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ANALYSIS OF TOTAL WATER VAPOUR CONTENT FROM GPS DATA, RADIOSONDES AND NUMERICAL WEATHER PREDICTION MODELS IN WEST AFRICA

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1. Context and objectives

This work has been conducted in the framework of the AMMA project (<http://www.amma-international.org/>). The first objective was to assess the potential and accuracy of GPS data in Africa for the retrieval of precipitable water vapour (PWV). To this aim, data from the permanent GPS network in Africa have been processed and PWV estimates have been compared to independent observations such as radiosondes (RS), AERONET sun photometers, and numerical weather prediction (NWP) model re-analyses from the ECMWF (ERA-40) and the NCEP (version 2, hereafter NCEP2). A second objective was to determine the climatological characteristics and meteorological features of the region from the GPS data. Various scales have been analysed: from seasonal cycle to diurnal cycle. The spectral characteristics retrieved from GPS PWV have been compared with the other datasets and with independent climatologies. Some interesting features could be evidenced from the GPS data, such as the modulation of PWV at intra-seasonal and synoptic scales. Synoptic scale variability could be related to easterly waves. The origin of intra-seasonal variability needs further investigation and correlation with the climatological and meteorological environment. The good performance of GPS data in Africa promoted the deployment of a dedicated AMMA GPS network, in coordination with the enhancement of the existing radiosounding network. Figure 1 shows the location of the GPS and RS data for the present study, as well as GPS stations planned within the AMMA project, during EOP and SOP phases. The aim of the EOP GPS network is to document PWV in three key regions: tropical forest of Benin, savanna in Niger and semi-arid climate in Mali. It will provide special insight into the meridian variability of the ITCZ and ITF during monsoon onset and retreat. The SOP network will extend the view in the horizontal, giving hence insight into the zonal variability at mesoscale, namely for the study of water budgets and atmospheric processes (e.g. mesoscale convective systems).

This paper presents mainly results from the intercomparison study. It provides evidence for: (i) the high accuracy of GPS and AERONET PWV data; (ii) the existence of dry biases in RS data; (iii) the limited accuracy of both ERA-40 and NCEP2 re-analyses; (iv) the better performance of ERA-40 over NCEP2.

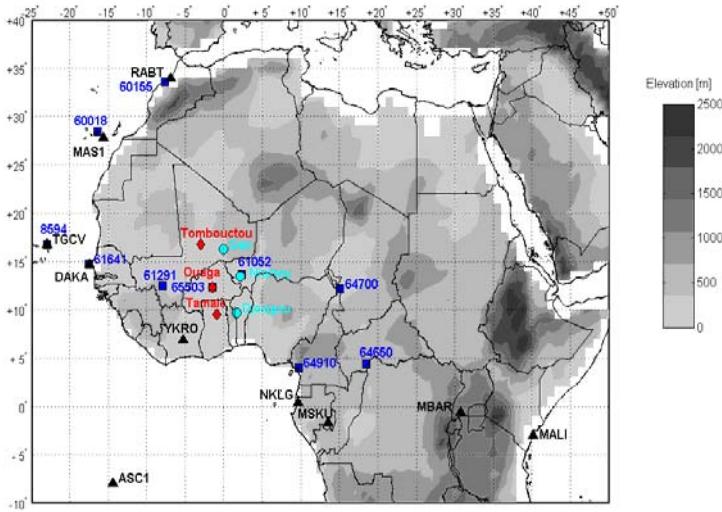


Figure 1: map of the domain and location of existing GPS station (black triangles with 4-letter identifier) and RS stations (blue squares with 5-digit identifier). GPS stations deployed during AMMA-EOP phase (2005-2007) are shown as cyan circles and those to be deployed during the SOP (April-September 2006) are shown as red triangles. Grey shading shows topography.

2. Results and discussion

RS and GPS PWV estimates have been compared at five GPS stations (DAKA, MAS1, NKLG, RABT, TGCV), over the period 1999 – 2005. The GPS – RS PWV differences show biases of 2 – 15%, standard deviations of 7 – 16%, and correlations of 81 – 96%. The two major findings are the identification of: (i) large errors in the RS data from Dakar in September and October 2003 (Fig. 2) and (ii) a nearly constant large bias ($6 - 7 \text{ kg m}^{-2}$) in the RS data from Libreville (not shown). At the other sites, the agreement between GPS and RS is $\sim 3 \text{ kg m}^{-2}$ RMS. GPS and AERONET PWV estimates have been compared at four stations (ASC1, DAKA, MAS1, TGCV). The agreement is slightly better than between GPS and RS. The relative (absolute) bias and standard deviation are in the range – 5% to 11% (-1.7 to 3.6 kg m^{-2}) and 5 – 14 % (1.4 – 3.6 kg m^{-2}), respectively.

Figure 2 shows PWV variations at Dakar reaching 20 kg m^{-2} (50%) within a few days. The seasonal cycle is also evident, with values of $\sim 50 \text{ kg m}^{-2}$ in summer and $10 - 20 \text{ kg m}^{-2}$ in winter. Fluctuations in September and October 2003 have 3 – 4 days and 8 – 10 days periods. They are linked to the propagation of easterly waves that develop over Central Africa. A wavelet spectral analysis also reveals significant energy in the 8 – 10 days and 15 – 30 days periods, in November – December, and ~ 40 days between January and June (not shown).

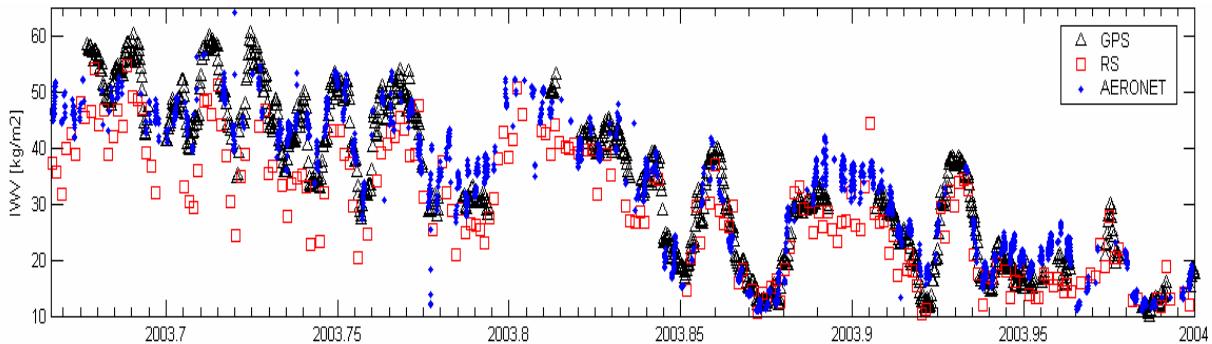


Figure 2 : Comparison of GPS, RS and AERONET sun photometer PWV data at Dakar, Senegal (15°N , 18°W), from 01 Sept to 31 Dec 2003. A large bias is seen in the GPS – RS difference: (9.1 kg m^{-2} in September and 6.9 kg m^{-2} in October). The comparison between GPS and AERONET shows a good agreement (better than 2 kg m^{-2}) all the time.

The PWV estimates from the GPS stations have been compared to ERA-40 and NCEP2 PWV fields. The GPS – ERA-40 relative (absolute) bias and standard deviation are in the range – 9% to 11% (-3 to 3 kg m^{-2}) and 9 – 16 % (3 – 4 kg m^{-2}). The GPS – NCEP2 relative (absolute) bias and standard deviation are in the range – 6% to 24% (-2 to 9 kg m^{-2}) and 11 – 21 % (3 – 7 kg m^{-2}). Both NWP models agree quite well with GPS at seasonal scale, but somewhat less at intra-seasonal and synoptic scales (Fig. 3). They reproduce very badly the diurnal cycle of PWV (Fig. 4). Both models have increased difficulties at continental stations. Overall, ERA-40 is found to perform better than NCEP2, especially at coastal stations (ASC1, MALI, RABT). This might be due to higher spatial resolution and assimilation of humidity data from satellites over the oceans in ERA-40.

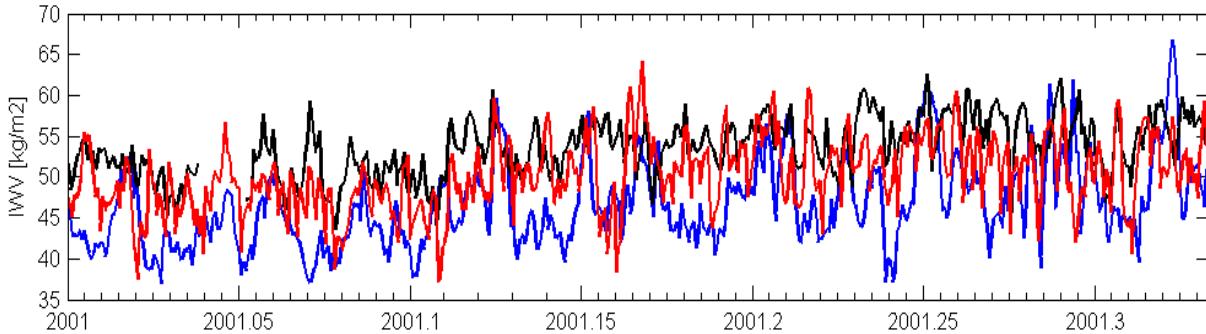


Figure 3: Comparison of GPS (black line), ERA-40 (red line) and NCEP2 (blue line) PWV fields at Libreville, Gabon (0°N , 10°E), from 01 Jan to 31 Mar 2001.

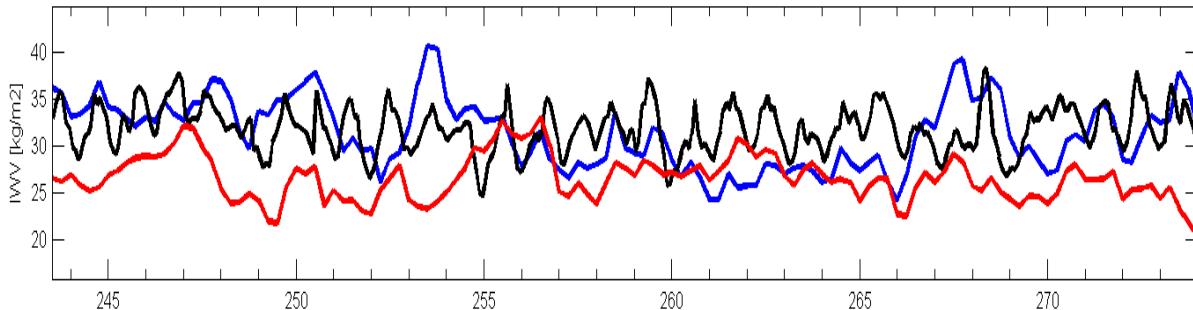


Figure 4: Comparison of GPS (black line), ERA-40 (red line) and NCEP2 (blue line) PWV fields at M'Barara, Ouganda (1°S , 31°E), for the month of September 2001. This site has a marked continental climate and strong diurnal cycle. Correlation coefficient between GPS and ERA-40 (NCEP2) is 59% (48%).

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ANALYSE DU CONTENU INTEGRE DE VAPEUR D'EAU DANS L'ATMOSPHERE A PARTIR DE DONNEES GPS, RADIOSONDAGES ET MODELES NUMERIQUES DE PREVISION EN AFRIQUE DE L'OUEST

La vapeur d'eau atmosphérique est un des composants principaux du cycle de l'eau dans la mousson en Afrique de l'Ouest. La variabilité de la vapeur d'eau intégrée est analysée à différentes échelles spatiales et temporelles en Afrique de l'Ouest, sur la période 1999 – 2005.

Pour cette étude, nous avons utilisé des observations du réseau GPS (Global Positioning System) au sol, de radiosondes (RS), et les ré-ERA-40 analyses du Centre Européen de Prévision Météorologique à Moyen Terme (CEPMMT). D'abord nous présentons une intercomparaison entre les trois jeux de données. L'accord entre GPS et RS est de 5-10% de biais et 10-15% d'écart-type. L'accord entre GPS et modèle est légèrement meilleur (biais < 5% et écart-type < 10%). L'analyse des séries temporelles révèle des cas où le modèle est largement en défaut (jusqu'à 10 kg m^{-2}). La variabilité intra-saisonnière est étudiée à l'aide d'une analyse en ondelettes des données GPS. Un signal fort est observé à Dakar dans la bande spectrale des ondes d'est (périodes de 3 à 9 jours). Le cycle diurne est également analysé à partir des données GPS. Il est cohérent avec les études passées utilisant des observations satellitaires. Le cycle diurne du modèle météorologique n'est pas cohérent avec ces observations. Ce résultat confirme la difficulté des modèles à représenter les processus intervenant dans le cycle diurne d'une manière générale et de la vapeur d'eau en particulier. Au cours de la phase EOP du projet AMMA (2005-2007), un réseau de 3 stations GPS sera déployé entre 10°N et 17°N , le long de 2°E .

Ces données permettront d'étudier plus précisément le cycle de l'eau, dont le cycle diurne de la vapeur d'eau, et sa variabilité spatiale (entre la région guinéenne au sud et le Sahel au nord) et temporelle (saisonnière à inter-annuelle).

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Convective wind system with aerosols, named “haboob”, Hombori in Mali,
West Africa.