Slobodan Fazlagic, Ph.D.
UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA
DIP. INGEGNERIA DEI MATERIALI E DELL'AMBIENTE, OSSERVATORIO GEOFISICO
Via Vignolese 905, 41100 MODENA, ITALY

FINAL REPORT
OF CADSEALAND WP 1.7 AND 1.8 – CINFAI STUDY RESEARCH
A.A. 2005

THE STUDY OF SIMULTANEOUS ATMOSPHERIC (HUMIDITY/PRECIPITATION) OBSERVATION BY MSG AND GPS FOR PERMANENT MONITORING OF THE STATE OF THE COASTAL ZONES IN SOUTH-EASTERN EUROPE (ADRIATIC AND IONIAN SEA)

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INTRODUCTION

This work is prepared fulfilling the requirements of the Contract signed at January 01st, 2005 between:

1) il Consorzio Interuniversitario Nazionale per la Fisica delle Atmosfere e delle Idrosfere (C.I.N.F.A.I.), con sede in Torino, via Pietro Giuria n. 1 – Codice Fiscale 97578350015 – P. IVA 07709290014, rappresentato dal Direttore Prof. Antonio Speranza, Codice Fiscale: SPR NTN 44L09 E047J;

2) il Dr. Slobodan Fazlagic, nato a Sarajevo (Bosnia-Herzegovina) il 13 gennaio 1948, residente a Castelnovo Ne' Monti (RE) in via Di Vittorio Giuseppe n. 13 – Codice Fiscale: FZL SBD 48A13 Z153W;

in order to assemble the specific items from Working Packages 1.7 and 1.8 of the CADSEALAND PROJECT.

CADSEALAND's Project Premises and Project Principal Data for WP 1.7 and 1.8

PROJECT TITLE:

Land-sea interaction: coastal state and evolution in CADSES

PRIORITY:

Environment protection, resource management and risk prevention

MEASURE:

Promoting integrated water management and prevention of floods

OBJECTIVES, RESULTS, GENERAL EFFECTS

1. *Developing international standards for the definition of a "state of the coast" useful for the territorial planning and management, engineering, insurance, etc., of the processes (both on land and at sea) that determine the coastal state through the land-sea interaction, of the processes (both natural and human) that determine the evolution (dynamics) of the coastal state.*
2. *Developing efficient monitoring systems for the state of the coast and its evolution, efficient techniques for the protection of endangered coastal areas and the reconstruction of damaged ones.*
3. *Developing and diffusing an integrated culture of land-sea interaction in coastal areas for their preservation and management as well as for planning of future development of CADSES area, together with guidelines to be adopted by public institutions for the protection of the coast.*

DESCRIPTION OF THE WORK PACKAGE

a) *Integrating land hydrology and marine dynamics for the defense and management of coastal areas*
b) *In this WP CINFAI will systematically work on the merging of the different activities and products of the project in the context of an integrated view of the land-sea (and atmospheric) processes which determine the state of the coast and its evolution. Particular attention will be devoted to the methods and procedures for assessing rigorously the existence of trends in the state of the coastal areas and their cause (whether natural or anthropogenic) and to the potential impact on the planning of territorial development.*

ACTION PLAN

1.7	*01/04*	*12/06*	*Study of the definition of the coast state, its trend and their statistical assessment from observations.*
1.8	*01/04*	*12/06*	*Study of the integrated view of coast evolution with special emphasis on extension to eastern Europe.*

I. THE STUDY OBJECTIVES AND DELIVERABLES

A. Study of Water Vapor (WV) Indexes for Coastal zones of the Adriatic and Ionian Sea applying the Tropospheric Humidity (TH) measurements by MSG and GPS

Observing and elaboration period: 12 months (01.02.2004 – 31.01.2005)

The start of the study epoch corresponds to the very beginning of the operational work of the Meteosat Second Generation (MSG) of the EUMETSAT (http://www.eumetsat.int). The obtained dataset represent the mean daily relative humidity (in %) for two (MSG) water vapor satellite channels (WV6.2 and WV7.3) producing the upper tropospheric humidity (TH) which is the mean layer relative humidity between 300 hPa and 850 hPa. Also, the Precipitable Water content in a vertical atmospheric column (mm) is obtained. The elaboration was programmed upon of 15-min satellite infra-red sampling and synoptic hours processing between the homogenous and continuous MSG observations for the costal pixels in comparison to the sharply localized permanent Global Positioning System (GPS) integrated water vapor (IWV) observations, i.e. Precipitable Water (PW) obtained at the referent GPS sites. The 12 GPS sites of: Venezia (VENE), Medicina (MEDI), Camerino (CAME) and Matera (MATE) for the Italian Adriatic coast (and inland), then Dubrovnik-Croatia (DUBR), Sarajevo–Bosnia (SRVJ), Osijek-Croatia (OSJE) and Ohrid-Macedonia (ORID) for the Balkanic Adriatic coast (and inland), Thessaloniki (AUT1), Atene (IGD1), Creta (TUC2) for the Ionian coast and Bucarest-Romania (BUCU) for the continental zone oriented toward the Black Sea coast were planned during the study preparation period and deliverables designation.

Throughout the elaboration work on GPS tropospheric solutions some lacking about planned GPS data are verified, mainly because of yet declared but, in involved period still existing in-situ meteorological measurements. To replace these missing meteorological or either GPS data, several other EUREF GPS Mediterranean zone sites are searched and added. Also the GPS site of Thessaloniki had to be omitted completely, having its observing period set afterward, only in 2005. The list of GPS sites used in this work is grown-up from previous 12 to definitive 19 and as follows: Venezia (VENE), Medicina (MEDI), Camerino (CAME), Matera (MATE), Caglari (CAGL), Genova (GENE) and Lampedusa (LAMP) for the Italian coasts (and inland); Dubrovnik (DUBR) and Osijek (OSJE) for the Croatian coasts (and inland); Sarajevo (SRVJ) for Bosnia's inland; Ohrid (ORID) for the Macedonia's lake coasts; Atene (IGD1) and Creta (TUC2) for the Greek Ionian coasts; Ankara (ANKR), Istambul (ISTA) and Trabzon (TRAB) for the Turkish Ionian and Black Sea coasts (and inland); Bucarest (BUCU) for the Romania' inland; Sofia (SOFI) for the Bulgarian inland; Nicosia (NICO) for the Cyprus Ionian coasts. All GPS sites are belonging to the European Reference Frame (EUREF) standardized network.

The elaboration results are offered as an assimilative contribution for the Numerical Weather Prediction (NWP) mathematical models, providing a temporal and spatial distribution of Precipitable Water (PW in mm) of the day of the year (DOY). The index obtained from the comparison between two observing systems is introduced on the coastal pixel values (based on Equivalent Black Body Temperature radiance - EBBT value).

B. <u>Study of High Resolution Precipitation Index (HPI) for Coastal zones of the Adriatic and Ionian Sea applying the measurements by MSG</u>

Observing and elaboration period: 12 months (01.02.2004 – 31.01.2005)

As the new Meteosat product, the High Resolution Precipitation Index (HPI or HRPI) MSG product is derived as the mean index for the convective rainfall (probability of occurrence) at the larger tropical latitudes from the infra-red MSG satellite channel IR10.8 (on pixel basis for Equivalent Black Body Temperature radiance - EBBT value) for the synoptic hours (every three hours). For the coastal pixels containing GPS EUREF sites from the MSG observing box bounded by ± 40° of latitude and ± 50° of longitude the current repeat cycles the HPI values are to be derived. In order to compare PW values with HRPI values, of the whole list of 19 GPS sites used in the Study A. item, only five southward located GPS sites are corresponding to MSG HRPI observing zone: Caglari (CAGL), Lampedusa (LAMP), Atene (IGD1), Creta (TUC2) and Nicosia (NICO). Since the observations of this parameter are at the their very beginning and because of data scarcity, the HRPI elaboration will be deferred until the first half of 2006.

II. <u>THE STUDY METHODOLOGY AND TECHNIQUE</u>

The research schedule deals with the integrated and multidisciplinary management of ground water and aquifer systems of Mediterranean coastal zones as an important operational method to prevent the floods risk. Numerical Weather Prediction (NWP) mathematical models at the local scale represent one of the very efficient tools for continuous monitoring of the state of the coast in the land-sea interaction (and atmospheric) providing the flood prevention function. An understanding of the mechanisms distributing precipitable water vapor (PWV) through the atmosphere and of water vapor's effects on atmospheric radiation and circulation is vital to estimating long-term changes in climate. Studies on South-Eastern Europe zone and in particular about the Mediterranean costal area, need a comprehension of water vapor distribution and dynamics, assuming with this respect, a specific importance of the Balkanic origin air mass fluxes perception. The most recent and advanced atmospheric water vapor observation technique is the satellite technology developed for the METEOSAT SECOND GENERATION (MSG), active from August 2002 (but operational from February 2004), where three monitoring channels are devoted to the water vapor (WV) bands observations. The second important methodology is that one derived from GPS (Global Positioning System) observation, where the column content of water vapor (or Precipitable Water – PW) is obtained from the GPS electromagnetic signal's non-hydrostatic tropospheric path delay.

The two techniques are convenient because the GPS observations own the advantage that they are continuous, portable and economic, and provide measurements which practically are not affected by rain and clouds, but the METEOSAT observations enclose the homogeneous filed of observation and can complete the continuity of atmospheric humidity monitoring in a certain area.

III. THE STUDY APPROACH AND DATA SOURCES

The two environmental observation systems used for this study are:

[1] Meteosat Second Generation (MSG) and
[2] Global Positioning System (GPS)

[1] Meteosat Second Generation (MSG)

With the progression of science, and developments in the accuracy of numerical weather prediction, the need for more frequent and comprehensive data from space had arisen. This had led to the work on the Meteosat Second Generation (MSG) system. Meteosat Second Generation is a significantly enhanced follow-on system to the previous generation of Meteosat. It has been designed in response to user requirements and serves the needs of Nowcasting applications and Numerical Weather Prediction in addition to provision of important data for climate monitoring and research. The more frequent and comprehensive data collected by MSG aids the weather forecaster in the swift recognition and prediction of dangerous weather phenomena such as thunderstorms, fog and explosive development of small but intense depressions which can lead to devastating windstorms.

ESA was responsible for the development of the first satellite according to a requirement baseline coordinated with EUMETSAT, and acts, on behalf of EUMETSAT, as procurement agent for MSG-2 and MSG-3 satellites. Based on these MSG satellites, the MSG Programme is expected to provide an operational service to the users over at least 12 years. The Meteosat satellite system has been operated successfully since 1977 providing almost continuous images and other services to the national Meteorological Services of EUMETSAT and ESA Member States.

Meteosat has also served operational and research users throughout West and East Europe and Africa, with many other users in North and South America, the Middle East and even in the Arctic and Antarctic areas. The MSG system, starting from 2003, has brought major improvements in the service to meteorologists, climate monitoring and other related disciplines through:

- Twelve spectral channels (three on the previous system) provide more precise data throughout the atmosphere giving improved quality to the starting conditions for Numerical Weather Prediction models
- Fifteen-minute cycle of imaging (30 minutes on the previous system) provides more timely data for Nowcasting, improving the accuracy in forecasting of severe weather such as thunderstorms, heavy rain, snow or fog
- Improved horizontal image resolution for the visible light spectral channel (1 km as opposed to 2.5 km on the previous Meteosat) also greatly aids weather forecasters in detecting and predicting the onset or cessation of severe weather
- The Geostationary Earth Radiation Budget (GERB) instrument carried on MSG provides important data for climate research
- MSG satellites have a nominal life in orbit of seven years (two years more than the previous system), this leading to an extended and more cost-effective life-span.

The **M**eteorological **P**roduct **E**xtraction **F**acility (MPEF) within the Operations Department of Eumetsat, operationally analyses Meteosat images to provide information about meteorological parameters like cloud cover, cloud motion, sea surface temperature, etc.

The extraction is performed in an automatic processing scheme (Figure 1.) and includes an automatic quality control step as an integral part of the processing. The products are produced and distributed in neural time to the meteorological user community in the form of products, and these products support the quantitative use of the Meteosat data in a wide range of applications.

The operational Meteorological Product Extraction Facility (MPEF) accepts in near-real time image lines from the image processing system, which performs the geometrical correction on the images. The corrected image lines are send to MPEF and blocks of 32 images lines are first analyzed by the MPEF Scenes and Cloud Analysis whose output is presented the to the various meteorological product applications as a classified pixel map and as segmented clustered scenes.

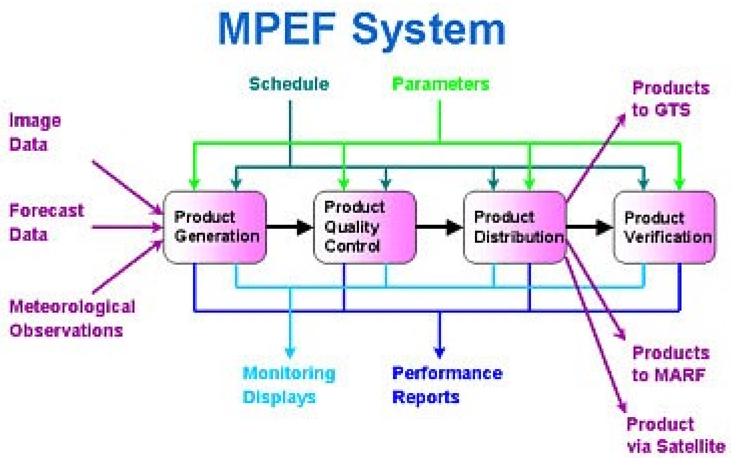

Fig. 1. Eumetsat MPEF System structure

Meteorological correction and calibration of MSG image data.

In addition to the image data, input from sources external to EUMETSAT is required for the processing and verification of the meteorological products. Forecast data and sea surface temperatures, received from ECMWF (European Center for Medium Range Forecasting, Reading, UK), are used for the determination of the atmospheric absorption by running a radiation model. Twice a day the ECMWF provides meteorological forecasts to MSG. The forecast data sets contain 12, 18, 24, 30 and 36 hours forecasts of Temperature, Humidity and Wind Profiles defined for different atmospheric height levels on a 1 degree grid. Sea Surface Temperatures information is produced by the National Center of Environmental Prediction (NCEP) in Washington DC. Also, every 6 hours MPEF regularly receives meteorological bulletins from the Global Telecommunications System (GTS) on Rawinsonde/radiosonde observations, significant wind information, aircraft wind and temperature observations and surface meteorological observations. Those data are used for the calibration of the MSG water vapor channels and for the verification of other MPEF products.

Most of the MPEF products are segmented products; i.e. the full earth disc image is divided into sub-areas (so-called 'segments'). For the low-resolution products a segment is 32x32 pixels, giving a ground resolution of 160 km at the sub-satellite point. Thereby the Meteosat area (including space) is covered by an 80x80 segment matrix. Each segment is at a fixed geographical position. In addition only those image segments are exploited for product generation which fall into the area of 60 degrees around the sub-satellite point (SSP). The high-resolution products are using a 160x160 segment matrix with segment size 16x16 pixels, giving a ground resolution of 80 km at the sub-satellite point and about 15000 processing segments.

[2] Global Positioning System GPS

The **G**lobal **P**ositioning **S**ystem (GPS), based on a defined constellation of telemetry satellites, is being developed since the early 1960s for primarily military purposes to be used later for many civilian applications. Recently, its big contribution is found in meteorology and climatology. The main contemporary issue in this field is connected to the weather prediction, for both improving parameterization in numerical weather prediction (NWP) and improving the short-range forecasts (now-casting) and the prediction of local meteorological events. GPS represents an enormous ongoing three-dimensional atmospheric observation system, capable to give many useful data for NWP in near real time (NRT).

Thus, the water vapor remains one of the most important variables in the atmosphere affecting weather and climate. Both fundamental meteorological approaches to GPS - weather forecasting and climatology - have as the main purpose to improve the tracking of precipitation and water vapor cycle. GPS signals are delayed in the neutral atmosphere because of the refraction, which is a function of temperature, pressure and water content. GPS satellites travel under different elevation angles, but taking a convenient mapping function, the zenith direction is commonly considered (Figure 2.).

All components of the troposphere contribute to such Zenith Total Delay (ZTD), but it is convenient to study its hydrostatic and non-hydrostatic (i.e. wet) terms separately. The induced dipole moment of the atmosphere is associated with the Zenith Hydrostatic Delay (ZHD). Zenith Wet Delay (ZWD, non-hydrostatic) is mainly due to the permanent dipole moment of water vapor, which is highly variable in space and time: the basic meteorological output is related to this wet path delay, which is roughly proportional to the integrated water vapor (IWV) content in the atmosphere.

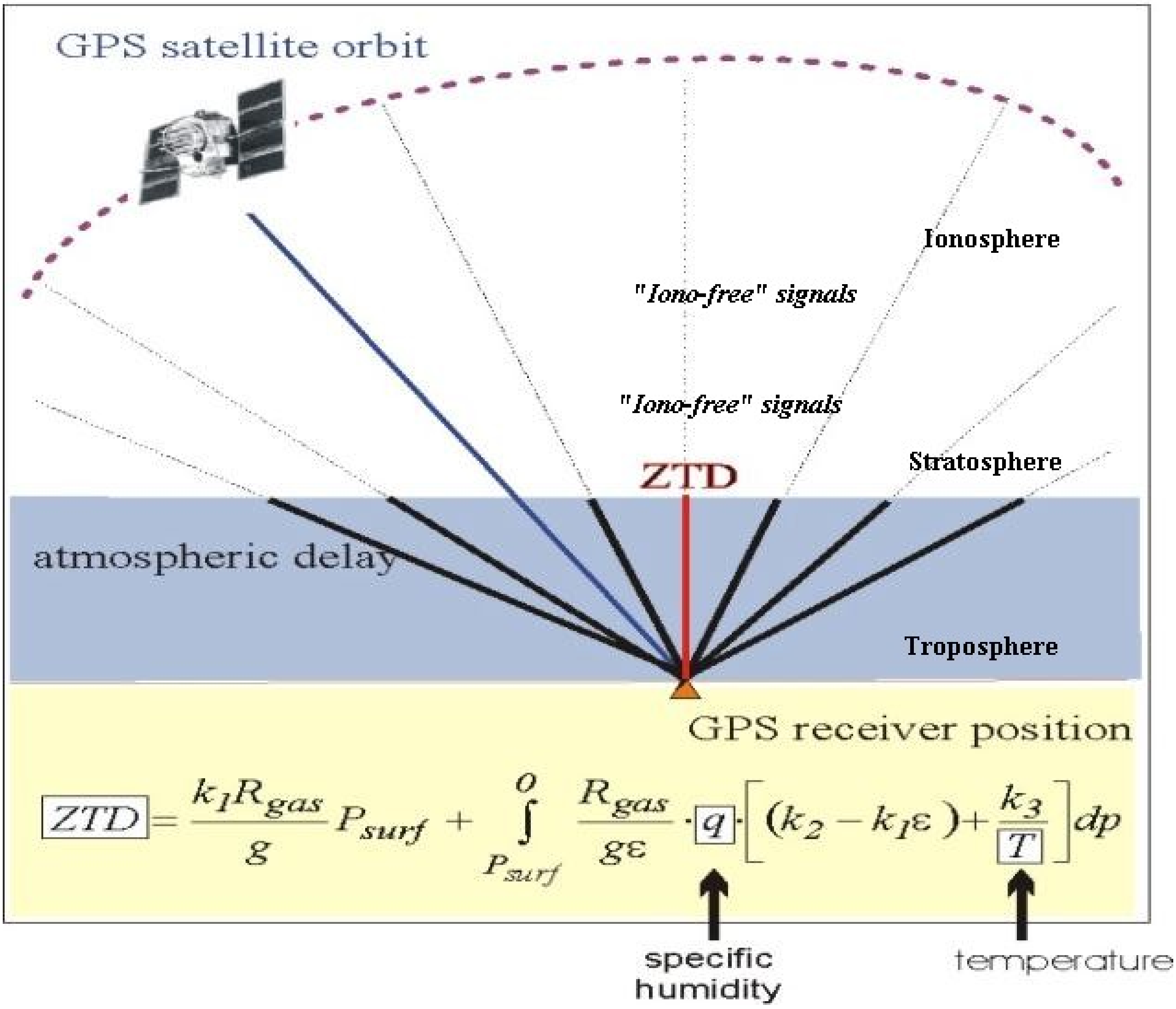

Fig. 2. ZTD schematic presentation for one GPS satellite and one GPS receiver

In practice, ZWD is fully attributed with the content of water vapor along the signal path, because other humidity contributions (i.e. water drops, precipitation) could be neglected. The ZHD has a typical magnitude of about 2.3 m at sea level. (expressed in terms of the equivalent excess pathlenght). The ZWD can vary from a few millimeters in very arid conditions to more than 350 mm in very humid conditions. In Table 1. some standard values of GPS path delay to be expected for different atmospheric processes and spatial scales are presented.

Table 1. Atmospheric temporal and spatial variability [Bock and Doerflinger, 2001]

ATMOSPHERIC PROCESS	SPATIAL SCALE	TEMPORAL SCALE	ATMOSPHERIC VARIABILITY	GPS PATH DELAY VARIABILITY (cm)
Seasonal variation	> 1000 km	1 year cycle	Standard atmosphere	ZHD: ± 3; ZWD: ± 5
Synoptic disturb.	~ 1000 km	Days	10 - 20 hPa;5 - 10°C	ZTD:1 - 5
Fronts	10 – 100 km	Hours	5°C/10 km; 1 cm PW/100 km	ZWD: 5 - 10
Rolls, thermals	1 – 10 km	Min – Hours	1 - 2°C; 20 – 30% Rel. Hum.	ZWD: 1 - 2
Turbulence	< 0.1 km	Sec – Min	2 - 3°C; 30 – 40% Rel. Hum.	ZWD: 2 - 3

The IAG Subcommision for the European Reference Frame (EUREF) , following its Resolution 1 adopted in Firenze meeting in 1990, recommends that the terrestrial reference system to be adopted by EUREF will be coincident with ITRS at the epoch 1989.0 and fixed to the stable part of the Eurasian Plate, named European Terrestrial Reference System 89 (ETRS89).

The EUREF reference frame, used in this work for the elaborated GPS data, is mainly realized using the GPS measurement technique. In the Figure 3. the map of EUREF Permanent GPS Network is presented, including also all 19 GPS sites selected for this Study.

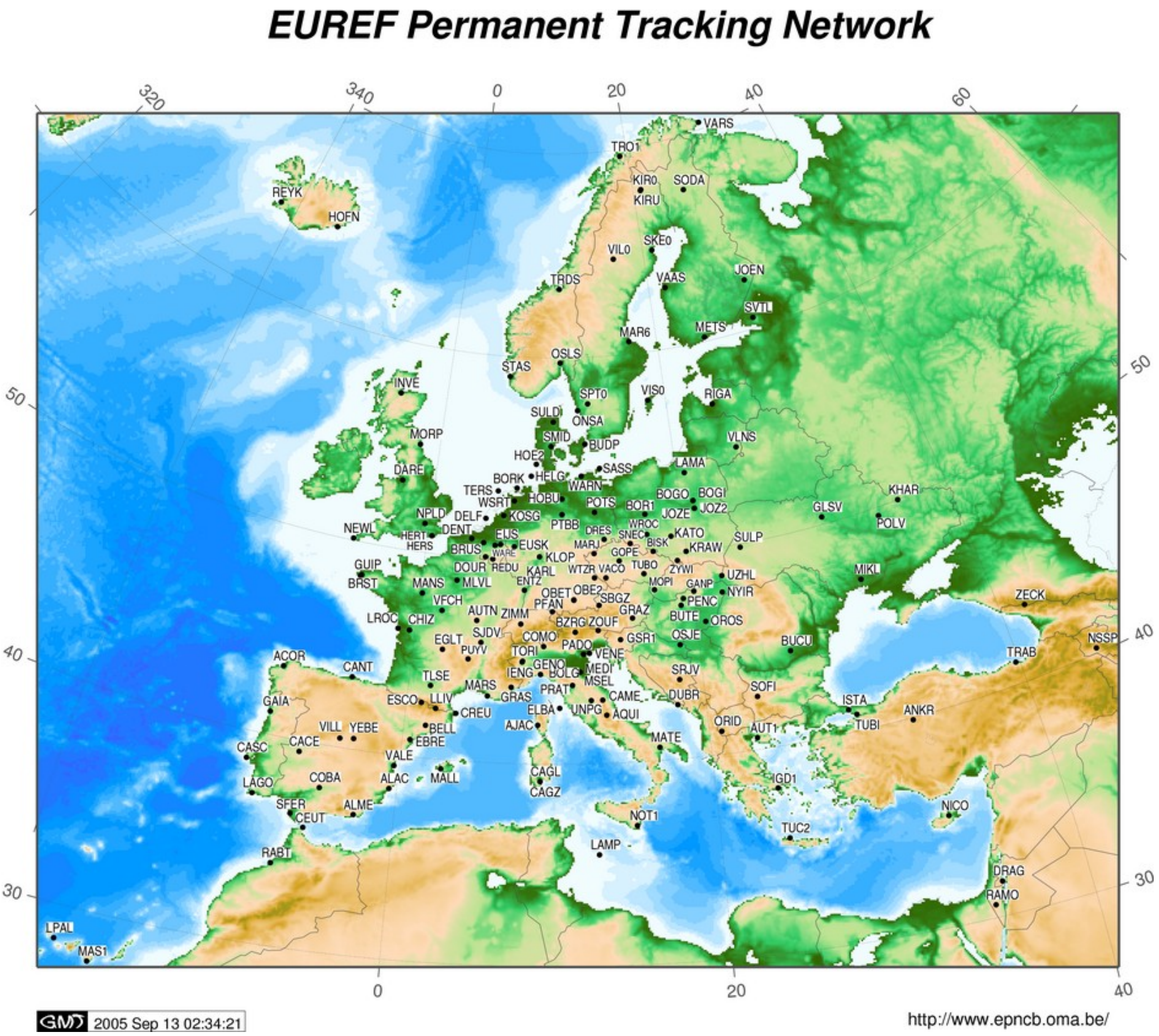

Fig. 3. EUREF Permanent GPS Network

The International Terrestrial Reference System (ITRS) is a world spatial reference System co-rotating with the Earth in its diurnal motion in space. The International Earth Rotation and Reference Systems Service (IERS) in charge of providing global references to the astronomical, geodetic and geophysical communities, promotes the realization of the ITRS. Realizations of the ITRS are produced by the IERS ITRS Product Center (ITRS-PC) under the name International Terrestrial Reference Frames (ITRF).

A first measurement campaign covering Western Europe was conducted in 1989 and since then other GPS campaigns were carried out ameliorating the results of previous campaigns and enlarging the territory covered to Eastern Europe. Taking into account the growing number of permanent GPS stations in Europe, the EUREF subcommission decided to take advantage of this situation for the maintenance of the European Reference Frame (Resolution No.2 of the EUREF Symposium in Helsinki).

The permanent tracking stations form the backbone of the EUREF network . This permanent network consists of more than 100 GPS tracking stations distributed over 30 European countries. The EUREF network consists of the following components:

- Tracking Stations (TS): They set up and operate the permanent GPS tracking receivers and antennae on suitable geodetic markers. More than 100 tracking stations belong to EUREF.
- Operational Centres (OC): They perform data validation, conversion of raw data to Receiver Independent Exchange Format (RINEX), data compression, and data upload to a data centre through the Internet.
- Local Data Centres (LDC): They receive the data of all stations of a local network and distribute them to the users (local and EUREF).
- Local Analysis Centres (LAC): They process a subnetwork of EUREF stations and deliver weekly free network solutions to the Combination Centre. The subnetworks have been designed in such a way that each station has minimally three analysis centres.
- A Combination Centre (CC): It combines the individual subnetwork solutions into one official EUREF solution including all tracking stations.
- A Central Bureau, which coordinates the activities of the tracking stations, data centres and analysis centres. It distributes standards and guidelines.

In this Study, for the CEDSEALAND MSG/GPS comparison, the GPS data are being taken from some of those EUREF Analysis Centers having elaborated GPS stations in the South-Eastern Europe and Mediterranean.

EUREF Analysis Centres

ASI, The Centro di Geodesia Spaziale "G. Colombo", Matera, Italy The Centro di Geodesia Spaziale processes a European subnetwork comprising IGS and EUREF stations in the South of Europe. Their solutions are incorporated in EUREF since September 1996.
BEK, The Bayerische Kommission für die Internationale Erdmessung of the Bavaria Academy of Science, Munich, *Germany*. The Bayerische Kommission für die Internationale Erdmessung of the Bavarian Academy of Science in Munich has been the Computing Center for the computation of the unified European Triangulation Network RETrig. It was also involved in the computation of the EUREF-89 GPS campaign. Since end of 1995, BEK has been producing weekly solutions of a EUREF subnetwork.
BKG, The Bundesamt für Kartographie und Geodäsie, Germany BKG has acquired the capacity to routinely process permanent IGS networks. Since early 1996 it has been processing part of the European Network on a weekly basis.

COE, The Centre for Orbit Determination in Europe, Astronomical Institute of the University of Bern, Switzerland.

CODE is processing almost the complete European Permanent Network in order to create a reference solution which is used as a comparison for the solutions of the other EUREF Local Analysis Centres. The Center for Orbit Determination in Europe is a joint operation of the four institutions :

- Astronomisches Institut (AIUB), Universität Bern, Switzerland
- Bundesamt für Landestopographie (L+T), Wabern, Switzerland
- Institut für Angewandte Geodäsie (IfAG), Frankfurt, Germany
- Institut Geographique National (IGN), Paris, France

DEO, Delft Institute for Earth-Oriented Space Research, Delft, The Netherlands

The Delft Institute for Earth-Oriented Space Research, a research group of Delft University of Technology, has started to process GPS networks on a regular basis since 1994. Currently, DEOS is processing several permanent and campaign networks in Europe and South-East Asia. A dedicated solution is incorporated in EUREF since February 2001.

GOP, The Geodetic Observatory Pecny, Pecny, *Czech Republic*

The Geodetic Observatory Pecny is processing permanent stations since February 1997.

IGE, The Instituto Geográfico Nacional de España, *Spain*

The Instituto Geográfico Nacional de España started its contribution to the EUREF combined solution since September 2001 (GPS Week 1130).

IGN, The Institut Géographique National, *France*

Since January 1998 the LAREG (Laboratoire de Recherche en Geodesie) processes a network of permanent French stations. It has started its contribution to the EUREF combined solution since November 1998 (GPS Week 982).

LPT, The Bundesamt für Landestopographie, Wabern, *Switzerland*

NKG, The Nordic Geodetic Commission GPS data Analysis Center, Chalmers University of Technology and Onsalo Space Observatory, Sweden

OLG, The Institute for Space Research (ISR/ASS), Graz, *Austria*

The ISR/AAS is the official data-center and one of the analysis centers of CERGOP/CEI. Since mid of January 1996 daily subnetwork solutions for all permanent Austrian GPS sites and some surrounding IGS and CEGRN site have been computed routinely. Since mid of May 1996 weekly results have been delivered for inclusion into a EUREF solution.

ROB, The Royal Observatory of Belgium, Brussels, *Belgium*

The Royal Observatory of Belgium is processing the 4 permanent sites operated in Belgium together with a number sites of the EUREF network since February 1996.

SGO, The FOMI Satellite Geodetic Observatory, Budapest, *Hungary*

The FOMI Satellite Geodetic Observatory is processing since December 2001 (GPSweek 1143) a network of stations distributed mainly in Eastern and Southern Europe.

SUT, The Slovak University of Technology, Bratislava, *Slovakia*

The Slovak University of Technology is processing since September 2002 a network of selected EUREF and IGS stations in Central Europe completed by EUREF stations situated mainly in western and northern Europe.

UPA, The University of Padova, Padova, *Italy*

The University of Padova is processing since January 1999 a network of Italian stations and additional stations distributed along the Alps.

WUT, The Warsaw University of Technology, Warsaw, *Poland*

The Institute of Geodesy and Geodetic Astronomy of the Warsaw University has been processing the Polish subnetwork of the IGS network together with IGS sites of surrounding countries since January 1996.

IV. THE GPS SITES AND MSG PRODUCTS USED IN THE COASTAL STUDY

IV.1. The GPS Stations List

For the Permanent Monitoring of atmospheric humidity over the Costal Zones in South-Eastern Europe the following GPS sites, belonging to the specific wider Mediterranean observing box shaped between the margins of
[**Latitude North** from **35,0** to **47,5** degrees / **Longitude East** from **07,5** to **40,0** degrees] are selected:

	GPS SITE NAME	*SITE ID*	*COUNTRY*
1.	Medicina	(**MEDI**)	Italy
2.	Matera	(**MATE**)	Italy
3.	Venezia	(**VENE**)	Italy
4.	Camerino	(**CAME**)	Italy
5.	Dubrovnik	(**DUBR**)	Croatia
6.	Sarajevo	(**SRVJ**)	Bosnia-Herzegovina
7.	Osijek	(**OSJE**)	Croatia
8.	Ohrid	(**ORID**)	Macedonia
9.	Atene	(**IGD1**)	Greece
10.	Creta	(**TUC2**)	Greece
11.	Bucarest	(**BUCU**)	Romania
12.	Istambul	**(ISTA)**	Turkey
13.	Nicosia	**(NICO)**	Cyprus
14.	Caglari	**(CAGL)**	Italy
15.	Genova	**(GENO)**	Italy
16.	Lampedusa	**(LAMP)**	Italy
17.	Ankara	**(ANKR)**	Turkey
18.	Sofia	**(SOFI)**	Bulgaria
19.	Trabzon	**(TRAB)**	Turkey

For those 19 GPS sites (belonging to the 9 different countries), the tropospheric solutions of GPS data (Zenith Total Delays ZTD) are being downloaded via ftp, using data basis from those three EUREF/IGS analysis centers:

- ftp://igs.ifag.de
- ftp://igs.ensg.ign.fr
- ftp://igsb.jpl.nasa.gov

The study period regards the time interval from the GPS Time week n° 1256 until the GPS Time* week n° 1308.

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* [GPS time was born at the 1/5/1980 to 1/6/1980 midnight. January 6, 1980 is a Sunday. GPS Time counts in weeks and seconds of a week from this instant. The GPS weeks begin at the

Saturday/Sunday transition. The days of the GPS week are numbered, with Sunday being 0, Saturday is day 6. GPS week 0 began at the beginning of the GPS Time Scale].

IV.2. Meteorological Data for GPS humidity estimations

Atmospheric humidity and water vapor

If all the water vapor in the atmosphere were to condense and fall as rain, it would cover the Earth with a layer about 25 mm deep on average. This is called precipitable water (PW). Variations in atmospheric vapor occur on time-scales from milliseconds to decades. On longer time scales, water vapor changes are thought to contribute to an important positive feedback mechanism for climate change. Warming of the surface, particularly the sea surface, leads to enhanced evaporation. Due to fact that water vapor is a greenhouse gas, enhanced water vapor in the lower troposphere results in further warming, allowing a higher water vapor concentration, thereby creating a positive feedback (Seidel D.J., 2002).

The variability of upper-tropospheric water vapor with sea and coast surface temperature is not well documented yet, mainly because of the lack of long-term measurements. But, with global warming, an increase in the rate of evaporation must be matched by an increase in the rate of precipitation, likely in the costal zones. Thus, the acceleration of the global hydrological cycle seems to lead to an increase in the frequency of extreme precipitation events, and also an increase in the proportion of precipitation falling in the same extreme events (Trenberth, 1999).

In general, results from the recent global atmospheric water vapor elaboration show that in oceanic areas, roughly 75% - 85% of the total water vapor is in the lowest atmospheric level (between surface and 700 hPa), i. e. is the subject of intense weather processes. (Randel D.L. et all, 1996). Moreover, since the amount of water vapor the atmosphere can hold before saturation depends on the temperature and the Northern Hemisphere (Mediterranean basin) has a greater seasonal temperature change and the majority of the land surface (coastal) area, thus brings the greater variability in the atmospheric water vapor. The total atmospheric water vapor and temperature vary together, as constrained by the Clausius-Clapeyron relationship, implying that the climate system follows a constant relative humidity rather than a constant absolute humidity. This high correlation causes the fact that water vapor is the principal greenhouse gas.

Since the infrared satellite techniques only work in the absence of significant cloud cover and radiosonde measurements are made mainly over the land and are widely spaced, the continuous GPS data may serve to complete the more accurate estimation of vertically integrated water vapor in the atmosphere. Surface atmospheric pressure values are required for all GPS sites where the water vapor is to be determined.

Total zenith delay (ZTD) is estimated during the GPS signal processing, then can be separated into zenith hydrostatic delay (ZHD) and zenith wet delay (ZWD). ZHD is proportional to the surface pressure, i.e. 10 hPa (mb) corresponds to approximately 23 mm of delay. ZWD is proportional to the total water vapor, i.e. 10 mm PW corresponds to approximately 65 mm of ZWD (Quinn K.J. and Herring.T.A ,1996).

Climatological data reanalysis used in this work

Meteorological data on the surface level air pressure for the determination of the hydrostatic GPS signal delay (ZHD) are obtained from the climatological reanalysis via ftp from the site:

- ftp://www.cdc.noaa.gov/cdc/data.ncep.html

of NCEP (National Centers for the Environmental Prediction) Daily Global Analyses NOAA-CIRES Climate Diagnostics Center from Boulder, University of Colorado, which produces global meteorological data analysis. NCEP prepares a twice-daily global analysis at 2.5 degrees resolution on pressure levels as a product of their operational forecast system. The original data set as stored at the National Center for Atmospheric Research (NCAR) starts in July 1976 and is being updated continuously at NCAR. Spatial NCEP/NCAR coverage:

- 2.5-degree latitude x 2.5-degree longitude global grid with 144x73 points
- 90N-90S, 0E-357.5E

As part of a research project supported by the National Science Foundation, the NCEP data has been processed by NCAR into a convenient format for climatological studies. The quality control and error-checking are done at this time. CDC has processed the twice-daily data by linearly interpolating to fill in missing values and then creating a daily average from the twice daily data.

The data set provided is the (00Z + 12Z)/2. (i.e., analyzed) data. In the analysis process, the observations are interpolated to a grid. Because large parts of the world (and many levels) have no observations and the data are not taken at one time (data is included if it is within 6 hours of the forecast time), a model forecast is used to help with the interpolation. Therefore, technically speaking, the data provided is an analyzed data set, which is a blend of observational and model data. These analyses are then initialized.

Precipitable Water (PW) from GPS

Zenith Total Delay may be calculated using a tropospheric delay model. For that purpose exist several models (Hopfield, Goad and Goodman, Black, Robinson, etc.) but the most applied is the well-known Saastamoinen model (Saastamoinen, 1972):

$$ZTD_{Saas} = ZHD_{Saas} + ZNHD_{Saas} = 0.002277\,p_s + 0.002277\left(0.005 + \frac{1255}{T_s}\right)e_s$$

Where, again, ZHD (m) is the Zenith Hydrostatic Delay, ZNHD (m) is the Zenith Non Hydrostatic Delay (or Zenith Wet Delay - ZWD), ps is the surface air pressure (hPa), Ts (K) is the surface temperature, es (hPa) is the surface water vapor pressure.

Once determined the Zenith Wet Delay in any segment of the time at a given GPS receiver, it gives the possibility to transform this values into a very good estimate of the Precipitable Water (PW). Precipitable Water (denoted with PWGPS) (mm) estimate from GPS data is based on ZWD which is nearly linearly proportional to PW (mm). According to (Bevis et al., 1994):

$$PW_{GPS} = ZWD_{GPS} \cdot \Pi\ (T_m)$$

where Π(Tm) is a constant depending by the mean atmospheric temperature Tm. The value of 0.15, usually accepted, was taken. ZWD is obtained by subtracting ZHD from the ZTD.

The same general procedure has been applied in this work. Using a convenient standardized interpolation scheme for the NCEP greed surface level air pressure data to the GPS station coordinates the ZHD calculations had been done, corrected for all GPS locations.

The principal characteristics and ITRF coordinates for 19 GPS sites used in this work are the following:

GPS SITES BASIC FACTS AND CHARACTERISTICS

MEDICINA	Site Name: *Medicina (Bologna)* Four Character ID : MEDI City or Town : Medicina State or Province: Emilia-Romagna Country : Italy Tectonic Plate : Adriatic-African Plate	*Approximate Position (ITRF)* X coordinate (m): 4461400.894 Y coordinate (m): 919593.443 Z coordinate (m): 4449504.669 Latitude (N is +): +443111.64 Longitude (E is +): +0113848.48 Elevation (m,ellips.): 00050.0 H (geoid) = 005,0 m

MATERA	Site Name: *Matera* Four Character ID : MATE City or Town : Matera State or Province :Basilicata Country : Italy Tectonic Plate : Adriatic-African Plate	*Approximate Position (ITRF)* X coordinate (m) : 4641949.709 Y coordinate (m) : 1393045.298 Z coordinate (m) : 4133287.333 Latitude (N is +) : +403856.76 Longitude (E is +) : +0164216.20 Elevation (m,ellips.): 00535.6 H (geoid) = 489,9 m

VENEZIA	Site Name: *Venezia* Four Character ID : VENE City or Town : Venezia State or Province : VENETO Country : Italy Tectonic Plate : Adriatic-African Plate	*Approximate Position (ITRF)* X coordinate (m) : 4379724.870 Y coordinate (m) : 957495.752 Z coordinate (m) : 4521605.119 Latitude (N is +) : +452612.84 Longitude (E is +) : +0121954.84 Elevation (m,ellips.): 00067.14 H (geoid) = 024,6 m

CAMERINO	Site Name: *Camerino* Four Character ID : CAME City or Town : Camerino State or Province : Marche Country : Italy Tectonic Plate : Adriatic-African Plate	*Approximate Position (ITRF)* X coordinate (m) : 4542008.4197 Y coordinate (m) : 1058963.6849 Z coordinate (m) : 4336934.0211 Latitude (N is +) : +430712.00 Longitude (E is +) : +0130744.04 Elevation (m,ellips.): 00506.9 H (geoid) = 459,4 m

DUBROVNIK	Site Name: *Dubrovnik* Four Character ID : DUBR City or Town : Dubrovnik State or Province : Dalmatia Country : Croatia Tectonic Plate : Eurasian	*Approximate Position (ITRF)* X coordinate (m) : 4465940.10 Y coordinate (m) : 1460594.41 Z coordinate (m) : 4299291.36 Latitude (N is +) : +423860.00 Longitude (E is +) : +0180637.44 Elevation (m,ellips.): 00454.3 H (geoid) = 415,4 m

SARAJEVO	Site Name*: Sarajevo/ University* Four Character ID : SRJV City or Town : Sarajevo State or Province : Capital Country : Bosnia-Herzegovina Tectonic Plate : Eurasian	*Approximate Position (ITRF)* X coordinate (m) : 4370269 Y coordinate (m) : 1454981 Z coordinate (m) : 4397960 Latitude (N is +) : +435204.44 Longitude (E is +) : +0182450.04 Elevation (m,ellips.): 00645.0 H (geoid) = 602,5 m

OSIJEK	Site Name: *Osijek* Four Character ID : OSJE City or Town : Osijek State or Province : Slavonia Country : Croatia Tectonic Plate : Eurasian	*Approximate Position (ITRF)* X coordinate (m) : 4237753.39 Y coordinate (m) : 1432791.64 Z coordinate (m) : 4531310.10 Latitude (N is +) : +453338.88 Longitude (E is +) : +0184049.80 Elevation (m,ellips.) : 00153.8 H (geoid) = 108,2 m

OHRID	Site Name: *Ohrid / Macedonia* Four Character ID : ORID City or Town : Ohrid State or Province : Lake Ohrid Country : Macedonia Tectonic Plate : Eurasian	*Approximate Position (ITRF)* X coordinate (m) : 4498451.81 Y coordinate (m) : 1708266.83 Z coordinate (m) : 4173591.78 Latitude (N is +) : +410738.30 Longitude (E is +) : +0204738.60 Elevation (m,ellips.) : 00773.0 H (geoid) = 733,3 m

ATENE	Site Name: *Athens* Four Character ID : IGD1 City or Town : Athens State or Province : Capital Country : Greece Tectonic Plate : Eurasian	*Approximate Position (ITRF)* X coordinate (m) : 4604626.372 Y coordinate (m) : 2030196.469 Z coordinate (m) : 3905963.006 Latitude (N is +) : +380015.37 Longitude (E is +) : +0234734.28 Elevation (m,ellips.): 00236.3 H (geoid) = 201,6 m

CRETA	Site Name: *Technical University of Crete* Four Character ID : TUC2 City or Town : Chania State or Province : Crete Country : Greece Tectonic Plate : Eurasian	*Approximate Position (ITRF)* X coordinate (m) : 4744543.851 Y coordinate (m) : 2119411.870 Z coordinate (m) : 3686258.942 Latitude (N is +) : +353159.48 Longitude (E is +) : +0240414.01 Elevation (m,ellips.): 00161.0 H (geoid) = 143,9 m

BUCAREST	Site Name: *Bucuresti / Romania* Four Character ID : BUCU City or Town : Bucuresti State or Province : Capital Country : Romania Tectonic Plate : Eurasian	*Approximate Position (ITRF)* X coordinate (m) : 4093760.994 Y coordinate (m) : 2007793.667 Z coordinate (m) : 4445129.862 Latitude (N is +) : +442750.20 Longitude (E is +) : +0260732.66 Elevation (m,ellips.): 00143.2 H (geoid) = 105,3 m

ISTAMBUL	Site Name: *Istambul* Four Character ID : ISTA City or Town Istambul State or Province : Country : Turkey Tectonic Plate : Eurasian	*Approximate Position (ITRF)* X coordinate (m) : 4208830.46 Y coordinate (m) : 2334850.14 Z coordinate (m) : 4171267.18 Latitude (N is +) : +410615.84 Longitude (E is +) : +0290109.48 Elevation (m,ellips.): 00147.2 H (geoid) = 111,8 m

NICOSIA	Site Name: *Nicosia -Athalassa* Four Character ID : NICO City or Town : Nicosia State or Province : Country : Cyprus Tectonic Plate: African plate near subduction	*Approximate Position (ITRF)* X coordinate (m) : 4359417.88 Y coordinate (m) : 2874117.01 Z coordinate (m) : 3650778.27 Latitude (N is +) : +350827.24 Longitude (E is +) : +0332347.04 Elevation (m,ellips.): 00155.0 H (geoid) = 128,8 m

CAGLARI	Site Name: *Cagliari - Astronomic Station* Four Character ID : CAGL City or Town : Cagliari State or Province : Sardegna Country : Italy Tectonic Plate : Eurasian Plate	*Approximate Position (ITRF)* X coordinate (m) : 4893378.944 Y coordinate (m) : 772649.645 Z coordinate (m) : 4004182.051 Latitude (N is +) : +390809.24 Longitude (E is +) : +0085822.08 Elevation (m,ellips.): 00238.4 H geoid) = 192,7 m

GENOVA	Site Name*: Genova - Istituto Idrografico della Marina* Four Character ID : GENO City or Town : Genova State or Province : Liguria Country : Italy Tectonic Plate : Eurasian Plate	*Approximate Position (ITRF)* X coordinate (m) : 4507890.2717 Y coordinate (m) : 707618.9744 Z coordinate (m) : 4441603.0081 Latitude (N is +) : +442509.84 Longitude (E is +) : +0085515.96 Elevation (m,ellips.): 00137.0 H (geoid) = 087,3 m

LAMPEDUSA	Site Name: *Lampedusa - Capitaneria di Porto* Four Character ID : LAMP City or Town : Lampedusa State or Province : Sicily Country : Italy Tectonic Plate : African Plate	*Approximate Position (ITRF)* X coordinate (m) : 5073182.337 Y coordinate (m) : 1134516.388 Z coordinate (m) : 3683155.965 Latitude (N is +) : +352958.92 Longitude (E is +) : +0123619.80 Elevation (m,ellips.): 00057.8 H (geoid) = 020,9 m

ANKARA	Site Name*:Ankara / Turkey* Four Character ID : ANKR City or Town : Ankara State or Province : Capital Country : Turkey Tectonic Plate : Eurasian (Anatolian)	*Approximate Position (ITRF)* X coordinate (m) : 4121934.260 Y coordinate (m) : 2652189.812 Z coordinate (m) : 4069034.911 Latitude (N is +) : +395315.04 Longitude (E is +) : +0324530.88 Elevation (m,ellips.): 00974.8 H (geoid) = 937,7 m

SOFIA	Site Name*: Sofia / Bulgaria* Four Character ID : SOFI City or Town : Sofia State or Province : Capital Country : Bulgaria Tectonic Plate : Eurasian	*Approximate Position (ITRF)* X coordinate (m) : 4319372.39 Y coordinate (m) : 1868687.57 Z coordinate (m) : 4292063.80 Latitude (N is +) : +423321.96 Longitude (E is +) : +0232340.92 Elevation (m,ellips.): 01119.6 H (geoid) = 1074,7 m

TRABZON	Site Name: *Trabzon / Turkey* Four Character ID : TRAB City or Town : Trabzon State or Province : Country : Turkey Tectonic Plate : Eurasian - Anatolian	*Approximate Position (ITRF)* X coordinate (m) : 3705250.47 Y coordinate (m) : 3084421.65 Z coordinate (m) : 4162044.65 Latitude (N is +) : +405940.92 Longitude (E is +) : +0394632.16 Elevation (m,ellips.): 00099.2 H (geoid) = 069,0 m

IV.3. MSG Meteorological Products

Meteorological products are generated from the Meteosat image data set at regular intervals, and contain derived geophysical data. Meteorological Data produced by MSG are subject of the previous Data Preparation process, Radiative Transfer Modeling, Calibration Monitoring and Scenes Analysis to be finally calculated and disseminated as MSG Meteorological Products. With the exception of the IDS data, which are comprised of reduced resolution image data, all of these products are derived on a segment basis. Segments are rectangular sub-areas of 32 x 32 infrared pixels.

The two MSG meteorological products interesting for this Study:

- Tropospheric Humidity **(TH)** and
- High Resolution Precipitation Index **(HRPI** or **HPI)**

are presented in following Tables 2. and 3. (distinguished by the orange colored fields).

The function of the TH algorithm is to derive a relative humidity (in %) measure for each of the two water vapor channels. The WV6.2 channel will produce an upper tropospheric humidity which is the mean layer relative humidity between, nominally 300 hPa and 600 hPa. The WV7.3 channel will produce an upper tropospheric humidity which is the mean layer relative humidity between nominally 600 hPa and 850 hPa. Both measurements are done on a pixel basis.

Table 2. MSG - Meteosat 8 Meteorological Products

MPEF Product Name	Region*	GTS Frequency (UTC)	Archive Frequency
Athmospheric Motion Vectors (AMV)	N T S	Hourly, 00:45, 01:45,..,23:45	
Cloud Analysis (CLAP)	N T S		
Total Ozone (TOZ)	N T S		
Tropospheric Humidity (TH)	N T S		
Clear-Sky Radiances (CSR)	N T S		

Table 3. MSG Products for Distribution from the Archive

MPEF Product Name	MTP Format	MTP Archive Frequency	MSG Format	MSG Archive Frequency
ISCCP Data Set (B1, B2 and AC)	ISCCP Internal Format	Archive Produced*	ISCCP Internal Format	3 hourly, 02:45, 05:45, …, 23:45
High Resolution Precipitation Index (HRPI)	GPCP Internal Format	Daily 02:30	Native	Daily 23:45
Calibration Product (CALC)	NA	NA	Native	Every 15 minutes 00:00, 00:15…
Global Instability Index (GII)	NA	NA	Native	Every 15 minutes 00:00, 00:15…
Cloud Top Height (CTH)	NA	NA	Native	Hourly 00:45, 01:45
Cloud Mask (CLMK)	NA	NA	Native	Every 15 minutes 00:00, 00:15…
Cloud Analysis Image (CLAI)	NA	NA	Native	3 hourly, 02:45, 05:45, …, 23:45
Climate Data Set (CDS)	BUFR/OpenMTP	Half hourly	BUFR	Every 15 minutes 00:00, 00:15…

The HRPI algorithm is responsible for the generation of the precipitation index data set, interesting to understand better the distribution of water in the atmosphere, its transport and its diurnal and seasonal change play with the respect of the actual climate change studies. The HRPI is generated on the base of relationship between the channel TOA radiance equivalent black body temperature (EBBT) of clouds and convective rainfall. The idea of this relationship is that clouds with cold tops in fact are the convective rain bearing clouds. The scheme is a cloud indexing method based on the pixel values of an IR channel.

MSG Data Volumes

The following Table 4. summarizes the typical size, production rate, and volume throughput of each meteorological data product that is archived. It should be noted, however, that the product sizes vary considerably from day to day.

Table 4. Meteosat 8 (MSG family of products)

MPEF Product Name	Unit Size (in Mb)	Products per Day	Daily Volume (in MB)
Clear-sky Radiances (CSKR)	4	24	96
Atmosphere Motion Vectors (AMV)	4.5	24	108
Climate Data Set (CLDS)	0.5	96	48
Cloud Analysis (CLAP)	1.5	24	36
Cloud Analysis (CLAI)	1.5	8	12
Cloud Mask (CLMK)	7	96	672
Cloud Top Height (CTH)	1	96	96
Global Instability Index (GII)	1	96	96
Total Ozone Product (TOZ)	1	24	24
High Resolution Precipitation Index HRPI	3.5	1	3.5
Upper Tropospheric Humidity (UTH)	0.5	24	12
ISCCP Data Set - B1 (IDSB1)	38	8	304
ISCCP Data Set - B2 (IDSB2)	3.5	8	28
Calibration Product (CALC)	1.5	96	144

Trough the official request procedure for getting all archived MSG data for the Study period (01.02.2004 – 31.01.2005) the data are downloaded from The Meteosat Archives.

The conversion procedure from original MSG archived formats (NATIVE and GPCP formats) into ordinary data files is done applying the different conversion techniques using "NetCDF Toolbox For Matlab" and Global Precipitation Climatology Project (GPCP) facilities, with the kind support of NCEP Daily Global Analyses and Meteosat Archive staff. This work is done with the technical support of the Geophysical Observatory of the University of Modena and Reggio Emilia.

Since the MSG data are distributed at the pixel level (2,5° x 2,5°) the interpolation to the ITRF coordinate positions (lat/lon values) for GPS sites had to be done. The interpolation was performed by one of the Matlab routines.

V. PRECIPITABLE WATER (PW) INDEXES BY GPS VS. PW INDEXES BY MSG TROPOSPHERIC HUMIDITY (TH)

The MSG Tropospheric Humidity (TH) product provides estimates of the relative humidity in the troposphere on a synoptic scale (i.e. 100 km or better). Due to the fact that MSG has two channels providing information about the water vapor content in the troposphere and one infrared (IR) channel highly affected by the low-layer humidity, the TH product is derived in the form of a mean layer tropospheric humidity, providing the mean layer humidity in two layers, a mid layer, and an upper layer. MSG channel WV6.2 is used to derive the mean layer humidity between 850 hPa and 600 hPa (mid-tropspheric humidity).

Each TH product is derived as a mean layer humidity in % with vertical layer information in terms of pressure (hPa), together with the position in degrees latitude/longitude and quality information. The product is checked and verified by comparing derived humilities with co-located radiosonde measurements situated in areas with no medium of high clouds. The TH values are extracted 24 times a day, and are frequently assimilated as an input for numerical prediction models and as a climatological product. The table 5. gives the general sensitivity of ZTD as a function of temperature, pressure and relative humidity (Hugentobler et al., 2001).

Table 5. ZTD dependence on variations of temperature, air pressure, and relative humidity for general classes of temperature (T), air pressure (P), and relative humidity (H)

T °C	P mbar	H %	$\left\| \frac{\partial \Delta \rho}{\partial T} \right\|$ mm/°C	$\left\| \frac{\partial \Delta \rho}{\partial P} \right\|$ mm/mbar	$\left\| \frac{\partial \Delta \rho}{\partial H} \right\|$ mm/1%
0°	1000	50	3	2	0.6
30°	1000	50	14	2	4
0°	1000	100	5	2	0.6
30°	1000	100	27	2	4

The following figures (from Fig. 4. to Fig. 22.) represent the simultaneous elaboration of tropospheric precipitable water obtained by GPS and by MSG (850-300 hPa) for the year 2004. In both graphs at the ordinate the daily mean PW (m) are presented versus DOY (Day of Year) from 32 (1st of February) to 366 (31st of December).

1.	Medicina	(MEDI)	Italy	Fig. 4.a. and Fig. 4. b.
2.	Matera	(MATE)	Italy	Fig. 5.a. and Fig. 5. b.
3.	Venezia	(VENE)	Italy	Fig. 6.a. and Fig. 6. b.
4.	Camerino	(CAME)	Italy	Fig. 7.a. and Fig. 7. b.
5.	Dubrovnik	(DUBR)	Croatia	Fig. 8.a. and Fig. 8. b.
6.	Sarajevo	(SRVJ)	Bosnia	Fig. 9.a. and Fig. 9. b.
7.	Osijek	(OSJE)	Croatia	Fig. 10.a. and Fig. 10. b.
8.	Ohrid	(ORID)	Macedonia	Fig. 11.a. and Fig. 11. b.
9.	Atene	(IGD1)	Greece	Fig. 12.a. and Fig. 12. b.
10.	Creta	(TUC2)	Greece	Fig. 13.a. and Fig. 13. b.
11.	Bucarest	(BUCU)	Romania	Fig. 14.a. and Fig. 14. b.
12.	Istambul	(ISTA)	Turkey	Fig. 15.a. and Fig. 15. b.
13.	Nicosia	(NICO)	Cyprus	Fig. 16.a. and Fig. 16. b.
14.	Caglari	(CAGL)	Italy	Fig. 17.a. and Fig. 17. b.
15.	Genova	(GENO)	Italy	Fig. 18.a. and Fig. 18. b.
16.	Lampedusa	(LAMP)	Italy	Fig. 19.a. and Fig. 19. b.
17.	Ankara	(ANKR)	Turkey	Fig. 20.a. and Fig. 20. b.
18.	Sofia	(SOFI)	Bulgaria	Fig. 21.a. and Fig. 21. b.
19.	Trabzon	(TRAB)	Turkey	Fig. 22.a. and Fig. 22. b.

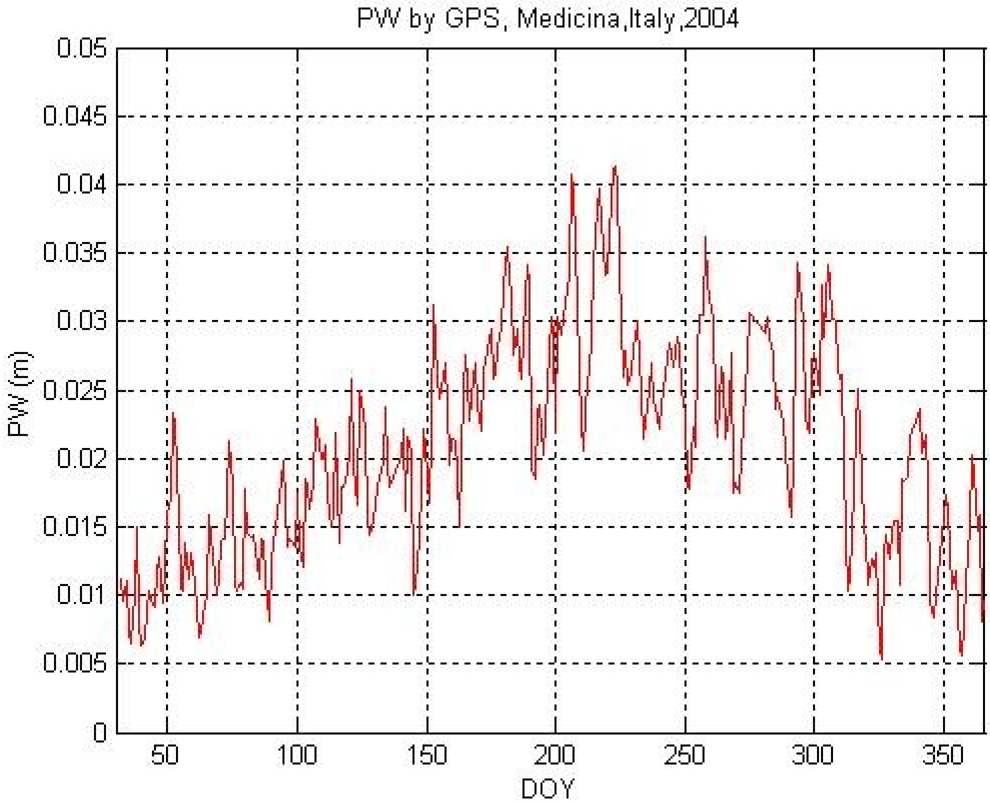

Fig. 4.a. Precipitable water by GPS for Medicina, Italy

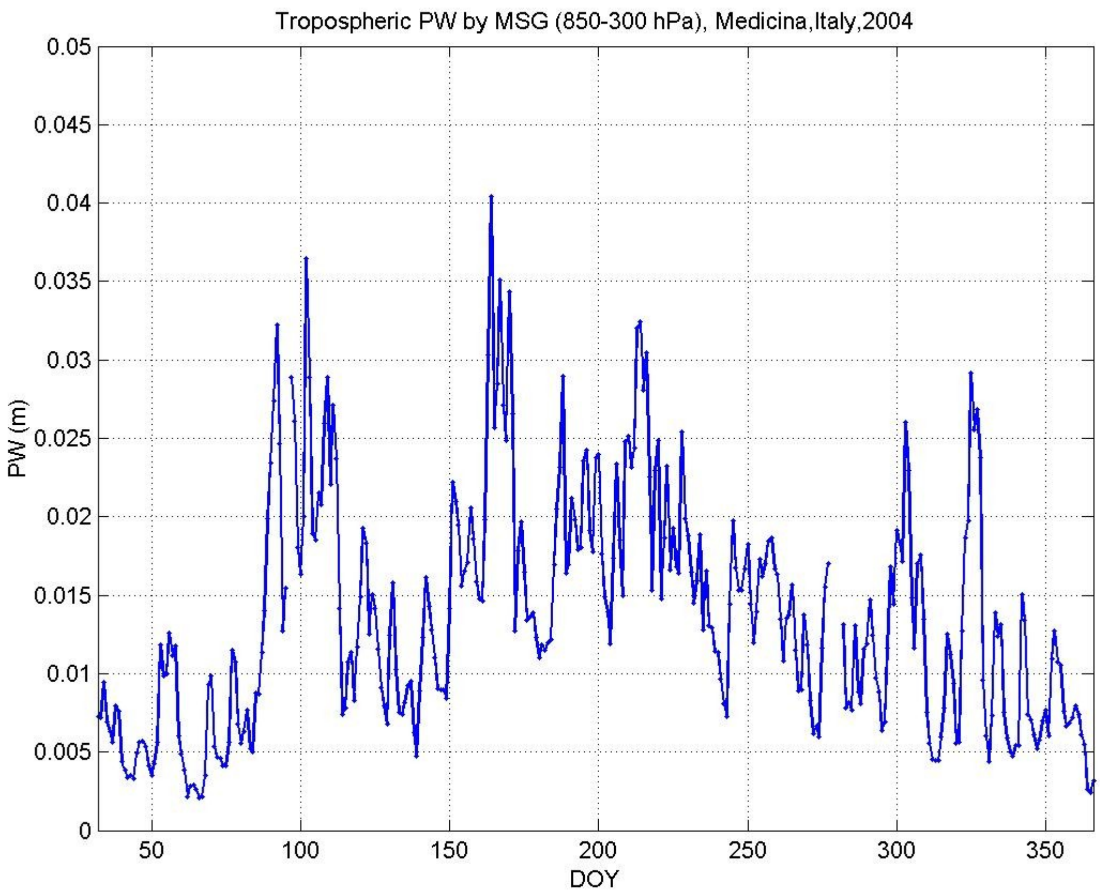

Fig. 4.b. Precipitable water by MSG for Medicina, Italy

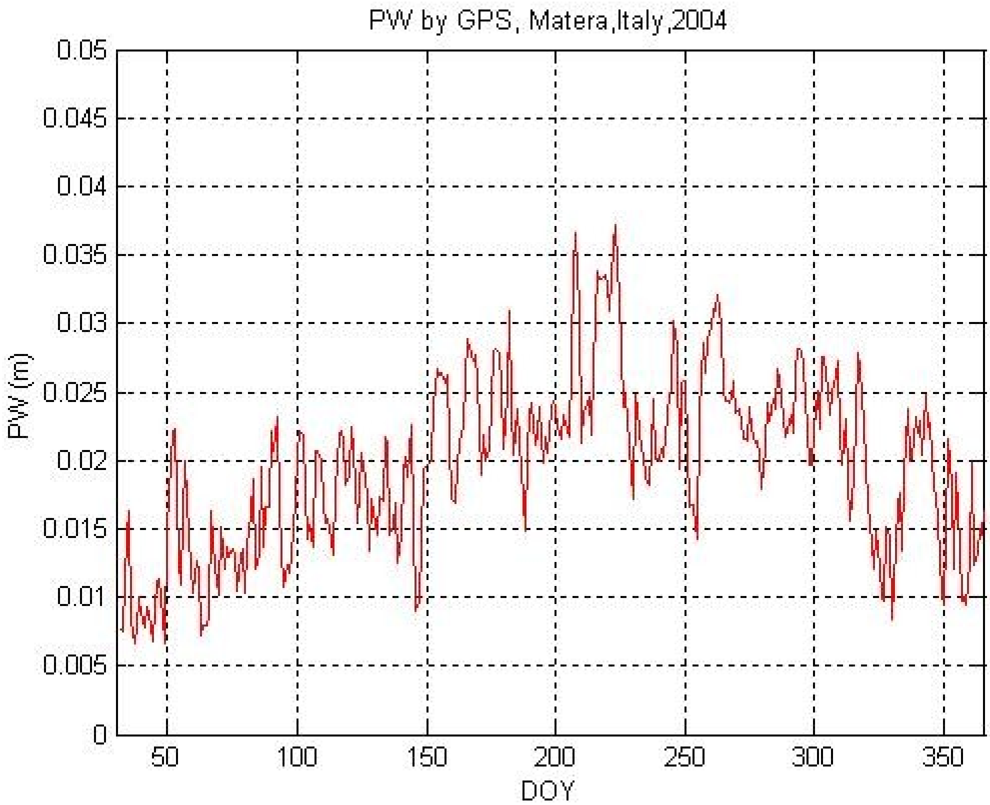

Fig. 5.a. Precipitable water by GPS for Matera, Italy

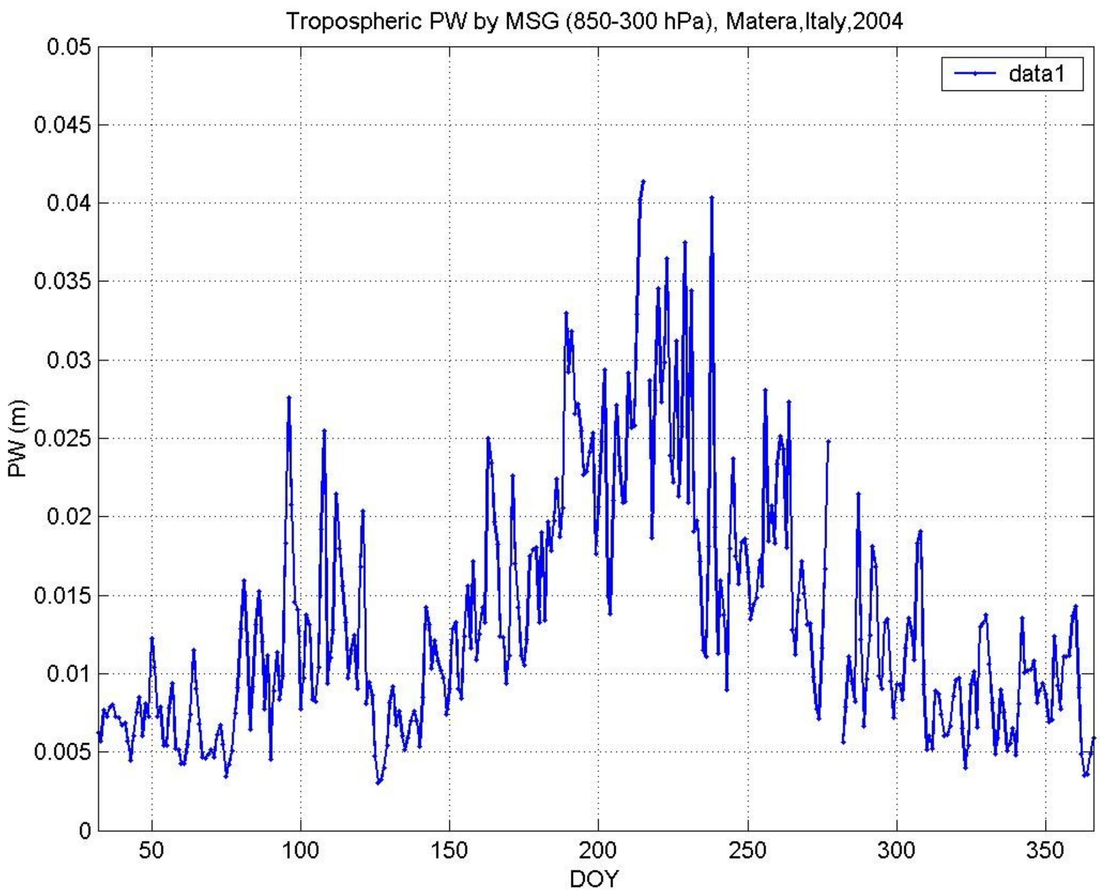

Fig. 5.b. Precipitable water by MSG for Matera, Italy

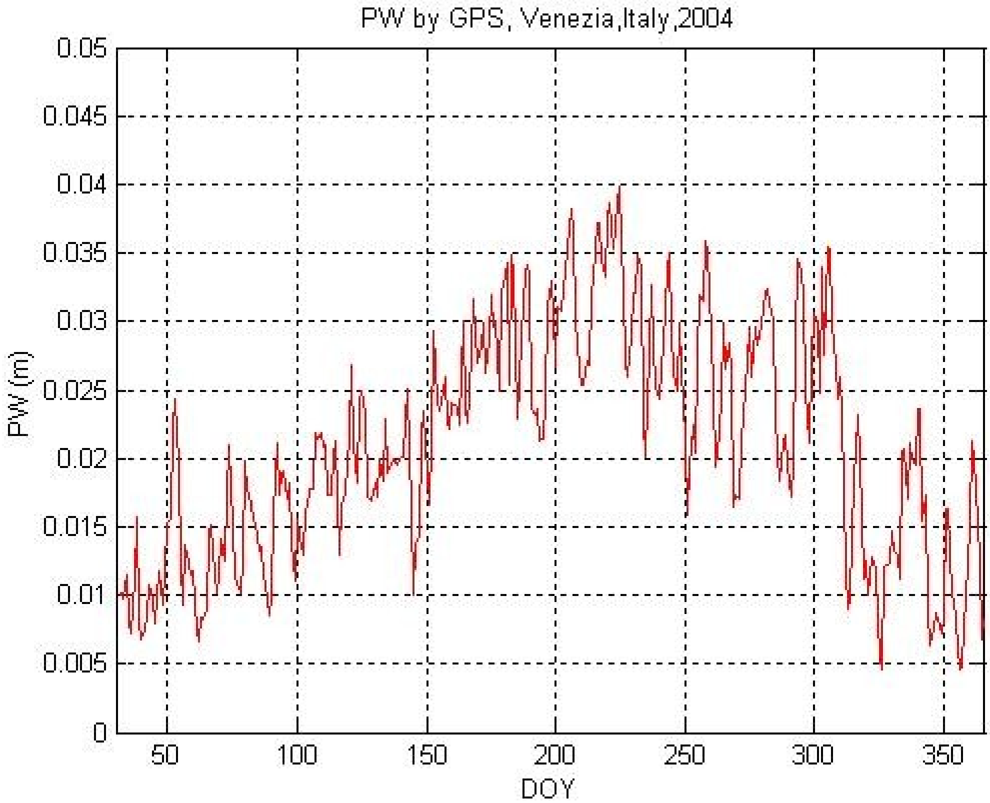

Fig. 6.a. Precipitable water by GPS for Venezia, Italy

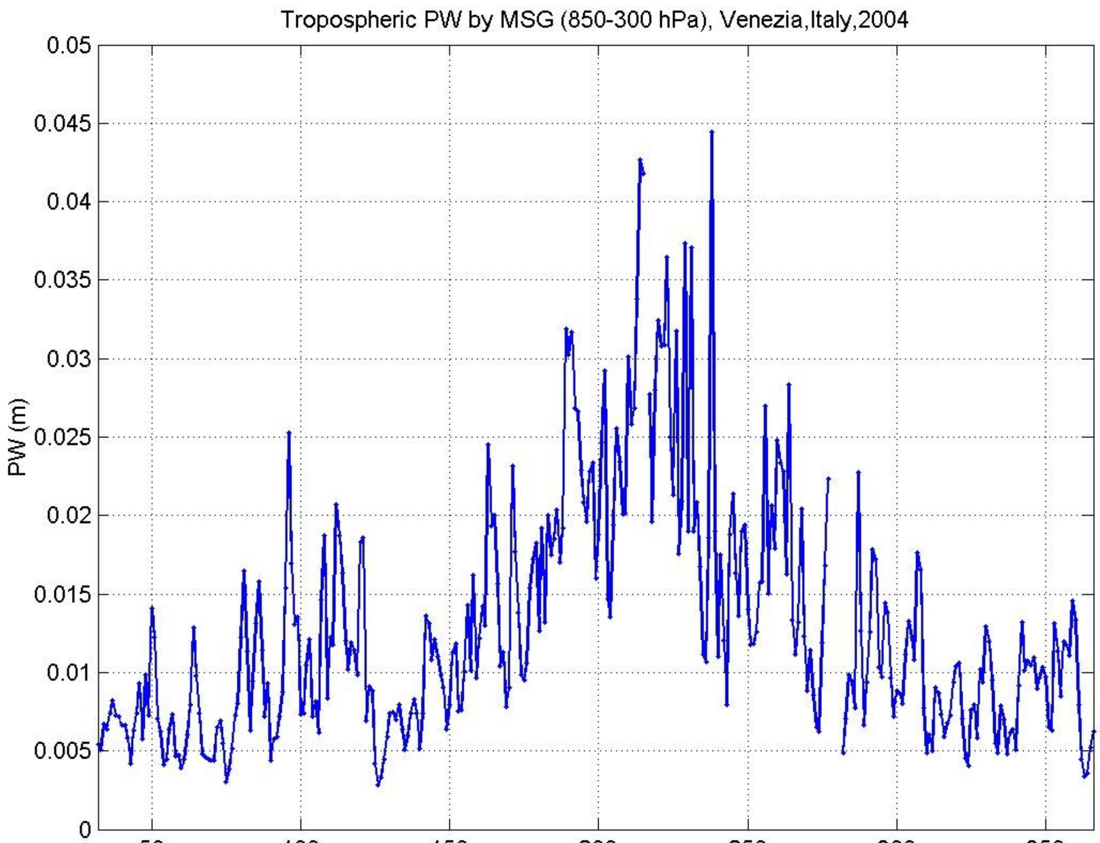

Fig. 6.b. Precipitable water by MSG for Venezia, Italy

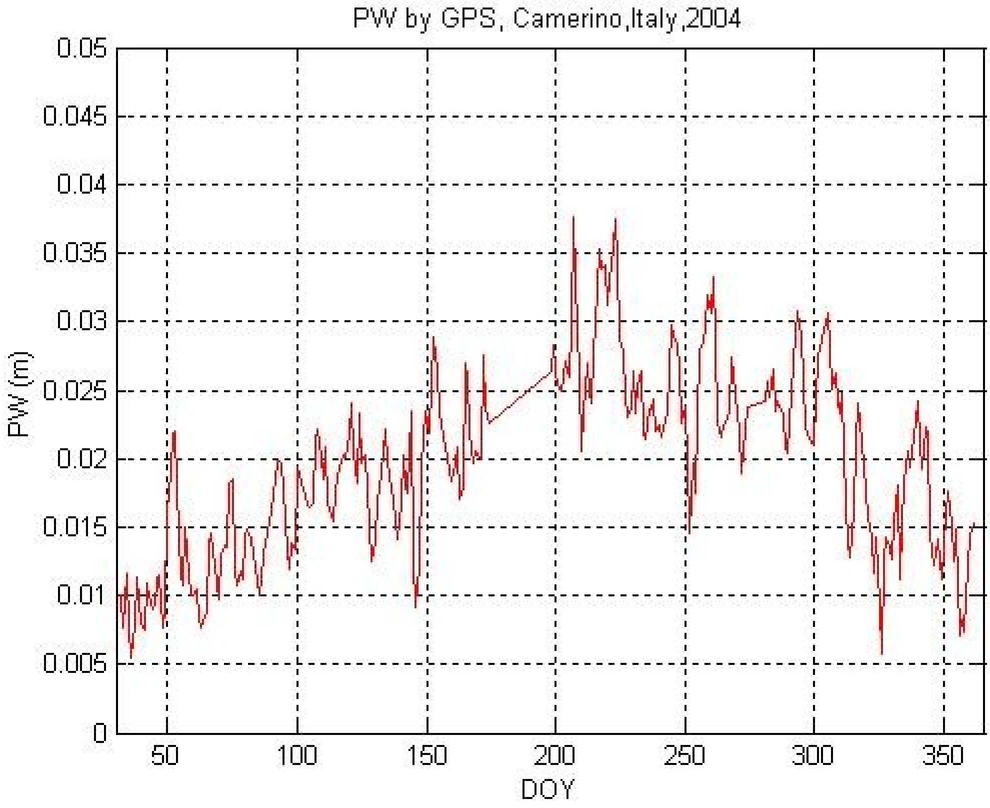

Fig. 7.a. Precipitable water by GPS for Camerino, Italy

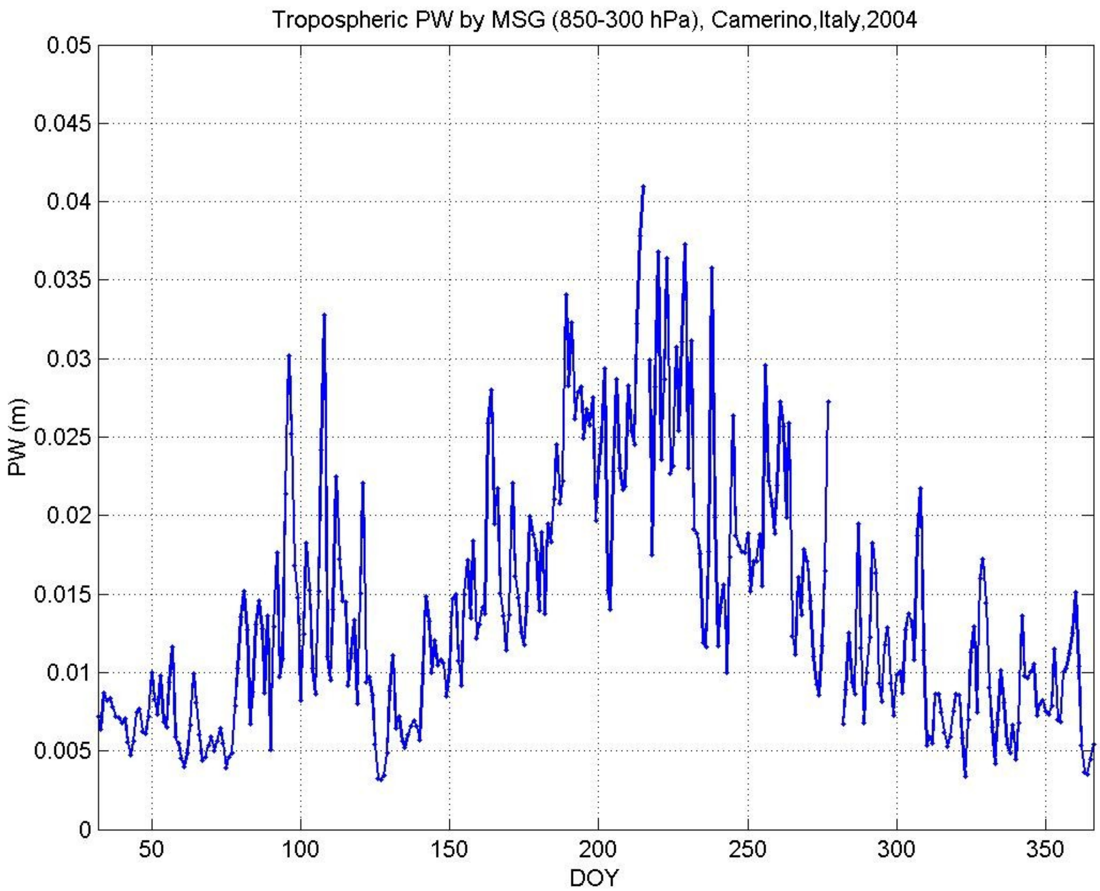

Fig. 7.b. Precipitable water by MSG for Camerino, Italy

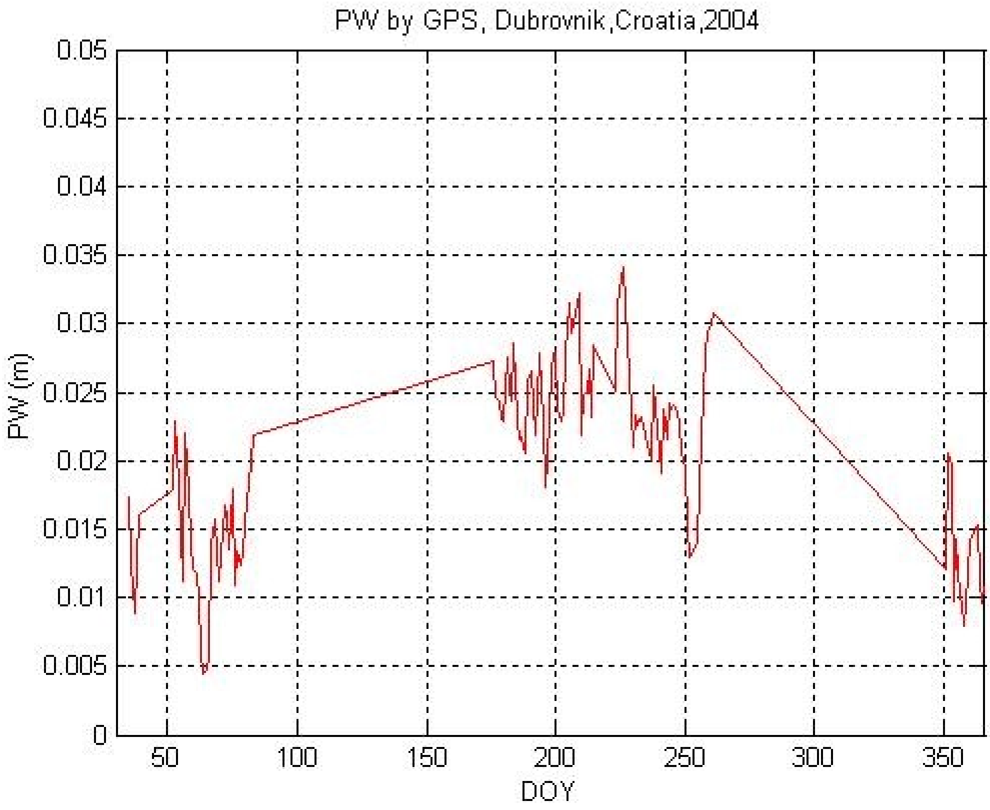

Fig. 8.a. Precipitable water by GPS for Dubrovnik, Croatia

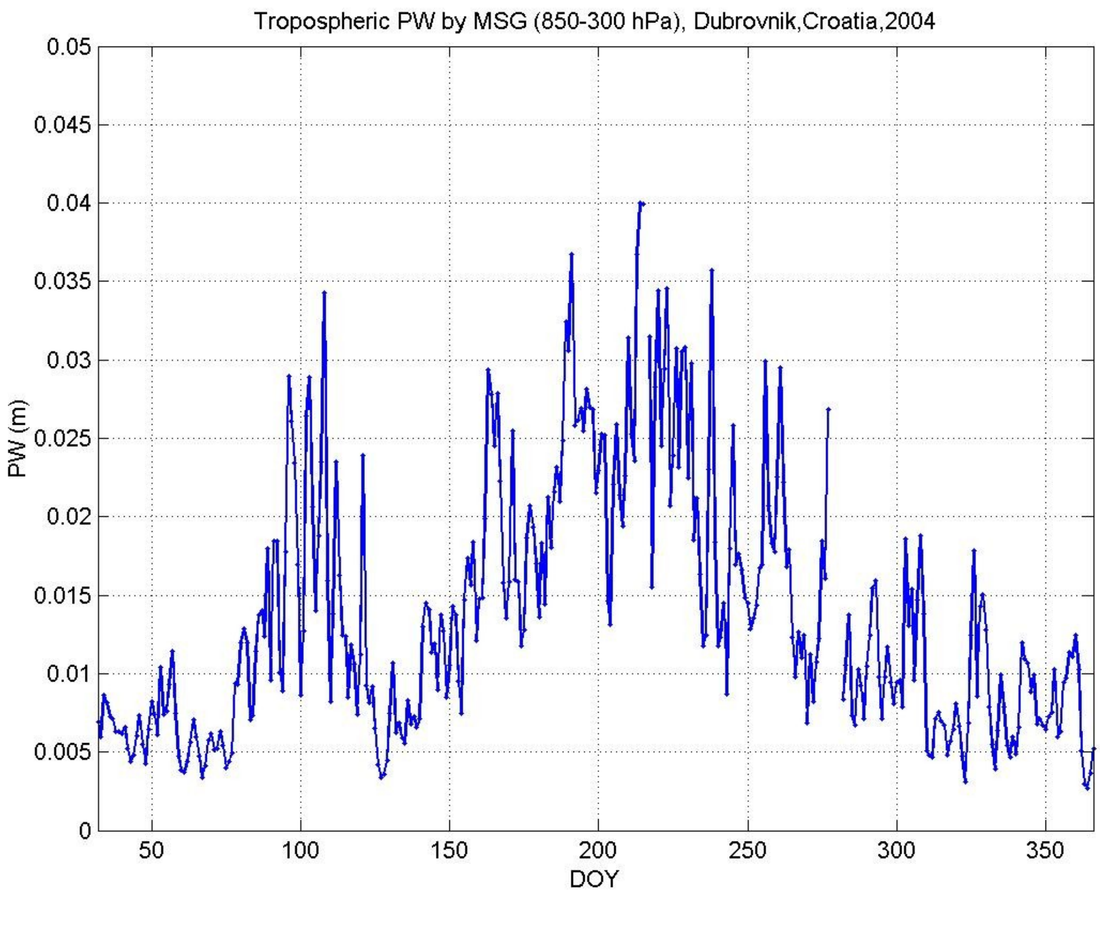

Fig. 8.b. Precipitable water by MSG for Dubrovnik, Croatia

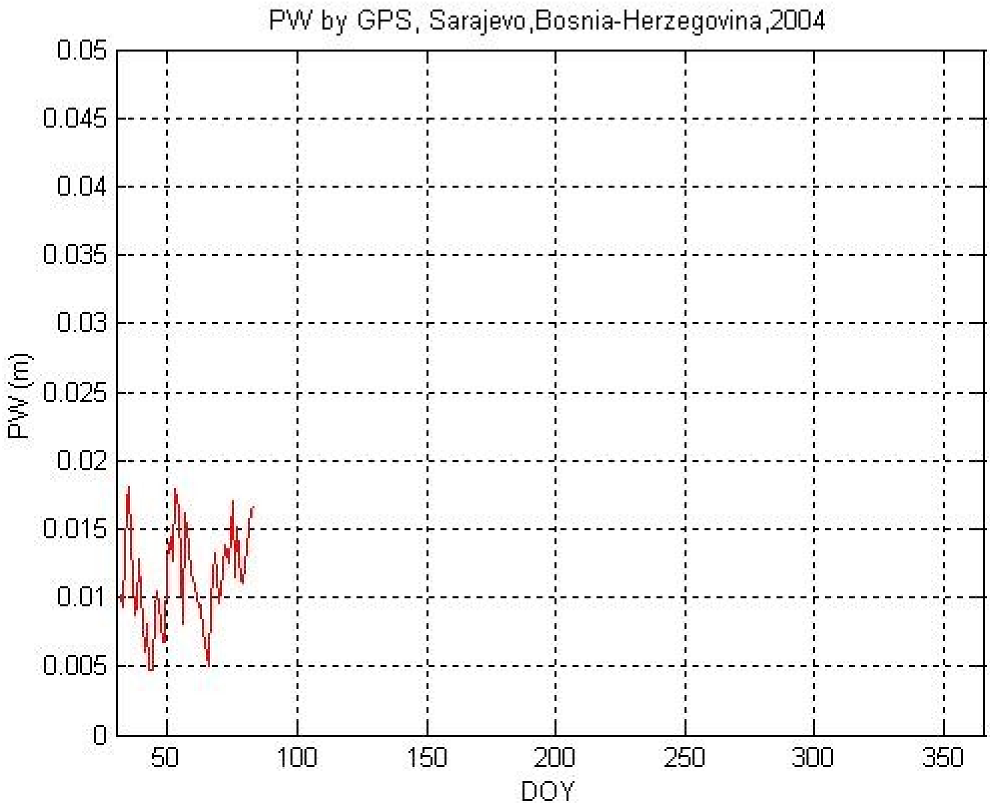

Fig. 9.a. Precipitable water by GPS for Sarajevo, Bosnia-Herzegovina

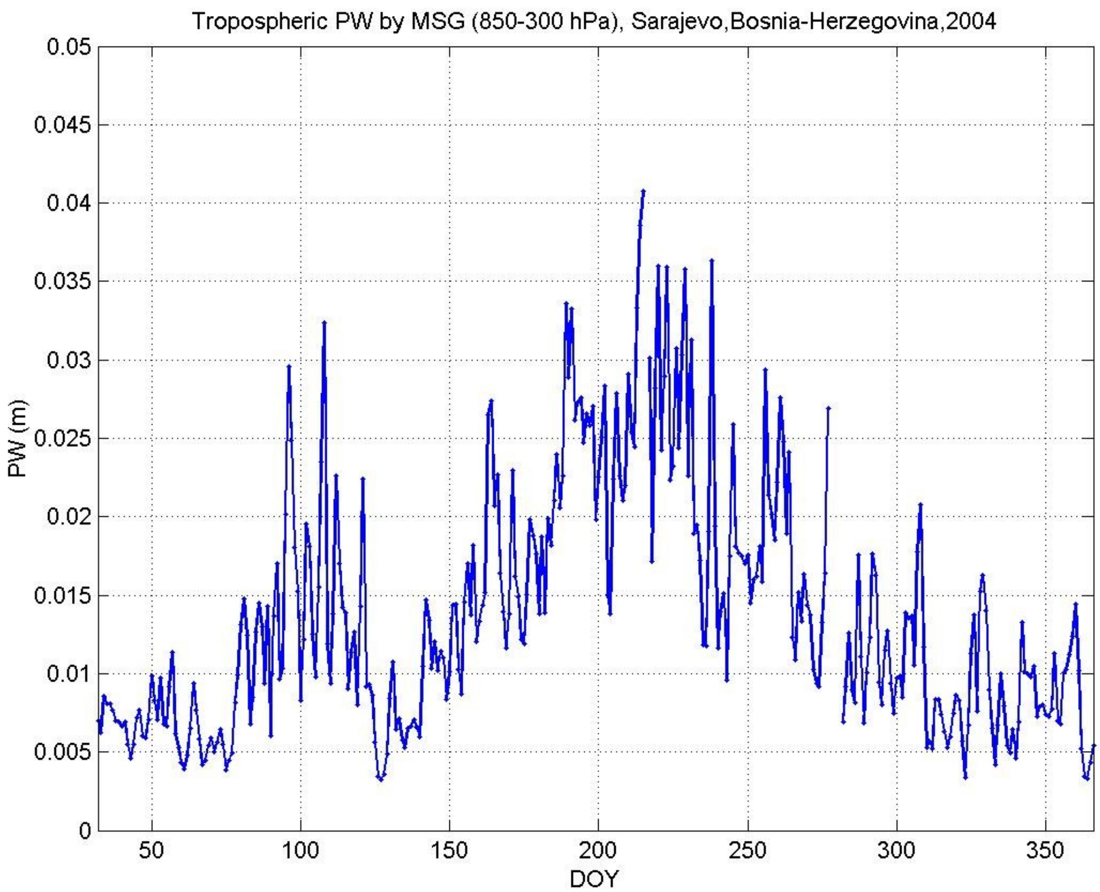

Fig. 9.b. Precipitable water by MSG for Sarajevo, Bosnia-Herzegovina

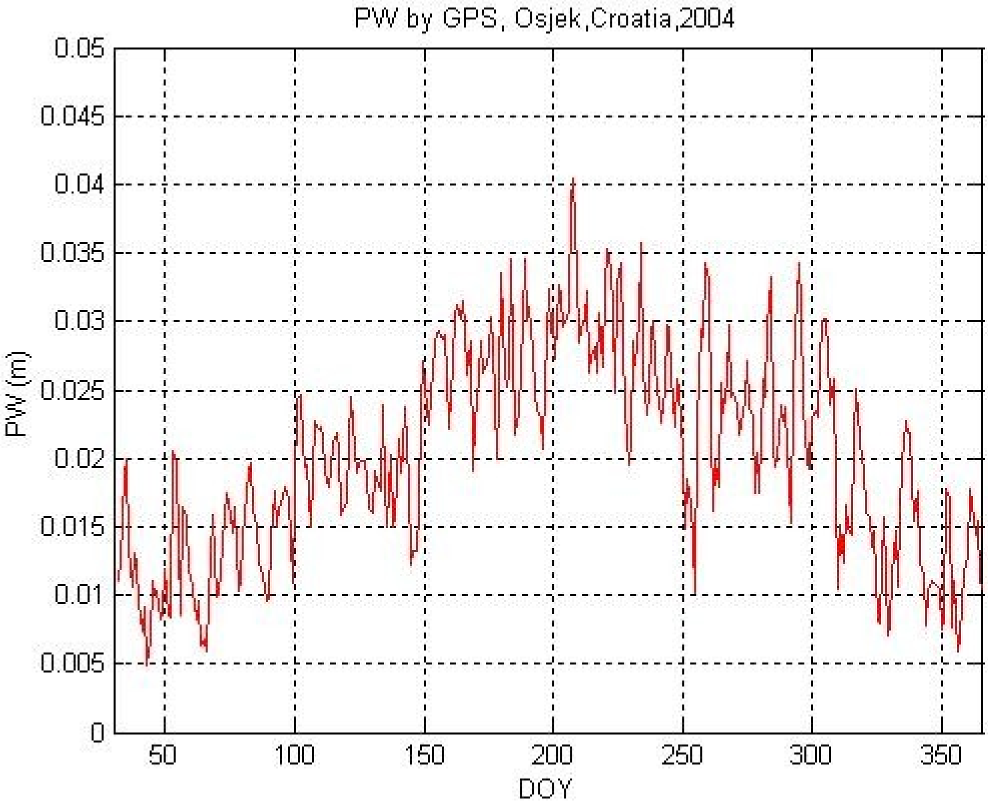

Fig. 10.a. Precipitable water by GPS for Osjek, Croatia

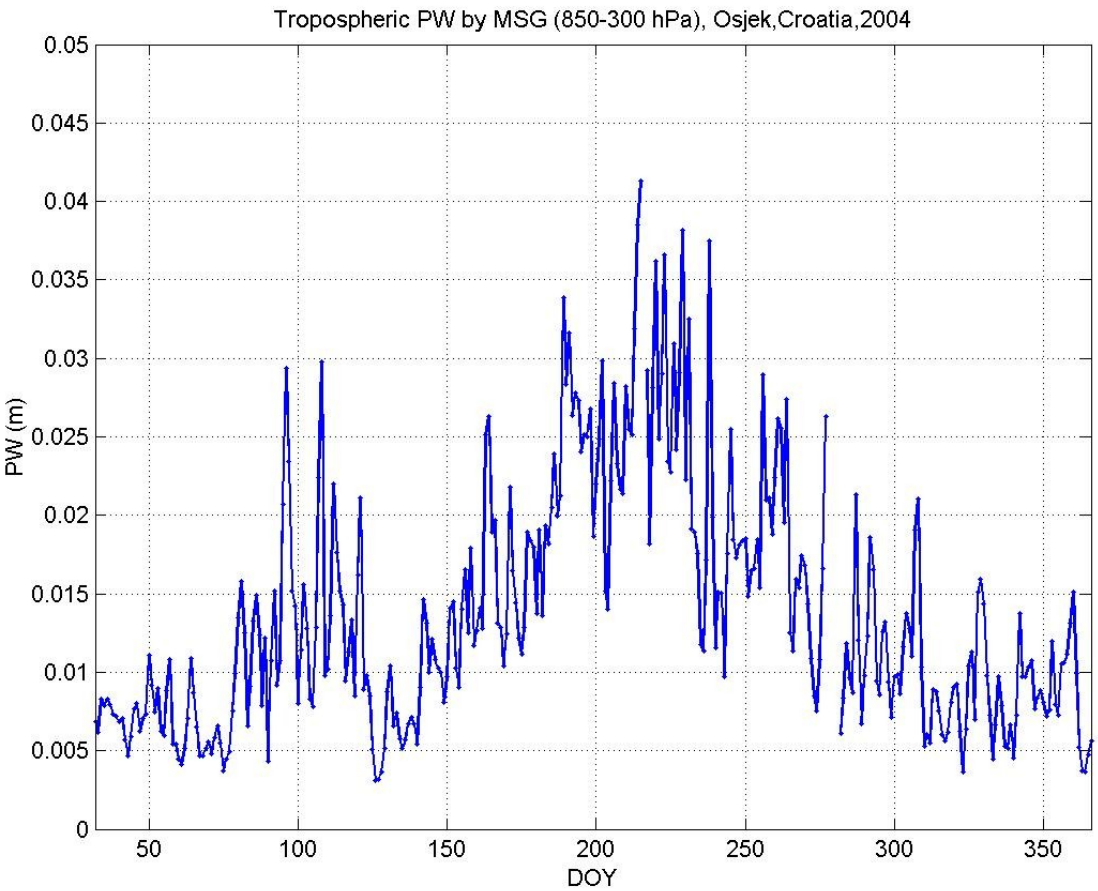

Fig. 10.b. Precipitable water by MSG for Osjek, Croatia

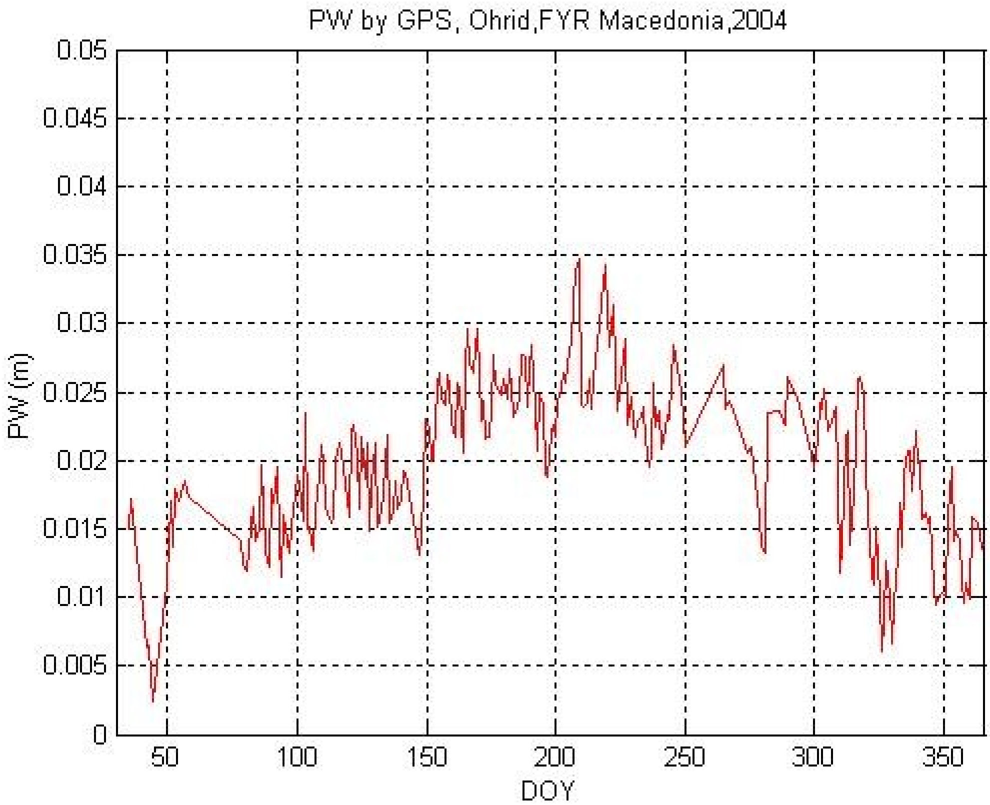

Fig. 11.a. Precipitable water by GPS for Ohrid, FYR Macedonia

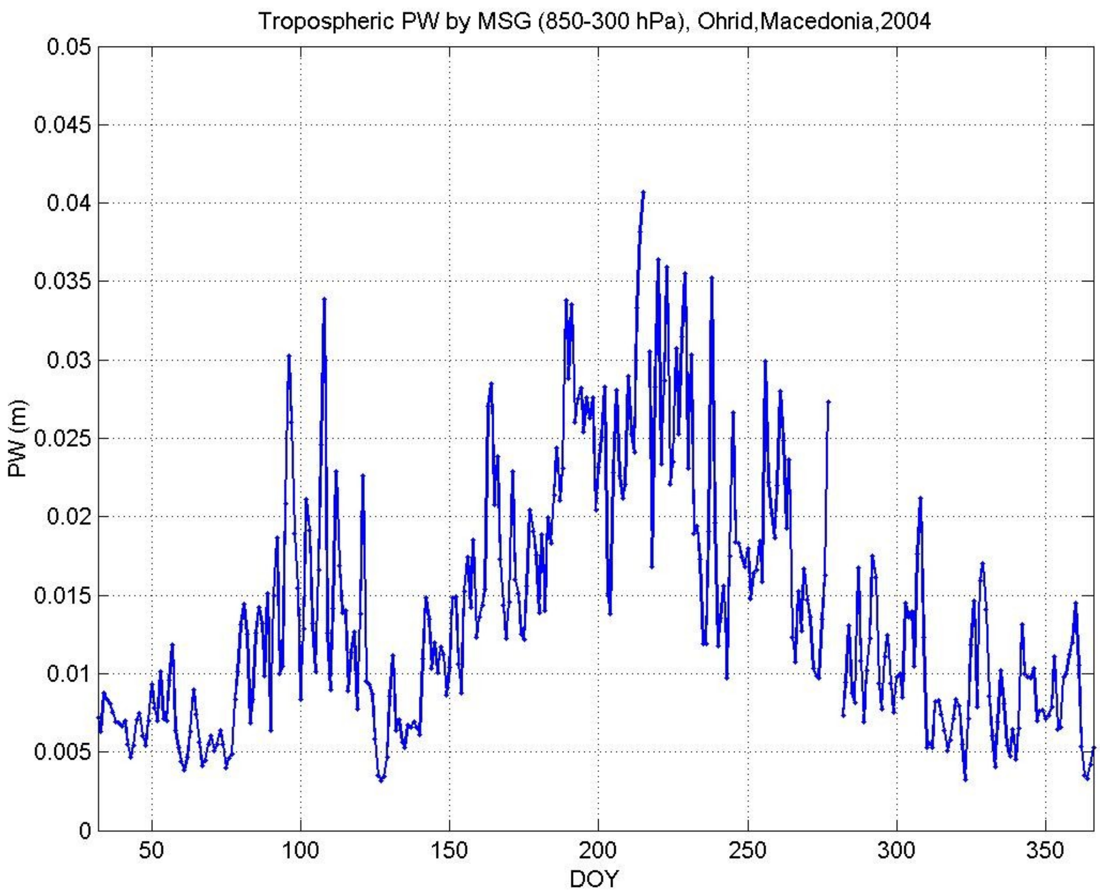

Fig. 11.b. Precipitable water by MSG for Ohrid, FYR Macedonia

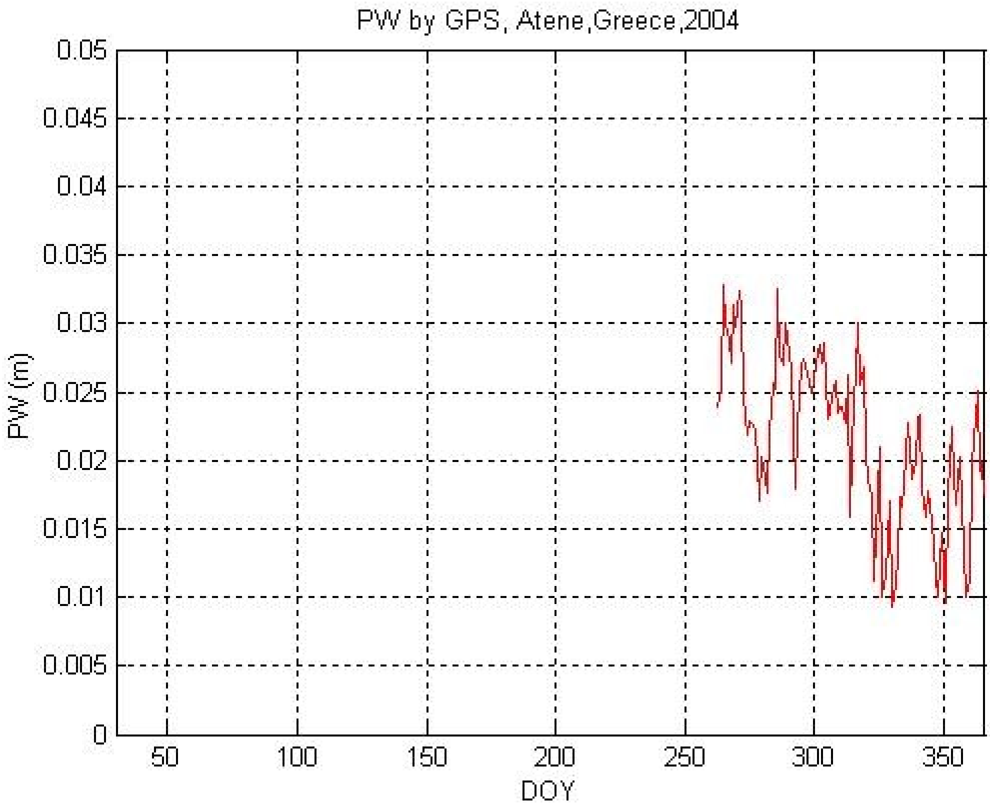

Fig. 12.a. Precipitable water by GPS for Atene, Greece

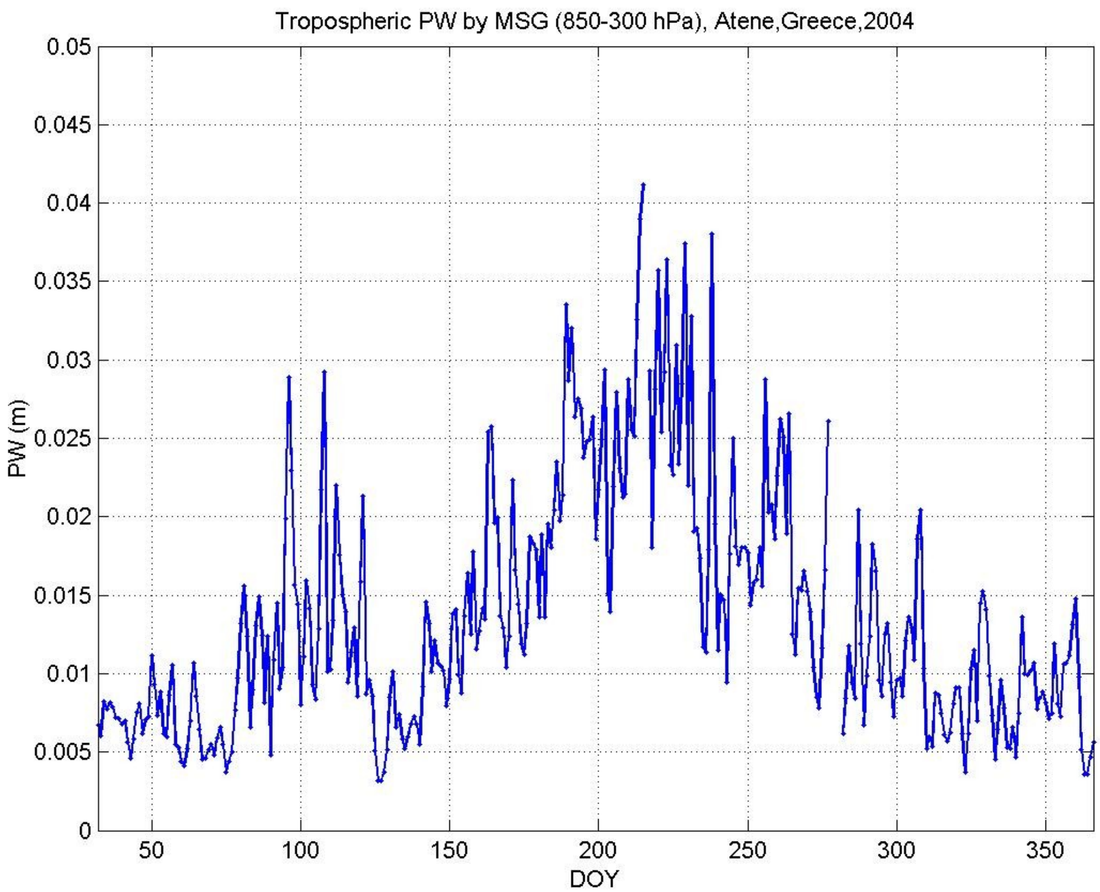

Fig. 12.b. Precipitable water by MSG for Atene, Greece

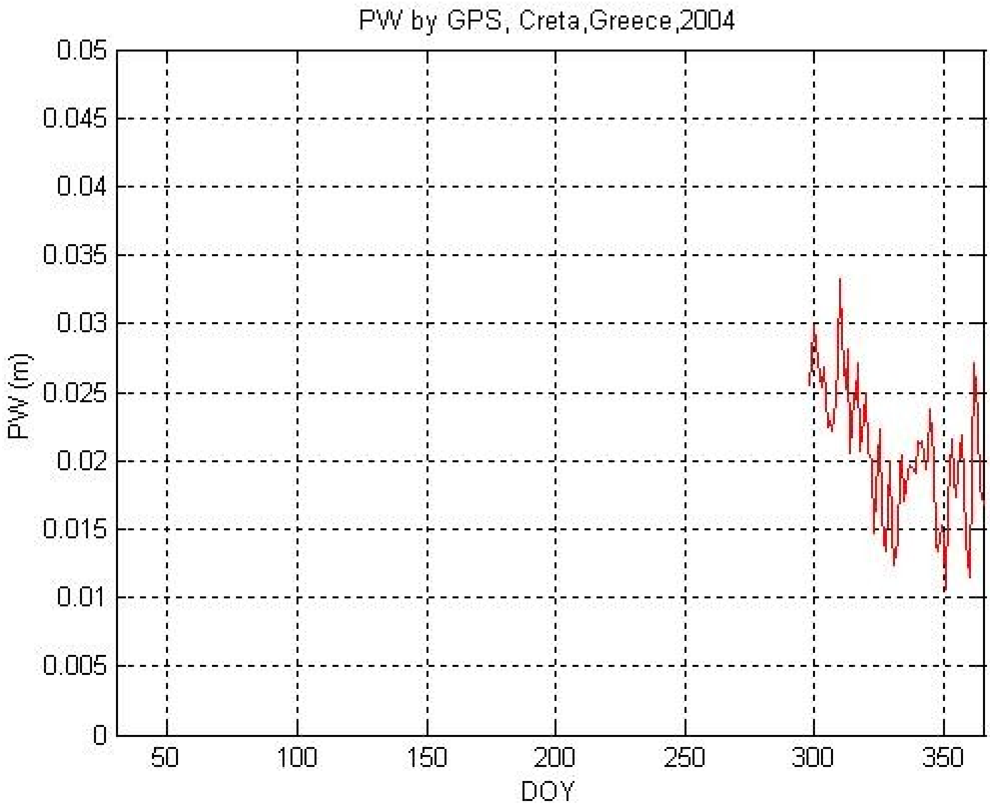

Fig. 13.a. Precipitable water by GPS for Creta, Greece

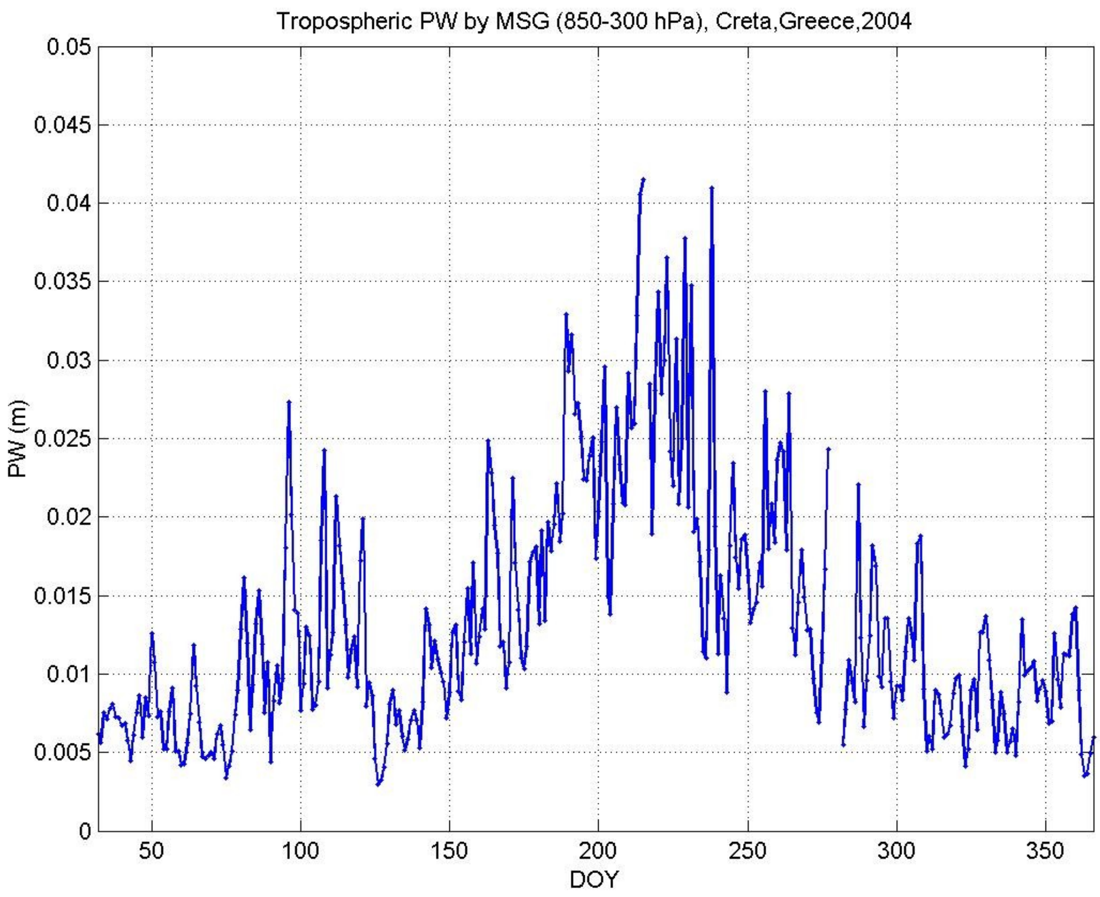

Fig. 13.b. Precipitable water by MSG for Creta, Greece

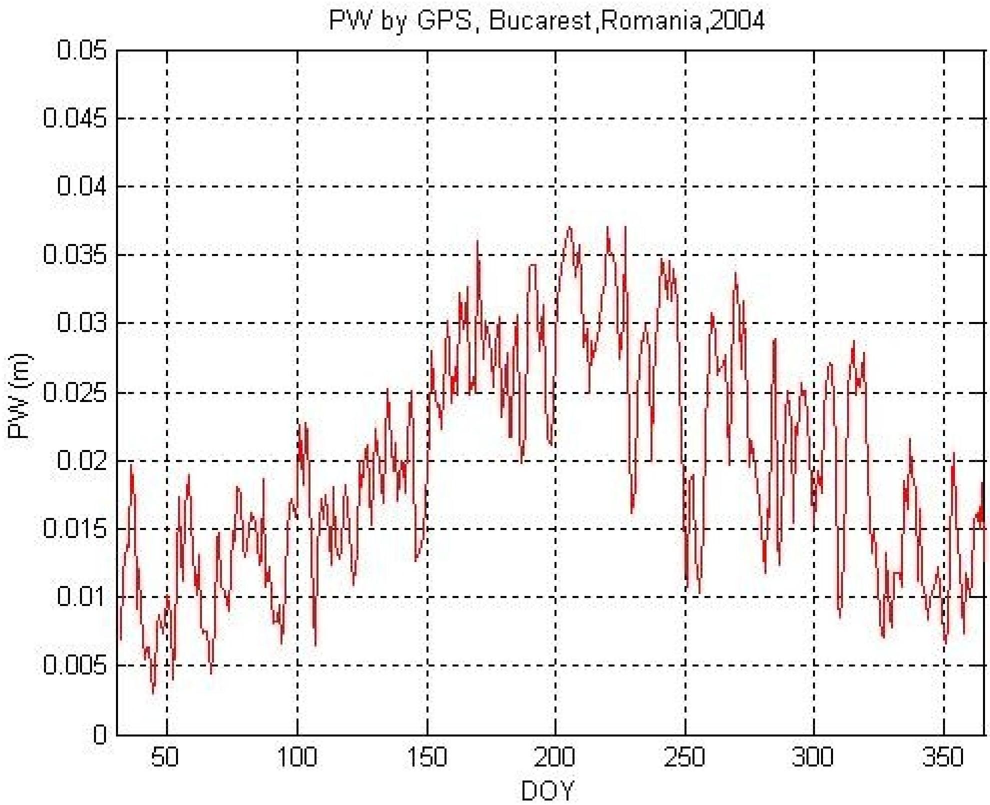

Fig. 14.a. Precipitable water by GPS for Bucarest, Romania

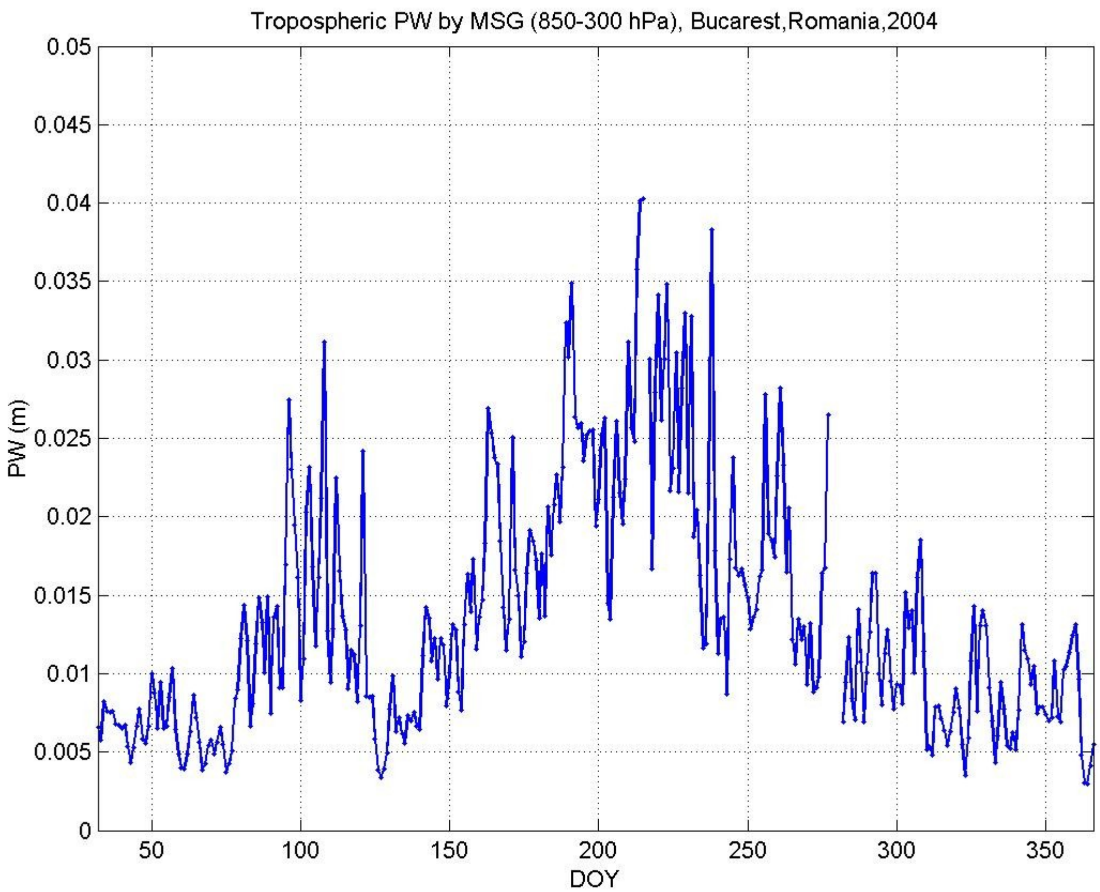

Fig. 14.b. Precipitable water by MSG for Bucarest, Romania

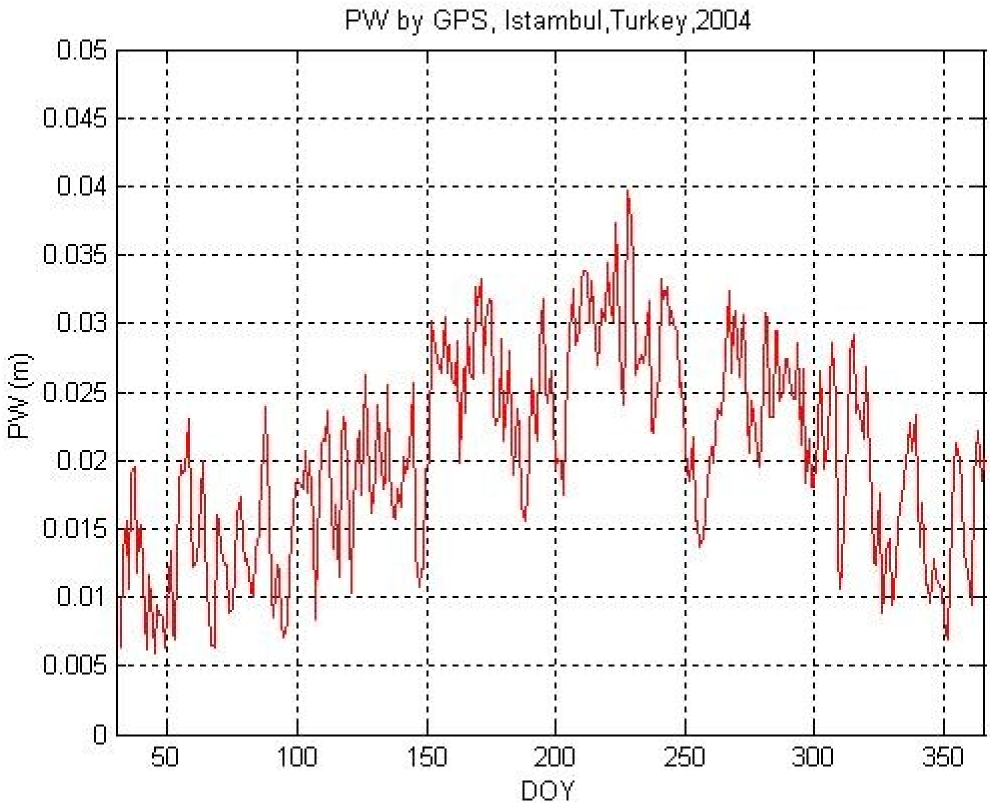

Fig. 15.a. Precipitable water by GPS for Istambul, Turkey

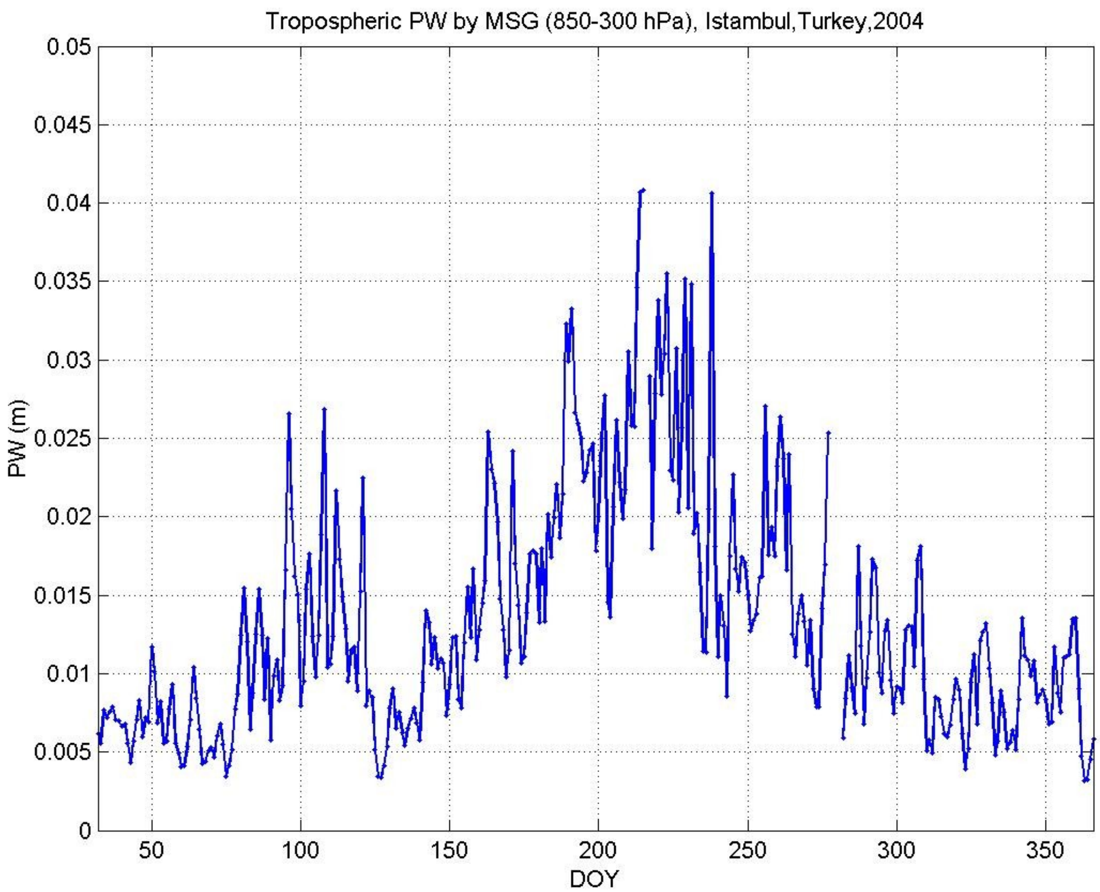

Fig. 15.b. Precipitable water by MSG for Istambul, Turkey

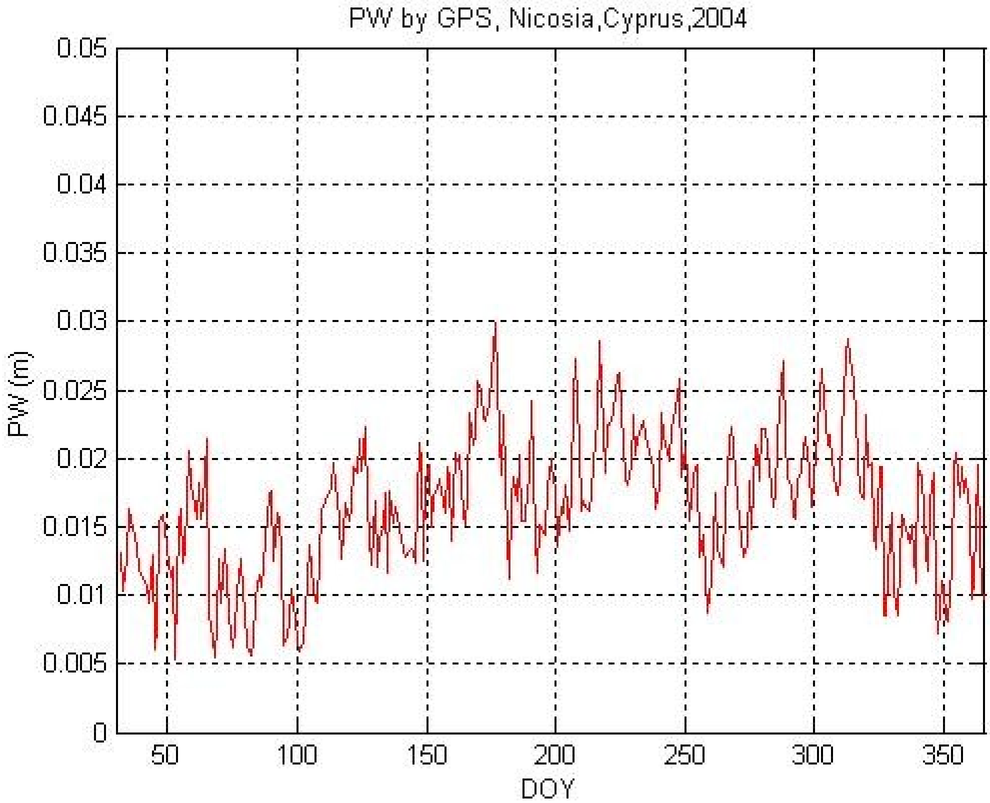

Fig. 16.a. Precipitable water by GPS for Nicosia, Cyprus

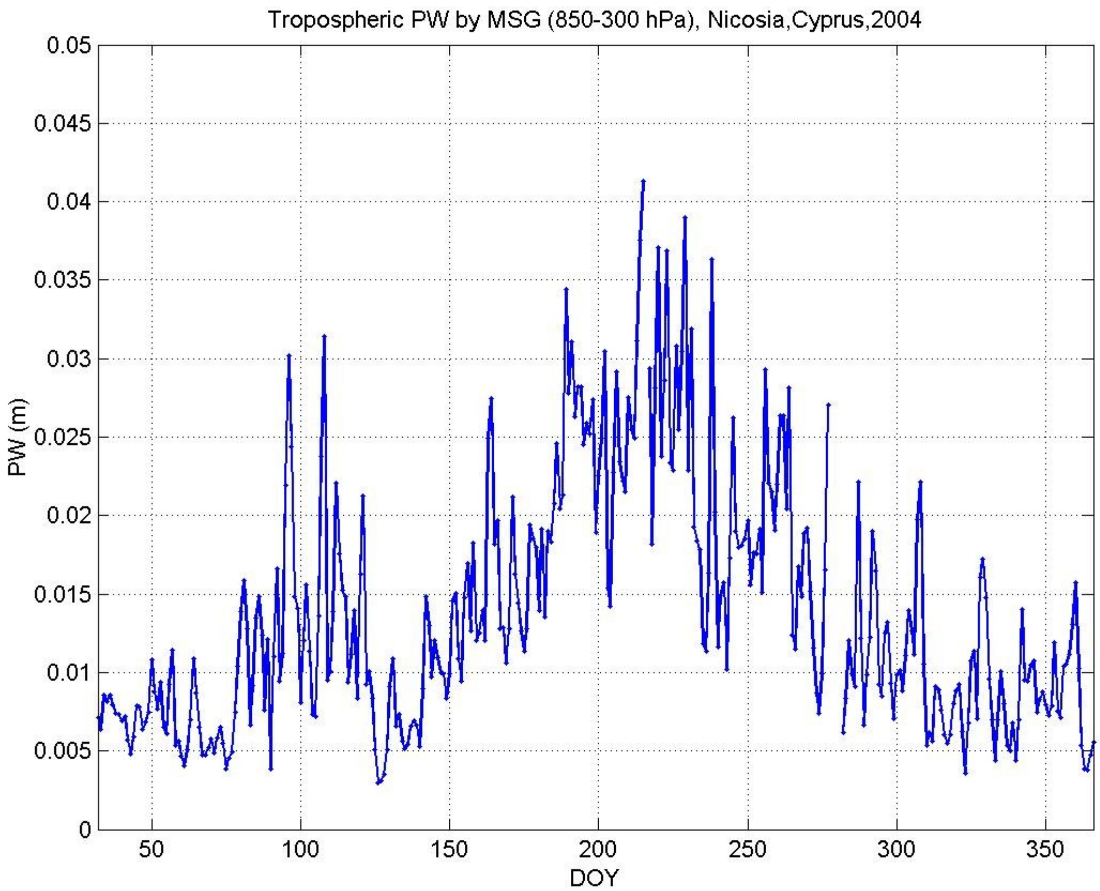

Fig. 16.b. Precipitable water by MSG for Nicosia, Cyprus

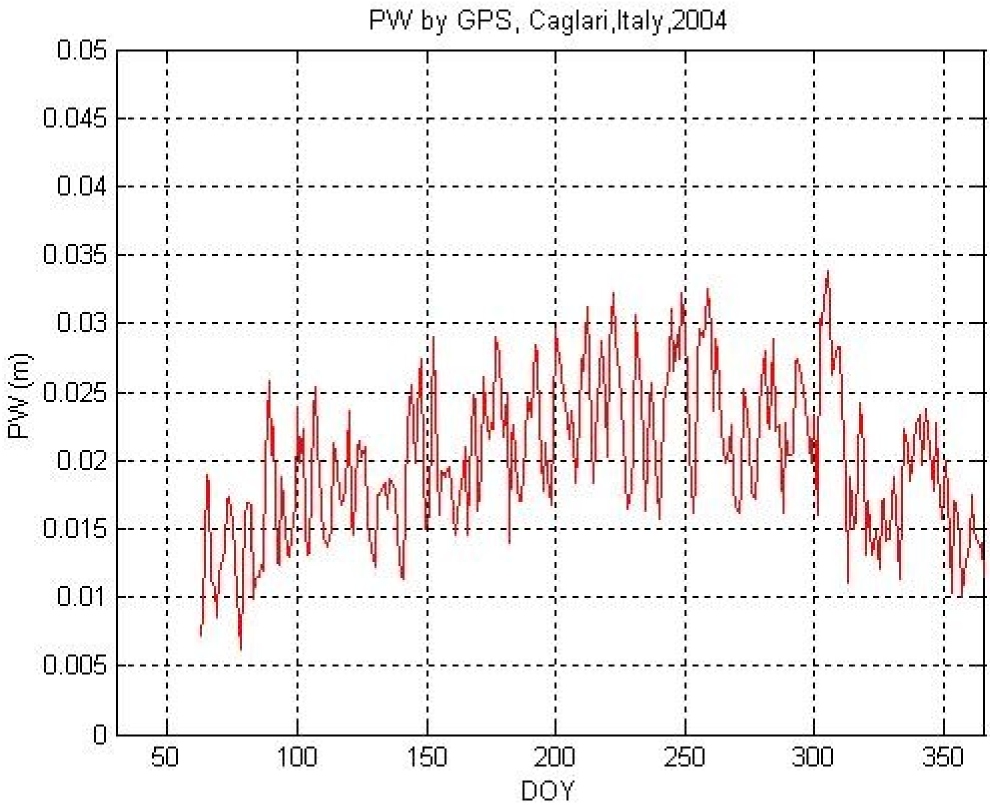

Fig. 17.a. Precipitable water by GPS for Caglari, Italy

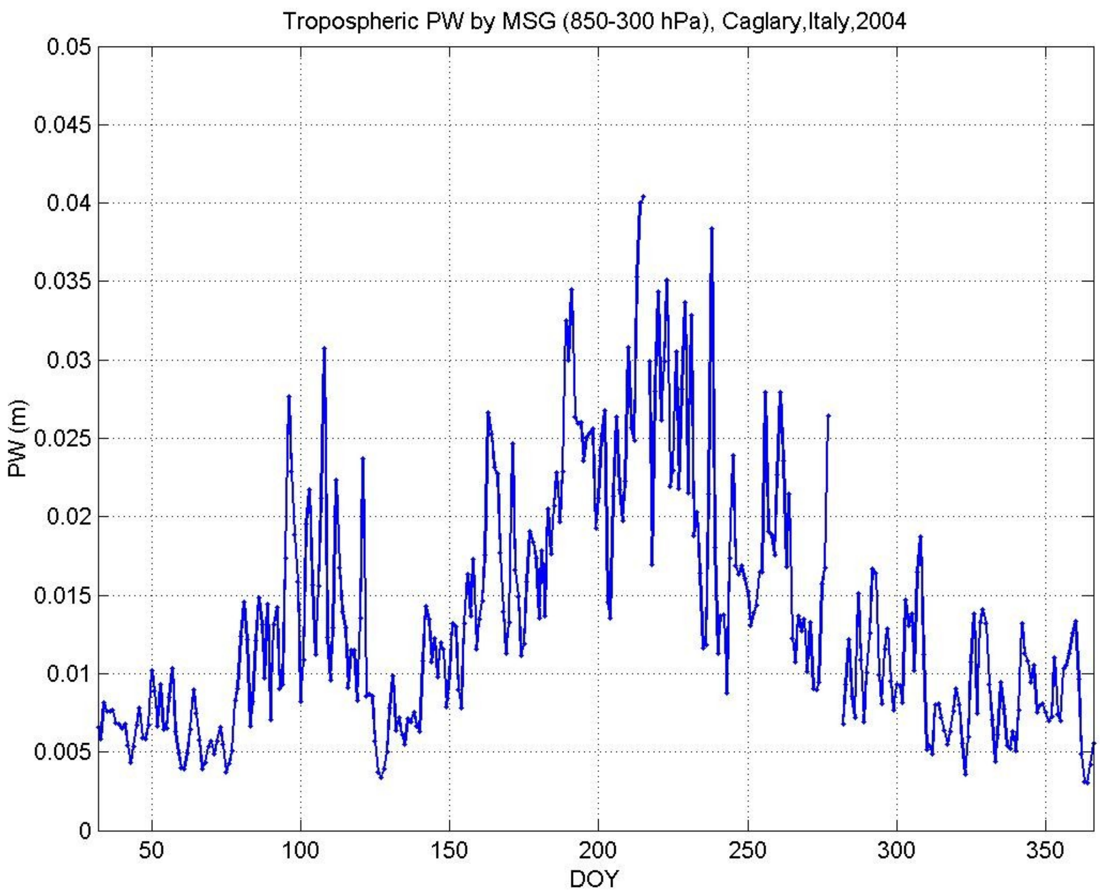

Fig. 17.b. Precipitable water by MSG for Caglari, Italy

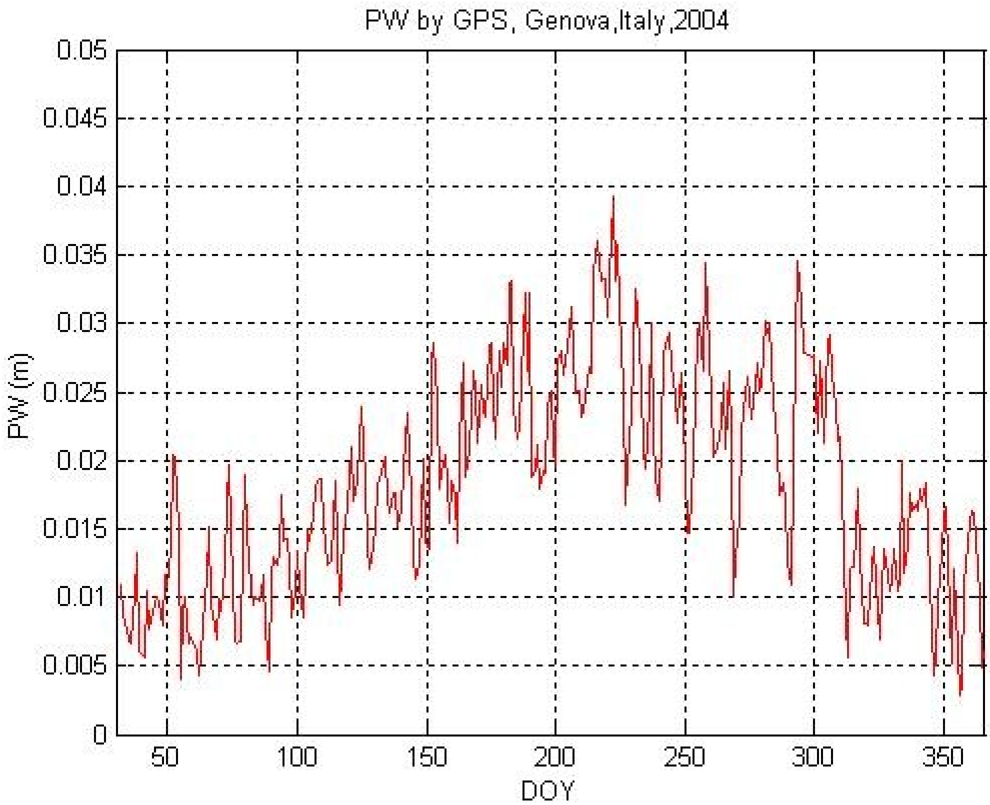

Fig. 18.a. Precipitable water by GPS for Genova, Italy

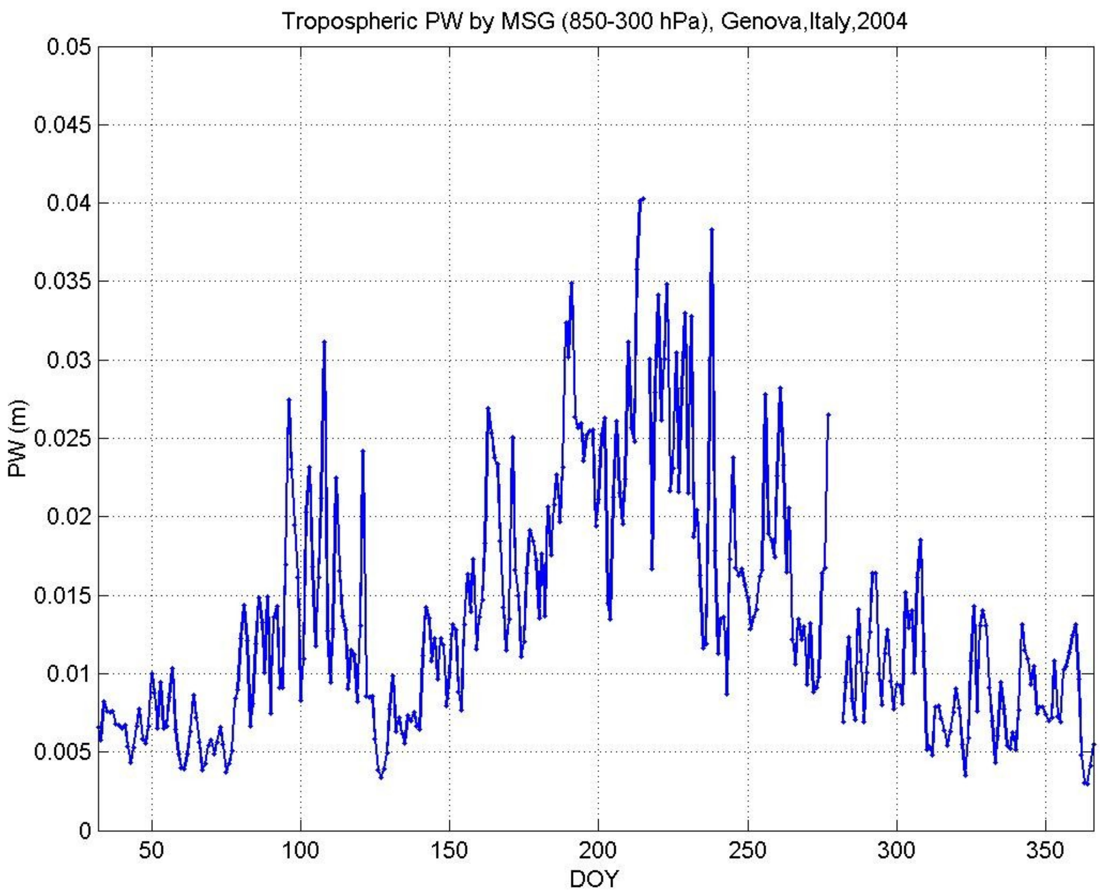

Fig. 18.b. Precipitable water by MSG for Genova, Italy

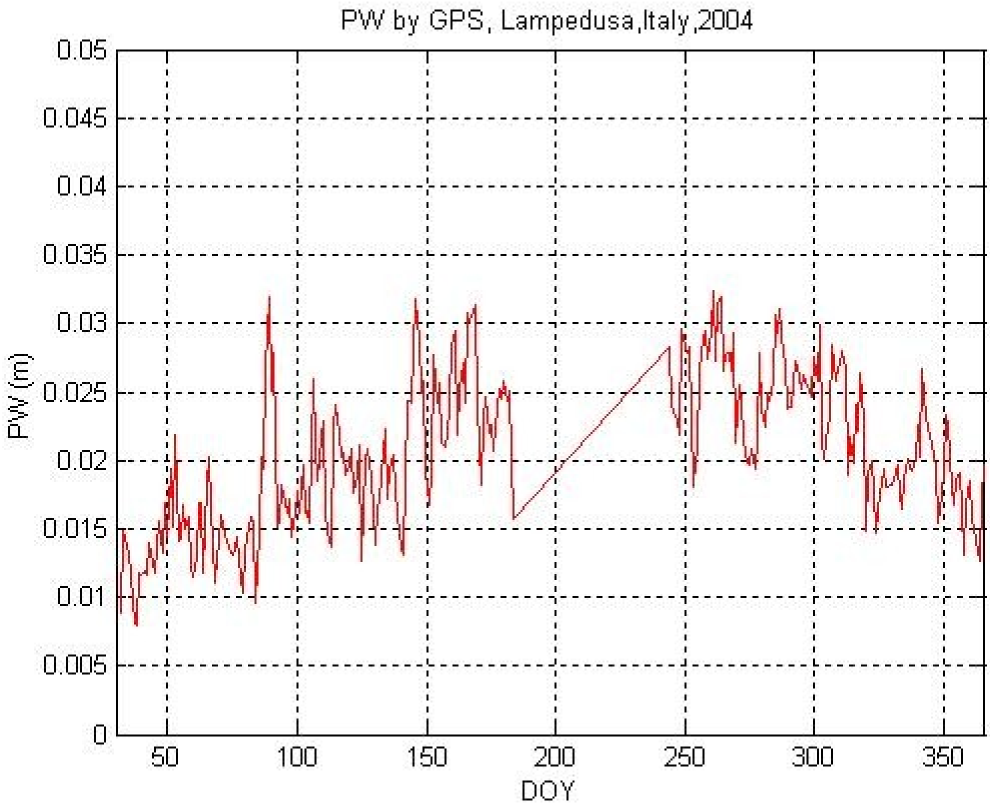

Fig. 19.a. Precipitable water by GPS for Lampedusa, Italy

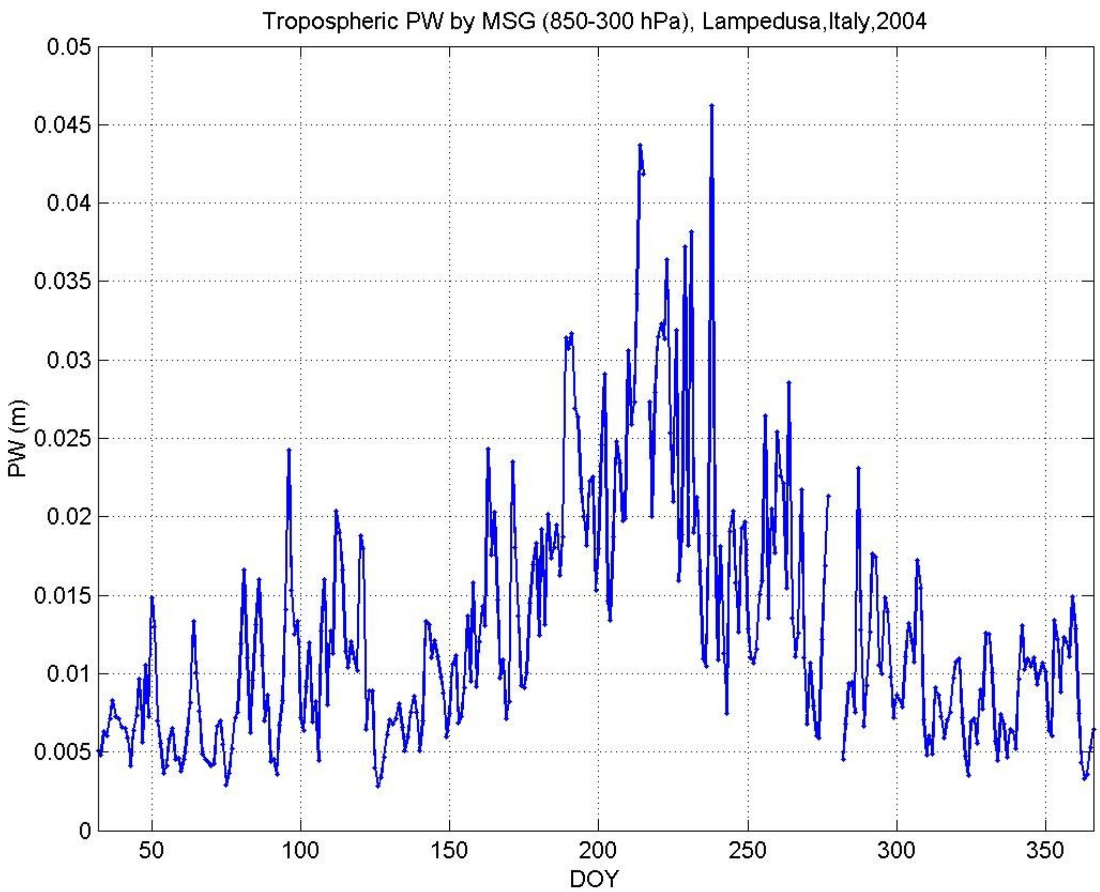

Fig. 19.b. Precipitable water by MSG for Lampedusa, Italy

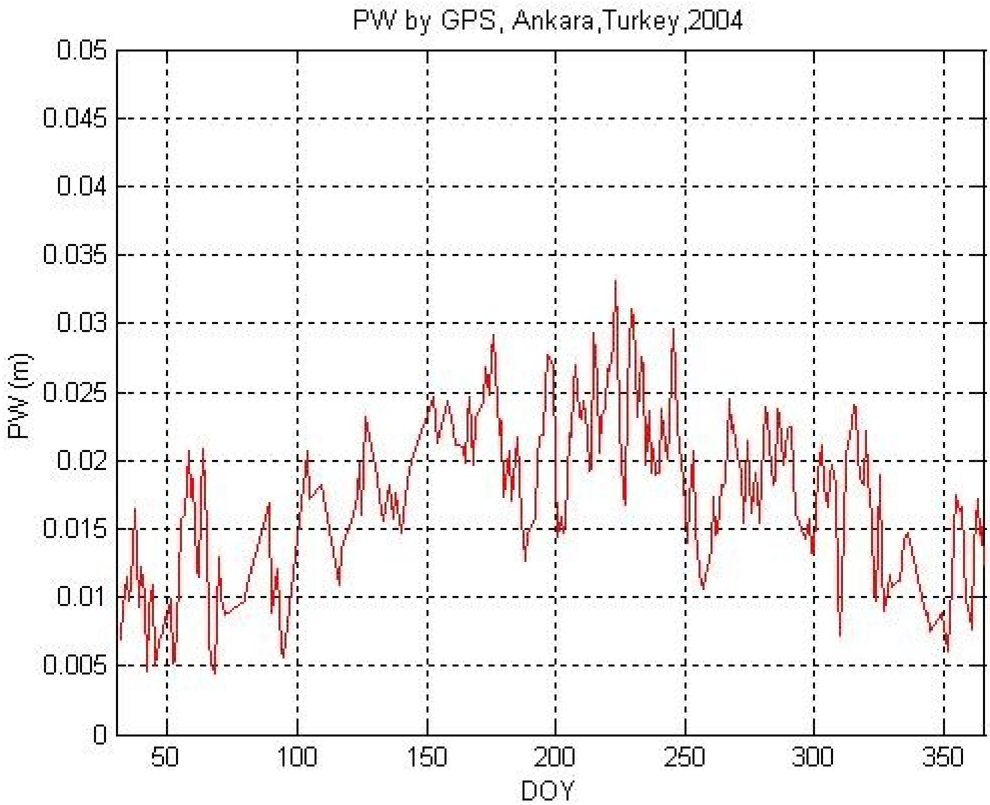

Fig. 20.a. Precipitable water by GPS for Ankara, Turkey

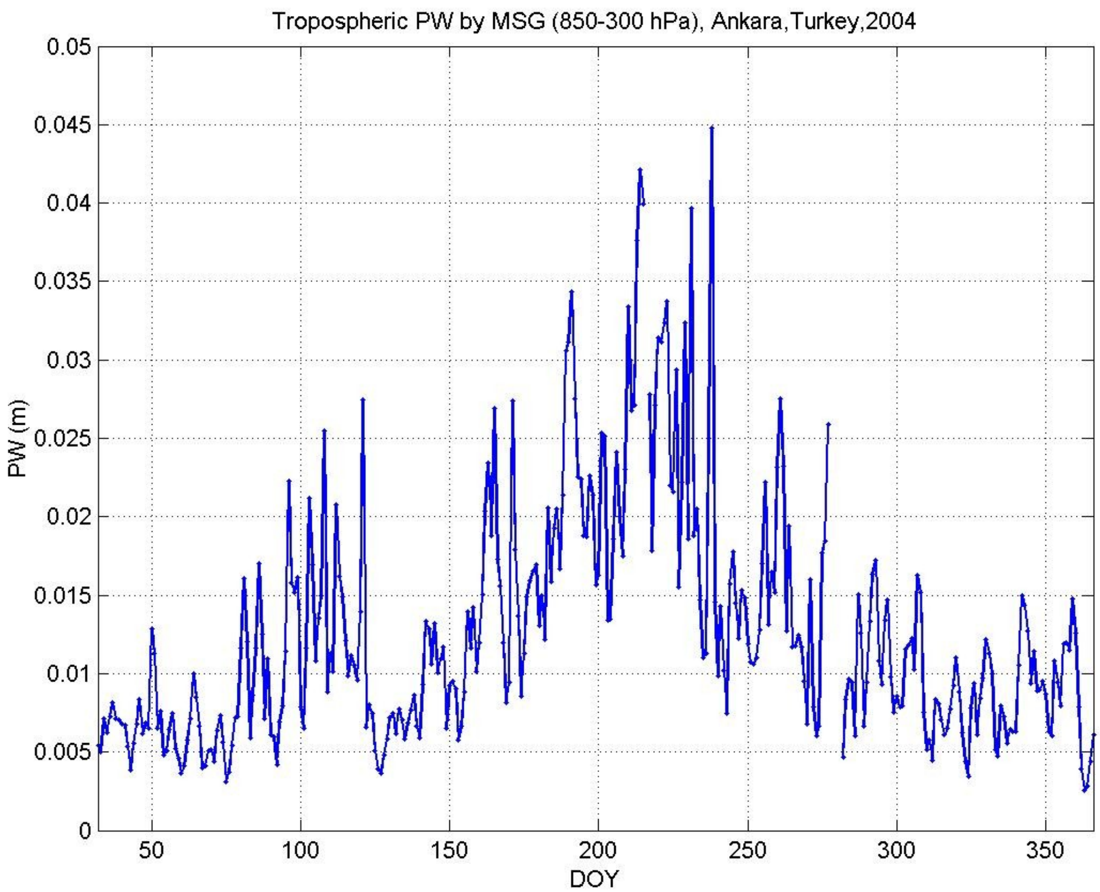

Fig. 20.b. Precipitable water by MSG for Ankara, Turkey

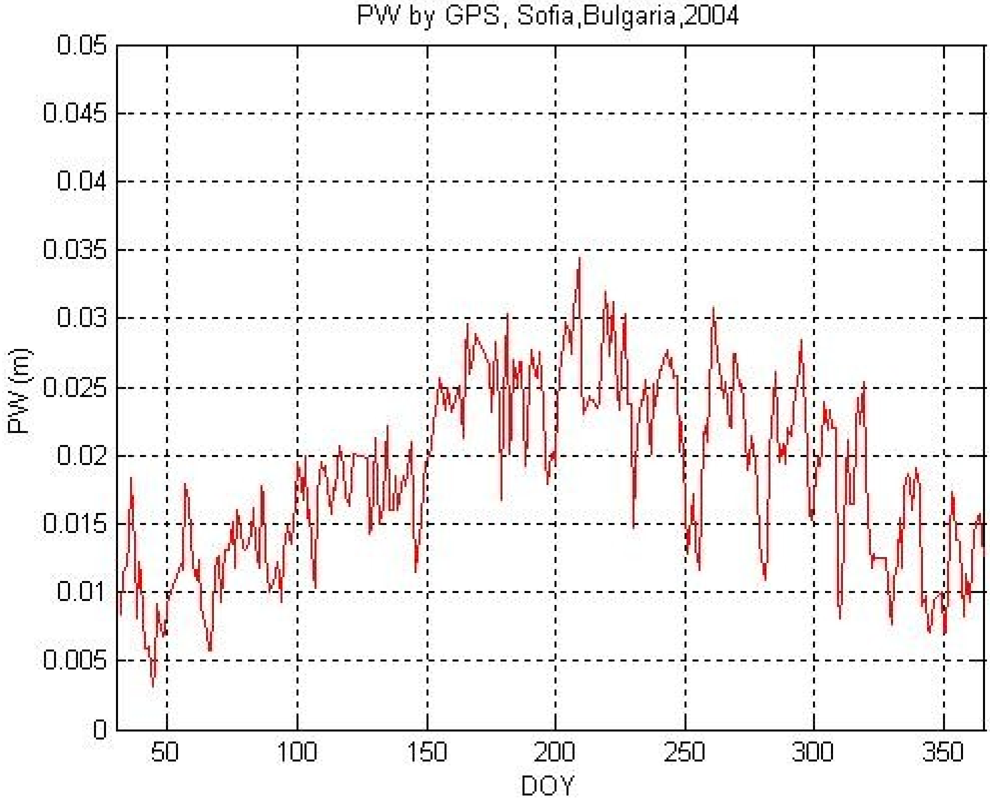

Fig. 21.a. Precipitable water by GPS for Sofia, Bulgaria

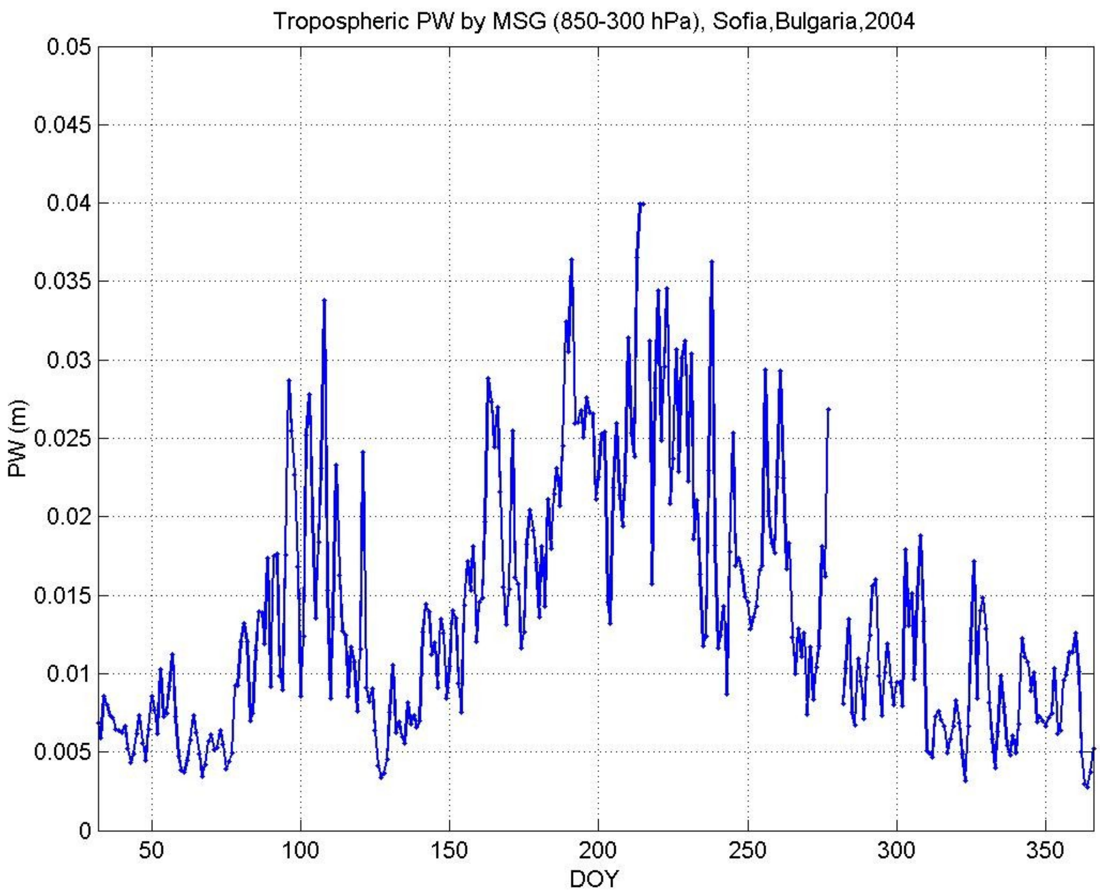

Fig. 21.b. Precipitable water by MSG for Sofia, Bulgaria

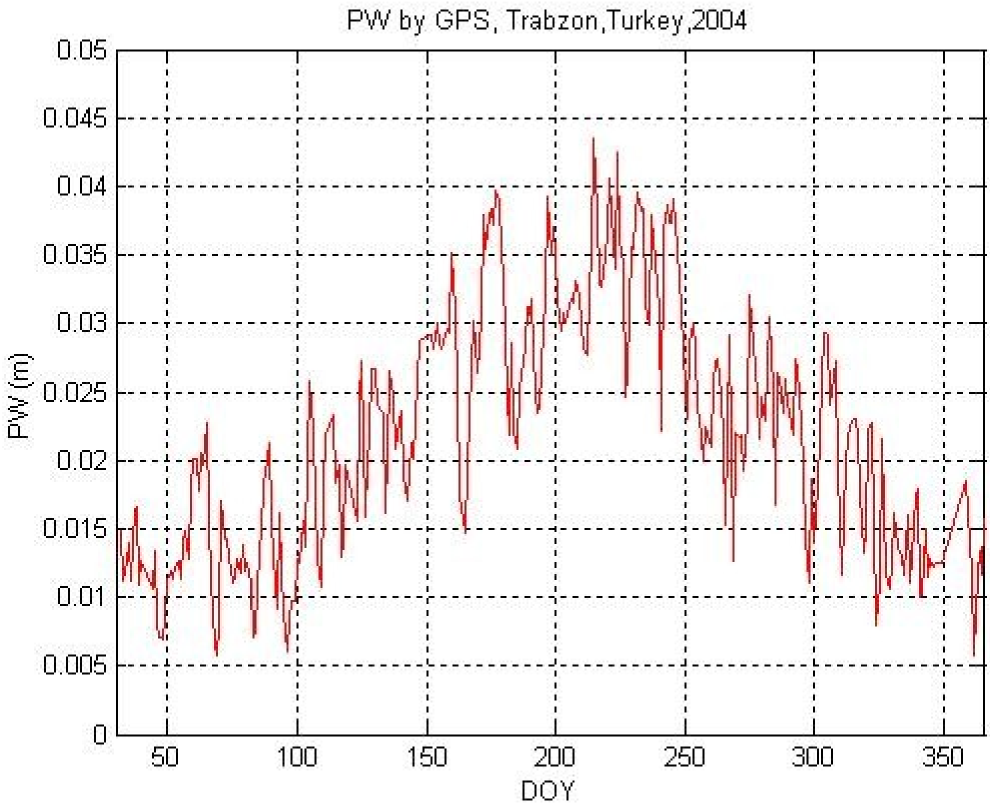

Fig. 22.a. Precipitable water by GPS for Trabzon, Turkey

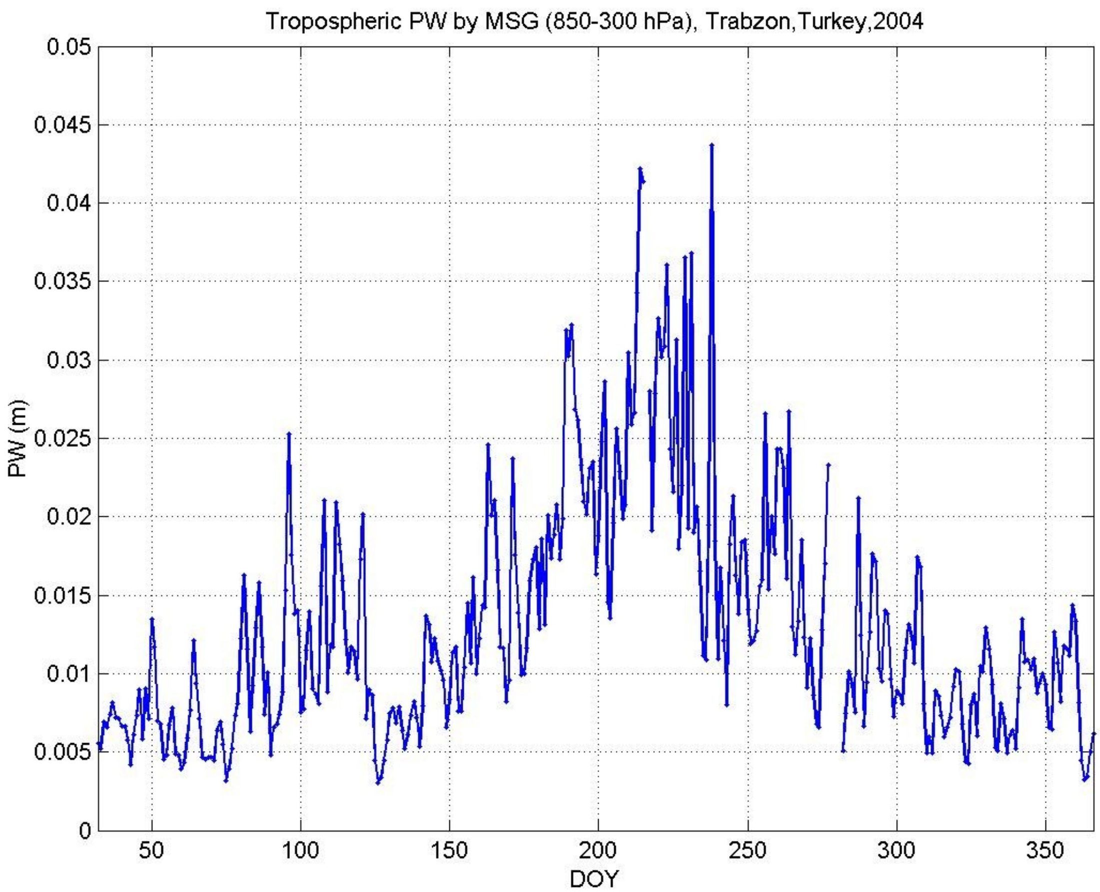

Fig. 22.b. Precipitable water by MSG for Trabzon, Turkey

The example of MSG derived Mean Daily Precipitable Water pixel values for the whole MSG observing area (- 65° to + 65° of latitude and - 65° to + 65° of longitude), as the mean daily values for 01/02/2004, elaborated at the Geophysical Observatory of University of Modena and Reggio Emila is given at the Fig. 23.

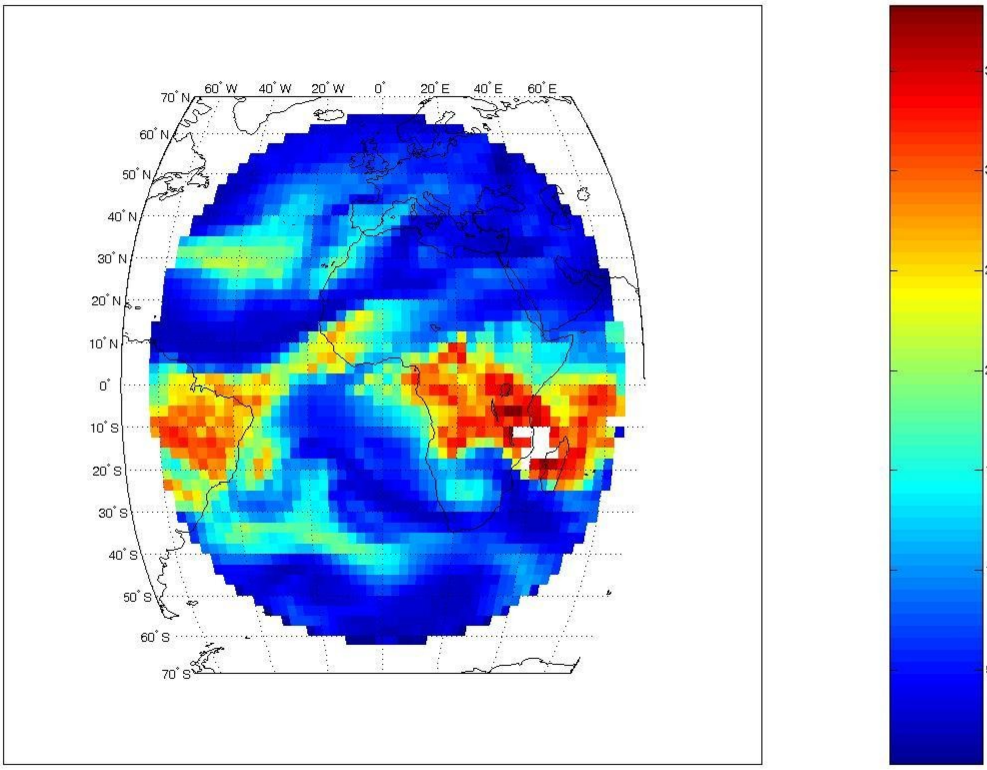

Fig. 23. The mean daily PW values from MSG for 01.12.2004

V.1. The comparison between Total PW obtained by the combined method and PW by MSG and GPS/NCEP

At the following figures (from Fig. 24. to Fig. 42.) the comparison between the total PW values obtained by the combined method against PW values by MSG and by GPS are given. The combined method is applied to overcome the lack of the lowest tropospheric layer humidity values by MSG (the layer from the surface up to 850 hPa). This layer is modeled using the standard surface pressure, temperature end humidity values (as explained in the Paragraph IV.2. Meteorological Data for GPS humidity estimations, pp. 12), upon of data retrieved from NCEP. It is interesting compare such a data set with the pure MSG humidity data set (for the layer between 850 and 200 hPa), and also with the integrated GPS humidity data referring to the entire signal path along the troposphere.

It can be noted, as expected, that Total PW values prevailing to MSG values, being combined to the lacking layer. The difference is to be studied further in terms of verified precipitations at the surface or convective weather processes occurred.

The comparison between the total PW and GPS PW shows a rather good agreement in the colder period of the year, especially in the autumn of 2004, and also is enhanced for the coastal stations (stations at the lower altitudes). This interesting result should be also studied for the successive periods, in order to be confirmed and calibrated on the longer time scale.

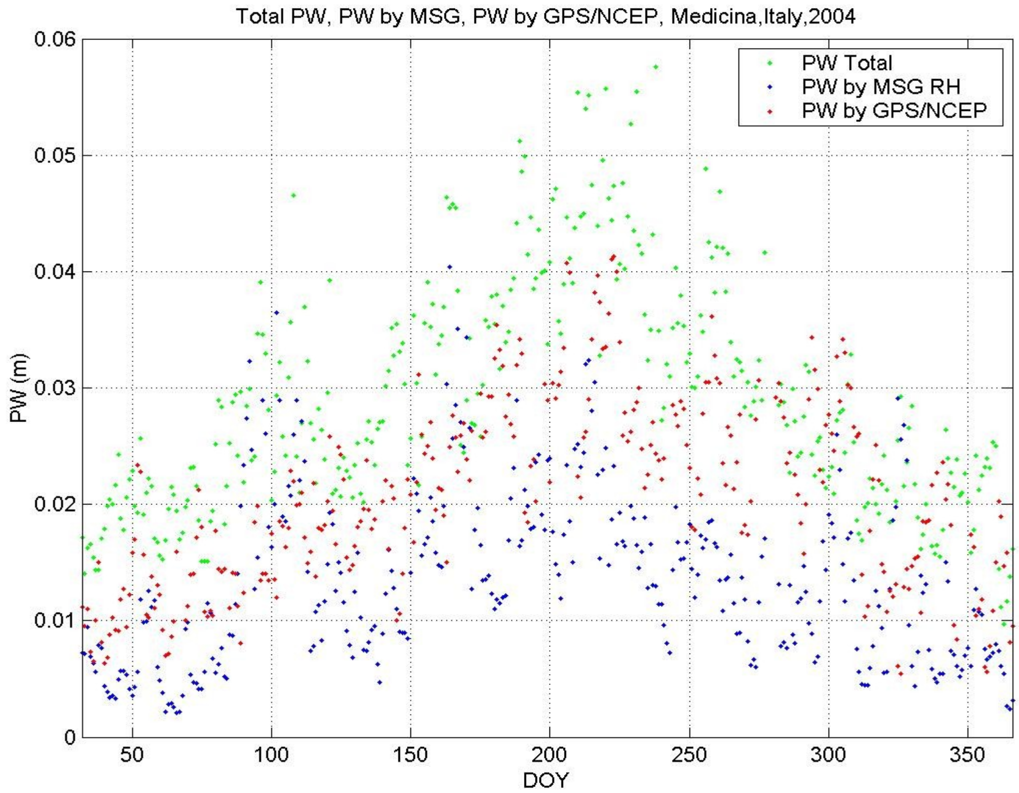

Fig. 24. PW by different methods comparison for Medicina, Italy

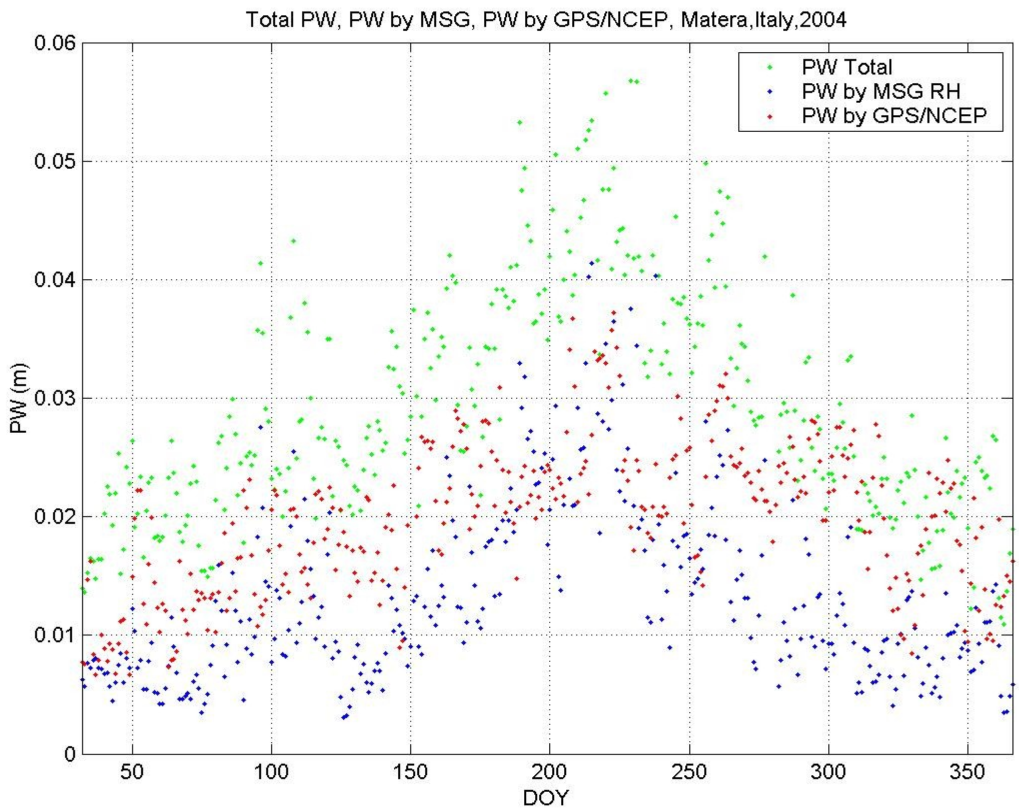

Fig. 25. PW by different methods comparison for Matera, Italy

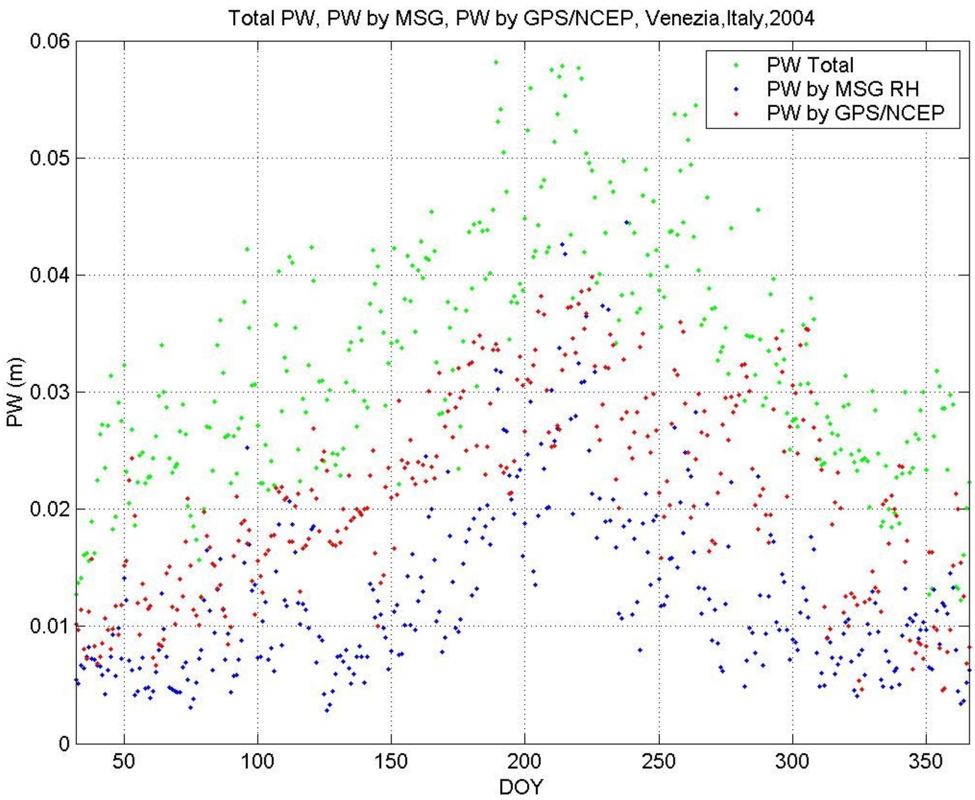

Fig. 26. PW by different methods comparison for Venezia, Italy

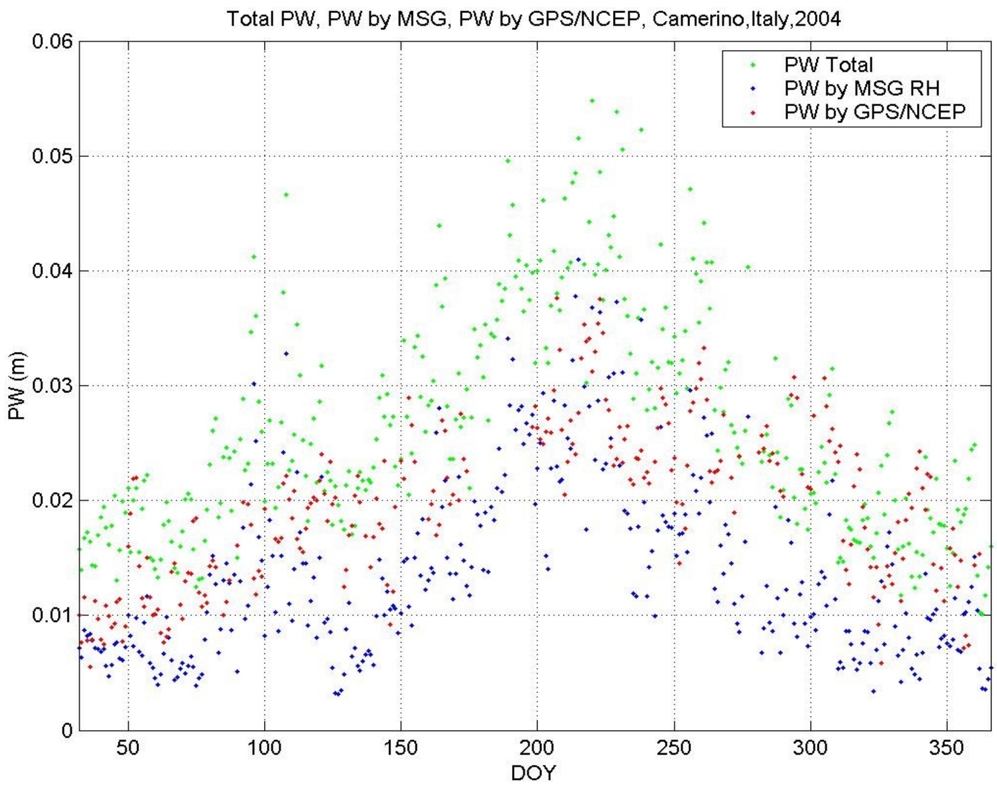

Fig. 27. PW by different methods comparison for Camerino, Italy

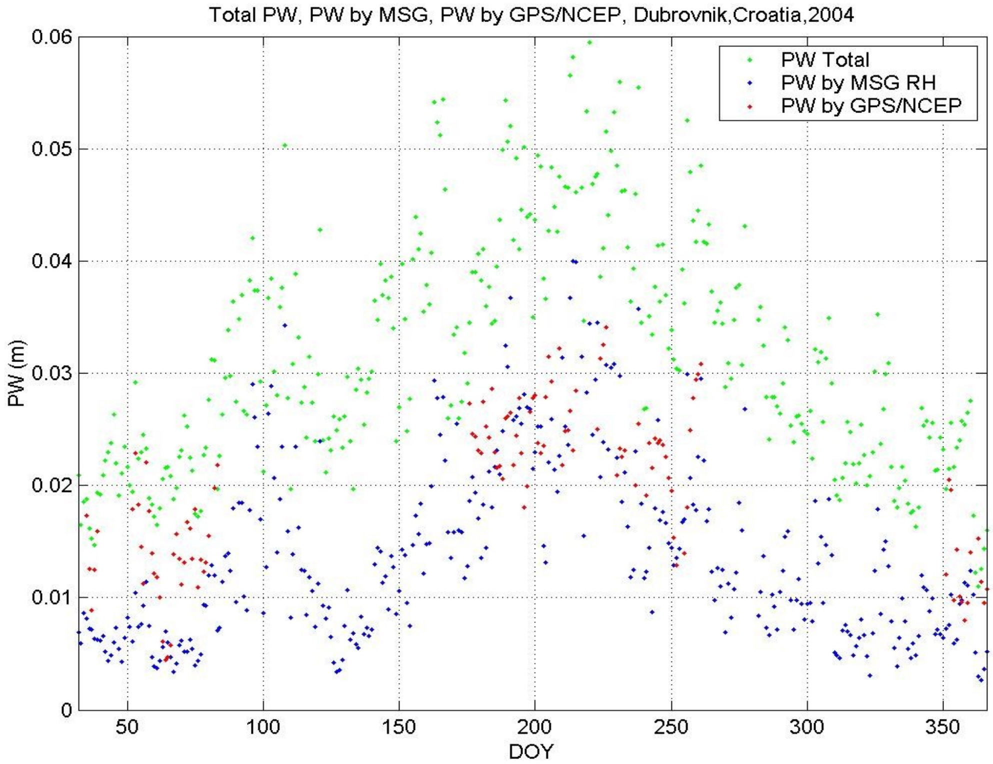

Fig. 28. PW by different methods comparison for Dubrovnik, Croatia

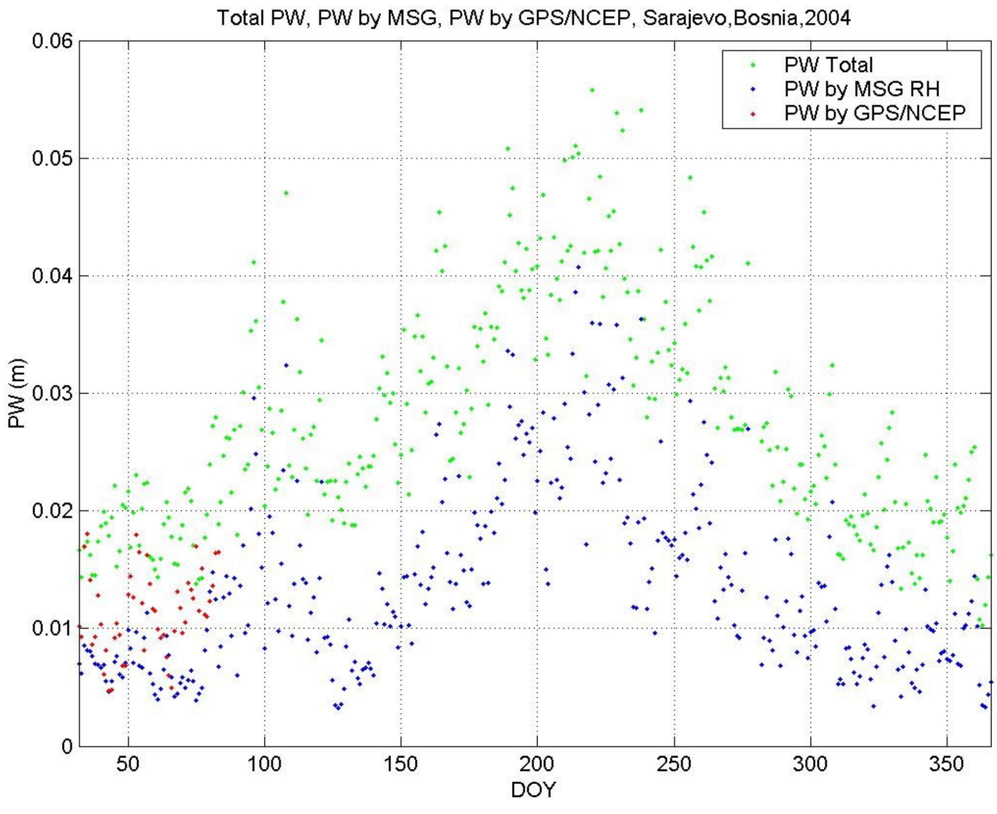

Fig. 29. PW by different methods comparison for Sarajevo, Bosnia

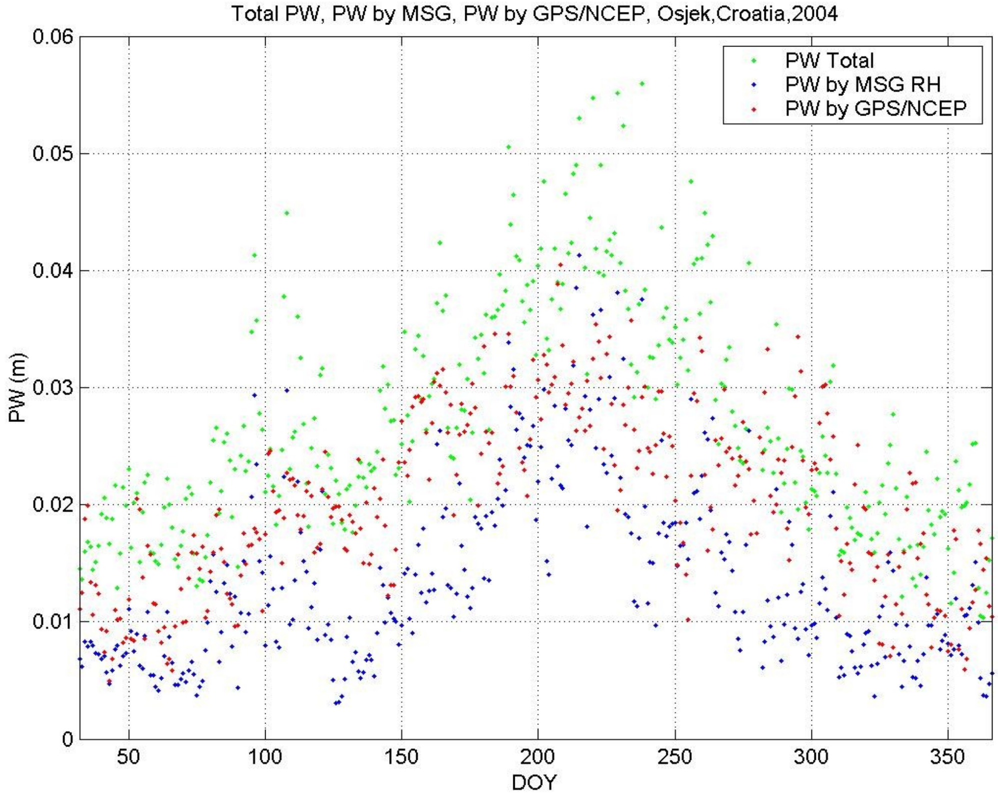

Fig. 30. PW by different methods comparison for Osjek, Croatia

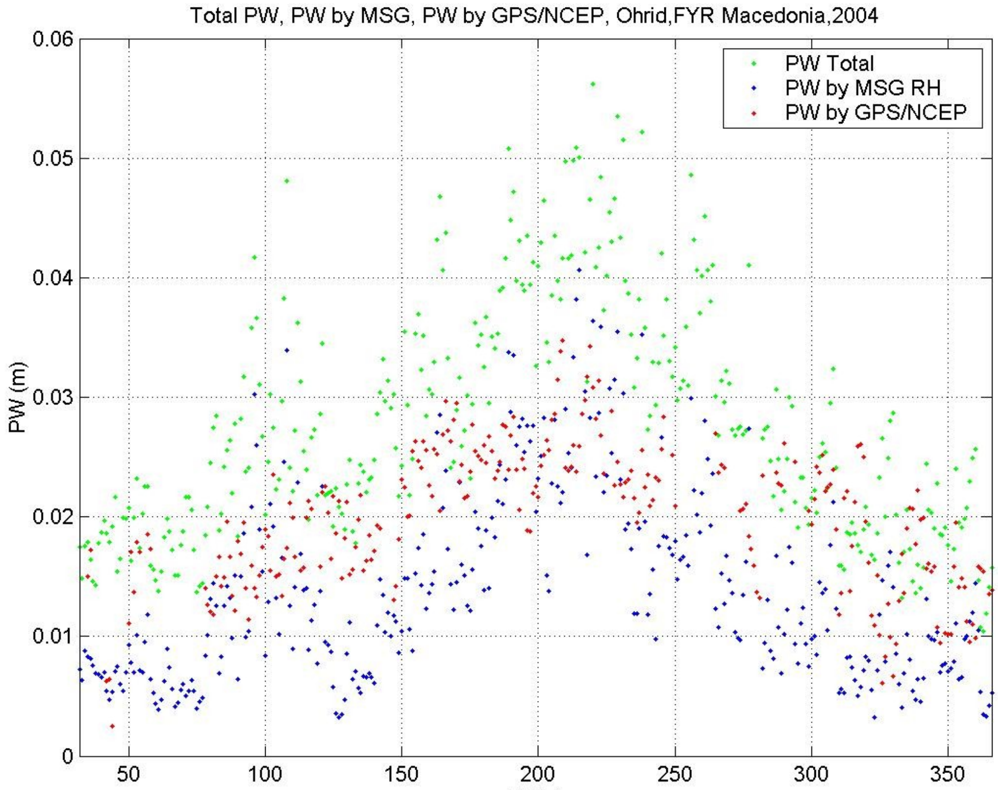

Fig. 31. PW by different methods comparison for Ohrid, FYR Macedonia

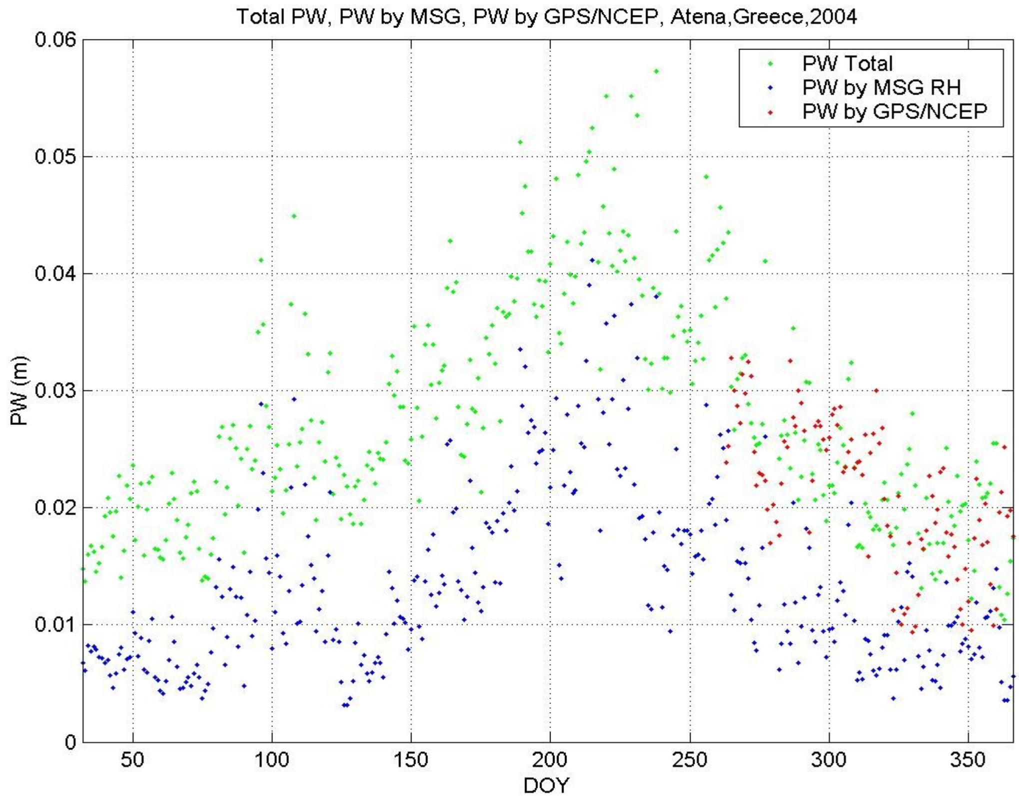

Fig. 32. PW by different methods comparison for Atena, Greece

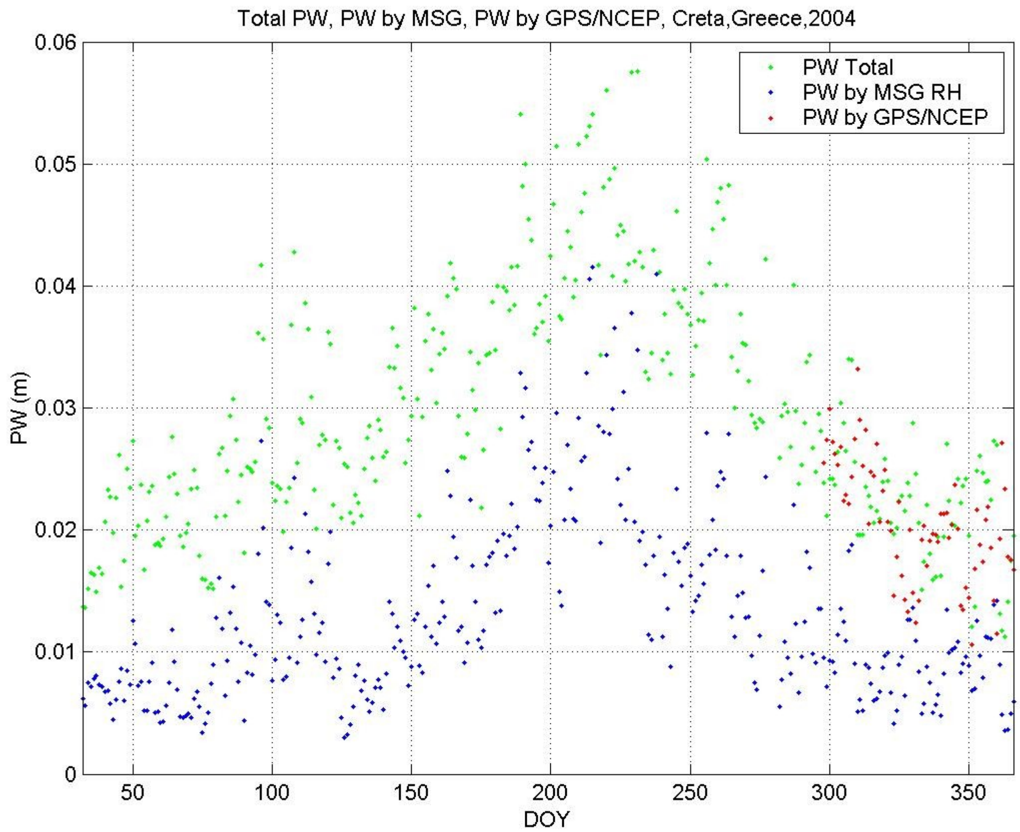

Fig. 33. PW by different methods comparison for Creta, Greece

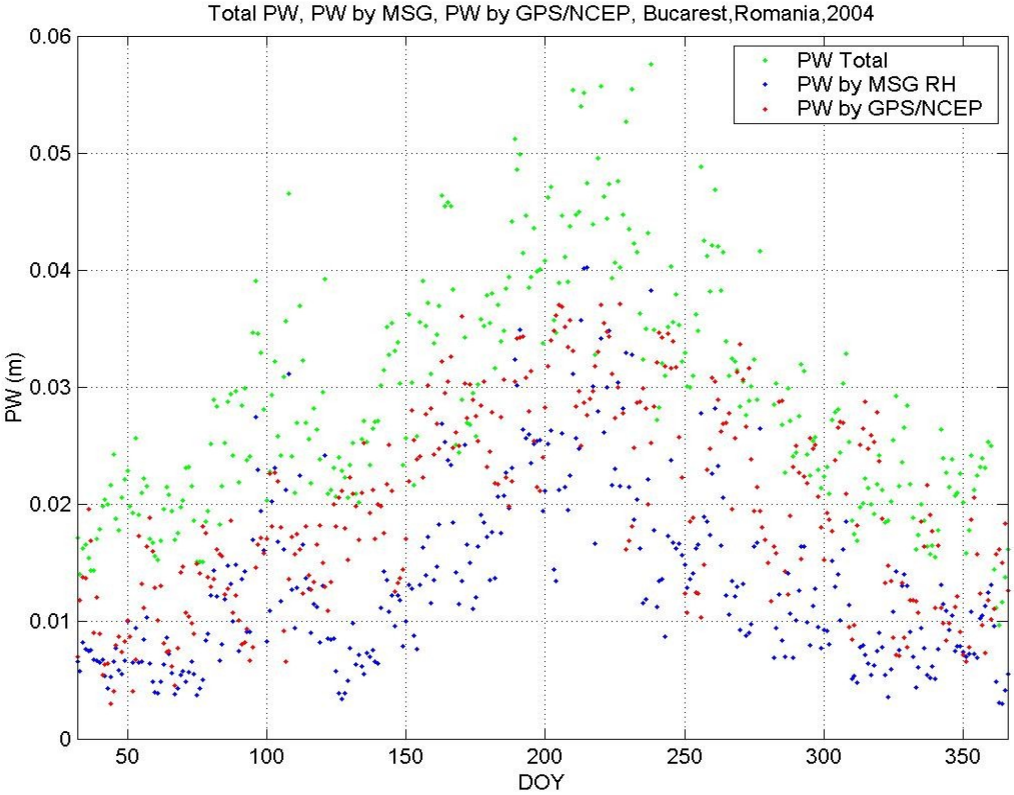

Fig. 34. PW by different methods comparison for Bucarest, Romania

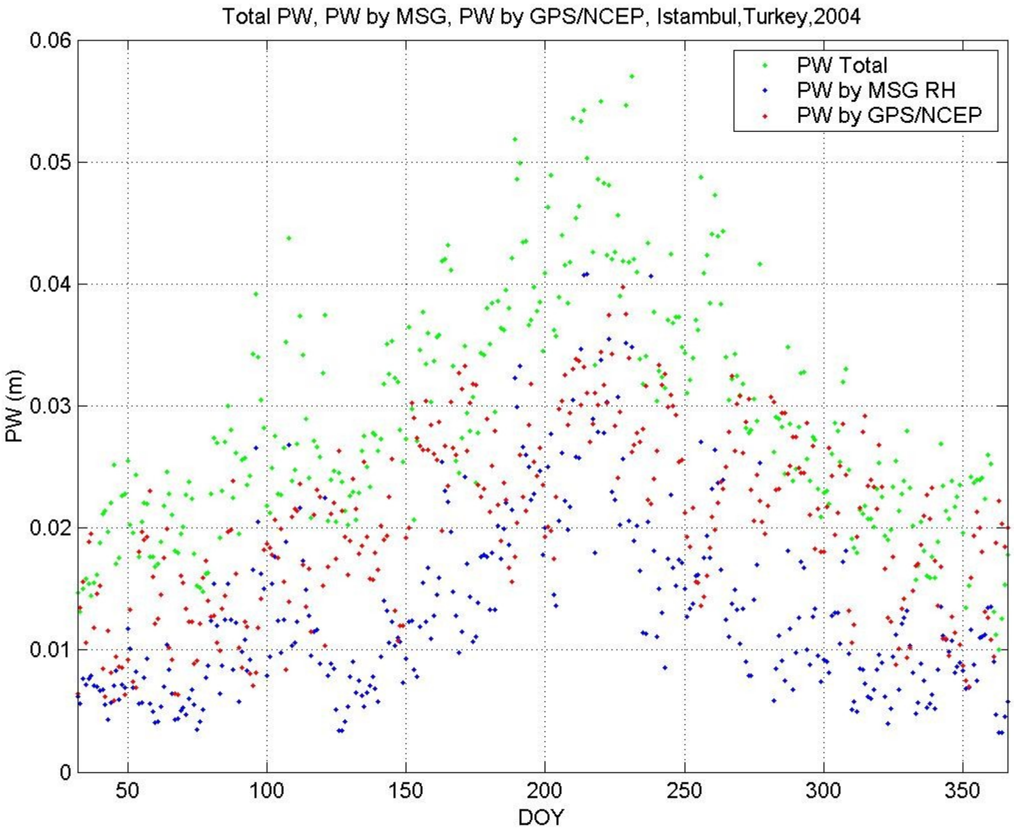

Fig. 35. PW by different methods comparison for Istambul, Turkey

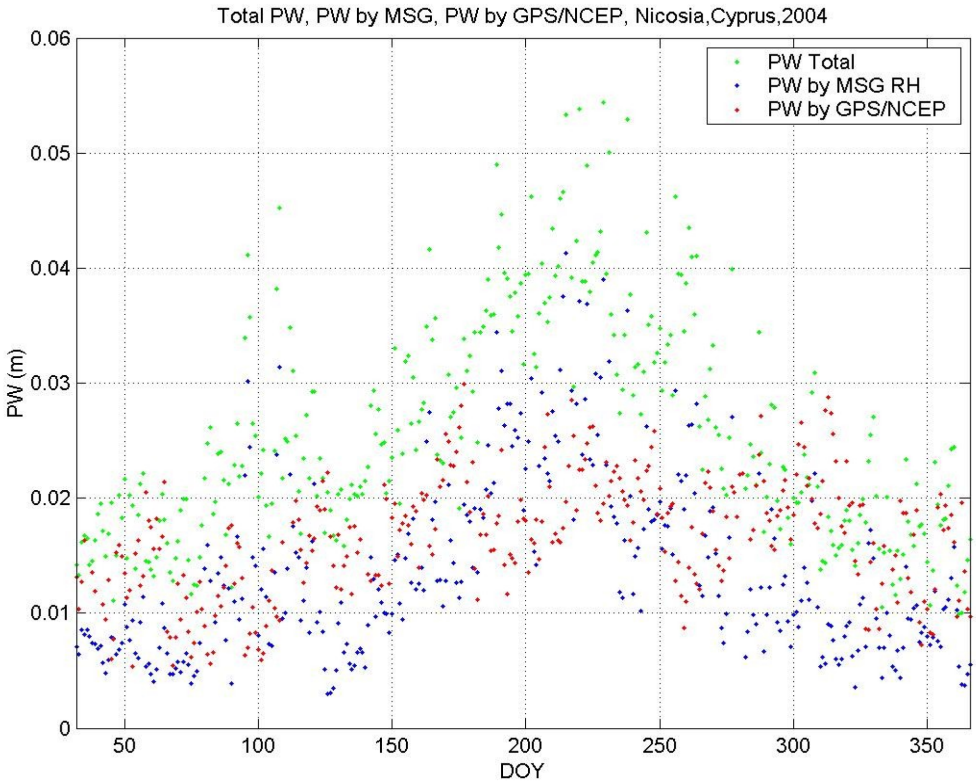

Fig. 36. PW by different methods comparison for Nicosia, Cyprus

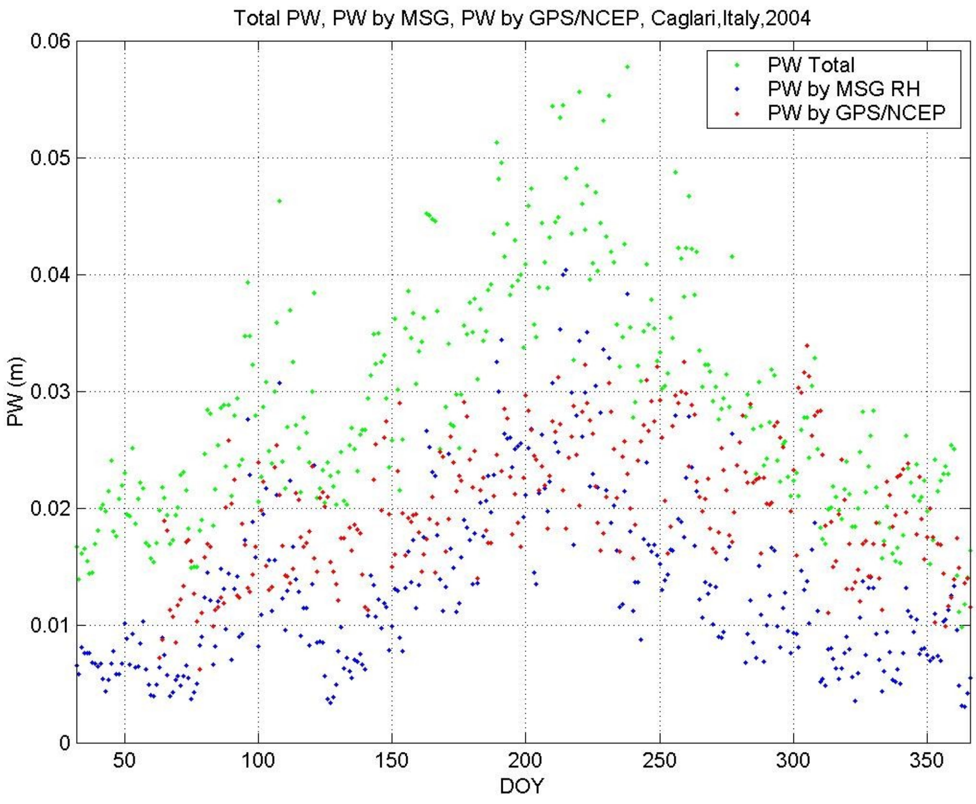

Fig. 37. PW by different methods comparison for Caglari, Italy

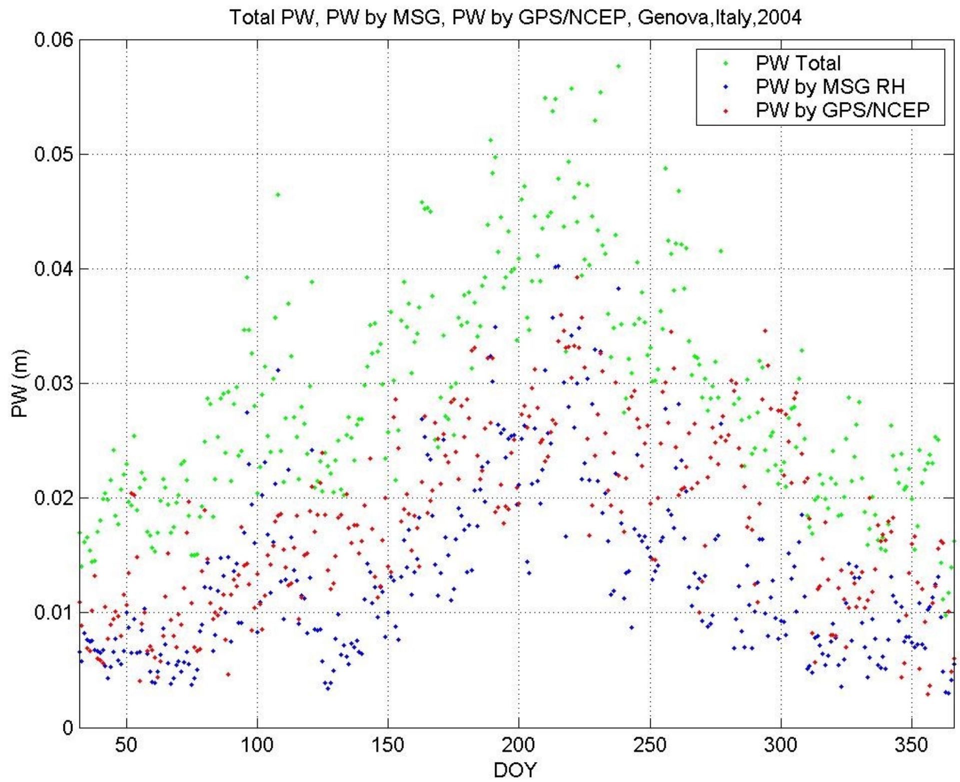

Fig. 38. PW by different methods comparison for Genova, Italy

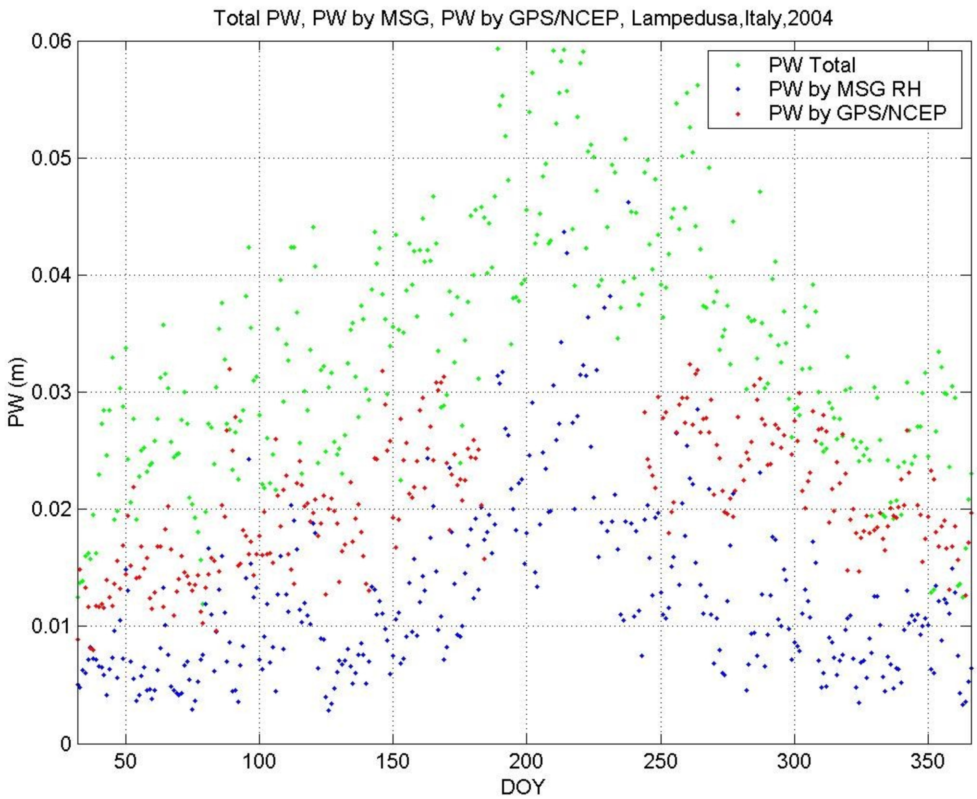

Fig. 39. PW by different methods comparison for Lampedusa, Italy

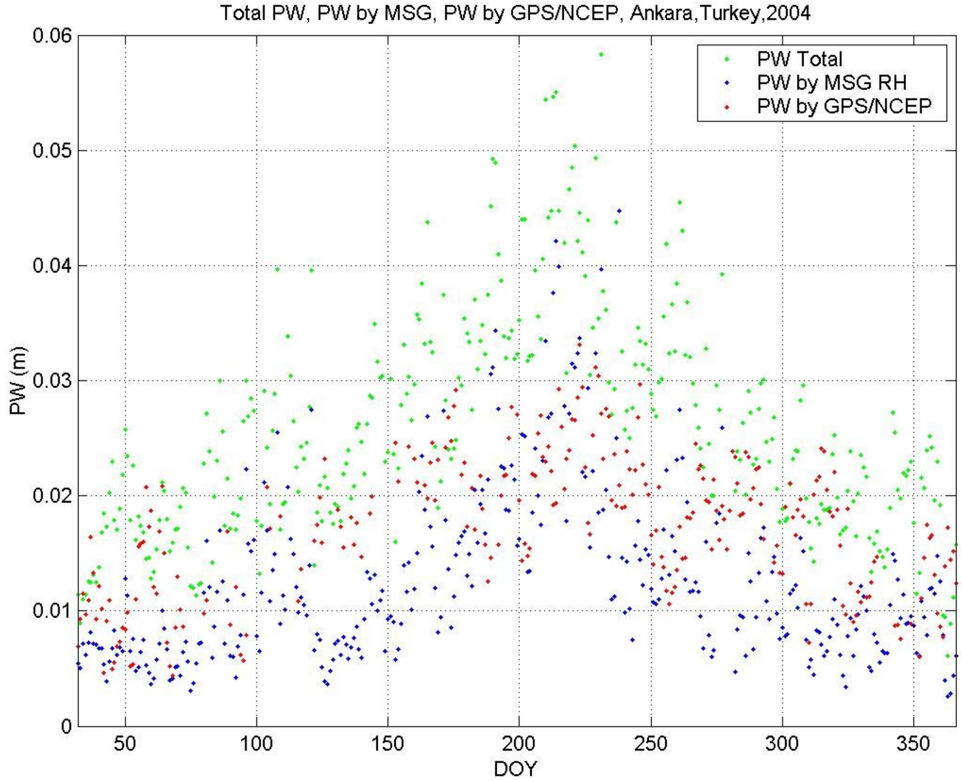

Fig. 40. PW by different methods comparison for Ankara, Turkey

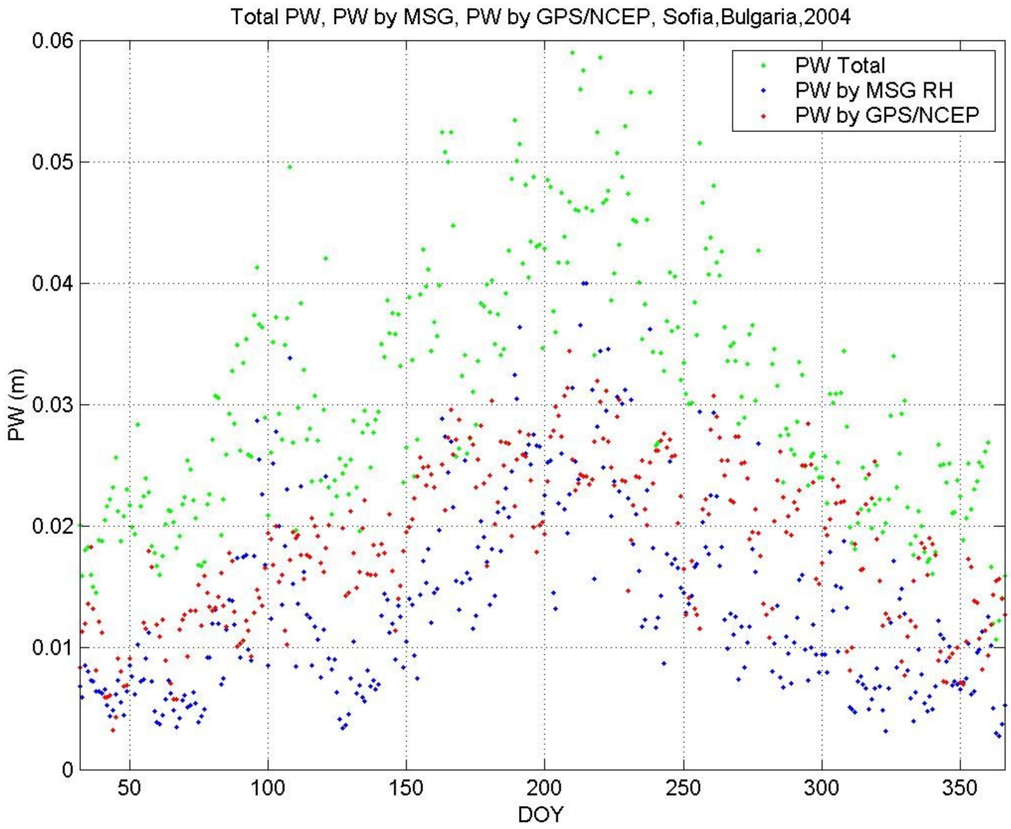

Fig. 41. PW by different methods comparison for Sofia, Bulgaria

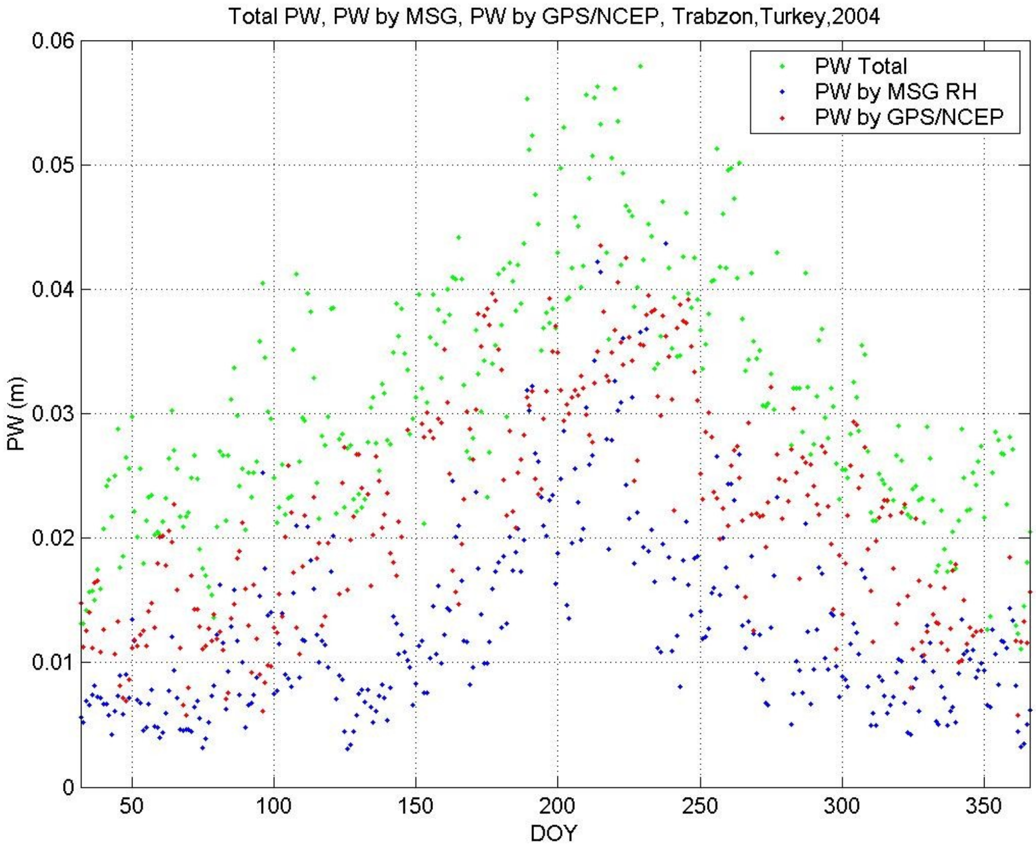

Fig. 42. PW by different methods comparison for Trabzon, Turkey

VI. HIGH RESOLUTION PRECIPITATION INDEX (HRPI) BY MSG VS. PERCEIVABLE WATER (PW) BY GPS

High Resolution Precipitation Index

The High Resolution Precipitation Index (HRPI or HPI) product is primarily generated to support the WMO's Global Precipitation Climatology Project (GPCP). HRPI is based on the relationship between the channel top-of-atmosphere (TOA) radiance equivalent black body temperature (EBBT) of clouds and convective rainfall. The idea of this relationship is that clouds with cold tops are convective rain-bearing clouds. Cloudy pixels colder that a pre-set threshold temperature are taken into account as contributing towards rainfall. The scheme is a cloud indexing method based on the pixel values of an IR channel.

The default HRPI processing area covers a box bounded by ±40° of latitude and ±50° of longitude. It is segmented into equal-angle latitude/longitude areas where the default size of the processing segments is 1° x 1° lat/lon.

Precipitation index values for the various HRPI processing segments are currently derived from satellite infrared image data for the synoptic hours (every three hours starting with 03:00 UTC). For each run of the HRPI product generation task an HRPI data set is generated. All HRPI data sets for one day are put into the final HRPI product, providing a temporal and spatial distribution of the precipitation indices for the day. The precipitation indices are based on the black body temperatures being equivalent to the pixel counts of a particular IR channel (nominally the IR10.8 μm channel). In addition to the precipitation indices, the final HRPI product contains also per processing segment the EBBT mean for each individual run (intermediate product) and the variance of the EBBT means of the individual runs of the day. EUMETSAT has to provide the precipitation index data set to the Global Precipitation Climatology Project (GPCP). The final HRPI product is not disseminated in real-time and delivery is carried out according to GPCP, i.e. it is sent to the EUMETSAT U-MARF once a day and stored. It is currently expected that during the era of MSG the scientific and technical advances of HRPI would result with an improvement to the operational applications.

To compare PW values with HRPI values, of the whole list of 19 GPS sites used in this study only five southward located GPS sites are corresponding to MSG HRPI observing zone: Caglari (CAGL), Lampedusa (LAMP), Atene (IGD1), Creta (TUC2) and Nicosia (NICO). The HRPI elaboration will be done until the first half of 2006.

VII. CONCLUSIONS AND SUGGESTIONS FOR THE FUTURE WORK

This study had shown the utility of GPS data for the vertical humidity analysis in the real time, end the possibility to tie those already verified method with the new Meteosat meteorological products. Such a comparison it should be done locally for the Mediterranean coastal regions in order to determine vertical humidity conditions in connection to registered precipitations, especially heavy, provoking floods, showers.

This good agreement about GPS humidity data in this analysis for the year 2004 is found even with the humidity data acquired from the ordinary meteorological observation network (obtained from NCEP), reaching that way the high level of liability.

Such a GPS/MSG data set in the real time (RT) or in the near real time (NRT), once calibrated with the local meteorological observations and precipitation intensity analysis on the longer time scale (couple of years with moving averages), can be used for the prompt assimilation in the local weather forecast (or climatological) models.

For the future work, eventually, the comparison against the available registered precipitation data (precipitation intensities on the temporal scale from 10 minutes to several hours) obtained by radar data and from the ordinary hydro-meteorological stations for the Adriatic and Ionian coast should be done. The lower tropospheric precipitation response to the vertical stratification of humidity and integrated precipitable water content might be the tool for better prediction of such disastrous events like heavy showers and floods. This time the knowledge about the vertical humidity structure in the real time is available for the very first time in the coupled GPS/MSG products (PW), giving the possibility to adjust locally the parameterization of the coastal precipitation regime. In order to achieve this goal the GPS network should be densified in many Balkanic countries, but also in the whole coastal region around the Mediterranean Sea, especially in flood vulnerable zones.

For the weather forecasting at the coastal zones the difference between the modeled Total PW values against MSG PW values is to be studied further in terms of verified precipitations at the surface or convective weather processes occurred.

Also, about the comparison between the total PW and GPS PW for the coastal regions, the obtained encouraging result should be also studied for the successive periods, in order to be confirmed and calibrated on the longer time scale.

Since the Meteosat Second generation is only at its beginning, new meteorological application can be expected.

Since the very first results of MSG have been applied in this study, the author strongly recommends the continuation of this work on the basis of longer time scales and different climatic conditions.

Acknowledgements

The data presented here have kindly been obtained from: METEOSAT (The Europe's operational agency for meteorological satellites); IGS (The International GNSS Service – GPS and GLONASS) EUREF centers and NCEP (National Centers for the Environmental Prediction) of NOAA-CIRES.

The retrieved data processing at the facilities of The Engineering Department of the University of Modena and Reggio Emilia, Geophysical Observatory, is gratefully acknowledged.

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Slobodan Fazlagić

Modena, 30.12.2005

Dipartimento Ingegneria dei Materiali e dell'Ambiente (OSSERVATORIO GEOFISICO)
Universita' di Modena e Reggio Emilia, Via Vignolese 905, 41100 Modena, Italia
telephone + 39 059 2056215 / fax. + 39 59 205 62 43 / mobile + 39 347 96 82 350
email: sfazlagic@unimore.it / fazslob@yahoo.com