Water Storage Variations in California, Oregon and Washington Estimated From GPS Observation of Loading Deformation

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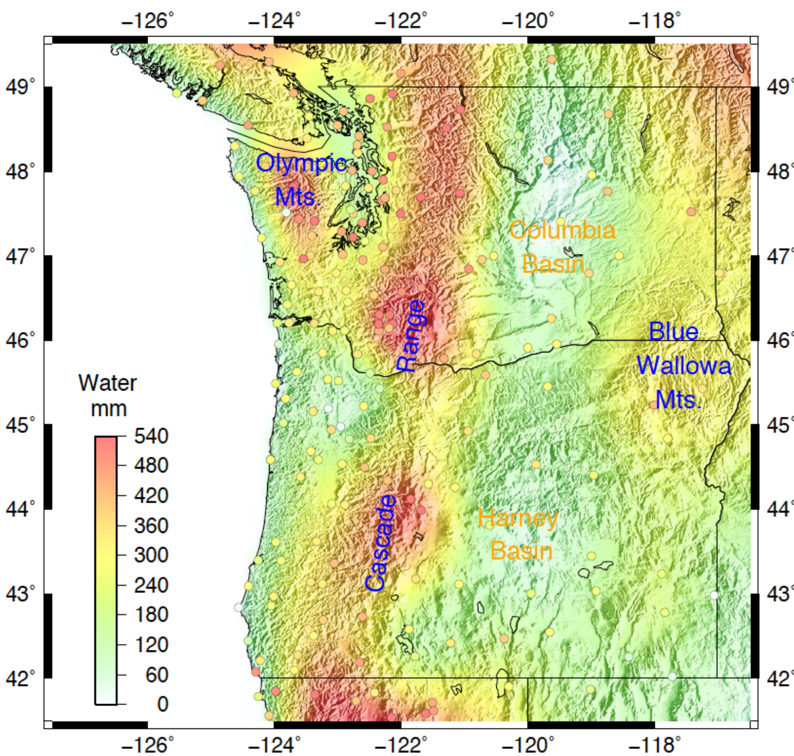
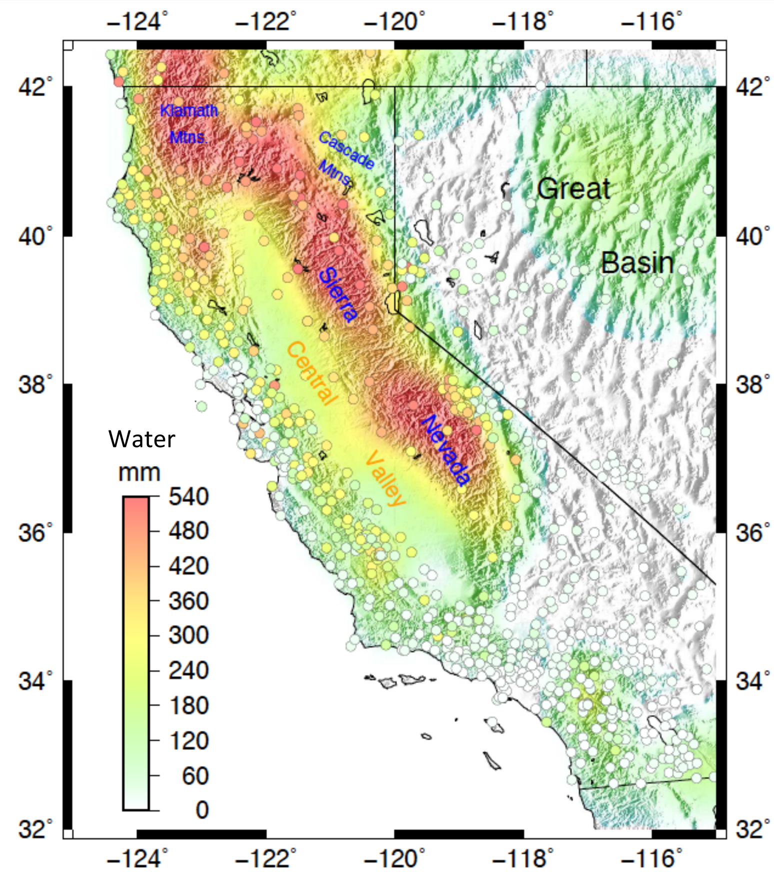


Washington & Oregon



California

Outlines

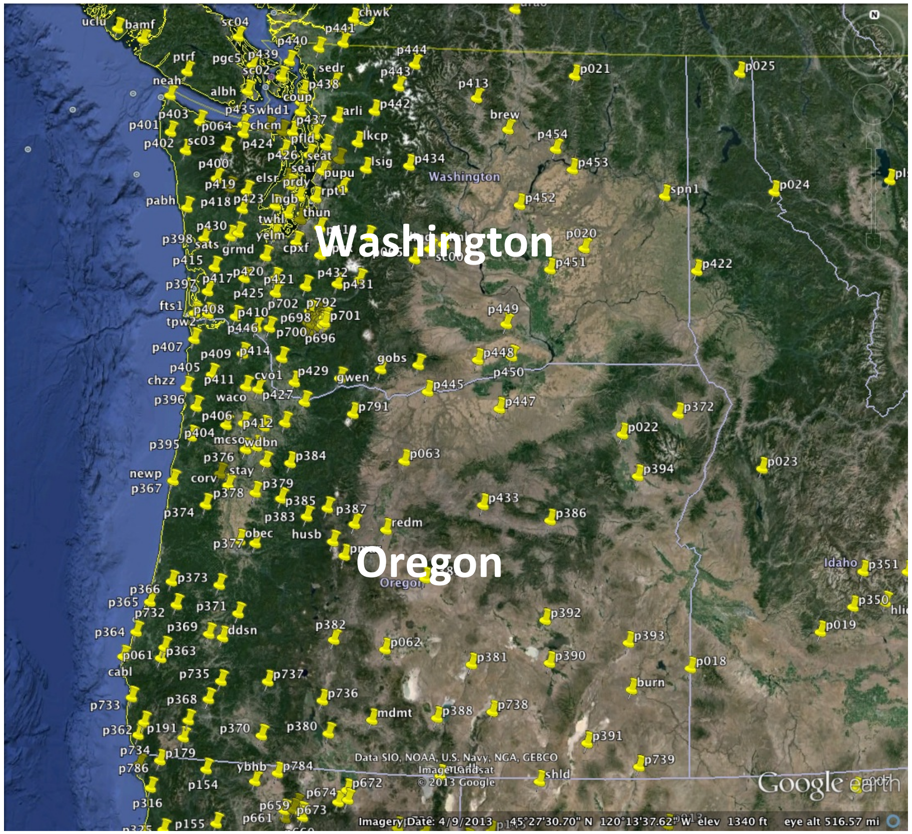
- Motivation.
- GPS measured vertical loading deformation in the western U.S.
- Forward model: Crustal elastic loading deformation.

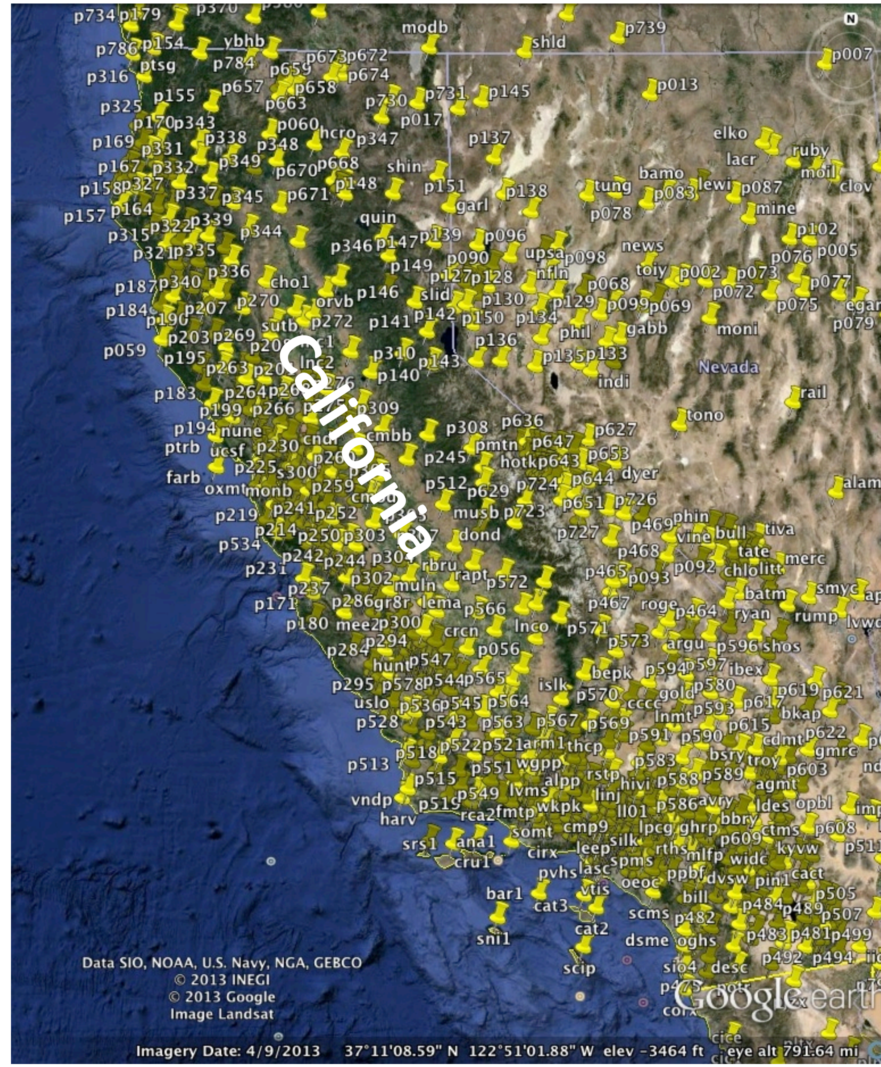
  Surface load → Deformation
- Inversion strategy.

  Deformation → Surface load
- Seasonal water storage in the western U.S.: California, Oregon and Washington.
- Time-variable monthly water storage change.
- GPS-inferred water: applications for GRACE and hydrological model.

Photo: UNAVCO

Motivation



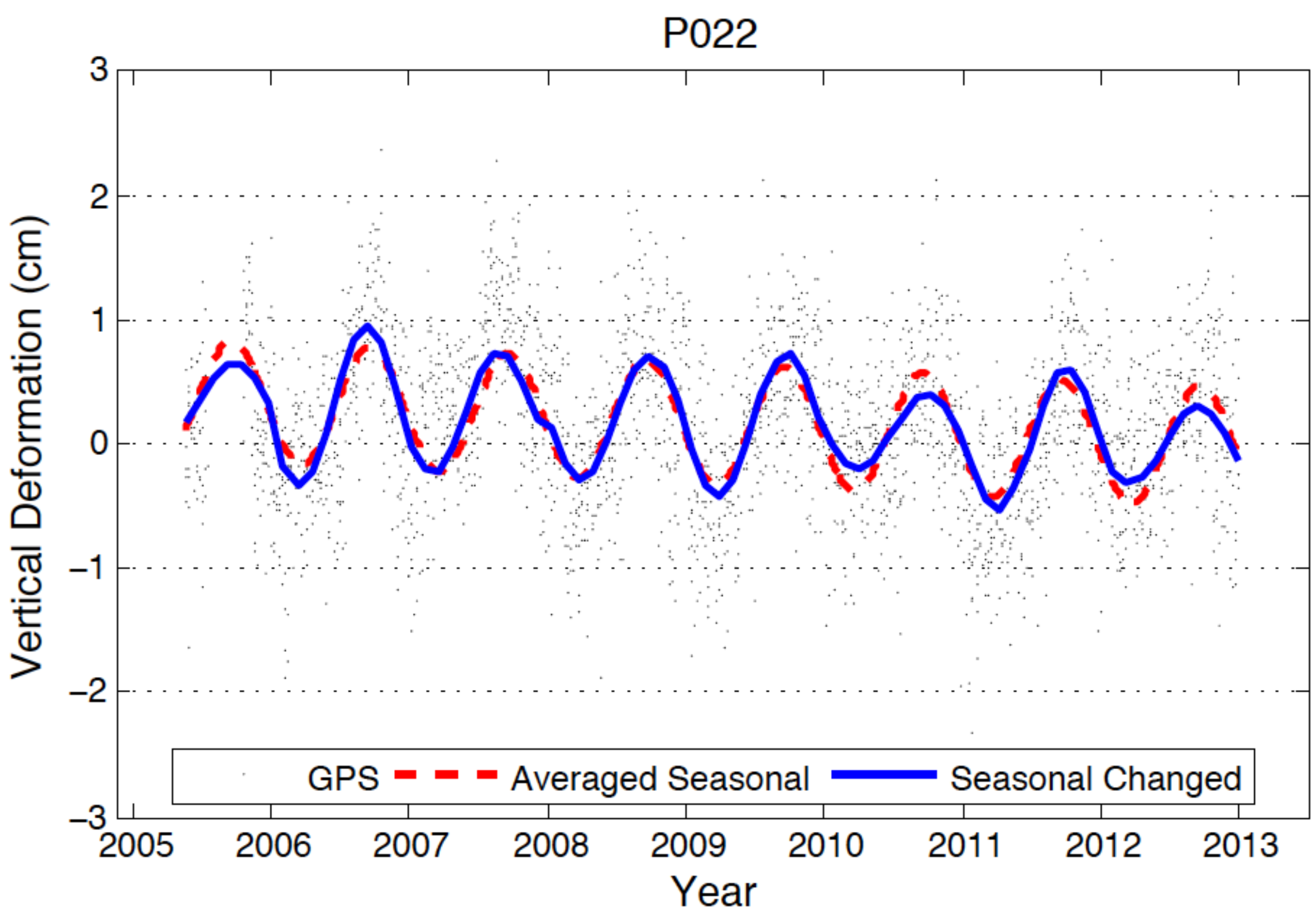


Acknowledgements

Plate Boundary Observatory UNAVCO
MEaSUREs NASA

GPS Measurement (Height)

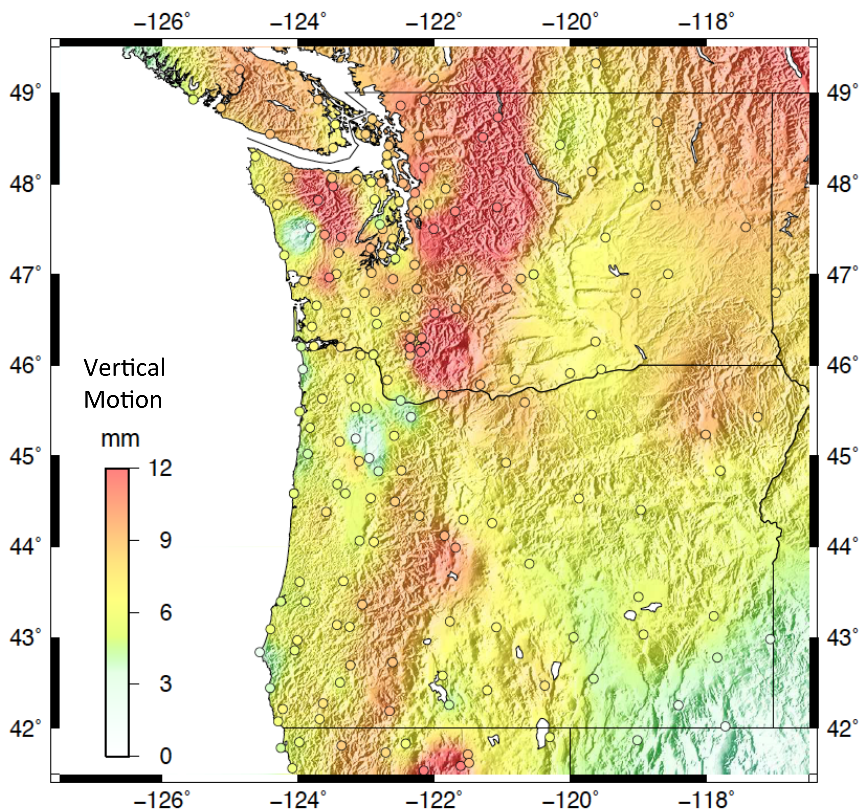
P022, located in La Grande, Oregon



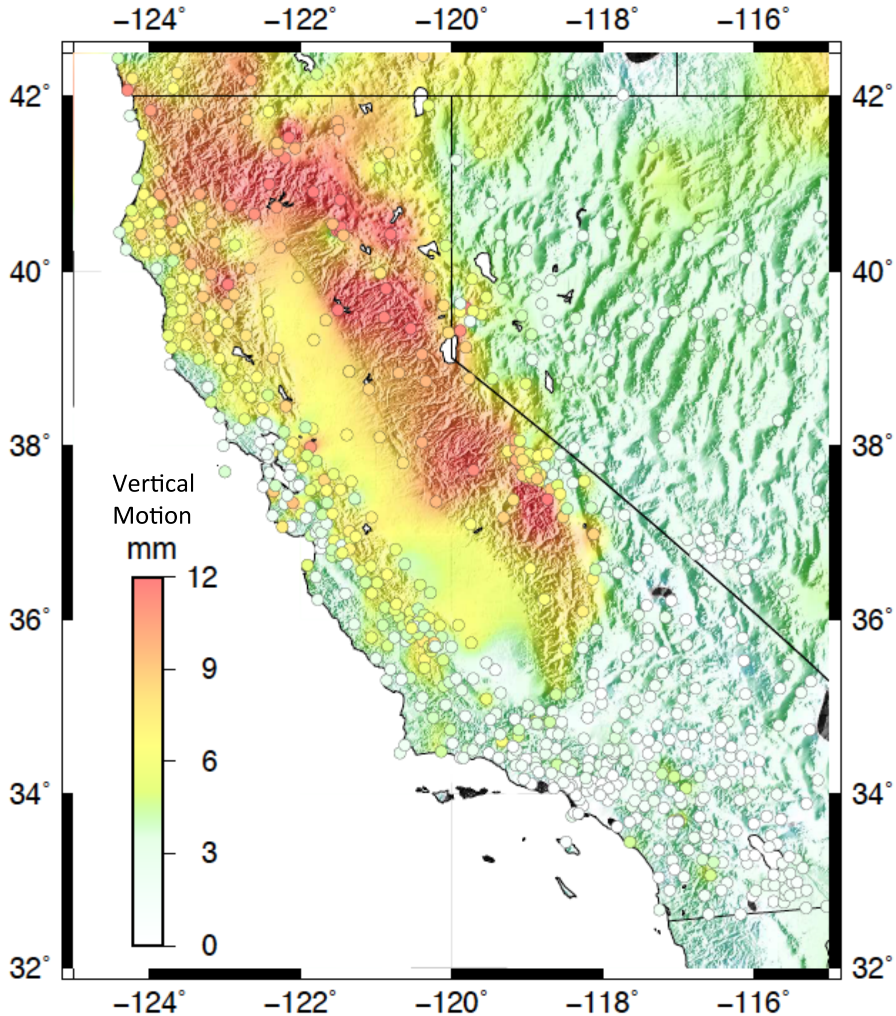
GPS Measured Multi-year Averaged Seasonal Vertical Motion

Vertical Motion

Oct to **Apr**



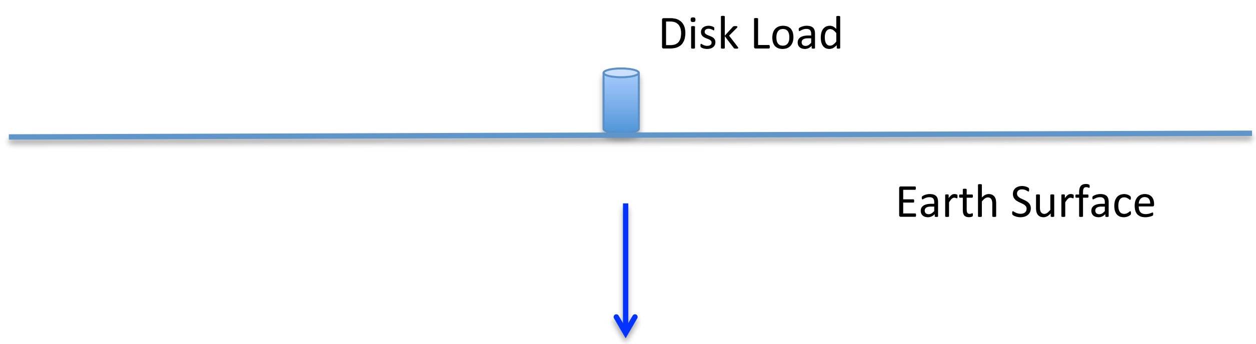
Washington & Oregon

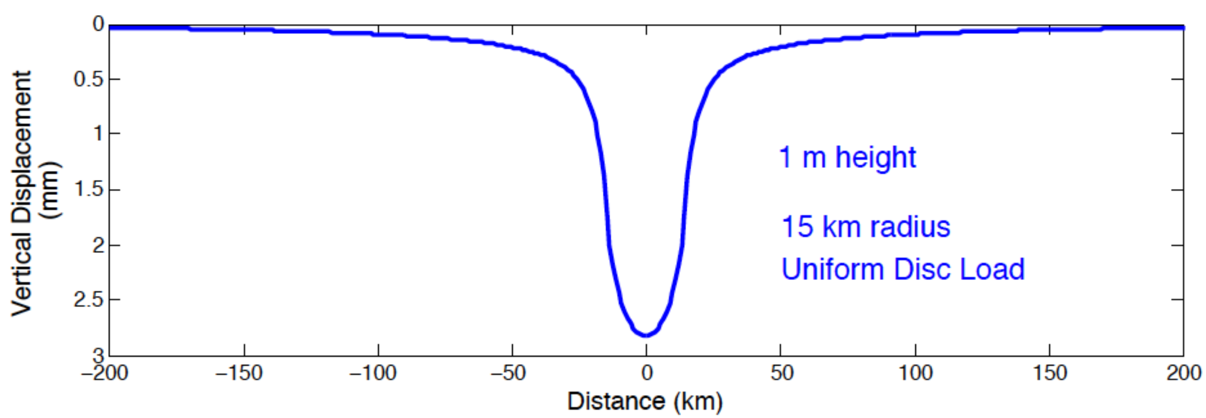


California

Forward model

Surface load → Deformation

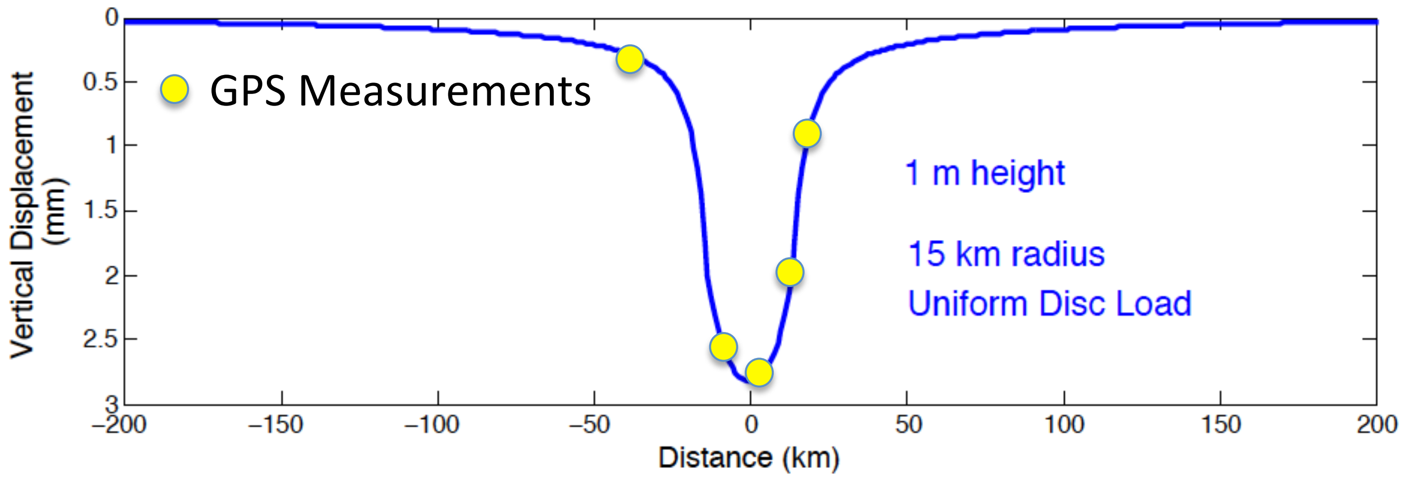


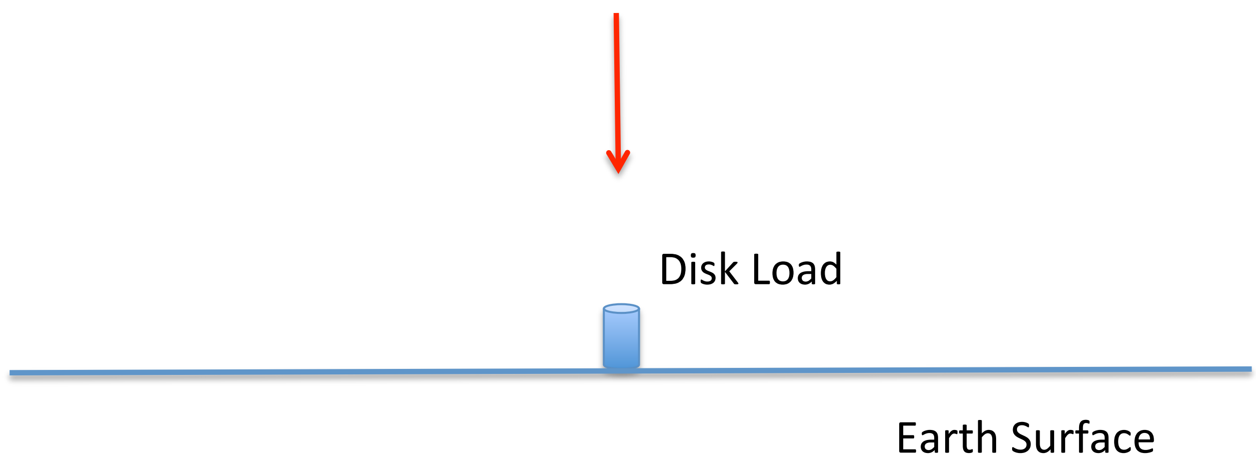


PREM Earth Structure

Inverse Model

Deformation → Surface Load





Inversion Strategy

- **Divide** the whole region of Washington, Oregon and California into **0.25° × 0.25°** patches.

- **A damped least square inversion strategy** to evaluate the optimal surface water mass variations from GPS measured vertical seasonal deformation.

Green's functions

roughness weight

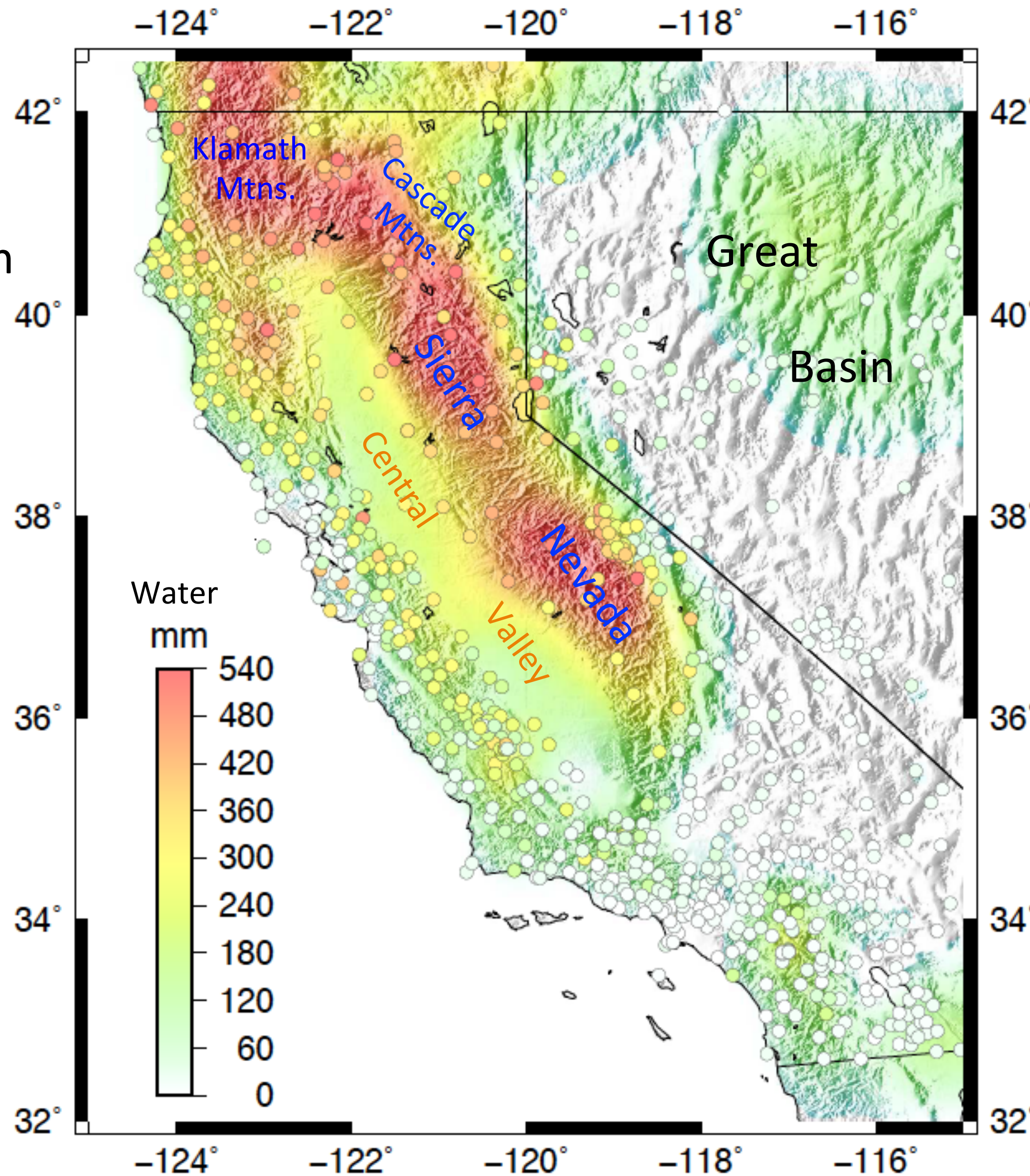
$$\underbrace{||W(Gx-b)||^2}_{Misfit(WRSS)} + \beta^2 \underbrace{||Lx||^2}_{Roughness} \rightarrow min$$

GPS observations

Laplacian smooth operator

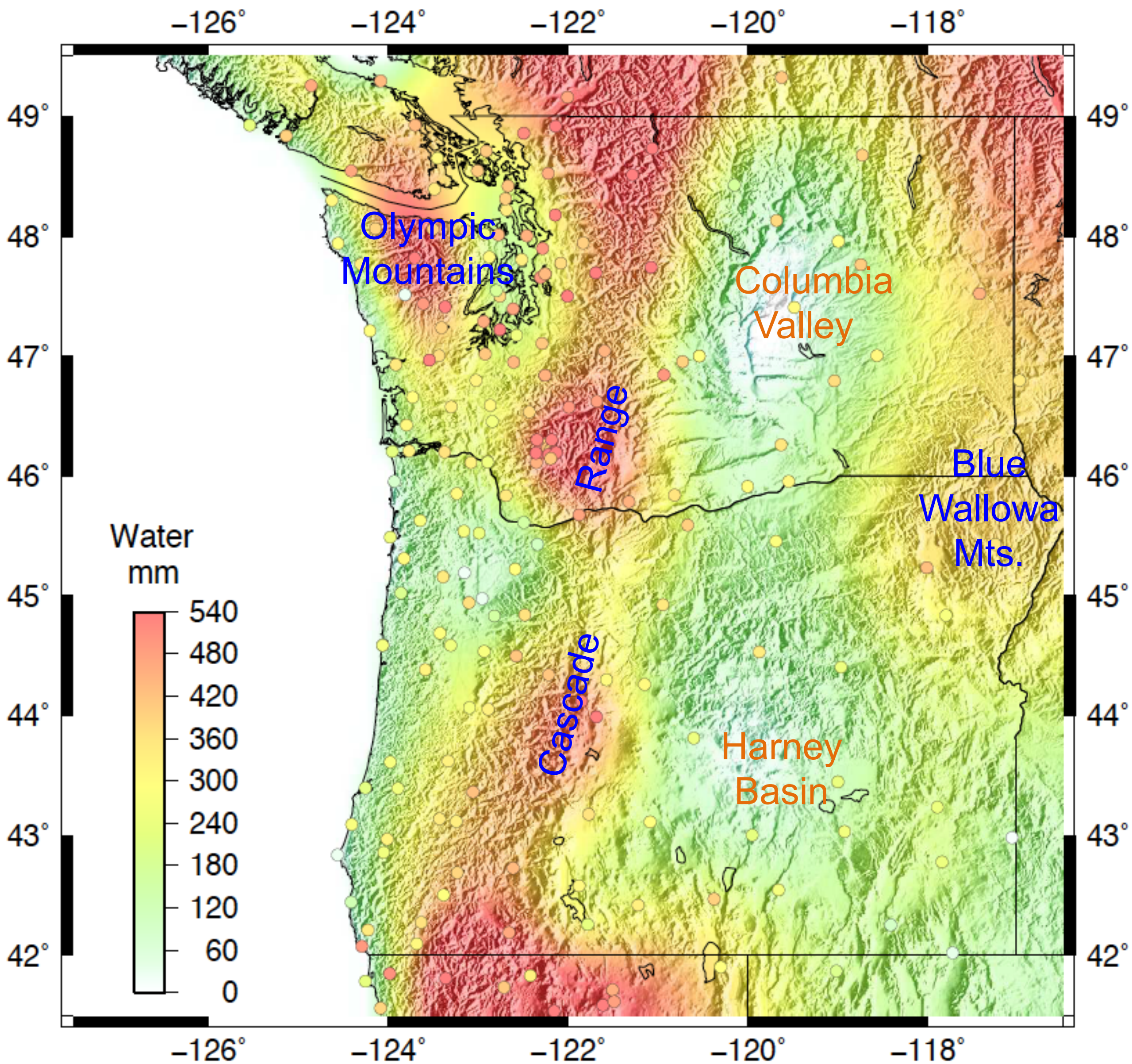
GPS Inversion Result: California

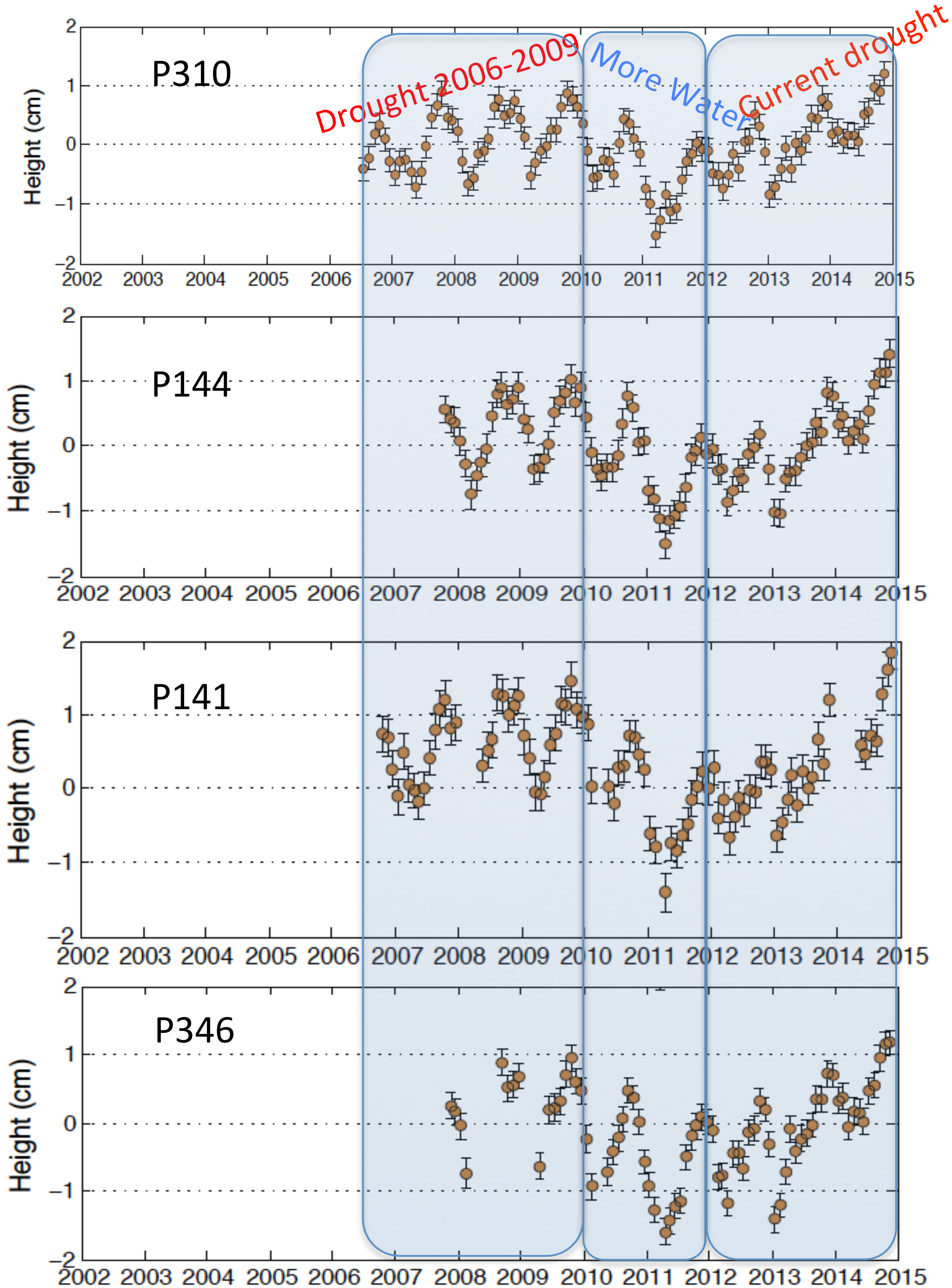
Seasonal
Water Variation
Oct to **Apr**



GPS Inversion Result: Washington and Oregon

Seasonal
Water Variation
Oct to **Apr**

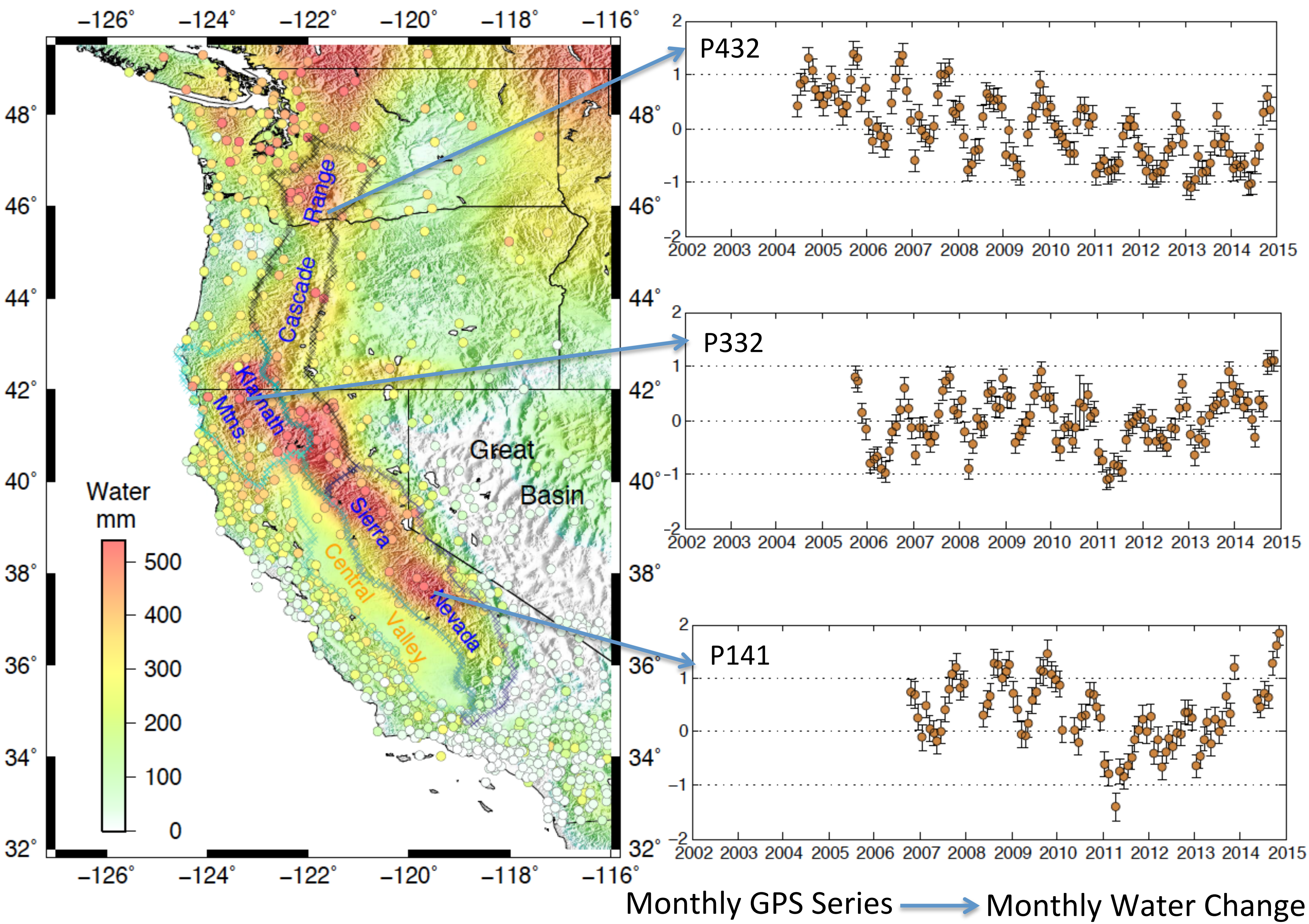




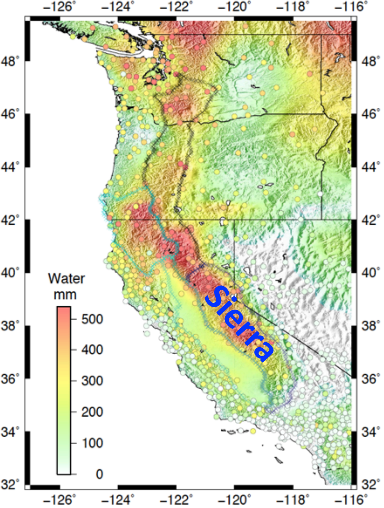
GPS monthly timeseries

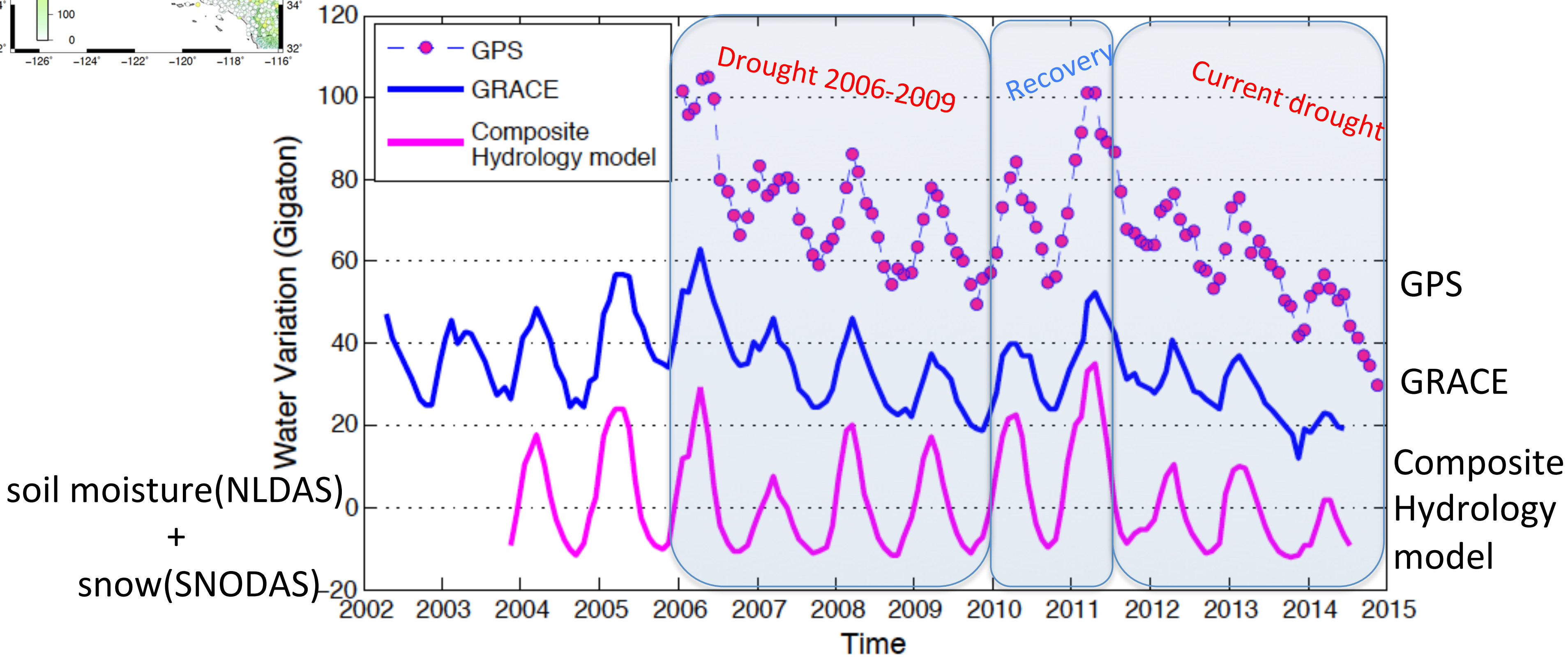
- **Sierra Nevada Mtns**
- Drought 2006-2009
- Heavy precipitation: 2010-2011
- Current drought: 2011 - now

Background: Seasonal Water Variation: Apr and Oct

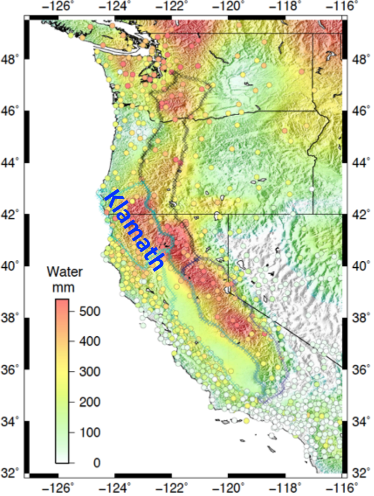


Sierra Nevada Mountains

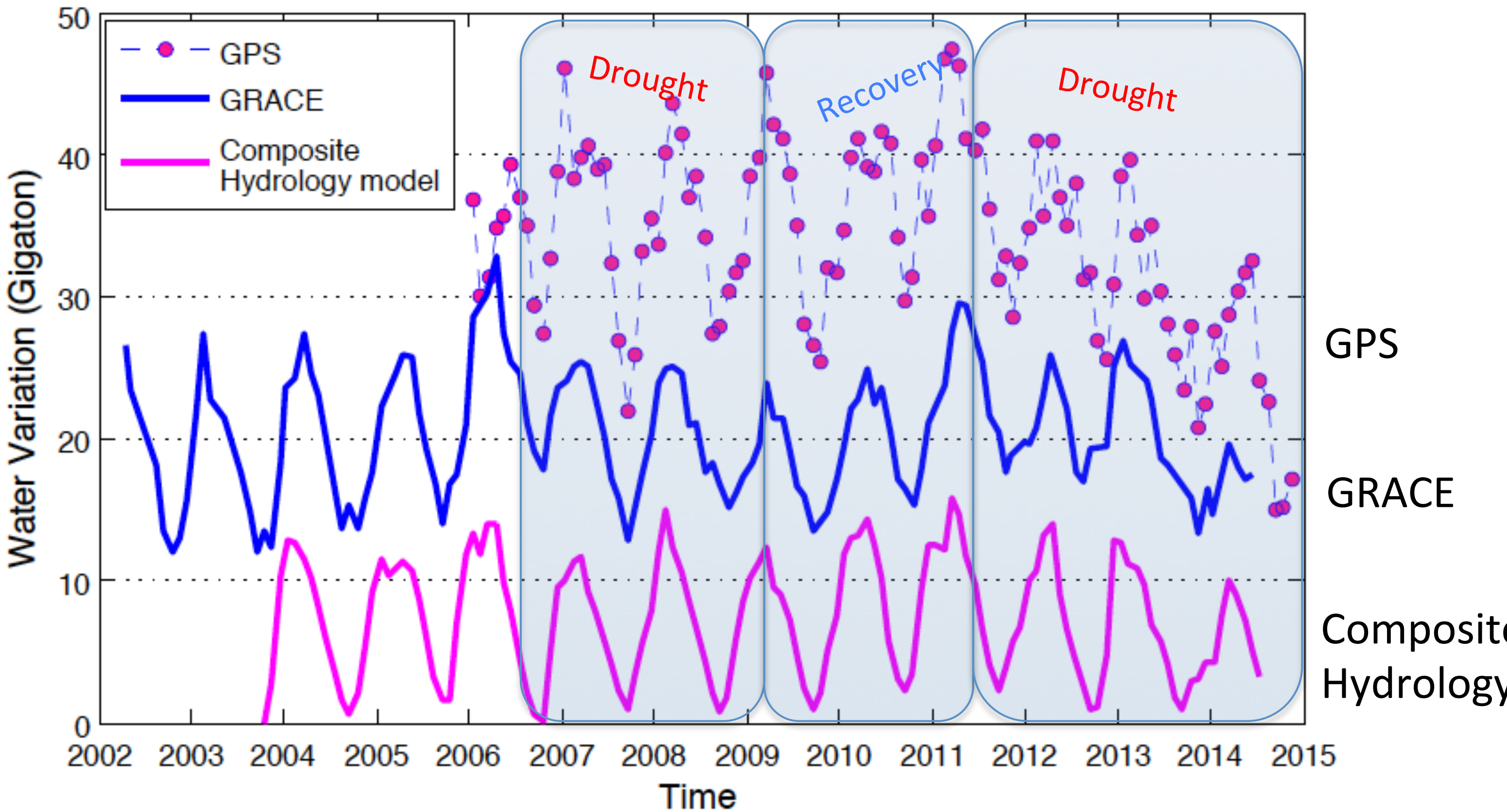




GRACE: JPL's mascon solutions, from D. Wiese, M. Watkins, and F. Landerer.



Klamath Mountain



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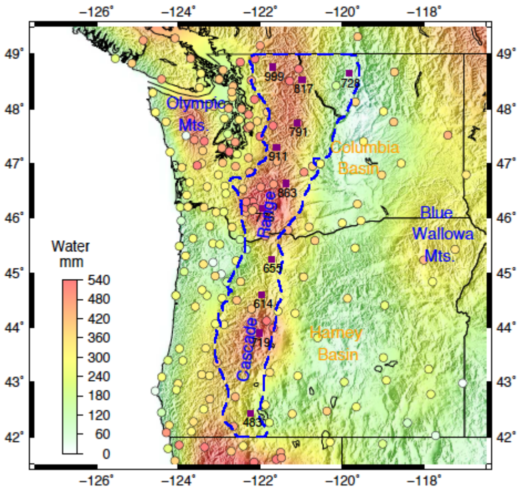
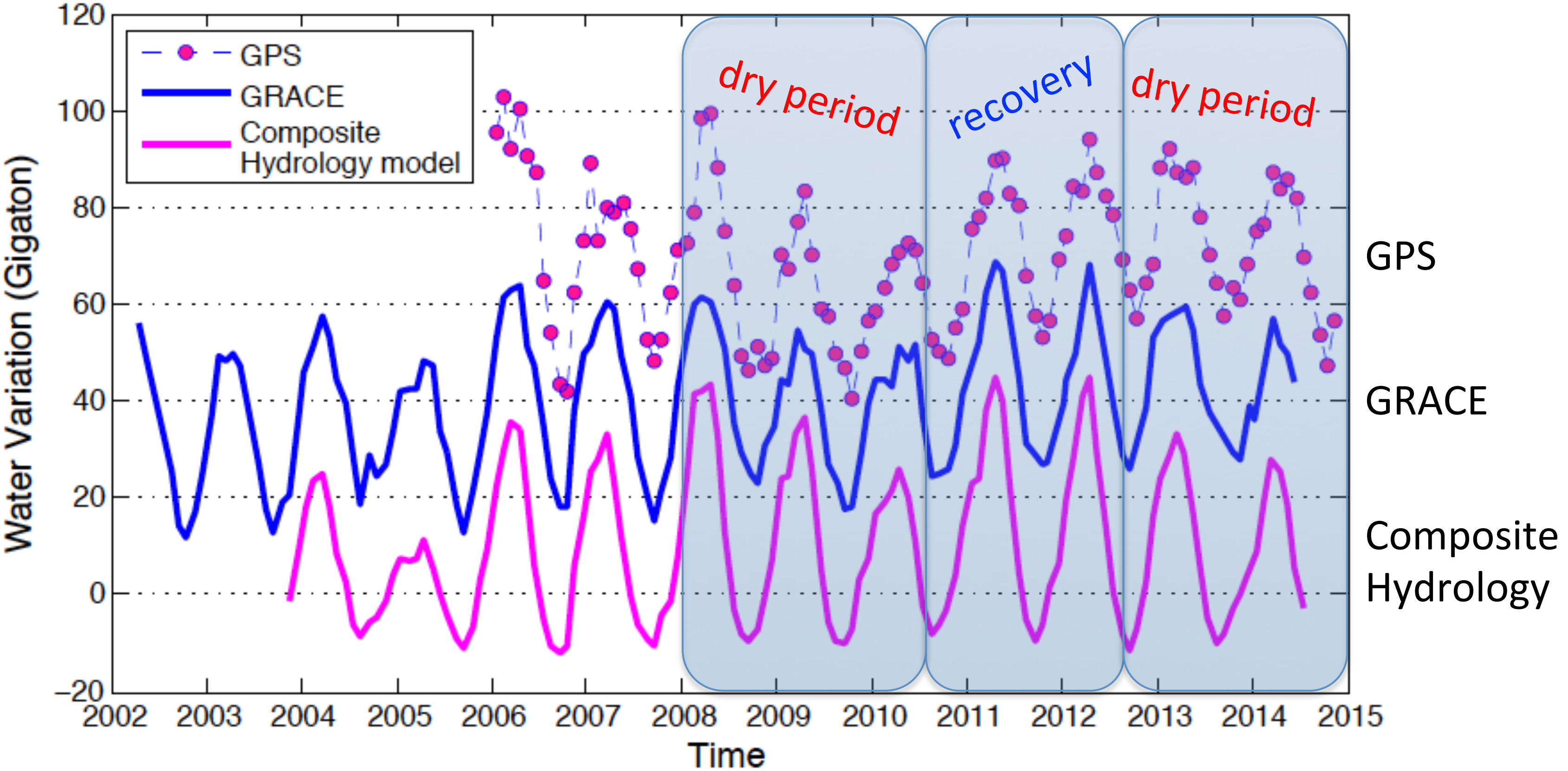
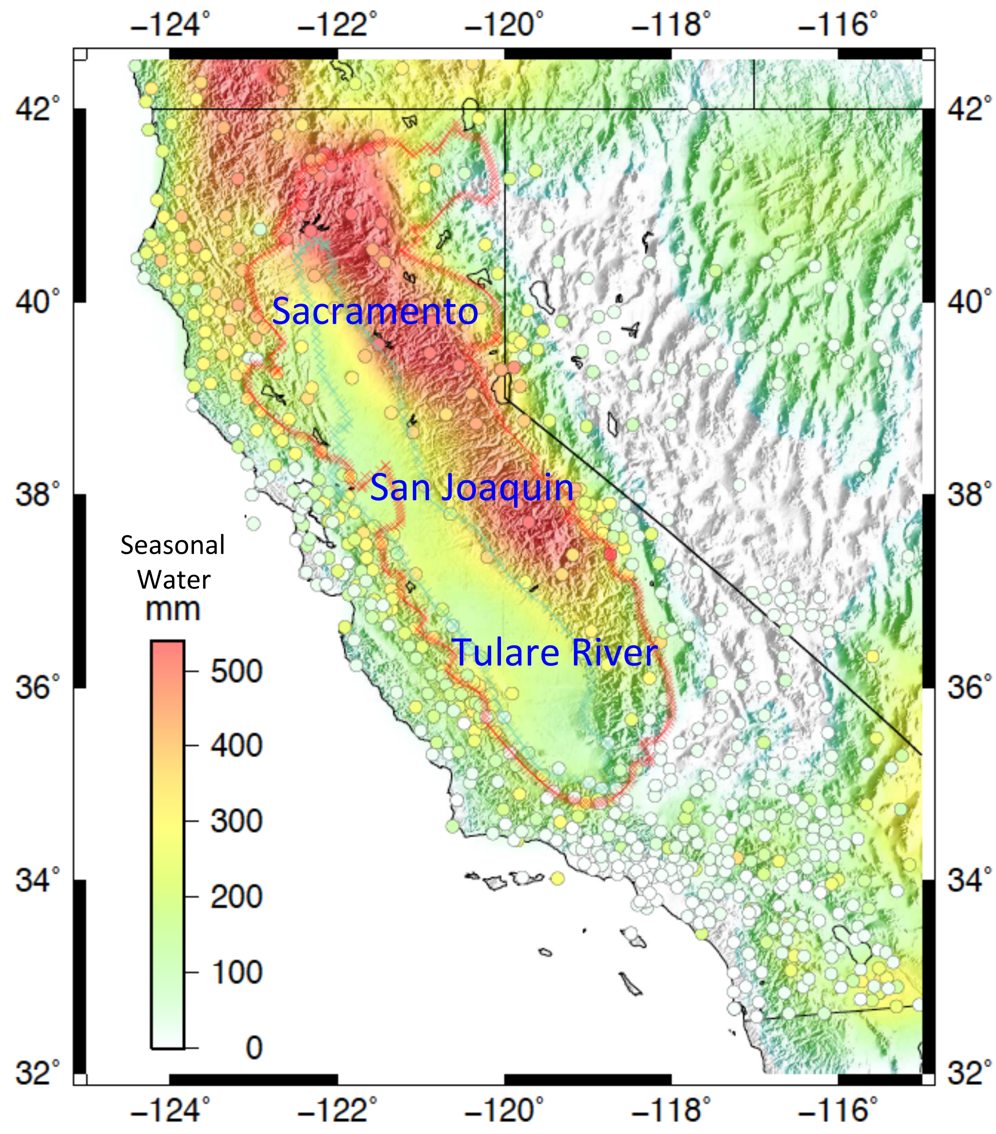


Cascade Range
in Washington & Oregon

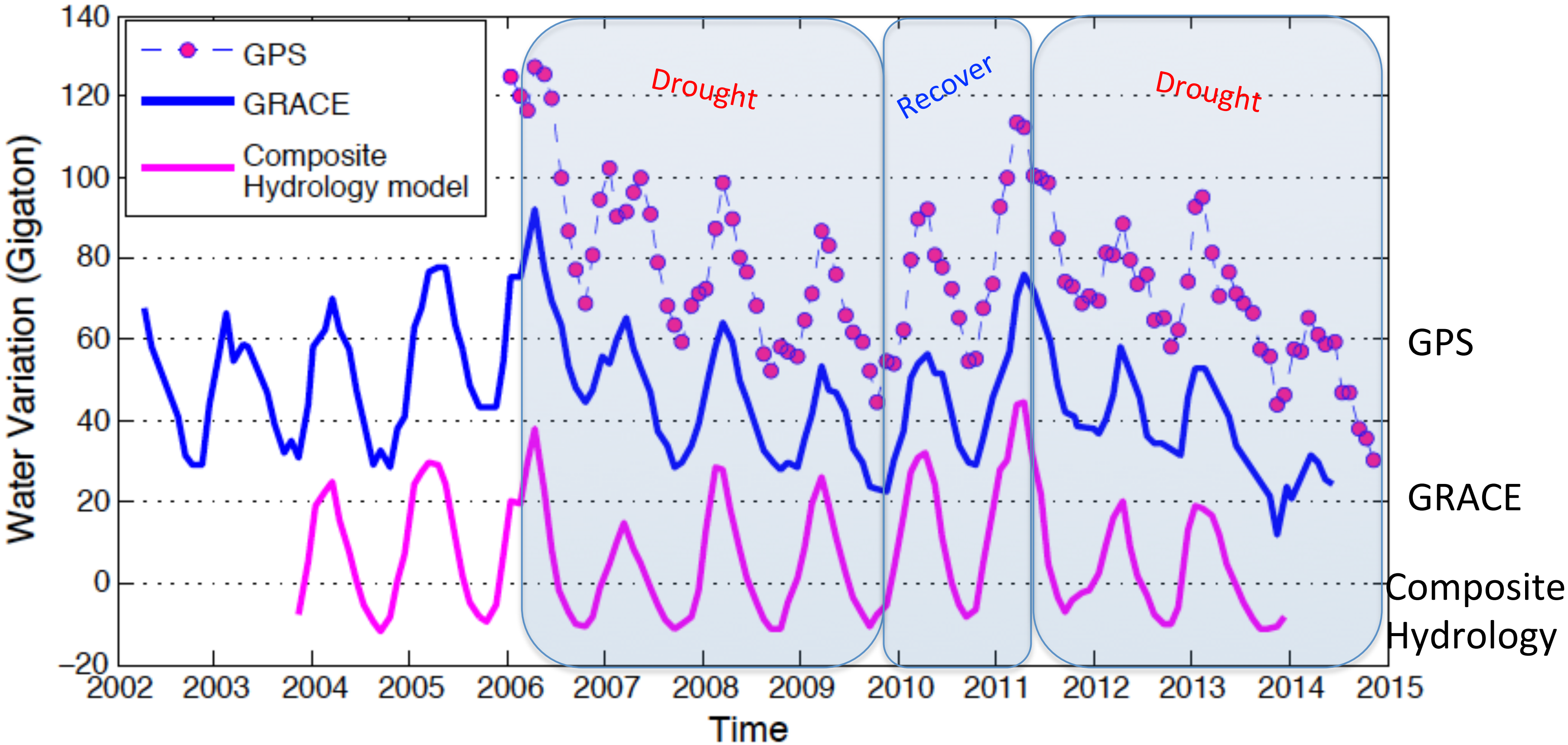


California
Sacramento + San Joaquin + Tulare River basin – Central Valley



California

Sacramento + San Joaquin + Tulare River basin – Central Valley



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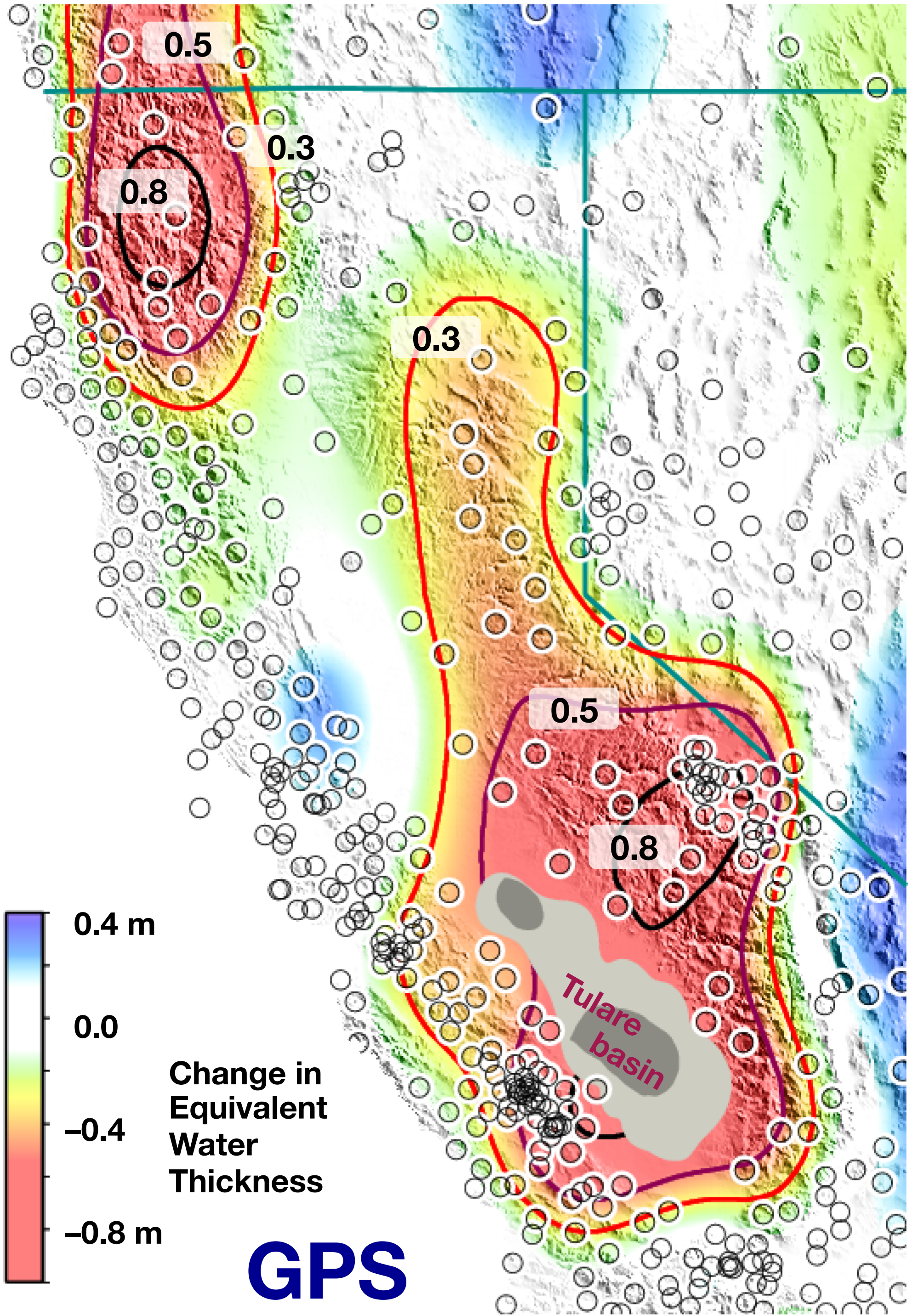


Decrease in Water Thickness during 3 Years of Drought GPS (Oct 2011–Oct 2014)

Changes in Reservoir Storage have been removed.

Because Snow in October is negligible, interpret to be the sum of:

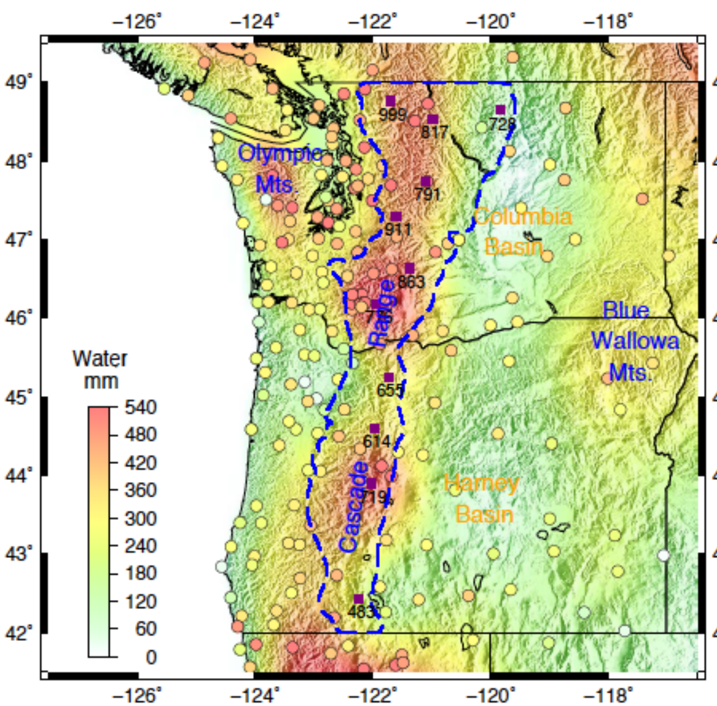
(1) Soil Moisture,

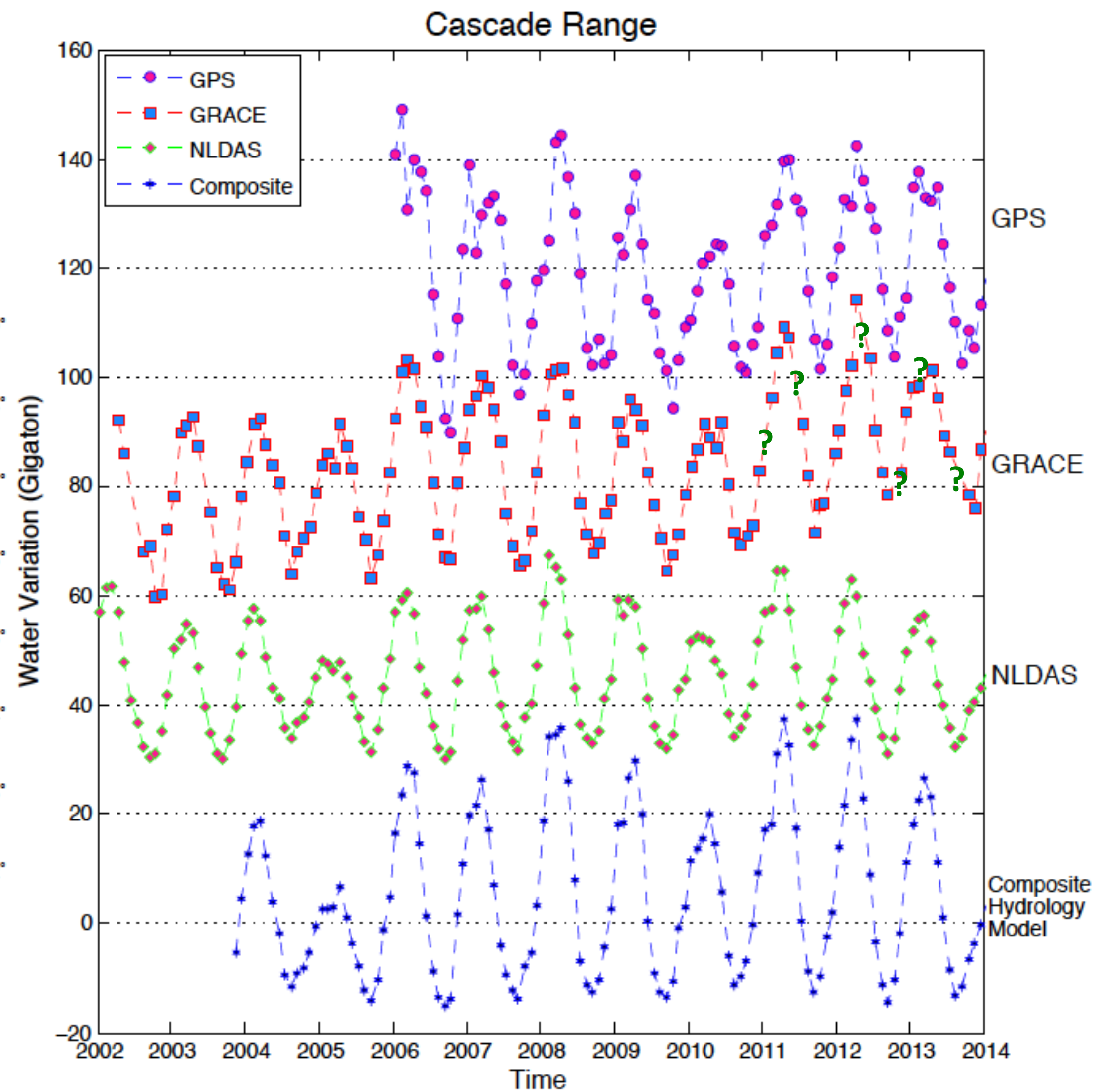
(2) Sierra Nevada Mountain Fracture Groundwater, and

(3) perhaps Central Valley Aquifer Groundwater

Result
The southern Sierra Nevada mountains lost 30 Gigatons of soil moisture and fracture groundwater from Oct 2011 to Oct 2014

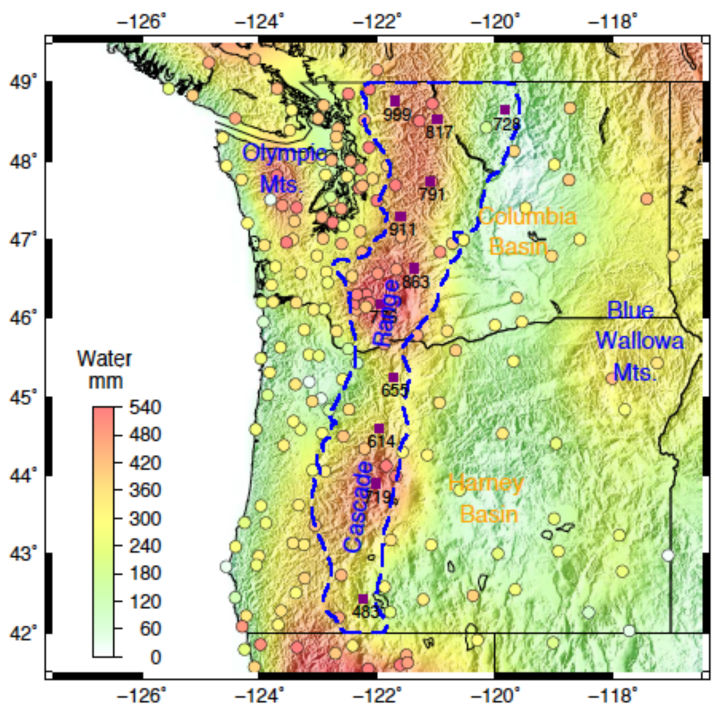
Application for GRACE:
Fill GRACE Missing Periods with GPS-determined Water

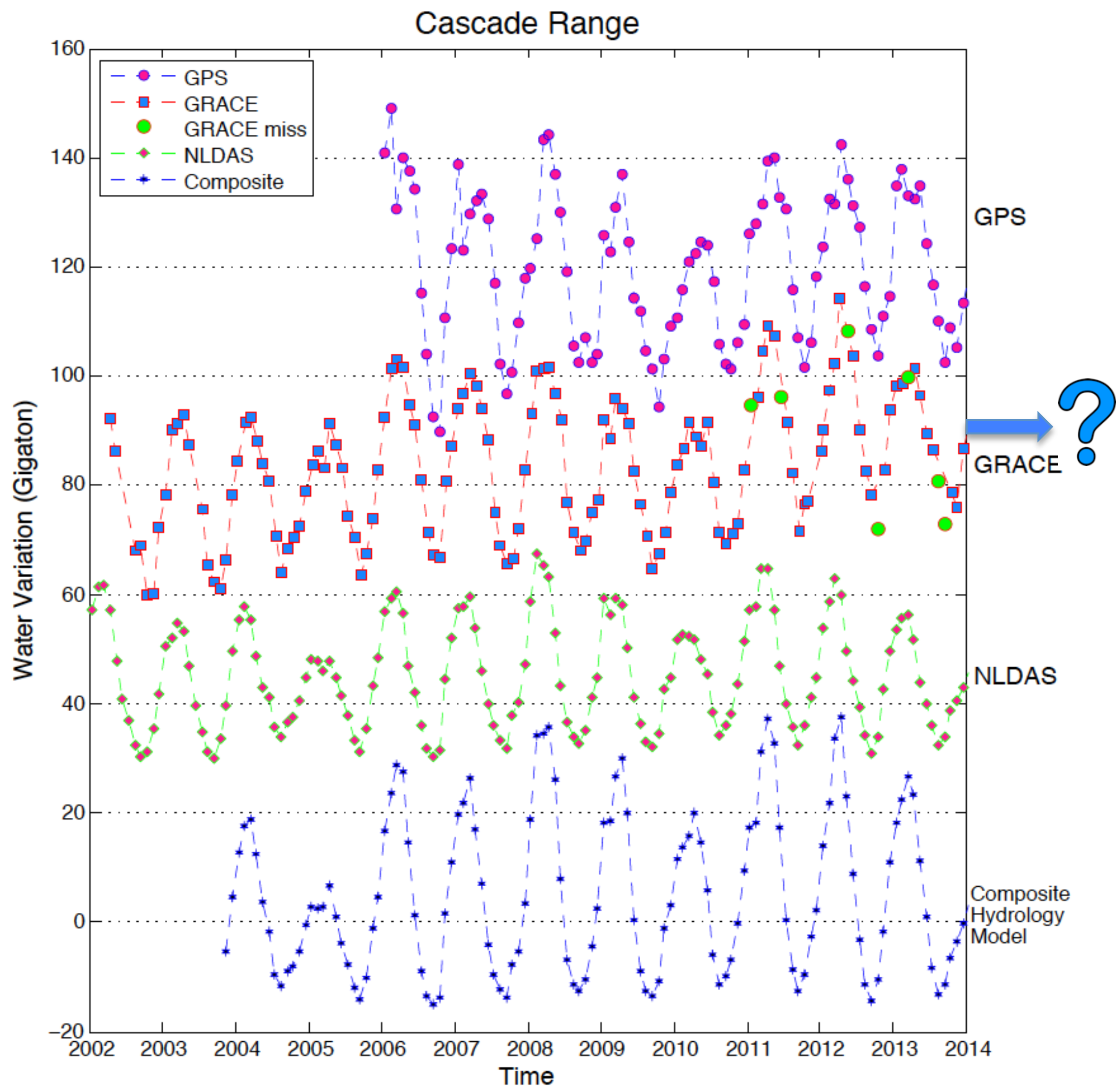




Fu, Argus and Landerer, JGR-Solid Earth, 2014

Application for GRACE:
Fill GRACE Missing Periods with GPS-determined Water





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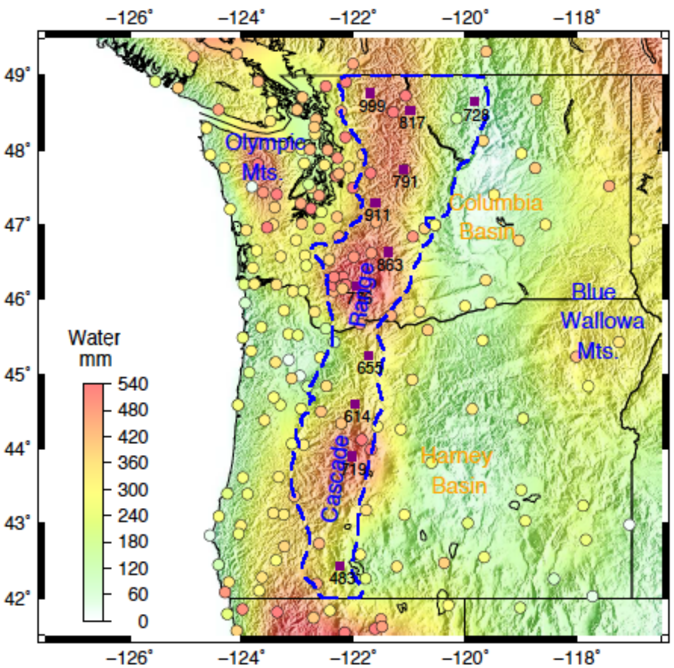
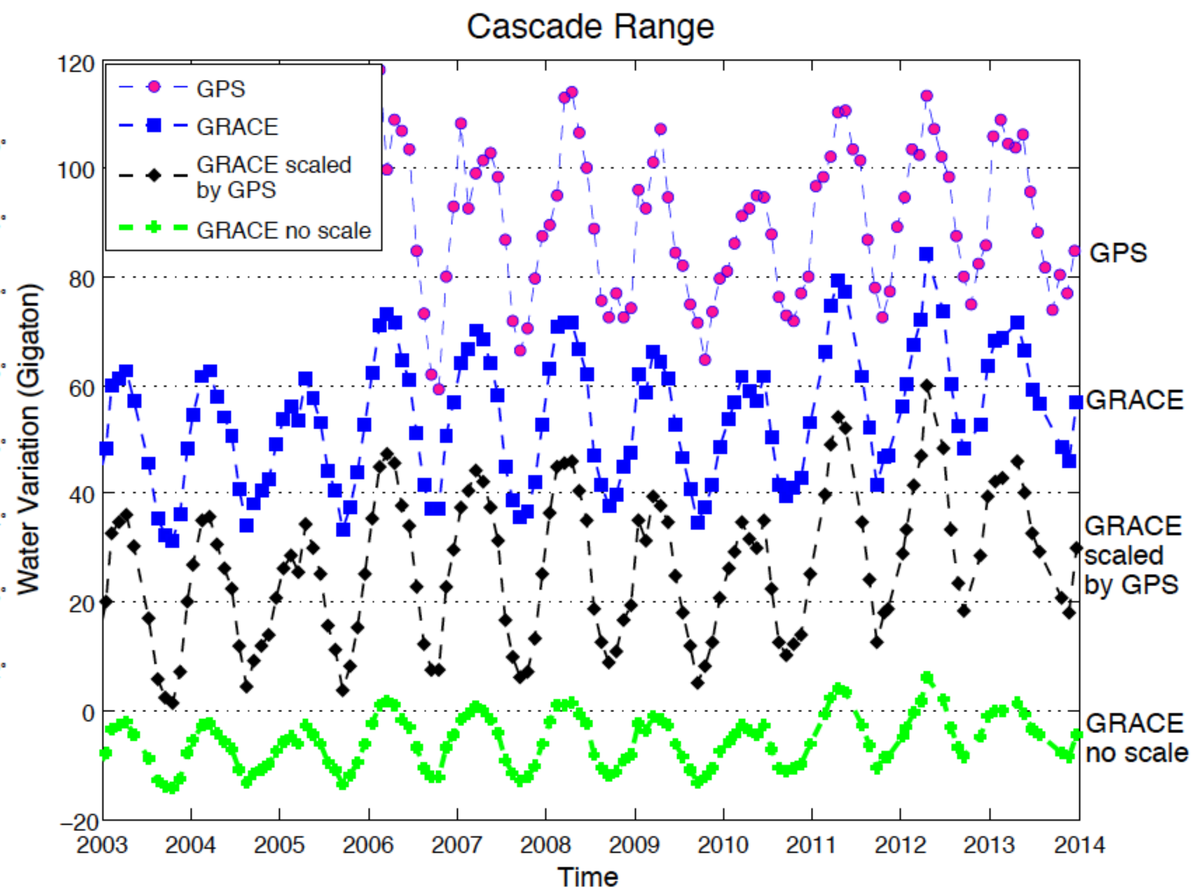
Application for GRACE
Determine Local Scaling Factors for GRACE from GPS





"GPS", GPS inversion result.

"GRACE no scale", GRACE original solution without scaling.

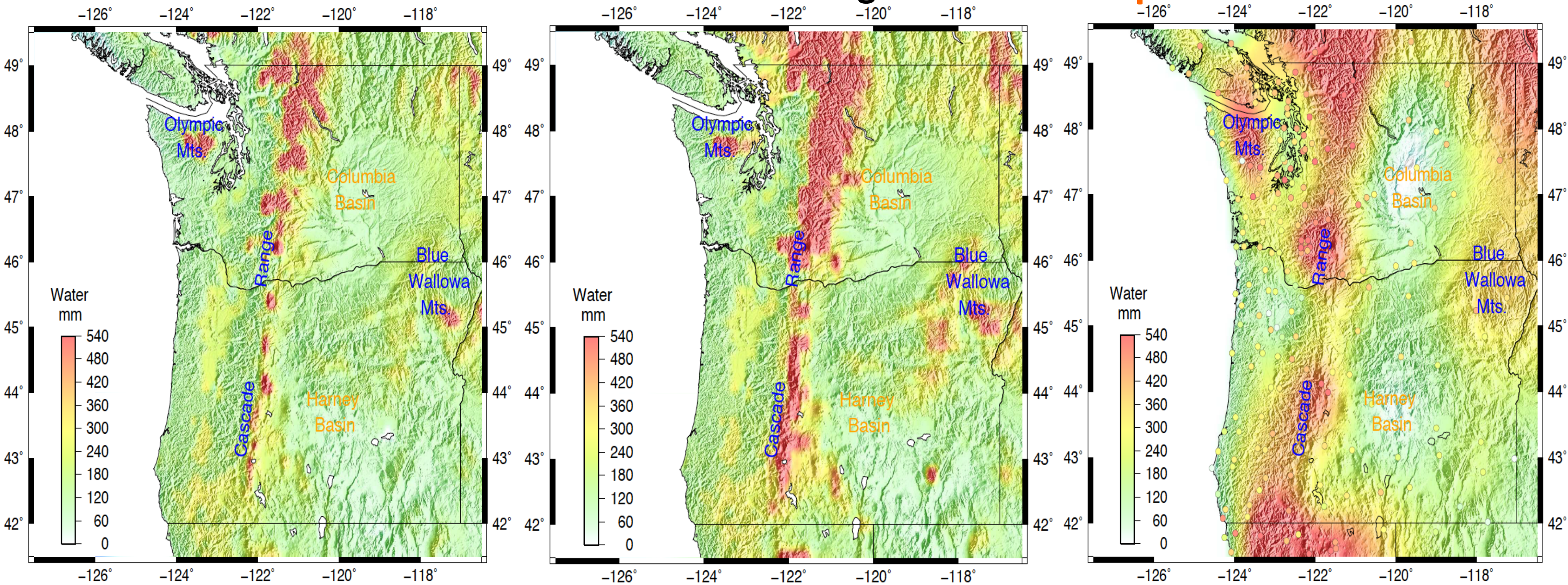
"GRACE", GRACE measurements scaled with gain factors from the GRACE Tellus website (http://grace.jpl.nasa.gov) [Landerer and Swenson, 2012].

"GRACE scaled by GPS", GRACE measurements scaled with GPS-determined water change series.

Fu, Argus and Landerer, JGR-Solid Earth, 2014

Application for Hydrology Model:
Distinguish Between Different Hydrological Models

Seasonal Terrestrial Water Change from Oct to Apr



NLDAS
(soil moisture + snow)

NLDAS(soil moisture)
+
SNODAS(snow)

GPS

- NLDAS underestimates the snowfall volume.
- GPS can be an independent measurement to distinguish different hydrology models.

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Summary and Conclusion

- As an independent measurement, a dense continuous GPS network provides high-resolution estimation of surface water storage variations.

- GPS-determined water series can fill gaps in the current GRACE mission, also in the transition period from the current GRACE to the future GRACE Follow-on mission.

- GPS distinguishes between different hydrological models, and indicates NLDAS underestimates the snowfall volume in the western U.S.

- GPS can resolve time-varying water storage change in the western U.S., and can be used to monitor water resource change in near real-time; complementary to GRACE.

Acknowledgments

- JPL's GPS processing team: A. Moore, S. Owen, M. Heflin, S. Desai, W. Bertiger and other members.
- Plate Boundary Observatory, UNAVCO, MEaSUREs NASA
- NASA Postdoctoral Program (NPP).


Thanks for your attention!
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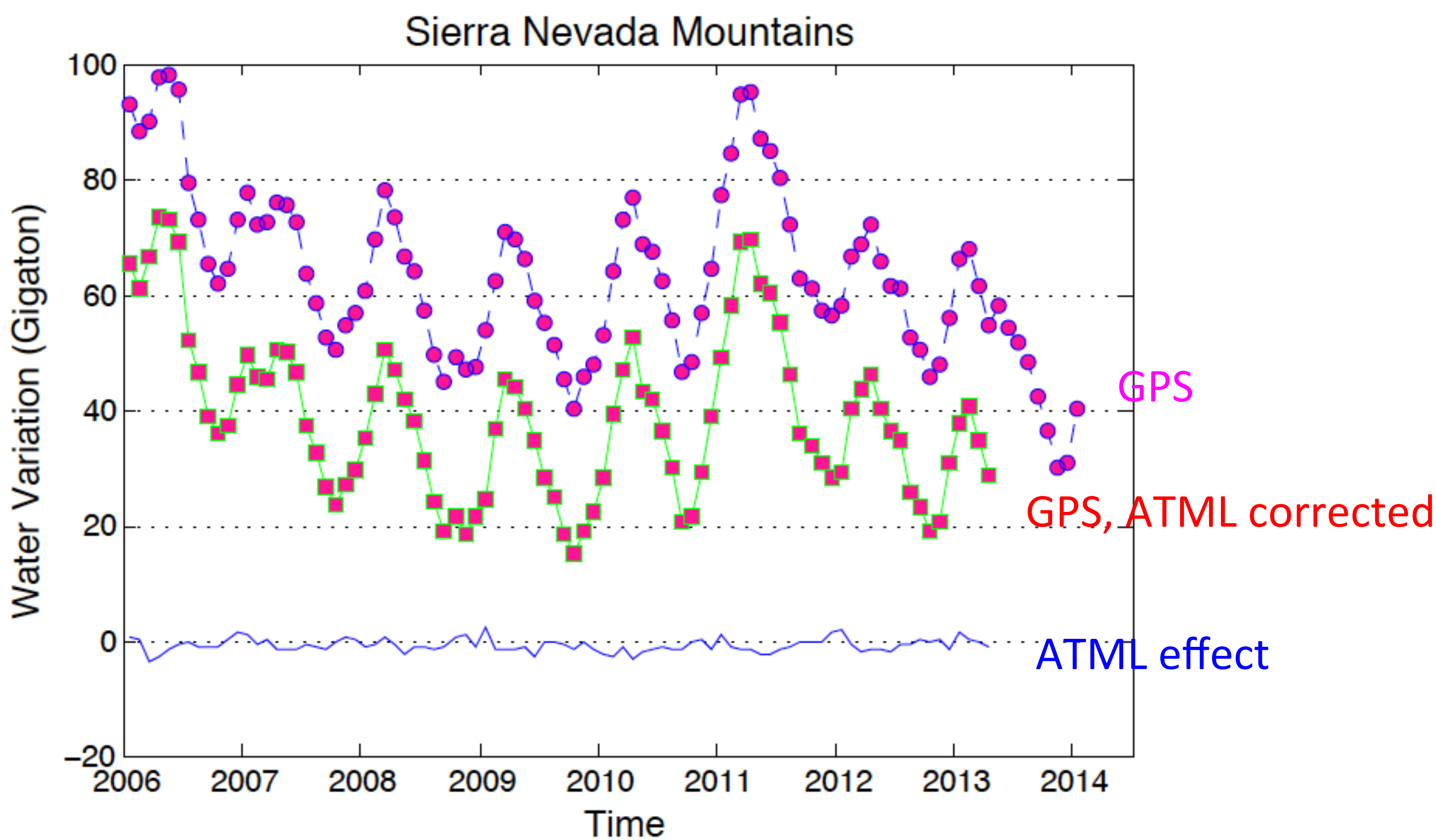
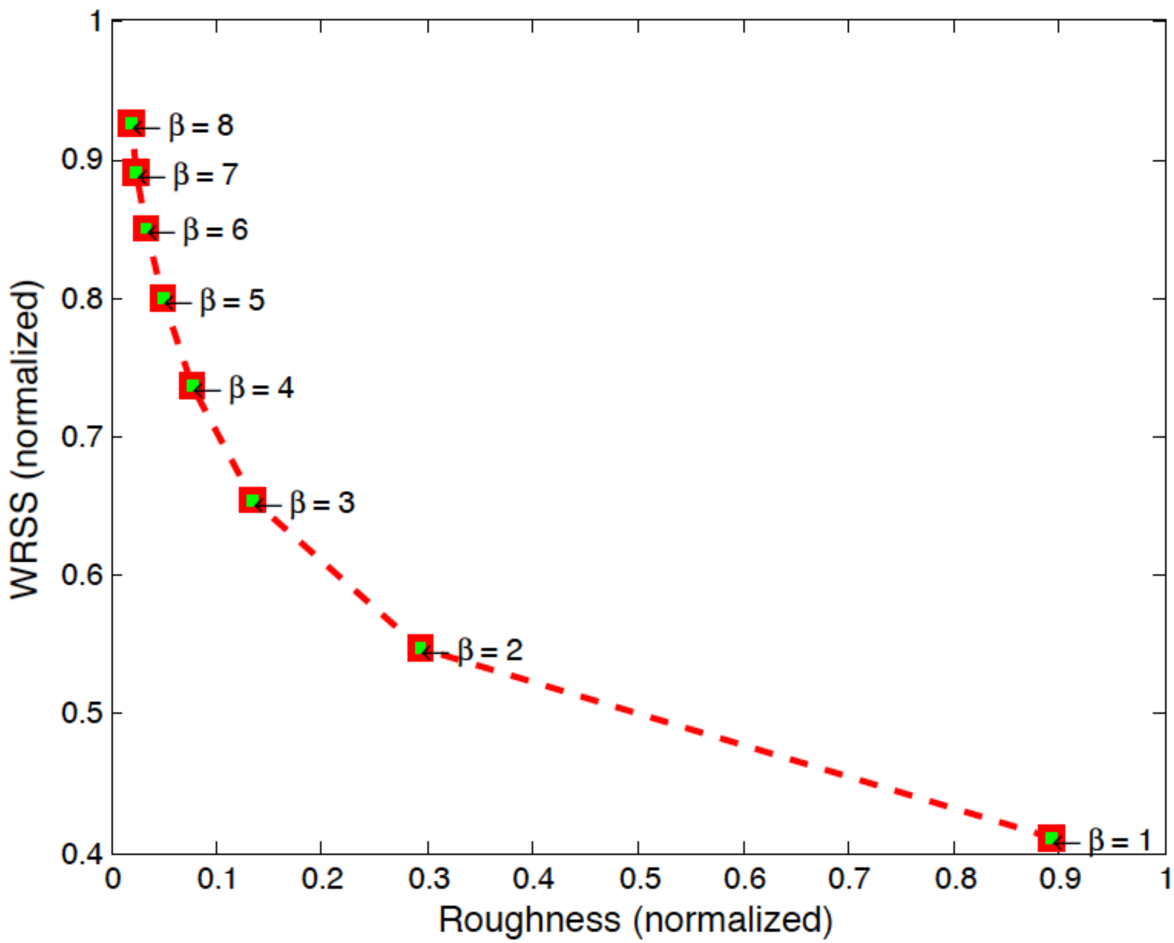
Photo: UNAVCO

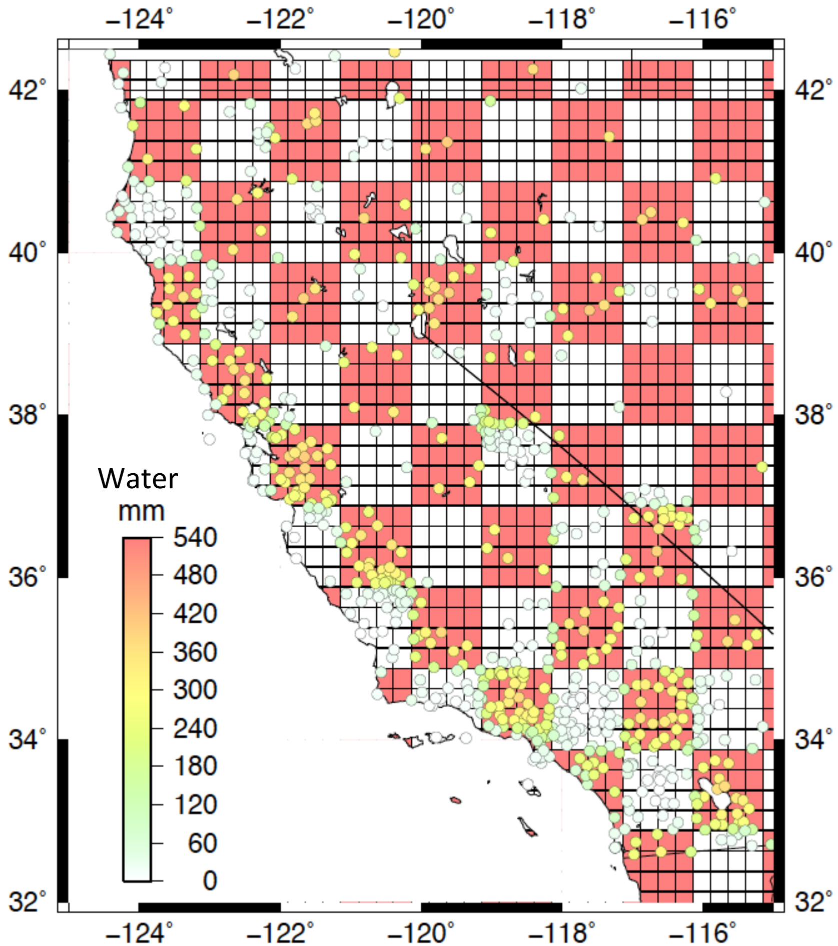
Backup slide: Atmosphere Effect
ECMWF (European Centre for Medium-Range Weather Forecast model)

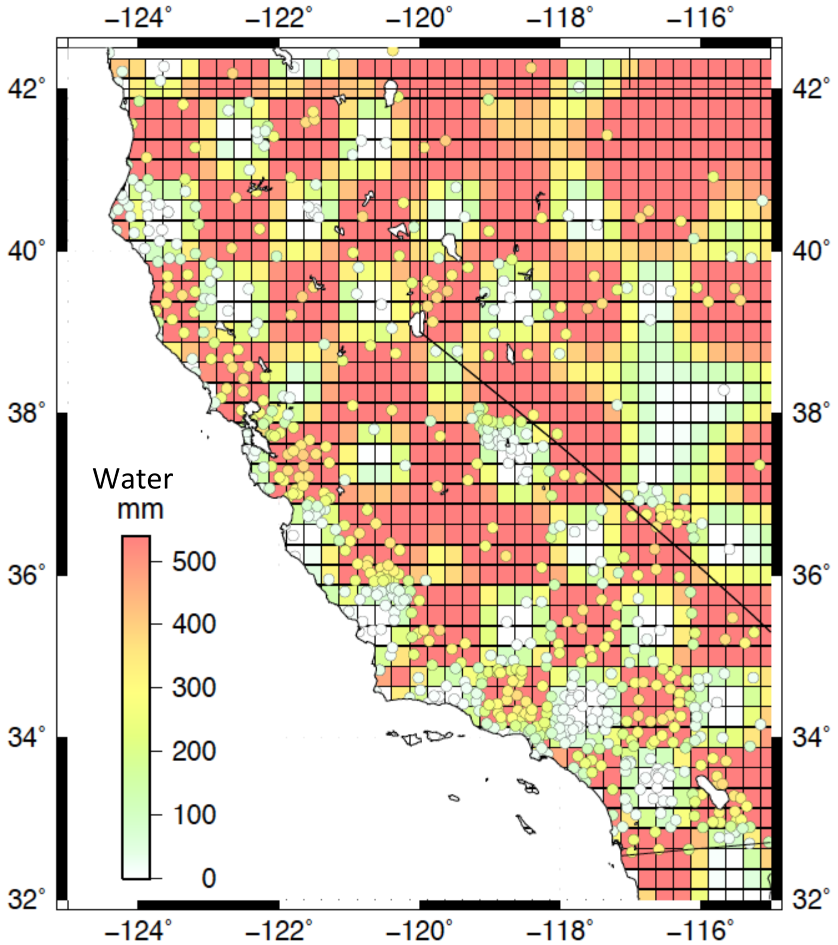


Backup slide: how to choose Roughness Weight



Backup slide: Checkerboard Test





Backup slide: Checkerboard Test