The RAP Net: A Geodetic Positioning Network for Andalusia (South Spain).

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Abstract

The Council of Public Works and Housing of the Government of Andalusia by means of the Andalusian Cartographic Institute has set a positioning geodetic network named Andalusian Positioning Network (RAP). The Laboratory of Astronomy, Geodesy and Cartography (LAGC) of the University of Cadiz is responsible for the design, development, quality checking, geodetic control and technical support of this network.

The RAP network main goal is providing GPS data in RINEX format for post-processing operations, and broadcasting differential corrections (RTK or DGPS) from the stations for real-time operations.

The RAP network is formed by 22 permanent stations distributed homogeneously as to solve the position problem along Andalusia, including the coast line. The network is referred to ETRF89 reference frame and it has become the geodetic reference frame to scientific and technologic applications, such as the geodynamic control of Andalusia; precise geoid determination; obtaining tropospheric and ionospheric models to regional climatological studies; setting photogrammetric points or marks for georeferencing of satellite images; establishing control points for reference networks in big civil works, for GIS applications, and for terrestrial, maritime and aerial navigation etc.

In this paper we present the proceedings to design and set up of the network, to the organization and quality checking of data and the stations. Finally we explain the methodology established to calculate and adjust the RAP network.

1. DESIGN AND DEVELOPMENT OF THE RAP NETWORK

The RAP network has been designed in two different stages, according to the equipment in the stations and their location. The first stage stations are further fitted up and they are located in the eight main cities of Andalusia and in Algeciras. On the other hand, those second stage stations are less fitted up and they are located in underpopulated areas, although they keep the geodetic characteristic.

The locations of the stations have been selected according to a spatial analysis performed with the ESRI software ArcGIS 9.0, where criteria such as homogenous geometric distribution, highest coverage of the population and coast have been imposed. It has also been considered the availability of 9 stations more equipped than the other ones

The first result concluded that one station had to be located in every Andalusian capital; moreover, it was necessary to setting up one more station in Algeciras to support shipping in the Straits of Gibraltar. This configuration in the first stage fixed the position for some of the stations in the second stage. In figure 1 it is shown the final distribution that mostly satisfied the imposed conditions. In the final design the stations have a separation between 50 and 70 km. from each other, approximately. So, the 100% of Andalusia is covered by the real-time differential corrections.

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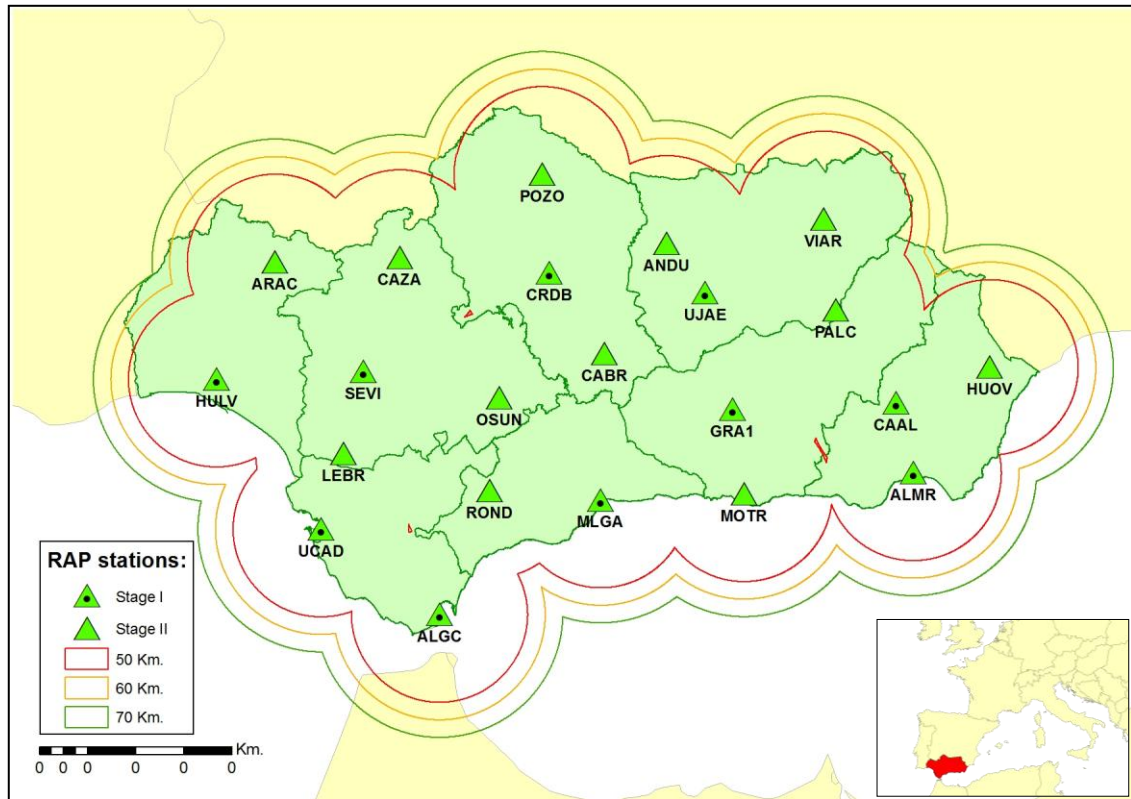
Figure 1: Distribution map of the RAP stations.

CODE	STAGE	RAP ID No.	EUREF DOMES No.	LOCATION
ALGC	1	3	13456M001	Algeciras (Cádiz)
ALMR	1	7	13437M002	Almería
ANDU	2	20	13477M001	Andújar (Jaén)
ARAC	2	13	13467M001	Aracena (Huelva)
CAAL	1	15	13474M001	Calar Alto (Almería)
CABR	2	16	13473M001	Cabra (Córdoba)
CAZA	2	18	13471M001	Cazalla de la Sierra (Sevilla)
CRDB	1	8	13461M001	Córdoba
~~GRAN~~	~~1~~	~~6~~	~~13459M001~~	~~Granada.~~ – *Former* –
GRA1	1	24	13459M002	Granada
HULV	1	2	13451M002	Huelva
HUOV	2	22	13479M001	Huercal-Overa (Almería)
LEBR	2	12	13466M001	Lebrija (Sevilla)
MLGA	1	5	13460M001	Málaga
MOTR	2	21	13478M001	Motril (Málaga)
OSUN	2	11	13465M001	Osuna (Sevilla)
PALC	2	23	19349M001	Pozo Alcón (Jaén)
POZO	2	14	13468M001	Pozoblanco (Jaén)
ROND	2	10	13464M001	Ronda (Málaga)
SEVI	1	4	13457M001	Sevilla
UCAD	1	1	13455M001	Puerto Real (Cádiz)
UJAE	1	9	13458M001	Jaén
VIAR	2	17	13472M001	Villanueva del Arzobispo (Jaén)

Table 1: RAP stations info

Ten of the stations are located in hospitals from the Andalusian healthy system. It is because their buildings are usually the highest in towns, so the visibility over the horizon is very clear. Moreover they have got uninterrupted power supply with emergency electrogenous groups in case the supply is down. These hospitals are in the corporative telecommunication network of the Andalusian Government, so the permanent link between the Control Centre and the stations is warranted through a wide band Internet connection.

The station CAAL (Calar Alto) is located in the installations of the Spanish-German Astronomic Centre, it being possible to connect celestial and terrestrial reference frames. It means an adding value to this network. Therefore, in spite of this station was initially considered to be part of the second stage, it has become one of the first stage.

The installation of the geodetic ground markers has been carried out in every location almost in the same way, except in Calar Alto. The monumentation has been made with a cylinder hollow steel mast, 10 centimetres in diameter and one and a half centimetre in thickness. Depending on the location of the station, is fixed by means of two brackets soldered and screwed on a vertical wall (see figure 2), or it may be a squared metal base of 20 centimetres for each side that is screwed on a pillar of the building (fig.3). In some cases, this cylinder is directly soldered to the structure of the building (fig. 4).

In the station CAAL, there is a geodetic pillar embedded in the ground where a two metres high steel cylinder was fixed. Three steel cables were fixed from the mast to the ground to secure its stability when strong winds blow.

Figure 2: CRDB station   Figure 3: UCAD station   Figure 4: ALGC station

As it is mentioned above, the installed instrumentation at the RAP stations is different depending on the stage to which it belongs. The first stage stations have the following components: geodetic antenna choke-ring (Dorne-Margolin) Leica AT504 with dome; double frequency receivers Leica GRX1200 Pro, with 4 serial ports and an ethernet port, UPS system, permanent Internet connection and meteorological station Paroscientific Met3 (pressure, humidity and temperature). The second stage stations only have the double frequency receivers Leica GRX1200 Pro, the geodetic antenna Leica AX1202, a UPS system and permanent Internet connection.
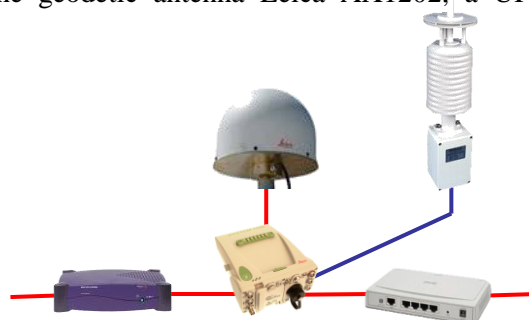

Figure 5: Equipment of first stage stations: double frequency GPS receivers, geodesic antenna with choke-ring and meteorological station.

2. QUALITY CHECKING OF THE STATIONS AND THE RECORDED DATA

The quality checking in the RAP network is being continuously performed to assure the user the quality of provided data. This quality checking is carried out to analyse the quality and stability of the stations and the time series of the GPS data. The geodetic network quality depends on not only on installed equipment but also the physical location of the station.

The quality checking of the stations is carried out by mean of the analysis of different parameters related to: the presence of obstacles over stations horizon; effects of multipath on the GPS signal; received signal strength; signal-to-noise ratio; number of obtained observations and stability of the navigation position.

To evaluate the obstacles that can interfere with the signal reception, the satellites orbits projections are represented in azimuth-elevation sky plot. In this way the existing obstacles are detected (Figure 6). These graphics are obtained with free software QC2SKY (M. Roggero, 2004). Analysing these graphics lets us determine those obstacles influence on the realized observations. To study the multipath effect and cycle slips on each L1 and L2 frequency it is used the TEQC software (Translate/Quality Check) of UNAVCO (University NAVSTAR Consortium).

Multipath effect in L1 frequency UCAD station

Multipath effect in L2 frequency UCAD station

Satellites orbits in Cartesian projection, observed from the UCAD station.

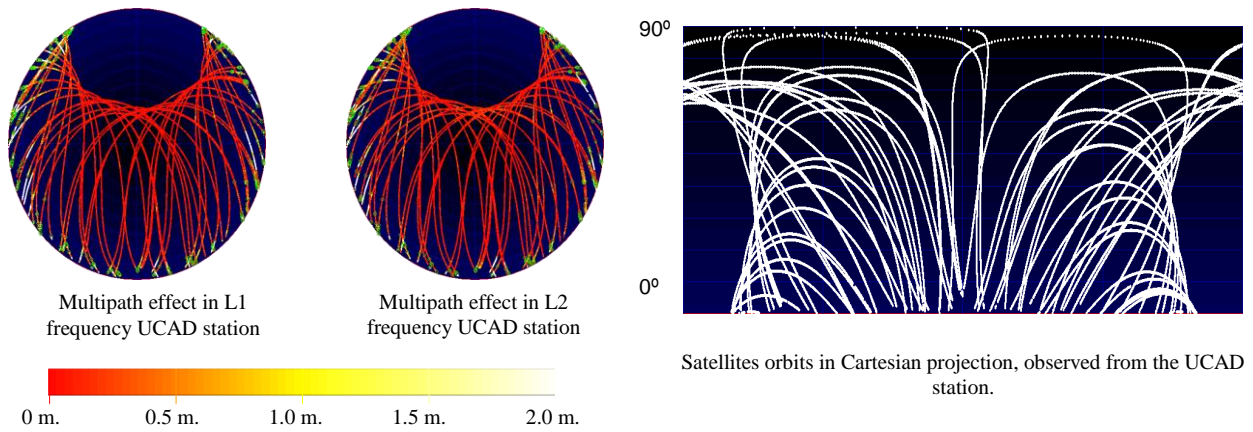0 m.   0.5 m.   1.0 m.   1.5 m.   2.0 m.

Figure 6: Satellites orbits projections observed from the UCAD station.

To study the SNR on the L1 and L2 frequencies daily graphics are done, representing the information kept in the RINEX files using a colour code (figures 7 and 8). If there is any incidence, the information is contrasted with that from Notice Advisory to NAVSTAR Users, NANU's, offered by the American Coastguards Centre, determining if the incidence is due to the satellites or the station.
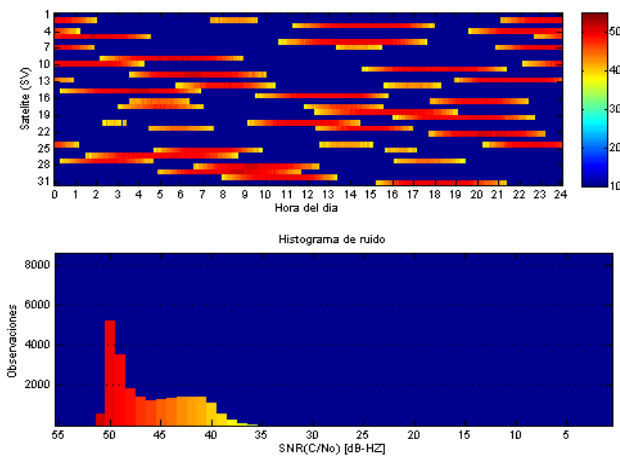

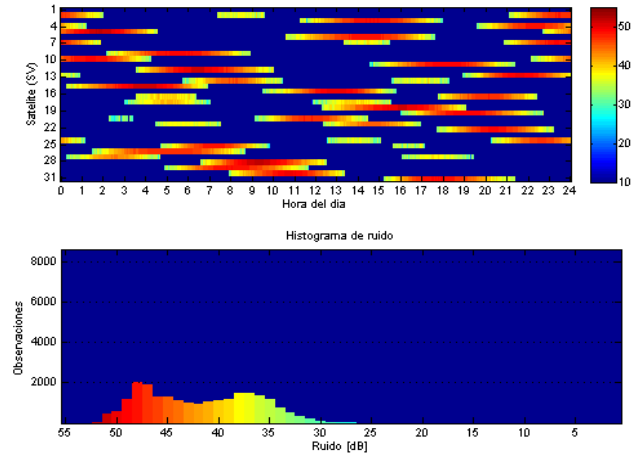Figure 7: Example of graphic to SNR in L1 frequency from the HULV station

Figure 8: Example of graphic to SNR in L2 frequency from the HULV station

The stability of the navigation position is analyzed. Changes on the calculated position per epoch by means of the C/A code are studied. Figure 9 shows the horizontal representation of the navigation positions to one day. The average and accuracy are evaluated by comparing these positions with the fixed to each station.
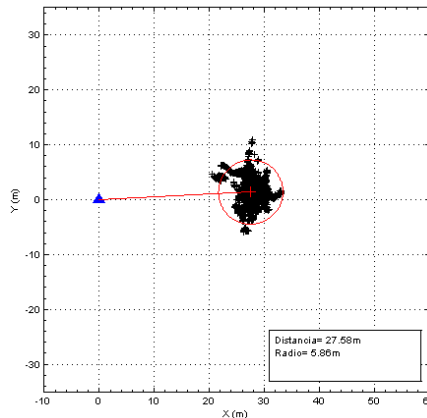

Figure 9: Horizontal representation of the navigation position per
epoch in the UCAD station for 24 hours.

Data quality checking is carried out comparing the parameters to those obtained by other international networks such as EUREF and IGS. The software TEQC (UNAVCO) is used for it. Different analyses are realized starting from RINEX daily files. Some applications programmed for MSDOS and MATLAB have been made specifically created by the Laboratory of Astronomy, Geodesy and Cartography (UCA) to carry out this quality checking.

First of all it is evaluated the number of realized observations as contrasted with the expected ones (Figure 10), agreeing with the criteria established by the International GNSS Service (IGS). To a permanent station with clear horizon and recording data at 30 seconds interval, the number of expected observations should be 20000 or more per 24 hours.
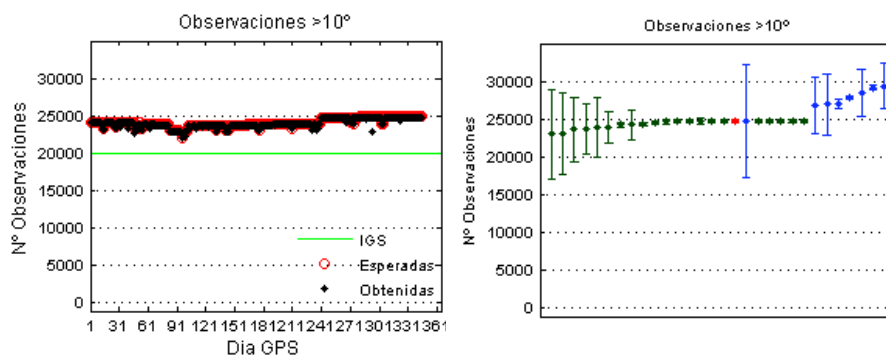

Figure 10: Number of expected and obtained observations for 2010 in the CRDB station and mean/variance
graphic for the RAP stations.

Another of the essential parameters is the root mean square of the multipath effect in L1 (Figure 11) and L2 signals (Figure 12). The RMS MP1 parameter value for the 50% of the IGS stations is less than 0.4 m. and for the 30% is less than 0.5 m. In case of the L2 signal, the respective values are 0.6 m. and 0.75 m.
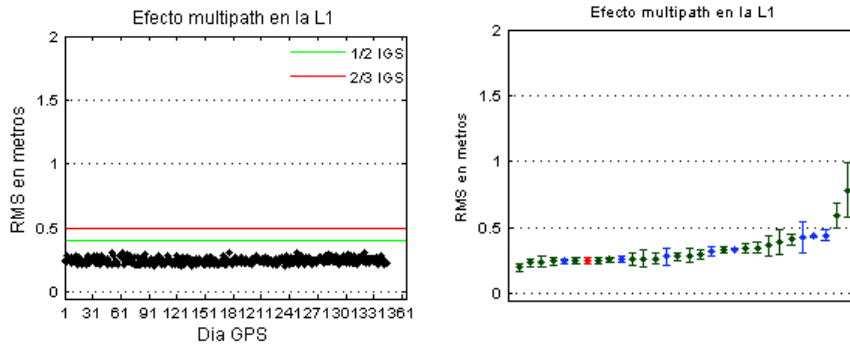
Figure 11: RMS of the multipath effect on the L1 signal, obtained for 2010 in the CRDB station and mean/variance graphic for the RAP stations.
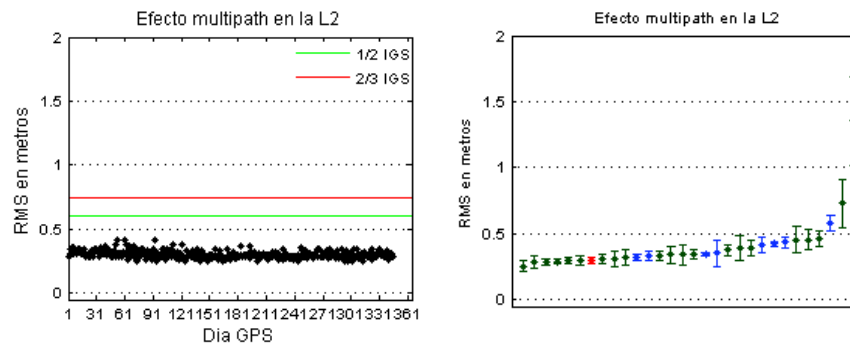

Figure 12: RMS of the multipath effect on the L2 signal, obtained for 2010 in the CRDB station and mean/variance graphic for the RAP stations.

Also is studied the cycle slips (x1000) compared to the total number of observations. These values are less than 5 for more than half of IGS stations, and less than 10 for more than 2/3 of IGS stations. (Figure 13).
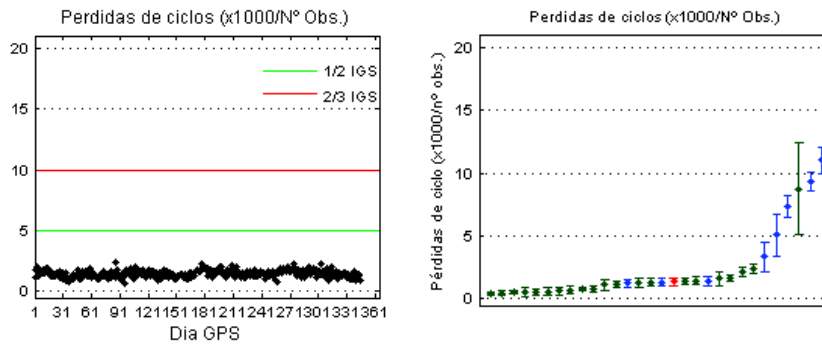

Figure 13: Cycle slips (x1000/Nº Obs.) for 2010 in the CRDB station and mean/variance graphic for the RAP stations.

3. NETWORK CALCULATION AND ADJUSTMENT

The final target for the establishment of a geodetic network is calculated absolute coordinates for the stations. Therefore, once the RINEX files have been obtained, it is realized an precise positioning and adjustment for the network stations, taking always as a reference some stations from permanents networks of upper order. For all this process it is used the Bernese 5.0 software, developed by the Astronomical Institute of the University of Bern (Switzerland), settings options according to IGS and EUREF processing (Table 2).

Ambiguity Fixing	In the final solution.
Antenna Phase Corrections	IGS Absolute Phase Center Variation files
Cut Off Angle	10°
Sampling Rate	180 sec for the final parameter estimation.
Orbits	IGS final orbits.
Earth Orientation Parameters	IGS final products
RMS in SINEX files	In the final solution
Ocean Tidal Loading	From Onsala Space Observatory
Mapping Function	Niell Model
Troposphere Parameters	Hourly

Table 2: Parameters set in the processing.

In the RAP stations, GPS observations are recorded for 24 hours to 1 Hz sampling rate and a 0º elevation mask, although to processing data they are resampled to 30 seconds and it is established a 10º elevation mask to reduce atmospheric refraction effect.

The network calculation and adjustment process is realized every week. Free daily solutions are determined by the adjustment of the least-mean square, being obtained a weekly solution for each station. Finally the network is minimal constrained on fiducial stations in IGS05 frame (http://igscb.jpl.nasa.gov/mail/igsmail/2006/msg00170.html): SFER (San Fernando-ROA), VILL (Villafranca-ESA) and RABT (Rabat-UNAVCO) (see Figure 14). The coordinates obtained are transformed to ITRF2005 (Ferland, R. (2006b). IGSMAIL-5447) and finally transformed to ETRF2005 (Boucher, C., Altamimi, Z., 2008). The stations coordinates are established for each considered epoch, this way it is constituted the RAP reference frame for Andalusia (see Table 3).
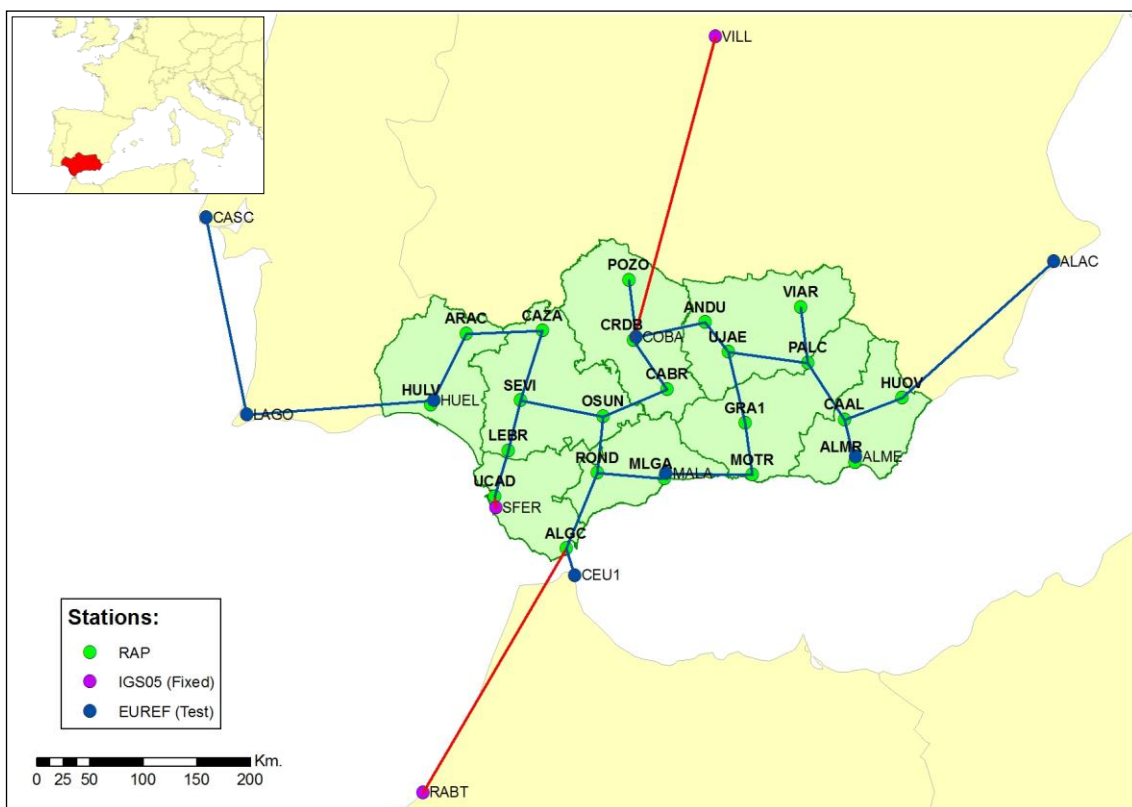

Figure 14: Site locations and processed baselines.

COORDINATES INCLUDES TO RTCM STREAM (ETRS89)				
STATION	ID	X	Y	Z
Algeciras	ALGC	5135570.639	-489449.719	3738221.726
Almería	ALMR	5104673.974	-217597.900	3805329.629
Andujar	ANDU	5017453.382	-353522.029	3909149.329
Aracena	ARAC	5007190.803	-576288.582	3896600.493
Calar Alto	CAAL	5081921.525	-226112.457	3838297.598
Cabra	CABR	5053918.413	-391028.409	3859089.821
Cazalla de la Sierra	CAZA	5011763.840	-505522.339	3900415.589
Córdoba	CRDB	5023360.654	-420749.298	3894832.066
Granada	GRA1	5077918.014	-319155.702	3834700.964
Huelva	HULV	5044358.209	-611644.328	3842260.051
Huercal-Overa	HUOV	5070413.844	-171934.990	3853104.551
Lebrija	LEBR	5076496.079	-540901.678	3810560.597
Málaga	MLGA	5103686.781	-395880.322	3792209.024
Motril	MOTR	5106803.442	-314181.536	3795723.027
Osuna	OSUN	5064632.624	-451576.052	3838171.732
Pozo Alcón	PALC	5046810.771	-258521.907	3879916.978
Pozoblanco	POZO	4988767.020	-423244.307	3939354.620
Ronda	ROND	5096416.987	-458741.918	3796043.529
Sevilla	SEVI	5049343.966	-528173.576	3848026.888
Cádiz	UCAD	5101039.418	-555095.877	3775797.721
Jaén	UJAE	5036325.112	-332899.123	3887177.068
Villanueva del Arzobispo	VIAR	5014599.640	-263899.023	3920551.445
Algeciras	ALGC	5135570.639	-489449.719	3738221.726
Almería	ALMR	5104673.974	-217597.900	3805329.629
Andujar	ANDU	5017453.382	-353522.029	3909149.329
Aracena	ARAC	5007190.803	-576288.582	3896600.493

Table 3: RAP stations coordinates.

A quality check of the adjusted coordinates is made by comparing our weekly solution for the test stations to the positions published weekly in the EPN combined solutions by EUREF. Examples of quality check at LAGO control stations are displayed below. Figures 18 show a good agreement between our solutions for LAGO coordinates with respect to EUREF results.
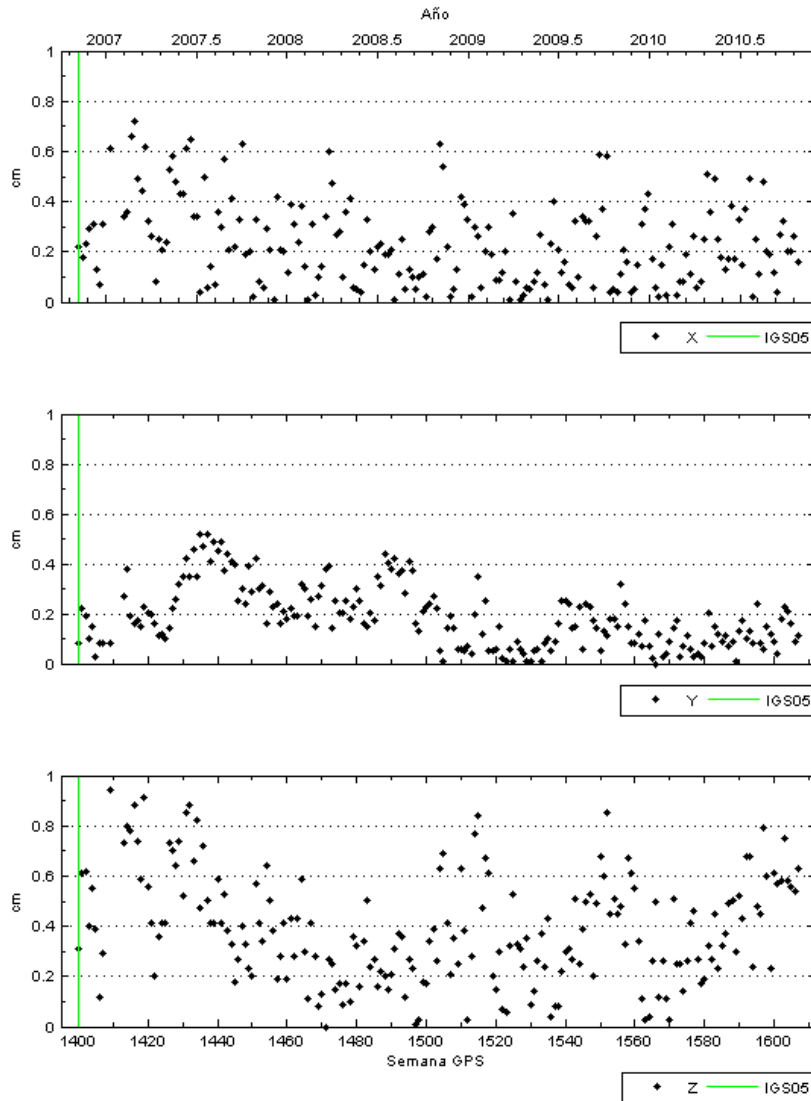
Figure 18: IGS05 Cartesian coordinates at RAP vs. EUREF AC´s for ALME solutions.

In the Web site for the Geodetic Control of the RAP network (rap.uca.es) can be found different studies about the parameters evaluated in the quality control and geodetic control of the network. In this site are possible consult the time series of IGS05 coordinates, ETRF05 coordinates (see Figure 19), and the residuals obtained after removing the trend and annual periodicity computed with CATS software) to all stations (Williams, S., http://www.pol.ac.uk/home/staff/?user=WillSimoCats (see Figure 20).

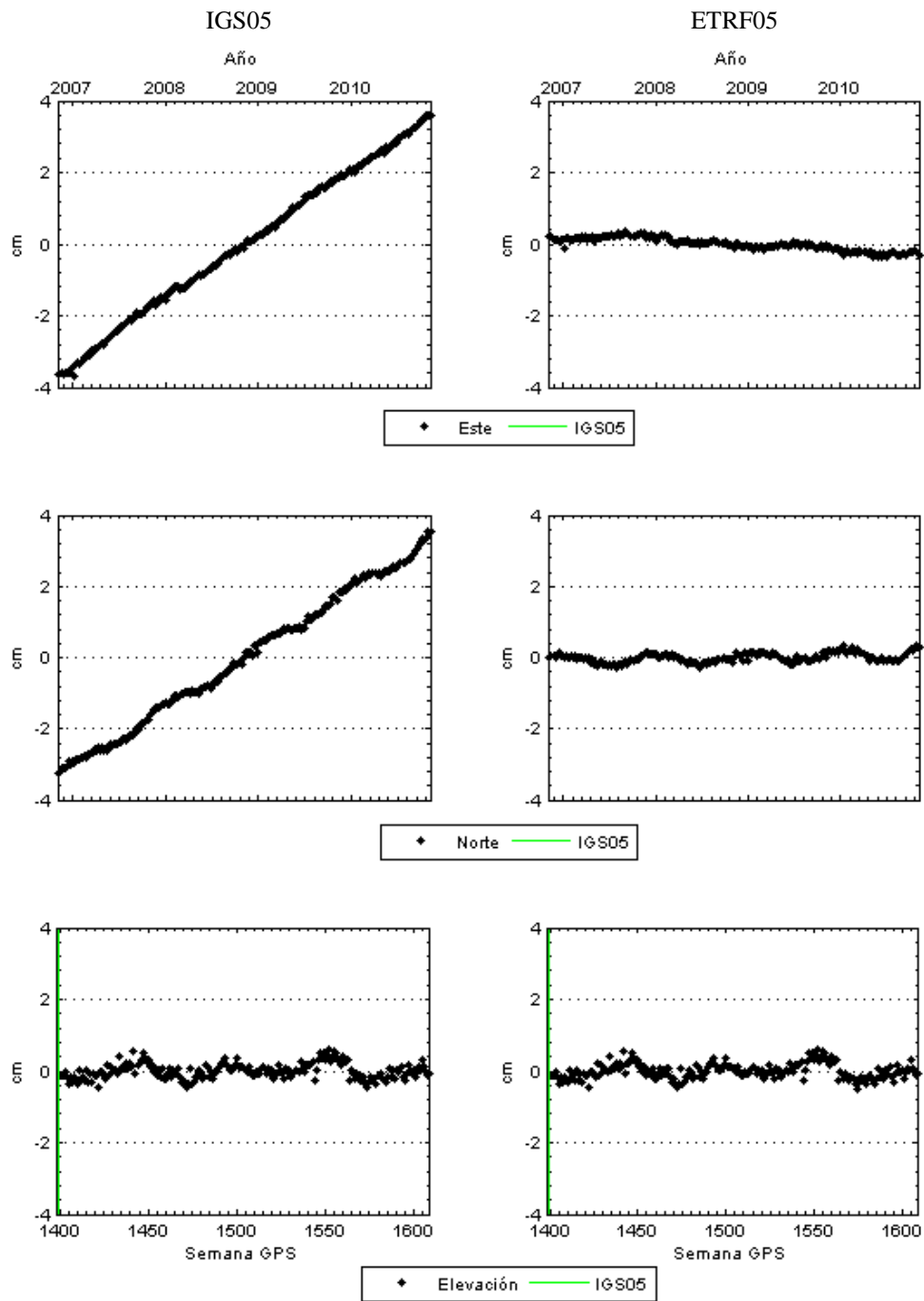IGS05   ETRF05

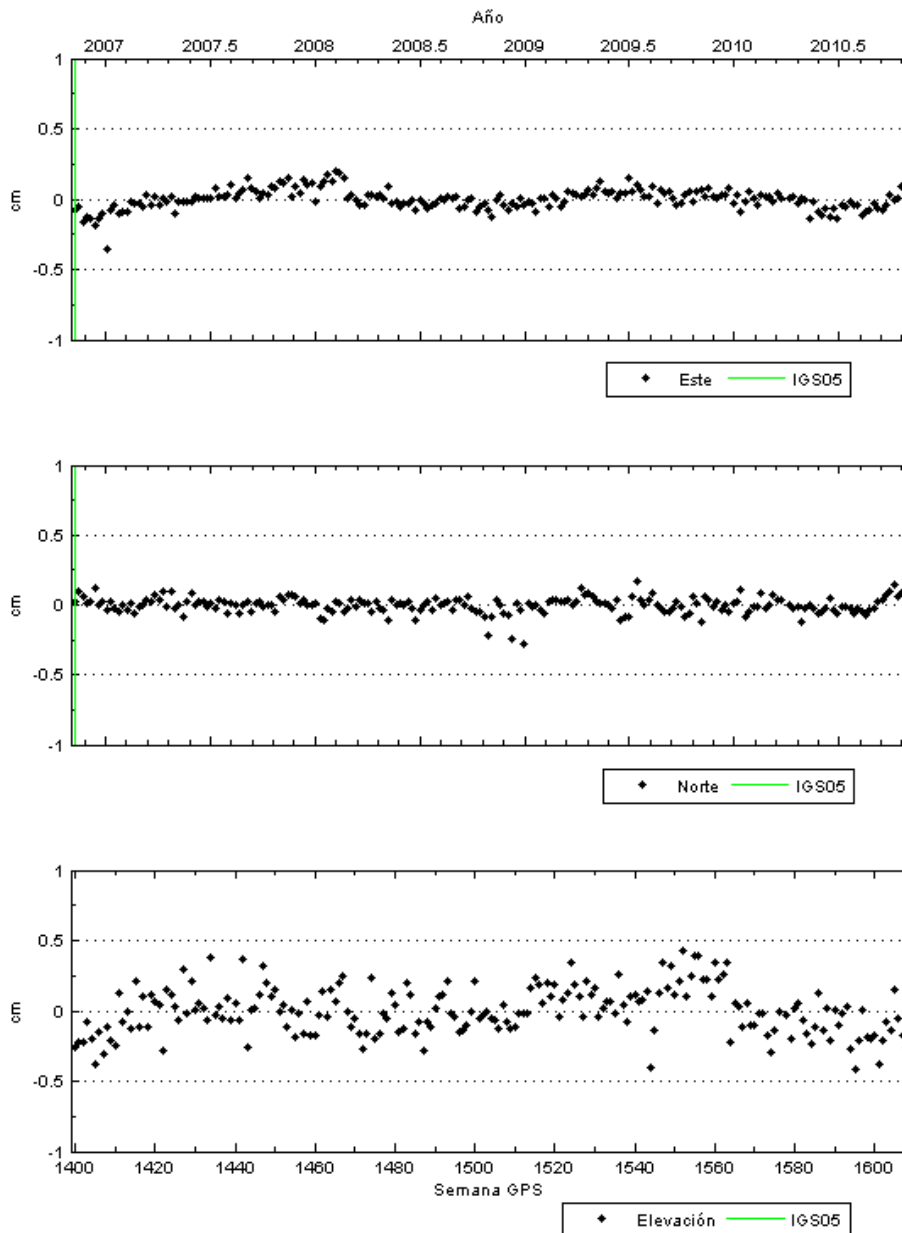Figure 19: IGS05 and ETRF05 ENU raw series of CRDB station.

Figure 20: Residuals ENU raw series of CRDB station.

4. RAP SERVICES

The RAP network provide RINEX files with different sampling rates to post-processing operations and differential corrections via radio or Internet to real-time positioning with a centimetric precision in optimum conditions.

The access to RINEX data, define the service named RAP-FTP. The broadcasting of differential corrections in real-time is done by means of the service RAP-IP.

The RAP-FTP service offers the chance of download RINEX files, from RAP WEB page (www.juntadeandalucia.es/viviendayordenaciondelterritorio/redandaluzadeposicionamiento). It is possible to download hourly RINEX files at 1 sec and daily RINEX files at 30 sec from all stations. A free register is necessary to download.

The RAP-IP service broadcast differential corrections (code and phase, RTCM 2.3 and RTCM 3) via Internet (see table 4). The user needs a NTRIP client application and access to Internet. The user logged to the NTRIP caster can choose the single station from where he wants to receive the differential corrections, or send his location to the NTRIP caster and this one decides the nearest site for the differential corrections to be broadcasted. It is also possible to receive differential corrections based on network solution (RTCM 3.0). In this case the user is required to send his position. A free register is necessary to connect with the NTRIP caster.

Real-time data products	Format	Messages (streaming interval in sec.)	Description
RTCM_18_19_*SITE*	RTCM 2.3	**1**(1), **2**(60), **3**(10), **18**(1), **19**(1), **22**, **23**(10) and **24**(10)	Correction delivered from a selected station (*SITE*=station location)
MAS_CERCANA_RTCM_18_19	RTCM 2.3	**1**(1), **2**(60), **3**(10), **18**(1), **19**(1), **22**, **23**(10) and **24**(10)	Correction delivered from nearest station
RTCM_20_21_*SITE*	RTCM 2.3	**1**(1), **2**(60), **3**(10), **20**(1), **21**(1), **22**, **23**(10) and **24**(10)	Correction delivered from a selected station (*SITE*=station location)
MAS_CERCANA_RTCM_20_21	RTCM 2.3	**1**(1), **2**(60), **3**(10), **20**(1), **21**(1), **22**, **23**(10) and **24**(10)	Correction delivered from nearest station
MAX_red_automatica	RTCM 3	**1004**, **1006**, **1008**, **1014**, **1015**, **1016** y **1033**	Differential correction based on MAC (Master-Auxiliary Concept)
iMAX_red_automatica	RTCM 3	**1004**, **1006**, **1008**, **1032** y **1033**	Differential correction based on network solution to legacy receivers not capable of using MAX_red_automatica

Table 4: RAP-IP Products

At present, there are over 2000 registered users in RAP-FTP service to download RINEX data and over 600 in RAP-IP service for access to NTRIP caster via Internet (see figure 21).
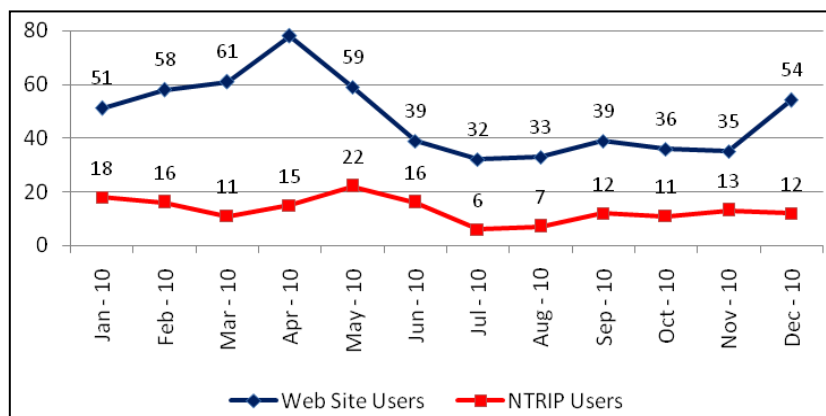

Figure 21: Registered users in 2010

The average of RINEX data available for the RAP stations has been 98.4% during 2010 (see figure 22). The RINEX files downloaded by users are approximately 5000 files per month, of which 40% are files of 1 hour to 1 sec and the remaining 60% are files of 24 hours at 30 sec.
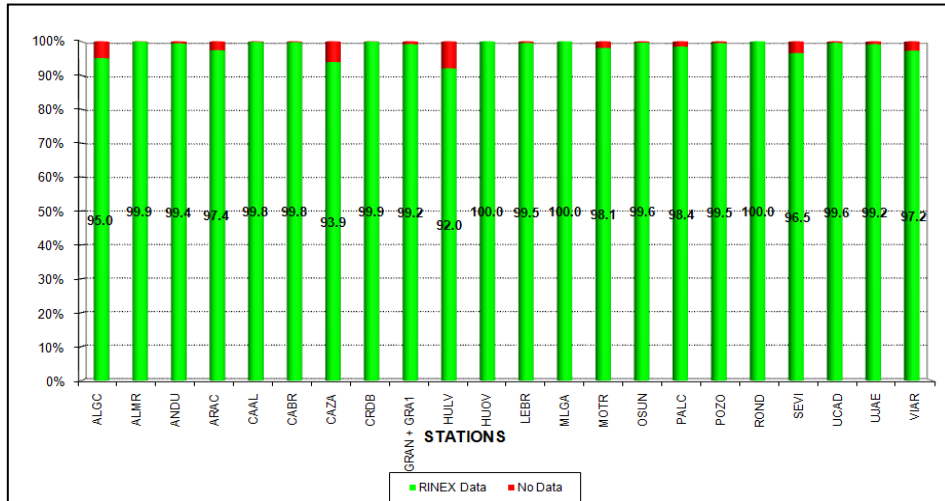

Figure 22: RINEX data available in 2010 per station

The RAP-IP service receives an average of 240 connections a day (see figure 23). Differential corrections from single stations are chosen by the most of users, followed by differential correction based on network solution MAX and IMAX (see figure 24 and 25).
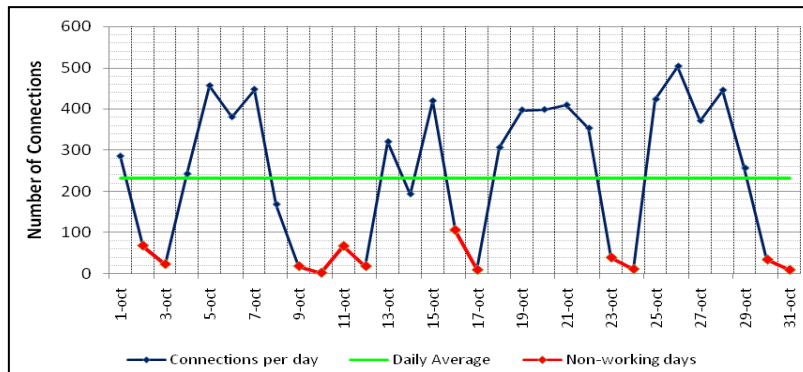

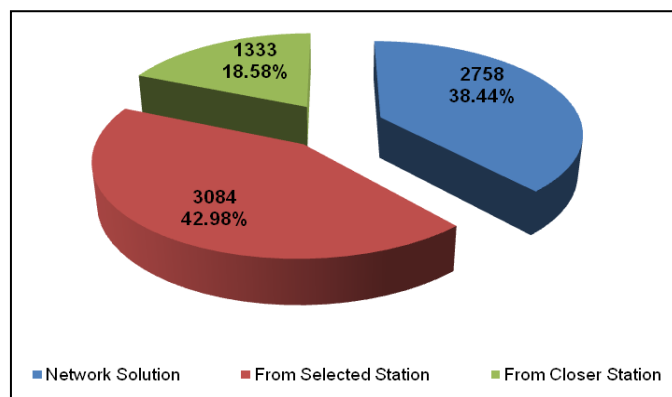Figure 23: Number of daily connections to NTRIP caster on 2010, Oct.

Figure 24: Connections to NTRIP caster per type of
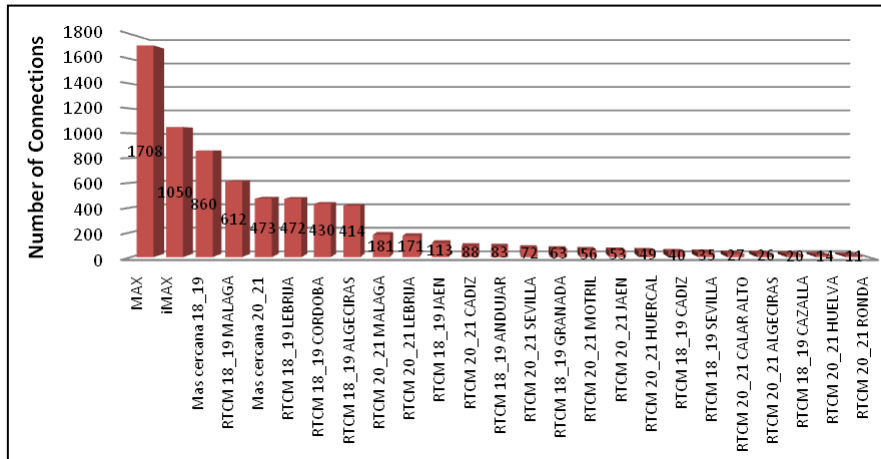correction on 2010, Oct.

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Figure 25: Connections to NTRIP caster per type of streaming on 2010, Oct.

The largest numbers of connections are located around the main cities and big civil works in Andalusia as high-speed railway lines and highways around some cities (see figure 26).
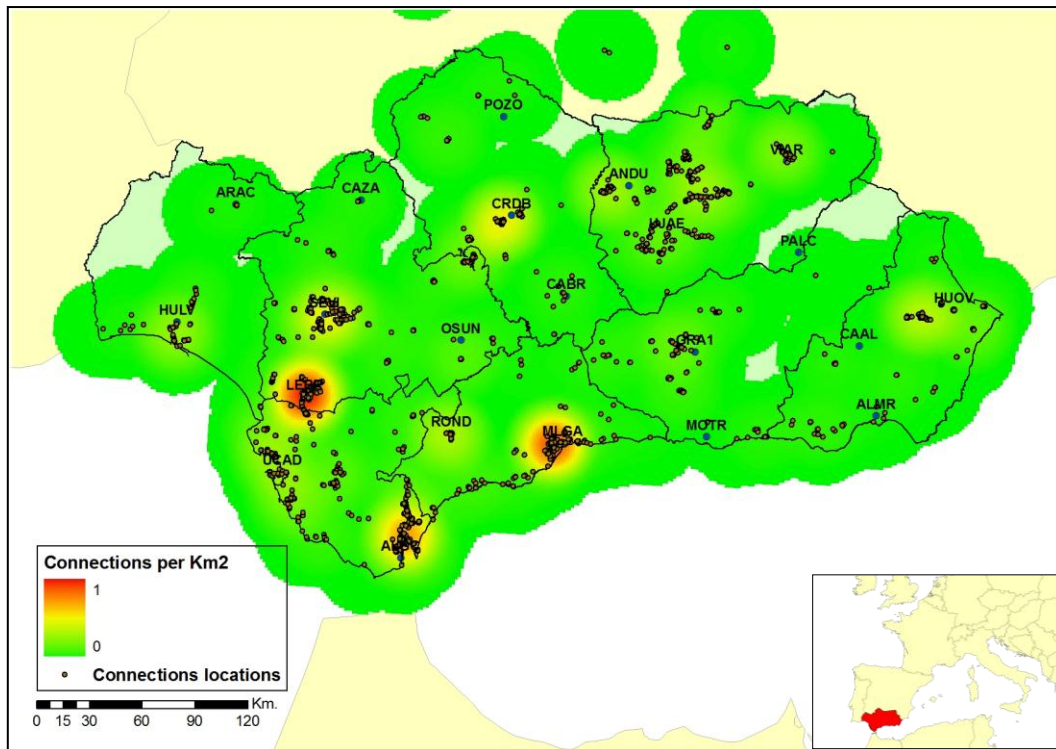

Figure 26: Density of connections to NTRIP caster per Km^2 on 2010, Oct.

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UNAVCO, University NAVSTAR Consortium. http://www.unavco.org