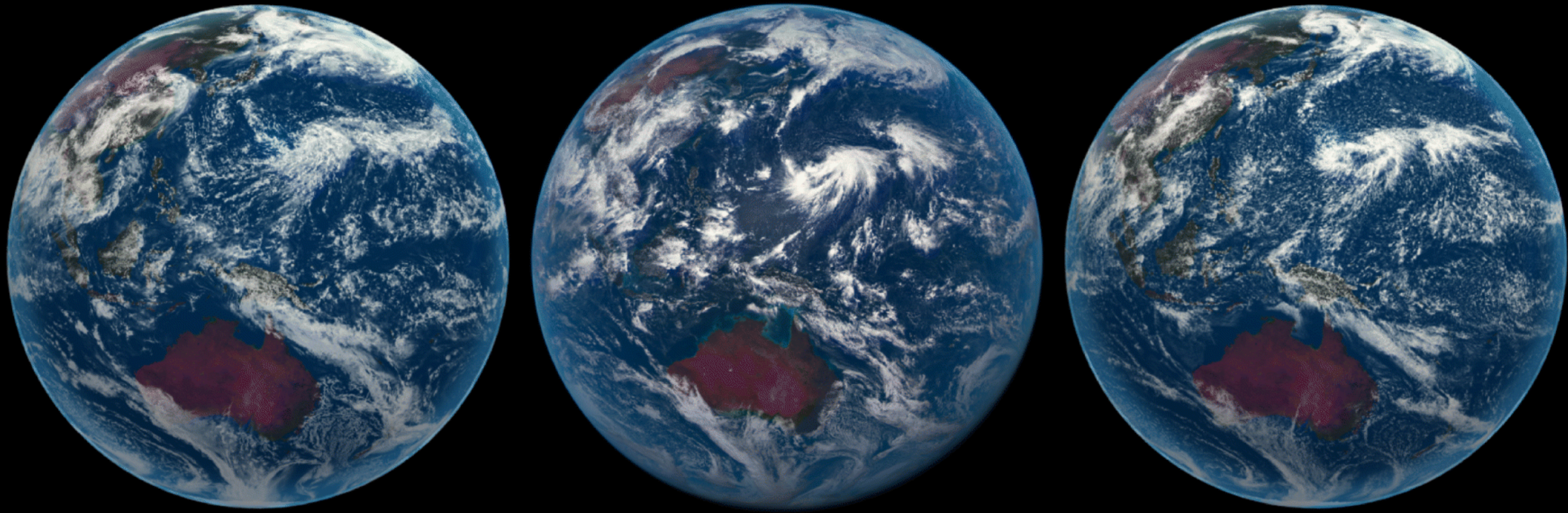
1. How much?
2. Why?
3. **Where?**

<u>Video source</u>: Zak M (Dec 2019)



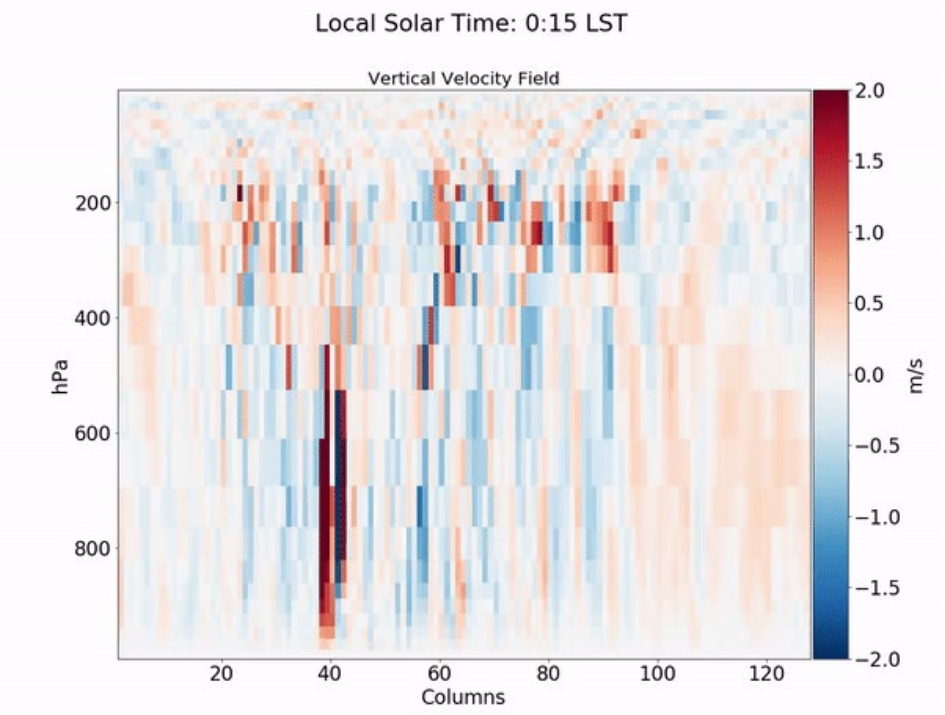
Source vidéo : Global Storm-Resolving and Large-Domain Large-Eddy Simulations with ICON LEM. Deutsches Klimarechenzentrum

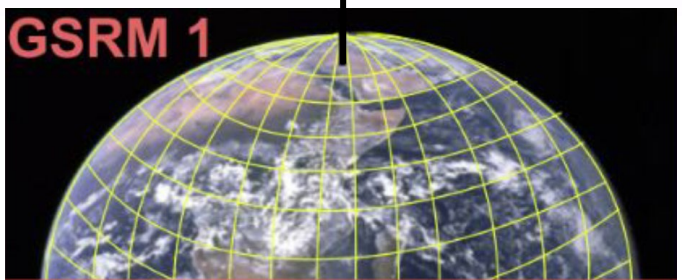
Progress in numerical modeling allows to create “Digital twins” of the Earth

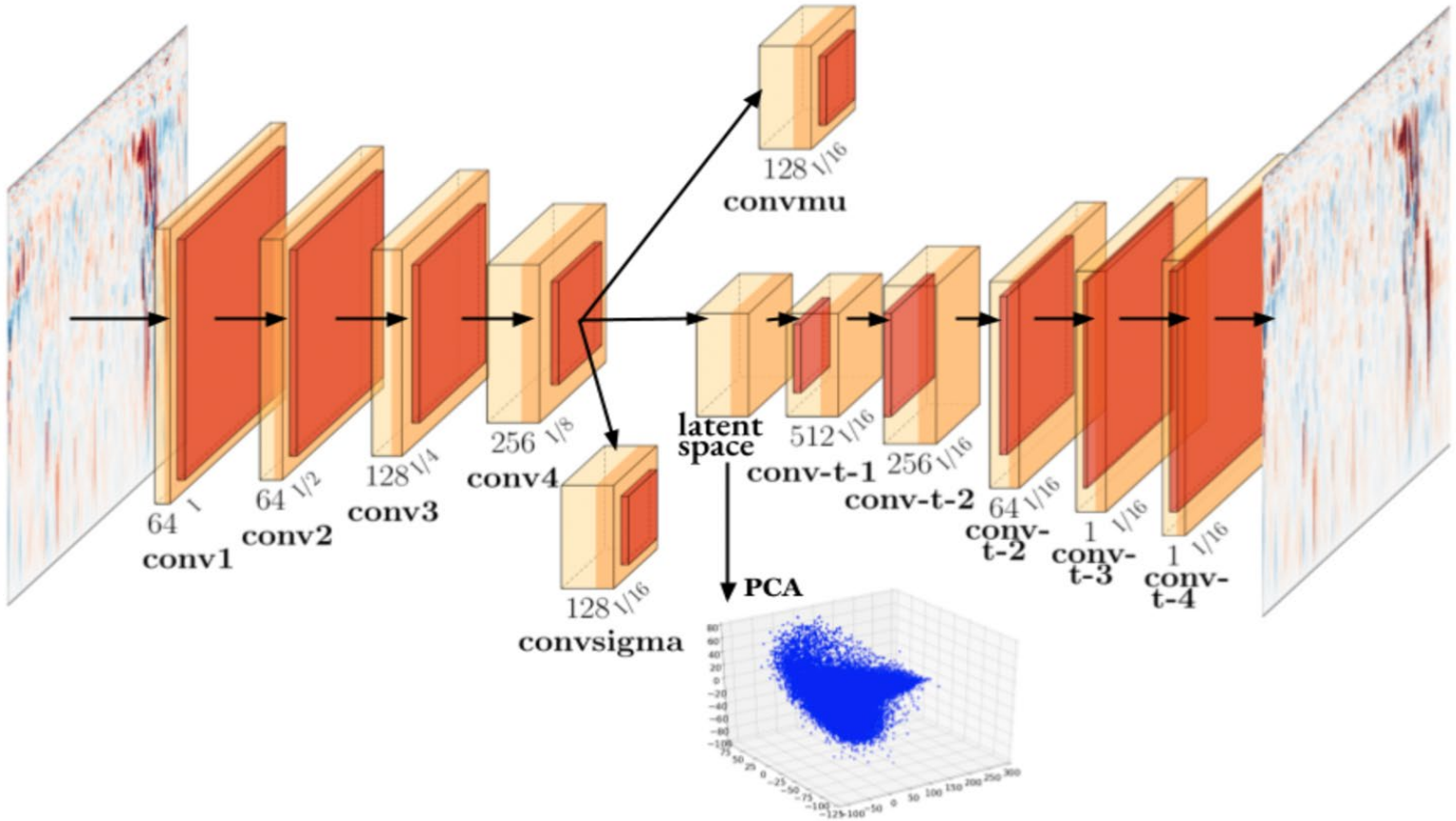


Source: Stevens et al. (2019)

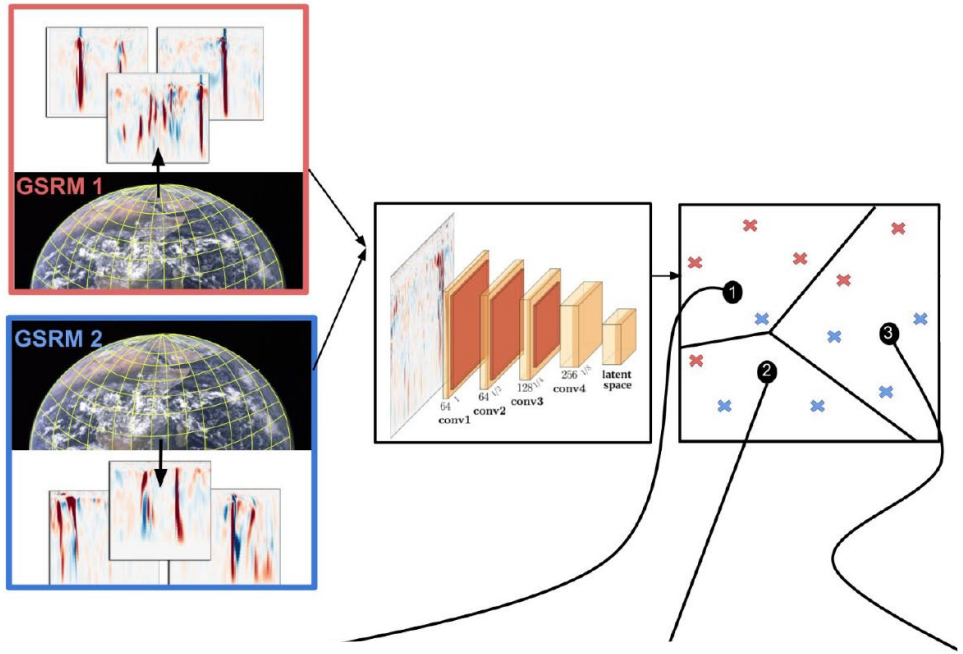
We Compress Millions of Vertical Velocity Profiles into a Human-Interpretable Space with a Variational Auto-Encoder







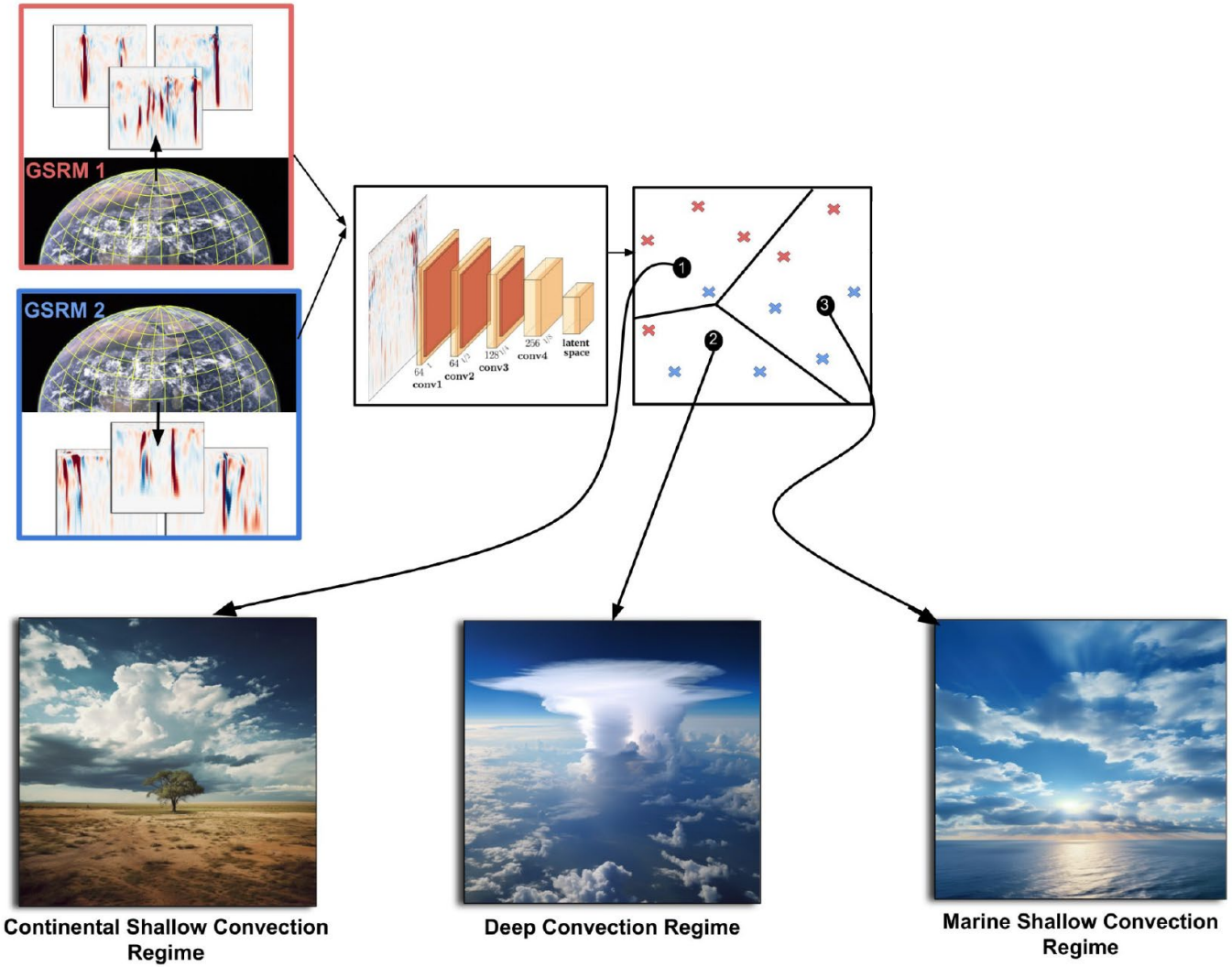
This human-interpretable space can be clustered into 3 regimes for extreme precipitation analysis



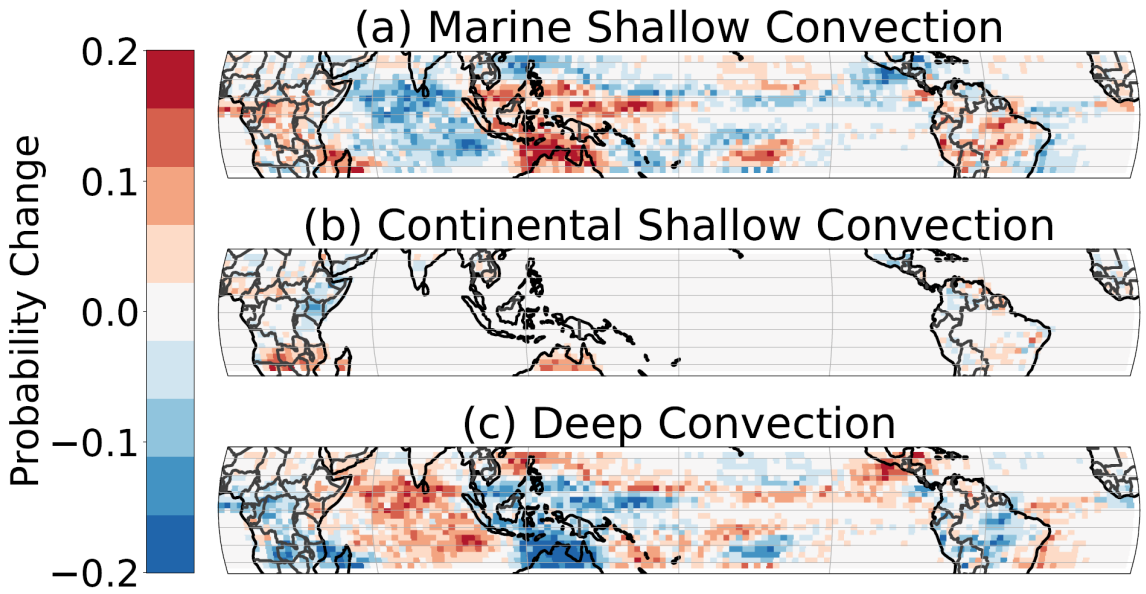
Regime changes (SP, +4K warming):

Source: Mooers et al. (2023), Mooers et al. (2024)

This human-interpretable space can be clustered into 3 regimes for extreme precipitation analysis



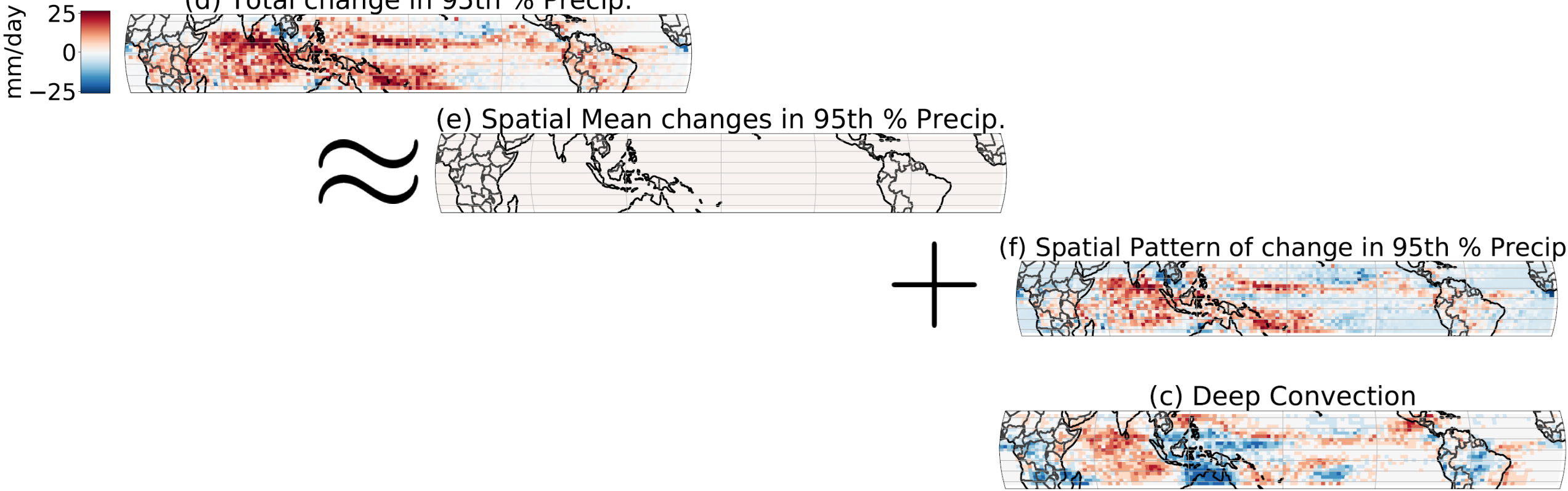
Regime changes (SP, +4K warming):



Source: Mooers et al. (2023), Mooers et al. (2024)

Using data-driven dynamical regimes, we find that precipitation changes are mainly due to **spatial shifts in storm regime occurrences**, rather than changes in how each regime generates precipitation.

$$\Delta\ (\%) \approx \Delta\ (\%) + \Delta\ (\%)$$



Using data-driven dynamical regimes, we find that precipitation changes are mainly due to **spatial shifts in storm regime occurrences**, rather than changes in how each regime generates precipitation.

Environmental Data Science (2024), 3: e3, 1–10
doi:10.1017/eds.2024.1

CAMBRIDGE UNIVERSITY PRESS

APPLICATION PAPER

Understanding precipitation changes through unsupervised machine learning

Griffin Mooers[1], Tom Beucler[2,3], Mike Pritchard[1,4] and Stephan Mandt[5]

[1]Earth System Science, University of California, Irvine, CA, USA
[2]Faculty of Geosciences and Environment, University of Lausanne, Lausanne, Switzerland
[3]Expertise Center for Climate Extremes, University of Lausanne, Lausanne, Switzerland
[4]NVIDIA Research, Santa Clara, CA, USA
[5]Department of Computer Science, University of California, Irvine, CA, USA
Corresponding author: Griffin Mooers; Email: gmooers96@gmail.com

Received: 02 March 2023; **Revised:** 24 November 2023; **Accepted:** 09 January 2024

Keywords: atmospheric dynamics; climate change; heavy precipitation; unsupervised learning; variational autoencoders

SPRINGER LINK

Find a journal | Publish with us | Track your research | Search

Home > Scientific Reports > Article

Comparing storm resolving models and climates via unsupervised machine learning

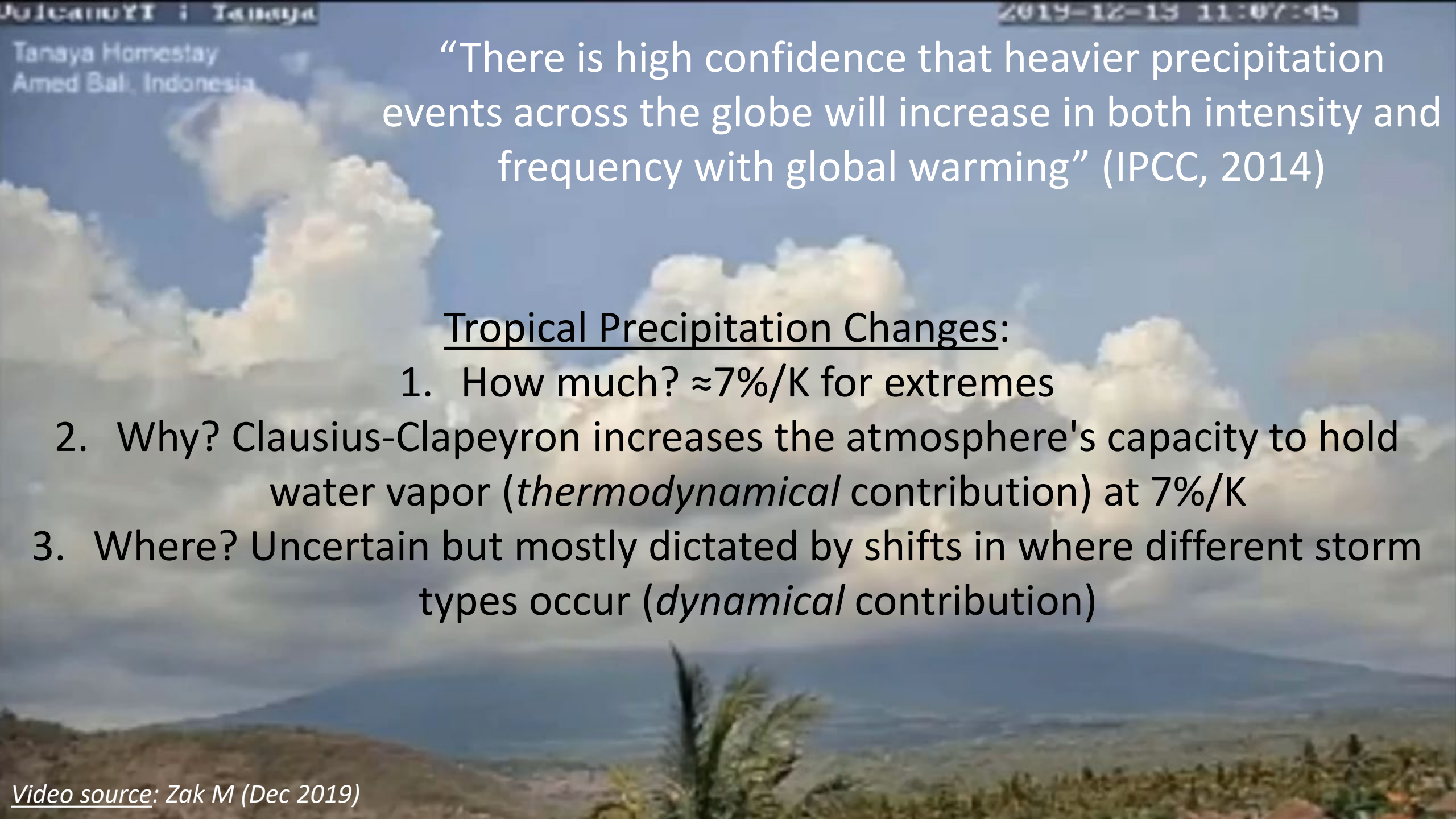
Article | Open access | Published: 15 December 2023

Volume 13, article number 22365, (2023) Cite this article

Download PDF

You have full access to this open access article

Griffin Mooers, Mike Pritchard, Tom Beucler, Prakhar Srivastava, Harshini Mangipudi, Liran Peng, Pierre Gentine & Stephan Mandt



"There is high confidence that heavier precipitation events across the globe will increase in both intensity and frequency with global warming" (IPCC, 2014)

Tropical Precipitation Changes:

1. How much? ≈7%/K for extremes
2. Why? Clausius-Clapeyron increases the atmosphere's capacity to hold water vapor (*thermodynamical* contribution) at 7%/K
3. Where? Uncertain but mostly dictated by shifts in where different storm types occur (*dynamical* contribution)

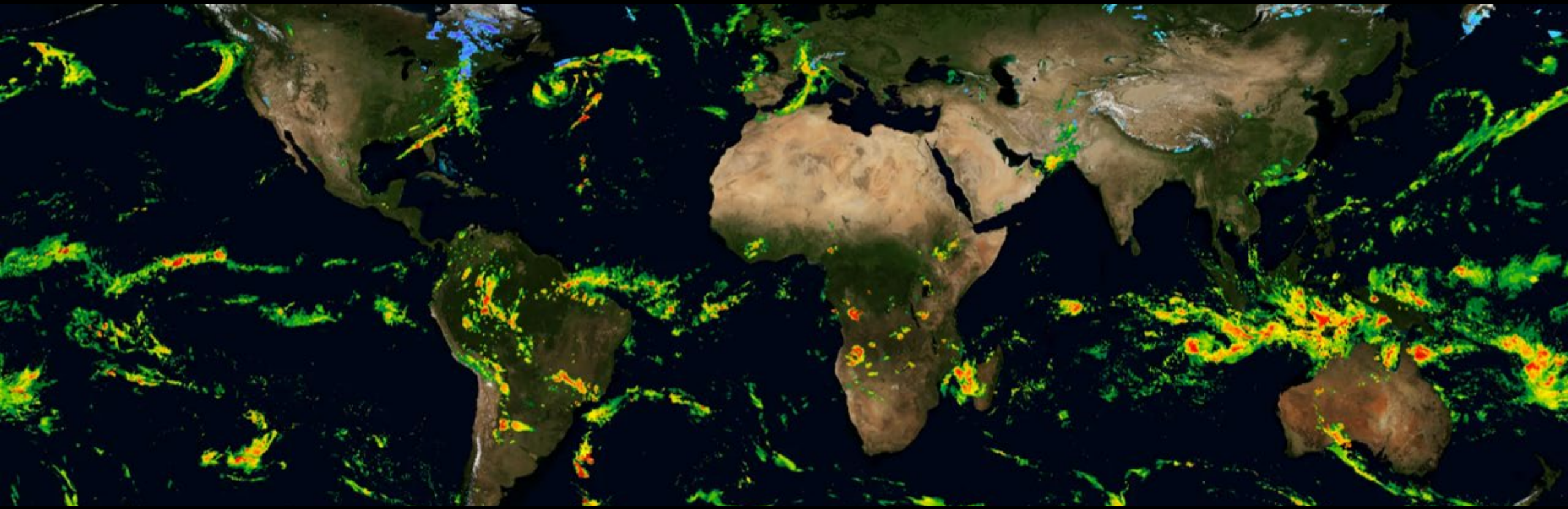
Video source: Zak M (Dec 2019)

∂³AWN
∂ata-∂riven
Atmospheric & Water
∂yNamics

clim↔act

Unil
Université de Lausanne
Expertise Center for
Climate Extremes (ECCE)

Tropical Precipitation in a Changing Climate



https://wp.unil.ch/dawn/

Source: IMERG (NASA)

Presenter: Tom Beucler (UNIL)

Collaborators: G. Mooers (MIT), T. Abbott (NOAA GFDL), M. Pritchard, S. Mandt (UCI), T. Cronin (MIT)