The West-African Climate in the CMCC General Circulation Model and the possible role of Sea Surface Temperature Biases.

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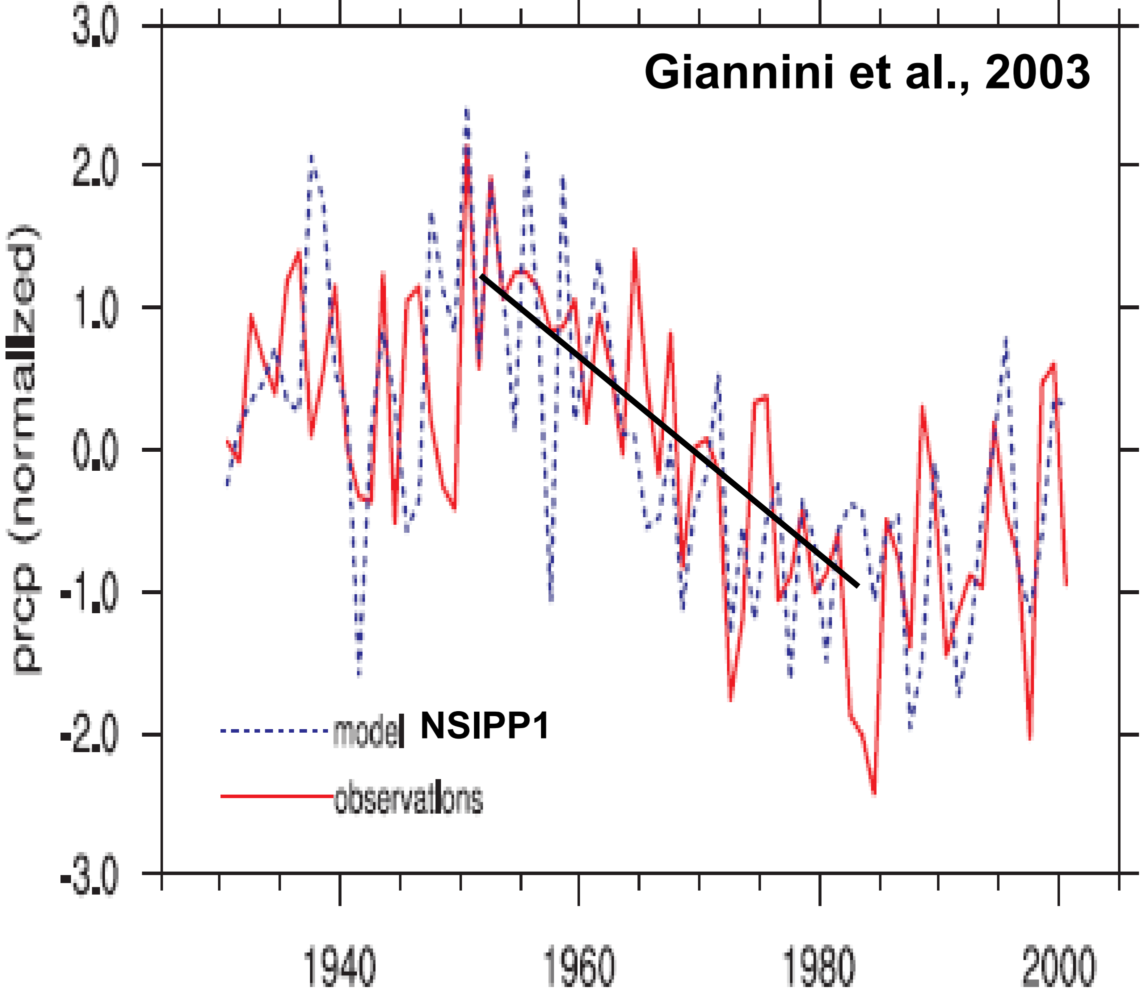
Importance of the oceanic influence on the variability of African climate on interannual to interdecadal time scales

Sahel Precipitation July-September 1930-2000


Giannini et al., 2003

* **Historical Sea Surface Temperature SST: only dominant external forcing**

* **Negative trend in rainfall**

* Correlation between the 2 time series 1950s-1980s: **0.60**

Conclusion:

The Oceans have played the dominant Role in shaping the climate of the Sahel over the last century

Long-term climate variability in the ***Sahel (10N-20N, 20W-35E)***

Main objectives of this work

* Investigate the capability of our model to reproduce the mean West African climate and variability in terms of rainfall, and the associated dynamical structures.

* Estimate the possible effects of the model's SST on the West African Climate

OUTLINE

- Description of the model & experimental design
- Results
- Conclusions
- Outlook

1- Experimental design:

All simulations are “Historical”

	AMIP	A-O COUP coupled Atmosphere-Ocean run	AMIP-like
Running time period	1950 - 2007	1850 - 2005	1950 - 2005
All forcings	Prescribed CMIP5 ***	Prescribed CMIP5 ***	Prescribed CMIP5 ***
SST & SEA ICE	**Prescribed Hadley SSTs + Sea ice 1950-2007**	**Coupled ocean-atm. (OPA-LIM / Echam 5) Model**	**Prescribed A-O COUP SSTs + Sea Ice 1950-2005**

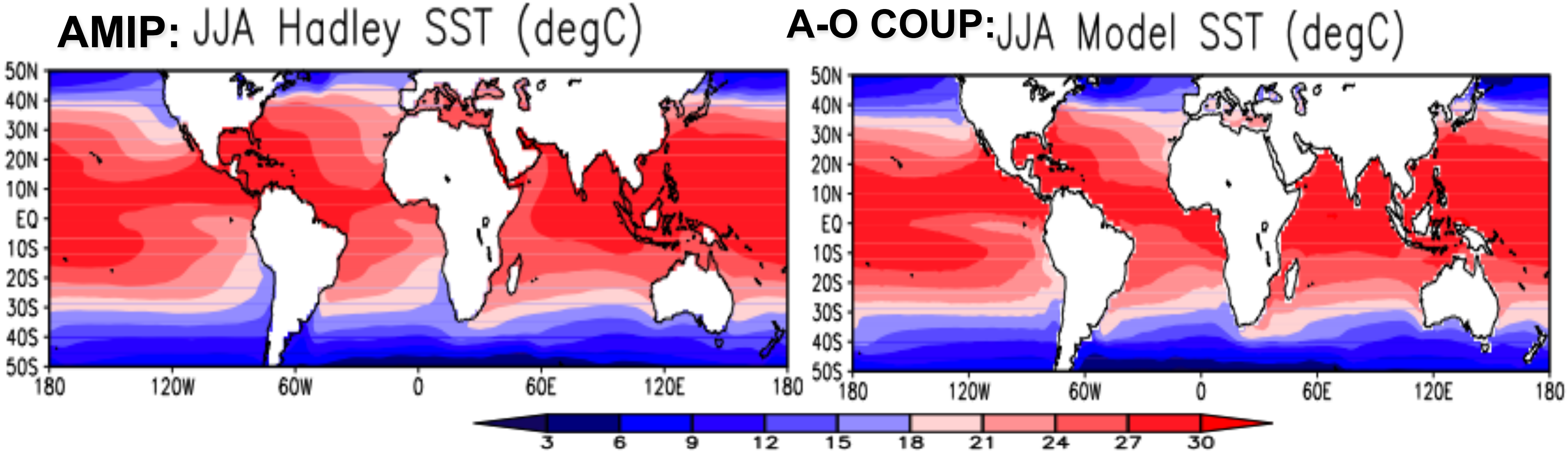
Atmospheric Core: ECHAM5 (T63 horizontal resolution, 95 vertical levels); Tiedtke-Nordeng convection scheme

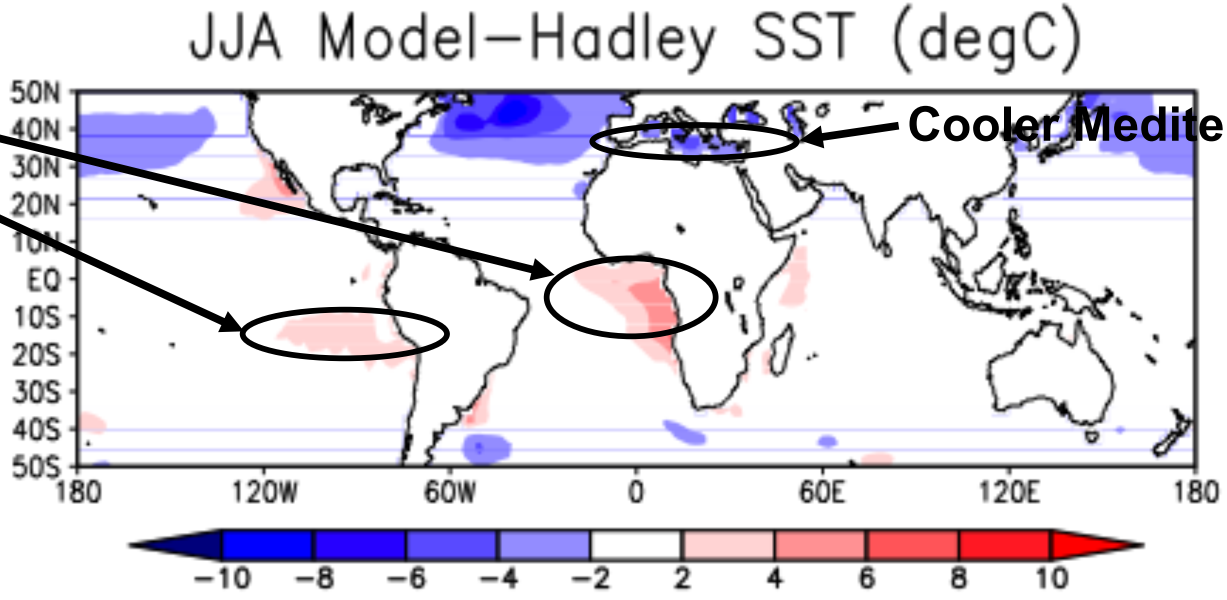
*** Solar cycle
*** WMGHG(CO2,CH4,N2O,HFCs,PFCs,SF6,CFCs,HCFCs,Halons,CCl4,CH3Br,CH3Cl); O3 (CMIP5);
*** No volcanoes; anthropogenic aerosols (SO4, CMIP5)

RESULTS

mostly for **June-July-August (JJA)** season

1950-2005 Hadley vs Model





warmer Eastern tropical Atlantic and Pacific

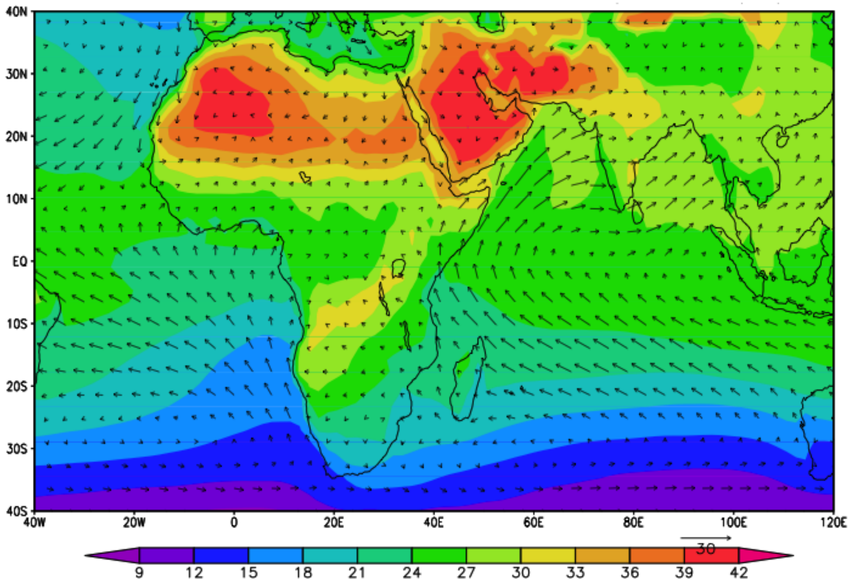
Cooler Mediterranean

Cooler Mediterranean ==> Reinforcement of the Harmattan
Warmer Eastern tropical Atlantic ==> weakening of the monsoon inflow

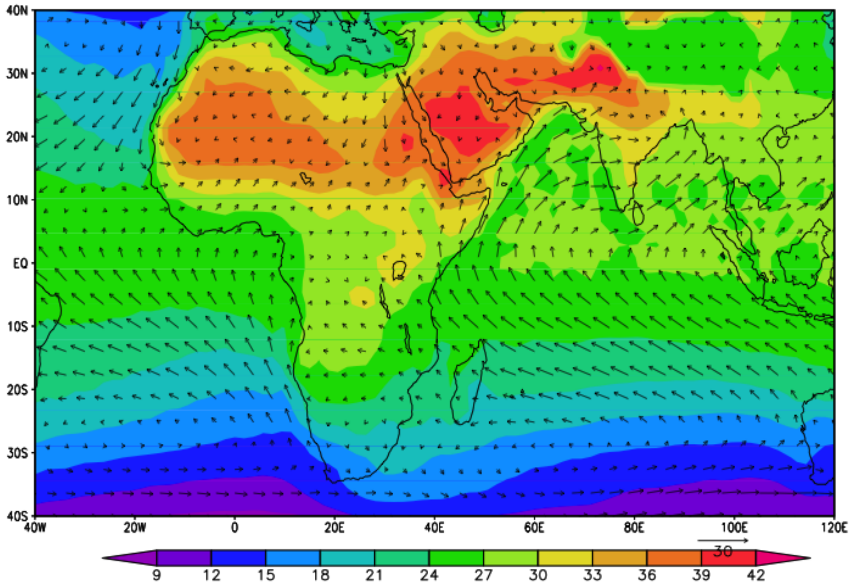
Southward displacement of the ITCZ ???

Summer Surface Temperature (deg C) & Winds (m/s): Climatology

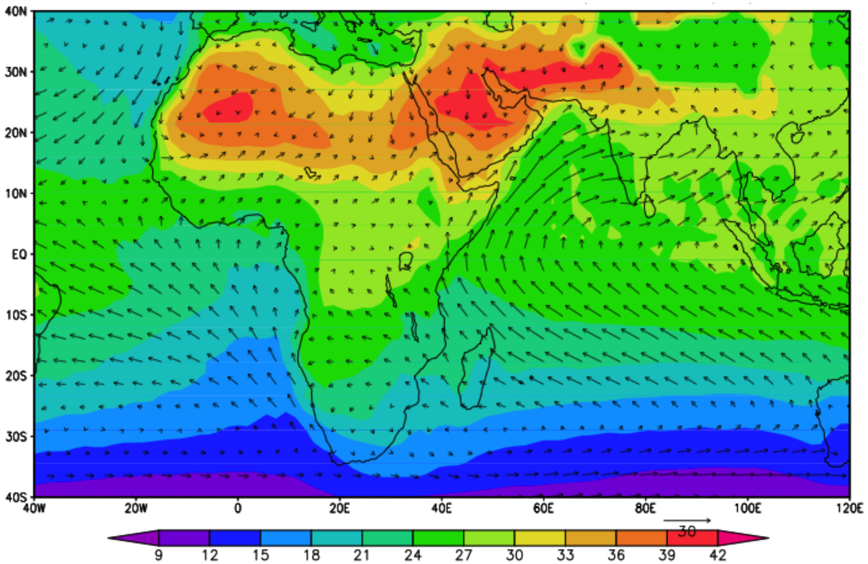
1989-2005 **ERAINTERIM**



1989-2005 **A-O COUP**

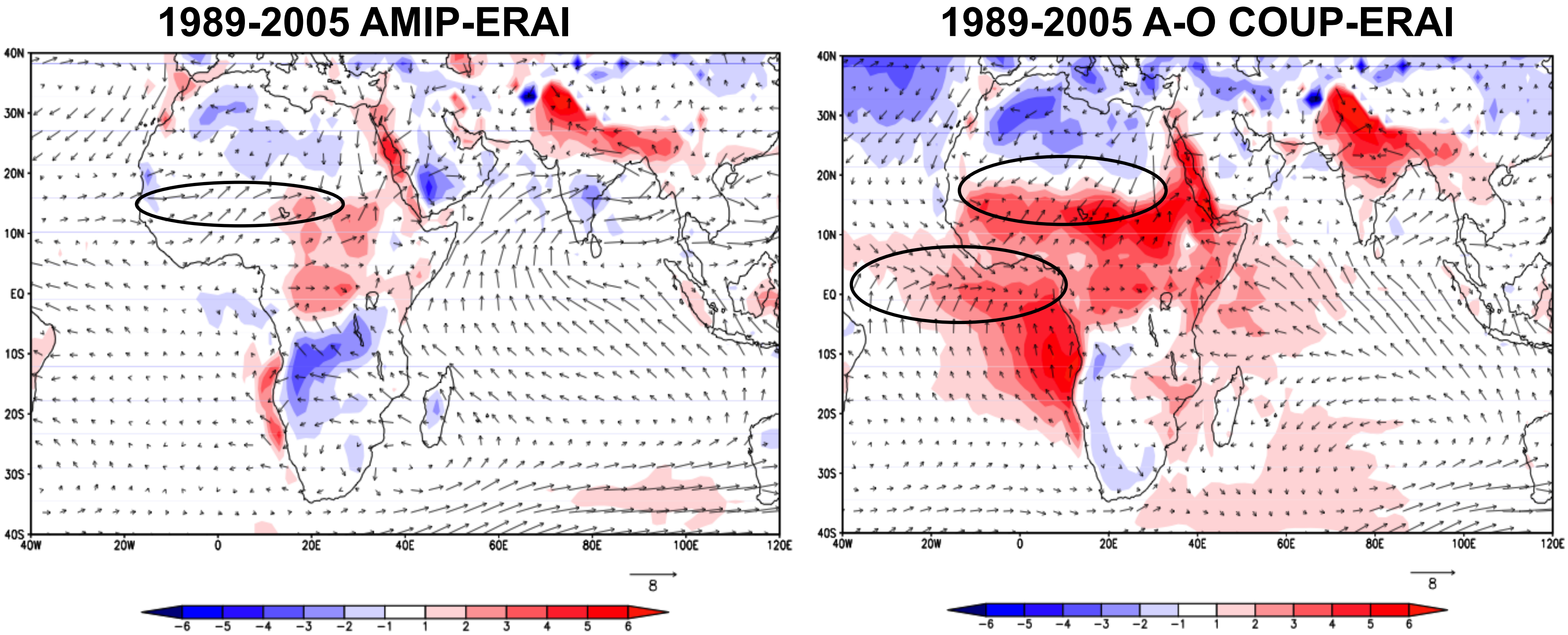


1989-2005 **AMIP**



Good representation of the model's Sahara Heat Low (SHL) but less intense in the Coupled one

Summer **Model - ERAI** Difference: 925 hPa winds (m/s) in vectors & Surface Temperature (degC) in Color



1989-2005 AMIP-ERAI

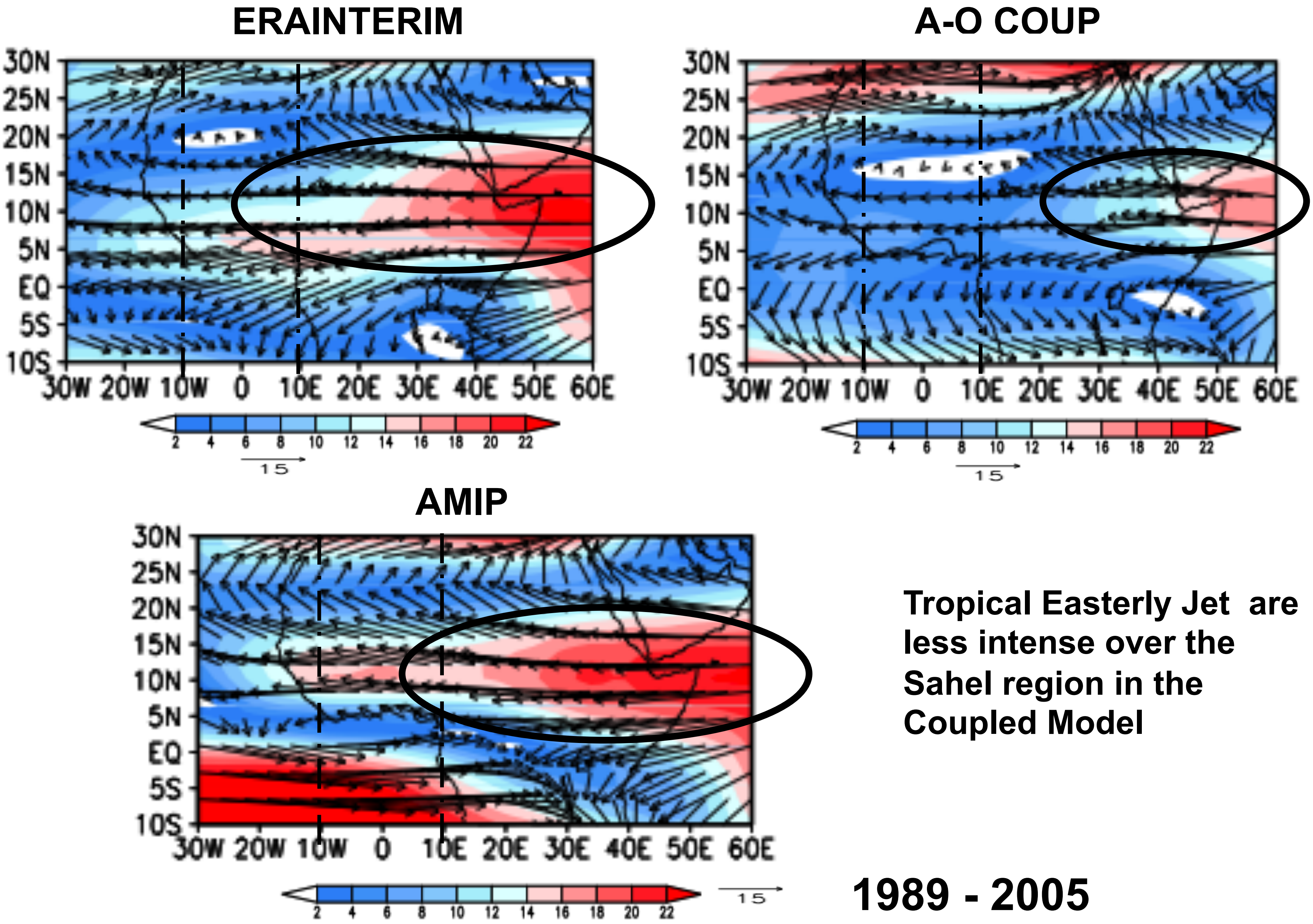
1989-2005 A-O COUP-ERAI

* Less intense monsoon and stronger Harmattan winds in the coupled model
* Warmer T over Eastern tropical Atlantic & over Sahel in the coupled model.
* Cooler Surface T in the model over North (Sahara) & South Africa but much cooler over Sahara in the coupled one

Rodriguez-Fonseca et al., 2011

Warmer Tropical Atlantic ==> decrease of land-ocean temperature & latitudinal pressure gradients ==> Maximum convection to the South + decrease of Sahelian convergence --> Decrease of Sahelian precipitation and increase of rainfall in the Gulf of Guinea ===> Dipole of anomalous precipitation

200 hPa JJA wind (m/s): Modulus (color) & Comp. (vectors)


ERAINTERIM

A-O COUP

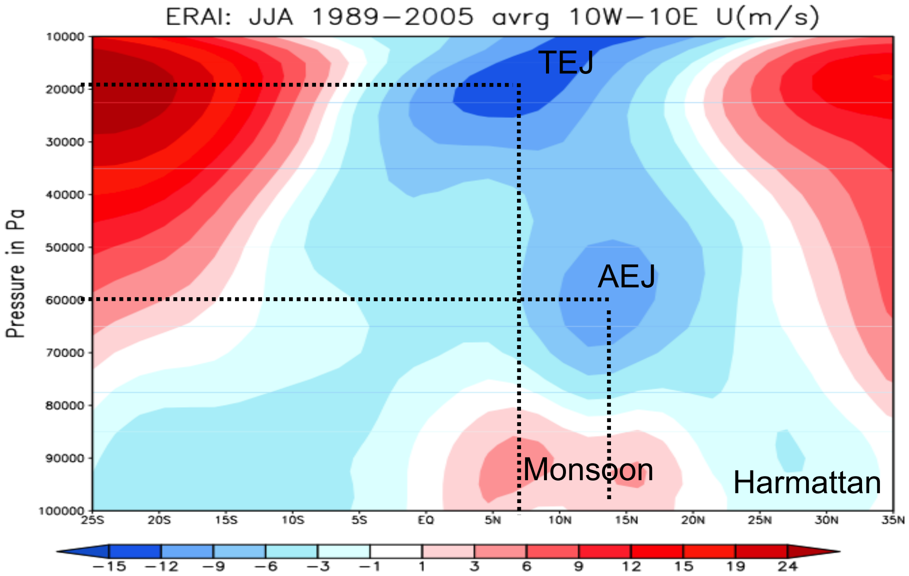
AMIP

Tropical Easterly Jet are less intense over the Sahel region in the Coupled Model

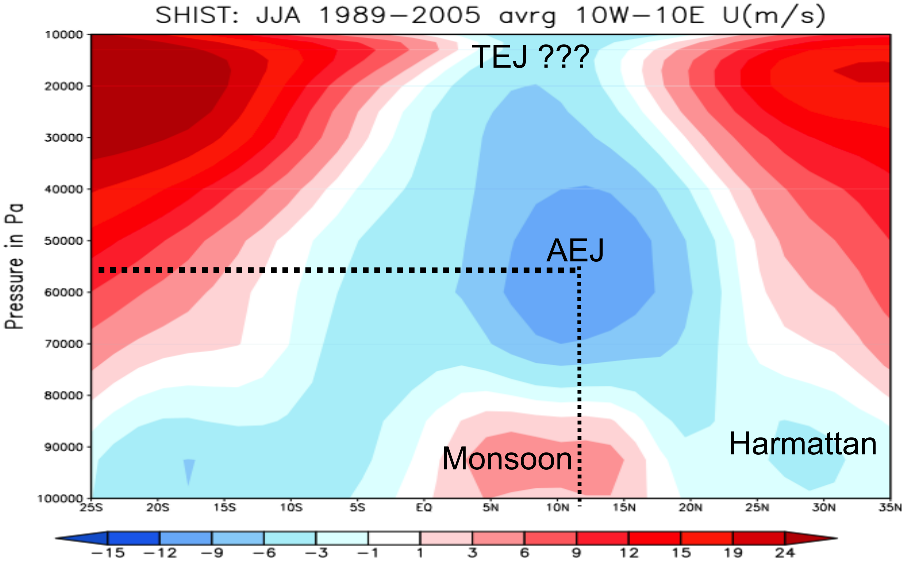
1989 - 2005

1989-2005 JJA Zonal Wind averaged betw. 10W - 10E

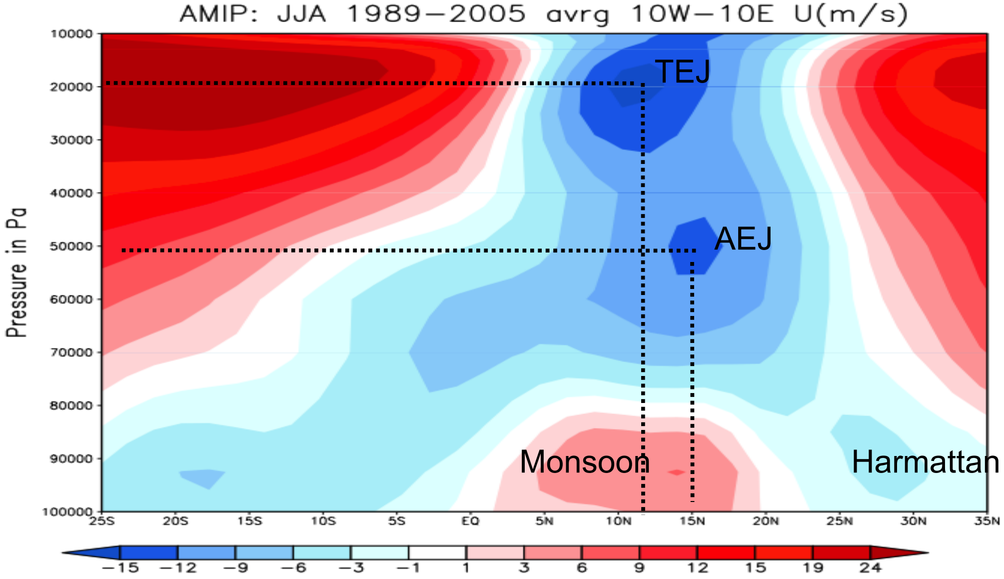
ERAINTERIM



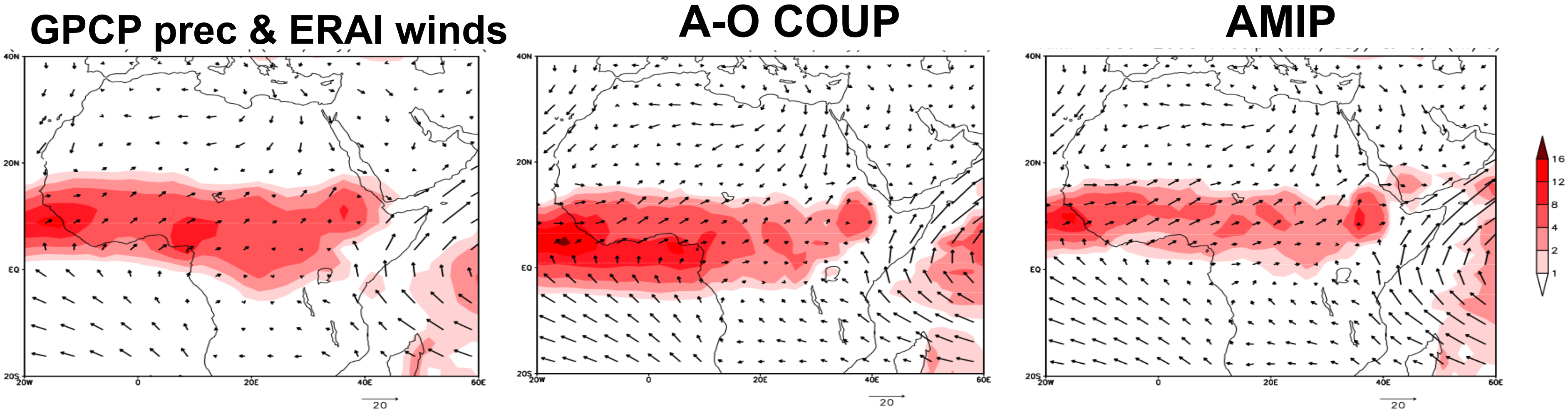
A-O COUP



AMIP



Averaged JJA precipitation (mm/day, shaded) with superimposed 925 hPa wind (vectors)

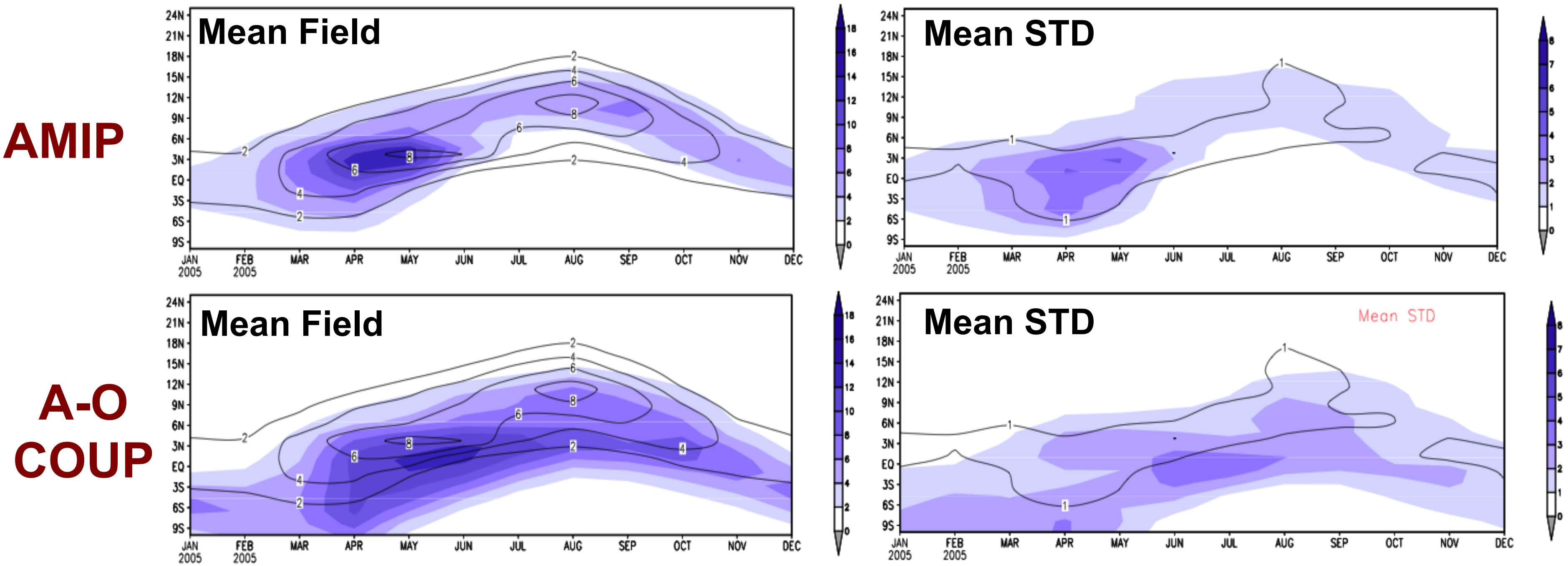


GPCP prec & ERAI winds

A-O COUP

AMIP

Seasonal evolution & variability of 10W-10E averaged rainfall in mm/day (GPCP in contours)



AMIP

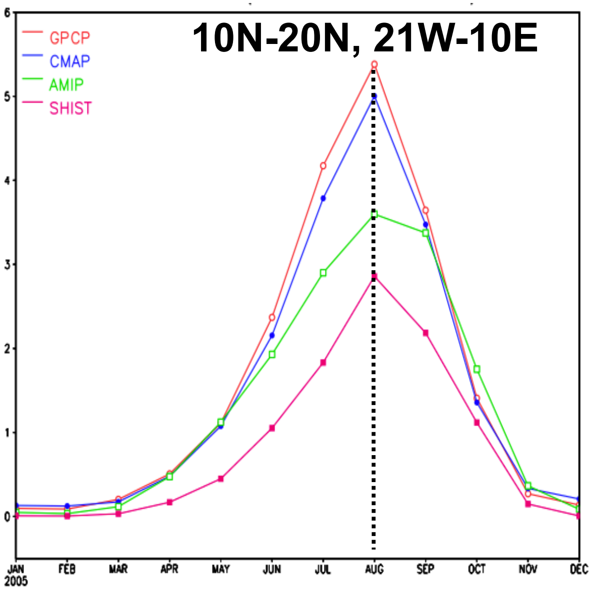
A-O COUP

Mean Field

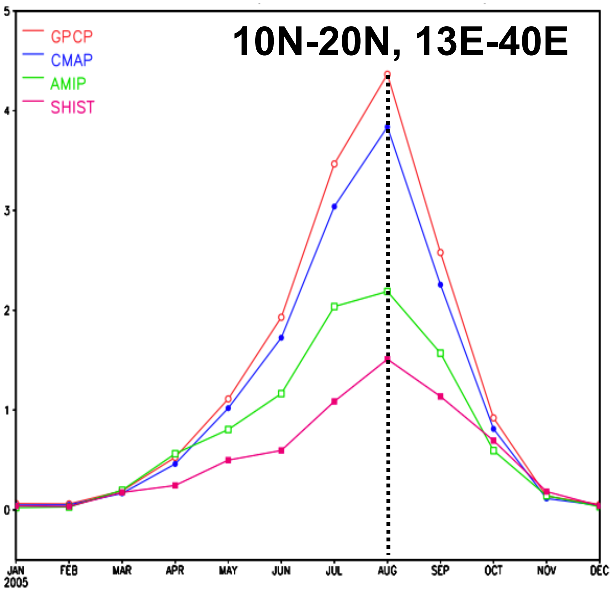
Mean STD

Mean annual cycle precipitation (mm/day) averaged for each sub-region

West Sahel



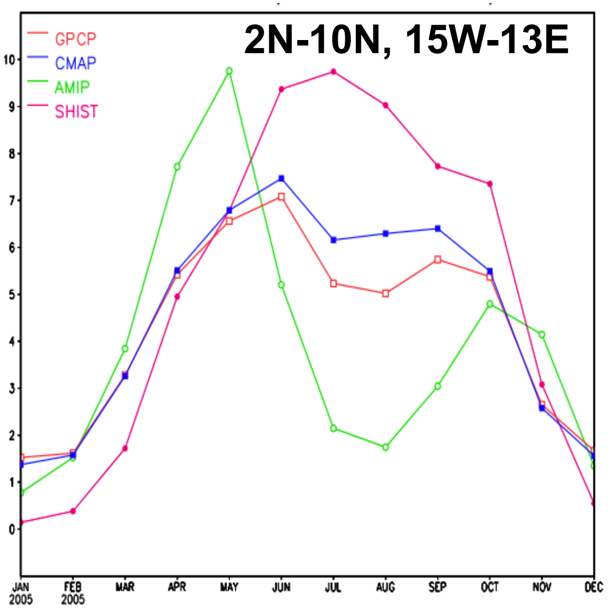
East Sahel



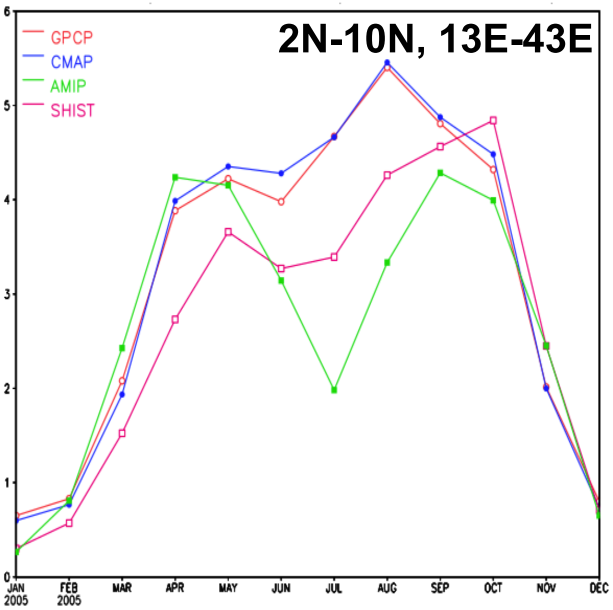
The model underestimates the Sahel rainfall but is able to capture the phase of the annual cycle

AMIP is closer to observations

Guinea Coast



North Eq. Central Africa



A-O COUP seems to perform better in the Equatorial regions

Why ???
Open question

CONCLUSION

** The CMCC General Circulation model is able to capture the main features that characterize the West-African Monsoon system: AEJ, Monsoon inflow, Harmattan, the summer Northward migration of the ITCZ

** The coupled model shows low skill in the representation of the Tropical Easterly Jet and acts to shift the main WAM system southward

** AMIP run seems to better reproduce the Sahel rainfall while the Coupled model seems to have better performance in the Equatorial regions. WHY? This is still an open question.

OUTLOOK

** We will run the atmospheric component in an AMIP-like simulation (with prescribed SST & Sea-ice from the coupled model) to investigate the role of the air-sea feedbacks on the WAM.

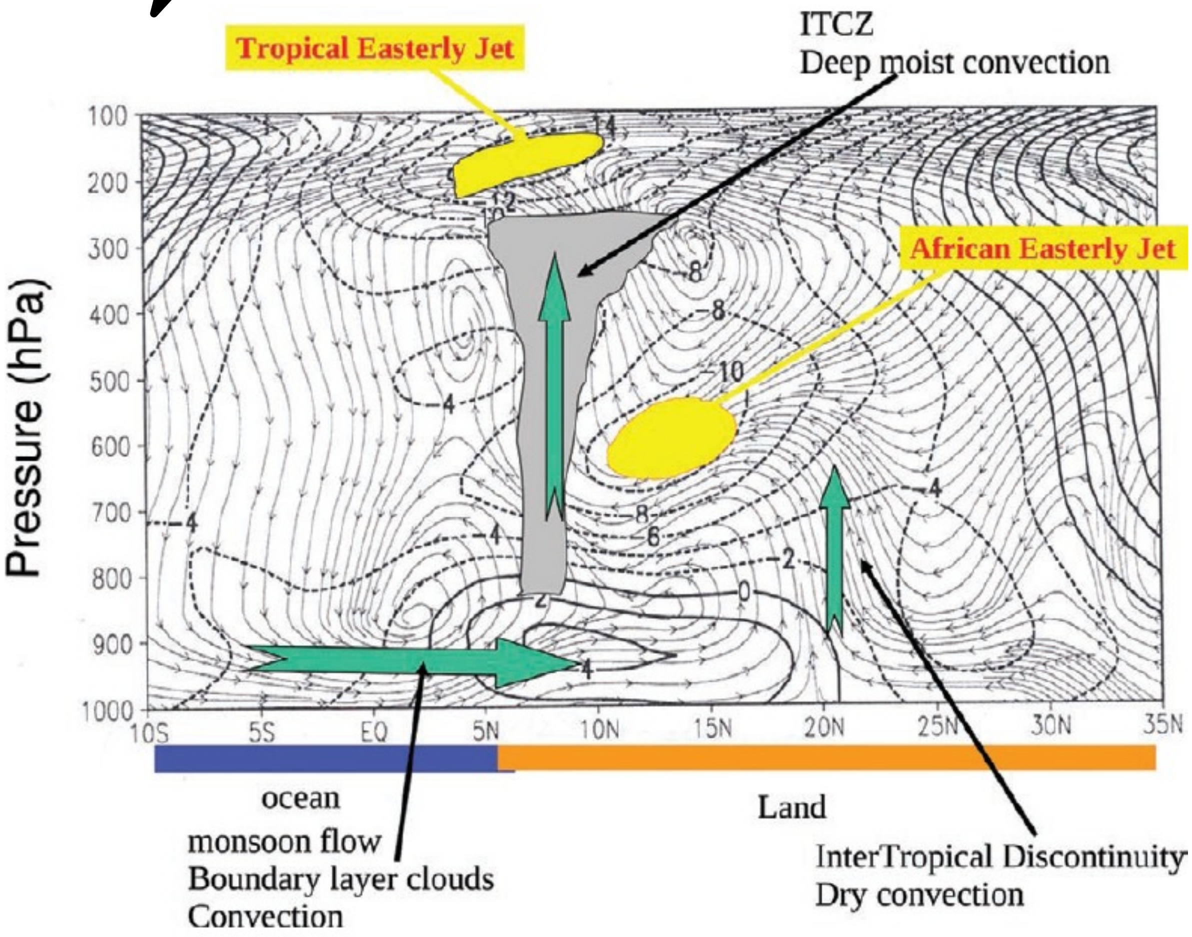
** Perform the previous runs and analyses for climate change scenarios.

THANKS FOR YOUR ATTENTION!!!

Introduction

Monsoon circulations are forced & maintained by land-sea thermal contrasts and by latent heat released into the atmosphere.

Hourdin et al., 2010



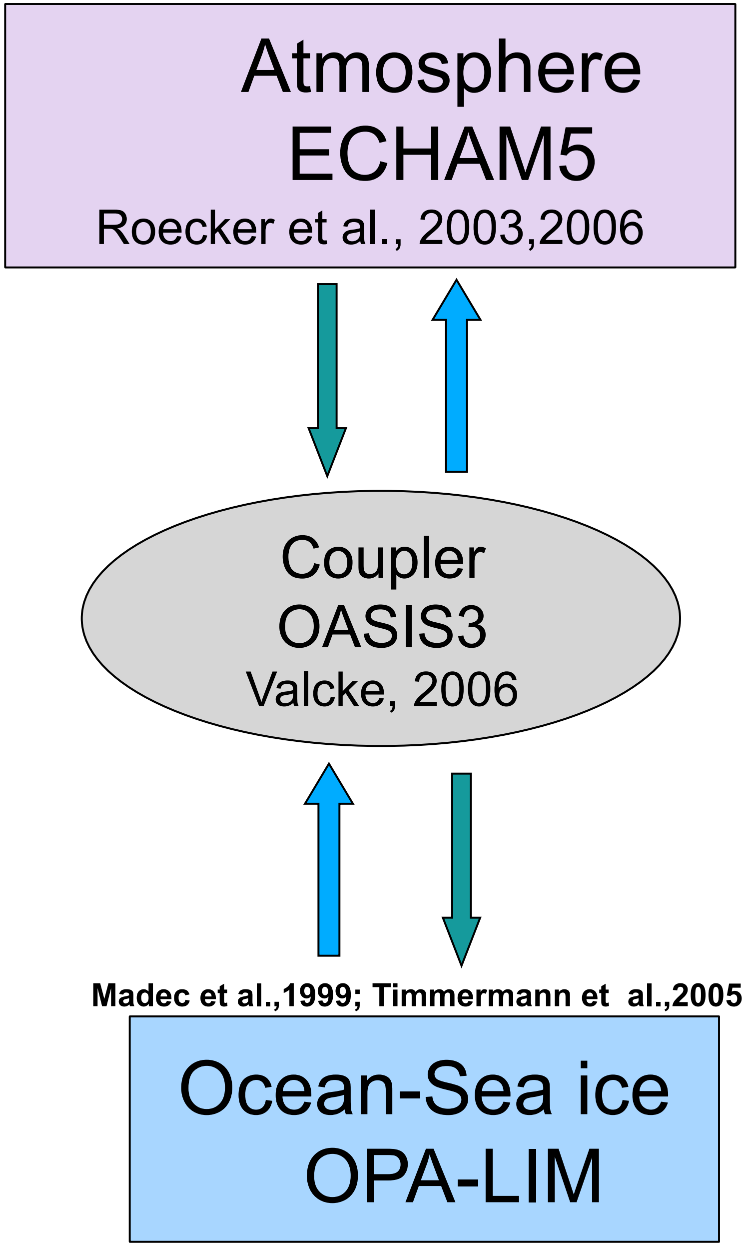
** Near surface monsoon flow brings evaporated water over the Gulf of Guinea & converges with the Southward dry airflow from the Sahara.

**** The AEJ (Summer) is a result of the strong meridional surface moisture and temperature gradients between the Sahara & equatorial Africa**.

** The TEJ is associated with the upper-level outflow from the asian monsoon & is a result of the reversal in the mid-tropospheric thickness gradient due to the heating over the Tibetan plateau & the Himalayas (heat source)

MMC (stream lines) & associated mean zonal wind (m/s, contours). Mean Jul-Sep (JAS) conditions from the NCEP reanalyses

1- Model Description



Atmosphere
ECHAM5
Roecker et al., 2003,2006

Coupler
OASIS3
Valcke, 2006

Madec et al.,1999; Timmermann et al.,2005

Ocean-Sea ice
OPA-LIM

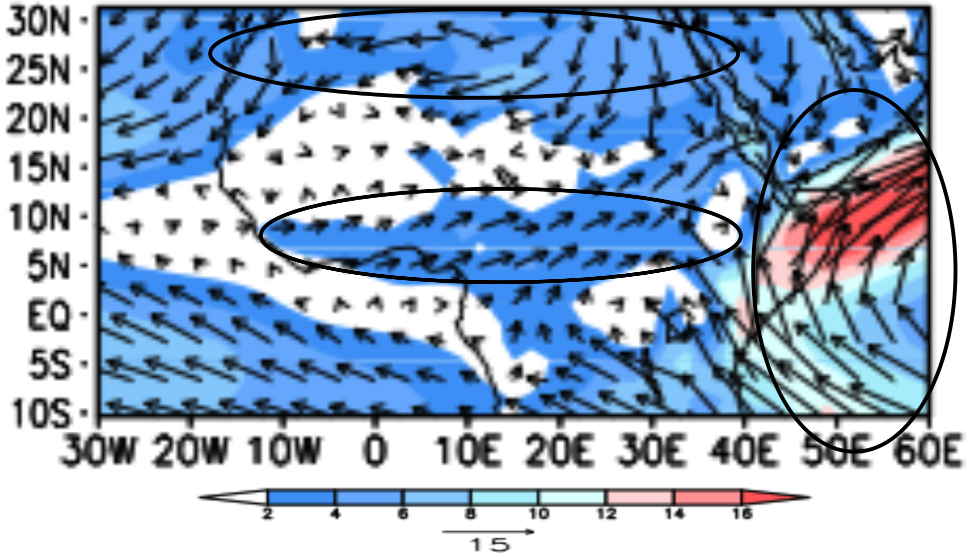
- Vertical resolution: 95 levels top at 0.01 hPa (~80km)
- Horiz. Resolution: T63 (1.875 deg* 1.875 deg)
- Convection scheme: Tiedtke - Nordeng
- 6 Bands SW radiation scheme (Cagnazzo et al.,2007)
- Stratospheric component: momentum conserving orographic & non orographic gravity wave drag (Manzini et al.,2006)
- Parametrization of metahne oxydation

** Daily Coupling frequency [Fogli et al., 2009];
** No flux ajustment

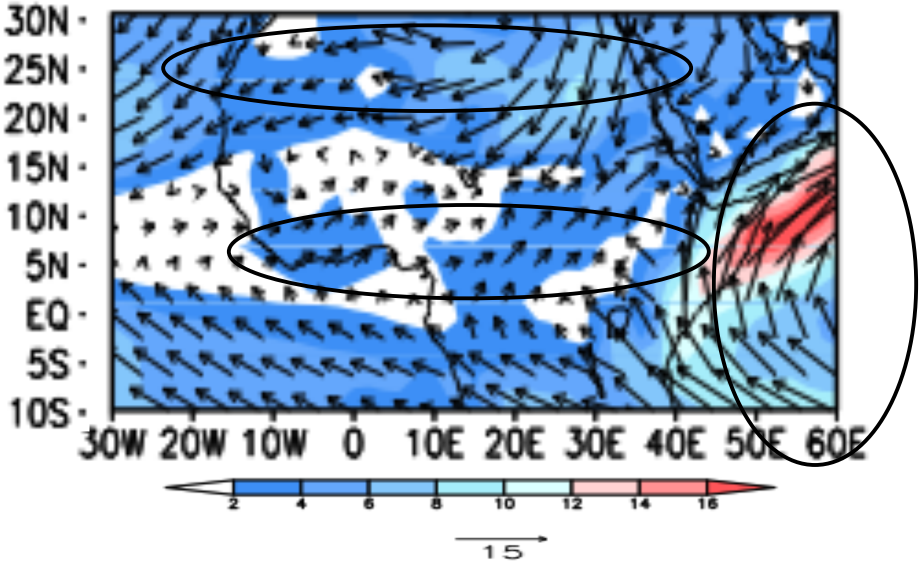
** 2*2deg (refined at the Equator & poles)
** Depth of 5km from the surface
** 31 levels with 10 levels at the top 100m
** No fluxes of heat and salt at the solid lateral and bottom boundaries

850 hPa JJA wind (m/s): Modulus (color) & Comp. (vectors)

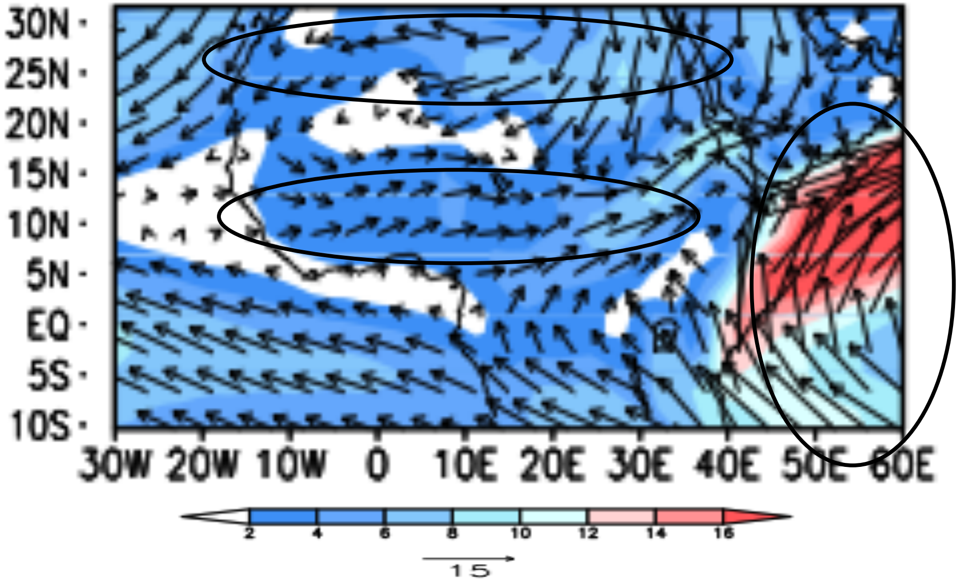
ERAI



A-O COUP

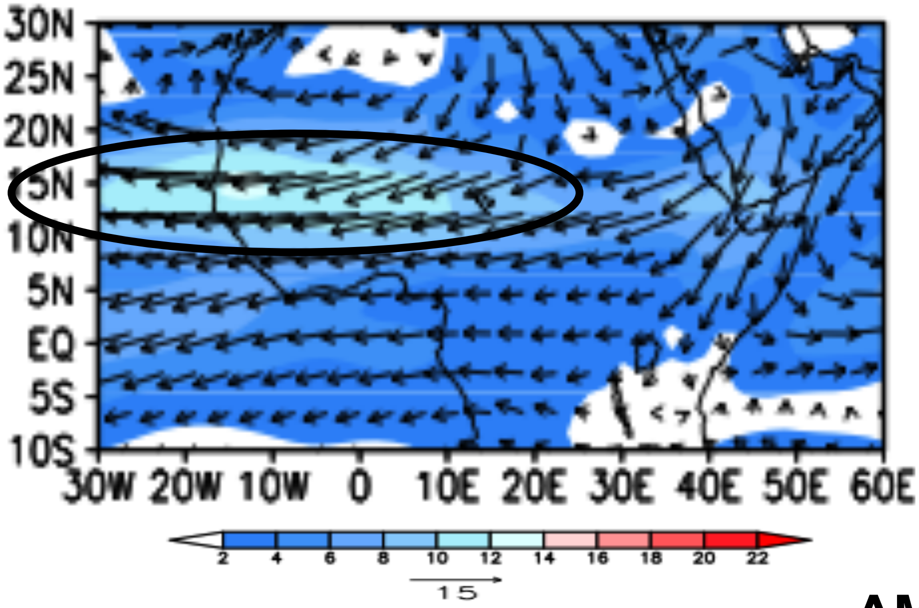


AMIP

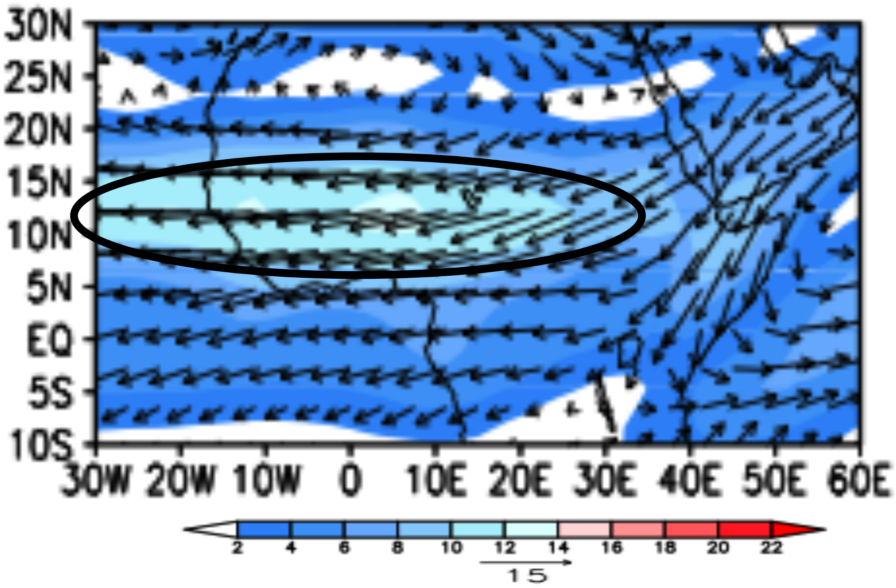


600 hPa JJA wind (m/s): Modulus (color) & Comp. (vectors)

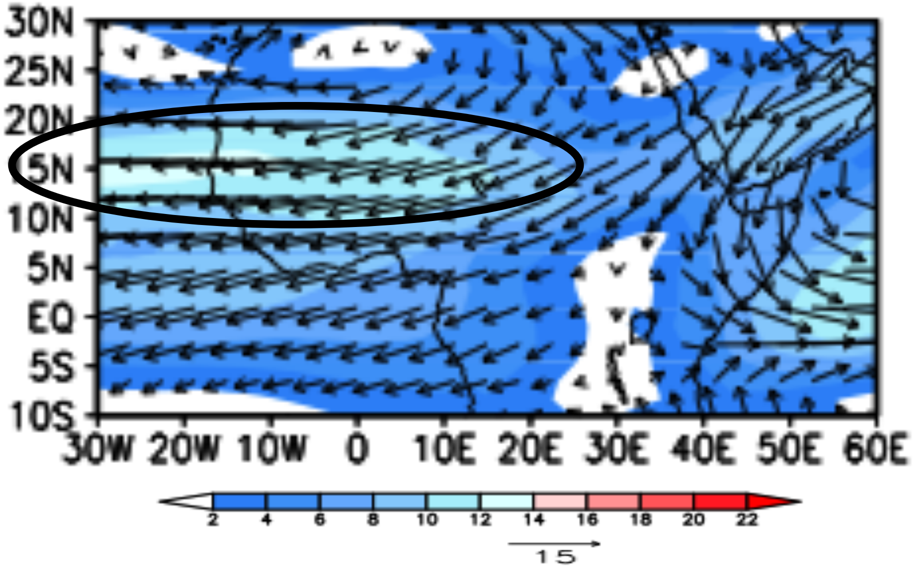
ERAINTERIM



A-O COUP



AMIP



The Moist Static Energy Equation

<u>Advantage</u>: Evaporation is part of both energy and water cycles.

$$\boxed{\partial_t m + \nabla \cdot m\mathbf{v} + \partial_p m\omega} = \boxed{g\partial_p F} \quad \text{where} \quad m = gz + c_pT + Lq$$

Changes in the Moist Static Energy (Dynamics)

Changes in the Net energy budget

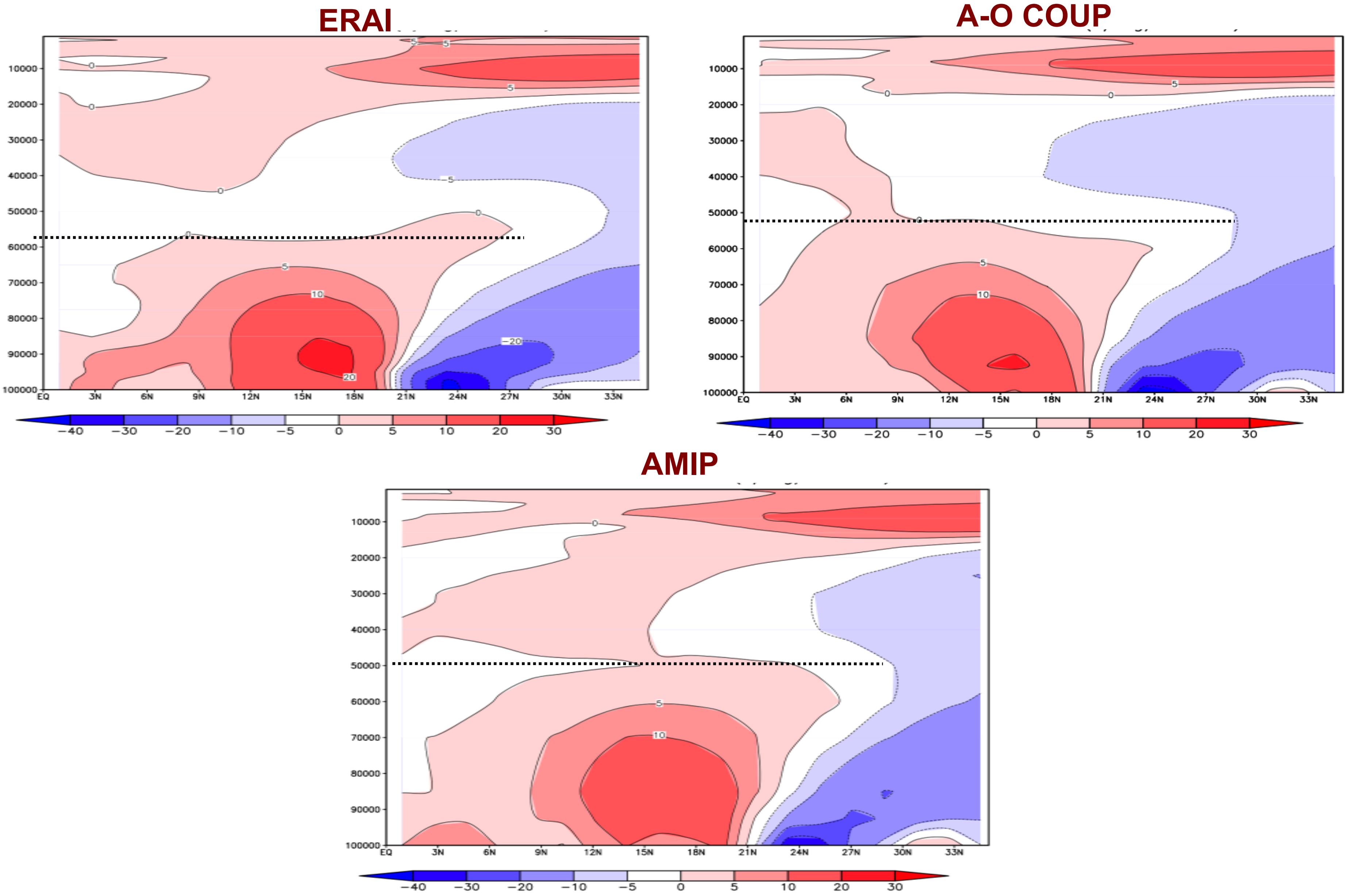
Moist Static Energy (MSE)

Neelin et al., 2003; Chou and Neelin, 2003; Chou et al., 2009 exploit this formulation to describe the contributions from changes in humidity or in horizontal gradients of humidity such as:

“Rich get richer” mechanism: wet, deep convective regions are projected to become wetter in a warmer, moister world

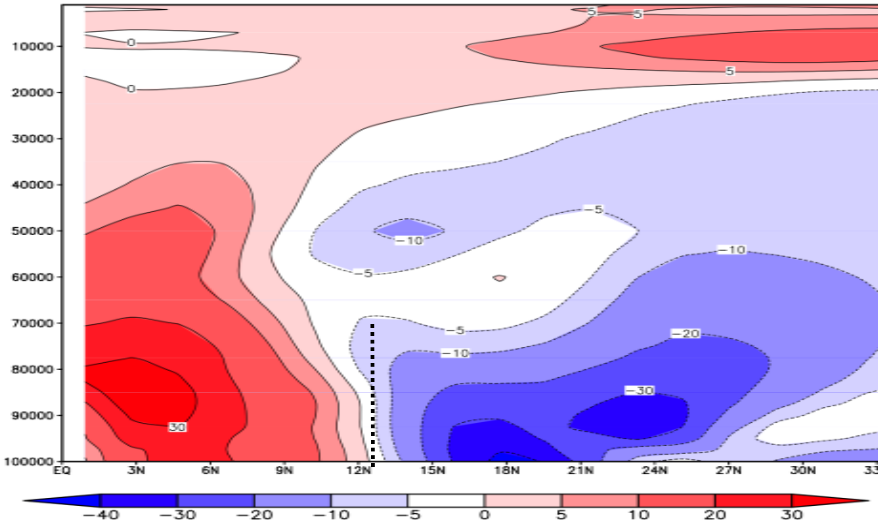
“upped ante” mechanism: core regions of deep convection are projected to become wetter at the expense of their margins which cannot import moisture as effectively

JJA Meridional gradient DSE at 15W (J/Kg/200km)

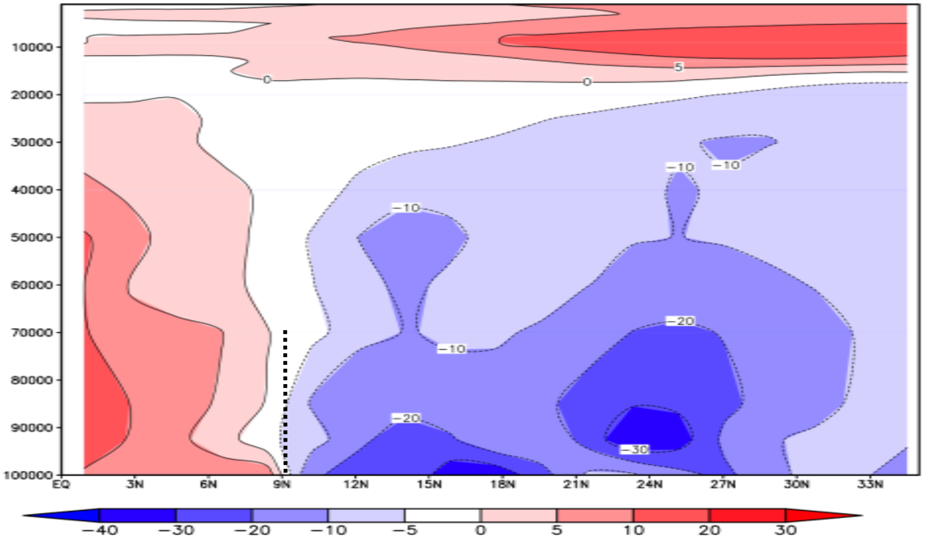


JJA Meridional gradient MSE at 15W (J/Kg/200km)

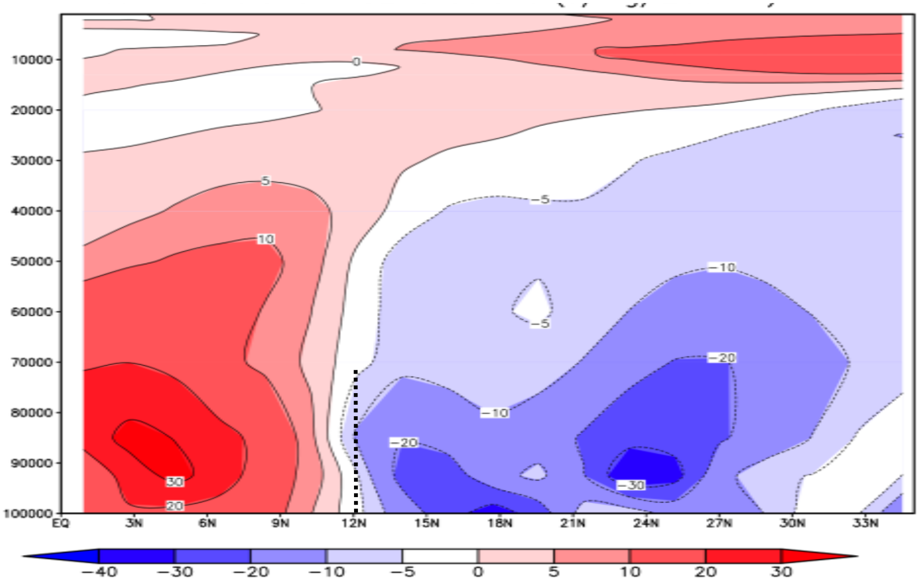
ERAI



A-O COUP



AMIP



The West African Heat Low (WAHL)

The **WAHL** has been identified as a key dynamical element of the West African Monsoon system. Over continental West Africa, it is an area of high surface temperatures and low surface pressures (high insolation & low evaporation). Its associated upward motion generates an anticyclonic circulation aloft which helps to strengthen and maintain (with the combination of the diabatically forced meridional circulation due to surface fluxes) the AEJ (Thorncroft & Blackburn 1999). Here we use the method (based on the heat-induced dilatation of the low levels) proposed by Lavaysse et al., 2009 to identify the presence of the WAHL.

WAHL: area over West Africa & Atlantic (Eq-40N;20W-30E) where the LLAT > 90% level of the monthly cumulative PDF of LLAT.

$$\text{LLAT}=\frac{R}{g}\int_{p2}^{p1} T\,d(\ln(p))$$

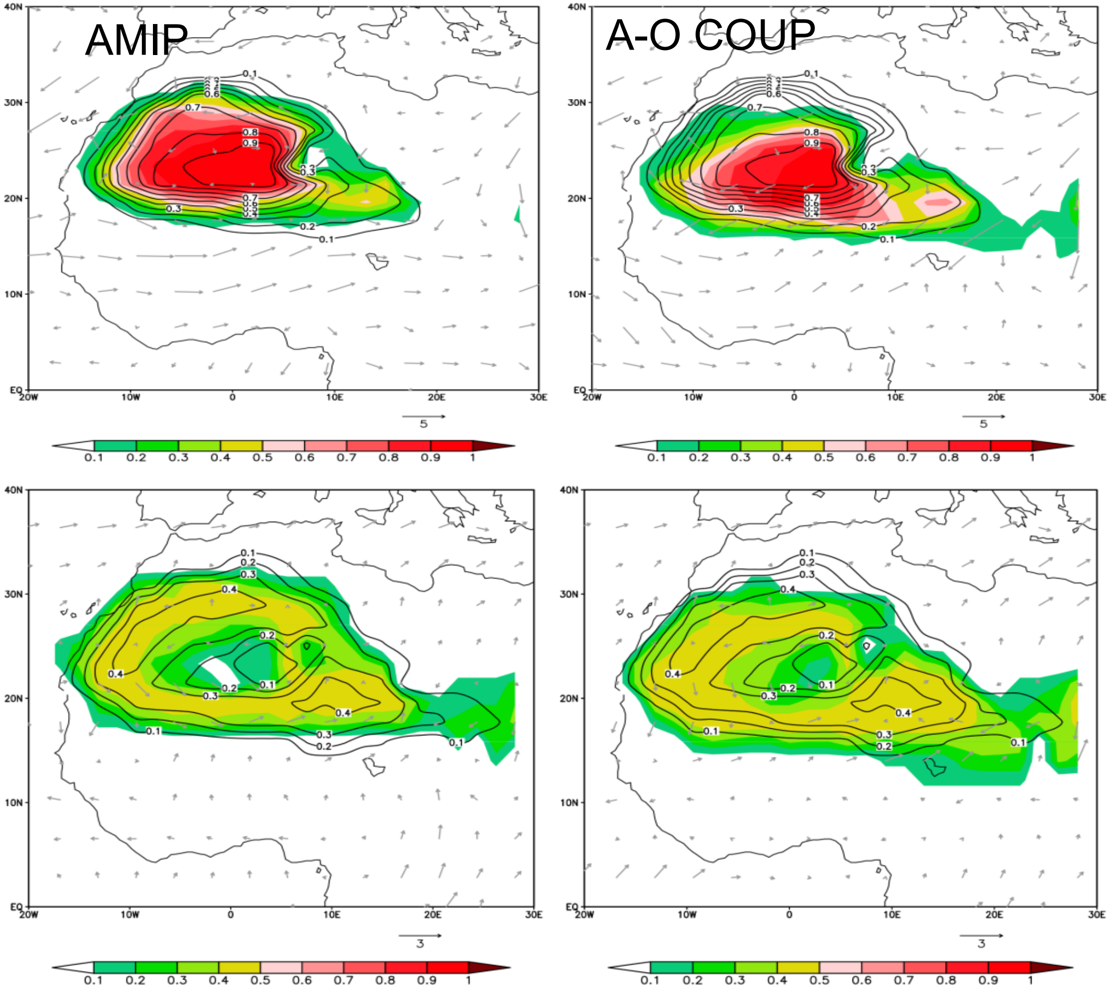
R: gas constant for air, g: gravitational acceleration, T: temperature, P1 & P2 pressure at 925hPa & 700hPa resp.

The LLAT is the difference of geopotential heights at 700 and 900hPa

Summer Monthly mean occurence frequency of the WAHL & variability

Mean Field

STD

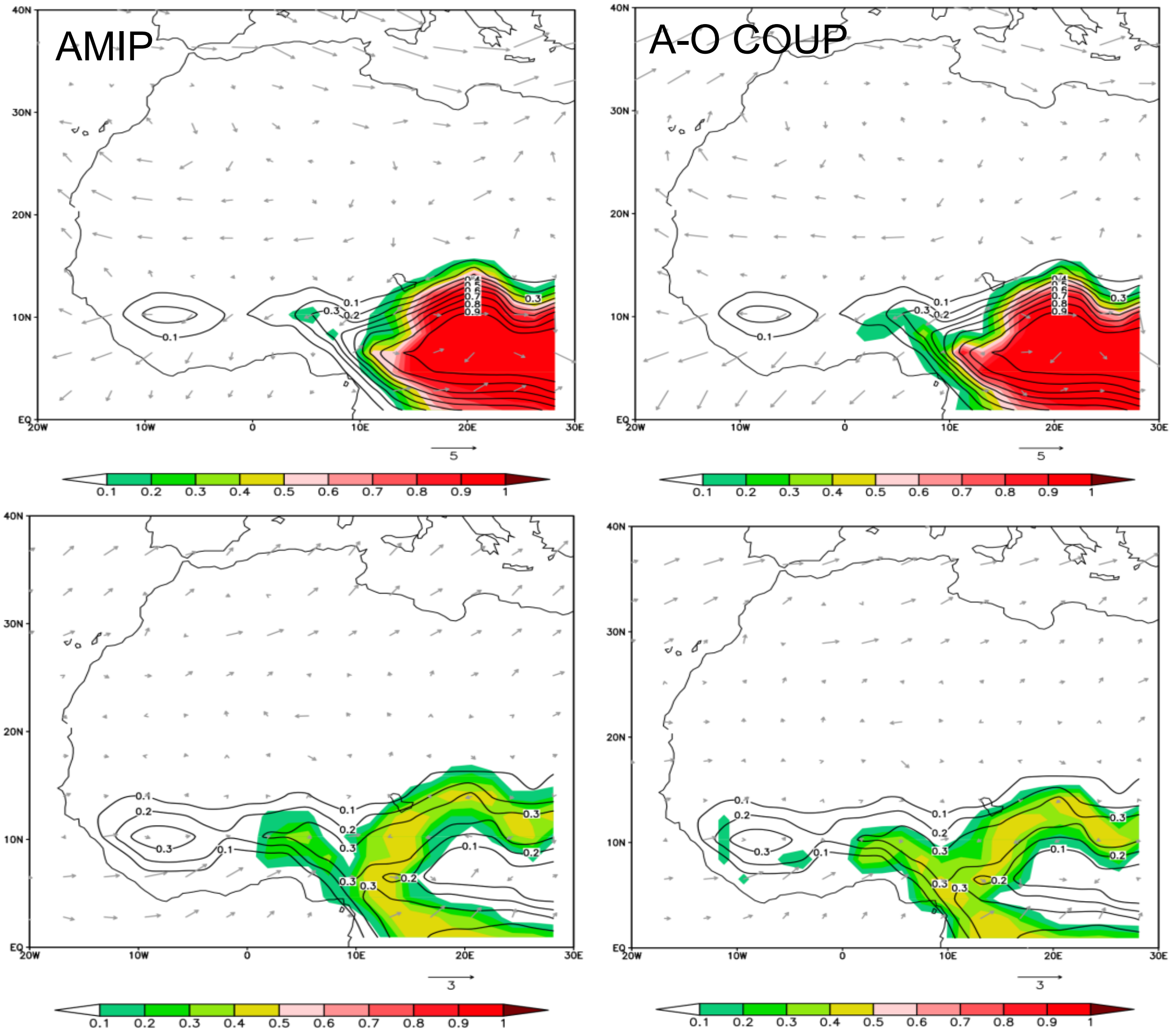


Up, monthly mean occurence frequency of the WAHL (Model in color & ERAINTERIM in contours); down, corresponding STD. Arrows indicate the 925hPa wind differences between model & ERAINTERIM

Winter Monthly mean occurence frequency of the WAHL & variability

Mean Field

STD



Up, monthly mean occurence frequency of the WAHL (Model in color & ERAINTERIM in contours); down, corresponding STD. Arrows indicate the 925hPa wind differences between model & ERAINTERIM