Karlsruhe Institute of Technology

Regional climate simulations for West Africa

Comparison of input bias correction methods

INSTITUTE OF METEOROLOGY AND CLIMATE RESEARCH, ATMOSPHERIC ENVIRONMENTAL RESEARCH (IMK-IFU)
Regional Climate Systems/Regional Climate and Hydrology

KIT-Campus Alpin
IMK-IFU: Atmospheric Environmental Research

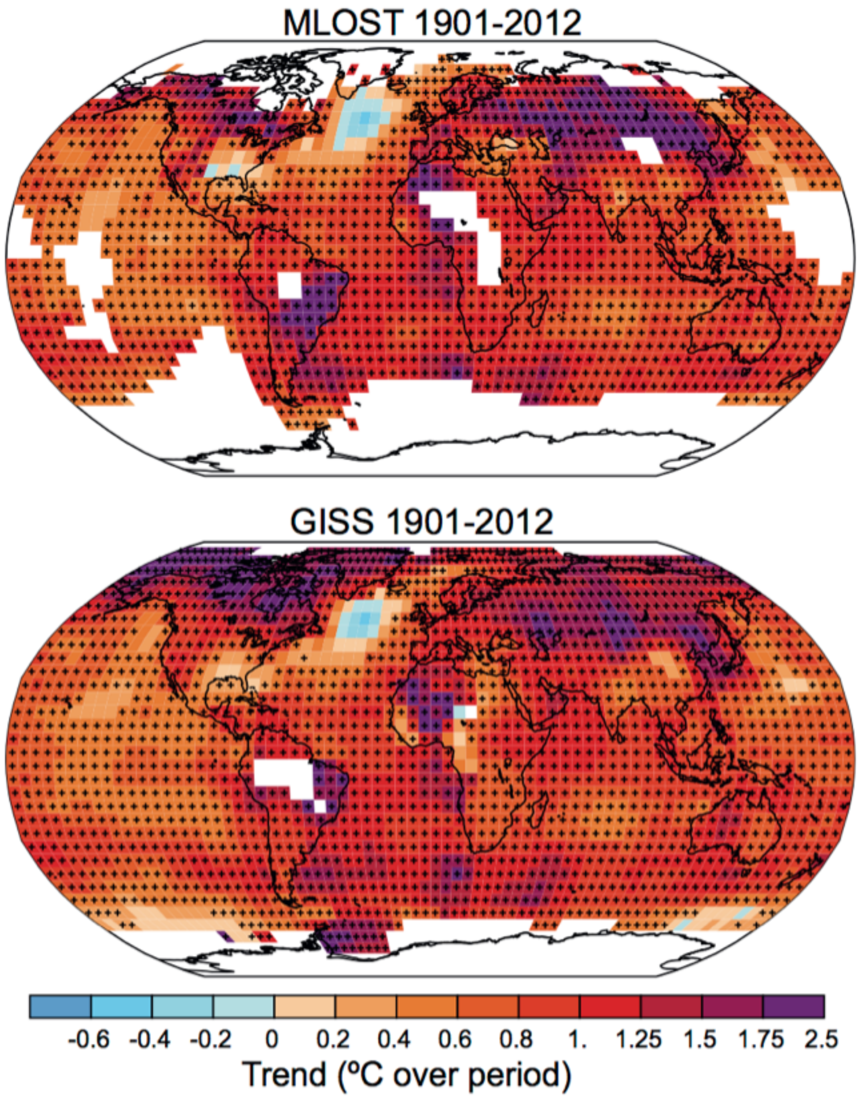
Future SOC Lab Day, Spring 2014

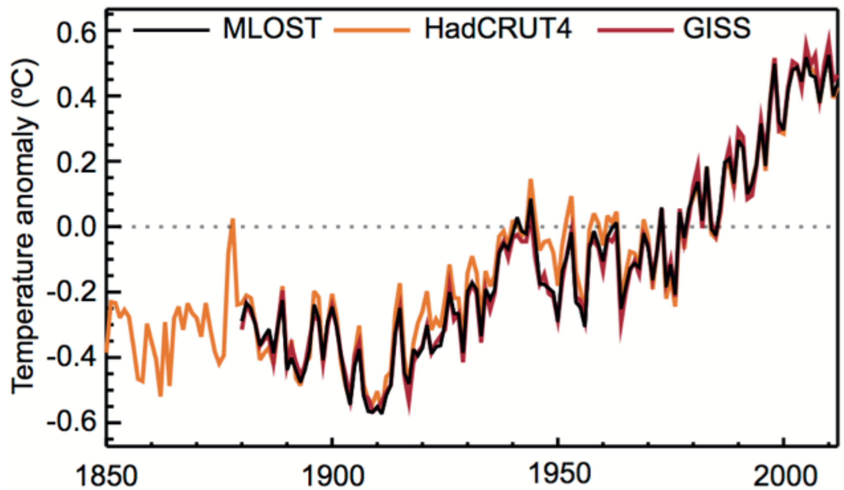
Dominikus Heinzeller & Harald Kunstmann

Supported by

Future SOC Lab
by Hasso-Plattner-Institut

Global climate change: warmer and wetter





IPCC Fifth Assessment Report (AR5), 2013

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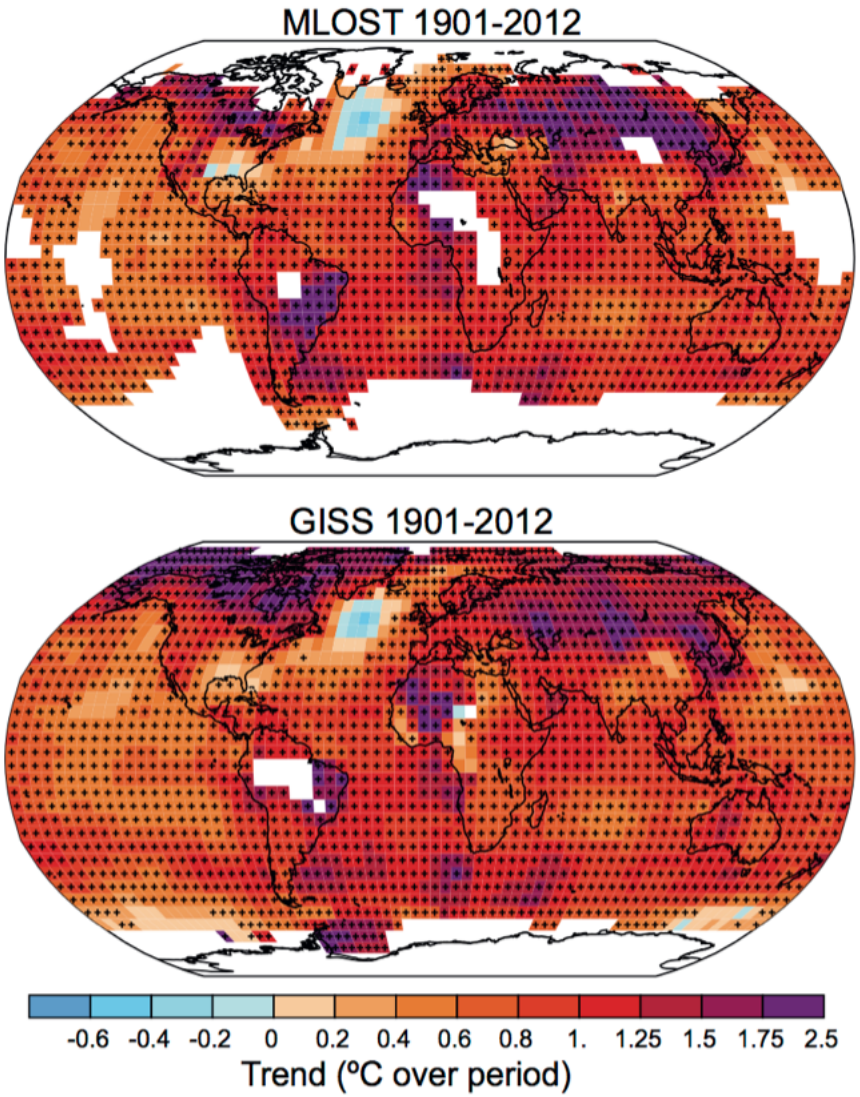

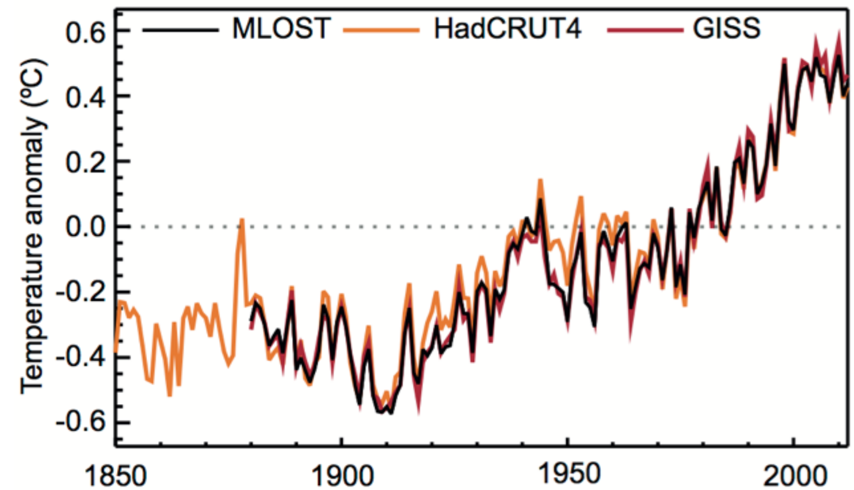

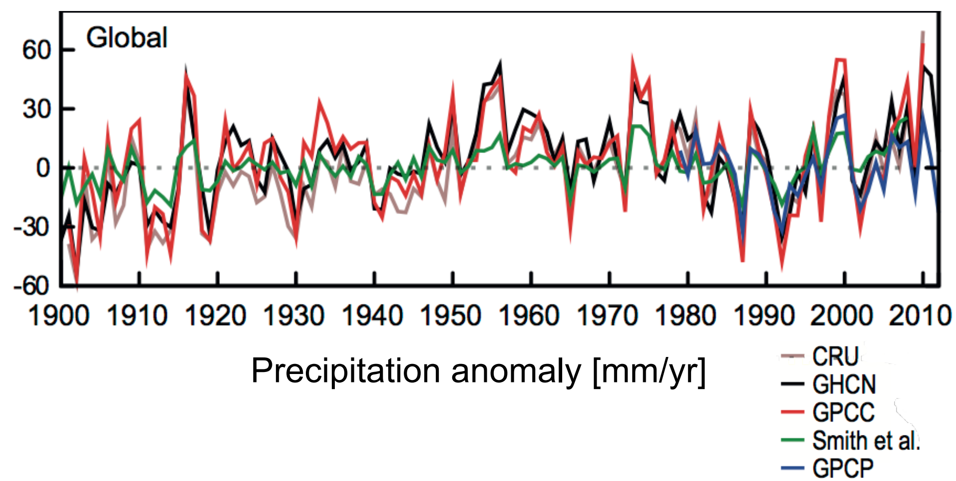

IPCC Fifth Assessment Report (AR5), 2013

West Africa: a region of low adaptive capacity

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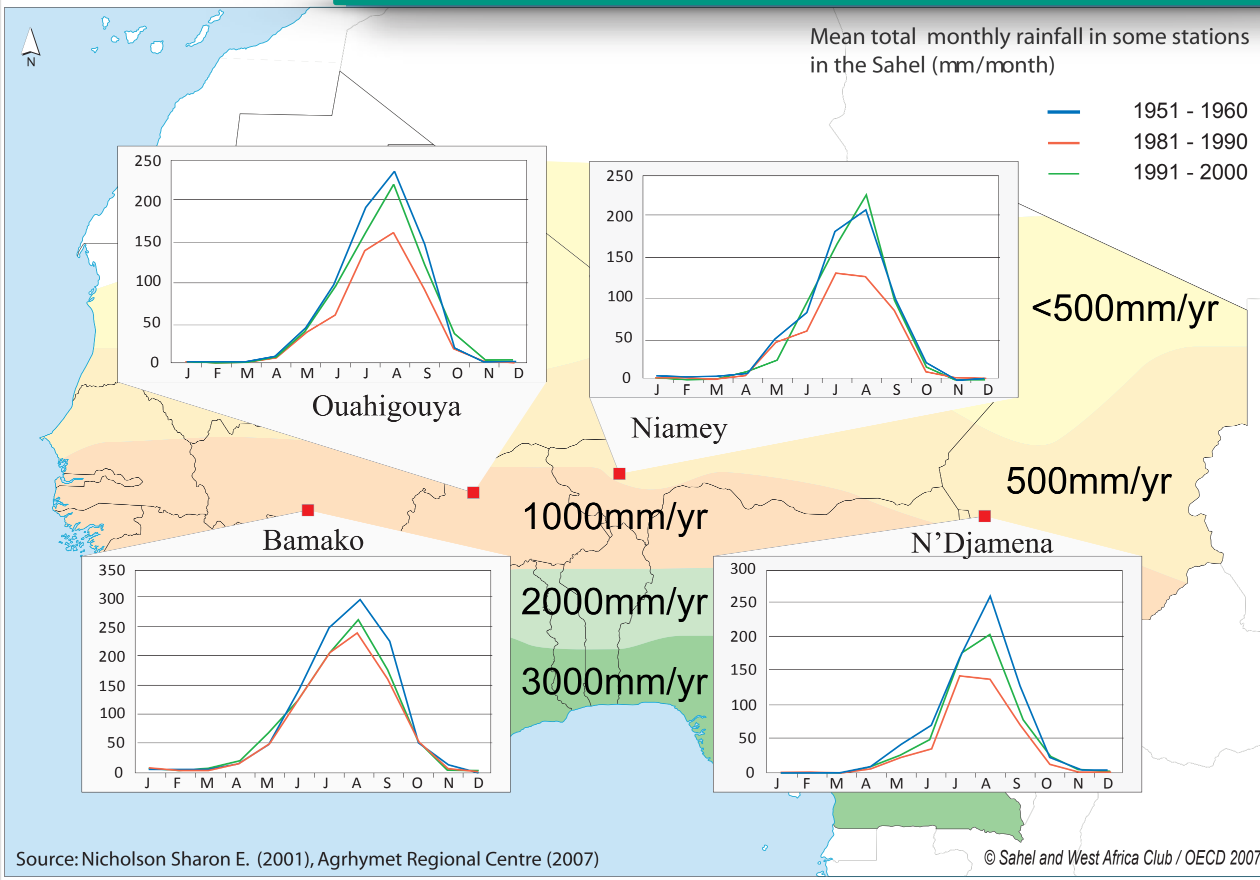
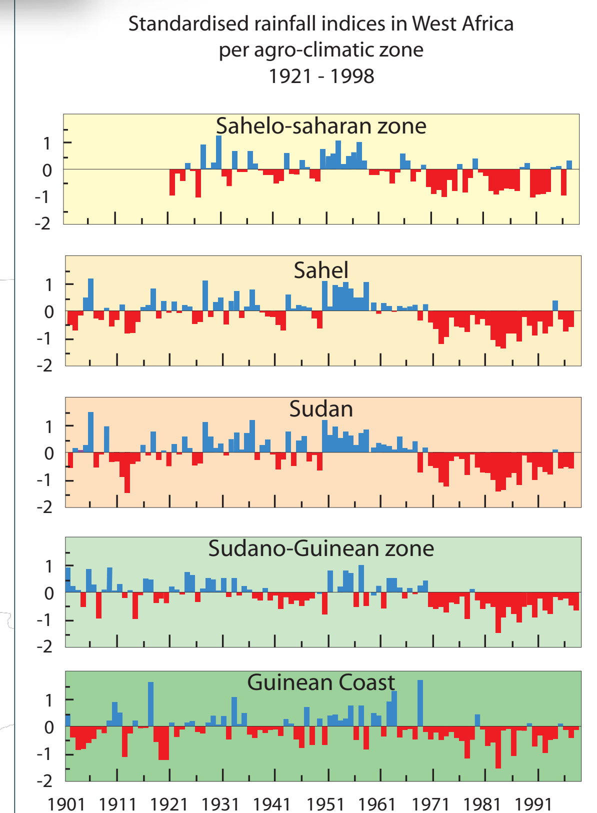
Changes in precipitation in West Africa





Source: Nicholson Sharon E. (2001), Agrhymet Regional Centre (2007)

West Africa: a region of low adaptive capacity

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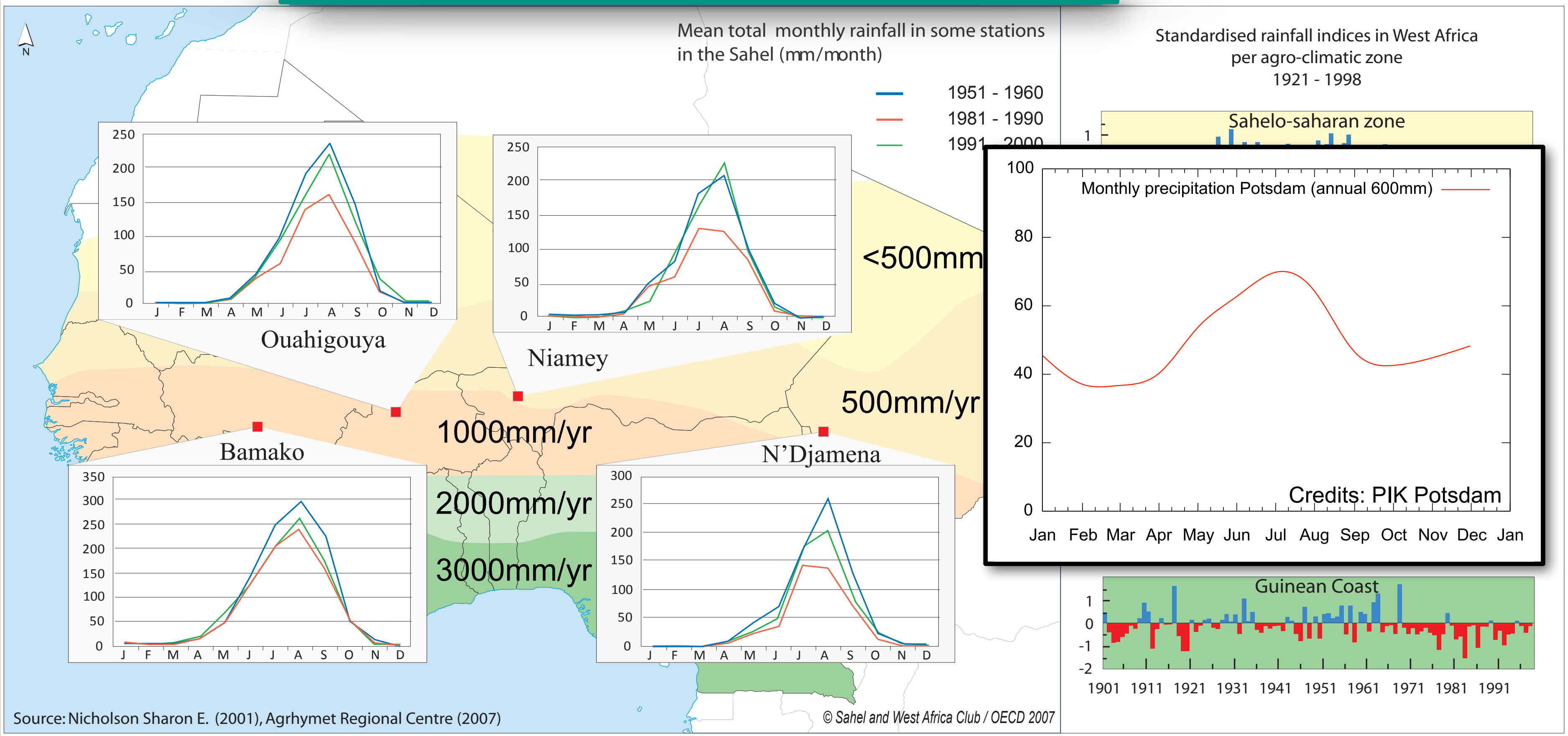

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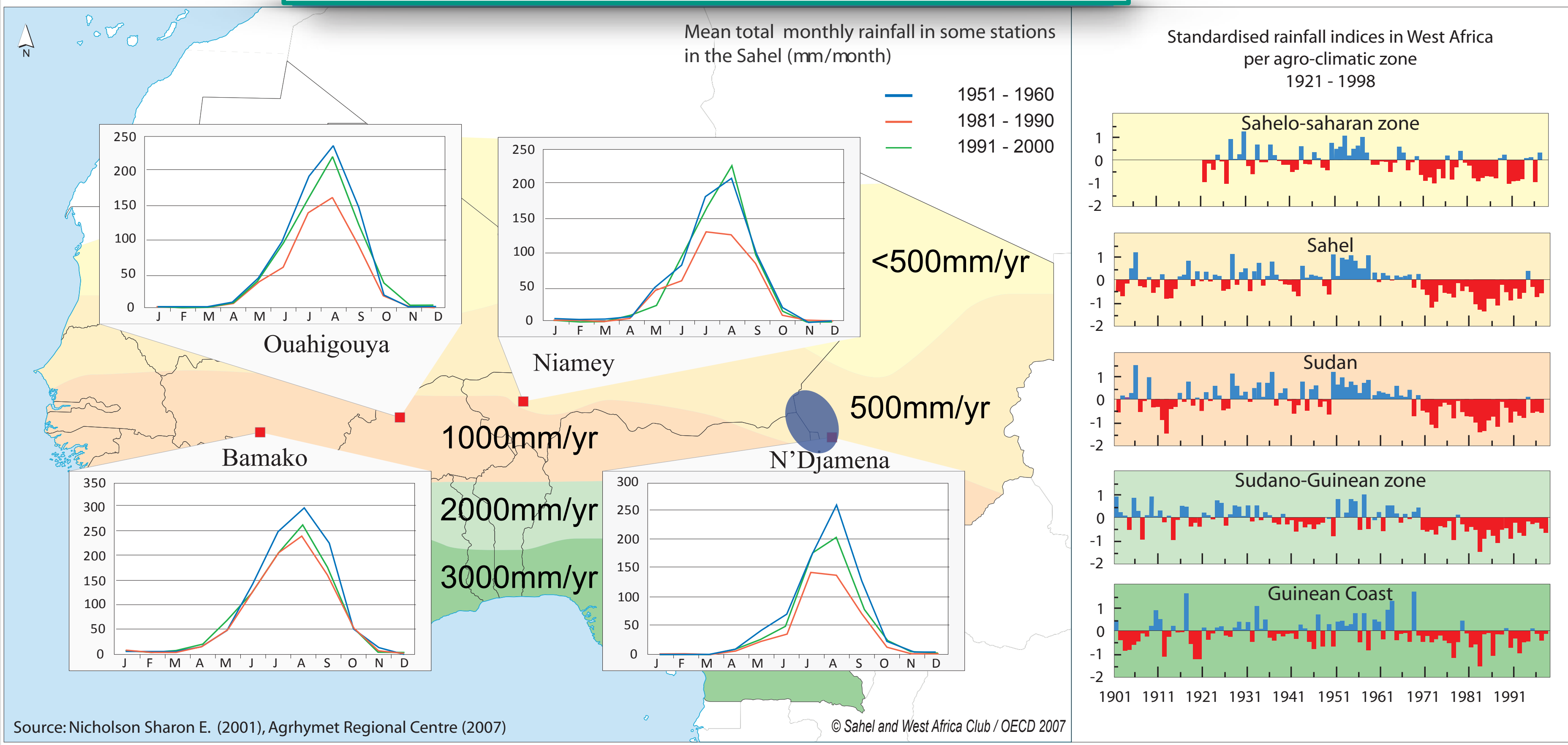

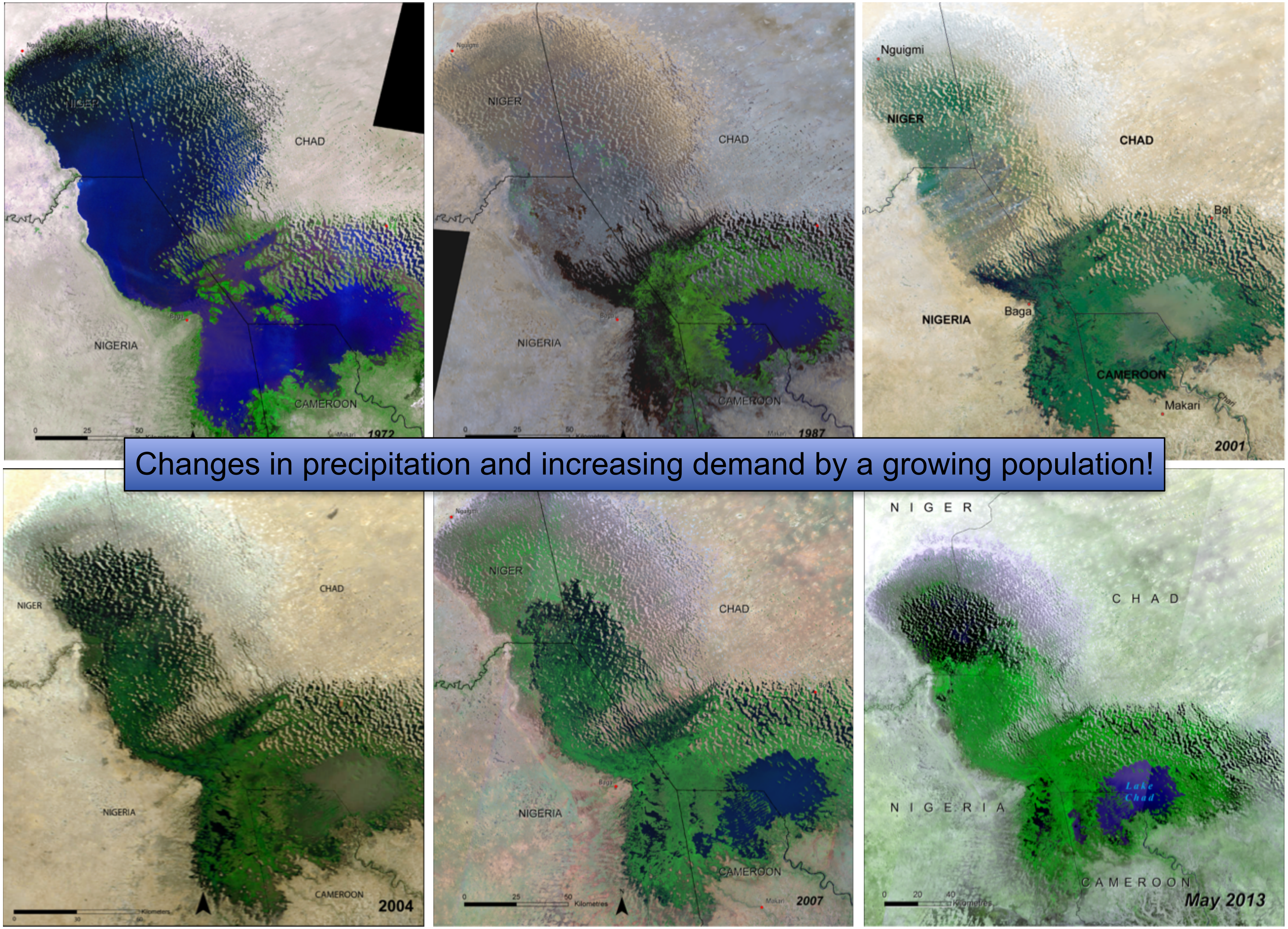

Changes in precipitation and increasing demand by a growing population!

United Nations Environment Programme (UNEP, 2013)

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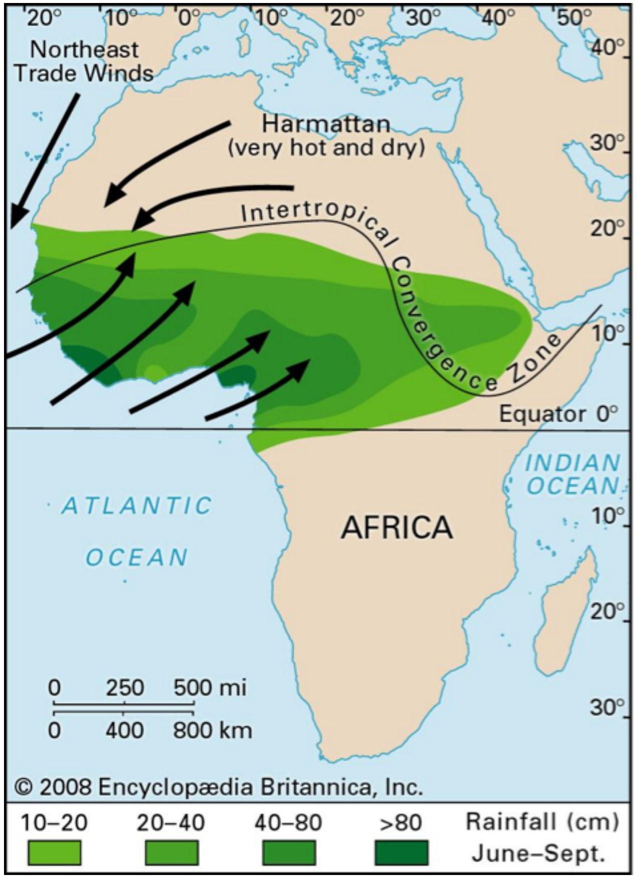
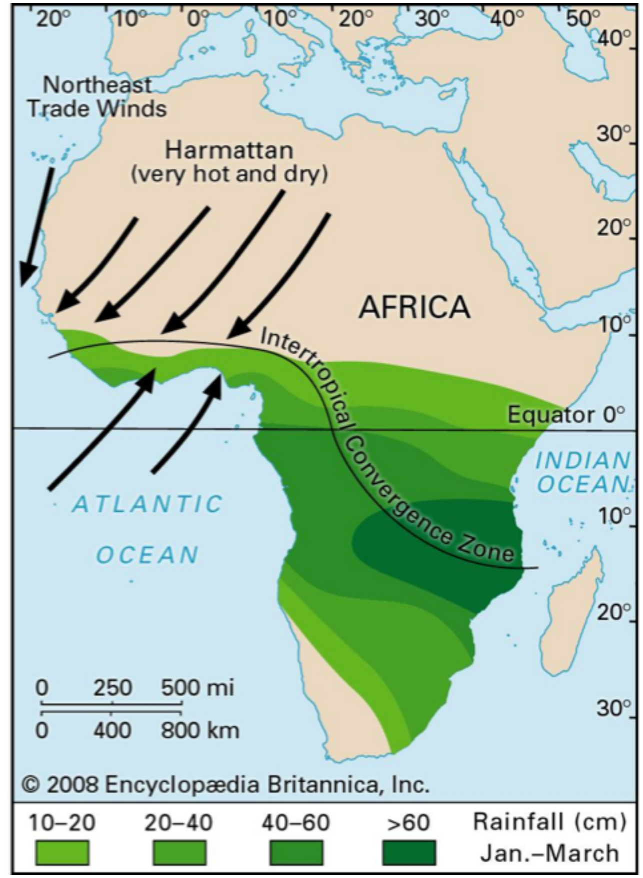
West African Monsoon - the big sea breeze

July - September



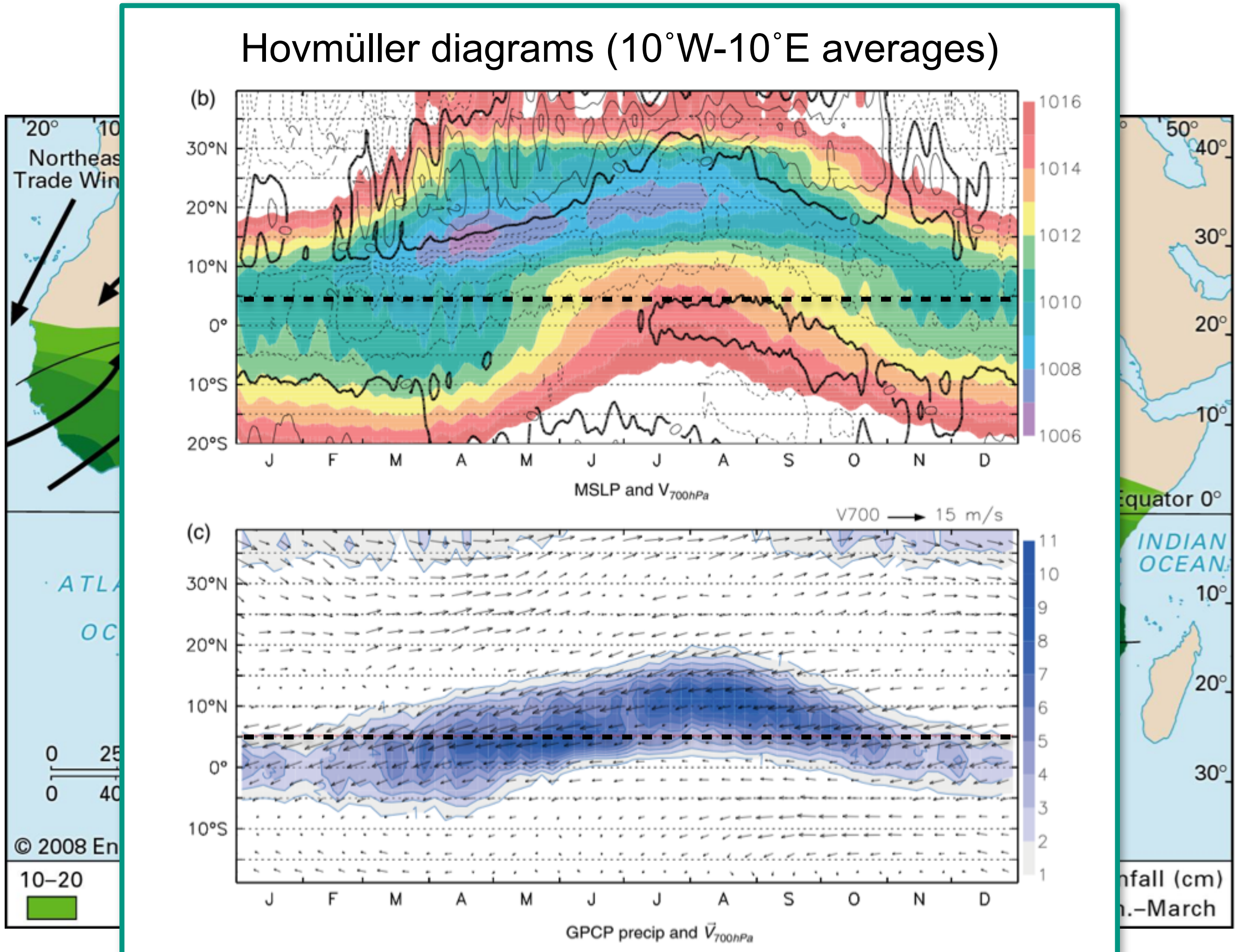
January - March



Credits: C. Klein

West African Monsoon - the big sea breeze

Hovmüller diagrams (10˚W-10˚E averages)



Mean sea level pressure [hPa] and daily precipitation [mm]

Credits: C. Klein

Thorncroft et al. (2011)

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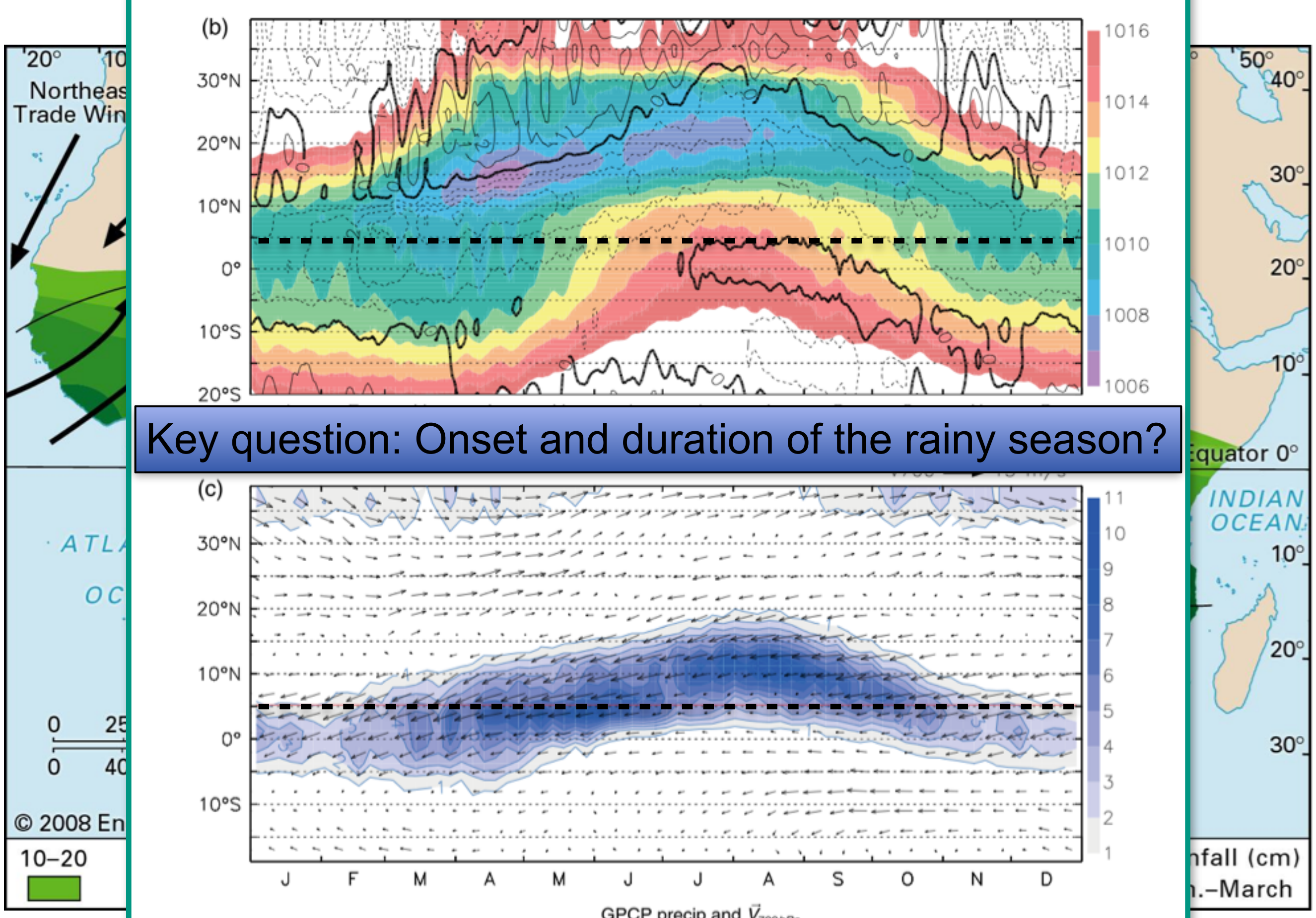

Key question: Onset and duration of the rainy season?

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The failure of global climate projections

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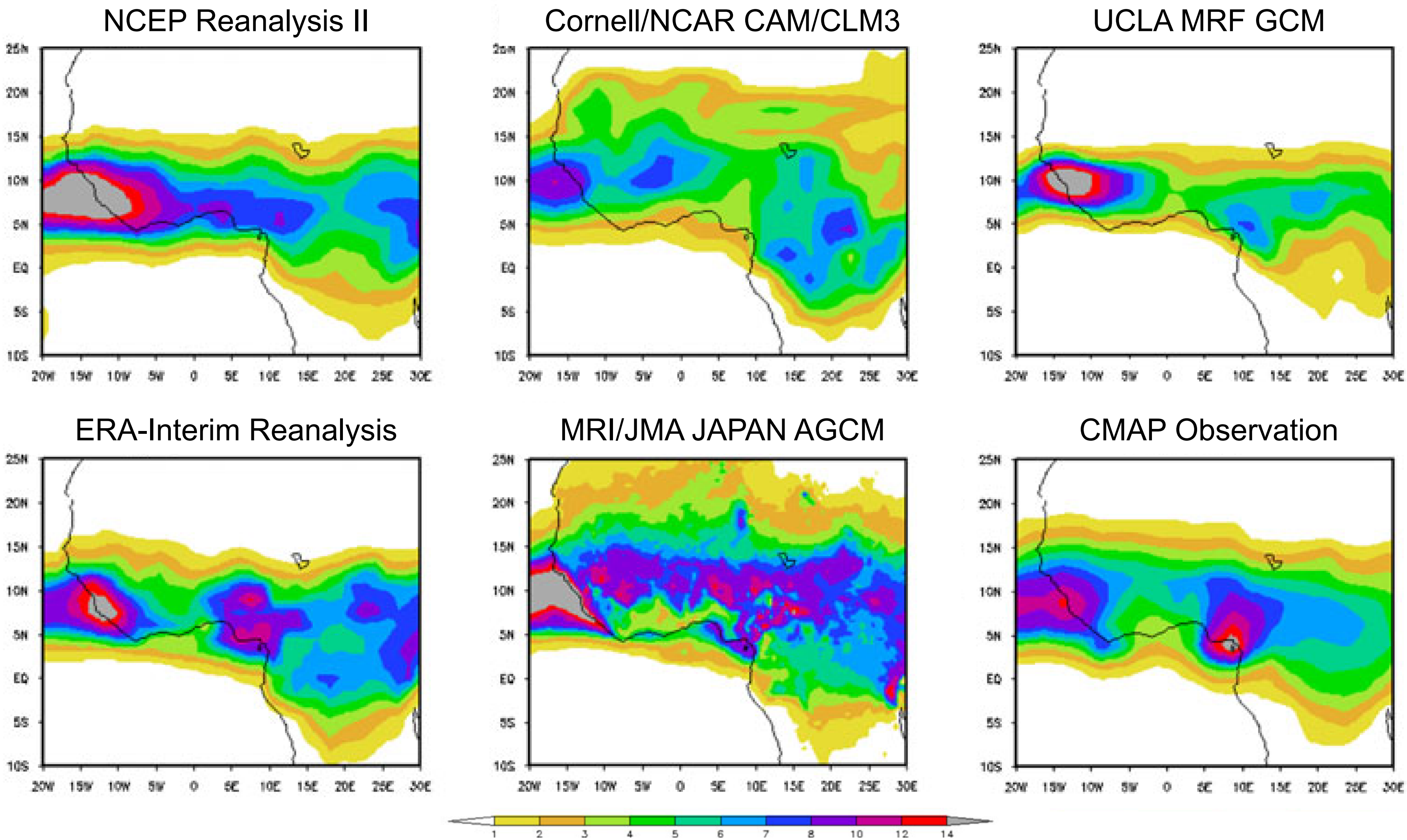

June-August 2003-2006 mean precipitation [mm/day]

Xue et al. (2010)

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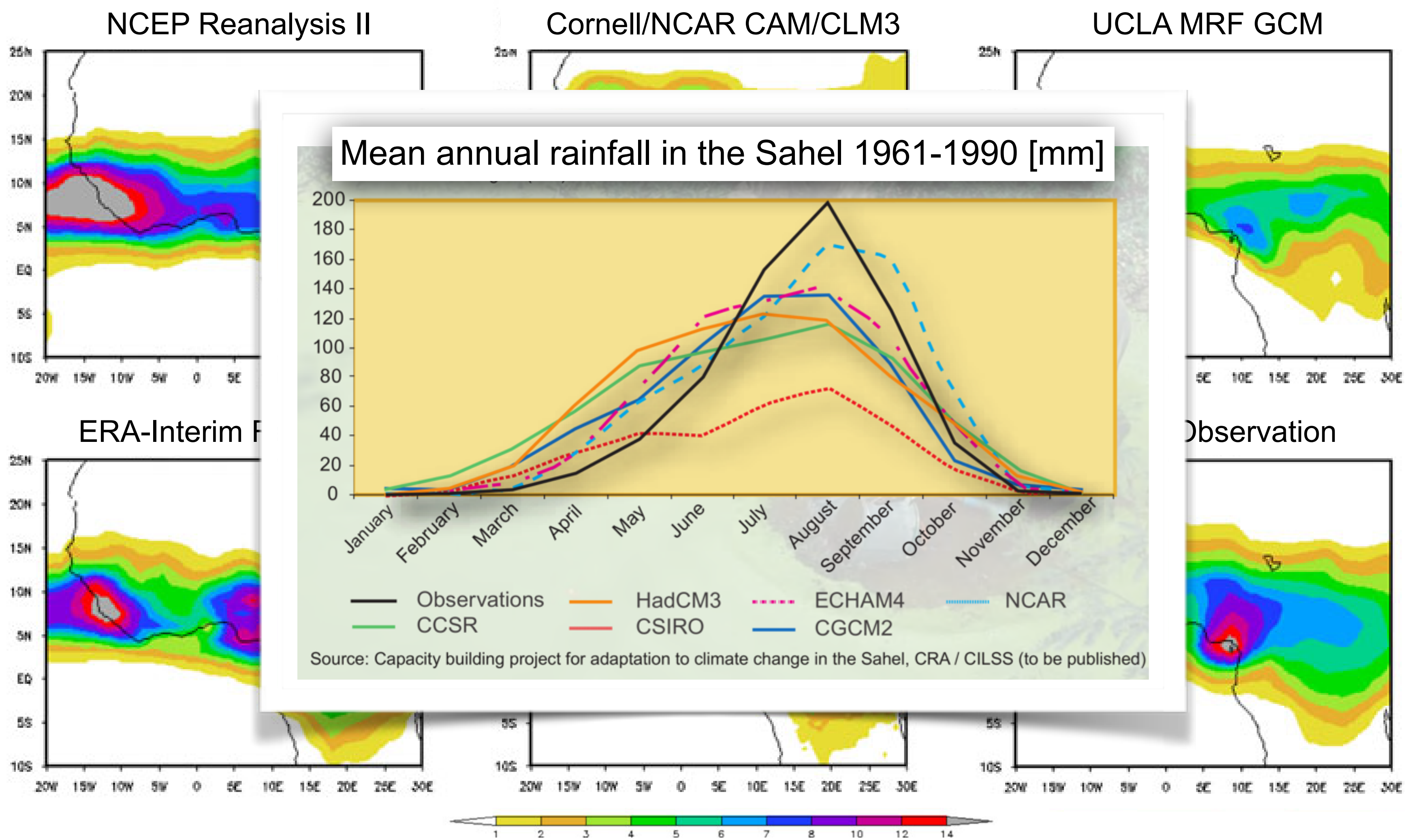

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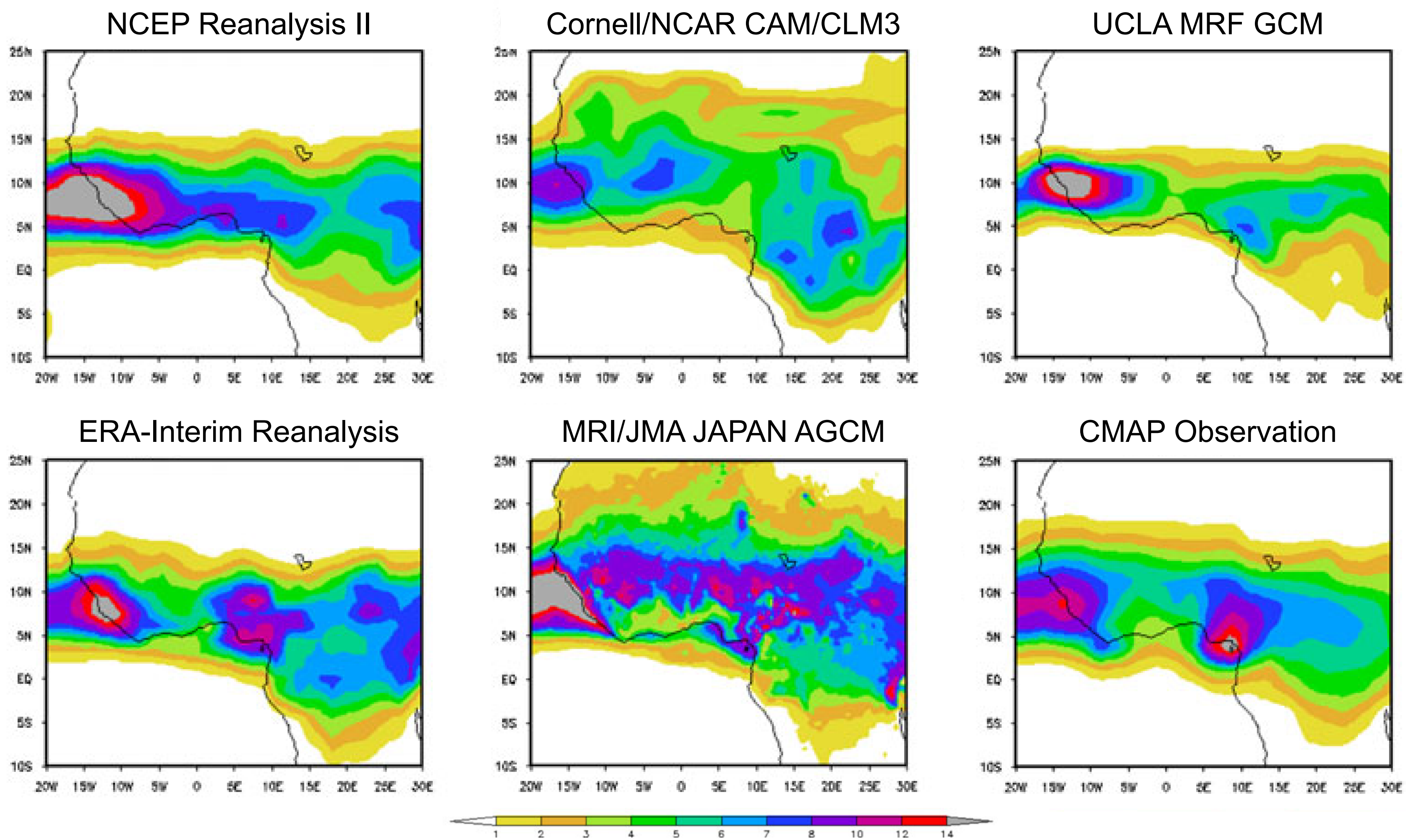

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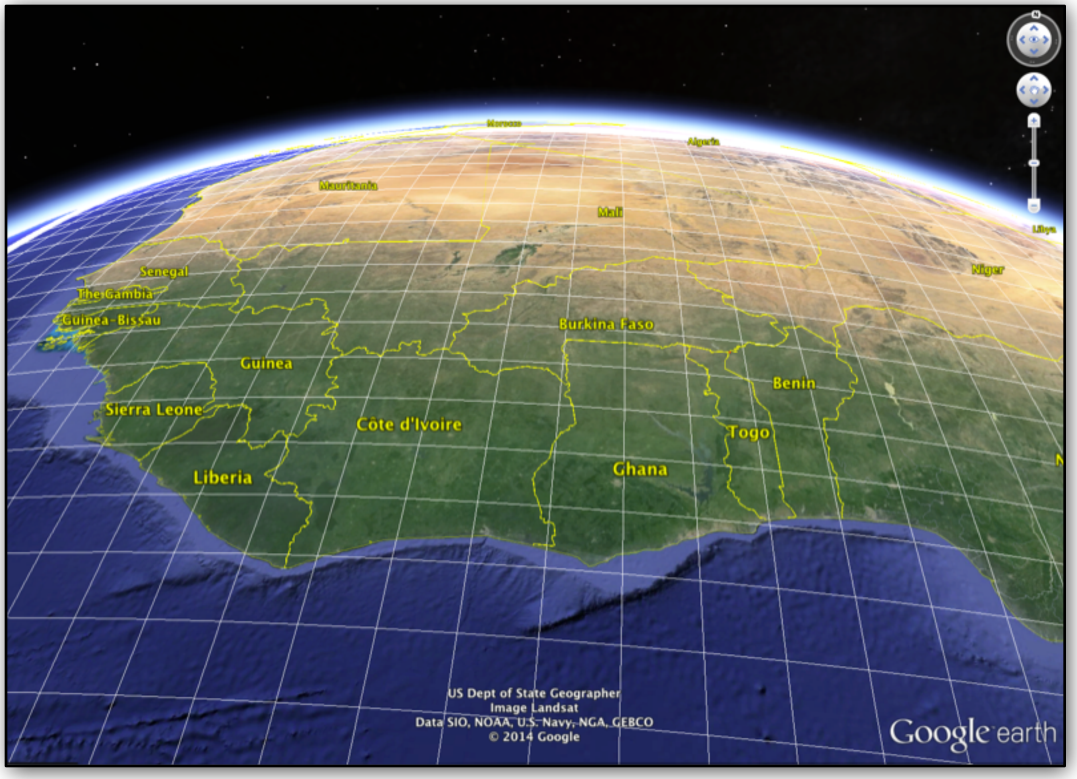
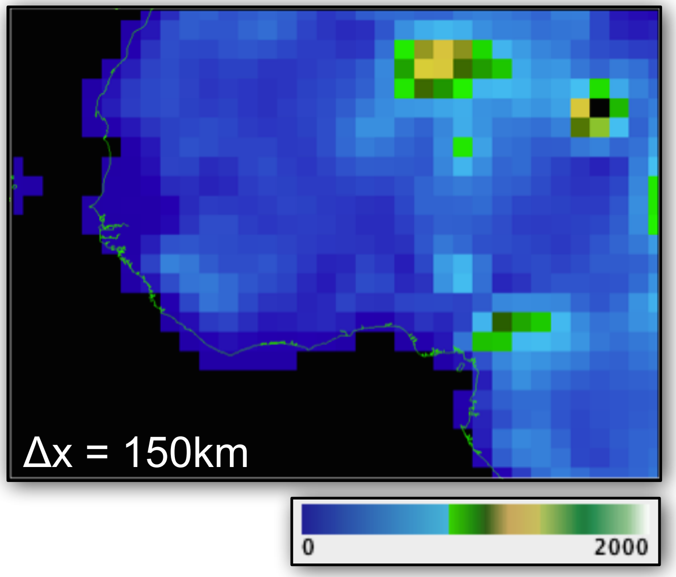
Why resolution matters: from global to regional



Terrain height [m]



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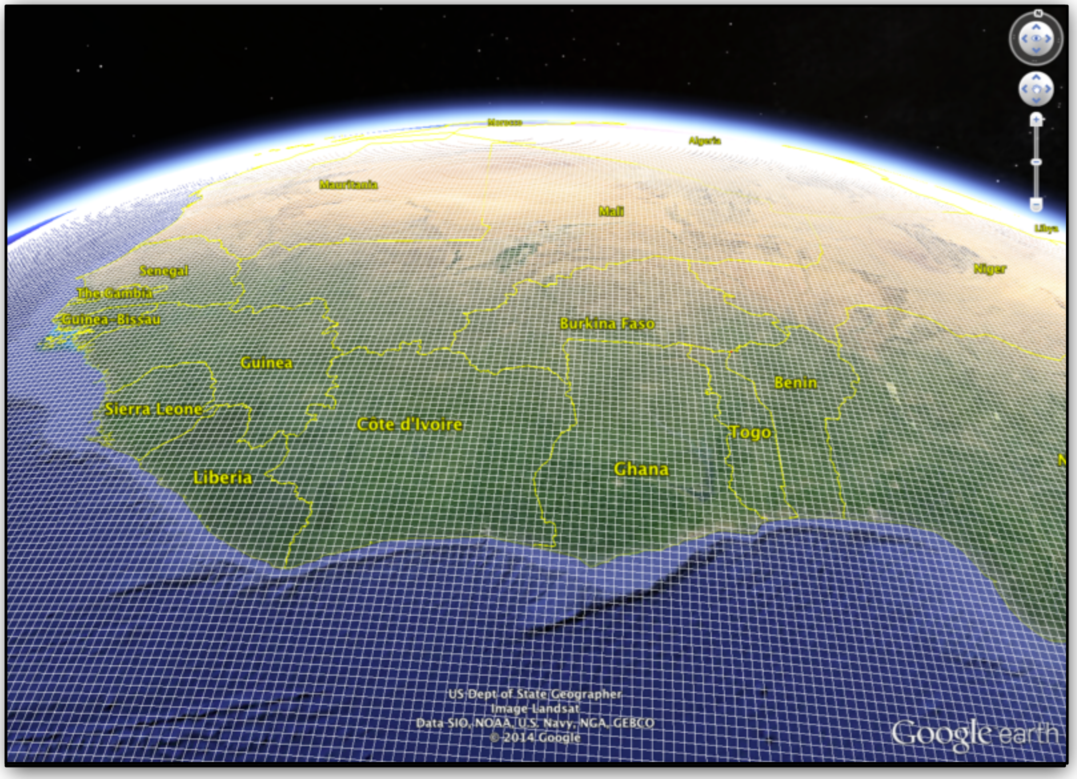

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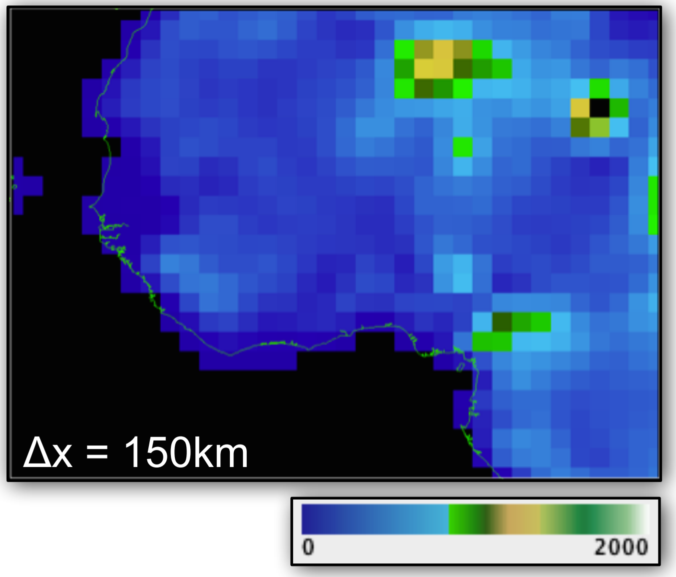

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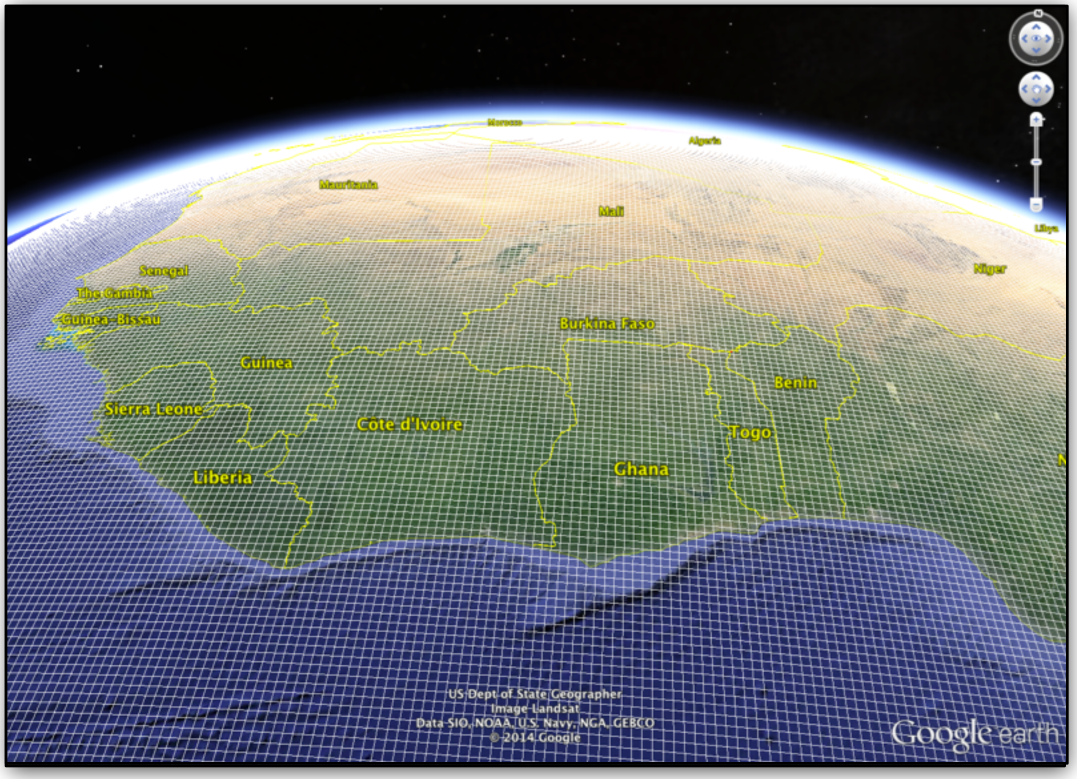

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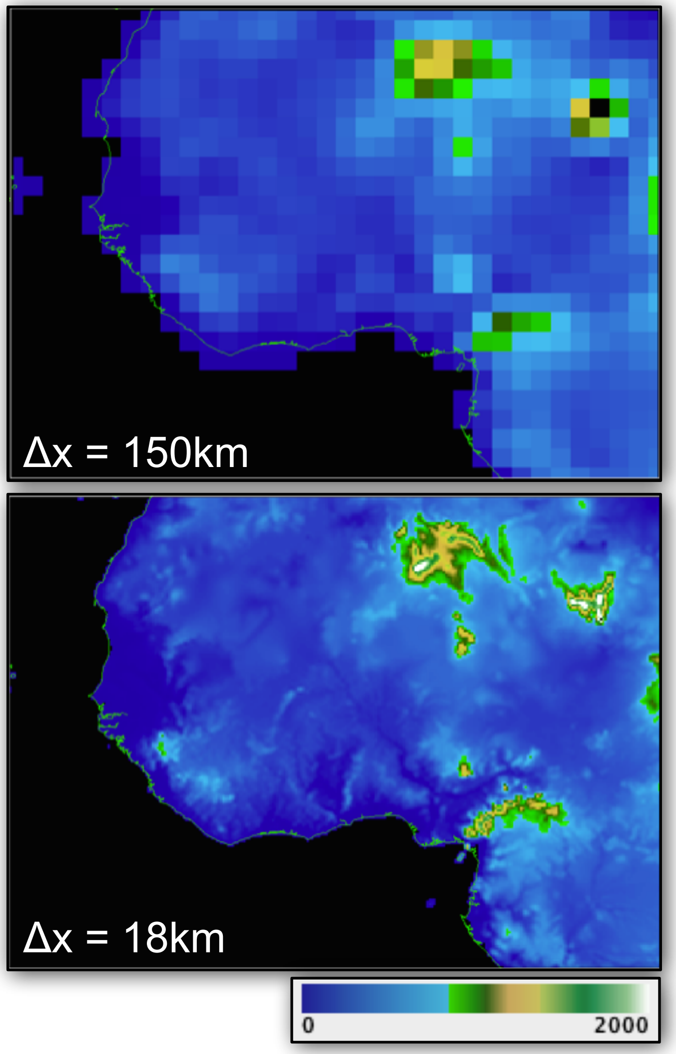

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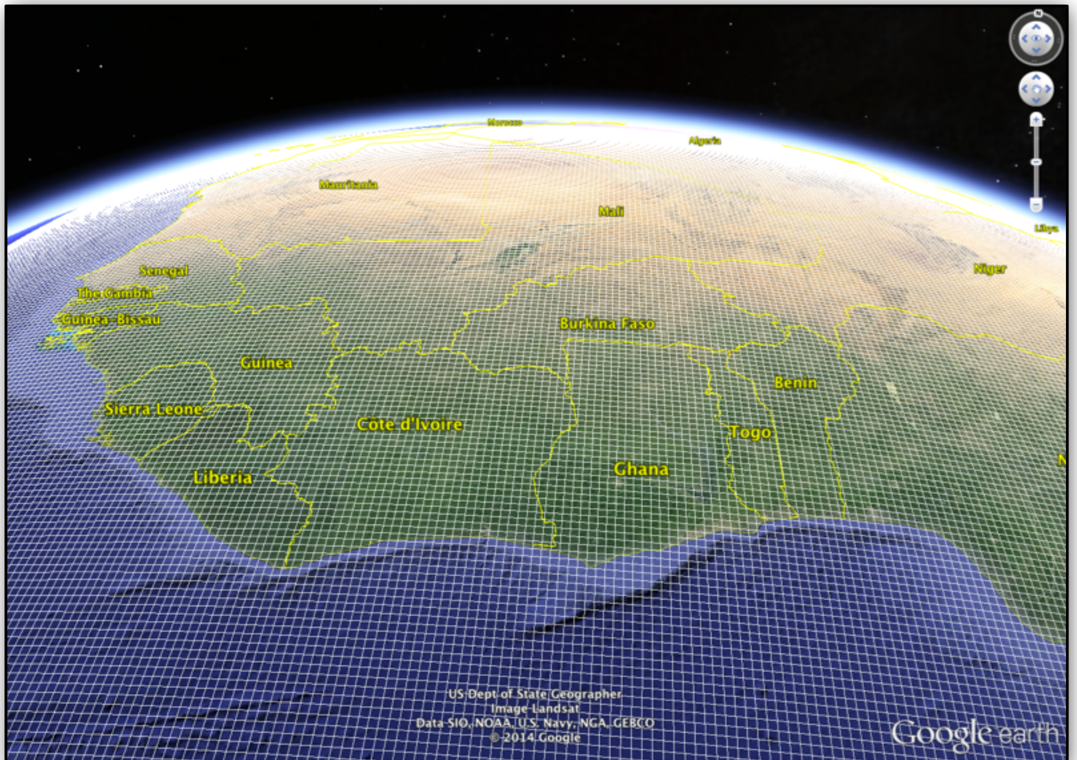

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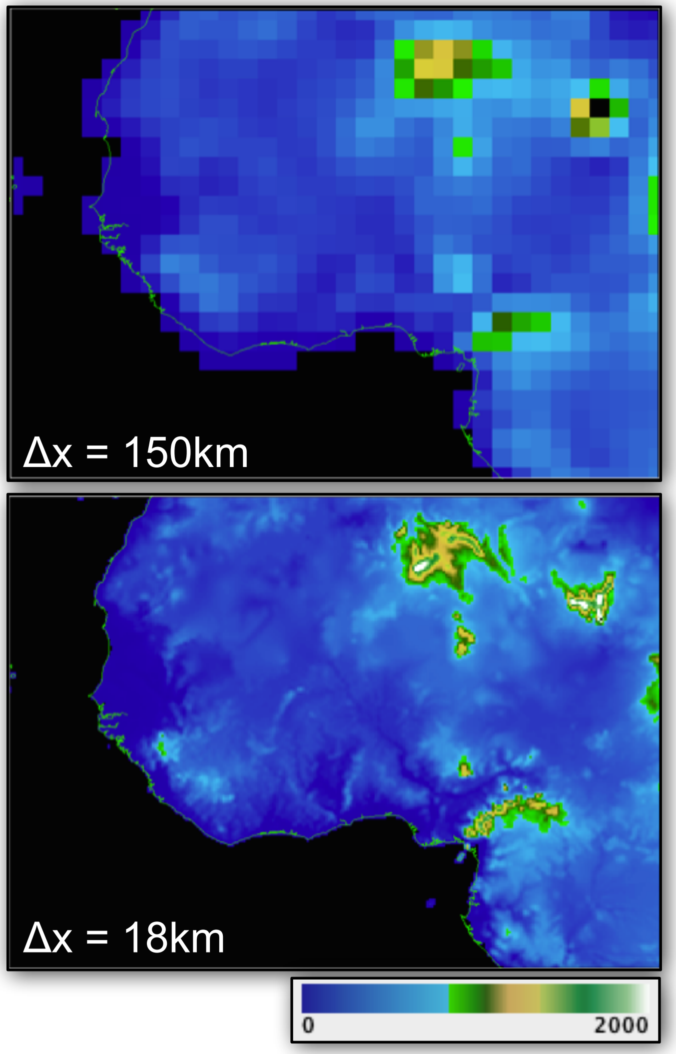

Model	Grid size	Time step
Global circulation model (GCM)	100-200km	10-20min
Global reanalysis (REA)	50-100km	(5-10min)
Regional climate model (RCM)	10-50km	1-5min

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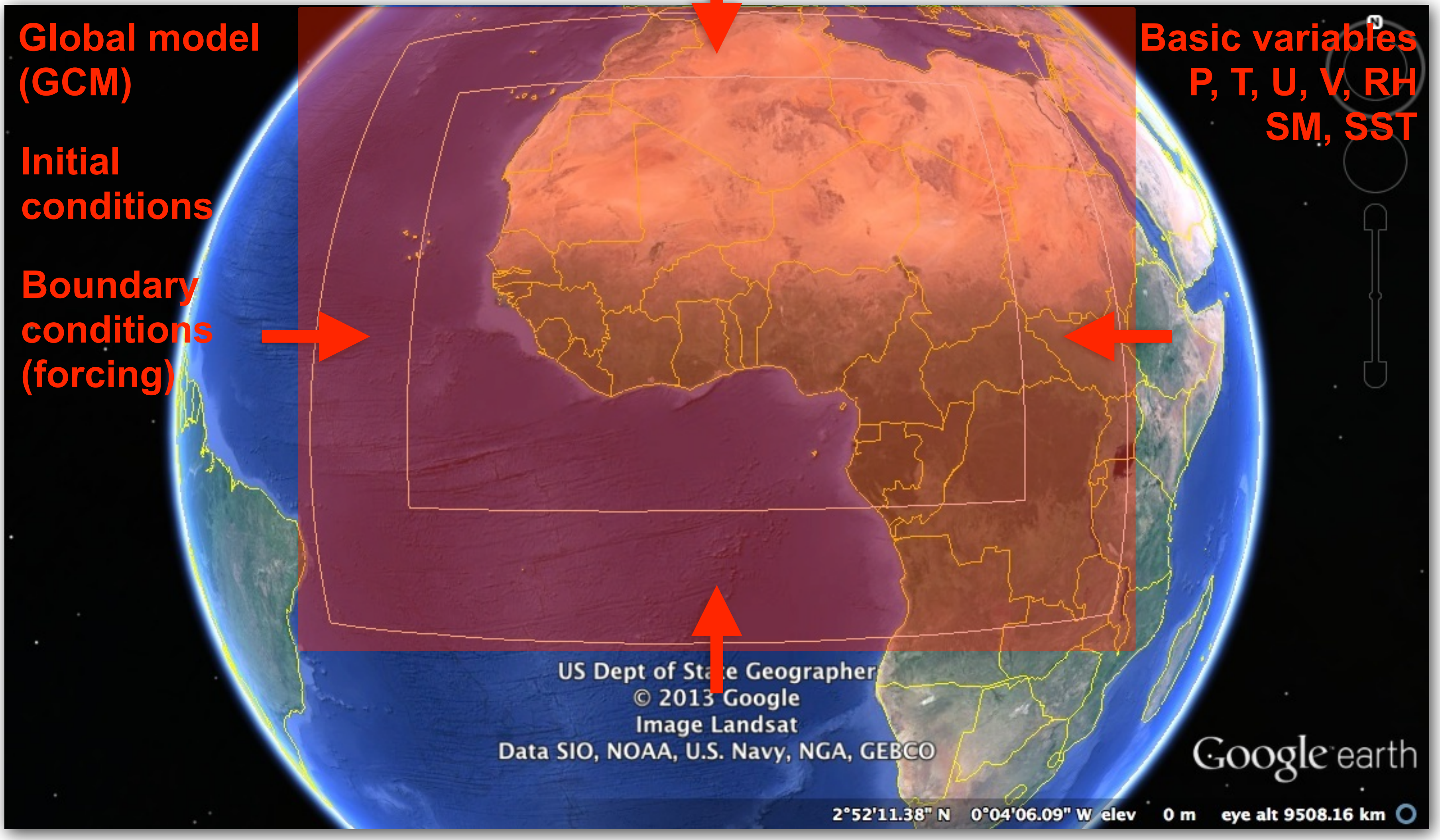
Regional downscaling at a glance



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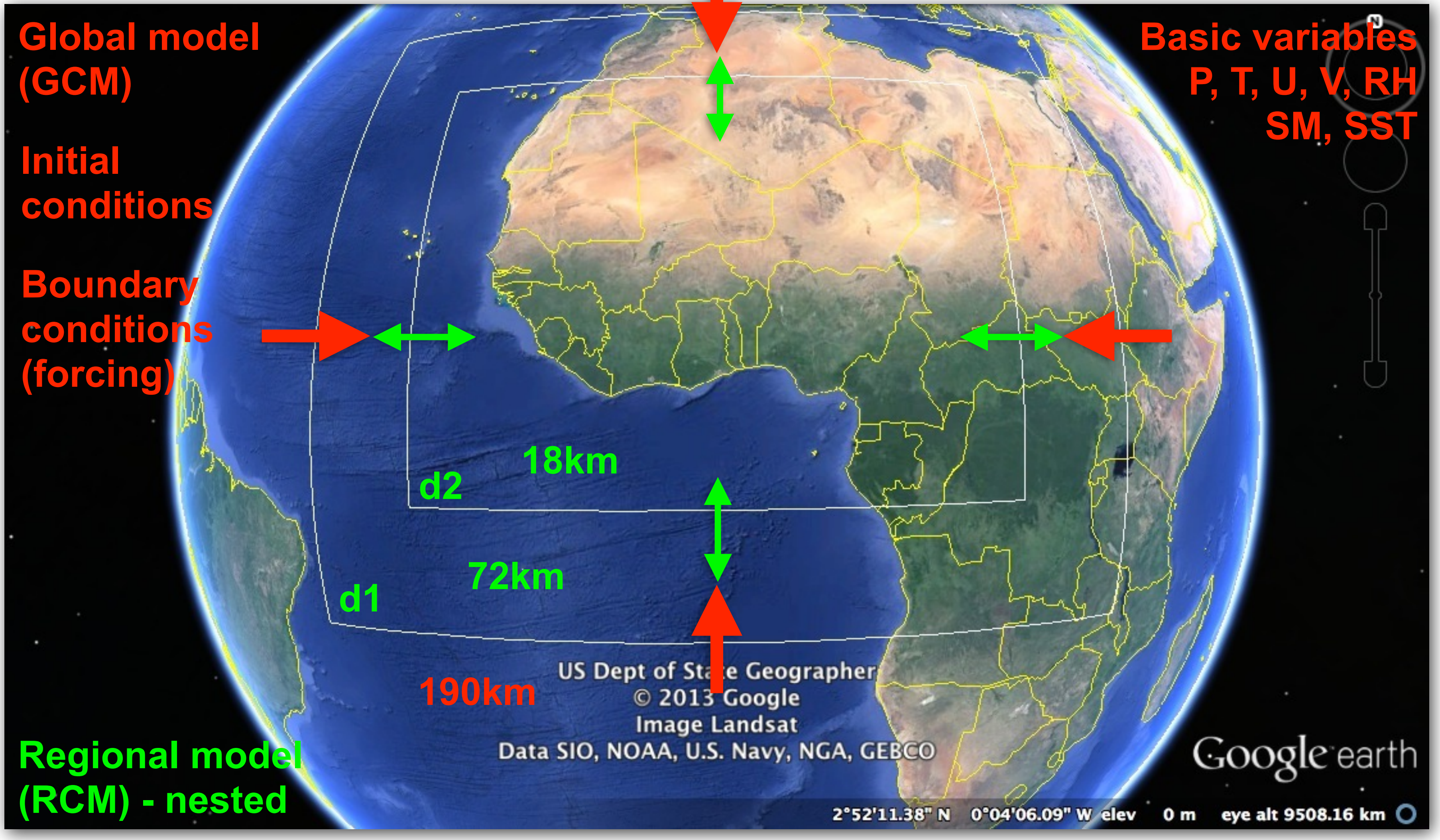
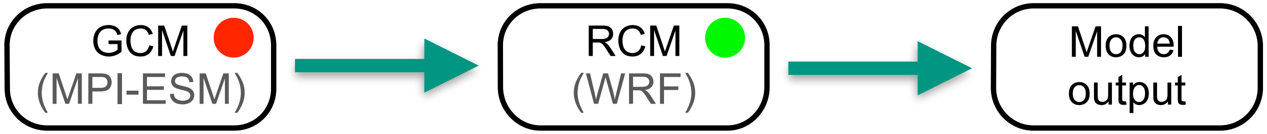


Garbage in, garbage out



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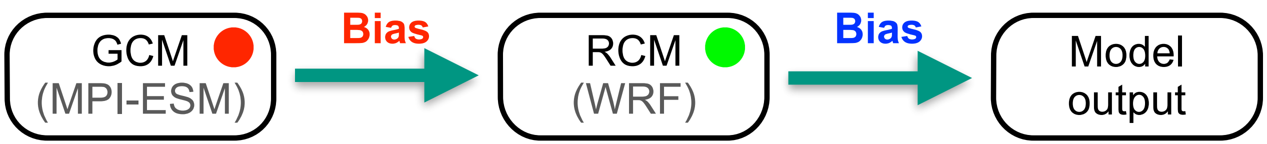

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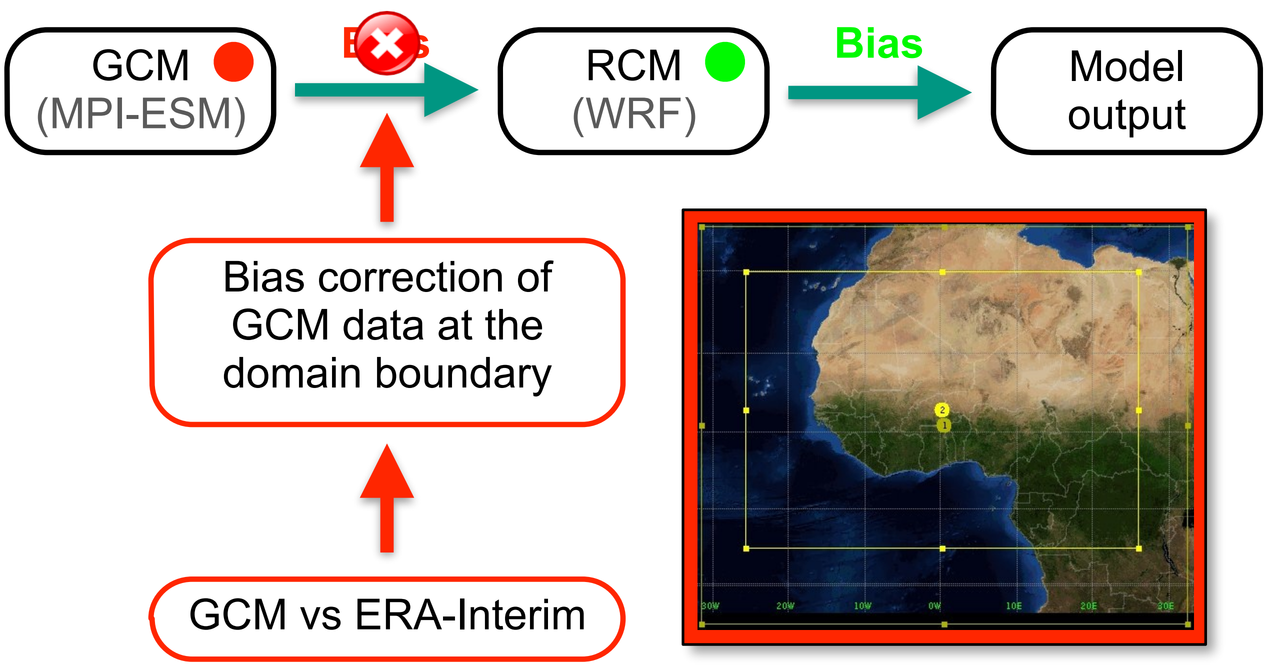

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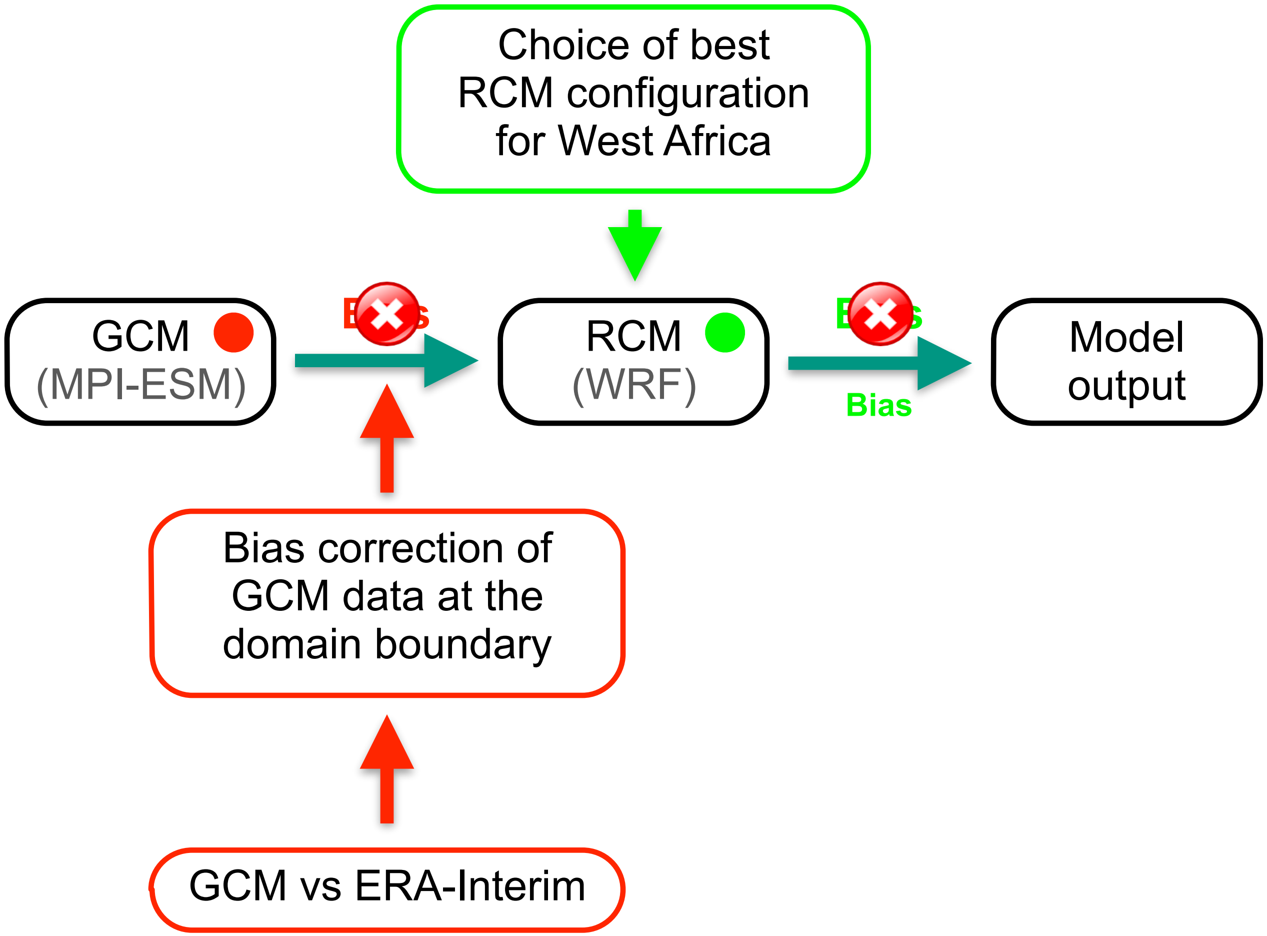

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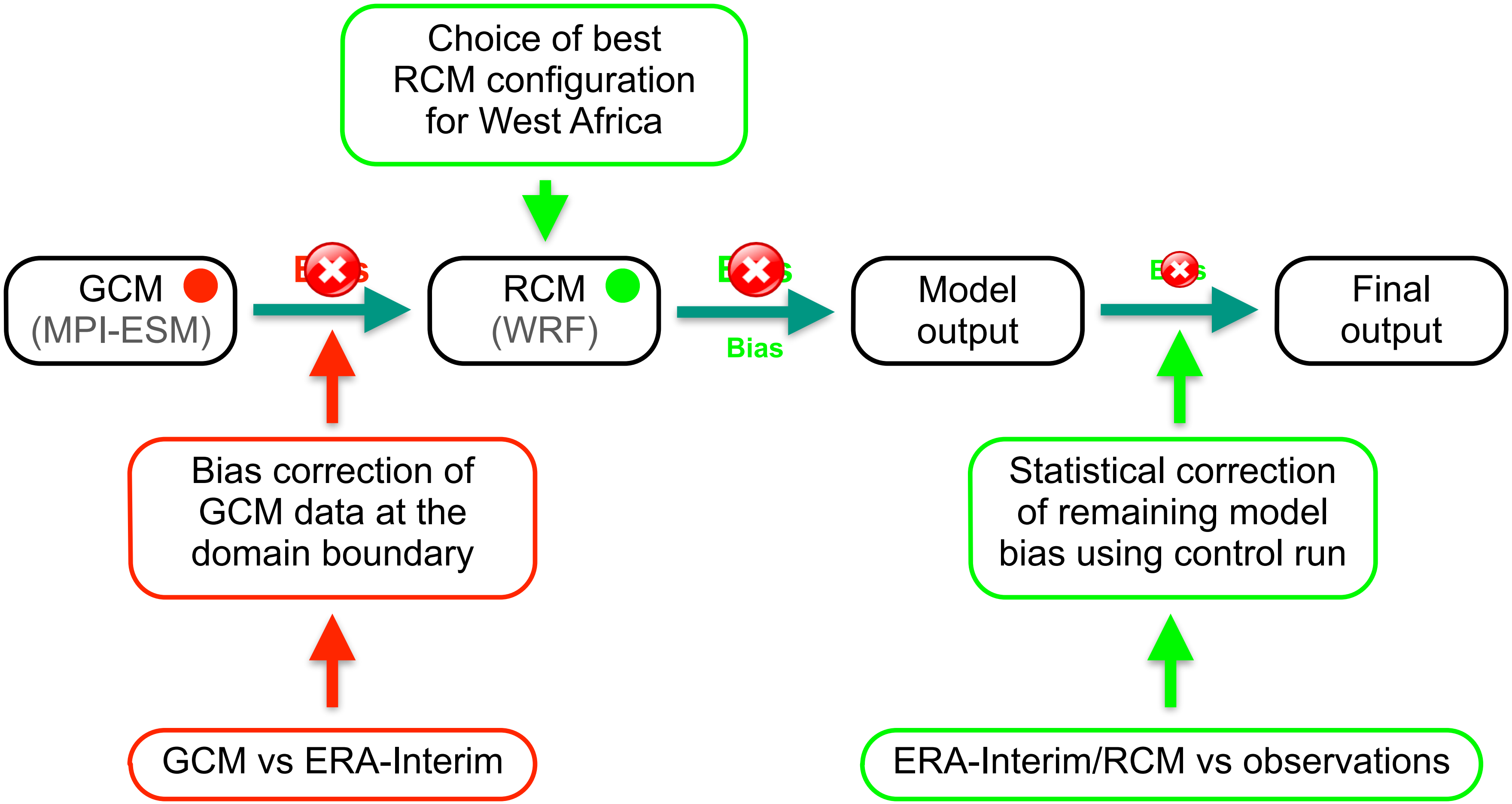
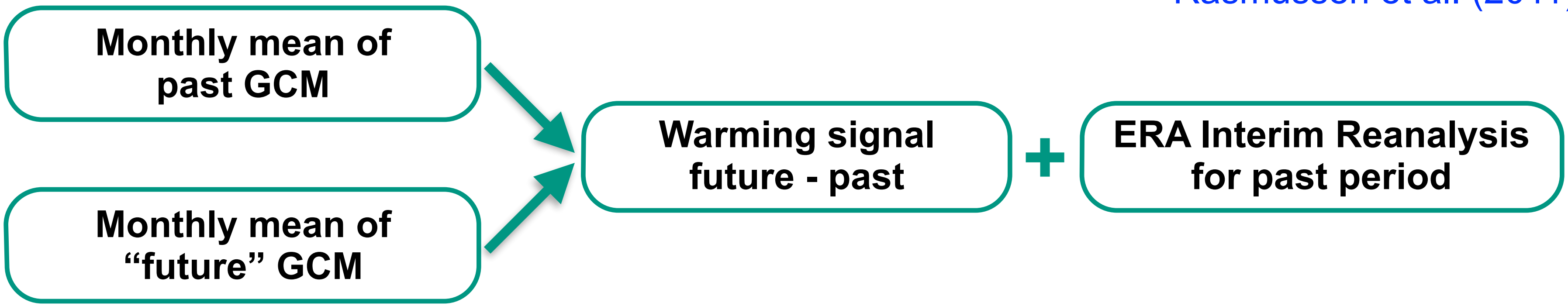


Two concurring bias correction algorithms

past: 1990-2000; “future”: 2000-2010

Pseudo-global warming
Rasmussen et al. (2011)



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Monthly mean of past GCM

Monthly mean of "future" GCM

A Interim Reanalysis for past period

Allows one to see how current weather would look like in the future. Assumes that key climate features do not change.

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Perturbed average climate
Done et al. (2012)

Average annual cycle of GCM for past → **Substract from future gives GCM'**

Average annual cycle of REA for past → **Use average annual cycle of past $\overline{\text{REA}}$**

→ **Revised $\underline{\text{climate}}$ data GCM = $\overline{\text{REA}}$ + GCM'**

Two concurring bias correction algorithms

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Done et al. (2012)

Average annual cycle of GCM for past

Average annual cycle of REA for past

Allows one to look at changes in weather and climate. Assumes that model biases are stationary in the future.

Revised climate data GCM = REA + GCM’

The code - from a pilot to a production stage

Python pilot code

Serial execution

Dictionary-based

Pro: easy to develop & debug
Con: damn slow, memory use

```
# Start

# Read data into dictionaries
RAW_REA[date/time] = array(…)
RAW_GCM[date/time] = array(…)

# Calculate averages and decompose
AVG_REA[date/time] = array(…)
AVG_GCM[date/time] = array(…)
VAR_GCM[date/time] = array(…)

# Combine to revised climate data
CMB_GCM[date/time] = array(…)

# Write to disk, finish
```

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Original proposal

Parallel Python/Fortran

Parallelized by model, period and files (np=9)

Array-based storage

Python shared-memory threads calling Fortran

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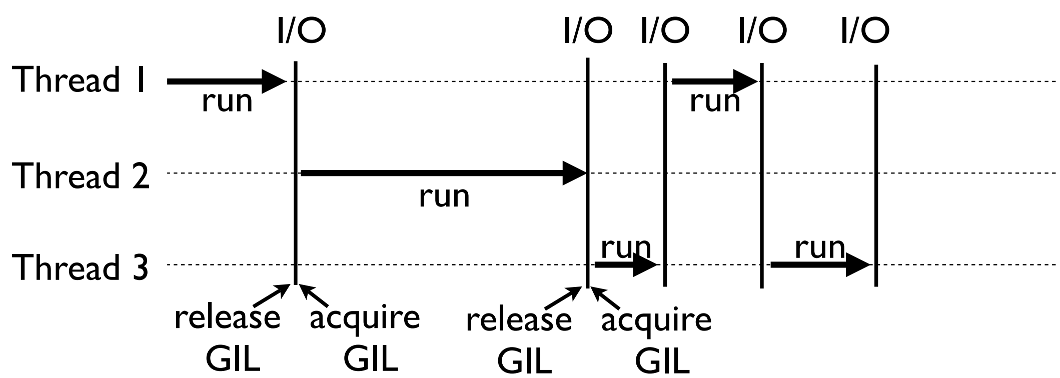
The Python Global Interpreter Lock (GIL)

Python threads are system threads (POSIX etc.), representing threaded execution of Python interpreter.

The GIL ensures only one thread runs in the interpreter at once (simplifies low-level details: memory …)

With the GIL, you get cooperative multitasking!



Beazley (2010), http://www.dabeaz.com/python/UnderstandingGIL.pdf

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The code - from a pilot to a production stage

Karlsruhe Institute of Technology

Python pilot code

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Pro: easy to develop & debug
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Current realization →

Parallel Python/Redis

Parallelized by model, period and files (np=9+9)

Storage in parallel Redis DB, arrays as binary string chunks

Python private-memory processes communicating with Redis database

↓ **Original proposal**

Parallel Python/Fortran

Parallelized by model, period and files (np=9)

Array-based storage

Python shared-memory threads calling Fortran

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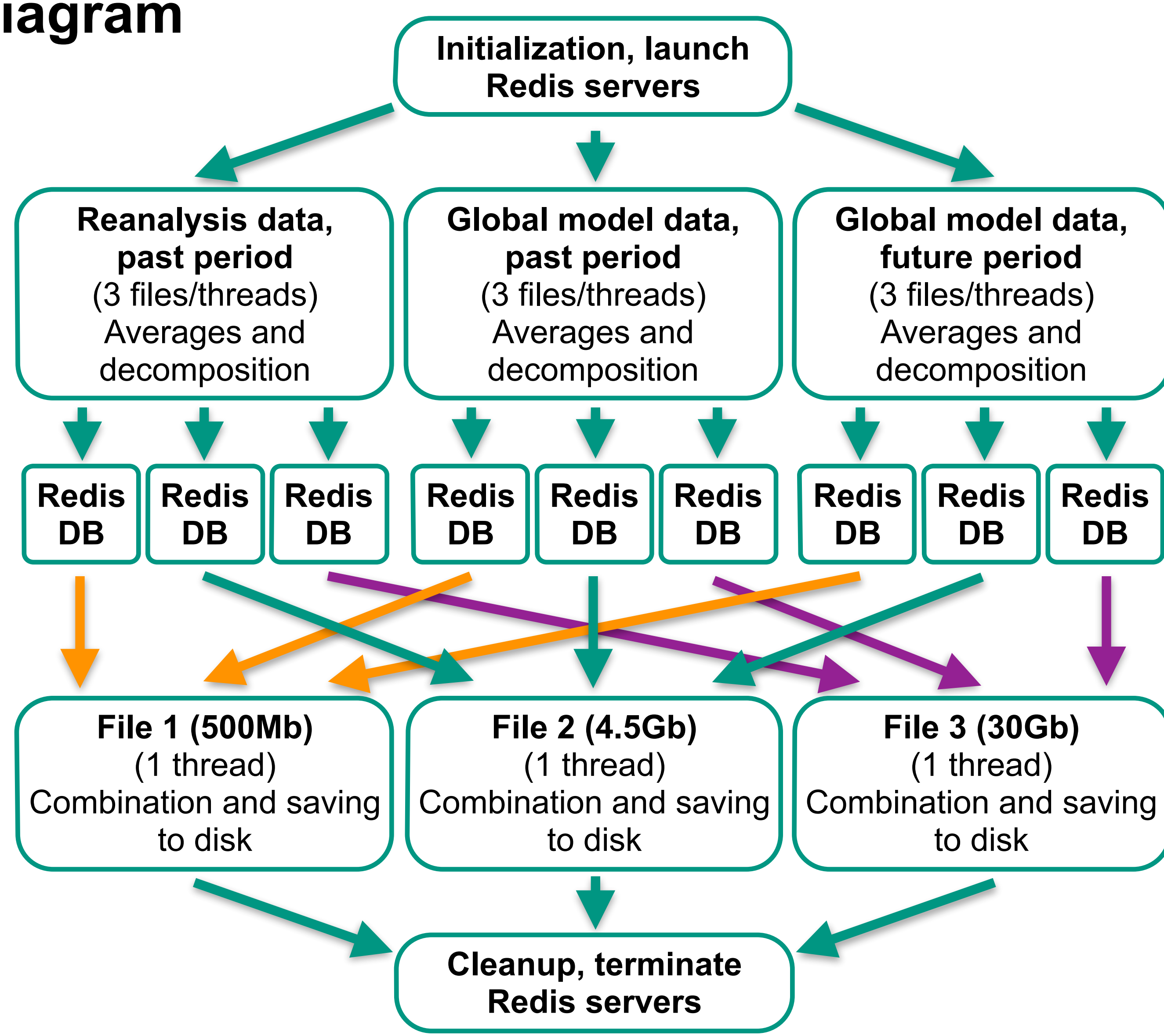
Flow diagram



Flow diagram

Initialization, launch Redis servers

Reanalysis data, past period (3 files/threads)

Global model data, past period (3 files/threads)

Global model data, future period (3 files/threads)

Runtime performance

Code version	Period length	Threads	Peak mem.	Runtime
Pilot code	2x30days	1	3.7Gb	73min
Current code	2x30days	9+9	2.7Gb	<2min
Current code	2x10years	9+9	320Gb	185/213min

File 1 (500Mb) (1 thread) Combination and saving to disk

File 2 (4.5Gb) (1 thread) Combination and saving to disk

File 3 (30Gb) (1 thread) Combination and saving to disk

Cleanup, terminate Redis servers

Scientific evaluation - 10-year climate runs

Domain configuration for climate simulations with WRF (http://www.wrf-model.org)

WRF model performance on a single Fujitsu RX600 S5 2, 64 threads (SMT)

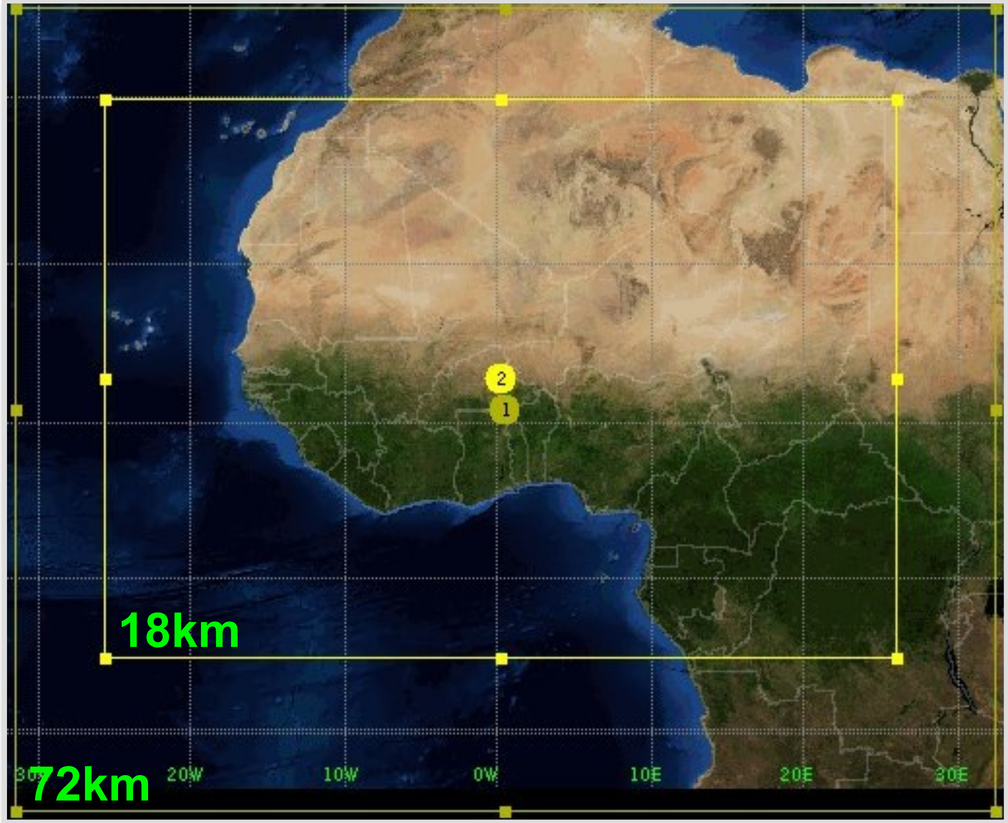
30min realtime (rt) per simulation day
58400 CPUh / 76 days rt. per 10-year run

WRF model performance on JUROPA (FZ Jülich), 5x8 threads per run

20min realtime (rt) per simulation day
47500 CPUh / 51 days rt. per 10-year run

Multiple model runs required

ERA INT, MPI ESM, PAC, PGW



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Scientific evaluation - precipitation amounts

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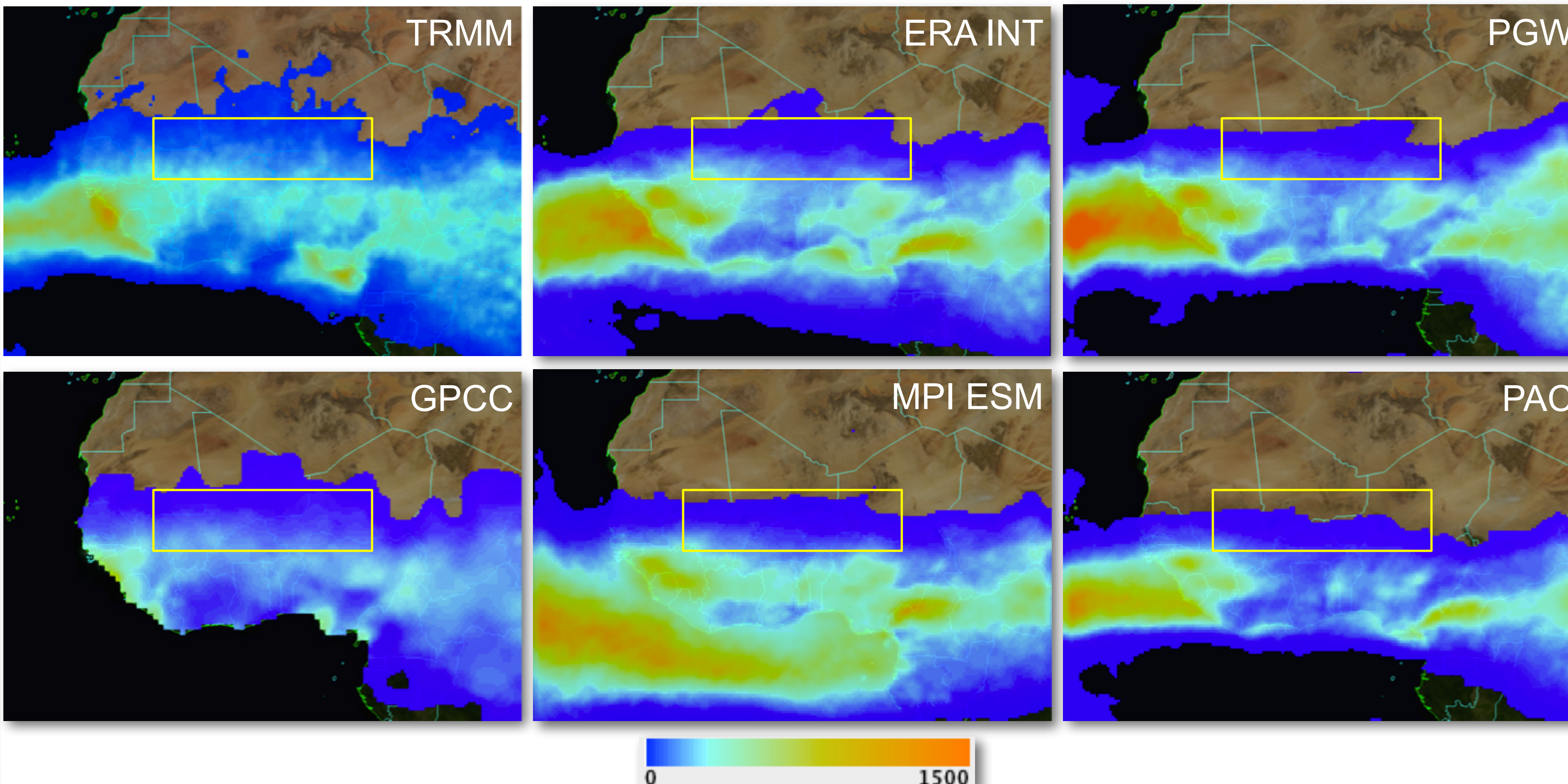
Average precipitation July (2001-2006) in mm



Scientific evaluation - precipitation statistics

Average precipitation and Pearson Correlation Coefficient wrt. TRMM July (2001-2006)

July	AVG [mm]			PCC		
	Total	Land	Sahel	Total	Land	Sahel
TRMM (ref)	110.1	114.7	130.5	1	1	1
GPCC	-	81.7	88.6	-	0.96	0.95
ERAINT	144.5	124.4	99.8	0.88	0.89	0.92
MPI ESM	195.6	118.2	49.0	0.39	0.82	0.91
PAC	87.1	75.1	23.0	0.80	0.79	0.86
PGW	136.2	118.1	69.8	0.85	0.87	0.91

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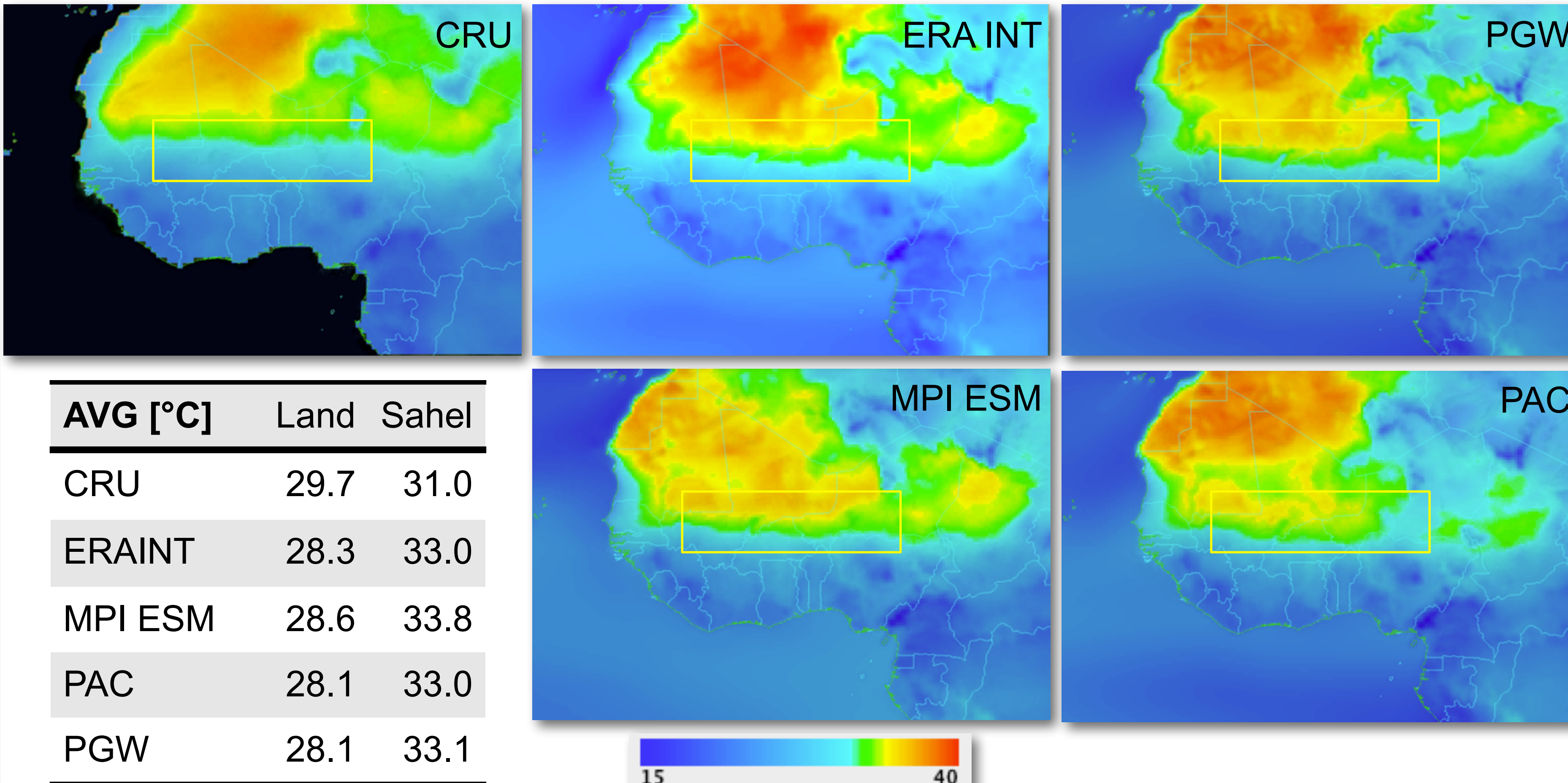
PGW	136.2	118.1	69.8	0.85	0.87	0.91

Scientific evaluation - 2m surface temperature

Average near surface temperature TRMM July (2001-2006) in °C



AVG [°C]	Land	Sahel
CRU	29.7	31.0
ERAINT	28.3	33.0
MPI ESM	28.6	33.8
PAC	28.1	33.0
PGW	28.1	33.1

Wrap up - what have we got, what's next?

Python pilot code

Serial execution

Dictionary-based

→

Parallel Python/Redis

Parallel execution (np=9+9)

Storage in parallel Redis DB

Wrap up - what have we got, what's next?

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Reading/writing the largest file (30Gb vs. 4.5Gb/500Mb) is the bottleneck of the current implementation

Parallel I/O (C/C++)

Wrap up - what have we got, what's next?

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Python pilot code		**Parallel Python/Redis**
Serial execution	→	Parallel execution (np=9+9)
Dictionary-based		Storage in parallel Redis DB

- ✗ Reading/writing the largest file (30Gb vs. 4.5Gb/500Mb) is the bottleneck of the current implementation — **Parallel I/O (C/C++)**
- ✗ 10-year reference/application periods may not be enough to smooth out patterns of inter-annual variability (El Niño…) — **Extension to 20-year periods**

Wrap up - what have we got, what's next?

Karlsruhe Institute of Technology

Python pilot code		Parallel Python/Redis
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- ✖ Reading/writing the largest file (30Gb vs. 4.5Gb/500Mb) is the bottleneck of the current implementation — **Parallel I/O (C/C++)**
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- ✖ Current code requires at least 320Gb (640Gb) of memory for 10-year (20-year) periods. We don't have such systems. — **Code to figure out parallelization**

Wrap up - what have we got, what's next?

Karlsruhe Institute of Technology

Python pilot code

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Current code requires at least 320Gb (640Gb) of memory for 10-year (20-year) periods. We don't have such systems.	**Code to figure out parallelization**

Model comparison and evaluation for full period 2000-2010

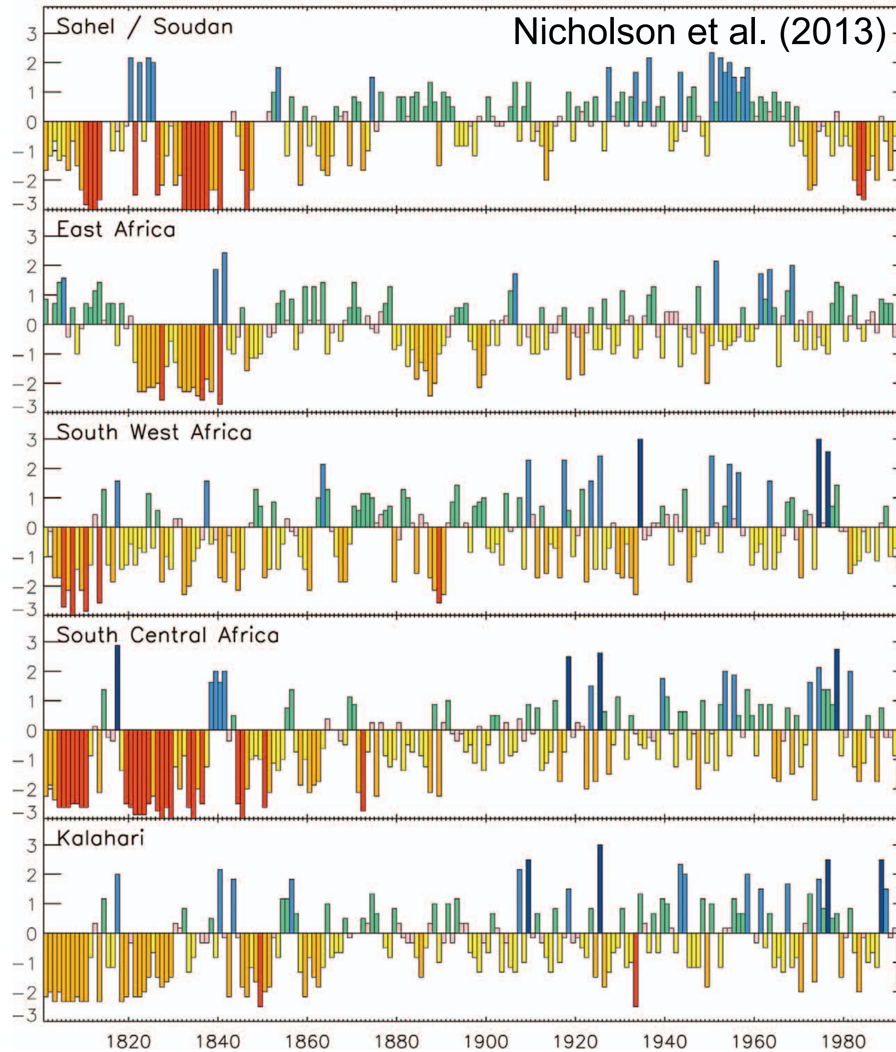
Sunset over the Sissili river, Northern Ghana (Nov. 2013)

Backup slides

Regional climate change: a rag rug with a trend

Karlsruhe Institute of Technology

Wetness/drought index



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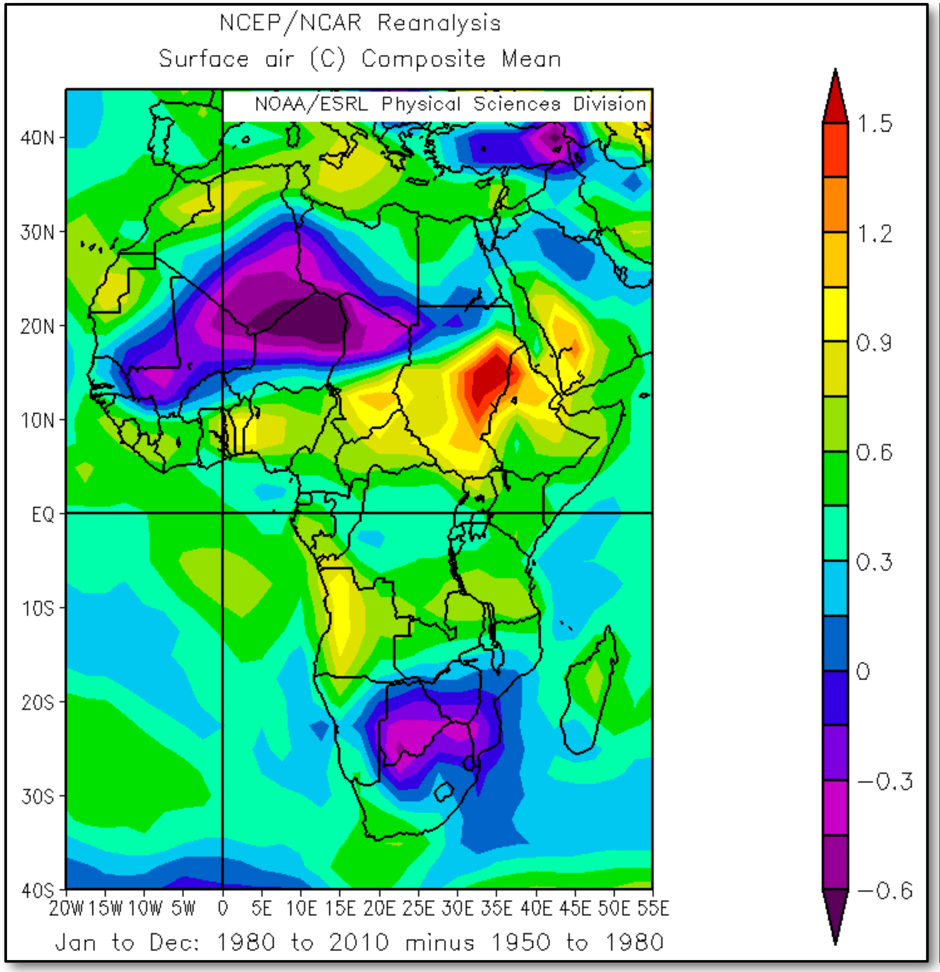
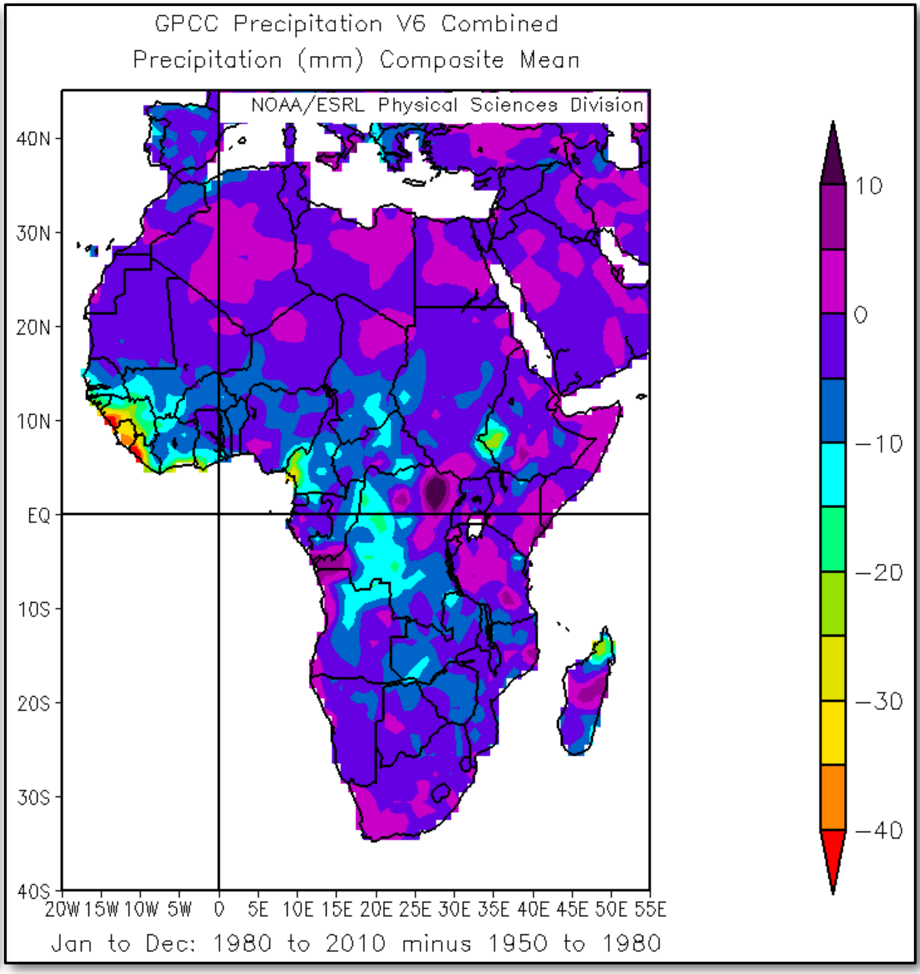
IMK-IFU: Atmospheric Environmental Research

Regional climate change: a rag rug with a trend

Monthly temperature and precipitation anomaly: 1980 to 2010 minus 1950 to 1980





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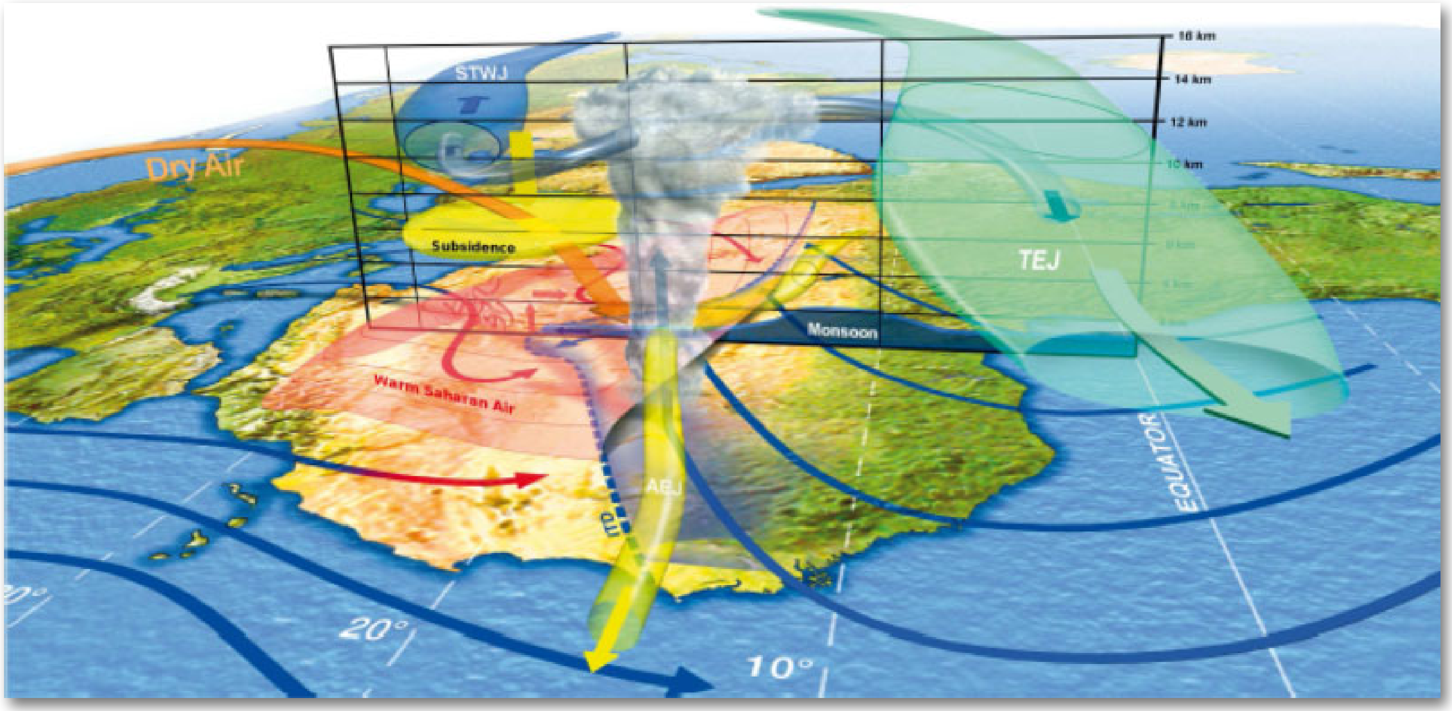
West Africa: a region of low adaptive capacity

Current average annual precipitation [mm]

West African Monsoon (WAM) - a cooking recipe

Karlsruhe Institute of Technology

Schematic view of West African Monsoon System



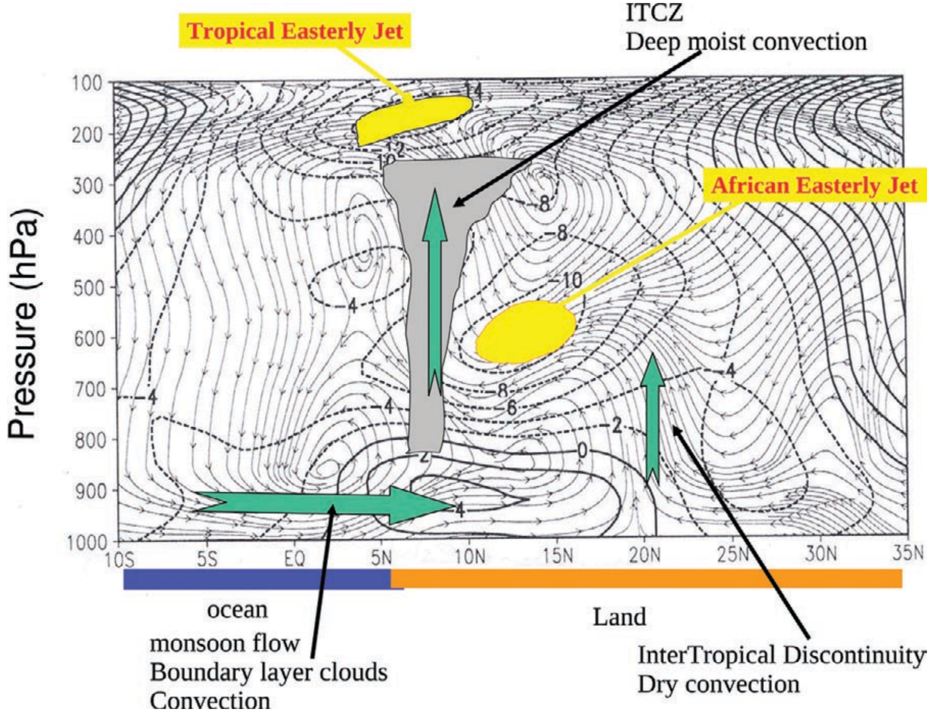
ITD: InterTropical Discontinuity (north of ITCZ)
AEJ: African Easterly Jet
TEJ: Tropical Easterly Jet
STWJ: SubTropical Westerly Jet

The oscillation of the AEJ yellow tube figures an African Easterly Wave.

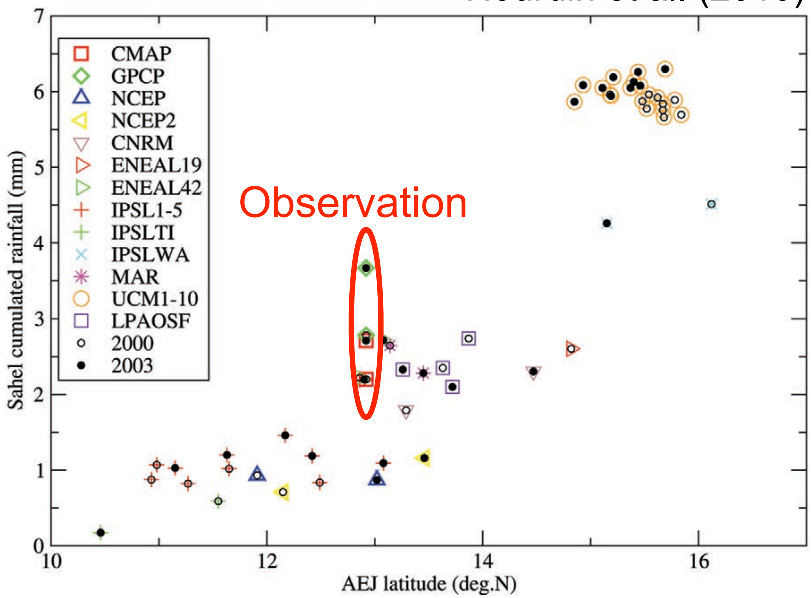
Lafore et al. (2010/2011), Sylla et al. (2012)

WAM key ingredients: getting the dynamics right

The rise and fall in Sahel rainfall accuracy with the position of the ITCZ

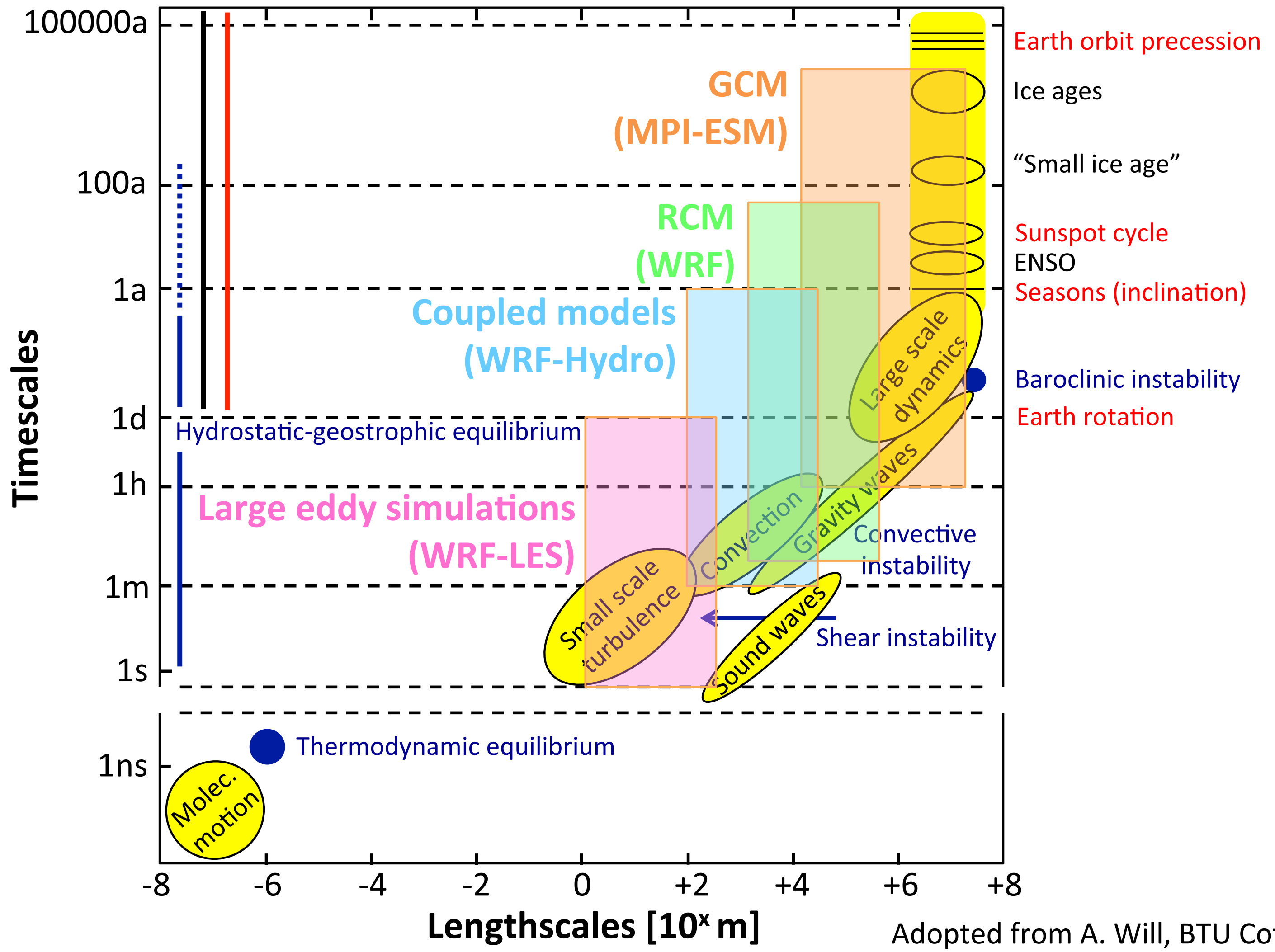


Hourdin et al. (2010)



Latitude of African Easterly Jet vs. mean daily rainfall [mm] for the Sahel 2000/2003

Length and time scales of atmospheric motion



Adopted from A. Will, BTU Cottbus

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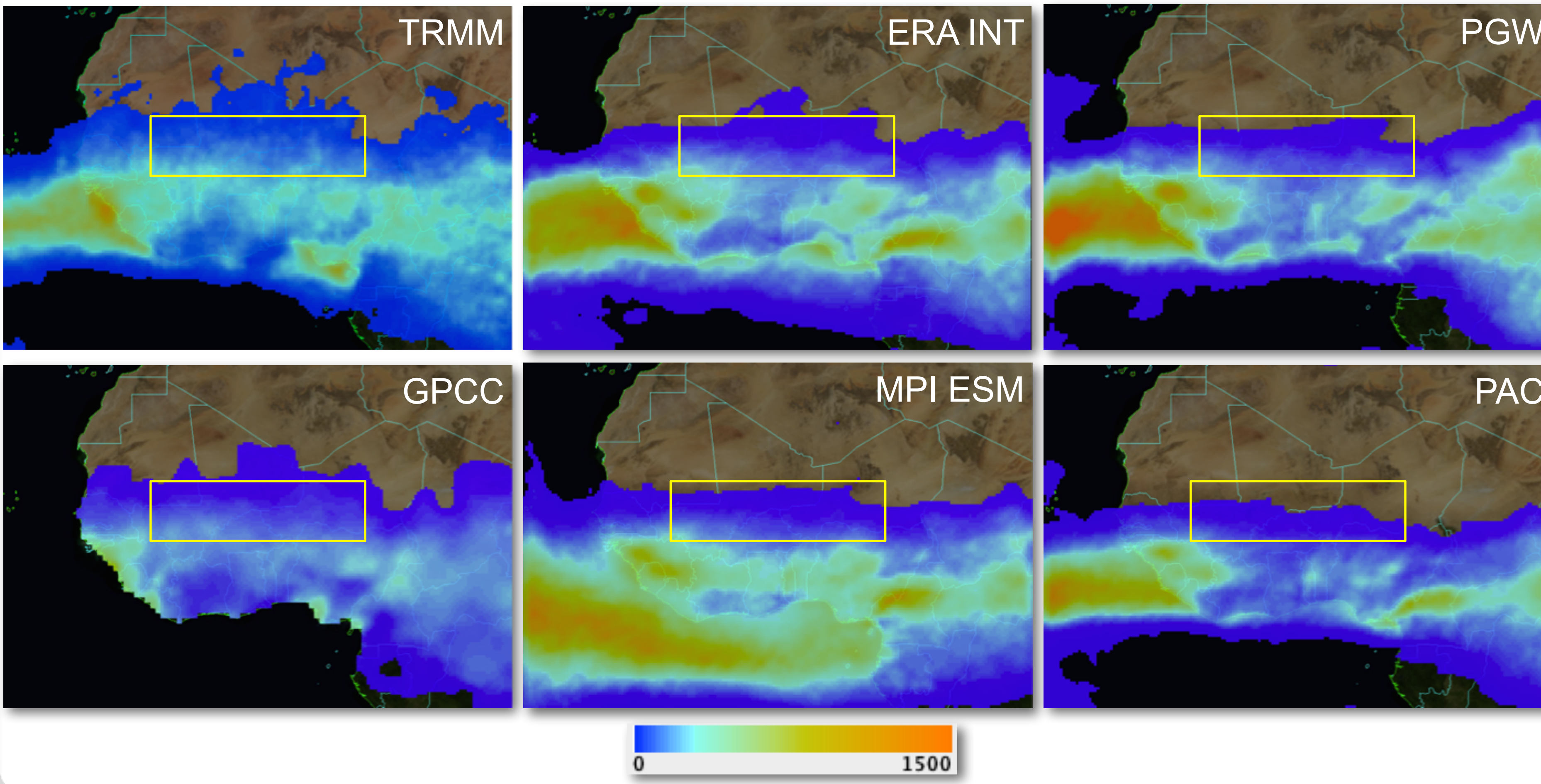
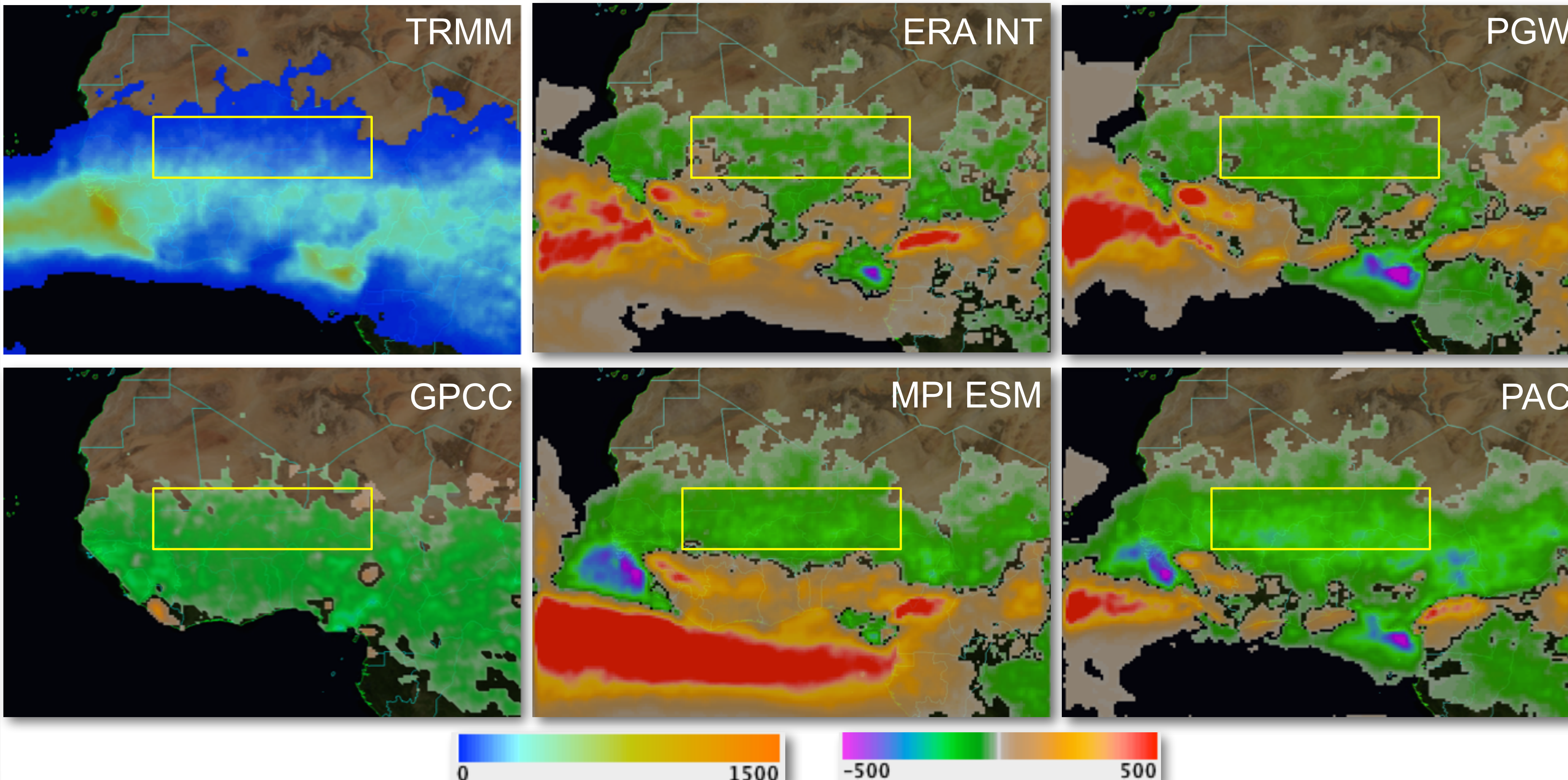
Scientific evaluation - precipitation amounts

Average precipitation July (2001-2006) in mm



Scientific evaluation - precipitation differences

Average precipitation / difference in avg. precipitation to TRMM July (2001-2006) in mm



Scientific evaluation - precipitation amounts

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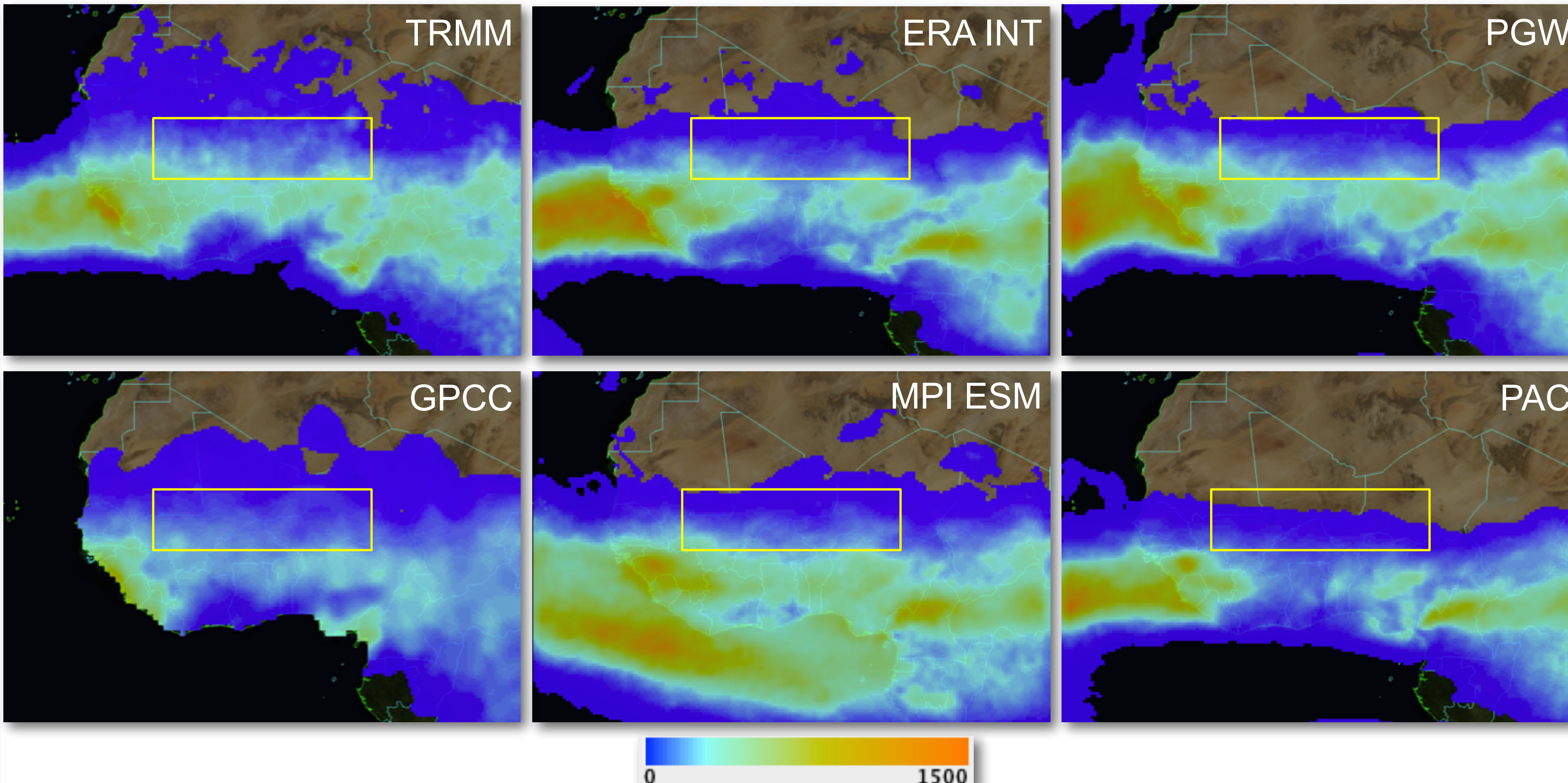
Average precipitation August (2001-2006) in mm



Scientific evaluation - precipitation differences

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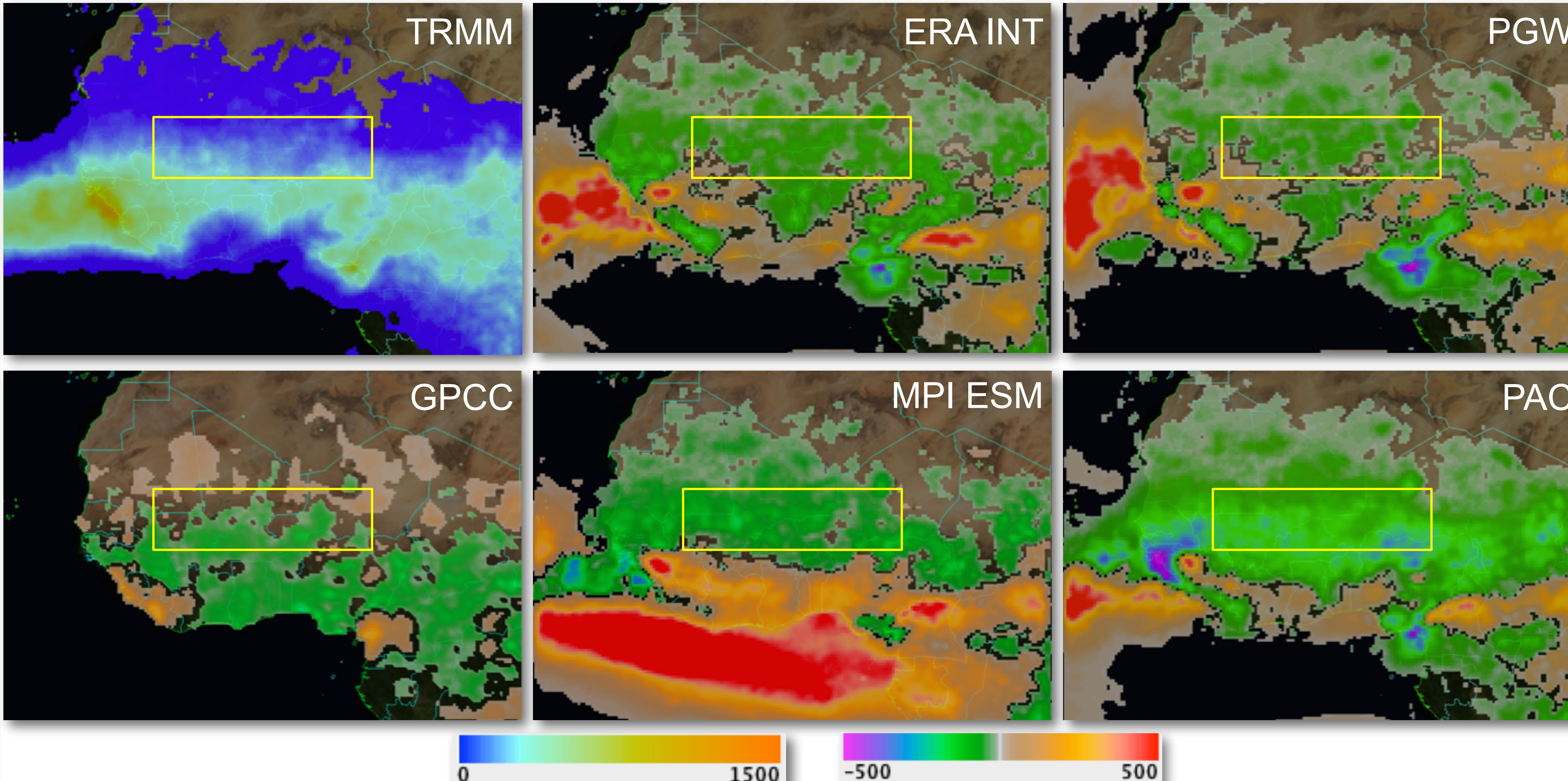
Average precipitation / difference in avg. precipitation to TRMM August (2001-2006) in mm



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Scientific evaluation - precipitation statistics

July	AVG [mm]			ME [mm]			PC		
	Total	Land	Sahel	Total	Land	Sahel	Total	Land	Sahel
TRMM	110.1	114.7	130.5	-	-	-	-	-	-
GPCC	-	81.7	88.6	-	-33.0	-41.7	-	0.96	0.95
ERAINT	144.5	124.4	99.8	34.4	9.7	-30.7	0.88	0.89	0.92
MPI ESM	195.6	118.2	49.0	85.6	3.5	-81.5	0.39	0.82	0.91
PAC	87.1	75.1	23.0	-23.0	-39.6	-107.5	0.80	0.79	0.86
PGW	136.2	118.1	69.8	26.1	3.4	-60.7	0.85	0.87	0.91

August	AVG [mm]			ME [mm]			PC		
	Total	Land	Sahel	Total	Land	Sahel	Total	Land	Sahel
TRMM	125.7	143.2	161.6	-	-	-	-	-	-
GPCC	-	103.1	88.6	-	-40.1	-73.0	-	0.95	0.88
ERAINT	139.0	138.9	119.2	13.3	-4.3	-42.4	0.90	0.90	0.93
MPI ESM	217.5	162.0	97.0	91.8	18.8	-64.6	0.50	0.84	0.88
PAC	98.3	94.6	31.0	-27.4	-48.6	-130.6	0.82	0.81	0.87
PGW	145.9	143.4	129.1	20.2	0.2	-32.5	0.87	0.91	0.93

Sunset over the Sissili river, Northern Ghana (Nov. 2013)