GPS Tomography and radar reflectivity reconstruction fast algorithm.

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Abstract

Since the early 90's, water vapor can be studied using Global Position System (GPS). We have developed, tested and validated a new software based on GPS tomography in order to retrieve the 3 dimensional field of water vapor density. In addition, we have developed two fast reflectivity interpolation algorithms. Those algorithms allow us to reconstruct reflectivity maps where data are damaged due to different effects such as radar pre-processing. Thus with both GPS and radar results, we expect to better understand the wet convergence, the precursor stages of heavy precipitations and the water vapor distribution in some cloud system.

1. Introduction

Water vapor is a very important parameter in atmospheric sciences. However, due to the spatial and temporal variability of water vapor, it is a parameter which is difficult to estimate with classical methods. Since few decades, this quantity can be estimated using remote sensing technologies as for example radio sounding, spectrometers, lidars, radiometers, and so on. Since the early 90's, researchers have focused on the study of the water vapor using the Global Positioning System. Indeed, the GPS offers an autonomous, all-weather and continuous system for the restitution of the water vapor. With such a technology we can retrieve the IWV (Integrated Water Vapor) over an area. This quantity has been validated by means of comparisons with other measurements and is now tested for assimilation in numerical weather prediction models. In addition, when a dense network of GPS stations exists, we can use the GPS to perform tomography in order to retrieve the 3 dimensional distribution of water vapor density. Tomography is a powerful mathematical tool of inversion which is used to retrieve information based on distant data. Although this technique is well known in different fields of sciences such as seismology or medicine, the use of this tool in atmospheric science is recent. A few software based on tomography have been developed by different groups over the last few years using different languages and have proven of great interest for atmospheric studies (WeRKaF, LOTTOS, LOFFT_K…). Nevertheless, looking in details at all these software we can see a lot of strong constraints to carry out the inversion. Some use forcing by radio sounding; some others use IWV extrapolations to fill empty voxels values, and so on.

2. Tomography principle

The main research work done the last years was to develop and validate a new tomography software to retrieve the water vapor. This software carry out the inversion without any external constrains to better understand the GPS inversion process and also to study the limitation of such a tool.

The second objective was to compare 3 dimensional water vapor fields with radar data. In fact, the comparison between the density of water vapor and the reflectivity of the rain can be interesting to study precipitation structures. For example, we expect to better understand the precursor stages of intense precipitation, the wet convergence or the water vapor distribution in some cloud systems…

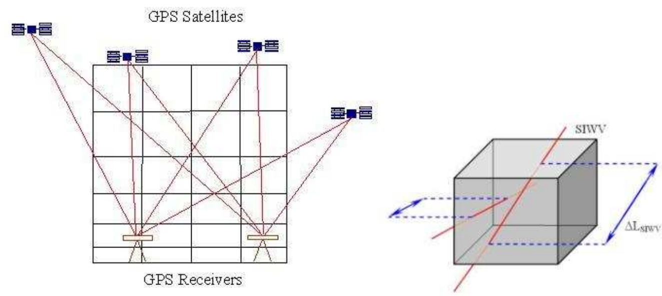

Figure 1. Principle of tomography. General configuration and zoom on a voxel.

The tomography algorithm is based on Slant Integrated Water Vapor (SIWV) inputs: the Integrated Water Vapor (IWV) along the receiver to satellite baselines. The principle of the tomography is as follow: the volume above the GPS network is divided into voxels. The height of the voxels is function of the altitude: to have a better resolution in the low layers of the atmosphere, where the water vapor is concentrated, it is advised to define smaller voxels. Then, an algorithm looks at the repartition of each SIWV through the voxels as shown in figure 1.

3. Sensitivity tests

After the development of the software, we have worked on sensitivity tests. Those tests were conducted without constraints. First we have run a 3D modeling software which has provided us synthetic atmospheres. That means for different epochs we had well known density of water vapor fields. Using these atmosphere and a GPS constellation, we have extracted SIWV by integrated the density of water vapor along the satellites-stations paths. Then we have conducted the inversion and looked at the results. Different important parameters such as the vertical and horizontal water vapor fields restitutions, the impact of the voxels numbers, the change of algorithm or the geometry network was tested. Two of my important results concern the vertical dilution of the water vapor if the inversion is conducted without any vertical forcing and the geometry of the network. It is better to perform the inversion with less GPS ground station if they are well distributed in space.

An example of such an application is the OHM-CV (Observatoire hydro-météorologique des Cévennes-Vivarais) campaign done in 2002 in south of France or more recently the COPS (Convective and Orographically-induced Precipitation Study) campaign done in summer 2007 in north Europe. During both campaigns, the deployment of a dense GPS network was done to produce a large set of data usable for a tomography treatment. Figure 2 is a vertical one of my result showing you a formation of a water vapor bubble in less than 1 hour 15 minutes. In fact, the tomography can produce water vapor field every 15 minutes. This time step allows us to look in details at some interesting structures.

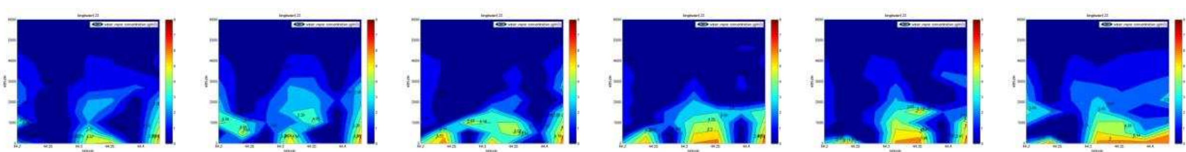

Figure 2. Bubble formation in 1h15.

4. Reflectivity reconstruction

To compare with density of water vapor, we use radar which provides reflectivity data over the same area where GPS stations are deployed. Unfortunately those data were damaged due to numerous problems including orography and initial radar processing. Those problems are mainly the consequences of the nearby mountains and of the distance between the radar and the position of our network (~70 km). In order to retrieve the lack of information, we have developed two fast algorithms based on reflectivity interpolation. Furthermore, we have studied the effect of the reconstruction on different damaged reflectivity map by proceeding as follow. We have selected non-damaged reflectivity map and have inserted some blank data. Then, we run our algorithms and look in details at the result after the different interpolations (nearest data for the first algorithm and horizontal, vertical and diagonals interpolations for the second algorithm). Even if the results still have some artifact, it can give us a really good approximation of the reflectivity as shown in figure 3.

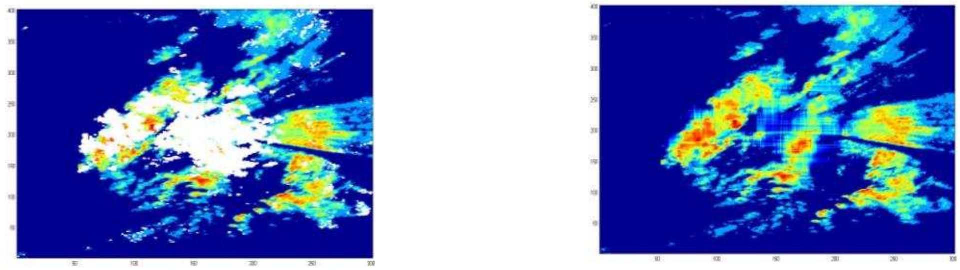

Figure 3. Radar algorithm used on damaged radar data.

With such vertical (or horizontal) cuts, we can do comparison with radar data. We can extract from those figures the average density of the water vapor for a given layer or for the entire volume. From the radar maps we can extract the reflectivity of the rain. Thus, it is possible to produce time series of density and reflectivity. We can do the same between IWV (curves black, blue and green) and radar reflectivity (red curve) as shown in figure 4.

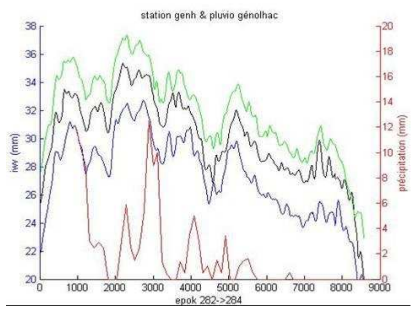

Figure 4. Time series of IWV and radar reflectivity.

5. Prospective work

I plan to continue to develop my tomography software to include and test vertical constraints. I have also the project to update my tomography software to carry out the inversion with direct STD (Slant Total Delay) instead of using ZTD (Zenith Total Delay) and Gradients. This new method should decrease the error done by computation.

I will also work on larger networks with the COPS campaign. It will give me interesting results to understand the inversions if the GPS ground stations are distant. I also work in collaboration with the IRMB (Institut Royal Météorologique de Belgique) to perform tomography over their country where a network of about 70 GPS stations with a mean space of 20 km exists in addition to continuous meteorology radar data.

6. Associated contributions

1. Reverdy.M, Van Baelen.J, Boudevillain.B. “Radar reflectivity reconstruction fast algorithm”. In preparation for Journal of Atmospheric and Oceanic Technology.

2. Reverdy.M, Van Baelen.J, Walpersdorf.A. “GPS water vapor tomography sensitivity tests”. To be submitted to Radio Science.

3. Reverdy.M, Van Baelen.J. “Estimation des paramètres atmosphériques à partir des signaux GPS”. CNES contract n°04/CNES/1928-5, June 2007.

4. Reverdy.M, Van Baelen.J, Walpersdorf.A., Boudevillain.B. “Tomography sensitivity tests and comparisons of water vapour fields with radar data”. EGU conference, Vienne, Austria, April 2007.

5. Reverdy.M, Van Baelen.J, Walpersdorf.A., Boudevillain.B. “Tomography sensitivity tests and comparisons of water vapour fields with radar data”. First HYMEX workshop, Toulouse, France, January 2007.

6. Reverdy.M, Van Baelen.J. “Estimation des paramètres atmosphériques à partir des signaux GPS”. CNES constract n°04/CNES/1928-4, December 2006.

7. Reverdy.M, Van Baelen.J, Walpersdorf.A., Boudevillain.B. “GPS estimates of atmospheric parameters: analysis of the spatial and temporal variability of water vapor”. European Research Course on Atmosphere, Grenoble, France, January 2006.