Potsdam Institute for Climate Impact Research

Methodological solutions Down-scaled climate change impact models

Fred F. Hattermann

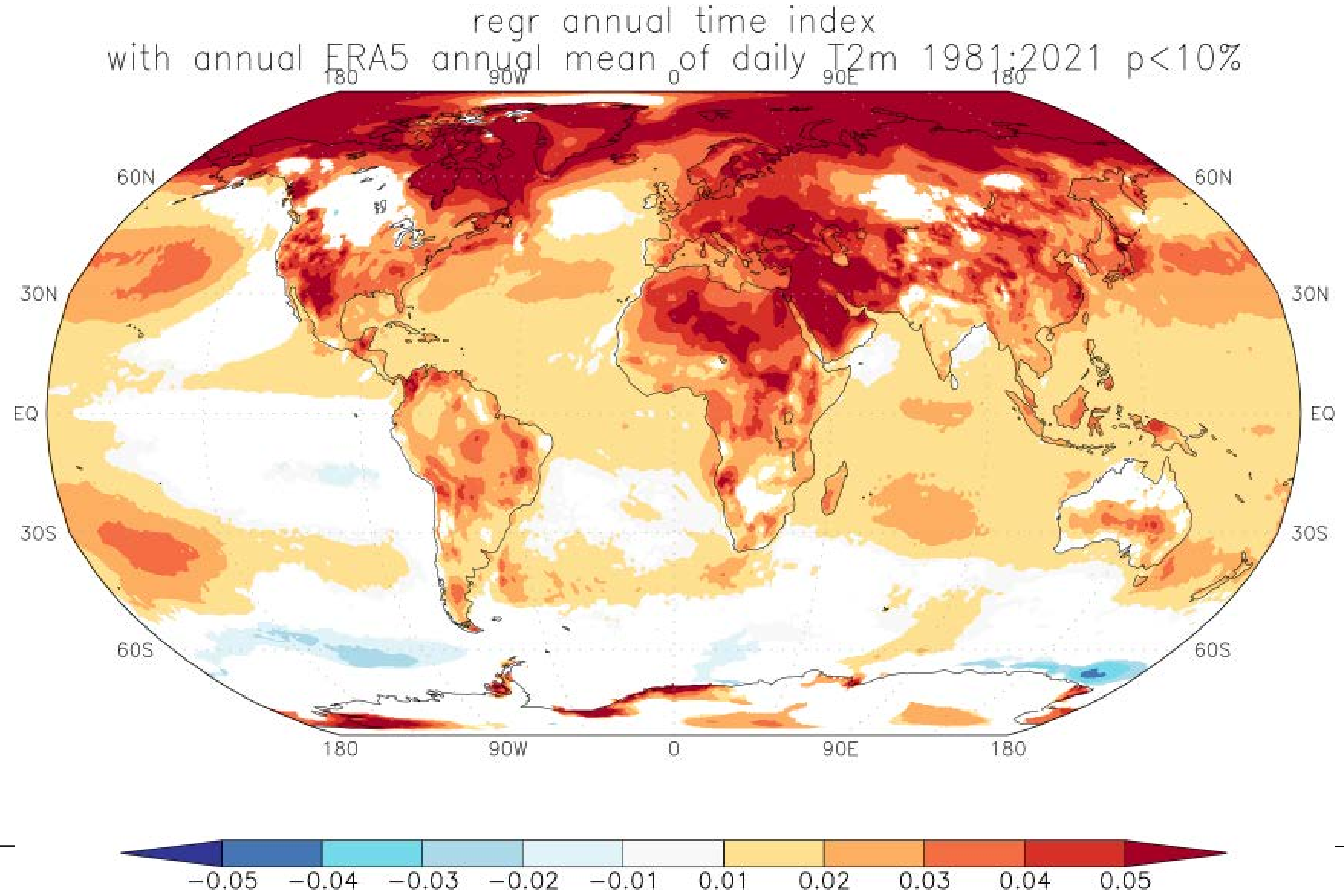
Leibniz Association

Outline

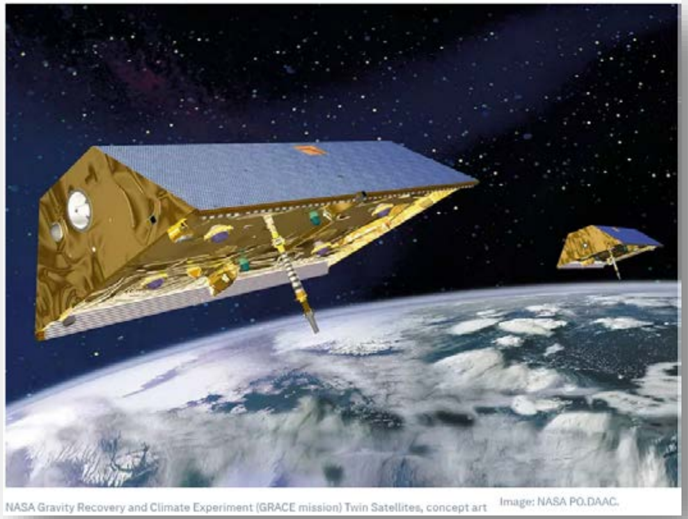
- Introduction
- Global and regional climate models
- Impact models
- Examples for downscaled impact modeling

Is this climate change?

Global Temperature increase 1981-2021 (per year)

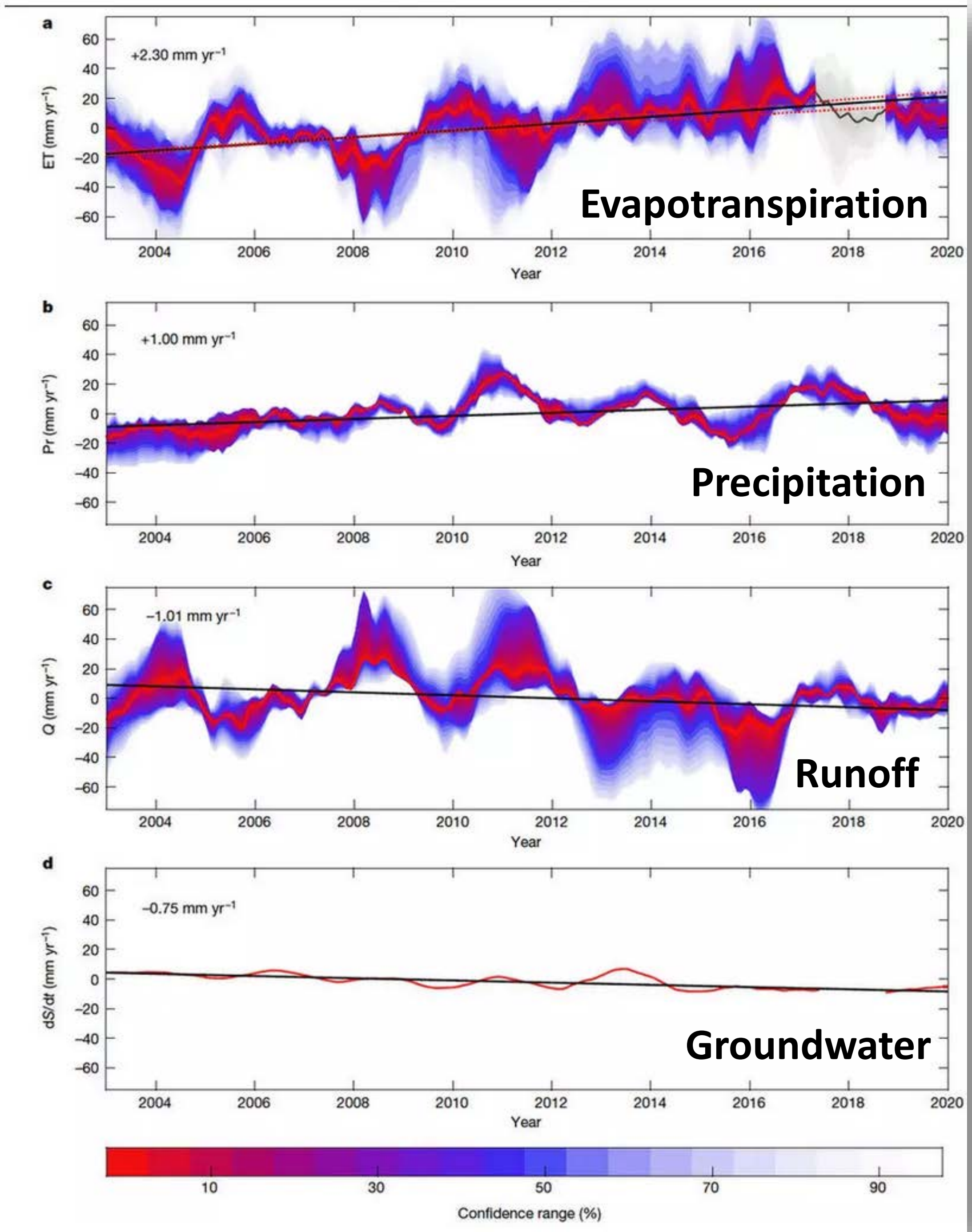


The water cycle intensified



Gravity Recovery and Climate Experiment (GRACE)

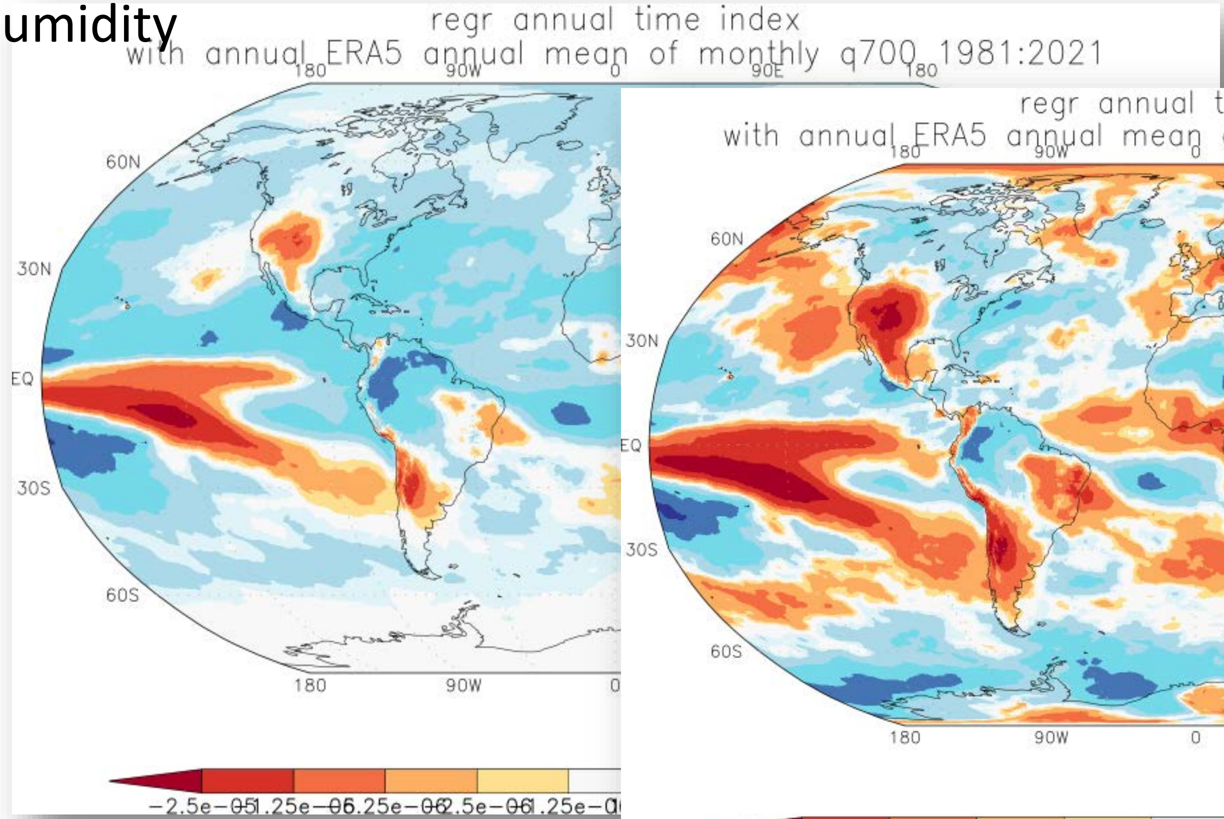
- Gemessen wird das Erdschwerefeld, dies wird beinflusst durch Änderungen in der Wassermenge
- Global mehr Niederschlag, aber eine noch stärkere Zunahme der Verdunstung und dadurch weniger Oberflächenwasser und weniger Grundwasser



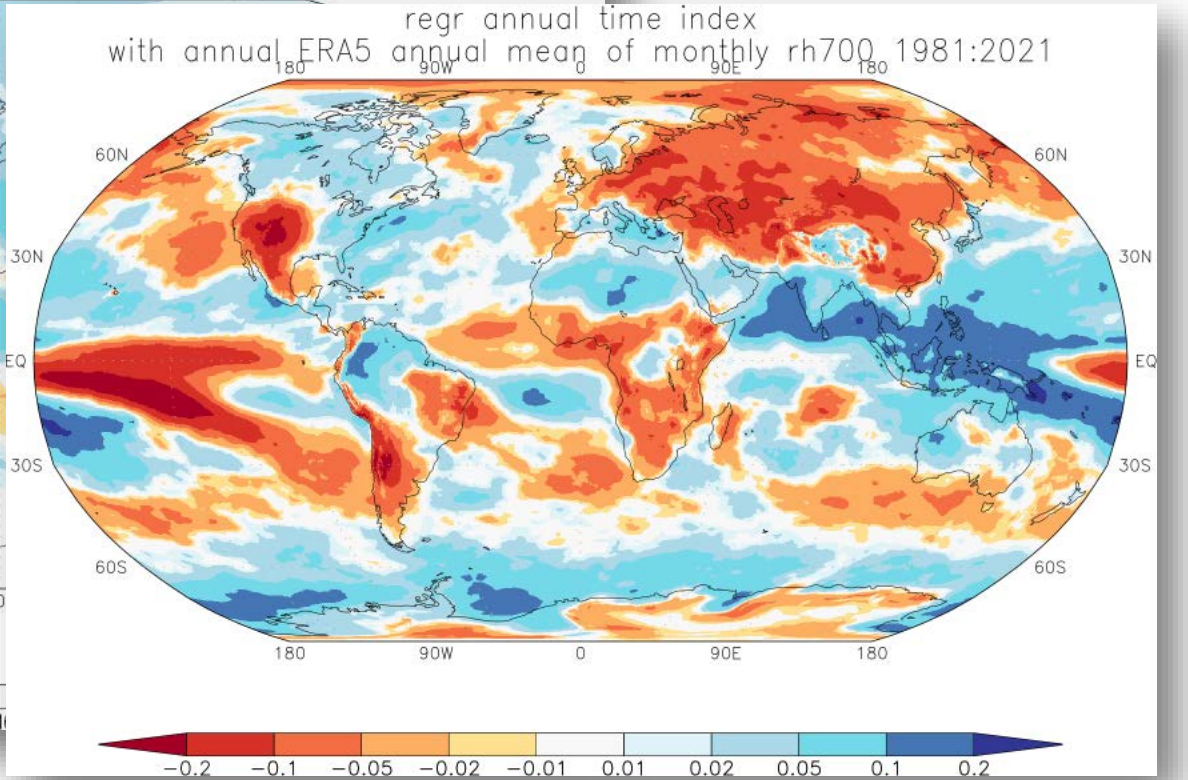
Pascolini-Campbell et al (2021)

Trends in atmospheric humidity

Spezific humidity

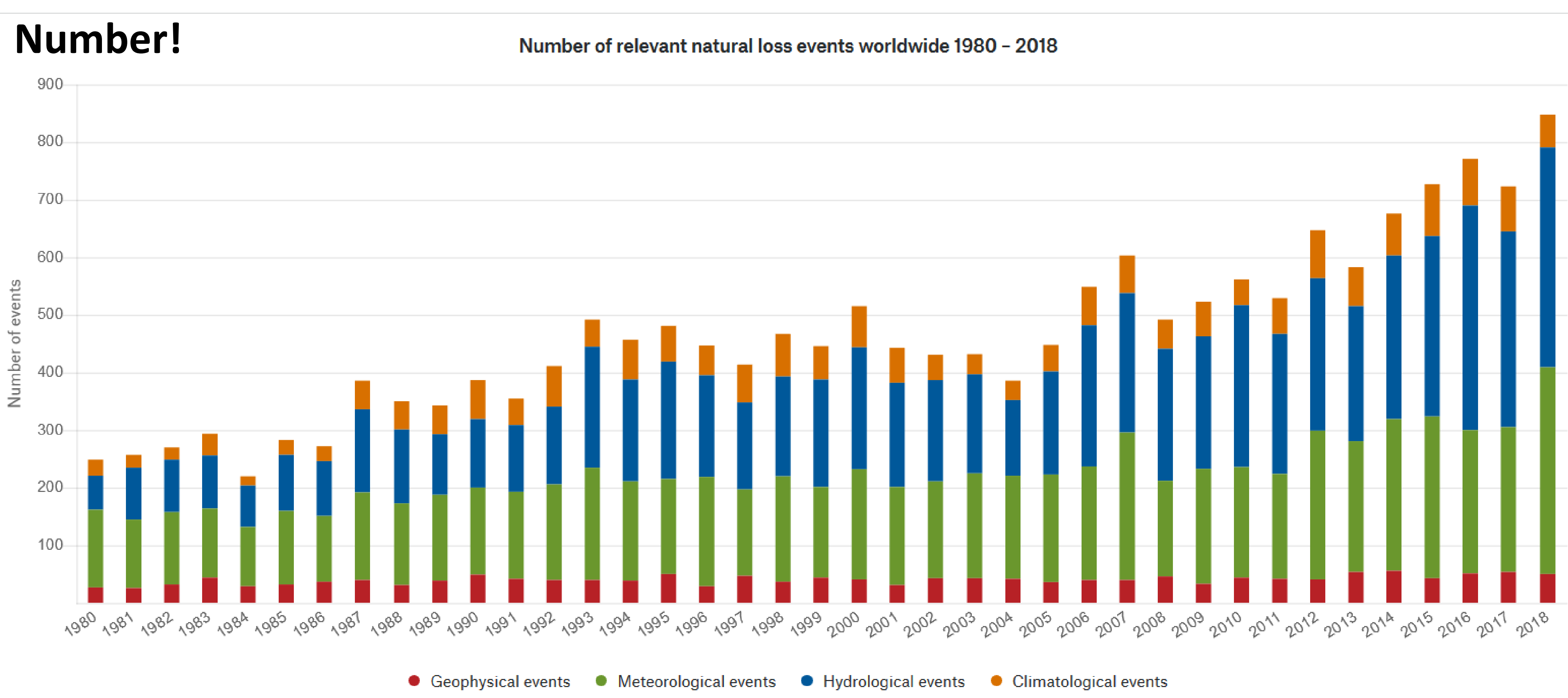


Relative Humidity



P. Hoffmann, personal communication

Number of events worldwide (Munich Re NatCat)



Linking climate impact modeling to human welbeing

Global Climate

Downscaling, Bias correction

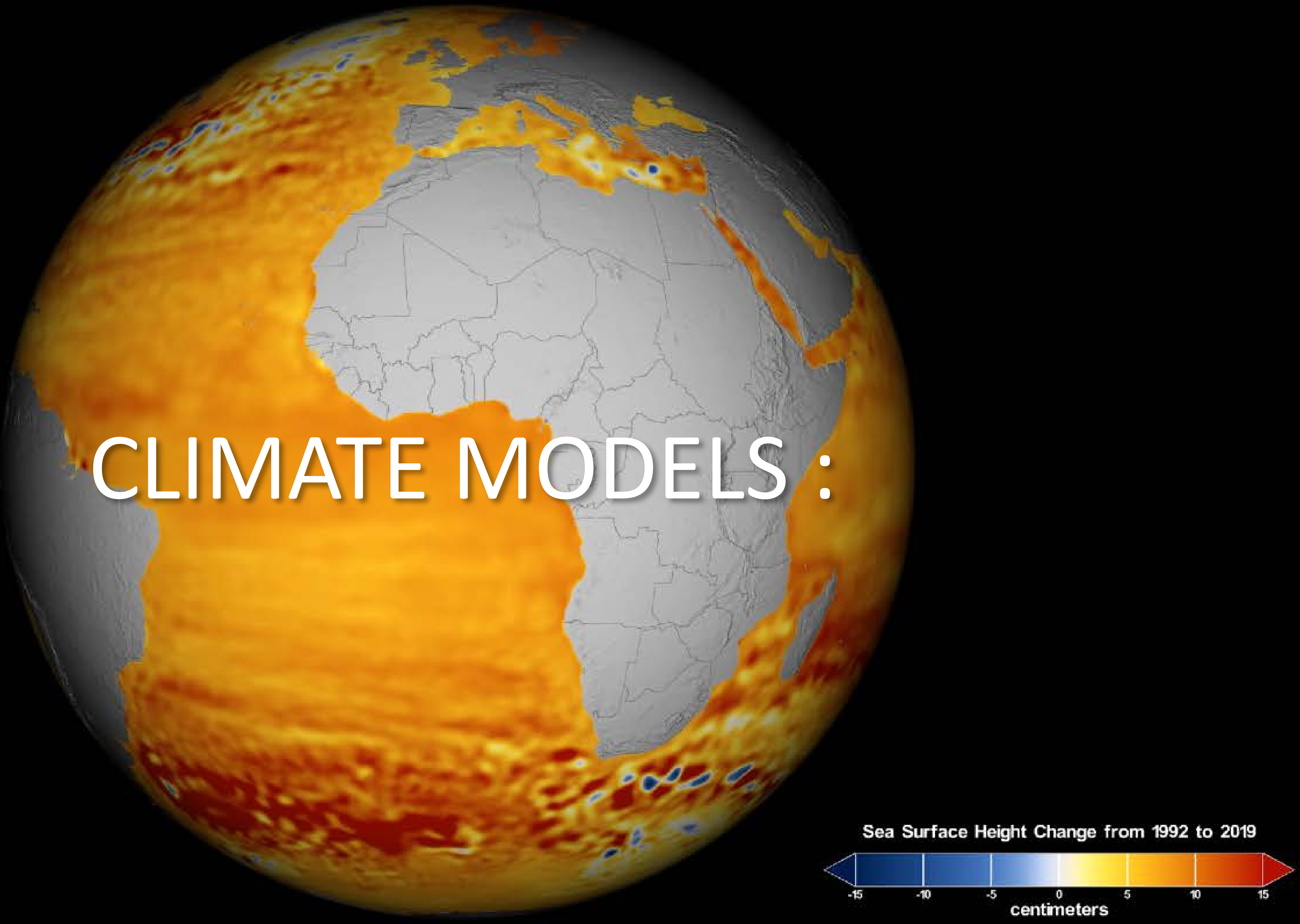
Regional Climate

Impact models
(ISIMIP, SWIM)

Biophysical impacts
(floods, droughts, yields)

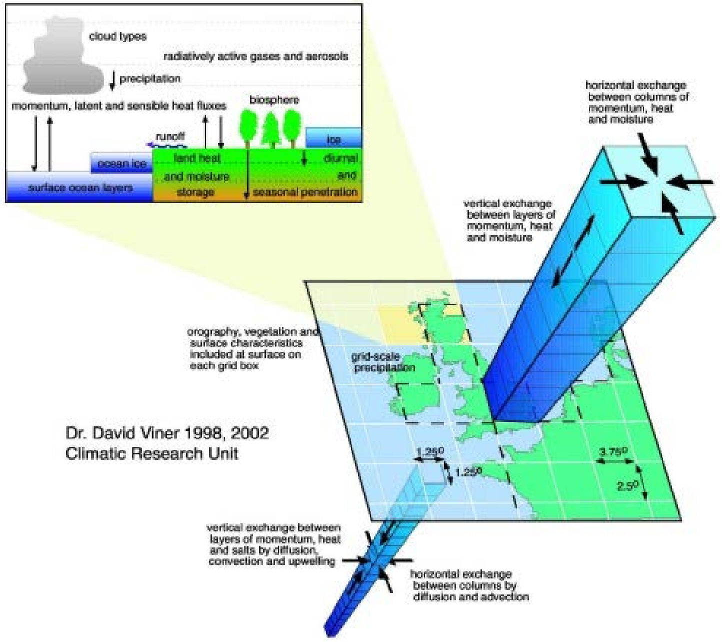
Malnutriton, Malaria,
Heat Stress

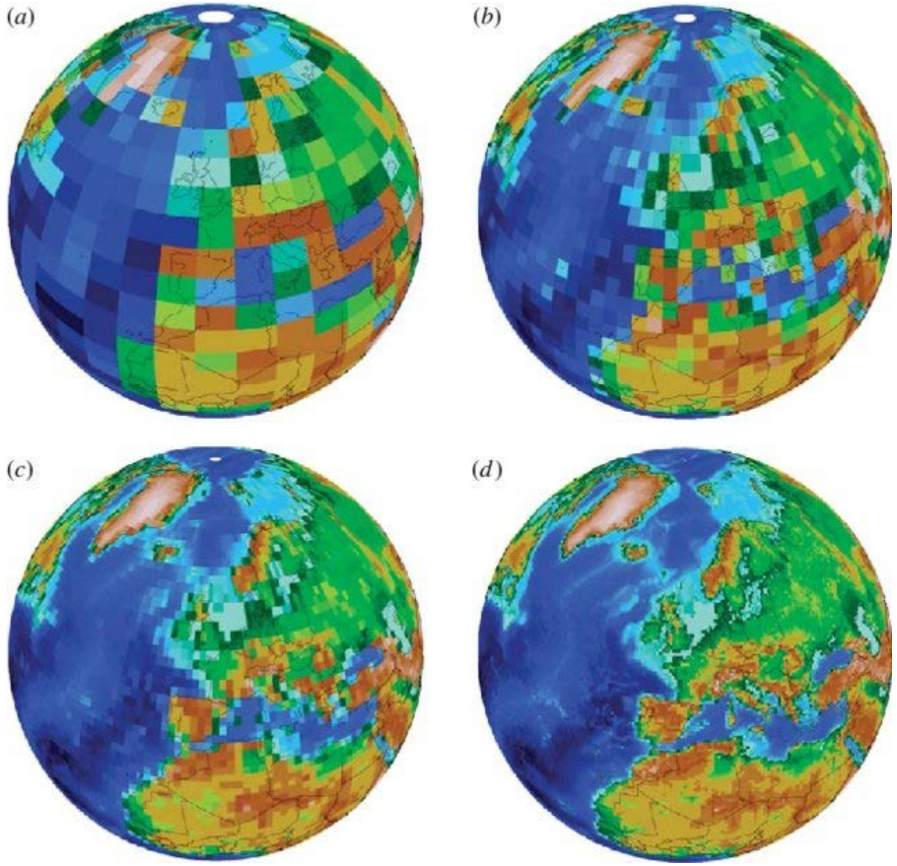
CLIMATE MODELS :



NASA

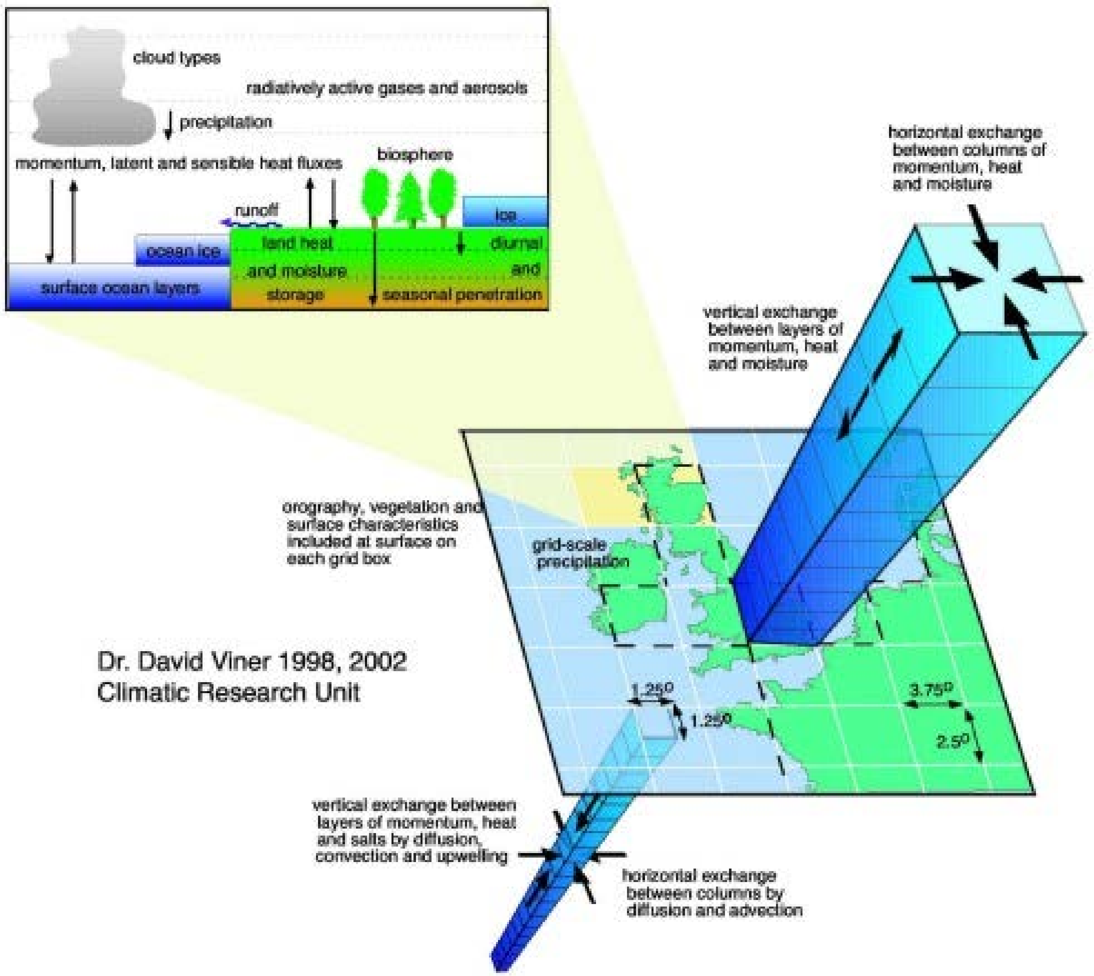
General Circulation Models





https://www.researchgate.net/publication/23668865_The_computational_future_for_climate_and_Earth_system_models_On_the_path_to_petaflop_and_beyond

General Circulation Models



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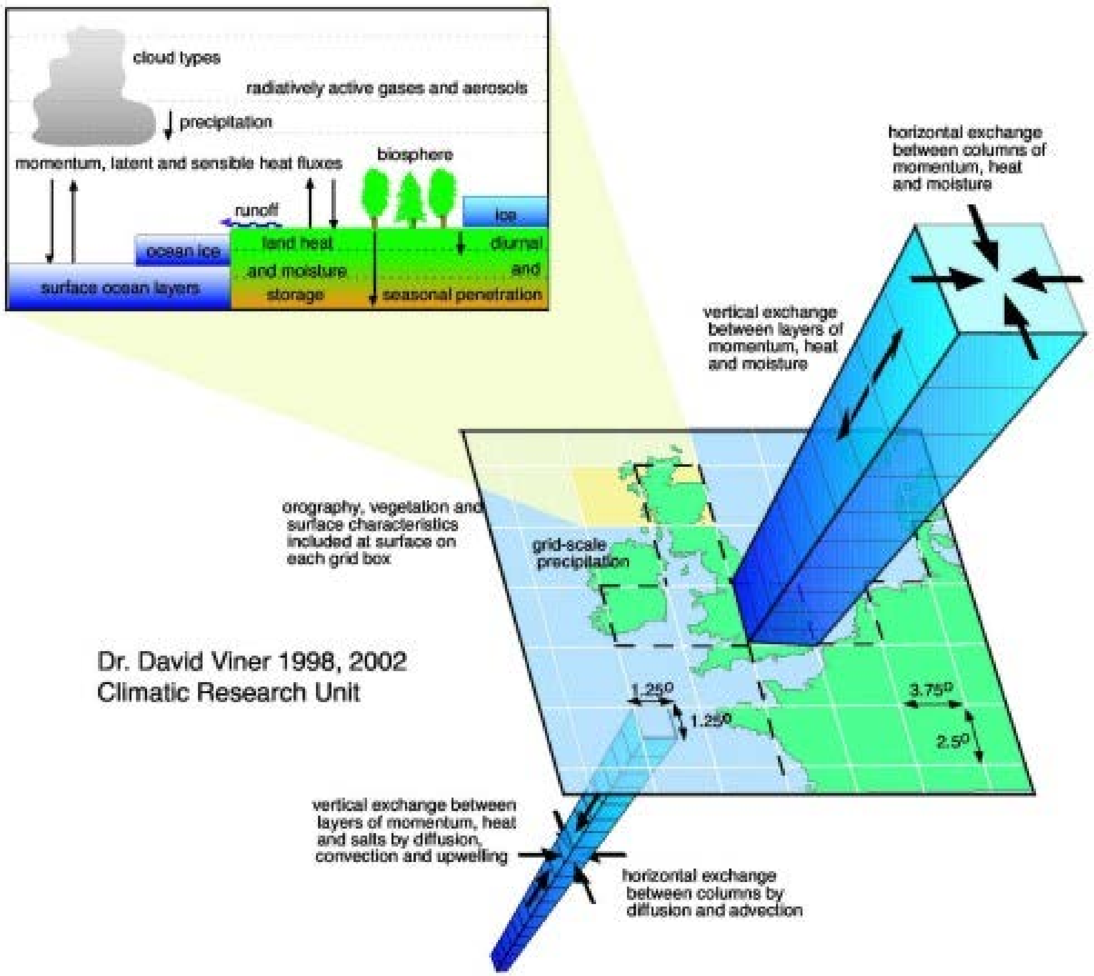
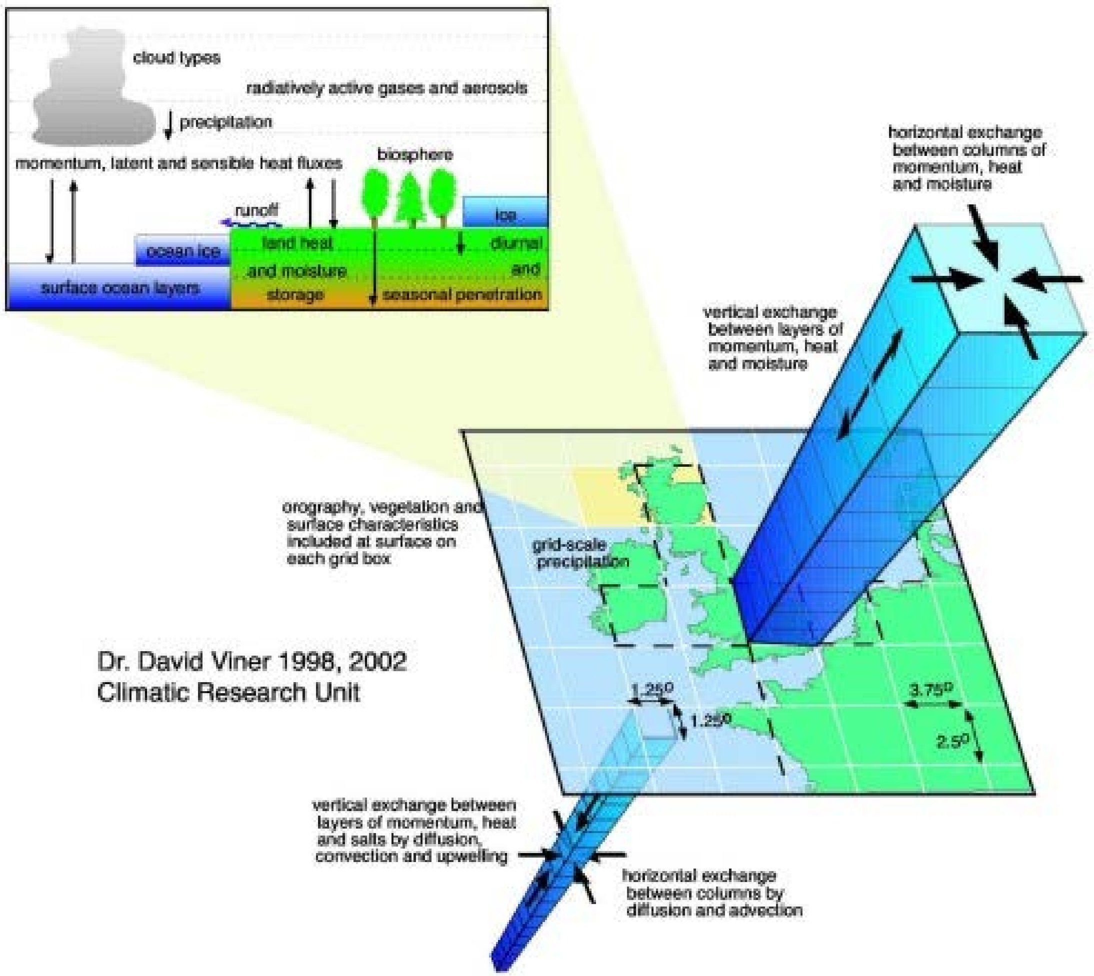
General Circulation Models



Atmospheric Ocean GCM (AOGCM)

https://www.researchgate.net/publication/23668865_The_computational_future_for_climate_and_Earth_system_models_On_the_path_to_petaflop_and_beyond

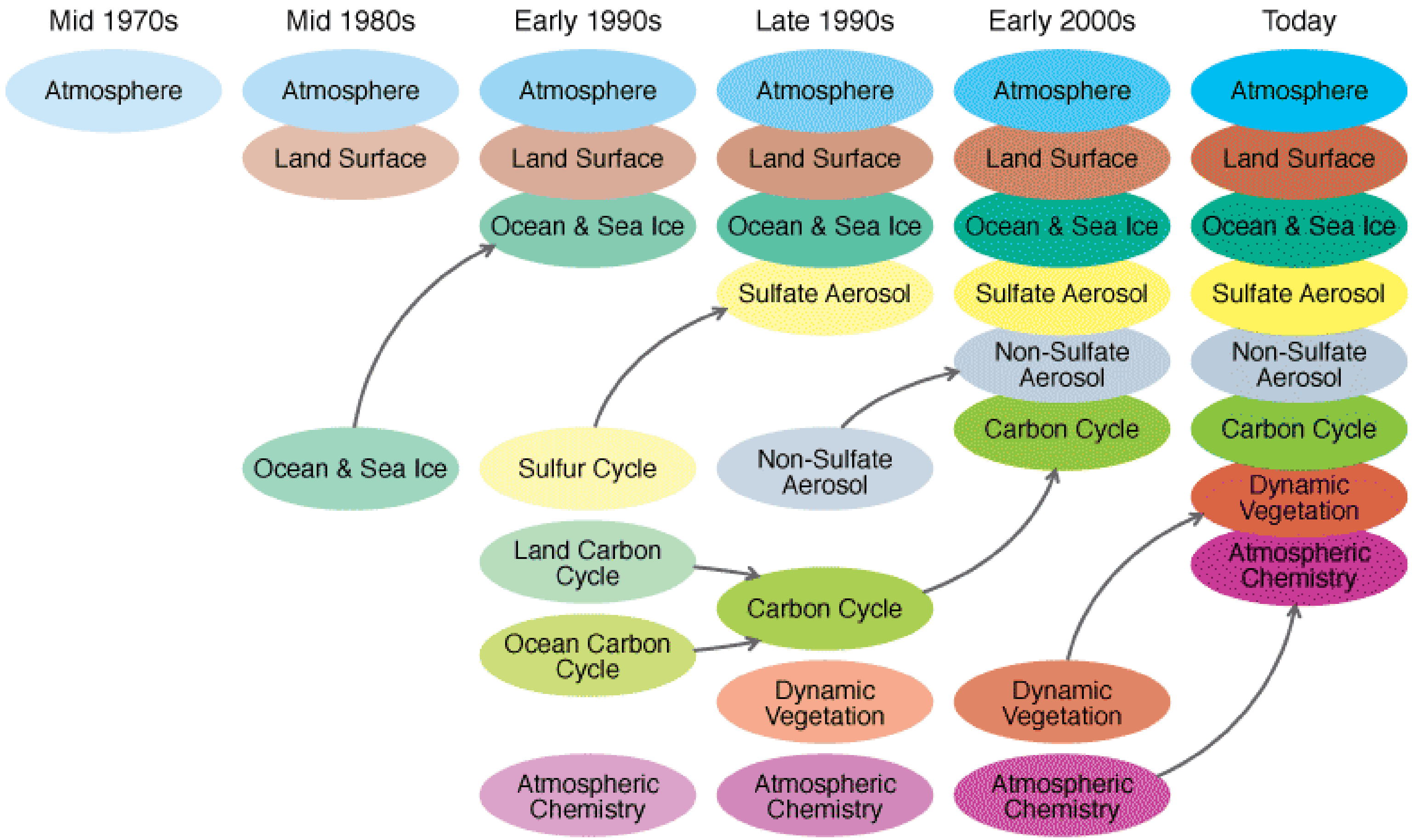
General Circulation Models



Fully Coupled Models.

https://www.researchgate.net/publication/23668865_The_computational_future_for_climate_and_Earth_system_models_On_the_path_to_petaflop_and_beyond

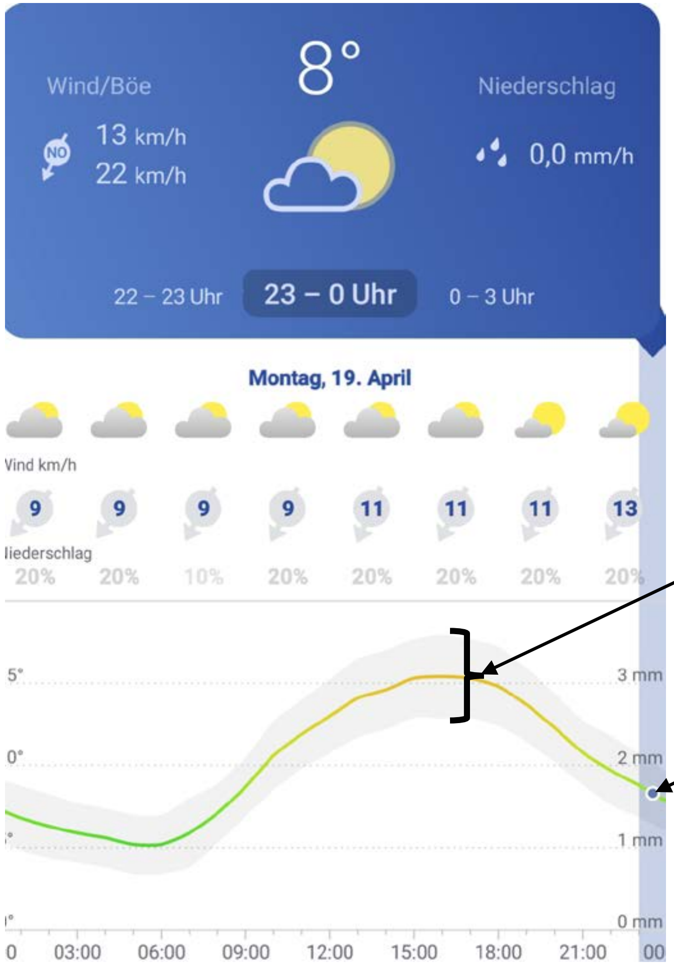
Development of Climate Models



Why Ensemble of Models?

https://mpimet.mpg.de/en/science/projects/integrated-activities

Why Ensemble of Models?

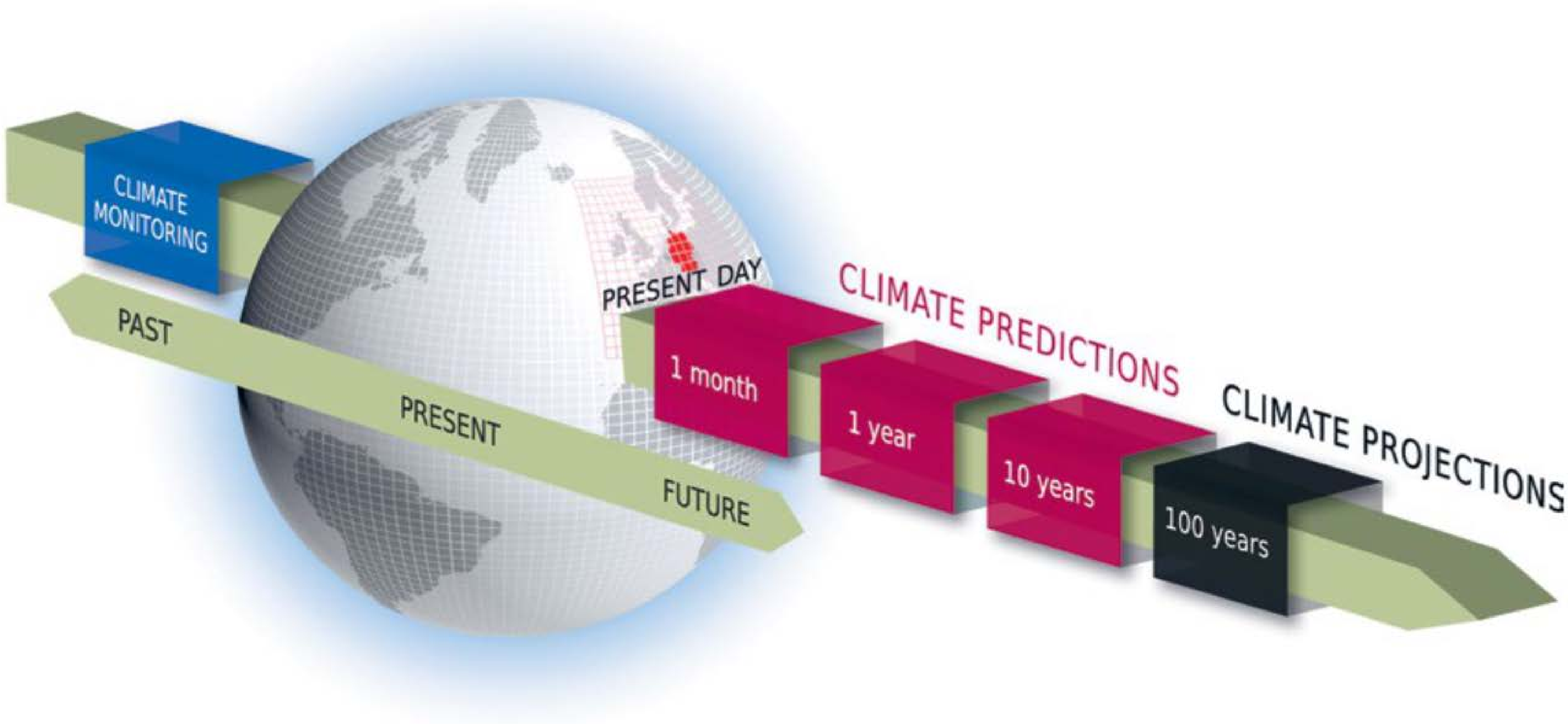


Ensemble Spread

Ensemble Mean

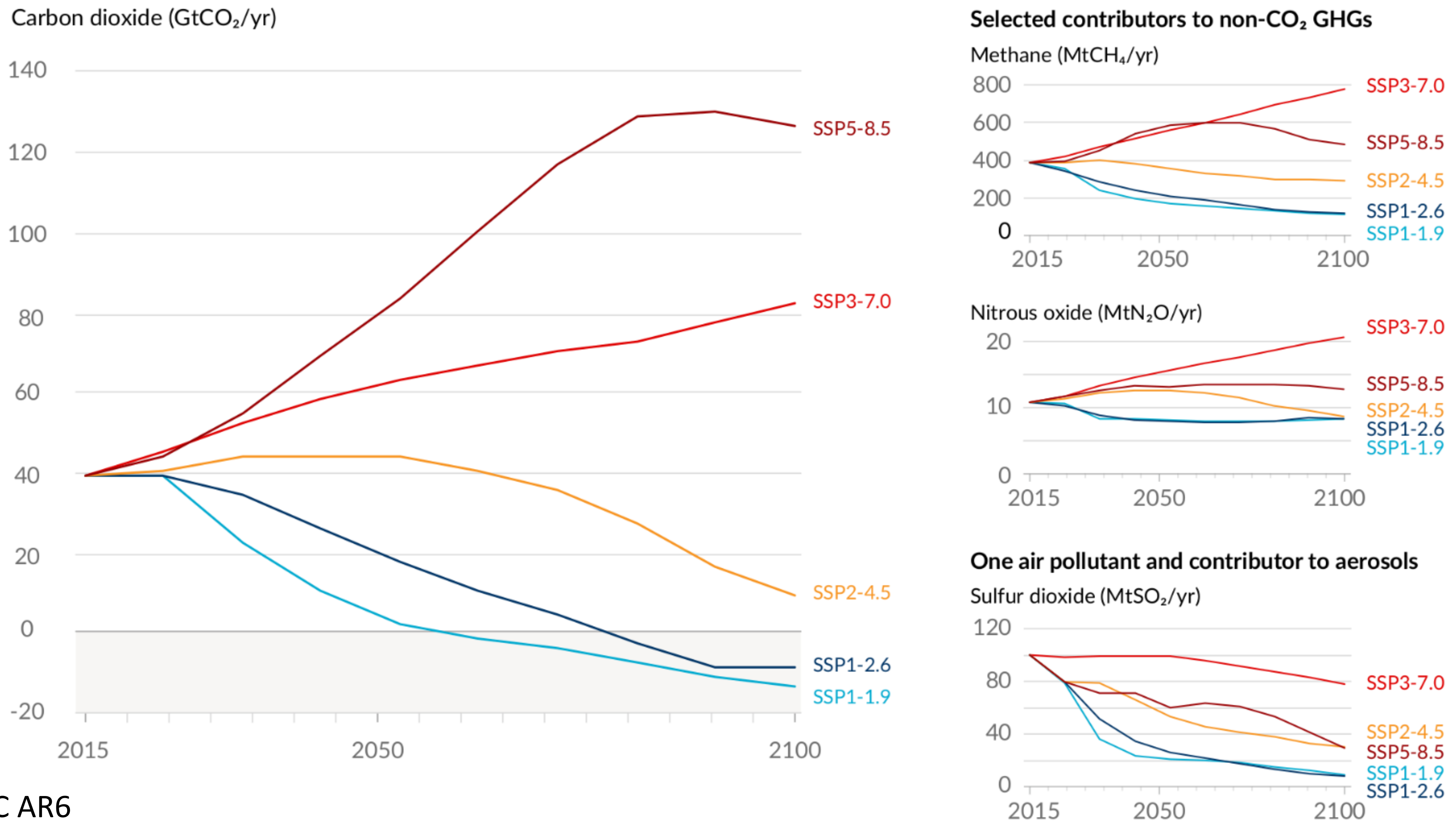
Screen shot of DWD app

Time scale of simulations



https://www.dwd.de/SharedDocs/broschueren/EN/climate/brochure_climateresearch.pdf?__blob=publicationFile&v=8

Projection of the Climate Change: CMIP6



IPPC AR6

Projection of the Climate Change: CMIP5

- **RCP2.6**: radiative forcing reached nearly 3 W/m^2 and will decrease to 2.6 W/m^2 by 2100

- **RCP4.5**: Stabilization with overshooting. 4.5 W/m^2 by 2100

- **RCP6**: Stabilization with overshooting. 6 W/m^2 by 2100

- **RCP8.5**: rising radiative forcing, leading to 8.5 W/m^2 by 2100

IPCC scenario design

- SSP1: The sustainable and "green" pathway describes an increasingly sustainable world. Global commons are preserved, and the limits of nature are respected. The focus is more on human well-being than on economic growth
- SSP2: The "Middle of the road" or medium pathway extrapolates the past and current global development into the future. Income trends in different countries diverge significantly. There is certain cooperation between states, but it is barely expanded. Global population growth is moderate, leveling off in the second half of the century.
- SSP3: Regional rivalry. A revival of nationalism and regional conflicts pushes global issues into the background. Policies increasingly focus on questions of national and regional security. Investments in education and technological development are decreasing. Inequality is rising. Some regions suffer drastic environmental damage.
- SSP4: Inequality. The chasm between globally cooperating developed societies and those stalling at a lower developmental stage with low income and a low level of education is widening. Environmental policies are successful in tackling local problems in some regions, but not in others.
- SSP5: Fossil-fueled Development. Global markets are increasingly integrated, leading to innovations and technological progress. The social and economic development, however, is based on an intensified exploitation of fossil fuel resources with a high percentage of coal and an energy-intensive lifestyle worldwide.

Linking climate impact modeling to human welbeing

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Regional Climate

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(ISIMIP, SWIM)

Biophysical impacts
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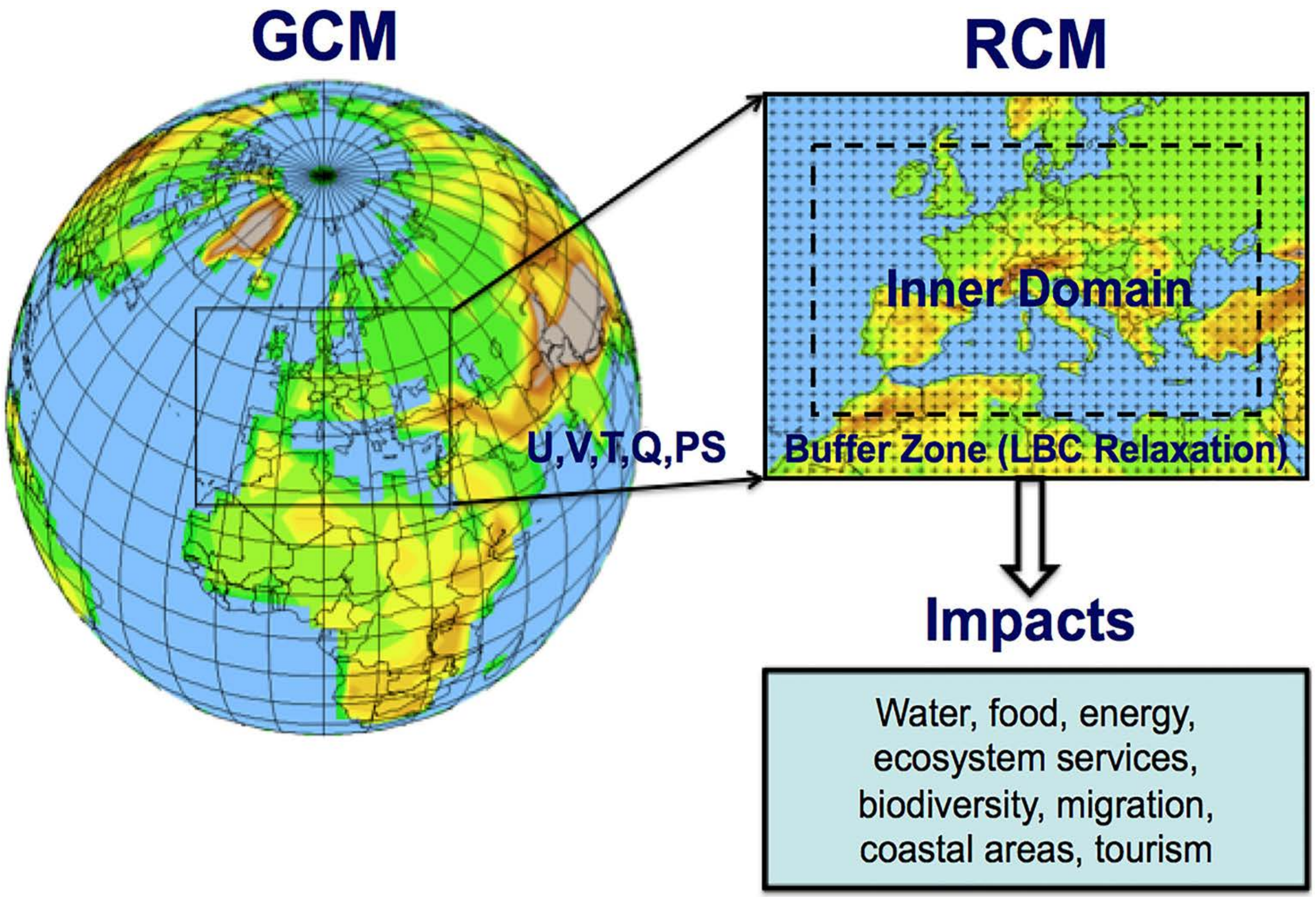
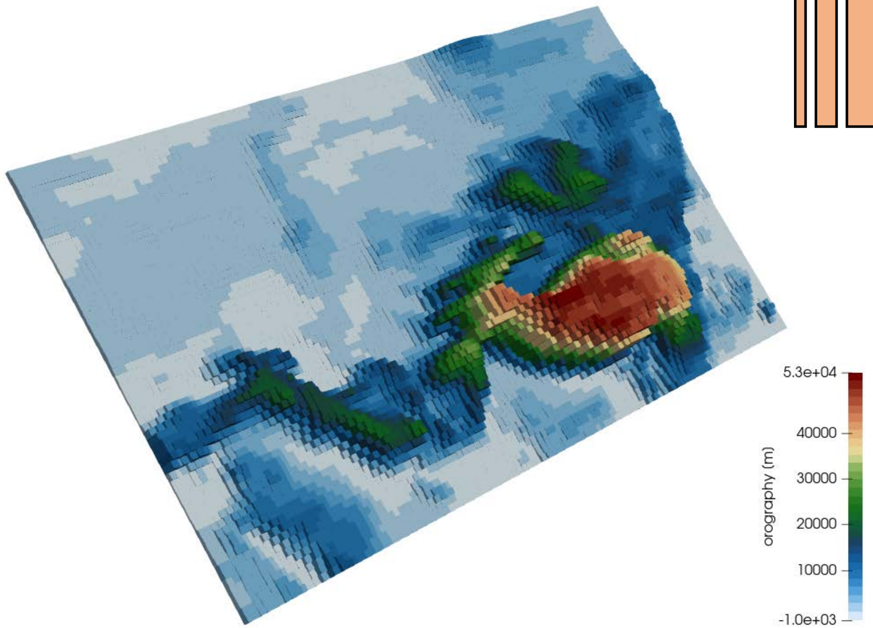
Malnutriton, Malaria,
Heat Stress

Regional Climate Models



Regional Climate Models

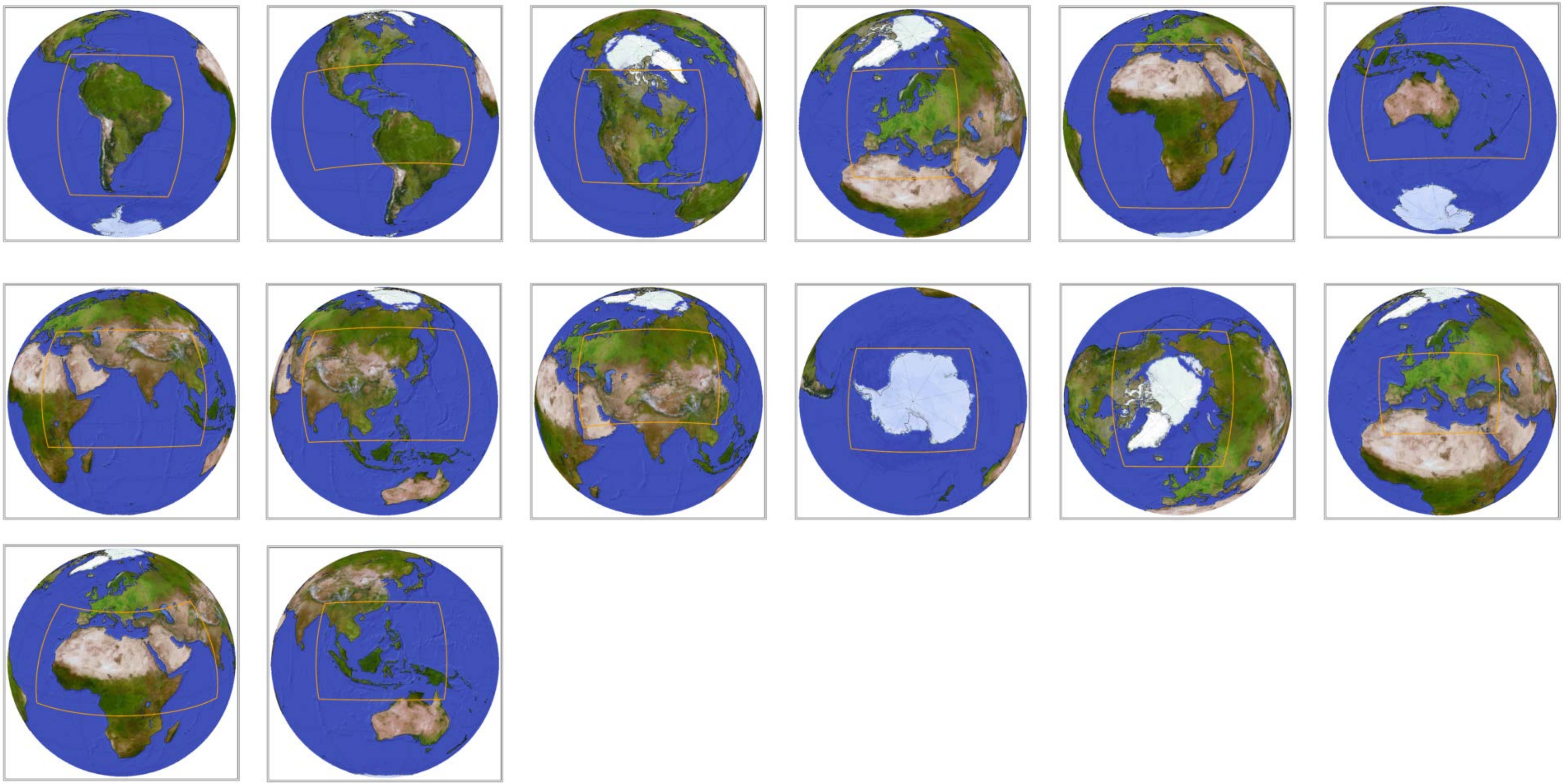
ERAInterim



Downscaling

CCLM

Coordinated Regional Climate Downscaling Experiment



Linking climate impact modeling to human welbeing

Global Climate

↓

Downscaling, Bias correction

↓

Regional Climate

↓

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(ISIMIP, SWIM)

↓

Biophysical impacts
(floods, droughts, yields)

↓

Malnutriton, Malaria,
Heat Stress

P I K

The Nexus Water – Energy – Food

FAO 2019:

Water security, energy security and food security are very much linked to one another, and

actions in one area have effects in one or both of the other areas.

One could add other sectors such as health and ecology.

Strong links to Sustainable Development Goals

https://www.water-energy-food.org/

Types of impact models

1 Physical representation of processes

Physically-based

- Processes based on physical equations, high data and computation demand
- Grid

Process-oriented

- Processes based on physical and empirical equations, medium data and computation demand
- HRUs (hydrological response units)

Empirical-statistical models

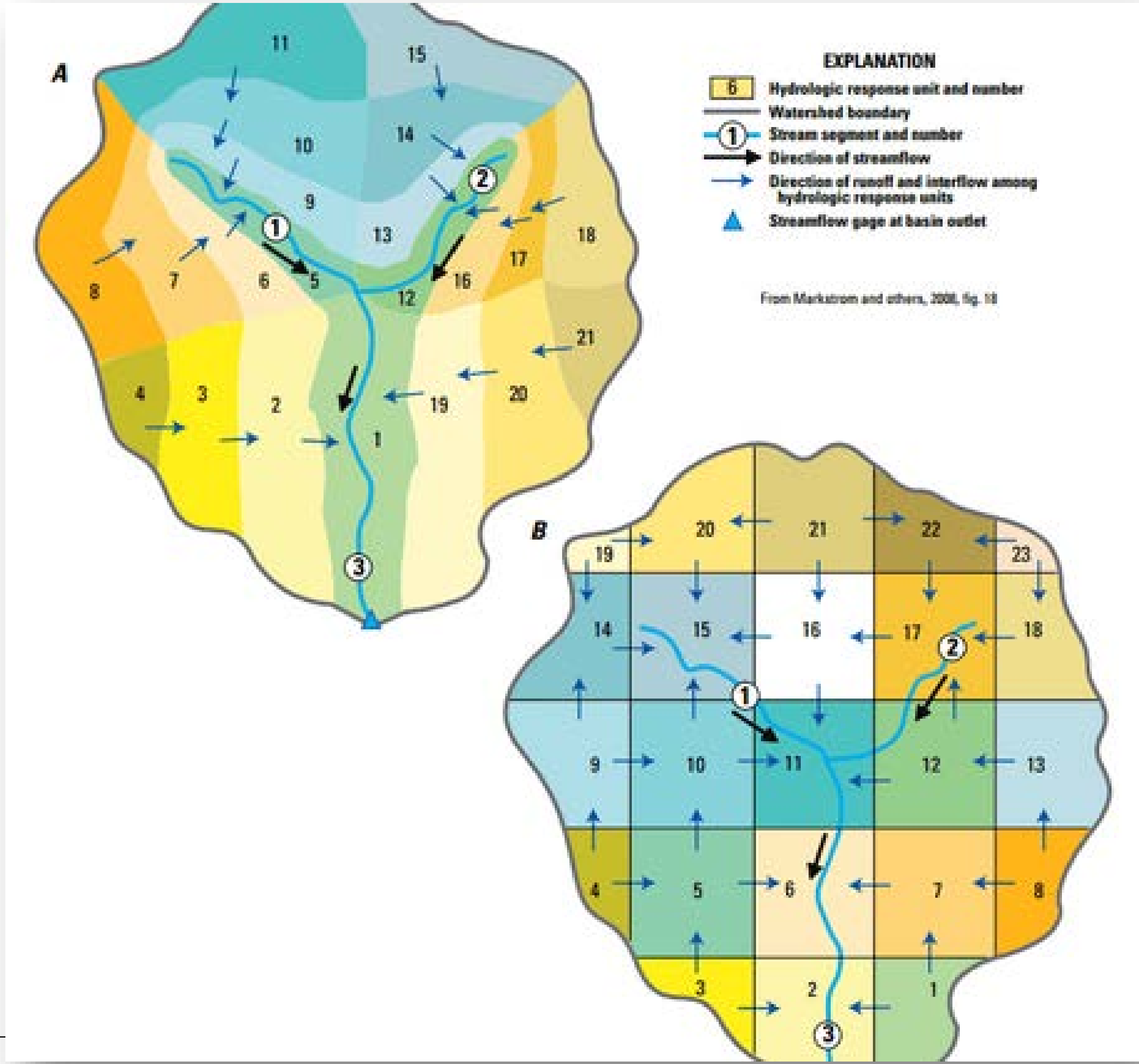
- Based on empirical equations
- Lumped

PIK

Types of hydrological models

2 Spatial disaggregation

Hydrological response units



Grid cells

POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH

PIK

SWIM

Soil and Water Integrated Model

Introduction

Model structure

Stefan Liersch

2021

Leibniz Association

SWIM

Soil and **W**ater **I**ntegrated **M**odel

Eco-hydrological model designed to

- Simulate processes at the catchment scale
- Simulation of water and nutrient fluxes
- Assess the impacts of
  - Climate change
  - Changed water resources management

Continuous development (5-10 developers)

- Adapted to new requirements
- Major developments over recent years to address water resources management (reservoirs, irrigation, water allocation...)

Modelling approach

Catchment-scale eco-hydrological model

Process-based

- Physical equations: evapotranspiration, percolation...
- Empirical approaches: curve number-based infiltration...
- Daily time step

Spatially semi-distributed

- Hydrological Response Units (HRUs)
- HRUs are laterally not connected

Mesoscale applications (>1000 km^2)

SWIM Soil and Water Integrated Model

based on

SWAT Soil & Water Assessment Tool

Version 1993

&

MATSALU

Eco-hydrological model

Natural processes

Weather / climate (input)

- Precipitation (rain & snow)
- Temperature, solar radiation, rel. humidity

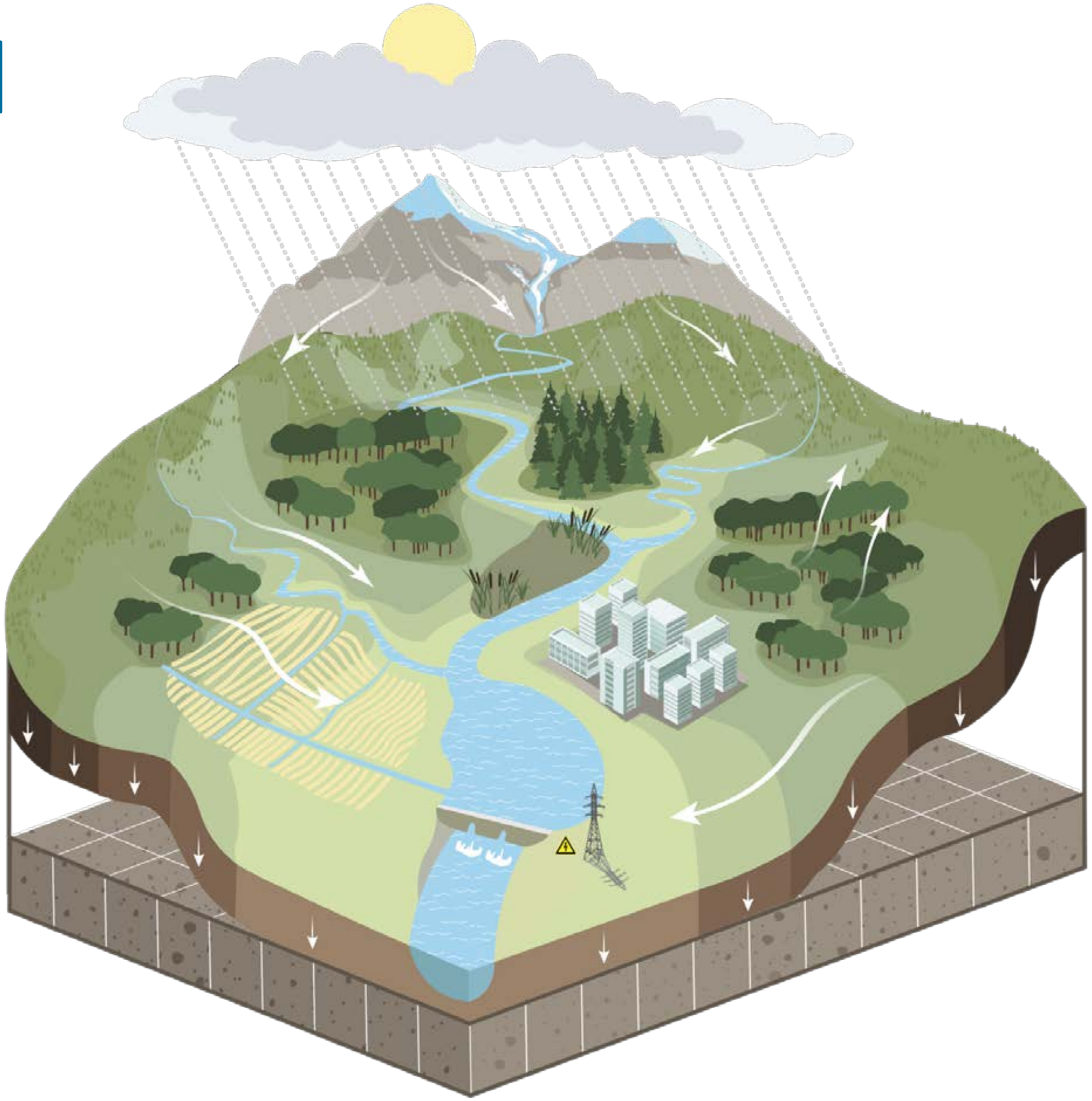
Hydrology

- Infiltration
- Runoff: surface, sub-surface, groundwater
- River discharge
- Evapotranspiration

Vegetation

- Natural: forests, grasslands, savannah...
- Managed crops

Glaciers



Eco-hydrological model

Water and land management

Crop management

- Crop rotations
- Fertilization

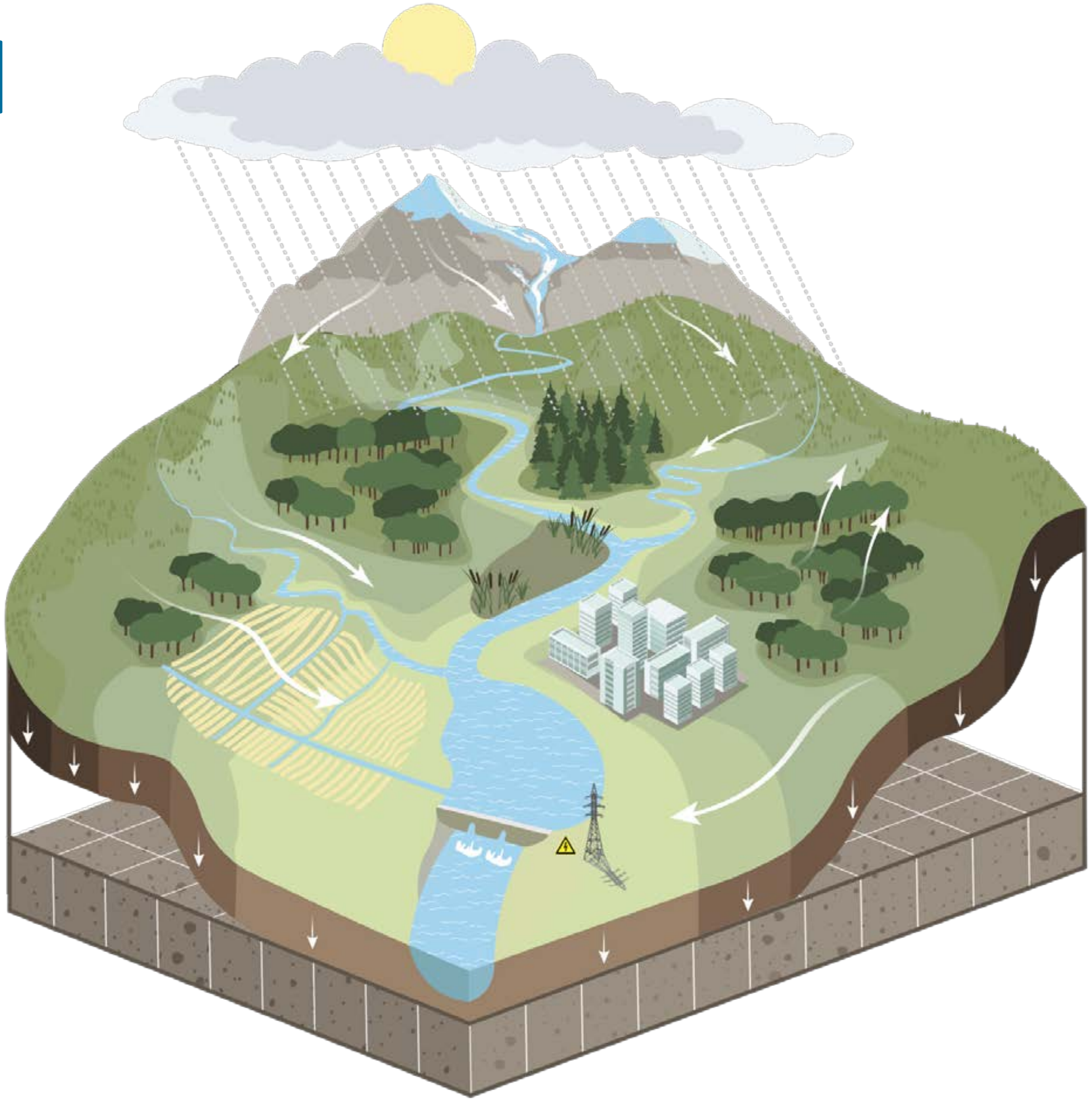
Irrigation

- Crop water demand / deficits
- Water use efficiency

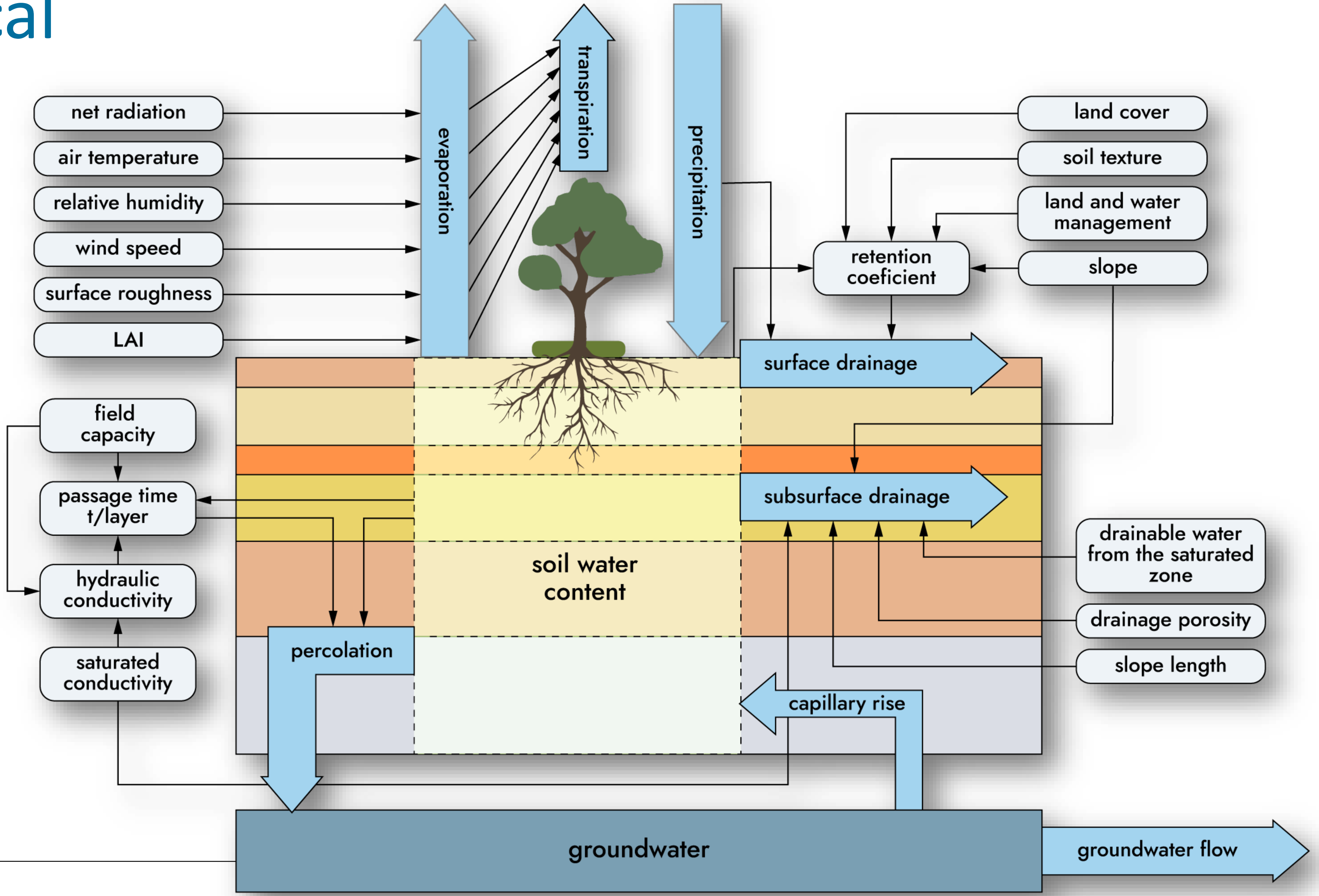
Water allocation

Reservoirs

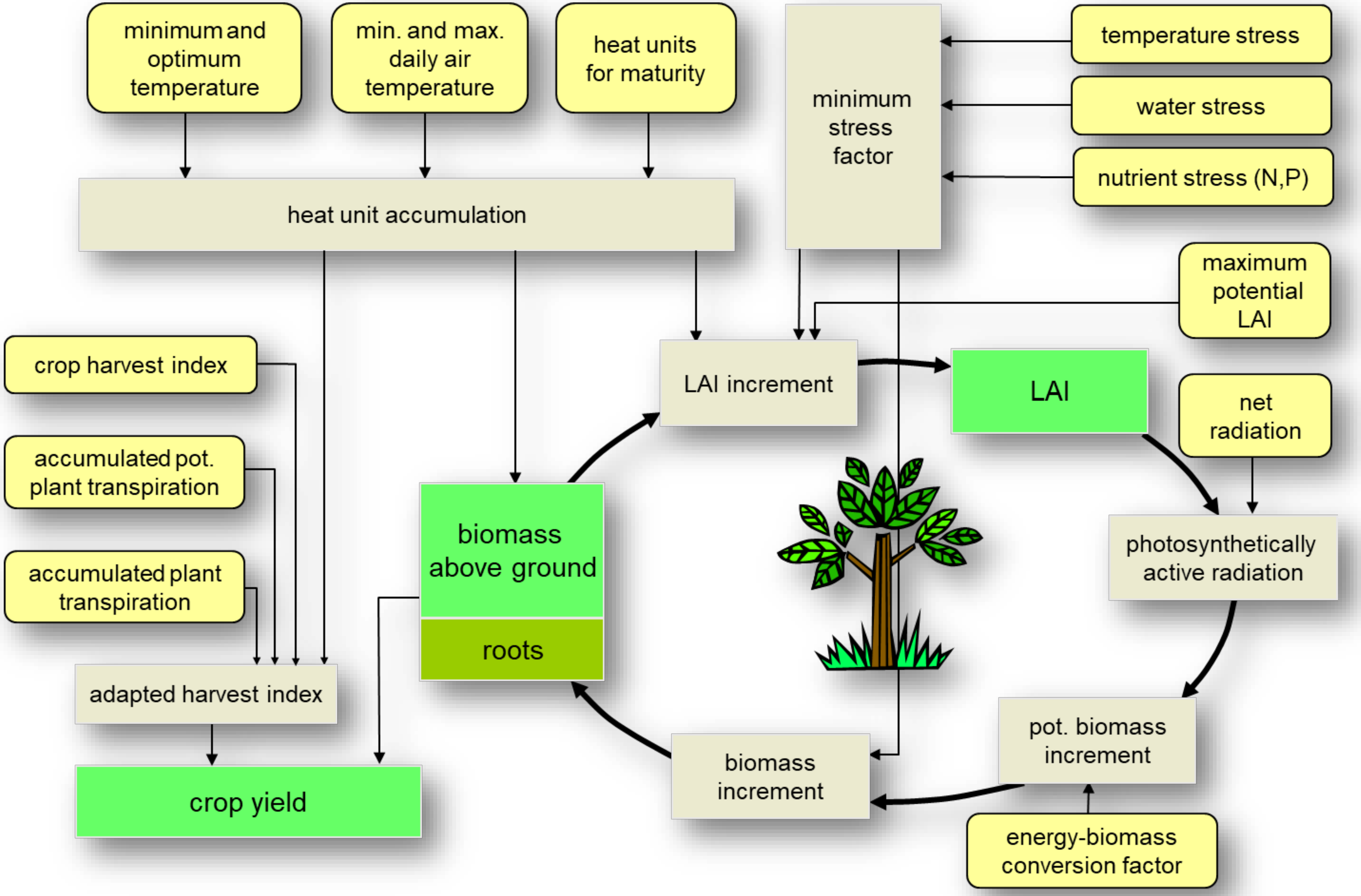
- Hydropower
- Flood protection
- Water supply



Hydrological processes



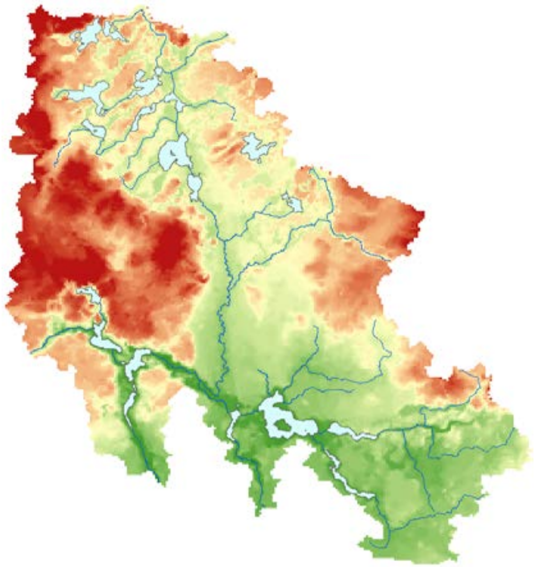
Plant processes

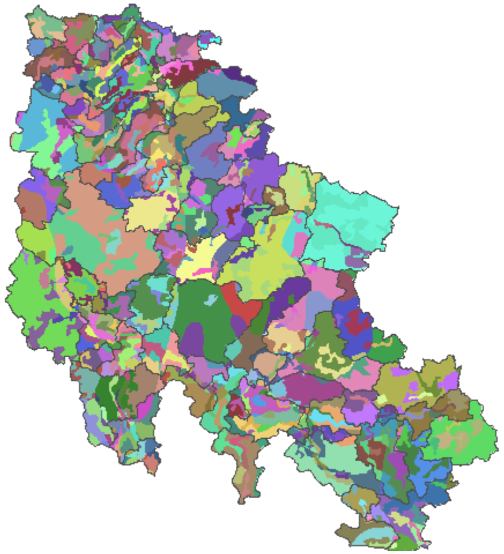


Spatial disaggregation in SWIM

3 levels

Basin → **Sub-basins/** → **Hydrotopes (HRUs)**



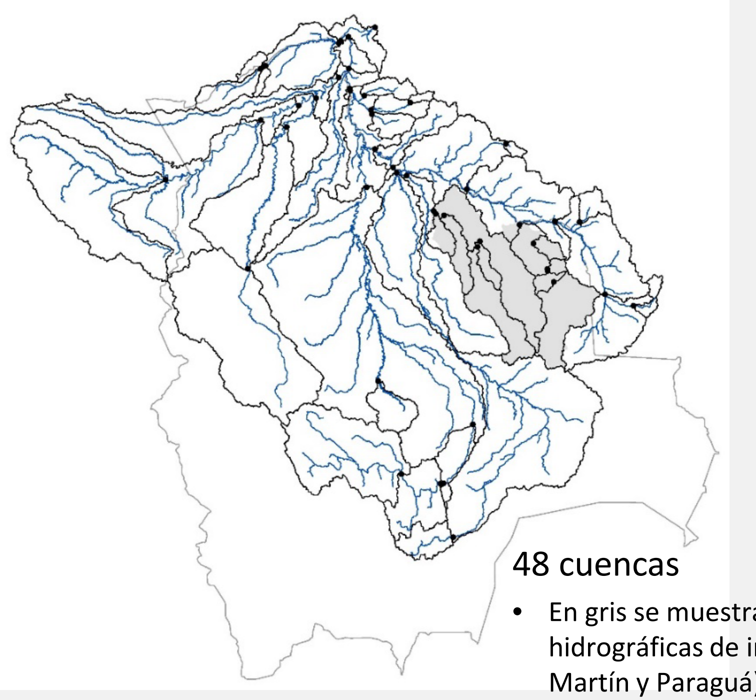


Routing in river (water, N, P, sediments) ← Aggregation of lateral flows ← Water, N, P cycles vegetation growth

37

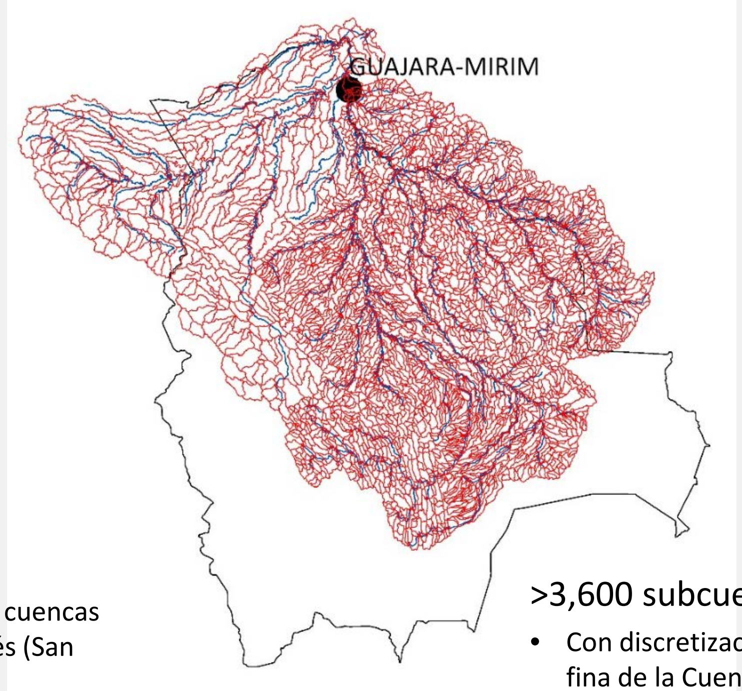
SWIM - desagregación espacial (ejemplo de la cuenca del Amazonas boliviano)

Escala de cuenca → Escala de subcuencas → Escala de hidrotopos



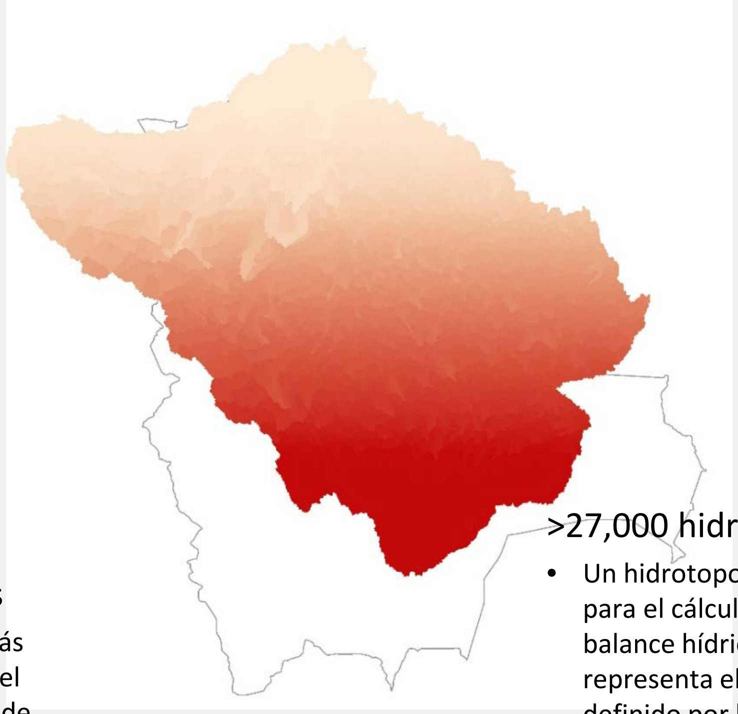
48 cuencas

- En gris se muestra las cuencas hidrográficas de interés (San Martín y Paraguá).
- Las estaciones de aforo en las regiones de estudio son hipotéticas



>3,600 subcuencas

- Con discretización más fina de la Cuenca en el área de aguas arriba de la estación hidrológica de Guajara-Mirim



>27,000 hidrotopos

- Un hidrotopo es la base para el cálculo del balance hídrico y representa el área definido por la combinación única de uso de suelo y tipo de suelo

Enrutamiento de flujo en la red de drenaje ← Agregación de los componentes del balance hídrico ← Ciclo hidrológico, dinámica de la vegetación

Spatial data

GIS layers

Elevation, slope (DEM)

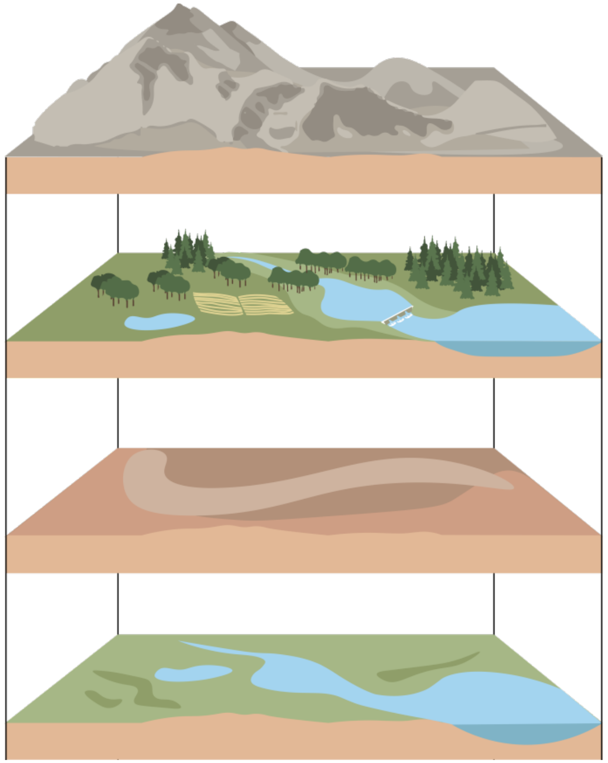
Land use / cover (LULC)

Natural, managed

Soils

Other

Reservoirs, irrigation, wetlands, glaciers, elevation

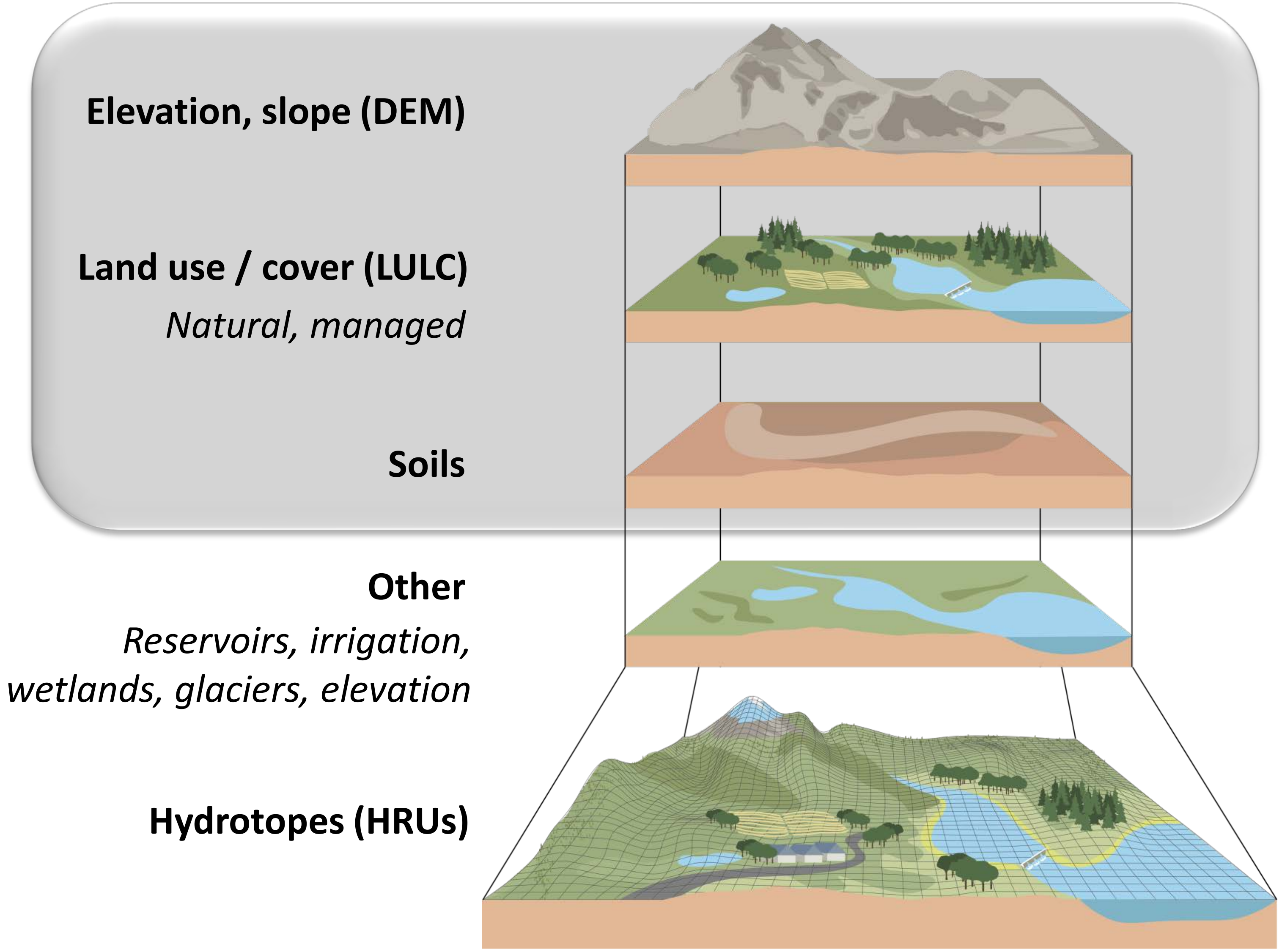


Spatial data

Basic GIS layers

Overlay in GIS

- HRUs
  Hydrological Response Units
- SWIM input file: ***.str**



Spatial data

Optional GIS layers

Overlay in GIS

- HRUs
  Hydrological Response Units
- SWIM input file: ***.str**

Optional layers

Elevation, slope (DEM)

Land use / cover (LULC)
Natural, managed

Soils

Other
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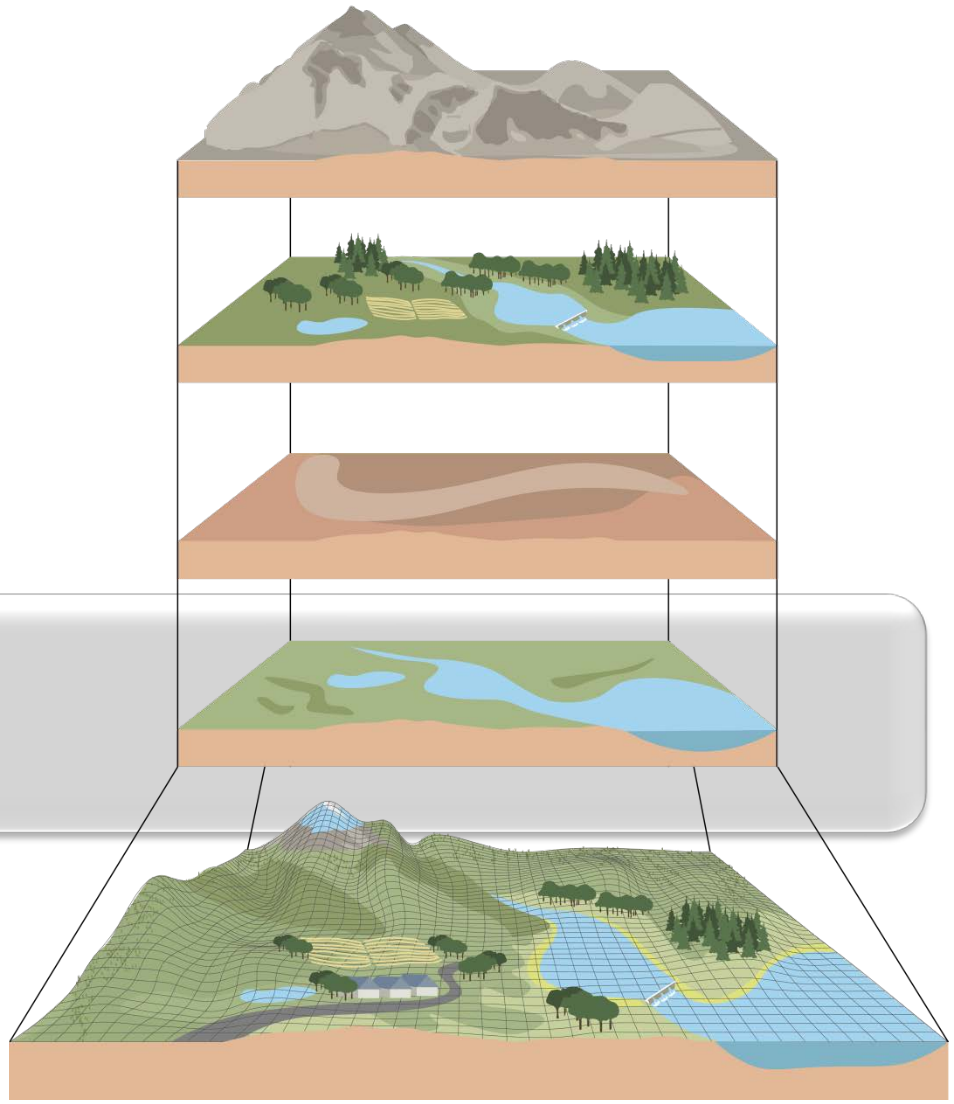
Hydrotopes (HRUs)



The model itself

Is simply a...

Data processor

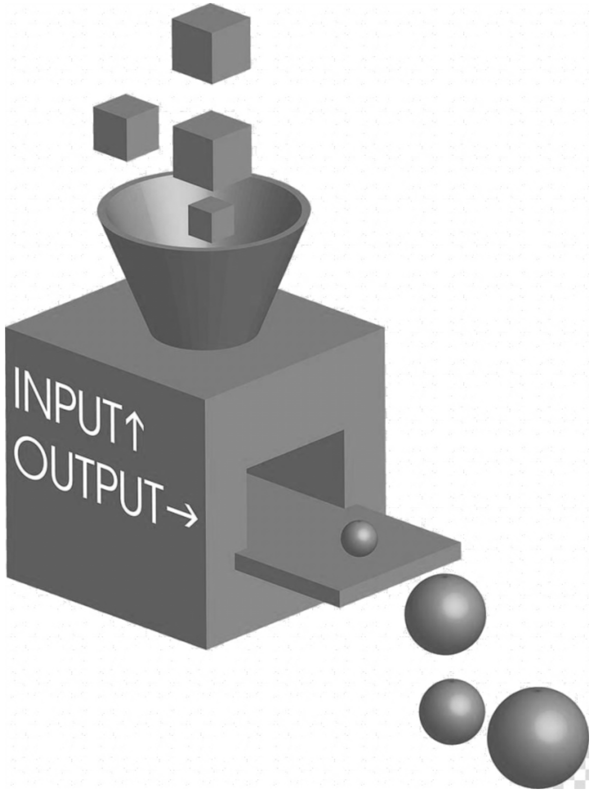
- Reading input → producing output

Input

- ASCII text files (readible / editable in a text editor)
- Produced during GIS (and other) pre-processing
- Representing spatio-temporal data

Output

- ASCII text files (readible / editable in a text editor)
- Time series
- GIS reclassification files at HRU level

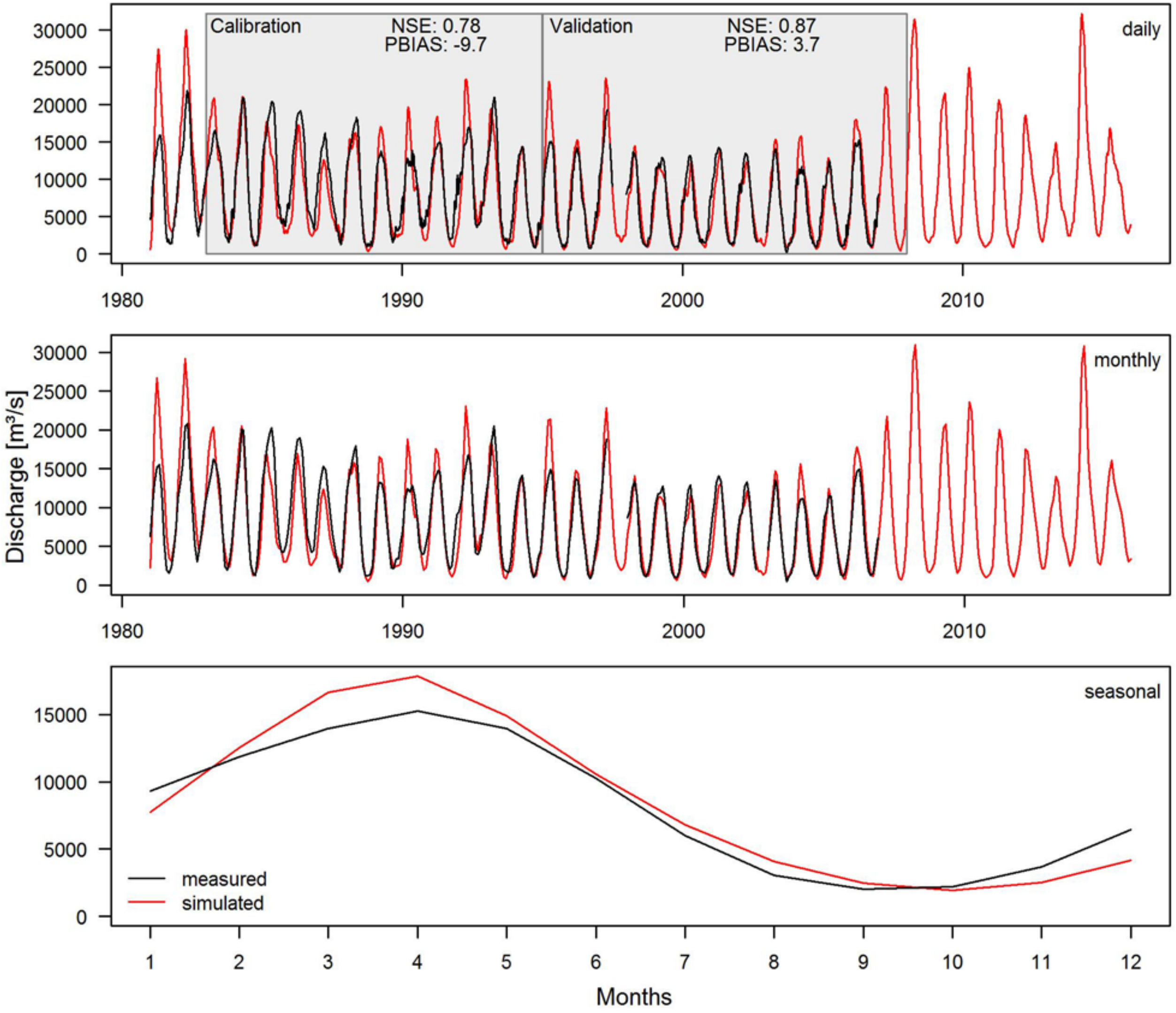


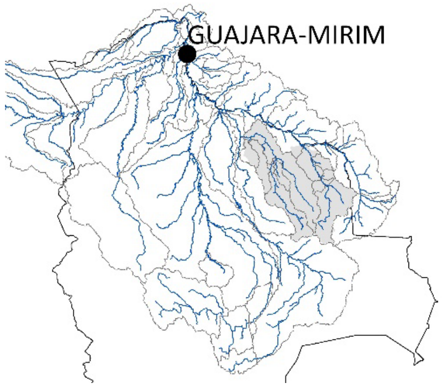
https://p7.hiclipart.com/

Discharge, observed vs. simulated

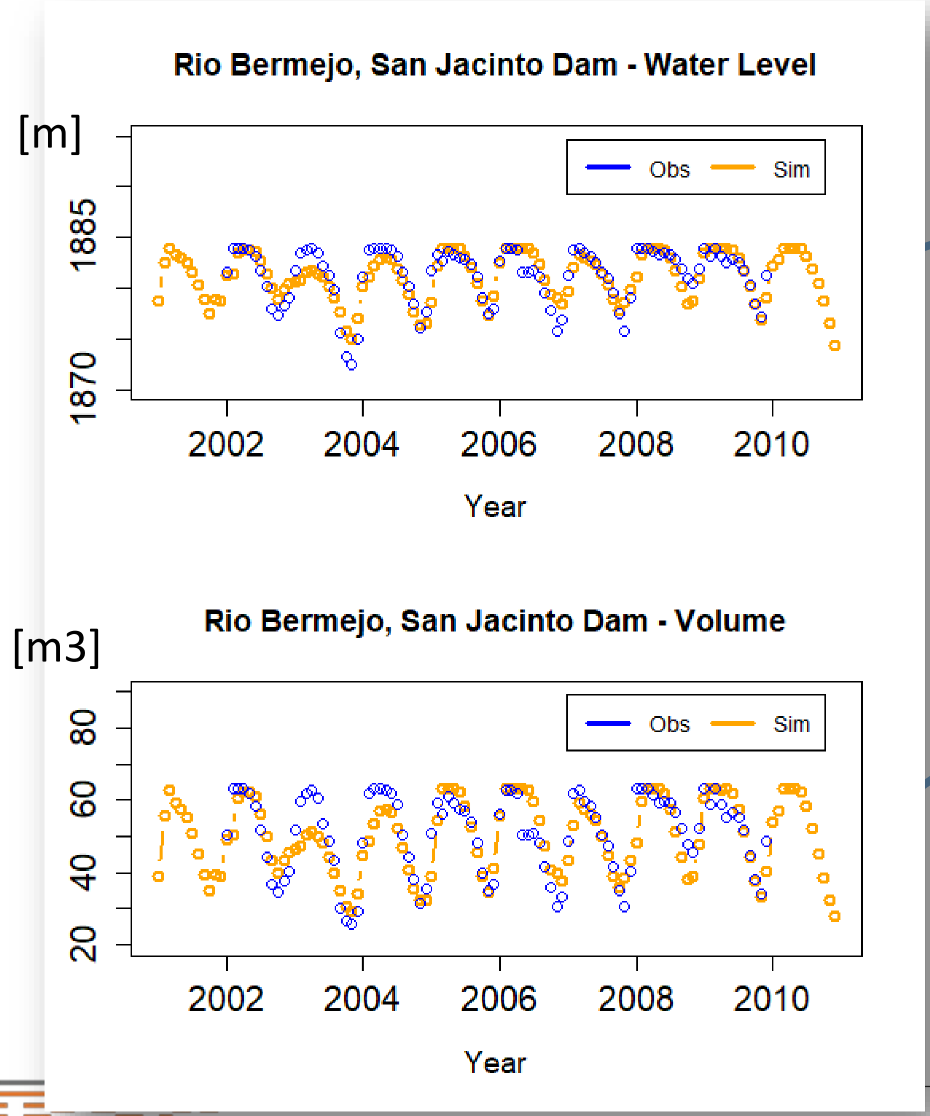
Guajara-Mirim

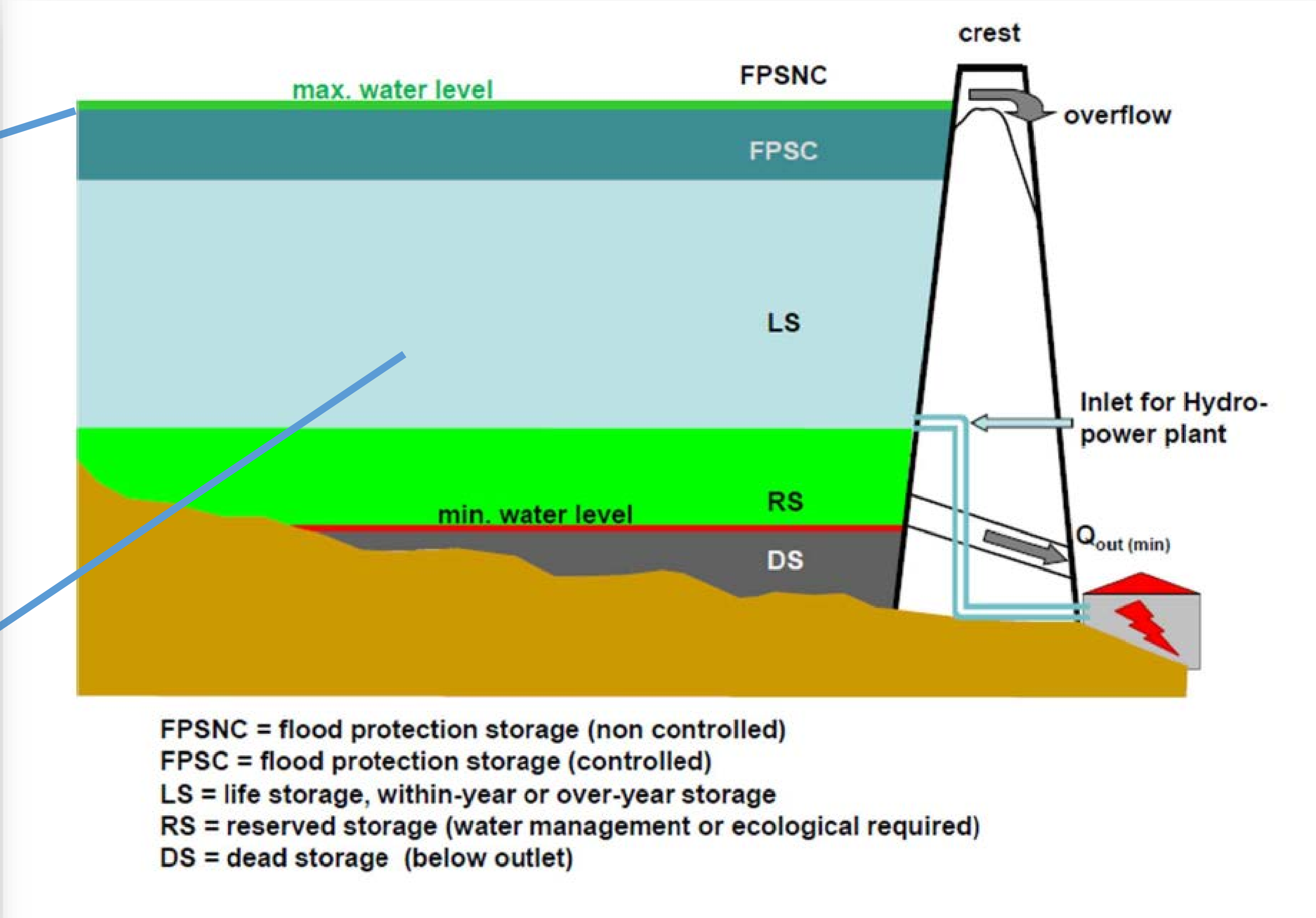
Average daily Q





Reservoir: Level and volume



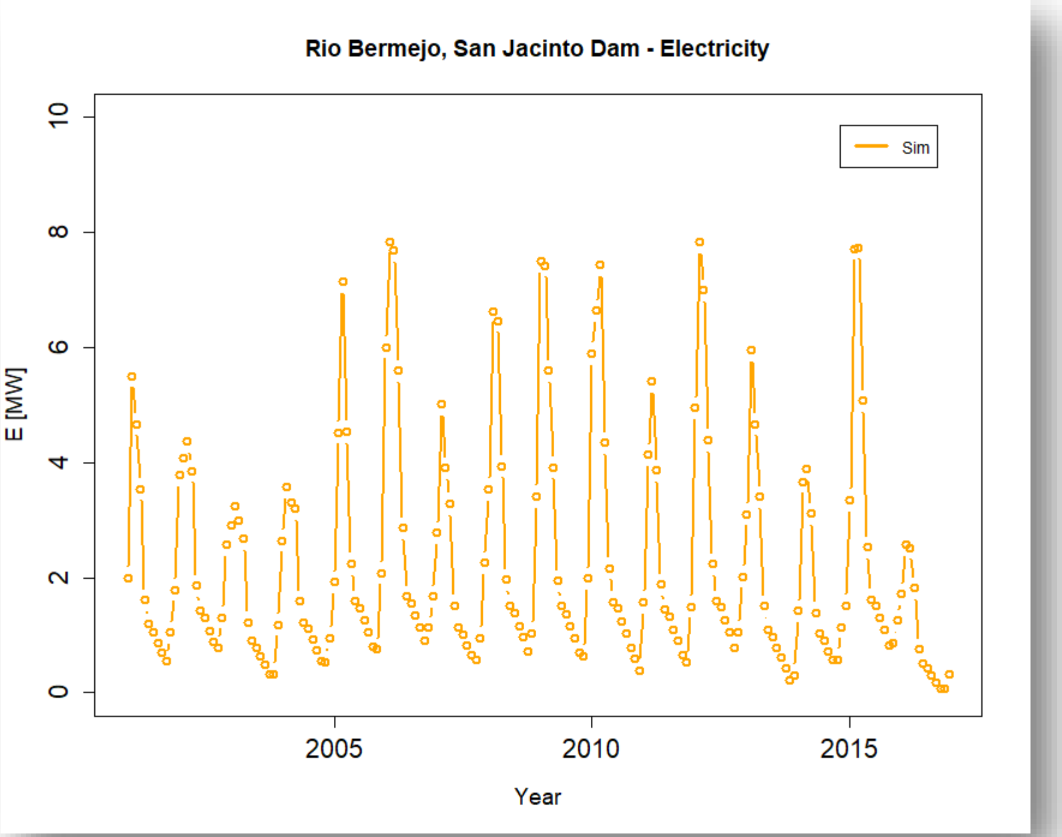


Hydropower potential

SSP126, ISIMIP3b, 8 GCMs

San Jacinto Dam

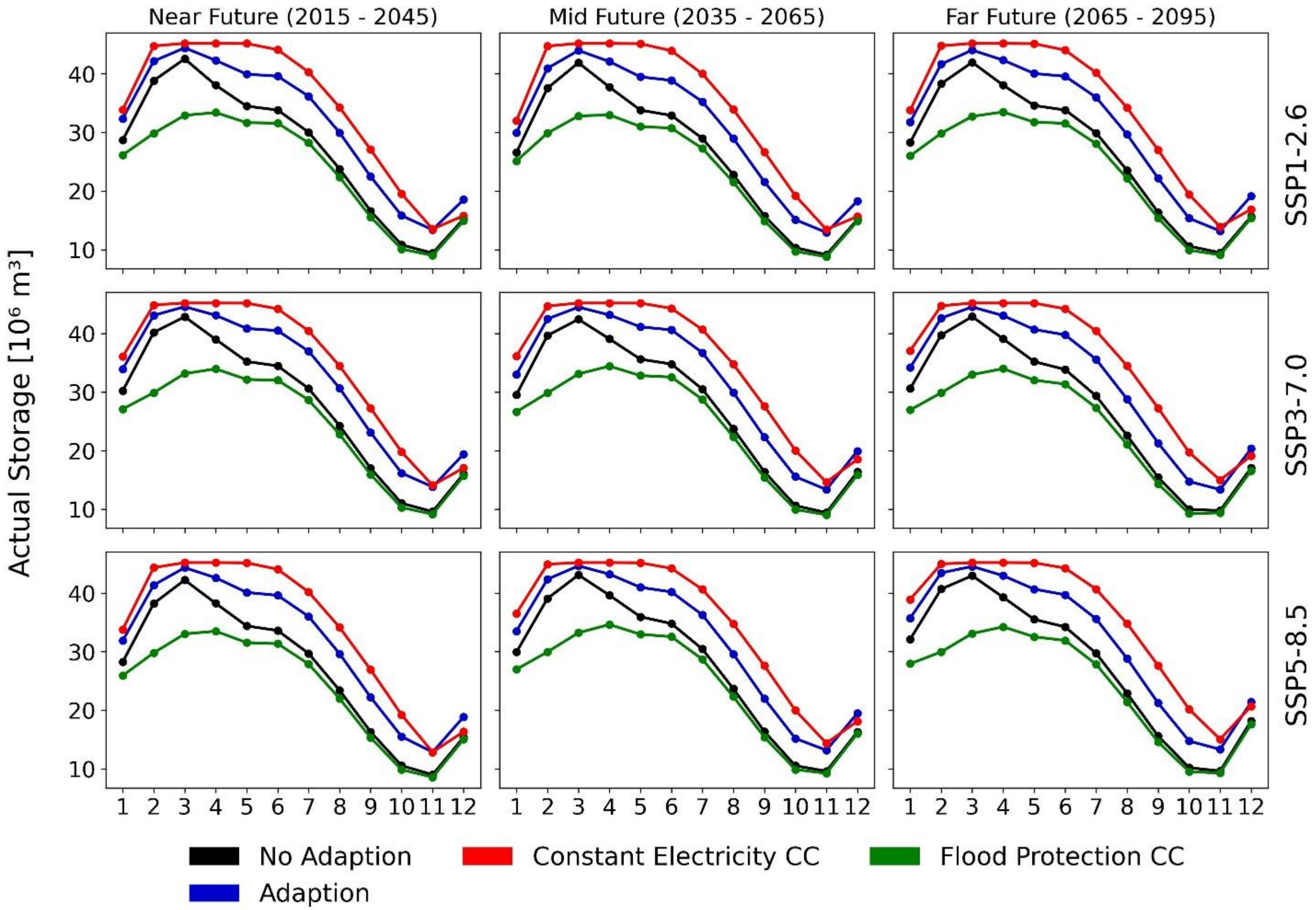
- Rio Bermejo
- Tarija



Scenario development Tarija

Scenarios	Change of crop rotations	Irrigation of strawberries	Change of reservoir management
Baseline (under current climate conditions)	Corn cultivation		Priority (first operational objective) on hydropower generation with generation peaks in rainy season, second objective is irrigation (no flood control)
Noadaptation (under CC)			
No regret (under current climate conditions)	Wine		Priority on irrigation, second goal hydropower generation (peak generation in rainy season, no flood control).
Adaptation (under CC)			

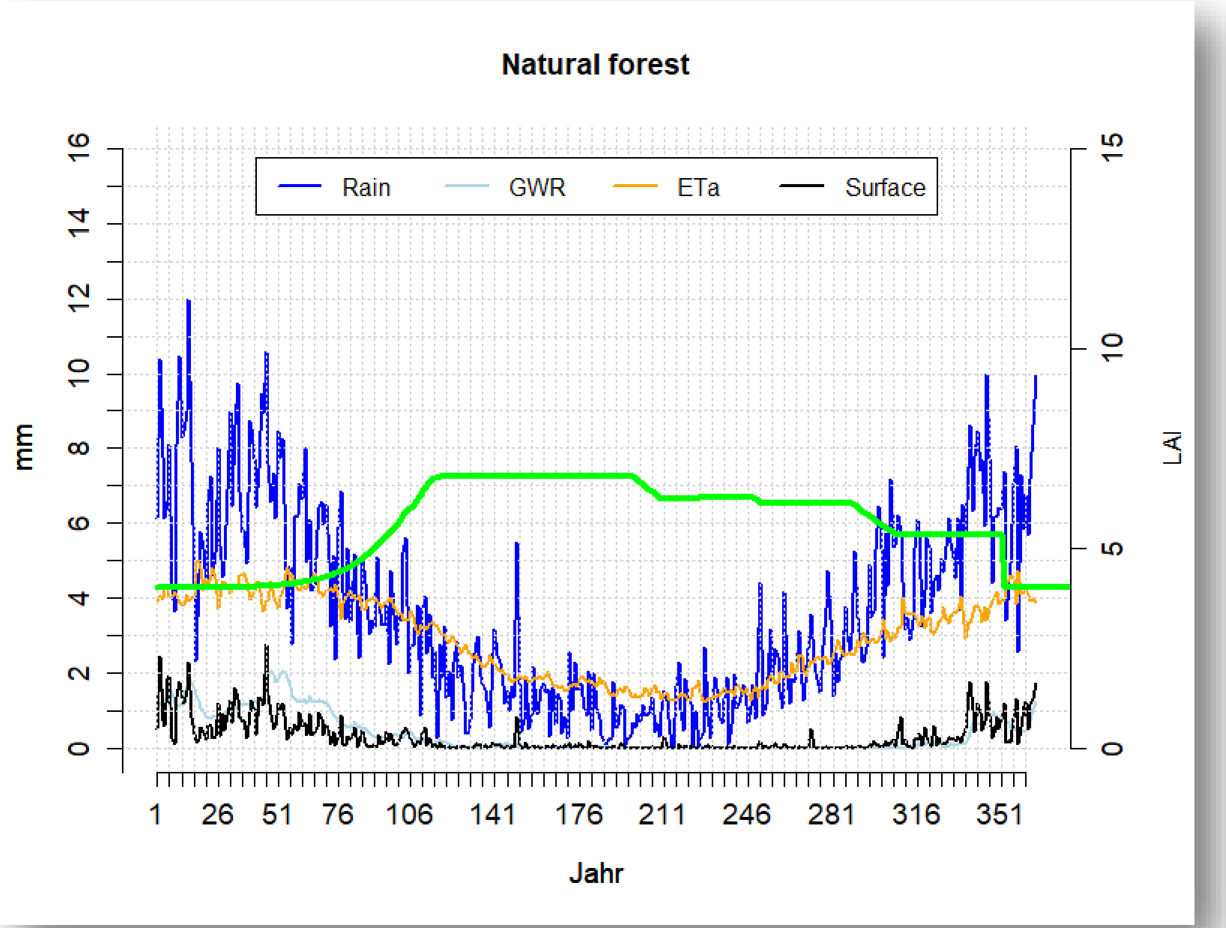
Volume in reservoir under scenario conditions



Some HRU output

Bagré irrigation site, WFDE5

- Precipitation
- Water stress
- Irrigation
- Leaf area index
- Percolation
- Biomass
- Root depth
- ...



Spatial output

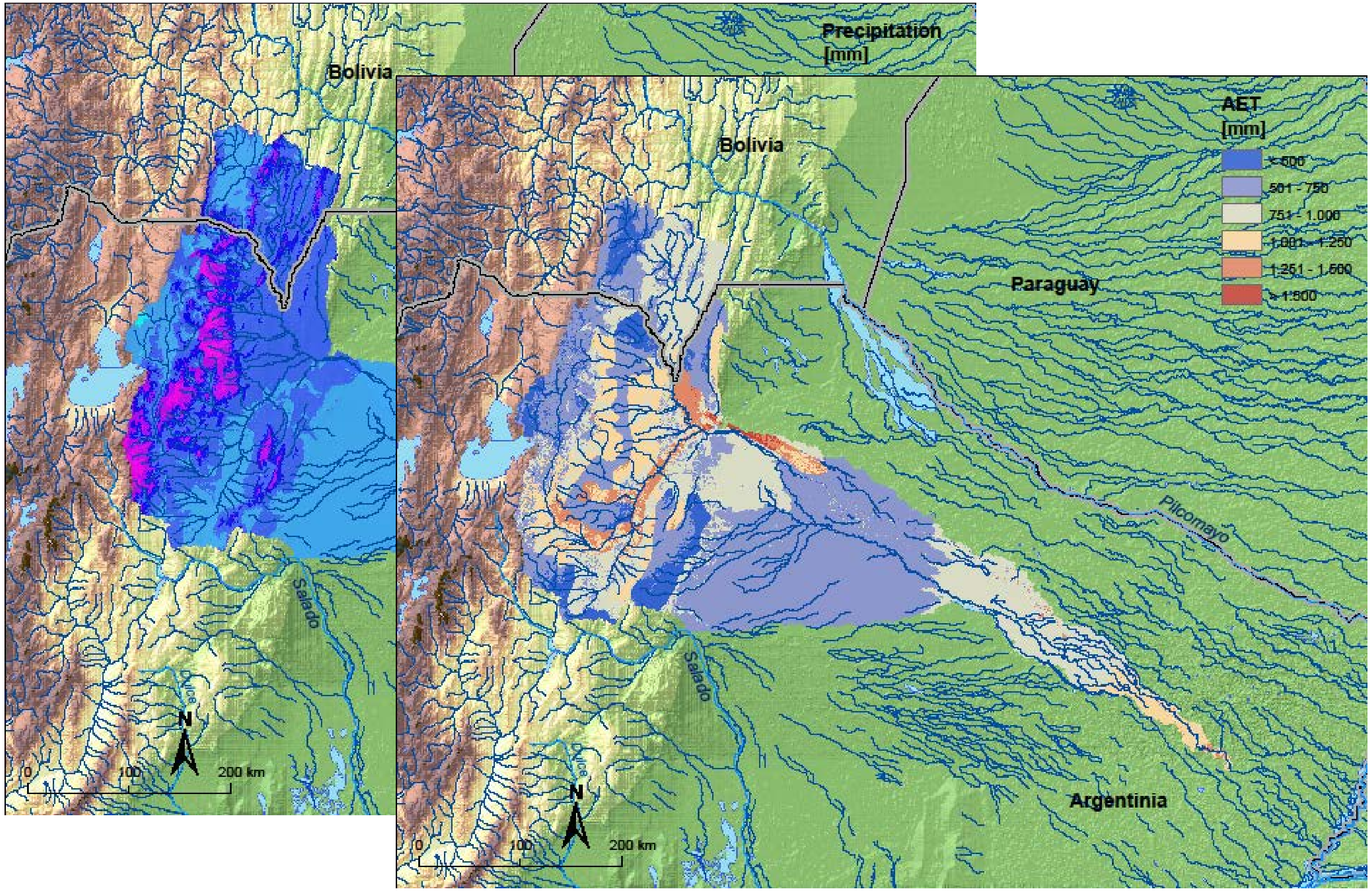
Tarija, ISIMIP3b

ETa change (example)

- Reference: 1984-2014

Spatial output

- Precipitation
- ETp, ETa
- Surface Q
- GW recharge
- Soil water index



SWIM code

Fortran programming language

Fortran

- „Old“ but not entirely outdated programming language, still maintained
- Computationally very efficient, like C

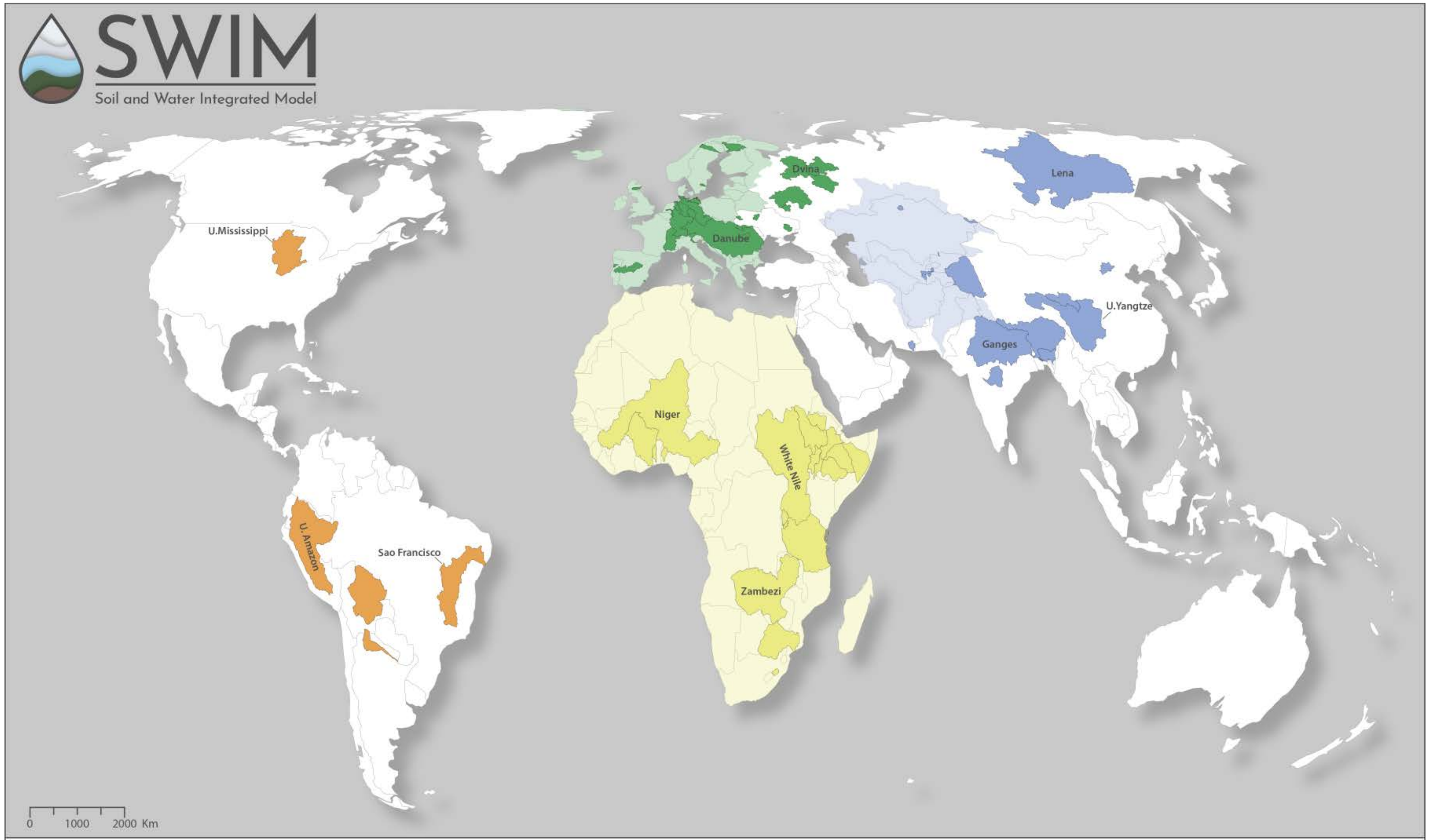
Redesign of SWIM code

- Conversion of the code into a modular struture (Fortran 90 / 95)
- Fully open source some time in 2022

Simulation (execution) time

- Mainly depending on number of HRUs
- Volta model (~9800 HRUs): 140 years ~3 hours or ~1 min / year

Worldwide applications



Europe

- 1.1. Tagus
- 1.2. Rhine
- 1.3. Lule
- 1.4. Rhine
- 1.5. Eman
- 1.6. Adige
- 1.7. Tay
- 1.8. Upper Tisza
- 1.9. Upper Prut
- 1.10. U. W. Bug
- 1.11. Samara
- 1.12. Teteriv
- 1.13. Danube
- 1.14. Dvina
- 1.15. Elbe
- 1.16. Weser
- 1.17. Oka
- 1.18. Rhone
- 1.19. Jizera
- 1.20. Saale
- 1.21. Tyligul
- 1.22. Vistula lag.
- 1.23. Mures
- 1.24. Warnow
- 1.25. Trave
- 1.26. Eider
- 1.27. Maas
- 1.28. Ems
- 1.29. Tagus
- 1.30. Sosna
- 1.31. Vyatka
- 1.32. Mar Menor
- 1.33. Ria de Aveiro

Africa

- 2.1. Blue Nile
- 2.2. Tanzania
- 2.3. Zambezi
- 2.4. Niger
- 2.5. Limpopo
- 2.6. White Nile
- 2.7. Mono
- 2.8. Volta
- 2.9. Awash
- 2.10. Omo
- 2.11. Shebelle
- 2.12. Sobat
- 2.13. Ogun
- 2.14. Genale
- 2.15. Thukela

America

- 3.1. U. Amazon
- 3.2. Sao Francisco
- 3.3. Mamore
- 3.4. Bermejo
- 3.5. U. Mississippi

Asia

- 4.1. Lena
- 4.2. U. Yangtze
- 4.3. Ganges
- 4.4. U. Yellow
- 4.5. Aspara
- 4.6. Isfara
- 4.7. Guanting
- 4.8. Upper Tarim
- 4.9. Tailan
- 4.10. Aksu
- 4.11. Yarkan
- 4.12. Hotan
- 4.13. Jinhe
- 4.14. Zerafshan
- 4.15. Tupalanga
- 4.16. Zhabay
- 4.17. Kafirnigan
- 4.18. Murgab
- 4.19. Buhtarma
- 4.20. Meghna
- 4.21. Brahmaputra

CLIMATE CHANGE AND HEALTH IN SUB-SAHARAN AFRICA

MOCK REVIEW | 21-22 June 2022 | HEIDELBERG

Funded by DFG

COORDINATION

courtesy of Stuart Rice

Malaria

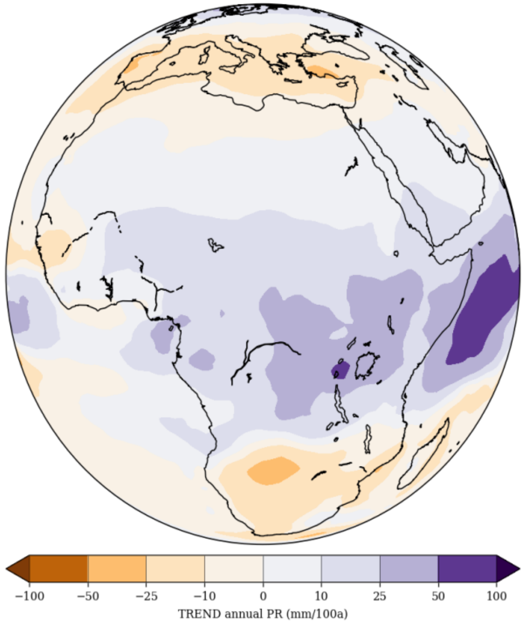
courtesy of Isabel Mank

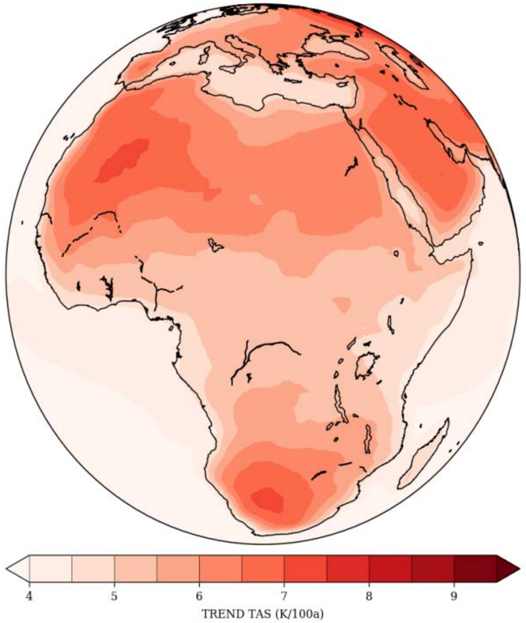
Undernutrition

courtesy of Jes Aznar

Heat stress

Rainfall





Temperature

Empirical population-based research

IMPACT

How much does climate change impact on diseases and for whom?

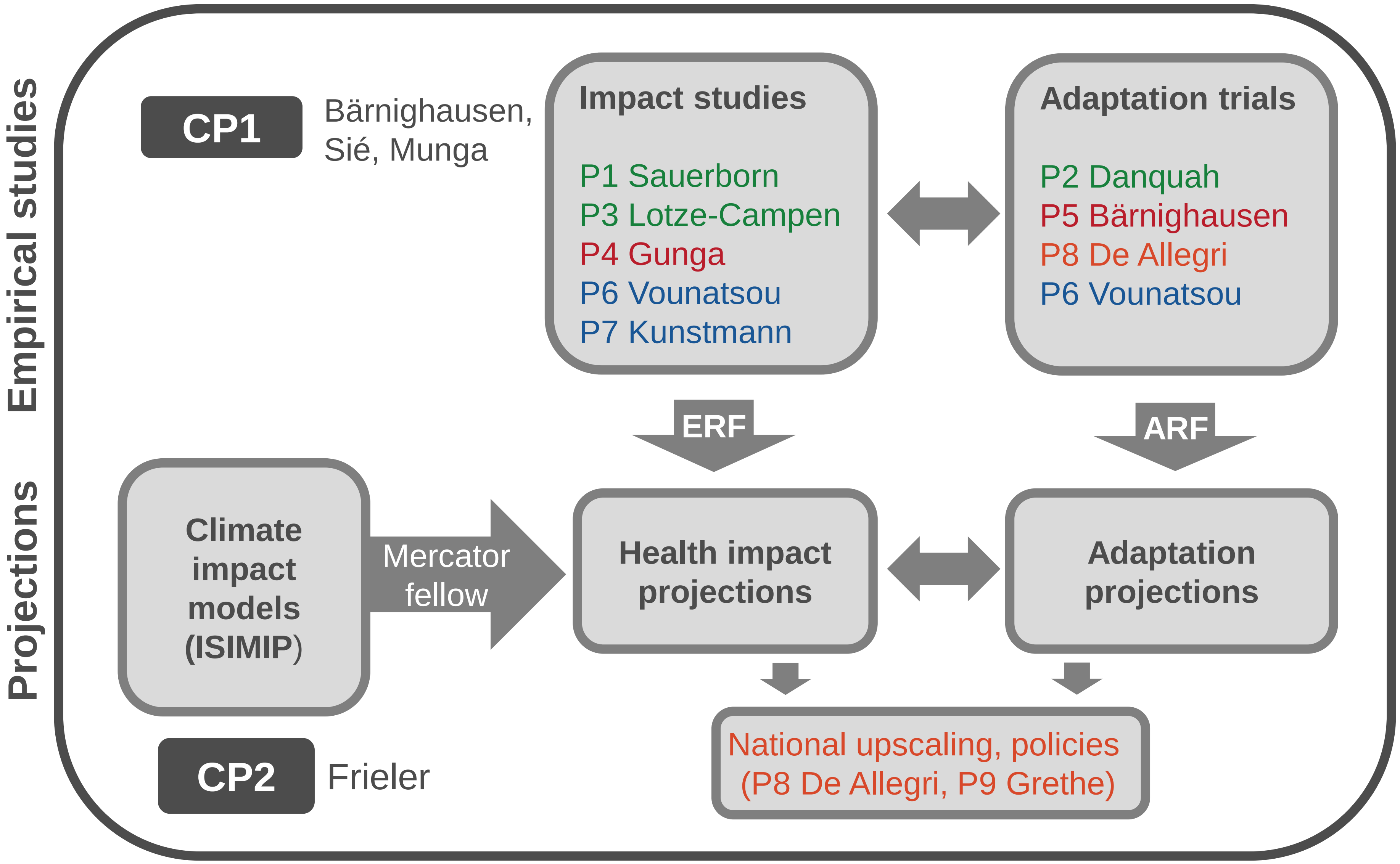
ADAPTATION

How effective are local adaptation interventions to protect population health?

PROJECTION

How will health impact projections unfold under different climate and adaption scenarios?

Logical flow of work



Location of two standardized population cohorts

Burkina Faso

Kenya

Kossi Province

Nyanza Province

Nouna cohort, *N*=106,000 in 58 villages
(14.4° - 12.5° north / 3.4° - 4.1° west)
Area: 1775 km^2

Kisumu cohort, *N*=180,000 in 394 villages
(-0.2° south - 0.2° north / 34.5° - 34.3° east)
Area: 700 km^2

Linking climate impact modeling to health

Typical impact model chain

Global Climate Models

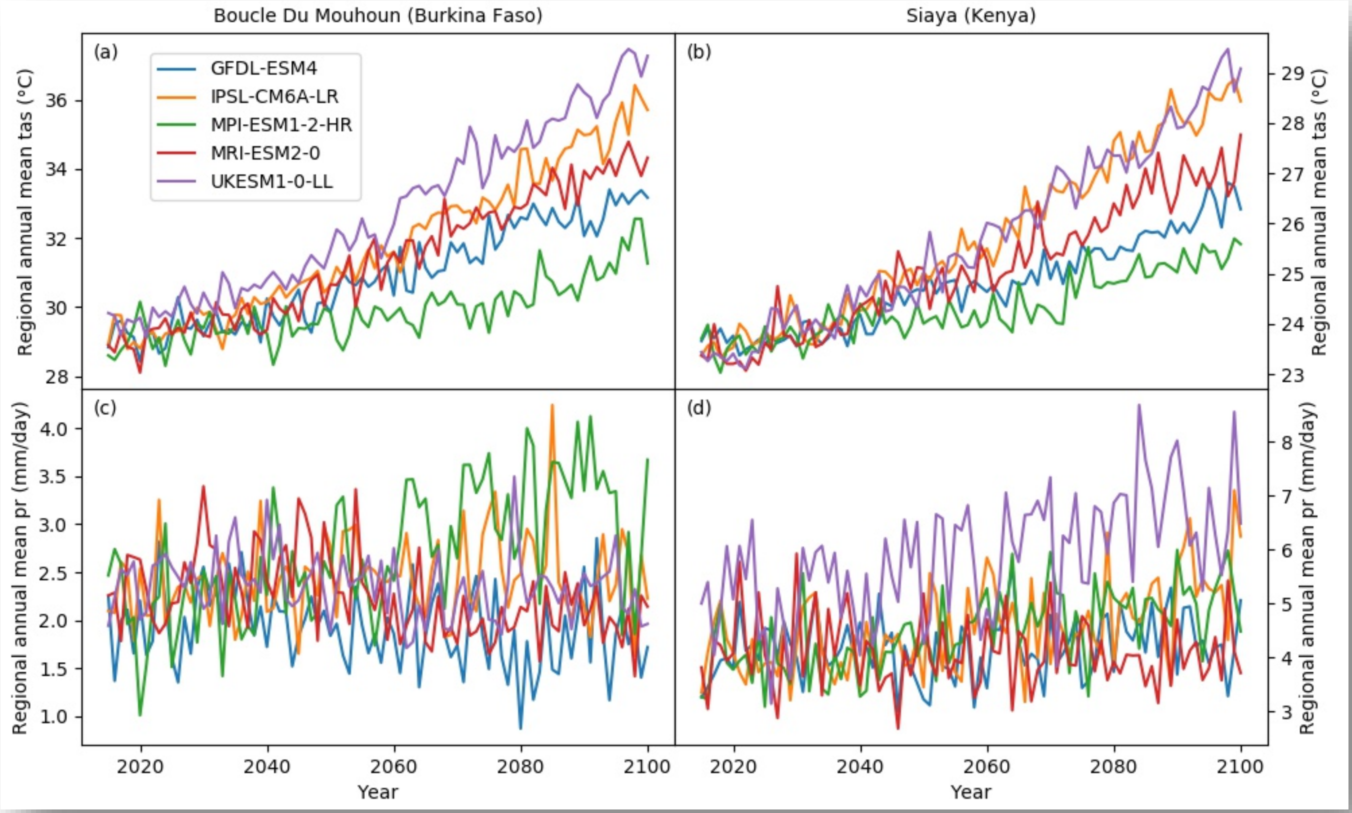
Regionalisation

Regional Climate Models

Correction

Impact Model (floods, droughts, yields)

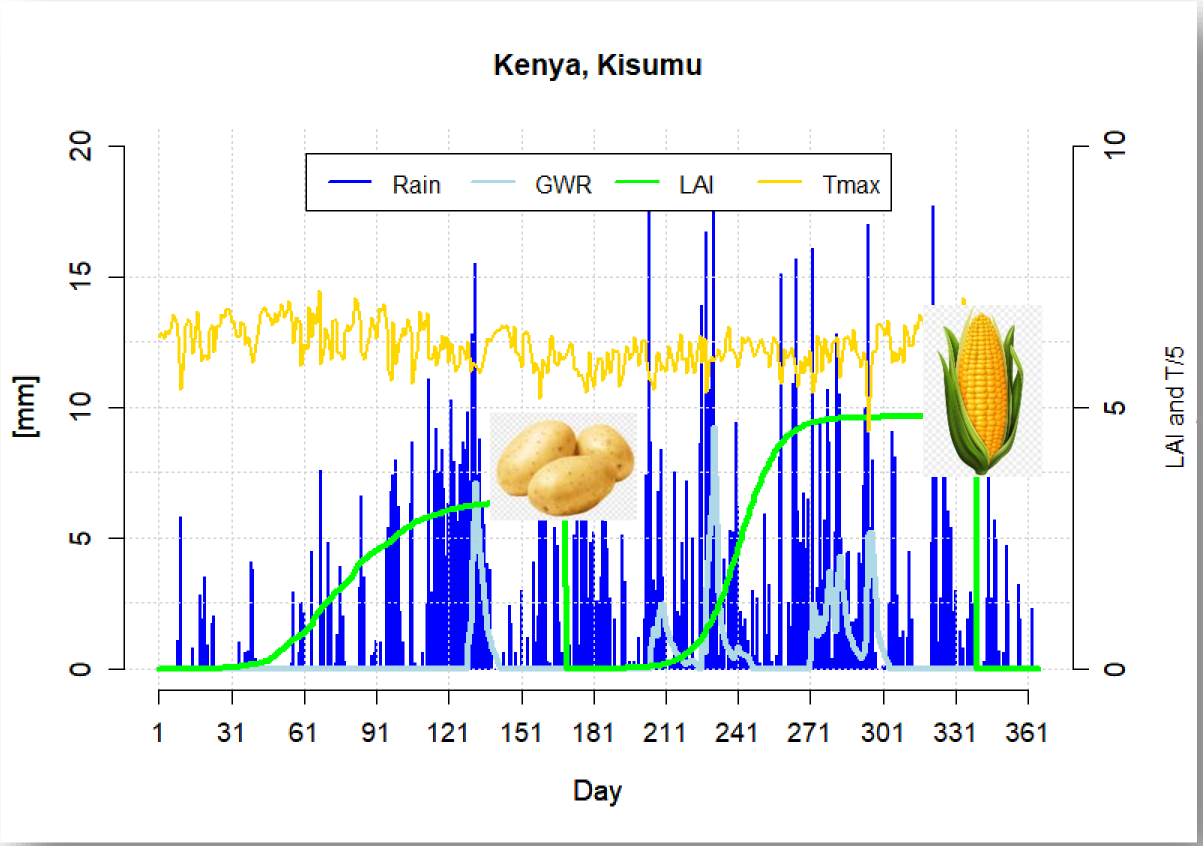
Typical outcome of climate models here relevant: Tmax, humidity, radiation

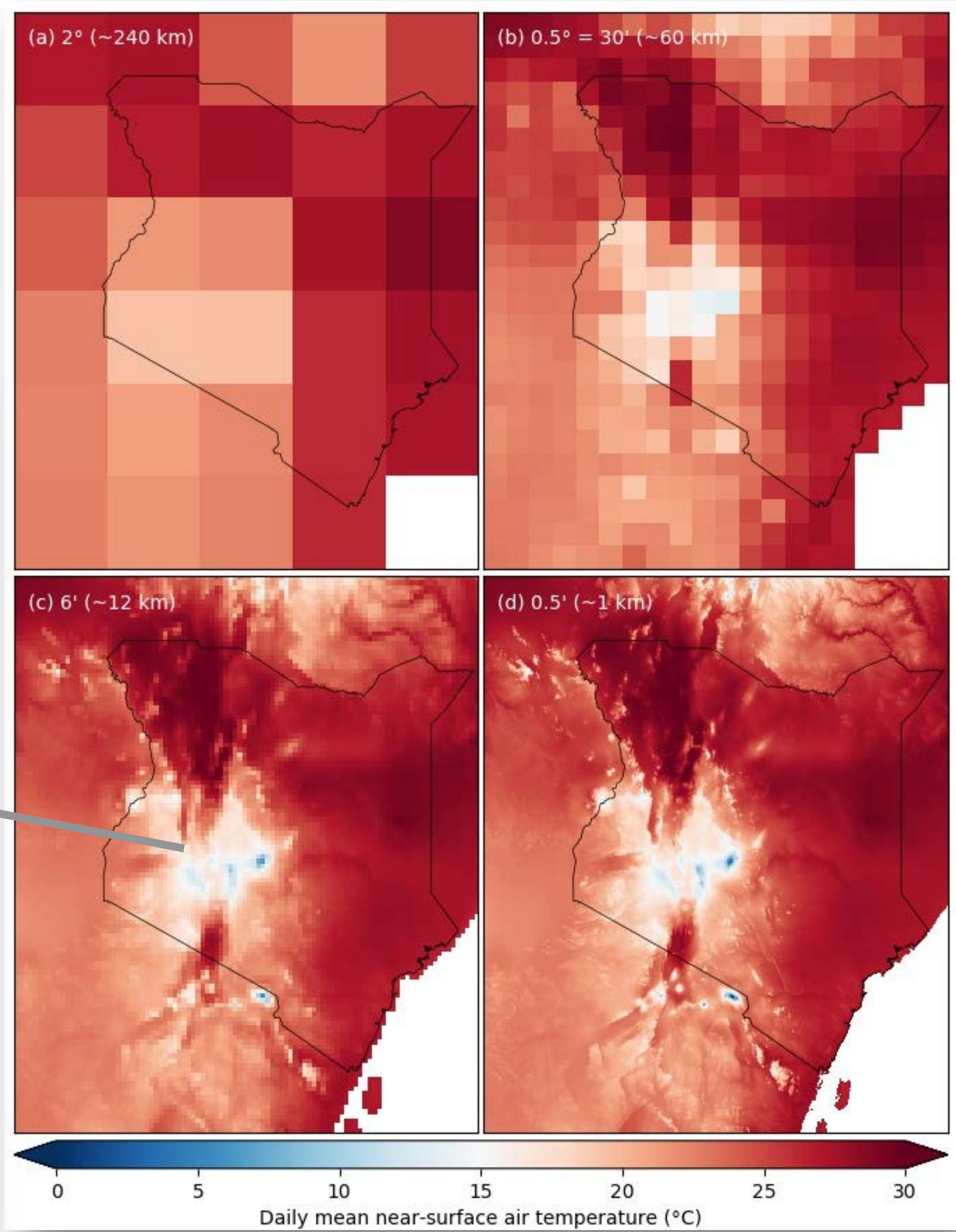


ELER, Potsdam

CENTRAL PROJECTS – CP2

Scientific progress during phase 1 – high-resolution biophysical data

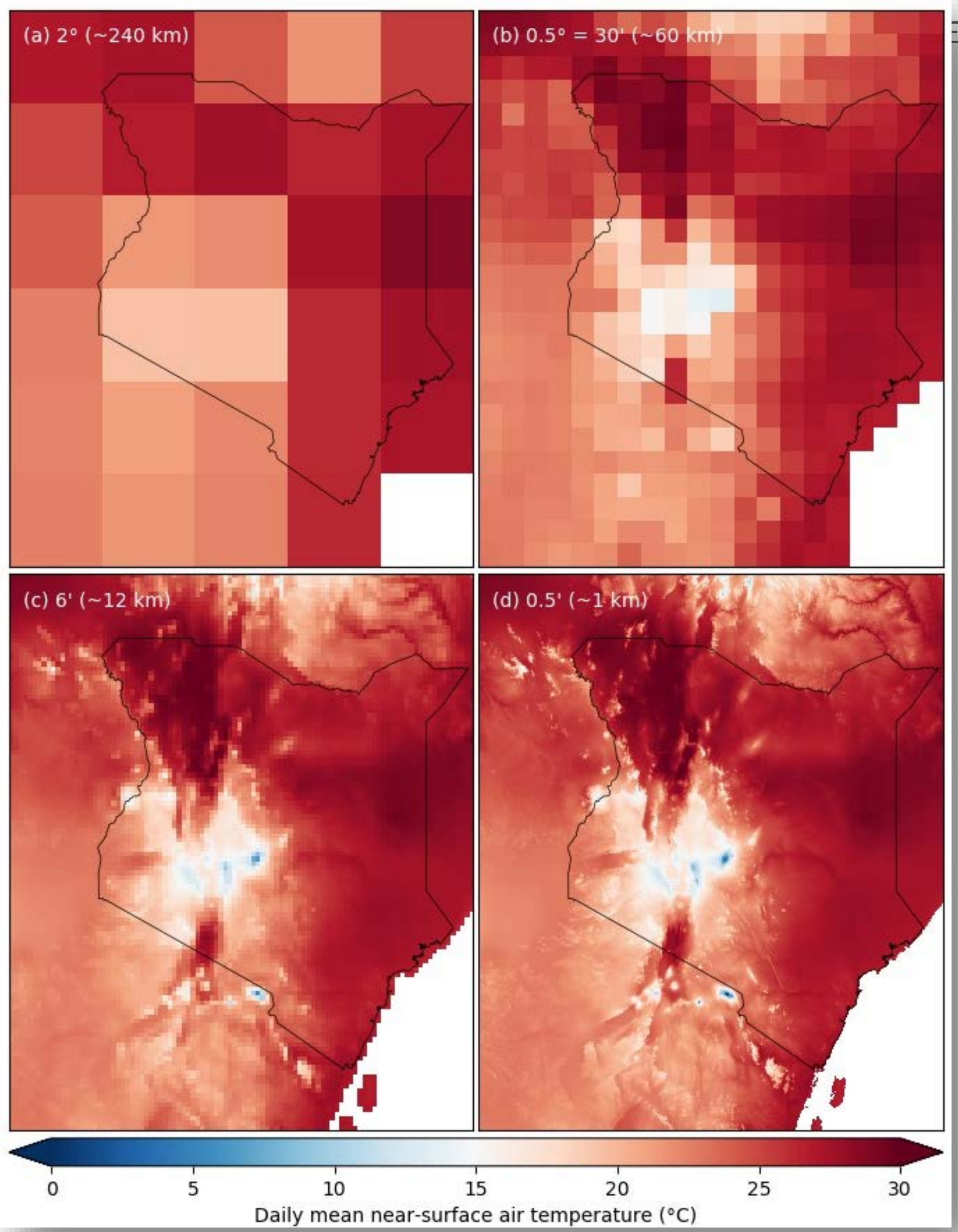




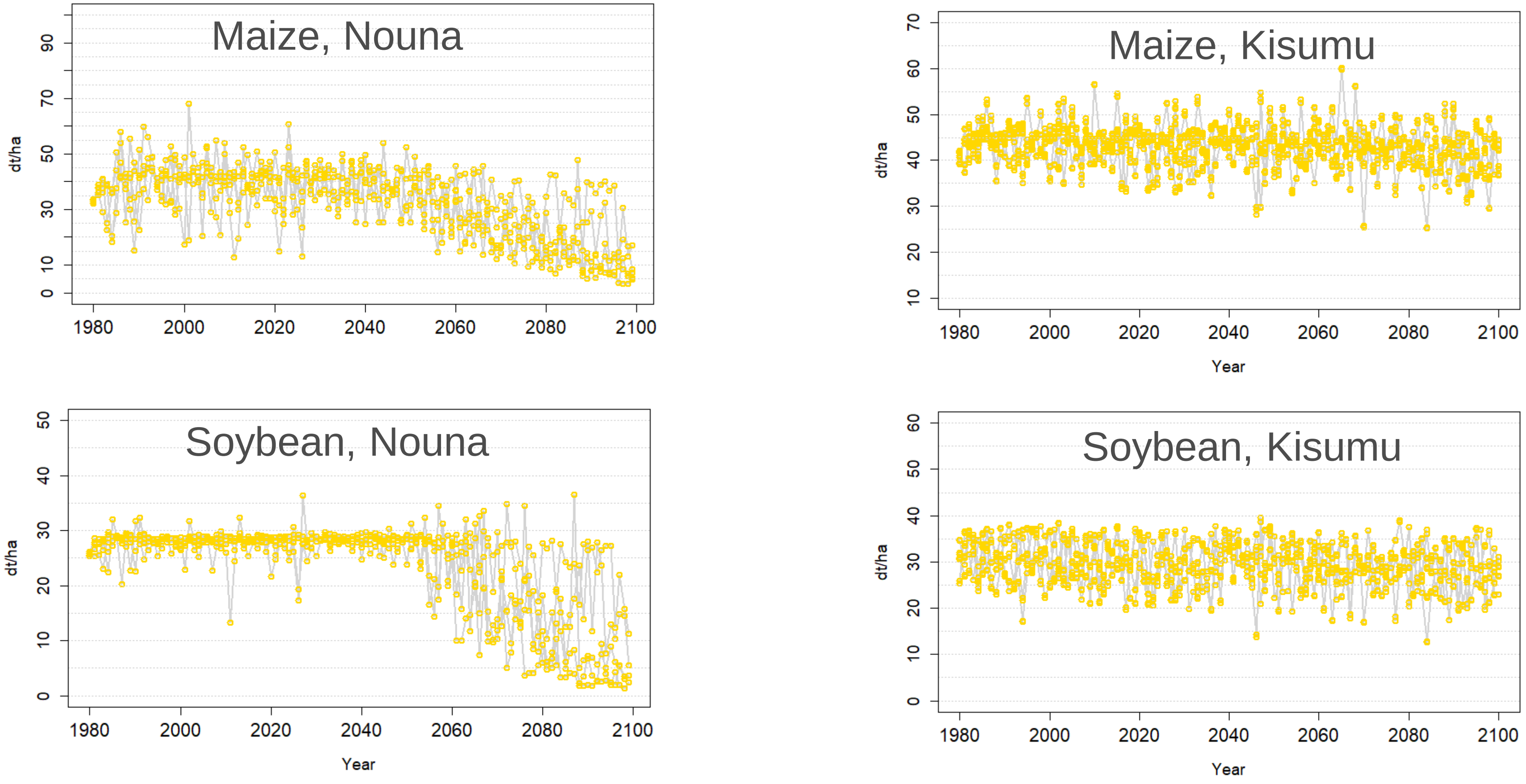
Scientific progress during phase 1 – combing biophysical impact with health

$$Health = f(T, P, Y, E \ldots)$$

$T = Temperature$
$P = Precipitation$
$Y = Yield$
$E = Extremes\ (floods, droughts)$
$\ldots$



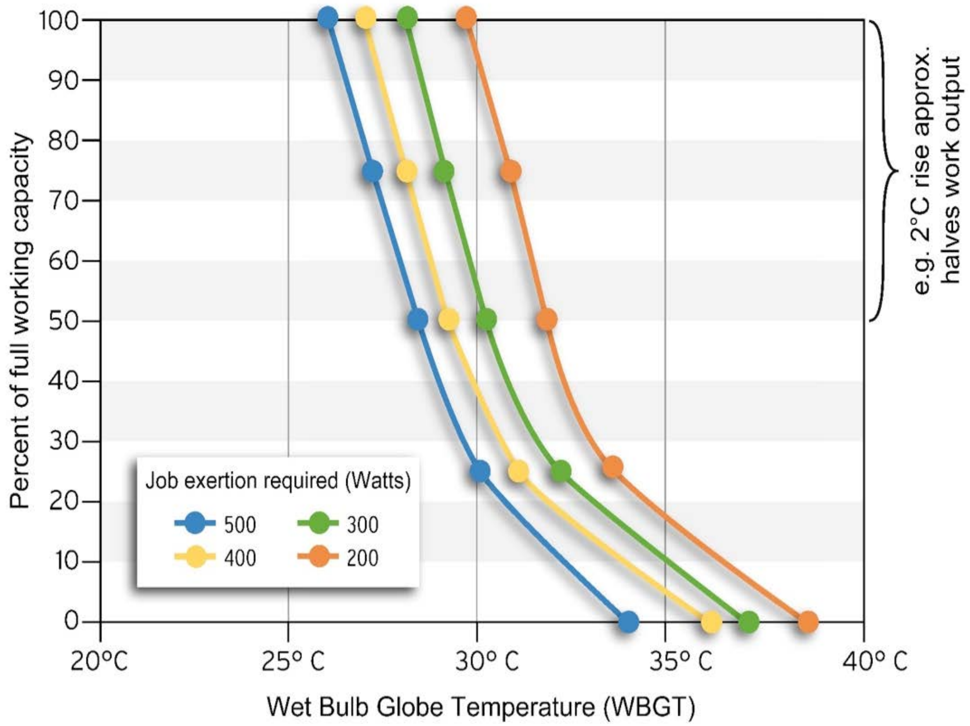
EXAMPLE 1: Projections of crop yields



Background: Scenario SSP5-8.5 („hot“ scenario), 5 GCM scenario runs downscaled to Nouna and Kisumu
Trend to less precipitation in Nouna and stable or increasing in Kisumu. Increase in variability and strong temperature increase in both regions

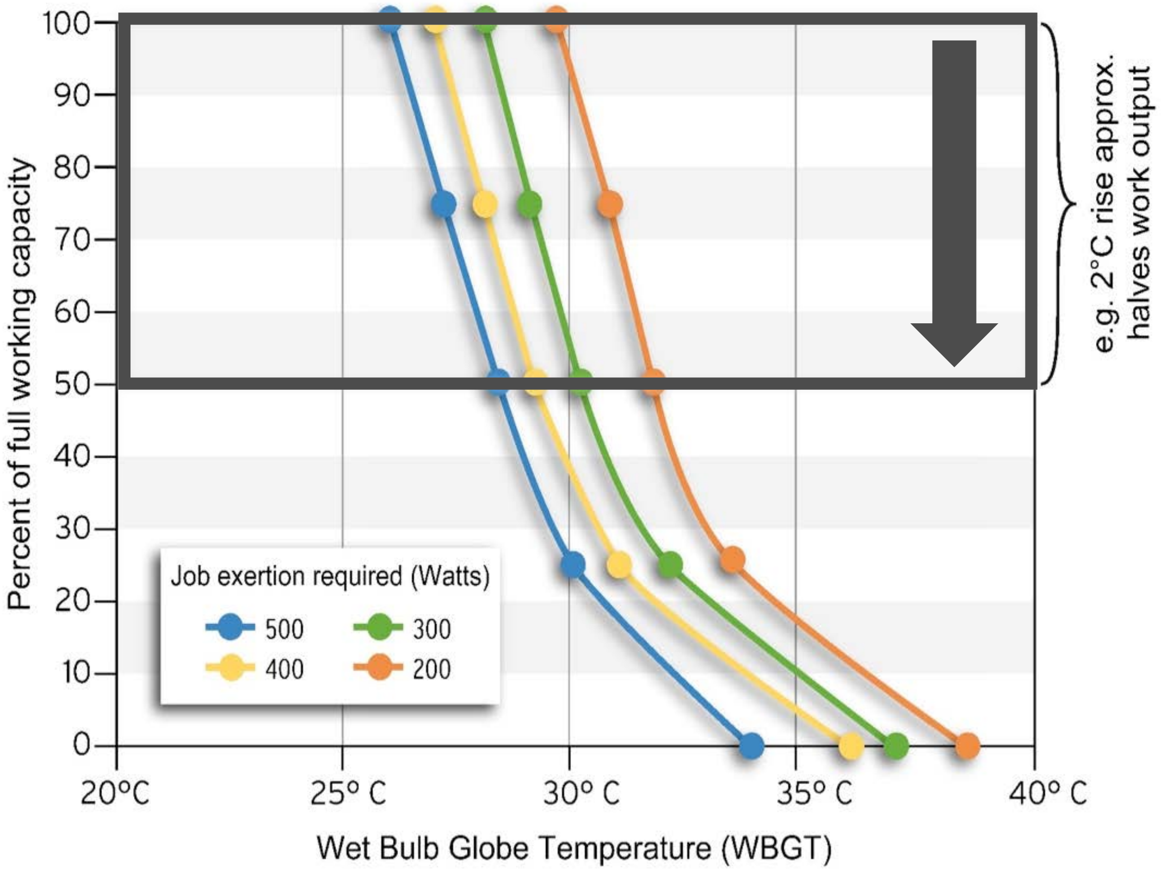
EXAMPLE 2: Heat Exposure Response

Percent of full working capacity with changing WBGT
and different workloads



WBGT = Wet Bulb Globe Temperature

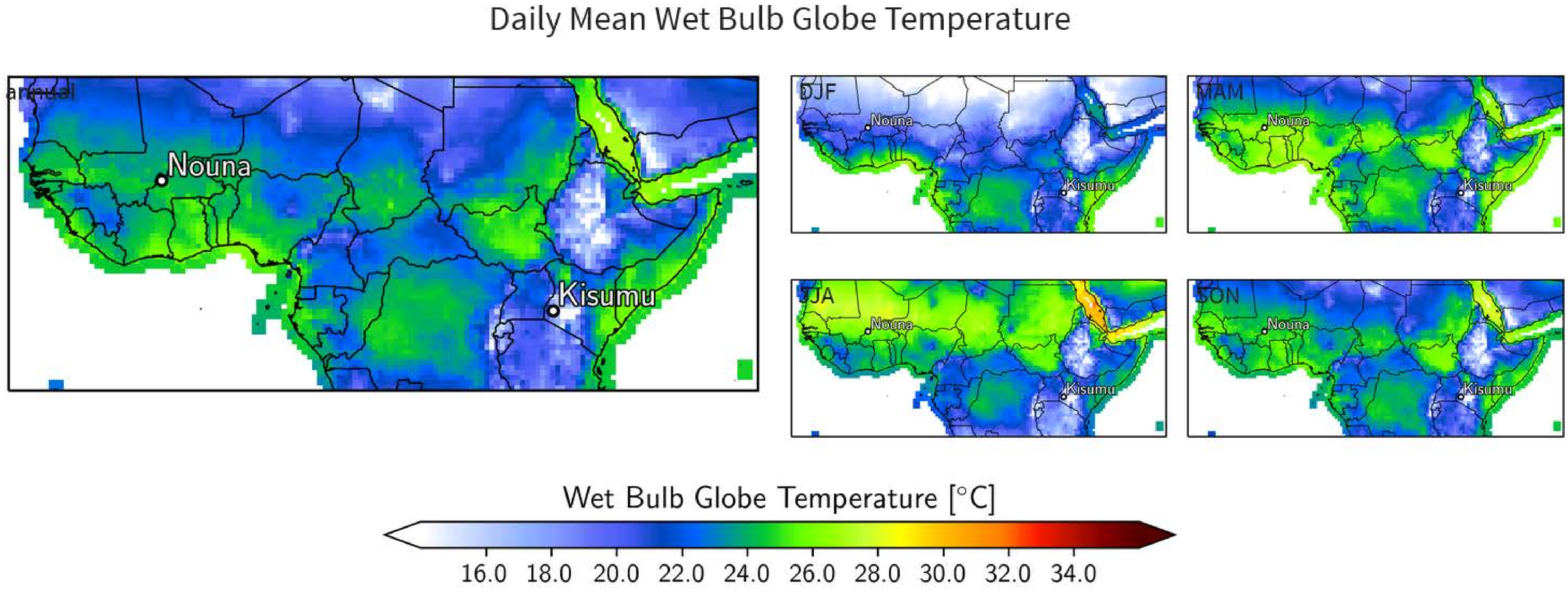
Definitions



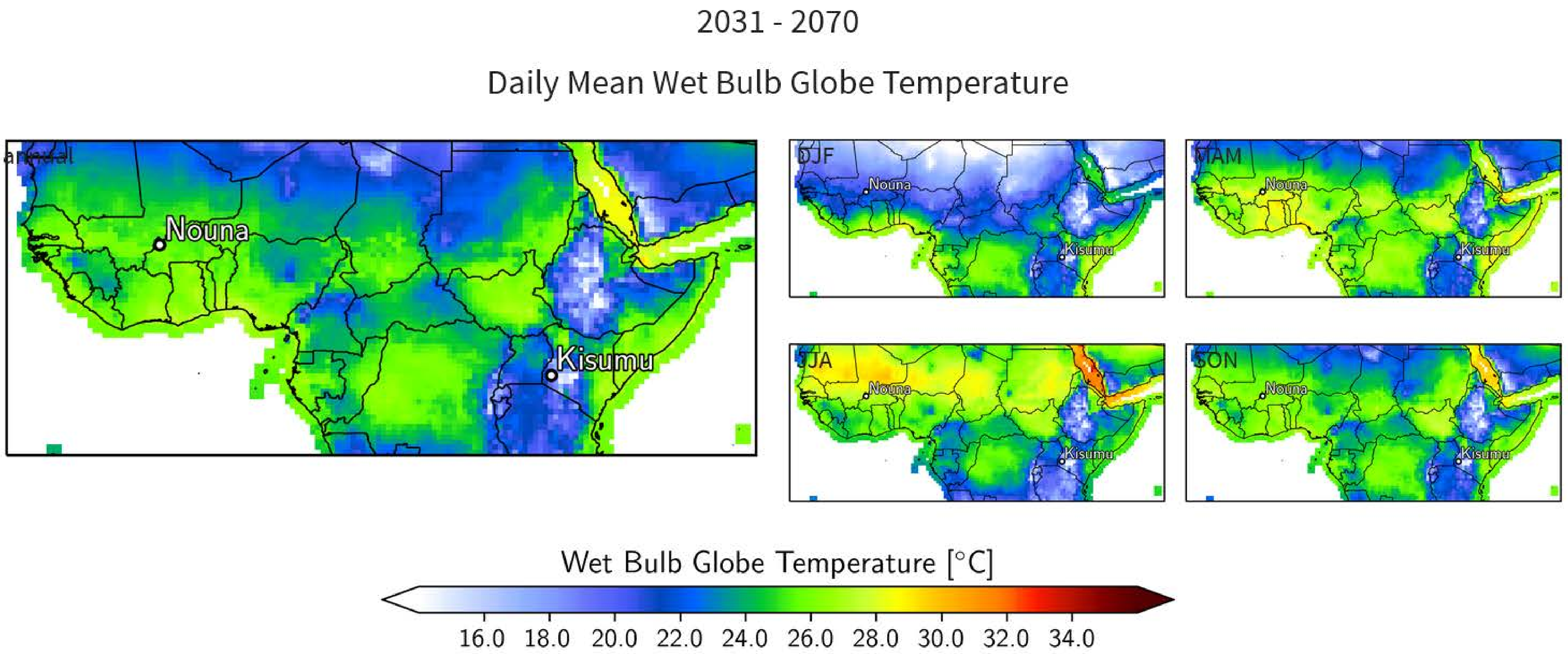
WBGT thresholds for thermal perception Table from Zare et al. (2019)

Thermal perception	WBGT
no thermal stress	below 18°C
moderate heat stress	18°C-23°C
strong heat stress	23°C-28°C
extreme heat stress	28°C-30°C
extreme danger	above 30°C

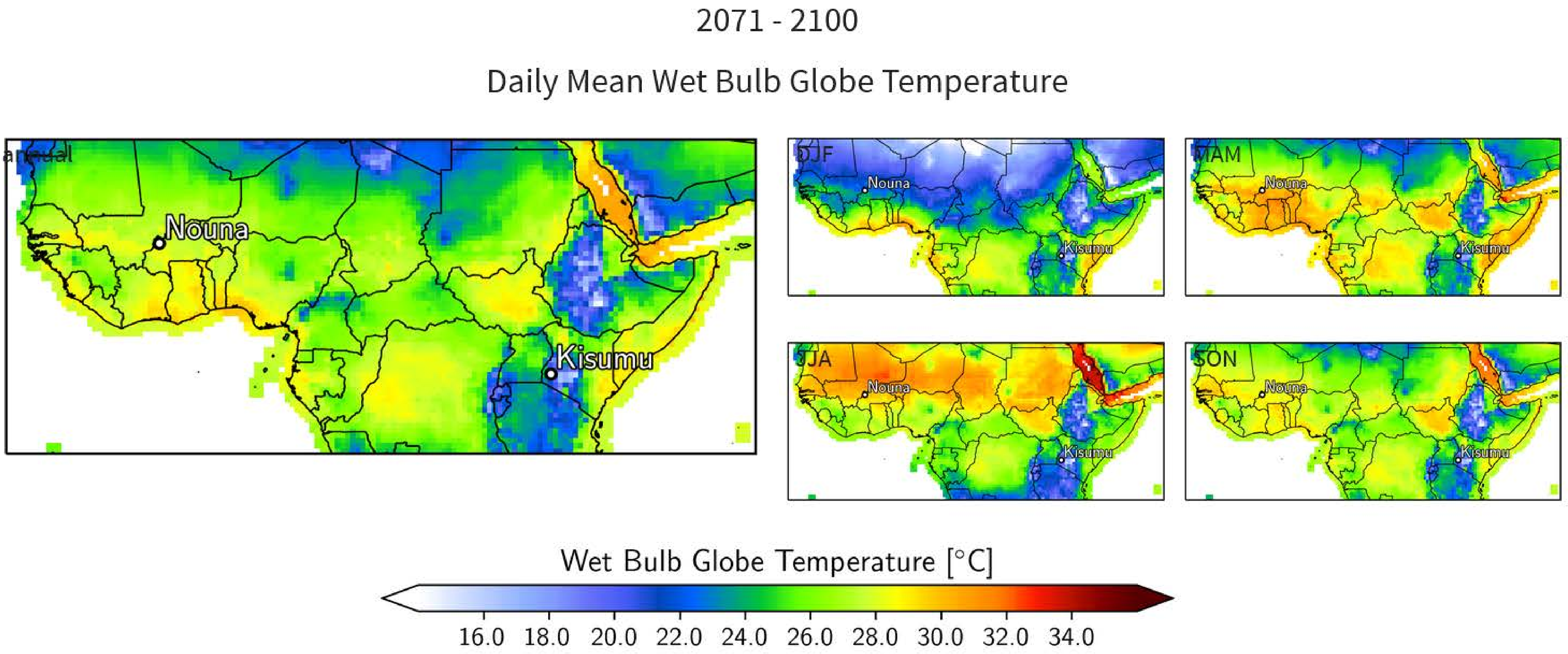
Daily mean WBGT now



Daily mean WBGT mid of the century



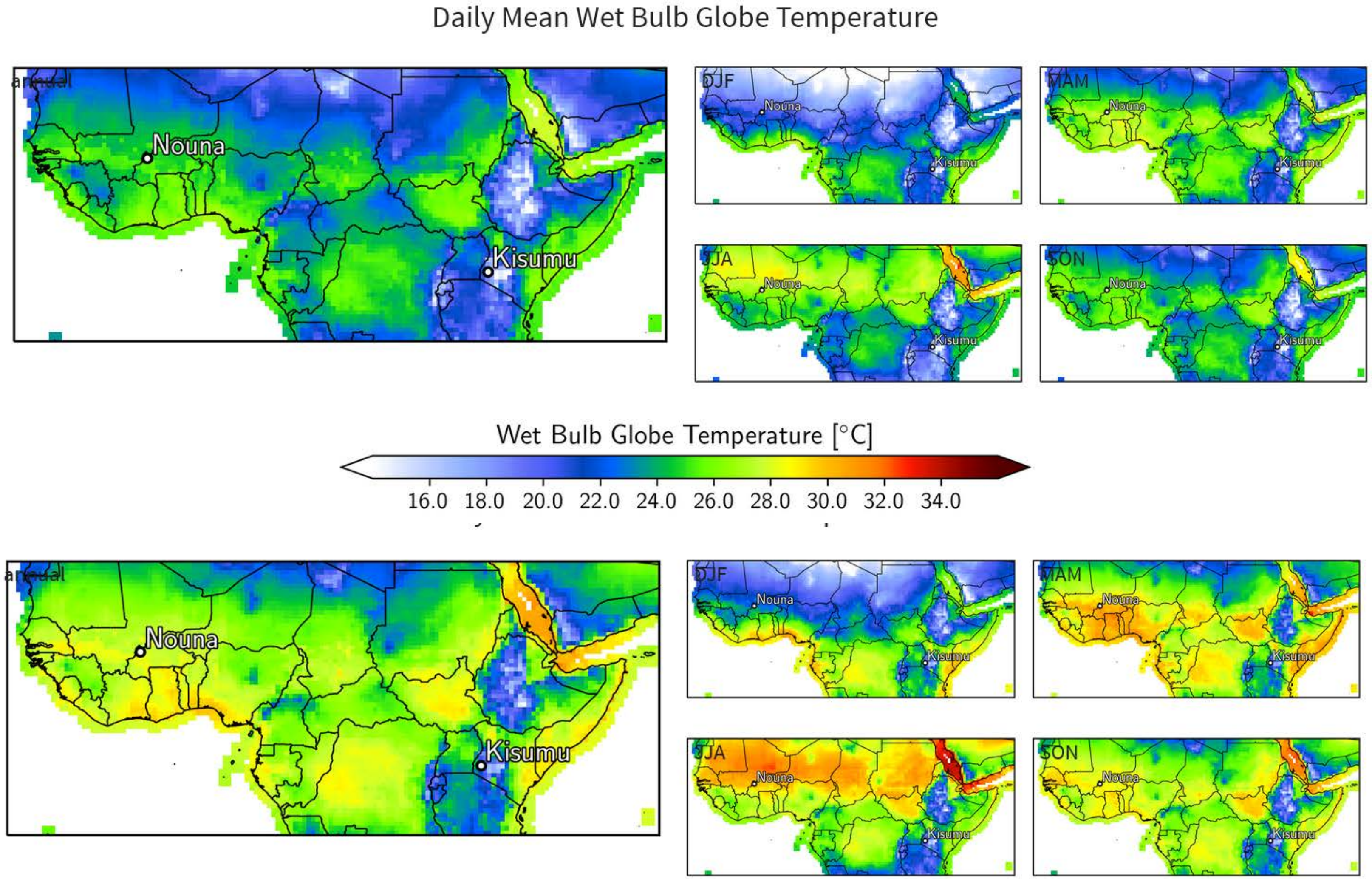
Daily mean WBGT end of the century



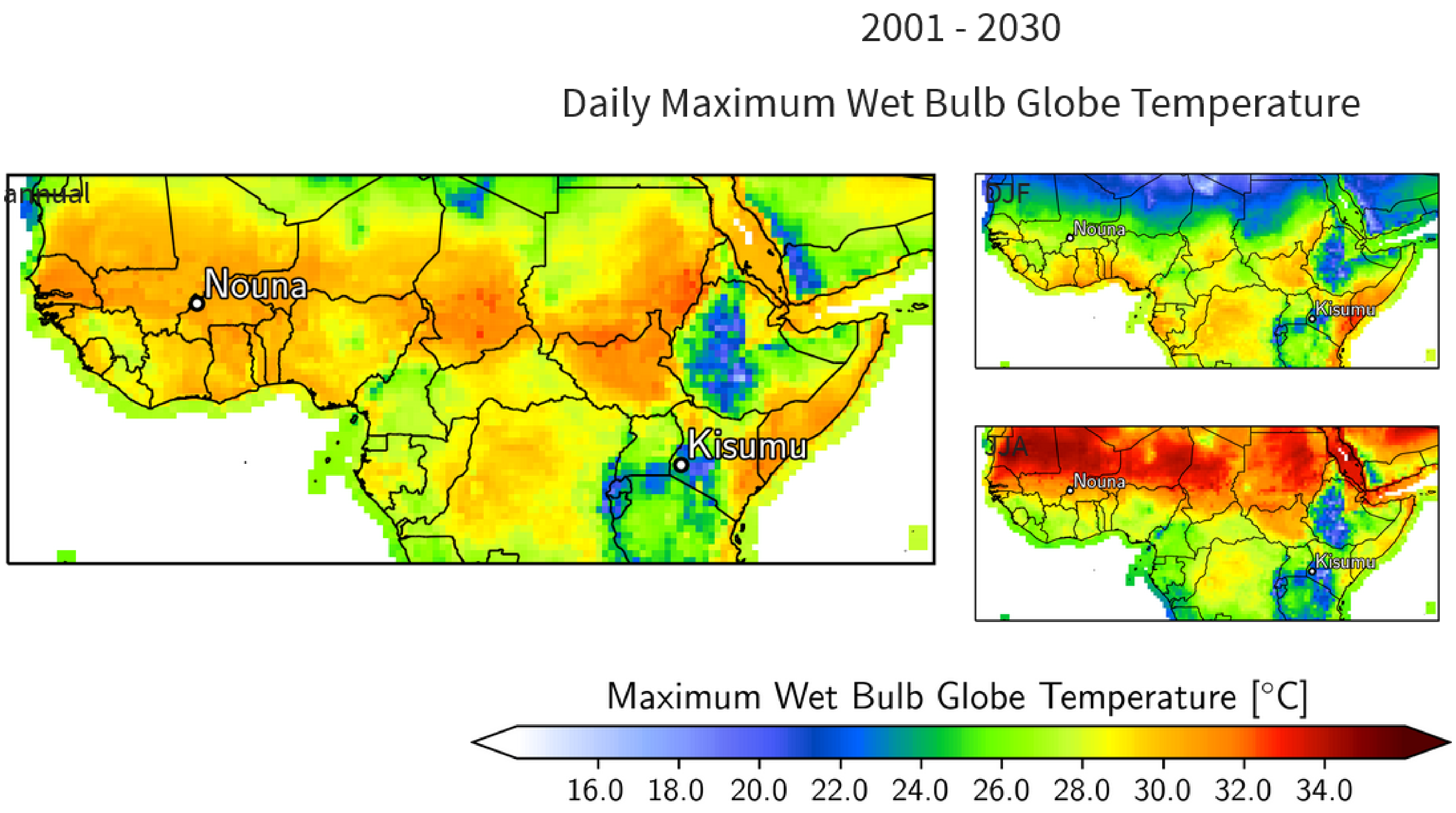
What do we gain with strong mitigation?

Mean daily WBGT end of century low increase of GHG

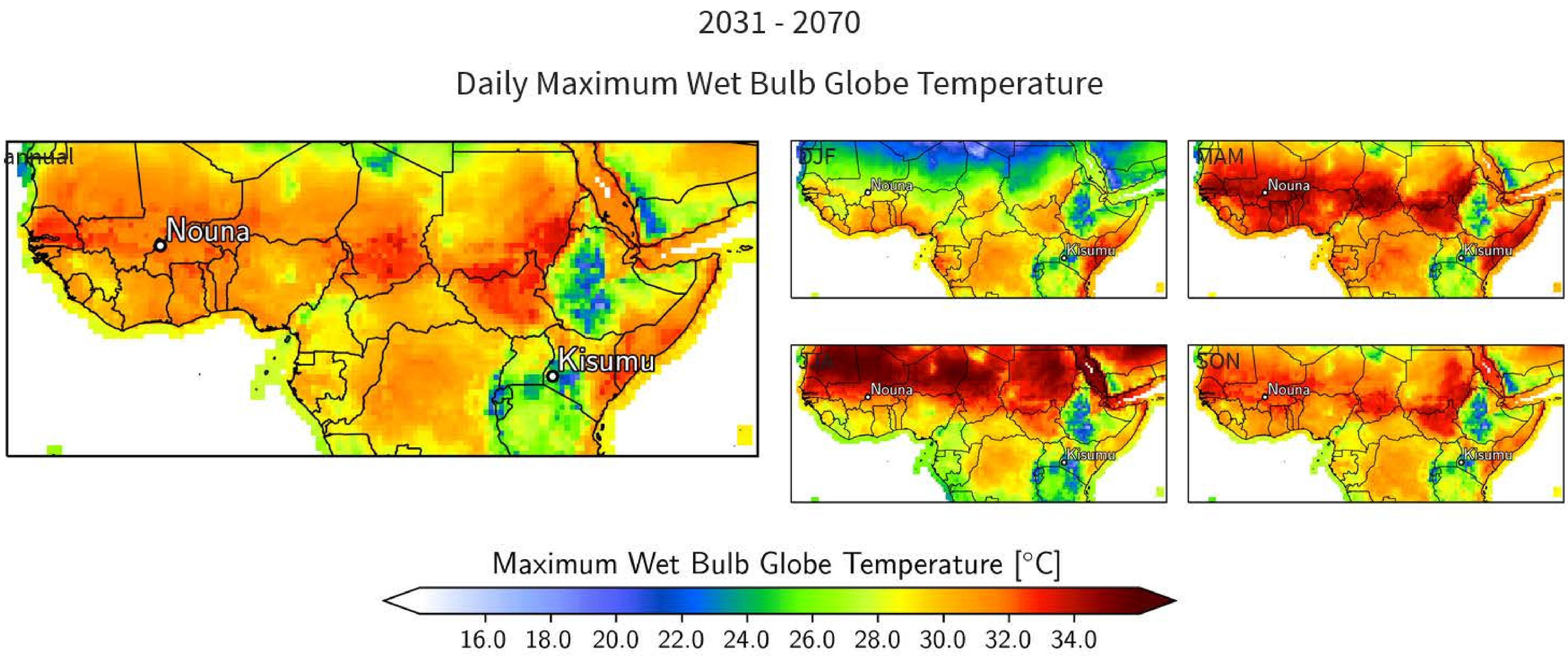
Mean daily WBGT end of century strong increase of GHG



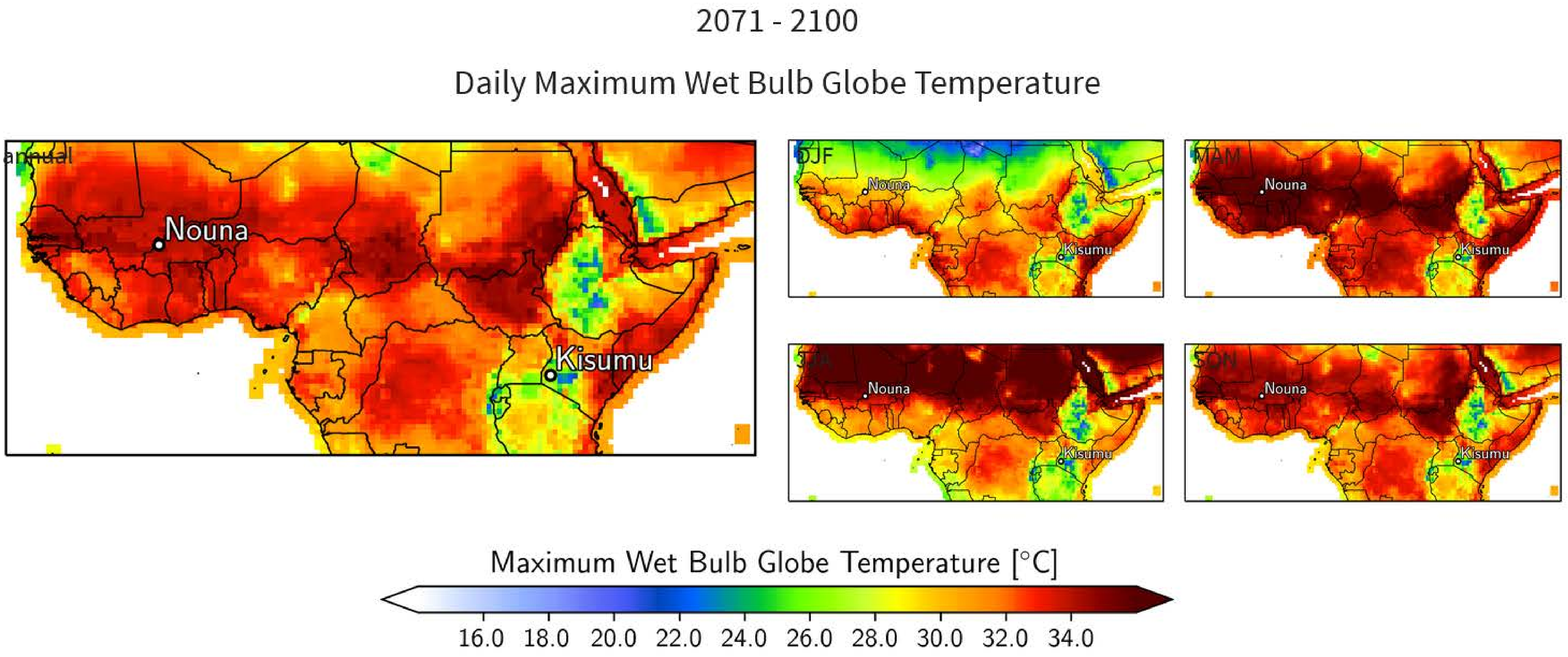
Daily max. WBGT now



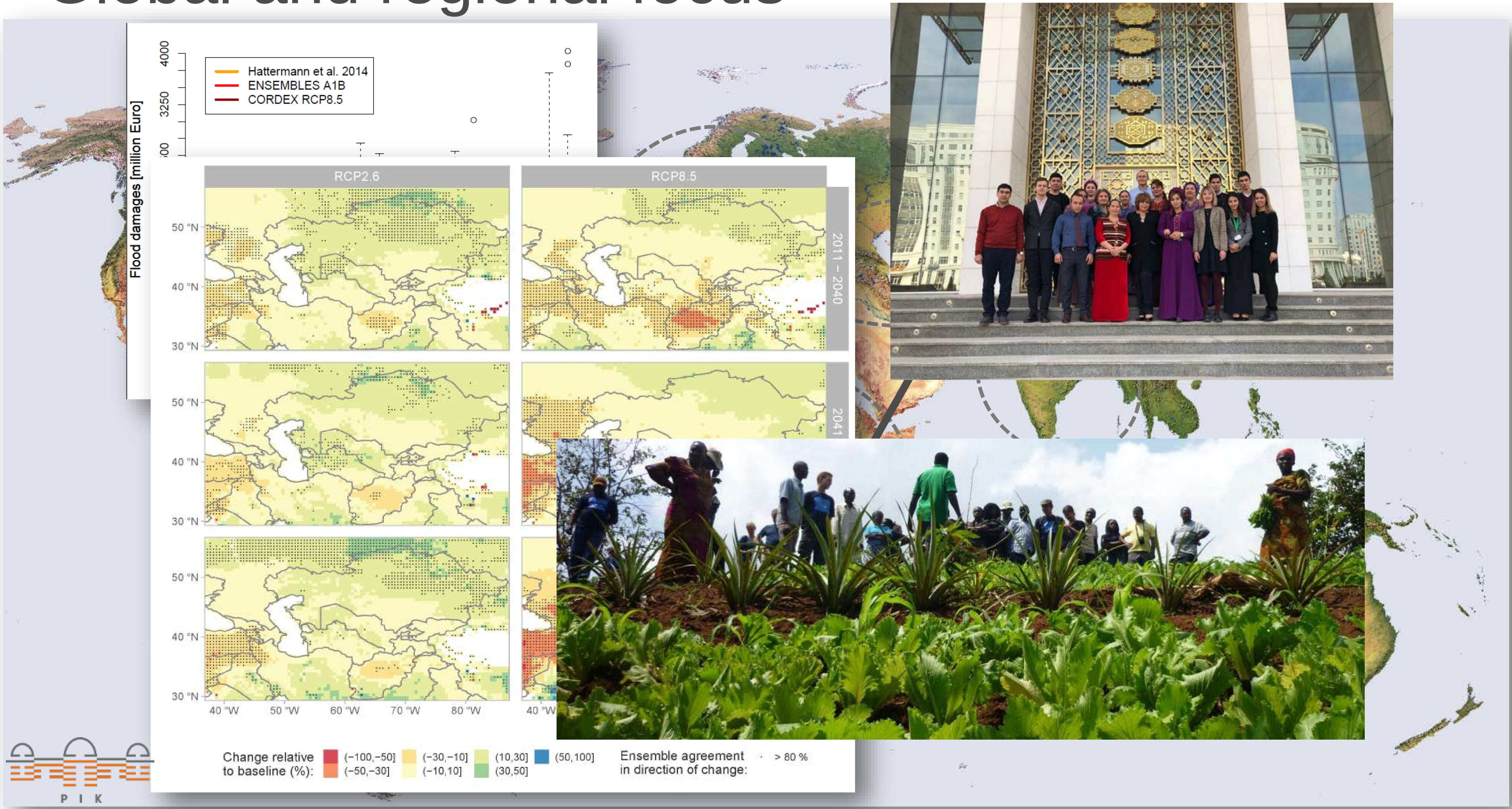
Daily max. WBGT mid of the century



Daily max. WBGT end of the century



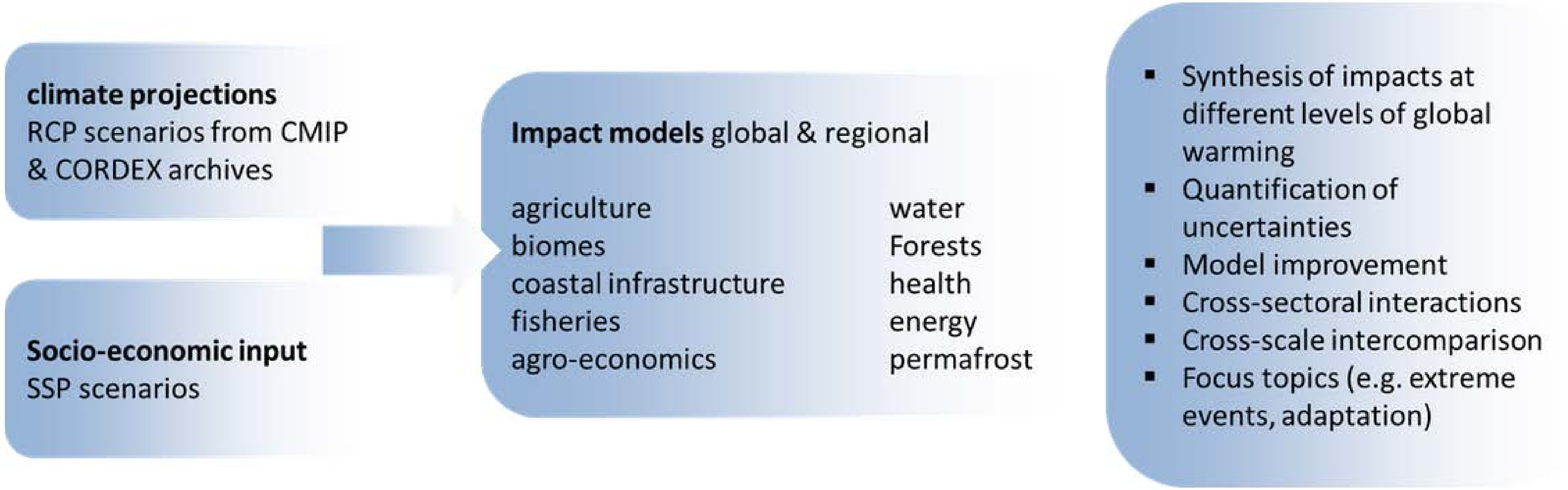
Global and regional focus



PIK

The Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) – Coordinted by PIK

ISIMIP was initiated by the Potsdam Institute for Climate Impact Research (PIK) and the International Institute for Applied Systems Analysis (IIASA) and has since grown to involve over 100 modelling groups from around the world.



Source: https://www.isimip.org/about/#simulation-rounds

Literature

Model description

Krysanova, V., Müller-Wohlfeil, D.I. & A. Becker (1998). Development and test of a spatially distributed hydrological/water quality model for mesoscale watersheds. Ecological Modelling, 106, 261-289.

Hattermann, F. F., Huang, S., Koch, H. (2015): Climate change impacts on hydrology and water resources. - Meteorologische Zeitschrift, 24, 2, 201-211.

Krysanova, V., Hattermann, F., Huang, S., Hesse, C., Vetter, T., Liersch, S., Koch, H. & Z. W. Kundzewicz (2015). Modelling climate and land use change impacts with SWIM: lessons learnt from multiple applications. Hydrological Sciences Journal, 60, 606-635.

Thanks!

PIK