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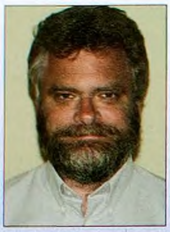

Analysis of NOAA-Generated Tropospheric Refraction Corrections for the Next Generation Nationwide DGPS Service

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Abstract

The U.S. Coast Guard has begun the modernization of its Nationwide Differential GPS (NDGPS) beacon network. One potential component of modernization is to provide the information necessary for long baseline, centimetre-level, differential carrier phase processing. In order to achieve these results, improved handling of atmospheric refraction of the incoming GPS signals must be achieved. The utility of the NOAA tropospheric delays in position determination was accomplished by supplying the NOAA zenith delay estimates to an in-house ionospheric-free relative GPS processor. Results indicate that the most significant improvement is observed in up-component bias reduction of a few centimeters to more than four decimeters.

Résumé

L'"U.S. Coast Guard" a entrepris de moderniser son réseau de balises NDGPS (GPS différentiel au niveau national). Une composante potentielle de cette modernisation consiste à fournir les informations nécessaires au traitement de longues lignes de base, de la phase porteuse différentielle, au centimètre près. Pour obtenir ces résultats, il est indispensable de parvenir à améliorer la gestion de la réfraction atmosphérique des signaux GPS entrant. L'utilité des retards de la NOAA dans la détermination de la position troposphérique a été menée à bien en fournissant à la NOAA des estimations de retard, au zénith, pour un processeur GPS interne relativement non ionosphérique. Les résultats montrent que l'amélioration la plus significative est observée dans la réduction des erreurs des composantes en amont, qui vont de l'ordre de quelques centimètres à plus de quatre décimètres.

Resumen

La "U.S. Coast Guard" ha iniciado la modernización de su red de balizas del GPS Diferencial a nivel nacional (NDGPS). Una componente potencial de esta modernización es proporcionar la información necesaria para el procesado de líneas base largas, de la fase portadora diferencial, a nivel de centímetro. Para lograr estos resultados se debe alcanzar un mejoramiento en la manipulación de la refracción atmosférica de las señales GPS entrantes. La utilidad de los retrasos troposféricos de la NOAA en la determinación de las posiciones fue llevada a cabo proporcionando a la NOAA estimaciones de retrasos cenitales para un procesador GPS interno relativamente no ionosférico. Los resultados indican que la mejora más significativa se observa en la reducción de bias (distorsiones) de componentes ascendentes, que van desde algunos centímetros hasta más de cuatro decímetros.

Introduction

There is no question that GPS has revolutionized positioning for hydrography. In the not so distant past, substantial time, effort and expense went into achieving positional accuracies in the 10s of meters. Now a ~$100 stand-alone handheld GPS receiver can achieve the same accuracies, almost anywhere in the world. In the days of Selective Availability (SA) high precision GPS receivers were capable of ~100 m positional accuracy, in real-time, stand-alone operations. Real-time Differential GPS (RTDGPS) reduced the horizontal positioning accuracy to the meter level, making it a very valuable resource for offshore navigation and positioning applications. To assist in the safe navigation of coastal and inland water transport, many IALA (International Association of Marine Aids to Navigation and Lighthouse Authorities) member nations established networks of radio beacon base stations for the transmission of GPS corrections. This enabled anyone, with the proper radio equipment, to receive differential GPS corrections and subsequently achieve 1-3 meter level horizontal positioning accuracy. [C2CEN, 2005; Hoppe, 2004, Strang et. al., 1997]

Advancements in GPS hardware and software reduced real-time GPS accuracy levels to the decimeter, and in some cases centimeter, level in all three dimensions, when using carrier phase information. However, to achieve these accuracy levels, it was necessary to be within ~20 km of a base station and it was necessary to transmit all of the GPS code and carrier information from the base station to the roving unit (or visa versa) [Hofmann-Wellenhof, 2001].

Long-range RTDGPS uses processing techniques that greatly reduce errors associated with satellite and receiver clocks as well as with satellite positions. However, atmospheric errors remain, specifically errors associated with the Ionosphere and the Troposphere. DGPS greatly reduces the effect of the atmosphere as long as the path between the base and a satellite, and the rover and the same satellite, are similar. As the range between base and remote increases, the likelihood of path similarity decreases. When there is a high variability in atmospheric conditions (e.g. a passing storm), path similarity decreases more rapidly.
An inter-agency team, including the US Coast Guard, Federal Aviation Administration, Federal Highway Administration, and others, has been chartered by the US Department of Transport, to implement a modernized version their highly successful DGPS base station network [Wolfe et. al., 2004]. Rather than simply buying new GPS receivers, they are looking to the future and how they can serve the civilian community better, both on land and at sea. One option for improvement is to transmit not only GPS code correctors, but also phase observation information, to enable the user to compute high-accuracy three-dimensional positions. Coastal and harbor shipping could use high-accuracy vertical positioning for determining under keel clearance to allow for increased shipping capacity and improved navigation safety. Coast monitoring buoys could use high-accuracy vertical positioning for tide and wave height monitoring and real-time reporting to enhance tidal predictions and further support under keel clearance determination onboard vessels. Hydrographic surveyors could use this information for determining seabed depths relative to the ellipsoid, which again would aid in the use of under keel clearance for shipping.

The US Coast Guard plans to transmit enough GPS information to enable users to compute high-accuracy three-dimensional positions. In order to extend the range of the usefulness of this information, they are also looking into transmitting atmospheric information in the form of troposphere and ionosphere corrector maps. The Hydrographic Science Research Center, of the University of Southern Mississippi, is conducting research into the use of corrector maps in long-range high-accuracy GPS position solutions. This research will show that the use of atmospheric correctors improves the accuracy of long baseline positioning to the point where ambiguity resolution is possible, well beyond the range of current methods (~20 km) [Hofmann-Wellenhof, 2001]. In order to accomplish this, in-house software will be enhanced to compute float and fixed ambiguity GPS positions using sequential least squares algorithms and to allow for the applications of ionosphere and troposphere models.

The Hydrographic Science Center, of the University of Southern Mississippi, was contracted by the US Coast Guard to conduct a study of the improvements to GPS observation and positioning that could be obtained by using the NOAA model as opposed to tradition models. This paper describes the position domain analysis including testing methodology and discussion of results.

Tropospheric Refraction of GPS Signals

The troposphere is the section of Earth's atmosphere extending from the surface to approximately 10 to 20km. It is generally characterized by a constant decrease in temperature with increasing height of approximately 6.5°C/km, on average [Mendes, 1999]. Both the hydrostatic or dry and wet constituents of the troposphere refract (reduce speed and alter direction) of electromagnetic waves, such as those of GPS. Unlike the ionosphere, the troposphere is not a dispersive medium, therefore additional GPS signals of varying frequency cannot be used to estimate and eliminate tropospheric refraction.

The effect of the hydrostatic component on the GPS signals accounts for about 90% of the total troposphere delay (zenith delay of ~240cm). It is a function of temperature and atmospheric pressure; however, it can be computed from atmospheric pressure observations at the receiving antenna [Leick, 2004]. This pressure value can be estimated from the height of the antenna above sea level; therefore, site-specific observations are not necessary. However, the wet delay component is more problematic. It comprises about 10% of the total troposphere delay (zenith delay of up to ~40 cm), and is far more variable than the dry component [Leick, 2004]. The irregularity of water vapor content, while small in magnitude, represents the major obstacle to precision estimation – i.e., cm-level [Bisnath et. al., 2005].

Methodology

In order to test positional accuracy improvements when using different troposhere models, in-house processing software was developed. This relative kinematic positioning software was designed to simulate Real-Time Kinematics (RTK) firmware in a GPS-based positioning/navigating scenario. The software processes ionosphere-free, double-difference observables to mathematically almost completely eliminate the effects of ionospheric refraction. This combination allows for robust long baseline processing, and removes the ionospheric effect, which otherwise would complicate the analysis, since both atmospheric effects affect GPS positioning in a similar fashion. Also, carrier phase ambiguities were not fixed to integers in the processing, as such an action could introduced biases due to incorrectly fixed terms, and therefore could vastly alter analysis statistics.

The USM in-house software was configured to simulate a real-time environment with the roving receiver in motion. To this end, broadcast ephemerides were used and position dynamics for the sequential least squares filter were set to 1 m/s^2. Position error statistics show solutions as good as 12cm, 12cm and 20cm (north, east and up 1σ r.m.s.) at 620km. It should be noted that this software is still under development, and although the results obtained for this study are very encouraging, improvements are required.

The in-house software was validated using GrafNav version 6.03. Several baselines were processed in GrafNav with one station in designated as "kinematic" and using the float solution in the forward direction only. The GrafNav software was used to ensure that the USM software was producing reasonable results, therefore the options used were selected to correspond to the USM processing scenario, and not to produce the optimal GrafNav solution.

Note the single-receiver, also known as point positioning, was not assessed in this effort. The reason being that due to unmodeled errors solutions exceed the 1 meter-level in each Cartesian component (1σ). Application of a refinement in tropospheric delay modeling from, e.g., the Saastamoinen to NOAA models would provide few cm improvements – two orders of magnitude smaller that the measurement precision of the technique.

Baselines from three areas of CONUS were processed: Michigan, California, and the South East (see Figure 1). Each baseline consisted of 18 to 24 hours of 30-second observations per day for three to six days. Each day was processed as a separate data set. The stations selected were Continuously Operating Reference Station (CORS) sites, given that they were readily available via the Internet. The use of CORS data will not significantly bias the results, even though CORS GPS meas-

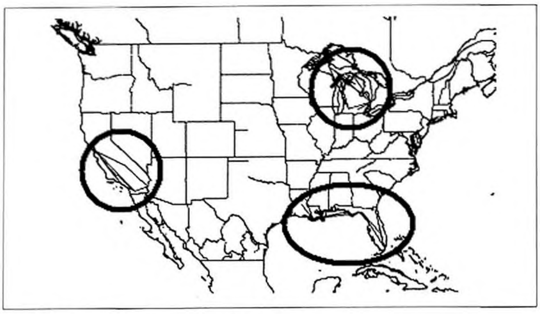

Figure 1: Map depicting the three regions used for position domain analysis, Michigan, California and the South East.

urements are being used in the generation of the NOAA product, since the product itself has been evaluated, and the position domain analysis is designed to evaluate the utility of the product in GPS positioning. Evaluation alternatives include: the use of International GNSS (Global Navigation Satellite System) Service (IGS) stations – however, an insufficient number of stations prevents such an analysis; the use of data from GPS networks not feeding into the NOAA product; or the use of GPS campaign data.
A comparison of positioning results using the Saastamoinen (USM SAAST) and NOAA (USM NOAA) tropospheric delay estimates was carried out. Due to its popularity, the Saastamoinen model was selected as the conventional solution. For comparison, the in-house software was run using the Saastamoinen model, and then using the NOAA model. The only difference between the two software runs was the troposphere correction applied.

The Saastamoinen model is a closed-form model that does not require any external meteorological information. The troposphere slant delay for each satellite is computed from the satellite elevation angle, receiver height above mean sea level, and the receiver latitude [Neill, 1996]. The NOAA delay estimates are supplied in the form of 10' x 10' zenith grid maps covering the continental US. The grid map values are computed from a combination of CORS station GPS observations and meteorological observations. It is left to the user to determine the slant range delay values, and for this study the zenith delay values are converted to slant values using the Neill mapping function [Neill, 1973].

Analysis for Single Baseline

Processing results for the SUP3-FRTG baseline (430km), from the Michigan region, are shown here as an example. Position errors and related statistics were determined by comparing computed rover positions to the published CORS station coordinates. Table 1 shows the mean, standard deviation (1σ), and RMS from GrafNav (using Saastamoinen), USM SAAST (Saastamoinen tropo- sphere model), and USM NOAA (using NOAA troposphere model). The statistics indicate that the USM SAAST results are comparable to the GrafNav solution, and that the USM NOAA solution is an improvement to both. Figure 2, Figure 3 and Figure 4 show North, East, and Up error time series plots for each of the three processing runs.

	GrafNav		
	Mean (m)	**Stdev (m) 1σ**	**RMS (m)**
N	0.035	0.095	0.101
E	0.006	0.108	0.108
U	-0.207	0.238	0.315
	SAASTAMOINEN		
	Mean (m)	**Stdev (m) 1σ**	**RMS (m)**
N	0.019	0.088	0.090
E	-0.089	0.084	0.123
U	-0.124	0.222	0.254
	NOAA		
	Mean (m)	**Stdev (m) 1σ**	**RMS (m)**
N	-0.004	0.066	0.066
E	-0.041	0.081	0.091
U	0.016	0.103	0.104

Table 1: Mean, Standard Deviation (1 σ) and RMS for Michigan baseline SUP3-FRTG (430 km).

Analysis Summary for All Baselines

Six days of observations, July 11 (day of year [doy] 193) through July 16 (doy 198) 2004, were used for this analysis. Each day was processed separately. Due to data gaps, not all stations could be used on all days. In the cases where one or more stations were eliminated due to large data gaps, the entire day was eliminated for all baselines in that region.

The baseline analysis summary has been divided into the three regions of Michigan, California and the South East. In each region, plots showing the

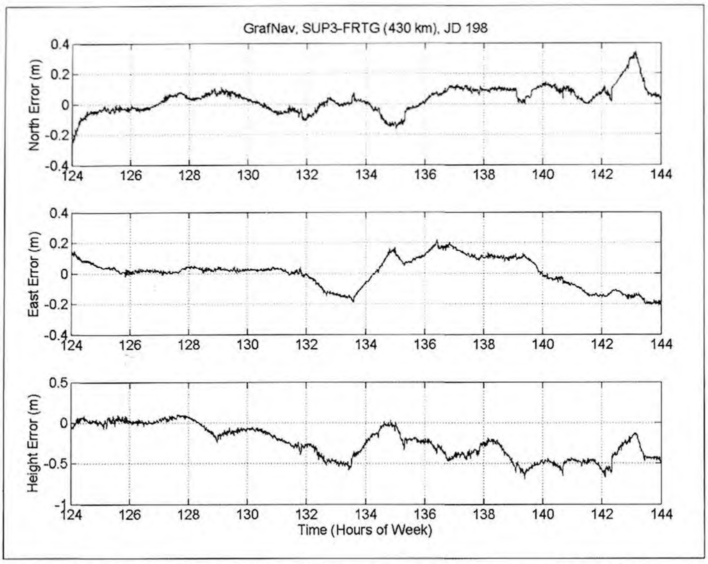

Figure 2: GrafNavTM position error plots for the Michigan SUP3-FRTG baseline.

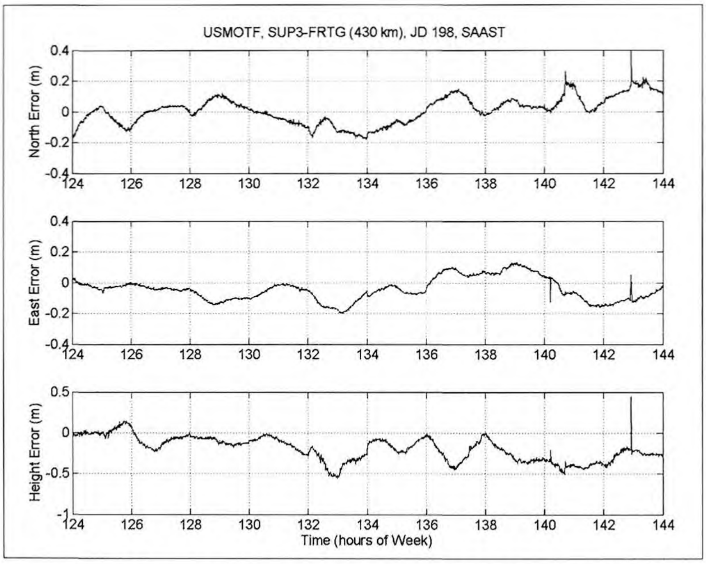

Figure 3: USM Saastamoinen position error plots for the Michigan SUP3-FRTG baseline.

mean (bias), standard deviation (1s) and r.m.s. for each baseline were generated. In this summary only the improvement in results between USM SAAST and USM NOAA are shown.

Michigan Region

Seven CORS sites, all equipped with Leica RS500 GPS receivers, were used for the Michigan region analysis (see Figure 5). Various combinations of these seven sites produced ten baseline pairs with lengths varying from 190 km to 620 km (see Table 2). Due to large data gaps in several stations, July 12 (doy 194) was not used. Five days of data (doy 193, doy 195 through doy 198) were used.

Number	Baseline	Length (km)
1	UNIV-FRTG	190
2	SUP2-NOR2	210
3	SOWR-FRTG	270
4	NOR2-FRTG	280
5	SUP1-NOR2	350
6	SUP2-SOWR	400
7	SUP3-FRTG	430
8	SUP2-FRTG	480
9	SOWR-SUP1	560
10	FRTG-SUP1	620

Table 2: Baselines and corresponding lengths for Michigan region.

Visual inspection of the zenith wet delay for the time period shows fairly homogeneous conditions for this region (see Figure 6). Even when conditions changed (see Figure 7) with increasing wet delays, the change was consistent throughout the area. Over the six-day observation span the zenith wet delay ranged between about 10cm and 25cm.

Figure 8 shows the 1σ r.m.s. (accuracy) improvement in the north, east and up components for the processed data sets as a function of baseline length. For this data set, the r.m.s. improvement did not appear to be a function of baseline length. The average improvement in the horizontal position was about 1cm in both north and east. There was sizeable r.m.s. improvement in the vertical component, ranging from a few centimeters to over a decimeter with the average being 5.5cm. Closer analysis indicated that the improvement was due to both a reduction in the error bias, with an average improvement of 4.4cm, and standard deviation (solution noise or dispersion), with an average improvement of 3.0cm (see Figure 9 and

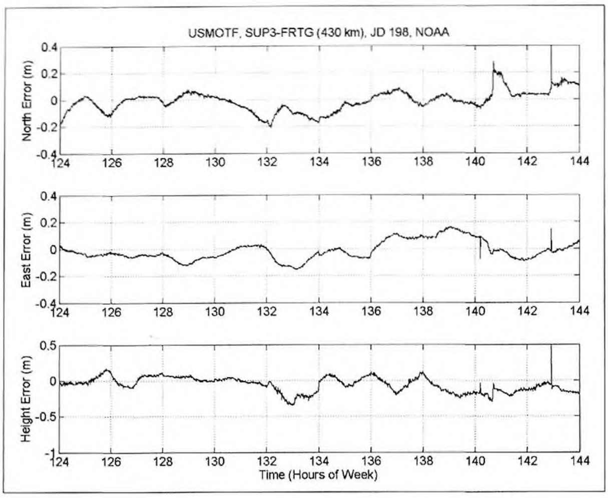

Figure 4: USM NOAA position error plots for the Michigan SUP3-FRTG baseline.

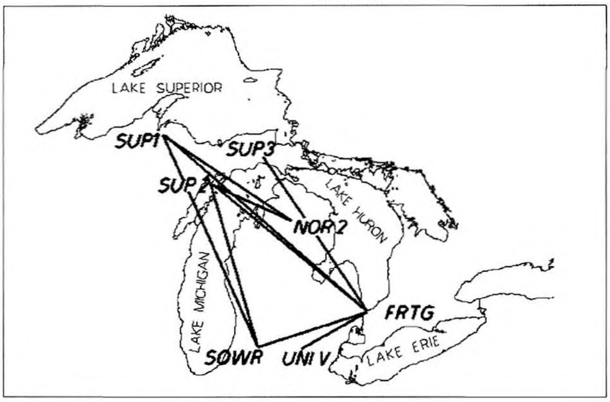

Figure 5: Baselines and CORS stations for Michigan region.

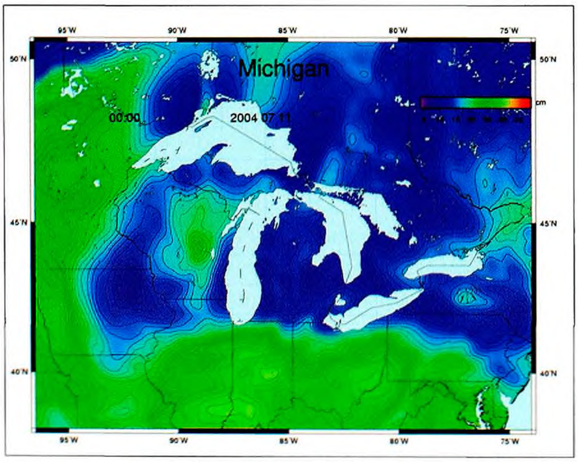

Figure 6: Michigan zenith wet delay (in cm) for July 11, 2004. Image derived from the NOAA troposphere zenith delay maps. The red square delimits the test area.

Figure 10). For the most part, position accuracy improved with the use of the NOAA troposphere model; however, in a minority of cases the accuracy did not change, or got slightly worse. Inspection of the bias and standard deviation plots showed that the NOAA-based position accuracy improvement was due to a reduction in the error bias compared to the SAAS-based solutions.

California Region

Six CORS sites, all equipped with Ashtech Z-XII3 GPS receivers, were used for the California region analysis (see Figure 11). Various combinations of these six sites produced nine baseline pairs with lengths varying from 140km to 740km. There were also significant height differences between some baseline pairs with variations from 235m to 1850m (see Table 3). All six days of data were used (doy 193 through doy 198).

Number	Baseline	Length (km)	ΔH (m)
1	BLYT-MONP	140	1756
2	TORP-MONP	200	1847
3	CHAB-CARH	260	250
4	TORP-CARH	310	485
5	COSO-BLYT	390	1541
6	COSO-CHAB	420	1225
7	MONP-CARH	500	1362
8	TORP-CHAB	560	235
9	MONP-CHAB	740	1612

Table 3: Baselines and corresponding lengths for California region.

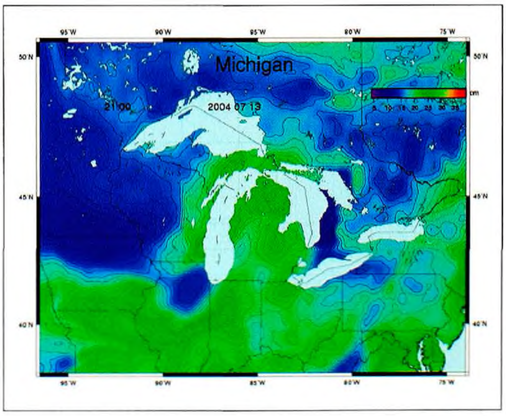

Figure 7: Michigan zenith wet delay (in cm) for July 13, 2004

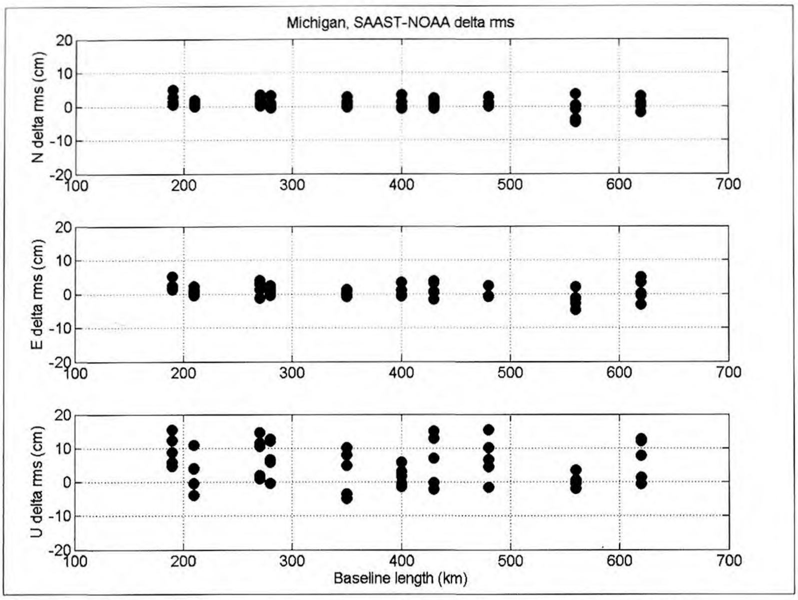

Figure 8: Michigan r.m.s. improvement in USM NOAA over USM SAAST.

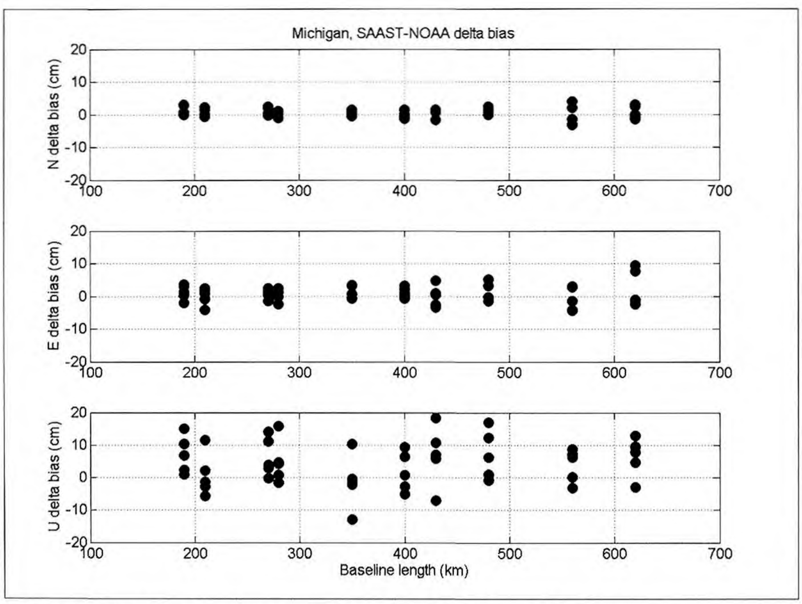

Figure 9: Michigan bias improvement in USM NOAA over USM SAAST.

Visual inspection of the zenith wet delay for the time period showed a wide variety of conditions for this region (see Figure 12). Over the six day observation span the zenith wet delay ranged between about 0cm and 30cm with, in many cases, both extremes occurring at the same time (see Figure 13).

Figure 14 shows the 1σ r.m.s. (accuracy) in the north, east and up components for the GrafNav (crosses) and USM SAAST (solid circles) processing results for doy 198, as a function of baseline length. These plots indicate that the two processes produced very similar results.

Figure 15, Figure 16, and Figure 17 show the r.m.s., bias, and standard deviation (1s) improvements, respectively, of the NOAA troposphere model over the Saastamoinen model. All of these plots show r.m.s. versus baseline length. The r.m.s. improvement does not appear to be a function of the baseline length. The r.m.s plots indicate general improvement in both horizontal and vertical position accuracy. The average horizontal improvements were 2.9cm in the north and 2.0cm in the east. The average improvement in the height was 14.3cm. In a few cases the USM NOAA solution was worse than the USM SAAST. For the most part, the USM NOAA results that were worse than USM SAAST (negative improvement) correspond to an increase in the USM NOAA bias error. This situation will require further investigation.

The position improvements seen here are much larger than those seen in the Michigan data set. Much of this can be attributed to the greater height difference, as well as the greater range and variability in wet delay between baseline pairs; however, some improvement may be due to the use of atmospheric pressure observations rather than estimated pressure values from station height, which are used in the Saastamoinen solution. Figure 18, Figure 19 and Figure 20 show the r.m.s., bias and standard deviation (1σ) improvements of the NOAA

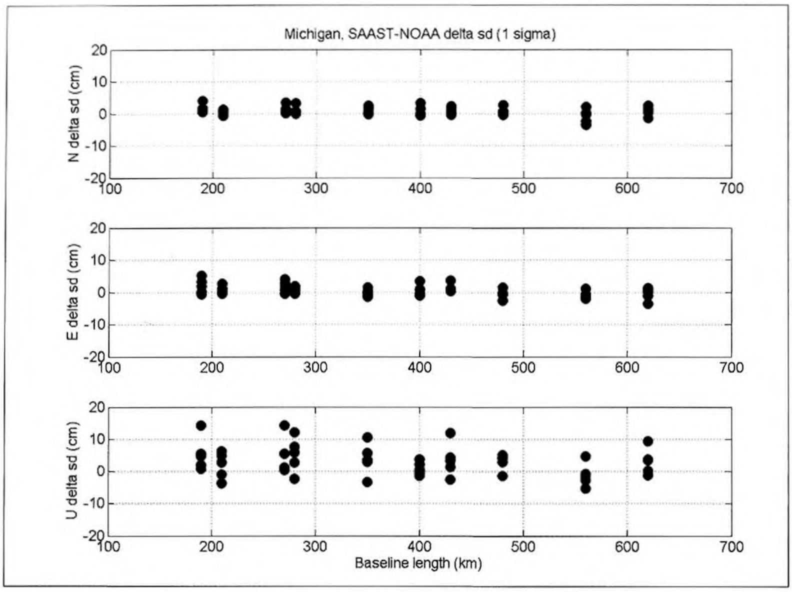

Figure 10: Michigan stdev improvement in USM NOAA over USM SAAS

troposphere model over the Saastamoinen troposphere model versus the difference in height between baseline pairs. There does appear to be an increase in height r.m.s. improvement with increasing station pair height difference. Further study into the effect of a difference in elevation is necessary.

South East Region

Eight CORS sites, all equipped with Ashtech Z-XII3 or UZ-12 GPS receivers, were used for the South East region analysis (see Figure 21). Various combinations of these eight sites produced nine baseline pairs with lengths varying from 190km to 690km (see Table 4). There were no significant height differences between baseline pairs. Only three day of data was used: July 11 (doy 193), July 13 (doy 195) and July 16 (doy 198).

Visual inspection of the zenith wet delay for the observation time period showed some dry areas in the beginning with wet delay readings as low as 15cm (see Figure 22). However, this region of the US is usually hot and humid during the summer months and Figure 23 is a more representative picture, with wet delay values consistently between 25cm and 35cm. Viewing all of the wet delay plots for the week, in the form of a movie, shows that weather variations occur very rapidly when compared to the other two areas (Michigan and California).

Figure 24, Figure 25 and Figure 26 show the r.m.s., bias, and standard deviation (1σ) improvements of the NOAA troposphere model over the Saastamoinen model. All of these plots show r.m.s. versus baseline length. The r.m.s. plots indicate general improvement in the vertical position accuracy. The average horizontal improvement was 0.2cm in the north and –0.4cm in the east. The average

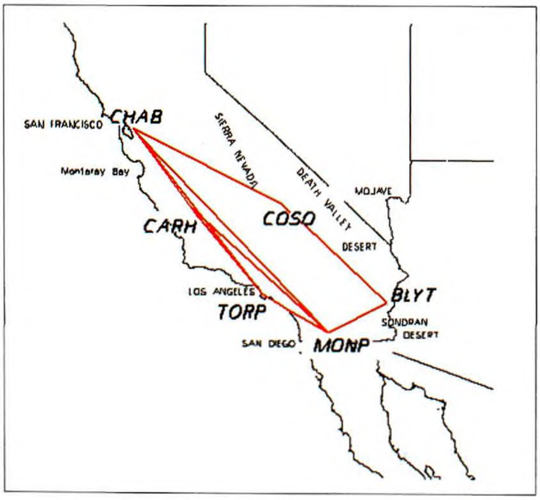

Figure 11: Baselines and CORS stations for California region.

Number	Baseline	Length (km)
1	OKCB-RMND	190
2	LSUA-LMCN	270
3	SIHS-LMCN	300
4	JXVL-OKCB	360
5	PRRY-OKCB	400
6	PNCY-LMCN	500
7	JXVL-RMND	560
8	PRRY-RMND	580
9	PRRY-LMCN	690

Table 4: Baselines and corresponding lengths for South East region.

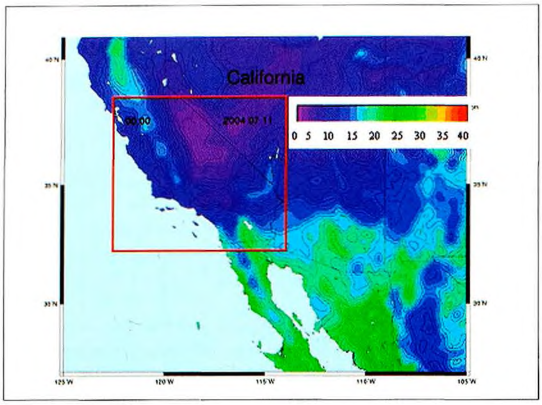

Figure 12: California zenith wet delay (in cm) for July 11, 2004

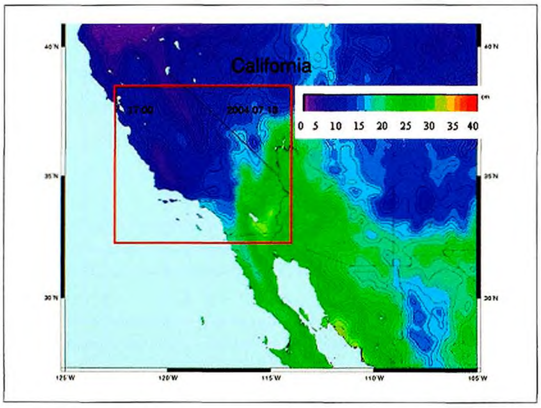

Figure 13: California zenith wet delay (in cm) for July 13, 2004

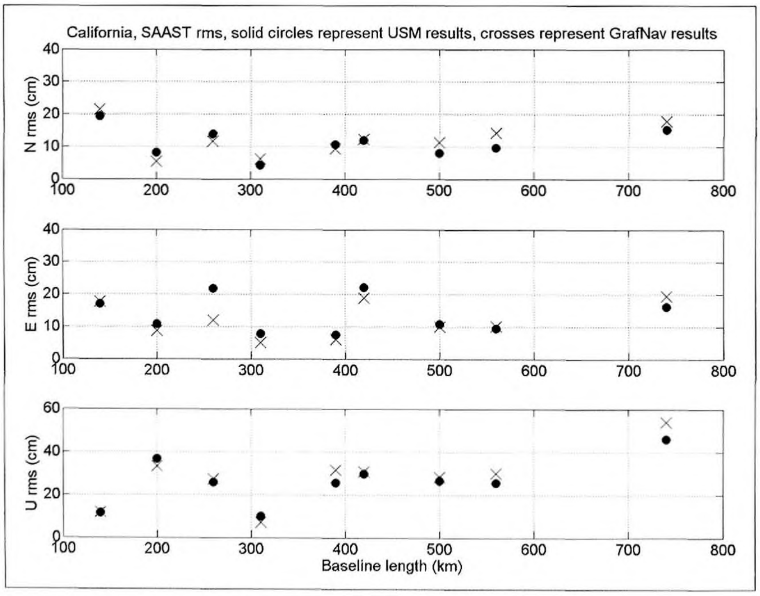

Figure 14: GrafNav and USM SAAST comparison for DOY198

height improvement was 4.3cm. The r.m.s. improvements do not appear to be a function of baseline length. In a few cases the USM NOAA solution is worse than the USM SAAST solution (negative improvement). For the most part, the USM NOAA results that are worse than USM SAAST results (negative improvement) correspond to an increase in the USM NOAA standard deviation. The average standard deviation improvement in the height was –8.0cm. The overall bias differences shows an improvement in all cases; however, in a few cases the standard deviation indicates a higher noise level for the NOAA solution, which leads to an overall negative r.m.s. improvement. The rapid weather pattern movement may be partially responsible for this, however; further investigation will be required to confirm this.

Conclusions and recommendations

For all three study areas, the horizontal r.m.s. improvements were negligible (few cm), whereas the vertical r.m.s improvements were consistently above one decimeter, and in some cases above three decimeters. For the data used in this study, with baselines between 140 and 740km, the r.m.s. improvements in height from USM SAAT to USM NOAA did not appear to be a function of baseline length. Table 5 shows the average position height error improvements (bias, standard deviation and r.m.s.) for each study area. Note that these values refer to improvements (SAAST-NOAA) and consequently a negative improvement indicates that the NOAA troposphere model resulted in a worse solution. For the South East, the average standard deviation improvement was –8.0, however; there was still an average r.m.s. improvement of 4.3.

For the data sets used in the positioning analysis it is quite apparent that the NOAA troposphere corrections improves long baseline, float solution positioning All areas showed a general improvement in

		bias (cm)	sd (cm)	r.m.s. (cm)
Michigan	SAAST	-0.9	15.9	19.5
	NOAA	-2.5	12.8	14.2
	SAAST-NOAA	4.4	3.0	5.5
California	SAAST	-1.6	19.7	35.6
	NOAA	7.8	15.3	21.2
	SAAST-NOAA	14.1	4.4	14.3
South East	SAAST	0.9	12.2	26.4
	NOAA	2.8	20.2	22.1
	SAAST-NOAA	6.5	-8.0	4.3

Table 5: Average position height bias, standard deviation and r.m.s. improvements for each study area.

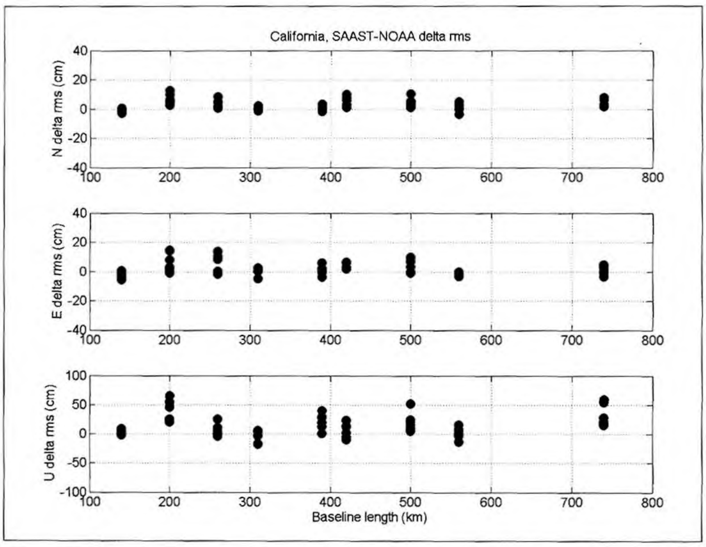

Figure 15: California r.m.s. improvement in USM NOAA over USM SAAST.

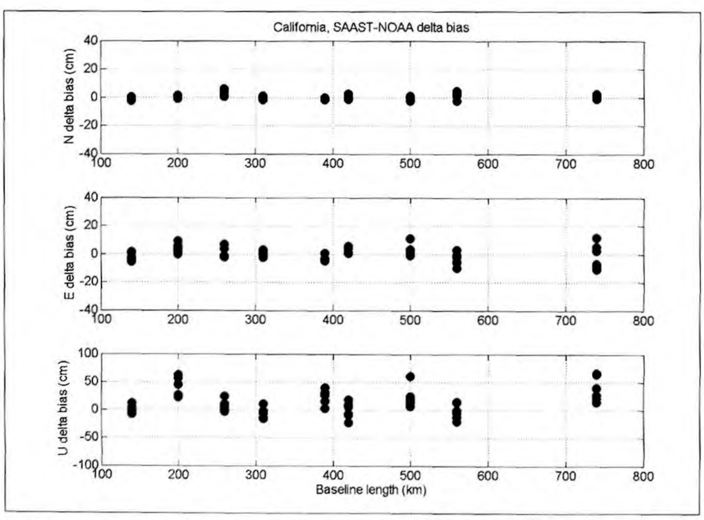

Figure 16: California bias. improvement in USM NOAA over USM SAAST.

results, especially in the vertical. In some cases the vertical r.m.s. improvement was as much as 50cm. However, all areas also showed a few situations where the application of the NOAA troposphere model actually made the results worse. For the California area, increased r.m.s. from the NOAA troposphere model (less accurate result) resulted from an increase in the bias error. For the South East area, increased r.m.s. from the NOAA troposphere model appeared to correspond to an increase in the standard deviation. For areas of high vertical variation, such as California, application of the NOAA troposphere model had the greatest effect on the vertical position bias (see Table 5). Whereas in areas of rapid weather pattern changes, such as the South East, application of the NOAA troposphere model resulted in higher standard deviation. These situations will require further investigation.

The results shown here are similar to those quoted by Alves et al. [2004], where NOAA tropospheric data were incorporated into single and multi-baseline processing. A significantly larger data set with longer baselines has been presented in the current work; however, more processing is required to better quantify the improvements.

In the position domain analysis, improvement and expansion of the float processing is needed. Once the float ambiguity analysis is complete, high-quality fixed L1 and L2 ambiguity processing should be attempted. Residual tropospheric estimation should also be introduced to determine if the application of a tropospheric scale factor provides similar results as applying the NOAA tropospheric product. A study of filter convergence should also be completed.

The purpose of this study was to evaluate the use of the NOAA troposphere correctors in the Nationwide DGPS service. This paper focused on the maritime user, however; the stations used were all on land. The

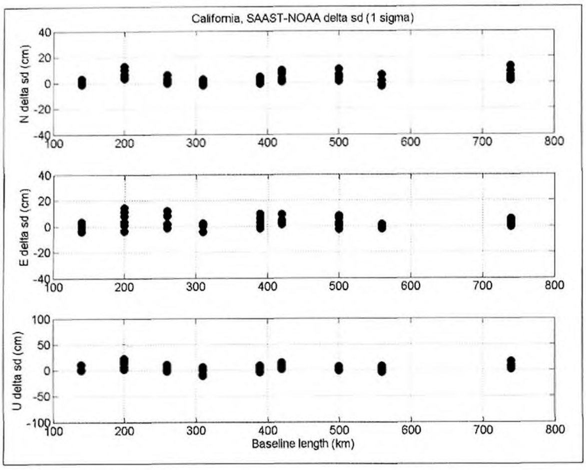

Figure 17: California stdev improvement in USM NOAA over USM SAAST.

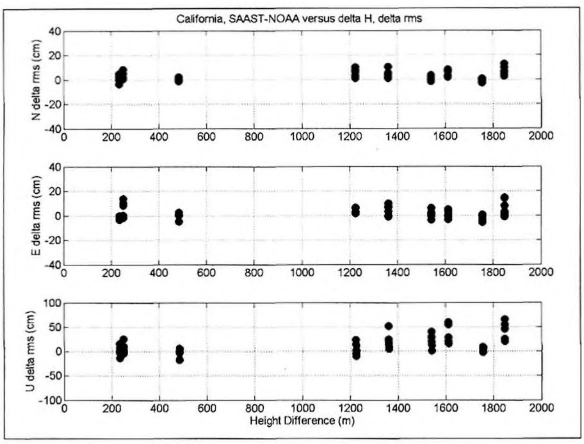

Figure 18: California r.m.s improvement in USM NOAA over USM SAAST versus height difference.

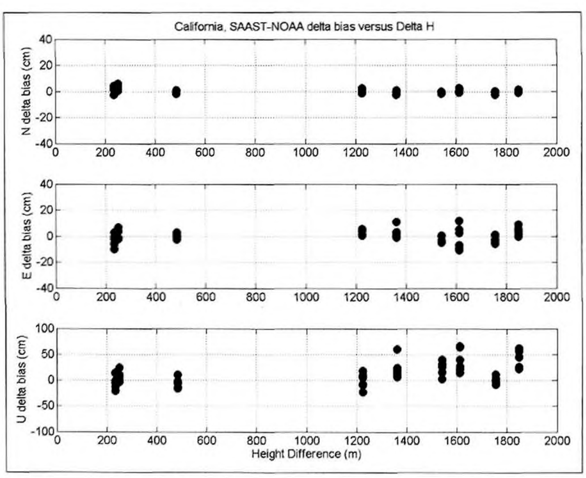

Figure 19: California bias improvement in USM NOAA over USM SAAST versus height difference.

regions and CORS stations were selected to simulate, as closely as possible, a maritime environment, and in most cases, some of the satellites in use would have been over a body of water. Therefore, the results shown here were indicative of what would be expected in a maritime environment. Any further position domain study should include the analysis of dynamic data from the marine environment (e.g. a data buoy).

Future studies will include a similar analysis of the ionosphere, as well as an evaluation of applying both ionosphere and troposphere models in both float and fixed ambiguity solutions.

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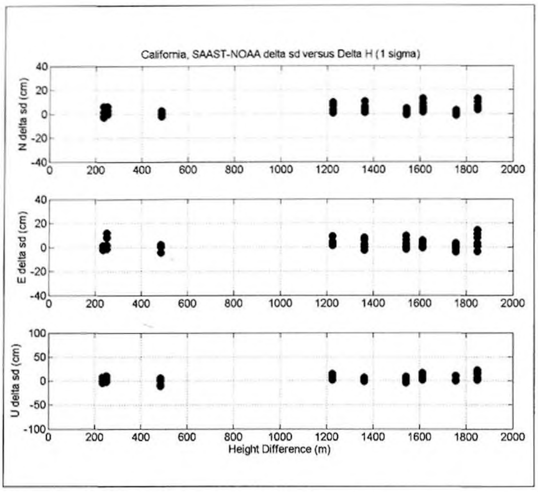

Figure 20: California stdev improvement in USM NOAA over USM SAAST versus height difference.

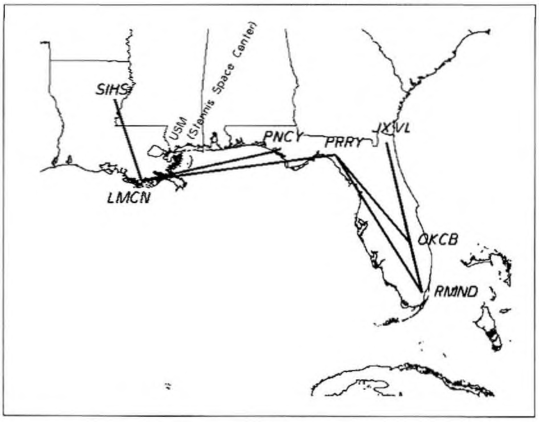

Figure 21: Baselines and CORS stations for South East region.

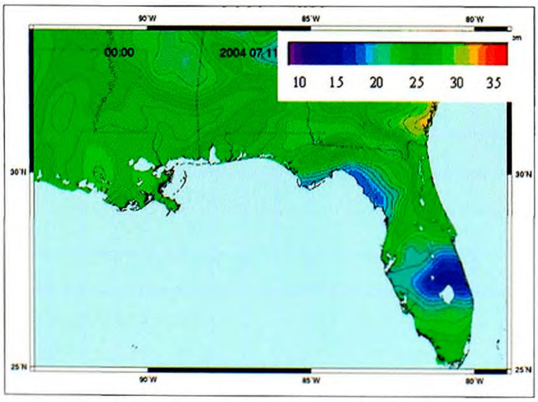

Figure 22: South East zenith wet delay (in cm) for July 11, 2004

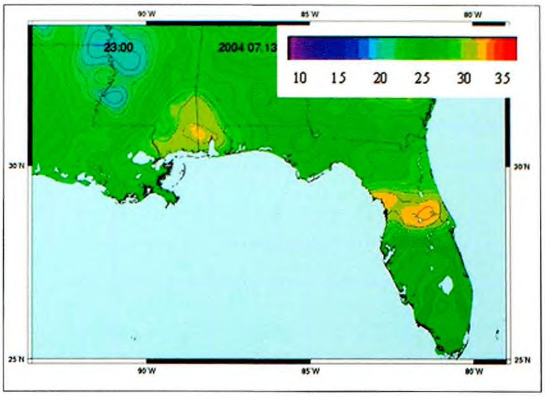

Figure 23: South East zenith wet delay (in cm) for July 13, 2004

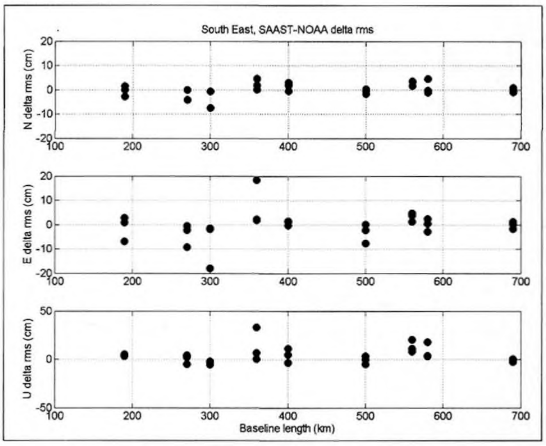

Figure 24: South East r.m.s improvement in USM NOAA over USM SAAST.

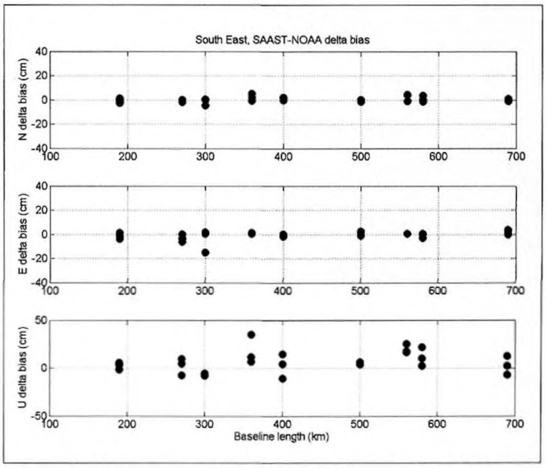

Figure 25: South East bias improvement in USM NOAA over USM SAAST.

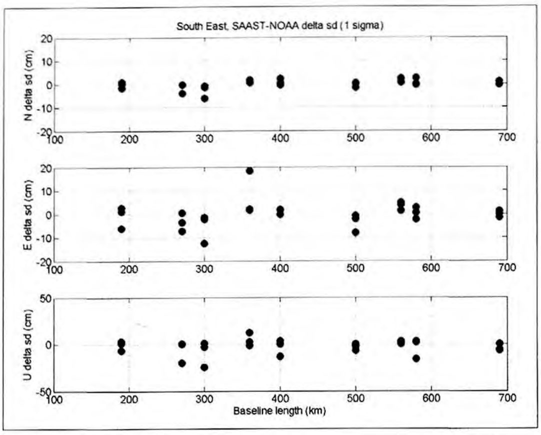

Figure 26: South East stdev improvement in USM NOAA over USM SAAST.

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