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A critical assessment of the current EGNOS performance

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Abstract

The main purpose of this paper is to evaluate the current performance of the European Geostationary Navigation Overlay Service (EGNOS) in comparison to commercial, local DGPS services. In full operational capability (FOC) EGNOS provides orbit and clock-corrections of all GPS satellites, ionospheric delays and integrity information of the GPS system.

The analysis is mainly based on the comparison of the trajectories of a slowly moving vehicle obtained simultaneously by two real-time correction techniques – EGNOS and WEP (Wienstrom Positioning Service Provider). The tests are carried out in urban environments with frequently varying obstructions and on a highway. Therefore the visibility of the EGNOS satellites varies during the test ride. During the trial session also raw data of the rover receivers as well as the reference station was logged. This allows to verify a posteriori the calculated real time position with respect to a reference of sub dm accuracy. Additionally an evaluation of the EGNOS ionospheric model is presented.

Kurzfassung

Die Hauptmotivation für die Arbeit ist die Untersuchung der derzeitigen Verfügbarkeit, Genauigkeit und Stabilität des European Geostationary Overly Service (EGNOS) im Vergleich zu kommerziellen, lokalen DGPS- Anbietern. Im Vollausbau (full operational capability – FOC) wird EGNOS Satellitenbahn- und Uhrenkorrekturen für alle GPS Satelliten, ionosphärische Laufzeitverzögerungen und Integritätsinformationen für das GPS System aussenden.

Die präsentierte Analyse basiert auf dem Vergleich zweier Trajektorien eines sich langsam bewegenden Fahrzeuges. Die Koordinatenlösungen werden gleichzeitig mit zwei unterschiedlichen Echtzeit Korrekturtechniken bestimmt – EGNOS und WEP (Wienstrom Positioning Service Provider). Die Testfahrt wurde in unterschiedlich bebautem Stadtgebiet und auf einer Autobahn ausgeführt, wodurch die Sichtbarkeit der geostationären EGNOS Satelliten während des Tests stark variierte. Um a posteriori die in Echtzeit bestimmten Positionen kontrollieren zu können, wurden die Rohdaten der Rover Stationen und einer Referenzstation gespeichert. Ergänzend wird auch eine Evaluierung des EGNOS- Ionosphärenmodells präsentiert.

1. Introduction – Differential GPS (DGPS) vs. Satellite Based Augmentation Systems (SBAS)

The positioning accuracy of a single frequency GPS- receiver used under optimal conditions (no obstructions and multipath effects, good satellite geometry) is in the range of about ten meters. However, for a wide range of applications an improved accuracy is needed. While random errors as the code measurement noise are receiver dependent and the hard to detect and to reduce multipath effects relate to the permanently changing environment a real improvement of positioning can be achieved by minimizing the systematic error influences on the raw measurements.

Systematic errors are mainly composed by inaccuracies in the satellite orbit- and clock navigation information and by atmospheric effects. The orbit- and clock errors can influence the raw range measurements each by about two meters. The atmospheric error can be separated in a ionospheric part and a tropospheric part. The tropospheric delay adds up to about 2,3 meters in zenith direction and is slightly affected by local weather conditions. The ionospheric delay on the contrary mainly depends on the geographic latitude, the local time and last but not least on the current activity of the sun. Dependent on the elevation of the satellite this delay can add up to several tenths of meters. Both atmospheric delays can be significantly reduced when using correction models (for a detailed description of GPS error sources see [8]).

An option to account for systematic errors in real-time is provided by different augmentation systems like WAAS or EGNOS (see weblink [6] and [1], [2]). All these systems make use of observations gathered in coordinative known base station networks. The mean distance between these stations is usually several hundreds of kilometers. In the systems central computer facility the network error models for the service area are calculated and then transformed into correction data that is transmitted to the user community (see [2] and weblink [3]). Another option is to make use of correction data offered by 'Local Service Providers' which might be private companies or national mapping authorities. Mean station distances within their GNSS networks are usually 50-80 kilometers (see weblink [7]).

The correction data is broadcasted by means of two different standard formats. Local services make use of the RTCM format (see [7] available via web link [5]) for the transmission of corrections. For example the RTCM v.2.3 message types 1 and 21 contain range corrections for raw pseudorange measurements. These corrections implicitly cover most of the systematic errors. The rover receiver adds the corrections to the raw measurements and does not need to apply any additional corrections (e.g.: error models for ionospheric or tropospheric effects).

Contrary, regional SBAS services use the RTCA format (see [6], available via web link [4]). This data format issues corrections (ionospheric delay, satellite position- and clock correction) valid for the whole service region. Therefore the receiver needs to calculate the range corrections for his position in a primary step before they can be added to the raw measurements.

One of the advantages of local networks is that their correction data covers the tropospheric delay whereas regional networks do not provide this information due to the fact that the tropospheric delay varies locally. A SBAS receiver therefore has to apply a tropospheric model. The update rates of RTCM corrections are generally one second while those for RTCA corrections are lower. For this reasons the positioning results obtained in local networks are generally more accurate. The expected DGPS coordinate accuracy is at the sub- meter level. SBAS positions are expected at the two meter accuracy level. It has to be noted that a major focus of SBAS Systems is the Integrity Monitoring of the GPS satellites (usually not provided by local DGPS services).

A further difference between local DGPS- and SBAS- systems is the transmission of the correction data. DGPS services mainly use GSM connections (in former days also radio links) whereas SBAS Systems broadcast their data via geostationary satellites. Due to the low elevation of geostationary satellites SBAS signals cannot be received everywhere. Therefore the EGNOS signals are also distributed via Internet (SISNeT (Signal in space through the Internet), see [9] and [10]). Via SISNeT the corrections can be received also in heavily obstructed areas.

A potential user has to take into account that the EGNOS signal can be used for free and no costs emerge for the data connection – except when using SISNeT. Local DGPS services charge for their data. Additionally the GSM data link has to be paid.

2. Purpose and description of the experiment

In this paper we want to carry out a comparison of vehicle trajectories applying on the one hand correction data from a local DGPS service provider and from the European SBAS System EGNOS on the other. These trajectories are compared to an aposteriori calculated precise trajectory. The main purpose is to test the current EGNOS performance. A rating between DGPS services and EGNOS has to be based on several components like accuracy, availability, price and intended application and has therefore to be left to the user.

The two different systems tested in this paper are:

- The local DGPS network WEP
- The regional SBAS network EGNOS

WEP (see web link [7]) is operated by the Viennese power supplier Wienstrom in cooperation with the OEBB (Austrian Railways) and the BEWAG (power supplier of Burgenland). The network currently covers 12 GPS/GLONASS reference stations in the east of Austria. The central processing unit which provides RTCM data to the users via a GSM router is located in Vienna.

EGNOS is the European SBAS System set up by the European Space Agency (ESA). About 30 RIMS (Ranging and Integrity Monitoring Stations) permanently observe the GPS satellites and transfer the data to the MCCs (Mission Control Centers). The MCCs are monitoring the integrity of the GPS system and calculate the error models and corrections. These data is transmitted by Up-Link stations (NLES – Navigation Land Earth Station) to three geostationary satellites which broadcast the RTCA corrections to the users. The system is highly redundant (e.g. just one MCC is calculating the corrections at a certain point in time – the others are purely backups). The system covers the European area and in future parts of Africa.

Figure 1: *Test configuration.*

In our experiment we wanted to test the performance of both systems under the same conditions at the same time. To fulfill these specifications we used one antenna and an antenna splitter to divide the received signal into two streams. Therefore both receivers got exactly the same incoming signals (see fig 1).

For the reception of the EGNOS- signal a Septentrio PolaRx2 Receiver was used. A Leica 1200 Receiver equipped with a GSM modem was deployed for operating in DGPS mode. Both receivers are originally two frequency receivers. For this experiment both receivers were set to L1 mode.

3. Static Experiment

To investigate the stability of both systems a static test on a coordinative known point was carried out. The experiment took place on March 9, 2007 between 8:10am and 16:36pm (CET) under perfect conditions (no obstructions and no multipath). The positions were logged in five seconds intervals and then transformed to local coordinates (east, north, height). Figure 2 shows the differences between the real time coordinates and the known coordinates over the whole observation span.

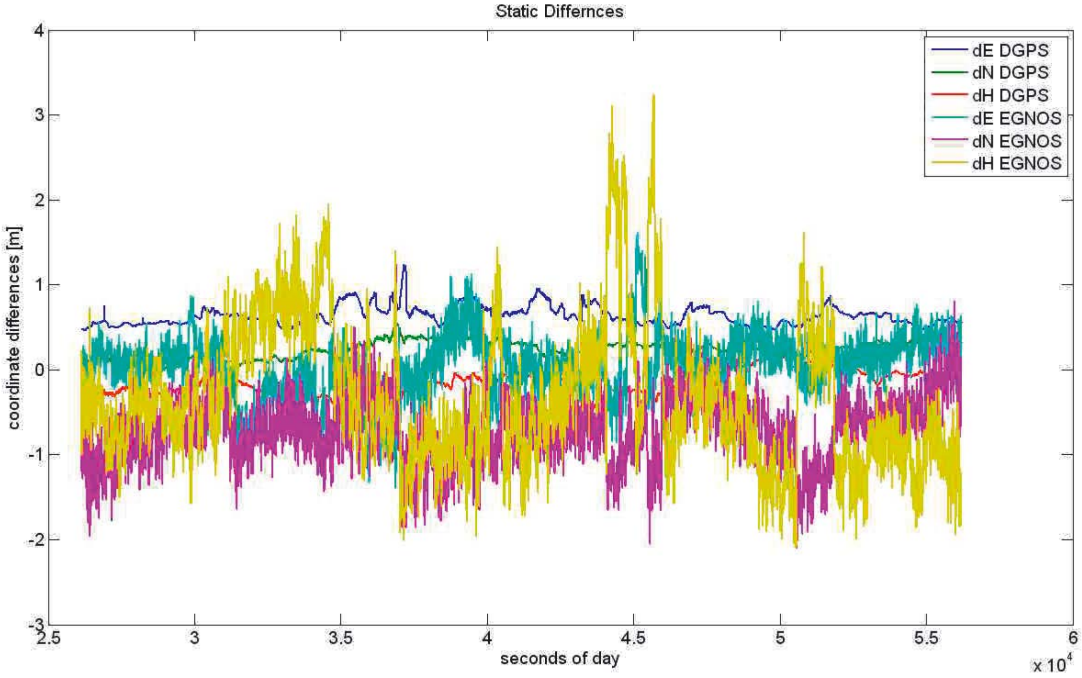

Figure 2: *Differences between real time coordinates and a priori known coordinates.*

The results are well in the expected range. During the whole observation time the differences between the DGPS coordinates and the reference coordinates are below one meter. No problems with the GSM connection could be observed.

The results obtained by the EGNOS receiver are noisier and the absolute coordinates differ up to more than 2 meters to the a priori known ones. Also it is clearly visible that the EGNOS solution is less stable and that outliers in the height occur occasionally.

Table 1 shows the maximum and mean values of the differences to the known coordinates over the whole observation time (6016 epochs). The superior accuracy of the DGPS coordinates can clearly be seen. The mean values of the EGNOS differences are also below one meter, but single measurements can differ up to 2,10 m in the plane and up to 3,24 m in height.

4. Kinematic Test

For the kinematic test the antenna was mounted on a car. The positions were logged every second and again transformed to the local coordinate system (east, north, height). In order to be able to calculate a posteriori a precise reference trajectory also the raw observation data was logged.

The test was carried out in Vienna on March 8, 2007 between 10:30am and 12:00am (CET). The route was around 9 km long and passed through different obstructed areas. The environment comprised the heavy obstructed inner city of Vienna, wide boulevards as well as a highway. The chosen track was therefore an ideal test area.

Figure 3 shows the 3 trajecories (green lines) on 3 maps of Vienna. Figure 3a represents the DGPS solution. The GSM connection to the DGPS provider did not fail through the entire test period. This line can be seen as the area where GPS positioning in general was possible. A part from some small pieces downtown everywhere enough GPS satellites could be observed.

The EGNOS results are represented by the graphic in 3b. As expected, the geostationary satellites were not visible in the inner city most of the time and therefore no comparison between DGPS and EGNOS coordinates could be performed for this area. It is planned to redo the experiment in this areas with a SISNeT capable receiver.

In the map 3c the a posteriori calculated reference trajectory is shown. Just the areas where the ambiguities could be fixed are plotted. A correct solution of the ambiguities was possible only for small parts of the trajectory. This can be caused on the one hand by the bad satellite geometry (and low number of satellites visible downtown) and on the other hand by the high velocity of the test vehicle on the highway.

(6016 observations)		dE[m]	dN[m]	d2D[m]	dH[m]
EGNOS	Absolute Maximum	1,62	2,10	2,10	3,24
	Mean of Absolute Differences	0,28	0,71	0,81	0,75
DGPS	Absolute Maximum	0,55	0,75	0,78	1,09
	Mean of Absolute Differences	0,23	0,18	0,32	0,22

Table 1: Statistics of the static measurements.

Figure 3a-c: Test Trajectories (a: DGPS, b: EGNOS, c: Post Processing).

(460 observations)		dE[m]	dN[m]	d2D[m]	dH[m]
EGNOS	Absolute Maximum	3,95	5,73	6,95	7,13
	Mean of Absolute Differences	0,74	0,75	1,15	0,97
DGPS	Absolute Maximum	0,51	0,70	0,72	1,16
	Mean of Absolute Differences	0,19	0,16	0,28	0,20

Table 2: Statistics of the kinematic experiment.

Table 2 shows the maximum and mean values of the differences between the EGNOS and DGPS points with respect to (w.r.t.) the a posteriori estimated positions. Solely those points were taken into consideration where DGPS and EGNOS positioning was possible and where in the post processing analysis the ambiguities could be fixed. Therefore only a total of 460 epochs was used for the statistics.

While the results for the DGPS solutions are more or less the same as in the static experiment the EGNOS results are worse. The mean values increased by 20-30cm. But the maximum values are three times worse than in the static experiment. If this effect can be led back to the movement of the car or more likely to a general poor performance of the EGNOS corrections (the system is still under development) could not be clarified and needs further investigations.

Figure 4 and Figure 6 show the differences between the real time and the a posteriori calculated reference coordinates for two sections of the trajectory where an estimation of the reference trajectory was possible.

The first part of figure 4 shows some unexplained variations in the EGNOS results with differences up to 7m. In figure 5 the three trajectories of this part of the experiment are plotted. The drift of the EGNOS results can clearly be seen. The second part of figure 4 displays the typical variations w.r.t. ground truth.

The results of section 2, displayed in figure 6, demonstrate an example for pretty good performance of both systems. Nevertheless, the benefits of the DGPS service are visible. These results are more accurate and more stable.

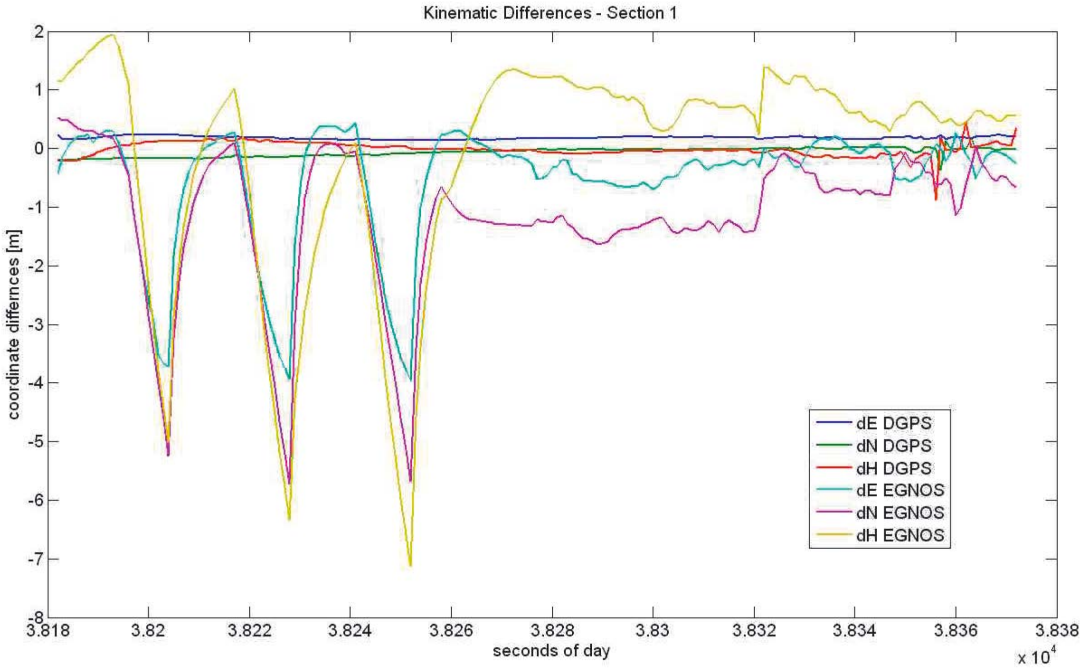

Figure 4: Differences of DGPS and EGNOS coordinates w.r.t. a posteriori estimated coordinates for section 1.

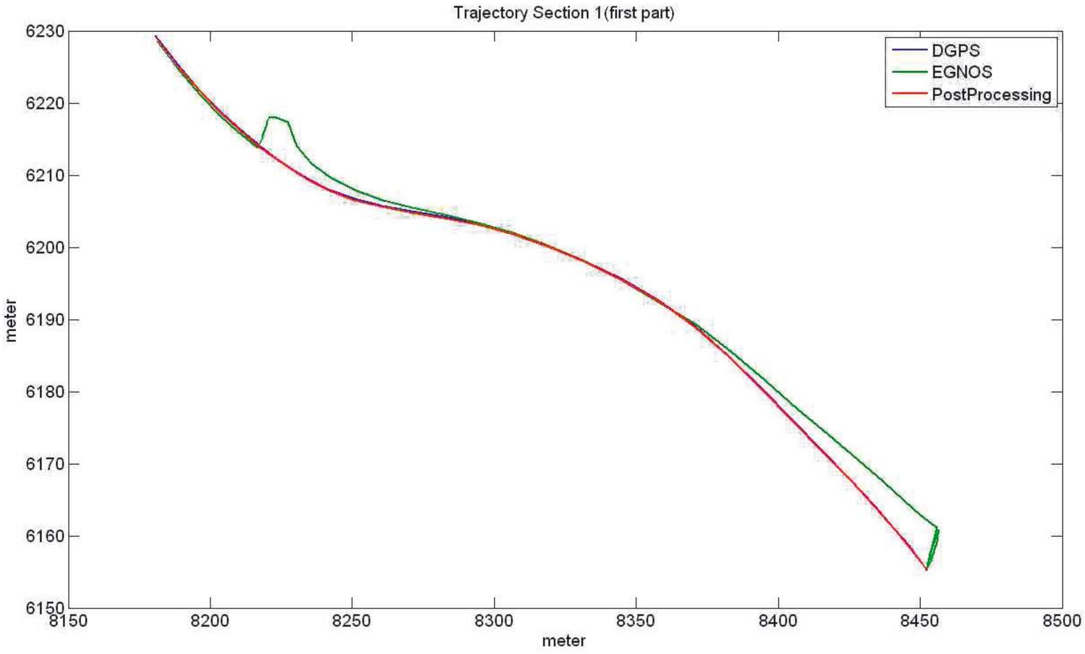

Figure 5: *Trajectory plot of section 1.*

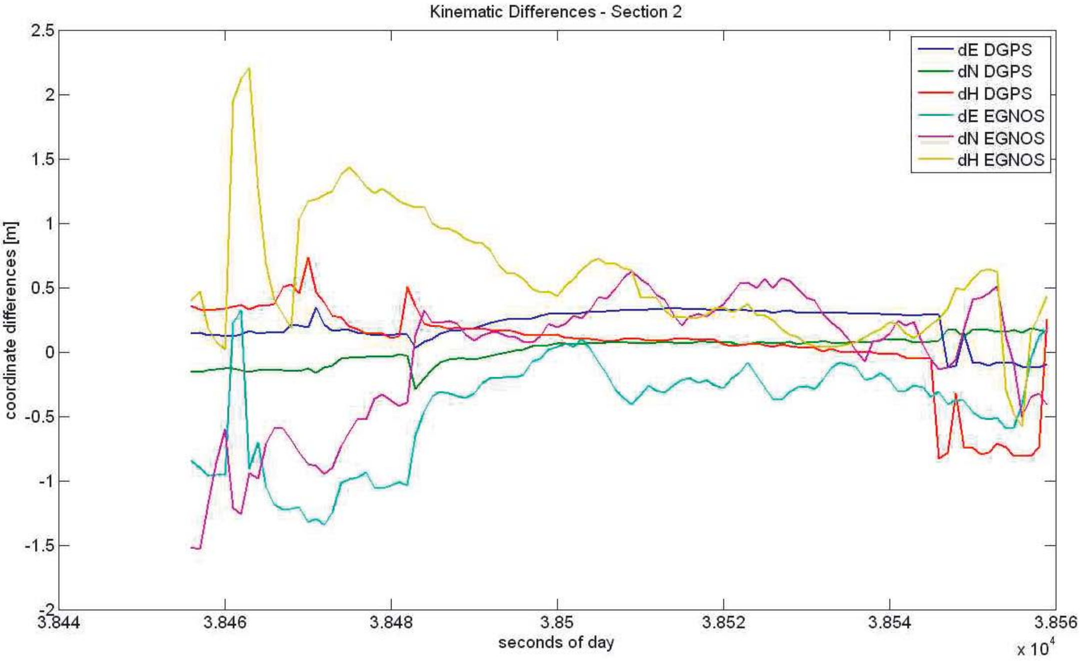

Figure 6: *Differences of DGPS and EGNOS coordinates w.r.t. a posteriori estimated coordinates for section 2.*

5. Ionospheric Model Comparison

A very important error source when using single frequency receivers is the ionospheric delay. There are different ionospheric models to diminish the error of raw pseudorange observations. One is the Klobuchar Model (see [3]). It corrects at least 50% of the ionospheric delay. The model is described by eight parameters. A priori values for these parameters are transmitted in the navigation message of the GPS broadcast ephemerides and are valid for some days. With the knowledge of approximate coordinates, the time, the elevation and the azimuth of an observed satellite the ionospheric correction to be applied can be calculated. This model is by default implemented in single frequency receivers.

EGNOS uses the NeQuick model (see [1]). In contrary to GPS, EGNOS transmits the ionospheric delay for well defined grid points (IGPs, ionospheric grid points). The rover receiver has to interpolate the ionospheric delay for its position. The values of the ionospheric delay are updated every five minutes and the accuracy should be better than 50 centimeters. For these reasons the EGNOS model should be superior to the GPS broadcast model (when working with DGPS services the ionospheric delay is implicitly included in the correction data).

Figure 7 shows the differences of the ionospheric delay between the EGNOS- and GPS-model at the European IGPs for one day. The data interval is 2 hours. The first image (most left, upper line) shows the differences for 02:00 am (UTC); the last one (right, bottom line) shows the differences for 12:00 pm (UTC) the same day.

It is visible that the two models do not match very well. The differences range from +2,5m to -2,5m. Generally the EGNOS corrections are lower than the broadcast values. In addition, the delays at various grid points are very often missing in the EGNOS data (blue colored IGPs in fig. 7). An analysis of the ionospheric delay over several days confirmed this effect for most of the considered time (see [11]). This might be a system data processing artifact because EGNOS is still in an introduction phase and therefore the ionospheric corrections currently do not reach the expected accuracy. A detailed analysis of the EGNOS ionospheric model can be found in [11].

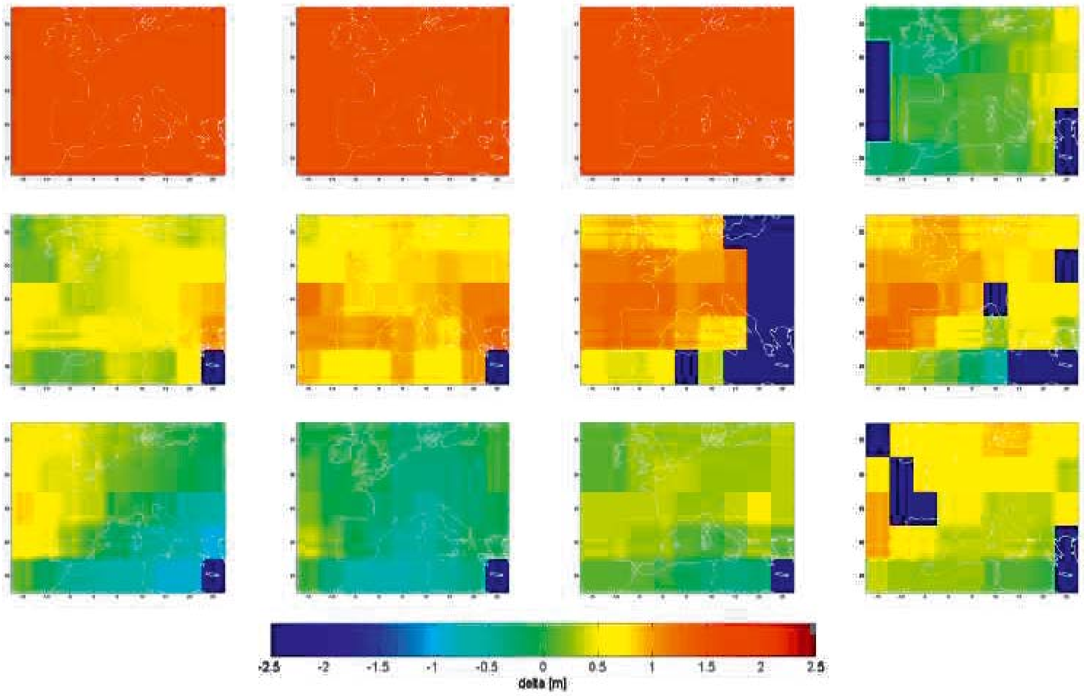

Figure 7: Difference GPS- broadcast-minus SBAS- model for day 189 (year 2006) (see [9]).

6. Summary and Outlook

In summary, the achieved results were as expected. The local DGPS service is superior to the EGNOS service concerning accuracy and availability of the service. On the other hand the user of a DGPS service has to pay for the service and for the GSM connection.

In the heavy obstructed inner city of Vienna positioning was frequently harmed or impossible. Especially the EGNOS signal could not be received there. Thus it is planned to repeat the experiment with a SISNeT receiver. Astonishing was the degraded accuracy when using EGNOS in kinematic mode. A similar behavior was not observed in the DGPS solution.

The raw data is recalculated with the software SISSIM (SISNeT Simulation) for carrying out tests with the corrections provided by EGNOS (see [2] and [3]). The comparison of different ionospheric models showed that the performance and stability of the EGNOS ionospheric corrections is not optimal so far. However, the situation might change after shifting EGNOS from the initial to regular operation.

Finally, we want to thank the company Wienstrom for offering their network services to carry out the presented DGPS tests and the Institute of Engineering Geodesy and Measuring Systems of TU-Graz for loaning the antenna splitter.

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Web-links (March, 2007)

[1] *EGNOS for professionals:* http://www.egnos-pro.esa.int/index.html

[2] *EGNOS, ESSP:* http://www.essp.be/

[3] *EGNOS information:* http://www.environmental-studies.de/Teilflachenbewirtschaftung/EGNOS_WAAS/3.html

[4] *RTCA:* http://www.rtca.org/

[5] *RTCM:* http://www.rtcm.org/

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