RETRIEVAL OF ATMOSPHERIC PROFILES FROM RADIO OCCULTATION MEASUREMENTS USING AN ARTIFICIAL NEURAL NETWORK

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Abstract. *A new method based on Artificial Neural Network (ANN) is applied to estimate high-resolution atmospheric profiles in the troposphere. The use of data satellites with the objective to study the atmosphere together GPS (Global Positioning System) data opens perspectives to improve the research on climate and the capacity on weather forecast. In this sense, many techniques were developed for retrieving atmospheric profiles (temperature, pressure and water vapor) using GPS radio occultation. ANN technique establishes a non-linear relation with the meteorological variables. The ANN retrieved profiles using meteorological variables from the CHAMP-ISCD (Challenging Mini-satellite Payload for Geoscientific Research and Application). It can be concluded that ANN is convenient and an accurate tool to get atmospheric profiles.*

1. Introduction

The atmosphere is made up of various gases that act as a protective shield for the Earth and allows life to exist. The atmosphere consists of five layers, held around the planet by the force of gravity. Moving upwards through the layers, the atmospheric pressure decreases rapidly with height and the air temperature also changes. The temperature variation is more complicated changes are used to divide the atmosphere into layers being the atmospheric air a mixture of gases constituted of dry added air of water steam (varying in space and time). The troposphere is the layer of the surface, the principal means of transport of mass (water, solid, pollutant particles, etc.) happens. The vapor transport in the atmosphere constitutes a very important component of the hydrological cycle, where a great quantity of water is transported in the form of vapor. The knowledge of the vertical and horizontal distribution of the water vapor in global scale is useful for applications of numerical weather forecast, climatic modeling and studies of climate global changes.

Vapor pressure (*vp*) is the pressure of the vapor over a liquid (and some solids) in equilibrium; it is the fraction of the pressure of the environment due to the fraction of water vapor in the air. The superior limit for the quantity of water vapor in the air is a function of the temperature (*T*). By using remote sensor data of the atmosphere (from meteorological satellites) vertical soundings have been estimated the humidity and temperature vertical profiles. The use of low Earth orbit (LEO) satellites together Global Positioning System (GPS) data can also help on the study of the atmosphere and such procedures opens perspectives to improve research on climate and weather forecasting. In this sense, many techniques have been developed for retrieving atmospheric profiles (temperature, pressure and water vapor) using GPS radio occultation.

2. Radio-Occultation data

Radio-occultation (RO) is the phenomenon for which a celestial body can be seen due to the occlusion of another celestial body. The atmospheric soundings of the temperature and of the water vapor are retrieved from the measures of RO from the GPS. The Figure 1 shows the behavior of the

GPS sign when it crosses the Earth atmosphere, just as an occultation of the satellite happens, and a schematic of atmospheric profiling by GPS radio occultation. For the receiver, an occultation occurs whenever a GPS satellite rises or sets and the ray path from its transmitter traverses the Earth's atmospheric limb.

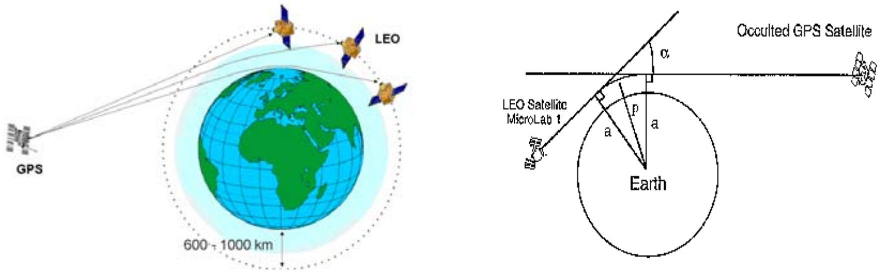

Figure 1. Occultation scheme for the LEO satellite and occultation geometry.

Under the assumption of spherical symmetry, the bending angle (α) determined from the Doppler shift, may be related to the refractivity through the Abel transform, using the GPS-LEO occultation geometry (Figure 1). During a GPS occultation, the GPS receiver placed on a Low-Earth Orbiting (LEO) satellite records the excess phase delay induced by the Earth's atmosphere, from which the atmospheric Doppler shift, bending angle and refractivity can be derived. The German satellite for LEO, called CHAMP, is part of the program to a geoscientific mission for determination of the gravity and magnetic field of the Earth, and it should be able to use the technique of GPS RO for the study of the atmosphere. The GPS constellation consists of 24 satellites distributed in six orbital planes around the planet. Each satellite orbit is circular with an inclination of 25 degree, a period of 12 h and an altitude of 20200 Km. A single GPS receiver will observe over 500 occultation per day distributed fairly uniformly all over the globe.The CHAMP satellite system collects daily up to 250 temperature profiles, distributed in a vertical resolution of 0.5 Km in the troposphere and 1.5 Km in the stratosphere. The CHAMP data is available in the Internet from the service in the GFZ - Centre of Data and System of Information of the CHAMP-ISDC (*Challenging Mini-satellite Payload for Geoscientific Research and Application*) in (http://isdc.gfz-postdam.de/).

3. Methodology

For this paper, the RO acquired period was from December 17, 2002 up to February 15, 2003 in the region of the South America between 35S and 5S of latitude, and 80W to 50W of longitude.

There are some methods for retrieving water vapor and temperature profiles. A new inverse method for retrieving profiles by using an ANN is presented. It may be used for estimating meteorological variables because they allow the establishment of non-linear relationships among them. The application of a Multilayer Perceptron (MLP) designed to estimate atmospheric variables in each point of the observation of LEO receiver. The MLP feed-forward neural networks is trained with the standard back-propagation algorithm, which is a supervised learning algorithm, and requires a target response to be trained. A MLP is made up of several layers of neurons. Each layer is fully connected to the next one. Each neuron of a layer other than the input layer first computes a combination of the outputs of the neurons with the previous layer, plus a bias. The coefficients of the combinations and the biases are called the synaptic weights. The supervised learning problem of the MLP can be solved with the *back-propagation algorithm*.

A fully connected MLP was designed with: three inputs (*altitude, refractivity, bending angle*), fifteen hidden neurons, and two outputs (*vapor pressure and temperature*). In the *forward pass*, the predicted outputs corresponding to the evaluated inputs. In the *backward pass*, partial derivatives of the cost function with respect to the different parameters are propagated back through the network. The network weights may adapted using any gradient-based optimization algorithm. The function a_j denotes the activation function of each node in the hidden layers. The linear function is presented as the transfer function: $y_j(t)=a_j(t)=f(\sum w_{ij}o_i(t)-b_j)$ where $a_j(t)$ is the activation function of neuron *j* at step *t*, w_{ij} is the connection weight between previous layer neuron *i* and neuron *j*, o_i is the output of the neuron from the previous layer at step *t*, b_j the bias of neuron *j* and $y_j(t)$ is the output of neuron *j*. The relationship between input vectors and output vectors is expressed by: $(vp_k, T_k) = f_k(z_k, r, b);\quad k = 1, \ldots, N_z$ where *r is refractivity, b is bending angle* , z_k is altitude in km; N_z is the number of atmospheric layers considered in the inversion; f (.) represents the MLP-ANN; vp_k is the water vapor pressure in hPa; and T_k is the temperature in ºC (the desired output vectors). In the training process, a criterion for convergence was the least mean squared error calculated between estimated and desired outputs. The amount of data consisted of 71 groups of CHAMP occultation data at 0.2 Km height intervals. The conducted experiments reported 49 pairs of *r*, *b* and *vp*, *T* (total of 2044 groups of examples) were used to train the ANN and to search for the relationship. The remainder 22 profiles were used in ANN generalization phase.

4. Results

The ANN retrieved profiles are compared with the corresponding ones from the CHAMP-ISCD data and its results show that ANN is convenient and an accurate tool to get atmospheric profiles. An advantage of this technique of using remote sensor with global range data is in the combination of high vertical resolution and high precision data.

The results are estimated values for each level of the profiles, for a specific latitude and longitude and for a given day/time. The following figures are from a determined profile. These examples were chosen inside the period (17-December up to 15-February).

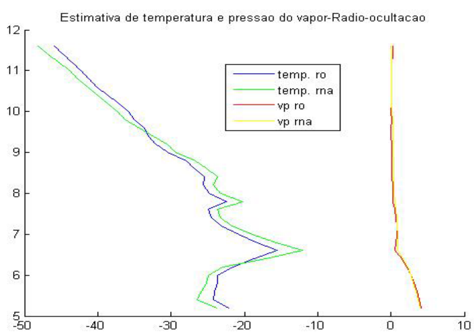

Figure 2-lat/lon -13.70/-74.97 at 19/12/2002

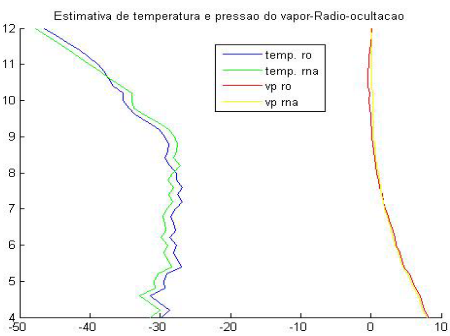

Figure 3-lat/lon -11.87/-56.27 at 09/01/2003

5. References

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