

Chapter 6

Conclusions

In this thesis we have gathered the work related to atmospheric tomography using radio navigation signals that we have developed during the last years. Most of it has been published in international journals and here it has been compiled together with new material. Along these years it has been needed to refine the data processing techniques and the tomographic approach. We have centered our efforts in the use of GPS signals but we have also presented the capabilities of the system to ingest other sources of data with the benefits of enhancing the solution and providing an absolute calibration of the systems.

First we have discussed the GPS signal in its structure and the atmospheric effects that distort the range measurement. Some widely used techniques to determine the ionospheric and tropospheric components of the total delay have been described. These measurements have been verified prior to enter in the tomographic section.

Once the GPS signal has been analyzed, we have carried on with a description of the mathematical background of tomography and given some interpretations that are useful for qualitative understanding of the problem before going into a detailed analysis. The core tool developed for the tomographic purpose is a Fortran 90 software package named GIST/LOTTOS that contains all the needed steps in the tomography. The development of such tool has given us the capability of analyzing different situations and simulate different strategies, as well as obtaining results with experimental data. The GIST/LOTTOS is currently being used not only at IEEC but also it has been requested by other institutions and at the time of this writing is working at the Onsala Space Observatory, Sweden, and at the University Corporation for Atmospheric Research, Colorado, USA. It is a unique set of tools that is still growing in capabilities and refinement and with these institutions a future working group for the maintenance of the tool may be formed.

We initiated our tomographic studies with the ionosphere because of the availability of global networks and the observable being more easily extracted. Starting with a two layer

model we increased the vertical resolution by incorporating GPS occultation data into the system, a practice nowadays commonly used. A step forward in the ionospheric tomography was the inclusion of other sources of data such as Radar Altimeter (RA) data, as well as GPS data for navigation purposes on board Low Earth Orbiters. The inclusion of RA data provided the evidence of ionospheric tomography being a robust tool for absolute instrument calibration.

Tropospheric tomography has long been debated. Since it required a finer analysis of the data to correctly extract the slant wet delays and local dedicated networks to obtain a dense geometry of rays within the region where water vapor structures are correlated, it was the focus of the last efforts made during this study. In fact, there are still many questions opened that can be considered as future research topics. The initial results were obtained using the permanent network in Kilauea, Hawaii, which is greatly suited for tomographic analysis thanks to the particular orography of the area which allows to have GPS receivers at a broad range of heights. This network provided very encouraging results and we moved further for the analysis of networks with a flat orography. The simulations provided evidence that the tomographic approach to the troposphere was feasible even with no height dependence of the stations. A set of experimental data was obtained during the campaign of the summer 1998, with 6 additional receivers deployed in the surroundings of the IGS site at Onsala Space Observatory, distributing the network in what it turned out to be a suitable geometry for tomographic purposes. The data was processed and tomography provided good spatio-temporal representations of the water vapor. Later, the meteorology of the area was deeply analyzed for comparison of the tomographic solution. The good agreement between tomography and meteorological data, including radiosonde data, provided the final evidence of the capability of the technique.

In every research project, every achievement opens the door for new questions and challenges to be answered. Regarding atmospheric tomography, there are still topics to be addressed and we here mention some of them.

In general, the software can be enhanced considering the use of other sets of basis functions and the solving algorithms can be optimized in terms of speed and feasible number of unknowns.

Regarding ionospheric tomography, it should be worked out the densification of the sources of opportunity to provide better ionospheric maps and use them for single-frequency instruments calibration. The use of TOPEX/POSEIDON data was very successful and other ionosphere-sounding regular systems such as DORIS, GLONASS, Galileo or even communications satellite systems should be investigated for its proper use.

In tropospheric tomography there is a broad field of interesting topics to be further addressed: first, the network geometry is actually a key element in the resolution capability and the link with antenna array theory should be investigated; second, the use of other instrumentation could be developed, in the same lines as with ionosphere.

Finally, the next step in atmospheric studies is to include nonlinearities such as ray bending and ultimately ingest the GPS measurements into the numerical weather prediction models to obtain accurate representations of the troposphere.

