Eye-Popping EarthScope Science: A Synthesis, Celebration and Exploration of New Horizons for Geodetic and Geodynamic Imaging

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NSF EarthScope National Meeting, Anchorage AK, May 16, 2017

Plug and Play GPS for Earth Science

Supporting Data Discovery, Ease of Access, Open Products

Spirit:

- What is EarthScope? Facility, Research Program, Community
- A single, gigantic, integrated sensor of Earth's movements.

Goals:

- Provide more fuel for the data explosion!
- Remove barriers limiting proliferation and scientific impact of GPS networks
- Promote open data products and maximize discovery

Who's involved? The Plug and Play Players:

- A collaboration between UNAVCO and UNR
- Funded by NASA ACCESS program

The Deal:

- NGL provides free GPS data processing service
- Under condition that data is made openly available via UNAVCO archive
- Project makes all data products available online, open to everyone
- Products include time series, plots, velocities, qa files, data discovery tools, etc.

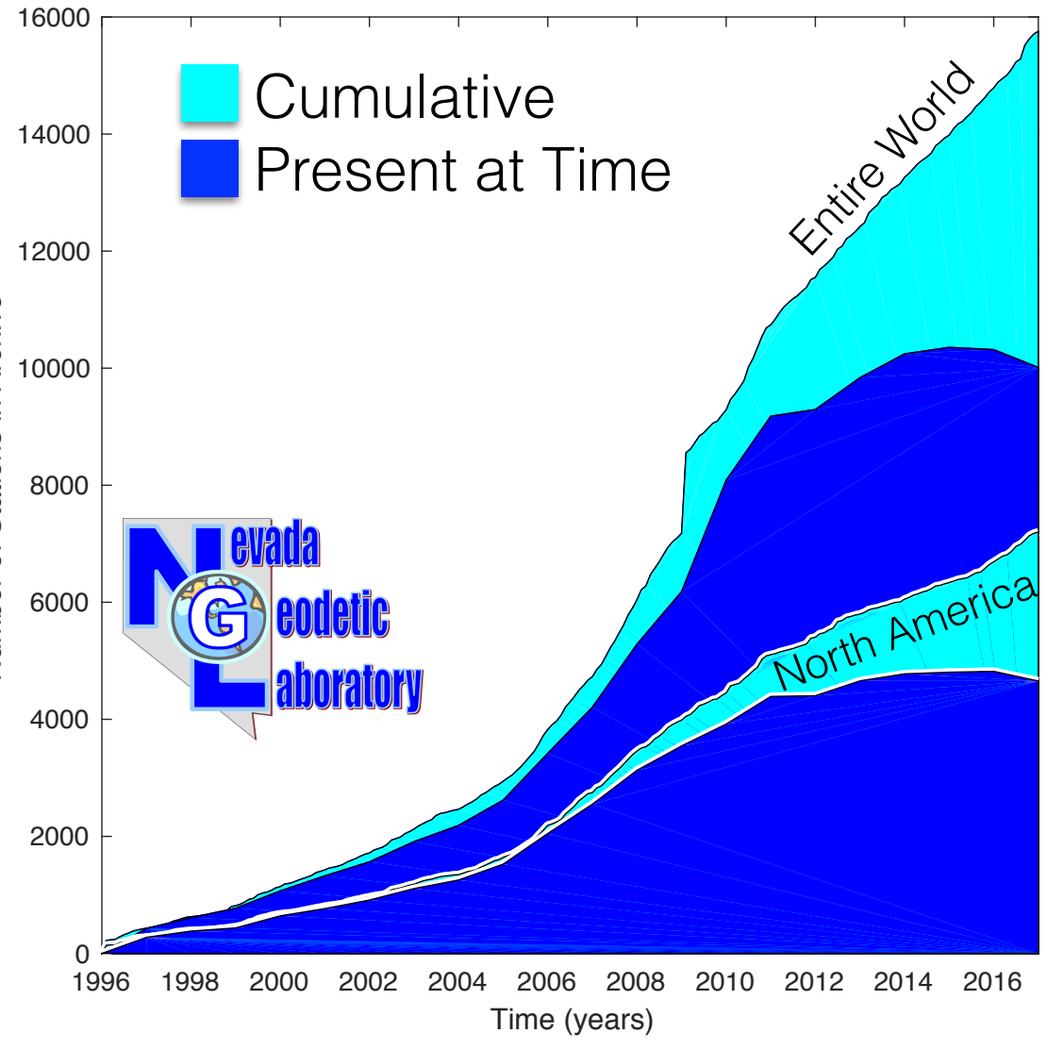
Explore

- Links via UNAVCO and UNR home pages: Search for Plug and Play
- Set up a network!

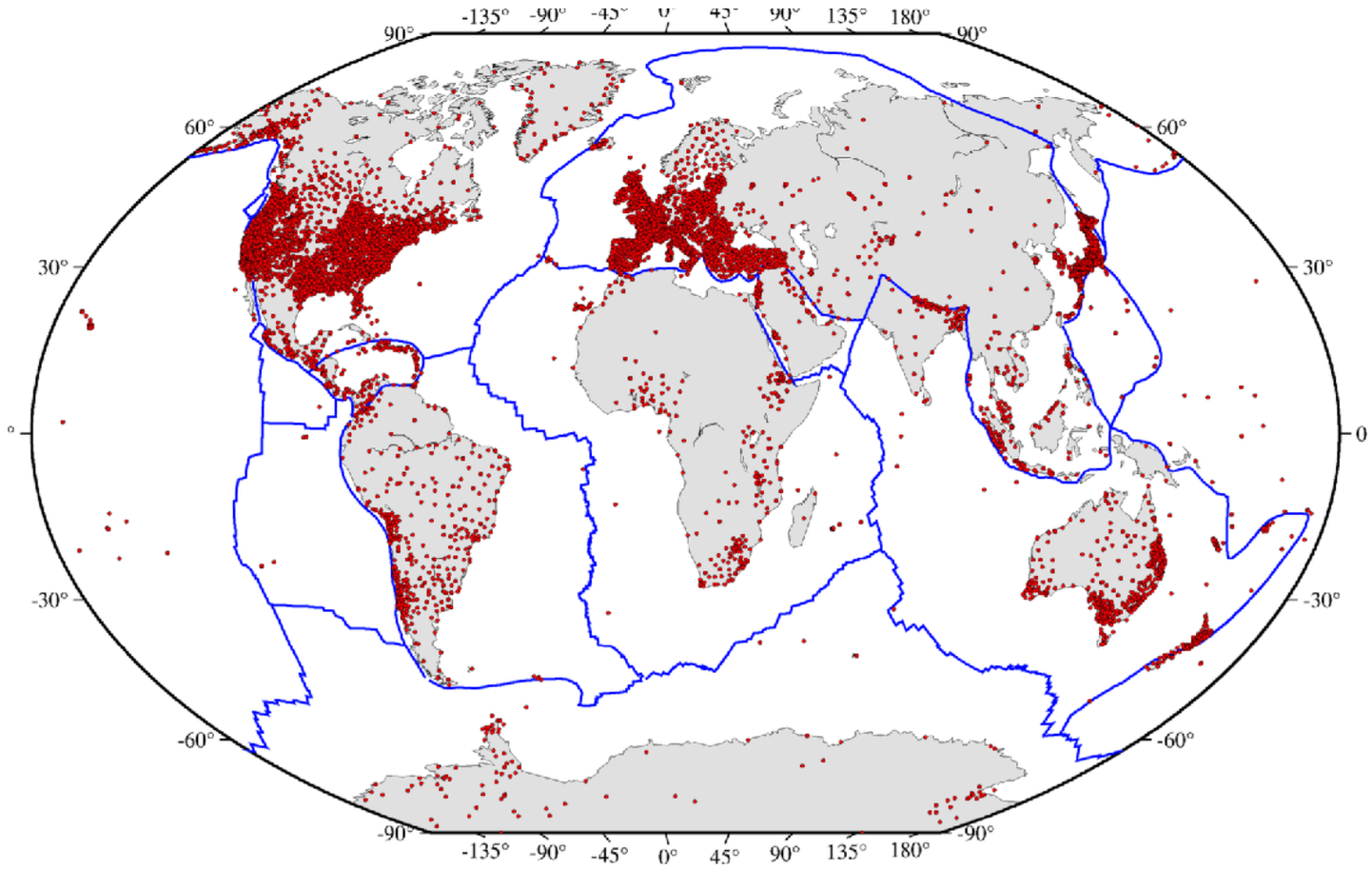
Scope of GPS Networks and Data Processing

PBO-like Mega-Network

15,899 Time Series from Continuous Stations



Global Distribution - Uneven

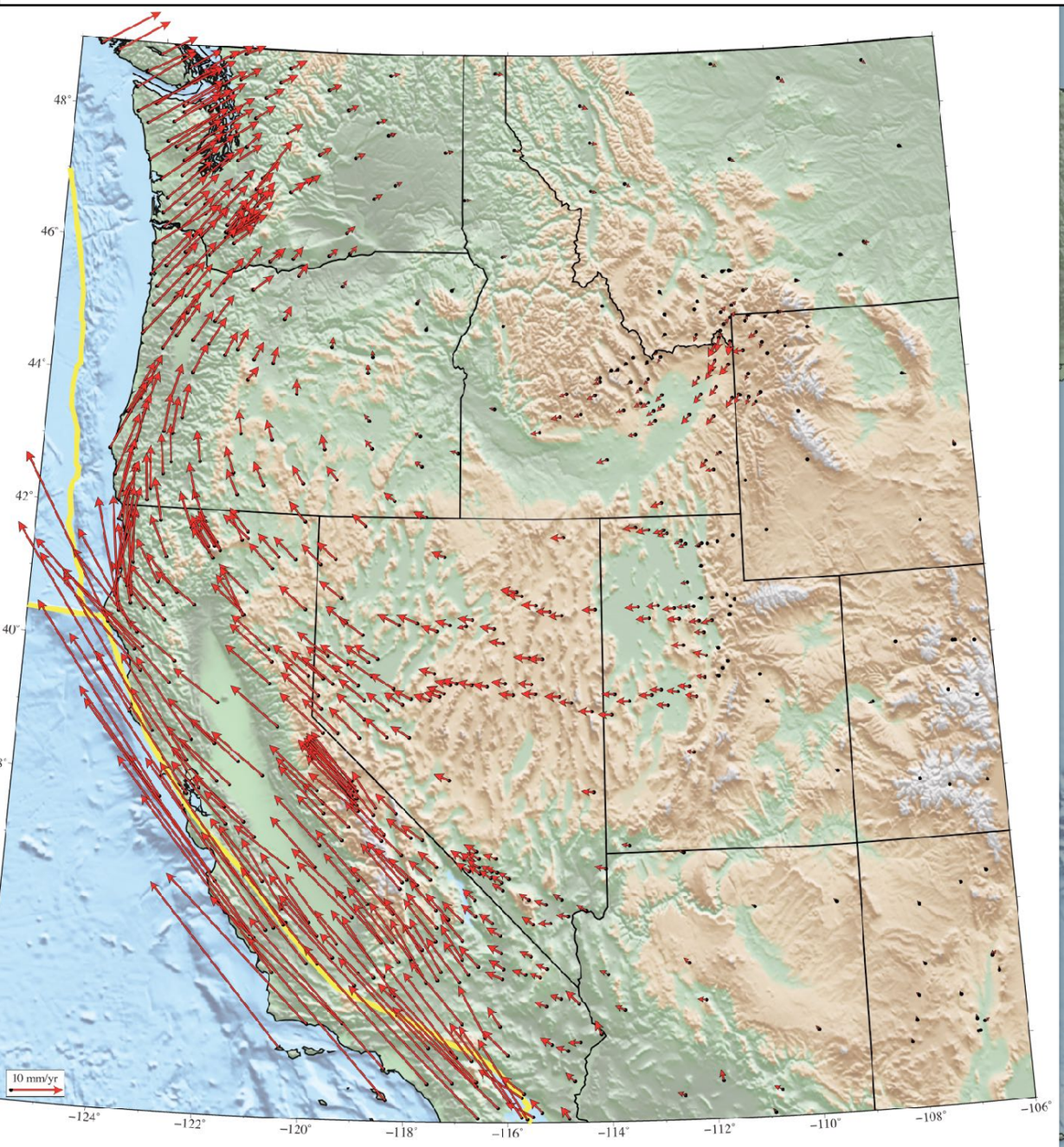


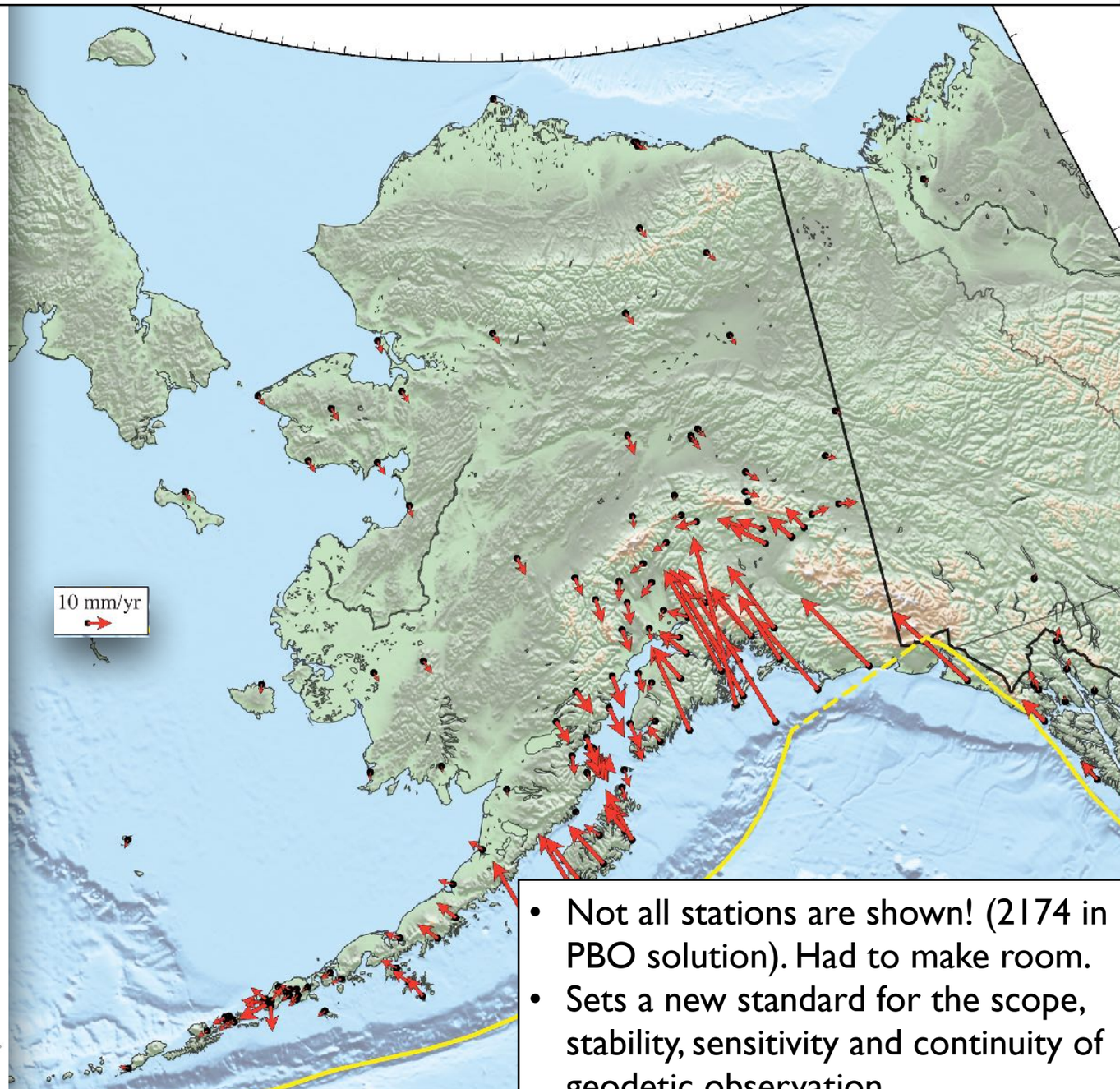
- In places the coverage is excellent, but not everywhere
- Continuing growth in number of stations is strong
- Number available at any instant leveling off?
- Partly attributable to latency of data delivery
- Same is true in North America subset

- But quantity of stations is in places transforming how we can use and interpret the data.
- Examples to follow

A Legacy of EarthScope: Precise Maps of Western US Tectonic Deformation

Tectonic Motions of the Western US including Alaska





- Not all stations are shown! (2174 in PBO solution). Had to make room.
- Sets a new standard for the scope, stability, sensitivity and continuity of geodetic observation.
- Provide new revelations about patterns in data.
- Still new discoveries to be made!

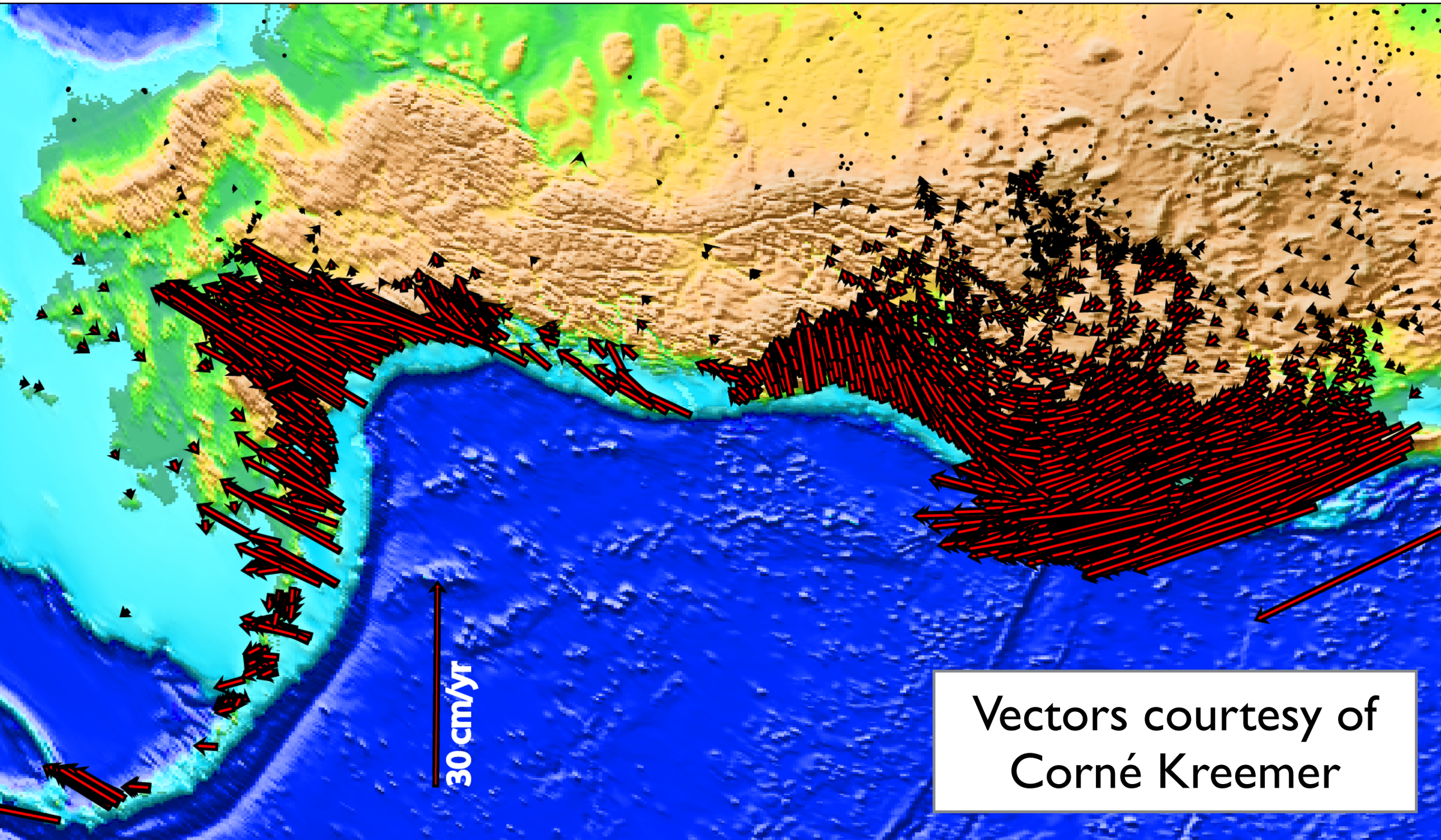
earthscope
www.earthscope.org

NSF

UNAVCO

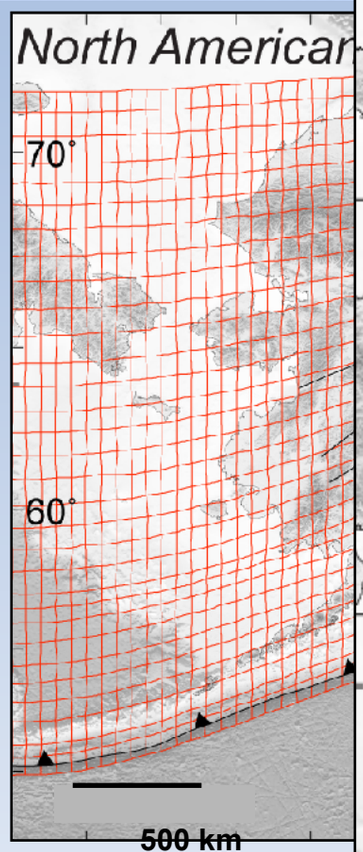
A Legacy of EarthScope:
Precise Maps of Western US Tectonic Deformation

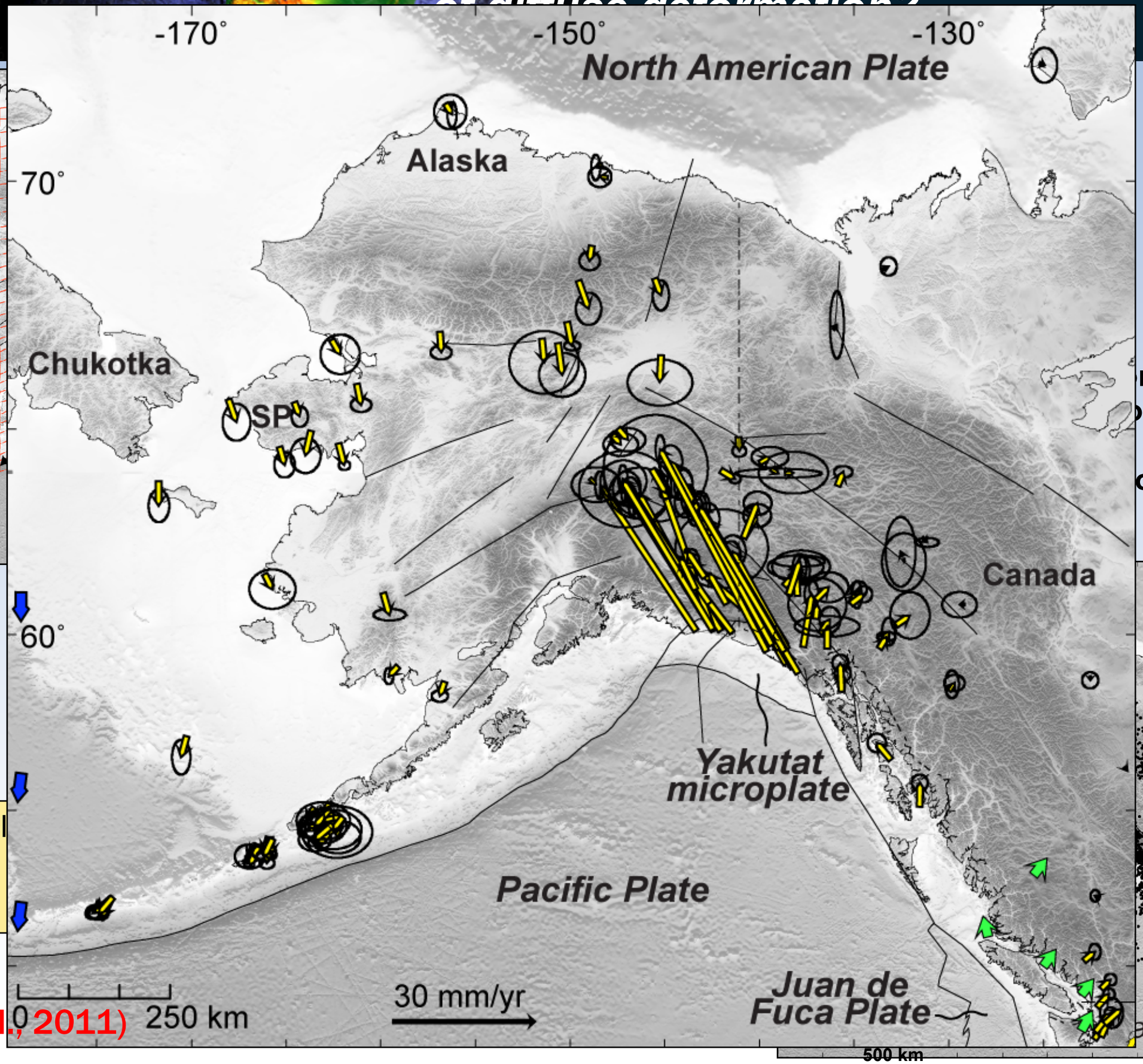
A Synoptic View of Surface Motions

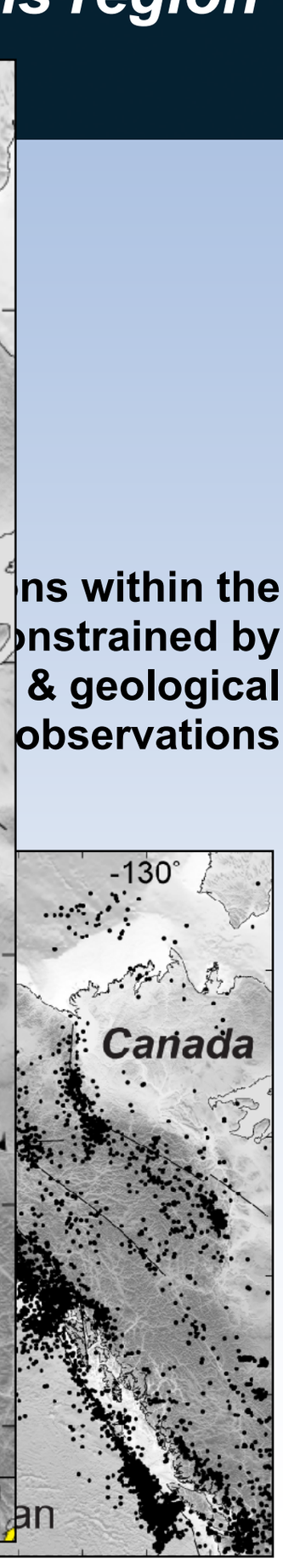


Vectors courtesy of
Corné Kreemer

How are relative motions being accommodated in this region of diffuse deformation?







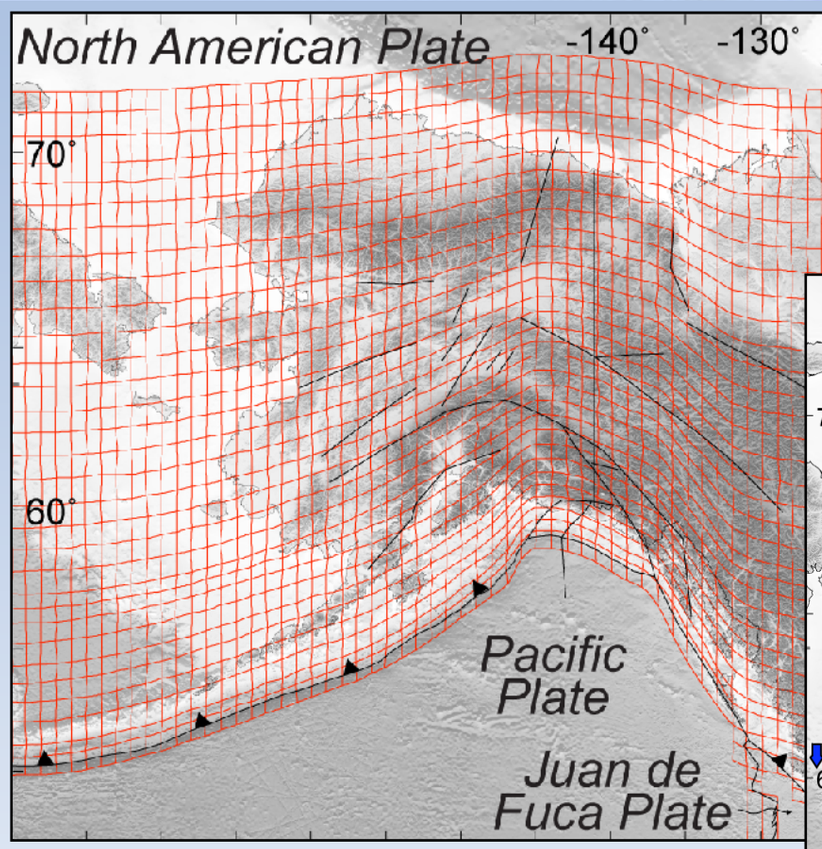
ns within the
onstrained by
& geological
observations

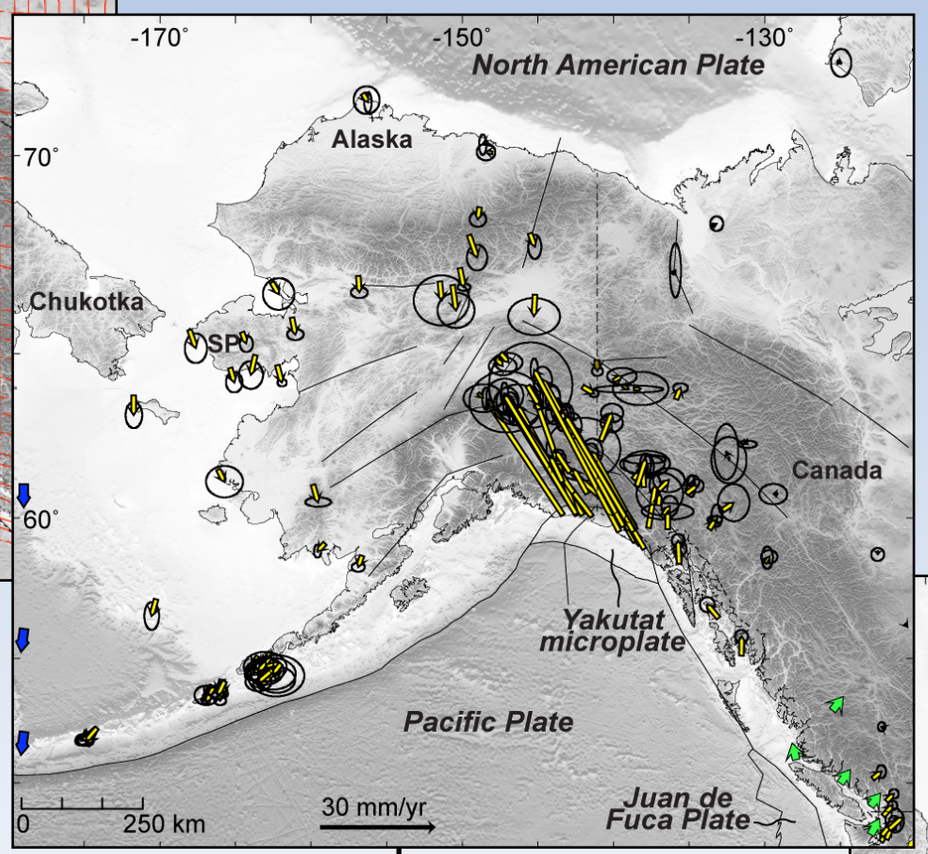
- Interpol
-

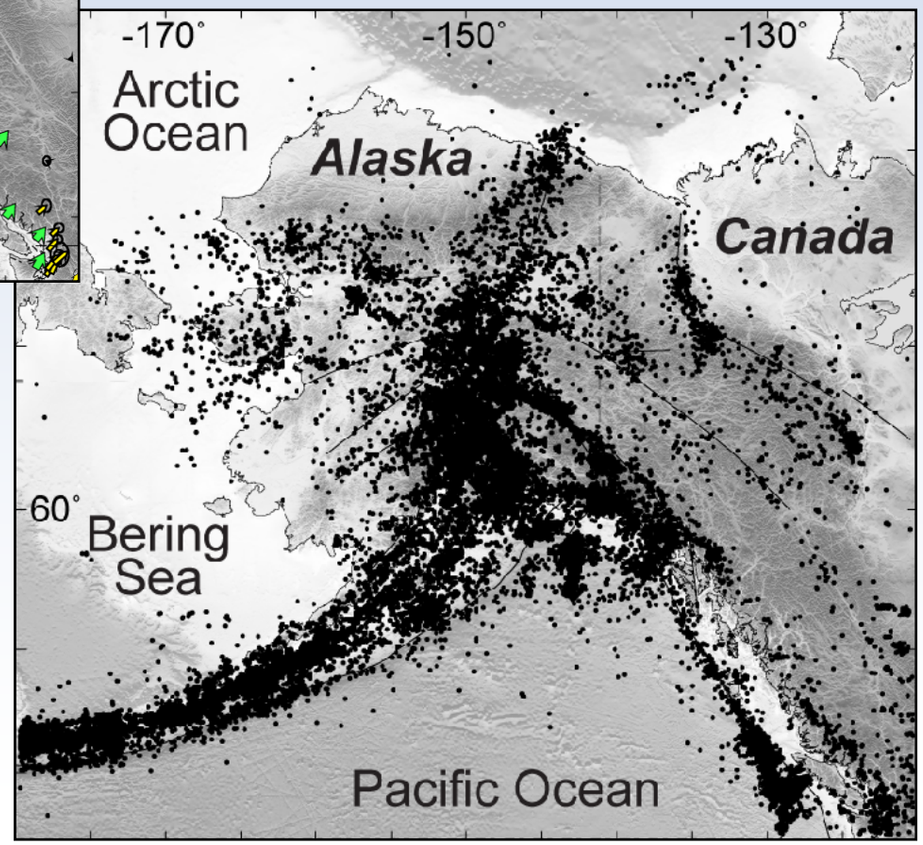
(Finzel et al., 2011)

an

How are relative motions being accommodated in this region of diffuse deformation?







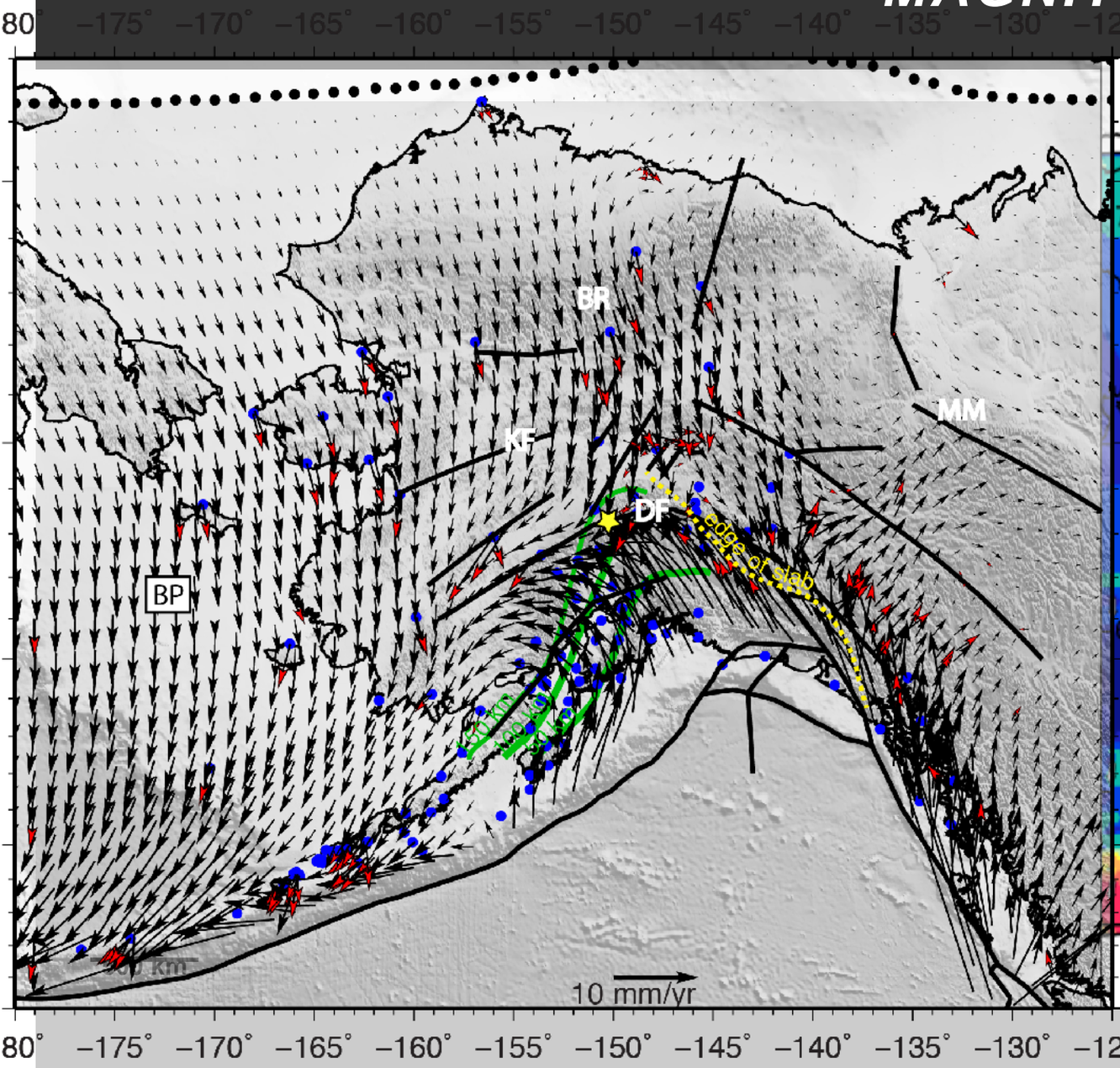
PBO GPS data; Mazzotti et al., 2003; Leonard et al., 2007; Cross and Freymueller, 2008; Freymueller et al., 2008; Elliott et al., 2008

- Account for non-permeant sources of deformation from post-seismic effects and elastic coupling at the trench

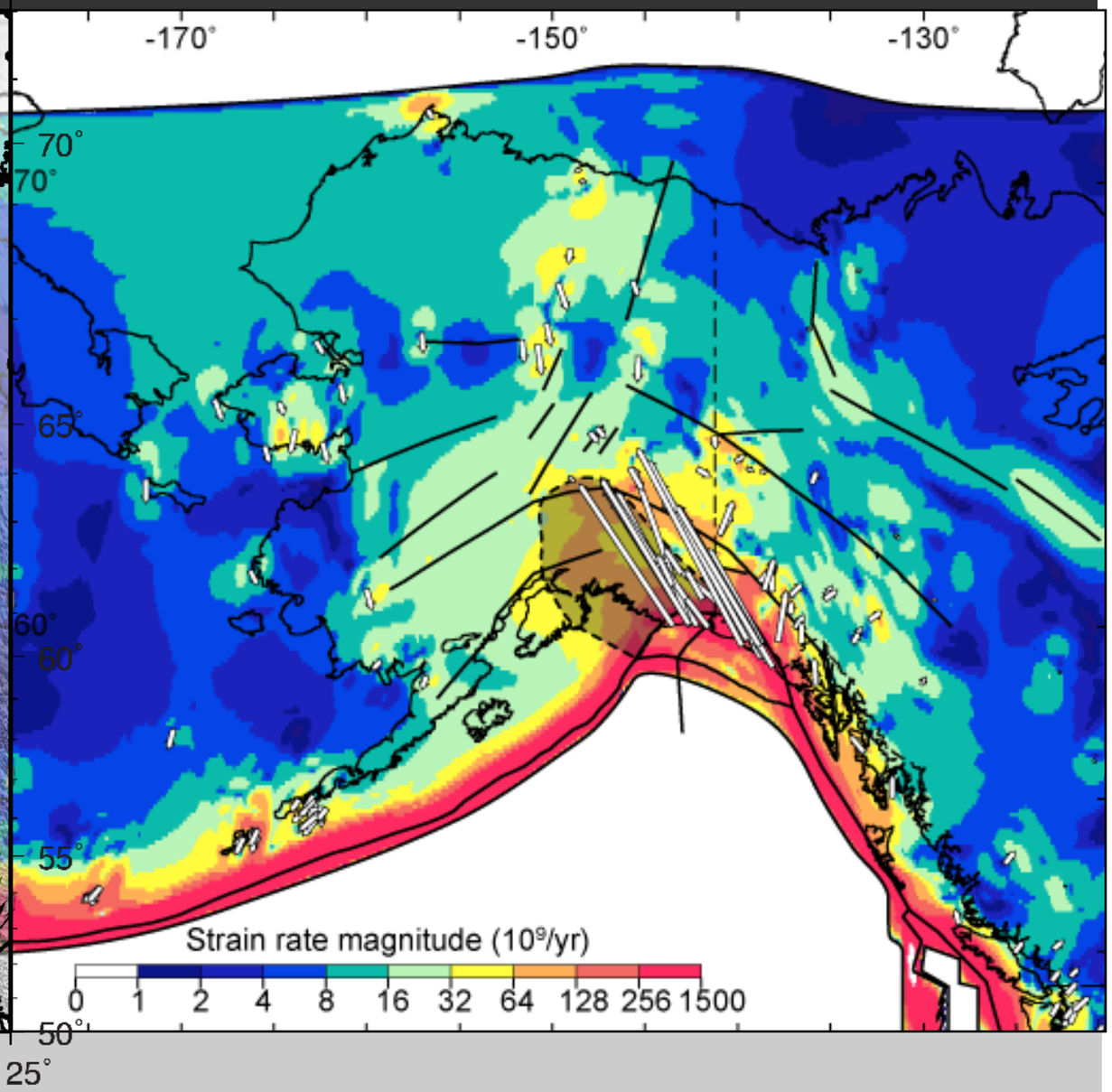
(Finzel et al., 2011)

SUMMARY OF KINEMATIC RESULTS

SIMULTANEOUSLY SOLVE FOR VELOCITY & STRAIN RATE MAGNITUDES



Modeled continuous velocity field



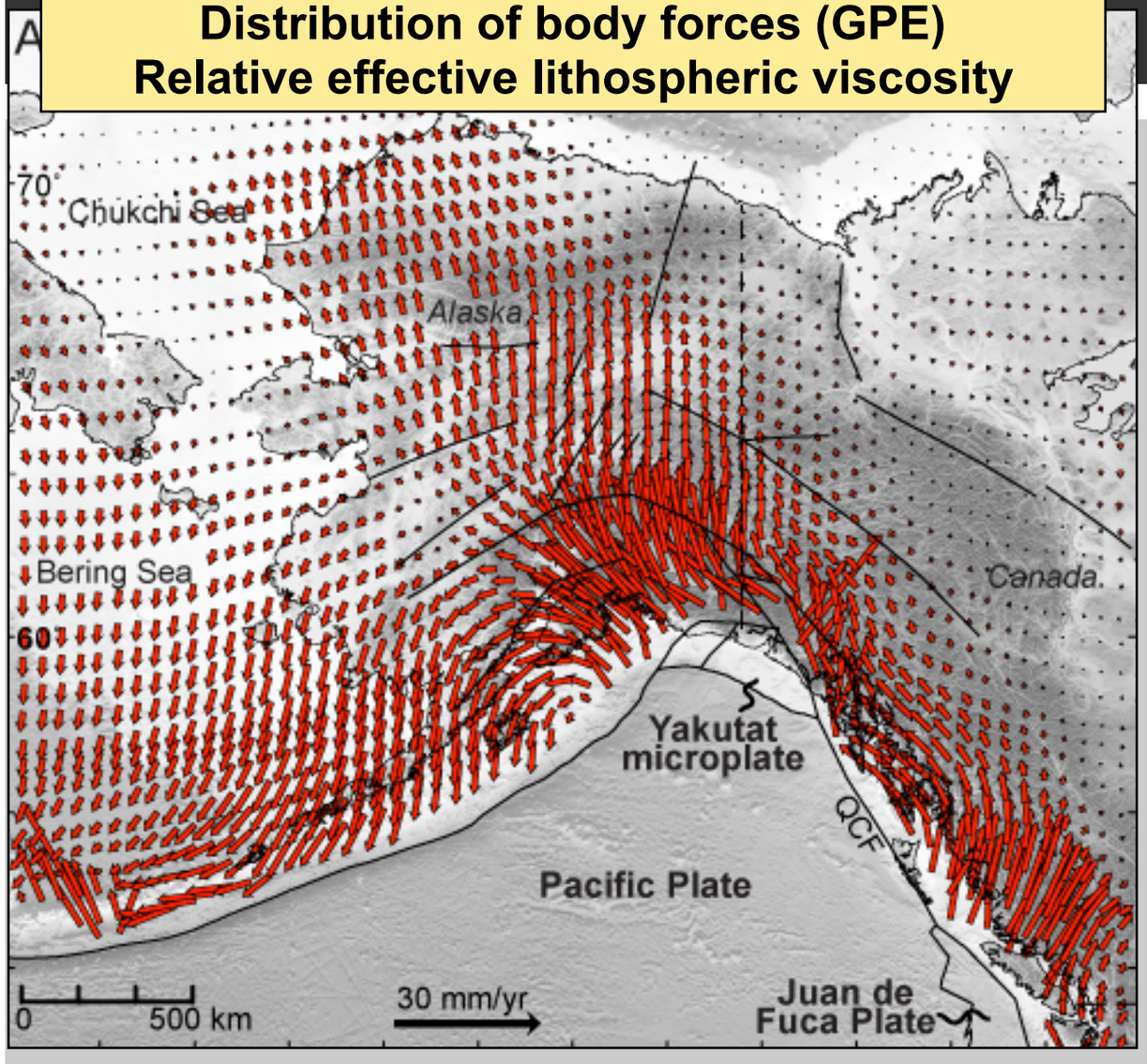
Modeled strain rate magnitudes

(Finzel et al., 2011)

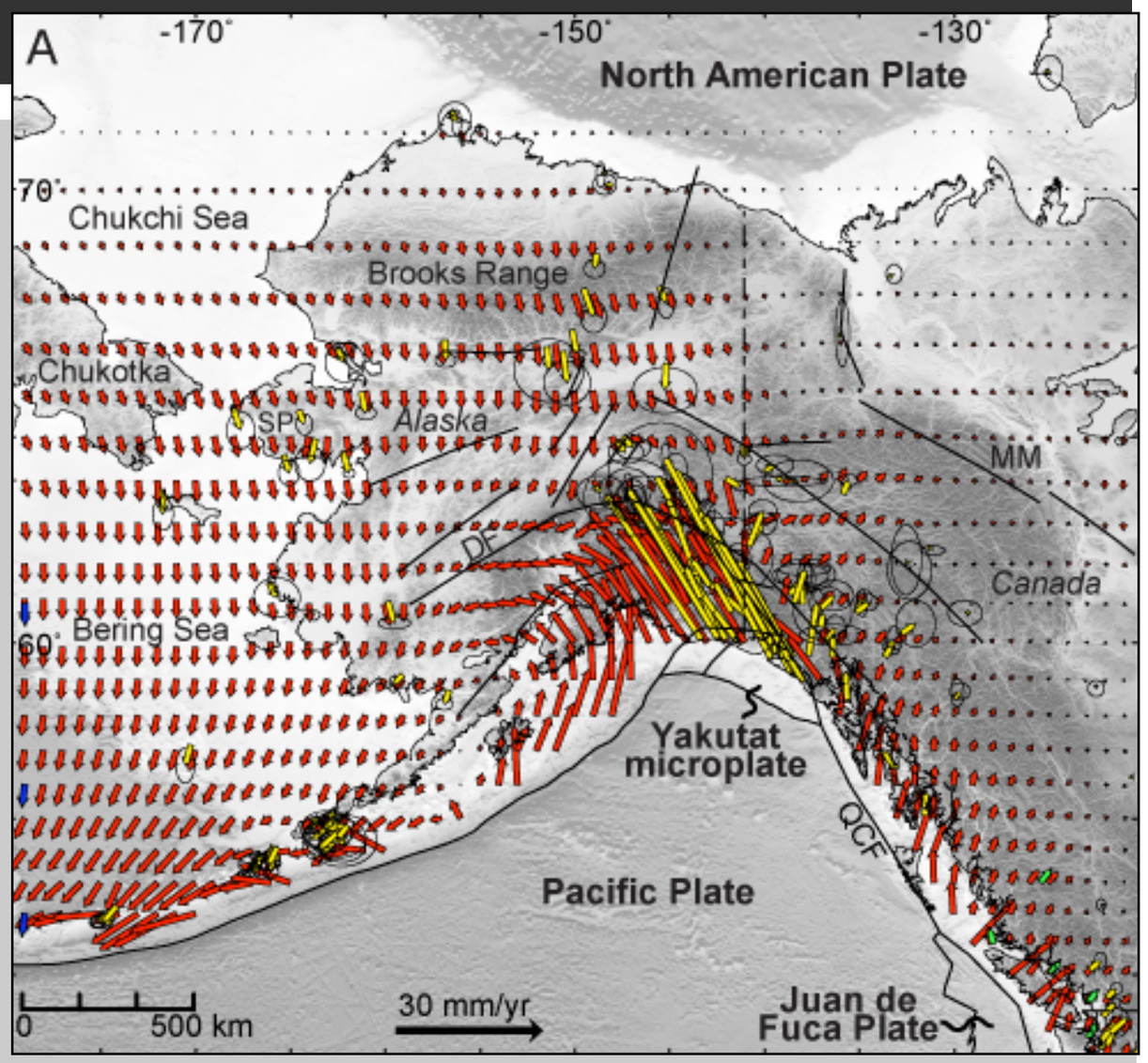
GENERATION OF A DYNAMIC VELOCITY FIELD

CAN ISOLATE CONTRIBUTIONS FROM BASAL TRACTIONS

Velocity boundary condition (plate motions)
Distribution of body forces (GPE)
Relative effective lithospheric viscosity



Dynamic model - accounts for deformation related to GPE variations and plate motions

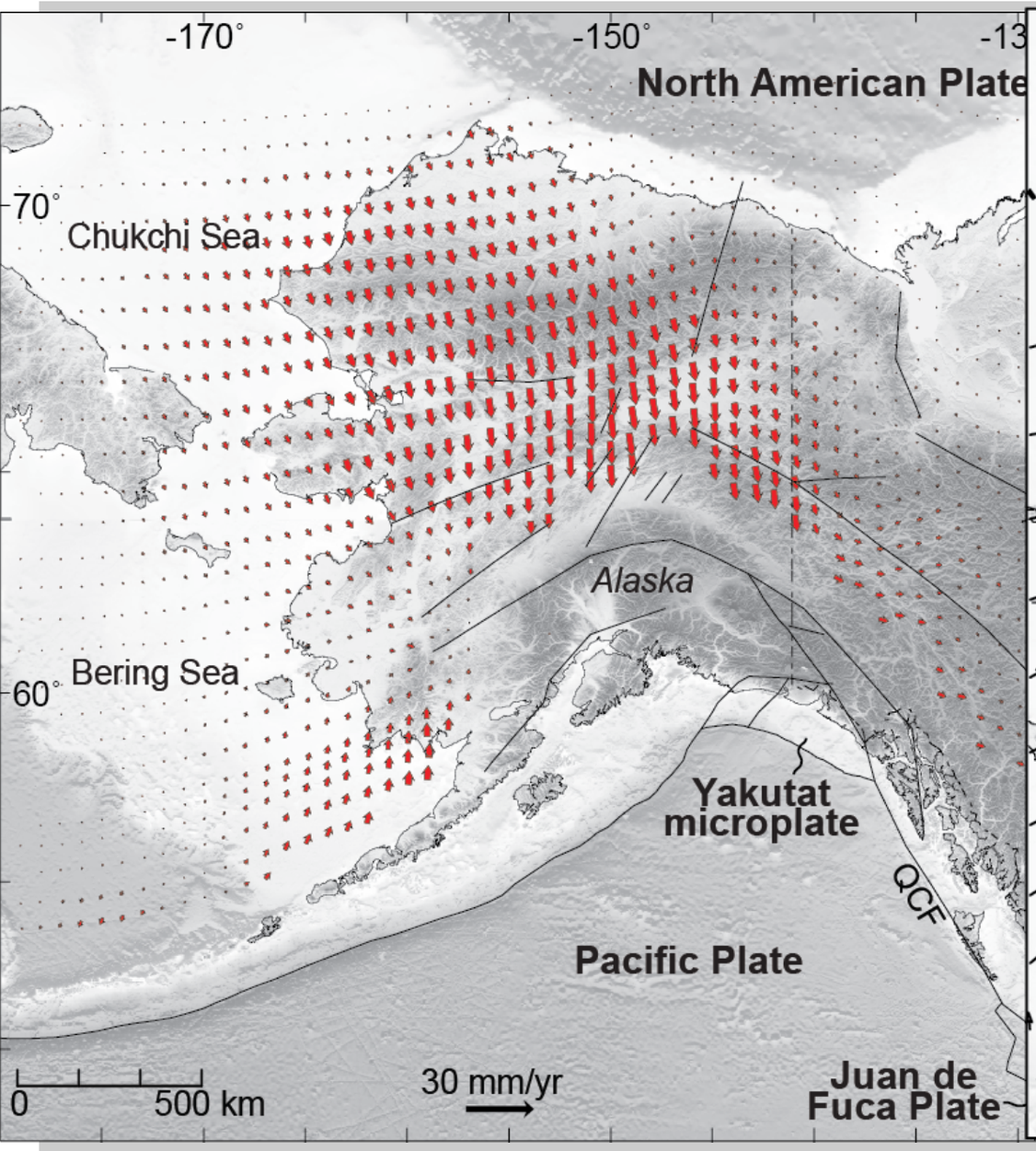


Kinematic model - reflects deformation related to GPE, plate motions, and basal tractions

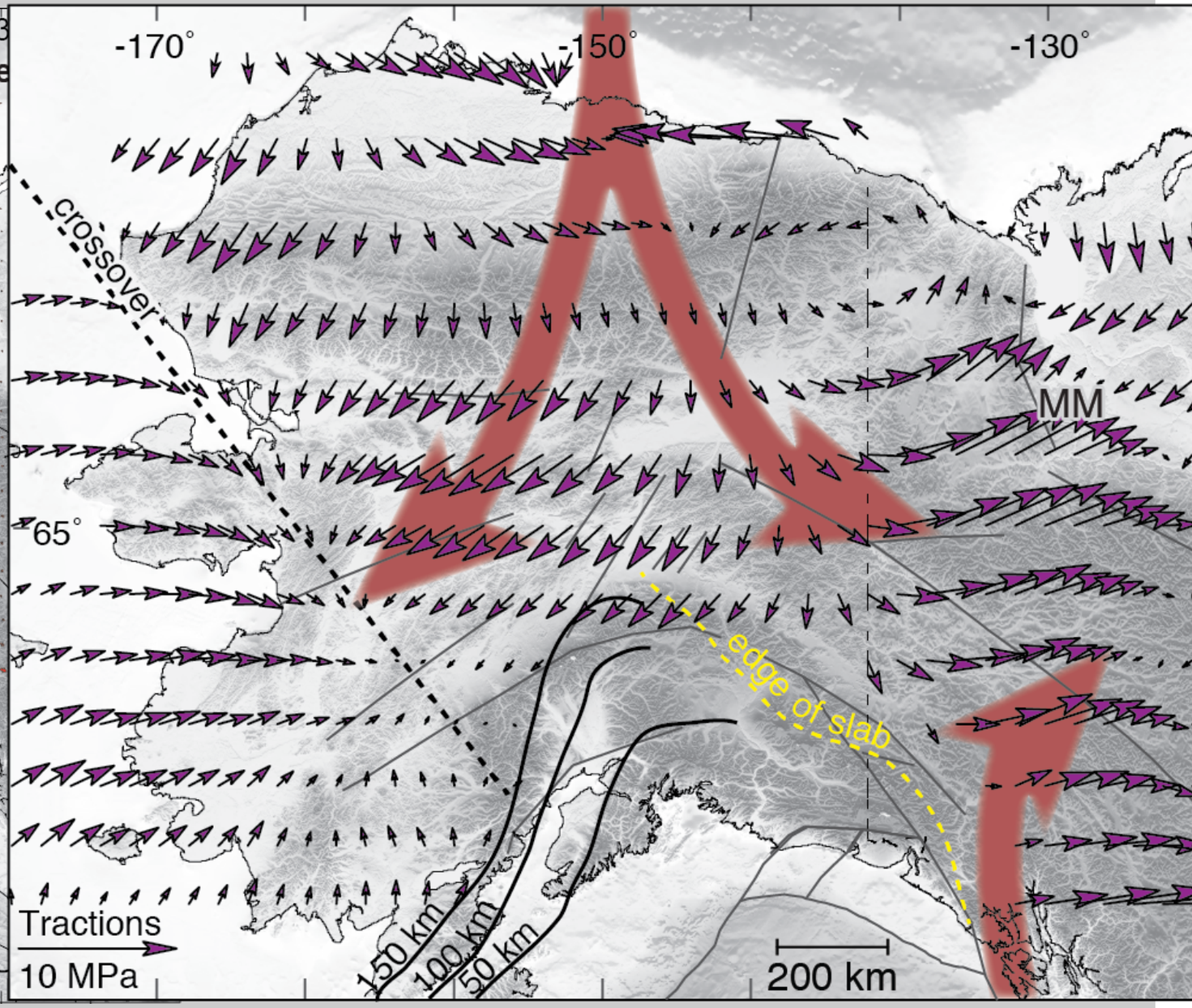
The differences between the velocity/strain rate fields is assumed to be due to the contribution from basal tractions.

(Finzel et al., 2015)

TRACTIONS ASSOCIATED WITH LARGE SCALE MANTLE FLOW DRIVE SURFACE MOTIONS



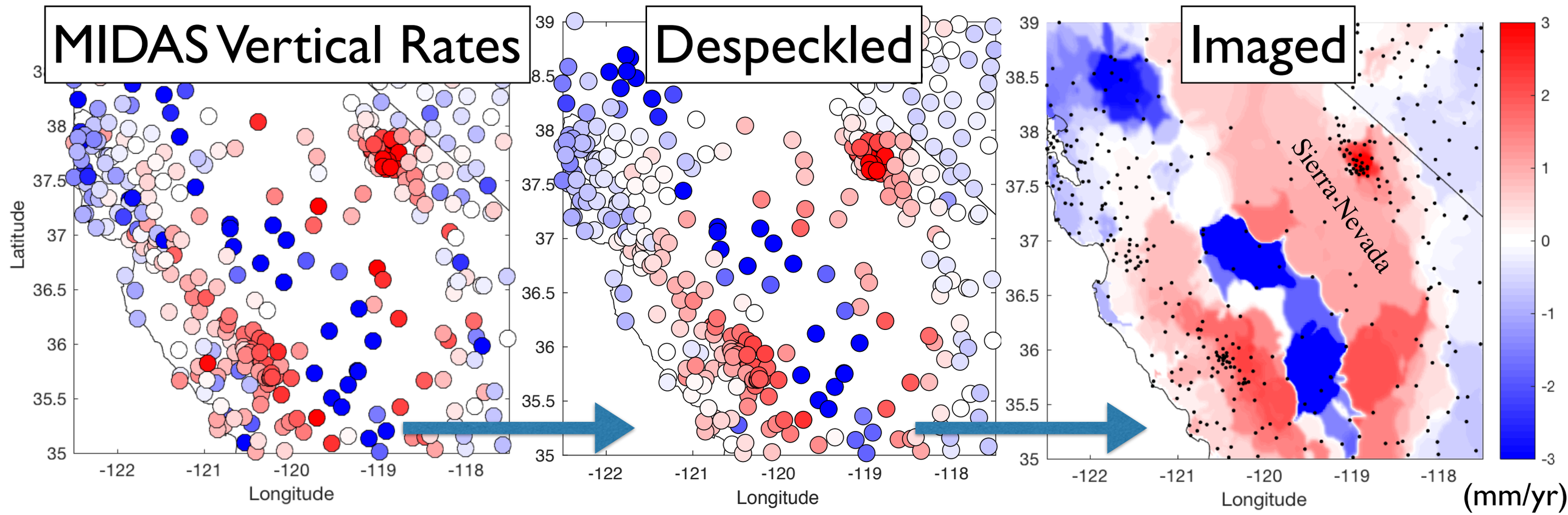
Velocity Difference



Predicted Basal Tractions
(Finzel et al., 2015)[10]

GPS Imaging - A New Data Visualization Tool

See the Spatially Coherent Signal in Noisy Data



weighted median spatial filtering repairs photos with lots of speckle noise

- New images of Earth's vertical motion.
- Despeckeled, imaged but not smoothed.
- Enhance interpretive value
- Example: Sierra Nevada uplift and subsidence from CA central valley aquifer depletion.

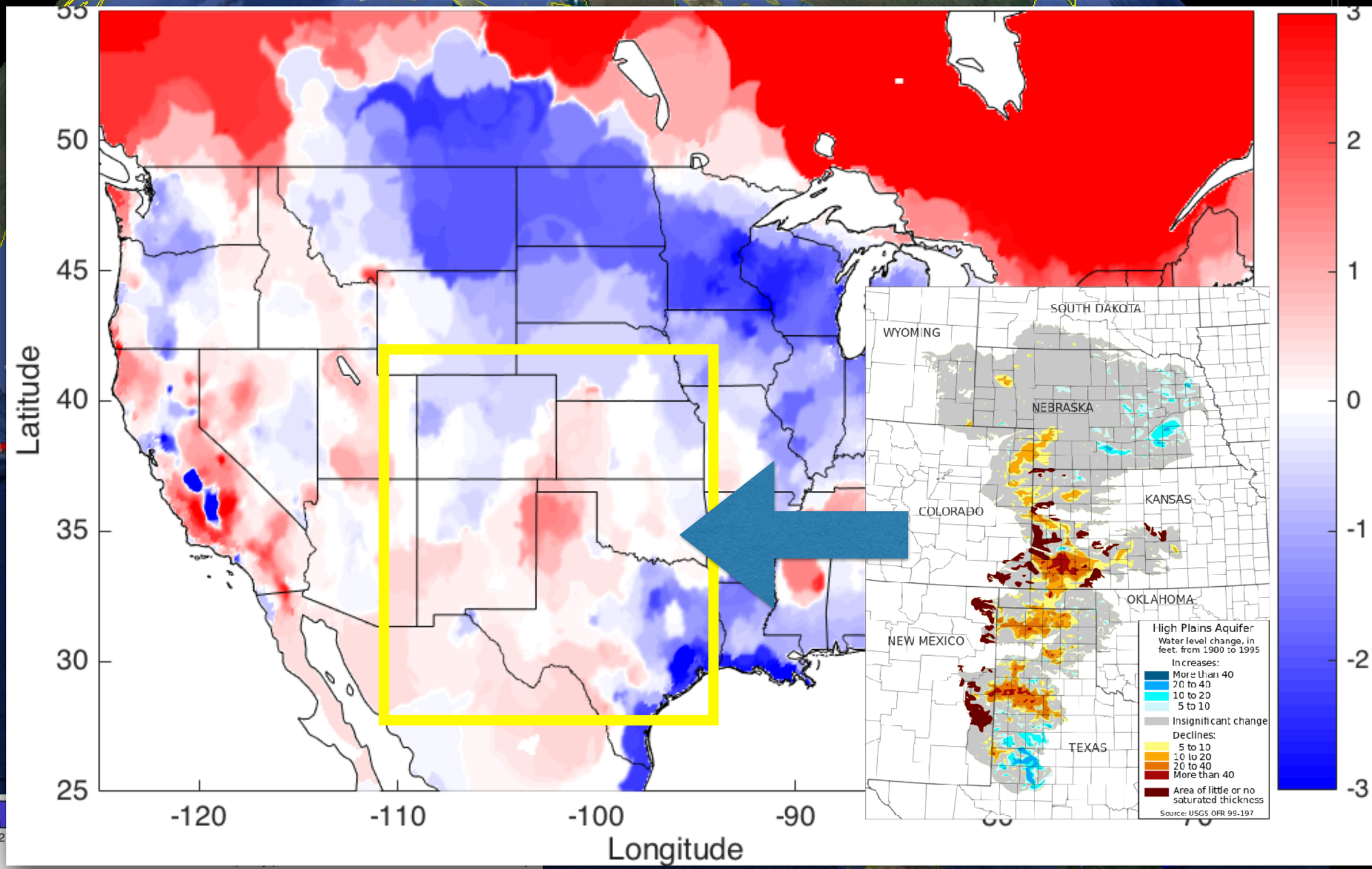
MIDAS - Non-parametric and unbiased estimation of time series trend. Robust to steps, outliers, seasonality, and heteroscedasticity. Uses Thiel-Sen statistics. See *Blewitt et al.*, 2016 JGR doi:10.1002/2015JB012552.

GPS Imaging - Hybrid between geostatistical Kriging and spatial filtering from image processing. Delaunay triangulation based, estimates weighted median of nearest neighbor. Preserves discontinuities, no classical smoothing. Despeckles and makes unbiased local estimation of underlying field from the data. See *Hammond et al.*, 2016, doi: 10.1002/2016JB013458.

North America - Signals of Vertical Motion

Water. Water… and Water.

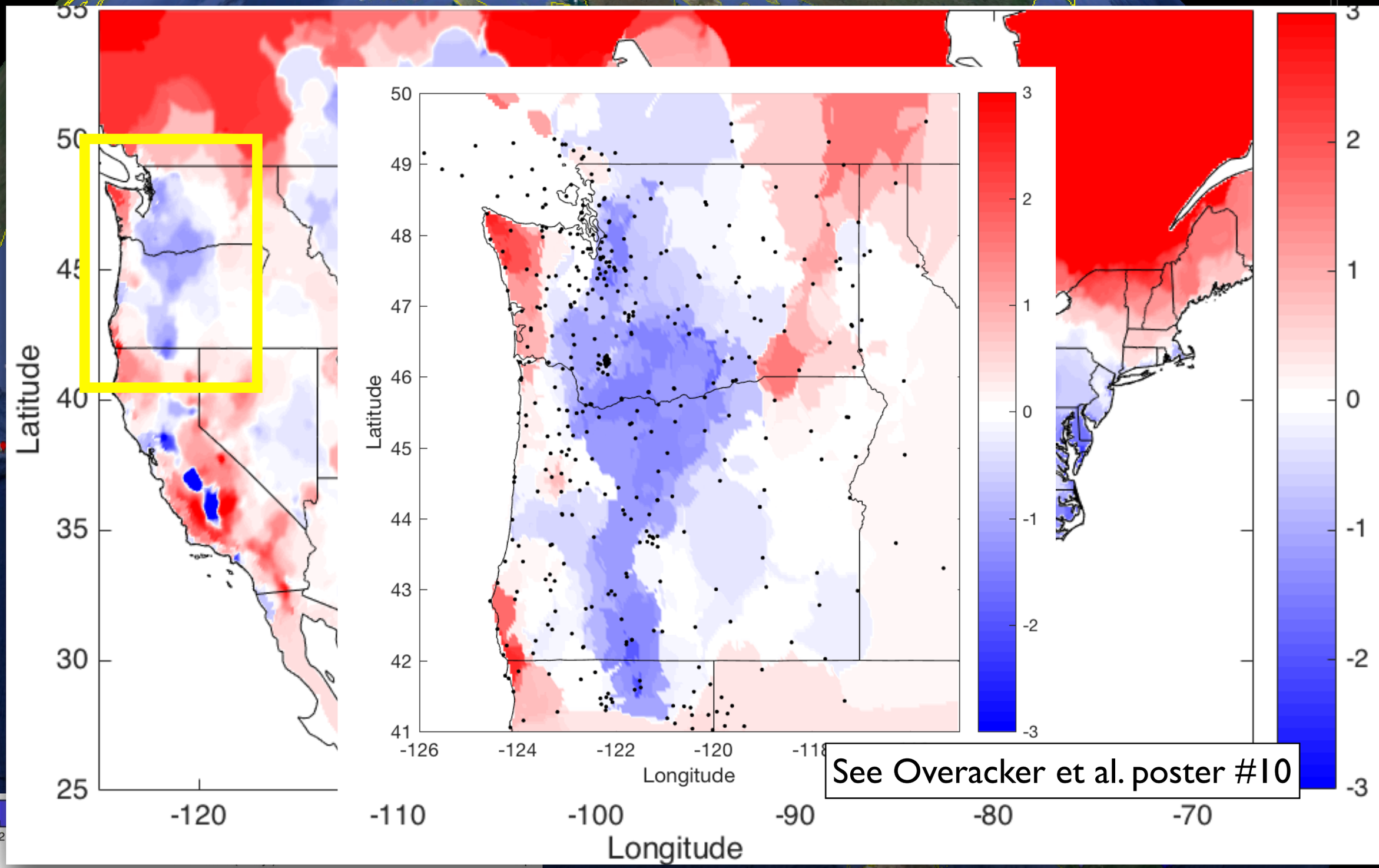
GPS Imaging of Vertical GPS Velocity : Lower 48



North America - Signals of Vertical Motion

Water. Water… and Water.

GPS Imaging of Vertical Land Motion : Pacific Northwest



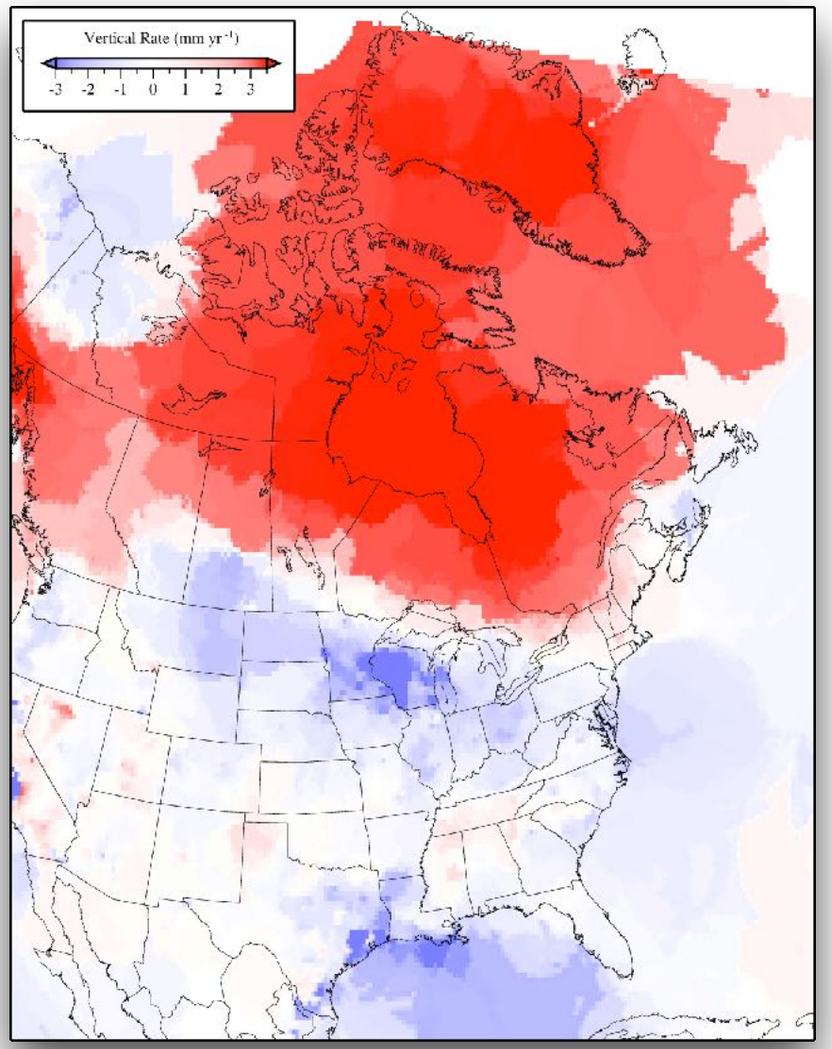
See Overacker et al. poster #10

Down

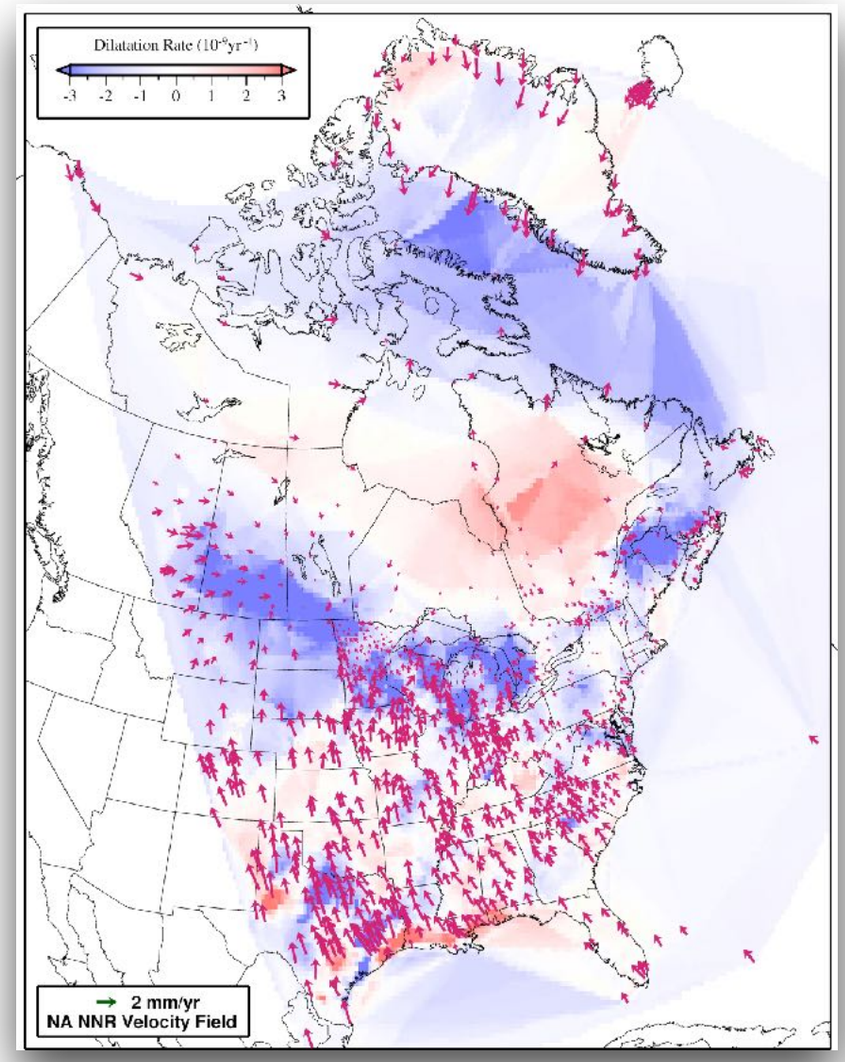
North America - A Rigid Plate?

Glacial Isostatic Adjustment Causes Extension, Contraction, Subsidence, Uplift

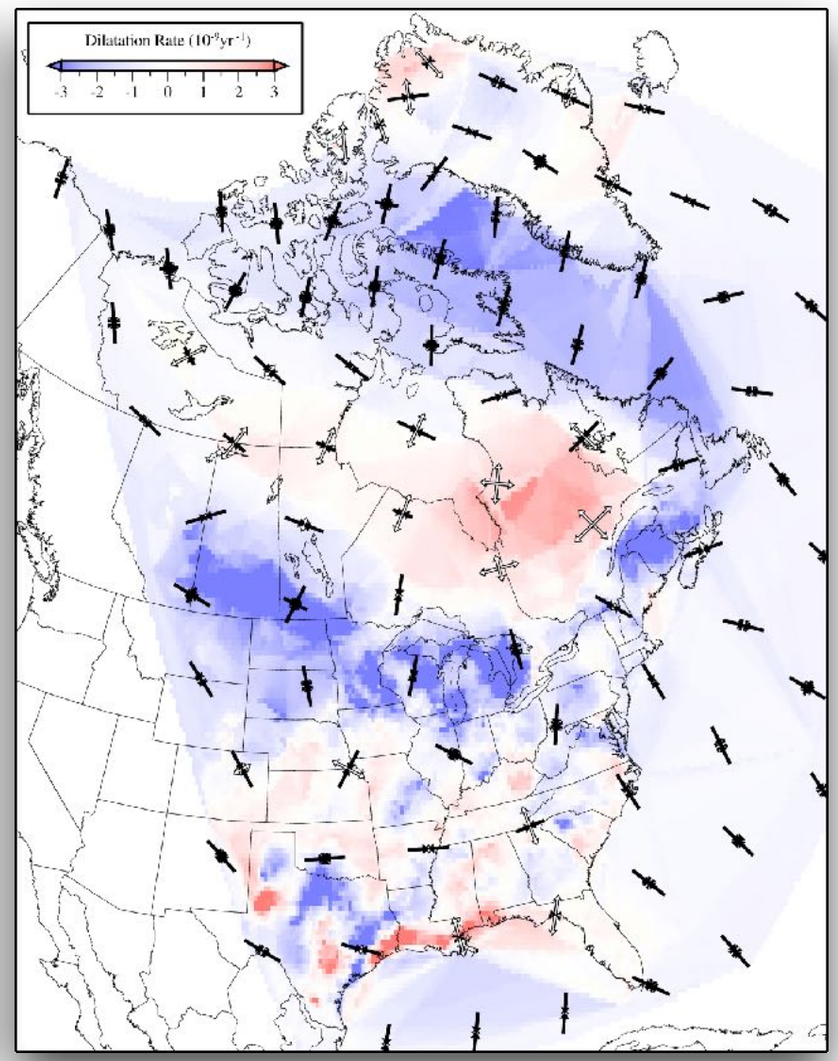
Vertical Velocity



Horizontal Velocity



Dilatation Rate + Strain Rate Tensors



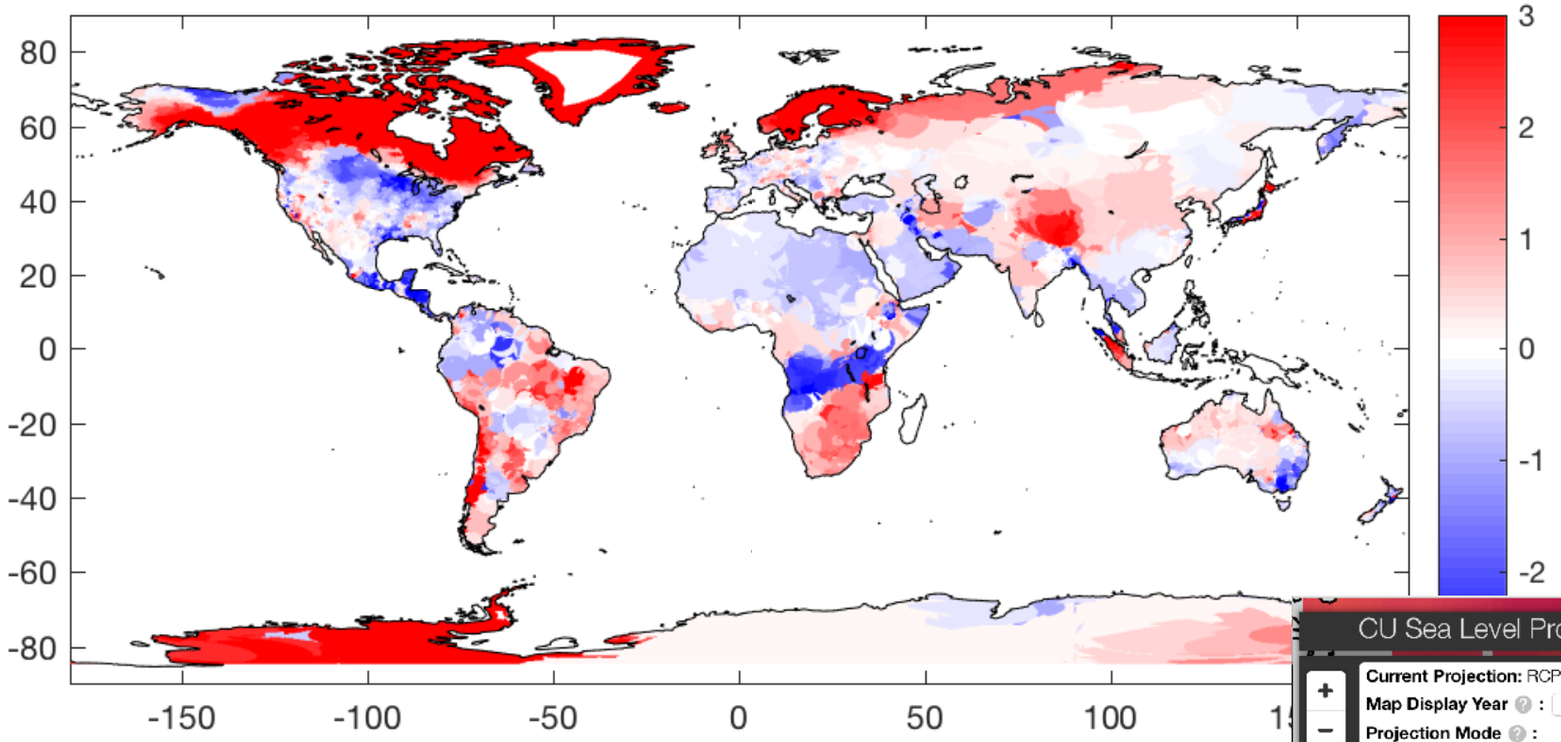
MIDAS, GPS Imaging and MELD techniques

GIA effects most of North America horizontally, much of it vertically

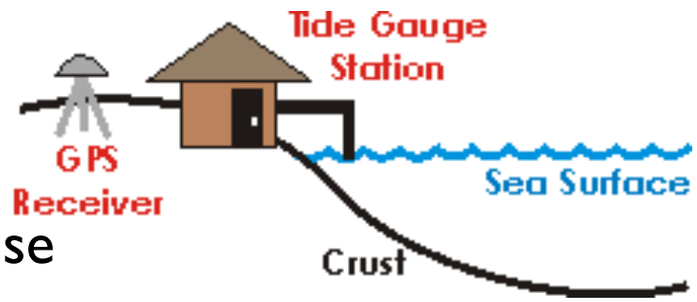
Similarities/Differences between GPS and GIA models (e.g. ICE6G of Peltier et al.)

[figures from Kreemer et al, SSA talk and upcoming IGS workshop]

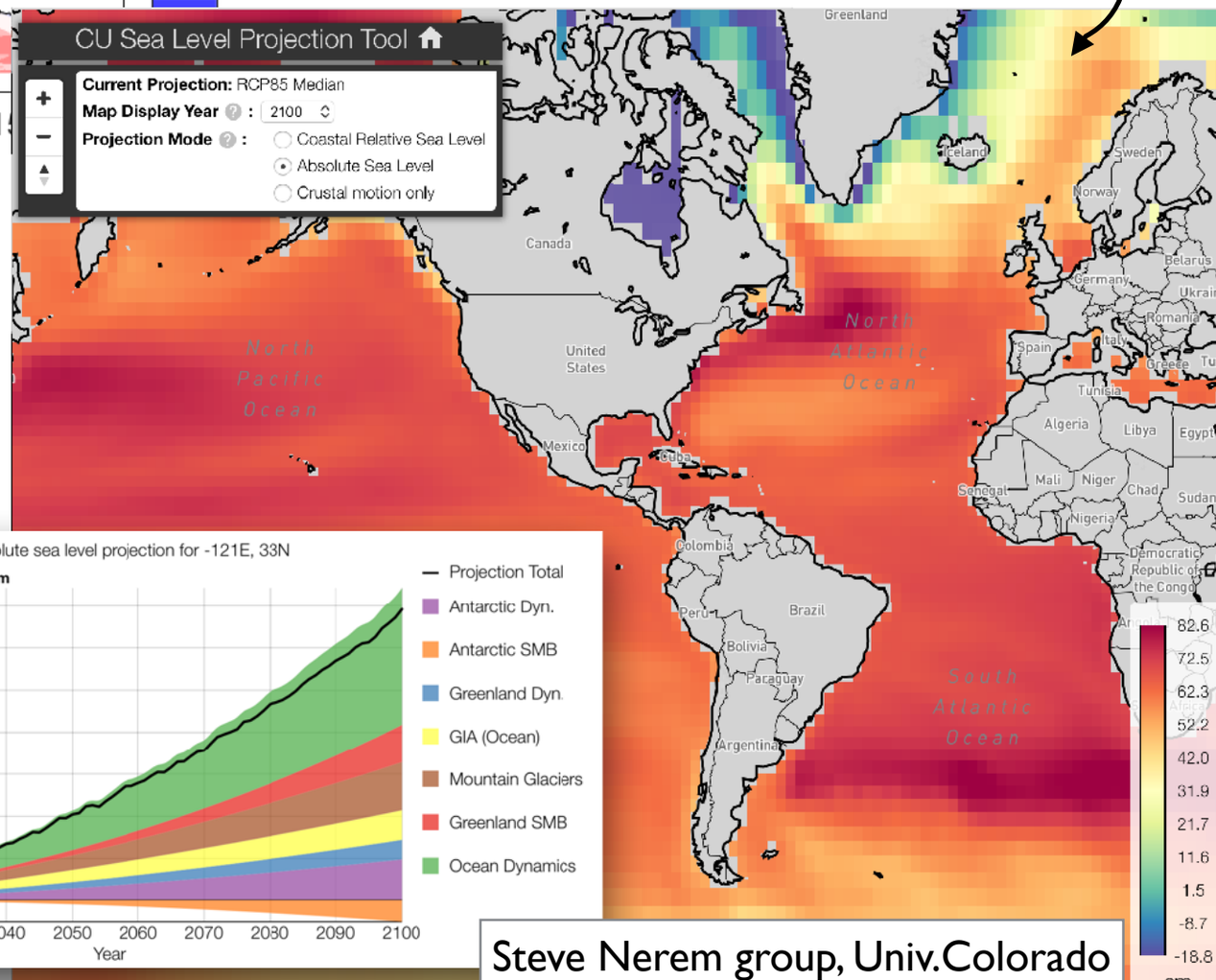
Global Vertical Land Motion for Sea Level Studies



- GPS Imaging of vertical land motion applied to entire Earth
- Resolution not the same everywhere
- Needed to correct sea level projections for VLM
- New NASA Sea Level Portal
- Built into the new CU tool



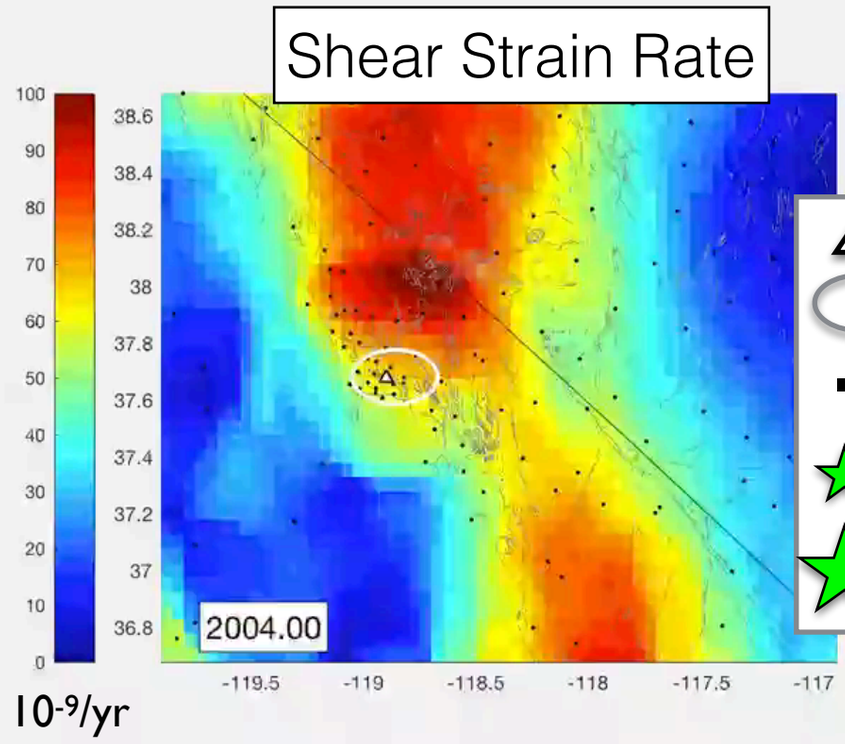
- Tide gauge + VLM provide geocentric sea level rise
- Order ~10% effect on GMSRL projections. More locally in regions with significant VLM
- See Hamlington et al., 2016 JGR, doi:10.1002/2016JC011747 and Kaj Johnson's talk later today for So. California viewpoint.

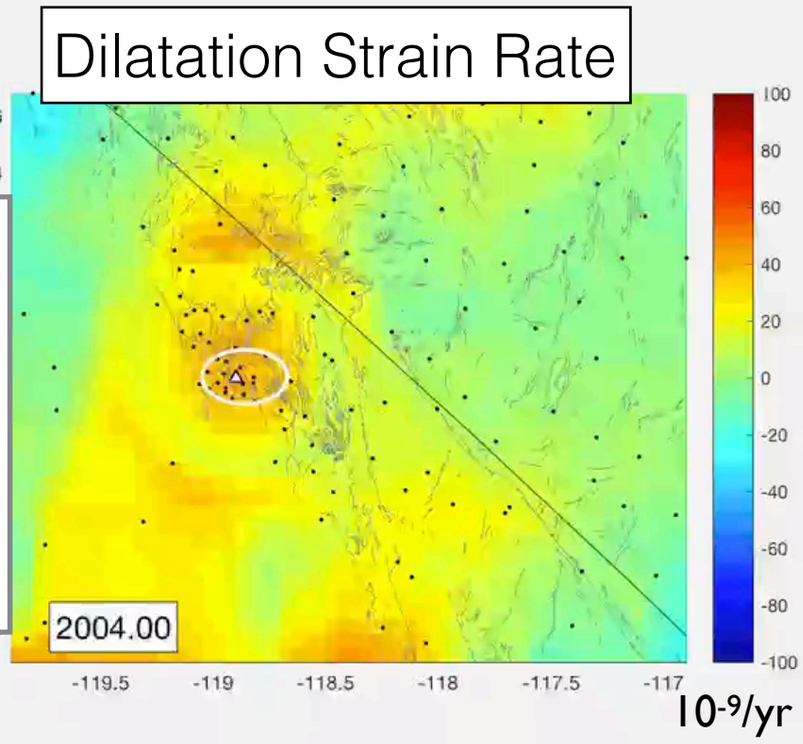


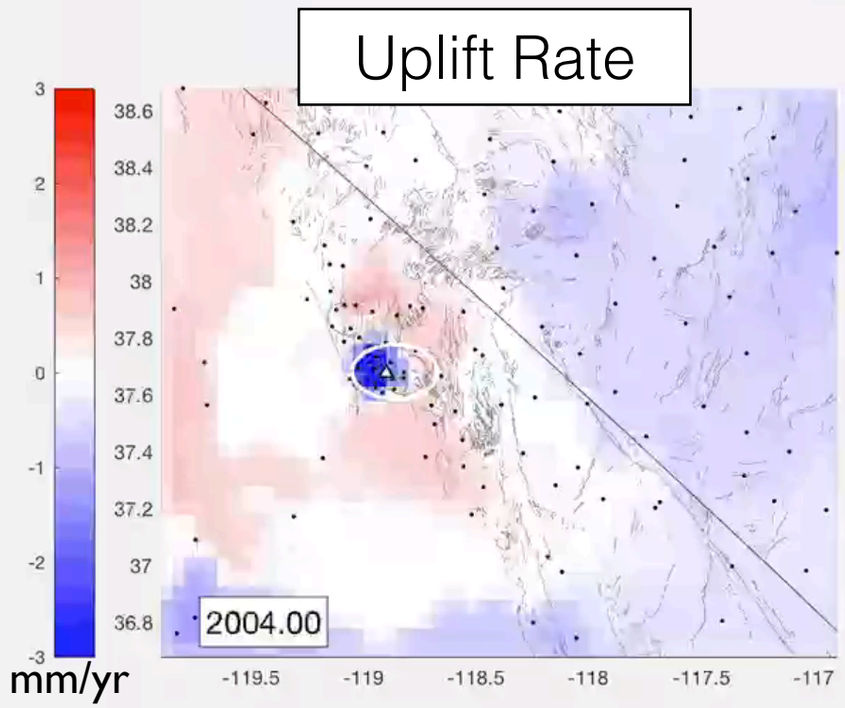
Steve Nerem group, Univ.Colorado

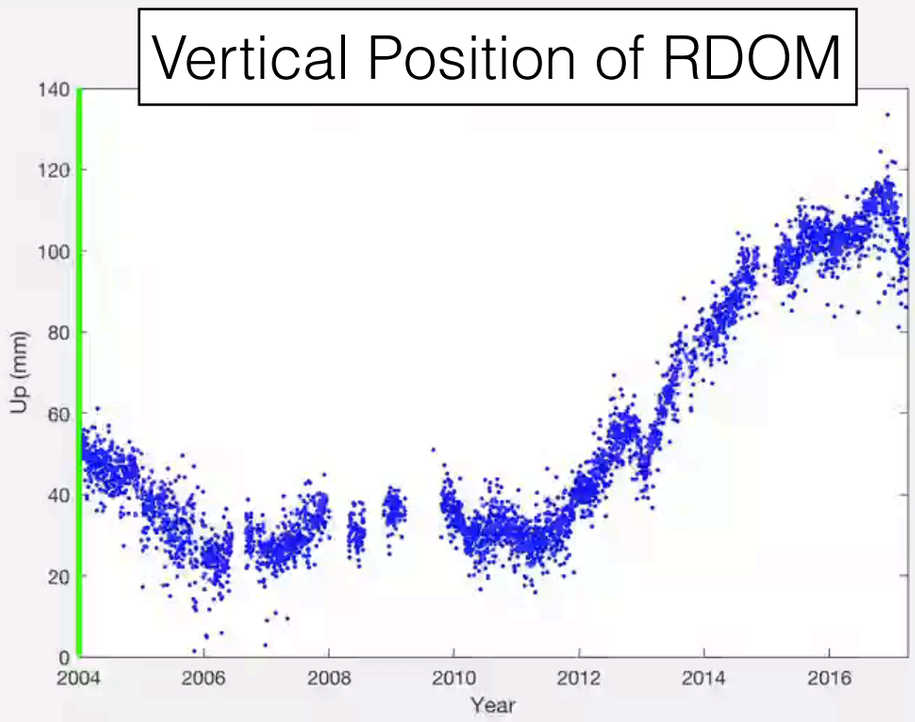
Long Valley Caldera/Central Walker Lane Climatic, Magmatic, Tectonic Interactions

- Example of using GPS Imaging to enhance interpretative value
- Animation constructed using GPS Imaging
- Uplift at RDOM on the Resurgent Dome reflects magmatic inflation
- Time variable inflation
- Really kicks in late 2011
- Shear strain, dilatation, uplift separable
- Shear strain interrupted by inflation
- Shear strain enhanced >80 km from LV!
- Seismicity correlated in time and location with shear strain





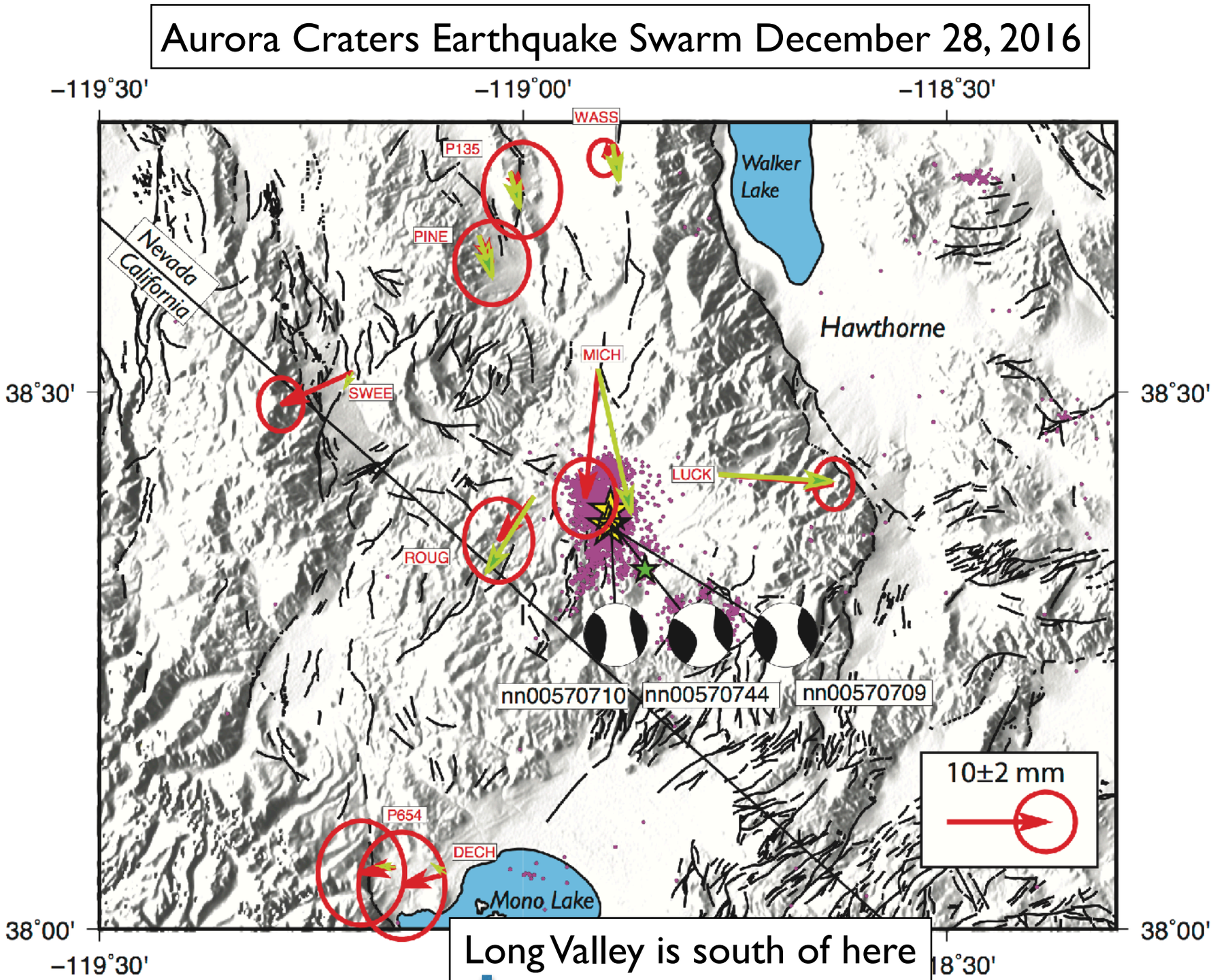




Long Valley Caldera
Climatic, Magmatic, Tectonic Interactions

- LV-related magmatism culminated in a seismic swarm with three mid-M5 events
- Up to 1 cm offsets seen with MAGNET GPS Network (No continuous stations close enough)
- GPS animation suggests a teleconnection between earthquakes and Long Valley magmatism
- Though resurgent dome, locus of historic inflation, is over 80 km distant

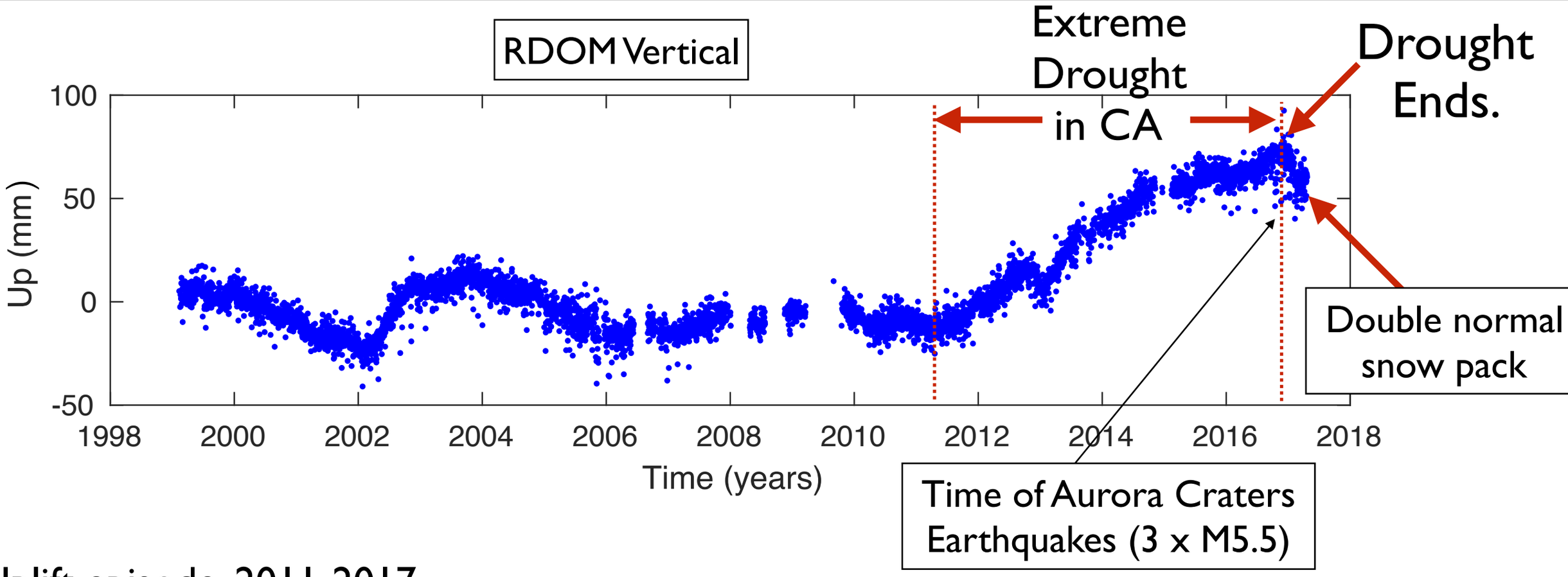
That's the magmatic/ tectonic interaction, but climate?



Long Valley is south of here
80 km to RDOM

USGS science for a changing world
Made possible with support from USGS Geodetic Networks

Long Valley Caldera/Central Walker Lane
Climatic, Magmatic, Tectonic Interactions

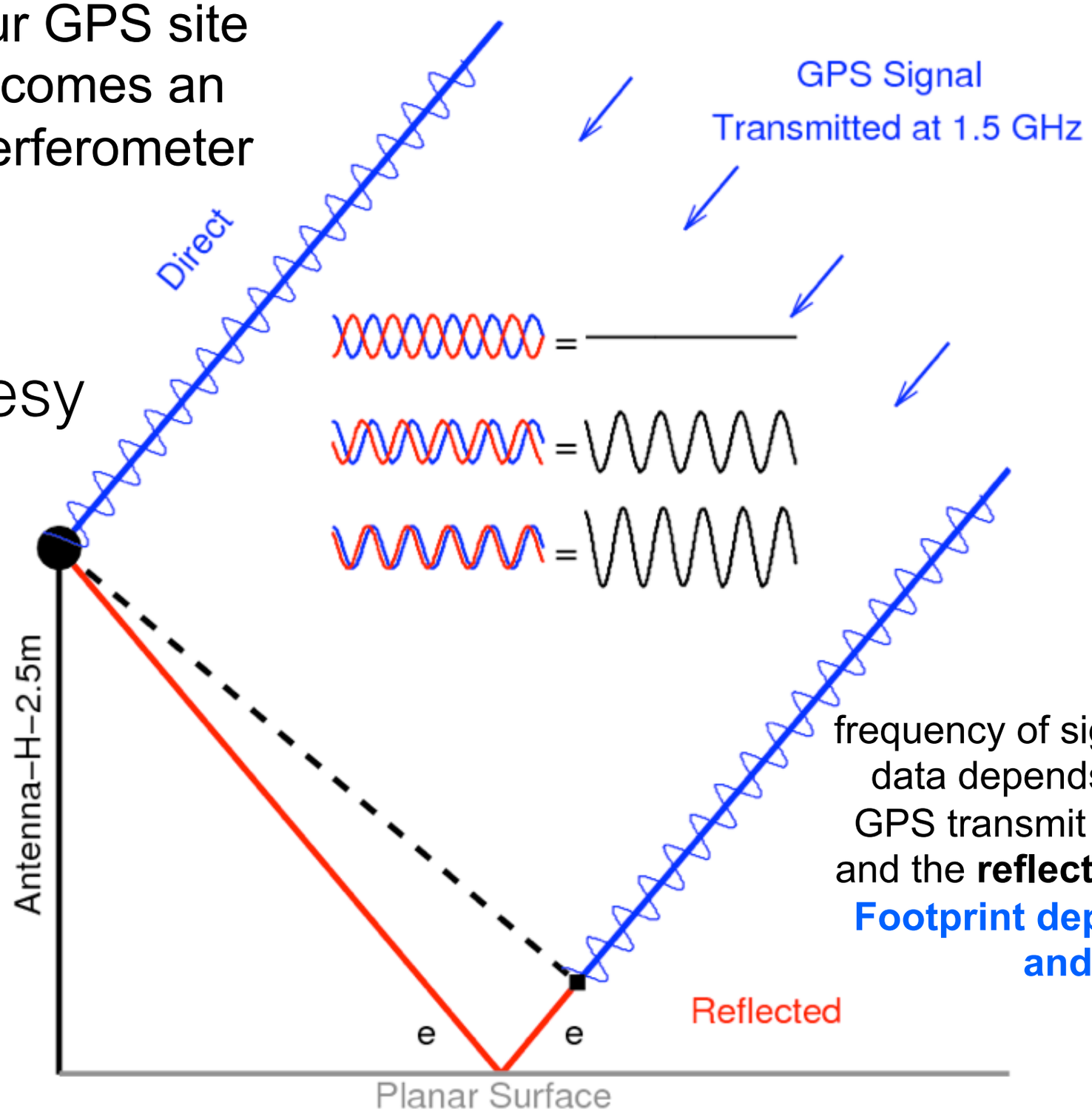


- Uplift episode, 2011-2017
- Beginning and end correlated in time with extreme drought in California
- Huge snow year 2016/17 (double normal snow pack)
- Timed with recent downturn in inflation

- Suggestive of climate influence on magmatic inflation, possibly via snow loading
- Looking further back (1978-2004) correlation between drought and inflation is weak.
- But climate is complicated.
- May be sensitive only to hardest droughts/wet years
- Mechanism documented in Iceland

Terrestrial Hydrology
soil moisture, snow, above-ground biomass

Your GPS site becomes an interferometer

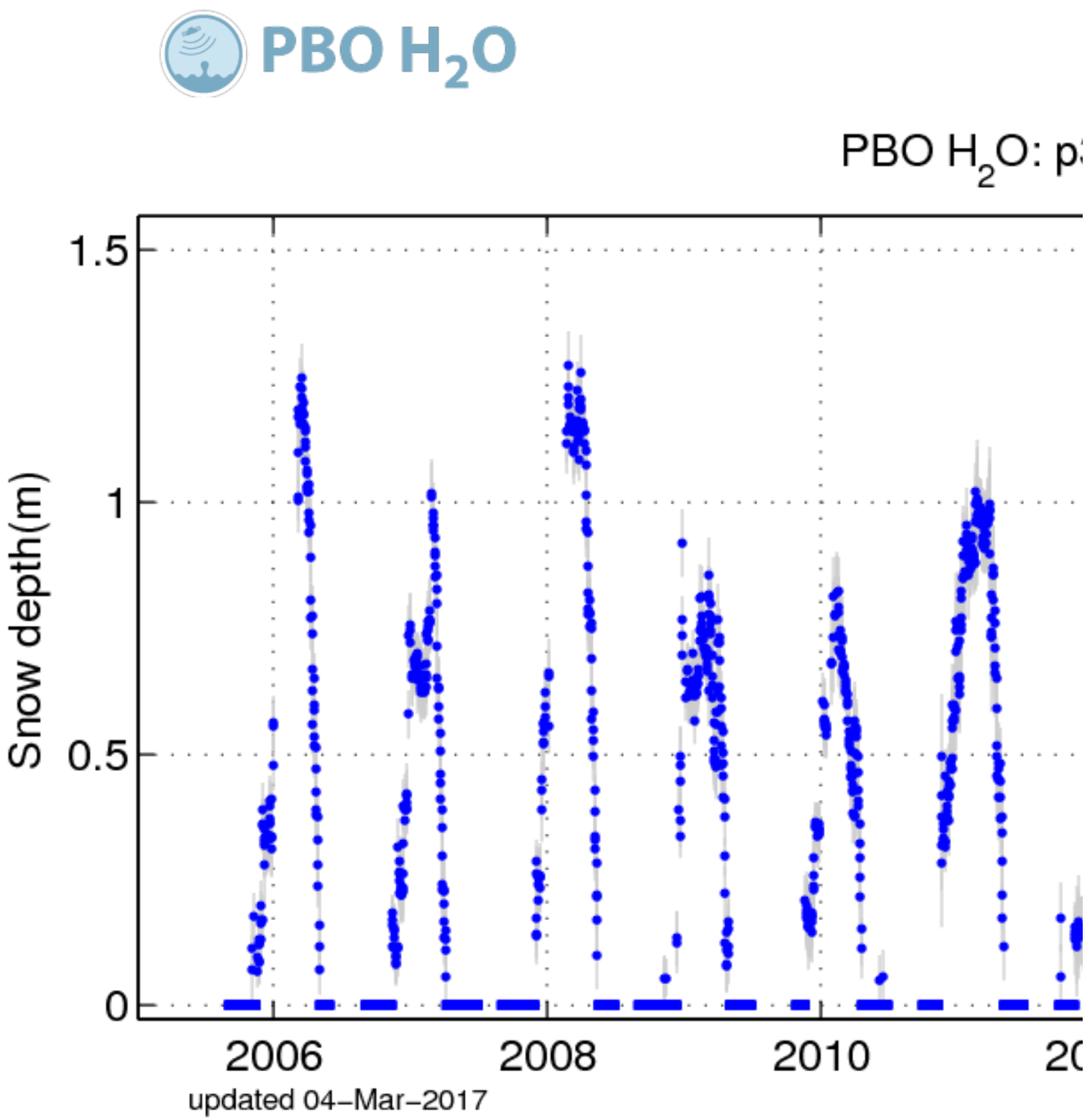


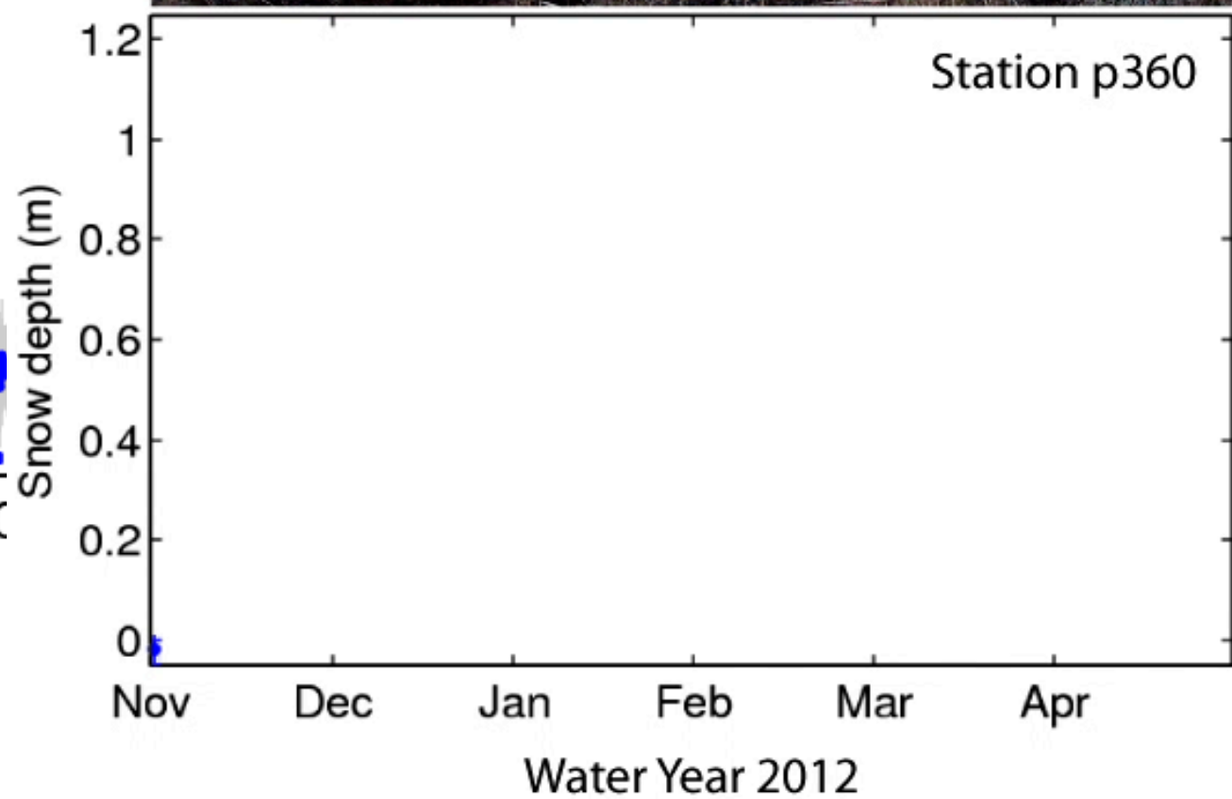
All PBO H_2O slides courtesy of Kristine Larson

frequency of signal strength data depends on **H**, the GPS transmit **frequency**, and the **reflecting medium.**

Footprint depends on H and e.

Snow Climatology

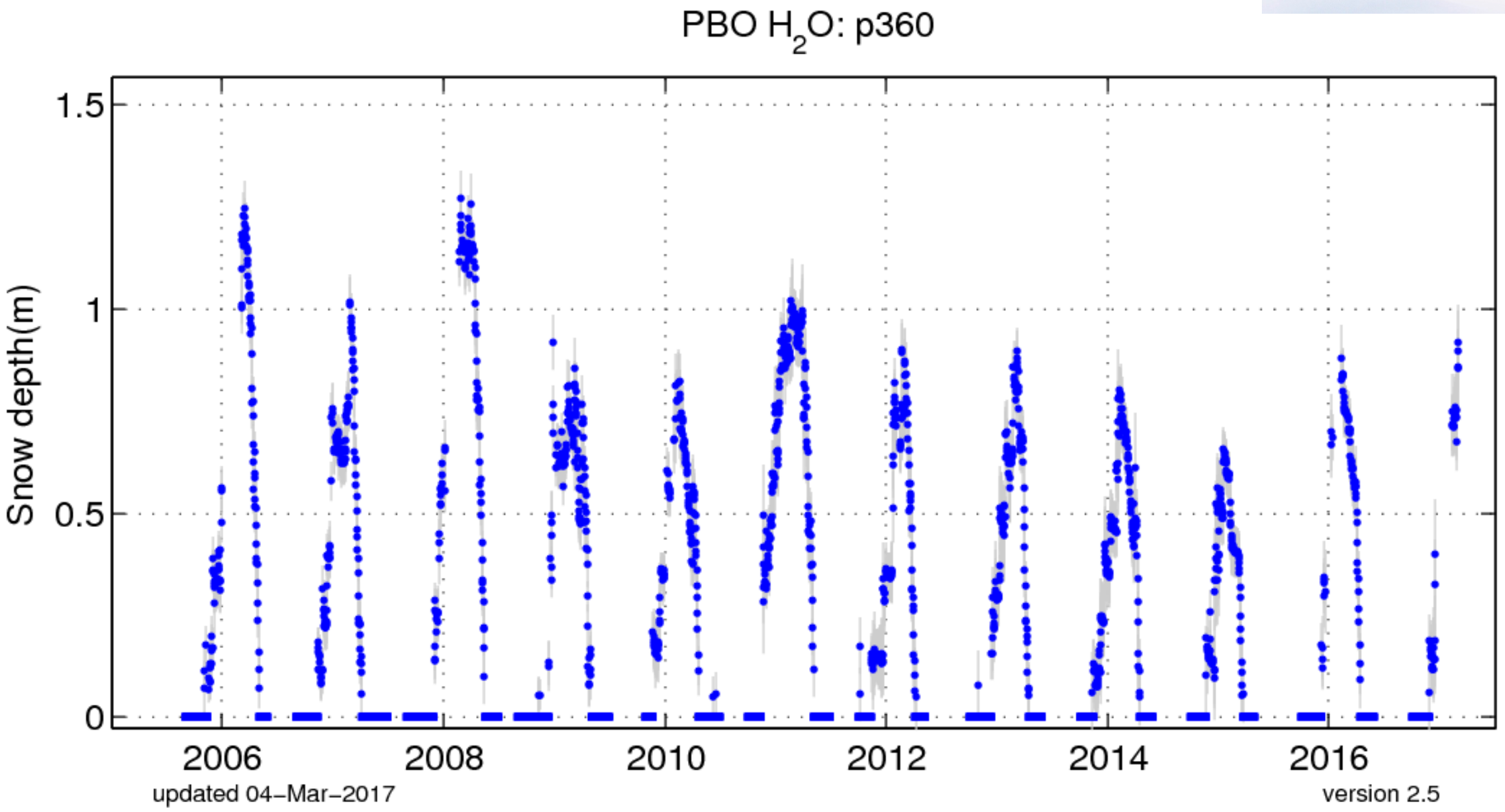




Note: we also provide a SWE product

Snow Climatology

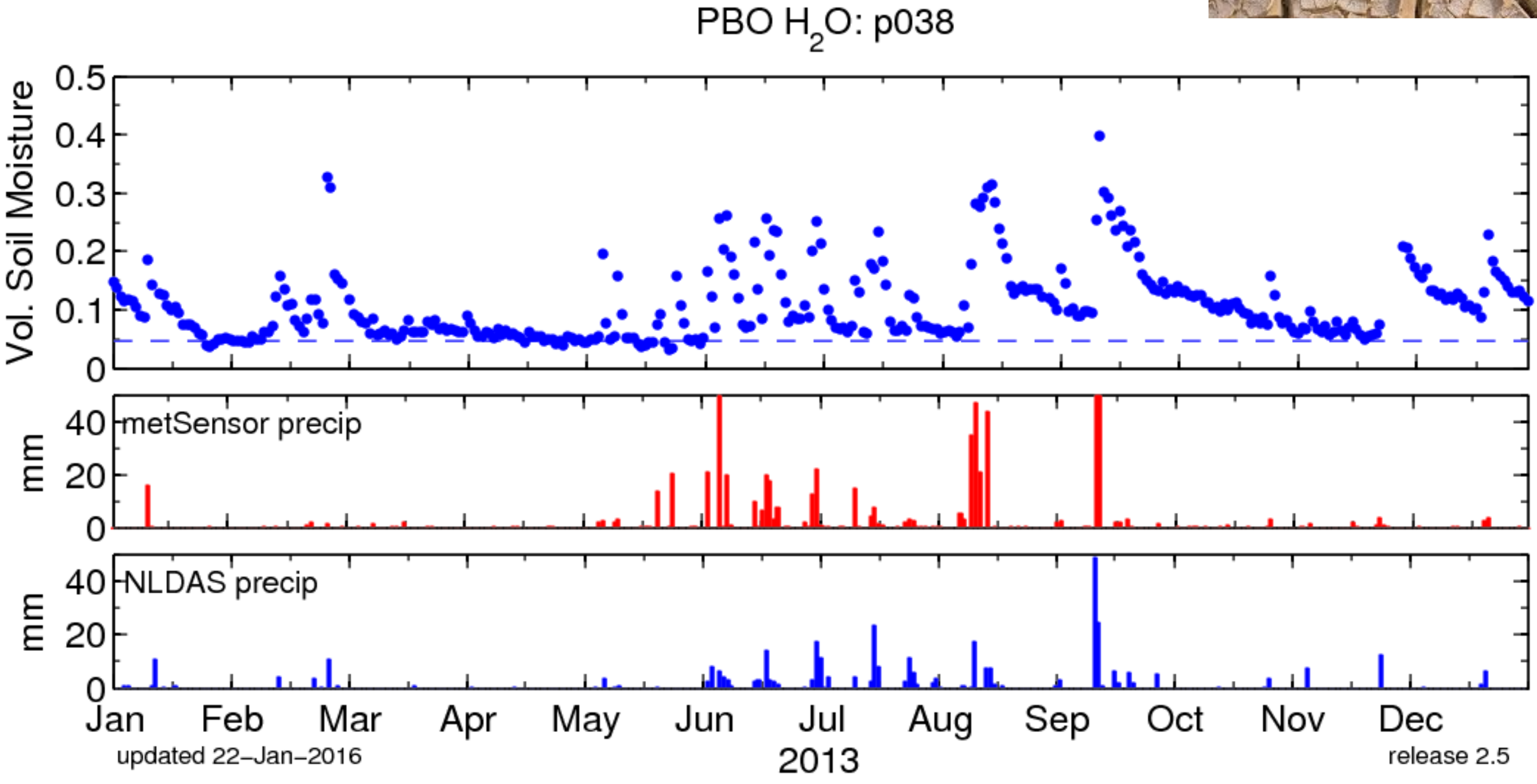
PBO H_2O



Note: we also provide a SWE product

Soil Moisture

PBO H_2O

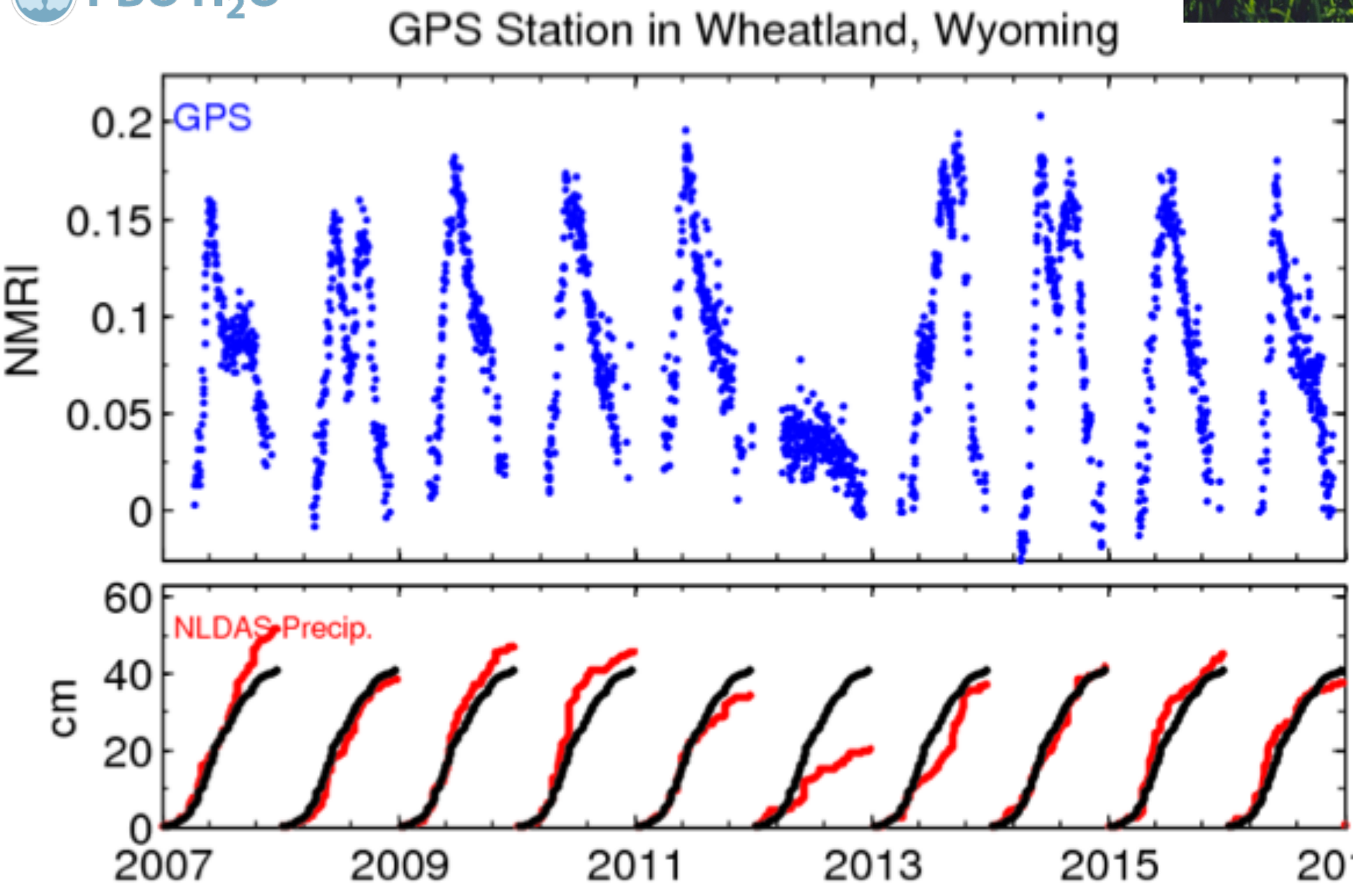


PBO H_2O

GPS Station Wheatland, WO

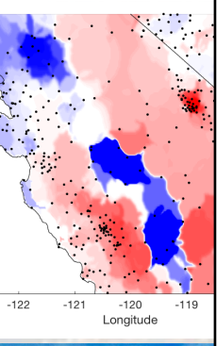
Above Ground Biomass

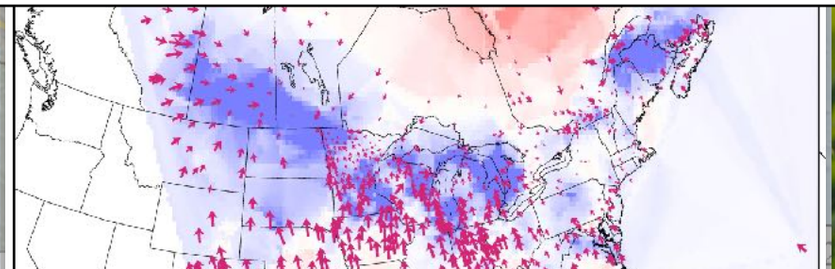
PBO H_2O



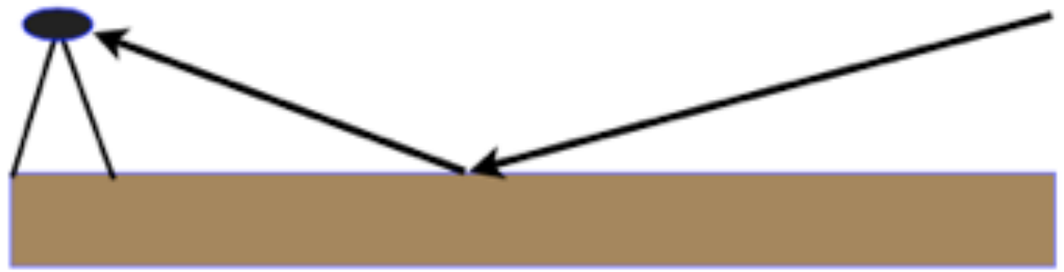
Legacy of PBO

- The **mega-network** illuminated synoptic continental-scale signals, in the EarthScope footprint and beyond.
- Enabled discovery and characterization of surface deformation and many classes of Earth processes.
- Provided a new appreciation for the role of water in controlling the vertical signals, from continents, to aquifers, to land cover, to magmatic systems.
- And we did not even mention early warning systems or seismic hazard analysis!
- PBO offspring array will be poised to continue to make exciting new discoveries!

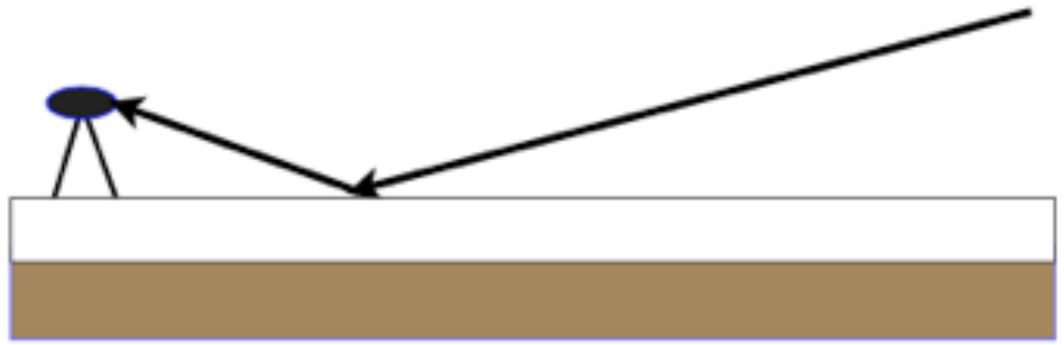




the reflections off bare soil produce this SNR curve

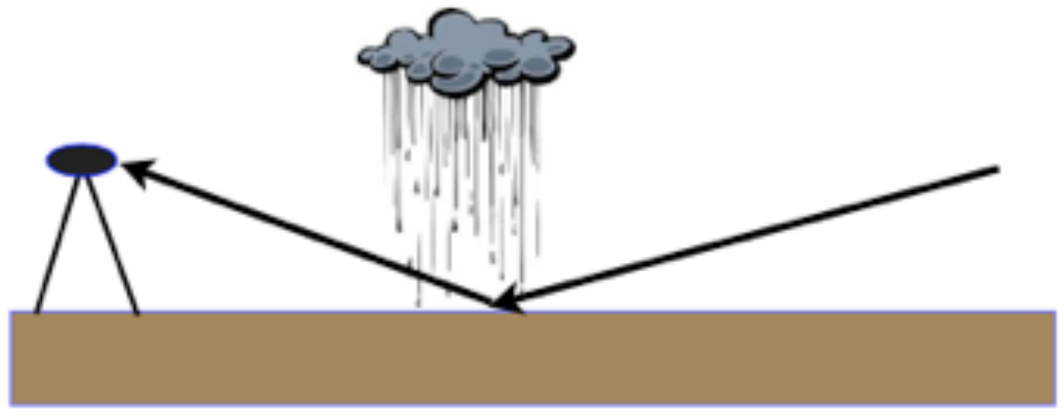


add a snow layer



add vegetation

make the soil wet



Larson et al., 2008; Larson et al., 2009; Small et al., 2010

http://xenon.colorado.edu/portal