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RESEARCH PAPER

Modeling investigation of wet tropospheric delay error and precipitable water vapor content in Egypt

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Abstract A set of 1092 radio soundings was performed at the Egyptian stations in the south of Egypt, near the Mediterranean Sea, and near the Red Sea in 2005. These measurements are mean monthly data that were used to determine the mean vertical profiles of water vapor pressure and its effect on GPS signal propagation (wet tropospheric delay) in the troposphere and lower stratosphere. Temperature data were corrected for errors due to radiation, heat exchange processes, and for the lag errors of the sensor. Due to temperature dependence and other dry bias effects, the humidity errors were also taken into account. The results showed that partial water vapor pressure in Egypt varies from 6.43 to 23.19 mb and decreases significantly with height. In addition, the quantity of water vapor pressure above 8 km is negligible. Results showed that, in Egypt zenith wet delay varies from 66.84 mm to 239.34 mm. It can be concluded that, the best model to predict zenith wet tropospheric delay for the atmospheric conditions of Egypt is the Saastamoinen model with a mean error of 11 mm and rms of 3.12 mm.

1. Introduction

The NAVSTAR GPS is an all-weather, space-based navigation system developed to determine ones position, velocity, and time accurately in a common reference system on the Earth. When radio signals propagate through the atmosphere, they are delayed due to the different refractivity indices of each layer of the atmosphere. The atmosphere has a significant effect on the propagation of GPS signal. The signal travels through the ionosphere, which is a region of charged particles with a large number of free electrons. The delay caused by the ionosphere is a dispersive delay, meaning that the delay is dependent upon the frequency of the signal. Because GPS broadcasts on two separate frequencies, the error can be eliminated by taking advantage of combinations of the two separate frequency signals.

Unlike the ionosphere, the delay caused by the neutral atmosphere is non-dispersive, or completely independent on the signal frequency (for GPS frequencies). The neutral atmosphere consists of the troposphere, tropopause, stratosphere, and part of the mesosphere. The delays caused by the neutral atmosphere in the radio signal propagation are mostly due to the troposphere. However, tropospheric delays can be detected or eliminated with accurate knowledge of the position of the GPS antenna and GPS satellite if the GPS applications require

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it. The tropospheric delay is measured in distance, and a typical zenith tropospheric delay would be 2.50 m, meaning that the troposphere causes a GPS range observation to have an apparent additional 2.50 m distance between the ground-based receiver and a satellite at zenith.

The delay caused by the troposphere can be separated into two main components: the hydrostatic delay and the wet delay (Saastamoinen, 1972). The hydrostatic delay is caused by the dry part of gases in the atmosphere, while the wet delay is caused by highly varying water vapor in the atmosphere. The hydrostatic delay makes up approximately 90% of the total tropospheric delay. The hydrostatic delay is entirely dependent on the atmospheric weather characteristics found in the troposphere. The hydrostatic delay in the zenith direction is typically about 2.30 m (Businger et al., 1996). The hydrostatic delay has a smooth, slowly time-varying characteristic due to its dependence on the variation of surface pressure; it can be modeled and range corrections applied for more accurate positioning results using measurements of surface temperature and pressure. However, the wet delay is dependent on water vapor pressure and is a few centimeters or less in arid regions and as large as 35 cm in humid regions. The wet delay parameter is highly variable with space and time, and cannot be modeled precisely with surface measurements (Bevis et al., 1992).

The study of atmospheric water vapor is important for two reasons. Firstly, short-term weather forecasting is affected by the content of water vapor in the atmosphere. Water vapor is highly variable both in time and space and sudden changes in water vapor in the atmosphere can result in changes in the local weather. Water vapor is fundamental to the transfer of energy in the atmosphere (Rocken and Ware, 1997; Senanayake, 2013). This transfer of energy often results in thunderstorms or even more violent atmospheric phenomena. Secondly, long-term climate changes are reflected in water vapor content.

In this study, in the first section, we have compared different formulas for surface humidity, vertical profile of humidity and wet tropospheric delay using 1092 radio soundings to calibrate which one will predict high accuracy for the atmospheric conditions of Egypt. In the second section, two data sets of the study area are presented. In the third section, the distributions of surface humidity in Egypt at different geographic regions and at different times of year are investigated. In the fourth section, the atmospheric models that provide atmospheric parameters with height are described. Then the different models which determine the vertical profile of humidity are tested. In the fifth section wet tropospheric delay correction models and their application for the atmospheric conditions of Egypt are presented.

2. Data description

The data used in this research were collected from the Egyptian Meteorological Authority (EMA) as average monthly values at 2005 (daily meteorology data set from January to December were collected in all stations and then average monthly can be determined). These data include maximum and minimum values for temperature, pressure, and relative humidity at sea level at five stations in Egypt (Aswan, Helwan, Mersa-Matrouh, Al-Arish, and Hurgada). They cover a large variety of climatic conditions in Egypt, and also include heights, temperatures, and relative humidity values at 11 levels of pressure, which are 1000, 850, 700, 600, 500, 400, 300, 250, 200, 150 mb, ranging from sea level to height about 14–15 km. These data are available for three stations Aswan which represents southern region, Helwan which represents central region, and Mersa-Matrouh which represents northern region of Egypt (near Mediterranean-sea). Fig. 1 shows the stations of Egyptian Meteorological Authority (EMA), which use differential GPS radiosonde model M2K2-DC in addition to Radiotidotite (RT 20A, Vaisala). These stations provide data about pressure, temperature, and relative humidity at sea level and at different levels of pressure.

The data are available in four months for the year (January, April, July, and October), which represent the worst case (the worst scenarios of temperature extremes) of the atmosphere and average data over the year are also presented.

3. Surface humidity in Egypt

The bulk of the vapor in Egypt is formed by evaporation of water from the surface of the seas and the Nile, the rest comes from transpiration by plants.

The data used are the monthly mean of temperature in °C and the monthly mean of relative humidity in % at sea level surface for five stations. To develop a surface profile for partial vapor pressure, the next sequence was followed:

Firstly, the suitable formula to estimate the saturation vapor pressure (e_s) in mb depending on the temperature will be investigated.

Secondly, partial vapor pressure (e) in mb was calculated using the next formula:

$$e = e_s \cdot f/100 \quad (1)$$

where $\boldsymbol{e}$ is partial vapor pressure in mb, $\boldsymbol{e_s}$ is saturation vapor pressure in mb, $\boldsymbol{f}$ *is* relative humidity.

In this section the Teten, Magnus, Buck, Wexler, Bolton, and Goff–-Gratch formulas for saturation vapor pressure calculation were evaluated under different temperature

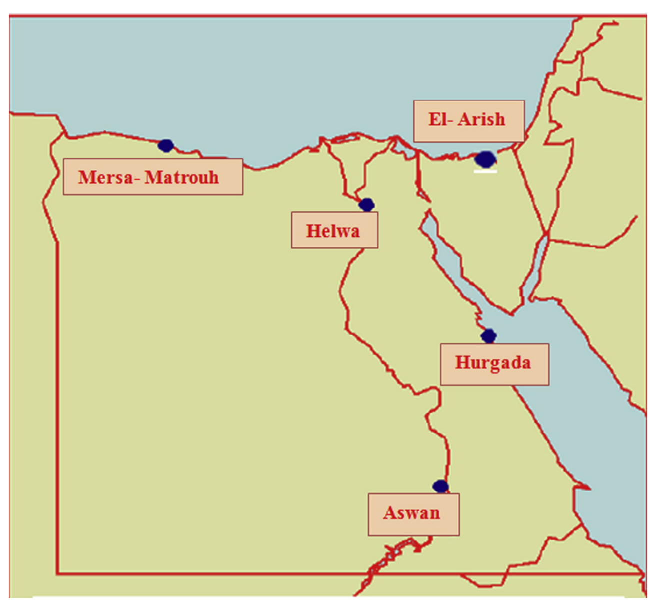

Figure 1 Meteorological stations at Egypt.