Subsurface water flux in California's Central Valley and its source watershed from space geodesy

Donald Argus (JPL), Hilary Martens (U Montana), Adrian Borsa (UC San Diego),
El Knappe, David Wiese, Sarfaraz Alam (Stanford U),
Mackenzie Anderson (UCLA), Ash Khatiwada, Athina Peidou,
Matthew Swarr, Alissa White, Felix Landerer

We are integrating
GPS elastic displacements
and GRACE gravity
to estimate change in
total water at Earth's surface.

GPS improves
GRACE's spatial resolution.
GRACE determines water change
in areas with no GPS data
(such as the southern Central Valley).

We remove snow accumulation and
known change in surface water
to infer change
in subsurface water.

GPS and GRACE are resolving
the seasonal oscilliaton, interannual
variation and long-term loss of
groundwater across Central Valley.

Inverting GPS elastic displacements and GRACE gravity for change in water at Earth's surface

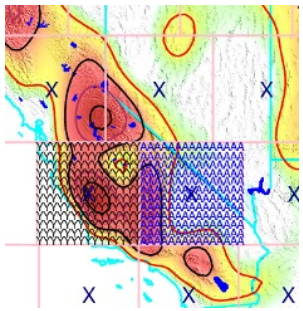
Minimize:

$$((\mathbf{Ax} - \mathbf{b}) / \sigma_1)^2 + ((\mathbf{Cx} - \mathbf{d}) / \sigma_2)^2 + (\nabla^2 (\mathbf{x}) / \sigma_3)^2$$

GPS elastic displacements

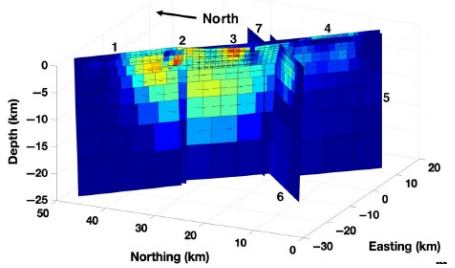
$u = m \times G(\Theta)$

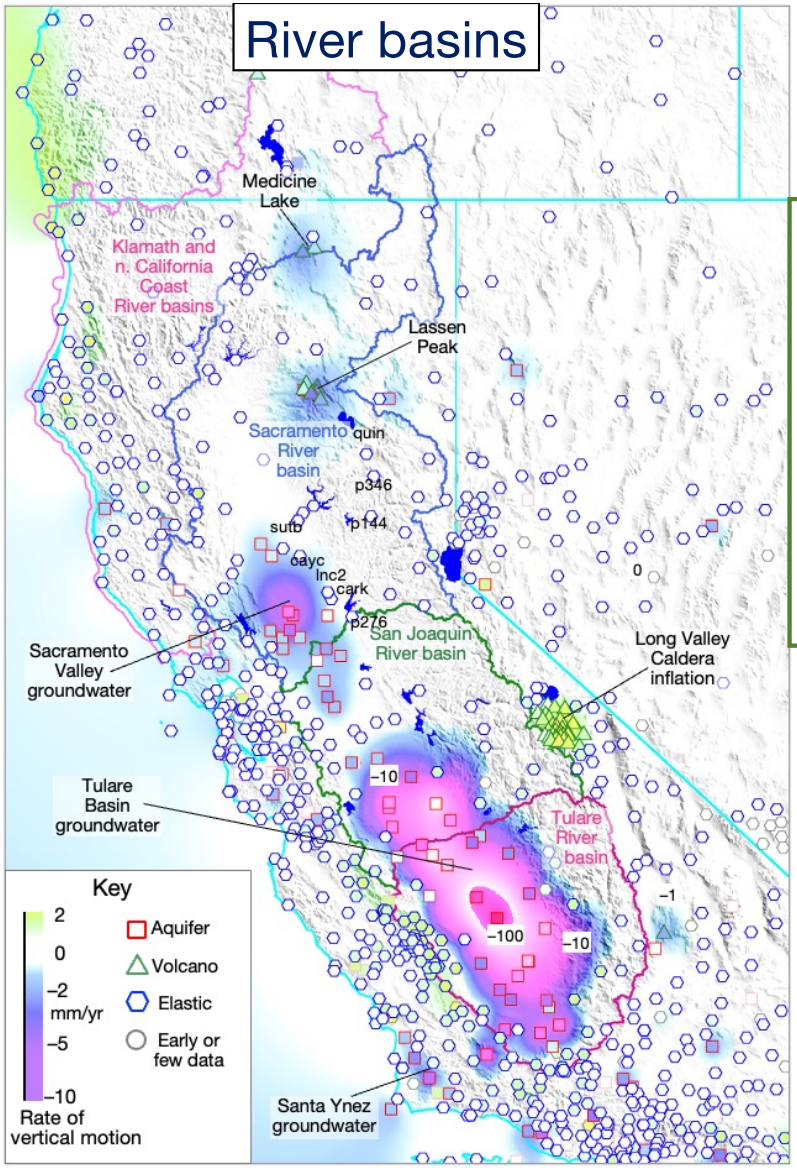
GRACE equivalent water thickness



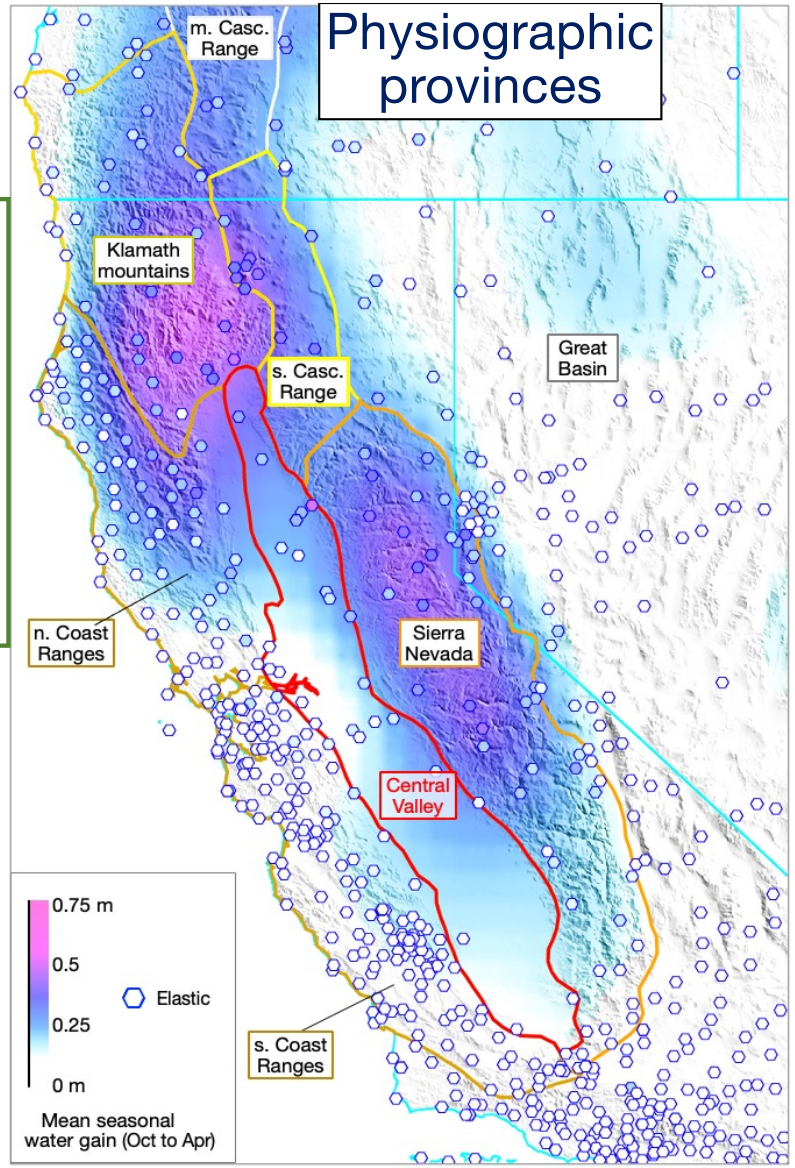
regularization

$$((x - (a + b + c + d)/4) / \sigma_3)^2$$





GRACE can resolve water change across the big Sacramento–San Joaquin–Tulare River basin (154,800 km^2), but cannot resolve water change in the small Central Valley (48,800 km^2) and Sierra Nevada (68,300 km^2).



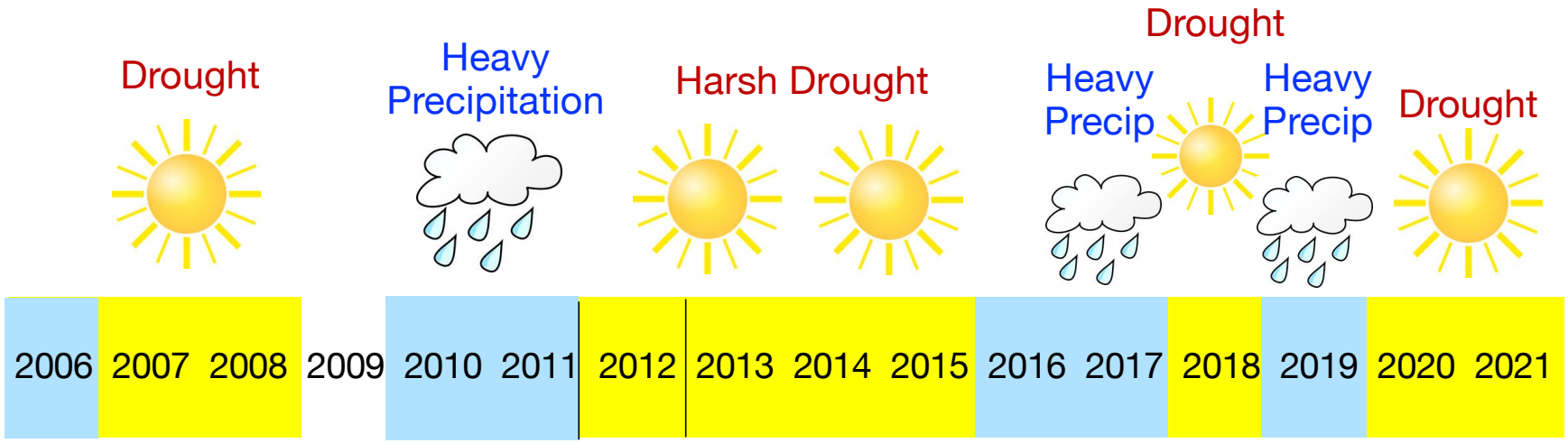
PART 1
Loss of water in the ground in the southwest U.S. during drought in 2020 and 2021

4 years harsh drought
1 in 1000 year

heavy snow
2017, 2019

moderate drought
2020

rain, snow ½ usual
2021



Water Year 2012
starts Oct, ends Sep

Sierra Nevada snow (km^3)

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
28	7	24	17	25	35	12	14	4	2	11	32	10	37	11	14

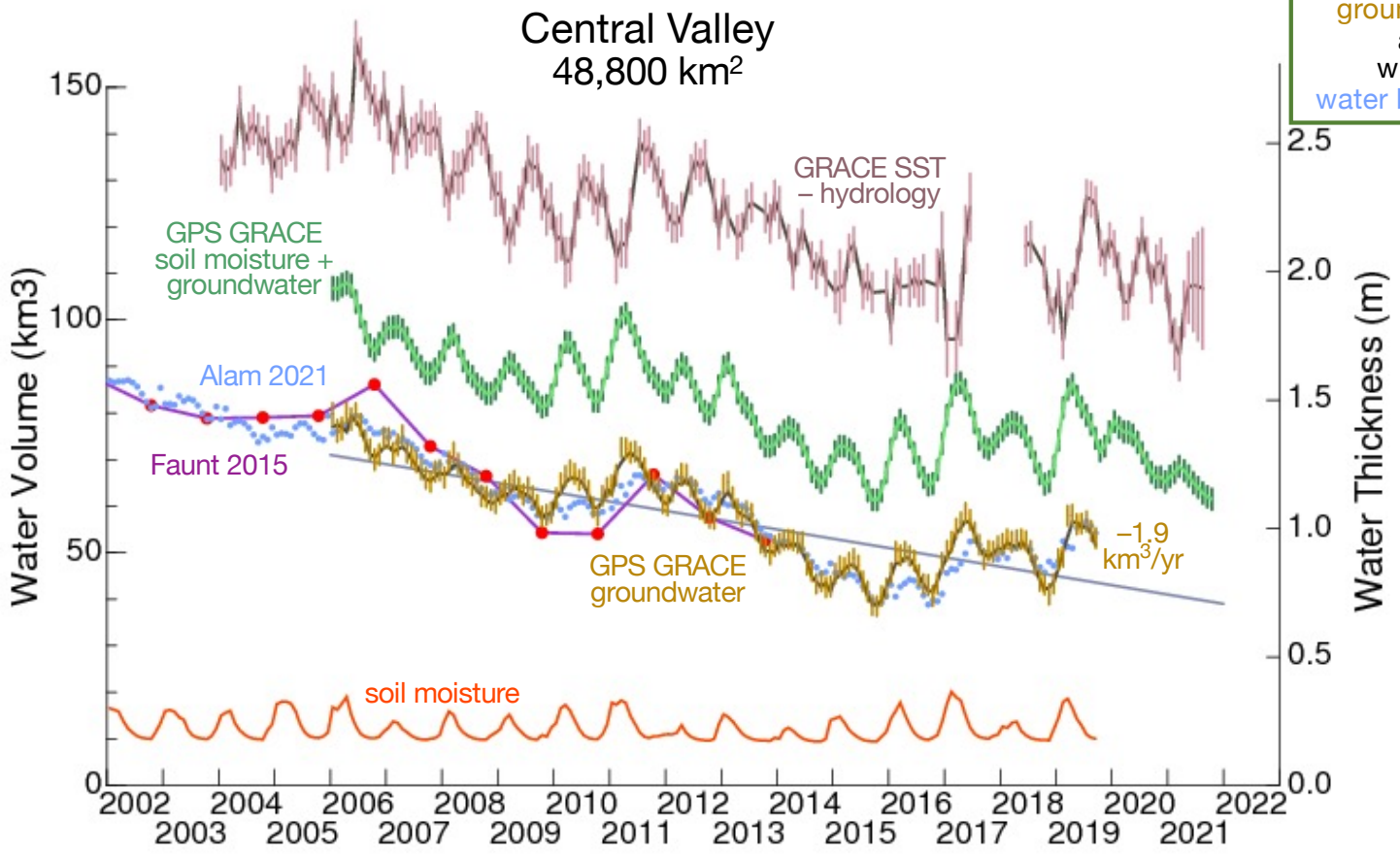
In Famiglietti 2011,
Central Valley ground water is
GRACE in SST River basin
minus
a hydrology model in
SST River basin.

The hydrology model
understates
changes in
subsurface water

Argus 2017
find more
subsurface water
is lost
during drought
and gained during
heavy precipitation
than
in land surface
hydrology models.

There are no
GPS sites
recording elastic
response
in southern C.V.

Plotted is



The GPS/GRACE
evolution of Central Valley
groundwater change
agrees well
with the UCLA
water balance estimate.

southern Central Valley water
is roughly
GRACE in SST River basin
minus
GPS everywhere else in SST River basin.

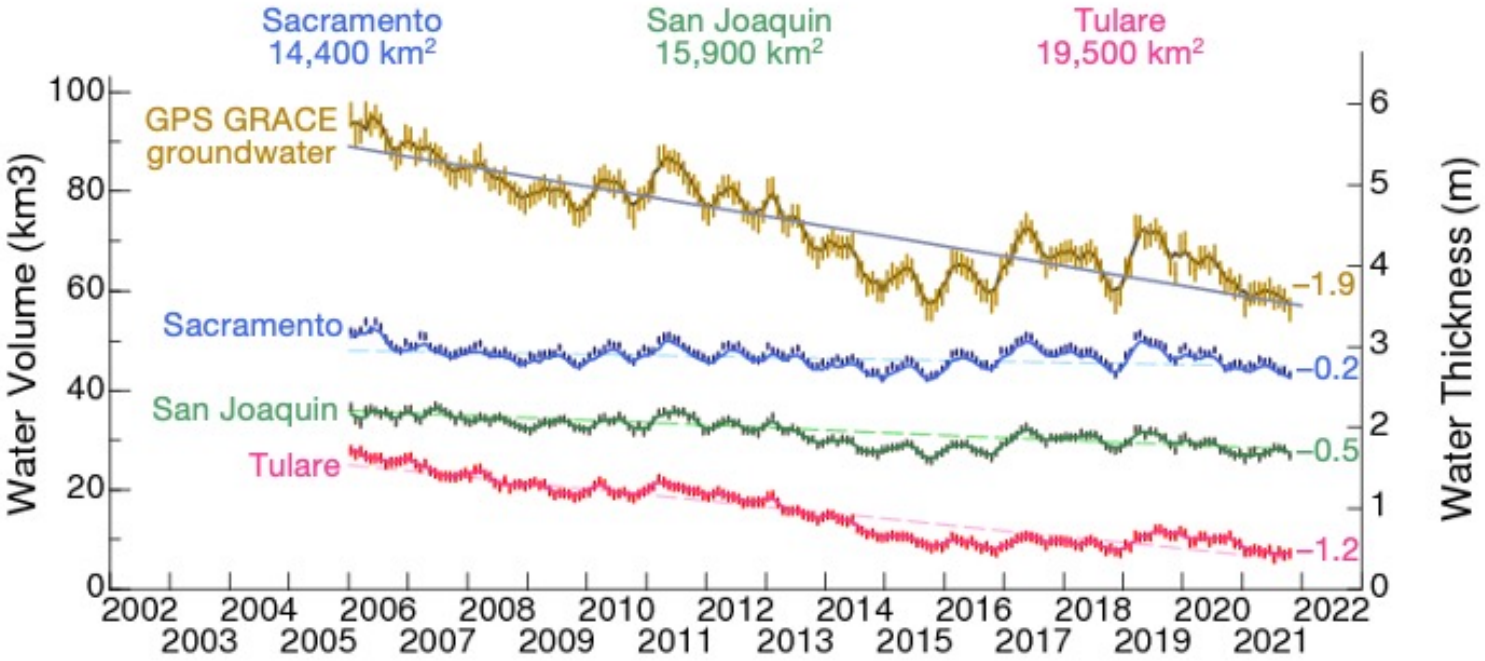
Central Valley groundwater
is taken to be
Central Valley water minus
LSM-VIC soil moisture.

Central Valley
seasonal oscillation in water
is 12 km^3
with maximum in April.

water also observed to be maximum in Apr

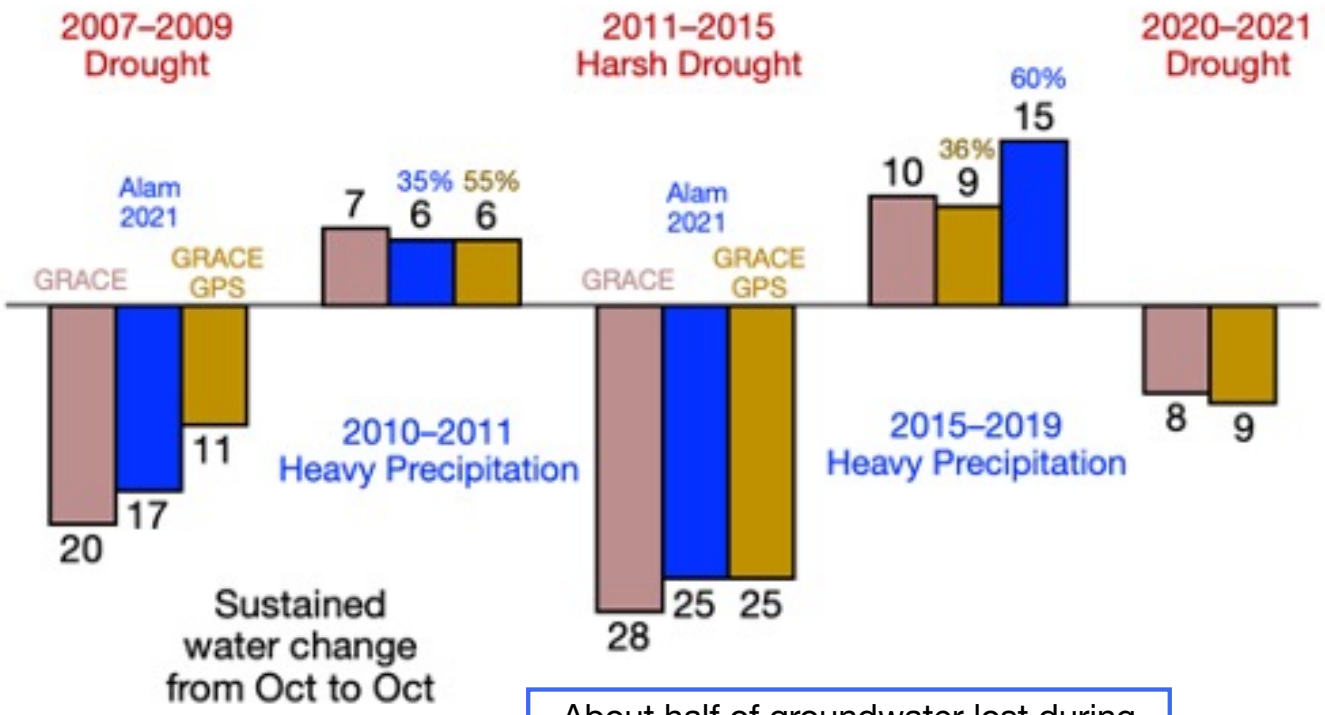
Central Valley
has lost groundwater
from 2006 to 2021
at a mean rate of 2 km^3/yr

GPS and GRACE are resolving the spatial distribution of groundwater loss across the Central Valley.



The southern Central Valley has lost groundwater at 1.2 km^3/yr since 2006, accounting for 63% of the total loss in the Valley.

Central Valley groundwater



About half of groundwater lost during periods of drought is replenished during subsequent years of heavy precipitation.

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Key Points

The seasonal oscillation in mountain groundwater is 1/5 of yearly cumulative precipitation and 1/3 of the oscillation in total water.

The southern Central Valley has lost groundwater at 1.2 km^3/yr since 2006, accounting for 63% of the total loss in the Valley.

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