

# 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

UNAVCO Headquarters, Boulder, Colorado, USA

18–22 July 2022

[https://geoweb.mit.edu/gg/courses/202207\\_UNAVCO/](https://geoweb.mit.edu/gg/courses/202207_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:

$$\epsilon_{BL} \sim \epsilon_{SV} \times BL/h_{SV}$$

# 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 be noisy due to stochasticity

# Zoom around border

Sites near the epicenter.

Blue circle is 60 km radius

Displacements

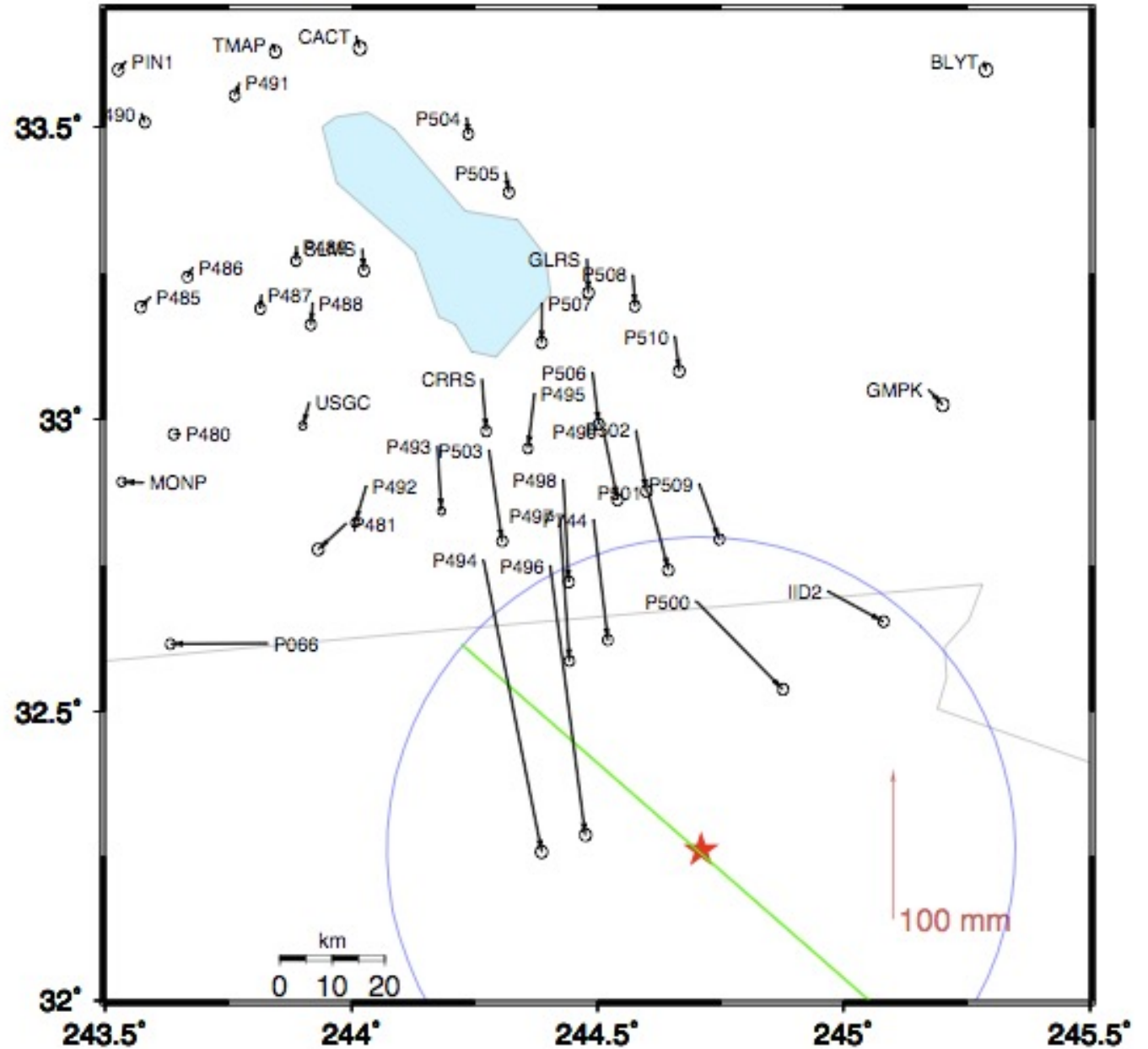
P494 200 mm

P496 182 mm

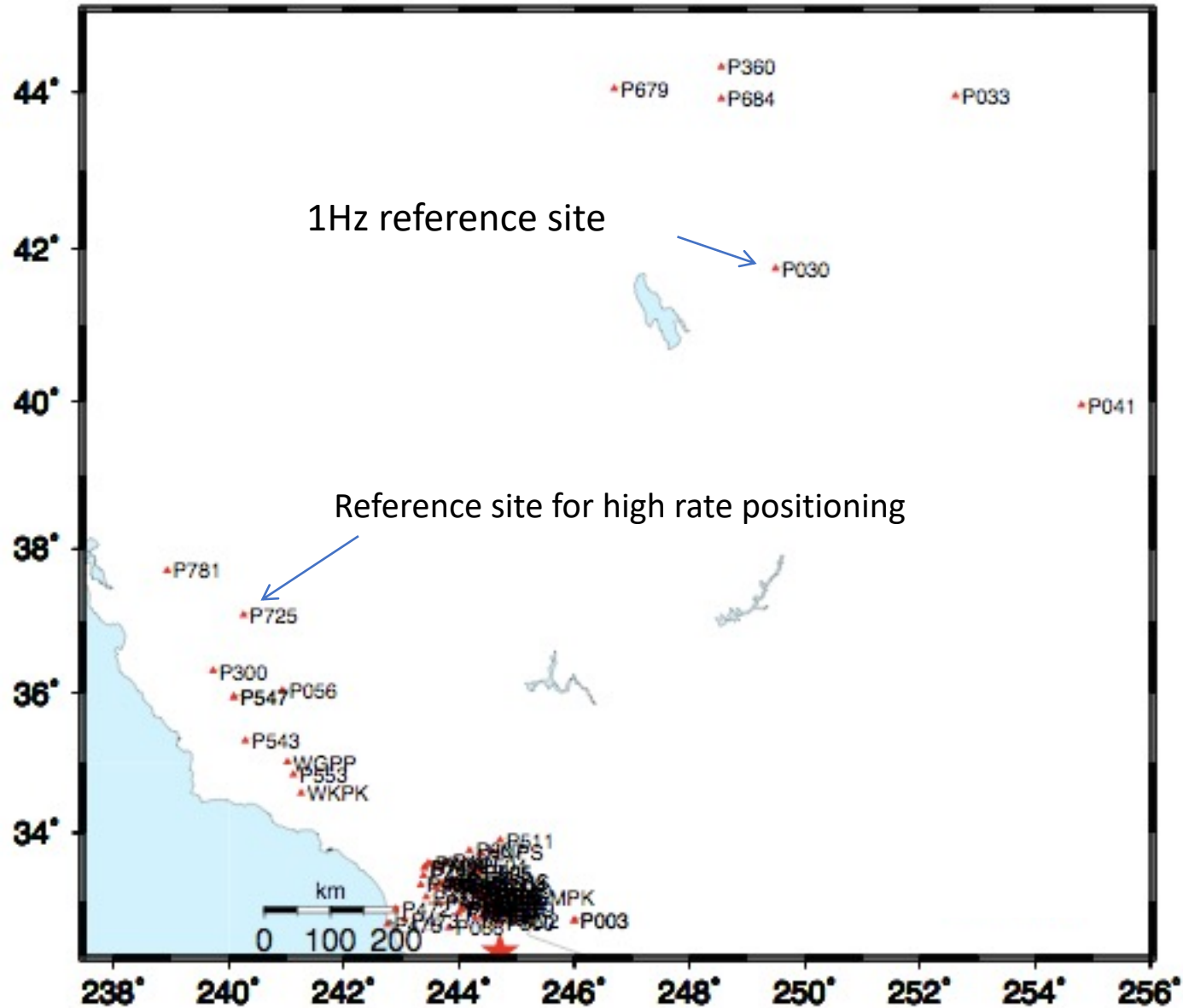
P497 97 mm

...

P491 9 mm



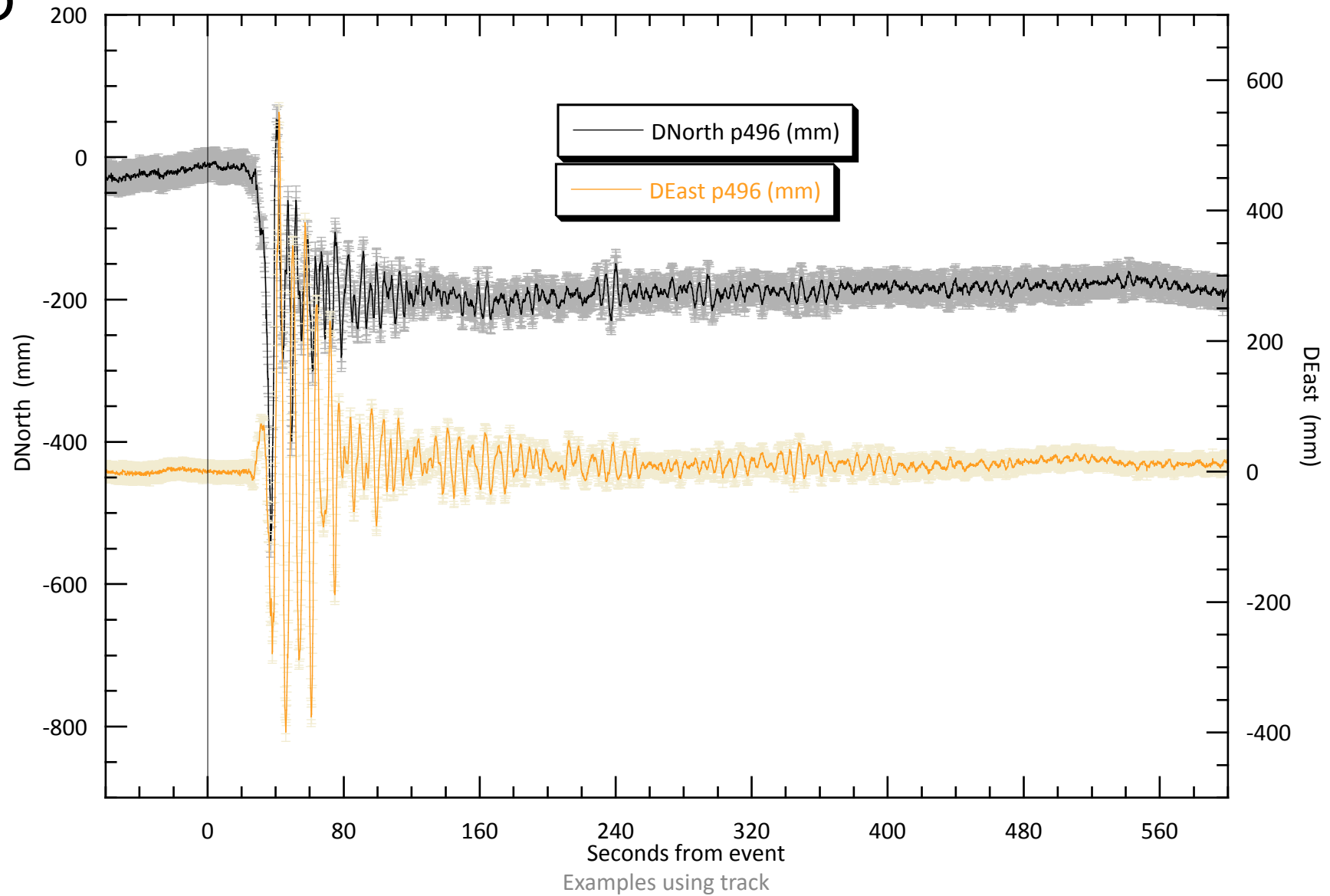




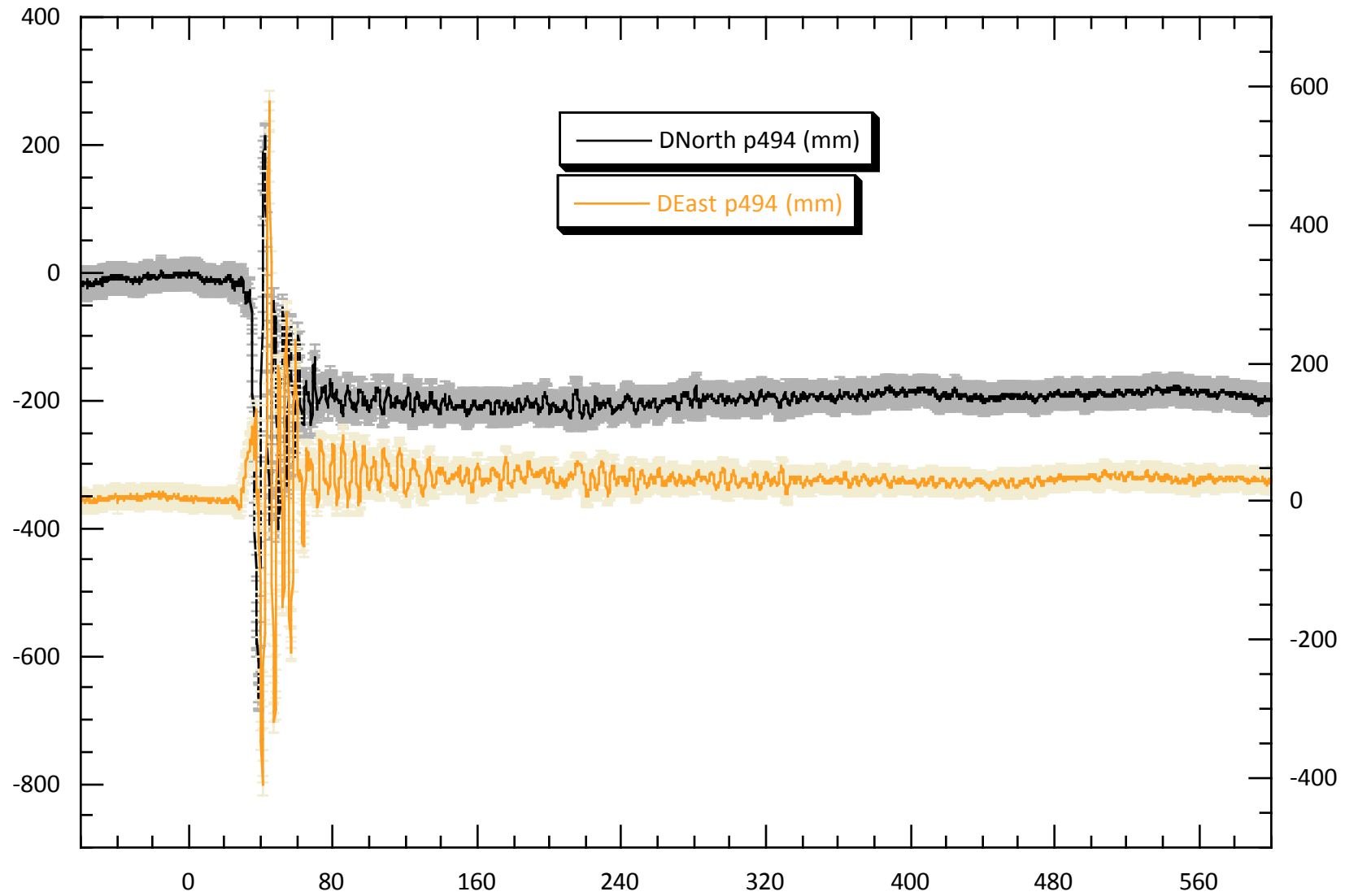
## High-rate GNSS site download

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

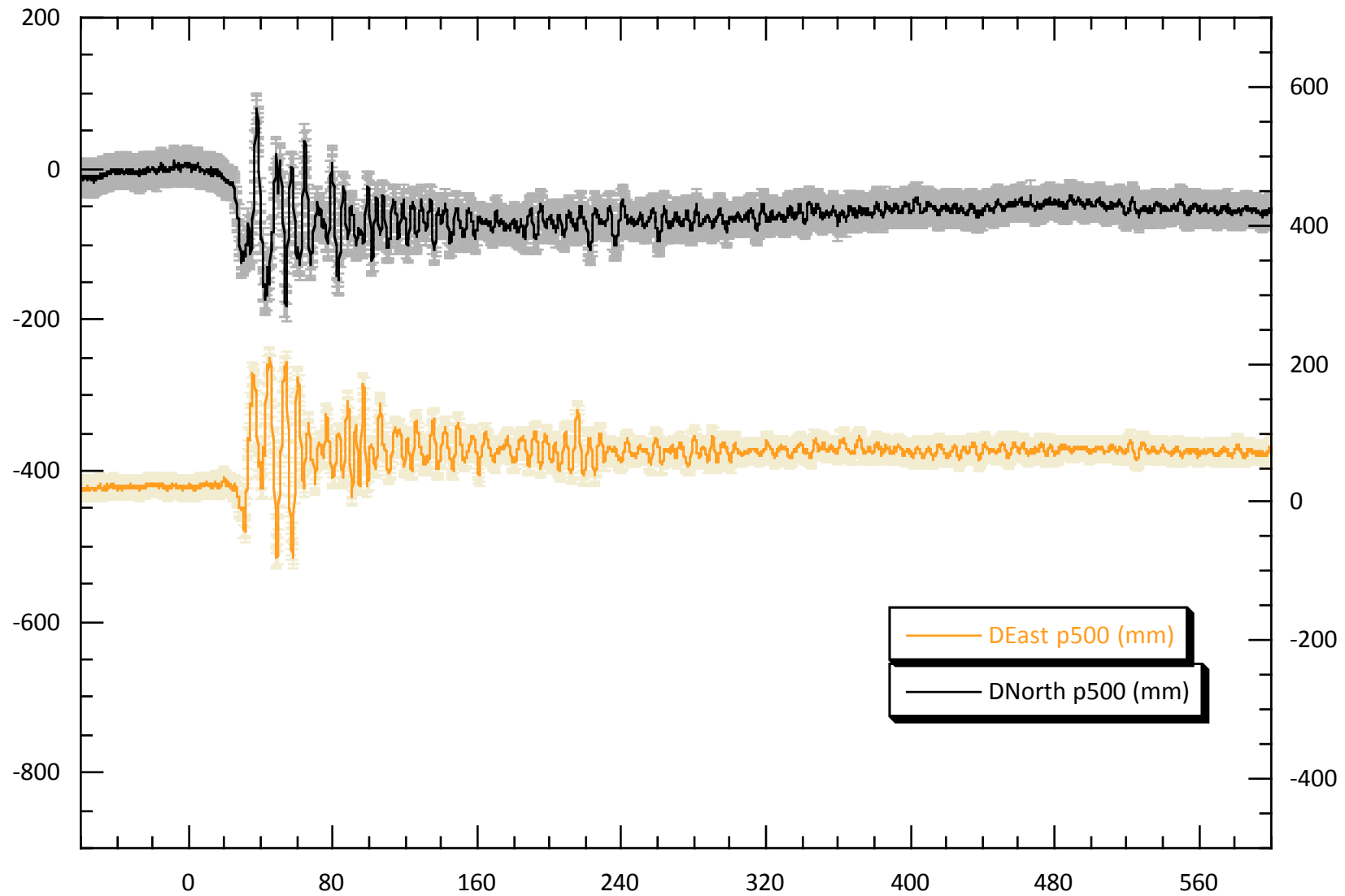
# P496



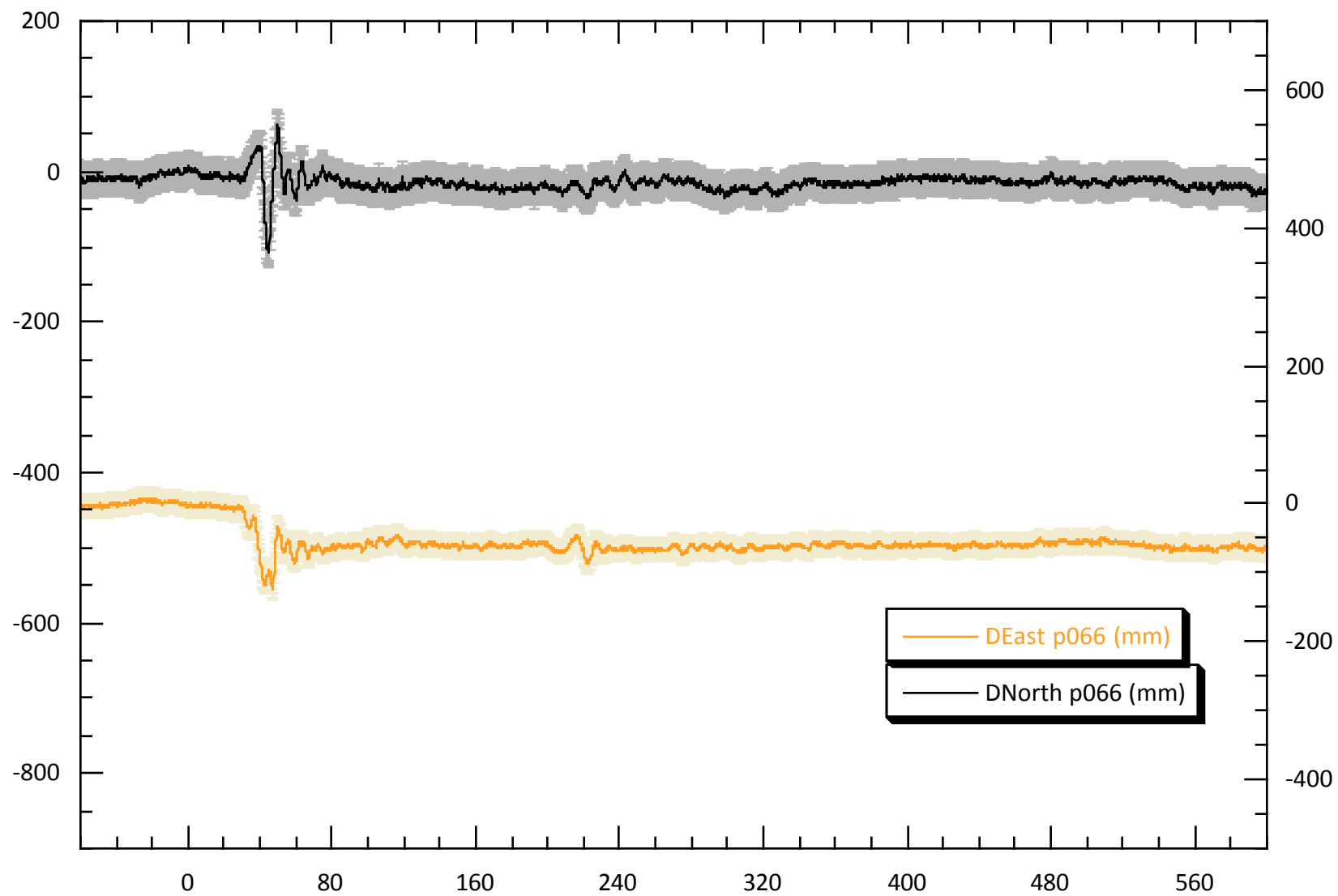
# P494



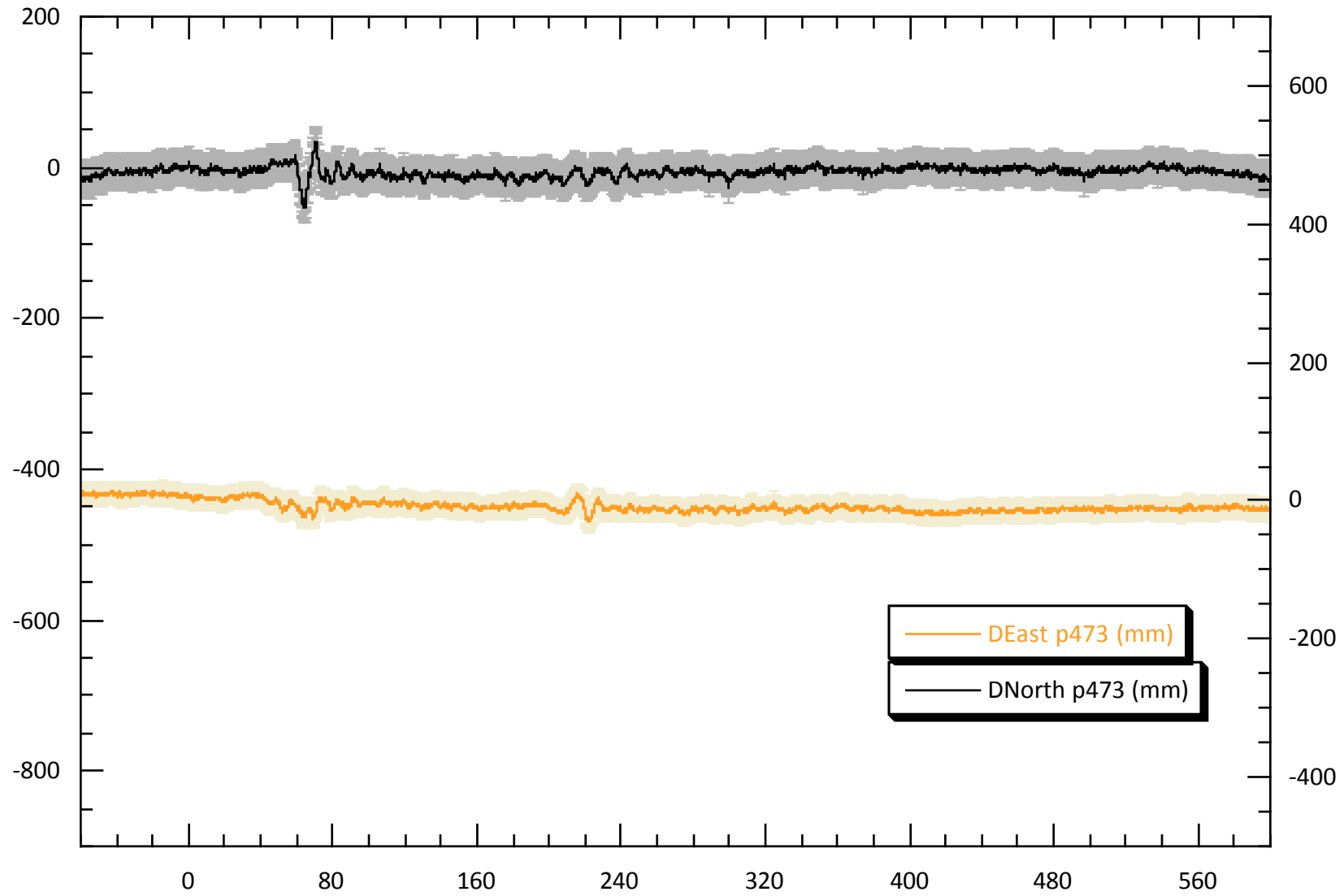
# P500



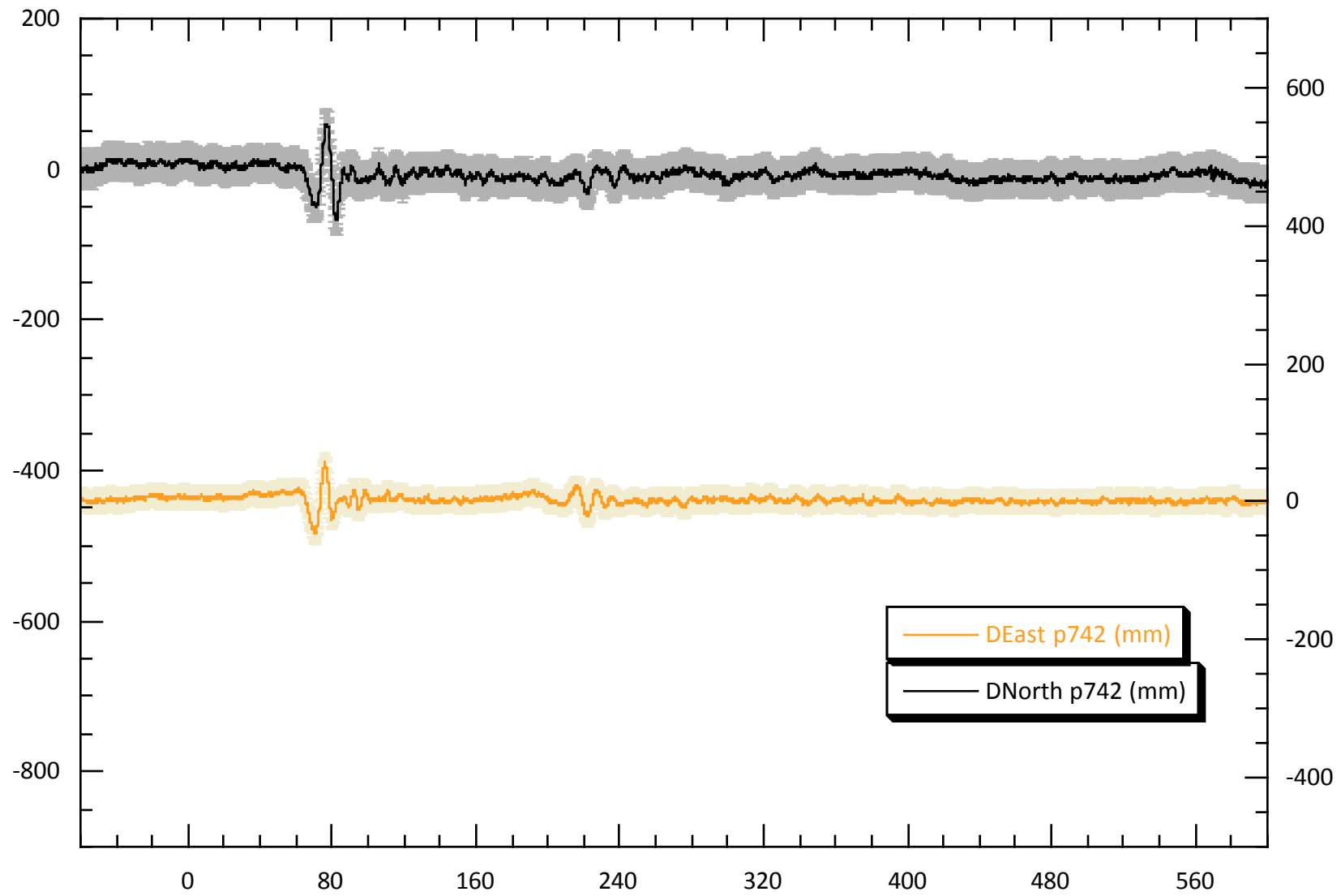
# P066



# P473

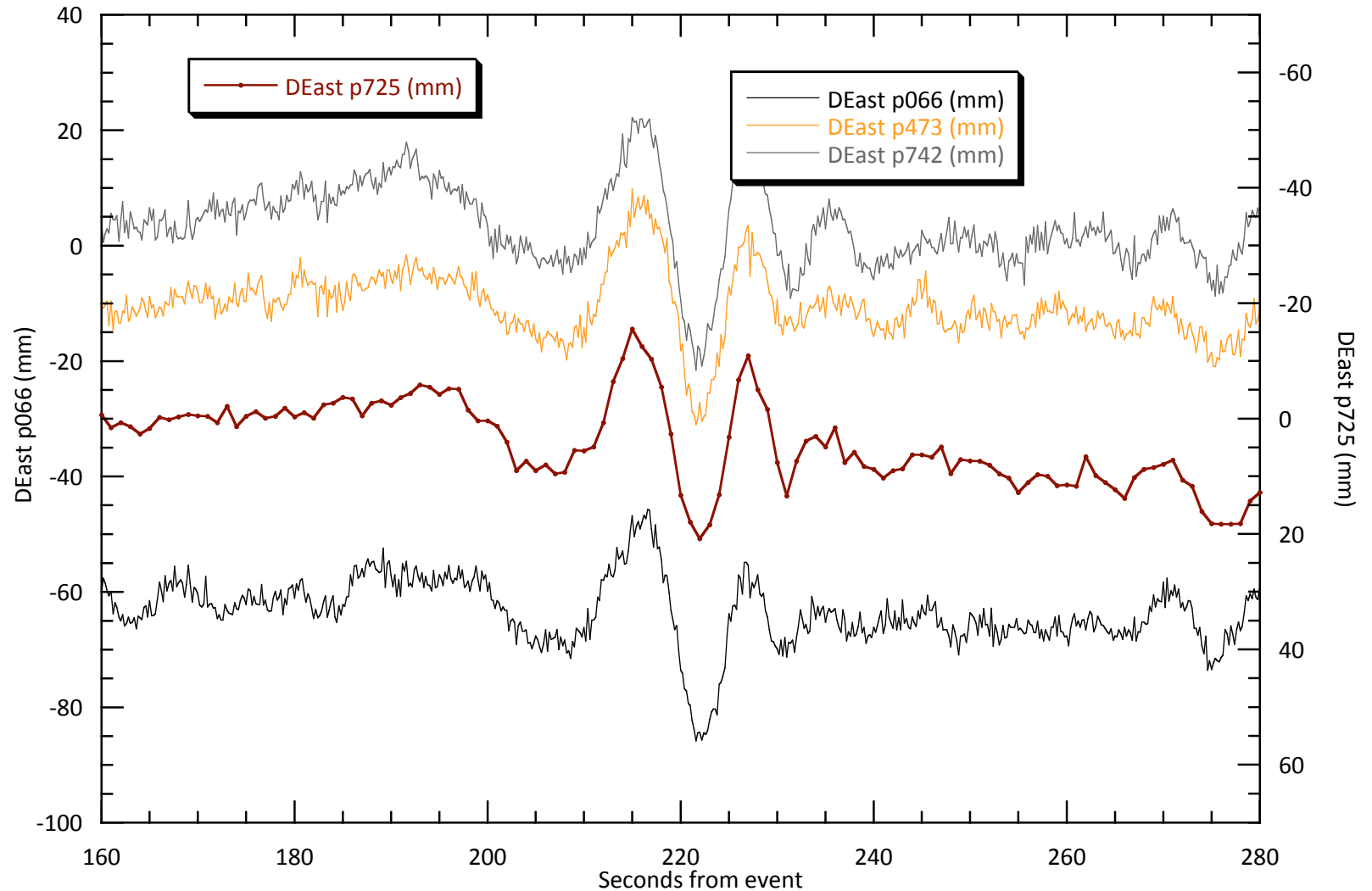


# P742



# Surface wave arrival at P725

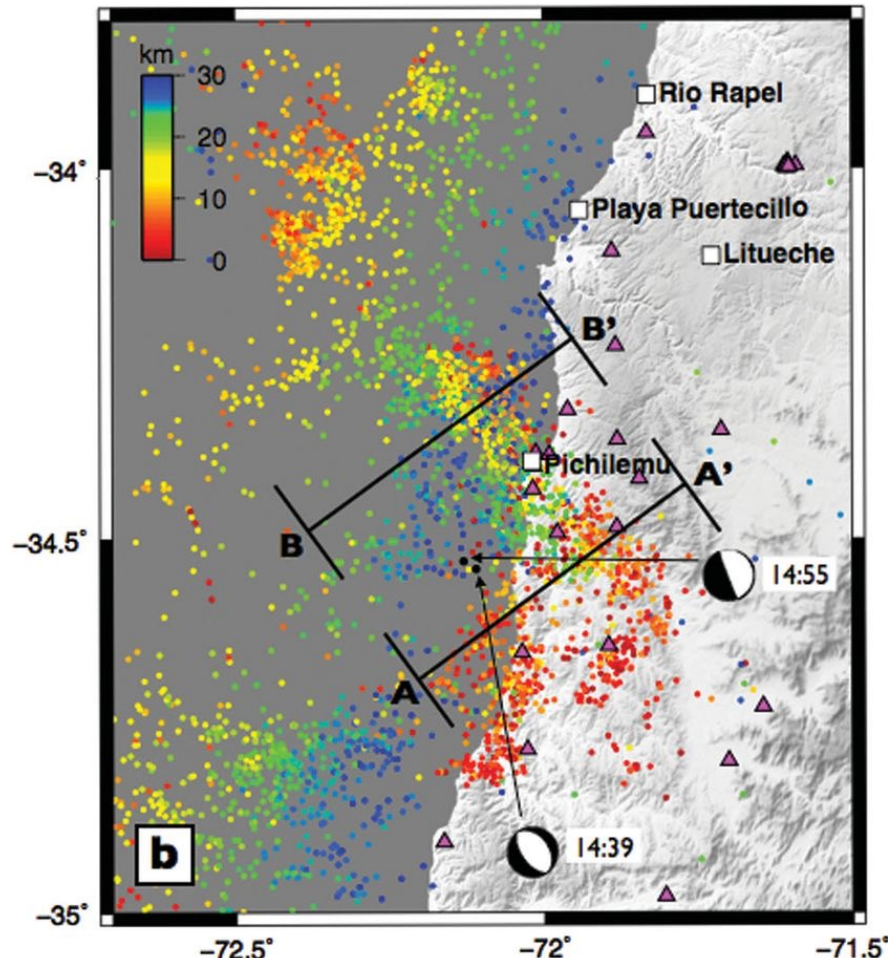
- P725 is ~600 km from epicenter. This signal common to sites is the arrival at the “reference site”





# Example 2: Rapid deformation

(from Ryder et al., 2012)

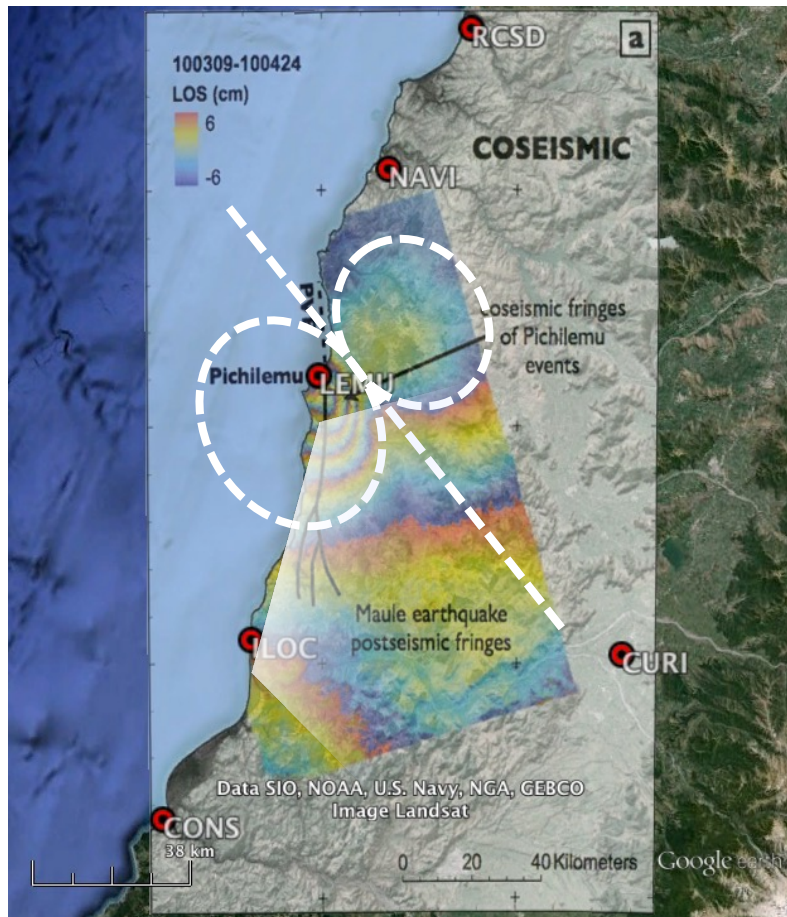


Ryder et al. (2012), Figure 1

- 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_procs
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):

```

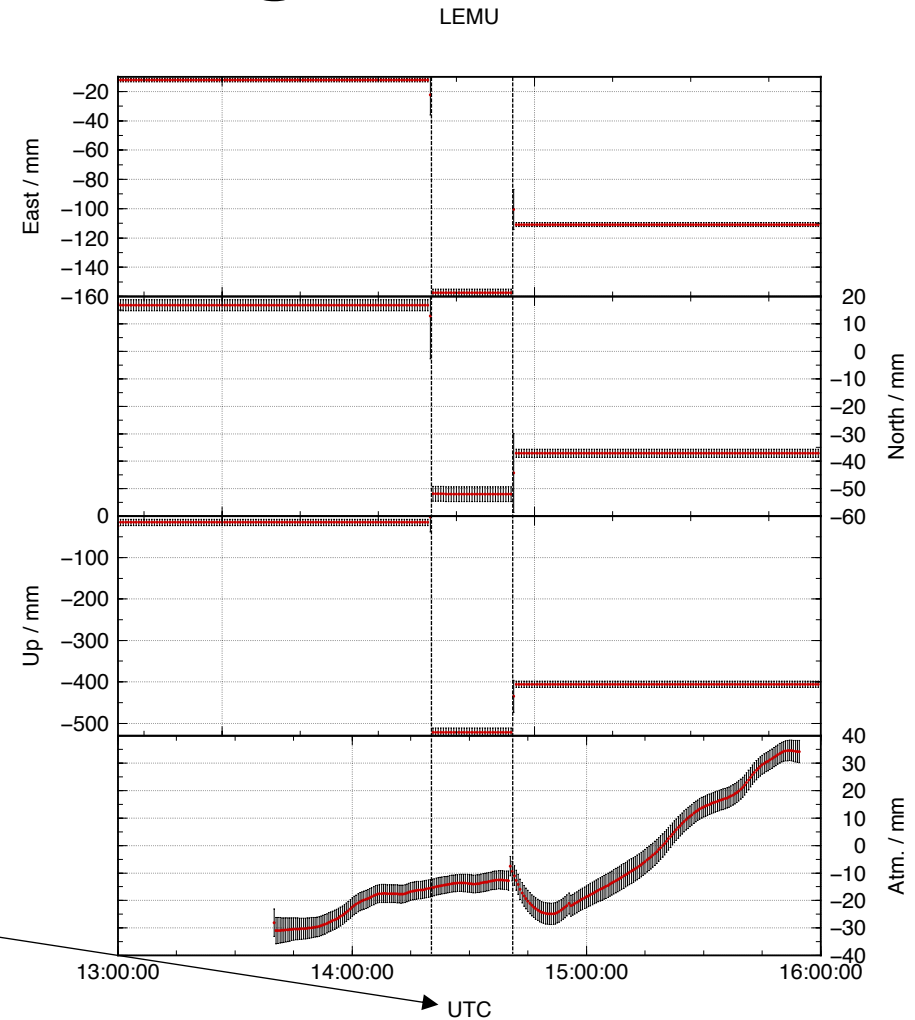
site_stats
iloc 0.02 0.02 0.02 0 0 0
lemu 0.02 0.02 0.02 0 0 0
navi 0.02 0.02 0.02 0 0 0

timedep_procs
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:

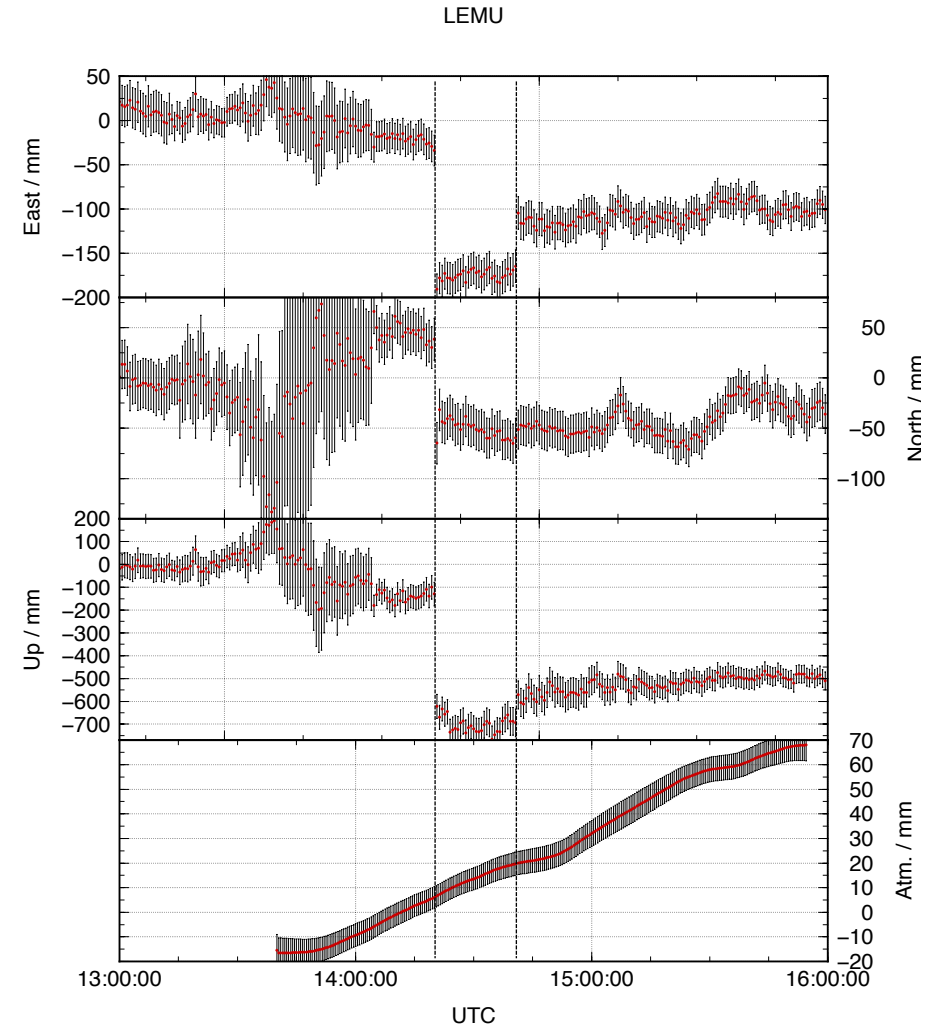
```
site_stats
```

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

```
timedep_procs
```

```
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
```

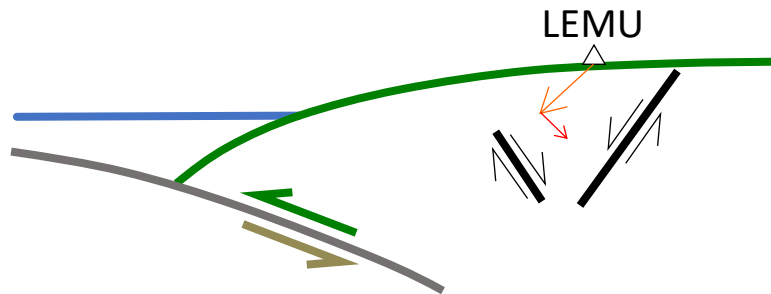
```
ambin_file track.amb
```



# Example 2: track alters perspective

## Initial hypothesis

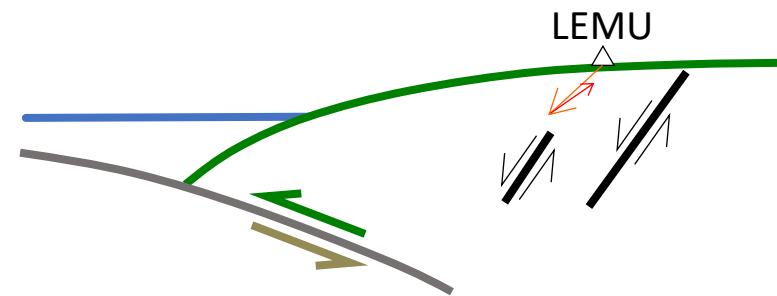
- Earthquakes took place on antithetic normal faults in the upper plate of subduction interface



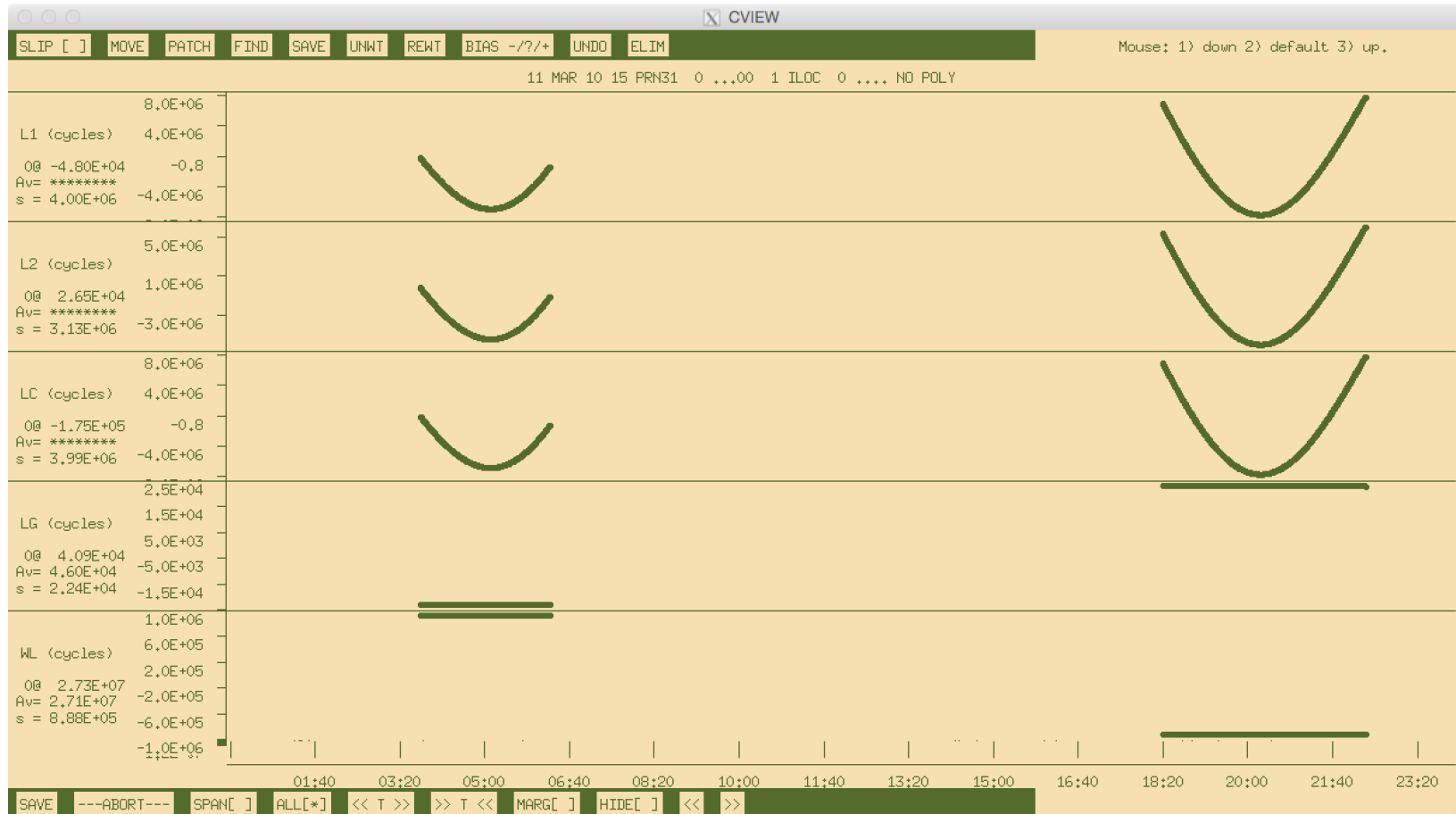
- But cGNSS site LEMU experiences opposite vertical motion due to first and second earthquakes

## Final conclusion

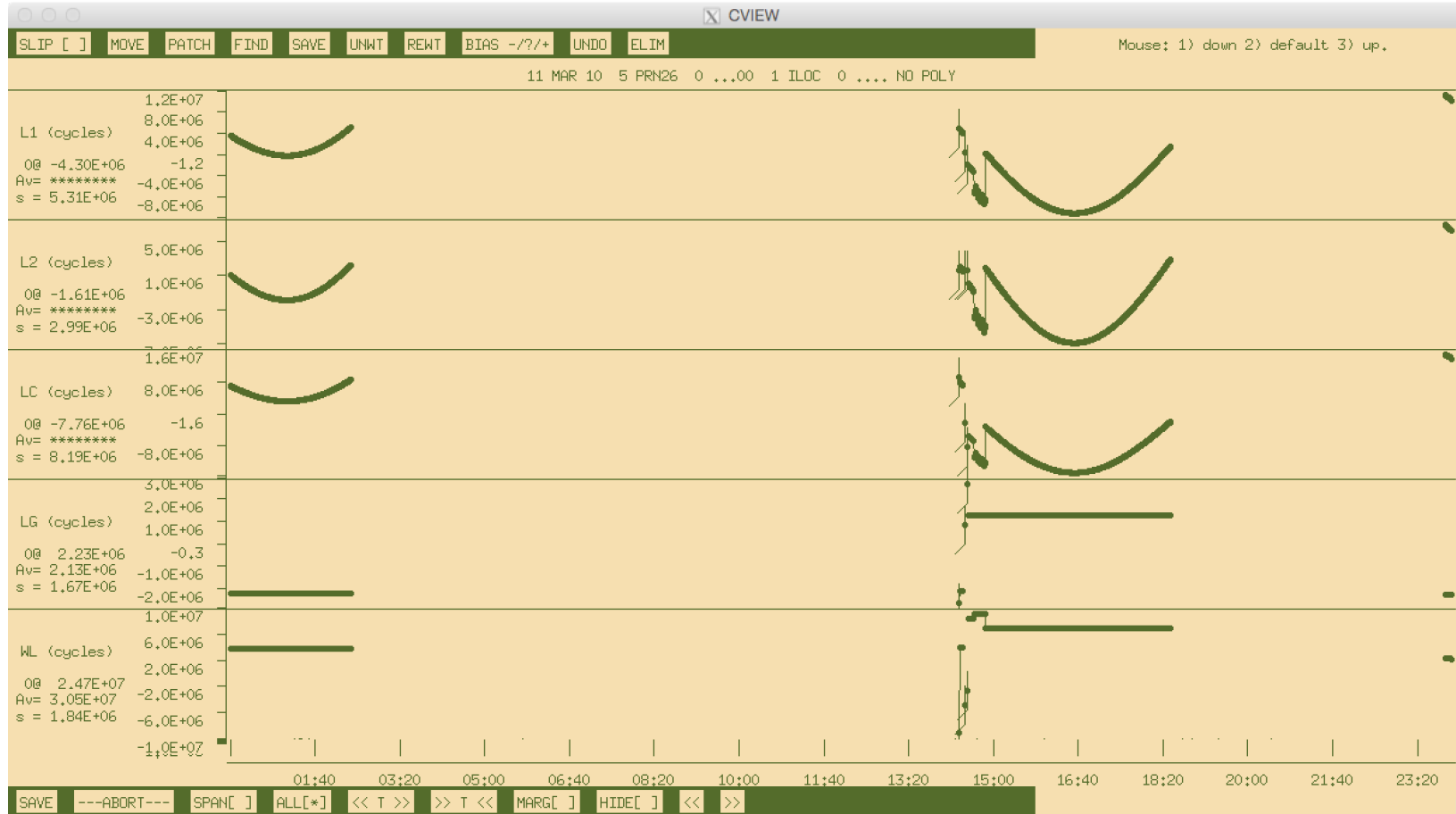
- LEMU is on the hanging wall of first earthquake and footwall of second
- Therefore faults must be synthetic normal faults



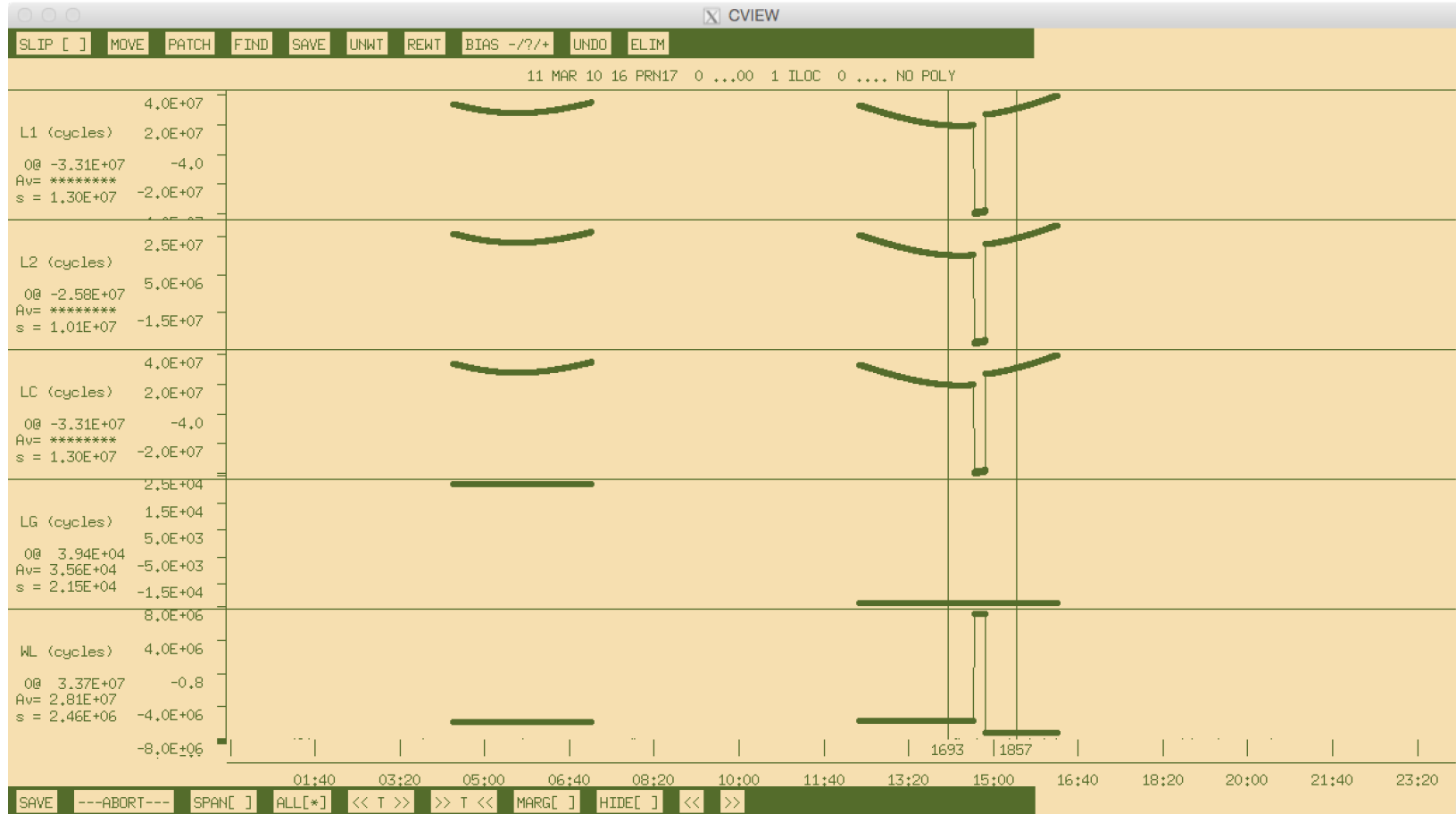
# A good satellite in cview



# A satellite with some problems cview

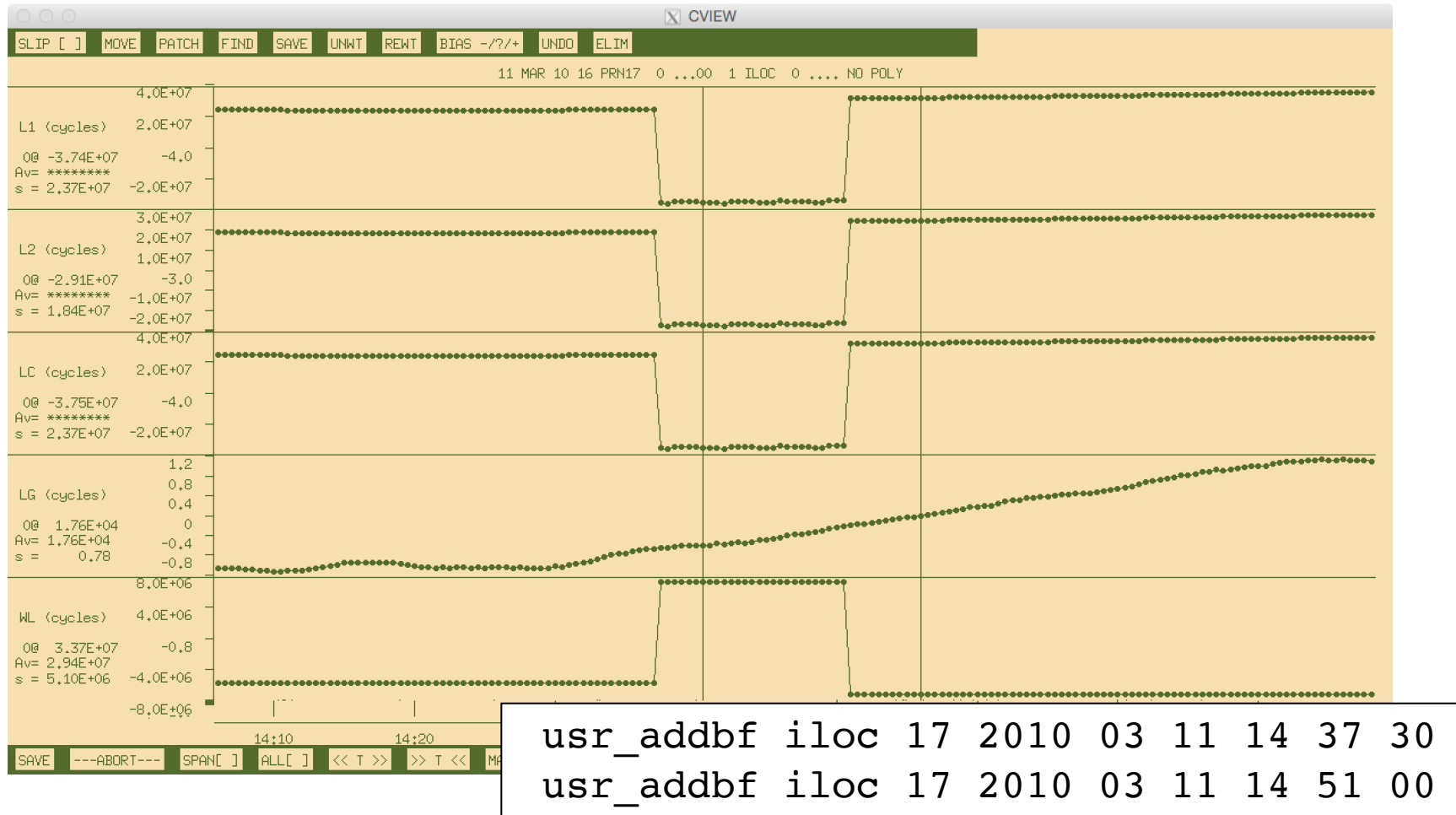


# A problematic satellite in cview





# A problematic satellite in cview



# 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>

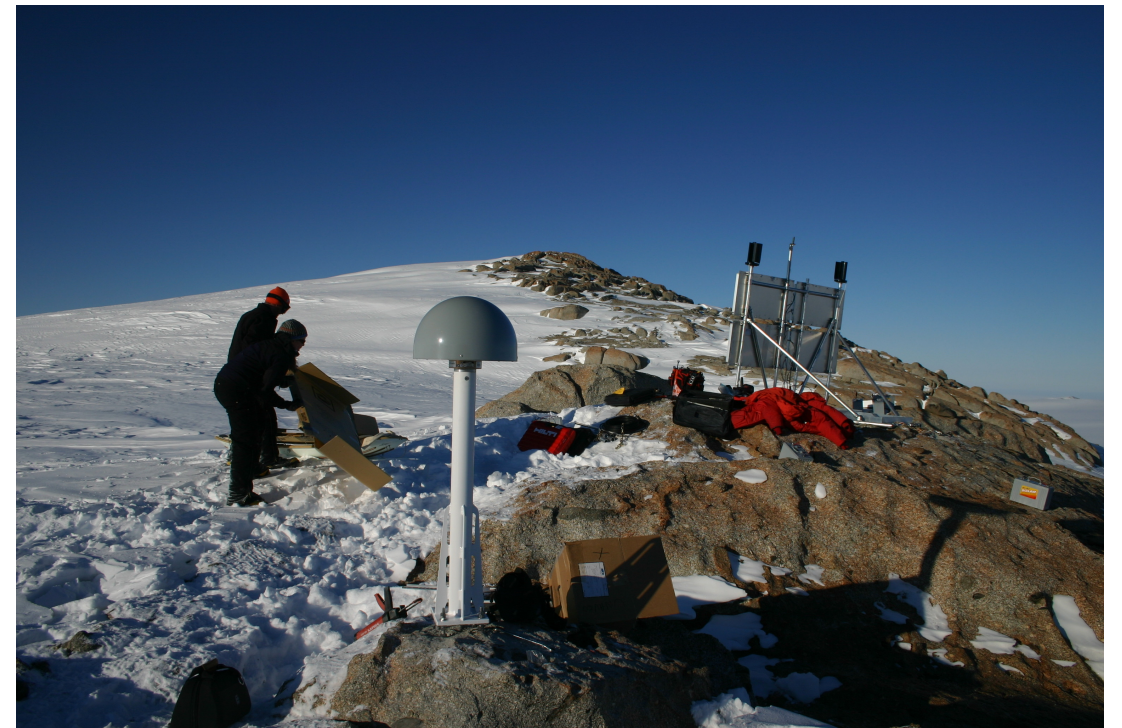
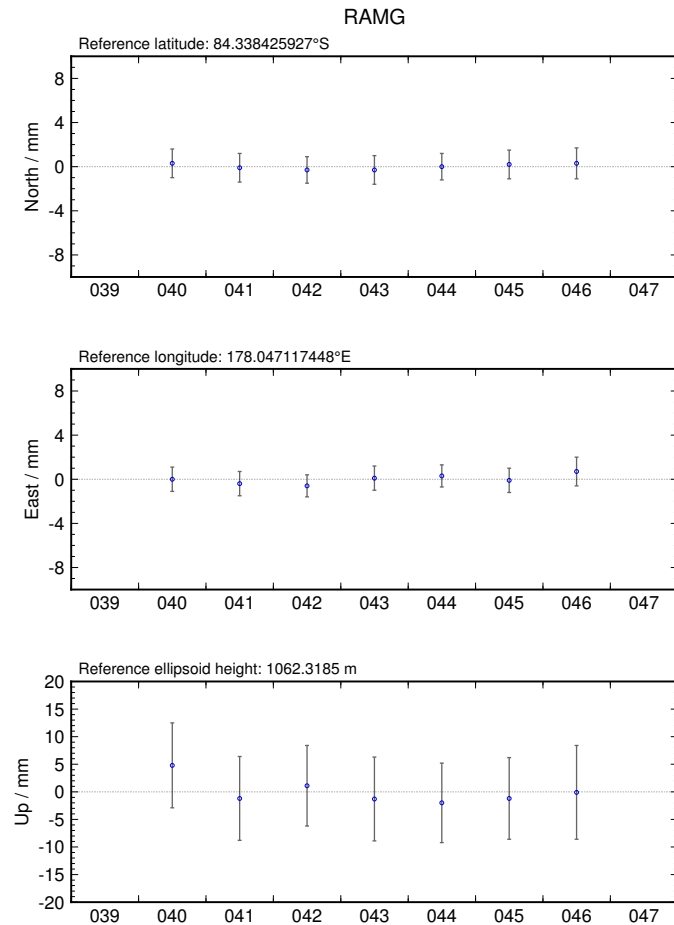
The screenshot displays the UNAVCO Data Archive Interface v2. The main content area shows a table of search results for 117 items. The table includes columns for 4chID, interval, name, lat, lon, earliest data, and latest data. The results are filtered to show stations in Antarctica.

4chID	interval	name	lat	lon	earliest data	latest data
ABBZ	15.0 sec	Abbott Peak	-77.4569	166.9089	2003 Jan 06 21:58	2015 Jun 08 23:59
AMU2	15.0 sec	Amundsen Scott South I	-89.9989	-110.754	2005 Nov 03 19:20	2015 Jun 08 23:59
BACK	30.0 sec	Backer Island	-74.4304	-102.4782	2011 Dec 27 02:00	2015 Jun 08 23:59
BEAN	15.0 sec	Bean Peaks	-75.9563	-69.3022	2010 Jan 07 19:35	2010 Sep 09 03:41
BENN	30.0 sec	Bennett Nunatak	-84.7865	-116.4598	2010 Dec 15 16:14	2015 Jun 08 23:59
BERP	30.0 sec	Bear Peninsula	-74.5459	-111.8846	2011 Jan 11 02:04	2015 Jun 08 23:59
BOAR	30.0 sec	Pine Island Glacier Cam	-75.0439	-100.5927	2012 Jan 09 00:50	2014 Apr 03 23:59
BOMZ	15.0 sec	Bombs	-77.5089	167.4402	2003 Jan 09 23:42	2014 Oct 09 11:33
BREN	30.0 sec	Brennecke Nunataks	-72.6729	-63.0258	2006 Dec 28 22:17	2010 Jul 13 23:59

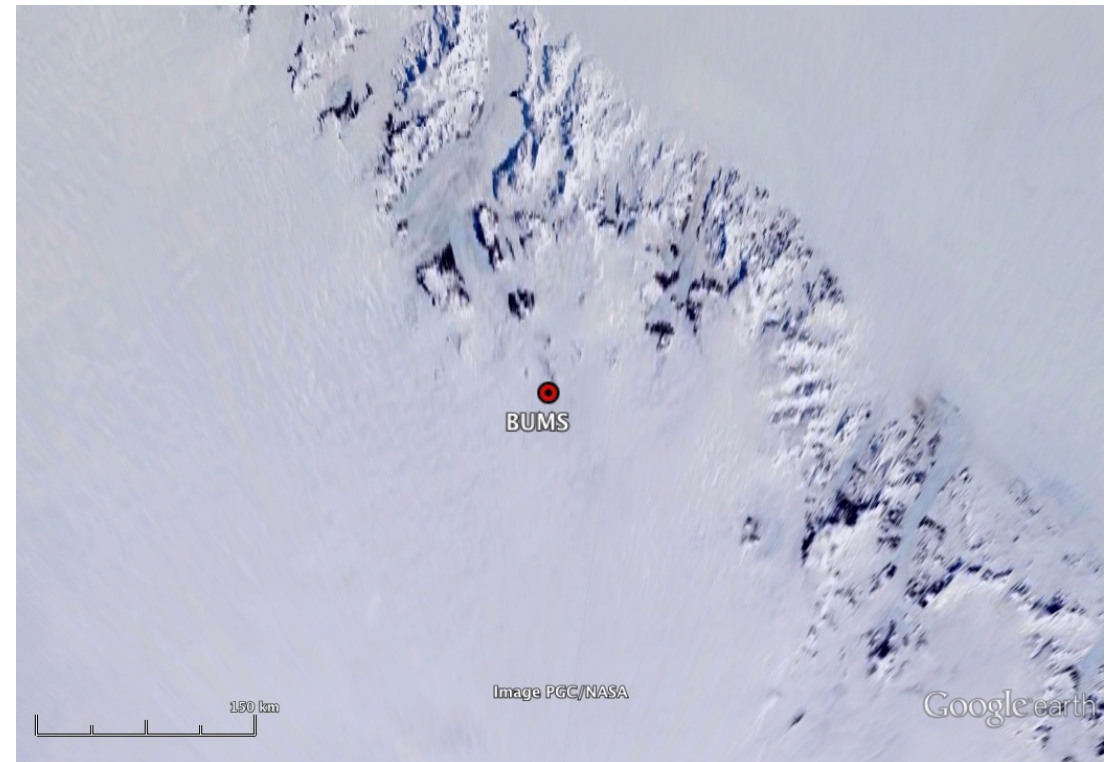
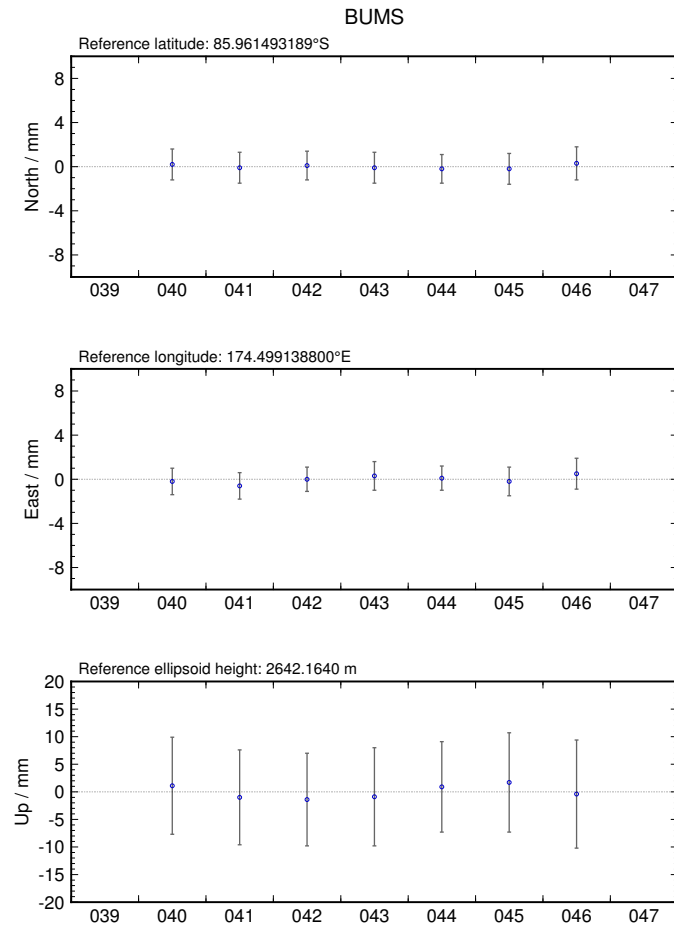
The interface also features a search bar, filters for metadata and spatial data, and a map of Antarctica showing the locations of the stations. The map is powered by Esri and includes a scale bar (1000 km / 500 mi).

Ice flow or bedrock?

# Ice flow or bedrock?

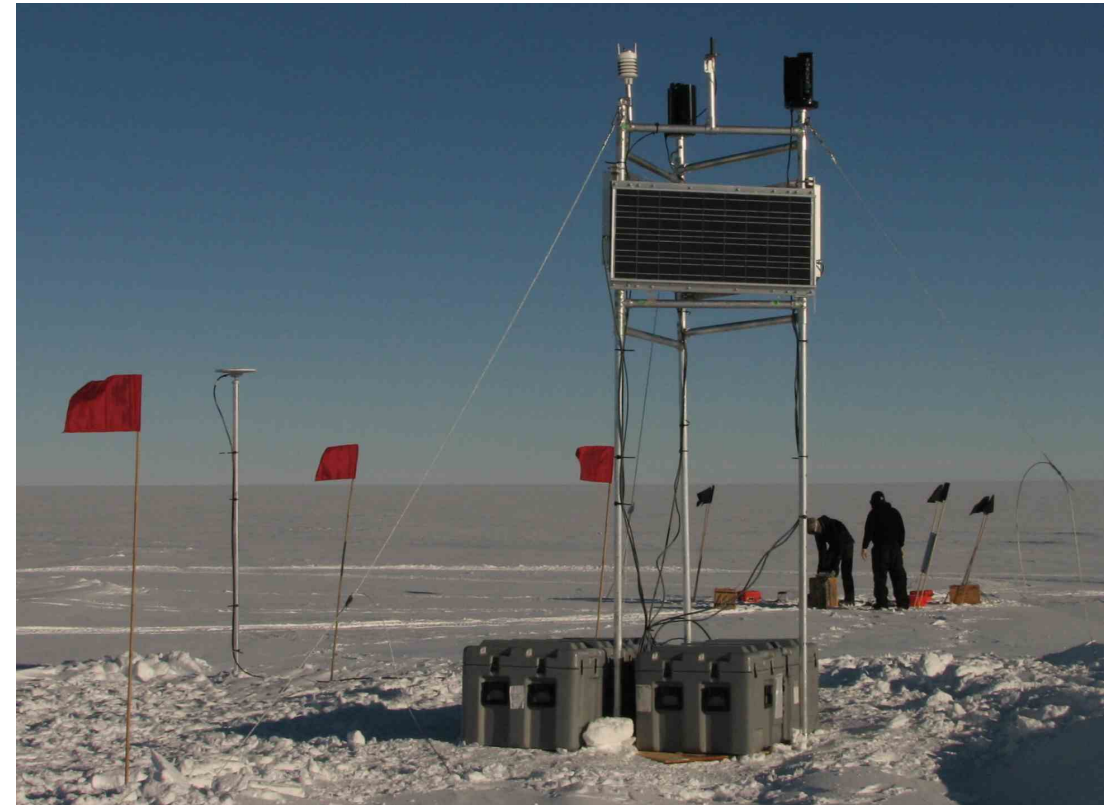
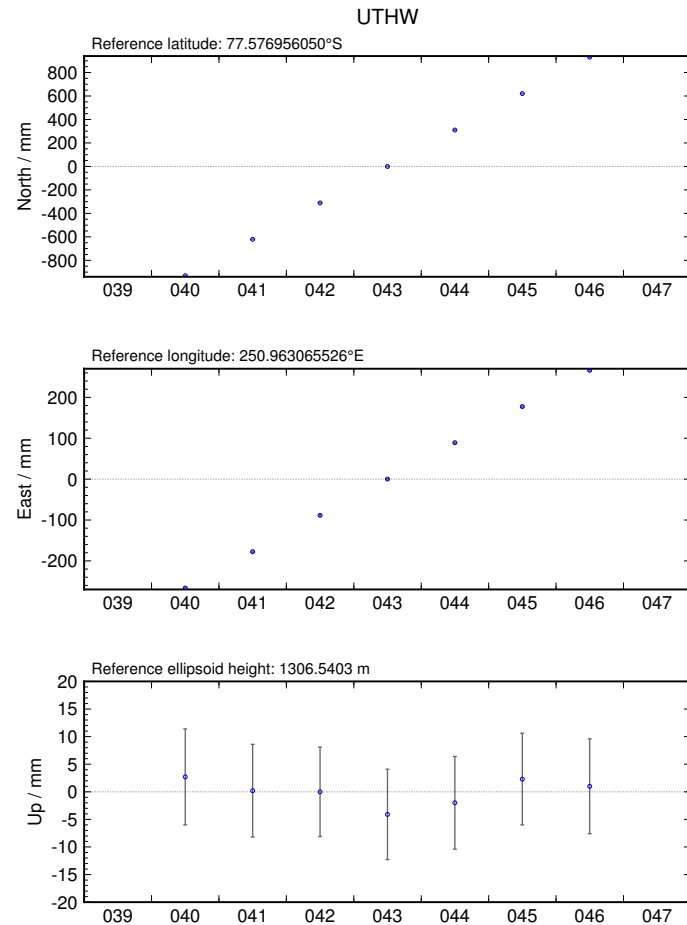


# Ice flow or bedrock?

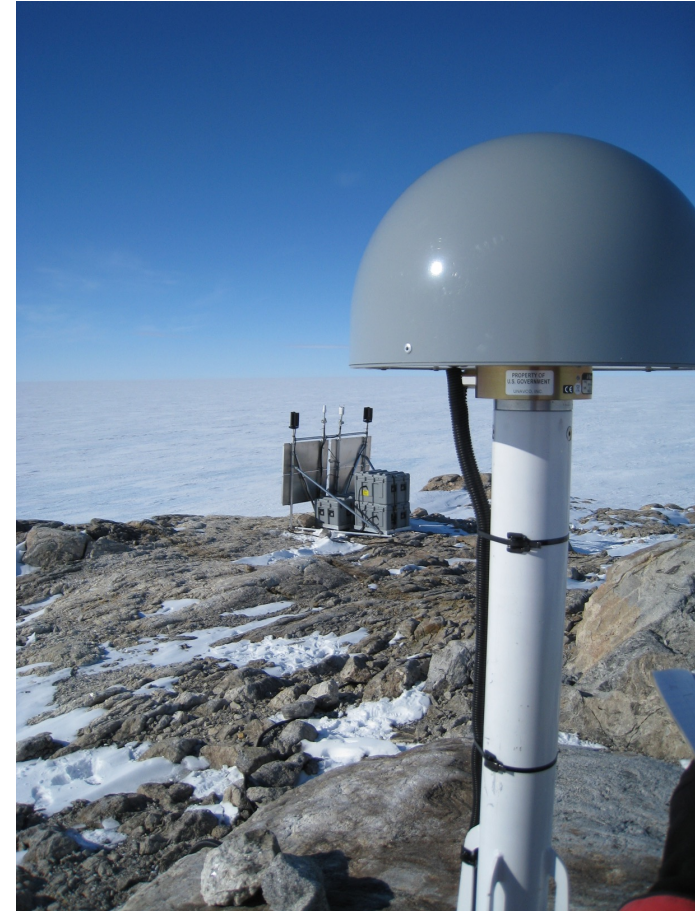
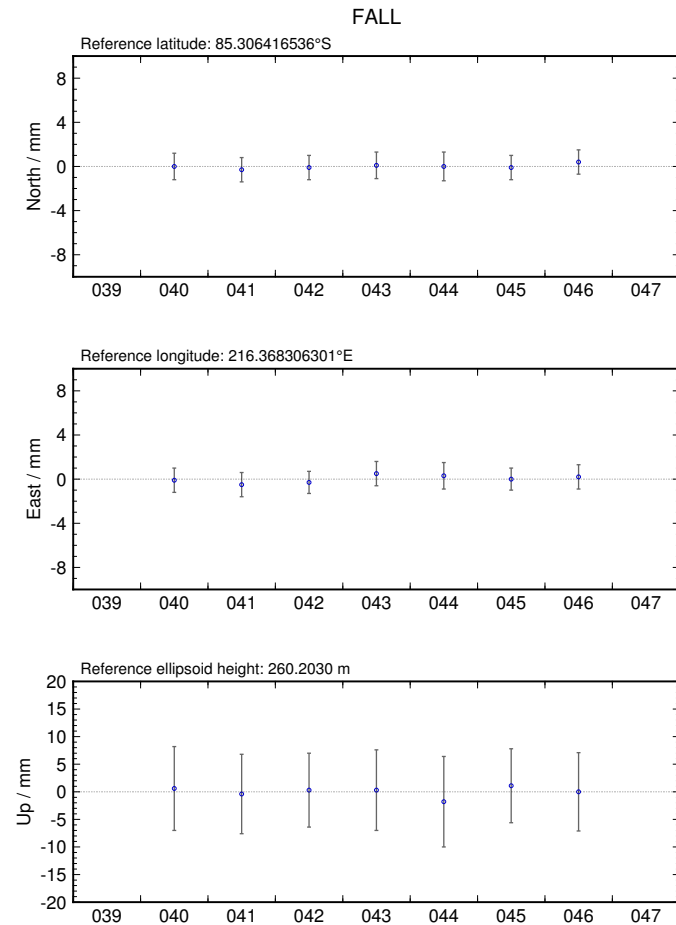




# Ice flow or bedrock?

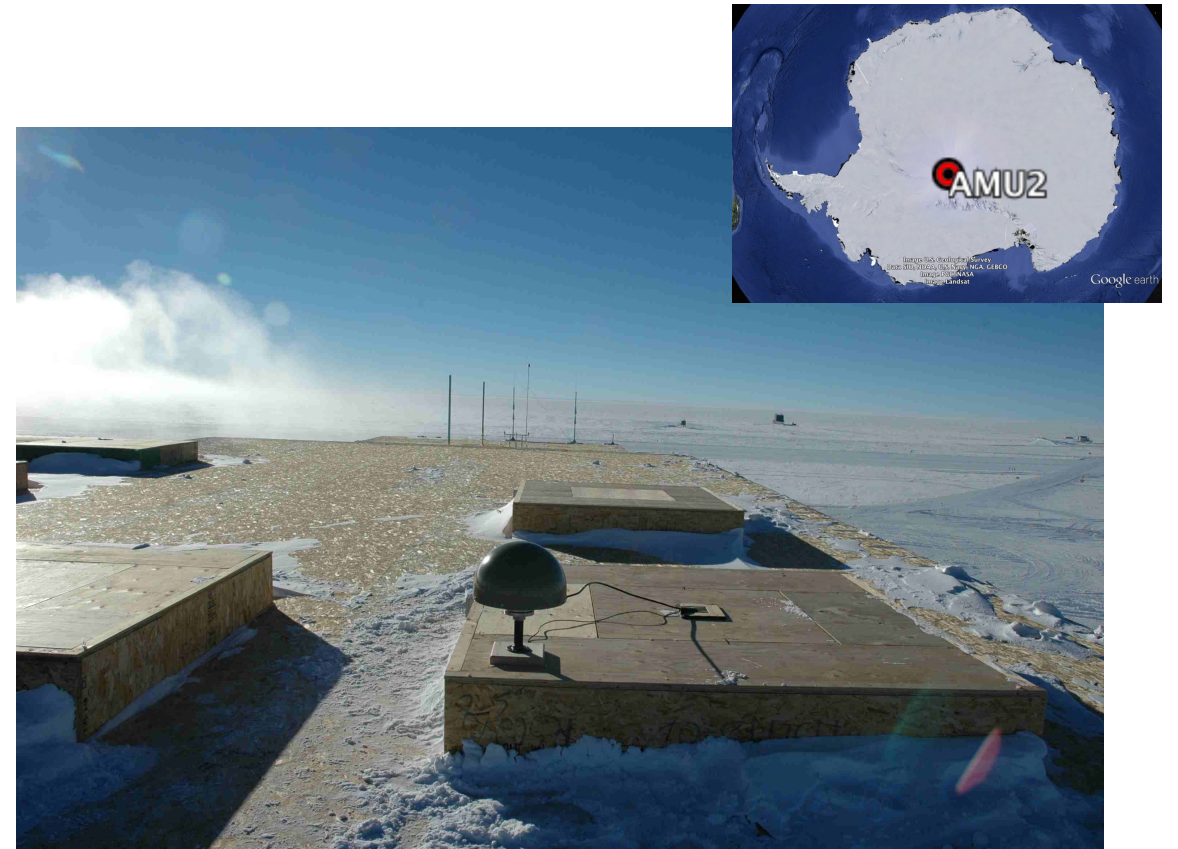
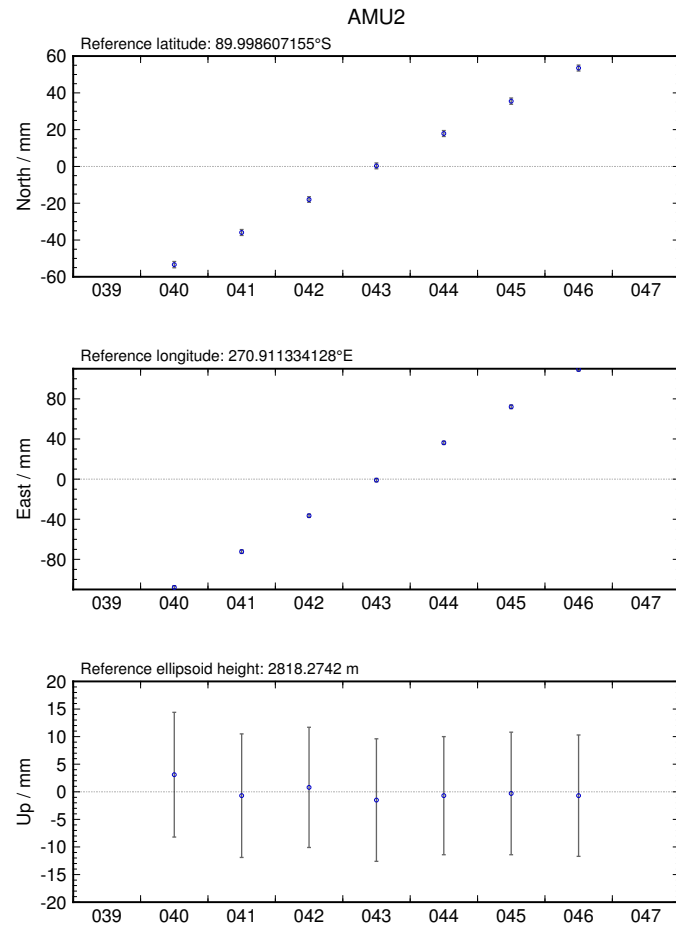


# Ice flow or bedrock?

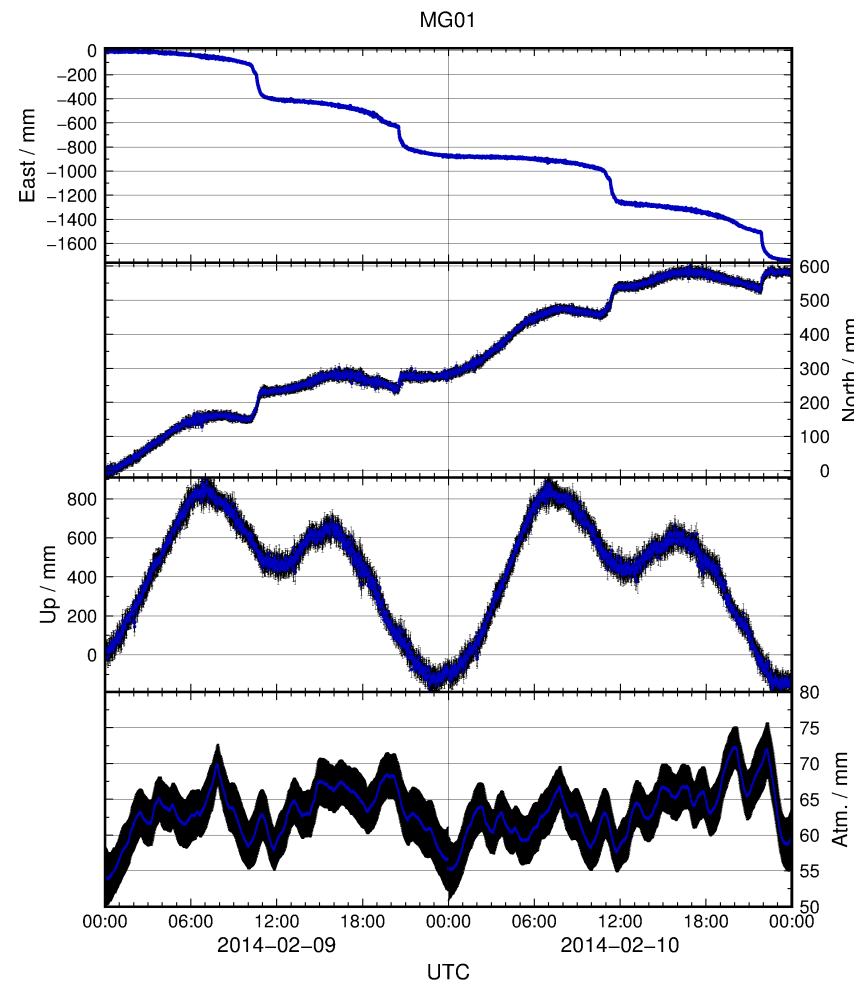
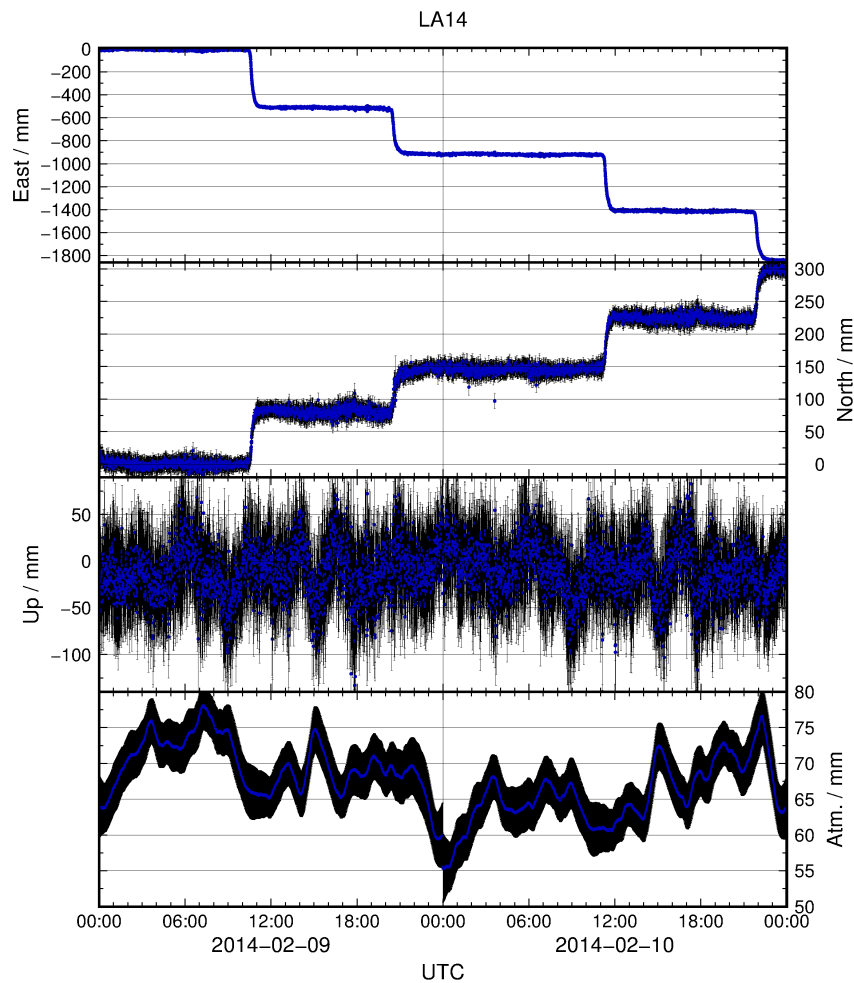




# Ice flow or bedrock?



# 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
```

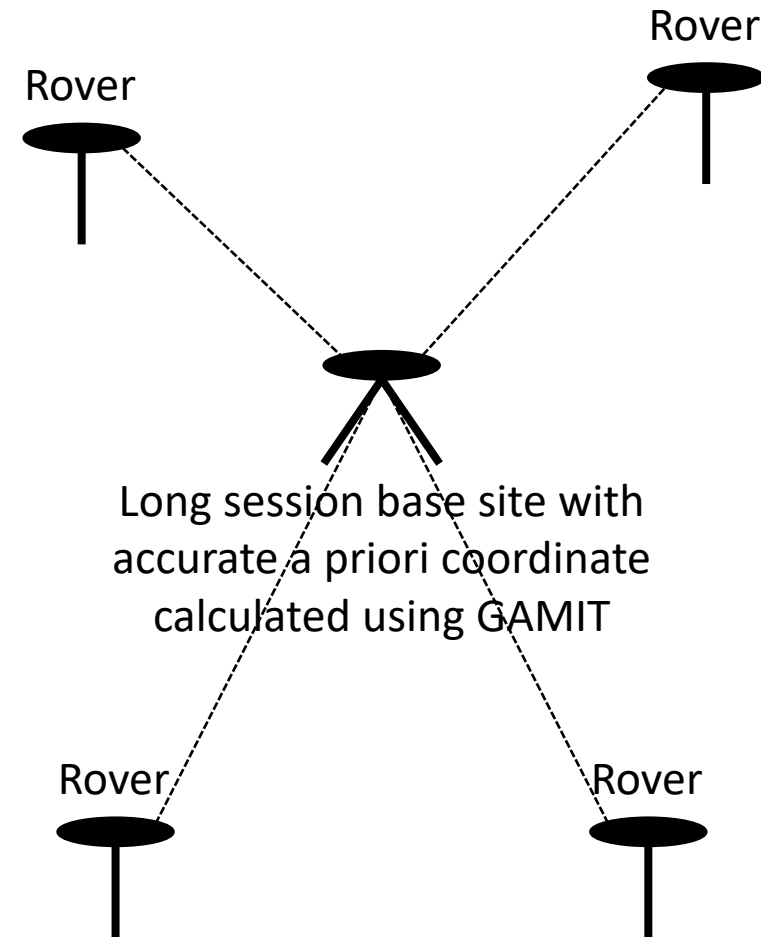
```
FALL 0.1 0.0001 0  
RAMG 0.1 0.0001 0  
: : : :
```

```
site_stats
```

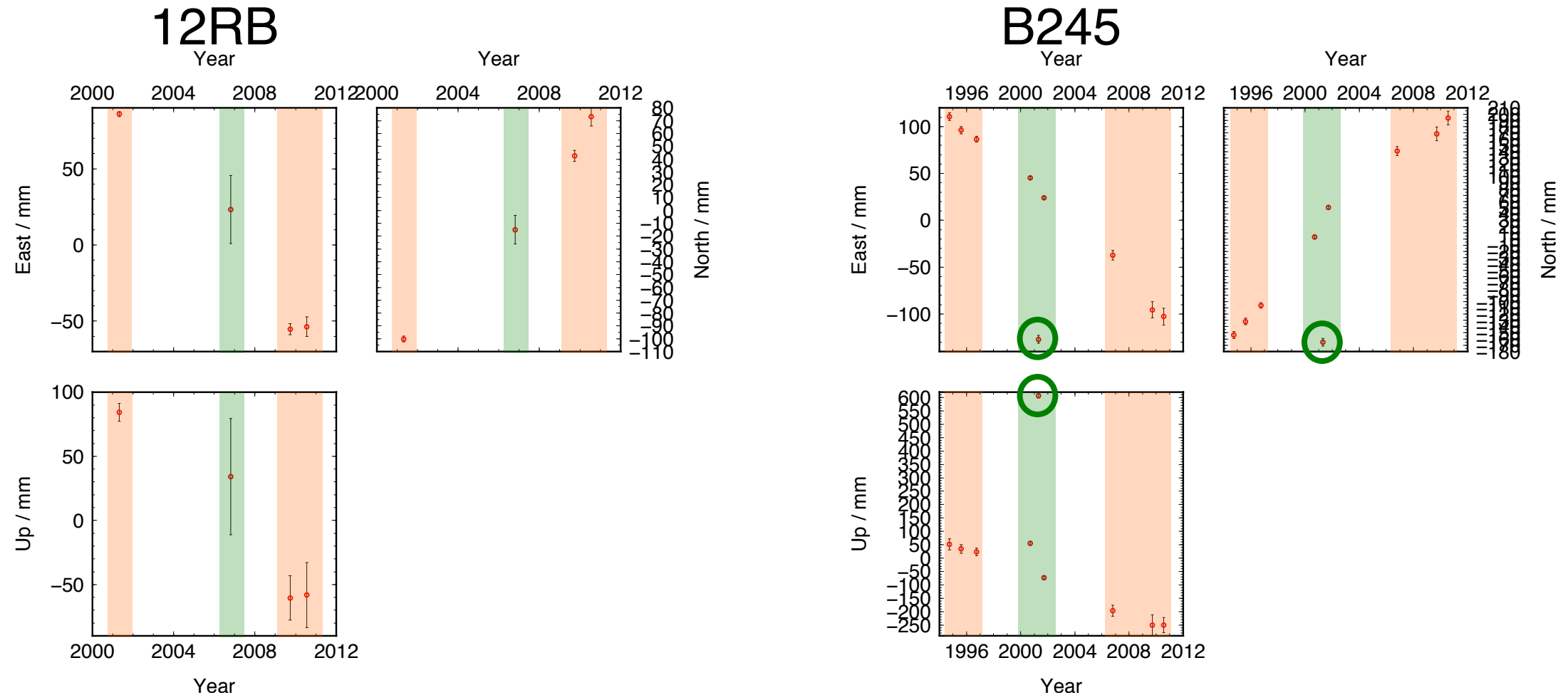
```
FALL 10 10 10 0 0 0  
RAMG 10 10 10 0 0 0  
: : : : : :  
LA14 10 10 10 0.1 0.1 0.1  
MG01 10 10 10 0.1 0.1 0.1
```

# 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 (`autclean`) 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







Sometimes, this happens...

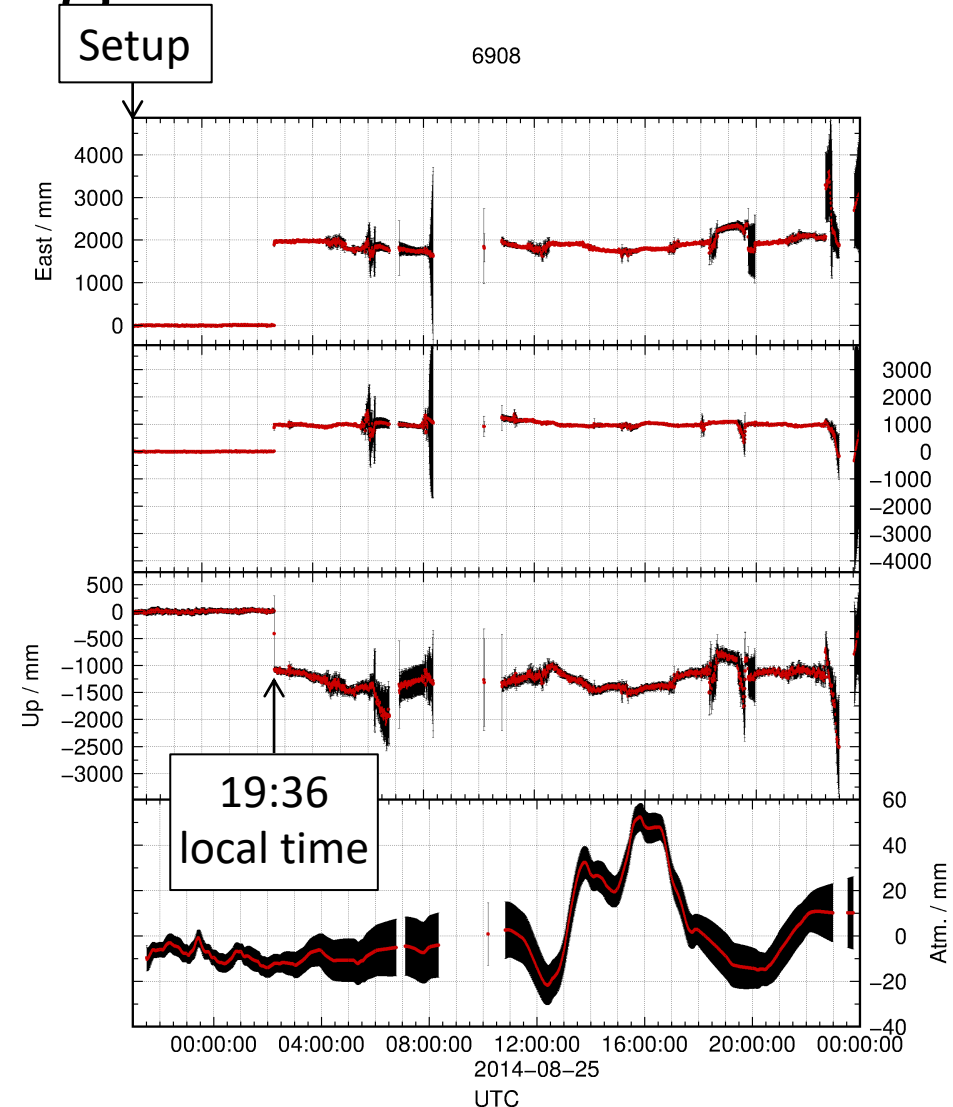
1.2810 m

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

