Analysis of small scale waves over the West African area

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1. Introduction

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).

The WAM occurs during four months (from June to September) and its establishment 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). 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 have been selected (Fig. 1); four stations in the Sahel domain from 12°N to 17°N: Bamako (Mali), Niamey (Niger), Dakar (Senegal) and Agadez (Niger) and one station near the Equator (Douala). The present study is performed for the tropical zone.

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 tropical area and the QBO is also investigated through 9- year (January 2001-December 2009) climatology of wave activity.

2. Data set and Analysis

Data

High vertical resolution radiosonde observations (vertical resolution is about 14 m) were performed daily or twice daily at 0000 UTC and 1200 UTC in several West and Central African sites during the 2006 AMMA Campaign. The data consist on the observations made at 1200 UTC at the selected sites (figure 1). The altitude range of the present study corresponds to the interval between 19 and 23 km in the Lower Stratosphere (LS). The procedure established in the framework of the SPARC initiative (Stratospheric Processes And their Role in Climate) on gravity wave climatologies was used to carry out the profiles used to compute wave energy densities and wave spectral parameters (Allen and Vincent, 1995; Wang and Geller, 2003; Chane-Ming et al., 2007 and Kafando et al., 2008).

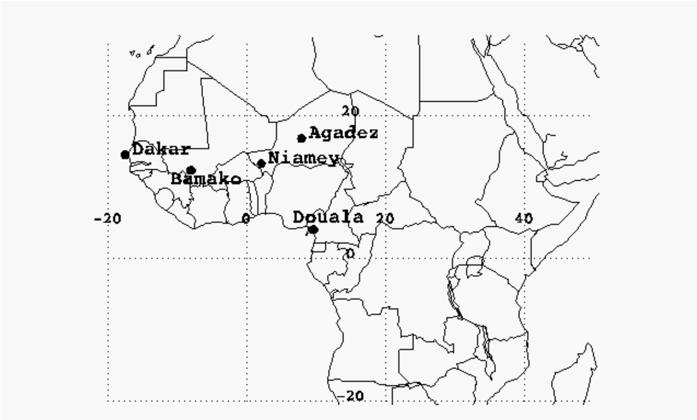

Figure 1: Location of the tropical and equatorial stations.

Wave activity

GW total energy density (E_T) given by Eq. (2) was determined to estimate the wave activity. E_T sum of the kinetic energy density (KE) and the potential energy density (PE), is defined by Eq. (1) (Vincent and Alexander 2000).

$$KE = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2}\right) \quad \text{and} \quad PE = \frac{1}{2}\frac{g^2}{N^2}\overline{\hat{T}'^2} \tag{1}$$

$$E_T = KE + PE \tag{2}$$

Spectral parameters

The normalised temperature spectrum was computed applying a Fast Fourier Transform (FFT) to the normalised temperature perturbation $\hat{T}'$ ($\hat{T}' = \frac{T'}{\overline{T}}$) and then fitted to the Desaubies model with least squares to extract the dominant modes (Van Zandt 1982; Allen and Vincent 1995). Dominant modes of vertical wavenumber m are identified from the peaks in the spectrum and the corresponding vertical wavelengths (λ_v) are derived via Eq. (3).

$$m = 2\,\pi/\lambda_v \tag{3}$$

The Stokes parameters, which relate the wave intrinsic frequency (ω^*) to the horizontal wind perturbation hodograph eccentricity (Vincent and Fritts 1987; Eckermann and Vincent 1989), are used to compute the wave spectral parameters. The Stokes parameters were determined from the FFT of horizontal wind perturbations. The wave parameters of interest (intrinsic frequency and horizontal direction of propagation) were extracted in the frequency domain. The horizontal wavenumber or wavelength (λ_h) is computed using the wave dispersion relation and the vertical modes resulting from Eq. (3).

3. Wave activity and spectral parameters

Wave activity

In the tropical zone (figure 2) 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.

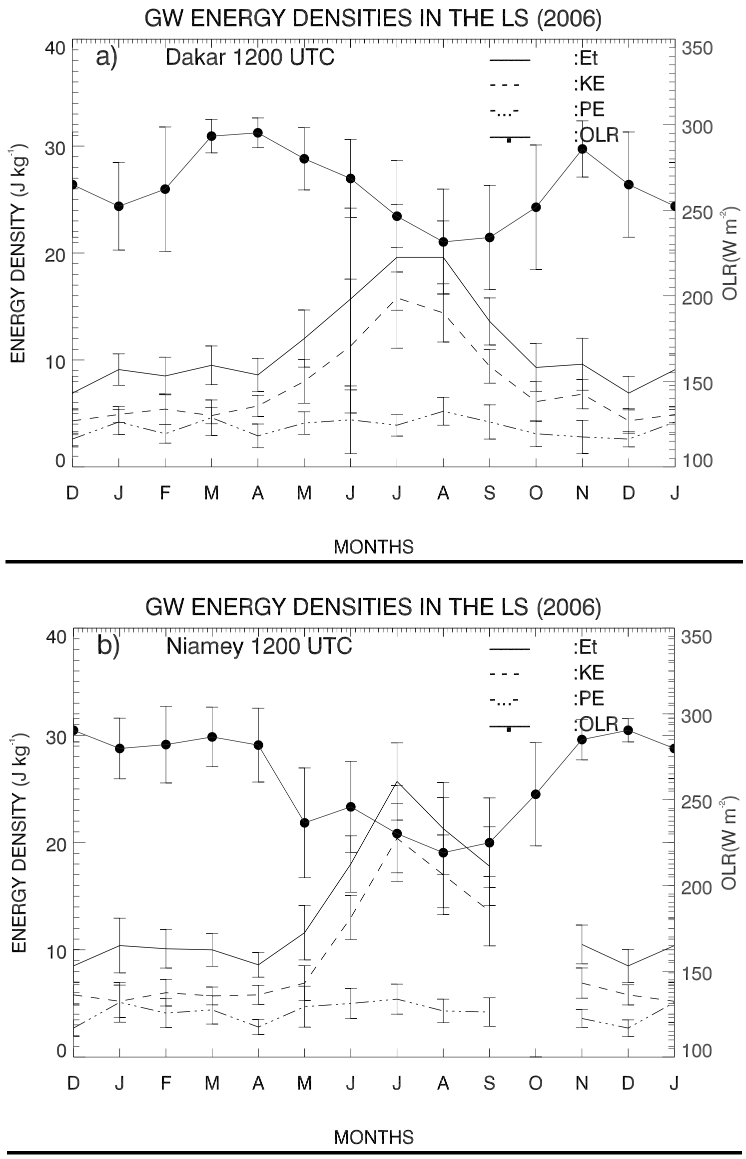

Figure 2: 2006 annual cycle of GW energy densities (left hand ordinate) and Outgoing Longwave Radiation (OLR) data (right hand ordinate) in the LS above the West African tropical area a) Dakar and b) Niamey.

Spectral parameters

Above the tropical area during the WAM spectral parameters are in the range 26-50 h (i.e. 1.1-2.1 days), 2.1 km and 860-4300 km for period, vertical and horizontal wavelengths respectively. The waves mostly propagate in the eastward direction.

4. Wave activity and QBO

9-year Time series of monthly wave total energy density in the LS (19–23 km) and monthly zonal wind at 24 km altitude (the Quasi-Biennal Oscillation-QBO) above the tropical zone (Niamey) is shown in figure 3. Stronger peak (>18 J kg^{-1}) occurs during the eastward phase of the QBO and lower peak is observed during the westward phase.

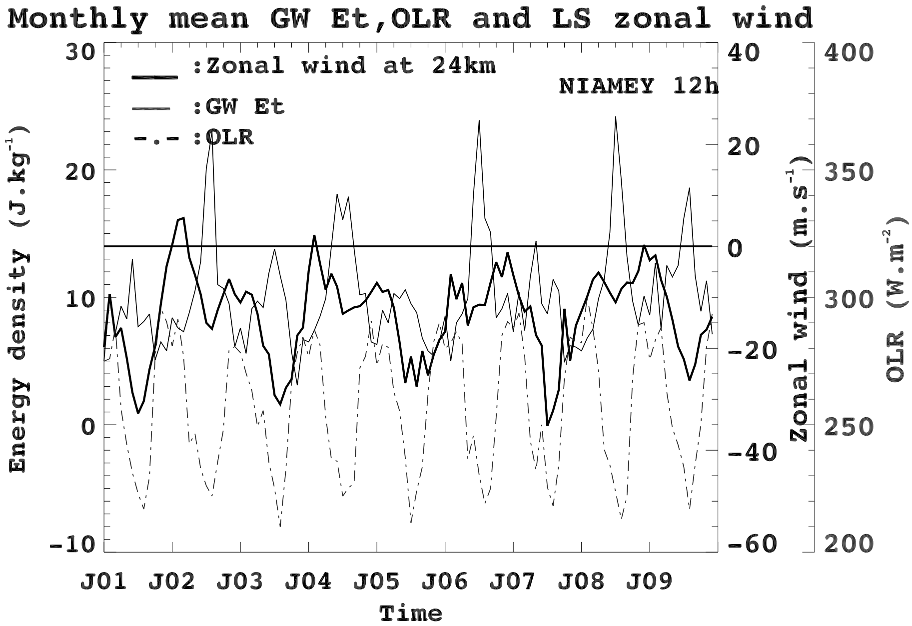

Figure 3: Monthly mean GW total energy density, zonal wind at 24 km height and OLR above Niamey.

5. Discussion and Conclusion

The maximum of wave activity, correlated with the minimum of OLR (deep convection) above the tropical area confirms that deep convection during the WAM is an important source of GWs over the West Africa. The QBO-like variation observed in the long-term wave activity behavior supports hypothesis of QBO's mechanism i.e. QBO is driven by the interaction of the stratospheric mean flow with the equatorial waves. The analysis of spectral characteristics reveals the presence of circularly polarized waves ($a/b=\omega^*/f \sim 1\text{-}1.4$) with periods of 1.1–2.1 days and horizontal wavelengths between 990 km to 3900 km in the tropical LS. The most probable candidate is inertia-GW (IGW). 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. Thus, it is more likely that eastward IGW are present during 2006 above the West African area.

Further prospects will be dedicated to the West African equatorial area to complete the study.

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