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Analysis of small scale wave over the West African area

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GOAL OF THE STUDY

The West African Monsoon (WAM) system is a climatological feature of major economic and social importance for the population of the region whose economy heavily relies on agriculture (Hagos and Cook, 2007). The WAM is characterized by intense and localized rainfalls of which the variability and the prediction are key elements. They are influenced by intraseasonal oscillations and convectively-coupled equatorial waves a such quasi-periodic oscillations of 25-60 days or 10-25 days and transient waves of 3-5 days responsible of monsoon onsets, breaks and evolution regionally (Janicot and Sultan, 2001; Sultan et al., 2003).

In order to characterize waves with period ≤ 5 days observed in the West African tropical and equatorial LS (19-23 km) during the WAM evolution, wave characteristics (energy densities and spectral parameters) are derived from radiosonde data obtained during the 2006 AMMA Campaign. The link between the activity of waves generated above the West African area and the QBO is also investigated through 9- year (January 2001-December 2009) climatology of wave activity.

AREA OF THE STUDY

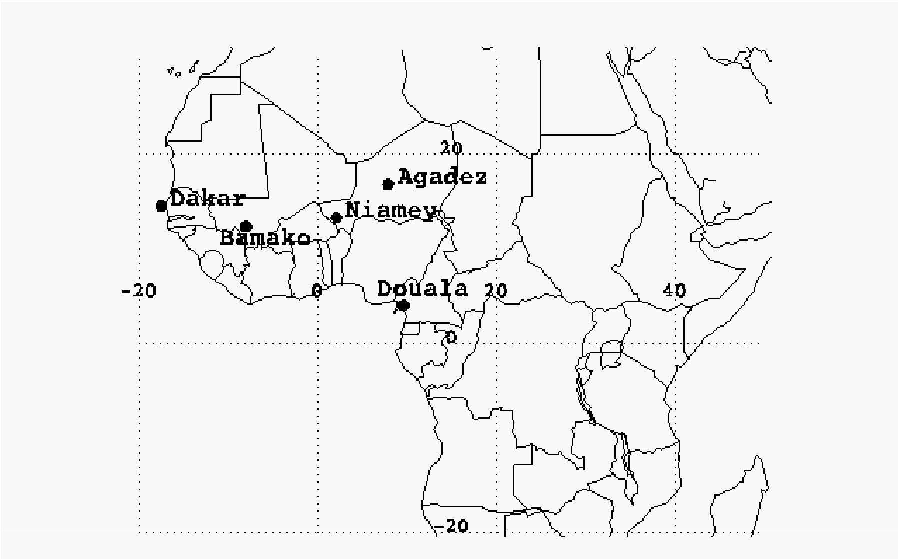


Fig 1: Location of the stations used for the study.

Table 1: Stations geographical characteristics.

Stations	Latitude (°)	Longitude (°)	Height (m)
Douala	4.01 N	9.70 E	5
Bamako	12.53 N	7.95 W	377
Niamey	13.48 N	2.16 E	222
Dakar	14.72 N	17.50 W	28
Agadez	16.96 N	7.98 E	501

The establishment of WAM is characterized by a progressive extension of the monsoon wind and humidity from the Gulf of Guinea (equatorial zone) as far as the latitude 18-20°N (tropical zone). The study has been performed for five meteorological radiosounding stations located in the area of coverage of the WAM i.e. in the belt ranging from 4°N to 17°N and from 20°W to 10°E (Fig. 1); 4 stations in the Sahel domain from 12°N to 17°N : Bamako (Mali), Niamey (Niger), Dakar (Senegal) and Agadez (Niger) and 1 station near the Equator (Douala).

METEOROLOGICAL CHARACTERISTICS OF THE AREA (1)

Sahelian zone

The latitudinal displacement of the ITCZ determines the cycle of the seasons in the West African zone. Two seasons are prevalent:

- a long dry season during 8 months (October-May) with low temperatures about 20°C and high temperatures greater than 40°C
- a rainy season during 4 months (June-September) with a relative humidity about 60%, westerly wind in the UT and at the surface increases.

Low latitudinal zone (Douala)

Through the year the relative humidity is always greater than 60%. The ITCZ crosses over the sites twice a year and induces:

- a dry season (November-February) whose characteristics are $25°C \leq T \leq 32°C$ and $50mm \leq p \leq 150mm$
- a long wet season (March-October) composed of a period of intense convection from March to June ($31°C \leq T_{max} \leq 33°C$; $p \sim 300mm$), a "rainy season" from July to September ($23°C \leq T \leq 27°C$; $p \geq 700mm$) and the end of the season, October ($T_{max} \sim 30°C$; $p \sim 400mm$).

At the surface, the winds system is similar to the sites located in the Sahel (an intensification of westerly wind during the two main rainy seasons and a decrease during the short dry season) and quite different in the UT.

METEOROLOGICAL CHARACTERISTICS OF THE AREA (2)

In the West African zone the prevailing winds are :

Winter monsoon wind (Harmattan): a NE dry wind coming from the Sahara desert

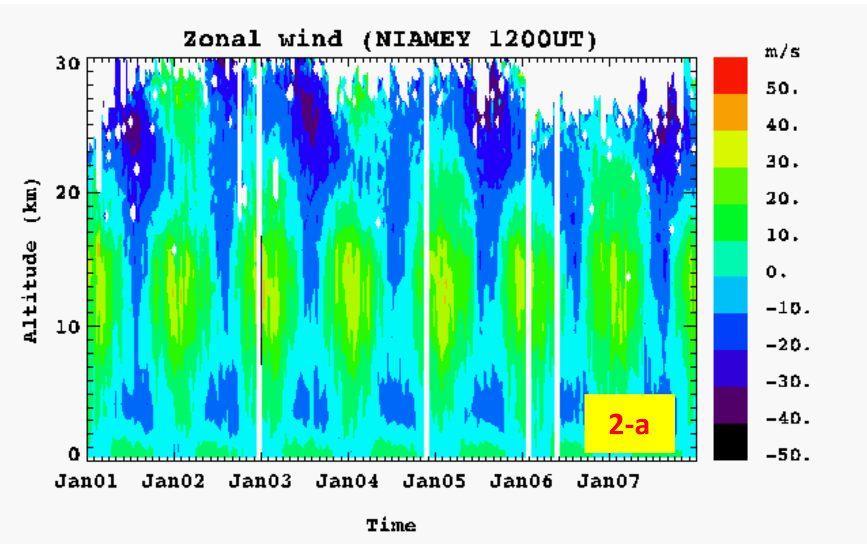
Summer monsoon wind : a SW wet warm wind coming from the ocean

TEJ : at about 14-15km height, is an easterly thermal wind due to the temperature difference between Tibetan High and the Indian Ocean.

STWJ : at about 12-14km height, is a westerly wind due to the kinetic/spin momentum conservation of an air parcel on the upper branch of the Hadley cell

AEJ : at about 3-4 km height, is an easterly wind due to the gradient of temperature between the continent and the Atlantic Ocean.

QBO: observed at around 25km altitude (well-marked above the equatorial site Douala)



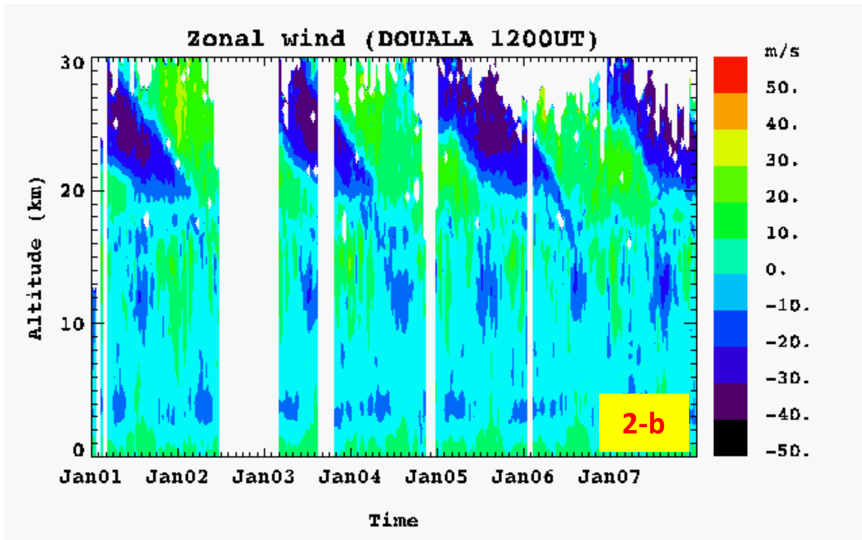


Figure 2: Time-height cross section of zonal wind above a) Niamey and b) Douala (2001-2007 period)

DATASET AND ANALYSIS

The data were daily Radiosonde data (1200 UTC) from the five meteorological radiosounding sites located in figure 1. Two datasets were used:

- Wyoming University website : January 2001- December 2009
- AMMA data base : January-December 2006

The study of GWs is based on 100-m interval vertical profiles of temperature and wind perturbations at heights between 19 km and 23 km in the LS (Kafando et al., 2008). More than 70 % of the daily radiosondes reached 23 km height. The GW energy procedure has been established in the framework of the SPARC initiative (Stratospheric Processes And their Role in Climate) on GW climatologies (Allen and Vincent, 1995 ; Chane-Ming et al., 2007 ; Kafando et al., 2008).

Total energy E_T which is the sum of kinetic and potential energies (KE and PE) is used as a measure of GW activity :

$$E_T = \frac{1}{2}[\overline{u'^2} + \overline{v'^2} + \frac{g^2}{N^2}\overline{\hat{T}'^2}] = KE + PE$$

E_T, KE and PE : Total, kinetic and potential energy densities

u', v' : zonal, meridional wind fluctuations

$\overline{\hat{T}'}$: temperature perturbations normalized by the background profile.

Wave spectral parameters (period, vertical and horizontal wavelengths) are calculated by the FFT Stokes method (Eckermann, 1996 ; Chane Ming et al., 2010). The vertical dominant modes are derived from peaks relative to the Desaubies model (Allen and Vincent, 1995).

WAVE ACTIVITY - Tropical area

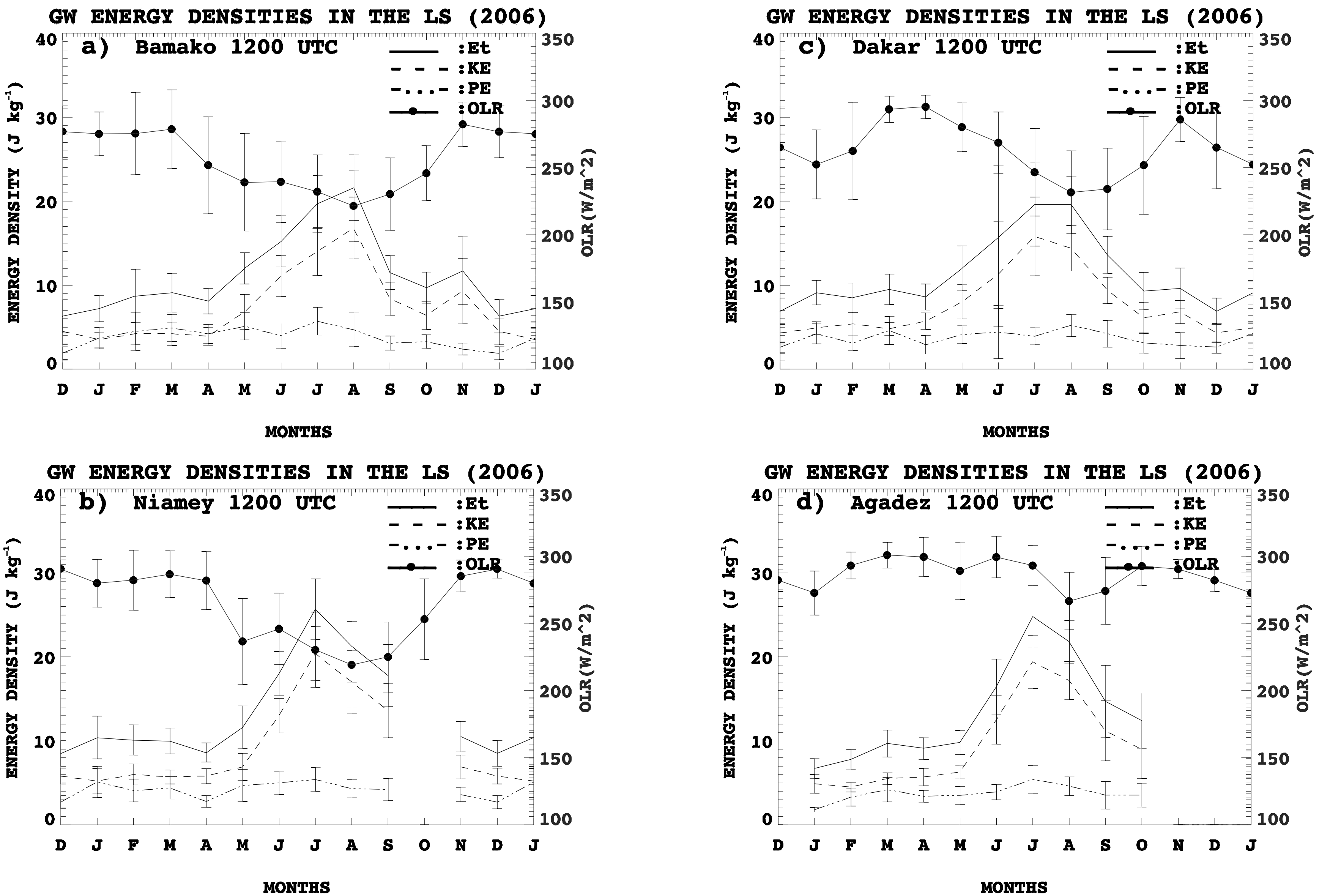


Figure 3: 2006 annual cycle of GW energy densities in the LS and Outgoing Longwave Radiation (OLR) data in the West African tropics (Bamako, Niamey, Dakar and Agadez).

WAVE ACTIVITY – Equatorial area

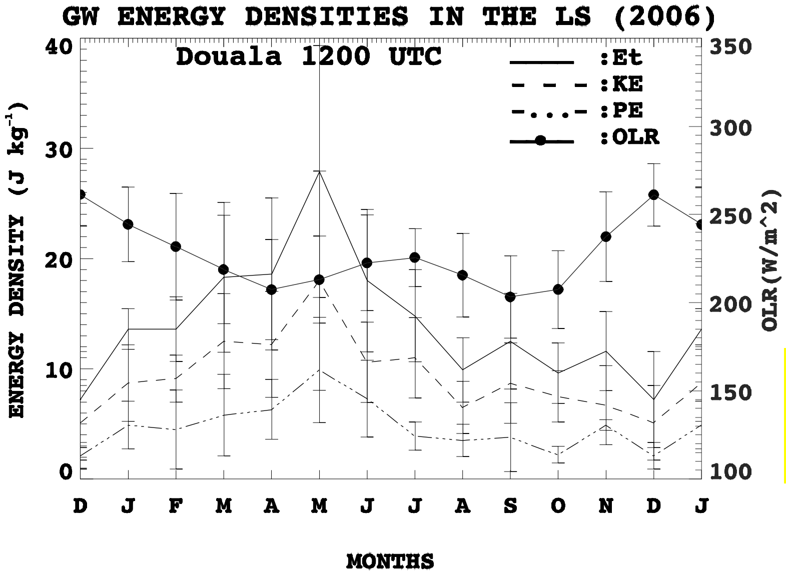


Figure 4: 2006 annual cycle of GW energy densities in the LS and Outgoing Longwave Radiation (OLR) data in the West African equatorial area (Douala).

Tropical zone (fig. 3): the annual cycle of wave activity presents a strong activity from June to August (maximum wave activity is observed in July and August) during the WAM period, while low activity is observed during the dry season from October to April.

Equatorial zone (fig. 4): wave activity annual cycle is composed of strong activity from March to June, a decrease is observed from July to August and an additional peak of activity is present in september .

In the two latitudinal ranges, the maximum of wave activity is correlated with the minimum of OLR (deep convection). This confirms that deep convection during the WAM is an important source of GWs over the West Africa.

WAVE SPECTRAL PARAMETERS (1)

A relation of wave activity with convection was highlighted in the annual cycle and led us to analyze wave spectral parameters (period, vertical and horizontal wavelengths) during the stages of the WAM.

- **For the tropical region (inertial periods 41.53-54.51h):**

❑ **during the onset (May-June), mean E_T is around 11J.kg^{-1} with vertical wavelengths of 2.1km, horizontal wavelengths of 990-3900km and periods of 28-50h.**

❑ **during the monsoon (July-August), E_T increases (22J.kg^{-1}) with vertical wavelengths of 2.1km, horizontal wavelengths of 1400-4300 km and periods of 36-47.2h.**

❑ **during the withdrawal of the monsoon (in September), mean value of E_T is 14.5J.kg^{-1}, vertical wavelengths of 2.1km, horizontal wavelengths of 860-2300km and periods of 26-47.2h.**

- **For the equatorial region (inertial period of 174.4h):**

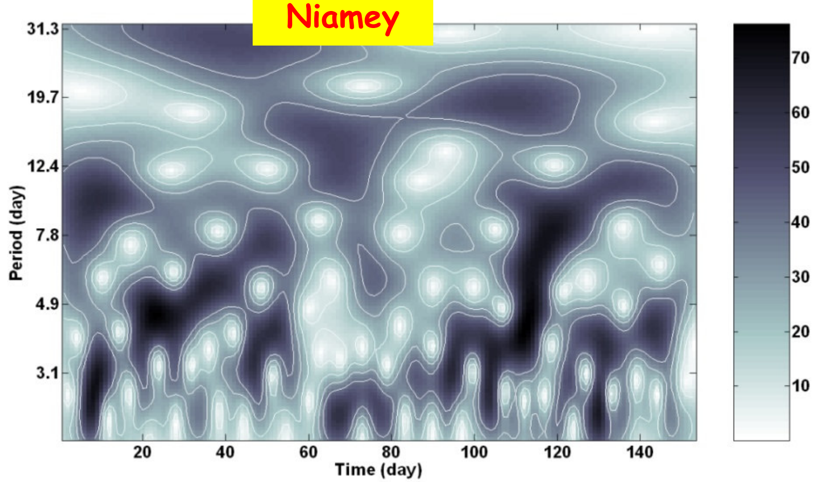
❑ **in May, E_T value is 28J.kg^{-1} with vertical wavelengths of 2.1km, horizontal wavelengths of 1400km and periods of 53h.**

❑ **the monsoon is characterized by E_T value of 10J.kg^{-1}, vertical wavelengths of 1.4-2.1km, horizontal wavelengths of 1600-2600 km and periods of 81-88.9h.**

❑ **after the monsoon, E_T value is 12J.kg^{-1} and the spectral parameters are 2.1km, 4500km and 122h for vertical wavelengths, horizontal wavelengths and periods respectively.**

WAVE SPECTRAL PARAMETERS (2)

Niamey



Douala

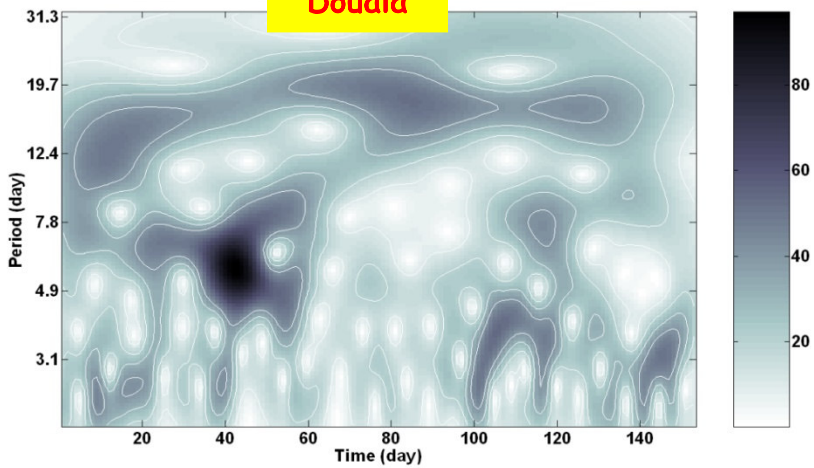


Fig 5: CWT diagrams of daily OLR time series from May to September 2006 above Douala and Niamey.

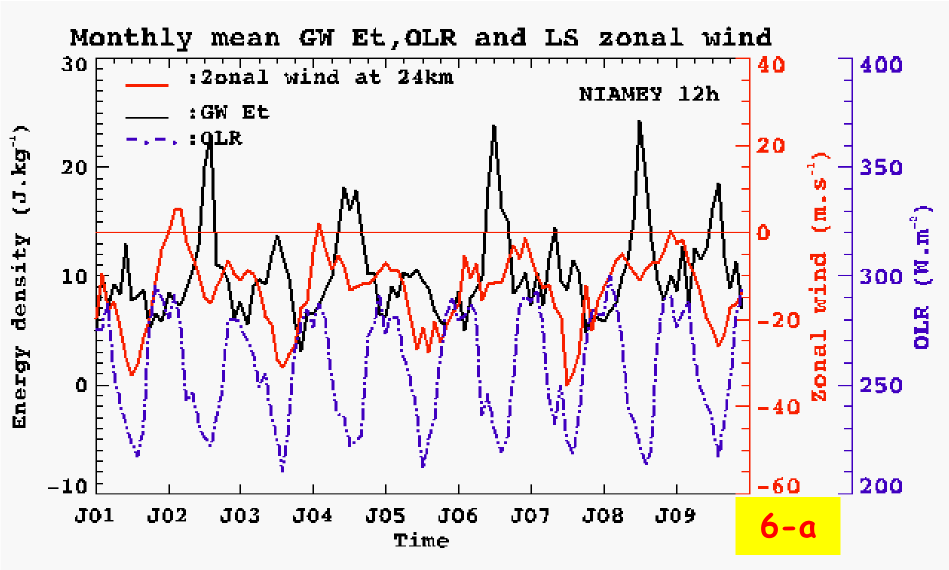
Continuous Wavelet Transform (CWT) was applied to daily OLR data. A wide range of wavelike structures was revealed in the diagrams (Fig 5) especially in the tropical area (Niamey) during the monsoon.

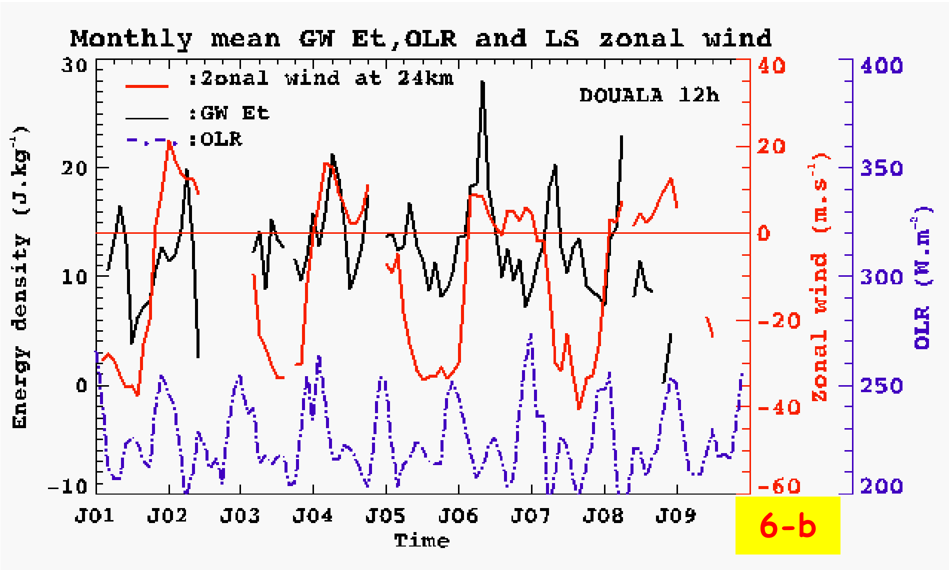
- Tropical region: periods T<5 days are dominant from May to September, T~ 6-12 days are present in June, August and September and T~ 10-25 days are observed from May to July.

- Equatorial region: T<5 days are observed in May and September, T~ 6-12 days are dominant in the beginning of June and are weaker in August-September and T~ 10-25 days are present from May to September.

FFT spectra of OLR data also confirm the presence of waves with 1.4-2.5-day periods above the two regions. Kiladis et al. (2006) also reported easterly waves (TD band) in Africa during northern summer for 2-6 day periods and 6-20 westward zonal wavenumbers.

CLIMATOLOGY OF WAVE ACTIVITY (1)





The Quasi-Biennal Oscillation (QBO) foot print is noticeable through the periodic behavior of monthly mean zonal wind time series. Seasonal and interannual variations are visible in the 9-year time series of wave activity. A QBO-like variation of wave activity is apparent on the plots.

Over the 2 areas, the temporal evolution of the wave activity and the LS zonal wind shows that stronger wave activity is mostly observed during the eastward phase of the QBO.

Figure 6: Monthly mean GW total energy density, zonal wind at 24 km height and OLR a) Niamey and b) Douala.

CLIMATOLOGY OF WAVE ACTIVITY (2)

- Tropical zone: wave activity is strongly related to the QBO during the intense convection period (correlation coefficients are 0.60 and 0.80 for June-September and July-August period respectively).

The investigation of wave activity with monsoon proxies (OLR, relative humidity and TRMM precipitations,…) shows that peak of wave activity is correlated with lowest OLR values (figure 6), highest mean relative humidity values and highest precipitations quantity. Linear regression performed between monthly wave activity and monsoon proxies during the intense convective period gives correlation coefficients -0.31 and 0.37 for monthly OLR data and monthly precipitation quantity respectively.

- Equatorial zone: the intense convection period (March-May) doesn't match the period of strongest precipitations (July-August), so the peak of wave activity is observed out of the period of highest relative humidity and highest precipitation quantity. Linear regression (for March-May period) gives correlation coefficients of -0.50 and 0.27 for monthly OLR data and monthly precipitation quantity respectively.

CLIMATOLOGY OF WAVE ACTIVITY (3)

The beginning of 2006 corresponds to the QBO's transition phase from easterlies to westerlies. Then, eastward wave will be mostly allowed to propagate because wave propagation properties were affected by the background winds.

The QBO phases are related to the upward zonal momentum. Observations or numerical models estimating vertical fluxes of zonal momentum required to drive the QBO need to take into account the presence of planetary-scale equatorial waves, Kelvin and Rossby-Gravity waves as well as IGW (Sato and Dunkerton, 1997; Baldwin et al., 2001; Tindall et al., 2006).

Thus, it is more likely that mixed tropical waves (Kelvin and eastward IGW) are present during 2006 above the area.

CONCLUSION

The present study aims to characterize GWs with periods< 5 days in the LS of the West African tropical and equatorial regions during 2006 AMMA campaign. Time and spatial distribution of GW activity and spectral parameters are analyzed in relation with the WAM. The annual peak of GW activity is associated with the maximum convective activity. It suggests that the observed waves are strongly coupled with convection.

The analysis of spectral characteristics also reveals the presence of different types of waves in the LS: inertia-GWs with periods of 1.3–2.1 days and horizontal wavelengths between1300 km to 3900 km in the tropical area and in addition other planetary-scale waves with periods of 3–5 days in the equatorial area.

Long term mean wave activity analysis shows a relation of wave activity with QBO (24 km altitude zonal wind) highest peak of wave activity was observed during the eastward phase of the QBO. The filtering effect of background wind allowed eastward or westward wave to propagate in the LS. During 2006 the QBO was in its eastward phase and Kelvin wave is likely observed.

Further prospects will focus on numerical modeling to validate present observations and to investigate GWs processes during the WAM.

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