# Measuring Subsidence in the Central Valley of California from space

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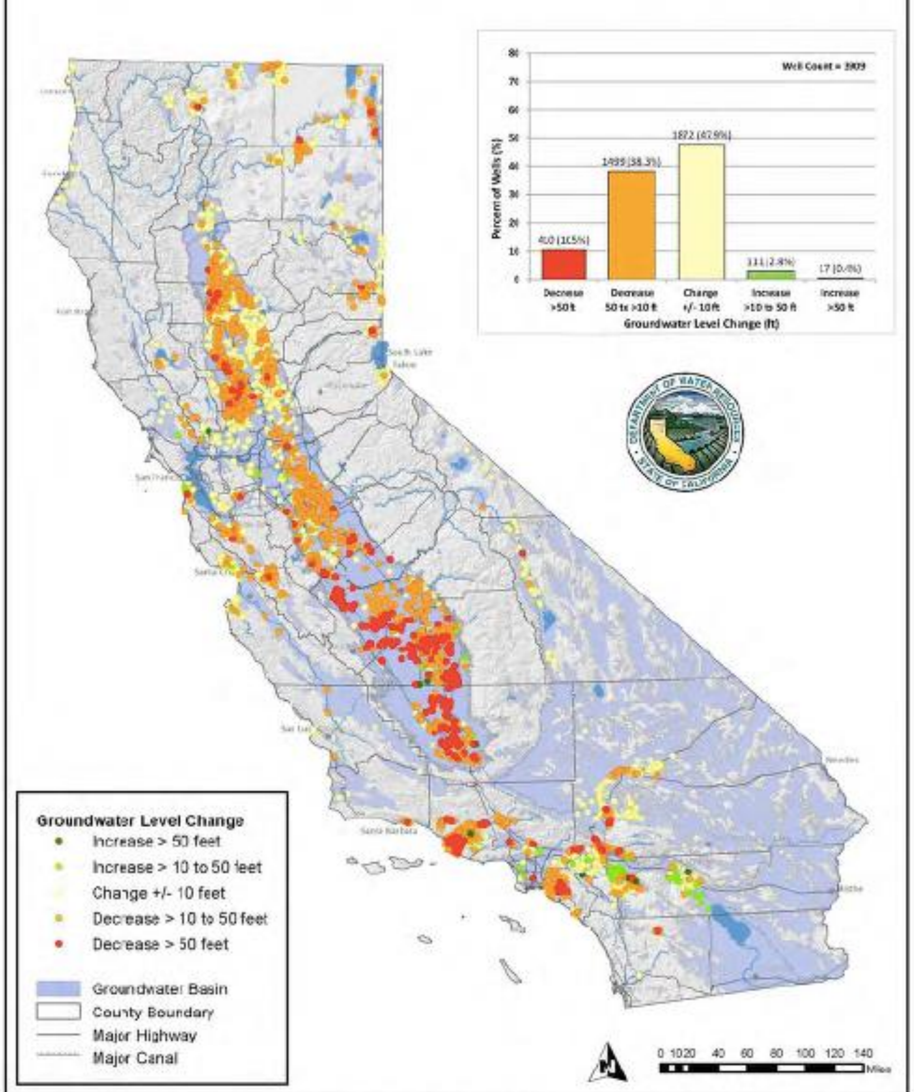
# Subsidence from Space

- Groundwater is becoming a more important part of water resources
- But knowledge of the groundwater level is not uniformly available
- Wells provide some monitoring capability, but there are political and practical difficulties
- Interferometric Synthetic Aperture Radar (InSAR) can provide information on groundwater levels by measuring surface deformation caused by withdrawal and recharge of aquifers
- Subsidence also causes problems for infrastructure such as roads, aqueducts, and trains
- We are developing information products for water managers, the public, and hydrologists including animations, maps of ‘hot spots’, pixel histories, and regional maps of subsidence
- Most of the work has been done for the Central Valley and LA basin, but we are beginning to process data for other basins of California

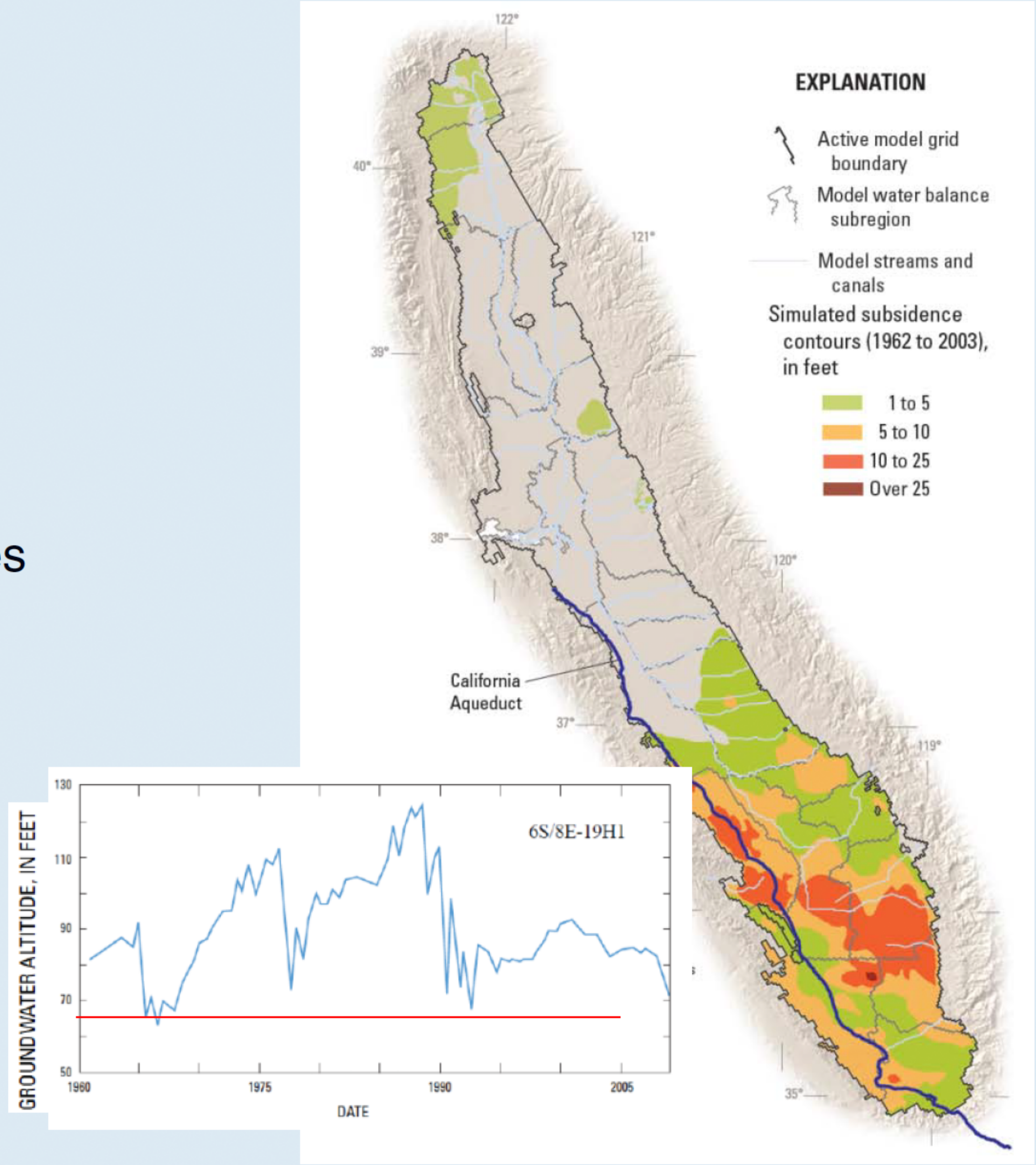
# Groundwater Level Change* - Fall 2011 to Fall 2015




*Groundwater level change determined from water level measurements in wells. Map and chart based on available data from the DWR Water Data Library as of 12/31/2015. Document Name: DOTMAP_F1511_JJ_50 Updated: 2/1/2016 Data subject to change without notice.

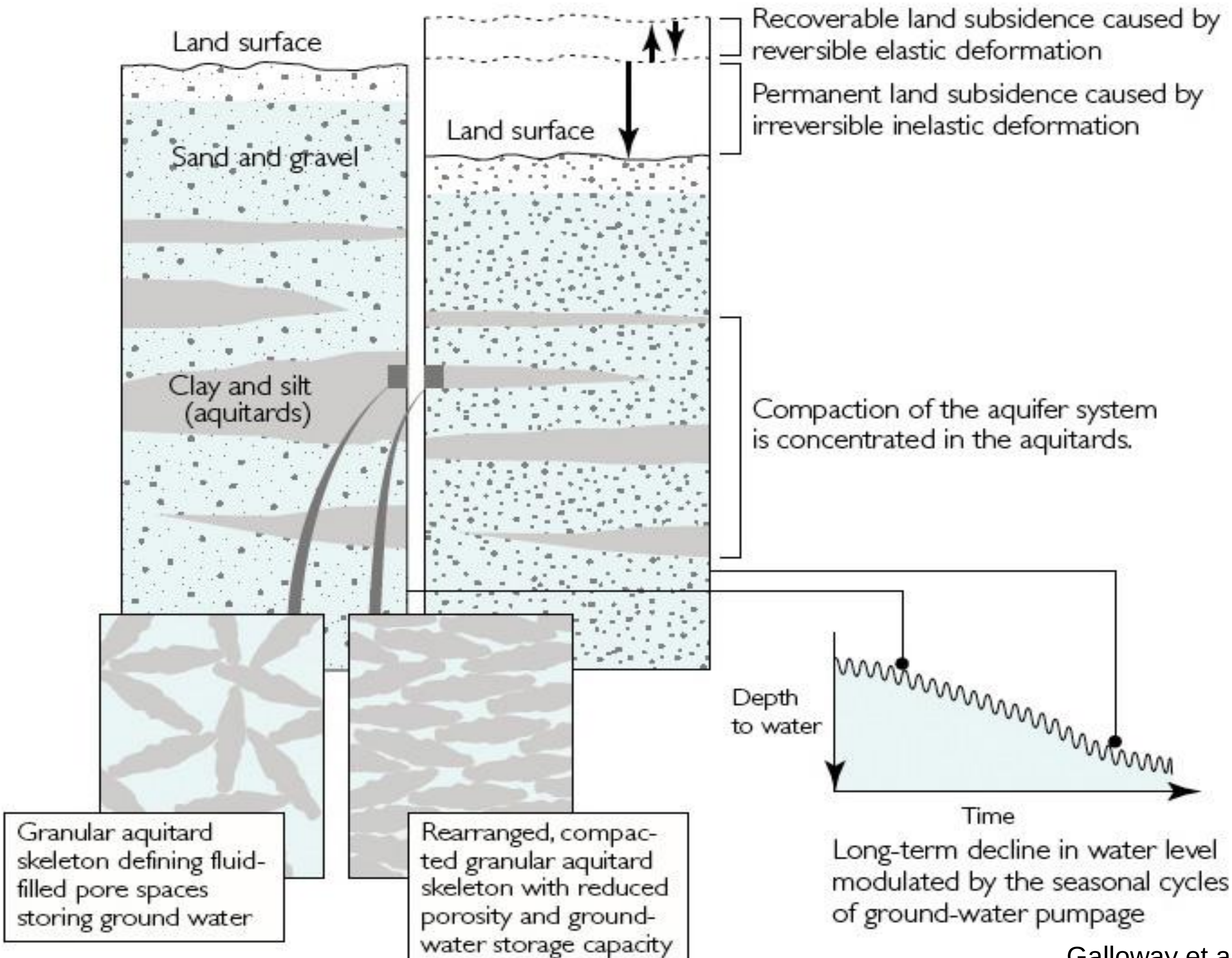
# Subsidence:

- In1960s, groundwater pumping caused water levels to decline
- Water-level declines cause compaction of fine-grained deposits, which results in subsidence
- Surface-water deliveries since the late 1960s have reduced the dependence on groundwater
- Water levels are again reaching their historic lows and subsidence may be renewed
- Management constraint




USGS

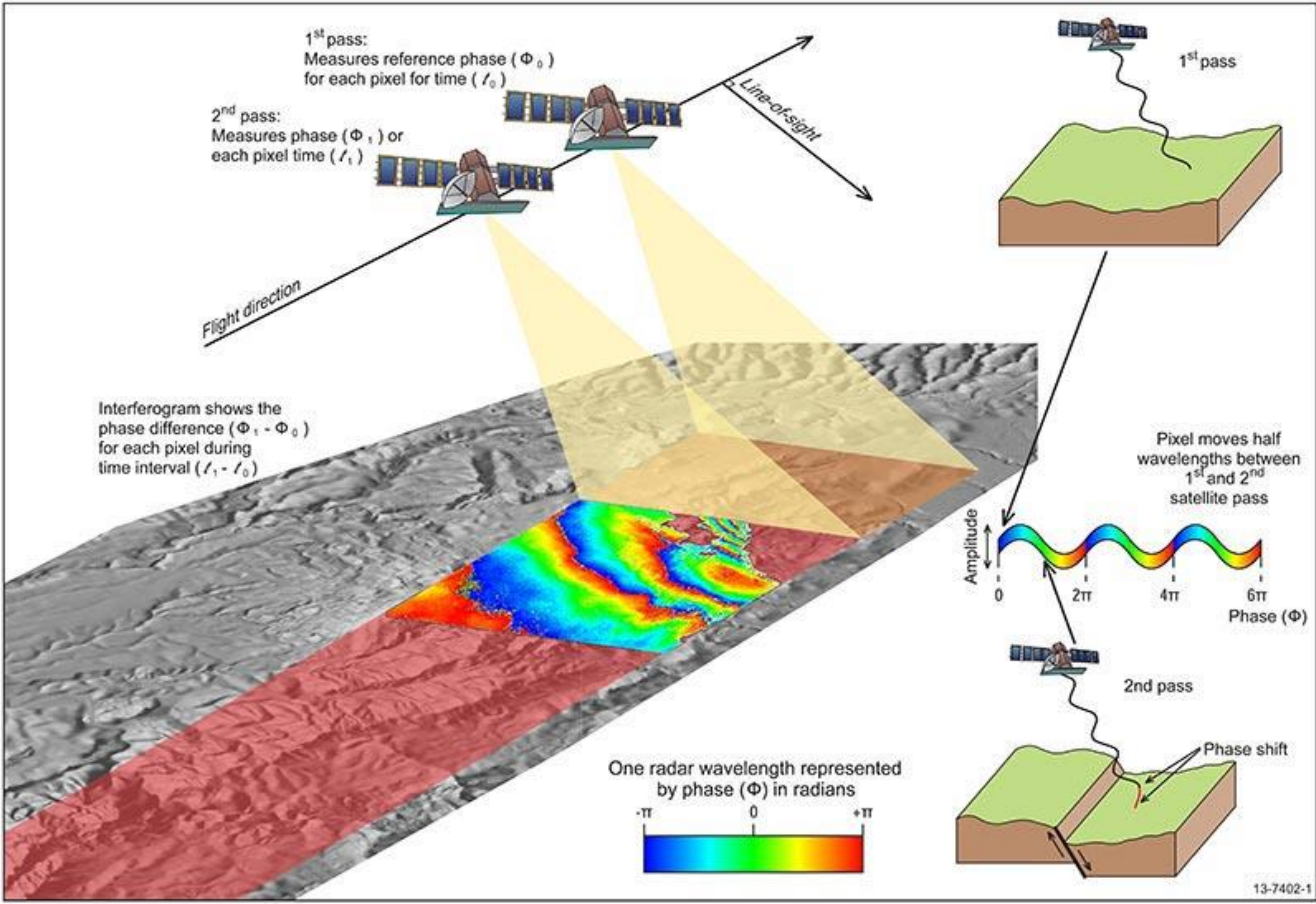
# Hydrology 101: Aquifer compaction




Galloway et al., 1999


1925
1955
SAN JOAQUIN VALLEY
CALIFORNIA
BM S661
SUBSIDENCE 9M
1925-1977
1977

# InSAR 101



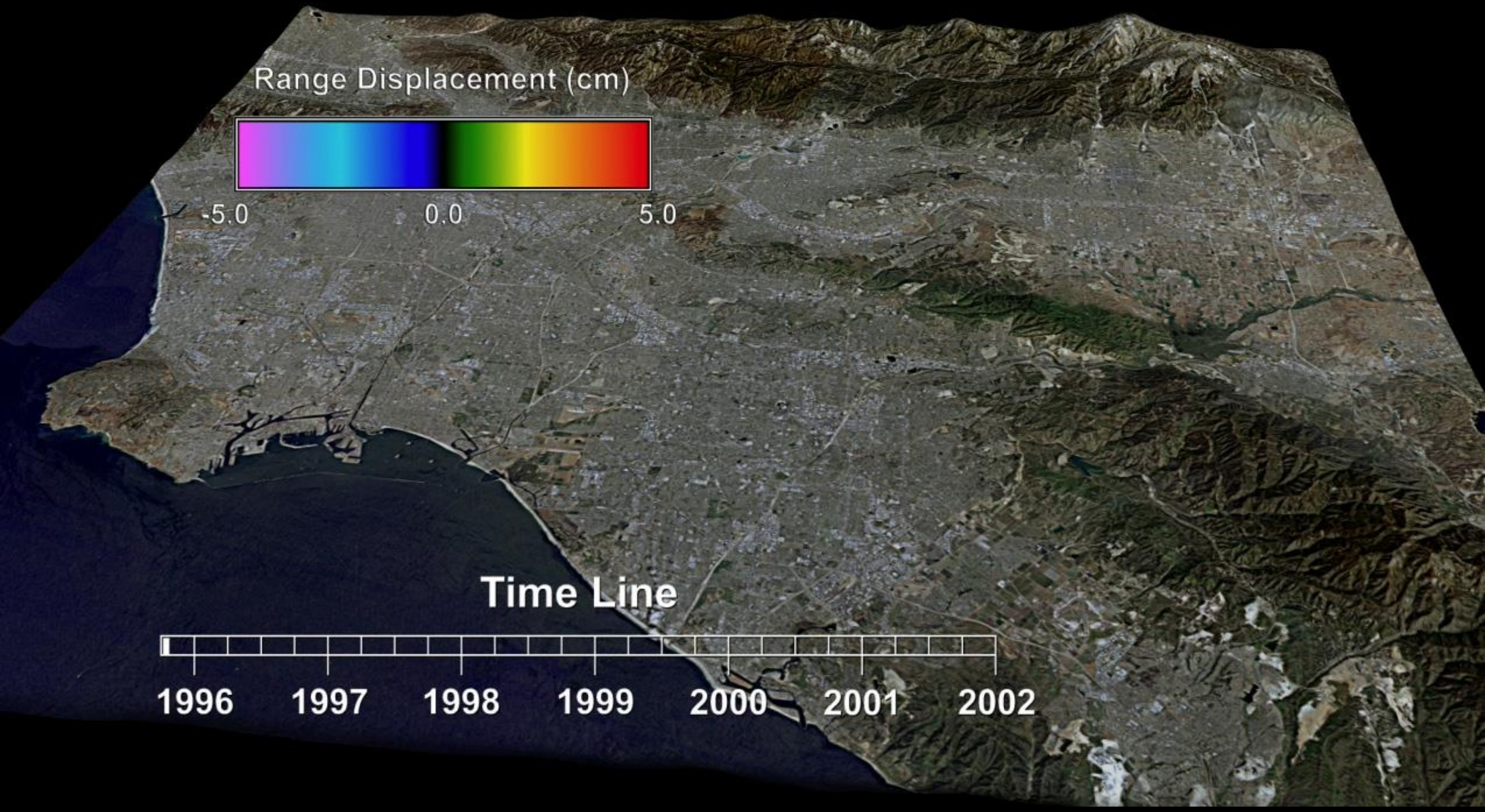
1st pass:
Measures reference phase (Φ0)
for each pixel for time (t0)
2nd pass:
Measures phase (Φ1) or
each pixel time (t1)
Line-of-sight
Flight direction
Interferogram shows the
phase difference (Φ1 - Φ0)
for each pixel during
time interval (t1 - t0)
1st pass
Pixel moves half
wavelengths between
1st and 2nd
satellite pass
Amplitude
0
2π
4π
6π
Phase (Φ)
2nd pass
Phase shift
One radar wavelength represented
by phase (Φ) in radians
-π
0
+π
13-7402-1

# Orbital Radars for Interferometry

| Satellite | dates | resolution (m) | swath (km) | incidence angles | minimum revisit (days) | band*/pol |
|---|---|---|---|---|---|---|
| ERS 1,2 | 1991-2010 | 25 | 100 | 25° | 35 | CVV |
| Envisat | 2002-2010 | 25 | 100 | 15-45° | 35 | CVV, CHH |
| PALSAR | 2006-2011 | 10-100 | 40-350 | 10-60° | 46 | L-quad |
| Radarsat 1 | 1995-2013 | 10-100 | 45-500 | 20-49° | 24 | CHH |
| Radarsat 2 | 2008- | 3-100 | 25-500 | 10-60° | 24 | C-quad |
| TerraSAR-X | 2007- | 1-16 | 5-100 | 15-60° | 11 | X-quad |
| Cosmo-Skymed | 2007- | 1-100 | 10-200 | 20-60° | <1 | X-quad |
| PALSAR-2 | 2014- | 3-60 | 50-350 | 8-70° | 14 | L-quad |
| Sentinel-1 | 2014- | 20 | 250 | 30-45° | 12 | C-dual |
| NISAR | 2020 | 35 | 350 | 15-60° | 12 | L-quad |

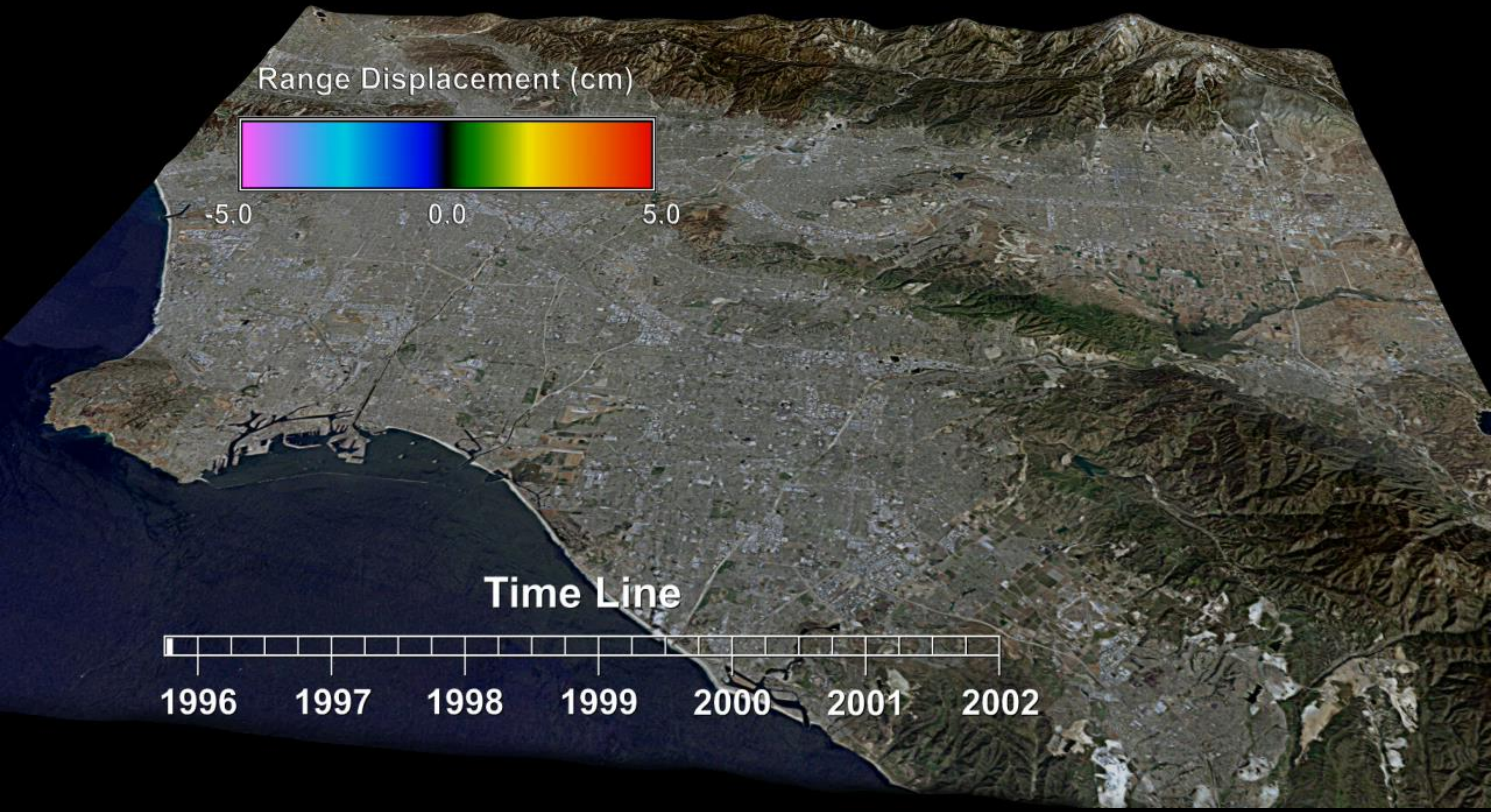
* wavelengths: X ~ 3 cm, C ~ 5 cm, L ~25 cm

# Monitoring LA Basin




Paul Lundgren, Vince Realmuto, JPL

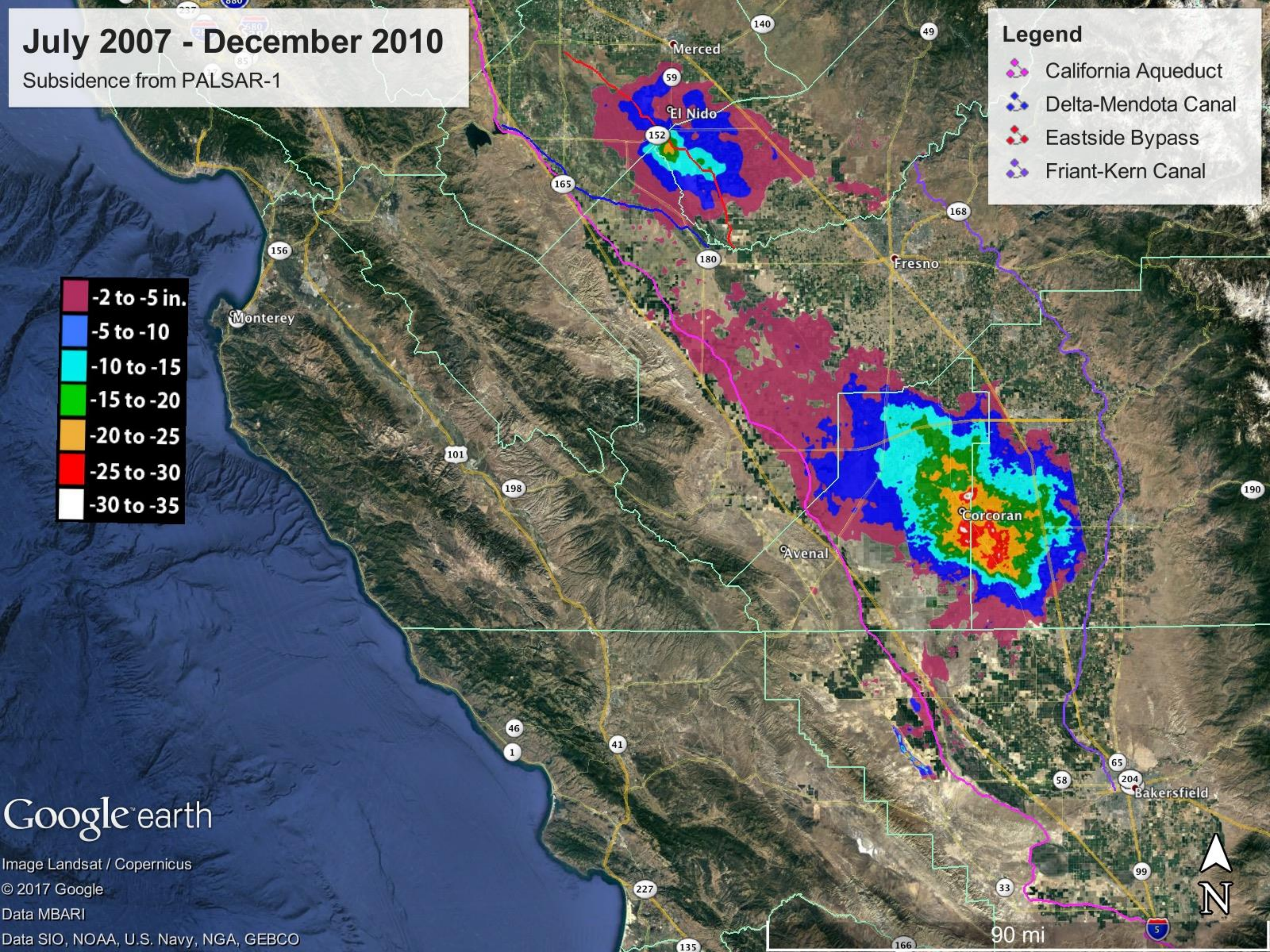
# Monitoring LA Basin



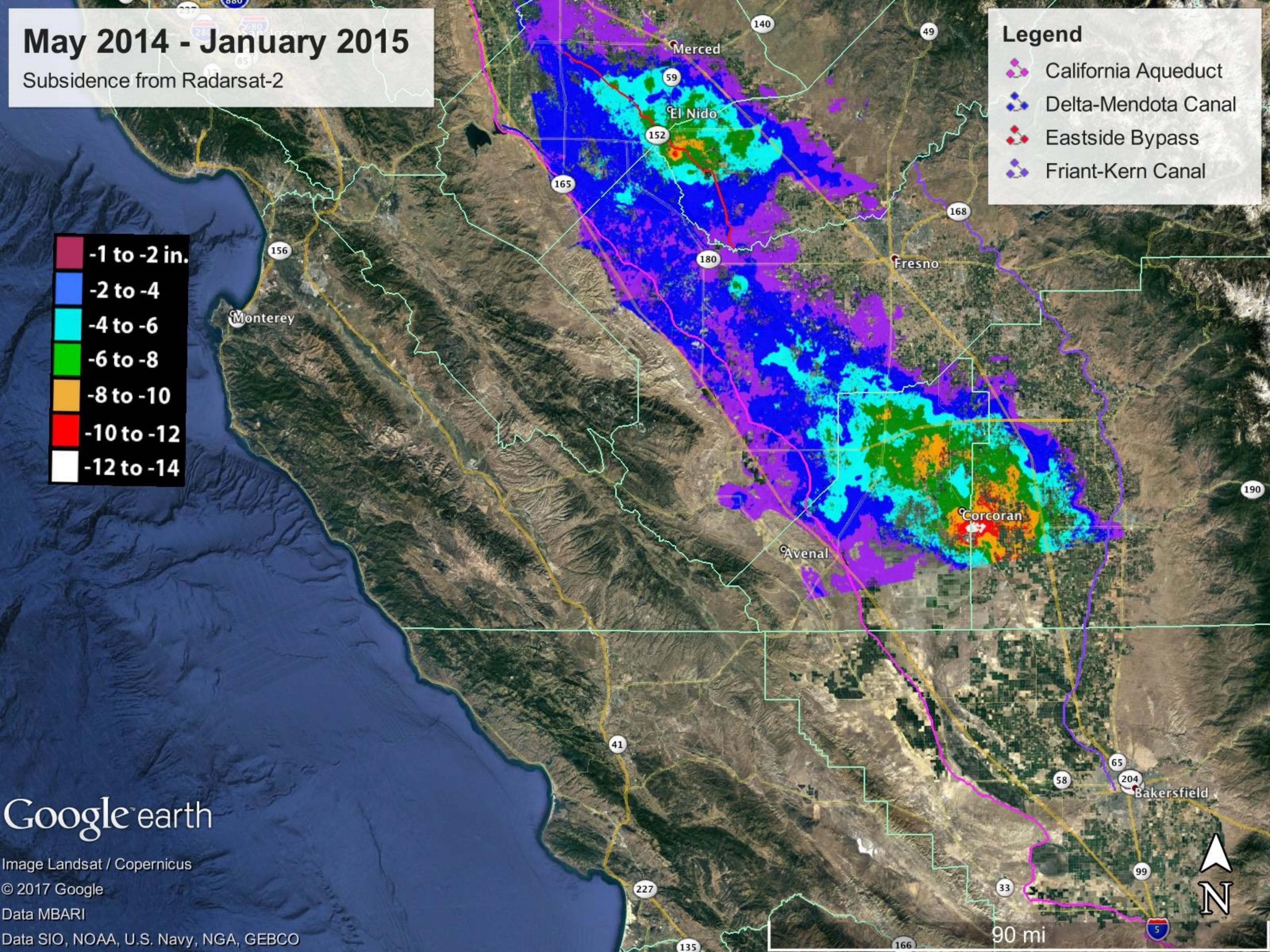

Paul Lundgren, Vince Realmuto, JPL

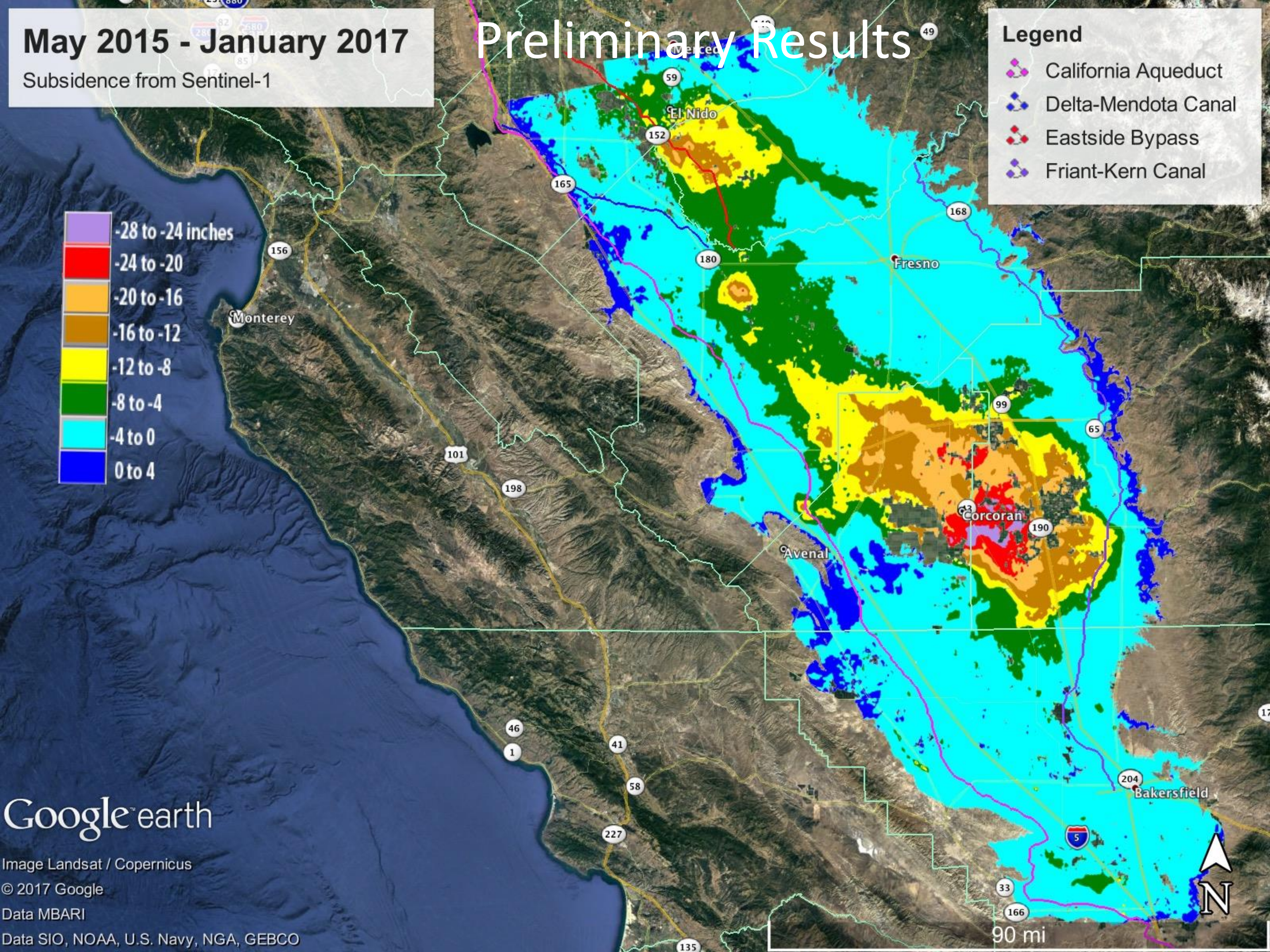
# *Subsidence in the San Joaquin Valley: PALSAR, 2007-2011*

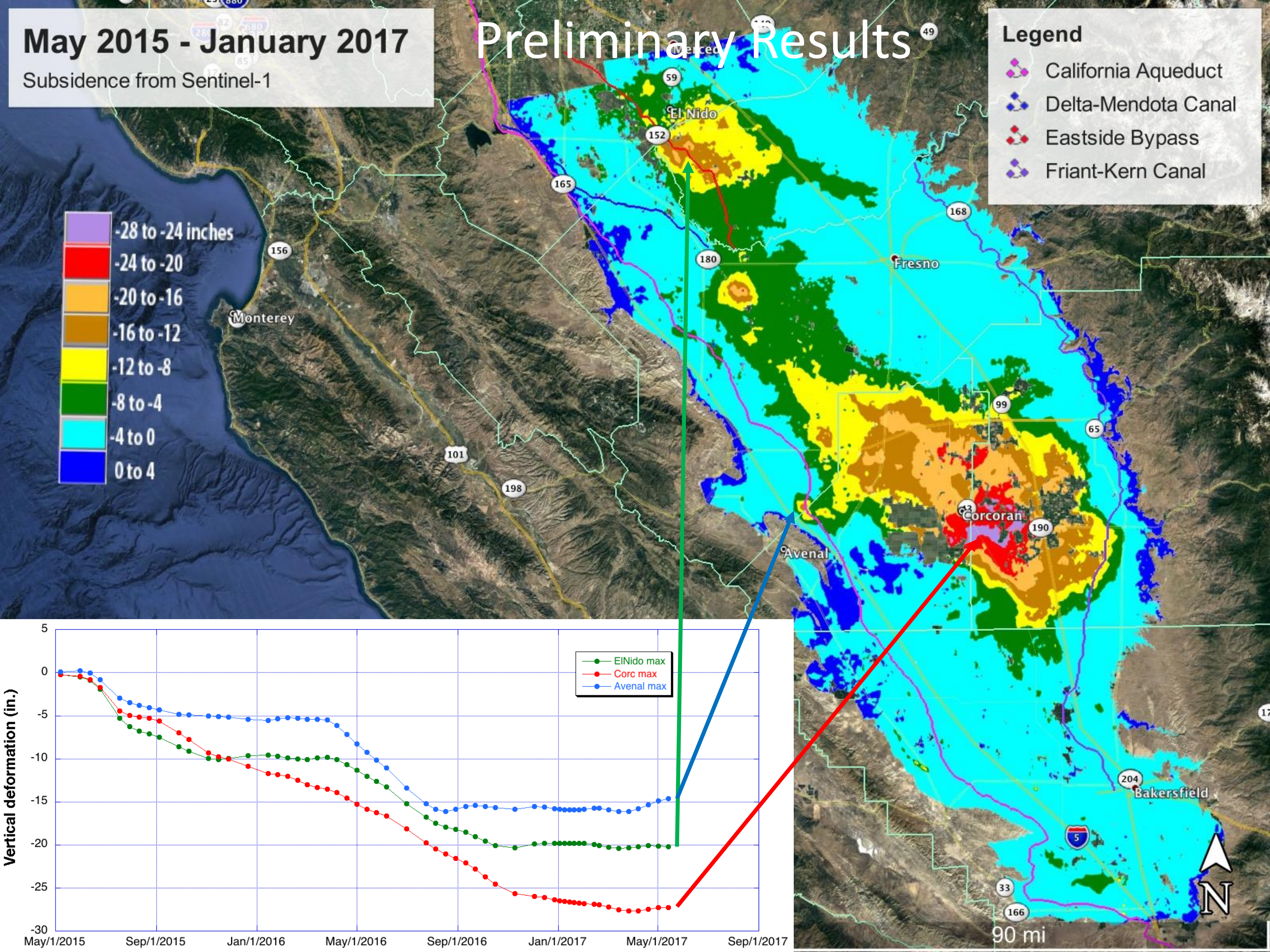
Zhen Liu, Vince Realmuto, Tom Farr, JPL

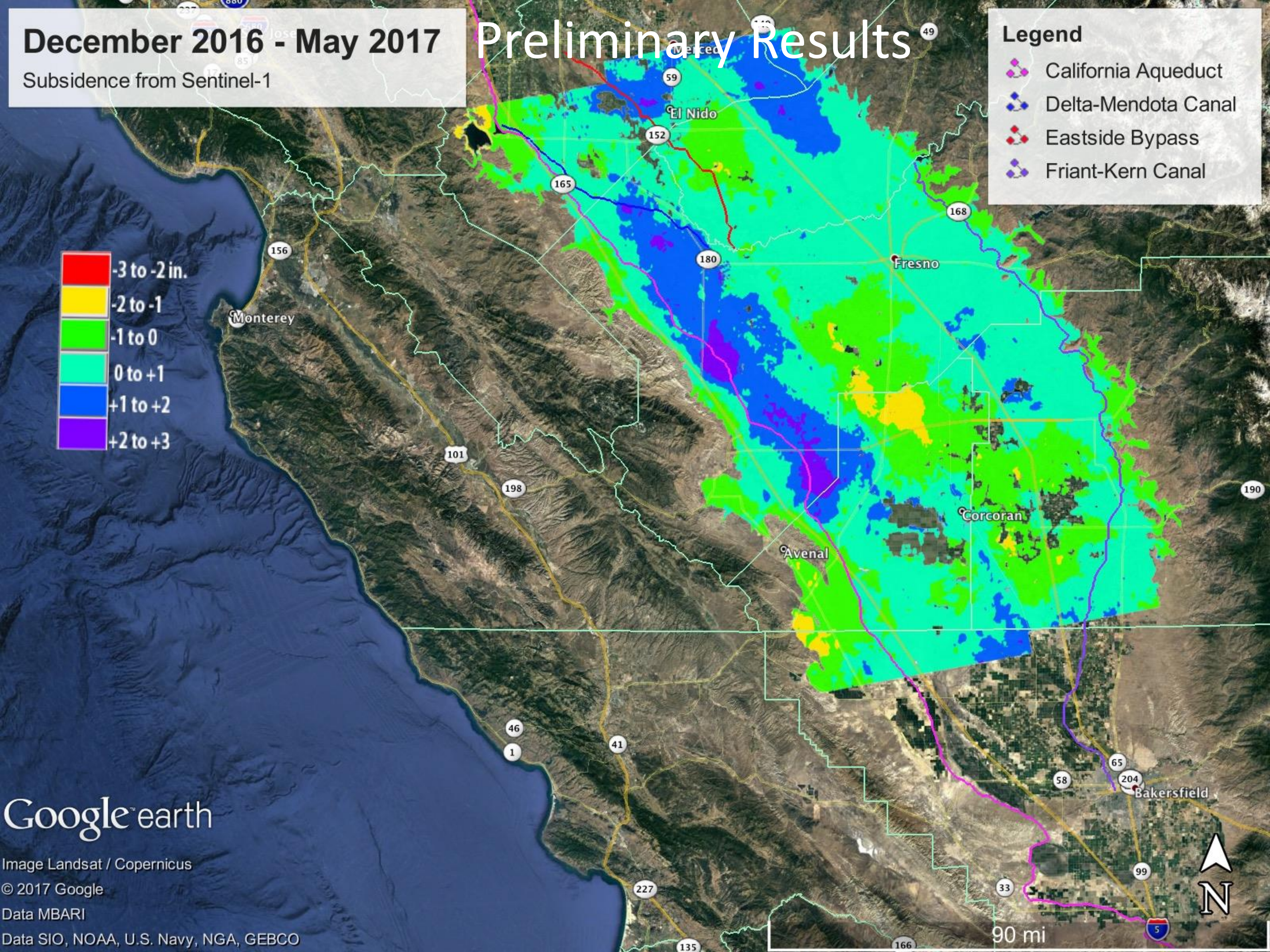


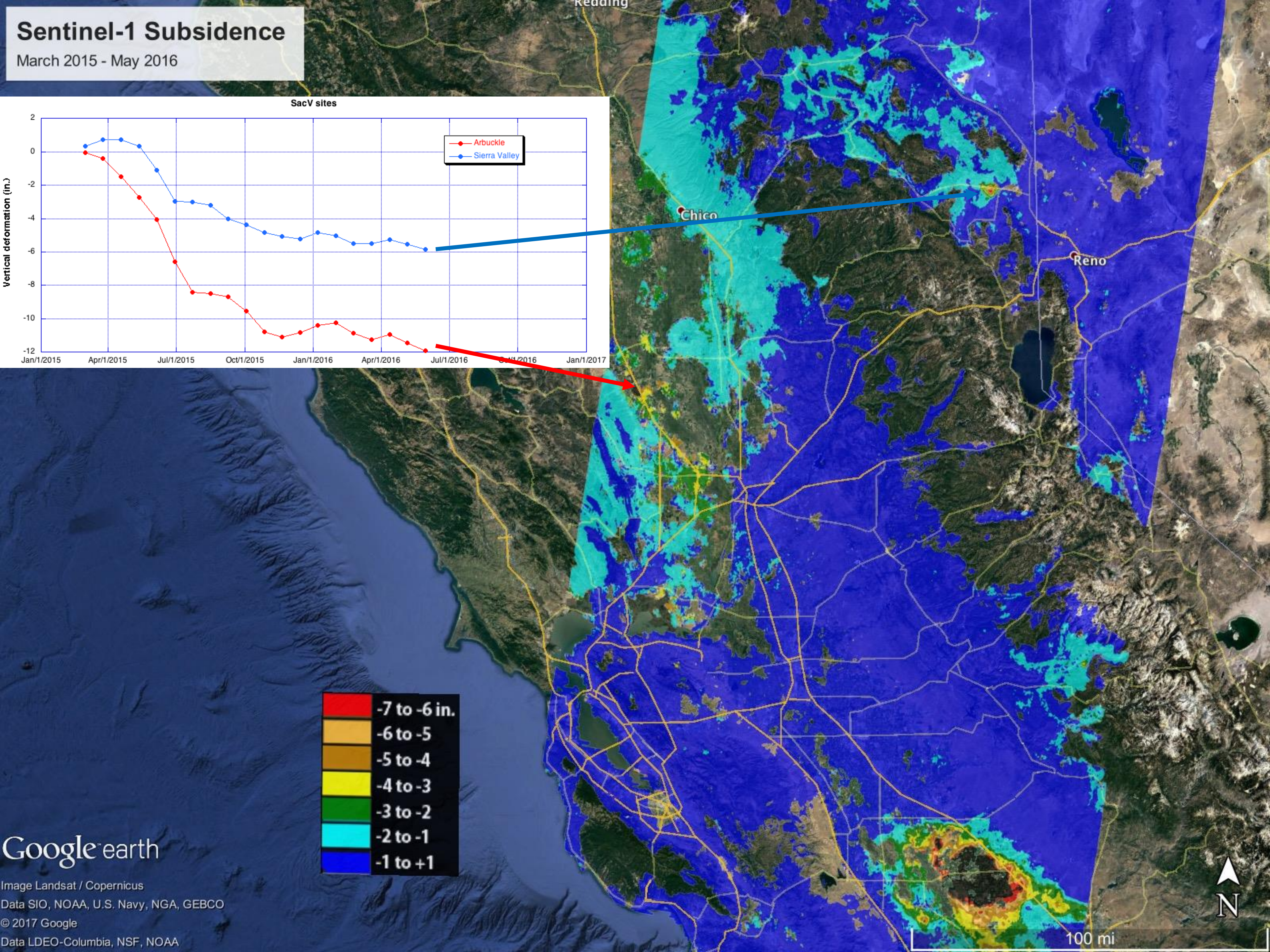
July 2007 - December 2010
Subsidence from PALSAR-1
Legend
California Aqueduct
Delta-Mendota Canal
Eastside Bypass
Friant-Kern Canal
-2 to -5 in.
-5 to -10
-10 to -15
-15 to -20
-20 to -25
-25 to -30
-30 to -35
Merced
El Nido
Fresno
Monterey
Corcoran
Avenal
Bakersfield
140
49
59
152
165
168
180
156
101
198
190
46
1
41
65
58
204
99
33
227
5
135
166
Google earth
Image Landsat / Copernicus
© 2017 Google
Data MBARI
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
90 mi
N


May 2014 - January 2015
Subsidence from Radarsat-2
Legend
California Aqueduct
Delta-Mendota Canal
Eastside Bypass
Friant-Kern Canal
-1 to -2 in.
-2 to -4
-4 to -6
-6 to -8
-8 to -10
-10 to -12
-12 to -14
Merced
El Nido
Fresno
Monterey
Corcoran
Avenal
Bakersfield
Google earth
Image Landsat / Copernicus
© 2017 Google
Data MBARI
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
90 mi
N


May 2015 - January 2017
Subsidence from Sentinel-1
Preliminary Results
Legend
California Aqueduct
Delta-Mendota Canal
Eastside Bypass
Friant-Kern Canal
-28 to -24 inches
-24 to -20
-20 to -16
-16 to -12
-12 to -8
-8 to -4
-4 to 0
0 to 4
Merced
El Nido
Fresno
Monterey
Corcoran
Avenal
Bakersfield
90 mi
N
Google earth
Image Landsat / Copernicus
© 2017 Google
Data MBARI
Data SIO, NOAA, U.S. Navy, NGA, GEBCO


May 2015 - January 2017
Subsidence from Sentinel-1
Preliminary Results
Legend
California Aqueduct
Delta-Mendota Canal
Eastside Bypass
Friant-Kern Canal
-28 to -24 inches
-24 to -20
-20 to -16
-16 to -12
-12 to -8
-8 to -4
-4 to 0
0 to 4
El Nido
Fresno
Monterey
Corcoran
Avenal
Bakersfield
90 mi
N
ElNido max
Corc max
Avenal max
Vertical deformation (in.)
5
0
-5
-10
-15
-20
-25
-30
May/1/2015
Sep/1/2015
Jan/1/2016
May/1/2016
Sep/1/2016
Jan/1/2017
May/1/2017
Sep/1/2017


December 2016 - May 2017
Subsidence from Sentinel-1
Preliminary Results
Legend
California Aqueduct
Delta-Mendota Canal
Eastside Bypass
Friant-Kern Canal
-3 to -2 in.
-2 to -1
-1 to 0
0 to +1
+1 to +2
+2 to +3
El Nido
Fresno
Monterey
Corcoran
Avenal
Bakersfield
Google earth
Image Landsat / Copernicus
© 2017 Google
Data MBARI
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
90 mi
N


Sentinel-1 Subsidence
March 2015 - May 2016
SacV sites
Vertical deformation (in.)
2
0
-2
-4
-6
-8
-10
-12
Jan/1/2015
Apr/1/2015
Jul/1/2015
Oct/1/2015
Jan/1/2016
Apr/1/2016
Jul/1/2016
Oct/1/2016
Jan/1/2017
Arbuckle
Sierra Valley
Chico
Reno
-7 to -6 in.
-6 to -5
-5 to -4
-4 to -3
-3 to -2
-2 to -1
-1 to +1
Google earth
Image Landsat / Copernicus
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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Data LDEO-Columbia, NSF, NOAA
100 mi
N

# Subsidence in the San Joaquin Valley

## Sentinel-1 May 2015 – Jan. 2017