Predicting Future Climate Changes in West Africa: Role of Land Dynamics

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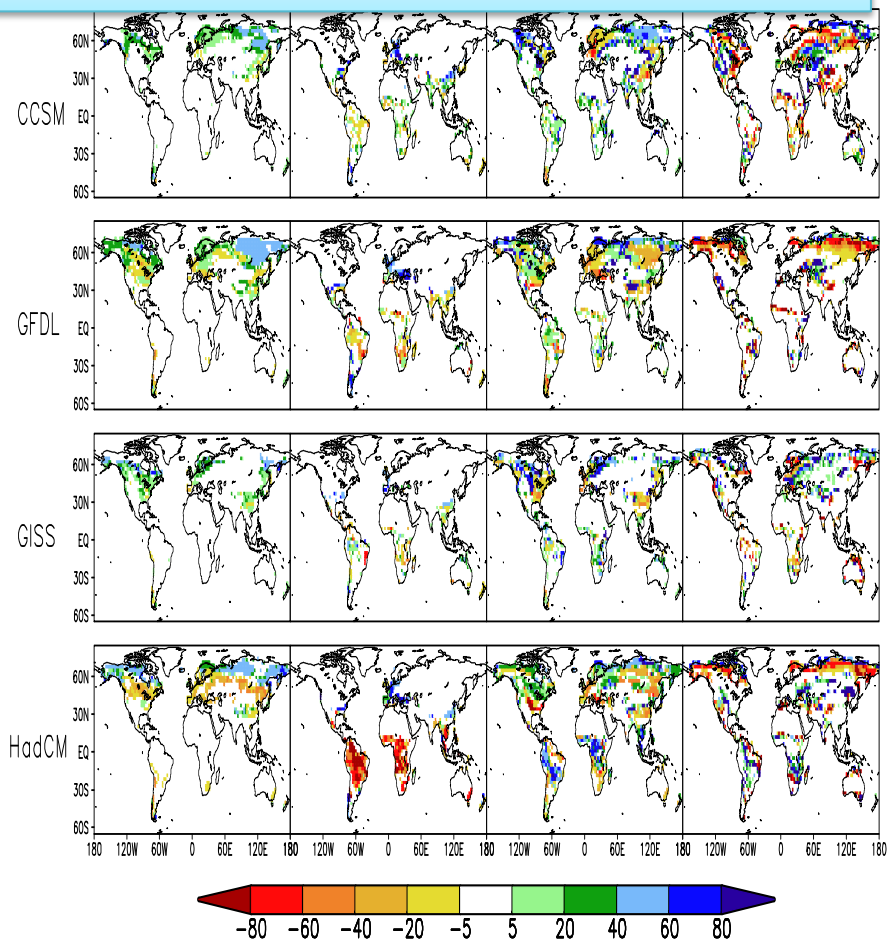
The research presented is supported by funding from

Climate & Land Dynamics

- **Natural Vegetation Dynamics** (establishment, growth, mortality, and competition of natural vegetation): Climate is the main driver for changes in the distribution and structure of natural vegetation at the decadal and centennial time scales.
- **Land Use Dynamics**:
  - Agricultural land use: Climate is an important biophysical driver, in addition to socio-economic drivers
  - Other types of land use: Climate impact is less direct

Changes in Fractional Coverage of Vegetation Types Predicted by CLM3-DGVM: Changes from Pre-industrial Control (PIC) to 2100_A1b

Needle-leaf Evergreen Broadleaf Evergreen Deciduous Grass



(Alo & Wang, 2008)

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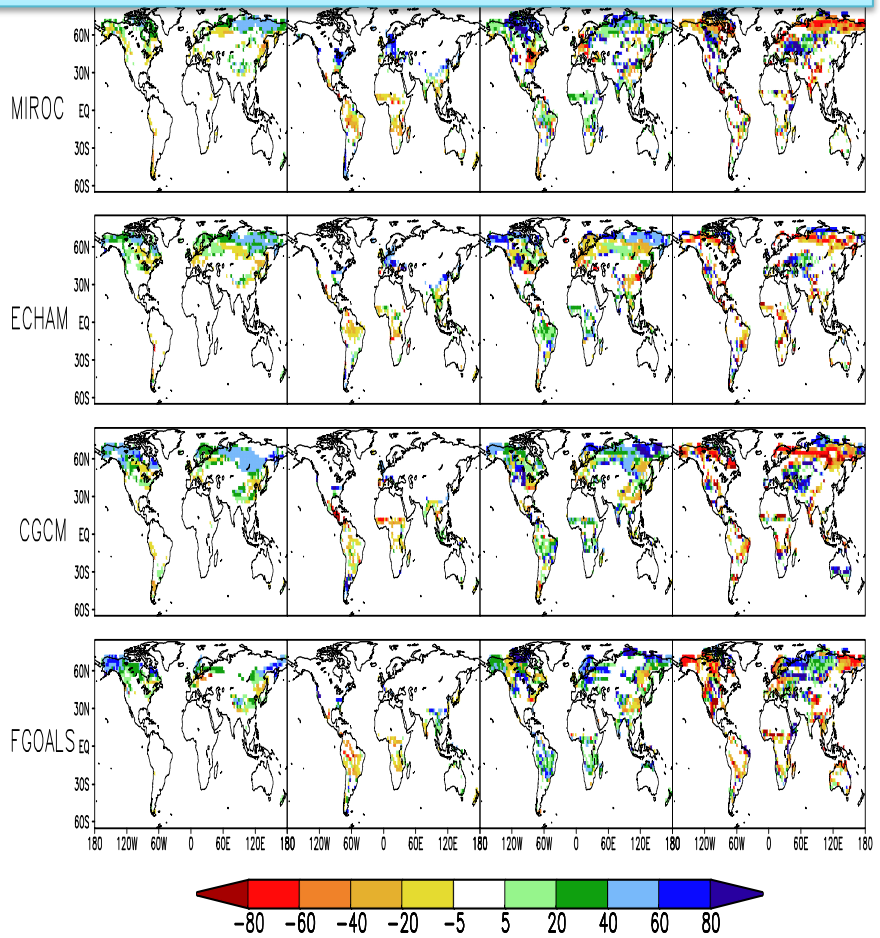


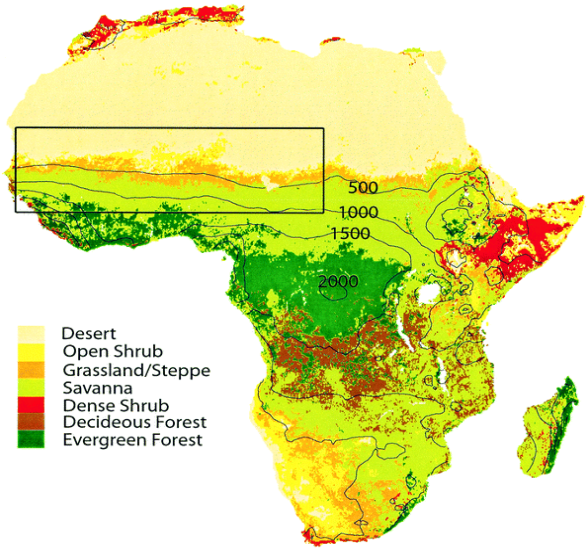
(Alo & Wang, 2008)

Overall Global Pattern of Vegetation Response to GCM-Projected Climate Changes

1. Tropics: Drought-deciduous trees (and grass) expand at the expense of evergreen trees.
2. Mid- and high-latitudes: evergreen trees expand at the expense of cold deciduous trees and grass.
3. Globally, future vegetation is denser and more productive (with the exception of the HadCM).

These changes will necessarily feed back to influence climate changes, a mechanism that has not been adequately considered in regional and global climate predictions.

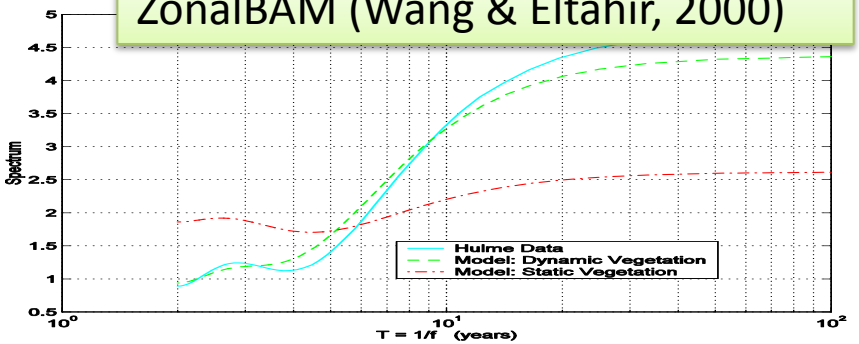
West Africa – A region of high climate sensitivity to land conditions



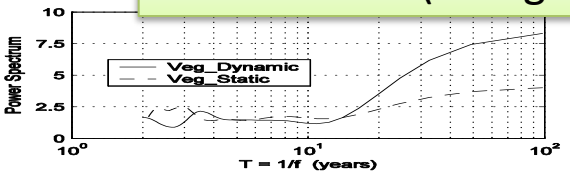
- Climate in West Africa, especially in the Sahel region, is highly sensitive to anthropogenic land cover changes (e.g., Xue & Shukla, 1993; Xue, 1997; Paeth et al., 2008)
- Vegetation feedback plays an important role in paleoclimate of West Africa (Claussen et al., 1999; Patricolar & Cook, 2007, 2008)
- Natural vegetation dynamics was found to enhance the impact of human land use and large-scale oceanic forcing on precipitation in the Sahel (e.g., Wang & Eltahir, 2000a; Wang et al., 2004)
- Natural vegetation dynamics was found to enhance the decadal and multi-decadal variability of precipitation in Sahel (e.g., Zeng et al., 1999; Wang & Eltahir, 2000b; Delire et al., 2004; Wang et al., 2004)

Spectrum of Sahelian annual rainfall during the 20th century

ZonalBAM (Wang & Eltahir, 2000)



GENESIS-IBIS (Wang et al., 2004)

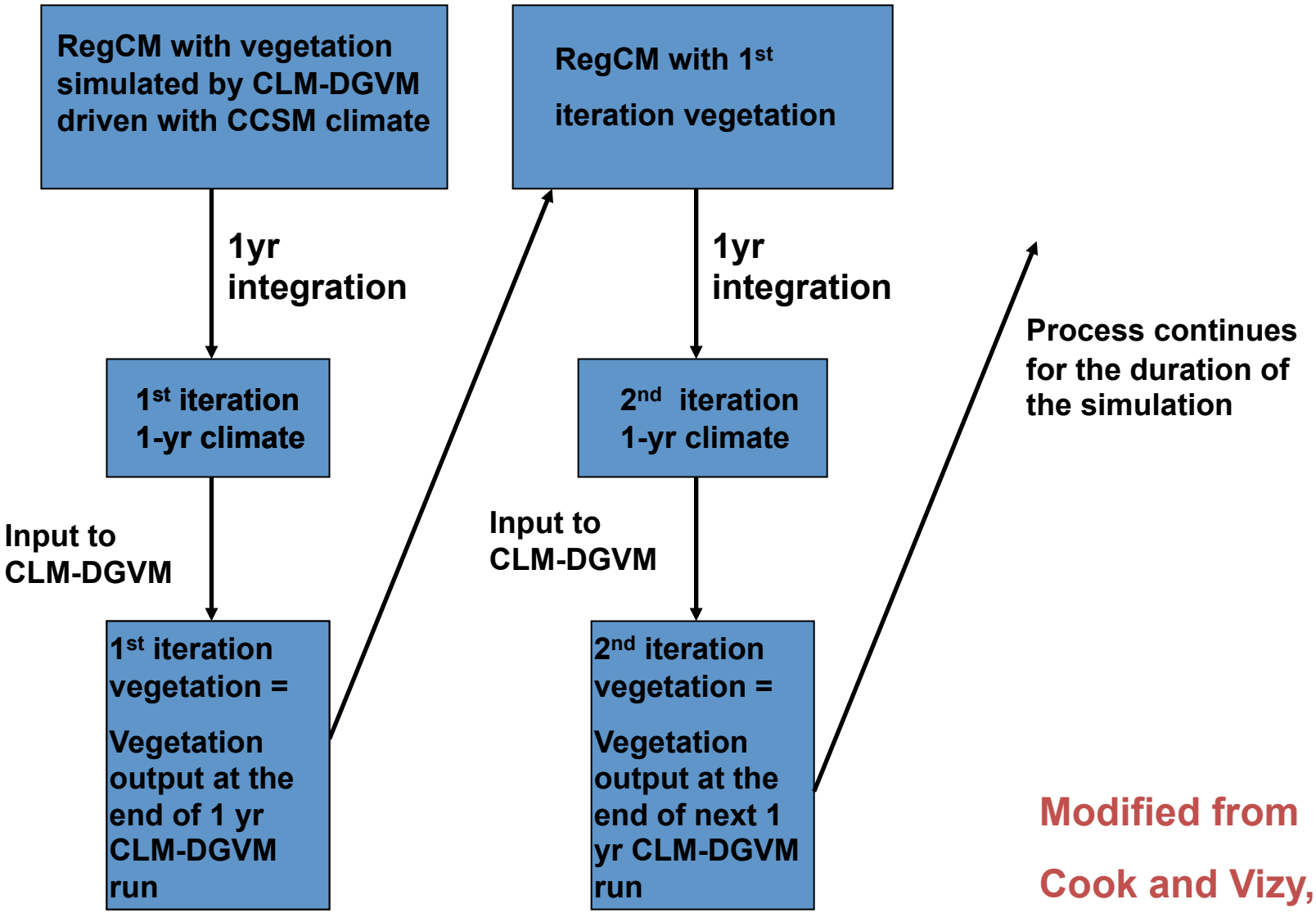


Focus of This Preliminary Study

Here we explore the impact of natural vegetation dynamics on regional climate predictions using the ICTP RegCM3 linked to a dynamic vegetation model CLM3-DGVM (LPJ-based), using the A1b scenario and focusing on the difference between the end of the 20th and 21st centuries.

- Domain chosen based on performance of RegCM3 driven with NCEP Reanalysis.
- 50 km horizontal resolution;
- 18 vertical levels
- MIT-Emanuel convection scheme
- Boundary & initial conditions from CCSM
- RegCM3 and CLM-DGVM are linked using an asynchronous coupling technique.

The Asynchronous Coupling Approach



Modified from

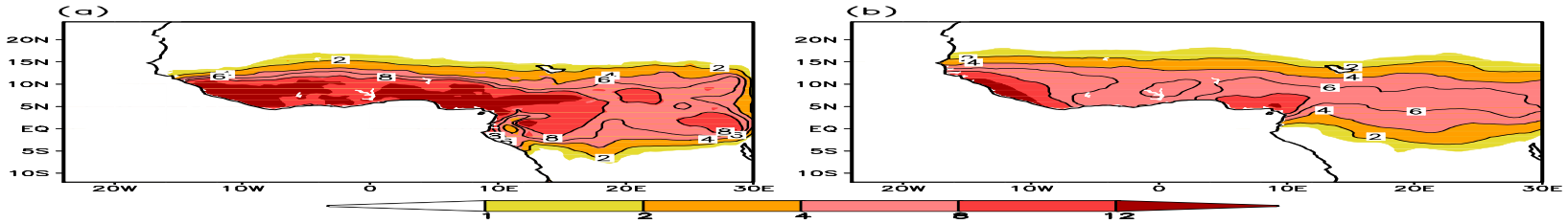
Cook and Vizy, 2007

Coupled Model Validation: JJA Rainfall

(for the period 1984-1993, in mm/day)

RegCM3/CLM

OBSERVED (CRU)



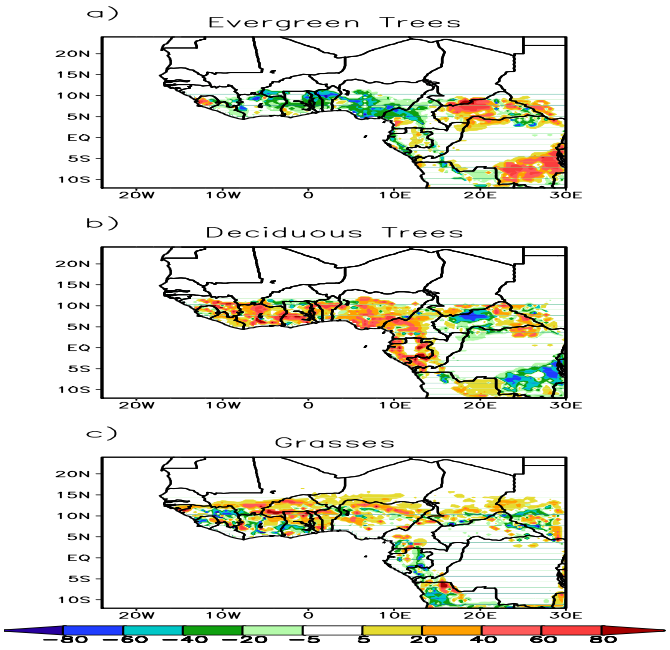
(Alo & Wang, 2010)

Experimental Design

Experiments	Boundary Conditions & SST	Initial Vegetation	CO_2	Short Description
20C3M	CCSM 20C3M	Simulated by CLM-DGVM, driven with CCSM 20C3M 1979-1993 climate	356ppm	20th century, 1979-1993 coupled RegCM3/CLM-DGVM run
A1B	CCSM SRESA1B	Simulated by CLM-DGVM, driven with CCSM SRESA1B 2079-2093 climate	720ppm	21th century, 2079-2093 coupled RegCM3/CLM-DGVM run
A1B_20C3M VEG	CCSM SRESA1B	Vegetation from experiment 20C3M	720ppm	2079-2093 RegCM3 run

CO_2 Radiative and physiological effect: A1B_20C3MVEG – 20C3M

Contribution from vegetation feedback: A1B – A1B_203MVEG



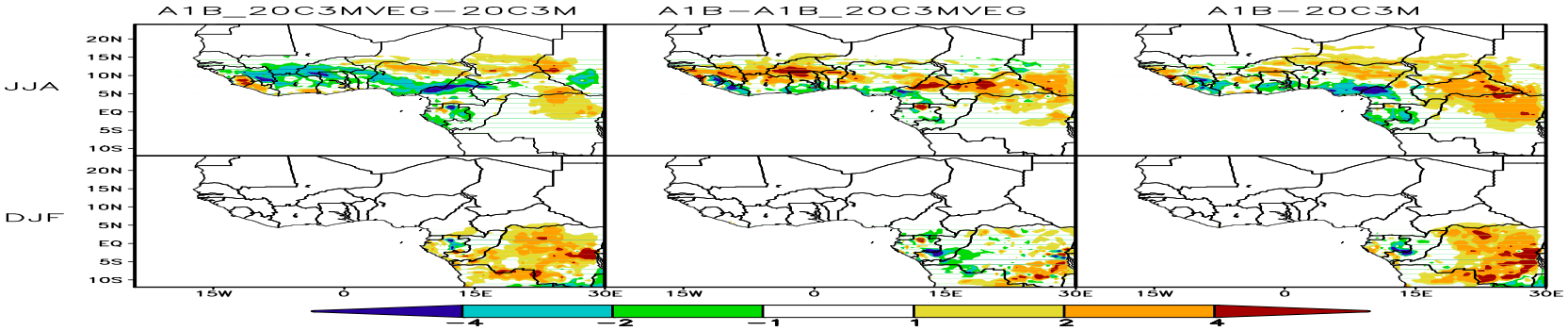
Projected changes (2084-2093 minus 1984-1993) in fractional coverage of vegetation types

- Drought deciduous trees and grass expand at the expense of evergreen trees, similar to the consensus from the 8 GCMs previously examined.

- Rate of such changes however is faster than changes driven with GCM predictions.

(Alo & Wang, 2010)

Rainfall Differences (21th -20th, in mm/day)



Climate change with static vegetation

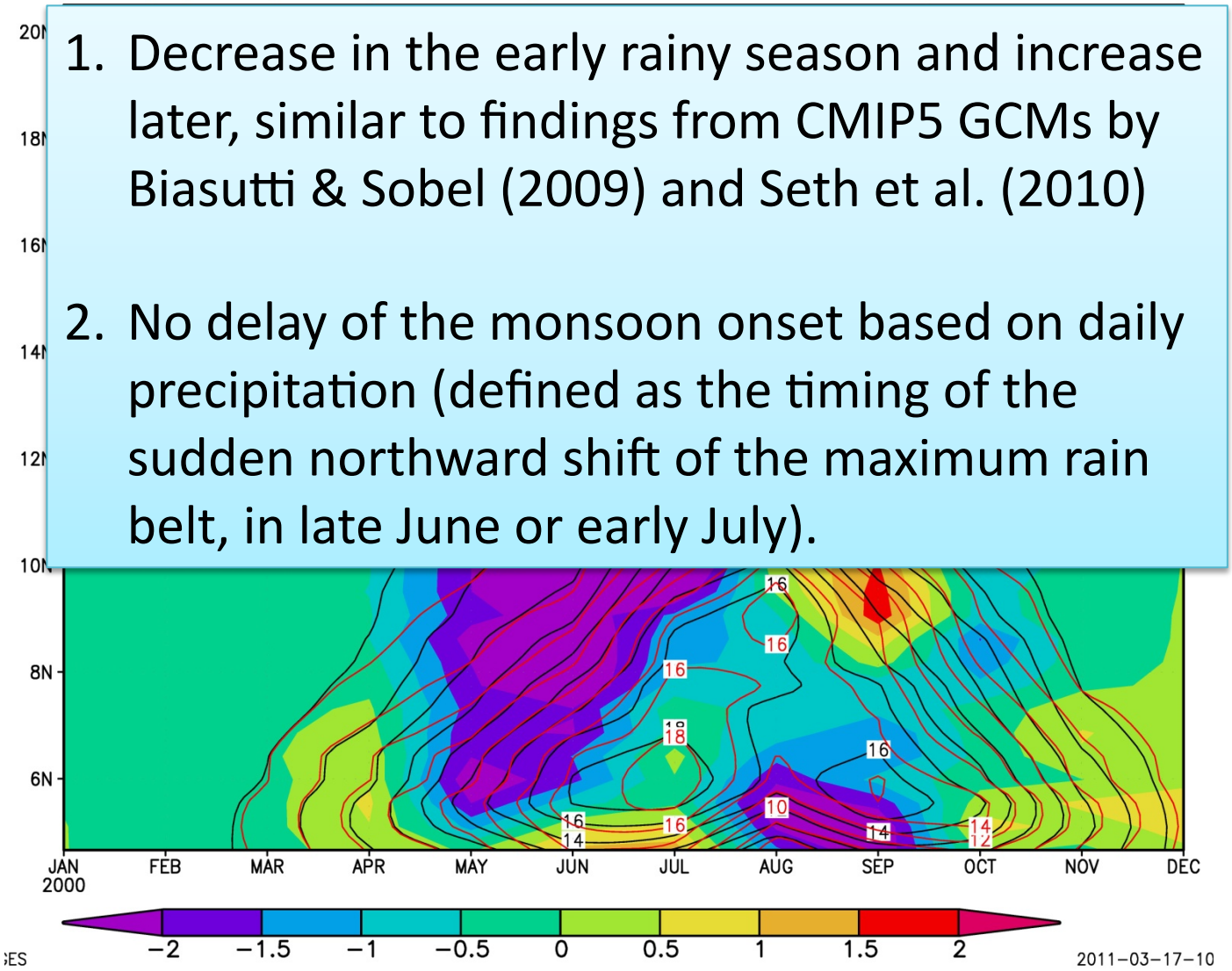
Impact of vegetation dynamics

Climate change with dynamic vegetation

Rainfall Differences (21th -20th, in mm/day, shaded): With Static Vegetation (Black lines– 1984-1993; Red lines – 2084-2093)

1. Decrease in the early rainy season and increase later, similar to findings from CMIP5 GCMs by Biasutti & Sobel (2009) and Seth et al. (2010)

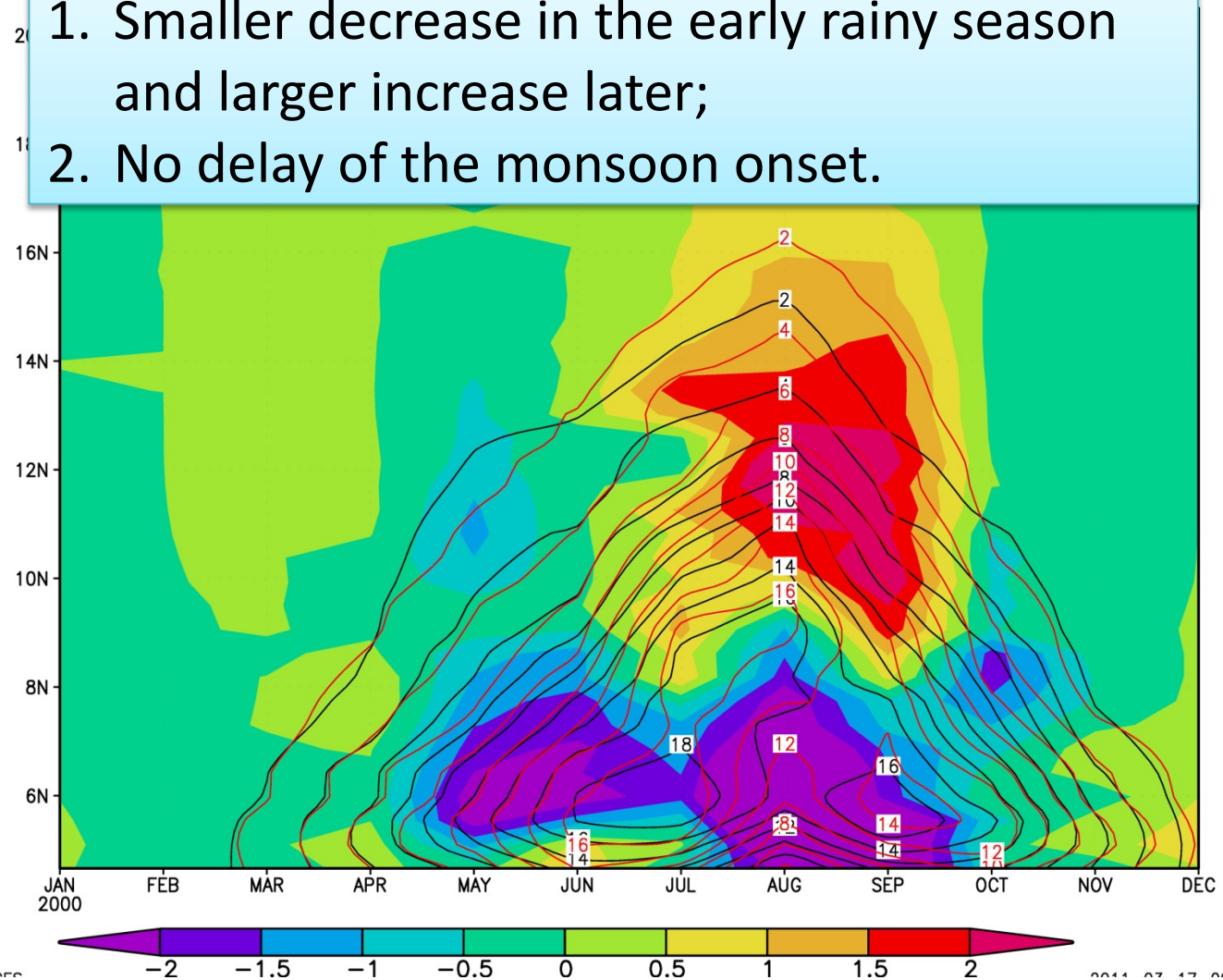
2. No delay of the monsoon onset based on daily precipitation (defined as the timing of the sudden northward shift of the maximum rain belt, in late June or early July).



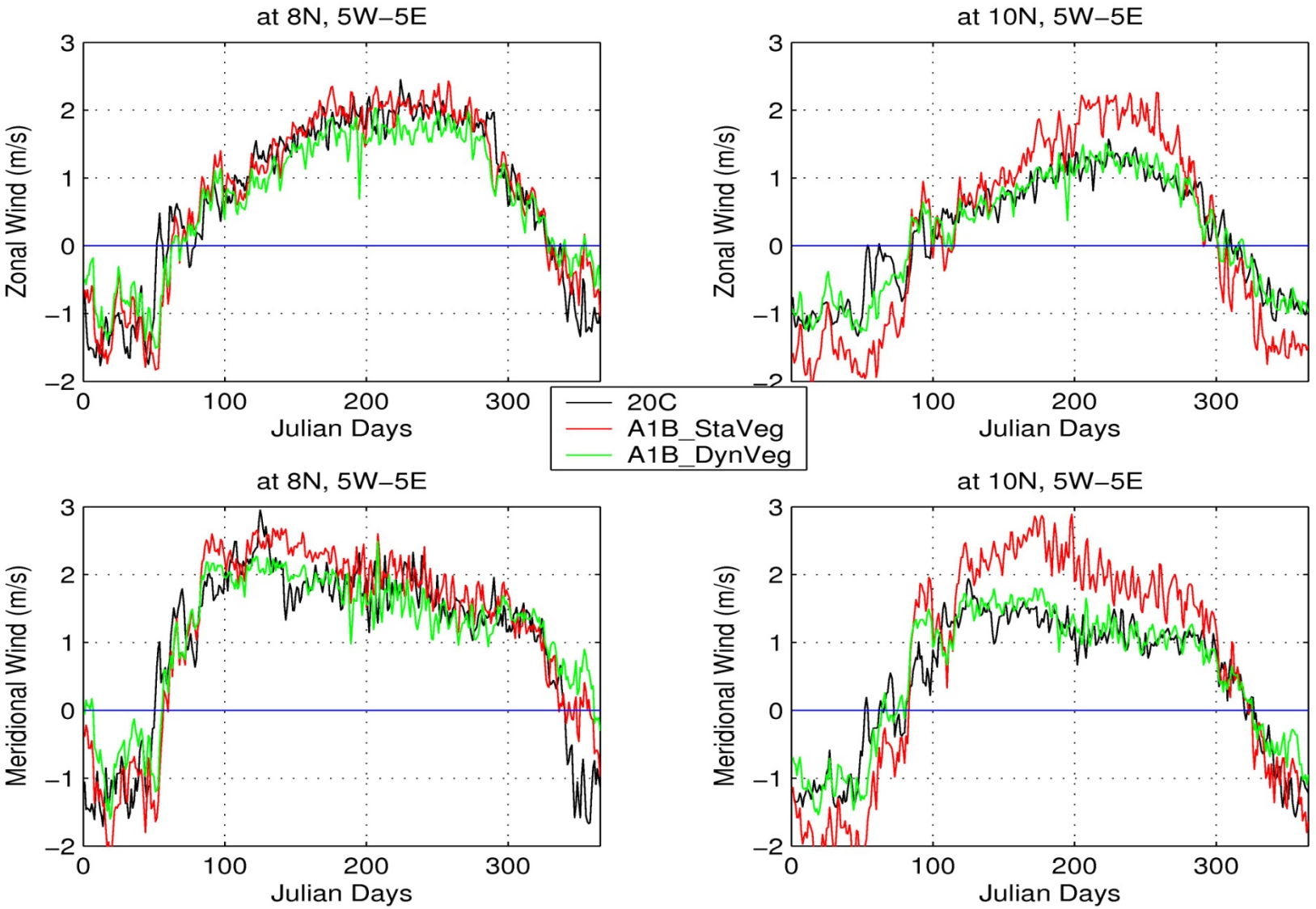
Rainfall Differences (21th -20th, in mm/day, shaded): With Dynamic Vegetation

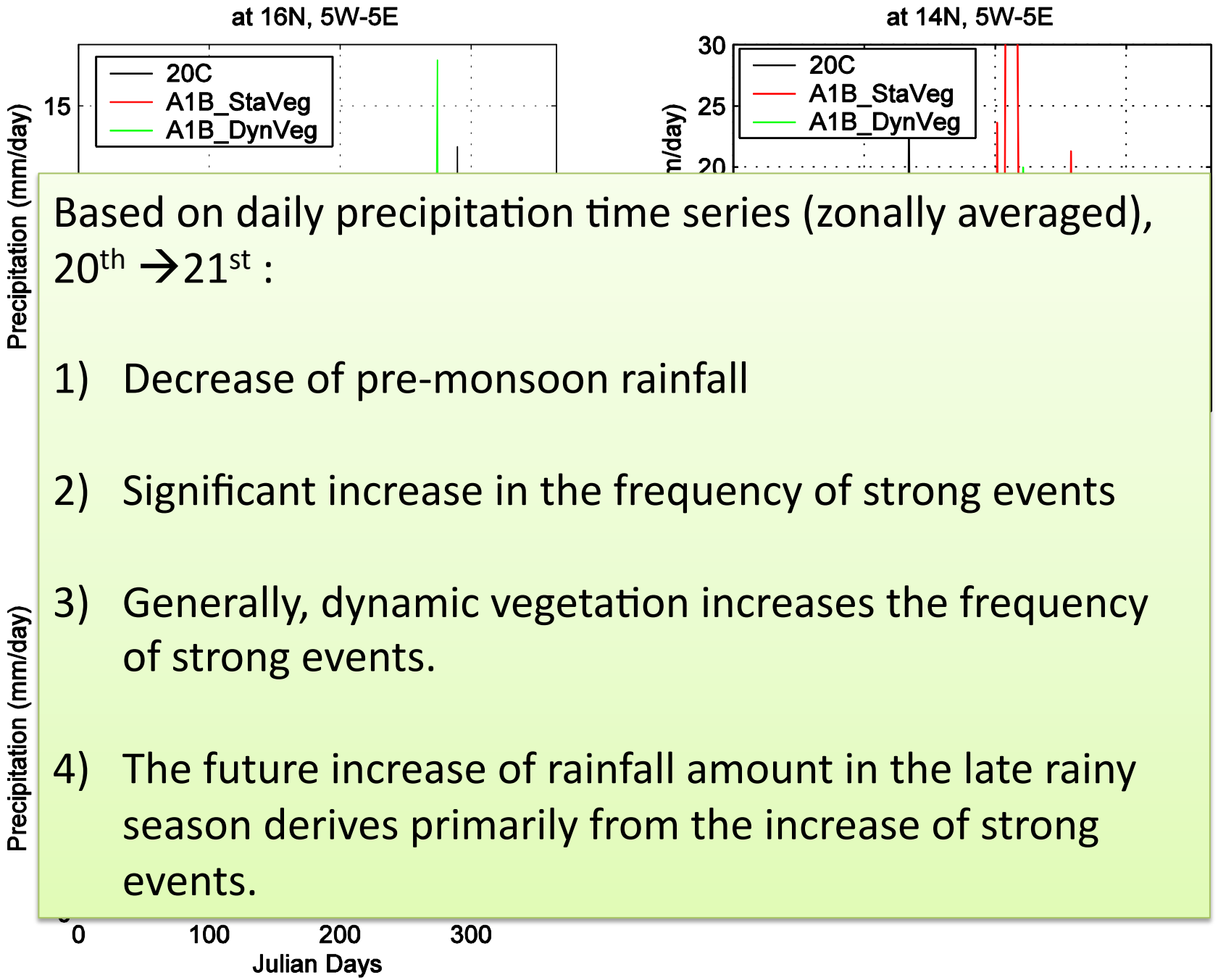
Black lines– 1984-1993; Red lines – 2084-2093

1. Smaller decrease in the early rainy season and larger increase later;
2. No delay of the monsoon onset.



Timing of sudden reversal of wind directions: no change





Based on daily precipitation time series (zonally averaged), $20^{th} \rightarrow 21^{st}$:

1) Decrease of pre-monsoon rainfall

2) Significant increase in the frequency of strong events

3) Generally, dynamic vegetation increases the frequency of strong events.

4) The future increase of rainfall amount in the late rainy season derives primarily from the increase of strong events.

Summary

- **Annual precipitation amount:** The physiological and radiative effect of higher CO_2 leads to a decrease in rainfall in most areas of West Africa. Structural vegetation feedback however mediates this effect, leading to net increase of precipitation especially in the Sahel.
- **Precipitation seasonality**: Regardless of whether dynamic vegetation is included or not, predicted future conditions are drier during the early rainy season and wetter during the peak and late rainy season, with a delayed onset of the pre-monsoon rainy period.
- **Monsoon onset**: The delayed onset of the rainy season however is not accompanied by a similar delay in the monsoon onset. Judged based on both the timing of sudden wind reversal and the timing of ITCZ (rainbelt) shift, the timing of monsoon onset is robust against future climate changes and how vegetation is treated.

Ongoing Research

We will use the CORDEX Africa domain in future experiments whenever appropriate to accommodate comparison with CORDEX results;

We welcome the opportunity to do inter-model comparison with other groups who will conduct similar experiments in the Africa domain.

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Thank you for your attention!