An incomplete inventory of suspected anthropogenic deformation in North America using InSAR

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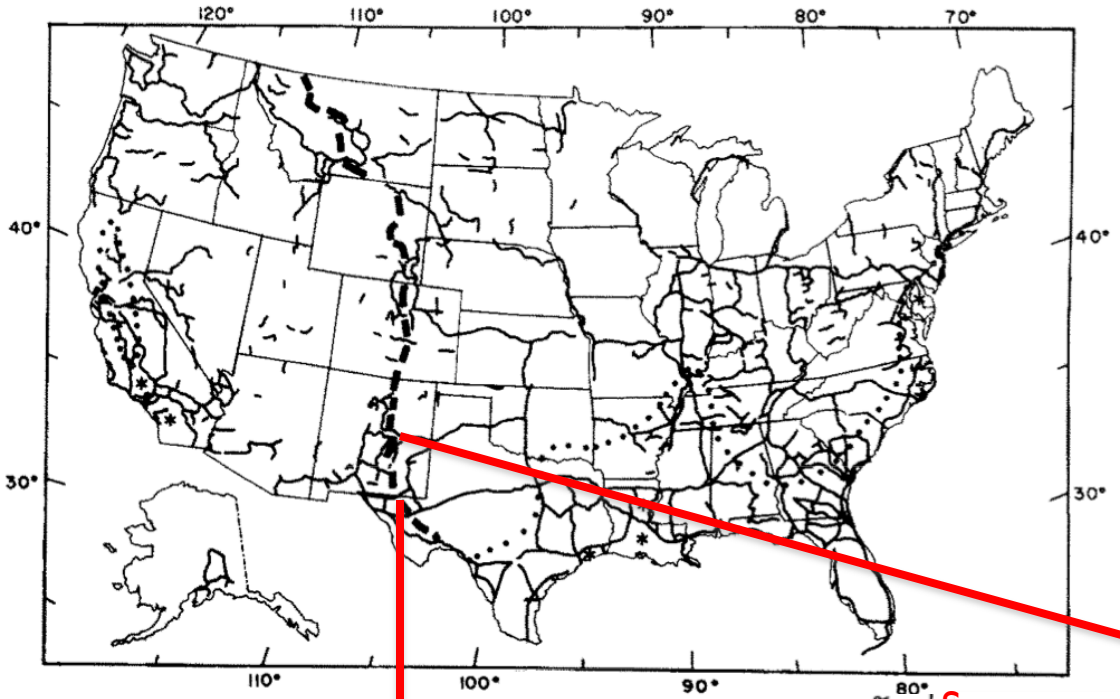
Key points:

- Anthropogenic deformation is interesting in its own right but is also a source of noise for other signals of interest
- > 225 areas of anthropogenic deformation are seen by InSAR
- InSAR works & interesting signals are seen in eastern North America
- The flood of data is here and will continue: need for education and outreach

Funding: NASA & NSF CAREER

Continental-scale deformation in the 1970's

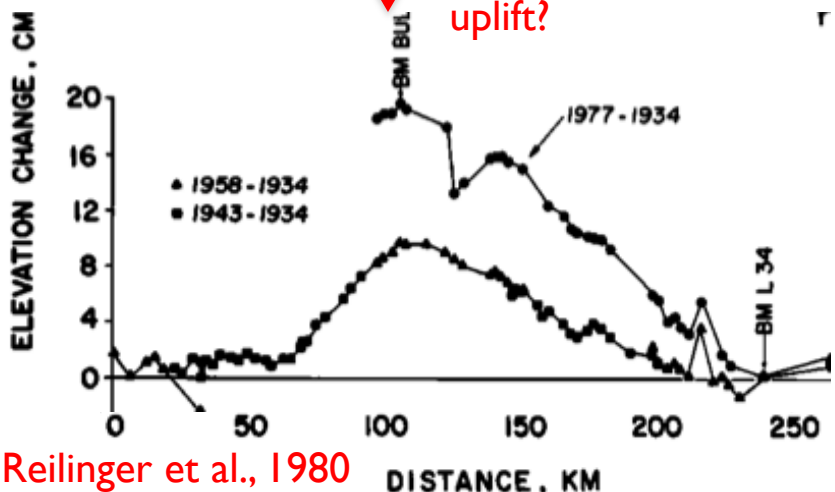


Continental-scale leveling

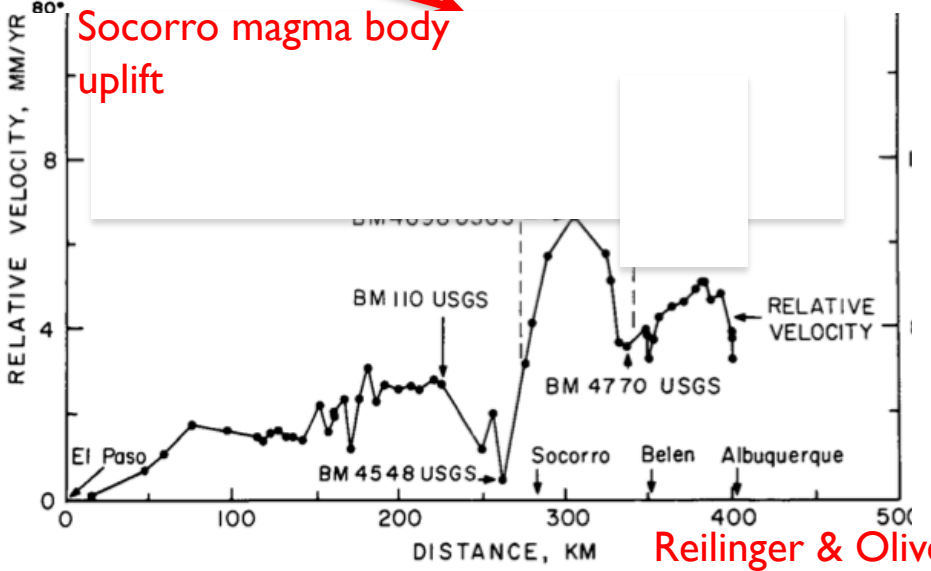
(Reilinger, Bevis, Jurkowski, 1984)

Diablo magma body uplift?

Socorro magma body uplift



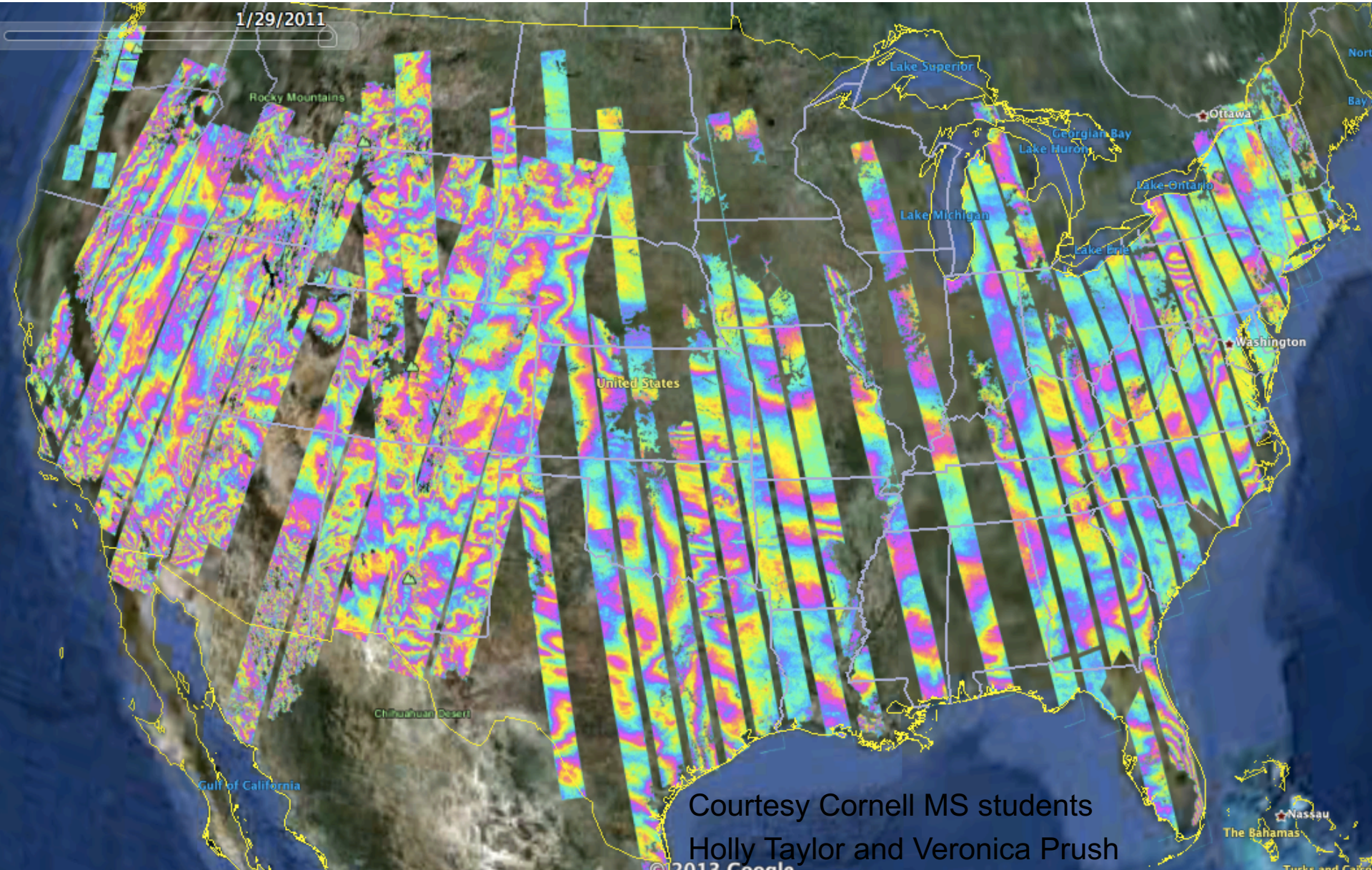
Reilinger et al., 1980



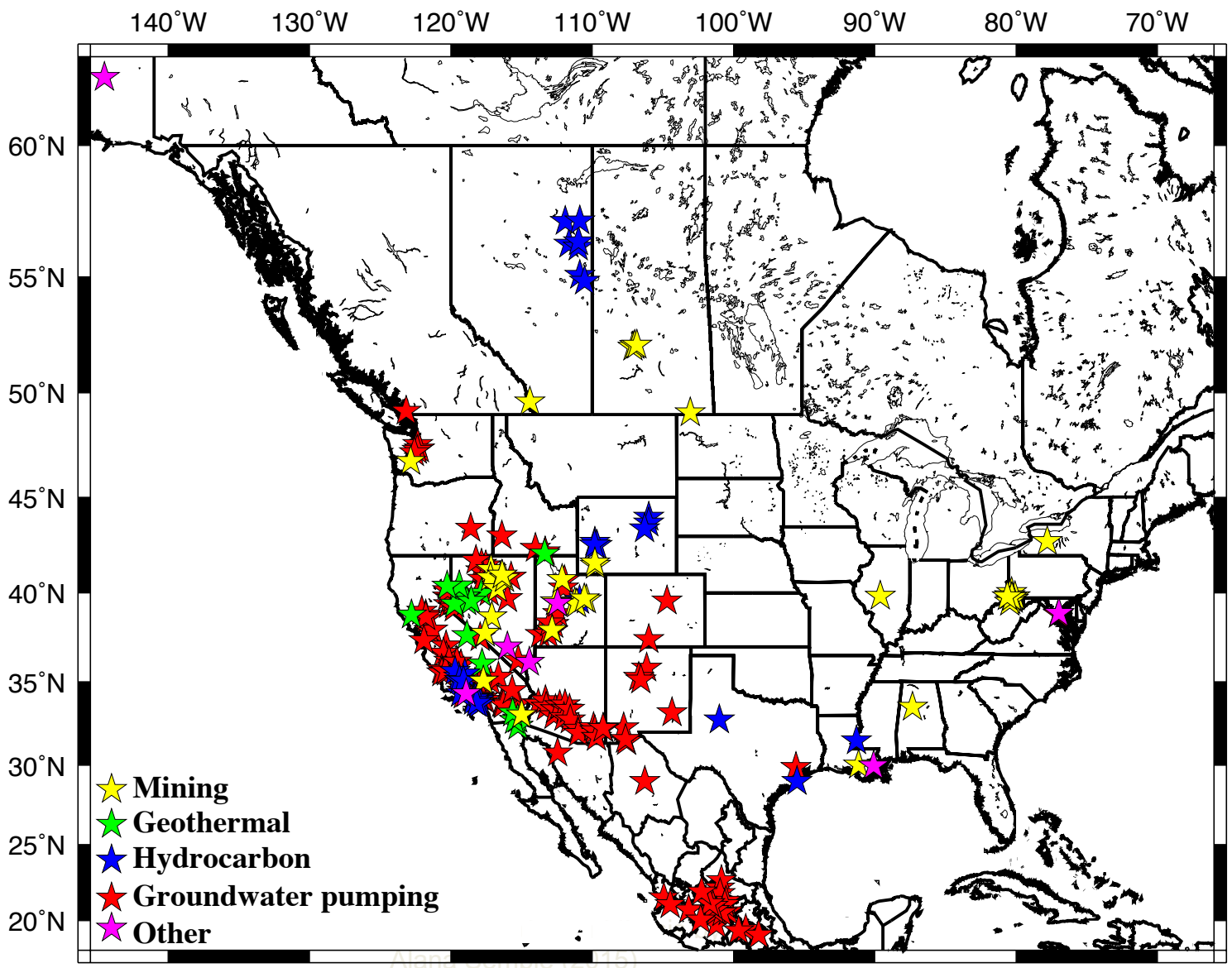
Reilinger & Oliver, 1976

In progress North America interferogram map

Composite map of data from ALOS, Envisat and ERS spanning 1992-2011



Incomplete summary of human-induced deformation



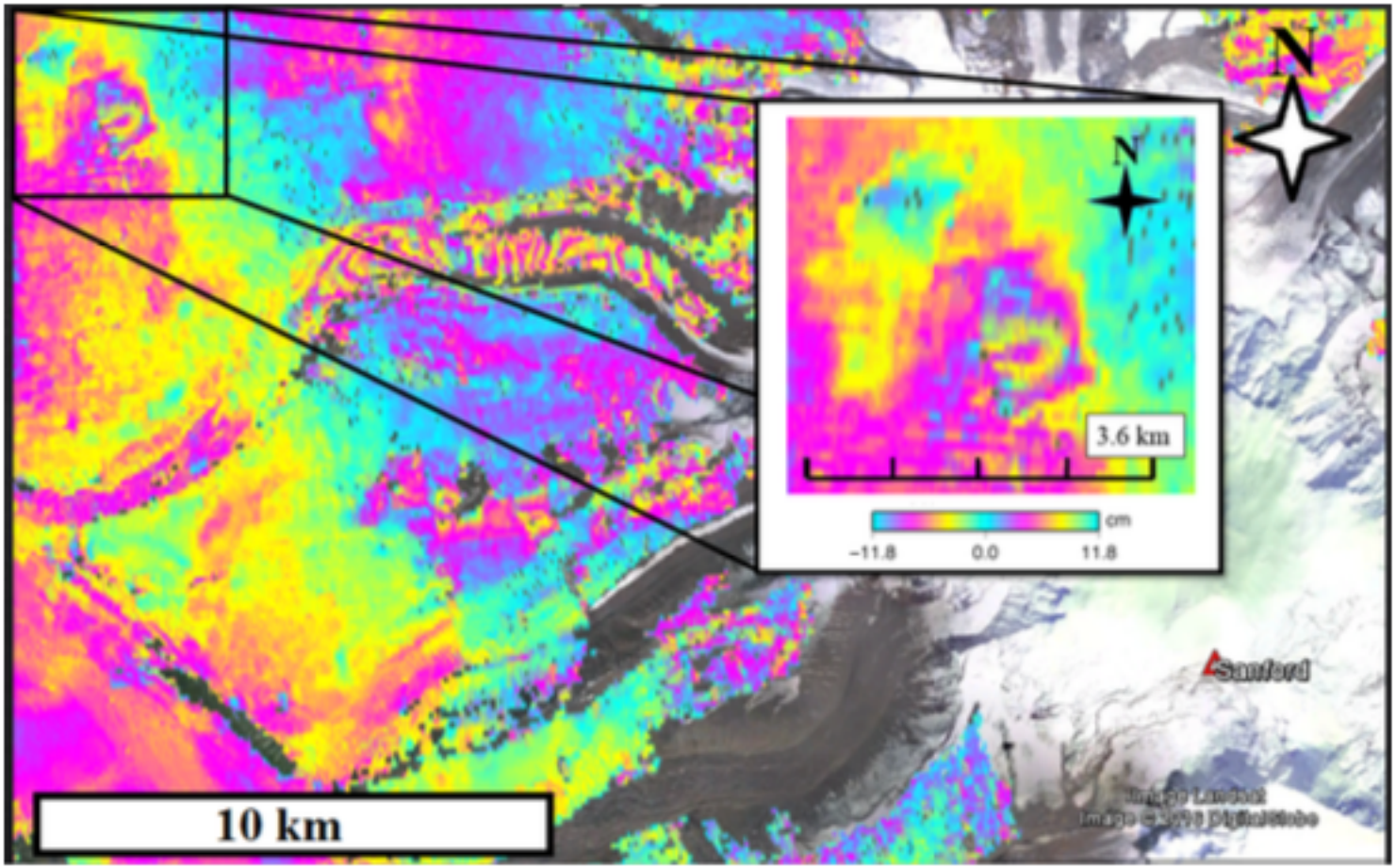
> 227 sites from literature & our analysis

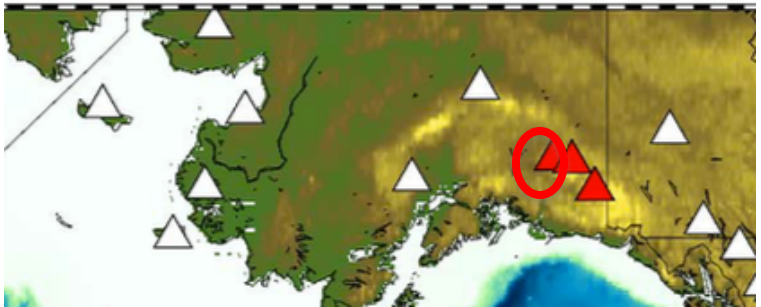
66% from groundwater

46 documented here for the first time

Started by Cornell undergraduate thesis of Alana Semple (2015), now PhD student at Rice University

Unknown deformation near Mount Sanford, Alaska

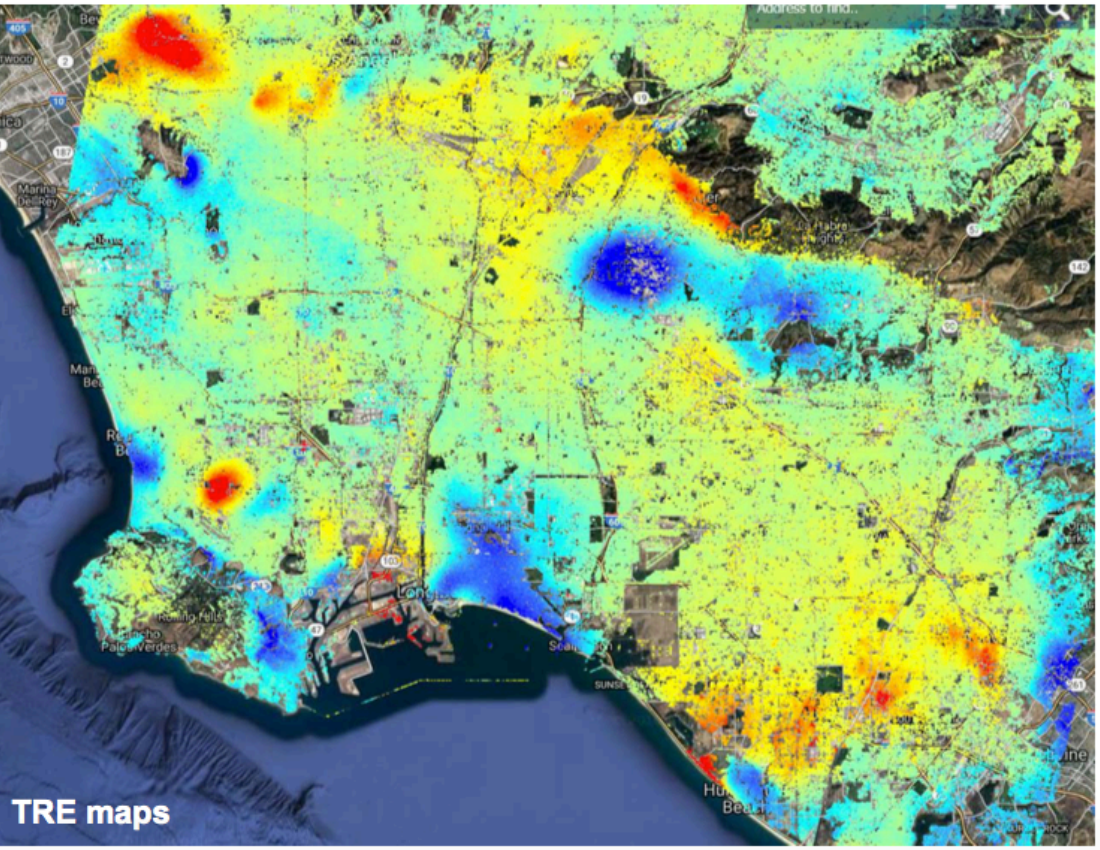




From Maria Furtney, M.S. thesis, Cornell

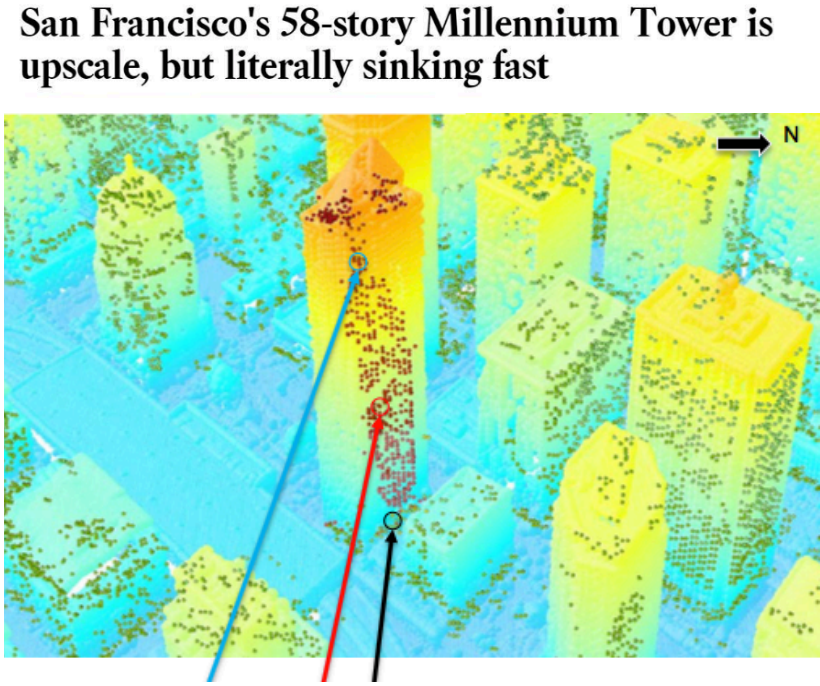
Multiple deformation sources in urban areas

Los Angeles



Impact on GPS in LA; Bawden et al., 2001; Watson et al., 2001; Argus et al., 2005; etc.

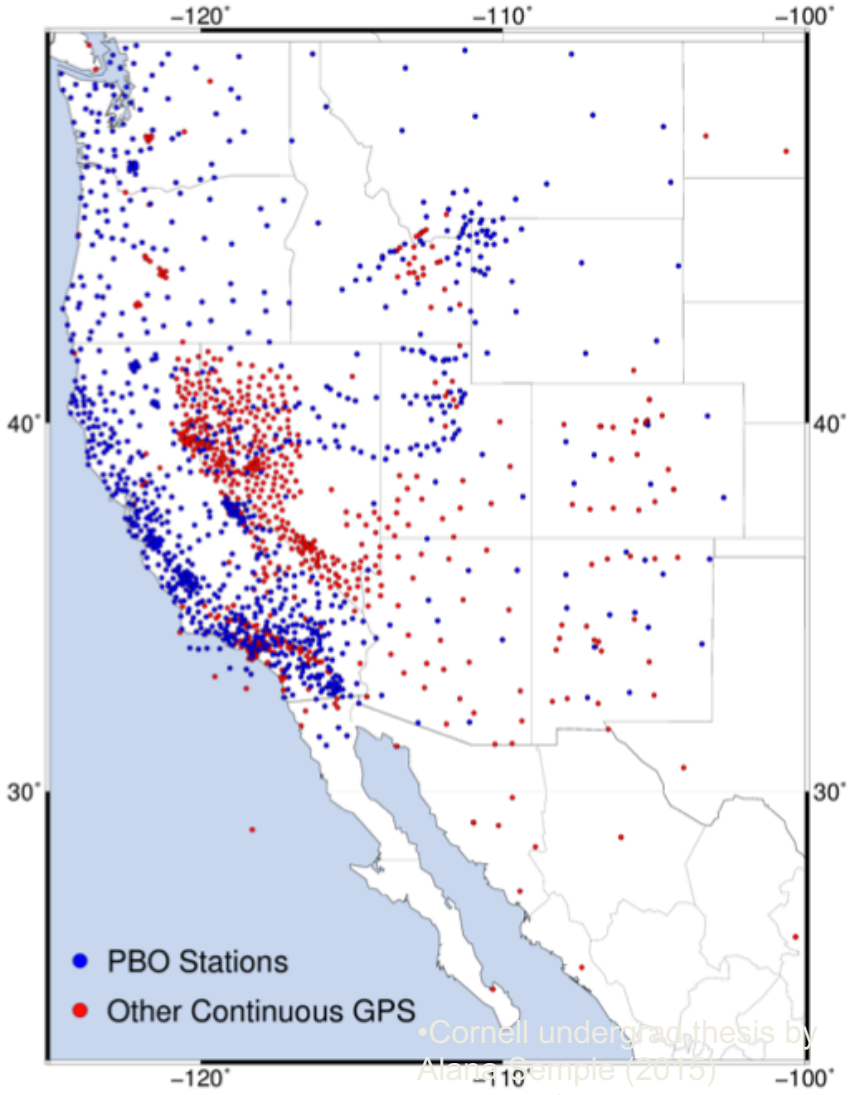
Millennium tower, San Francisco



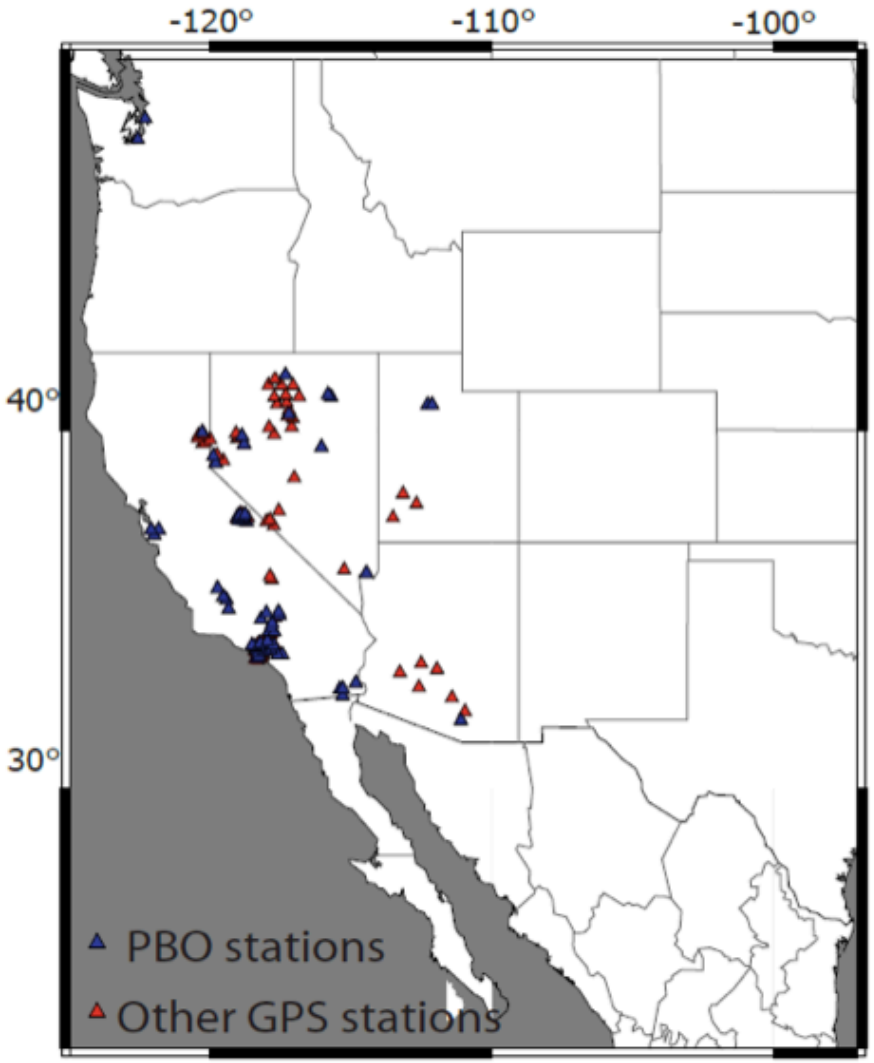
Courtesy Vicky Hsiao, TRE Canada

Impact on PBO & other GPS sites

1100 GPS sites



82 sites within 20 km of anthropogenic deformation

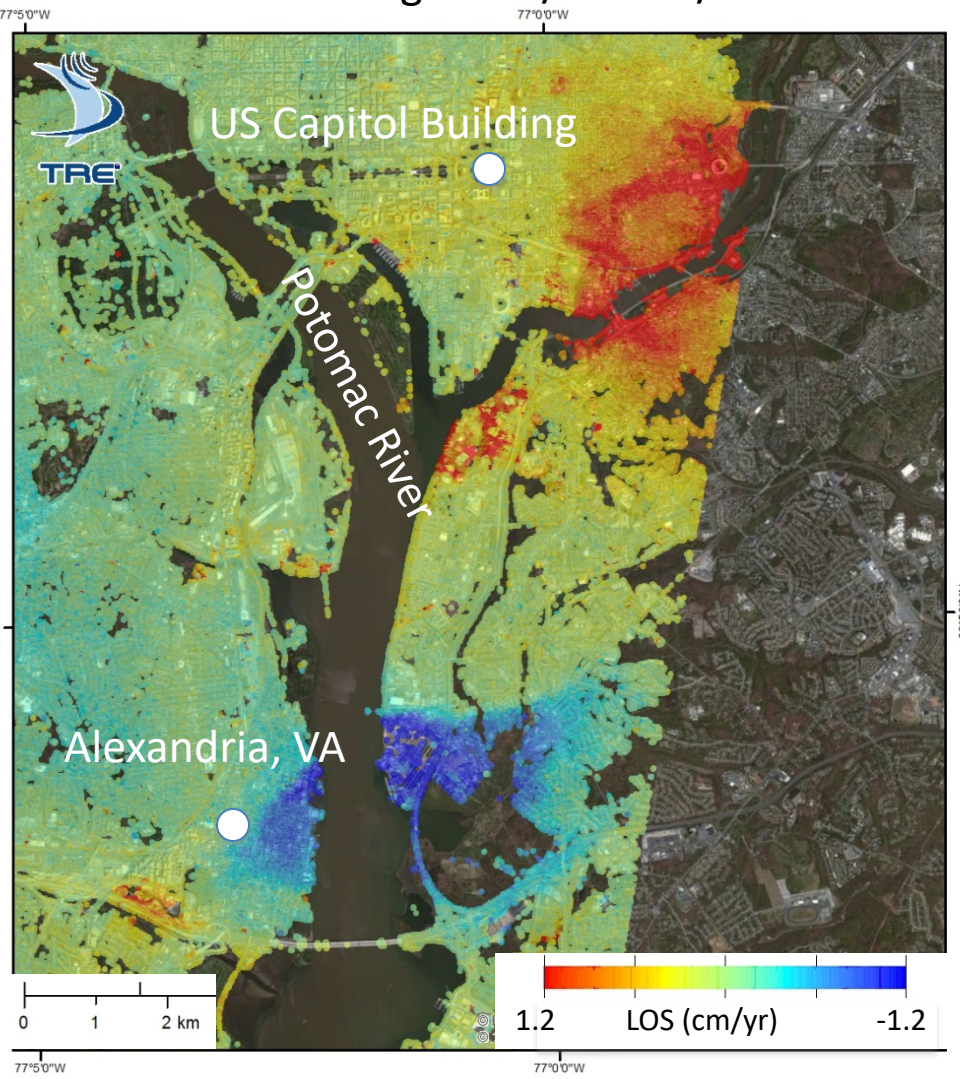


•Cornell undergrad thesis by Alana Semple (2015)

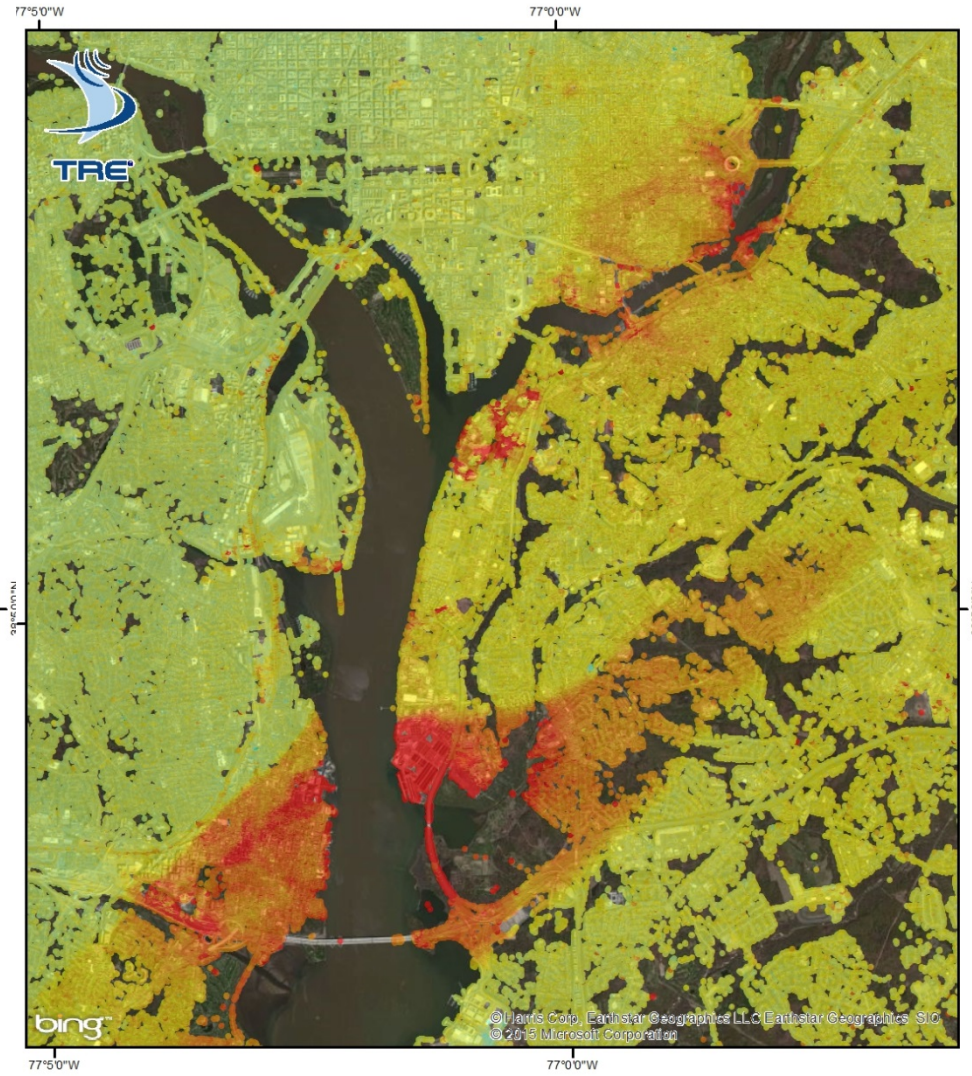
See also work by Bawden et al., 2001; Gourmelen et al., 2007, etc.

Newly identified signals in Washington, DC, Virginia & Maryland

Descending CSK 3/2014-6/2015



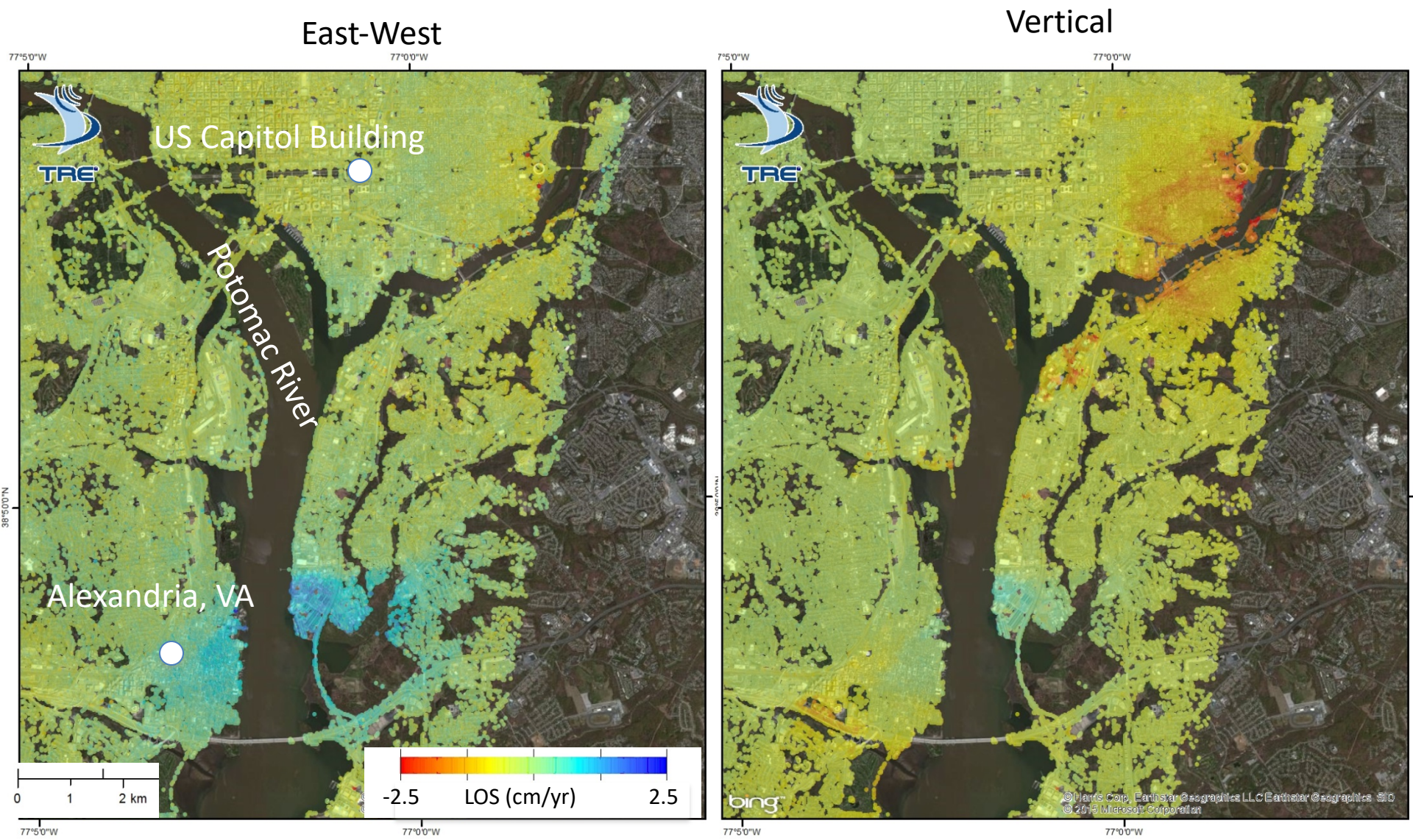
Ascending CSK 2/2013-8/2015



Courtesy: TRE Canada; Ed Hoppe, Virginia Department of Transportation; Scott Acton, University of Virginia

Funded by US Department of Transportation, Research and Innovative Technology Administration (RITA)

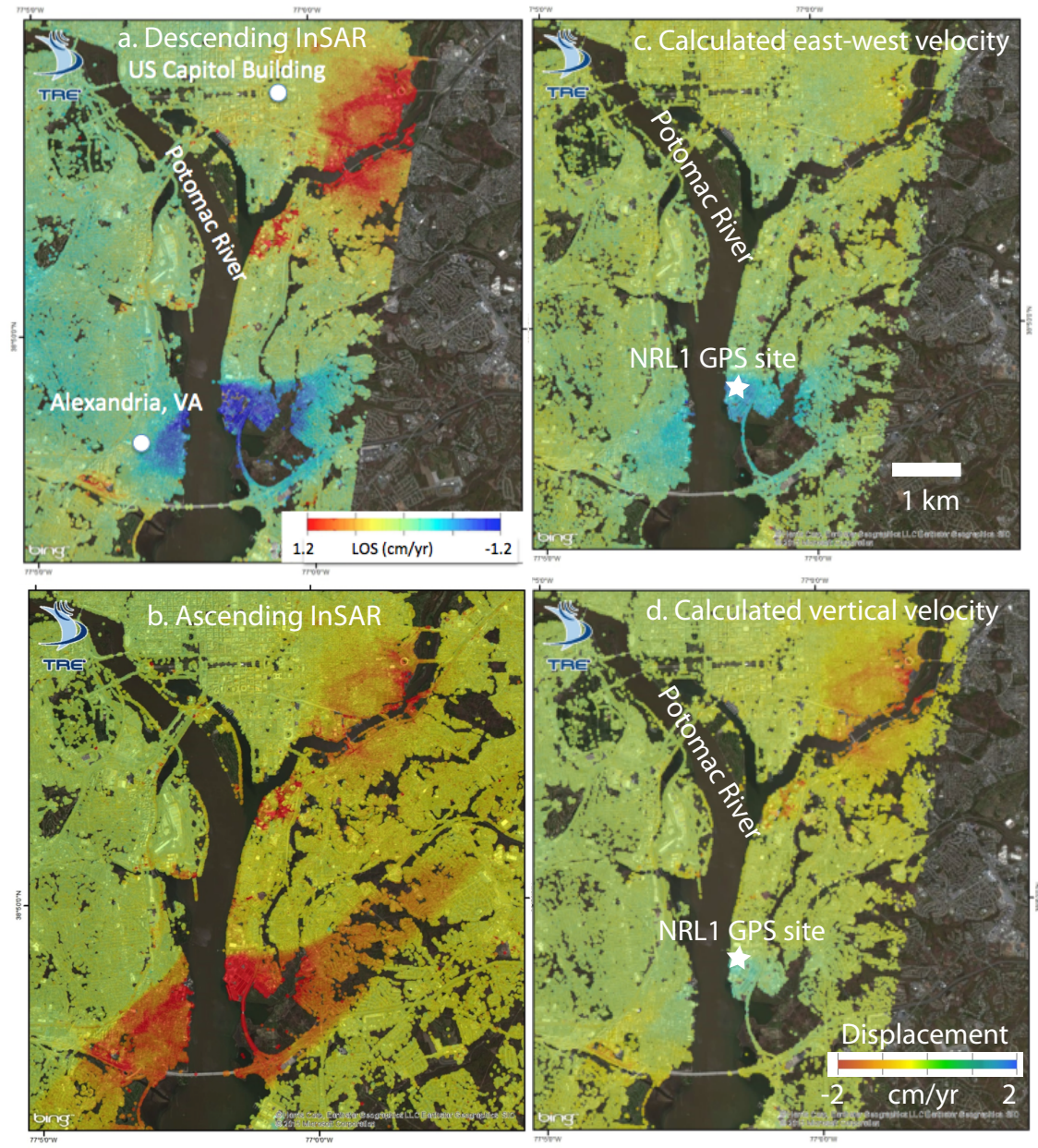
Newly identified signals in Washington, DC, Virginia & Maryland

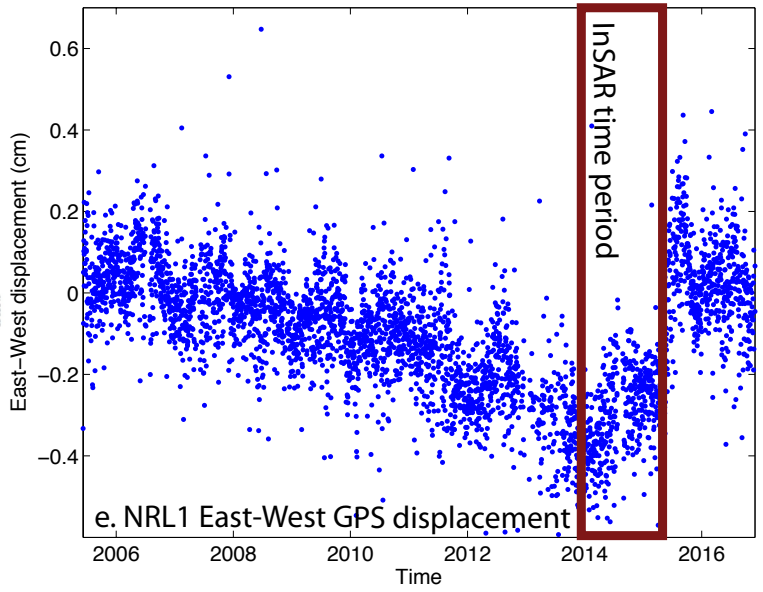


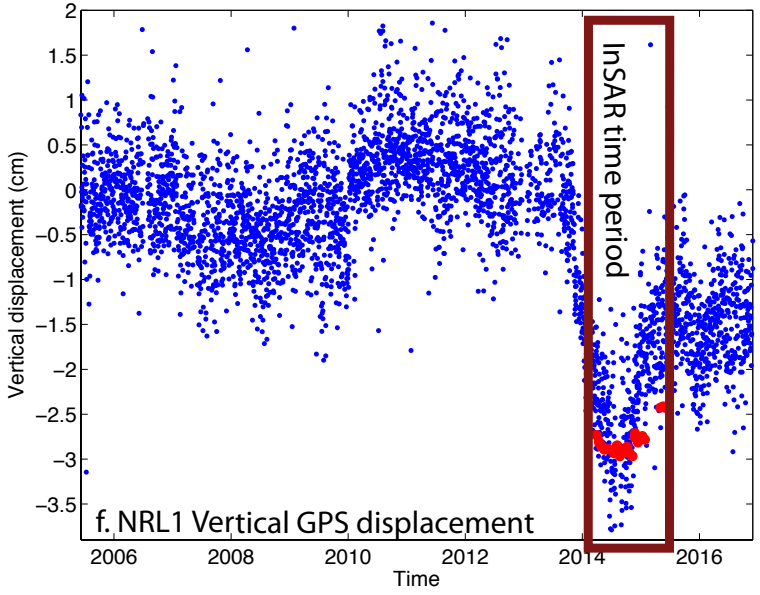
Courtesy: TRE Canada; Ed Hoppe, Virginia Department of Transportation; Scott Acton, University of Virginia

Funded by US Department of Transportation, Research and Innovative Technology Administration (RITA)

GPS signal from Naval Research Lab



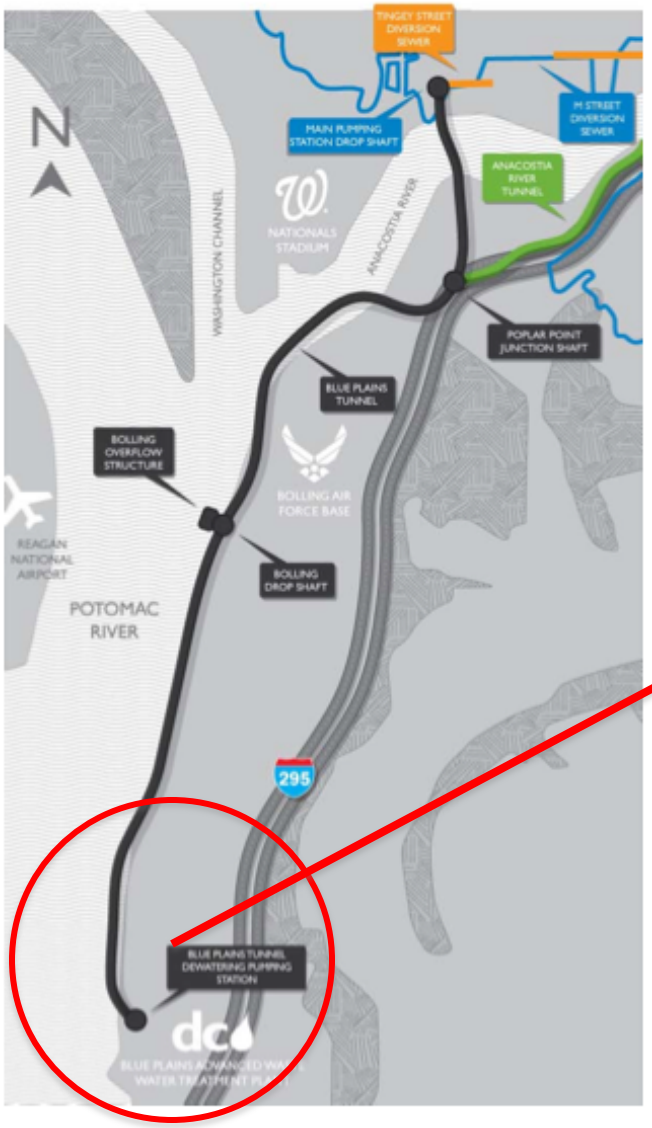




GPS data processed by
University of Nevada, Reno

What is the cause of the deformation?

DC Water & Sewage Authority Blue Plains Tunnel



From: DC Clean Rivers Project

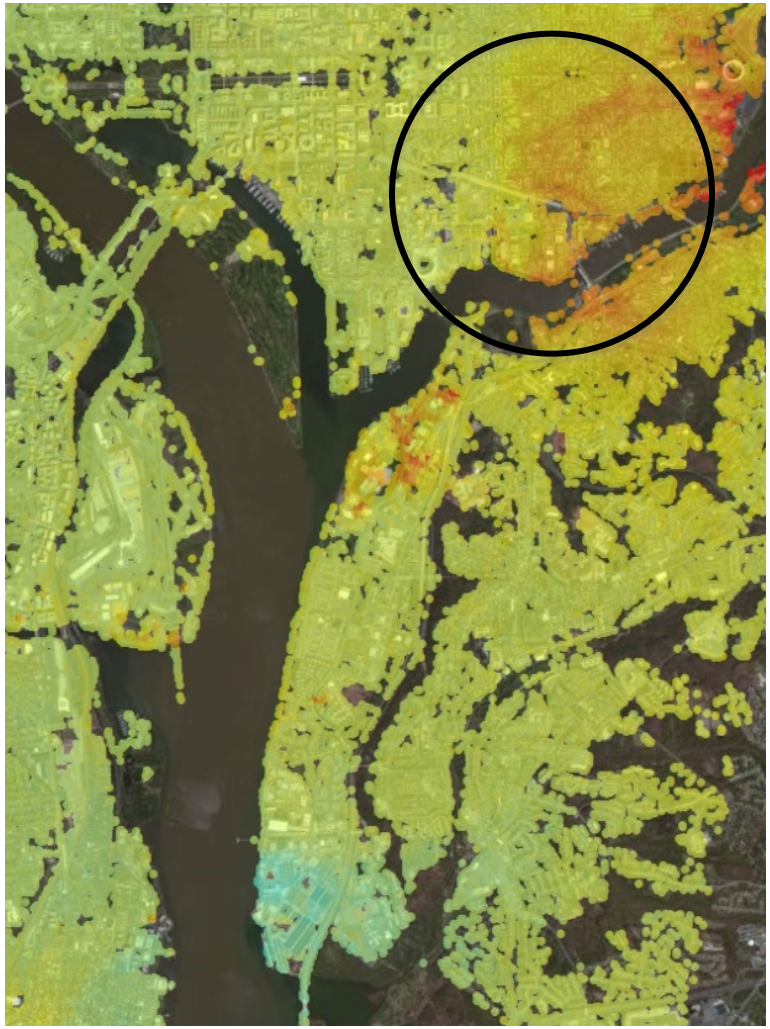
From: ENR.com

What is the cause of the deformation?

DC Water & Sewage Authority Blue Plains Tunnel

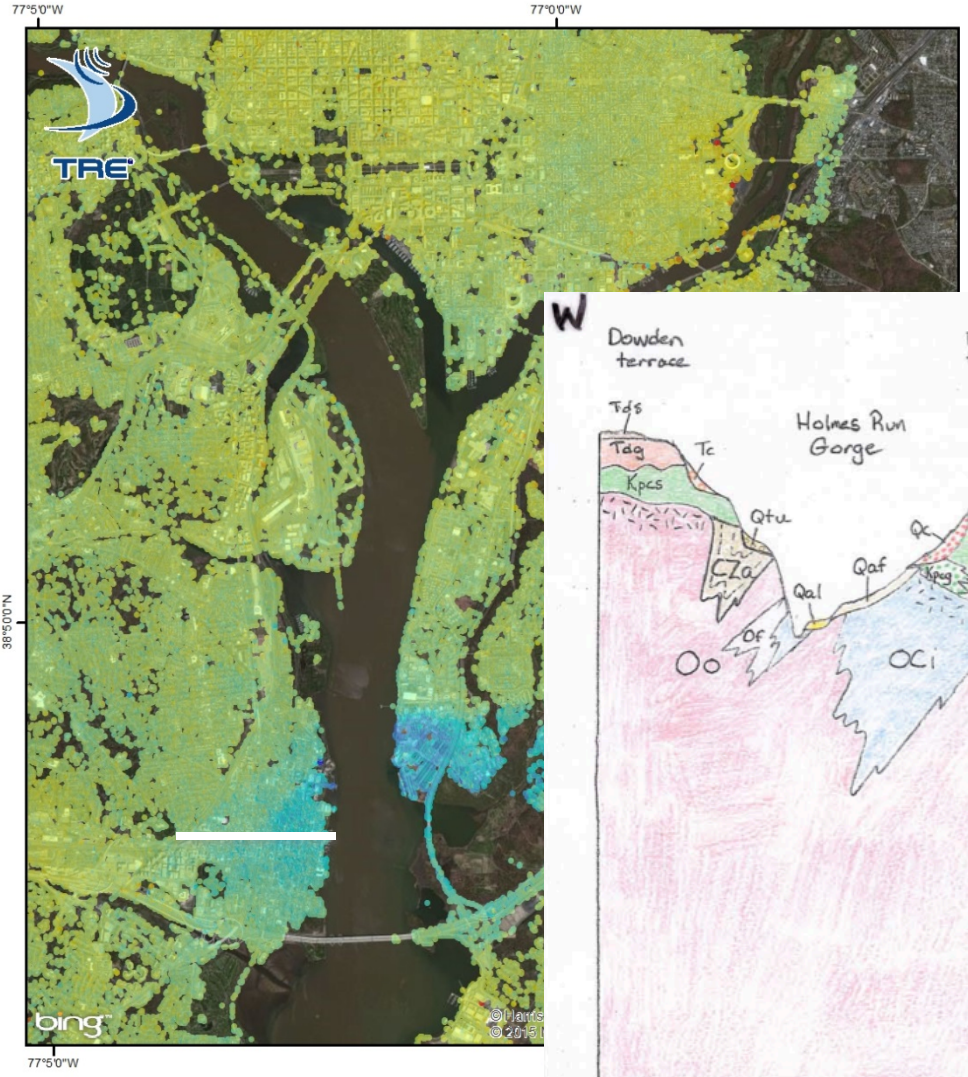
From: DC Clean Rivers Project

Vertical

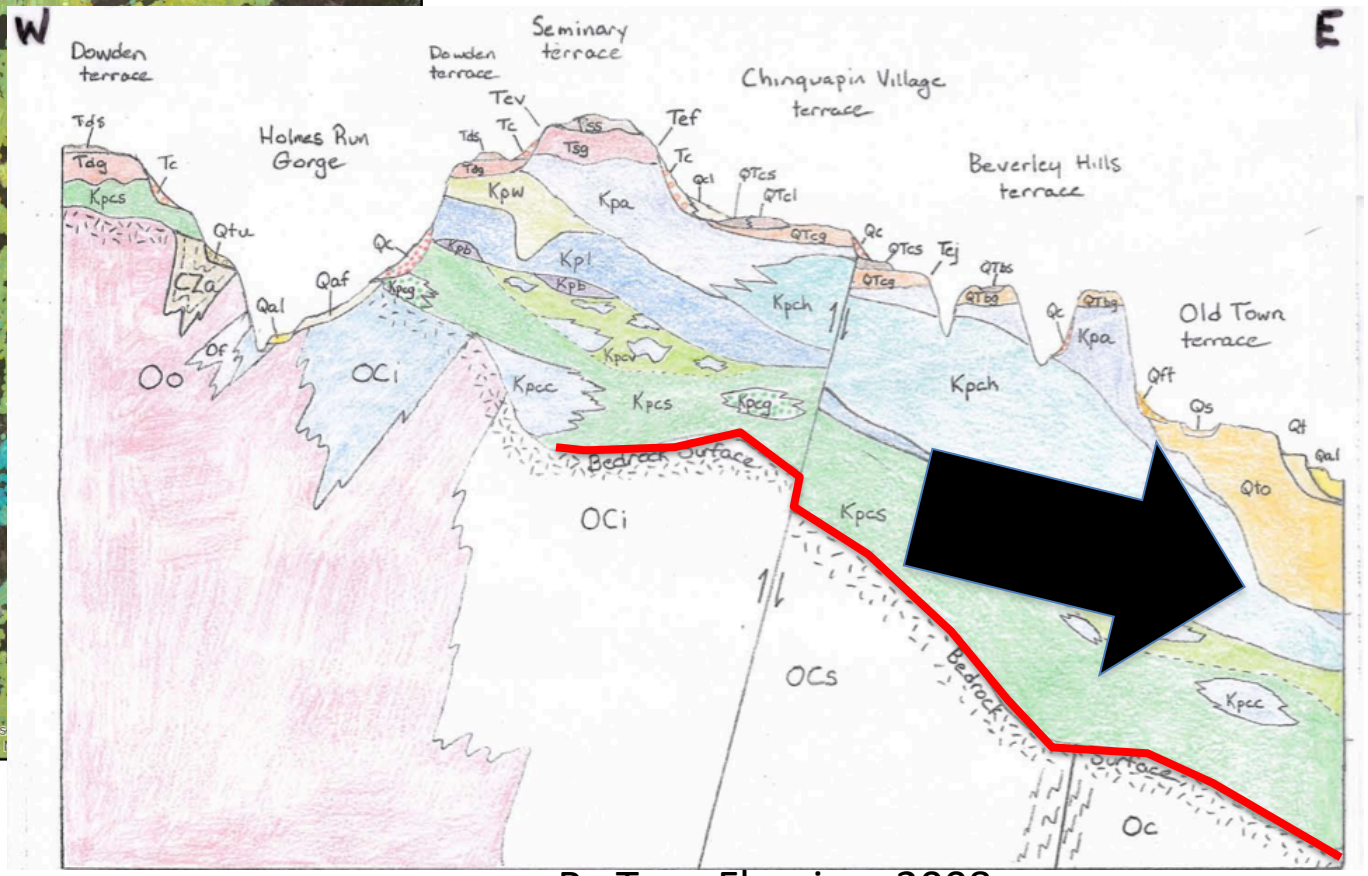


What is the cause of the deformation?

East-West

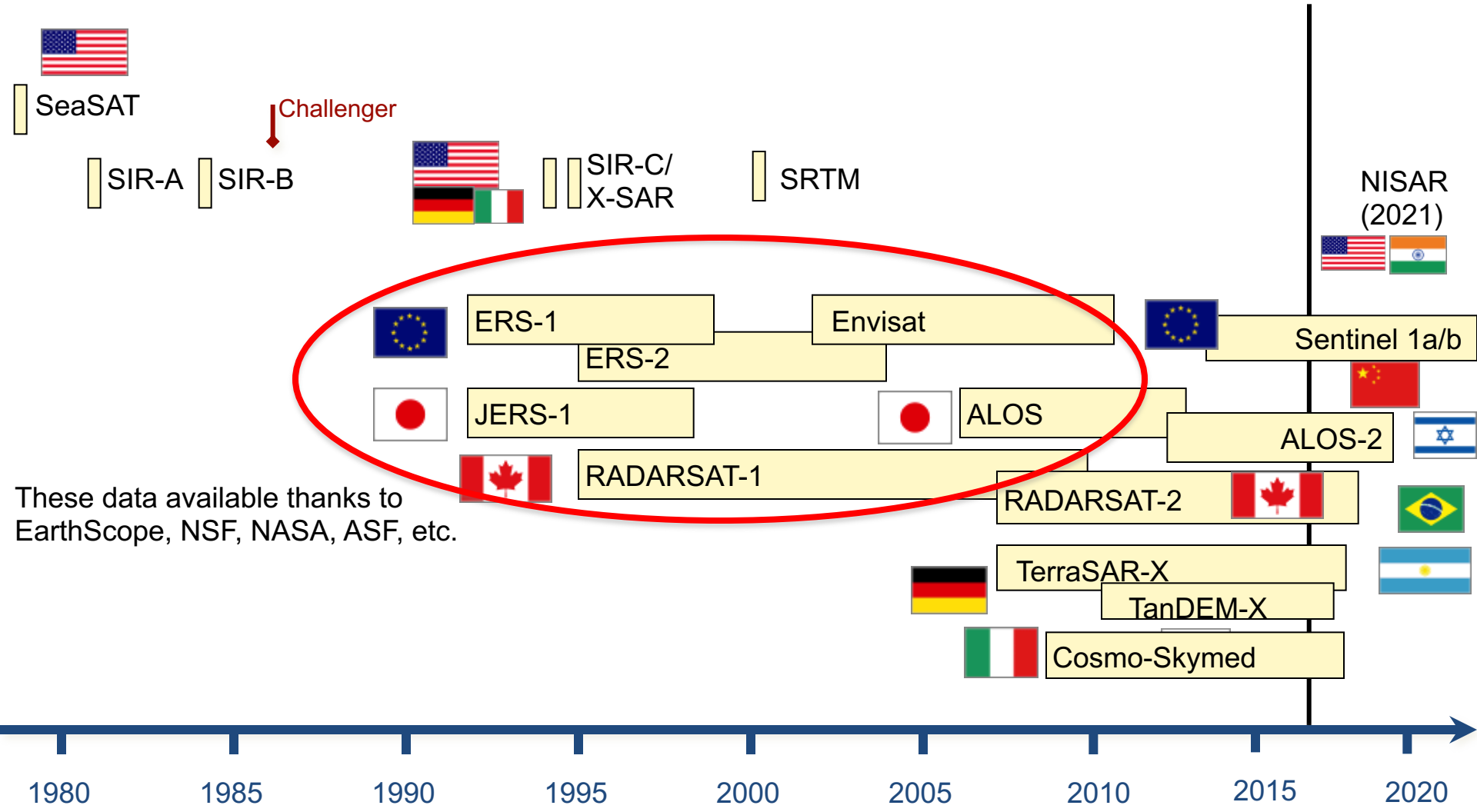


Geologic cross-section of Alexandria Virginia



By Tony Fleming, 2008

InSAR missions for science

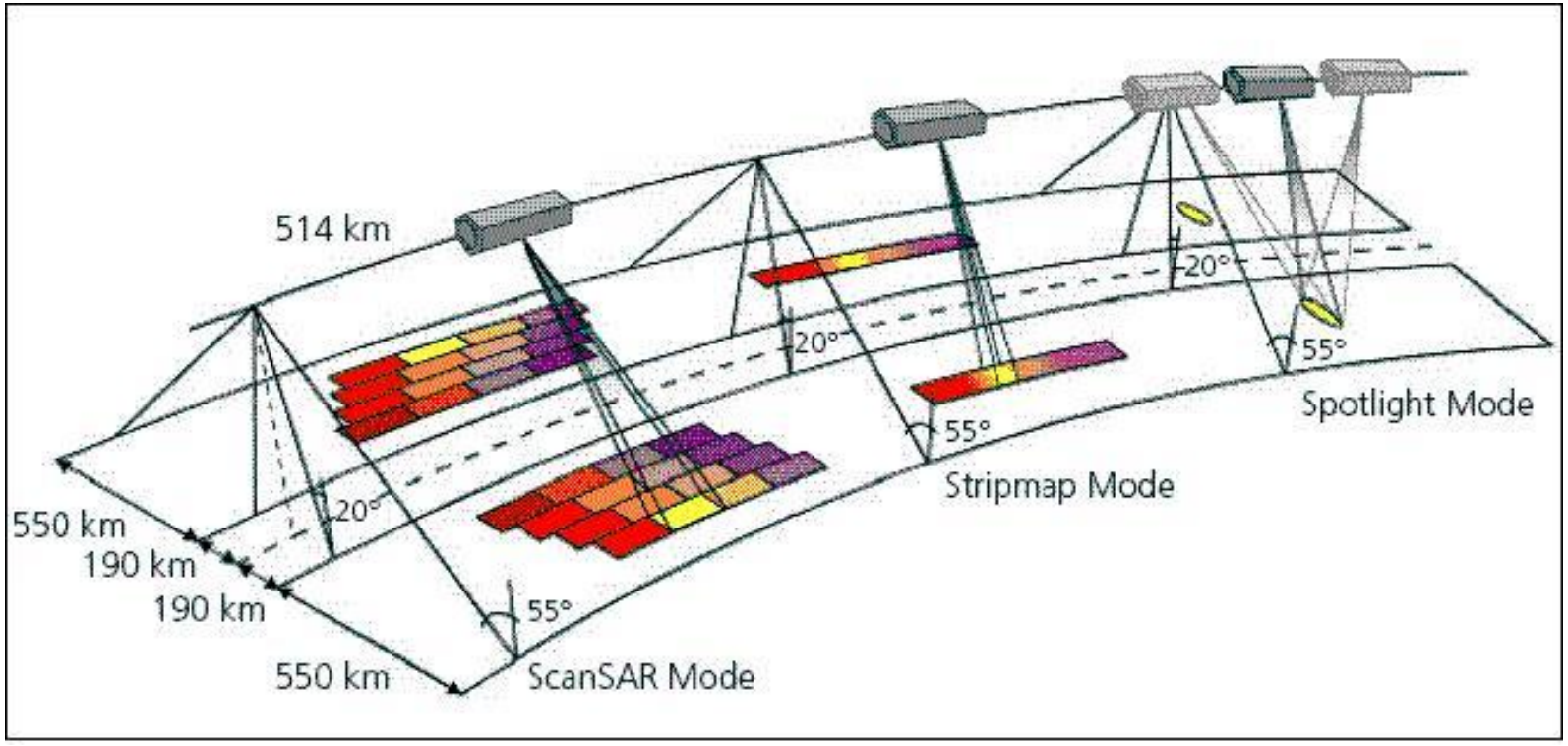


These data available thanks to
EarthScope, NSF, NASA, ASF, etc.

From: Paul Rosen, JPL

Why so many satellites?

A range of applications, radar wavelengths, and observation modes

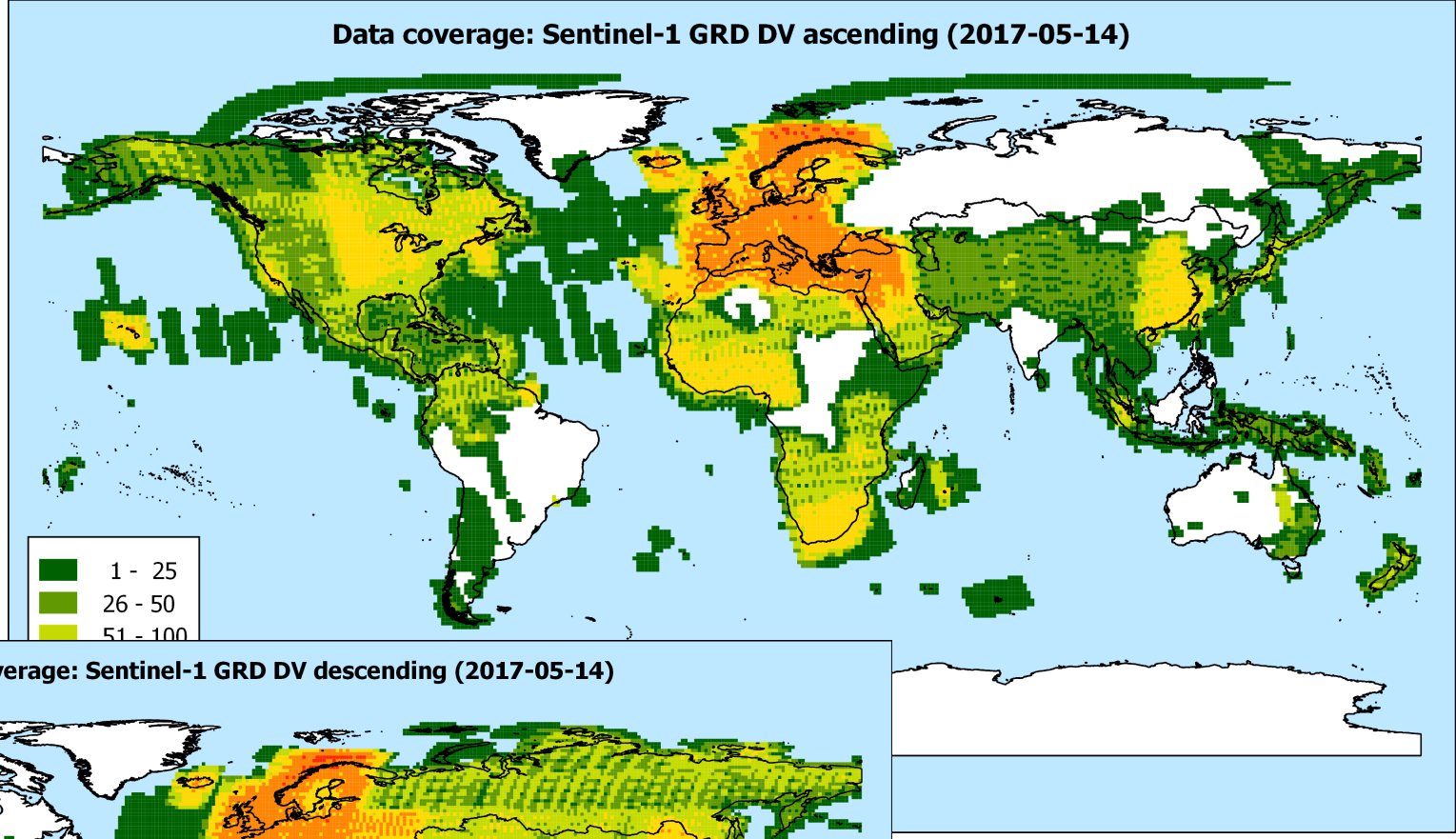


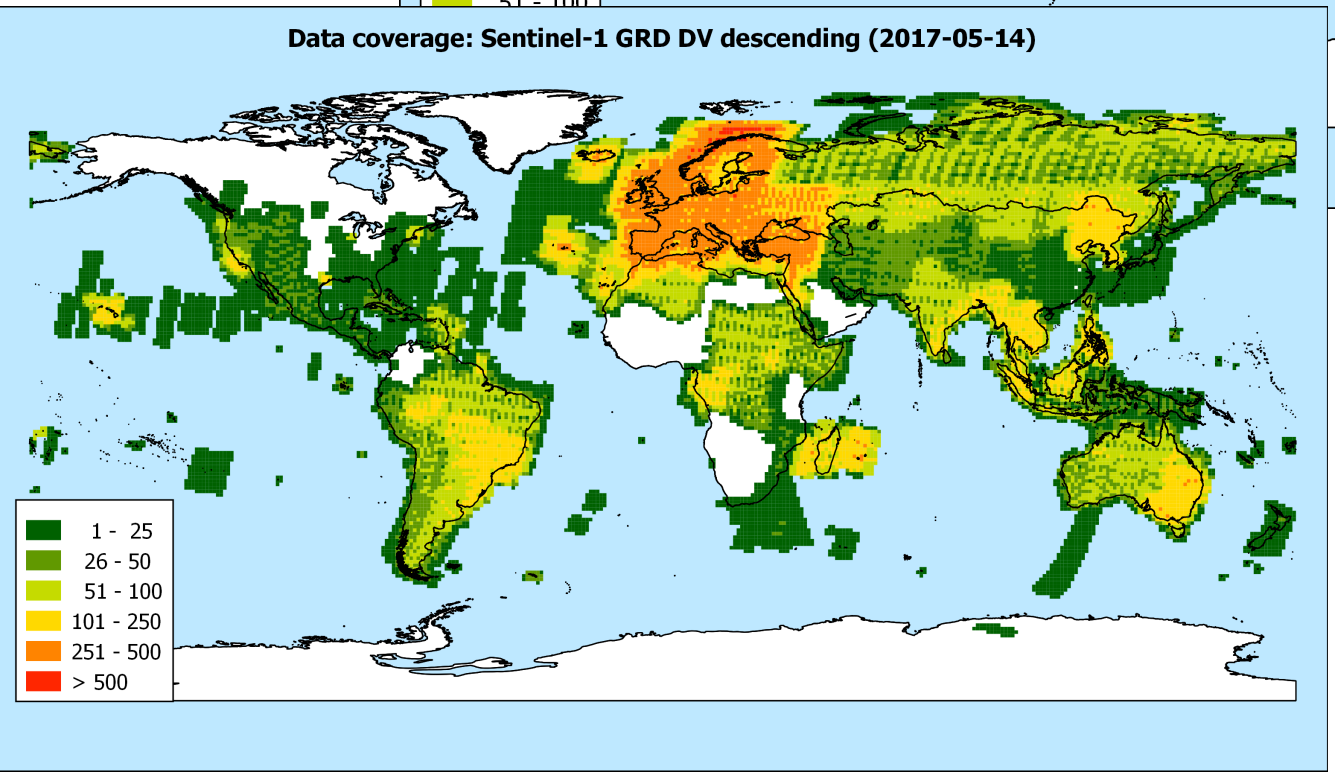
Many of the missions

1) do not have global data coverage
2) the data are expensive

But 2 missions have an open data policy

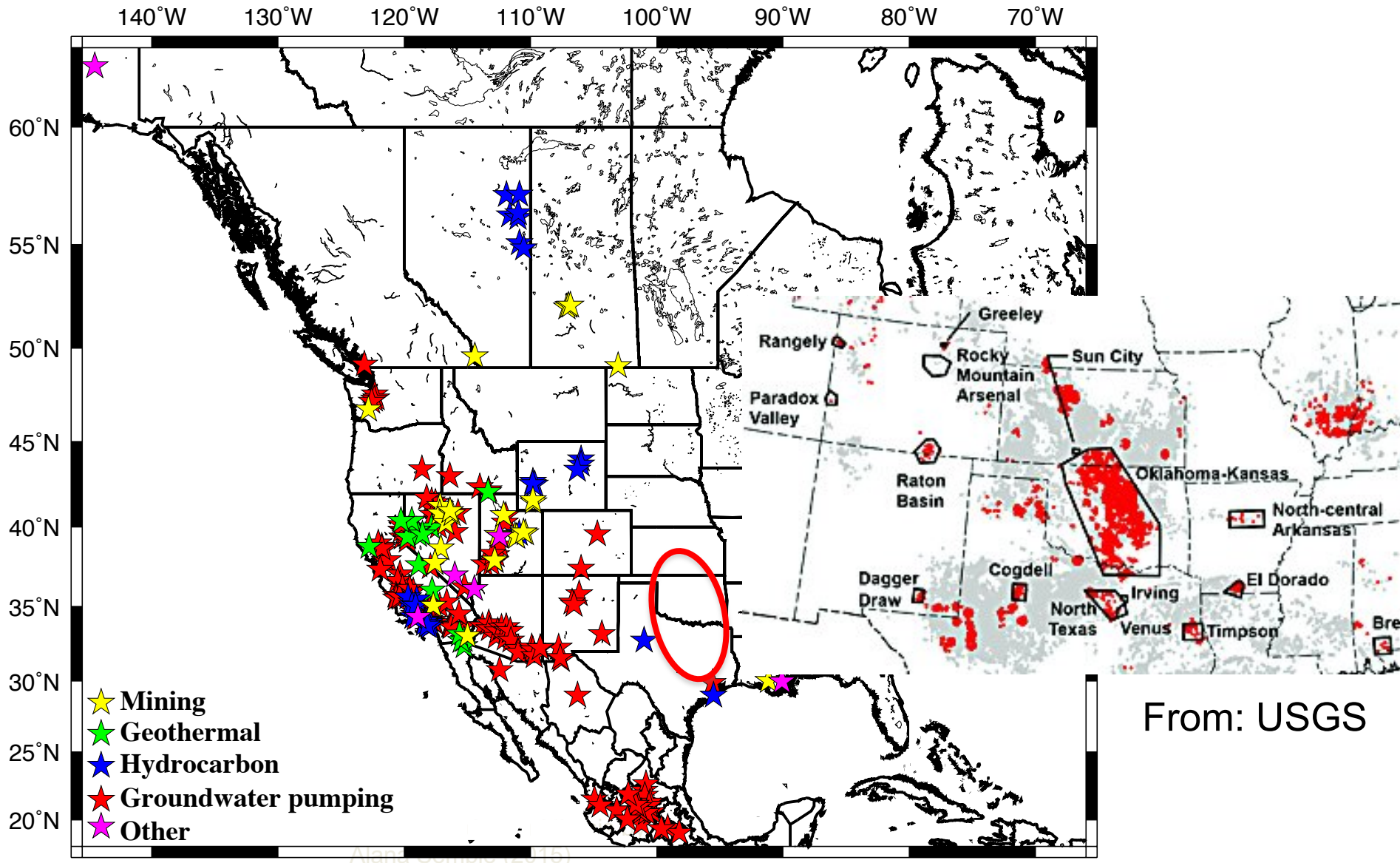
Sentinel-1 data **now** at Alaska Satellite Facility





Courtesy Franz Meyer, University of Alaska, Fairbanks

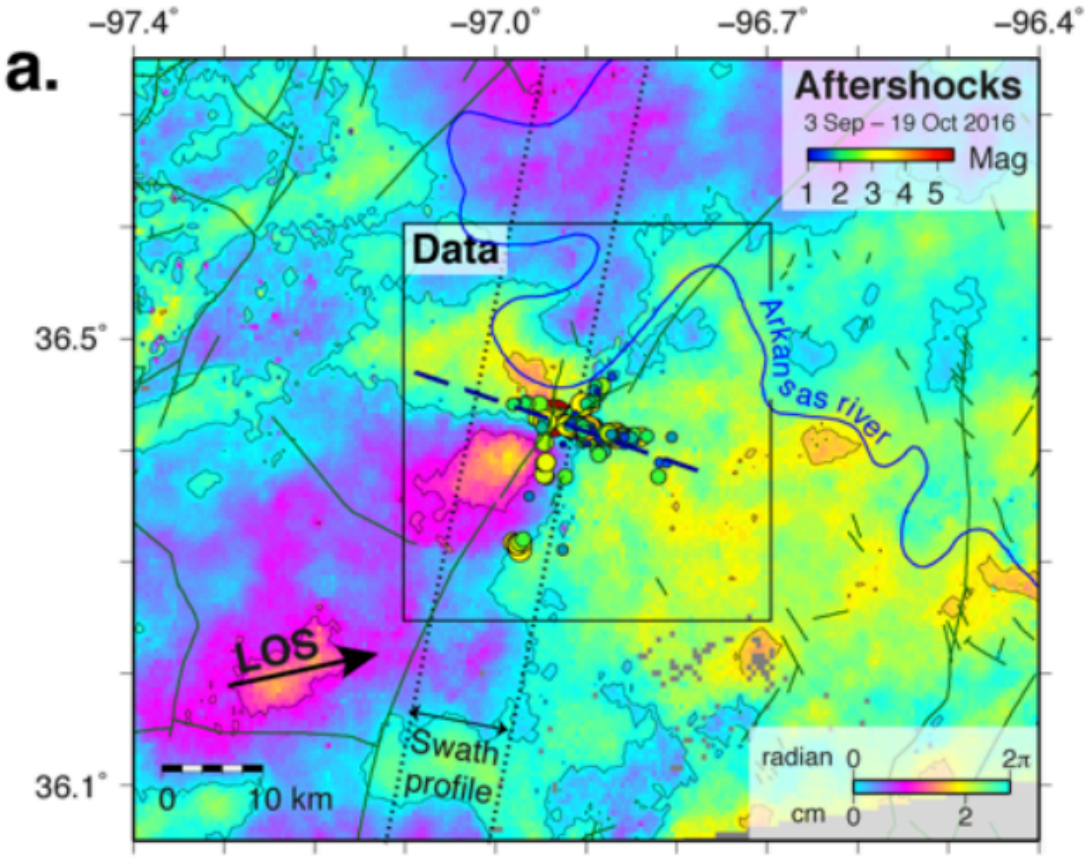
Signature of wastewater injection?



From: USGS

What can we do now that we couldn't before?

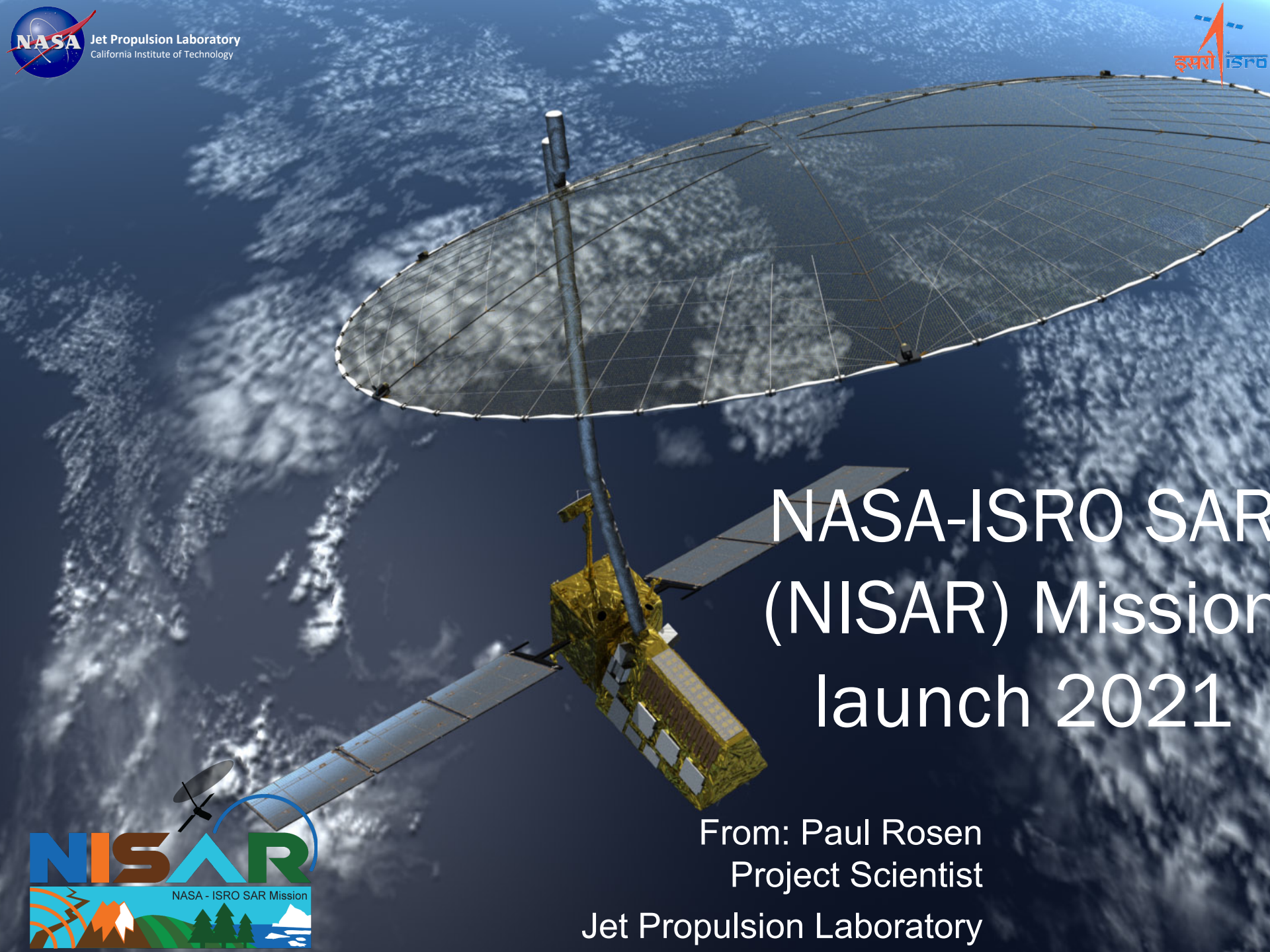
Mw 5.8 Pawnee, OK earthquake: Sept. 3, 2016



Grandin et al., 2017

But no convincing evidence yet for deformation from injection in OK/TX:

1. Is available InSAR sensitive enough?
2. What is the magnitude of deformation in the porous sedimentary cover?

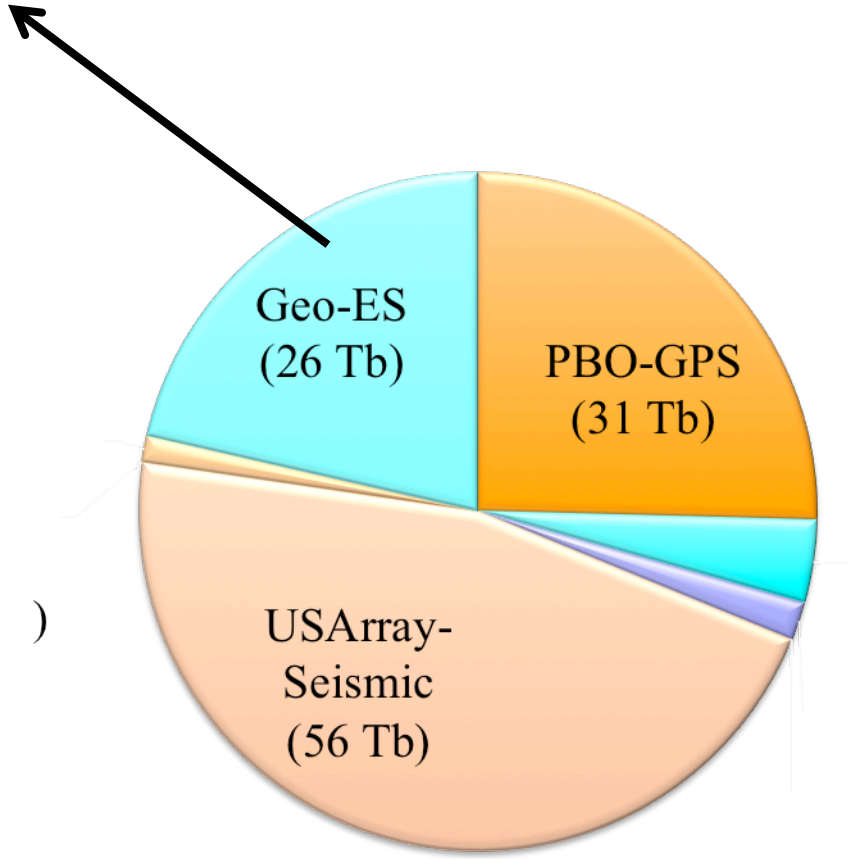


NASA-ISRO SAR (NISAR) Mission launch 2021

From: Paul Rosen
Project Scientist
Jet Propulsion Laboratory

Earthscope data holdings (Sept. 2013): 121 Tb

~300 Tb Earthscope relevant data at Alaska Satellite Facility



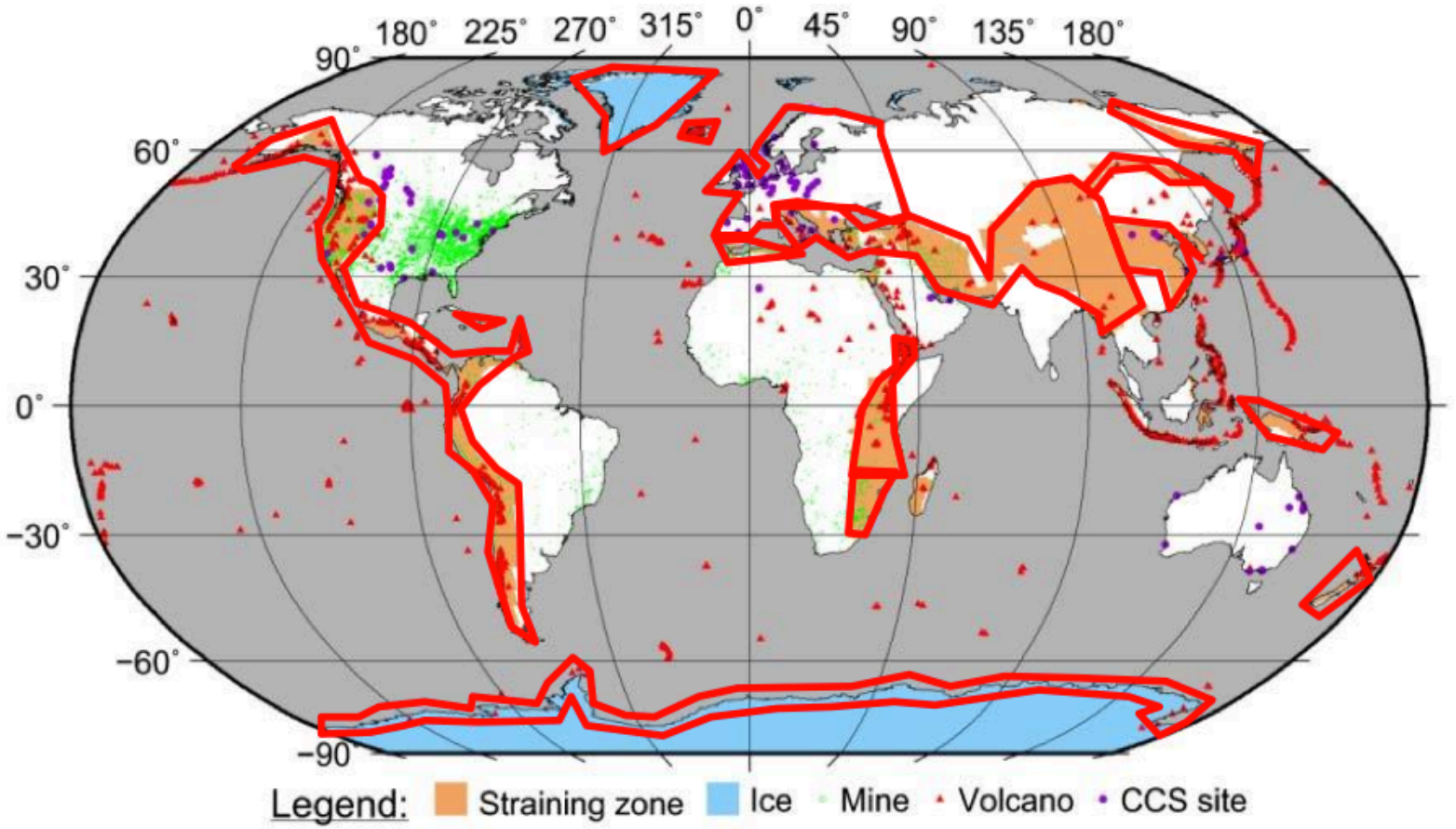
The future:

Sentinel: 1-2 Tb/day raw data

NISAR: 2.5 Tb/day raw data

Processed products 10's of petabytes/year

How to deal with the data volume?
Routine processing plan from COMET (UK), also JPL and ASF



Global Tectonics: 55 Mkm^2 Ice: 5 Mkm^2
Europe: 10 Mkm^2

Total: 70 Mkm^2

From: Tim Wright (Leeds)

Data throughput = 0.5 TB/day [~1PetaByte over 5 years]

Opportunities for Education and Outreach

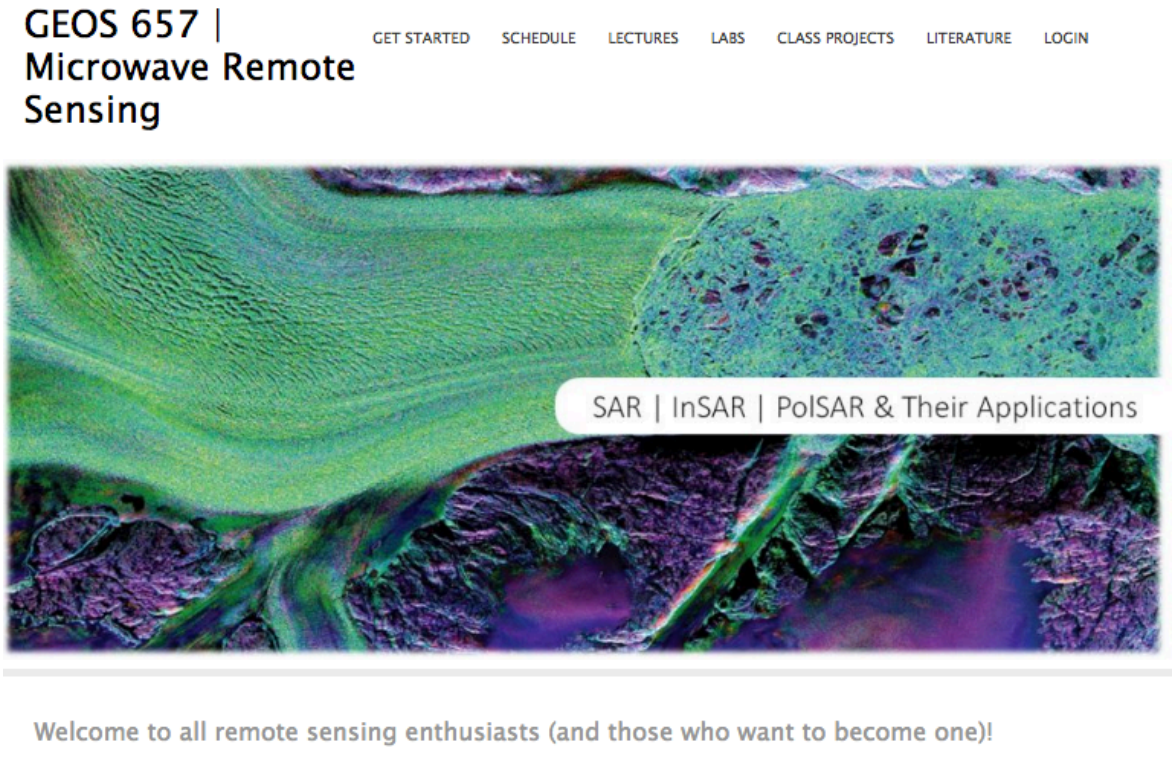
- GETSI: Geodesy Tools for Societal Issues: http://serc.carleton.edu/getsi

- Short courses (1-3) days: In 2017: at UNAVCO, UCSD, IAVCEI

- Online courses: UAF, others

- Online GUI tool:
ESA's Sentinel Application Platform (SNAP – http:// step.esa.int/main/toolboxes/snap/

- You don't have to process your own data – processed interferograms are available (geo-gateway.org UNAVCO, COMET, others) and will become more so In the future…



Conclusions

InSAR complements other efforts to document anthropogenic effects in western US
(perhaps 7% of GNSS sites effected)

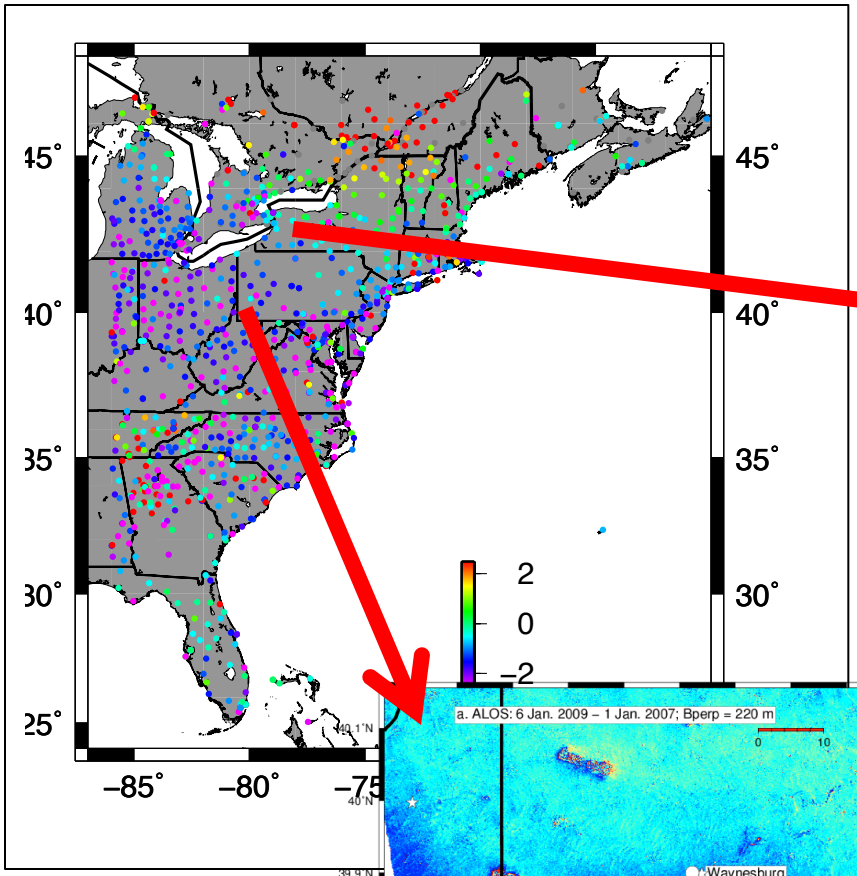
-measurable deformation is also occurring in eastern North America -- anthropogenic and more

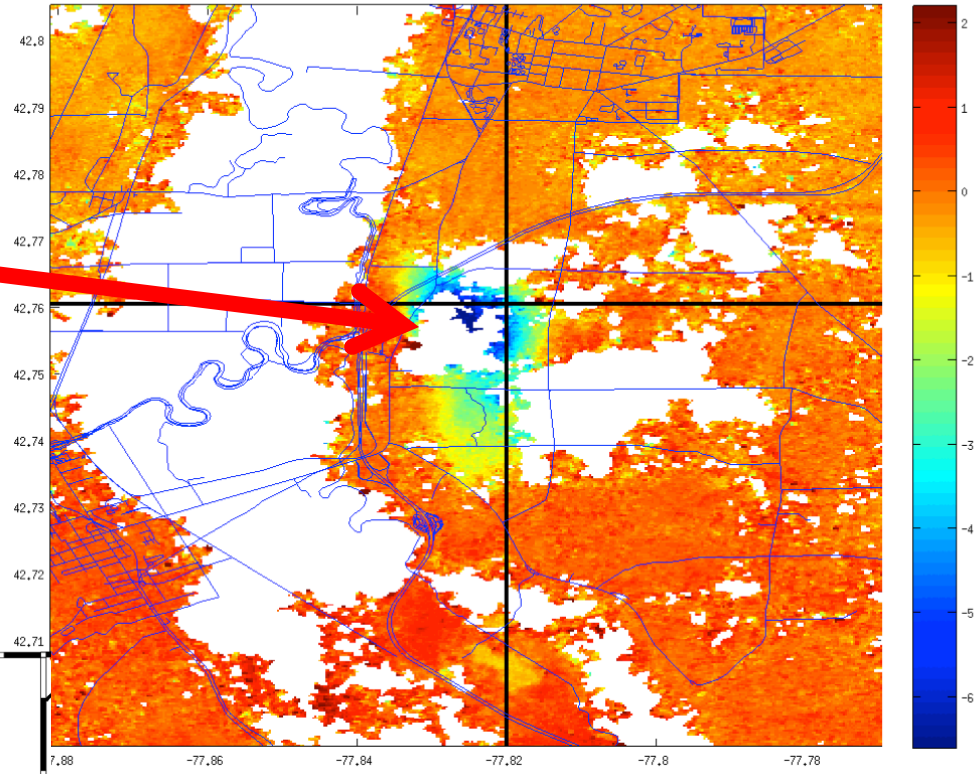
-InSAR can detect deformation in eastern North America (& GNSS if we are lucky)
NY, PA, WV mine subsidence, IL and OK earthquakes, DC/VA/MD mystery

-There is a huge amount of data that no one is looking at: Opportunity for Education and outreach:

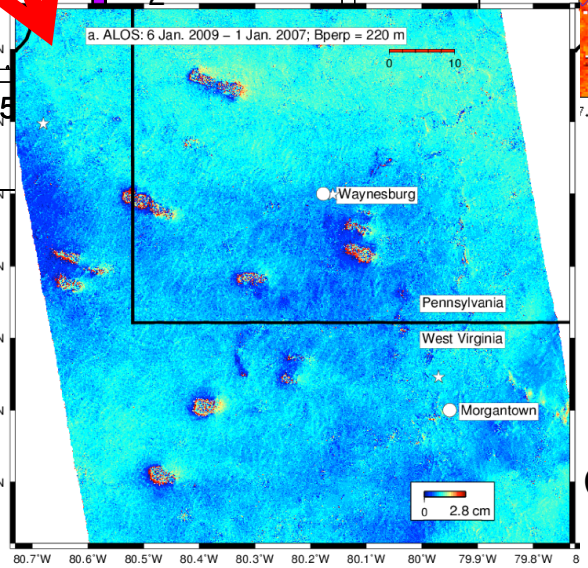
- Need be skeptical of InSAR results, especially in central North America

Other signals in eastern North America not seen by GNSS





Salt mine subsidence: NY State
-6 cm/yr south of Geneseo (2007-2011)
Ben Valentino, Cornell MS thesis



Coal mines in PA & WV (2007-2011)

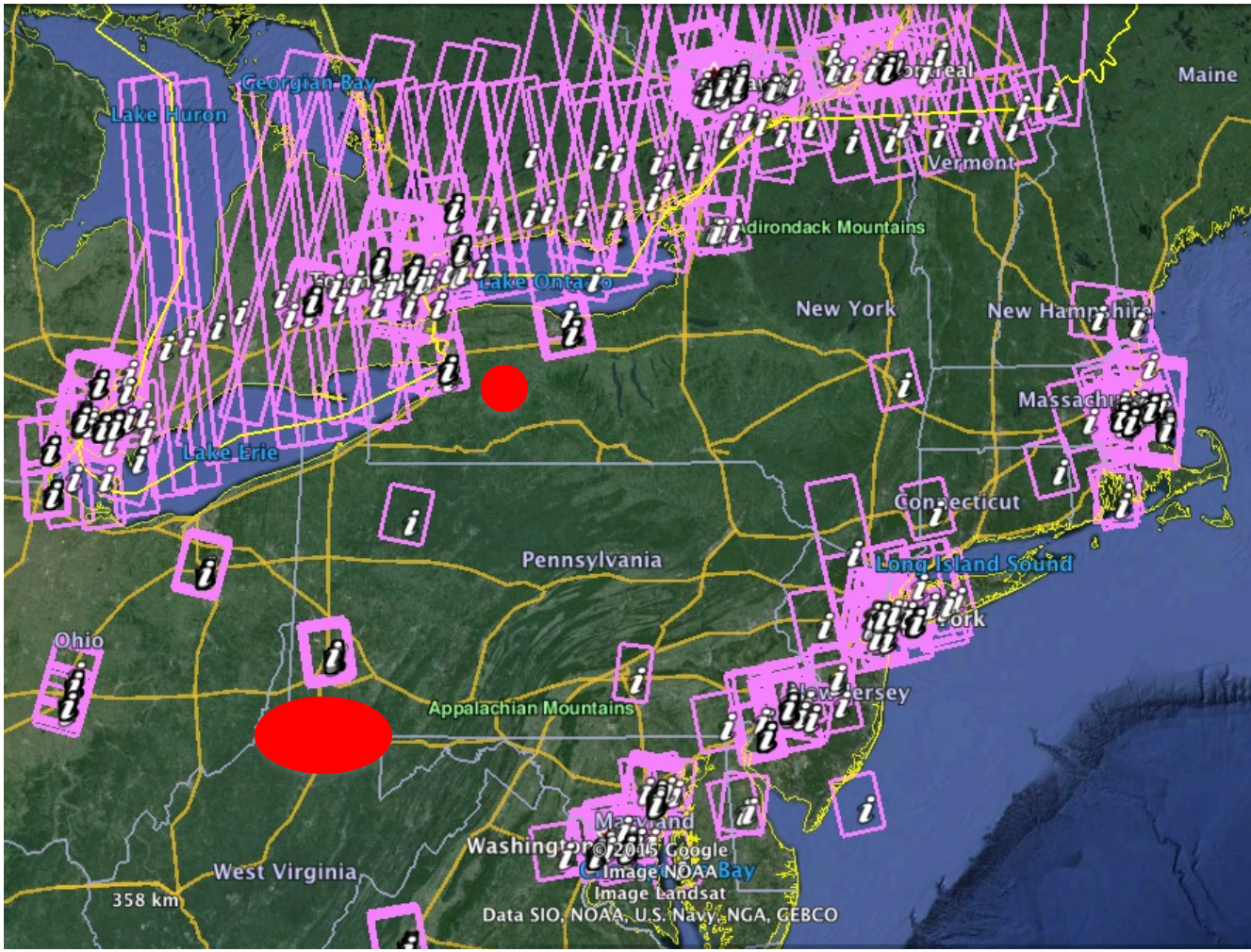
Need to collect more InSAR in eastern North America

For New York Mine:

3 IW Sentinel: March, August, Sept, 2015
No CSK
No TSX pairs

For Alexandria:

- 2 IW Sentinel: March & Sept. 2015
- CSK: ascending (2013-present; 40+ dates) and descending (2014-present; 28+ dates)
- TSX: descending track 2011-present (100+ scenes)



CSK stripmap data available as of Dec. 11