Peak-Structure of Extreme Precipitation-Temperature Relationships and its Future Changes

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NCAR and U Connecticut

The peak structure and future changes of the relationships between extreme precipitation and temperature

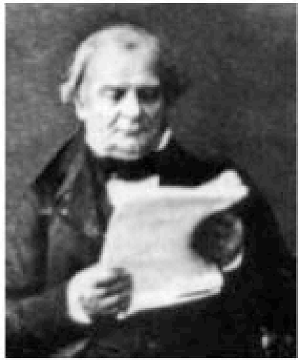
- Wang, G., D. Wang, K. Trenberth, A. Erfanian, M. Yu, M. Bosilovich, D. Parr, 2017:
- *Nature Climate Change*, doi:10.1038/NCLIM-3239, in press.
- Embargoed till March 6

Clausius-Clapeyron Equation

Who are these people?

Rudolf Clausius
1822-1888
German
Mathematician / Physicist

"Discovered" the Second Law
Introduced the concept of entropy

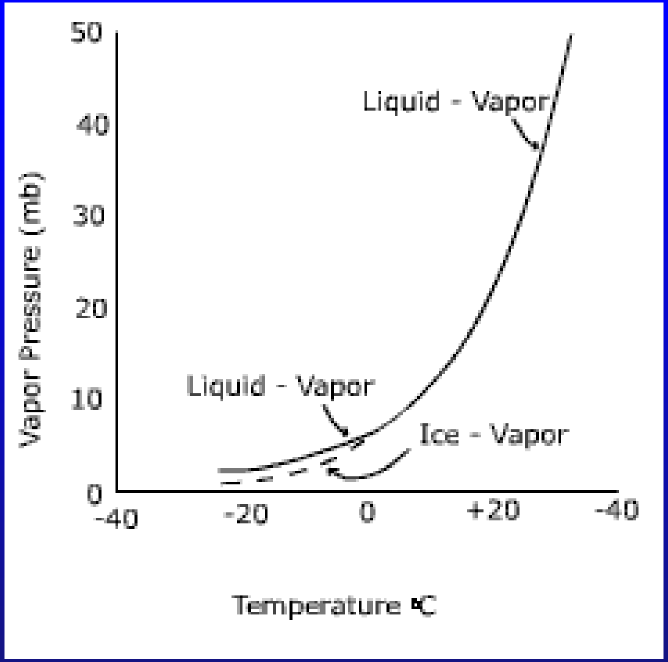


Benoit Paul Emile Clapeyron
1799-1864
French
Engineer / Physicist

Expanded on Carnot's work

$$\frac{dP}{dT} = \frac{L}{T\Delta v}$$

$$\ln\left(\frac{P_1}{P_2}\right) = \frac{\Delta H_{vap}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$



At the surface, the exponential nature of the increase in water-holding capacity of the atmosphere, means that moisture increases at about

7% K^{-1} (or about 4% F^{-1})

if the RH remains the same.

Most precipitation comes from moisture convergence by weather systems

Low level winds bring in moisture from afar

More moisture means heavier rains

Precipitation characteristics

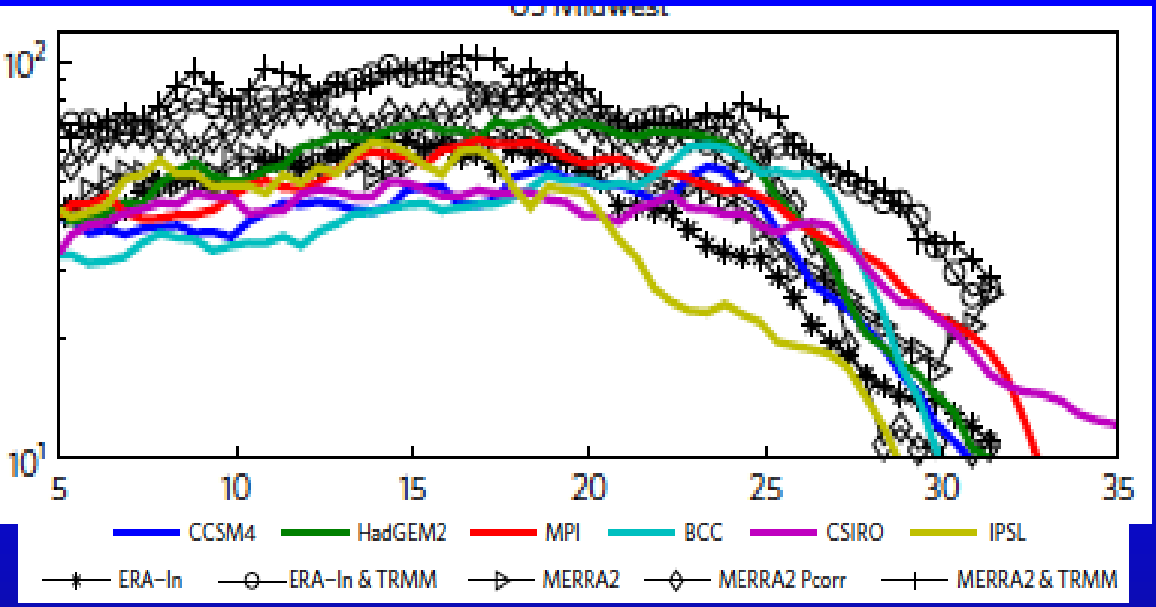
Amount: governed by energy budget plus supply
Intensity: governed by atmospheric moisture available
(Clausius-Clapeyron)
Frequency: Amount/Intensity

With climate change, the amount change is limited by how much evaporation changes, and estimates are about 2%/K
- (limited also by aerosols)

But if moisture is not limited (oceans and coastal), the moisture convergence goes up 7%/K and further intensifies some disturbances, so that a super C-C rate can occur

Precipitation limitations

Observations show that this occurs but with a limit:
At high temperatures, the rate falls off.



For the US Midwest, Daily precipitation extremes (in mm/day) with local temperature (°C): (top) based on observations and reanalysis data (black with symbols) (1991-2015) as well as six global models (thick color lines);

Precipitation limitations

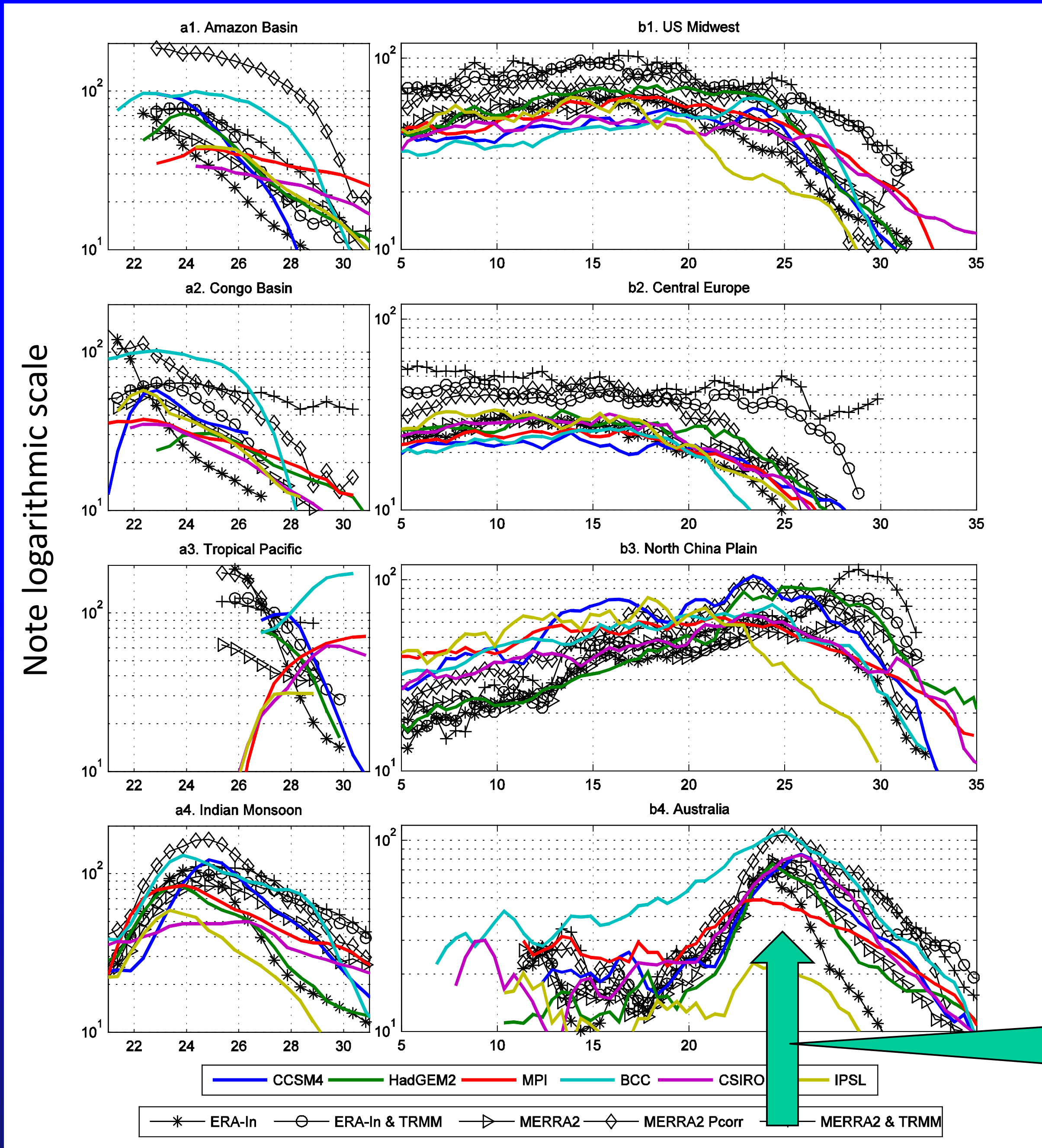
**Observations show that this occurs but with a limit:
At high temperatures, the rate falls off.**

1) At very high T, a large saturation deficit occurs: insufficient moisture, especially over land, and RH goes down;   also the moisture laden-air may come from cooler oceans.

2) In anticyclonic or "settled" conditions, convective clouds and precipitation are suppressed, leading to more sunshine, lighter winds and smaller surface evaporative fluxes, and thus higher surface temperatures

OR in cases of extreme precipitation events, the cloud radiative effect, strong latent heat fluxes and, in the case of the ocean, strong mixing, all contribute to surface cooling.

i.e. The precipitation processes control the temperature, not temperature controlling precipitation

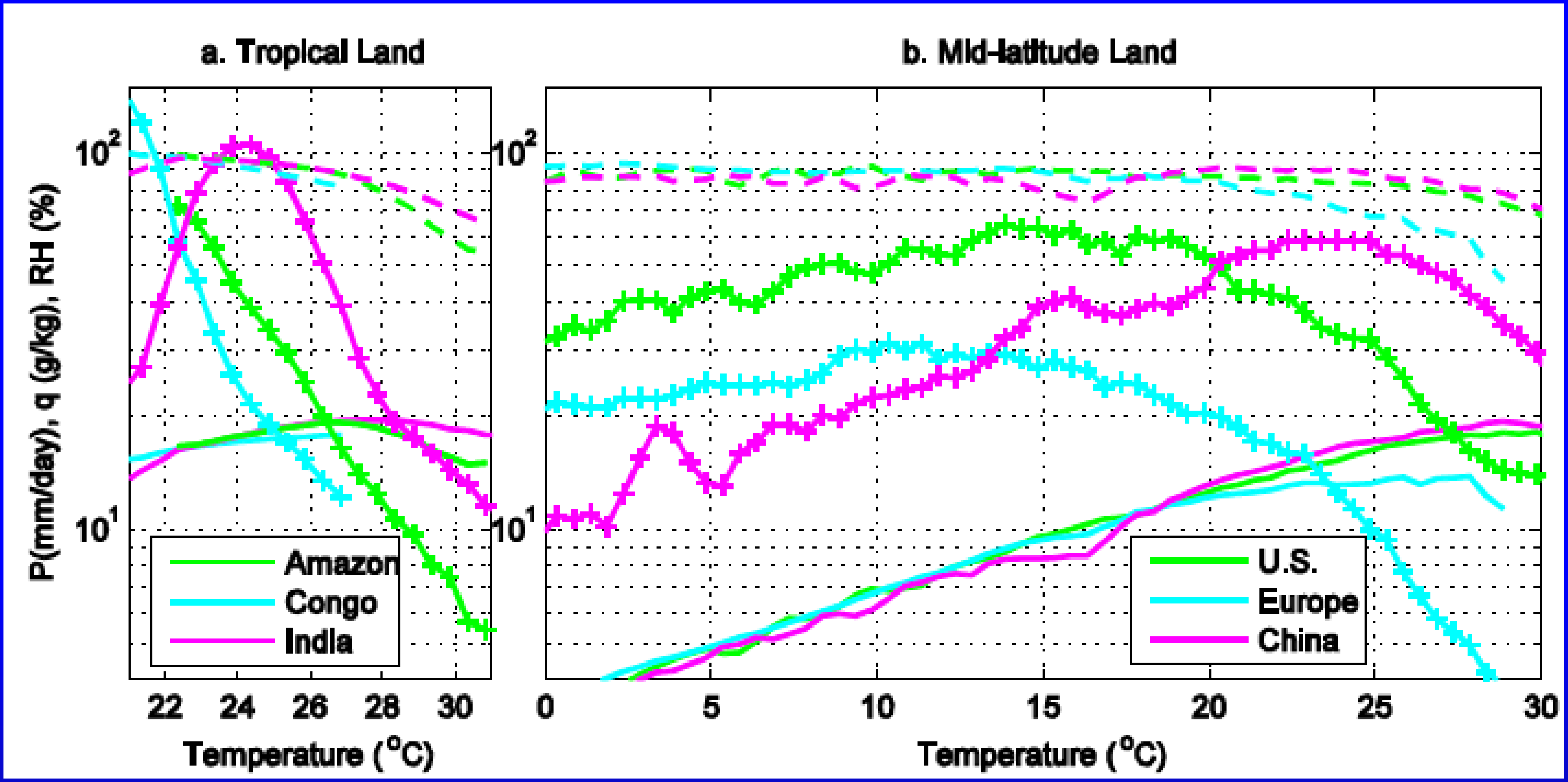


Daily precipitation extremes (in mm/day)
with local temperature (°C):

based on observations and reanalysis data (black with symbols) (1991-2015) as well as six global models (thick color lines),

- Amazon Basin (60°W,0°)
- Congo Basin (22°E, 4°S)
- Tropical Pacific (150°E, 0°)
- Indian monsoon (80°E,20°N)
- U.S. Midwest (90°W, 37°N)
- central Europe (22°E, 47°N)
- North China (117°E, 36°N)
- Australia (131°E, 20°S)

Peak precipitation and temperature

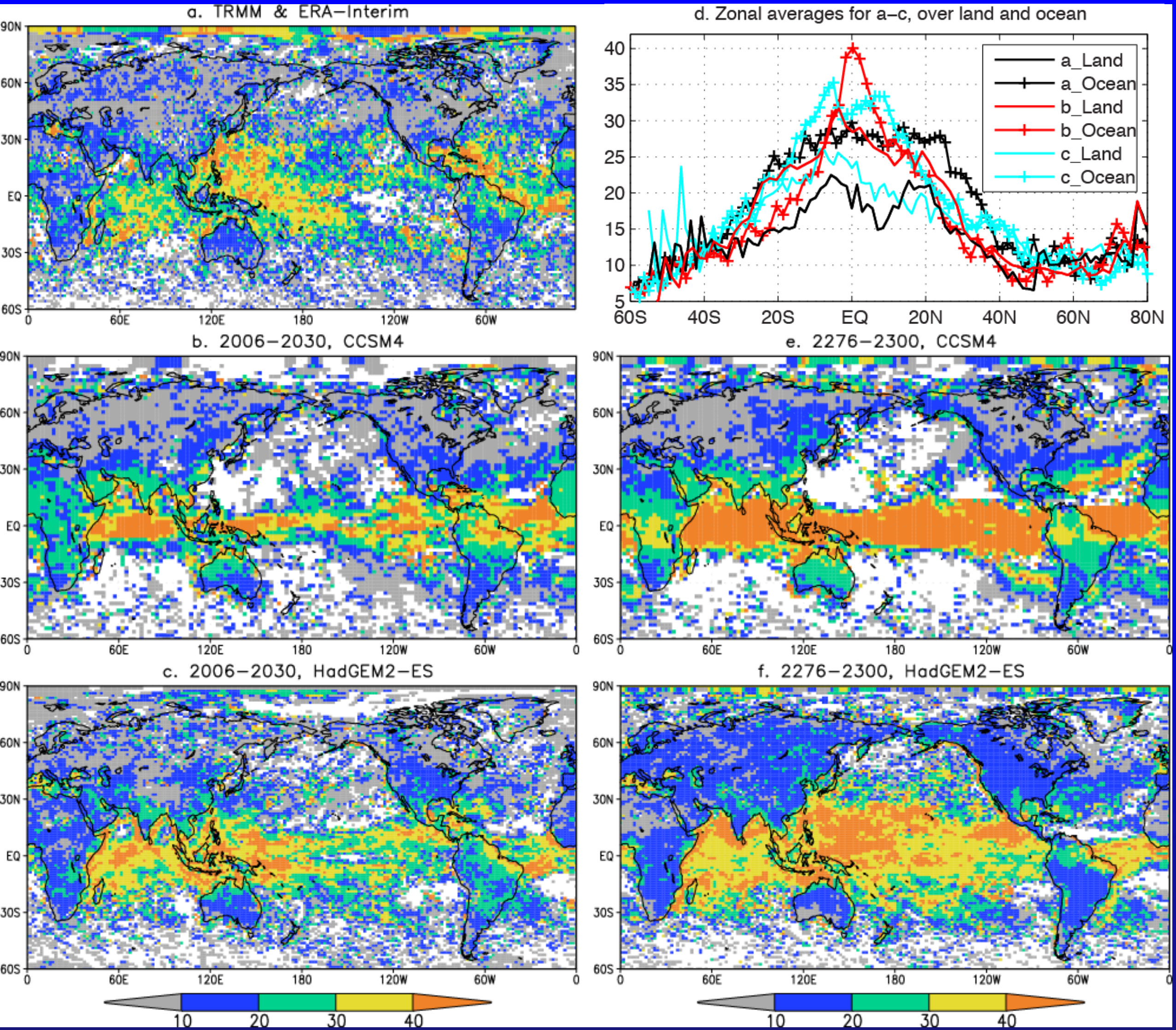


Daily precipitation extremes (in mm/day) with local temperature (°C): +-+-+-

Relative humidity - - - - - -

Specific humidity ———

Rate of decrease of extreme daily precipitation with local T at the high T-range



In % per °C.

a) P: TRMM 3B42 (50°S-50°N) + ERA-I (50°-90°)
T: ERA-I

b-c) 2006-2030

e-f) 2276-2300

For RCP8.5 for

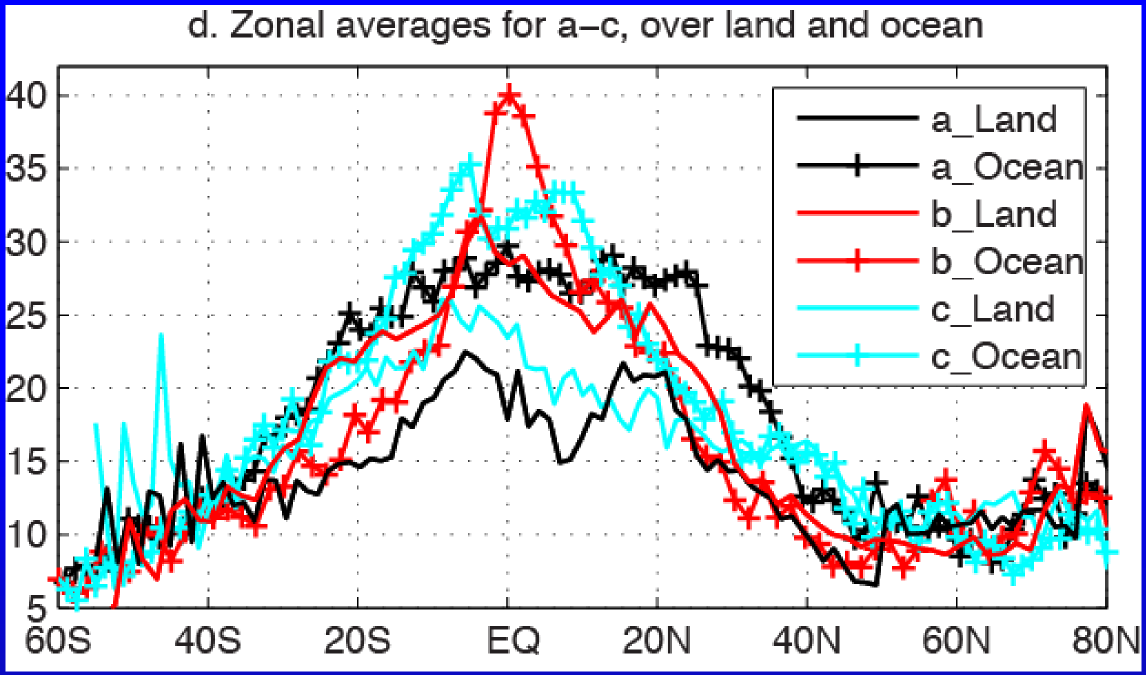
b-e) CCSM4

c-f) HadGEM2-ES

d) zonal average over land and ocean for a-c).

Over the unshaded areas, decrease of extreme precipitation at high temperature was not detected.

Rate of decrease of extreme daily precipitation with local T at the high T-range



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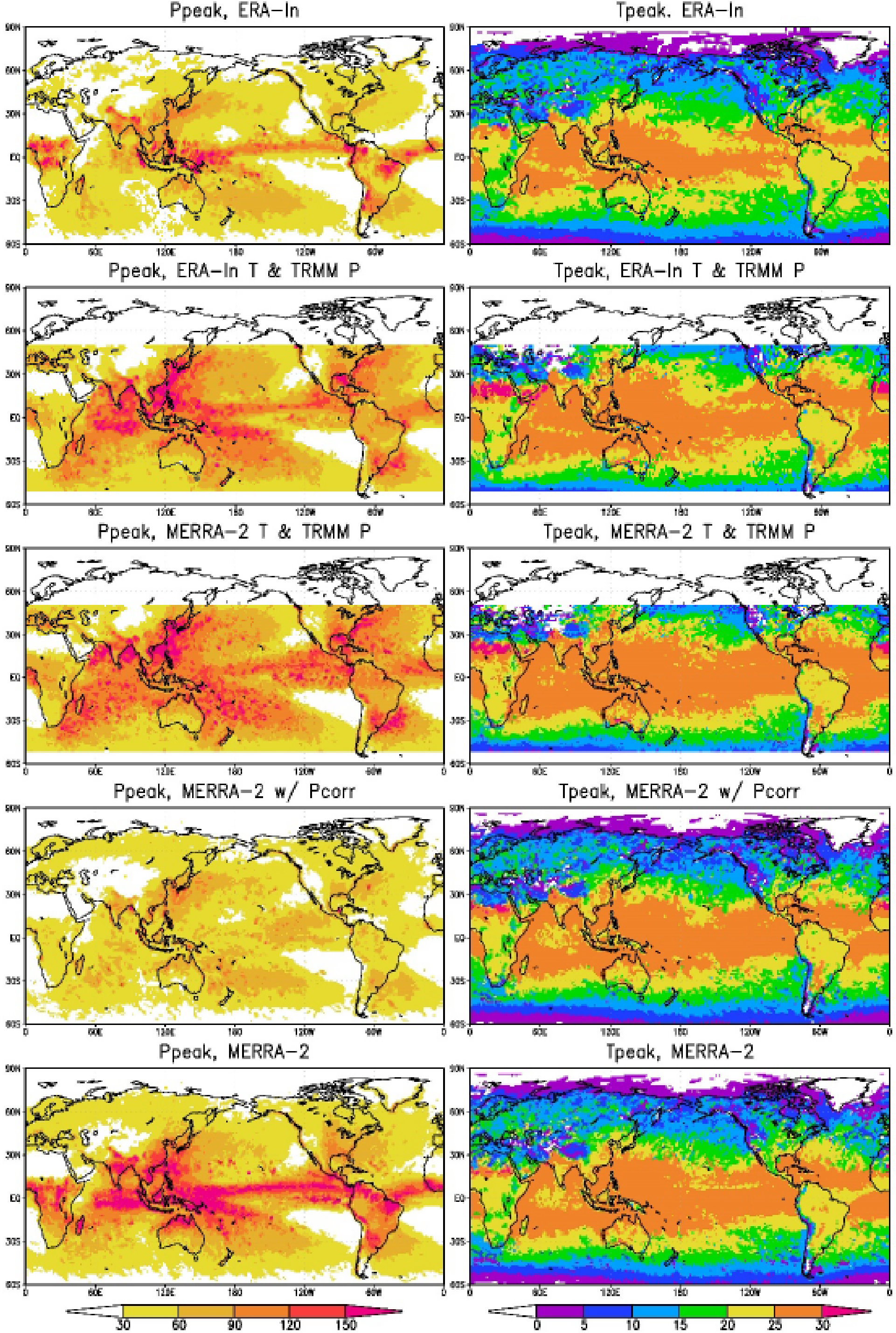
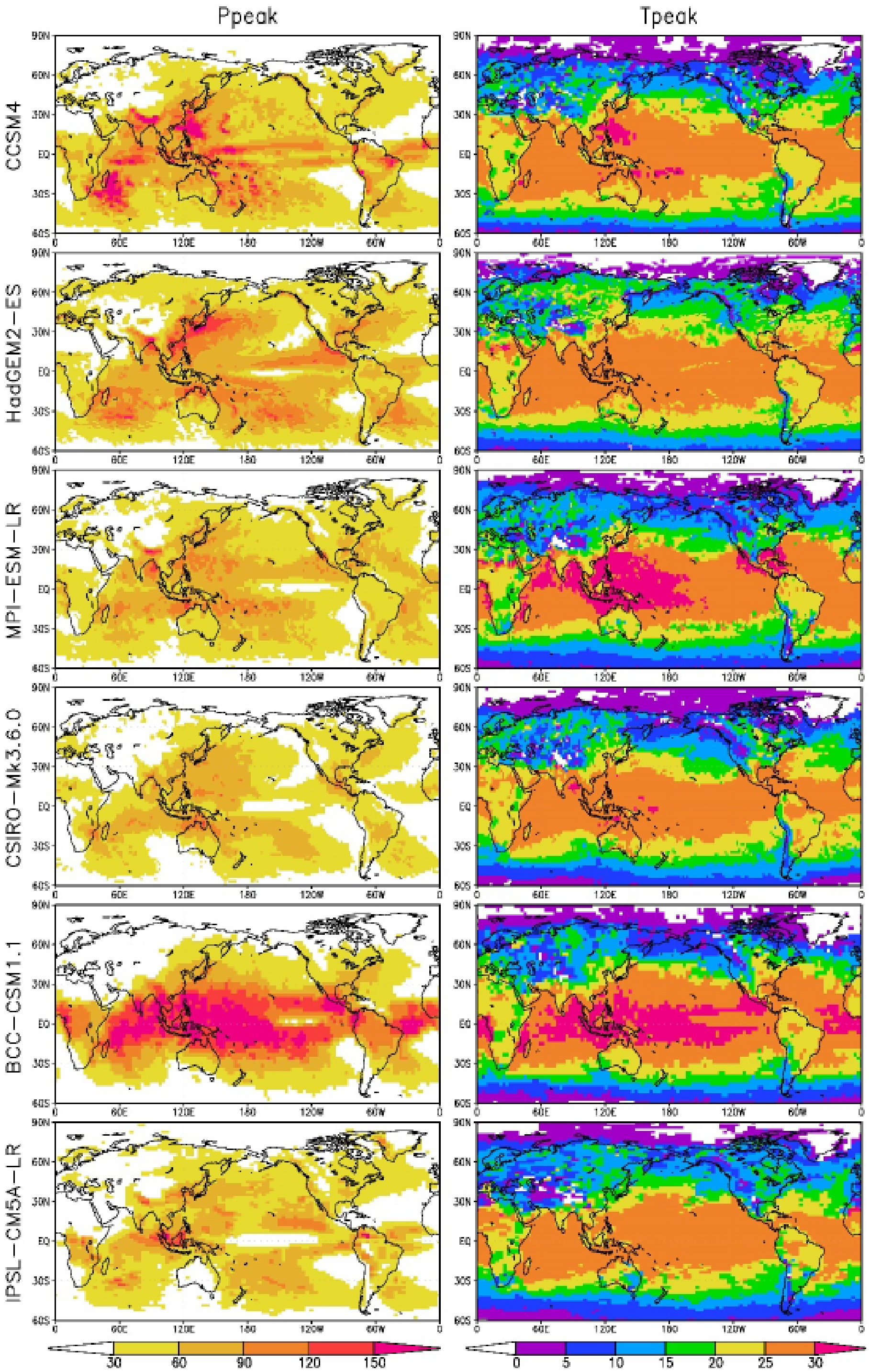


P_{peak} and T_{peak}

In mm/day (left) and °C (right).

Obs: ERA-I (model), MERRA-2 (P_{model}; and P_{corr}: corrected based on obs (gauge +sat.)); TRMM 3B42 (v 7a).



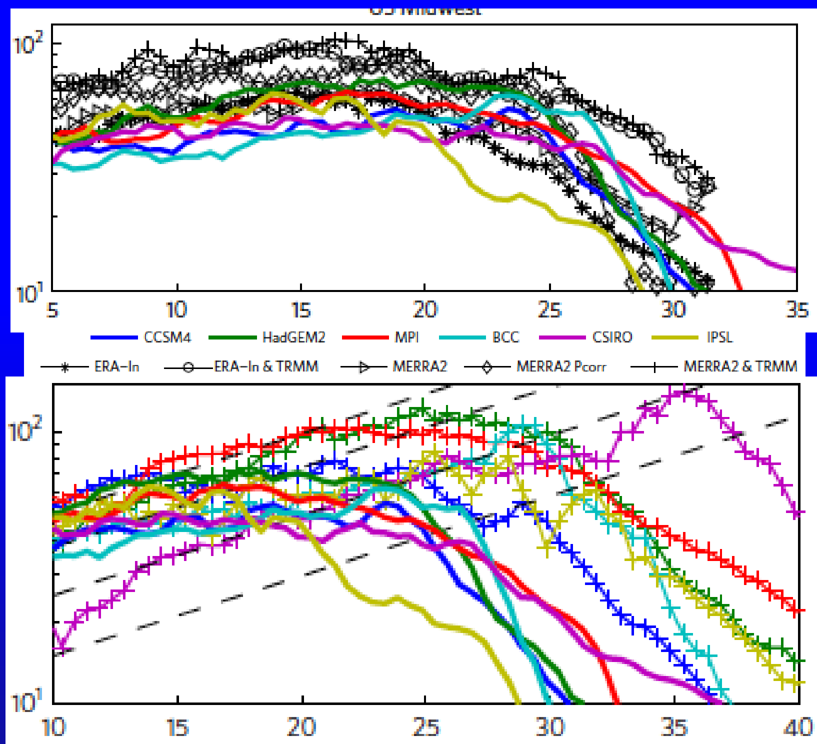
P_{peak} and T_{peak}

In mm/day (left) and °C (right)

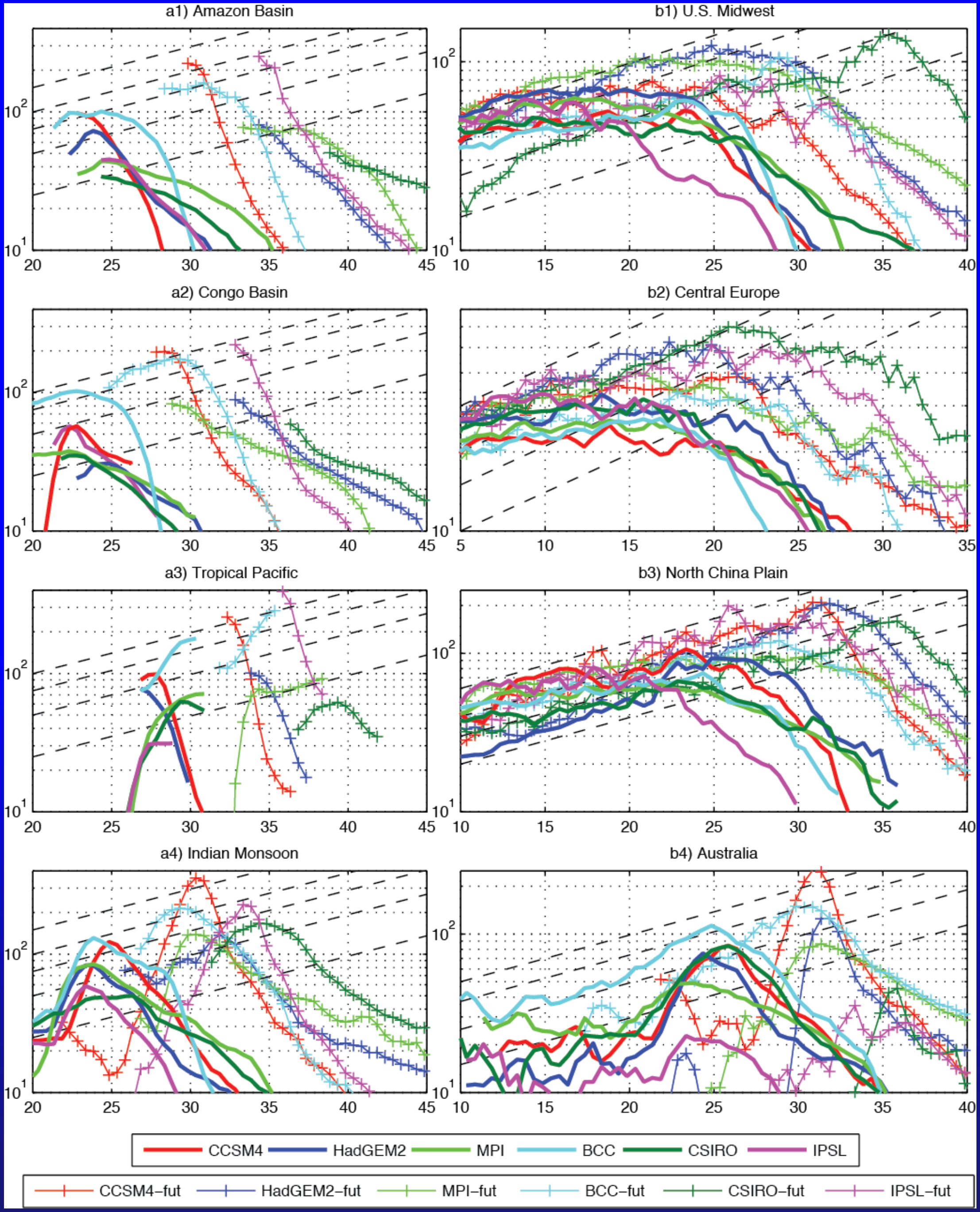
For 2006-2030 for models using RCP 8.5.

Precipitation limitations

Observations show that this occurs but with a limit:
At high temperatures, the rate falls off.



For the US Midwest, Daily precipitation extremes (in mm/day) with local temperature (°C): (top) based on observations and reanalysis data (black with symbols) (1991-2015) as well as six global models (thick color lines); (bottom) Projected: 2276-2300 RCP8.5 +-+-+- vs 2006-2030 ------



PROJECTED:

2276-2300 RCP8.5

vs 2006-2030

Daily precipitation extremes (in mm/day)

with local temperature (°C):

based on six global models

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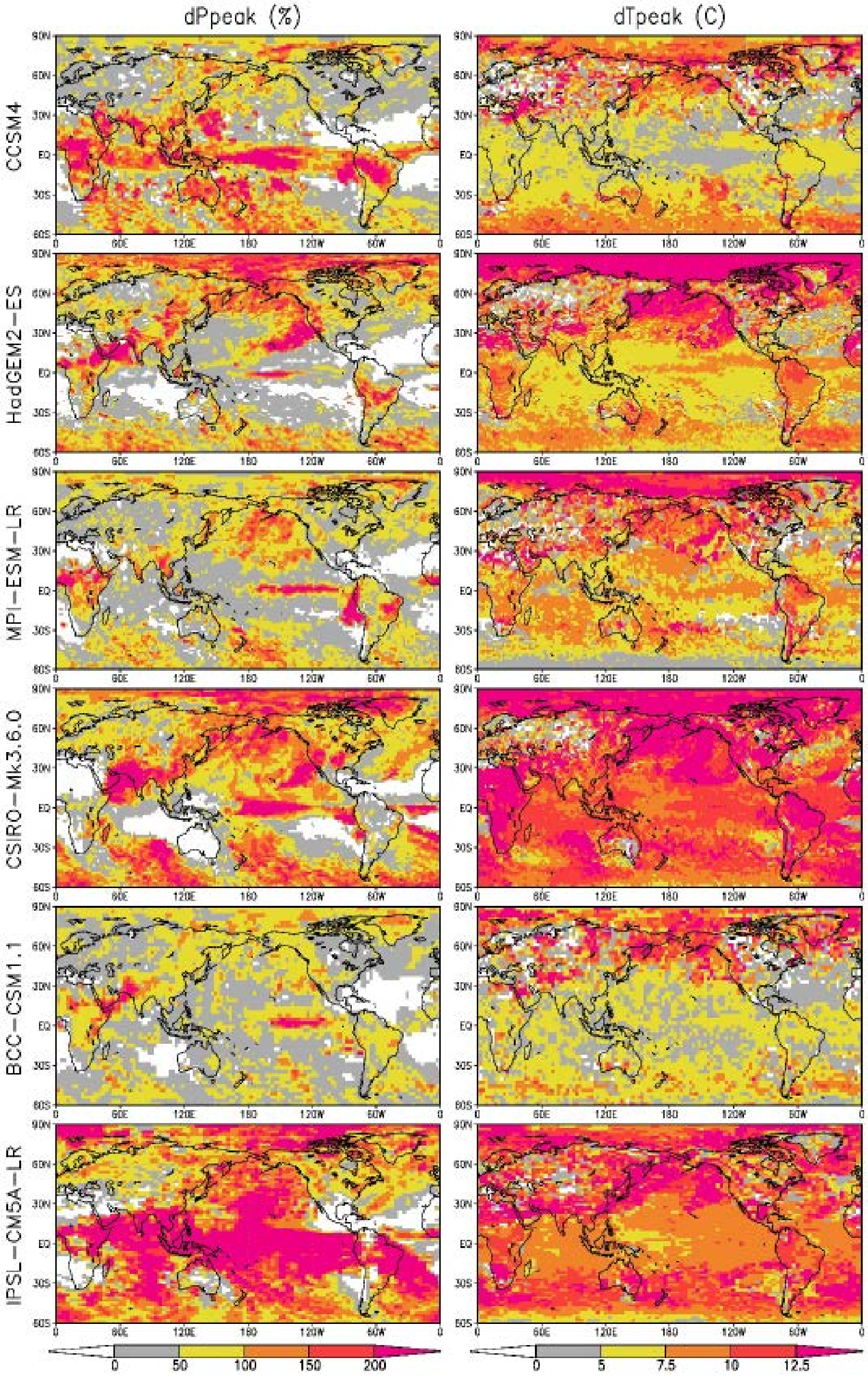


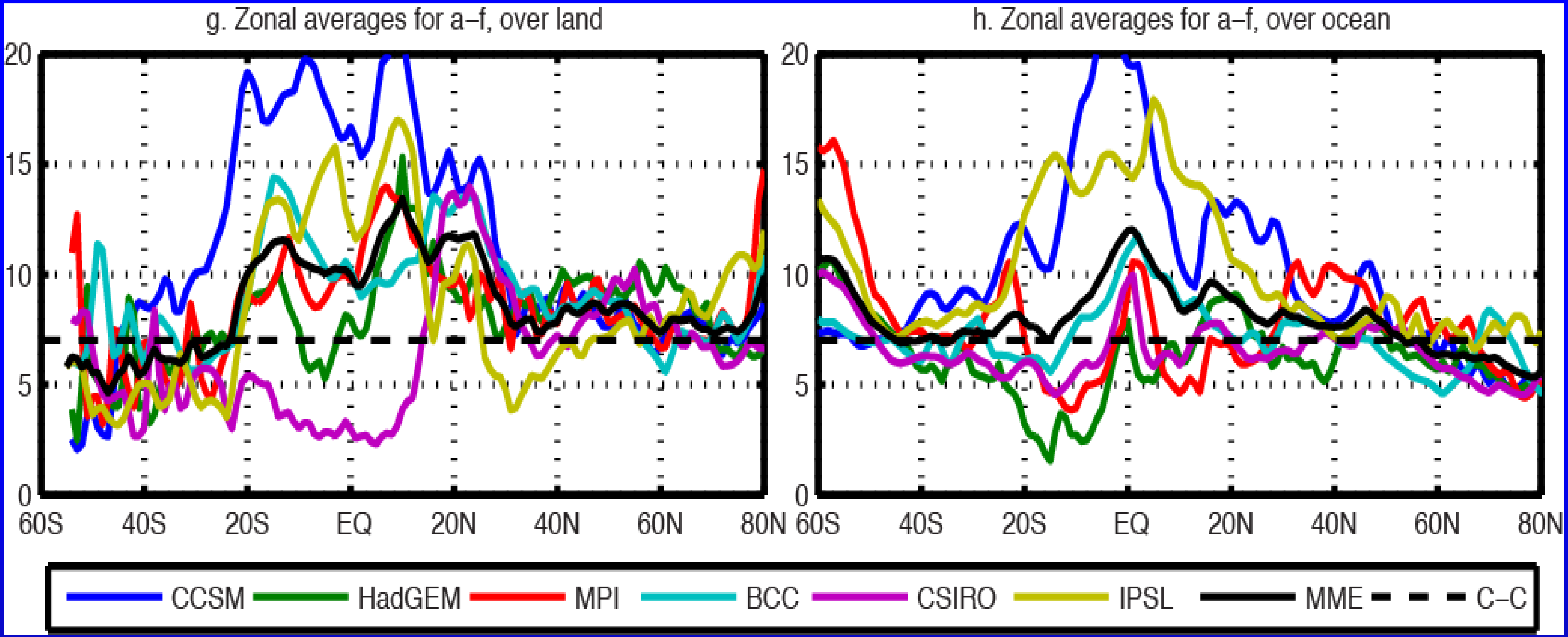
Changes in P_{peak} and T_{peak}

In % (left) and °C (right)

For 2076-2300 vs 2006-2030 for models using RCP 8.5.

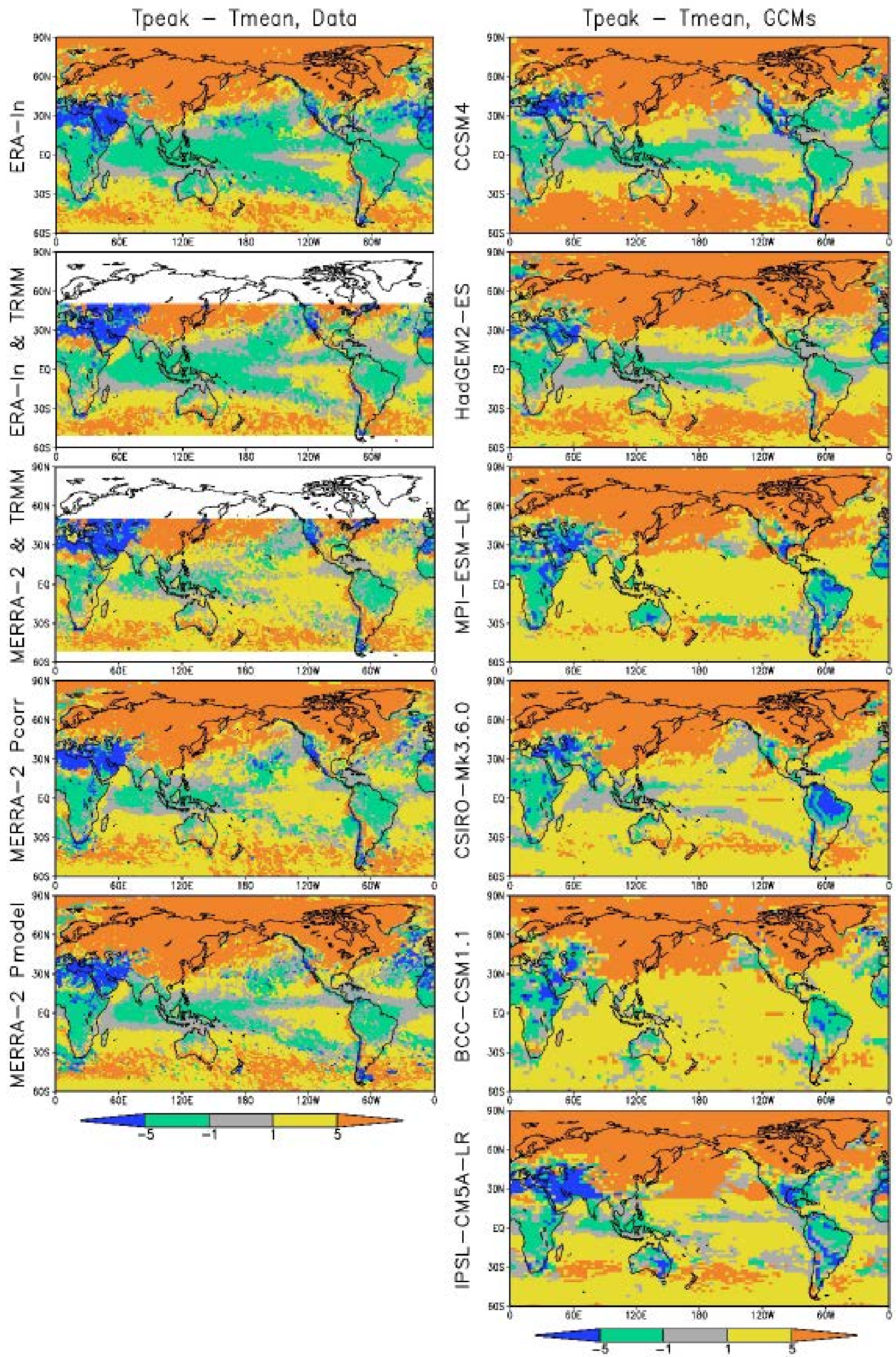
In spite of model differences, the scaling of P_{peak} with T_{peak} based on the multi-model ensemble average is in the range of 5-10% per C (close to the CC rate), a bit higher in tropics.

Scaling rate of peak of daily precipitation extreme (P_{peak}) with temperature at which it peaks (T_{peak}).



In % per °C.

Based on changes between 2006-2030 and 2276-2300 from each of the six models' RCP8.5 runs.



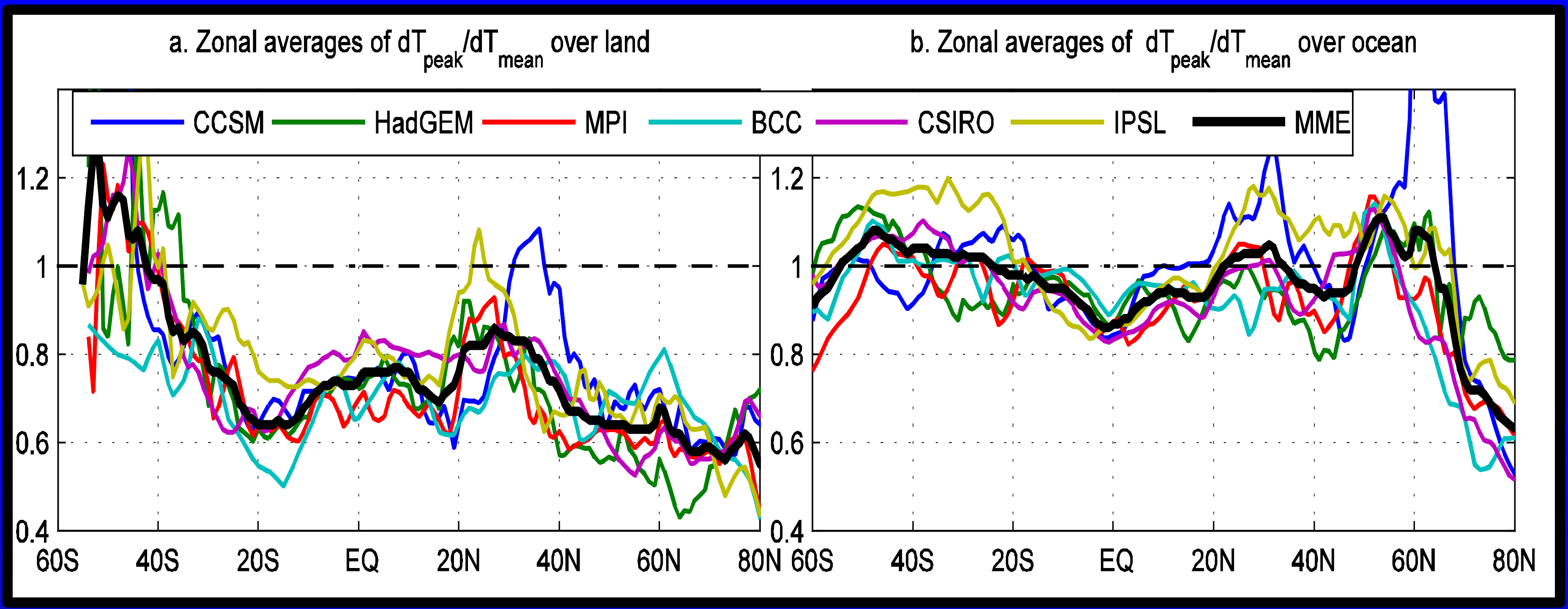
T_{peak} vs T_{mean}

In °C.

For 2006-2030 for models using RCP 8.5.

Studies that use T_{mean} instead of T_{peak} find much lower scaling, does not relate to C-C. Increase of T_{peak} <<T_{mean}.

Scaling rate of peak of daily precipitation extreme (T_{peak}) with mean temperature (T_{mean})



In % per °C.

Based on changes between 2006-2030 and 2276-2300 from each of the six models' RCP8.5 runs.

Several studies have used T_{mean} instead of T_{peak}.
The latter scales with C-C but the former does not!

C-C works

- There are good physical reasons why there are departures from C-C in terms of extreme precipitation.
- These relate especially to moisture sources.
  1) airflow from cooler ocean,
  2) land regions remote from oceans, and
  3) some synoptic situations.

- Hence there is a negative scaling of precipitation extremes with T at high T. There is a peak value for precipitation rate that can be identified with a $T_{peak.}$
- This varies with region and model!

- But this does not limit changes.
- Rather models show that both P_{peak} and T_{peak} (but not T_{mean}) **increase** together largely following C-C
  -in mid to high latitudes
  - and to a super C-C scaling in the tropics .