Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

How do extremes change in the context of climate change?

Sonia I. Seneviratne

Institute for Atmospheric and Climate Science, ETH Zurich, Switzerland
sonia.seneviratne@env.ethz.ch

Acknowledgements: Boris Orlowsky, Simon Allen

Outline

How are extremes affected by climate change?

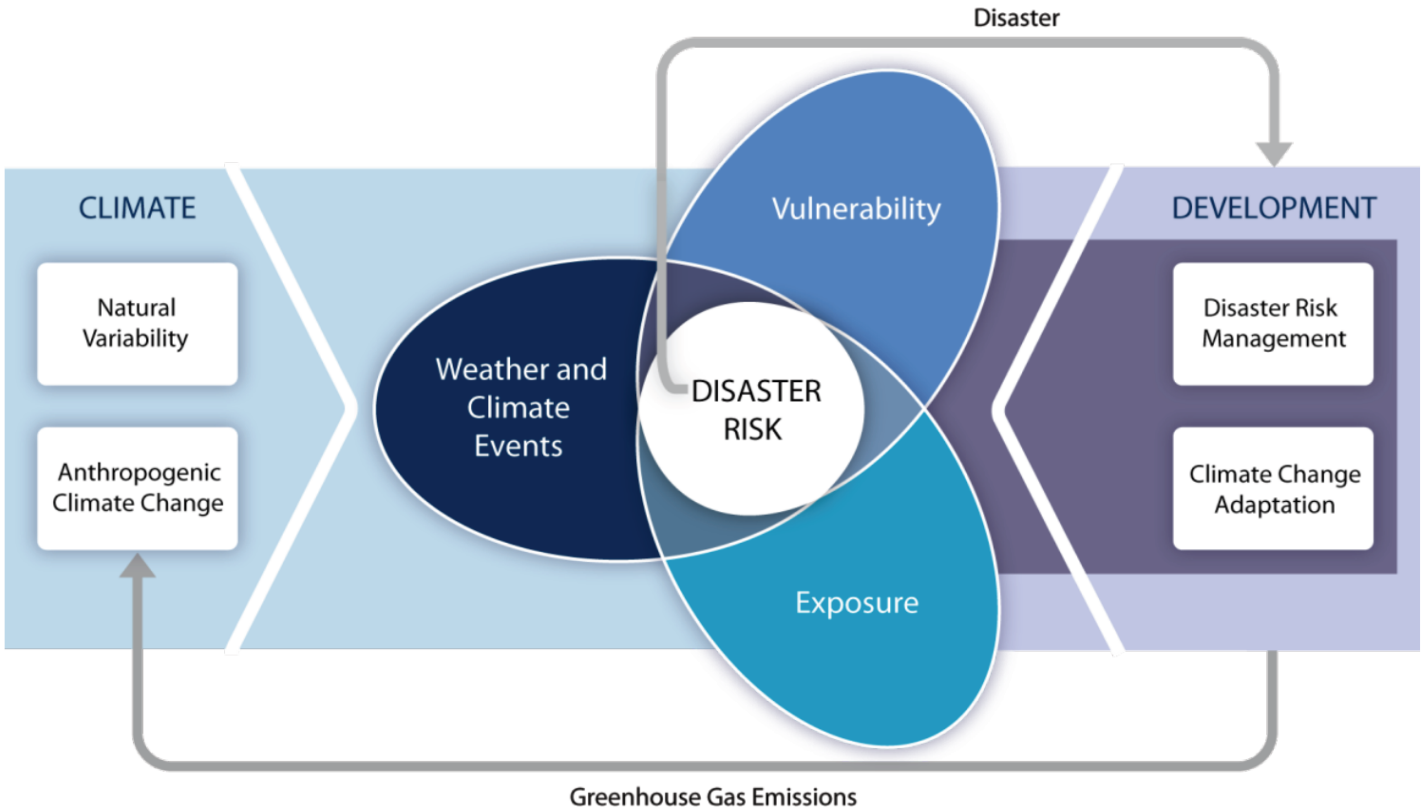
- Mean vs variability
- Role of feedback processes

Historical and projected changes in extremes

- IPCC SREX / AR5 assessments
- Some current research issues

Conclusions

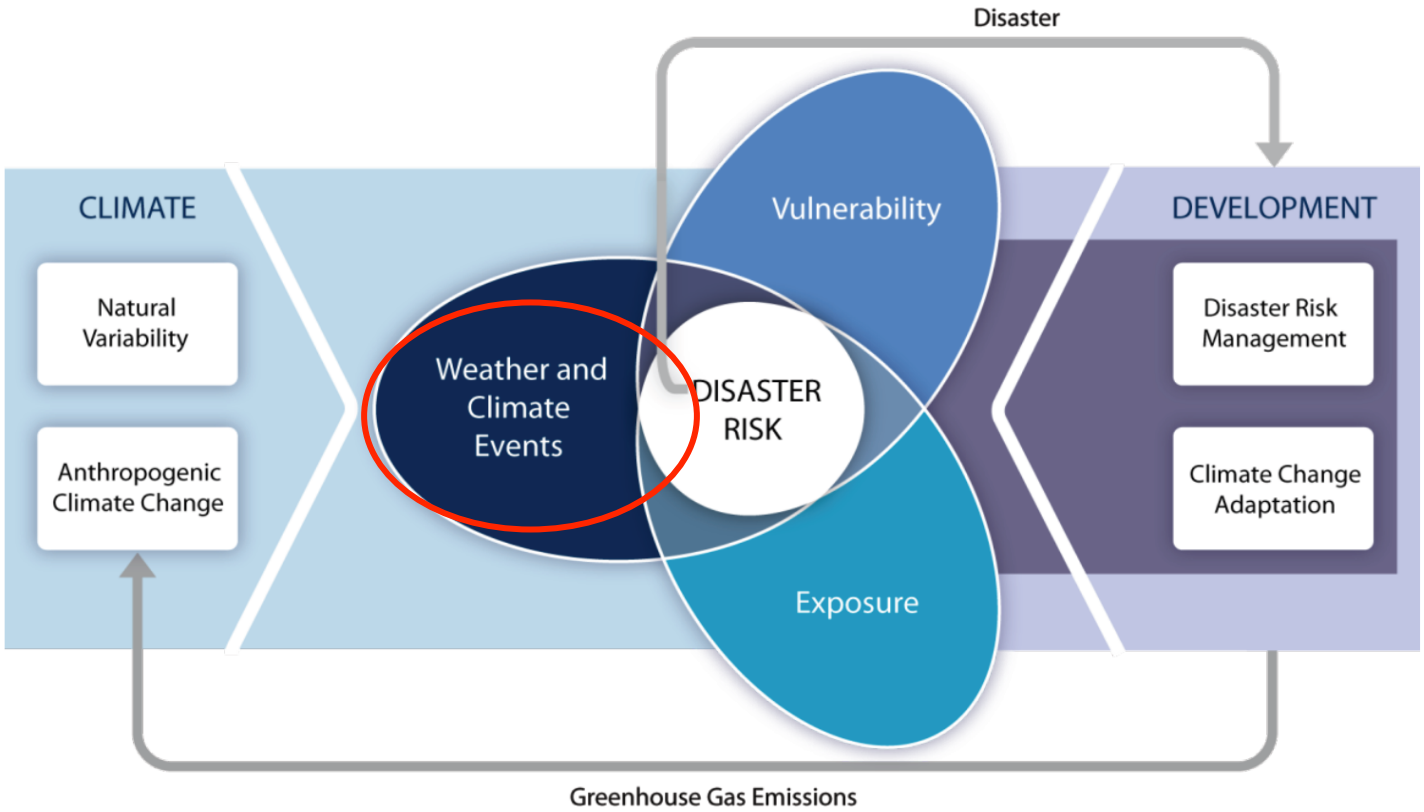
Introduction: Contributors to extreme impacts



ipcc
INTERGOVERNMENTAL PANEL ON climate change

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

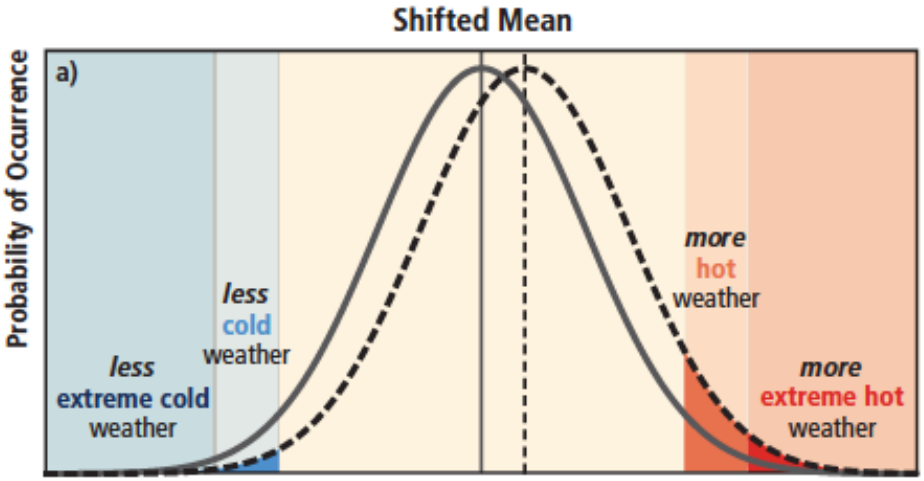
Introduction: Contributors to extreme impacts



ipcc
INTERGOVERNMENTAL PANEL ON climate change

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

Changes in extremes vs changes in mean

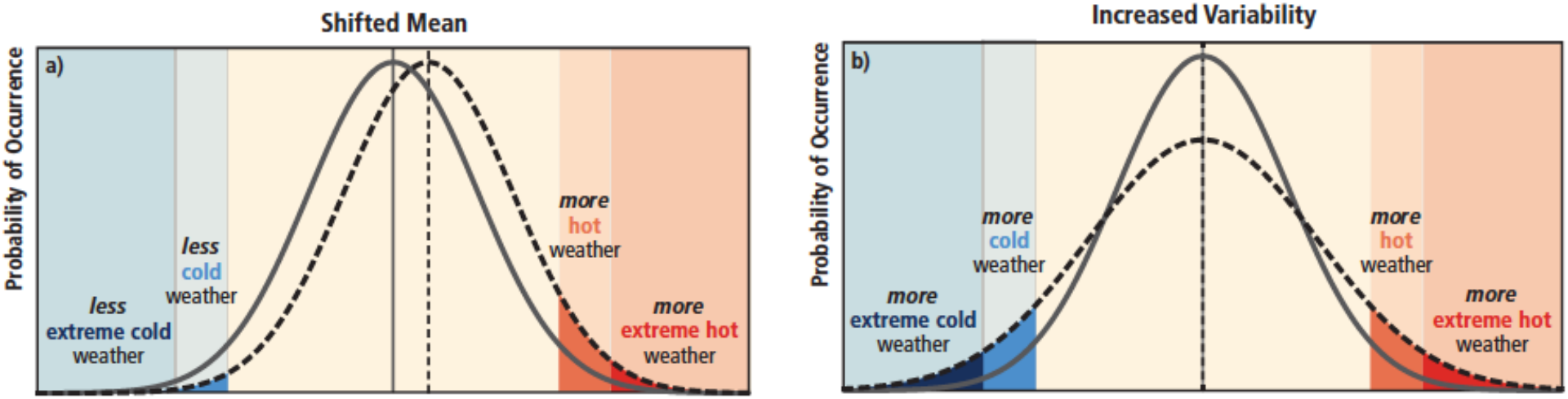


Changes in extremes can occur:

- As a result of shifts in mean climate

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

Changes in extremes vs changes in mean

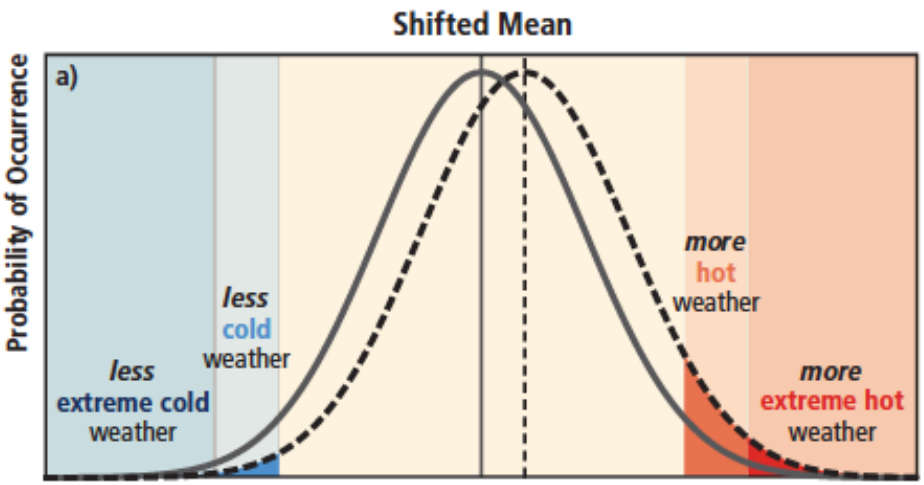


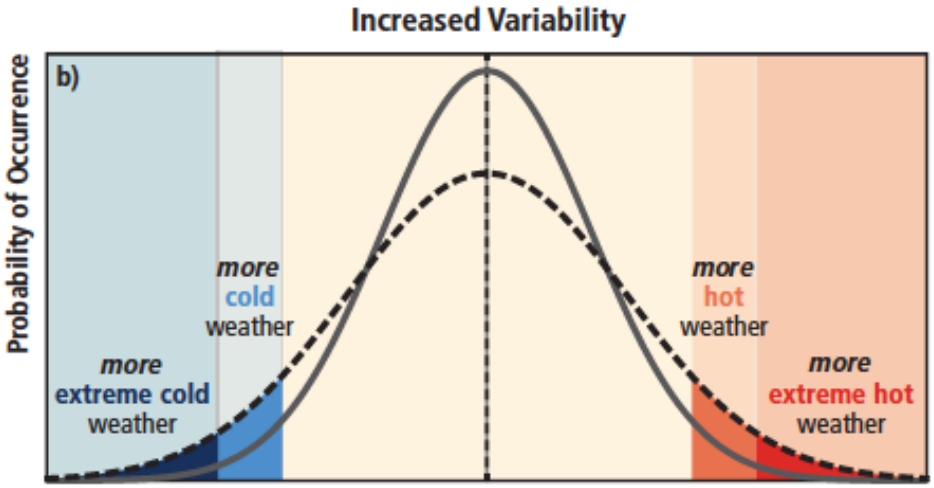
Changes in extremes can occur:

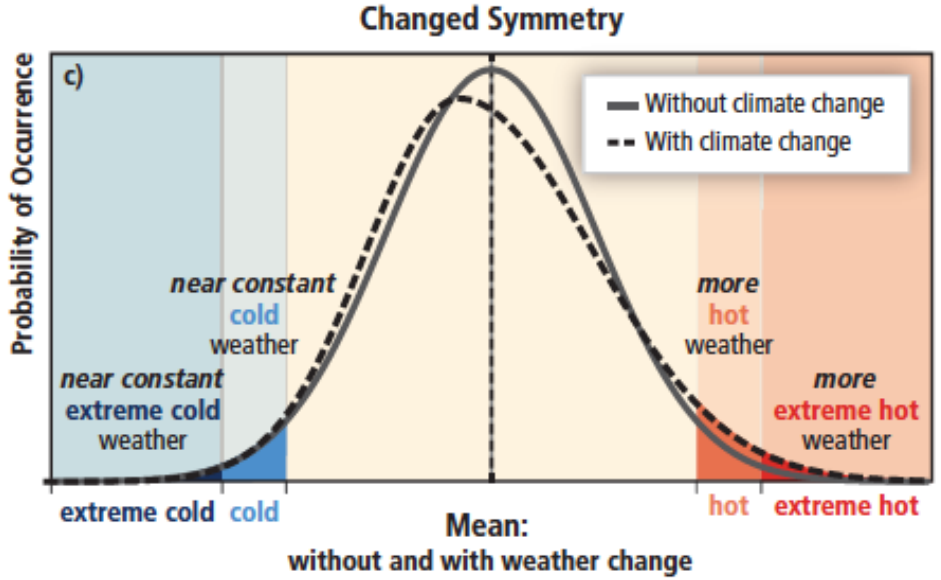
- As a result of shifts in mean climate
- Without any changes in mean climate

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

Changes in extremes vs changes in mean







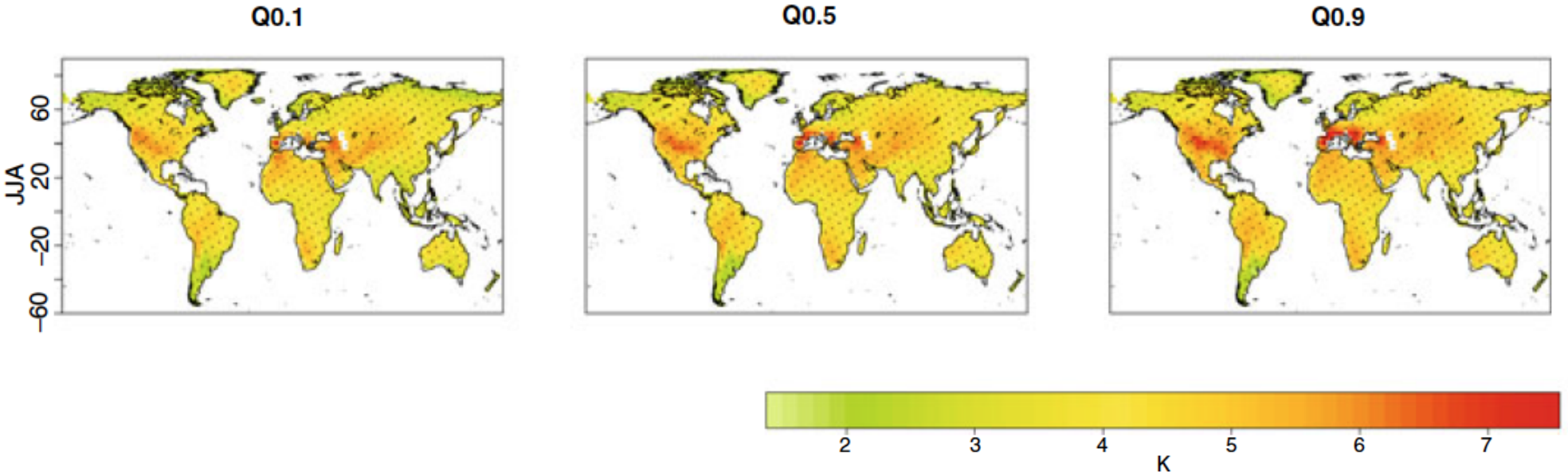
Changes in extremes can occur:

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

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

Asymmetric warming of extremes

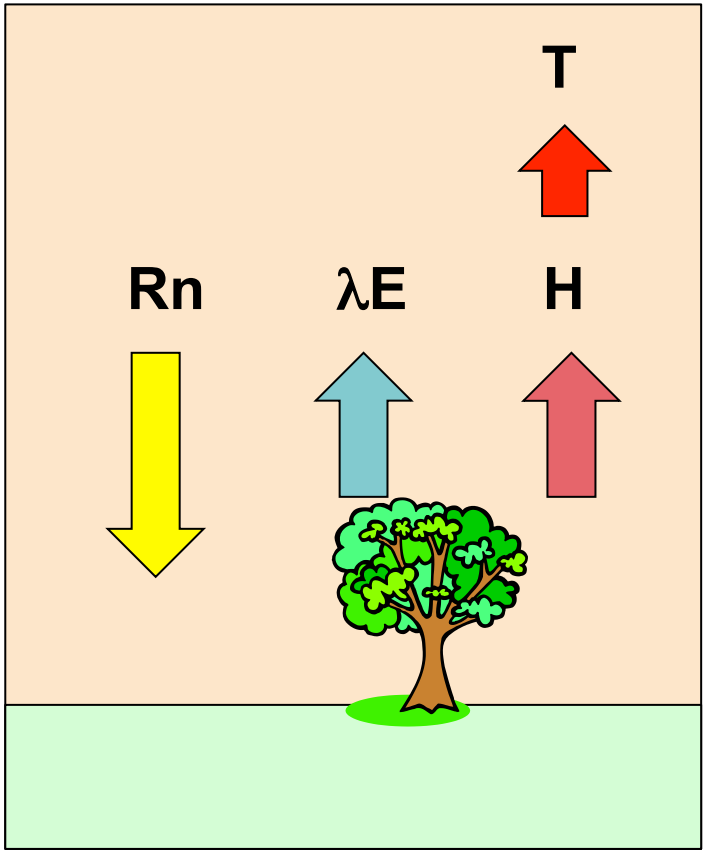
ΔTmax [(2081-2100)-(1980-1999)] for 10th (left), 50th (middle), and 90th percentile (right)



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

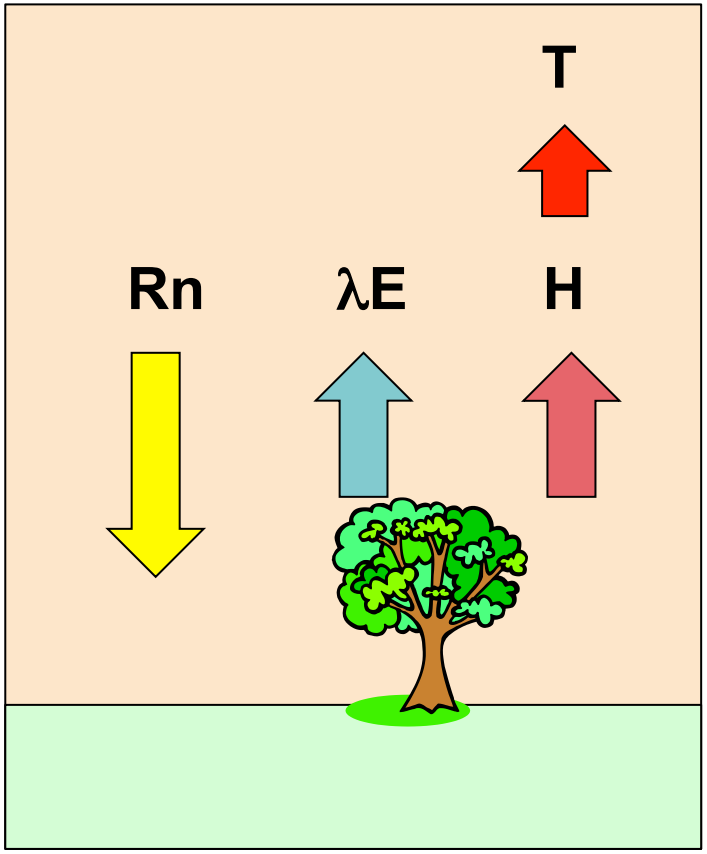
(Orlowsky and Seneviratne 2012, Climatic Change)

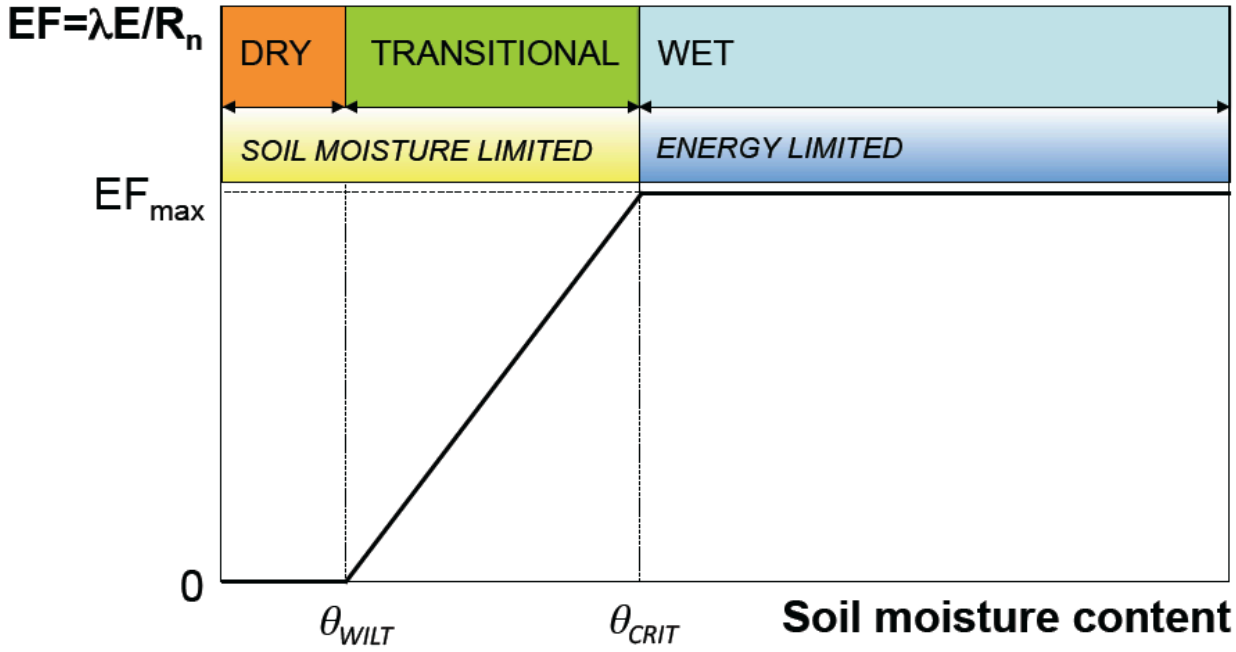
Surface energy balance



Surface energy balance

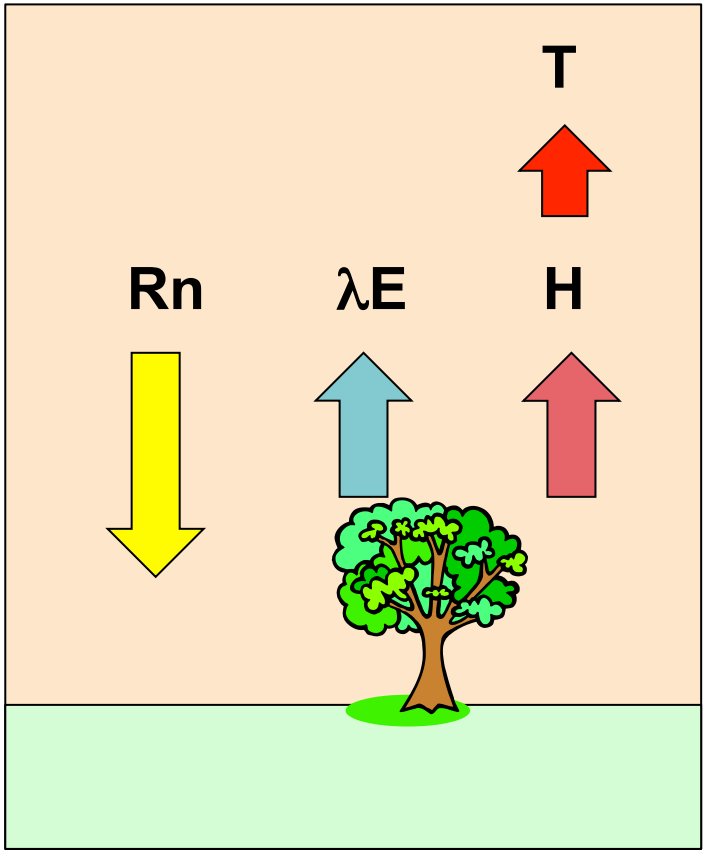
(after Budyko 1956)



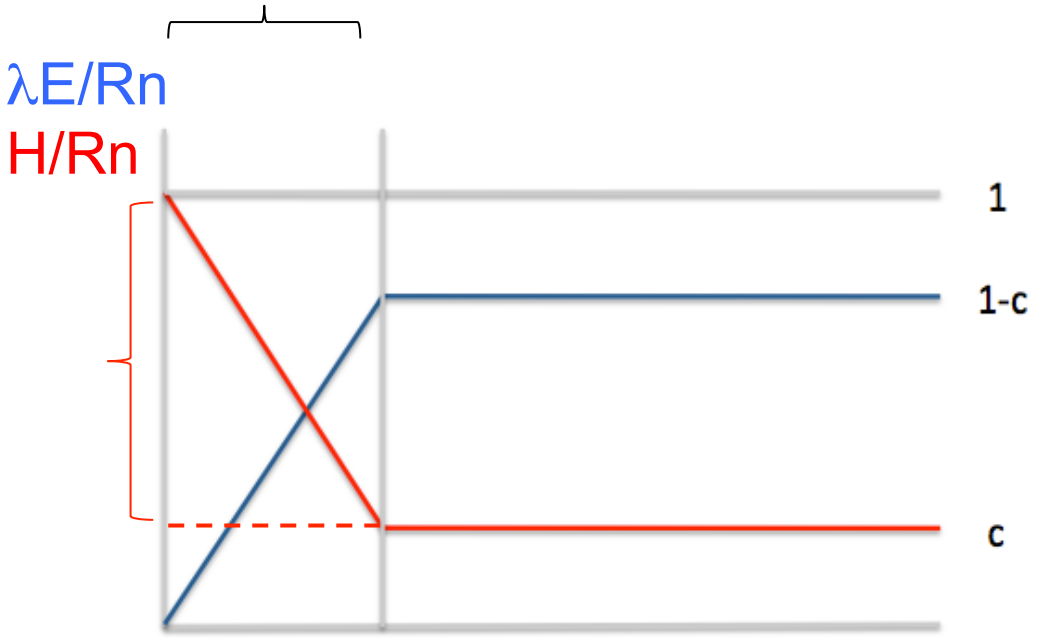


(Seneviratne et al. 2010, Earth-Science Reviews)

Surface energy balance



Transitional climate regime

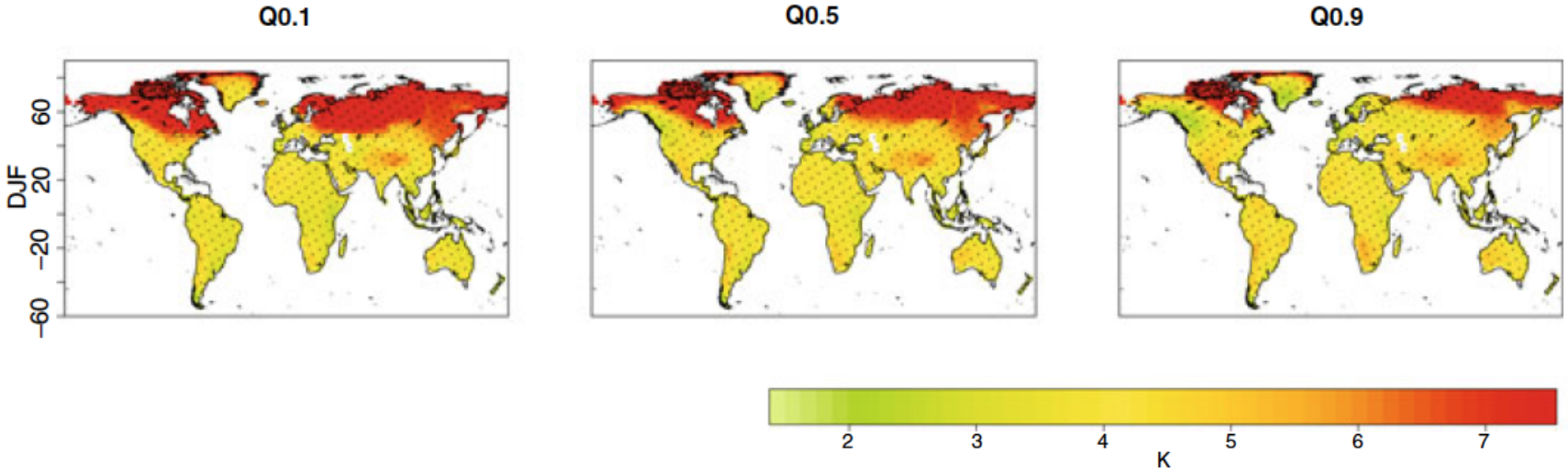


Soil moisture

λE=50-60%Rn

Asymmetric warming of extremes

ΔTmax [(2081-2100)-(1980-1999)] for 10th (left), 50th (middle), and 90th percentile (right)

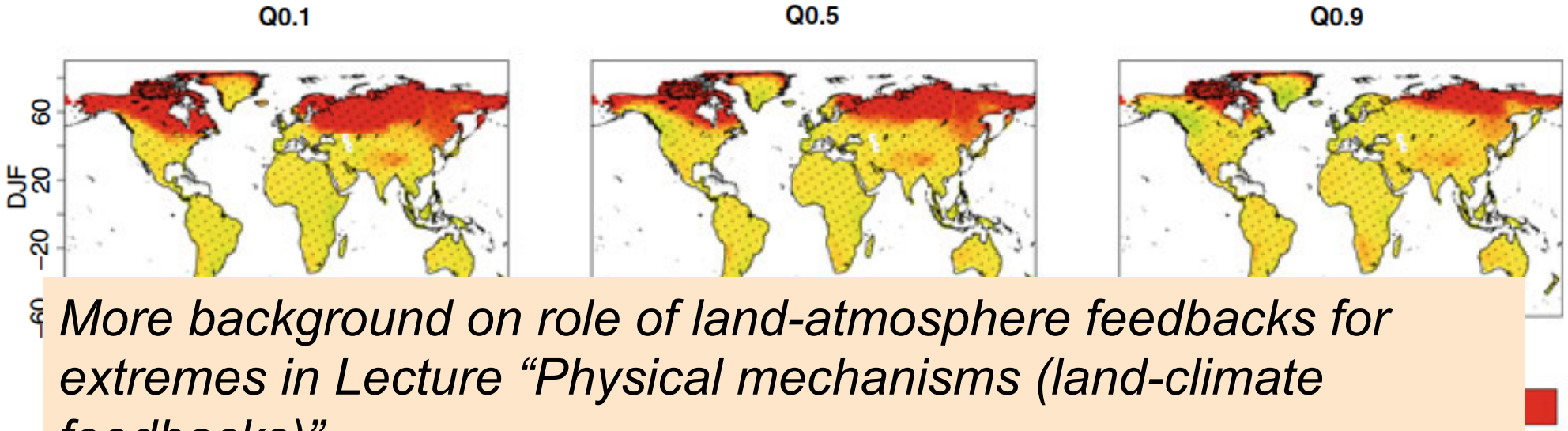


Stronger warming of cold extremes in high-latitude regions: Snow feedback

(Orlowsky and Seneviratne 2012, Climatic Change)

Asymmetric warming of extremes

ΔTmax [(2081-2100)-(1980-1999)] for 10th (left), 50th (middle), and 90th percentile (right)



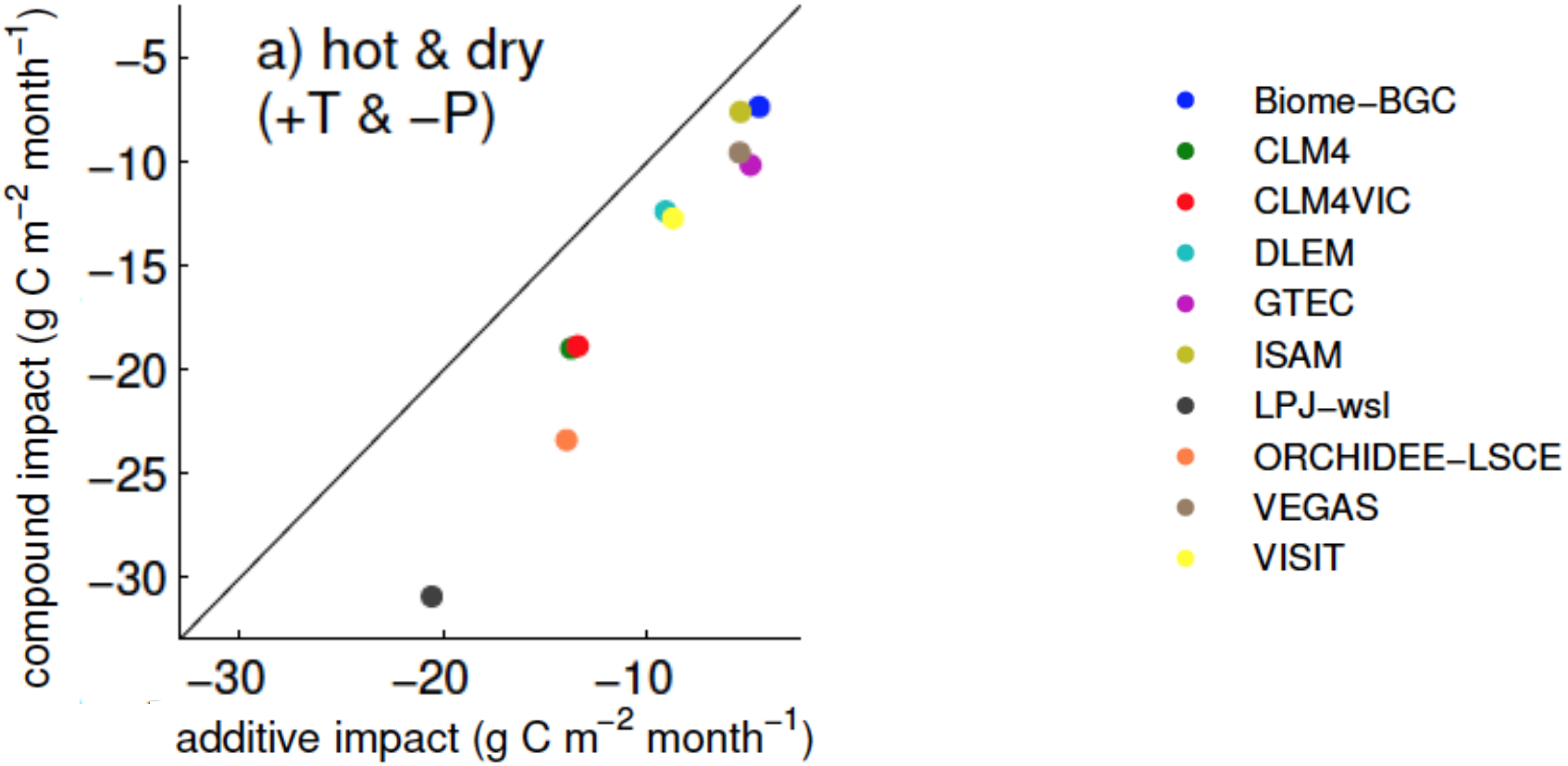
More background on role of land-atmosphere feedbacks for extremes in Lecture "Physical mechanisms (land-climate feedbacks)"

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

(Orlowsky and Seneviratne 2012, Climatic Change)

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

Gross primary production (Plant CO_2 uptake)



(Zscheischler et al. 2014, Global Biogeochemical Cycles)

Outline

How are extremes affected by climate change?

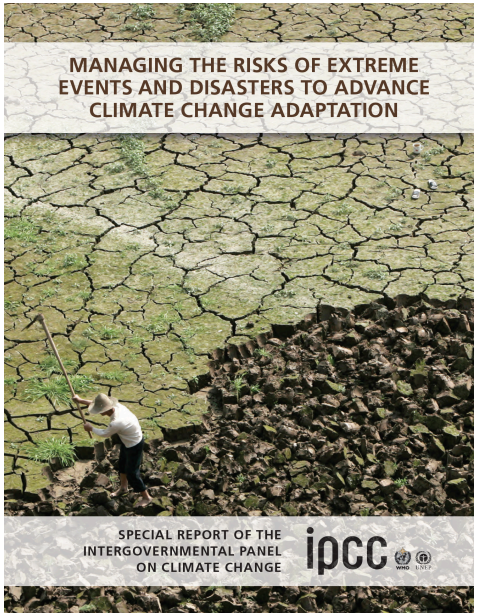
- Mean vs variability
- Role of feedback processes

Historical and projected changes in extremes

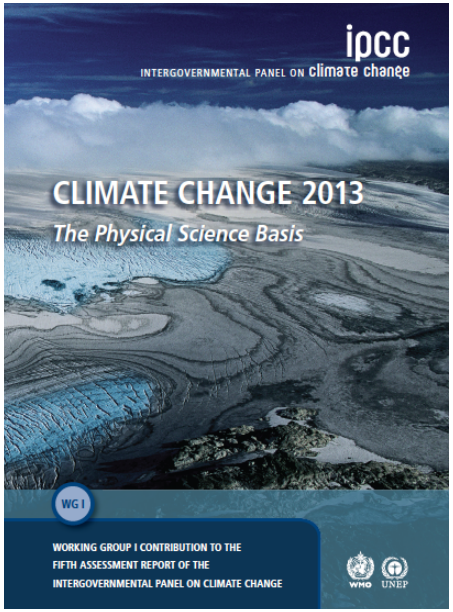
- IPCC SREX / AR5 assessments
- Some current research issues

Conclusions

IPCC SREX and IPCC AR5



IPCC, 2012



IPCC, 2013

Observed changes: AR5

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

(www.ipcc.ch)

Observed changes since 1950 (AR5)

- ***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**

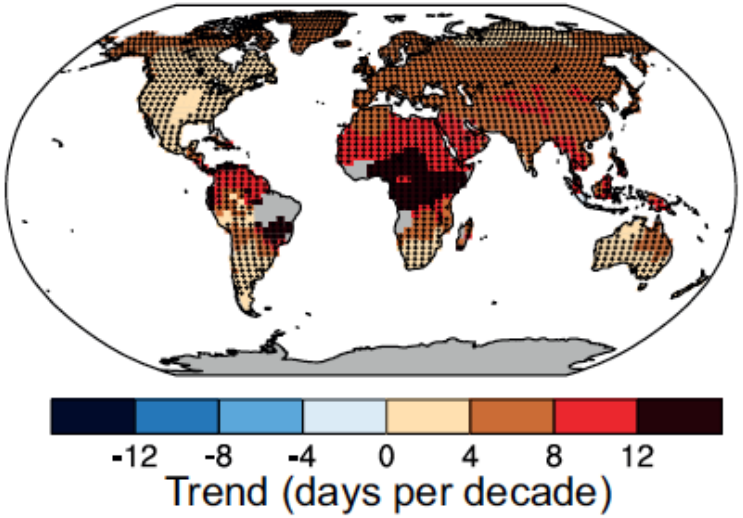
- ***Confidence*** remains ***low*** for long-term (centennial) changes in **tropical cyclone activity** (but virtually certain that frequency and intensity of strongest tropical cyclones in the North Atlantic has increased since 1970)

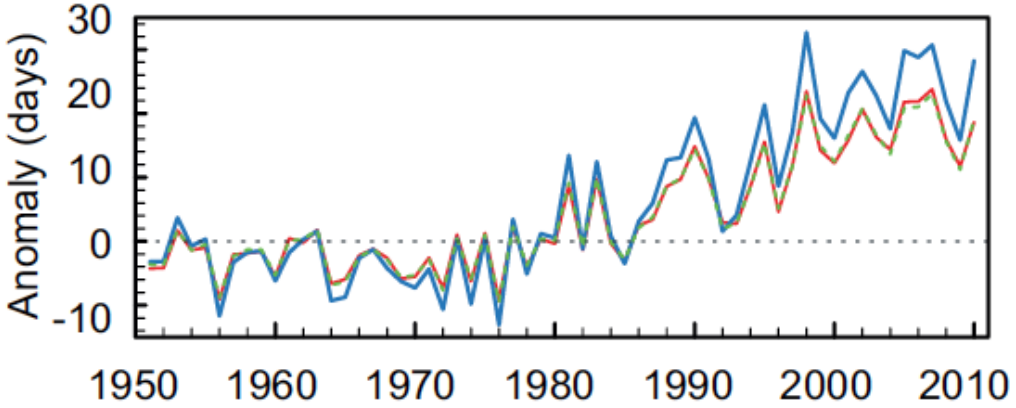
- ***Confidence*** is ***low*** for a global-scale observed trend in **drought** owing to lack of direct observations, methodological uncertainties, and geographical inconsistencies in the trends

- ***Confidence*** is ***low*** for large-scale trends in **storminess**

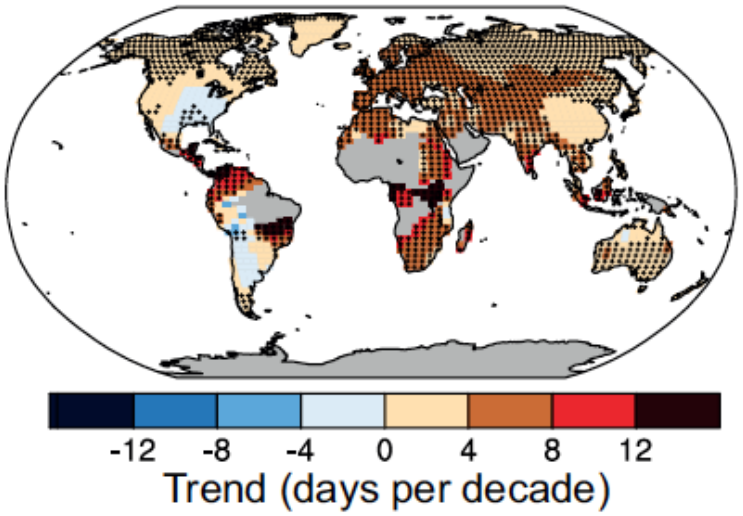
Observed trends: Temperature extremes

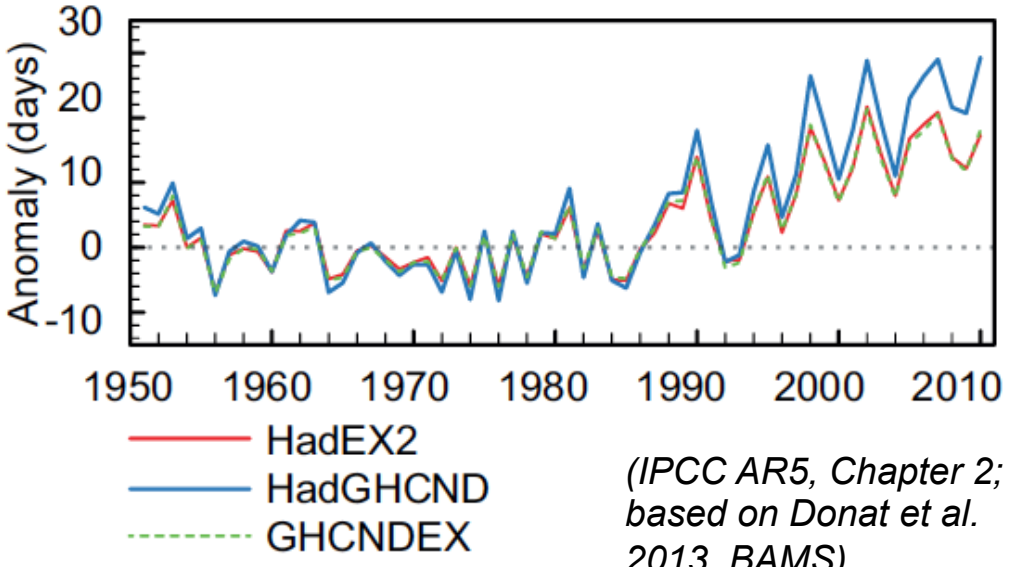
Warm Nights (frequency of 90th percentile)





Warm Days (frequency of 90th percentile)

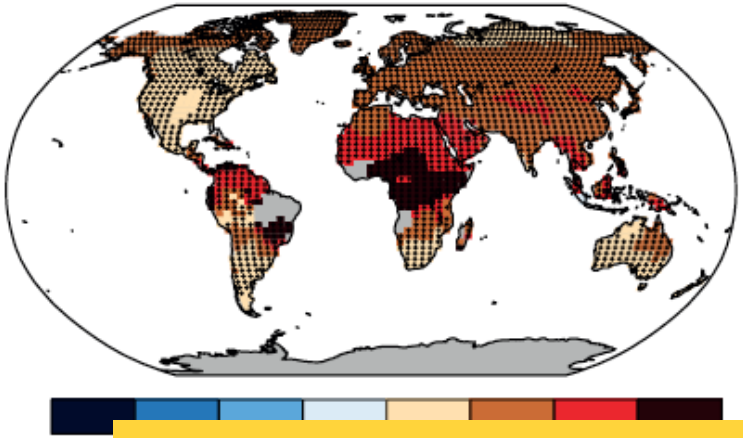


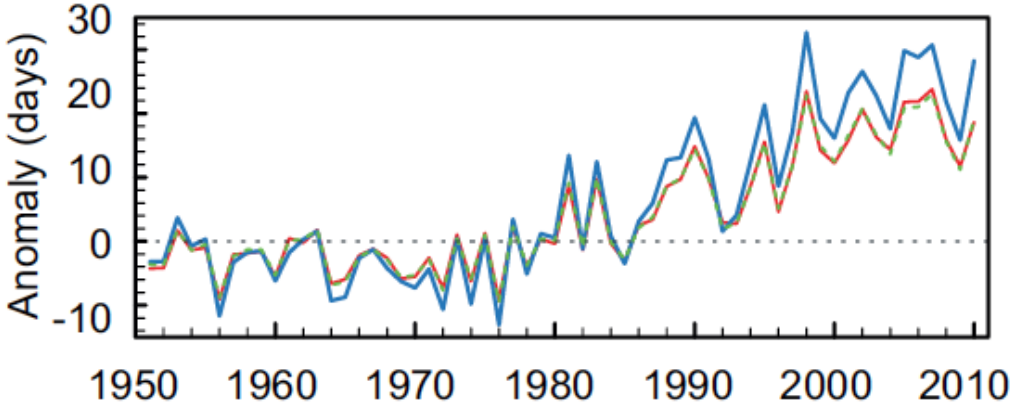


(IPCC AR5, Chapter 2; based on Donat et al. 2013, BAMS)

Observed trends: Temperature extremes

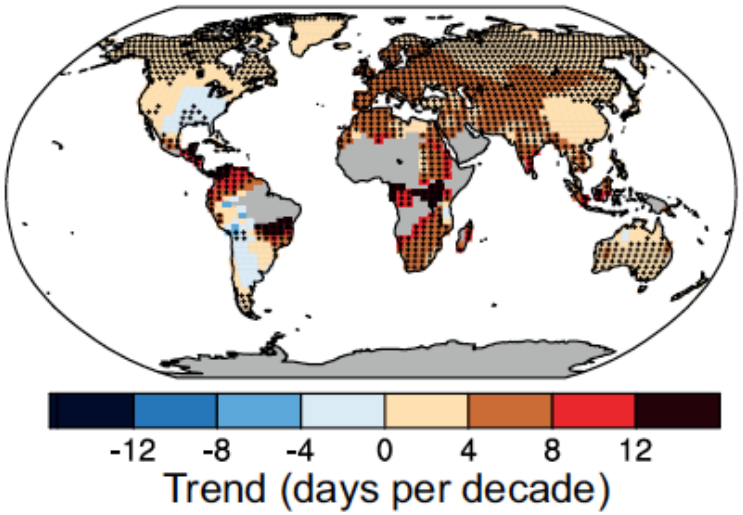
Warm Nights (frequency of 90th percentile)

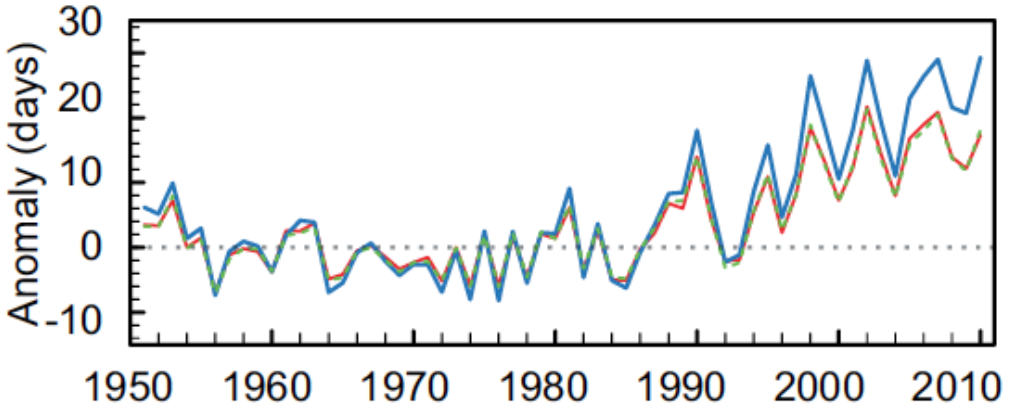




See presentation on data issues (L. Alexander)

Warm Days (frequency of 90th percentile)

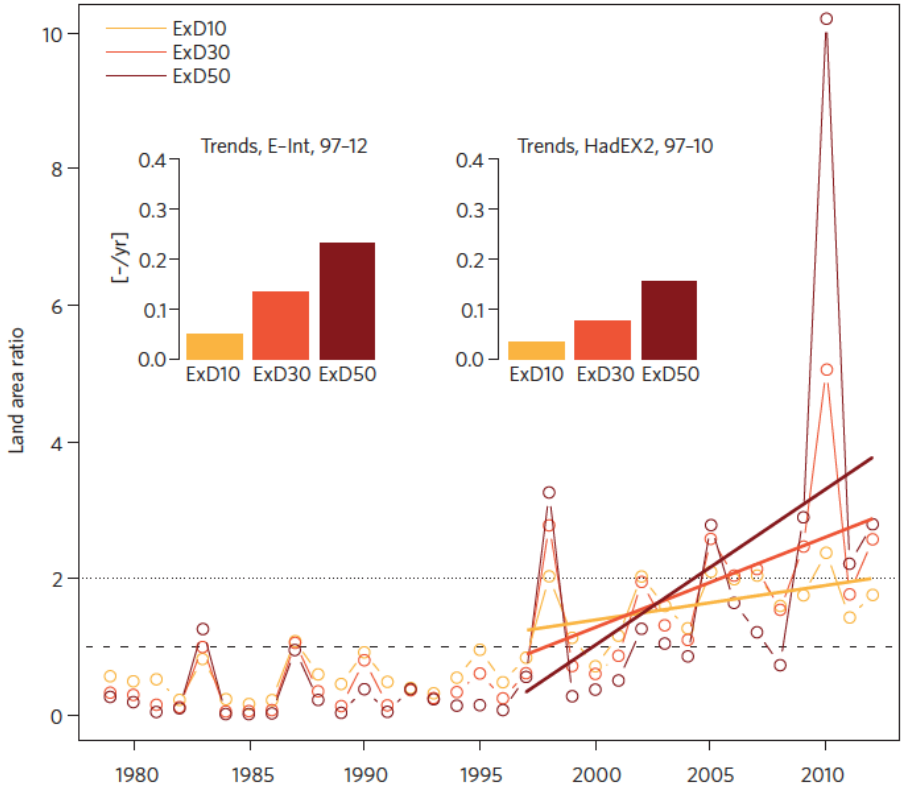




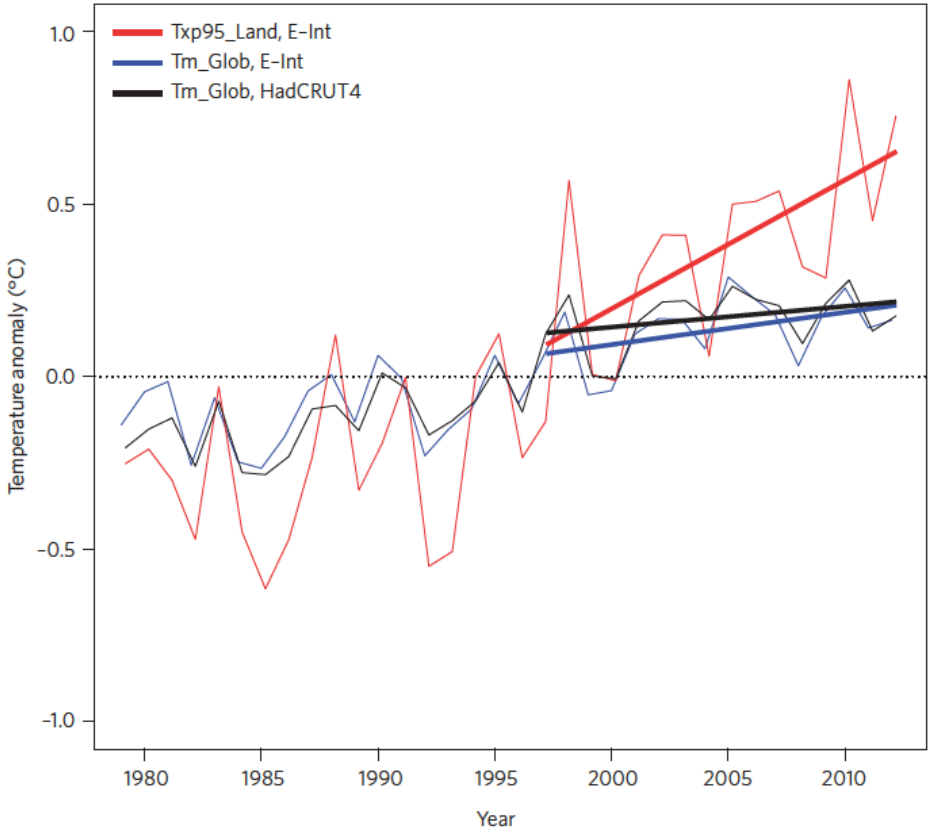
(IPCC AR5, Chapter 2; based on Donat et al. 2013, BAMS)

Trends in temperature extremes in “hiatus” period

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



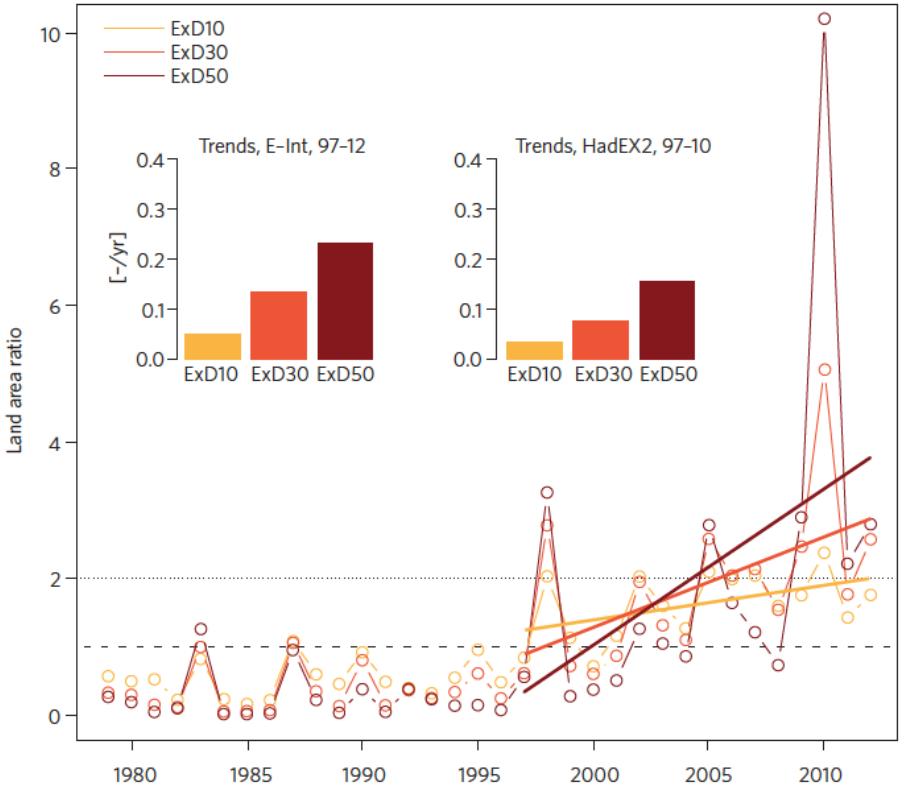
Temperature trends (ERA-interim, HadCRUT4)



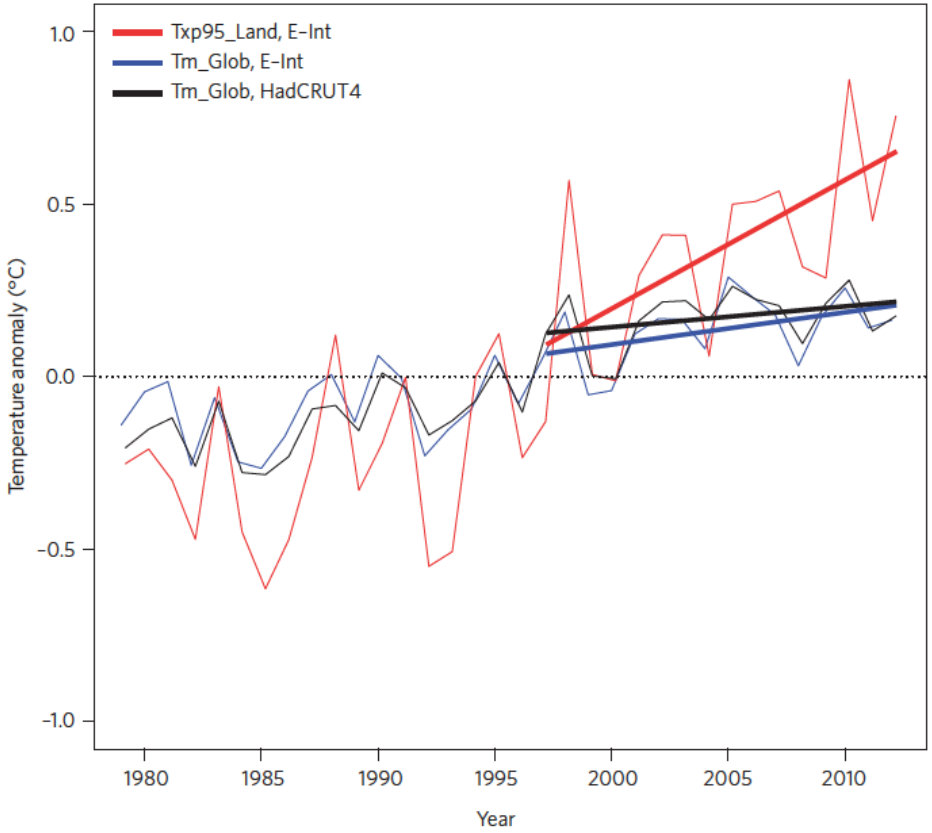
(Seneviratne, Donat, Mueller, and Alexander, 2014, Nature Climate Change)

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)

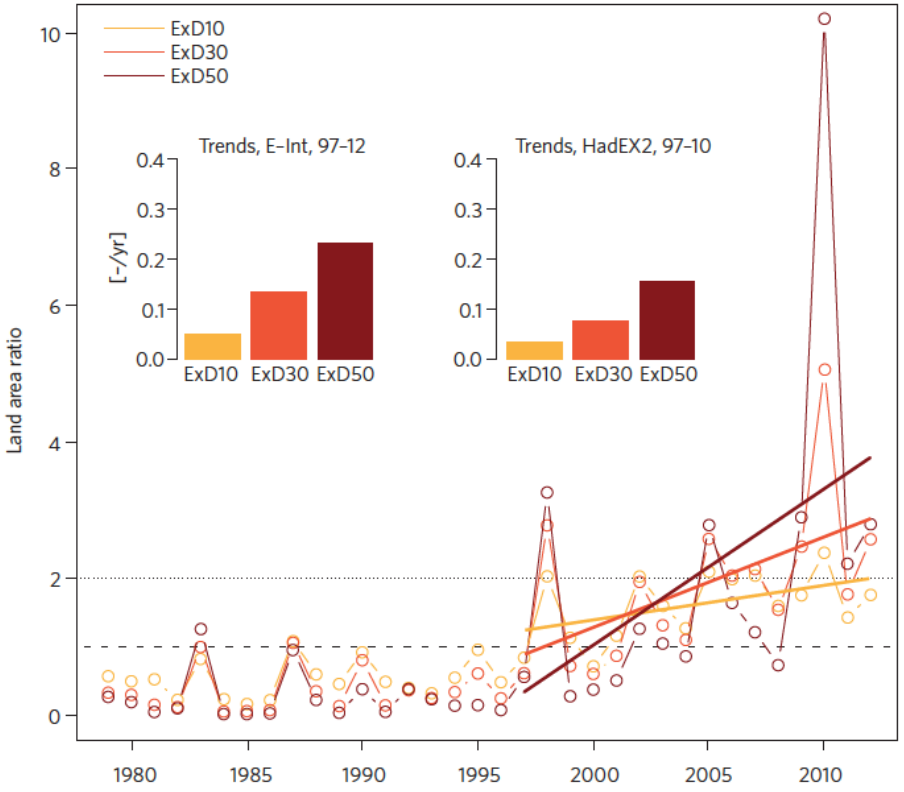


Continued increase of measures of hot extremes despite apparent pause of global mean temperature

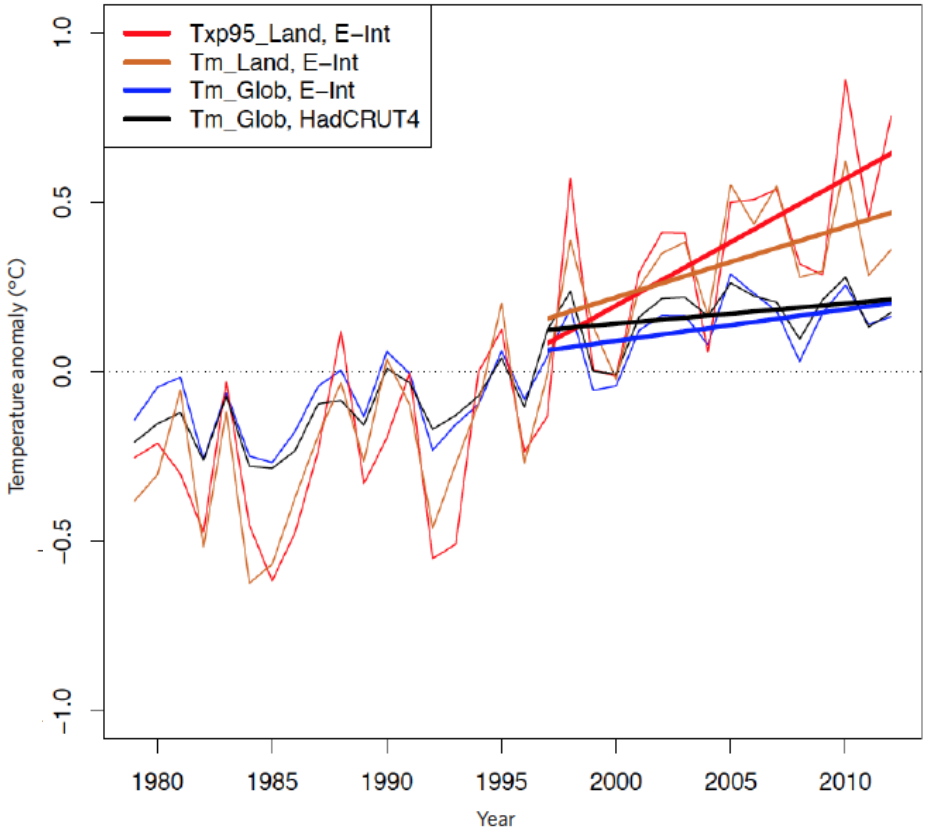
(Seneviratne, Donat, Mueller, and Alexander, 2014, Nature Climate Change)

Trends in temperature extremes in “hiatus” period

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



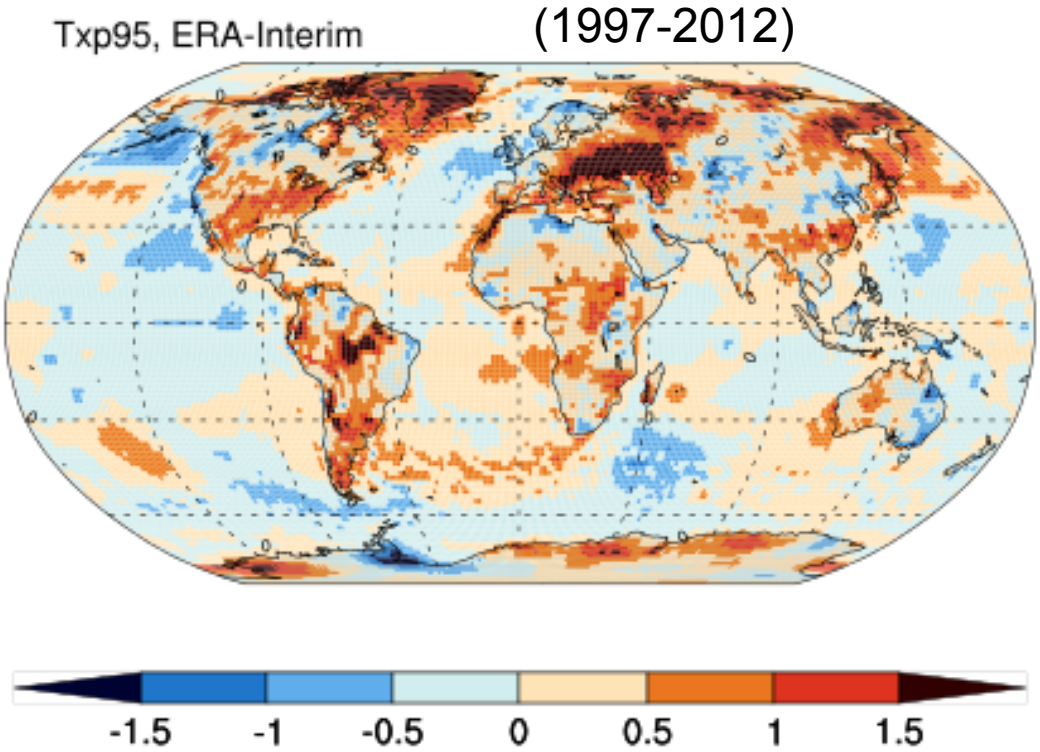
Temperature trends (ERA-interim, HadCRUT4)



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

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

Trends in temperature extremes in “hiatus” period



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

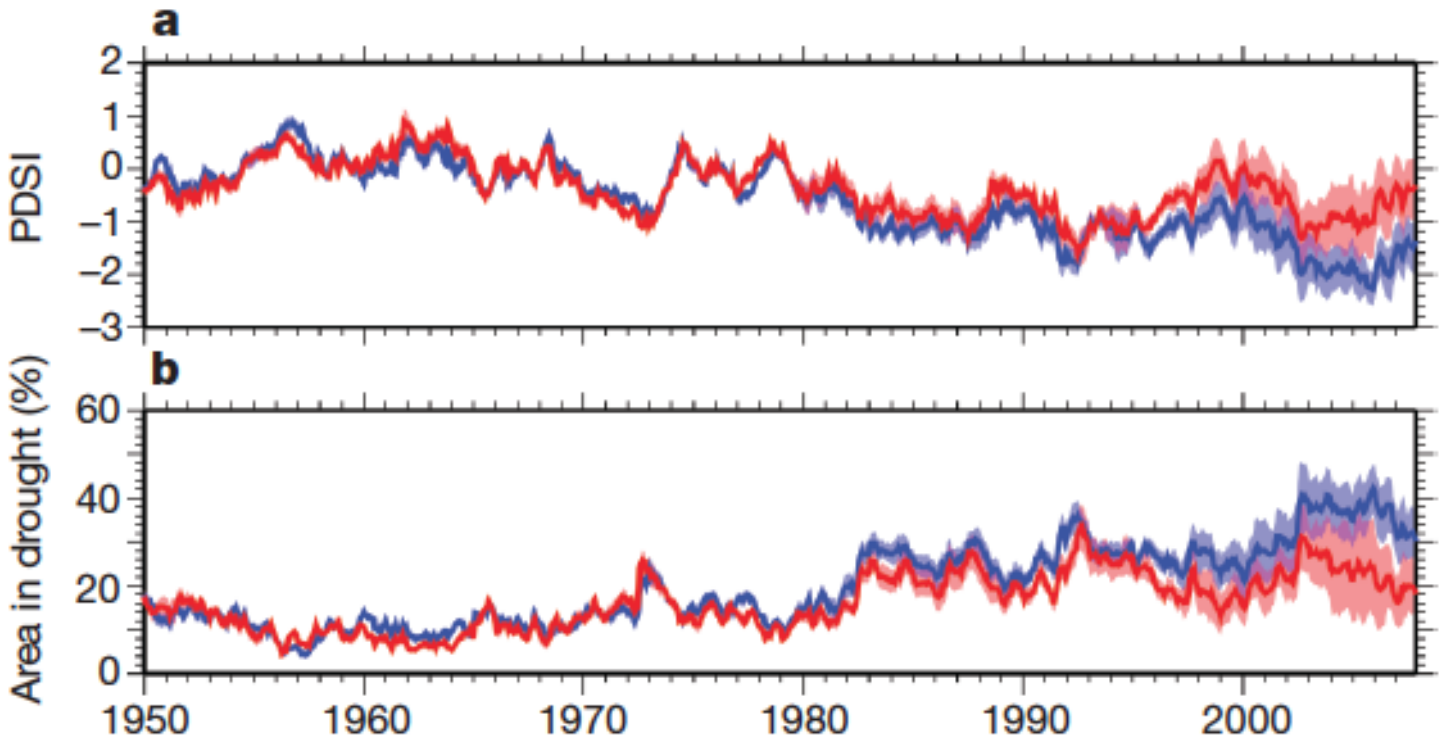
(Seneviratne, Donat, Mueller, and Alexander, 2014, Nature Climate Change)

Observed changes since 1950 (AR5)

- *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**

Trends in global drought

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

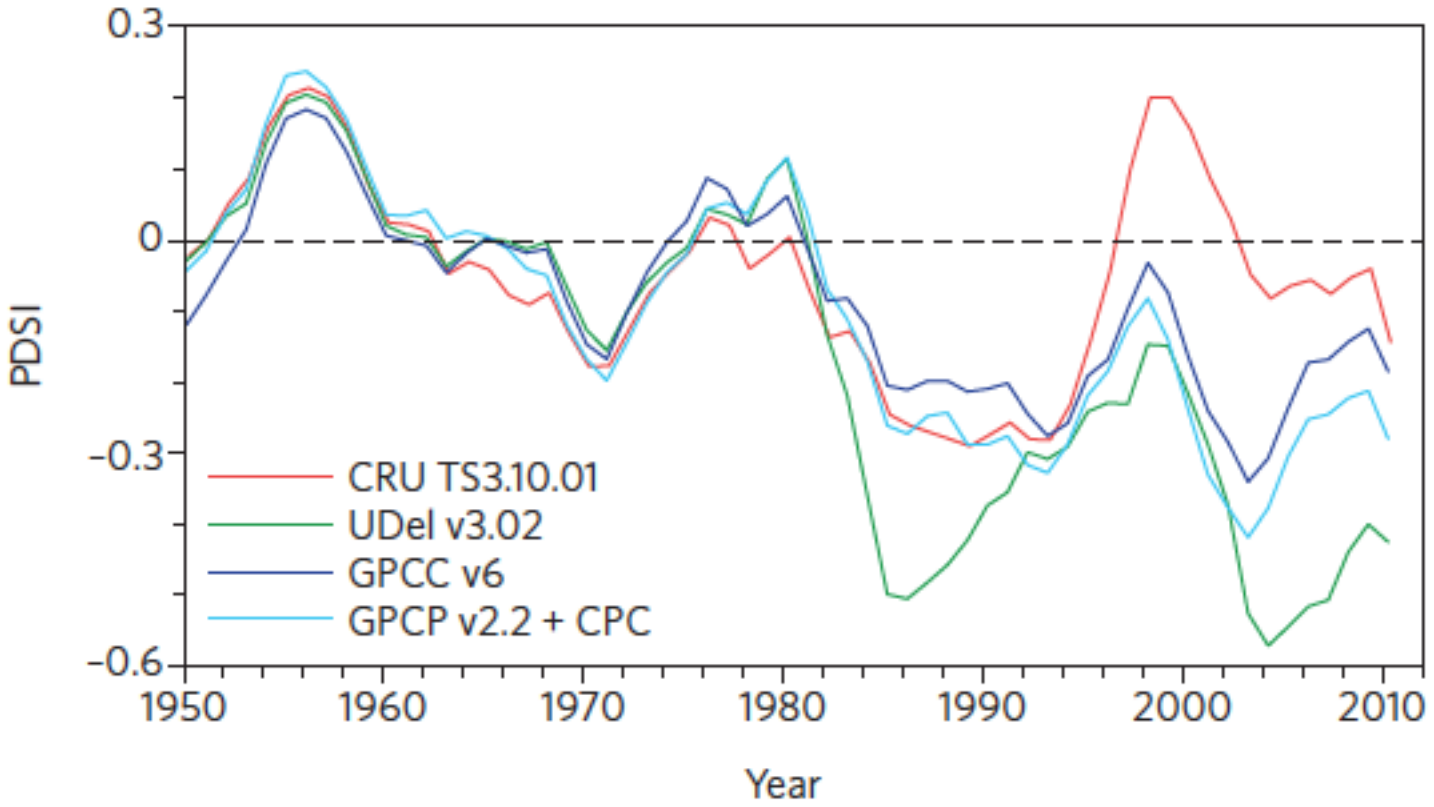


Impact of parameterization of potential evapotranspiration

(Sheffield et al. 2012, Nature)

Trends in global drought

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

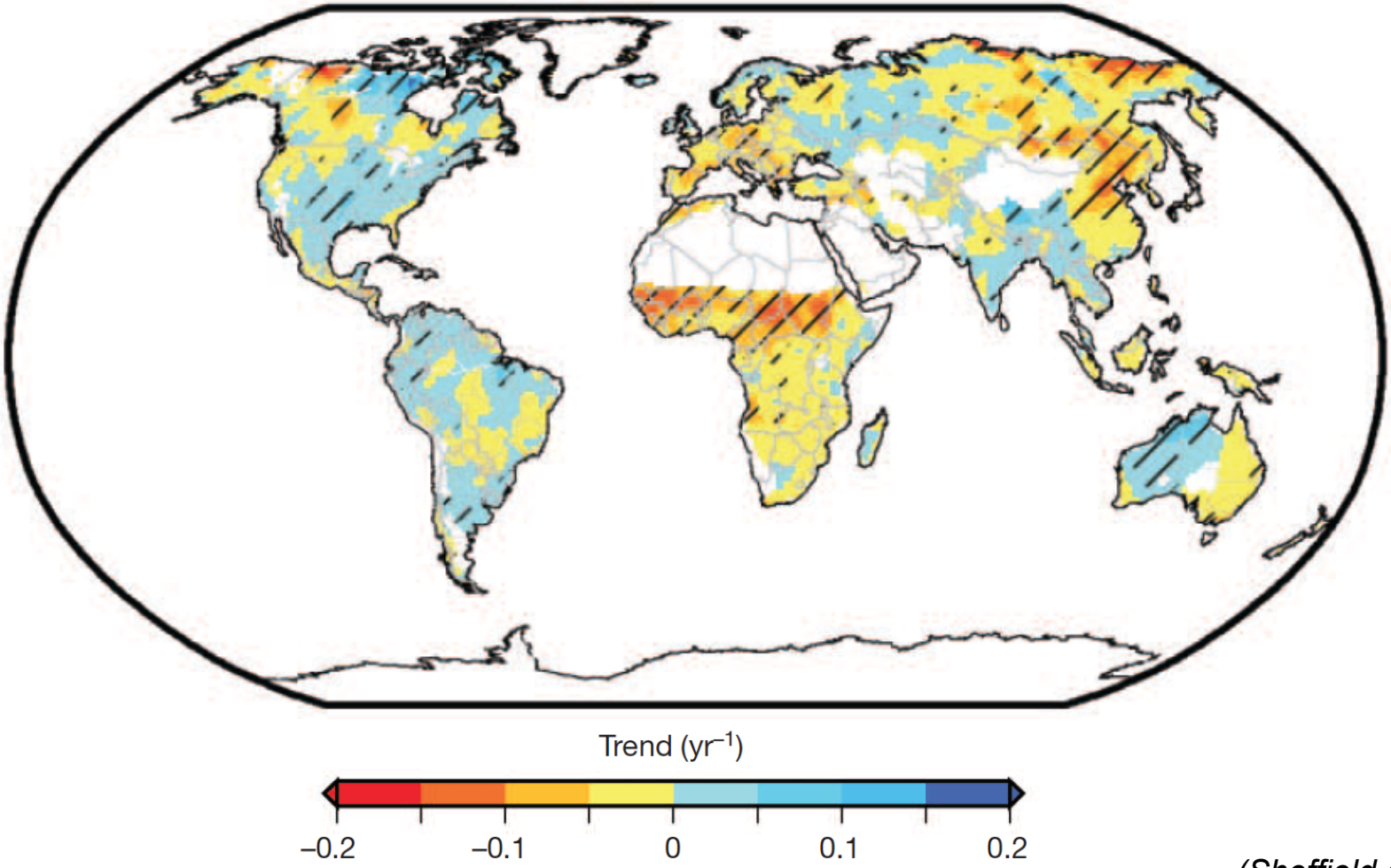


Impact of uncertainty in driving precipitation datasets

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

Trends in regional vs global drought

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



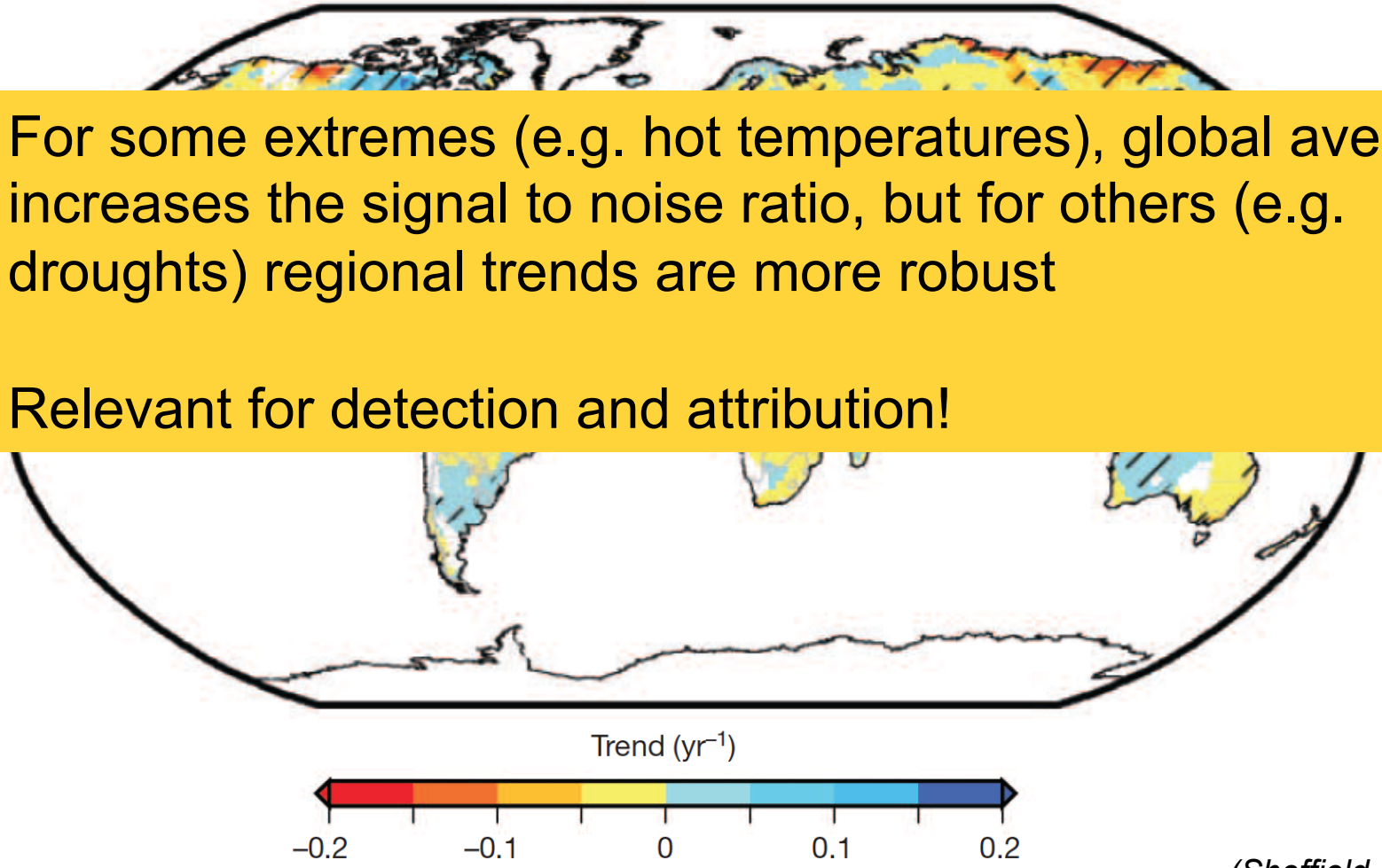
(Sheffield et al. 2012, Nature)

Trends in regional vs global drought

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

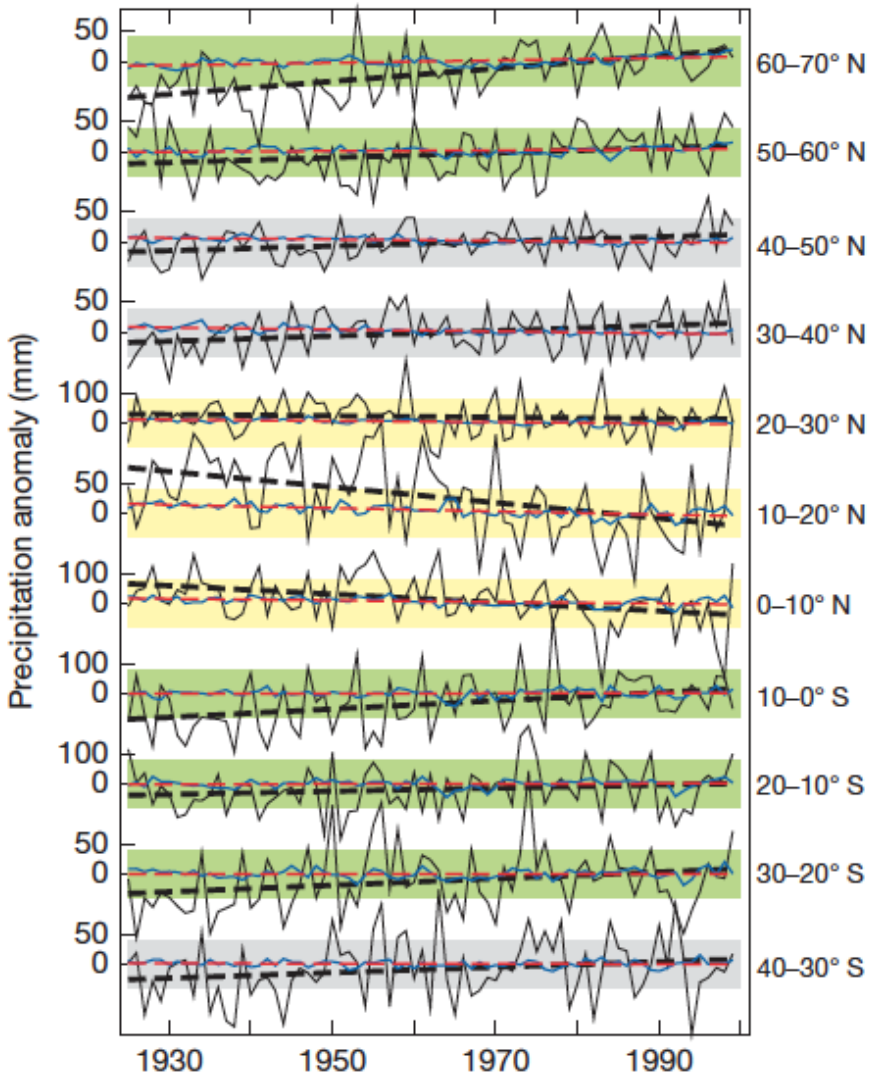
For some extremes (e.g. hot temperatures), global averaging increases the signal to noise ratio, but for others (e.g. droughts) regional trends are more robust

Relevant for detection and attribution!



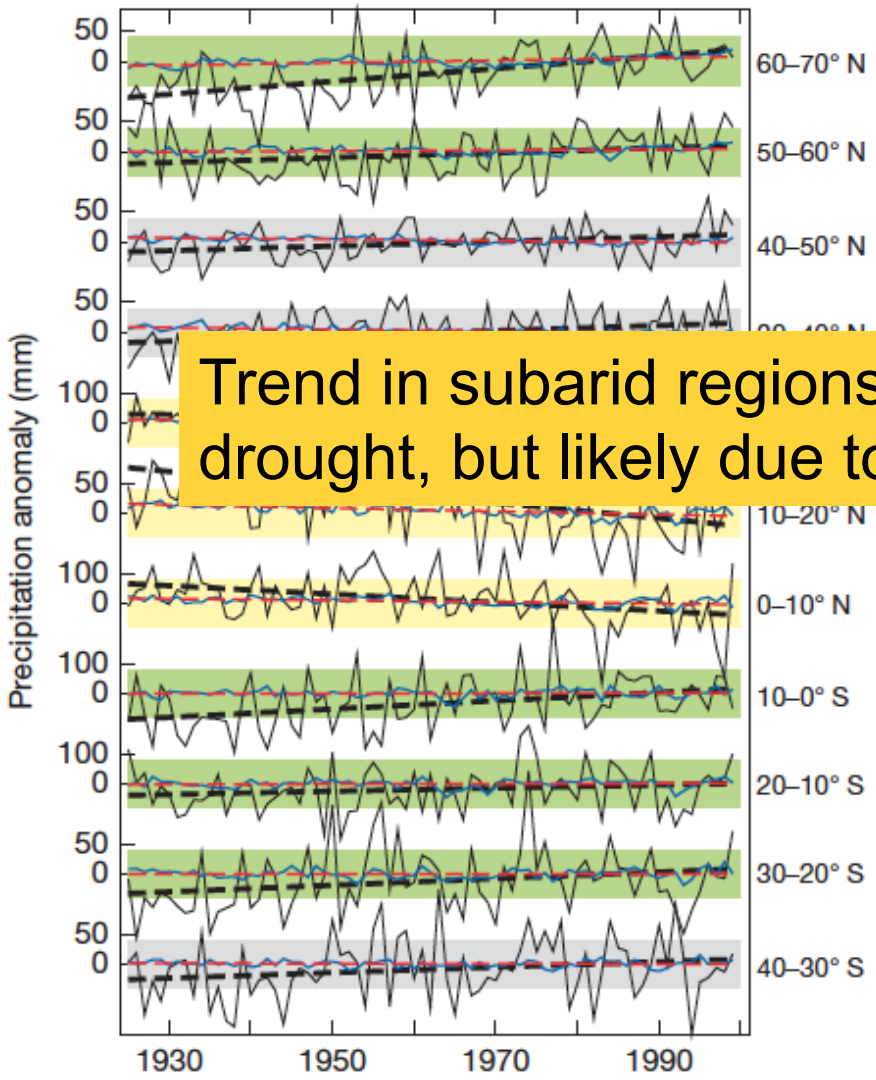
(Sheffield et al. 2012, Nature)

Trends in regional vs global drought

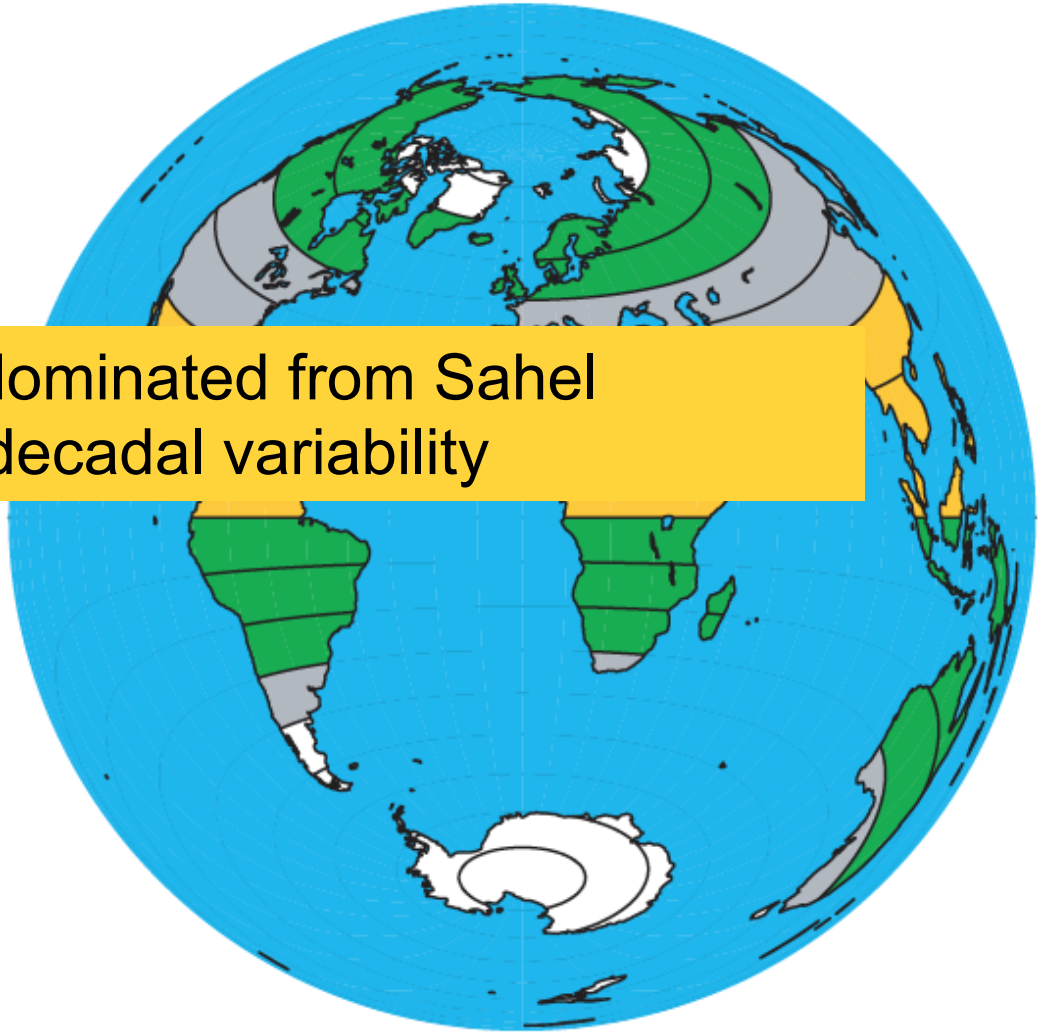


(Zhang et al. 2007, Nature)

Trends in regional vs global drought



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



(Zhang et al. 2007, Nature)

Outline

How are extremes affected by climate change?

- Mean vs variability
- Role of feedback processes

Historical and **projected** changes in extremes

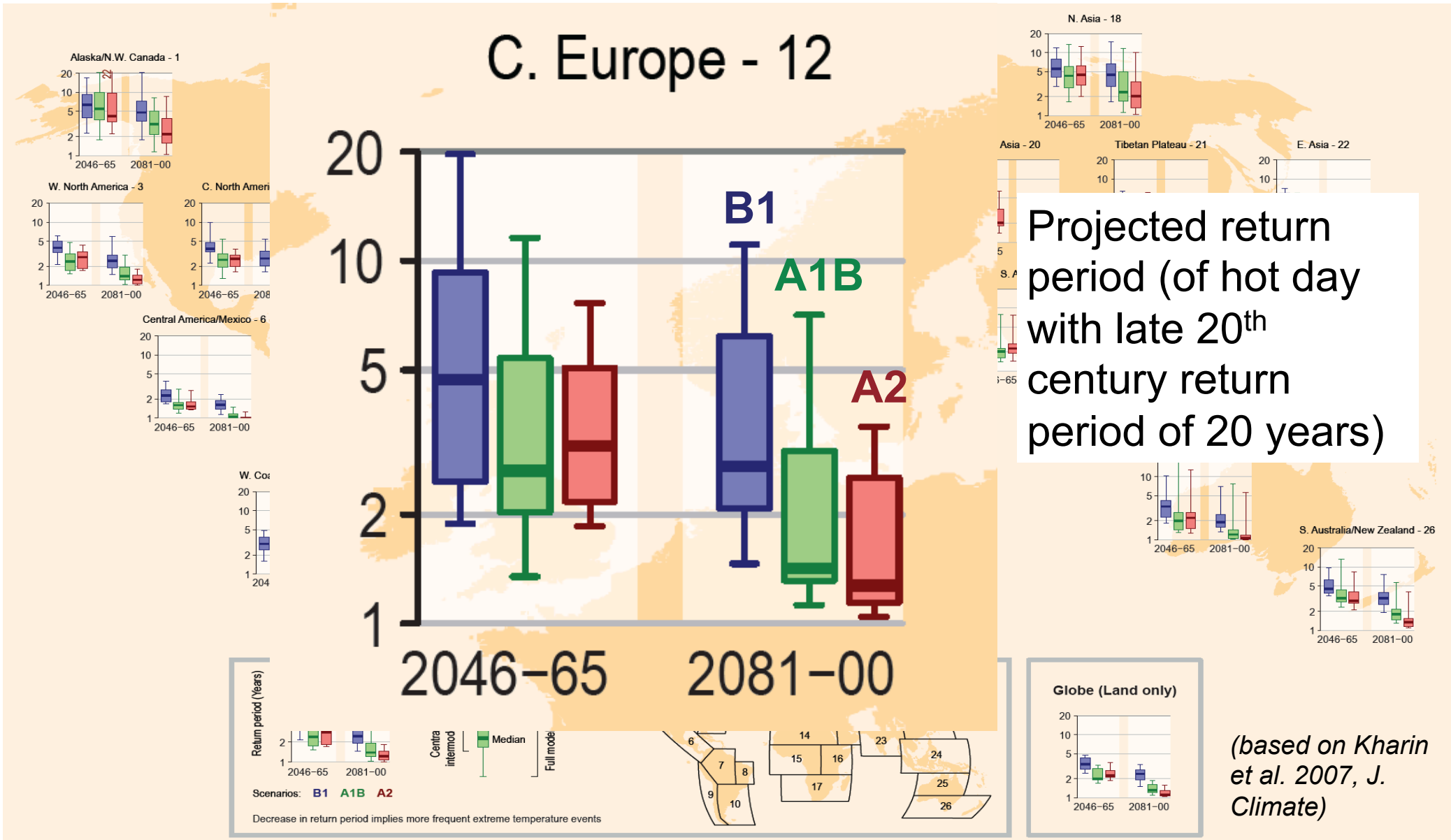
- IPCC SREX / AR5 assessments
- Some current research issues

Conclusions

Projected changes for end of 21st century (SREX)

- ***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**

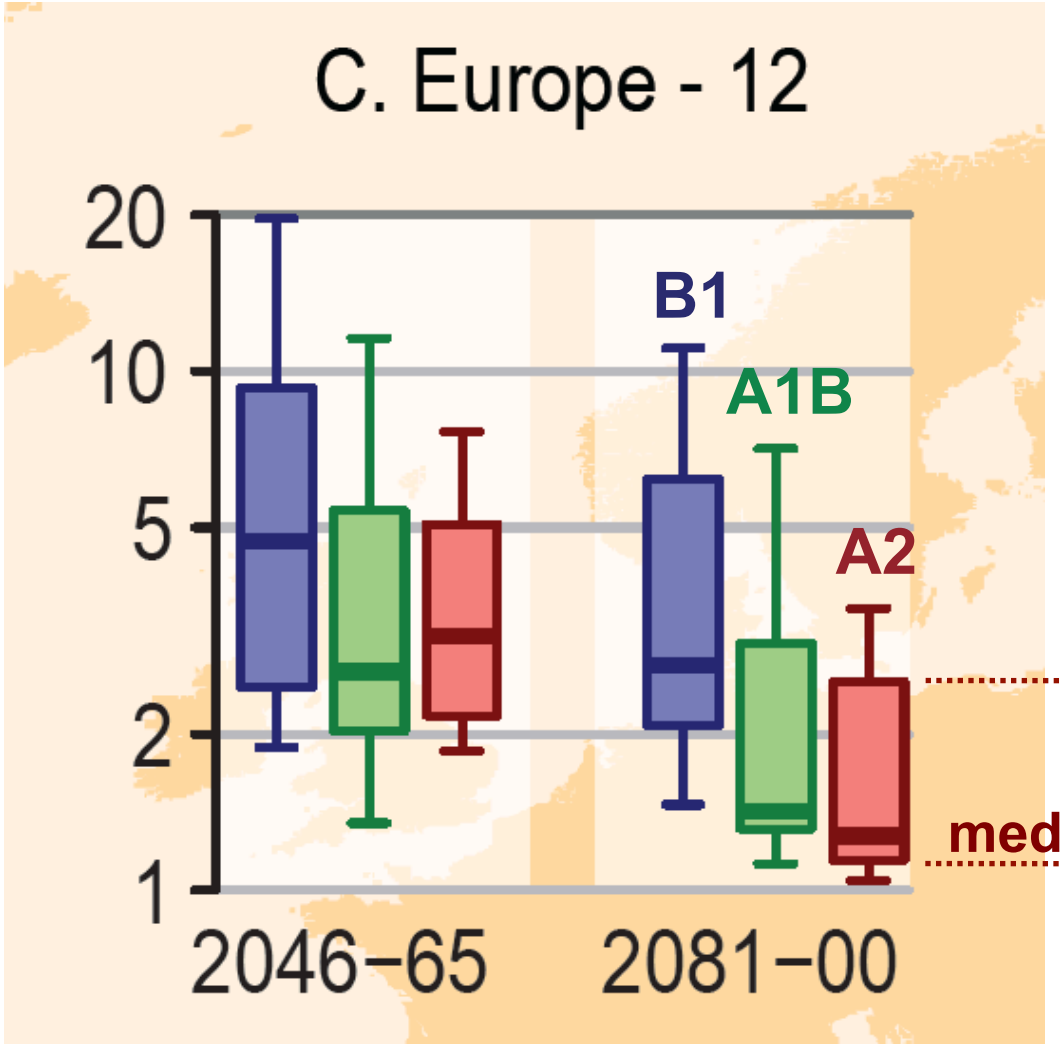
IPCC SREX: Regional projections



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

(based on Kharin et al. 2007, J. Climate)

IPCC SREX: Regional projections

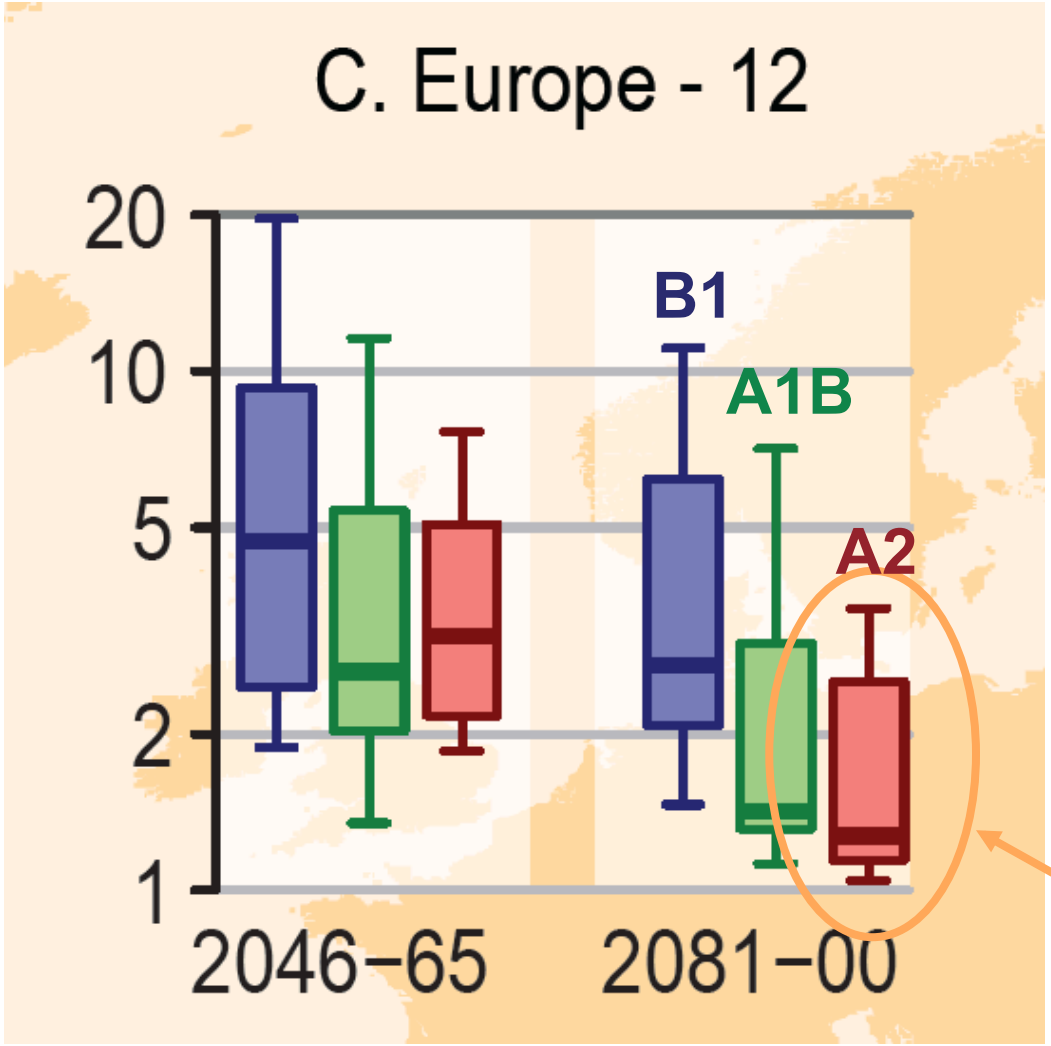


Projected return period (of hot day with late 20th century return period of 20 years)

50% model range

median

IPCC SREX: Regional projections



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

10 times increase in frequency

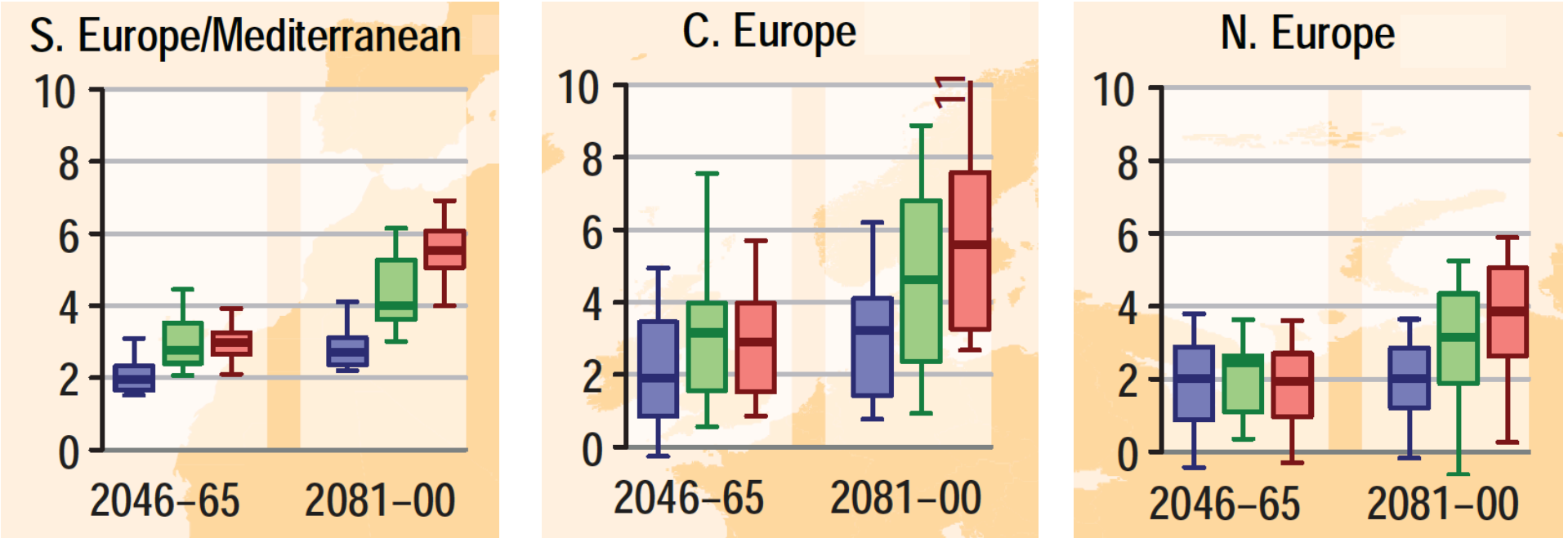
IPCC SREX projections: Temperature & Precipitation ➔ 2100

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

Temperature extremes: Absolute changes

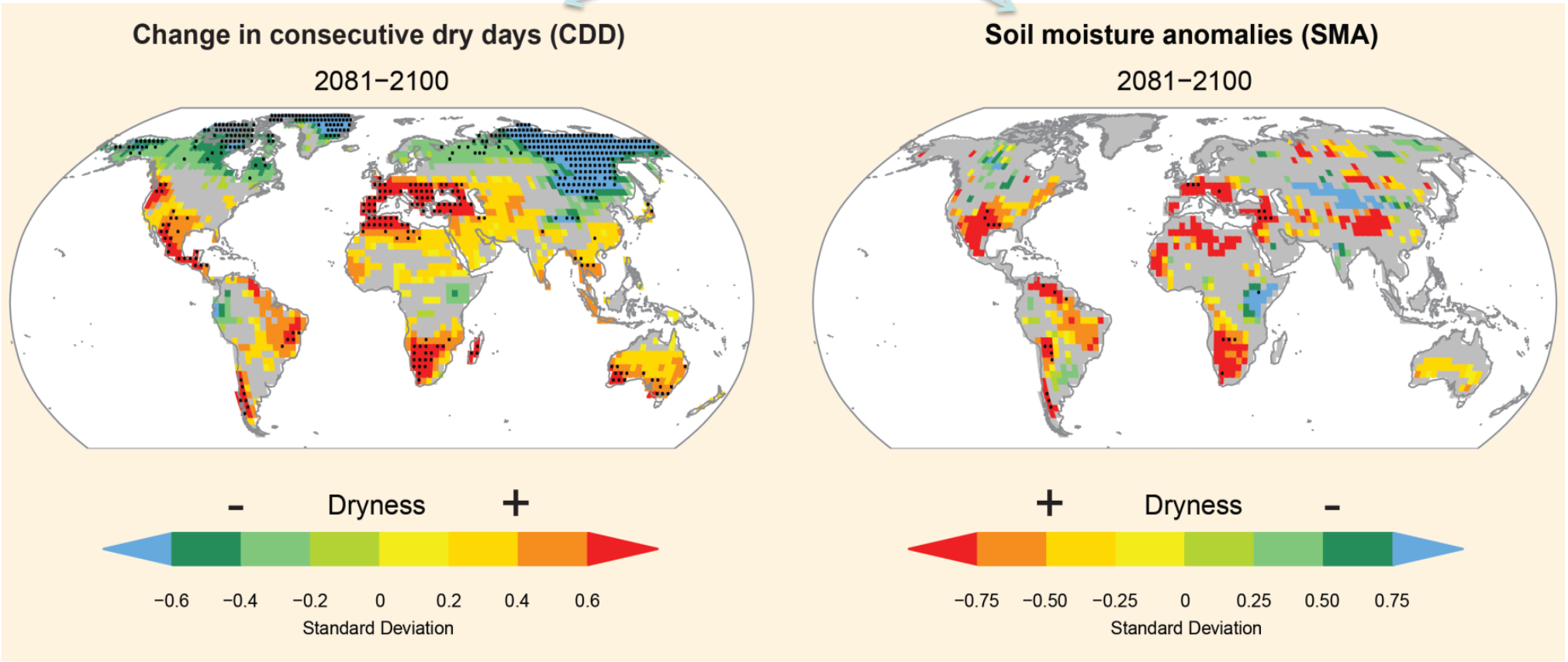
Projected changes in 20-year return values of annual maximum Tmax (vs late 20th century, 1981-2000)



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

SREX Projections: Dryness assessments

Two dryness indices



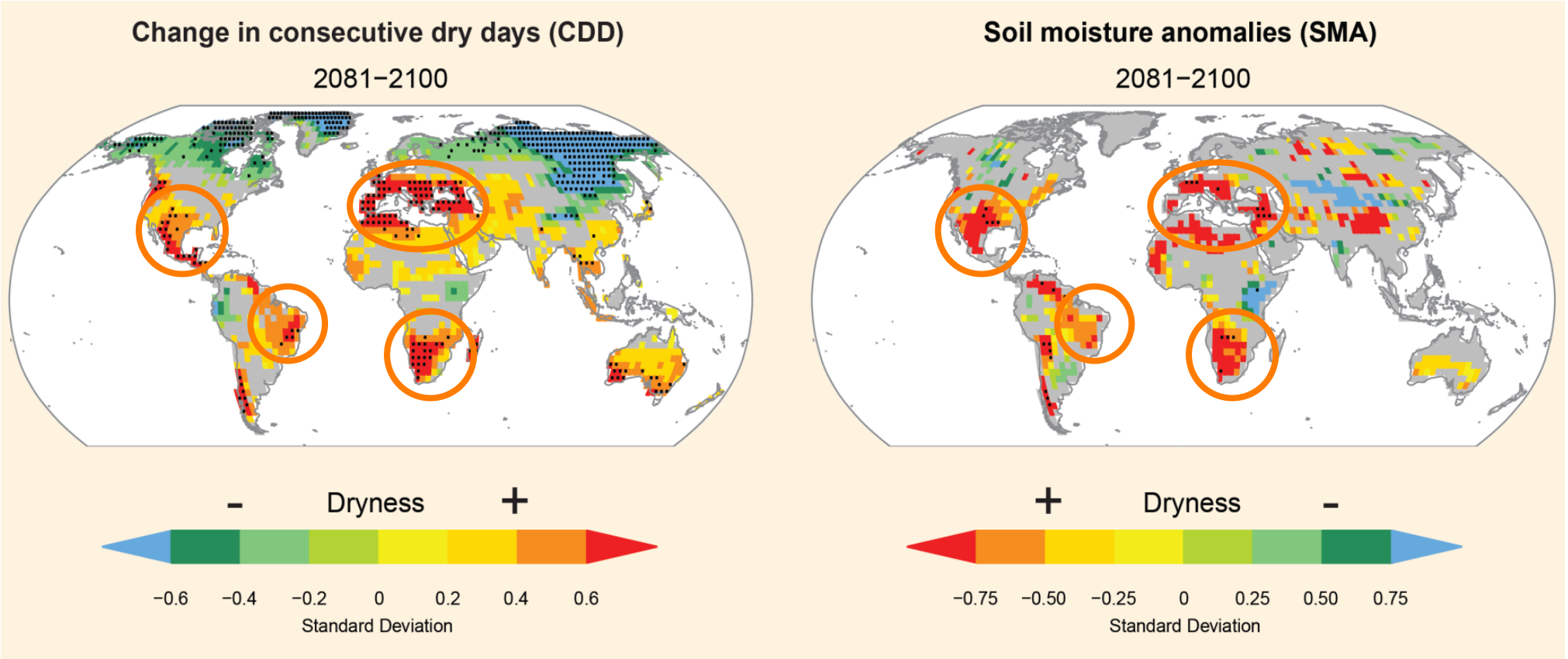
Gray shading: less than 66% model agreement on sign of change

Coloured shading: ≥ 66% model agreement on sign of change

Stippling: ≥ 90% model agreement on sign of change

SREX Projections: Dryness assessments

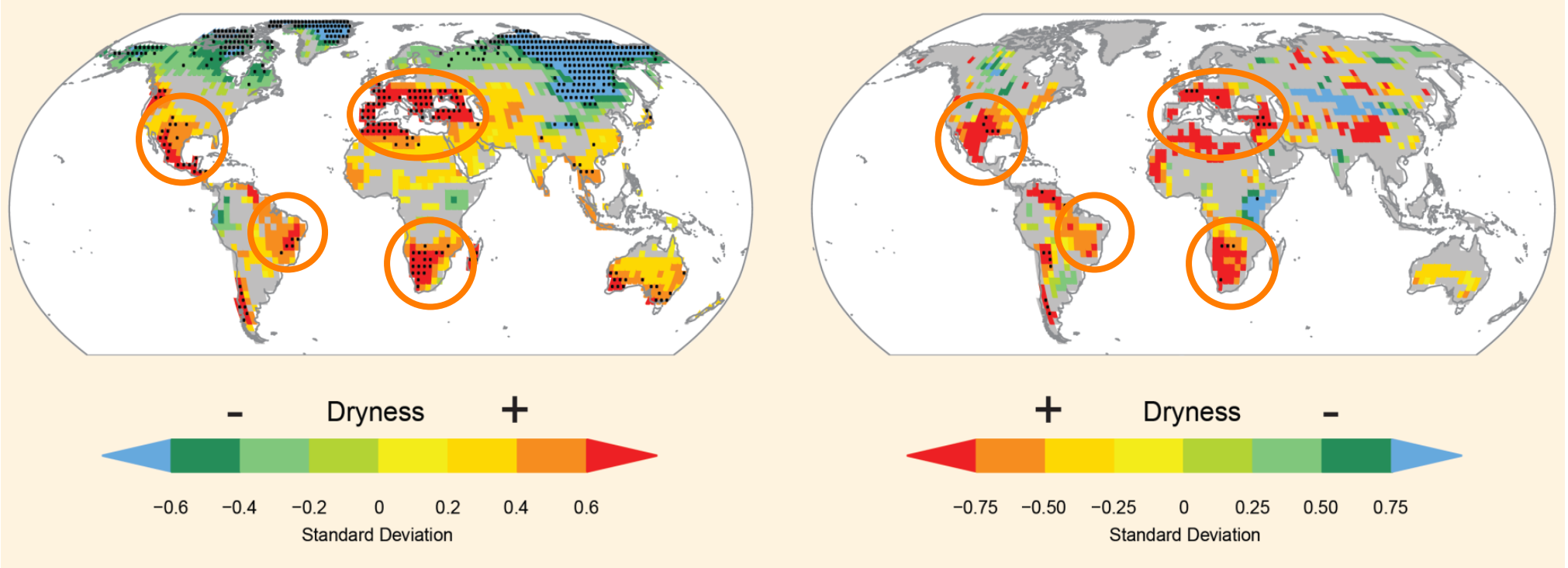
Consistency between indices



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

SREX Projections: Dryness assessments

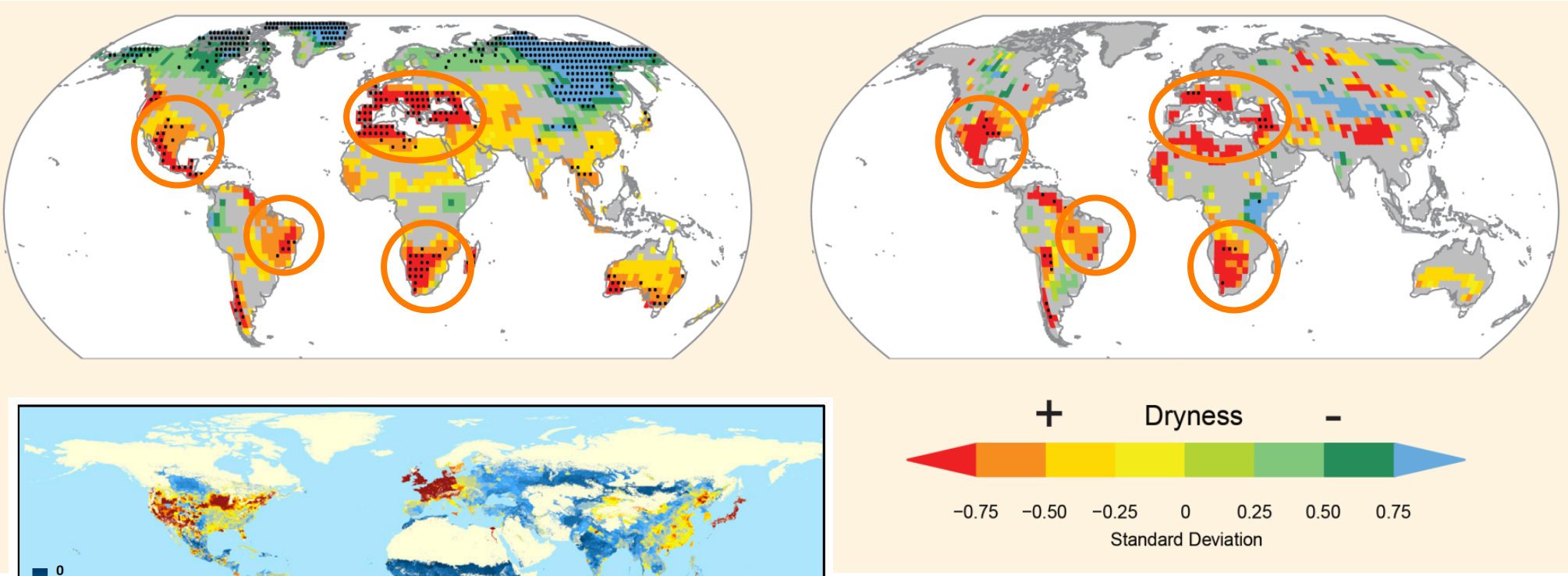
Limited number of regions with agreement, but including important agricultural regions ➔ global implications



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

SREX Projections: Dryness assessments

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

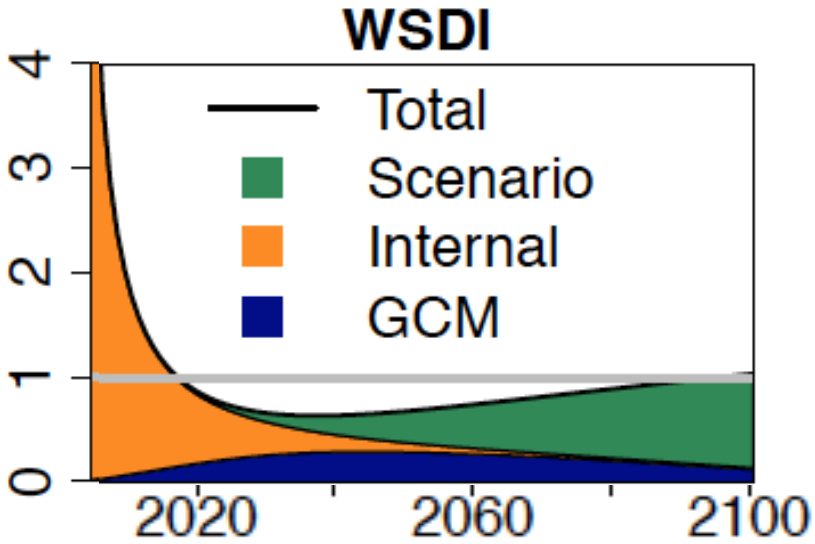


(West et al. 2010, PNAS)

Uncertainties of projections: Droughts vs warm spells

Warm spells (very likely)

Warm spell duration index



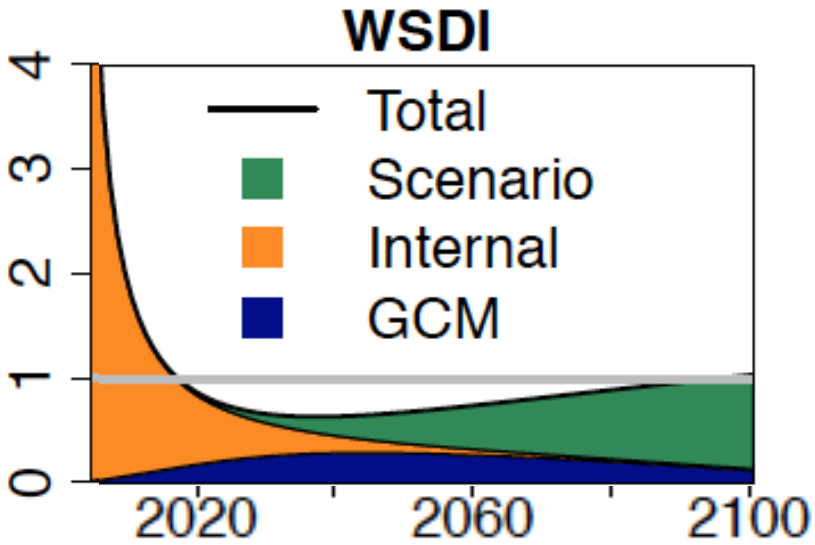
(Orlowsky and Seneviratne 2013, HESS; approach adapted from Hawkins and Sutton 2009, BAMS)

Uncertainties of projections: Droughts vs warm spells

Warm spells (very likely)

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

Warm spell duration index



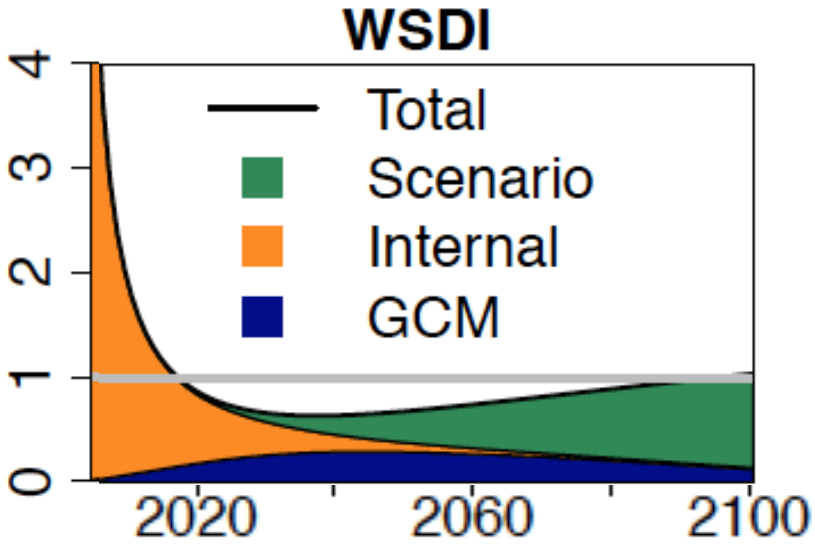
(Orlowsky and Seneviratne 2013, HESS; approach adapted from Hawkins and Sutton 2009, BAMS)

Uncertainties of projections: Droughts vs warm spells

Warm spells (very likely)

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

Warm spell duration index



"Time of detection": $\sigma_{tot}/\Delta<1$

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

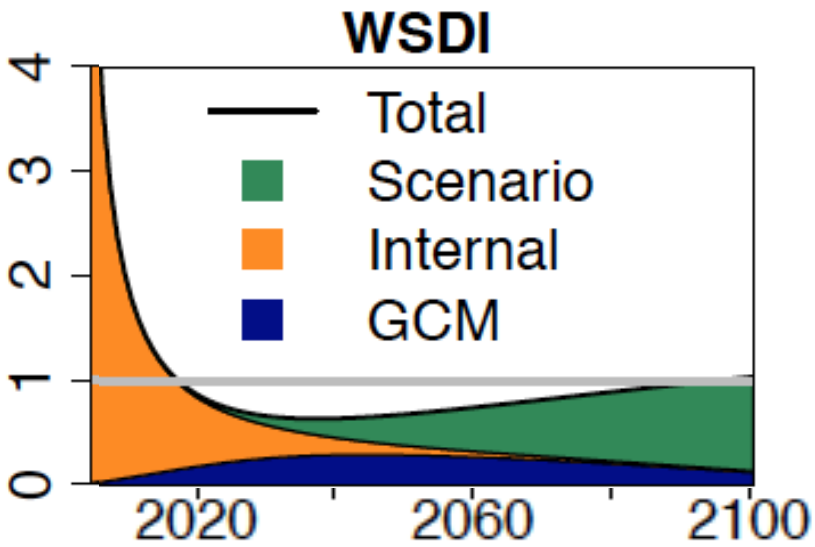
Uncertainties of projections: Droughts vs warm spells

Warm spells (very likely)

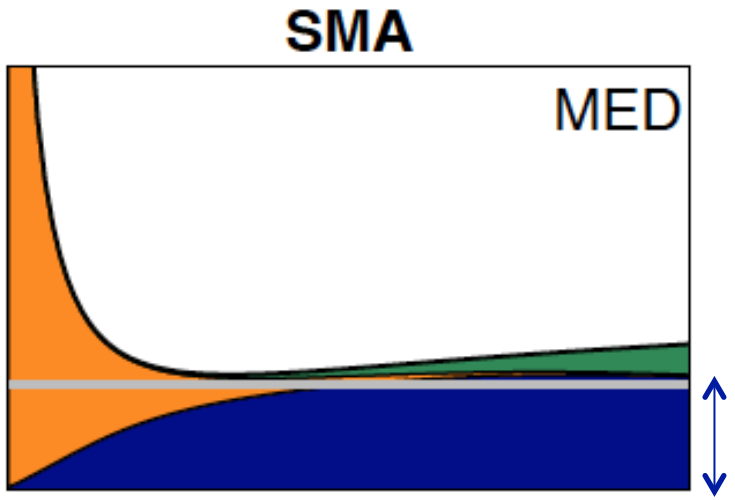
Droughts (medium confidence)

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

Warm spell duration index



Soil moisture anomalies



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

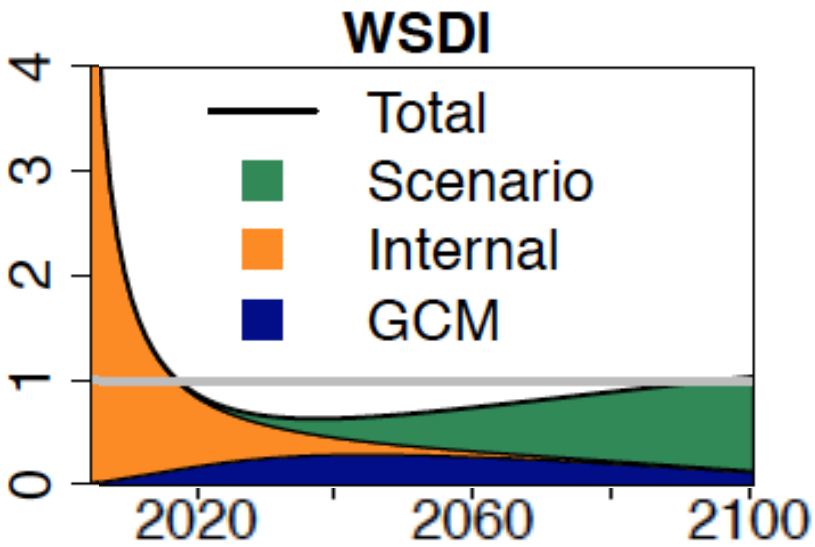
Uncertainties of projections: Droughts vs warm spells

Warm spells (very likely)

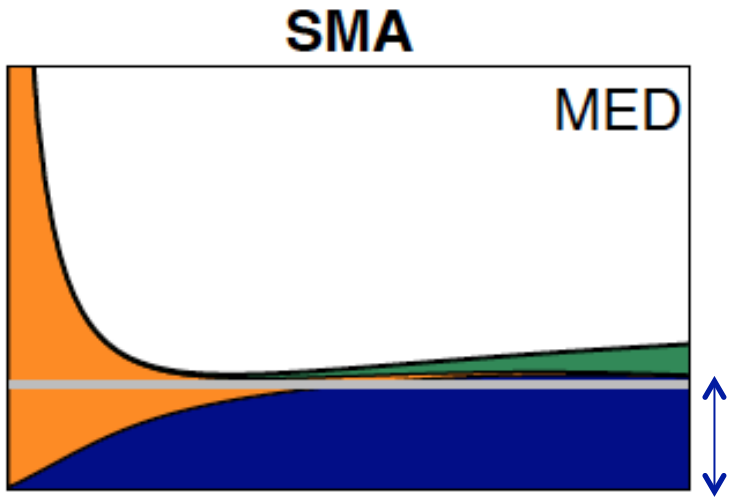
$$\sigma_{tot}/\Delta = (\sigma_{scen} + \sigma_{int} + \sigma_{GCM})/\Delta$$

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

Warm spell duration index



Soil moisture anomalies



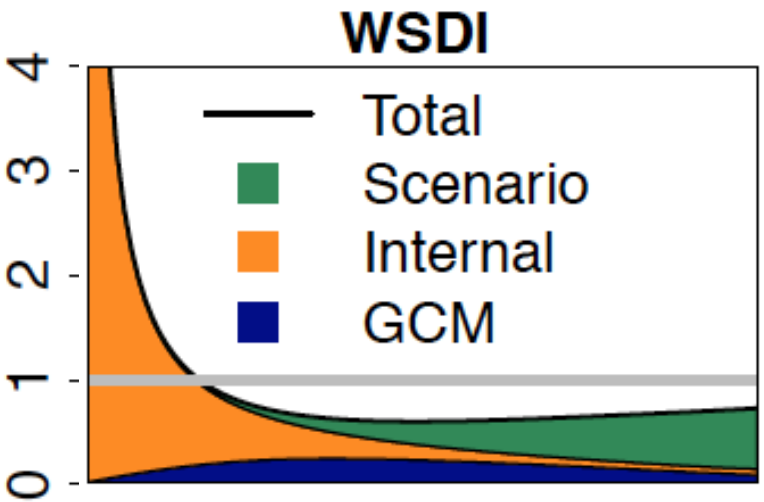
(Orlowsky and Seneviratne 2013, HESS; approach adapted from Hawkins and Sutton 2009, BAMS)

Uncertainties of projections: Droughts vs warm spells

Warm spells (very likely)

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

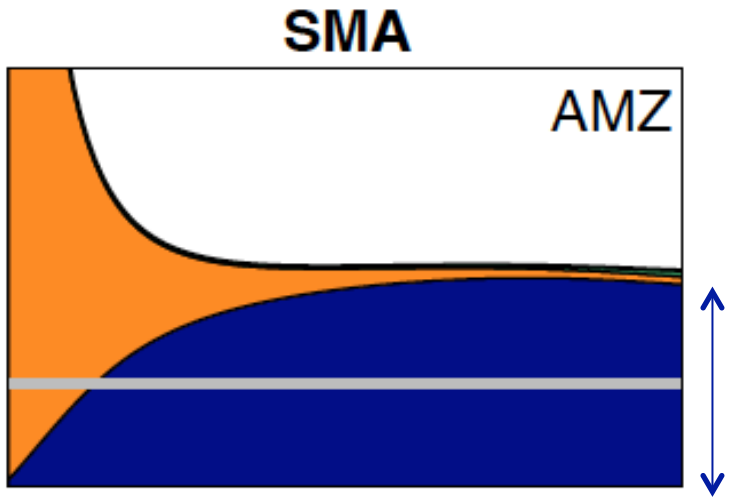
Warm spell duration index



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

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

Soil moisture anomalies



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

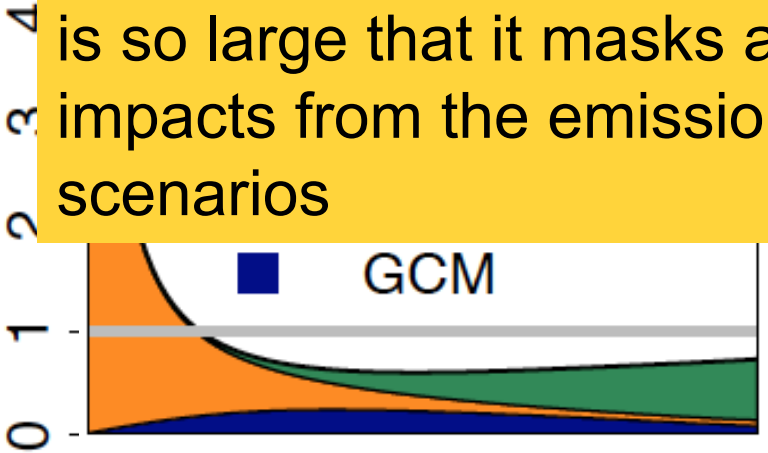
Uncertainties of projections: Droughts vs warm spells

Warm spells (very likely)

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

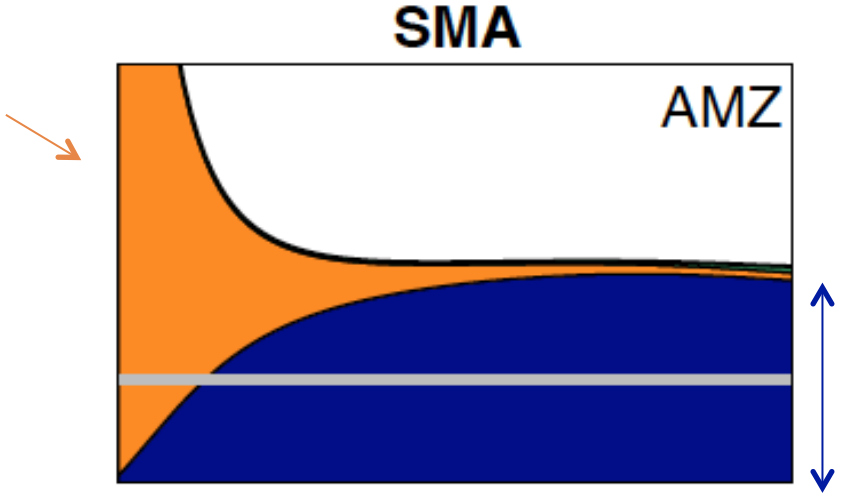
Droughts (medium confidence) – Assessment also based on model performance and intrinsic uncertainties (e.g. lack of data to validate models)

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



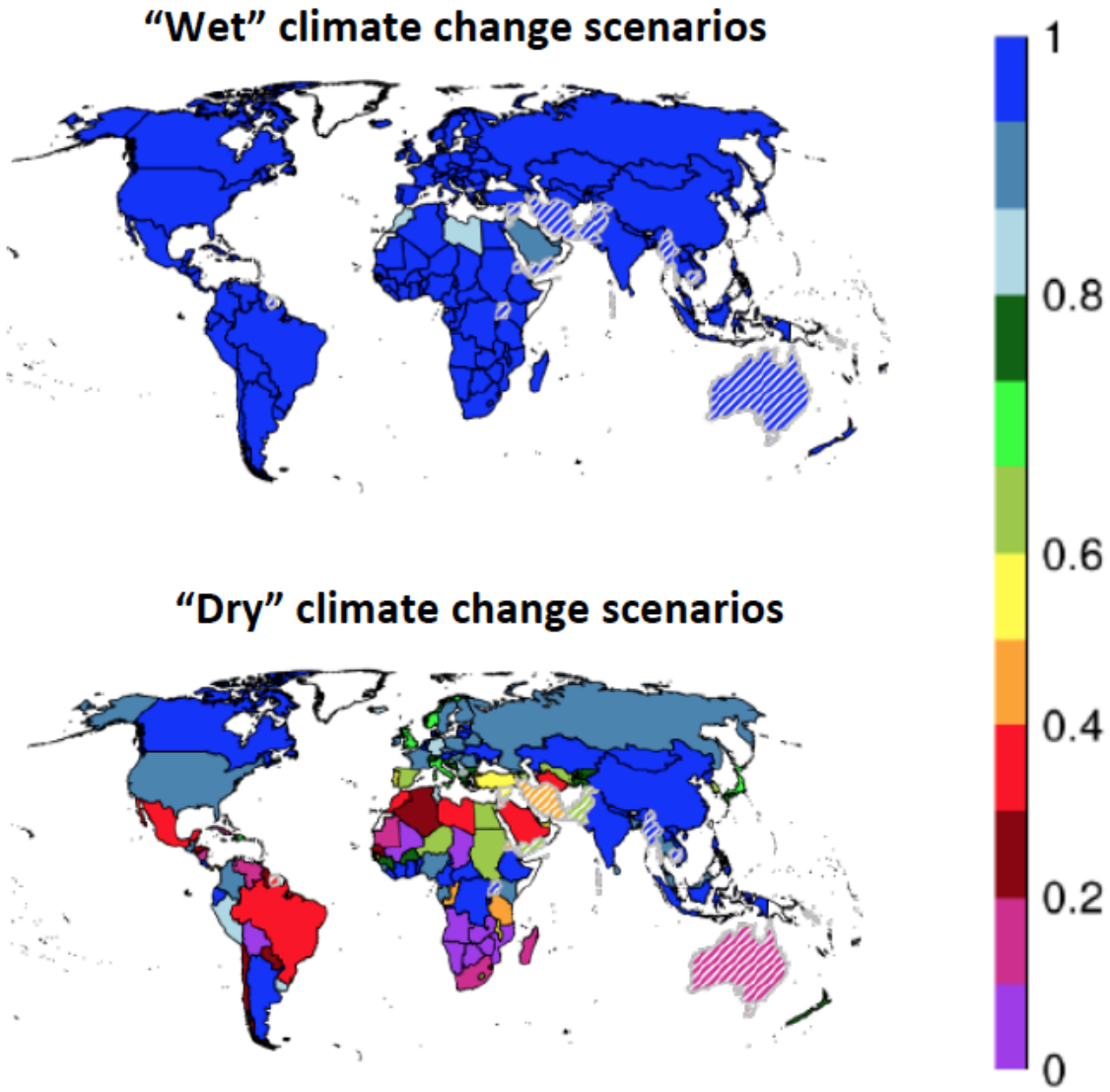
$$\sigma_{tot}/\Delta = (\sigma_{scen} + \sigma_{int} + \sigma_{GCM})/\Delta$$

Soil moisture anomalies



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

Impact of uncertainties for adaptation



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

(Orlowsky et al. 2014, ERL)

Outline

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

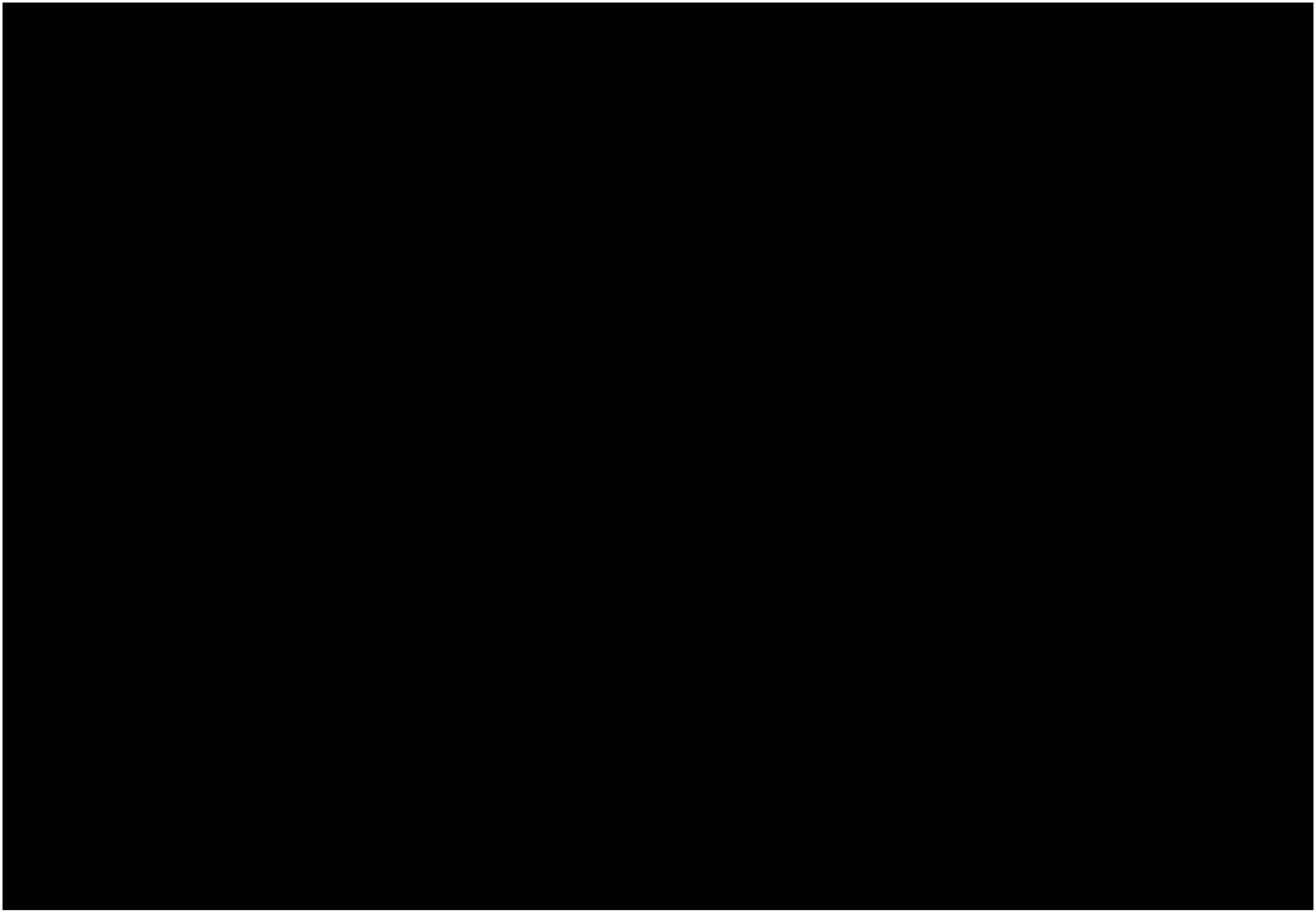
Conclusions

Conclusions

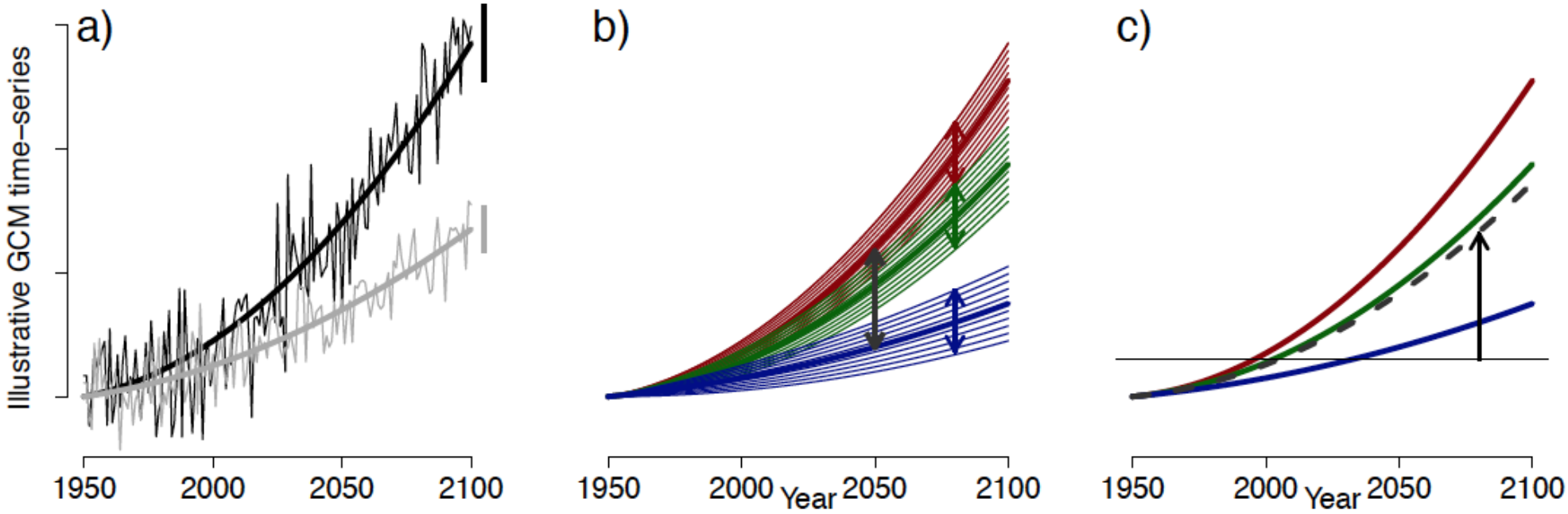
- Substantial changes in several extremes (mostly temperature extremes, heavy precipitation events) both in historical period and in projected scenarios

- 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

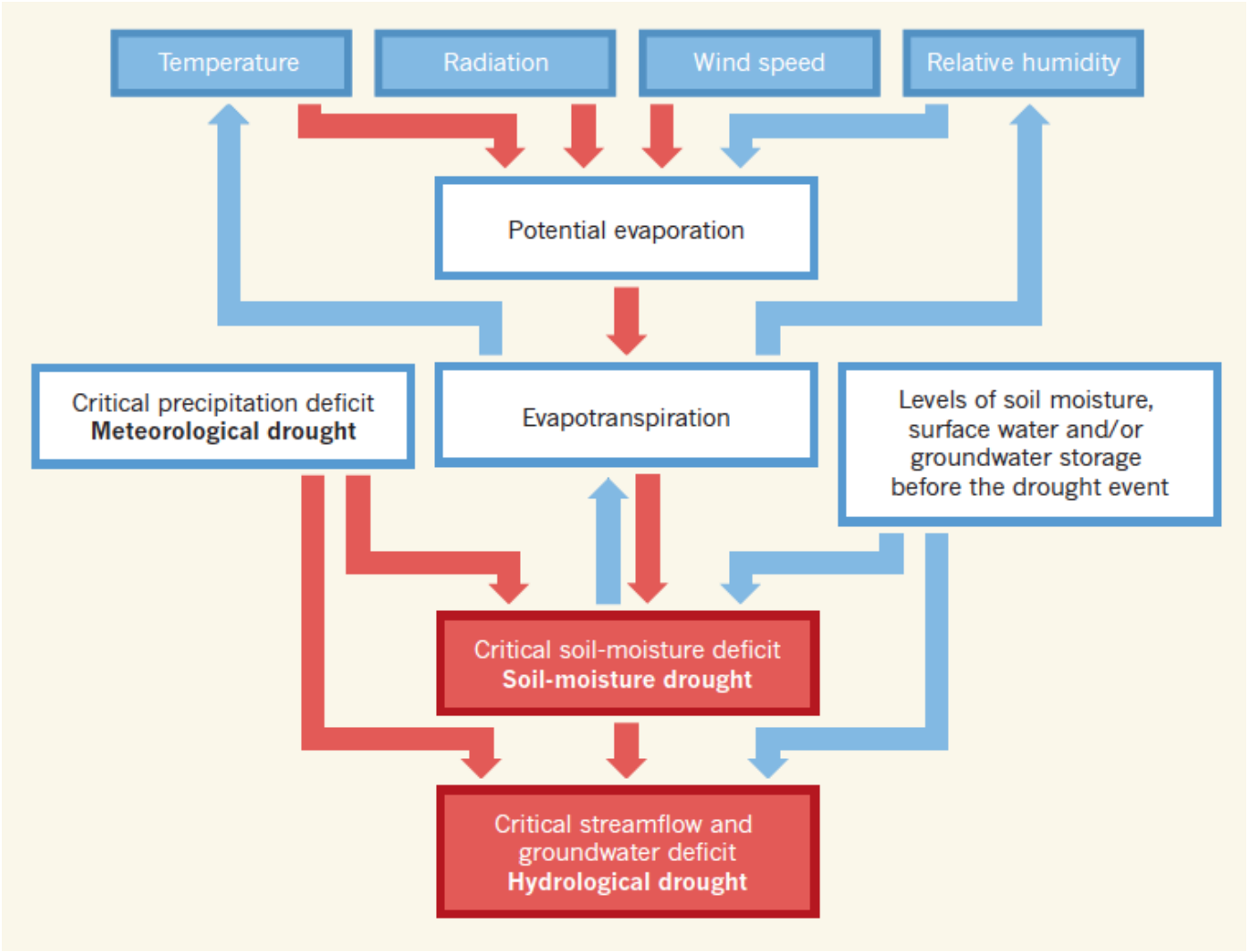


Computation of uncertainty



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

Drivers of drought



(Seneviratne 2014, Nature News and Views)