Ocean-Atmosphere interactions in the Gulf of Guinea: AMMA Phase 1 perspective

Jean-Luc Redelsperger thanks to contributions from

African Monsoon Multidisciplinary Analyses
Analyses Multidisciplinaires de la Mousson Africaine
Afrikanischer Monsun : Multidisziplinäre Analysen
Analisi Multidisciplinare per il Monsone Africano
Afrikanske Monsun : Multidisiplinaere Analyser
Analisis Multidiciplinar de los Monzones Africanos
Afrikaanse Moesson Multidisplinare Analyse
AMMA: An international program on West African monsoon, its variability and society-environnement-ressources-climat Interactions

Aim 1: To improve our understanding of the West African Monsoon variability

Aim 2: To provide the underpinning science to relate WAM variability to related societal issues
To define & implement relevant monitoring & prediction strategies

Aim 3
To ensure that the AMMA research is integrated with prediction & decision making activities (Forecast/EWS)

Coordination: Pluridisciplinary, Different communities
International: ~600 persons from 30 countries

Africa: ~250 pers; Research and Application (Forecast/EWS) communities
~ 600 peer review publications / 10 special issues AMMA:
RMS/Weather & Forecast AMS/J. of Atmospheric Sciences AMS/Climate Dynamics/ASL RMS/

AMMA coordinated with international programmes and bodies:

Research field experiments / Database & library
Observation networks; Modelling; Satellite Products tailored & validated

Training/Education: PhD (160 incl 80 Africans!!) Masters, Summer Schools, Workshops
Communication (external & internal)
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Research field experiments

LOP 2002-2010; EOP 2005-2007; SOP 2006:
- First international field experiment in Africa at regional scale
- Simultaneous observations of Ocean-Atmosphere-Land system on full seasonal cycle & eco-climatic transect
Ship operations 2005-2007 during Monsoon

- shipborne measurements
- buoys

2006 Monsoon

**R/V US RON BROWN**
North Atlantic
6 June – 9 July

**R/V D METEOR**
Tropical Atlantic
23 May – 16 July

**R/V F ATALANTE**
Gulf of Guinea
24 May – 6 July

- Oceanic circulation
- Ocean – atmosphere interactions
- Role of oceanic forcing on monsoon onset & dynamics
- Atmospheric profiles on GTS (=> ECMWF…)

- Oceanic profiles in quasi-real time (at least daily) (also for CORIOLIS/ARGO and MERCATOR/GODAE projects).

Radiosoundings at least twice a day from each vessel ~250 profiles

XBT profiles 0-800m Atalante & Ron Brown ~ 250 profiles

CTD profiles 0-500/1000m every ½° along meridional sections at 35°W, 23°W, 10°W, 3°E and 6°E ~ 300 profiles
Flux & turbulence measurements

- Foredeck boom (Net radiation sensors)
- Instrumented mast (classical met. Parameters and turbulence sensors)
- Central mast (Downward long and shortwave radiation sensors)
- TKE dissipation in ocean

+ 6 long duration stations (24h min)

Skin SST:

Evolution of atmospheric parameters (June 4 - 14)

Tair

Tsea

Tsea-Tair

Radiation

RH

Wind speed

equatorial upwelling
Key phases of the annual cycle of the West African monsoon

- **Mid-April**
  - Oceanic phase
  - Cold Tongue formation
  - Coastal rain onset

- **End of June**
  - Coastal phase
  - Oceanic meridional circulations

- **Mid-July**
  - Transitional phase
  - Mature stage of monsoon

Thorncroft et al. 2011
AMMA observations June 2005 & 2006: Two contrasted years

Bourles et al 2007, Brandt et al 2011
Cold Tongue Formation

Equations in an homogeneous frictional surface layer, on a beta-plan centered on the equator (Zebiak and Cane, 1987)

\[
\begin{aligned}
ru_s - \beta yv_s &= \frac{\tau_x}{\rho_0 H} \\
\beta yu_s + rv_s &= \frac{\tau_y}{\rho_0 H}
\end{aligned}
\]

Ekman pumping

\[
w(-H) = \frac{1}{\rho_0 (r^2 + \beta^2 y^2)} \left\{ \frac{\beta (\beta^2 y^2 - r^2)}{r^2 + \beta^2 y^2} \tau_x + \frac{-2\beta^2 yr}{r^2 + \beta^2 y^2} \tau_y + r\nabla \tau + \beta y \nabla \wedge \tau \right\}
\]

Caniaux et al 2011

1. Zonal wind stress
2. Meridional wind stress
3. Wind stress divergence
4. Wind stress curl
CT develops consequently to the strengthening of the south hemispheric winds

Positive pumping confined 3°S-0°N explaining the shape of the CT

Meridional wind stress term is the leading term

Differential cooling across the equator generate SST gradient

Caniaux et al 2011
Key region and period

- Cooling starts as soon as winds strengthen near 3°S (April)
- Cooling strengthens in May-June
- Sharp SST gradients 0-2°S
- SST gradients decrease in September

As soon as a SST gradient threshold is reached:
- winds weaken S of equator
- winds strengthen N of equator up to the continent in July-August

Caniaux et al 2011
**Interaction Cold Tongue & Atmosphere**

**Composites**
Tref = Date when winds between Equator and coast become stronger than southerlies further south

**Wind**

**Water vapour (color) & SST (black contours)**

**TRMM rain**

Enhanced convection and precipitation on the Guinean coast

Does the continent influence back the SST in the GG? For example through the Shallow Meridional Circulation (Zhang et al. 2008)

Leduc-Leballeur et al in prep
Interaction Cold Tongue & Atmosphere

- Net flux > 0 over CT (ocean warming)
- Differential cooling N/S of the equator generates increasing of SST gradients & net heat flux gradients (May to Sept around 1°S-1°N)
- Minimum of net heat flux gradient occurs before maximum of SST gradients (~3 weeks; N/S difference in cloud cover / solar heat fluxes)

Caniaux et al. 2011

SST Gradients

Net Surface Heat Flux

Net Surface Heat Flux Gradients

1998-2007; 10°W-4°E
**Interaction Cold Tongue & Atmosphere**

Linear regression against Northern Cold Tongue Index of wind stress (magnitude: color) & SST (black contour)

**Lag -2 (the wind leads the SST by 2 days):**
Positive feedback north of 2°N

![Image of wind stress and SST distribution with arrows and color scale]

- **Wind stress:** Quikscat
- **SST:** TMI
- **NCTI:** Average over 8W-4W / 0.5S-1N with a minus sign, and high-pass filtered with a Lanczos window (1/90 days)

**Lag 0 (in phase):** Negative feedback around the Equator

![Image of wind stress and SST distribution with arrows and color scale]

- Possible mechanism for this negative feedback:
  - Wind increasing induces a cold SST anomaly (horizontal advection & vertical mixing), max. 5-6 days after
  - SST decreasing slows down the overlying wind through the enhancement of vertical stability in the MABL, max 2-3 days after

De Coetlogon et al 2010
Lag -2 (the wind leads the SST by 2 days): positive feedback north of 2°N

Possible mechanism for this negative feedback:
- Wind increasing induces a cold SST anomaly (horizontal advection & vertical mixing), max. 5-6 days after,
- a colder SST slows down the overlying wind through the enhancement of vertical stability in the MABL, max 2-3 days after.

Lag 0 (in phase): negative feedback around the Equator

Wind stress: Quikscat
SST: TMI
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Interaction Cold Tongue & Atmosphere Characteristics of the MABL on either side of the SST front

The marine boundary layer is thicker over the warm SST than over the cold SST.

True also in ECMWF operational analyses

Leduc-Leballeur et al 2011
9 boxes sampling the different dynamics & thermodynamics regional characteristics of the EEA

**Northern boxes** (warmer SSTs, Guinea Current, heavy precipitation)

**Cold Tongue boxes** (SEC and EUC)

**Southern boxes** (SECC, Angola dome)
Mean Annual MLD Heat Budgets

- Heat storage positive except in southern boxes
- Net surface heat fluxes dominate
- Storage and residual terms compare well with Foltz et al 2003 (PIRATA estimates)
- Significant part of solar heat flux goes out of the ML base
- Mean horizontal advection important in boxes 1, 2, 8, 9
- Weak contribution of entrainment

**Net surface heat flux**

**Entrainment**

**Residual**

**Mean hori. advec.**

**Fsol*I(-h)**

**Heat storage**

Wade et al 2011
• Negative residuals (reaching -120 Wm$^{-2}$)

• Weak residuals in the southernmost boxes;

• Turbulence data collected during AMMA/EGEE (Dengler et al., 2010) and other studies (Rhein et al., 2010) compare well with the residuals (phase, amplitude, spatial distribution);

=> Vertical mixing at the ML base is probably the leading missing term

Wade et al 2011
1D model representing a single column of 3D ocean model

Surface & horizontal forcings deduced from observations

Time evolution of profiles (T,S,U,V) compared to independent observations

=> Necessity to adjust the diapycnal mixing intensity

Wade et al 2011b
• Good agreement between AMMA obs & model (shape, magnitude, diurnal cycle) except for intermittent patches not present in model
• Similar results to Pacific (Moum et al 1985, 1992; ....)
Modeling vs AMMA observations: Bias in CNRM-CM5 (ARPEGE-NEMO); Example for Zonal current

Vertical profil of zonal current
June (Eq - 10W)

Voldoire 2010
Bias in CNRM-CM5 (ARPEGE-NEMO): Example for Zonal current; Nudging towards ERA sfc winds

Vertical profile of zonal current
June (Eq - 10W)
Bias in CNRM-CM5 (ARPEGE-NEMO): Example for Zonal current; Nudging towards ERA sfc winds

- CNRM-CM5 globally nudged
- CNRM-CM5 regionally nudged
- CNRM-CM5 nudged towards the winds predicted by ARPEGE forced by observed SST

No Equatorial Under Current

Latitude

Voldoire 2010
Conclusions

• Unprecedented dataset on the coupled ocean-atmosphere-land African monsoon system
  ➔ Improved understanding (more on land-atmosphere including chemistry/aerosol than on ocean-atmosphere)

• Two shortcomings in regard to oceanic processes:
  # Ocean cruises during monsoon onset and mature stage (June-Sept)
    ➔ Need to observe coupled system when cold tongue formation occurs (April-May)
  # Not enough observations and modeling dedicated to the understanding of ocean-atmospheric interactions
    ➔ Need to observe coupled system response to the sharp STT front (May-June) (e.g. in AMMA no rain/cloud observation over ocean)

• Need to investigate more the retroaction of continental circulation onto Gulf of Guinea
Strategy combining 1D and 3D oceanic models with observations should be developed to address model issues (e.g. diapycnal mixing): to use atmospheric model strategy (GCSS) for ocean?
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Thank you

http://www.amma-international.org

International Science Plan  AMMA-Phase 2  (2010-2020)