RegCM3-CLM3: Land surface modeling in RegCM and impact on aerosols

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Workshop on Aerosol-Climate Interactions

Hurghada, Egypt

13 February 2008

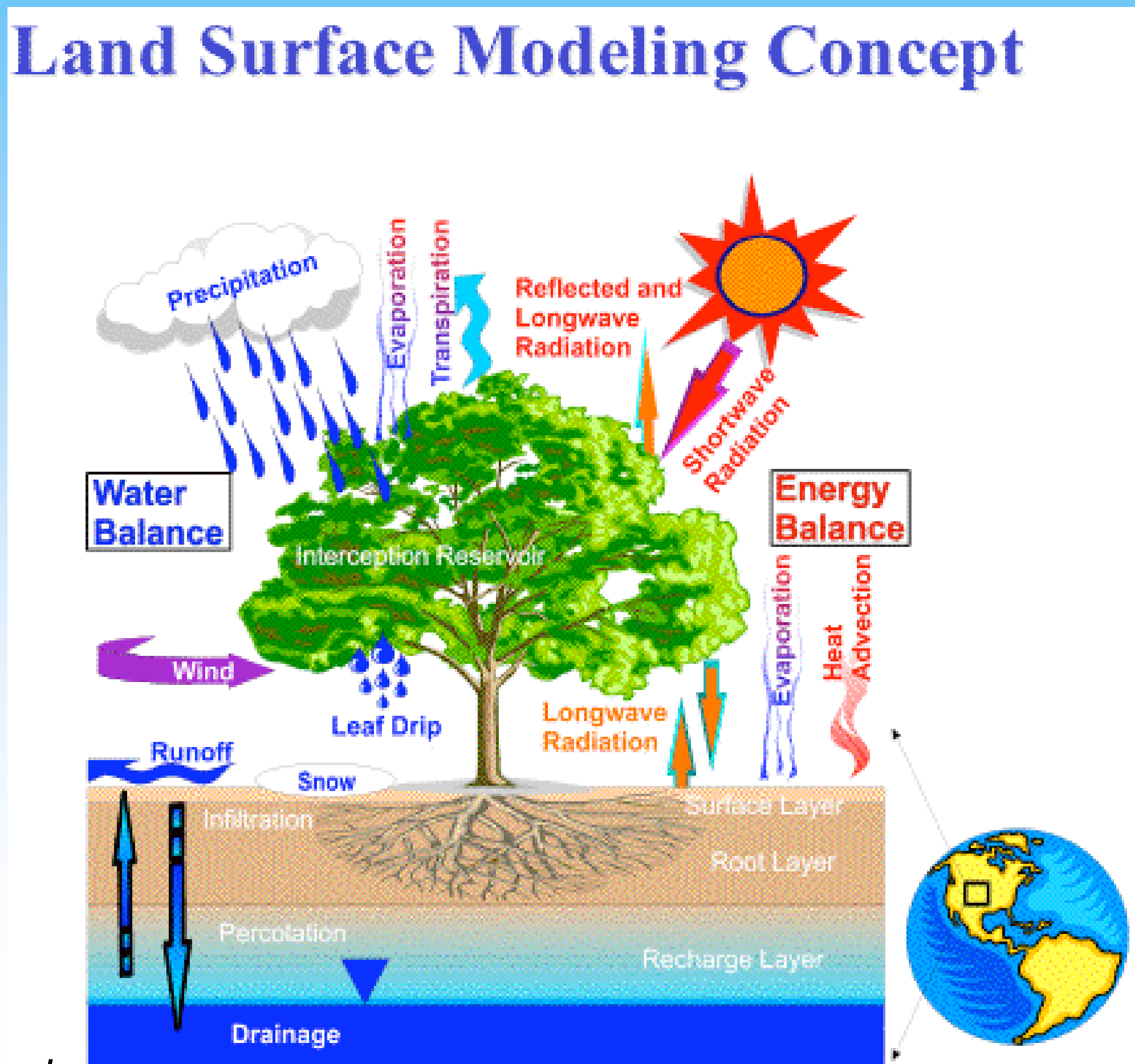
What it looks like in Michigan now…

Talk Outline

1. Overview of Land Surface Parameterizations
2. RegCM3-CLM3 simulation results: An improvement in the simulation of the west African monsoon
3. The land surface and aerosols

1. Introduction

Land Surface Parameterizations



NASA Goddard

1. Introduction

Generations of Land Surface Schemes

Generation	Description	Example
First Generation	Basic surface energy & water balance 1. Radiation exchange 2. Latent & sensible heats 3. Surface drag 4. Soil "bucket" model	Simple LSPs (e.g., weather forecasting models)
Second Generation	Vegetation-soil interactions 1. Canopy radiation absorption 2. Vegetation/momentum interaction 3. Biophysical control of ET (empirical) 4. Canopy interception of precip 5. Soil moisture/root systems 6. Canopy insolation of surface	BATS
Third Generation	Interactive biochemistry 1. Biochemical model for photosynthesis 2. Coupled photosynthesis-stomatal conductance 3. Integration of satellite data	CLM

Sellers et al., 1997

1. Introduction

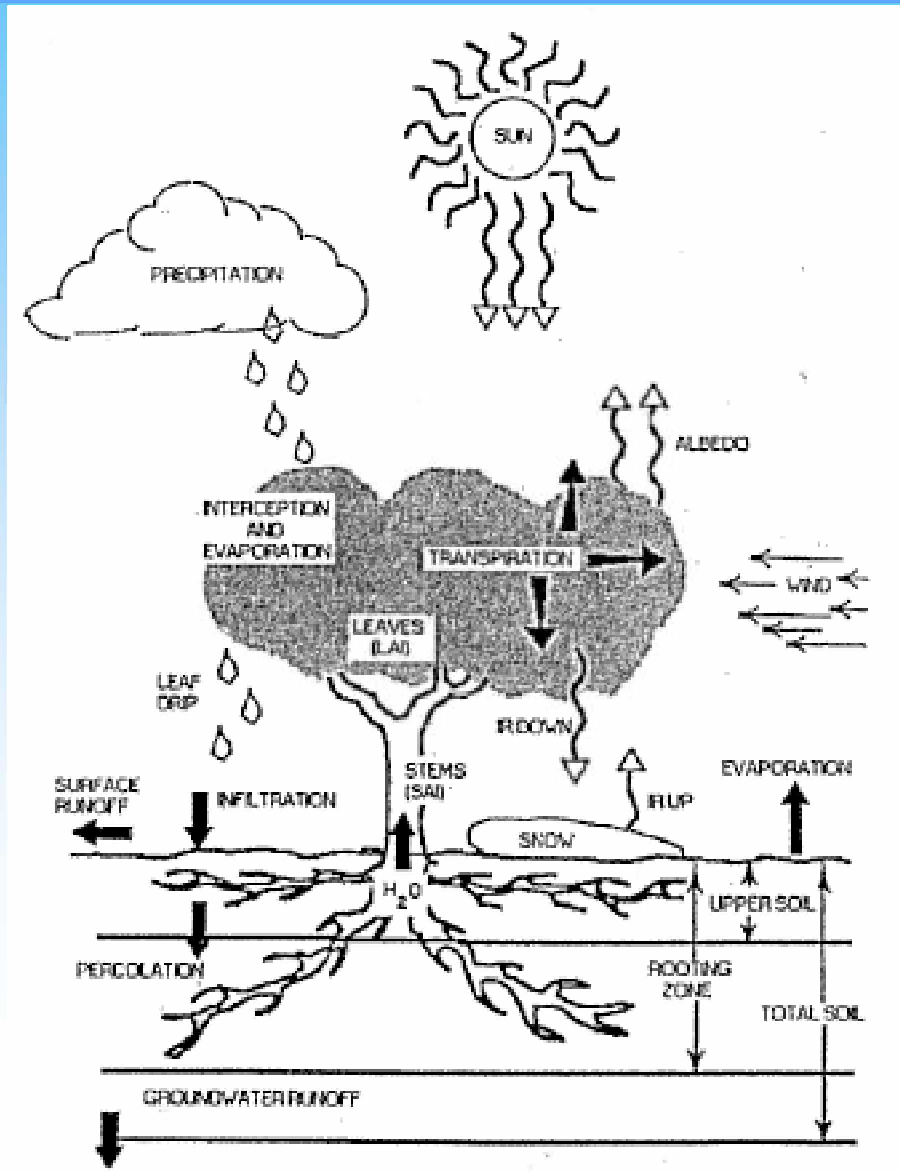
RegCM Land Surface Schemes

RegCM Version	Land Model Options
RegCM1 Dickinson et al. (1989) Giorgi & Bates (1989)	→ **BATS 1a** Dickinson et al. (1986)
RegCM2 Giorgi et al. (1993a,b)	→ **BATS 1e** Dickinson et al. (1993)
RegCM2.5 Giorgi & Shields (1999) Pal et al. (2000)	→ **BATS 1e** **CLM0** (Steiner et al. 2005)
RegCM3	→ BATS 1e SUBBATS (Giorgi et al., 2003) CLM3 (Steiner et al, in prep)

Pal et al., 2007

1. Introduction

BATS: Biosphere-Atmosphere Transfer Scheme



Dickinson et al., 1993

1. Introduction

CLM0: Common Land Model v. 0

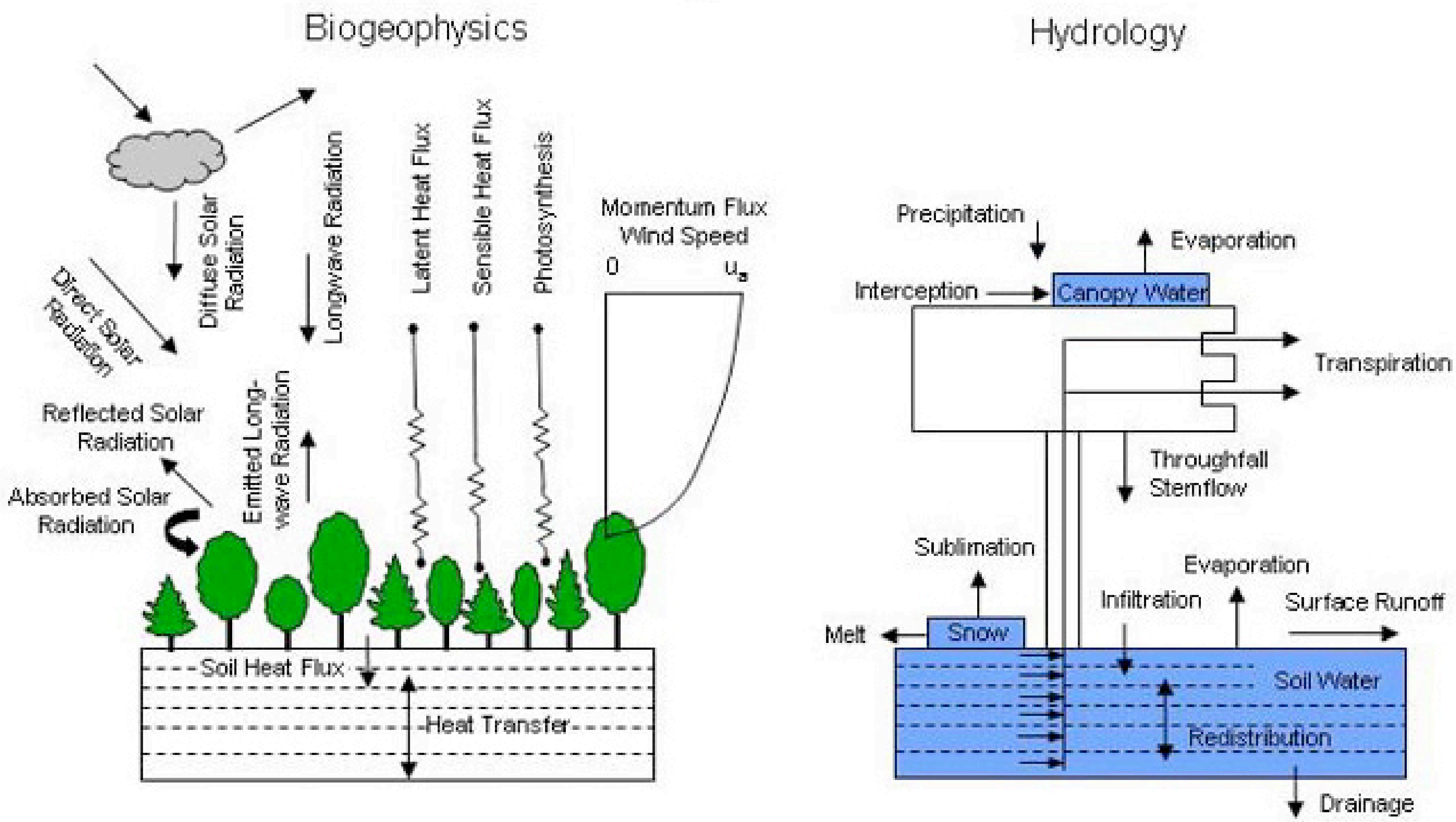


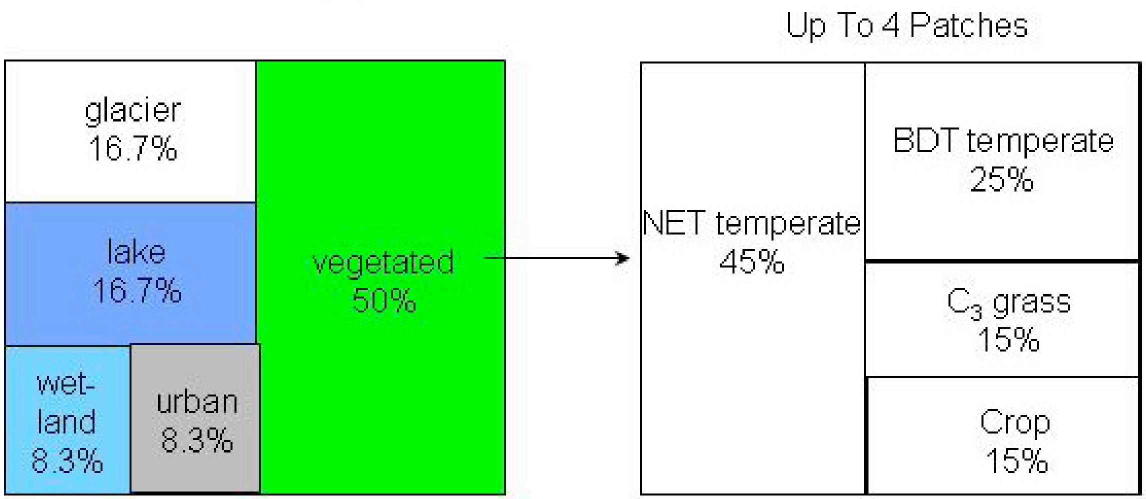
Figure 1. Biogeophysics and hydrology represented in the Community Land Model.

www.cgd.ucar.edu

1. Introduction

CLM0: Common Land Model v. 0

Subgrid land cover and plant functional types



Each patch is defined by:

- PFT and its fractional coverage
- Monthly leaf and stem area index
- Monthly canopy top and bottom height

15 Plant Functional Types

Needleleaf evergreen tree
- temperate
- boreal

Needleleaf deciduous tree

Broadleaf evergreen tree
- tropical
- temperate

Broadleaf deciduous tree
- tropical
- temperate
- boreal

Shrub
- broadleaf evergreen, temperate
- broadleaf deciduous, temperate
- broadleaf deciduous, boreal

Grass
- C_3, arctic
- C_3
- C_4

Crop

Figure 2. CLM represents a grid cell as a mosaic of up to 5 primary land cover types. Vegetated land is further represented as a mosaic of up to 4 plant functional types. Each subgrid tile is represented as a separate soil-plant-atmosphere column.

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1. Introduction

CLM3: Community Land Model v. 3

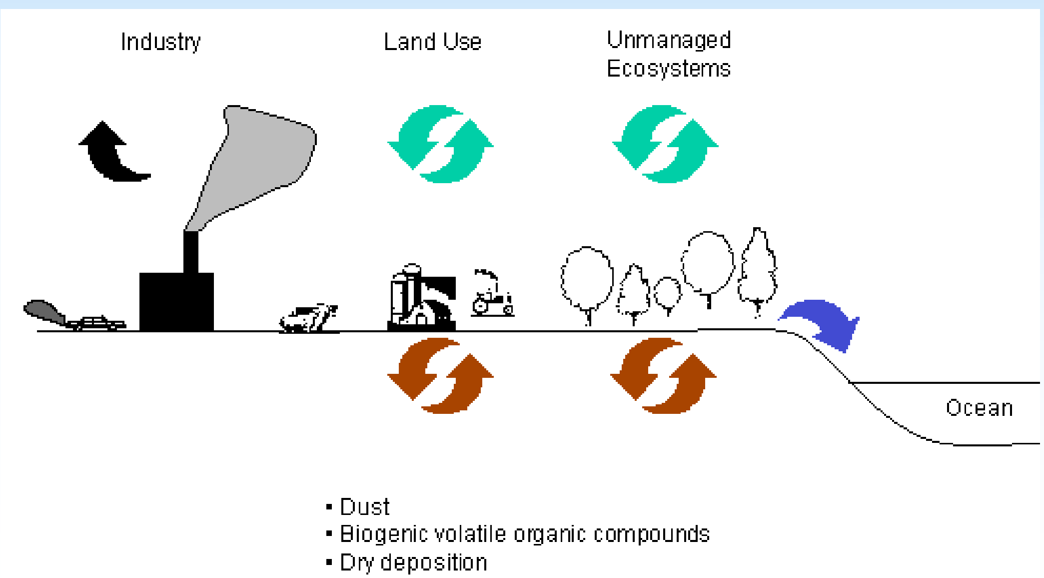
Biogeophysics

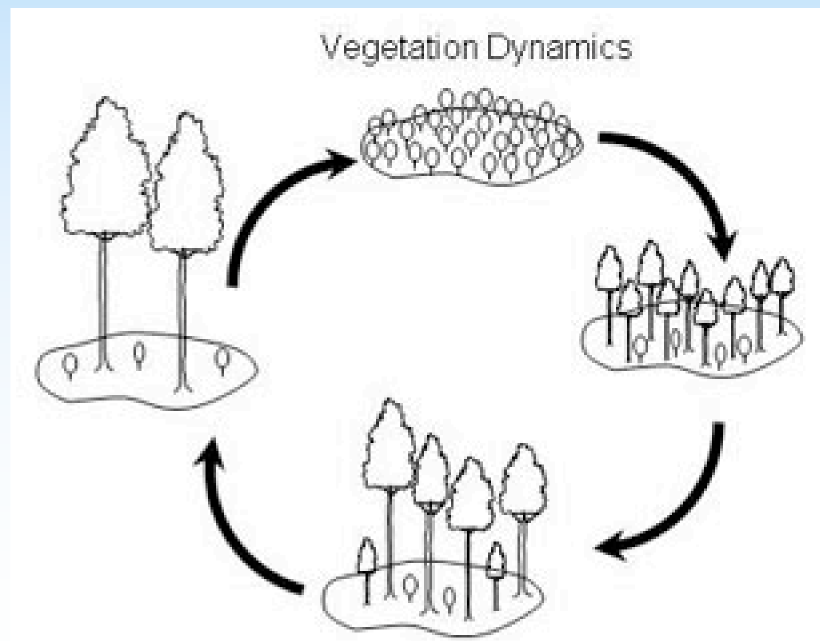
CLM3.0

Hydrologic Cycle

Biogeochemistry

Dynamic Vegetation





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1. Introduction

Biogeophysical changes: BATS vs. CLM

BATS

One canopy layer

Simple stomatal conductance model

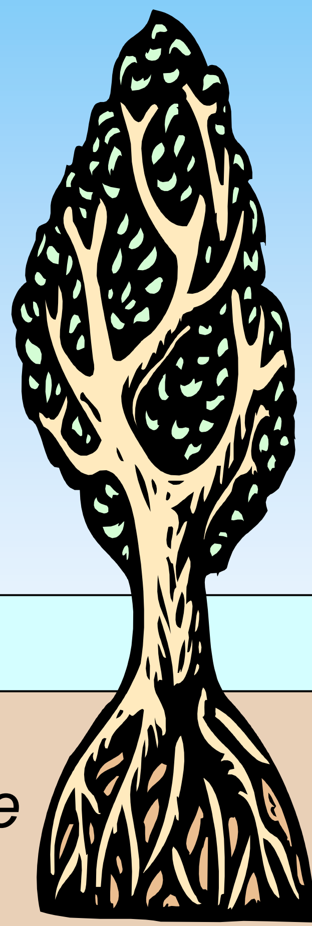
No photosynthesis

One snow layer

3 soil layers

Soil T: Force-restore

Soil moisture: Diffusive/gravitational



CLM3

One canopy layer

Sunlit/shaded leaves

Stomatal conductance-photosynthesis model

TOPMODEL-based runoff

Up to five snow layers

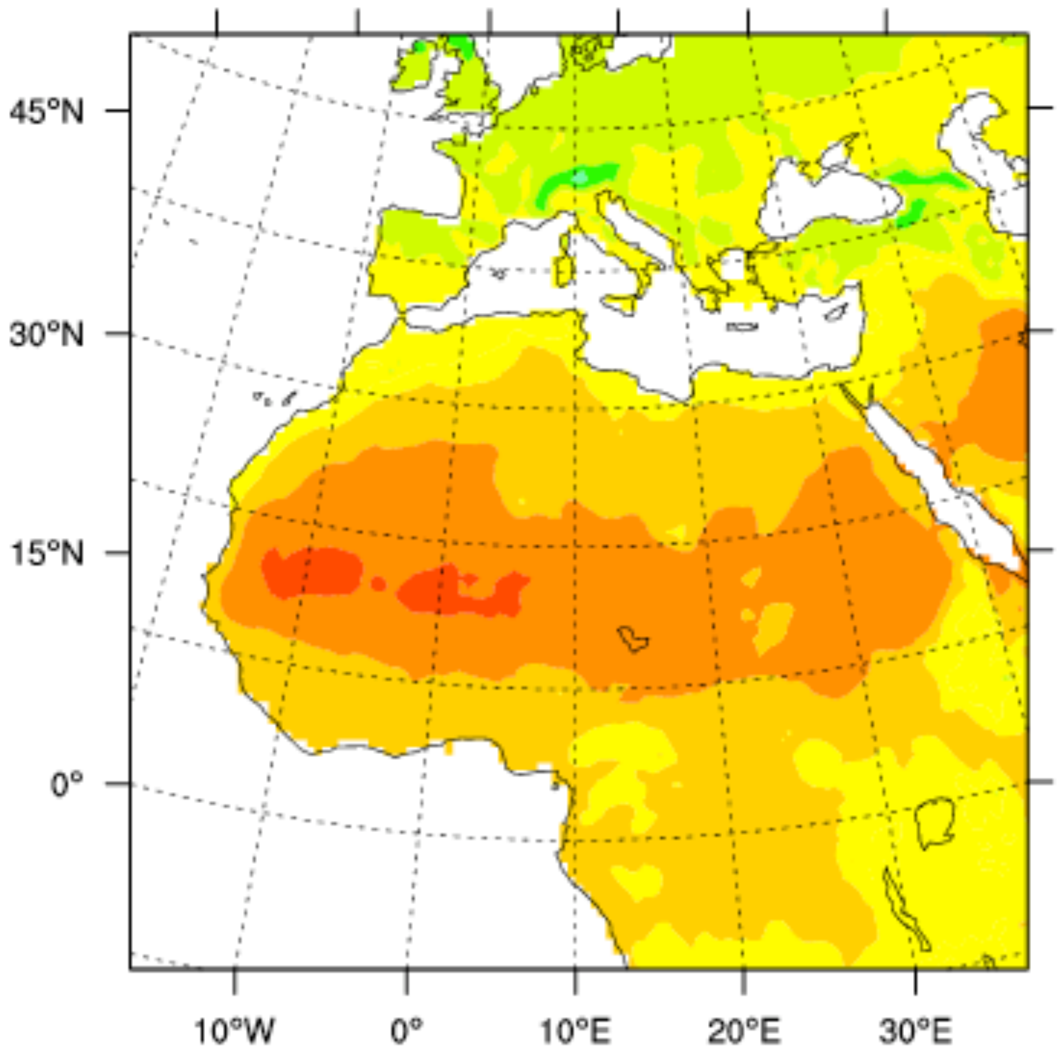
10 uneven soil layers

Soil T and moisture: Solved numerically

Includes liquid H_2O/ice

2. RegCM3-CLM3 Simulation

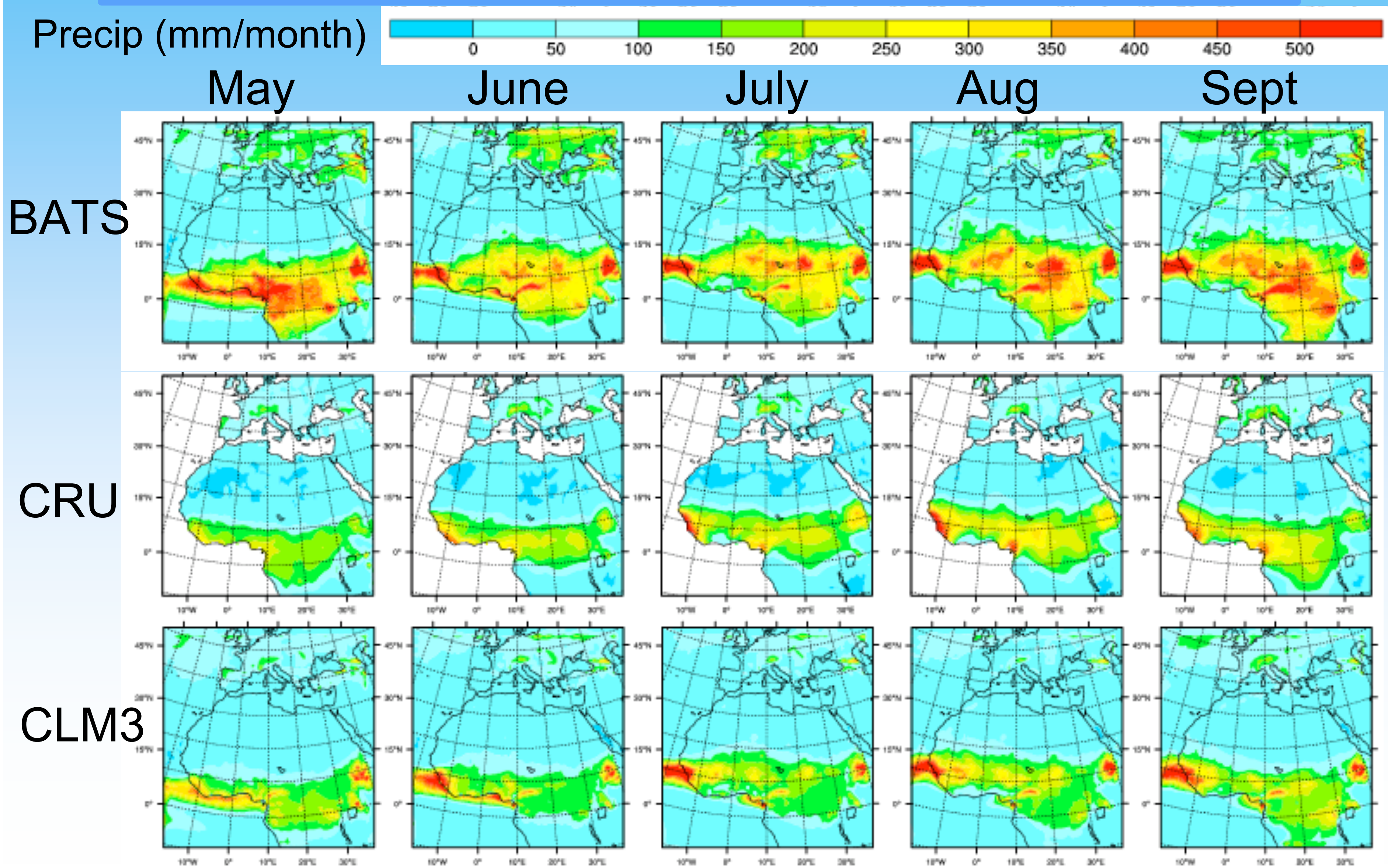
Simulation details



- Regional Climate Model (RegCM3; Pal et al., 2007)
- Changed land surface scheme from BATS to CLM3
- 2 year spin-up + 10 year simulations (1992-2001)
- 120x125 grid at 60km resolution
- ERA-40 boundary conditions
- Emanuel precip scheme

2. RegCM3-CLM3 Simulation

Change to CLM3 substantially improves simulation of African monsoon precipitation



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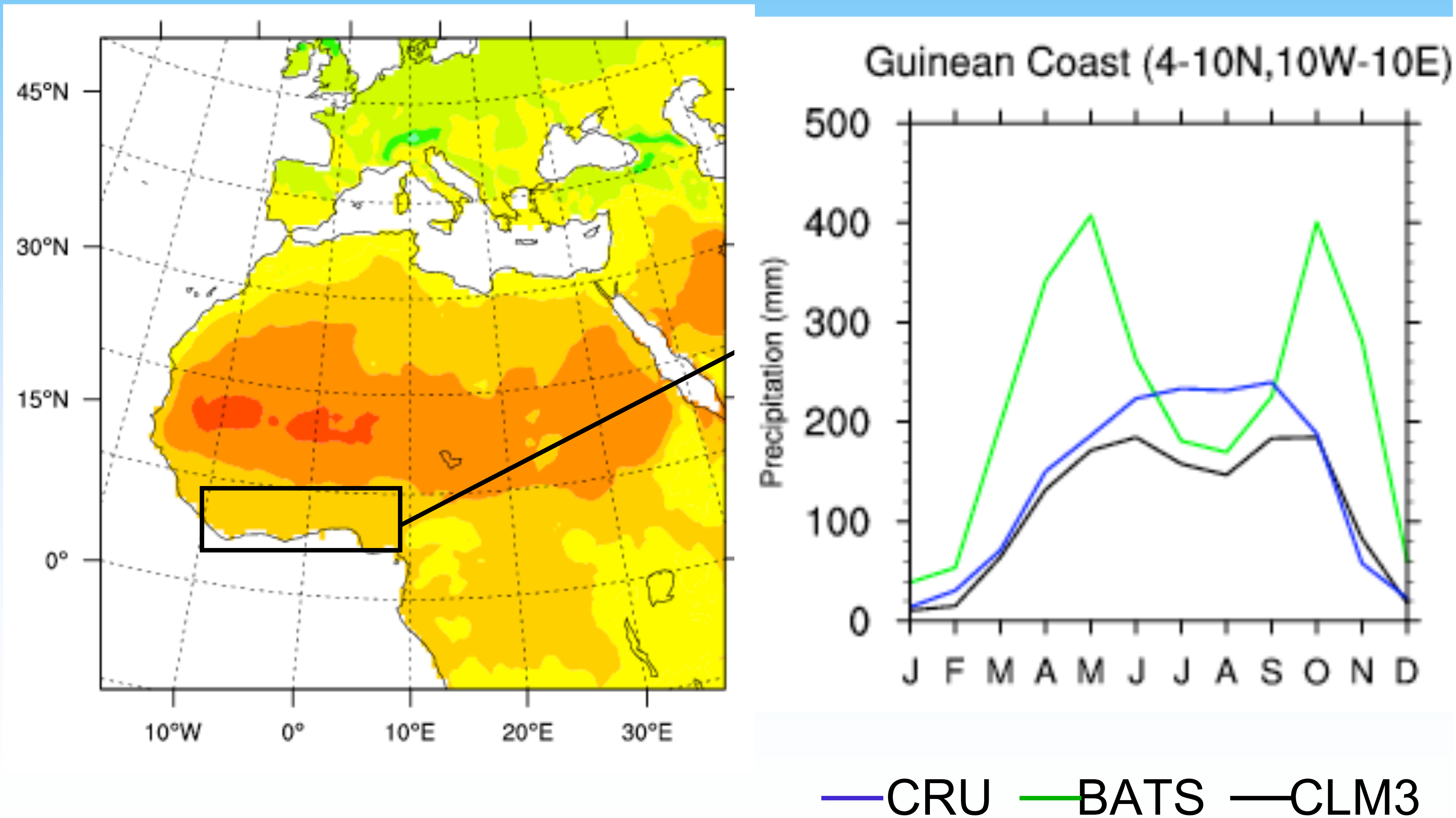

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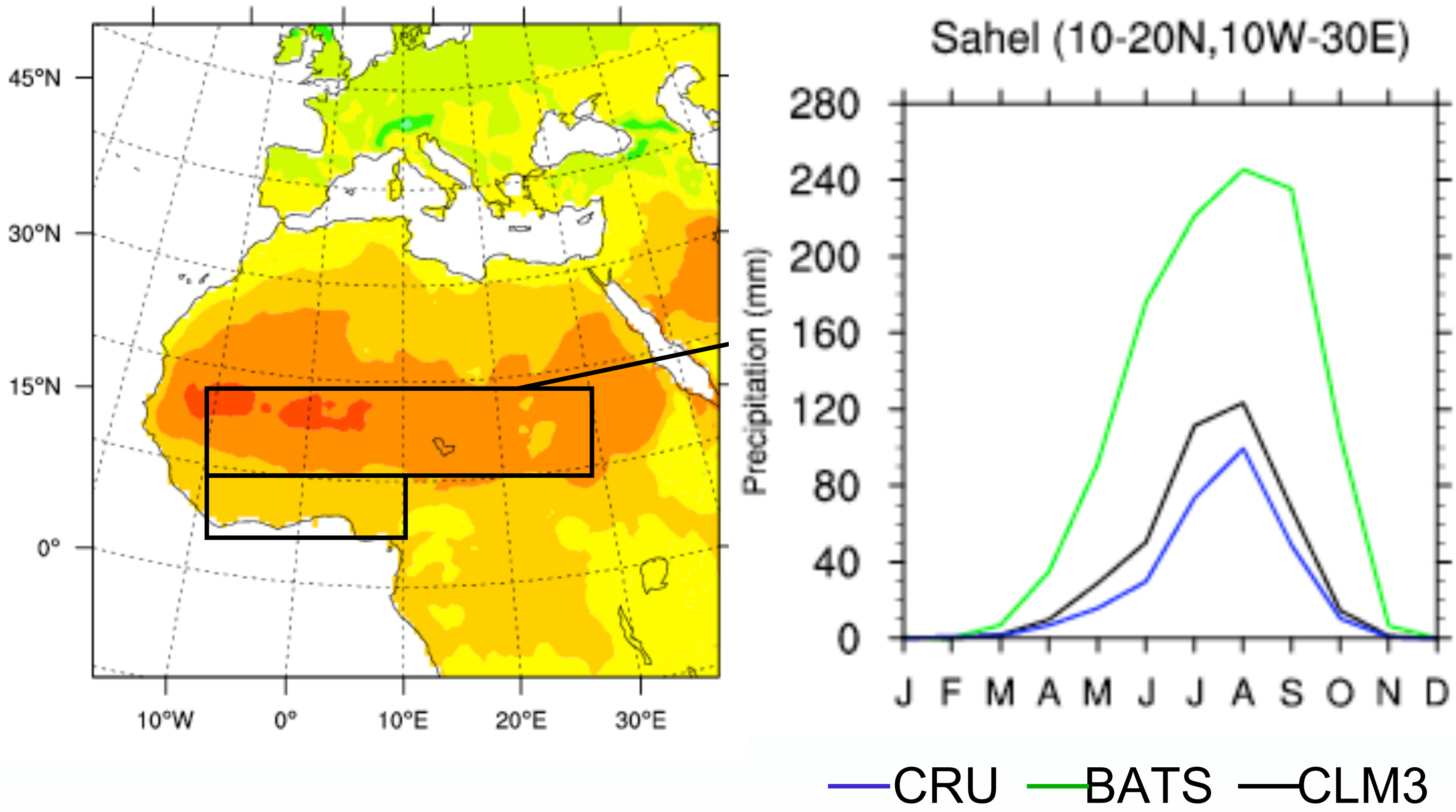

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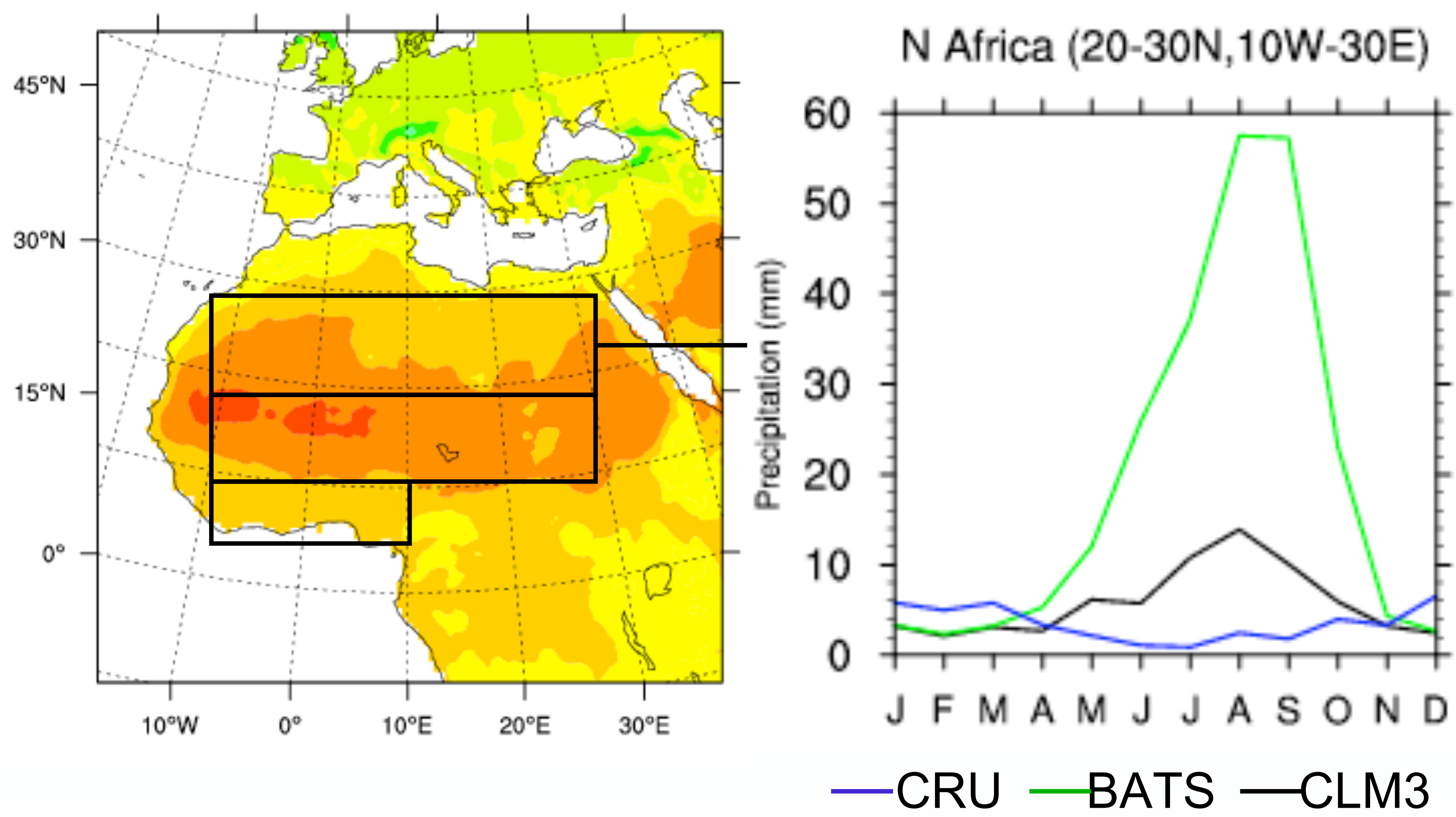
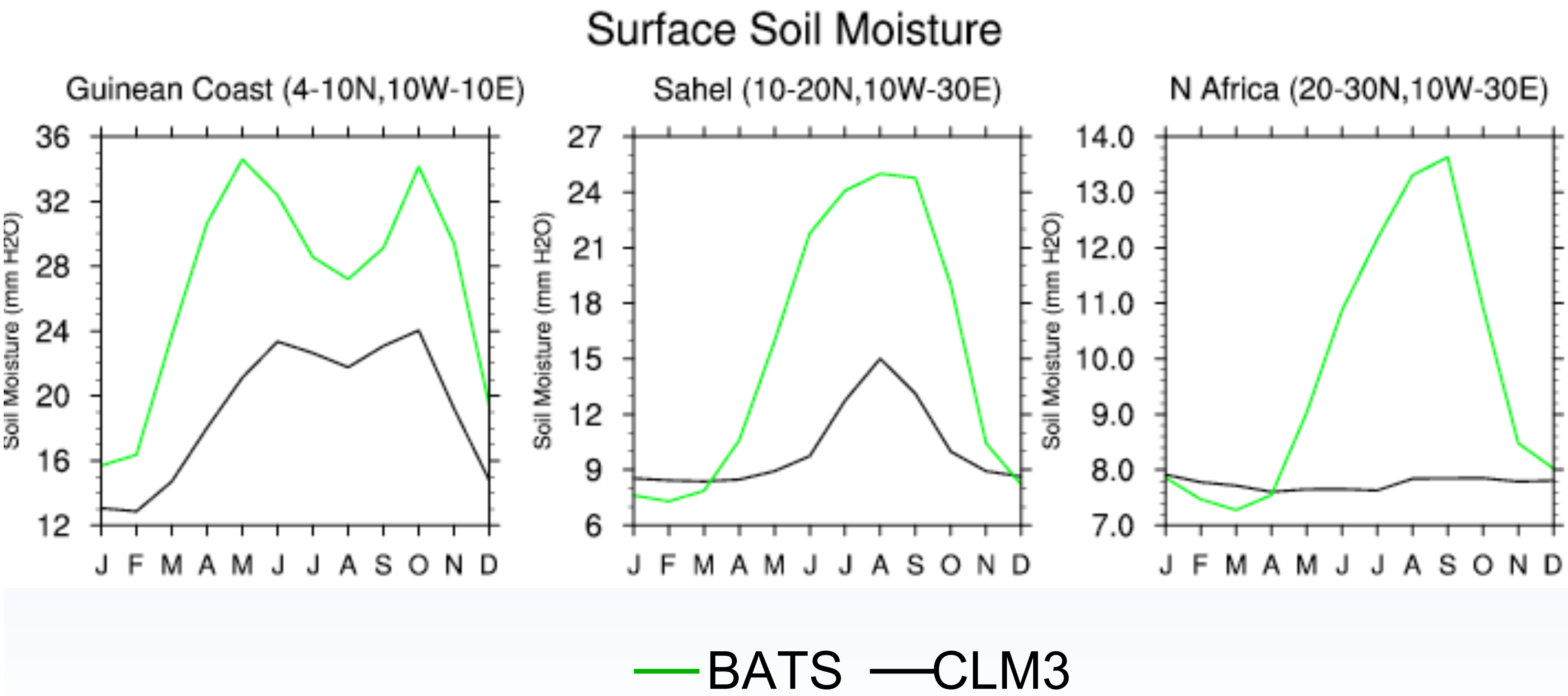


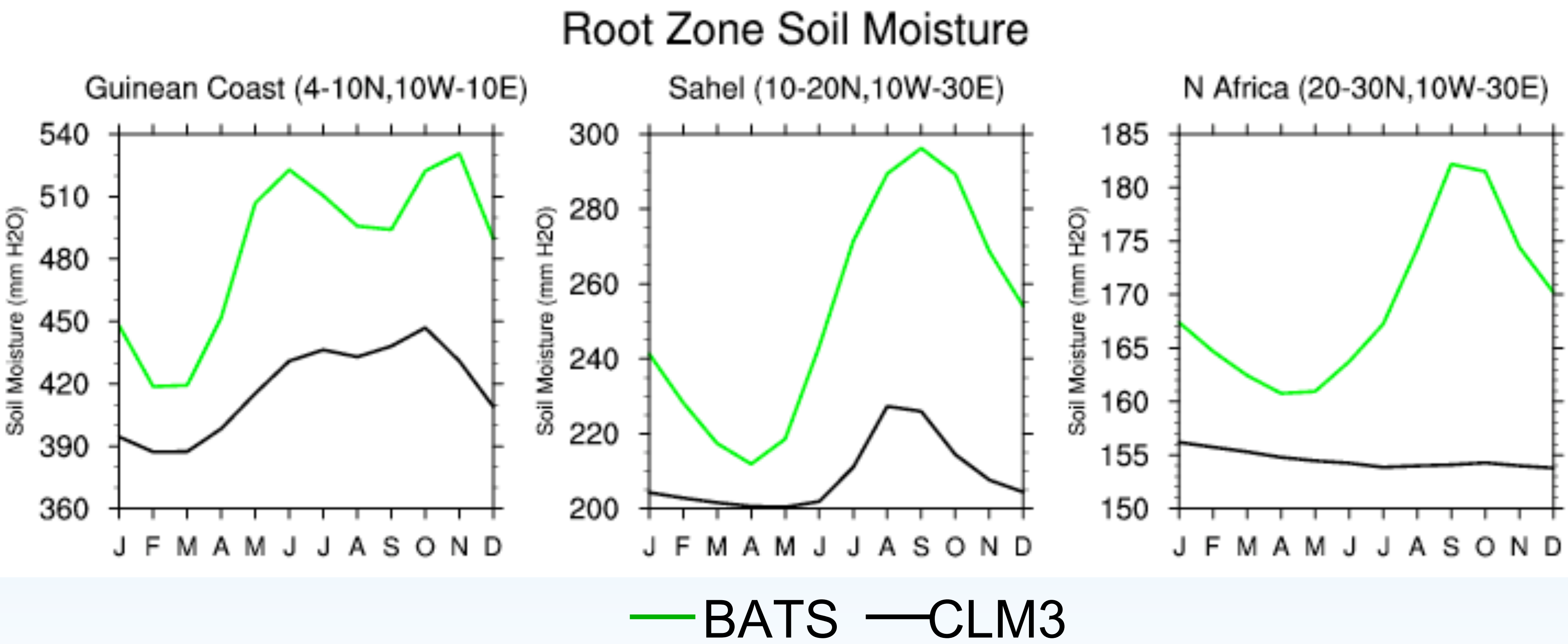
2. RegCM3-CLM3 Simulation

CLM3 is much drier than BATS simulations in the surface layer (first 10cm)



2. RegCM3-CLM3 Simulation

CLM3 is much drier than BATS simulations in the root zone (1-2 m)

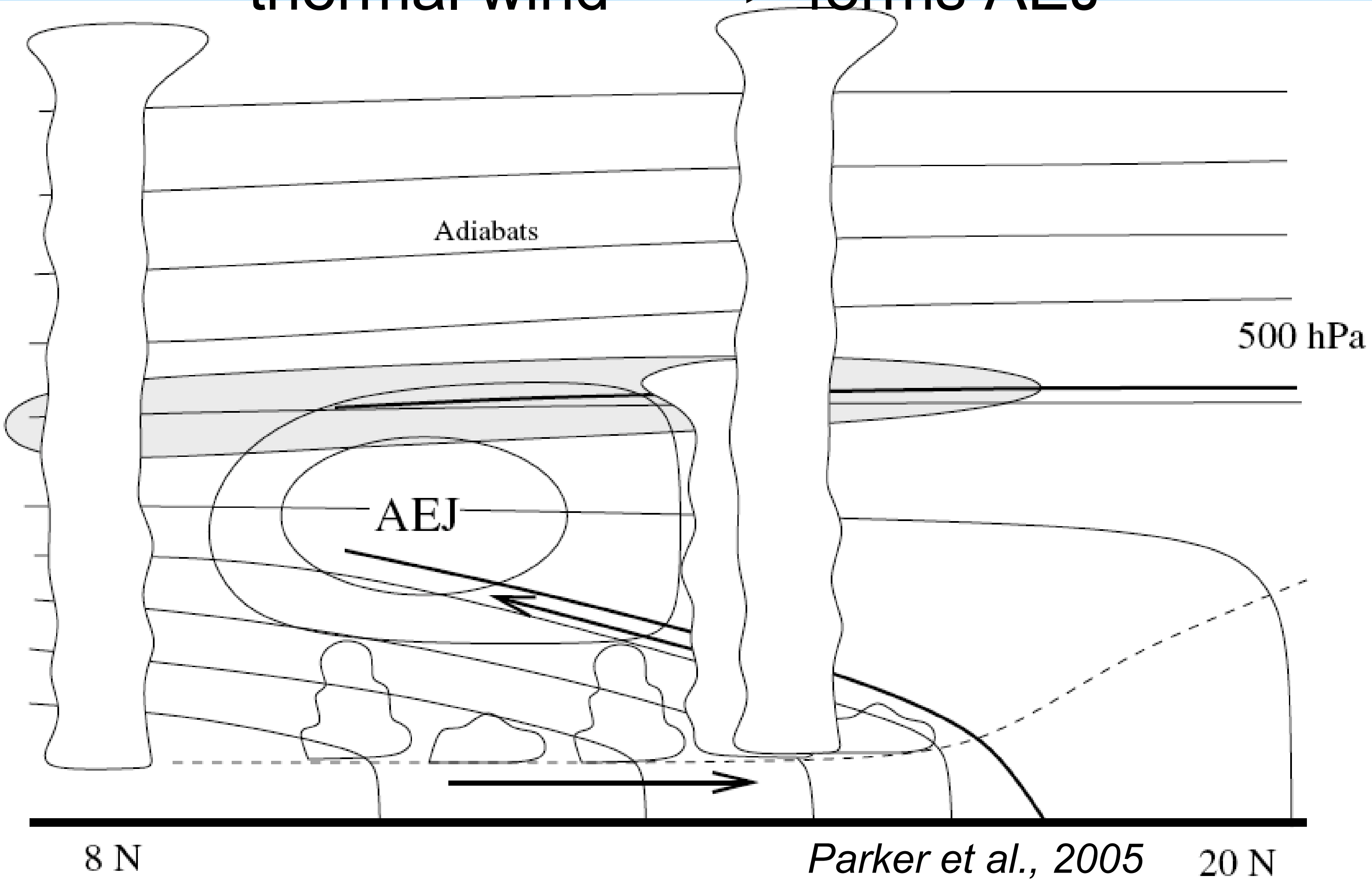


• Drier soils have also been noted in global model comparisons with CLM2 (Bonan et al., 2002; Zeng et al., 2002)

2. RegCM3-CLM3 Simulation

Formation of the African Easterly Jet (AEJ)

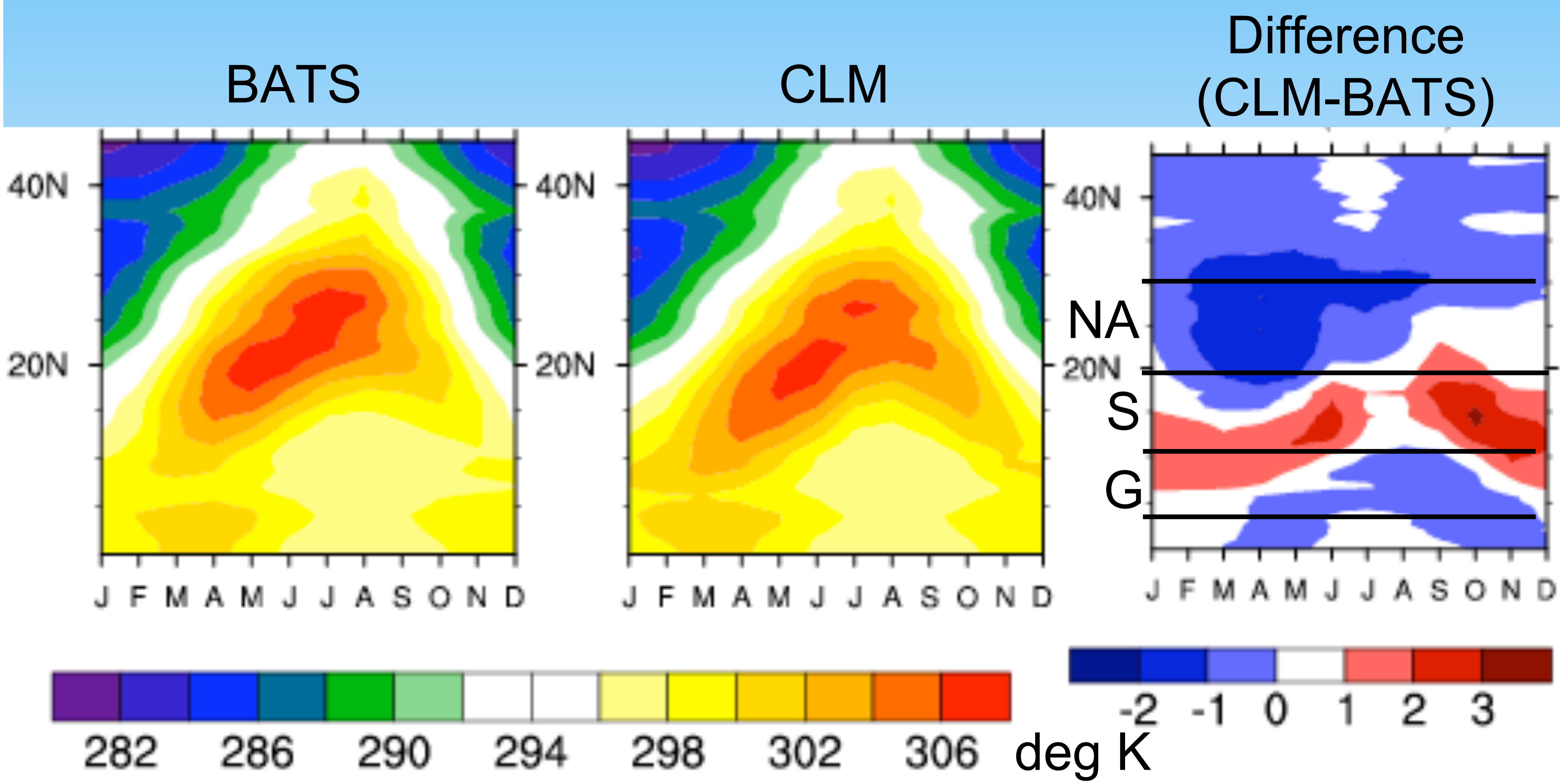
Seasonal heating → surface T gradient → thermal wind → forms AEJ



Parker et al., 2005

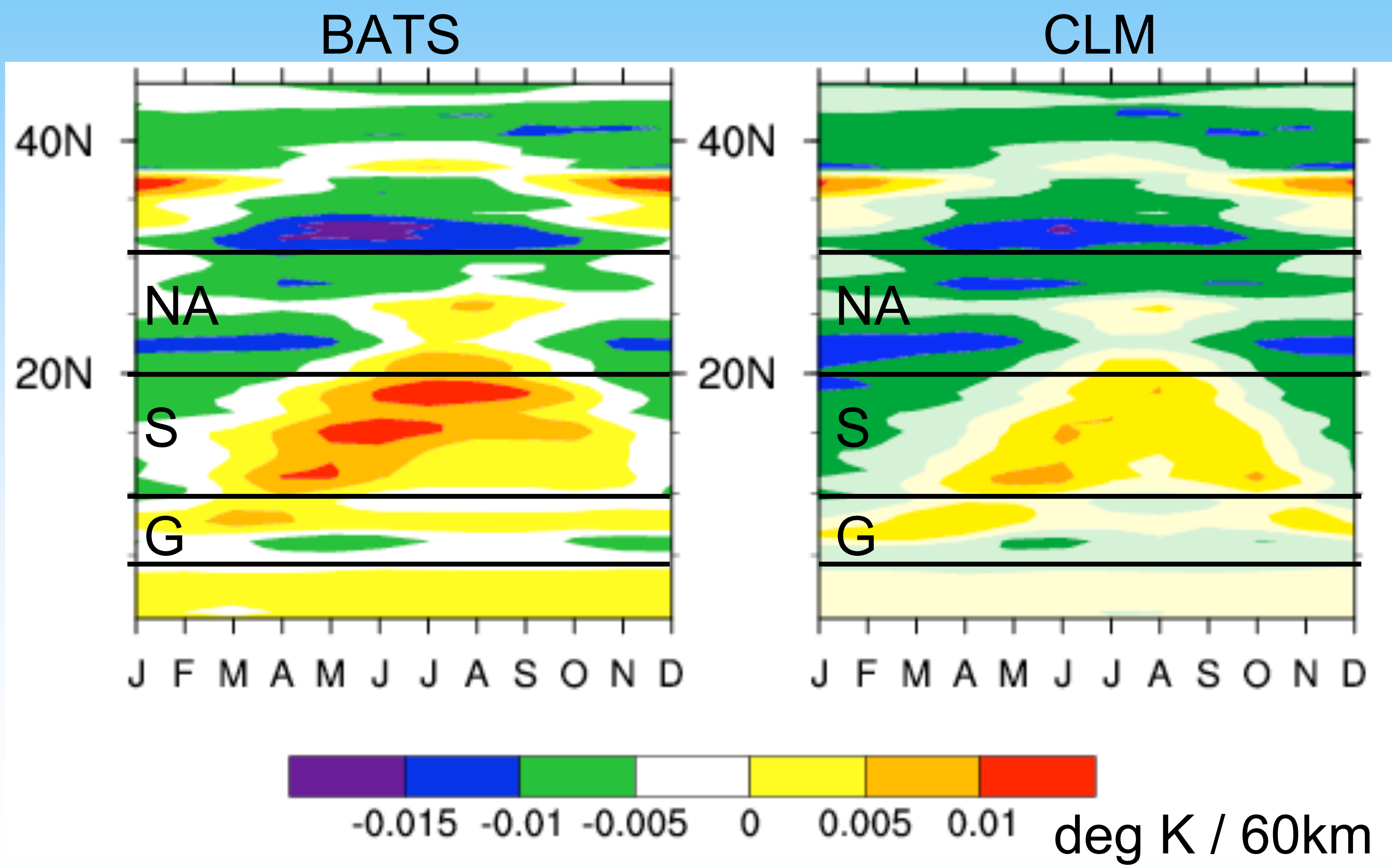
2. RegCM3-CLM3 Simulation

Southern latitude surface temperatures are cooler in RegCM3-BATS simulations



2. RegCM3-CLM3 Simulation

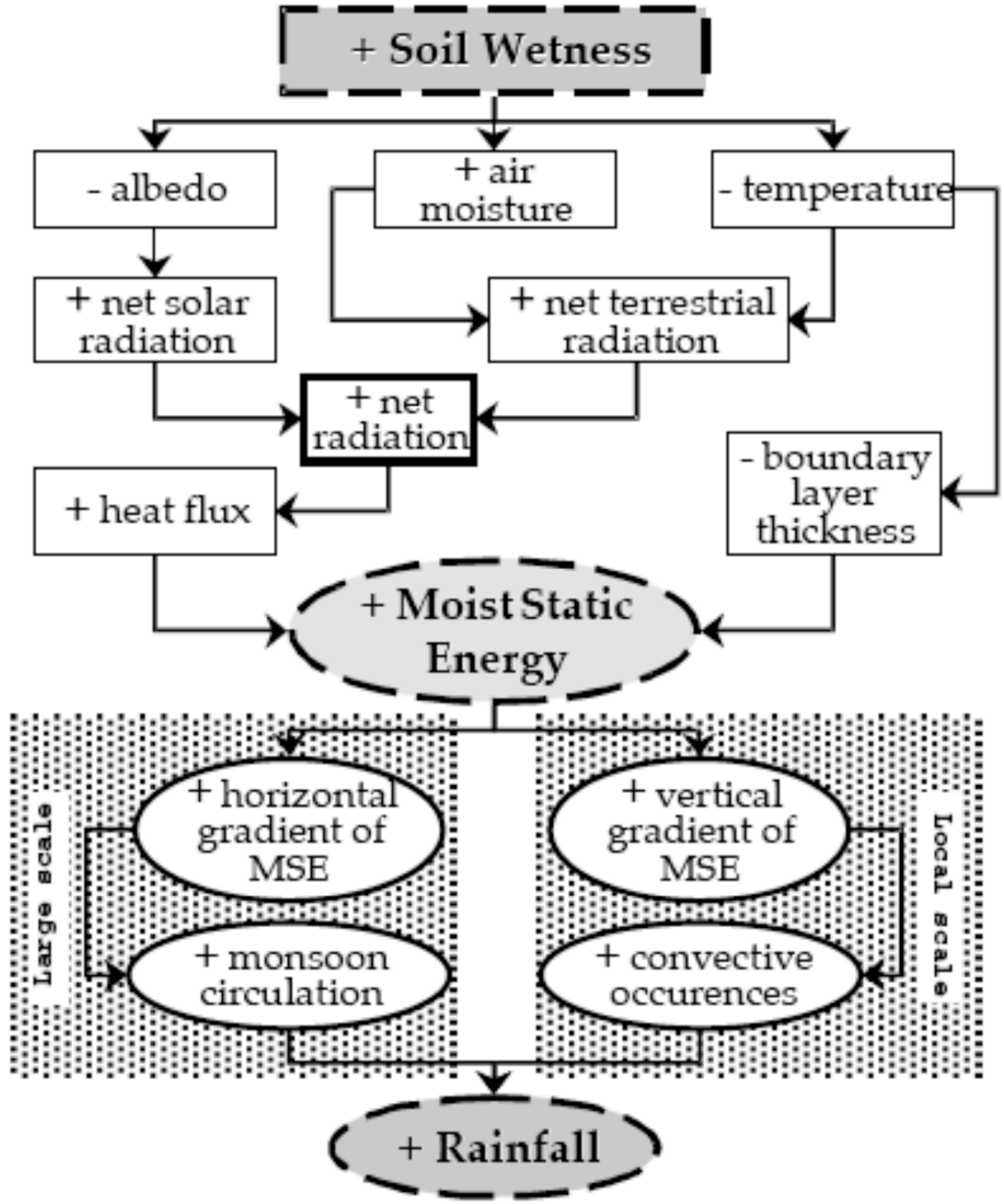
RegCM3-BATS simulations have stronger meridional surface T gradient



2. RegCM3-CLM3 Simulation

Known soil moisture-precipitation feedbacks

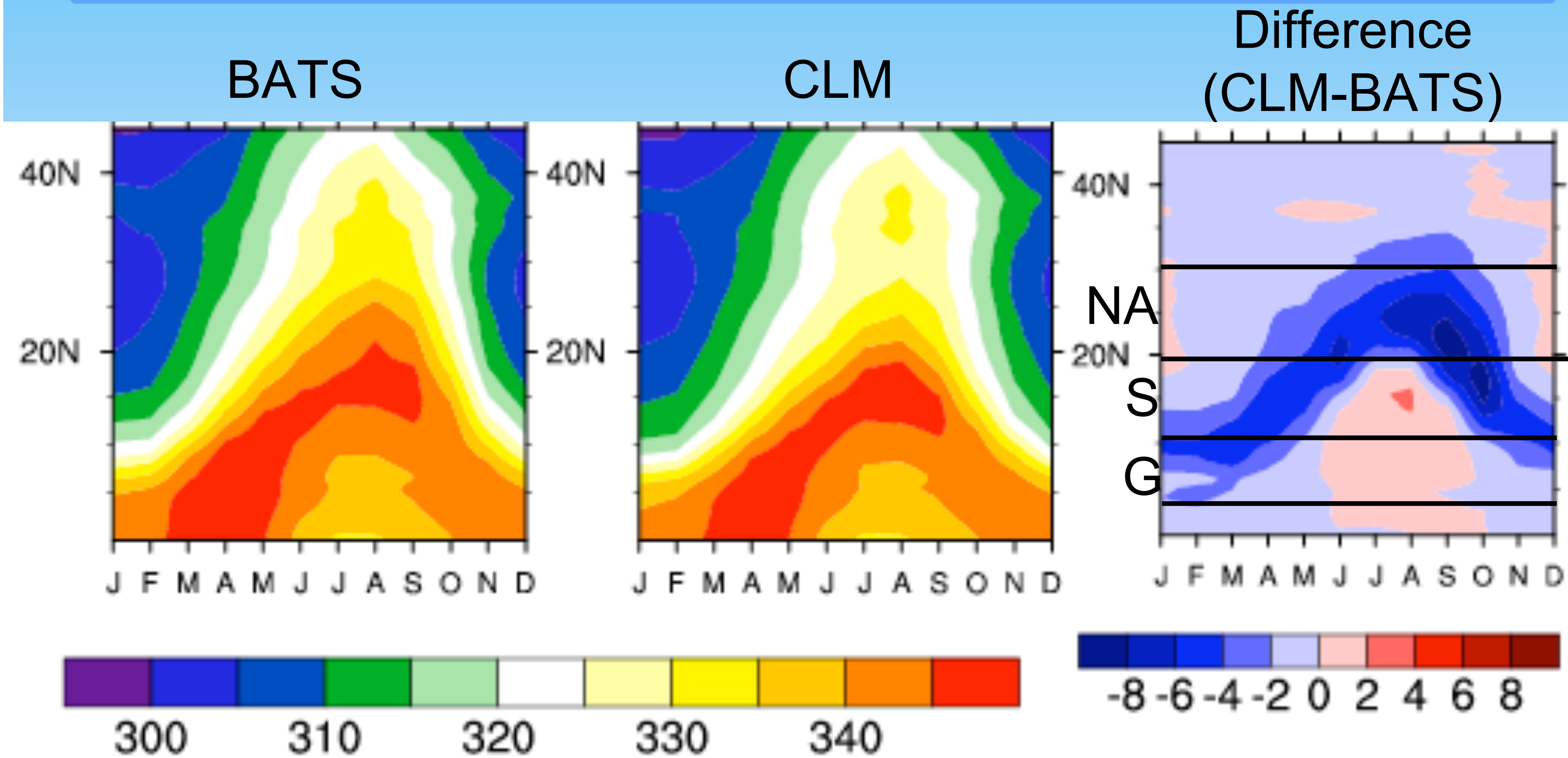
- Wetter soils
- Increased Moist Static Energy (MSE)
- Position of African Easterly Jet (AEJ) at 600 mb
- Increased precipitation



Philippon & Fontaine, 2002

2. RegCM3-CLM3 Simulation

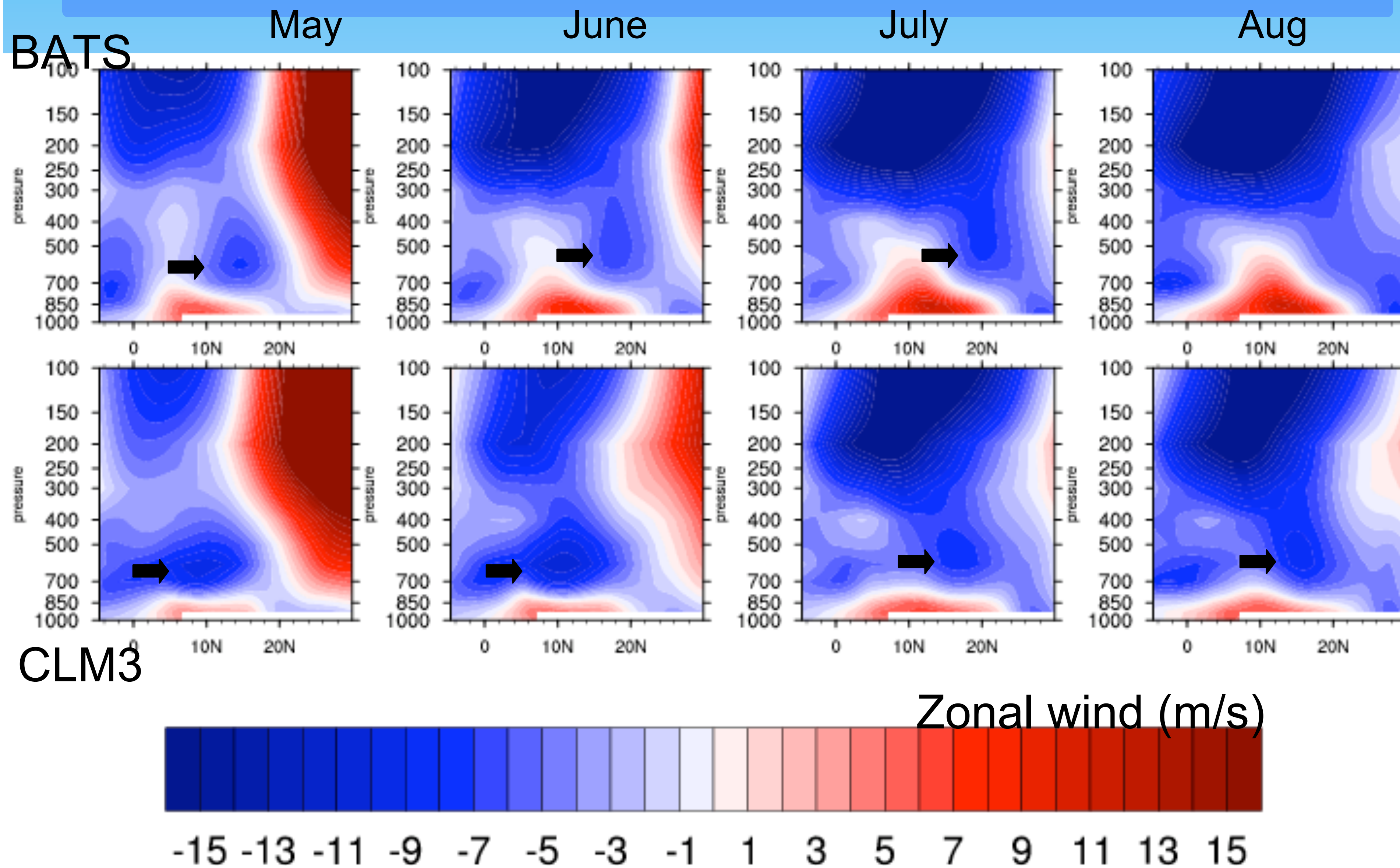
Greater Moist Static Energy (MSE) in northern latitudes in RegCM3-BATS



Surface MSE (kJ/kg)

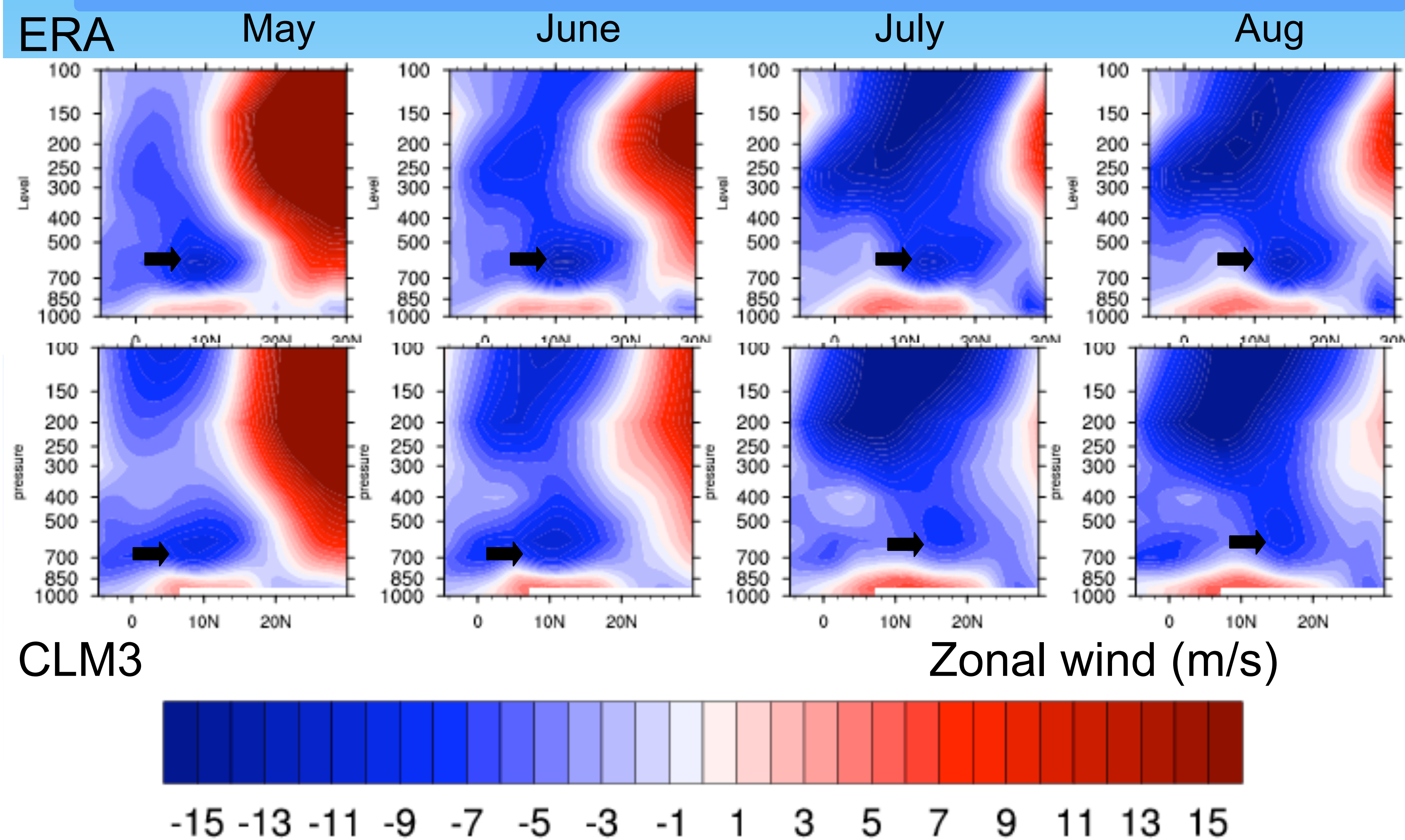
2. RegCM3-CLM3 Simulation

MSE leads to a northward shift in the RegCM3-BATS African Easterly Jet (~600mb)



2. RegCM3-CLM3 Simulation

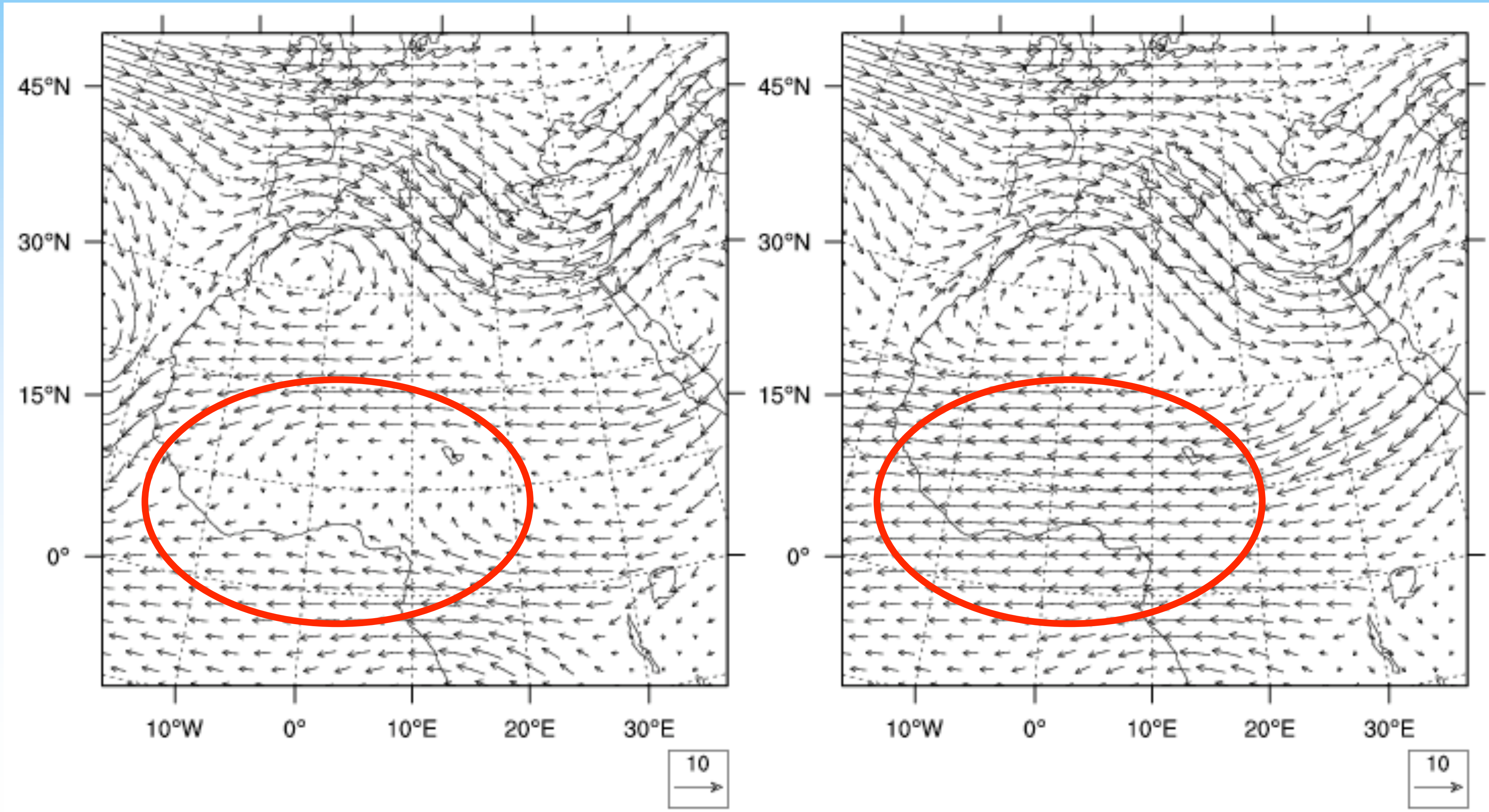
RegCM3-CLM3 simulation produces jet more like the driving ERA-40 conditions



2. RegCM3-CLM3 Simulation

AEJ location impacts large scale circulation

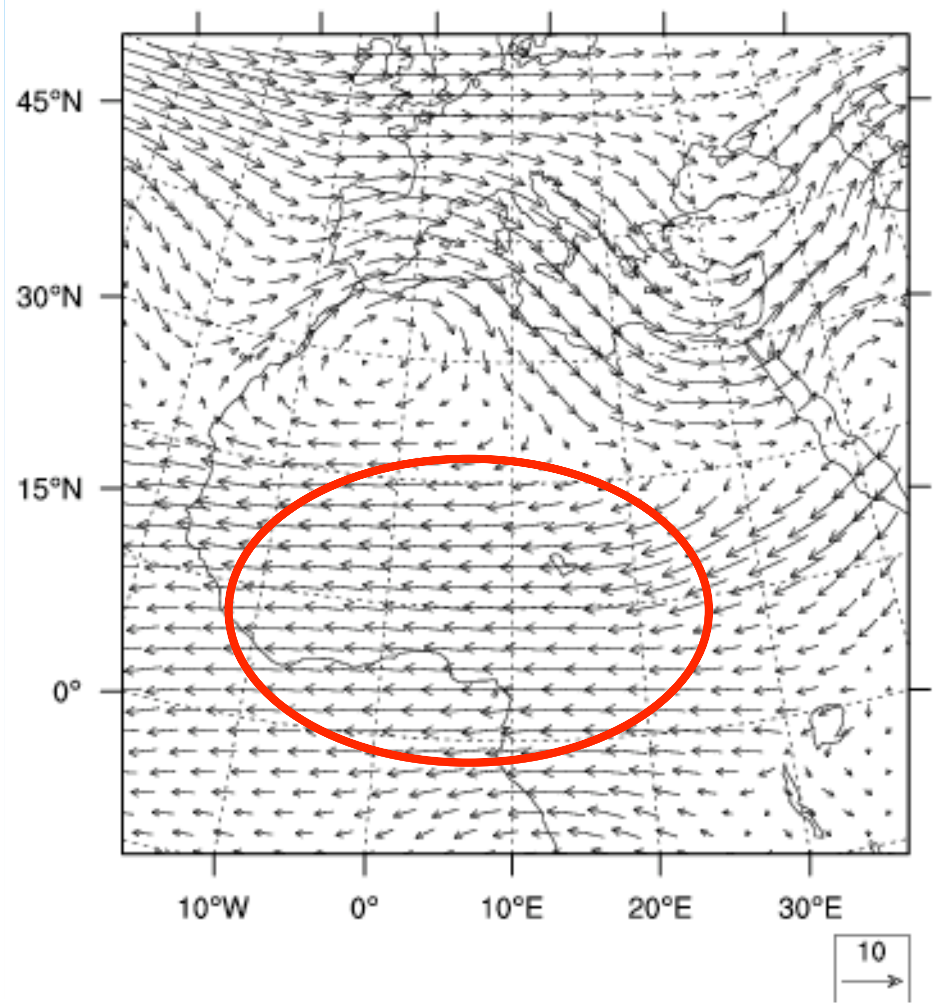
BATS JJA 600mb winds | CLM JJA 600mb winds



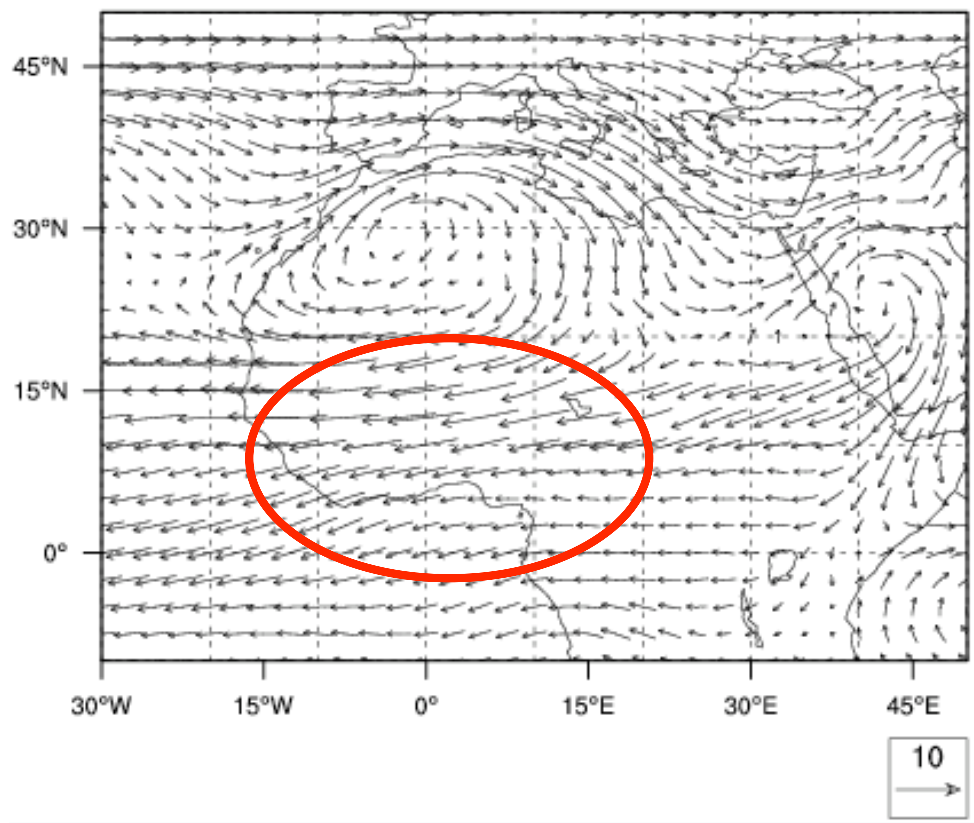
2. RegCM3-CLM3 Simulation

RegCM-CLM3 circulation looks more like ERA-40 winds

CLM JJA 600mb winds



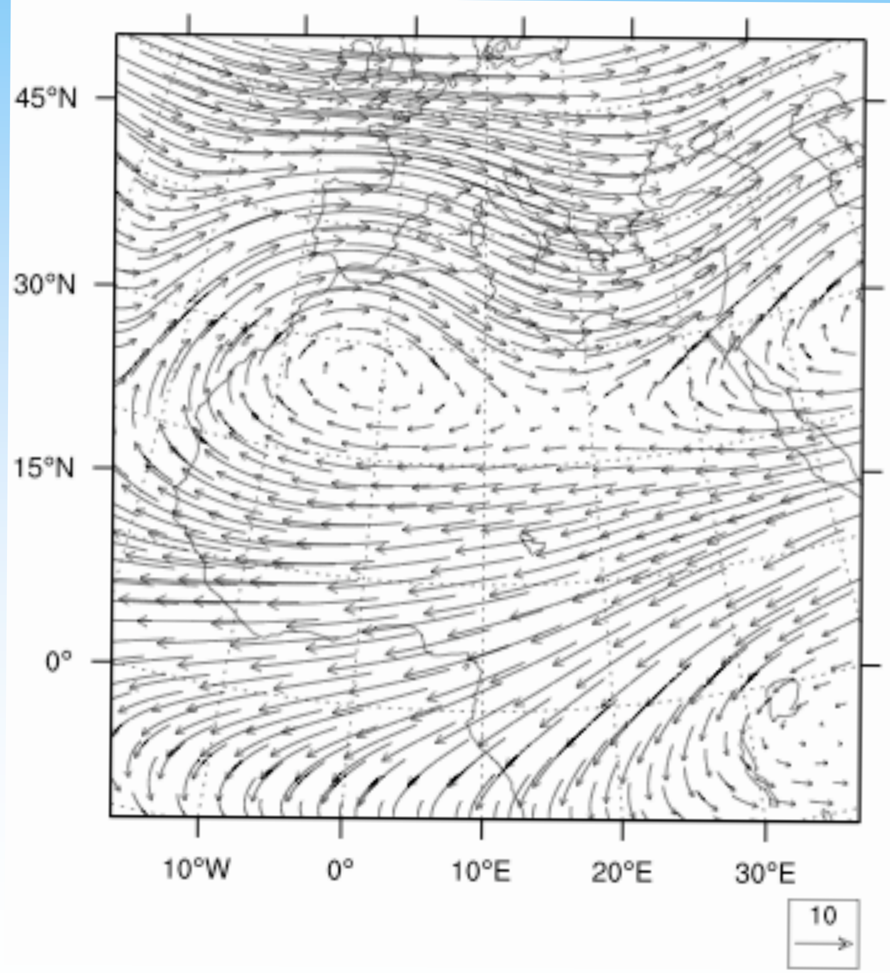
ERA-40 JJA 600mb winds



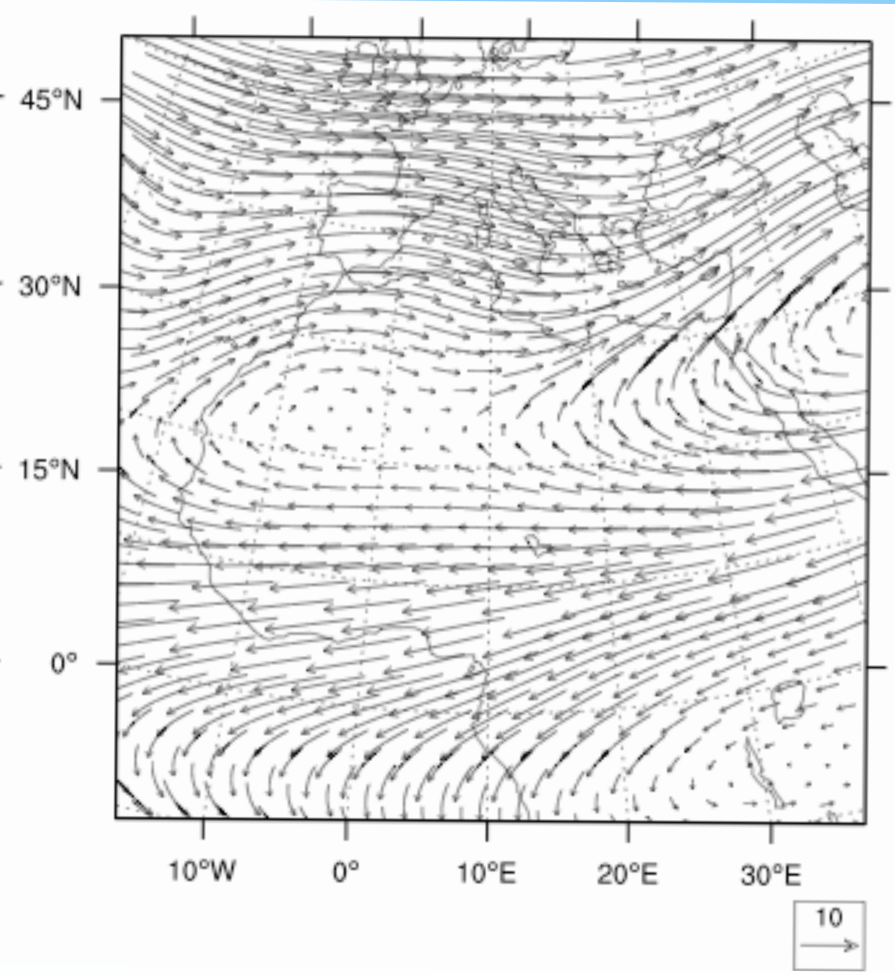
2. RegCM3-CLM3 Simulation

Also impacts the 200 mb level (Tropical Easterly Jet)

BATS JJA 200mb winds



CLM JJA 200mb winds



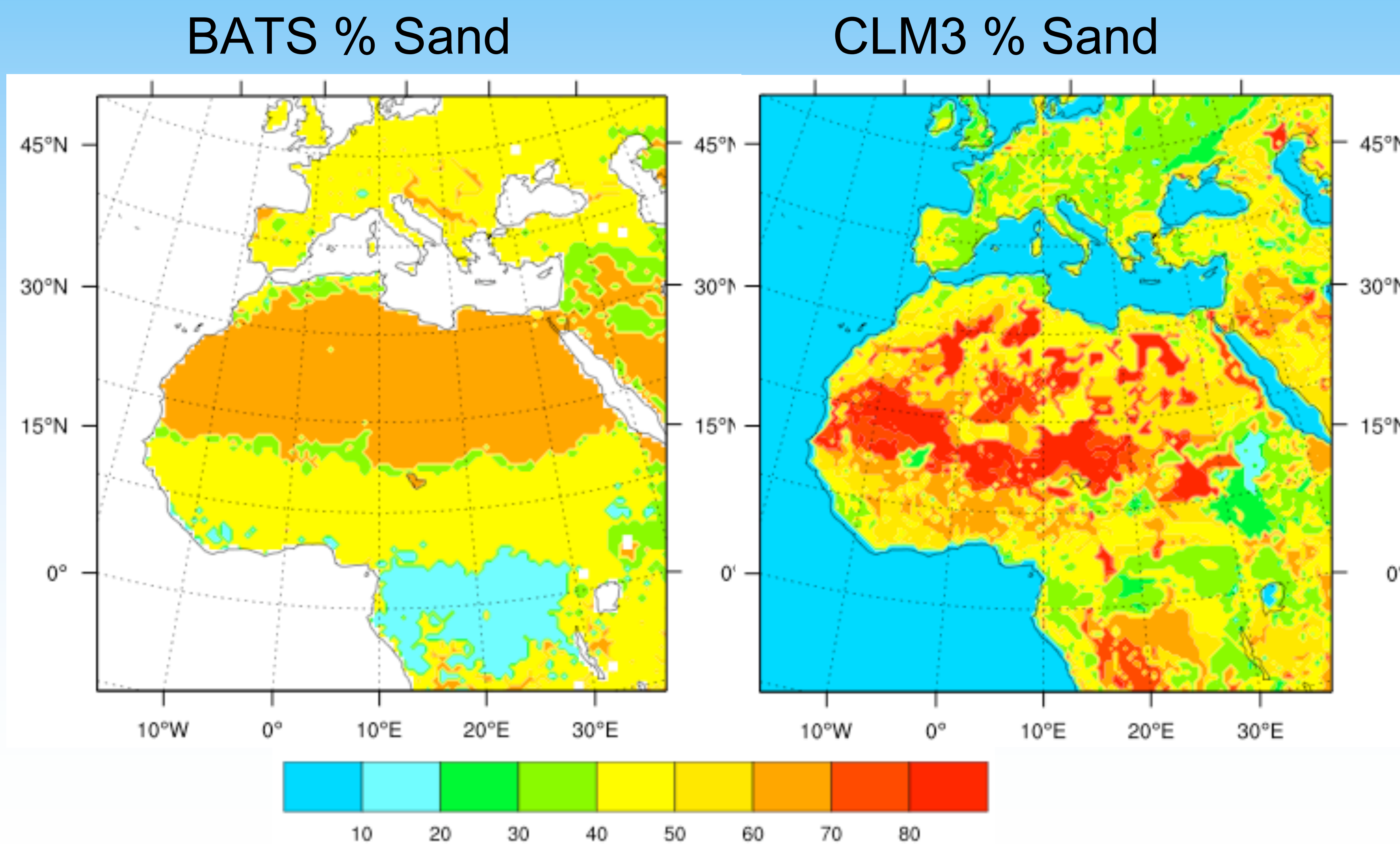
2. RegCM3-CLM3 Simulation

What drives the difference in soil moisture?

- Water balance terms are different
  - BATS has greater precip, greater evapotranspiration and greater runoff than CLM3
  - When normalized to incoming precip, terms are similar
- Difference in soil column description
  - soil texture (% sand, silt, clay)
  - sandier soil allows more drainage
  - clayey soil has more surface area, holds more water
  - BATS = old FAO dataset (1980s)
  - CLM3 = IGBP Global Soil Data Task 2000

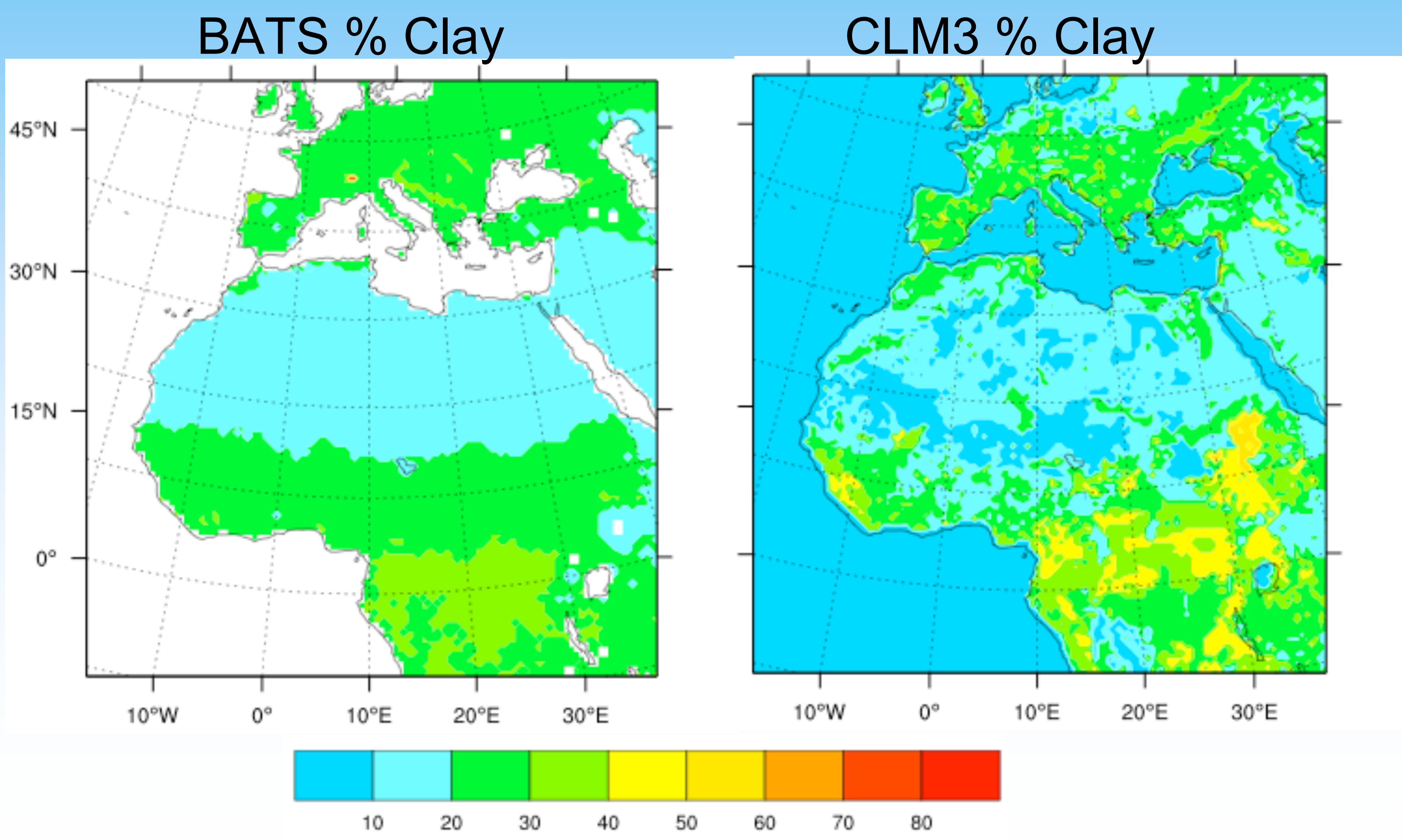
2. RegCM3-CLM3 Simulation

Soil texture is driving most of the land surface differences - CLM3 more sand



2. RegCM3-CLM3 Simulation

Soil texture is driving most of the land surface differences - CLM3 less clay



2. RegCM3-CLM3 Simulation

Conclusions

• Changing the RegCM3 land surface parameterization from BATS to CLM3 caused:

- drier soils
- improved timing of African monsoon
- reduced magnitude of precipitation during monsoon
- improved simulation of large scale circulation

• Differences in soil moisture due to new and revised soil texture description of CLM3

• Selection of land surface parameterization can have significant impacts on regional climate simulations in regions of strong land-atmosphere coupling

3. Land Surface-Aerosol Interactions

Aerosol types

- Natural or biogenic emissions
  - Dust
  - Primary biogenic particles
  - Secondary biogenic particles
- Anthropogenic emissions
  - Urban and industry (function of land cover type)
  - Biomass burning

3. Land Surface-Aerosol Interactions

Impact of land surface on dust

Dust emissions are a function of:

1. Soil texture
   - c.f. Zakey et al., 2006 Table 1
2. Wind shear
   - wind speed
   - boundary layer conditions (friction velocity)
3. Soil moisture

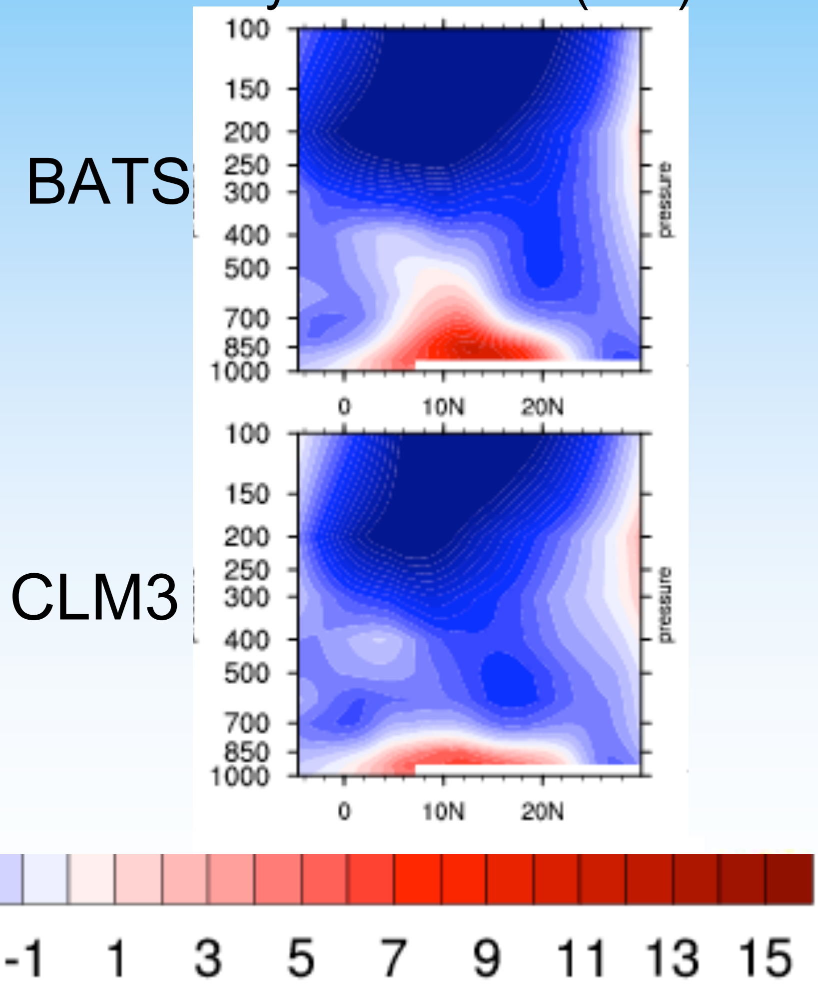
Optical properties are also likely affected by soil color

3. Land Surface-Aerosol Interactions

Potential dust emission changes due to change to CLM3

1. Soil texture
   - CLM3 more sandy in northern Africa, less clay
   - Could shift to larger size distribution (clay particles are smaller)
2. Soil moisture
   - CLM3 drier soils, more dust emissions
3. Wind shear
   - CLM3 slower surface winds, less dust

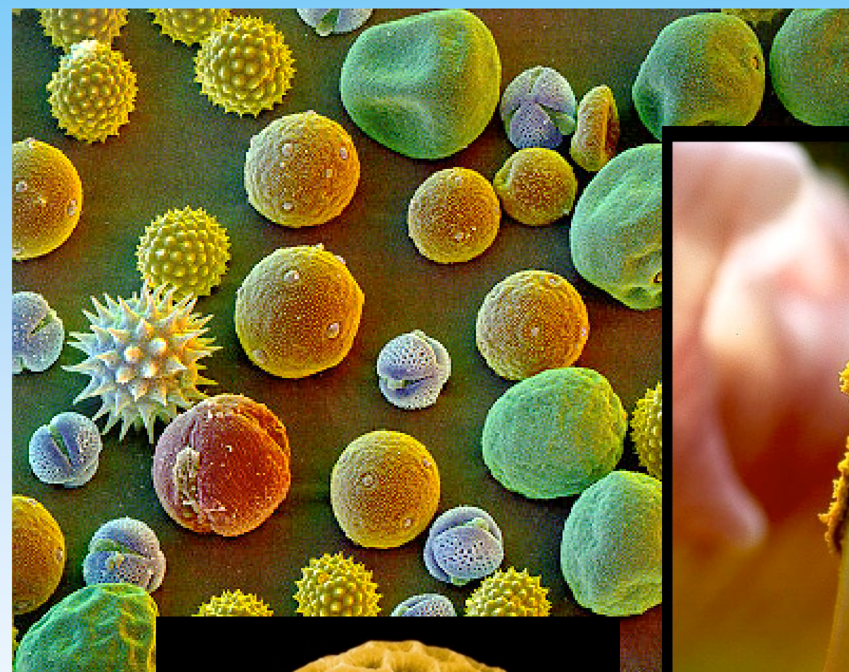
July zonal wind (m/s)

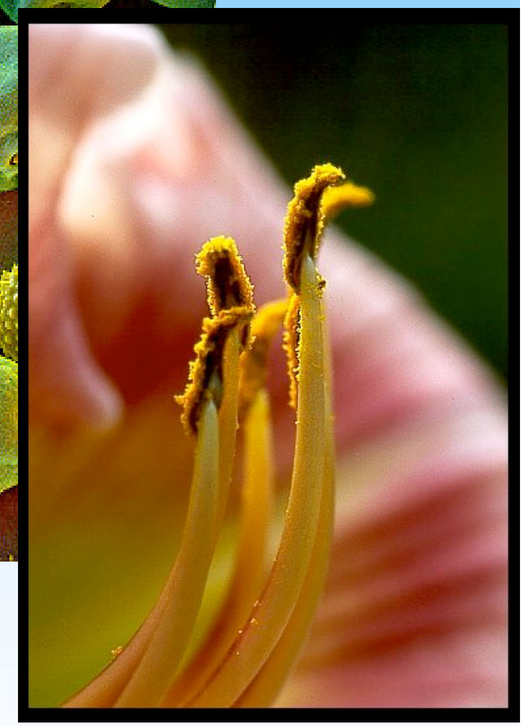


3. Land Surface-Aerosol Interactions

Biogenic Primary Particles: Pollen

- Size range >10 μm
- Composition: organic carbon
- Emitted seasonally from trees, grasses & crops
- Human health impacts
- Radiative impacts
    - Direct
    - Indirect (CCN ability unknown, proven to be ice nuclei)

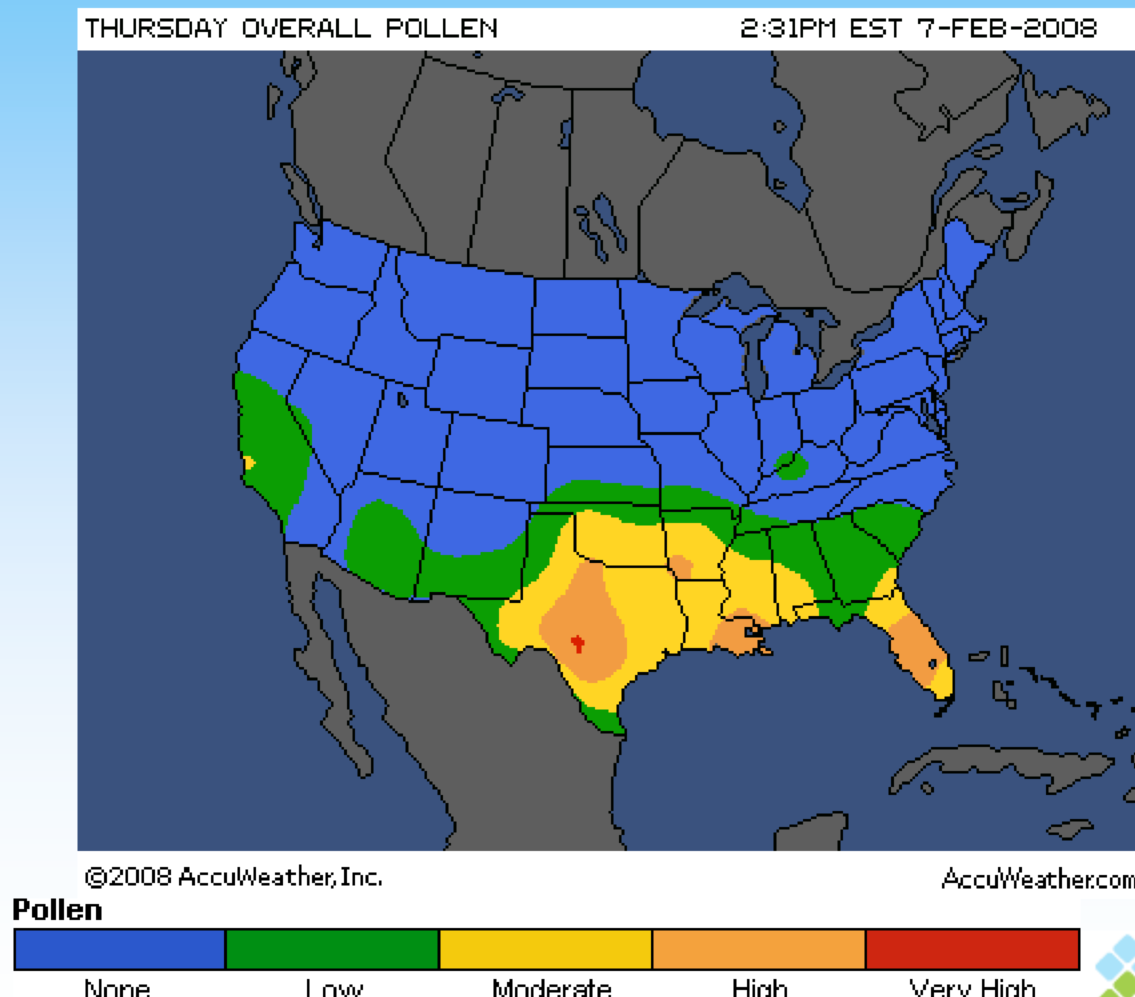




3. Land Surface-Aerosol Interactions

Biogenic Primary Particles: Pollen

- Pollen count = number of grains/cm^3 of a particular species (24 hour average)



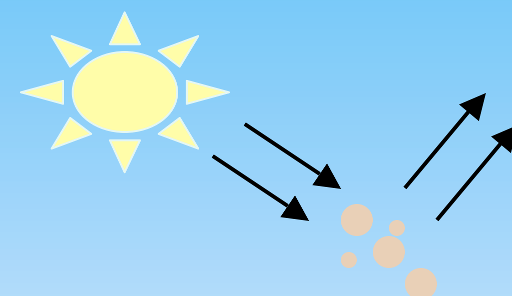
3. Land Surface-Aerosol Interactions

Biogenic Primary Particles: Bacteria & Fungi

- Bacteria (unicellular microorganisms)
  - Size range 0.25-8 μm
  - Emitted from desert and crop areas
  - Can act as CCN and IN
- Fungi
  - Can cause chemical transformations in the atmosphere
  - Can act as CCN
- Don't know very much about these emissions or their impact on atmospheric processes!

3. Land Surface-Aerosol Interactions

Secondary organic aerosols (SOA)



Isoprene
OxVOCs
Terpenes
Sesquiterpenes

$\xrightarrow[O_3 \;\; NO_3]{OH}$

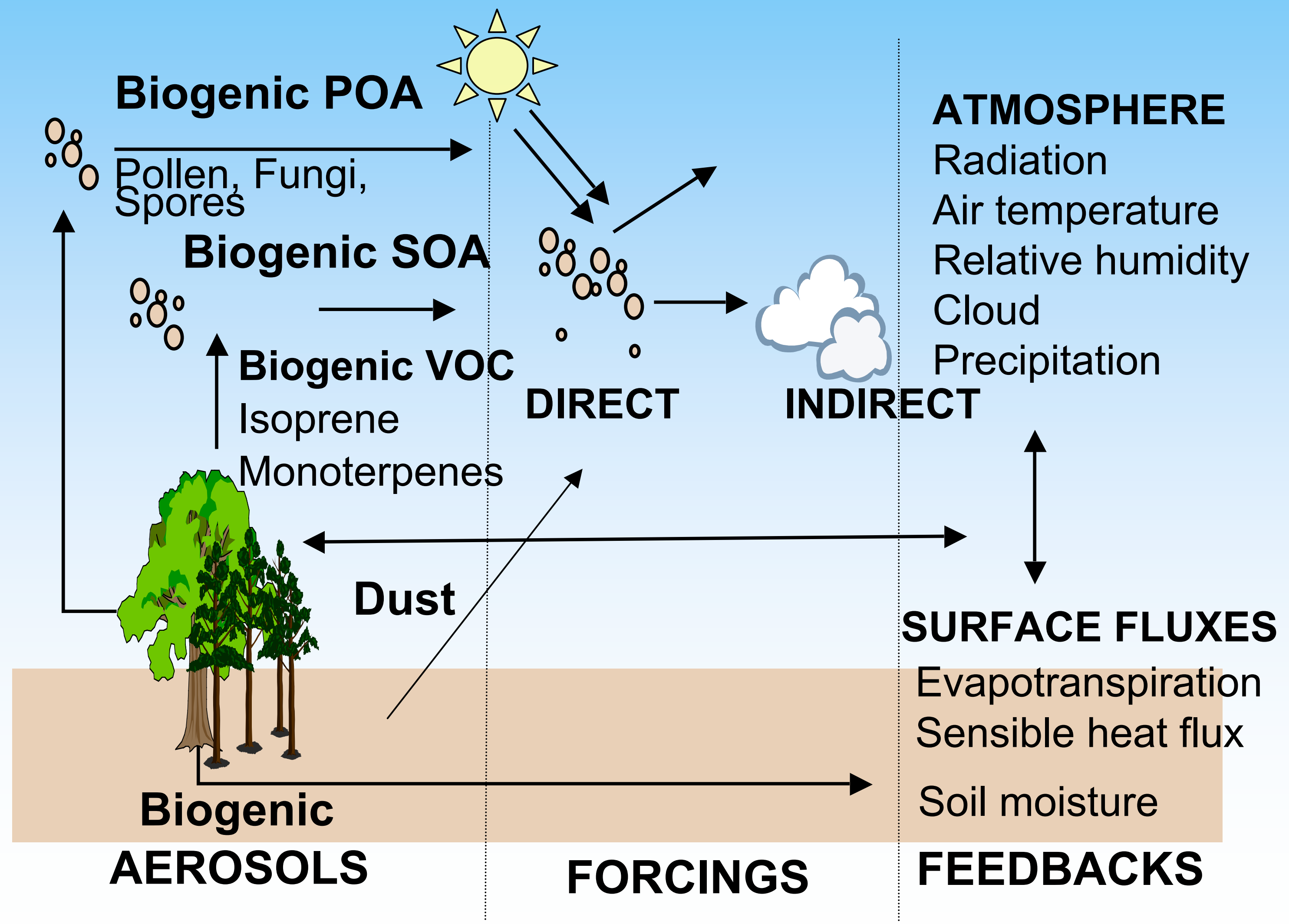
Gas Phase
Oxidation
products

$\xrightarrow[\text{Condensation} \;\; \text{Coagulation}]{\text{Nucleation}}$

Particle Phase
Secondary
Organic Aerosol

3. Land Surface-Aerosol Interactions

Biosphere-Atmosphere Feedbacks



Conclusions

- Land surface parameterization plays an important role in atmospheric dynamics

- Change of land surface parameterization can have significant impacts on regional climate simulations (e.g., case of the west African monsoon)

- Land surface will also impact emissions of natural aerosols and need to be considered on the regional scale