Chapter 1

Introduction

The Global Positioning System (GPS) has conveyed to the scientific and engineering community an unprecedent source of data to be exploited in many research fields. It was conceived as a military tool to provide the capability of absolute positioning and timing with the only help on ground of a dedicated portable receiver; during the years, however, the availability of a constellation of satellites constantly sending precise time stamps encoding electromagnetic waves, has led to the use of these data not only for coordinate determination but also as global coverage sounding signals. Thus, civilian uses of the GPS range from the millimeter accuracy level monitoring of crustal motion to real time atmospheric profiling, including in this wide range roving receivers tracking, buoys, fleet control, spacecrafts' orbit determination and maintenance of both time and frequency standards (for a good recent overview of GPS and its applications, see [1]).

The positioning system is based on the accurate determination of the delay experienced by the signal. Data processing techniques have improved together with receivers quality so that it is now possible to discriminate effects on the order of millimeters over a whole measurement of 20,000 Km (a ratio of 10^{-10}). With this assessment in mind, it is conceivable to use the GPS as a data source to infer the state of the atmosphere, since it introduces delays into the electromagnetic signals on the order of tens of meters in the ionosphere and meters in the neutral atmosphere, and even to study the water vapor contents of the troposphere, which causes delays in the centimeter level. This is of particular importance since the monitoring of the ionosphere may have a positive impact in communications systems and the knowledge of the spatio-temporal distribution of water vapor can certainly help in the weather forecast systems. Therefore, by pursuing in the use of the GPS for atmospheric studies, we are, in fact, contributing to many different applications.

The GPS has been used for the ionospheric calibration of other systems such as interplanetary probes or Very Long Baseline Interferometry ([2], [3] [4], and [5] for an overview).

Later the imaging of the four dimensional structure of the ionosphere was stated [6]. The application of tomography to the troposphere came later because of the higher difficulty in its implementation, as it shall be described in this work.

The concept of retrieving a field from integrated values of its distribution is referred as tomography, a subset in inverse theory. This has found applications in medicine, geophysics and now, in atmospheric sciences. However, while in the former fields the deployment of the sensing rays could be chosen to yield a favorable geometry and a good inverting situation, the atmospheric tomography using the GPS constellation (not designed for tomography purposes) has particular aspects to be worked out.

Along this thesis it has been attempted to thoroughly present what GPS actually provides, a background on inverse theory and finally the application of tomography to the ionosphere and to the troposphere, with examples of possible applications and extensions of the concept. The application of tomography to the atmosphere is here focused on the use of GPS signals, but, as it will be shown, other sources of satellite data such as radar altimeter can as well be used for tomographic purposes. The goal of this research work has been to demonstrate that existing radio navigation satellite systems provide enough information about the atmosphere as to infer its spatio-temporal structure. Different approaches and enhancements such as the use of numerical weather models are left for future work.

The thesis is hence organized as follows:

- Chapter 2 is devoted to the description of the GPS signal structure and the different effects contributing to the measured delay, including those produced when traversing the atmosphere. The GPS data processing is also described.

- Chapter 3 summarizes the Inverse Theory used in the tomographic analysis as well as some considerations on the numerical solution.

- Chapter 4 includes the application of tomographic techniques to stochastic three dimensional imaging of the ionosphere. Results and different scenarios are considered and an assessment on the possible applications to instrument calibration is made.

- Chapter 5 contains the particular application of tomography to the neutral atmosphere using local dense networks, both through simulations and with experimental data. Meteorological data are used to verify the results.

- Chapter 6 concludes the thesis summarizing the main aspects of the work, highlighting the principal contributions and finally outlining future trends of work.

The results here described have been published in different journals, and presented at conferences. Others are currently in preparation. We will refer to those publications whenever necessary.