Application of GPS Vertical Positioning to Seasonal Water Variations in California and Postglacial Rebound in Antarctica

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PART 1
Technical Advances in GPS Vertical Positioning
**Result 1**
Series for scale has become straighter.

Vertical positions on opposite sides of Earth are more accurate.

Operational scale depends on solar, phase, QC.
GPS series for Z component of CM is straight, suggesting that GPS can be used to constrain the velocity of CM.

Annual oscillation
5.6 mm maximum July

Annual oscillation
1.1 mm maximum June

Garcia–Fernandez & Desai
2nd order ionosphere
Inference
SLR estimate of the velocity of CM is uncertain, as evident in the 1.15 mm/yr difference in estimates of Z component from distinct data subsets (ARGUS JGR 2012).
PART 2
GPS as a High-Resolution Technique for Evaluating Water Resources Available to California
Vertical position of GPS site P310

Peak-to-peak amplitude: 9.6 mm

April 1

October 1
Seasonal vertical displacement
Fall & Winter

**OPPORTUNITY**
- 500 GPS sites deployed in California since 2007
- PBO built by UNAVCO and funded by NSF and NASA.
Elastic response of Earth’s surface to a mass load

Well known, Given by Green’s functions, and Insensitive to Earth structure

Vertical displacement resolves water storage at very high spatial resolution.

Elastic vertical displacement

Water disk
radius 7 km
thickness 4 m
mass 0.62 Gt

Vertical displacement 20 km from load Is half than 10 km from load
Seasonal vertical displacement
Fall & Winter

Vertical displacement
Oct to Apr

Great Basin
Klamath Mountains
Sierra Nevada
Central Valley

Seasonal water thickness GPS
Fall & Winter

Water thickness
Oct to Apr

rigorous 1/4° Laplacian Fu
GPS resolves water storage at a spatial resolution of 75 km, compared to 300 km from GRACE.
Observations
GPS
GRACE

Hydrology models
NLDAS
Composite model

Atmosphere
EMCWF
RESULT
GPS distinguishes between different hydrology models. Seasonal water storage inferred from GPS is 50% larger than in NLDAS, ...
Great Basin Seasonal water thickness

RESULT
But is consistent a composite model consisting of soil moisture, snow, & reservoir water (Famiglietti et al. 2011).

Composite is:
- NLDAS soil
- SNODAS snow
- CDEC reservoir

Seasonal water thickness GPS
Fall & Winter

Seasonal water thickness
Composite hydrology model
Observations
- GPS
- GRACE

Hydrology models
- NLDAS
- Composite model

Atmosphere
- EMCWF

Graph showing equivalent water thickness with labels for specific regions such as Sierra and Coast.
PART 3B

ICE-6G_C (VM5a)
in Antarctica

Fits all data:
GPS vertical rates,
ice thickness changes,
relative sea level histories.
An elastic model of current ice loss near Pine Island Bay & in northern Antarctica peninsula was constructed.

The 42 sites used are insignificantly affected by current ice loss.
Mantle viscosity profile

**Comparison**

**Upper Mantle Viscosity**

$10^{20}$ Pa s

- **most of Antarctica**
  - 1 Nield et al. 2014
  - 2 Ivins et al. 2013
  - 5 Argus, Peltier, et al. 2014
  - 10 Whitehouse et al. 2012
  - 10 Nield et al. 2014

- **southern Antarctica peninsula**
  - 1 Nield et al. 2014

- **northern Antarctica peninsula**
  - 0.1 Nield et al. 2014

- Argus et al. 2014 has twice the relaxation time as Whitehouse et al. 2012,
  Half the relaxation time as Ivins et al. 2013
Viscous relaxation time

PGR MODEL
This straightforward example illustrates differences between Whitehouse 2012, Argus 2014.

Whitehouse 2012 has twice the relaxation time, half the ice loss compared to Argus et al. 2014.

Current uplift rate is nearly identical in Whitehouse 2012, Argus 2014.
Deglaciation history

**RESULTS**

ICE-6G has nearly twice the ice loss as W12, IJ05 R2.

ICE-6G has fast ice loss at and after Meltwater Pulse 1B (11.5 ka – 7 ka)

**INFERENCE**

W12 ice loss is too early, IJ05 R2 ice loss is too late.
CONCLUSION

Technical advances in GPS vertical positioning have improved our understanding of:

(1) Water changes in California and

(2) Postglacial rebound in Antarctica and North America.
Northern metropolitan Los Angeles is shortening and thickening.

Puente Hills thrust
Slip rate 8 mm/yr
Locking depth 12 km