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Study of seasonal-scale atmospheric water cycle with ground-based GPS receivers, radiosondes and NWP models over Morocco

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ABSTRACT

This study investigates the seasonal variation of precipitable water vapor, moisture transport and precipitation over Morocco and the Canary Islands using data from ground-based GPS receivers, radiosondes, GPCP and NCEP reanalysis II. In a first part, the datasets are inter-compared. Humidity biases are evidenced in both radiosonde observations (dry) and NCEP reanalysis (dry and wet) compared to GPS. Moisture transport and precipitation from the reanalysis and observations show a good agreement. Precipitable water shows a maximum in late summer whereas precipitation is peaking in winter and spring over Morocco. Moisture transport occurs preferentially in two layers, below and above 850 hPa. The monthly mean precipitable water variation over Morocco is controlled by the upper layer zonal and meridional moisture flux. Precipitation is rather controlled by the lower layer moisture flux and the upper layer meridional flux. The GPS tropospheric gradients show also a consistent seasonal evolution, which is explained by gradients both in the thickness of the troposphere and in the precipitable water vapor. Tropospheric gradients are correlated with moisture fluxes, mostly in the upper layer, and may therefore provide valuable information for meteorology and climatology.

1. Introduction

The weather and climate of Morocco is influenced by many factors. The most important ones are the large-scale atmospheric circulation dominated by the influence of the North Atlantic storm track and the orographic effects induced by the Atlas mountain range (Fig. 1). Morocco lies within the influence of moist air advections from the Atlantic Ocean to the West, the Mediterranean Sea to the North-East and the dry Saharan air to the East (Peixoto et al., 1982; Mariotti et al., 2002; Knippertz et al., 2003). All these factors have a strong impact on precipitation and moisture transport. Morocco similar to most of the North-Western Mediterranean countries experiences severe weather with occasionally extreme precipitation episodes (Doswell et al., 1998; Trigo and DaCamara, 2000; Rudari et al., 2004; Knippertz et al., 2003; Knippertz and Martin, 2005; Ducrocq et al., 2008).

Relatively few studies investigated the seasonal evolution of atmospheric water vapor over Morocco and its link with moisture transport and precipitation. The primary scope of this study is to fill this gap. However, the choice of observational and/or modeling datasets for such an investigation is of special importance since the pertinent atmospheric parameters are difficult to observe directly and the representation of the water cycle in atmospheric models is still not satisfying in many respects. Trenberth and Guillemot (1998) showed that the global water cycle represented in the National Center for Environmental Prediction (NCEP) reanalysis I suffers from a number of deficiencies which are typical of the uncertainties encountered in most Numerical Weather Prediction (NWP) systems (Meynadier et al., 2010). They comprise large and significant biases in the moisture and precipitation fields, especially in the tropics, which can originate from biases in

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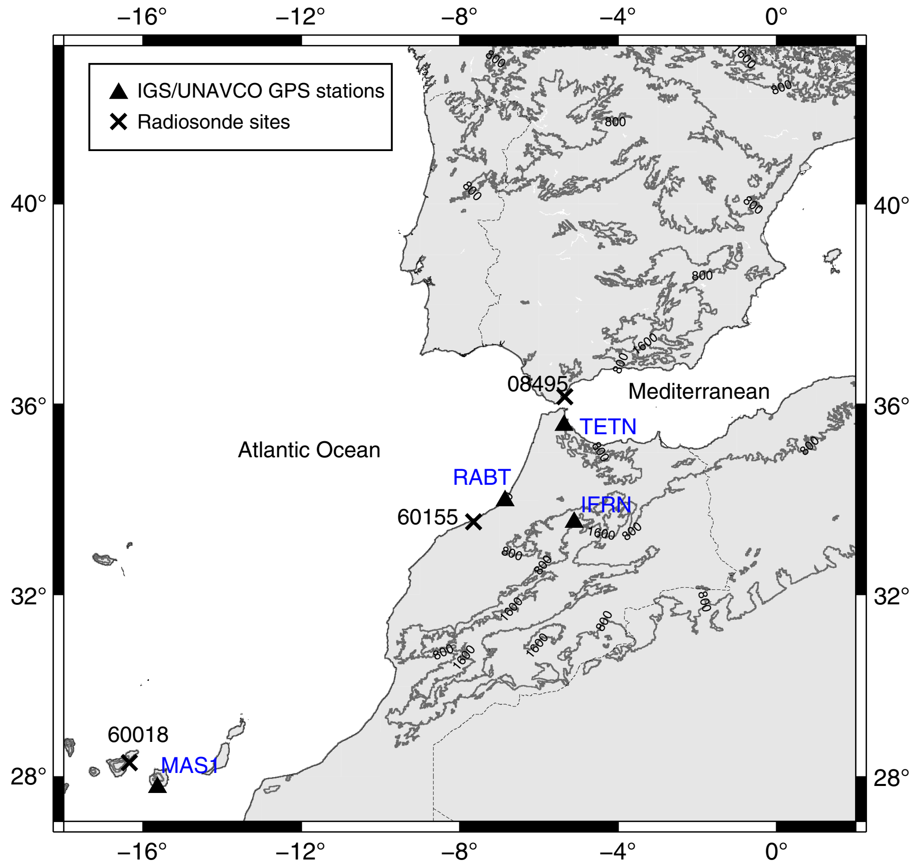

Fig. 1. View of the domain of study and the location of the continuous GPS stations and radiosonde sites.

the model (e.g. parameterization of convection), errors in the observations, or simply differences of representativeness between the model and the observations (e.g. radiosondes) being assimilated. A feedback of errors between the velocity divergence field and the moisture budget is possible also. A secondary objective of this study is thus to assess the consistency between different observational and modeling datasets for documenting the atmospheric water cycle over Morocco. The present study uses NCEP reanalysis II (Kanamitsu et al., 2002) to investigate precipitable water vapor (PWV) and moisture transport at a regional scale.

The reanalysis dataset is complemented with PWV and moisture transport computed from radiosonde data and PWV estimates provided by ground-based Global Positioning System (GPS) receivers. Radiosonde observations have been used as a reference in meteorology for a long time. However, a number of past studies revealed that many radiosonde systems exhibit a dry bias in the humidity data, but especially the Vaisala RS80 sondes, which were widely used globally between 1990 and 2005 (e.g. Wang et al. (2002); Bock et al. (2007a)). This dry bias is dramatically reduced with the more recent Vaisala RS92 sondes. More recently, it was also established that during the daytime solar radiation heating was responsible for an additional dry bias in most radiosonde systems, hence introducing a day–night offset in the observations, even with Vaisala RS92 systems (Wang and Zhang, 2009; Bock, and Nuret, 2009). Nevertheless, radiosondes remain a crucial component of the upper air meteorological observing system at global scale. Since the 1990s, GPS has become a standard technique for measuring PWV (Bevis et al., 1992) with some of the noticeable advantages over radiosondes such as high accuracy (1 kg.m^{-2}), high sampling rate (5 min to 1 or 2 h, depending exclusively on data processing choices), operations in all weather conditions and low cost allowing for a high spatial sampling.

Ground-based GPS networks have been extensively developed since the 1990s in Europe, USA and Japan, and more recently in a number of Southern countries. Our study over Morocco is based on three GPS stations that are operated continuously and deliver data to the International GNSS (Global Navigation Satellite System) Service (IGS) and the University NAVstar COnsortium (UNAVCO). Other permanent stations exist in Morocco but the data are not freely available. In many studies, independent ground-based GPS PWV estimates proved useful for the validation of satellite and NWP model products (Haase et al., 2003; Hagemann et al., 2003; Bock et al., 2005; Bock and Nuret, 2009). Recent GPS experiments have been conducted in West Africa in the framework of the AMMA project (Bock et al., 2007b, 2008; Walpersdorf et al., 2007). Few other GPS studies focused so far on the tropical weather and climate (Sridevi and Vijayan, 2008) and none on North Africa.

Section 2 describes the data and methods, including the GPS data processing and PWV estimation steps. Section 3 assesses the consistency between the three datasets and therefore provides an inter-comparison of PWV estimates.