ETH
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Land water and energy budgets and their impacts on extremes

Sonia I. Seneviratne

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

ECMWF Seminar: Physical Processes
3 September 2015

Outline

Introduction

Global vs land climate (temperature, droughts)

Soil moisture-temperature interactions and extremes, relevance to predictability

Land albedo-climate interactions

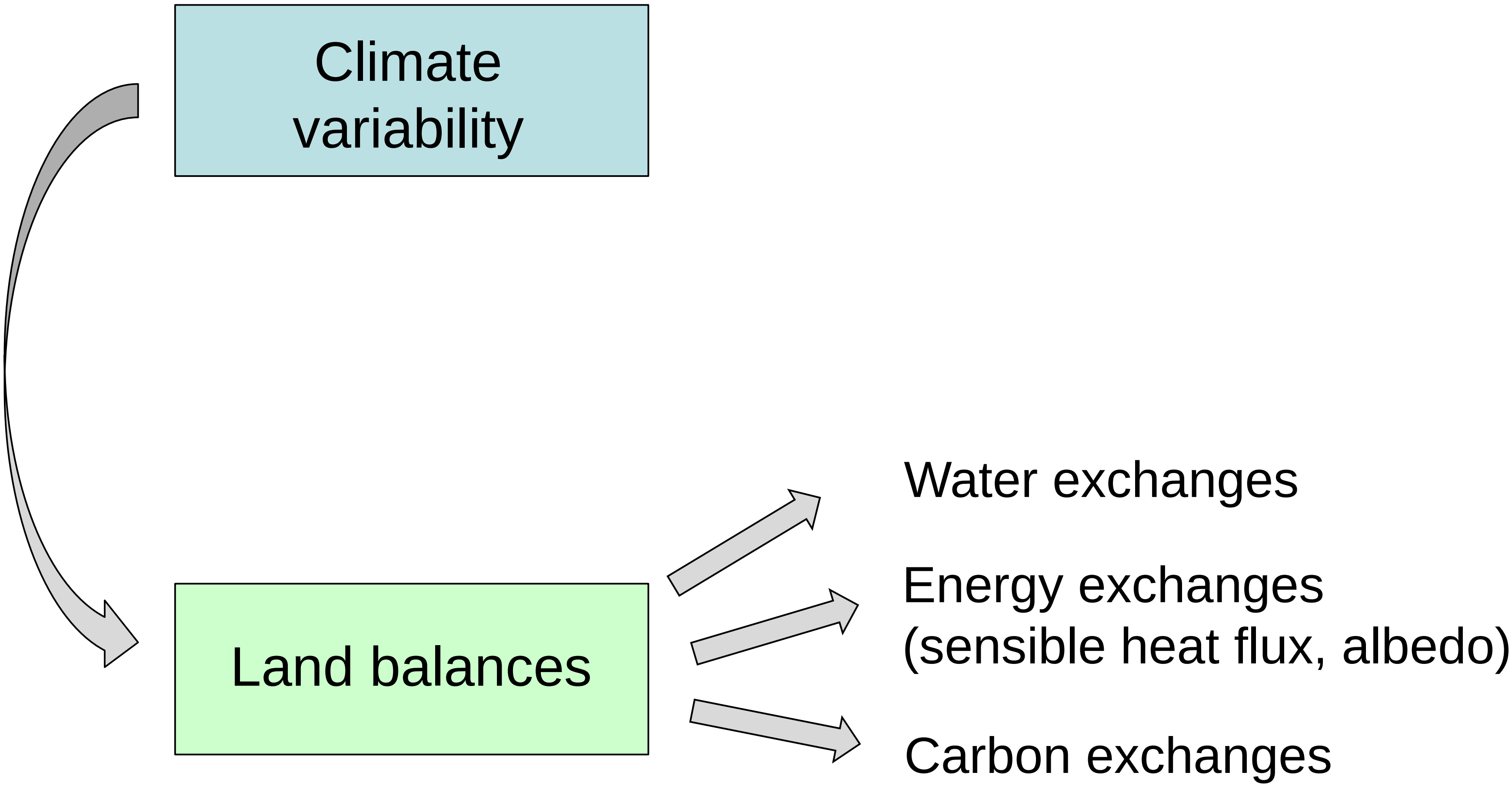
Conclusions

Introduction

Climate variability

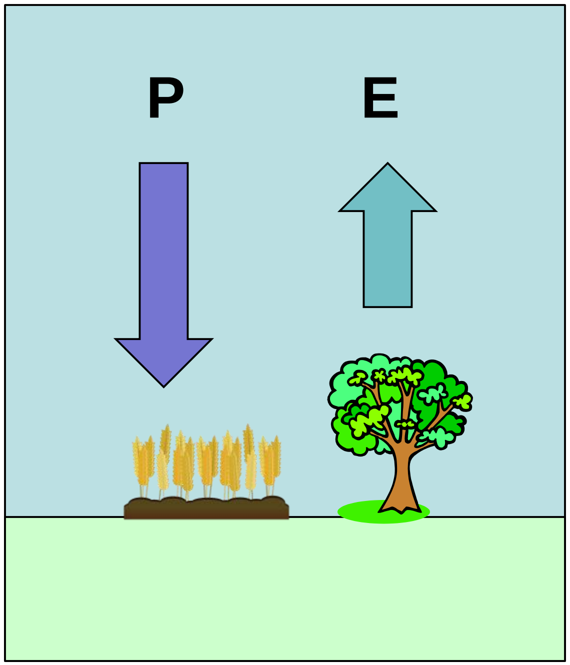
Land balances

Introduction



Land water and energy balances

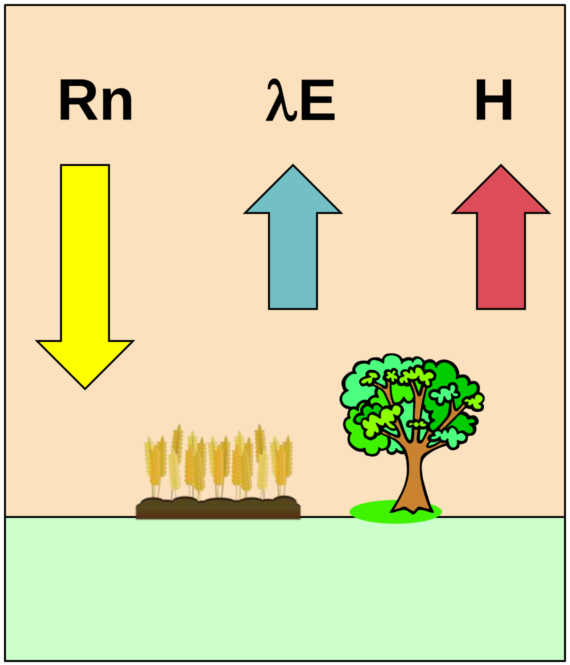
Water



E=60%P

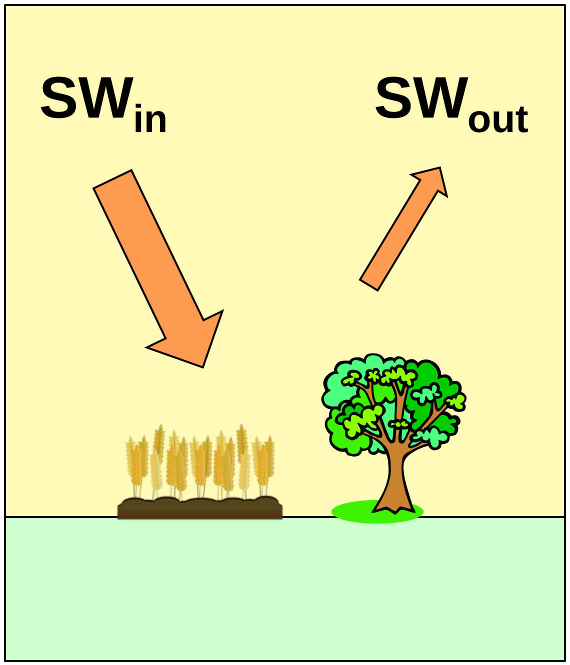
Energy

Evaporative cooling



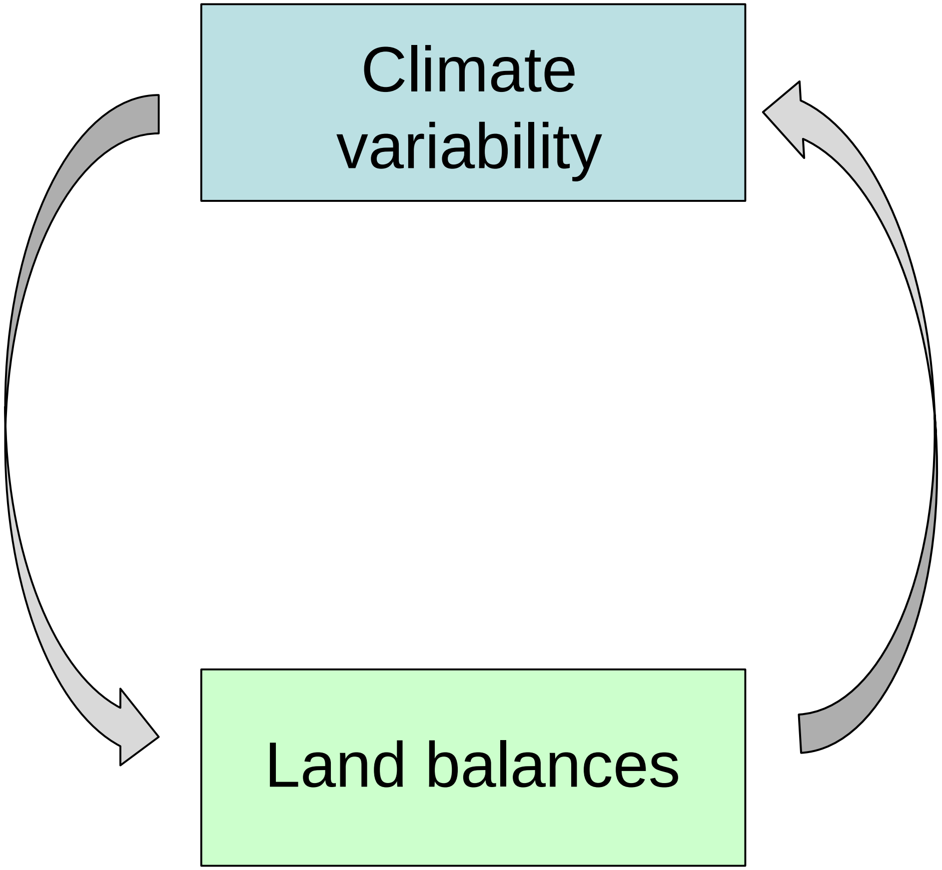
λE=50-60%Rn

Radiative budget



Variations of α: 0.1-0.2

Introduction

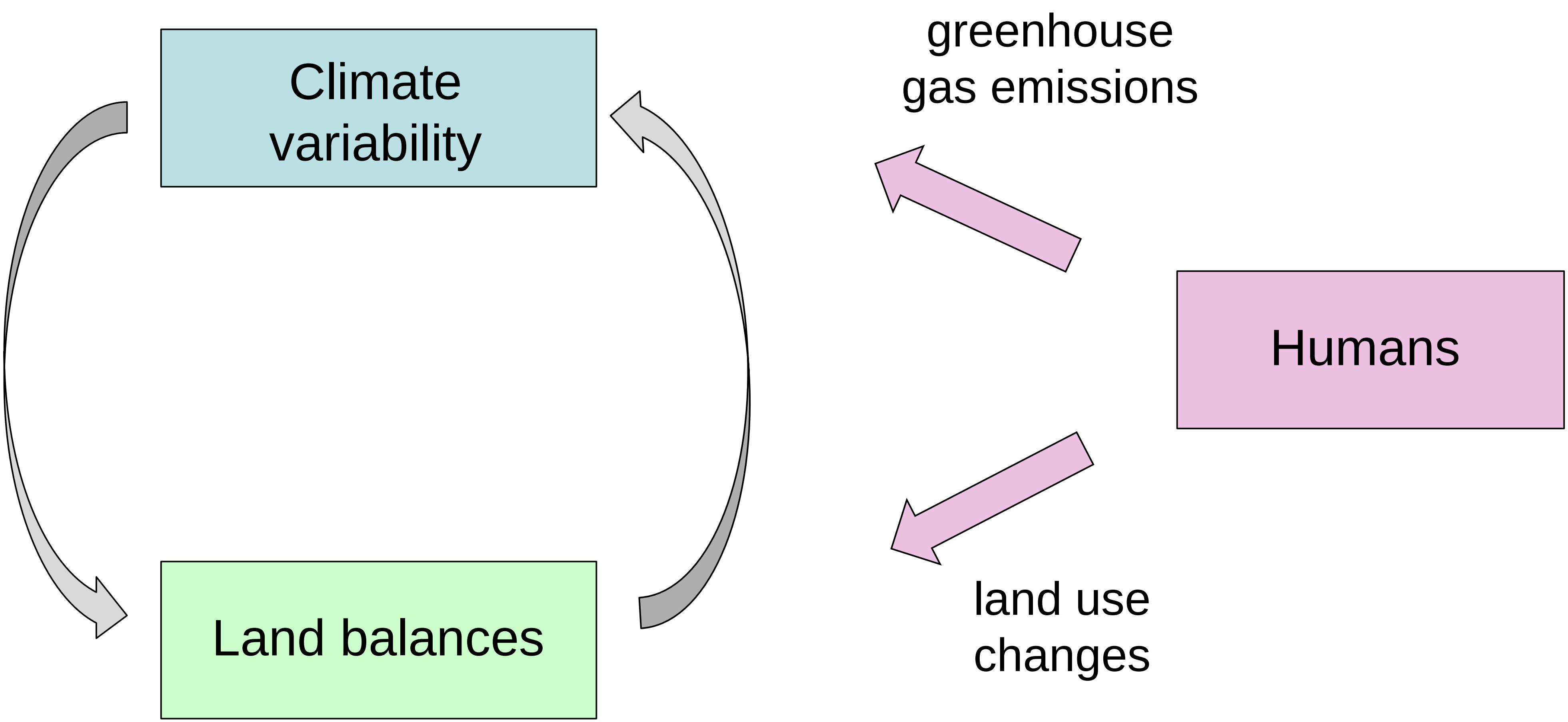


Introduction

Introduction

Chicken or Egg?

Introduction



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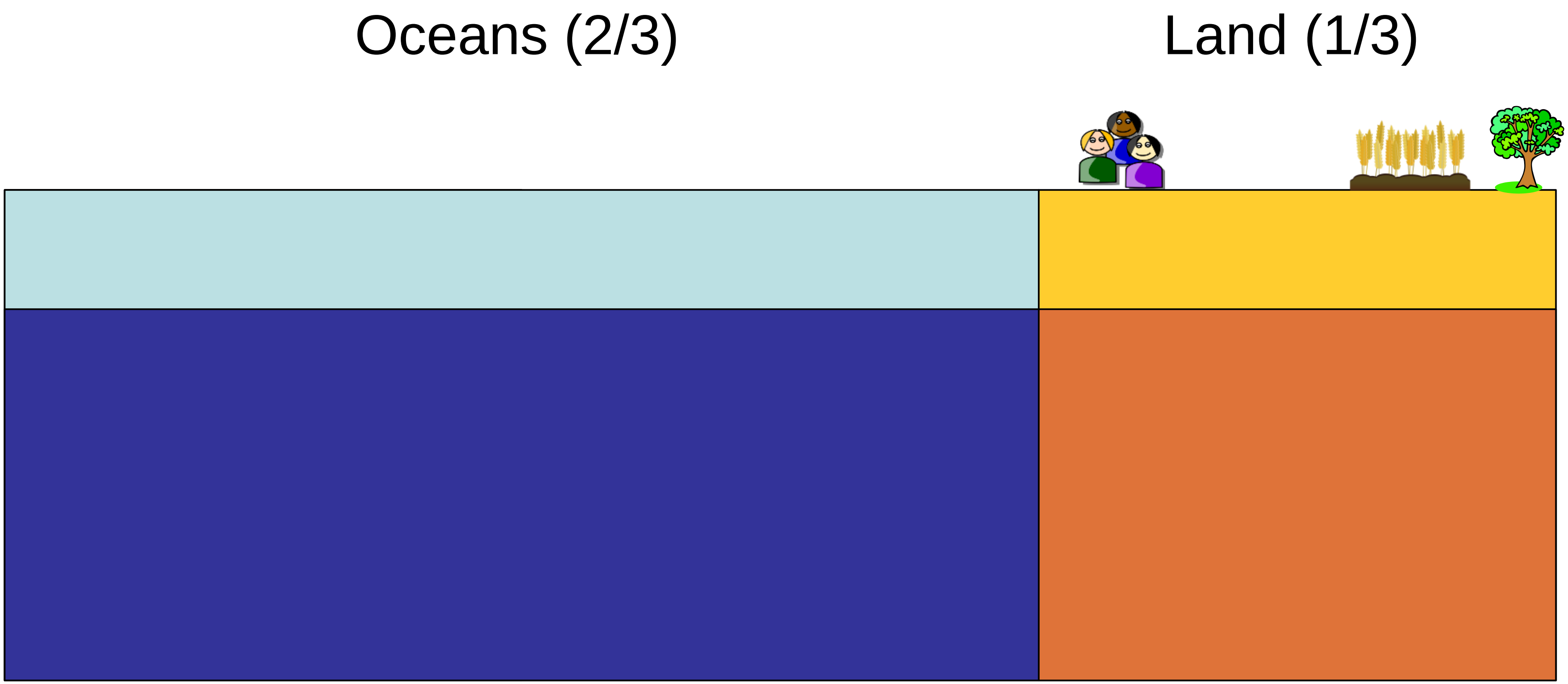
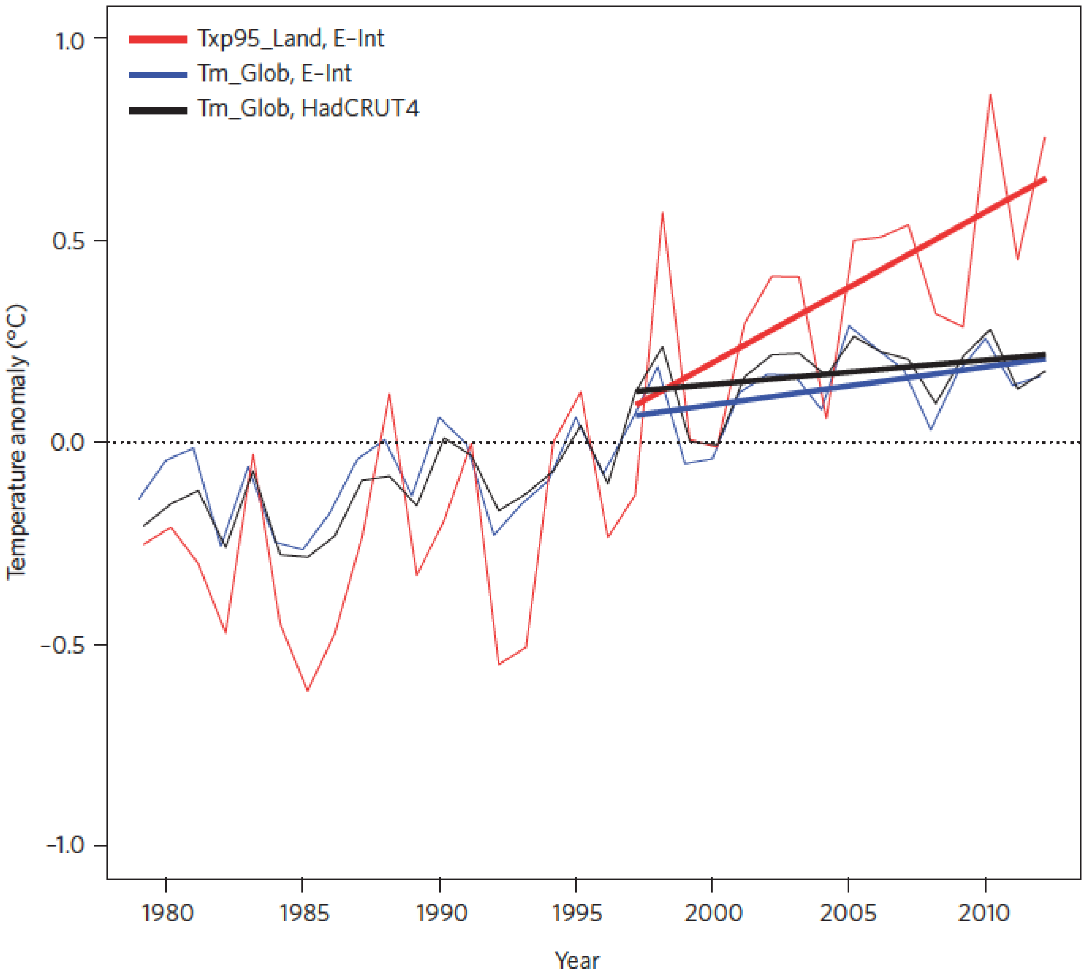
Land-climate dynamics



Mean global climate properties are often discussed: But they are strongly affected by the ocean response and may not be relevant to understand land climate (!)

Trends in land temperature extremes in "hiatus" period

Temperature trends (ERA-interim, HadCRUT4)



COMMENTARY:

No pause in the increase of hot temperature extremes

Sonia I. Seneviratne, Markus G. Donat, Brigitte Mueller and Lisa V. Alexander

Observational data show a continued increase of hot extremes over land during the so-called global warming hiatus. This tendency is greater for the most extreme events and thus more relevant for impacts than changes in global mean temperature.

- Tx95p (ERA-Int)
- Tm_Glob (ERA-Int)
- Tm_Glob (HadCRUT4)

(Seneviratne et al., 2014, Nature Climate Change)

Trends in land temperature extremes in “hiatus” period

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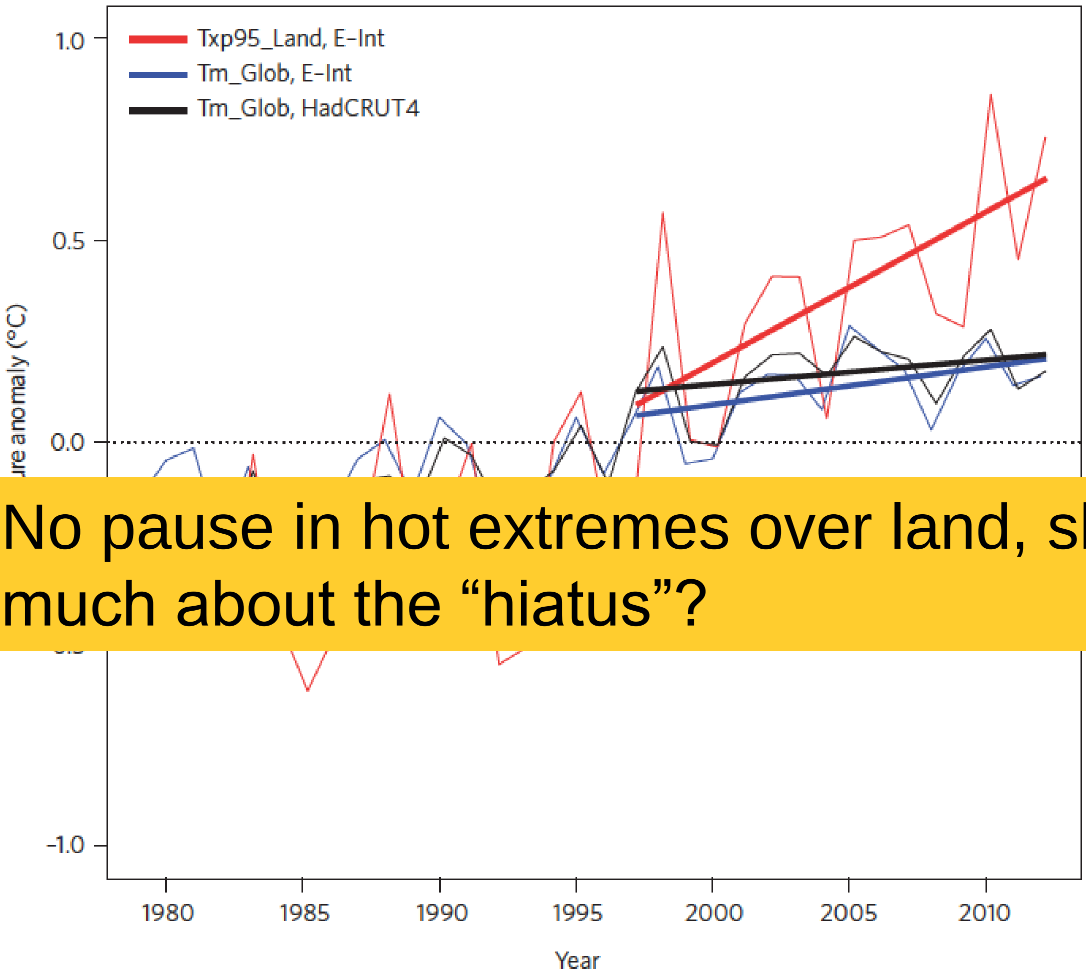

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Tx95p (ERA-Int)
Tm_Glob (ERA-Int)
Tm_Glob (HadCRUT4)

No pause in hot extremes over land, should have we cared that much about the “hiatus”?

(Seneviratne et al., 2014, Nature Climate Change)

Global climate vs land climate

Responses derived based on global climate do not necessarily apply on land: Need for specific consideration of land-climate dynamics

Global climate vs land climate

Responses derived based on global climate do not necessarily apply on land: Need for specific consideration of land-climate dynamics

Other example: The “dry gets drier, wet gets wetter” paradigm

The "dry gets drier, wet gets wetter" paradigm

GLOBAL WARMING

The Greenhouse Is Making the Water-Poor Even Poorer

How bad will global warming get? The ques- face floats under the Argo program. Argo behaving the same way.

After comparing the magnitude and geographical pattern of salinity change in models and in the real world, Durack and colleagues concluded that the water cycle had sped up roughly 4% while the surface warmed 0.5°C. That 8% increase per degree of warming is

And wet places getting wetter can lead to more severe and more frequent flooding. Dry places getting drier would mean longer and more intense droughts.

(Kerr 2012, *Science*)

The "dry gets drier, wet gets wetter" paradigm

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Ocean Salinities Reveal Strong Global Water Cycle Intensification During 1950 to 2000

Paul J. Durack,[1,2,3,4*] Susan E. Wijffels,[1,3] Richard J. Matear[1,3]

several decades from atmospheric observing networks (*12*, *20*).

It has long been noted that the climatological mean sea surface salinity (SSS) spatial pattern is highly correlated with the long-term mean E-P spatial pattern (*21*) (Fig. 1, A and D), reflecting the balance between ocean advection and mixing processes and E-P forcing at the ocean surface (*21*–*23*). Several studies of multidecadal SSS changes reveal a clear pat-

(Durack et al. 2012, *Science*)

The “dry gets drier, wet gets wetter” paradigm

Observations show that ocean basins with P-E > 0 (sinks) have had an increased P-E over 1950-2000, while basins with P-E < 0 (sources) have had a decreased P-E over the same time period

The "dry gets drier, wet gets wetter" paradigm

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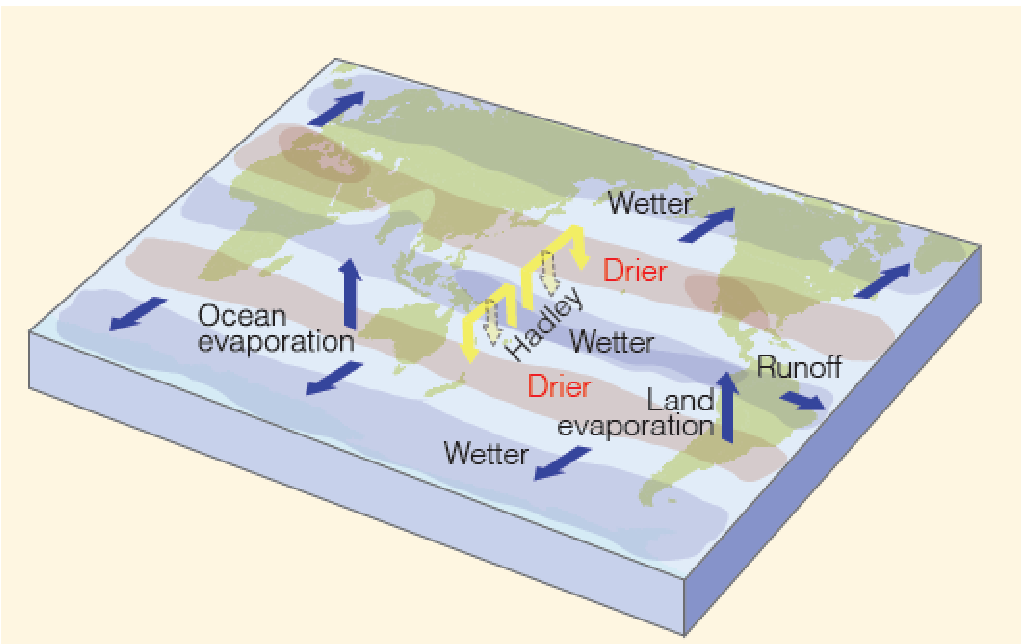
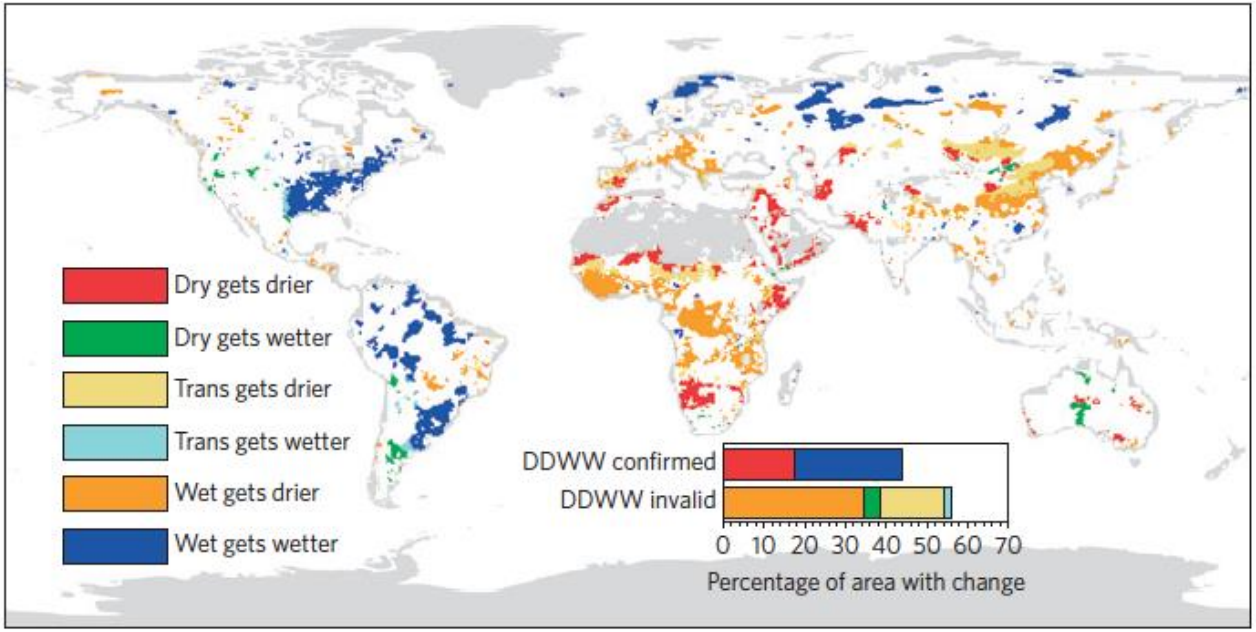
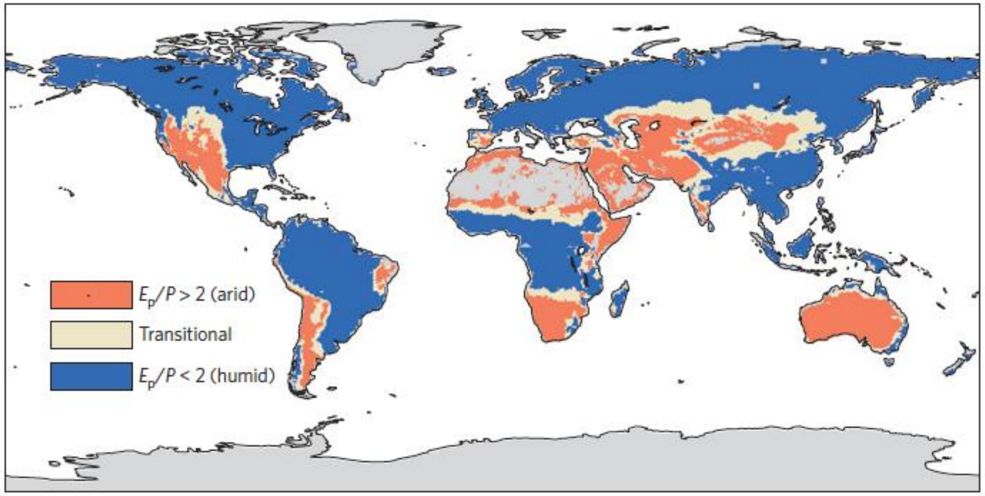
Does this has implications for land climate? The latest IPCC report suggests so…



(IPCC 2013, FAQ 12.2 Fig. 1; Collins et al. 2013)

The "dry gets drier, wet gets wetter" paradigm



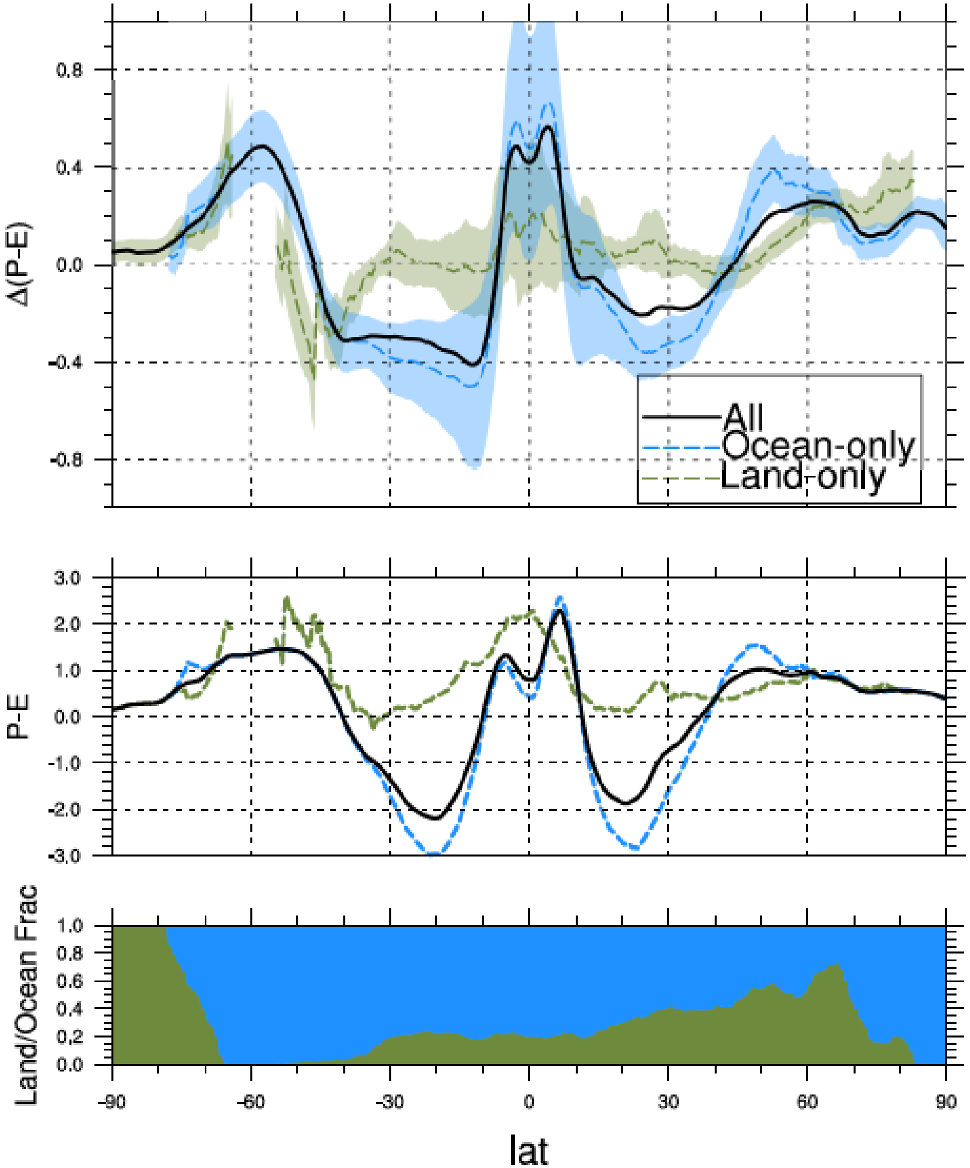


Analysis of observed robust drying trends (from 1948-1968 to 1985-2005):

No support for "dry gets drier, wet gets wetter" paradigm

(Greve et al. 2014, Nature Geoscience)

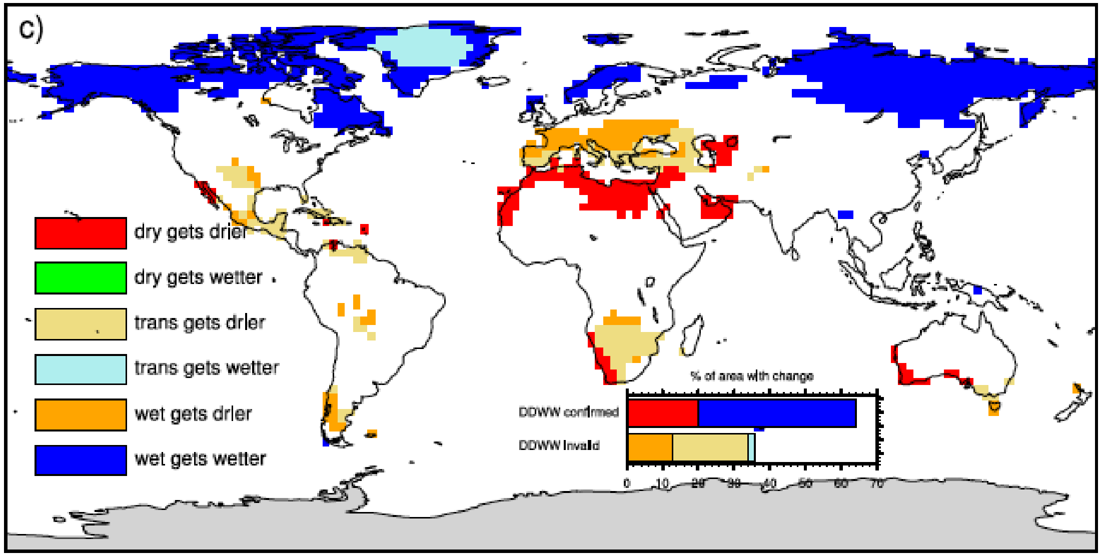
Droughts: Detecting robust trends



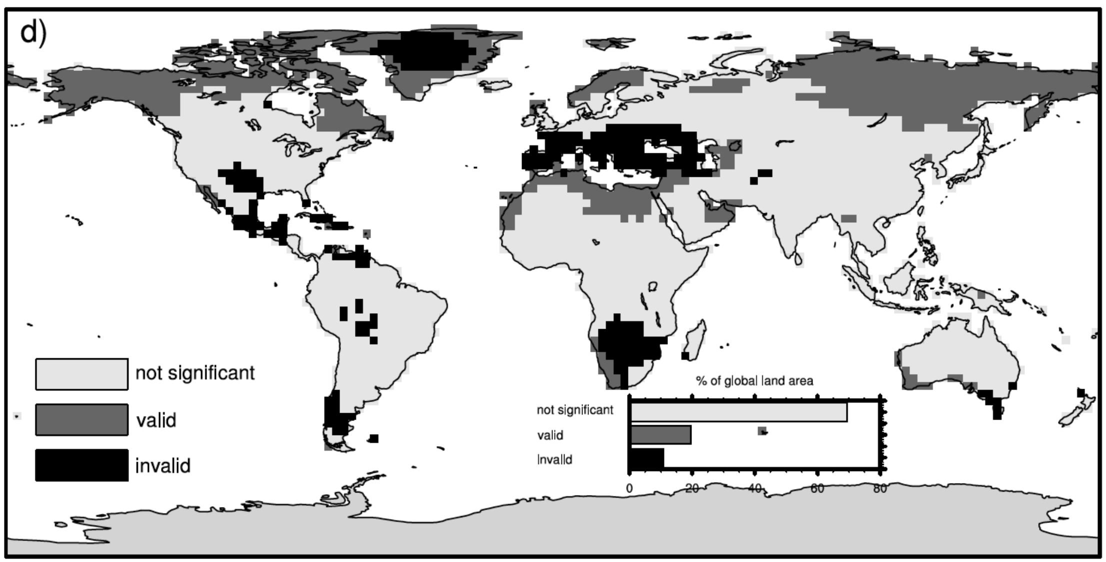
Different response over land compared to global and ocean behaviour: Because of soil moisture limitation!

(Greve et al. 2014, Nature Geoscience; Greve and Seneviratne 2015, GRL)

The “dry gets drier, wet gets wetter” paradigm

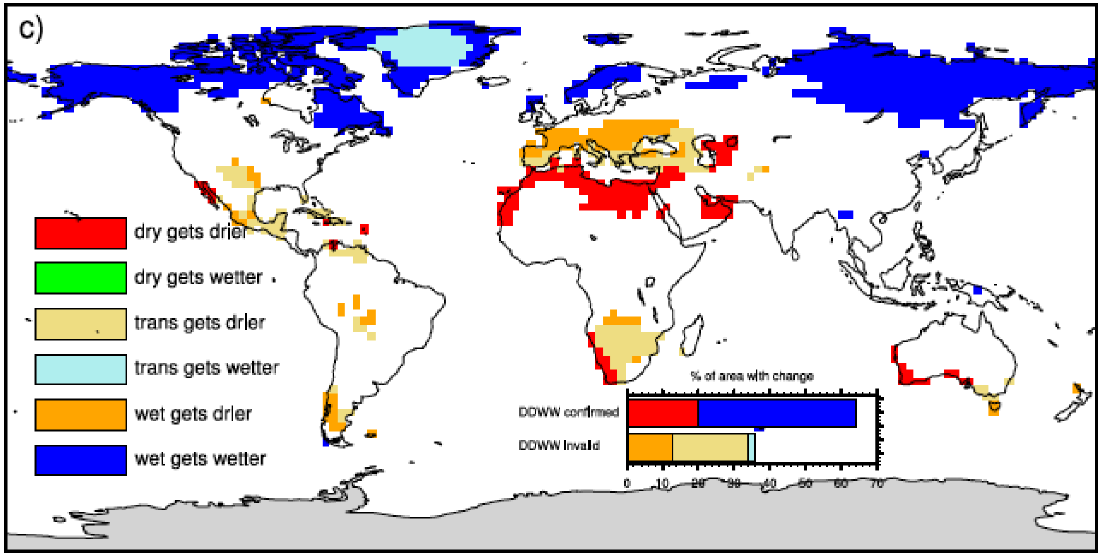


For projections, the DDWW paradigm applies better, but the dominant signal on land is the lack of significant changes in water availability in most regions



(Greve and Seneviratne 2015, GRL)

The “dry gets drier, wet gets wetter” paradigm



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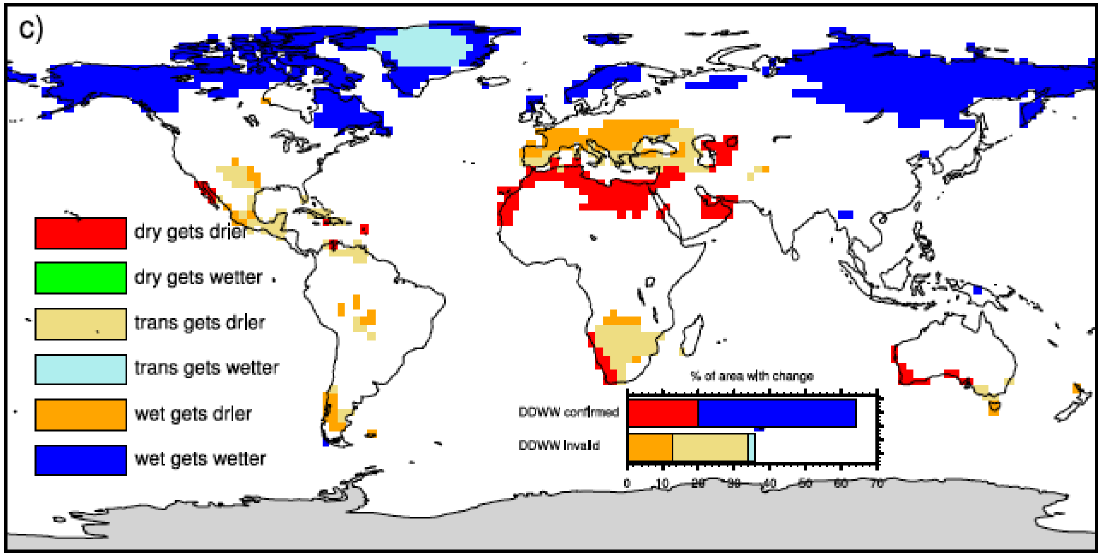
Robust evidence (historical and projected changes):

•The “dry gets drier, wet gets wetter” paradigm *does not apply to historical changes* in annual water balance over land

The "dry gets drier, wet gets wetter" paradigm



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Robust evidence (historical and projected changes):

•The "dry gets drier, wet gets wetter" paradigm *does not apply to historical changes* in annual water balance over land

•*Large uncertainties in drought projections* in most land regions, but:

- Projected poleward expansion of *some* subtropical regions (including important agricultural regions)
- Projected wetting in wet high-latitude regions (but *no clear signal in wet tropics*)

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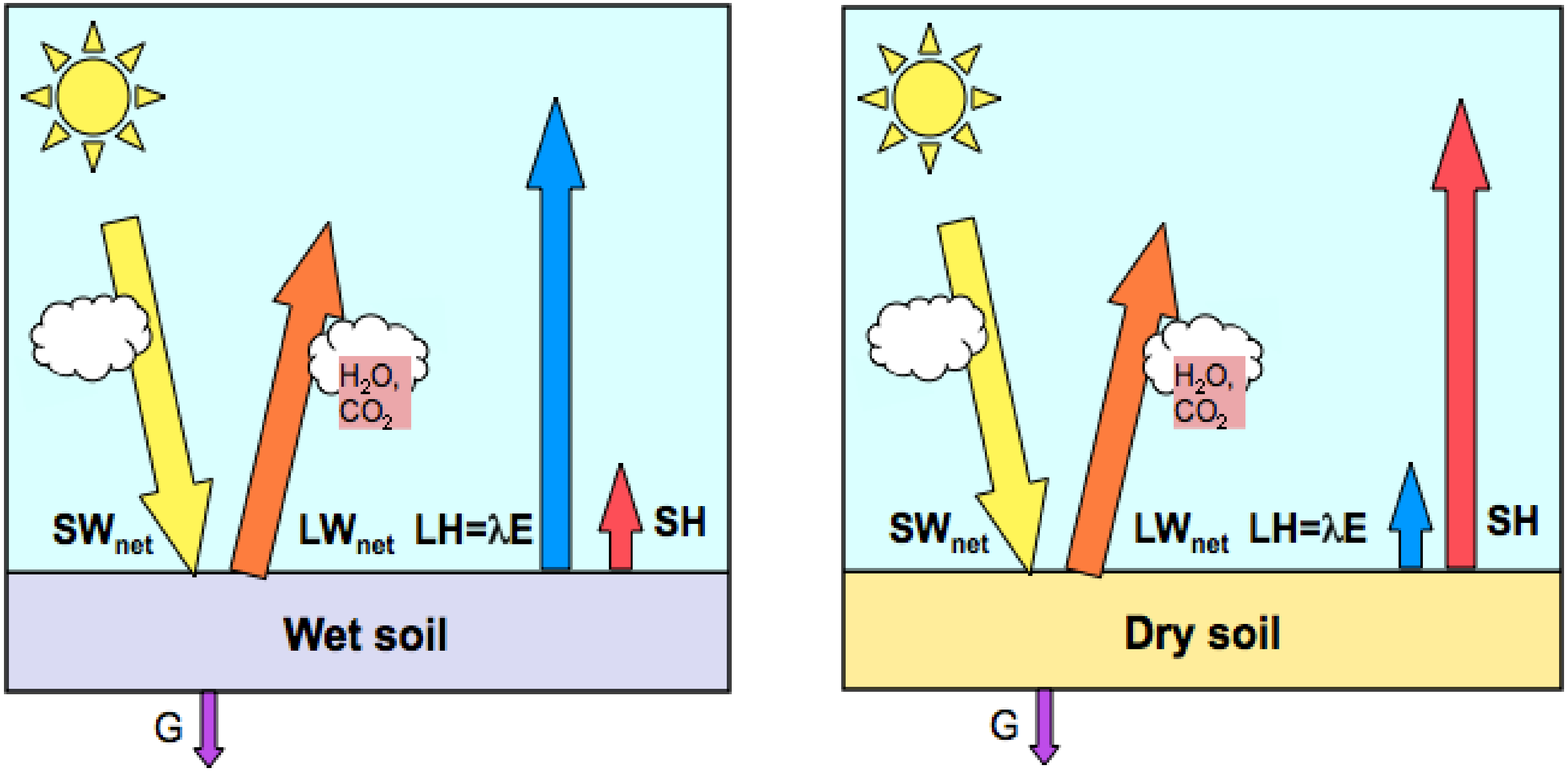
Evaporation & temperature

Our body uses evaporation for cooling

➔ **Similar mechanism maintains cool temperatures on land surfaces!**

Soil moisture – temperature feedbacks



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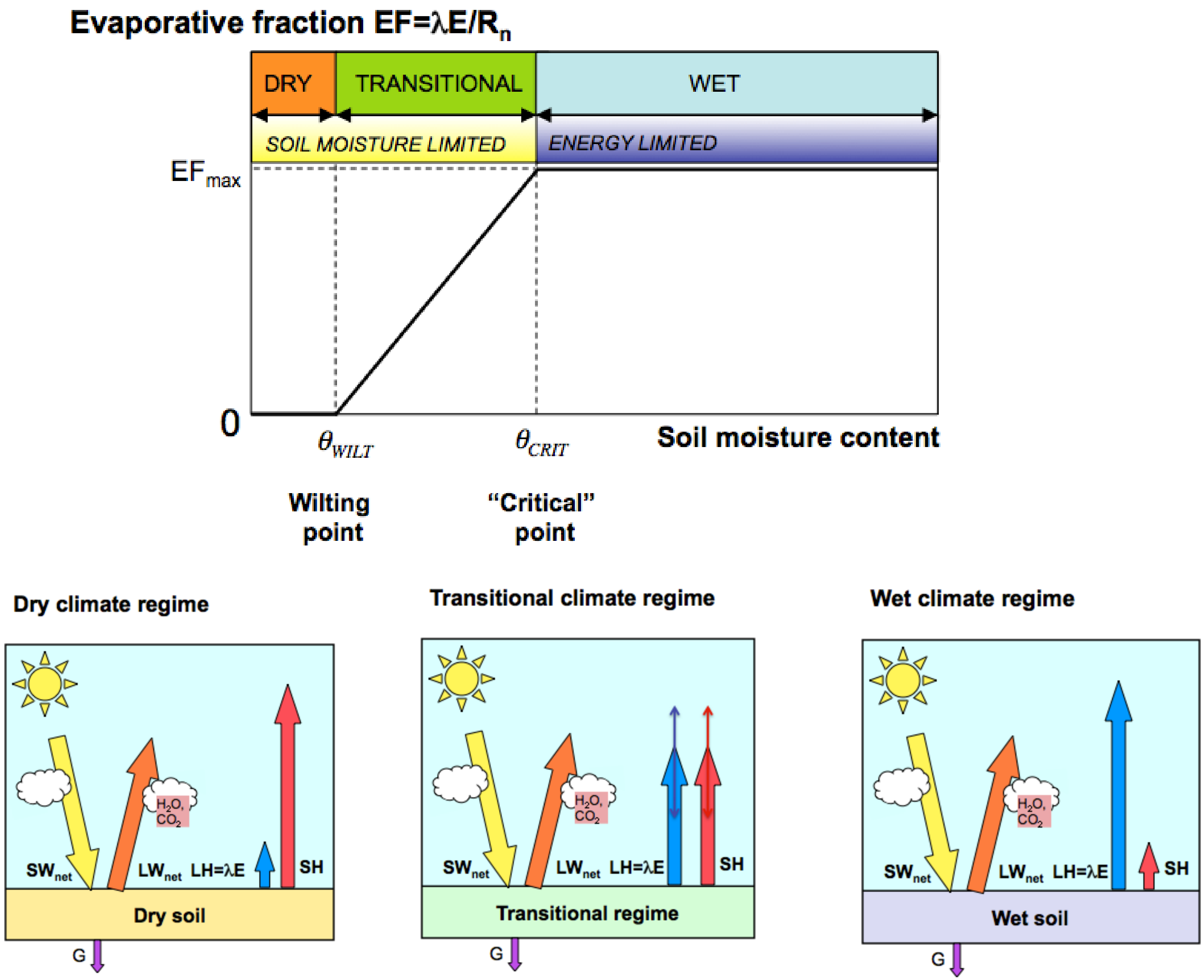

(Seneviratne et al. 2010, Earth Science Reviews)

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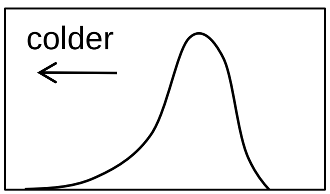

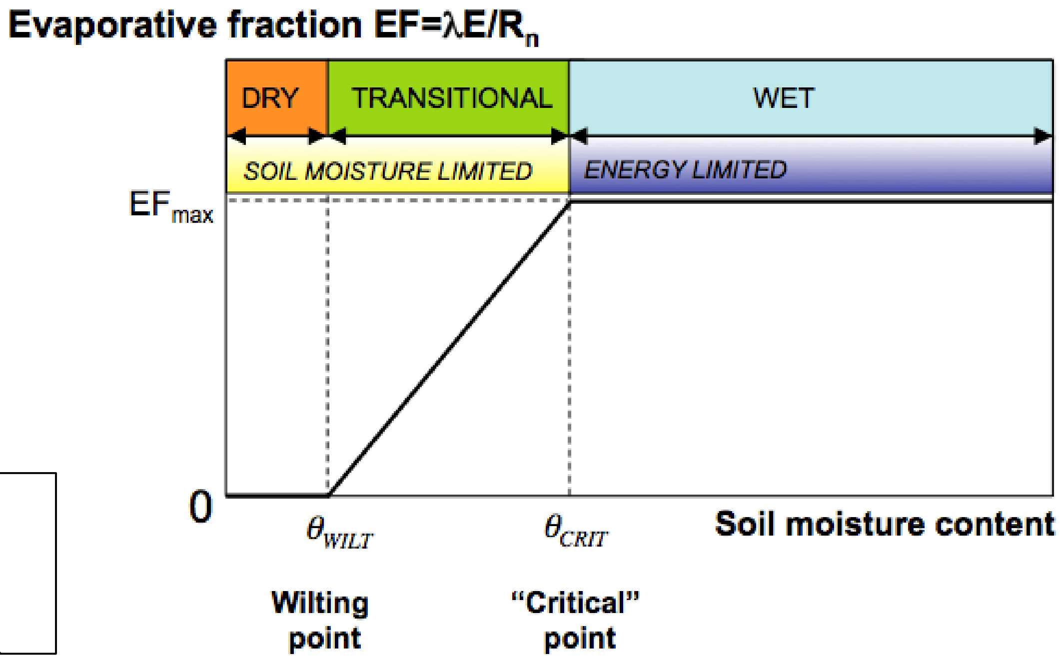

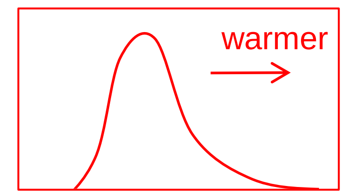

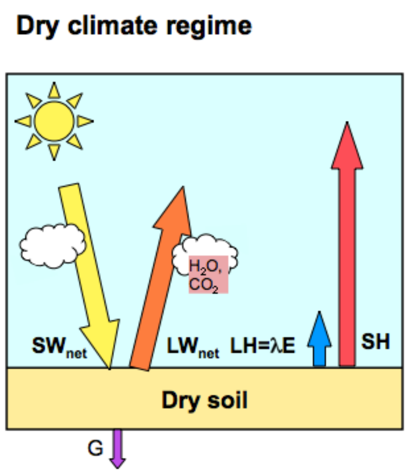

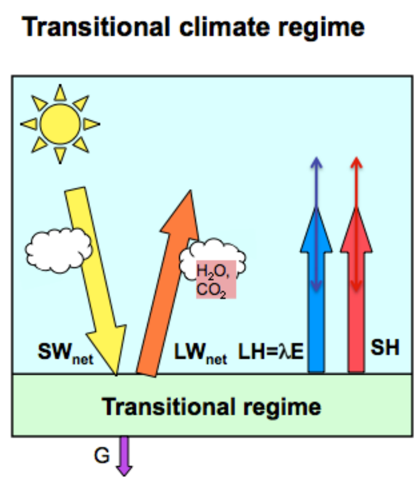

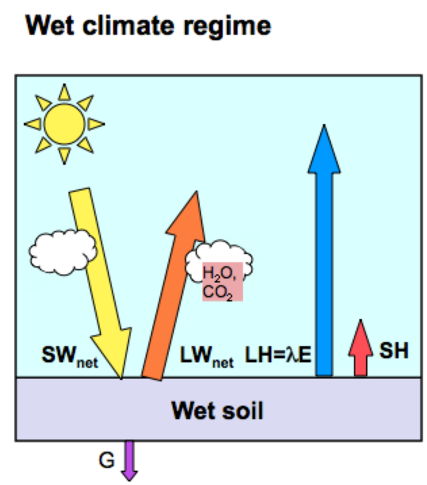

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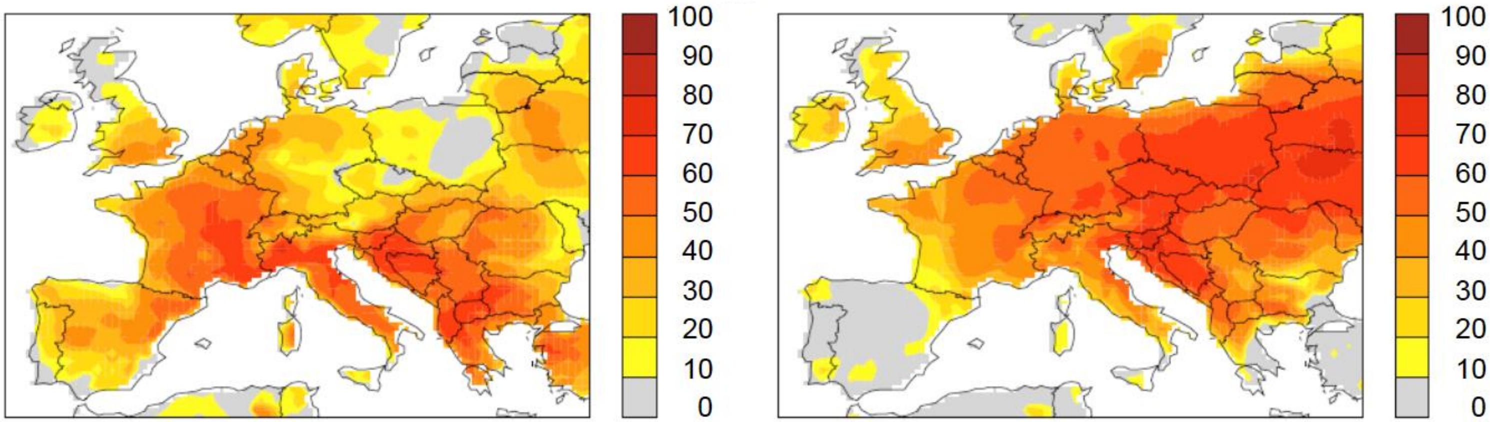
Model-based evidence for soil moisture-temperature coupling

- Several **modeling studies** suggest a strong effect of soil moisture on temperature variability and extremes in summer in several regions, in both present and future climate (Seneviratne et al. 2006, Nature; Koster et al. 2006, JHM; Fischer et al. 2007, GRL; Vautard et al. 2007, GRL; Zampieri et al. 2009, J. Climate; Diffenbaugh and Ashfaq 2010, GRL; Quesada et al. 2012, Nature Climate Change; Seneviratne et al. 2013, GRL, Berg et al. 2015, J. Climate)

Soil moisture – temperature feedbacks

Soil moisture variability found to be a main driver for temperature variability in Europe in model simulations *for both present and future*

1970-1989 **2080-2099**



%age of summer temperature variability attributable to soil moisture variability (model estimate)

(Seneviratne et al. 2006, Nature)

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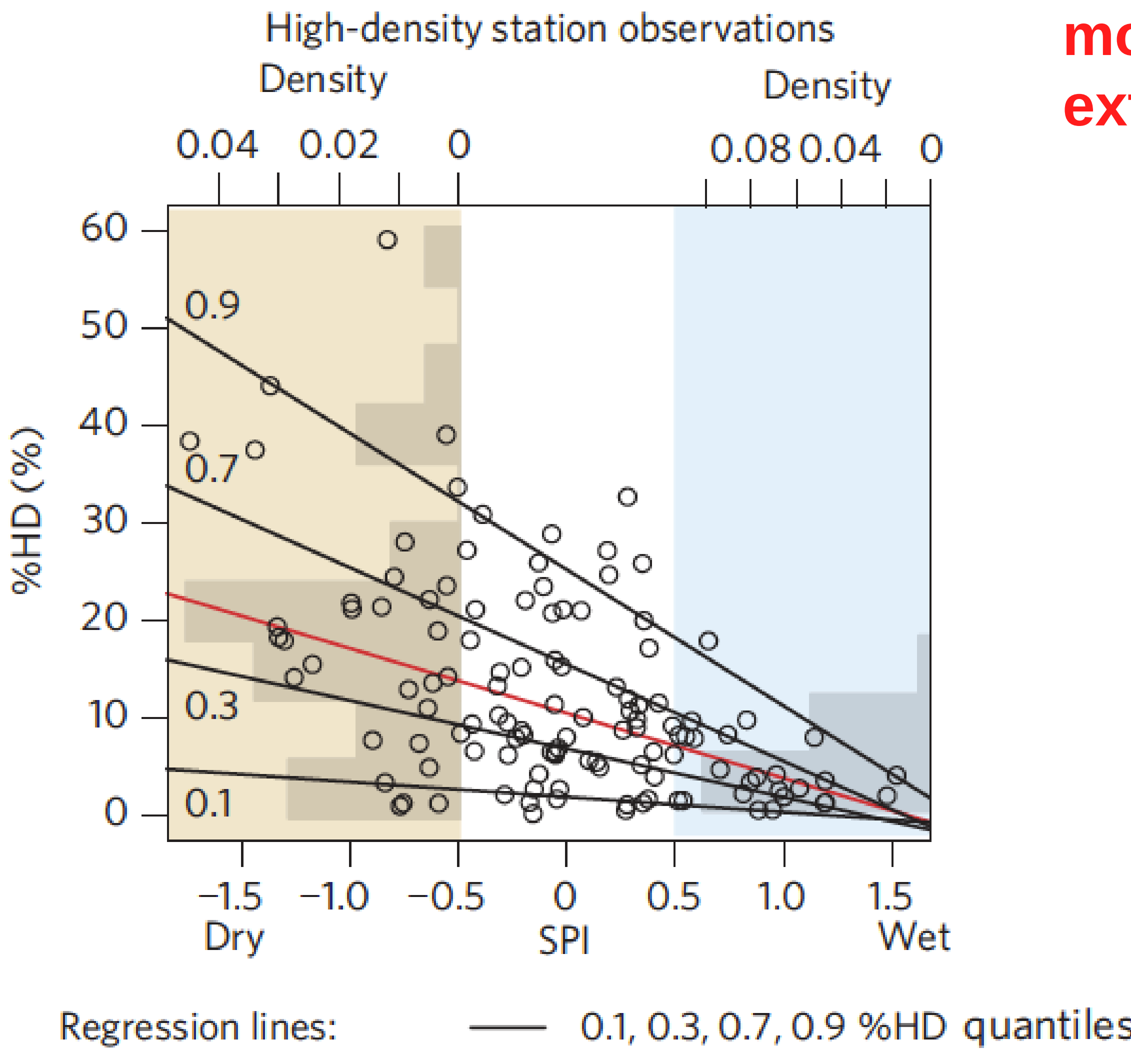
- **What is the evidence based on observations?**

Soil moisture – temperature feedbacks: Observations

Analysis for Southeastern Europe

Quantile regression of %HD with 6-month SPI



Impact of soil moisture on hot extremes

(Hirschi et al. 2011, Nature Geoscience)

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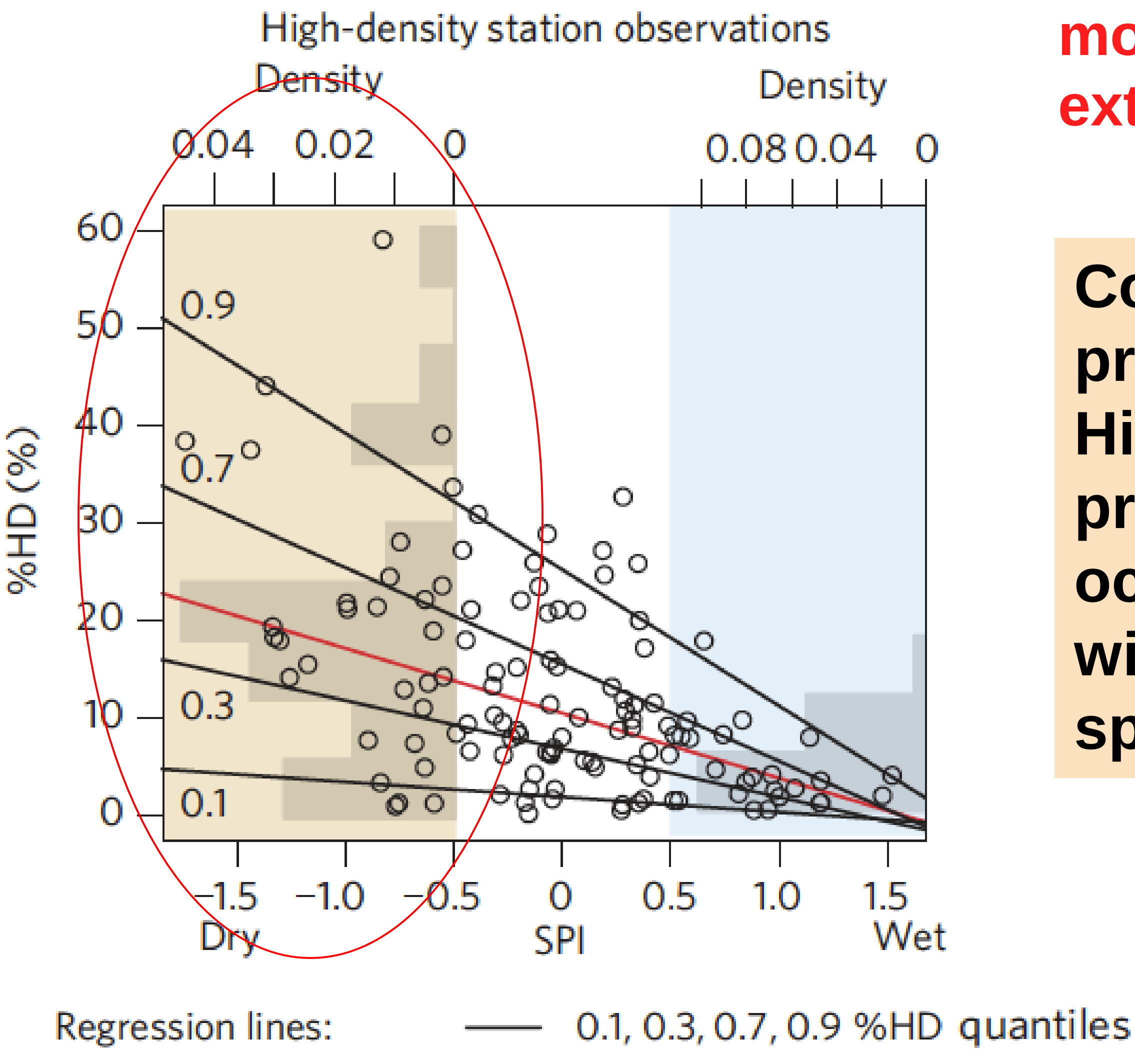
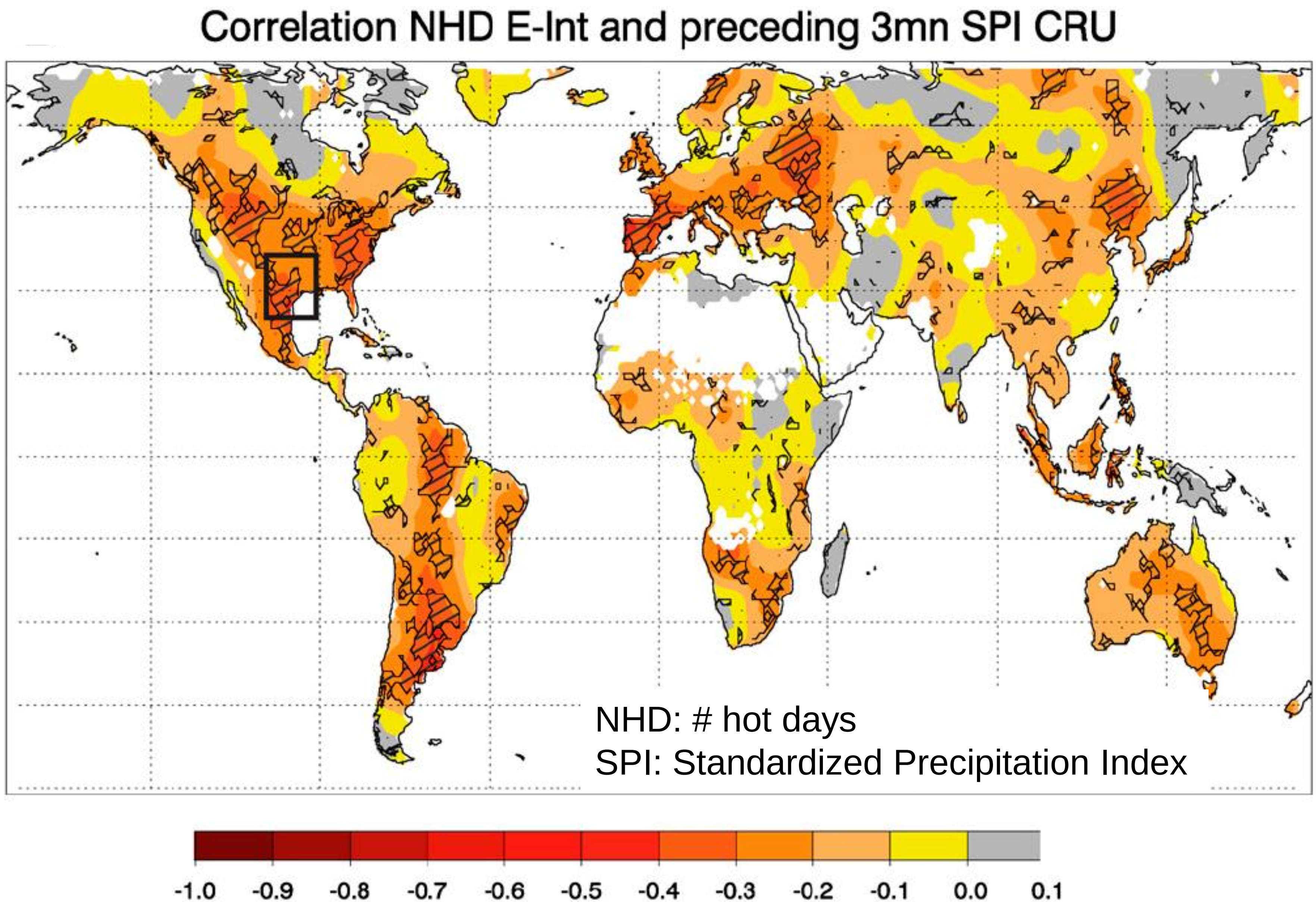


Impact of soil moisture on hot extremes

Conditional probability: Higher probability of occurrence with drier springs

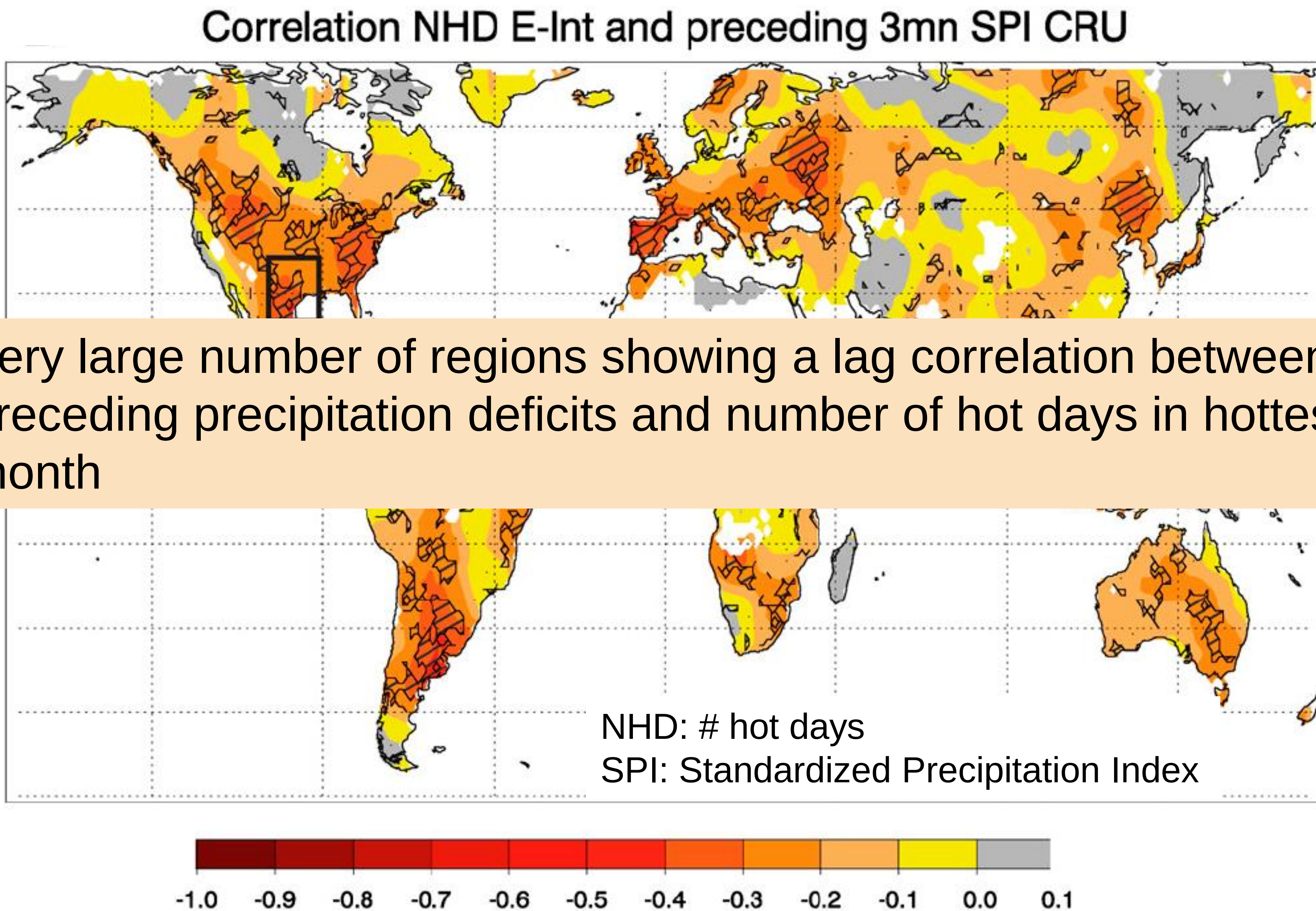
(Hirschi et al. 2011, Nature Geoscience)

Soil moisture – temperature feedbacks: Observations



(Mueller and Seneviratne 2012, PNAS)

Soil moisture – temperature feedbacks: Observations

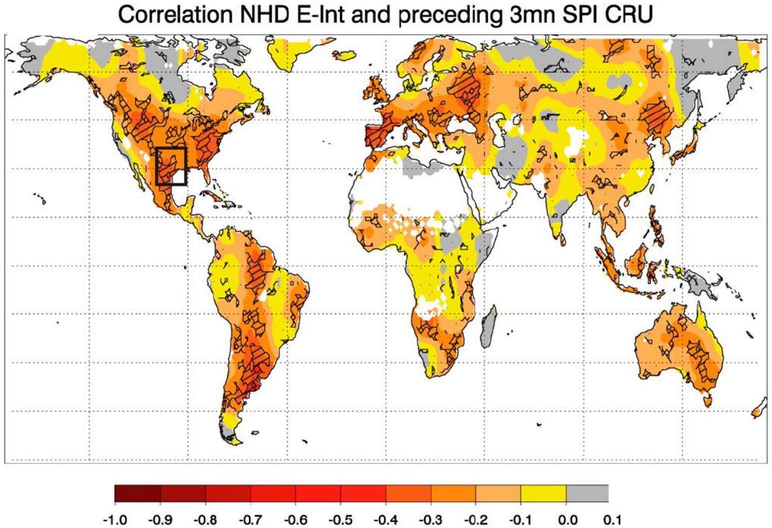


Very large number of regions showing a lag correlation between preceding precipitation deficits and number of hot days in hottest month

NHD: # hot days
SPI: Standardized Precipitation Index

(Mueller and Seneviratne 2012, PNAS)

Soil moisture – temperature feedbacks: Observations



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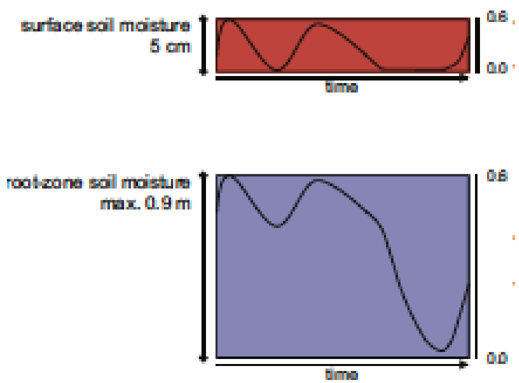
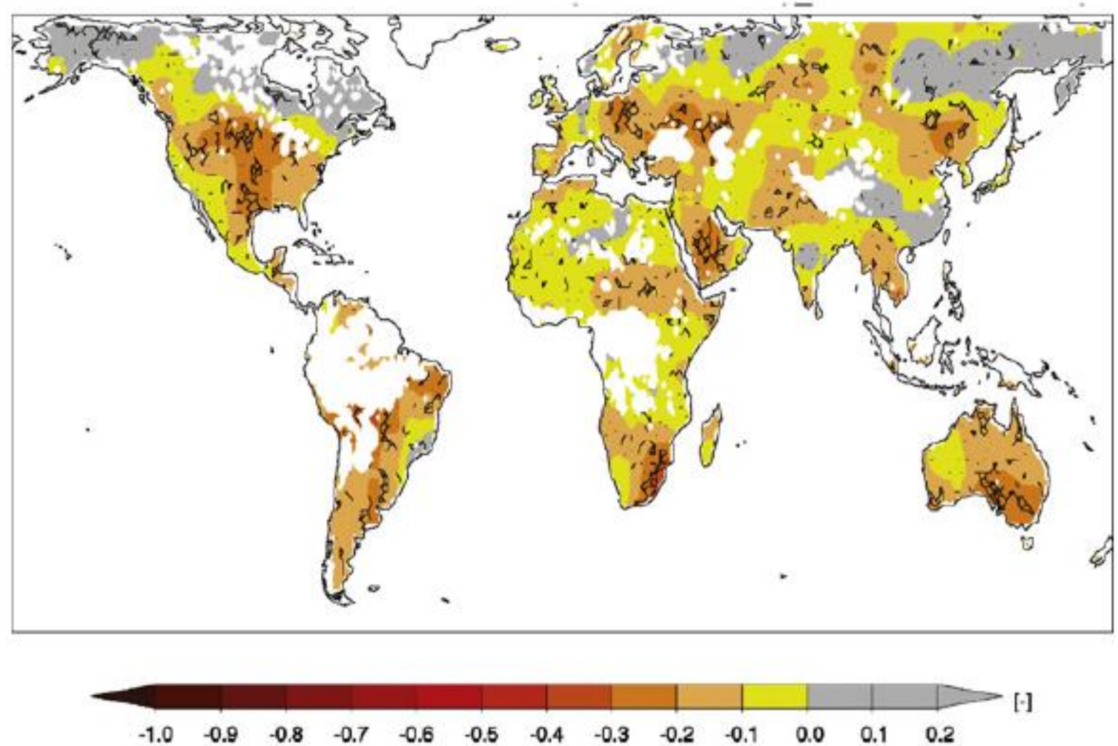


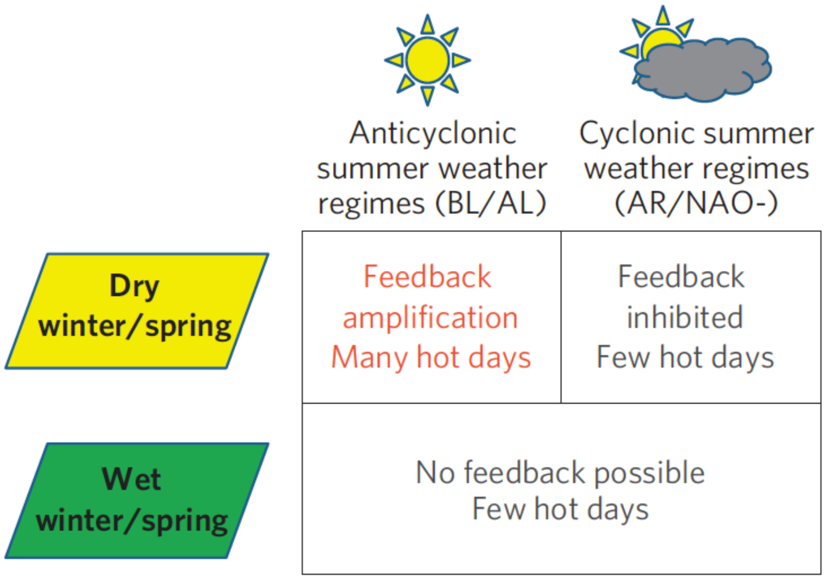
Remote sensing based analyses (ESA CCI microwave soil moisture product)

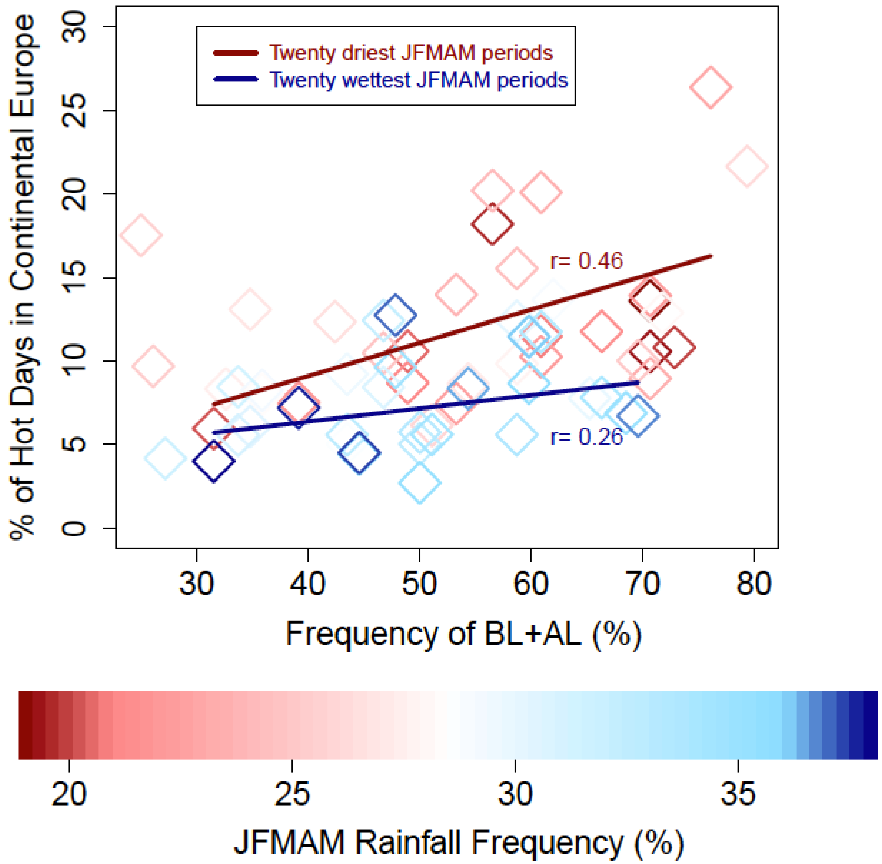


(Hirschi et al. 2014, Remote Sensing Env.)

Combined roles of soil moisture & circulation

European analysis: High percentage of hot days found for combination of 1) dry springs and 2) anticyclonic summer weather regimes





(Quesada et al. 2012, Nature Climate Change)

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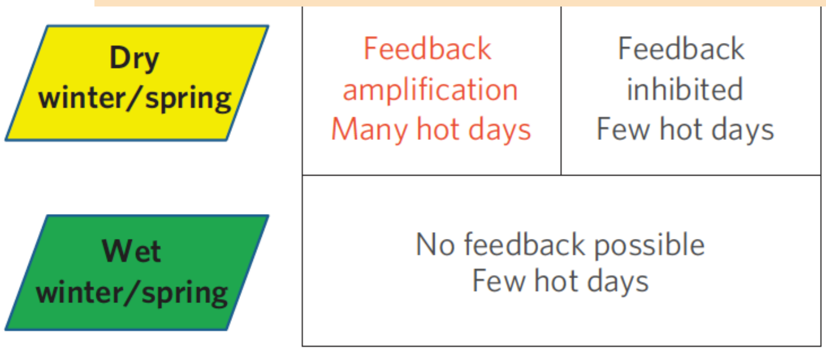
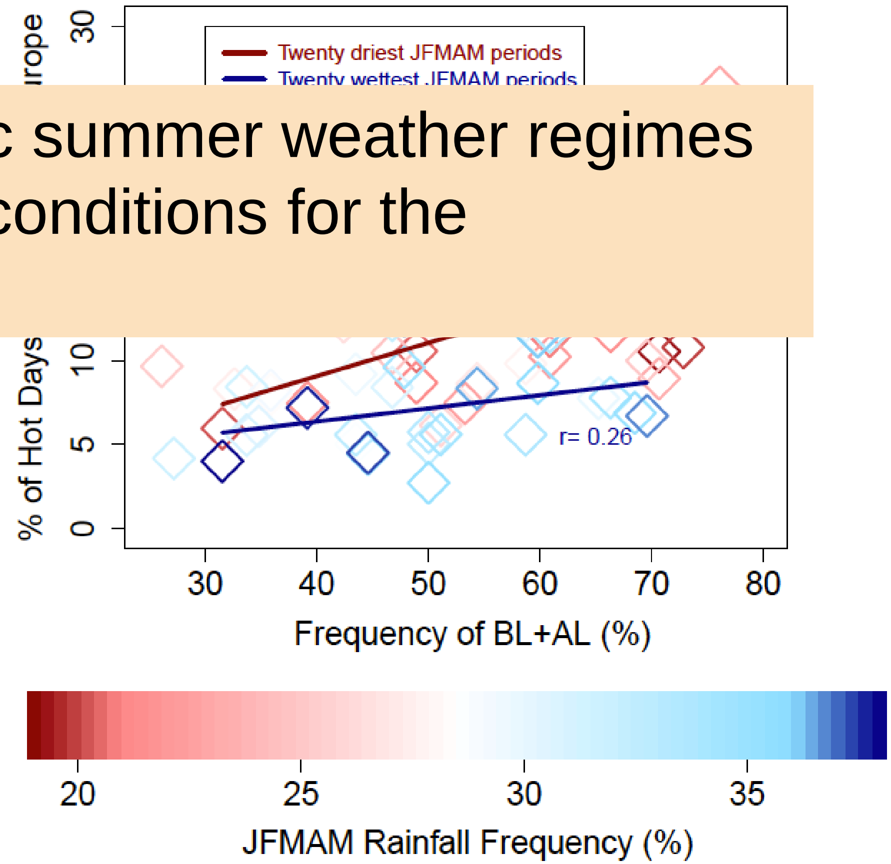
Both dry springs and anticyclonic summer weather regimes are necessary but not sufficient conditions for the occurrence of hot extremes

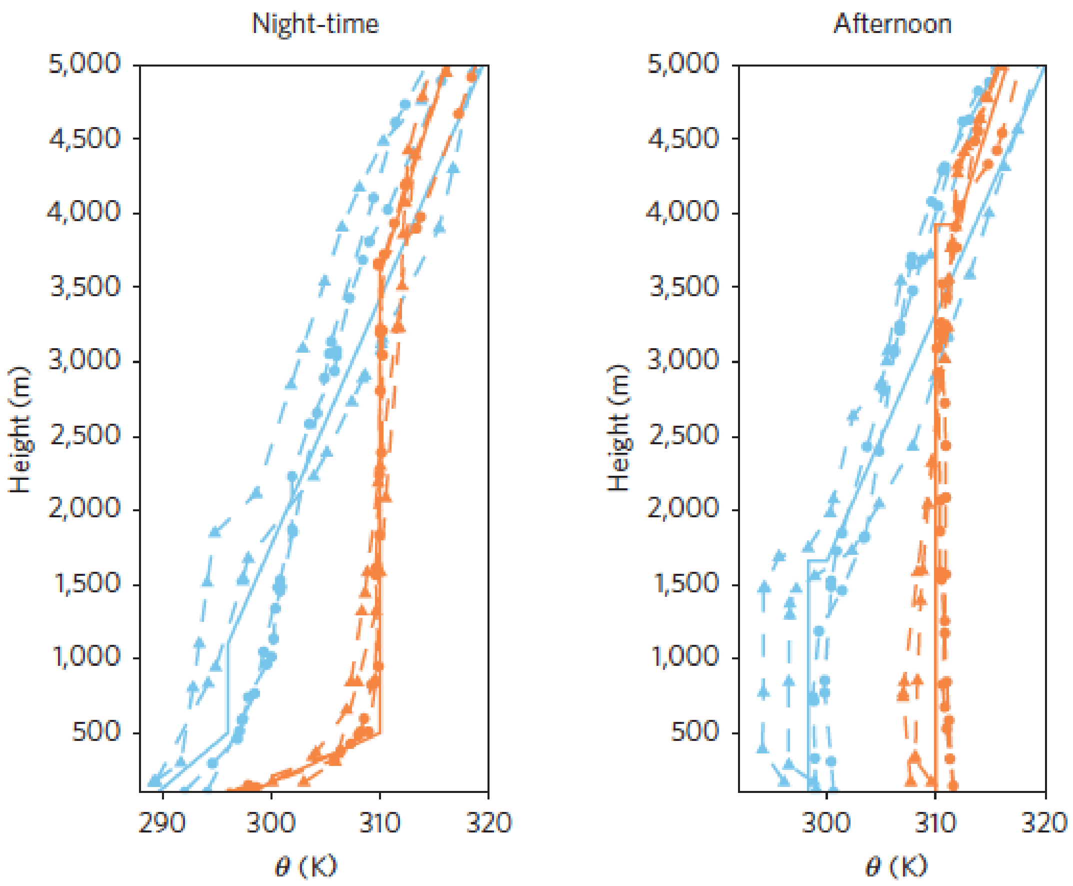




(Quesada et al. 2012, Nature Climate Change)

Role of boundary-layer development

Atmospheric profiles (2003 France, 2010 Russia)



Pre-heatwave conditions
“Mega-heatwave” conditions

(Miralles et al. 2014, Nature Geoscience)

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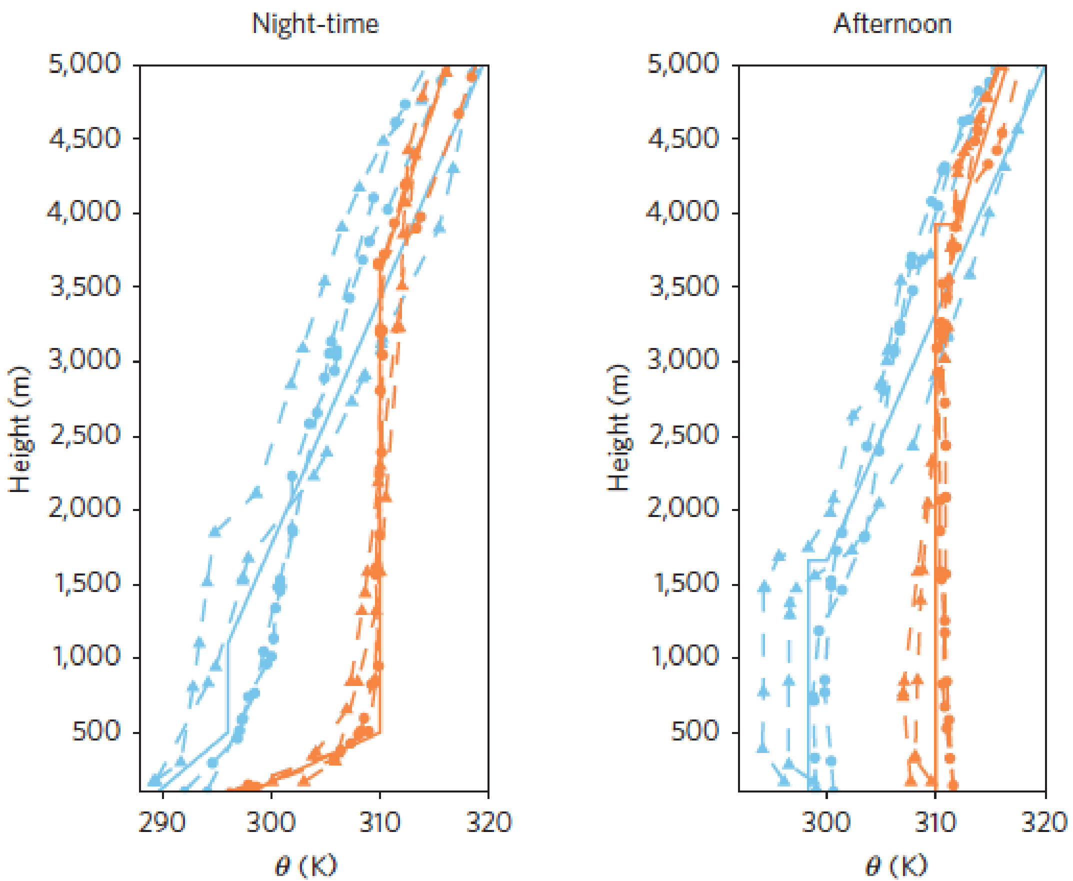

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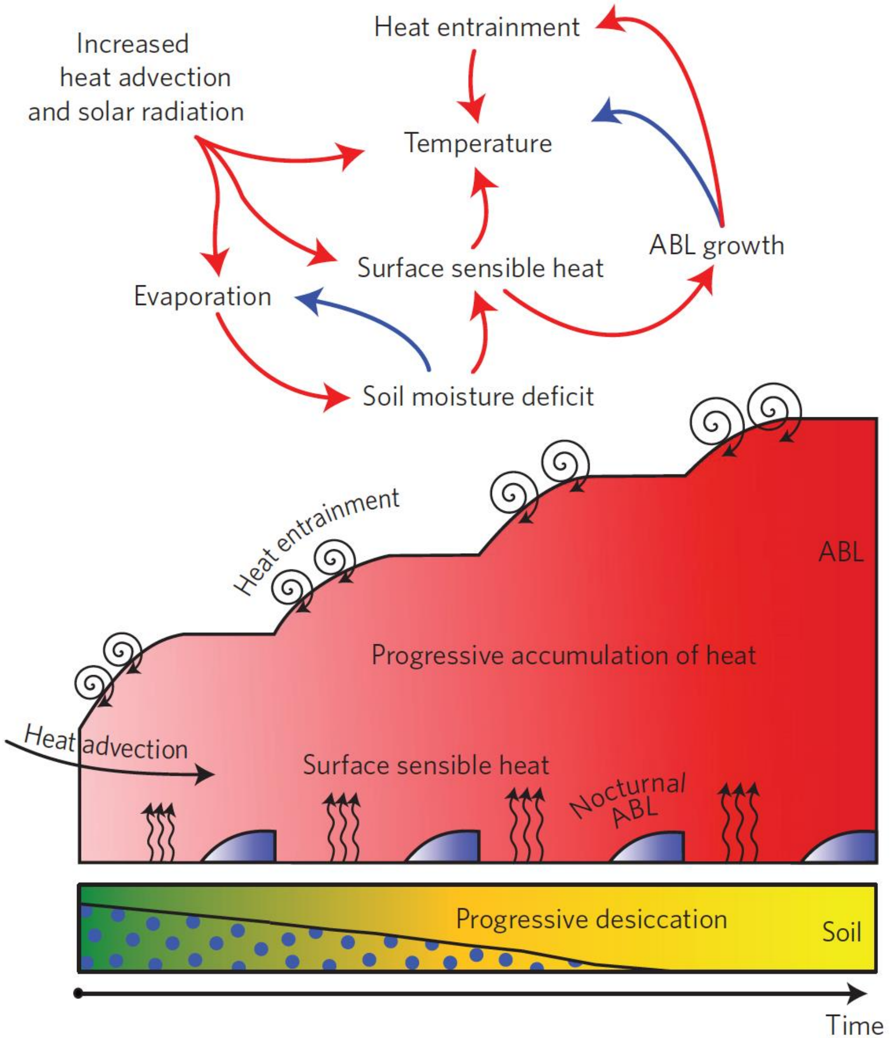
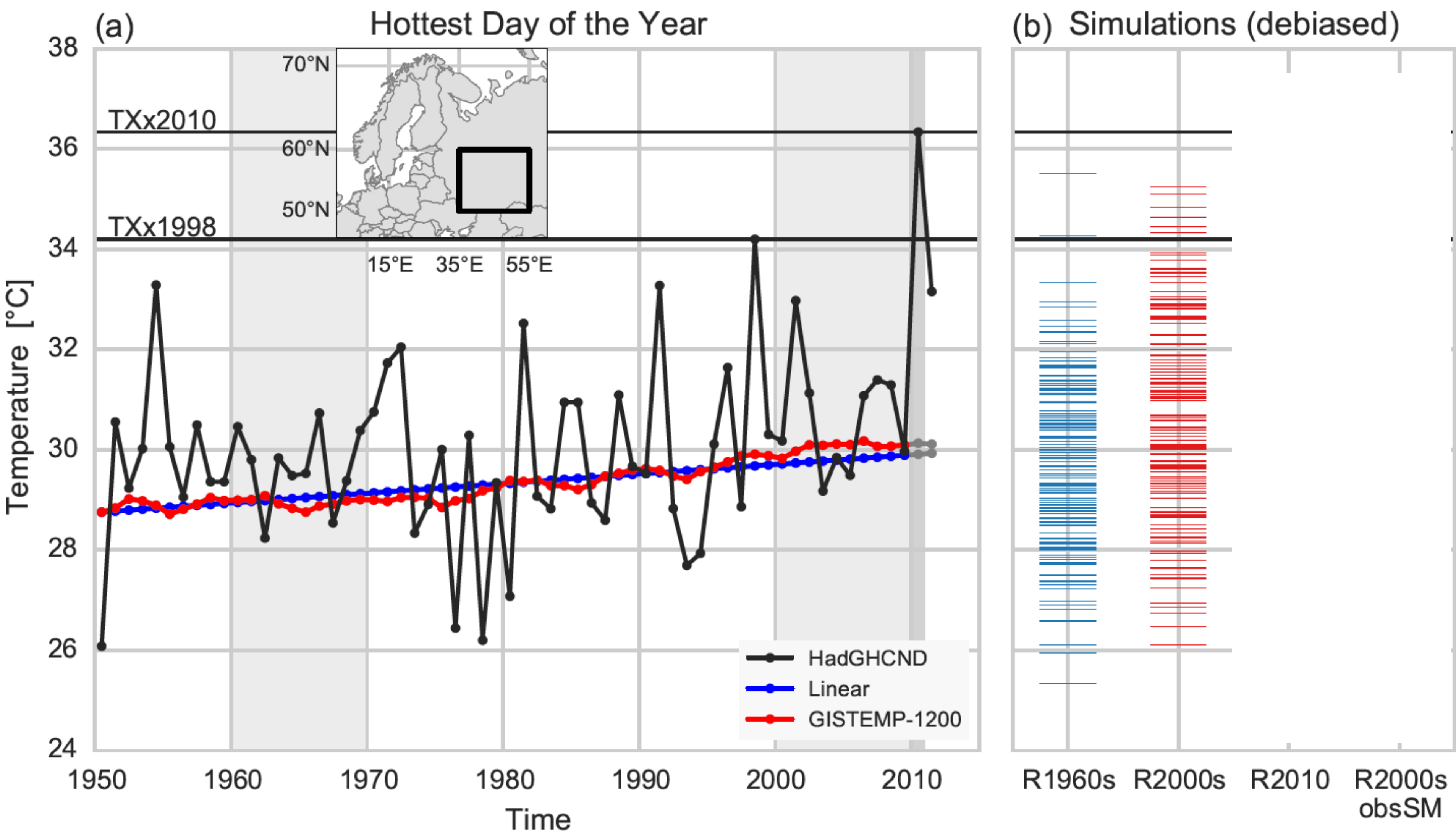


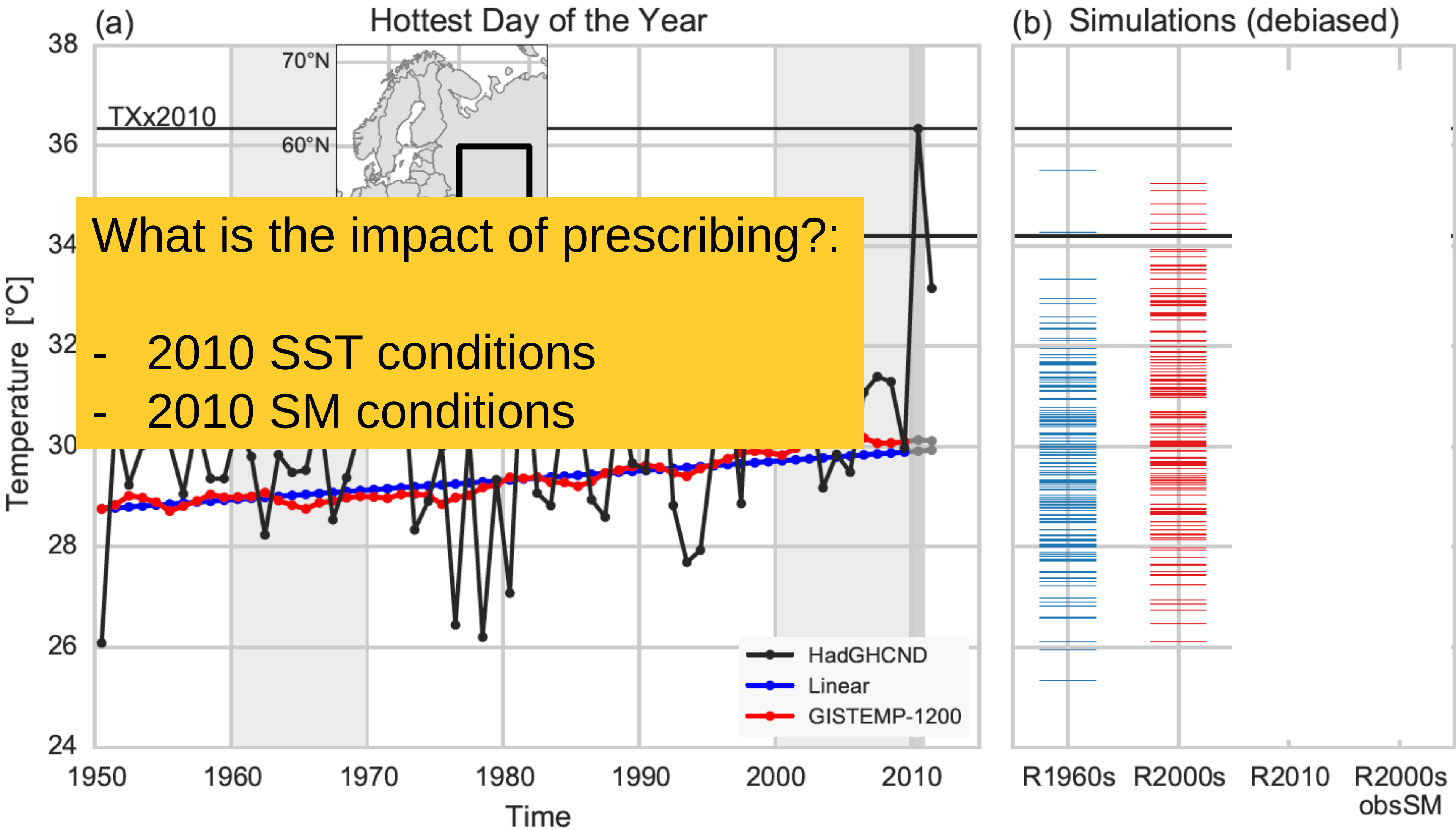
(Miralles et al. 2014, Nature Geoscience)

2010 Russian heatwave



(Hauser et al., in prep.)

2010 Russian heatwave

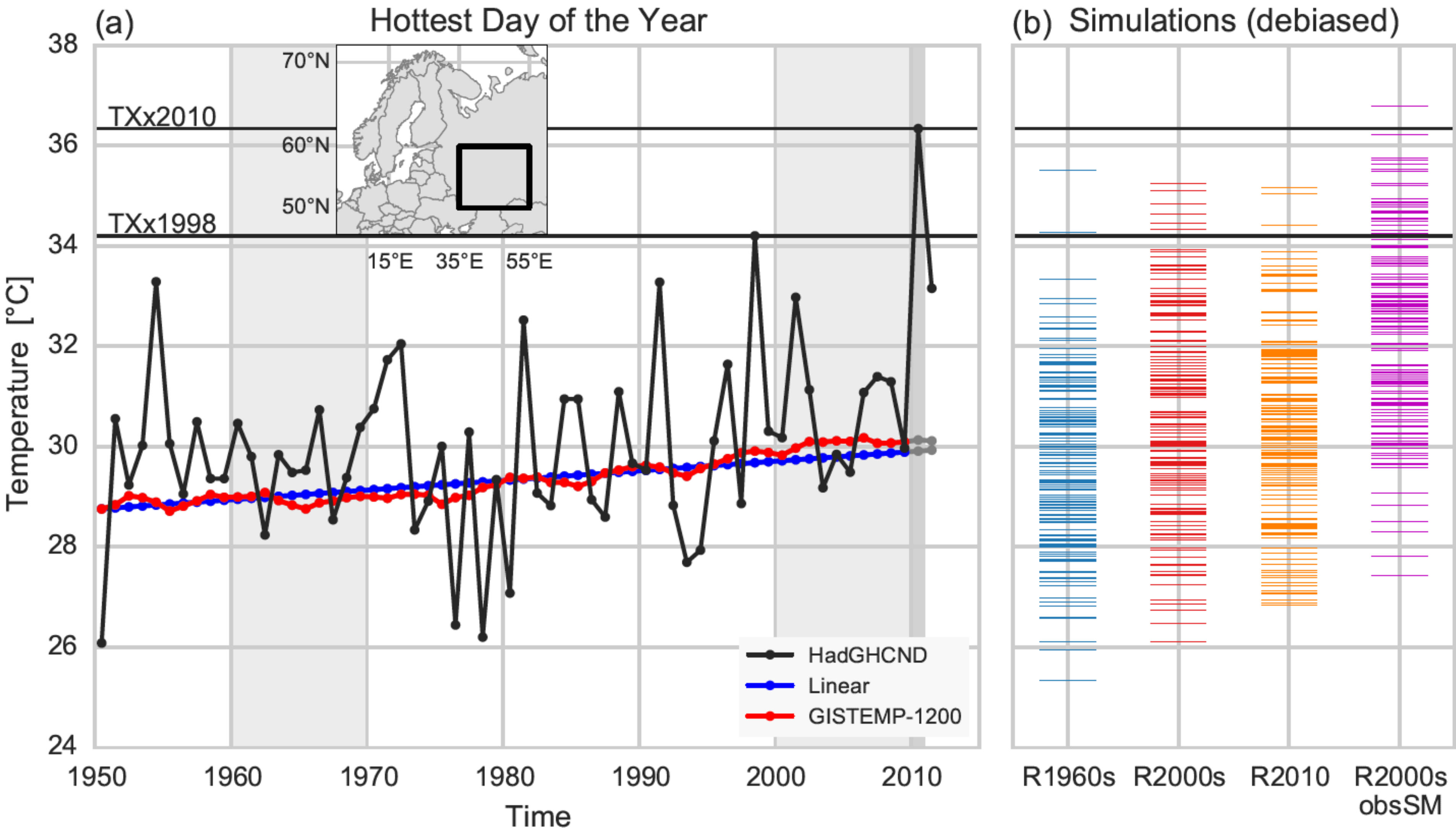


What is the impact of prescribing?:

- 2010 SST conditions
- 2010 SM conditions

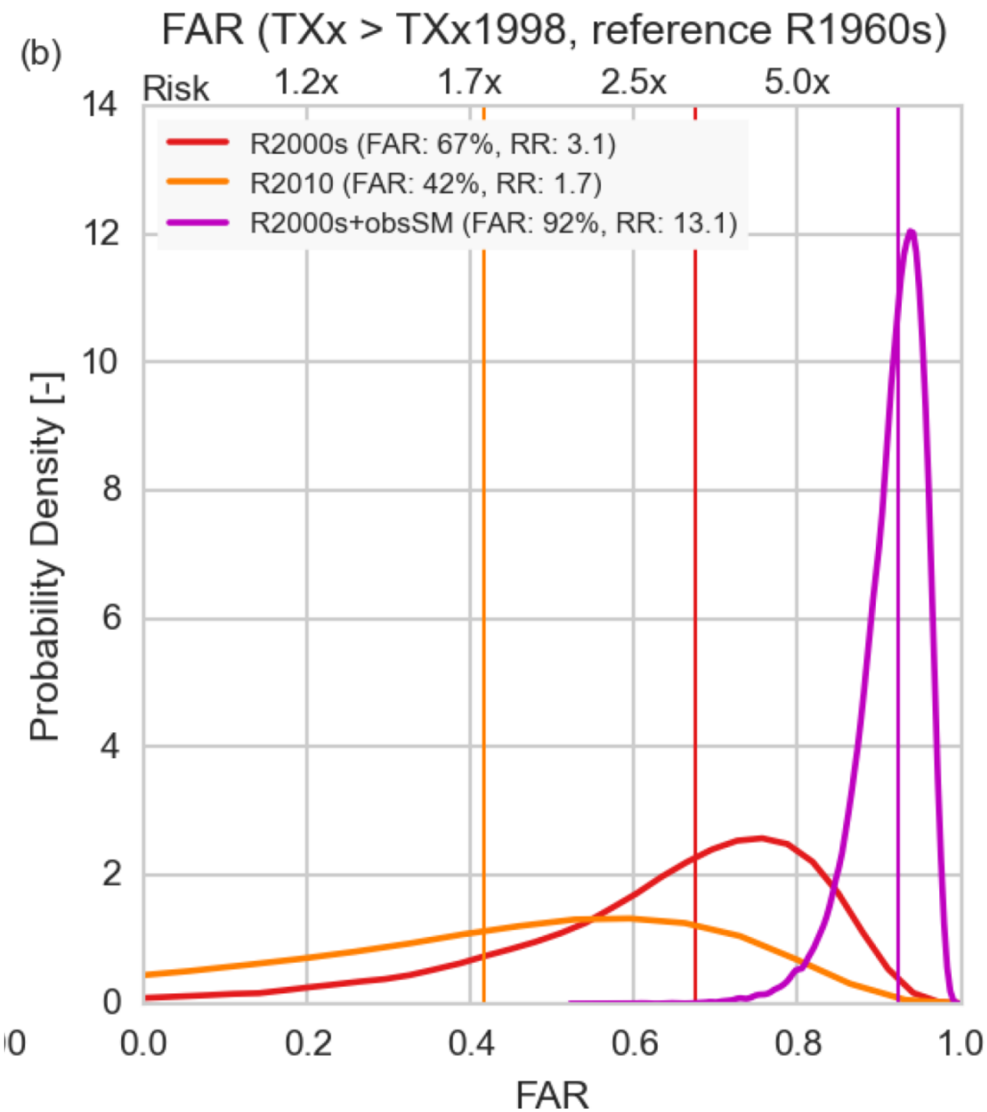
(Hauser et al., in prep.)

2010 Russian heatwave



(Hauser et al., in prep.)

Fraction of attributable risk (FAR)



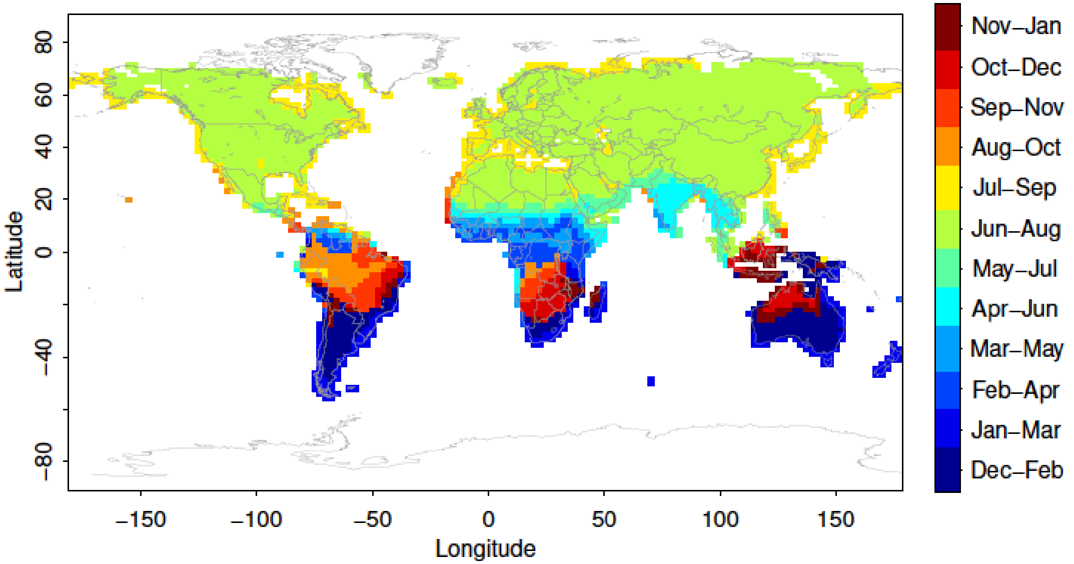
Compared to historical conditions (1960s):

- 2010 SST increased risk of >1998 by ~1.7
- Anthropogenic forcing (general warming) increased risk of >1998 by ~3
- Soil moisture conditions increased risk by ~13

(Hauser et al., in prep.)

Comparing soil moisture vs SST forcing

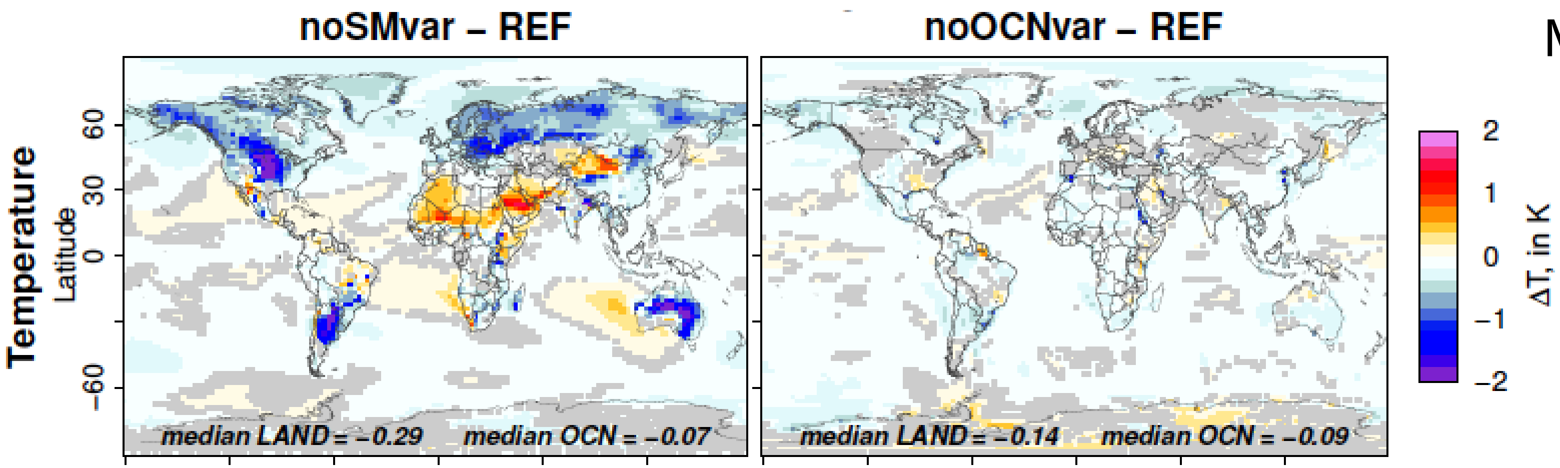
What are the impacts of soil moisture vs SST variability during the local warm season? (global CESM simulations)



(Orth and Seneviratne, submitted to J. Climate)

Comparing soil moisture vs SST forcing

Respective impacts of removed soil moisture vs removed SST variability in warm season on land (1996-2005 climate)



Mean changes

(Orth and Seneviratne, submitted to J. Climate)

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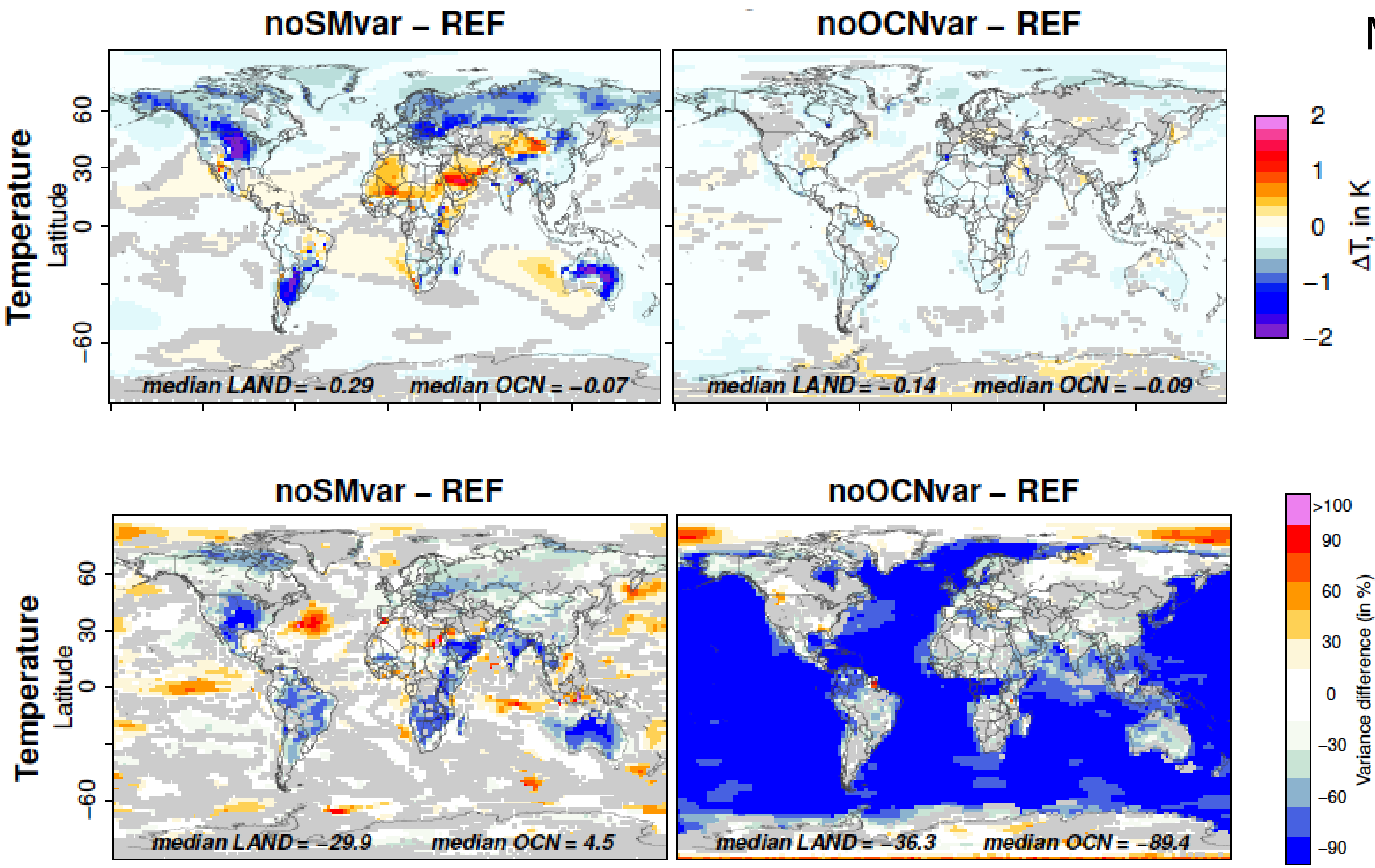
Mean changes

Variance change

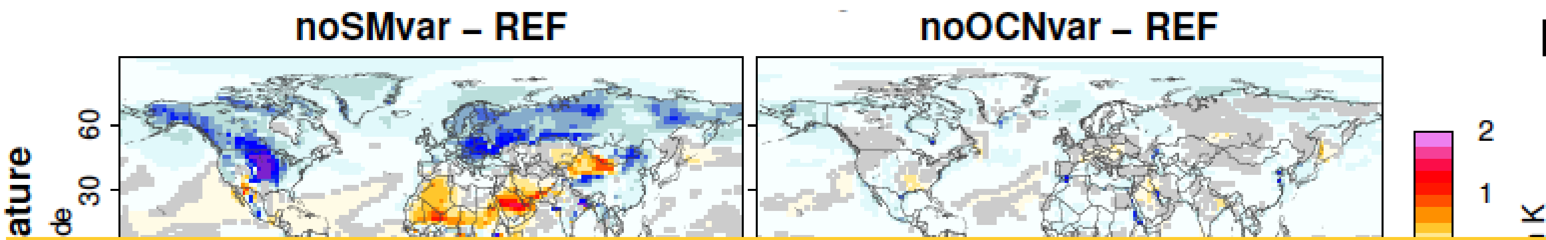


(Orth and Seneviratne, submitted to J. Climate)

Comparing soil moisture vs SST forcing

Respective impacts of removed soil moisture vs removed SST variability in warm season on land (1996-2005 climate)

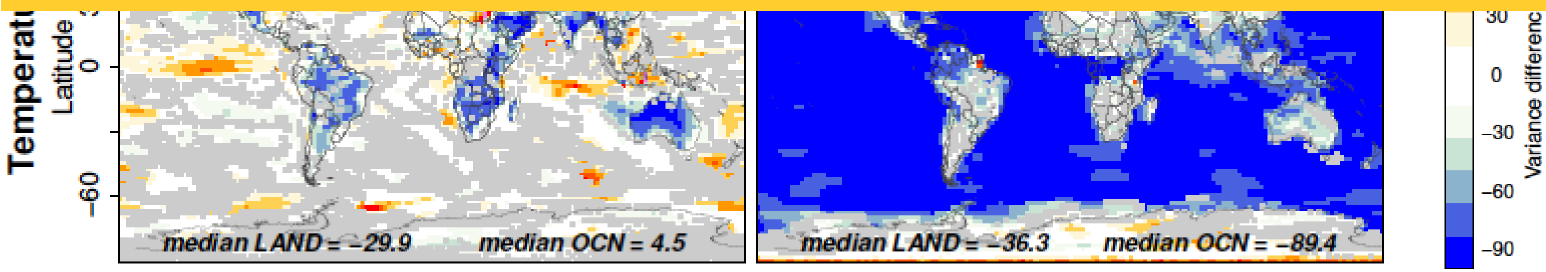
Mean changes



Effects of soil moisture are at least as large as those of the SST

No strong support for the concept of soil moisture dynamics acting as feedback to SST forcing

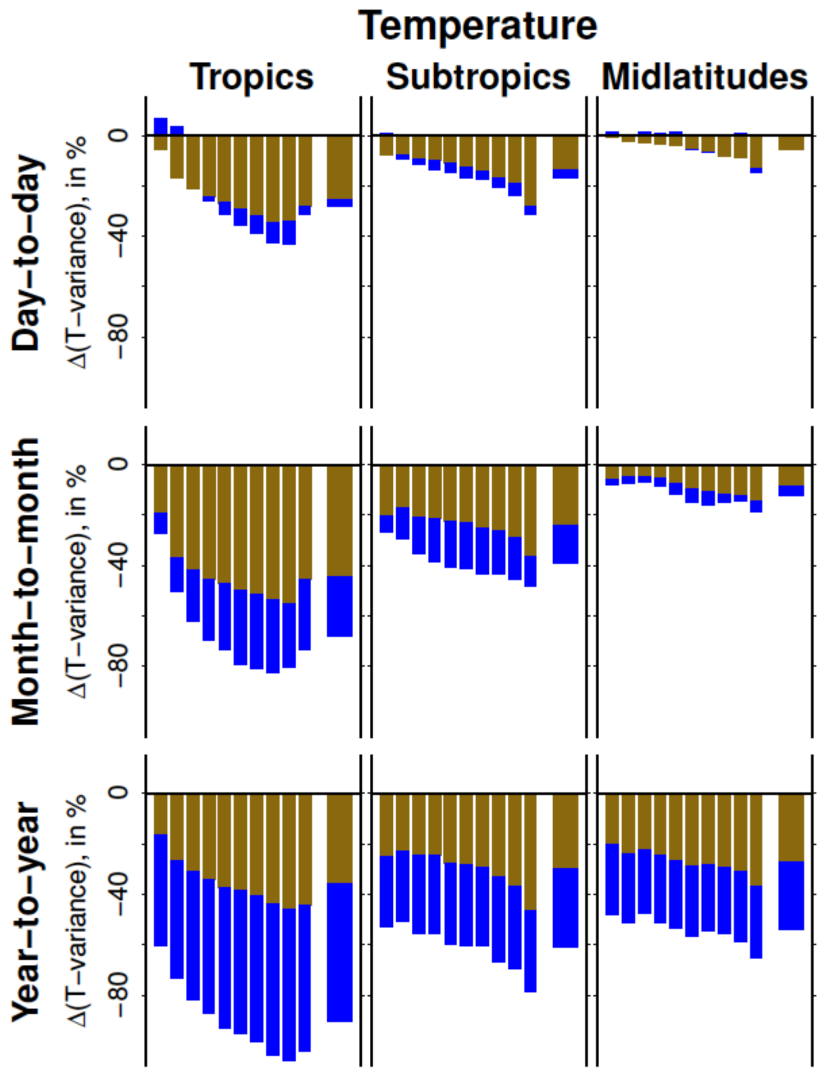
Non-local effects of soil moisture variability on the oceans



(Orth and Seneviratne, submitted to J. Climate)

SM vs SST forcing

Respective impacts of removed soil moisture vs removed SST variability in warm season on land (1996-2005 climate)



Variability changes

Effects in the mid-latitudes, subtropics, and tropics!

On daily and monthly time scale: SM dominant factor (relevant for ECMWF!)

(Orth and Seneviratne, submitted to J. Climate)

SM-T feedbacks: Summary

- Soil moisture-temperature feedbacks are an essential contributor to temperature on land, especially during extreme events

- In warm climate on land: Similar effect as SST in all latitudinal bands between 65S and 65N (and larger than SST in many regions)

Outline

Introduction

Global vs land climate (temperature, droughts)

Soil moisture-temperature interactions and extremes, relevance to predictability

Land albedo-climate interactions

Conclusions

Albedo – temperature effects

Surface albedo can either be modified externally (forcing):

- Land cover changes (deforestation)
- Land use changes, changes in land management (e.g. agricultural practices: see later)
- White roofs, reflective pavement, etc.

or through feedbacks:

- Changes in snow cover
- Changes in soil moisture (affect soil albedo, vegetation albedo)
- Plant phenology
- Vegetation dynamics

or through combination of both!

Albedo: Typical values

	DJF		JJA
Land cover group	snow-covered	snow-free	snow-free
Crops			0.178 ± 0.017
Grasses			0.176 ± 0.022
Evergreen trees			0.104 ± 0.012
Deciduous trees			0.153 ± 0.010
Bare soil			0.246 ± 0.055

* The mean ± one standard deviation surface albedo values are indicated. Values computed from the ensemble of grid cells (at 0.5°) with dominant land cover within the area of study

DJF: December-January-February; **JJA:** June-July-August
SC: Snow covered
SF: Snow free

(Boisier et al. 2013, Biogeosciences)

Albedo: Typical values

	DJF		JJA
Land cover group	snow-covered	snow-free	snow-free
Crops		0.141 ± 0.023	0.178 ± 0.017
Grasses		0.161 ± 0.023	0.176 ± 0.022
Evergreen trees		0.094 ± 0.017	0.104 ± 0.012
Deciduous trees		0.117 ± 0.021	0.153 ± 0.010
Bare soil		0.205 ± 0.050	0.246 ± 0.055

* The mean ± one standard deviation surface albedo values are indicated. Values computed from the ensemble of grid cells (at 0.5°) with dominant land cover within the area of study

DJF: December-January-February; **JJA:** June-July-August
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(Boisier et al. 2013, Biogeosciences)

Albedo: Typical values

	DJF		JJA
Land cover group	snow-covered	snow-free	snow-free
Crops	0.546 ± 0.066	0.141 ± 0.023	0.178 ± 0.017
Grasses	0.568 ± 0.080	0.161 ± 0.023	0.176 ± 0.022
Evergreen trees	0.205 ± 0.035	0.094 ± 0.017	0.104 ± 0.012
Deciduous trees	0.244 ± 0.054	0.117 ± 0.021	0.153 ± 0.010
Bare soil	0.535 ± 0.112	0.205 ± 0.050	0.246 ± 0.055

* The mean ± one standard deviation surface albedo values are indicated. Values computed from the ensemble of grid cells (at 0.5°) with dominant land cover within the area of study

DJF: December-January-February; **JJA:** June-July-August
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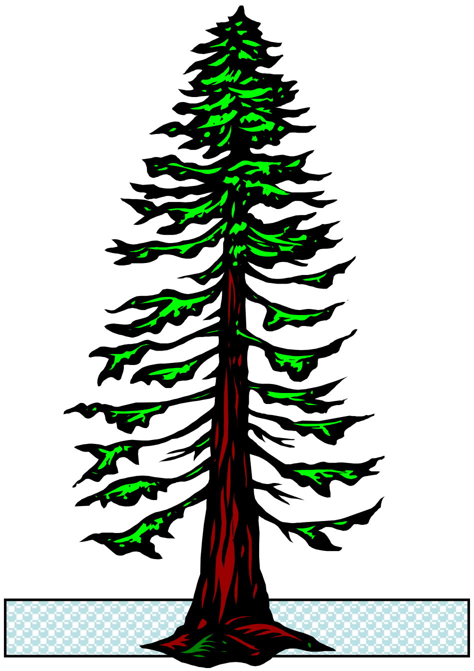
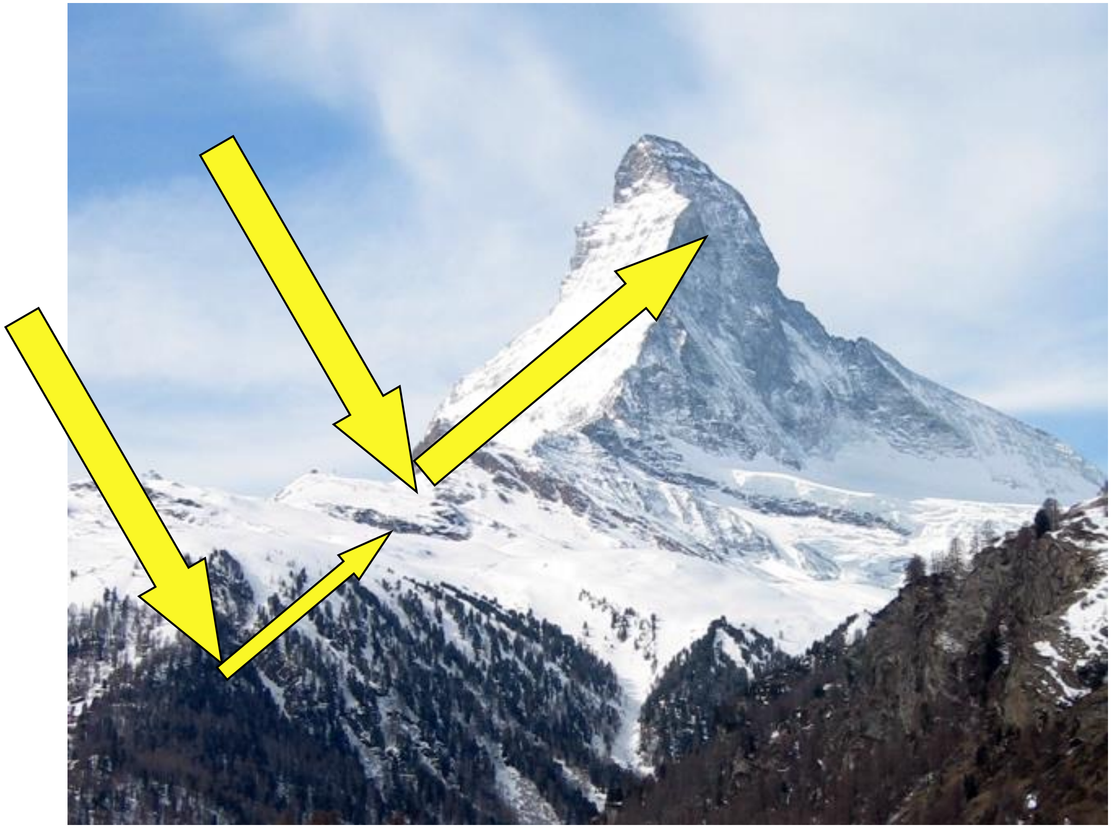
(Boisier et al. 2013, Biogeosciences)

Strength of snow-albedo feedback depends on the background vegetation (forests can also warm the climate!)

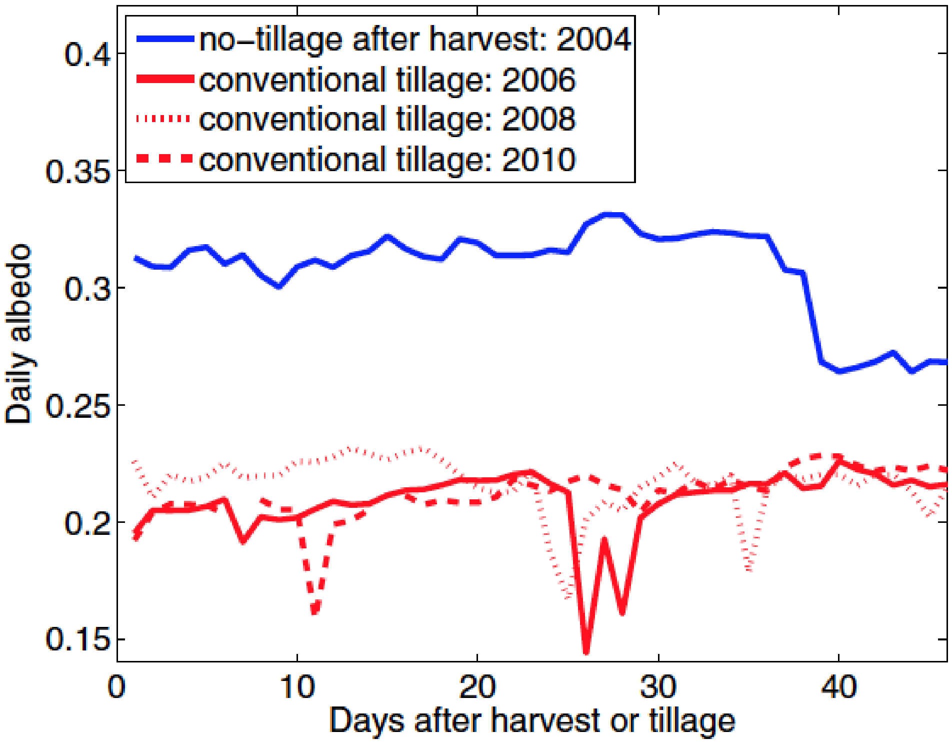




Changes in albedo induced by agricultural management

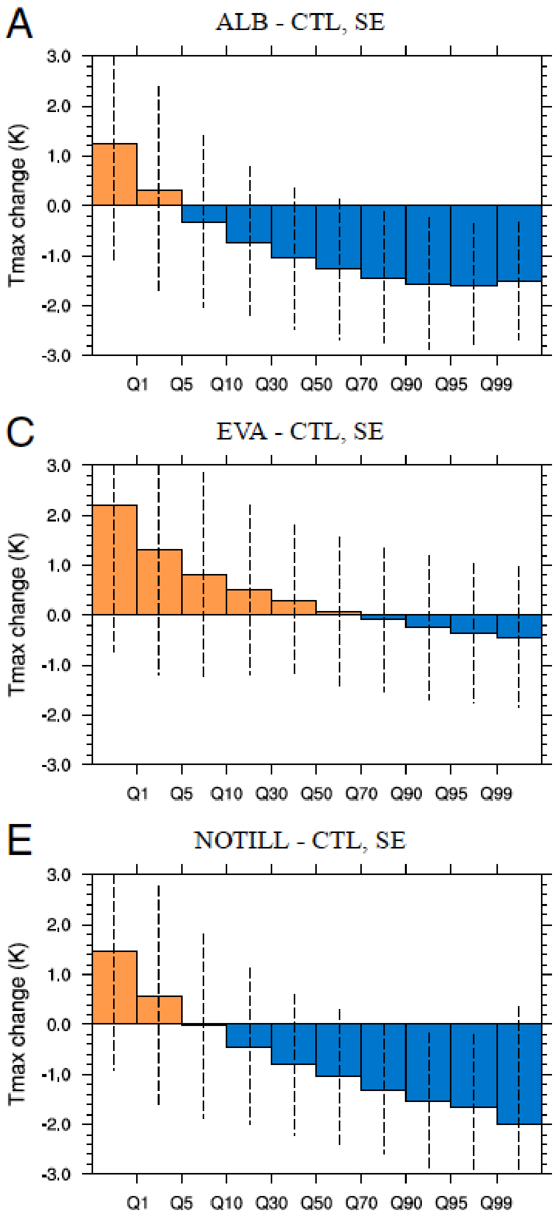
Photograph by Jim Richardson (National Geographic)

Differences in surface albedo from no-till farming



(Davin et al. 2014, PNAS)

Changes in albedo induced by agricultural management



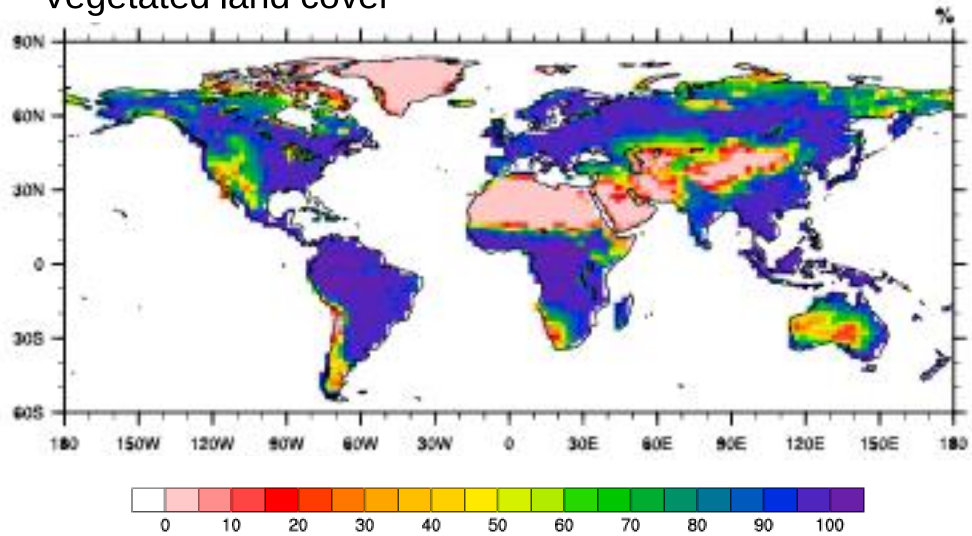
Overall effect of no-till farming (also including evaporation impacts):

Strong preferential cooling of hot extremes!

(Davin et al. 2014, PNAS)

Global impacts of changes in albedo over vegetated surfaces

Vegetated land cover

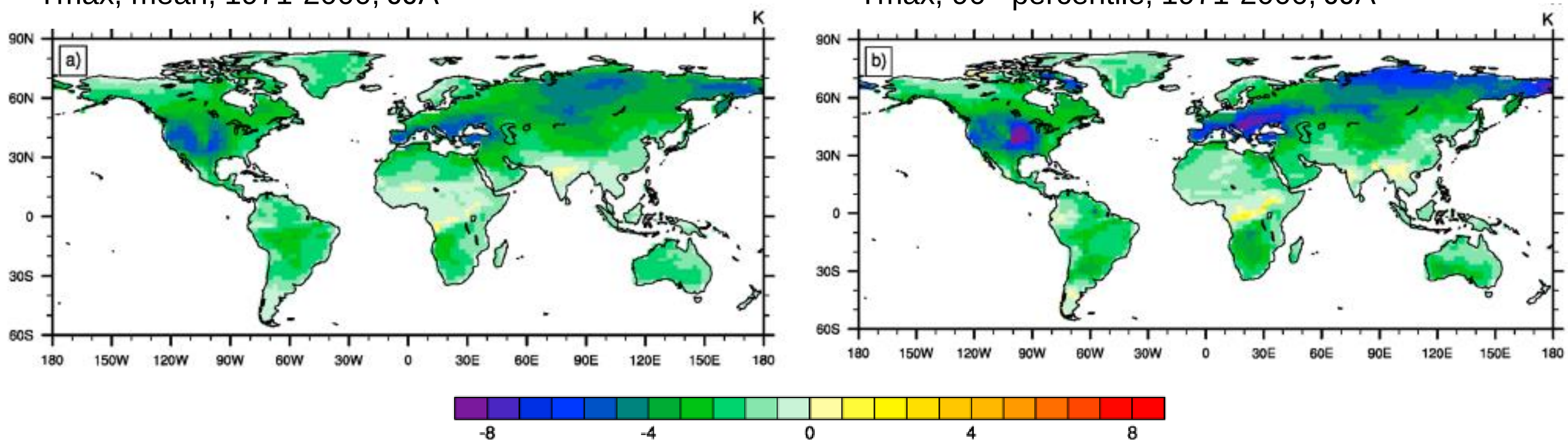


Changing albedo by 0.1 over all of vegetated land (NCAR CESM global climate model)

(Simulations for 20th century)

Tmax, mean, 1971-2000, JJA

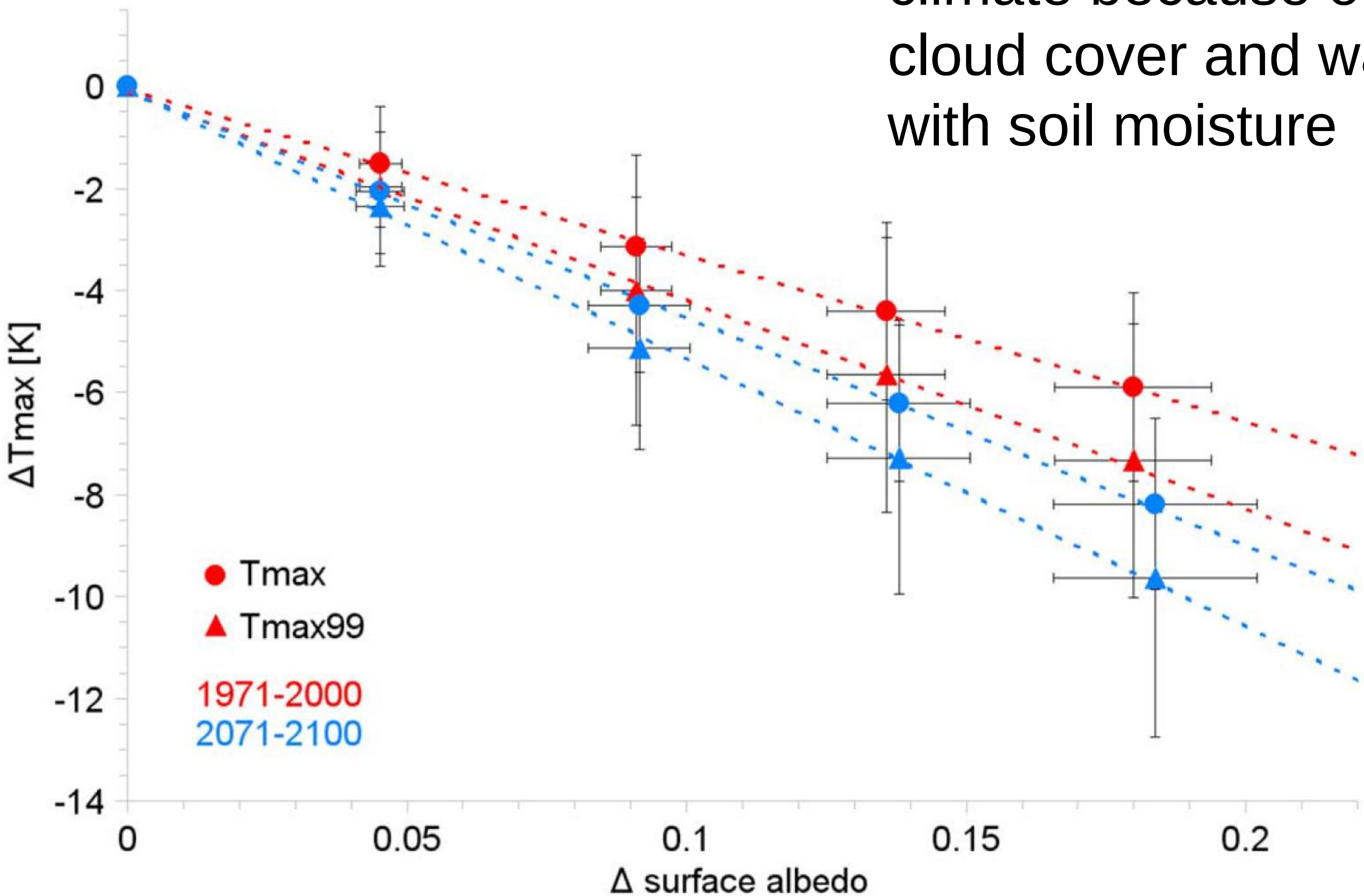
Tmax, 90th percentile, 1971-2000, JJA



(Wilhelm et al. 2015, JGR)

Albedo-climate feedbacks: Present vs future

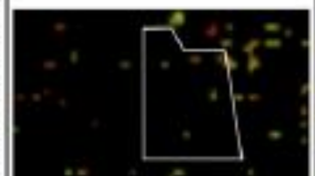
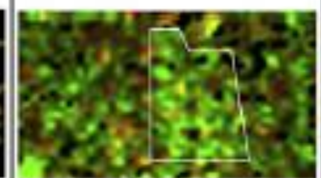
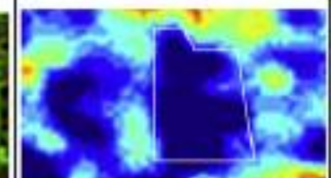
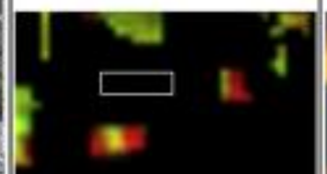
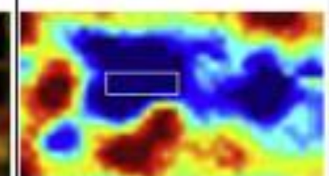
Stronger effect under future climate because of decreased cloud cover and water savings with soil moisture



(Wilhelm et al. 2015, JGR)

Albedo-climate feedbacks: Urban climates

Changes in surface albedo as means for climate adaptation

UHI Effort	1998 Aerial	2010 Aerial	NDVI Change	Albedo Change	Temp. Change
New Reflective Roof Neighbor-hood			N/A 	+0.07 	-3.4°C 
New Ware-house Reflective Roof			N/A 	+0.16 	-5.0°C 

(Mackey et al. 2012, Building and Environment)

Surface albedo – temperature interactions: Summary

- Changes in albedo (either as feedback or forcing) strongly impact temperature mean *and extremes* and also include non-linear effects
- Stronger cooling of hot temperatures in mid-latitude summer when surface albedo is increased
- Intentional modifications of albedo (in cities or through changes in land use) possibly relevant for climate adaptation/climate engineering?

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Conclusions

- Land climate is different from global climate!
- Land surface water and energy budgets and their interactions with the atmosphere are of high relevance for climate in inhabited regions
- The response of extremes to land-atmosphere interactions is different (and generally larger) than for mean climate