P6.2 VALIDATION OF PRECIPITABLE WATER FROM ECMWF MODEL WITH GPS DATA DURING THE MAP SOP

O. Bock[1], C. Flamant[1], E. Richard[2], C. Keil[3], M.N. Bouin[4]

[1] Service d Aéronomie / CNRS, Université Paris VI, Paris, France
[2] Laboratoire d Aérologie / CNRS, Observatoire Midi-Pyrénées, Toulouse, France
[3] DLR-Institut fuer Physik der Atmosphaere, Oberpfaffenhofen, D-82234 Wessling, Germany
[4] LAREG, Institut Géographique National, Marne-la-Vallée, France

1. INTRODUCTION

A good description of the three-dimensional water vapour field is crucial for the simulation of convective systems and heavy precipitation (Koch et al., 1997; Ducrocq et al., 2000; Falvey et al, 2002; Lascaux et al, 2003). During the MAP-SOP (Mesoscale Alpine Programme - Special Observing Period), a huge set of special observations (SYNOP surface data, windprofilers, dropsondes, high-resolution radiosonde data, and aircraft flight data) has been accumulated, which has been used for the production of a set of re-analyses at ECMWF (Keil and Cardinali, 2004).

In this paper we present the first results of a comparison of total precipitable water vapor content (PWC) from operational analyses available during the field experiment (referred to as OPER99) and re-analyses (MAPRA) released in 2003. This study covers the whole MAP-SOP (7 Sept. - 16 Nov. 1999) and a domain extending slightly the Alpine region. Statistics are presented for a limited number of GPS sites, mainly located in Italy.

2. DESCRIPTION OF THE DATA SET

2.1. ECMWF operational analyses and MAP-reanalysis

OPER99 analyses were produced at ECMWF with a 6-hour 4D-VAR global assimilation system, with a horizontal resolution of ~60 km and 50 vertical levels. These analyses used only conventional data (SYNOP, TEMP, AMDAR commercial aircraft data, and TOVS/AMSU-A and SSM/I satellite data). During 2000, the ECMWF forecast model and assimilation system were deeply modified: the resolution of the model was increased to 60 vertical levels and 40-km horizontal resolution, the assimilation time window has been increased to 12H, and an improved radiative transfer model was implemented, leading to an increased number of satellite data being now assimilated. The MAPRA reanalysis has been performed with the new version of the model and a large number of special data from the MAP-SOP have been assimilated (Keil and Cardinali, 2004). The MAPRA has been shown to lead to better forecast of daily rainfall (based on comparison with surface data in the Po-catchment) and slightly moister conditions in the southern Alpine region, southern France and the Adriatic Sea (Keil and Cardinali, 2004). This new set of analyses is intended to be used for further simulation studies of special MAP events (heavy precipitation, convection, foehn…).

2.2. GPS data

GPS Zenith Tropospheric Delay (ZTD) solutions from the MAGIC network (www.acri.fr/magic) have been used and complemented with data from a special station deployed at Milan, Italy, during October 1999 (referred to as MILA), see Figure 1. The MAGIC solutions were produced by CNRS, France, with GAMIT GPS software (Haase et al., 2001). The data from MILA station have been processed with Bernese GPS software (Bock et al., 2001), within a network including some of the MAGIC stations. Agreement between ZTD solutions from the two analyses, at common stations, is ~ 5mm RMS (due to slightly different analysis procedures).

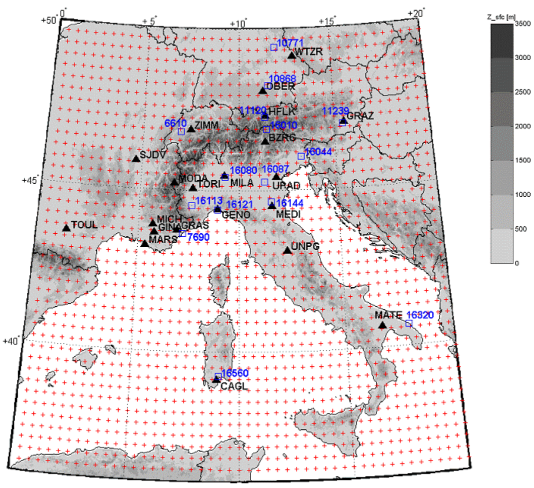

Fig. 1. Domain of analysis showing real topography from Globe30 (grayscale), ECMWF model grid valid for the MAP reanalysis (red pluses), GPS stations (black triangles) and radiosonde stations (open blue squares).

* *corresponding author address*: Olivier Bock, Service d'Aéronomie / CNRS, Université Paris VI, Paris, France. Email: Olivier.Bock@aero.jussieu.fr

3. COMPUTATION OF PRECIPITABLE WATER CONTENT

3.1 ECMWF model

In the model, all variables are represented on a reduced gaussian grid (RGG) (Hortal and Simmons, 1991). In order to avoid any loss of information due to horizontal interpolation of the model variables, we retrieved model variables at the nearest gridpoint of the RGG for every GPS station. Due to the quite coarse horizontal resolution of the model, the atmospheric column represented in the model and that sensed by a GPS receiver are not the same. In the MAP domain, the difference in topographic height of the GPS station and the model surface is up to 1000m at some stations. The difference in precipitable water content (PWC) expected from this height difference might be modelled but would not lead to a perfect correction. Therefore we do not perform this correction. The PWC from the model used here is thus defined by the following equation:

$$PWC_{\mathrm{model}} = \int_{P_b}^{P_t} \frac{q}{g} dP$$

where q is specific humidity on model levels and P is pressure of the model levels. Integration is performed between model top and bottom levels. For MAPRA (60 vertical levels), P_t = 0.1 hPa and P_b is pressure at the model's surface height.

3.2. GPS

GPS ZTD estimates are converted into PWC is obtained in two steps:

(1) formation of zenith wet delay: ZWD=ZTD-ZHD, where ZHD is zenith hydrostatic delay which is estimated using surface pressure (at the height of the GPS receiver):

$$ZHD = 2.279 \times P_{surf}$$

(2) conversion of ZWD into PWC using surface temperature (at the height of the GPS receiver):

$$PWC_{\mathrm{GPS}} = \kappa(T_{surf}) \times (ZTD_{GPS} - ZHD)$$

Under standard conditions, k = 155 kg m^{-2} / m (Bevis et al., 1994). P_{surf} and T_{surf} are retrieved from nearest surface stations operated during the MAP SOP (http://www.map.ethz.ch/). The data are corrected for possible difference in altitude with GPS station (<200m for most stations). The uncertainty associated to a 200m extrapolation is ~ 0.4 hPa and ~ 2°C (based on radiosonde data analysis). Sensitivity of PWC to errors in P_{surf} and T_{surf} is 0.35 kg m^{-2} / hPa and 0.05 kg m^{-2} / K. Accuracy of GPS ZTD estimates is ~5-10 mm. Finally, the accuracy of GPS PWC is estimated to ~1-2 kg m^{-2}.

3.3. Radiosondes

PWC is computed from radiosonde (RS) data by integrating specific humidity profiles converted from relative humidity (RH) and temperature measurements, between the altitude of either a GPS station or model surface and the highest altitude where RH data are reported by the RS :

$$PWC_{rs} = \int_{P_0}^{P_1} \frac{q_{rs}}{g} dP$$

STA	mean GPS_PWC [kg m-2]	MAP Reanalysis ΔH [m]	ΔPWC bias [kg m-2]	ΔPWC std [kg m-2]	bias/mean [%]	std/mean [%]	Nb	Operational analysis ΔH [m]	ΔPWC bias [kg m-2]	ΔPWC std [kg m-2]	bias/mean [%]	std/mean [%]	Nb
BZRG	21,9	1095	-10,4	3,6	-47	16	466	1203	-9,7	3,2	-44	15	466
CAGL	23,0	-94	-1,9	2,8	-8	12	492	-109	-0,8	2,9	-3	13	492
GENO	24,4	205	-2,9	3,3	-12	13	511	407	-4,4	3,5	-18	14	511
GINA	20,8	123	-1,5	2,6	-7	12	512	3	-0,9	2,7	-4	13	512
GRAS	16,0	-742	3,5	2,7	22	17	486	-993	5,6	2,9	35	18	486
GRAZ	18,4	167	-1,3	2,4	-7	13	522	-41	0,0	2,1	0	11	522
HFLK	9,1	-727	2,2	1,8	24	20	375	-1019	4,5	2,4	49	26	375
MARS	25,8	60	-1,7	2,9	-7	11	426	115	-3,3	3,0	-13	12	426
MATE	19,1	-295	2,2	3,4	11	18	457	-288	1,3	3,7	7	19	457
MEDI	24,8	58	-0,8	3,1	-3	12	510	75	-1,5	2,9	-6	12	510
MICH	18,9	154	-1,5	2,5	-8	13	521	385	-3,6	2,8	-19	15	521
MILA	20,2	31	-0,5	1,9	-24	9	92	16	0,7	2,1	3	11	92
MODA	15,2	1061	-6,5	2,7	-43	17	504	905	-5,6	2,3	-37	15	504
OBER	16,6	56	-0,5	2,5	-3	15	447	17	-0,3	2,4	-2	15	447
SJDV	19,8	-142	0,7	2,5	3	13	426	95	-1,3	2,3	-6	12	426
TORI	22,2	117	-2,5	3,1	-11	14	489	737	-6,2	3,4	-28	15	489
TOUL	22,1	30	-1,9	3,2	-9	14	482	-8	-1,1	3,4	-5	15	482
UNPG	23,4	166	-3,3	3,5	-14	15	419	166	-3,5	3,1	-15	13	419
UPAD	22,9	-92	0,2	2,6	1	11	393	-19	0,4	2,5	2	11	393
WTZR	17,2	4	-0,1	2,1	-1	12	476	-71	0,0	1,8	0	10	476
ZIMM	15,2	-109	0,3	2,2	2	15	497	-45	-0,1	1,9	-1	13	497
mean	*19,9*	*54*	*-1,3*	*2,7*	*-7*	*14*	*453*	*73*	*-1,4*	*2,7*	*-5*	*14*	*453*

Table 1: Comparisons of 6 hourly model PWC to GPS PWC, throughout the MAP-SOP.

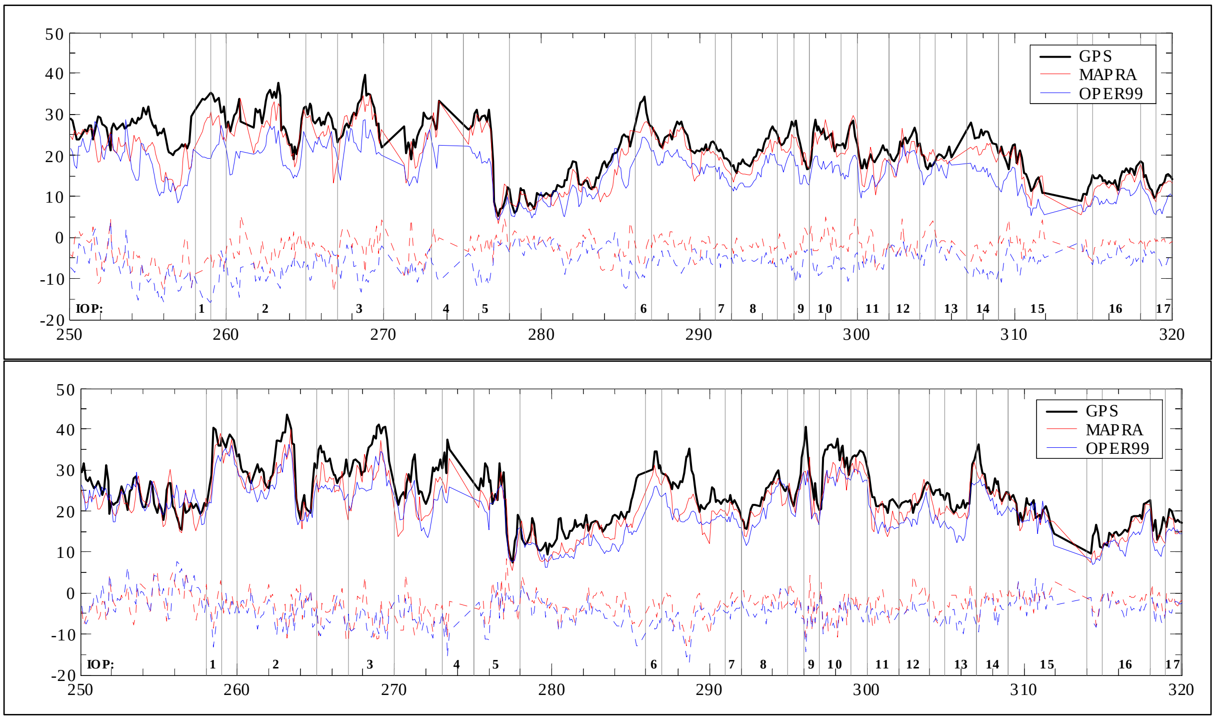

Fig. 2. Plot of model and GPS PWC (solid lines) and differences (lower dashed lines), at two Italian stations around the Po catchment, during the MAP-SOP.

When the GPS station height or model surface height is below RS station, RS data are extrapolated as for surface data (see 2.2.). The resulting uncertainty in q is of ~1g/kg for 200m height difference. High-resolution (~50m) RS data were retrieved from the MAP database (http://www.map.ethz.ch/). Most of the sondes operated during the MAP SOP were Vaisala RS80. At present, these data are not corrected for biases in humidity measurement.

Note that with present definitions, PWC is expressed in kg m^{-2} (with 1 kg m^{-2} = 1 mm in conventional PW unit).

4. COMPARISON OF GPS AND MODEL PWC

Table 1 shows that the bias is generally < 3 kgm^{-2}, but at some stations it can reach 6-10 kg m^{-2} (MODA, BZRG). MAPRA and OPER99 have nearly similar bias, but MAPRA bias is smaller for stations GENO, GRAS, and TORI. Standard deviation between GPS and model is ~2.7 kg m^{-2} or 14%. In fact, that there is a nearly-linear relationship between fractional bias, (model-GPS)/GPS, and height difference (such a dependence was expected since mode PWC is not corrected for height difference). A linear fit of fractional bias versus altitude difference yields a slope of nearly - 40% / 1000m (computed over all 21 stations). When this bias is corrected using the fitted linear relationship, the residual bias is < 2 kg m^{-2} at all stations (0.6-0.7 kg m^{-2} RMS). This residual bias is smaller for MAPRA than OPER99, and is smaller than 1 kg m^{-2} at all stations, except CAGL. Model PWC at this latter station is thought to be biased from the assimilation of radiosonde humidity data with known dry bias problems.

Figure 2 shows that PWC is varying in a large extent (between 10 and 40 kg m^{-2}) during the MAP SOP. At GENO and UPAD (not shown) this variability is directly connected to moist inflow from the Mediterranean and Adriatic Sea during most of the IOPs. At UPAD, the model is in very good agreement with GPS observations. At GENO and TORI differences are slightly larger, with peaks of 5-10 kg m^{-2}, though MAPRA is in better agreement with GPS than OPER99. At BZRG (not shown), the time evolution of model PWC roughly follows that of GPS, but a slowly varying offset indicates a dependence of PWC error on weather situation which might be due to model errors. When bias and standard deviation (STD) are computed over the different IOPs, it is again observed that they are largely varying during the SOP and seem to depend on the weather situations. For IOPs 6-8 and 13-17, both bias and STD are smaller than for the other IOPs. These IOPs are characterized by stratiform rain, except IOP15 (frontal passage with heavy rain). This seems to indicate that model PWC is better estimated under such conditions.

Figure 3 shows that model PWC is very close to RS PWC, when RS PWC is integrated over the atmosphere column represented in the model. This is a result of the assimilation of RS data in both OPER99 and MAPRA. It is seen also, that GPS PWC and RS PWC now integrated from the GPS receiver altitude, are in good agreement, except at stations CAGL, GRAS and UPAD. Biases at these stations might be due to RS humidity sensor biases. Slope, offset and RMS of linear fit with respect to RS PWC are very similar for GPS and model. Scale factors < 1 indicate a dependence of RS humidity data to PWC. However, one should note that linear fit parameters and RMS values indicated in Fig. 3 might be slightly biased due to outliers that were not removed.

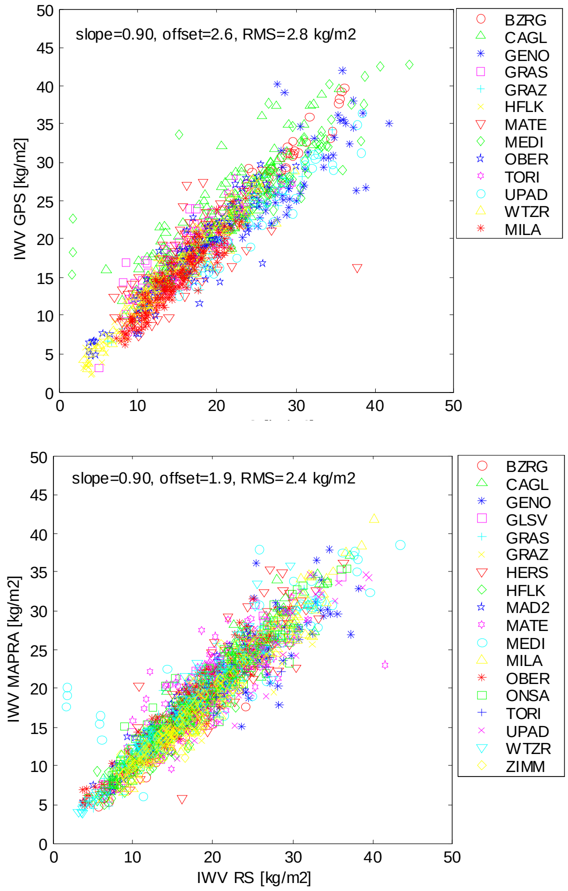

Fig. 3. Scatterplot of GPS (upper) and MAPRA (lower) vs. RS PWC, throughout the MAP-SOP, with linear fit parameters indicated.

5. CONCLUSION

GPS data have been useful for the validation of operational analyses and re-analyses of the MAP-SOP. The accuracy of the GPS data, which is at the 1-2 kg m^{-2} level with respect to radiosonde data, allowed to highlight biases in model estimates of PWC. The bias to the first order is linked to altitude differences between model and GPS stations. It is also shown to depend on weather situation. Possible reasons for these biases are: the coarse spatial resolution of the model, the general lack of humidity data (both upper air and total column) and the presence of biases in assimilated humidity data (especially radiosonde data). GPS data are presently considered to be assimilated in numerical weather prediction models in near real-time for short-term weather forecasting and climate studies, and in mesoscale models for dedicated studies of atmospheric processes.

6. REFERENCES

Bevis, M., S. Businger, S. Chiswell, T.A. Herring, R.A Anthes, C. Rocken, and R.H. Ware, GPS Meteorology: Mapping zenith wet delay onto precipitable water, J. Appl. Meteorol., Vol. 33, 379–386, 1994.

Bock, O., C. Flamant and T. Duquesnoy, "Integrated water vapor estimated by GPS compared to independent observations during MAP," 8th International Symposium on Remote Sensing, Toulouse, 17-20 Sept. 2001, Proc. SPIE Vol. 4539.

Keil, C. and C. Cardinali, The ECMWF Re-Analysis of the Mesoscale Alpine Programme Special Observing Period, *Q. J. R. Meteorol. Soc., in press*, 2004.

Koch, S.E., Aksakal, A., McQueen, J.T., “The influence of mesoscale humidity and evapotranspiration fields on a model forecast of a cold-frontal squall line, Mon. Wea. Rev., 125, 384-409, 1997.

Ducrocq, V., J-P Lafore, J.L. Redelsperger, and F. Orain, « Initialization of a fine-scale model for convective-system prediction: A case study, » Quart. J. Roy. Meteor. Soc., 126, 3041-3065, 2000.

Falvey, M, and Beavan, J, “The Impact of GPS Precipitable Water Assimilation on Mesoscale Model Retrievals of Orographic Rainfall during SALPEX’96,” Mon. Wea. Rev., 130, 2874-2888, 2002.

Haase, J., et al., The contributions of the MAGIC project to the COST 716 objectives of assessing the operational potential of ground-based GPS meteorology on an international scale, Phys. Chem. Earth, 26, 433-437, 2001.

Hortal, M., and A.J. Simmons, Use of reduced Gaussian grids in spectral models. Mon. Weather Rev., 119, 1057-1074, 1991.

Lascaux, F., E. Richard, C. Keil and O. Bock, 2003: Numerical simulations of the precipitation event observed during the MAP IOP2a: Sensitivity to the initial conditions, ICAM2003.

Lascaux, F., E. Richard, C. Keil, O. Bock, Impact of the MAP reanalysis on the numerical simulation of the MAP-IOP2a convective system, ICAM 2003, Meteorologische Zeitschrift, 13, 49-54, 2004.