INFERRING LARGE-SCALE TERRESTRIAL WATER STORAGE THROUGH GRACE AND GPS DATA FUSION

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INFERRING GROUNDWATER CHANGES WITH GPS

- Explore ability to monitor groundwater using GPS
- Utilize Computer-Aided Discovery system that allows offloading work to the cloud
- Correlate vertical position from GPS with measurements of equivalent water depth from the Gravity Recovery and Climate Experiment (GRACE)
- Compare GRACE measurements to direct groundwater wells
GROUNDWATER

- The load of water deforms the solid Earth and removing the water will cause Earth to rebound
- In an aquifer, water pressure supports the poroelastic material
- When the water is removed the material will compress
- When excessive amounts water is removed the compaction can be permanent
- The motion of the surface depends on whether elastic loading or poroelastic expansion dominates

http://water.usgs.gov/edu/gallery/landsubsidence-poland.html
PLATE BOUNDARY OBSERVATORY

Vertical position time series

Example station P156

Locations of PBO GPS stations around US

https://www.unavco.org/instrumentation/networks/status/pbo/overview/P156
ANTENNA FIXES

When a GPS receiver's antenna is changed, a break may occur in the time series.
GROUNDWATER AND GPS

• Large amount of rain in San Gabriel Valley during 2005

• Comparison between groundwater well and GPS

• PCA decomposition of GPS stations revealed correlation with water level

Black arrows show horizontal PCA, red arrows show vertical PCA, and blue square is well location

Ji, K. H. and Herring, T. A., 2012, GRL, 39, L01301

\[
\begin{array}{c|c|c}
\text{Time (year)} & \text{Amplitude (mm)} & \text{Water level (m)} \\
2004.75 & -20 & 50 \\
2005.75 & 20 & 90 \\
2005.50 & 0 & 50
\end{array}
\]
GRAVITY RECOVERY AND CLIMATE EXPERIMENT

1x1 square degree GRACE terrestrial water storage equivalent water depth measurements over US

Artist impression of GRACE

http://photojournal.jpl.nasa.gov/catalog/PIA04235
COMPARISON OF GRACE AND GPS

Vertical GPS position (triangles) and GRACE (squares) with linear detrending

Left symbols are from March 2010, and right symbols are from August 2010
OFFLOADING CORRELATIONS

Laptop / Computer

Web Browser

Cloud Instance (e.g. Amazon EC2)

CAD System

Cloud Instance (e.g. Amazon EC2)

CAD System

Cloud Instance (e.g. Amazon EC2)

CAD System
CORRELATIONS OF GPS AND GRACE ACROSS THE US (PEARSON)

- Linear, annual, and semi annual detrending
- Thirty-one day weighted average

Pearson Correlations between GRACE and Vertical GPS Position
CORRELATIONS OF GPS AND GRACE ACROSS THE US (SPEARMAN)

Difference between Pearson and Spearman Correlations

Spearman Correlations between GRACE and Vertical GPS Position
Correlations between GRACE and GPS around Minnesota

Vertical Position (mm)

Equivalent Water Thickness (cm)
GPS VS GRACE

Vertical position versus equivalent water depth

The one station with no correlation contains outliers

Equivalent Water Thickness (cm)

Vertical Position (mm)

Zoomed in
GRACE AND GROUNDWATER IN MINNESOTA

Locations of wells

Wells track local water changes

Equivalent Water Thickness (cm)

Well Water Height (cm)
SUMMARY

• The response of GPS stations to changes in ground water depends on whether the motion is dominated by aquifer expansion or solid Earth deformation.

• The majority of GPS stations across the US are negatively correlated with GRACE.

• This result has been tested using two different correlation metrics.

• The majority of GPS stations are measuring a response to surface loading and not aquifer expansion.
WHAT’S NEXT

• Integrate additional GPS data

• Use “GPS imaging” techniques to provide a map of groundwater changes inferred from GPS measurements

• Compare GPS results to groundwater wells to determine response of local groundwater changes to GPS
THANK YOU

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PCA of positively correlated GPS stations in California

Middle of Central Valley

Li, J. D., et al, in prep