

How do extremes change in the context of climate change?

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Acknowledgements: Boris Orlowsky, Simon Allen



ICTP summer school on extremes, Trieste, Italy, July 21 2014

How are extremes affected by climate change?

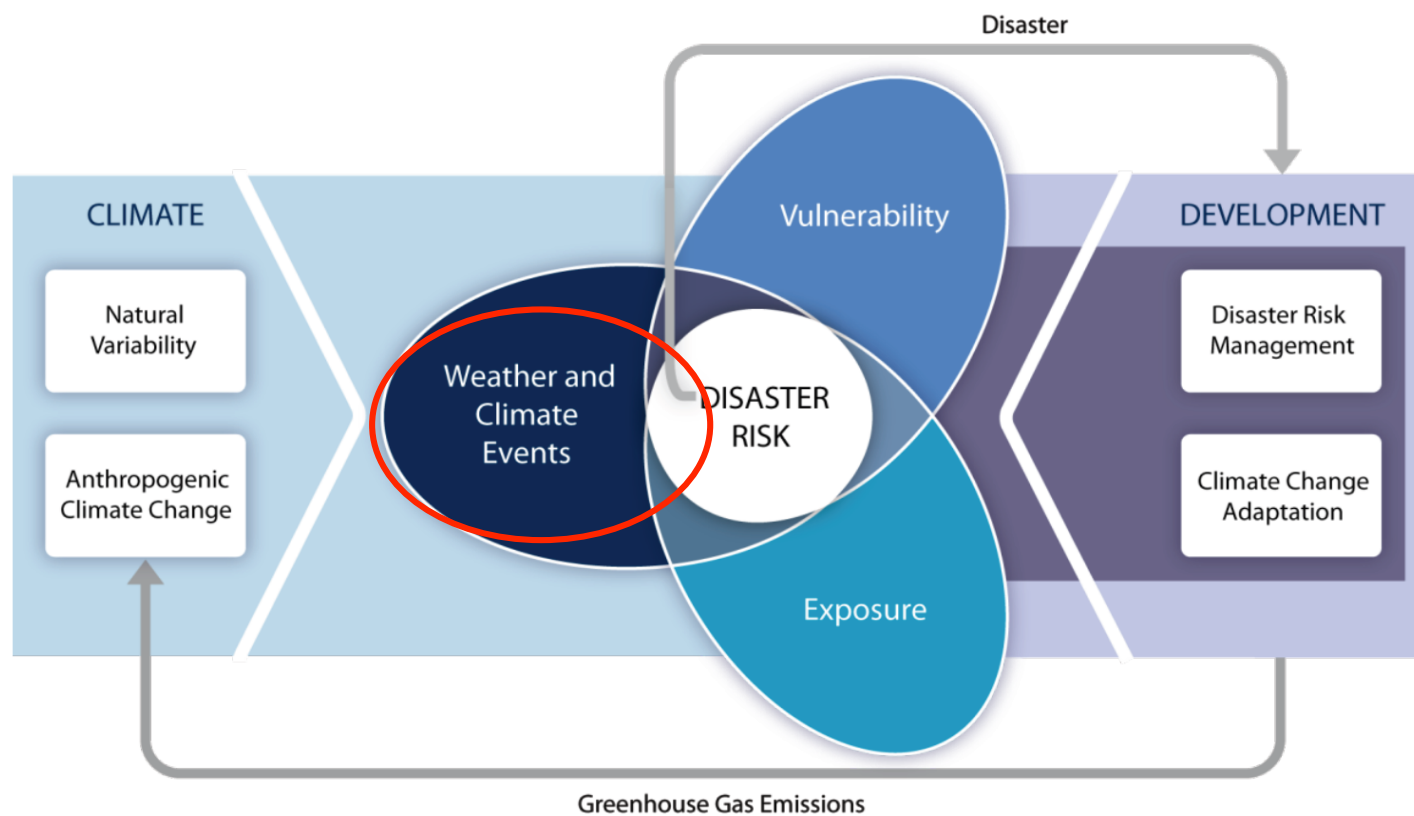
- Mean vs variability
- Role of feedback processes

Historical and projected changes in extremes

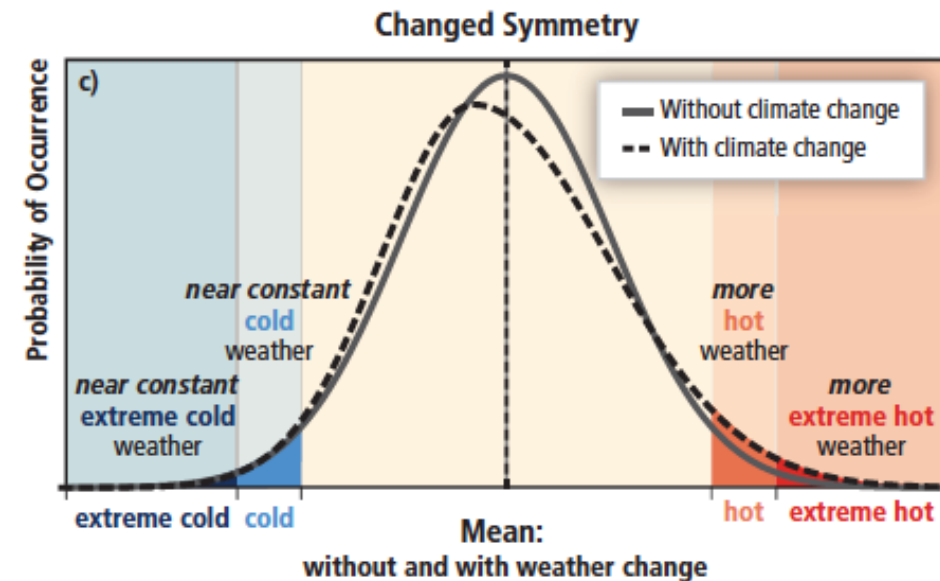
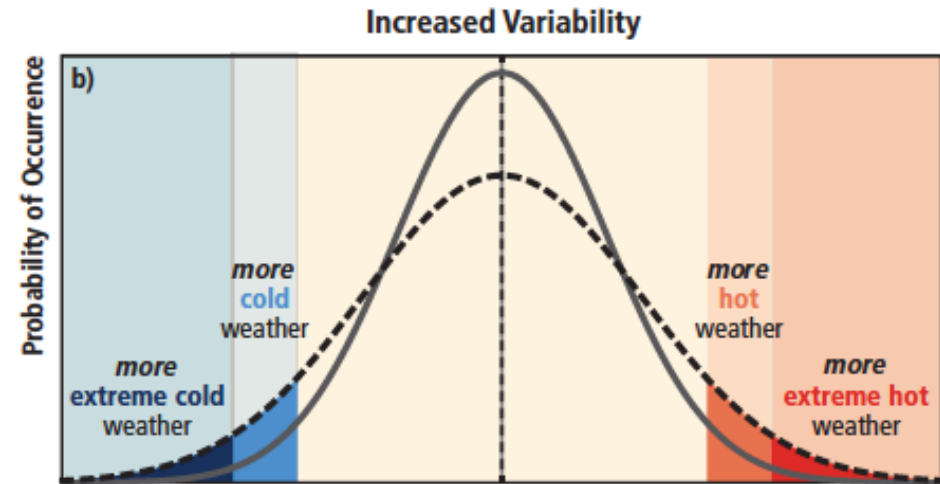
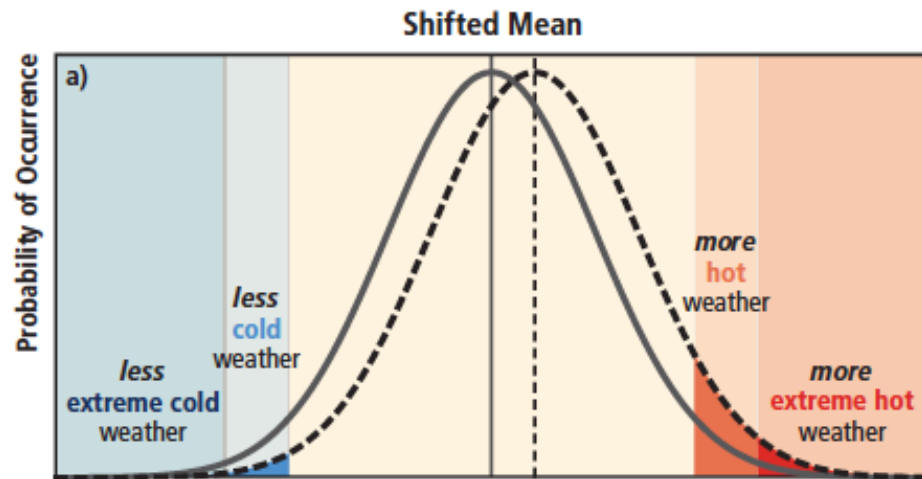
- IPCC SREX / AR5 assessments
- Some current research issues

Conclusions

Introduction: Contributors to extreme impacts



Changes in extremes vs changes in mean

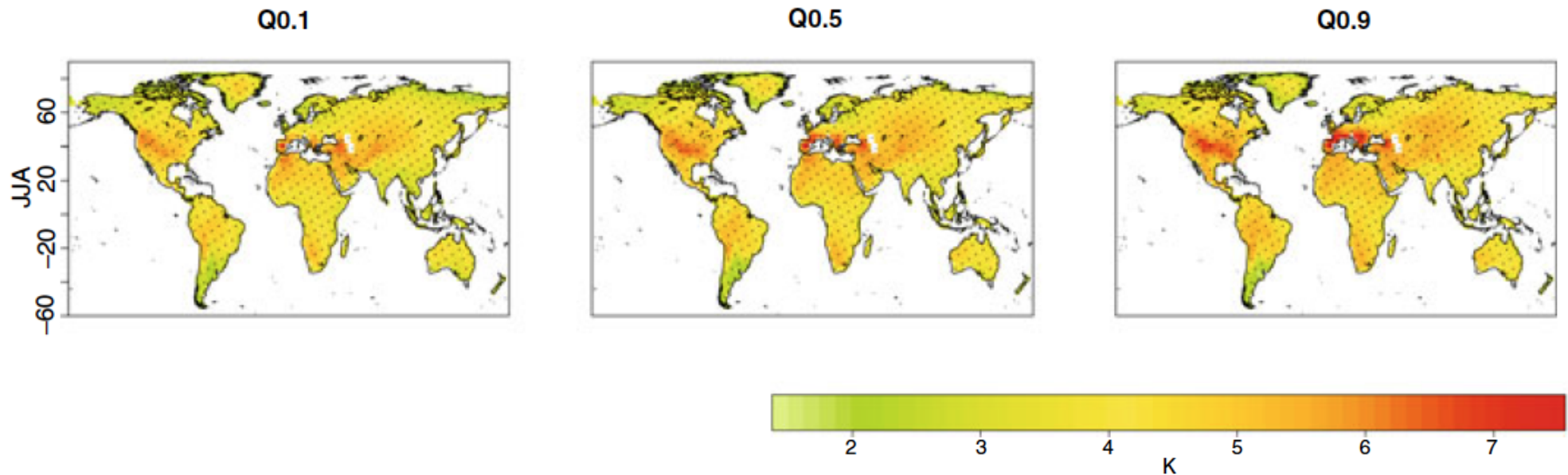


Changes in extremes can occur:

- As a result of shifts in mean climate
- Without any changes in mean climate

(IPCC SREX, 2012: <http://ipcc-wg2.gov/SREX/>)

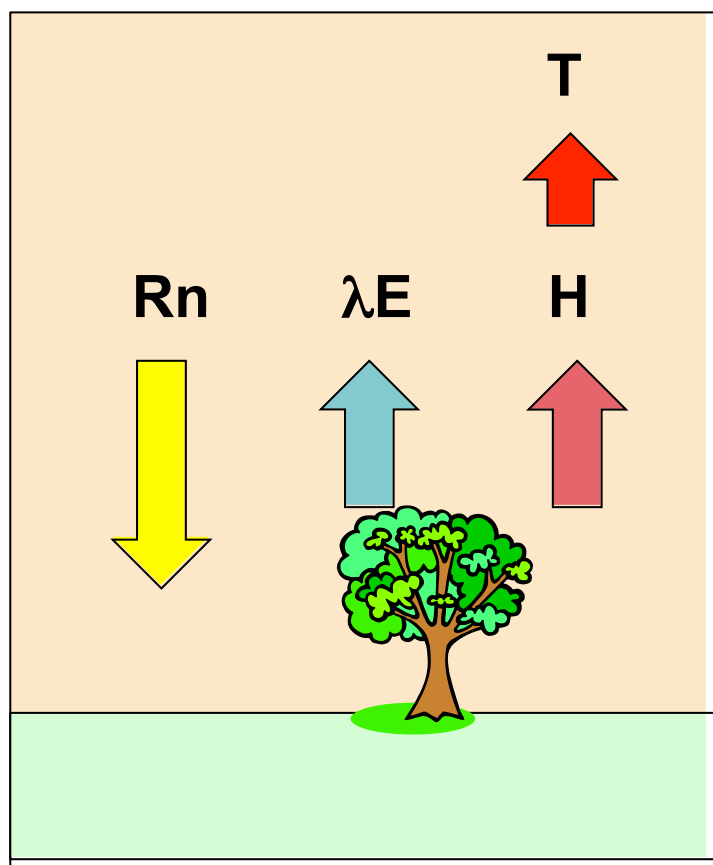
ΔT_{\max} [(2081-2100)-(1980-1999)] for 10th (left), 50th (middle), and 90th percentile (right)



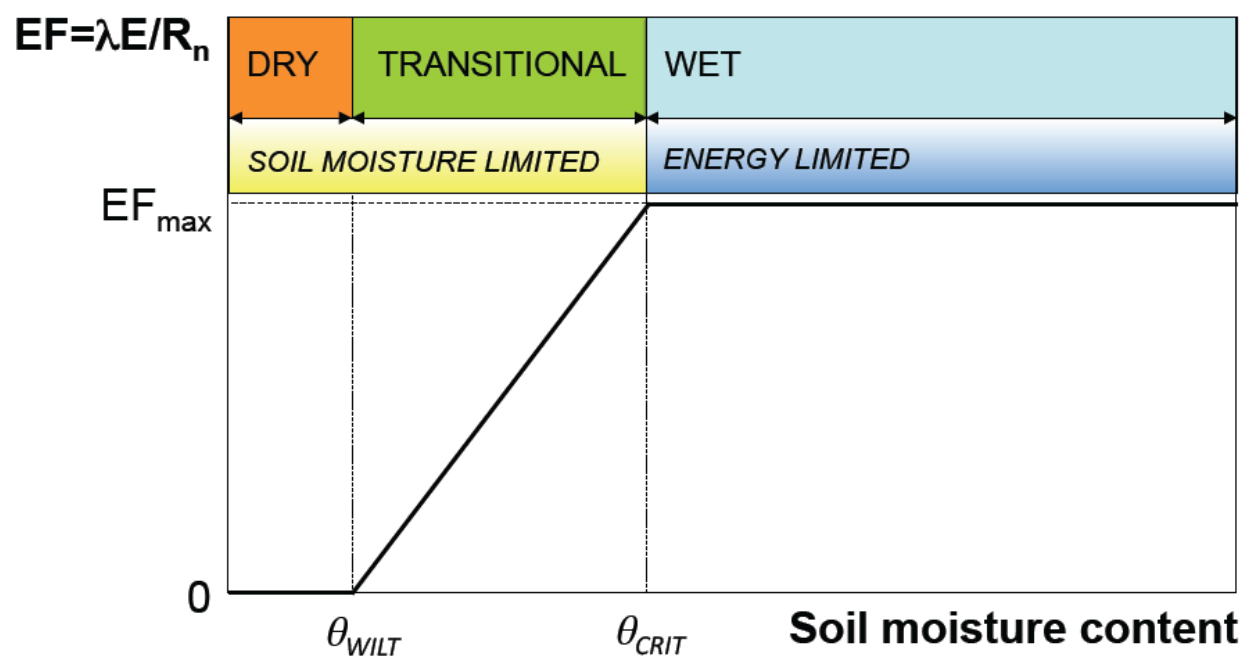
Stronger warming of hot extremes in mid-latitude regions: Soil moisture feedback

(Orlowsky and Seneviratne 2012, *Climatic Change*)

Surface energy balance

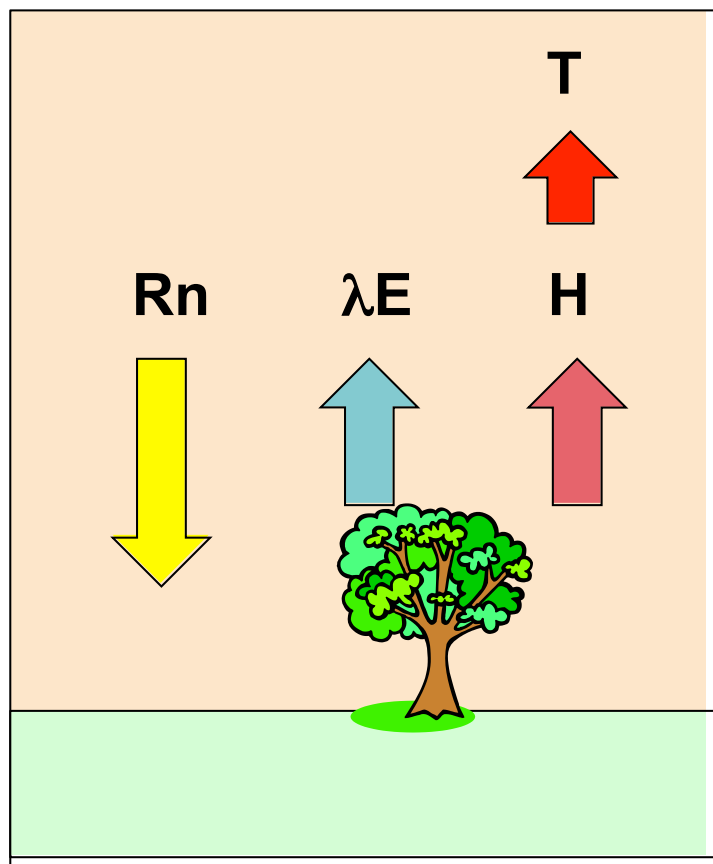


(after Budyko 1956)



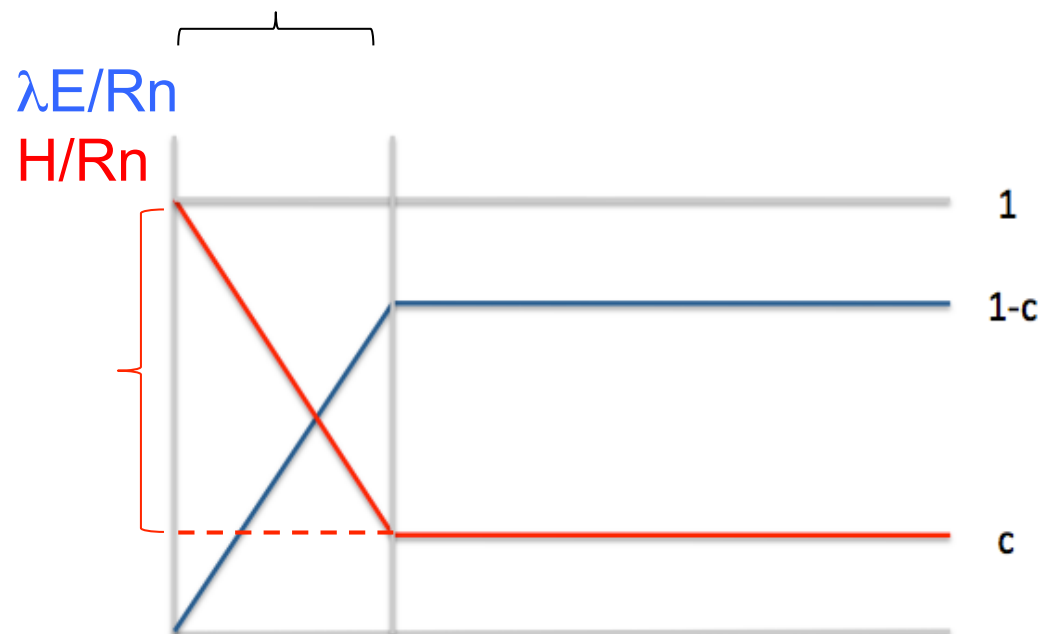
(Seneviratne et al. 2010, Earth-Science Reviews)

Surface energy balance



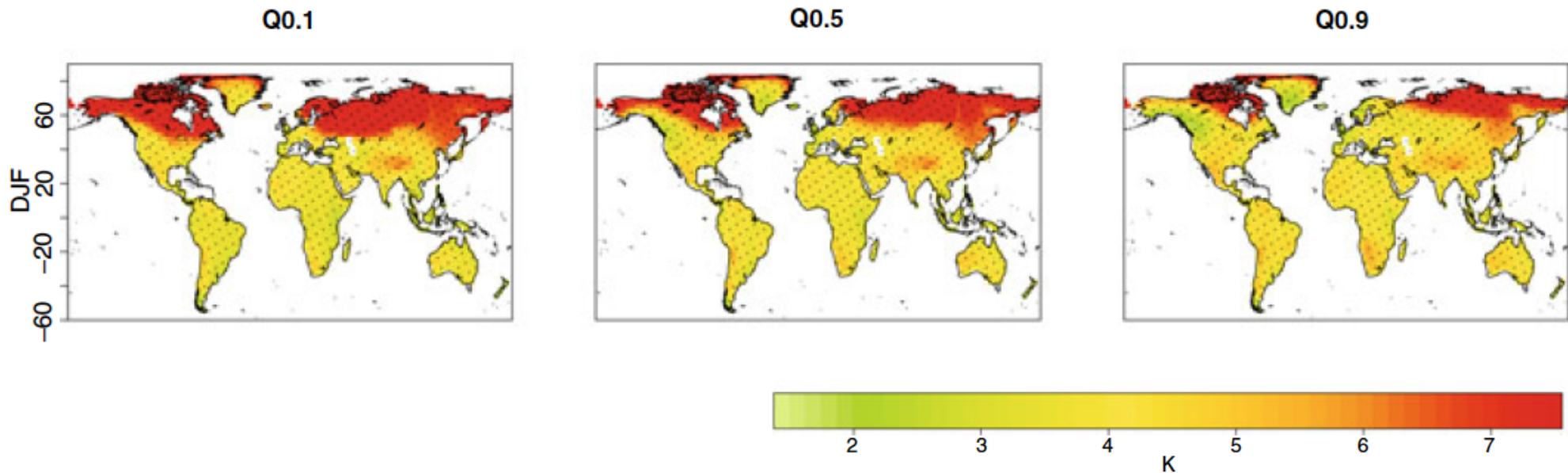
$$\lambda E = 50-60\% R_n$$

Transitional climate regime



Soil moisture

ΔT_{\max} [(2081-2100)-(1980-1999)] for 10th (left), 50th (middle), and 90th percentile (right)



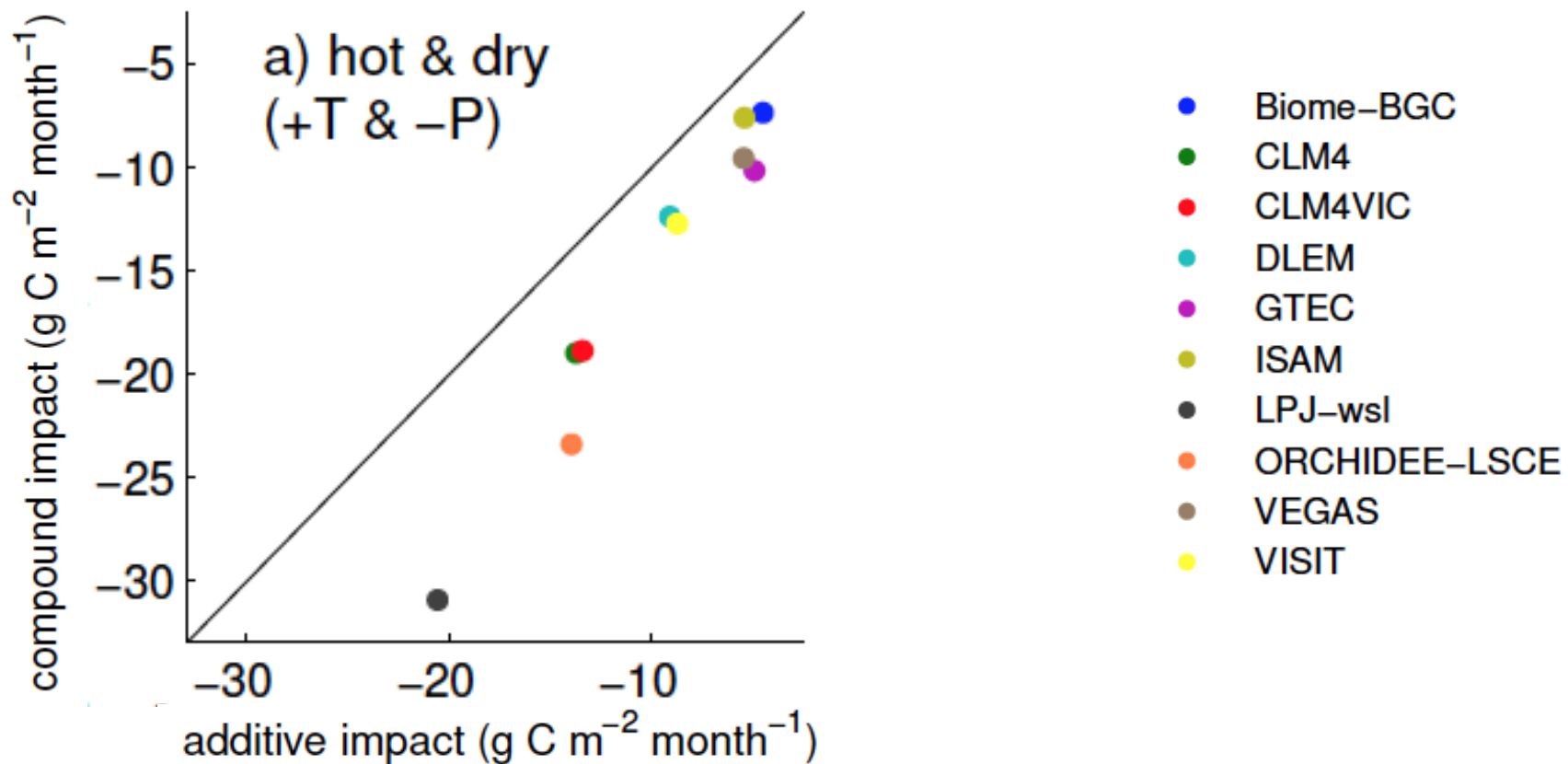
Stronger warming of cold extremes in high-latitude regions: Snow feedback

(Orlowsky and Seneviratne 2012, *Climatic Change*)

More background on role of land-atmosphere feedbacks for extremes in Lecture “Physical mechanisms (land-climate feedbacks)”

There can also be non-linear effects with respect to impacts!

Gross primary production (Plant CO₂ uptake)



(Zscheischler et al. 2014, *Global Biogeochemical Cycles*)

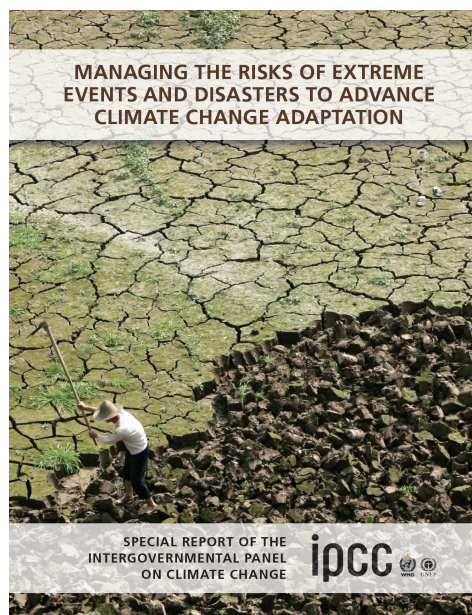
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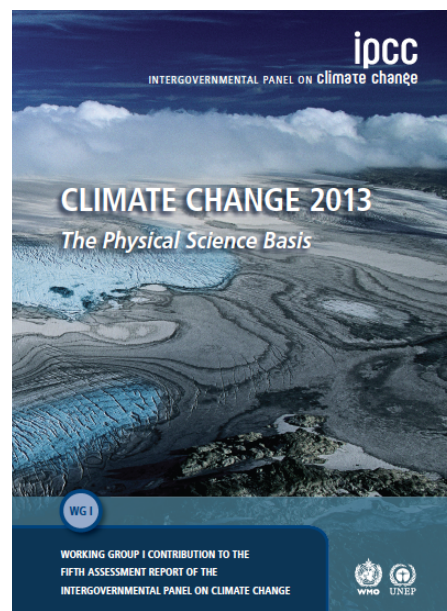
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IPCC, 2012



IPCC, 2013

Observed changes: AR5

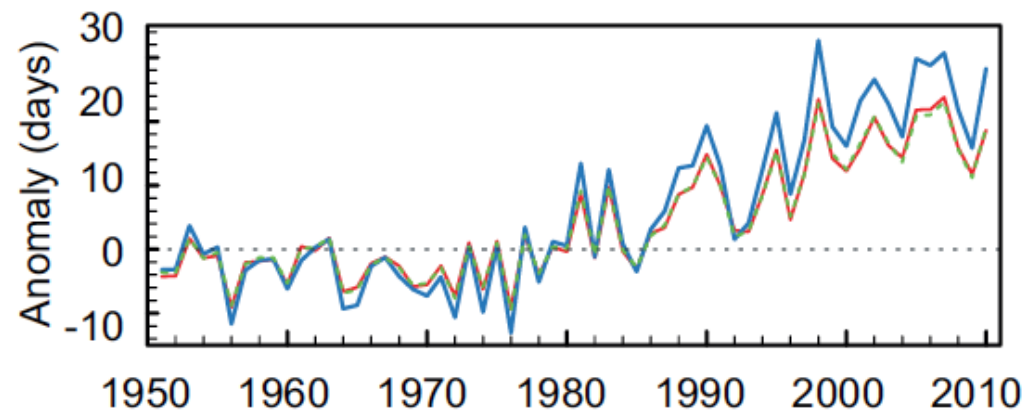
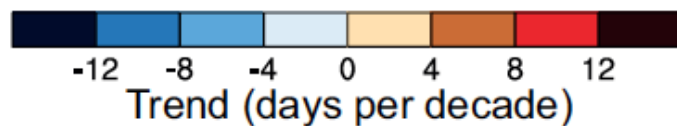
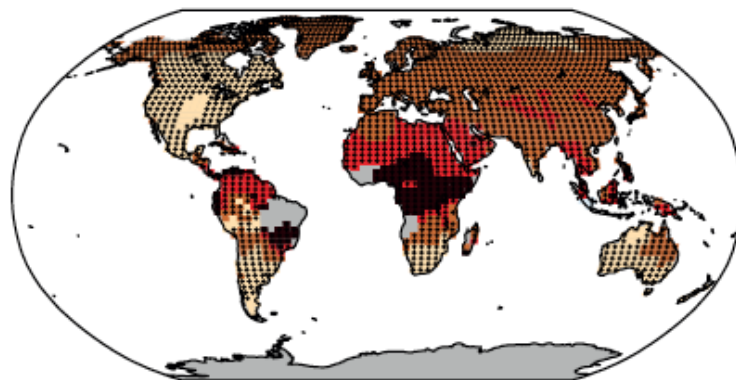
Projected changes: based on
SREX (Chapter 3; *Seneviratne,
Nicholls, et al. 2012*)

(www.ipcc.ch)

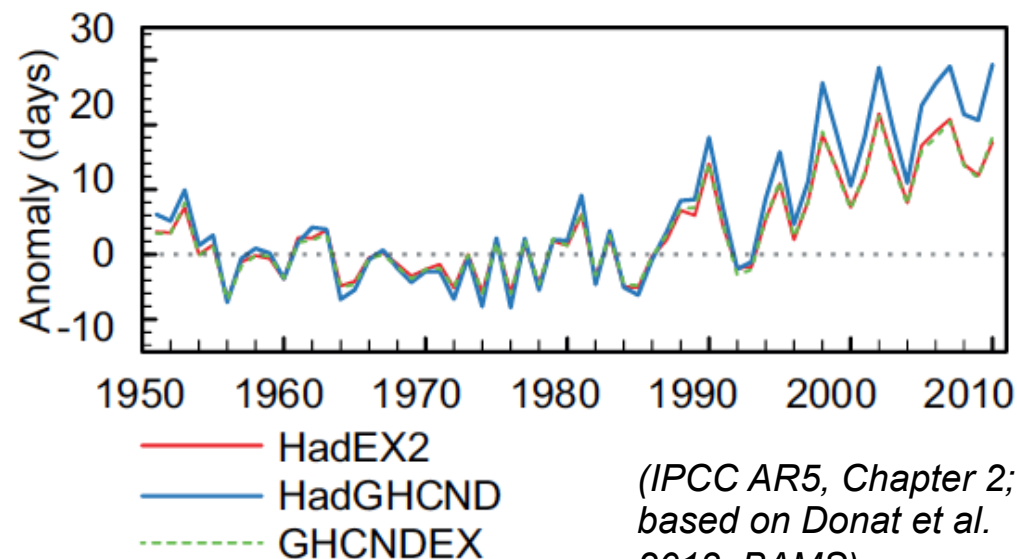
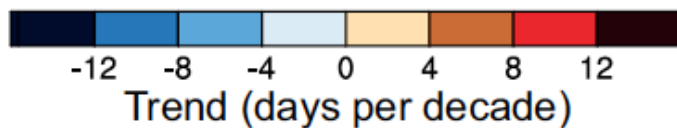
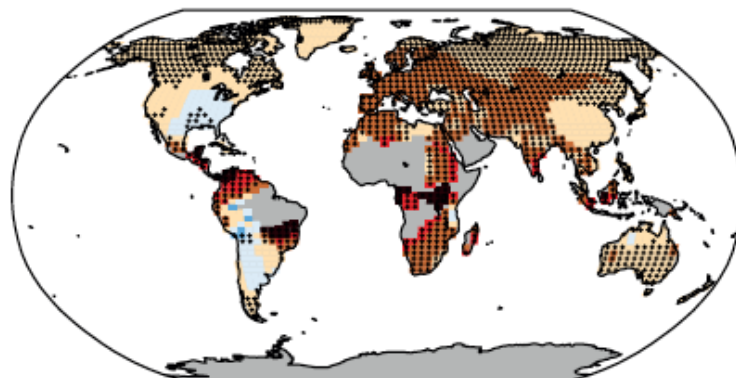
- **Very likely** increase in number of warm days and nights & decrease in number of cold days and nights globally
- **Likely** that the number of heavy precipitation events has increased in more regions than it has decreased
- **Confidence** remains **low** for long-term (centennial) changes in **tropical cyclone activity** (but virtually certain that frequency and intensity of strongest tropical cyclones in the North Atlantic has increased since 1970)
- **Confidence** is **low** for a global-scale observed trend in **drought** owing to lack of direct observations, methodological uncertainties, and geographical inconsistencies in the trends
- **Confidence** is **low** for large-scale trends in **storminess**

Observed trends: Temperature extremes

Warm Nights (frequency of 90th percentile)



Warm Days (frequency of 90th percentile)



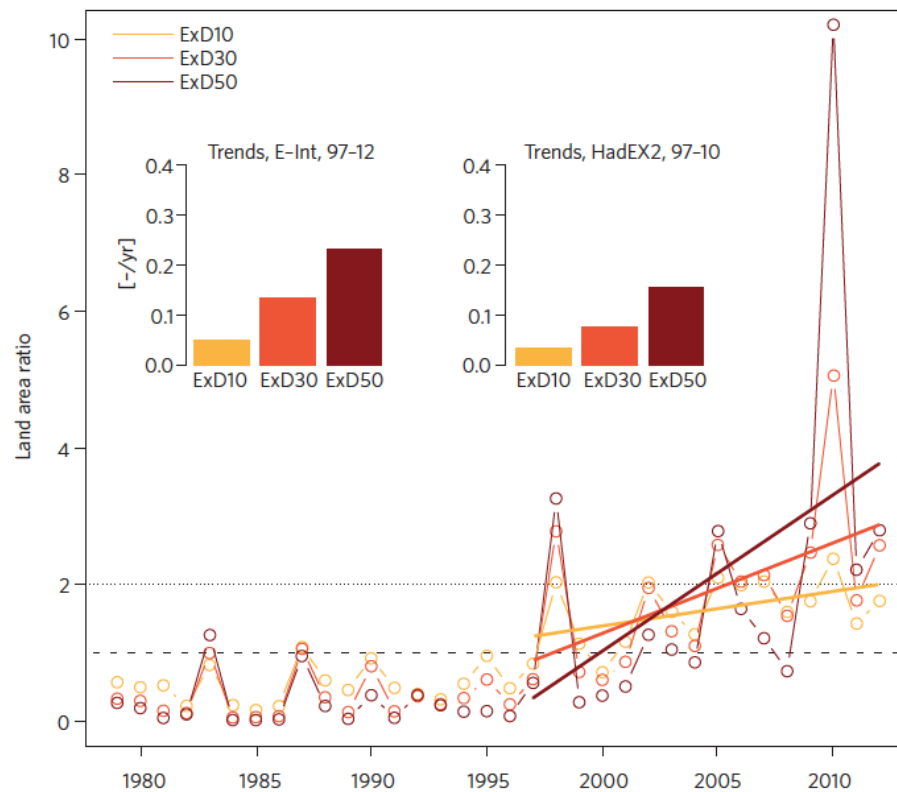
(IPCC AR5, Chapter 2;
based on Donat et al.
2013, BAMS)

Observed trends: Temperature extremes

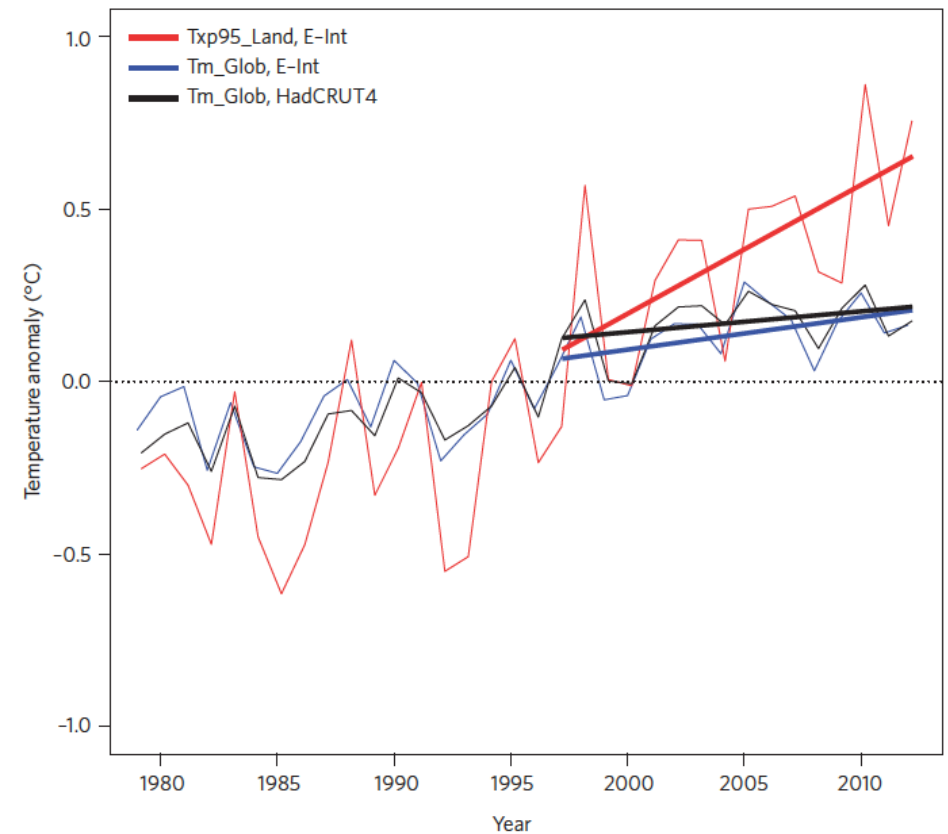
See presentation on data issues (L. Alexander)

Trends in temperature extremes in “hiatus” period

Land area ratio affected by exceedant warm days (relative to 1979-2010 average)



Temperature trends (ERA-interim, HadCRUT4)

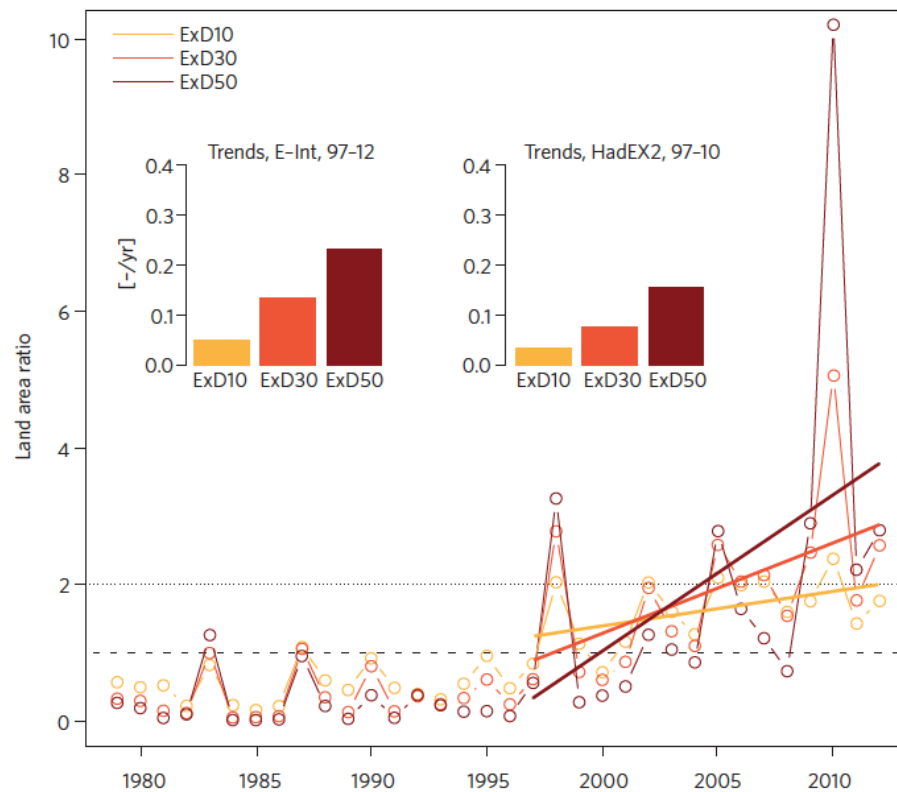


Continued increase of measures of hot extremes despite apparent pause of global mean temperature

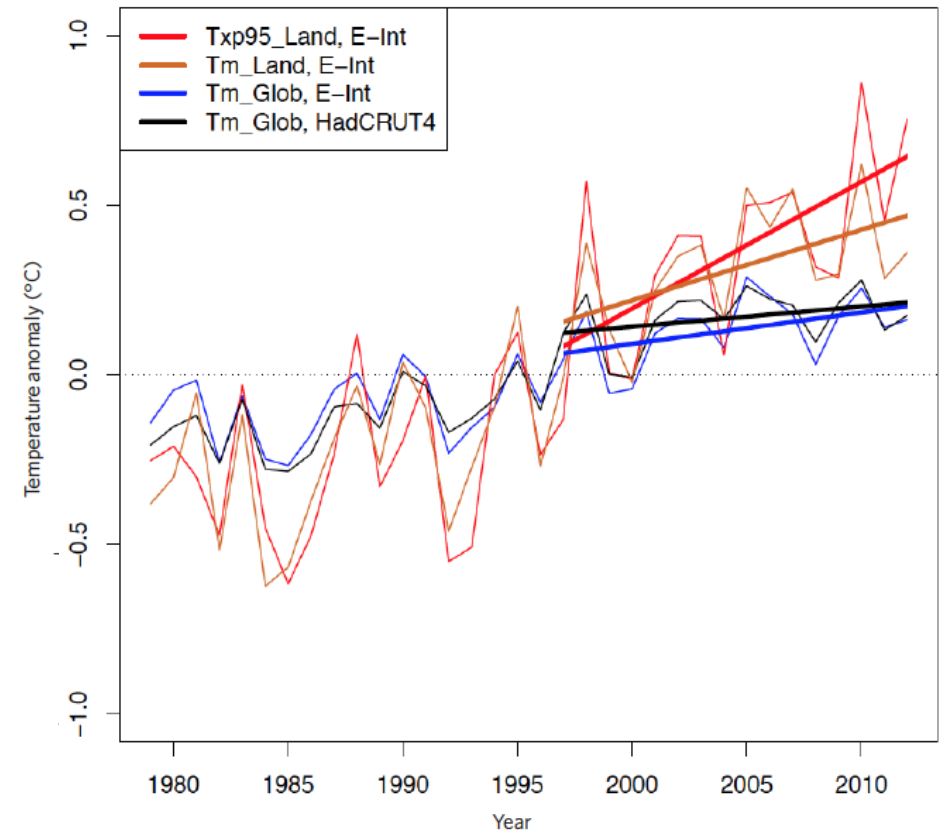
(Seneviratne, Donat, Mueller, and Alexander, 2014, *Nature Climate Change*)

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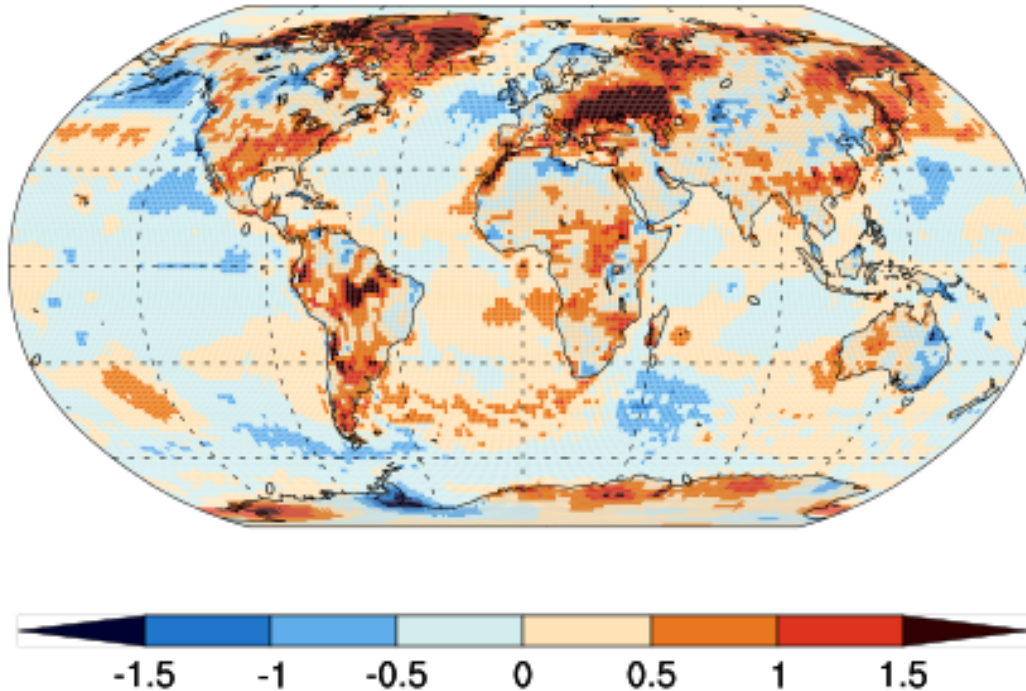


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Trends in temperature extremes in “hiatus” period

Txp95, ERA-Interim (1997-2012)



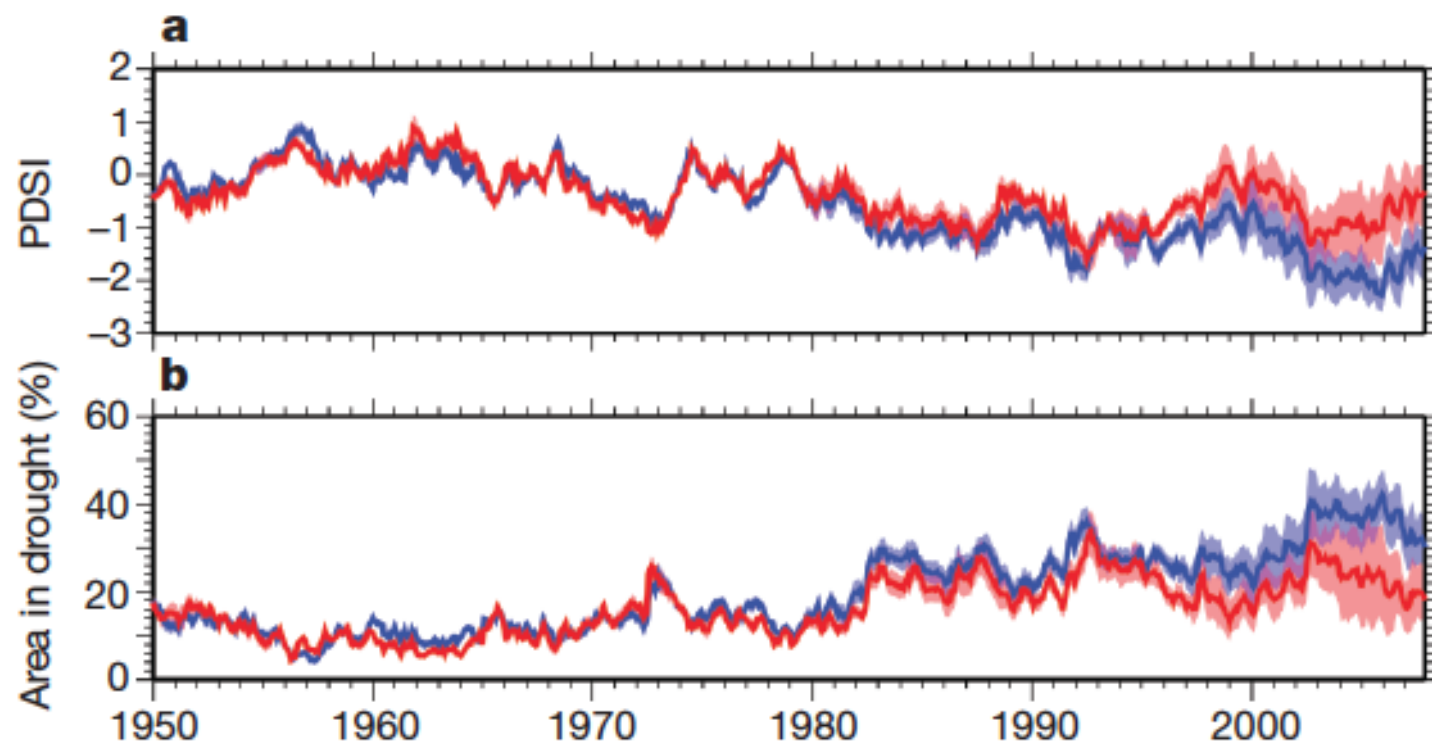
Increases over land due to recent dry and hot events in Russia, North America, and South America as well as to some high-latitude regions

Decreases over most ocean area

(Seneviratne, Donat, Mueller, and Alexander, 2014, *Nature Climate Change*)

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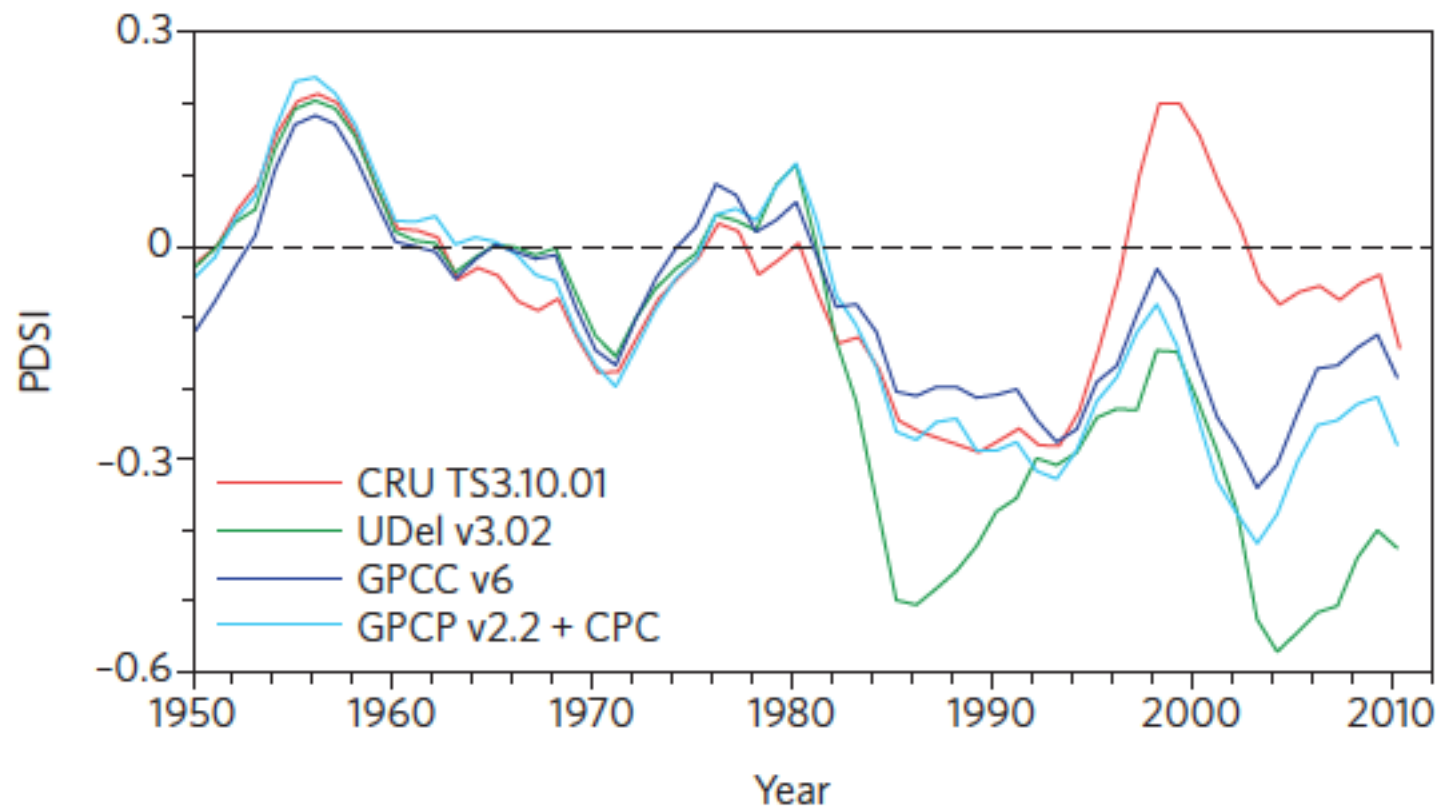
Compared to trends in temperature extremes, much higher uncertainty in trends in global droughts (due to modeling approaches and input datasets)



Impact of
parameterization
of potential
evapotranspiration

(Sheffield et al. 2012, Nature)

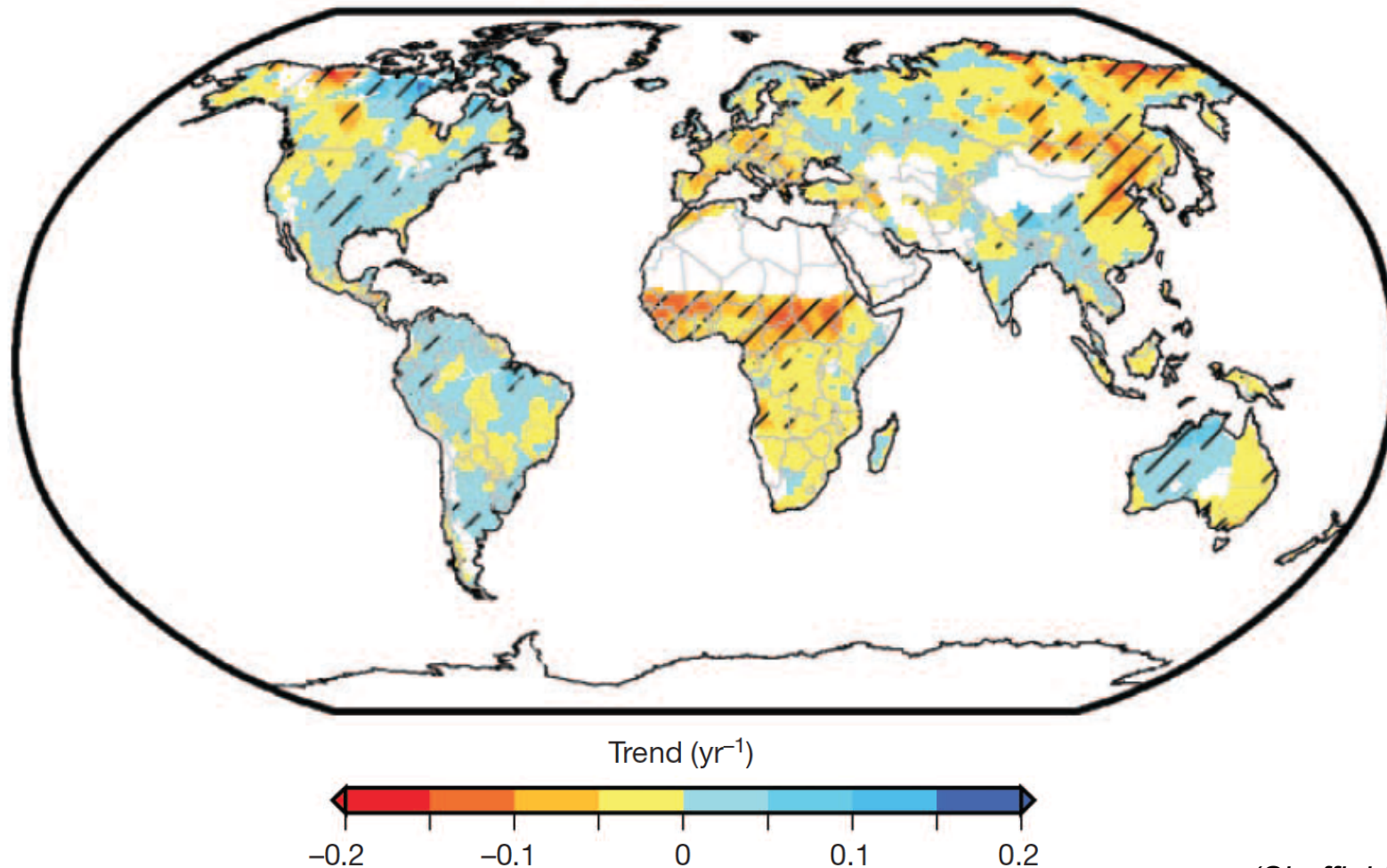
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Impact of
uncertainty in
driving precipitation
datasets

(Trenberth et al. 2013, *Nature Clim. Change*)

Large regional variations in drought trends: “Global drought” is not a meaningful measure

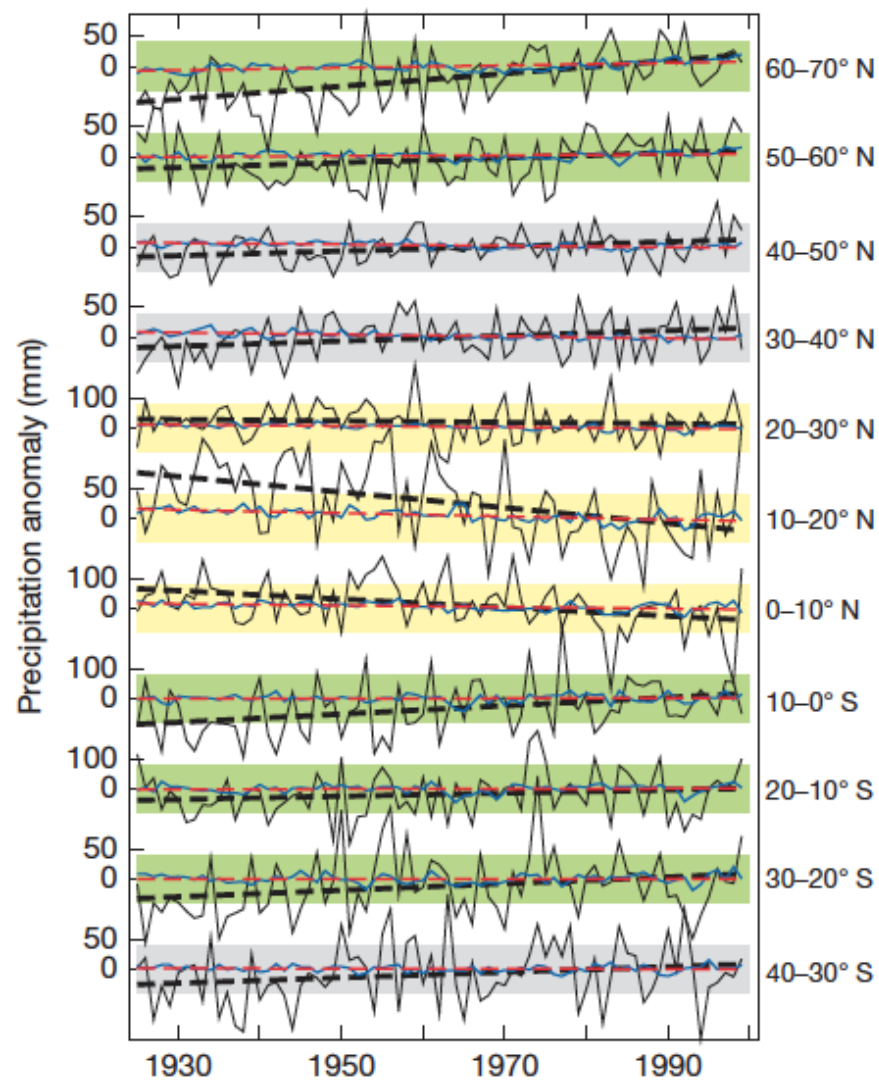


(Sheffield et al. 2012, Nature)

For some extremes (e.g. hot temperatures), global averaging increases the signal to noise ratio, but for others (e.g. droughts) regional trends are more robust

Relevant for detection and attribution!

Trends in regional vs global drought



(Zhang et al. 2007, Nature)

Trend in subarid regions dominated from Sahel drought, but likely due to decadal variability

How are extremes affected by climate change?

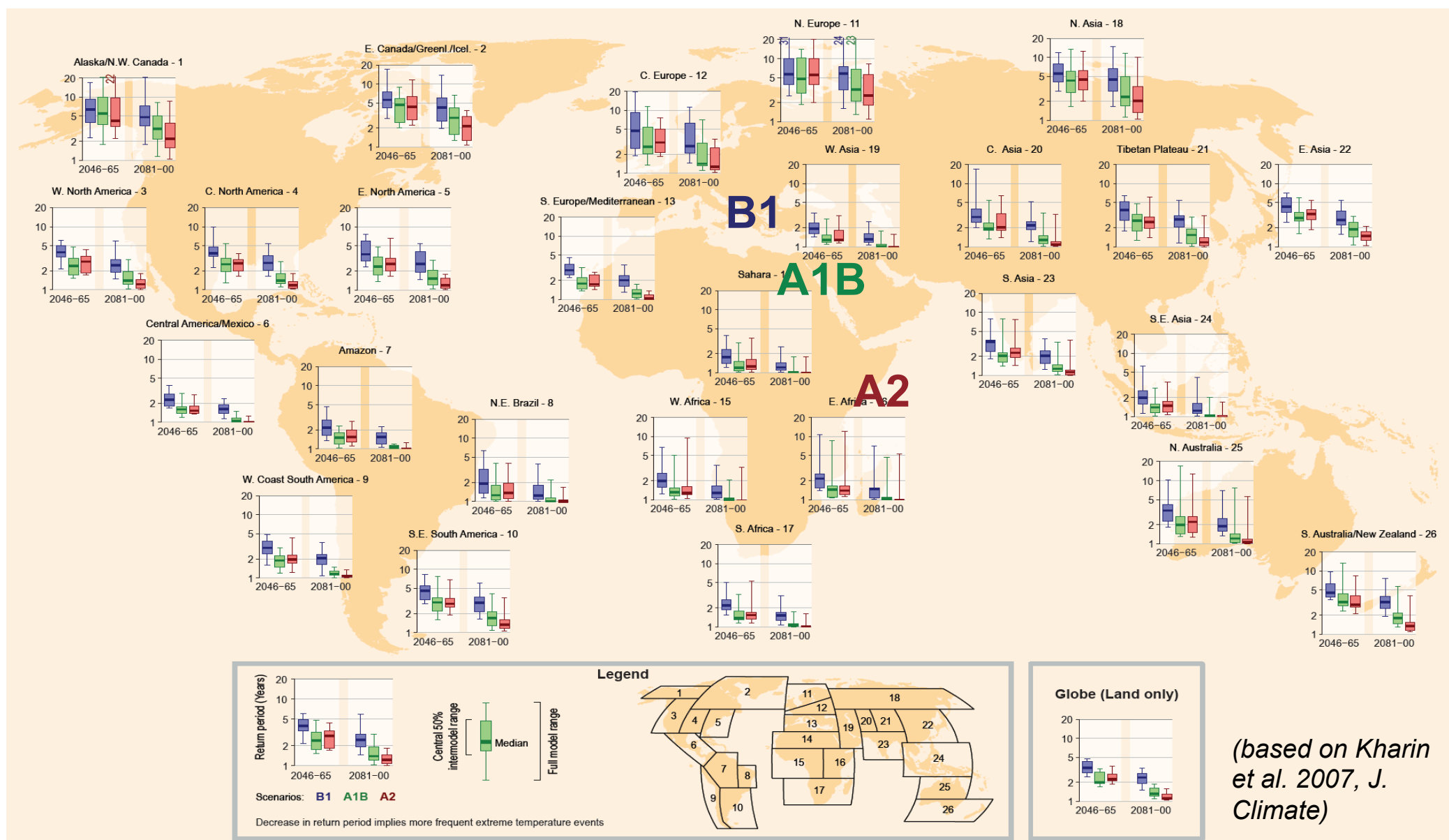
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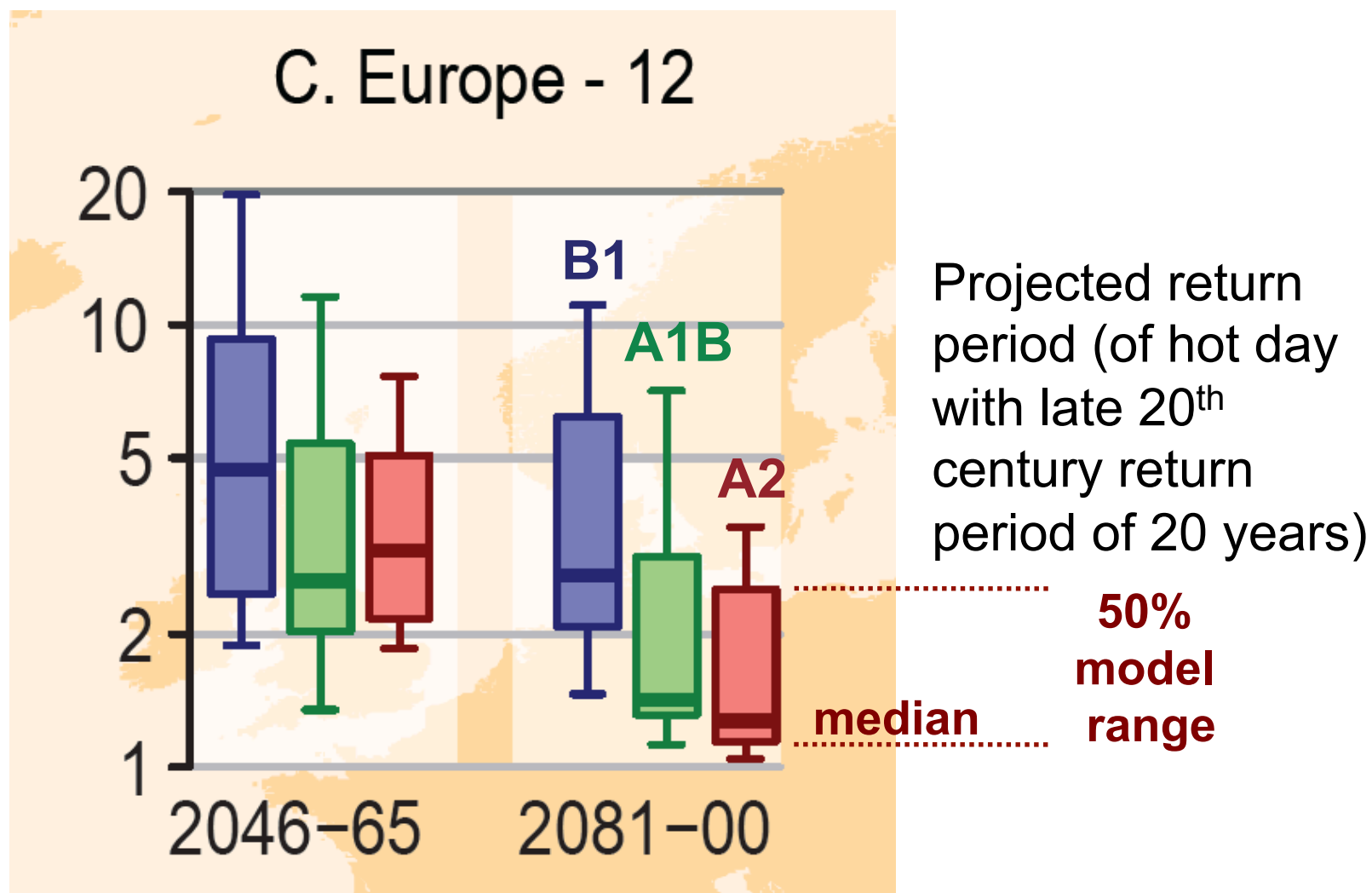
Historical and **projected** changes in extremes

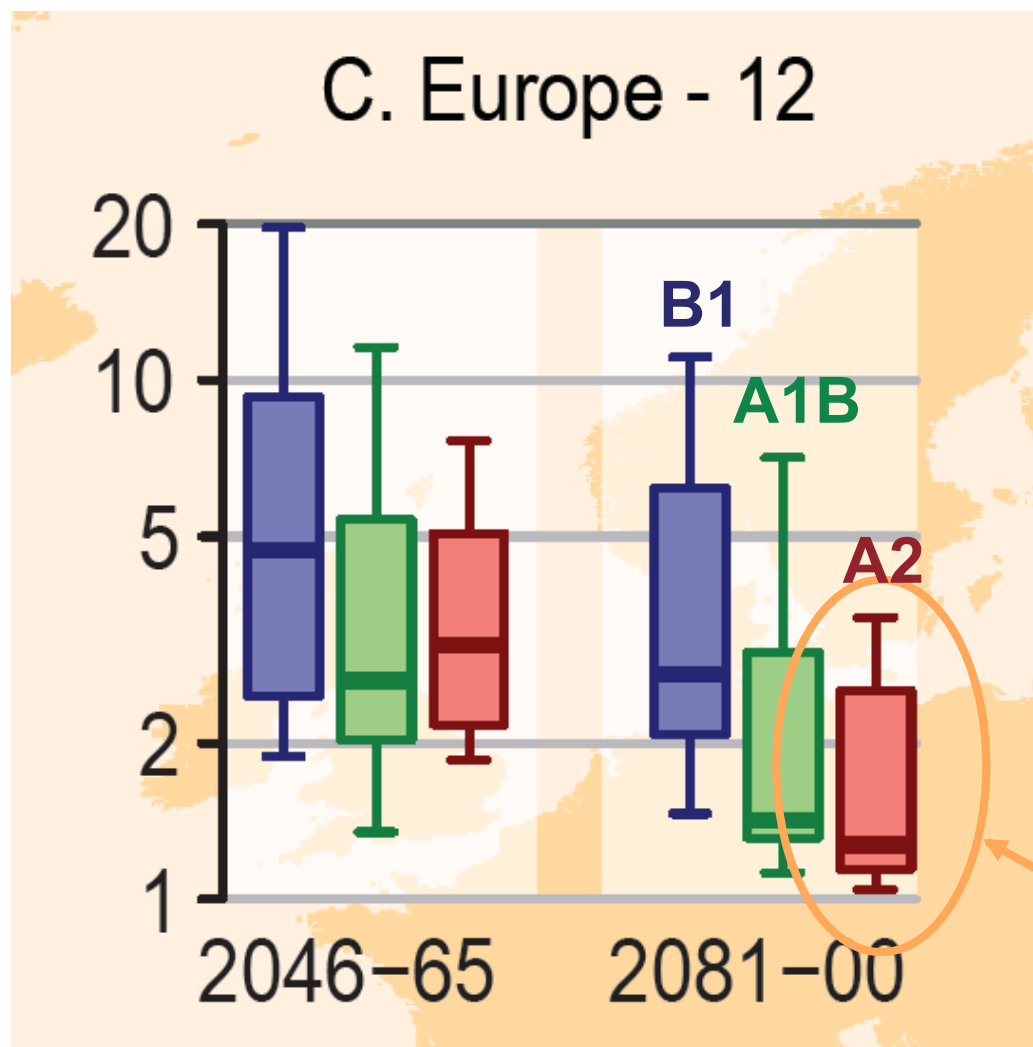
- IPCC SREX / AR5 assessments
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Conclusions

- ***Virtually certain*** that increases in the frequency and magnitude of **warm daily temperature extremes** and decreases in **cold extremes** will occur. ***Very likely*** increase of warm spells.
- ***Likely*** that the frequency of **heavy precipitation** or the proportion of total rainfall from heavy falls will increase over many areas
- ***Medium confidence*** that **droughts** will intensify in some seasons and areas
- Average **tropical cyclone** maximum wind speed is ***likely*** to increase, although increases may not occur in all ocean basins. It is ***likely*** that the global frequency of tropical cyclones will either decrease or remain essentially unchanged
- Low confidence in projections of changes in **extreme winds**







Projected return period (of hot day with late 20th century return period of 20 years)

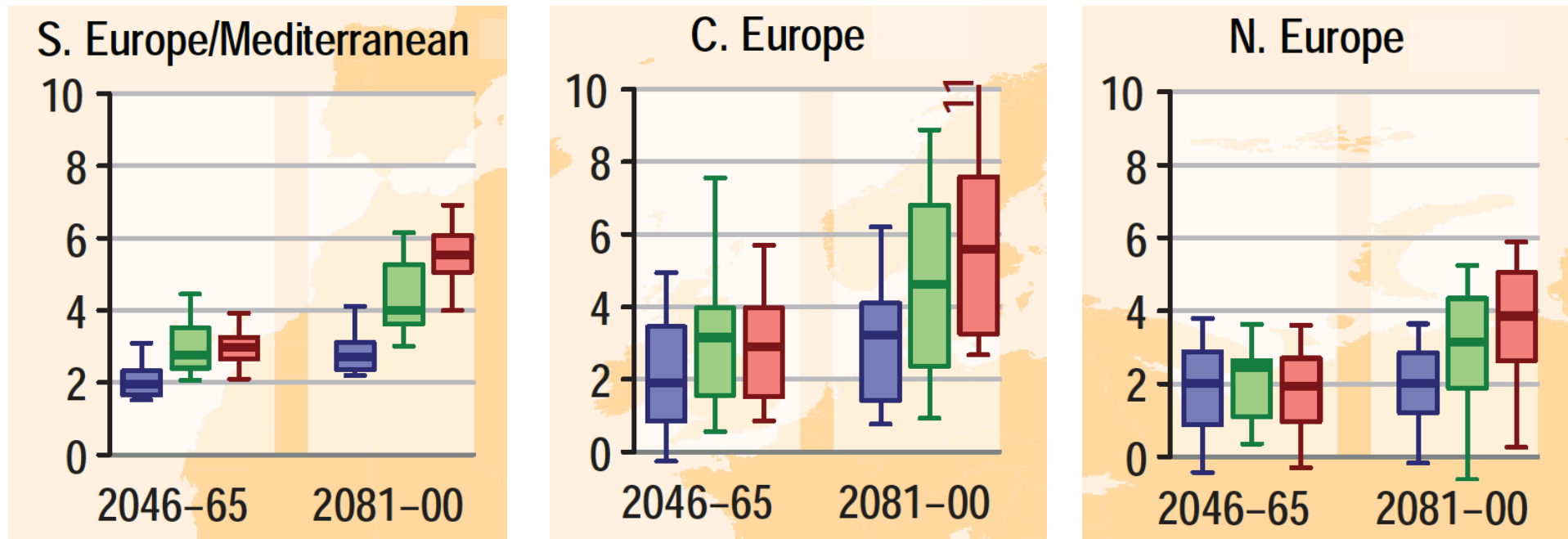
10 times increase in frequency

Temperature: A (late 20th-century) **1-in-20 year** hottest day is *likely* to become a **1-in-2 year (B1: 1-in-5 year)** event in most regions
[exception: high latitudes of Northern Hemisphere: *likely* **1-in-5 year (B1: 1-in-10 year)** event]

Precipitation: A (late 20th-century) **1-in-20 year** annual maximum daily precipitation amount is *likely* to become a **1-in-5 to 1-in-15 year** event in many regions



Projected changes in 20-year return values of annual maximum Tmax (vs late 20th century, 1981-2000)

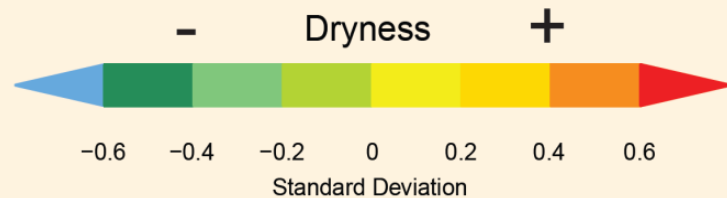
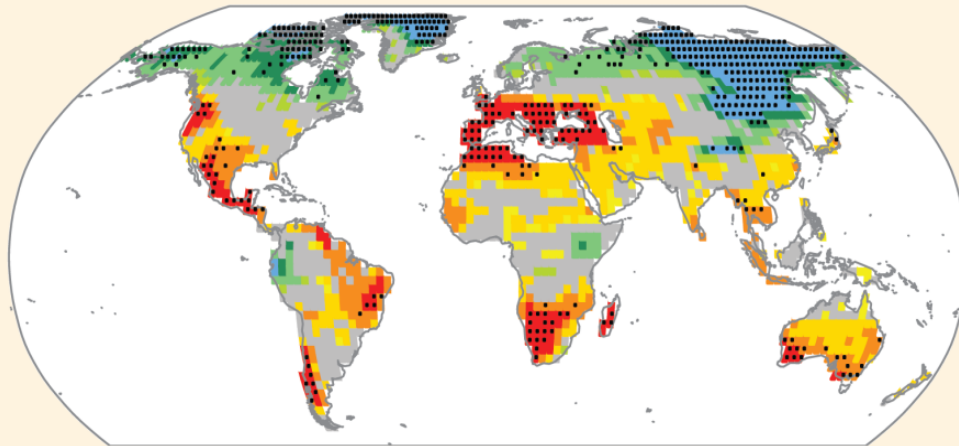


2°-5° increase by the end of the 21st century
Large range in some regions

Two dryness indices

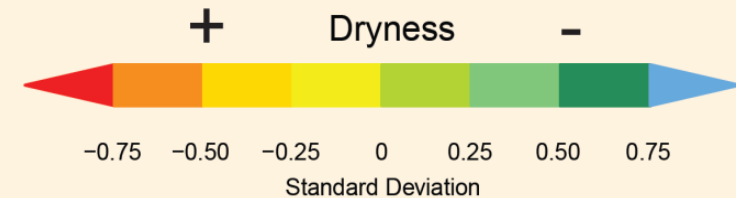
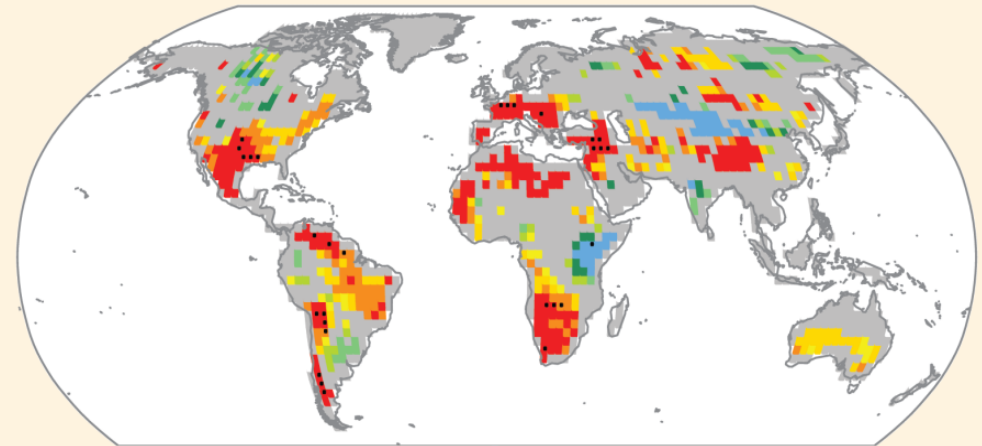
Change in consecutive dry days (CDD)

2081–2100



Soil moisture anomalies (SMA)

2081–2100

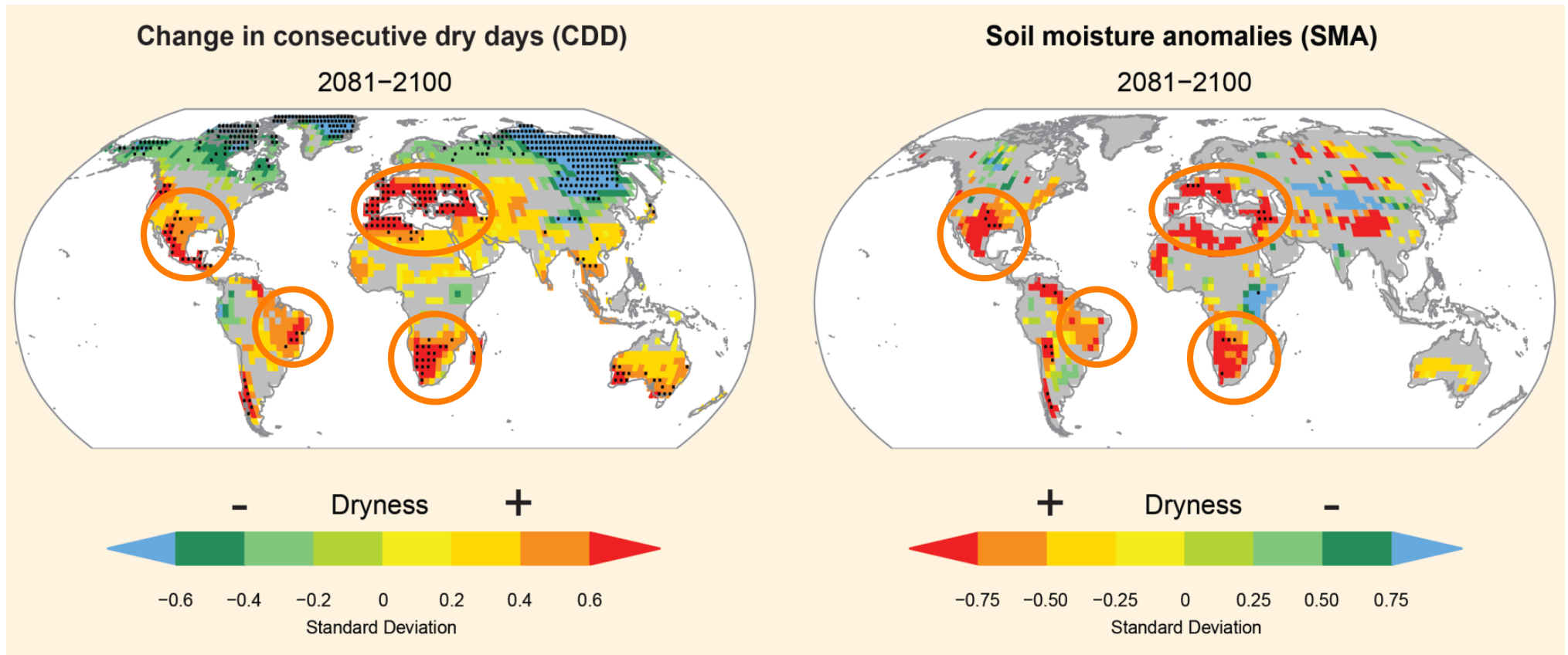


Gray shading: less than 66% model agreement on sign of change

Coloured shading: $\geq 66\%$ model agreement on sign of change

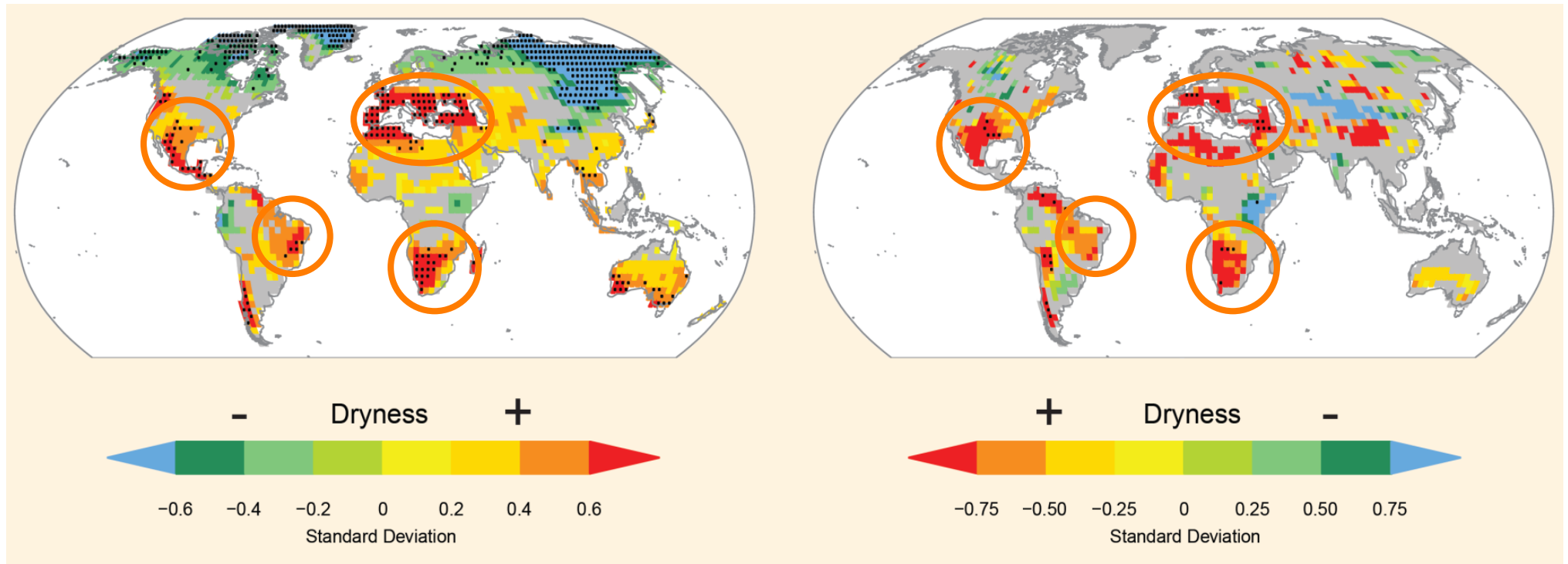
Stippling: $\geq 90\%$ model agreement on sign of change

Consistency between indices



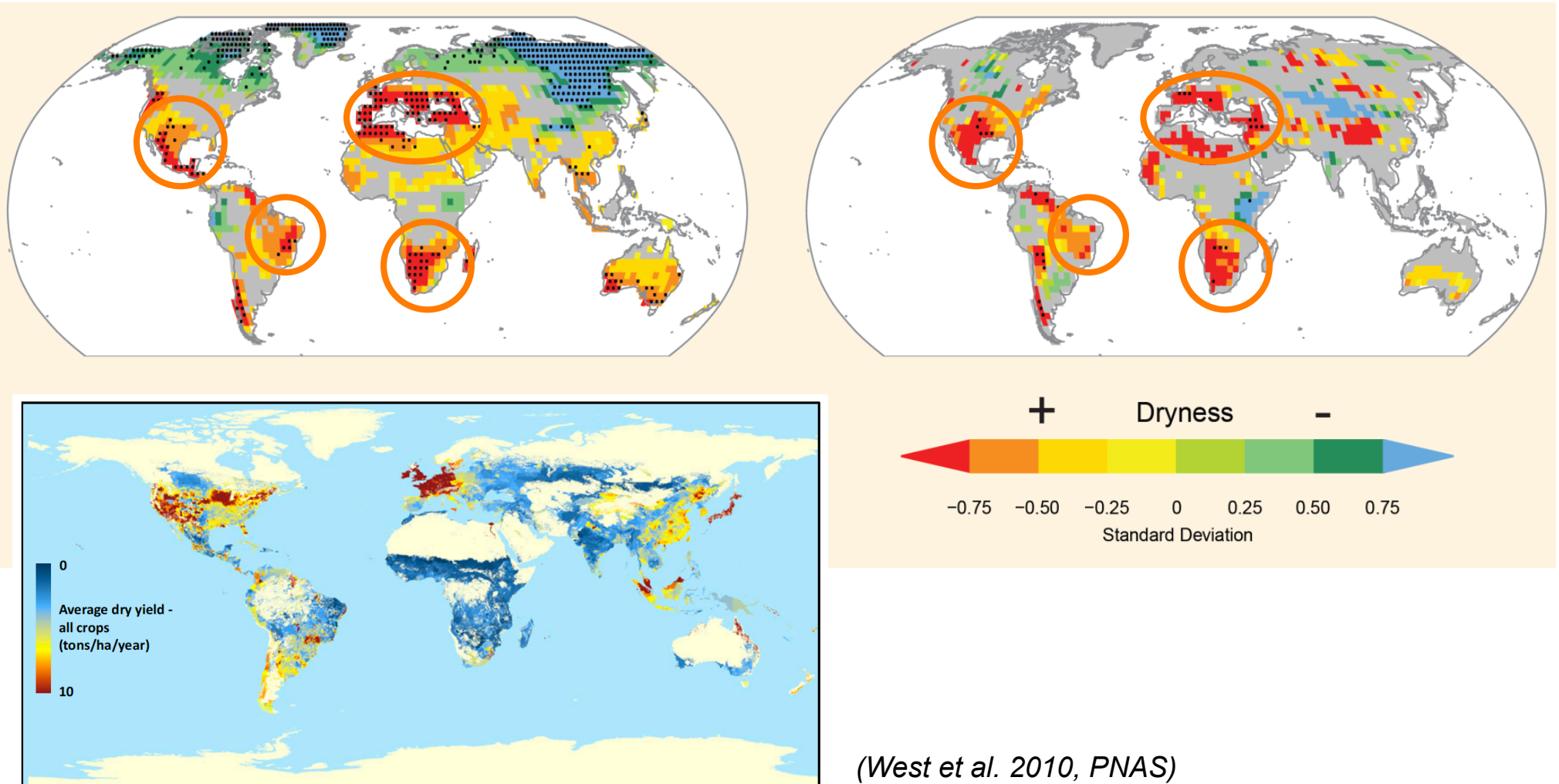
Consistent projections of increased dryness for these (and other) indices in the Mediterranean region, central Europe, central North America, Central America and Mexico, northeast Brazil, and southern Africa

Limited number of regions with agreement, but including important agricultural regions → global implications



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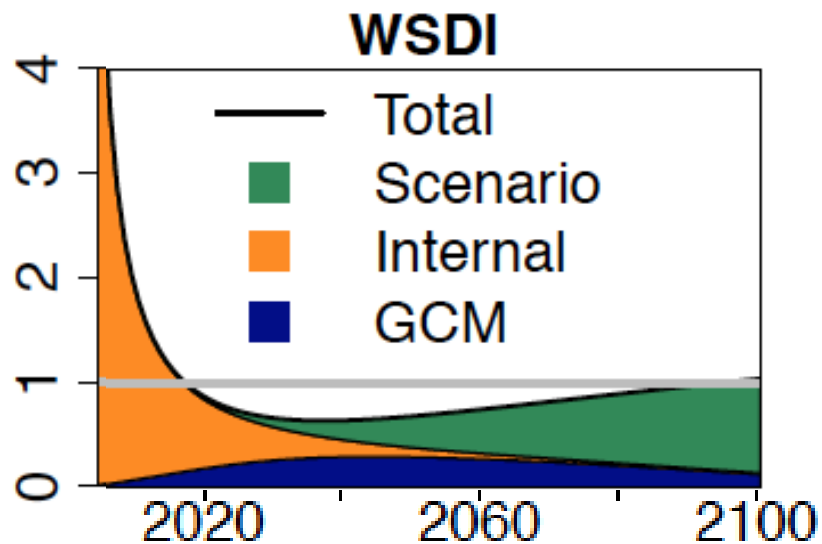


(West et al. 2010, PNAS)

Warm spells (very likely)

$$\sigma_{\text{tot}}/\Delta = (\sigma_{\text{scen}} + \sigma_{\text{int}} + \sigma_{\text{GCM}})/\Delta$$

Warm spell duration index



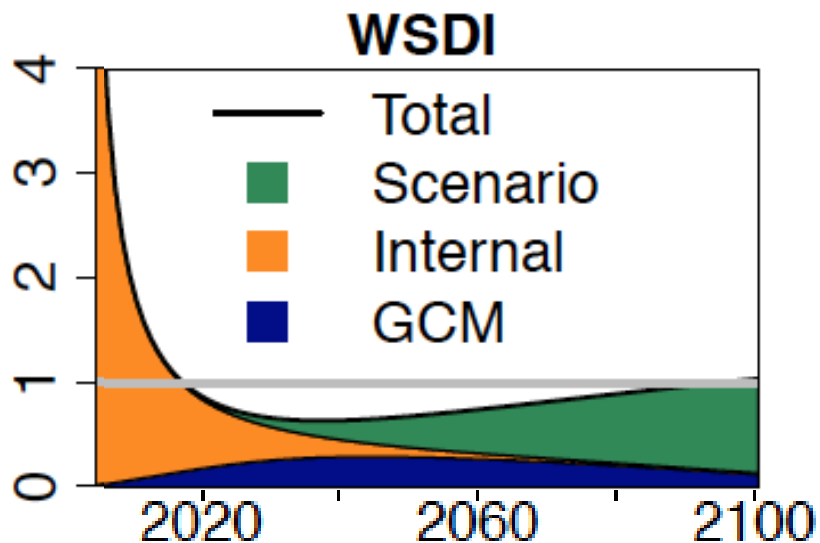
“Time of detection”: $\sigma_{\text{tot}}/\Delta < 1$

(Orlowsky and Seneviratne 2013, HESS; approach adapted from Hawkins and Sutton 2009, BAMS)

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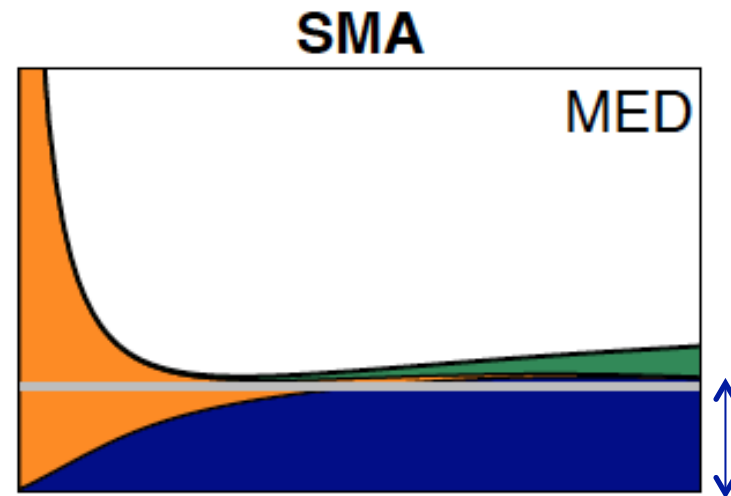
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Droughts (medium confidence)

– Assessment also based on model performance and intrinsic uncertainties (e.g. lack of data to validate models)

Soil moisture anomalies

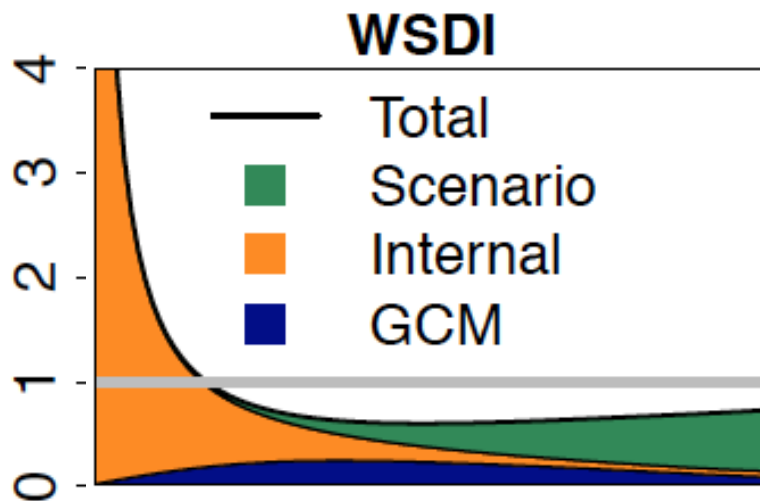


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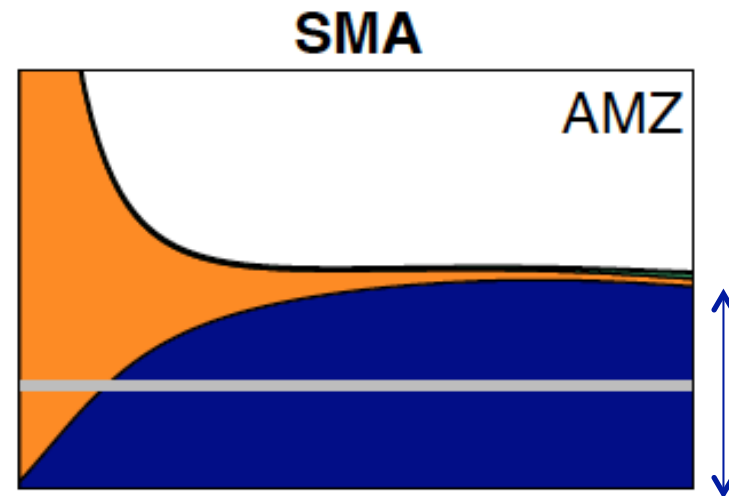


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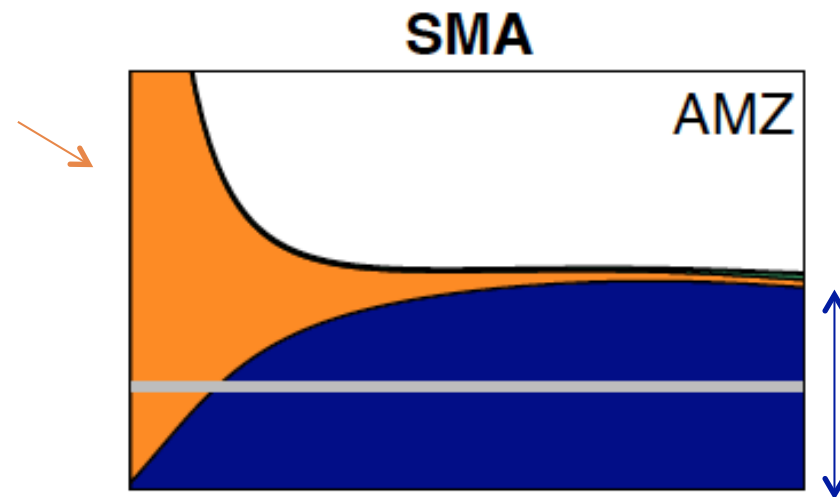
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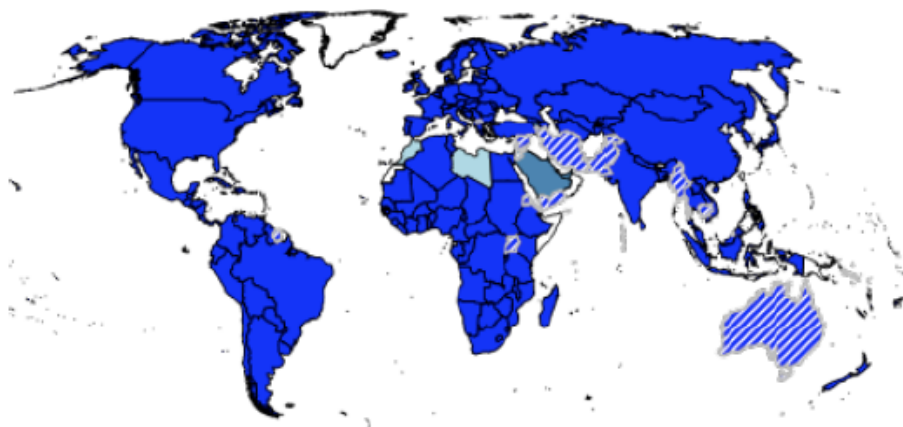
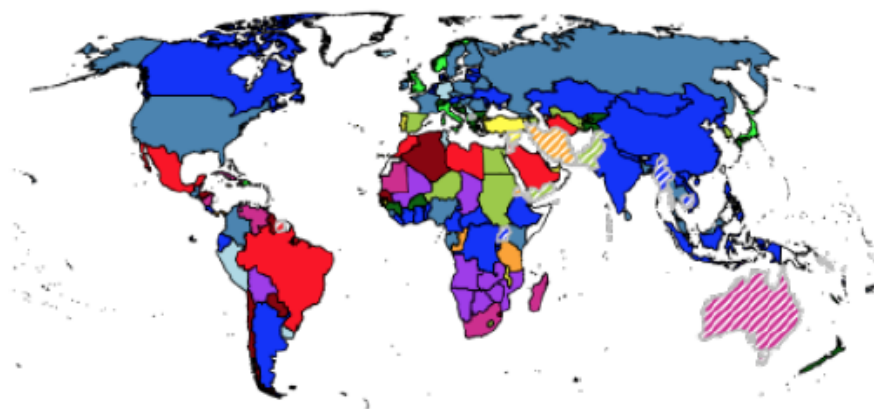
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For droughts in the Amazon region the model uncertainty is so large that it masks any impacts from the emission scenarios

Soil moisture anomalies



(Orlowsky and Seneviratne 2013, HESS; approach adapted from Hawkins and Sutton 2009, BAMS)

“Wet” climate change scenarios**“Dry” climate change scenarios**

Sustainability of present-day water consumption under late 21st century conditions

(Orlowsky et al. 2014, ERL)

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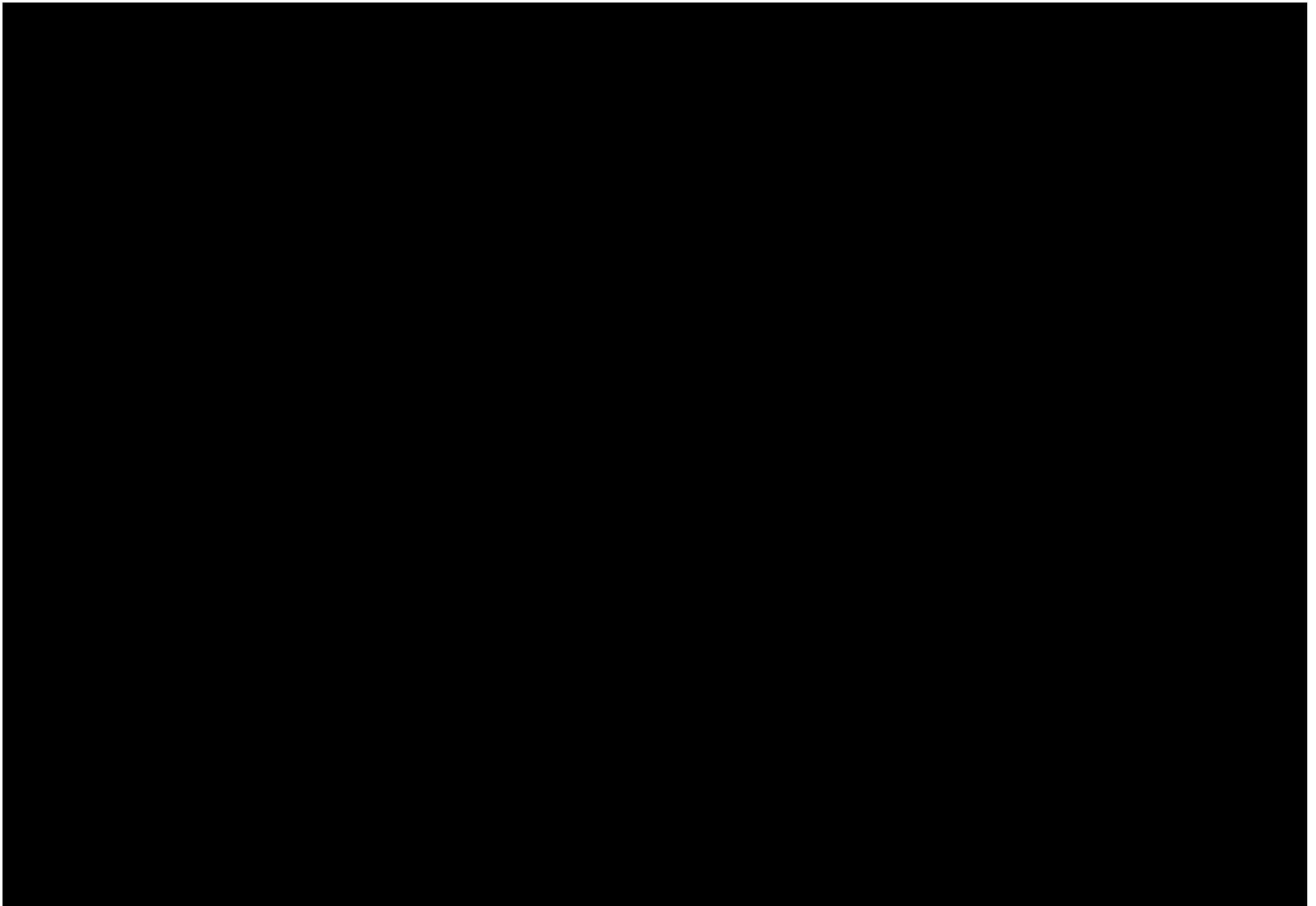
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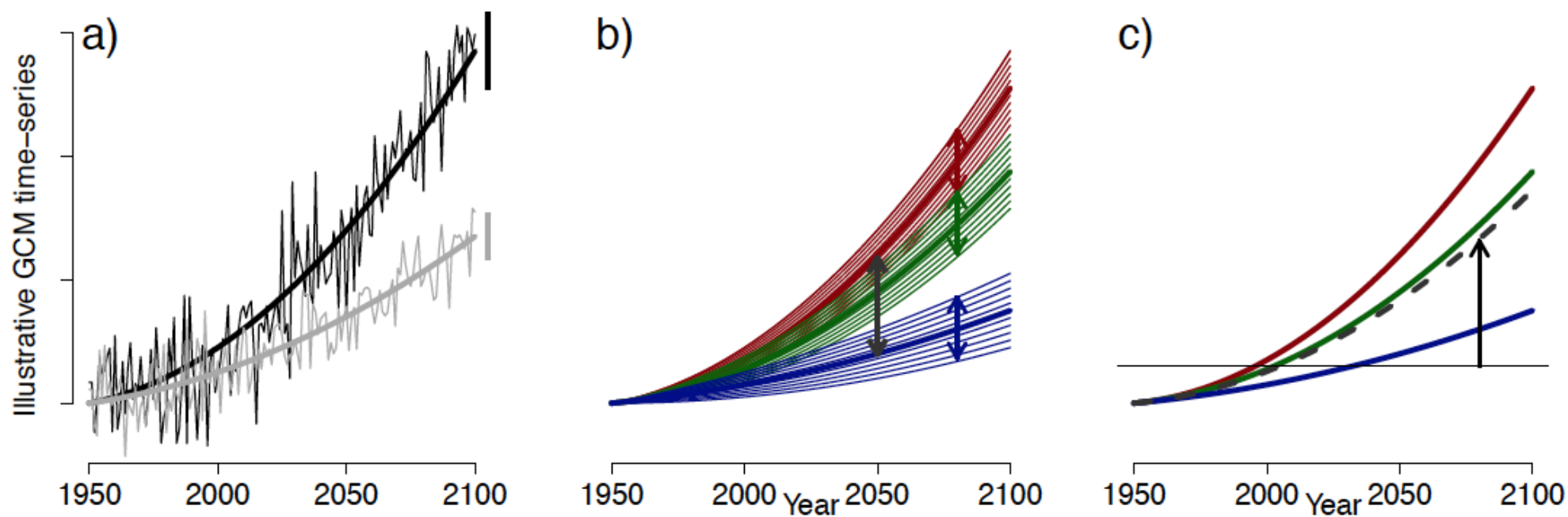
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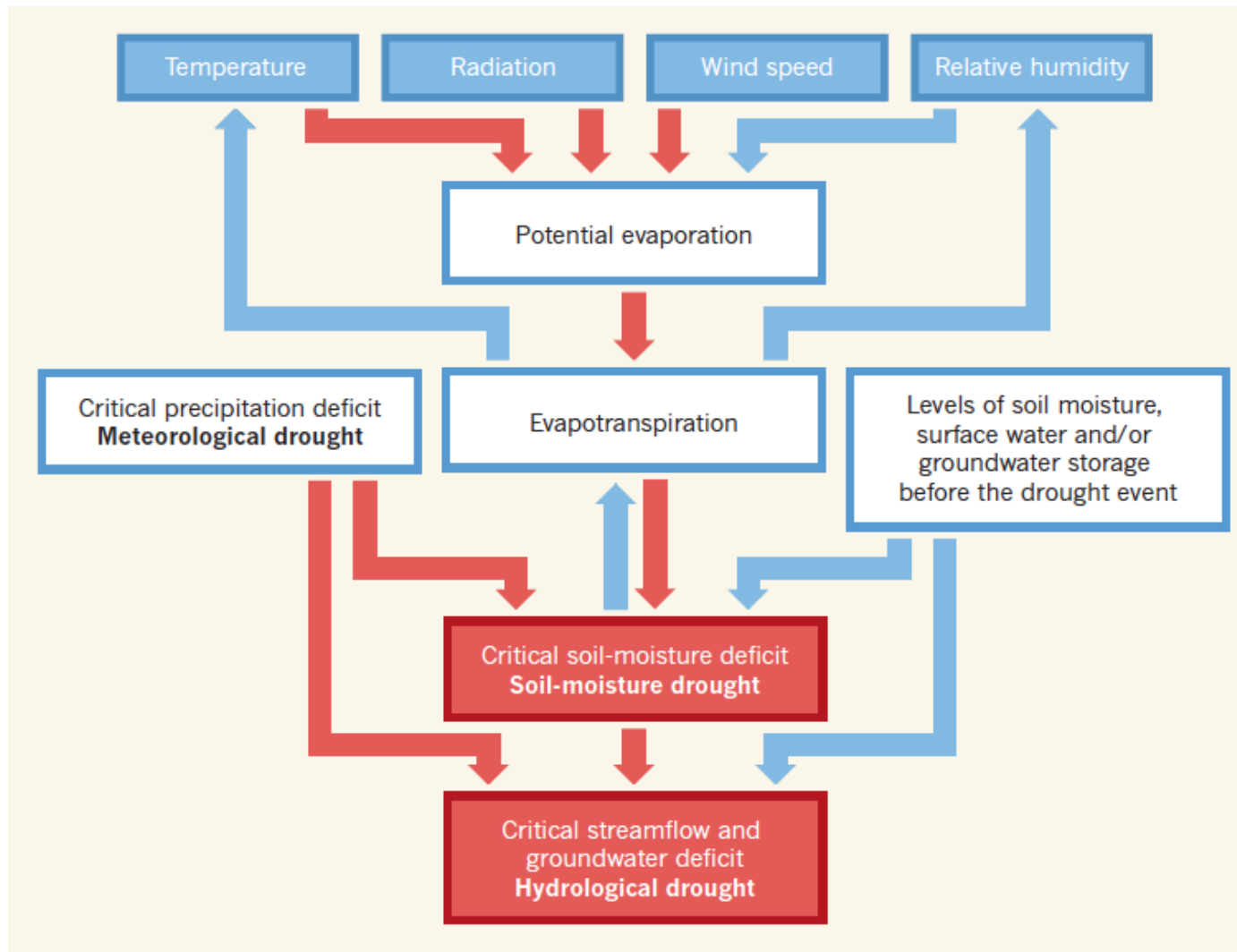
Conclusions

- Substantial changes in several extremes (mostly temperature extremes, heavy precipitation events) both in historical period and in projected scenarios
- However, signal depends very much on considered extreme, and there remains large uncertainties for several extremes (droughts, except for a few regions, as well as tropical cyclones, extreme winds/storminess)
- Climate feedbacks can be an important factor amplifying extremes in some regions (e.g. soil moisture-temperature feedbacks, snow-temperature feedbacks): Imply non-linear effects





(Orlowsky and Seneviratne 2013, HESS; approach adapted from Hawkins and Sutton 2009, BAMS)



(Seneviratne 2014, Nature News and Views)