Usage and Upgrade of the CROatian POsitioning System - CROPOS

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Key words: transformation model, on-line transformation services, system upgrade

SUMMARY

The Republic of Croatia launched its GNSS positioning system – CROPOS in December 2008. In just two years after its launch, the CROPOS system has found its wide application in the field of geodesy, cadastre and other economic branches in Croatia. According to the system use indicators, in the past two years CROPOS has been used more than the networks in the neighbouring, larger and better populated countries. The reasons for this are higher quality and reliability of the system on the one hand and in a reasonable pricing policy on the other hand, as well as in continuous system upgrade.

This paper describes the indicators of quality, reliability and system use volumes while the financial effects of its use have been derived from the pricing policy. Subsequently, preparing the framework for the transfer onto the new Croatian referential framework and map projections in practice, the paper shows system upgrade activities undertaken during the two years of the CROPOS functioning as well as the effects that it has yielded or is expected to yield.

Special emphasis with regards to the system upgrade is put on the development of a universal transformation model and its integration into the CROPOS system with the help of a transformation generator and operations implemented by the State Geodetic Administration with the objective of implementing the transformation model. Finally, the paper offers perspectives of the CROPOS system future development and its role in the implementation of the new Croatian referential framework and map projections.

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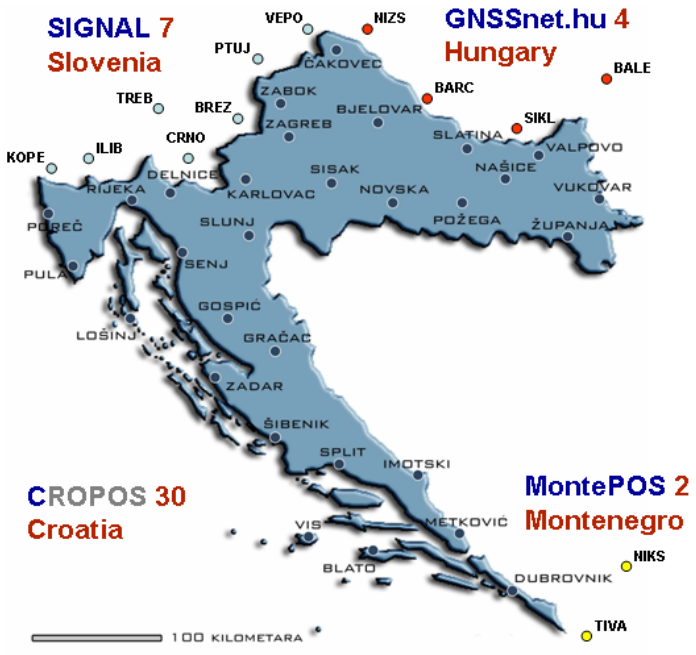
1. INTRODUCTION

The establishment of global positioning satellite systems (GNSS) along with its application in a series of economic activities and systems has not got around the geodetic activity either. One of the main aspirations of the geodetic science and practice has always been to determine the position precisely and reliably with the time consumption and material costs as low as possible, which can be achieved by applying GNNS technology. Due to its accelerated development, the satellite positioning is today a part of the habits and needs of a large number of experts and citizens on daily basis who use it for the most various purposes.

Coping with the modern solutions that increase the efficiency, accuracy and reliability of used satellite positioning and navigation systems, as well as due to the growing needs of the Croatian society, the State Geodetic Administration (SGA) has established a national network of permanent stations - CROPOS (CROatian POsitioning System) that started to be officially used on 9. December, 2008.

2. CROPOS – basic information

2.1. Technical characteristics of the system



CROPOS is a national network of permanent reference GNNS-stations of the Republic of Croatia providing for the users the determination of positions in the so called real time with the accuracy better than +/- 2 cm on the entire territory of the Republic of Croatia, and it consists of 30 reference GNNS-stations (Figure 1.) distributed in such a way that they cover the whole area of the Republic of Croatia, and of a control centre for processing and distribution of data in Zagreb.

Figure 1: CROPOS network design

CROPOS stations are distributed at the mutual distance of about 70 km, and they consist of standardized supporting structures, antenna (Trimble Zephyr Geodetic GNSS), GNSS receiver (Trimble NetR5) and other ITC equipment placed in standard communication cabinets.

The control centre is placed in the data centre in the Central Office of the State Geodetic Administration, and it consists of computer equipment (Helwet Pachard) and communication equipment (Cisco). Trimble GPS RTK software is used for continuous monitoring of reference station coordinates, and parameters, and Trimble GPS Net software is used for the adjustment of the network and computation of correction parameters.

Measuring data processing and the adjustment of the coordinates of reference GNNS stations of the CROPOS system are performed with Bernese GPS Software Ver. 5.0., ITRF2005 reference framework, epoch 2008.83, respecting all prescribed procedures and standards, and the obtained coordinates are transformed into ETRF00 (R05) reference framework. The mean standard deviation of the reference station coordinates is obtained on the basis of the comparison among seven daily solutions, and the mutual adjustment is σ_φ = 1.2 mm, σ_λ = 0.8 mm, σ_h = 3.4 mm.

2.2. CROPOS services

The users have got three types of services at their disposal that are distinguished by solution method, data transfer, accuracy and data format, and the basic characteristics are presented in the table below:

CROPOS services	SOLUTION METHOD	DATA TRANSFER	ACCURACY	DATA FORMAT
DSP	network solution of coded surveys in real time	Wireless Internet (GPRS, UMTS), NTRIP protocol GSM	±0.3 do ±0.5 m	RTCM 2.3
VPPS	network solution of phase surveys in real time	Wireless Internet (GPRS, UMTS), NTRIP protocol GSM	±2 cm (2D) ±4 cm (3D)	RTCM 2.3 RTCM 3.1
GPPS	*post-processing*	Internet (FTP, e-mail)	±1 cm (2D, 3D)	RINEX RINEX VRS

Table 1: **CROPOS** services and their characteristics

2.3. Pricelist of services

CROPOS services are charged, and the price of services (Table 2.) is defined by the Book of Rules on Determination of the amount of real costs being made in using the data of the state survey and real estate cadastre documentation (National Gazette 148/2008).

Type of service	Accuracy	Data Format	Unit	Price	Registration Costs
CROPOS - DPS Differential positioning service	0.3 - 0.5 m	RTCM 2.3	1 year*	HRK 1.000	HRK 300*** (1€ = 7,4 HRK)
CROPOS - VPPS High-precision positioning service	0.02 - 0.04 m	RTCM 2.3 RTCM 3.1	1 minute 1 year	HRK 0,35 HRK 5.000	
CROPOS - GPPS Geodetic precision positioning service	*post-processing*	RINEX RINEX VRS	1 minute**	HRK 0,50	

* **CROPOS - DPS** service is charged on the annual basis only
** **CROPOS - GPPS** service is charged based on the selected time interval only
***Registration costs amount to HRK 300 and are being charged once when filing the application for registration regardless on the required number of services.
- for each additional user device of the same, already registered user, the fee will be calculated so as to multiply the fee for the previously registered user device by 0.9 without charging the costs of registration.

Table 2: **CROPOS** Services Pricelist

When defining the price model we wanted to offer to the users the acceptable prices of services and payment model that would motivate and stimulate them to use the system on the one hand, and to cover the costs of annual system maintenance on the other hand. We have also taken into account that the price model provides simple monitoring and payment of costs made by users. For that purpose the analysis of price models in a few European countries was made, as well as the estimation of maintenance costs on annual basis, and the estimation of the number of possible users (i.e. their needs for licences).

3. SYSTEM USAGE

3.1. Registration of users

CROPOS started to be officially used on 9. December, 2008, and on that day the registration of users was initiated as well, because the services of CROPOS are available only to registered users. In order to be registered, the users submit a request by means of a standardized from, and after being registered by obtaining user name and password, they can access specific service. With one user name and one password the users can access the system using only one device.

From the beginning of its becoming operative, the number of CROPOS users has been growing continuously, and on 01. March 2011 it reached the number of 340 users. The largest number of users was of course registered immediately after it had been put into operation as over 200 users were registered within the first six months (Figure 2.).

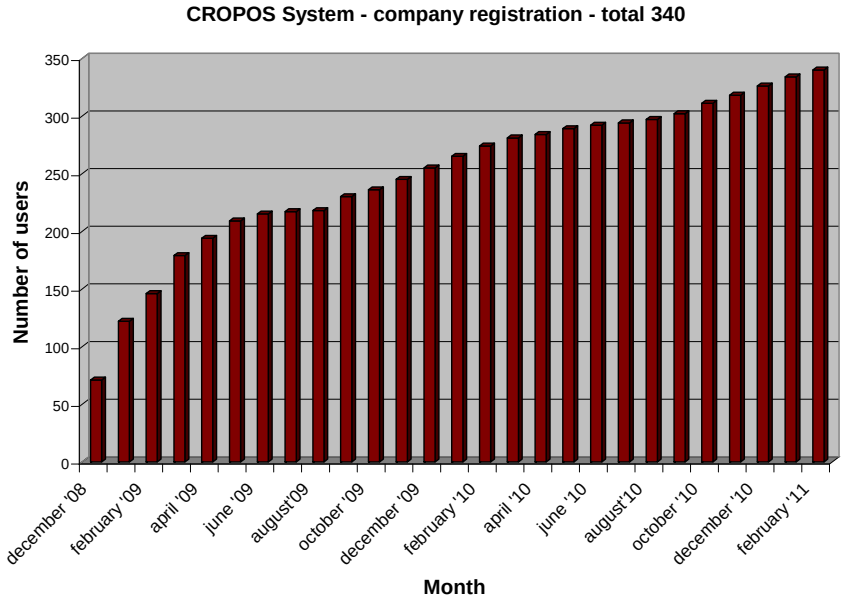


Figure 2.

The largest number of users is also licensed for the usage of VPPS service – 466 licences (Figure 3.) out of which 158 (34%) refer to payment model according to the real time of usage, and the other – 308 (66%) refer to the annual subscription model, which we actually wanted to achieve at the moment of creating a price model. All users registered for using VPPS service are also registered for using GPPS services.

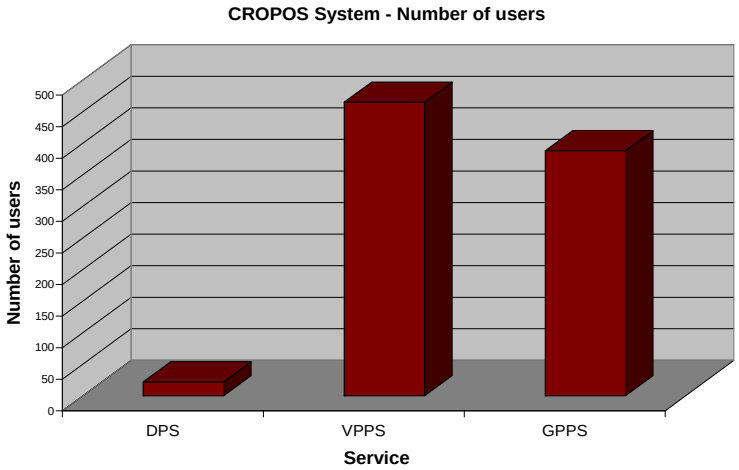


Figure 3.

In the last two year the least interest has been shown in DPS service having only 22 users, and we have to pay more attention to its promotion in the future, primarily referring to other state bodies and public companies for the purpose of using this service in the maintenance of their GIS systems.

3.2. User support

In the last two years of work the system has proved to be very reliable both from the technical point of view and from the point of view of communication with users. Sudden interruptions of telecommunication connections or the malfunction of measuring equipment have been solved in a very short periods of time, and what is the most important, without negative consequences for end users. Apart from good technical performances and reliable system operation, well prepared public information campaign has greatly contributed its quick acceptance by users, but also a well prepared user support system.

For that purpose the regional information workshops (4) were organized before the system was directly put into operation (November 2008) that were attended by over 800 participants (potential users) who were thus directly acquainted with the technical characteristics and demands to be met by them in order to access CROPOS services, as well as with usage conditions.

Figure 4. CROPOS web site

There was also the promotion material made and distributed to users: leaflet, brochure, CROPOS usage manual and education video. For the purpose of providing the information about the current condition of the system, there was also CROPOS web page established (**www.cropos.hr** Figure 4.**)** together with the information system, so called newsletter.

In order to provide better information about the possibilities of the system through the exchange of Croatian and international experiences in using permanent GNNS networks, there was CROPOS conference organized in June 2009 attended by over 350 participants, and in the programme part there were 23 scientific and professional works presented that are available for the entire public in the printed Proceedings and on the web page. In this way the users of CROPOS could become highly trained, which can be concluded from the fact in the last two years of system operation we have had an almost negligible number of inquiries sent by users in connection with the access to the system and its usage.

3.3. System usage

The high reliability of the system operation, good information services and user support, as well as acceptable prices of services have created great confidence of users in the system, which consequently resulted in a large number of minutes spent in using the system.

Already after half a year of system operation, the most popular service – VPPS was used for 300.000 minutes, and the maximum usage was reached in April 2010 with over 550.000 minutes. Ever since, the average usage per month is about 400.000 minutes (Figure 5).

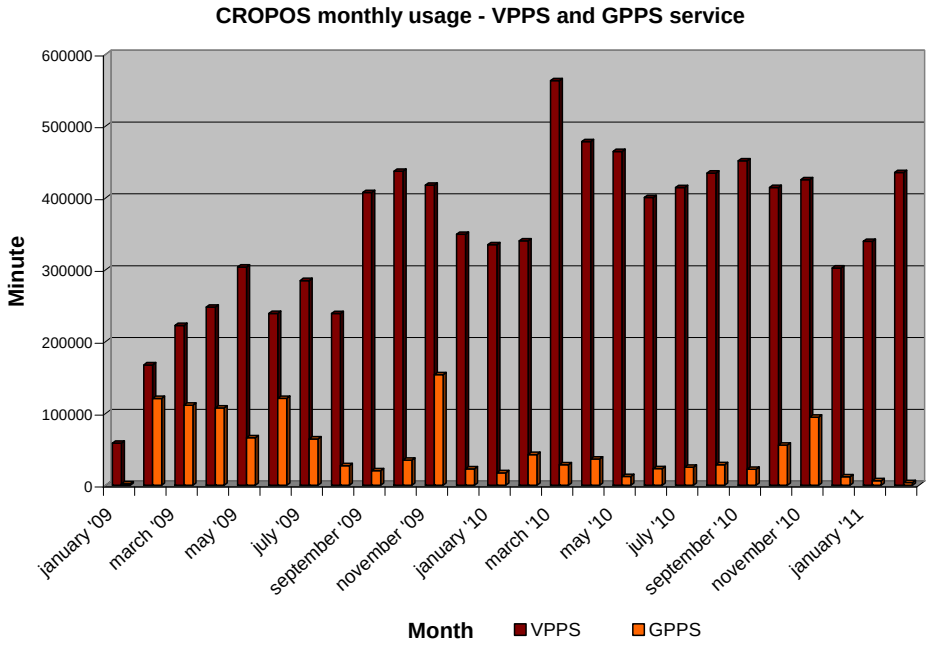


Figure 5.

The usage of GPPS service has also reached an enviable level, and the usage statistics shows that its usage is being continuously reduced. It can be therefore concluded, that the confidence of users in reliability and accuracy of VPPS service is constantly growing, i.e. the GPRS signal coverage has been improved in the meantime.
The annual profit of the system in 2009 was 1.528.147,00 Kn (206.500 €), and in 2010. 1.801.973,00 kn (243.500 €). The collected funds are the income of the state budget, and their amount covers completely (and more than that) the amount of total annual costs of system maintenance (personnel, telecommunication, the costs of maintaining the programme, computer and measuring equipment).

4. SYSTEM UPGRADING

4.1. Networking with neighbouring countries

In order to increase the quality and reliability of data in border areas of countries the agreements were signed at the midyear of 2009 with the Republic Hungary, the Republic Slovenia and Montenegro, and there was the data exchange among border stations established, so that there are now 43 reference GNSS stations included into the networking solution and computation of correction parameters. The system was also upgraded in 2009 for back-up data, and the system for maintenance, surveillance and remote control of all system servers was installed.

4.2. Reference systems in the Republic of Croatia

Pursuant to the Act on State Survey and Real Estate Cadastre (National Gazette 116/99), the Decree on Defining the Official Geodetic Datums and Horizontal Map Projections of the Republic of Croatia was passed in 2004 (National Gazette 110/04 and 117/04). The implementation of new official datums in practice is very complex and long-lasting process, and it is performed on the basis of the Programme of Introducing Official Geodetic Datums and Map Projections.

According to the Decree, the Croatian Terrestrial Reference System was defined as a new positional system HTRS96 – Croatian realisation of ETRS89 (GRS80, ellipsoid heights), and the old Croatian coordinate system HDKS (Bessel, orthometric height) is still being used in practice until the complete transfer to the new reference system.

The new vertical system of the Republic of Croatia – HVRS71 is determined by the geoid datum defined by the mean sea level for the epoch 1971.5 on five tide gauges equally distributed along the Adriatic coast (Dubrovnik, Split, Bakar, Rovinj and Kopar). Just as it is the case with the positional datum, the old vertical reference system defined by the tide gauge in Trieste as its original point is still used.

Referring to the above mentioned, the following reference coordinate systems are officially used in the Republic of Croatia (Table 3.):

Name of the coordinate system	Ellipsoid	Types of coordinates	Vertical datum	Note
HTRS96 = ETRS89 = ETRF00(R05)	**GRS80**	**φ, λ, h (X,Y,Z)**		**Ellipsoid heights h**
HTRS96/TM	**GRS80**	**E,N, H Transverse-Mercator projection**	**HRVS71**	**Orthometric heights $H = h - N_{HVRS71}$**
HDKS	**Bessel**	**x, y, H Gauss – Krüger projection**	**Trieste**	**Orthometric heights $H = h - N_{Trieste}$**

Table 3. Coordinate systems in official use in Croatia

4.3. Development of geoid model

The system CROPOS generates a set of ellipsoid coordinates (φ, λ) together with the ellipsoid height h in ETRF00(R05) system coinciding with ETRS89 system, i.e. the Croatian official reference system – HTRS96. In practical usage we need orthometric heights instead of ellipsoid heights, and they are obtained if the geoid undulation N is known, in other words, we

should know the relation between the surfaces of geoid and ellipsoid. For that purpose a new significantly improved geoid model HRG2009 was developed in collaboration with the Faculty of Geodesy in Zagreb at the end of 2009.

The following has been taken into consideration in the calculation of new geoid surfaces:

- point values of free-air anomalies(over 30000),
- geoid undulations obtained on the basis of precise levelling and GNSS measurements (for 495 points),
- geoid undulations obtained from satellite altimetry in the area of the Adriatic Sea (400),
- global geopotential model EGM2008

The final result is a very reliable geoid surface relating to the new official vertical system with standard deviation of +/- 0,03 m referring to internal accuracy, and the external accuracy estimation with standard deviation of +/- 0.04 m is obtained by comparing it with control points (59 points) that are not used in the model development. These data indicate a well selected methodology and the execution of numeric computation, as well as high absolute reliability of HRG2009 geoid model for the entire area of the state.

For the purpose of mutual transformation of the heights from the old reference vertical system (Trieste) into the new Croatian vertical reference system (HVRS71) the transformation height model – HTMV08 was developed. The transformation model includes datum and distortion components that are realized in the form of grid density of 45“ x 30“ on the basis of 8448 bench marks with the heights in both systems, and there was the external accuracy of the model obtained with the standard deviation of +/- 0.01 m on the basis of 1589 points that were not used for the production of the model. The model is installed into the computer programme T7D and as such it is used for the transformation of heights between the height systems, i.e. for the computation of geoid surface.

4.4. Development of transformation model T7D

One of the most important and key tasks of the Programme for the introduction of official geodetic datums and map projections is the development and defining of a unique transformation model that would provide a simple and for all users uniform procedure for the transformation of data and cartographic and cadastral documents made in the historical reference system into the new official geodetic references system – HTRS96/TM and vice versa.

A unique transformation model called T7D, has been developed in collaboration with the Faculty of Geodesy, University of Zagreb at the end of 2009. There were 5200 identical points used for the development of the model, and these points cover the entire territory of the state with known coordinates in both reference systems. The model is based on the principle of GRID transformation and includes the whole territory of the state, and it consists of parameter transformation being in 15“ x 20“ regular raster of predicted distortion values for

the positional coordinates and heights.

The final product is the computer programme T7D (software) that provides positional and vertical accuracy of the transformation of +/- 0.06 m (in both directions) for the whole state area. HRG2009 geoid model and the height transformation model are integrated in the programme.

4.5. CROPOS on-line transformation services

Coping with the technological development and trying to provide as simple and as efficient performing of field measurements as possible for our users we started the process of integrating HRG2009 geoid model and T7D transformation model into CROPOS during the year 2009 for the purpose of establishing on-line transformation services. In order to do that, the system has bee upgraded in its application part with Trimble Transformation Generator Software, as well as with adequate computer equipment. The final result of these activities are new CROPOS services enabling the on-line transformation of coordinates:

1. CROPOS_VRS_HTRS96
2. CROPOS_VRS_HDKS

4.5.1. CROPOS_VRS_HTRS96

CROPOS system generates in its original form the ellipsoid coordinates (φ, λ, h) in ETRS89 system, however the projection coordinates (E,N, H) in the plane of the map projection – HTRS96/TM are much more useful to users.

For this purpose a new service CROPOS_VRS_HTRS96 has been developed making it possible for the user to determine the coordinates directly in the new map projection – HTRS96/TM and the new official height system - HVRS71 of the Republic of Croatia without any additional computations of coordinates. Since we deal here with the same reference systems using GRS80 ellipsoid as a mathematical model, but using various types of coordinates for the presentation of position, we need to know the geoid undulation as well, i.e. geoid surface in the official height system – HRVS71 in order to make the transfer to projection coordinates.

By means of the service CROPOS_VRS_HTRS96 the user rover determines the official ETRS89 (HTRS96) ellipsoid coordinates (φ, λ) by applying RTK corrections sent by CROPOS system, and the users need to set up on their rovers the parameters for the presentation of the coordinates in the projection plane HTRS96/TM (E, N). Within the frame of this service there are also the geoid undulations N sent of the new geoid model HRG2009 in the official height system HVRS71, and the obtained ellipsoid heights h are computed into the orthometric heights H in real time (H = h – N, Figure 6.).

The testing of CROPOS_VRS_HTRS96 service was performed on 604 control points by comparing the on-line results and by using HRG2009 geoid in T7D model. The differences of

the obtained orthometric heights (on-line vs post-processing) are of accidental character (0 mm, +1 mm or -1 mm), which is completely satisfactory for the practical application. The service has been officially applied since 3. January 2011.

4.5.2. CROPOS_VRS_HDKS

Sine the old reference system – the Croatian coordinate system – HDKS is still used in the Republic of Croatia, the determination of coordinates directly in this system has got large practical value for the users in their field work. With respect to such needs we have concluded that it is necessary to develop the second CROPOS on-line transformation service CROPOS_VRS_HDKS that would make it possible for the users to determine the coordinates directly in the Croatian state coordinate system (Gauss-Krüger projection) and the old height system (Trieste) without any additional computation of coordinates.

Using CROPOS_VRS_HDKS service, the user rover determines the official ETRS89 (HTRS96) ellipsoid coordinates (φ, λ) by applying RTK corrections sent by CROPOS system, and the users need to set up on their rovers the parameters for the presentation of coordinates in the plane of the projection HDKS (y, x). By means of RTCM 3.1 message the data about transformation parameters and the values of distortion correction needed to perform the datum transformation in real time are emitted, as well as the geoid undulations that refer to the old height system (Trieste) and by which the ellipsoid heights h are computed into orthometric heights H in real time (H = h – N, Figure 6.).

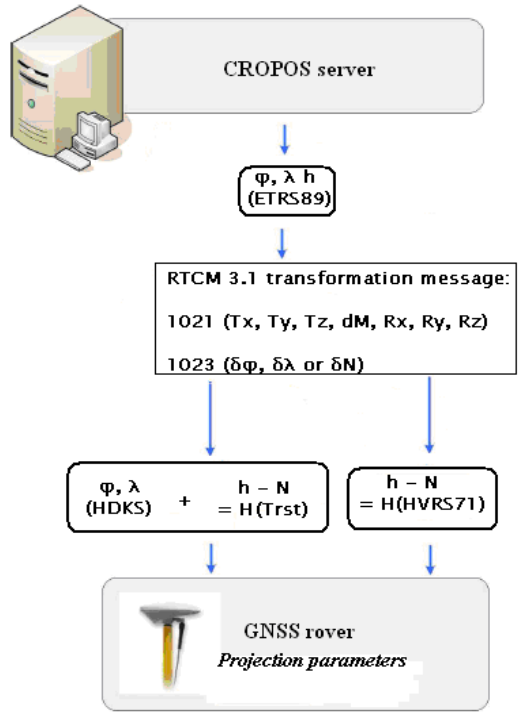


Figure 6. CROPOS online transformation services

CROPOS_VRS_HTRS96 service was implemented into CROPOS at the beginning of March 2011 as the first test measurements were also made. The coordinates of test points determined

by means of on-line transformation using CROPOS_VRS_HDKS services and post-processing transformation using T7D model coincide completely, the deviations are in the amount of +/- 0.01 m. Within the frame of the complete testing of CROPOS_VRS_HDKS we plan to make test measurement on 1000 points equally distributed on the entire state territory and then compare the obtained results (on-line vs. post processing), we intend to start using the service at the beginning of June 2011 officially.

The usage of new services demands from the user rovers to have the possibility of receiving RTCM 3.1 format messages (the usage of transformation messages 1021 and 1023), i.e. the possibility of applying the emitted RTCM within the user rover. The usage of new services does not require any additional registration of users, the needed service is only selected when connecting to CROPOS.

5. CONCLUSION

In the last two years of its operation CROPOS has been widely used in the areas of geodesy and cadastre, as well as in other economic branches. According to the usage indicators, it has been used much more than the system in the neighbouring countries. The reason is surely in its high quality and the reliability of services on the one hand, but also the acceptable price strategy on the other hand, as well as continuous investments into the system upgrading.

The establishment of CROPOS has provided the basic conditions for a wide application and implementation of new official geodetic datums and map projection on the entire territory of the state, a unique and homogeneous coordinate system has been developed and the determination of coordinates provided with the same accuracy on the whole state territory.

The performance of geodetic works accompanied by the usage of CROPOS services is quicker, simpler and above all more efficient, enabling simultaneous increase of reliability and accuracy in determining the coordinates. High technological and technical quality of all system components, as well as its administration and maintenance have provided a reliable operation and accessibility of the system in the amount of 99,9%. Due to these advantages in only two last years CROPOS has become an inevitable tool in performing everyday tasks for a large majority of economic subjects within the geodetic and cadastral system.

We are therefore obliged to maintain the system on high technical level and reliability by coping with and installing new technological solutions into the system. By introducing new services we want to enlarge the group of users in as short period of time as possible including all economic subjects in the geodetic and cadastral system, and to provide for the existing users even more efficient usage of the system.

We also pay a lot of attention to further education of users, and this year collaborating with the Faculty of Geodesy and the Croatian Chamber of Chartered Engineers of Geodesy we have started to organise the 2. CROPOS conference that will be held on 8. April, 2011. At the time this text was being written, there were already 350 participants registered at the

conference, and 17 works are expected to be presented. The goal of the conference is improve CROPOS in the performance of ever larger number of everyday tasks by exchanging the Croatian and international experiences, and to introduce its application in other state administration bodies, public companies, economy and the entire public.

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