Swiss Activities in Combining GPS with Meteorology

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1 Introduction

A fruitful collaboration between four Swiss institutions, the Federal Office of Topography, MeteoSwiss, the Institute of Applied Physics of the University Berne and the Institute of Geodesy and Photogrammetry of the ETH Zurich in the field of GPS meteorology, began simultaneously with the European project COST 716.

21 permanent AGNES sites have continuously been delivering GPS data at a 1-second interval since the beginning of 2001 (see Fig.1). The data are primarily used for surveying by means of RTK methods [*Schneider, 2000* and *Brockmann, 2001*].

In addition, the network is used for defining and densifying the Swiss reference frame LV95.

Recently a possible contribution of the GPS-derived total zenith path delays (TZD) for numerical weather prediction applications was studied. comparisons of hourly derived path delays with radiosonde data and with numerical weather prediction models were performed.

Another approach is to compute 4-dimensional refraction fields from meteorological ground measurements of pressure, temperature and humidity and to derive zenith path delays from such

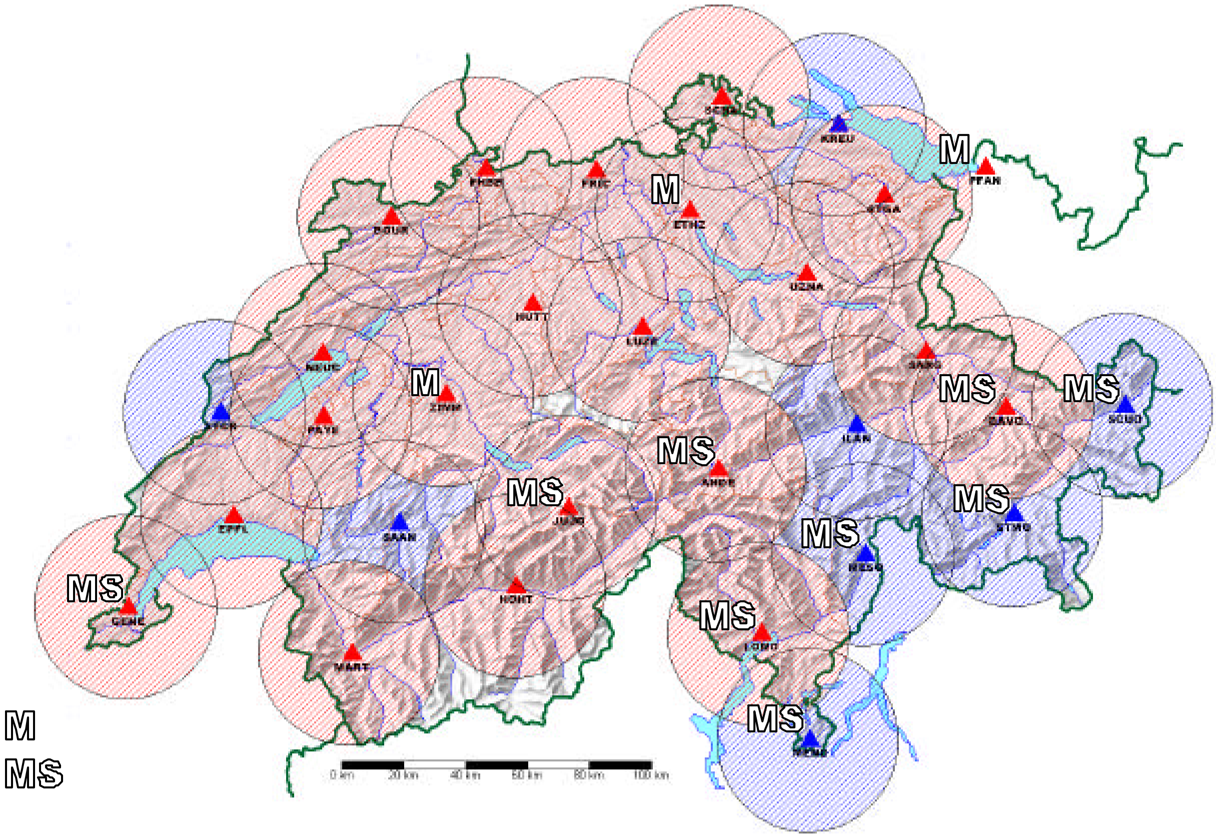

Fig. 1: The AGNES network of permanent sites and the availability of surface meteorological data at the GPS sites

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In order to interpret the total zenith path delays, a model (called COMEDIE). This approach was already applied in order to improve the accuracy of GPS height estimates [*Wiget, 1996* and *Brockmann, 2000*]. Comparisons of GPS and COMEDIE will be also shown in this presentation.

In the scope of COST 716 [*van der Marel, 2001*] the Federal Office of Topography is taking part in a near real-time (NRT) project with the aim to deliver total zenith path delays with a time delay shorter than 1 hour 45 minutes.

2 GPS Meteorology

2.1 Partnerships

Our partners in the field of GPS meteorology are MeteoSwiss, the Institute of Applied Physics of University Berne and the Institute of Geodesy and Photogrammetry of ETH Zurich.

As already mentioned, we benefiting from the very fruitful collaboration in the COST 716 project.

2.2 Data and methods used

Fig. 1 shows the present status of the AGNES network of permanent GPS stations. Furthermore, most of the sites are collocated with MeteoSwiss sites in order to guarantee the availability of ground-based meteo data. The radiosonde station Payerne (two balloon launches per day) is also equipped with a permanent GPS receiver.

The GPS data are analyzed on a daily basis in a postprocessing mode (time delay = 1 week) together with 20 EUREF sites using the Bernese 4.2 scientific software package [*Rothacher, 1996*, *Schneider, 2000*]. From these solutions hourly estimates of the zenith total delay are obtained.

The MeteoSwiss network consists of approximately 70 ANETZ sites equipped with automated surface meteorological sensors. From these data MeteoSwiss computes a 48 hour local weather prediction model LM (7 km grid) twice a day. It is based on the global model of the German weather service DWD covering Western and Central Europe from Ireland to south of Italy.

Profiles (pressure, temperature and humidity) are available from the radiosonde data itself as well as from the computed numerical weather prediction model LM. Furthermore, GPS-derived total zenith delay estimates which are converted with surface pressure and temperature to integrated water vapor (IWV) are available. When integrating the profiles of the radiosondes and the LM model, an IVW quantity can be derived which is comparable to the GPS-derived IWV values. Comparisons will be shown in Chapter 3.

Another approach to compare the GPS-derived zenith path delays with meteorological values is the COMEDIE model [*Hirter, 1998*]. With collocation methods a 4-dimensional refraction field is computed from the ANETZ sites. From these refraction fields, total zenith path delay estimates could be derived for any place and time. An example of zenith total delay estimates derived from COMEDIE is shown in Fig. 2. Due to the fact that the TZD values are mainly a function of station height (pressure), the topography of the Swiss Alps is clearly evident.

3 Comparisons

3.1 Comparing GPS with radiosondes and MeteoSwiss numerical weather forecast models

Fig. 3 shows comparisons of the GPS-derived IWV estimates (hourly estimates) with radiosonde results and with the weather prediction model.

It may be concluded that the radiosonde overestimates the humidity in dry periods compared to the weather model (where the radiosonde observations were introduced) and compared to the GPS estimates. This effect is a known problem of the radiosonde used.

Only in one or two cases does the weather prediction model show a different behavior than GPS and than the radiosonde. We suppose that in such periods an error in the weather prediction occurs (which we all know may happen from time to time).

Fig. 4 shows the direct differences between GPS and the LM (in units of IWV) for the sites Payerne, Berne, Davos and Andermatt. We generally see a very good agreement between all estimates (approximately 1-2 mm IWV). On the other hand, this is a prerequisite for using the contribution of GPS for numerical weather prediction in the future. In a near real-time processing mode the numerical weather prediction certainly may benefit from GPS estimates (see Chapter 3.3).

3.2 Comparing GPS with the COMEDIE model

The total zenith delay estimates derived from GPS (hourly estimates) were compared with the estimates derived from COMEDIE (based on the surface meteorological parameters of the ANETZ sites only) for different time periods in 2000 for station Zimmerwald.

For this comparison the zenith path delay estimates provided by the IGS were also included as a combination of 7 IGS analyses centers (hourly estimates).

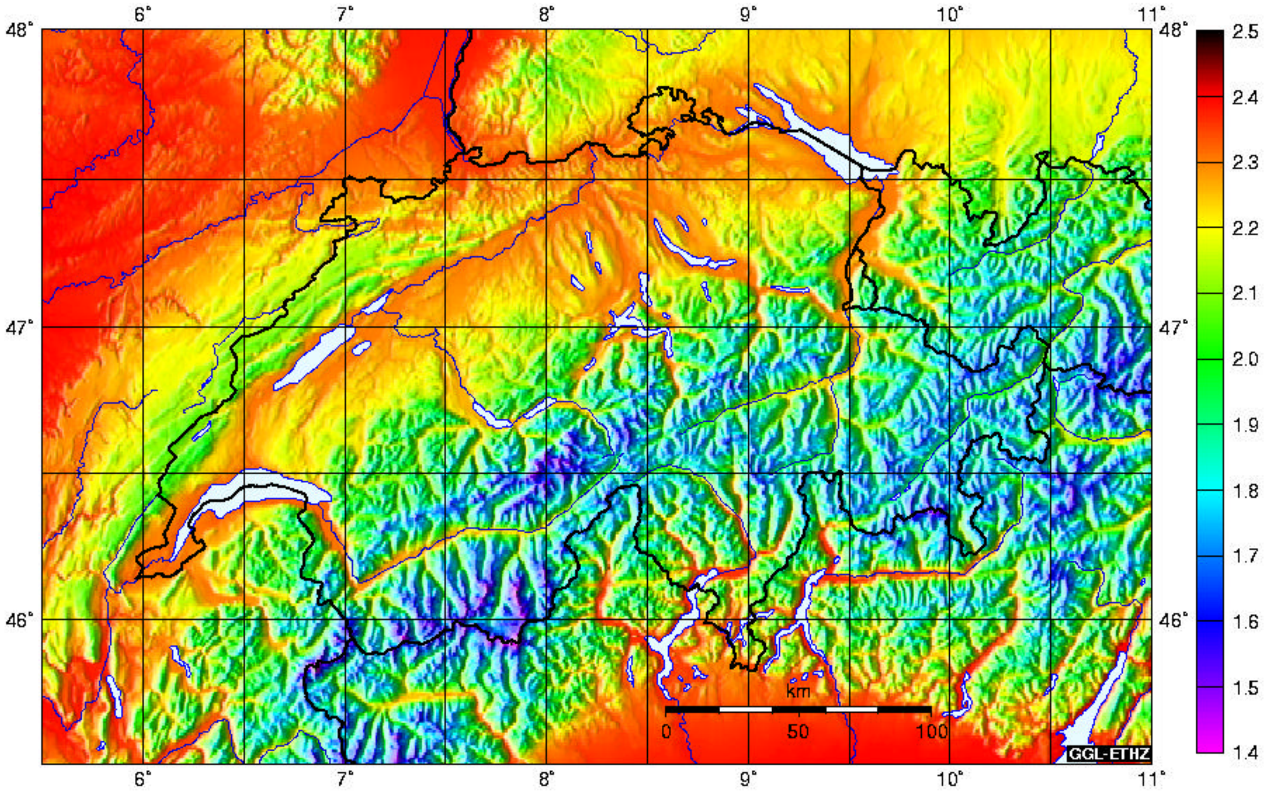

Fig. 2: Total zenith path delays in meters at 12:00 UT (21.1.2001) derived from the COMEDIE model

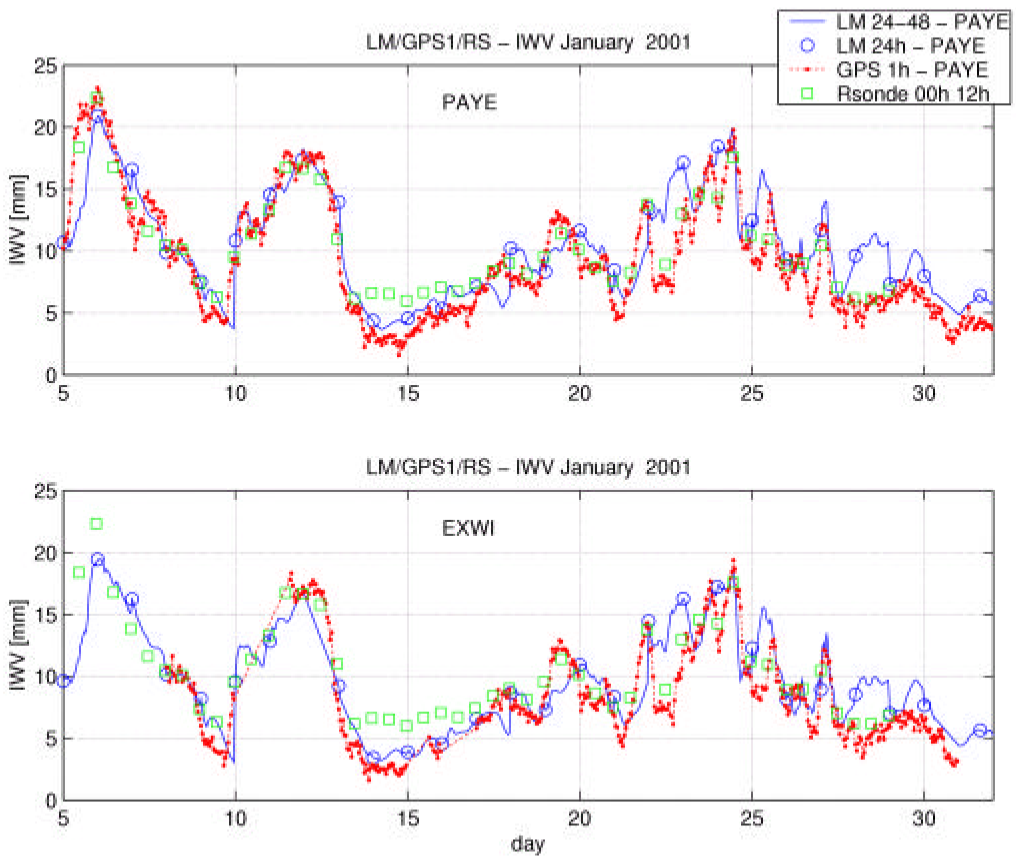

Fig. 3: Integrated water vapor (IWV) estimates from GPS, radiosonde and a 24-hour prediction of the local weather model LM for the sites Payerne (PAYE) and Berne (EXWI) for the time January 2001

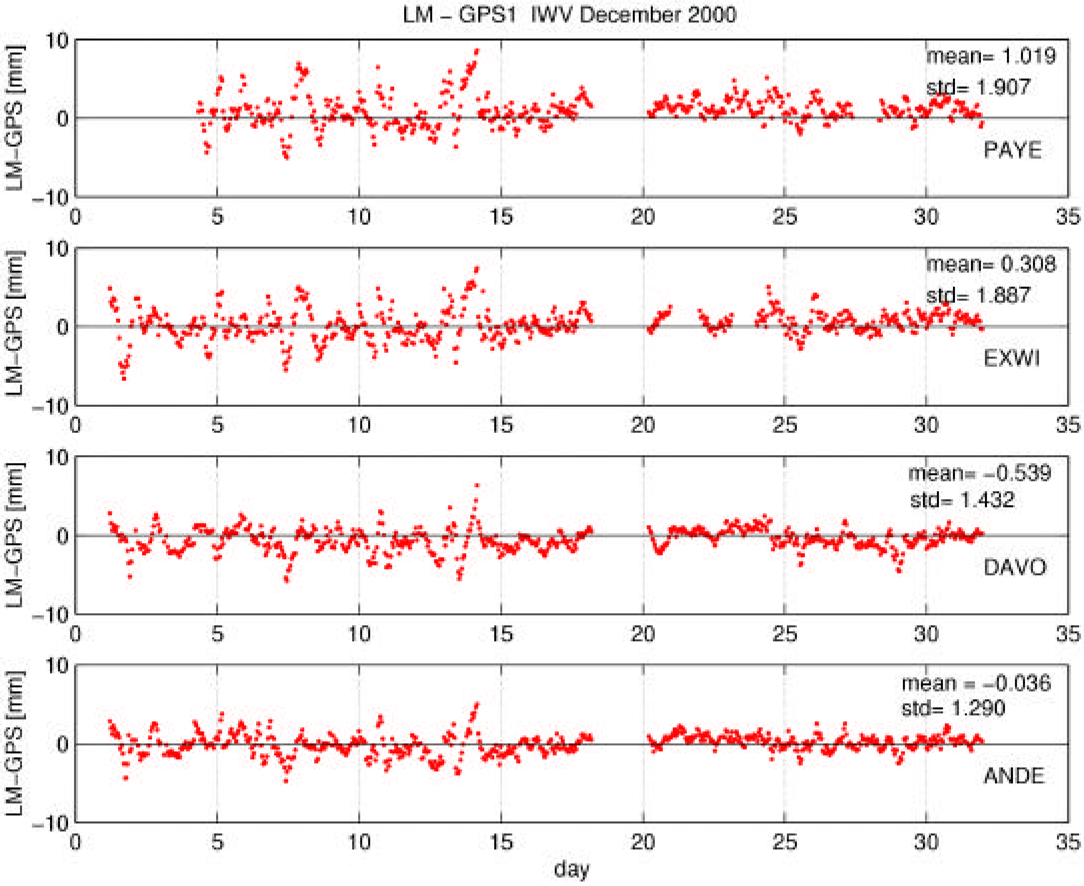

Fig. 4: Differences of integrated water vapor (IVW) estimates between GPS and the local model LM (24-hour weather prediction) for the sites Payerne, Zimmerwald, Davos and Andermatt (Dec. 2000).

	COMEDIE		IGS		AGNES	
	Mean [mm]	RMS [mm]	Mean [mm]	RMS [mm]	Mean [mm]	RMS [mm]
20.-25. Aug. 2000	18.1	10.1	-10.9	3.9	-7.3	7.5
16.-25. Oct. 2000	10.5	7.1	-4.7	3.7	-5.8	4.6
20.-25. Nov. 2000	2.2	4.7	-3.3	3.3	1.1	3.4

Tab. 1: Total zenith total delay comparisons of the three different series COMEDIE (from meteorological sensors) and the GPS estimates of IGS and AGNES.

Tab. 1 shows the mean bias as well as the rms of the comparison between the three solutions. Reference is the mean value of all 3 estimates. In general there is a good agreement between the solutions. The rms values of the comparison are between 3 mm (winter) and 7 mm (summer).

Please note that we compared total zenith delay estimates which can be converted to the corresponding rms of integrated water vapor (IVW) by a division of 6, which means that the series are comparable on a level below 1 mm IVW.

The biases between the two GPS series are almost constant (1-4 mm ZTD), whereas the biases of the COMEDIE model show larger differences in the different time periods.

3.3 Comparisons in the framework of COST 716

Since summer 1999 the Federal Office of Topography and the Swiss partners MeteoSwiss and the Institute of Applied Physics of the University of Berne have been actively involved in the COST 716 project "Exploitation of Ground-Based GPS for Climate and Numerical Weather Prediction Applications". The primary objective of the project is the assessment of operational potential on an international scale to provide near real-time observations.

In a first step a benchmark data set (15 days of 44 sites in Europe) was analyzed by 7 different analysis centers in a simulated near real-time mode. The results are presented in [*van der Marel, 2001*]. They prove the potential of GPS to provide

IVW estimates on a level of below 1 mm IVW in a near real-time processing scheme.

Comparisons with water vapor radiometers and radiosondes and tests to assimilate the values in the numerical weather prediction are planned.

Two analyses centers began the demonstration phase in April 2001 in which total zenith delay estimates are delivered to the UK Met Office on an hourly basis within 1h:45min. The Federal Office of Topography is preparing a contribution to the near real-time demonstration phase.

4 Conclusions

In addition to the work which has already been done in Switzerland to compare GPS derived zenith path delays with other measurement techniques like water vapor radiometer [e.g. *Bürki 1995*, *Rohrbach, 1999, Kruse, 2000*] or solar spectrometer [e.g. *Sierk 1997, Ingold 2000*], a good agreement of GPS estimates (in postprocessing and near real-time) with numerical weather models could be demonstrated. The results are very encouraging for including GPS as a contribution in the numerical weather prediction. The assimilation procedure for the GPS estimates in the numerical weather prediction have not yet been developed. In the scope of the European project COST 716, Switzerland will contribute with GPS-derived total zenith delay estimates in near real-time. Progress made on the European level may then also improve the data flow and processing schemes in Switzerland and vice versa.

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