Modeling land-atmosphere interactions: the impact of deforestation in tropical Africa on the regional climate.

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1. Introduction

- **Deforestation**: a climate forcing with regionally very different consequences.
- **This research**: climatological impact of anthropogenic forest degradation in tropical Africa.
  - Until now, relatively few attention to this study area
  - Building on previous studies, using additional and new research methods
- Focus on **surface temperature** and **precipitation**.
- The regional climate model **COSMO-CLM** (CCLM) will be used. Instead of using the standard TERRA module, the model will be coupled to the **Community Land Model** (*CLM3.5*).
  - Standard version (cosmo version 4.8) = CCLM
  - Coupled version (cosmo version 4.0) = CCLM + *CLM3.5* = CCLM²

2. Ultimate research goals

Tropical deforestation causes regional warming and drying

But quantifying...

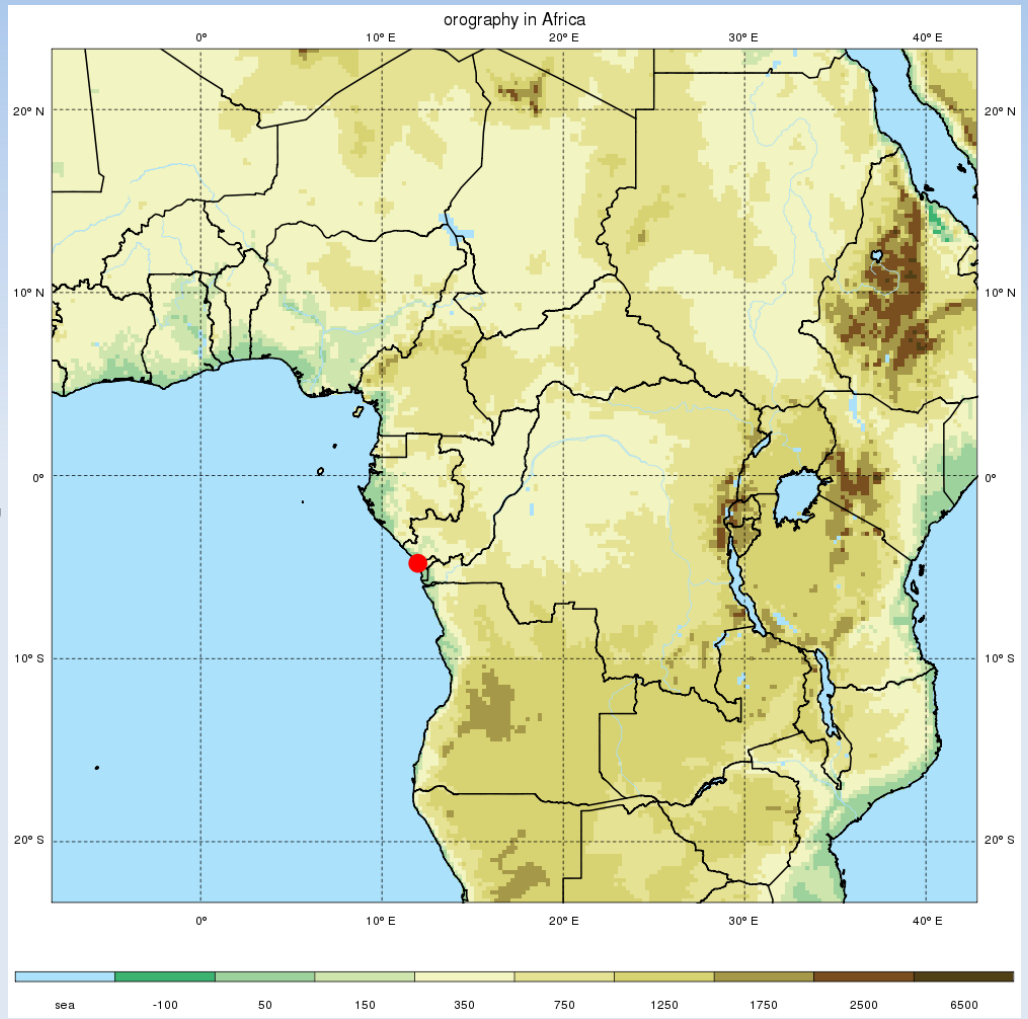
- the overall impact of deforestation.
  - e.g. with total deforestation estimates of 20% vs. 40% (year 2050)
- the influence of spatial deforestation patterns.
  - e.g. concentrated vs. dispersed wood logging scenarios
- the importance of climate-vegetation feedbacks.
  - physiological effects (CO2 on photosynthesis & stomatal conductance)
  - dynamical vegetation (phenology dependent on dry spells & heat stress)
- the consequences for detailed atmospheric processes such as convection.

3. Research overview

- **Evaluation of the offline (single-column mode) Community Land Model (*CLM3.5*) component.**
  - Observations: sensible and latent heat fluxes
  - Atmospheric forcing: measured values at observation site. Advantage: independent of CCLM performance (!)
- **Evaluation** of CCLM(²) on the tropical African domain.
  - Observations: TRMM (precipitation), MODIS (cloud cover), AVHRR (sea surface temperatures), CRU (temperature),..
- **Model runs** with CCLM² with different vegetation scenarios.
  - Reference run: driven by ERA-interim (1989-2008)
  - Future reference run: driven by ECHAM5 (2040-2060)
  - Future deforestation runs: with different vegetation scenarios (2040-2060)

4. Results: offline *CLM3.5* evaluation

- **Measurements**: eddy covariance (”flux tower”) from the CARBOAFRICA project:
  - Site ”Kissoko” (Rep. Of Congo): -4.79°S, 11.98°E; landcover: **eucalyptus** plantation; cfr. red dot
  - Site ”Hinda” (Rep. Of Congo): -4.68°S, 12.00°E; landcover: forest



Nouvellon Y. et al., 2010. Within-stand and seasonal variations of specific leaf area in a clonal Eucalyptus plantation in the Republic of Congo. *Forest Ecology and Management* 259, 1796-1807.

4. Results: offline *CLM3.5* evaluation

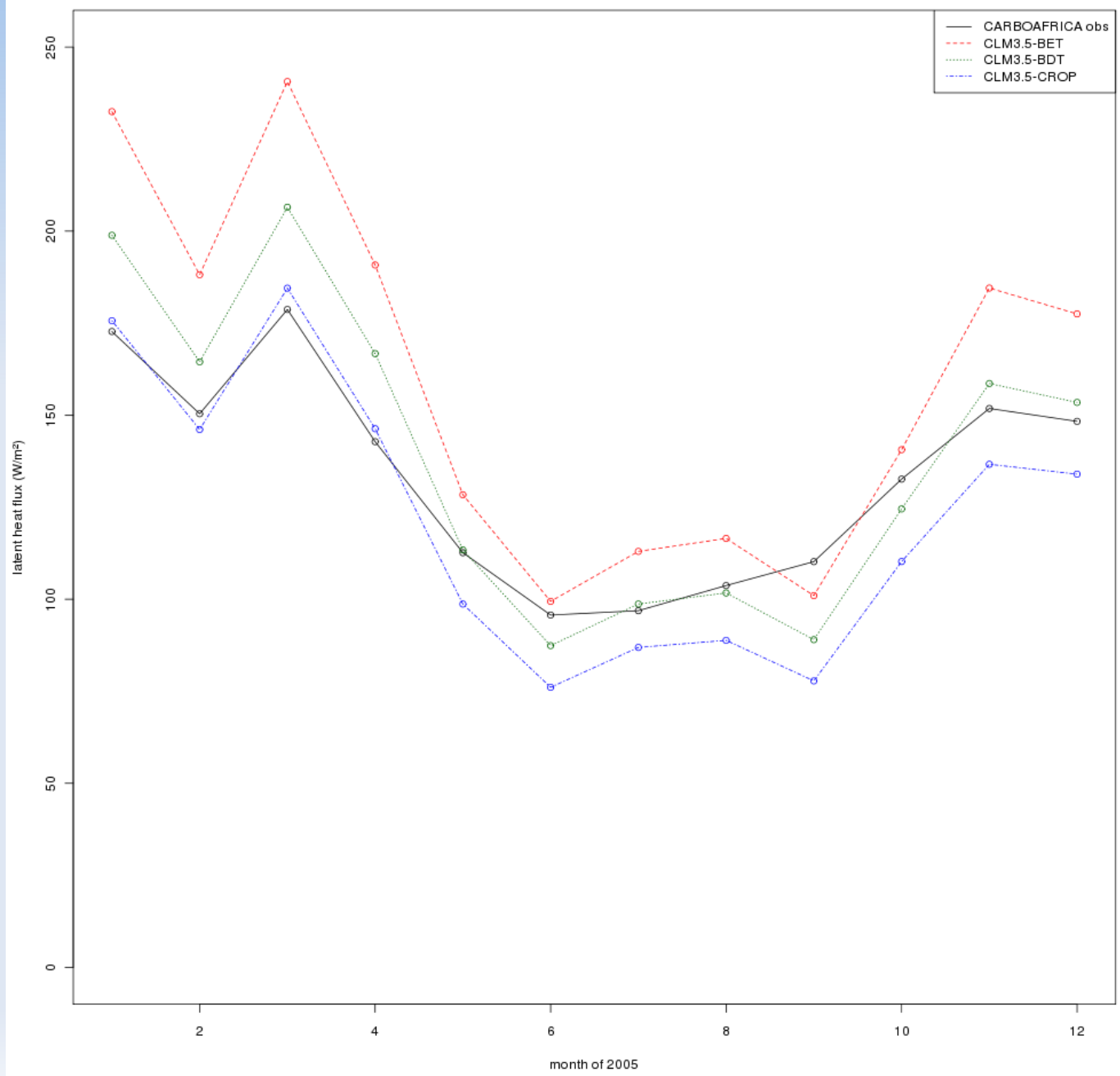
Modelling latent and sensible heat fluxes = simulating behaviour of vegetation (type).

- **Manual input parameters**: LAI, SAI, canopy heights: observed monthly values on the actual site (Nouvellon et al., 2010)
- **All other parameters**: model values (estimates) specific for each ”plant functional type” (PFT). Because *”eucalyptus tree”* is not one of the 17 pre-defined PFT's, the evaluation is done with three of these PFT's which are typical for tropical Africa:
  - Broadleaf evergreen tropical tree, BET (most logical choice)
  - Broadleaf deciduous tropical tree, BDT
  - Crop
- PFT-specific values for evergreen tree (BET) and deciduous tree (BDT) are given on the next slide.

PARAMETER	explanation	values BET		values BDT	
z0mr	ratio of momentum roughness length to canopy top height (no units)	0.075		0.055	
displar	ratio of displacement height to canopy top height (no units)	0.670		0.670	
dleaf	characteristic leaf dimension (m)	0.040		0.040	
c3psn	photosynthetic pathway: 0. = c4, 1. = c3	1.000		1.000	
vcmx25	max rate of carboxylation at 25C (umol CO2/m**2/s)	**75.000**		**40.000**	
mp	slope of conductance-to-photosynthesis relationship	9.000		9.000	
qe25	quantum efficiency at 25C (umol CO2 / umol photon)	0.060		0.060	
rhol	leaf reflectance: 1=vis, 2=nir	0.100	0.450	0.100	0.450
rhos	stem reflectance: 1=vis, 2=nir	0.160	0.390	0.160	0.390
taul	leaf transmittance: 1=vis, 2=nir	0.050	0.250	0.050	0.250
taus	stem transmittance: 1=vis, 2=nir	0.001	0.000	0.001	0.000
xl	leaf/stem orientation index (no units)	**0.100**		**0.010**	
roota_par	CLM rooting distribution parameter (1/m)	**7.000**		**6.000**	
rootb_par	CLM rooting distribution parameter (1/m)	**1.000**		**2.000**	
slasun	specific leaf area at the top of the canopy, projected area basis (m^2/gC)	**0.012**		**0.030**	
dsladlai	dSLA/dLAI: rate of change of SLA with LAI through canopy, projected area basis (m^2/gC)	**0.002**		**0.004**	
leafcn	leaf C:N (gC/gN)	**30.000**		**25.000**	
flnr	fraction of leaf N in Rubisco enzyme (no units)	**0.060**		**0.090**	
smpso	soil water potential at full stomatal opening (mm)	**-66000.000**		**-35000.000**	
smpsc	soil water potential at full stomatal closure (mm)	**-255000.000**		**-224000.000**	
fnitr	nitrogen limitation factor for non-CN mode (-)	**0.830**		**0.660**	
woody	binary flag for woody lifeform: 1. = woody, 0. = not woody	1.000		1.000	
lflitcn	leaf litter C:N (cG/gN)	**60.000**		**50.000**	
frootcn	fine root C:N (gC/gN)	42.000		42.000	
livewdcn	live wood (phloem and ray parenchyma) C:N (gC/gN)	50.000		50.000	
deadwdcn	dead wood (xylem and heartwood) C:N (gC/gN)	500.000		500.000	
froot_leaf	allocation parameter: new fine root C per new leaf C (gC/gC)	1.000		1.000	
stem_leaf	allocation parameter: new stem c per new leaf C (gC/gC)	2.000		2.000	
croot_stem	allocation parameter: new coarse root C per new stem C (gC/gC)	0.300		0.300	
flivewd	allocation parameter: fraction of new wood that is live (phloem and ray parenchyma) (no	0.100		0.100	
fcur	allocation parameter: fraction of allocation that goes to currently displayed growth, remainder to s	**1.000**		**0.500**	
lf_flab	leaf litter labile fraction	0.250		0.250	
lf_fcel	leaf litter cellulose fraction	0.500		0.500	
lf_flig	leaf litter lignin fraction	0.250		0.250	
fr_flab	fine root litter labile fraction	0.250		0.250	
fr_fcel	fine root litter cellulose fraction	0.500		0.500	
fr_flig	fine root litter lignin fraction	0.250		0.250	
dw_fcel	dead wood cellulose fraction	0.750		0.750	
dw_flig	dead wood lignin fraction	0.250		0.250	
leaf_long	leaf longevity (yrs)	**2.000**		**1.000**	
evergreen	binary flag for evergreen leaf habit (0 or 1)	**1.000**		**0.000**	
stress_decid	binary flag for stress-deciduous leaf habit (0 or 1)	**0.000**		**1.000**	
season_decid	binary flag for seasonal-deciduous leaf habit (0 or 1)	0.000		0.000	
resist	fire resistance index (unitless)	**0.120**		**0.500**	

4. Results: offline *CLM3.5* evaluation

- Monthly means of **latent heat flux** (W/m²), 2005
- Half-hourly values.
  - Obs: black
  - CLM3.5-BET: red
  - CLM3.5-BDT: green
  - CLM3.5-CROP: blue
- Only daytime, 6-18h
- *Systematic overestimation for BET parameters*



4. Results: offline *CLM3.5* evaluation

- Monthly means of **sensible heat flux** (W/m²), 2005
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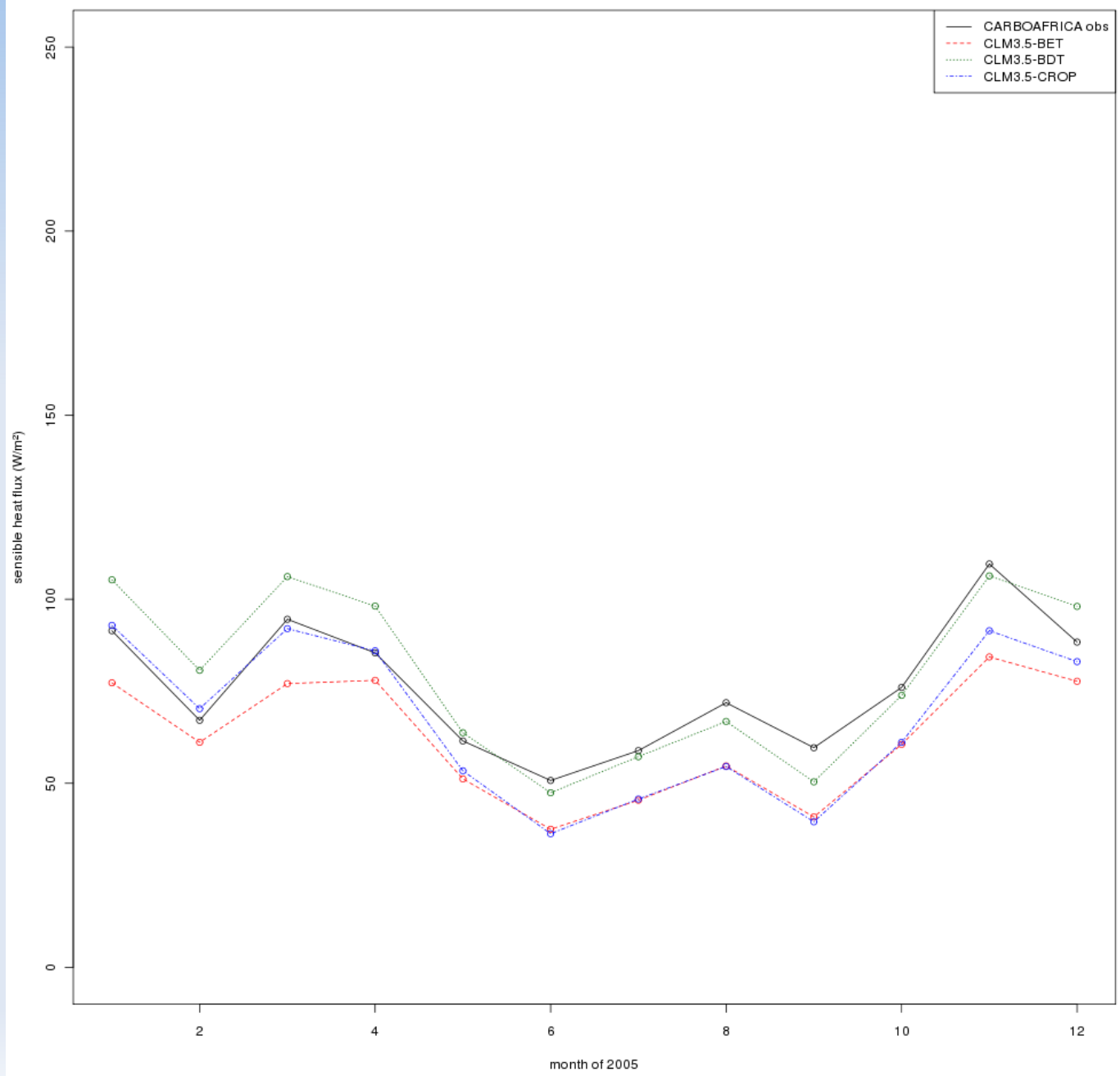
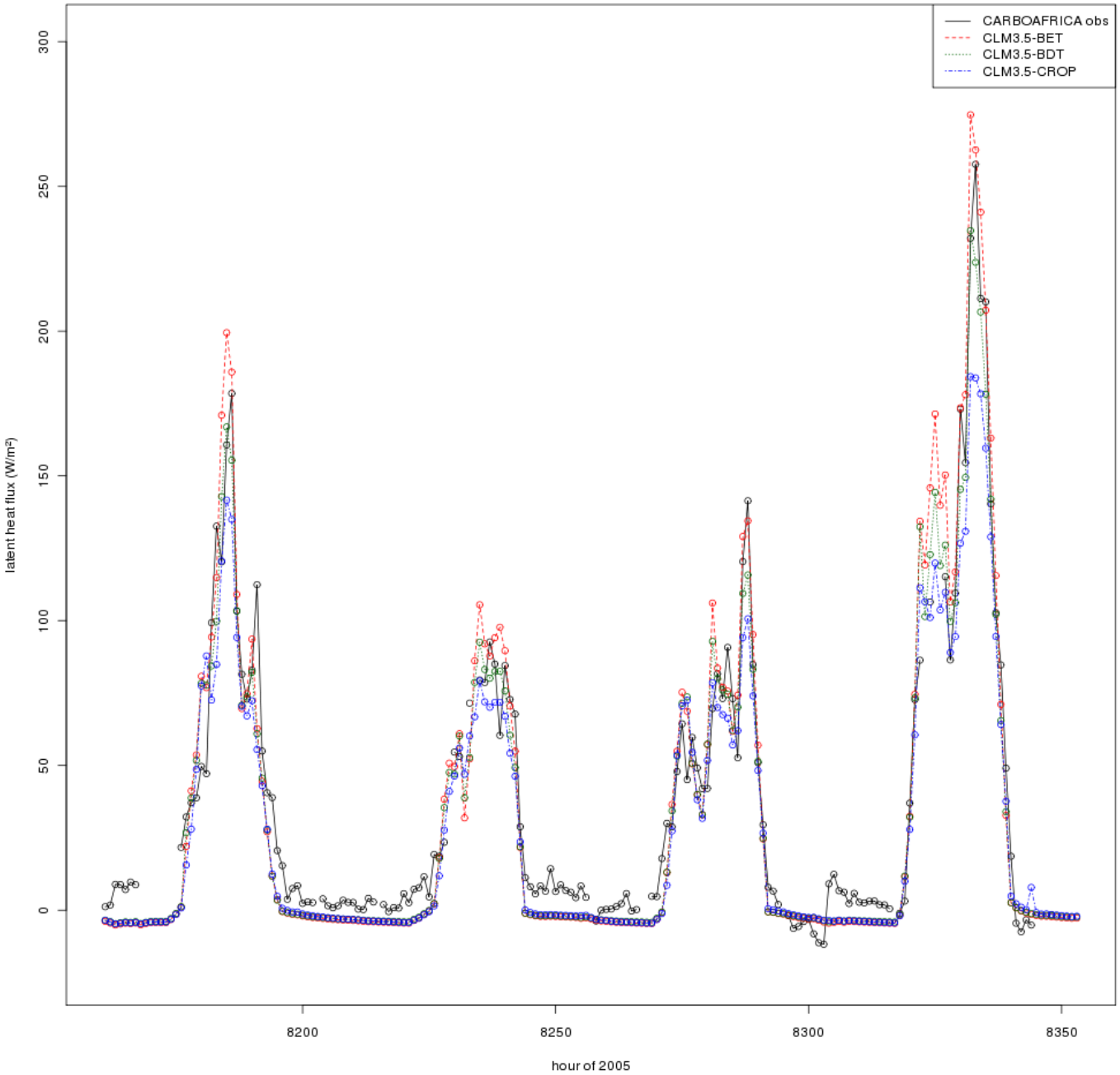


4. Results: offline *CLM3.5* evaluation

- Daily cycle of **latent heat flux** (W/m²), e.g. 20-24/06/2005
- Half-hourly values.
  - Obs: black
  - CLM3.5-BET: red
  - CLM3.5-BDT: green
  - CLM3.5-CROP: blue
- *Good performance of CLM3.5*



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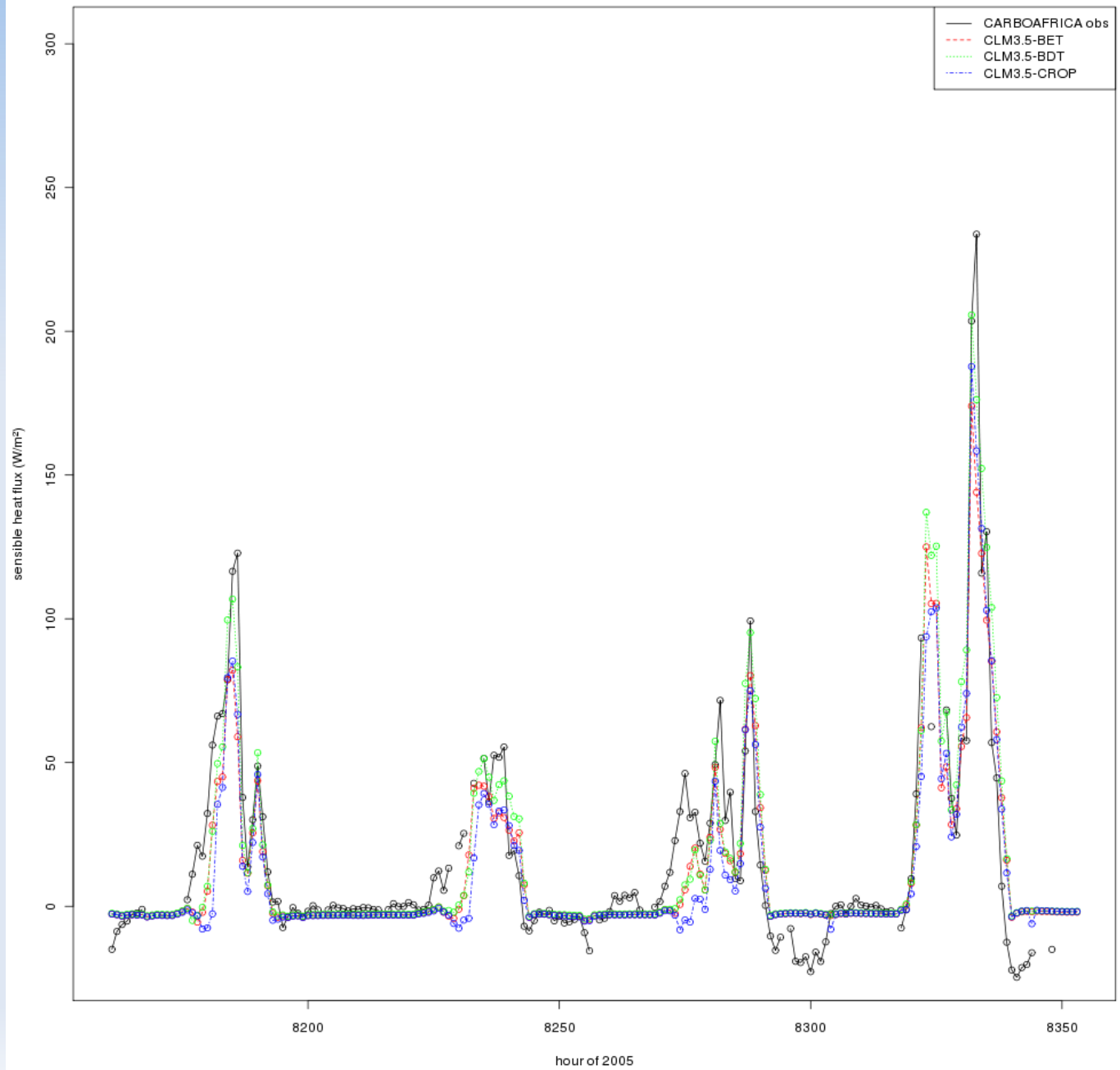


5. Results: CCLM evaluation: clouds

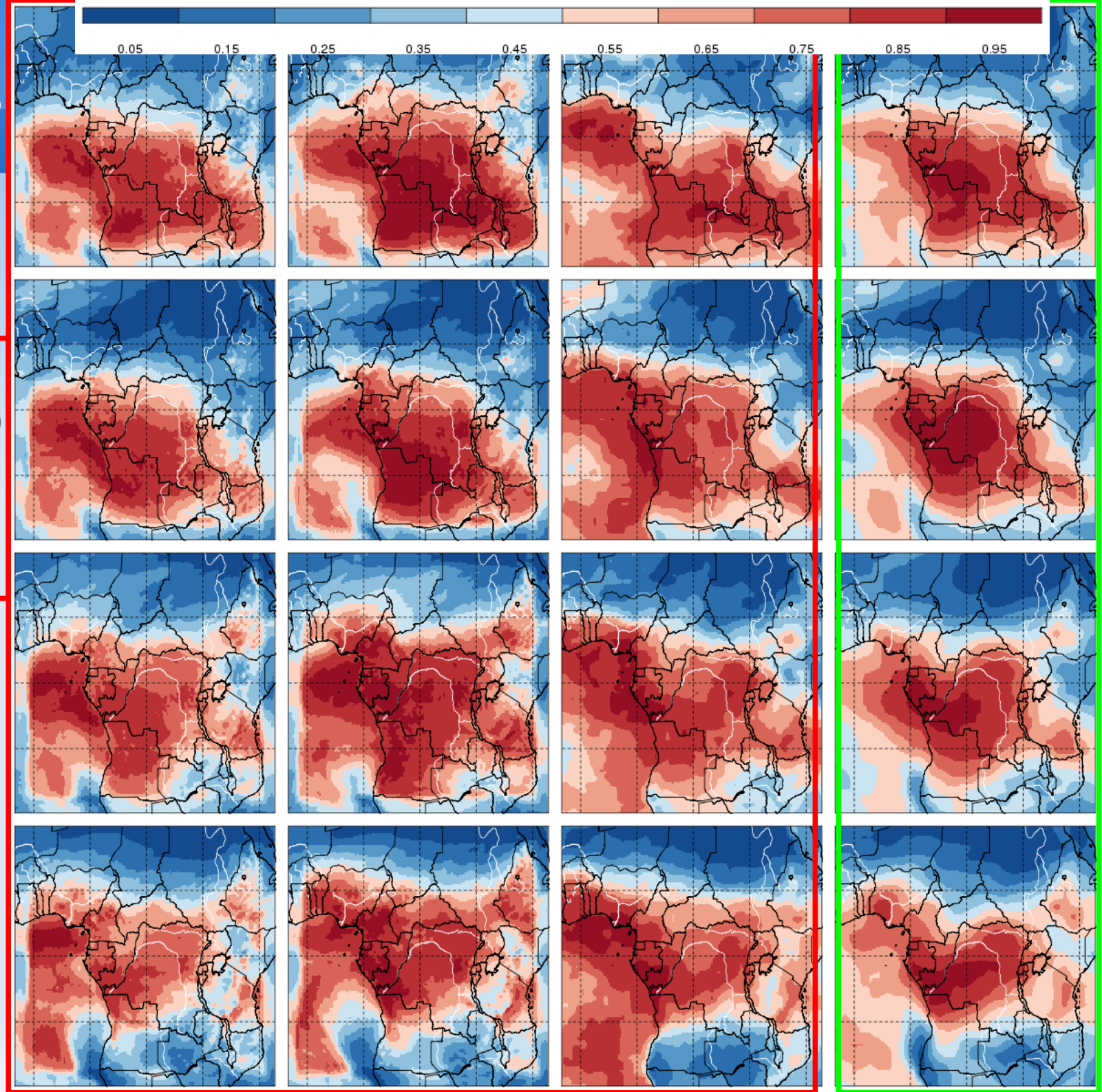
A good representation of cloud cover is necessary when dealing with energy fluxes.

- Comparison of monthly averages of total cloud cover, for:
  - CCLM² output (variable: CLCT): column 1
  - CCLM output (variable: CLCT): column 2
  - MODIS monthly cloud fraction (res. 1°): column 3
  - ERA-interim, boundary conditions (res. 1.5°): column 4
- CCLM configuration:
  - COSMO4.0+*CLM3.5* (**CCLM²**) & COSMO4.8+terra (**CCLM**)
  - Horizontal resolution: 0.22°
  - 210 x 180 grid points (LL corner -3.26°E, -19.69°S)
  - Namelist: CORDEX-Africa defaults, except:
    - No Runge-Kutta dynamics (irunge_kutta=0)
    - Neumann instead of Dirichlet bound.cond. (imode_turb=1)
    - 3 instead of 2 boundary lines (nboundlines=3)

5. clouds

January – April 2005 (rows)

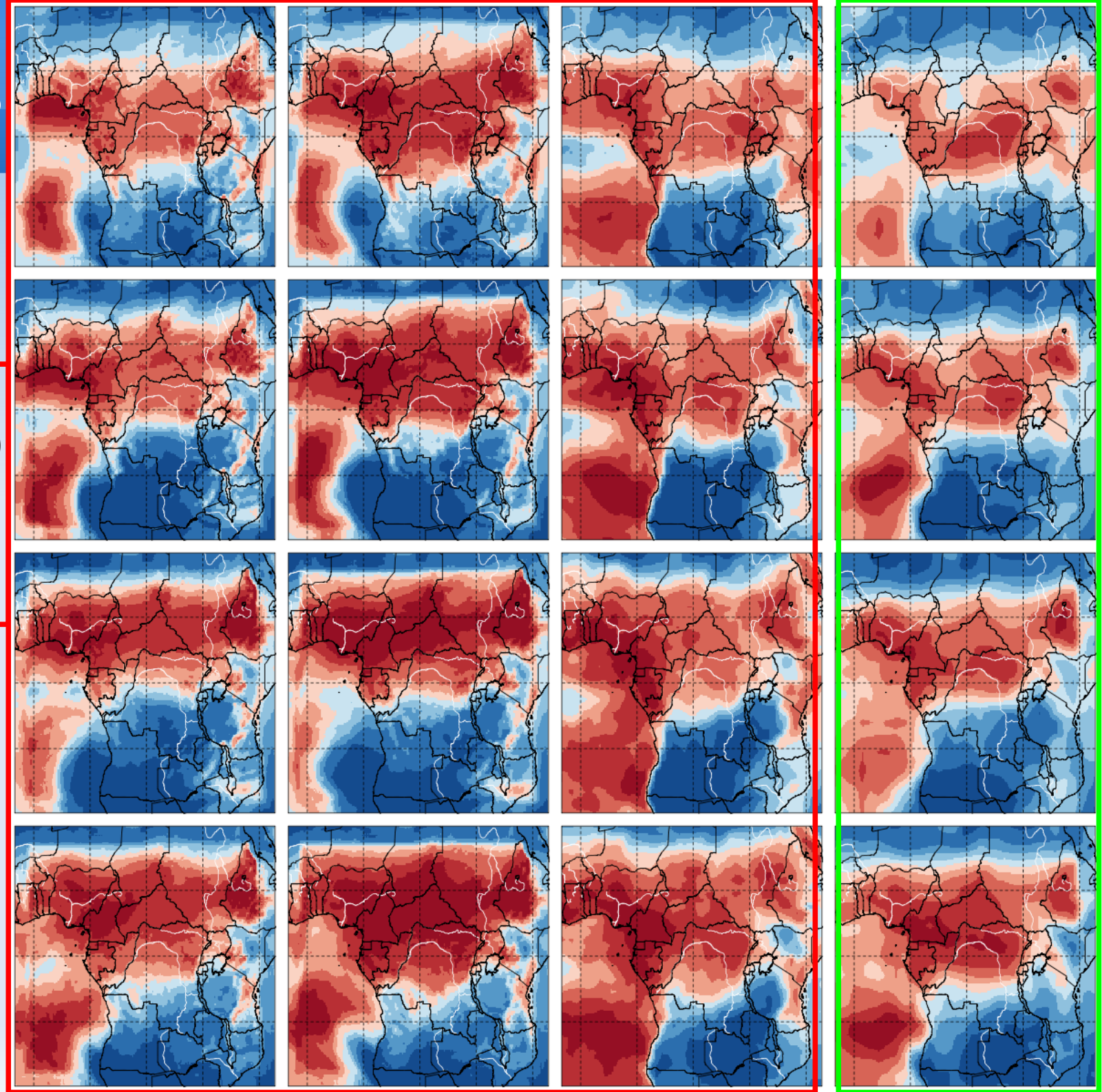
- CCLM² output, C4.0+*CLM3.5* (col1)
- CCLM output, C4.8+terra (col2)
- MODIS (col3)
- ERA-interim (col4)



5. clouds

May – August 2005 (rows)

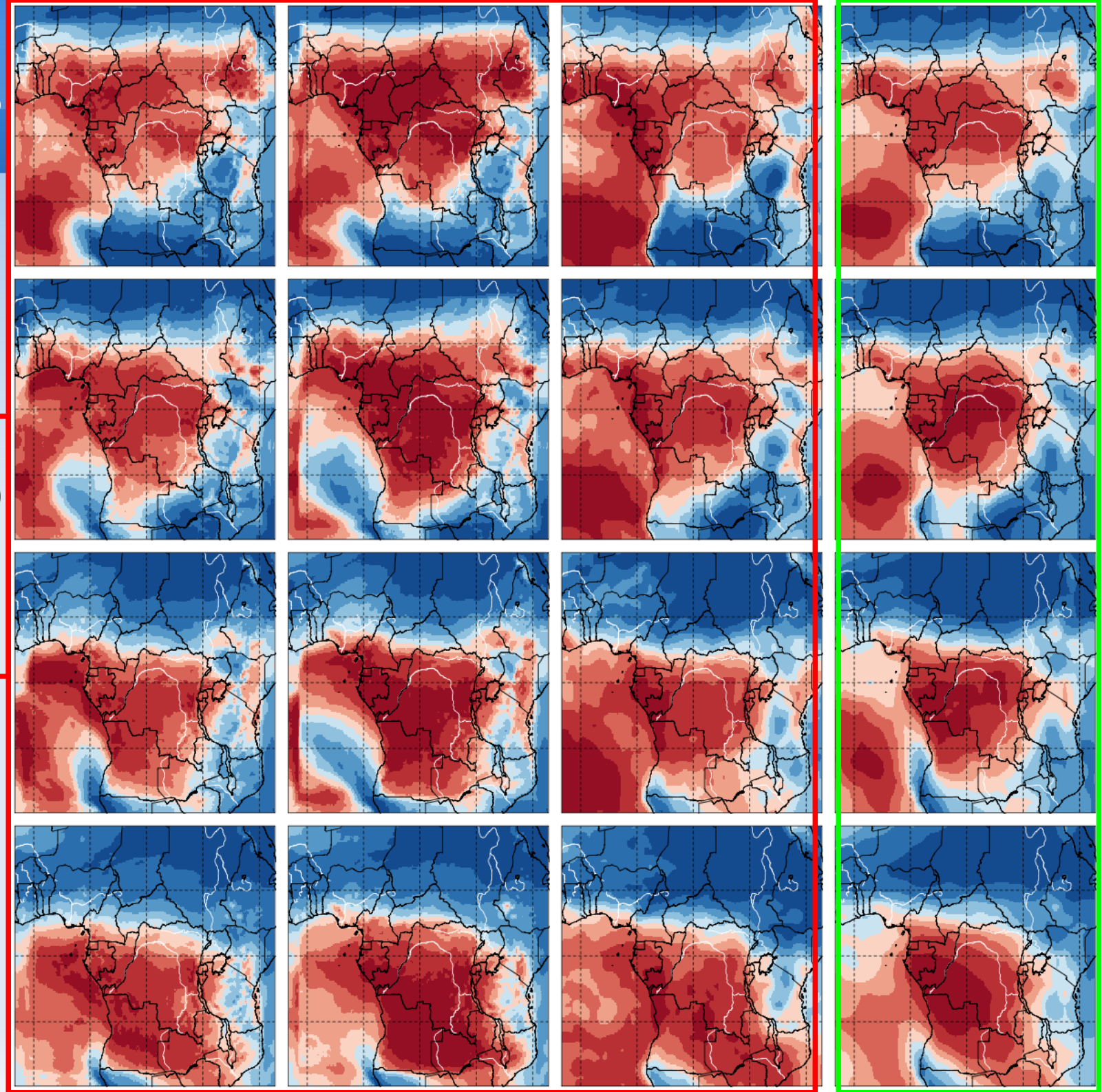
- CCLM² output, C4.0+*CLM3.5* (col1)
- CCLM output, C4.8+terra (col2)
- MODIS (col3)
- ERA-interim (col4)



5. clouds

September – December 2005 (rows)

- CCLM² output, C4.0+*CLM3.5* (col1)
- CCLM output, C4.8+terra (col2)
- MODIS (col3)
- ERA-interim (col4)



Conclusion: CCLM doesn't develop the cloud fields very well over the Atlantic, ”cloud gaps”

5. Results: CCLM evaluation: clouds

- One **reason** could be the ERA-interim **sea surface temperatures**. *Observations show that above a ”treshold” SST of 26°C, convective activity increases sharply*, pointing to the importance of good SST.
  - Cfr paper Tompkins (2001) On the relationship between Tropical convection and Sea Surface Temperature, Journal of Climate, vol.14, 633-637
- Comparing monthly ERA-interim SST with the monthly **AVHRR** SST product gives a general *under*-estimation of around 3K (pictures not shown)
- **Conclusion**: the SST distribution as well as the general underestimation could contribute to the ”cloud gaps” which we observe over the Atlantic Ocean in the CCLM output.

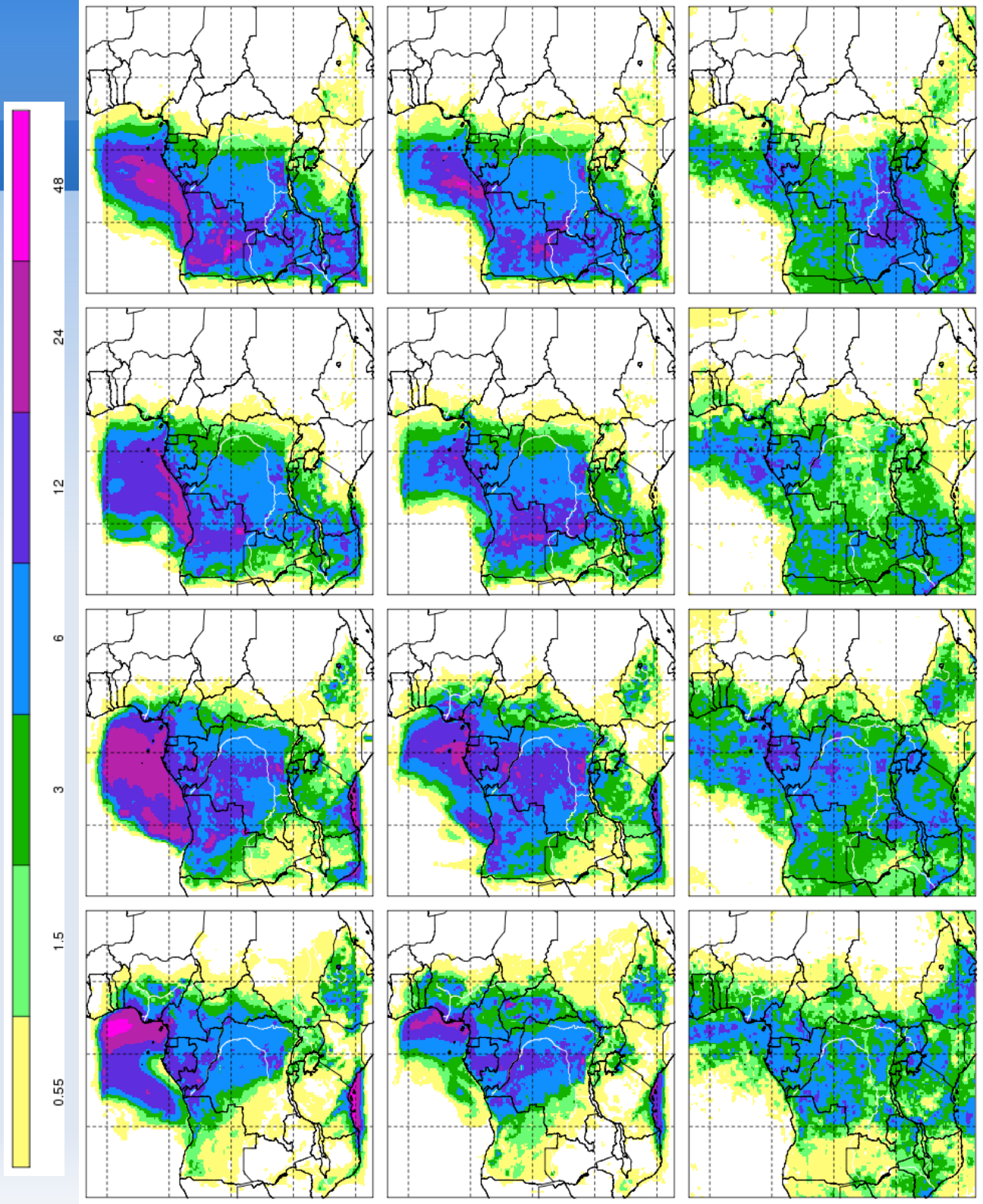
6. Results: CCLM evaluation: precip

- Comparison of monthly averages of daily precipitation for:
  - CCLM² output (variable: TOT_PREC): column 1
  - CCLM output (variable: TOT_PREC): column 2
  - TRMM product (res. 25km): column 3
- CCLM configuration:
  - COSMO4.0+*CLM3.5* (**CCLM²**) OR COSMO4.8+terra (**CCLM**)
  - Horizontal resolution: 0.22°
  - 210 x 180 grid points (LL corner -3.26°E, -19.69°S)
  - Namelist: CORDEX-Africa defaults, except:
    - No Runge-Kutta dynamics (irunge_kutta=0)
    - Neumann instead of Dirichlet bound.cond. (imode_turb=1)
    - 3 instead of 2 boundary lines (nboundlines=3)

6. Precipitation

January – April 2005 (rows)

- CCLM² output, C4.0+*CLM3.5* (col1)
- CCLM output, C4.8+terra (col2)
- TRMM (col3)



6. Precipitation

May – August 2005 (rows)

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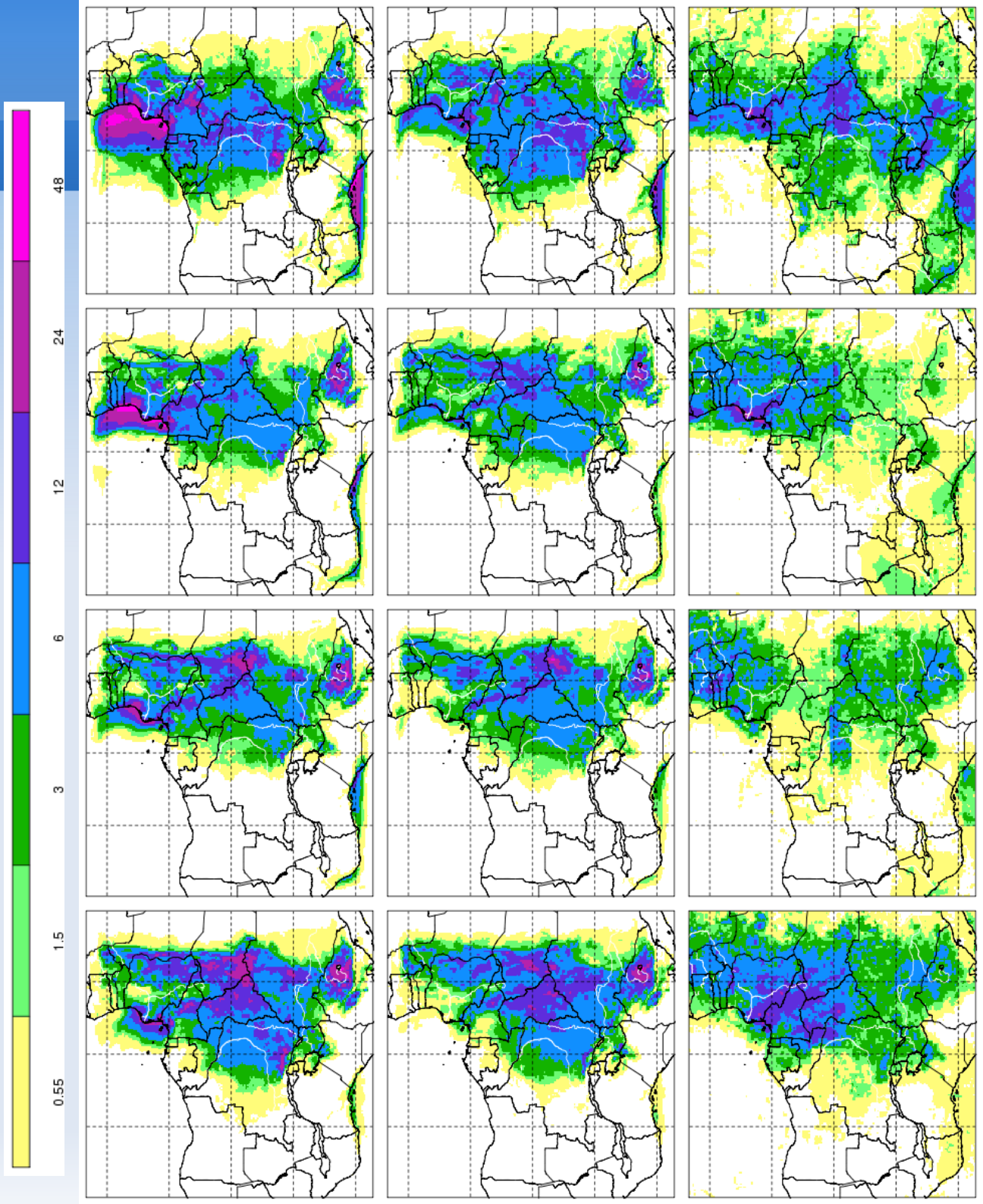
- CCLM output, C4.8+terra (col2)
- TRMM (col3)



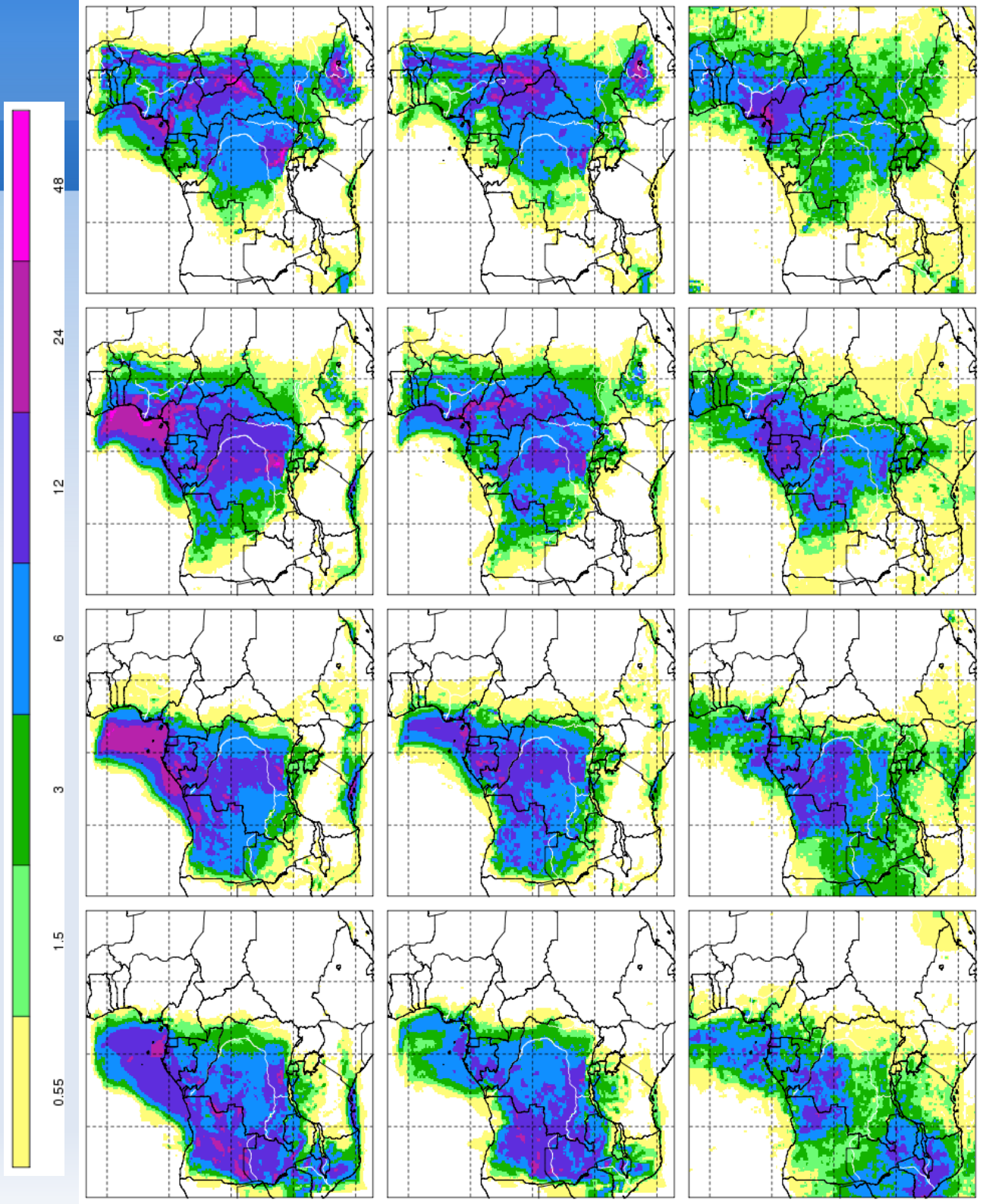
6. Precipitation

September – December 2005 (rows)

- CCLM² output, C4.0+*CLM3.5* (col1)
- CCLM output, C4.8+terra (col2)
- TRMM (col3)

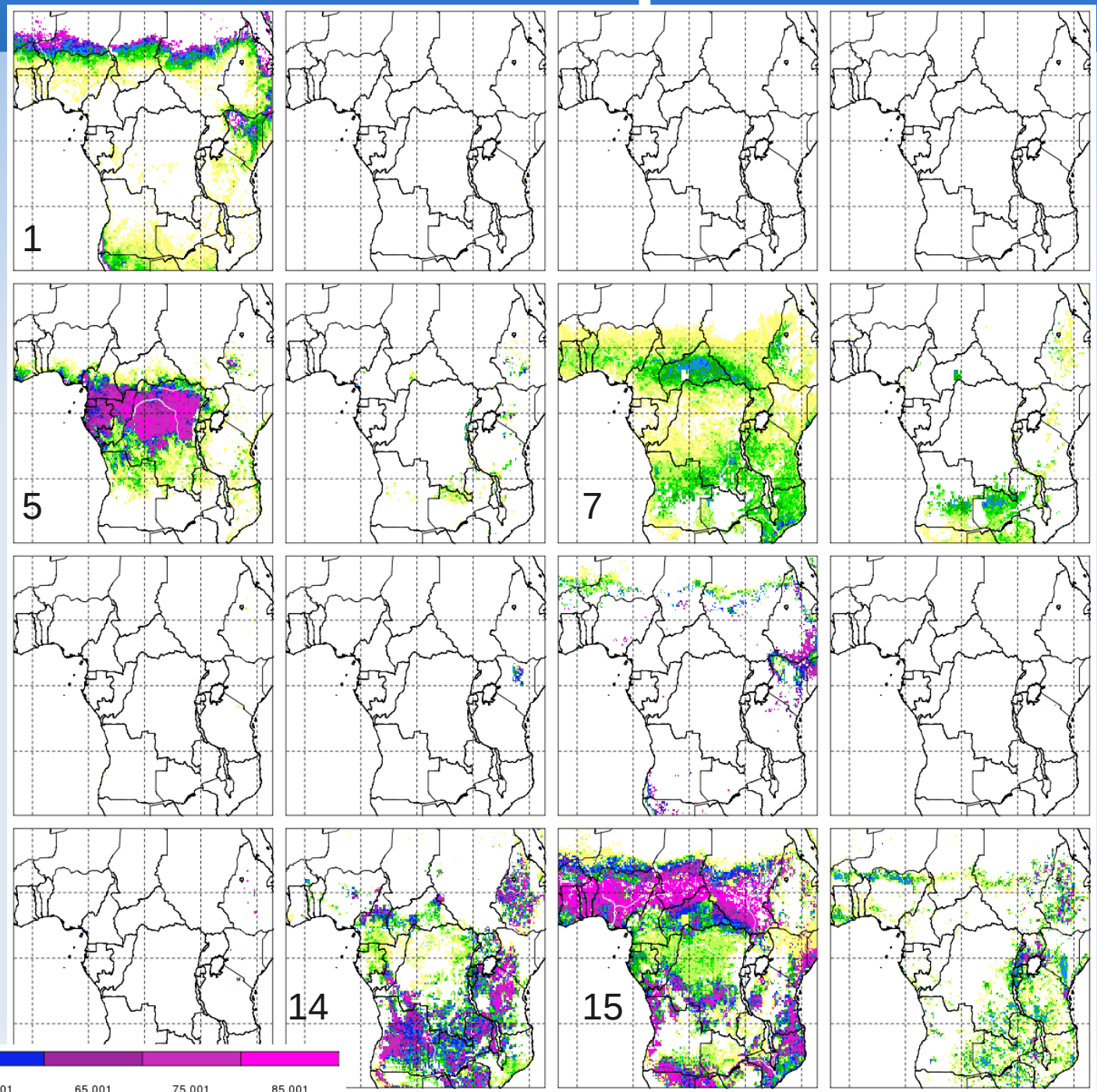
Conclusion:

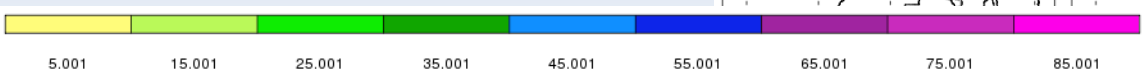
CCLM² (cosmo4.0) overestimates a lot above the Atlantic, but this seems to be mostly fixed in CCLM (cosmo4.8).



7. Results: deforestation experiment

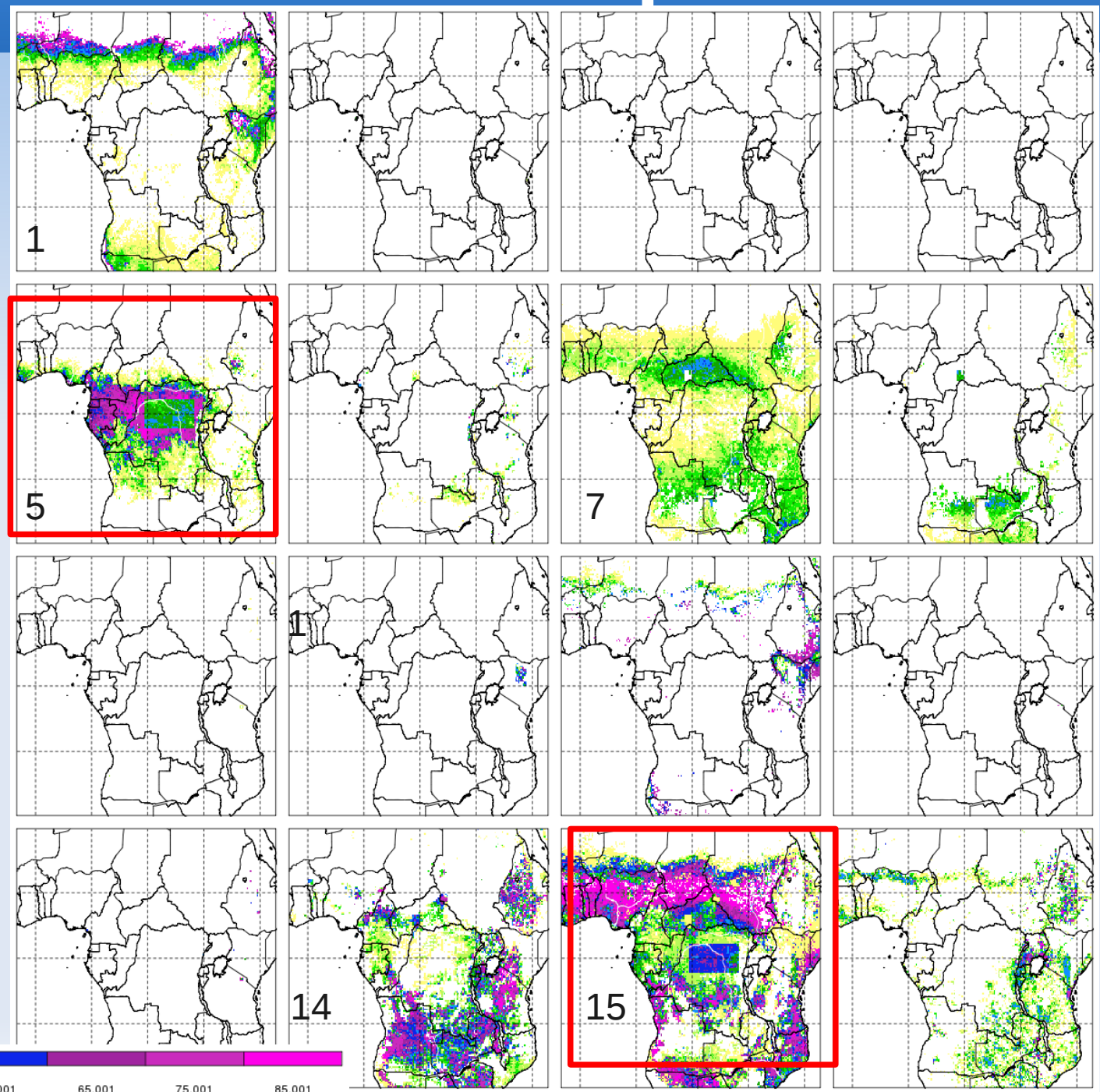
- PFT's (% of pixel area):
  - 1. Bare ground
  - 5. Evergreen tropical tree
  - 7. Deciduous tropical tree
  - 14. non-arctic grass C3
  - 15. grass C4





7. Results: deforestation experiment

- PFT's (% of pixel area):
  - 1. Bare ground
  - **5. Evergreen tropical tree: - 40%**
  - 7. Deciduous tropical tree
  - 14. non-arctic grass C3
  - **15. grass C4: + 40%**



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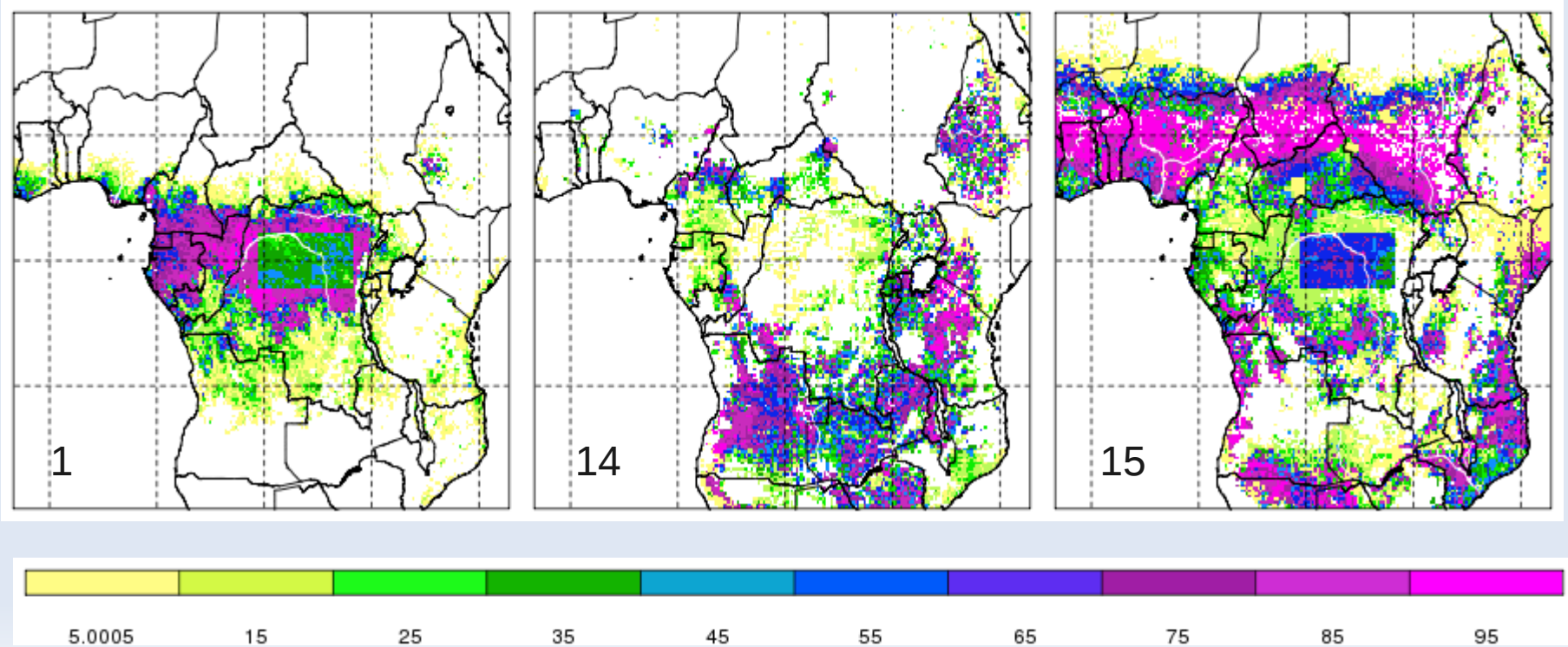
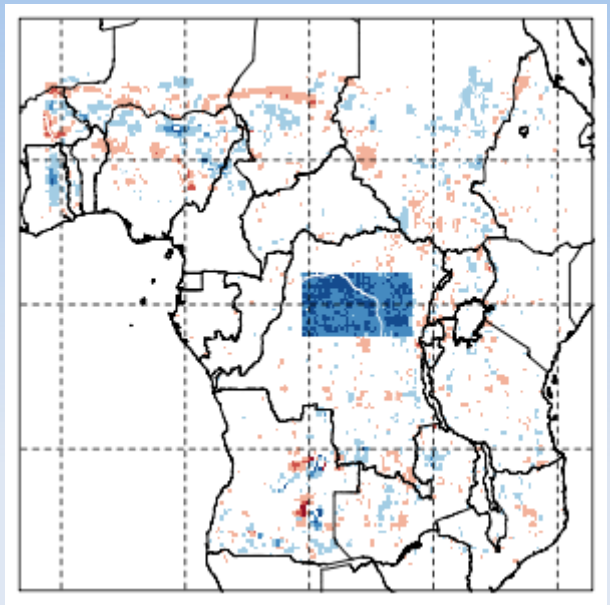
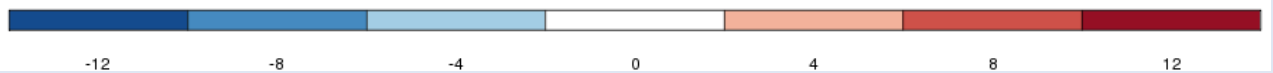


7. Results: deforestation experiment

- Result on average **latent** heat flux:
  - Local **decrease** from 8 - 12 W/m²
  - Mean of 2005



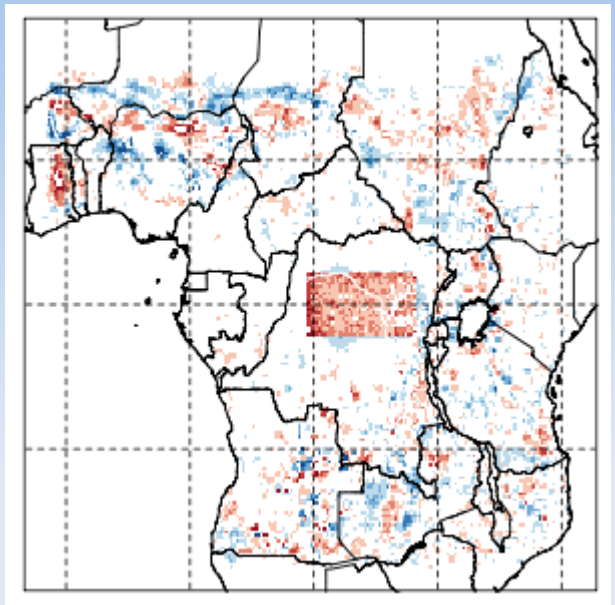
ALHFL_S: Deforested minus reference



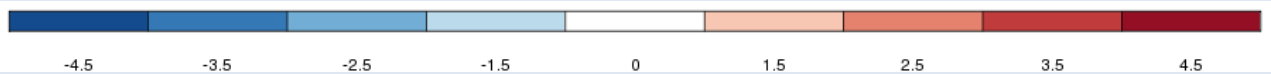
- CCLM configuration:
  - COSMO4.0 + CLM3.5 (CCLM²)
  - Horizontal resolution: 0.22°
  - 210 x 180 grid points
  - Namelist: CORDEX-Africa defaults with same exceptions

7. Results: deforestation experiment

- Result on average **sensible** heat flux:
  - Local **increase** from 1.5 - 3.5 W/m²
  - Mean of 2005



ASHFL_S: Deforested minus reference



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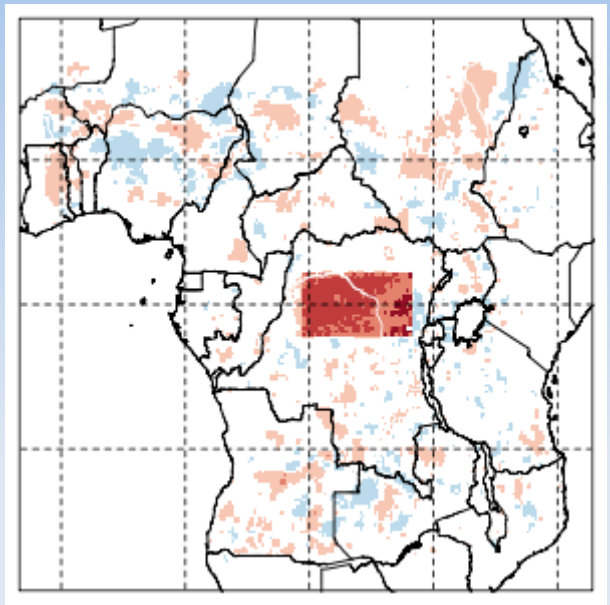
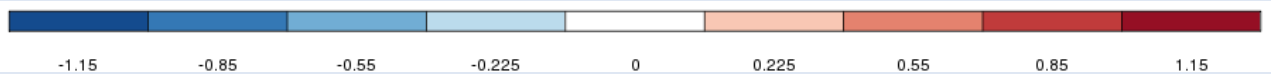
  - COSMO4.0 + CLM3.5 (CCLM²)
  - Horizontal resolution: 0.22°
  - 210 x 180 grid points
  - Namelist: CORDEX-Africa defaults with same exceptions

7. Results: deforestation experiment

- Result on average 2m temperature:
  - Local **increase** from 0.8 - 1.1 °C
  - Mean of 2005



T_2M_AV: Deforested minus reference



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  - COSMO4.0 + CLM3.5 (CCLM²)
  - Horizontal resolution: 0.22°
  - 210 x 180 grid points
  - Namelist: CORDEX-Africa defaults with same exceptions

8. Outlook

- The **Community Land Model** (*CLM3.5*) component has to be evaluated further with more flux observations. This will be done by additional flux series for natural forest environment. (data by Nouvellon, Y.)
- The performance of **CCLM** over Africa should be better, especially in respect to cloudiness which is important for the surface energy balance.
- Development of a range of possible **deforestation scenarios.** Hereby, the goal is *not* to establish a future state of the forest ”as realistic as possible” (the uncertainty over a timespan of 50 years is anyway too high), but to get a good understanding of the sensitivity of vegetation-climate feedbacks
- Performing the **long-term runs** (1989-2008, 2040-2060)

Vielen dank!