On the potential causes of the non-stationary correlations between West African precipitation and Atlantic hurricane activity

Andreas H. Fink*

Institute for Geophysics and Meteorology

University of Cologne

held at the YOTC Int'l Science Symposium,

Beijing, China, 16-19 May 2011

with contributions from: J. Schwendike, S. Jones (both KIT, Germany),

C. D. Thorncroft (SUNY, Albany), J. M. Schrage (Creighton, Omaha)

and S. Diatta (UCAD Dakar/ IGM Cologne)

* e-mail: fink@meteo.uni-koeln.de
Internet:http://www.geomet.uni-koeln.de/en/general/the-institute/research-groups/research-group-fink/

Outline

1. Detection of the relation between West African rainfall and Atlantic tropical cyclone (TC) activity in the early 1990s
2. Revisiting the relation for the longer period 1921-2007
3. Two hypotheses on the causes of the non-stationary correlations
4. Recent understanding of the role of African Easterly Waves (AEWs) on climatology of Atlantic TCs and their genesis
5. Some open questions suggested to YoTC

Detection of the relation between West Sahel rainfall & Atlantic TC activity

Linear correlation between June-September (JJAS) West Sahel rainfall and various measures of Atlantic TC activity (1949-1990)

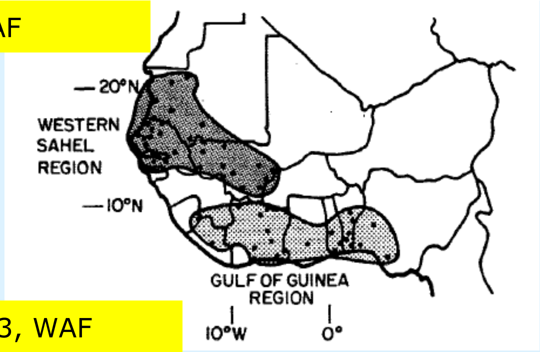
Four-fold increase in intense hurricane days (IHD) in the TC season after the ten wettest (Aug.-Nov, ASON) Guinea Coast years (1950-1990)

Tropical cyclone parameter	Correlation coefficient
Named storms	0.35*
Named storm days	0.56**
Hurricanes	0.47**
Hurricane days	0.67**
Intense hurricanes	0.71**
Intense hurricane days	0.76**
HDP	0.73**

Source: Landsea and Gray 1992, JCLIM

	Ten wettest	Ten driest	Ratio
No. of hurricanes	8.0	4.6	1.74
No. of hurricane days	39.0	17.7	2.20
No. of intense hurricanes	4.7	1.8	2.61
No. of intense-hurricane days	12.0	2.9	4.16

Source: Gray 1992, WAF

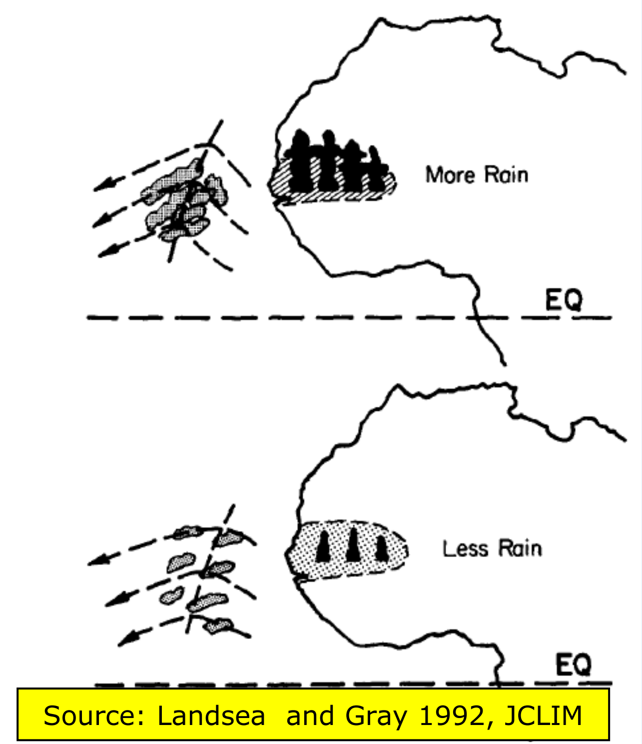


Source: Gray et al. 1993, WAF

West Sahel: Proposed physical mechanisms

Seedling disturbances:

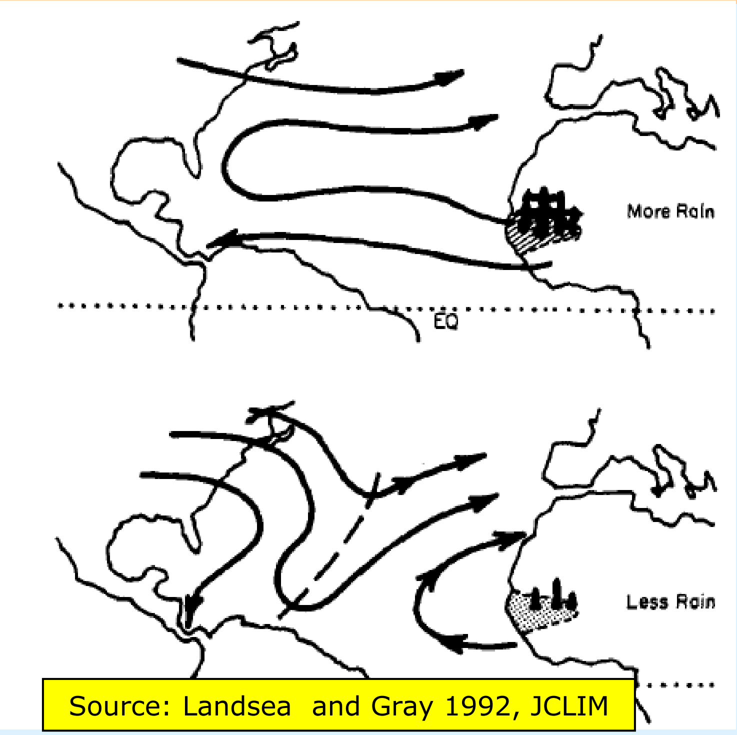
Better organized (in terms of wave amplitude & convection) African Easterly waves (AEWs)



Source: Landsea and Gray 1992, JCLIM

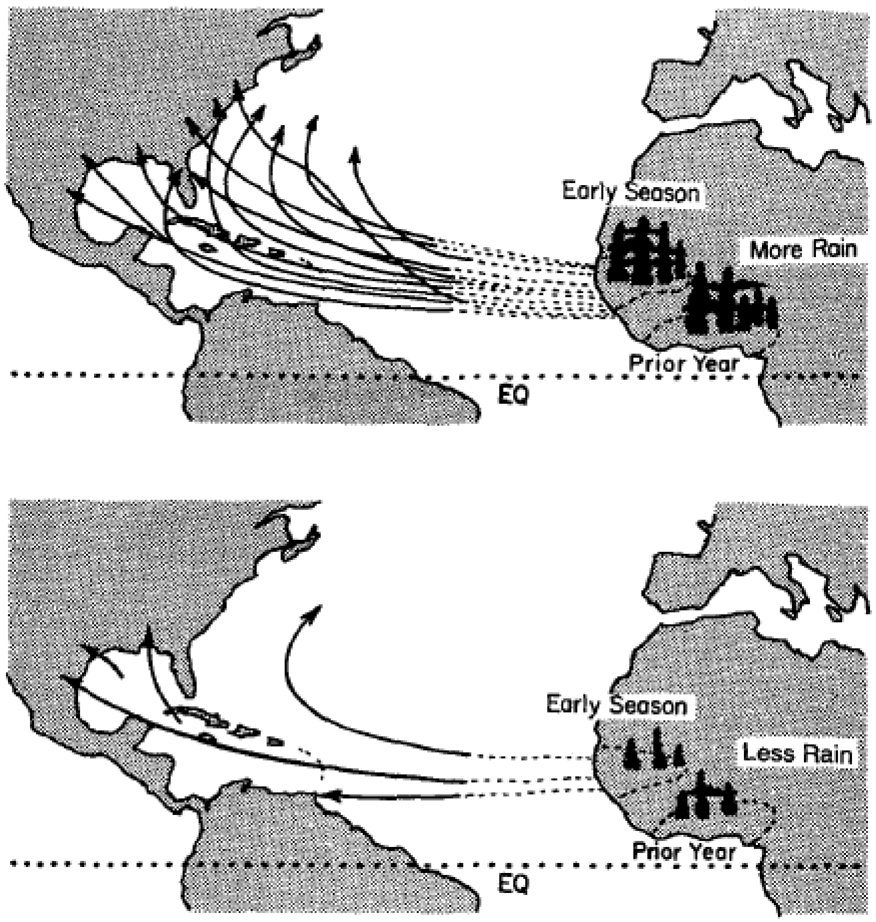
Environmental conditions:

(Top):Less wind shear due to stronger 200-hPa tropical easterly jet (TEJ) and weaker 600-hPa African Easterly Jet (AEJ, Goldenberg & Shapiro 1996)



Source: Landsea and Gray 1992, JCLIM

Guinea Coast: Proposed physical mechanism



Source: Gray and Landsea , 1992, BAMS

Soil moisture /vegetation feedback mechanism has been proposed by Gray et al. (1992, WAF):

More rains in the 2nd, less pronounced ASON rainy season at the Guinea Coast shall lead to more Sahel rains in the early tropical cyclone season of the following year.

Soil moisture memory & year-to-year persistence in Sahel rainfall: Best predictors in seasonal prediction of Atlantic Hurricane variability were in the past the two West African rainfall indices

Goals of the Fink et al. 2010 study

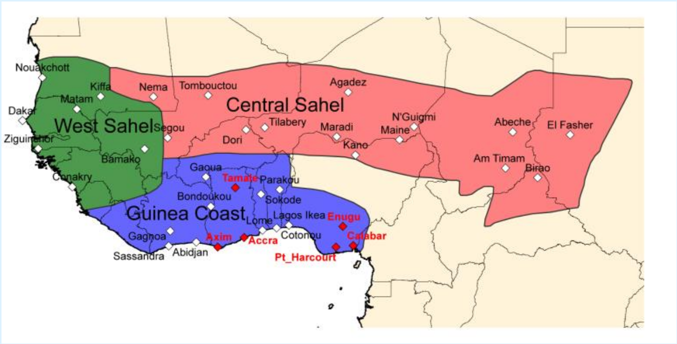
1. Revisit the nature of the correlation between West African rainfall and Atlantic tropical cyclone activity for a longer period, 1921-2007.

2. Use the enhanced and updated University of Cologne station rainfall data set for West Africa.

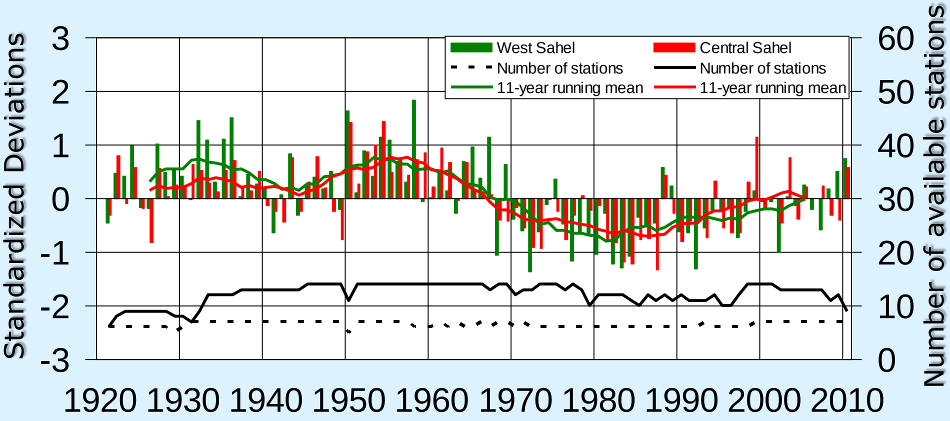
3. Include some more recent measures of Atlantic tropical cyclone activity like ACE (Accumulated Cyclone Energy) or PDI (Power Dissipation Index).

4. Explore potential physical causes of the unexpected breakdown in the correlation around 1995.

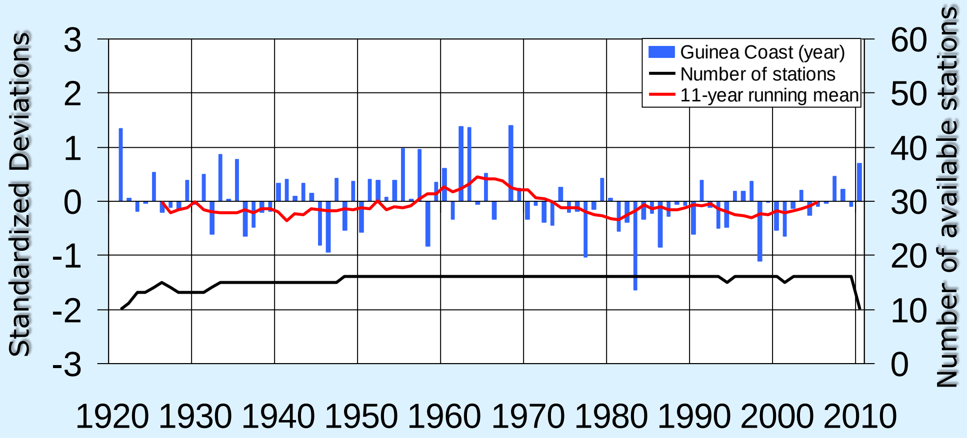
West African Monsoon: Rainfall Variability



West/Central Sahel Rainfall 1921-2010
JJAS (base period: 1950-1990)



Guinea Coast Rainfall 1921-2010
year (base period: 1950-1990)

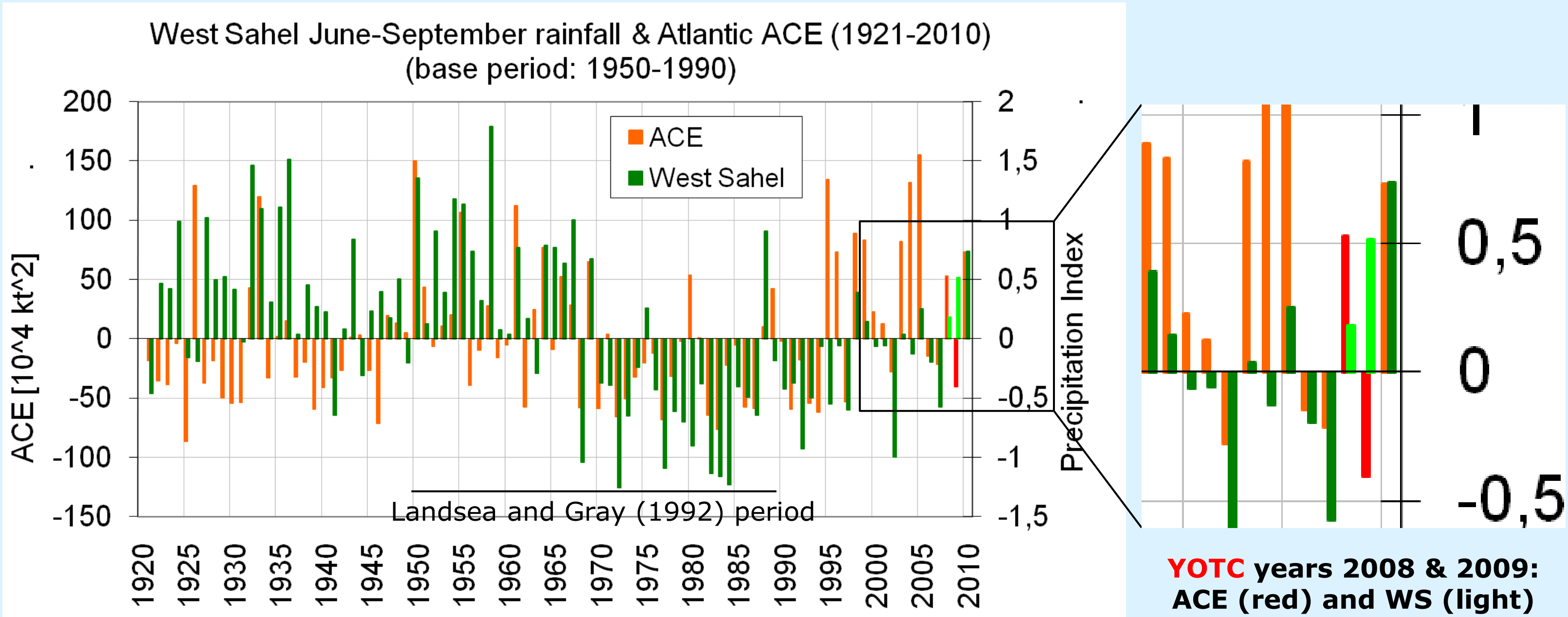


After: Fink et al. 2010, JCLIM, updated & amended

Index values can be downloaded at: http://www.impetus.uni-koeln.de/rainfall-indices.html

ACE anomalies vs. JJAS West Sahel Rainfall

After: Fink et al. 2010, JCLIM, updated and amended



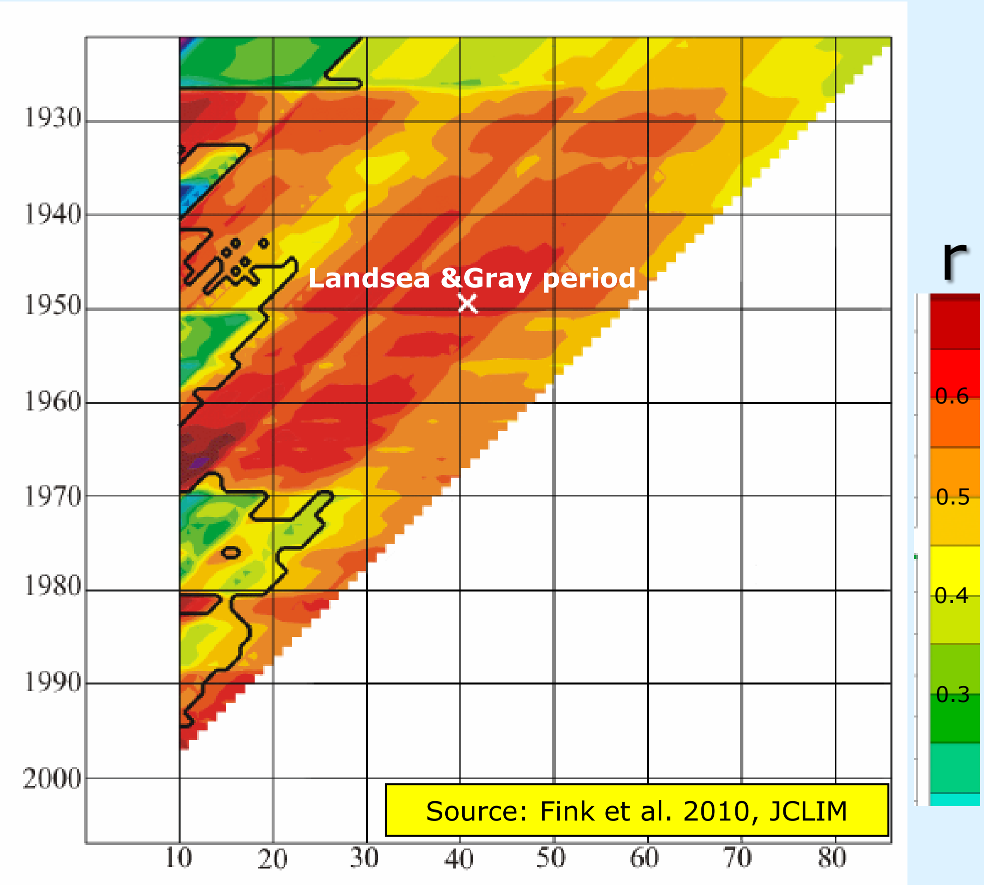
YOTC years 2008 & 2009: ACE (red) and WS (light)

Three epochs: poor correlation | good positive correlation | poor correlation

- About 1995 unexpected „**Correlation breakdown**“ between West Sahel rainfall and Atlantic Hurricane Activity
- West Sahel rainfall no longer a useful predictor of Atlantic hurricane activity (cf. Klotzbach and Gray 2004, WAF)

ACE (Accumulated Cyclone Energy): Square of six-hourly maximum sustained winds summed up over all named storms of a season (Bell et al. 2000, BAMS)

The non-stationary nature of the ACE vs. West Sahel JJAS rainfall correlation



- Over the entire 87-year period, the correlation is „only" about 0.35, though statistically significant
- The Landsea and Gray (1992) period „accidently" was a „good" period with correlations at bout 0.65
- The high linear correlation between 1995–2007 is due to a few outliers

Explanation "Triangle linear correlation plot":

- **Going into the direction of the positive X-axis: Increasing time series length at a fixed start year on Y-axis**
- **Going into the direction of the negative Y-axis: Moving a fixed length window (x-axis numbers) across the 1921-2007 period**
- **Solid lines delineate area of statistical significance**

The non-stationary nature of the ACE vs. West Sahel JJAS rainfall correlation

Tropical cyclone parameter	Correlation coefficient
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Source: Landsea and Gray 1992, JCLIM

	Western Sahel (JJAS)				
Activity measure	1949–90	1921–48	1921–2007	1949–2007	1968–2007
NS	0.34	0.35	0.16	0.24	**0.55**
NSD	**0.55**	0.32	**0.32**	**0.41**	**0.55**
H	**0.45**	0.32	0.21	**0.39**	**0.55**
HD	**0.63**	0.26	**0.36**	**0.53**	**0.54**
IH	**0.65**	0.17	**0.36**	**0.56**	**0.64**
IHD	**0.67**	0.16	**0.37**	**0.55**	**0.53**
ACE	**0.64**	0.28	**0.36**	**0.51**	**0.56**
HDP	**0.65**	0.26	**0.38**	**0.55**	**0.54**
PDI	**0.64**	0.26	**0.36**	**0.52**	**0.54**

Source: Fink et al. 2010, JCLIM

The Landsea & Gray 1949-1990 period was a unique investigation period with the highest correlation between West Sahel rainfall & various measures of Atlantic hurricane activity. This holds true for the Guinea Coast ASON relation as well (not shown)

Idea: Stratify relation ACE vs. West Sahel rainfall according to a third independent variable

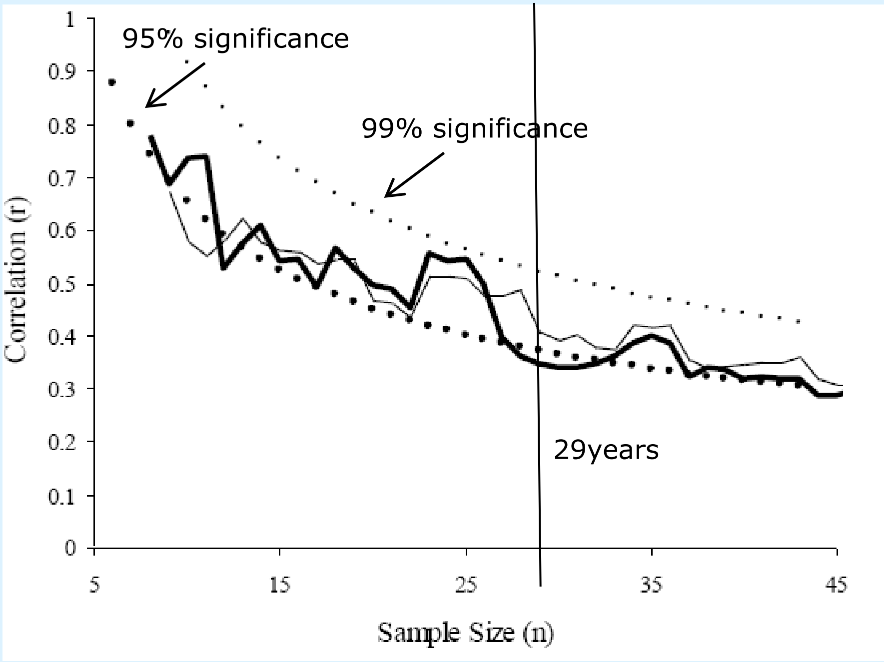
1. Hypothesis: (Not necessarily time consecutive) Sub-samples of pairs of ACE & WS precipitation, stratified according to the third variable, show a statistically significant difference in the linear correlation coefficient "r".

2. Stratification variables selected were: Sea surface temperatures (SST), Southern Oscillation Index (SOI), vertical wind shear, and 700-hPa relative vorticity.

3. Differences in „r“ were statistically tested using a Monte Carlo approach (cf. Fink et al. 2010)

Note: The stratification variables can be correlated among themselves and non-linearities can enhance or reduce differences in „r“.

Stratification variable: Southern Oscillation Index (SOI)



Period: 1921-2007

SOI: Normalized mean-sea level pressure difference Darwin vs. Tahiti

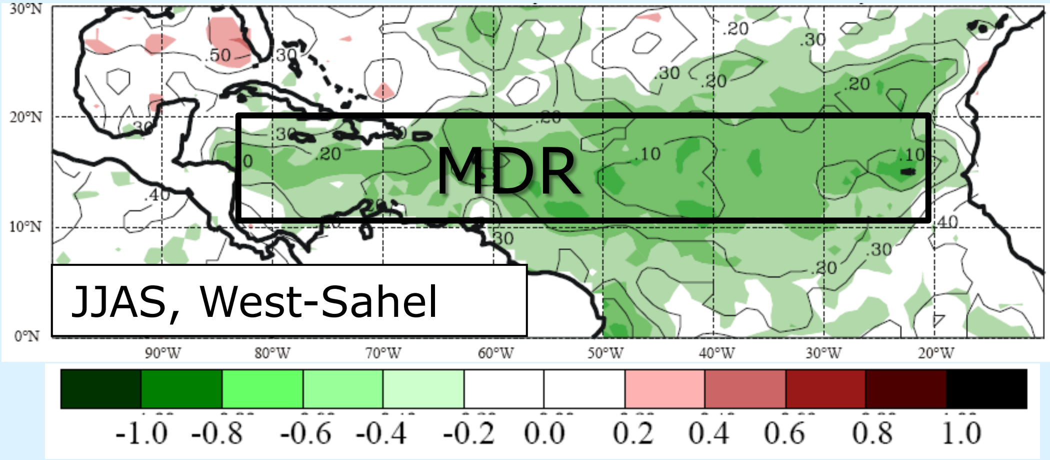
Source: Fink et al. 2010, JCLIM

Explanation "Correlation plot":

Contours: Bold (thin) curve is the linear correlation coefficient between ACE and West Sahel rainfall for the n years with the lowest (highest) SOI values, where the size n of the sub-sample is given along the abscissa.

-> Though statistically significant at the 95% level, the correlation between ACE and WS rainfall is not modulated by El Niño or La Niña like conditions – The difference in "r" is near zero.

Stratification variable: „local“ Aug-Oct. sea-surface temperature in the Atlantic basin



Period: 1921-2007

SST: HADISST

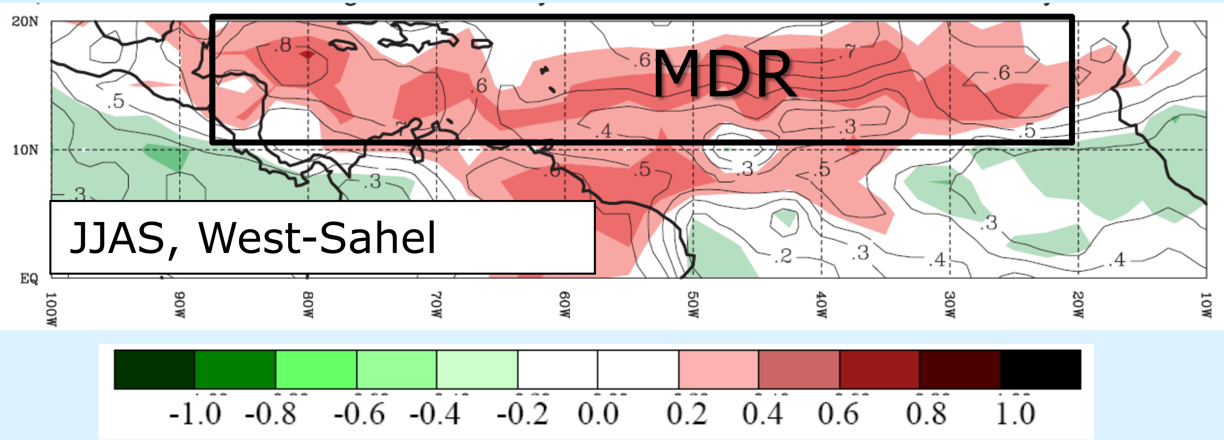
Source: Fink et al. 2010, JCLIM

Explanation "Correlation plot":

- **Contours: Linear correlation "ACE vs. WS rainfall" in the warmest 29-years (1/3 of the total sample) at any given SST grid point**
- **Shading: Difference in the linear correlation coefficients "ACE vs. WS rainfall" between the subsamples of the 29 warmest minus coldest local SST values.**

Statistically significant negative values in correlation difference (green areas) indicate "no correlation" in the 29 warmest (contours) and a "large" positive correlation in the 29 coldest SST years

Stratification variable: „local“ Aug-October 200–850-hPa vector wind shear in the Atlantic basin



Period:

NCEP Reanalyses
1958-2007

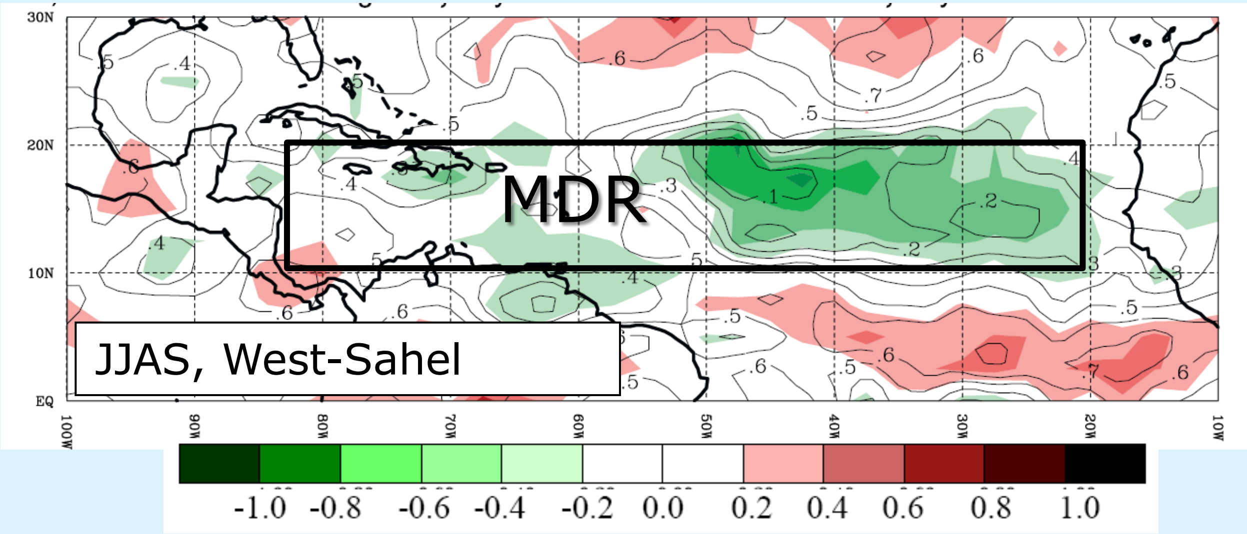
Source: Fink et al. 2010, JCLIM

Explanation "Correlation plot":

- **Contours: Linear correlation "ACE vs. WS rainfall" in the 17-years (1/3 of the total sample) with the highest tropospheric wind shear at any given rid point**
- **Shading: Difference in the linear correlation coefficients "ACE vs. WS rainfall" between the subsamples of the 17 years with the highest and lowest tropospheric wind shear.**

-> Statistically significant positive values (contours) indicate a "positive correlation" in the 17 years with highest shear, but no significant correlation in the 17 "low-shear years" (red shading)

Stratification variable: „local“ Aug.-Oct. 700-hPa relative vorticity



Period:

NCEP Reanalyses 1958-2007

Source: Fink et al. 2010, JCLIM

Explanation "Correlation plot":

- **Contours: Linear correlation "ACE vs. WS rainfall" in the 17-years (1/3 of the total sample) with the highest 700-hPa relative vorticity at any given rid point**
- **Shading: Difference in the linear correlation coefficients "ACE vs. WS rainfall" between the subsamples of the 17 years with the highest and lowest 700-hPa relative vorticity .**

-> Statistically non-significant correlation (contours) indicate no "correlation" in the 17 years with highest 700-hPa relative vorticity, but a significant "positive correlation" in the eastern MDR in years with the lowest relative vorticity.

Findings of the Fink et al. 2010 study

1. The non-stationary character of the Sahel-Atlantic hurricane activity correlations was documented for both temporally continuous and discontinuous data samples.

2. When conditions are marginal in the MDR for tropical cyclogenesis (low SST, high shear, low relative vorticity), West Sahel rainfall is a good contemporaneous indictor of Atlantic hurricane activity.

3. Guinea Coast preceding years ASON rainfall matters in a statistical sense also in years with unfavorable genesis conditions (not shown)

How can these statistical results be interpreted?

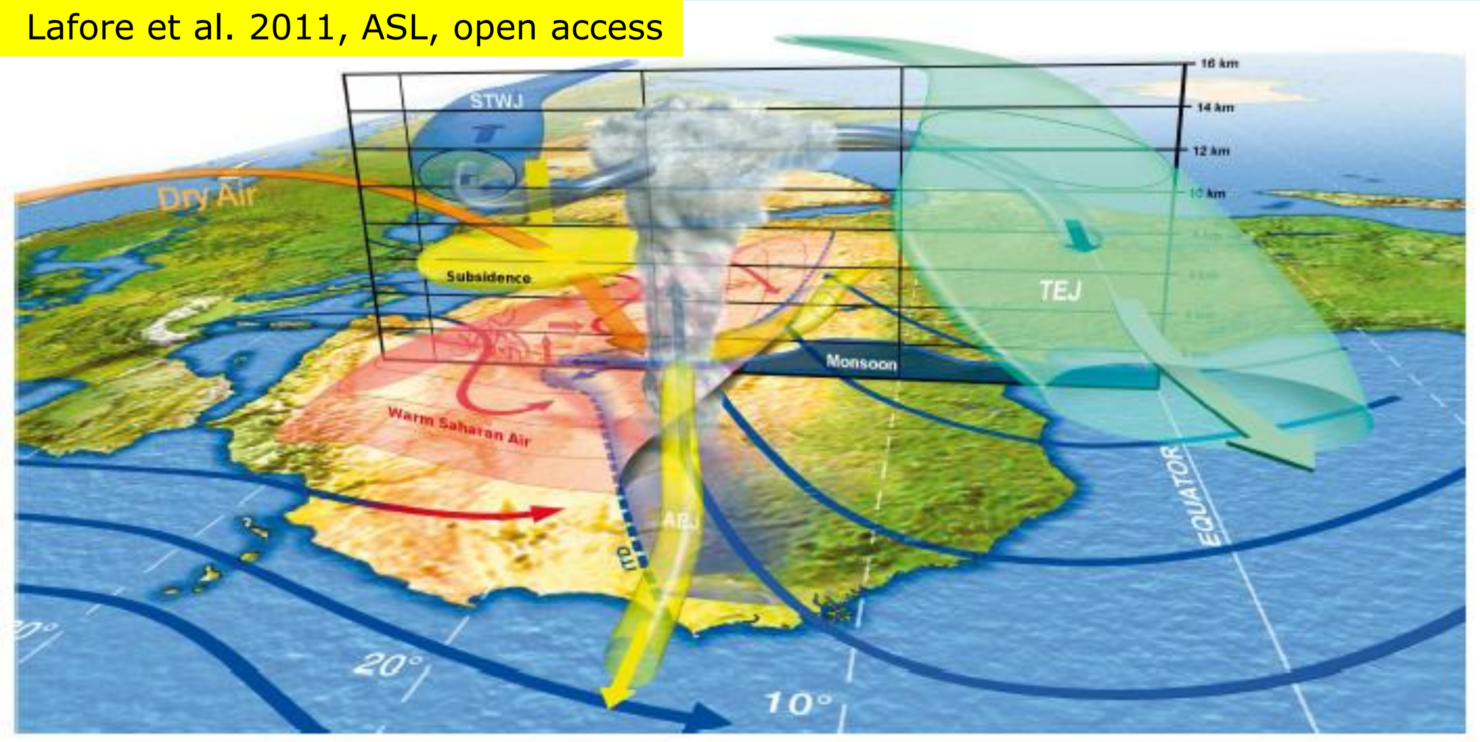
Hypotheses

1. In years with marginal conditions for tropical cyclogenesis in the MDR, the dynamic and convective organization of African Easterly Waves (AEWs) as the seedling disturbances matters (cf. Landsea & Gray 1992).

2. The Atlantic Meridional Mode (AMM) modulated both the environmental conditions governing Atlantic tropical cyclone activity and West African rainfall activity (Kossin and Vimont 2007). This "in phase" relation (AMM+ and ACE+/WS Rain+ deteriorated at about 1995 (vegetation degradation over Africa?)

Conceptual Model of the West African Monsoon

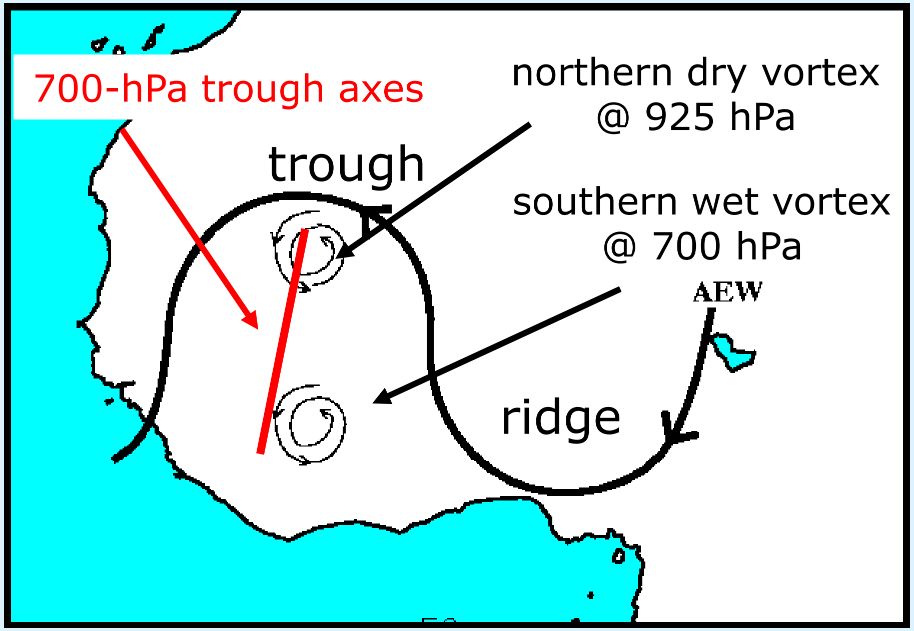
Lafore et al. 2011, ASL, open access



1. **Saharan Heat Low (HL) ⇒ two convergent low-level flows**
 dry northerly wind (Harmattan) → ITD ← moist monsoon flux
2. **Mid-level (~4km) African Easterly Jet & African Easterly Waves**
3. **Upper-level (~12 km) Tropical Easterly Jet (TEJ)**
4. **ITCZ sandwiched between AEJ and TEJ**
5. **Waves in the Subtropical Jet (STJ)**
 and mid-latitude dry intrusions

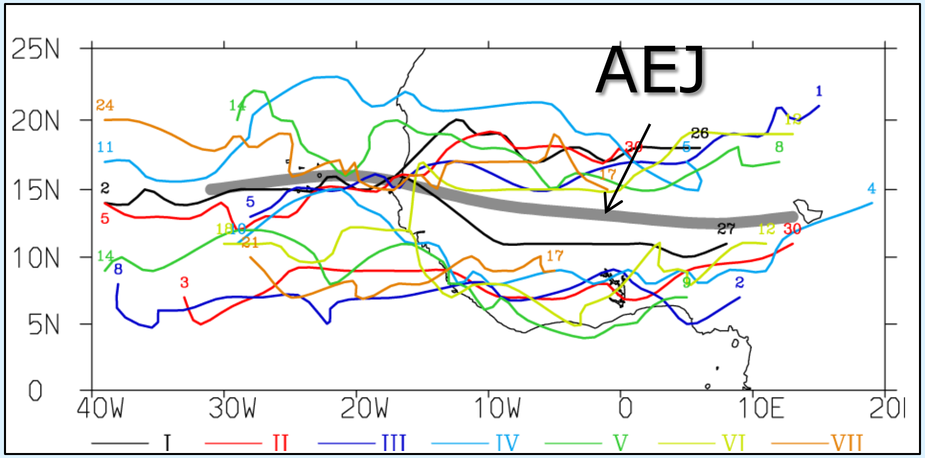
An idealized AEW and real tracks of its vortices

An idealized AEW



Source: Fink, unpublished

Track northerly/southerly AEW vortices
(GATE Phase III, 30.8-19.9.74)

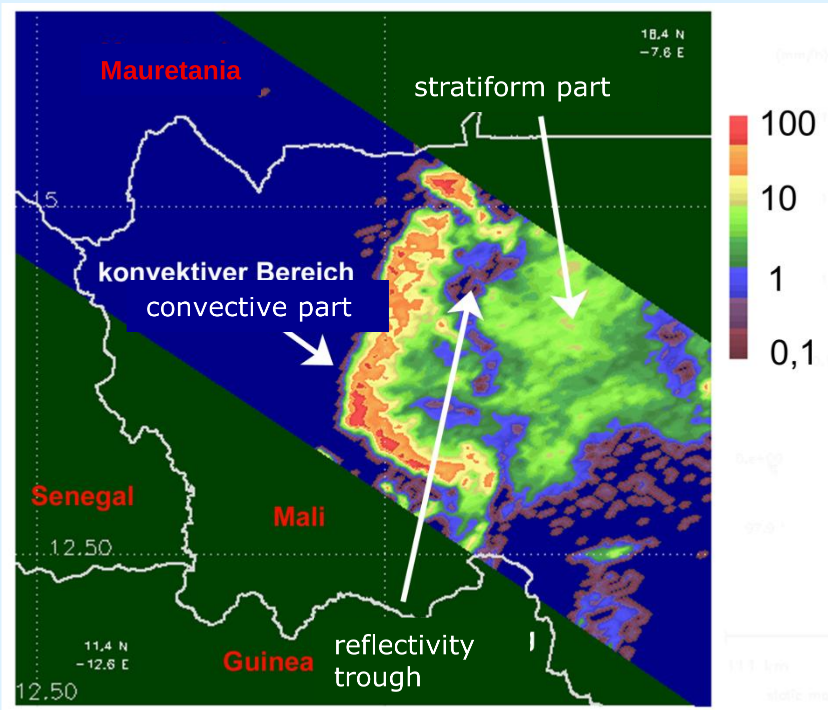


Source: Fink et al. (2004)

- An AEW consists of a northerly „dry" & a southerly „wet" vortex maximizing at 925 hPa and 700 hPa, respectively. The vortices straddle the African Easterly Jet (AEJ)
- The northerly vortex sometimes crosses the AEJ equatorward over the ocean and apparently undergoes a merger with its southerly counterpart
- A southwest-northeast trough alignment signifies barotropic energy conversion

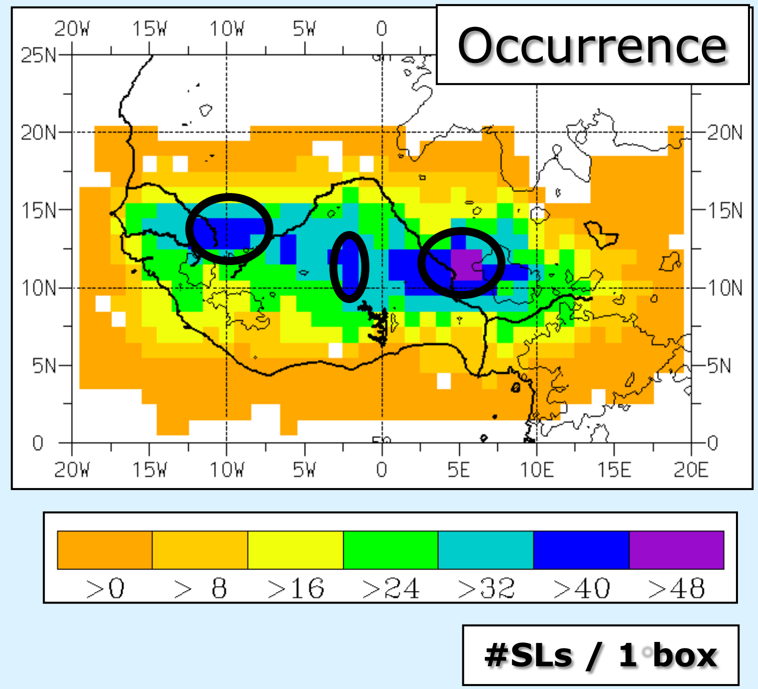
West African squall lines

Squall Line, TRMM radar reflectivity (07.09.2002)



Fink (2006)

Squall Line Climatology May – October 1998/99

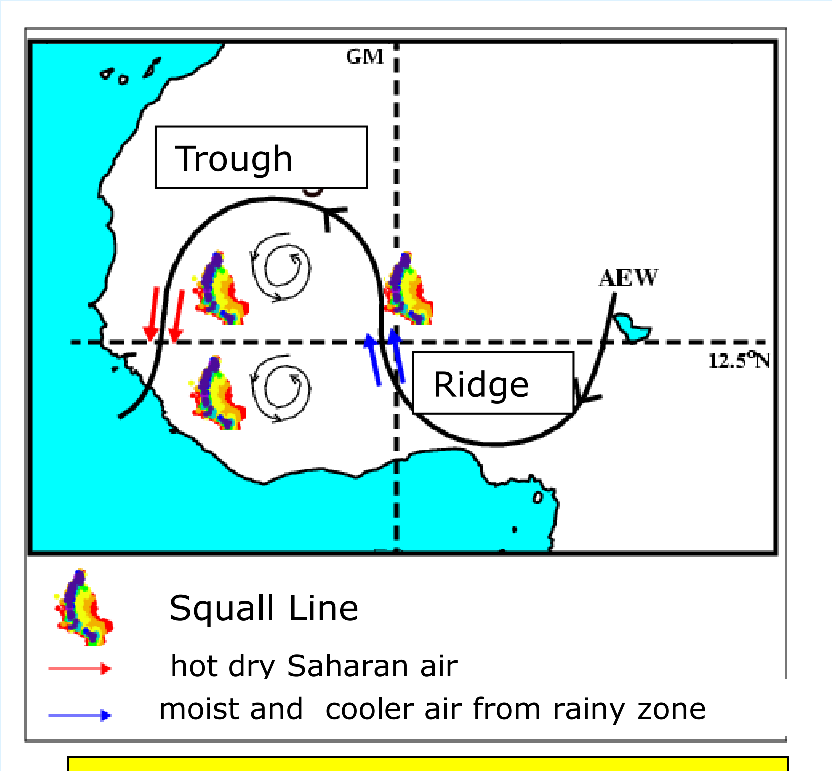


Fink & Reiner (2003)

- Stratiform part: Vorticity production tends to maximize at 600-700 hPA
- Convective part: PV production closer to the ground (cooling, convergence)
- Squall lines are a land feature (dry low-level air required)

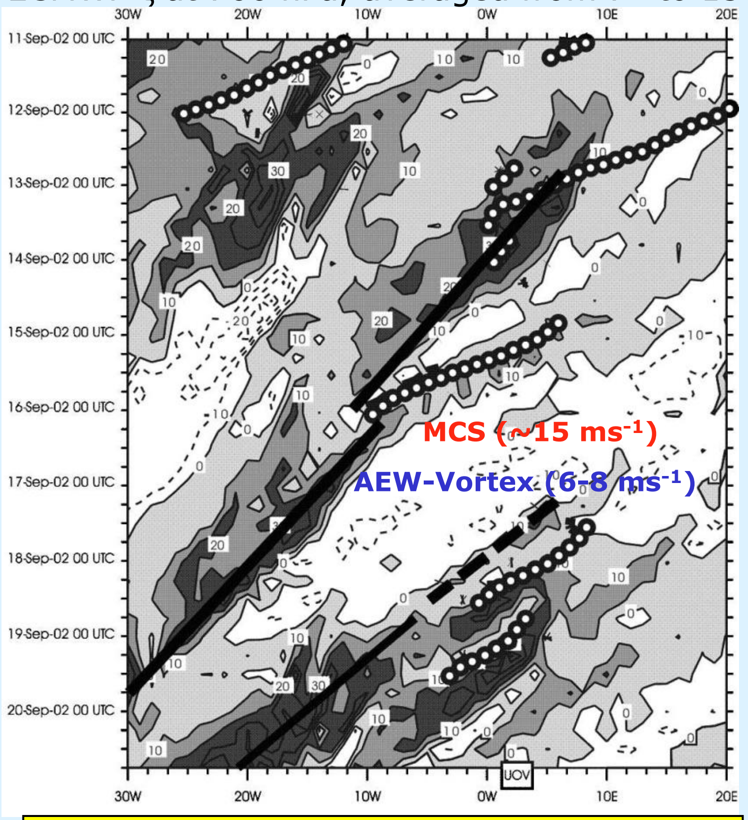
The relation between AEWs and Squall Lines

AEW and Squall line genesis



After Fink (2006)

ECMWF ξ at 700 hPa, averaged from 7° to 13°N

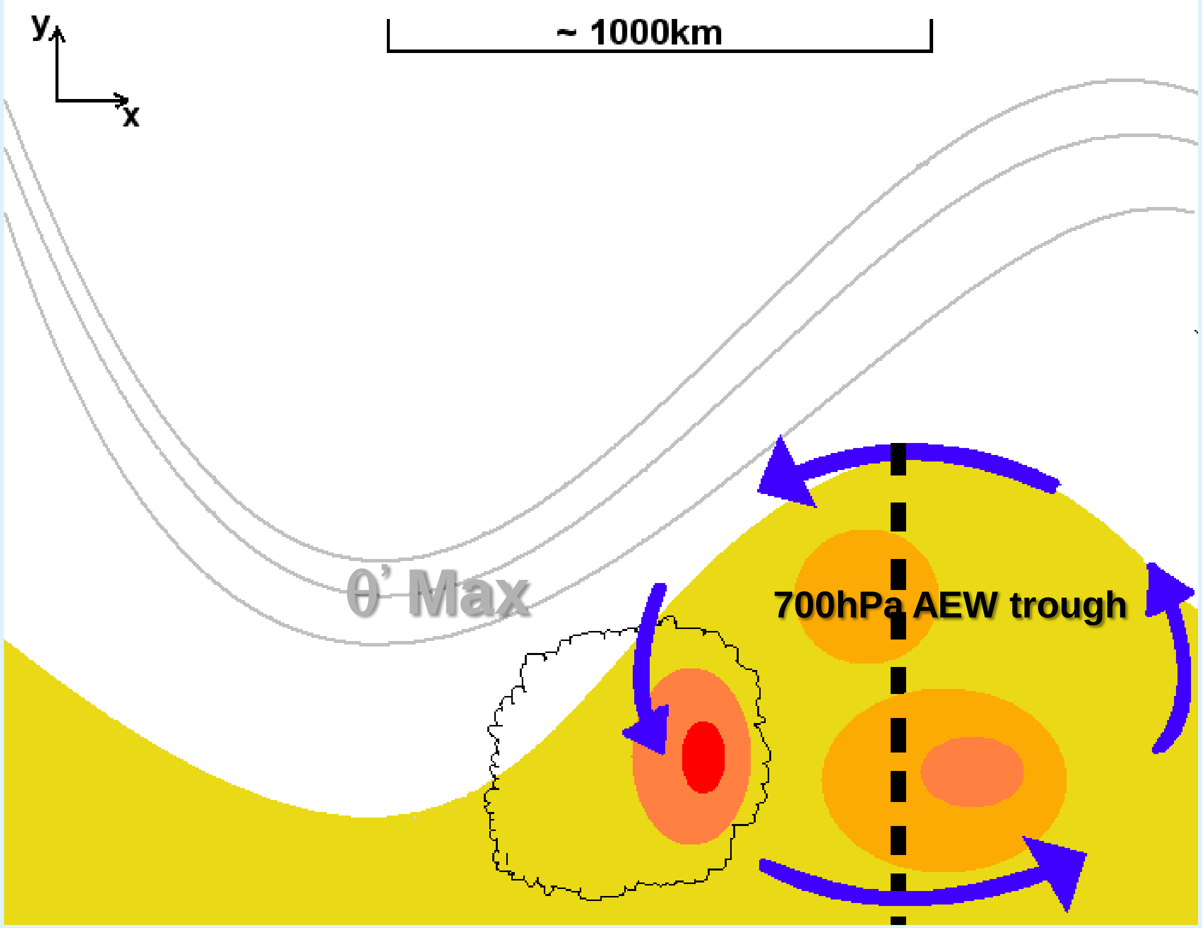


Schrage et al. (2006)

- Two preferred squall line genesis regions: Ahead of AEW trough and behind it (in the northern region only, GATE 1974 result). Relation increases substantially while AEWs approach the West Coast (Fink and Reiner 2003)

- Left: Faster moving squall lines generate relative vorticity at 700 hPa

New view on the amplification of AEWs



furnished by C. Thorncroft, adapted from Berry and Thorncroft (2005)

AEWs grow through an interaction with Mesoscale Convective Systems (mostly squall line systems)

Scant climatological evidence of AEW – TC relation

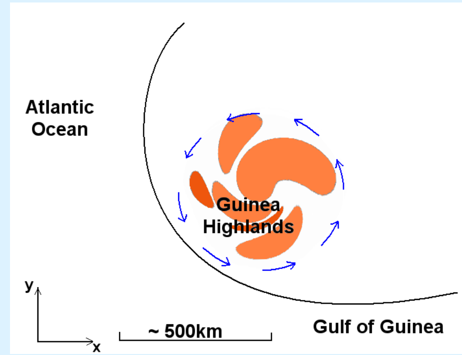
Hopsch et al. (2007):

Investigation period: 1958-2002

- African easterly wave activity – as measured by the 2-6-day bandpass-filtered wind @ 850 hPa - shows a significant, positive correlation with downstream tropical cyclone activity at interannual time scales.
- Atlantic tropical cyclone activity is only significantly related to the number of AEWs on longer (e. g. decadal) time scales.

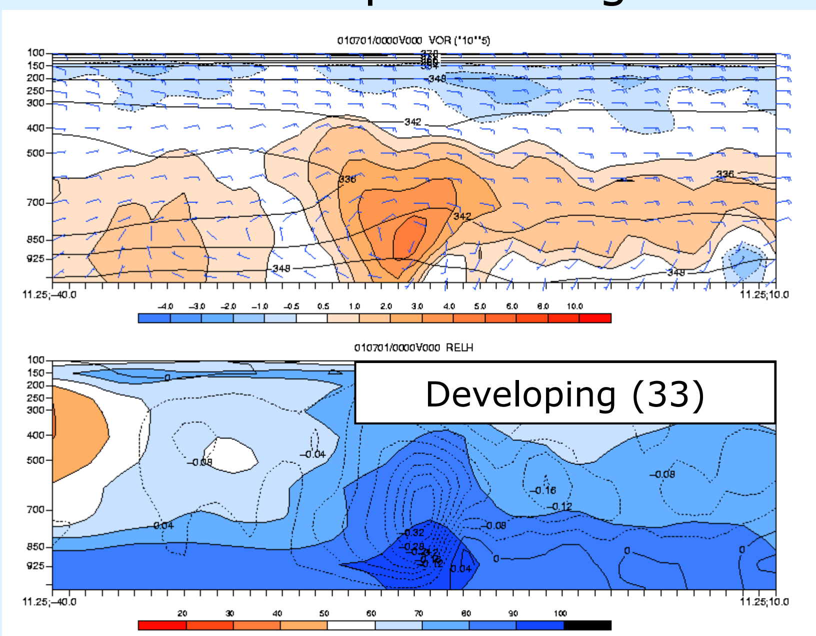
Vorticity and moisture signatures of developing and non-developing AEWs

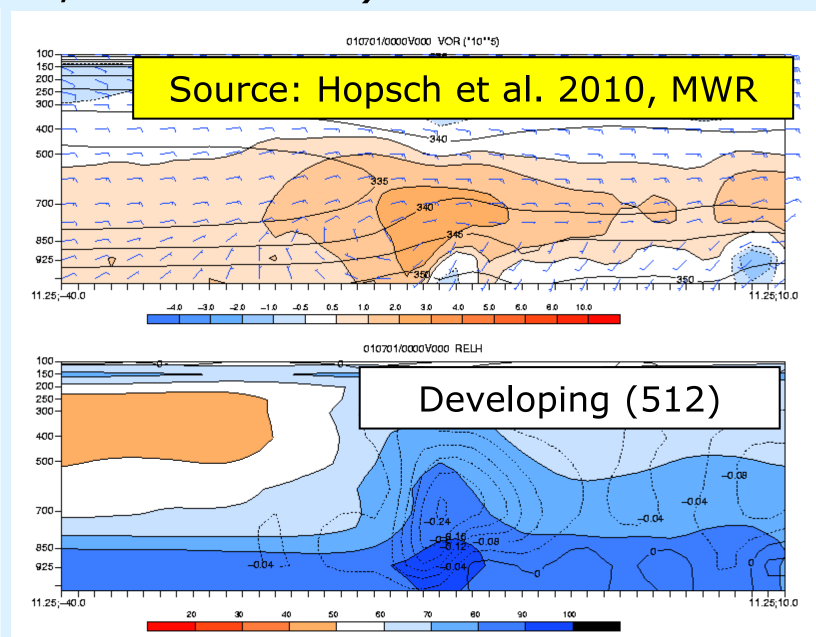
AEWs often get a “boost” before they leave Africa; associated with mergers of PV from upstream and in situ generation.



furnished by Thorncroft

Composite longitude 20°E, 1979-2001)





Developers: higher vorticity near surface, moister ahead of AEW trough

Characteristics of AEWs associated with cyclogenesis in the Cape Verde Island region

Investigation period: 2004-2008

Investigation domain: < 40°W

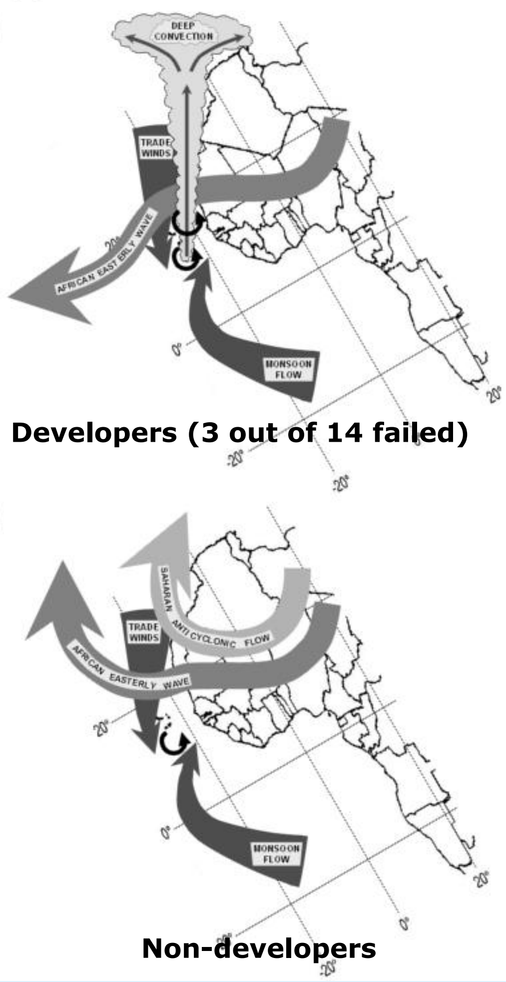
Characteristics of Developers:

(a) strong 700 AEW trough

(b) Strong vorticity signature at the surface of non-convective origin: Secondary heat low cyclone (Schwendike & Jones, 2010) or northerly AEW vortex (Ross and Krishnamurti 2007) can undercut 700 hPa vortex

(c) Deep convection in AEW vortex. Vorticity production by convection

(d) No Saharan anticyclonic flow associated with upstream AEW ridge (stretching and disorganization of vortex)



Developers (3 out of 14 failed)

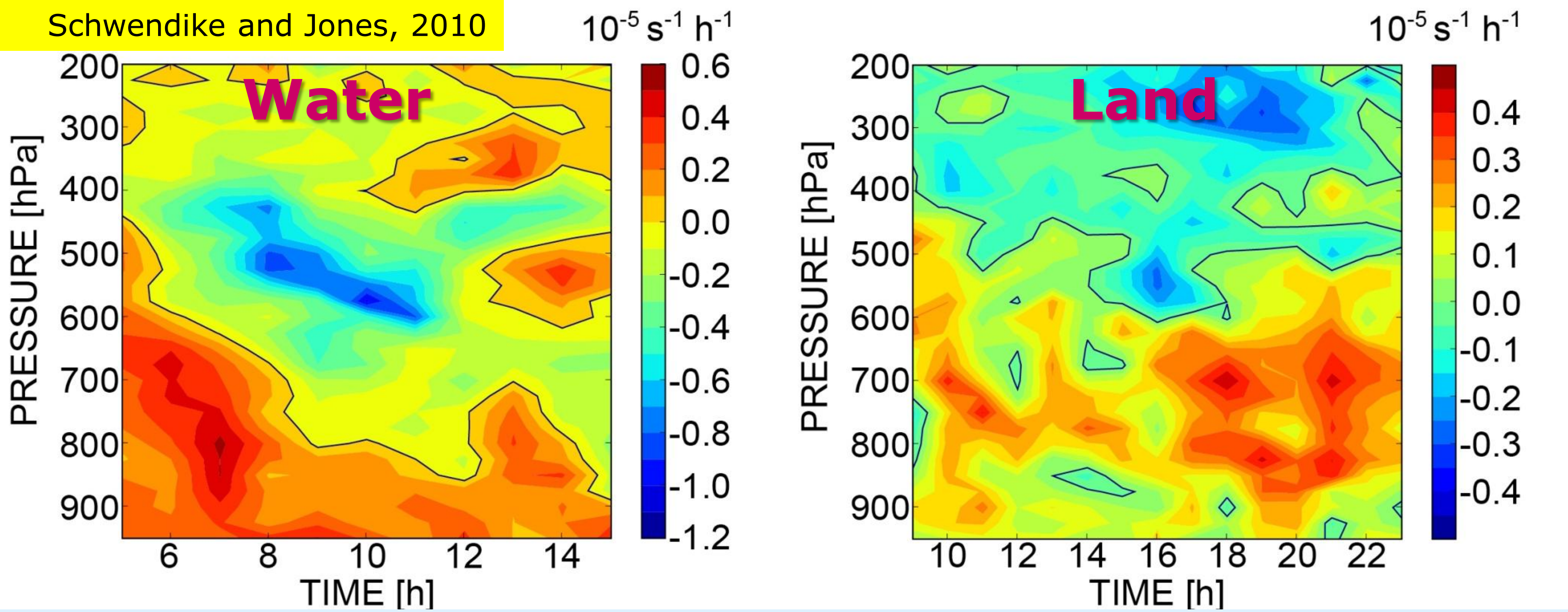
Non-developers

Source: Arnault and Roux 2011, AR

Land-based vs. ocean based mesoscale convection

Vorticity tendency (COSMO Model, 2.8 km resolution, initialized with ECMWF analysis at 12 Sept. 2006 00 UTC)

Schwendike and Jones, 2010



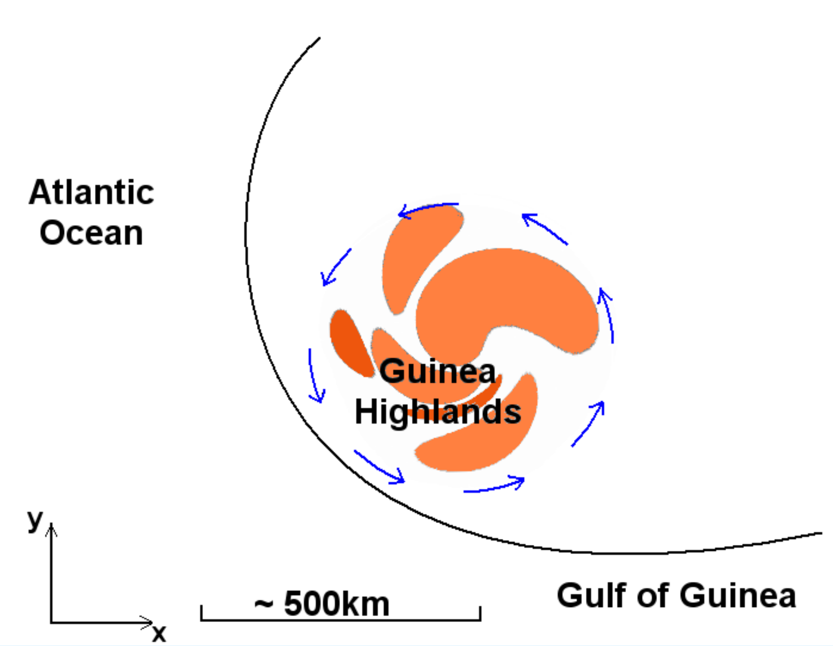
Fast moving, highly organized MCS over land: Vorticity accumulates at 800 700 hPa through eddy flux term in vorticity budget equation

Slow, short-lived oceanic MCS: Near-surface vorticity accumulation through stretching in untilted „hot tower" like system

Some unresolved questions – challenges for YOTC

1. What is the role of organized convection in AEW triggering in the East Sahel and amplification (different AEW and MCS propagations speed!)-> Vorticity budget studies with YoTC analyses & models, 2008 still some AMMA activated radiosonde stations active.
2. Do northerly and southerly AEWs merge off the West Coast of Africa, and if, how?->YoTC analyses, models
3. What distinguishes those special “developing AEWs” (yearly activity in number is quite constant) from all of the non-developers? -> Cases, but bridge to climate

Some unresolved questions – challenges for YOTC



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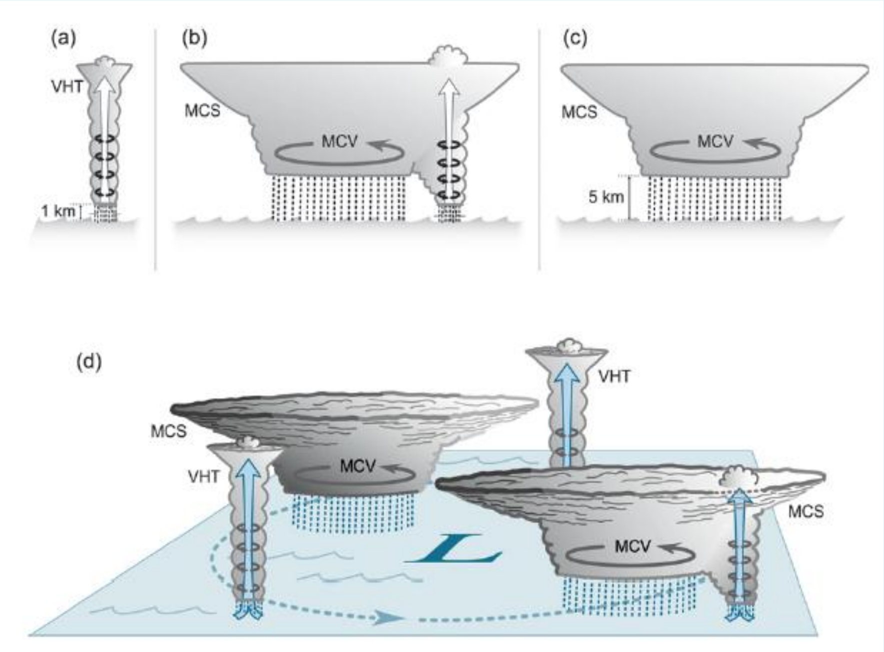
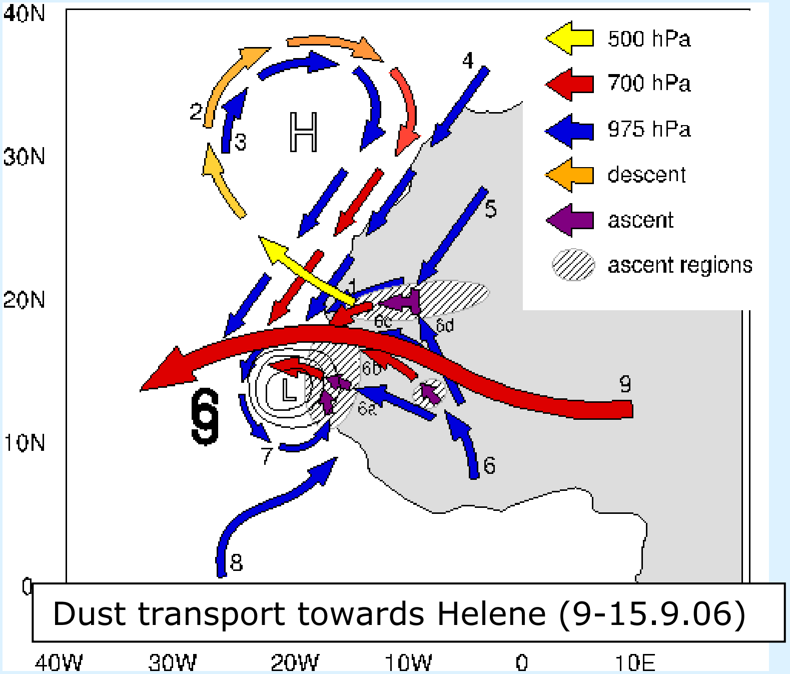


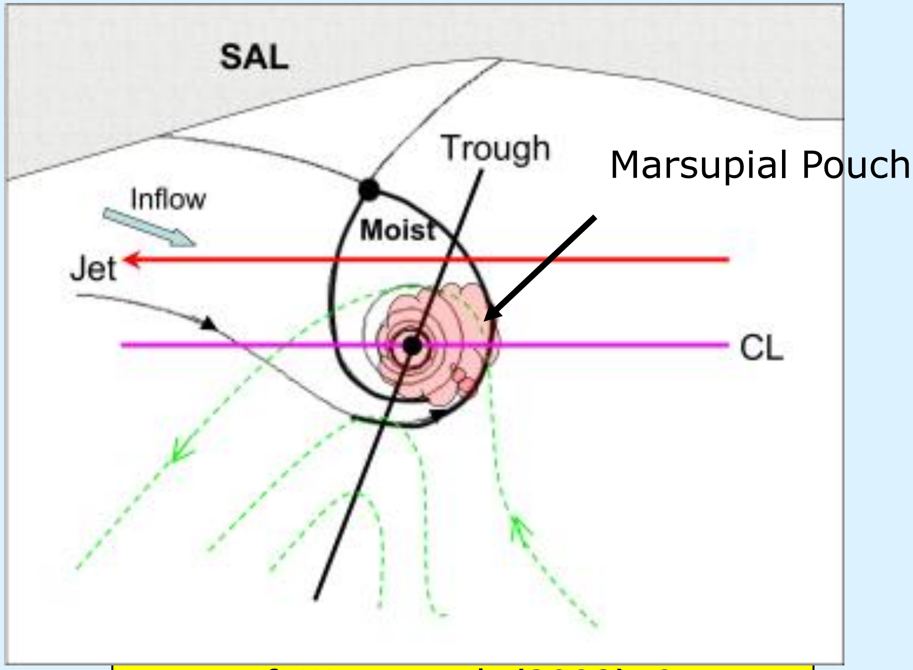
taken from Houze (2010, MWR)

Do upstream processes (e.g. West African rainfall systems) and their impacts on the AEW's relative vorticity signature matter vs. vorticity generation by convective and stratiform convection in the AEW trough over the ocean?

What is the role of the dusty and dry Saharan Air Layer?



from Ph. D. thesis J. Schwendike



cf. Wang et al. (2008) & Dunkerton etal. 2009

Is dusty and dry mid-level air favoring or disfavoring tropical cyclogenesis, or both depending on the case?

Or is the inner core “protected” from SAL or subtropical dry air intrusions (“Marsupial Pouch” hypothesis)?

A remark

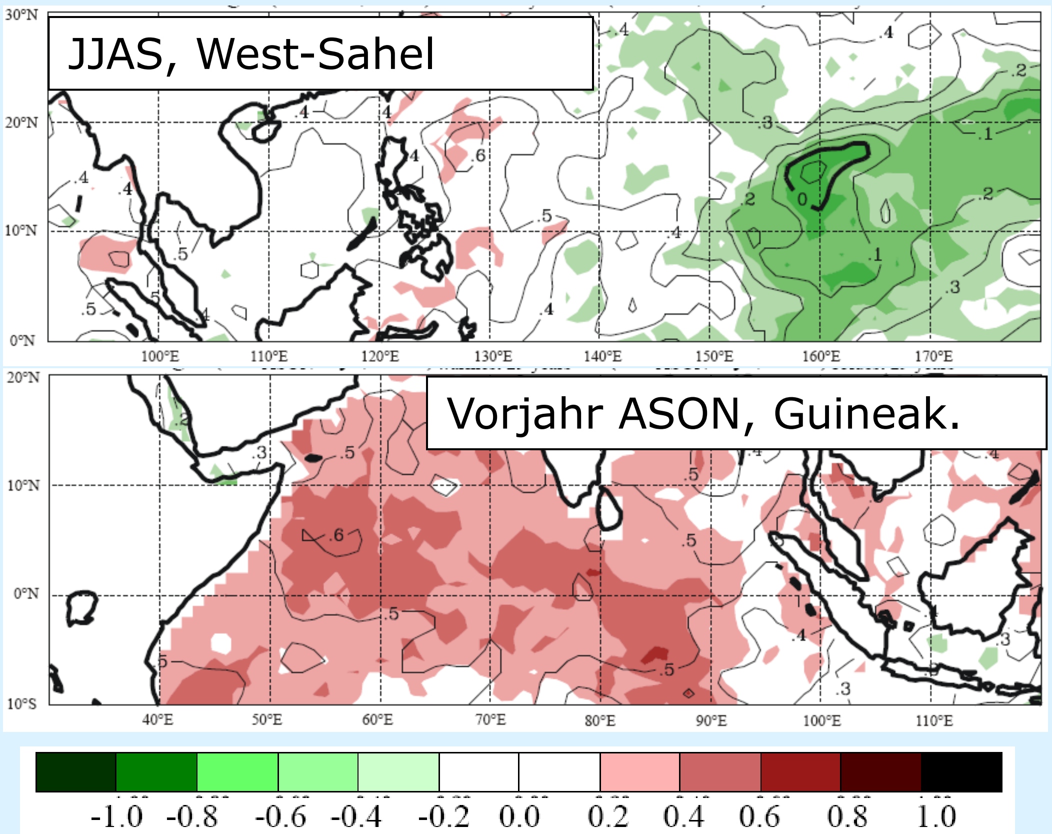
The open questions solicit case studies using models and YoTC diagnostic products. (N)AMMA has also fostered numerous case studies. HOWEVER:

A bridge to the importance of any individually detected process in climatology will be needed (climatological studies)

Thank you for your attention!

* e-mail: fink@meteo.uni-koeln.de
Internet:http://www.geomet.uni-koeln.de/en/general/the-institute/research-groups/research-group-fink/

Einfluss Ozeanoberflächentemperatur auf Beziehung Niederschlag-Hurrikanaktivität (Aug.-Okt. ACE)



Periode: 1921-2007

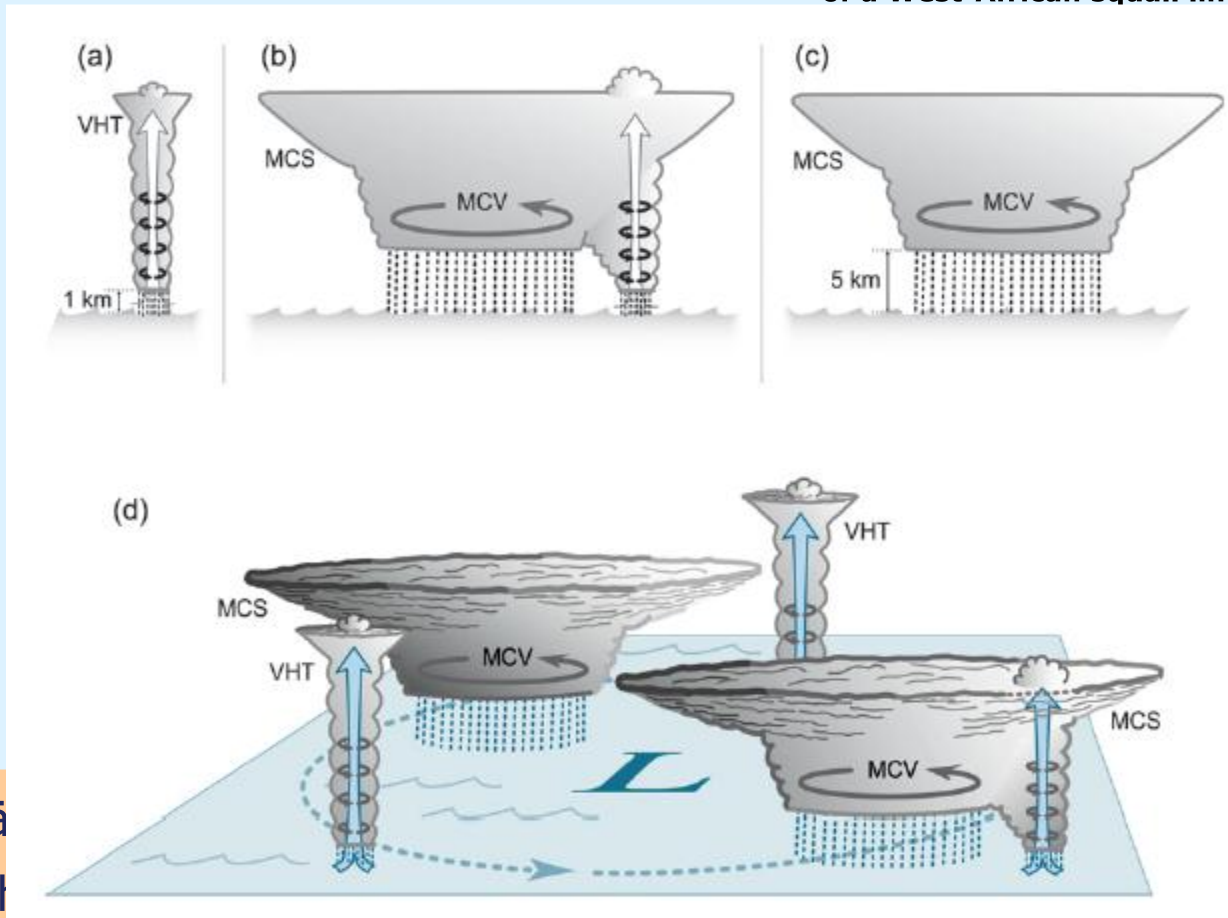
SST: HADISST

Interpretation der Diagramme:

1. Isolinien: Korrelation Niederschlag und ACE für 29 wärmsten SST Jahre
2. Einfärbung: Differenz des Korrelationskoeffizienten warme – kalte SST

Zusammenhang zwischen AEWs und MCSs

An idealized scheme for the development of a West-African squall line:

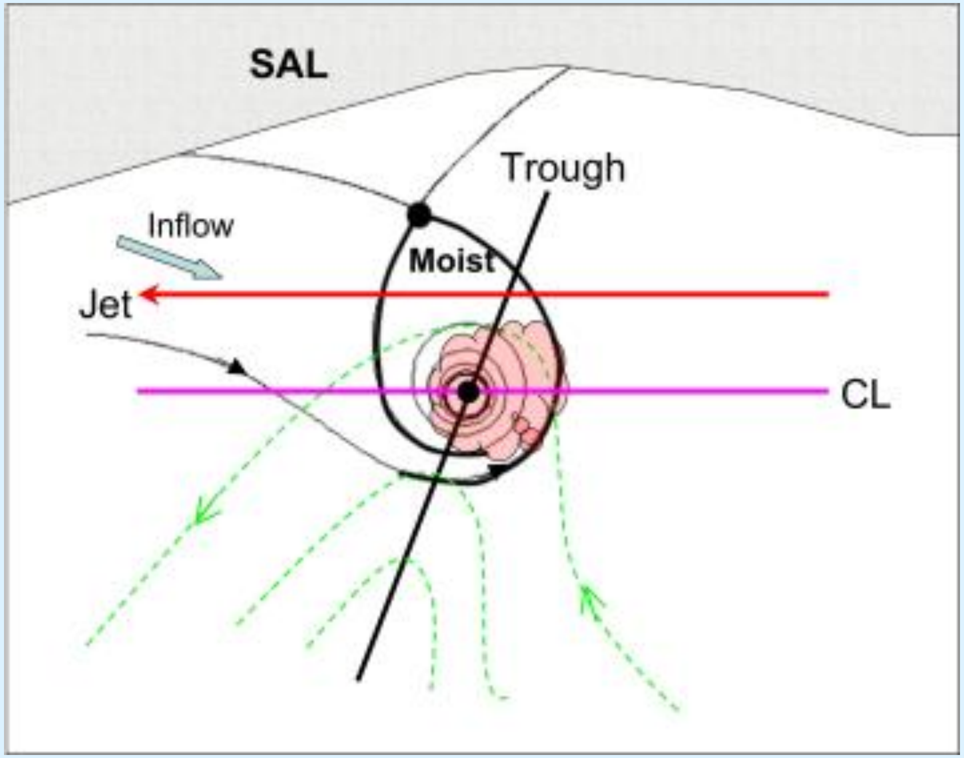


•Maximale Hä … dbereich (stärkere Sc … nz in mittlerer Troposphäre)

•im Sahel im Bereiche der Südwinde (hohes CAPE)

•Beziehung östlich v. Greenwich kaum vorhanden, am stärksten an der Küste

Marsupial Pouch



- http://met.nps.edu/~mtmontgo/marsupial.html
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