



21st Century Climate Prediction for West Africa and the Sahel

Kerry H. Cook, Edward K. Vizy, Julien Crétat, Naresh Neupane

**Understand how summer (JAS) rainfall may change
over West Africa and the Sahel
during this century due to increased greenhouse gas forcing**

- I. Evaluation of GCM and RCM simulations of the current climate**
- II. Mid- and Late 21st century rainfall projections from GCMs and RCM**
- III. Assessing confidence: Physical analysis of the RCM predictions**

Model's description – CMIP5 Atmosphere-Ocean Global Circulation Models

- 5 Models with prescribed CO₂

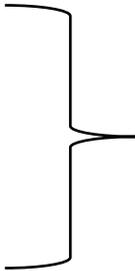
	Hor. Res.
CCSM4	1.25 x 0.94
CNRM-CM5	1.41 x 1.4
GFDL-CM3	2.5 x 2.0
MIROC5	1.4 x 1.4
MRI-CGCM3	1.12 x 1.12



- available online in January 2012
- retained due to their realistic seasonal SST patterns during the 21st century

- 2 Experiments

	Period
Historical	the last 20-years
RCP8.5	2040 – 2060
	2080 – 2100



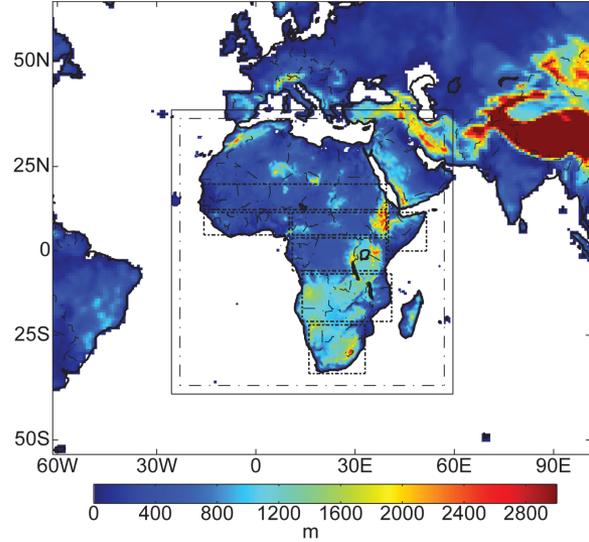
- evaluate RCM simulations
- construct RCM driven fields for the Mid- and Late-21st century

Model's description – Regional Climate Model

- 3 Simulations: Control – Mid-21C – Late-21C**

- ✓ **Main common settings**

- WRF v3.1.1
- two one-way nested domains set at 90-km (D1) & 30-km (D2)
- 6-hourly boundary conditions
- same physical parameterizations [Yonsei PBL; Monin-Obukhov SL; Kain-Fritsch CU; Purdue Lin MP; RRTM LWR & Dudhia SWR; NOAA LSM]
- spin-up: ~10 months
- 20-year continuous simulation



- ✓ **Differences**

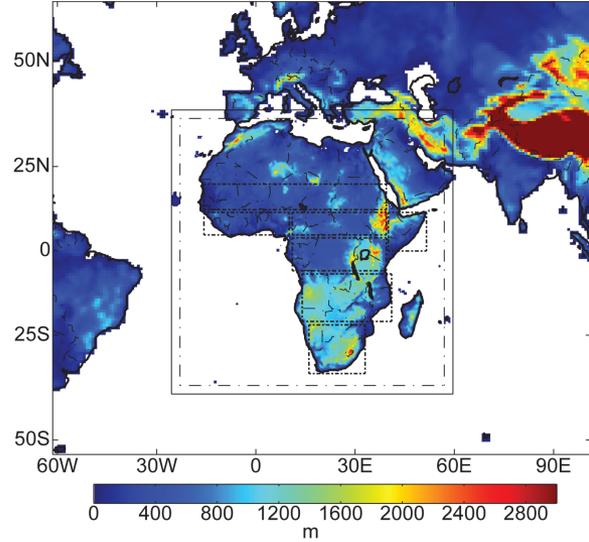
	Control (1989 – 2008)	Mid-21C (2041 – 2060)	Late-21C (2081 – 2100)
Boundary forcings	NCEP2	NCEP2 + monthly anomaly values averaged over the 5 AOGCMs linearly interpolated at 6-hourly timescale	
CO₂ concentration	367 ppmv	546 ppmv	850 ppmv

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✓ Differences

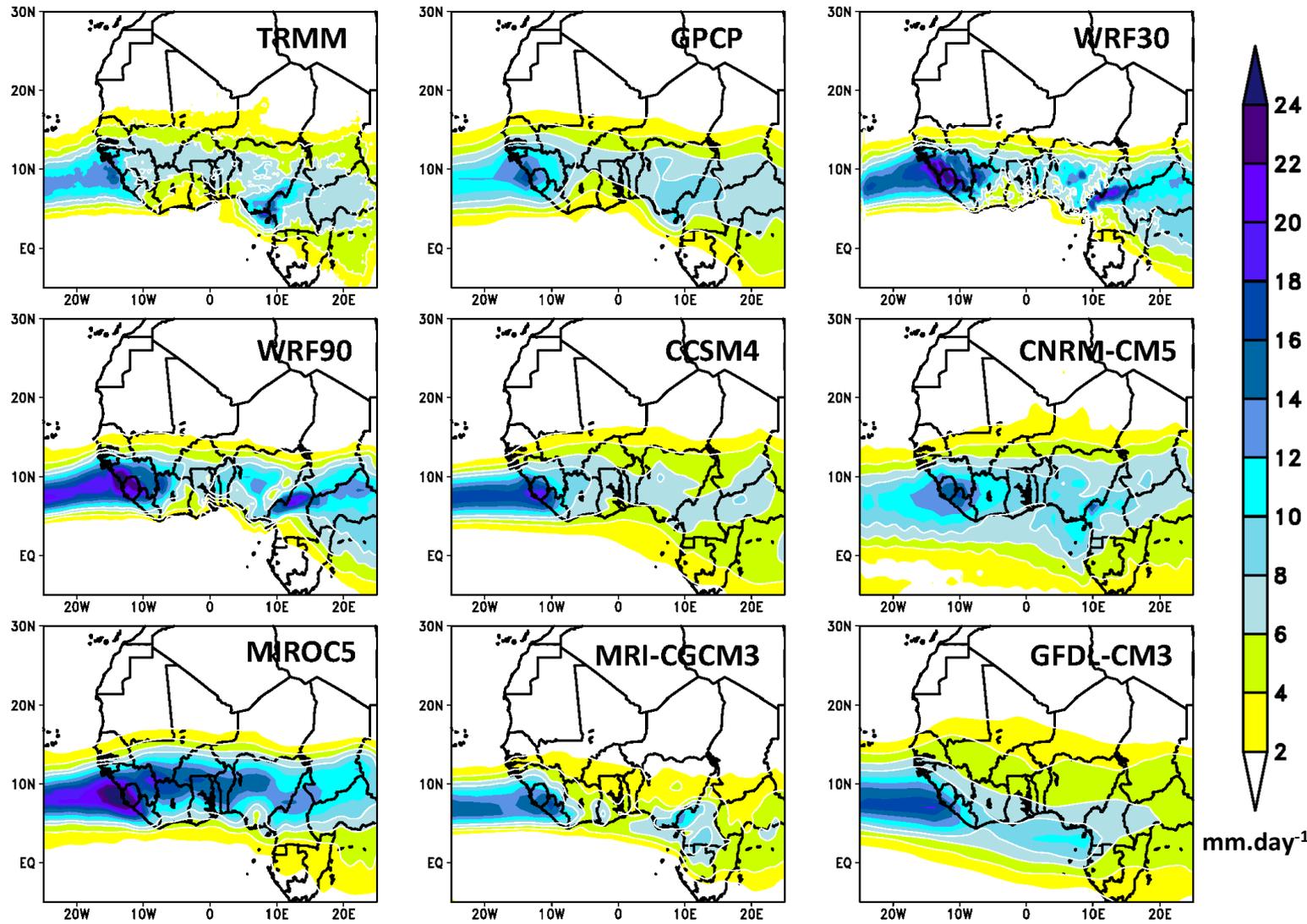
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Only 9 years available at 30-km due to technical issues

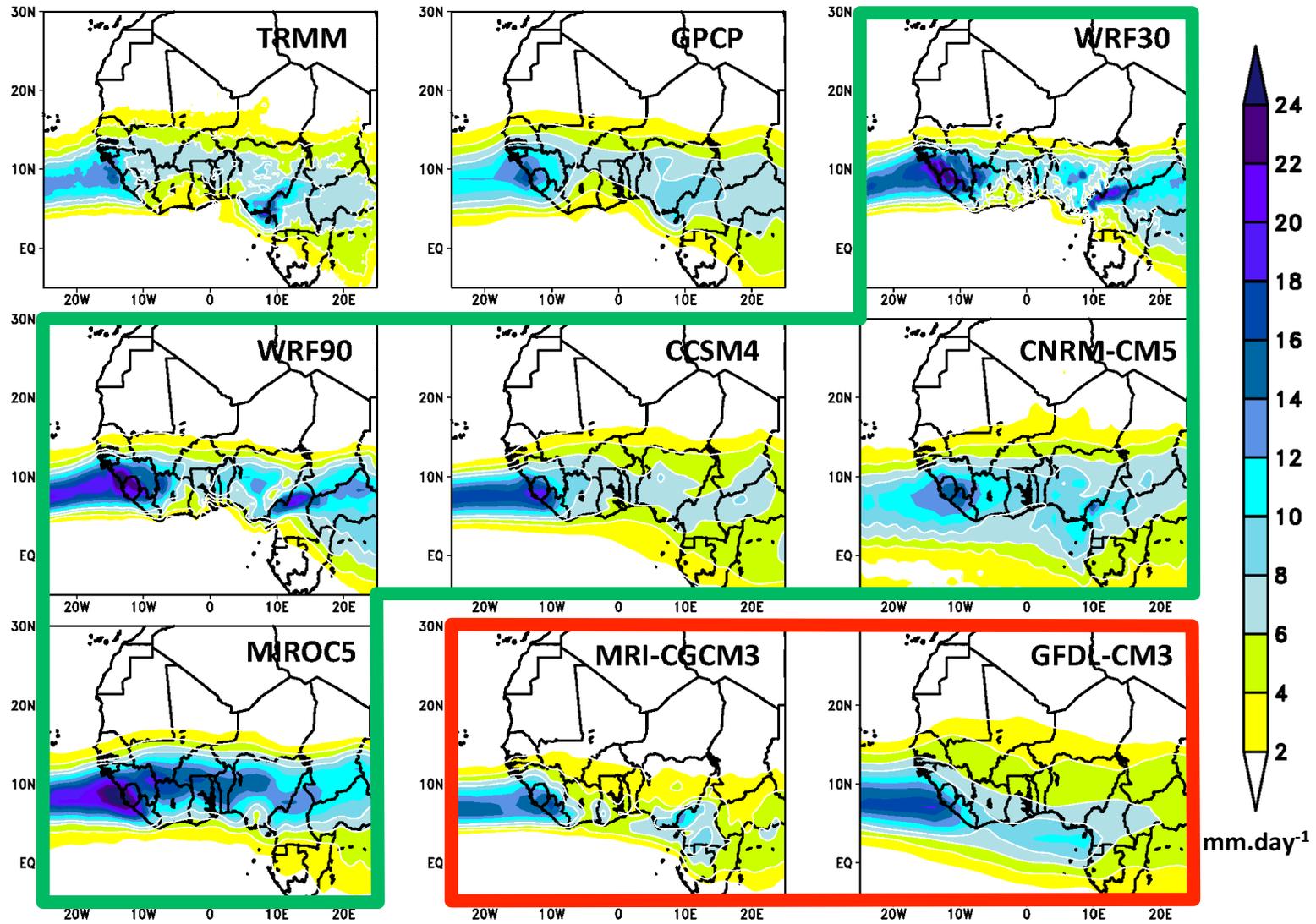
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Seasonal (JAS) rainfall

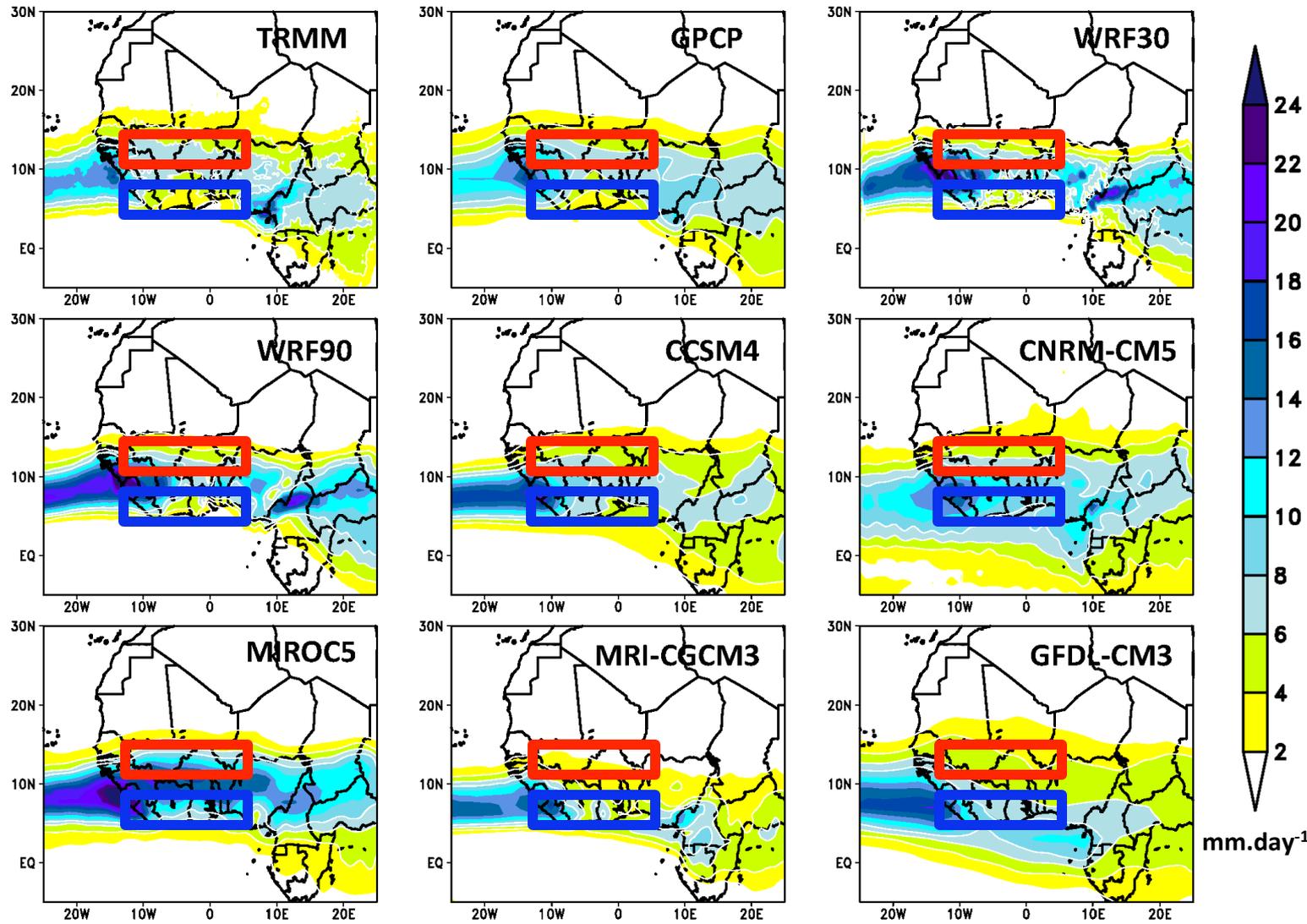


Seasonal (JAS) rainfall



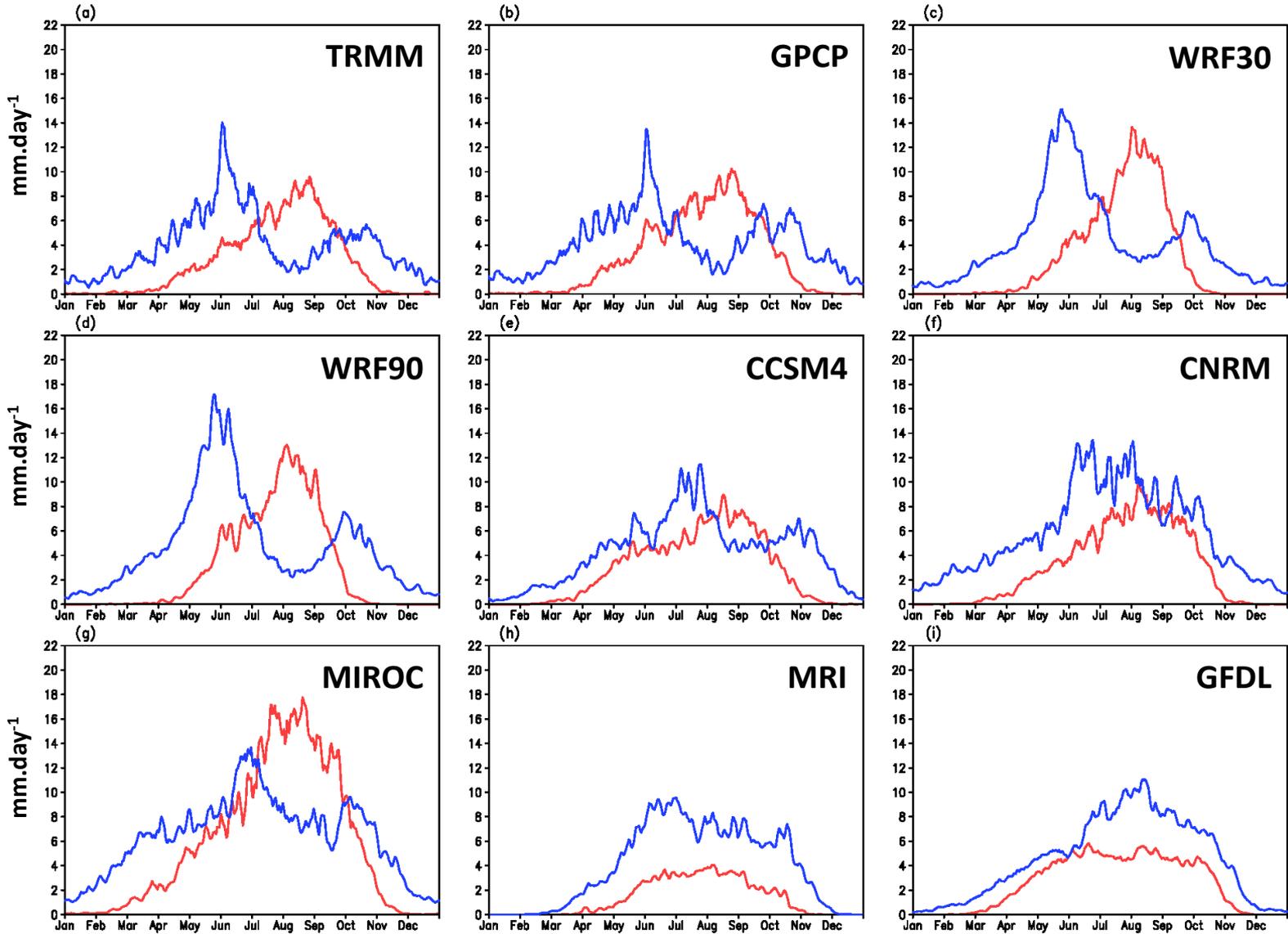
Seasonal distribution generally well captured (except MRI & GFDL)

Seasonal (JAS) rainfall



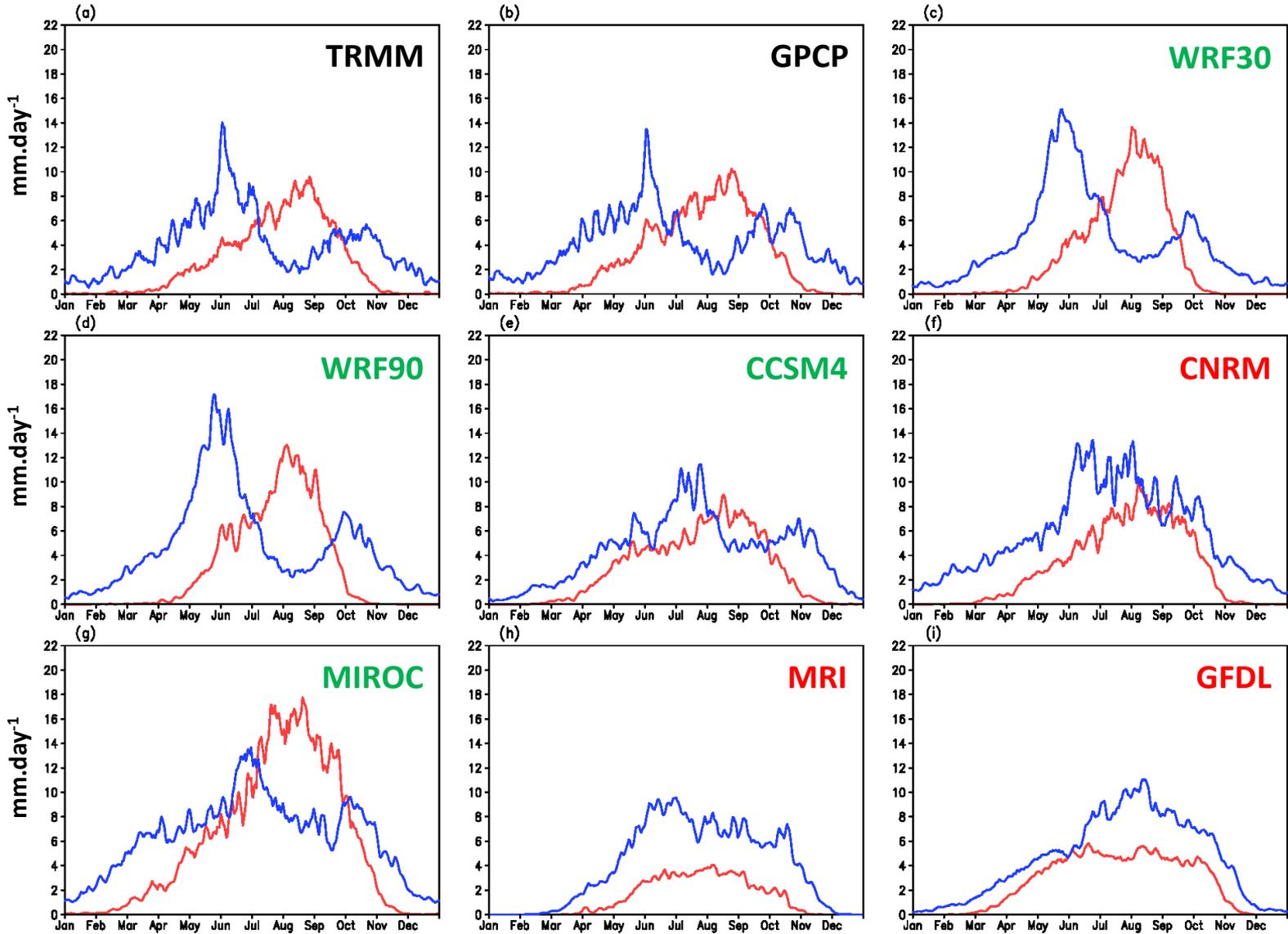
Gulf of Guinea [4-7N] & Sahel [10-13N]

Annual rainfall* cycle [12W – 6E] over Gulf of Guinea [4-7N] & Sahel [10-13N]



* 5-day average

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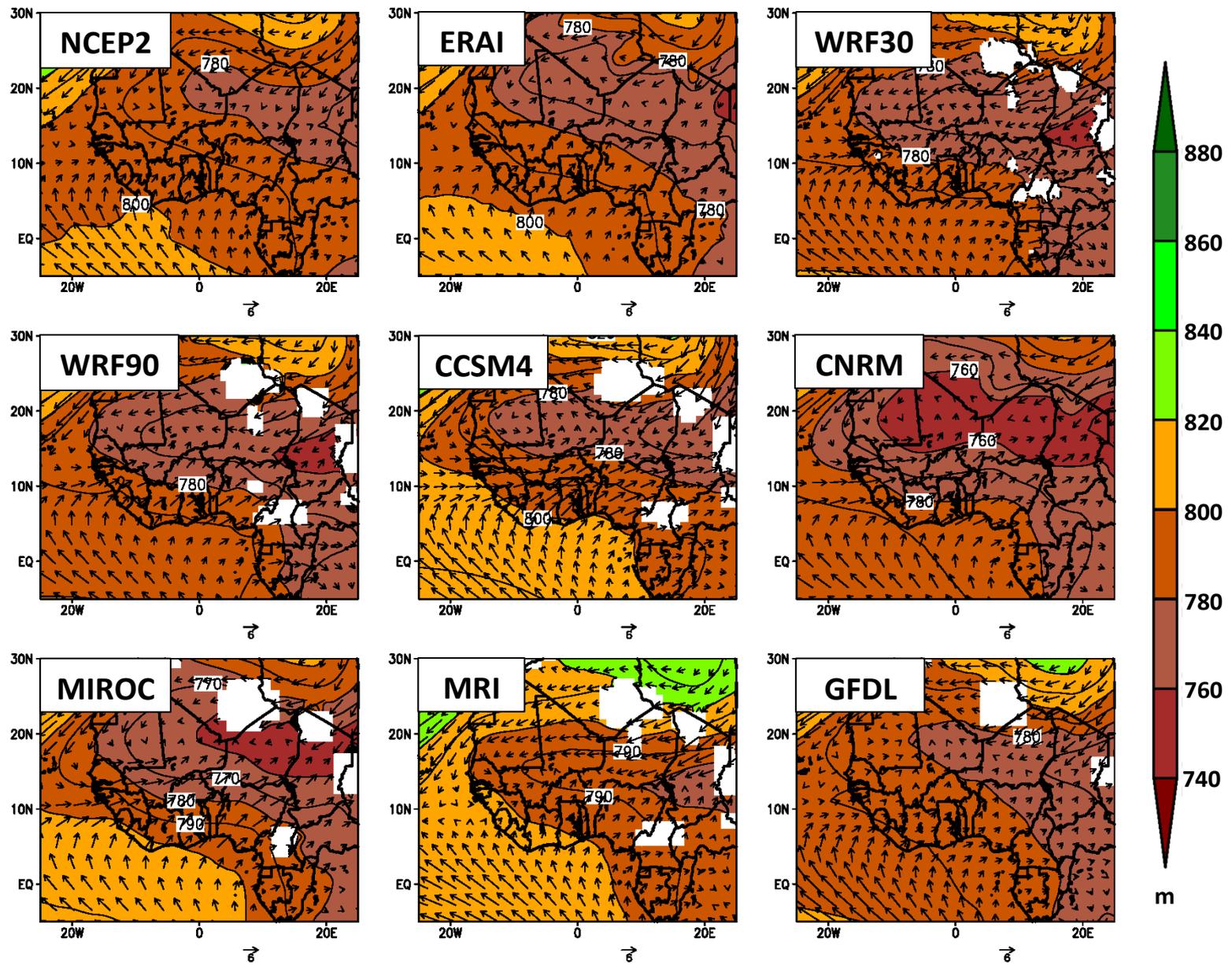


Realistic seasonal evolution with bimodal *versus* unimodal rainfall regime

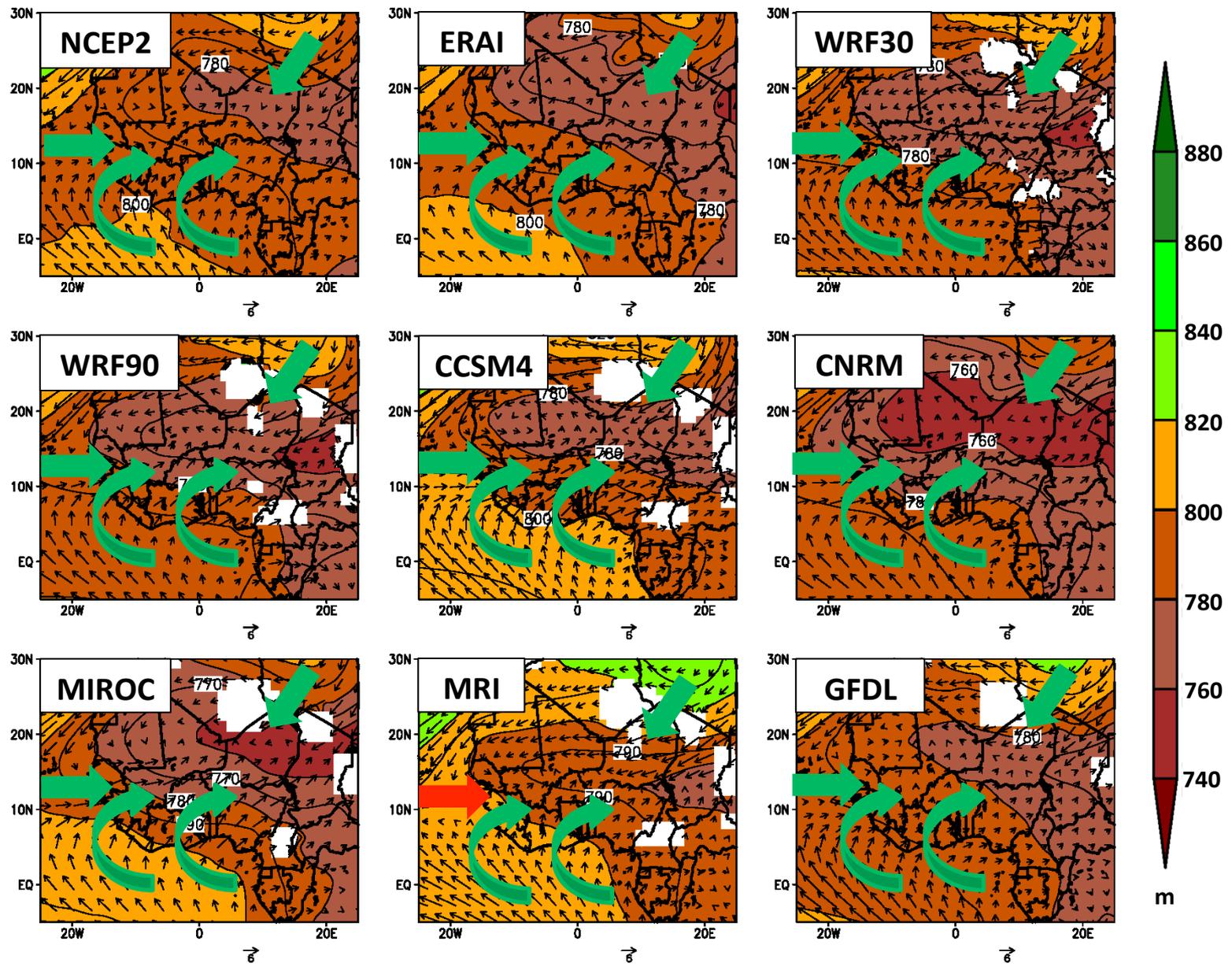
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Only unimodal rainfall distribution

Seasonal (JAS) low-level circulation: 925hPa geopotential height and wind



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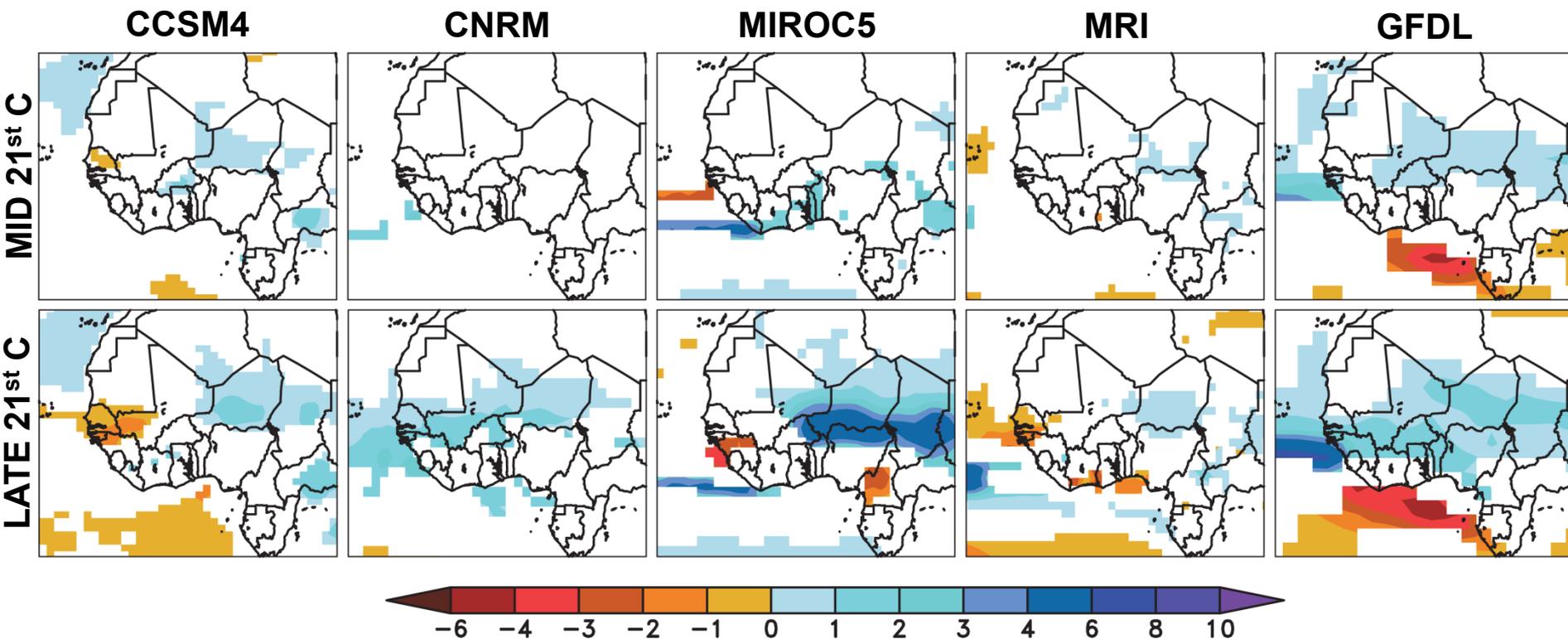


Main patterns well simulated (except the West African westerly jet in MRI)

**Mean rainfall characteristics reasonably captured
over West Africa**

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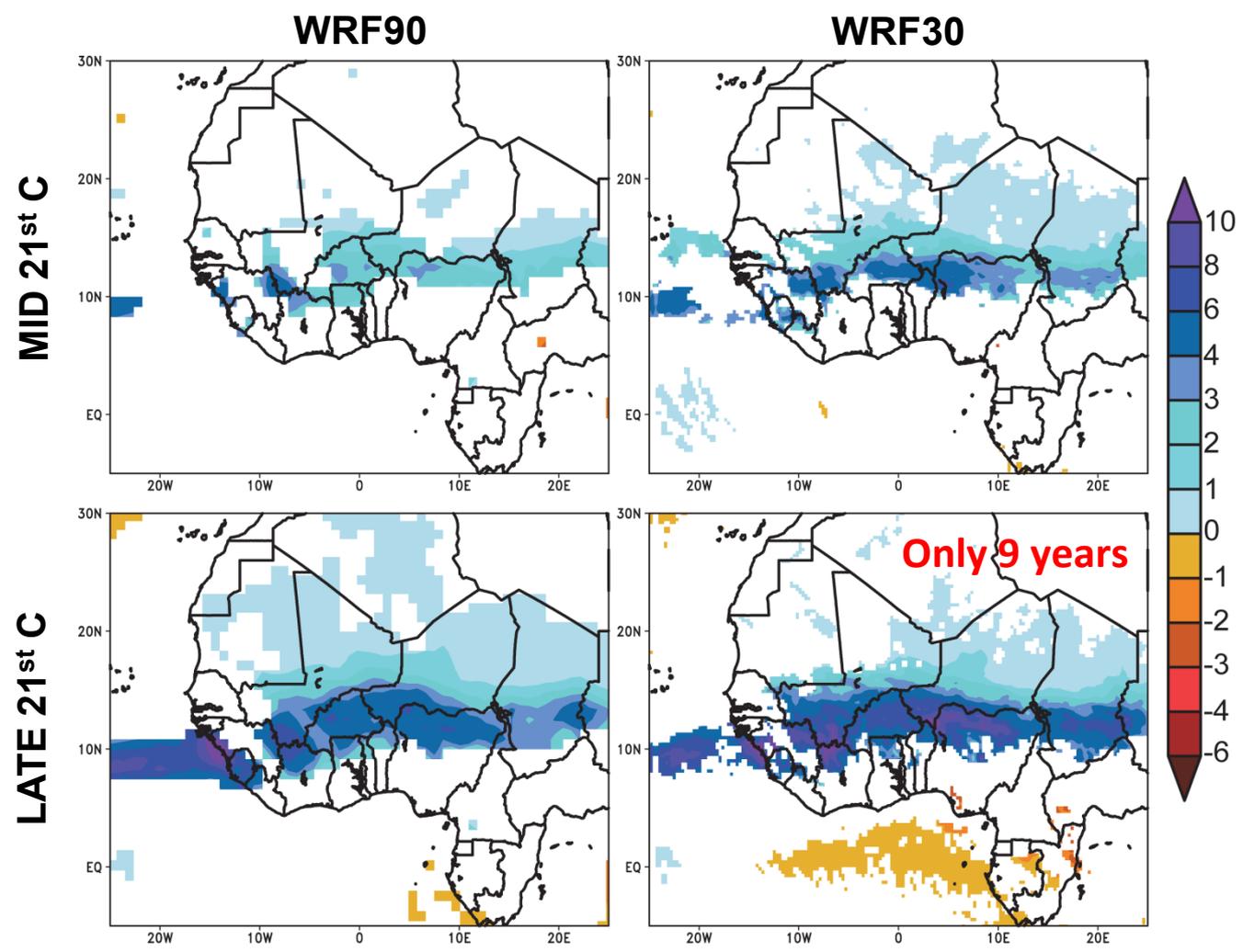
Seasonal summer (JAS) rainfall projections: CMIP5 AOGCM significant anomalies



MID 21st C: weak increase in the Sahel => 2 models

LATE 21st C: wetter than MID 21st C => all models

Seasonal summer (JAS) rainfall projections: RCM significant anomalies



~ Similar results with higher values

**Rather good agreement between global and regional simulations in the Sahel:
increase of seasonal rainfall amounts**

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Where is the moisture coming from to supply the increase precipitation in the Sahel?

Changes in observed modes of variability?

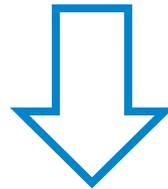
Stronger monsoon flow across the Guinean coast

Weaker and or repositioned African easterly jet

Stronger West African westerly jet

& / OR

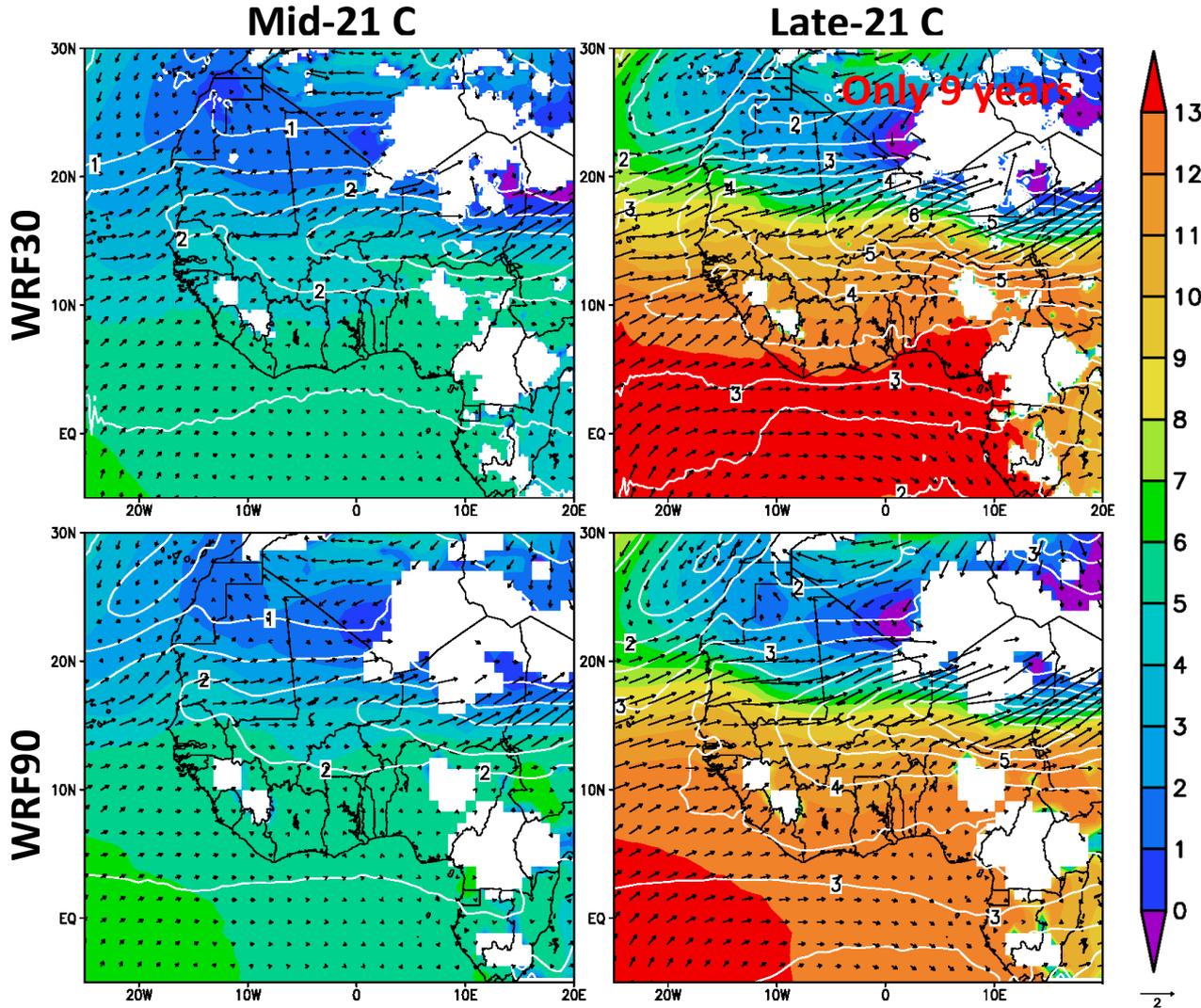
New physical processes emerging?



Low-level circulation modification

Where is the moisture coming from to supply the increase precipitation in the Sahel?

925hPa circulation anomalies



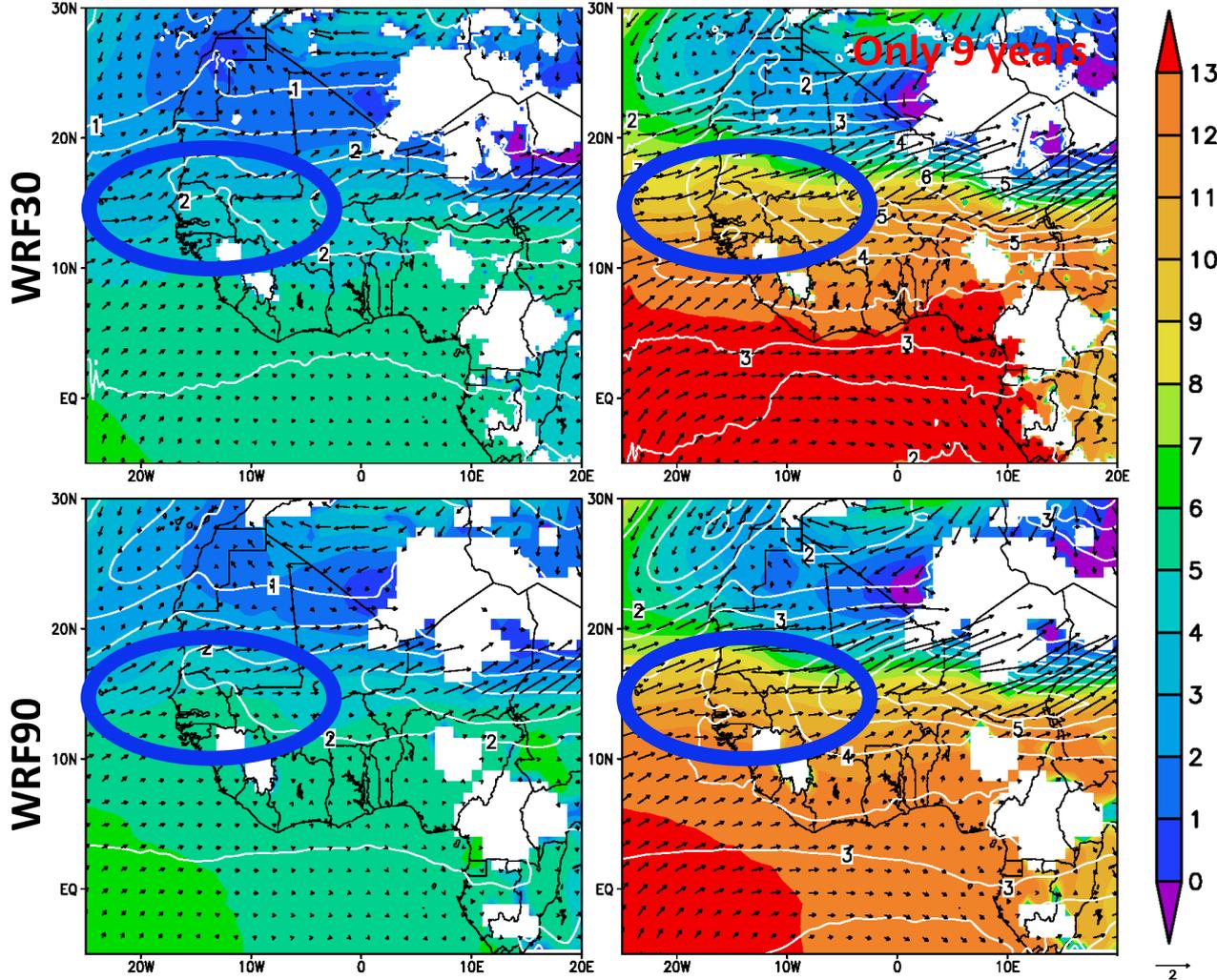
Shading = heights (m) / Vectors = winds(m.s⁻¹) / Contour = mixing ratio (g.kg⁻¹)

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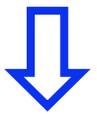
925hPa circulation anomalies

Mid-21 C

Late-21 C



Strengthening of West African Westerly jet



Response to the strength and shape of the thermal low (Pu and Cook 2011, 2012)

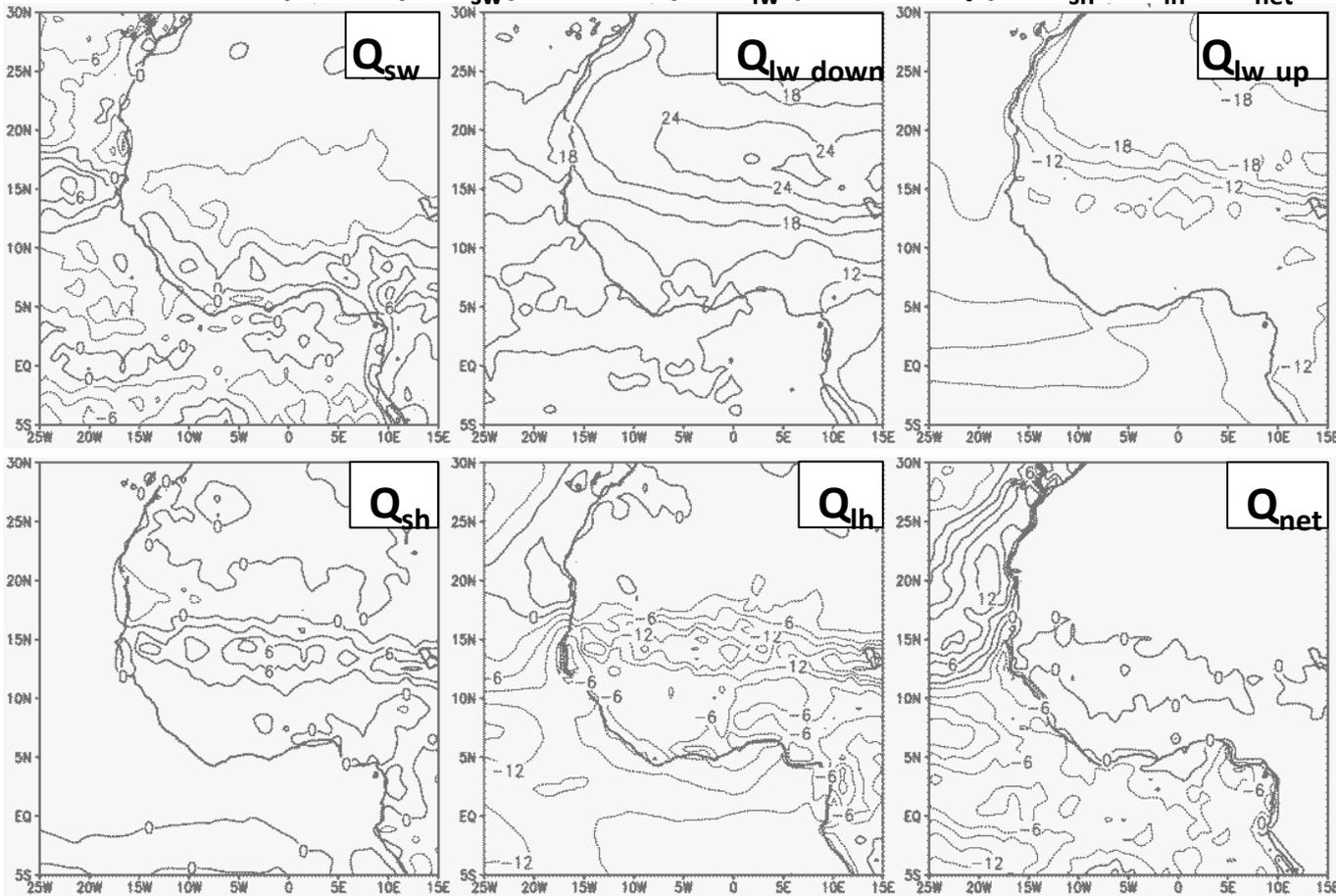
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What is controlling the thermal low?

Case study: WRF90 [Mid-21st C – Control]

(same results obtained for Late-21st C [with higher values])

Heat Balance ($W.m^{-2}$): $Q_{sw}(1-\text{albedo}) + Q_{lw}(\text{down} + \text{up}) + Q_{sh} + Q_{lh} = Q_{net}$



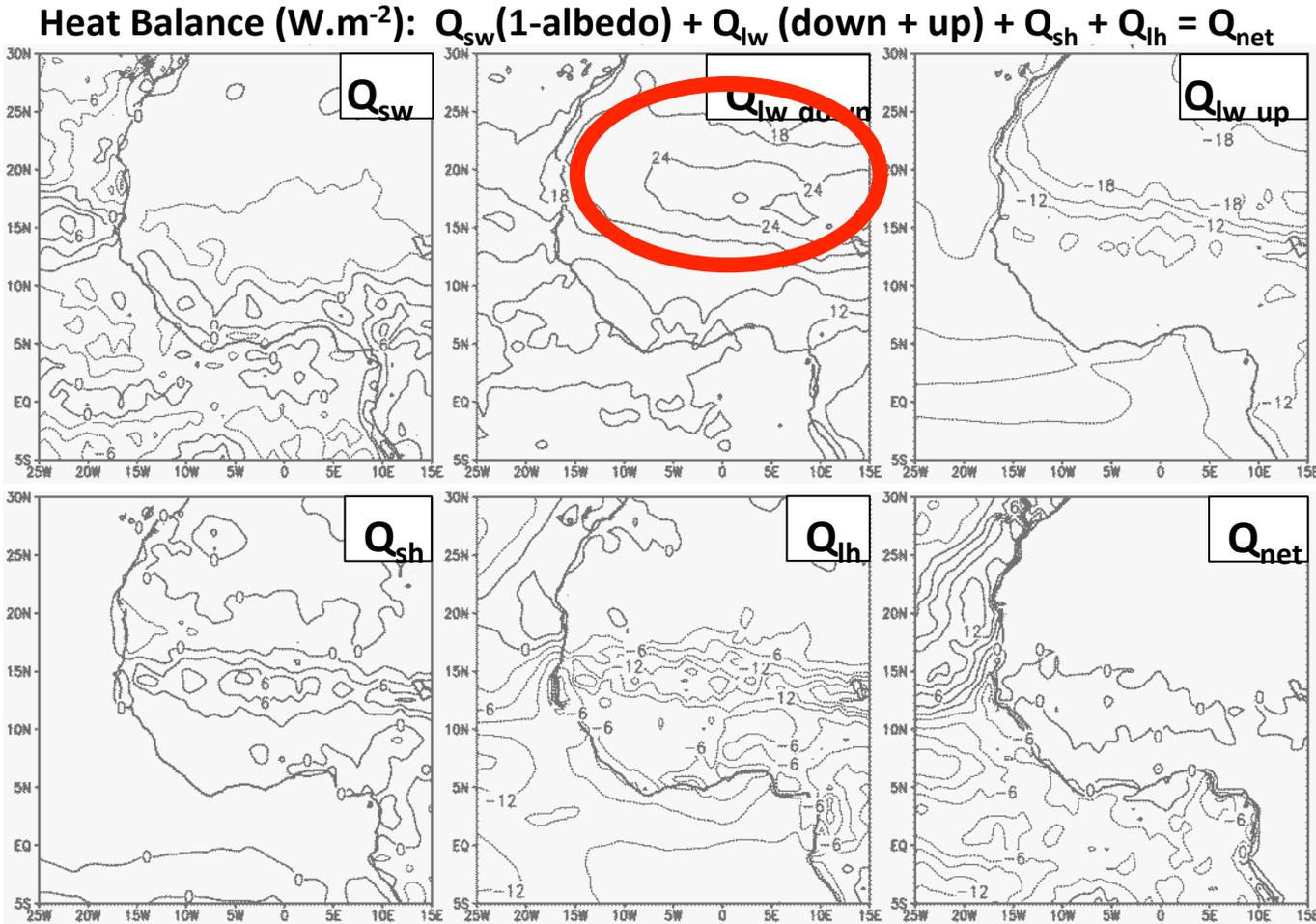
Contour interval at 3 W/m^2

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Increase of
LW back radiation
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Sahara and Sahel



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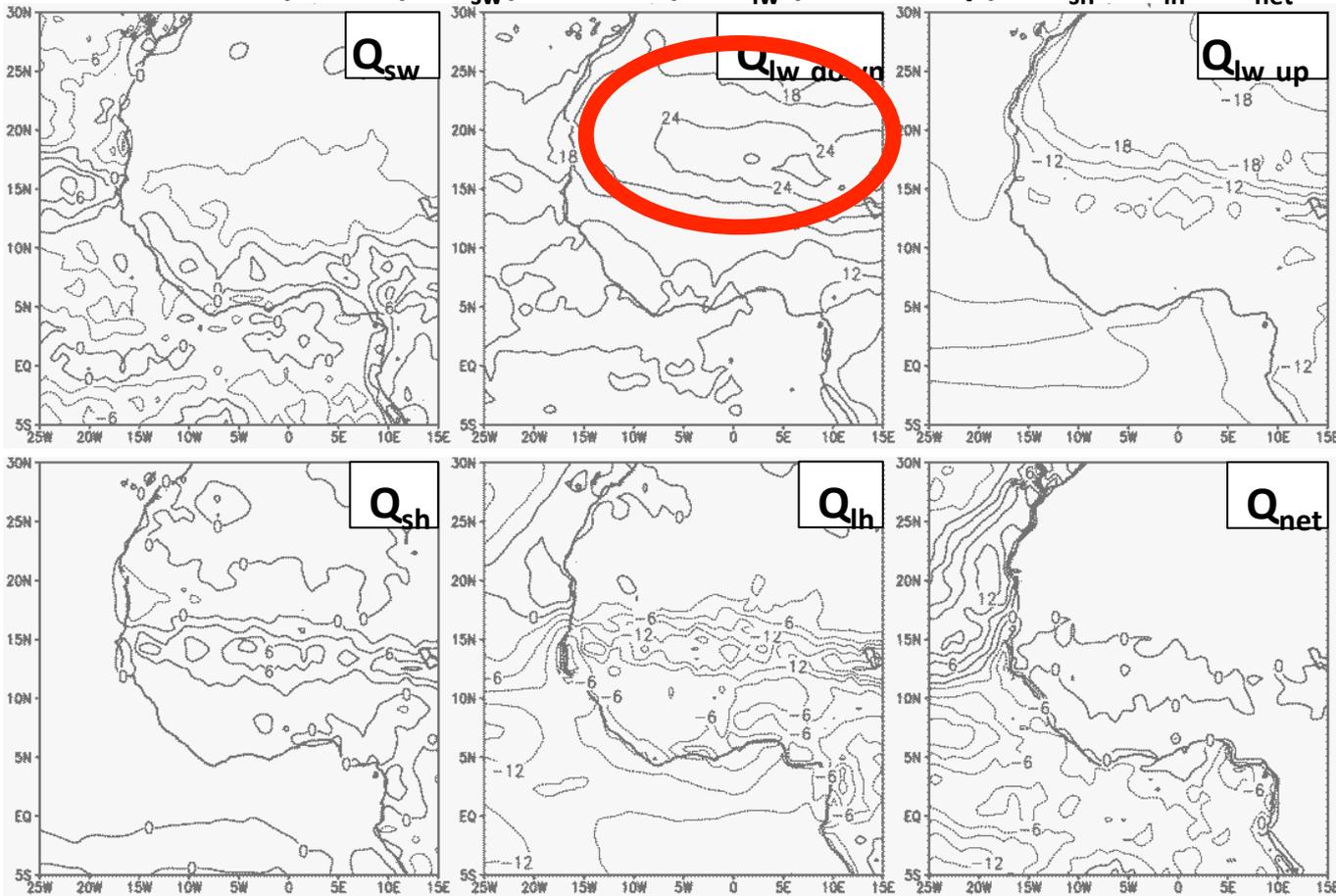
Increase of
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According to
LW_{down}-CO₂
relationship
[DF(CO₂) = 6.3 ln (C/C₀)]



2.5 W.m⁻²

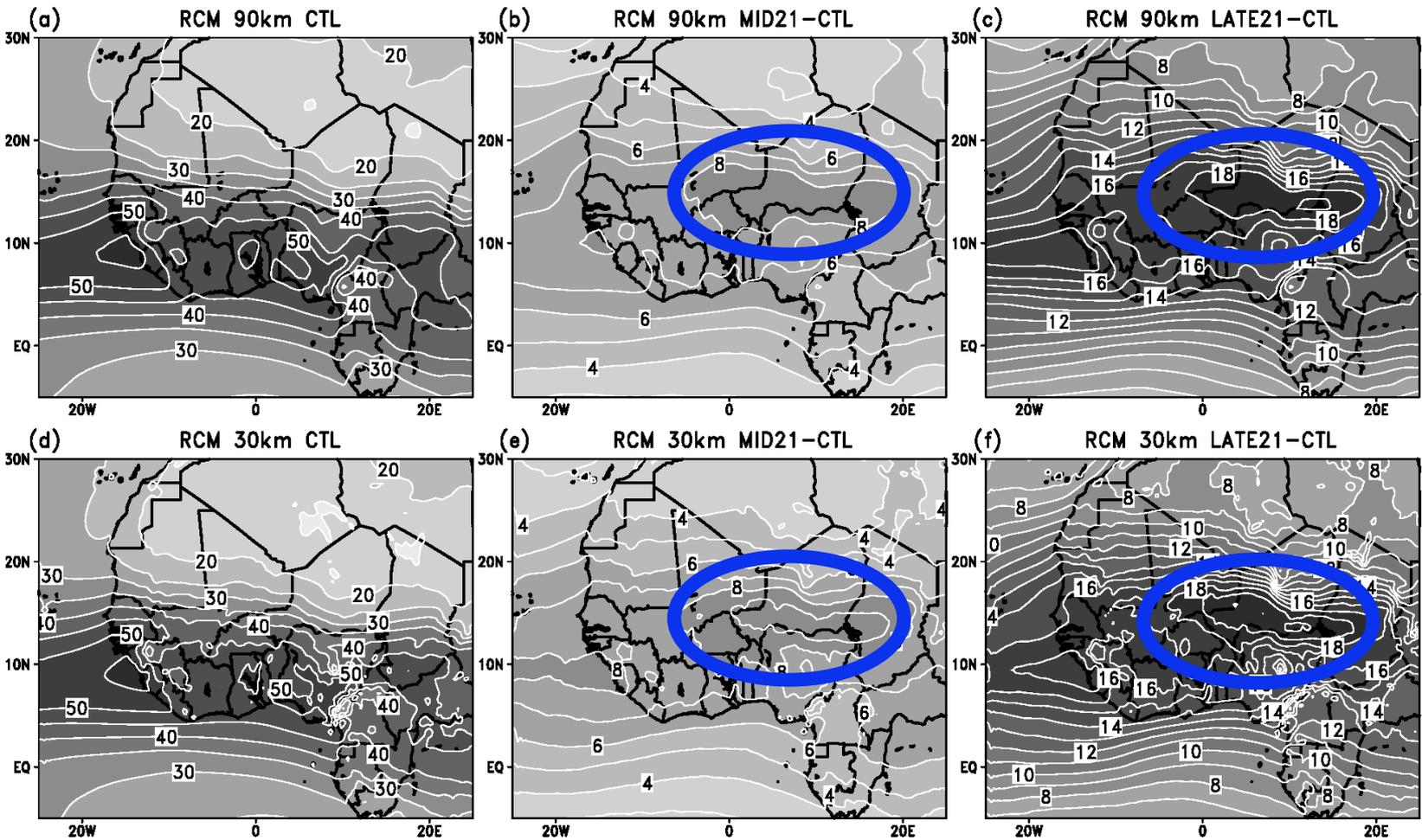
Heat Balance (W.m⁻²): $Q_{sw}(1-\text{albedo}) + Q_{lw}(\text{down} + \text{up}) + Q_{sh} + Q_{lh} = Q_{net}$



10-15% of LW back radiation changes related to direct greenhouse gas forcing

How to explain the remaining part?

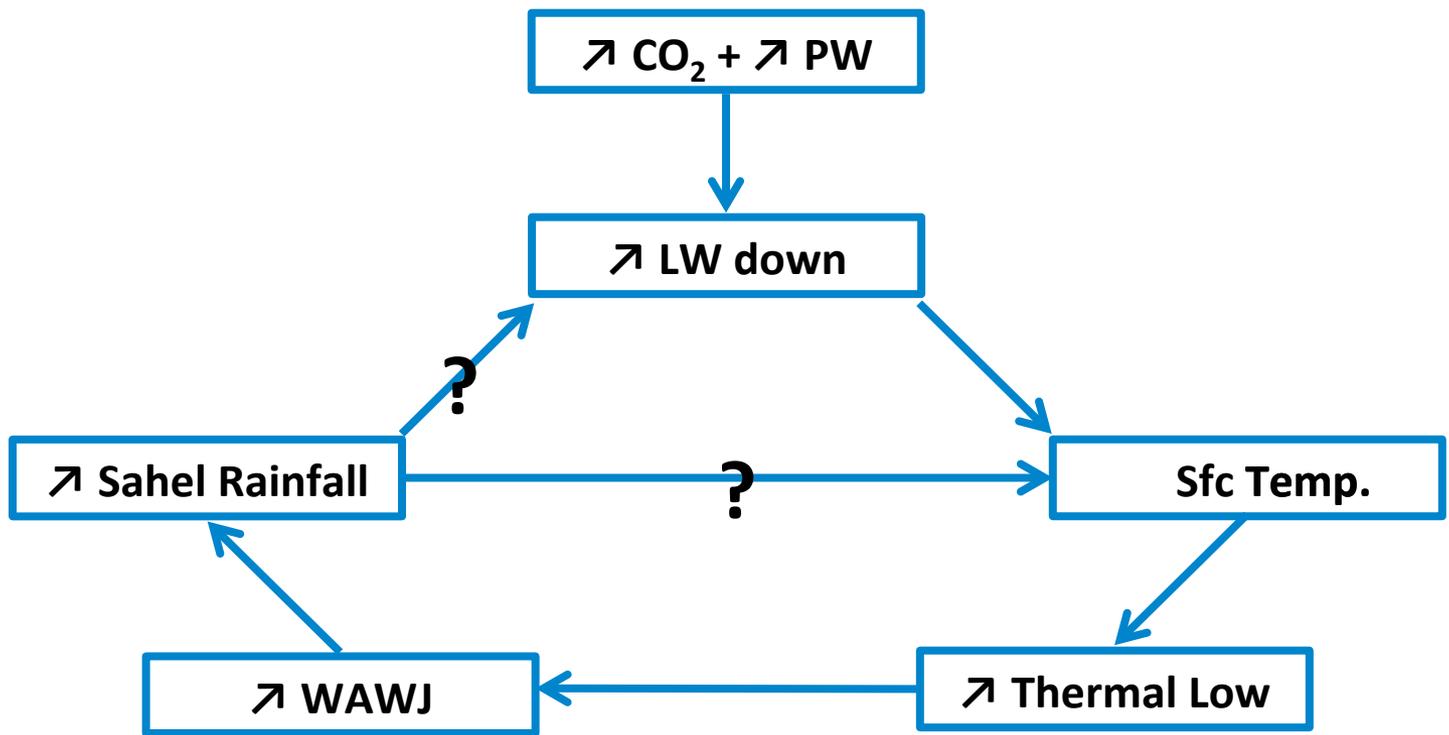
Seasonal precipitable water (mm)



Mostly related to increase in water vapor

Conclusion | Prospects

Significant increase of Sahel precipitation with a realistic physics

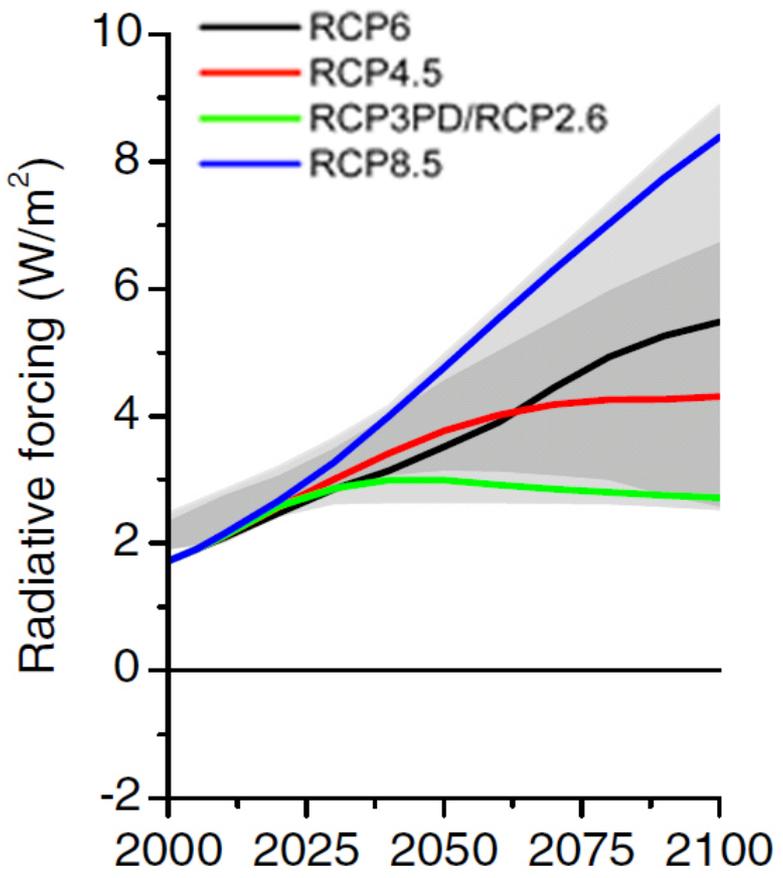


seasonal increase to changes in daily extreme rainfall events

Thank you!

Extra Slides

Representative Concentration Pathways (RCPs)



Vuuren *et al* 2011

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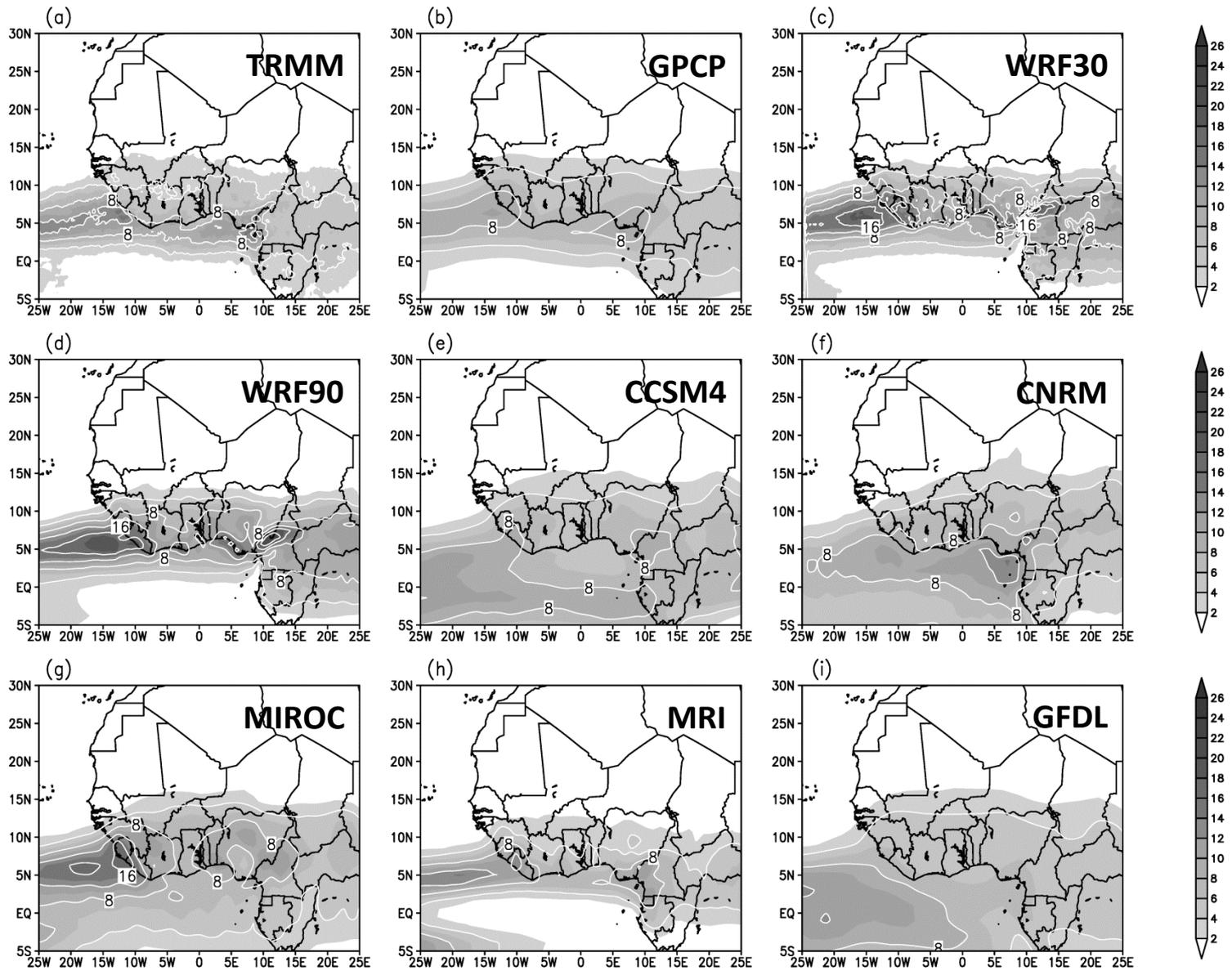
Region	Scenario	Variable	Unit	2000	2005	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
World	MESSAGE - RCP 8.5	Concentration - CO2	ppm	368.865	378.813	389.324	415.780	448.835	489.435	540.543	603.520	677.078	758.182	844.805	935.874
Region	Historic	Variable	Unit	1980	1990	2000	2005								
World	ID - hist	Concentration - CO2	ppm	338.360	353.855	368.865	378.813								

© RCP Database (Version 2.0.5) <http://www.iiasa.ac.at/web-pps/tnt/RcpDb>
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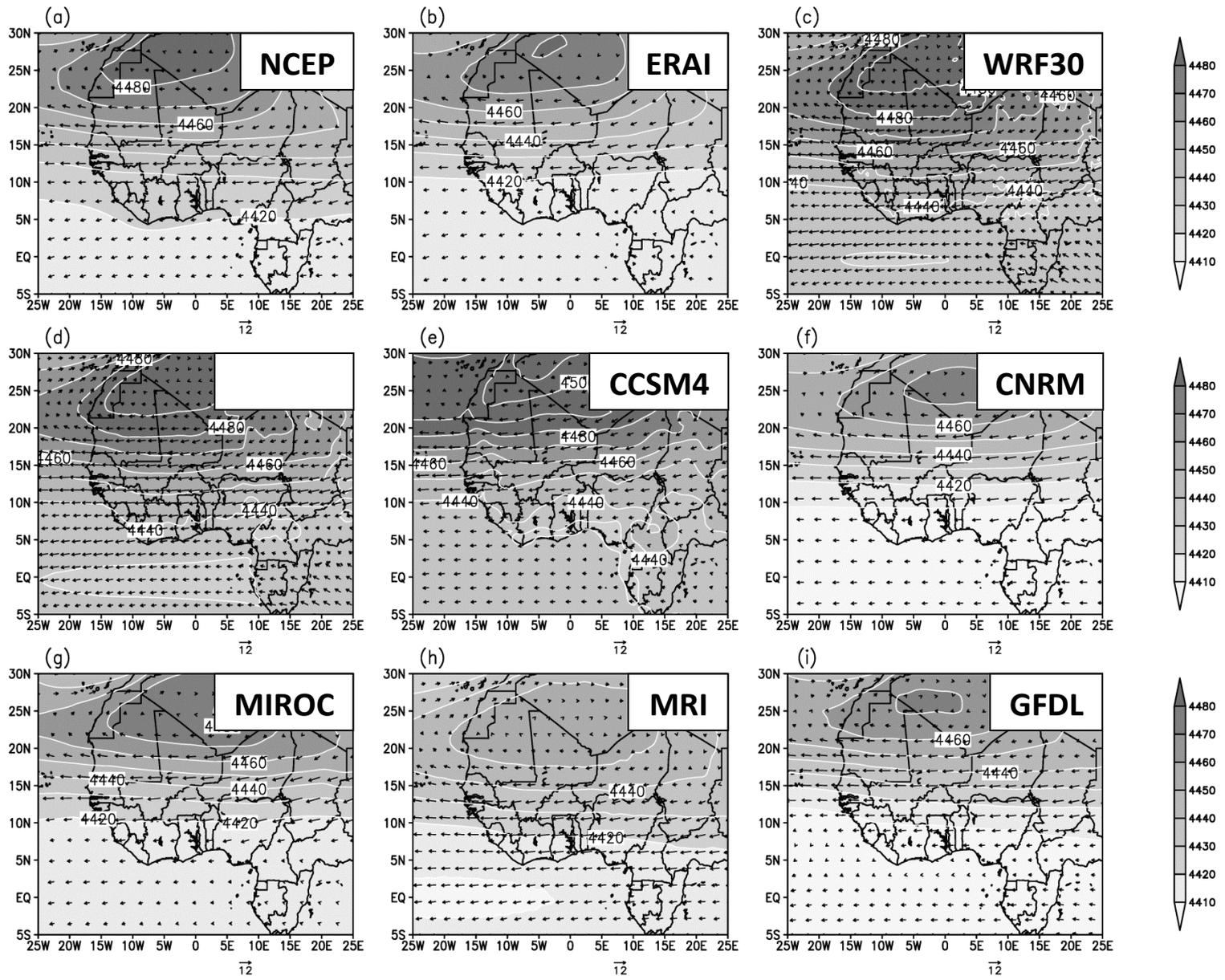
I. Evaluation of GCM and RCM climatology of the current climate

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May-June rainfall (mm.day⁻¹)



Seasonal (JAS) low-level circulation: 600hPa geopotential height and wind



II. Mid- and Late 21st century rainfall projections from GCMs and RCM

III. **Assessing confidence in the projections: Analysis of the RCM predictions**

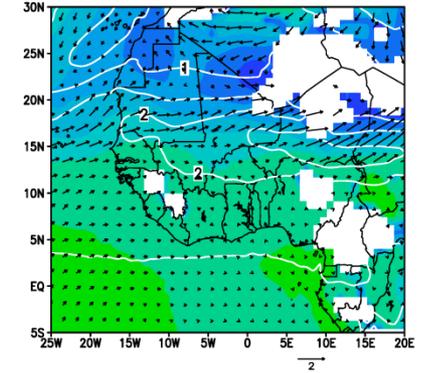
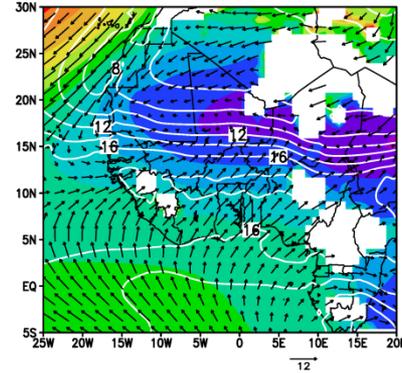
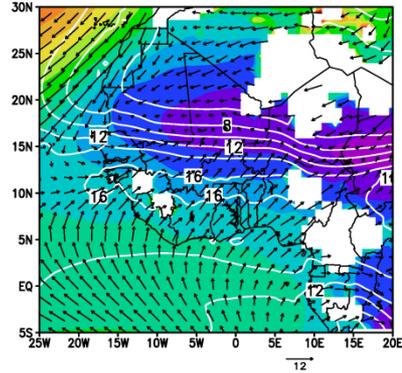
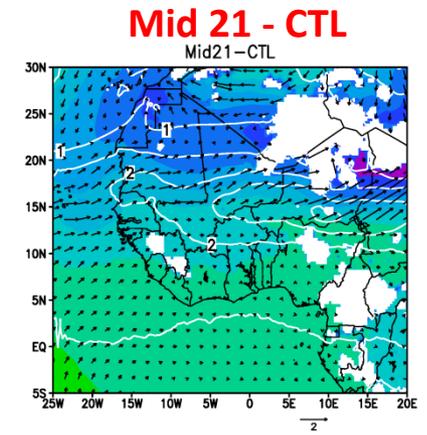
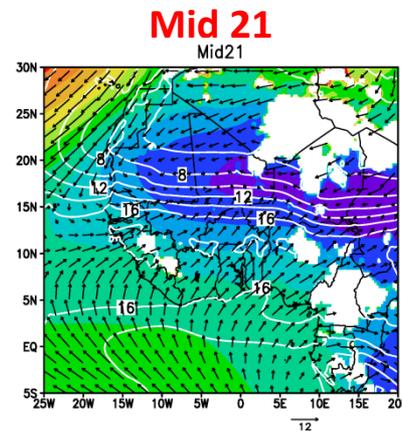
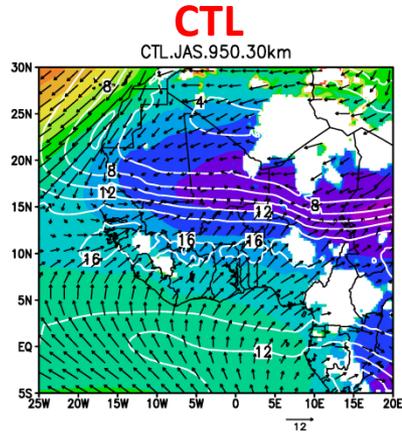
20 years avg. heights (shaded, m), winds(vectors, m/s) and mixing ratio (contour, g/kg) at 950 hPa

JAS

30km

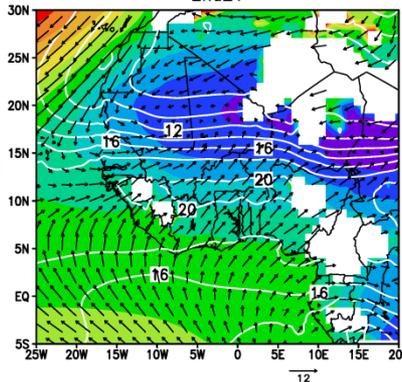
90km

90km



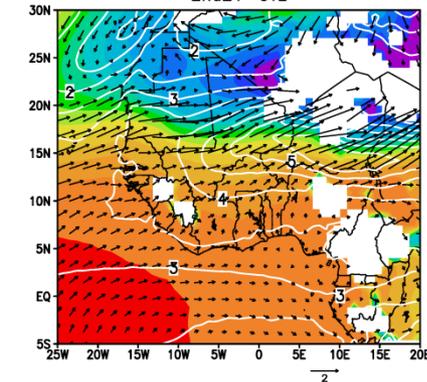
End 21

End21



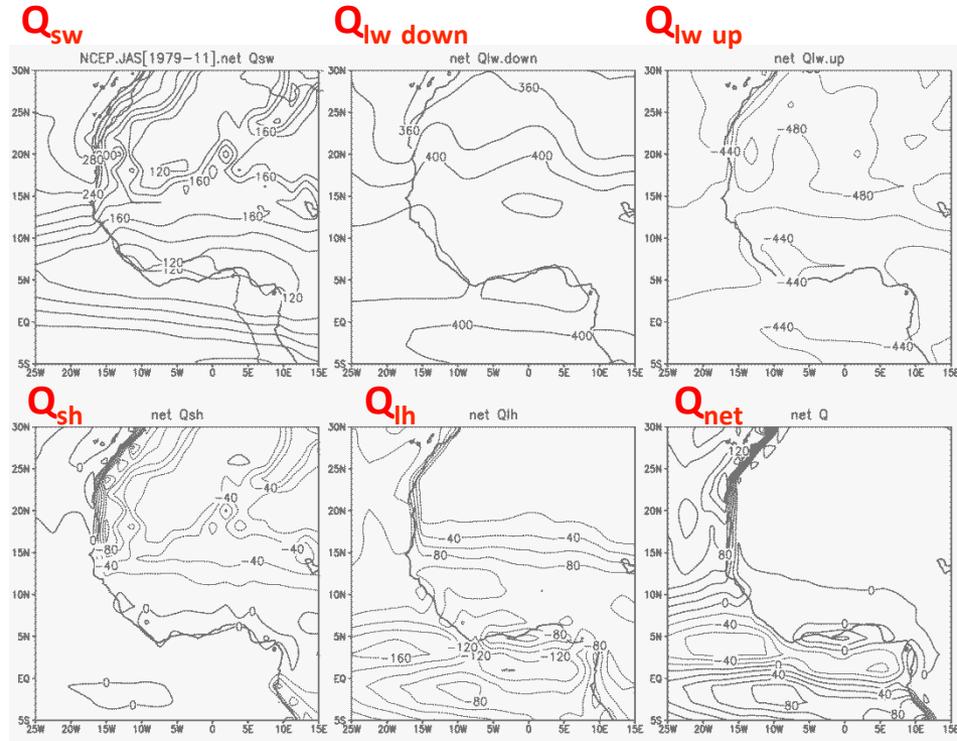
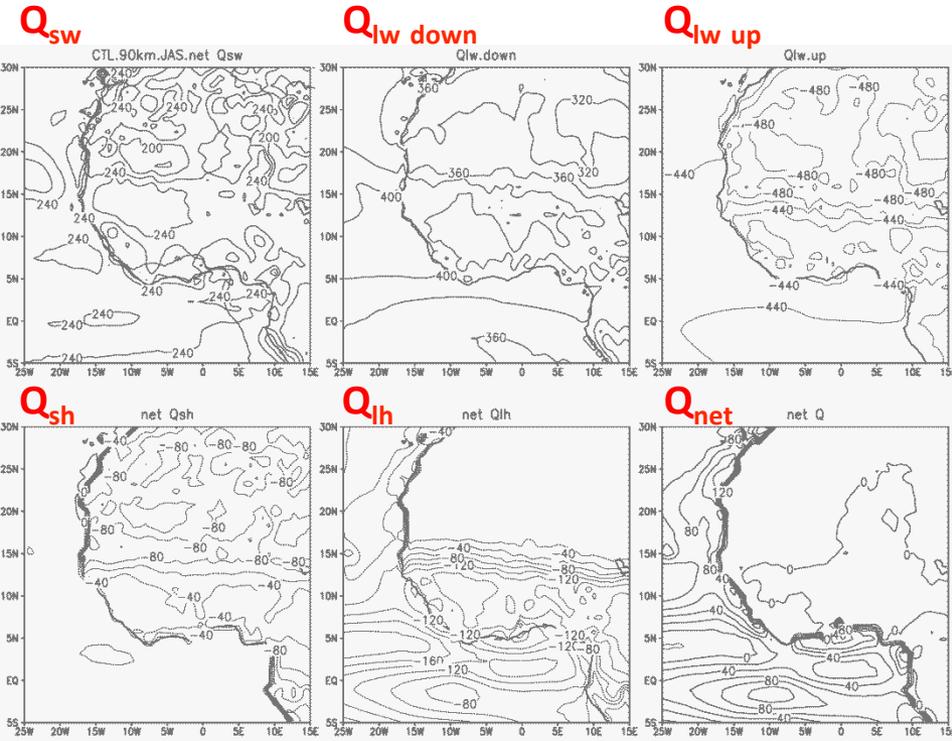
End 21 - CTL

End21-CTL



CTL 90km

NCEP2



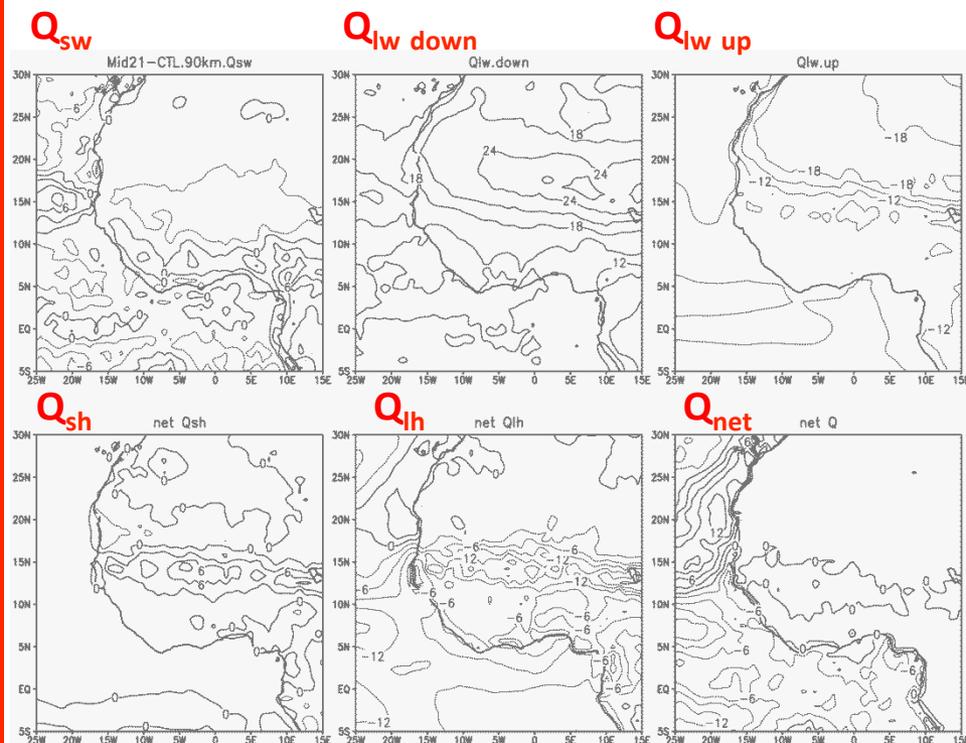
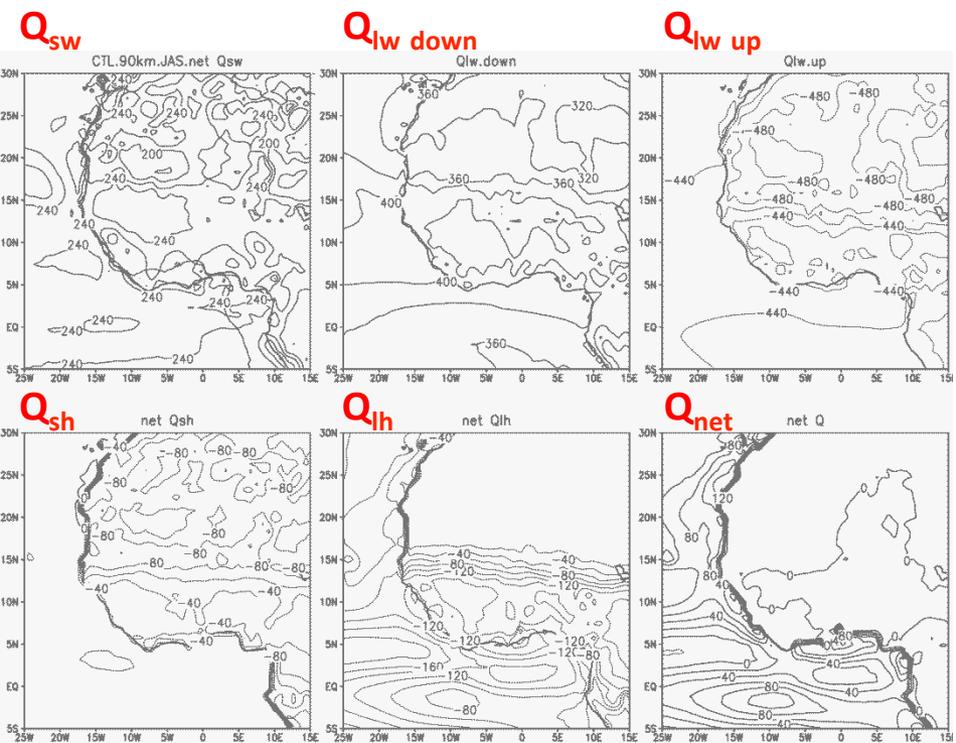
Contour interval at 20 W/m²

JAS 20 years average Heat Balance : $Q_{sw(1-\text{albedo})} + Q_{lw(\text{down} + \text{up})} + Q_{sh} + Q_{lh} = Q_{net}$

Units: W/m^2

CTL 90km

Mid21c.- CTL



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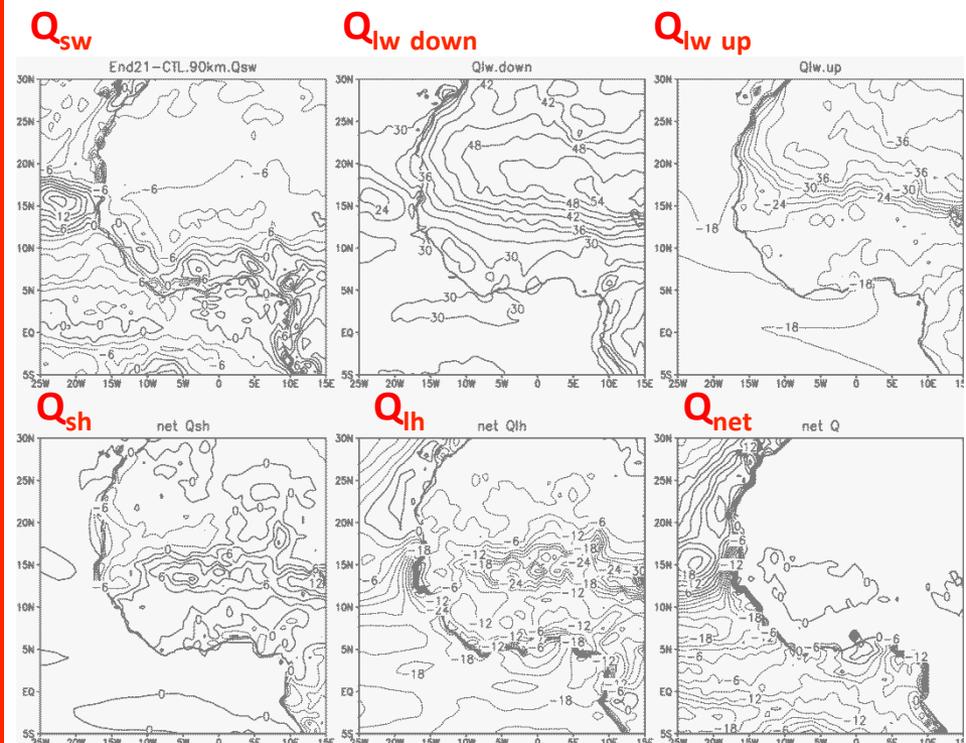
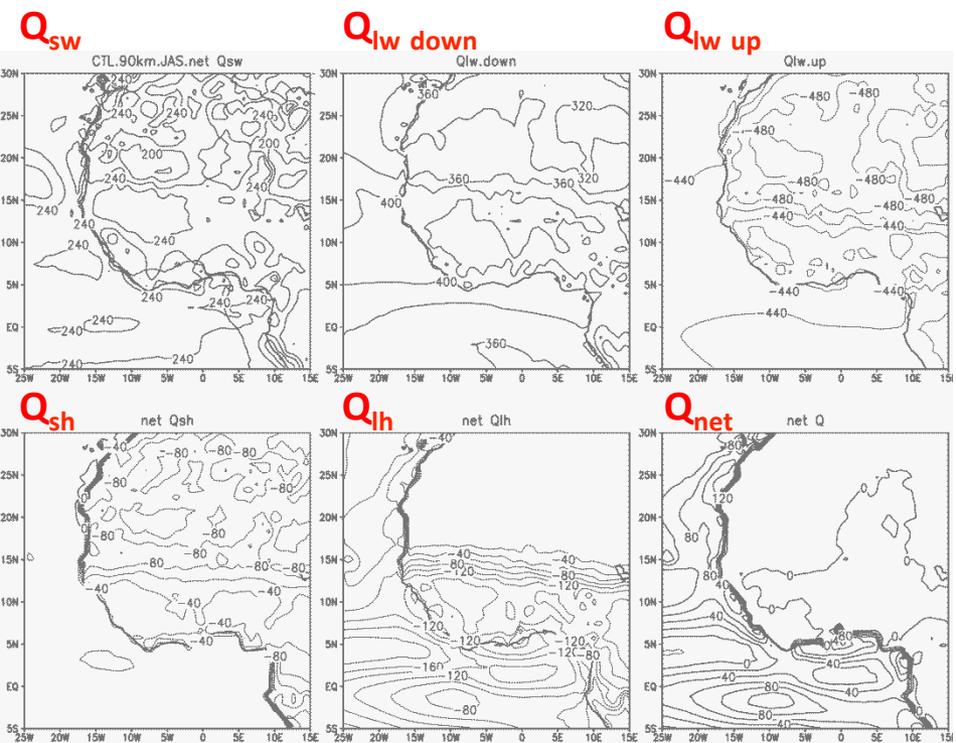
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Units: W/m^2

CTL 90km

End21c.- CTL



Contour interval at 20 W/m^2

Contour interval at 3 W/m^2