Climate model studies on the impact of tectonics and Earth's orbital changes on African climate

Kerstin Prömmel, Ulrich Cubasch, Frank Kaspar

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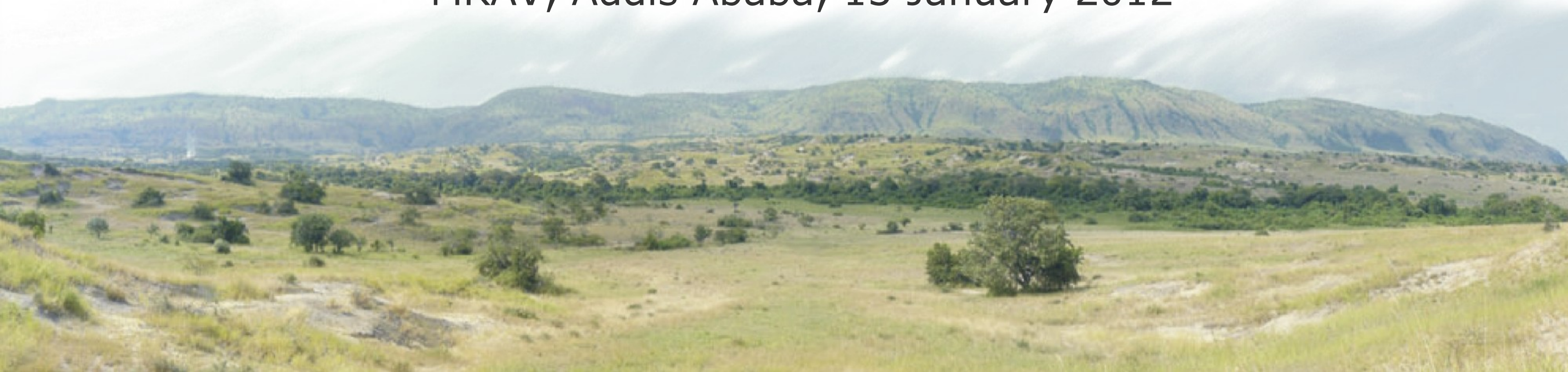


Climate modelling - Motivation

How strong is the impact of the development of the EARS (tectonic forcing) on regional climate (esp. precipitation) in East Africa?

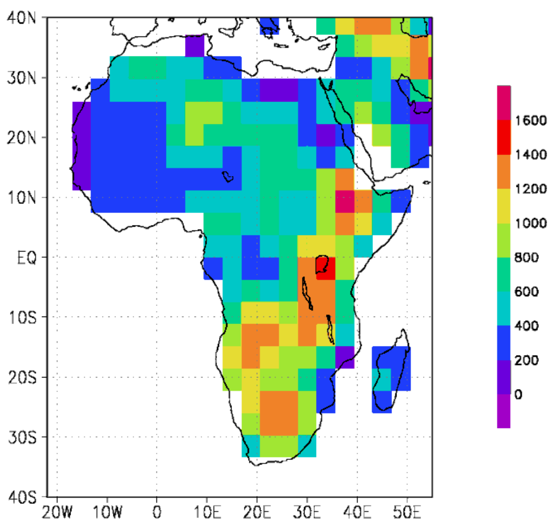
Spatial and temporal development of the EARS and topography not yet sufficiently known → assumptions about topography → application of different topographies in the climate model (50% reduction as an example)

How strong is the impact of changes in insolation (orbital forcing) on regional climate in East Africa?

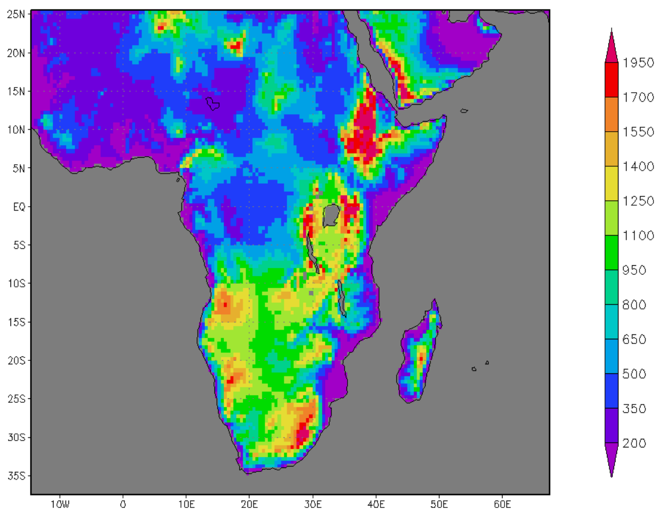
As an example of a strong insolation change compared to today the last interglacial (Eemian) at 125 ka BP is chosen → change of orbital parameters in the climate model to Eemian values

Climate models

Global Model: **ECHO-G**
- coupled model
- Atmosphere: **EC**HAM4
  T30 (3.75°) horizontal resolution,
  19 vertical layers
- Ocean: **HO**PE-**G**
  T42 (2.8°) horizontal resolution,
  20 vertical layers
- Legutke and Voss (1999)



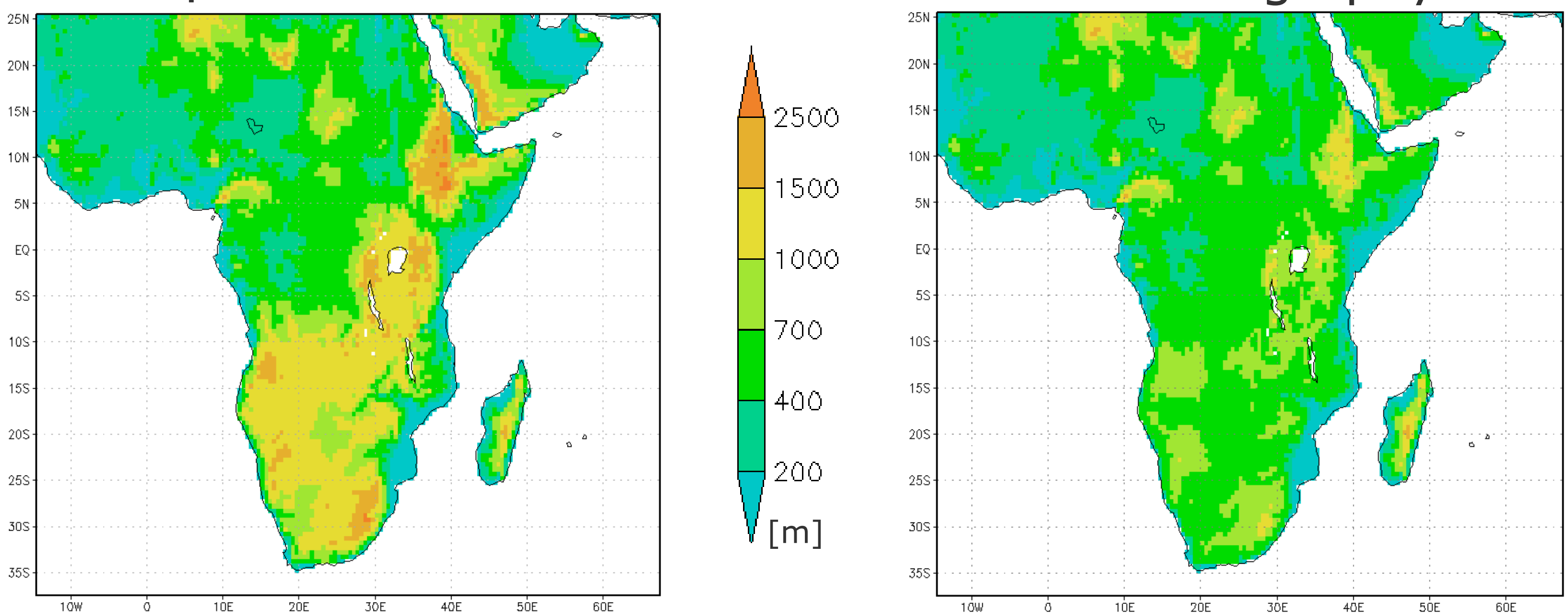
Regional Model: **CCLM**
- non-hydrostatic model
- 0.5° horizontal resolution,
  32 vertical layers
- Model area: 37°S to 25°N,
  15°W to 67°E
- Forcing at the lateral
  boundaries with analog
  global simulations
- www.clm-community.eu



Tectonic forcing

- Simulation of one possible stage during the development of the East African Rift System during the last 20 million years
- Reduction of orography over Southern and Eastern Africa by 50%

preindustrial 50% orography

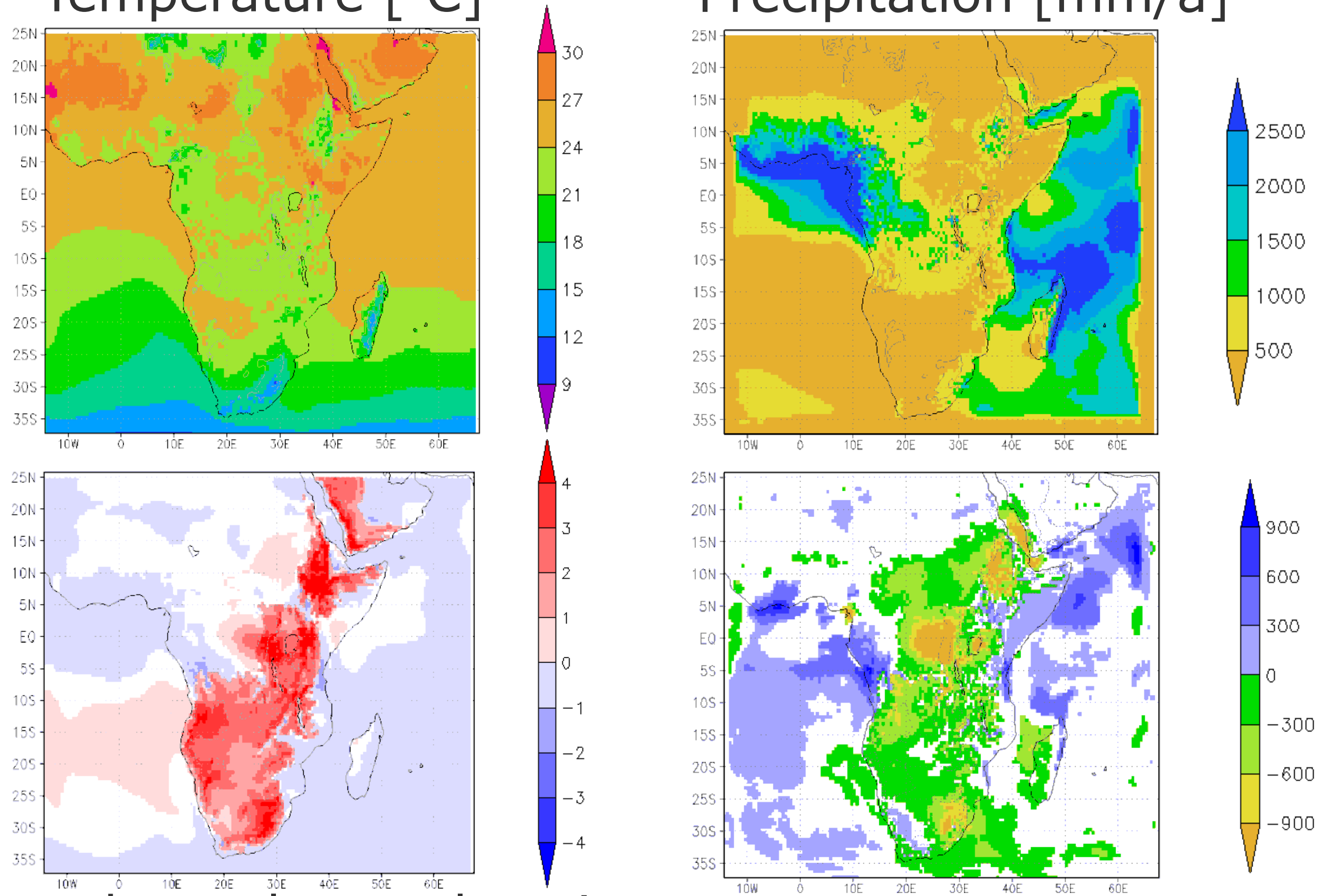


Annual values

Temperature [°C] | Precipitation [mm/a]

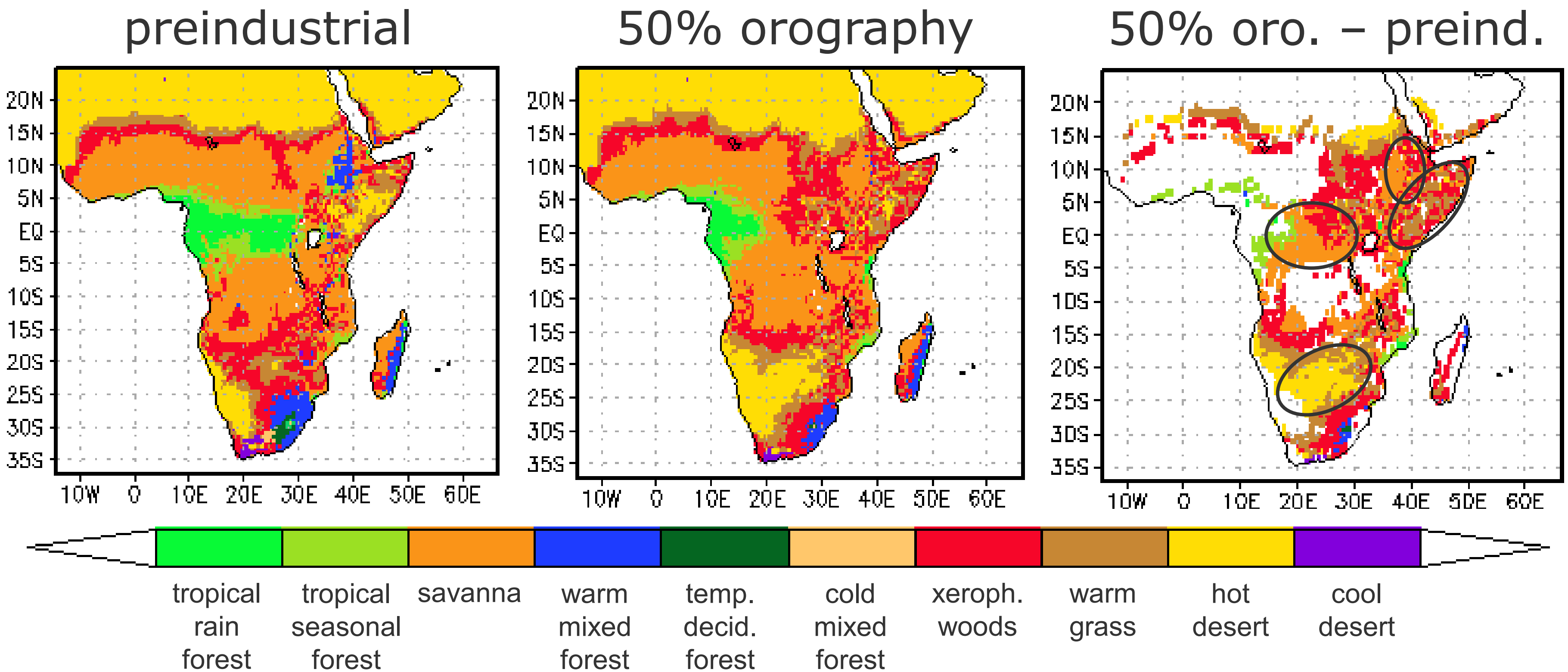
50% orography

50% orography – preindustrial



- Temp: warming due to lower elevations
- Precip: decrease due to less orographic precipitation windward of the mountains, slight increase in East Africa -> aridification

Biome (Prentice et al. 1992 , J Biogeogr)

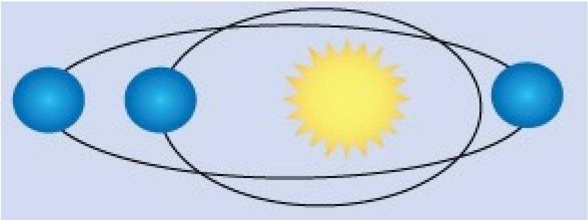


- Replacement of tropical forests by savanna and xerophytic woods
- Change from warm mixed forest to savanna and xerophytic woods over Ethiopian Highlands
- Expansion of hot desert over southern Africa
- Change from desert to xerophytic woods and warm grass over Horn of Africa

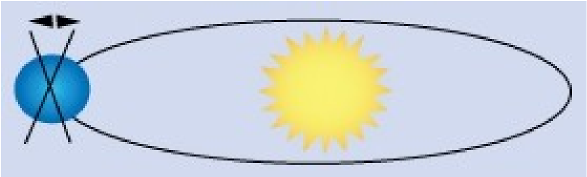
Orbital forcing

Adjustment of orbital parameters to Eemian values at 125 ka BP as an example of a strong insolation impact.

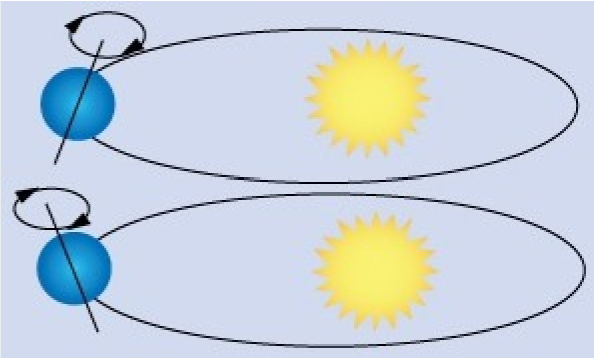
Eccentricity

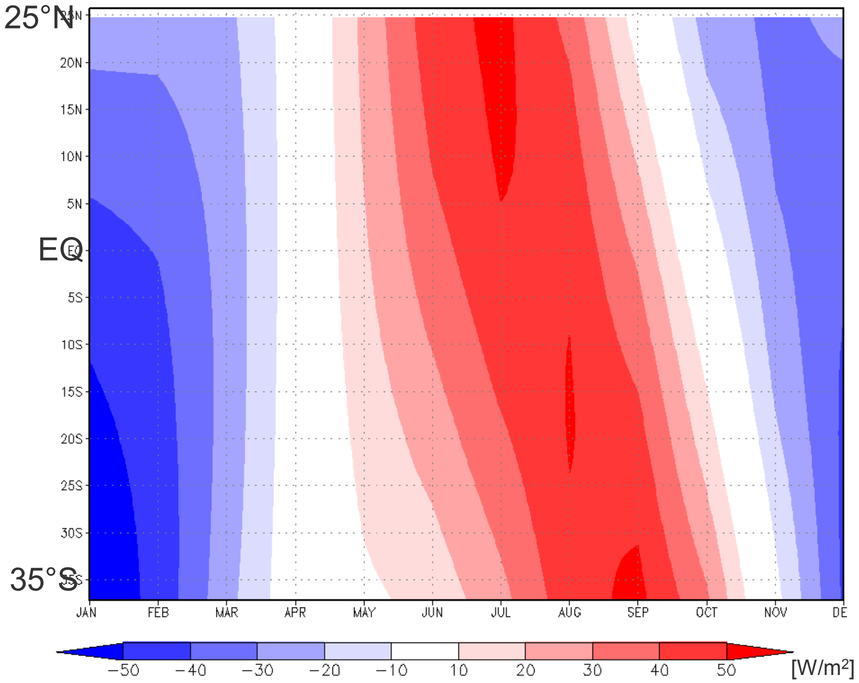


Obliquity



Precession



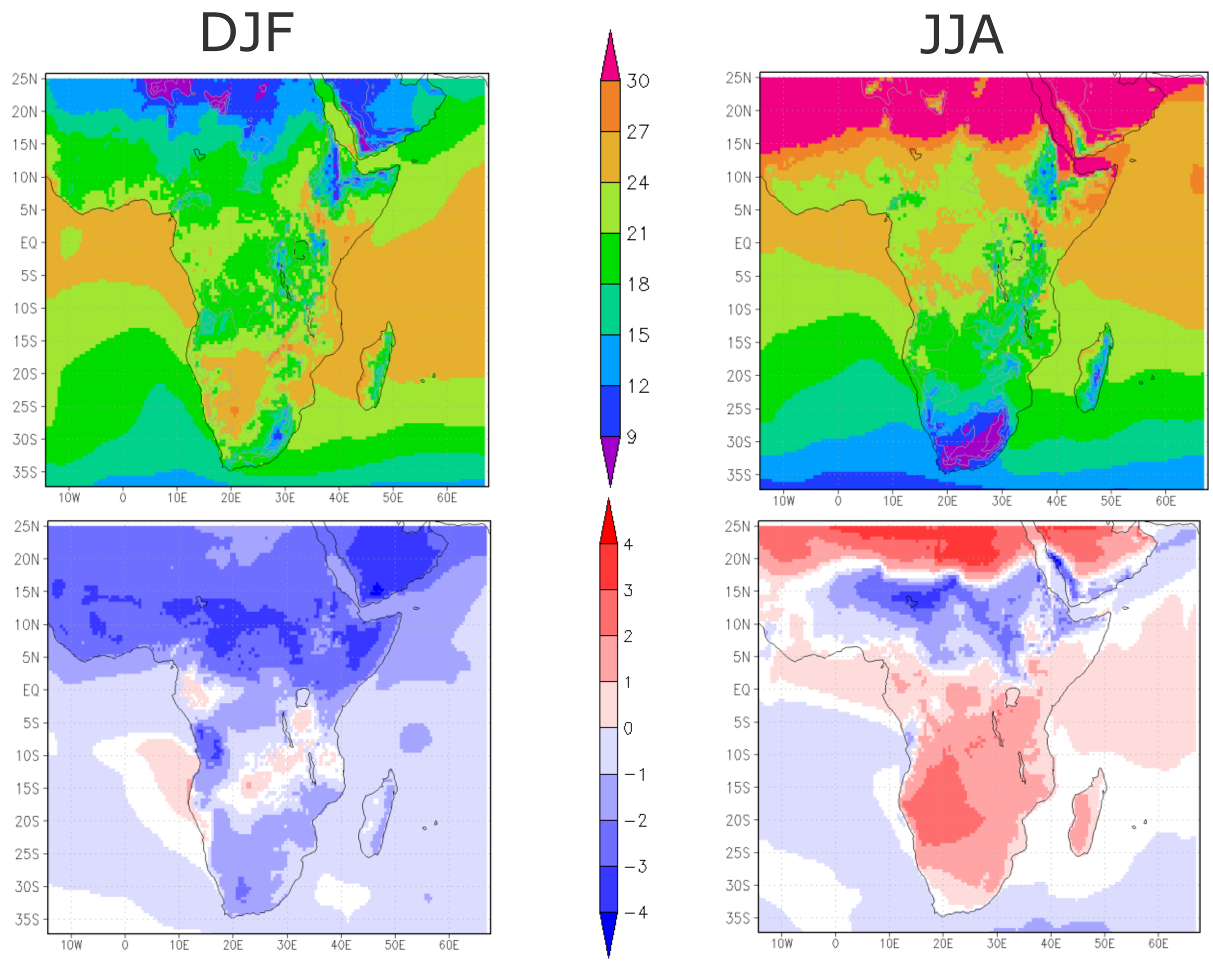


Top of atmosphere insolation at 125 ka BP compared to present-day

Temperature [°C]

Eemian

Eemian – preindustrial



- DJF: weaker incoming solar radiation → general cooling
- JJA: stronger incoming solar radiation → warming over large parts of Africa and cooling (5-17°N) due to precipitation increase

Precipitation [mm/mon]

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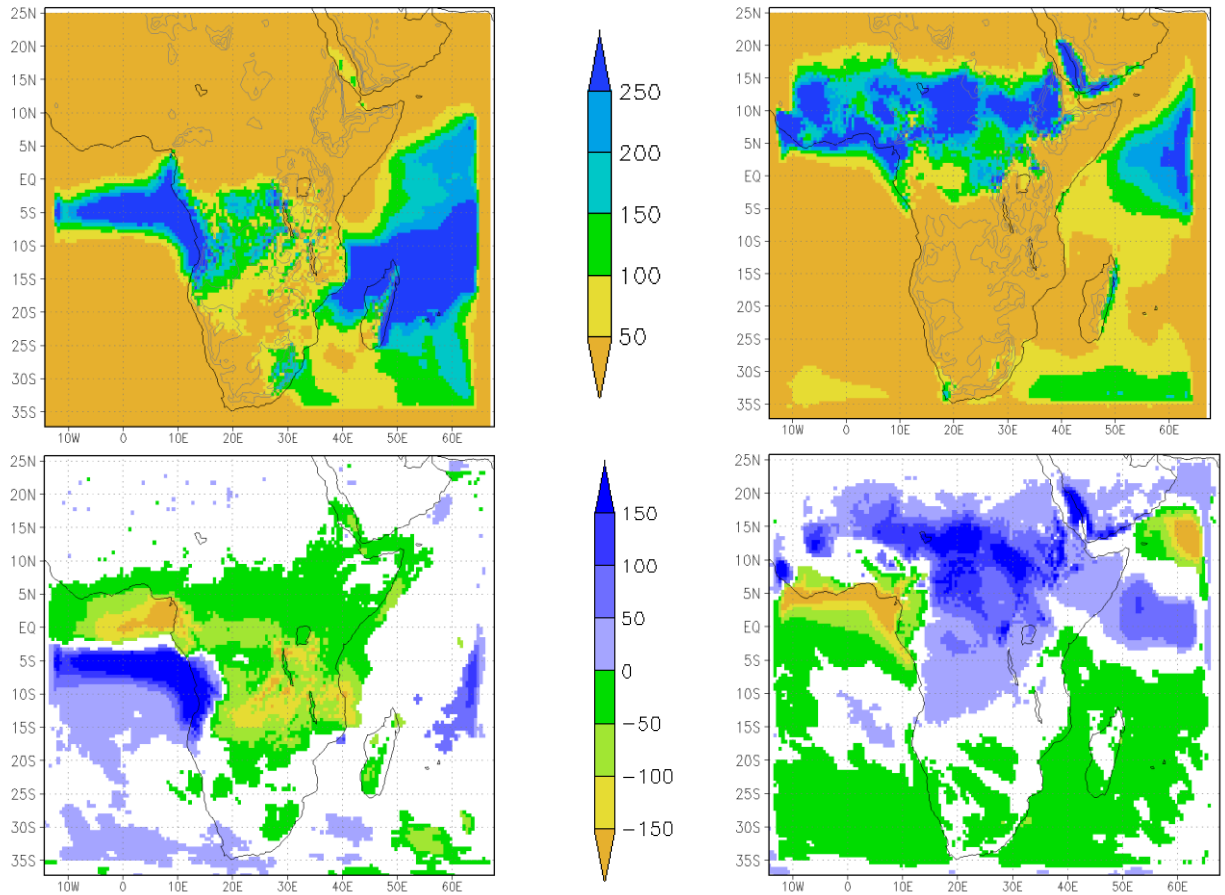
DJF JJA

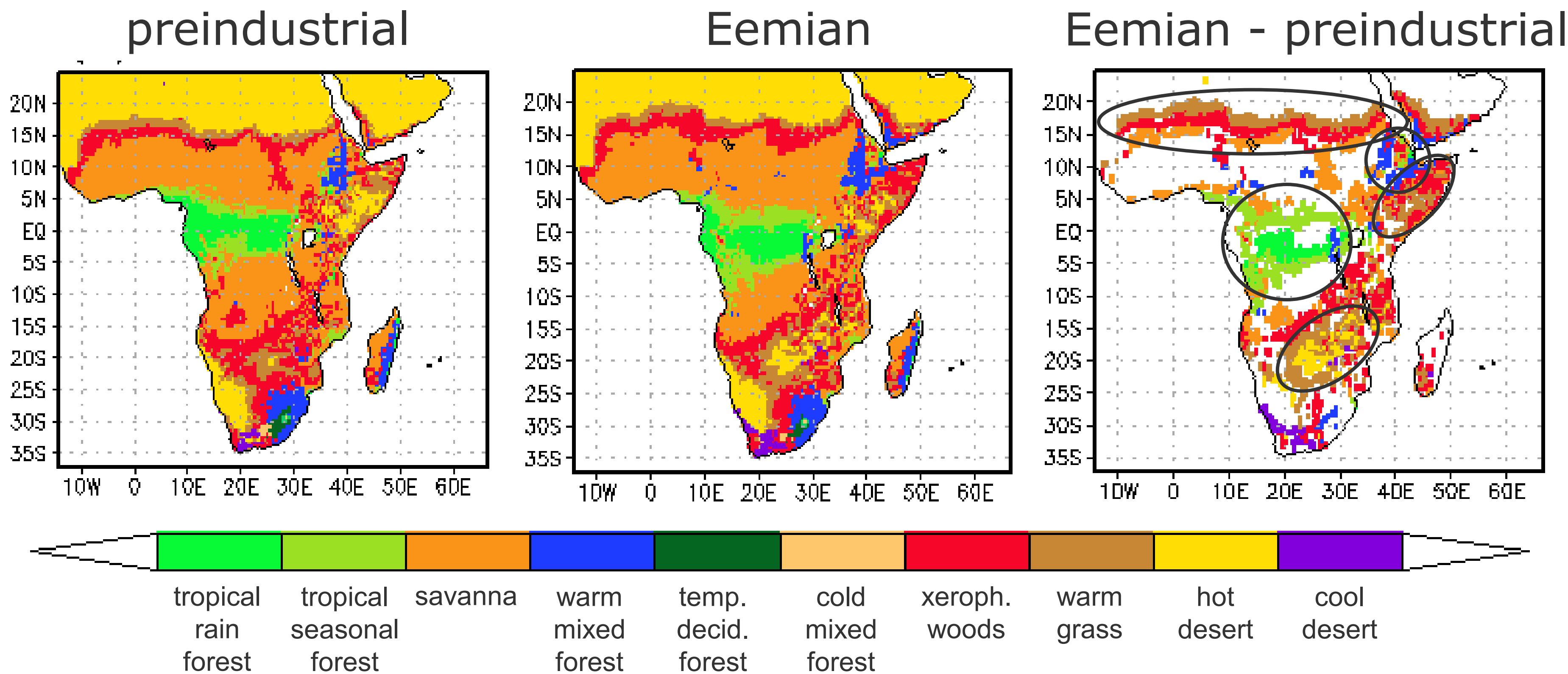
Eemian

Eemian – preindustrial



- DJF: less precipitation due to weaker moisture transport
- JJA: stronger moisture transport from the Atlantic and Indian Ocean into Africa leads to precipitation increase

Biome (Prentice et al. 1992 , J Biogeogr)



- Northward shift of southern Sahara border of roughly 2°
- Meridional enlargement of tropical forests
- Development of a desert over Botswana and Zimbabwe
- Change from desert to xerophytic woods over Horn of Africa
- Enlargement of warm mixed forest over Ethiopian Highlands

Summary and conclusions

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The **tectonic forcing** represented in the model by changes in topography has an impact on precipitation in Africa:
- decrease in precipitation windward of the modified mountains
- Slight increase in East Africa (but tectonic forcing alone can not fully explain the aridification during the Neogene)

Using the example of the last interglacial (Eemian) the **orbital forcing** shows a strong impact on precipitation over large parts of Africa, which is caused by altered moisture transport and shows strong differences between the seasons.

These sensitivity studies show that both tectonic and orbital forcing have an equally strong impact on African climate, which can intensify or weaken each other, depending on the season.

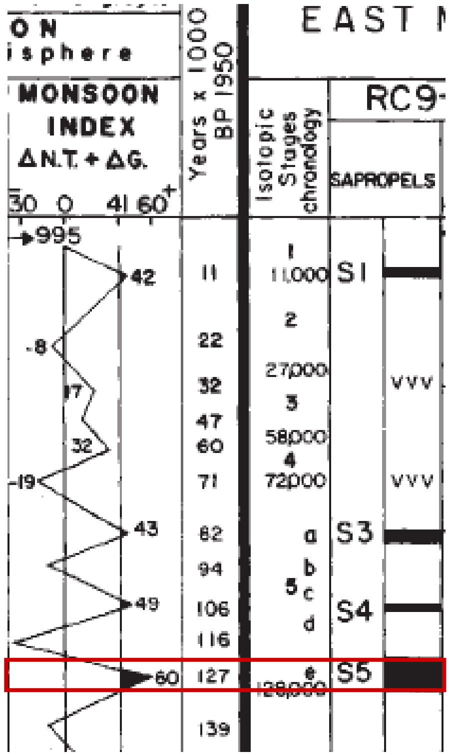
Both forcing factors have to be considered when interpreting proxy data or setting up palaeo climate simulations.

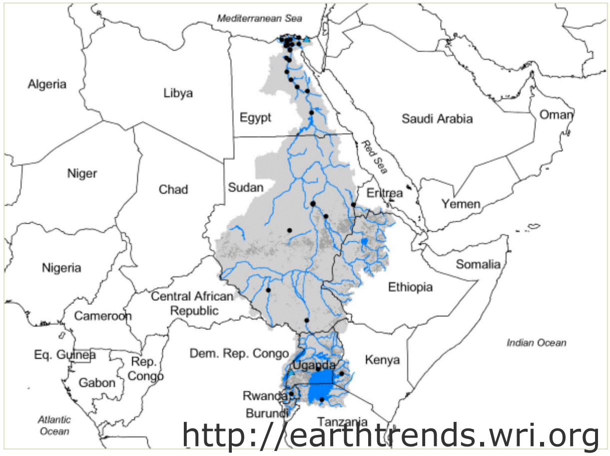
Thank you for your attention!

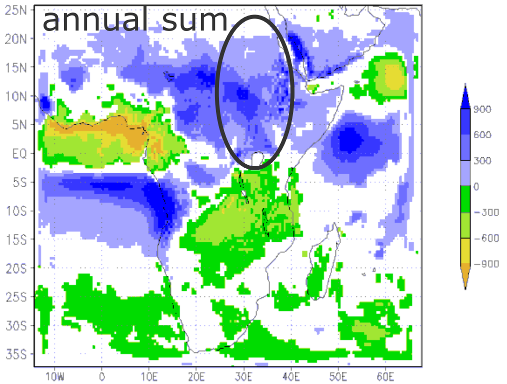
Comparison to proxy data I

Rossignol-Strick (1983, Nature):

- Black organic-rich layers (sapropels) recorded in subsurface of East Mediterranean due to heavy discharge from Nile River
- During the Eemian interglacial larger precipitation amounts occur at least over the Nile River catchment





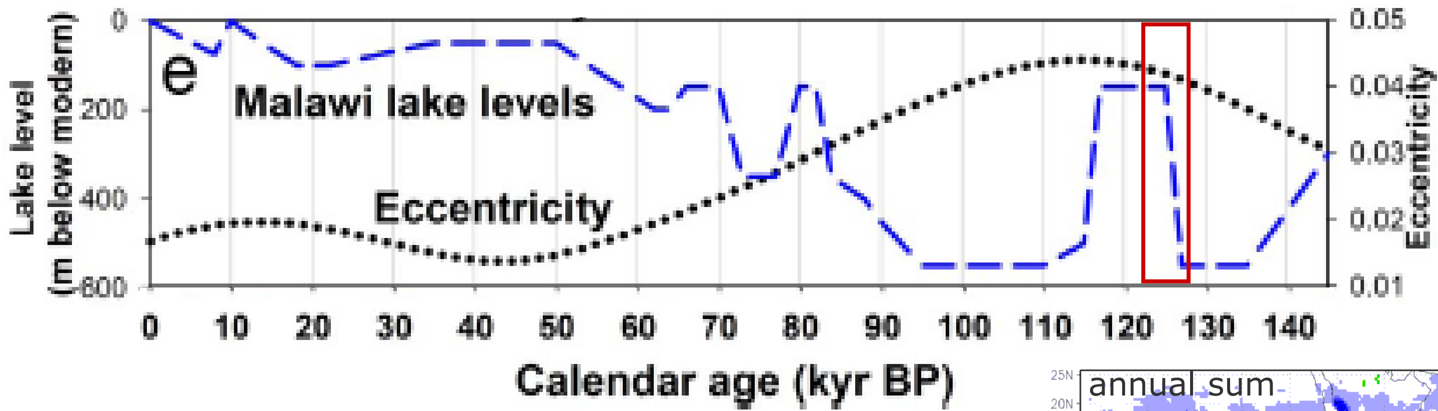


→ in agreement with model results

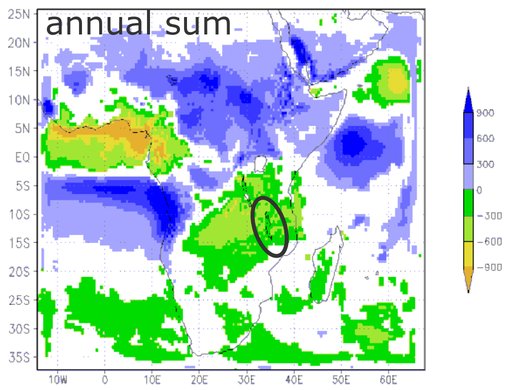
Comparison to proxy data II

Scholz et al. (2007, PNAS):

- Sediment core from Lake Malawi → lake level reconstruction showing periods of dramatically lower lake levels
- During the Eemian interglacial Malawi lake level was moderately to dramatically lower than today



→ in agreement with model results



Annual mean/sum

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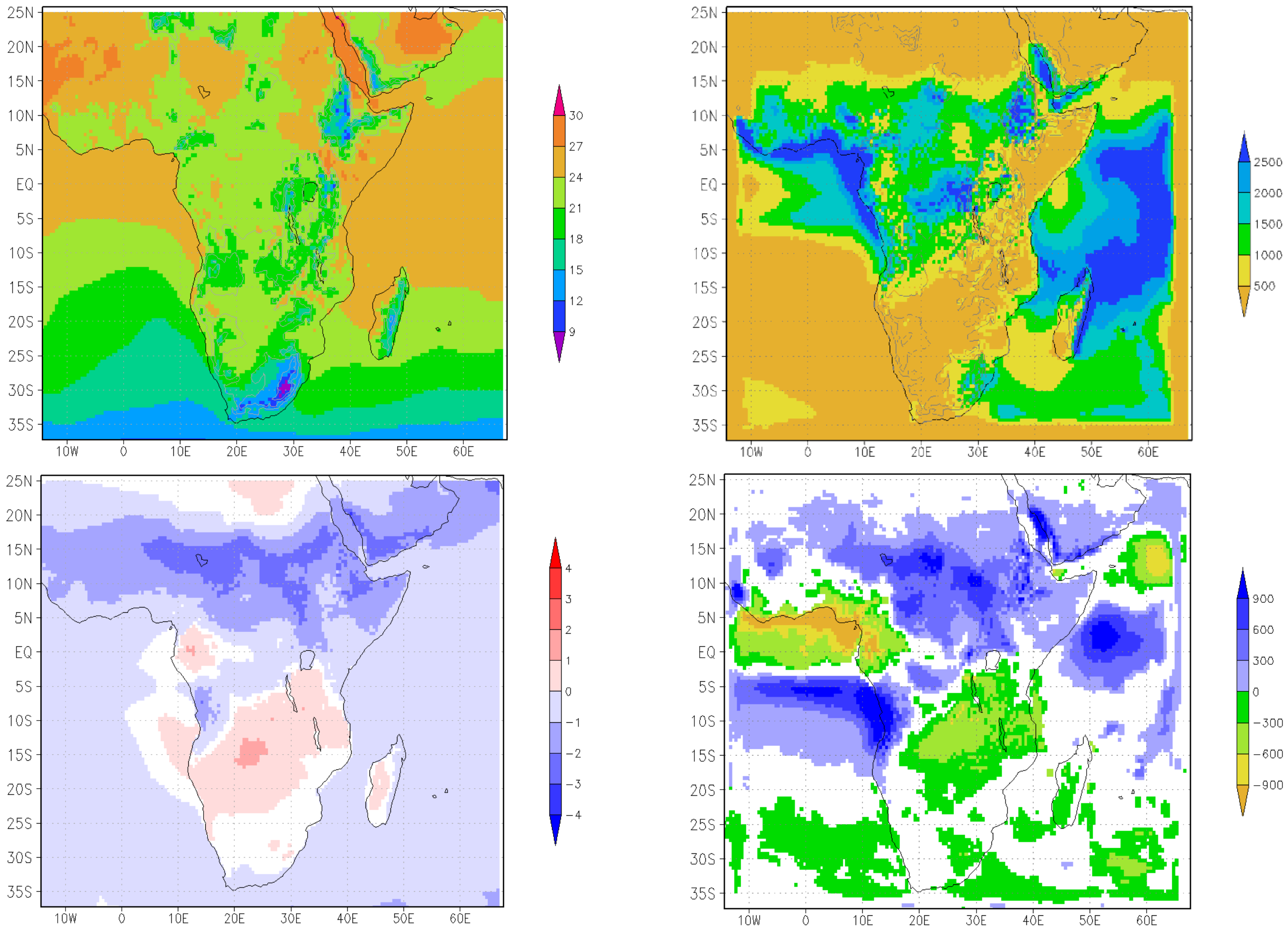
Temperature [°C]

Precipitation [mm/a]

Eemian

Eemian – preindustrial



Motivation

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- Why studying the Eemian interglacial?
  Only very few proxy data exist for the Eemian in Africa, however strong insolation differences indicate the potential for strong changes in climate and therefore also in vegetation.
- Why using a climate model?
  Model simulations show a 3-dimensional realisation of the past only by changing some external forcing factors.
- Why using a regional climate model?
  Regional climate models provide more spatial details than global models and are more appropriate when comparing to proxy data, which represent local to regional conditions.
- Why applying a biome model?
  Application of biome model leads to vegetation description covering the whole simulation area and not only special locations.

Vegetation Model

- BIOME (Prentice et al. 1992, J Biogeogr)
- Input: annual cycles of 2m temperature, precipitation and total cloud cover
- Combinations of plant functional types (based on environmental constraints) → 17 biomes:

tropical rain forest	tropical seasonal forest
savanna	warm mixed forest
temperature deciduous forest	cool mixed forest
cool conifer forest	taiga
cold mixed forest	cold deciduous forest
xerophytic woods	warm grass
cool grass	tundra
hot desert	cool desert
polar desert	