

Wintersemester 2023/2024

Physische Geographie 1

(Grundkursvorlesung PG 1 – Vorlesungsteil Klimatologie)

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Lehrstuhl für Physische Geographie mit Schwerpunkt Klimaforschung

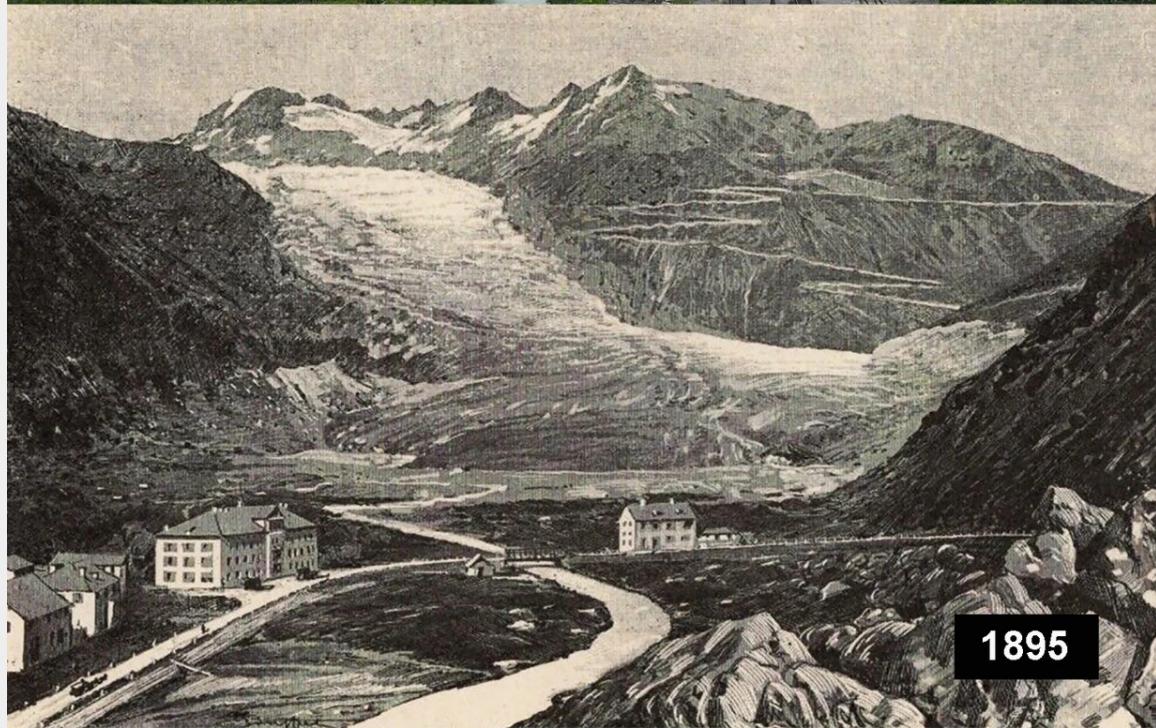
Institut für Geographie

Universität Augsburg

Tschievagletscher Berninagruppe



Rhonegletscher Wallis



Lodalsbreen & Stigaholtsbreen

Norwegen



Boyabreen

Norwegen



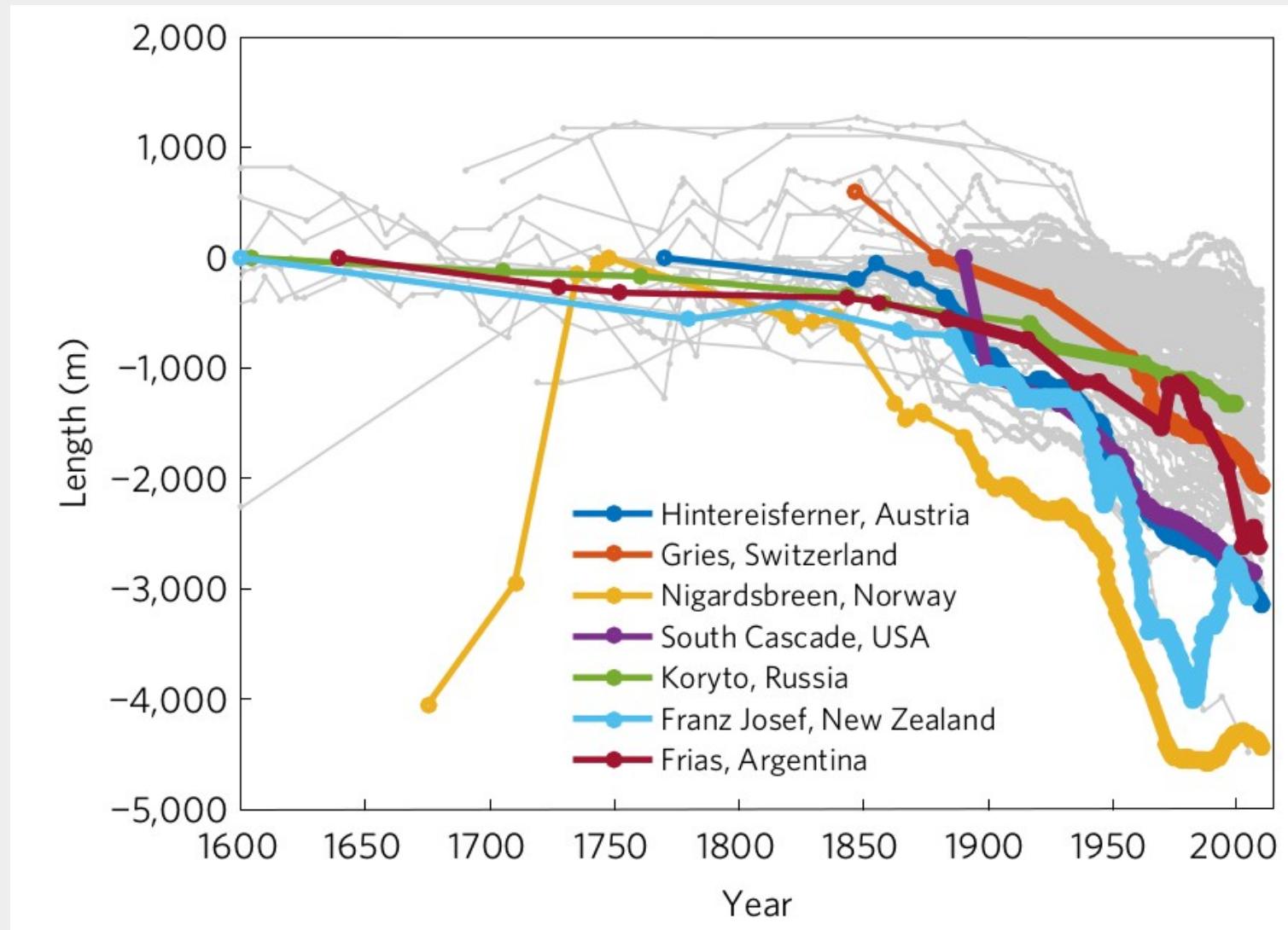
Schwarzensteinkees

Zillertaler Alpen



Gletscherschwund seit Mitte des 19. Jahrhunderts

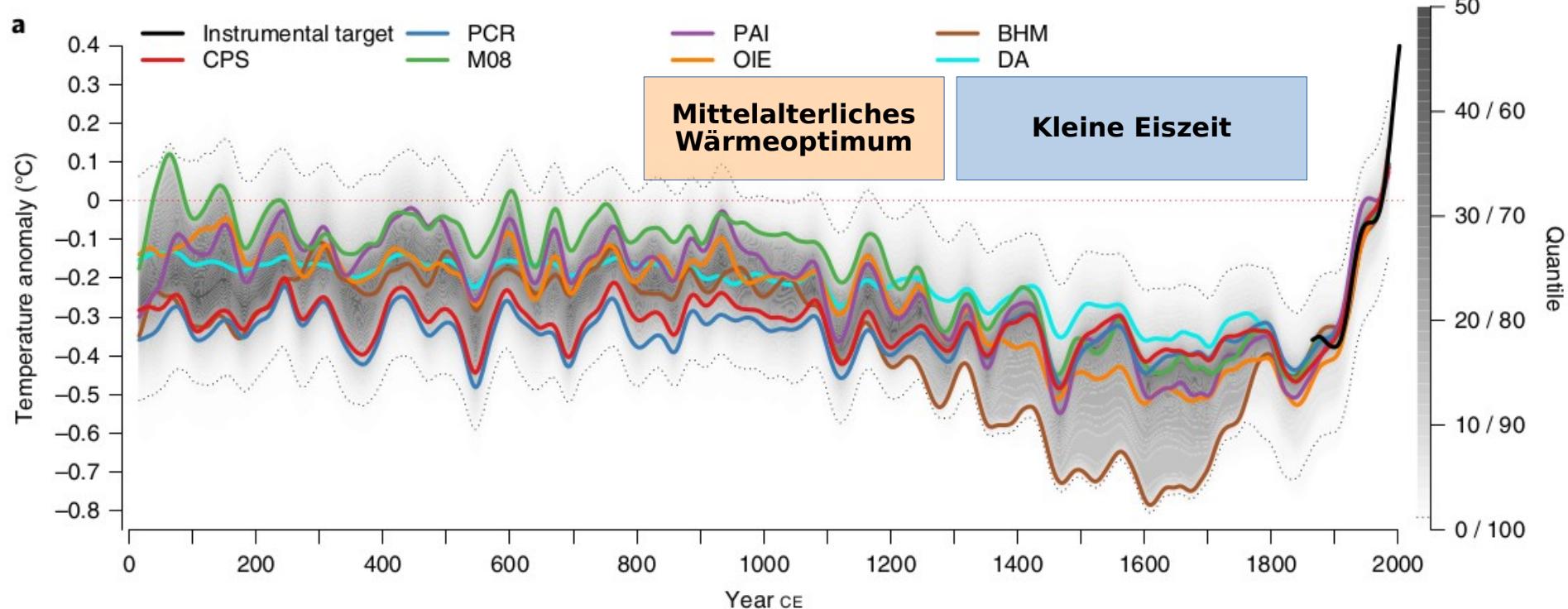
(Längenentwicklung von 158 Gletschern)



Globale Mitteltemperatur über die letzten 2000 Jahre

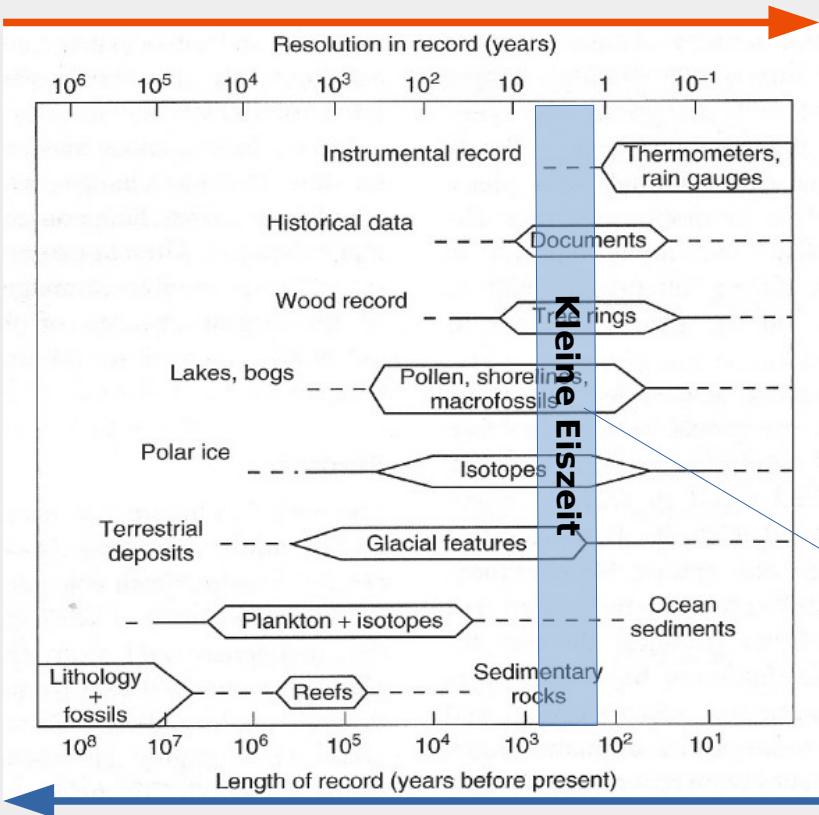
(Anomalien zu 1961 - 1990)

10

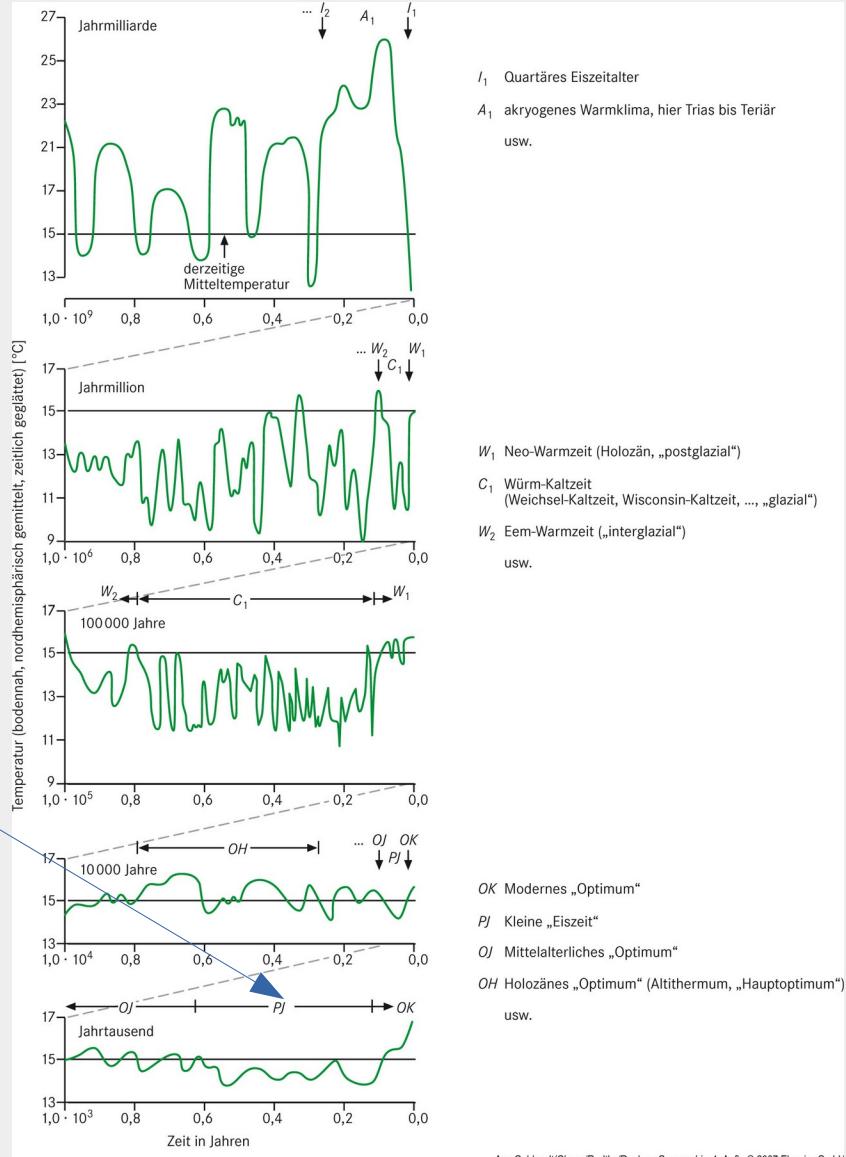


Klimadaten und Klimaproxies

Klimaindikatoren für unterschiedliche Zeiträume



(Hardy 2003)



Ursachen von Klimaänderungen

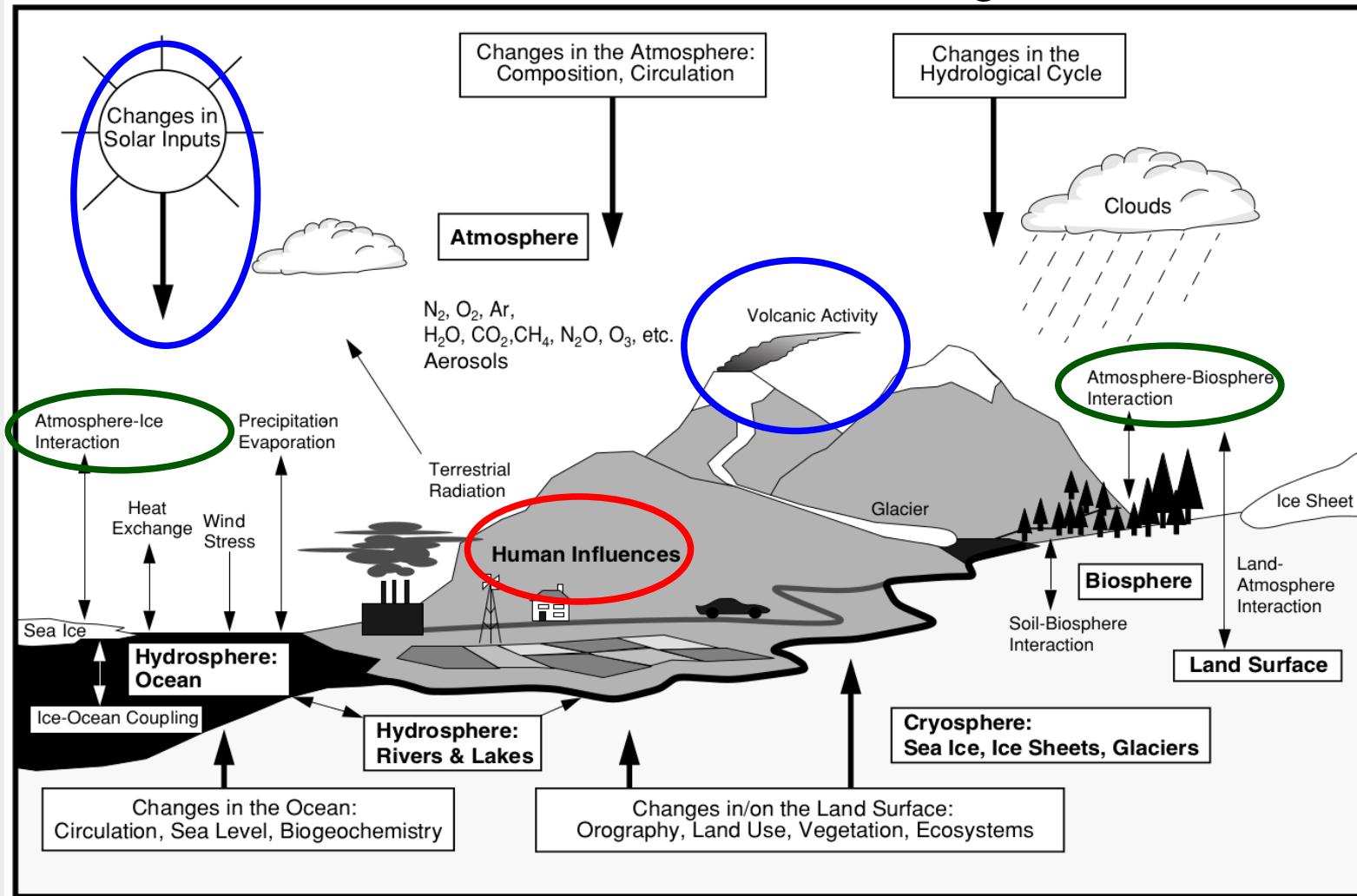


Figure 1.1: Schematic view of the components of the global climate system (bold), their processes and interactions (thin arrows) and some aspects that may change (bold arrows). (IPCC 2001)

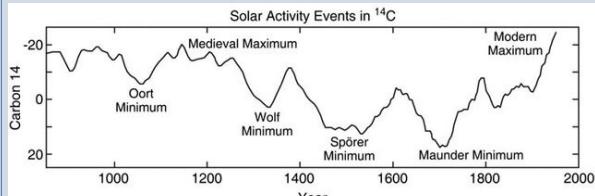
Ursachen von Klimaänderungen:

- **Externe natürliche Ursachen** (solare Aktivitätsschwankungen, astronomische Rahmenbedingungen, explosiver Vulkanismus, Tektonik)
- **Externe anthropogene Ursachen** (Zusammensetzung der Atmosphäre, Landnutzungsänderungen)
- **Interne Ursachen** (Wechselwirkungen zwischen Komponenten des Klimasystems)

Die Kleine Eiszeit (Little Ice Age) ca. 1300 - 1850

Ursachen

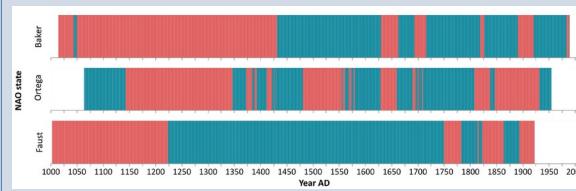
Minima solarer Aktivität



Explosiver Vulkanismus (z.B. Laki 1783, Tambora 1815)



Atmosphärische Zirkulation (mehrheitlich negativer Modus der Nordatlantischen Oszillation - NAO)



Phänomene

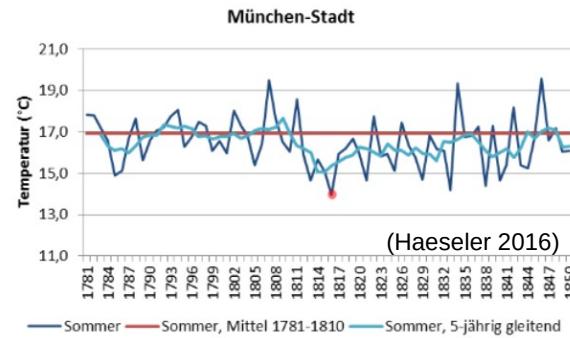
Gletschervorstöße (Alpen, Neuseeland, Alaska, ...)

ca. 0.6°C niedrigere
Jahresmitteltemperaturen

lange kalte Winter



kühle niederschlagsreiche Sommer 1816 „Year without a summer“



Auswirkungen

Missernten, Hungersnöte, ...



1816 „Year without a summer“
(Brönnimann & Krämer 2016)

Klimaauswirkungen auf die Gesellschaft

Temperature and precipitation anomalies
extreme events (floods, droughts, windstorms etc.)



Biophysical impacts: lower yield and lesser nutritional value (e.g. losses from mould and insects in storage etc.)



Economic impacts: prices of food, animal feed and fire-wood



Demographic and social impacts: malnutrition, drop in birth-rate, rise in death-rate, social disruption and food-migration (*subsistence crises*)



* * *

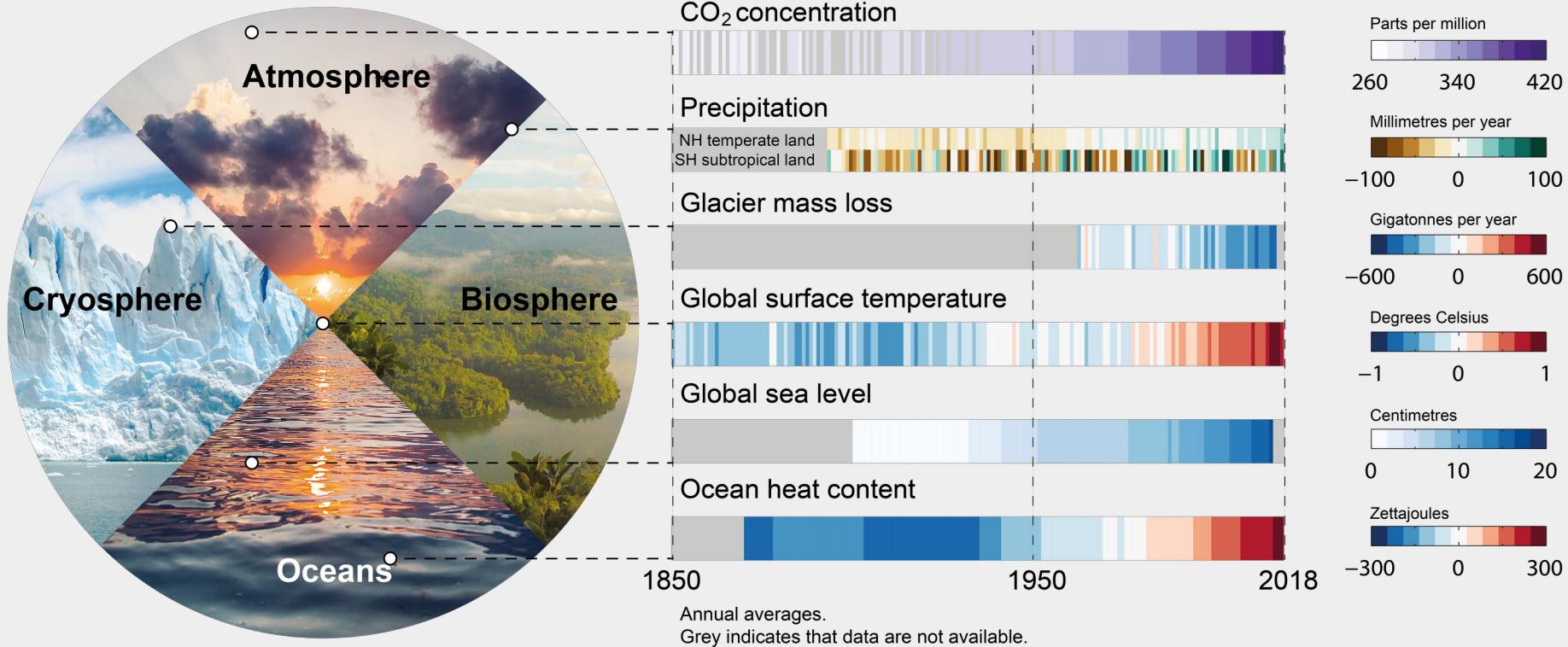


Severity of climate impact compared to buffering and adaptation

(Pfister & Brazdil 2006)

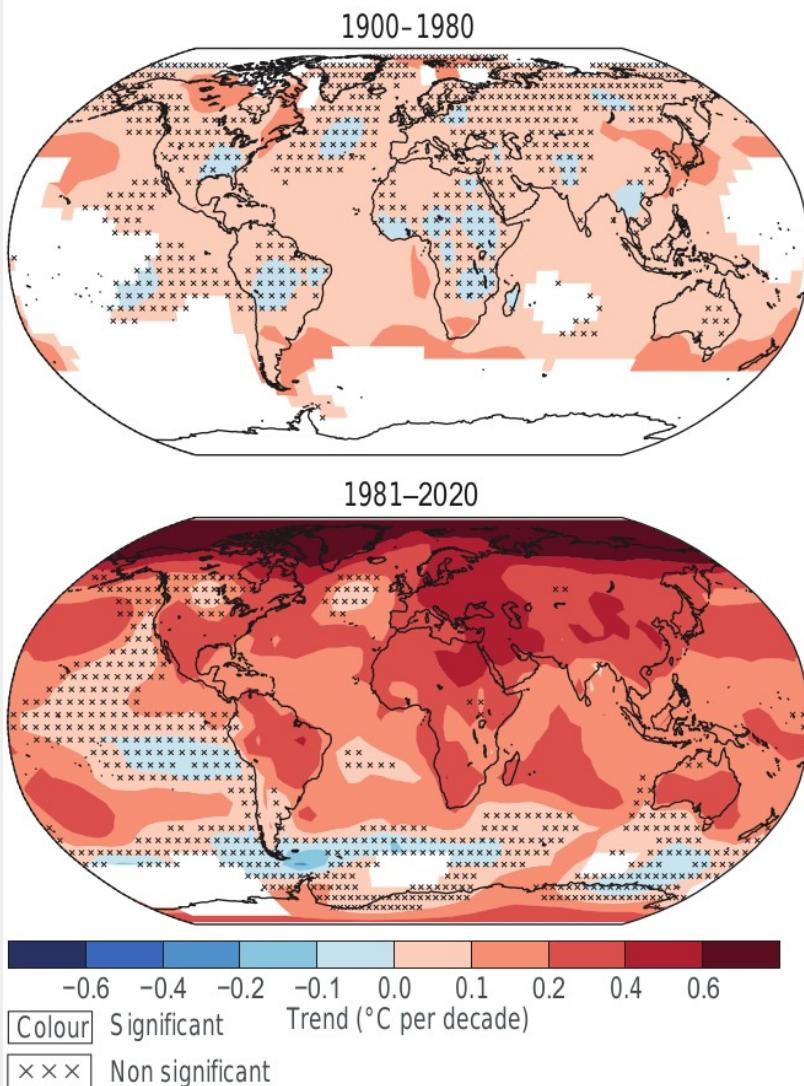
Beobachtete Veränderungen im Klimasystem seit 1850

17

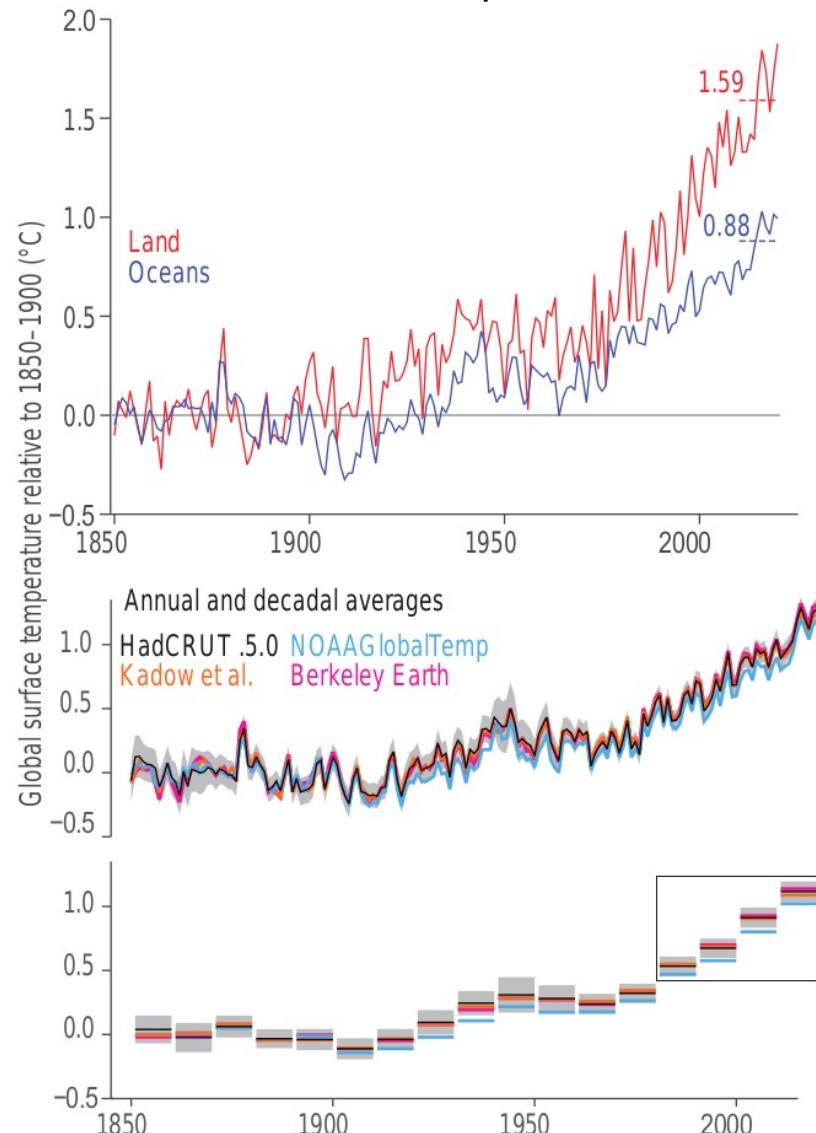


Klimavariabilität seit 1850

Trends der bodennahen Lufttemperatur



Bodennahe Lufttemperatur seit 1850



Arktische Amplifikation

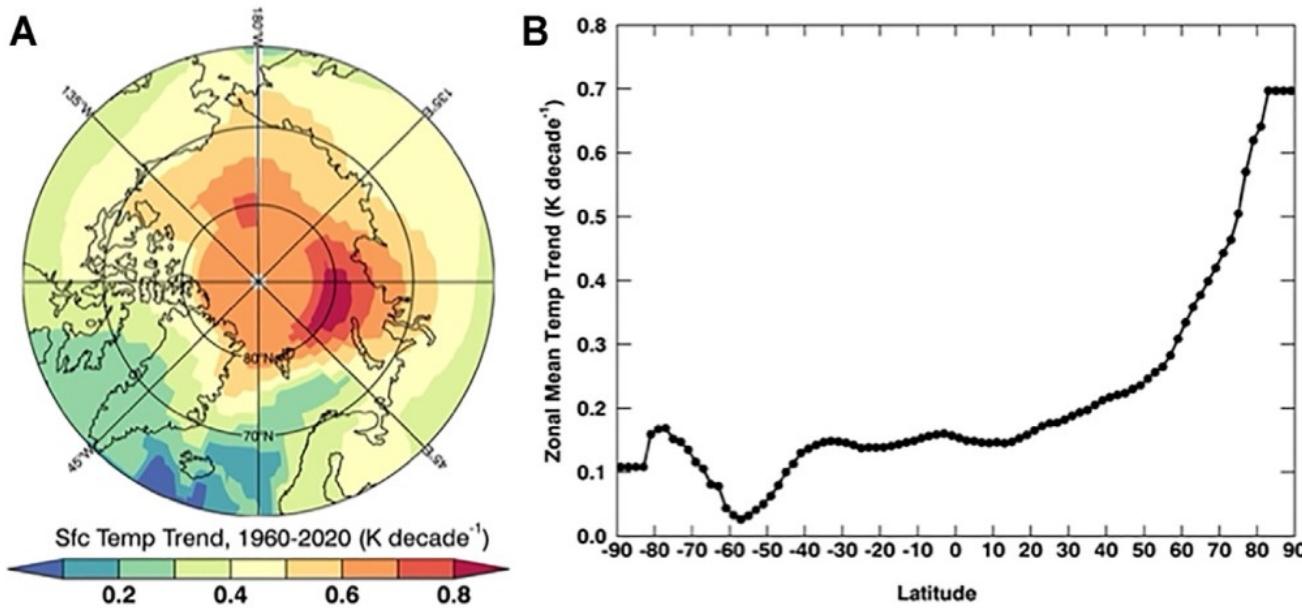


FIGURE 1 | Arctic and zonal mean linear surface temperature trends since 1960. **(A)** The spatial pattern of the surface temperature trend at $2^\circ \times 2^\circ$ resolution and **(B)** the zonal mean surface temperature trend (K decade^{-1}) assessed by applying a ordinary least squares fit linear regression to the GISTEMP time series (Lenssen et al., 2019; GISTEMP Team 2021).

Klimavariabilität seit 1850

Arktische Amplifikation

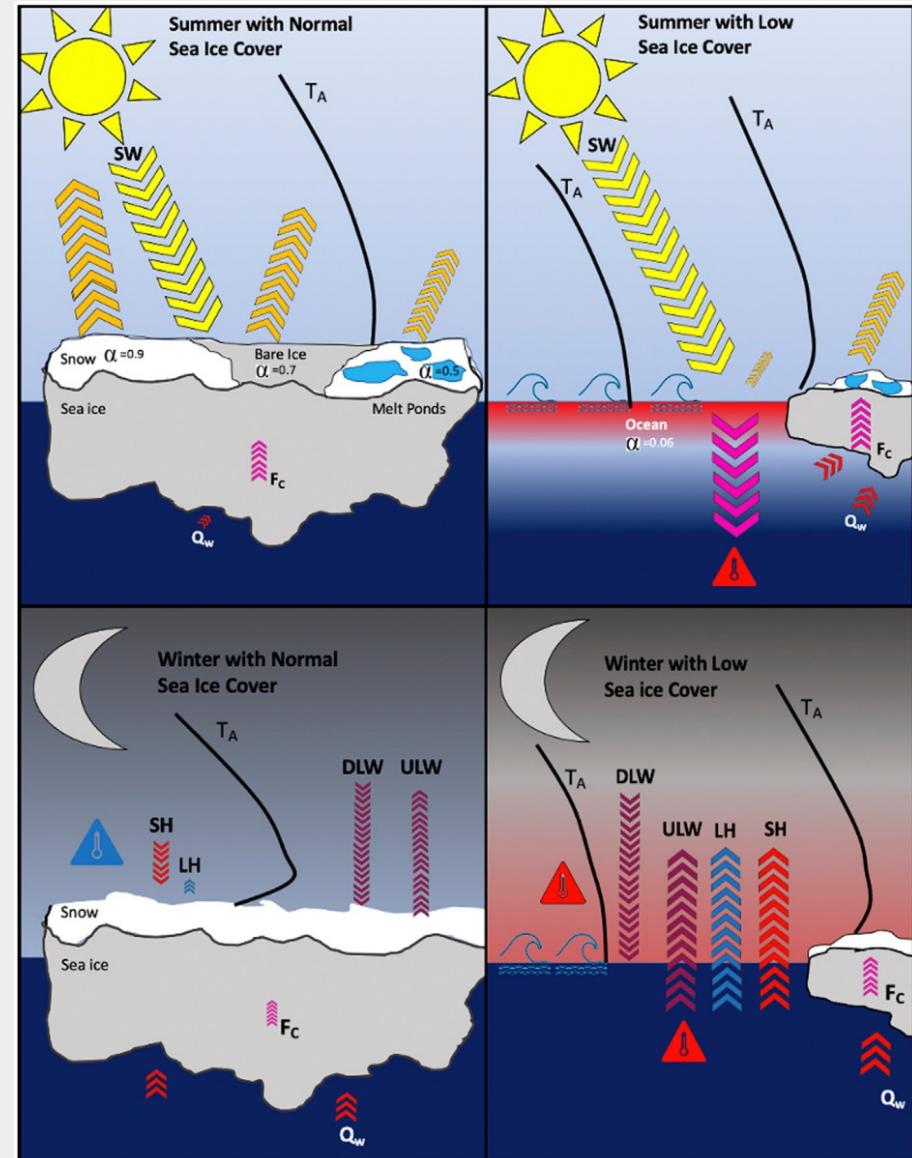
Eis-Albedo-Effekt als ein Beispiel positiver Rückkopplungen im Klimasystem

Radiation fluxes:

- shortwave (SW)
- downwelling longwave (DLW)
- upwelling LW (ULW)

Heat fluxes:

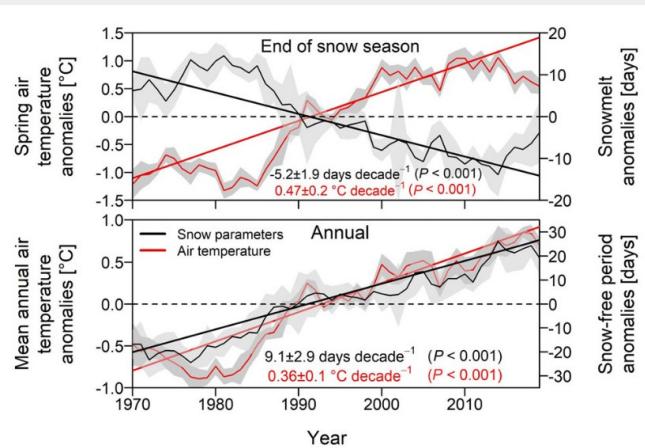
- sensible heat (SH)
- latent heat (LH)
- conductive heat flux through sea ice (F_c)
- oceanic heat flux to sea ice (Q_w)
- atmospheric temperature profiles (T_A)



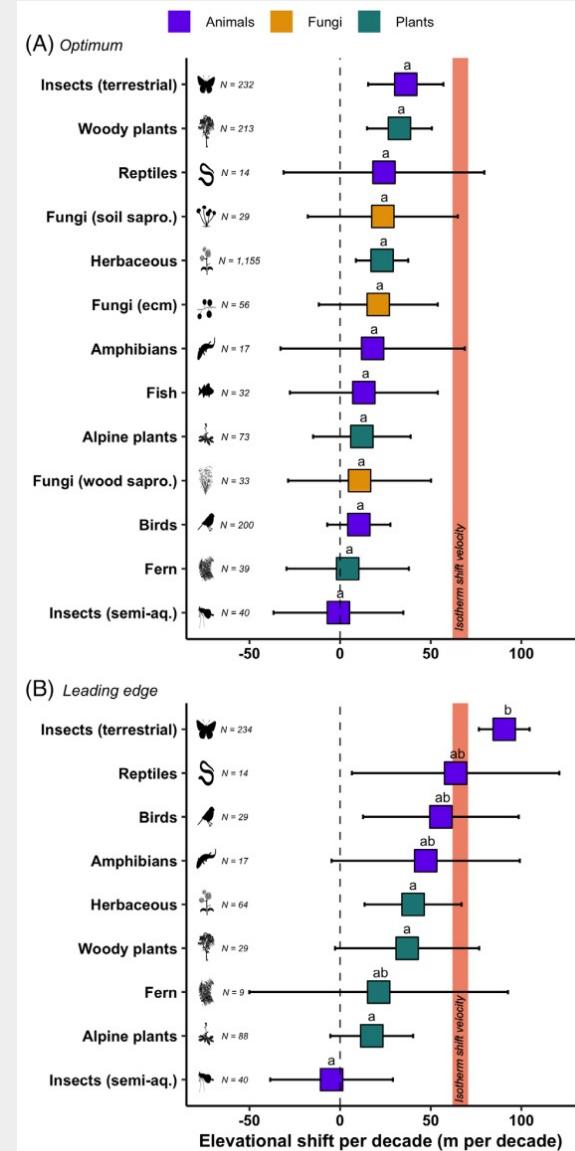
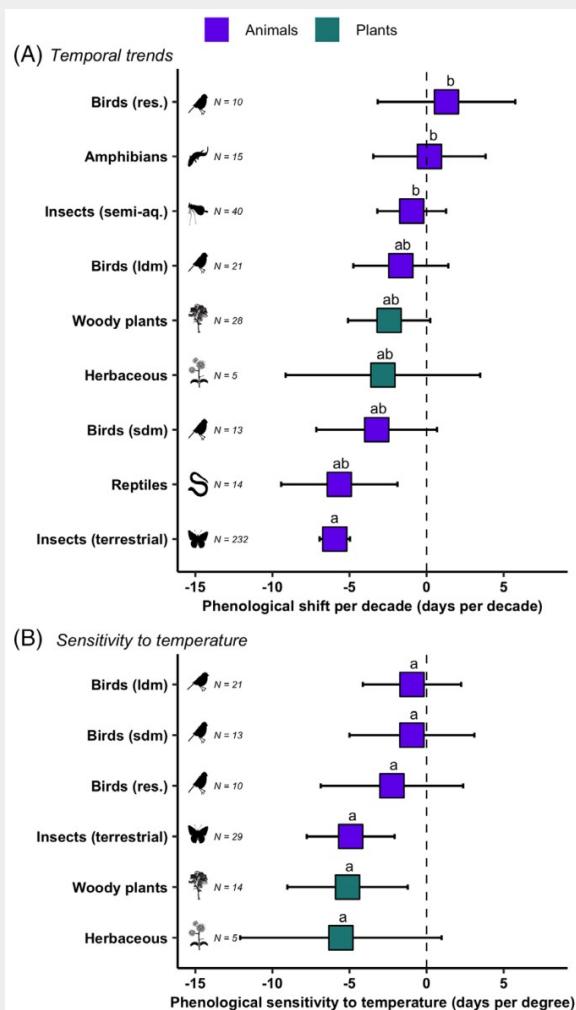
Klimavariabilität seit 1850

Phänologische und Höhenverschiebungen in den Europäischen Alpen

Lufttemperatur und Schneebedeckung in den Schweizer Alpen



Verschiebung der Frühjahrsphänologie

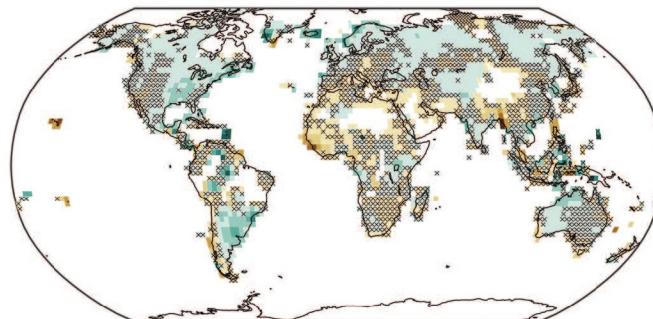


Höhenmigration

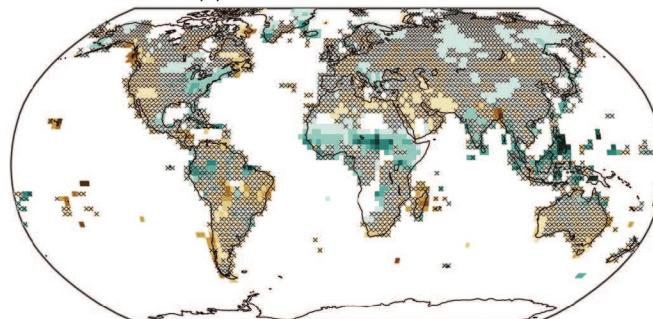
Klimavariabilität seit 1850

Trends des Niederschlags

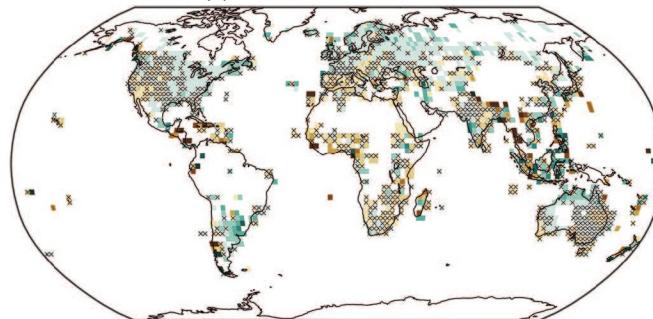
(a) CRU TS 4.04 1901–2019



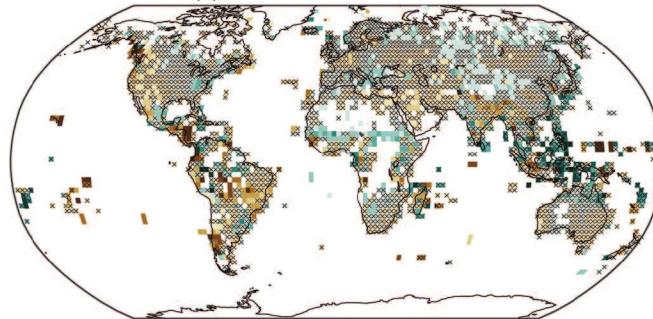
(d) CRU TS 4.04 1980–2019



(b) GPCC V2020 1901–2019

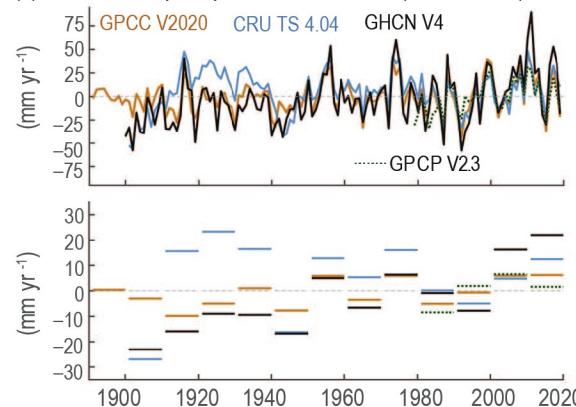


(e) GPCC V2020 1980–2019

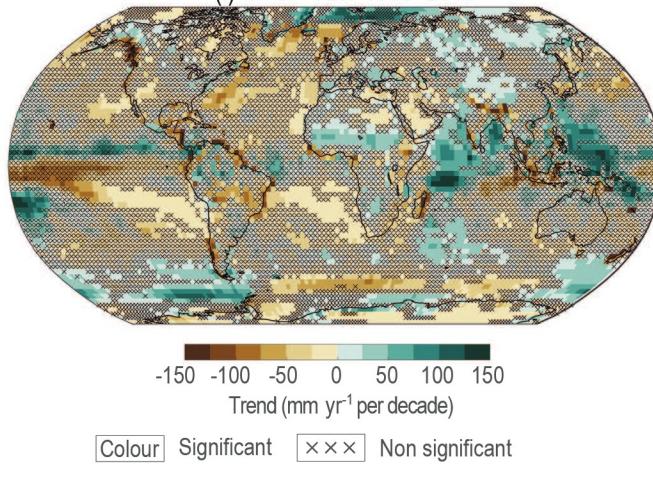


-60 -40 -20 0 20 40 60
Trend (mm yr^{-1} per decade)

(c) Global land precipitation anomalies (1891–2019)



(f) GPCP V2.3 1980–2019



Klimavariabilität seit 1850

Niederschlagsänderungen in S-Deutschland

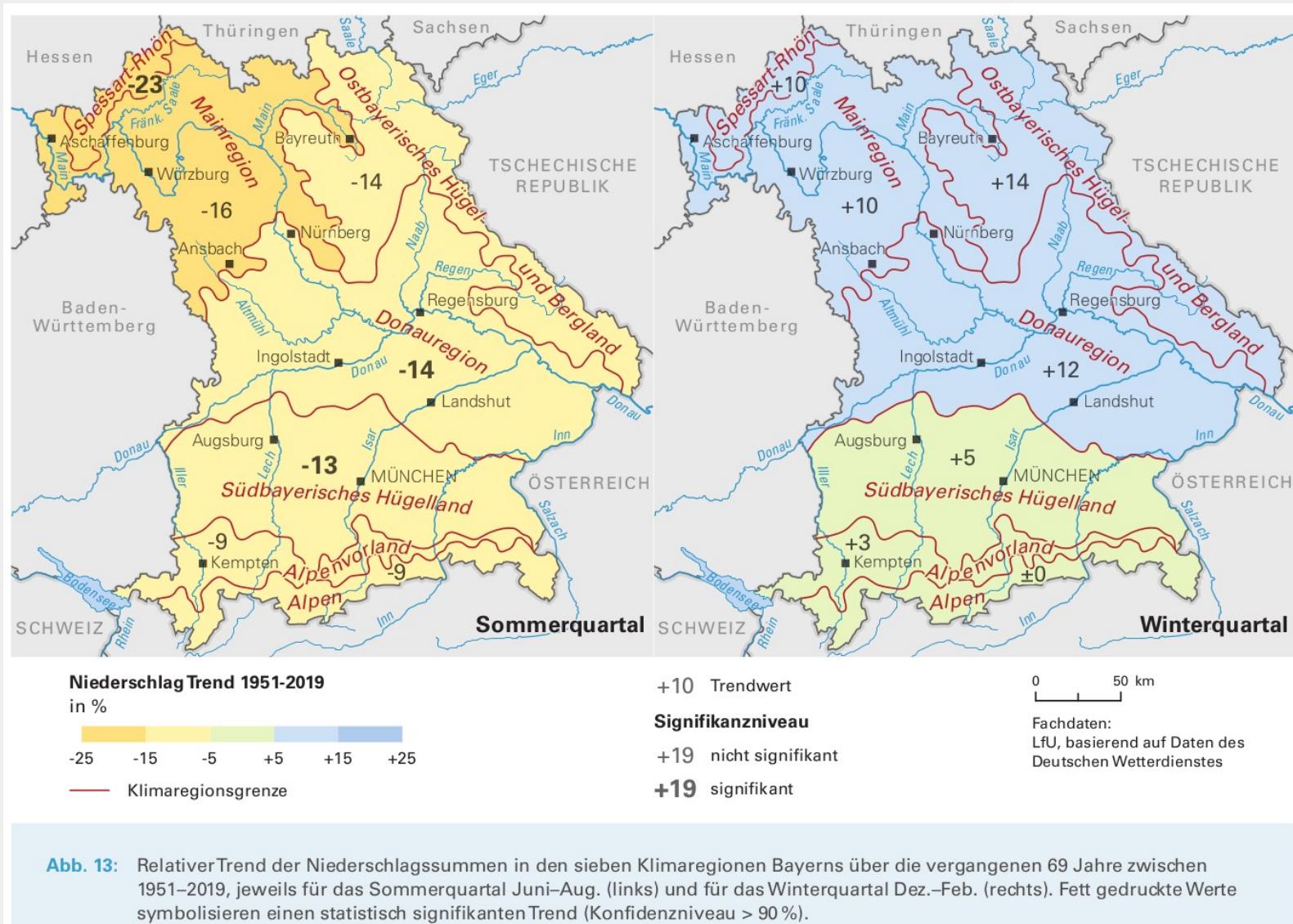
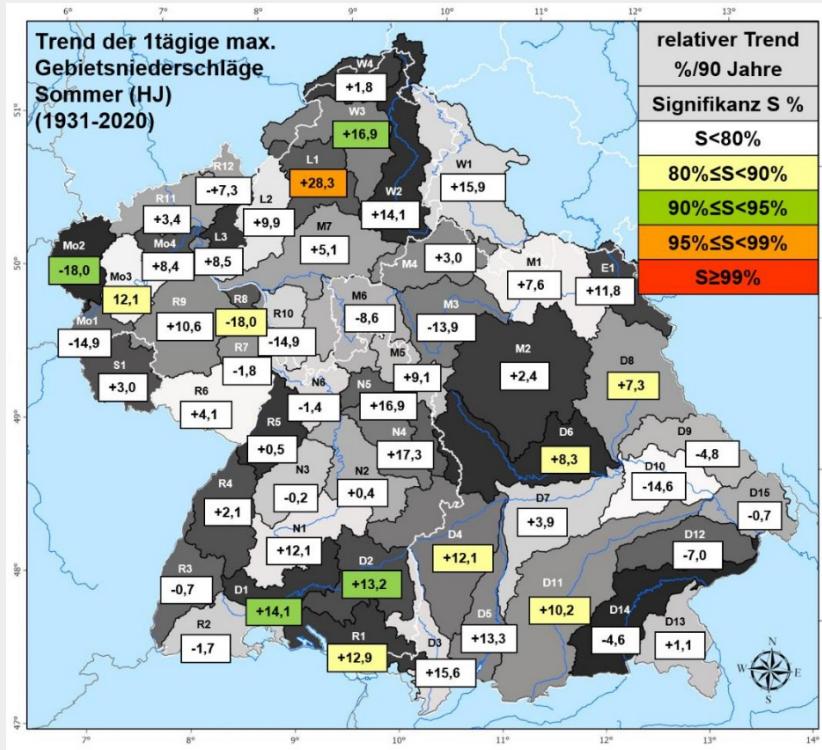


Abb. 13: Relativer Trend der Niederschlagssummen in den sieben Klimaregionen Bayerns über die vergangenen 69 Jahre zwischen 1951–2019, jeweils für das Sommerquartal Juni–Aug. (links) und für das Winterquartal Dez.–Feb. (rechts). Fett gedruckte Werte symbolisieren einen statistisch signifikanten Trend (Konfidenzniveau > 90 %).

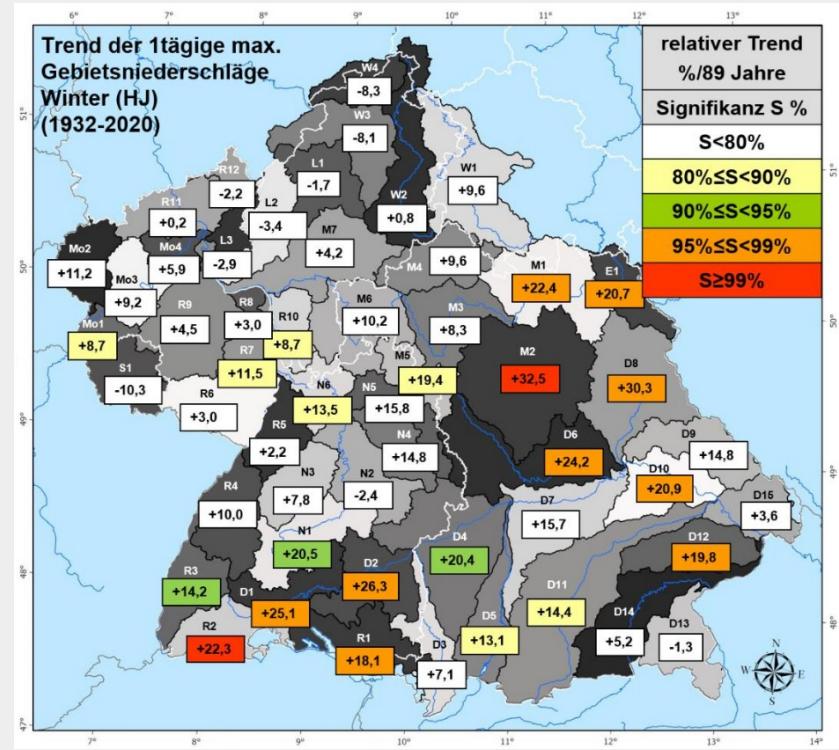
Klimavariabilität seit 1850

Starkniederschlagsänderungen in S-Deutschland

Sommerhalbjahr

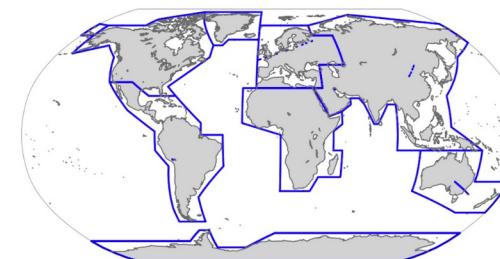
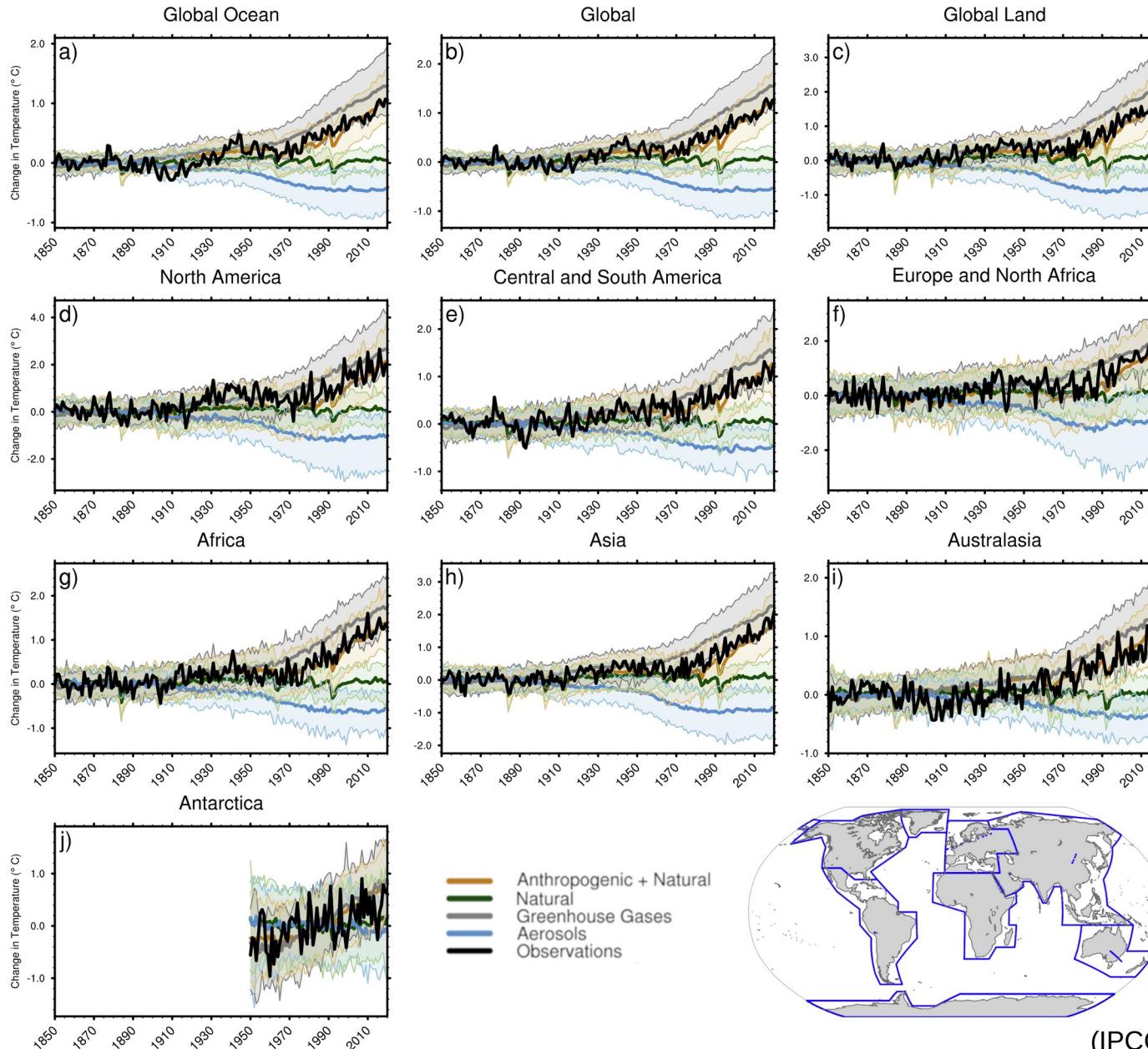


Winterhalbjahr

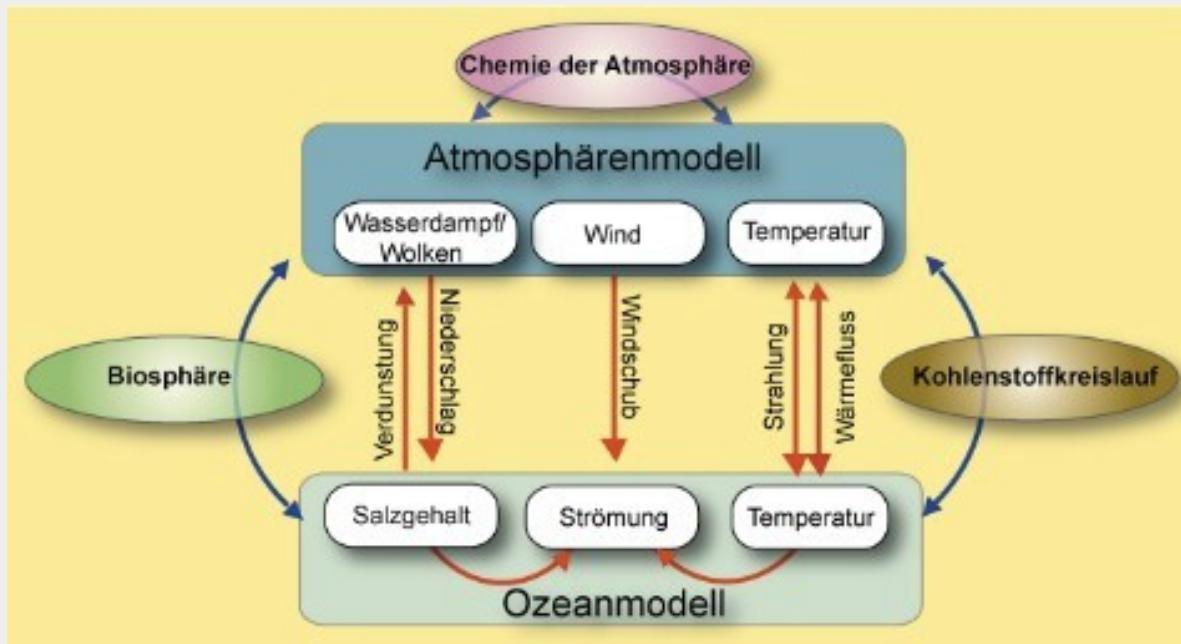


Klimawandel - natürlich oder anthropogen bedingt?

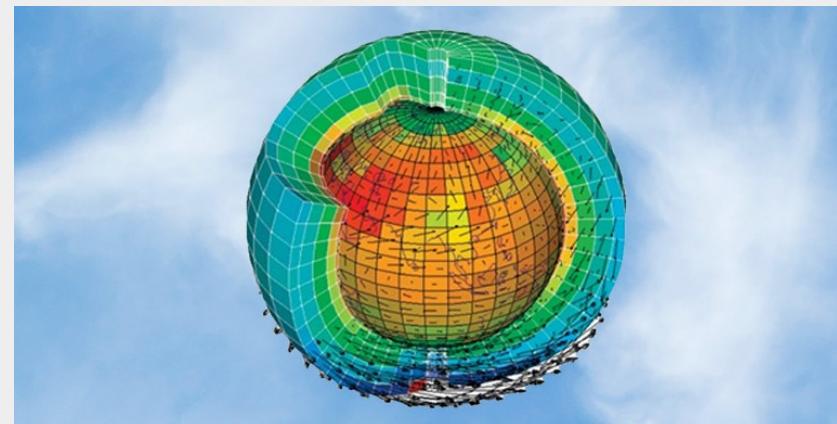
Modellierte Lufttemperatur (Anomalien zu 1850-1900)



(IPCC 2022)



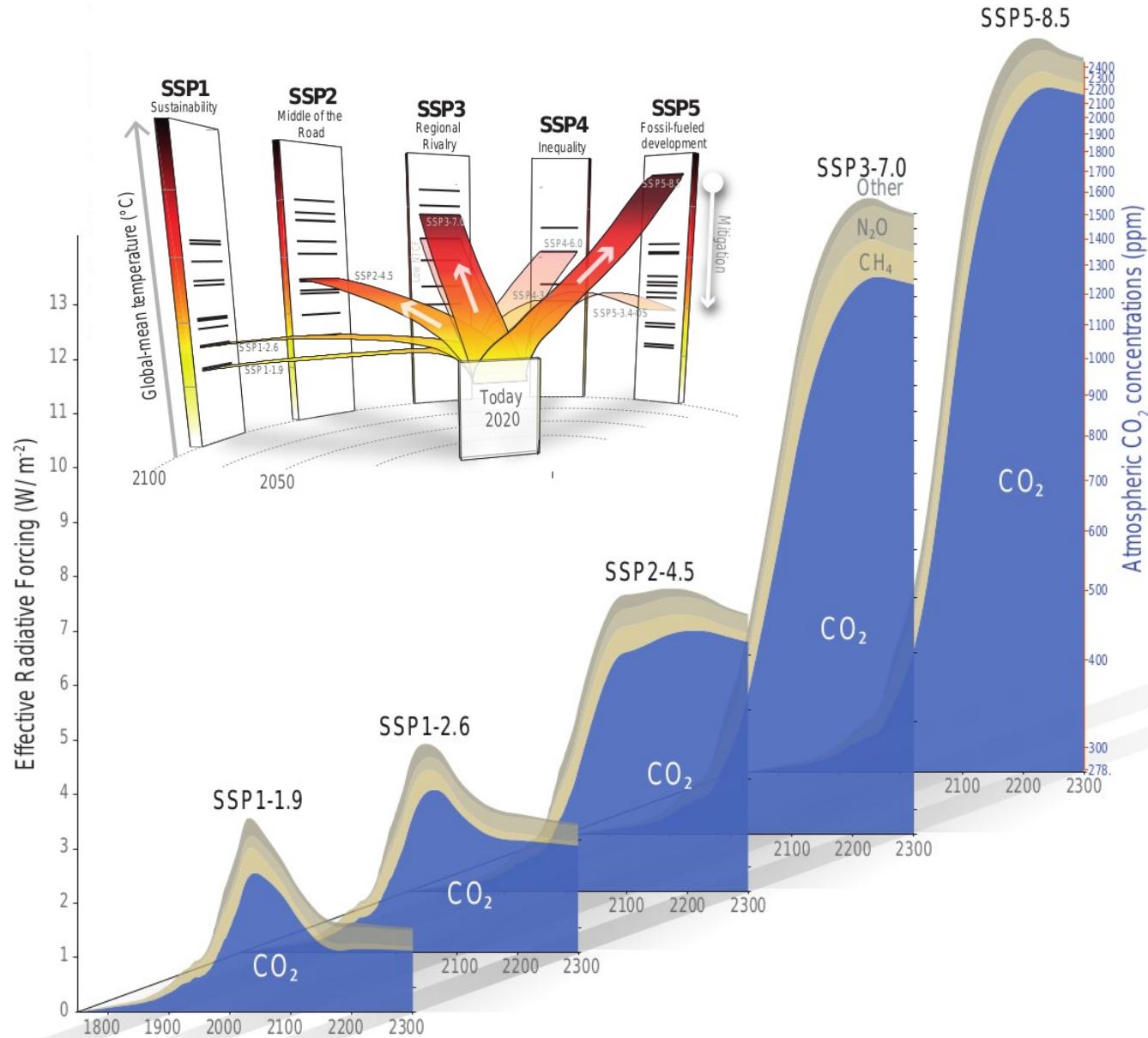
Schema eines gekoppelten Ozean-Atmosphäremodells mit weiteren angegliederten Modellen



Modellierung in einem 3-dimensionalen „Rechengitter“

Abschätzungen zukünftiger Klimaänderungen

Shared Socio-economic pathways scenarios



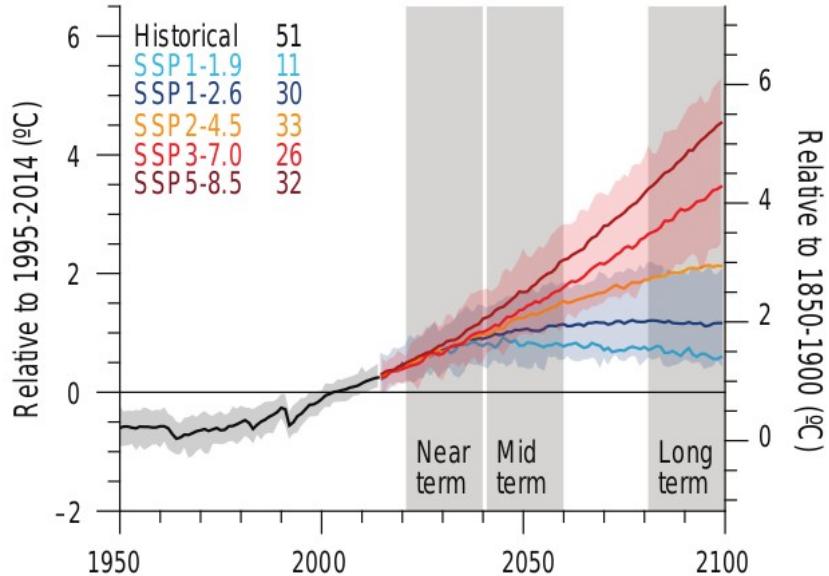
Abschätzungen zukünftiger Klimaänderungen

Shared Socio-economic pathways scenarios

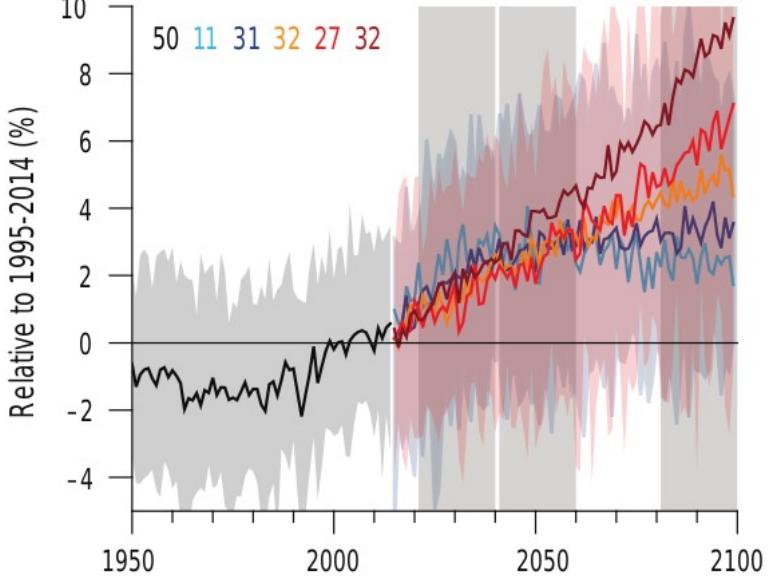
SSPX-Y Scenario	Description From an Emissions/Concentrations and Temperature Perspective (Table 4.2)		
SSP1-1.9	Holds warming to approximately 1.5°C above 1850–1900 in 2100 after slight overshoot (median) and implied net zero CO ₂ emissions around the middle of the century.		
SSP1-2.6	Stays below 2.0°C warming relative to 1850–1900 (median) with implied net zero CO ₂ emissions in the second half of the century.		
SSP4-3.4	A scenario between SSP1-2.6 and SSP2-4.5 in terms of end-of-century radiative forcing. It does not stay below 2.0°C in most CMIP6 runs (Chapter 4) relative to 1850–1900.		
SSP2-4.5	Scenario approximately in line with the upper end of aggregate NDC emissions levels by 2030 (Sections 1.2.2 and 4.3; SR1.5, (IPCC, 2018), Box 1). CO ₂ emissions remaining around current levels until the middle of the century. The SR1.5 assessed temperature projections for NDCs to be between 2.7°C and 3.4°C by 2100 (Section 1.2.2; SR1.5 (IPCC, 2018); Cross-Chapter Box 11.1), corresponding to the upper half of projected warming under SSP2-4.5 (Chapter 4). New or updated NDCs by the end of 2020 did not significantly change the emissions projections up to 2030, although more countries adopted 2050 net zero targets in line with SSP1-1.9 or SSP1-2.6. The SSP2-4.5 scenario deviates mildly from a ‘no-additional-climate-policy’ reference scenario, resulting in a best-estimate warming around 2.7°C by the end of the 21st century relative to 1850–1900 (Chapter 4).		
SSP4-6.0	The end-of-century nominal radiative forcing level of 6.0 W m ⁻² can be considered a ‘no-additional-climate-policy’ reference scenario, under SSP1 and SSP4 socio-economic development narratives.		
SSP3-7.0	An intermediate-to-high reference scenario resulting from no additional climate policy under the SSP3 socio-economic development narrative. CO ₂ emissions roughly double from current levels by 2100. SSP3-7.0 has particularly high non-CO ₂ emissions, including high aerosols emissions.		
SSP3-7.0-lowNTCF	A variation of the intermediate-to-high reference scenario SSP3-7.0 but with mitigation of CH ₄ and/or short-lived species such as black carbon and other short-lived climate forcers (SLCF). Note that variants of SSP3-7.0-lowNTCF differ in terms of whether CH ₄ emissions are reduced ^a (Sections 4.4 and 6.6).		
SSP5-3.4-OS (Overshoot)	A mitigation-focused variant of SSP5-8.5 that initially follows unconstrained emissions growth in a fossil fuel-intensive setting until 2040 and then implements the largest net negative CO ₂ emissions of all SSP scenarios in the second half of 21st century to reach SSP1-2.6 forcing levels in the 22nd century. Used to consider reversibility and strong overshoot scenarios in, or example, Chapters 4 and 5.		
SSP5-8.5	A high-reference scenario with no additional climate policy. CO ₂ emissions roughly double from current levels by 2050. Emissions levels as high as SSP5-8.5 are not obtained by integrated assessment models (IAMs) under any of the SSPs other than the fossil-fuelled SSP5 socio-economic development pathway.		

Abschätzungen zukünftiger Klimaänderungen

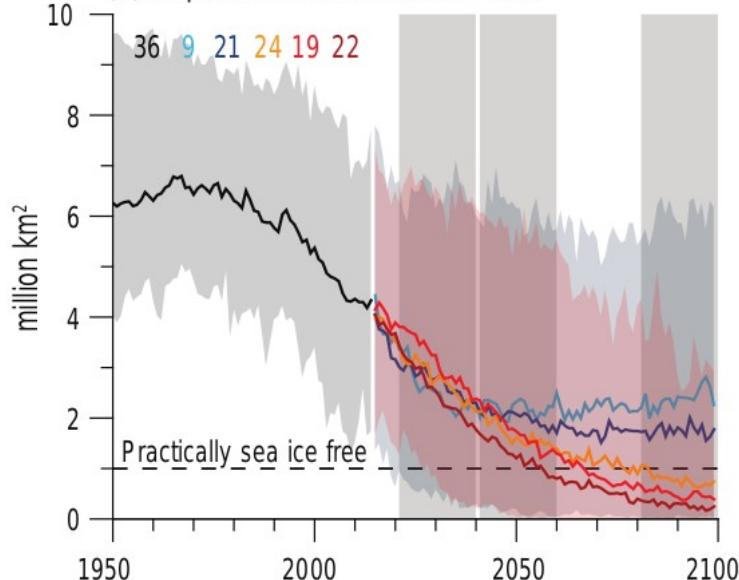
(a) Global temperature change



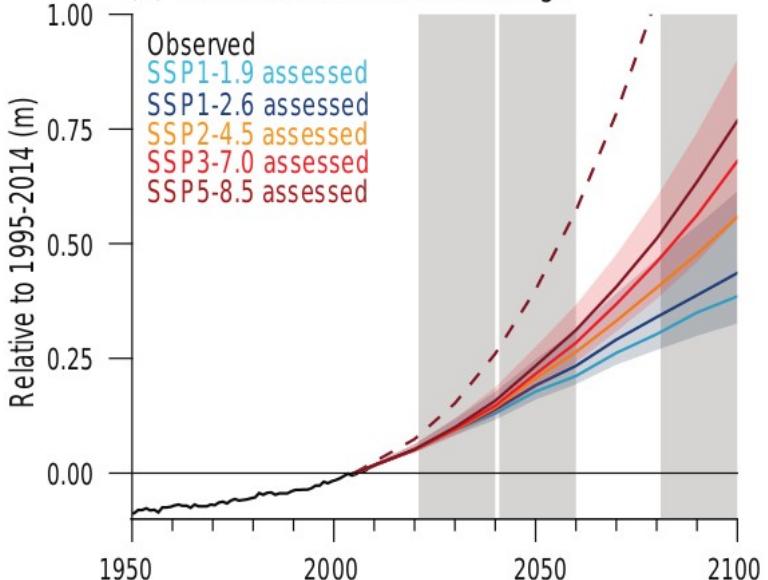
(b) Global land precipitation change



(c) September Arctic sea ice area

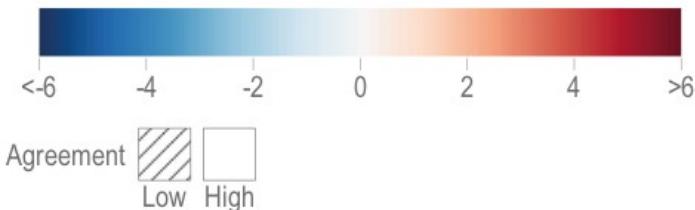


(d) Global mean sea level change



Abschätzungen zukünftiger Klimaänderungen

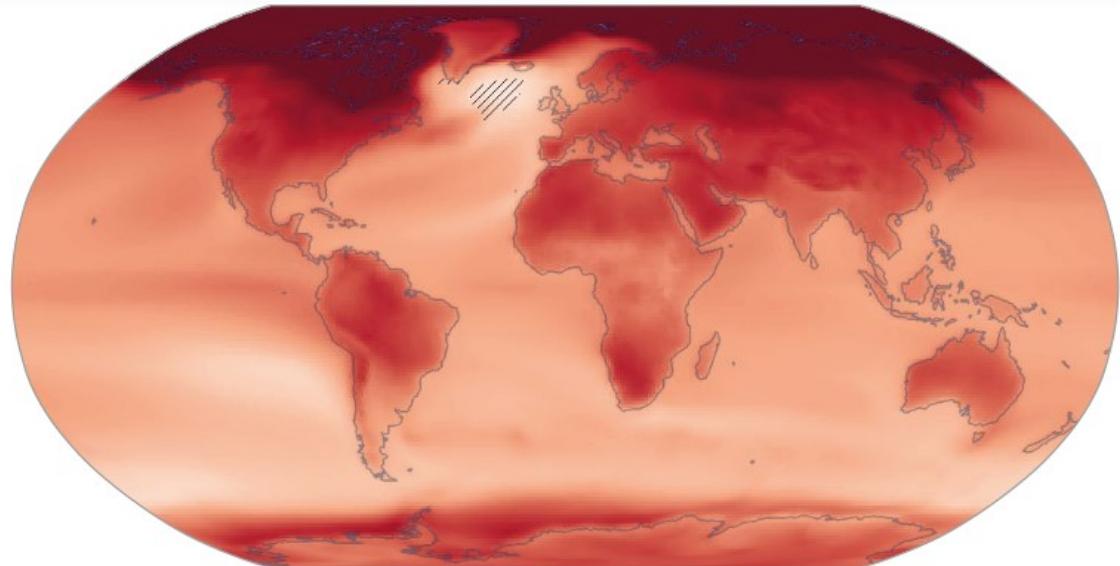
Projected changes ($^{\circ}\text{C}$)



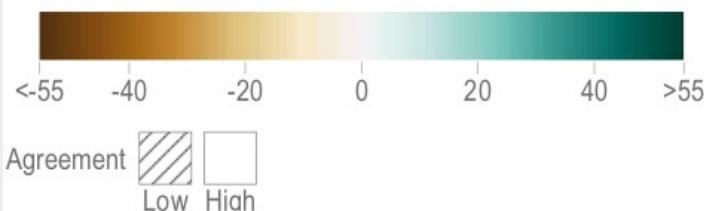
Mean temperature change at $+4.0^{\circ}\text{C}$ Global Warming

SSP5 8.5 relative to period 1995–2014

CMIP6 - Annual (20 models)



Projected changes (%)

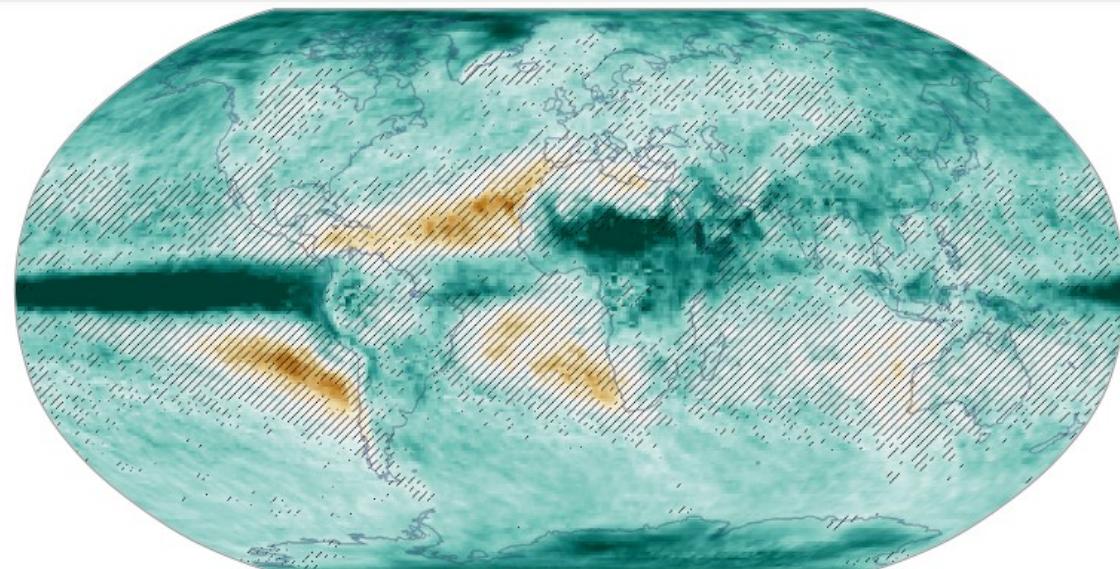


Maximum 1-day precipitation change (RX1day) (%)

at $+4.0^{\circ}\text{C}$ Global Warming

SSP5 8.5 relative to period 1995–2014

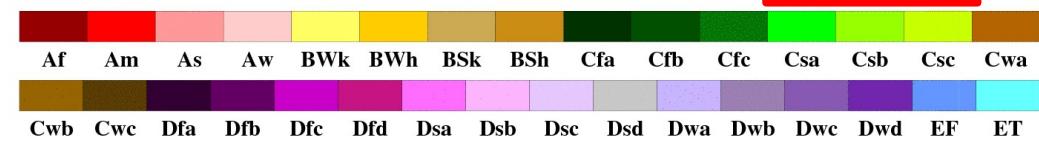
CMIP6 - Annual (19 models)



Abschätzungen zukünftiger Klimaänderungen

World Map of Köppen–Geiger Climate Classification

observed using CRU TS 2.1 temperature and GPCC Full v4 precipitation data period 1976 to 2000



Main climates

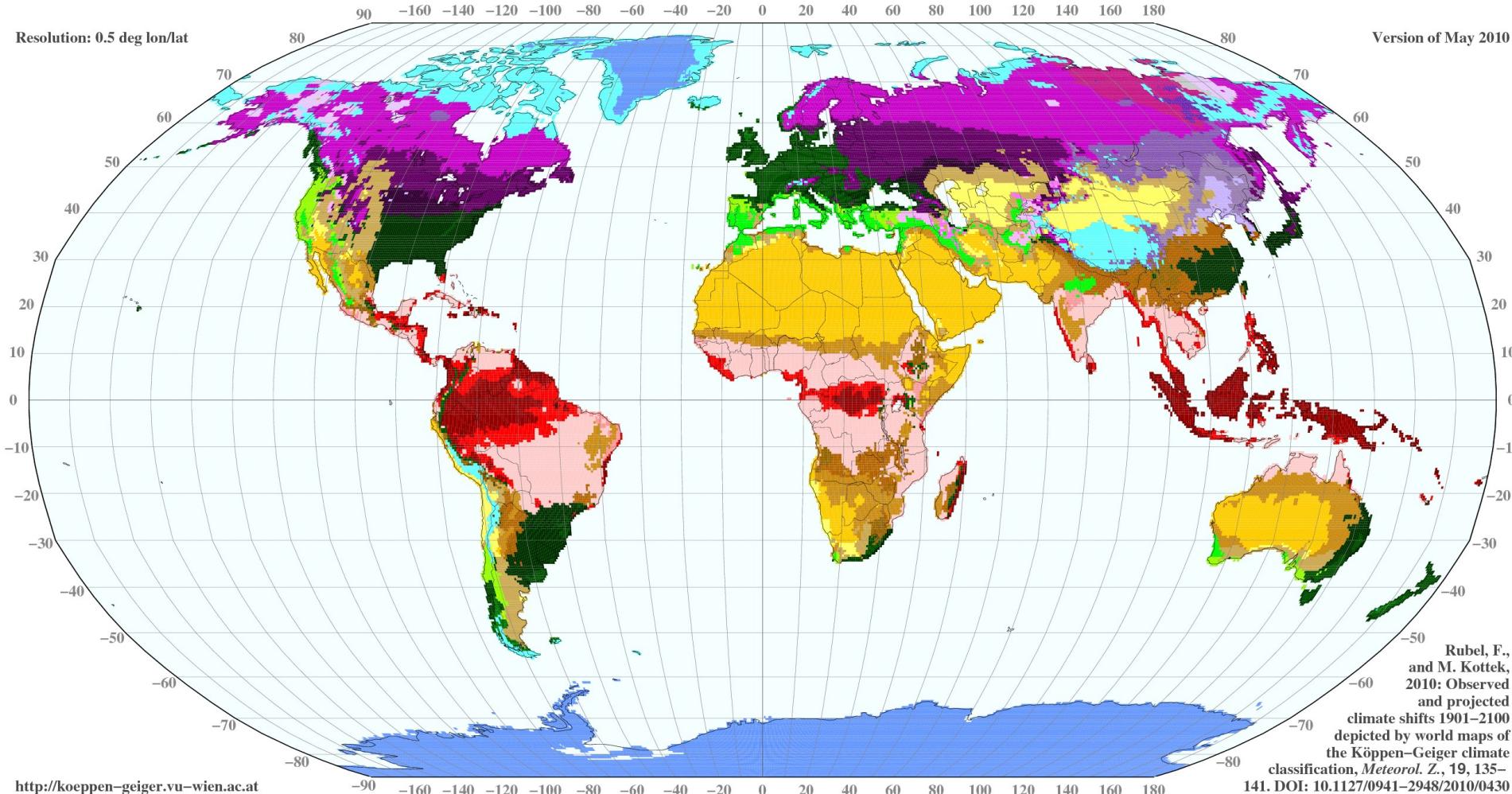
- A: equatorial
- B: arid
- C: warm temperate
- D: snow
- E: polar

Precipitation

- W: desert
- S: steppe
- f: fully humid
- s: summer dry
- w: winter dry
- m: monsoonal

Temperature

- | | |
|--------------------------|-----------------|
| h: hot arid | F: polar frost |
| k: cold arid | T: polar tundra |
| a: hot summer | |
| b: warm summer | |
| c: cool summer | |
| d: extremely continental | |

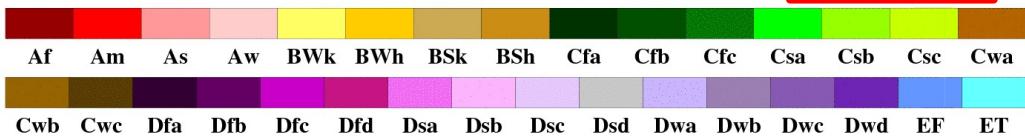


Abschätzungen zukünftiger Klimaänderungen

World Map of Köppen–Geiger Climate Classification

projected using IPCC B2 Tyndall SC 2.03 temperature and precipitation scenarios

period 2076 to 2100



Main climates

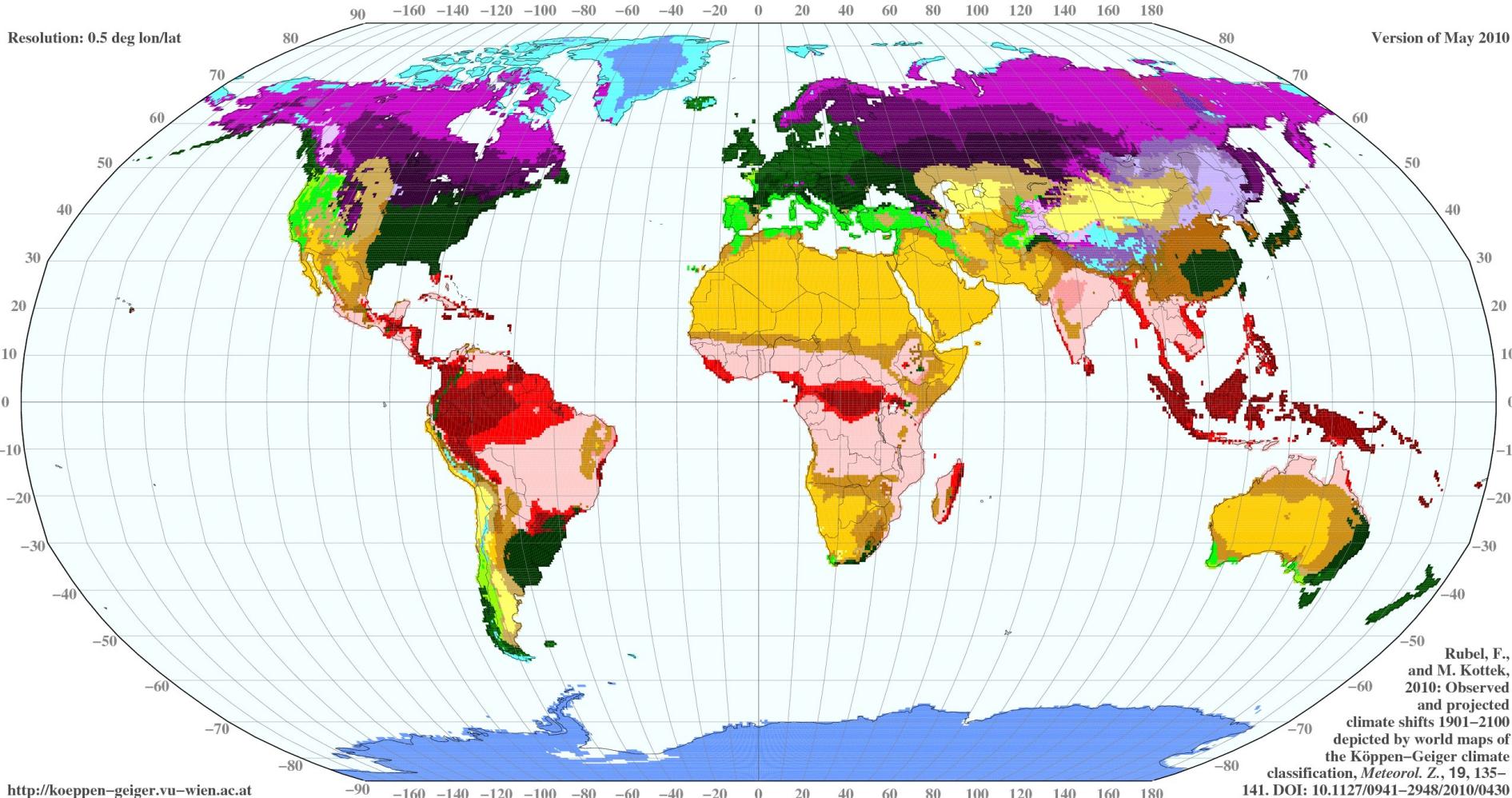
- A: equatorial
- B: arid
- C: warm temperate
- D: snow
- E: polar

Precipitation

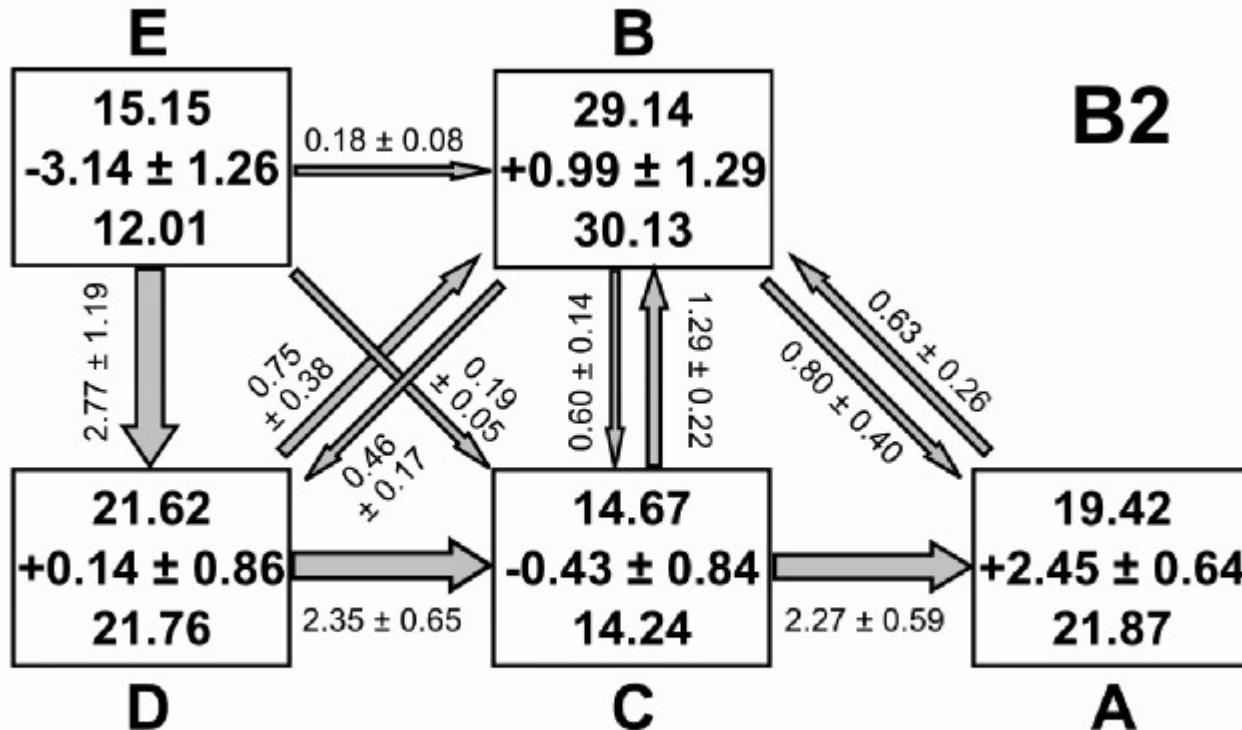
- W: desert
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Temperature

- h: hot arid
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Abschätzungen zukünftiger Klimaänderungen

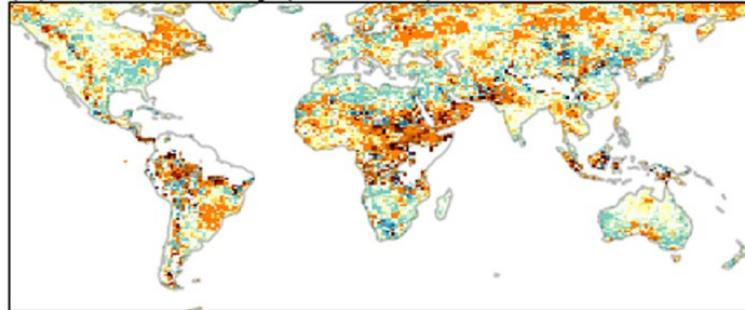


Shifts between the main Köppen-Geiger climates of the periods 1976-2000 vs. 2076-2100 for IPCC B2 emission scenario. Mean values and ranges of 5 GCM projections are given in percentage of the global land area. 1 % corresponds to an area of $1.43 \cdot 10^6 \text{ km}^2$.

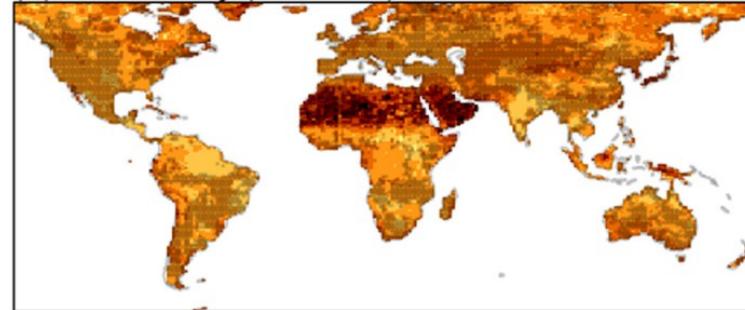
Abschätzungen zukünftiger Klimaänderungen

Veränderungen „kombinierter“ Extremereignisse („compound events“)
(2066-2100 vs. 1980-2014)

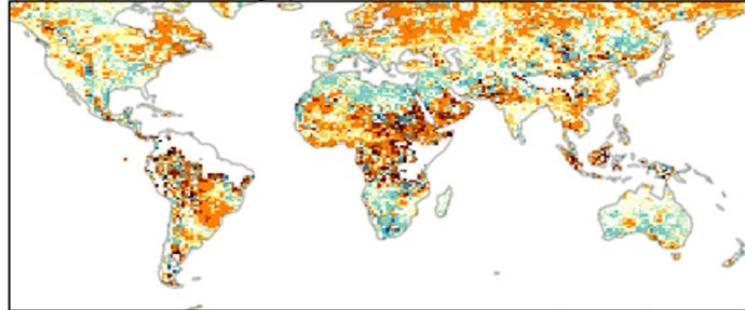
(a) Wet and windy (SSP1-2.6)



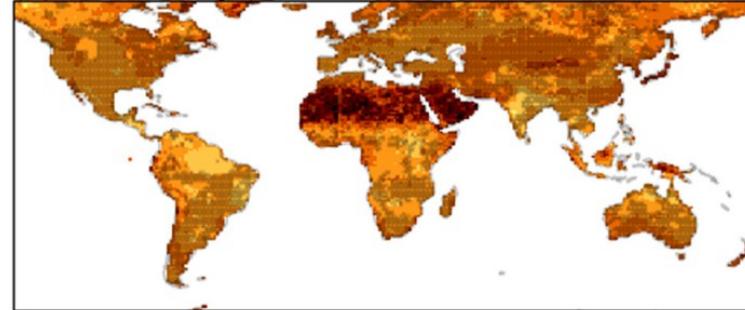
(d) Hot and dry (SSP1-2.6)



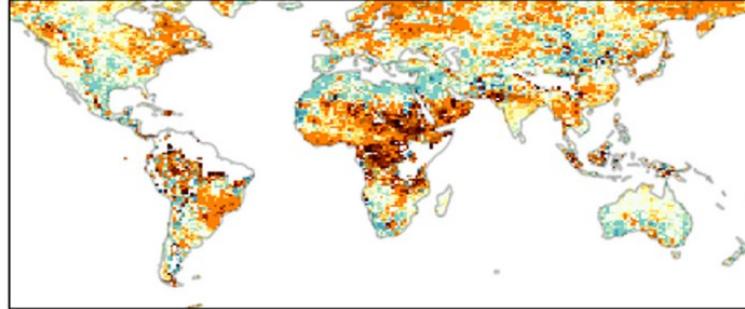
(b) Wet and windy (SSP2-4.5)



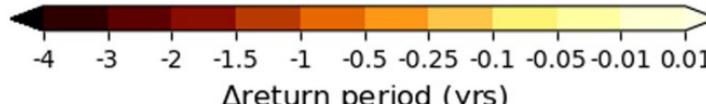
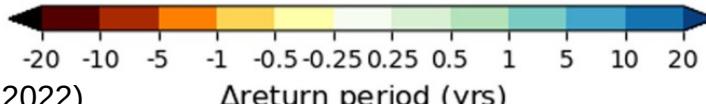
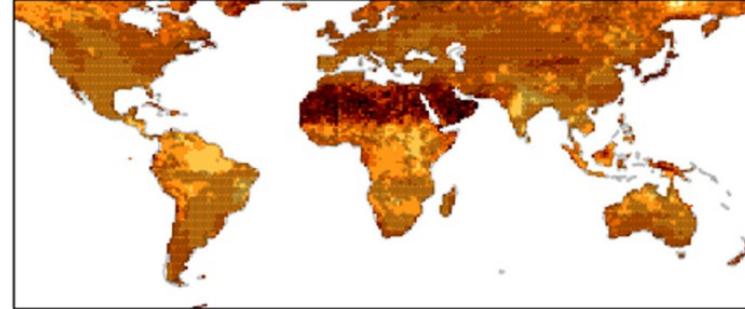
(e) Hot and dry (SSP2-4.5)



(c) Wet and windy (SSP5-8.5)



(f) Hot and dry (SSP5-8.5)



Abschätzungen zukünftiger Klimaänderungen

Thermische Klima-Kennwerte für Bayern

Tab. 2: Bayernweite Änderung von Klima-Kennwerten. Der Trend der Vergangenheit wurde aus einer Zeitreihe von Messwerten zwischen 1951 und 2019 ermittelt. Die Klimaänderung der nahen Zukunft (2021–2050) und fernen Zukunft (2071–2100) stellt die im **Median** simulierte Änderung des 30-jährigen Mittels gegenüber dem Referenzzeitraum 1971–2000 dar, jeweils für ein Klimaschutzzszenario gemäß „2-Grad-Obergrenze“ (RCP2.6) und ein Szenario „ohne Klimaschutz“ (RCP8.5).

Klima-Kennwert	Trend der Vergangenheit (1951 – 2019)		Nahe Zukunft (2021–2050) (Erwartete Änderung pro 50 a)		Ferne Zukunft (2071–2100) (Erwartete Änderung pro 100 a)	
	Seit 1951	Pro 50 a	RCP2.6	RCP8.5	RCP2.6	RCP8.5
Temperatur [°C]	+1,9	+1,4	+1,0	+1,4	+1,1	+3,8
Hitzetage ($T_{\max} > 30^{\circ}\text{C}$)	+8,5	+6,2	+3	+5	+4	+22
Sommertage ($T_{\max} > 25^{\circ}\text{C}$)	+25	+18	+10	+12	+11	+40
Tropennächte ($T_{\min} > 20^{\circ}\text{C}$)	+0,03	+0,02	+0,2	+0,3	+0,3	+6,2
Frosttage ($T_{\min} < 0^{\circ}\text{C}$)	-26	-19	-18	-28	-19	-65
Eistage ($T_{\max} < 0^{\circ}\text{C}$)	-15	-11	-8	-12	-10	-23

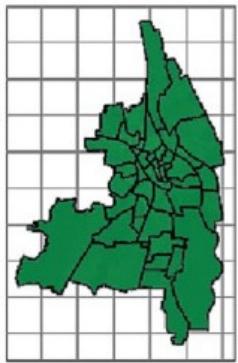
Abschätzungen zukünftiger Klimaänderungen

Entwicklung der Anzahl von Hitzetagen in Augsburg

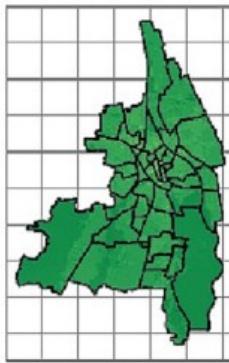
Number of heat days for different 31 year periods in Augsburg

Multi-Model Mean

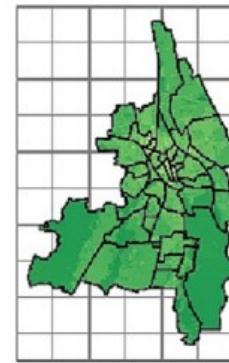
1970-2000



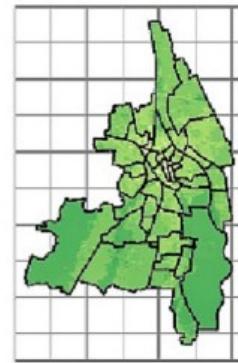
2010-2040



2040-2070

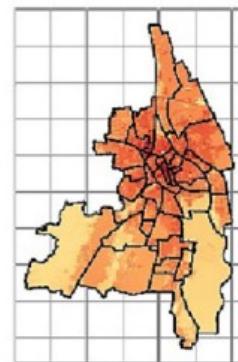
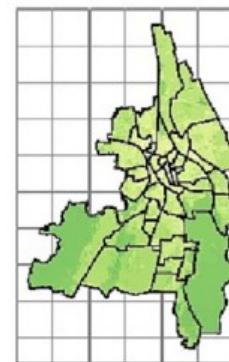
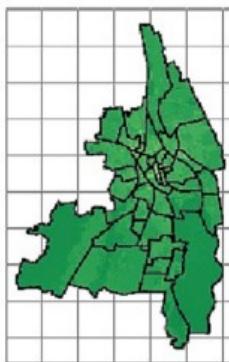
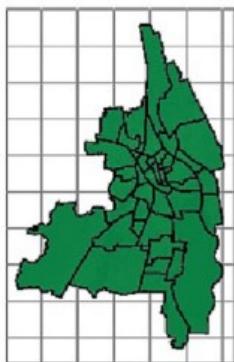


2070-2100



RCP 4.5

RCP 8.5



Number of heat days



Klimawandelanpassung

Anpassung an Hitzebelastung im urbanen Raum

Numerische Modellierung von Hitze-Hotspots

Mittels ENVImet für 300m x 300m Modell-Domains



Modell-Domain „Karlstrasse“

Klimawandelanpassung

Anpassung an Hitzebelastung im urbanen Raum

Numerische Modellierung von Hitze-Hotspots

„Modellwelt“ - Ist-Zustand



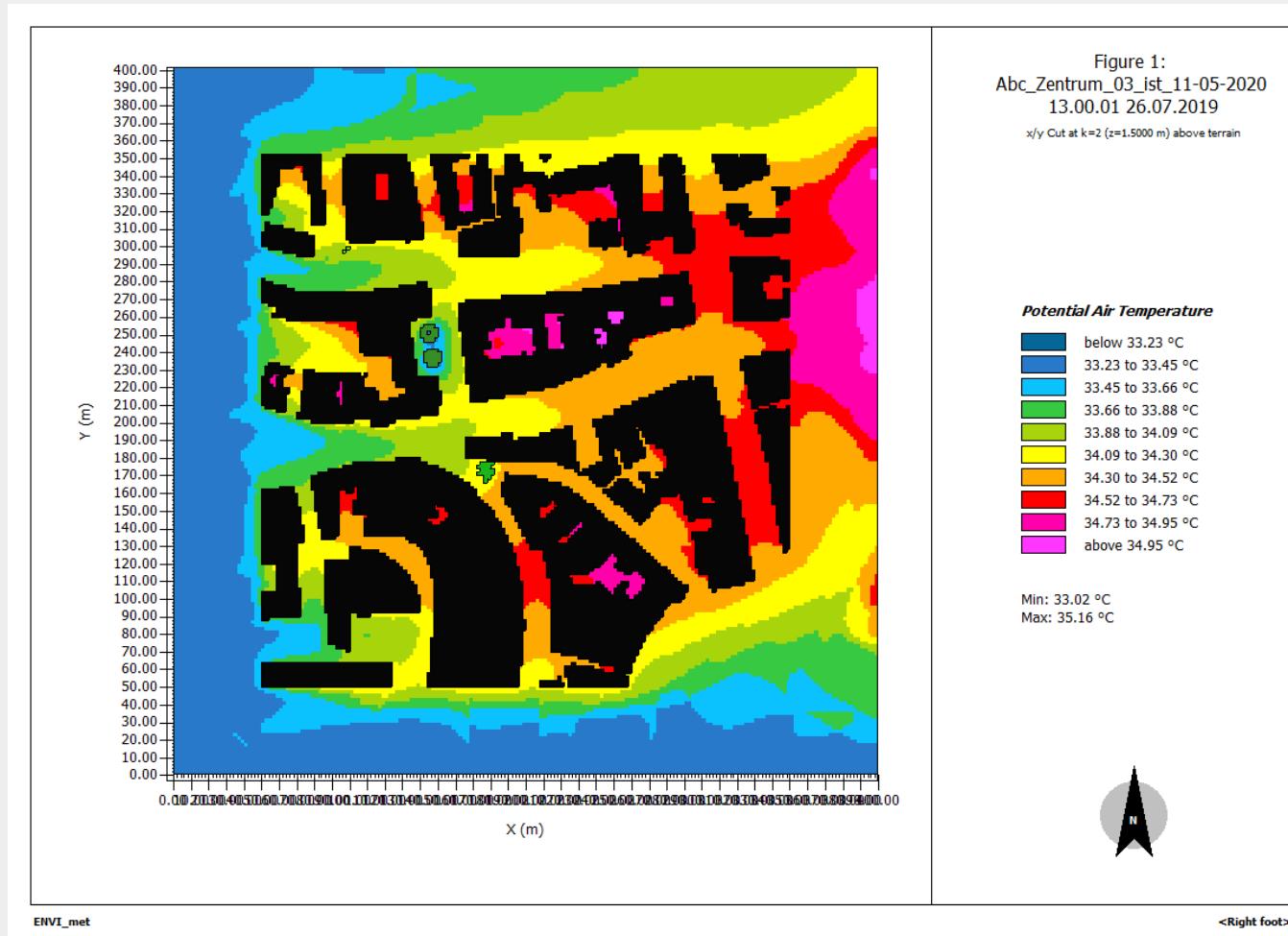
Modell-Domain „Karlstrasse“

Klimawandelanpassung

Anpassung an Hitzebelastung im urbanen Raum

Numerische Modellierung von Hitze-Hotspots

„Modellwelt“ - Ist-Zustand → modellierte Lufttemperatur (13:00)



Modell-Domain „Karlstrasse“

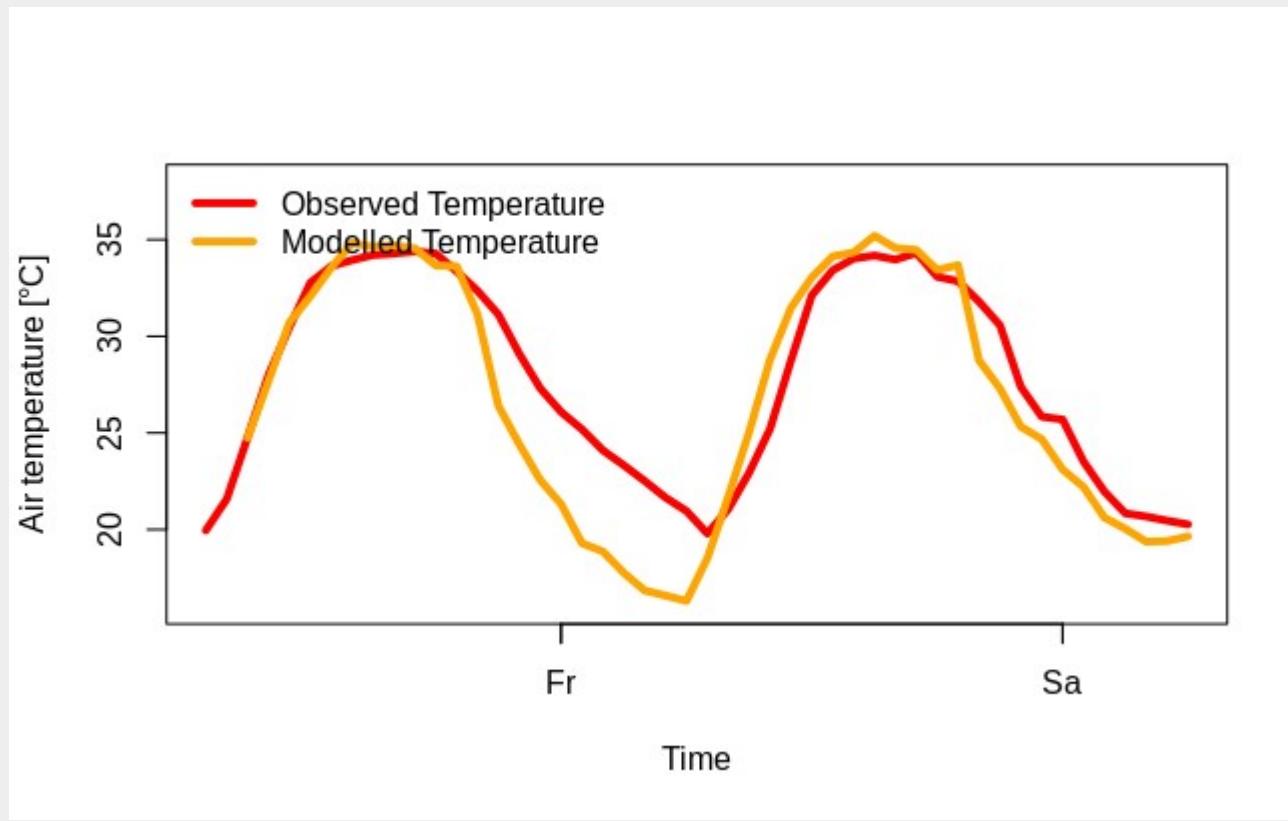
Klimawandelanpassung

Anpassung an Hitzebelastung im urbanen Raum

Numerische Modellierung von Hitze-Hotspots

„Modellwelt“ - Ist-Zustand → → Modellvalidierung

Vergleich gemessener Lufttemperaturen (Loggermessnetz Uni A/HMGU) mit modellierten Werten (für nächstgelegenen Gitterpunkt)



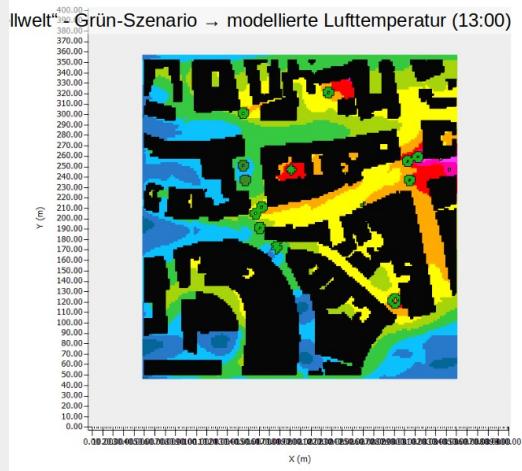
Modell-Domain „Karlstrasse“

Klimawandelanpassung

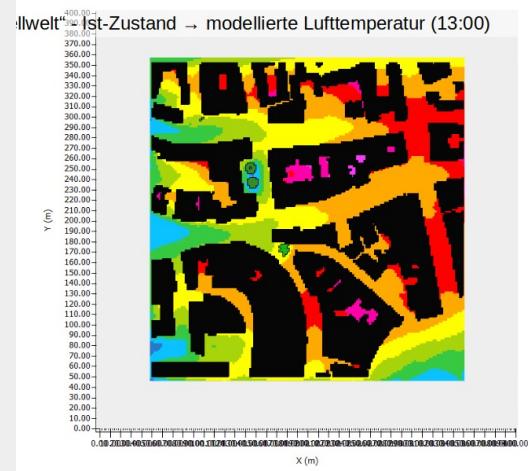
Anpassung an Hitzebelastung im urbanen Raum

Numerische Modellierung von Hitze-Hotspots

„Modellwelt“ - Grün-Szenario minus Ist-Zustand



minus



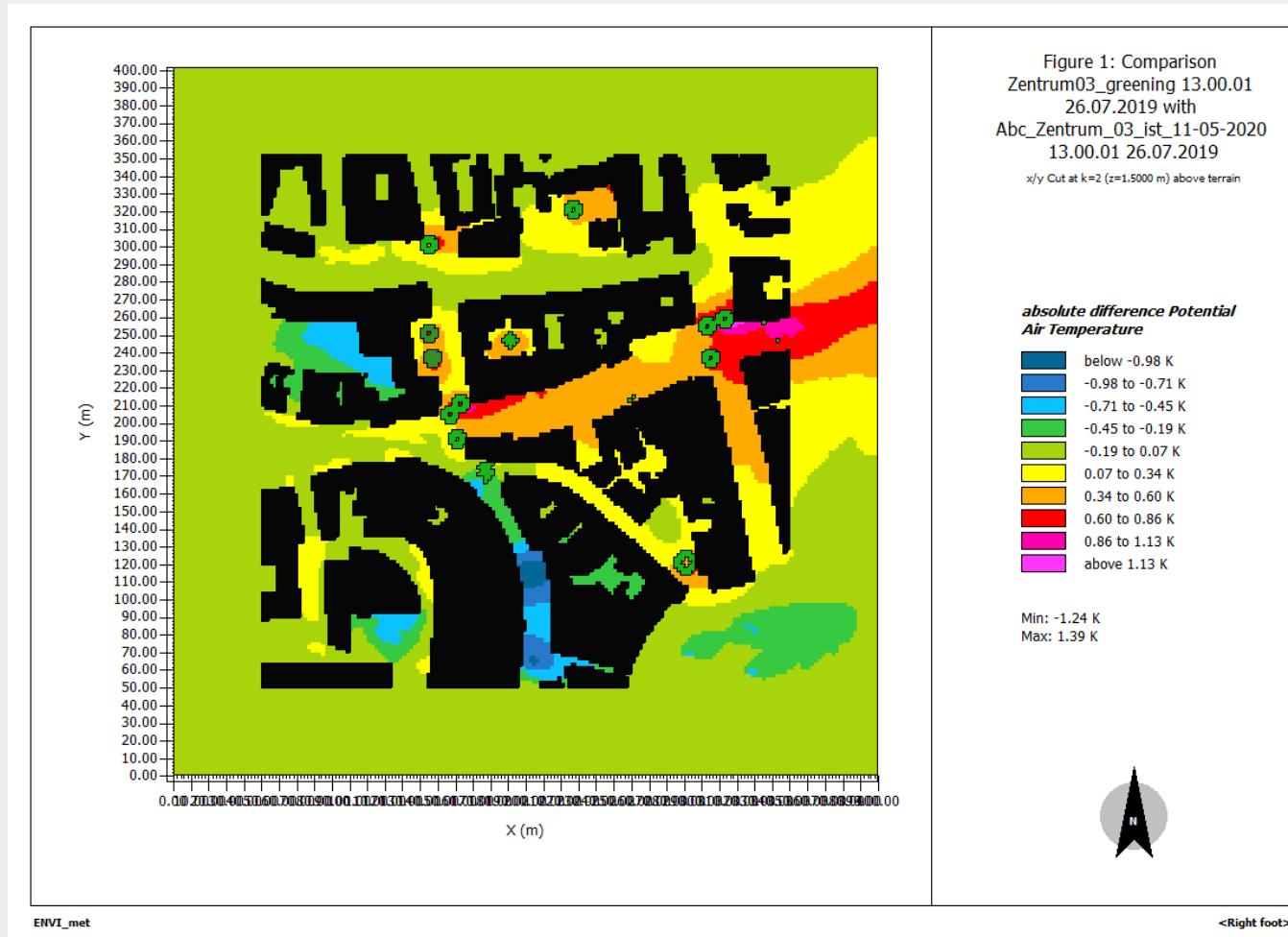
Modell-Domain „Karlstrasse“

Klimawandelanpassung

Anpassung an Hitzebelastung im urbanen Raum

Numerische Modellierung von Hitze-Hotspots

„Modellwelt“ - Grün-Szenario minus Ist-Zustand



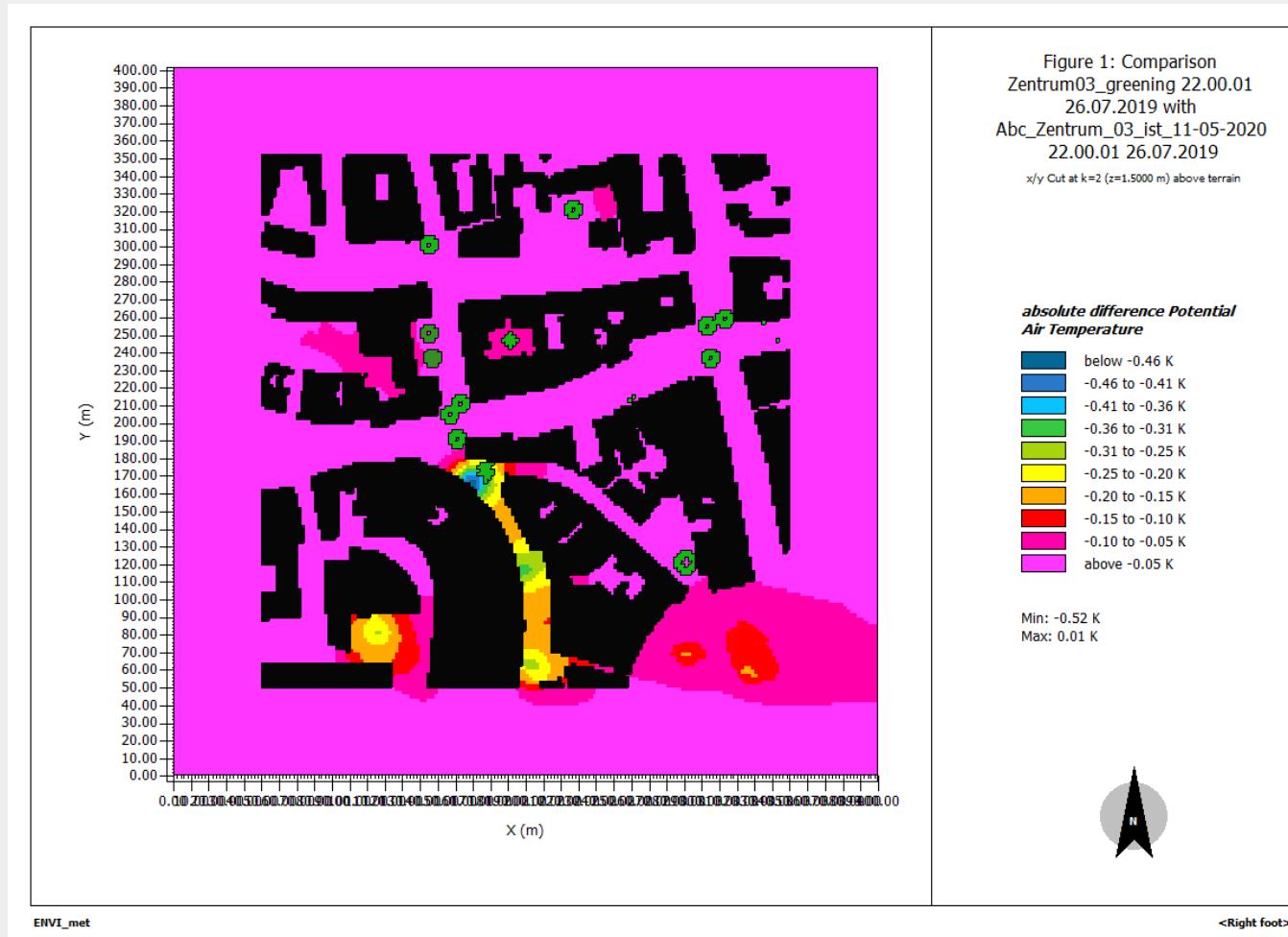
Modell-Domain „Karlstrasse“

Klimawandelanpassung

Anpassung an Hitzebelastung im urbanen Raum

Numerische Modellierung von Hitze-Hotspots

„Modellwelt“ - Grün-Szenario minus Ist-Zustand



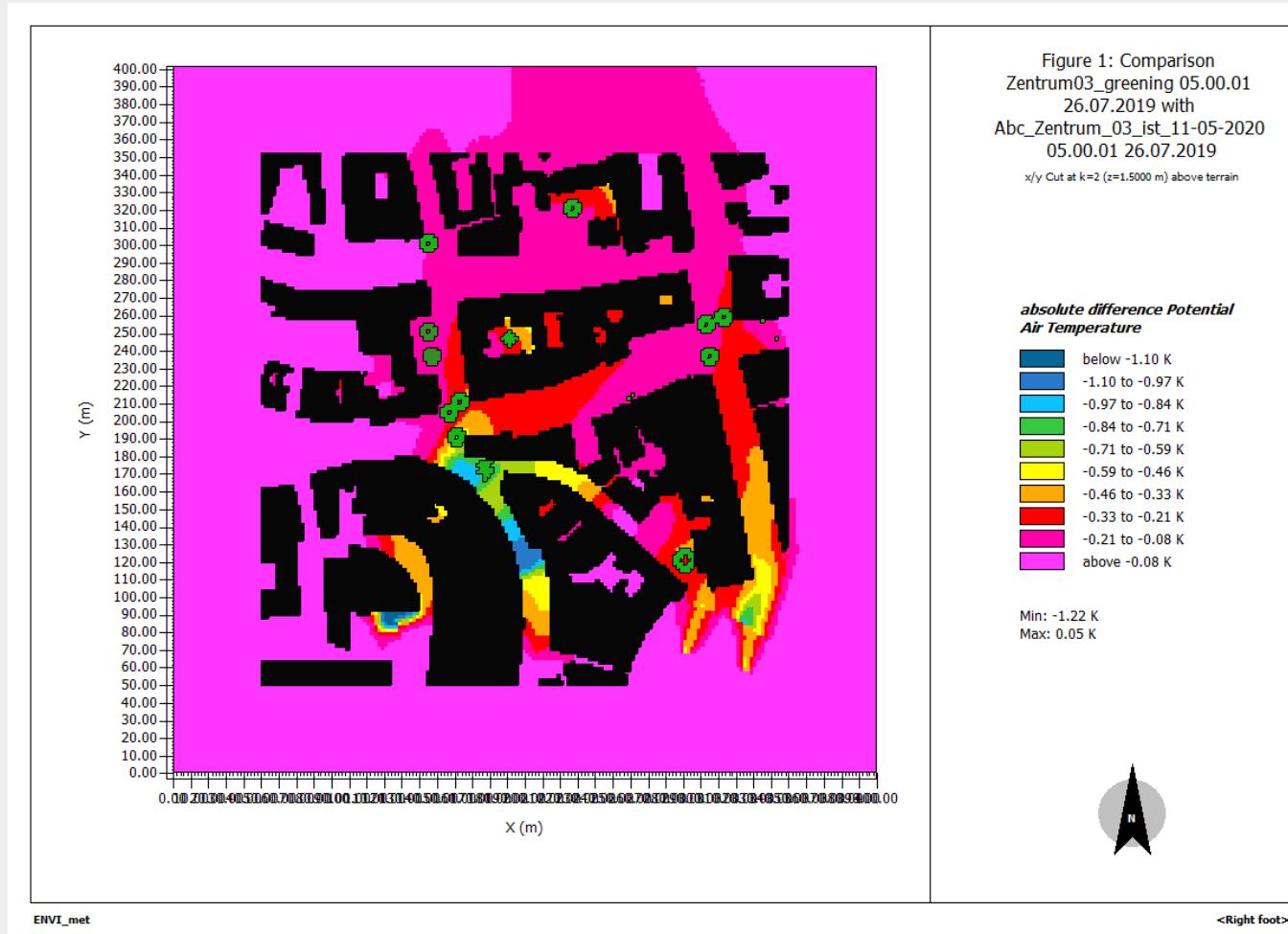
Modell-Domain „Karlstrasse“

Klimawandelanpassung

Anpassung an Hitzebelastung im urbanen Raum

Numerische Modellierung von Hitze-Hotspots

„Modellwelt“ - Grün-Szenario minus Ist-Zustand



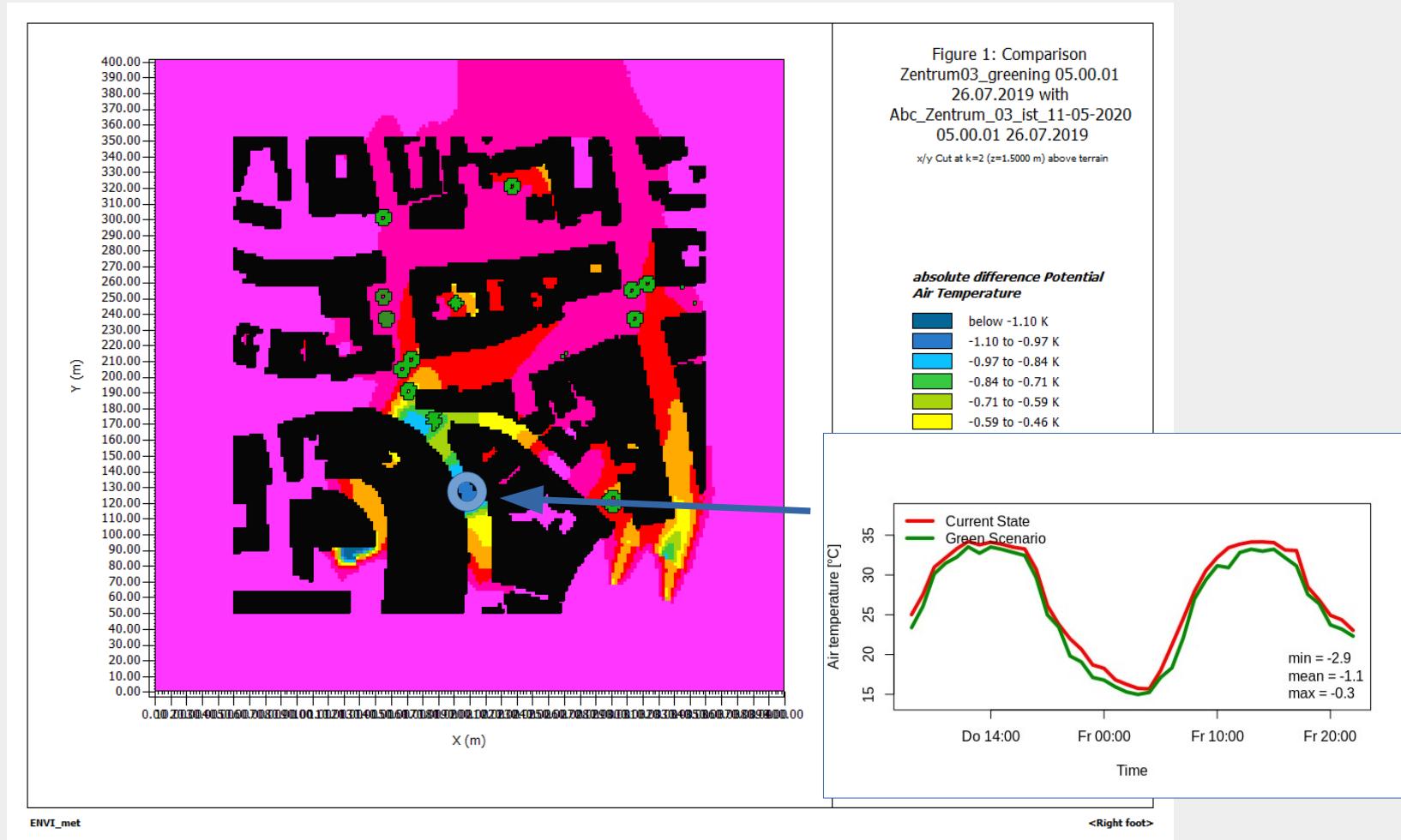
Modell-Domain „Karlstrasse“

Klimawandelanpassung

Anpassung an Hitzebelastung im urbanen Raum

Numerische Modellierung von Hitze-Hotspots

„Modellwelt“ - Grün-Szenario minus Ist-Zustand



Modell-Domain „Karlstrasse“

... ein Blick in die Zukunft der Alpengletscher

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Modeled retreat of Grosser Aletschgletscher, Switzerland, according to the moderate emission scenario RCP4.5 computed with a coupled model for mass balance and ice flow dynamics