Examples using `track`

M. A. Floyd T. A. Herring
Massachusetts Institute of Technology, Cambridge, MA, USA

GNSS Data Processing and Analysis with GAMIT/GLOBK and `track`
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http://geoweb.mit.edu/~floyd/courses/gg/202008_UNAVCO/

Material from R. W. King, T. A. Herring, M. A. Floyd (MIT) and S. C. McClusky (now at ANU)

Outline

- Kinematic examples
  1. GNSS seismology
- Kinematic/static example
  2. Rapid deformation
  3. Episodic and continuous deformation
- Static examples
  4. Short-static occupations
  5. Deciphering interference
- Remember the rule-of-thumb for proportional errors:

$$\varepsilon_{\mathrm{BL}} \sim \varepsilon_{\mathrm{SV}} \times \mathrm{BL}/h_{\mathrm{SV}}$$

Example 1: GNSS seismology

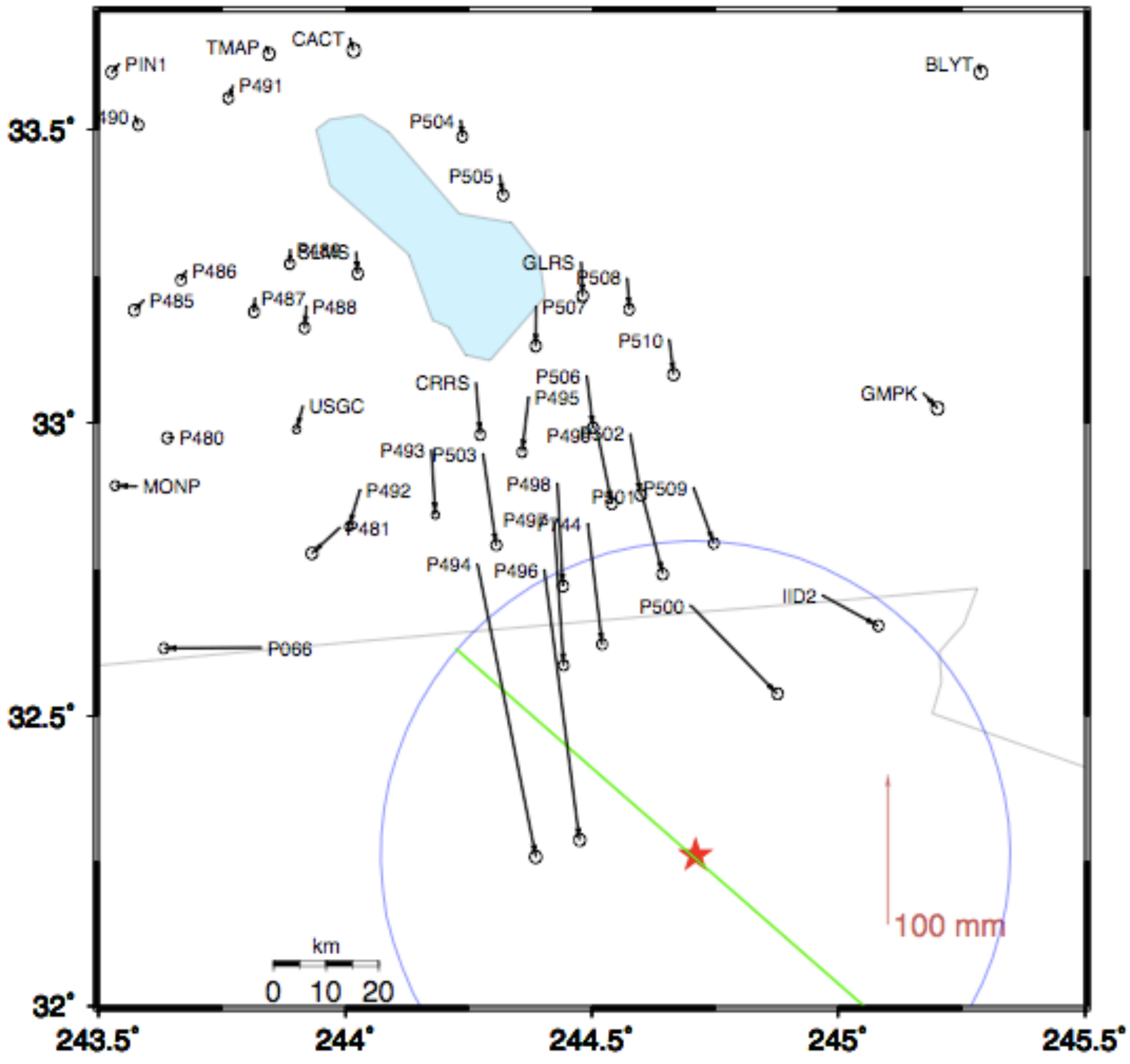
- April 4, 2010 El-Mayor Cucapah earthquake in Baja California
  - 5-Hz results
  - Look later at long baseline processing for these sites
- Track results are generated in two steps:
  - First solution uses zero process noise except during time of earthquake (long baseline solution)
  - Final results generated with fixed ambiguities from first solution read in (`-a` option)
  - Long baseline ambiguity resolution with stochastic site coordinates needs LC estimate which can noisy due to stochastics

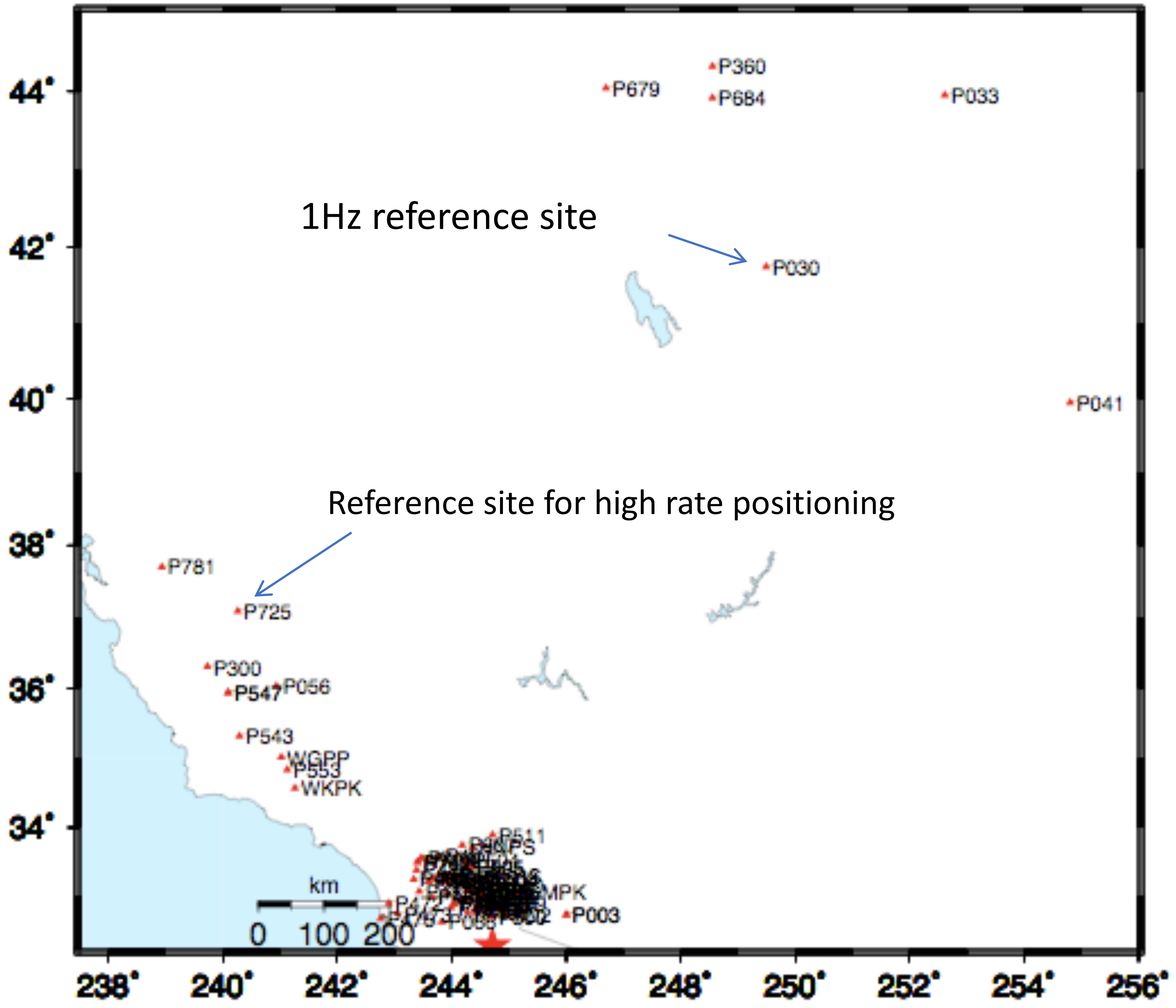
Zoom around border

Sites near the epicenter.

Blue circle is 60 km radius

Displacements
P494 200 mm
P496 182 mm
P497   97 mm
…
P491   9 mm

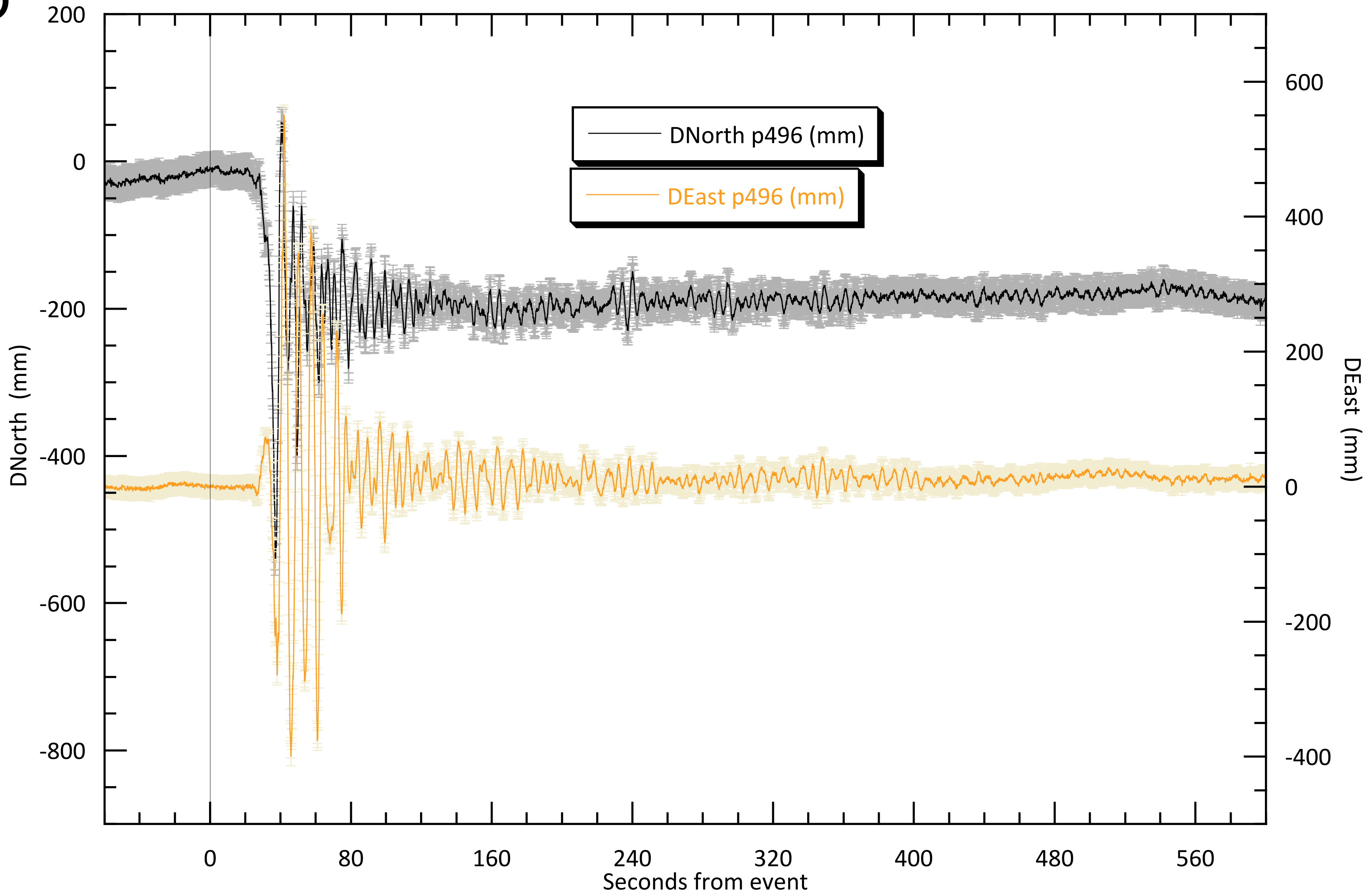




High-rate GNSS site download

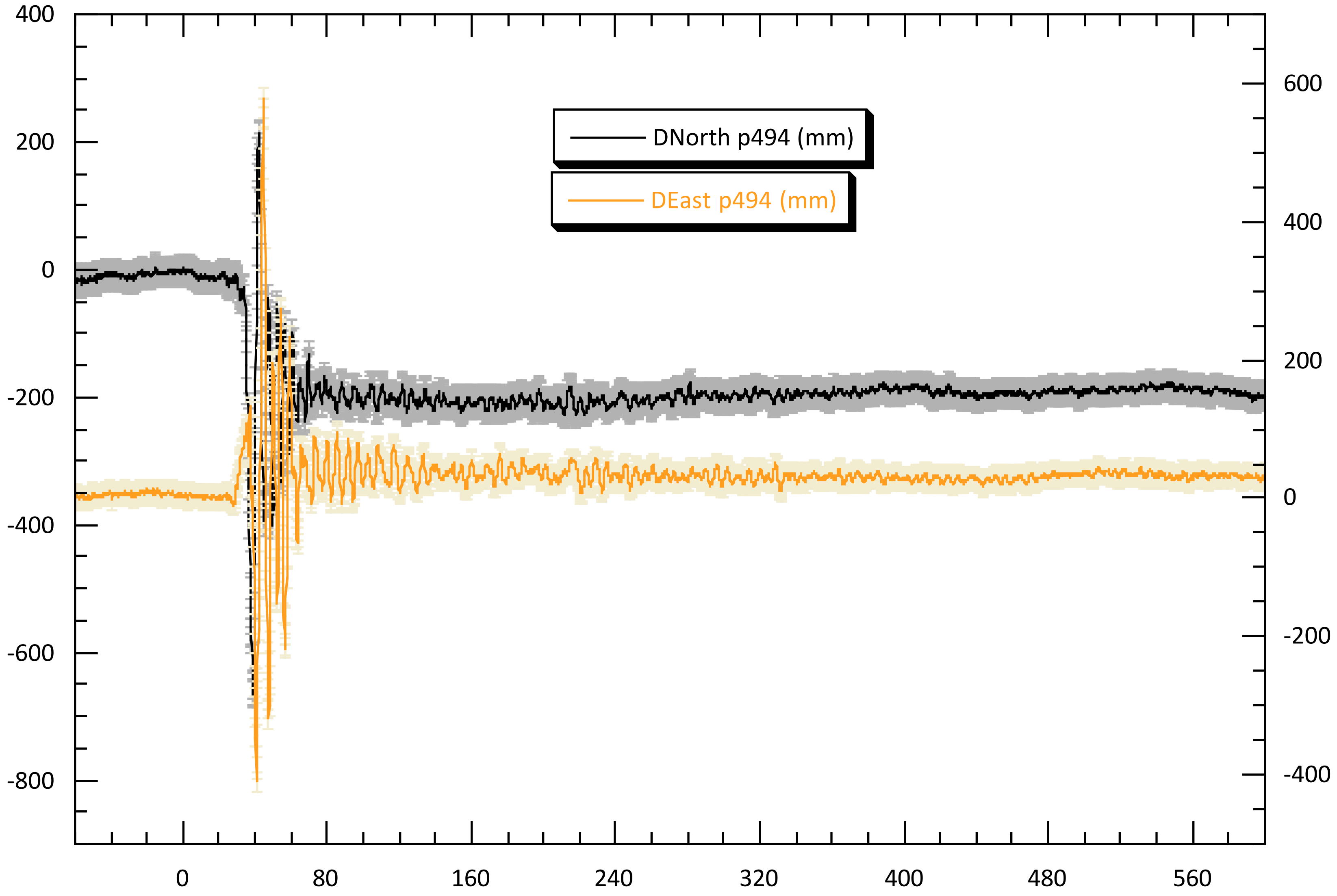
- High rate data from these sites downloaded after event.
- Most sites are 5-Hz; more distant sites are 1-Hz.

P496



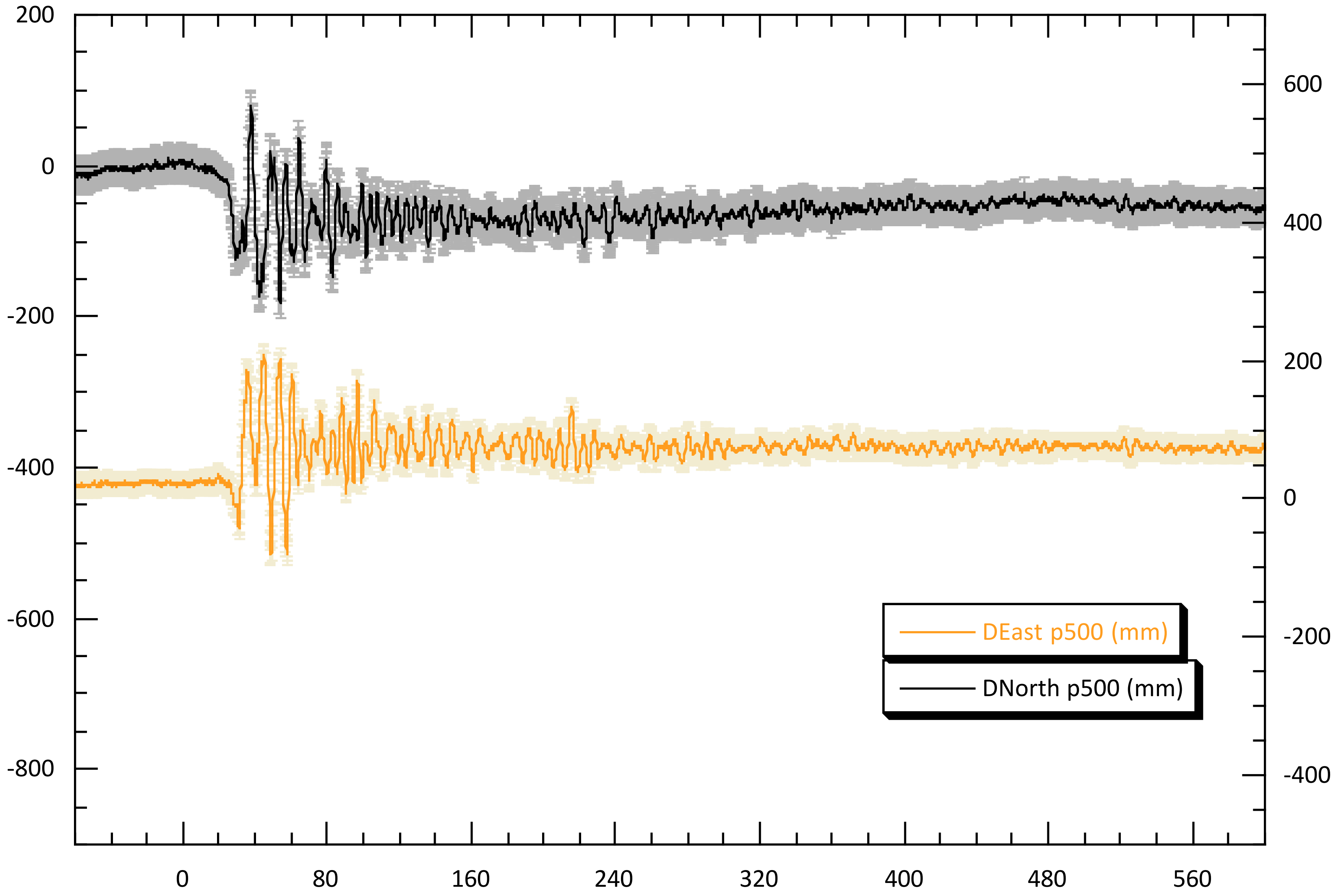
DNorth p496 (mm)
DEast p496 (mm)
200
0
-200
-400
-600
-800
DNorth (mm)
600
400
200
0
-200
-400
DEast (mm)
0
80
160
240
320
400
480
560
Seconds from event

P494



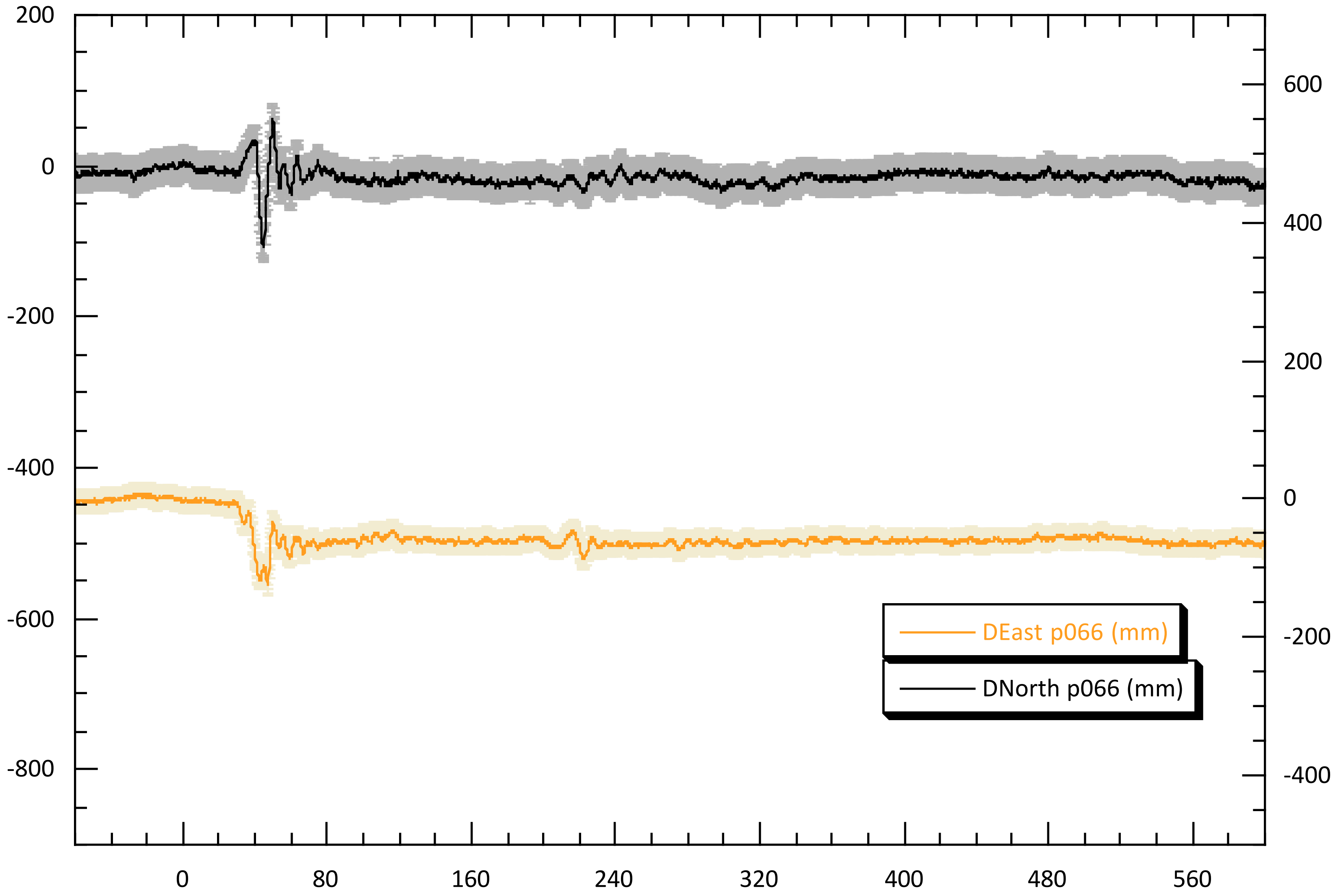
DNorth p494 (mm)
DEast p494 (mm)
400
200
0
-200
-400
-600
-800
600
400
200
0
-200
-400
0
80
160
240
320
400
480
560

P500

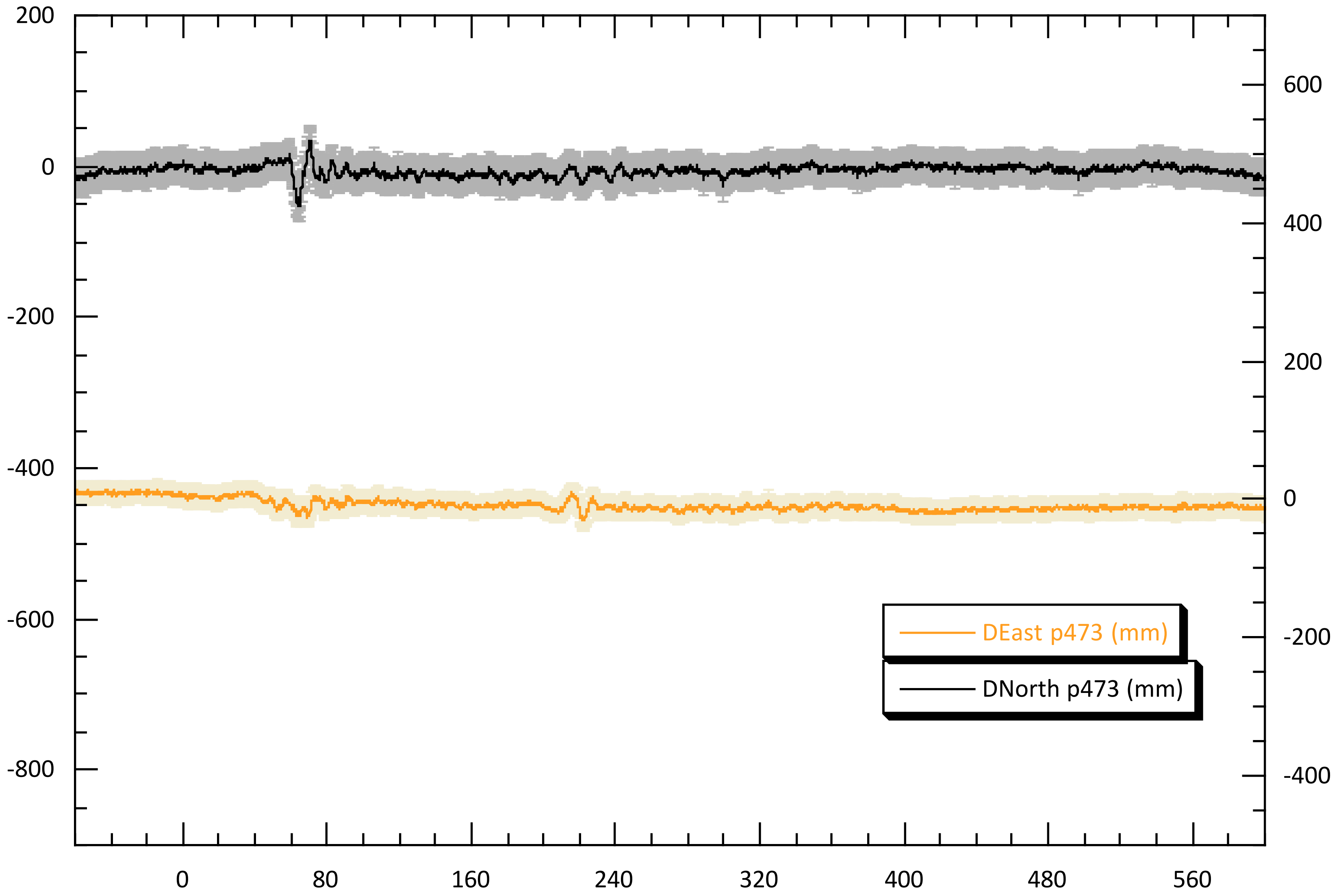


200
0
-200
-400
-600
-800
600
400
200
0
-200
-400
0
80
160
240
320
400
480
560
DEast p500 (mm)
DNorth p500 (mm)

P066

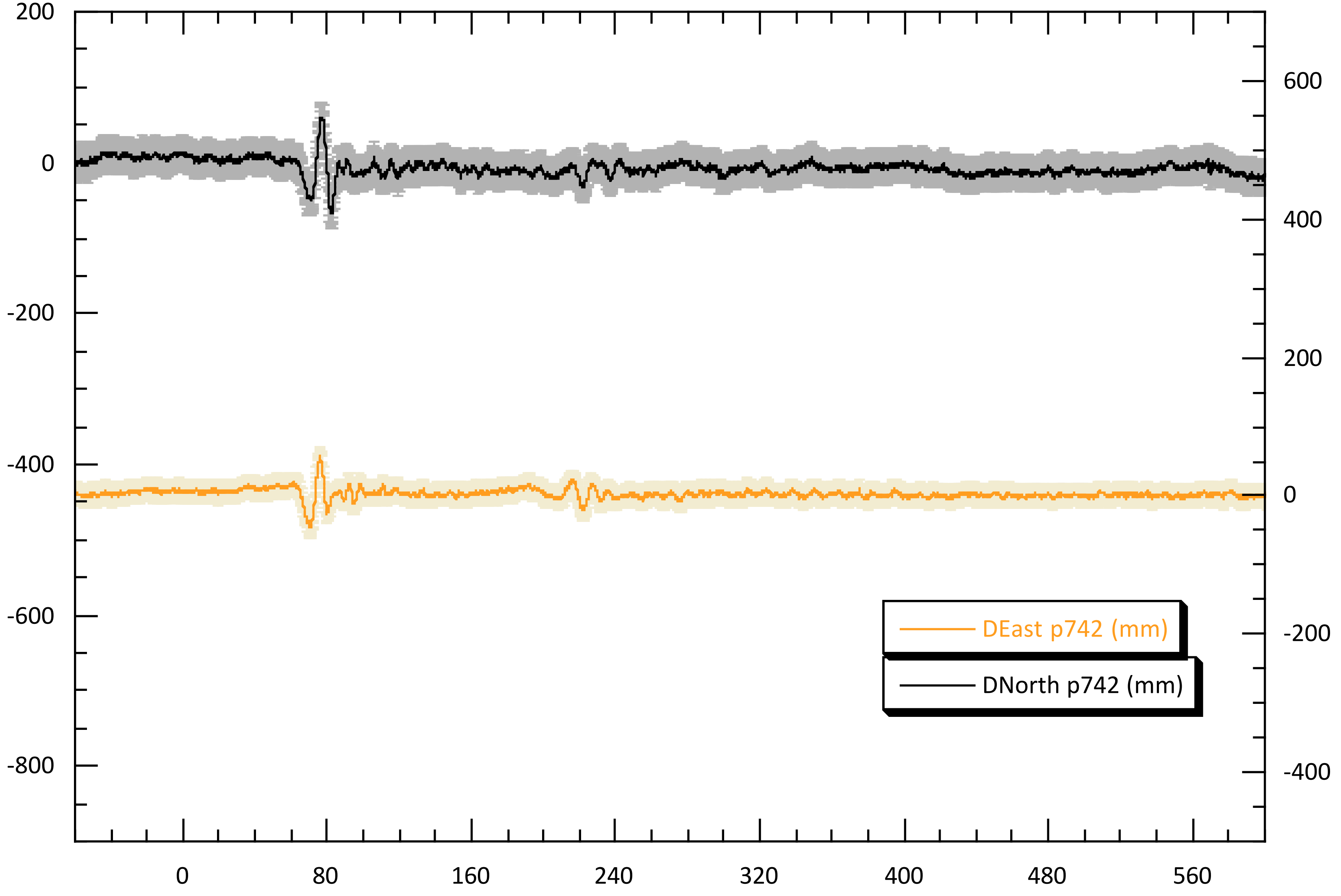

200
0
-200
-400
-600
-800
600
400
200
0
-200
-400
0
80
160
240
320
400
480
560
DEast p066 (mm)
DNorth p066 (mm)

P473



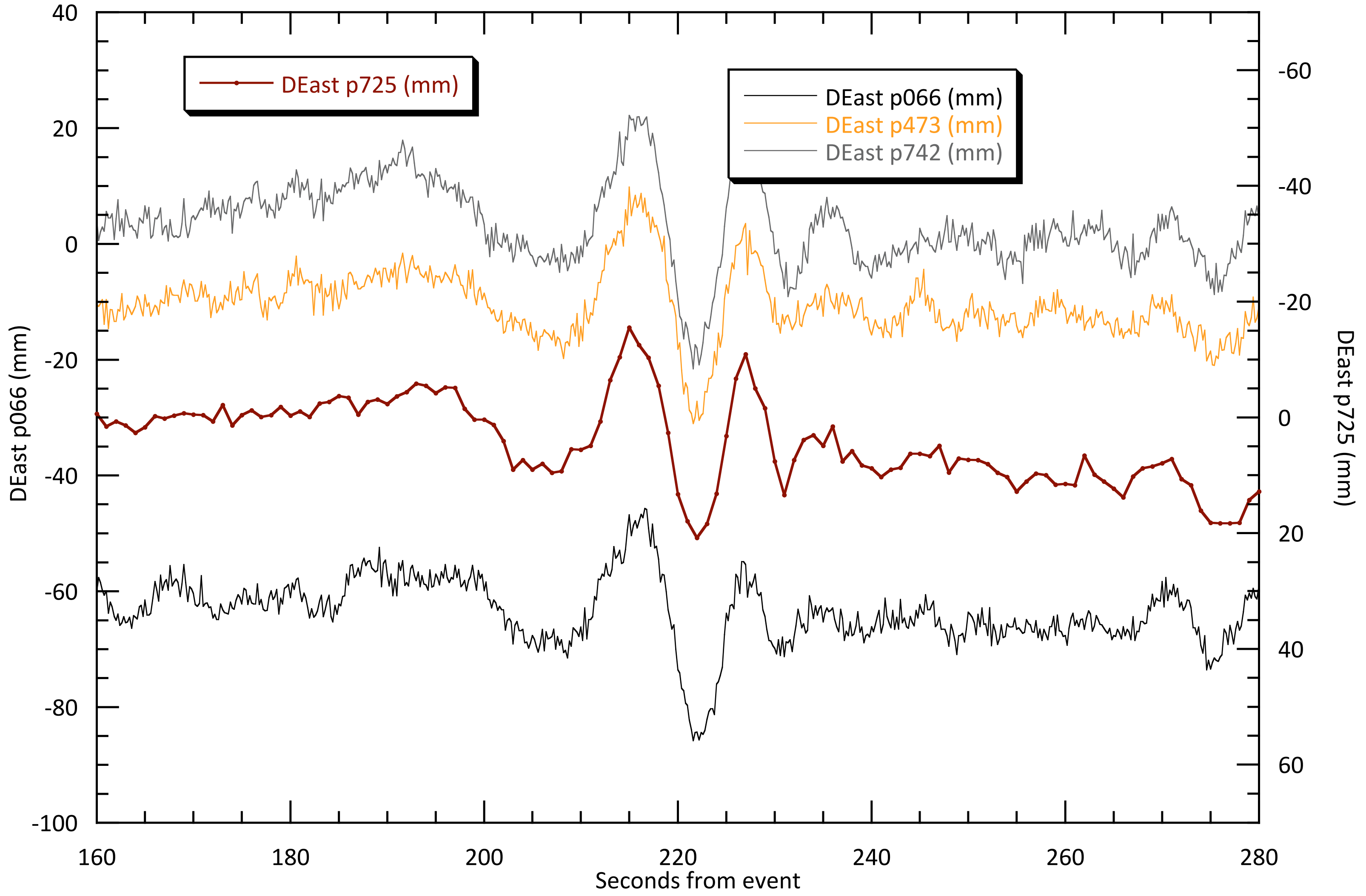
200
0
-200
-400
-600
-800
600
400
200
0
-200
-400
0
80
160
240
320
400
480
560
DEast p473 (mm)
DNorth p473 (mm)

P742

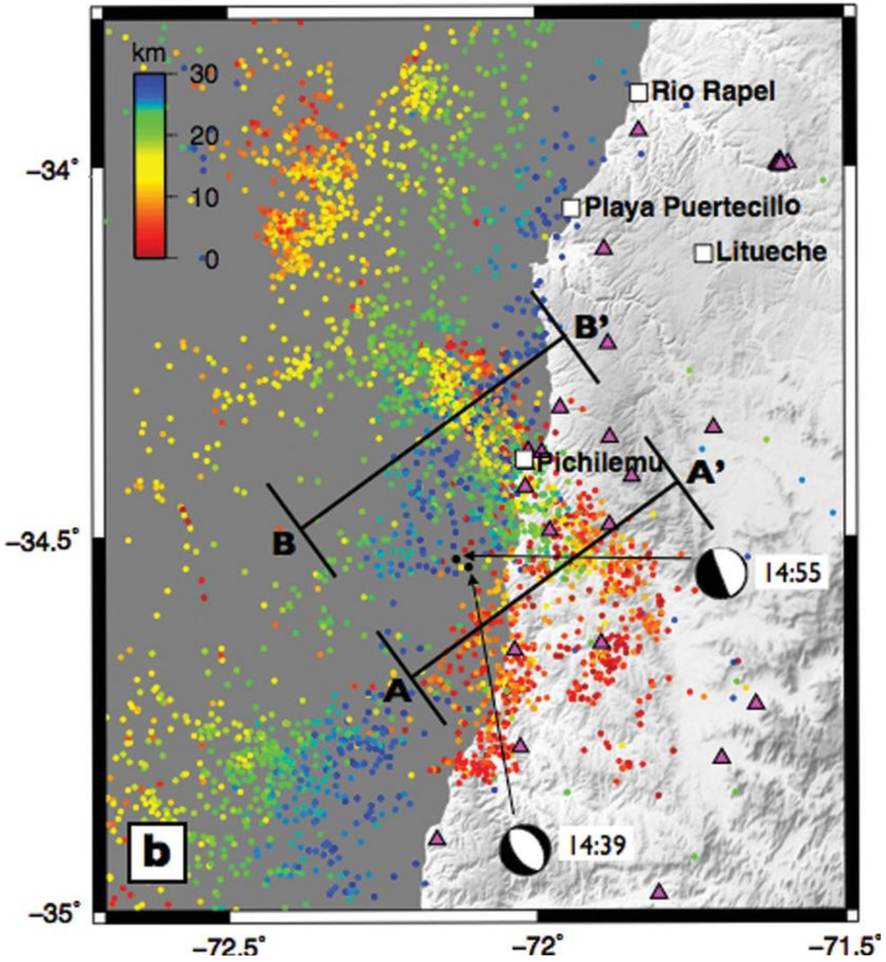

200
0
-200
-400
-600
-800
600
400
200
0
-200
-400
0
80
160
240
320
400
480
560
DEast p742 (mm)
DNorth p742 (mm)

Surface wave arrival at P725

- P725 is ~600 km from epicenter. This signal common to sites is the arrival at the "reference site"



Example 2: Rapid deformation
(from Ryder et al., 2012)

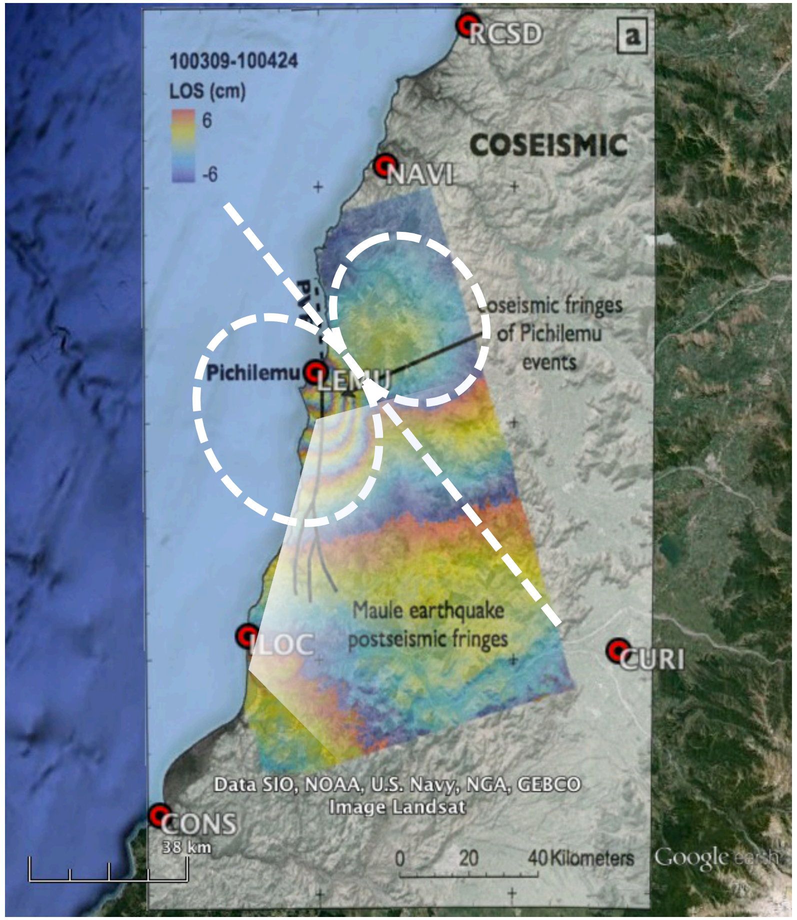


Ryder et al. (2012), Figure 1

- Two earthquakes within 15 minutes of one another
- InSAR shows cumulative deformation with no way to separate events
- Epoch-by-epoch (rather than batch) GNSS processing may help...

Example 2: Rapid deformation

(from Ryder et al., 2012)



Ryder et al. (2012), Figure 3a
overlaid in Google Earth

- Selecting fixed site:
- CURI is
  - Further from the main subduction earthquake
  - Outside the deformation zone of the major aftershocks
  - Along the nodal (zero deformation) plane of the major aftershocks

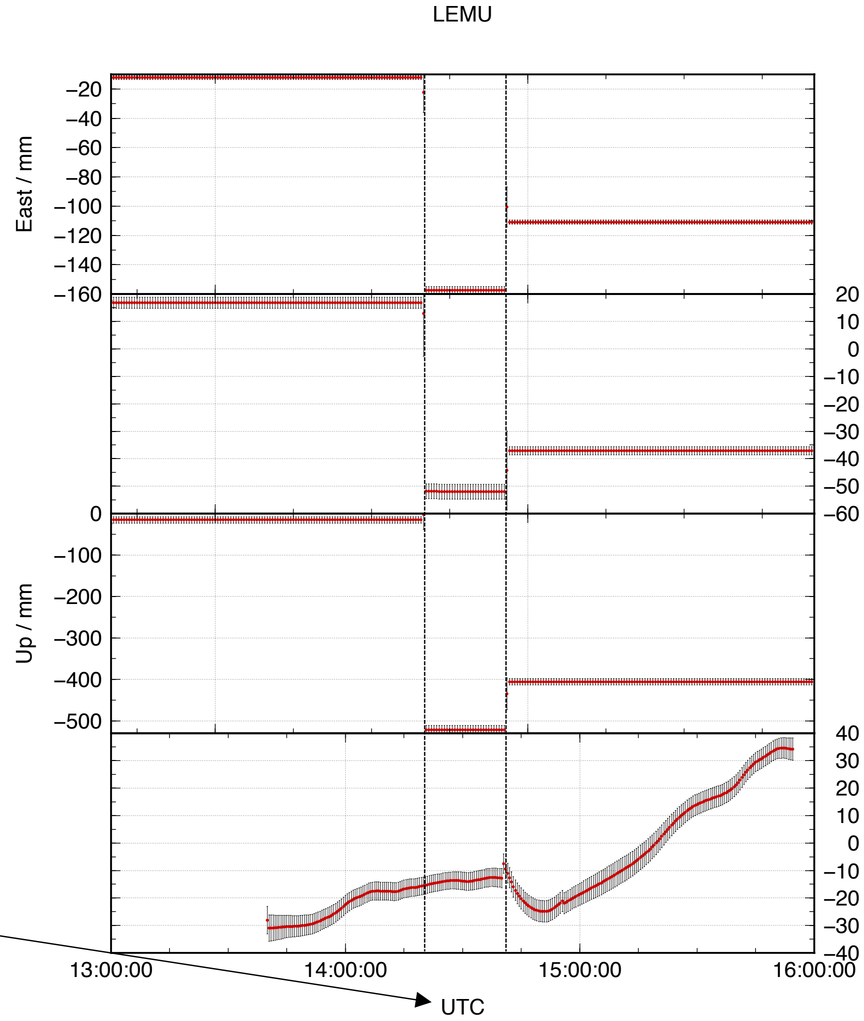
Example 2: Preliminary run Constrained first runs for ambiguities

- Key `track` commands:

```
site_stats
 iloc 10 10 10 0 0 0
 lemu 10 10 10 0 0 0
 navi 10 10 10 0 0 0

timedep_procns
 iloc 1 1 1 2010 03 11 14 40 29 2010 03 11 14 40 30
 lemu 1 1 1 2010 03 11 14 40 29 2010 03 11 14 40 30
 navi 1 1 1 2010 03 11 14 40 29 2010 03 11 14 40 30
 iloc 1 1 1 2010 03 11 14 55 59 2010 03 11 14 56 00
 lemu 1 1 1 2010 03 11 14 55 59 2010 03 11 14 56 00
 navi 1 1 1 2010 03 11 14 55 59 2010 03 11 14 56 00
```

Second run (updated apr):

```
site_stats
 iloc 0.02 0.02 0.02 0 0 0
 lemu 0.02 0.02 0.02 0 0 0
 navi 0.02 0.02 0.02 0 0 0

timedep_procns
 iloc 1 1 1 2010 03 11 14 40 29 2010 03 11 14 40 30
 lemu 1 1 1 2010 03 11 14 40 29 2010 03 11 14 40 30
 navi 1 1 1 2010 03 11 14 40 29 2010 03 11 14 40 30
 iloc 1 1 1 2010 03 11 14 55 59 2010 03 11 14 56 00
 lemu 1 1 1 2010 03 11 14 55 59 2010 03 11 14 56 00
 navi 1 1 1 2010 03 11 14 55 59 2010 03 11 14 56 00

site_pos
 ...
```



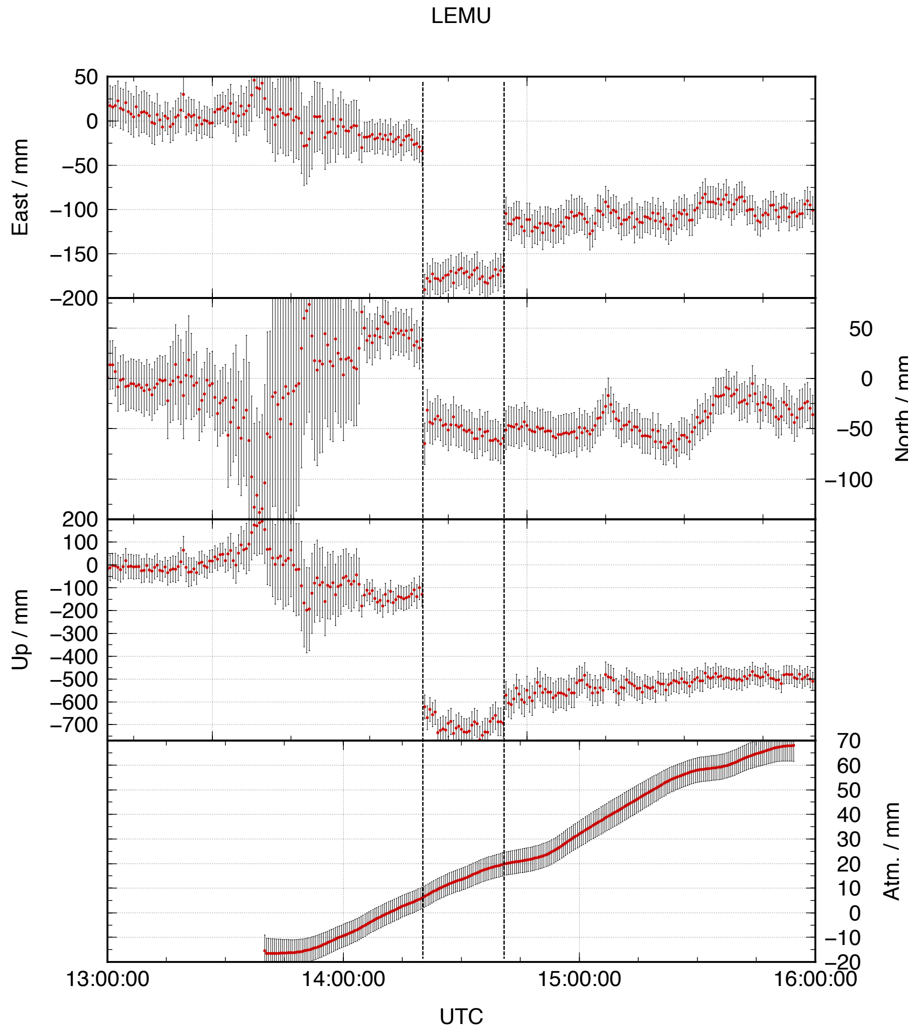
N.B. Remember GNSS is in GPS time, not UTC (need to add leap seconds; axis label is incorrect)

Example 2: Final run
Let the data freely define the noise

Read ambiguities from preliminary, constrained run, e.g
`grep 'FINAL' <sum-file> > track.amb`

- Key track commands:

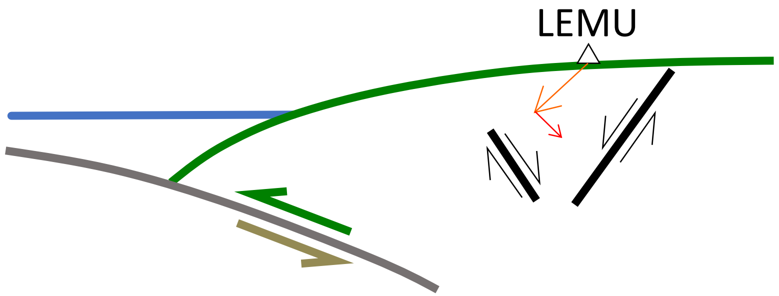
```
site_stats
 iloc 10 10 10 1 1 1
 lemu 10 10 10 1 1 1
 navi 10 10 10 1 1 1

timedep_procns
 iloc 1 1 1 2010 03 11 14 39 52 2010 03 11 14 40 00
 lemu 1 1 1 2010 03 11 14 39 52 2010 03 11 14 40 00
 navi 1 1 1 2010 03 11 14 39 52 2010 03 11 14 40 00
 iloc 1 1 1 2010 03 11 14 55 35 2010 03 11 14 56 00
 lemu 1 1 1 2010 03 11 14 55 35 2010 03 11 14 56 00
 navi 1 1 1 2010 03 11 14 55 35 2010 03 11 14 56 00

ambin_file track.amb
```



Example 2: `track` alters perspective

Initial hypothesis

- Earthquakes took place on antithetic normal faults in the upper plate of subduction interface

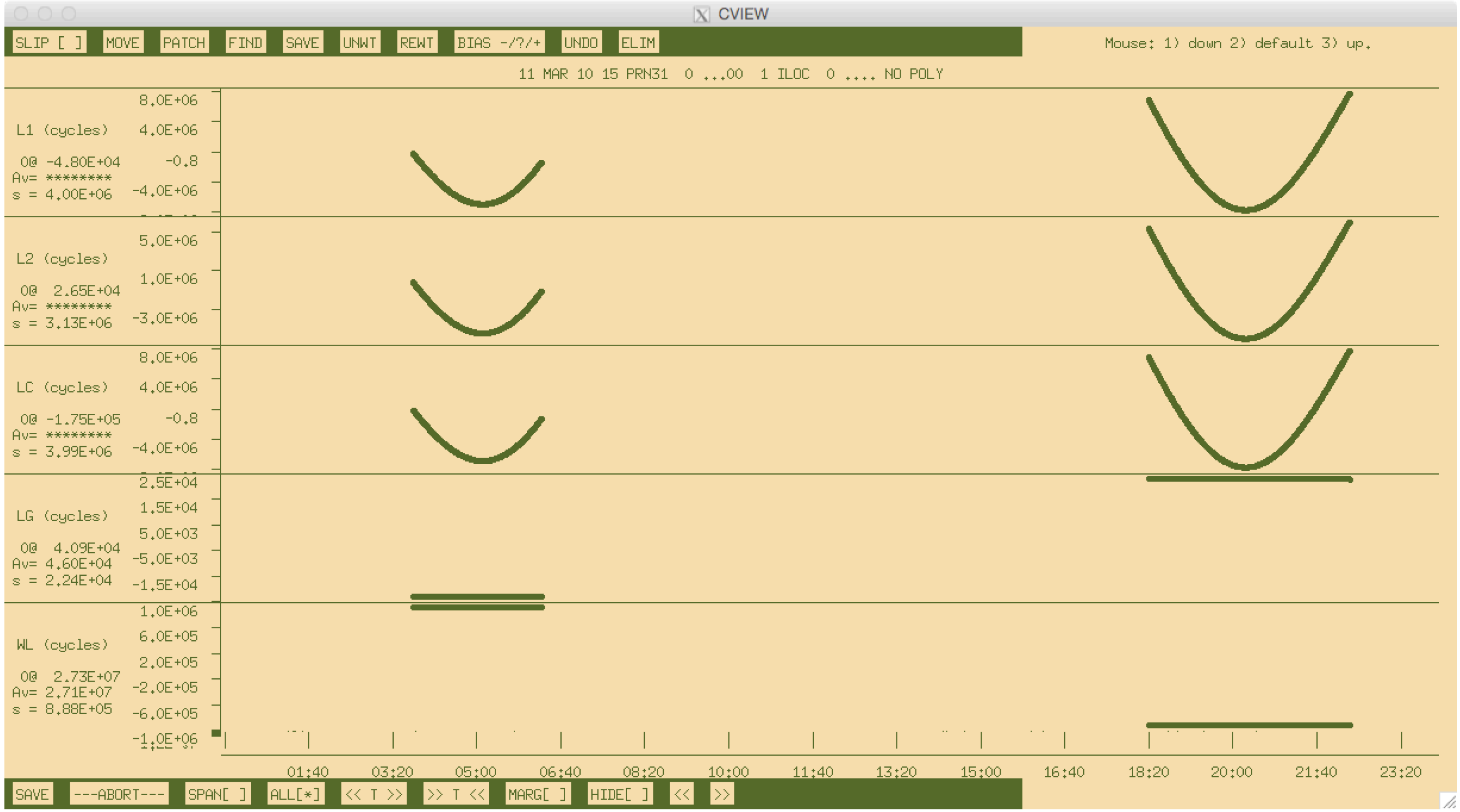


- But cGNSS site LEMU experiences opposite vertical motion due to first and second earthquakes

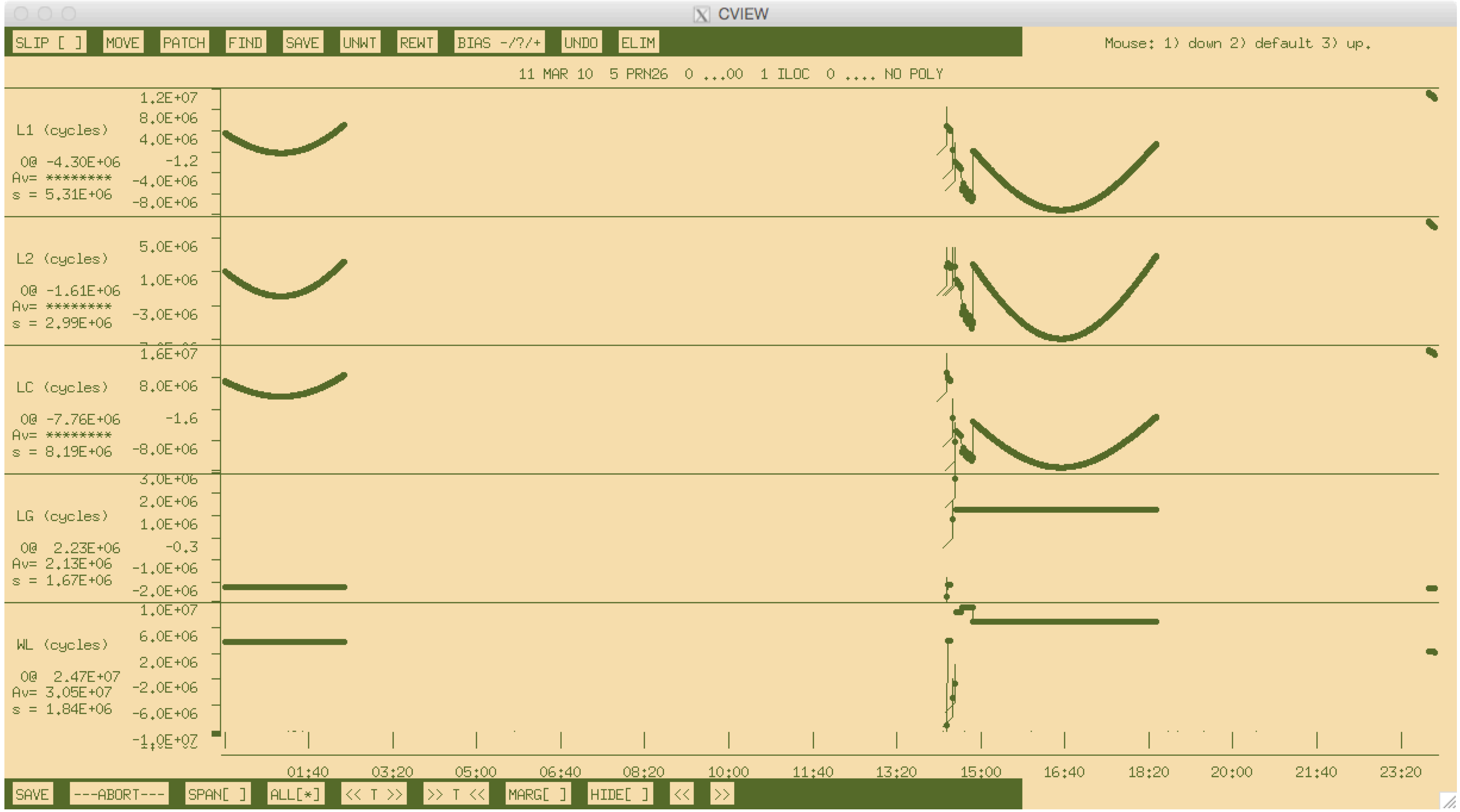
Final conclusion

- LEMU is on the hanging wall of first earthquake and footwall of second
- Therefore faults must be synthetic normal faults

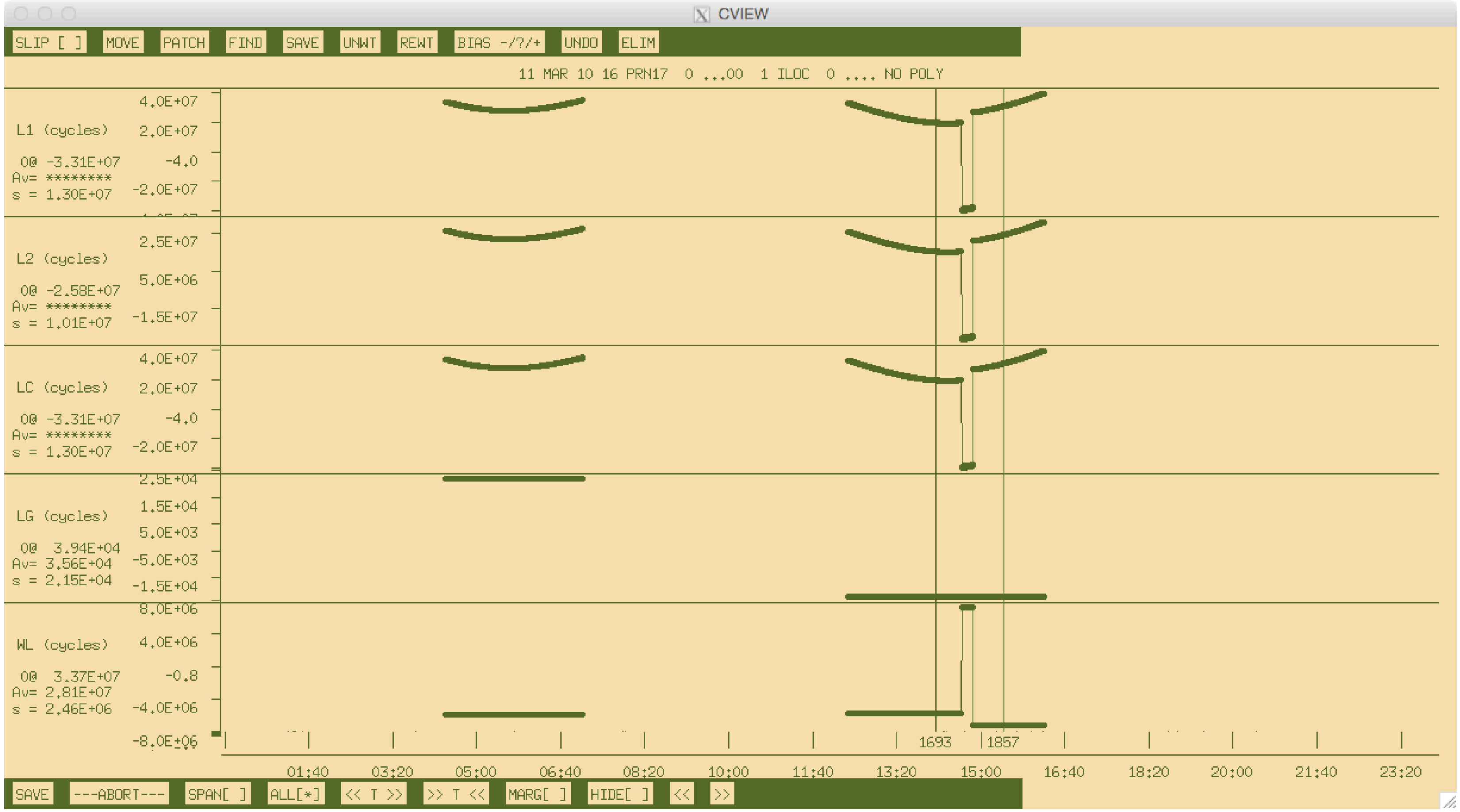
A good satellite in `cview`



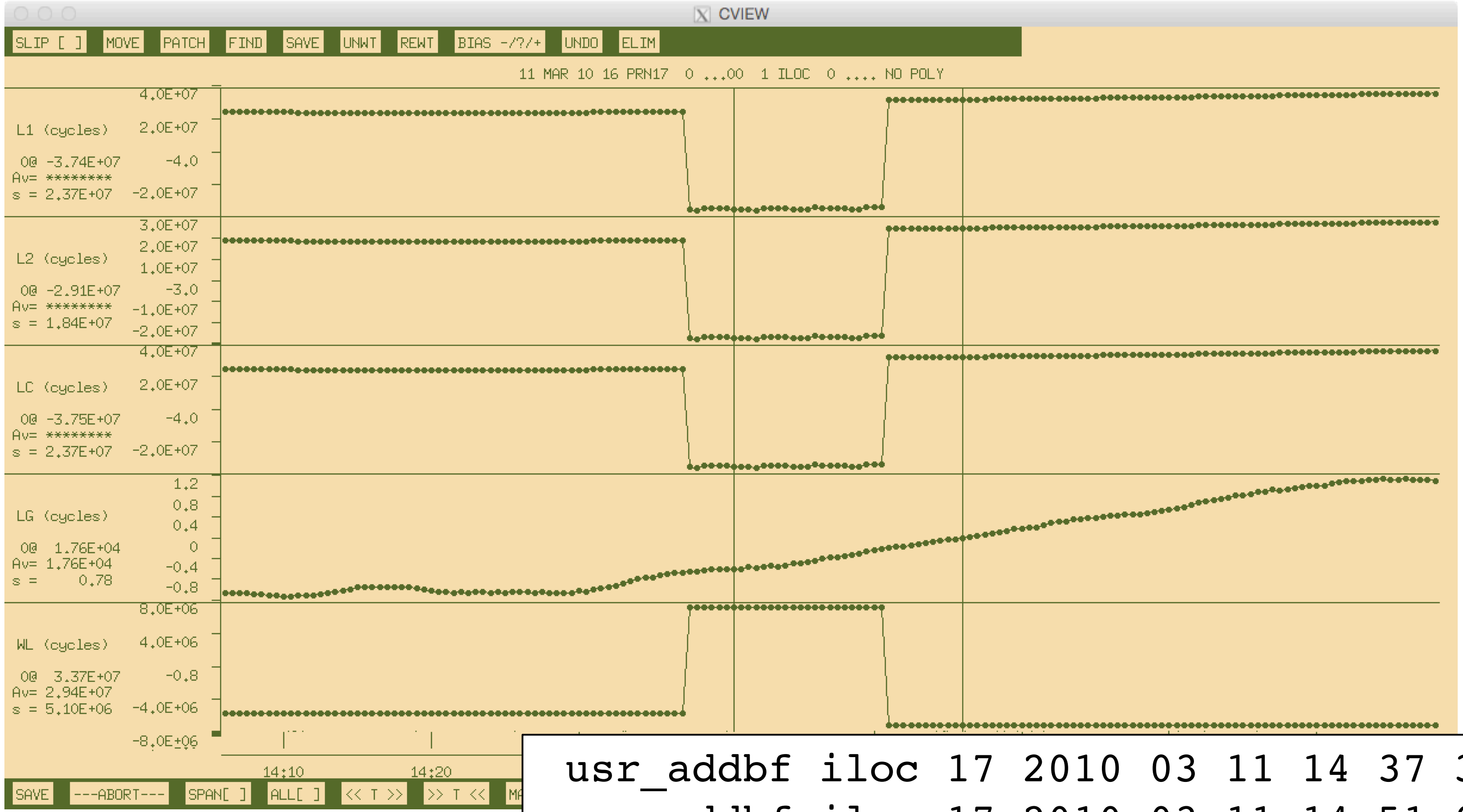
A satellite with some problems `cview`



A problematic satellite in `cview`



A problematic satellite in `cview`




```
usr_addbf iloc 17 2010 03 11 14 37 30
usr_addbf iloc 17 2010 03 11 14 51 00
```

Example 3: Episodic and continuous deformation

GAMIT/GLOBK processing

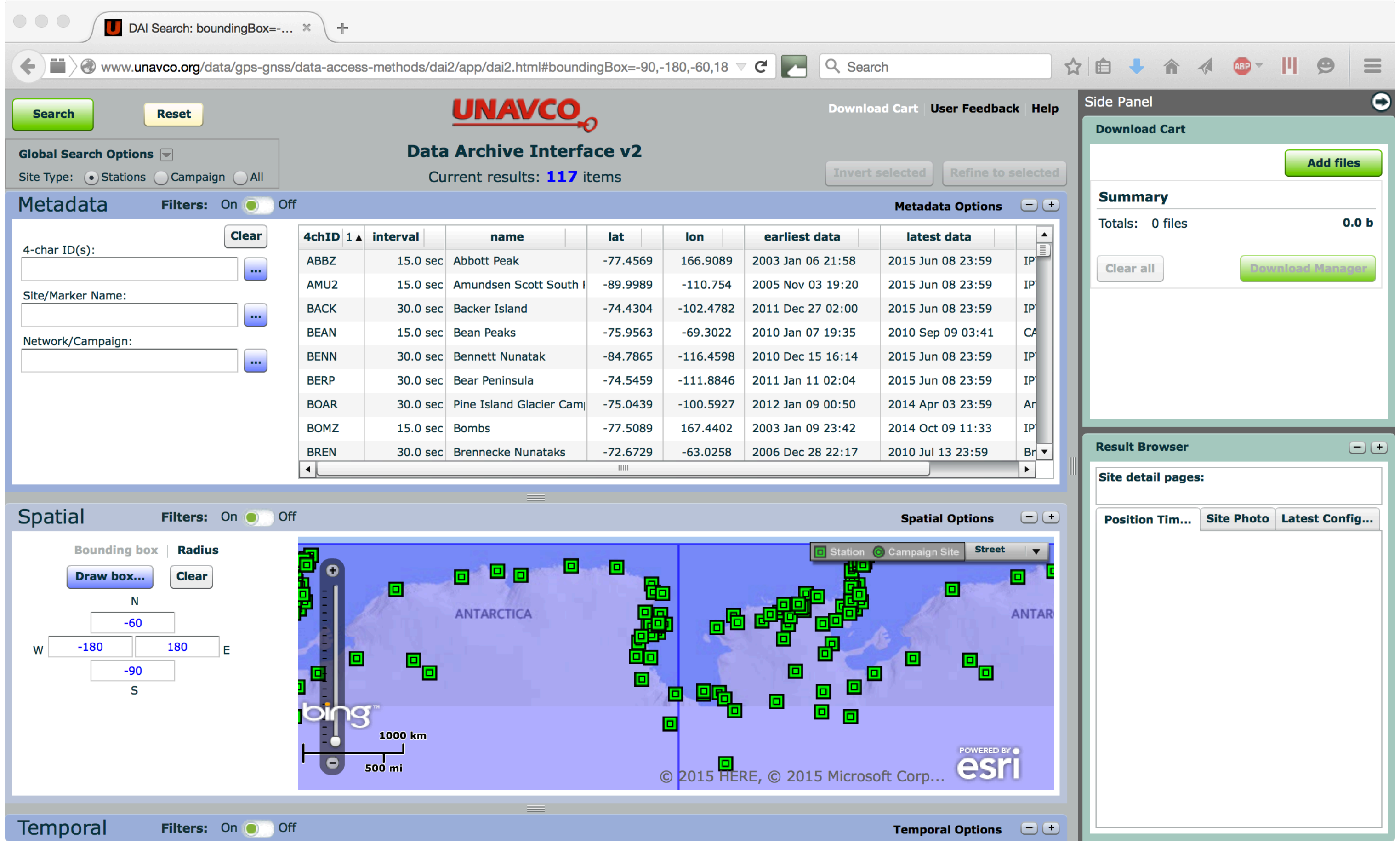
- Process network of available data at nearby sites
- Find candidate stable fixed site(s)
- Ensure accurate coordinate coordinates for fixed site(s)

`track` processing

- Use network of nearby, bedrock sites as base sites for kinematic processing of ice-flow
- One fixed site natural but multiple constrained sites may provide redundancy
- Ambiguities must still be resolved correctly

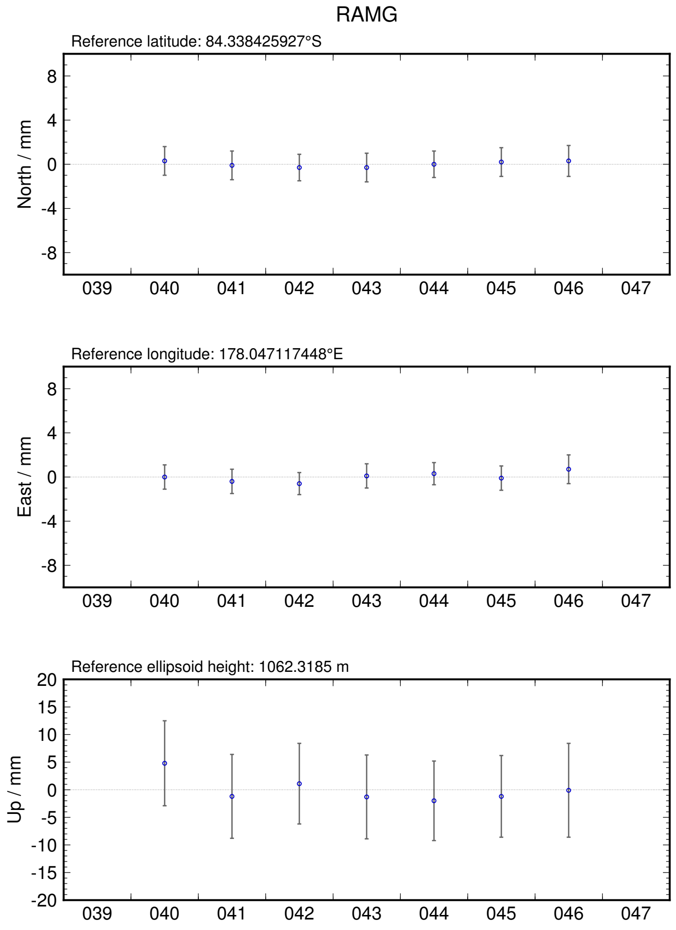
Building the static network

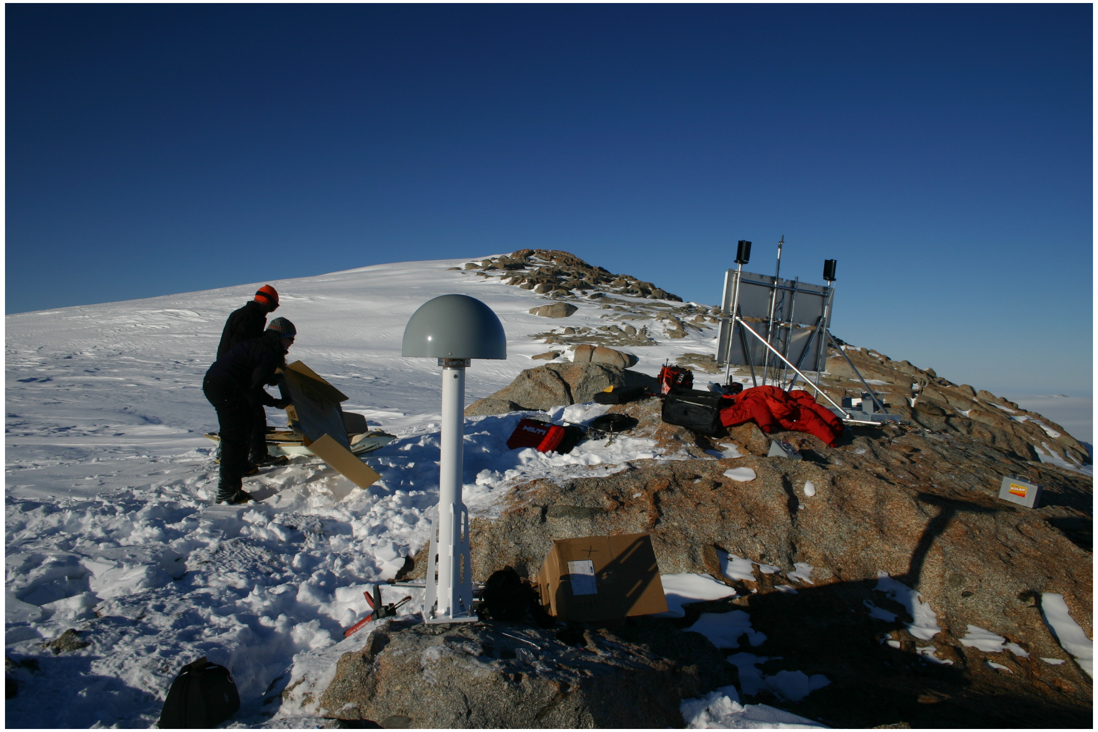
http://www.unavco.org/data/gps-gnss/data-access-methods/dai2/app/dai2.html



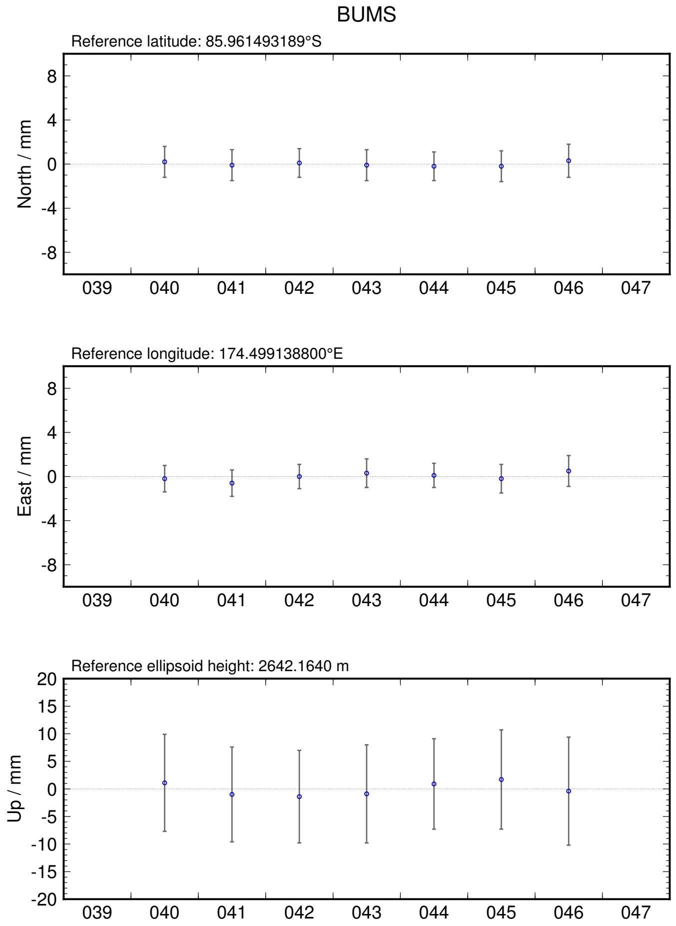
Ice flow or bedrock?

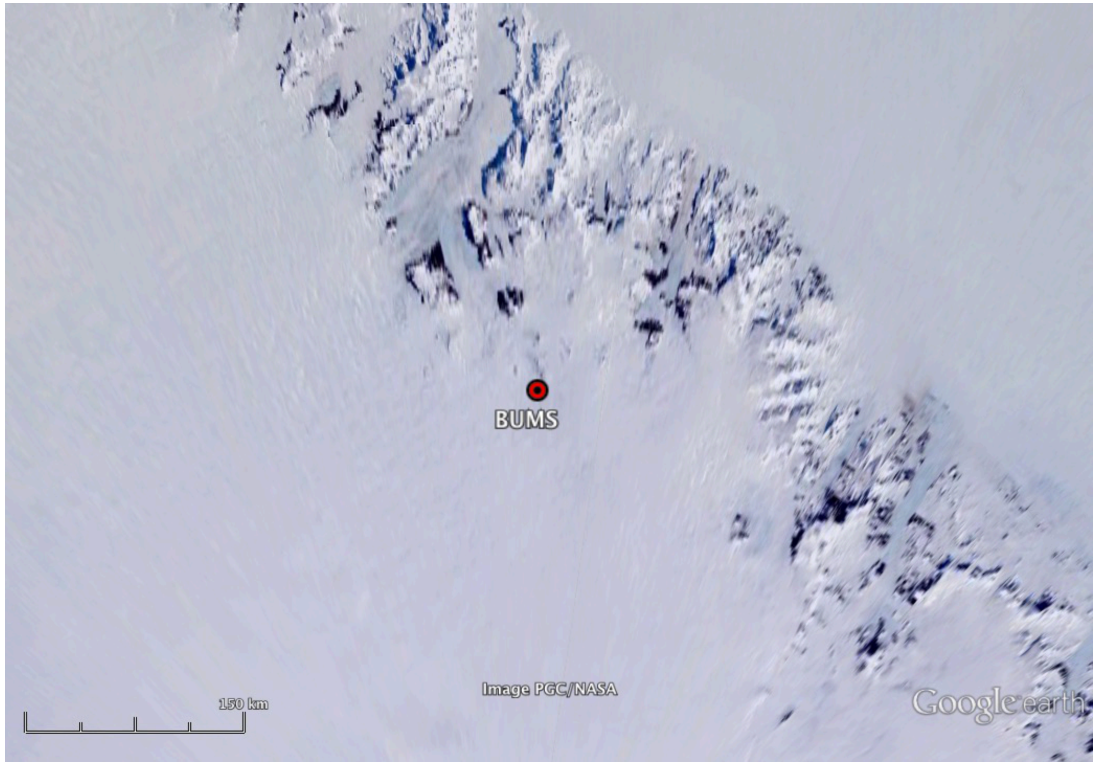
Ice flow or bedrock?



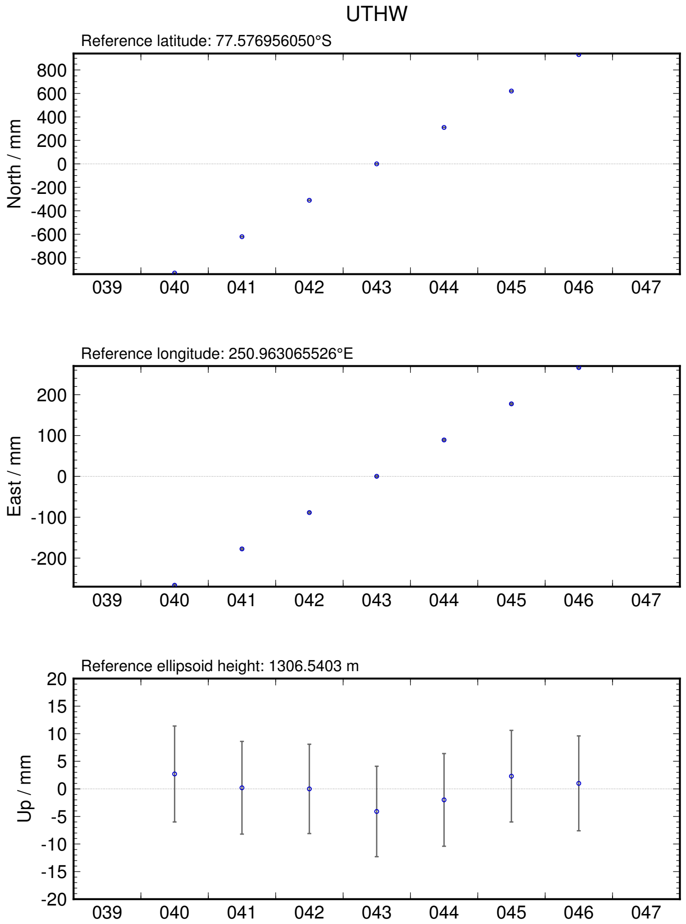


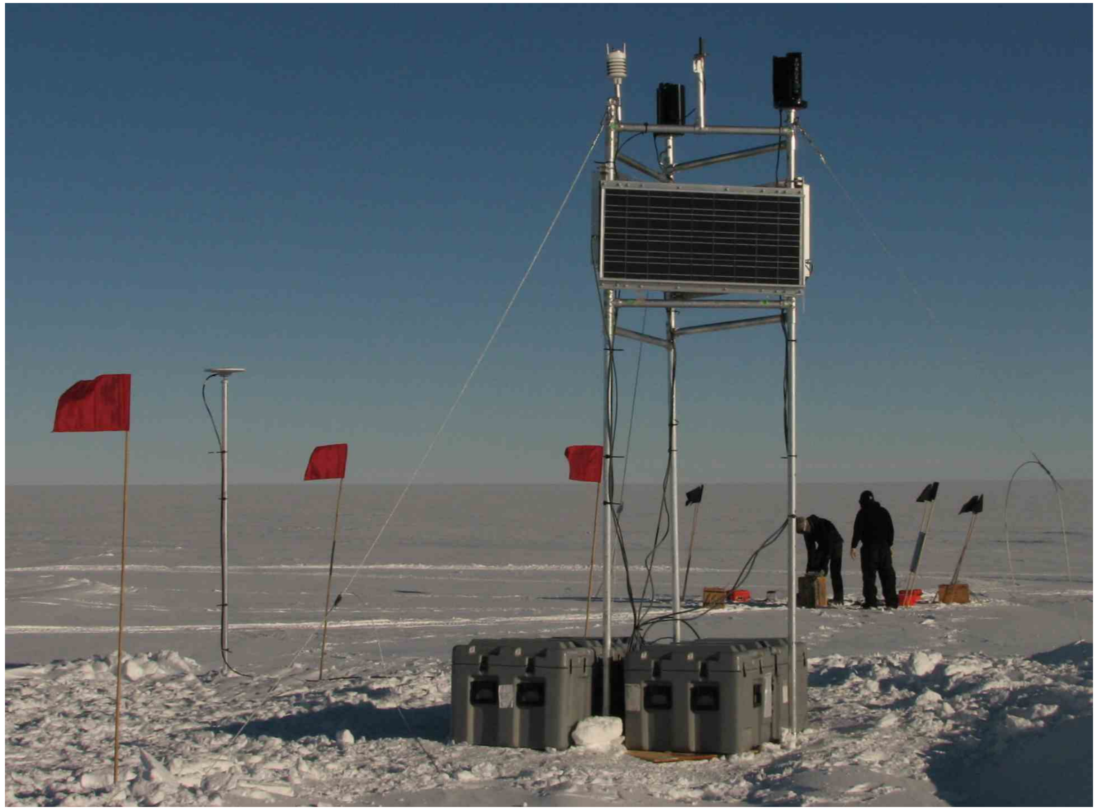
Ice flow or bedrock?



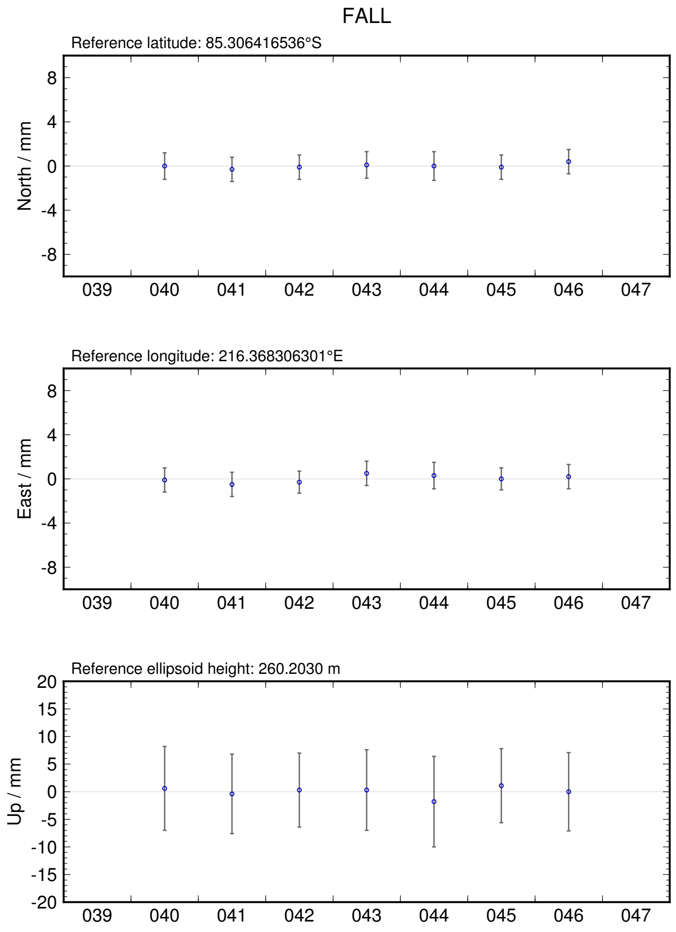


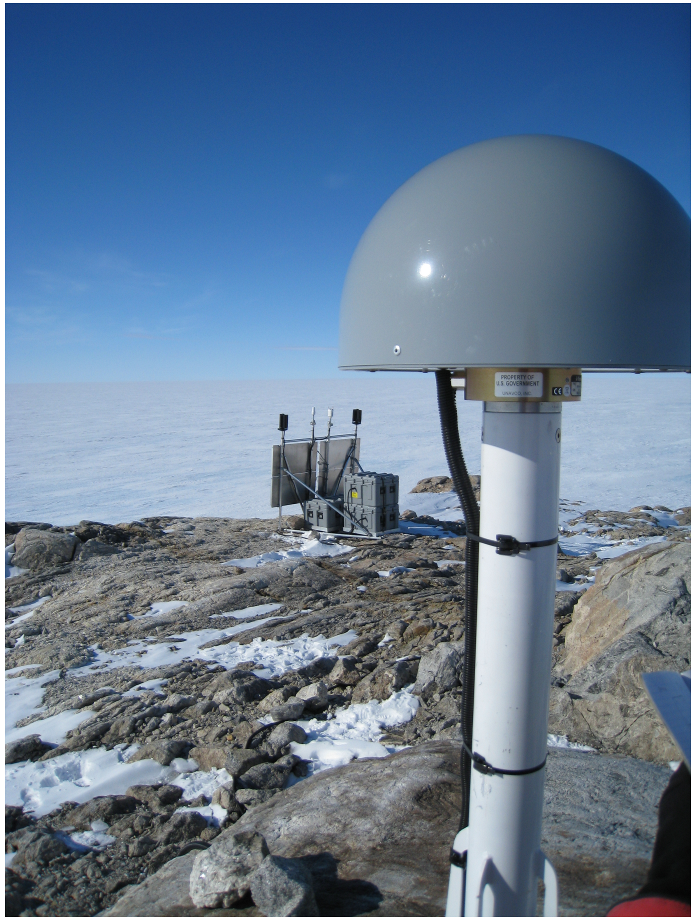
Ice flow or bedrock?



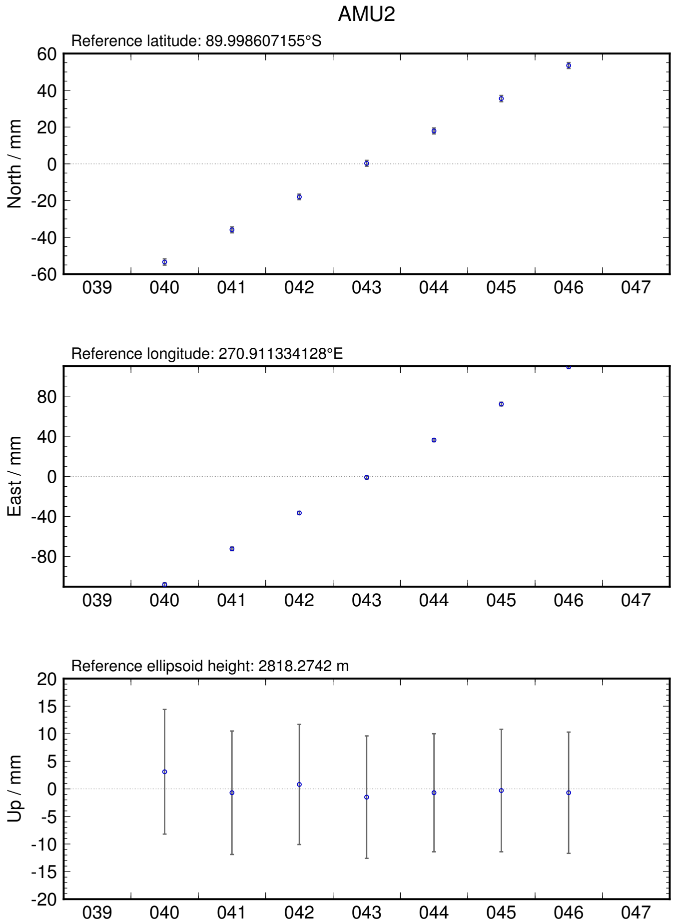


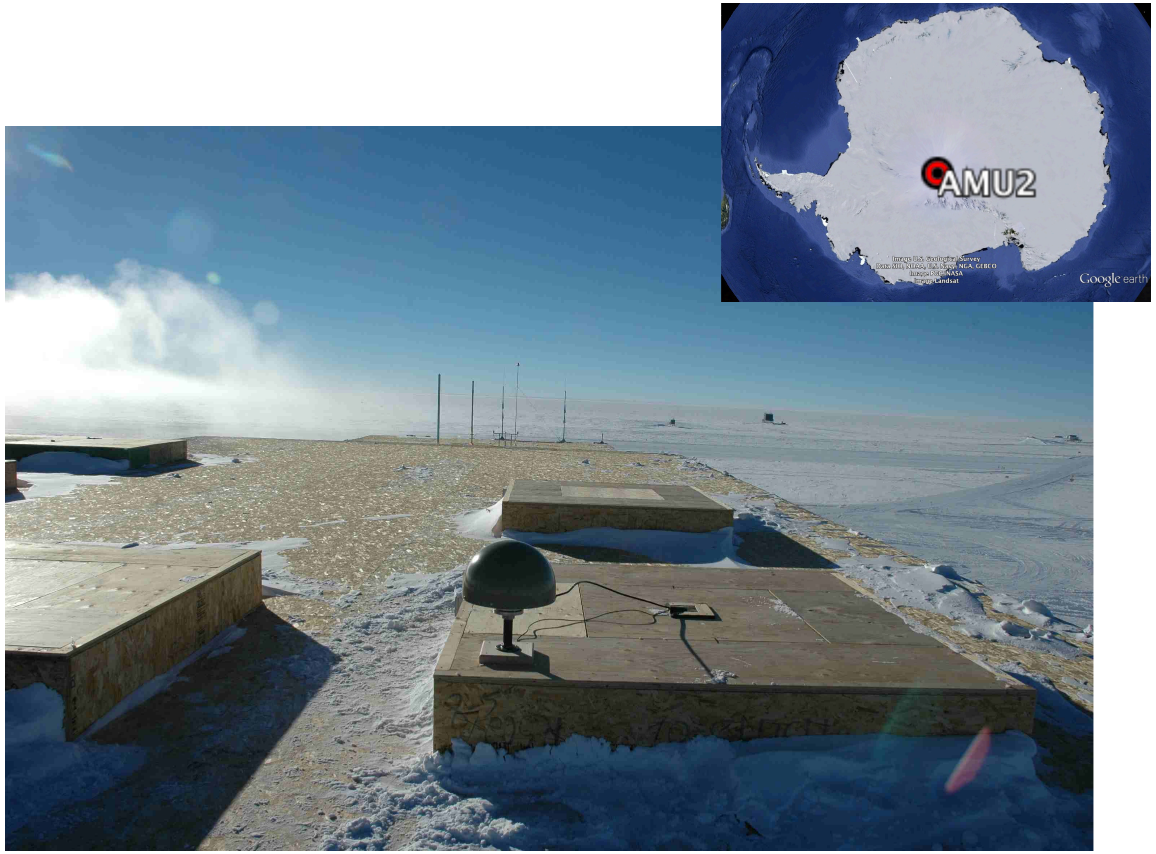
Ice flow or bedrock?



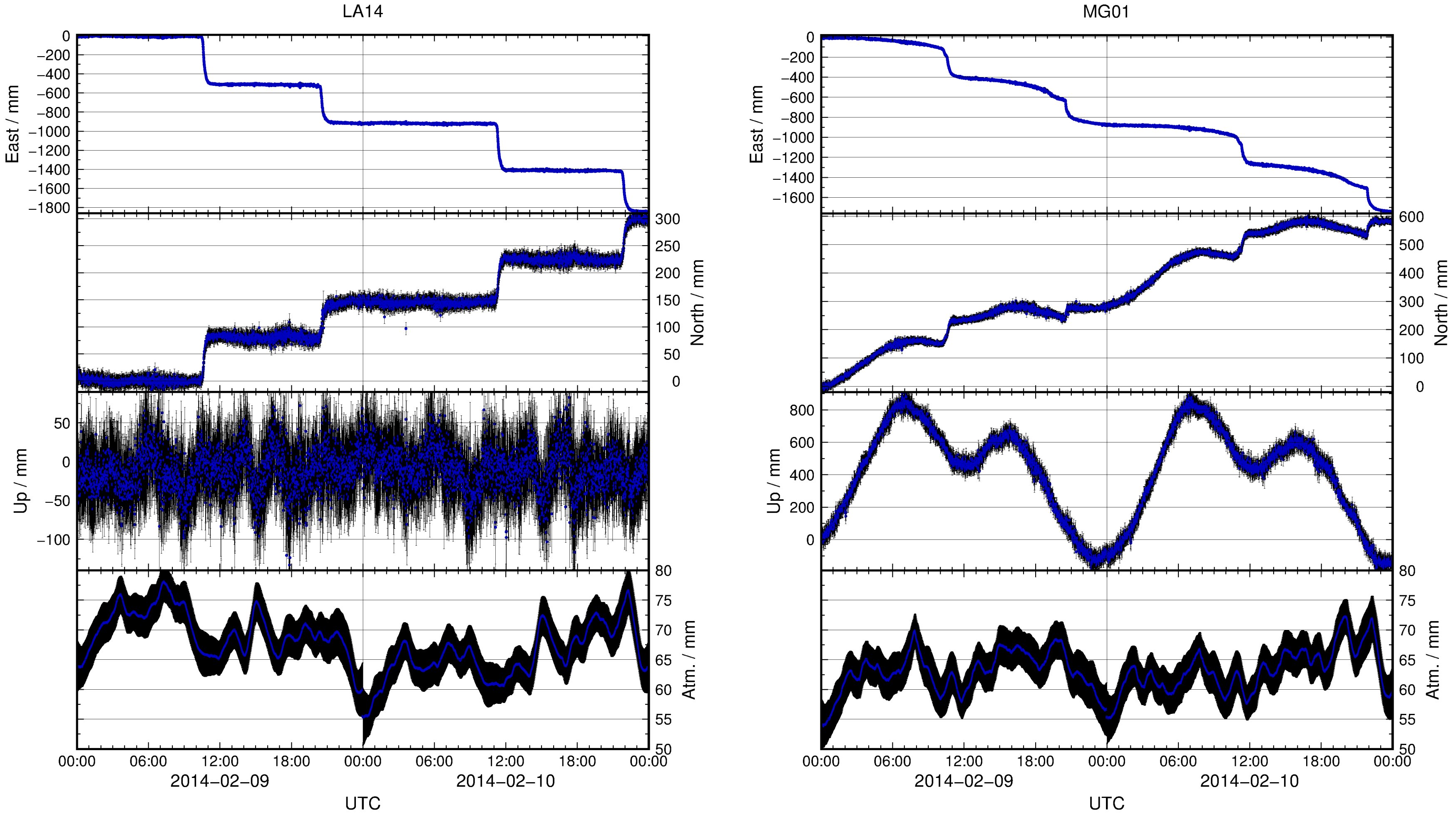


Ice flow or bedrock?





Kinematic results using FALL, RAMG and BUMS as fixed sites*



* FALL is the declared fixed site (“F” flag under “obs_file” option); RAMG and BUMS are technically kinematic sites (“K” flag) but are constrained by zero process noise.

Experiment-specific constraints

Justification

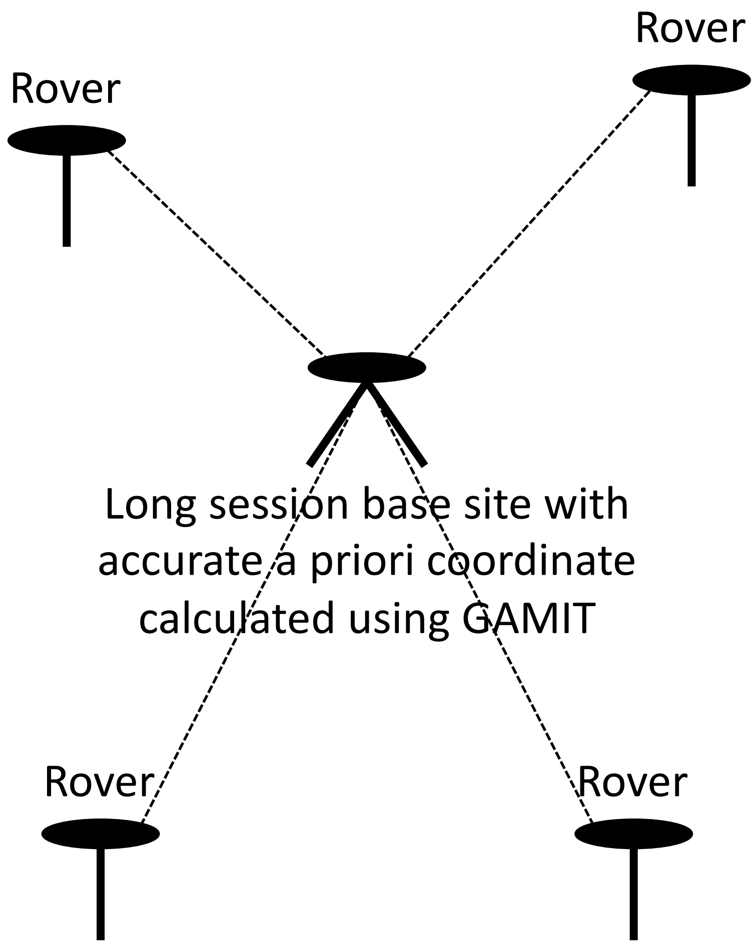
- We wish to apply our own temporal constraints (we have moving sites), so let's be clear on units
- Atmosphere is more stable in Antarctica (cold, high pressure)
    - Evident in daily GAMIT processing "o"-files
- Previous studies show maximum displacement rates of 0.5 m over 30 mins (but loosen temporal constraints for final solution with "ambin_file")

Key `track` commands

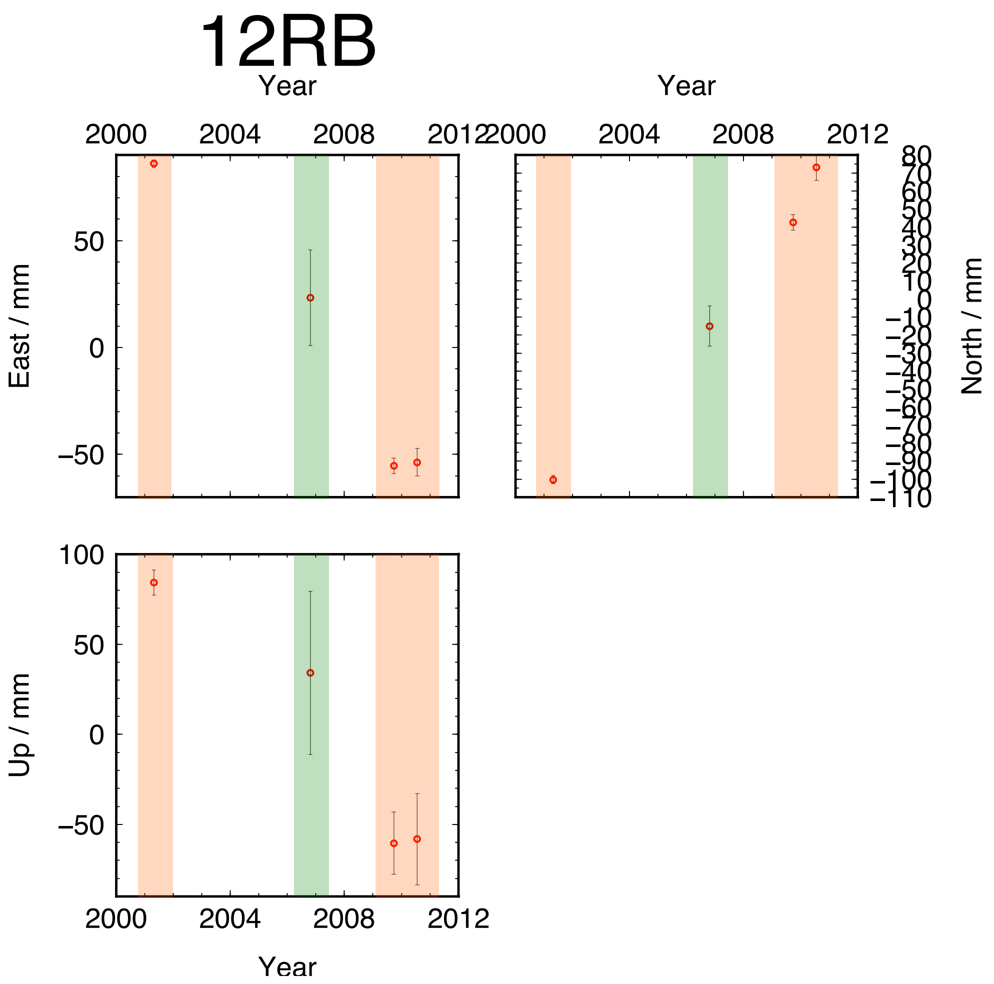
```
time_unit second


atm_stats
 FALL  0.1  0.0001  0
 RAMG  0.1  0.0001  0
  :     :      :    :

site_stats
 FALL  10 10 10  0 0 0
 RAMG  10 10 10  0 0 0
  :     :  :  :  : : :
 LA14  10 10 10  0.1 0.1 0.1
 MG01  10 10 10  0.1 0.1 0.1
```

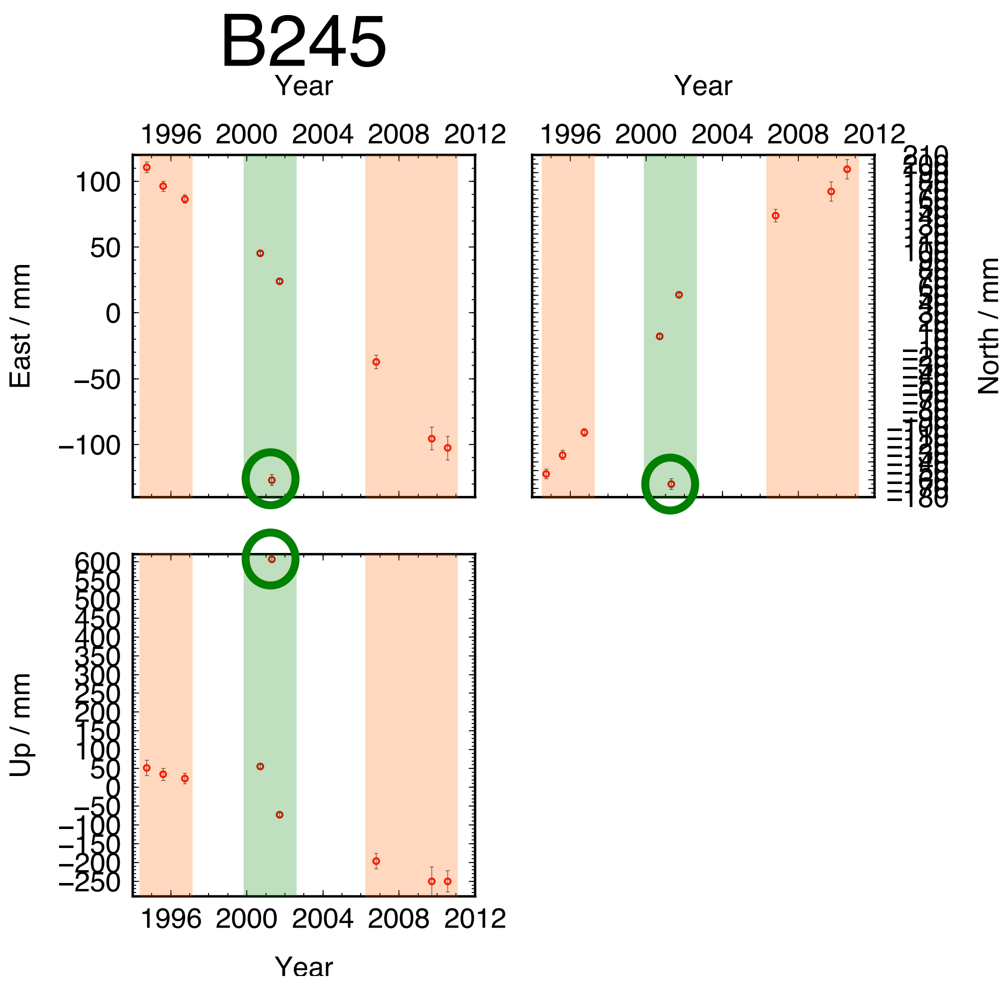
Example 4: Short-static occupations

- Short spans of data (e.g. 30 minutes) may be processed with GAMIT
- Risk of all data being removed during cleaning (`autcln`) if not high quality
- `track` may be used in "short-static" approach with fixed, continuously recording and well positioned base site



Example 4: Short-static occupations

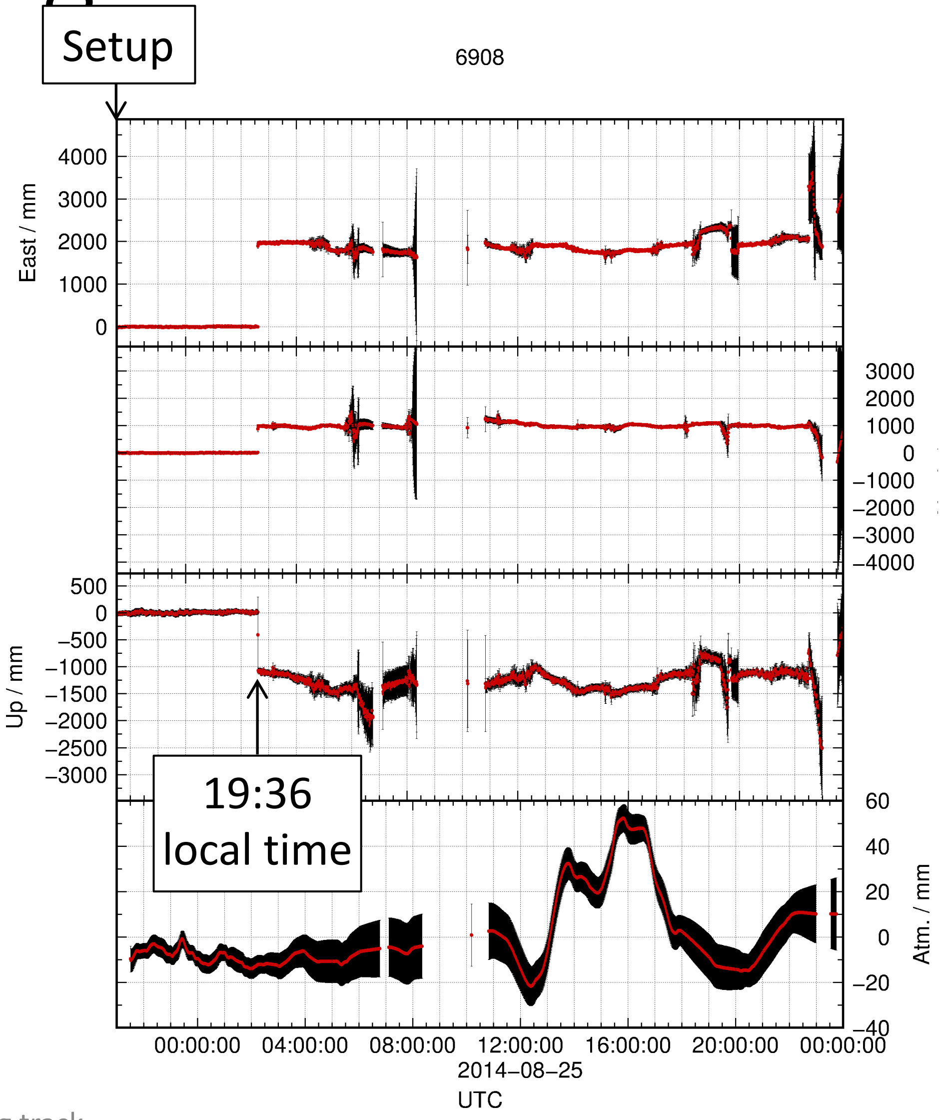





N
Sometimes, this happens…
1.2810 m
Photographs courtesy of Gareth Funning (University of California, Riverside)

Example 5(a): Deciphering interference

- First, run `track` with loose constraints to identify probable epoch of disturbance
- Update a priori position and re-run `track` for solution
- Re-run `teqc` with "-e" option to truncate RINEX file at epoch of disturbance so as not to propagate bad data



Example 5(b): A complex example