UNAVCO

STABILITY OF GNSS MONUMENTATION:
ANALYSIS OF CO-LOCATED MONUMENTS IN THE PLATE BOUNDARY OBSERVATORY

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MIT

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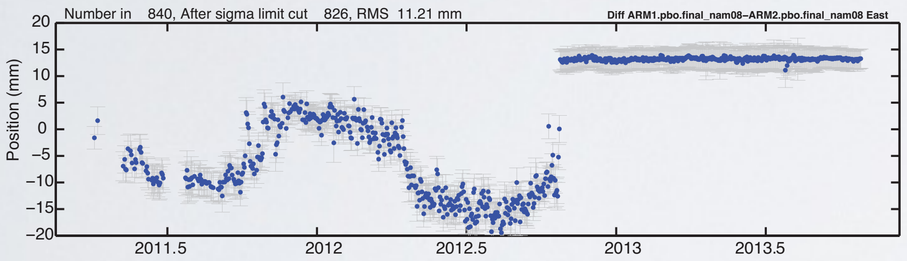
G51B-04

PREVIOUS STUDIES

Existing Multi-Monument Sites in North America

SCIGN DDBM Pair

ARM1, ARM2 located in Bakersfield, CA (2001)
Deep-Drilled Braced Monuments (DDBM) separated by ~34m



Yucca Mountain

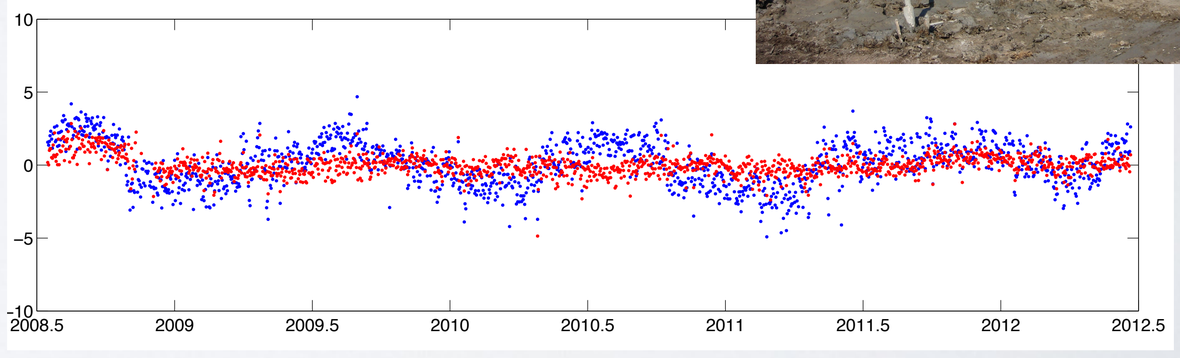
Hill et al. 2009
Drilled-braced monuments in bedrock)REPO, REP2, REP3, REP4 - Varied baseline lengths (~10, 100, and 1000 m)
Mixed anchoring depth

New Madrid Seismic Zone

Matioli and Jansma, 2007
Two new deep-drilled braced GPS monuments (HCEX and PTGX) were installed in the New Madrid Seismic Zone. These sites are co-located with existing driven I-beam monuments (HCES and PTGV) in unconsolidated sediment.

East Bay, Hayward Fault

WIN2 (deep-drilled braced), installed 2008
PBO Nucleus upgrade of 1991 USGS shallow driven rod enclosure at Winton



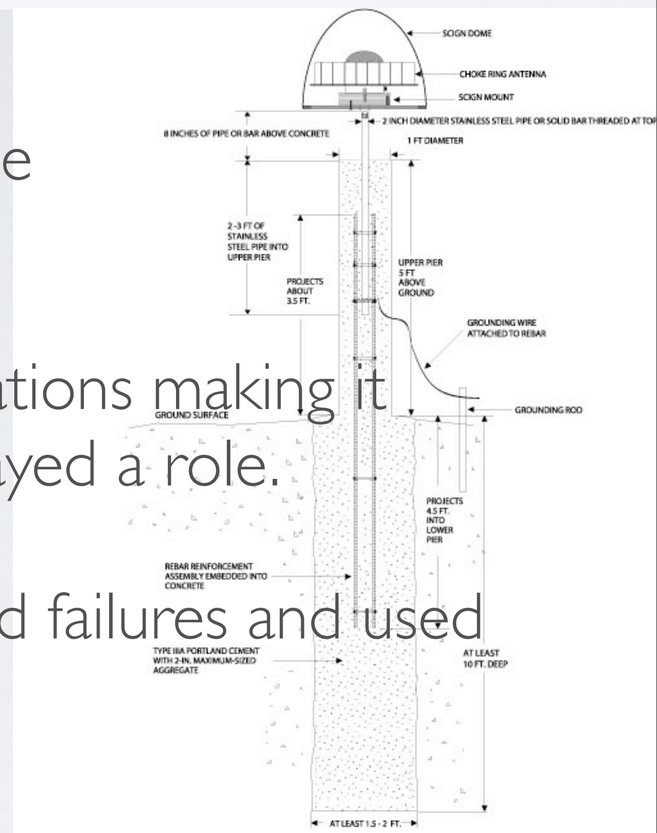
PBO MULTI-MONUMENTATION 2013

- DDBM's are very expensive, high-impact and labor-intensive
  - >50% of PBO are DDBM; were installed wherever logistically possible
  - Pillars are much cheaper at soil sites, but are they stable?

- Previous multi-monument sites were either pairs or had varying separations making it difficult to discern which monument was stable or if baseline length played a role.

- Many previous monument studies have had multiple antenna swaps and failures and used inconsistent equipment reducing their value for stability studies.

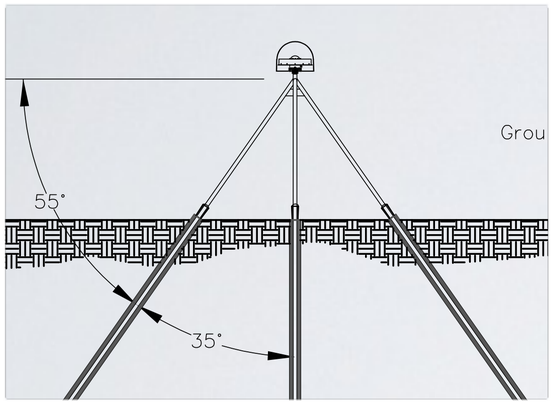
  - Receivers at PBO multi-monuments are all the same type (NETR9)
  - Antennas are all DM choke rings
    - New installations used TRM59800.00 GNSS while existing DDBMs were left with original TRM29659.00 GPS models to preserve time-series integrity.



PBO MULTI-MONUMENTATION 2013

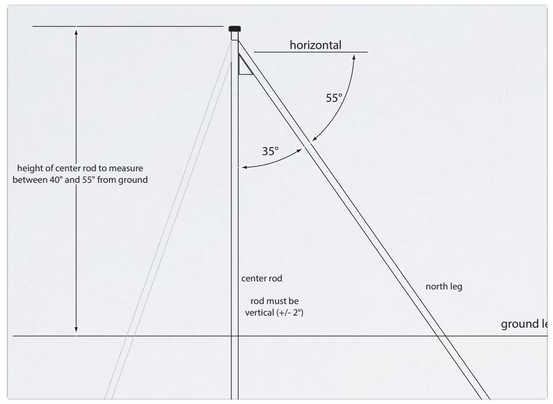
Five different monument types will be evaluated

Deep-Drilled Braced Monument



Cost: $7500-15000
Labor: 3-4 people
Time: 2-4 days
Impact: High
Depth: 35’

Shallow-(Drilled and Driven) Braced Monument



Cost: $800
Labor: 2-3 people
Time: 1-3 days
Impact: Med
Depth: 5’

Short Mast Style Monument

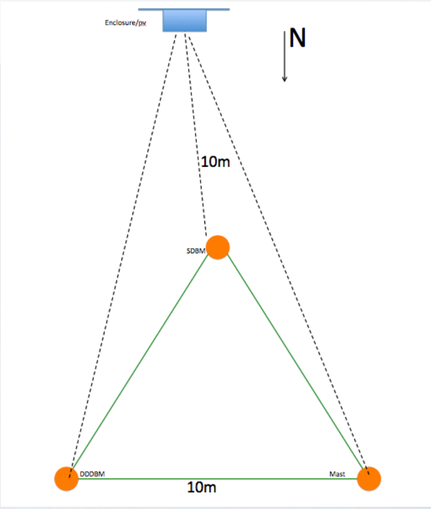
Cost: $150
Labor: 1-2 people
Time: 1 days
Impact: Low
Depth: 2’

Pillar Style Monument

Cost: $500-2000
Labor: 2-3 people
Time: 1-3 days
Impact: Med-High
Depth: 11’

MULTI-MONUMENT LOCATIONS

	4-Char Code	Monument Type	Installation
The Rock, GA	P804	DDBM	Oct 2012
Granite	P805	SDBM	Oct 2012
	P806	Mast	Oct 2012
Wilbur, WA	P453	DDBM	Oct 2005
Basalt	P813	Mast	Aug 2013
	P814	SDBM	Aug 2013
Forks, WA	P401	DDBM	Apr 2005
Clay Substrate	P815	Pillar	Aug 2013
	P816	Driven SBM	Aug 2013
Delano, CA	P565	DDBM	Nov 2005
Clay/Silt/Sand	P809	Pillar	Feb 2013
	P810	Driven SBM	Feb 2013
California City, CA	P591	DDBM	June 2005
Sand	P811	Pillar	Feb 2013
	P812	Driven SDBM	Feb 2013



- 5 localities were chosen
  - 2 in California
  - 2 in Washington
  - 1 in Georgia
- 3 monument types at each
- Existing DDBM were utilized at 4 installations
  - Delano, CA - California City, CA - Wilbur, WA - Forks, WA
- Site selection criteria:
  - Low multi-path
  - Clear sky view
  - Multiple geological conditions

- Site Geometry
  - Triangular with 10m spacing

PROCESSING STRATEGIES

- All the sites are processed by the PBO analysis centers (GAMIT + GISPY)
- Uncombined solutions are available as well (NMT and CWU).
- The current processing uses the standard LC combination.
- Also L1+L2 independently has also been completed.
  - Atmosphere-independent

- Current LC results show sub-millimeter RMS.
- Already seeing lower RMS between DDBM/SDBM vs. DDBM/PILLAR.
- Also seeing smaller slope estimates between DDBM/SDBM vs. DDBM/PILLAR.
- Kinematic processing has revealed periodic RF interference at Delano Airport.

LC PROCESSING RESULTS

The Rock, GA	Baseline	Component	Slope (mm/yr)	WRMS (mm)
Granite	P804-P805	North	-1.65 ± 0.1	0.76
	DDBM-SDBM	East	-4.11 ± 0.2	1.16
		Up	-0.38 ± 0.22	1.27
	P805-P806	North	-3.26 ± 1.62	9.66
	SDBM-MAST	East	-6.78 ± 1.38	8.43
		Up	5.59 ± 1.55	9.35
	P804-P806	North	-5.28 ± 1.72	10.21
	DDBM-MAST	East	-11.15 ± 1.43	8.75
		Up	5.36 ± 1.63	9.83
Delano, CA	Baseline	Component	Slope (mm/yr)	WRMS (mm)
Clay/Silt/Sand	P565-P809	North	1.40 ± 0.1	0.20
	DDBM-PILLAR	East	-0.10 ± 0.1	0.20
		Up	0.30 ± 0.3	0.96
	P809-P810	North	-1.17 ± 0.1	0.22
	PILLAR-DSBM	East	0.01 ± 0.1	0.23
		Up	-0.17 ± 0.3	0.69
	P565-P810	North	0.12 ± 0.1	0.19
	DDBM-DSBM	East	0.05 ± 0.1	0.19
		Up	-0.46 ± 0.3	0.96
California City, CA	Baseline	Component	Slope (mm/yr)	WRMS (mm)
Sand	P591-P811	North	-2.90 ± 0.1	0.27
	DDBM-PILLAR	East	0.34 ± 0.12	0.34
		Up	3.50 ± 0.28	0.78
	P811-P812	North	2.94 ± 0.1	0.28
	PILLAR-DSBM	East	-0.54 ± 0.1	0.14
		Up	-1.83 ± 0.3	0.80
	P591-P812	North	-0.17 ± 0.1	0.21
	DDBM-DSBM	East	0.07 ± 0.1	0.26
		Up	1.41 ± 0.2	0.73

At Delano and California City the slope estimates for the DDBM-SDBM baselines were smaller than for the DDBM-PILLAR baselines.

These preliminary results are starting to suggest that PILLAR type monuments in soft conditions underperform the SDBM type monuments.

Note: Red text denotes estimates affected by antenna failure.

BASELINE SLOPE ESTIMATES

Delano, CA	Baseline	Component	Slope (mm/yr)	WRMS (mm)
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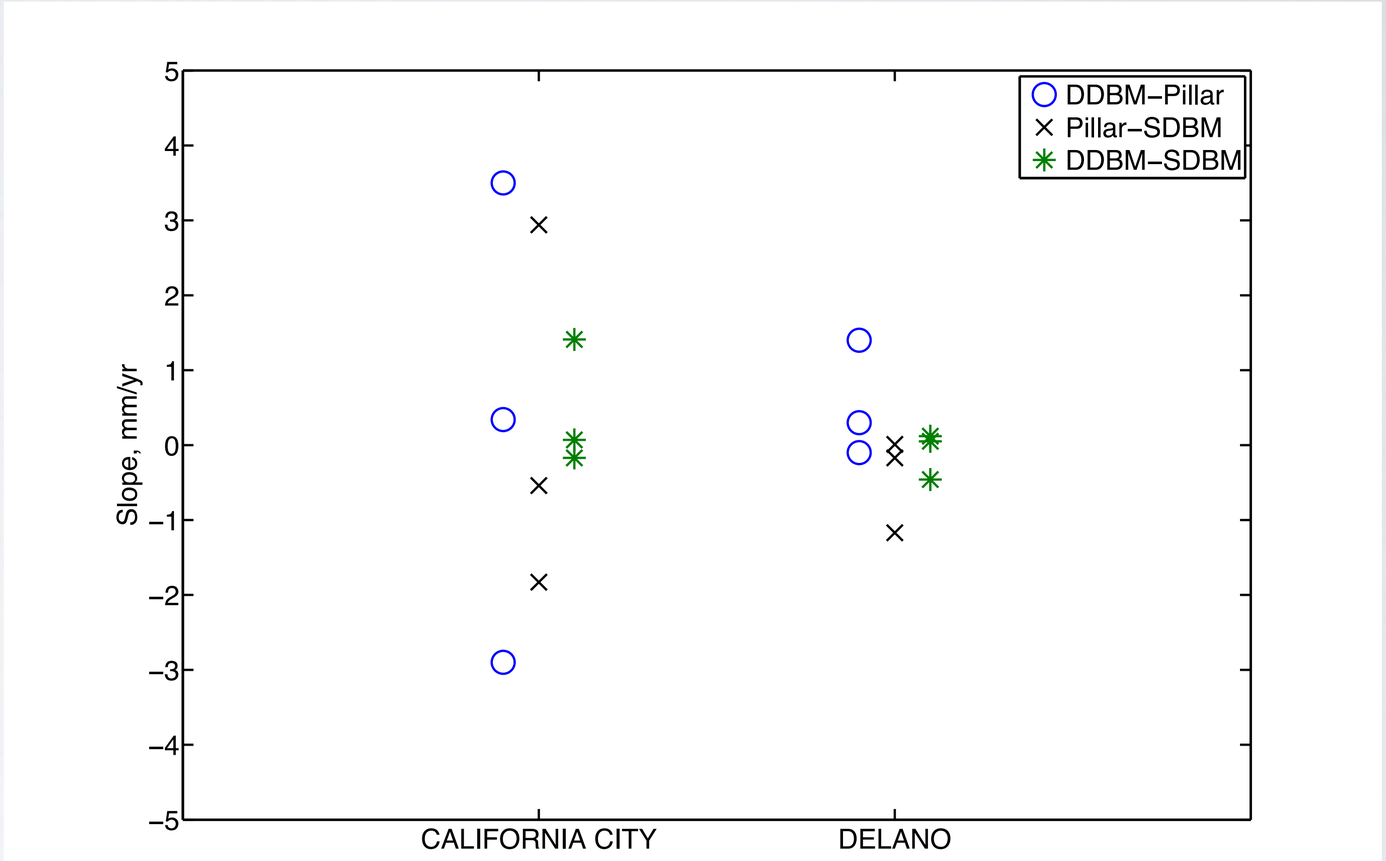

DELANO, CA

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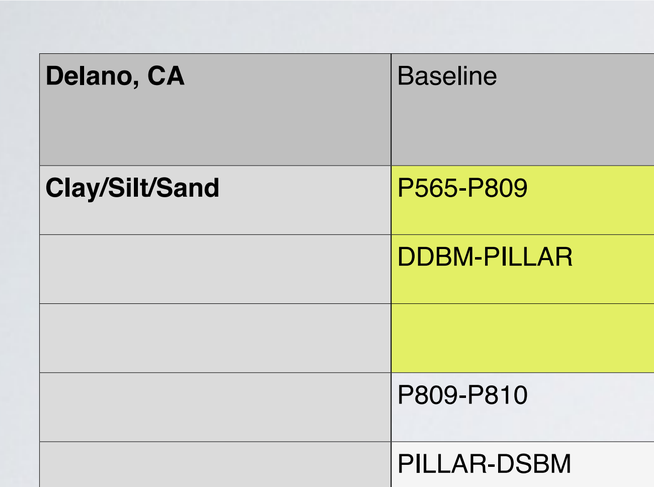
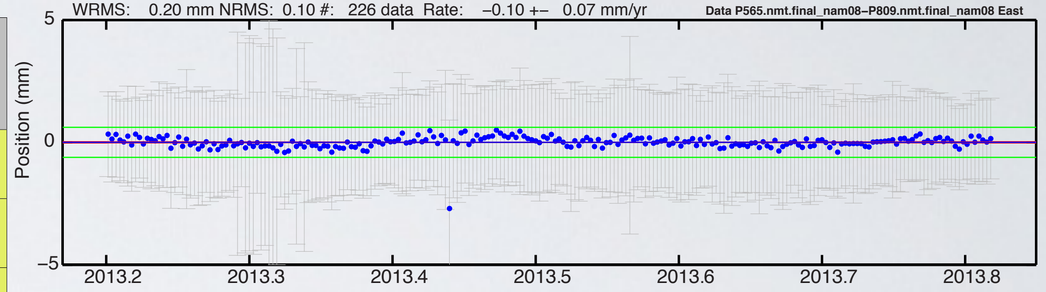
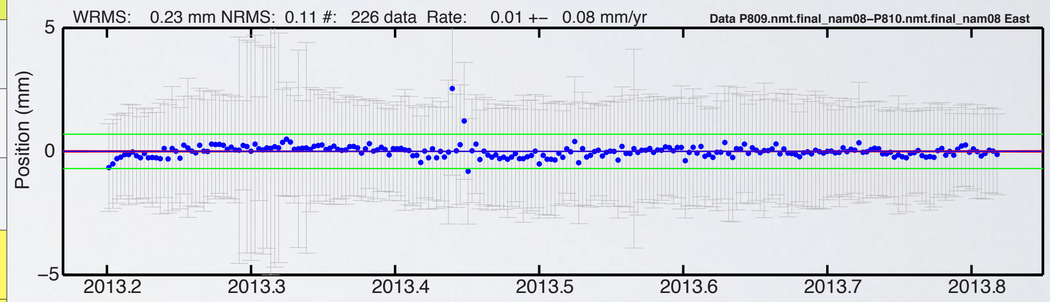
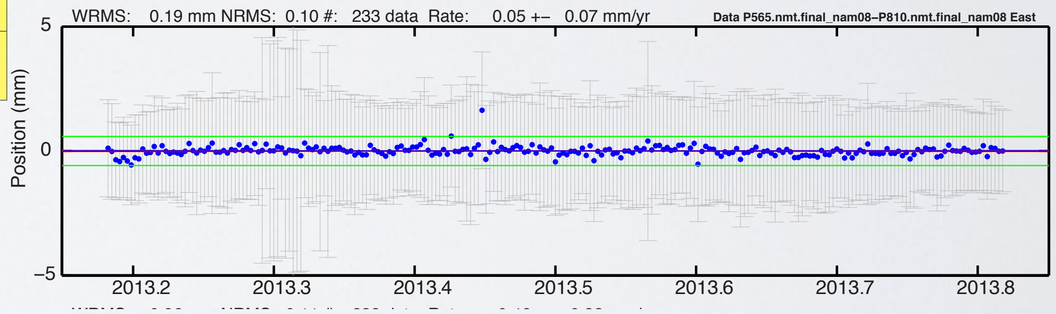




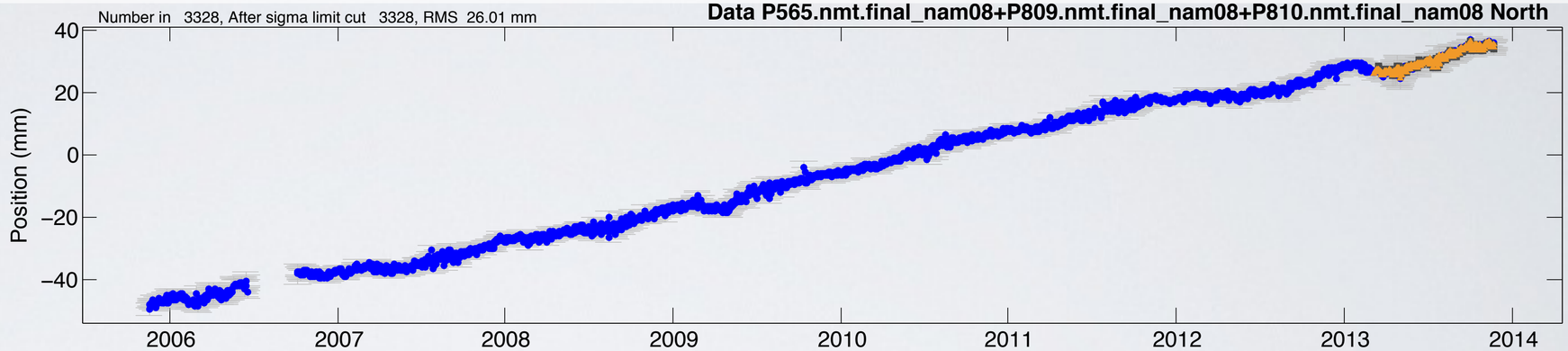


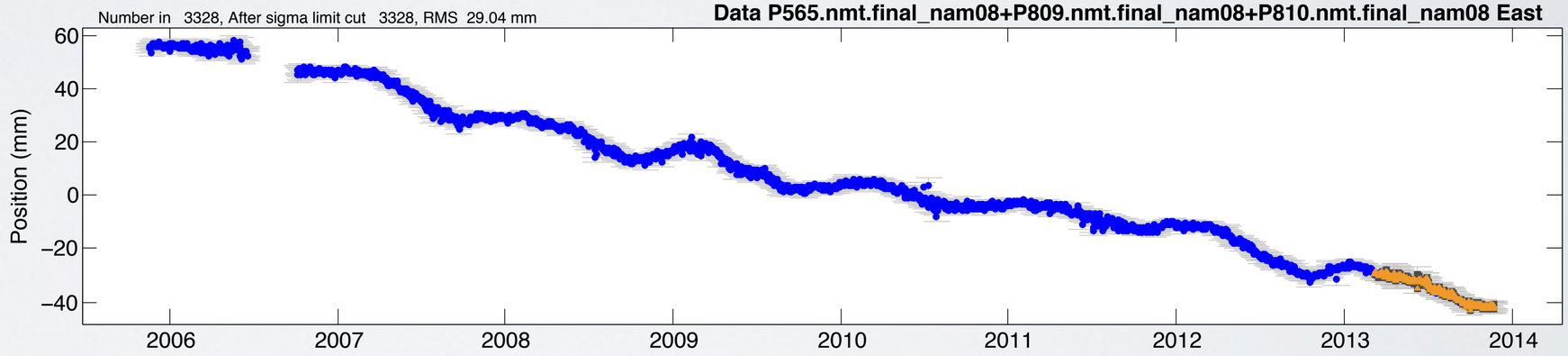


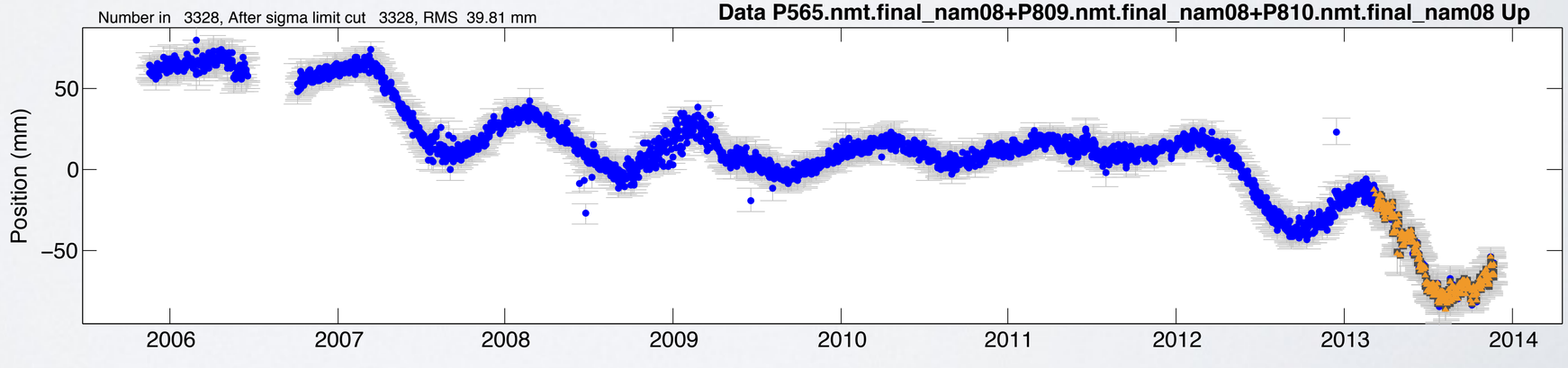
UNAVCO

DELANO, CA

Unconsolidated sand/silt/clay soil







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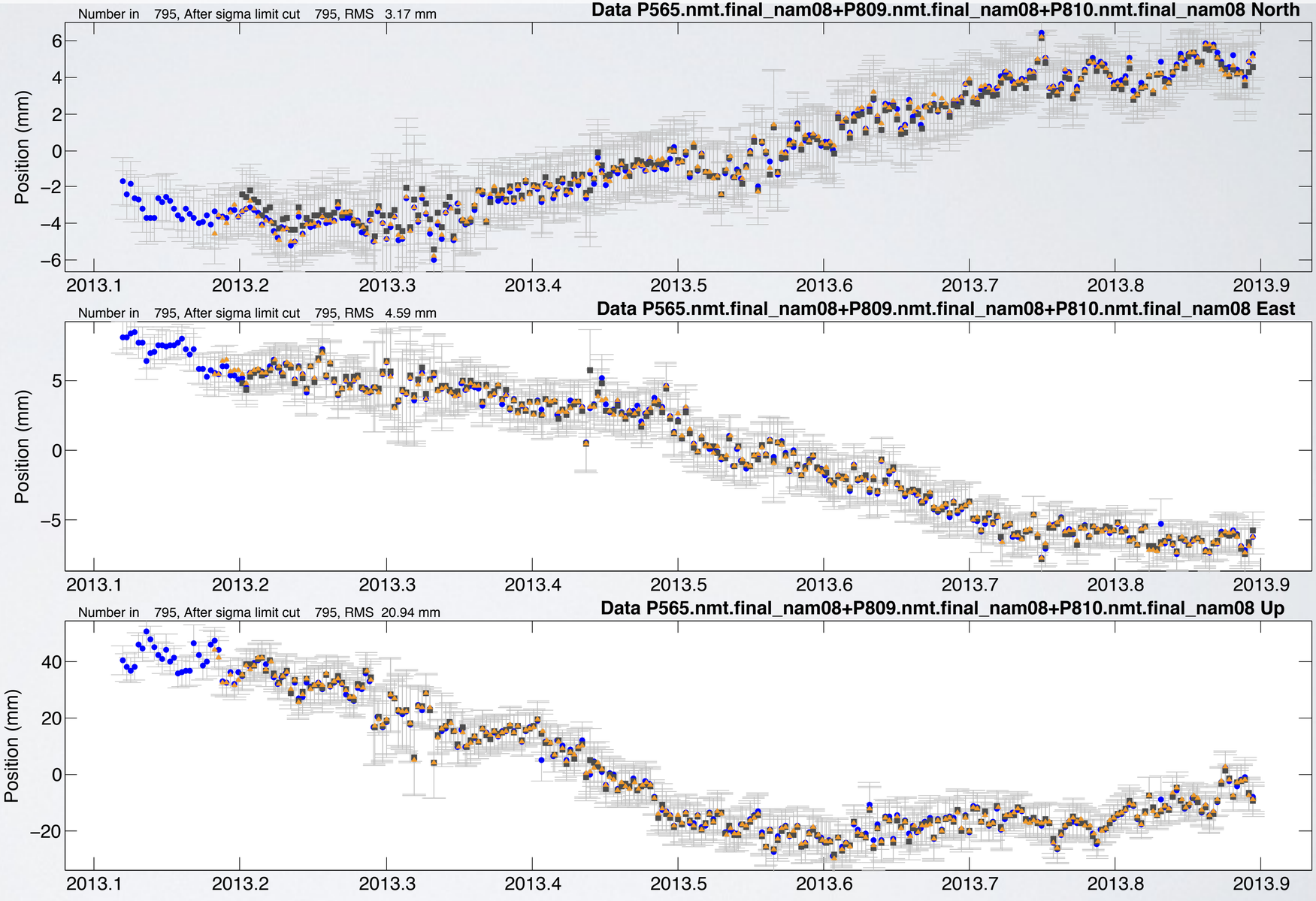

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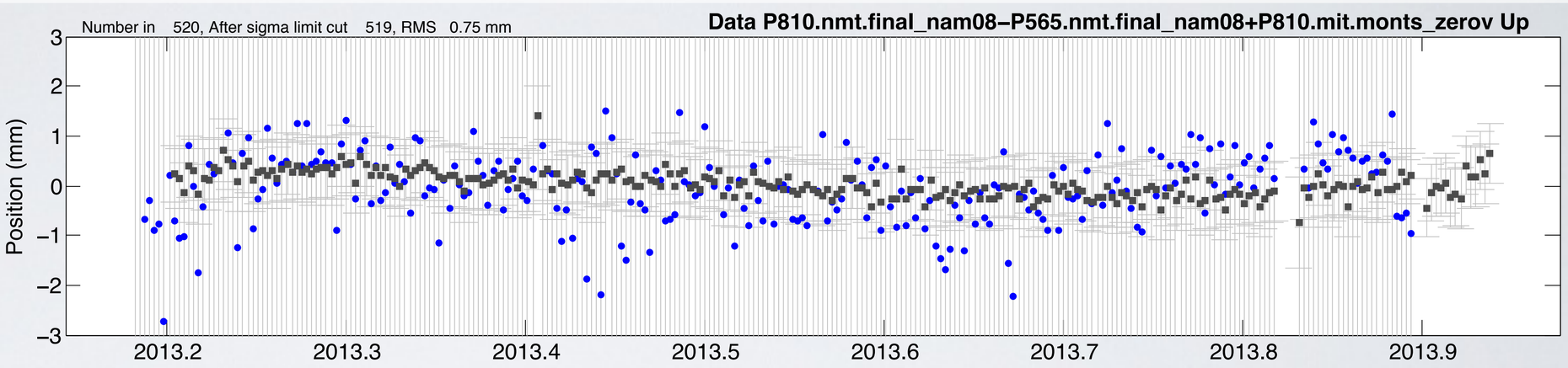
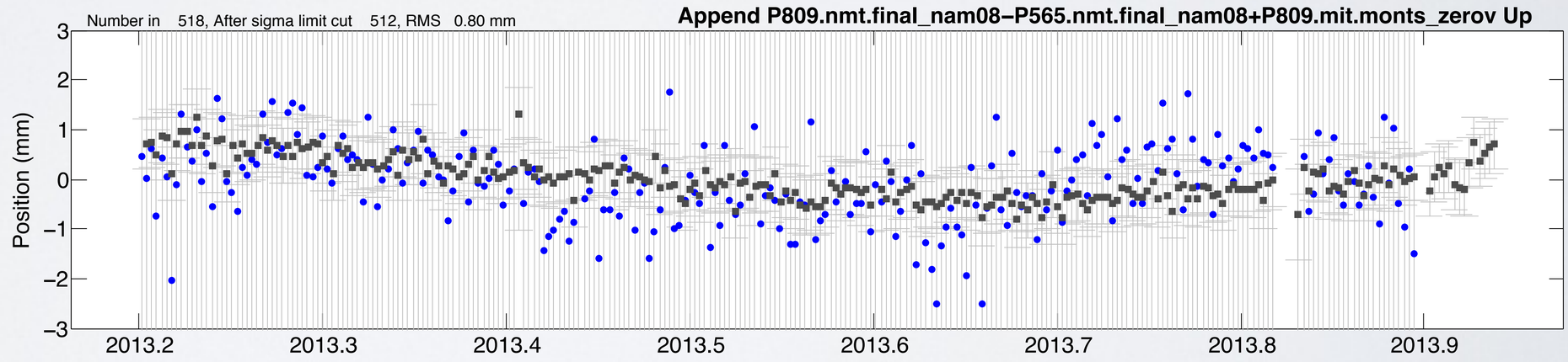


DDBM - SDBM (Vertical, LC (blue), L1 +L2 (Green)



DDBM - Pillar (Vertical, LC (blue), L1 +L2 (Green)

UNAVCO

DELANO, CA

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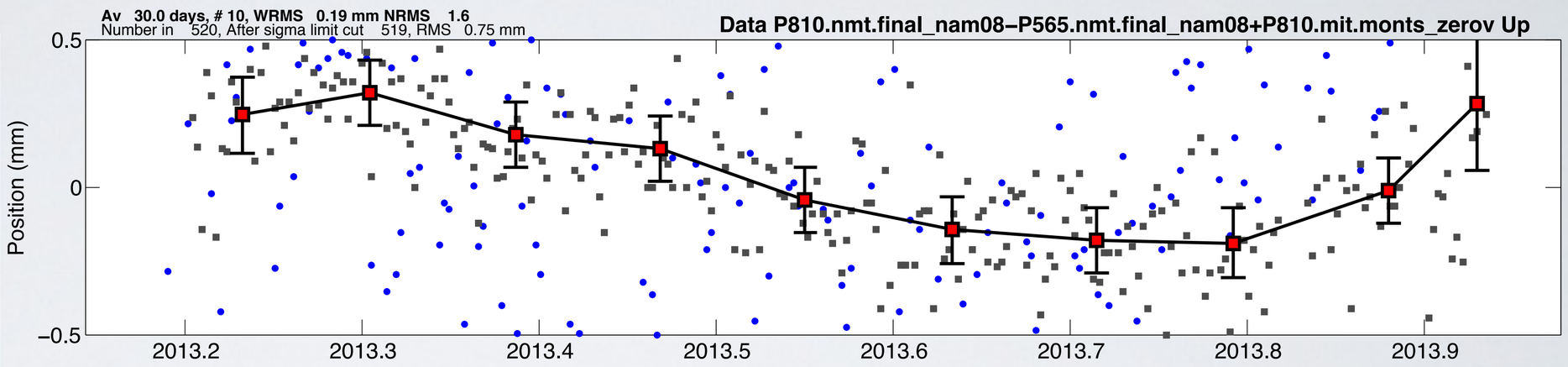
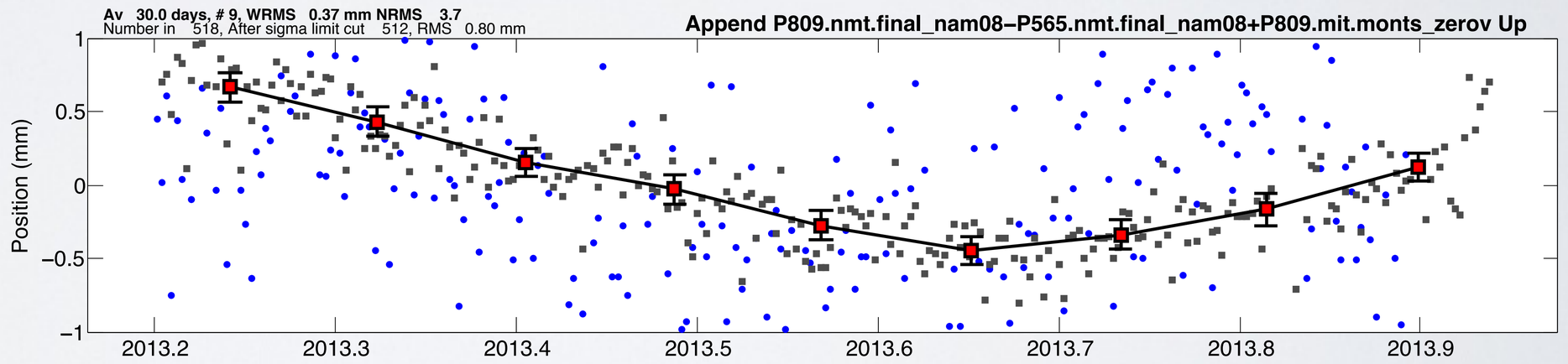


DDBM - SDBM (Vertical, LC (blue), L1 +L2 (Green)



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UNAVCO

DELANO, CA

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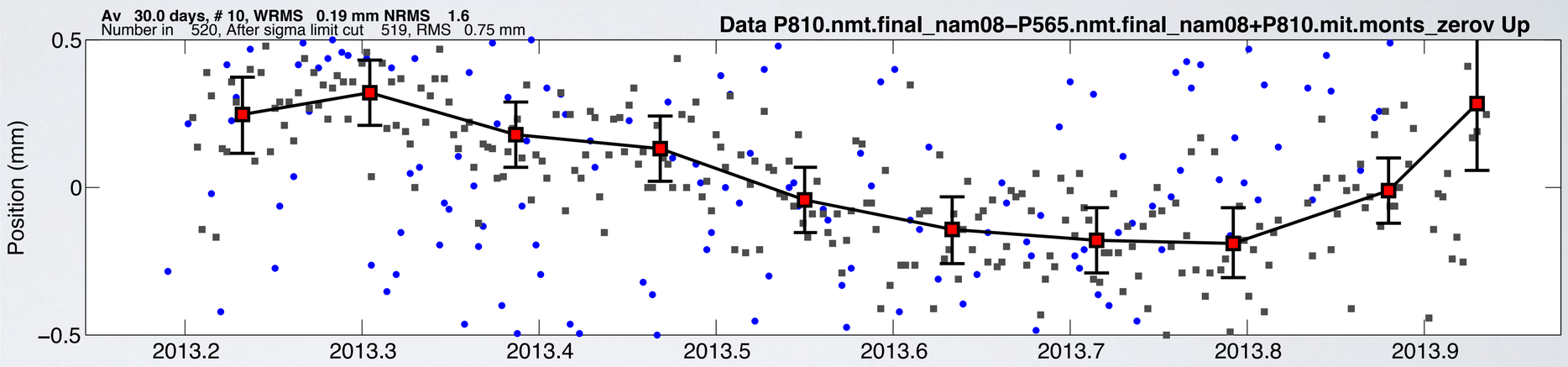
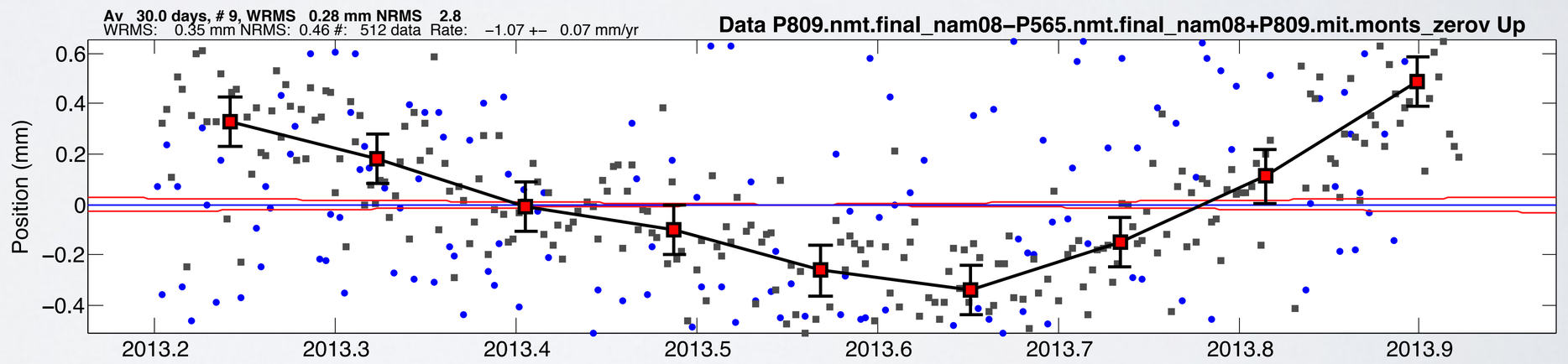


DDBM - SDBM (Vertical, LC (blue), L1 +L2 (Green)



DDBM - Pillar (Vertical, LC (blue), L1 +L2 (Green)

CALIFORNIA CITY, CA

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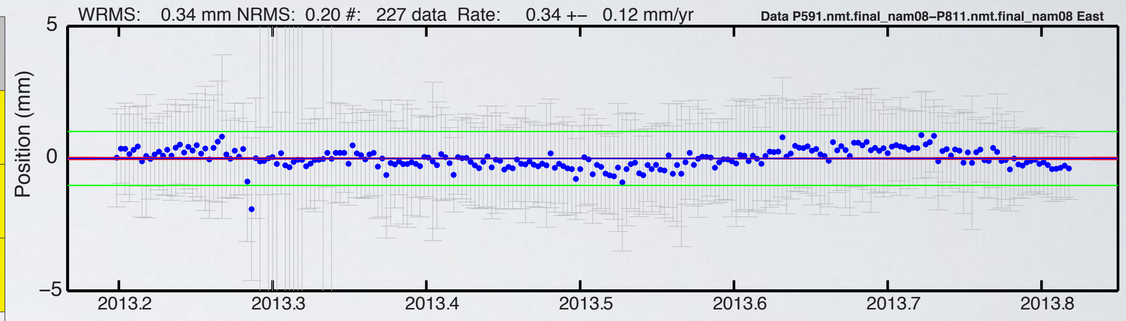

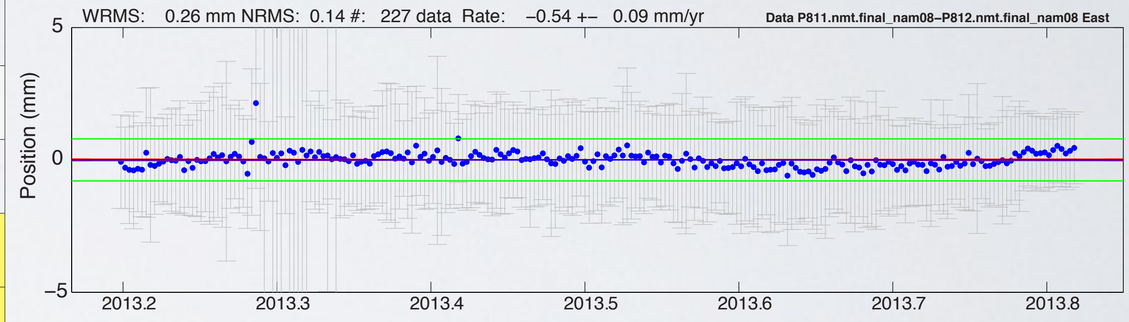

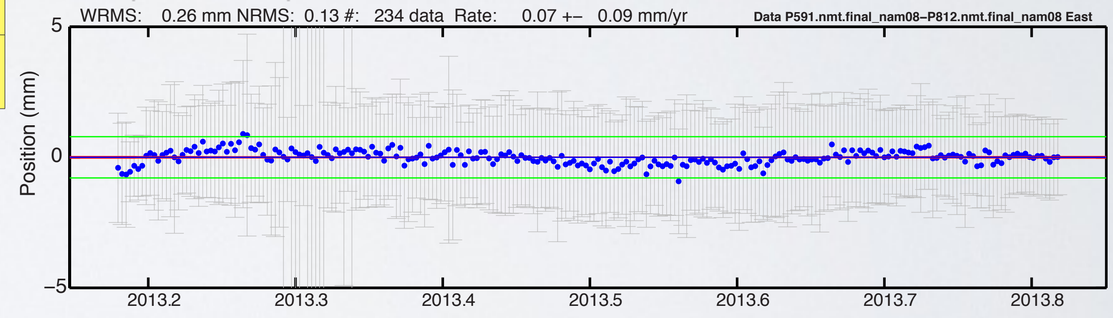

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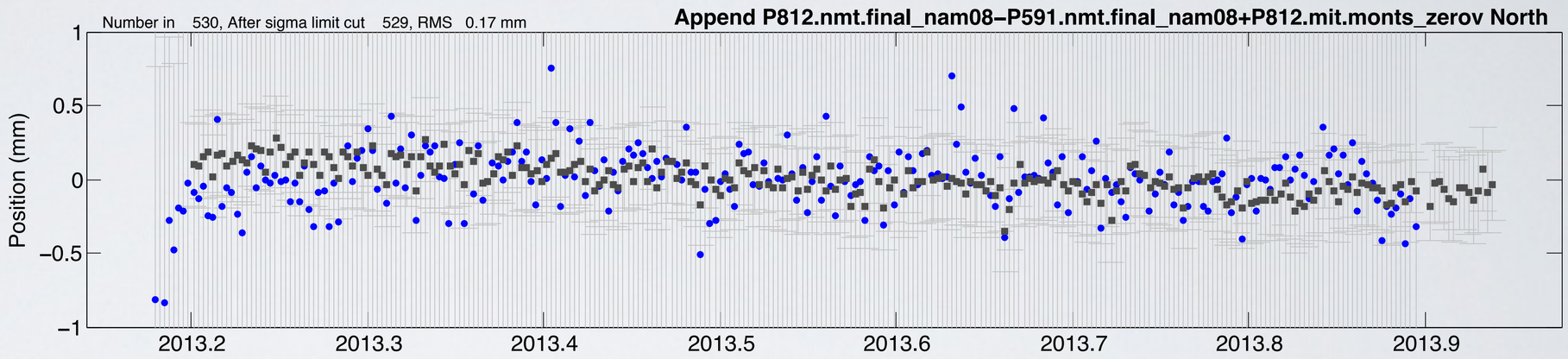
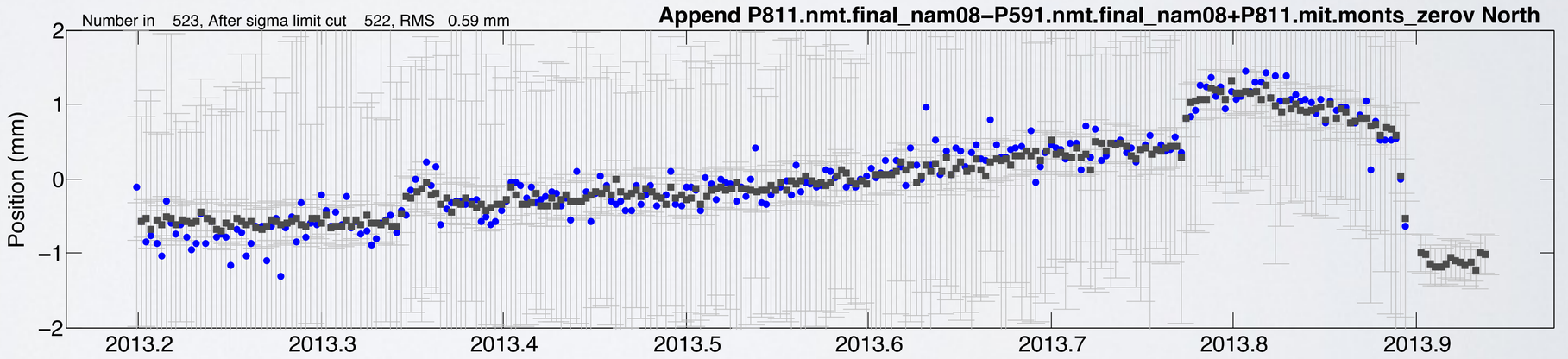


DDBM - SDBM (North, LC (blue), L1 +L2 (Green)

Unconsolidated sandy soil



DDBM - Pillar (North, LC (blue), L1 +L2 (Green)

THE ROCK, GEORGIA

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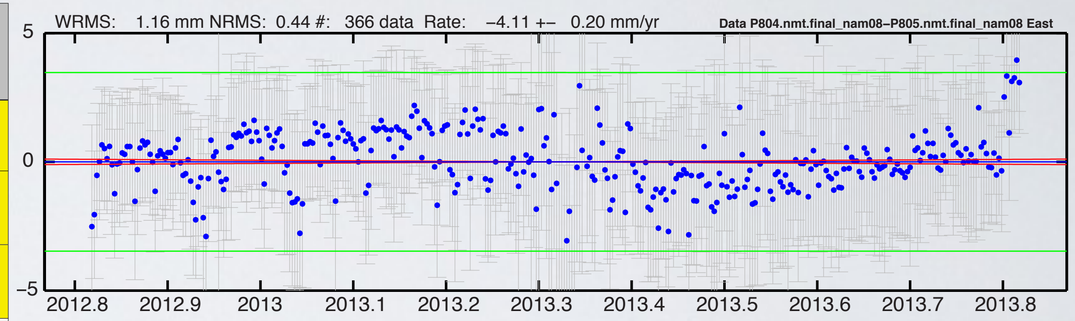

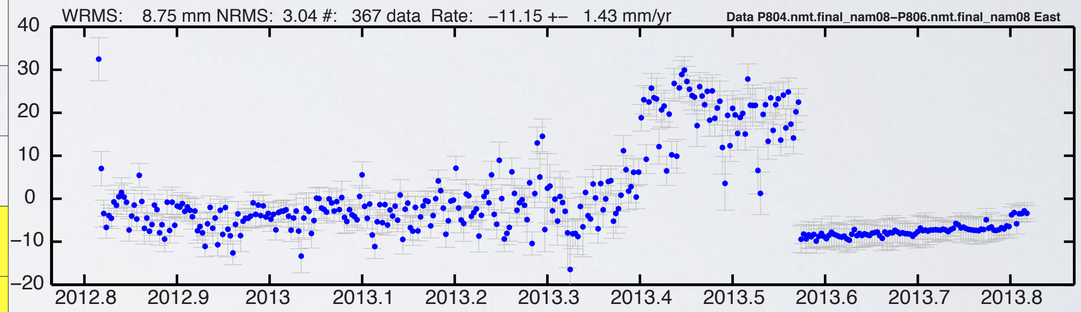

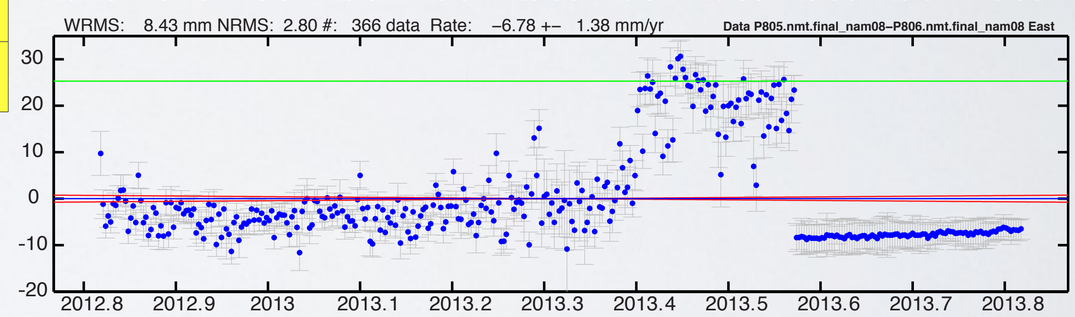

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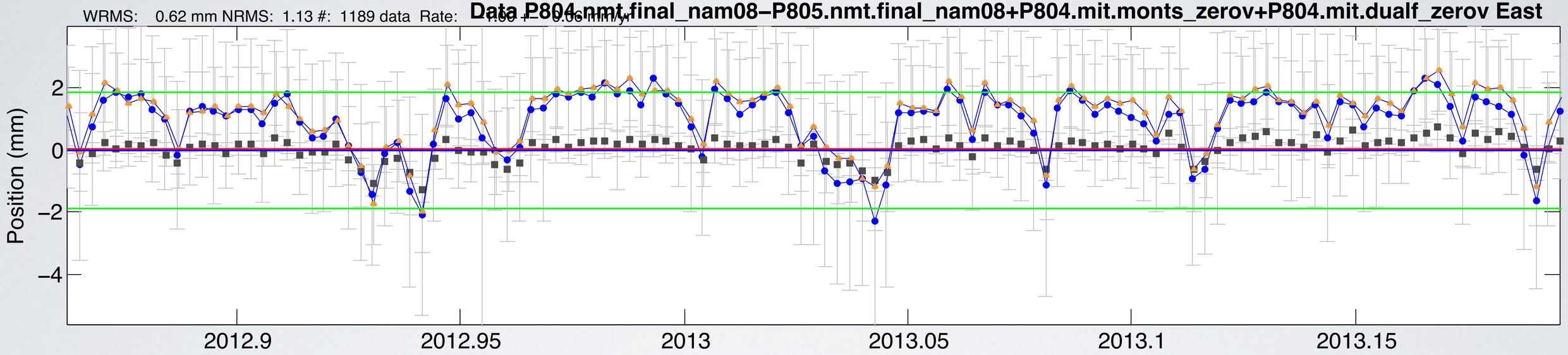
THE ROCK, GEORGIA



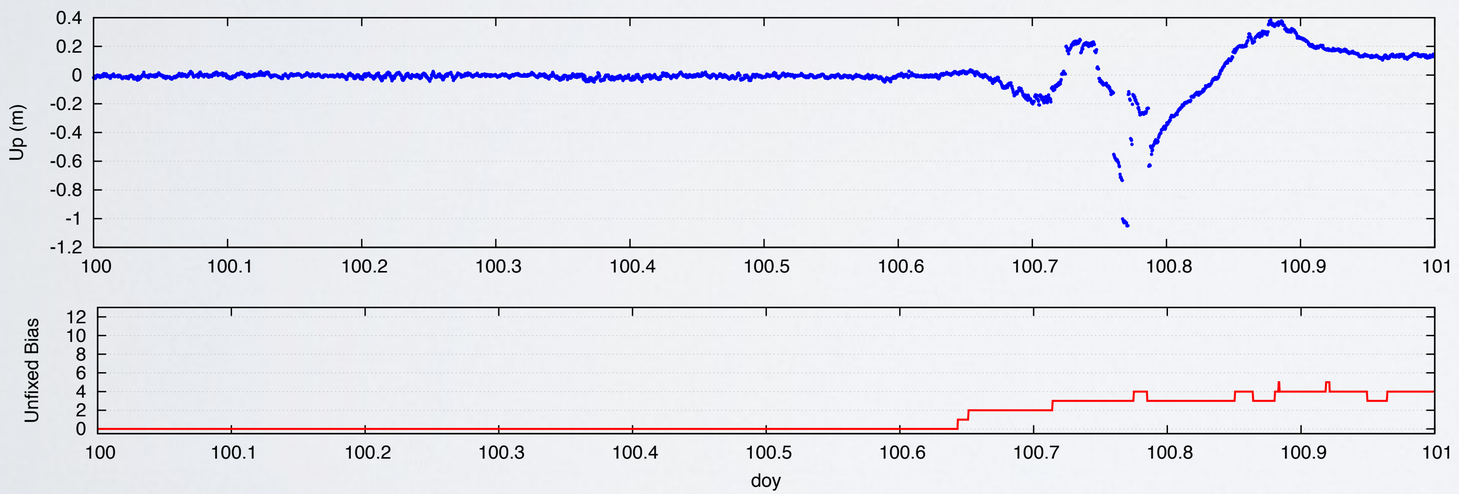
DDBM - SDBM (East)

LC GAMIT Network (blue)
LC No Atmosphere (yellow)
L1 +L2 (Green)

sub-mm stability in Granite

RF INTERFERENCE

- Kinematic processing at Delano has shown position outliers after ~17:00 UTC due to unfixed bias estimates
- QC results from P810 and P809 both show Loss of Lock Indicators for all satellites at ~17:00 and 23:00 UTC (GNSS Choke).
- QC results from the P565 are normal (GPS Choke).
- If the frequency can be identified, it may be possible to use a filter to mitigate the interference at Delano.

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version: teqc  2013Mar18

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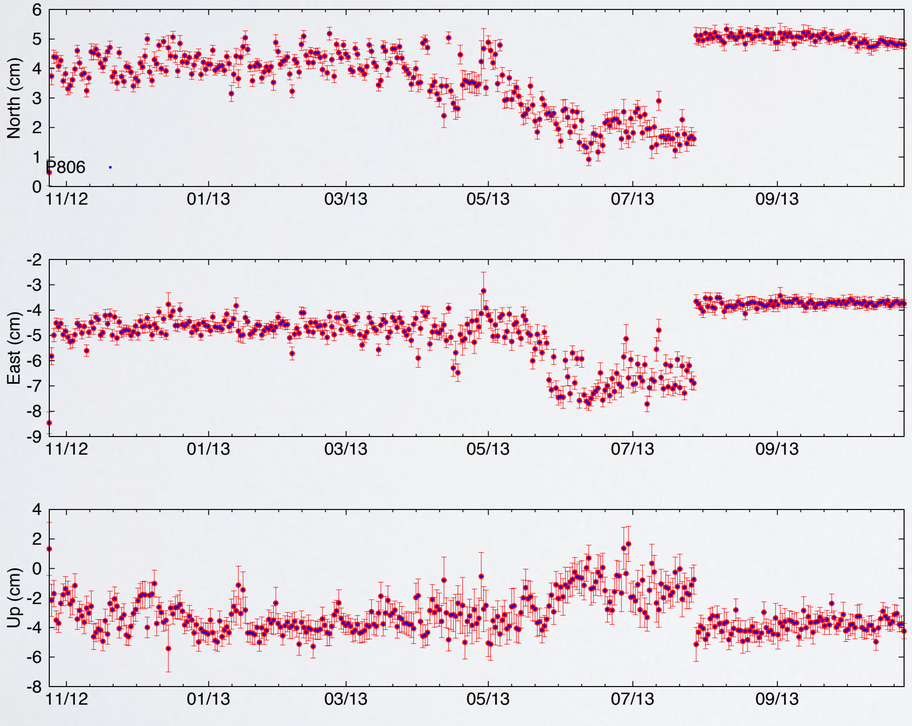
 26|LLooooooooooooo+LL          LL+ooooooooo+L                               | 26
 11|LL+LooooooLL                                LL+ooLLooooooooo+LL        L| 11
 28|ooooooooooooooooooo+LL                                              LLoo| 28
  5|ooooLLL           LL+ooooooooooooLL^                                LL+o| 5
 19|oooooo+L                                 LLooooooooLoo+L          LL+LLoo| 19
  6|oLL                                  LLooooooooooooLL          LLLooLLoo| 6
  3|ooo+L                                  _L+ooooooooooLLL         LLLooLLoo| 3
  8|ooooooooooooooo+L                                               LL+ooLoo| 8
 10|ooooLLL         LL+ooooooooooLL                                  LL+ooLLoo| 10
 16|L                           L+ooooooooLLL          LLLooooooooooooLoL| 16
 13|ooooLL                                             _LLooooooooooLoLoo| 13
  7|oooooooooooLL                                          L+ooooooLooo| 7
 23|oo+LL                                                LLooooooooooooooLLoo| 23
  9| LLLooooooooooooooooo+L                 L+L_                          | 9
 17|  L+ooooooooooooooooooLL_                                             | 17
  1|   LLLooooooo+LL                                L+oLooooooooooLLL      | 1
 15|     LLooooooooo+LL          L+ooooooooooo+L_                          | 15
  4|         L+oooooooooooooooLL                                LLL+o++LL  | 4
 24|         LL+ooooooooooooLLL           LLLooooLoLL_                     | 24
  2|            LLooooooooooooooooo+LL                                     | 2
 12|            _LLooooooooooooooooLL                                      | 12
 20|              _LLLL                                        LLLooooooooooooooLLL | 20
 25|                 LL+oooooooooooooooLL                      _L+MLLLL    | 25
 29|                    LLLooooooooooooooooo+L^                            | 29
 31|                       _LLLooL+LL              L+ooooooooooooooooLL     | 31
 21|                         LL+oooooooooooooooooo+LL                       | 21
 18|                            _L+ooooooooooooooooooL+LL                   | 22
 22|                               LLooooooooooooooLooooooLL                | 22
 14|                                    L+ooooooooooLooooooLL+              | 14
 32|                                          LLooLooooooooooooooooLL       | 32
-dn|++++++++ +++++++++++++++++++ +++++++++++++++++++ ++++++++++++++++++++++|-dn
+dn|                                                                        |+dn
+10|aabbbb9999aa9a9987888898887888898899aba9889bbaa8889888887898aaababbb|+10
Pos|ooooo                                                                  |Pos
Clk|                                                                        |Clk
   +|--------|--------|--------|--------|--------|--------|--------|--------+
00:00:00.000                                                    23:59:45.000
2013 Apr  5                                                      2013 Apr  5

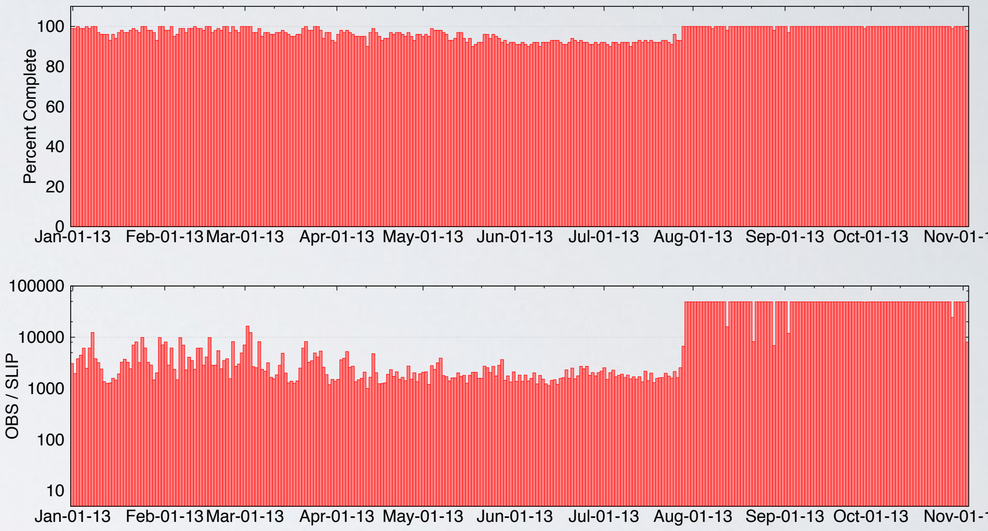
**********************
QC of RINEX  file(s) : /ap/local/tmp/.rinex/.238180/p8100950.13o
input RnxNAV file(s) : /ap/local/tmp/.rinex/.238180/p8100950.13n
**********************

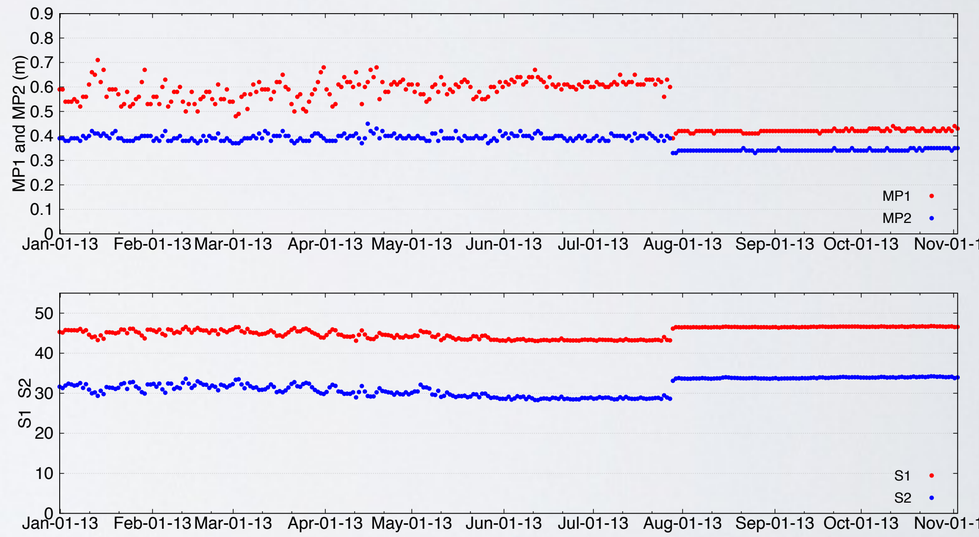
4-character ID          : P810
Receiver type           : TRIMBLE NETR9 (# = 5213K83433) (fw = 4.70)
Antenna type            : TRM59800.00     SCIT (# = 5151354361)
```

ANTENNA FAILURES

- Antenna failures have occurred at 2 of the 5 MM installations.
- The antenna at the MAST monument in Georgia, P806, failed and was replaced in late July of 2013.
- QC statistics show improvement in MP1 & MP2, S1 & S2 and observations per slip.
- Position RMS has also improved after swapping antennas.







CONCLUSIONS AND FUTURE WORK

Based on a few months of data at new installations:

- GNSS monuments are as stable as the ground they are put in.
- Pillars do not perform well in unconsolidated sediments; SDBM are better than Pillars but probably not as good as DDBM
  - **If you don't have bedrock - drill as deep as you can afford**
- Monumentation selection may not have a significant impact at sites with competent bedrock.
  - **If you have good bedrock, use a mast and save $$$ for other stations.**

Wilbur, WA: P453/P813/P814

Ongoing continued QC and detailed analysis over months and years will provide further clarity

- Data are available to the public at UNAVCO Archive...
- Additional monument farms should be installed to improve sample size and assess a wide variety of geological regimes.

Forks, WA: P401/P815/P816