The Use of Ground Motion Data from InSAR to Explore and Manage the Groundwater Systems in California's Central Valley

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SEPTEMBER 17, 2019

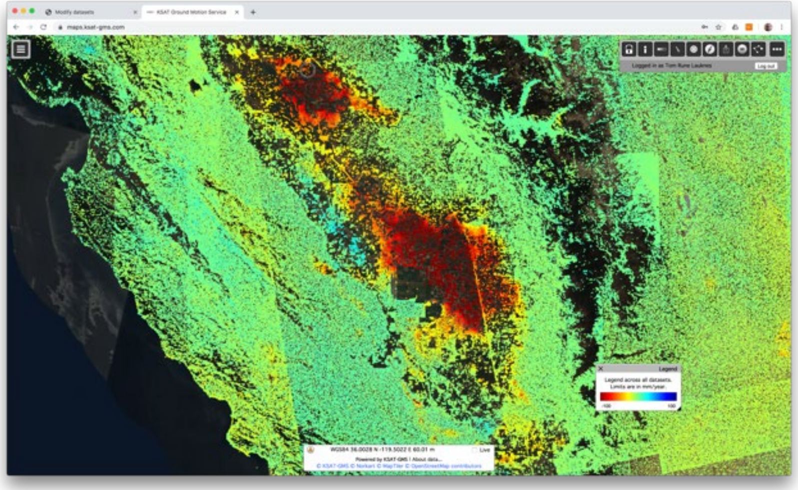
We will study applications of InSAR to groundwater management in California

Credit: J. Poland (USGS, 1977)

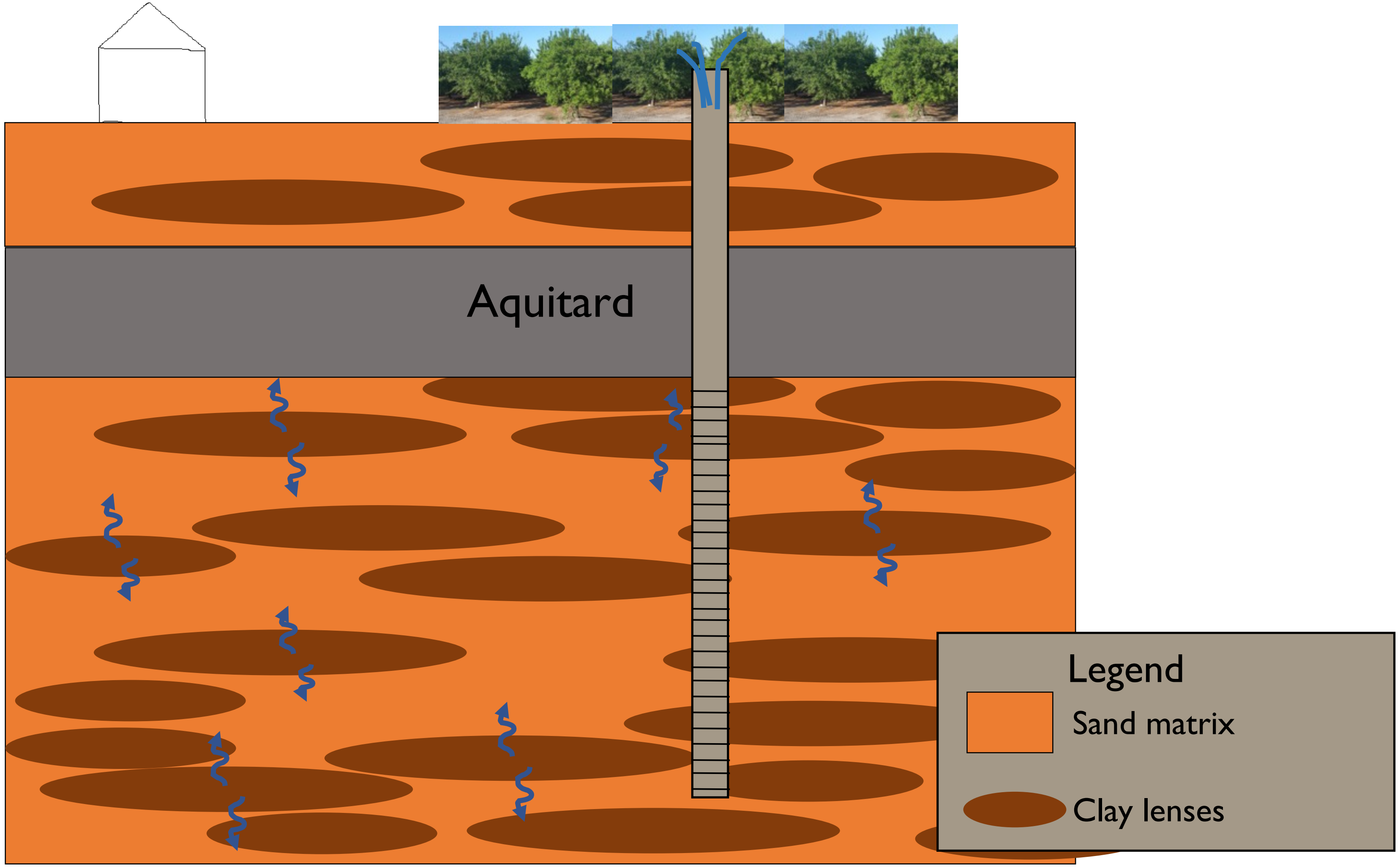
Motivation

InSAR exploration platform

InSAR in Central Valley

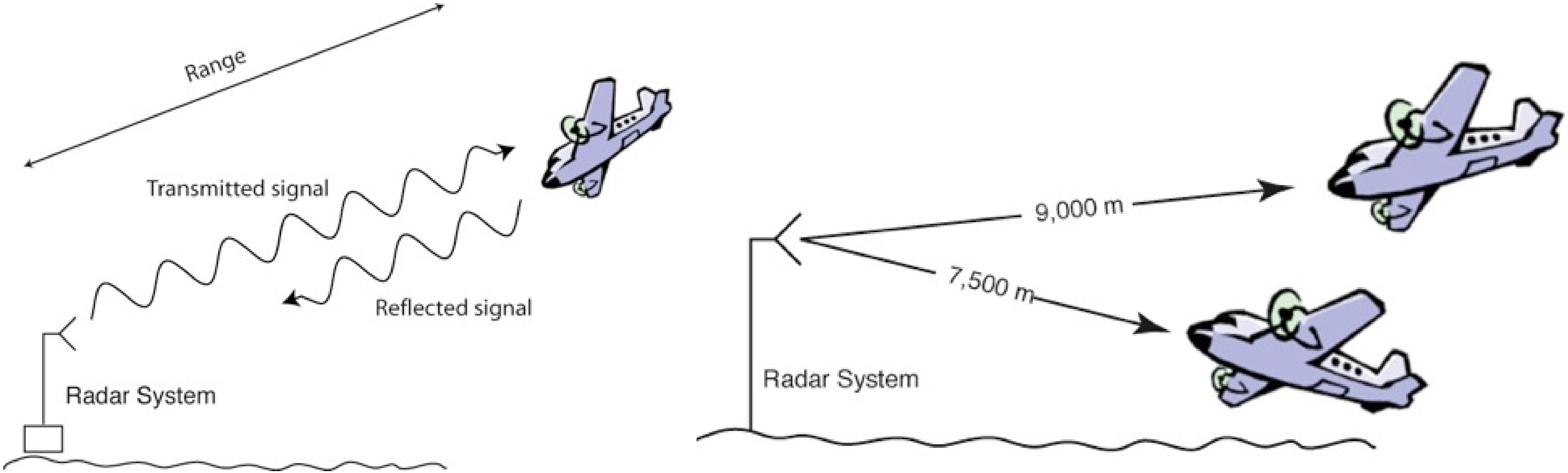


Ground subsidence caused by extraction of ground water



Credit: Ryan Smith

A radar transmits electromagnetic pulses and measures time for echo to return



Satellite synthetic aperture radar remote sensing has many advantages

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No need for external illumination

Penetrates clouds, vegetation

Can measure phase (distance) at a fraction of the wavelength

Continuous spatial and temporal coverage

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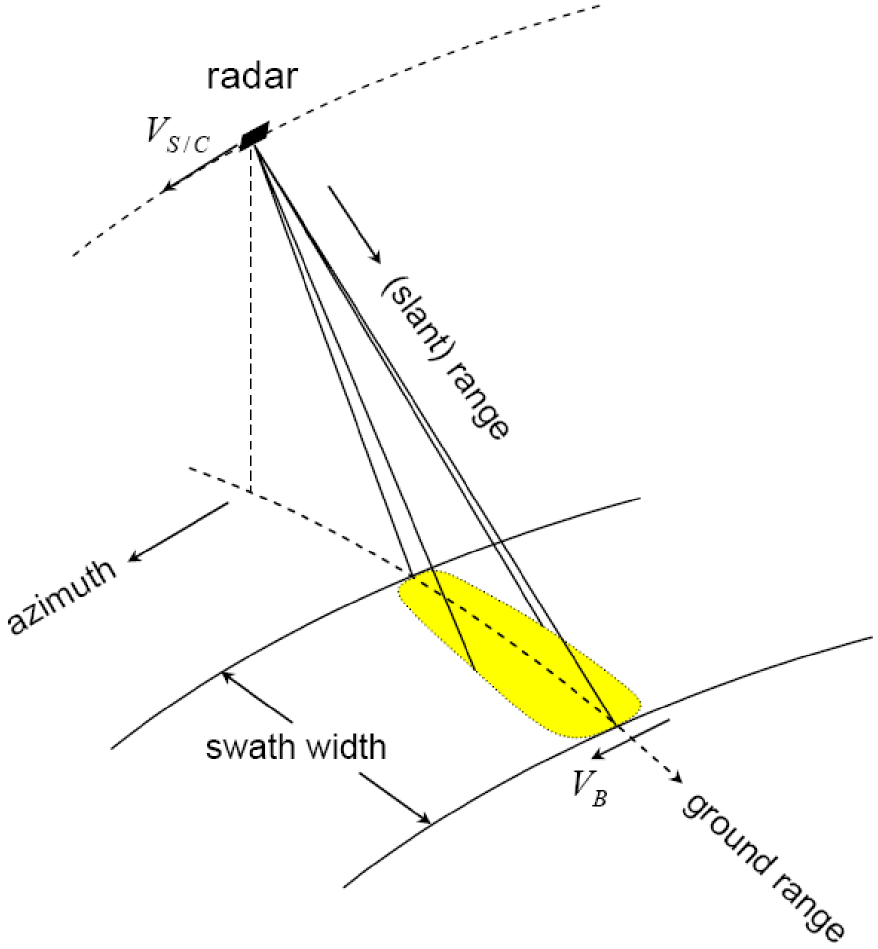
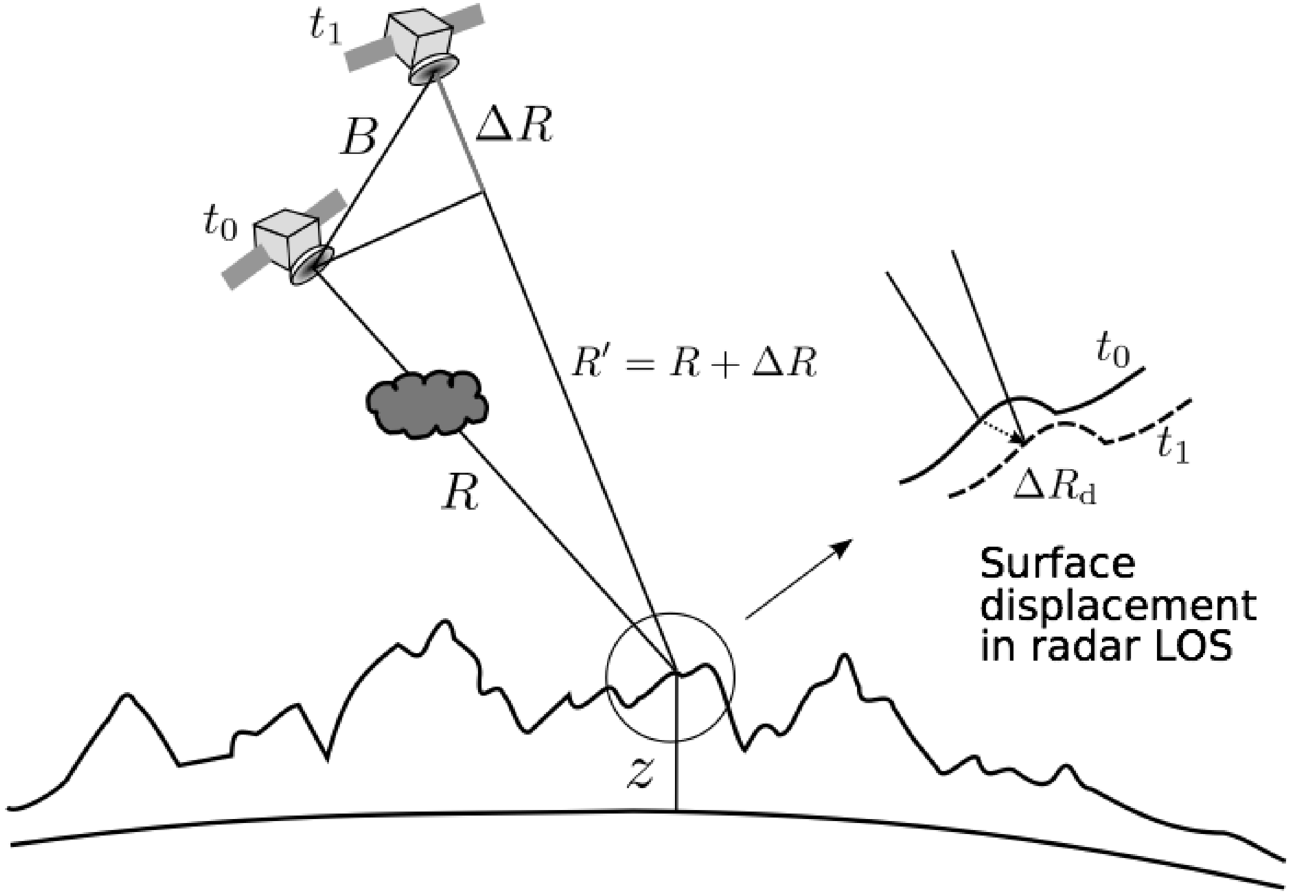
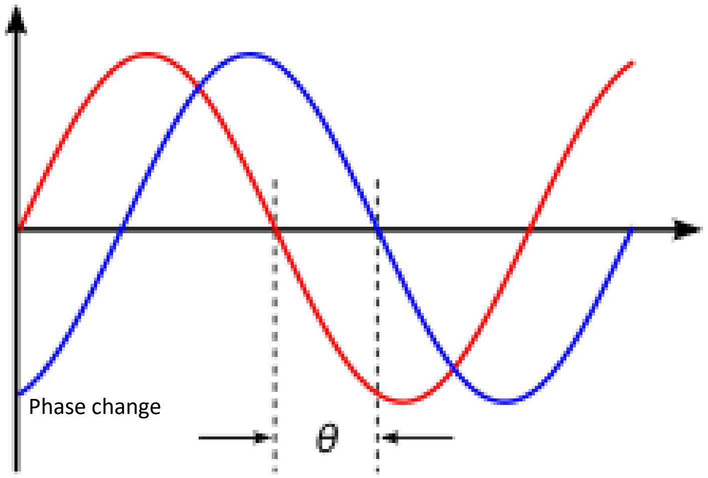


InSAR studies phase difference between two SAR images



InSAR is sensitive to mm-level displacement in the radar LOS

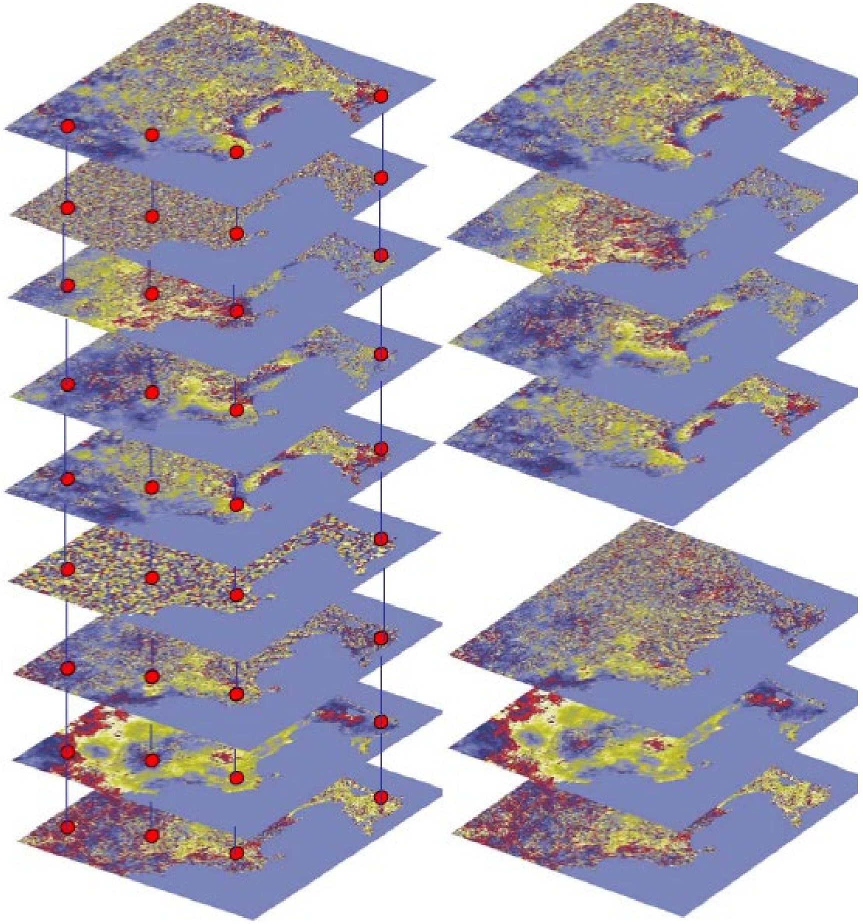


Advanced InSAR methods use information from many SAR images to extract deformation signal

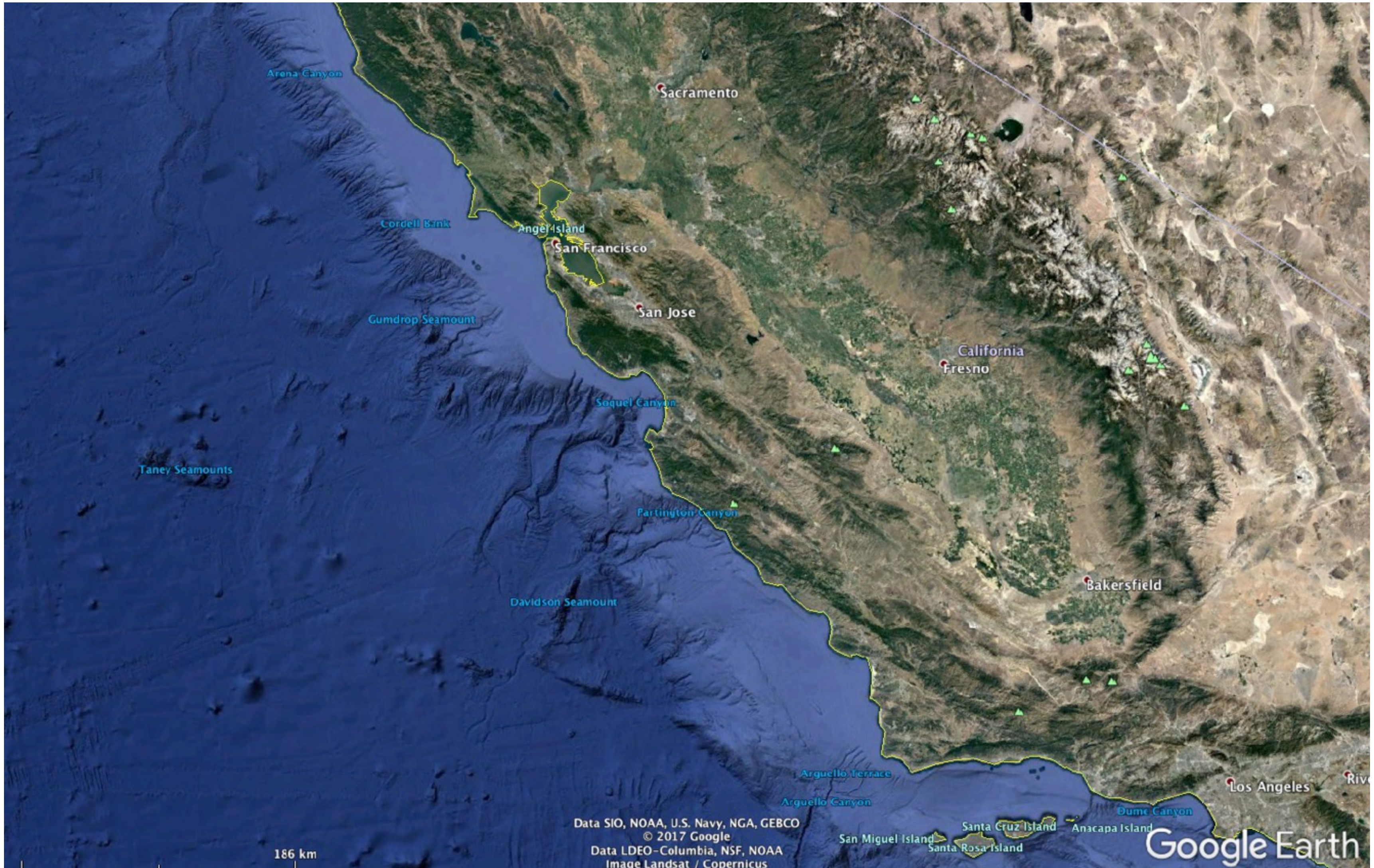
Separates *deformation* from noise sources

By using many SAR images (typically > 30)

Very active research field!



Ground subsidence in Central Valley, CA, observed by satellite InSAR



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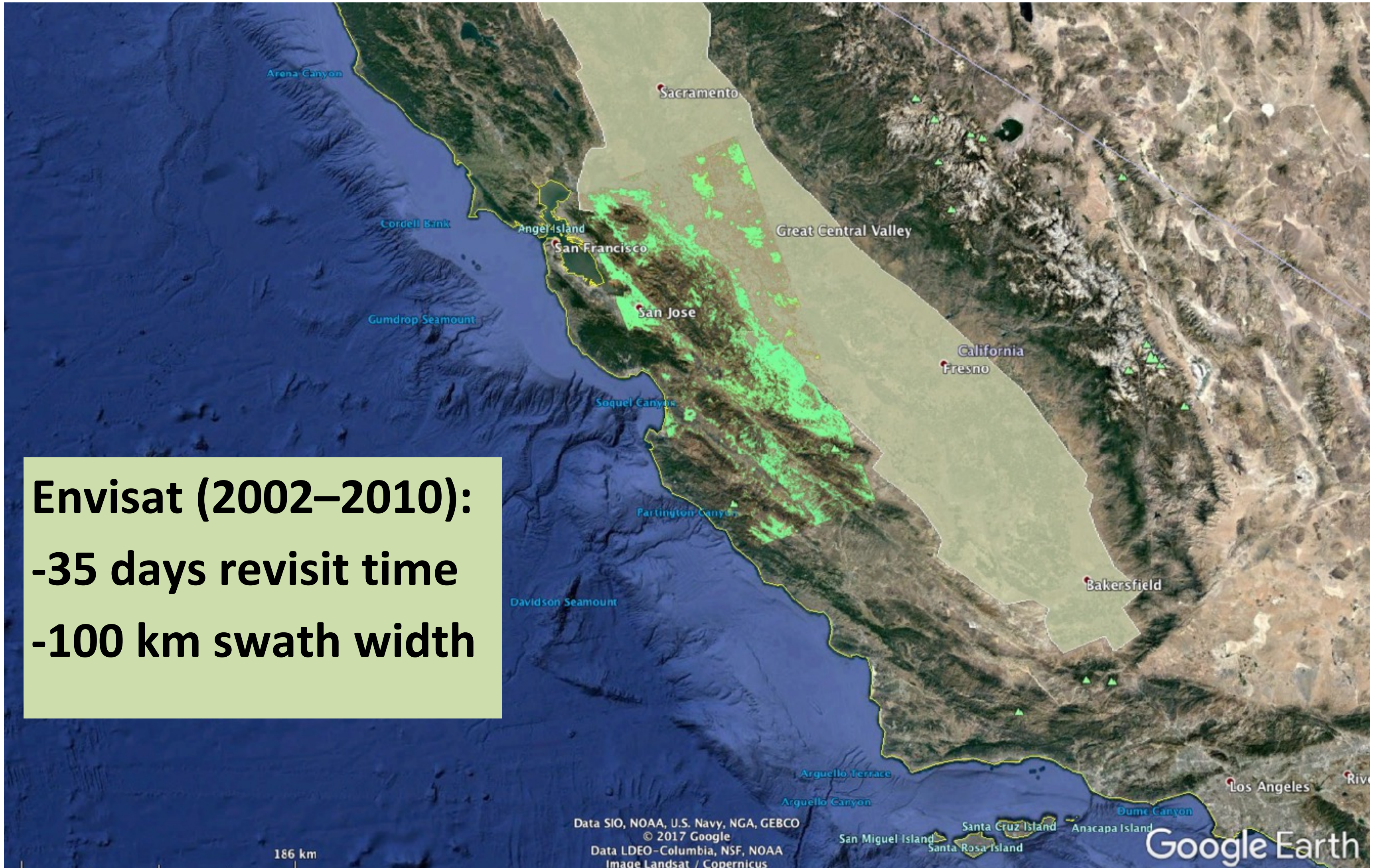
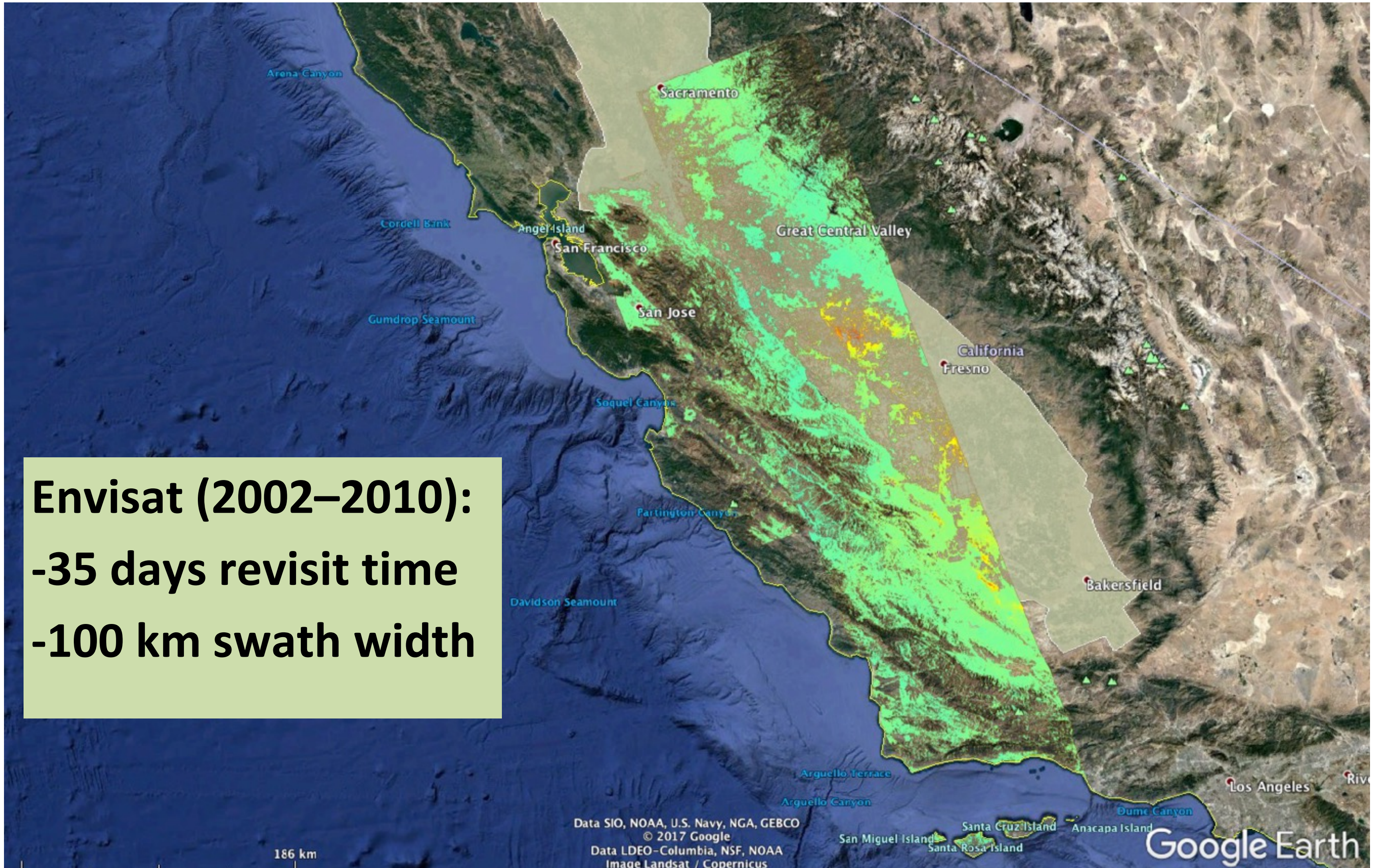


Envisat (2002–2010):

-35 days revisit time

-100 km swath width

Ground subsidence in Central Valley, CA, observed by satellite InSAR



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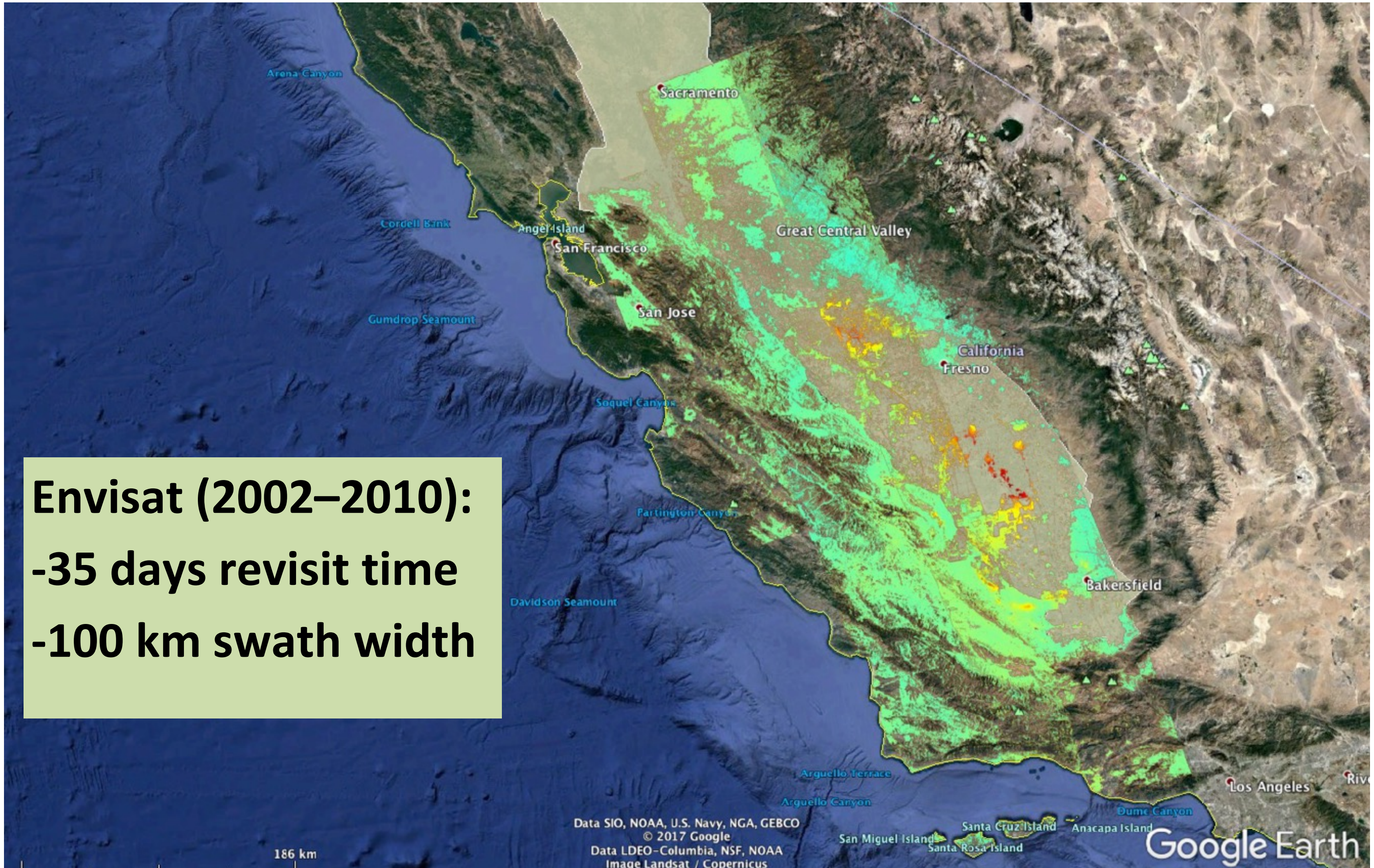

Ground subsidence in Central Valley, CA, observed by satellite InSAR

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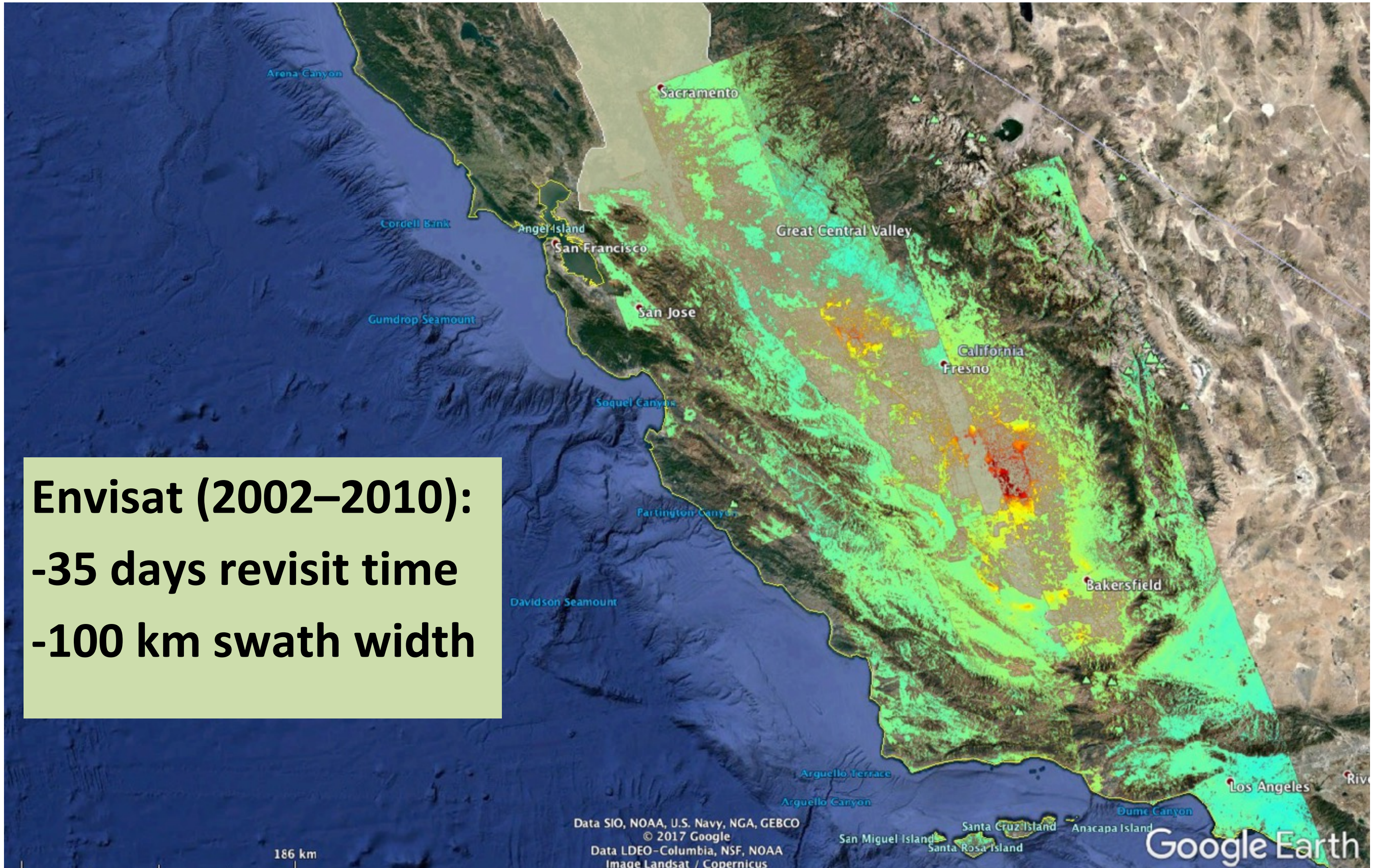
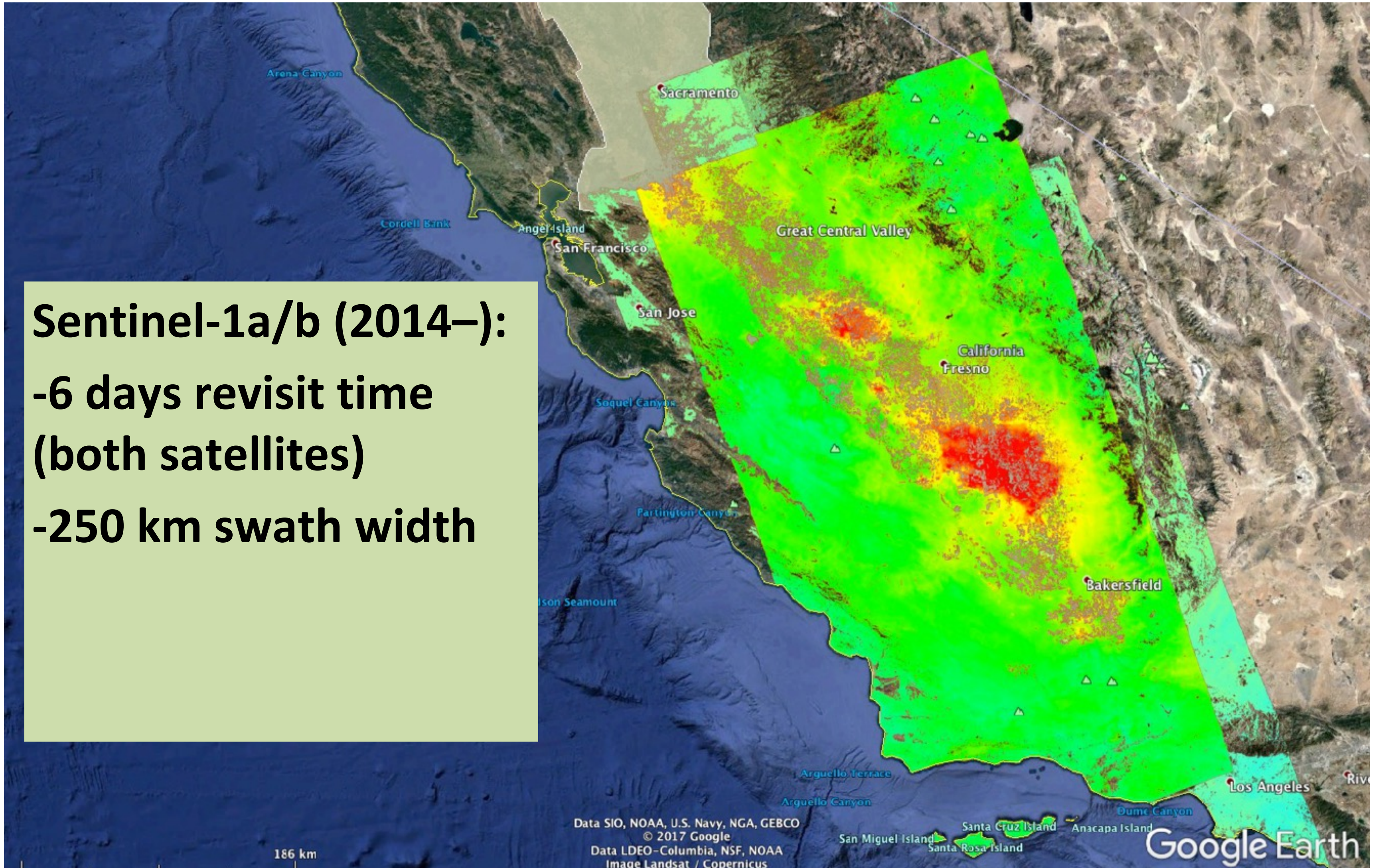


Ground subsidence in Central Valley, CA, observed by satellite InSAR

NORCE



Sentinel-1a/b (2014–):

-6 days revisit time (both satellites)

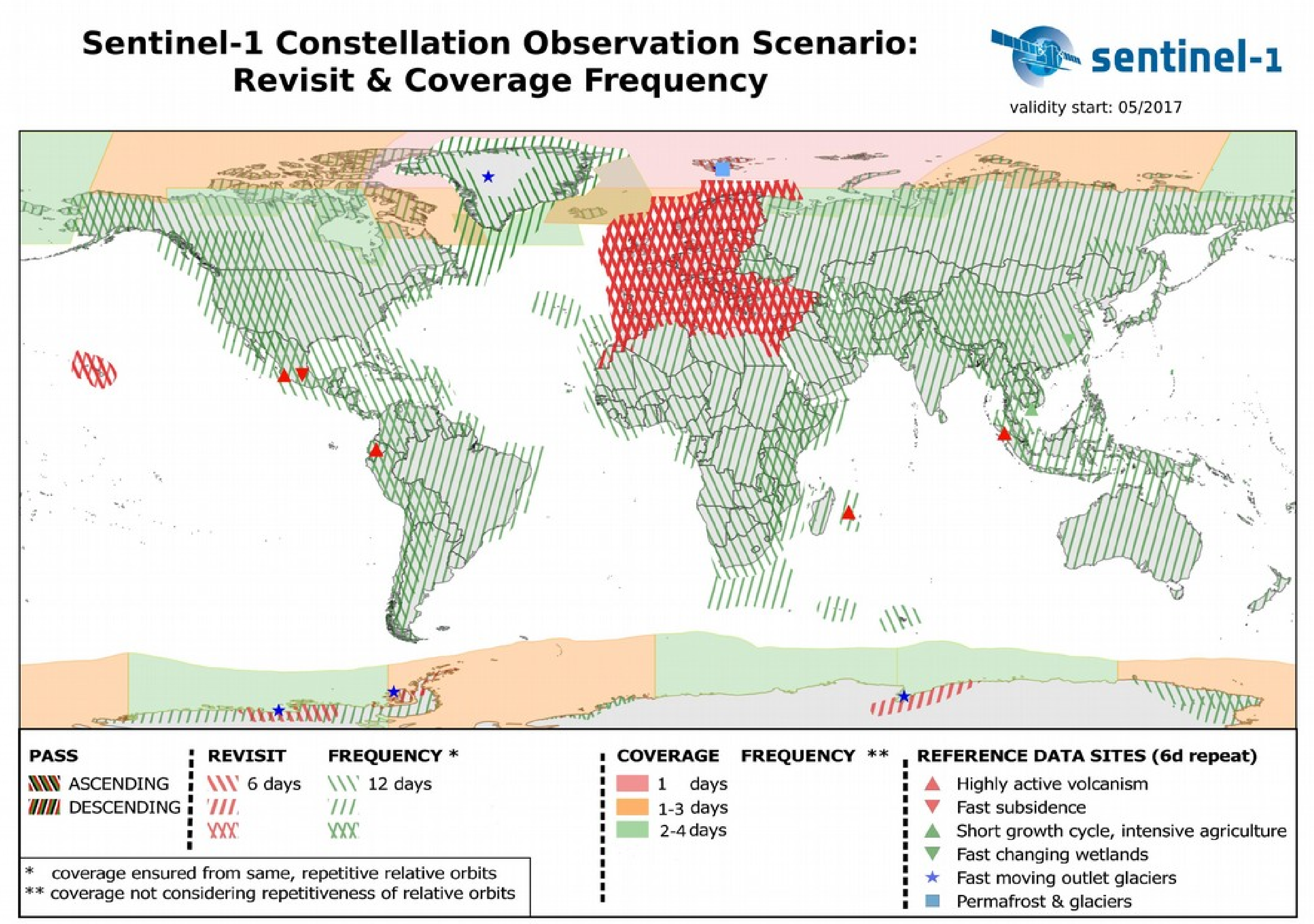
-250 km swath width

Sentinel-1 has started a new era for operational InSAR

Data → free & open data distribution policy

Acquisition plan →6/12/24 days

Lifetime → decade



InSAR.no: Norwegian ground motion service

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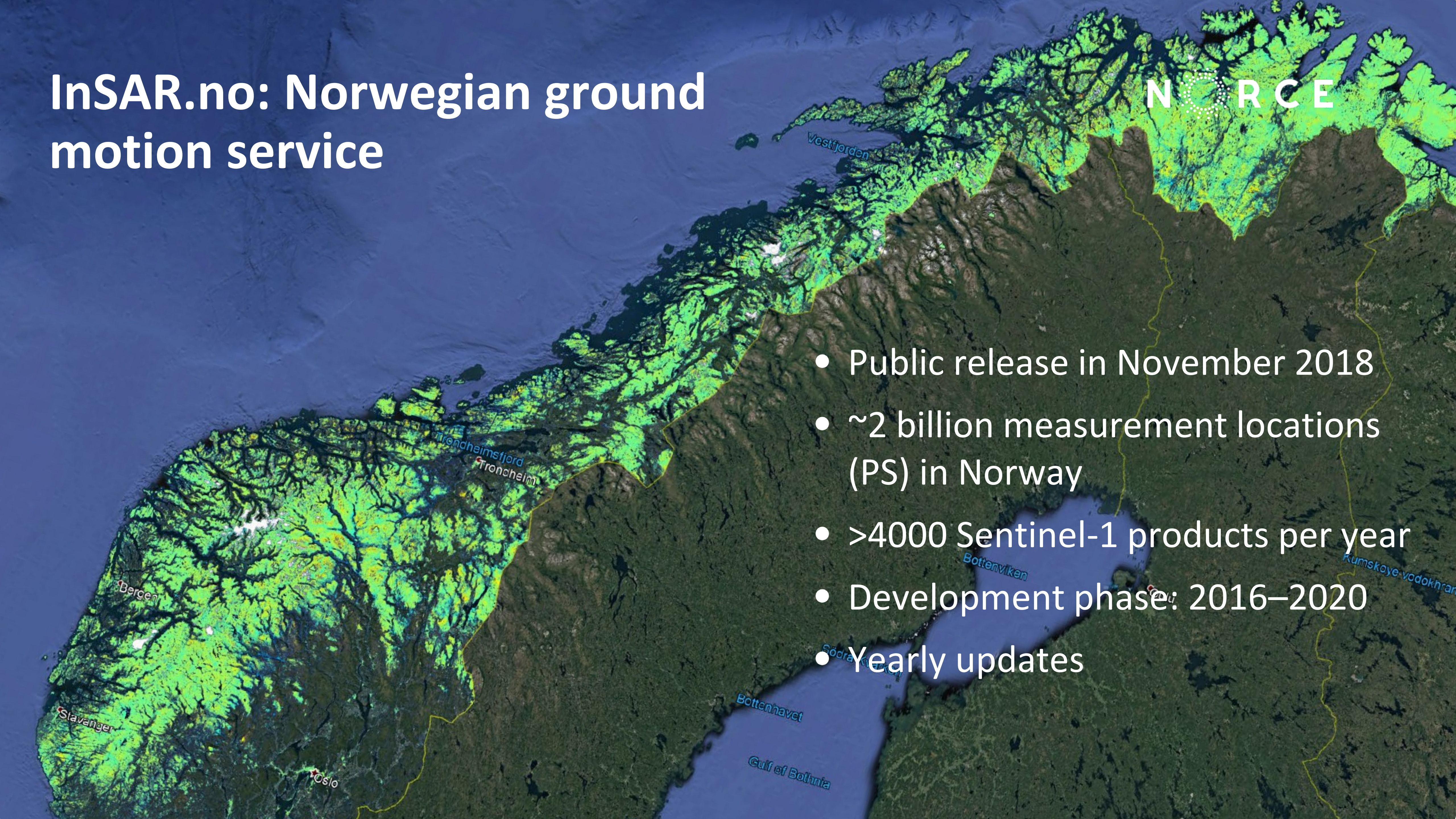
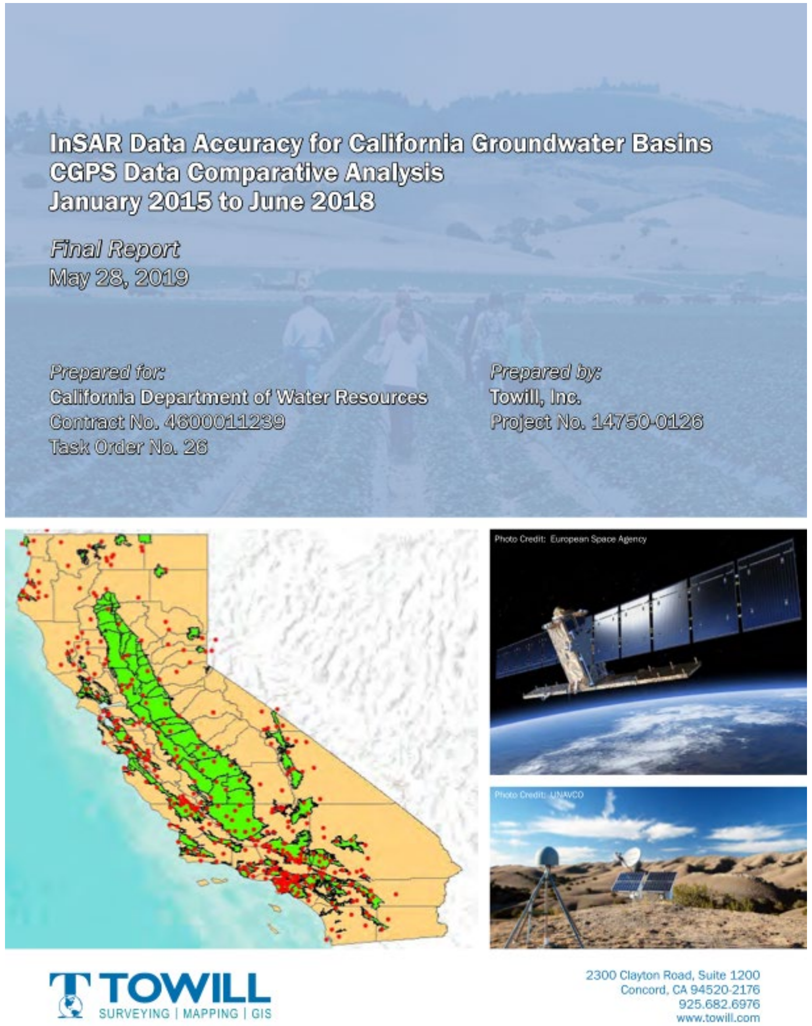
- Public release in November 2018
- ~2 billion measurement locations (PS) in Norway
- >4000 Sentinel-1 products per year
- Development phase: 2016–2020
- Yearly updates



InSAR data is also available for parts of California



InSAR land surveying and mapping services in support of the DWR SGMA program
Technical Report - May 2019

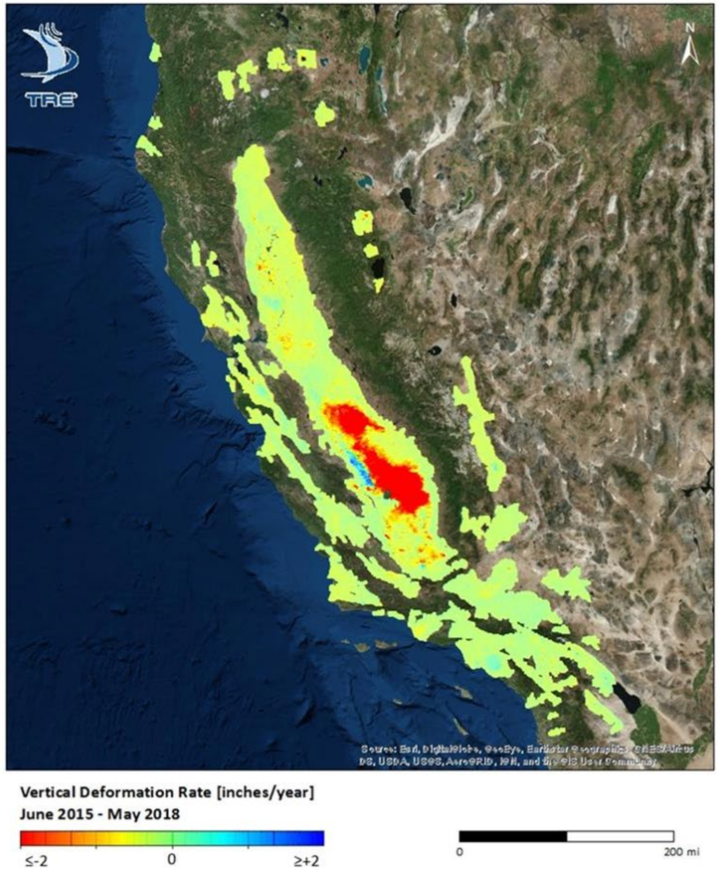
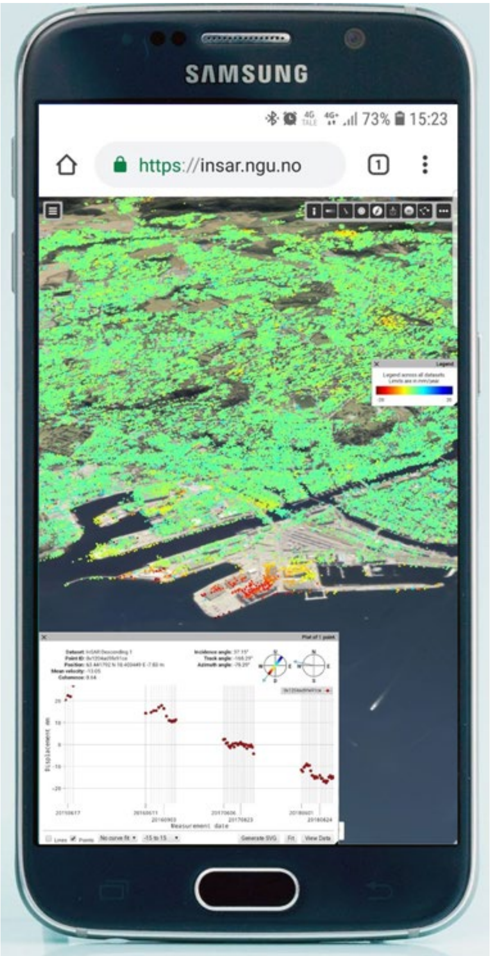
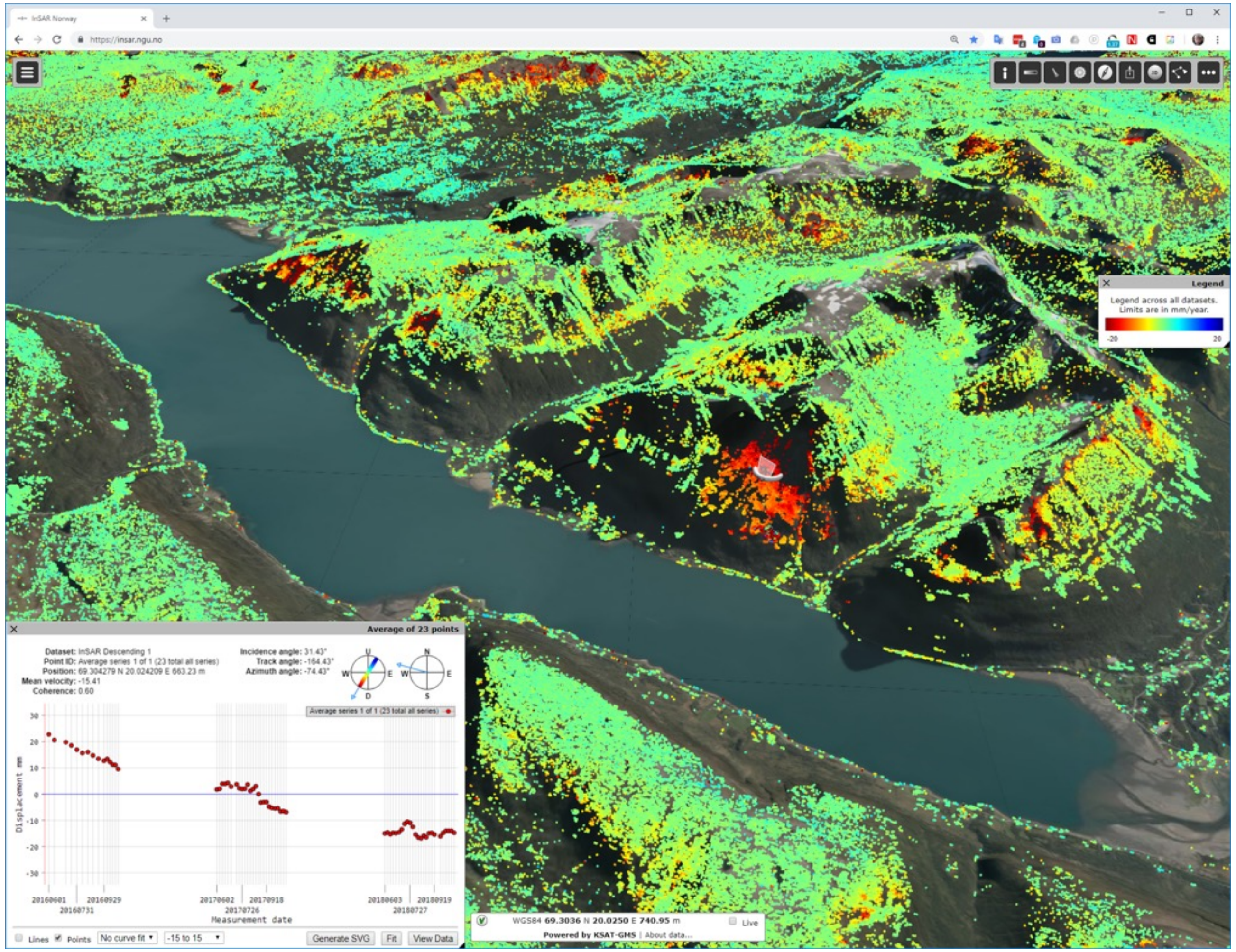
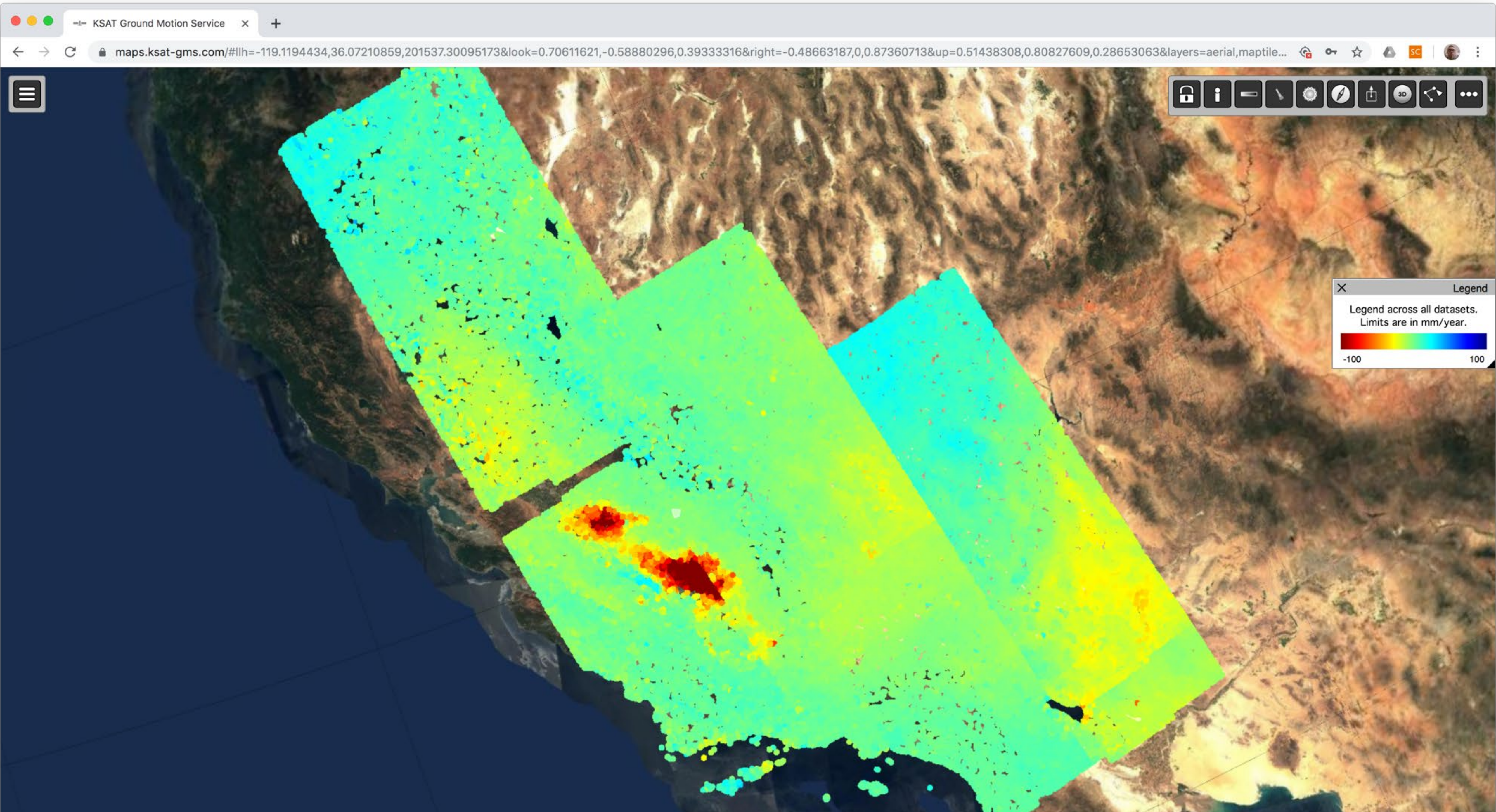


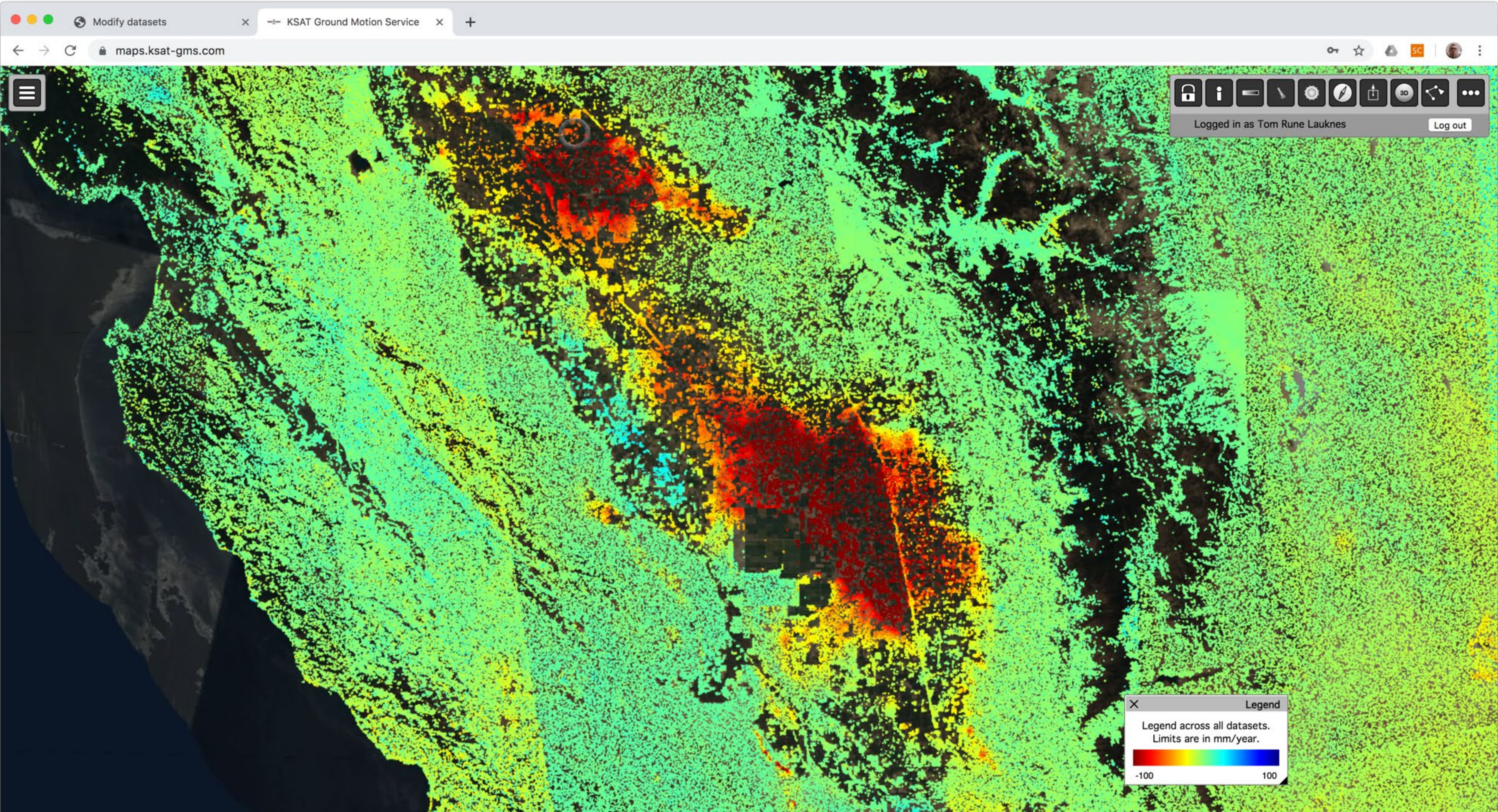
Figure 13: Vertical deformation rate map over the AOI. The sMP are colour coded according to their annual deformation rate (inches/year) within the common period (June 2015 – May 2018).

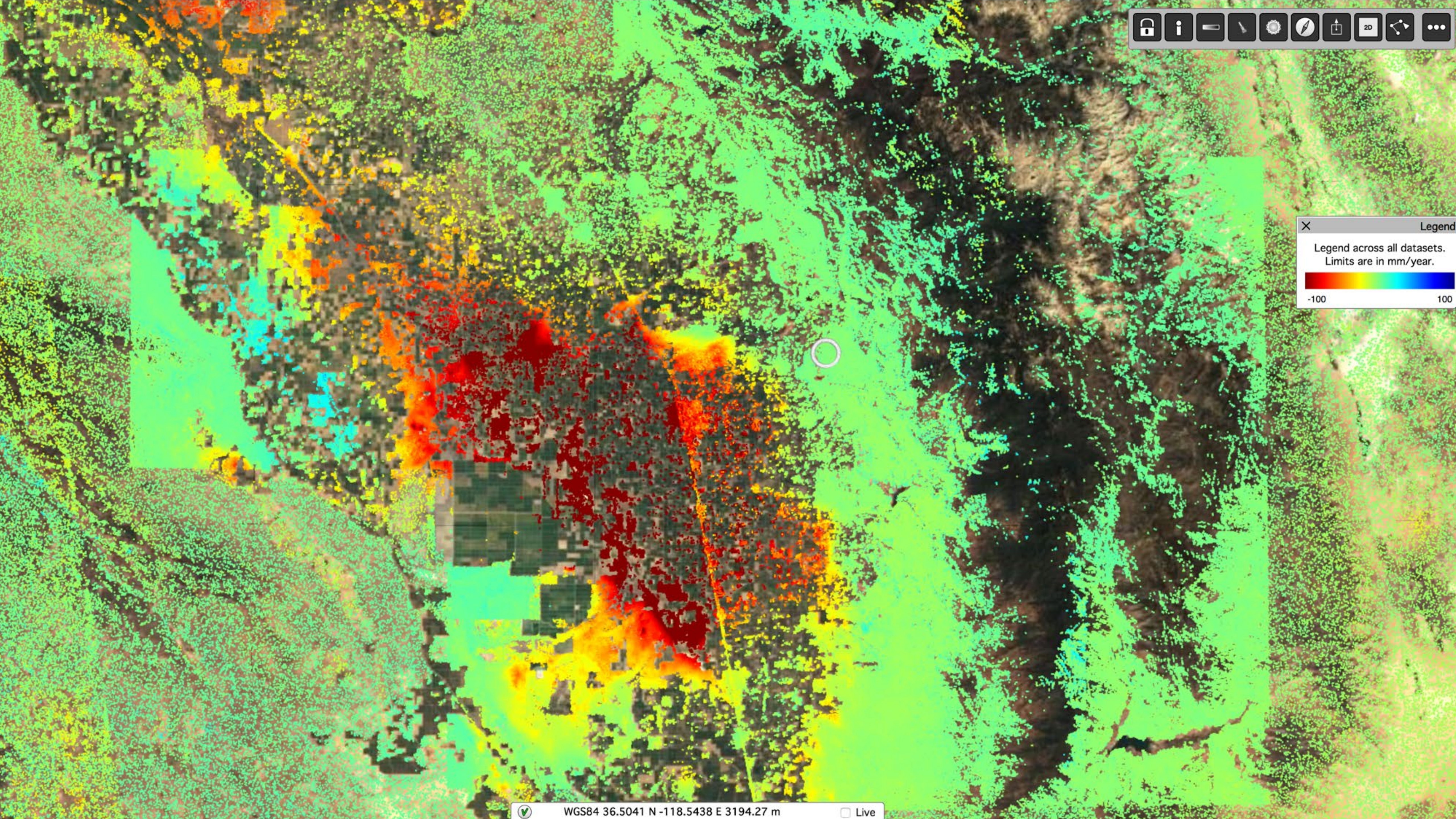
A cross-platform Data Exploration Tool is important to browse the InSAR data

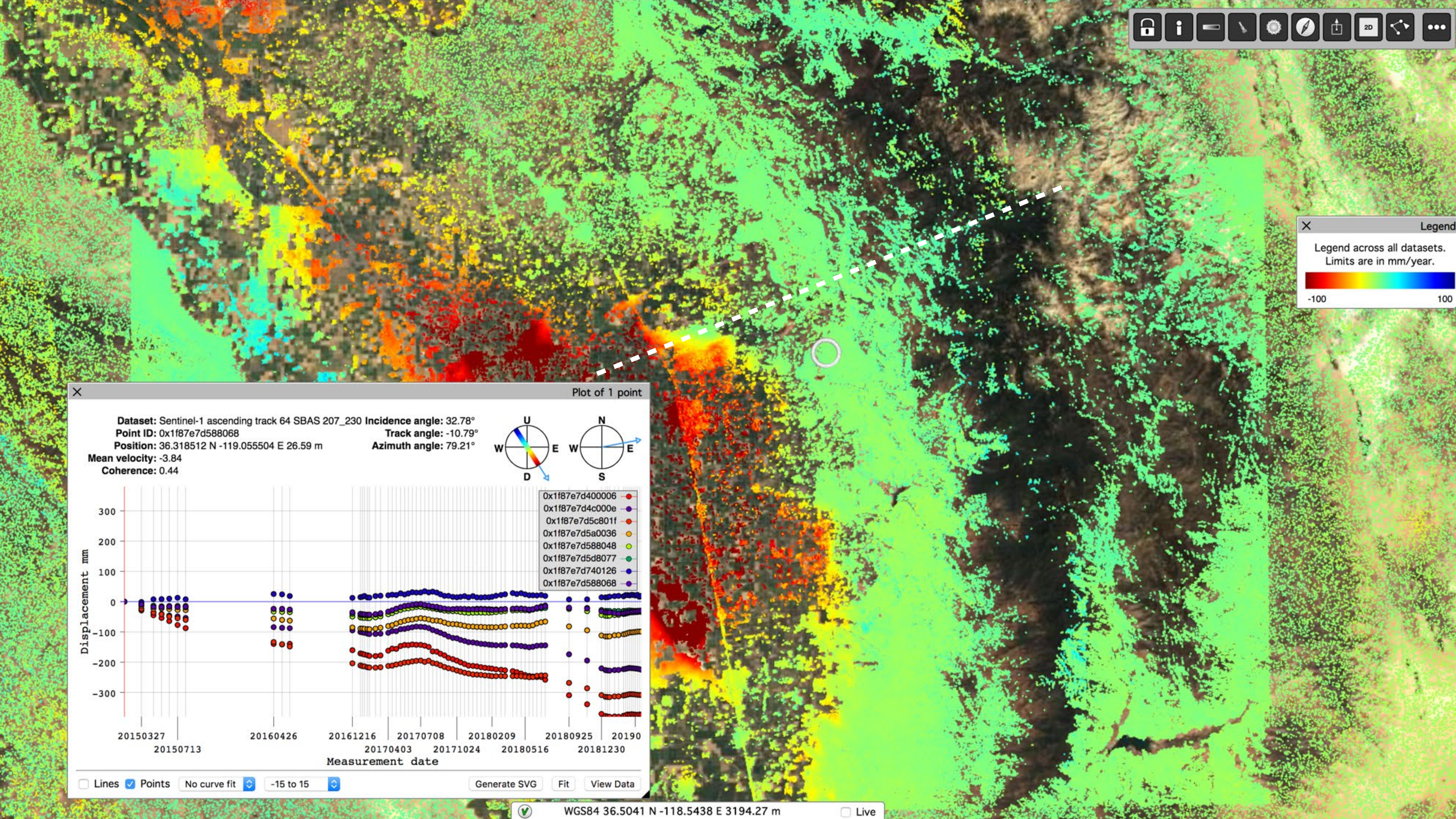





KSAT Ground Motion Service
maps.ksat-gms.com/#llh=-119.1194434,36.07210859,201537.30095173&look=0.70611621,-0.58880296,0.39333316&right=-0.48663187,0,0.87360713&up=0.51438308,0.80827609,0.28653063&layers=aerial,maptile...
Legend
Legend across all datasets.
Limits are in mm/year.
-100
100


Modify datasets
KSAT Ground Motion Service
maps.ksat-gms.com
Logged in as Tom Rune Laukness
Log out
Legend
Legend across all datasets.
Limits are in mm/year.
-100
100


Legend
Legend across all datasets.
Limits are in mm/year.
-100
100
WGS84 36.5041 N -118.5438 E 3194.27 m
Live

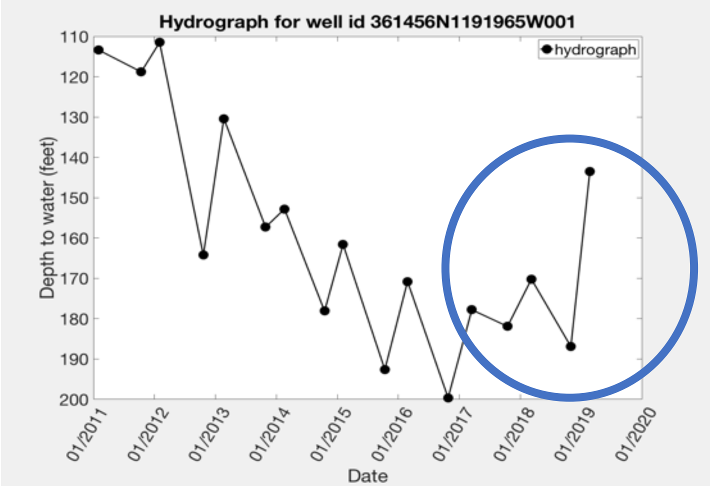


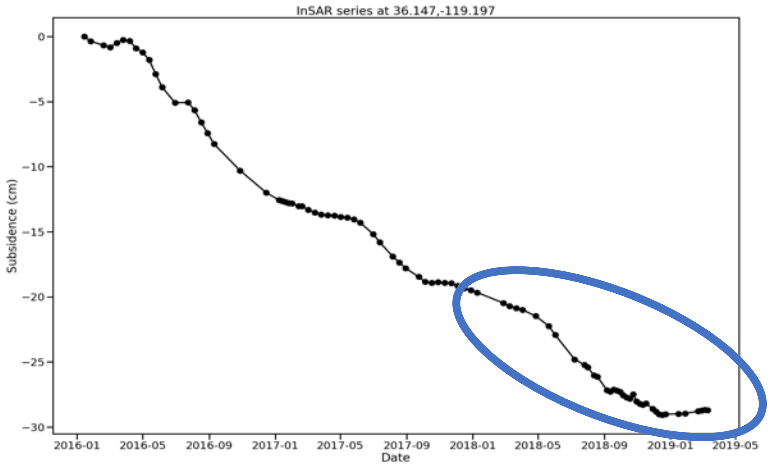
Legend
Legend across all datasets.
Limits are in mm/year.
-100
100
Plot of 1 point
Dataset: Sentinel-1 ascending track 64 SBAS 207_230
Point ID: 0x1f87e7d588068
Position: 36.318512 N -119.055504 E 26.59 m
Mean velocity: -3.84
Coherence: 0.44
Incidence angle: 32.78°
Track angle: -10.79°
Azimuth angle: 79.21°
U
W
E
D
N
W
E
S
0x1f87e7d400006
0x1f87e7d4c000e
0x1f87e7d5c801f
0x1f87e7d5a0036
0x1f87e7d588048
0x1f87e7d5d8077
0x1f87e7d740126
0x1f87e7d588068
Displacement mm
300
200
100
0
−100
−200
−300
20150327
20150713
20160426
20161216
20170403
20170708
20171024
20180209
20180516
20180925
20181230
20190
Measurement date
Lines
Points
No curve fit
-15 to 15
Generate SVG
Fit
View Data
WGS84 36.5041 N -118.5438 E 3194.27 m
Live

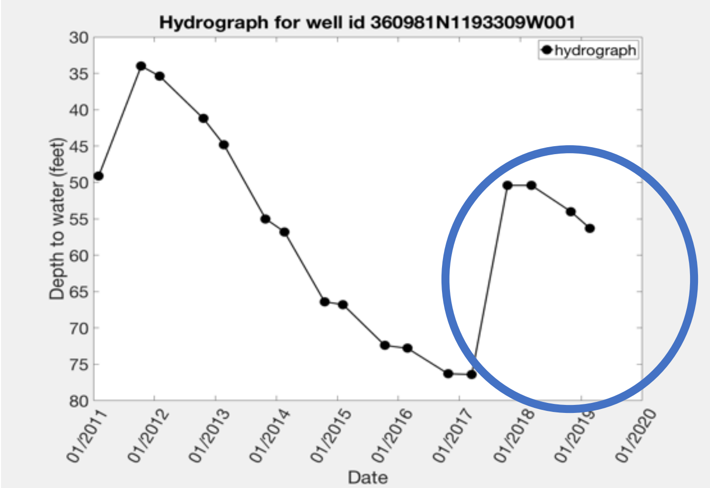
1. Understanding time lags between head changes and subsidence

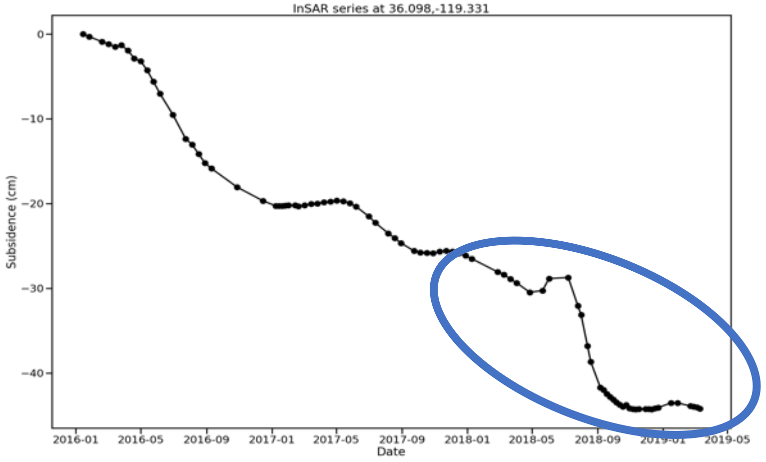
In many places, head levels have recovered after the 2012–15 drought

Yet subsidence is continuing due to slow draining of fine clays

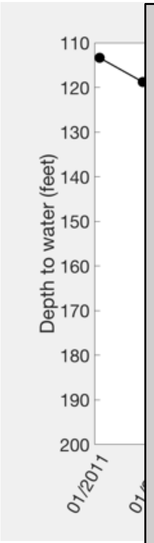


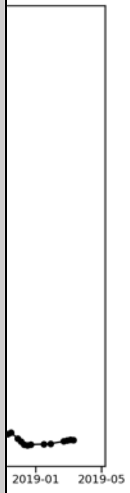






2. Calibrating specific storage values using InSAR

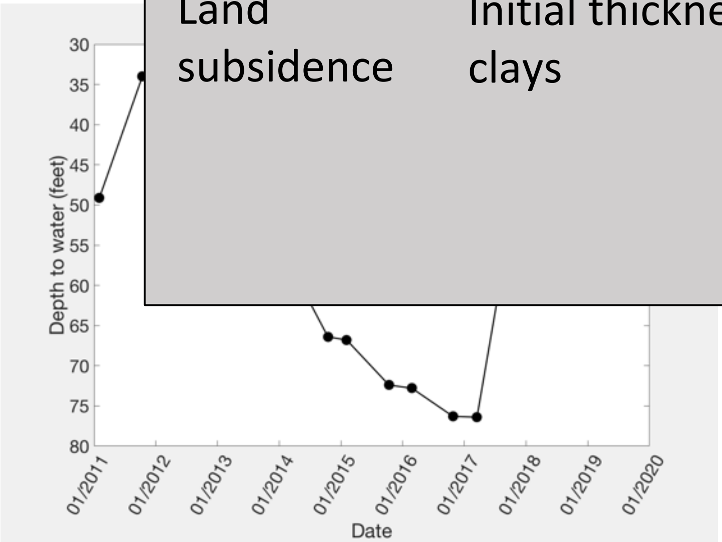


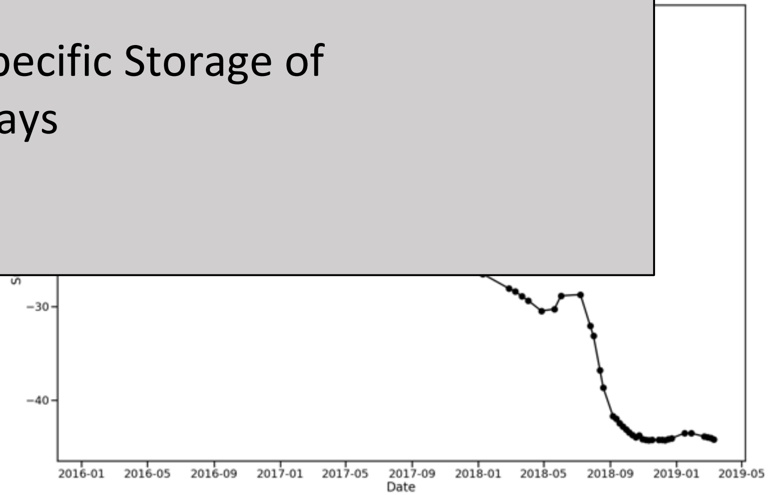


Equation relating subsidence to head changes:

$$\Delta b = b_0 \; S_s \; \Delta h$$

- Δb: Land subsidence
- b_0: Initial thickness of clays
- S_s: Specific Storage of clays
- Δh: Head change in clays (time dependent)





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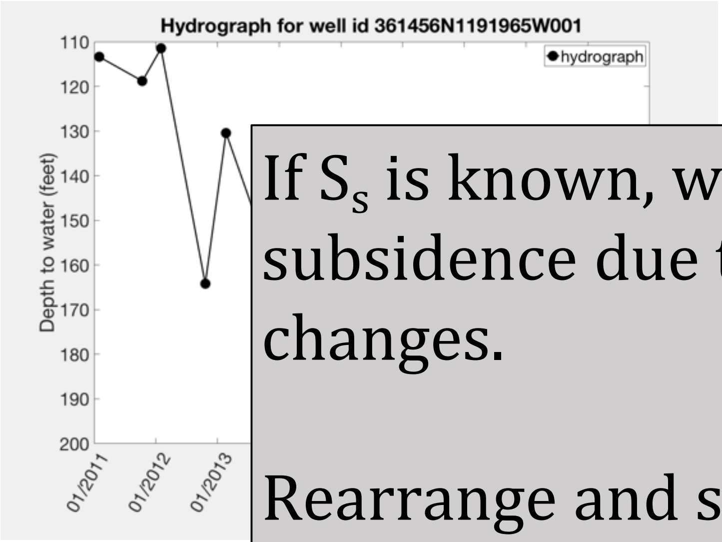
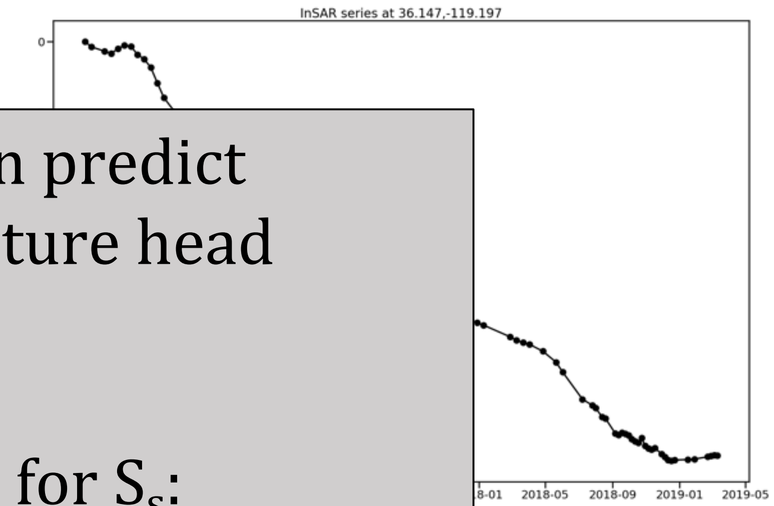
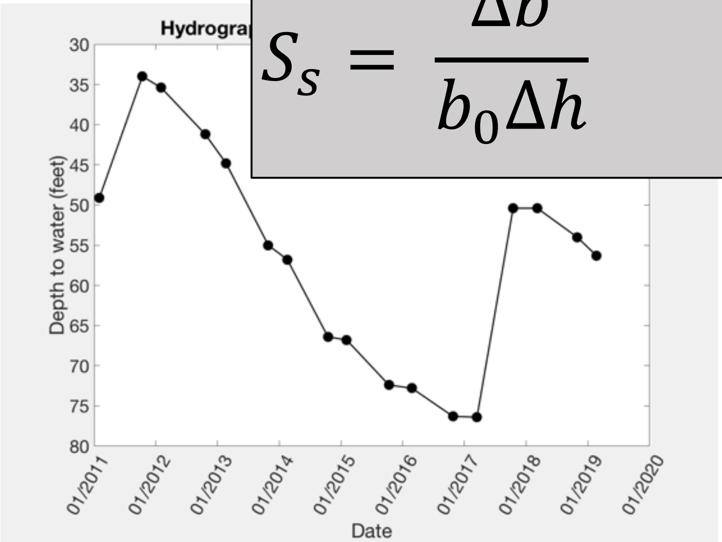


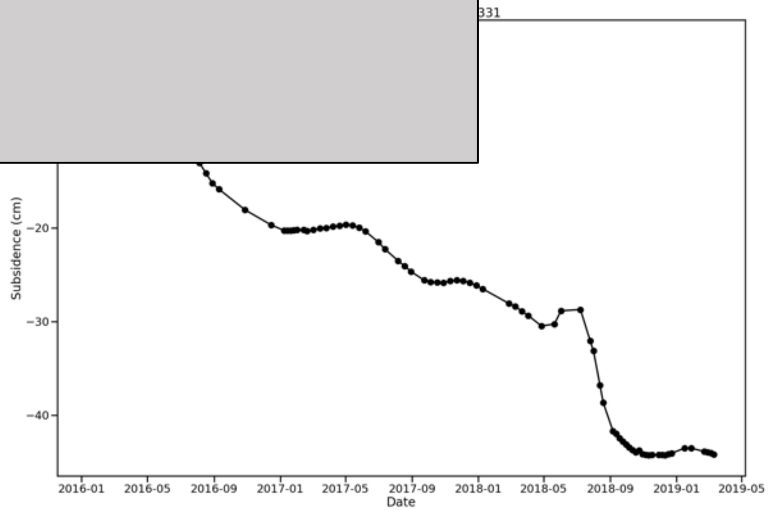


If S_s is known, we can predict subsidence due to future head changes.

Rearrange and solve for S_s:

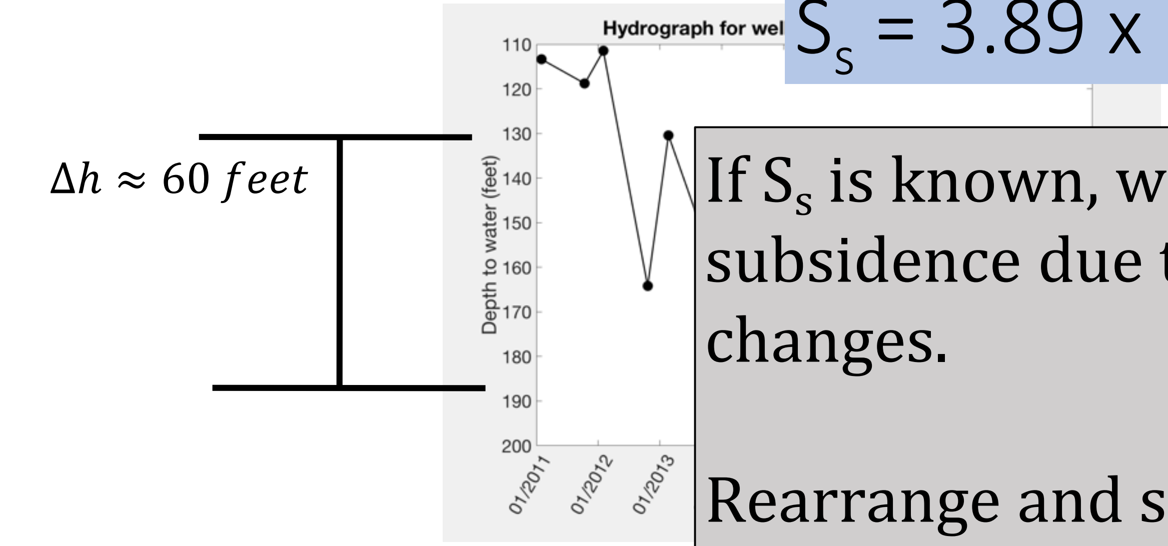
$$S_s = \frac{\Delta b}{b_0 \Delta h}$$

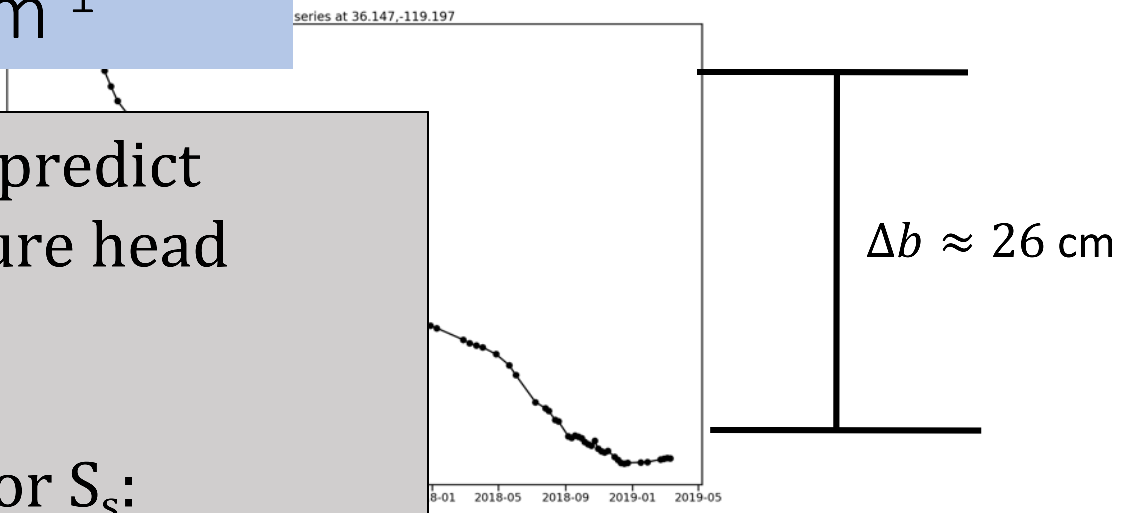




2. Calibrating specific storage values using InSAR

$S_s = 3.89 \times 10^{-4}\ m^{-1}$





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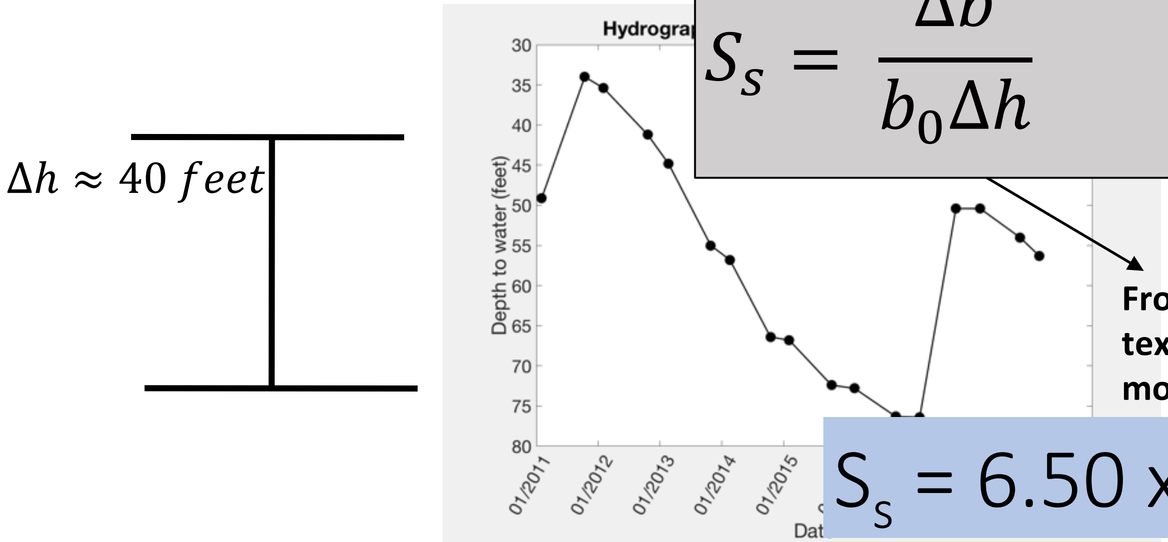
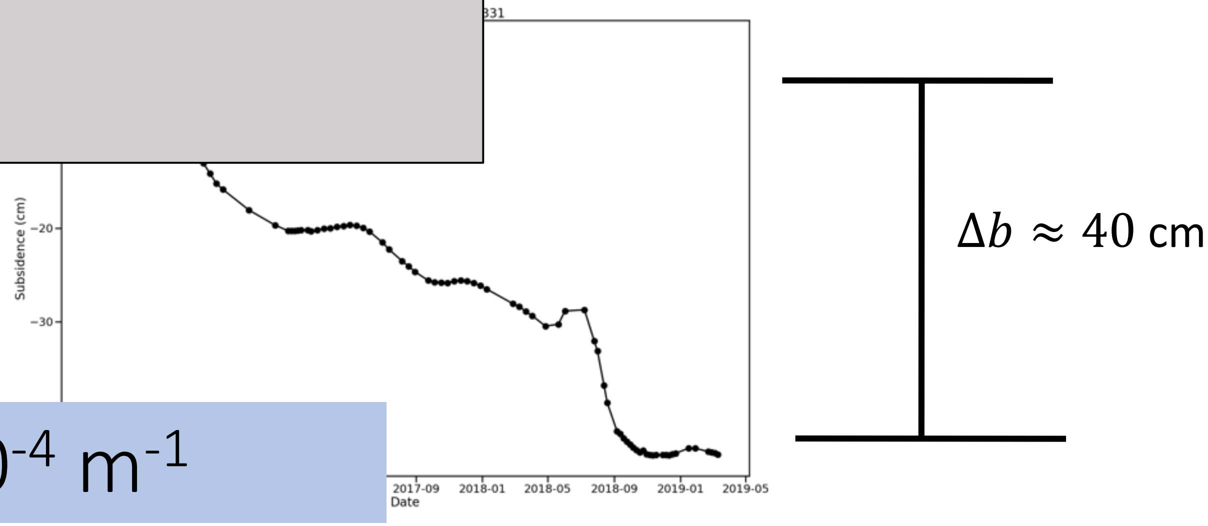
From texture models





$S_s = 6.50 \times 10^{-4}\ m^{-1}$

3. InSAR allows interpolating sparse head measurements from wells in semi/confined aquifers

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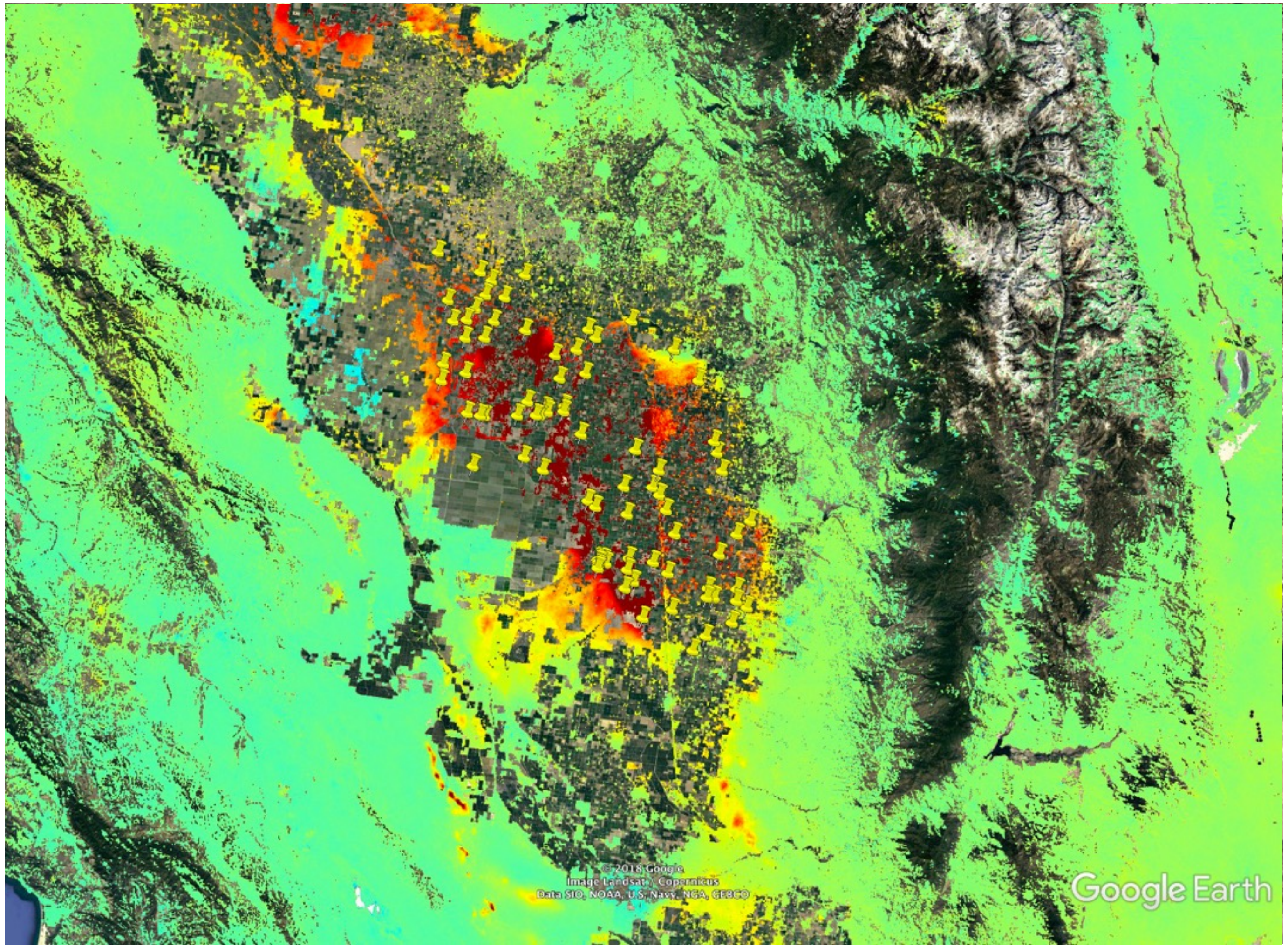
Wells make point measurements of water levels at a given time

Wells containing high quality data are sparse

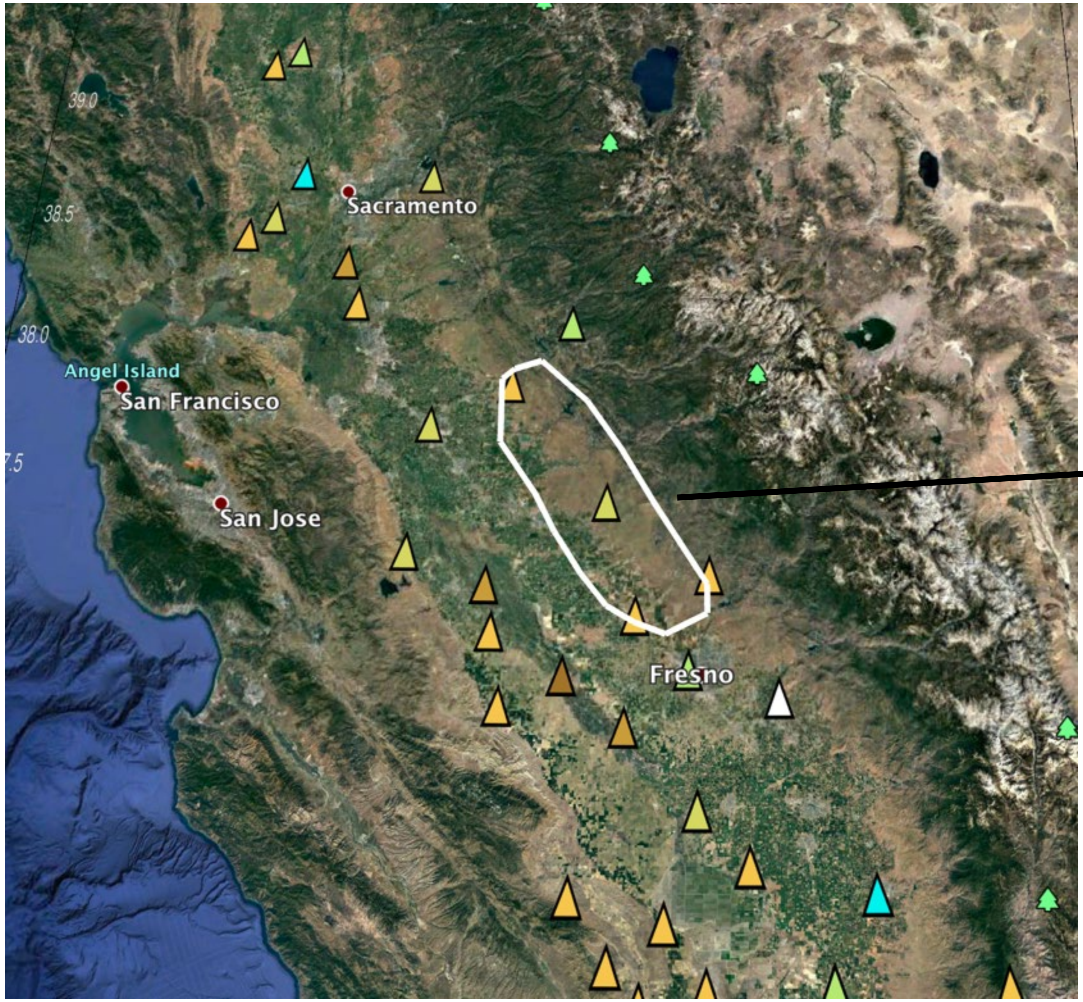
InSAR pixels are almost continuous in space and regular in time

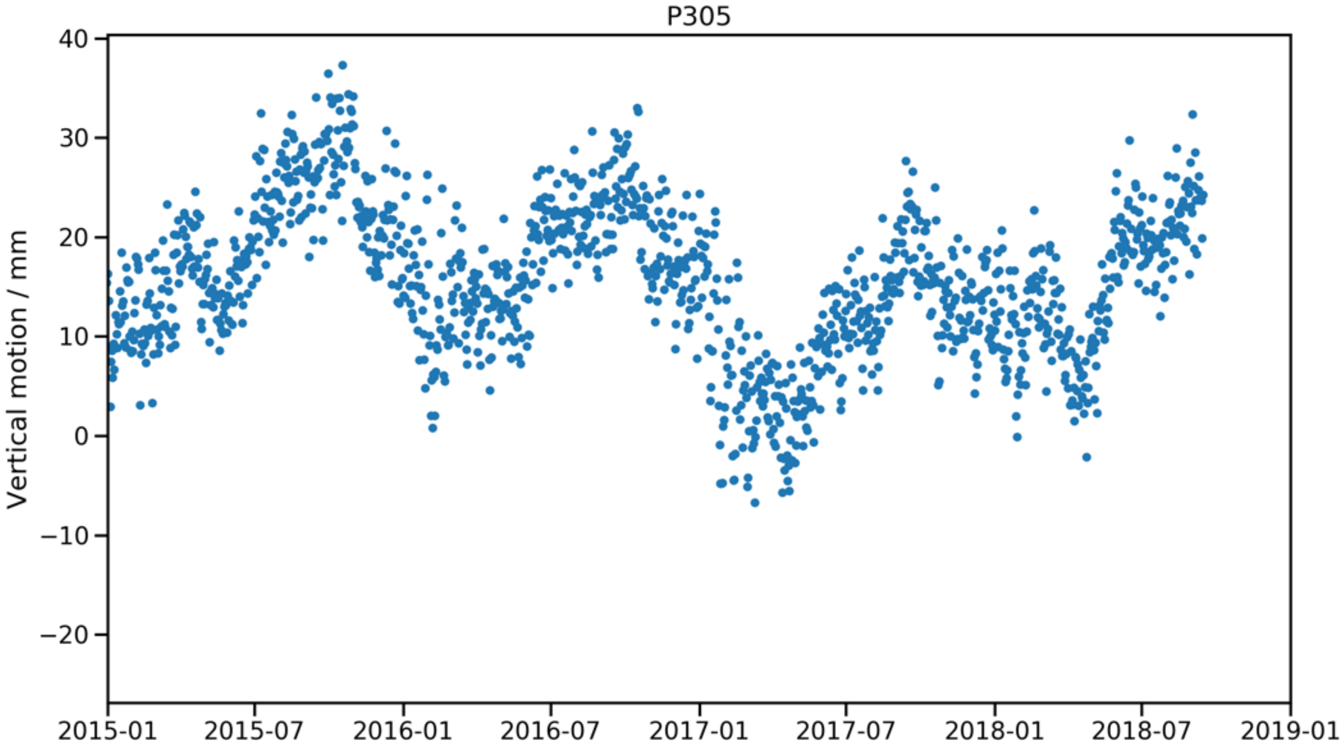
$$\Delta h = \frac{\Delta b}{b_0 S_s}$$

Use S_s values to interpolate head measurements between wells

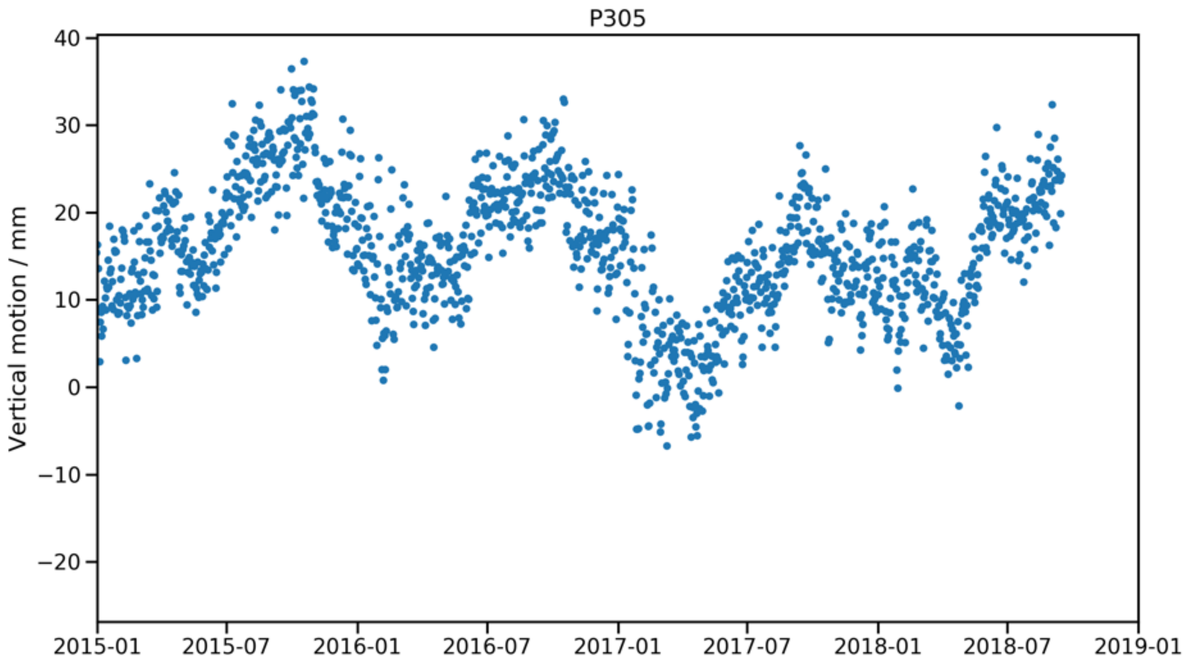


4. Spotting the InSAR signature of range-front groundwater recharge





4. Spotting the InSAR signature of range-front groundwater recharge?



Understanding the seasonal loading:

Sierra Nevada snowpack 5–10 mm

Shallow groundwater 1–10 mm

Soil moisture 5–10 mm

Estimates are highly uncertain!

In summary, satellite InSAR is a valuable tool for managing groundwater resources

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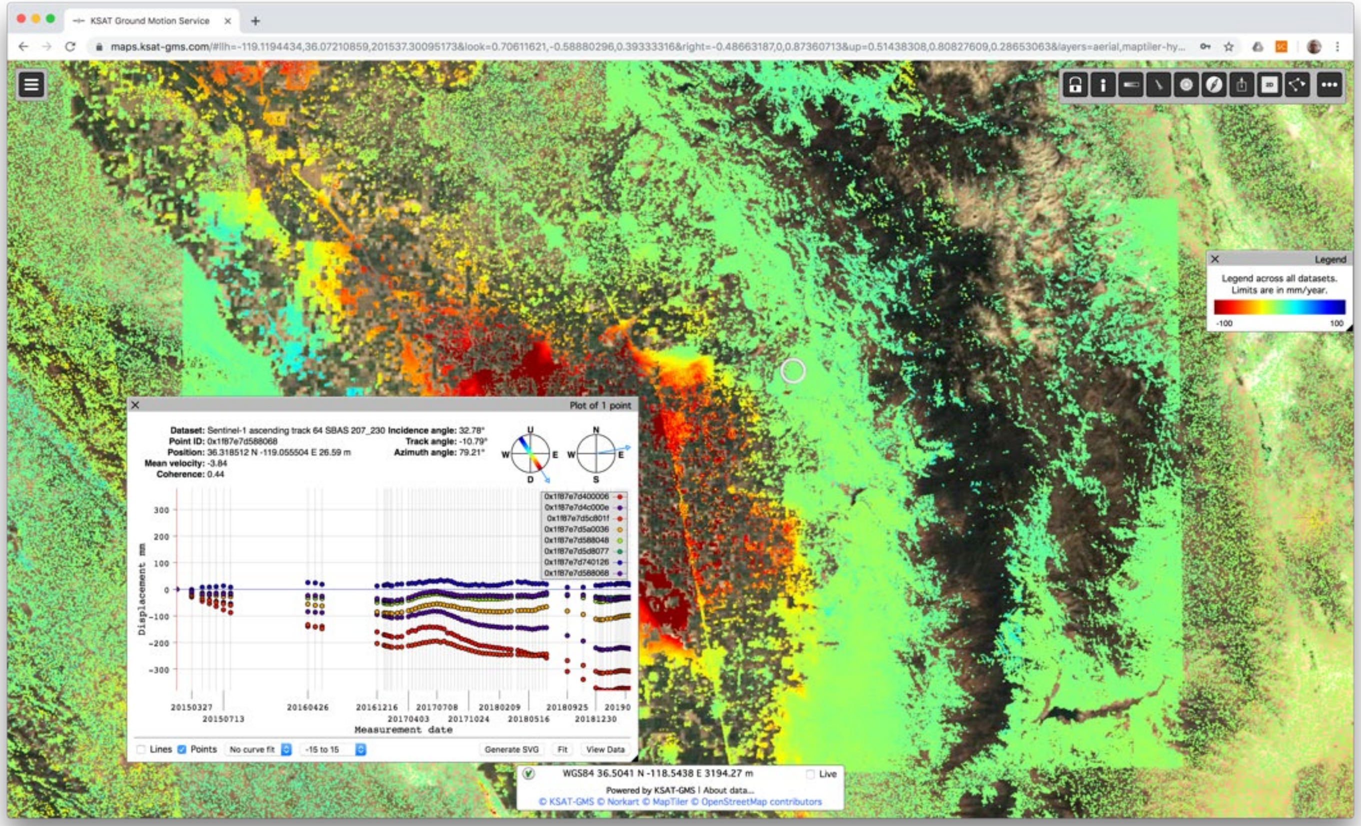
Measure surface deformation with mm-precision at high spatial resolution

Sentinel-1 satellites allows regular coverage and updates every 6. day

InSAR can improve understanding of groundwater resources

Data exploration tools essential for *operational* use



Questions?

http://maps.ksat-gms.com
grac2019/grac2019

Thank you for your attention

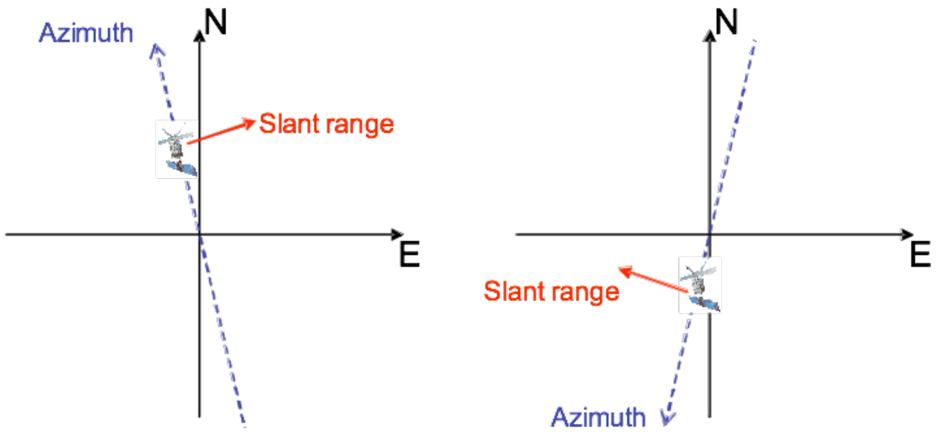
TOM RUNE LAUKNES

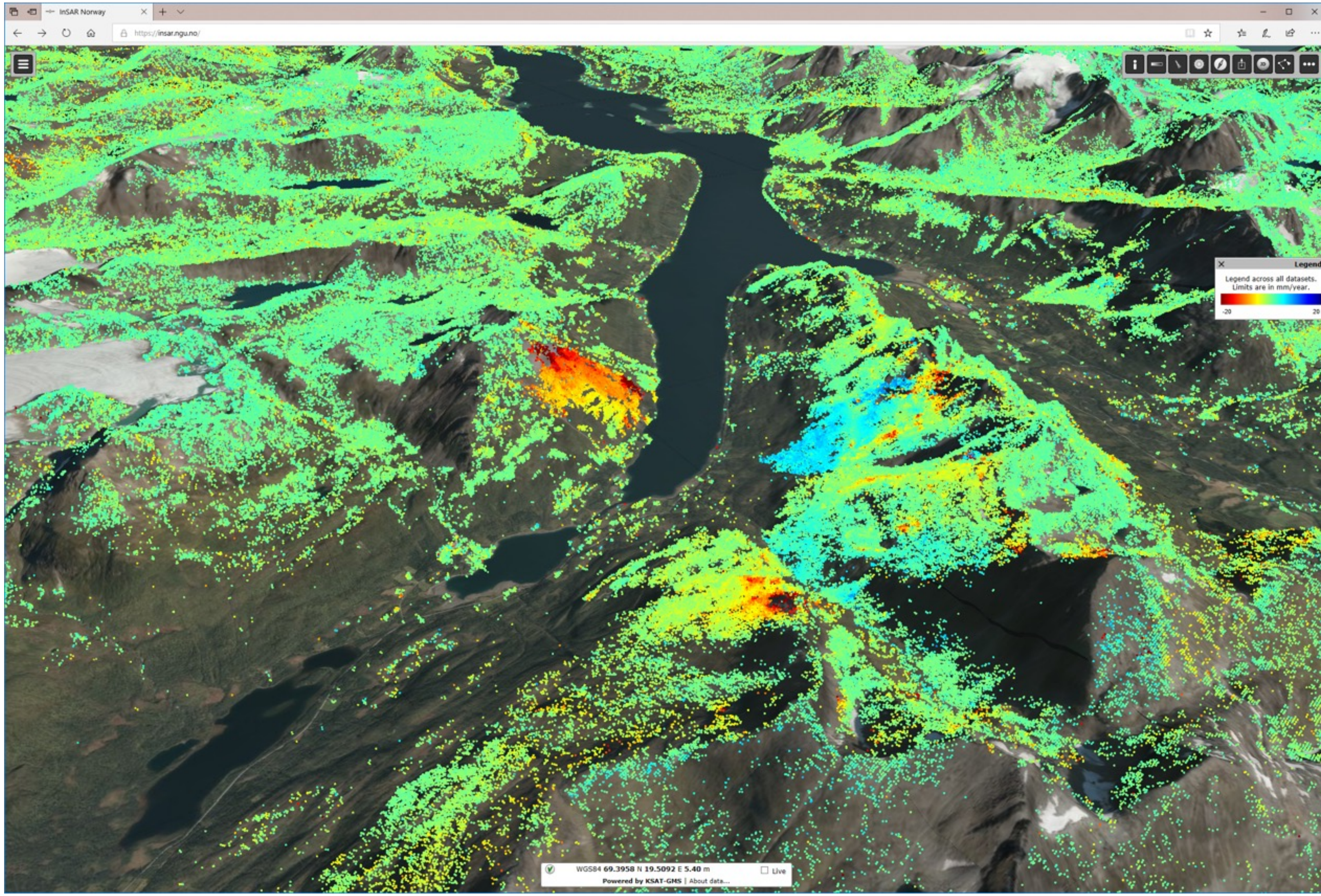
tom.rune.lauknes@norceresearch.no

norceresearch.no

@TRLauknes @NORCEresearch

We need both ascending and descending geometries

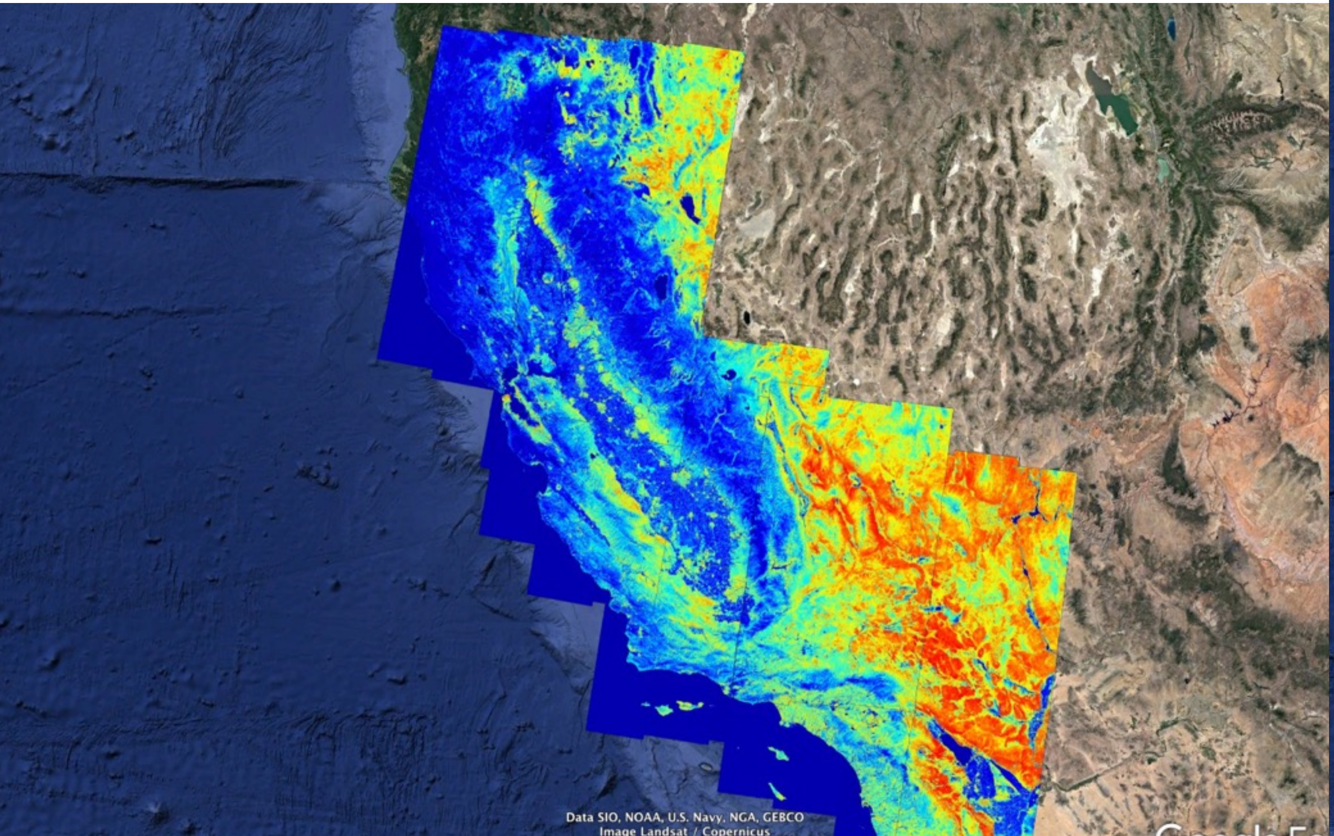


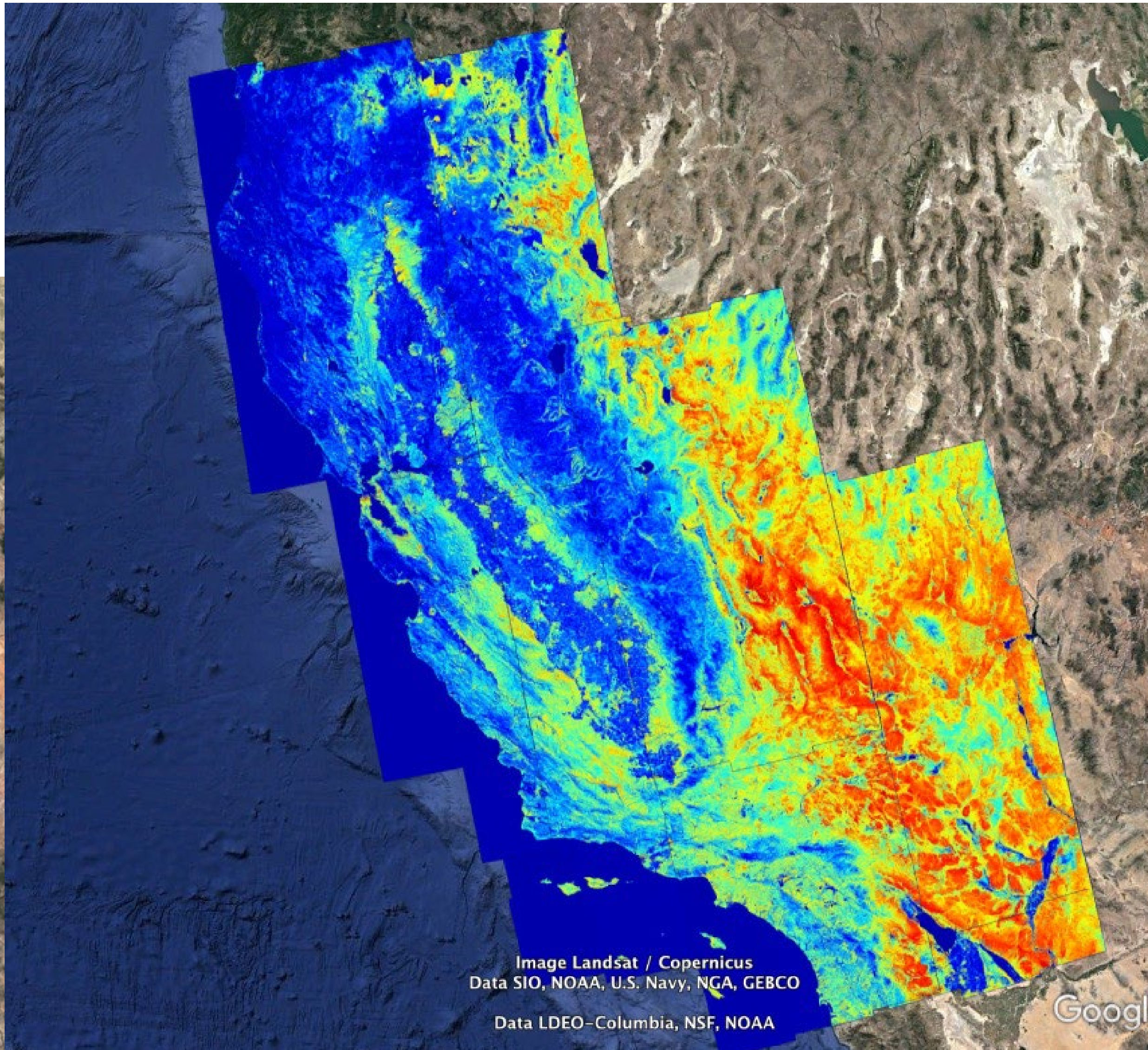


Coherence is a quality measure for InSAR

Desert and dry areas high coherence (red)

Agricultural areas low coherence (blue)

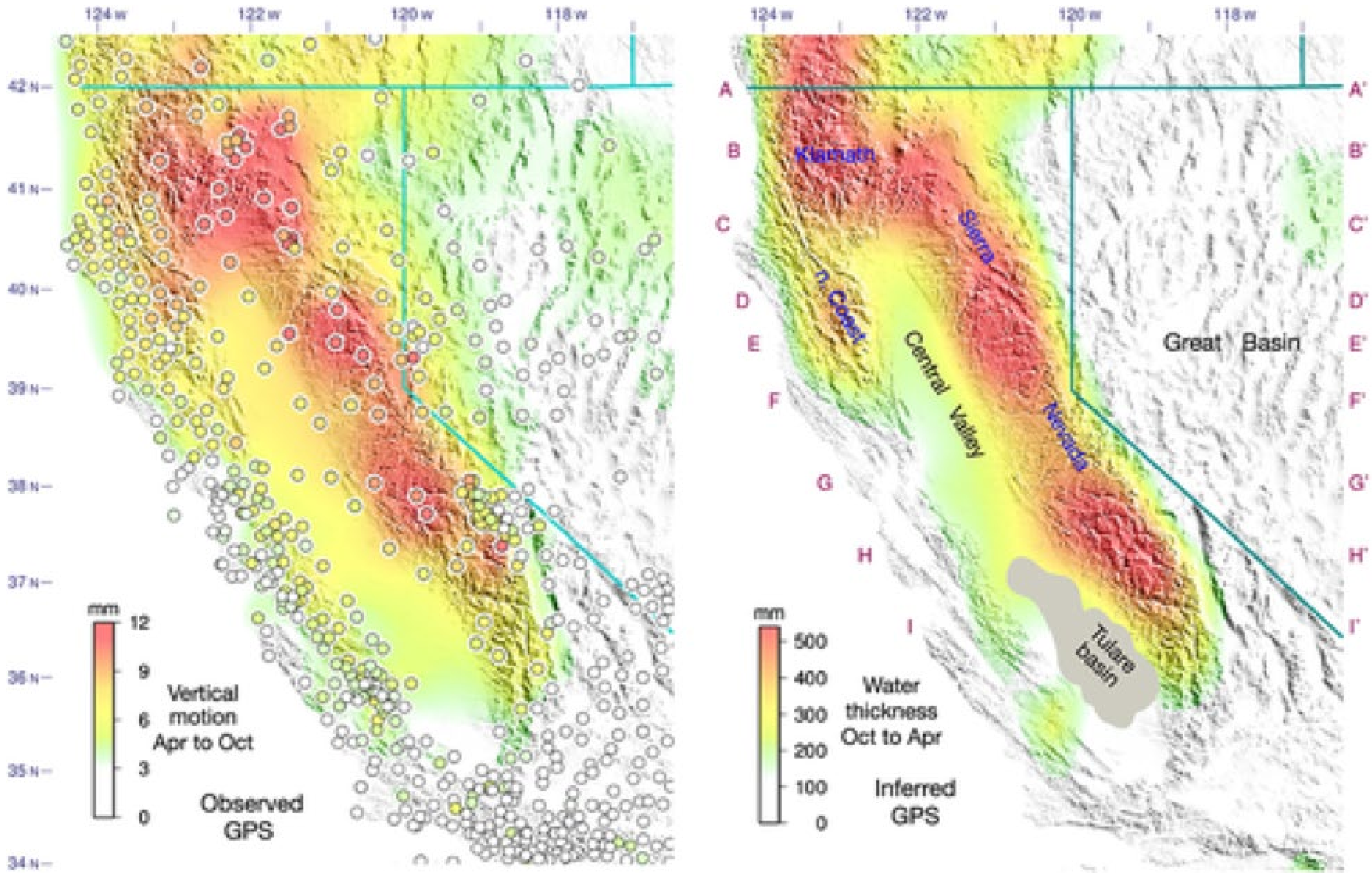




Reginal uplift and subsidence at the cm and sub cm scale relates to hydrologic loading

California's mountains subside ~12 mm during winter

…and rise again in spring and summer



Credit: Argus et al., GRL, 2014