GPS Tomography and Remote Sensing Techniques for Water Vapor Determination in the ESCOMPTE Campaign

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Abstract

The comparison of the integrated precipitable water vapor (IPWV) retrieved by GPS, microwave radiometer, solar spectrometer and radiosondes, operated within the French field campaign ESCOMPTE, shows an overall good agreement. The time dependent relative fluctuation as well as the absolute amount of water vapor match with high accuracy. The software package AWATOS (Atmospheric WAter vapor TOmography Software), developed at the Geodesy and Geodynamics Lab, ETH Zürich, is used to determine the spatial distribution and variation of water vapor in the troposphere by double differenced GPS measurements. The comparison with refractivity profiles derived from radiosonde data shows the success of this method.

Outline

The ESCOMPTE field campaign (Expérience sur Site pour COntraindre les Modèles de Pollution atmosphérique et de Transport d'Emissions) [Cros et al., 2002], undertaken by MétéoFrance and other organizations, was carried out in the region of Marseille (France) in June 2001 (see Fig. 1). It aimed at studying summer pollution in industrialized areas and its impact on the complex processes in the atmosphere. Several techniques were deployed to provide independent data sets for validation purposes. Particularly, the field experiment called GPS/H2O focused on the assessment of the amount of atmospheric water vapor [Bock et al., 2003].

Water vapor is the most variable parameter of the major constituents of the atmosphere and has a strong effect on the refraction of the microwave signals emitted by GPS satellites. For geodetic applications, it is mandatory, either to model or determine the water vapor content and its variation with high accuracy to correct the GPS observations.

In the framework of the ESCOMPTE field campaign, several GPS receivers, a microwave radiometer, a solar spectrometer, and radiosondes were deployed to determine the integral amount as well as the spatial distribution and variation of tropospheric water vapor.

Integrated Precipitable Water Vapor

The Integrated Precipitable Water Vapor (IPWV) is the equivalent liquid water height of a vertical column of water vapor in the atmosphere. In the ESCOMPTE field campaign, its value is retrieved by four different techniques:

- The Water Vapor Radiometer (WVR) measures the radiation intensity emitted by H_2O molecules due to thermal excitation at the 22.235 GHz spectral line [Kruse, 2001; Somieski et al., 2002].
- The solar spectrometer SAMOS measures the amount of absorption of the solar radiation traversing the atmosphere due to water molecules [Somieski et al., 2002].
- GPS data are used to estimate the IPWV with the GPS analysis package GAMIT extracting the total path delay in zenith direction [King and Bock, 1999].
- Radiosondes provide meteorological profiles for pressure, temperature and water vapor pressure from which the IPWV can be derived [Bevis et al., 1992].

Fig. 2 shows the time series of this data. A significant variation between 7 and 26 mm of the IPWV during the measurement period of WVR and SAMOS is visible. A general good agreement of the different techniques is identifiable. Assigning the differences of the various methods compared to the GPS solution, the mean value and the RMS of the differences are calculated and presented in Tab. 1.

Technique	mean diff. [mm]	RMS of diff. [mm]
WVR	– 1.8	1.2
SAMOS	– 0.7	1.5
RS (Aix-les-Milles)	+ 0.0	1.3
RS (Nimes)	– 1.2	2.8
RS (Cinq)	+ 0.8	0.8

Tab. 1: Comparison of different IPWV techniques with the GPS solution. 1 mm IPWV affects a path delay by approximately 6 mm. Only the differences to WVR and the radiosonde (RS) at Nimes exceed this amount. Latter is the most distant sensor and has most likely different meteorological conditions. The RMS indicates an accuracy of the IPWV derived from GPS better then 1.5 mm (except for the radiosonde at Nimes).

Focusing on the differences WVR to GPS in Fig. 3, one observes a rapid change of the mean offset at date 52079 from about – 3 mm to – 1 mm. The end of a strong decrease of atmospheric water vapor content during the four previous days (Fig. 2) could explain this phenomenon.

GPS Tomography

In the tomographic approach, the extraction of time dependent 3D wet refractivity fields of the troposphere is elucidated. A wet slant path delay is obtained by integrating the wet refractivity index along the ray path. The software package AWATOS, developed at the Geodesy and Geodynamics Lab at the ETH Zürich, is based on the assimilation of double-differenced GPS observations to calculate the wet refractivity in a voxel model applying a least-squares adjustment [Troller, M. et al.; 2002]. Due to the limited number of GPS satellites and receivers, the adjustment system is partially under-determined. Therefore, additional constraints have to be introduced (see Fig. 4, on the right hand side). Finally, refractivity profiles are obtained with a high temporal resolution and at any location in the area of the GPS receiver network.

The refractivity profiles from the preliminary tomographic results represented in Fig. 5 fit quite well with the corresponding radiosonde profiles. Evaluating only the radiosonde data, we find very special meteorological conditions: high amount of water vapor below 1 km, then a rapid decrease and, at the level of about 4 km, another local maximum. Due to the intervoxel constraints in AWATOS, these irregularities are smoothed out in the tomography profiles.

Conclusions

The determination of IPWV has shown a good quality comparing GPS with other independent techniques. The mean offset does not exceed 2 mm with a RMS of about 1.4 mm. Also the extraction of tomographic profiles has been successful. After introducing additional constraints, a mean offset (compared to radiosonde data) of less than 1.5 ppm has been reached. Further investigations are currently in progress to improve the accuracy and reliability of the tomography software.

References

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Appendix

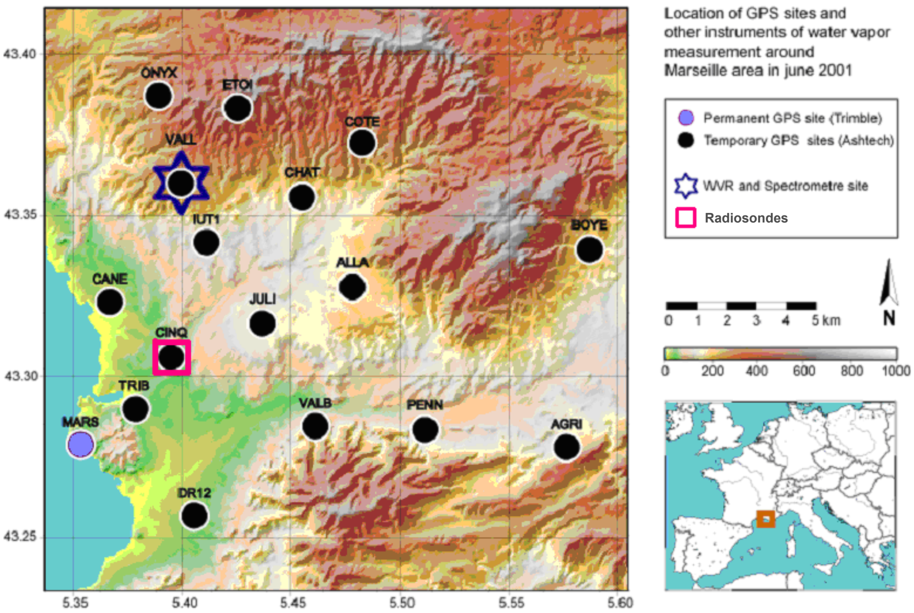


Fig. 1: GPS network and sites with further instrumentation in the ESCOMPTE campaign. Additional radiosondes were launched at Aix-les-Milles and Nimes (20 and 100 km to the Northwest). The height distribution of the GPS stations ranges between 33 m (station TRIB) and 586 m (station ETOI).

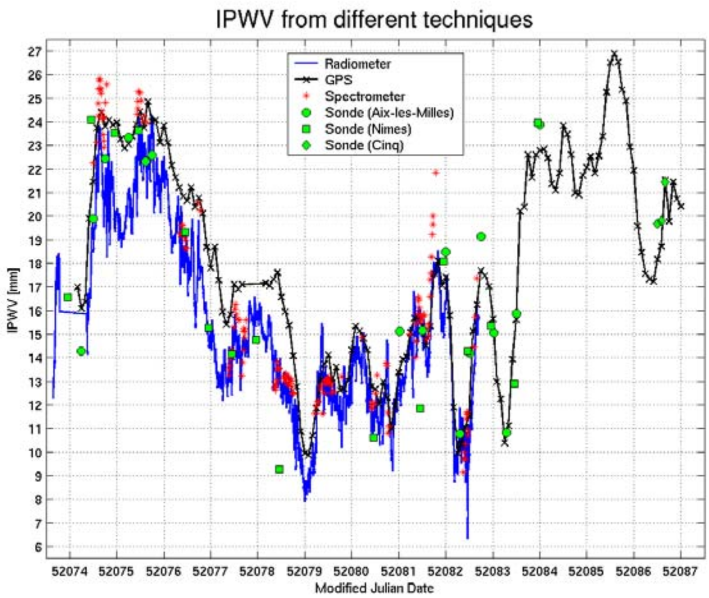


Fig. 2: Comparison of IPWV retrieved by different remote sensing instruments mounted at station VALL and additional data from several radiosondes nearby. The characteristic changes of the water vapor content above the station during the measurement period (14 to 27 June 2001) can be observed in the time series of the different measurement techniques.

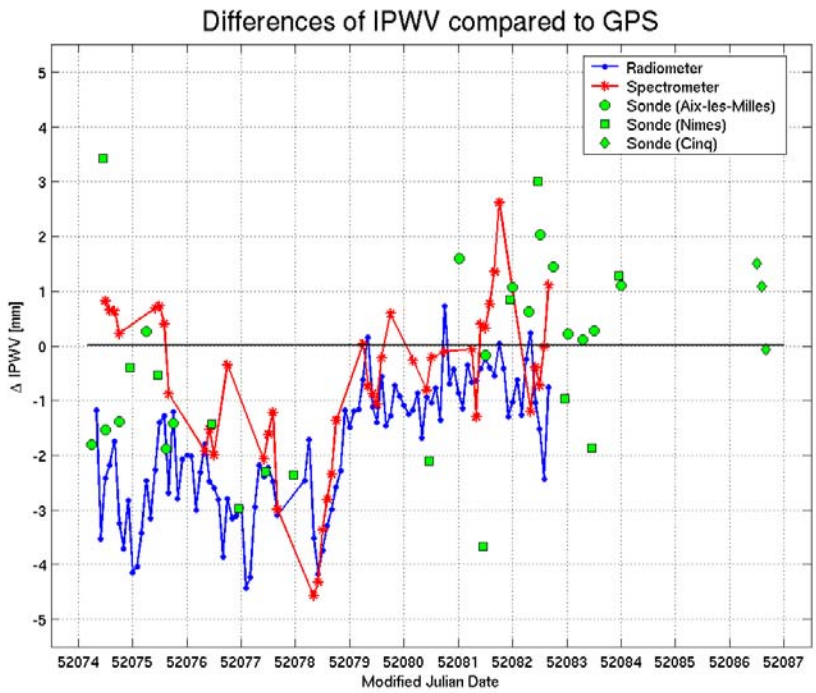


Fig. 3: Differences of IPWV. The reference is the GPS derived solution. A general overestimation of water vapor by GPS in the first half of the time span gets better in the second half.

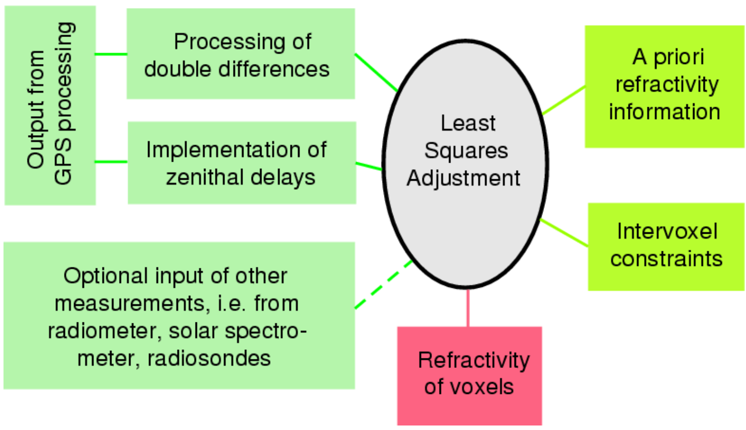
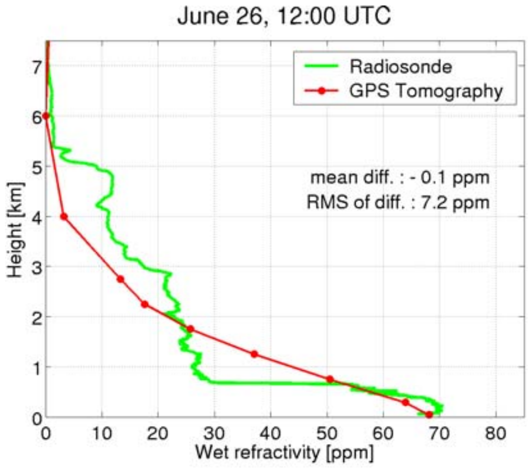
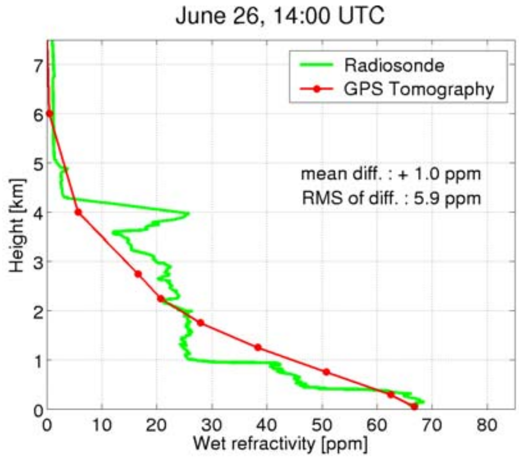


Fig. 4: Flow chart of the GPS Tomography software package AWATOS. The input data is shown on the left-hand side. On the right side, the possible introduction of additional pseudo-observations is outlined. They are necessary to get accurate and feasible results. Then, the refractivity can be calculated for each single voxel.





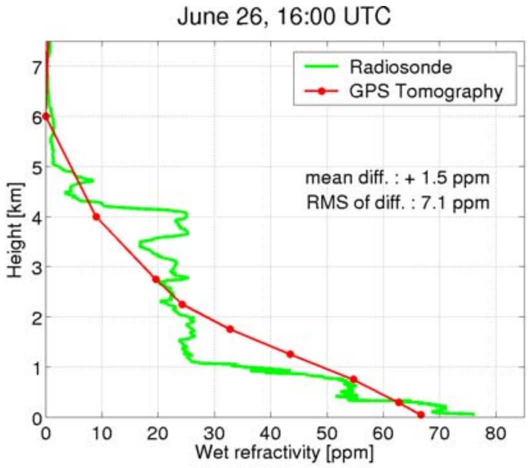


Fig. 5: Comparison of wet refractivity profiles derived from radiosonde observations and preliminary GPS Tomography results at station CINQ. The dots in the tomography profiles represent the layers of the voxel model.