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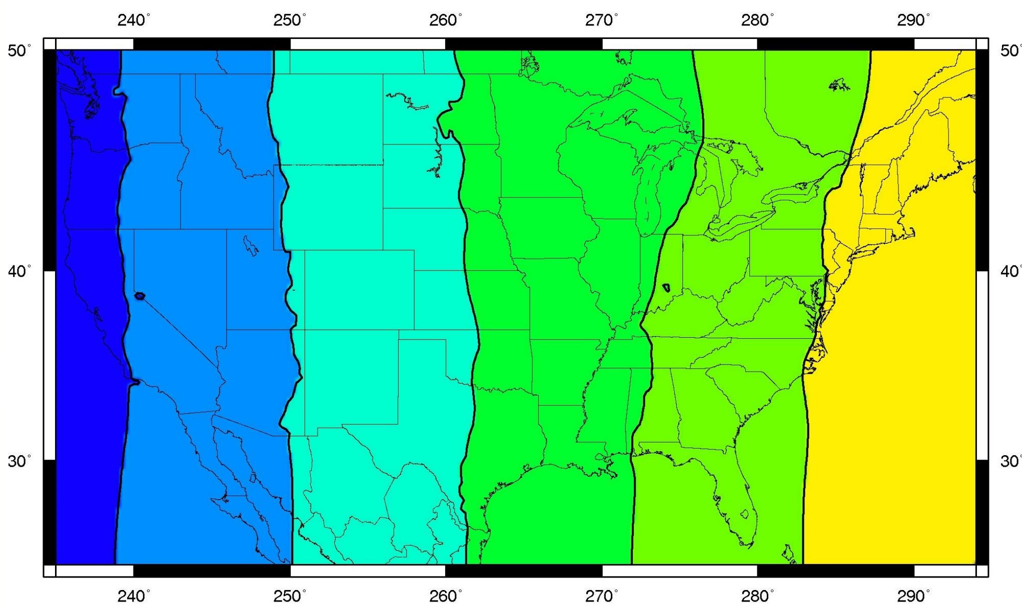
NOAA Technical Report NOS NGS 63

NADCON 5.0: Geometric Transformation Tool for points in the National Spatial Reference System



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July 24, 2017	Original Release
August 31, 2020	Corrected a typo in figure 6-48

Executive Summary

NOAA Technical Report NOS NGS 63

NADCON 5.0: Geometric Transformation Tool for points in the National Spatial Reference System

The transformation of geometric coordinates from one datum to another is a historic service of the National Geodetic Survey (NGS). Two primary programs implemented the transformations across various datums and realizations: NADCON (for North American Datum coordinate CONversion program) and GEOCON. As NGS produced more datums, and eventually adjustments (known as "realizations") of those datums, NADCON and GEOCON expanded and went through different versions. Unfortunately, the incorporation of new datums and adjustments was handled in an inconsistent and poorly-documented way, leading to confusion on how to best handle future transformations.

This report serves as documentation for **NADCON version 5.0**, a comprehensive rebuild and replacement for all versions of NADCON and GEOCON and their respective transformations. This rebuild focused on three areas: 1) improving how users interface with NGS datum transformation software, 2) correcting known bugs and scientific issues with the existing software, and 3) preparing for the replacement of NAD 83 in 2022. For the NADCON 5.0 release provided with this report, 44 separate transformations (30 latitude/longitude, 14 ellipsoid height) were computed in 9 different regions.

The report details how data were pre-processed, analyzed, plotted, and released, for each of the transformations. The analysis software is included, so that the 2022 reference frames can be similarly transformed and integrated into NADCON 5.0 in the future.

The final NADCON 5.0 product was integrated into a newly expanded Geodetic Toolkit, available online from NGS in three forms: 1) As an online interface, 2) as a web service or 3) as a downloadable program.

Contents

Author's Note regarding report highlights and a "user guide" for the general public: This extensive report was written primarily for internal NGS usage. As such, many sections contain exhausting detail beyond the level of interest for most NADCON 5.0 users. As an aid to the general public, the authors recommend the following sections for different readers:

NADCON 5.0 users hoping to understand NADCON 5.0 tool results in deeper detail:

6 Report on each transformation

11 Guide to Digital Archive

NADCON 5.0 users who want to understand how this tool relates to NADCON and GEOCON:

1 History of geometric (horizontal) datums, datum realizations and transformations at NGS

7 Comparison to previous transformations

8 How well does NADCON 5.0 perform?

Author's Note regarding Latitude and Longitude Conventions: Throughout this document, the convention used to designate Latitudes and Longitudes will be as follows. Latitudes will always have a NADvalue between -90 degrees (South Pole) and +90 degrees (North Pole). Longitudes will always have a value between 0 degrees (Greenwich meridian) and 360 degrees (eastward back to the Greenwich meridian). While other conventions have been used in older NGS products and services, they will only be mentioned herein if it is necessary to clarify some issue with that product or service.

Author's Note regarding Transformation Sign Conventions: Throughout this document the convention used to designate the sign of a transformation is always that of "New coordinate minus Old coordinate". For example, consider the transformation between NAD 83(NSRS2007) and NAD 83(2011). Such a transformation consists of three grids (one for latitude, one for longitude, one for ellipsoid heights). The actual values found in those grids are of this form: "NAD 83(2011) minus NAD 83(NSRS2007)". Therefore, to apply this transformation one should to the following:

NAD 83(2011) = NAD 83(NSRS2007) + Grid

or

NAD 83(NSRS2007) = NAD 83(2011) - Grid

In generic terms:

Coordinate in New Datum = Coordinate in Old Datum + Grid
Coordinate in Old Datum = Coordinate in New Datum – Grid
Grid = Coordinate in New Datum – Coordinate in Old Datum

Author's Note regarding Scientific Notebook Documentation: One major part of documenting the process of building NADCON 5.0 was kept in scientific laboratory notebooks by Dr. Dru Smith. These notebooks contain handwritten notes, plots, derivations and other critical evidence supporting the scientific method spanning the entire NADCON 5.0 project. Each notebook is named "DRU-##" sequentially (with ## being "12" by 2016) and contains 152 pages. As such, a footnote that reads "see DRU-11 pages 113-121" means in notebook #11 in the series, on pages 113-121 will be found handwritten notes and derivations relevant to that particular part of NADCON 5.0.

Author's Note concerning file naming conventions: A systematic naming convention was developed for the NADCON 5.0 project. Most file names contain references at least to the "old datum", "new datum" and "region" to which a particular transformation refers. Additional information in a file name may include the "map flag", "grid spacing" or "area mapped". In order to simplify this report, when a file name is mentioned in a generic way, this report will use the following shorthand notation:

od	old datum
nd	new datum
rg	region
mf	map flag
gs	grid spacing
am	area mapped

1 History of geometric (horizontal) datums, datum realizations and transformations at NGS

1.1 The first U.S. datums (1807-1986)

The National Geodetic Survey (NGS) is the oldest scientific agency in the nation, tracing its roots back through the Coast and Geodetic Survey (C&GS), the Coast Survey and ultimately the Survey of the Coast, established by Congressional act and signed into law by President Thomas Jefferson in 1807. One of the primary functions of NGS and its predecessors has been the establishment of datums. A datum can be considered a coordinate system which is accessed through geodetic control points. These geodetic control points have historically been a metal disk or rod set into the crust of the Earth, and surveyed to the highest possible accuracy. Networks of these marks, and all of the measurements between them could be analyzed through a process called Least Squares Adjustments (or just "an adjustment"), which would minimize errors and yield highly accurate, mutually consistent coordinates on all of the marks. Such an adjustment would establish a datum. Datums are established to provide starting (known) coordinates for other surveyors, map makers, chart makers, etc so that all of the maps created would be consistent with one another.

Historically, two types of datums were established: horizontal and vertical. Until the advent of GPS, these were generally independent of one another and used different geodetic control marks. Horizontal datums defined latitude and longitude, while vertical datums defined elevations (specifically orthometric heights, or, colloquially "height above sea level"). This report is concerned entirely with horizontal datums. (However, it should be mentioned that with the rise of GPS, horizontal datums gained a 3rd coordinate type, the "ellipsoid height". Ellipsoid heights are not the same as orthometric heights.)

Because the establishment of a datum was historically a very labor-intensive process, the initial datums were local, often serving only a particular part of a state, or perhaps the coastal regions of a few states. Unless these regional datums were connected to one another through surveys, they stood independent and not necessarily consistent with one another. Examples of such stand-alone datums were the "Saint Paul 1897" and "Saint George 1897" datums, established by C&GS on the Pribilof Islands of St. Paul and St. George, off the coast of Alaska.

It was thus over a century before the first nationwide (coast to coast in the Conterminous USA, CONUS, only) datums were established. In 1901, the U.S. Standard Datum (USSD) became the first nationwide horizontal datum[1](C&GS, 1901.) By 1927 it had been expanded and corrected, and the North American Datum of 1927 (NAD 27) was made available.

[1] By 1913, the USSD had been adopted by Canada and Mexico. This caused the name to change to "North American Datum", though the coordinates in the datum did not change.

The C&GS performed other surveys and adjustments, establishing datums in the late 1800s and early 1900s, conterminous with the work being done in CONUS. Because of "Seward's Folly", much of that work established local datums in Alaska. In Puerto Rico, enough surveys had been done by 1915 that an adjustment of survey data was performed. By 1940, C&GS had performed a new adjustment (C&GS, 1940) and thus the Puerto Rico 1915 and Puerto Rico 1940 datums were established. By 1928 the "Old Hawaiian Datum" had been established as well (Mitchell, 1930).

Through the mid 20th century, C&GS continued to establish datums on other U.S. Territories. These included: St. Paul 1952, St. George 1952, St. Lawrence 1952, St. Matthew 1952, American Samoa 1962, Guam 1963 as well as a variety of others on more far-flung, less populated territories (Midway 1961, Johnston Island 1961, etc).

Through the mid 20th century, improvements in technology, especially Electronic Distance Measuring (EDM) as well as emerging space geodetic techniques such as TRANSIT (Doppler) and Very Long Baseline Interferometry (VLBI), identified weaknesses in NAD 27. This led to a new wave of much-expanded nationwide surveys, so that by 1986 NAD 27 was replaced with the North American Datum of 1983 (NAD 83).

1.2 The first datum transformation tool (1990): NADCON 1.0

At the time of the release of NAD 27, the Coast and Geodetic Survey did not produce any sort of publicly available tool to transform coordinates from USSD to NAD 27. It seems likely that, at that time, the standard operating procedure for users of geodetic control wishing to "transform" coordinates would have been to re-adjust original survey observations to the newly established NAD 27 geodetic control.

With the release of NAD 83 in 1986, NGS was aware that a significant number of maps (particularly by the U.S. Geological Survey, USGS) had been created using NAD 27, which would need to be corrected to refer to NAD 83. Re-creating each paper map using original survey data tied to new geodetic control was out of the question, so a tool for performing "datum transformations" was needed. Geodesists, like those working at NGS, have been long versed in the concept of datum transformations (moving data from one datum to another), but the methods popular in the 1980s[2] were less capable of capturing the regional subtleties of coordinate differences between NAD 27 and NAD 83.

After a variety of experiments, a decision was made to rely on a grid-based datum transformation method. By 1990 NGS had developed NADCON (for North American Datum CONversion), a grid-based tool for converting NAD 27 latitudes and longitudes into NAD 83 and back. Along with support for the NAD 27/NAD 83 conversion (in both Alaska and CONUS), NADCON also provided transformations between the following older datums and NAD 83: the Old Hawaiian Datum (OHD), the Puerto Rico Datum of 1940 (PR40), the Saint Paul Island 1952 Datum (SP1952), the Saint George Island 1952 Datum

[2] Most popular were 3 or 7 parameter Helmert transformations which would be able to capture little more than a bias and tilt across something the size of CONUS

(SG1952) and the St. Laurence (sp) Island 1952 Datum (SL1952).[3] This original release of NADCON is known as NADCON 1.0.

1.3 The first datum realizations (1986-1996): HARNs

New data available in the 1980s and 1990s, primarily surveys using positions from the newly developed Global Positioning System (GPS), showed that the original release of NAD 83 had its own weaknesses. Therefore, NGS began a state-by-state GPS survey campaign, originally called the High Precision Geodetic Network (HPGN), but this name was soon replaced with High Accuracy Reference Network (HARN), with the intent of improving latitudes and longitudes using GPS. As each state was surveyed, an adjustment of data was made and an updated set of coordinates released. The data adjusted included both traditional traverse (angles and distances) as well as GPS-derived vectors. Neither the origin nor ellipsoid of the datum had changed and (importantly) both the federal and state communities were still transitioning to the use of NAD 83. NGS therefore viewed these updated coordinates as being within NAD 83 still, and did not see any wisdom in changing the datum name. However, some method needed to be adopted by which the older NAD 83 coordinates could be distinguished from the newer ones. As such, these new sets of coordinates were released under the name "NAD 83", but the use of a "datum tag" was introduced to distinguish one set of NAD 83 coordinates from another. A datum tag was simply the year of the adjustment, so the original NAD 83 came to be called "NAD 83(1986)", while an adjustment done in 1992, based on a HARN survey, would be called "NAD 83(1992)[4]". Later, these various adjustments of NAD 83 came to be known as "realizations" of NAD 83.

It should be pointed out that NGS was releasing multiple adjustments (realizations) every year, generally covering one medium sized state, one fraction of a large state or group of small states Continuing the example above, one can see NAD 83(1992) coordinates on a datasheet from Alabama but also on a datasheet from Arizona. These two states had their HARN data adjusted in 1992 in separate, but correlated[5] adjustments, yet nothing on a datasheet would tell the user that "NAD 83(1992)" in Alabama isn't from the same exact adjustment of NAD 83 as the "NAD 83(1992)" adjustment in Arizona. Therefore, for purposes of absolute clarity in this report, all realizations which have duplicate names but are actually from separate but correlated state-specific adjustments, will also have the state added to the

[3] The original NADCON software and documentation did not distinguish between NAD 27 and these other datums, despite the fact that they are entirely different from one another. Such seemingly small oversights have caused significant confusion in the user community in the intervening decades. As such, one of the many places of improvement in NADCON 5.0 over previous transformation tools by NGS is clear and precise documentation, in conjunction with as a concerted effort to correct mislabeled information in the NGS Integrated Database (NGSIDB).

[4] The adjustment year, and not the observation year, was usually used as the datum tag.

[5] "Separate but correlated" is used because the HARN adjustments were certainly computed independent from one another, but their input data built upon previous HARN adjustments. For instance, in Ohio the HARN adjustment was done in 1995, leading to NAD 83(1995) coordinates in Ohio. But this adjustment relied on selected results from previous, neighboring HARN adjustments, such as Michigan (1994), Pennsylvania (1992) or Kentucky (1993). And all HARNs, even the earliest ones, were all reliant upon some data from the original NAD 83(1986). In this way, the intent of the HARN adjustments was to create one self-consistent set of new NAD 83 coordinates. When NADCON 5.0 was built, the spirit of this intent was respected, and "NAD 83(HARN)" was used as a single realization across CONUS in the transformation tool.

datum tag. That is, to continue the example above, this report will use “NAD 83(1992:AL)” and “NAD 83(1992:AZ)” for those two separate by correlated realizations of NAD 83.

The use of GPS in the HARN surveys allowed for the computation of ellipsoid heights for the first time, though the goal of the HARNs was improved latitudes and longitudes only. Therefore some ellipsoid heights were computed and stored in the database from the HARNs, but certainly not for all HARN points.

1.4 Expanding NADCON (1992-2010): NADCON 2.1

As the HARNs were released, so too did NGS release expansions of NADCON to go with it. Unlike the original NADCON tool whose CONUS support came in the form of a single pair of grids (one for latitude, one for longitude), each HARN adjustment had grids associated with it which encompassed *only* the area of the HARN. For example, supporting the transformation from NAD 83(1986) to NAD 83(1992:AZ) was a grid that was only big enough to encompass Arizona (in this particular case, a rectangle bounded by the 30th and 38th parallels and by the 244th and 252nd meridians. See Figure 1-1.) This expansion of NADCON through HARN-specific grids was known as NADCON 2.1, which was released on January 15, 1992, with all available HARN grids at that time. As new grids were created, they were added to the list of files supported by NADCON 2.1.

Since few states are actually rectangular, and since each one of these HARN-specific grids was built with a small buffer, it is easy to understand why the various grids overlapped one another. What is not obvious, but is true, is that the grids were never forced to *agree* in such an overlap area. In the case of the Arizona grid (Figure 1-1), it can be seen that this particular transformation would overlap with those of California (South grid only), Nevada, Utah, Colorado and New Mexico.

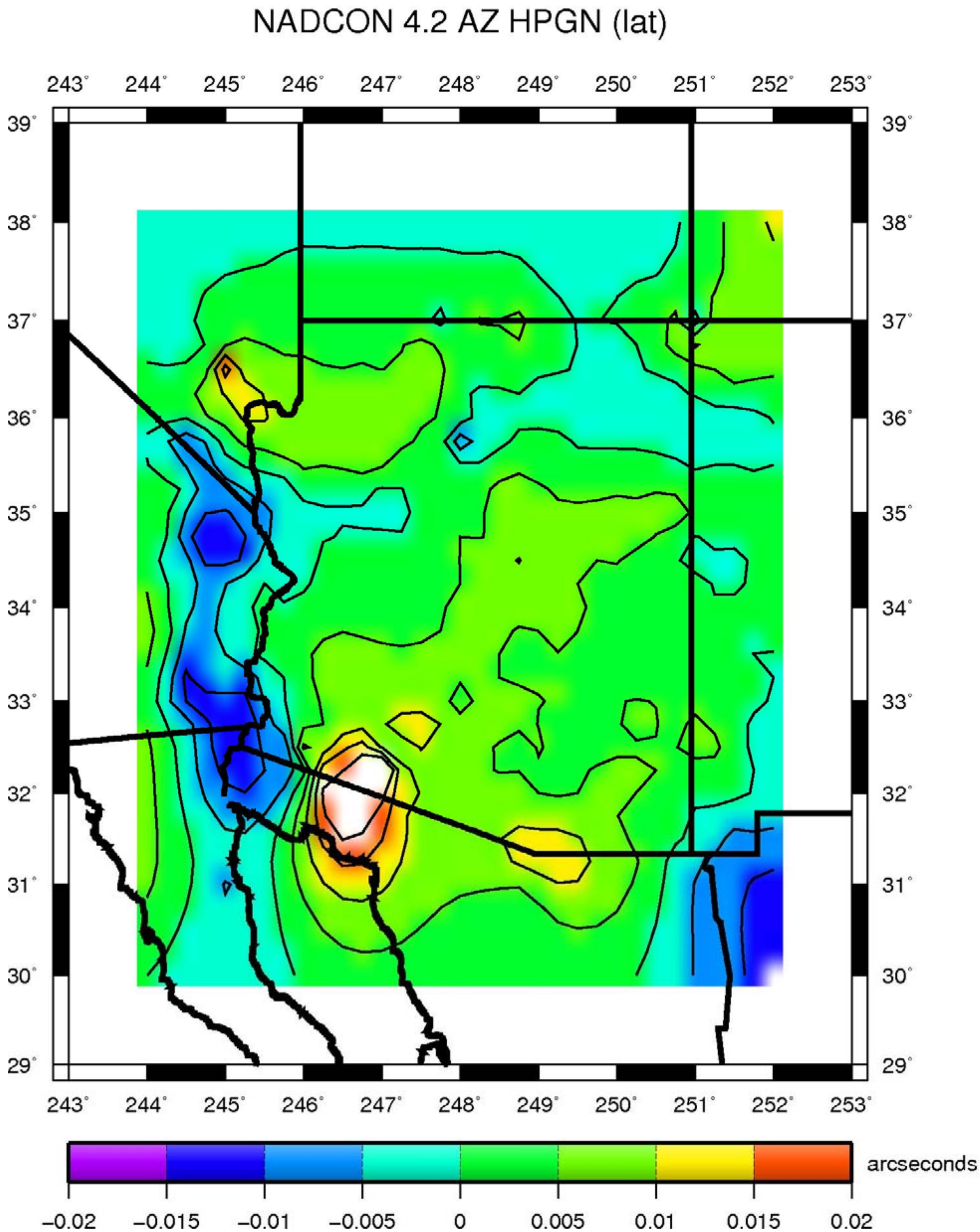

Figure 1-1: The Arizona HPGN latitude grid from NADCON 2.1 (and 4.2)

By way of exemplifying how the various NADCON HARN grids were allowed to remain out of agreement with one another, consider the Four Corners Monument (latitude 37, longitude 251). An examination of the above plot should make it clear that all four states which border that monument have NADCON HARN grids which extend across that point, just as the Arizona grid does. Yet those four different transformations have four magnitudes of coordinate shift, as follows:

Table 1-1: Disagreeing values of NADCON HARN grids at Four Corners Monument

State	HARN Year	Latitude Shift (arcseconds / cm)	Longitude Shift (arcseconds / cm)
AZ	1992	-0.001969 / -6.1 cm	+0.003709 / +9.1 cm
UT	1994	+0.003720 / +11.5 cm	+0.003005 / +7.4 cm
CO	1992	+0.003504 / +10.8 cm	+0.002720 / +6.7 cm
NM	1992	-0.001967 / -6.1 cm	+0.003861 / +9.5 cm

Note that the transformations range from -6.1 cm to +11.5 cm (in latitude) and +6.7 cm to +9.5 cm (in longitude), with no apparent correlation to the date released. Without any consistency to the grids, it is obvious that users moving across state lines, beyond the confines of one grid, faced a difficult choice with little guidance[6].

This pattern of surveying a HARN and then releasing its associated NADCON grid continued through the 1990s.

1.5 The second datum realizations (1997-2006): FBNs

Toward the end of the 1990s, NGS began to realize that, with certain approaches to using GPS, that ellipsoid heights were also obtainable with greater accuracy than previous expected (as good as 2 cm or so in some cases). With the increased interest in geoid modeling, the need for ellipsoid heights grew. Furthermore, through the 1990s the Continuously Operating Reference Station (CORS) network was expanding rapidly, and NGS saw this new tool as the backbone of the National Spatial Reference System (NSRS). As such, NGS embarked on another round of state-by-state GPS surveys, with the express intent of tying the passive control coordinates to the CORS network while attempting to obtain accurate ellipsoid heights. These surveys became known as the Federal Base Network (FBN). Like the HARNs, the FBNs were also generally adjusted on a state-by-state basis, only unlike the HARNs, the use of traverse data was not part of the FBN adjustments.

In 30 of the 49 states and territories (48 states plus District of Columbia) that make up CONUS, the adjustment of the FBN data yielded an accurate ellipsoid height and confirmed (to better than 5 centimeters) the existing HARN-based latitude and longitude. In these 30 states therefore, a data sheet

[6] The use of a state-by-state grid approach was seen as a serious disadvantage in the application of the existing NADCON software, and one to be rectified in the NADCON 5.0 release.

(after the FBN survey) would generally show the datum tag of the ellipsoid height as the same as the HARN, despite being different surveys and different adjustments. An example of this would be Ohio, which had a HARN in 1995 and an FBN in 2003. Because the 2003 latitudes and longitudes were (generally) within 5 cm of the 1995 latitudes and longitudes, they were not changed in the official database (the NGS IDB). However, the 2003 ellipsoid heights were new and loaded into the NGS IDB without a datum tag. The result of this approach was that they were effectively "tagged" as NAD 83(1995) on NGS datasheets.

In 19 of the 49 states and territories of CONUS, differences in the latitudes and longitudes between the HARN and the FBN were significant enough (> 5 cm) that a new, distinct realization had to be created. An example of this would be Wisconsin, which had a HARN in 1991 and an FBN in 1997. Datasheets for Wisconsin points could show latitudes and longitudes and ellipsoid heights in NAD 83(1991) or in NAD 83(1997), giving the citizens of Wisconsin a choice of which realization to use.

1.6 Impact of FBNs on datum transformations (1997-2006)

In the 19 states where the FBN stood independent of the HARN, NGS was inconsistent in how it expanded NADCON to deal with the situation. In 6 of the 19 states, NGS chose to build a transformation grid into NADCON 2.1 skipping directly over the HARN and connecting NAD 83(1986) to the FBN in that state, while in the 13 others NADCON 2.1 connected NAD 83(1986) to the HARN and provided no support for the FBN. Table 1-2 summarizes the situation. The NADCON 2.1 grids transform NAD 83(1986) to the particular realization in green in Table 1-2. Note that these are horizontal-only transformations; the emphasis on ellipsoid heights from the FBN surveys did not extend into NADCON, which continued to support the transformation of latitude and longitude only.

In the interest of scientific completeness, it should be pointed out that there is no documentation extant which directly corroborates Table 1-2. The only evidence at hand to support it is (a) the year in which each set of transformation files was created[7] and (b) a comparison to the NADCON 5.0 grids, to see if the historic transformations more closely resembled a link to HARNs or to FBNs. The difficulty with the latter piece of evidence is that the magnitude of the NAD 83(HARN) to NAD 83(FBN) transformation is much smaller than that of NAD 83(1986) to NAD 83(HARN). As such, it is visually very difficult to distinguish between an "NAD 83(1986) to NAD 83(HARN)" and an "NAD 83(1986) to NAD 83(FBN)" transformation in these states. Still, the best evidence at hand was used to create Table 1-2.

[7] The date actually associated with each file on the NGS Unix server supporting NADCON 2.1

Table 1-2: Inconsistent support in NADCON in those 19 states with an FBN (realization supported in NADCON 2.1 is colored green)

State(s)	HARN	FBN
CA	1992	1998
CT, MA, NH, RI, VT	1992	1996
FL	1990	1999
ID, MT	1992	1999
ME	1992	1996
NC	1995	2001
NJ	1992	1996
NY	1992	1996
NV	1994	1999
OR, WA	1991	1998
SC	1995	2001
TN	1990	1995
WI	1991	1997

1.7 Non-CONUS GPS improvements to NAD 83 (1990-2002)

The improvements to NAD 83 using GPS, such as the HARN and FBN surveys, were not restricted entirely to the CONUS region[8]. In 1992 NGS readjusted data for Alaska without new observations (Julie Prusky, NGS, Personal Communication; GPS project #450). This re-adjustment was not part of the HARN effort. In 1993, NGS embarked on GPS surveys (GPS project #667) in Hawaii, Guam, The Commonwealth of the Northern Mariana Islands and American Samoa (Frakes 1994)[9]. Of these surveys, only the Hawaiian one was labeled as a "HARN". Separately from this project, a HARN was surveyed and adjusted on Puerto Rico and the U.S. Virgin Islands in 1993. All of these efforts yielded

[8] However, the terms "HARN" and "FBN" will be restricted entirely to CONUS throughout this document.

[9] In addition to these states and territories, GPS surveys were also performed at a variety of Pacific locations outside of the USA. As NGS is not responsible for the official datums of other countries, these surveys can not rightly be called "HARN" surveys, as that acronym is a component of the history of realizations of NAD 83, which in turn is part of the USA's National Spatial Reference System.

NAD 83(1992:AK) as well as NAD 83(1993:HI), NAD 83(1993:GU), NAD 83(1993:CQ), NAD 83(1993:AS), NAD 83(1993:PR) and NAD 83(1993:VI).

In 1997 a flaw in the 1993 adjustments in PR and VI was detected, and a new adjustment (yielding a new realization) was released in those regions as NAD 83(1997:PR) and NAD 83(1997:VI).

In 2000, NGS for the first time officially addressed the difficulties caused by secular velocities on the Pacific and Mariana plates which differed from the North American plate. At that time, NGS separated NAD 83 into three distinct reference frames, but with the unfortunately confusing choice to continue using "NAD 83" as the name for all three. CORS data in CONUS, Alaska and the Caribbean used "NAD 83(CORS96)" as its realization, while two new frames called "NAD 83(PACP00)" and "NAD 83(MARP00)" were defined for CORS data on the Pacific and Marianas plates, respectively. This raised another new confusion, in that CORS data were given on a realization that did not match that of any passive control, making it impossible to know exactly what realization should be used when users tied their surveys to both CORS and passive control. Thankfully that situation was corrected in 2011. But between 2000 and 2011, the situation was that no passive control marks were being given coordinates in any of these three reference frames. As such, they are not part of any gridded transformation tool and will not be discussed further.

In 2002, NGS continued to expand the GPS projects beyond CONUS, and into other states and territories. Although the 2000-era CORS-specific reference frames existed (see previous paragraph), these coordinates, like all passive control coordinates, were published simply with a datum tag showing the year of adjustment as usual. As such, these realizations were created: NAD 83(2002:AS), NAD 83(2002:GU), NAD 83(2002:CQ), NAD 83(2002:PR) and NAD 83(2002:VI).

Although the term "HARN" was not used in areas like Guam, etc., the term "FBN" *was* applied to the 2002 surveys of these same regions. Due to the inconsistent use of "HARN" and "FBN" in these non-CONUS regions, the shorthand use of "NAD 83(HARN)" and "NAD 83(FBN)" will be entirely restricted to CONUS within NADCON 5.0, and in all other states and territories, the actual datum tag (year) is used. For example, "NAD 83(1993)" in Hawaii will not be called "NAD 83(HARN)".

1.8 A new *nationwide* adjustment for NAD 83 (2007)

In 2007, after two full rounds (HARN and FBN) of state-by-state releases of realizations of NAD 83, NGS finally embarked on the first nationwide adjustment of the NAD 83 datum since the original 1986 release. Dubbed "NAD 83(NSRS2007)" (and thus breaking with the tradition of the datum tag being simply a year) this adjustment included GPS vectors only, and encompassed all of CONUS as well as Alaska, Puerto Rico and the U.S. Virgin Islands.

The state of Hawaii as well as the territories of Guam, CNMI and American Samoa were not adjusted as part of NAD 83(NSRS2007). Furthermore, the CORS data continued to be published in NAD 83(CORS96) while the newly adjusted passive control were published in NAD 83(NSRS2007).

1.9 A new datum transformation tool (2010): GEOCON 1.0

Upon the release of NAD 83(NSRS2007), NGS began receiving requests from the NSRS user community requesting an expansion to NADCON to support this new realization. NGS's general, informally provided answer was "the shifts are so small that they are approaching the noise in the data, so such a transformation would equate to just 'gridding noise'". That answer stood somewhat apocryphally for years before NGS engaged a formal investigation into its validity.

In 2010 an investigation (Milbert 2010) into the feasibility of a transformation tool for NSRS2007 showed that the signal was small, but it was systematic. As such, an entirely new transformation tool was created called GEOCON 1.0. This new tool transformed latitudes, longitudes *and* (for the first time) ellipsoid heights into NAD 83(NSRS2007). However it did not transform *from* one specific realization. Rather, it used (what came to be described as) "the most recent adjusted coordinate on a point after 1986 but before 2007".[10] One positive, though somewhat inactionable result of this study was that NAD 83(CORS96) and NAD 83(NSRS2007) were seen as functionally equivalent for many purposes.

1.10 Another new *nationwide* adjustment for NAD 83 (2011)

In 2011 NGS again re-adjusted all GPS data, only this time including states and territories that had not been in the 2007 adjustment (Hawaii, Guam, CNMI and American Samoa). For the first time ever, all CORS data and all passive control data were adjusted into a common realization of the reference frame appropriate to their tectonic plate. These most recent realizations of the North American, Pacific and Marians plate-specific frames are known as "NAD 83(2011)", "NAD 83(PA11)" and "NAD 83(MA11)" (continuing the unfortunately confusing use of "NAD 83" for data not on the North American continent).

1.11 Another new datum transformation tool (2011): GEOCON11 1.0

As the aforementioned 2011 adjustments were ongoing during the Milbert (ibid) analysis, that project was expanded to analyze, and build if appropriate, a transformation tool between NAD 83(NSRS2007) and NAD 83(2011) in CONUS, Alaska, Puerto Rico and the U.S. Virgin Islands. This analysis revealed (in alarming clarity) the fact that NAD 83 (at least in CONUS) had ceased to be a "plate fixed" datum, though exactly how and when was not clear. But because of this, the overwhelming signal in the transformation from NAD 83(NSRS2007) to NAD 83(2011) was one of a "residual plate rotation".

A very generalized version of the vectors which support this transformation is presented in Figure 1-2. Only a handful of vectors are shown, for clarity, though there were actually over 73,000 vectors available in this transformation. Note that, aside from expected areas of disagreement such as southern California, the overwhelming signal is one of a rotation, reminiscent of the North American Plate rotation, only in the opposite direction. This implies that the NAD 83(2011) coordinates (at epoch 2010.0) are rotationally

[10] The reasons for this decision are complicated, but ultimately were reversed and were corrected in GEOCON 2.0 (see later).

clockwise of the NAD 83(NSRS2007) coordinates (at epoch 2002.0), even though a truly plate-fixed frame should have shown no rotational signal between the two epochs whatsoever.

Because of this residual rotational signal and its obvious systematic shift of NAD 83(NSRS2007) coordinates into NAD 83(2011) coordinates, a transformation tool was seen as justifiable and was released as GEOCON11 1.0.

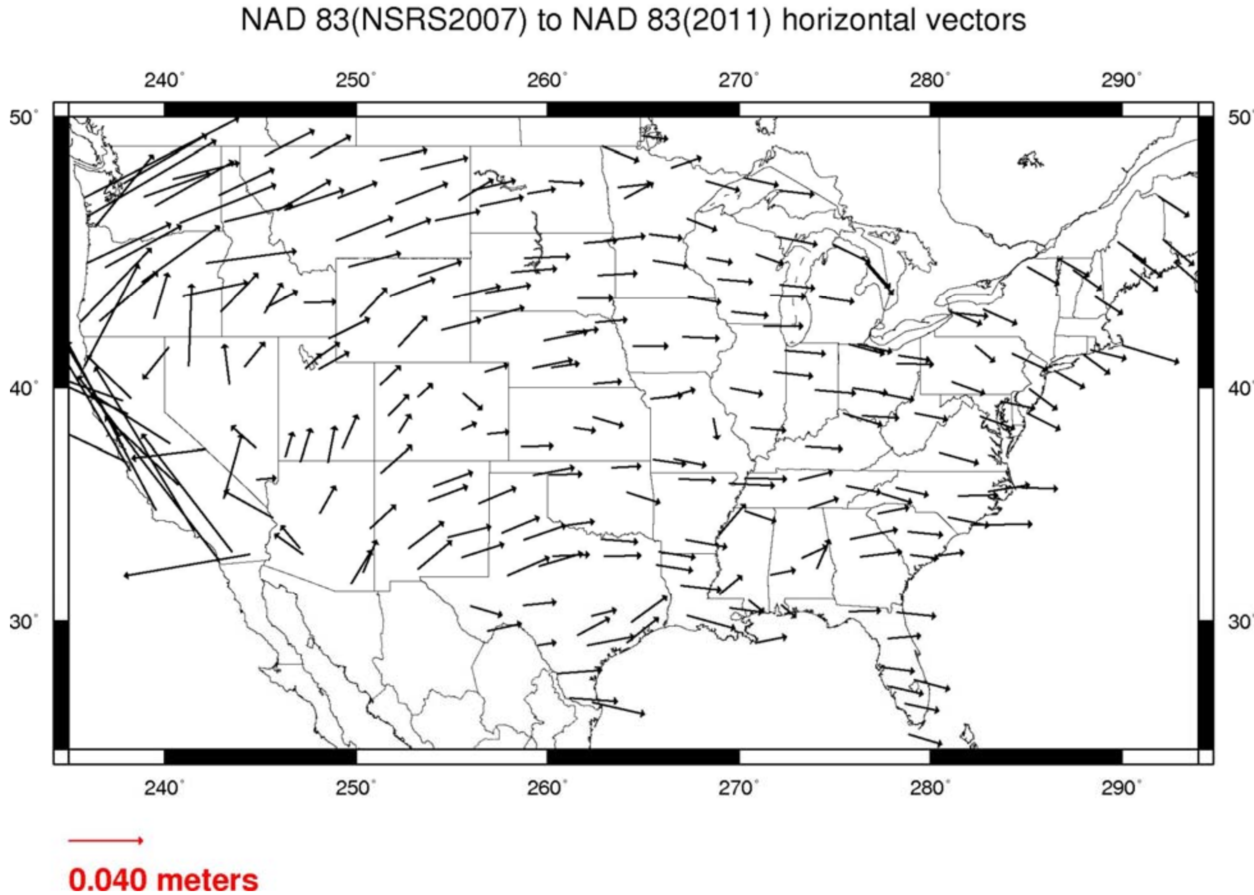

Figure 1-2: A small sampling of the horizontal transformation vectors from NAD 83(NSRS2007) to NAD 83(2011) exhibiting "residual plate rotation" behavior

1.12 Adding USSD and a GUI to NADCON (2011): NADCON 4.2

In June 2011, NGS released a new version (4.2) of NADCON, written in Java and with a graphic user interface (GUI) very different than previous versions. Because the project to upgrade NADCON was part of an ongoing contract, there was no attempt to introduce GEOCON nor GEOCON11 functionality into this new version of NADCON.

Additionally, in 2005, NOAA's Coastal Services Center had requested from NGS that NADCON should support the U.S. Standard Datum (USSD), specifically to move "t sheets" from the USSD to

NAD 83(1986). Years of effort, manually checking hundreds of books from the NGS archives and digitally entering them into the NGS IDB went into this effort. NADCON already supported a transformation from NAD 27 to NAD 83(1986), and NGS could have created a USSD-to-NAD 27 transformation to satisfy this need. However the choice was made to leap over NAD 27 and create a direct USSD-to-NAD 83(1986) transformation[11]. This functionality was also added to the newly released NADCON 4.2.

1.13 Fixing GEOCON and GEOCON11 (2014): GEOCON 2.0

In 2014, some bug fixes and additional I/O functionality yielded GEOCON 1.1 and GEOCON11 1.1 (Smith, 2014a).

However later in 2014 a new tool, combining the joint functionality of GEOCON 1.1 and GEOCON11 1.1 was developed, called GEOCON 2.0 (Smith 2014b). This new tool also removed the use of "the most recent adjusted coordinate on a point after 1986 but before 2007", and instead used a carefully determined list of "officially supported realizations" in each state. Two main operations could be performed in GEOCON 2.0. The first was, for any 1 of the 19 states which had both a HARN and an FBN (see earlier), a state-specific transformation could be performed between the HARN and FBN. Secondly, a nationwide transformation could be performed, moving to NAD 83(NSRS2007) as well as a nationwide transformation to NAD 83(2011). In Puerto Rico there was the additional support to go from NAD 83(1993) to NAD 83(1997) to NAD 83(2002).

In hindsight, some unfortunate choices were made in GEOCON 2.0. First, in states where the FBN did not replace the HARN, that state's HARN was referred to (in GEOCON 2.0 documentation) as an "FBN". This was done so that it could accurately be said that there was a "nationwide transformation from NAD 83(FBN) to NAD 83(NSRS2007)". Furthermore, the use of state-specific grids is now known to have been completely unnecessary. Such state-specific grids (from both NADCON and GEOCON) have been removed from NADCON 5.0.

1.14 A new all-use transformation tool (2016): NADCON 5.0

In 2016, NGS decided to update its online toolkit to include NADCON functionality. Thus, the opportunity arose to erase mistakes of the past and provide a ready-built tool to work with the 2022 reference frames. The end result of that decision is the new functionality known as NADCON 5.0.

1.15 Summary of the history of datums and transformations

Table 1-3 below summarizes all of the events mentioned above, as well as a few additional highlights.

[11] This choice to "leap over" a datum was reversed in NADCON 5.0.

Table 1-3: Chronology of Datums, Datum Realizations and Transformation Tools

Year(s)	Datum/Realization Release	Transformation Release	Notes
1897	SP1897, SG1897		Astronomic datums on Pribilof islands
1901	U.S. Standard Datum		First nationwide horizontal datum
1915	PR15		1915 Adjustment of "Puerto Rico Datum"
1927	NAD 27		No transformation to USSD provided
1940	PR40		1940 Adjustment of "Puerto Rico Datum"
1952	SP1952, SG1952, SL1952, SM1952		"SM" for Saint Michael Island. This 1952 datum was the first and only one defined on that island.
1962	AS62		American Samoa astronomic datum
1963	GU63		Guam and CNMI astronomic datum
1986	NAD 83(1986)		CONUS, Hawaii, Alaska and PR/VI
1990		NADCON 1.0	NAD27 / NAD 83(1986)
1991-1996	NAD 83("HARN")	NADCON 2.1	State-by-State grids from NAD 83(1986) to NAD 83("HARN")
1997-2004	NAD 83("FBN")		
2007	NAD 83(NSRS2007)		
2010		GEOCON 1.0	From a mix of HARN/FBN to NSRS2007
2011	NAD 83(2011)	GEOCON11 1.0	From NSRS2007 to NAD 83(2011)
2011		NADCON 4.2	Supported USSD
2013		GEOCON 1.1, GEOCON11 1.1	Minor improvements
2014		GEOCON 2.0	HARN to FBN FBN to NSRS2007 NSRS2007 to 2011
2016		NADCON 5.0	

Readers interested in additional details about the history of datums, datum realizations and adjustments are directed to Pursell and Potterfield (2008).

2 Motivation for NADCON 5.0

In the previous section, a number of decisions were listed which, in hindsight, seem less than optimal in the creation of NADCON and GEOCON. In addition to these decisions, numerous other disadvantages exist in the current NADCON and GEOCON software. Further complicating the situation was the impending 2022 deadline for replacing NAD 83, necessitating a transformation tool between NAD 83 and its replacement.

With that in mind, NGS decided to completely overhaul its geometric transformation software, and rebuild it from scratch. The advantage of that approach was twofold -- it allowed for all previous difficulties to be removed, and it also allowed for a design structure that could quickly and easily incorporate the changes coming in 2022 (and, for that matter, any changes beyond that).

Knowing that such an overhaul would replace NADCON 4.2 (as well as GEOCON 2.0), and considering NADCON's longer history and presumed name recognition, the newly built software was designated from the beginning as "NADCON 5.0".

Beginning in the 1970s, computers played a significant role in NGS's day to day mission execution. As personal computers became prevalent in the 1980s, NGS began serving the public by writing and distributing software in FORTRAN 77 to perform a variety of tasks. One of these was the original NADCON 1.0 release. In those early years, few programming languages and platforms were available. Many NGS products were written in FORTRAN 77 and compiled into executable (*.exe) files, for running in a Microsoft DOS environment.

Although NGS eventually provided online (browser-based) software to perform these functions, such a browser-based approach was little more than a shell wrapped around a DOS-based FORTRAN executable. That approach continued all the way through GEOCON 2.0.

With the rise of high speed internet, smartphones, web services and dozens of programming languages, NGS has long viewed the continuation of this approach to be archaic and in need of a complete change. NADCON 5.0 was a perfect project to apply a complete rebuild from the ground up, in both "behind the scenes" methodology and method of delivery to end-users.

2.1 Data Formats

Transformation software such as NADCON runs entirely on grids. The original release of NADCON 1.0 used a grid file format which was an archaic mix of ASCII and binary data (whose history goes back to the 1970's). This set the standard for all grids that were later released under the NADCON name, even as late as 2006. That format was abandoned with the release of GEOCON and GEOCON11. The grid format used in NADCON 5.0 (called ".b" or "dot b") is the same as that used in all versions of GEOCON and GEOCON11. See Chapter 10 for further details on the actual grid formats.

2.2 Program execution and accessibility

All NADCON versions prior to 4.2 were only released as executable (.exe) files, with source code written in FORTRAN 77, intended for command line running in a DOS environment. This functionality was expanded to a new JAVA-based, windows-environment application with version 4.2. But still, the functionality remained local to the user's machine, requiring a download and installation. The use of FORTRAN 77 and exe files was continued with all versions of GEOCON (and GEOCON11), though those also had a browser based support. However, that support merely made use of the existing exe file.

The approach for NADCON 5.0 was to avoid such archaic (though functional) approaches, with the specific intent of not requiring the user to download anything, and running as a webservice.

2.3 Better Documentation

While NADCON 1.0 had a small report to support it (Dewhurst 1990), there were significant details about the actual creation of the NADCON tool missing. This was apparently intentional. From the original report (ibid): "The difficult aspect of data selection and the computation of the grids has been done by NGS, and is of little concern to most users." It would appear that a longer, more detailed report (Dewhurst and Drew, 1990a) was intended to contain these details "of little concern to most users", but such a report does not appear to ever have been completed (Dewhurst, 2016, Personal Communication).

While GEOCON (versions 1.0, 1.1 and 2.0) had extensive documentation, that documentation contains some decisions that have since been rejected in the creation of NADCON 5.0. Nonetheless, NGS felt it was necessary to have a comprehensive documentation available, so part of this project was this report.

2.4 Consistency

In hindsight, many choices made in creating NADCON or GEOCON could have been better. Some of these choices are:

a) <u>"Jump Over" transformations:</u> Creating a USSD to NAD 83(1986) transformation in NADCON, effectively "jumping over" NAD 27. Jumping over a datum is seen as dangerous, as it sets the precedent that any two datums can have one single grid, and opens up the possibility that the sum of two transformations (say USSD to NAD 27 and then NAD 27 to NAD 83(1986)) will not agree perfectly with the jump-over transformation. To avoid this likelihood, the choice in NADCON 5.0 was to never jump over a datum.
b) <u>State-by-state grids</u>: Beginning with the NAD 83(1986) to NAD 83(HARN) grids and continuing into GEOCON 2.0, NGS set the precedent of using state-by-state grids. The trouble there is that such grids are difficult for users to work with if they have multi-state data to transform. Furthermore, overlapping grids do not have the same data at the same grid nodes.
c) <u>Skipping realizations</u>: Some of NADCON's grids for NAD 83(1986) to NAD 83(HARN) actually are NAD 83(1986) to NAD 83(FBN), and NGS did not provide any way to transform to the actual HARN in some states (North and South Carolina, New England, Puerto Rico)
d) <u>Inconsistent synthesis</u>: NADCON and GEOCON took radically different approaches to almost every step of the process in creating transformation grids. This is partly due to different

personnel with different training approaching these similar tasks from vastly different places of knowledge.

e) Errors in naming: Various historic datums are improperly or inconsistently named in either the NGS IDB and/or NADCON. For example, there was significant confusion between the 1897 and 1952 datums on the St. Paul and St. George islands.

f) Treatment of latitude and longitude: The grids in American Samoa are in the Southern hemisphere, and this caused them to be inadvertently stored in mirror image (south is north, north is south). Furthermore, NGS has a long history of using West longitude -- a system which was easy enough to adopt when "the USA" means CONUS only and the USA didn't have territory crossing the international date line. However, the USA now has territories (the Aleutian islands, Guam, CNMI) that fall into the eastern hemisphere. Nonetheless, rather than supporting the more scientifically standardized global longitude (0 to 360) NGS chose to expand "West longitude" in a non-standard way, with products and services in these eastern-hemisphere regions displaying West longitude values greater than 180 degrees. This choice has been discontinued in NADCON 5.0.

2.5 Scientific Analysis

The creation of all historic NADCON grids was approached differently than GEOCON and even NADCON 5.0. For historic NADCON, while much analysis was done in finding data and cleaning it, the actual creation of the grids had become something of a button pushing exercise without a lot of scientific analysis. The most obvious evidence of this is the continued use of a 1970s-era mixed ASCII/binary file format when other, better formats were available, as well as very little actual surviving documentation of process and method. NGS wanted to begin with a clean slate and treat the analysis of data and synthesis of grids as a full scientific research project.

3 Approach for NADCON 5.0

As Section 0 should have made obvious, many different choices have been made in earlier versions of NADCON and GEOCON which were viewed as needing correction. Therefore, NADCON 5.0 was approached with one overarching rule of thumb:

> *Be beholden to no decisions of the past, but make every attempt not to disrupt any existing transformations which have no scientific errors.*

3.1 Decide: Grids or something else?

A comprehensive discussion of the use of grids, as opposed to traditional (3, 7 or 14 parameter) transformations, is provided in Dewhurst (1990). Users interested in this choice of approach are directed there for further details. Without further discussion, the choice to stick with grids was effectively a foregone conclusion.

3.2 Decide: Extents of Grids

The original NADCON grids covered CONUS, Alaska, PR&VI and St. Paul Island, St. George Island and St. Laurence (sp) Island. The HARN grids generally covered 1 state with a buffer, though in some cases (California, Texas) two grids covered 1 state, while in others (Washington/Oregon, New England) 1 grid covered multiple states. As NADCON was expanded (for example to include the now-defunct USSD-to-NAD 83(1986) transformation), *the boundaries chosen to encompass the region of CONUS were not consistent*. Nor were they consistent with GEOCON.

Therefore, each region was re-evaluated for its size, the land it should contain and an appropriate buffer. The final grid extents chosen are noted in Section 6.

3.3 Decide: Gridding Method

All NADCON grids prior to version 5.0 were created using "minimum curvature" (Briggs, 1974). This method was replaced in GEOCON and GEOCON 11 and in NADCON 5.0 with "splines in tension" as implemented in the Generic Mapping Tools (GMT) software (Smith and Wessel 1990), due to minimum curvature's ability to cause "undesired oscillations and false local maxima or minima" (ibid).

Other methods were considered (such as Least Squares Collocation, aka "Kriging"), but were ultimately rejected due to the large computational load necessary to properly implement them, even on thinned data sets. For NADCON 5.0, all grids were created using splines in tension as encoded in GMT's "surface" routine.

In brief, "splines in tension" relies upon a "tension parameter", which falls between 0.0 and 1.0. While a spline in general may be though of as a "rubber sheet" fit through two dimensional irregularly distributed data points, the "tension" may be though of as how tightly someone at the edge of such a sheet is pulling on that rubber sheet. A tension of 0.0 means no tension, and the spline (rubber sheet) may have large oscilations as it 'droops' between points. A tension of 1.0 means the highest tension, and comes very close to approximating a Triangulated Irregular Network (with flat planes between sets of three points), with almost no oscillations between points. It is something of a mix of art and science to pick the "perfect" tension for the data at hand. Users interested in more detail are referred to Smith and Wessel (ibid).

3.4 Decide: Interpolator Method

In order to provide transformation values at any point within the gridded area, it is necessary to interpolate between grid-defined points. Dewhurst (1990a) set the interpolator for NADCON 1.0 at bilinear[12]. This was continued in the HARN extensions. While bilinear is not a bad choice, it does contain sharp gradient discontinuities at grid edges. Biquadratic was used in all versions of GEOCON

[12] There is a typo in the Dewhurst manual for NADCON (Dewhurst, 1990) related to the indexing of the four points surrounding the point of interest. That typo represents a mathematical error. However the typo does not reflect what was actually in the code itself, which has the correct mathematics properly implemented.

and GEOCON11 and chosen again for NADCON 5.0. While it also suffers gradient discontinuities when the window is shifted, they were less extreme than those from bilinear.

A bicubic spline approach was considered, but ultimately rejected due to the need to make the interpolator fast and less intensive on RAM for users. Readers interested in various two dimensional interpolation methods are directed to section 3.6 of Press et al (1992).

3.5 Fresh pull of data from the NGS IDB

Thus, with an effective "clean sheet of paper", the first step was to use a fresh pull of data from the NGS IDB. As such a pull had been done on Sept 21, 2013 for the GEOCON 2.0 build, that same data was used again for NADCON 5.0. This accomplished the next rule:

> *If it isn't in the NGS IDB, it isn't going into NADCON 5.0.*

There is a substantial description of the rules followed in the GEOCON 2.0 report (Smith, 2014b, pp. 10-32). The final input files to NADCON 5.0 were the ".in" files mentioned in that report. More details will be presented in Section 4.

3.6 Define "supported realizations" of various datums

The release of GEOCON 2.0 was the first attempt by NGS to create a definitive list of "supported realizations" of datums. NADCON 5.0 continued that effort, and expanded and clarified it.

Having a list of supported realizations is critical, as the use of "datum tags" meant that such a mix of data was available in each state that a transformation tool could not be created to support them all. To quote from the GEOCON 2.0 technical report (Smith, 2014b), where the discussion showed that the only supported realization of NAD 83 between 1986 and 2007 in a state was "NAD 83(1995)" :

> *For example, in the state of Ohio, where the HARN was actually published as "NAD 83 (1995)" and over 6000 NAD 83(1995) published points exist in that state, there are also over 1200 points whose "most recent post-1986, pre-2007" published realization were in NAD 83(1992), NAD 83(1993), NAD 83(1994), NAD 83(1996) and NAD 83(1997).*

It would be wholly ridiculous for NGS to try to support a transformation tool which spanned all of these sparsely populated realizations in Ohio. The same argument can be made across the entire HARN and FBN spectrum. Once the list of supported realizations was solidified, that effectively represented all of the datums/realizations which NADCON 5.0 would support. There were, however, datums which were left out, for a variety of reasons. See the next section for details.

3.7 Decide which datums will not be incorporated

Does NADCON 5.0 support every datum ever created in the United States? Absolutely not; not by a long shot. However, for a variety of reasons, NGS is not currently planning to expend resources to build further transformations to the variety of other datums currently held in the NGS IDB. Such datums tend to fall into at least 1 (but often more) of the following four categories:

a. Small (sub-state) regions
b. Old (pre 1900)
c. Unpopulated territories
d. Other countries

The following is a list of most of the current datums in the NGS IDB for which there are no plans to build a transformation:

Anchorage Pt Astro	Iliamna Astro	Prince William Sound
Barter Island 1948	Johnston Island 1961	Southeast Alaska
Camp Colona 1890	Mary Island Pt Simpson	Valdez Datum
Charleston and Savannah	Astro	Vicksburg Natchez
El Paso	Missouri River Commission	Wake-Eniwetok 1960
Kripniyuk - Kwiklokchun	Midway Astro 1961	Wake Island 1952
Flaxman Island 1912	New Orleans and Mobile	Yakutat 1892
Golofin Bay 1899	Point Barrow 1945	Yukon
Independent Astro 1880	Port Clarence Astro	

The choice to skip these datums was not based on the absence or presence of data, but only to concentrate energy on the more frequently used datums. There are likely many more datums than even this, but this list makes up the bulk of the remaining data in the NGS IDB to which horizontal coordinates have been attributed.

3.8 Skip no realizations

Once the official list of supported realizations existed, they could be sorted into chronological order. It was then decided that there would be no "jump over" transformations. A simple diagram might serve to best describe why. Consider the example below of supported realizations in CONUS:

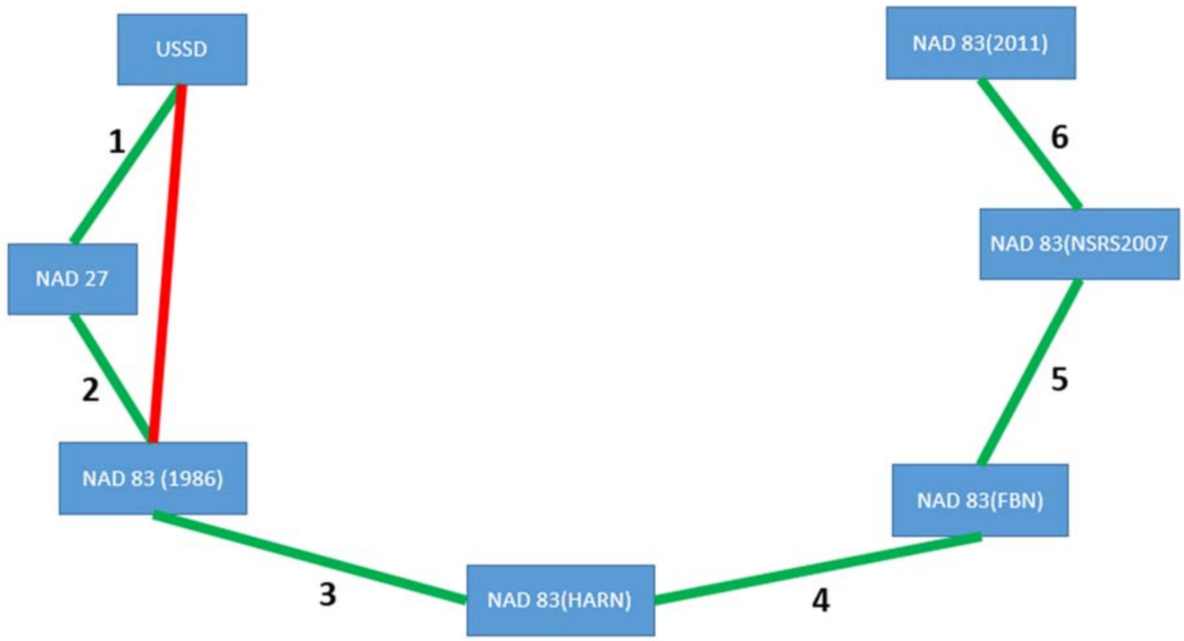

Figure 3-1: Chronological chain of transformations in CONUS (green), with potential realization skipping transformation (red)

Consider a potential transformation from USSD to NAD 83(1986), shown as a red line. Because each transformation is built by pairs of coordinates, there is absolutely no way to ensure (in fact, it's a ridiculous assumption) that the points with USSD/NAD 27 pairs, and the points with NAD 27/NAD 83(1986) pairs are the same, or that either one would align with the points with USSD/NAD 83(1986) pairs. As such, knowing the very data itself can not be identical, it is a simple matter to predict that a grid created along the red line will not be identical to that created by going through the two green lines (1 and 2). Therefore, with non-uniqueness being an issue, NGS chose not to create multiple paths to connect supported datums and realizations of datums. Therefore, the green lines alone are supported in NADCON 5.0. Put another way, NADCON 5.0 only allows transformations in a region between chronologically adjacent realizations of datums. Users wishing to go from USSD to NAD 83(2011) will end up applying 6 transformations.

A list of all of the supported datums, or supported datum transformations, currently available in NADCON 5.0 may be found in Section 4.3.

3.9 Build a new suite of analysis tools

One of the motivations for NADCON 5.0 was to have a suite of tools capable of quickly creating transformation tools for the transition to the new geometric reference frames in 2022. As such, the choice of which language and/or platform needed to be considered. While the variety of tools available were much broader than at any other time in history, the choice was to work primarily in FORTRAN 77, with additional support through c-shell scripts, GMT and MATLAB. The reasons for this choice are:

a) FORTRAN 77 remains popular in most scientific computing environments
b) FORTRAN 77 requires nothing more than a compiler and is platform independent

c) There is a 50 year library of tools available

In summary, languages and platforms come and go in popularity, but FORTRAN's dominance in the scientific computing community for half a century was seen as a strength, when considering a suite of tools that would be around and useful 6 years or more into the future.

3.10 Rigorous Outlier Removal

A transformation tool should help transform large sets of geospatial data (maps, etc) from one datum to another, but should not be expected to yield geodetic quality coordinates. As such, the view taken with NADCON 5.0 was that it should have *representative* information, not *all* information connecting one datum to another. Thus, if a particular point contained a pair of coordinates in the old and new datum whose difference was viewed as an outlier relative to other surrounding points, the view of the NADCON 5.0 team was that (a) such an outlier would have been identified by a professional surveyor and likely not used in creating a map, and (b) such an outlier is not representative of the general field, and thus breaks with the rule of thumb.

Once outliers were removed, then the data were considered for gridding. It should be noted that the gridding algorithm benefits from evenly spaced data which is not over-sampled at the spacing of the grid. To accomplish this, the non-outlier data were then separated into 'thinned' and 'dropped' datasets. The thinned data were the smallest subset of data which were also representative of the entire dataset; whereas the dropped data are the remaining points. Figure 3-2 should help clarify these terms, using the transformation from the USSD to NAD 27.

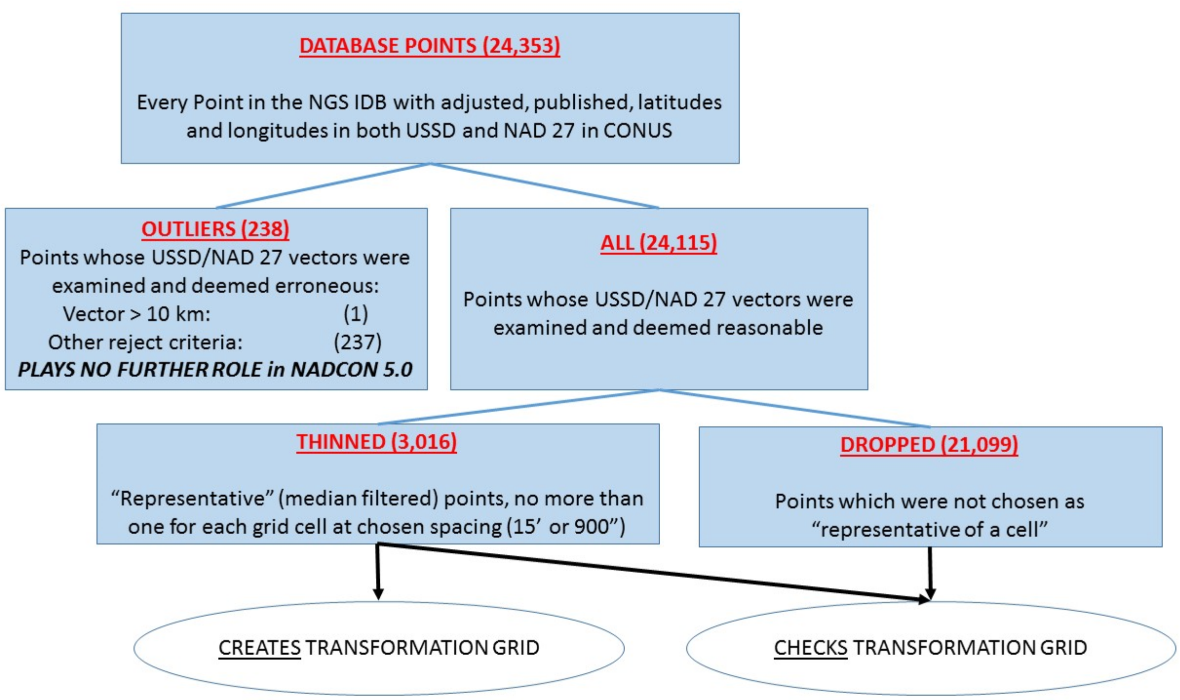

Figure 3-2: The role of outliers, thinned data and dropped data (example from the USSD/NAD 27/CONUS transformation.)

3.11 Generate new grids from scratch

Although grids for most transformations exist in either NADCON 4.2 or GEOCON 2.0, the need for absolute consistency in one tool meant that all grids had to be generated anew. If there was no reason to doubt the scientific accuracy of a standing grid (say, for example, the grids for the original NAD 27 to NAD 83(1986) transformation in CONUS), then the new grids would be checked against the old grids to confirm that the old grids were in reasonable agreement with the new grids (though the new grids would still replace them). What constitutes "reasonable agreement" is discussed in Section 8. Any discrepancies would need to be reported and explained. In cases where the grids were viewed as questionable or poorly known (such as the HARN grids), such checks would also be done, but only to understand any missteps of the past.

As per Section 3.11, it was decided that GMT's surface routine (splines in tension) would create grids from the point data. However, use of that method requires choosing a tension value between 0.0 to 1.0. Smith and Wessell (1990) offer some guidance, but no unbreakable rules. Experience during the creation of GEOCON and experiments led to a decision to use a tension of 0.4 (see section 3.3) for geometric transformation data, and this decision was adopted without further investigation for NADCON 5.0.

3.12 Produce Local Error Estimates

Providing users with an estimate of the quality of the transformation has always been part of NGS's transformation tools. For NADCON 1.0, Dewhurst (1990a) mentions the importance of checking a grid against independent data, yet claims to have no independent data as all data was used in the grid. This seems unreasonable for it appears from the grid that Dewhurst likely thinned his data a-priori. The jury remains out on this. Still, Dewhurst did provide error estimates on a regional basis.

In GEOCON and GEOCON11, Milbert chose a cross-validation method. This had the advantage of checking grids against real data, but aggressive outlier removal was not performed prior to the grid creation. Therefore significant mismatches, yielding "warnings" were part of GEOCON and GEOCON11. Milbert also chose to do error estimates, but based on cross validation and "anti median" thinning. That is, the error estimates are estimates of the worst case fit at a point, not a statistical representation of the overall fit.

However, neither the region-wide one-statistic approach (NADCON 1.0 through 4.2) nor the worst case outlier, with warnings approach (GEOCON and GEOCON11) were seen as the best choice when developing NADCON 5.0. As outlier removal was to be done (and done vigorously) prior to gridding, the latter approach could be dismissed. The former approach could be expanded, using newly developed analysis tools. The intent would be to allow users to receive an error estimate that reflected both the quality and geographic distribution of the input data.

As many GMT (surface) based gridding tools were readily available from the GEOCON (and other NGS) product builds, no significant investigation into alternative gridding methods was performed. For example, a Least Squares Collocation approach could have been used, and such a method would have provided formal geographically dependent error estimates (a goal of NADCON 5.0). However, the computational load as well as the need to build entirely new gridding algorithms from scratch were dismissed in favor of building upon existing tools.

With the choice of using GMT's surface routine (splines in tension) for gridding the data, discussions about how best to represent the formal accuracy of that grid were initiated. It was determined that two primary sources of error, independent from one another, contribute to the uncertainty of that grid. These two sources were referred to as "method noise" and "data noise" and will be discussed below.

3.12.1 Method Noise

The term "method noise" refers to the fact that the tension (as in "splines in tension") of the GMT surface routine was chosen as 0.4, though values for gridding could range from 0.0 to 1.0. Different tensions allow the grid to flex up and down with greater and greater amplitude across data gaps. In order to quantify this flexibility in the gridded surface (at tension 0.4), additional grids were created with tensions 0.0 and 1.0. Inspired by the work of Schwarz (2006), the maximum tension (1.0) and minimum tension (0.0) were viewed as samples of a normally distributed set of tensions (with the presumption that tensions could flex higher or lower than the set 1.0/0.0 limits with slightly different equations for the spline). At each grid node, the difference between a 1.0 and 0.0 tension grid was created (in absolute value) and treated as the span of the max/min values of a 3-sample set (the third sample being the 0.4 tension grid value). Then this value was scaled, as per Schwarz (2006) by 0.5907, and that value treated as the standard deviation of the grid, based solely on the tension variability. This grid was named "method noise" because it depends on the method of tension of the grid.

3.12.2 Data Noise

"Data Noise" refers to data variability within each cell. The creation of the the final transformation grid begins with thinning the data in each cell down to a single "median" value. That median is done solely by sorting on vector length, and not on azimuth. Once the median vector is chosen, the gridding commences. Afterwards all of the data (thinned plus dropped) is compared to the gridded data. On a cell by cell basis, these data are turned into an RMS value of disagreement in lat, lon and eht, geolocated at the average latitute and longitude for the data that went into that comparison. Turning these cell-by-cell RMS variabilities into a grid of RMS required choosing a tension. As we did not want an expression of the tension flexibility across voids, we chose 0.9 to grid the RMS, which gave a nearly linear fit to the RMS across voids. This, combined with the artificial requirement that no grid cell of RMS could be negative, led to the grid known as "data noise".

3.12.3 Total Error

As the method noise is an expression of data gaps while the data noise is an expression of in-cell variability, these two grids should be statistically independent. Therefore, they were combined on a cell by cell basis by squaring both sources of noise, summing them and then taking the square root. This final grid was called the "total error" grid and was released with each transformation grid as the geographically dependent formal accuracy estimates of the transformation grid.

4 Preparing for the Build

Data preparation and preprocessing was an important and time-consuming step in formulating the NADCON 5.0 transformations. This section describes how the authors selected and organized data for the transformations. All programs and files discussed in this document are available as part of the electronic archive of the NADCON 5.0 project; see Chapter 11 for more information.

4.1 Pull data from IDB

In preparation for NADCON 5.0 (in fact, in preparation for GEOCON 2.0), a pull of the NGS IDB was performed by Srinivas Reddy and given to Dru Smith on Sept 21, 2013. This file contained one record for every instance that a latitude or a longitude or an ellipsoid height was loaded into the NGS IDB. Through various filters and re-formats (see page 12 of the GEOCON v2.0 technical report), eventually a file (pull4_us) containing only adjusted (not scaled or otherwise useless for transformations) positions was made. A variety of experiments were performed on these data, and decisions on which data to include or exclude were made[13]. Also done during this time was the identification of the official NADCON 4.2 grids and converting them out of their anachronistic *.las and *.los format into the standard NGS *.b format.

Ultimately, a filter (nr25.f) was applied to "pull4_us" to implement a number of rules to the datasets[14]. Most importantly, this filter followed the basic logic first set out in GEOCON 2.0 about such issues as bringing forward a "datum tag" from old lat/lon loads to apply to eht loads which had no datum tag, or removing "unsupported" realizations in states.

4.2 In-Files

A final program (finalize.f) grouped the coordinate pairs into files. These files, which are referred to as "in files", contain the pairs of coordinates in chronologically adjoining realizations. Individual in-files were written for each U.S. state or protectorate sub-region, for example, Guam (GU) and Commonwealth of the Northern Mariana Islands (CQ). The in-files are the fundamental data set from which NADCON 5.0 transformations are computed.

As an example, here are the first few lines of the in-file for Georgia, for points with realizations in both NAD 83(1986) and NAD 83(1994):

```
$ head InFiles/NADCON5.NAD83_1986.NAD83_1994_GA.GA.in
                    NAD 83(1986)          |          NAD 83(1994:GA)
AA2771 GA 071 N311010.54893 W0833853.24219     N/A | N311010.55044 W0833853.22933    58.438
AA2772 GA 271 N315124.37347 W0830343.53546     N/A | N315124.37299 W0830343.53555    63.090
AA2777 GA 191 N312626.52519 W0813202.84418     N/A | N312626.51353 W0813202.83831   -26.329
AA2779 GA 281 N344804.92458 W0834102.17262     N/A | N344804.91482 W0834102.16884  1319.167
AA2837 GA 287 N313619.04699 W0833922.55264     N/A | N313619.03507 W0833922.54898    89.647
AA2839 GA 099 N311435.77795 W0845504.02419     N/A | N311435.77518 W0845504.01629    39.292
AA2840 GA 103 N323110.55597 W0811539.47040     N/A | N323110.53299 W0811539.46539      N/A
AA3389 GA 123 N343749.64864 W0842928.96876     N/A | N343749.64325 W0842928.96522   604.942
AA3390 GA 121 N340343.20643 W0840954.64523     N/A | N340343.20012 W0840954.64391   315.939
```

[13] See DRU-11, p. 99-123.
[14] See DRU-11, p. 124.

From the filename NADCON5.NAD83_1986.NAD83_1994_GA.GA.in (which takes the form NADCON5.*od.nd.state*.in), we can see that the original datum or "old datum" is NAD83_1986 and the next chronologically adjacent datum or "new datum" is NAD 83(1994:GA), that is, the NAD 83(1994) realization of NAD 83 released in Georgia.

After a header line, we see that each record contains point identification information (PID, 2-character state/region, and 3-digit county code), then the latitude, longitude and ellipsoid height in the old datum, a spacer bar, and the latitude, longitude and ellipsoid height in the new datum. Values that do not exist are given "N/A".

Note that, during processing, these positions are differenced (new datum minus old datum; see note in the header of this document) to form a vector. More details on the processing stages which generate vectors are given in Section 5.

4.3 Control files

In order that the final transformation grids of NADCON 5.0 would ONLY be regional (not state-wide, as per the HARN expansion of NADCON up until 4.2), a set of control files were made, telling the processing engines which realizations go with which regional grids. The directory */Control* in the digital archive contains the files which group the in-files; these control files are definitive and not open to change.

The full list of control files is given below. Note that each control file uses the *og.ng.rg* naming convention (see Author's Note at beginning of this document).

Region: **conus** (lower 48 + DC)

control.ussd.nad27.conus
control.nad27.nad83_1986.conus
control.nad83_1986.nad83_harn.conus
control.nad83_harn.nad83_fbn.conus
control.nad83_fbn.nad83_2007.conus
control.nad83_2007.nad83_2011.conus

Region: **prvi** (Puerto Rico and the U.S. Virgin Islands)

control.pr40.nad83_1986.prvi
control.nad83_1986.nad83_1993.prvi
control.nad83_1993.nad83_1997.prvi
control.nad83_1997.nad83_2002.prvi
control.nad83_2002.nad83_2007.prvi
control.nad83_2007.nad83_2011.prvi

Region: **as** (American Samoa)

control.as62.nad83_1993.as

control.nad83_1993.nad83_2002.as
control.nad83_2002.nad83_pa11.as

Region: **hawaii** (Hawaii)
control.ohd.nad83_1986.hawaii
control.nad83_1986.nad83_1993.hawaii
control.nad83_1993.nad83_pa11.hawaii

Region: **guamcnmi** (Guam and the Commonwealth of the Northern Mariana Islands)
control.gu63.nad83_1993.guamcnmi
control.nad83_1993.nad83_2002.guamcnmi
control.nad83_2002.nad83_ma11.guamcnmi

Region: **alaska** (Alaska)
control.nad27.nad83_1986.alaska
control.nad83_1986.nad83_1992.alaska
control.nad83_1992.nad83_2007.alaska
control.nad83_2007.nad83_2011.alaska

Region: **stpaul** (St. Paul Island, Alaska)[15]
control.sp1897.sp1952.stpaul
control.sp1952.nad83_1986.stpaul

Region: **stgeorge**(St. George Island, Alaska)
control.sg1897.sg1952.stgeorge
control.sg1952.nad83_1986.stgeorge

Region: **stlawrence** (St. Lawrence Island, Alaska)
control.sl1952.nad83_1986.stlawrence

4.3.1 "HARN" and "FBN" in CONUS

As noted in Section 1.13, the history of HARN and FBN realizations, and their use in transformation software is extremely complicated, and mistakes were made. Most egregious was the GEOCON 2.0 terminology decision regarding what was an "FBN". In creating NADCON 5.0, we have explicitly reverted back to the following (correct) terminology:

[15] The "Saint" regions (stpaul, stgeorge and stlawrence) are small sub-regions contained within the greater "alaska" region. Prior to 1986, they had their own local datums. As such, their transformations into NAD 83(1986) rely on their own respective 1952 datums. After 1986 however, these sub-regions have data in NAD 83(1986) and all transformations post-1986 within the "alaska" region will include these islands. See also section 6.2.

HARN means the first post-1986 GPS-survey-based realization in a state/region;
FBN means the second (if it existed) post-1986 GPS-survey-based realization in a state.

In the control files, we introduce a simplification for HARN and FBN, introducing datum groupings “nad83_harn” and “nad83_fbn”. These special names contain multiple realizations that make up their sets. For example, the file *control.nad83_1986.nad83_harn.conus* lists 49 separate files, telling the processing engines that, when creating a region-wide transformation grid covering CONUS, and transforming between “nad83_1986” and “nad83_harn” that the listed 49 “in” files be used.

In order to facilitate the use of CONUS-wide grids where different HARN years and different FBN years were used in each state (and not every state had an FBN), it was important to specify exactly what realizations were “HARN” and what were “FBN”. Table 4-1 summarizes the situation.

Table 4-1: Official NADCON 5.0 designations for HARN and FBN

State	HARN realization	FBN realization
Alabama	NAD 83(1992:AL)	
Arkansas	NAD 83(1997:AR)	
Arizona	NAD 83(1992:AZ)	
California	NAD 83(1992:CA)	NAD 83(1998:CA)
Colorado	NAD 83(1992:CO)	
Connecticut	NAD 83(1992:CT)	NAD 83(1996:CT)
District of Columbia	NAD 83(1991:DC)	
Delaware	NAD 83(1991:DE)	
Florida	NAD 83(1990:FL)	NAD 83(1999:FL)
Georgia	NAD 83(1994:GA)	
Iowa	NAD 83(1996:IA)	
Idaho	NAD 83(1992:ID)	NAD 83(1999:ID)
Illinois	NAD 83(1997:IL)	
Indiana	NAD 83(1997:IN)	
Kansas	NAD 83(1997:KS)	
Kentucky	NAD 83(1993:KY)	
Louisiana	NAD 83(1992:LA)	
Massachusetts	NAD 83(1992:MA)	NAD 83(1996:MA)
Maryland	NAD 83(1991:MD)	
Maine	NAD 83(1992:ME)	NAD 83(1996:ME)
Michigan	NAD 83(1994:MI)	
Minnesota	NAD 83(1996:MN)	
Missouri	NAD 83(1997:MO)	
Mississippi	NAD 83(1993:MS)	
Montana	NAD 83(1992:MT)	NAD 83(1999:MT)
North Carolina	NAD 83(1995:NC)	NAD 83(2001:NC)
North Dakota	NAD 83(1996:ND)	
Nebraska	NAD 83(1995:NE)	
New Hampshire	NAD 83(1992:NH)	NAD 83(1996:NH)
New Jersey	NAD 83(1992:NJ)	NAD 83(1996:NJ)
New Mexico	NAD 83(1992:NM)	
Nevada	NAD 83(1994:NV)	NAD 83(1999:NV)
New York	NAD 83(1992:NY)	NAD 83(1996:NY)
Ohio	NAD 83(1995:OH)	
Oklahoma	NAD 83(1993:OK)	
Oregon	NAD 83(1991:OR)	NAD 83(1998:OR)
Pennsylvania	NAD 83(1992:PA)	
Rhode Island	NAD 83(1992:RI)	NAD 83(1996:RI)
South Carolina	NAD 83(1995:SC)	NAD 83(2001:SC)
South Dakota	NAD 83(1996:SD)	
Tennessee	NAD 83(1990:TN)	NAD 83(1995:TN)
Texas	NAD 83(1993:TX)	
Utah	NAD 83(1994:UT)	
Virginia	NAD 83(1993:VA)	
Vermont	NAD 83(1992:VT)	NAD 83(1996:VT)

Washington	NAD 83(1991:WA)	NAD 83(1998:WA)
Wisconsin	NAD 83(1991:WI)	NAD 83(1997:WI)
West Virginia	NAD 83(1995:WV)	
Wyoming	NAD 83(1993:WY)	

Outside of CONUS, the terms "HARN" and "FBN" are not used in NADCON 5.0. Thus, for example, in the region of Puerto Rico and the U.S. Virgin Islands, there will be three realizations of NAD 83 between 1986 and 2007. They are called, simply:

NAD 83(1993:PR) and NAD 83(1993:VQ)
NAD 83(1997:VQ) and NAD 83(1997:VQ)
NAD 83(2002:VQ) and NAD 83(2002:VQ)

This reverses another choice in GEOCON 2.0 of using the terms "HARN0", "HARN" and "FBN" in those regions. That is now completely gone from NADCON 5.0 for this region.

4.4 Outlier identification

While the "in" files are the result of significant filtering and cleaning of the original IDB pull, they nonetheless are not perfect. As research on NADCON 5.0 proceeded, it became increasingly clear that very serious outliers existed in the "in" files. By "outlier", we simply mean "relative to the general transformation field surrounding a given point". To deal with such an "outlier" one must briefly discuss the philosophy of datum transformations.

In GEOCON 1.0, a philosophy was chosen, through mutual agreement by Dru Smith and Dennis Milbert that "all pairs of adjusted coordinates that are in the IDB and accessible to the public, should be reflected in the transformation … if not the grid itself, at least in the accuracy assessment of the grid". This philosophy, like any, has pros and cons. It's biggest "pro" was that the public used data from the IDB, whether that data was good, bad or ugly, and therefore a transformation should reflect said data.

In NADCON 5.0, in discussions between Andria Bilich and Dru Smith, a change in philosophy was achieved. It was felt that, given the very smooth and systematic nature of a great deal of the transformational vectors, that outliers were not only disruptive to the creation of a well-behaved grid, but they reflected coordinates so far outside the norm that most professional surveyors would have rejected such points from their work. As such, outliers were identified at various points in this work, and those outliers, and their reason for being called an outlier, were put into file "workedits".

The *workedits* file is structured so that points could be thrown out on the basis of latitude, longitude, and/or height, and only for specific transformations. In *workedits*, the analyst typically provides a note on why this point was considered an outlier for that transformation. The file uses a 3-character set of flags to indicate for which components the point is considered an outlier. The characters correspond to latitude, longitude, and height (in that order), where zero (0) or blank ( ) indicate the point is kept, and one (1) means that the point should be rejected. While the *workedits* file allows a zero or blank in the reject flag to indicate "acceptable", the files derived from *workedits* during processing will only use blank ( ) to mean "acceptable". For example, for the nad83_fbn.nad83_2007.conus transformation, PID BG5017 was identified as a horizontal outlier whose magnitude was too large, but was deemed to be of sufficient quality in the vertical. Thus, the corresponding line in *workedits* sets latitude, longitude, and ellipsoidal height flags, and gives a verbal explanation for why this point was rejected:

```
nad83_fbn |nad83_2007|conus     |BG5017|110|ALB: 2015 12 08 Outlier in
magnitude relative to overall field
```

After flagging in *workedits*, outliers were removed from the derived files used in the processing and analysis. Note that, if a point where thrown out on the basis of latitude or longitude, that point was also excluded from the ellipsoidal height dataset. The NADCON 5.0 developers felt this was a reasonable approach, given that GPS was unlikely to yield a reliable vertical position if the horizontal position were suspect. However, if a point were flagged only on the basis of a poor height, that point was still included in the horizontal transformations. Again, the NADCON 5.0 developers felt this was a reasonable approach, as historically GPS yielded more accurate horizontal positions than heights - if the height was suspect, the horizontal components still needed to be evaluated on their own merit.

Outliers were identified using a combination of statistical tools and visual analysis applied to a vector field of “new coordinate minus old coordinate” vectors. We should note that, for both analysis methods, outliers in the horizontal field were analyzed as a total horizontal vector (latitude plus longitude, yielding a vector with a 0-360 degree direction and lat+lon composite magnitude) rather than by latitude or longitude alone. Ellipsoidal heights were also analyzed as a vector field, but as single-valued quantities using an expected sign convention to orient the vectors - when plotted on a map, positive magnitude values are upward-pointing vectors, negative magnitude values are downward-pointing vectors.

When vector fields are plotted on a map, the human eye can quickly discern outliers in either magnitude or direction relative to the field dictated by the surrounding points. To aid the visual detection and identification of outliers, the authors developed a Matlab toolbox with functions that can plot any vector file. The plots are interactive, allowing users to zoom in and out so they may discern details of the fields, as well as click on individual points to yield identifying information. Figure 4-1 shows a plot example from the horizontal field for ussd.nad27.conus in the state of Illinois. Here, the user has clicked on the base of an obvious outlier, which is then identified in a tooltip window as LC1865.

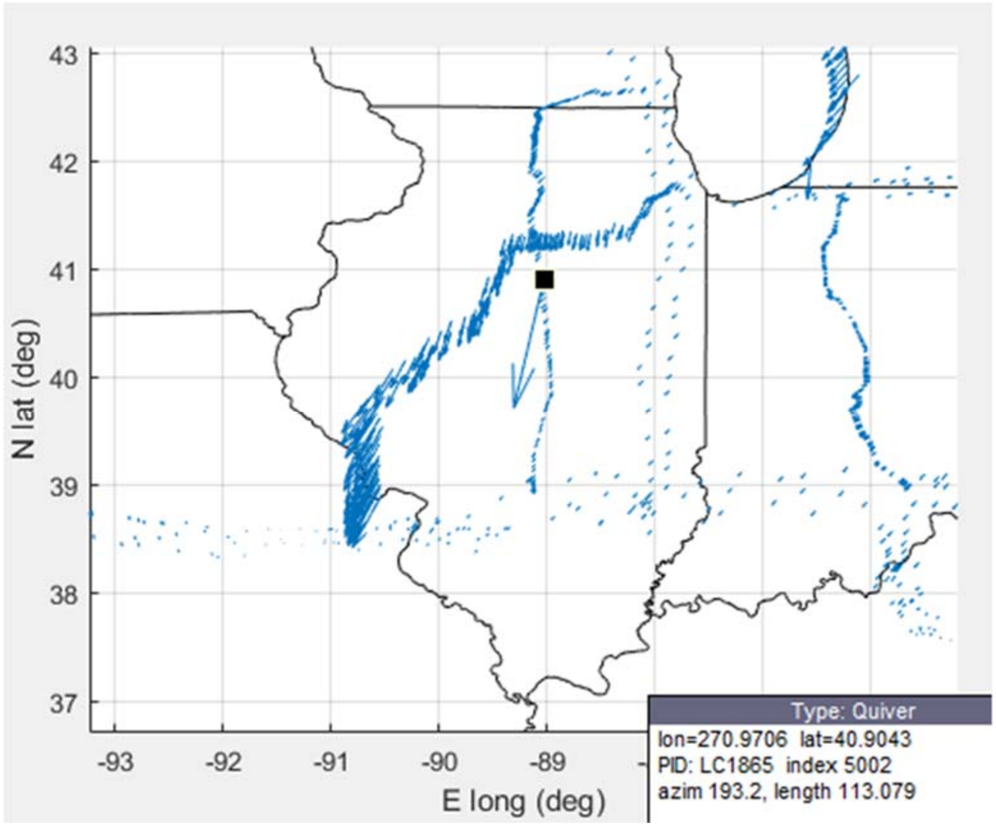

Figure 4-1: Plot of vmacdhor.ussd.nad27.conus using Matlab function plotVectors, where the user has clicked on an outlier point to identify its PID, location, azimuth and magnitude (length).

It is more efficient to use a statistical approach to outlier identification which does not require a lot of user intervention. The program *findoutliers* scans any vector-formatted file (any data file beginning with "vc" or "dv") and identifies outliers in that dataset by applying user-defined criteria for radial search distance and a maximum sigma-multiplier. For example, if the user inputs "0.5" arcdegrees for the search distance and "5" as the sigma multiplier, then every point will be compared to every other point within 0.5 arcdegrees (box distance, not radial), and if the point is more than 5 sigma away from the mean of all points in that search box, it is flagged as a potential outlier. The program computes the average and standard deviation of both magnitude (vector length) and azimuth (vector orientation), and will flag a potential outlier if one or both sigma-multiplier thresholds are exceeded. The azimuth approach only makes sense when working with horizontal (lat+lon) vector fields, so it is possible to disable the azimuth analysis when dealing with 1-D vector files (lat, lon, or eht). A companion program *findvectors* scans any vector-formatted file and based on a user-provided central latitude+longitude and search distance this program will display (1) all vectors in the specified box, or (2) only outliers, using the same sigma-multiplier approach described above. *Findvectors* is useful for identifying point names for visually obvious outliers, serving as a programmatic companion to the Matlab toolbox previously described.

We stress that points identified by *findoutliers* or *findvectors* are potential outliers because the results may be unreliable in some special cases. When the number of neighboring points is small (in our experience, 20 or fewer points in a search box), the statistical test lacks significance; *findoutliers* consequently includes an option to not flag points when the number of neighbors is below a user-defined threshold. Also, outlier identification can be suspect when a cluster of small-magnitude vectors exists; these will produce a very small, tight sigma and cause points to be easily flagged as outliers. Therefore, *findoutliers* was run to identify potential outliers, but an analyst would manually insert these points into *workedits* after deciding that indeed certain points needed to be excluded.

In the following example, *findoutliers* was run on the horizontal data for ohd.nad83_1986.hawaii, using a 0.1 arcdegree search box, a 4-sigma threshold, ignoring points with fewer than 10 neighbors, and with azimuth analysis enabled. We show two illustrative points returned by the program; note that the output lines wrap. Point TU1085 has 137 neighbors, and was flagged as an outlier in azimuth but not magnitude. Its azimuth of 141.00 degrees is just barely outside the very tight 4-sigma range (141.03-141.23); this point should not be written to *workedits* as an outlier. Contrast this with point TU2093, which has 36 points in the search box, and was also flagged as an outlier in azimuth but not magnitude. Its azimuth of 165.79 degrees is well outside the 4-sigma range (137.04-141.42) and therefore should be written to *workedits* as an outlier.

```
Opening file: vmacdhor.ohd.nad83_1986.hawaii
Type   : hor
OldDtm : ohd
NewDtm : nad83_1986
Region : hawaii
Done reading file.
      Total pts found              :       2617
MagStatus/AzmStatus     Pt  Nbrs   MagSigs  AzmSigs    Lon    Lat    Azm
MapVec   ArcSec    Mag    PID  Ranges:
Good Mag /  Bad Az:    244   137     -1.15    -5.12 202.23  21.47 141.00
0.50 15.09731 452.664 TU1085(452.891+/- 4.0*  0.198=   452.101-  453.681),(
141.13+/- 4.0*   0.02=141.03-141.23)
Good Mag /  Bad Az:   1233    36     -3.38    48.50 205.11  19.48 165.79
0.47 13.78515 424.192 TU2093(445.929+/- 4.0*  6.430=   420.209-  471.649),(
139.23+/- 4.0*   0.55=137.04-141.42)
```

In all, 5751 horizontal and 405 ellipsoidal outliers were removed from consideration (Table 4-2). Comparing this to the 693,582 points across all NADCON 5.0 horizontal transformations and 147,059 points across the vertical transformations, we note that the outlier removal process eliminated less than 1% of points. Related tables in Section 6 provide details on the number of points in each transformation. If the outliers are returned to the mix and checked against the transformation grids, they will obviously skew the statistics for the worse. While such statistics have some informational value, they are not included herein, for the sake of brevity. Rather, just to exemplify the nature of the outliers, the count of outliers and the largest residual potentially caused by an outlier are presented below.

Table 4-2: Residual counts and statistics for all transformations; the last column provides the largest residual for an outlier relative to the final transformation grid, to illustrate the potential damage to a transformation grid that would be created by not excluding these data.

	old datum (od)	***new datum (nd)***	***# outliers***	***largest residual***

				(re: transformation)
CONUS	USSD	NAD27	241	117.76 km[16]
	NAD27	NAD83_1986	565	7804 m
	NAD83_1986	NAD83_HARN	2590	4611 m
	NAD83_HARN	NAD83_FBN	170 / 59	Hor: 12.8 m Eht: -28.1 m
	NAD83_FBN	NAD83_2007	1430 / 62	Hor: -269.6 m Eht: -28.1 m
	NAD83_2007	NAD83_2011	432 / 194	Hor: 0.4 m Eht: -0.4
Hawaii	OHD	NAD83_1986	15	219 m
	NAD83_1986	NAD83_1993	6	-2.3 m
	NAD83_1993	NAD83_PA11	6 / 0	Hor: -0.7 m Eht: n/a
Alaska	NAD27	NAD83_1986	134	526.3 m
	NAD83_1986	NAD83_1992	19	129.0 m
	NAD83_1992	NAD83_2007	51 / 24	Hor: 0.59 m Eht: 154.8 m
	NAD83_2007	NAD83_2011	58 / 35	Hor: 2.34 m Eht: 0.60 m
Alaska - St. George	SG1897	SG1952	1	28.4 m
	SG1952	NAD83_1986	1	68.4 m

[16] To confirm: that is 117+ km in error, somewhere. Either the USSD or the NAD 27 coordinate of a point (or some combination of both), as stored in the NGS IDB is in error by that much. This ridiculously large residual helps exemplify why outlier removal was done prior to gridding and why outliers are not included in the error estimates or in any part of the NADCON 5 process. It was felt(hopefully with reasonable justification), that no professional surveyor would tie a survey to a single point, and thus with at least 1 (likely more) points to compare to, said surveyor would not keep a point with such an egregious error in the survey. Therefore it was concluded that few (if any) maps should exist which had retained this error and thus it did not need to be in the transformation tool.

Alaska - St. Paul	SP1897	SP1952	0	n/a
	SP1952	NAD83_1986	1	127.4 m
Alaska - St. Lawrence	SL1952	NAD83_1986	1	4.0 m
American Samoa	AS62	NAD83_1993	3	208.8 m
	NAD83_1993	NAD83_2002	4 / 0	Hor: 208.2 m Eht: n/a
	NAD83_2002	NAD83_PA11	0 / 1	Hor: n/a Eht: 0.12 m
Guam/CNMI	GU63	NAD83_1993	0	n/a
	NAD83_1993	NAD83_2002	0	n/a
	NAD83_2002	NAD83_MA11	3 / 4	Hor: 0.14 m Eht: -0.02 m
Puerto Rico / US Virgin Islands	PR40	NAD83_1986	0	n/a
	NAD83_1986	NAD83_1993	7	-0.48 m
	NAD83_1993	NAD83_1997	7 / 2	Hor: 0.17 m Eht: 0.14 m
	NAD83_1997	NAD83_2002	0 / 4	Hor: n/a Eht: -0.26 m
	NAD83_2002	NAD83_2007	7 / 13	Hor: -0.07 m Eht: -0.26 m
	NAD83_2007	NAD83_2011	1 / 10	Hor: 0.12 m Eht: 0.04 m

4.5 Choosing a grid spacing

A few overarching principles drove the selection of a grid size. In this study, the best choice of grid size:

1. Is the coarsest grid which adequately explains the data;
2. Should result in small residuals (difference between the transformation and the original coordinate difference for each point);
3. Does not create gaps where vectors are present in the original field (i.e. does not undersample data);

4. Avoids clusters of similar vectors (i.e. does not oversample data).

To start the grid selection process, program *gridanalyzer4* was executed. This program would find the closest neighbor for every point in a file and compute the distance to that neighbor, and perform statistics. In addition, the program would overlay a grid on top of all the possible points and compute statistics on point density: number of cells with and without data, and points per cell (minimum, maximum, average, standard deviation, and RMS). These point density calculations were computed for a range of possible grid sizes: 1, 2, 3, 5, 7.5, 10, 15, 30, and 60 arcminutes.

The output of *gridanalyzer4* was used to determine a starting point for discussion on best grid size. Ideally, 20-40 points per cell (PPC) RMS and/or 15-25 median PPC would result in sufficient point density inside each cell so that the median filter would definitely choose a representative point when thinning the data. If neither measure were achievable, the authors agreed that 30' was the maximum grid spacing that seemed reasonable for any transformation.

Next, the median magnitude of the transformation was computed. This was done to loosely characterize the size of the transformation (e.g. a large signal, or closer to 1 cm-level noise), and to provide a baseline against which the magnitude of the residuals would be compared.

Then, for each individual datum pair, the authors computed the full transformation for a range of possible grid sizes: 1, 2, 3, 5, 7.5, 10, 15, 30 arcminutes (60, 120, 180, 300, 450, 600, 900, 1800 arcseconds). The Matlab toolbox described in Chapter 11 was used to plot histograms of the proportion of residuals which exceeded a certain percentage of the median transformation size. When the number of points in the transformation was sufficiently high, these histograms were useful in determining the grid sizes at which no appreciable improvement could be gained by moving to a finer grid size.

With all these metrics in hand, the authors discussed the data and chose a final grid. All attempts were made to follow the guidelines stated above, but there were cases where the statistical data did not lead the authors to an obvious conclusion on the ideal grid size. For example, when very localized signals were present which deviated from the overall vector field, it would often be necessary to look at maps of residual fields to qualitatively assess which grid sizes would capture that variation without penalty to the rest of the region. Similarly, some transformation vector fields are so highly variable that special care had to be taken when analyzing the residuals, and to not rely strictly upon PPC measures. Also, the authors considered vectors and residuals smaller than 1 cm to be noise; in these cases, the statistical thresholds were relaxed.

The exact implementation of these principles and the resultant final choice for each transformation's grid size is detailed in Section 6, where the authors provide details on the quantitative and qualitative considerations which led to the choice of the final grid size for each transformation and region.

5 Performing the Build

This section describes how any NGS user could recreate the exact results of NADCON 5.0 from the fundamental files described in Section 4. In general, the process is fairly automated. Programs and scripts required to conduct the build are part of the NGS distribution of NADCON 5.0 (see Section 11).

5.1 System setup

NADCON 5.0 was generated on the NGS UNIX Sun cluster, specifically on the machine "uranus". The authors tested the build process on other NGS Sun machines and determined that the results could be replicated on other machines in the NGS Sun cluster. The authors did not test the builds on Linux.

In order for programs and shell scripts to run properly, it is necessary to modify a few shell variables. The following file contains details: *FinalBuilds.20160901/RunNADCON5/Code/README*.

If these programs and shell scripts are run on a different platform or shell, they may not work properly. The authors noticed that changing shell or UNIX system would lead to some programs not executing properly, so caution should be used when using NADCON 5.0 code in the future.

5.2 Sequence of programs

A word of caution is necessary here:

> *The following sequence of programs will build up all of the grids, plots and supporting files needed for one transformation, <u>provided the grid spacing has already been determined</u>. Obviously such knowledge is not known up front, and as part of the NADCON 5.0 research process, a "build" was performed using a variety of different grid spacings. These were then analyzed relative to one another and a final grid spacing determined. At that point, all of the experimental builds were "unbuilt" (erased) and the final build re-done by itself.*

The sequence of building one transformation can be described at the highest level as consisting of four batch files. These four batch files are named: *doit.bat, doit2.bat, doit3.bat* and *doit4.bat*. As each batch file is run, it takes input from prior steps in the process, and creates new files. An associated set of batch files will un-do (erase) all of the work of a previous batch file. Not surprisingly, the associated un-doing batch files are called *undoit.bat, undoit2.bat, undoit3.bat* and *undoit4.bat*. To re-iterate, all files created by running *doit.bat* can be erased by running *undoit.bat*, etc. A complete explanation of each batch file is found below. Note that the file naming convention is detailed in the Author's Notes at the beginning of this report.

5.2.1 doit.bat

This batch file creates a "work" file, based on "in" files listed in the appropriate "control" file. A "work" file is in a sense a reformatted version of the "in" file, after outliers have been removed by applying "workedits". The "work" file itself contains a number of pre-computed values, such as differences in latitude (in both arcseconds and meters), differences in longitude (in both arcseconds and meters), differences in ellipsoid height (in meters), azimuth of the horizontal (combined latitude and longitude) difference vector and its magnitude (in meters). All "work" files get stored in sub-directory Work.

<u>What must exist prior to running:</u>	
The manual edits file:	*Work/workedits*
1 "control" file:	*Control/control.od.nd.rg*
All "in" files mentioned in the Control file:	*InFiles/NADCON5.?.?.?.in*
<u>doit.bat syntax:</u>	*doit.bat od nd rg* <return>
<u>undoit.bat syntax:</u>	*undoit.bat od nd rg*<return>
<u>Example doit syntax:</u>	*doit.bat ussd nad27 conus* <return>
<u>Example undoit syntax:</u>	*undoit.bat ussd nad27 conus* <return>
<u>What will be created by running doit.bat:</u>	
The "work" file:	*Work/work.od.nd.rg*

Table 5-1 describes each step that is executed inside of doit.bat:

Table 5-1: Workflow and files generated by executing "doit.bat"

Step	**What does it do**	**What does it create**
makework.f	Guided by the "control" file, it reads the appropriate "in" files, and generates coordinate differences (aka "vectors"), geographically located at the latitude and longitude of the "old datum". It computes a variety of things, such as the azimuth of the horizontal vector, and magnitudes of vectors in both meters (lat, lon, eht and hor) and arcseconds (lat, lon, hor only). It will then attempt to write all of this information to the "work" file, with one record of the "work" file for each point. Each record has the potential to have up to 3 reject codes (one each for lat, lon or eht). Some reject codes will automatically be generated if certain criteria are sensed (such as a vector greater than 10 km, or a point that lies outside the region's boundaries). However, the program generate the majority of its reject codes by accessing the "workedits" file and looking for manually determined edits that were created earlier. If it finds one, it adds a reject	*work.od.nd.rg*

	code for latitude and/or longitude and/or ellipsoid height to the record as appropriate.	

5.2.2 doit2.bat

This batch file creates "vector" and "coverage" files, as well as writes and executes a batch file to plot the vector and coverage files as JPGs. "Vector" files represent the coordinate shift in latitude, longitude, ellipsoid height, and as azimuthally-correct horizontal (latitude + longitude) values. "Coverage" files are the location of the points with coordinate shifts in the associated "vector" files.

What must exist prior to running:

The "work" file:	*Work/work.od.nd.rg*
doit2.bat syntax:	*doit2.bat od nd rg mf* <return>
undoit2.bat syntax:	*undoit2.bat od nd rg*[17]<return>
Example doit2 syntax:	*doit2.bat ussd nad27 conus 2* <return>
Example undoit2 syntax:	*undoit2.bat ussd nad27 conus* <return>

What will be created by running doit2.bat:

The first "GMT batch file":	*gmtbat01.od.nd.rg.mf*
Coordinate Difference Coverage files:	*cvacd*.od.nd.rg*
True[18] Coordinate Difference Vector files (meters):	*vmacd#.od.nd.rg*
True Coordinate Difference Vector files (arcseconds):	*vsacd@.od.nd.rg*
Coordinate Difference Coverage maps:	*cvacd*.od.nd.rg.am.jpg*
True Coord Difference Vector maps (meters):	*vmacd#.od.nd.rg.am.jpg*
True Coord Difference Vector maps (arcseconds):	*vsacd@.od.nd.rg.am.jpg*

Where

* can be lat, lon or eht
# can be lat, lon, eht or hor
@ can be lat, lon or hor

Table 5-2 describes each step that is executed inside of doit2.bat:

Table 5-2: Workflow and files generated by executing "doit2.bat"

Step	**What does it do**	**What does it create**
makeplotfiles01.f	Working with the data in the "work" file, this program sets up a number of GMT-ready data files of both coverage and coordinate differences in the form of vectors.	*gmtbat01.od.nd.rg.mf* *cvacd*.od.nd.rg* *vmacd#.od.nd.rg* *vsacd@.od.nd.rg*

17 The "undoit2" run requires no mapflag

18 "True" Coordinate Differences are the differences between published coordinates in the "new datum" minus published coordinates in the "old datum". Contrast this with later-determined "Grid Interpolated" Coordinate Differences which come from the grid after it has been created, and also with the later-determined "Double Differences" which are the differences between "True" and "Grid Interpolated" Coordinate Differences.

	It then creates a batch file full of GMT scripts.	Where * can be lat, lon or eht # can be lat, lon, eht or hor @ can be lat, lon or hor
gmtbat01.od.nd.rg.mf	Runs GMT scripts to create plots, in JPG format. The number of maps made depends on the "mapflag" given at the "doit2.bat" call. The "mapflag" can be 0, 1 or 2 depending on how fine of a scale is desired for the maps. A "0" means just maps for the entire region. A "1" means additional maps at a sub-regional scale. A "2" is generally not used except for region "conus" where it will create state-by-state maps. Each map contains a shorthand name for its "area mapped", such as "entire" or "northwest" or "OH".	*cvacd*.od.nd.rg.am.jpg* *vmacd#.od.nd.rg.am.jpg* *vsacd@.od.nd.rg.am.jpg* Where * can be lat, lon or eht # can be lat, lon, eht or hor @ can be lat, lon or hor

5.2.3 doit3.bat

This batch file primarily generates the transformation. First, it applies the median filter, separating the data into one file containing points used in the transformation ("thinned") and saving all other points ("dropped") to a second file for later error analysis. Second, using GMT's *surface* routine, the thinned data are gridded by latitude, longitude, and ellipsoidal height to generate the transformation (tension 0.4); the same data are gridded at tension 0.0 and 1.0 Third, method noise is calculated (see Section 3.12.1) for later error estimate construction. The thinned and dropped vectors and their coverage are plotted, as well as a color contour plots of the gridded transformations and method noise.

<u>What must exist prior to running:</u>

The "work" file:	*Work/work.od.nd.rg*
Coordinate Difference Coverage files:	*cvacd*.od.nd.rg*
True Coordinate Difference Vector files (meters):	*vmacd#.od.nd.rg*
True Coordinate Difference Vector files (arcseconds):	*vsacd@.od.nd.rg*

<u>doit3.bat syntax:</u>	*doit3.bat od nd rg* gs[19] *mf* <return>
<u>undoit3.bat syntax:</u>	*undoit3.bat od nd rg* gs[20]<return>

<u>Example doit3.bat syntax:</u>	*doit3.bat ussd nad27 conus* 900 *2* <return>
<u>Example undoit3.bat syntax:</u>	*undoit3.bat ussd nad27 conus* 900 <return>

<u>What will be created by running doit3.bat:</u>

The second "GMT batch file":	*gmtbat02.od.nd.rg.gs*
Thinned Coordinate Difference Coverage files:	*cvtcd*.od.nd.rg.gs*
Thinned True Coordinate Difference Vector files (meters):	*vmtcd#.od.nd.rg.gs*
Thinned True Coordinate Difference Vector files (arcseconds):	*vstcd@.od.nd.rg.gs*
Dropped Coordinate Difference Coverage files:	*cvdcd*.od.nd.rg.gs*
Dropped True Coordinate Difference Vector files (meters):	*vmdcd#.od.nd.rg.gs*
Dropped True Coordinate Difference Vector files (arcseconds):	*vsdcd@.od.nd.rg.gs*
Surface-ready Thinned True Coordinate Difference files (meters):	*smtcd*.od.nd.rg.gs*
Surface-ready Thinned True Coordinate Difference files (arcseconds):	*sstcd%.od.nd.rg.gs*
Gridded Coordinate Difference files, Tension 0.0, grd format (meters):	*vmtcd*.od.nd.rg.gs.00.grd*
Gridded Coordinate Difference files, Tension 0.4, grd format (meters):	*vmtcd*.od.nd.rg.gs.04.grd*
Gridded Coordinate Difference files, Tension 1.0, grd format (meters):	*vmtcd*.od.nd.rg.gs.10.grd*
Gridded Coordinate Difference files, Tension 0.0, grd format (arcsec):	*vstcd%.od.nd.rg.gs.00.grd*
Gridded Coordinate Difference files, Tension 0.4, grd format (arcsec):	*vstcd%.od.nd.rg.gs.04.grd*
Gridded Coordinate Difference files, Tension 1.0, grd format (arcsec):	*vstcd%.od.nd.rg.gs.10.grd*
Gridded Coordinate Difference files, Tension 0.0, xyz format (meters):	*vmtcd*.od.nd.rg.gs.00.xyz*
Gridded Coordinate Difference files, Tension 0.4, xyz format (meters):	*vmtcd*.od.nd.rg.gs.04.xyz*
Gridded Coordinate Difference files, Tension 1.0, xyz format (meters):	*vmtcd*.od.nd.rg.gs.10.xyz*
Gridded Coordinate Difference files, Tension 0.0, xyz format (arcsec):	*vstcd%.od.nd.rg.gs.00.xyz*

[19] The grid spacing chosen here must be the same as chosen when running "doit4.bat"
[20] The "undoit3" run requires no mapflag

Gridded Coordinate Difference files, Tension 0.4, xyz format (arcsec): *vstcd%.od.nd.rg.gs.04.xyz*
Gridded Coordinate Difference files, Tension 1.0, xyz format (arcsec): *vstcd%.od.nd.rg.gs.10.xyz*
Gridded Coordinate Difference files, Tension 0.0, dot-b format (meters): *vmtcd*.od.nd.rg.gs.00.b*
Gridded Coordinate Difference files, Tension 0.4, dot-b format (meters): *vmtcd*.od.nd.rg.gs.04.b*
Gridded Coordinate Difference files, Tension 1.0, dot-b format (meters): *vmtcd*.od.nd.rg.gs.10.b*
Gridded Coordinate Difference files, Tension 0.0, dot-b format (arcsec): *vstcd%.od.nd.rg.gs.00.b*
Gridded Coordinate Difference files, Tension 0.4, dot-b format (arcsec): *vstcd%.od.nd.rg.gs.04.b*
Gridded Coordinate Difference files, Tension 1.0, dot-b format (arcsec): *vstcd%.od.nd.rg.gs.10.b*
Grid Differences, Tensions 1.0 minus 0.0, dot-b format (meters): *vmtcd*.od.nd.rg.gs.d1.b*
Grid Differences, Tensions 1.0 minus 0.0, dot-b format (arcseconds): *vstcd%.od.nd.rg.gs.d1.b*
Abs[21] Grid Differences, Tensions 1.0 minus 0.0, dot-b format (meters): *vmtcd*.od.nd.rg.gs.d2.b*
Abs. Grid Differences, Tensions 1.0 minus 0.0, dot-b format (arcsec): *vstcd%.od.nd.rg.gs.d2.b*
Scaled[22] Abs. Grid Diffs, Tensions 1.0 minus 0.0, dot-b format (meters): *vmtcd*.od.nd.rg.gs.d3.b*
Scaled Abs. Grid Diffs, Tensions 1.0 minus 0.0, dot-b format (arcsec): *vstcd%.od.nd.rg.gs.d3.b*
Scaled Abs. Grid Diffs, Tensions 1.0 minus 0.0, grd format (meters): *vmtcd*.od.nd.rg.gs.d3.grd*
Scaled Abs. Grid Diffs, Tensions 1.0 minus 0.0, grd format (arcsec)[23]: *vstcd%.od.nd.rg.gs.d3.grd*
The third "GMT batch file": *gmtbat03.od.nd.rg.gs.mf*
Thinned Coordinate Difference Coverage maps: *cvtcd*.od.nd.rg.gs.am.jpg*
Dropped Coordinate Difference Coverage maps: *cvdcd*.od.nd.rg.gs.am.jpg*
True, Thinned Coordinate Difference Vector maps (meters): *vmtcd#.od.nd.rg.gs.am.jpg*
True, Thinned Coordinate Difference Vector maps (arcseconds): *vstcd@.od.nd.rg.gs.am.jpg*
True, Dropped Coordinate Difference Vector maps (meters): *vmdcd#.od.nd.rg.gs.am.jpg*
True, Dropped Coordinate Difference Vector maps (arcseconds): *vsdcd@.od.nd.rg.gs.am.jpg*
Gridded Coordinate Difference maps, Tension 0.4 (meters): *cmtcd*.od.nd.rg.gs.04.am.jpg*
Gridded Coordinate Difference maps, Tension 0.4 (arcsec): *cstcd%.od.nd.rg.gs.04.am.jpg*
Scaled Abs. Grid Diff maps (w/ cvg)[24], Tensions 1.0 minus 0.0, (meters): *cmtcd*.od.nd.rg.gs.d3.am.jpg*
Scaled Abs. Grid Diff maps (w/ cvg), Tensions 1.0 minus 0.0, (arcsec): *cstcd%.od.nd.rg.gs.d3.am.jpg*

Where

* can be lat, lon or eht
# can be lat, lon, eht or hor
@ can be lat, lon or hor
% can be lat or lon

Table 5-3 describes each step that is executed inside of doit3.bat:

Table 5-3: Workflow and files generated by executing "doit3.bat"

Step	What does it do	What does it create

[21] Absolute values
[22] Scaled by 0.59070. See section 3.8.
[23] Also known as "Method Noise" (meters for eht, arcseconds for lat and lon)
[24] With Coverage -- The "method noise" (or "d3") grids had their maps created with the thinned coverage data shown, if creating a mapflag 1 or 2 map.

mymedian5.f	Reads in the coverage files and the coordinate difference files. It then determines, based on the given grid spacing (“gs”, in arcseconds), into which cell each particular coordinate difference (vector) falls. Then, on a cell-by-cell basis, it finds the “median vector” as follows: A) In Latitude and Longitude, the absolute horizontal lengths of the vectors are sorted and the median length used to pick the PID called the “median”. This point is then saved into the “thinned” files while all other points in that cell are saved into the “dropped” files. B) In Ellipsoid Height, a similar filtering is done, again on the absolute value of the height. It then creates a batch file (the “second GMT file”) full of GMT scripts, but only for gridding data using the GMT routine “surface”, not for creating plots.	*gmtbat02.od.nd.rg.gs* *cvtcd*.od.nd.rg.gs* *vmtcd#.od.nd.rg.gs* *vstcd@.od.nd.rg.gs* *cvdcd*.od.nd.rg.gs* *vmdcd#.od.nd.rg.gs* *vsdcd@.od.nd.rg.gs* *smtcd*.od.nd.rg.gs* *sstcd%.od.nd.rg.gs* Where * can be lat, lon or eht # can be lat, lon, eht or hor @ can be lat, lon or hor % can be lat or lon
gmtbat02.od.nd.rg.gs	Runs GMT scripts (surface, xyz2grd and grd2xyz) as well as pre-compiled grid translation and manipulation programs (such as xyz2b.f, subtrc.f, gabs.f, gscale.f, b2xyz.f) to create a variety of gridded data files. The different data formats are because GMT works well in “grd” format, while many grid-manipulation programs are NGS-specific and work in the “dot-b” format, thus necessitating some translation back and forth (but the translation from grd to dot-b or back again requires a step into xyz format, either direction) The primary grid files of interest after this runs are: Transformations: “vstcdlat….04.b” “vstcdlon….04.b” “vmtcdeht….04.b”	*vmtcd*.od.nd.rg.gs.00.grd* *vmtcd*.od.nd.rg.gs.04.grd* *vmtcd*.od.nd.rg.gs.10.grd* *vstcd%.od.nd.rg.gs.00.grd* *vstcd%.od.nd.rg.gs.04.grd* *vstcd%.od.nd.rg.gs.10.grd* *vmtcd*.od.nd.rg.gs.00.xyz* *vmtcd*.od.nd.rg.gs.04.xyz* *vmtcd*.od.nd.rg.gs.10.xyz* *vstcd%.od.nd.rg.gs.00.xyz* *vstcd%.od.nd.rg.gs.04.xyz* *vstcd%.od.nd.rg.gs.10.xyz* *vmtcd*.od.nd.rg.gs.00.b* *vmtcd*.od.nd.rg.gs.04.b* *vmtcd*.od.nd.rg.gs.10.b* *vstcd%.od.nd.rg.gs.00.b* *vstcd%.od.nd.rg.gs.04.b* *vstcd%.od.nd.rg.gs.10.b* *vmtcd*.od.nd.rg.gs.d1.b* *vstcd%.od.nd.rg.gs.d1.b* *vmtcd*.od.nd.rg.gs.d2.b*

	Method noise: “vstcdlat...d3.b” “vstcdlon…d3.b” “vmtcdeht....d3.b”	*vstcd%.od.nd.rg.gs.d2.b* *vmtcd*.od.nd.rg.gs.d3.b* *vstcd%.od.nd.rg.gs.d3.b* *vmtcd*.od.nd.rg.gs.d3.grd* *vstcd%.od.nd.rg.gs.d3.grd* Where * can be lat, lon or eht # can be lat, lon, eht or hor @ can be lat, lon or hor % can be lat or lon
makeplotfiles02.f	Program to create the third GMT batch file, and fill it with calls which will make a variety of maps based on previously created data files and grids.	*gmtbat03.od.nd.rg.gs.mf*
gmtbat03.od.nd.rg.gs.mf	Calls GMT scripts to create a variety of coverage and vector maps (of both thinned and dropped data) in black and white and a variety of color maps of grids (transformation or “04” grids and method noise or “d3” grids)	cvtcd*.od.nd.rg.gs.am.jpg cvdcd*.od.nd.rg.gs.am.jpg vmtcd#.od.nd.rg.gs.am.jpg vstcd@.od.nd.rg.gs.am.jpg vmdcd#.od.nd.rg.gs.am.jpg vsdcd@.od.nd.rg.gs.am.jpg cmtcd*.od.nd.rg.gs.04.am.jpg cstcd%.od.nd.rg.gs.04.am.jpg cmtcd*.od.nd.rg.gs.d3.am.jpg cstcd%.od.nd.rg.gs.d3.am.jpg Where * can be lat, lon or eht # can be lat, lon, eht or hor @ can be lat, lon or hor % can be lat or lon

5.2.4 doit4.bat

This batch file generates the error estimates. First, it computes the data noise via RMS of the "double difference vector" (coordinate difference of a point, minus the grid-interpolated transformation value of each point) for each cell that had data; these RMS values are then gridded with tension 0.9. Second, the data noise and the method noise grids are summed to generate final error estimates. All vectors and their coverage are plotted, as well as a color contour plots of the data noise (gridded RMS) and the final error estimates.

<u>What must exist prior to running:</u>

Thinned True Coordinate Difference Vector files (meters):	*vmtcd#.od.nd.rg.gs*
Thinned True Coordinate Difference Vector files (arcseconds):	*vstcd@.od.nd.rg.gs*
Dropped True Coordinate Difference Vector files (meters):	*vmdcd#.od.nd.rg.gs*
Dropped True Coordinate Difference Vector files (arcseconds):	*vsdcd@.od.nd.rg.gs*
Gridded Coordinate Difference files, Tension 0.4, dot-b format (meters):	*vmtcd*.od.nd.rg.gs.04.b*
Gridded Coordinate Difference files, Tension 0.4, dot-b format (arcsec):	*vstcd%.od.nd.rg.gs.04.b*

<u>doit4.bat syntax:</u>	*doit4.bat od nd rg* gs[25] *mf* <return>
<u>undoit4.bat syntax:</u>	*undoit4.bat od nd rg* gs[26]<return>

<u>Example doit4.bat syntax:</u>	*doit4.bat ussd nad27 conus* 900 *2* <return>
<u>Example undoit4.bat syntax:</u>	*undoit4.bat ussd nad27 conus* 900 <return>

<u>What will be created by running doit4.bat:</u>

Grid-Interpolated[27] Coordinate Difference Vector files (meters):	*vmagi#.od.nd.rg.gs*
Grid-Interpolated Coordinate Difference Vector files (arcseconds):	*vsagi@.od.nd.rg.gs*
Grid-Interpolated,Thinned Coordinate Difference Vector files (meters):	*vmtgi#.od.nd.rg.gs*
Grid-Interpolated,Thinned Coordinate Difference Vector files (arcseconds):	*vstgi@.od.nd.rg.gs*
Grid-Interpolated, Dropped Coordinate Difference Vector files (meters):	*vmdgi#.od.nd.rg.gs*
Grid-Interpolated, Dropped Coordinate Difference Vector files (arcseconds):	*vsdgi@.od.nd.rg.gs*
Double Differenced[28] Coordinate Difference Vector files (meters):	*vmadd#.od.nd.rg.gs*
Double Differenced Coordinate Difference Vector files (arcseconds):	*vsadd@.od.nd.rg.gs*
Double Differenced, Thinned Coordinate Difference Vector files (meters):	*vmtdd#.od.nd.rg.gs*
Double Differenced, Thinned Coordinate Difference Vector files (arcseconds):	*vstdd@.od.nd.rg.gs*
Double Differenced, Dropped Coordinate Difference Vector files (meters):	*vmddd#.od.nd.rg.gs*
Double Differenced, Dropped Coordinate Difference Vector files (arcseconds):	*vsddd@.od.nd.rg.gs*
Basic Statistics File:	*dvstats.od.nd.rg.gs*
The fourth GMT batch file:	*gmtbat04.od.nd.rg.gs.mf*

[25] The grid spacing chosen here must be the same one that was used in "doit3.bat"

[26] The "undoit4" run requires no mapflag

[27] "Grid-Interpolated" Coordinate Differences come from a biquadratic interpolation off of the transformation grid and represent "new datum minus old datum" values. Contrast this with earlier-determined "True" Coordinate Differences which come from differencing the actual published "new datum" minus "old datum" coordinates.

[28] Double Differenced means that the "True" Coordinate Differences have been subtracted from the "Grid Interpolated" Coordinate Difference.

Grid Interpolated Coordinate Difference Vector maps (meters): *vmagi#.od.nd.rg.gs.am.jpg*
Grid Interpolated Coordinate Difference Vector maps (arcseconds): *vsagi@.od.nd.rg.gs.am.jpg*
Grid Interpolated, Thinned Coordinate Difference Vector maps (meters): *vmtgi#.od.nd.rg.gs.am.jpg*
Grid Interpolated, Thinned Coordinate Difference Vector maps (arcsec): *vstgid@.od.nd.rg.gs.am.jpg*
Grid Interpolated, Dropped Coordinate Difference Vector maps (meters): *vmdgi#.od.nd.rg.gs.am.jpg*
Grid Interpolated, Dropped Coordinate Difference Vector maps (arcsec): *vsdgi@.od.nd.rg.gs.am.jpg*
Double Differenced Coordinate Difference Vector maps (meters): *vmadd#.od.nd.rg.gs.am.jpg*
Double Differenced Coordinate Difference Vector maps (arcseconds): *vsadd@.od.nd.rg.gs.am.jpg*
Double Differenced, Thinned Coordinate Diff. Vector maps (meters): *vmtdd#.od.nd.rg.gs.am.jpg*
Double Differenced, Thinned Coordinate Diff. Vector maps (arcsec): *vstdd@.od.nd.rg.gs.am.jpg*
Double Differenced, Dropped Coordinate Diff. Vector maps (meters): *vmddd#.od.nd.rg.gs.am.jpg*
Double Differenced, Dropped Coordinate Diff. Vector maps (arcsec): *vsddd@.od.nd.rg.gs.am.jpg*
The fifth GMT batch file: *gmtbat05.od.nd.rg.gs*
RMS Double Difference Coordinate Difference Vector files (arcseconds): *vsrdd@.od.nd.rg.gs*
RMS Double Difference Coordinate Difference Vector files (meters): *vmrdd#.od.nd.rg.gs*
Coverage of RMS DD Coordinate Difference Vectors files: *cvrdd*.od.nd.rg.gs*
Surface-ready RMS DD Coordinate Difference files (meters): *smrdd*.od.nd.rg.gs*
Surface-ready RMS DD Coordinate Difference files (arcseconds): *ssrdd%.od.nd.rg.gs*
Gridded RMS DD Coord. Diff. files, Tension 0.9, grd format (meters): *vmrdd*.od.nd.rg.gs.09.grd*
Gridded RMS DD Coord. Diff. files, Tension 0.9, grd format (arcsec)[29]: *vsrdd%.od.nd.rg.gs.09.grd*
Gridded RMS DD Coord. Diff. files, Tension 0.9, xyz format (meters): *vmrdd*.od.nd.rg.gs.09.xyz*
Gridded RMS DD Coord. Diff. files, Tension 0.9, xyz format (arcsec): *vsrdd%.od.nd.rg.gs.09.xyz*
Gridded RMS DD Coord. Diff. files, Tension 0.9, dot-b format (meters): *vmrdd*.od.nd.rg.gs.09.b*
Gridded RMS DD Coord. Diff. files, Tension 0.9, dot-b format (arcsec): *vsrdd%.od.nd.rg.gs.09.b*
Transformation Error Grids, dot-b format(meters): *vmete*.od.nd.rg.gs.b*
Transformation Error Grids, dot-b format(arcseconds)[30]: *vsete%.od.nd.rg.gs.b*
Transformation Error Grids, grd format(meters): *vmete*.od.nd.rg.gs.grd*
Transformation Error Grids, grd format(arcseconds): *vsete%.od.nd.rg.gs.grd*
The sixth GMT batch file: *gmtbat06.od.nd.rg.gs.mf*
Coverage of RMS DD Coordinate Difference maps: *cvrdd*.od.nd.rg.gs.am.jpg*
RMS Double Difference Coord. Difference Vector maps (meters): *vmrdd#.od.nd.rg.gs.am.jpg*
RMS Double Difference Coord. Difference Vector maps (arcseconds): *vsrdd@.od.nd.rg.gs.am.jpg*
Gridded RMS DD Coord. Diff. maps, Tension 0.9 (meters): *cmrdd*.od.nd.rg.gs.09.am.jpg*
Gridded RMS DD Coord. Diff. maps, Tension 0.9 (arcsec): *csrdd%.od.nd.rg.gs.09.am.jpg*
Transformation Error maps (meters): *cmete*.od.nd.rg.gs.am.jpg*
Transformation Error maps (arcseconds): *csete%.od.nd.rg.gs.am.jpg*

Where

* can be lat, lon or eht
# can be lat, lon, eht or hor
@ can be lat, lon or hor
% can be lat or lon

[29] Also known as "Data Noise" (meters for eht, arcseconds for lat and lon)
[30] Also known as "Total Error" grids, being an RMS combination of "Method Noise" and "Data Noise" (meters for eht, arcseconds for lat and lon)

Table 5-4 describes each step that is executed inside of doit4.bat:

Table 5-4: Workflow and files generated by executing "doit4.bat"

Step	What does it do	What does it create
checkgrid.f	Program to interpolate the previously created transformation grids and then compare these grid interpolated values to the true values of coordinate differences. It then sets up calls in the fourth GMT batch file to map all of these vectors.	*vmagi#.od.nd.rg.gs* *vsagi@.od.nd.rg.gs* *vmtgi#.od.nd.rg.gs* *vstgi@.od.nd.rg.gs* *vmdgi#.od.nd.rg.gs* *vsdgi@.od.nd.rg.gs* *vmadd#.od.nd.rg.gs* *vsadd@.od.nd.rg.gs* *vmtdd#.od.nd.rg.gs* *vstdd@.od.nd.rg.gs* *vmddd#.od.nd.rg.gs* *vsddd@.od.nd.rg.gs* *dvstats.od.nd.rg.gs* *gmtbat04.od.nd.rg.gs.mf* Where # can be lat, lon, eht or hor @ can be lat, lon or hor
gmtbat04.od.nd.rg.gs.mf	Calls GMT scripts to create a variety of vector maps (of "all", "thinned" and "dropped" data) in black and white for both the "Grid Interpolated" coordinate differences and the "Double Differences" ("Grid Interpolated" minus "True")	*vmagi#.od.nd.rg.gs.am.jpg* *vsagi@.od.nd.rg.gs.am.jpg* *vmtgi#.od.nd.rg.gs.am.jpg* *vstgid@.od.nd.rg.gs.am.jpg* *vmdgi#.od.nd.rg.gs.am.jpg* *vsdgi@.od.nd.rg.gs.am.jpg* *vmadd#.od.nd.rg.gs.am.jpg* *vsadd@.od.nd.rg.gs.am.jpg* *vmtdd#.od.nd.rg.gs.am.jpg* *vstdd@.od.nd.rg.gs.am.jpg* *vmddd#.od.nd.rg.gs.am.jpg* *vsddd@.od.nd.rg.gs.am.jpg* Where # can be lat, lon, eht or hor @ can be lat, lon or hor

myrms.f	Program to compute an "RMS Double Difference vector" for each cell that had data. Such a vector consists of the RMS mismatch between Grid Interpolated and True Coordinate differences, computed in lat, lon or eht. The RMS is entirely about magnitude. The "hor" RMS values are derived from those of lat and lon ,and as such, their azimuths are NOT an RMS value of individual "hor" DD vectors, but rather the azimuth formed by combining the RMS lat and RMS lon DD vectors. It registers the RMS vectors at the average latitude and average longitude of all the vectors that went into the RMS. All this data is then stored in files, and the fifth GMT batch file, used to grid this RMS DD data is created.	*gmtbat05.od.nd.rg.gs* *vsrdd@.od.nd.rg.gs* *vmrdd#.od.nd.rg.gs* *cvrdd*.od.nd.rg.gs* *smrdd*.od.nd.rg.gs* *ssrdd%.od.nd.rg.gs* Where * can be lat, lon or eht # can be lat, lon, eht or hor @ can be lat, lon or hor % can be lat or lon
gmtbat05.od.nd.rg.gs	Runs GMT scripts (surface, xyz2grd and grd2xyz) as well as pre-compiled grid translation and manipulation programs (such as xyz2b.f, gsqr.f, addem.f, gsqrt.f) to create a variety of gridded data files. The different data formats are because GMT works well in "grd" format, while many grid-manipulation programs are NGS-specific and work in the "dot-b" format, thus necessitating some translation back and forth (but the translation from grd to dot-b or back again requires a step into xyz format, either direction) The primary grid files of interest after this runs are: Total Transformation Error Grids: "vsetelat…..b" "vsetelon…..b" "vmeteeht….b"	*vmrdd*.od.nd.rg.gs.09.grd* *vsrdd%.od.nd.rg.gs.09.grd* *vmrdd*.od.nd.rg.gs.09.xyz* *vsrdd%.od.nd.rg.gs.09.xyz* *vmrdd*.od.nd.rg.gs.09.b* *vsrdd%.od.nd.rg.gs.09.b* *vmete*.od.nd.rg.gs.b* *vsete%.od.nd.rg.gs.b* *vmete*.od.nd.rg.gs.grd* *vsete%.od.nd.rg.gs.grd* Where * can be lat, lon or eht % can be lat or lon
makeplotfiles03.f	Takes the previously determined RMS DD data, in either vector form or in gridded form and creates the sixth GMT batch file, which will map all of that data.	*gmtbat06.od.nd.rg.gs.mf*

gmtbat06.od.nd.rg.gs.mf	Calls GMT scripts to create a variety of coverage and vector maps (of RMS DD data) in black and white and a variety of color maps of grids ("method noise" or "09" grids and total error or "ete" grids)	*cvrdd*.od.nd.rg.gs.am.jpg* *vmrdd#.od.nd.rg.gs.am.jpg* *vsrdd@.od.nd.rg.gs.am.jpg* *cmrdd*.od.nd.rg.gs.09.am.jpg* *csrdd%.od.nd.rg.gs.09.am.jpg* *cmete*.od.nd.rg.gs.am.jpg* *csete%.od.nd.rg.gs.am.jpg* Where * can be lat, lon or eht # can be lat, lon, eht or hor @ can be lat, lon or hor % can be lat or lon

5.3 Releasing NADCON 5.0 products

The most fundamental products coming out of the NADCON 5.0 process are the transformation grids and their associated error grids. From the process described in Section 5.2, the respective production filenames are:

Transformation grids:

vstcd%.od.nd.rg.gs.04.b for latitude and longitude, where "%" is either 'lat' or 'lon'

vmtcdeht.od.nd.rg.gs.04.b for ellipsoidal height

Error grids:

vsete%.od.nd.rg.gs.b for latitude and longitude, where "%" is either 'lat' or 'lon'

vmeteeht.od.nd.rg.gs.b for ellipsoidal height

Implicit in these production-level filenames is that latitude and longitude transformations are released with units of arcseconds, whereas ellipsoidal height transformations are released with units of meters, and that the grids are provided in the dot-b format described in Section 10.

For final distribution of the NADCON 5.0 products, the authors thought it was necessary to add a release tag to the filenames. This was done so that a new release could be easily differentiated from previous releases, if it became necessary to regenerate and re-release NADCON 5.0 data at some point in the future. Also, the grid size was dropped from the filename convention, as grid sizes are traceable based on the release tag.

For the September 1, 2016 release of NADCON 5.0 detailed in this report, the final transformation and error filenames use the format:

Transformation: *nadcon5.**od.nd.rg.coord**.trn.20160901.b*

Error: *nadcon5.**od.nd.rg.coord**.err.20160901.b*

where *od*, *nd*, and *rg* are the original datum, new datum, and region as previously described, and *coord* is 'lat', 'lon', or 'eht' for latitude, longitude, or ellipsoidal height. The new filename convention was applied only to the final transformation and error grids; all other products coming out of the processing stream retain the original filenames as detailed in Section 5.2.

5.4 NADCON 5.0 in the Geodetic Toolkit

The transformation and error grids developed here are only useful if they are combined with a user-friendly tool which can apply the transformations and correctly report the errors for specific points. In the past (Sections 1 and 0), NGS has distributed executable software to implement the GEOCON and NADCON transformations, which either needed to be downloaded locally to a user's computer, or else was invoked by a web page "wrapper". Such approaches lacked flexibility and do not represent modern geospatial tool approaches, such as Web Services. With the release of NADCON 5.0, transformation implementation is available through the NGS's recently updated online Geodetic Toolkit. Prior to its update, each tool in the Geodetic Toolkit was a stand alone, usually FORTRAN based, program without any integration between tools.

Recently (but prior to NADCON 5.0), the Geodetic Toolkit update now supports a fully integrated set of tools to transform between geodetic coordinate types (Latitude/Longitude/Ellipsoid Height (LLh), State Plane Coordinates (SPC), Universal Transverse Mercator (UTM) coordinates, Cartesian coordinates (XYZ), and U.S. National Grid (USNG) coordinates). It features transformation of single or multiple points through a web GUI, Web services, and software downloads for standalone use of the tools. Integration of NADCON 5.0 grids and errors into the Toolkit now enables users to transform positions between datums as well as changing coordinate types, in a single step. The transformation and error grids are defined only at specific points on a uniform grid; the Geodetic Toolkit uses biquadratic interpolation to provide the local transformation and error for requested points. By way of example, one can now use the toolkit to enter UTM coordinates in NAD 83(2011) and ask for State Plane Coordinates in NAD 27. Not only will it perform the proper coordinate type translation, it will transform across datums and provide an error estimate of said transformation.

NADCON 5.0 datum transformations are valid only within the gridded areas of each region (Table 5-5). If a user requests a datum transformation for coordinates outside of the defined regions, the toolkit will issue an error. Outside of these boundaries, the Toolkit is still able to transform between coordinate types within the same datum.

As of the writing of this report, NADCON 5.0 in the geodetic toolkit has not been released to the public, but expect the beta release for public testing by February 2017. The beta site can be found at http://beta.ngs.noaa.gov/gtkweb/.

Table 5-5: Official regions and their boundaries for NADCON 5.0

	Grid boundaries (degrees latitude or longitude)			
region	***north***	***south***	***west***	***east***
conus	50	24	235	294

alaska	73	50	172	232
hawaii	23	18	199	206
prvi	19	17	291	296
as	-13	-16	188	193
guamcnmi	22	12	143	147
stpaul	57.4	56.9	189.3	190.4
stgeorge	56.8	56.3	190.0	190.8
stlawrence	64.0	62.7	187.5	192.0
stmatthew	61.0	60.0	186.0	188.5

6 Report on each transformation

In all, 44 separate transformations (30 horizontal, 14 vertical) were computed in 9 different regions. An individualized grid spacing was chosen for each transformation, to best capture the overall field as well as important local details of a field, when appropriate.

The remainder of this section contains individual reports for each transformation. In each report, we summarize the transformation field and its pertinent characteristics, provide a synopsis of the considerations for selecting the grid size, and include graphics and discussion on the final transformation and its associated error. In most cases, we also discuss the residuals of the transformation, that is, original input data (here, the thinned vectors) minus the model (transformation grid), to assess the goodness of fit of the transformation to the constituent data. At the start of each regional report, we provide some basic statistics:

- **# of points**: All points which were evaluated by the NADCON 5.0 team as not being an outlier.
- **# of outliers**: Points identified as outliers, see Section 4.4. As a reminder, such points were removed from the list of points early in the build process, prior to any median filtering or gridding algorithms.
- **# of thinned points**: Points used to define the transformation, after selecting a grid size and applying the median filter
- **Transformation size (median)**: Median magnitude of all points (column '# of points').
- **Grid size**: Final grid size selected by NADCON 5.0 team.

The reports include summary graphics for the field, transformation, and errors, but a full suite of detailed plots is available in a digital archive. See Section 5.2 and Section 11 for the description of the archive contents and structure.

6.1 Conterminous United States + Washington DC (conus)

For NADCON 5.0, the "conus" region encompasses the conterminous United States, with a bounding box of 24-50 latitude, 235-294 longitude for the gridded area. To facilitate analysis over such a huge area, the digital archive includes plots at the regional level (subdividing CONUS into 9 regions of roughly equivalent size; mapflag = 1) and the state level (48 states plus Washington DC; mapflag = 2). In general, the datasets contain tens of thousands of points, so finer-scaled plots are helpful for discerning details and trends in the data.

Nine frame transformations are released as part of NADCON 5.0 (Table 6-1), where the last three transformations (HARN and later) include ellipsoidal heights. The history of CONUS transformations is complicated, as detailed in Section 1 of this report. We remind the reader that the HARN and FBN labels are for state-level realizations on a year-by-year basis which have been grouped, for simplicity, into single realizations called "HARN" or "FBN", spanning the CONUS region, see Sections 1 and 4.3.1 for additional detail.

Due to the large point density in most CONUS transformations, the authors were able to rely more heavily on statistical measures to drive the grid size selection. The authors recognize that the large number of points in most CONUS transformations lead to a lack of clarity for the CONUS maps – for a better assessment of the field's details, please see regional and state maps in the digital archive. Method overview is provided in Section 4.5, and the exact implementation of this method is detailed with each transformation discussed below.

Table 6-1: NADCON 5.0 transformations for CONUS

old datum (od)	***new datum (nd)***	***# of points***	***# outliers***	***# thinned points***	***transformation size (median)***	***grid size***
Horizontal						
USSD	NAD27	24K	241	3016	17.2 m (trimodal 11/18/42 m)	15'
NAD27	NAD83_1986	225K	565	13104	33.3 m (bimodal 29/95 m)	15'
NAD83_1986	NAD83_HARN	230K	2590	90156	26 cm	3'
NAD83_HARN	NAD83_FBN	43K	170	24099	5 cm	1'
NAD83_FBN	NAD83_2007	61K	1430	48683	2 cm	1'
NAD83_2007	NAD83_2011	74K	432	58460	2 cm	1'

Vertical						
NAD83_HARN	NAD83_FBN	11K	59	9663	-1.6 cm median 8.1 cm RMS	1’
NAD83_FBN	NAD83_2007	61K	62	48758	-0.006	1’
NAD83_2007	NAD83_2011	74K	194	58575	-2 cm	1’

6.1.1 CONUS / USSD / NAD 27 / Horizontal

The horizontal transformation from USSD to NAD 27 (Figure 6-1) is centered around Meades Ranch, Kansas. Because the adjustment for NAD 27 and USSD held the coordinates at Meades Ranch as the same, but had a difference of azimuth to the primary azimuth mark, there is a “twisting” pattern discernable, centered around Meades Ranch. The magnitude of the transformation has a population median of 17 meters, but a trimodal distribution of vectors with three peaks of 11, 18, and 43 meters. The large magnitude, sparse nature and localized consistency of this transformation field (Figure 6-1) led us toward selecting a coarse grid, to allow a median filter to have a real effect on the data. We subsequently chose the 900” (15’) grid size because this was the coarsest grid which had fewer than 10% of dropped vectors exceeding 10% of the median transformation size, 1.7 meters; coarser grids nearly doubled the number of vectors exceeding this threshold, but finer grids did not result in appreciable gains. As shown in Figure 6-5, the 15’ grid yielded residuals for the majority of thinned vectors which do not exceed 1 meter.

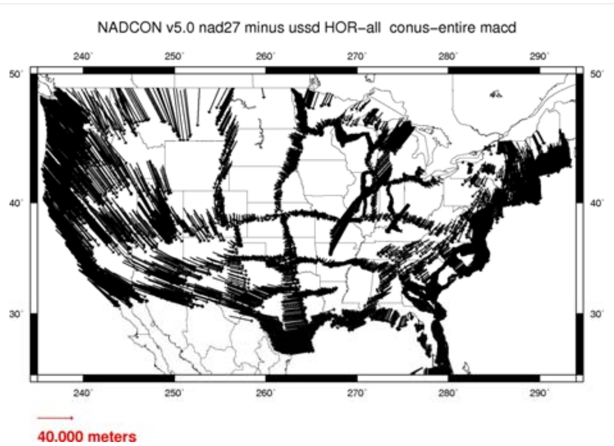

Figure 6-1: All horizontal vectors for USSD/NAD 27/CONUS

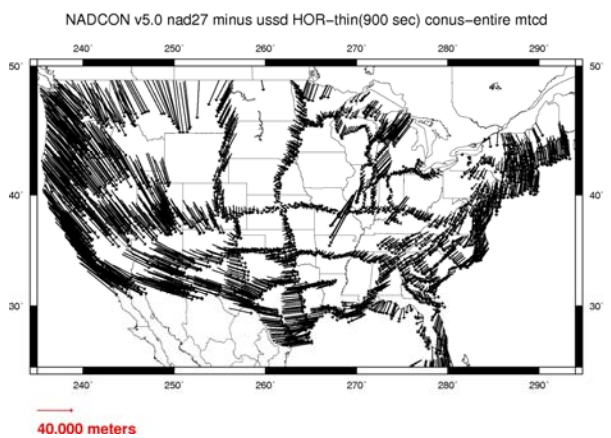

Figure 6-2: Thinned horizontal vectors after applying 15' grid spacing for USSD/NAD 27/CONUS

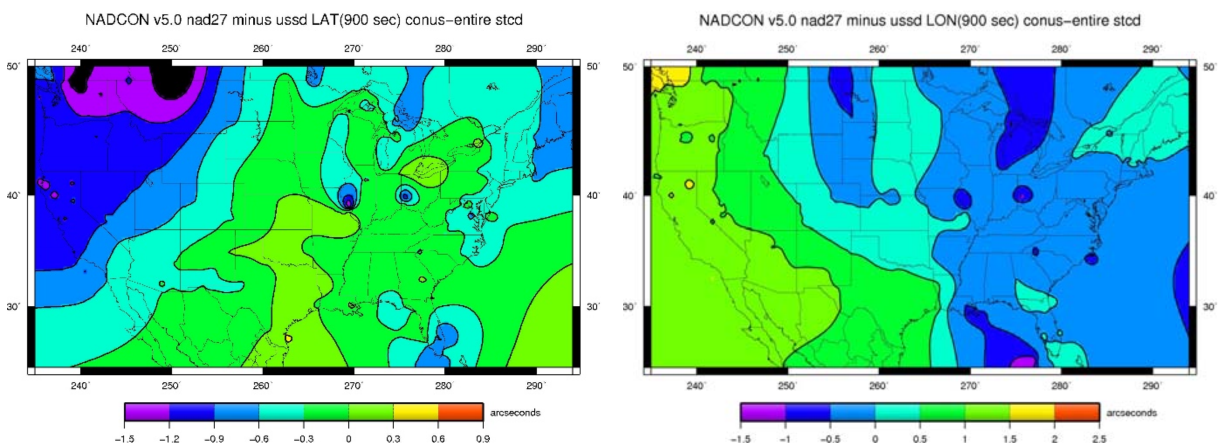

Figure 6-3: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for USSD/NAD 27/CONUS.

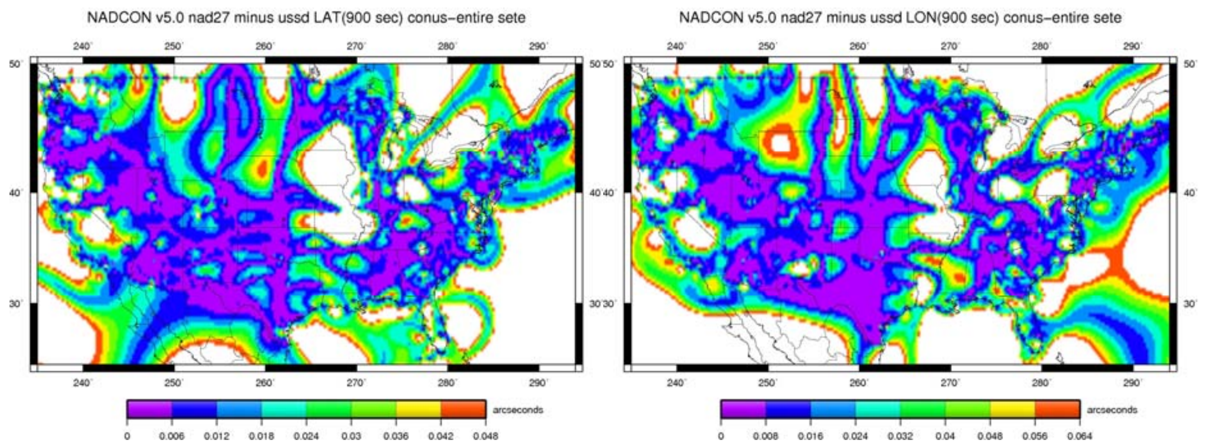

Figure 6-4: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for USSD/NAD 27/CONUS

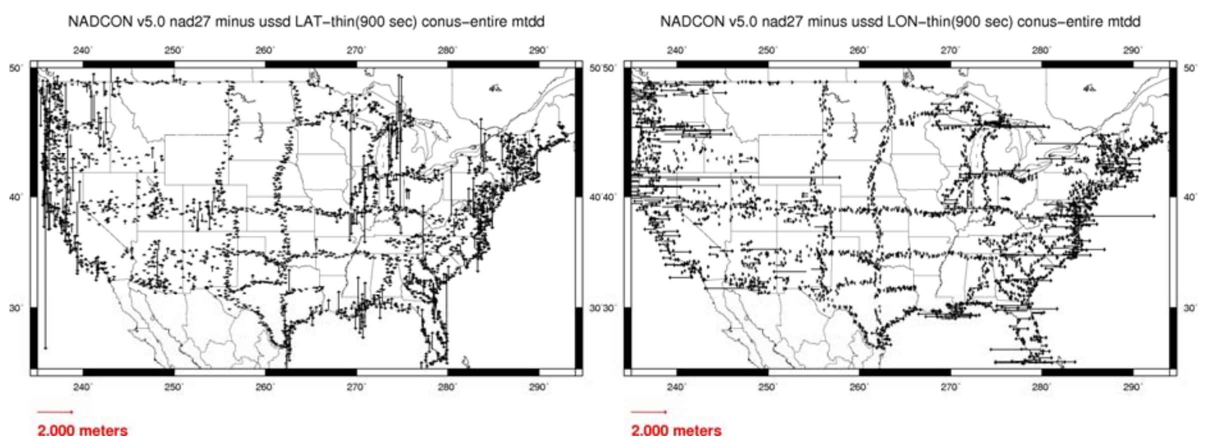

Figure 6-5: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for USSD/NAD 27/CONUS.

6.1.2 CONUS / NAD 27 / NAD 83(1986) / Horizontal

The horizontal-only transformation from NAD 27 to NAD 83(1986) has a strong latitude component (Figure 6-6 and Figure 6-8), and also a large magnitude: median 33.3 meters; bimodal distribution with means of 29 and 95 meters. The field is very dense, with 225,227 points well distributed across CONUS. The data are generally clean, although analysis of dropped residuals did indicate that more outliers could have been eliminated. However, all potential grid sizes studied did an excellent job of matching the transformation: for all grid sizes, fewer than 1% of thinned or dropped vectors exceeded 10% of the transformation median, or 3.3 meters. In the end, we stood by the historical grid size used in NADCON, 15 arcminutes, because there were no statistical gains by going to finer grids.

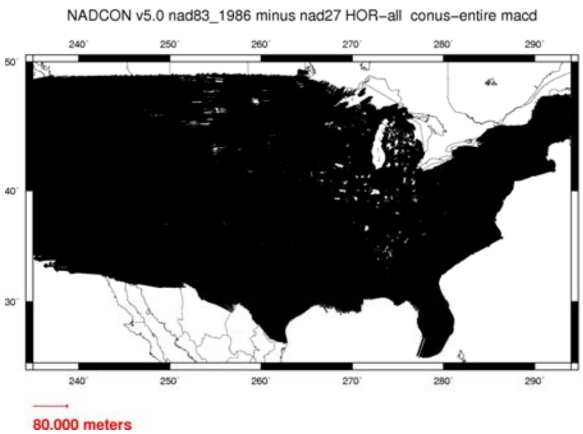

Figure 6-6: All horizontal vectors for NAD 27/NAD 83(1986)/CONUS.

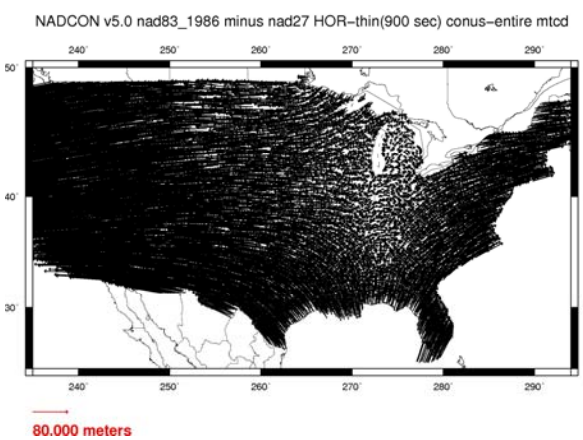

Figure 6-7: Thinned horizontal vectors after applying 15’ grid spacing for NAD 27/NAD 83(1986)/CONUS.

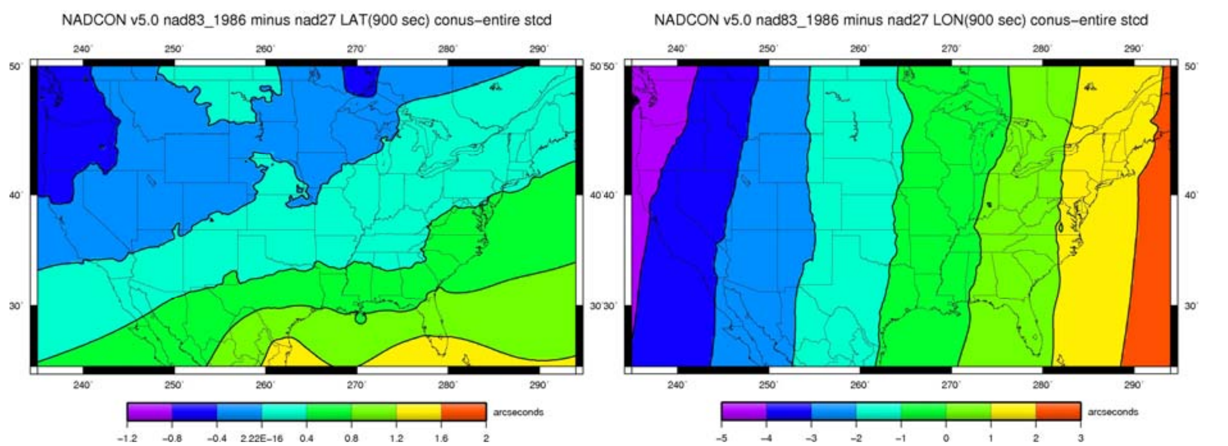

Figure 6-8: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 27/NAD 83(1986)/CONUS.

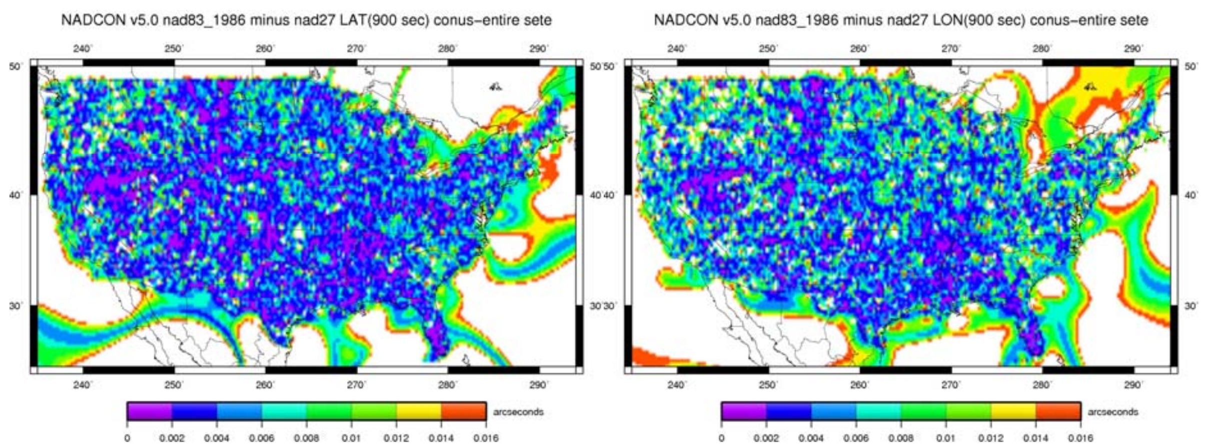

Figure 6-9: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 27/NAD 83(1986)/CONUS.

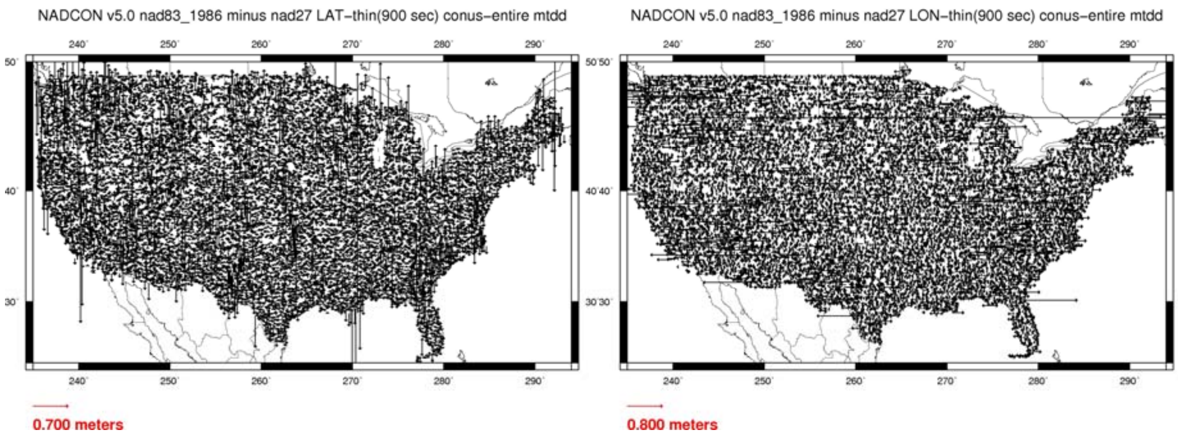

Figure 6-10: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 27/NAD 83(1986)/CONUS.

6.1.3 CONUS / NAD 83(1986) / NAD 83(HARN) / Horizontal

With 230,740 points, the NAD 83(1986) to NAD 83(HARN) transformation is very dense, where the average distance between points is 1.04 +/- 1.62 arcminutes. The median size of the transformation is 26 cm, far smaller in magnitude than previous transformations. The field is decidedly more variable than previous transformations (Figure 6-12).

The initial NGS product for this transformation was 15', and was the first transformation tool to use state-by-state grids, rather than one regional grid. With the NADCON 5.0 approach to group all HARNs into a single nation-wide realization of NAD 83, a finer grid spacing is required to capture the local variations within each state. Significant local signals were found in VT, IN, and CA (Figure 6-13). The authors chose 3' grid spacing because this was the coarsest grid spacing which would adequately capture the local signal in those states. The 3' grid also resulted in fewer than 10% of dropped residuals exceeding 2.6 cm or 20% of the median transformation size, a criteria discussed in Section 4.5. Although some thinned residuals can be very large in magnitude (Figure 6-16), the vast majority of the residuals are less than 5 cm (Figure 6-17).

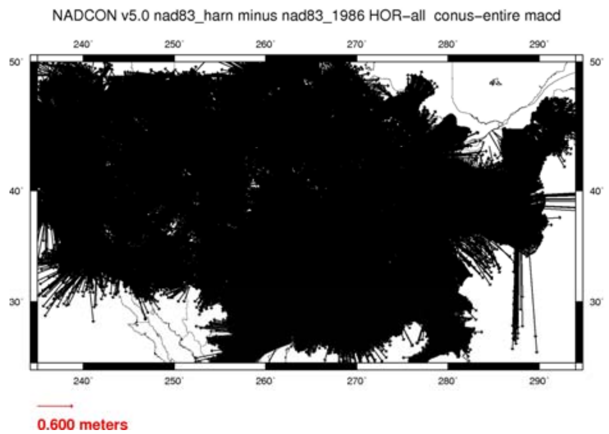

Figure 6-11: All horizontal vectors for NAD 83(1986)/NAD 83(HARN)/CONUS.

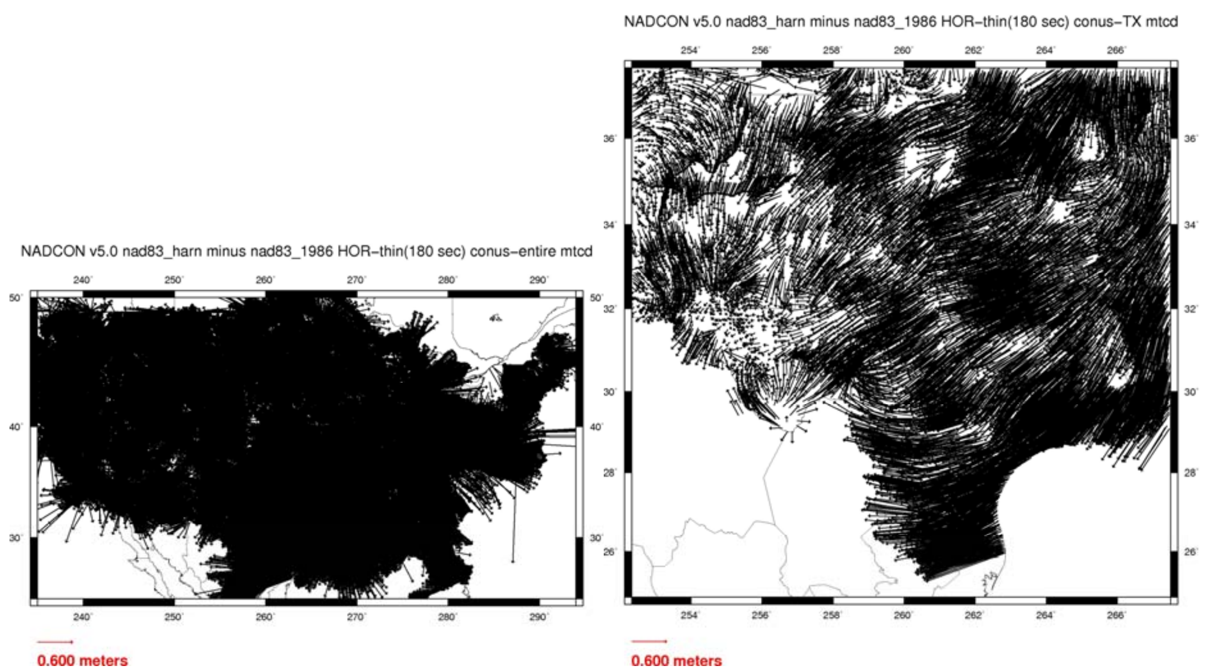

Figure 6-12: Thinned horizontal vectors after applying 3' grid spacing; CONUS (left), with zoom on Texas (right) to show local variability in the field for NAD 83(1986)/NAD 83(HARN)/CONUS.

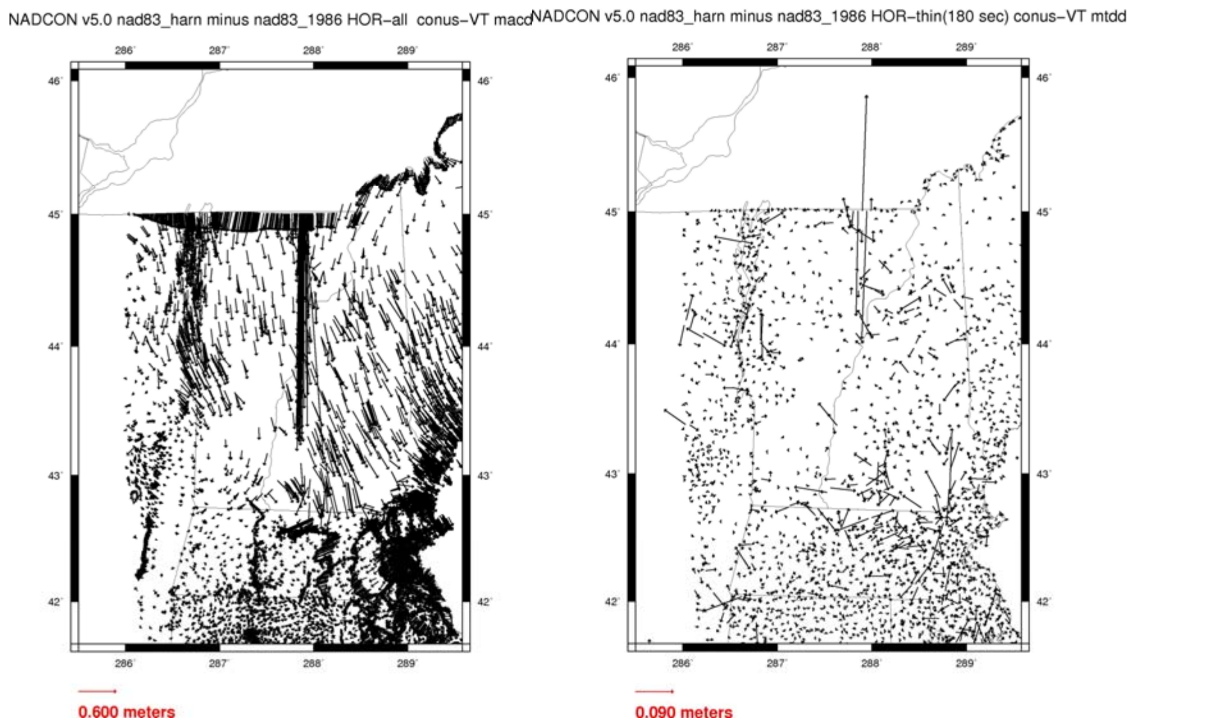

Figure 6-13: Treatment of large-magnitude local horizontal signal in Vermont: original vectors before thinning (left), and thinned vector residuals relative to 3' transformation grid (right) for NAD 83(1986)/NAD 83(HARN)/CONUS.

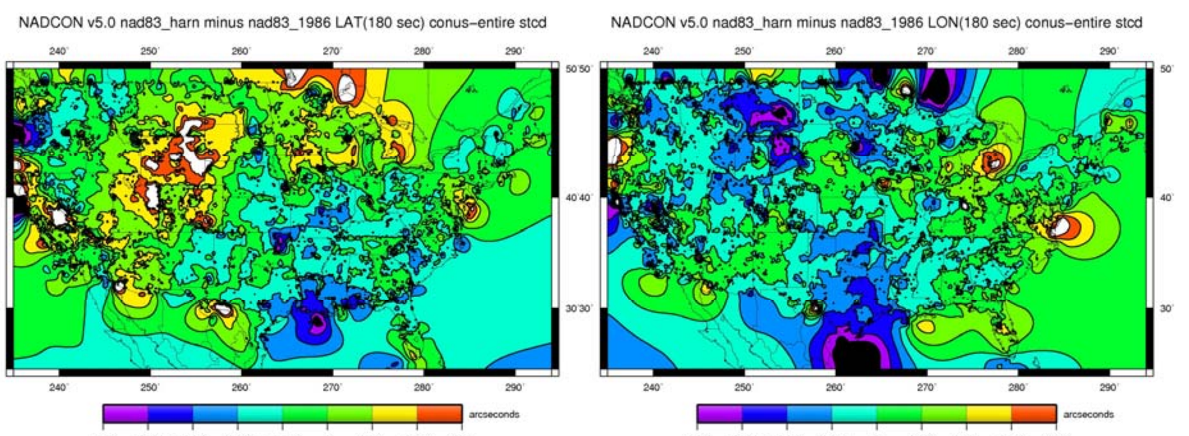

Figure 6-14: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1986)/NAD 83(HARN)/CONUS.

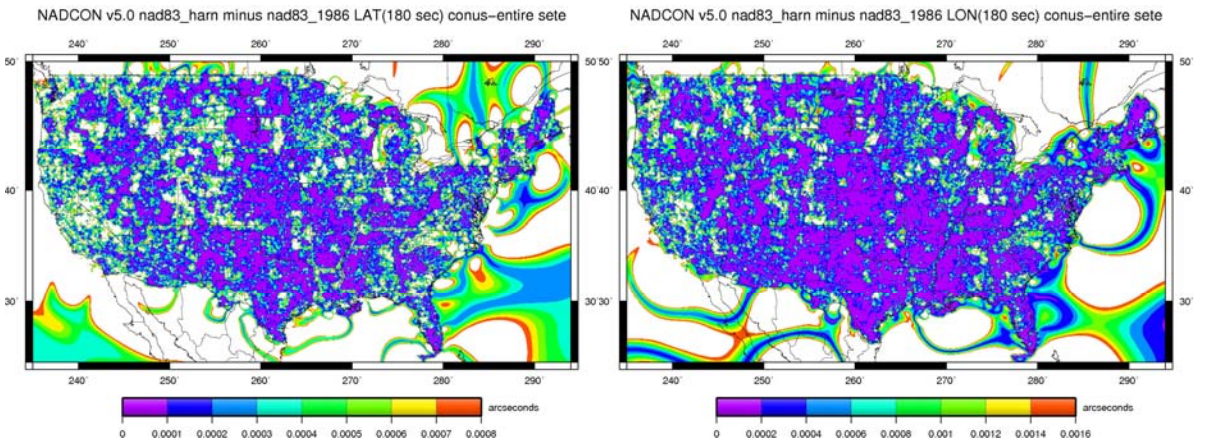

Figure 6-15: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1986)/NAD 83(HARN)/CONUS.

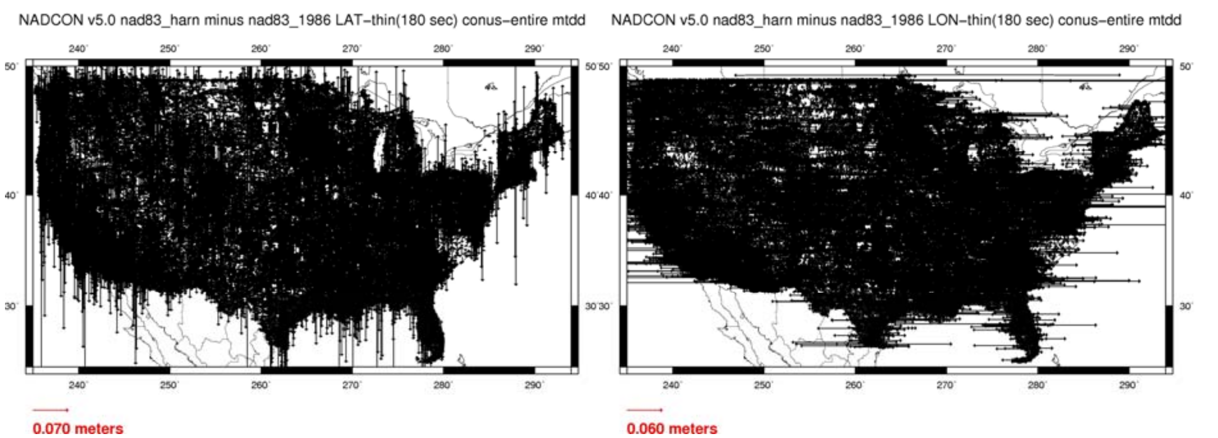

Figure 6-16: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 83(1986)/NAD 83(HARN)/CONUS.

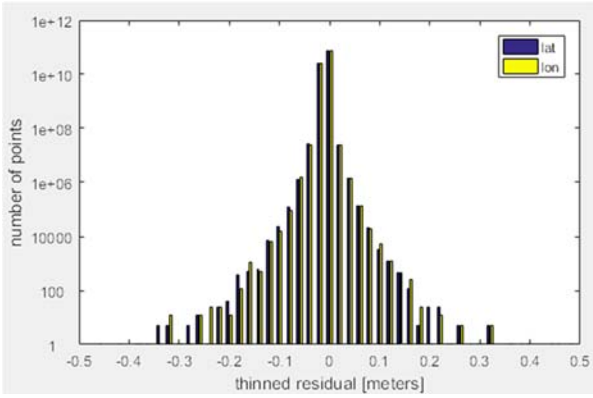

Figure 6-17: Histogram of magnitude of thinned vector residuals, both latitude and longitude, in meters; note the logarithmic scale for the number of points for NAD 83(1986)/NAD 83(HARN)/CONUS.

6.1.4 CONUS / NAD 83(HARN) / NAD 83(FBN) / 3-D

There are only 19 states in which an FBN realization was computed, unique from the HARN realization (Section 1). As such, for large swaths of the nation the NAD 83(HARN) to NAD 83(FBN) transformation should be defined as zero. To accomplish this, the data were thinned and gridded as with any other transformation, but a mask was applied to the transformation and error grids so that a sharp transition to zero occurs at the boundaries of states without FBN coordinates. For both horizontal and vertical transformations, the authors felt that this masking operation required a 1' grid size, so that the state boundaries were as sharp as possible and a ghost transformation would not 'bleed' into adjacent areas where the FBN adjustment was identical to the HARN (within reasonable error bounds).

6.1.4.1 Horizontal

The transformation size is small for the majority of points (4.6 cm median), although a few states contain significant signal in the 0.2-1.2 meter range (Figure 6-19). In states with an FBN, the point distribution is sparse, with most cells having 4 or fewer points for all the fine- to medium-grained grids considered, meaning that median filter would not have much effect on the data when using a finer grid. Regardless, as stated above, the masking operation required accepting a 1' grid size, even though this resulted in a few additional large thinned residuals in the northeastern states and Tennessee (Figure 6-22).

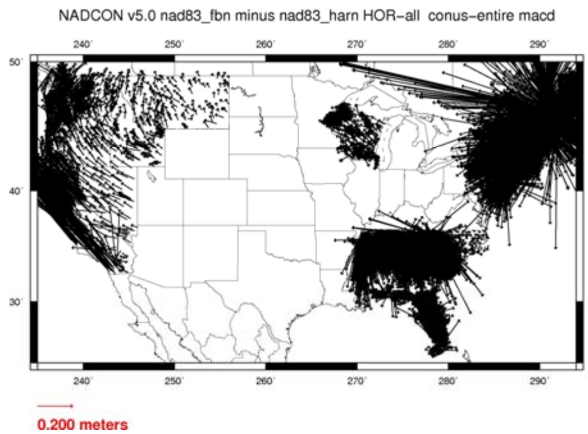

Figure 6-18: All horizontal vectors for NAD 83(HARN)/NAD 83(FBN)/CONUS.

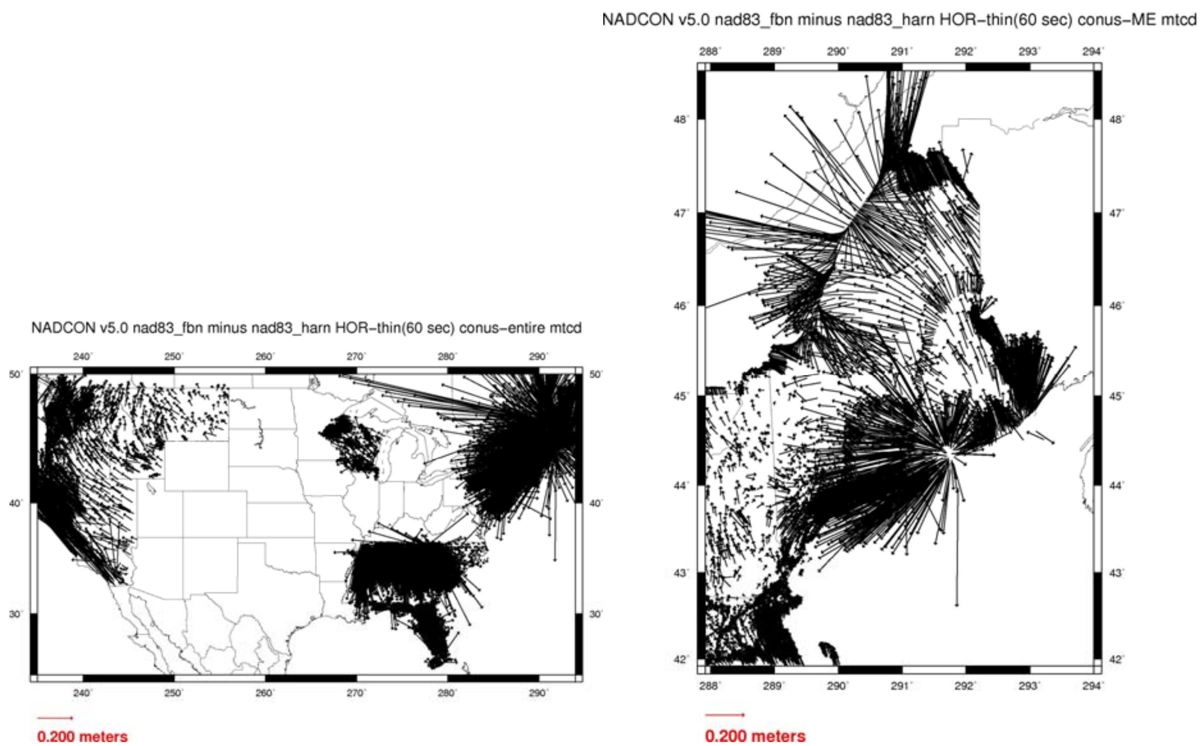

Figure 6-19: Thinned horizontal vectors after applying 1’ grid spacing, with zoom on Maine (right) to show large magnitude vectors with local variability in the field for NAD 83(HARN)/NAD 83(FBN)/CONUS.

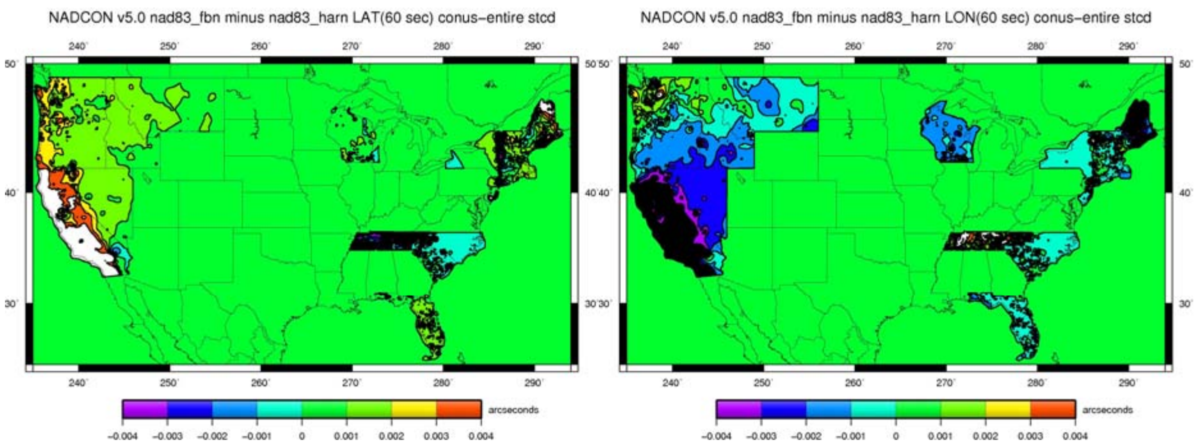

Figure 6-20: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(HARN)/NAD 83(FBN)/CONUS.

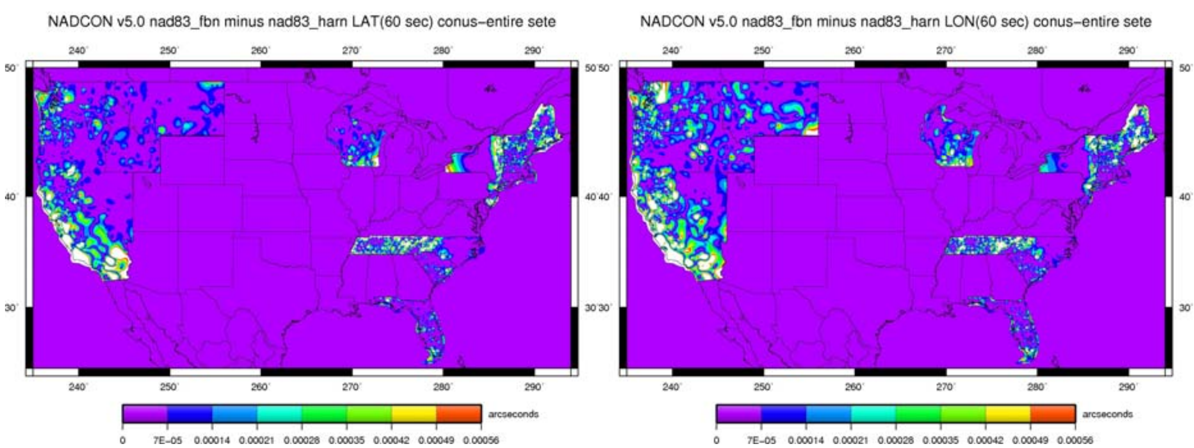

Figure 6-21: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(HARN)/NAD 83(FBN)/CONUS.

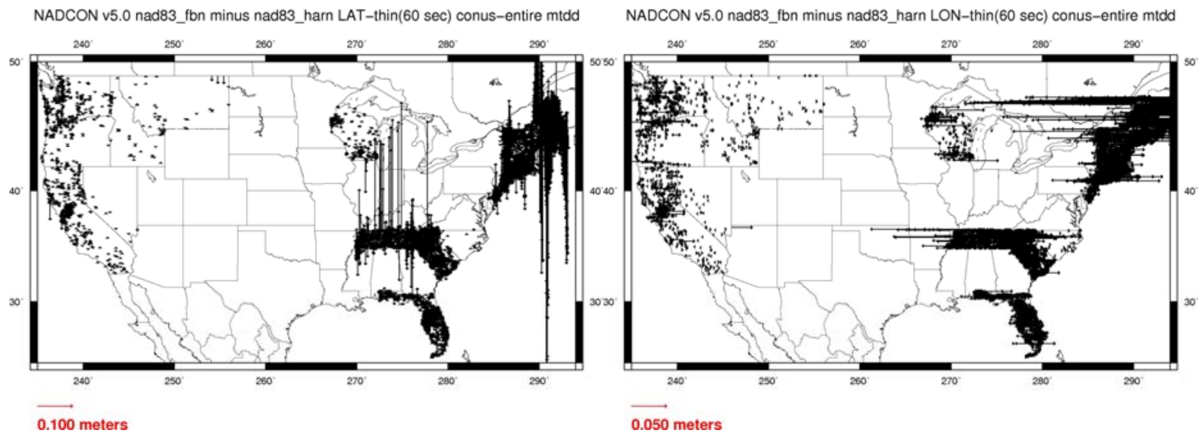

Figure 6-22: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 83(HARN)/NAD 83(FBN)/CONUS.

6.1.4.2 Vertical

The vertical transformation is also small in magnitude, with an RMS of 8.1 cm, a main magnitude histogram peak of 2 cm, and a secondary histogram peak of 20 cm. Again, the field has strong local variability, and the masking operation required accepting a 1' grid size.

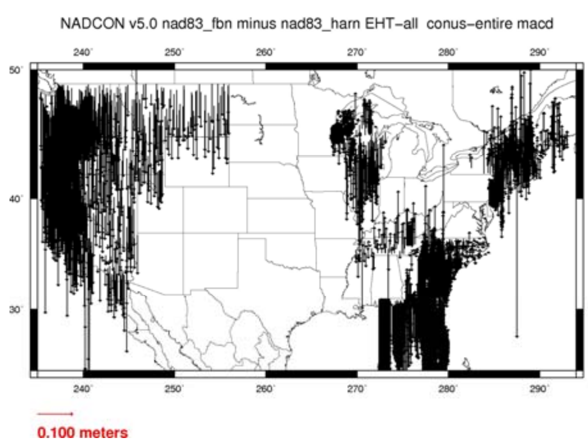

Figure 6-23: All vertical vectors for NAD 83(HARN)/NAD 83(FBN)/CONUS.

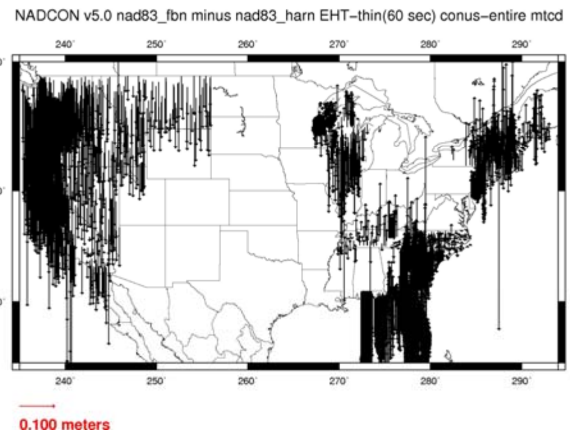

Figure 6-24: Thinned vertical vectors after applying 1' grid spacing for NAD 83(HARN)/NAD 83(FBN)/CONUS.

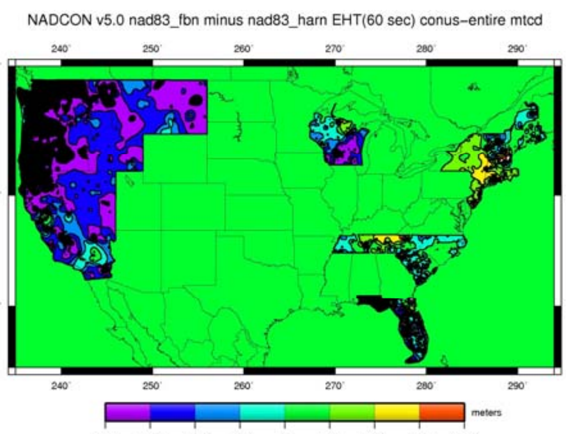

Figure 6-25: Vertical transformation, in meters for NAD 83(HARN)/NAD 83(FBN)/CONUS.

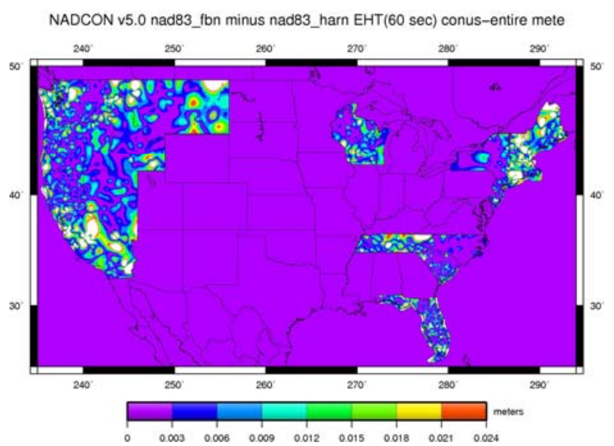

Figure 6-26: Errors for vertical transformation, in meters for NAD 83(HARN)/NAD 83(FBN)/CONUS.

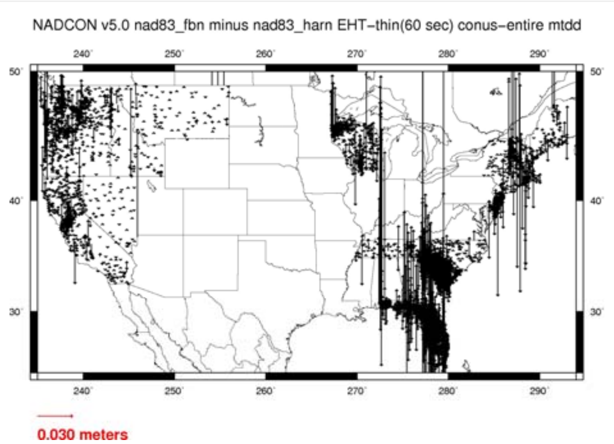

Figure 6-27: Thinned vector residuals (coordinate differences, minus the transformation grid), in meters for NAD 83(HARN)/NAD 83(FBN)/CONUS.

6.1.5 CONUS / NAD 83(FBN) / NAD 83(NSRS2007) / 3-D

Recall from Sections 1 and 4.3.1 that in 29 states and the District of Columbia, the FBN adjustment did not significantly (within a few cm) differ from the existing HARN adjustment, and therefore no separate FBN realization was adopted in those states. For those 30 areas, there can be no defined transformation from NAD 83(HARN) to NAD 83(FBN), nor can there be a transformation from NAD 83(FBN) to NAD 83(NSRS2007). Both transformation require an NAD 83(FBN) to exist in the state. And yet, there is data in all 48 states and DC for the FBN to NSRS2007 transformation. Let's examine why.

Since NADCON 5.0 works in regional grids only, not in state-by-state grids, a transformation from NAD 83(HARN) to NAD 83(NSRS2007) in a non-FBN state required a two-step transformation. The first step uses NAD 83(HARN) to NAD 83(FBN) grids. Recall from the previous section that such a transformation is *forced to be zero in non-FBN states*, whereas in the FBN states an actual transformation into the FBN occurs. The next step is to use grids for the NAD 83(FBN) to NAD 83(NSRS2007) transformation. In the FBN states, the data which goes into that grid are actually coordinate pairs for NAD 83(FBN) and NAD 83(NSRS2007). But in the non-FBN states the data used are actually *coordinate pairs for NAD 83(HARN) and NAD 83(NSRS2007)*. This had to be the case since the non-FBN states (after the HARN to FBN transformation) were *still on the HARN*! As such, to take the next step meant that a full transformation from HARN to NSRS2007 needed to be done in those non-FBN states.

This approach allows us to properly daisy-chain NADCON 5.0 transformations when moving across multiple datums for any state in CONUS. For example, there is no FBN for Ohio, so the NAD 83(HARN) to NAD 83(FBN) transformation from the previous section is defined as zero; requesting a HARN to FBN transformation for points in Ohio will yield an error as will requesting an FBN to NSRS2007 transformation. However, requesting a transformation from HARN to NAD 83(2007) will sum successive grids NAD 83(HARN)/NAD 83(FBN) (all zeroes in Ohio) and NAD 83(FBN)/NAD 83 (NSRS2007) (with non-zero values).

Other approaches could've been taken, but the elegance of putting all of the HARN to NSRS2007 transformation into the second step supported the general feel that "the HARN and the FBN are the same in a non-FBN state". While not exactly true (truth would be "no FBN exists"), it is not entirely false either.

6.1.5.1 Horizontal

The horizontal transformation is very small, with a 2 cm median value. However, there are parts of the country with greater than 10 cm transformation size, and these areas required a 1' grid to adequately capture the local signal.

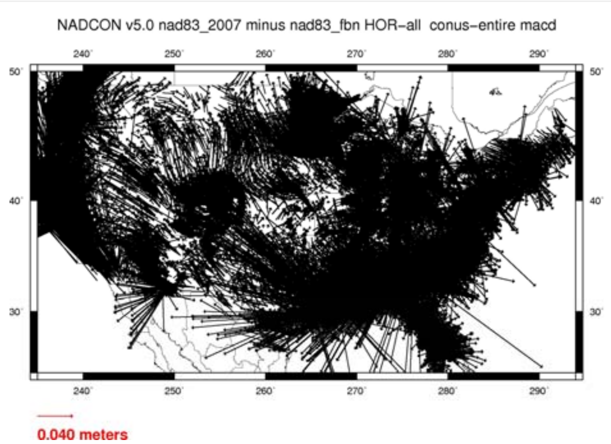

Figure 6-28: All horizontal vectors for NAD 83(FBN)/NAD 83(NSRS2007)/CONUS.

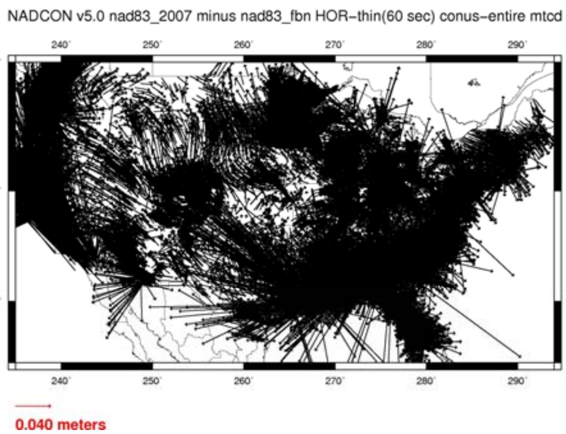

Figure 6-29: Thinned horizontal vectors after applying 1’ grid spacing for NAD 83(FBN)/NAD 83(NSRS2007)/CONUS.

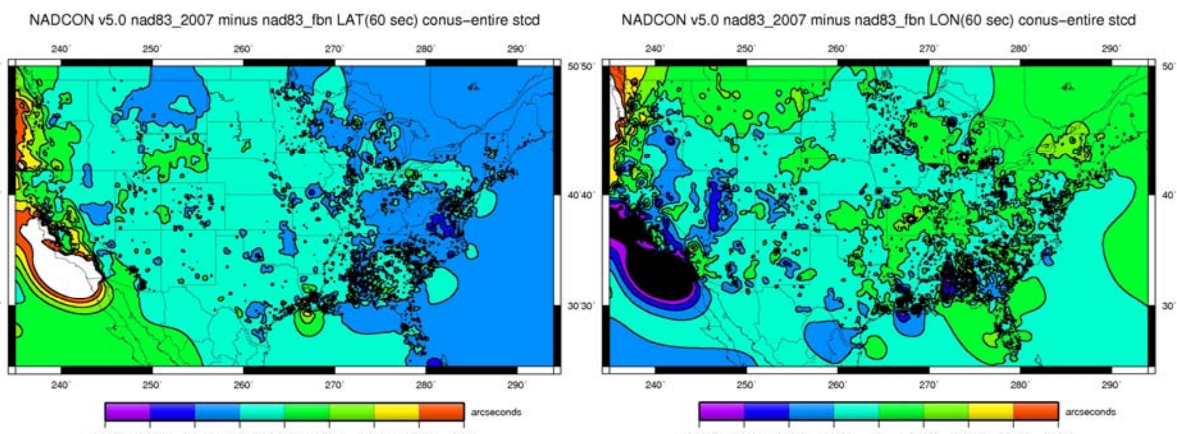

Figure 6-30: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(FBN)/NAD 83(NSRS2007)/CONUS.

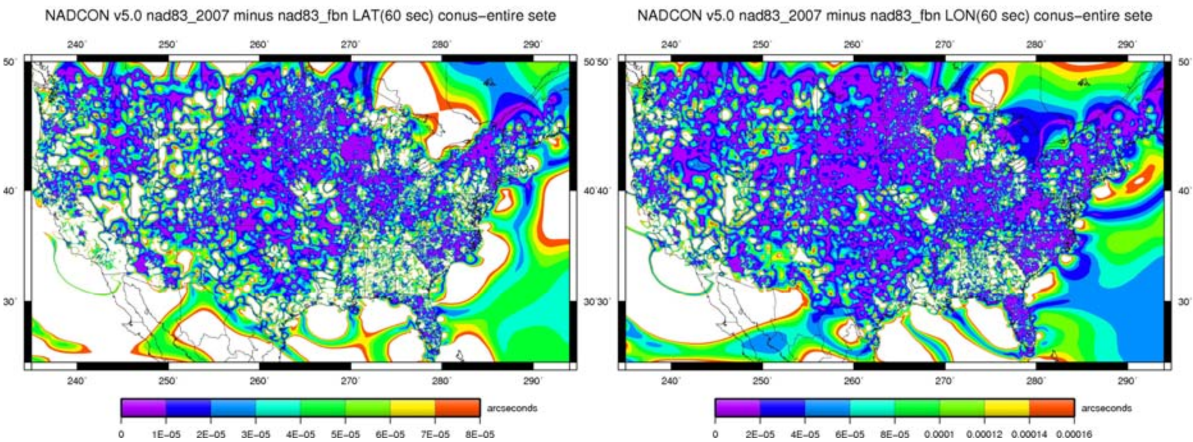

Figure 6-31: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(FBN)/NAD 83(NSRS2007)/CONUS.

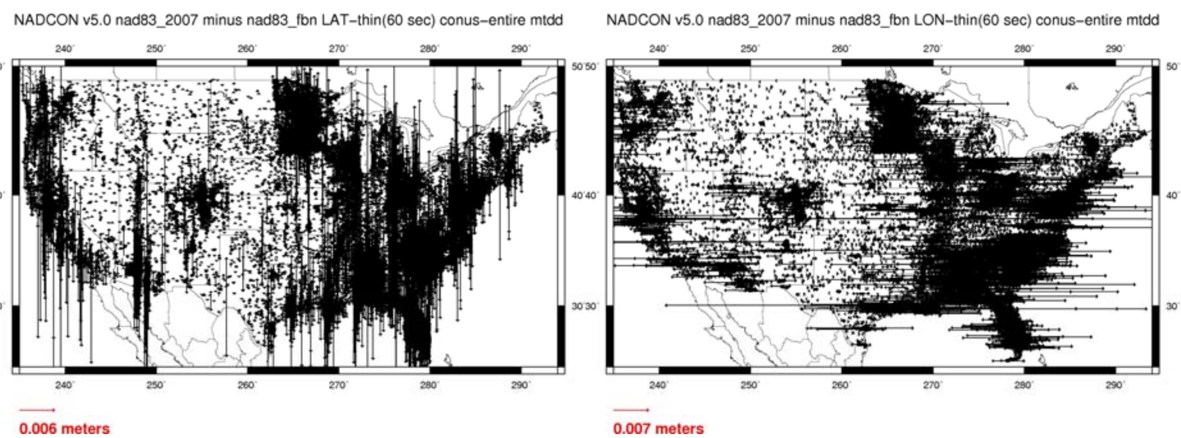

Figure 6-32: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 83(FBN)/NAD 83(NSRS2007)/CONUS.

6.1.5.2 Vertical

The vertical field does not contain any obvious patterns of size, with zero mean and a slight histogram tail towards negative or down values; the population median is 6 mm. The field is highly chaotic, with no systematic trends or even discernible local signals. Gridding at 1' results in an error grid with more near-zero values (Figure 6-36), because extremely localized 'signals' are represented by the grid.

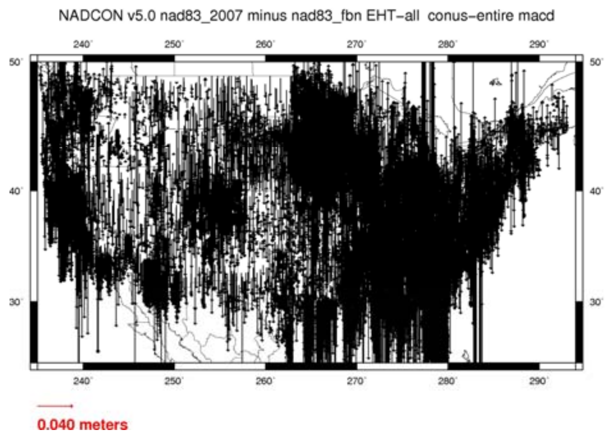

Figure 6-33: All vertical vectors for NAD 83(FBN)/NAD 83(NSRS2007)/CONUS.

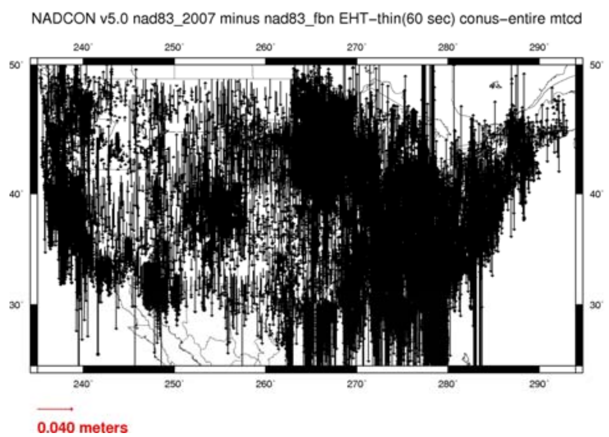

Figure 6-34: Thinned vertical vectors after applying 1’ grid spacing for NAD 83(FBN)/NAD 83(NSRS2007)/CONUS.

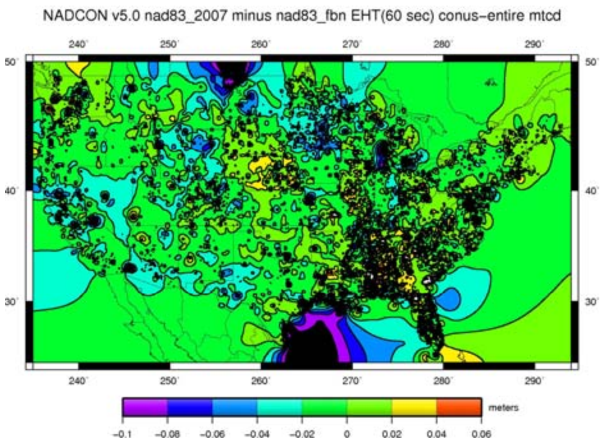

Figure 6-35: Vertical transformation, in meters for NAD 83(FBN)/NAD 83(NSRS2007)/CONUS.

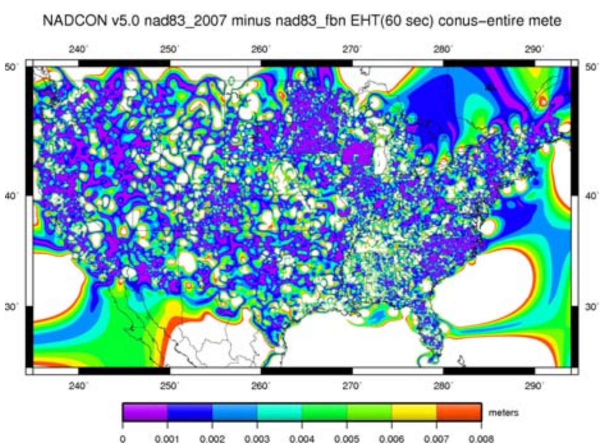

Figure 6-36: Errors for vertical transformation, in meters for NAD 83(FBN)/NAD 83(NSRS2007)/CONUS.

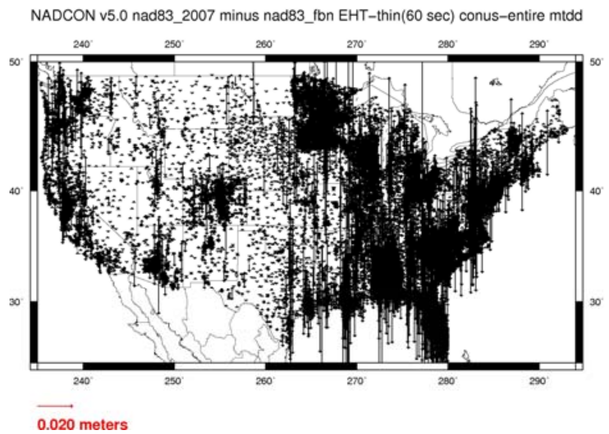

Figure 6-37: Thinned vector residuals (coordinate differences, minus the transformation grid), in meters for NAD 83(FBN)/NAD 83(NSRS2007)/CONUS.

6.1.6 CONUS / NAD 83(NSRS2007) / NAD 83(2011) / 3-D

6.1.6.1 Horizontal

The horizontal transformation has a 2 cm mean, which is completely driven by a residual plate rotation signal. The nationwide adjustment is smooth overall at all potential grid sizes. However, we noted that there are areas of the country where the horizontal transformation is much larger than overall plate rotation values, primarily the western US coast and southwest Louisiana. Therefore, when choosing a grid, we ignored the smoothly-varying central US and concentrated on the areas where grid size would really affect the transformation. The areas with 10-20 cm horizontal vectors required 1’ grid to capture the variation, resulting in residual vectors in these areas which are equivalent to the transformation size in the systematic areas of the country.

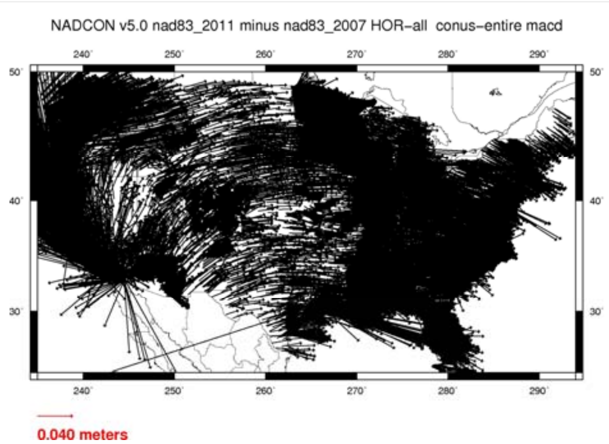

Figure 6-38: All horizontal vectors for NAD 83(NSRS2007)/NAD 83(2011)/CONUS.

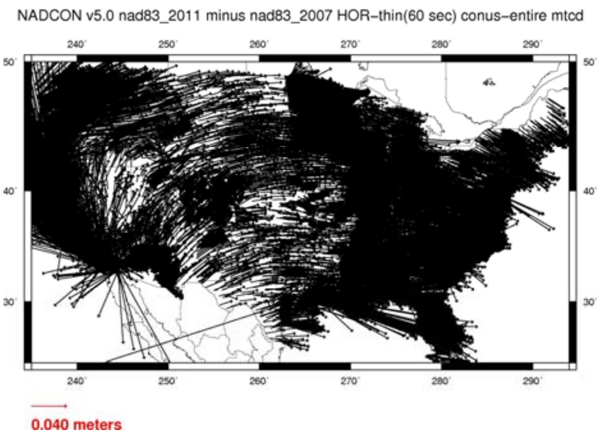

Figure 6-39: Thinned horizontal vectors after applying 1’ grid spacing for NAD 83(NSRS2007)/NAD 83(2011)/CONUS.

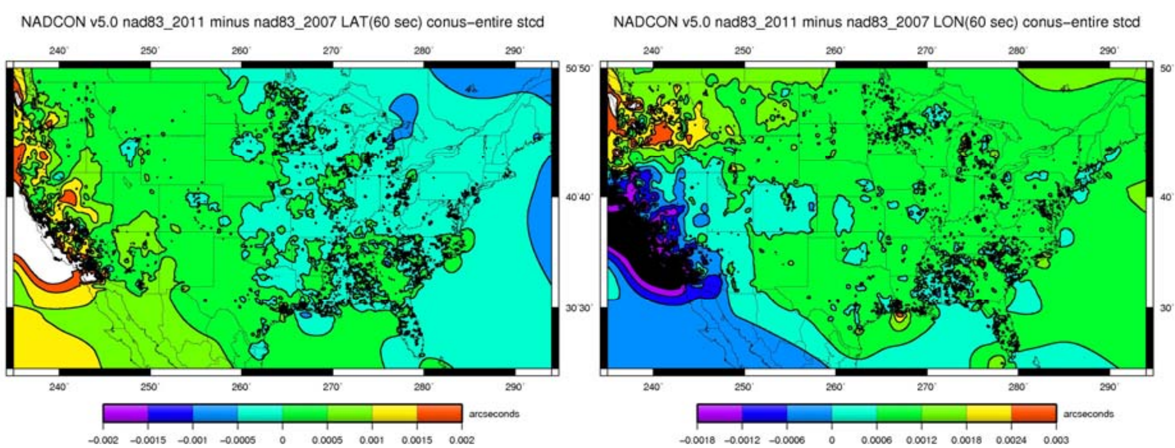

Figure 6-40: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(NSRS2007)/NAD 83(2011)/CONUS.

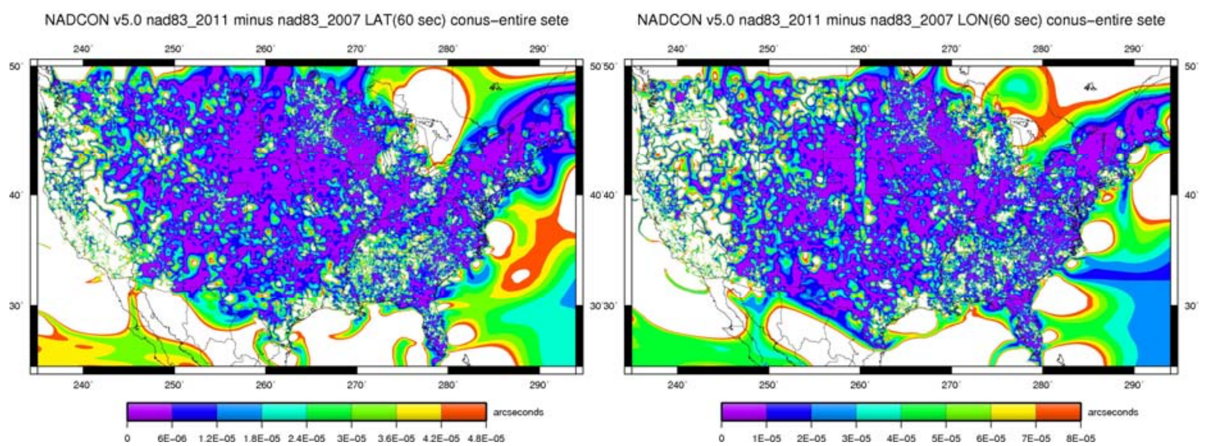

Figure 6-41: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(NSRS2007)/NAD 83(2011)/CONUS.

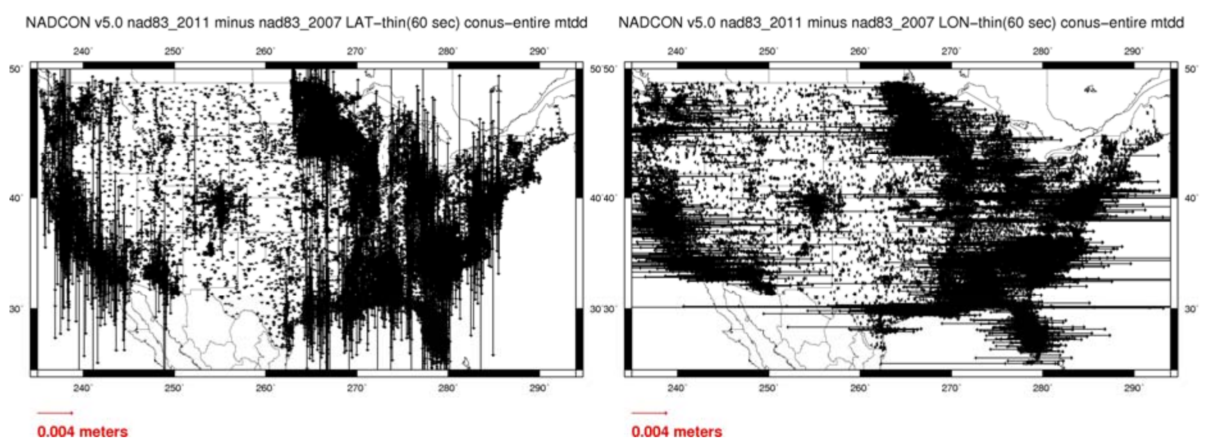

Figure 6-42: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 83(NSRS2007)/NAD 83(2011)/CONUS.

6.1.6.2 Vertical

The mean value for the vertical transformation is -2 cm, with the majority of points in the -5 cm to +2 cm range. We noted that there are regions where vector size is much larger than the median/mean values. A fine 1’ grid drives the residuals for these large-magnitude regions down to the same level as the more representative regions of the country. Therefore we chose the 1’ grid to capture local variability.

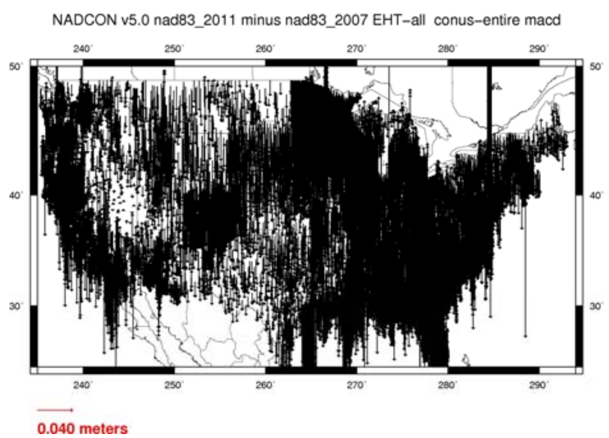

Figure 6-43: All vertical vectors for NAD 83(NSRS2007)/NAD 83(2011)/CONUS.

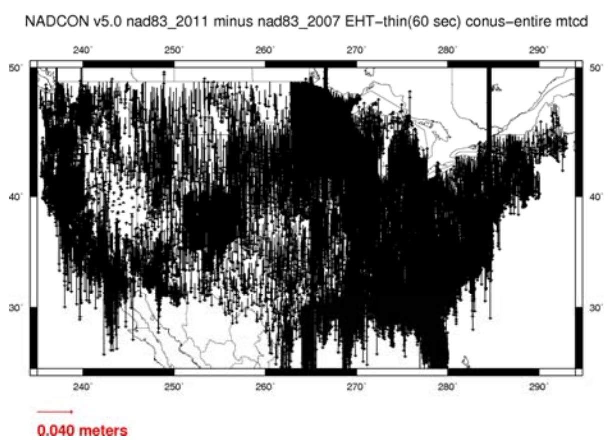

Figure 6-44: Thinned vertical vectors after applying 1' grid spacing for NAD 83(NSRS2007)/NAD 83(2011)/CONUS.

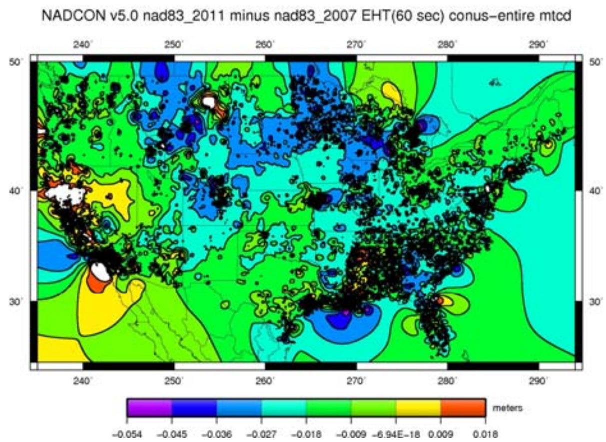

Figure 6-45: Vertical transformation, in meters for NAD 83(NSRS2007)/NAD 83(2011)/CONUS.

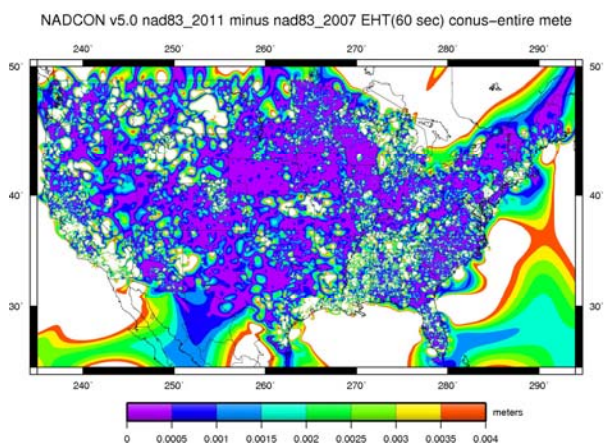

Figure 6-46: Errors for vertical transformation, in meters for NAD 83(NSRS2007)/NAD 83(2011)/CONUS.

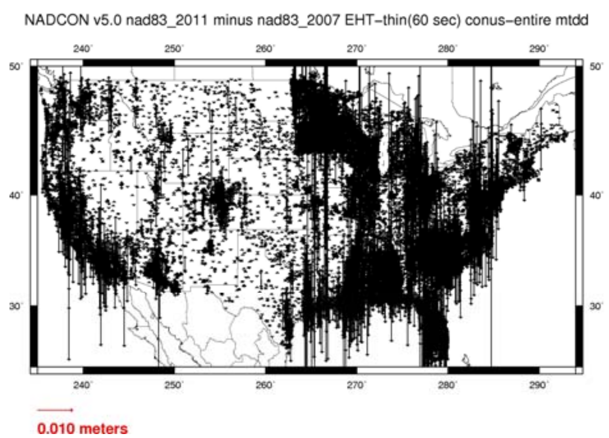

Figure 6-47: Thinned vector residuals (coordinate differences, minus the transformation grid), in meters for NAD 83(NSRS2007)/NAD 83(2011)/CONUS.

6.2 Alaska (alaska) and Saint islands (stpaul, stgeorge, stlawrence, stmatthew)

Although this section is titled "Alaska", it actually deals with a total of 5 regions. The largest of these five regions, given the name "alaska" in the NADCON 5.0 build, has a bounding box of 50-73 latitude, 172-232 longitude and the entire state of Alaska is contained therein. But there are four smaller regions of interest here, one for each of the primary "Saint" Islands offshore of mainland Alaska: St. Paul, St. George, St. Lawrence and St. Matthew (called "stpaul", "stgeorge", "stlawrence" and "stmatthew" during the build). These four regions encompass the four island groups of St. Paul, St. George, St. Lawrence and St. Matthew with bounding boxes of 56.9-57.4 latitude, 189.3-190.4 longitude for stpaul; 56.3-56.8 latitude, 190.0-190.8 longitude for stgeorge; 62.7-64.0 latitude and 187.5-192.0 longitude for stlawrence and 60.0-61.0 latitude, 186.0-188.5 longitude for stmatthew.

These four Saint islands are too far from mainland Alaska for line-of-sight surveying to connect them to the mainland. As such, until the advent of space geodesy, these islands had stand-alone astronomically determined horizontal datums. The St. Paul and St. George islands were visited in 1897 by C&GS and datums established then. Then in 1952, C&GS re-visited these two as well as visiting St. Lawrence and St. Matthew, establishing four separate island-specific astronomic datums at that time. In between these dates, the NAD 27 datum had been expanded into mainland Alaska, but because that datum was entirely a line-of-sight datum, it could not be expanded to any of the Saint islands.

The creation of NAD 83(1986) included some early space geodetic techniques, and the islands of St. Paul, St. George and St. Lawrence were again surveyed as part of that project and they were included in the general adjustment which created NAD 83(1986). However, St. Matthew was not surveyed as part of NAD 83(1986).

Given this history, transformations on the islands of St. Paul and St. George can be traced from their 1897 datums, onwards to their 1952 datums and then into NAD 83(1986), and are built only in the small regions called “stpaul” and “stgeorge”. On St. Lawrence, one transformation goes from its 1952 datum to NAD 83(1986), and was only built in the small region “stlawrence”. Mainland Alaska transformations begin with NAD 27 to NAD 83(1986), and cover the entire region of “alaska”, but minus the regions of stpaul, stgeorge, stlawrence and stmatthew. After NAD 83(1986), however, all transformations in Alaska work in the entire region of “alaska” without need to exclude the Saint regions. These transformation connections are depicted in Figure 6-48.

Unfortunately, since St. Matthew was not re-surveyed after 1952 there are no possible transformations to be built on that island. The St. Matthew 1952 (SM1952) datum remains the most recent datum established on that island. See Figure 6-48 below.

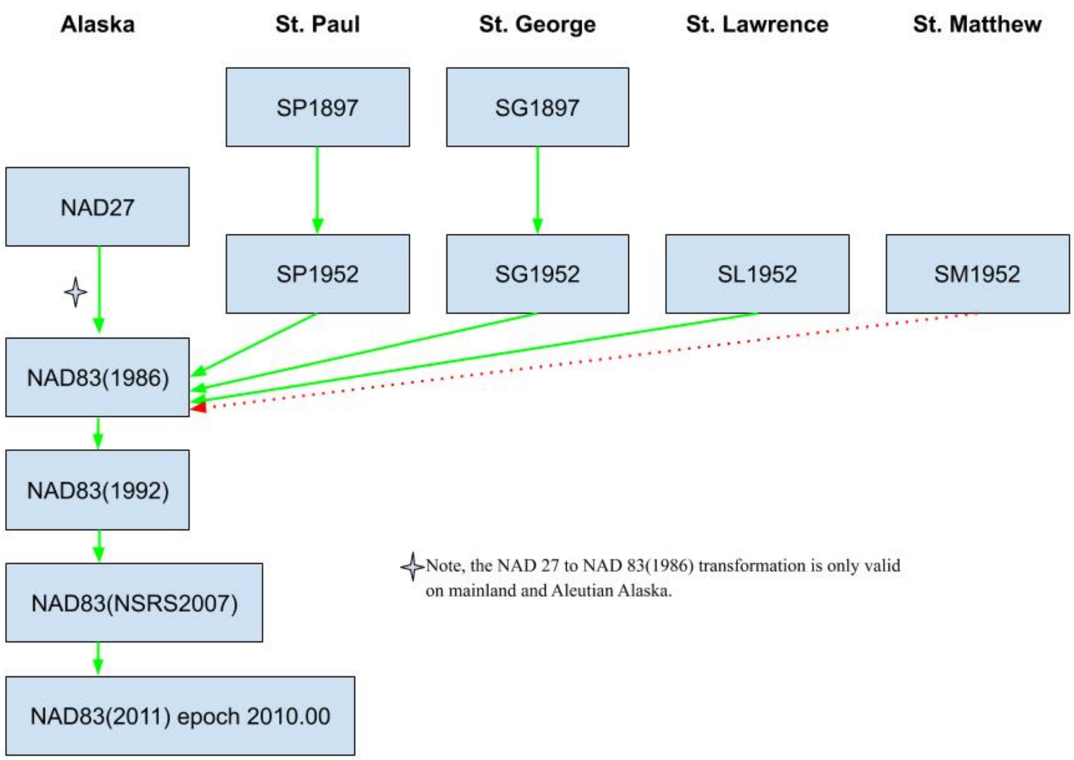

Figure 6-48: Flowchart of supported transformations in the Alaska and “Saint” regions.

To facilitate analysis over such a huge area, the digital archive includes plots at a secondary level, subdividing mainland Alaska into 4 quadrants (mapflag=1), with an additional subplot level for the Aleutian Islands and each of the Saint islands (St. Paul, St. George, St. Matthew, and St. Lawrence), using mapflag=2. See Table 5-2 for a discussion of the mapflag parameter.

Combining all transformations discussed here, there are 11 separate transformations, only two of which are ellipsoidal height (Table 6-2 through Table 6-5). We should note that the areal extent of the individual Saint island's gridded areas is far smaller than any other region in NADCON 5.0. Grid analysis was therefore conducted only up to 10'. Furthermore, the authors assumed that 1' grids were likely to be the best choice for the Saint island regions, and were inclined to deviate from this default choice only if proof existed that is was the wrong size. Grid selection for the "alaska" region (Alaska mainland plus Aleutian Islands region) was conducted in the usual method described in Section Choosing a grid spacing4.5.

Table 6-2: NADCON 5.0 transformations for St. Paul

old datum (od)	*new datum (nd)*	*# of points*	*# outliers*	*# thinned points*	*transformation size (median)*	*final grid size selected*
SP1897	SP1952	20	0	19	182.544 m	1'
SP1952	NAD83_1986	50	1	27	156.332 m	1'

Table 6-3: NADCON 5.0 transformations for St. George

old datum (od)	*new datum (nd)*	*# of points*	*# outliers*	*# thinned points*	*transformation size (median)*	*final grid size selected*
SG1897	SG1952	27	1	16	195 m	1'
SG1952	NAD83_1986	19	1	17	189 m	1'

Table 6-4: NADCON 5.0 transformations for St. Lawrence

old datum (od)	*new datum (nd)*	*# of points*	*# outliers*	*# thinned points*	*transformation size (median)*	*final grid size selected*
SL1952	NAD83_1986	160	1	154	65.56 m	1'

Table 6-5: NADCON 5.0 transformations for Alaska

old datum (od)	*new datum (nd)*	*# of points*	*# outliers*	*# thinned points*	*transformation size (median)*	*final grid size selected*

Horizontal						
NAD27	NAD83_1986	22,916[31]	134	1288	113.065 m	30’
NAD83_1986	NAD83_1992	314[31] 374[34]	19	196	0.888 m[31] 170.621[32] 179.708[33] 170.801 m[34]	15’
NAD83_1992	NAD83_2007	671	51	417	0.071 m	7.5’
NAD83_2007	NAD83_2011	775	58	493	0.074 m	5’
Vertical						
NAD83_1992	NAD83_2007	696	24	352	0.023 m	15’
NAD83_2007	NAD83_2011	798	35	368	0.009 m	15’

6.2.1 St. Paul / SP1897 / SP1952 / Horizontal

The horizontal transformation for SP1897 to SP1952 had median 182 meters; the easternmost island, Otter Island, has a single 192 m vector whereas the remaining vectors range 180-182 m; all azimuths are nearly identical. A transformation using 1’ grid is able to adequately capture the variation on Otter Island and decimeter-level variations on St. Paul (Figure 6-51), with transformation errors of less than 1 meter in the onshore areas of the grid (Figure 6-52).

[31] Not including St. Paul, St. George nor St. Lawrence
[32] Only St. Paul
[33] Only St. George
[34] All of Alaska, including St. Paul and St. George (none on St. Lawrence)

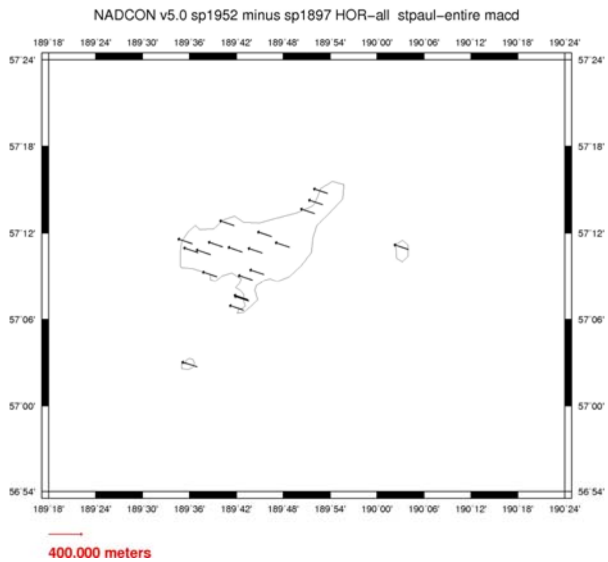

Figure 6-49: All horizontal vectors for SP1897/SP1952/St. Paul.

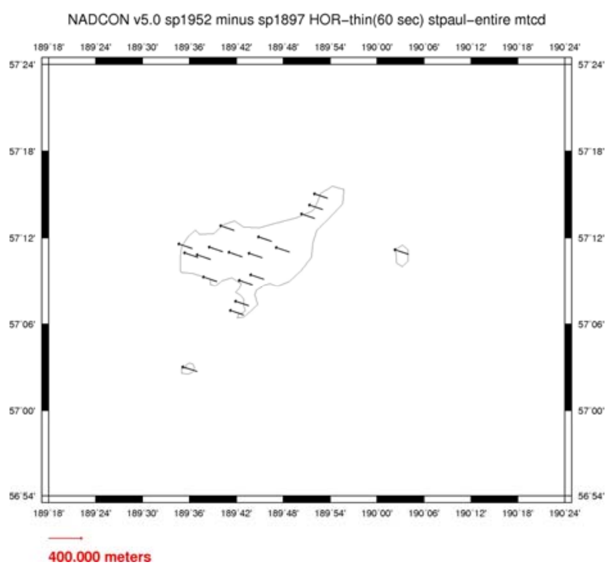

Figure 6-50: Thinned horizontal vectors after applying 1' grid spacing for SP1897/SP1952/St. Paul.

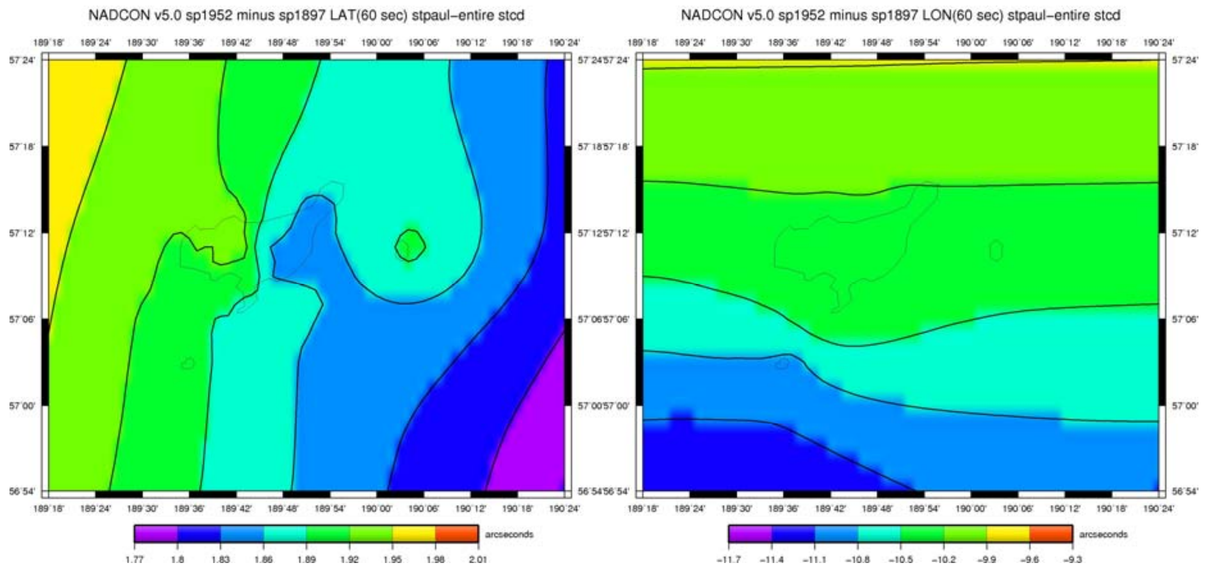

Figure 6-51: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for SP1897/SP1952/St. Paul.

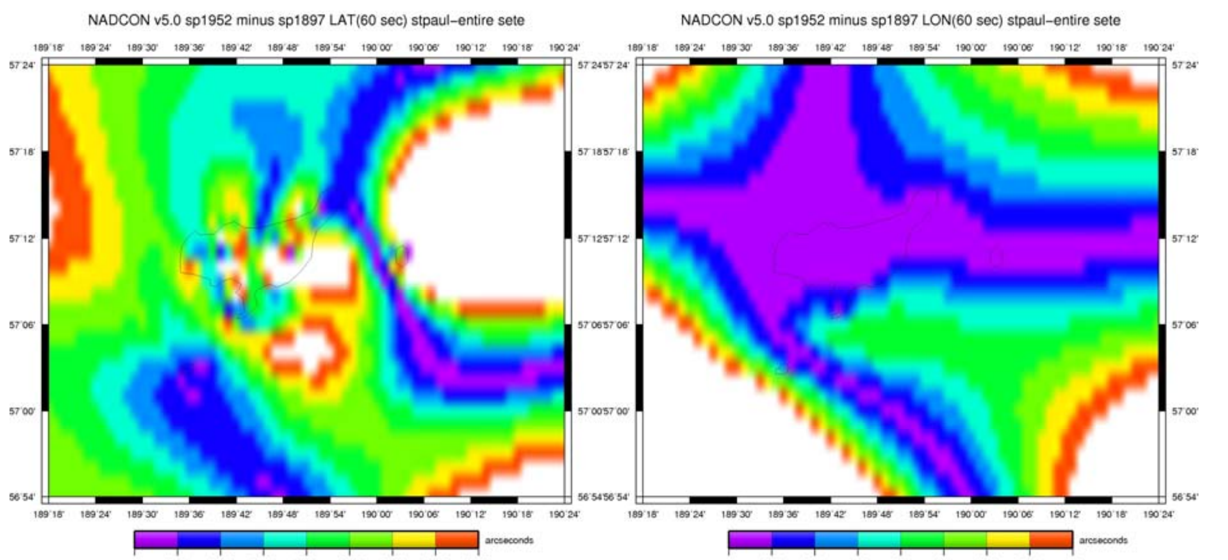

Figure 6-52: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for SP1897/SP1952/St. Paul.

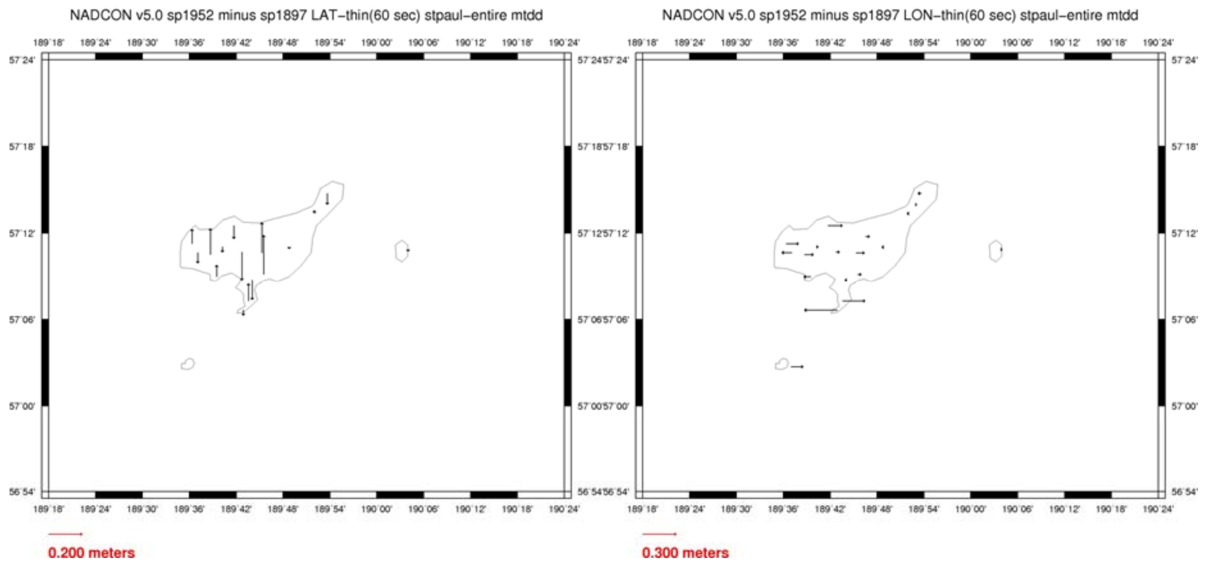

Figure 6-53: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for SP1897/SP1952/St. Paul.

6.2.2 St. Paul / SP1952 / NAD 83(1986) / Horizontal

The horizontal transformation for SP1952 to NAD 83(1986) has vectors ranging 154-159 m in magnitude with highly consistent azimuths. Analysis showed that all grids between 1' and 10' resulted in maximum residuals of 1.5-2.0 meters, with the lowest residual accomplished with a 1' grid. Therefore, we selected 1' grid size to capture the decimeter-level variations in the field.

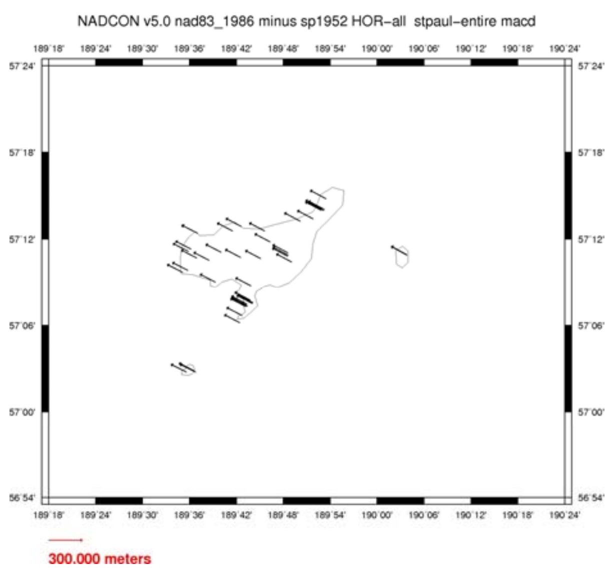

Figure 6-54: All horizontal vectors for SP1952/NAD 83(1986)/St. Paul.

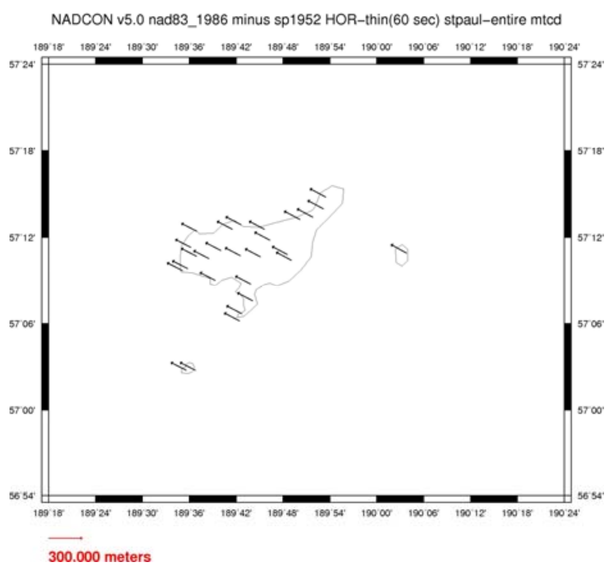

Figure 6-55: Thinned horizontal vectors after applying 1’ grid spacing for SP1952/NAD 83(1986)/St. Paul.

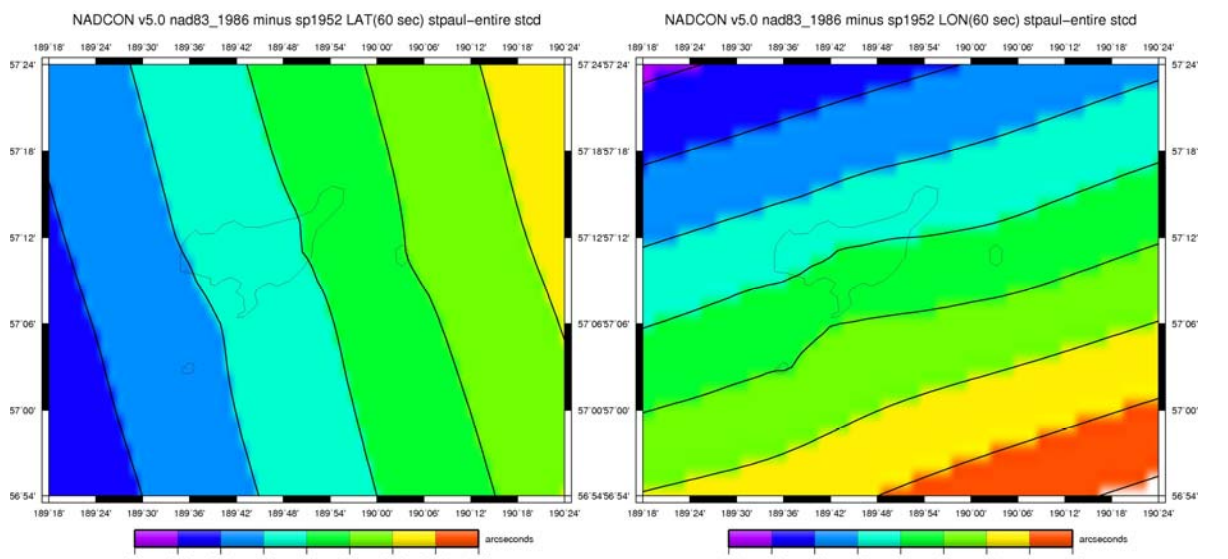

Figure 6-56: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for SP1952/NAD 83(1986)/St. Paul.

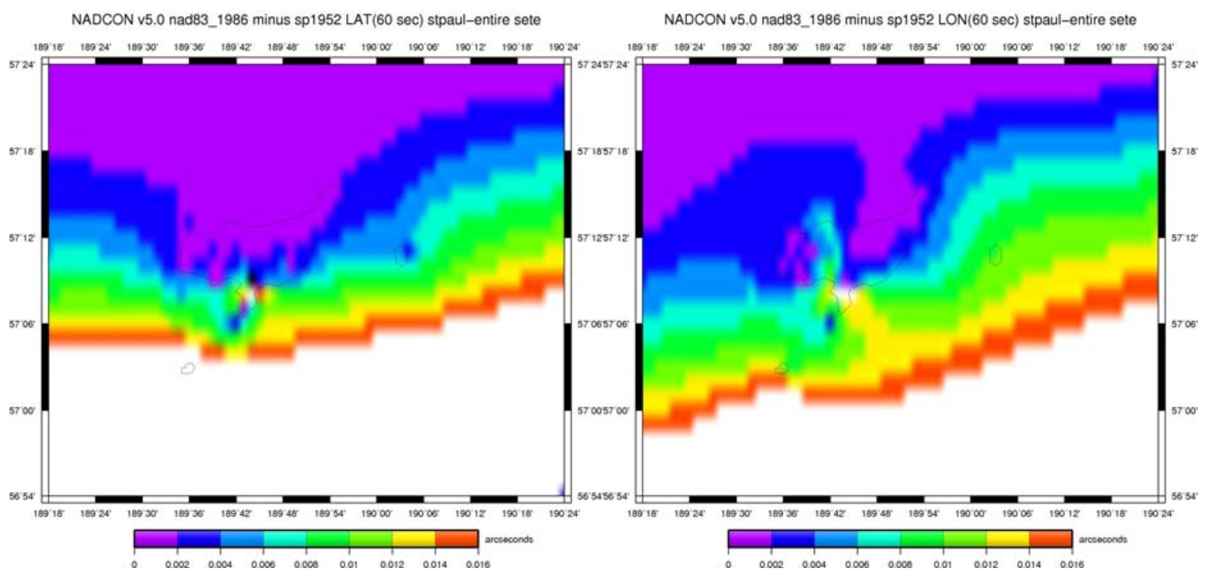

Figure 6-57: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for SP1952/NAD 83(1986)/St. Paul.

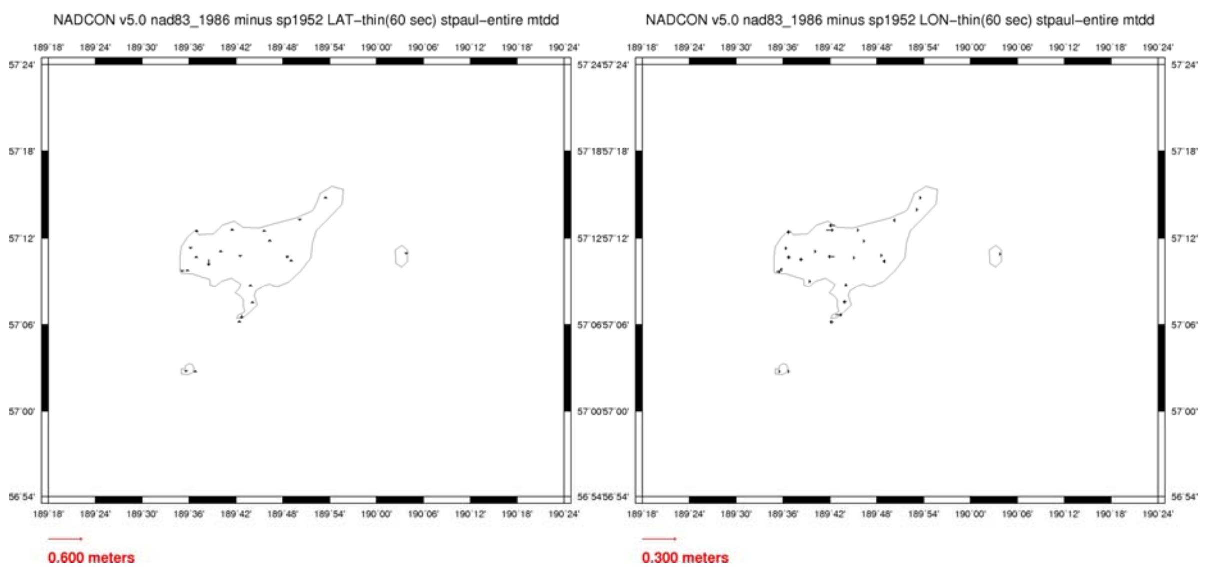

Figure 6-58: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for SP1952/NAD 83(1986)/St. Paul.

6.3 St. George / SG1897 / SG1952 / Horizontal

As with St. Paul, this transformation is very large (195.5 m median; 0.27 m standard deviation) and azimuthally consistent (spread of only 0.6 degrees). The 1' grid yields the smallest residuals: median 2 cm, maximum 16 cm. The 1' grid is also able to pick up fine detail in the center of the island (Figure 6-61) which is lost when using coarser grids.

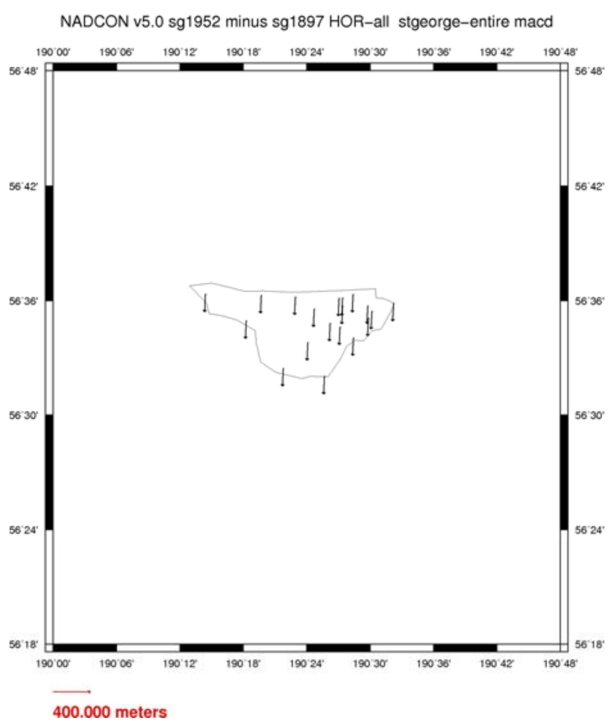

Figure 6-59: All horizontal vectors for SG1897/SG1952/St. George.

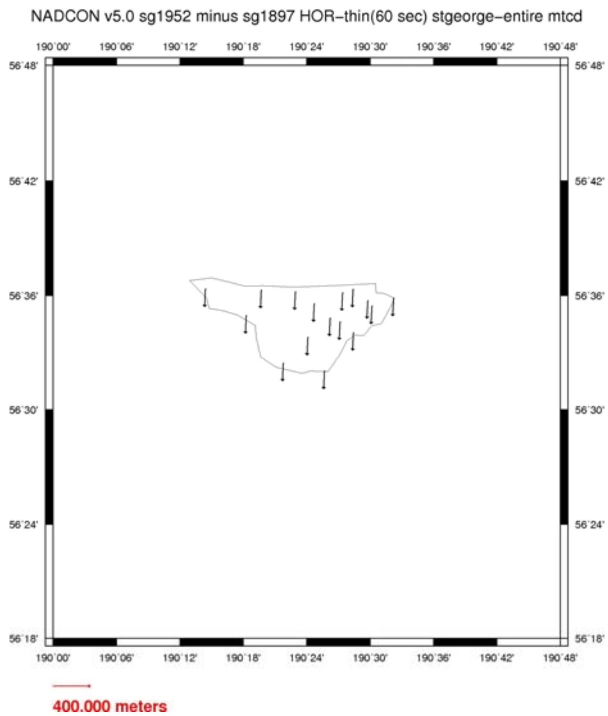

Figure 6-60: Thinned horizontal vectors after applying 1’ grid spacing for SG1897/SG1952/St. George.

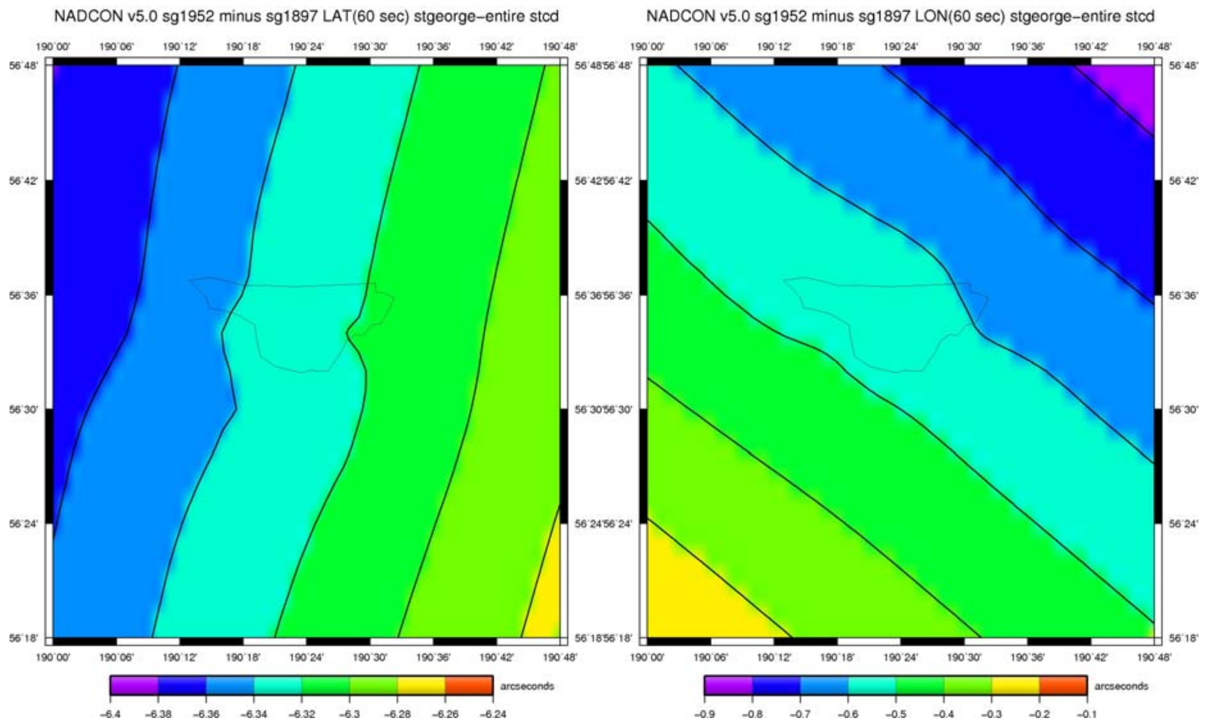

Figure 6-61: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for SG1897/SG1952/St. George.

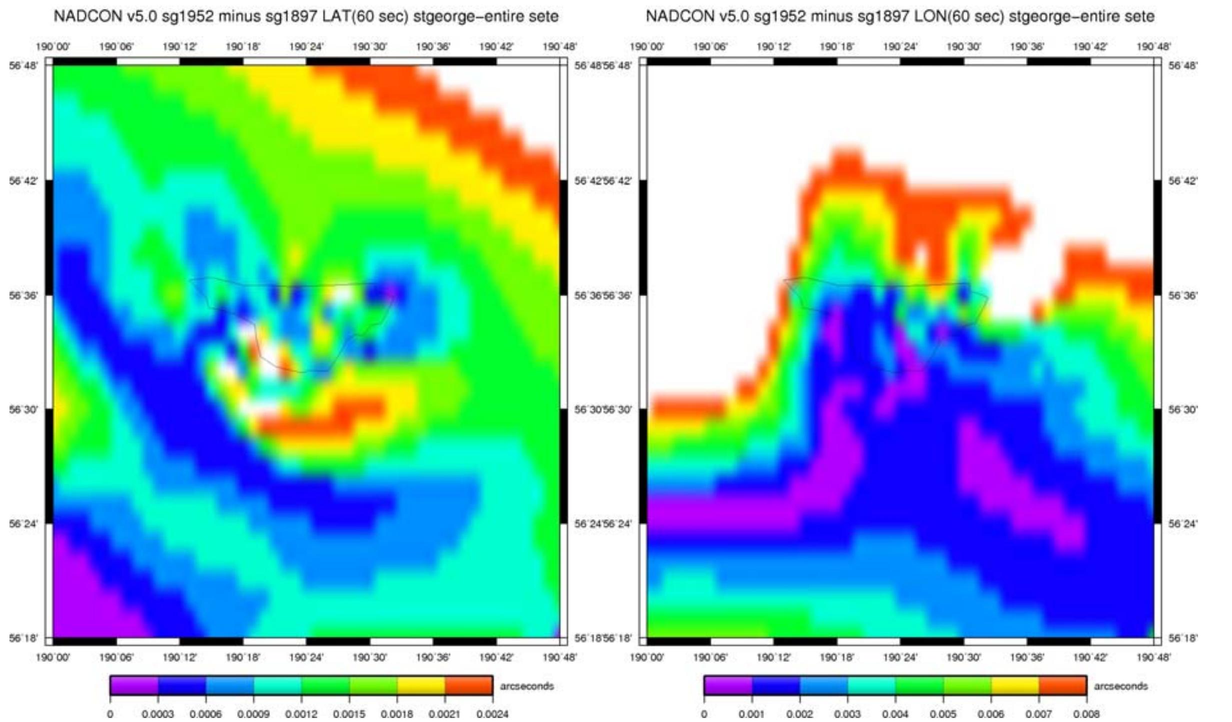

Figure 6-62:Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for SG1897/SG1952/St. George.

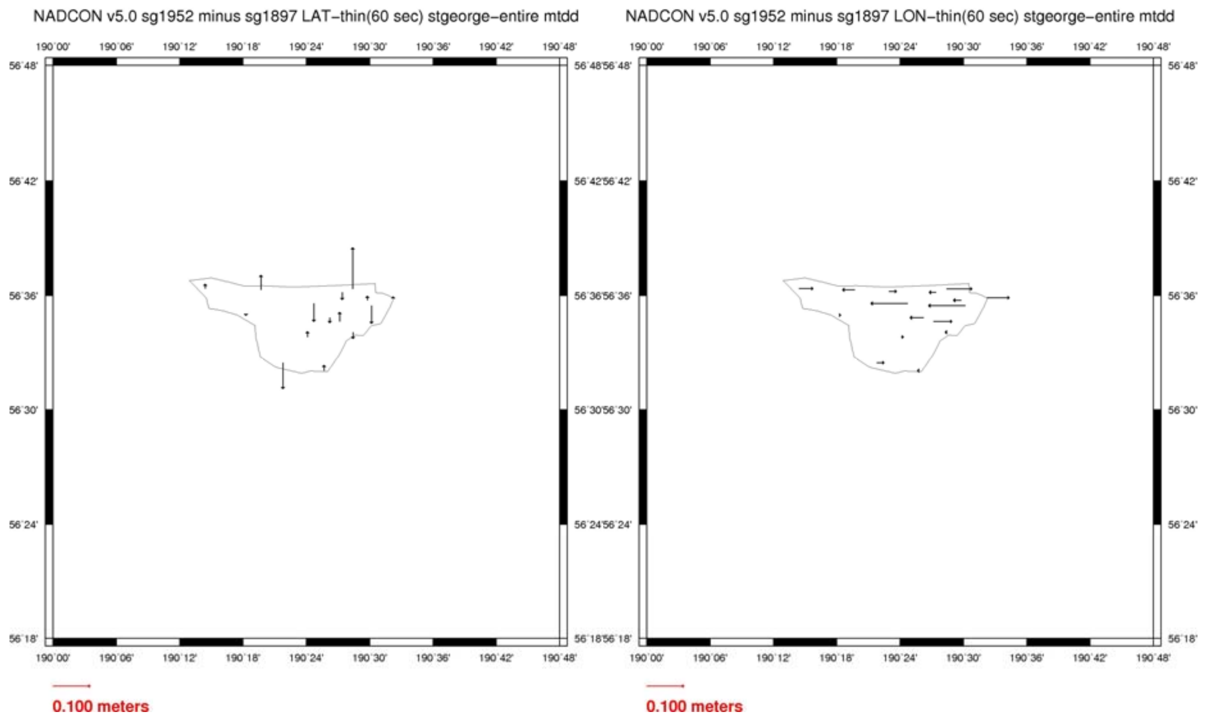

Figure 6-63: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for SG1897/SG1952/St. George.

6.3.1 St. George / SG1952 / NAD 83(1986) / Horizontal

As with the previous transformation on St. George, the SG1952 to NAD 83(1986) transformation is very large (189.0 m median; 1.0 m standard deviation) and azimuthally consistent (spread of 2.2 degrees). The 1’ grid was selected as it yields the smallest residuals: median 2 cm, maximum 13 cm.

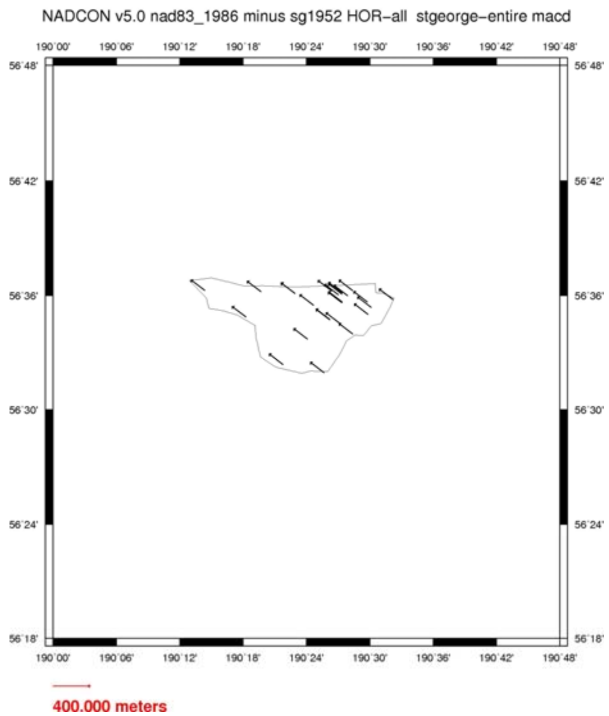

Figure 6-64: All horizontal vectors for SG1952/NAD 83(1986)/St. George.

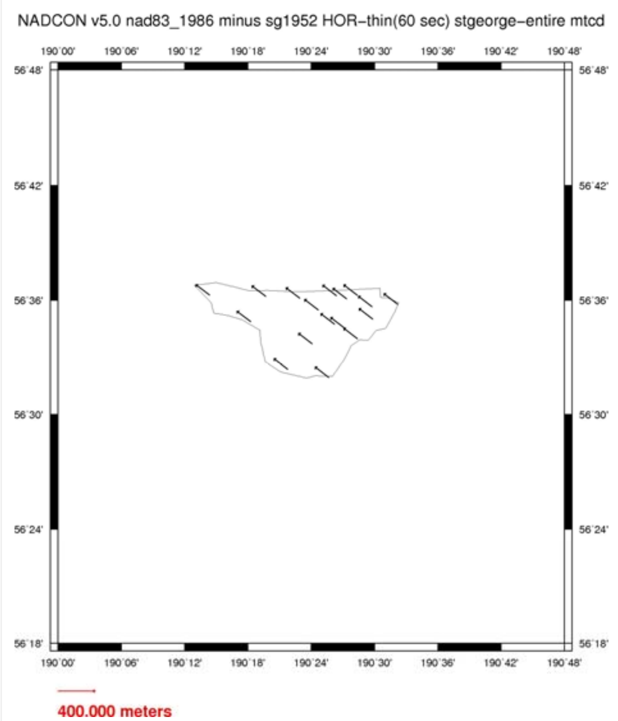

Figure 6-65: Thinned horizontal vectors after applying 1' grid spacing for SG1952/NAD 83(1986)/St. George.

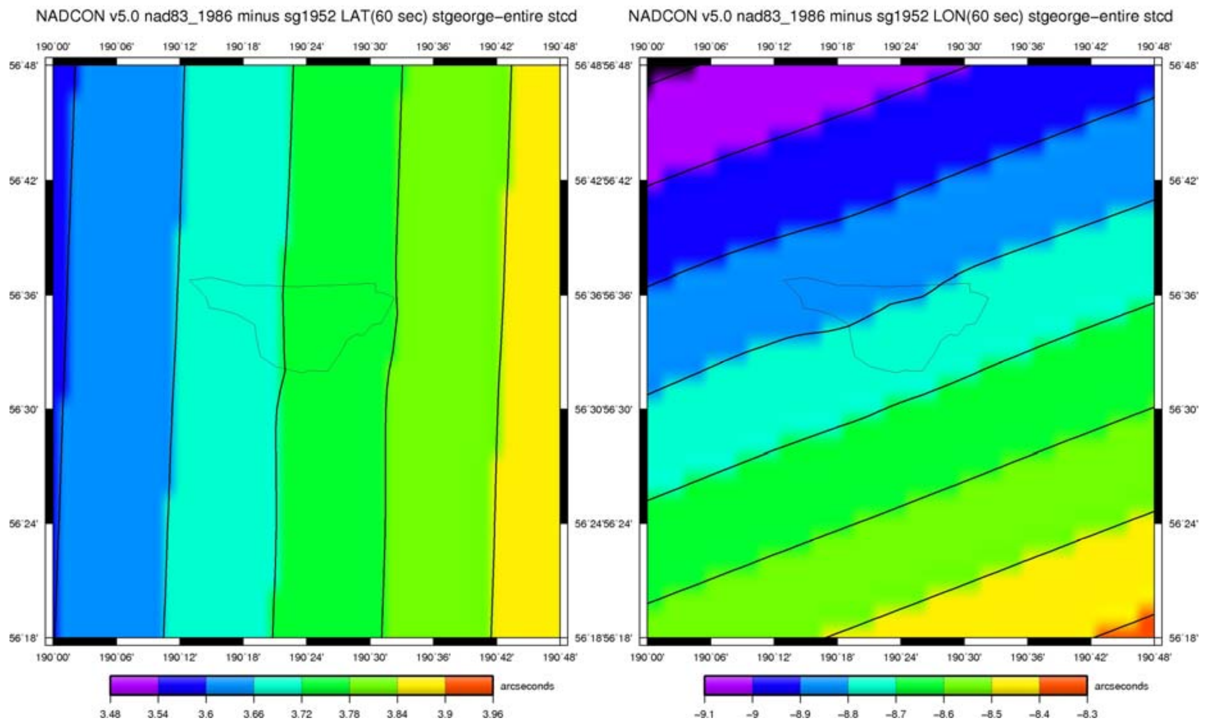

Figure 6-66: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for SG1952/NAD 83(1986)/St. George.

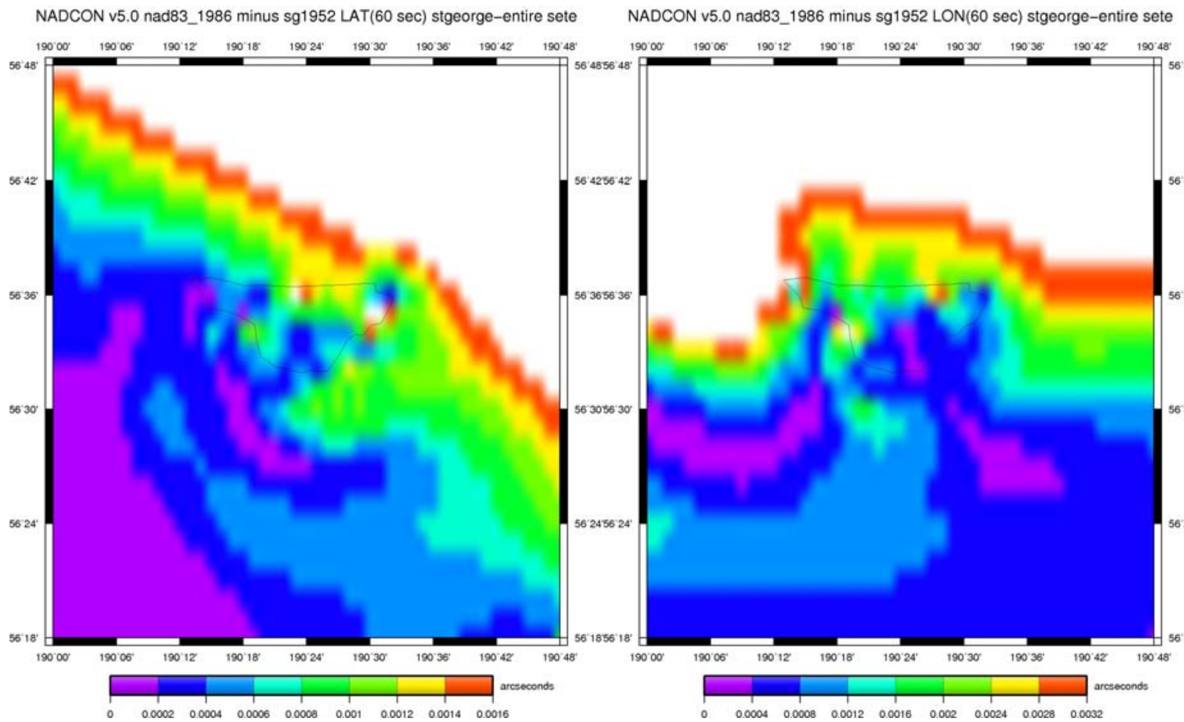

Figure 6-67: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for SG1952/NAD 83(1986)/St. George.

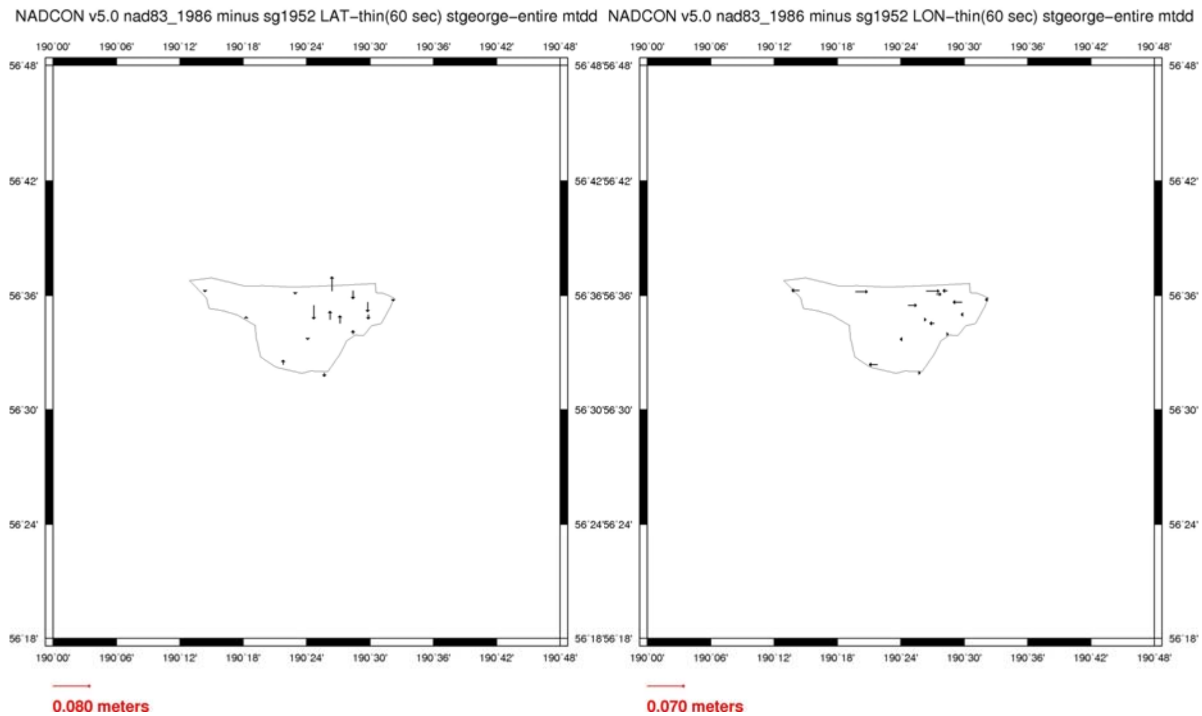

Figure 6-68: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for SG1952/NAD 83(1986)/St. George.

6.3.2 St. Lawrence / SL1952 / NAD 83(1986) / Horizontal

The SL1952 to NAD 83(1986) transformation is large (65.6 m median; 1.0 m standard deviation) and azimuthally consistent (spread of 2 degrees). The 1’ grid was selected as it yields the smallest residuals: median 2 mm (Figure 6-73) with one extremely large 17 cm vector off the northern coast of the island.

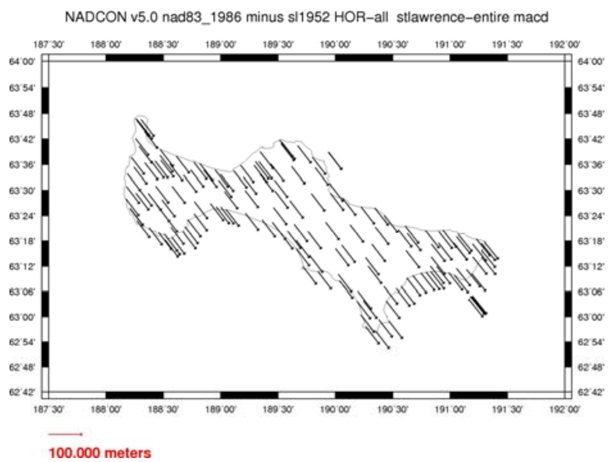

Figure 6-69: All horizontal vectors for SL1952/NAD 83(1986)/St. Lawrence.

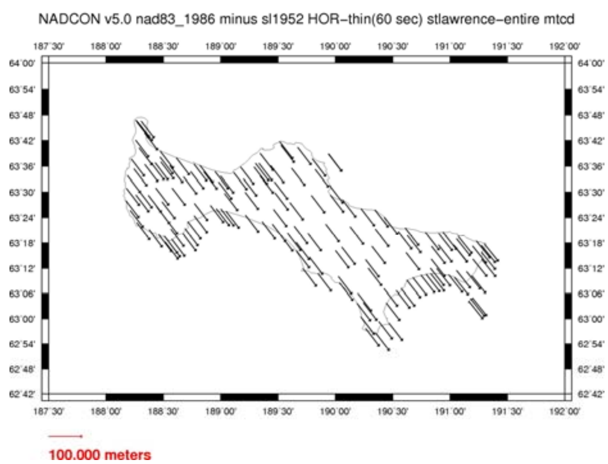

Figure 6-70: Thinned horizontal vectors after applying 1' grid spacing for SL1952/NAD 83(1986)/St. Lawrence.

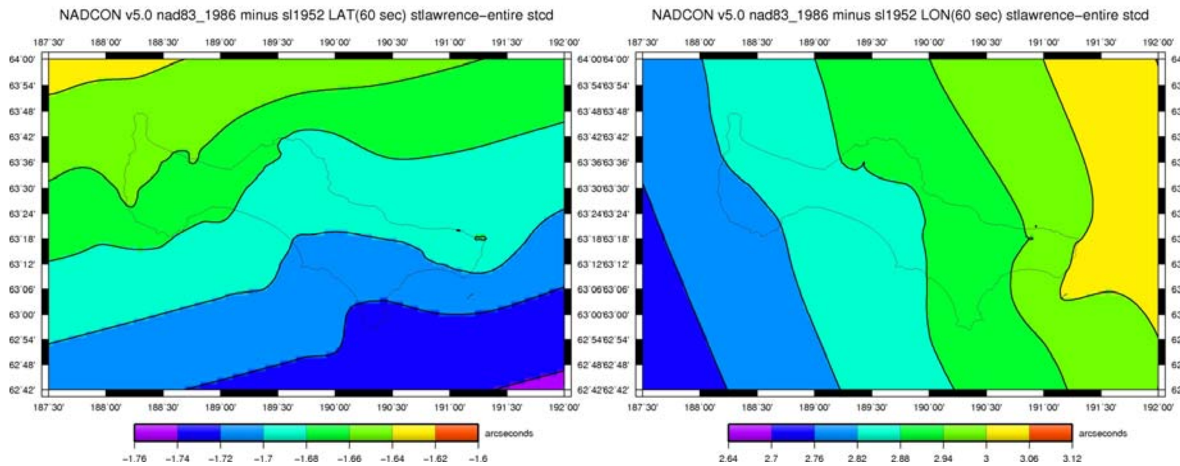

Figure 6-71: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for SL1952/NAD 83(1986)/St. Lawrence.

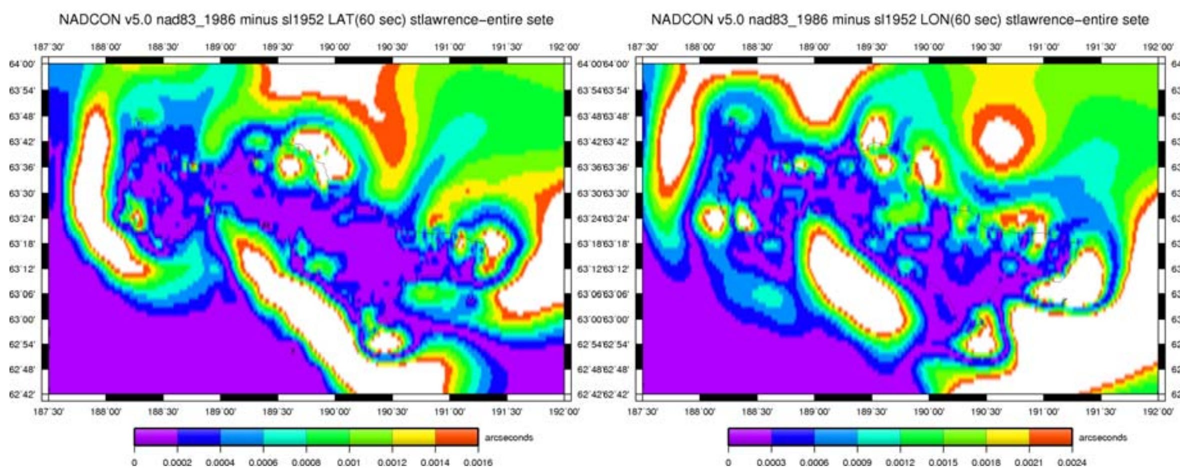

Figure 6-72: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for SL1952/NAD 83(1986)/St. Lawrence.

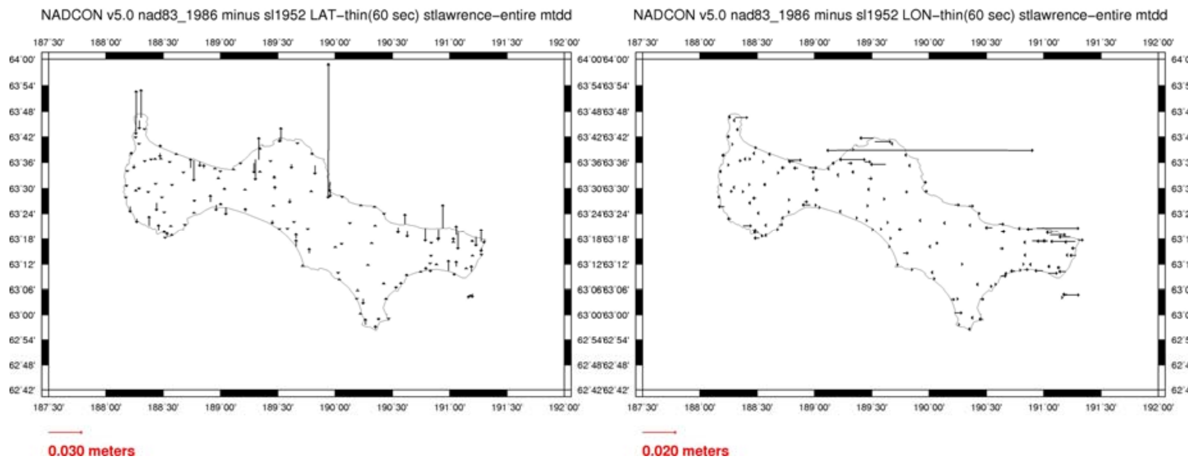

Figure 6-73: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for SL1952/NAD 83(1986)/St. Lawrence.

6.3.3 Alaska / NAD 27 / NAD 83(1986) / Horizontal

Recall that for the NAD 27 to NAD 83(1986) transformation in region "Alaska", that region should be thought of as the full "Alaska" region, minus the three smaller regions of St Paul, St. George and St. Lawrence, as NAD 27 does not exist in those small regions.[35]

The field is very large magnitude (131 meters) and very consistent in azimuth. At all possible grid spacings analyzed, the residuals were nearly identical. Therefore the authors relied upon the most basic guiding principle and selected the coarsest possible grid which adequately explains the data, 30'. This grid resulted in a huge reduction in the number of points defining the transformation, from 23,050 original points (Figure 6-74) down to 1288 thinned points (Figure 6-75). The resulting residuals are decimeter-level for the majority of the state and have maximum magnitudes of 5 meters along the southern coast (Figure 6-78).

[35] The plots will not reflect any sort of "cut out" of those island sub regions, but the transformation software will not operate inside of those sub regions.

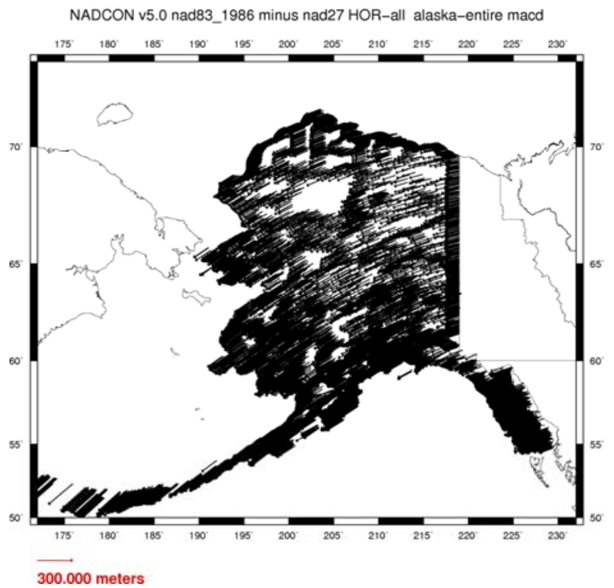

Figure 6-74: All horizontal vectors for NAD 27/NAD 83(1986)/Alaska.

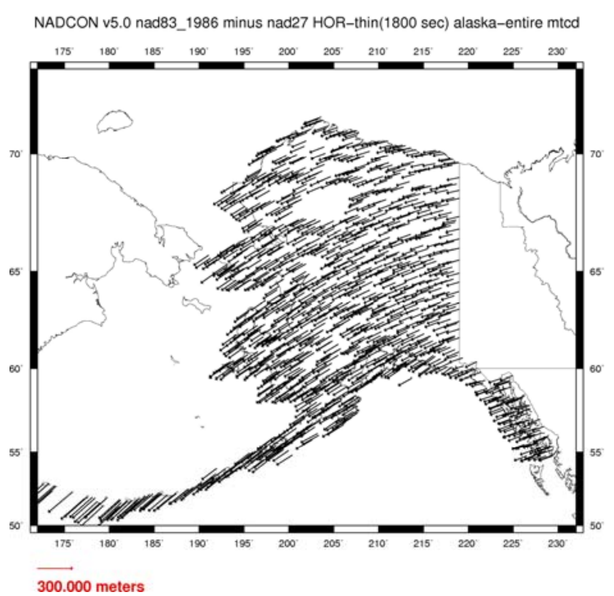

Figure 6-75: Thinned horizontal vectors after applying 30’ grid spacing for NAD 27/NAD 83(1986)/Alaska.

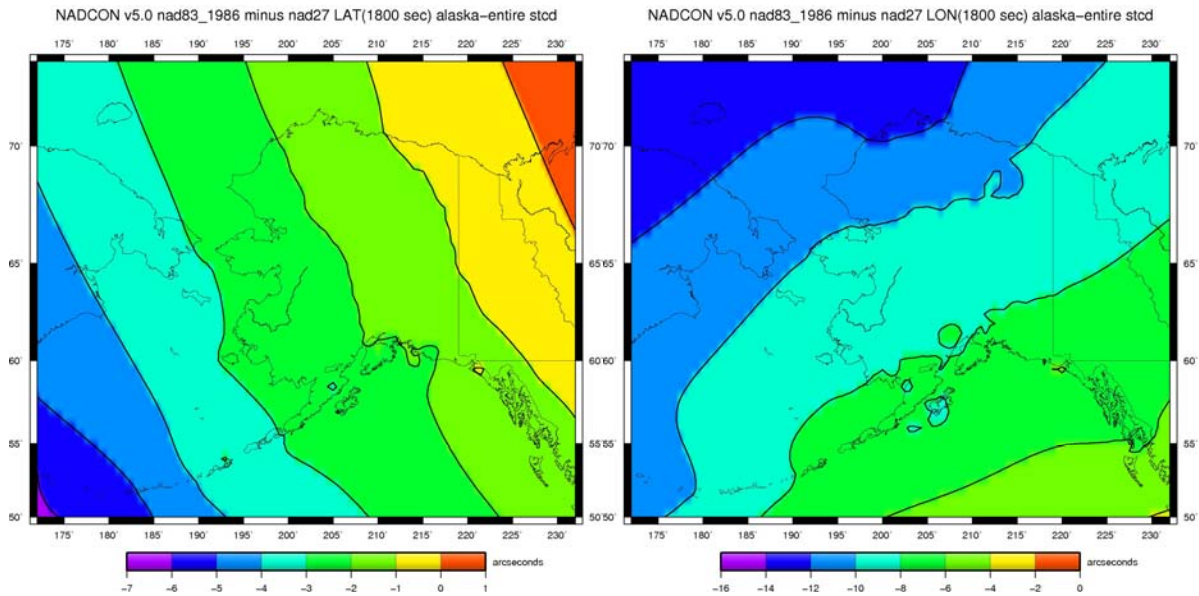

Figure 6-76: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 27/NAD 83(1986)/Alaska.

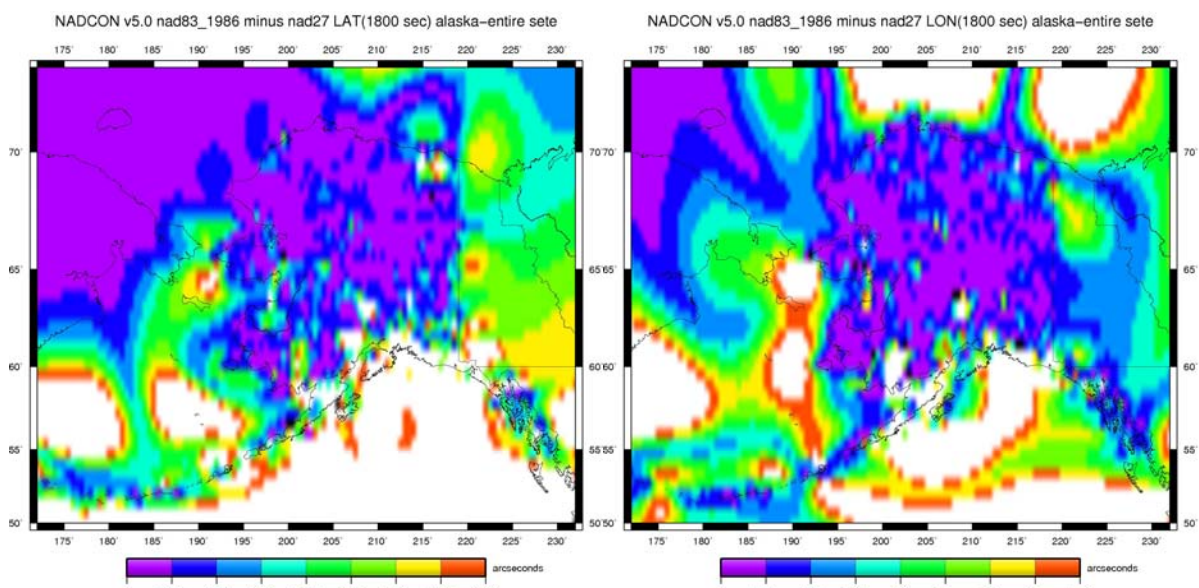

Figure 6-77: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 27/NAD 83(1986)/Alaska.

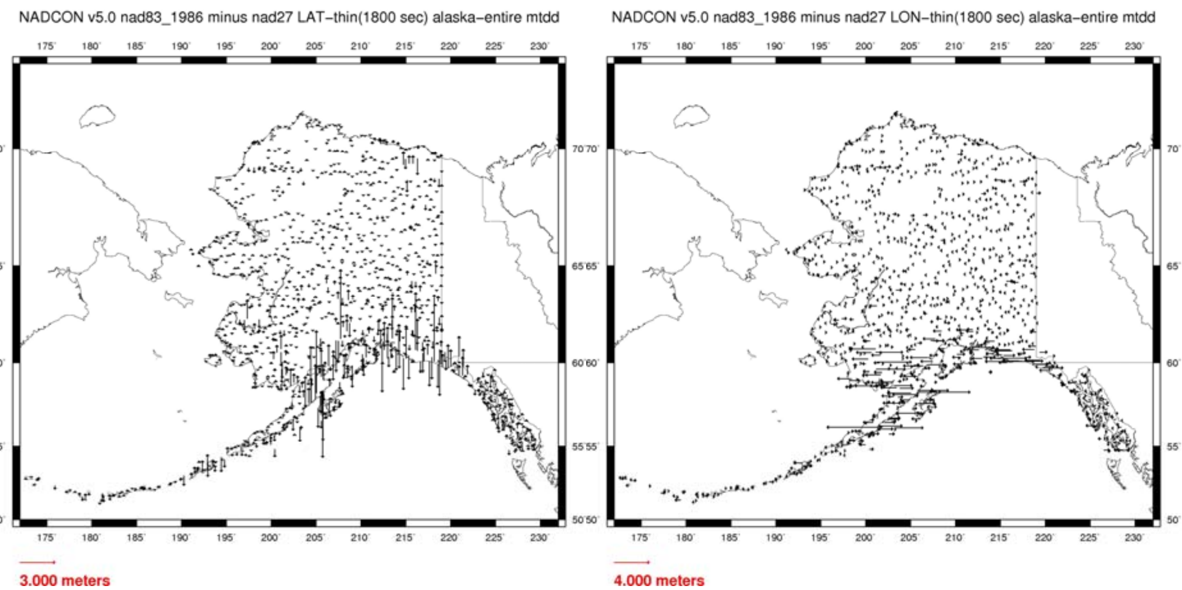

Figure 6-78: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 27/NAD 83(1986)/Alaska.

6.3.4 Alaska / NAD 83(1986) / NAD 83(1992) / Horizontal

The NAD 83(1986) to NAD 83(1992) transformation has two strikingly different fields: 170-200 meters on the Pribilof Islands (St. Paul and St. George), and 0.67 meters everywhere else. This reflects the fact that, despite being part of the NAD 83(1986) adjustment, the remoteness of the Pribilof islands from mainland Alaska obviously had a detrimental impact on the determination of horizontal coordinates consistent with the mainland. As there were no points on St. Lawrence island with paired NAD 83(1986) and NAD 83(1992) coordinates, it cannot be determined if a similar anomaly would have occurred there.

The point density is extremely sparse on the Alaskan mainland interior, with points most readily available along the southern and northern coasts, and in the Anchorage area. The Anchorage area has disparate signals, resulting in very noisy grids for fine grid spacings. Statistics on the thinned residuals revealed that a 15’ grid averages through the noisy vectors in Anchorage and adequately describes the sparse dataset on the whole, with thinned residual magnitudes less than 20 cm for 89% of the points.

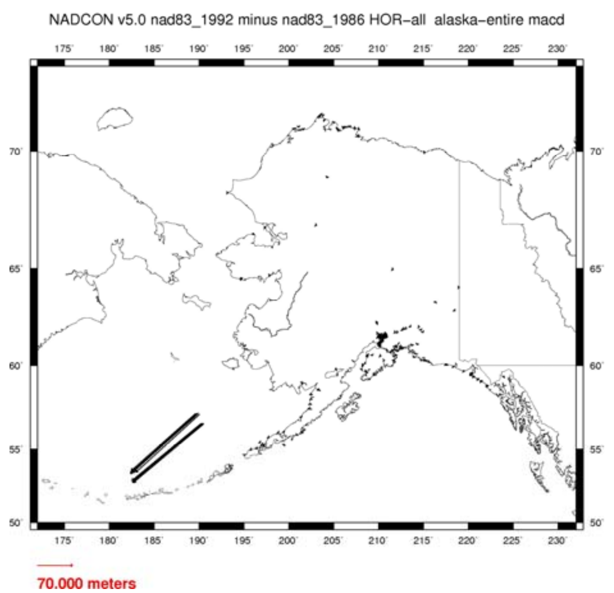

Figure 6-79: All horizontal vectors for NAD 83(1986)/NAD 83(1992)/Alaska.

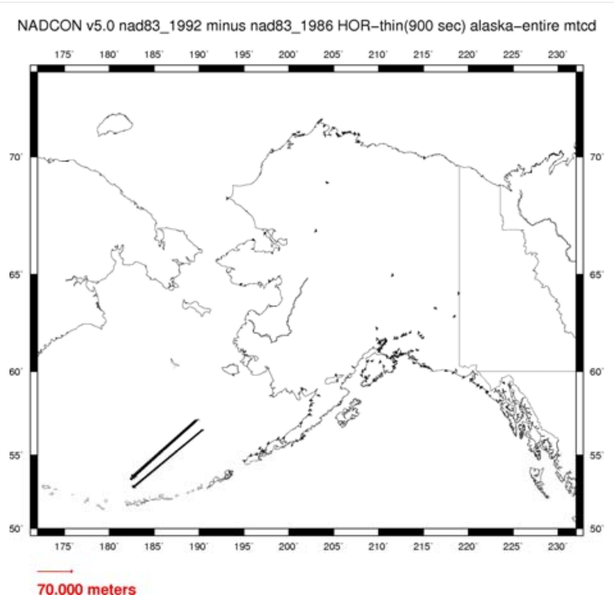

Figure 6-80: Thinned horizontal vectors after applying 15' grid spacing for NAD 83(1986)/NAD 83(1992)/Alaska.

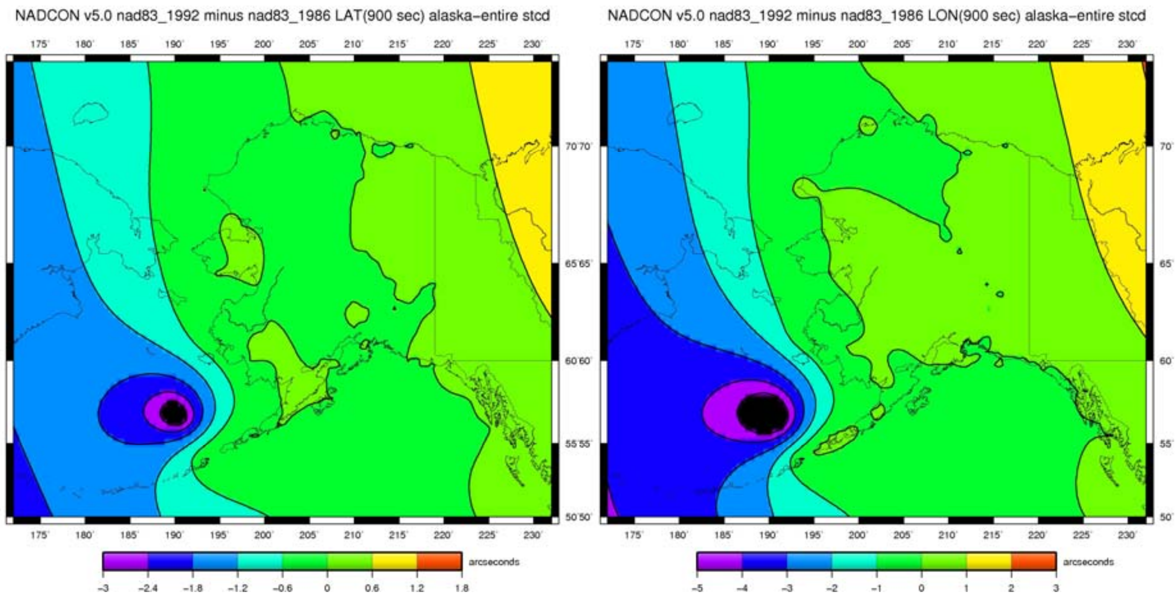

Figure 6-81: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1986)/NAD 83(1992)/Alaska.

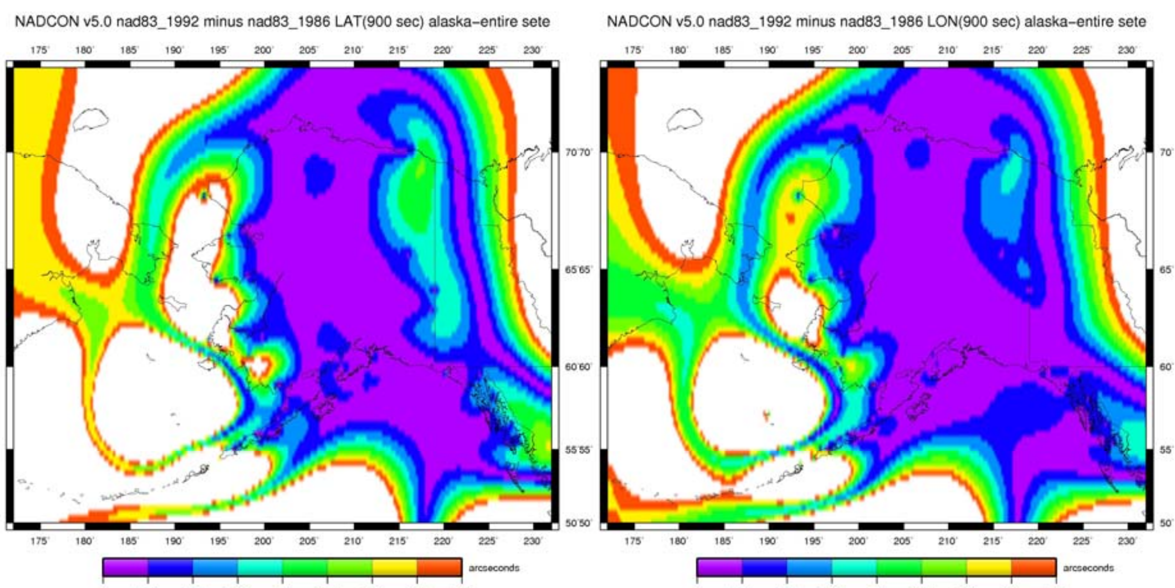

Figure 6-82: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1986)/NAD 83(1992)/Alaska.

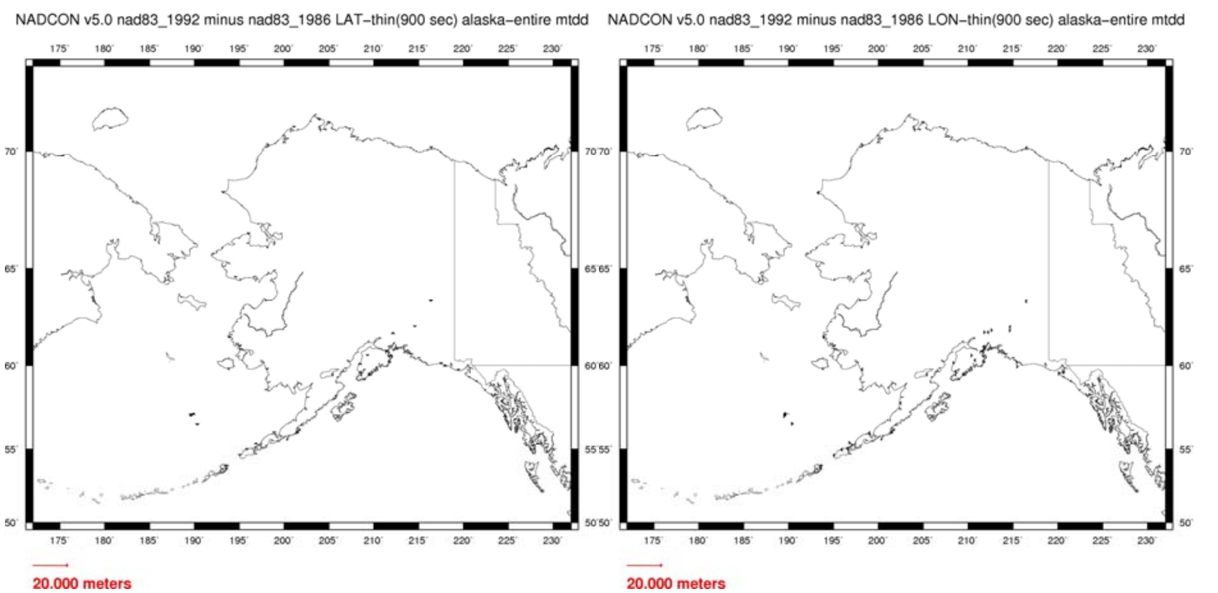

Figure 6-83: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 83(1986)/NAD 83(1992)/Alaska.

6.3.5 Alaska / NAD 83(1992) / NAD 83(NSRS2007) / 3-D

6.3.5.1 Horizontal

The transformation is small, with median magnitude of 7 cm. Vector azimuths are regionally clustered (Figure 6-84), so the final grid size should not be overly coarse. Considered statewide, the dataset is sparse, with the majority of cells having only one point per cell at all grids finer than 30'. The final 7.5' grid resulted in less than 1 cm magnitude for 90% of the thinned residuals, indicating that this grid adequately reflected the transformation.

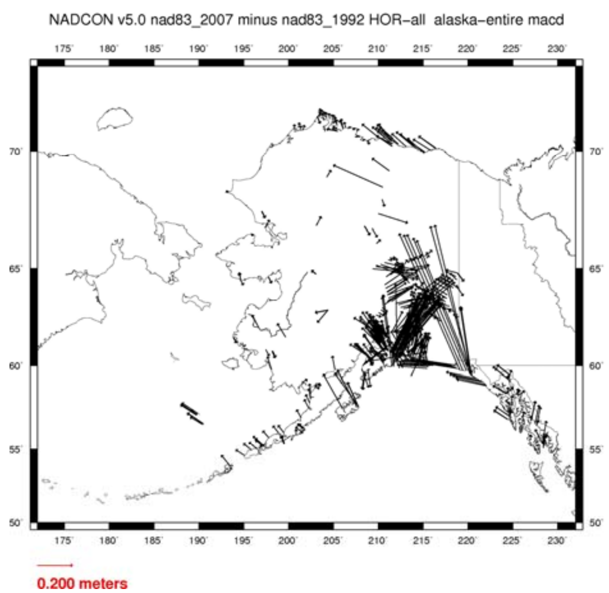

Figure 6-84: All horizontal vectors for NAD 83(1992)/NAD 83(NSRS2007)/Alaska.

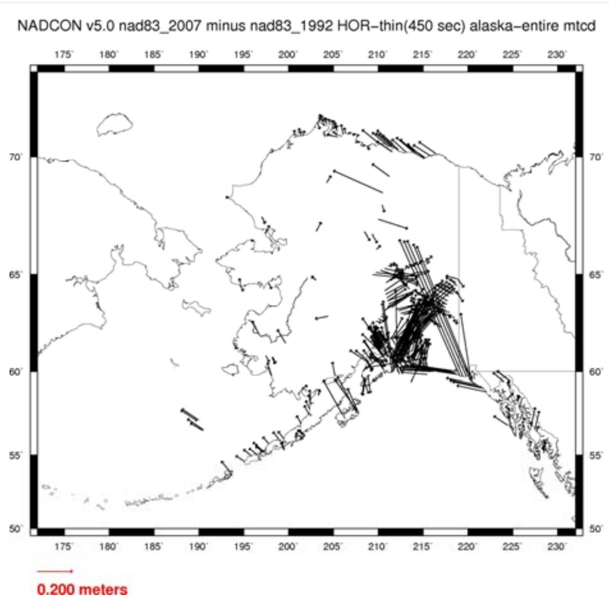

Figure 6-85: Thinned horizontal vectors after applying 7.5' grid spacing for NAD 83(1992)/NAD 83(NSRS2007)/Alaska.

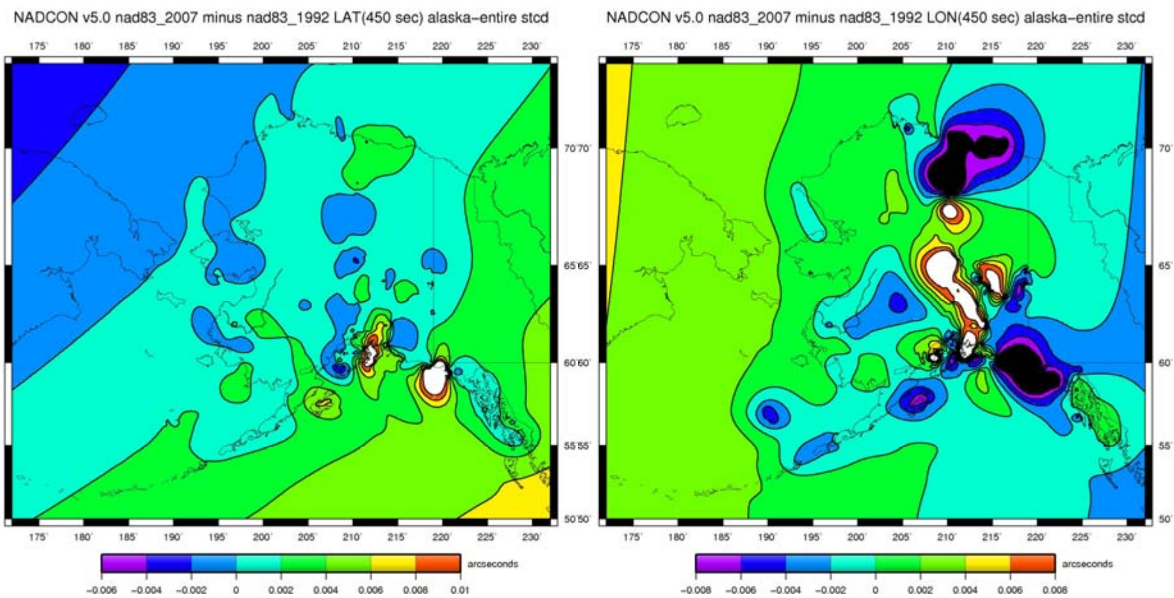

Figure 6-86: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1992)/NAD 83(NSRS2007)/Alaska.

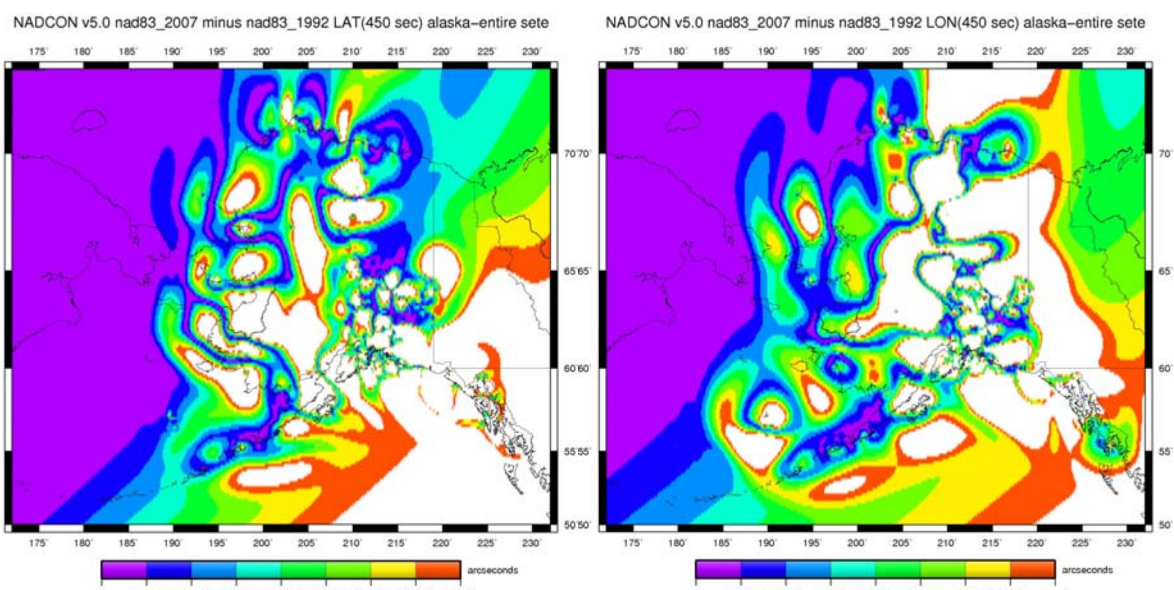

Figure 6-87: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1992)/NAD 83(NSRS2007)/Alaska.

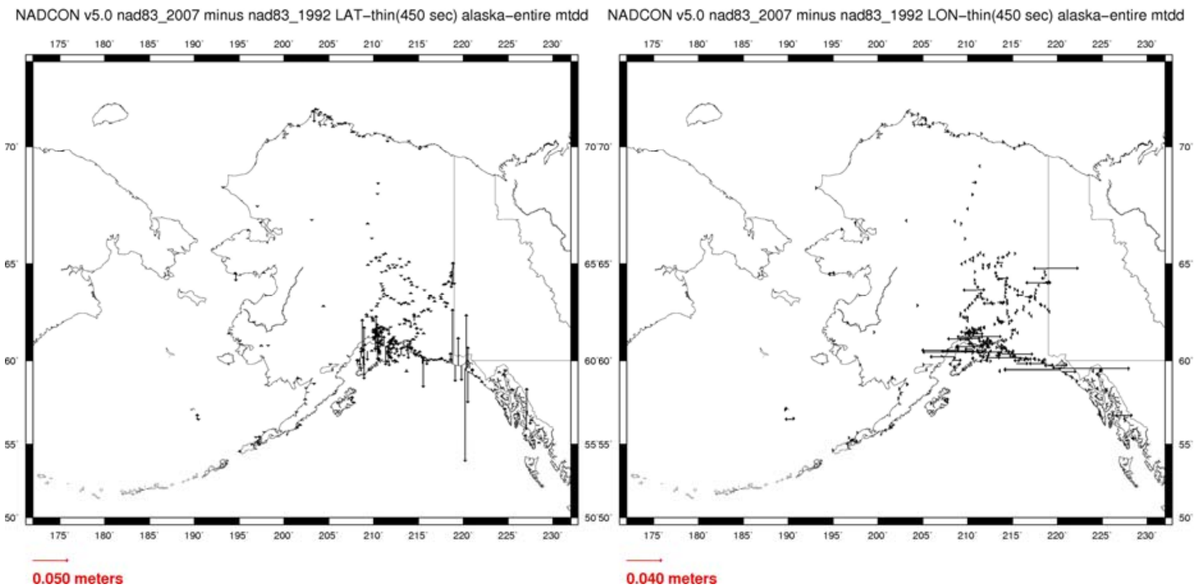

Figure 6-88: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 83(1992)/NAD 83(NSRS2007)/Alaska.

6.3.5.2 Vertical

The vertical field is generally small, with median 2.3 cm but most vectors falling in the +/- 20 cm range (Figure 6-89); the small magnitude made it difficult to rely upon residual statistics when choosing the final grid size. We analyzed the transformation grids directly, and determined that all grids between 1’ and 15’ were effectively the same. Therefore, we selected 15’ as the coarsest grid which adequately explained the data, resulting in 5 mm or smaller residuals for the majority of points (Figure 6-93).

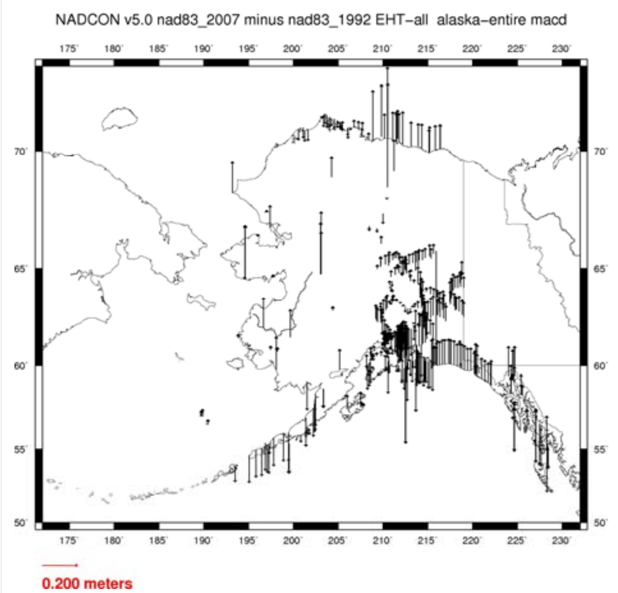

Figure 6-89: All vertical vectors for NAD 83(1992)/NAD 83(NSRS2007)/Alaska.

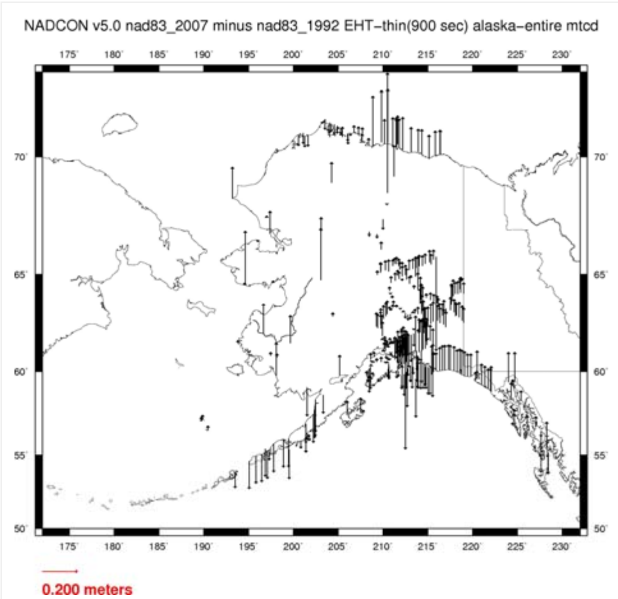

Figure 6-90: Thinned vertical vectors after applying 15' grid spacing for NAD 83(1992)/NAD 83(NSRS2007)/Alaska.

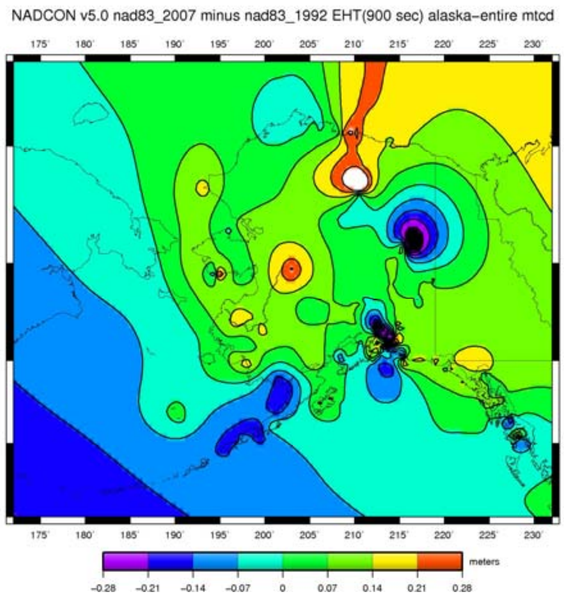

Figure 6-91: Vertical transformation, in meters for NAD 83(1992)/NAD 83(NSRS2007)/Alaska.

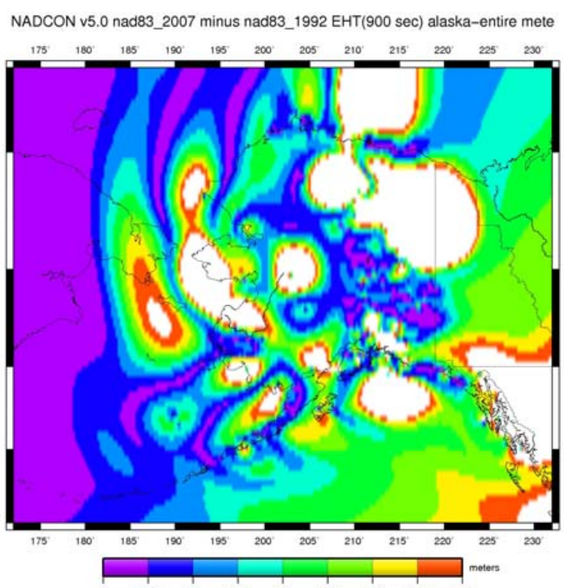

Figure 6-92: Errors for vertical transformation, in meters for NAD 83(1992)/NAD 83(NSRS2007)/Alaska.

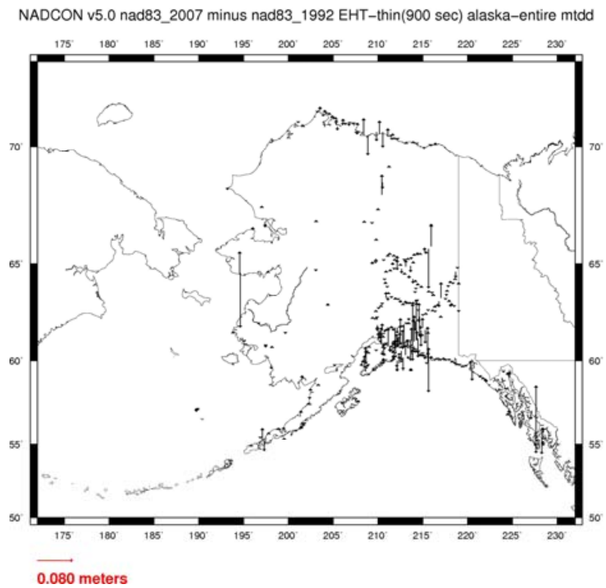

Figure 6-93: Thinned vector residuals (coordinate differences, minus the transformation grid), in meters for NAD 83(1992)/NAD 83(NSRS2007)/Alaska.

6.3.6 Alaska / NAD 83(NSRS2007) / NAD 83(2011) / 3-D

6.3.6.1 Horizontal

The NAD 83(2007) to NAD 83(2011) horizontal transformation has a median of 7.4 cm, with visually-dominant vectors of up to 1 m (Figure 6-94). The authors noted that the number of thinned and dropped residuals exceeding the transformation size dropped significantly when moving from 7.5’ to 5’ grid spacings, and finer grid sizes did not result in substantial improvement in residual size. The final 5’ grid size resulted in thinned residuals of 1 cm or less for the majority of points (Figure 6-98).

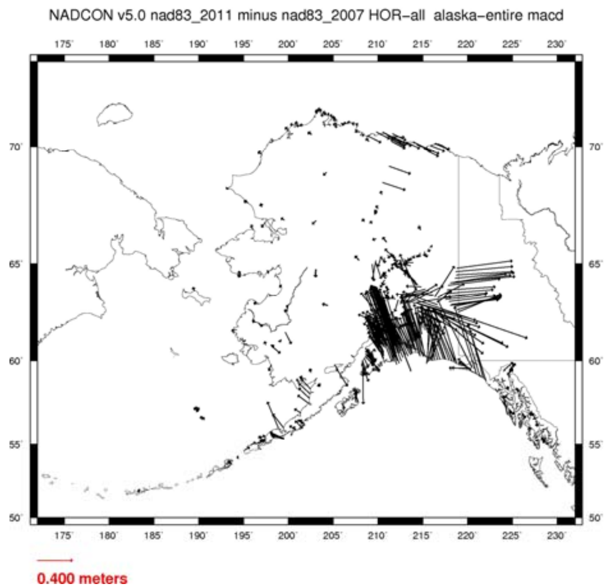

Figure 6-94: All horizontal vectors for NAD 83(NSRS2007)/NAD 83(2011)/Alaska.

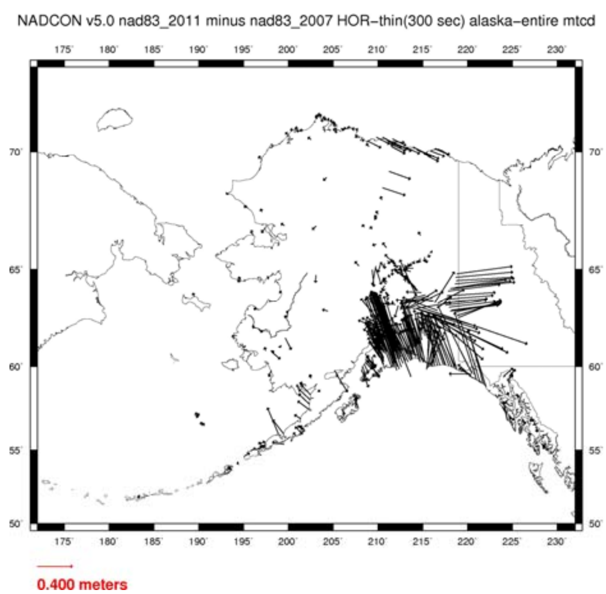

Figure 6-95: Thinned horizontal vectors after applying 5' grid spacing for NAD 83(NSRS2007)/NAD 83(2011)/Alaska.

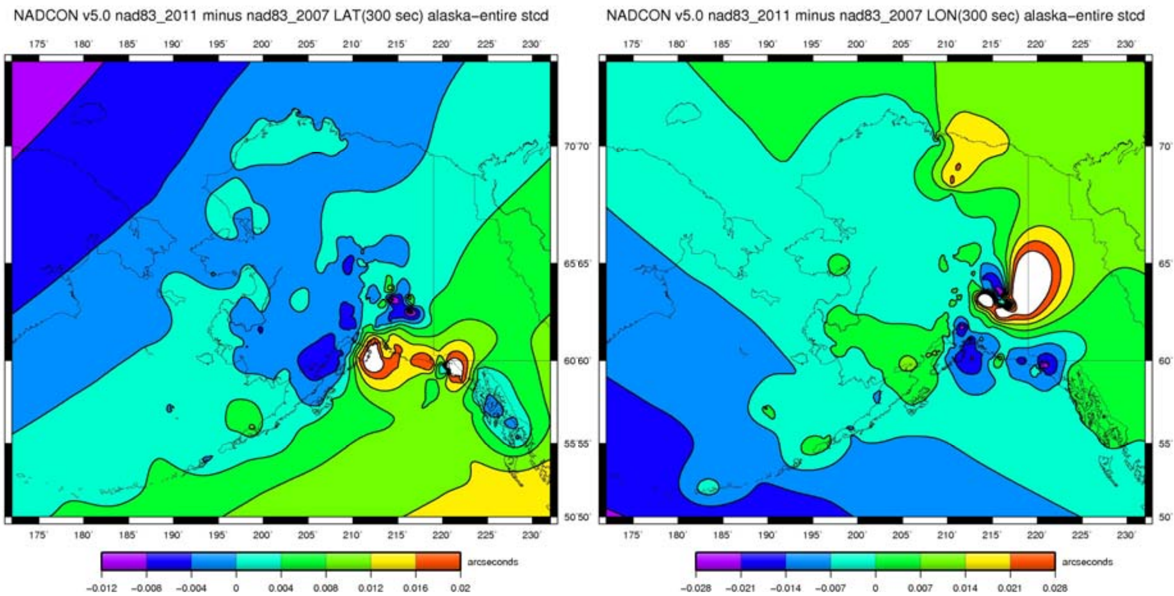

Figure 6-96: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(NSRS2007)/NAD 83(2011)/Alaska.

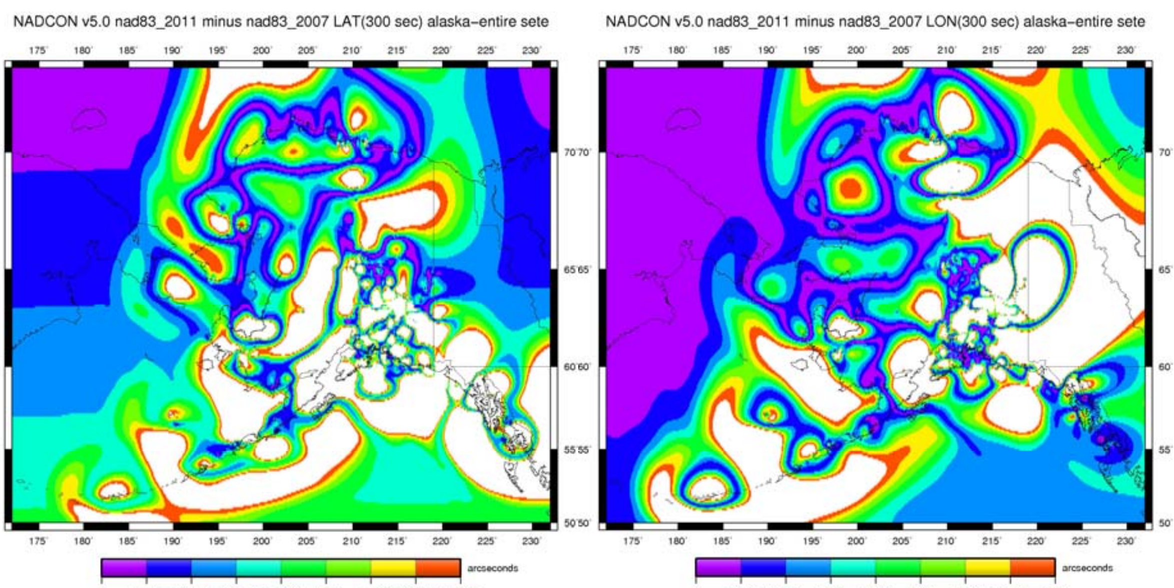

Figure 6-97: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(NSRS2007)/NAD 83(2011)/Alaska.

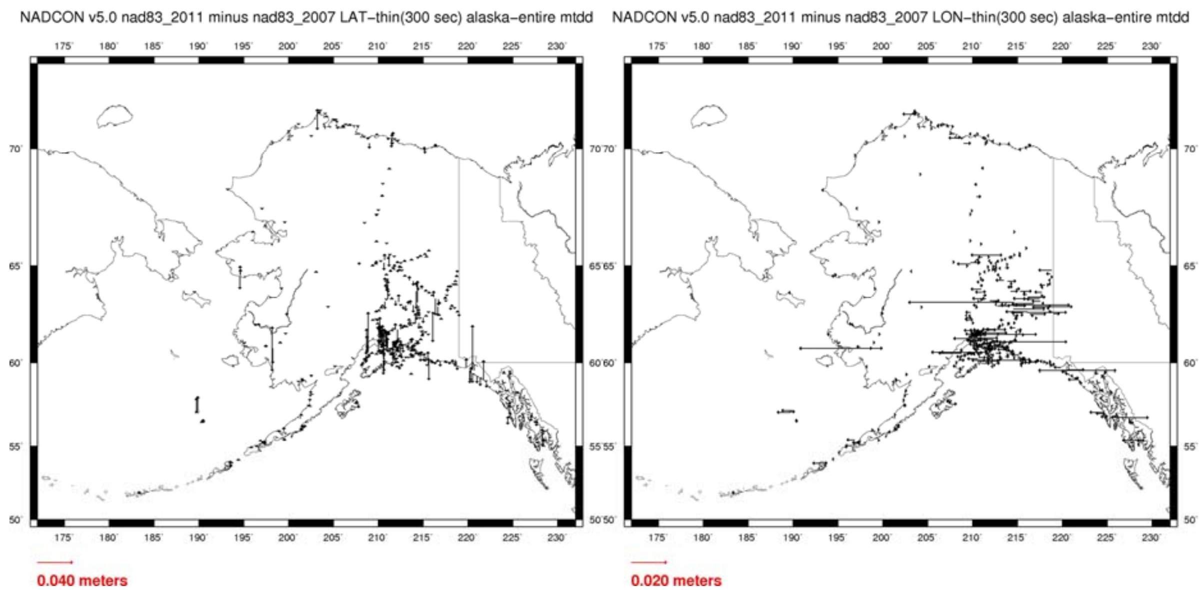

Figure 6-98: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 83(NSRS2007)/NAD 83(2011)/Alaska.

6.3.6.2 Vertical

The vertical field is generally small, with median 0.9 cm but most vectors falling in the +/- 20 cm range (Figure 6-99). The small transformation size combined with the well-controlled nature of the height grids justified selecting the 15' grid. This grid resulted in 5 mm or smaller residuals for the majority of points (Figure 6-103).

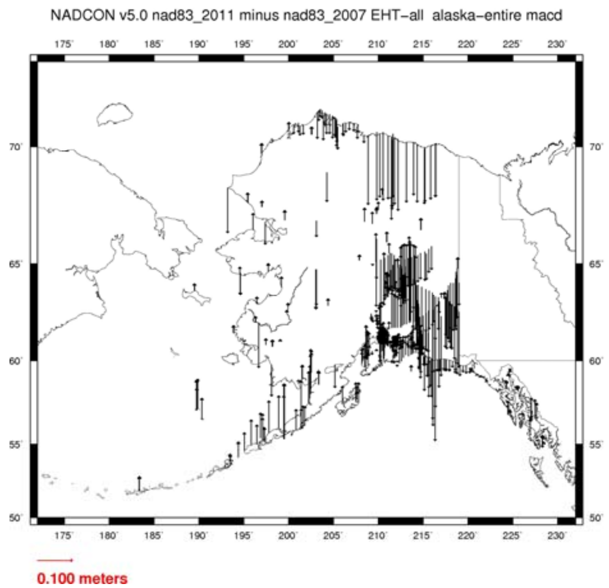

Figure 6-99: All vertical vectors for NAD 83(NSRS2007)/NAD 83(2011)/Alaska.

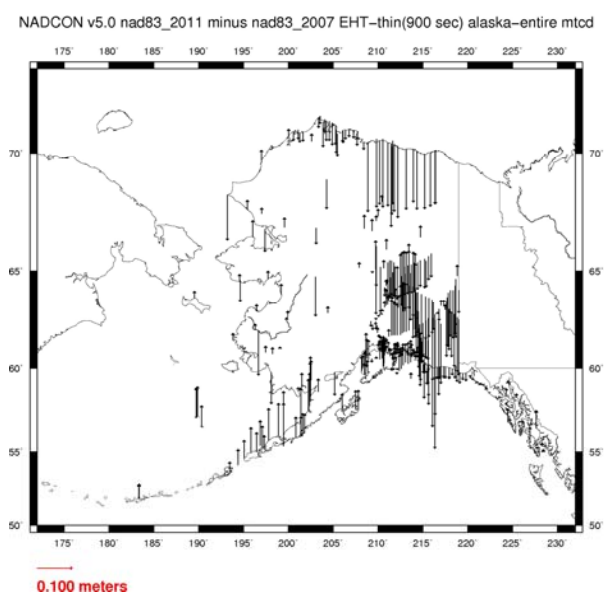

Figure 6-100: Thinned vertical vectors after applying 15' grid spacing for NAD 83(NSRS2007)/NAD 83(2011)/Alaska.

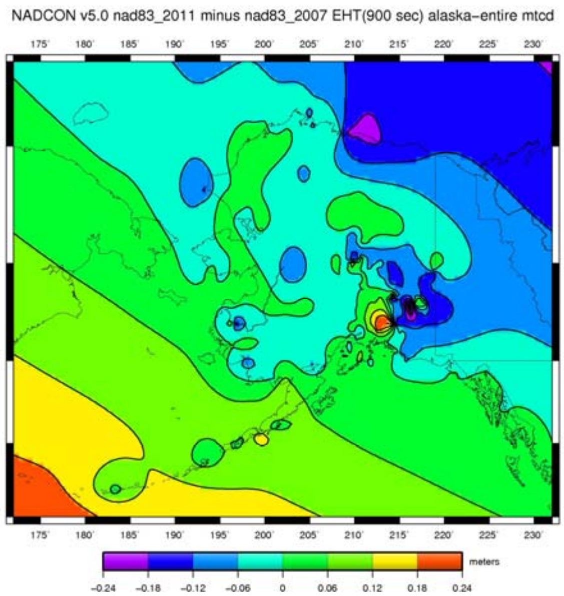

Figure 6-101: Vertical transformation, in meters for NAD 83(NSRS2007)/NAD 83(2011)/Alaska.

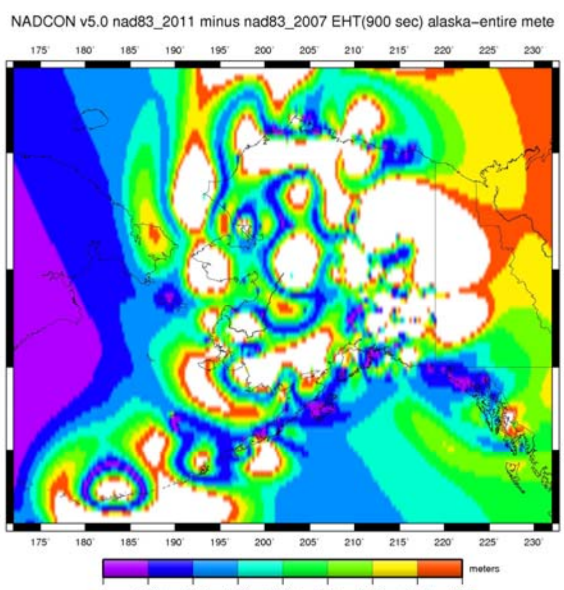

Figure 6-102: Errors for vertical transformation, in meters for NAD 83(NSRS2007)/NAD 83(2011)/Alaska.

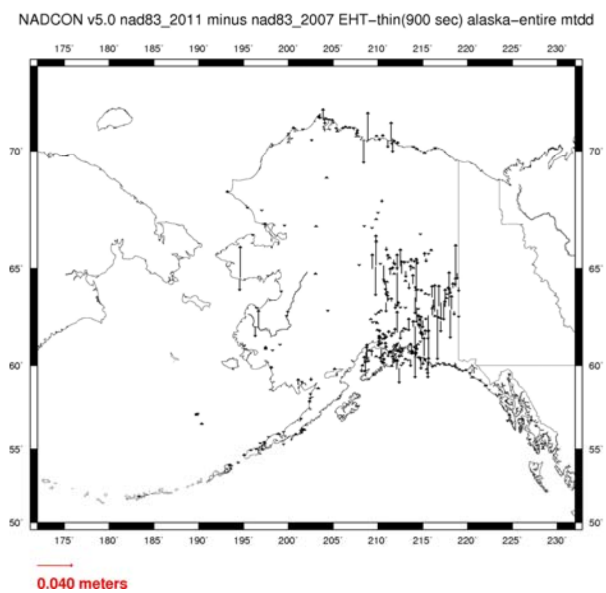

Figure 6-103: Thinned vector residuals (coordinate differences, minus the transformation grid), in meters for NAD 83(NSRS2007)/NAD 83(2011)/Alaska.

6.4 Hawaii (hawaii)

For NADCON 5.0, the "hawaii" region does not include the full Hawaiian archipelago; instead, the bounding box is truncated to the west of Ni'ihau, (18-23 latitude, 199-206 longitude). This made the transformation grids about 1/16 the size of grids which would have extended across the entire Northwest island chain. Although occasional surveys occurred in the Northwest islands, very few points exist with enough data to support a realization (sometimes just 1 point on an island), which could not justify expanding the transformation grids by a factor of 16. To facilitate analysis, the digital archive includes plots at a secondary level by islands or island groups: the 'big island' of Hawai'i, Kauai and adjacent areas, Maui and adjacent areas, and Oahu (mapflag=1).

Four frame transformations are released as part of NADCON 5.0 (Table 6-6), 3 horizontal and 1 vertical. The horizontal transformation from the Old Hawaii Datum (OHD) to NAD 83(1986) is very large. Subsequent horizontal transformations are smaller: 1.5 meters for NAD 83(1986) to NAD 83(1993) and a 2 cm median for NAD 83(1993) to NAD 83(PA11).

Table 6-6: NADCON 5.0 transformations for Hawaii

old datum (od)	*new datum (nd)*	*# of points*	*# outliers*	*# thinned points*	*transformation size (median)*	*grid size*

Horizontal						
OHD	NAD83_1986	2602	15	1231	452.736 m	1’
NAD83_1986	NAD83_1993	2637	6	1225	1.513 m	1’
NAD83_1993	NAD83_PA11	243	6	75	0.017 m	3’
Vertical						
NAD83_1993	NAD83_PA11	244	0	134	-0.009 m	1’

6.4.1 Hawaii / OHD / NAD 83(1986) / Horizontal

The horizontal vector field for OHD to NAD 83(1986) appears extremely consistent to the first order, with a generally southeast trend with magnitude 440-460 meters (Figure 6-104). Several potential grid sizes were analyzed, all of which adequately captured the overall field and resulted in thinned residuals with maximum magnitude of 10-40 meters; the finer the grid, the smaller the residual. A final grid size of 1’ was chosen specifically to capture variance in the vector field on the west coast of the Island of Hawai’i. As shown in Figure 6-109, the 1’ grid results in dropped residuals which are balanced, with some vectors pointing NW and some pointing NE; all other potential grid sizes resulted in dropped residual fields with a systematic trend (pointing only NW). Thus it was concluded that only the 1’ grid was capable of capturing the entirety of the systematic signal at all wavelengths in this transformation, resulting in the randomly-oriented vectors one would expect if the grid properly captures all of the systematic signal.

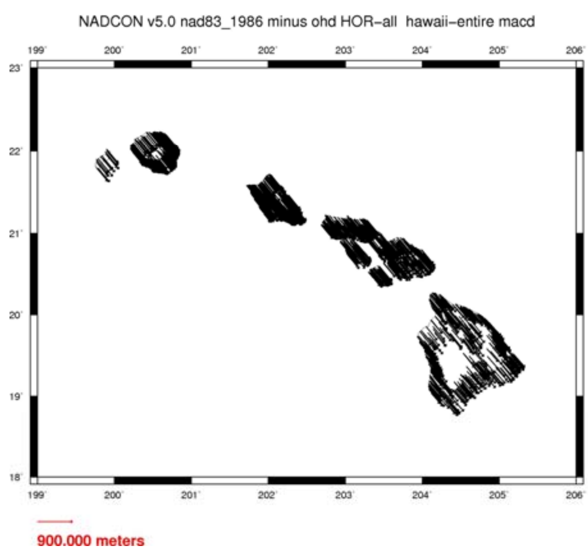

Figure 6-104: All horizontal vectors for OHD/NAD 83(1986)/Hawaii.

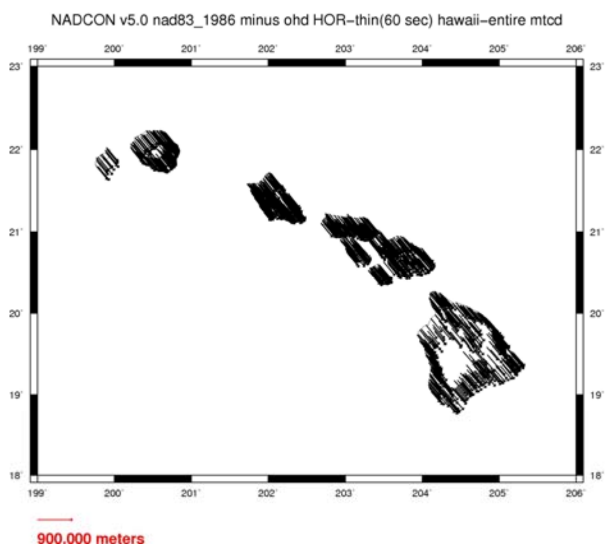

Figure 6-105: Thinned horizontal vectors after applying 1' grid spacing for OHD/NAD 83(1986)/Hawaii.

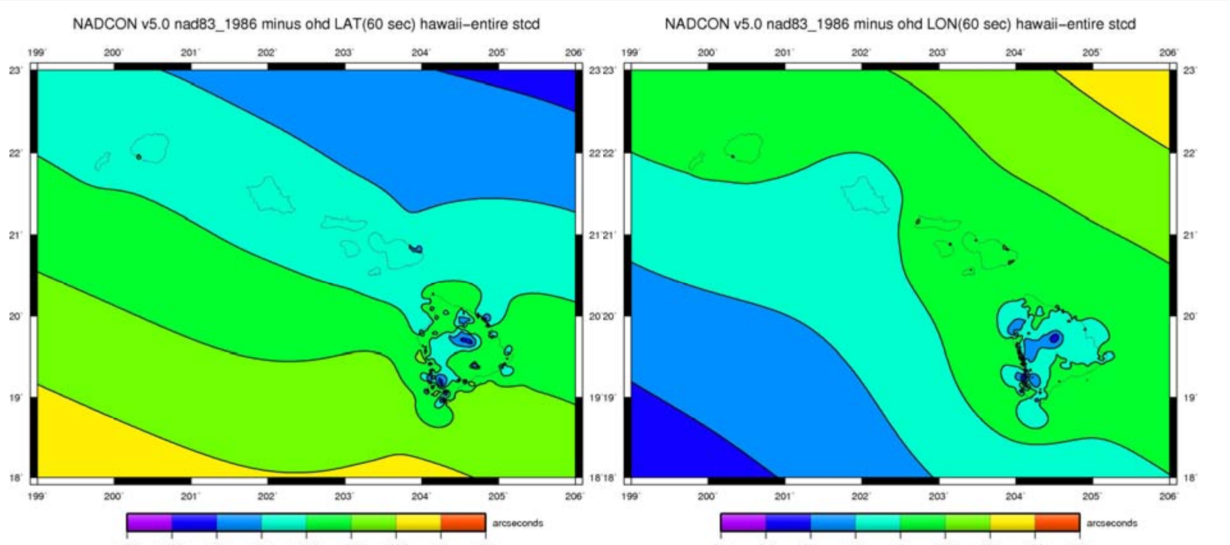

Figure 6-106: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for OHD/NAD 83(1986)/Hawaii.

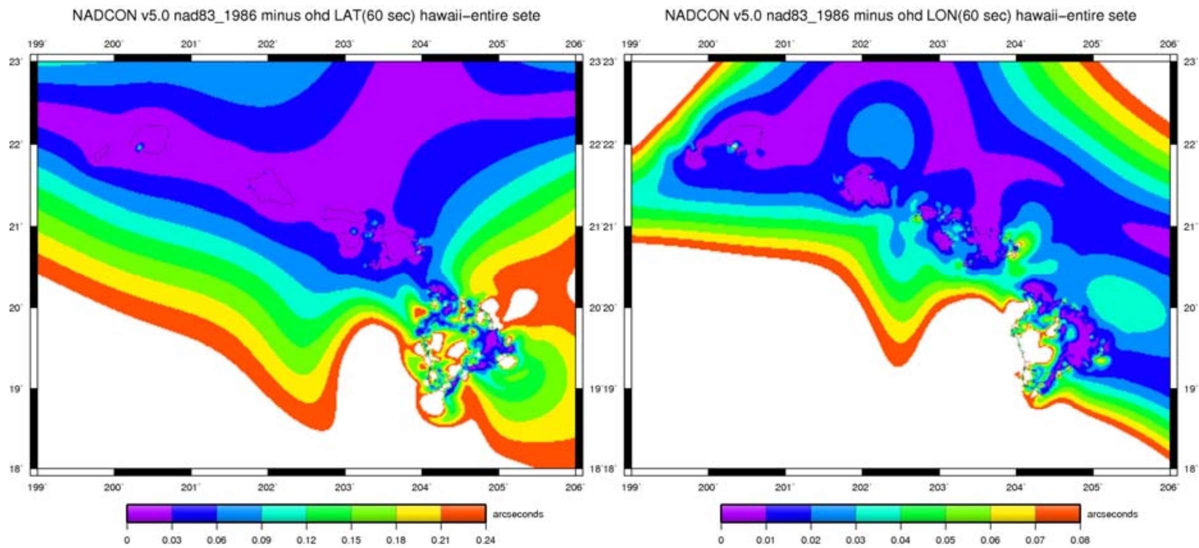

Figure 6-107: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for OHD/NAD 83(1986)/Hawaii.

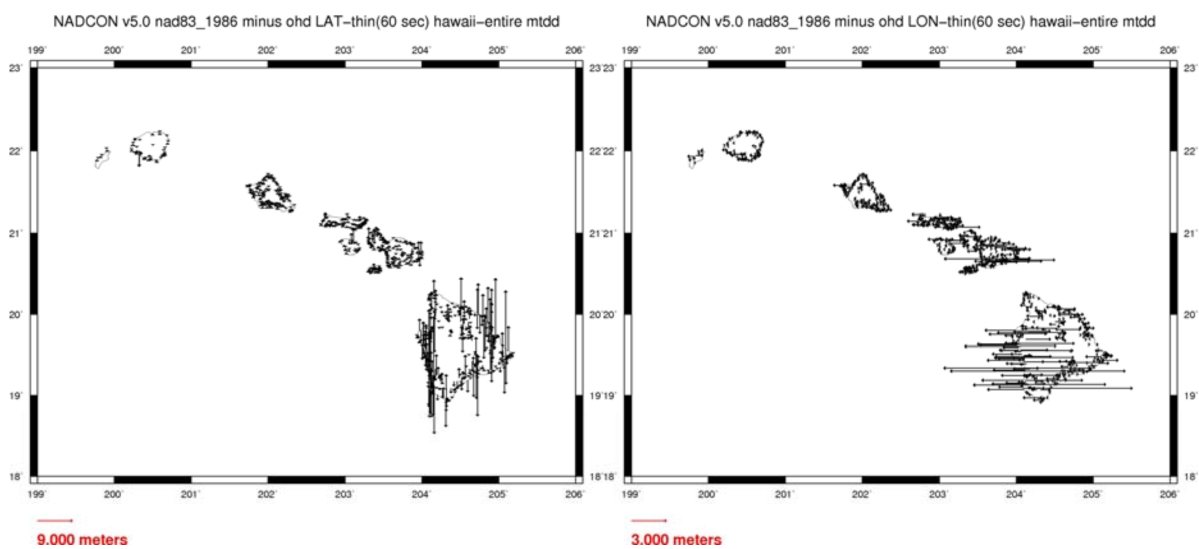

Figure 6-108: Thinned vector residuals (coordinate differences, minus the transformation grid) for the final 1' grid, latitude (left) and longitude (right) components, in meters for OHD/NAD 83(1986)/Hawaii.

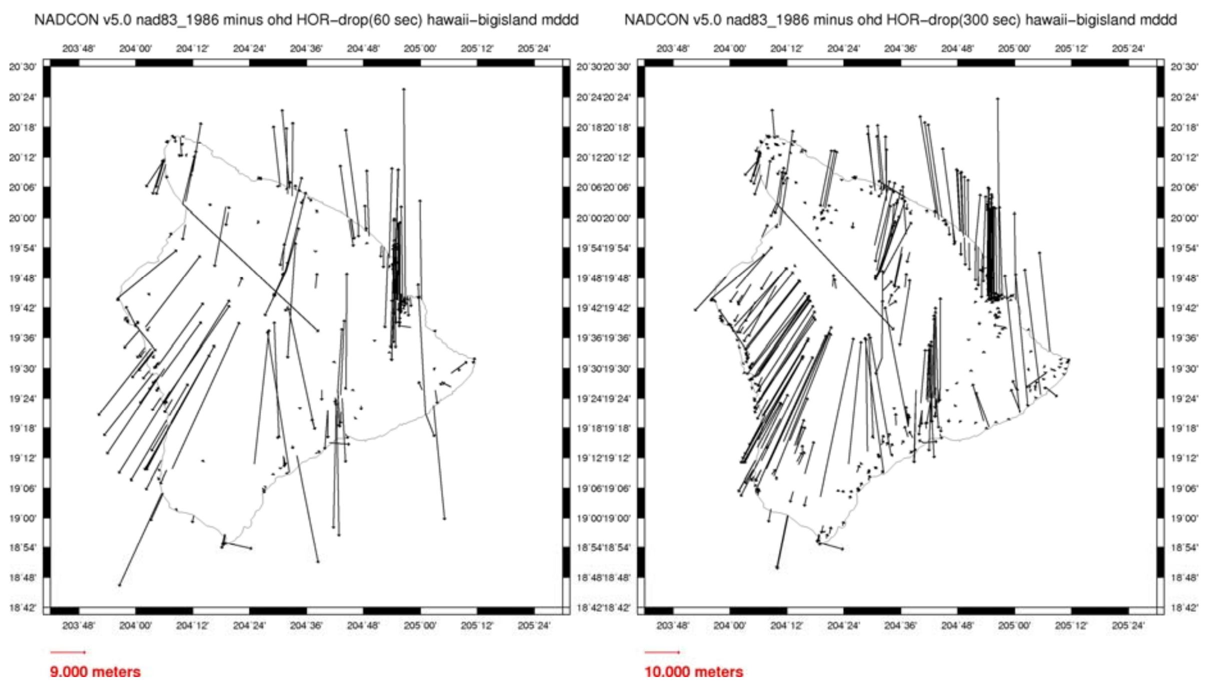

Figure 6-109: Dropped vector horizontal residuals, in meters, on the Island of Hawai'i, for 1' (left) and 5' (right) grid sizes for OHD/NAD 83(1986)/Hawaii.

6.4.2 Hawaii / NAD 83(1986) / NAD 83(1993) / Horizontal

Horizontal magnitudes vary between 0.5 and 1 meters, with a strong median at 1.5 meters. However, each island has its own specific horizontal field, instead of a single overarching field for the entire region, and the Island of Hawai'i has some highly variant behavior on its southeast coast (Figure 6-110). As such, a fine grid size would be required to sequester vectors into separate cells and adequately capture variation across the region. Thus we chose the finest grid allowed in NADCON 5.0, 1', resulting in the majority of thinned residuals with horizontal magnitude of less than 5 cm (Figure 6-114).

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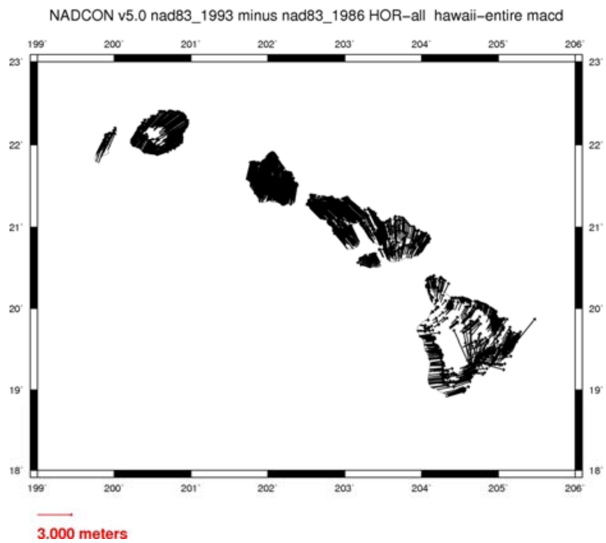

Figure 6-110: All horizontal vectors for NAD 83(1986)/NAD 83(1993)/Hawaii.

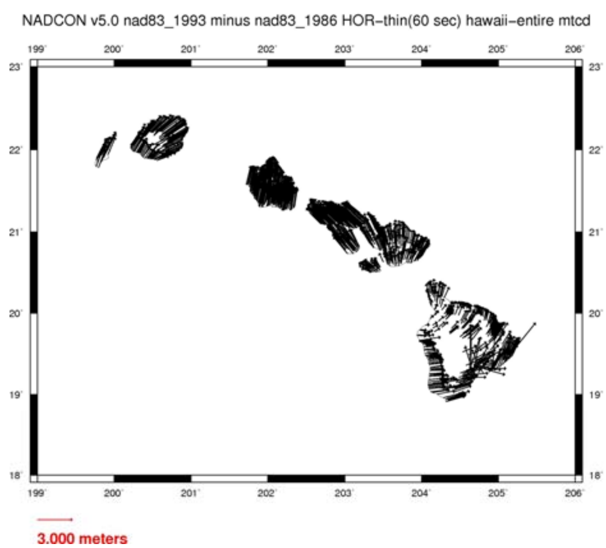

Figure 6-111: Thinned horizontal vectors after applying 1' grid spacing for NAD 83(1986)/NAD 83(1993)/Hawaii.

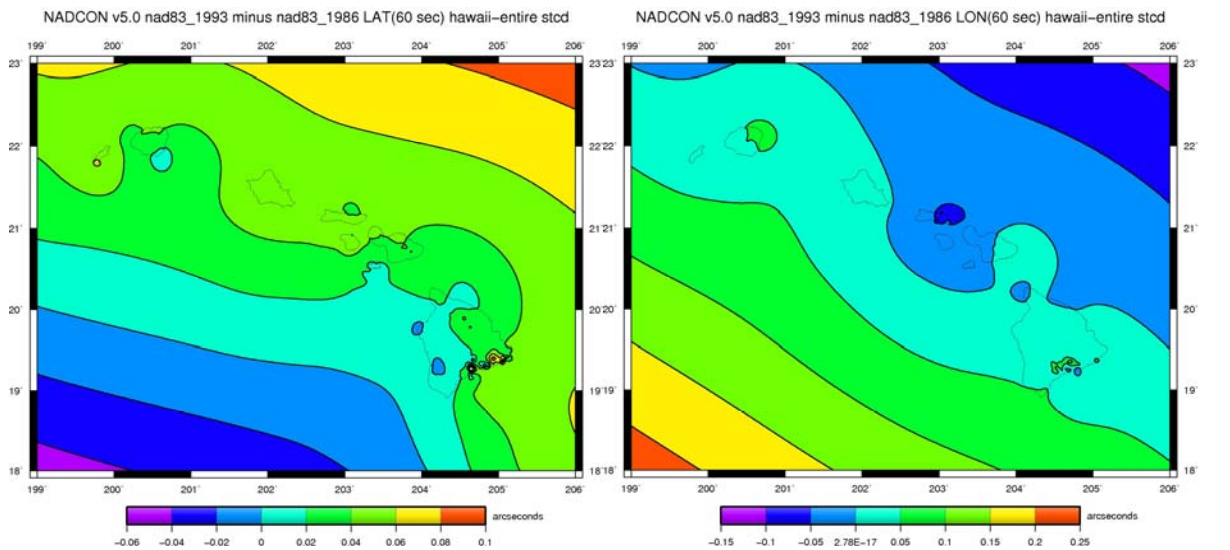

Figure 6-112: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1986)/NAD 83(1993)/Hawaii.

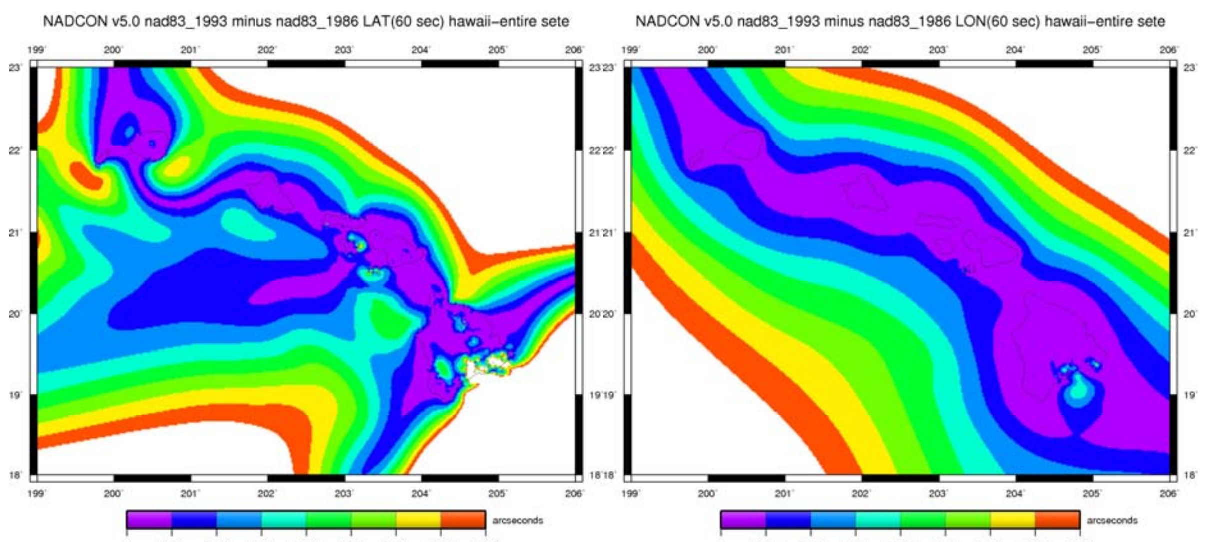

Figure 6-113: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1986)/NAD 83(1993)/Hawaii.

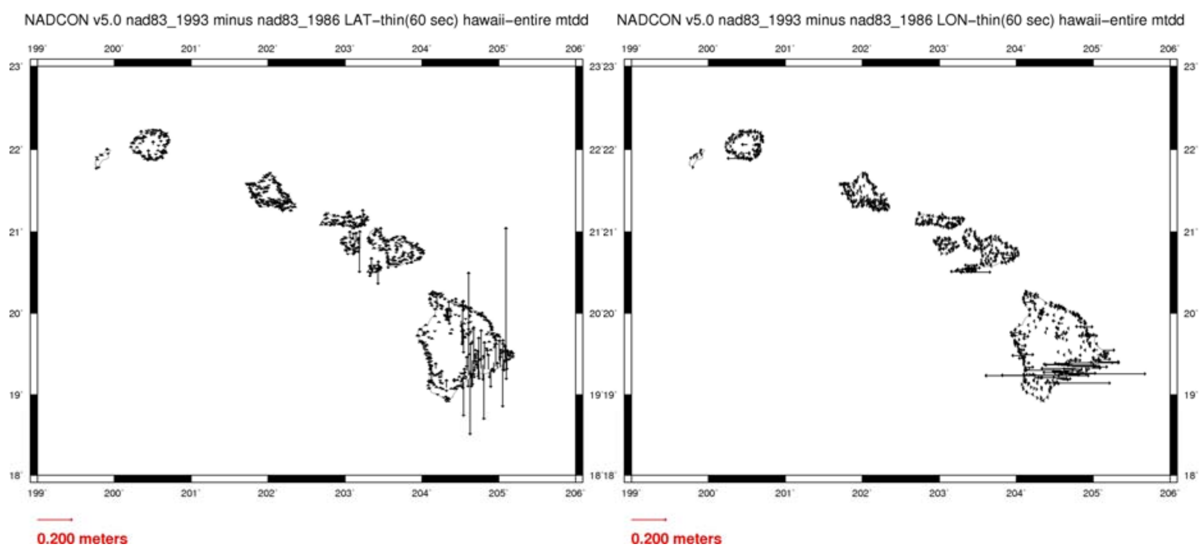

Figure 6-114: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 83(1986)/NAD 83(1993)/Hawaii.

6.4.3 Hawaii / NAD 83(1993) / NAD 83(PA11) / 3-D

6.4.3.1 Horizontal

There are relatively few points, with a bimodal field orientation of ~ 100 degrees and ~ 200 degrees azimuth (Figure 6-115). Unfortunately, the bimodal fields overlap, with the potential to have both orientations within the same cell. As such, while there are two “systematic looking” fields overlapping, their inability to be separated at even a 1’ cell size means there is no logical way to pick a “representative” transformation in each cell. Furthermore, the size of the median vectors is only 1.7 cm. This study attempted to only model systematic signals with at least 1 cm magnitude, so this size and the bimodal nature of the azimuths means that very little useful signal could be drawn out of these vectors. An overly fine grid would effectively be gridding noise and not be physically representative of the regional or even local field. Looking at the statistics of the dropped double-difference (ddd) vectors, e.g. the residuals of the dropped vectors (Figure 6-120), we observed that the 3’ (180’’) grid was at the inflection point between an increasing number of large vectors (> 1 cm) when moving to coarser scales, and a decreasing number of small vectors (< 0.5 cm) as you move to finer scales. Therefore, the 3’ grid size was chosen as a nice balance between sampling the field variability while yielding a desirable distribution to the magnitude of the dropped vectors.

Figure 6-115: All horizontal vectors for NAD 83(1993)/NAD 83(PA11)/Hawaii.

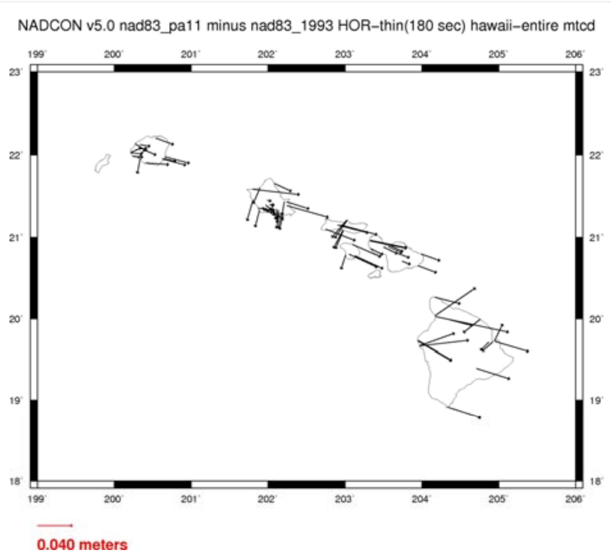

Figure 6-116: Thinned horizontal vectors after applying 3’ grid spacing for NAD 83(1993)/NAD 83(PA11)/Hawaii.

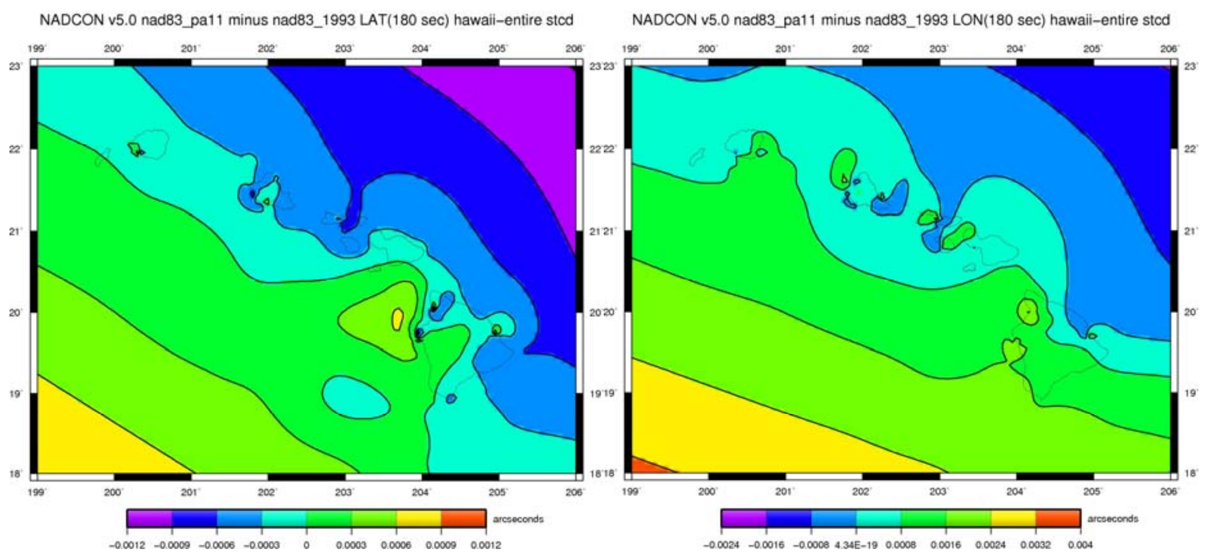

Figure 6-117: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1993)/NAD 83(PA11)/Hawaii.

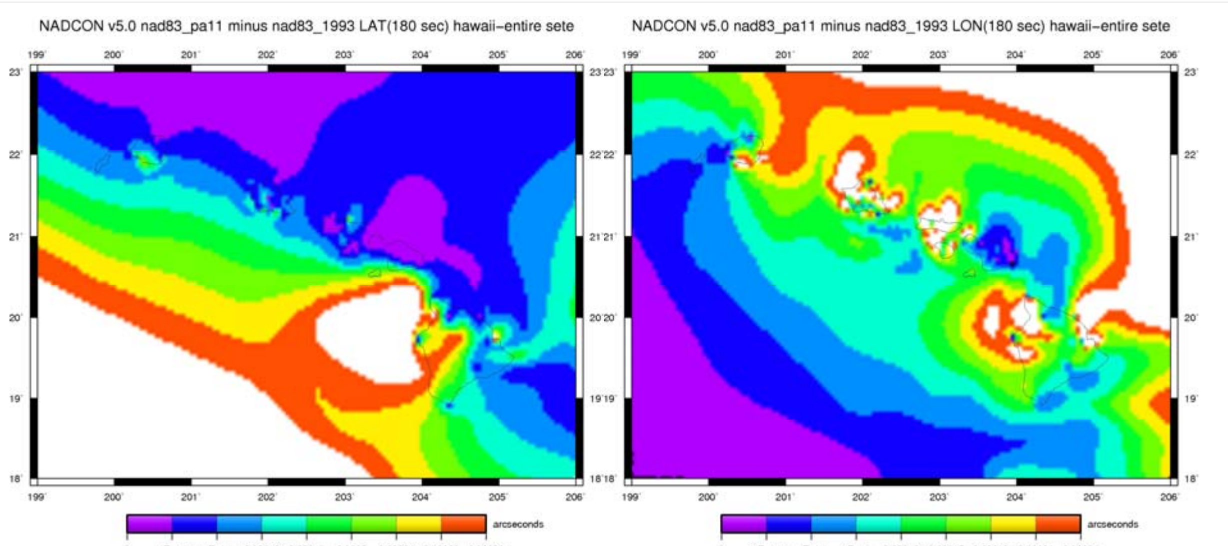

Figure 6-118: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1993)/NAD 83(PA11)/Hawaii.

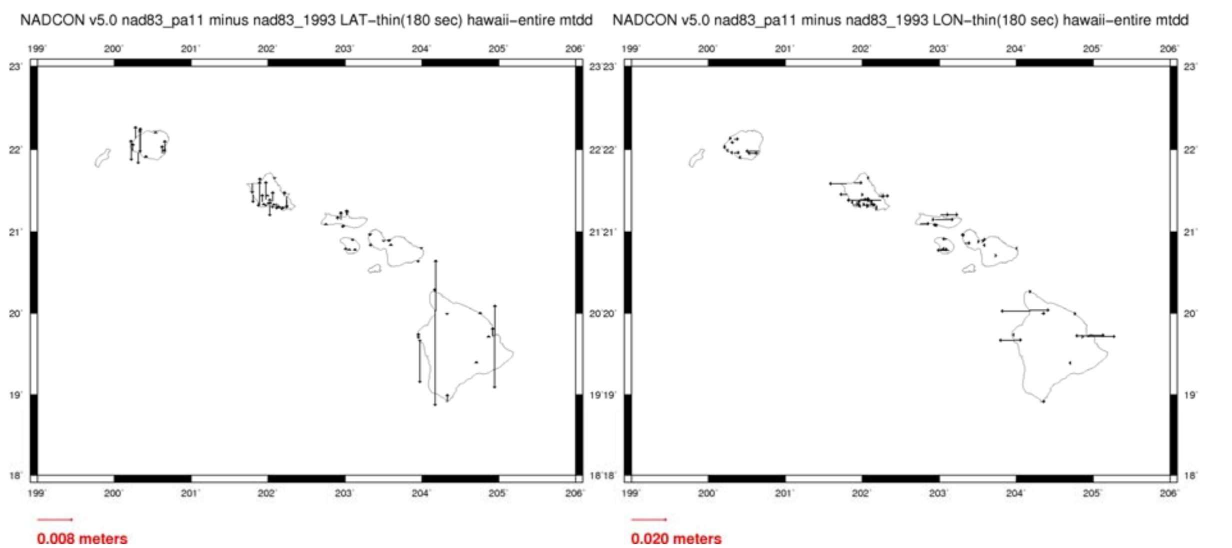

Figure 6-119: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 83(1993)/NAD 83(PA11)/Hawaii.

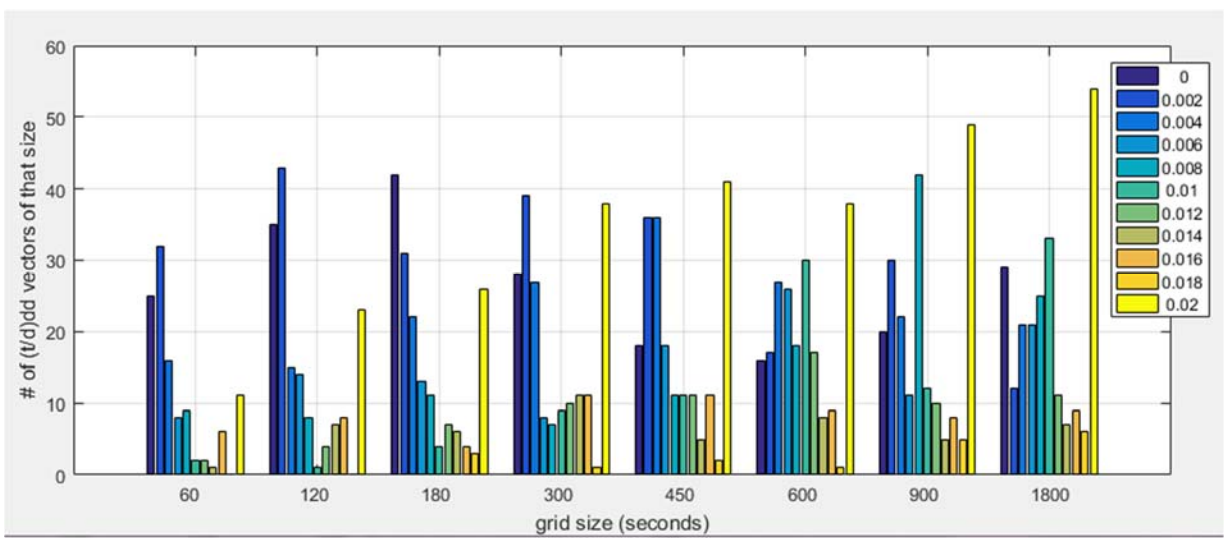

Figure 6-120: Clustered bar graphs for the number of dropped double difference (ddd) vectors for sizes 0-0.02 meters, with each cluster counting up the vectors for a tested grid size ranging between 60" and 1800" for NAD 83(1993)/NAD 83(PA11)/Hawaii.

6.4.3.2 Vertical

In this vertical field, the data are very sparse with median 0.0 meters, where the majority of vertical vectors are actually zero length, with unrepresentative long vectors catching the eye (Figure 6-121). To create a meaningful transformation, isolated vectors must be captured by the grid. The 1' grid results in small residuals where the vectors are non-zero, while still adequately capturing the zero-size transformation where those vectors exist (Figure 6-125).

Figure 6-121: All vertical vectors for NAD 83(1993)/NAD 83(PA11)/Hawaii.

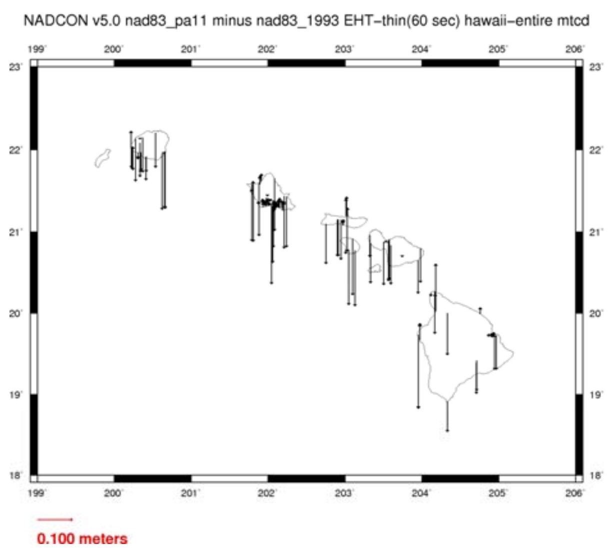

Figure 6-122: Thinned vertical vectors after applying 15' grid spacing for NAD 83(1993)/NAD 83(PA11)/Hawaii.

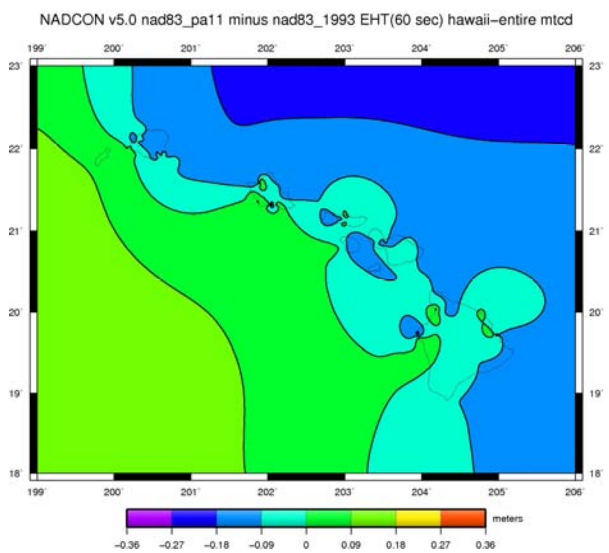

Figure 6-123: Vertical transformation, in meters for NAD 83(1993)/NAD 83(PA11)/Hawaii.

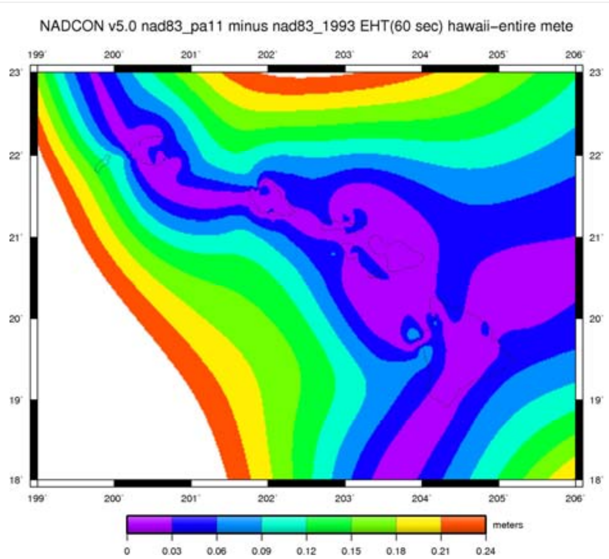

Figure 6-124: Errors for vertical transformation, in meters for NAD 83(1993)/NAD 83(PA11)/Hawaii.

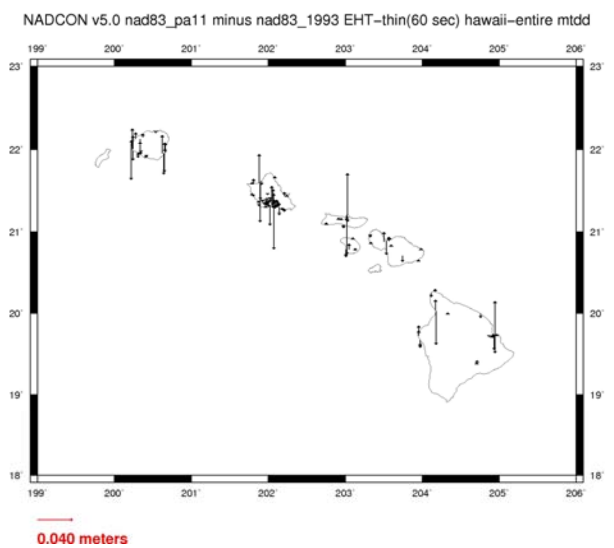

Figure 6-125: Thinned vector residuals (coordinate differences, minus the transformation grid), in meters for NAD 83(1993)/NAD 83(PA11)/Hawaii.

6.5 Puerto Rico and the US Virgin Islands (prvi)

The NADCON 5.0 region “prvi” encompasses Puerto Rico as well as the US Virgin Islands. Thus a bounding box (17-19 latitude, 291-296 longitude) with large oceanic sections is required for the gridded area. To facilitate more detailed analysis, the digital archive includes plots at the island level: Puerto Rico, Culebra, Desecheo, Mona, Vieques, St. Croix, St. John, and St. Thomas (mapflag=1).

Ten frame transformations are released as part of NADCON 5.0 (Table 6-7); two are horizontal only, whereas the remaining 8 transformations are horizontal + vertical pairs. Data are dense for the first 3 horizontal transformations (over 1000 points), but sparse for the latter 3 horizontal transformations and all vertical transformations (less than 120 points). Section 1 contains additional information on the meaning of specific Puerto Rico datum tags and adjustments.

Table 6-7: NADCON 5.0 transformations for Puerto Rico and the U.S. Virgin Islands

old datum (od)	***new datum (nd)***	***# of points***	***# outliers***	***# thinned points***	***transformation size (median)***	***grid size***
Horizontal						
PR40	NAD83_1986	1460	0	176	224 m	5’
NAD83_1986	NAD83_1993	1469	7	175	1.1 m	5’

NAD83_1993	NAD83_1997	1559	7	769	29 cm	1’
NAD83_1997	NAD83_2002	55	0	38	9 cm	5’
NAD83_2002	NAD83_2007	101	7	69	1 cm	1’
NAD83_2007	NAD83_2011	127	1	41	15 cm	7.5’
Vertical						
NAD83_1993	NAD83_1997	68	2	38	- 8 cm	5’
NAD83_1997	NAD83_2002	60	4	39	-11 cm	3’
NAD83_2002	NAD83_2007	101	13	65	- 3 cm	1’
NAD83_2007	NAD83_2011	127	10	41	1.3 cm	7.5’

6.5.1 Puerto Rico & U.S. Virgin Islands / PR40[36] / NAD 83(1986) / Horizontal

This is a very large magnitude transformation, with median 224.75 meters. The horizontal vector field is extremely uniform in azimuth and dense (Figure 6-126), which allows selection of a coarser grid so that the median filter can select median vectors during the thinning operation (Figure 6-127). The authors chose the 5’ grid size because this grid led to 22 RMS points per cell and residuals at the decimeter level (Figure 6-130).

[36] The “PR40” datum means “Puerto Rico Datum, adjustment of 1940”. Paper records at NGS indicate that there were seemingly two Puerto Rico datum adjustments -- one in 1915 and one in 1940, but the digital data in the NGS IDB is only labeled “Puerto Rico Datum”. It is not 100% clear that the data labeled as “Puerto Rico Datum” in the NGS IDB is all from the 1940 adjustment, but the consistency of vectors from that datum to the NAD 83(1986) datum provide indirect evidence that all “Puerto Rico Datum” points were from one adjustment. If that is true, it seems most likely it would be the later adjustment, 1940. As such, we have chosen to label such points “PR40” both in NADCON and in the NGS IDB.

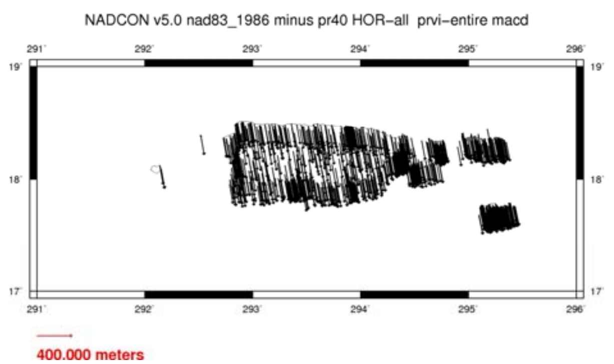

Figure 6-126: All horizontal vectors for PR40/NAD 83(1986)/PRVI.

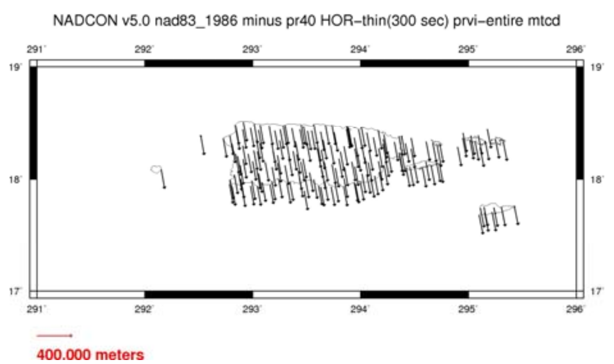

Figure 6-127: Thinned horizontal vectors after applying 5' grid spacing for PR40/NAD 83(1986)/PRVI.

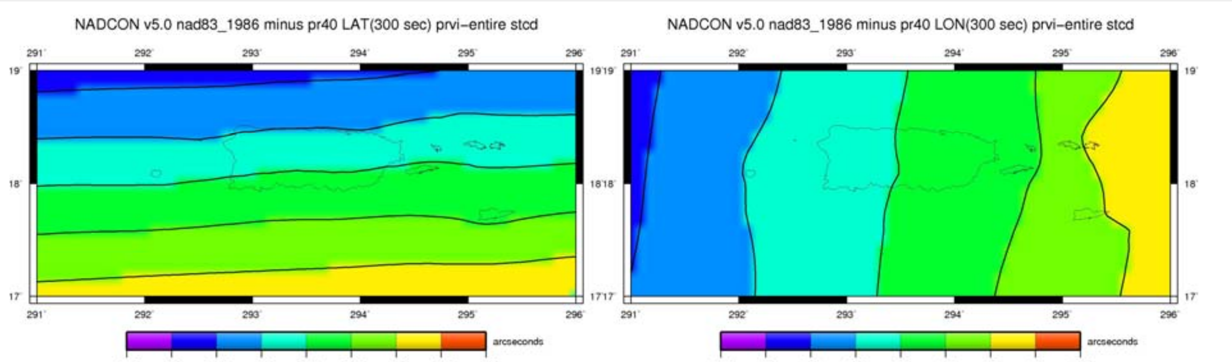

Figure 6-128: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for PR40/NAD 83(1986)/PRVI.

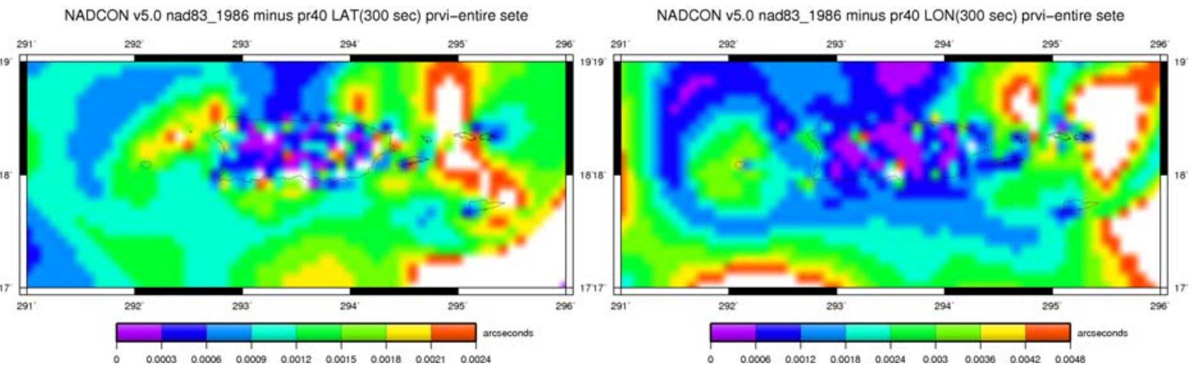

Figure 6-129: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for PR40/NAD 83(1986)/PRVI.

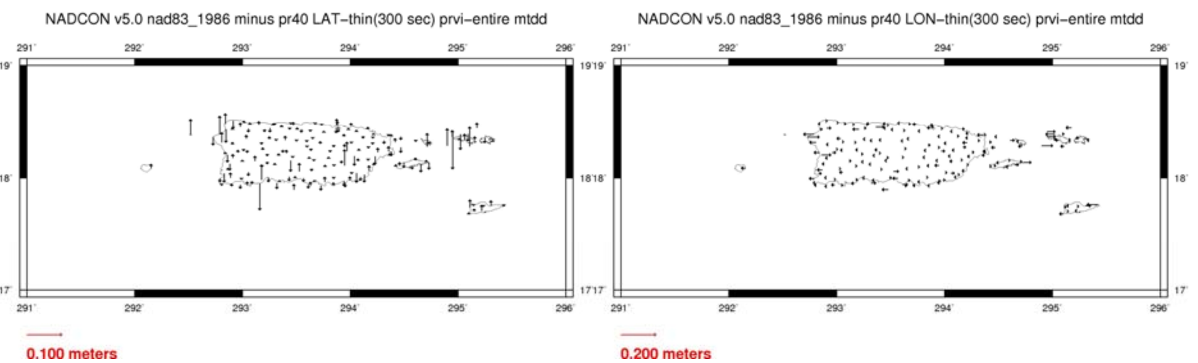

Figure 6-130: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for PR40/NAD 83(1986)/PRVI.

6.5.2 Puerto Rico & U.S. Virgin Islands / NAD 83(1986) / NAD 83(1993) / Horizontal

The NAD 83(1986) to NAD 83(1993) transformation has nearly identical density to the previous transformation, but a much smaller magnitude - median 1.1 meters, with horizontal magnitudes varying between 0.7 and 1.5 meters. The horizontal field has a smoothly-varying change in azimuth (Figure 6-131), and a 5' grid adequately samples the field (Figure 6-132). With this grid size, fewer than 1% of the thinned vectors (Figure 6-135) and 10% of the dropped vectors have a magnitude exceeding 5% of the transformation size.

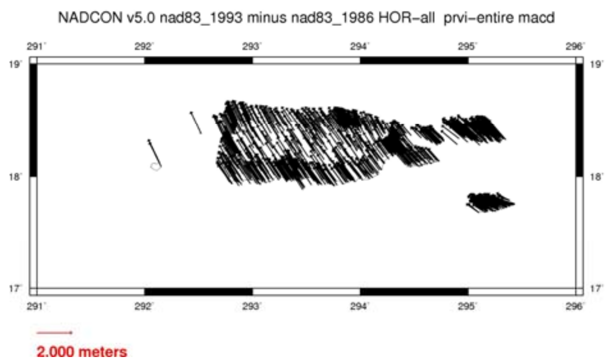

Figure 6-131: All horizontal vectors for NAD 83(1986)/NAD 83(1993)/PRVI.

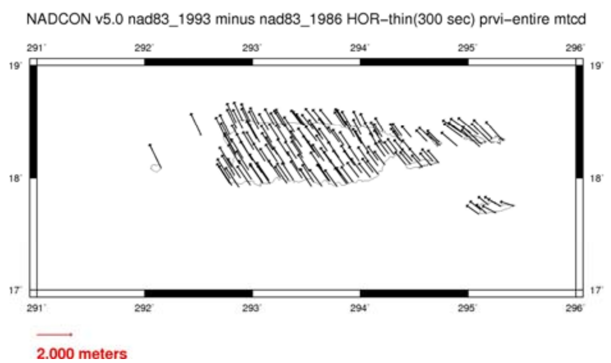

Figure 6-132: Thinned horizontal vectors after applying 5' grid spacing for NAD 83(1986)/NAD 83(1993)/PRVI.

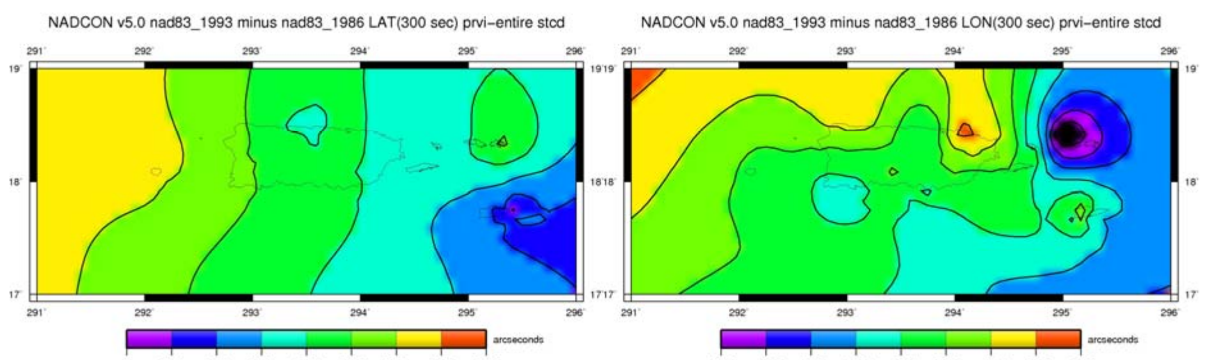

Figure 6-133: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1986)/NAD 83(1993)/PRVI.

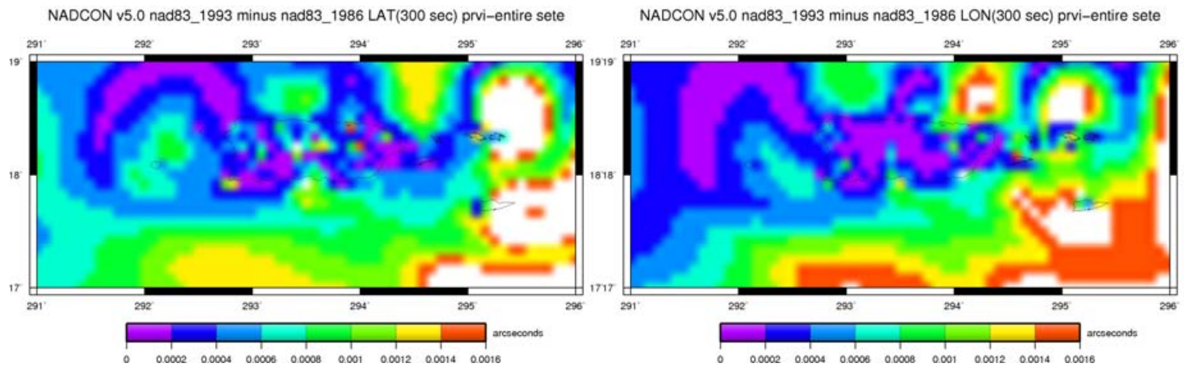

Figure 6-134: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1986)/NAD 83(1993)/PRVI.

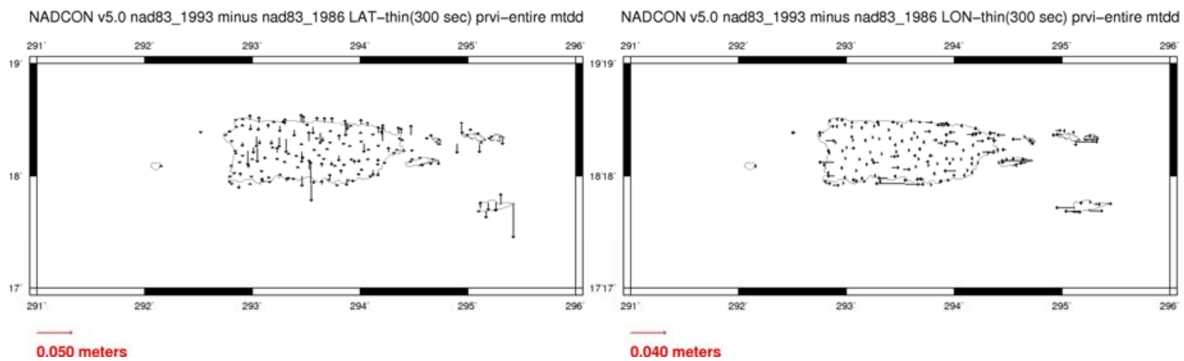

Figure 6-135: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 83(1986)/NAD 83(1993)/PRVI.

6.5.3 Puerto Rico & U.S. Virgin Islands / NAD 83(1993) / NAD 83(1997) / 3-D

6.5.3.1 Horizontal

The horizontal transformation for NAD 83(1993) to NAD 83(1997) has a median of 0.29 meters, with clusters of smaller vectors on the Virgin Islands (Figure 6-136). The 20-40 points per cell threshold was achievable with 15' and coarser grids and the field is very consistent in Puerto Rico, however the authors selected the 1' grid to capture the rapidly changing field in the northern US Virgin Islands (St. Thomas & St. John - see Figure 6-136). Even with this fine grid spacing, residuals in the northern Virgin Islands reach 5 cm, but are small on Puerto Rico (Figure 6-140).

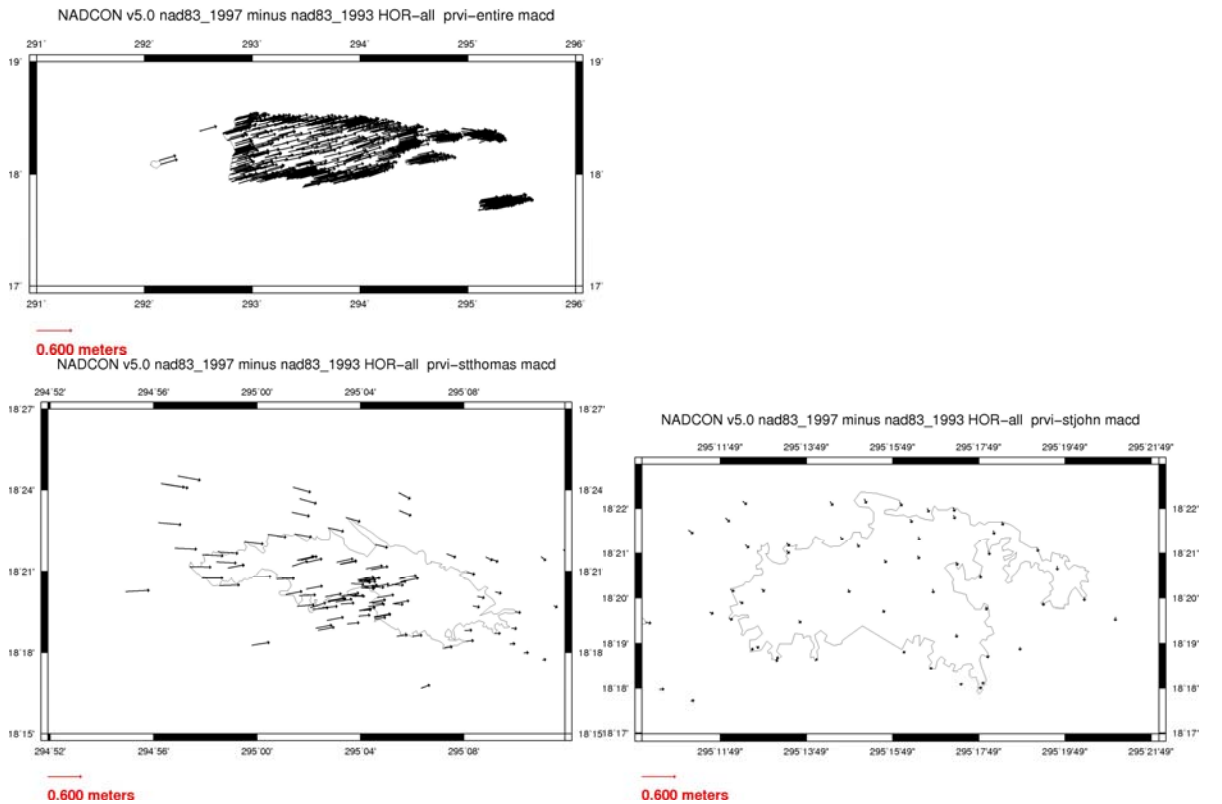

Figure 6-136: All horizontal vectors, for the entire PRVI region (upper left), and zoomed in on St. Thomas (bottom left) and St. John (bottom right) to highlight the rapidly changing field for NAD 83(1993)/NAD 83(1997)/PRVI.

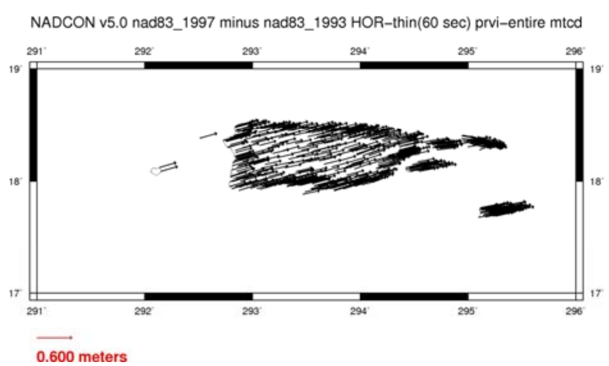

Figure 6-137: Thinned horizontal vectors after applying 1' grid spacing for NAD 83(1993)/NAD 83(1997)/PRVI.

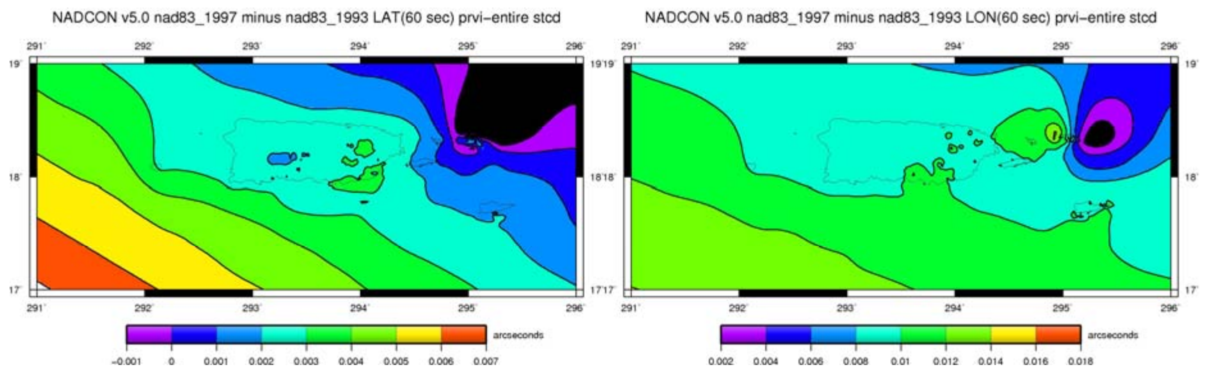

Figure 6-138: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1993)/NAD 83(1997)/PRVI.

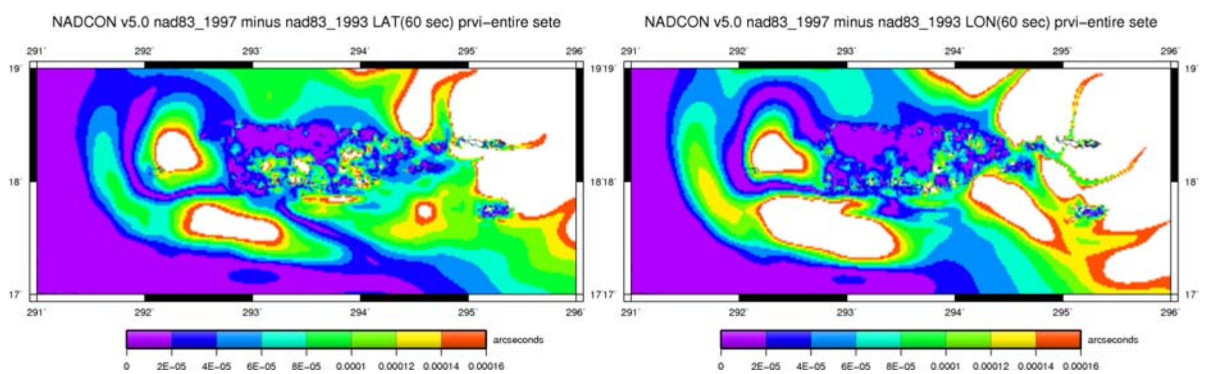

Figure 6-139: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1993)/NAD 83(1997)/PRVI.

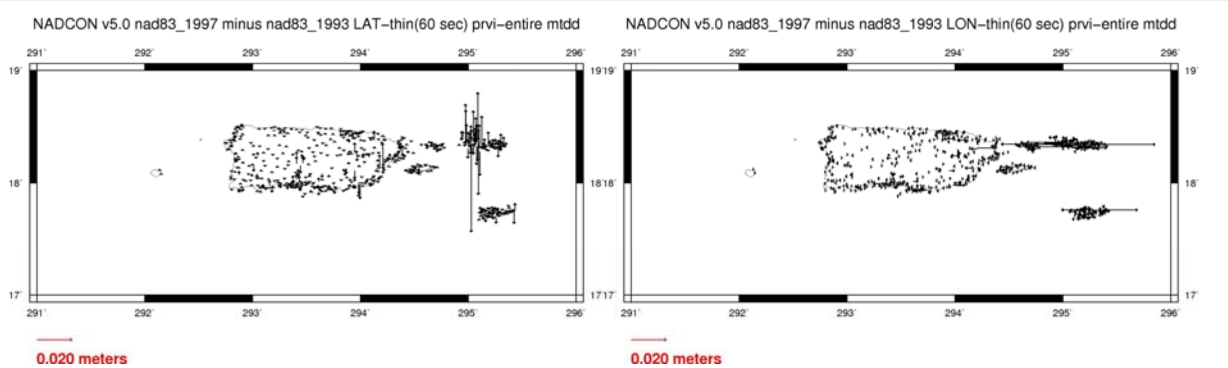

Figure 6-140: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 83(1993)/NAD 83(1997)/PRVI.

6.5.3.2 Vertical

The vertical field is sparsely populated, but uniformly down with some variability in magnitude, from 4 to 15 cm (Figure 6-141). The 5' grid was chosen because this grid left multiple thinned vectors in the Virgin

Islands (Figure 6-142), and with only 2 exceptions, resulted in very small residuals throughout the region (Figure 6-145).

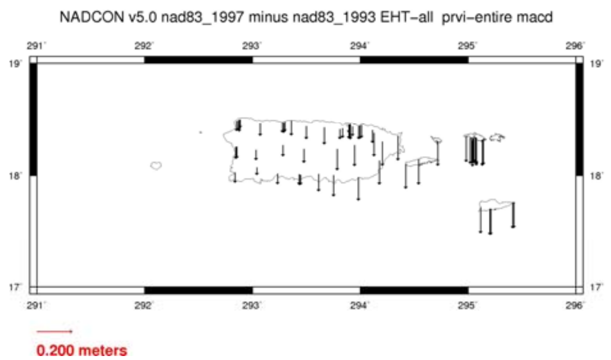

Figure 6-141: All vertical vectors for NAD 83(1993)/NAD 83(1997)/PRVI.

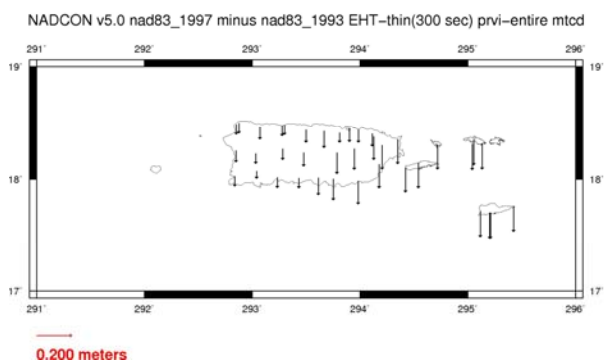

Figure 6-142: Thinned vertical vectors after applying 5' grid spacing for NAD 83(1993)/NAD 83(1997)/PRVI.

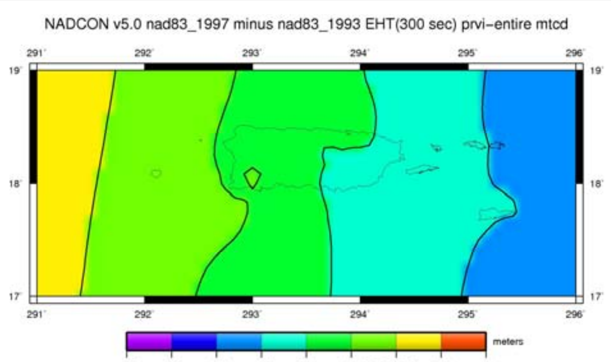

Figure 6-143: Vertical transformation, in meters for NAD 83(1993)/NAD 83(1997)/PRVI.

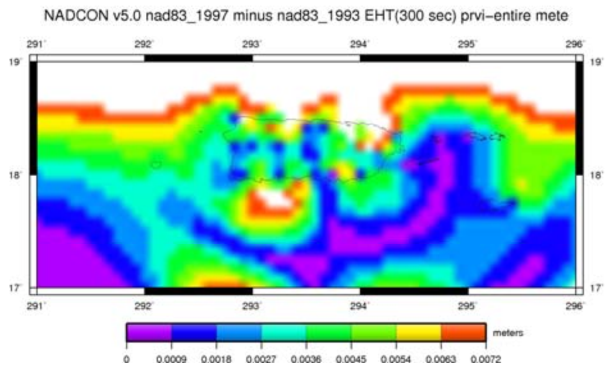

Figure 6-144: Errors for vertical transformation, in meters for NAD 83(1993)/NAD 83(1997)/PRVI.

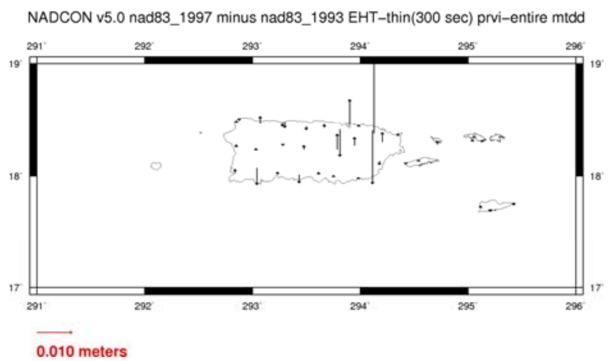

Figure 6-145: Thinned vector residuals (coordinate differences, minus the transformation grid), in meters for NAD 83(1993)/NAD 83(1997)/PRVI.

6.5.4 Puerto Rico & U.S. Virgin Islands / NAD 83(1997) / NAD 83(2002) / 3-D

6.5.4.1 Horizontal

With 56 points, the horizontal field is too sparse to have the grid selection driven by points-per-cell requirements. The 5' grid was chosen as a nice equalization between thinned and dropped residuals being small (approximately 1 cm length, see Figure 6-150) without going so fine as to accept all vectors.

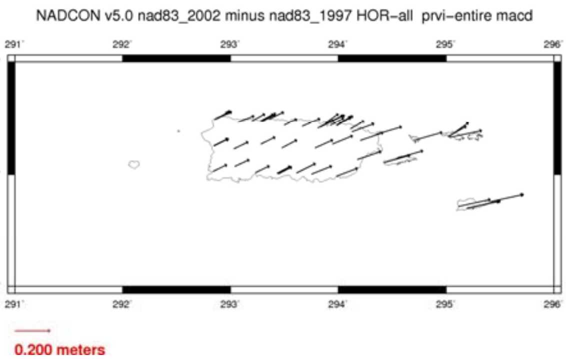

Figure 6-146: All horizontal vectors for NAD 83(1997)/NAD 83(2002)/PRVI.

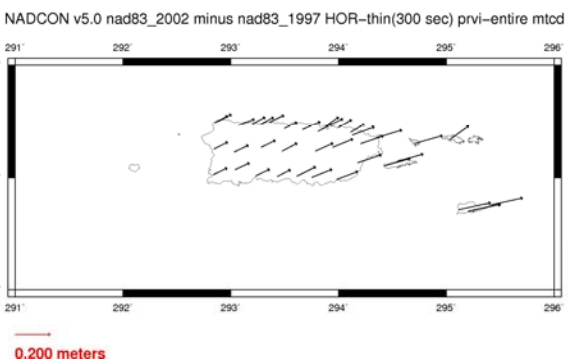

Figure 6-147: Thinned horizontal vectors after applying 5' grid spacing for NAD 83(1997)/NAD 83(2002)/PRVI.

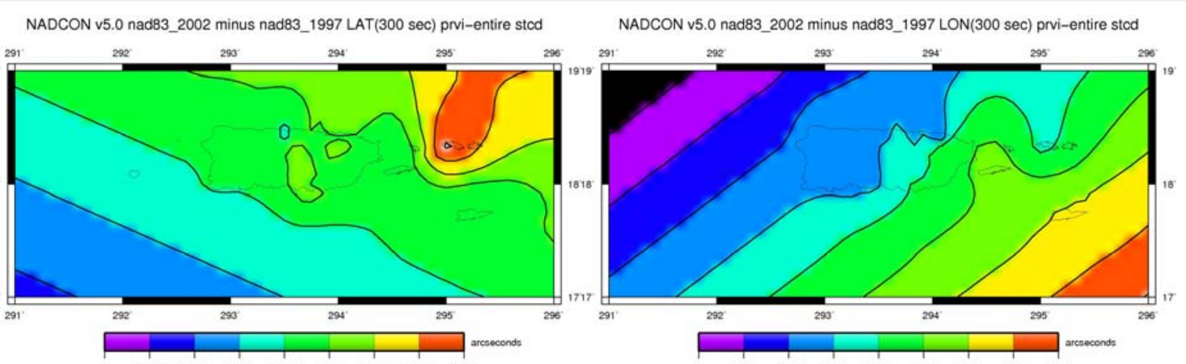

Figure 6-148: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1997)/NAD 83(2002)/PRVI.

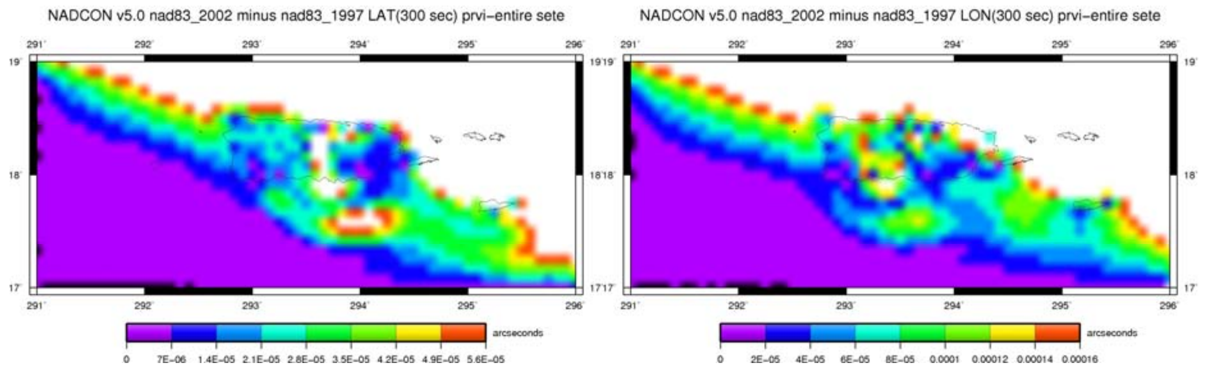

Figure 6-149: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1997)/NAD 83(2002)/PRVI.

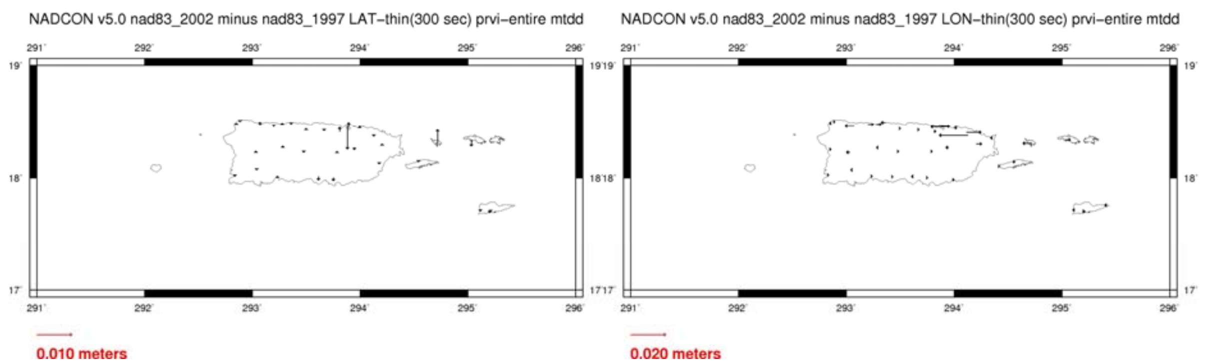

Figure 6-150: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 83(1997)/NAD 83(2002)/PRVI.

6.5.4.2 Vertical

The vertical field has some significant differences across this small region, but with those differences change systematically, not randomly, from "large down" in the west to "medium, up" in the east. Vectors vary between approximately 15 cm down to 10 cm up (Figure 6-151). The 3' grid was chosen for the final grid, due to thinned and dropped residuals of 1 cm or less (Figure 6-155); 5' and larger grids possessed 2 cm residuals, thus supporting selecting the 3' grid.

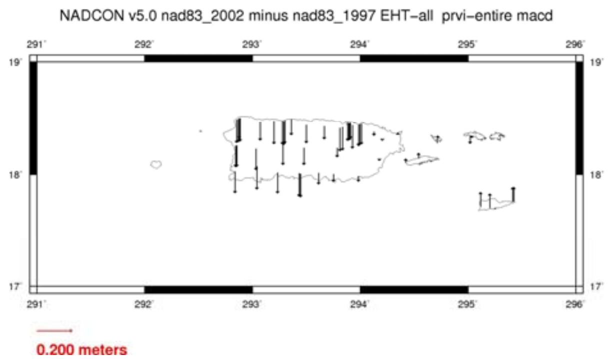

Figure 6-151: All vertical vectors for NAD 83(1997)/NAD 83(2002)/PRVI.

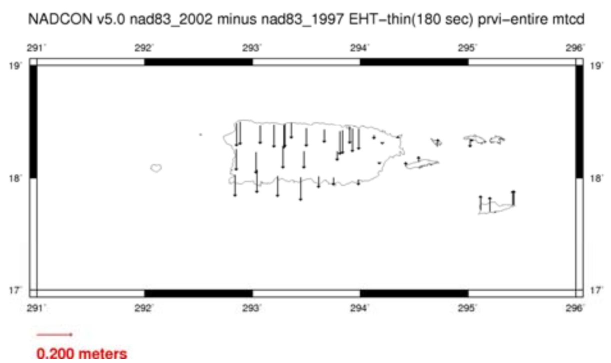

Figure 6-152: Thinned vertical vectors after applying 3' grid spacing for NAD 83(1997)/NAD 83(2002)/PRVI.

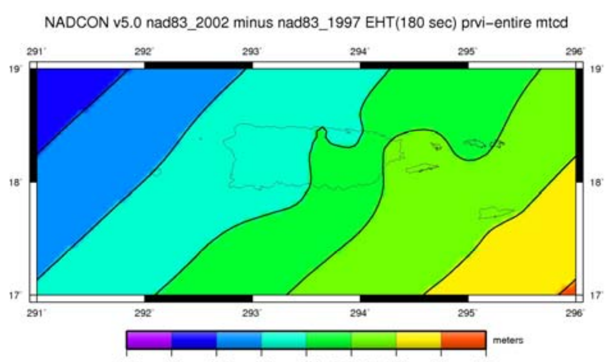

Figure 6-153: Vertical transformation, in meters for NAD 83(1997)/NAD 83(2002)/PRVI.

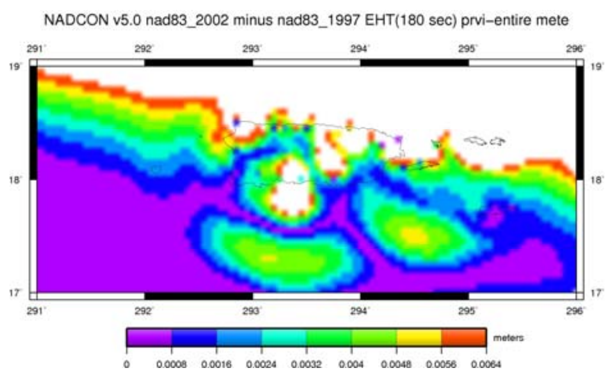

Figure 6-154: Errors for vertical transformation, in meters for NAD 83(1997)/NAD 83(2002)/PRVI.

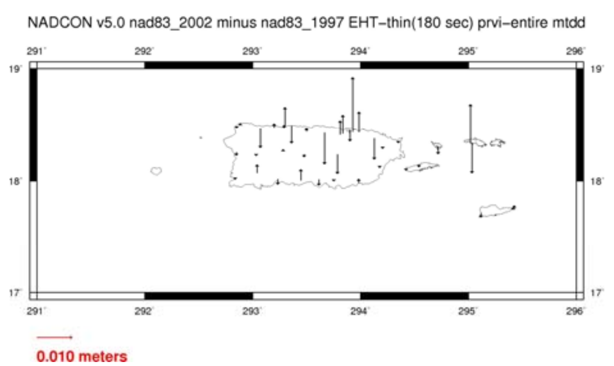

Figure 6-155: Thinned vector residuals (coordinate differences, minus the transformation grid), in meters for NAD 83(1997)/NAD 83(2002)/PRVI.

6.5.5 Puerto Rico & U.S. Virgin Islands / NAD 83(2002) / NAD 83(NSRS2007) / 3-D

6.5.5.1 Horizontal

The horizontal transformation has two different regimes, with 8 cm SE-pointing vectors on St. Thomas and less than 2 cm SW-pointing vectors everywhere else, with a notably messy field on the northern coast of Puerto Rico (Figure 6-156). To get the residuals below the median size of the transformation (1 cm) while also capturing the noticeably large signal on St. Thomas, it was necessary to choose an extremely fine grid. Therefore, the 1’ grid was selected.

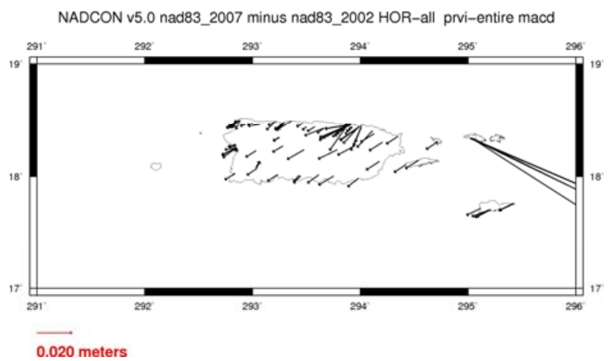

Figure 6-156: All horizontal vectors for NAD 83(2002)/NAD 83(NSRS2007)/PRVI.

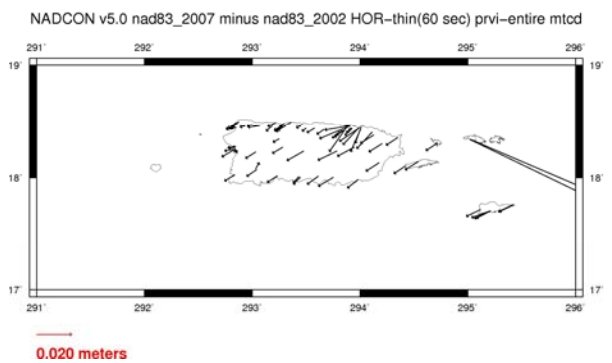

Figure 6-157: Thinned horizontal vectors after applying 1’ grid spacing for NAD 83(2002)/NAD 83(NSRS2007)/PRVI.

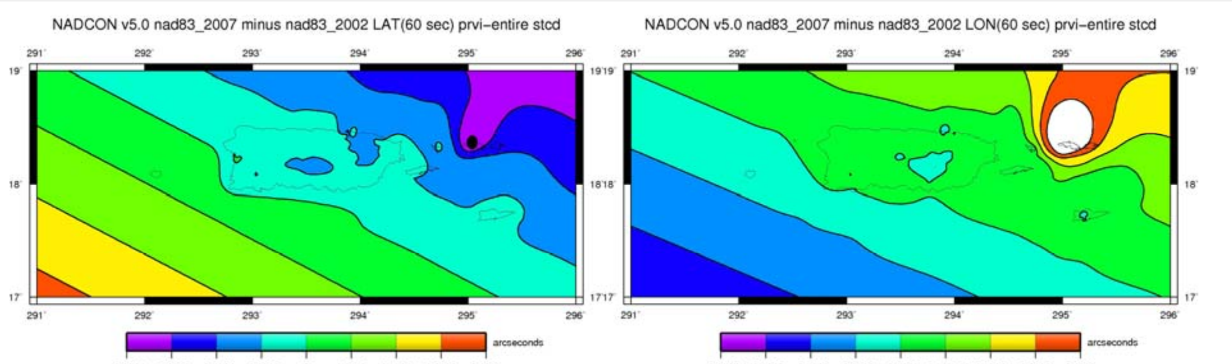

Figure 6-158: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(2002)/NAD 83(NSRS2007)/PRVI.

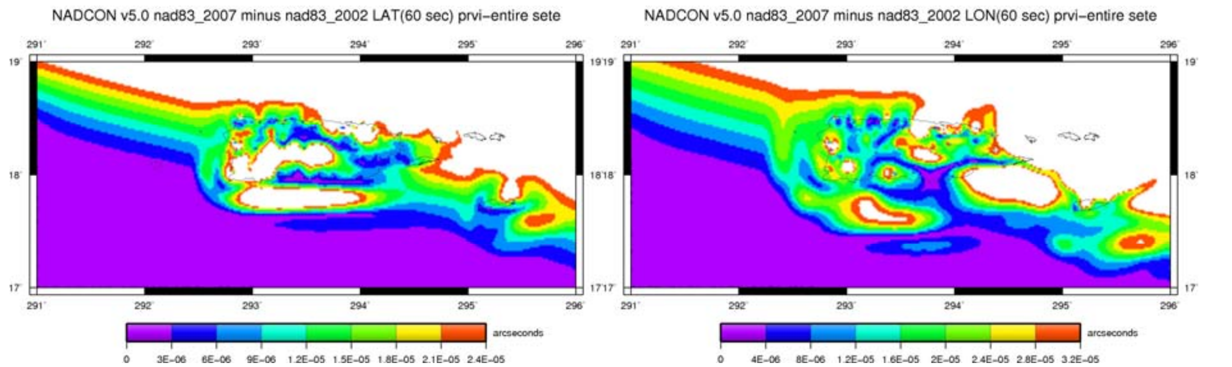

Figure 6-159: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(2002)/NAD 83(NSRS2007)/PRVI.

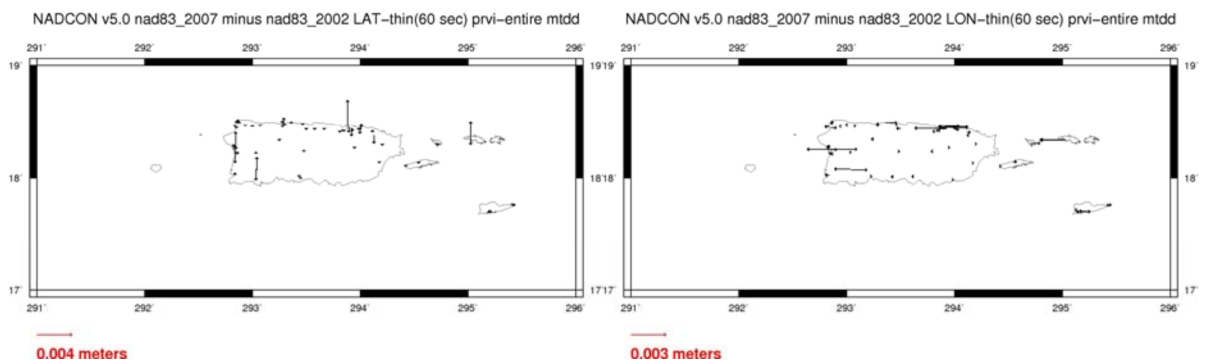

Figure 6-160: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 83(2002)/NAD 83(NSRS2007)/PRVI.

6.5.5.2 Vertical

Similar to the horizontal transformation for the same datum pair, the NAD 83(2002) to NAD 83(2007) ellipsoidal height field is bimodal, with up vectors on St Thomas (6-8 cm) and down vectors everywhere else (median 3 cm) (Figure 6-161). With this field, it was possible to drive the residuals below the level of the transformation at any grid size. For clarity and consistency with the horizontal field, the 1’ grid was selected for the vertical as well. The resulting thinned residuals are extremely small (Figure 6-165).

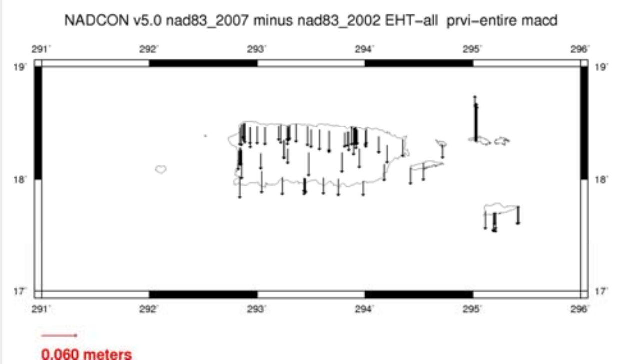

Figure 6-161: All vertical vectors for NAD 83(2002)/NAD 83(NSRS2007)/PRVI.

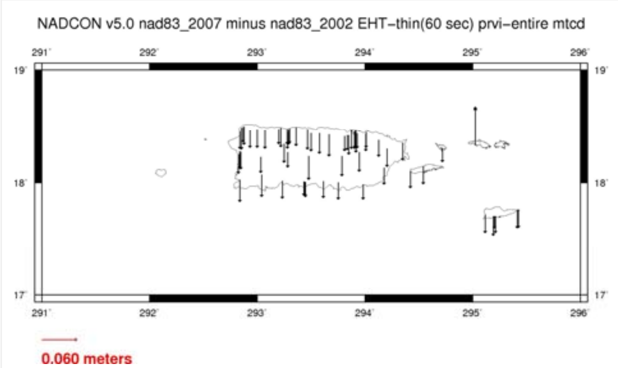

Figure 6-162: Thinned vertical vectors after applying 1' grid spacing for NAD 83(2002)/NAD 83(NSRS2007)/PRVI.

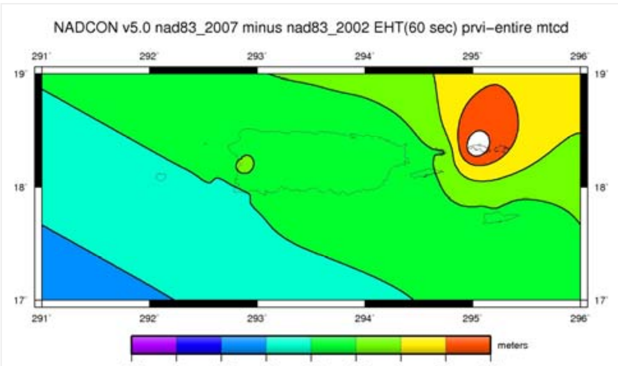

Figure 6-163: Vertical transformation, in meters for NAD 83(2002)/NAD 83(NSRS2007)/PRVI.

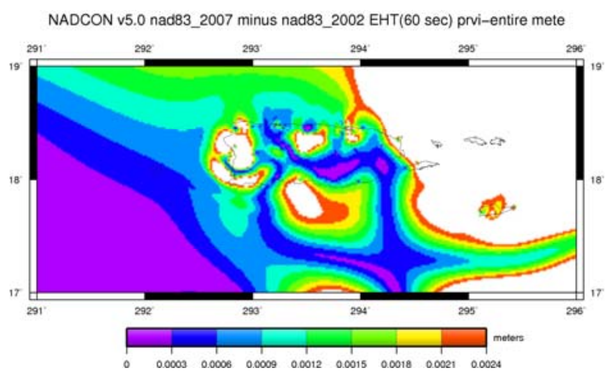

Figure 6-164: Errors for vertical transformation, in meters for NAD 83(2002)/NAD 83(NSRS2007)/PRVI.

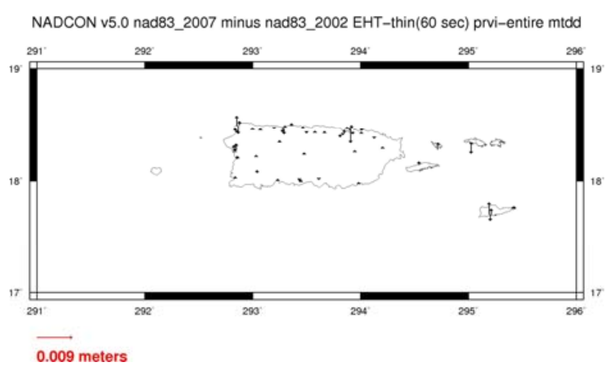

Figure 6-165: Thinned vector residuals (coordinate differences, minus the transformation grid), in meters for NAD 83(2002)/NAD 83(NSRS2007)/PRVI.

6.5.6 Puerto Rico & U.S. Virgin Islands / NAD 83(NSRS2007) / NAD 83(2011) / 3-D

6.5.6.1 Horizontal

The horizontal field for the NAD 83(NSRS2007) to NAD 83(2011) transformation is extremely uniform in both azimuth and magnitude, with median 15 cm. Analysis showed that the majority of residuals were less than 1 mm at all possible grid sizes; the authors chose the 7.5' grid to match the companion vertical grid (see next section).

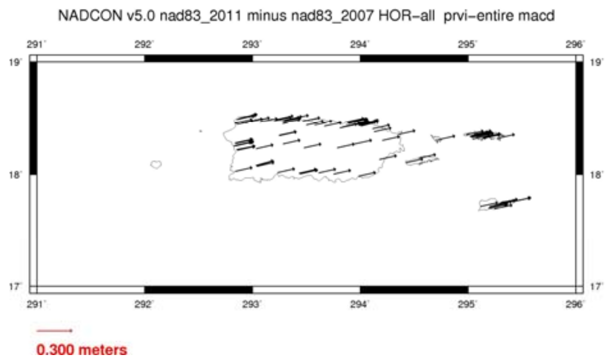

Figure 6-166: All horizontal vectors for NAD 83(NSRS2007)/NAD 83(2011)/PRVI.

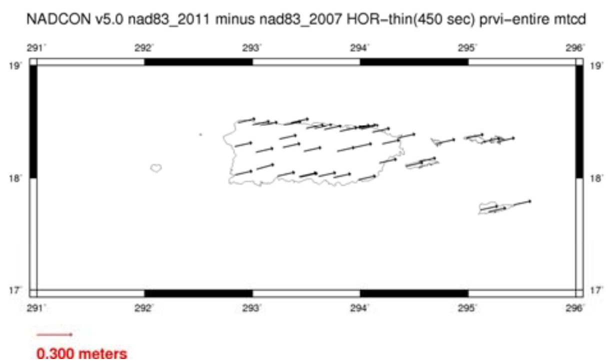

Figure 6-167: Thinned horizontal vectors after applying 7.5' grid spacing for NAD 83(NSRS2007)/NAD 83(2011)/PRVI.

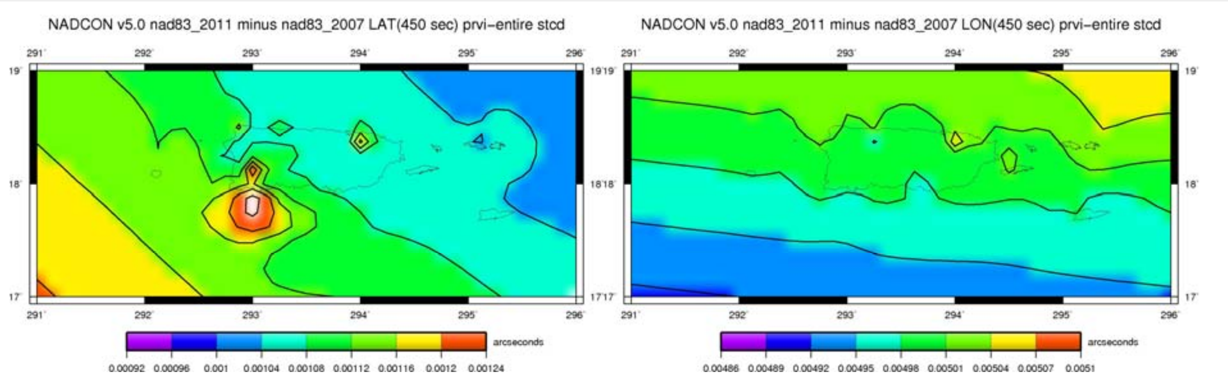

Figure 6-168: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(NSRS2007)/NAD 83(2011)/PRVI.

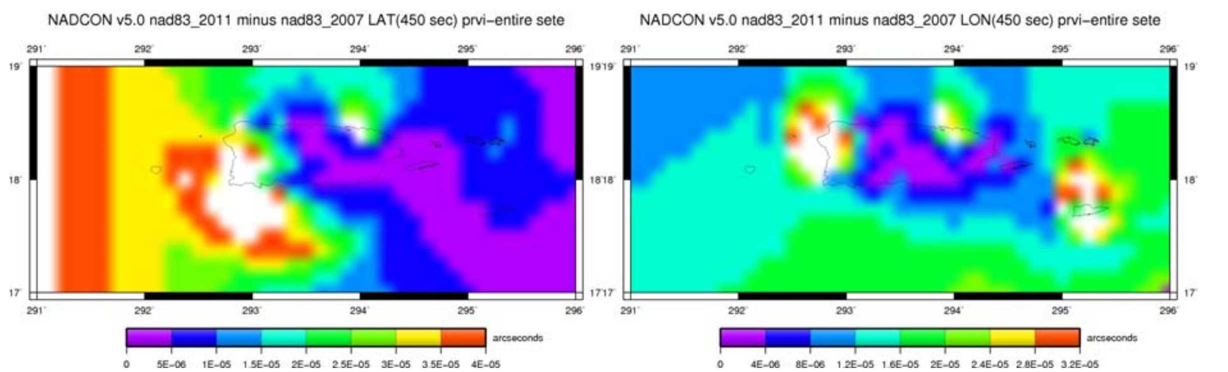

Figure 6-169: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(NSRS2007)/NAD 83(2011)/PRVI.

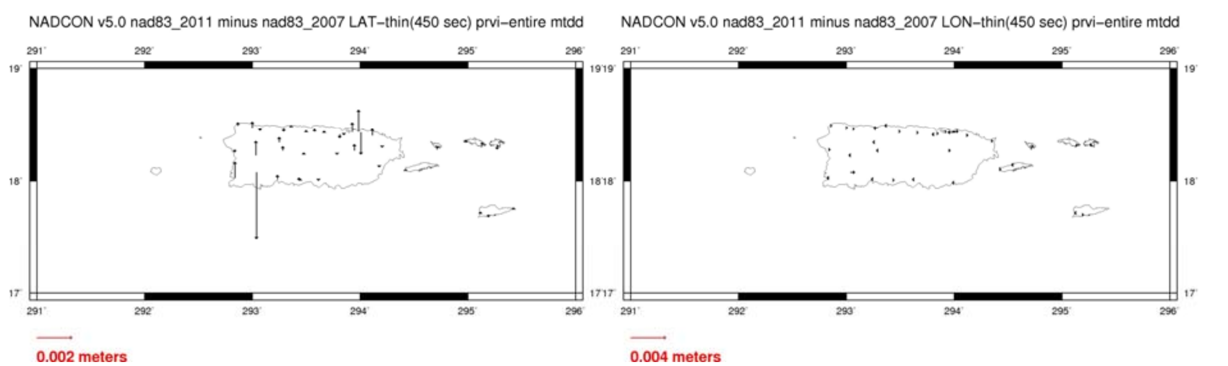

Figure 6-170: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 83(NSRS2007)/NAD 83(2011)/PRVI.

6.5.6.2 Vertical

The ellipsoidal height field is bimodal, with 1.5 cm vectors in the majority of locations but 3 cm vectors on St. Thomas and the west coast of Puerto Rico. The large vectors are mixed in with the median sized vectors, so these should probably be considered not a poor representation of the general field when forming the grid. The authors chose the 7.5' grid because it resulted in small thinned residuals and thinned vector coverage on every outlying island, with dropped residuals which were below the transformation size and also appear to be largely composed of the larger magnitude vectors thought to be spurious.

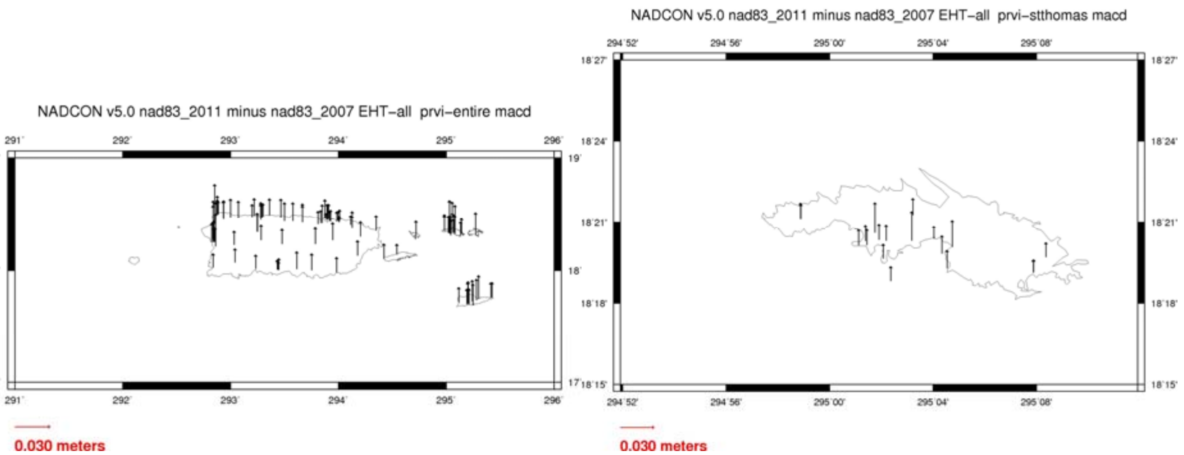

Figure 6-171: All vertical vectors, for the entire prvi region (left) and zoomed in on St. Thomas (right) to show the mix of 3 cm and 8 cm vectors for NAD 83(NSRS2007)/NAD 83(2011)/PRVI.

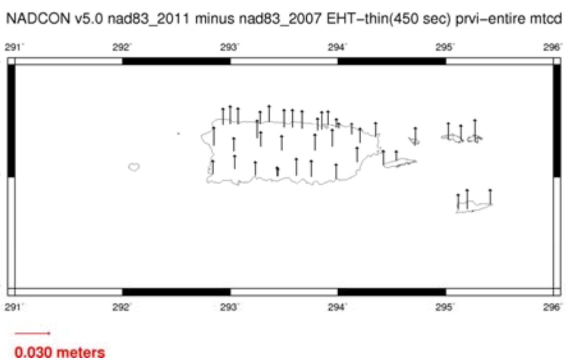

Figure 6-172: Thinned vertical vectors after applying 15' grid spacing for NAD 83(NSRS2007)/NAD 83(2011)/PRVI.

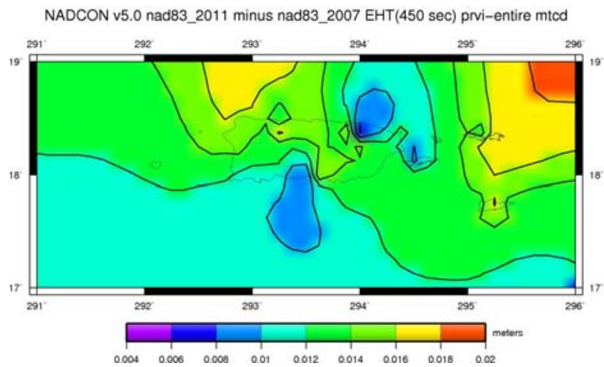

Figure 6-173: Vertical transformation, in meters for NAD 83(NSRS2007)/NAD 83(2011)/PRVI.

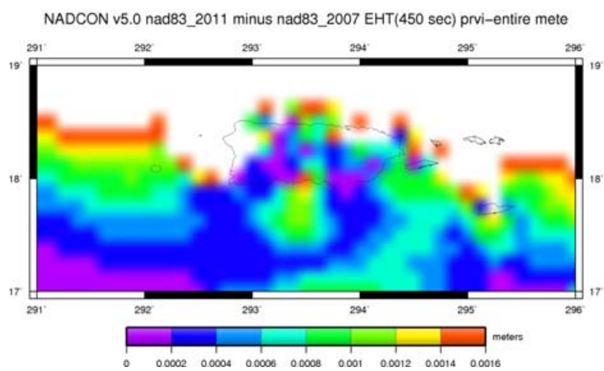

Figure 6-174: Errors for vertical transformation, in meters for NAD 83(NSRS2007)/NAD 83(2011)/PRVI.

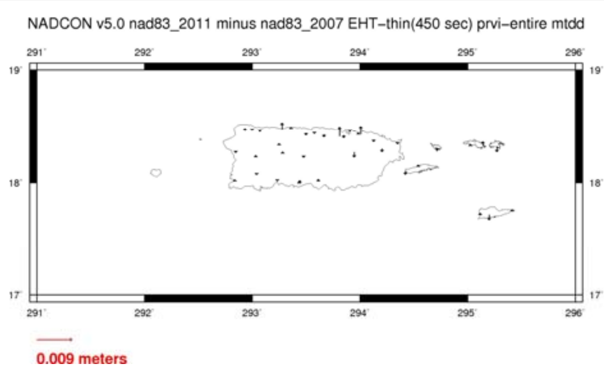

Figure 6-175: Thinned vector residuals (coordinate differences, minus the transformation grid), in meters for NAD 83(NSRS2007)/NAD 83(2011)/PRVI.

6.6 American Samoa (AS)

For NADCON 5.0, the "as" region encompasses much of American Samoa, requiring a bounding box of -13 to -16 latitude and 188-193 longitude. This excludes Swains Island to the north, but does extend eastward enough to encompass Rose Atoll. Swains was excluded for lack of data -- including it would have significantly increased the size of the grids with no data to support it. The islands are small compared to the overall size of the bounding box, resulting in large sections of the grid representing only ocean. To facilitate more detailed analysis, the digital archive includes "zoom" plots of individual islands or sets of islands: Tutuila, Ofu-Olosega + Ta'u, and Rose Atoll (mapflag=1).

Five frame transformations are released as part of NADCON 5.0 (Table 6-8), 3 horizontal and 2 vertical. The horizontal transformation from the AS62 to NAD 83(1993) is extremely large. Subsequent horizontal and vertical transformations are sub-meter. Note that all transformations used a 1' grid size. In none of the transformations was it possible to reach the 20-40 points per cell criteria outlined in Section 4.5, so other criteria were necessary. In all cases, the fields were very consistent and did not require averaging via median filter (so it should be allowable for points to stand alone in a grid cell), and the overall grid dimensions were sufficiently small to support a fine grid, as the resulting transformation files will not be computationally expensive to interpolate through when applying these transformations to real data.

Table 6-8: NADCON 5.0 Transformations for American Samoa

old datum (od)	*new datum (nd)*	*# of points*	*# outliers*	*# thinned points*	*transformation size (median)*	*grid size*
Horizontal						
AS62	NAD83_1993	164	3	72	566.177	1'
NAD83_1993	NAD83_2002	189	4	70	0.283	1'
NAD83_2002	NAD83_PA11	55	0	23	0.119	1'
Vertical						
NAD83_1993	NAD83_2002	38	0	15	-0.470	1'
NAD83_2002	NAD83_PA11	54	1	23	-0.081	1'

6.6.1 American Samoa / AS62 / NAD 83(1993) / Horizontal

As stated above, the horizontal transformation magnitude for AS62 to NAD 83(1993) is huge: median 566 meters, but with two different regimes on the island of Tutuila (566 m) and the eastern pair of islands, Ofu-Olosega and Ta'u (581 m). Note that there is no data on Rose island (far east). On each individual island, the vectors are highly consistent, so it is not necessary to force a coarse grid size to allow multiple vectors per cell for the median filter. All grid sizes studied yielded nearly identical transformations and similar sizes to the error grids. In the end, the authors selected a fine grid size of 1’ for this small grid area.

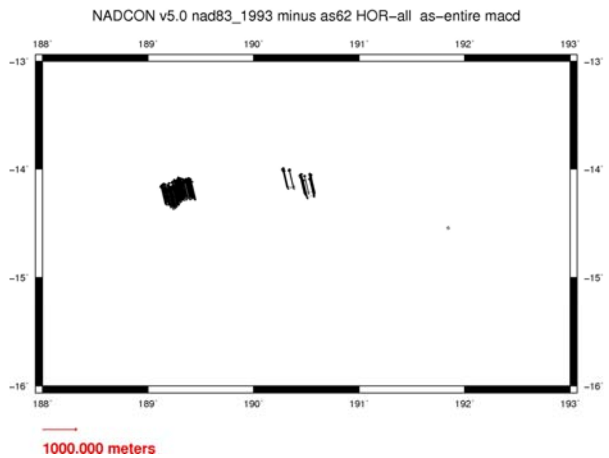

Figure 6-176: All horizontal vectors for AS62/NAD 83(1993)/AS.

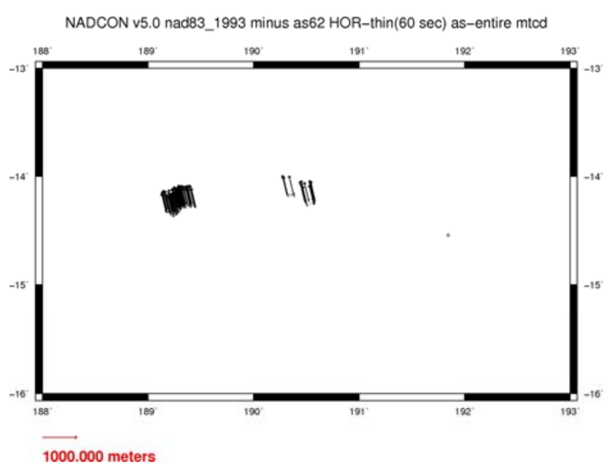

Figure 6-177: Thinned horizontal vectors after applying 1’ grid spacing for AS62/NAD 83(1993)/AS.

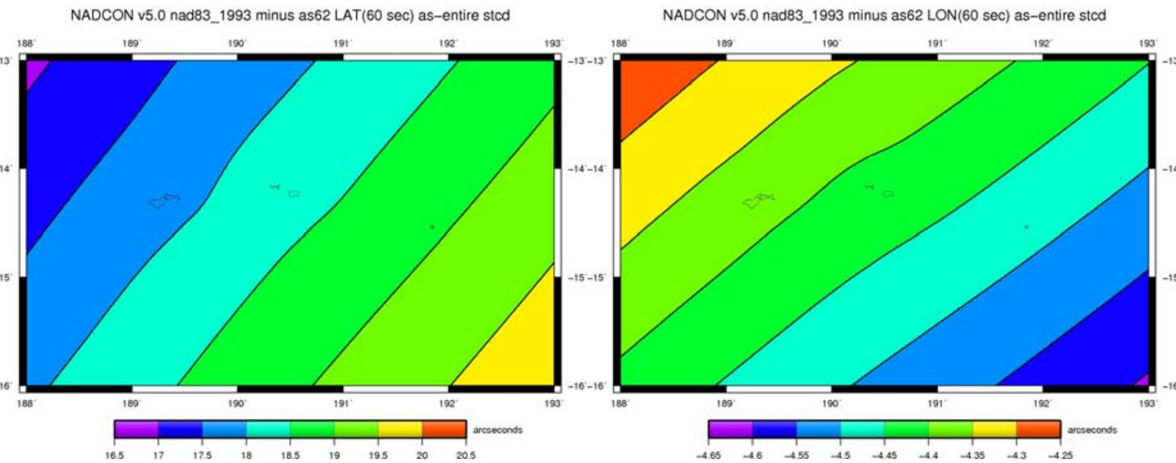

Figure 6-178: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for AS62/NAD 83(1993)/AS.

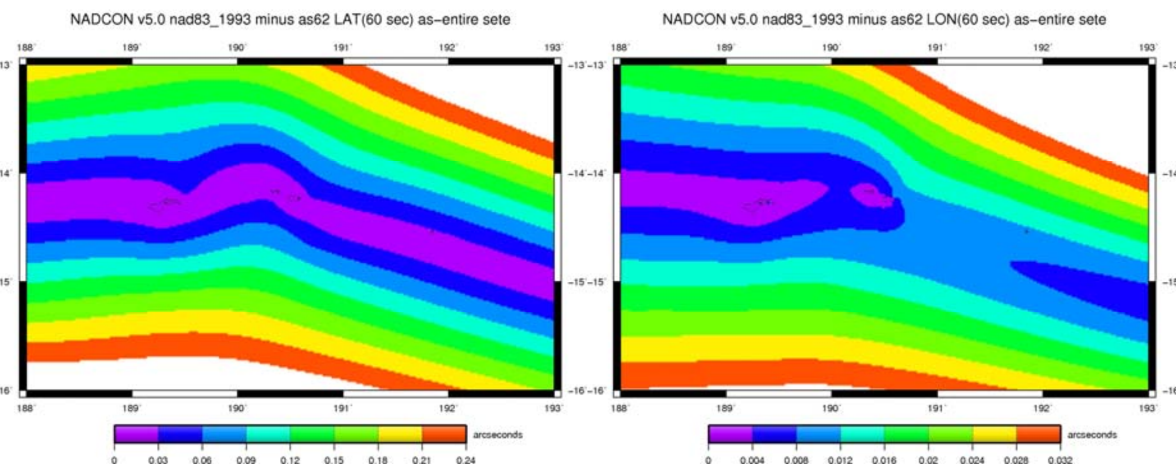

Figure 6-179: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for AS62/NAD 83(1993)/AS.

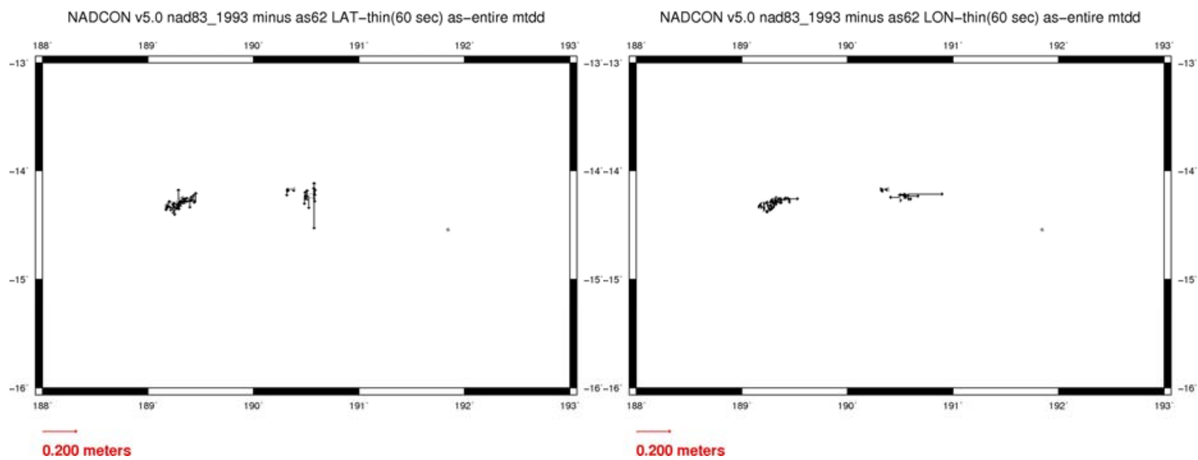

Figure 6-180: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for AS62/NAD 83(1993)/AS.

6.6.2 American Samoa / NAD 83(1993) / NAD 83(2002) / 3-D

6.6.2.1 Horizontal

The horizontal transformation has a median value of 28 cm, but there is some variation in azimuth and magnitude in different areas, most notably on Ofu-Olosega and Ta'u (Figure 6-181). The variations occur in self-consistent groups of multiple vectors, so we believe it to be signal and not spurious noise. To capture these variations, a fine grid is required, thus we selected 1' for the final grid spacing. Unfortunately at any grid spacing it is impossible to avoid relatively large residuals in the Ofu-Olosega and Ta'u zones (Figure 6-185), which is not surprising given that there are two conflicting sub-fields on top of each other (Figure 6-181).

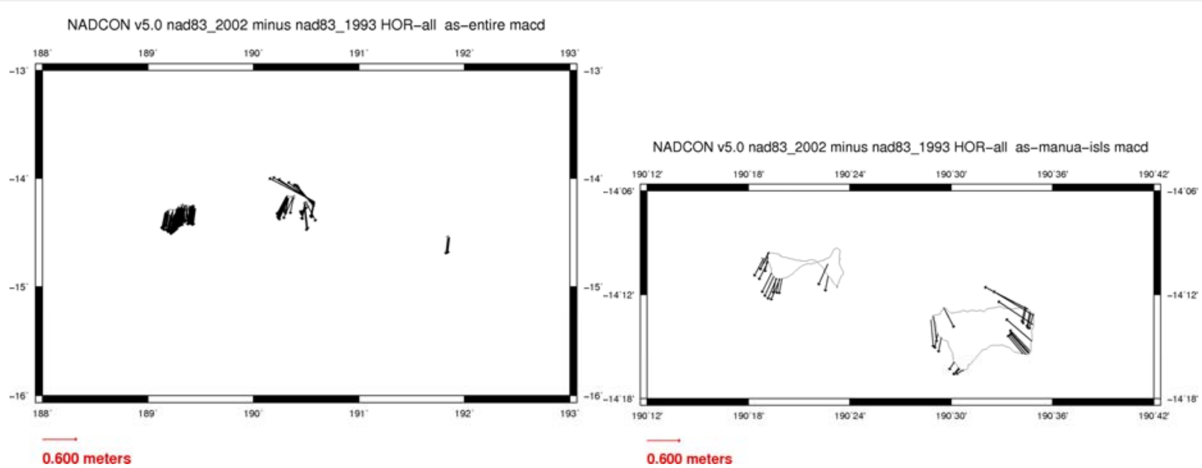

Figure 6-181: All horizontal vectors, for the entire region (left) and zoomed in on the islands of Ofu-Osega and Ta'u (right) for NAD 83(1993)/NAD 83(2002)/AS.

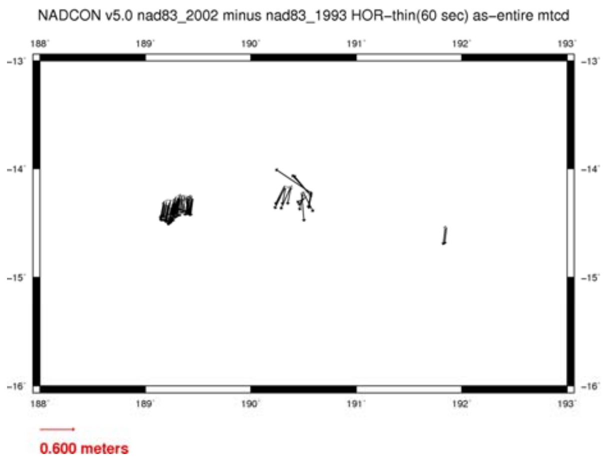

Figure 6-182: Thinned horizontal vectors after applying 1' grid spacing for NAD 83(1993)/NAD 83(2002)/AS.

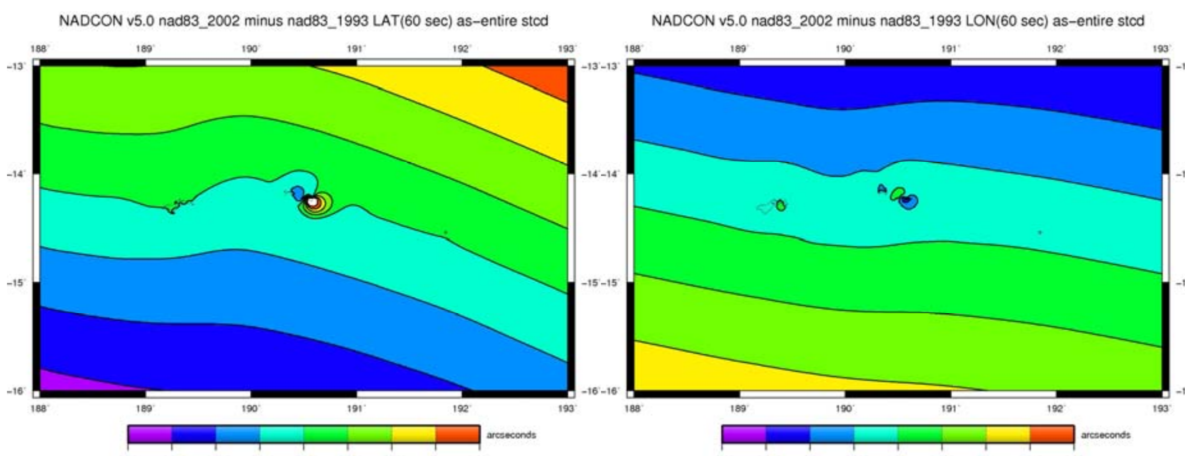

Figure 6-183: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1993)/NAD 83(2002)/AS.

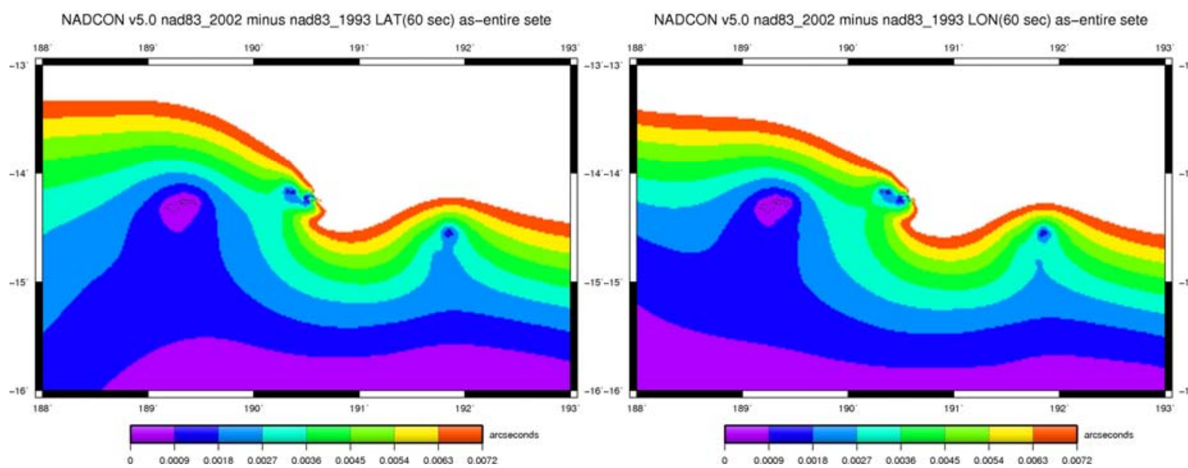

Figure 6-184: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1993)/NAD 83(2002)/AS.

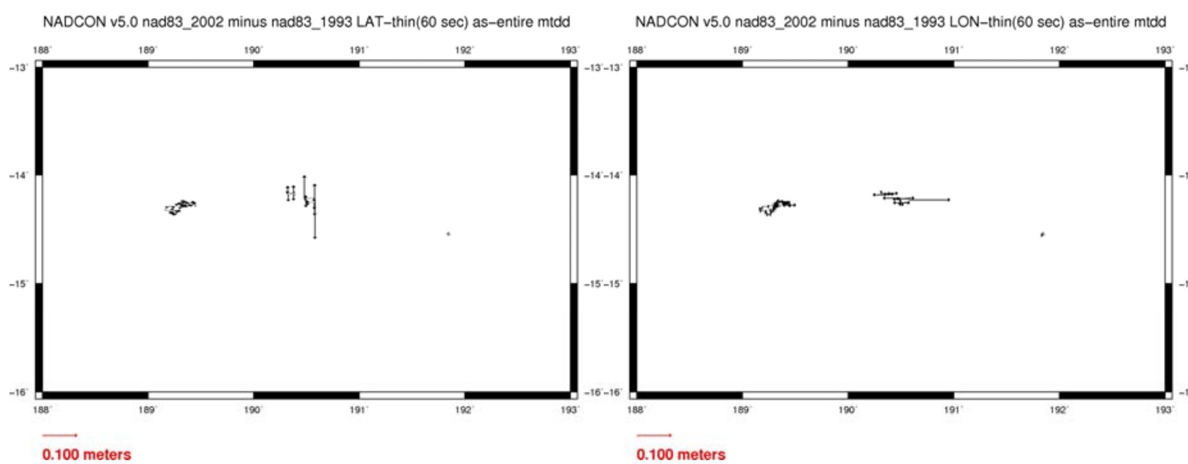

Figure 6-185: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 83(1993)/NAD 83(2002)/AS.

6.6.2.2 Vertical

The vertical field is uniformly down, with magnitudes in the 40-50 cm range. All grid sizes at 5’ and finer resulted in thinned residuals which do not exceed 5% of the transformation size for the majority of vectors, and does not exceed 20% for all vectors (Figure 6-190). For consistency across the various American Samoa transformations, we choose the 1’ grid size.

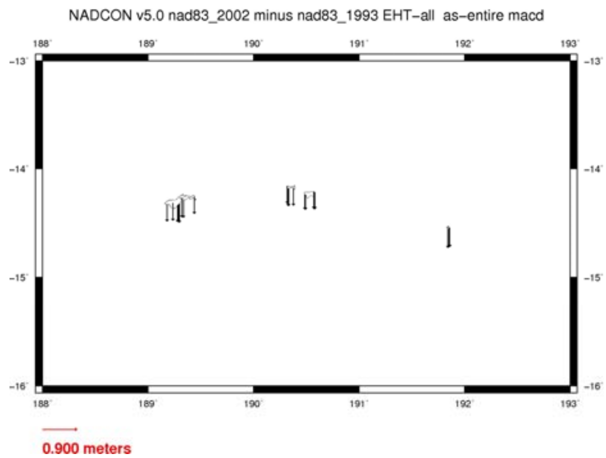

Figure 6-186: All vertical vectors for
NAD 83(1993)/NAD 83(2002)/AS.

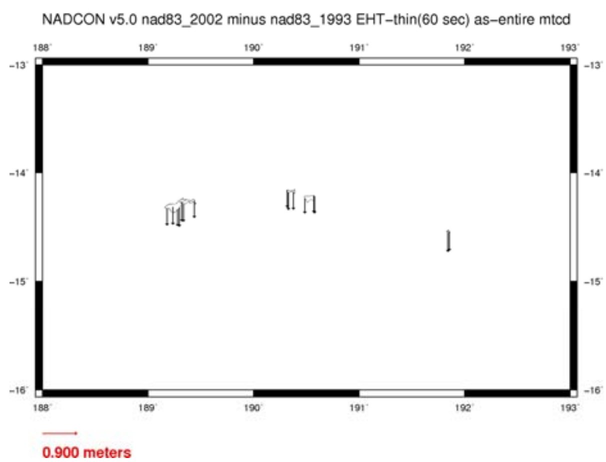

Figure 6-187: Thinned vertical vectors after
applying 1' grid spacing for
NAD 83(1993)/NAD 83(2002)/AS.

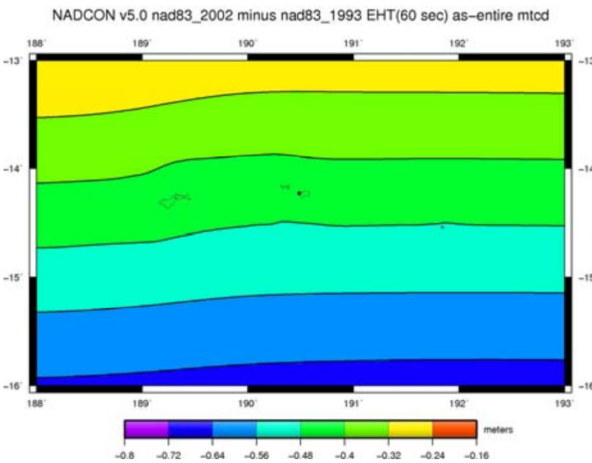

Figure 6-188: Vertical transformation, in meters for NAD 83(1993)/NAD 83(2002)/AS.

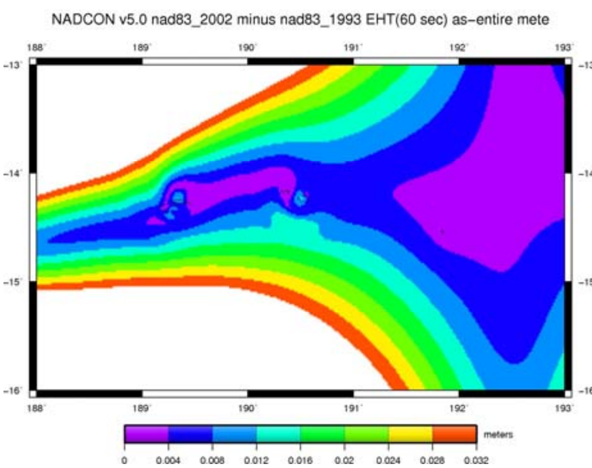

Figure 6-189: Errors for vertical transformation, in meters for NAD 83(1993)/NAD 83(2002)/AS.

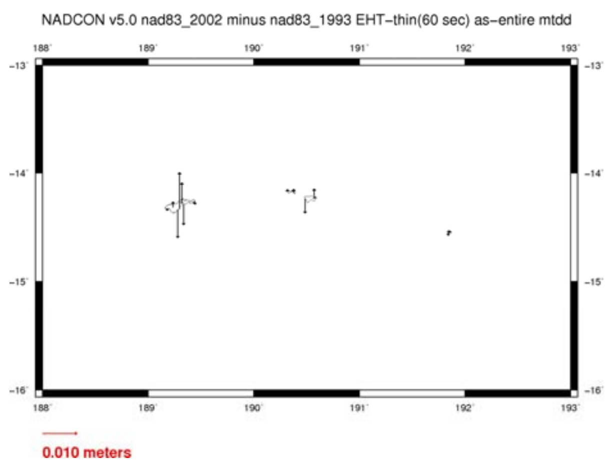

Figure 6-190: Thinned vector residuals (coordinate differences, minus the transformation grid), in meters for NAD 83(1993)/NAD 83(2002)/AS.

6.6.3 American Samoa / NAD 83(2002) / NAD 83(PA11) / 3-D

6.6.3.1 Horizontal

The horizontal field is very consistent, with azimuths to the northeast at about 12 cm magnitude, with only +/- 6mm of variation in magnitude. As with the AS62 to NAD 83(1993) transformation, the authors selected the 1’ grid size because there were no statistical gains by going to coarser grid sizes and the small transformation area meant that a fine grid would not be computationally expensive.

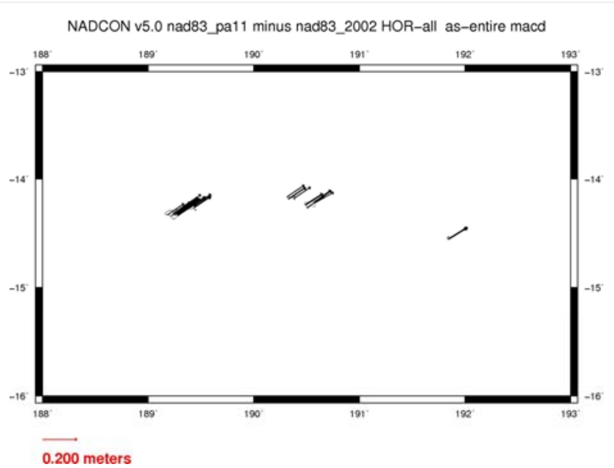

Figure 6-191: All horizontal vectors for NAD 83(2002)/NAD 83(PA11)/AS.

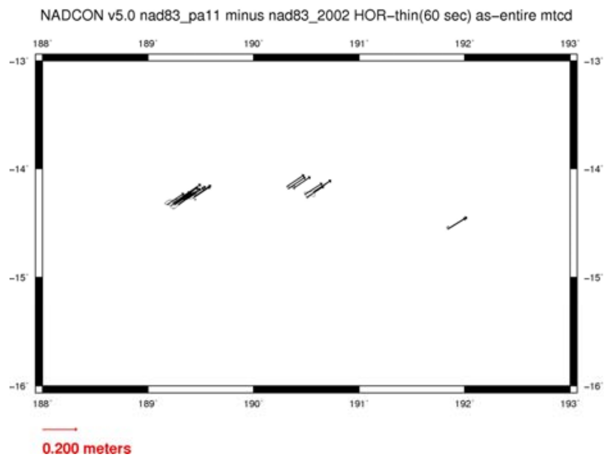

Figure 6-192: Thinned horizontal vectors after applying 1' grid spacing for NAD 83(2002)/NAD 83(PA11)/AS.

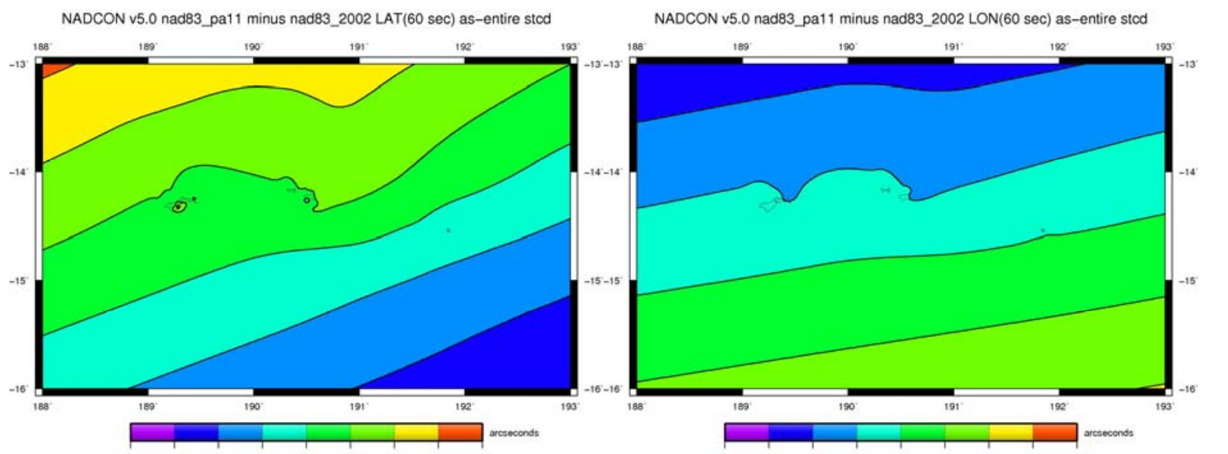

Figure 6-193: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(2002)/NAD 83(PA11)/AS.

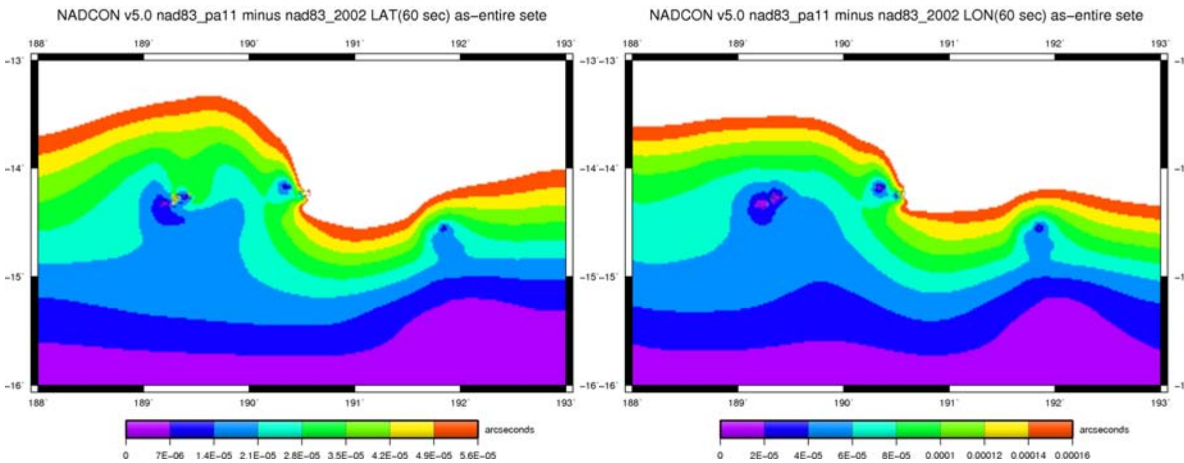

Figure 6-194: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(2002)/NAD 83(PA11)/AS.

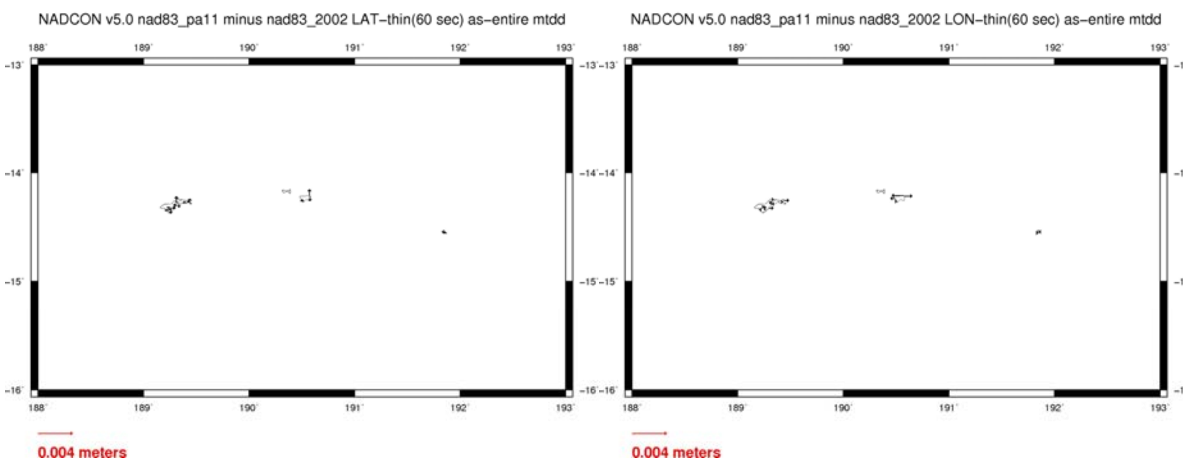

Figure 6-195: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 83(2002)/NAD 83(PA11)/AS.

6.6.3.2 Vertical

The vertical field is uniformly down, with magnitude median -8.1 cm, but with a bimodal field: -7 cm in Rose and parts of Tutuila, but -10 cm on Ofu-Osega and Ta'u and parts of Tutuila. Again, there were no statistical gains to be had with coarse vs. fine grids, so to maintain consistency with other transformations in this region, the authors selected 1' for the final grid size.

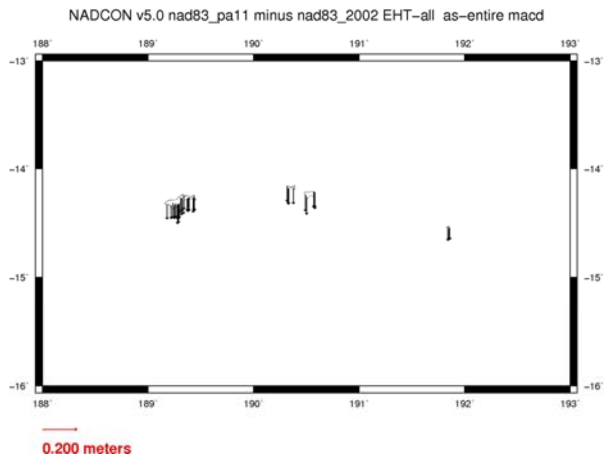

Figure 6-196: All vertical vectors for NAD 83(2002)/NAD 83(PA11)/AS.

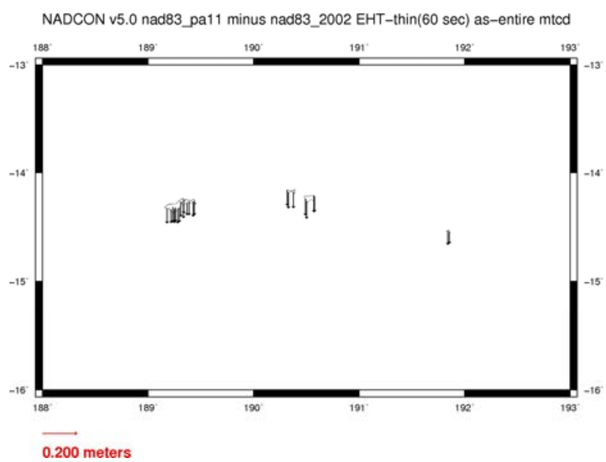

Figure 6-197: Thinned vertical vectors after applying 1' grid spacing for NAD 83(2002)/NAD 83(PA11)/AS.

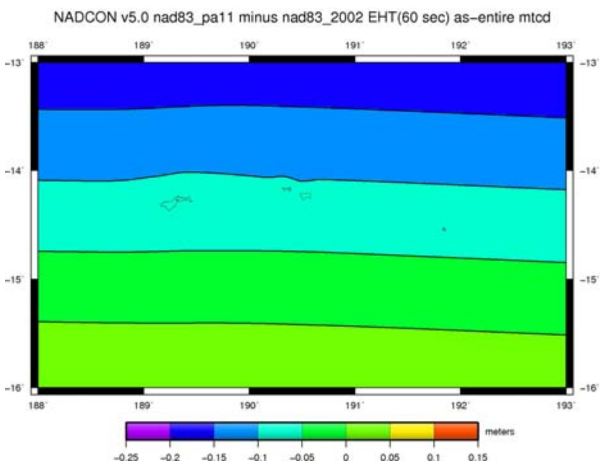

Figure 6-198: Vertical transformation, in meters for NAD 83(2002)/NAD 83(PA11)/AS.

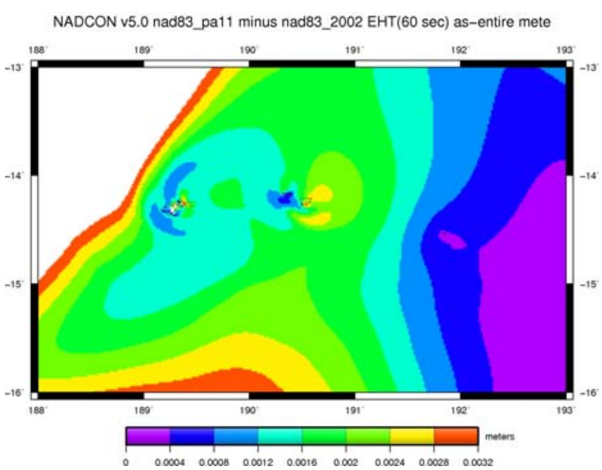

Figure 6-199: Errors for vertical transformation, in meters for NAD 83(2002)/NAD 83(PA11)/AS.

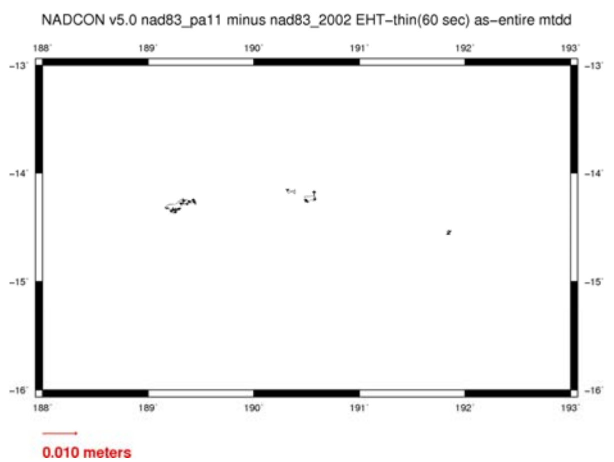

Figure 6-200: Thinned vector residuals (coordinate differences, minus the transformation grid), in meters for NAD 83(2002)/NAD 83(PA11)/AS.

6.7 Guam and the Commonwealth of the Northern Mariana Islands (guamcnmi)

For NADCON 5.0, the "guamcnmi" region encompasses the island of Guam as well as all of the Commonwealth of the Northern Mariana Islands. These islands form a long archipelago, requiring a long but narrow bounding box (12-22 latitude, 143-147 longitude) for the gridded area. To facilitate more detailed analysis, the digital archive includes "zoom" plots of individual islands or sets of islands: Guam, Rota, Tinian + Saipan; all islands north of 16 deg latitude are grouped into a 'northern islands' plot (mapflag=1).

Three frame transformations are released as part of NADCON 5.0 (Table 6-9), the latter two of which include ellipsoidal heights. Data are sparse for all transformations, with substantial gaps between islands with control. The GU63/NAD 83(1993) transformation is strictly horizontal but with a large magnitude. The other two transformations (NAD 83(1993)/NAD 83(2002) and NAD 83(2002)/NAD 83(MA11)) are sub-meter. On the whole, the magnitude of the transformations combined with the sparsity of the data dictated that relatively coarse grids would adequately capture the transformation.

Table 6-9: NADCON 5.0 Transformations for Guam and the Commonwealth of the Northern Mariana Islands

frame1	*frame2*	*# of points*	*# outliers*	*# thinned points*	*transformation size (median)*	*grid size*

Horizontal						
GU63	NAD83_1993	175	0	21	306 m	5’
NAD83_1993	NAD83_2002	7	0	5	0.6 m	15’
NAD83_2002	NAD83_MA11	72	3	32	0.025 m (south) 0.08 m (north)	3’
Vertical						
NAD83_1993	NAD83_2002	6	0	4	-0.6 m	15’
NAD83_2002	NAD83_MA11	71	4	21	0.066 m	5’

6.7.1 Guam & CNMI / GU63 / NAD 83(1993) / Horizontal

Although the archipelago and therefore the grid ranges in latitude from 12° to 22°, data for this transformation are only present in the latitude 13°-15.5° range. Therefore we considered only islands between Guam (S) and Saipan (N) when selecting a grid (Figure 6-201). Only horizontal data were available for this transformation.

The horizontal field is visually and statistically uniform with large magnitude (median = 306.35 meters). For all grid sizes analyzed, the thinned vector residuals were very small, at most 36 cm. An extremely coarse grid would have resulted in fewer than 10 points being used to define the grid; to insure a robust number of vectors were captured by the thinned data set, we selected the 5’ grid, yielding 21 points (Figure 6-202). The resulting transformation grids (Figure 6-203) yielded thinned vector residuals which were 30 cm or less (Figure 6-205), which was considered quite successful relative to a 300+ meter transformation.

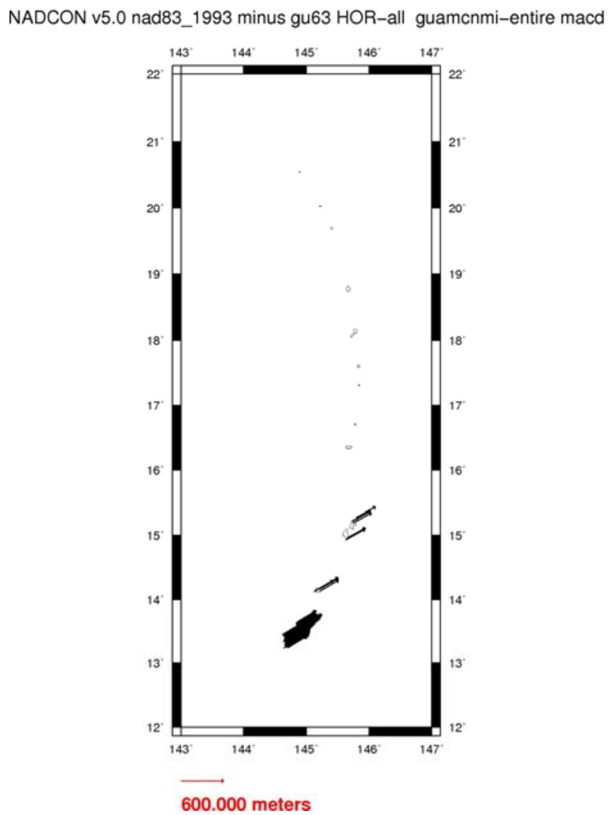

Figure 6-201: All horizontal vectors, GU63/NAD 83(1993)/Guam&CNMI.

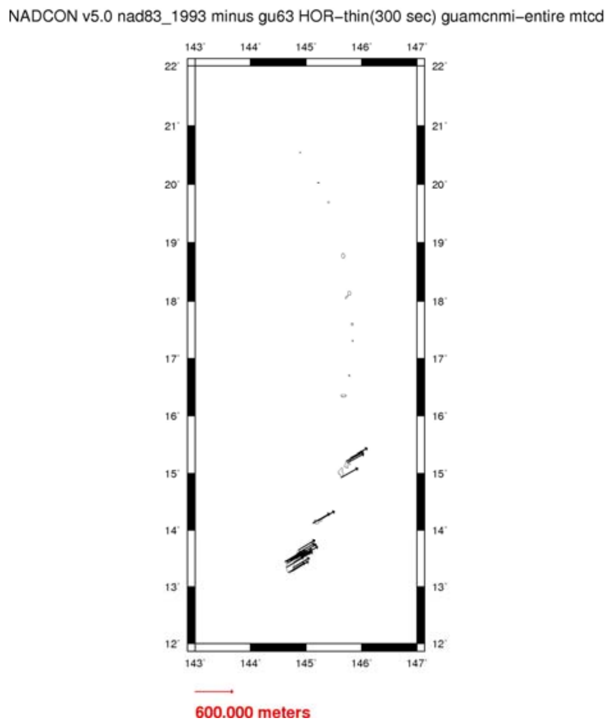

Figure 6-202: Thinned horizontal vectors for 5' grid spacing, GU63/NAD 83(1993)/Guam&CNMI.

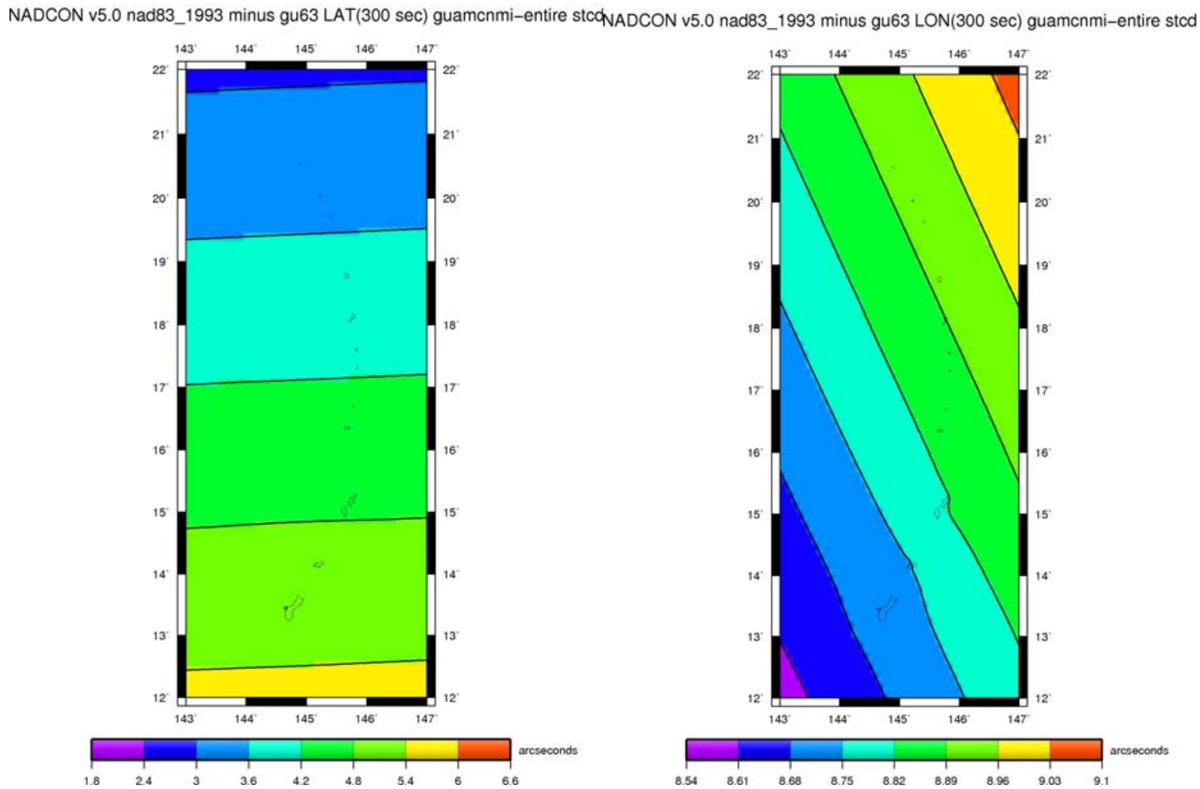

Figure 6-203: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for GU63/NAD 83(1993)/Guam&CNMI.

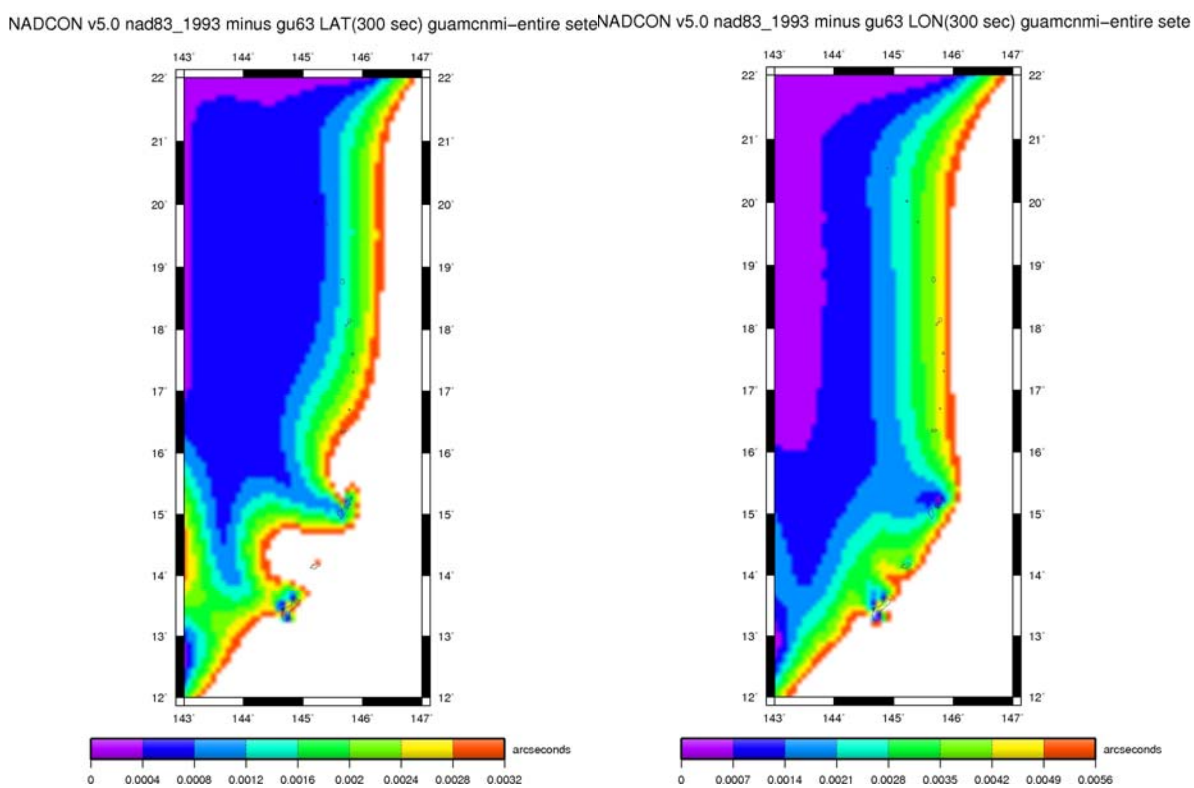

Figure 6-204: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for GU63/NAD 83(1993)/Guam&CNMI.

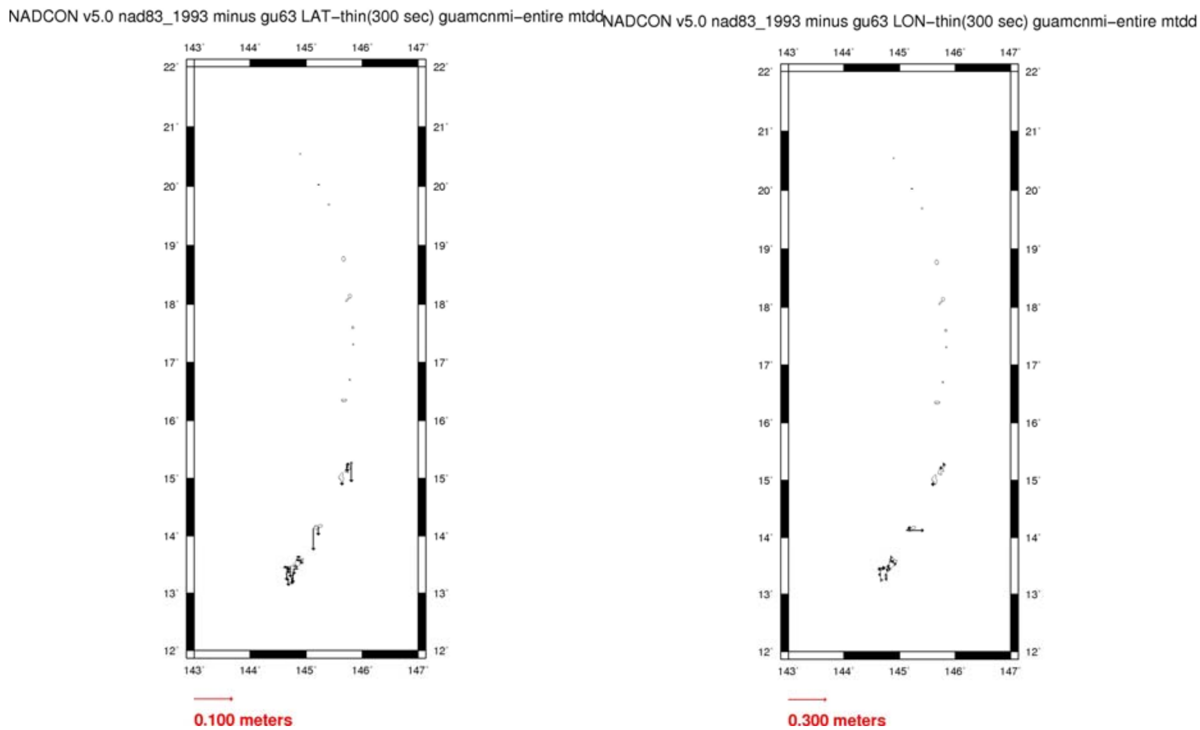

Figure 6-205: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for GU63/NAD 83(1993)/Guam&CNMI.

6.7.2 Guam & CNMI / NAD 83(1993) / NAD 83(2002) / 3-D

6.7.2.1 Horizontal

The horizontal data set had only 7 points: one each on Guam, Saipan, and Pagan, two each on Songsong and Tinian. The vectors vary smoothly from south to north (248 to 263 degrees; 0.56 to 0.71 meters), and the double points on Songsong and Tinian were self-consistent. Therefore we felt it would be reasonable to choose a grid which is somewhat coarse but still retained one point per island. The 15' grid was the coarsest grid which had 5 points (one per island). Figure 6-206 through Figure 6-210 give the horizontal vectors and horizontal transformation with errors and residuals.

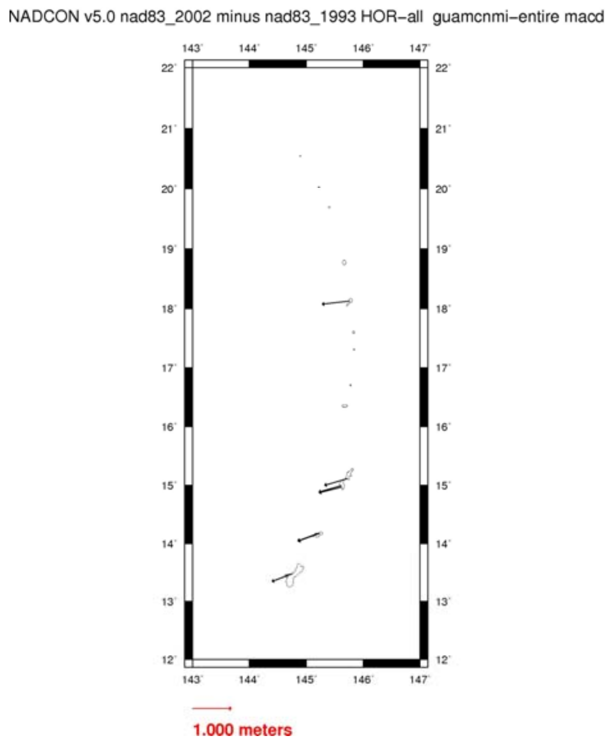

Figure 6-206: All horizontal vectors for NAD 83(1993)/NAD 83(2002)/Guam&CNMI.

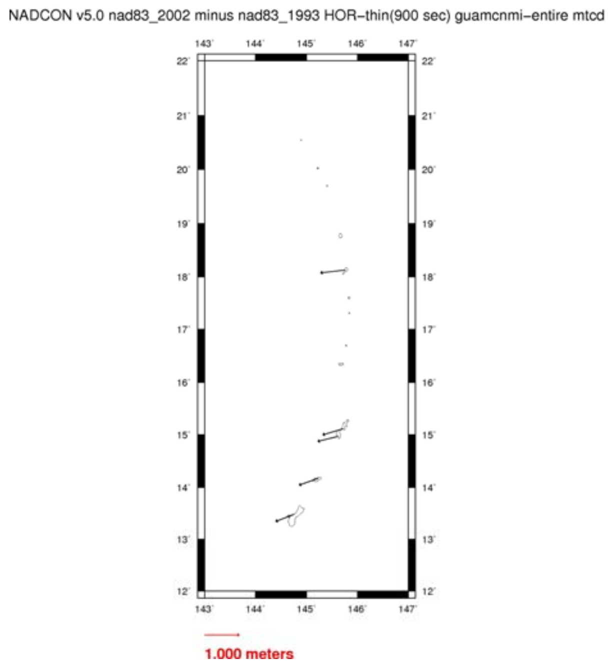

Figure 6-207: Thinned horizontal vectors after applying 15' grid spacing for NAD 83(1993)/NAD 83(2002)/Guam&CNMI.

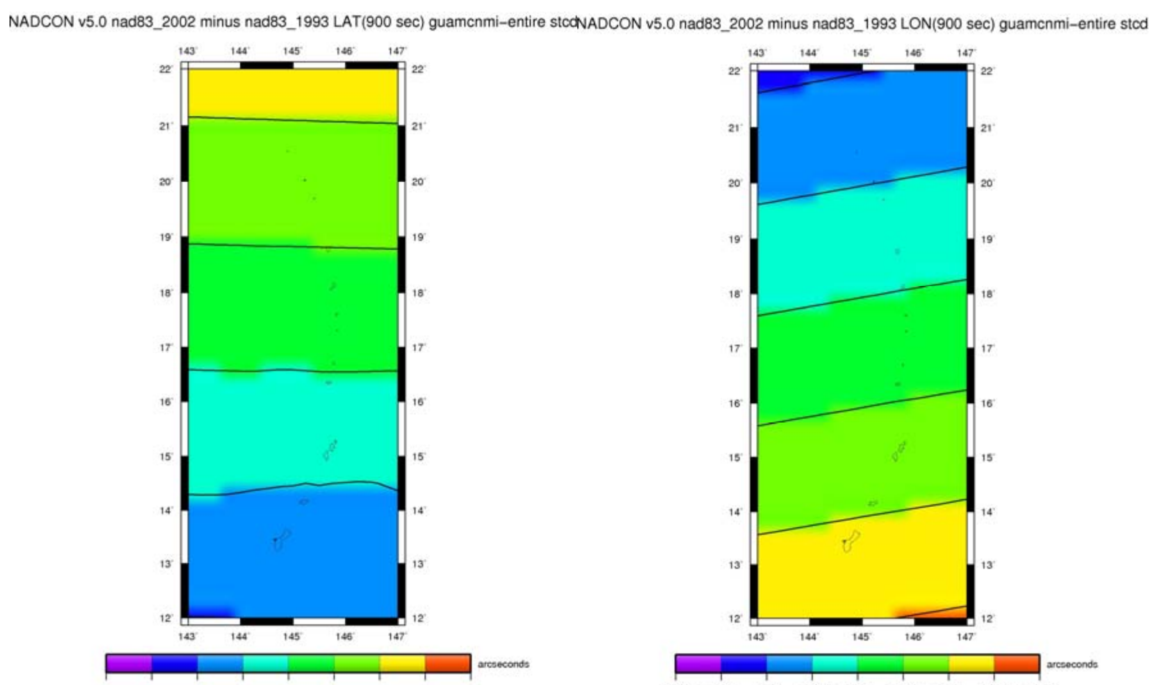

Figure 6-208: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1993)/NAD 83(2002)/Guam&CNMI.

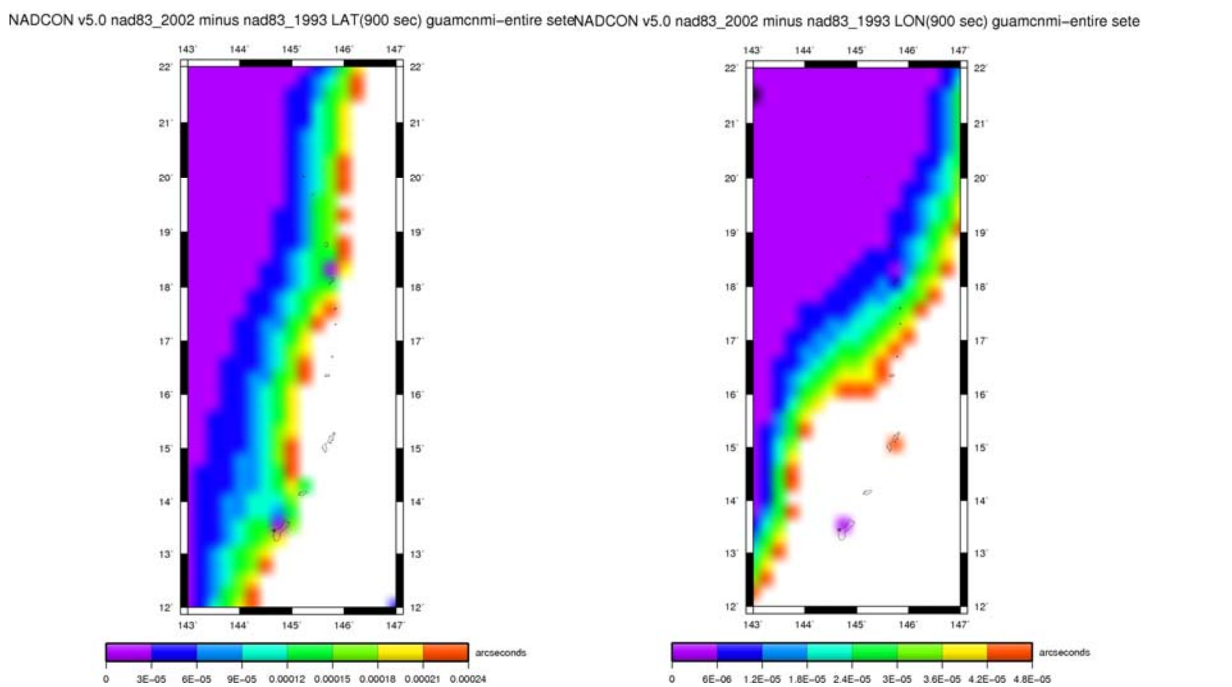

Figure 6-209: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(1993)/NAD 83(2002)/Guam&CNMI.

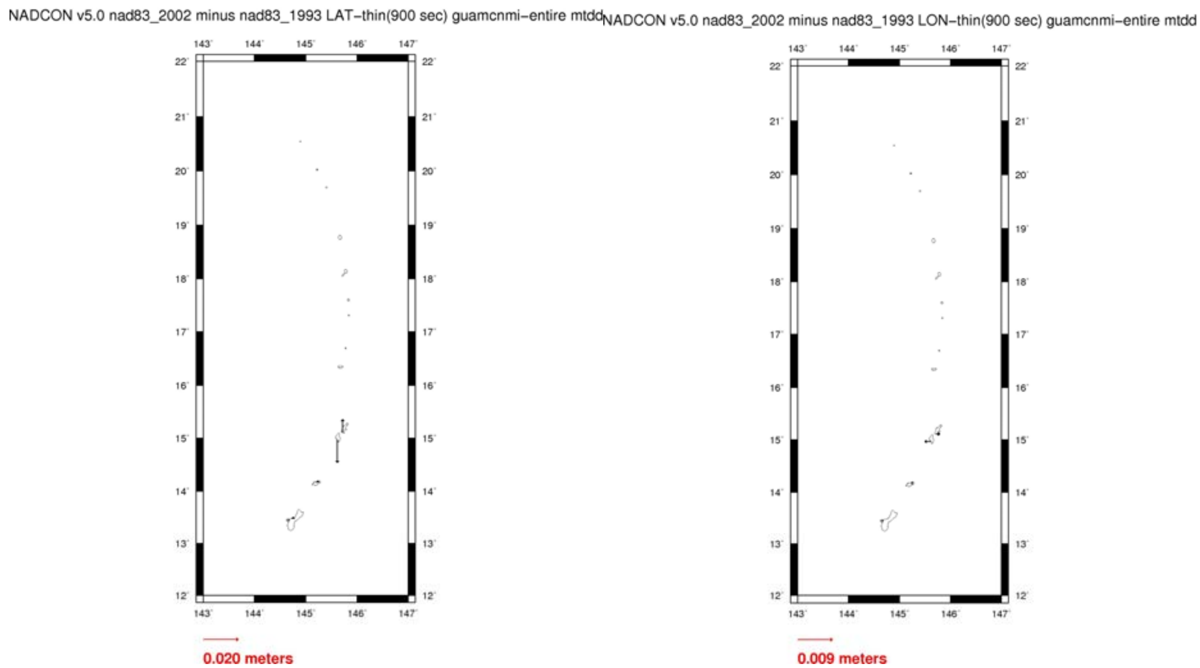

Figure 6-210: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 83(1993)/NAD 83(2002)/Guam&CNMI.

6.7.2.2 Vertical

Only 6 points were available for this 60 cm transformation, with two points per island in two locations. The magnitudes of the paired points are self-consistent, therefore, as with the accompanying horizontal field, we felt it was reasonable to choose a grid which is somewhat coarse but still retained one point per island. Residuals were less than 4 cm.

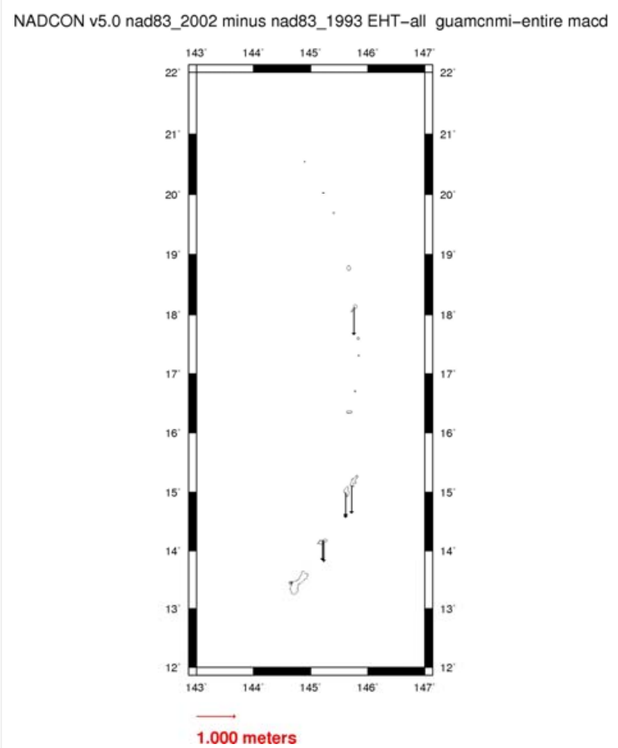

Figure 6-211: All vertical vectors for NAD 83(1993)/NAD 83(2002)/Guam&CNMI.

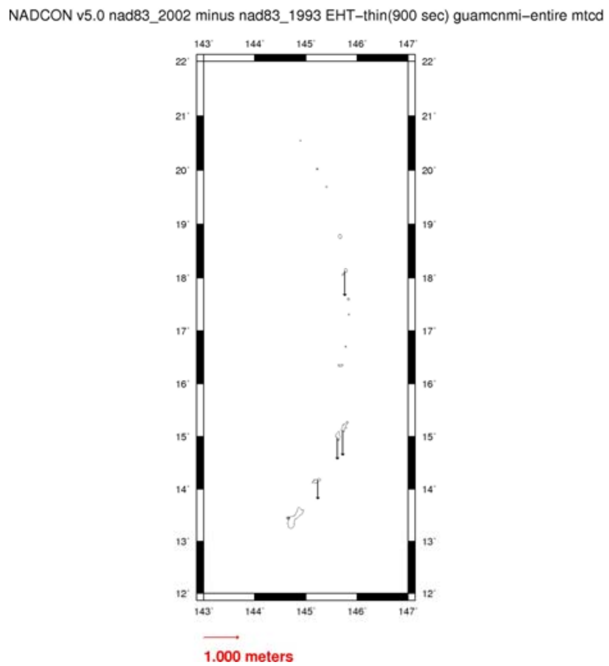

Figure 6-212: Thinned vertical vectors after applying 15' grid spacing for NAD 83(1993)/NAD 83(2002)/Guam&CNMI.

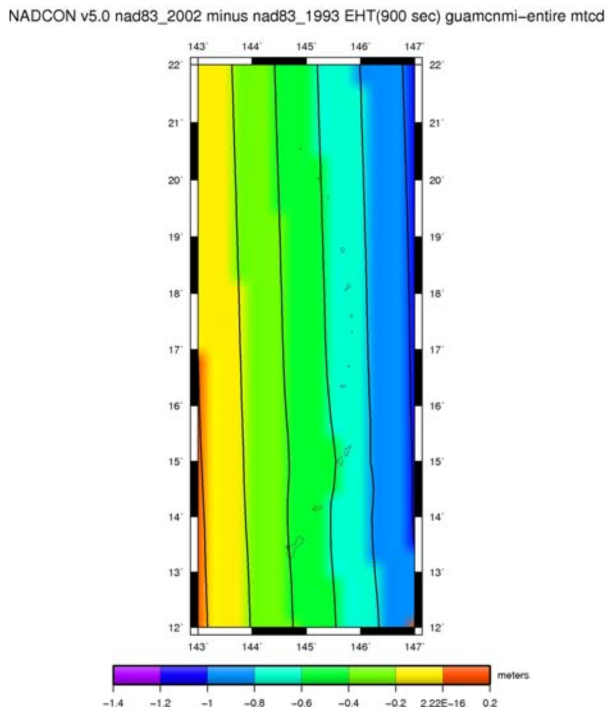

Figure 6-213: Vertical transformation, in meters for NAD 83(1993)/NAD 83(2002)/Guam&CNMI.

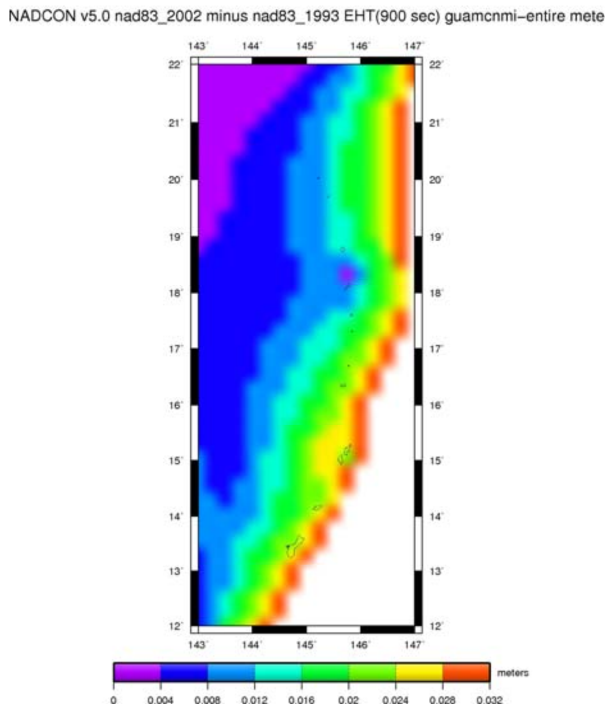

Figure 6-214: Errors for vertical transformation, in meters for NAD 83(1993)/NAD 83(2002)/Guam&CNMI.

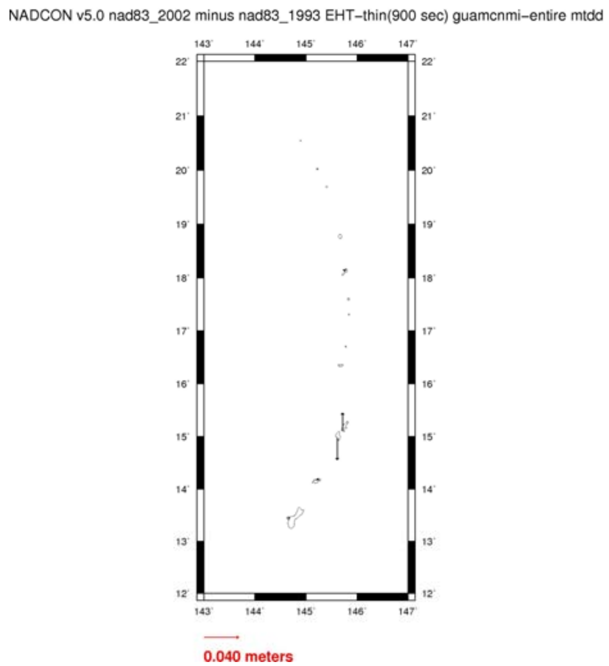

Figure 6-215: Thinned vector residuals (coordinate differences, minus the transformation grid), in meters for NAD 83(1993)/NAD 83(2002)/Guam&CNMI.

6.7.3 Guam & CNMI / NAD 83(2002) / NAD 83(MA11) / 3-D

6.7.3.1 Horizontal

There are two regimes to the transformation: (1) south of 16° latitude (Guam to Saipan): 2-3 cm length, mostly 310 deg azimuth (median); (2) north of 16° latitude: 8 cm length, uniformly 316 azimuth;
The final grid needs to respect these two regimes, while also preserving at least one point per island in the northern regime (Figure 6-216). We selected the 3’ grid size because this grid yielded a small residual on Antahan, the southernmost island of the 8 cm regime - the small residual gave us confidence that the grid was able to make the transition between the two vector regimes.

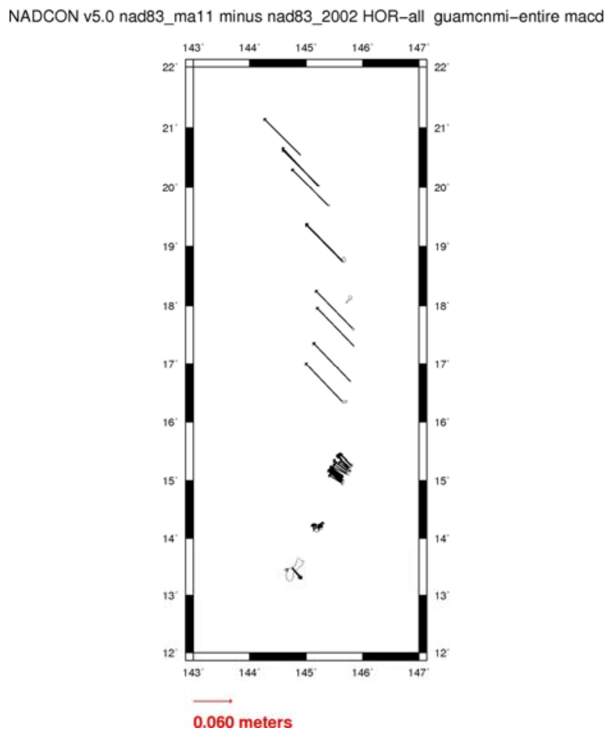

Figure 6-216: All horizontal vectors for NAD 83(2002)/NAD 83(MA11)/Guam&CNMI.

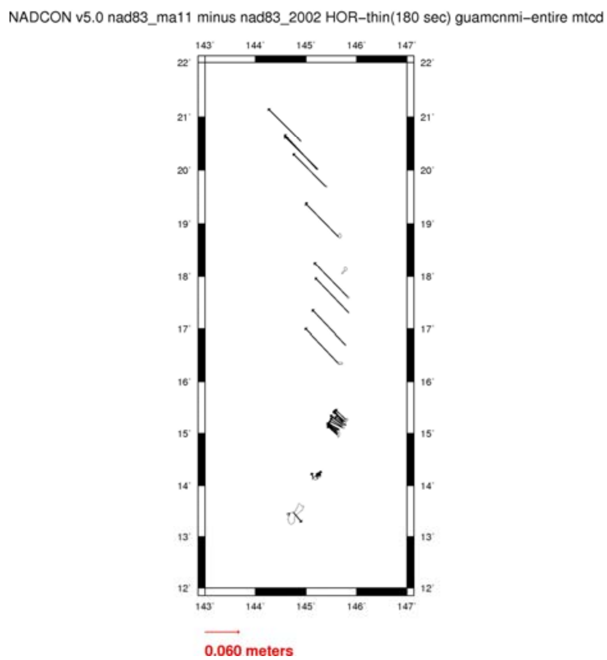

Figure 6-217: Thinned horizontal vectors after applying 3' grid spacing for NAD 83(2002)/NAD 83(MA11)/Guam&CNMI.

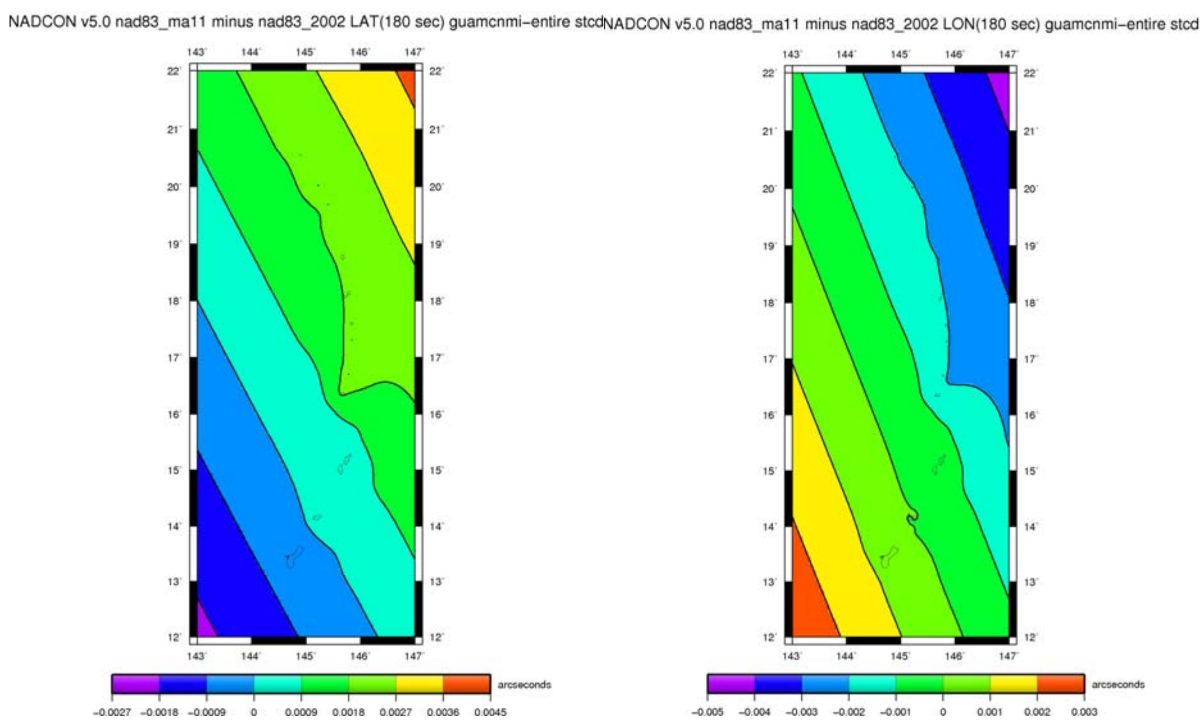

Figure 6-218: Horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(2002)/NAD 83(MA11)/Guam&CNMI.

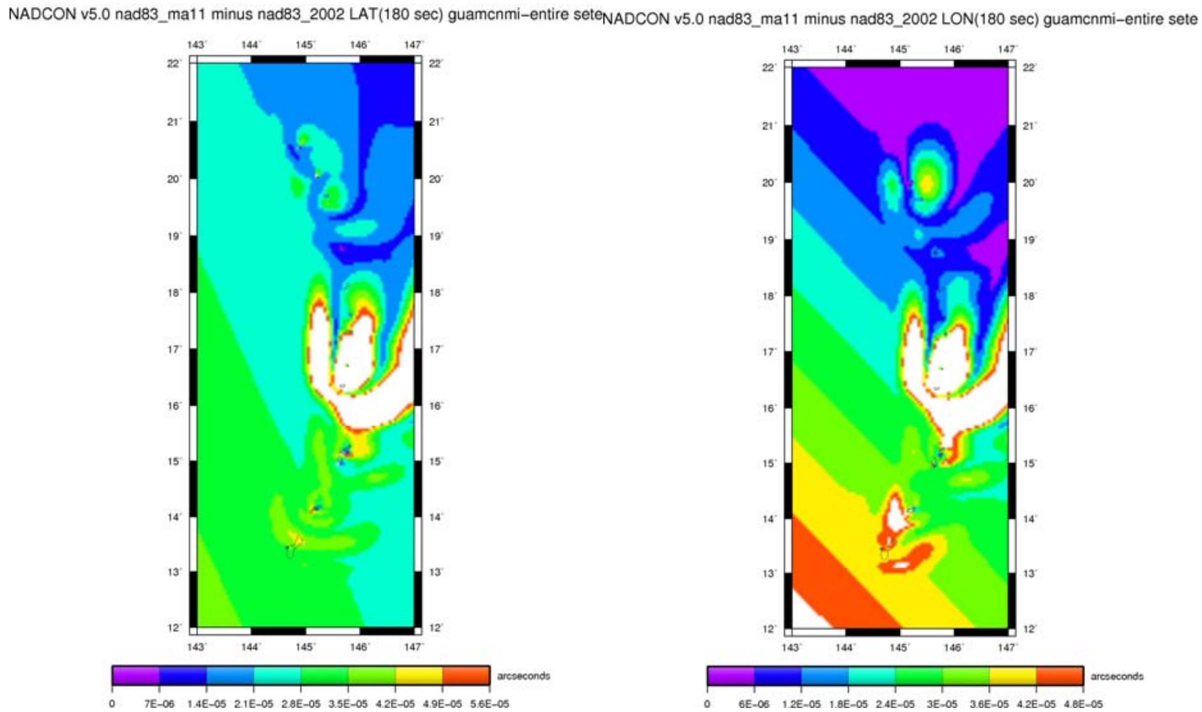

Figure 6-219: Errors for horizontal transformation, latitude (left) and longitude (right) components, in arcseconds for NAD 83(2002)/NAD 83(MA11)/Guam&CNMI.

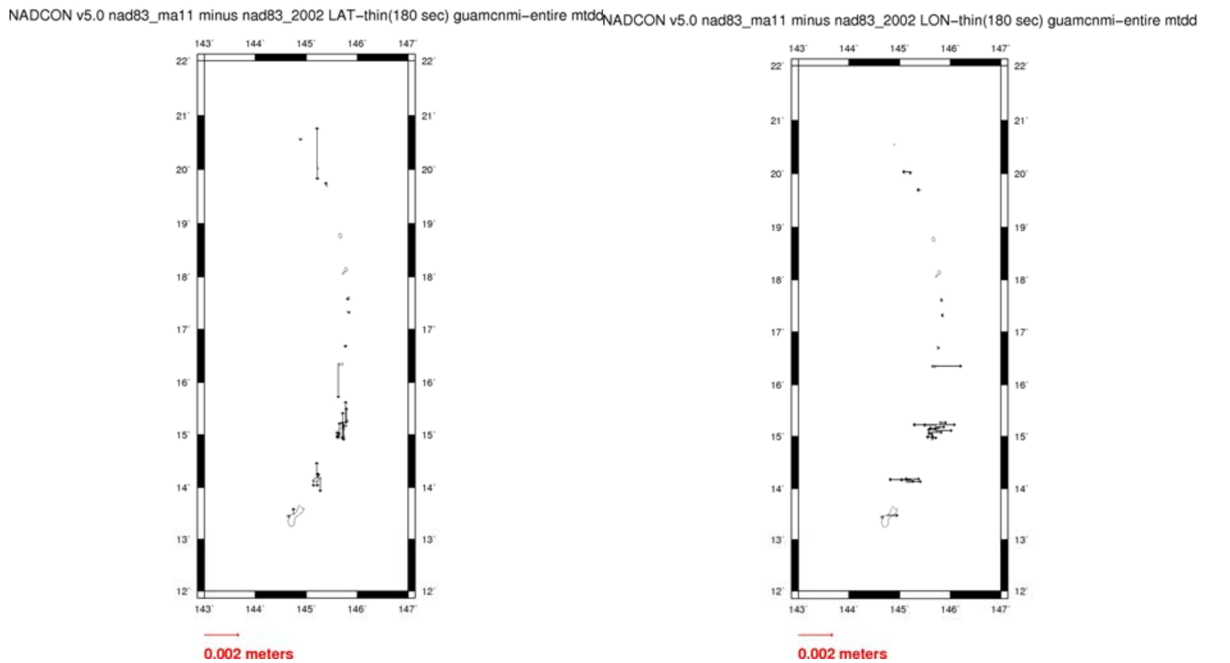

Figure 6-220: Thinned vector residuals (coordinate differences, minus the transformation grid), latitude (left) and longitude (right) components, in meters for NAD 83(2002)/NAD 83(MA11)/Guam&CNMI.

6.7.3.2 Vertical

The vertical field is small, ranging 0-8 cm with magnitudes which were local to each island. The 5' grid provides small residuals on the island with 0-2cm vectors, while also keeping residuals comparably small in the 4.5 cm and 7 cm regimes.

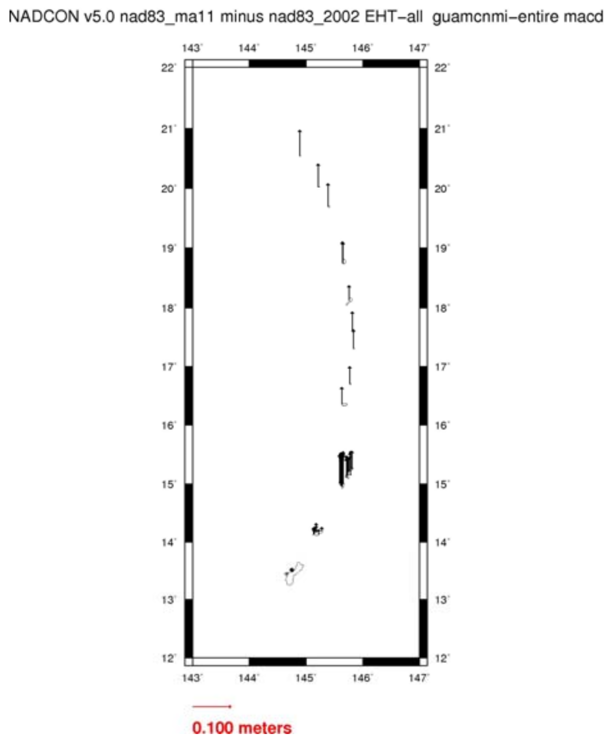

Figure 6-221: All vertical vectors for NAD 83(2002)/NAD 83(MA11)/Guam&CNMI.

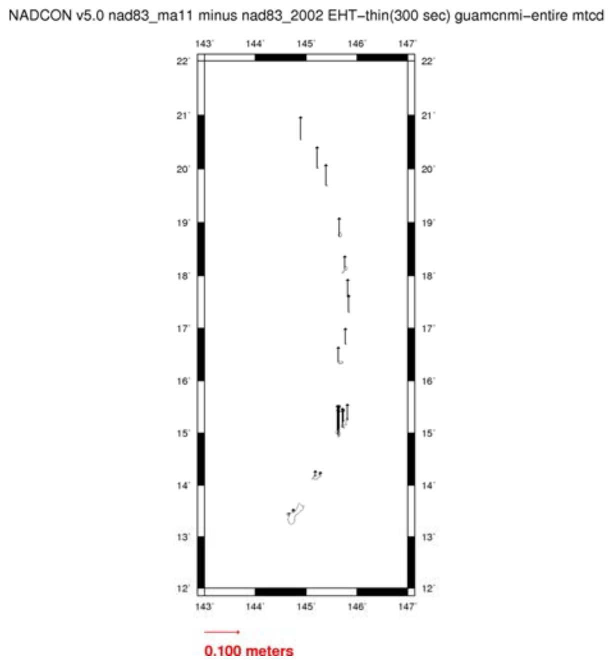

Figure 6-222: Thinned vertical vectors after applying 15' grid spacing for NAD 83(2002)/NAD 83(MA11)/Guam&CNMI.

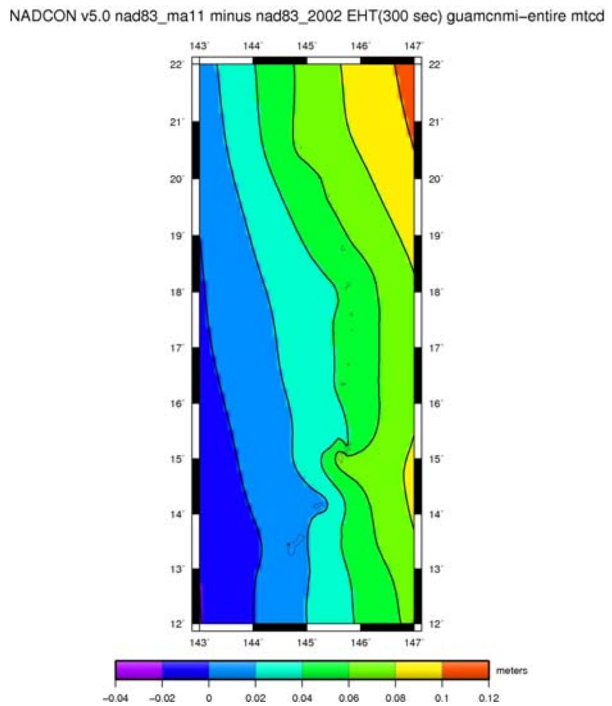

Figure 6-223: Vertical transformation, in meters for NAD 83(2002)/NAD 83(MA11)/Guam&CNMI.

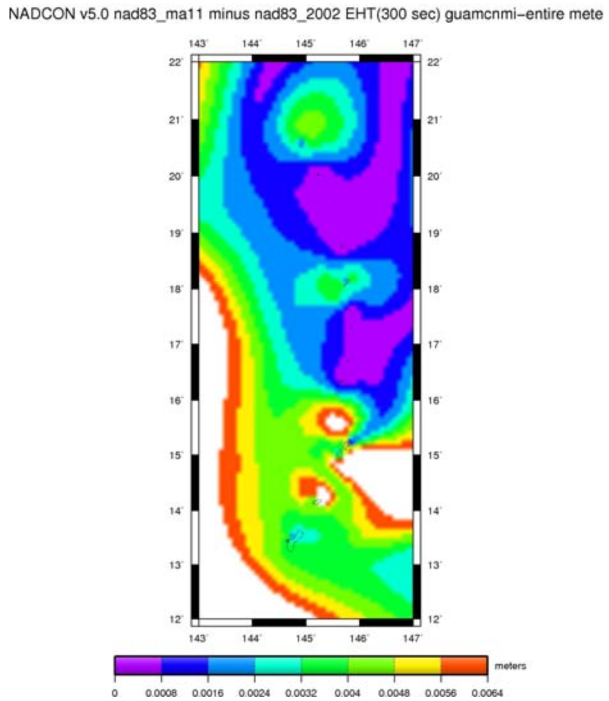

Figure 6-224: Errors for vertical transformation, in meters for NAD 83(2002)/NAD 83(MA11)/Guam&CNMI.

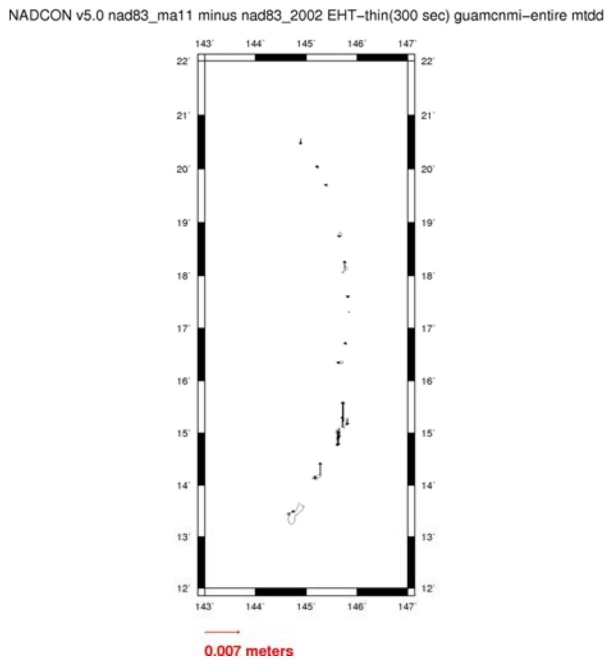

Figure 6-225: Errors for vertical transformation, in meters for NAD 83(2002)/NAD 83(MA11)/Guam&CNMI.

7 Comparison to previous transformations

As mentioned earlier, one of the overriding principles of NADCON 5.0 was to not significantly alter an existing grid unless there were scientific reasons to do so. In many cases, that scientific reason was "undo a poor choice of the past". Such choices include (a) picking a different rectangular boundary every time a new CONUS grid was made or (b) choosing state grids when nationwide grids would work or (c) choosing a grid spacing that does not adequately capture the transformation signal. However, for overall consistency, all grids were created from scratch in NADCON 5.0, even if there was no significant reason to doubt the existing grid. In such cases, a check between the existing grid and the new grid were made to ensure that the new grid showed consistency with the old grid.

Still, it would be fair and accurate to say that most of the decisions NGS made about transformation tools in the past have been thrown out, in favor of greater overall consistency and a rigorous scientific approach to building NADCON 5.0.

In Table 7-1, changes between pre-NADCON 5.0 software and NADCON 5.0 are colored orange-brown. Where there is some question about which realization is in the current software, the realization is highlighted and a footnote describes the issue. Each row represents one set of transformation grids (in existing software, prior to NADCON 5.0) which transform between the two listed datums/realizations in the Old/New columns, for the coordinates (Lat/Lon and/or h) listed in the LLh column.. Note also that in NADCON 5.0, the grid spacing for the latitude and longitude grids are always the same as one another.

However, the ellipsoid height transformation grids were evaluated independently and in some cases, the information content supported having a different grid spacing than the latitude and longitude grids. In such cases, there will be a row for the "LL" grids and a row for the "h" grids.

Table 7-1: Comparison between existing transformation support and NADCON 5.0

Transformation				Current Support			NADCON 5.0	
LLh	**Old**	**New**	**Where**	**Program**	**Cvg**	**Spcg**	**Cvg**	**Spcg**
LL	USSD	NAD 27	CONUS	None[37]			N[38]	15'
LL	NAD 27	NAD 83(1986)	CONUS	NADCON 4.2	N[39]	15'	N	15'
LL	NAD 83(1986)	NAD 83(1992:AL)[40]	AL	NADCON 4.2	30-36/270-276	15'	N	3'
LL	NAD 83(1986)	NAD 83(1997:AR)	AR	NADCON 4.2	32-37/265-271.25	15'	N	3'
LL	NAD 83(1986)	NAD 83(1992:AZ)	AZ	NADCON 4.2	30-38/244-252	15'	N	3'
LL	NAD 83(1986)	NAD 83(1992:CA)	CA(north)	NADCON 4.2	36-43/235-246	15'	N	3'
LL	NAD 83(1986)	NAD 83(1992:CA)	CA(south)	NADCON 4.2	32-37/238-247	15'	N	3'
LL	NAD 83(1986)	NAD 83(1992:CO)	CO	NADCON 4.2	36-42/250-259	15'	N	3'
LL	NAD 83(1986)	NAD 83(1996:CT) NAD 83(1996:MA) NAD 83(1996:NH) NAD 83(1996:RI) NAD 83(1996:VT)[41][42]	"New England" CT, MA, NH, RI, VT	NADCON 4.2	40-46/285-291	15'	N	3'

[37] NADCON 4.2 contains support for a USSD-to-NAD 83(1986) transformation. Because that transformation ignores the existing NAD 27-to-NAD 83(1986) transformation, it has been removed from NADCON 5.0. Users wishing to transform from USSD-to-NAD83(1986) may do so in NADCON 5.0, but the program will apply two transformations (USSD to NAD 27 , NAD 27 to NAD 83(1986)). This build-up of transformations is the standard operating procedure for all transformations between datums/realizations which are not chronologically adjacent to one another in every other part of NADCON, every part of GEOCON and is the way it is done in NADCON 5.0.

[38] Nationwide coverage 24-50 , 235-294 (good for all CONUS "nationwide" grids in NADCON 5.0)

[39] Nationwide coverage 20-50 , 229-297

[40] A datum tag that is a year followed by a state, "1992:AL", refers to a supported realization of NAD 83 adjusted for that specific state. Datasheets from NGS will not display the datum tag this way. In Alabama, for instance, one will just see "NAD 83(1992)". Similarly in Arizona, one will see "NAD 83(1992)". These two realizations are not identical (being "separate, but correlated" as discussed earlier), as they stemmed from two different adjustments done in two different states but in the same year, 1992. As such, to be very particular about what exact realization is being supported, the use of the "year:state" datum tag is adopted here.

[41] When listed in a group, a single adjustment was performed, and a single transformation grid provided for that adjustment. Nonetheless, to maintain compatibility with the previous naming scheme, multiple realizations are listed.

[42] The New England file was created on 12/14/1998. It is most likely that it reflects connections to the 1996(FBN), and not the 1992(HARN), realizations of NAD 83. In fact, the NADCON 4.2 prompt explicitly states that this is the case.

LL	**NAD 83(1986)**	**NAD 83(1991:DC)[43] NAD 83(1991:DE) NAD 83(1991:MD)**	**DC, DE, MD**	**NADCON 4.2**	**37-41/280-286**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1990:FL)**	**FL**	**NADCON 4.2**	**24-32/272-280**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1994:GA)**	**GA**	**NADCON 4.2**	**30-36/274-280**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1996:IA)**	**IA**	**NADCON 4.2**	**40-44/262-271**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1992:ID) NAD83(1992:MT)**	**ID and MT(west)**	**NADCON 4.2**	**41-50/241-251**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1992:MT)**	**MT(east)**	**NADCON 4.2**	**41-50/247-257**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1997:IL)**	**IL**	**NADCON 4.2**	**36-43/268-275**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1997:IN)**	**IN**	**NADCON 4.2**	**37-45.5/271-279.5**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1997:KS)**	**KS**	**NADCON 4.2**	**36-41/257-266**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1993:KY)**	**KY**	**NADCON 4.2**	**36-40/270-279**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1992:LA)**	**LA**	**NADCON 4.2**	**27-34/265-272**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1994:MI)**	**MI**	**NADCON 4.2**	**41-48/269-278**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1996:MN)**	**MN**	**NADCON 4.2**	**43-50/262-272**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1993:MS)**	**MS**	**NADCON 4.2**	**29-36/268-274**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1997:MO)**	**MO**	**NADCON 4.2**	**35-42/263-272**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1995:NE)**	**NE**	**NADCON 4.2**	**39.5-43.5/255.5-265.5**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1994:NV)**	**NV**	**NADCON 4.2**	**34.5-42.5/239.5-246.5**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1996:NJ)[44]**	**NJ**	**NADCON 4.2**	**38-44/284-290**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1992:NM)**	**NM**	**NADCON 4.2**	**31-38/250-259**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1996:NY)[45]**	**NY**	**NADCON 4.2**	**40-46/279-290**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(2001:NC)[46]**	**NC**	**NADCON 4.2**	**33-38/275-285**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1996:ND)**	**ND**	**NADCON 4.2**	**45-50/255-265**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1995:OH)**	**OH**	**NADCON 4.2**	**38-43/274-280**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1993:OK)**	**OK**	**NADCON 4.2**	**33-38/256-266**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1991:OR) NAD 83(1991:WA)**	**OR and WA**	**NADCON 4.2**	**41-50/235-244**	**15'**	**N**	**3'**

[43] The realization in DC is 1991. The NADCON 4.2 prompt says "1993", which is not a supported realization in that area, and most likely just a typo.
[44] The New Jersey file was created on 12/29/1999. It is most likely that it reflects a connection to the 1996(FBN) and not the 1992(HARN), realization of NAD 83. In fact, the NADCON 4.2 prompt explicitly states that this is the case.
[45] The New York file was created on 8/24/1999. It is most likely that it reflects a connection to the 1996(FBN) and not the 1992(HARN), realization of NAD 83. In fact, the NADCON 4.2 prompt explicitly states that this is the case.
[46] The North Carolina file was created on 4/13/2006. It is most likely that it reflects a connection to the 2001(FBN), and not the 1995(HARN), realization of NAD 83. In fact, the NADCON 4.2 prompt explicitly states that this is the case.

LL	**NAD 83(1986)**	**NAD 83(1992:PA)**	**PA**	**NADCON 4.2**	**39-44/278.5-286.5**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(2001:SC)**[47]	**SC**	**NADCON 4.2**	**31-36/276-282**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1996:SD)**	**SD**	**NADCON 4.2**	**41-47/255-265**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1990:TN)**	**TN**	**NADCON 4.2**	**34-37/269-279**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1993:TX)**	**TX(east)**	**NADCON 4.2**	**25-35/260-272.25**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1993:TX)**	**TX(west)**	**NADCON 4.2**	**25-37/253-261**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1994:UT)**	**UT**	**NADCON 4.2**	**36-43/245-253**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1993:VA)**	**VA**	**NADCON 4.2**	**36-40/276-285**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1991:WI)**	**WI**	**NADCON 4.2**	**42-48/266-274**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1995:WV)**	**WV**	**NADCON 4.2**	**36-41/276-283.25**	**15'**	**N**	**3'**
LL	**NAD 83(1986)**	**NAD 83(1993:WY)**[48]	**WY**	**NADCON 4.2**	**40-46/248-257**	**1'**	**N**	**1'**
LLh	**NAD 83(1992:CA)**	**NAD 83(1998:CA)**	**CA**	**GEOCON 2.0**	**31.5-43°5m/ 234°20m-246°55m**	**1'**	**N**	**1'**
LLh	**NAD 83(1992:CT)**	**NAD 83(1996:CT)**	**CT**	**GEOCON 2.0**	**39°55m-43°5m/ 285.25-289.25**	**1'**	**N**	**1'**
LLh	**NAD 83(1990:FL)**	**NAD 83(1999:FL)**	**FL**	**GEOCON 2.0**	**23°20m-32°5m/ 271°20m-281.25**	**1'**	**N**	**1'**
LLh	**NAD 83(1992:ID)**	**NAD 83(1999:ID)**	**ID**	**GEOCON 2.0**	**40°55m-50°5m/ 241.75-250°**	**1'**	**N**	**1'**
LLh	**NAD 83(1992:MA)**	**NAD 83(1996:MA)**	**MA**	**GEOCON 2.0**	**40°5m-43°55m/ 285°25m-291°20m**	**1'**	**N**	**1'**
LLh	**NAD 83(1992:ME)**	**NAD 83(1996:ME)**	**ME**	**GEOCON 2.0**	**41°55m-48.5/ 287°55m-294°10m**	**1'**	**N**	**1'**
LLh	**NAD 83(1992:MT)**	**NAD 83(1999:MT)**	**MT**	**GEOCON 2.0**	**43°20m-50°/ 242°55m-257°**	**1'**	**N**	**1'**
LLh	**NAD 83(1995:NC)**	**NAD 83(2001:NC)**	**NC**	**GEOCON 2.0**	**32°45m-37°40m/ 274°40m-285°40m**	**1'**	**N**	**1'**
LLh	**NAD 83(1992:NH)**	**NAD 83(1996:NH)**	**NH**	**GEOCON 2.0**	**41°40m-46°20m/ 286°25m-290°30m**	**1'**	**N**	**1'**
LLh	**NAD 83(1992:NJ)**	**NAD 83(1996:NJ)**	**NJ**	**GEOCON 2.0**	**37°50m-42°25m/ 283°25m-287°10m**	**1'**	**N**	**1'**
LLh	**NAD 83(1994:NV)**	**NAD 83(1999:NV)**	**NV**	**GEOCON 2.0**	**34°-43°5m/ 238°55m-247°**	**1'**	**N**	**1'**
LLh	**NAD 83(1992:NY)**	**NAD 83(1996:NY)**	**NY**	**GEOCON 2.0**	**39°25m-46°5m/ 279°10m-289°15m**	**1'**	**N**	**1'**

[47] The South Carolina file was created on 7/28/2004. It is most likely that it reflects a connection to the 2001(FBN), and not the 1995(HARN), realization of NAD 83. In fact, the NADCON 4.2 prompt explicitly states that this is the case.
[48] The Wyoming file was created on 7/29/2009. It is possible, but highly unlikely, that it reflects a connection to the NSRS2007, and not the 1993, realization of NAD 83. However, the NADCON 4.2 prompts imply it is the 1993 realization.

LLh	**NAD 83(1991:OR)**	**NAD 83(1998:OR)**	**OR**	**GEOCON 2.0**	**40°55m-47°20m/ 234°15m-244°35m**	**1'**	**N**	**1'**
LLh	**NAD 83(1992:RI)**	**NAD 83(1996:RI)**	**RI**	**GEOCON 2.0**	**40°10m-43°5m/ 287°5m-290°**	**1'**	**N**	**1'**
LLh	**NAD 83(1995:SC)**	**NAD 83(2001:SC)**	**SC**	**GEOCON 2.0**	**31°-36°15m/ 275°35m-282°35m**	**1'**	**N**	**1'**
LLh	**NAD 83(1990:TN)**	**NAD 83(1999:TN)**	**TN**	**GEOCON 2.0**	**33°55m-37°45m/ 268°40m-279°25m**	**1'**	**N**	**1'**
LLh	**NAD 83(1992:VT)**	**NAD 83(1996:VT)**	**VT**	**GEOCON 2.0**	**41°40m-46°5m/ 285°30m-289°35m**	**1'**	**N**	**1'**
LLh	**NAD 83(1991:WA)**	**NAD 83(1998:WA)**	**WA**	**GEOCON 2.0**	**44°30m-50°5m/ 234°5m-244°10m**	**1'**	**N**	**1'**
LLh	**NAD 83(1991:WI)**	**NAD 83(1997:WI)**	**WI**	**GEOCON 2.0**	**41°25m-48°20m/ 266°5m-274°45m**	**1'**	**N**	**1'**
LLh	**NAD 83(1992:AL)**[49] **NAD 83(1997:AR)** **NAD 83(1992:AZ)** **NAD 83(1998:CA)** **NAD 83(1992:CO)** **NAD 83(1996:CT)** **NAD 83(1991:DC)** **NAD 83(1991:DE)** **NAD 83(1999:FL)** **NAD 83(1994:GA)** **NAD 83(1996:IA)** **NAD 83(1999:ID)** **NAD 83(1997:IL)** **NAD 83(1997:IN)** **NAD 83(1997:KS)** **NAD 83(1993:KY)** **NAD 83(1992:LA)** **NAD 83(1996:MA)** **NAD 83(1991:MD)** **NAD 83(1996:ME)** **NAD 83(1994:MI)** **NAD 83(1996:MN)** **NAD 83(1997:MO)** **NAD 83(1993:MS)** **NAD 83(1999:MT)** **NAD 83(2001:NC)** **NAD 83(1996:ND)** **NAD 83(1995:NE)**[50] **NAD 83(1996:NH)** **NAD 83(1996:NJ)** **NAD 83(1992:NM)** **NAD 83(1999:NV)** **NAD 83(1996:NY)** **NAD 83(1995:OH)** **NAD 83(1993:OK)** **NAD 83(1998:OR)** **NAD 83(1992:PA)** **NAD 83(1996:RI)** **NAD 83(2001:SC)** **NAD 83(1996:SD)** **NAD 83(1995:TN)** **NAD 83(1993:TX)**	**NAD 83(NSRS2007)**	**AL** **AR** **AZ** **CA** **CO** **CT** **DC** **DE** **FL** **GA** **IA** **ID** **IL** **IN** **KS** **KY** **LA** **MA** **MD** **ME** **MI** **MN** **MO** **MS** **MT** **NC** **ND** **NE** **NH** **NJ** **NM** **NV** **NY** **OH** **OK** **OR** **PA** **RI** **SC** **SC** **TN** **TX**	**GEOCON 2.0**	**N(2)**	**1'**	**N**	**1'**

49 Despite the fact that each of these realizations is state (or multistate) specific, and thus unique, they were treated as one nationwide set of data in GEOCON 2.0 for building the transformation to the NSRS2007 realization. This was because the evidence at the time showed that, with the correction of 19 states from HARNs to FBNs, most of these adjustments were converging toward consistency with one another.

50 NE for "Nebraska". In the NADCON 4.2 grid files, "ne" was used to mean "New England" while "nb" meant "Nebraska"

	NAD 83(1994:UT) NAD 83(1993:VA) NAD 83(1996:VT) NAD 83(1998:WA) NAD 83(1997:WI) NAD 83(1995:WV) NAD 83(1993:WY)		UT VA VT WA WI WV WY					
LLh	NAD 83(NSRS2007)	NAD 83(2011)	CONUS	GEOCON 2.0	N(2)	1’	N	1’
[redacted]								
LL	NAD 27	NAD 83(1986)	Alaska[51]	NADCON 4.2	46-77/166-232	7.5’	50-73/172-232	30’
LL	NAD 83(1986)	NAD 83(1992:AK)	Alaska[52]	None			50-73/172-232	15’
LL	NAD 83(1992:AK)	NAD 83(NSRS2007)	Alaska	GEOCON 2.0	46-77/166-232	1’	50-73/172-232	7.5’
h	NAD 83(1992:AK)	NAD 83(NSRS2007)	Alaska	GEOCON 2.0	46-77/166-232	1’	50-73/172-232	15’
LL	NAD 83(NSRS2007)	NAD 83(2011)	Alaska	GEOCON 2.0	46-77/166-232	1’	50-73/172-232	5’
h	NAD 83(NSRS2007)	NAD 83(2011)	Alaska	GEOCON 2.0	46-77/166-232	1’	50-73/172-232	15’
[redacted]								
LL	OHD	NAD 83(1986)	Hawaii	NADCON 4.2	18-23/199-206	1.5’	18-23/199-206	1’
LL	NAD 83(1986)	NAD 83(1993:HI)	Hawaii	NADCON 4.2	18-24/198-206	15’	18-23/199-206	1’
LL	NAD 83(1993:HI)	NAD 83(PA11)	Hawaii	GEOCON 2.0	17°50m-23.25/ 199.75-206.25	1’	18-23/199-206	3’
h	NAD 83(1993HI)	NAD 83(PA11)	Hawaii	GEOCON 2.0	17d50m-23.25/ 199.75-206.25	1’	18-23/199-206	1’
[redacted]								
LL	PR40	NAD 83(1986)	PR,VI	NADCON 4.2	17-19/292-296	3’	17-19/291-296	5’
LL	NAD 83(1986)	NAD 83(1993:PR) NAD 83(1993:VI)[53]	PR,VI	NADCON 4.2	17-20.5/292-298	15’	17-19/291-296	5’
LL	NAD 83(1993:PR)	NAD 83(1997:PR)	PR	GEOCON 2.0	16°55m-19°35m/ 291-295°50m	1’	17-19/291-296	1’
h	NAD 83(1993:PR)	NAD 83(1997:PR)	PR	GEOCON 2.0	16°55m-19°35m/ 291-295°50m	1’	17-19/291-296	5’

[51] Excluding all parts of Alaska where NAD 27 is not defined. These areas include, but are not necessarily limited to, the St. Paul, St. George, St. Matthew and St. Lawrence island groups.
[52] Excluding all parts of Alaska where NAD 83(1986) is not defined. These areas include, but are not limited to, the St. Matthew island groups.
[53] The PR/VI HPGN grid was created on 10/06/1997. It is most likely that it reflects a connection to the 1997, and not the 1993, realization of NAD 83. In fact, the NADCON 4.2 prompt explicitly states that this is the case.

LL	**NAD 83(1993:VI)**	**NAD 83(1997:VI)**	**VI**	**None[54]**			**17-19/291-296**	**1'**
h	**NAD 83(1993:VI)**	**NAD 83(1997:VI)**	**VI**				**17-19/291-296**	**5'**
LL	**NAD 83(1997:PR)**	**NAD 83(2002:PR)**	**PR**	**GEOCON 2.0**	**16°55m-19°35m/ 291°-295°50m**	**1'**	**17-19/291-296**	**5'**
h	**NAD 83(1997:PR)**	**NAD 83(2002:PR)**	**PR**	**GEOCON 2.0**	**16°55m-19°35m/ 291°-295°50m**	**1'**	**17-19/291-296**	**3'**
LL	**NAD 83(1997:VI)**	**NAD 83(2002:VI)**	**VI**	**None[54]**			**17-19/291-296**	**5'**
h	**NAD 83(1997:VI)**	**NAD 83(2002:VI)**	**VI**				**17-19/291-296**	**3'**
LLh	**NAD 83(2002:PR)** **NAD 83(2002:VI)**	**NAD 83(NSRS2007)**	**PR, VI**	**GEOCON 2.0**	**17-19/292-296**	**1'**	**17-19/292-296**	**1'**
LLh	**NAD 83(NSRS2007)**	**NAD 83(2011)**	**PR, VI**	**GEOCON 2.0**	**17-19/292-296**	**1'**	**17-19/292-296**	**7.5'**
LL	**GU 63**	**NAD 83(1993:GU)[55]**	**GU**	**NADCON 4.2**	**13-19/141-147**	**15'**	**12-22/143-147**	**5'**
LL	**GU 63[56]**	**NAD 83(1993:CQ)**	**CQ (NW?)**	**None**	**14.75-20.75/ 145.5-151.5**	**15'**	**12-22/143-147**	**5'**
LL	**GU 63[56]**	**NAD 83(1993:CQ)**	**CQ (SE?)**	**None**	**14-20/144-150**	**15'**	**12-22/143-147**	**5'**
LL	**NAD 83(1993:GU)**	**NAD 83(2002:GU)**	**GU**	**GEOCON 2.0**	**12°10m-14°40m/ 143°35m-146°**	**1'**	**12-22/143-147**	**15'**
h	**NAD 83(1993:GU)**	**NAD 83(2002:GU)**	**GU**	**None[57]**			**12-22/143-147**	**15'**
LLh	**NAD 83(1993:CQ)**	**NAD 83(2002:CQ)**	**CQ**	**GEOCON 2.0**	**13°5m-16°20m/ 144°5m-146°50m**	**1'**	**12-22/143-147**	**15'**
LL	**NAD 83(2002:GU)** **NAD 83(2002:CQ)**	**NAD 83(MA11)**	**GU,CQ**	**GEOCON 2.0**	**12°10m-16°20m/ 143°35m-146°50m**	**1'**	**12-22/143-147**	**3'**
h	**NAD 83(2002:GU)** **NAD 83(2002:CQ)**	**NAD 83(MA11)**	**GU,CQ**	**GEOCON 2.0**	**12°10m-16°20m/ 143°35m-146°50m**	**1'**	**12-22/143-147**	**5'**

[54] GEOCON 2.0 contained a transformation from NAD 83(1993:VI) to NAD 83(2002:VI), skipping 1997. This was intentional at the time, yet proved to be incorrect in hindsight. At the time of creating GEOCON 2.0, it was mistakenly believed that the 1997 "fix" to the 1993 HARN was restricted to PR only. However, the differences between the 1993 and 1997 realizations on VI are as large and significant as they are on PR.

[55] The grid limits for this transformation do not go far enough north to encompass the entirety of CNMI, nor does the NADCON 4.2 software indicate any support for CNMI

[56] In the master files for NADCON 4.2 were found two that overlapped significantly with one another, excluded Guam, and together encompassed all of CNMI (aka "CQ"). No support to *use* these grids exists in the NADCON 4.2 software, but the evidence suggests that there may have been plans to introduce them, so they are listed here for completeness.

[57] In GEOCON 2.0, the sparseness of ellipsoid height data on Guam itself between NAD 83(1993) and NAD 83(2002) led to the decision not to support a transformation for that coordinate. This decision was reversed with NADCON 5.0

[redacted]								
LL	**AS 62**	**NAD 83(1993:AS)**	**AS(East?)**[58]	**NADCON 4.2**	**-20 to -14 / 189 to 195**	**15'**	**-16 to -13/ 188 to 193**	**1'**
LL	**AS 62**	**NAD 83(1993:AS)**	**AS(West?)**	**NADCON 4.2**	**-20 to -14 / 189 to 195**	**15'**	**-16 to -13/ 188 to 193**	**1'**
LLh	**NAD 83(1993:AS)**	**NAD 83(2002:AS)**	**AS**	**GEOCON 2.0**	**-15.5 to -13d5m / 188°5m to 192°55m**	**1'**	**-16 to -13/ 188 to 193**	**1'**
LLh	**NAD 83(2002:AS)**	**NAD 83(PA11)**	**AS**	**GEOCON 2.0**	**-15.5 to -13°5m / 188°5m to 192°55m**	**1'**	**-16 to -13/ 188 to 193**	**1'**
[redacted]								
LL	**SP1897**	**SP1952**	**St. Paul**	**None**[59]			**56.9-57.4/ 189.3-190.4**	**1'**
LL	**SP1952**[60]	**NAD 83(1986)**	**St. Paul**	**NADCON 4.2**	**57-58/189-191**	**3'**	**56.9-57.4/ 189.3-190.4**	**1'**
[redacted]								
LL	**SG1897**	**SG1952**	**St. George**	**None**[59]			**56.3-56.8/ 190.0-190.8**	**1'**
LL	**SG1952**[61]	**NAD 83(1986)**	**St. George**	**NADCON 4.2**	**56-57/189-191**	**3'**	**56.3-56.8/ 190.0-190.8**	**1'**
[redacted]								
LL	**SL1952**	**NAD 83(1986)**	**St. Lawrence**	**NADCON 4.2**	**62-64/188-192**	**3**	**62.7-64.0/ 187.5-192.0**	**1'**

[58] Although the NADCON 4.2 software clearly indicates support for "Eastern Islands" and "Western Islands", the grids which support those two different services are identical in boundaries, yet do not contain the same data.

[59] The St Paul 1897 and St George 1897 coordinates were re-discovered by NGS during the early 2010s, during a meticulous search of original field books while searching for USSD data. Because these older datums have points in common with, yet with coordinates different from, the St Paul 1952 and St George 1952 datums, a transformation was built between the 1897 and 1952 datums. Furthermore, NGS corrected its Integrated Database to explicitly use the 1897 and 1952 monikers in the datum names (in 2010 the 1897 points were incompletely loaded into the database as simply "St Paul" or "St George" datums, without a year, while the 1952 points were incorrectly labeled as "NAD 27". Note that NADCON 4.2 referred to the "St Paul" or "St. George" "Island Datums", yet with the data in the database for the 1952 datums saying "NAD 27" it had the false appearance of supporting the 1897 datums.). This was yet another mistake which has caused confusion and which was corrected in the NADCON 5.0 project.

[60] NADCON 4.2 simply refers to this as "Island Datum"

[61] NADCON 4.2 simply refers to this as "Island Datum"

8 How well does NADCON 5.0 perform?

Both the original NADCON 1.0 release (Dewhurst 1990) and NADCON 2.1 (NGS 2004) made broad statements about how well a transformation via grids replicated actual published coordinates. This sort of comparison is very informative, and has been continued for NADCON 5.0. Although broad, region-wide statistics will be provided below, it should be remembered that NADCON 5.0 provides actual point-by-point error estimates as part of its functionality.

A comprehensive evaluation of NADCON 5.0 against all previous transformation software has not been performed. While possible, such an evaluation would be lengthy and, frankly, not terribly interesting. Still, considering the extensive reporting of accuracy which was done in the NADCON 1.0 report (Dewhurst 1990), it was felt that at least a general comparison with NADCON 5.0 should be done.

8.1 Comparison between NADCON 5.0 and NADCON 1.0

There are a number of things preventing a direct one-to-one comparison of the performance of NADCON 1.0 to NADCON 5.0. First is that NADCON 5.0 did not explicitly build upon any particular survey order or class of points. If a point had an adjusted set of coordinates in NAD 27 and NAD 83(1986), it was part of the overall pool of considered points. Second, NADCON 5.0 thinned data by block-median[62], whereas NADCON 1.0 thinned data by first restricting to 1st and 2nd order control, and then applying an inverse distance squared scheme with a forced agreement at points "near" grid nodes (see Dewhurst, 1990; p. 15-17). Although it is assumed that an outlier thinning was performed in NADCON 1.0, similar to what was done in NADCON 5.0, that assumption can not be definitively proven.

With all those caveats in place, the tables below show how well grids agree with input data, for both NADCON 1.0 and NADCON 5.0, as a way of seeing how well the new grids perform compared to past performance. The tables below reflect the residuals between published coordinates and coordinates transformed with the proper grid from the respective software.

[62] As per section 5.2.3, using, as a sorting criteria, the magnitude (absolute value) of the horizontal vector to select points for both latitude and longitude grids (so that the exact same points are used in creating the latitude and longitude grids.) For the ellipsoid height grids the true value (with sign) of the ellipsoid height vector was used for sorting. See program "mymedian5.f" for more details.

8.1.1 NADCON 5.0 versus NADCON 1.0: CONUS

Table 8-1: Residual Latitude Statistics for Transformation NAD 27 / NAD 83(1986) / CONUS

NADCON Version (Grid Spacing)	Type of Points used	Number of Points	Ave	Std	Min	Max
1.0 (15')	1st order	33,280	0.002 m	0.145 m	Not given	Not given
	2nd order	81,803	-0.001 m	0.162 m	Not given	Not given
	3rd order	42,070	0.009 m	0.454 m	Not given	Not given
	"All"[63]	115,296	-0.001 m	0.159 m	-8.774 m	3.388 m
5.0 (15')	Thinned	13,104	0.000 m	0.119 m	-2.356 m	4.759 m
	Dropped	212,047	0.003 m	0.365 m	-10.822 m	14.754 m
	All	225,151	0.003 m	0.355 m	-10.822 m	14.754 m

Table 8-2: Residual Longitude Statistics for Transformation NAD 27 / NAD 83(1986) / CONUS

NADCON Version (Grid Spacing)	Type of Points used	Number of Points	Ave	Std	Min	Max
1.0 (15')	1st order	33,280	0.001 m	0.131 m	Not given	Not given
	2nd order	81,803	0.002 m	0.149 m	Not given	Not given
	3rd order	42,070	0.010 m	0.446 m	Not given	Not given
	"All" (footnote 30)	115,296	0.002 m	0.148 m	-8.101 m	4.172 m

[63] Appears that be almost entirely 1st and 2nd order points only

5.0 (15')	Thinned	13,104	0.001 m	0.153 m	-10.505 m	5.729m
	Dropped	212,047	-0.001 m	0.399 m	-13.150 m	18.023 m
	All	225,151	-0.001 m	0.389 m	-13.150 m	18.023 m

In examining Table 8-1 and Table 8-2, it is reassuring to see that an agreement better than 40 cm is achievable with NADCON 5.0, which is an improvement on the approximately 45-47 cm accuracy of NADCON 1.0, while remaining generally "consistent with" the original release. The larger standard deviation for NADCON 5.0 for "All" points is likely due to the inclusion of points that are worse than 2nd order, which were not considered in the "All" comparison of NADCON 1.0.

8.1.2 NADCON 5.0 versus NADCON 1.0: Alaska

Table 8-3: Residual Latitude Statistics for Transformation NAD 27 / NAD 83(1986) / Alaska

NADCON Version (Grid Spacing)	Type of Points used	Number of Points	Ave	Std	Min	Max
1.0 (7.5')	1st/2nd order	16,284	0.003 m	0.479 m	-6.905 m	8.646 m
5.0 (30')	Thinned	1,288	0.016 m	0.607 m	-5.613 m	5.941 m
	Dropped	21,628	-0.058 m	1.726 m	-46.225 m	32.878 m
	All	22,916	-0.054 m	1.683 m	-46.225 m	32.878 m

Table 8-4: Residual Longitude Statistics for Transformation NAD 27 / NAD 83(1986) / Alaska

NADCON Version (Grid Spacing)	Type of Points used	Number of Points	Ave	Std	Min	Max
1.0 (7.5')	1st/2nd order	16,284	-0.003 m	0.463 m	-12.215 m	6.339 m

5.0 (30’)	Thinned	1,288	0.008 m	0.588 m	-6.225 m	6.060 m
	Dropped	21,628	0.012 m	1.968 m	-25.841 m	55.982 m
	All	22,916	0.012	1.917 m	-25.841 m	55.982 m

While the statistics for this Alaskan transformation appear to have worsened, it must be remembered that all published (adjusted) coordinates of any order were considered valid in NADCON 5.0. This was especially important in such a large, sparsely surveyed region as Alaska. As such, the 6000 or so additional points which were not in the original NADCON grids, and the sparse grid spacing chosen for NADCON 5.0 (30’ rather than 7.5’) contribute to the larger variations in transformation for this state. See earlier in this report for a discussion about why it was felt that the data did not support any signal beyond 30’ spacing.

8.1.3 NADCON 5.0 versus NADCON 1.0: Hawaii

Table 8-5: Residual Latitude Statistics for Transformation OHD / NAD 83(1986) / Hawaii

NADCON Version (Grid Spacing)	Type of Points used	Number of Points	Ave	Std	Min	Max
1.0 (1.5’)	1st/2nd order	1257	0.047 m	0.215 m	-0.989 m	0.974 m
5.0 (1’)	Thinned	1231	-0.020 m	2.081 m	-13.530 m	20.092 m
	Dropped	1371	0.219 m	5.541 m	-34.926 m	53.203 m
	All	2602	0.106 m	4.270 m	-34.926 m	53.203 m

Table 8-6: Residual Longitude Statistics for Transformation OHD / NAD 83(1986) / Hawaii

NADCON Version (Grid Spacing)	Type of Points used	Number of Points	Ave	Std	Min	Max
1.0 (1.5’)	1st/2nd order	1257	-0.006 m	0.147 m	-0.930 m	0.980 m
5.0 (1’)	Thinned	1231	-0.005 m	0.846 m	-6.993 m	9.298 m
	Dropped	1371	-0.016 m	2.007 m	-14.613 m	34.591 m
	All	2602	-0.011 m	1.568 m	-14.613 m	34.591 m

The residual statistics for Hawaii appear to have significantly worsened between NADCON 1.0 and NADCON 5.0, but they must be taken in context. Specifically, in the original NADCON report (Dewhurst, 1990), it was stated that “Hawaii, although modeled to 15 cm (1σ) appears to have large datum inconsistencies which require attention prior to the application of any transformation technique.” Unfortunately, the nature of those inconsistencies was not addressed in the report.

However, in the creation of NADCON 5.0, it appears that the nature of those datum inconsistencies became clearer. In order to understand them, first examine Figure 8-1.

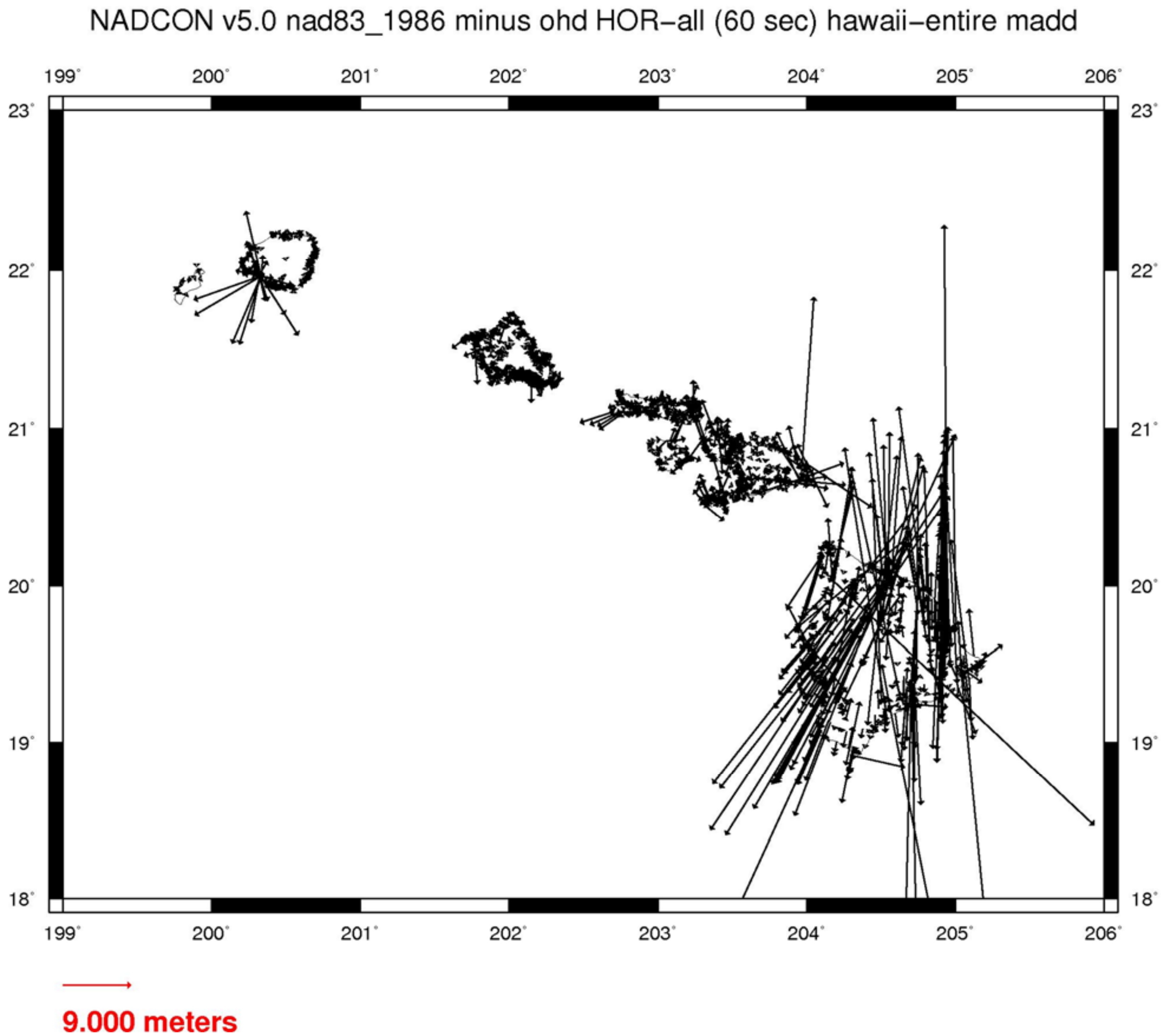

Figure 8-1: Residual horizontal shifts from OHD to NAD 83(1986) in Hawaii between true coordinate shifts and gridded (60") shifts

Figure 8-1 shows residual vectors between true coordinate differences and grid-based coordinate differences (both of the nature "NAD 83(1986) minus OHD"). What Figure 8-1 shows is that, despite best efforts to pick representative (median) vectors on a cell-by-cell basis in order to build the grid, such efforts appear to have failed, at least on the Big Island. If one then examines how well all of the vectors compare to the grid in Figure 8-1, one sees a great deal of chaos, particularly on the Big Island. In other words, one can conclude that:

The nature of the OHD-to-NAD 83(1986) transformation is so chaotic on the Big Island that it is impossible to form a grid that is representative of the total field to a high level of accuracy.

As such, our choices are to either (a) remove most vectors on the Big Island as "outliers" (or, as Dewhurst says to pay "attention" to "datum inconsistencies") or (b) to leave them in and report the statistics as much worse than 15 cm. We have chosen the latter.

8.1.4 NADCON 5.0 versus NADCON 1.0: Puerto Rico and the USVI

Table 8-7: Residual Latitude Statistics for Transformation PR 40 / NAD 83(1986) / PRVI

NADCON Version (Grid Spacing)	Type of Points used	Number of Points	Ave	Std	Min	Max
1.0 (3')	1st/2nd order	873	0.000 m	0.041 m	-0.222 m	0.158 m
5.0 (5')	Thinned	176	0.000 m	0.018 m	-0.107 m	0.056 m
	Dropped	1284	0.007 m	0.060 m	-0.860 m	0.437 m
	All	1460	-0.007 m	0.056 m	-0.860 m	0.437 m

Table 8-8: Residual Longitude Statistics for Transformation PR 40 / NAD 83(1986) / PRVI

NADCON Version (Grid Spacing)	Type of Points used	Number of Points	Ave	Std	Min	Max
1.0 (3')	1st/2nd order	873	-0.002 m	0.045 m	-0.241 m	0.266 m
5.0 (5')	Thinned	176	0.000 m	0.019 m	-0.063 m	0.069 m
	Dropped	1284	0.001 m	0.111 m	-0.538 m	3.105 m
	All	1460	0.000 m	0.104 m	-0.538 m	3.105 m

The statistics for the PR40/NAD 83(1986) transformation appear to compare well. The standard deviation is somewhat larger for NADCON 5.0, especially in longitude, but this might be explained by the additional 600 or so points used in NADCON 5.0 which may have been of a lower order than the 873 used in NADCON 1.0.

8.1.5 NADCON 5.0 versus NADCON 1.0: St. Paul

Table 8-9: Residual Latitude Statistics for Transformation SP1952 / NAD 83(1986) / St. Paul

NADCON Version (Grid Spacing)	Type of Points used	Number of Points	Ave	Std	Min	Max
1.0 (3’)	1st/2nd ord	41	0.041 m	0.174 m	-0.131 m	1.007 m
5.0 (1’)	Thinned	27	-0.001	0.031 m	-0.110 m	0.004 m
	Dropped	23	0.167 m	0.416 m	-0.177 m	1.321 m
	All	50	-0.076m	0.291 m	-1.321 m	0.177 m

Table 8-10: Residual Longitude Statistics for Transformation SP1952 / NAD 83(1986) / St. Paul

NADCON Version (Grid Spacing)	Type of Points used	Number of Points	Ave	Std	Min	Max
1.0 (3’)	1st/2nd ord	41	0.004 m	0.101 m	-0.263 m	0.280 m
5.0 (1’)	Thinned	27	0.000 m	0.028 m	-0.054 m	0.064 m
	Dropped	23	-0.039 m	0.237 m	-0.886 m	0.354 m
	All	50	0.018 m	0.161 m	-0.354 m	0.886 m

It’s not clear why there are 9 points missing from the NADCON 1.0 build, but they do have a few centimeters of impact between 1.0 and 5.0. However, considering the magnitude of the transformation itself (about +70 meters latitude, -140 meters longitude), differing residual statistics of a few cm or even a decimeter still show great performance of both transformations.

8.1.6 NADCON 5.0 versus NADCON 1.0: St. George

Table 8-11: Residual Latitude Statistics for Transformation SG1952 / NAD 83(1986) / St. George

NADCON Version (Grid Spacing)	Type of Points used	Number of Points	Ave	Std	Min	Max
1.0 (1’)	1st/2nd order	23	0.003 m	0.028 m	-0.030 m	0.088 m
5.0 (1’)	Thinned	17	0.000 m	0.015 m	-0.030 m	0.031 m
	Dropped	10	-0.032 m	0.053 m	-0.116 m	0.036 m
	All	27	-0.012 m	0.037 m	-0.116 m	0.036 m

Table 8-12: Residual Longitude Statistics for Transformation SG1952 / NAD 83(1986) / St. George

NADCON Version (Grid Spacing)	Type of Points used	Number of Points	Ave	Std	Min	Max
1.0 (1’)	1st/2nd order	23	0.001 m	0.018 m	-0.028 m	0.040 m
5.0 (1’)	Thinned	17	0.000 m	0.012 m	-0.017 m	0.024 m
	Dropped	10	0.018 m	0.051 m	-0.098 m	0.088 m
	All	27	0.007 m	0.033 m	-0.098 m	0.088 m

Much of what was said for St. Paul may be repeated here. It’s unclear why there are four points missing from NADCON 1.0, but despite that, both NADCON 1.0 and 5.0 show fantastic residual statistics at the few centimeters level between the input vectors and the grid based vectors, especially considering the magnitude of the actual transformation (115 meters latitude, -150 meters longitude).

8.1.7 NADCON 5.0 versus NADCON 1.0: St. Lawrence

Table 8-13: Residual Latitude Statistics for Transformation SL1952 / NAD 83(1986) / St. Lawrence

NADCON Version (Grid Spacing)	Type of Points used	Number of Points	Ave	Std	Min	Max
1.0 (3')	1st/2nd order	146	0.001 m	0.025 m	-0.094 m	0.127 m
5.0 (1')	Thinned	154	0.000 m	0.009 m	-0.043 m	0.077 m
	Dropped	6	0.037 m	0.069 m	-0.018 m	0.155 m
	All	160	0.002 m	0.017 m	-0.043 m	0.155 m

Table 8-14: Residual Longitude Statistics for Transformation SL1952 / NAD 83(1986) / St. Lawrence

NADCON Version (Grid Spacing)	Type of Points used	Number of Points	Ave	Std	Min	Max
1.0 (3')	1st/2nd order	146	-0.001 m	0.017 m	-0.081 m	0.091 m
5.0 (1')	Thinned	154	0.000 m	0.008 m	-0.057 m	0.066 m
	Dropped	6	0.010 m	0.047 m	-0.062 m	0.071 m
	All	160	0.001 m	0.012 m	-0.062 m	0.071 m

As per St. Paul and St. Lawrence, it's not clear why there is a slight difference in point counts between NADCON 1.0 and 5.0. And, as per the same, the residual statistics of a few centimeters are remarkably good considering the size of the transformation (-52 meters latitude, 39 meters longitude).

8.1.8 NADCON 5.0 versus NADCON 1.0: Summary

The previous sections have shown that, with explainable deviations, NADCON 5.0 tends to behave as well as NADCON 1.0. This satisfies one of the primary objectives of NADCON 5.0, which was to not upend any standing transformations which did not have a scientific error. However the intent of that objective was not to keep the transformations identical at all points, and this was not done. Each grid was re-created using the consistent approaches of NADCON 5.0.

Overall, the primary reason why NADCON 5.0 does not statistically agree with NADCON 1.0 was due to the inclusion of significant numbers of additional points in NADCON 5.0. In some cases (CONUS) this meant 3rd order data was in the mix. In others (Hawaii), it meant that significantly disparate vectors were left in, causing much larger error estimates than NADCON 1.0. All in all, NADCON 5.0 was both created with, and errors reflect the use of, all published data in the IDB, with the exception of egregious outliers.

8.2 NADCON 5.0 Formal Error Estimates

One of the innovations that come with NADCON 5.0 are geographically dependent error estimates. But just how accurate are they? That question was answerable, we felt, if the actual mismatches between transformed coordinates and published coordinates compared to the formal error estimates in a normal distribution. By way of example, consider the following: Take all points with a published coordinate set in USSD and also a published coordinate set in NAD 27. Using the NADCON 5.0 grids and interpolation software, input the USSD coordinate and request a transformed NAD 27 coordinate. What NADCON 5.0 will give you is not just the transformed NAD 27 coordinate but also a formal error estimate (an estimate of how much error NADCON 5.0 thinks might be associated with that transformed NAD 27 coordinate). If one then compares the transformed NAD 27 coordinate to the published NAD 27 coordinate, a difference is generated. What is hypothesized is that this difference will be smaller than the formal error estimate about 68% of the time. Further it is hypothesized that the difference will be smaller than twice the formal error estimate about 95% of the time, and smaller than three times the formal error estimate about 99.7% of the time. That is, the formal error estimates compared to the true differences will follow a normal distribution. To test this hypothesis, the statistics of transformed minus published coordinates were compared to the formal error estimates coming out of the transformation. The results are in Table 8-15.

The statistics in Table 8-15 indicate that the formal error estimates coming out of NADCON 5 are doing their job as far as representing the expected error of the transformed coordinate. If it were perfect, it should be expected that the 1 σ column would show generally 68%, the 2σ column about 95% and the 3σ column about 99.7%. While not quite at that level, the general trend toward those numbers is encouraging and enough that no change in the formal error estimation scheme was viewed as necessary. With this successful set of results, we feel these error estimates are robust. The method developed (mixing method noise with data noise) was untested and therefore had the potential to behave radically different than a normal distribution. But with a near-normal behavior, it is felt that the error estimates satisfy their primary objective of reflecting the size of expected random errors of the transformation.

Table 8-15: Percentage of time NADCON 5 transformations and error estimates match published coordinates[64]

Transformation	1 σ	2 σ	3 σ
USSD / NAD 27 / CONUS	78	96	99
NAD 27 / NAD83(1986) / CONUS	77	95.7	98.7
NAD 83(1986) / NAD 83(HARN) / CONUS	75.5	96.2	99.2
NAD83 (HARN) / NAD 83(FBN) / CONUS	73 (hor) 80 (eht)	92 (hor) 98 (eht)	94.7 (hor) 99.3 (eht)
NAD 83(FBN) / NAD 83(NSRS2007) / CONUS	71 (hor) 78 (eht)	96 (hor) 98 (eht)	98.8 (hor) 99.9 (eht)
NAD 83(NSRS2007) / NAD 83(2011) / CONUS	69 (hor) 82 (eht)	94 (hor) 98.3 (eht)	98.3 (hor) 99.9 (eht)
NAD 27 / NAD 83(1986) / Alaska	77	95	97.8
NAD 83(1986) / NAD 83(1992) / Alaska	82	97	99.3
NAD 83(1992) / NAD 83(NSRS2007) / Alaska	79 (hor) 74 (eht)	96.5 (hor) 95.7 (eht)	99.4 (hor) 99.4 (eht)
NAD 83(NSRS2007) / NAD 83(2011) / Alaska	84 (hor) 75 (eht)	98.5 (hor) 96.7 (eht)	99.5 (hor) 99.2 (eht)
OHD / NAD 83(1986) / HAWAII	73	96	99.4
NAD 83(1986) / NAD 83(1993) / Hawaii	75	95.1	99.3
NAD 83(1993) / NAD 83(PA11) / Hawaii	71 (hor) 76 (eht)	95.4 (hor) 97 (eht)	98.5 (hor) 99.6 (eht)
PR40 / NAD 83(1986) / PR&VI	76	95	98.5
NAD 83(1986) / NAD 83(1993) / PR&VI	74	94	98.4
NAD 83(1993) / NAD 83(1997) / PR&VI	71 (hor)	94.8 (hor)	98.8 (hor)

[64] The data from this table may be re-generated by running scripts described in DRU-12, p. 70.

	69 (eht)	94 (eht)	100 (eht)
NAD 83(1997) / NAD 83(2002) / PR&VI	75 (hor) 78 (eht)	96.7 (hor) 98 (eht)	99 (hor) 100 (eht)
NAD 83(2002) / NAD 83(NSRS2007) / PR&VI	70 (hor) 79 (eht)	94 (hor) 95 (eht)	99.5 (hor) 100 (eht)
NAD 83(NSRS2007) / NAD 83(2011) / PR&VI	67 (hor) 71 (eht)	85 (hor) 90 (eht)	97.6 (hor) 98.3(eht)
GU 63 / NAD 83(1993) / Guam & CNMI	83	90	94
NAD 83(1993) / NAD 83(2002) / Guam & CNMI	60 (hor) 67 (eht)	97(hor) 100 (eht)	100 (hor) 100(eht)
NAD 83(2002) / NAD 83(MA11) / Guam & CNMI	63 (hor) 79 (eht)	96.5 (hor) 100 (eht)	100 (hor) 100 (eht)
AS 62 / NAD 83(1993) / American Samoa	76	93	98
NAD 83(1993) / NAD 83(2002) / American Samoa	82 (hor) 86 (eht)	97 (hor) 100 (eht)	99.2 (hor) 100(eht)
NAD 83(2002) / NAD 83(PA11) / American Samoa	77 (hor) 78 (eht)	96 (hor) 96.3 (eht)	97 (hor) 100 (eht)
SP1897 / SP1952 / St. Paul	80	100	100
SP1952 / NAD 83(1986) / St. Paul	84	95	100
SG1897 / SG1952 / St. George	76	100	100
SG1952 / NAD 83(1986) / St. George	76	98	100
SL1952 / NAD 83(1986) / St. Lawrence	87	99.5	99.5

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10 Grid File Formats

All versions of NADCON and GEOCON used grids. The NADCON grids (prior to NADCON 5) had extensions of "las" and "los" (for "latitude, seconds" and "longitude, seconds"), while GEOCON grids had extensions of ".b" (for "binary"). Each format is detailed below.

10.1 "las" and "los" grids (NADCON 4.2 and earlier)

Grid files associated with NADCON (4.2 and earlier), ended in "las" or "los". The las/los format consists of a mix of ASCII and binary data.

10.1.1 Header

Each las/los grid begins with a *variable length* header of mixed ASCII and binary data. The total number of bytes in this header is dependent upon the number of columns in the grid according to this formula:

Header_bytes = (nc + 1) x 4

Where "nc" is the number of columns in the grid. The header consists of two components: A 96 byte metadata field and blanks. There will always be 96 bytes in the metadata field (consisting of a mix of 64 ASCII bytes and 32 binary bytes), which leads to the first problem with this format: Any grid with less than 23 columns can not be properly stored in NADCON format, as the header will be set to under 96 bytes and the metadata will not fit. The number of bytes of blank data, presuming a grid of over 23 columns, will be:

Header_blank_bytes = (nc + 1) x 4 - 96

The metadata component of the header consists of the following values:

Table 10-1: Header contents for .las/.los format

Bytes	Data type	Value
56	ASCII	"NADCON EXTRACTED REGION" (followed by 33 blanks)
8	ASCII	"NADGRD" (followed by 2 blanks)
4	Binary (Integer)	Number of columns ("nc")
4	Binary (Integer)	Number of rows ("nr")
4	Binary (Integer)	Number of layers (always exactly 1)

4	Binary (Real)	Longitude of SW corner (in a -180 to 180 system; decimal degrees)
4	Binary (Real)	Spacing between columns (decimal degrees)
4	Binary (Real)	Latitude of SW corner (in a -90 to 90 system; decimal degrees)
4	Binary (Real)	Spacing between rows (decimal degrees)
4	Binary (Real)	Azimuthal rotation of grid (always exactly 0.0)

10.1.2 Data

Following the metadata and the variable number of blanks that encompass the entire header, the actual grid data begins. It is stored one row at a time, beginning with the southernmost row and ending with the northernmost row. Each row of data stores values from the westernmost to the easternmost.

Each record, containing 1 row of data, will have (nc+1) x 4 bytes of binary (real) data. The record begins with a "null" character of 4 bytes. After that will be "nc" real values of 4 bytes each. There will be a total of "nr" such records, where "nr" is the number of rows in the grid. The following illustration summarizes the las/los data layout.

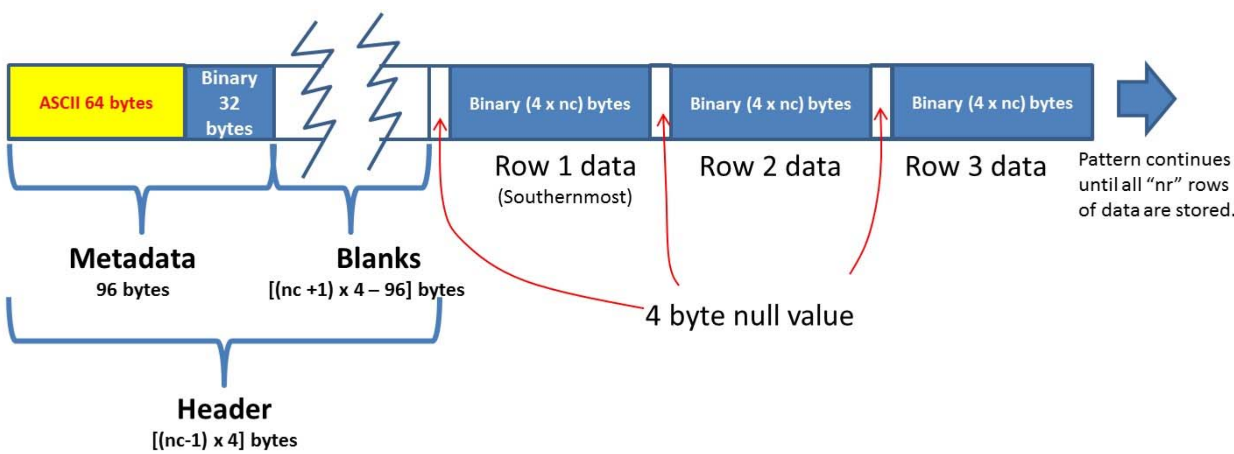

Figure 10-1: Contents of .las/.los format

10.1.3 Difficulties

Already mentioned are the joint issues of mixing ASCII and binary data, as well as reliance upon a variable length header. Add to that the impossibility of using this format with a grid smaller than 23 columns wide and you basically have an extraordinarily poor choice of a grid for common usage.

In addition to all of the above, NGS incorrectly loaded the American Samoa data into this format for earlier versions of NADCON even into 4.2, inverting the grids (which should have run from -20 latitude to -14 latitude) into mirror image grids that run from 14 to 20. Needless to say, careless attention to the sense of the signs was yet another reason to completely build NADCON 5.0 from scratch.

A comprehensive overview of this problem is found in NGS internal research notebook "DRU-11" on pages 113-121.

A program for converting las/los grids into the ".b" (or "dot b") format (see below) called "nad2dotb.f" is found on the NGS servers at /home/dru/Goal2/Nadcongrids

10.2 ".b" grids (GEOCON and NADCON 5.0)

Grid files associated with NADCON 5.0, as well as all versions of GEOCON and GEOCON11 end in ".b".

10.2.1 History

The .b format was invented by Dennis Milbert in the 1990's for the purpose of standardizing grid manipulation within the geoid computational software of NGS. It is highly generic to any gridded data with geographic coordinates, and so has been adopted for use in other NGS software which uses grids, such as GEOCON.

10.2.2 Overview

The .b format is binary, and created using FORTRAN software. As such, it carries the FORTRAN artifact that each record (vector of multiple binary values created with a single "write" statement) has both a leading and trailing 4-byte buffer. The contents of that buffer are not terribly important, and relate solely to the length of the record itself. As such, any non-FORTRAN program which reads a ".b" file should be prepared to skip 4 bytes at the beginning and end of each record.

The .b format begins with one header record of fixed length (52 bytes, all binary), containing basic information about the grid. After that, the rest of the file is filled with records representing actual data in the grid. The first record after the header will contain all of the gridded values on the southernmost row of the grid, with the values in that record arranged from west to east. Each subsequent record contains data for one row northward from the previous row until the final record contains the gridded data (still west to east) of the northernmost row of the grid. This layout was chosen so that the column index would increase with increasing (east) longitude and the row index would increase with increasing latitude.

The header record is laid out as such:

Table 10-2: Header contents for .b format

(buffer)	xlatsw	xlonsw	dlat	dlon	nlat	nlon	ikind	(buffer)

These values are described as such:

Table 10-3: Header details for .b format

Name	Type	Bytes	Units	Description
(buffer)	Real	4	N/A	FORTRAN header for each record
xlatsw	Real	8	Decimal degrees	Latitude of SW corner of grid (-90 to 90)
xlonsw	Real	8	Decimal degrees	East longitude of SW corner of grid (0 to 360)
dlat	Real	8	Decimal degrees	Spacing between rows
dlon	Real	8	Decimal degrees	Spacing between columns
nlat	Integer	4	N/A	Number of rows
nlon	Integer	4	N/A	Number of columns
ikind	Integer	4	N/A	Code for type of data in grid
(buffer)	Real	4	N/A	FORTRAN footer for each record

The possible codes for ikind are:

Table 10-4: ikind codes for .b format

ikind value	Data in grid
-1	2 byte integer (special encryption for heights in the USA)
0	4 byte integer
1	4 byte real

2	2 byte integer

Following the header record, each row of the grid fills subsequent records. The type of data (real, integer, etc) in the grid (the "d" values) are determined by "ikind" from the header. The records look like this:

Table 10-5: Data layout by row for .b format

(buffer)	d(1,1)	d(1,2)	...	d(1,nlon)	(buffer)
(buffer)	d(2,1)	d(2,2)	...	d(2,nlon)	(buffer)
	...	...	...	...	
(buffer)	d(nlat,1)	d(nlat,2)	...	d(nlat,nlon)	(buffer)

Do not confuse the layout in Table 10-5 (showing records from top to bottom) with how the data itself actually falls geographically (which is south to north). The first record contains data in the southernmost row:

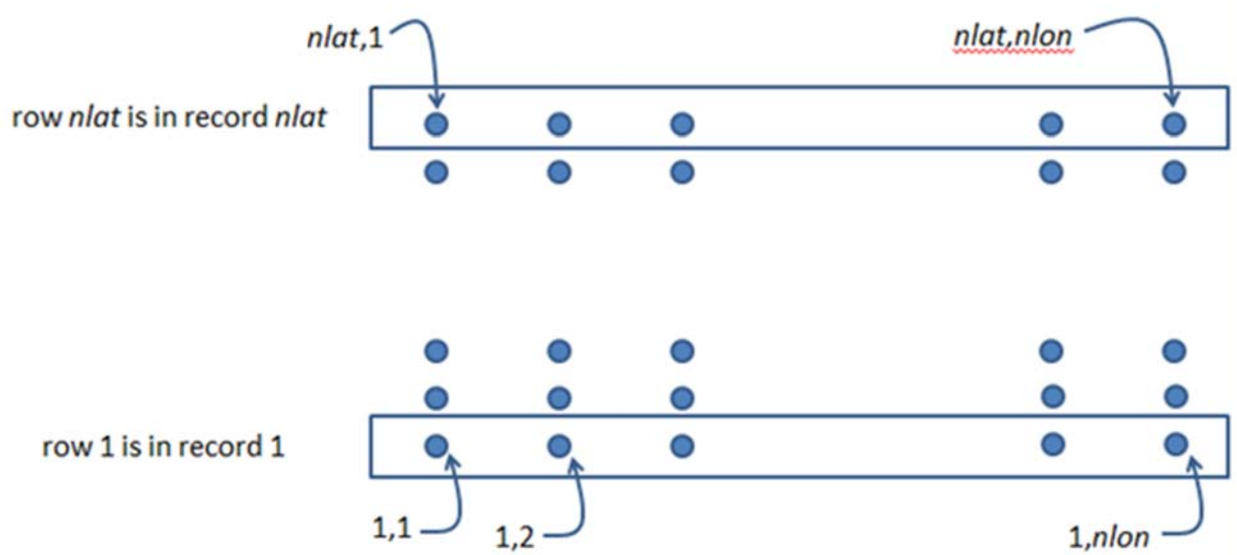

Figure 10-2: Details of data layout for .b format

The latitude of row 1 (record 1) is xlatsw. The latitude of row 2 (record 2) is xlatsw+dlat. The latitude of row 3 (record 3) is xlatsw+2*dlat, etc. The latitude of the final row (nlat) is xlatsw+(nlat-1)*dlat.

Similarly, the longitude of the first grid point in any record is xlonsw. The next grid point to the east has longitude xlonsw+dlon, etc. The final grid point (easternmost) in any record will have longitude of xlonsw+(nlon-1)*dlon.

ikind = -1[65]

As a way to store DEMs in the USA using a minimum of space (by using 2 byte integers, rather than 4 byte reals or 4 byte integers), the "ikind = -1" option was developed. It takes advantage of the fact that, in all territories of the USA, orthometric heights range from about -86 meters (Death Valley) to about +6194 meters (Mt. McKinley), a span of some 6280 meters. Converting to decimeters, the span is 62,800 decimeters.

The range of values able to be stored by 2-byte integers is -32766 to +32767, or a total span of 65533. As such, the span of possible orthometric heights in the USA, expressed in decimeters, will fit inside the span of numbers possible using 2-byte integers. The following formula is used to changes heights (in meters) to stored 2 byte integers, and back:

To store heights: $I = (H_m - 3000) * 10$ [Range : -30860 to 31940]

To recover heights: $H_m = (I/10) + 3000$

[65] Invented 6/10/1999. See book DRU-4, p. 135.

11 Guide to Digital Archive

A full digital archive of data, programs, and plots has been included as part of the NADCON 5.0 release. The archive is entitled *FinalBuilds.20160901*, clearly tagging the origin of the release at September 1, 2016. The archive is accessible on the web at: There will be a link from the NADCON 5.0 webpage; we need to insert it here.

This section provides an overview of the archive contents; specifics are available in various README files at appropriate levels in the archive itself.

The archive is broken into three main directories:

Table 11-1: Digital Archive Directories

Builds	Final results and NADCON 5.0 products.
RunNADCON5	Code and supporting files to generate results.
AnalyzeNADCON5	Code used for outlier identification and statistical analysis.

All of the final transformations comprising NADCON 5.0 are contained in the *Builds* sub-directory. Each transformation is contained in a subdirectory one level down, titled by *od.nd.rg* (see Author's Notes on file naming convention). Each directory contains the data files used to generate each grid, the final transformation and error grids themselves, GMT scripts used to generate plots, as well as all products which were derived along the way. A guide to the individual files is contained in Section 5.2. The README file in the Builds directory provides information on ASCII file formats.

Each transformation has a *plots* subdirectory, containing all the JPG plots generated during processing. For ease of navigation, the plots are grouped into subdirectories as follows:

Table 11-2: Details of plots directory in digital archive

coverage	Location plots for data points.
vectors	Vector plots for data points, where the vector is formed as "new coordinate minus old coordinate." All vector plots include a scale arrow in the lower lefthand corner of the plot.
datanoise	Colored surface plots for noise introduced by variation within the data themselves; see Section 3.8.
methodnoise	Colored surface plots for error potentially introduced by the GMT *surface* routine and the choice of tension = 0.4; see Section 3.8.
errors	Transformation errors, which are the sum of data noise and method noise; see Section 3.8.

transformation	Colored surface plot depicting the transformation itself; latitude and longitude transformations are shown in both arcseconds and meters, whereas ellipsoidal height transformations are only shown in meters.

The *RunNADCON5* directory is structured so that a user can copy the full directory tree to a local machine, compile the code using the provided help script, then run the code to generate NADCON 5.0 results. Contained within the *RunNADCON5* directory are a number of sub-directories:

Table 11-3: Details of sub-directories in the RunNADCON5 directory of the digital archive

Boundaries	Boundaries of continents, islands, and states, used for drawing maps.
Code	All code needed to generate this release; see Section 5.
Control	Files which group realizations into regional grids; see Section 4.3.
Data	Supporting grid and boundary files for the runs.
InFiles	The fundamental data files for NADCON5; see Section 4.2.
Masks	Code and mask to exclude all data outside HARN to FBN area; see Sections 4.3.1 and 6.1.4, and README file in /Masks directory
Work	Contains only file “workedits”, which lists the points marked for deletion; see Section 4.4.

Finally, the *AnalyzeNADCON5* directory contains helper programs used for user-friendly analysis of the data previous to doing a complete NADCON 5.0 run. These codes were useful for mapping vectors, identifying outliers, and choosing the appropriate grid size for each transformation. The README file at this level gives an overview of each program and its usage, and includes an end-to-end example for how the authors analyzed data when creating NADCON 5.0 grids.