Hydro-gravity signals, from large to small

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Outline

- The "large signal" case study – artificial recharge
- The "small signal" case study – groundwater pumping
- The USGS Southwest Gravity Program
- Discussion points

Research question:

Are gravity data useful for identifying groundwater-flow model parameters?

A: It depends on if the predicted gravity change is sensitive to model parameters.

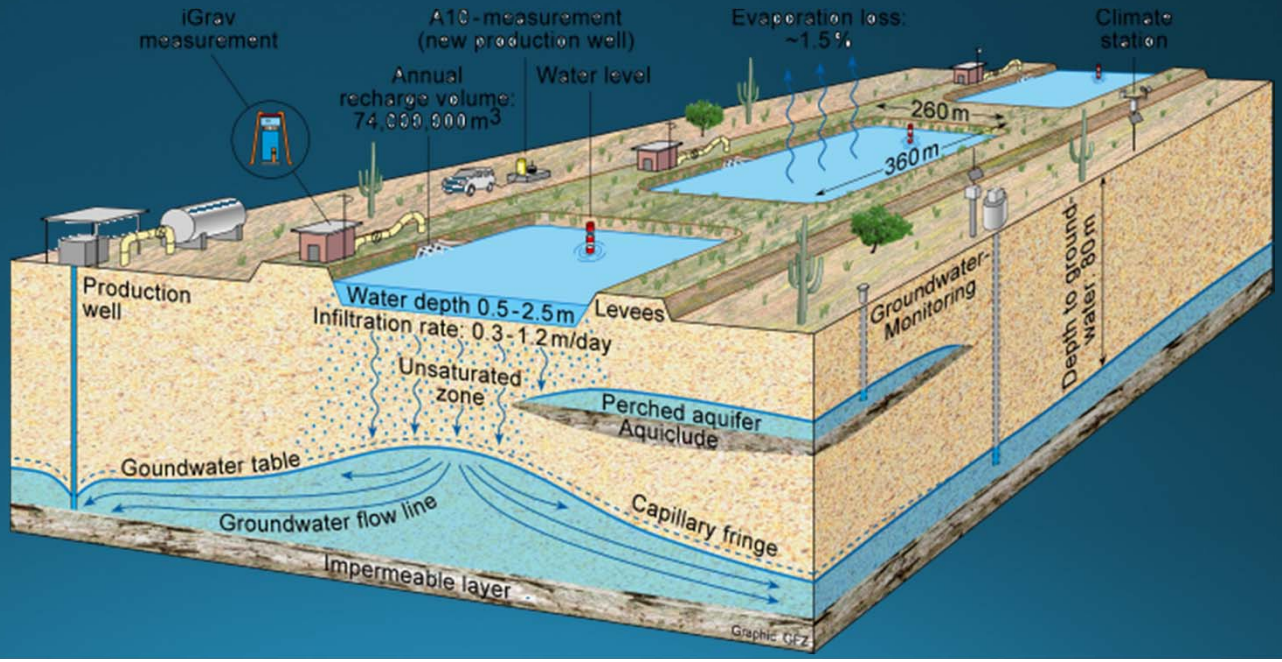
Case study: Artificial recharge

Study area

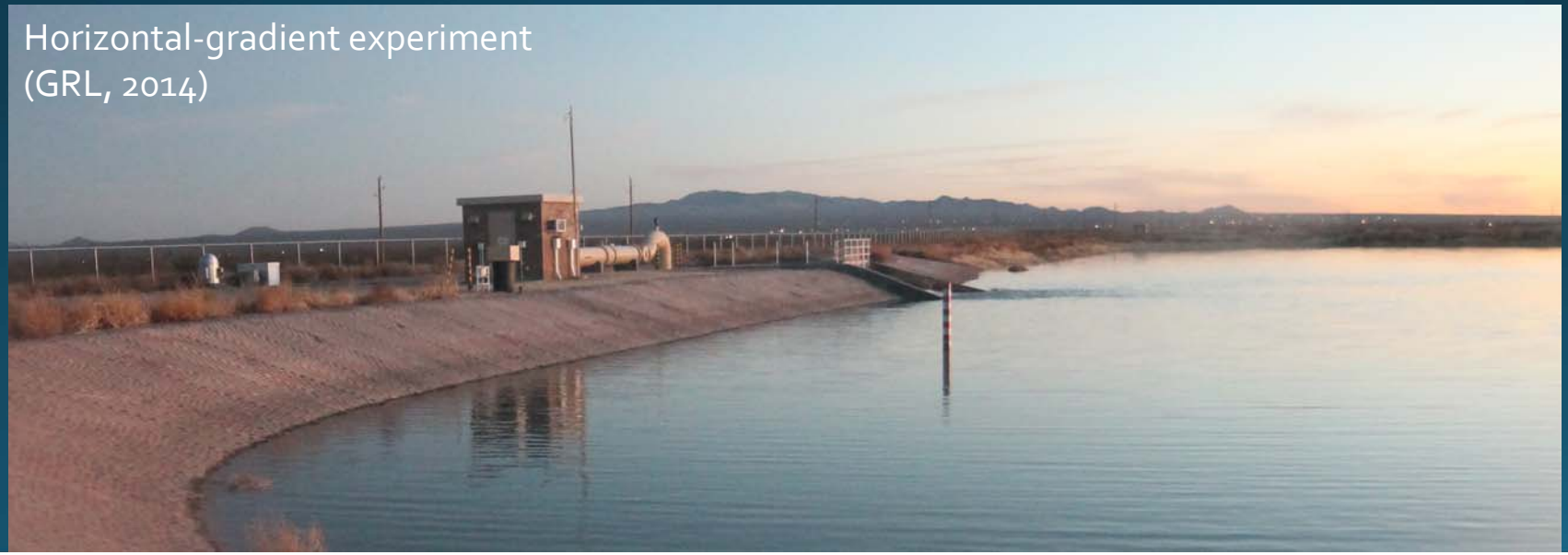
- Recharge in 9 passive infiltration basins, each about 2 hectares
- Recharge occurs in cycles: ~2 months infiltration, 2 months dry
- 74 x 10^6 cubic meters of water per year

Instrumentation

- 2 iGrav
- 3 gPhone
- A-10 (270 meas.)
- FG-5 (4 meas.)
- Relative-gravity surveys
- Groundwater-level measurements

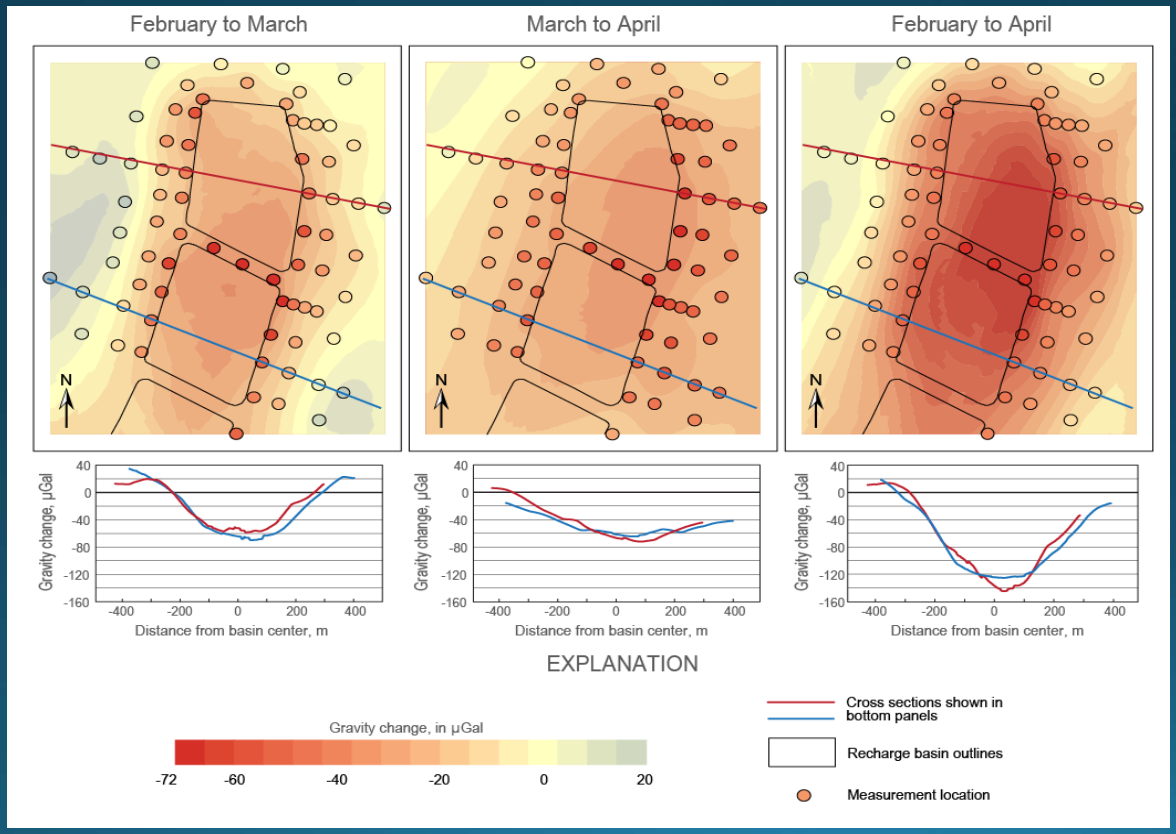


Horizontal-gradient experiment
(GRL, 2014)



Case study: Artificial recharge

Relative-gravity surveys during a drying period



(GJI, 2015)

Infiltration flux increases with time (not typical for recharge basins)

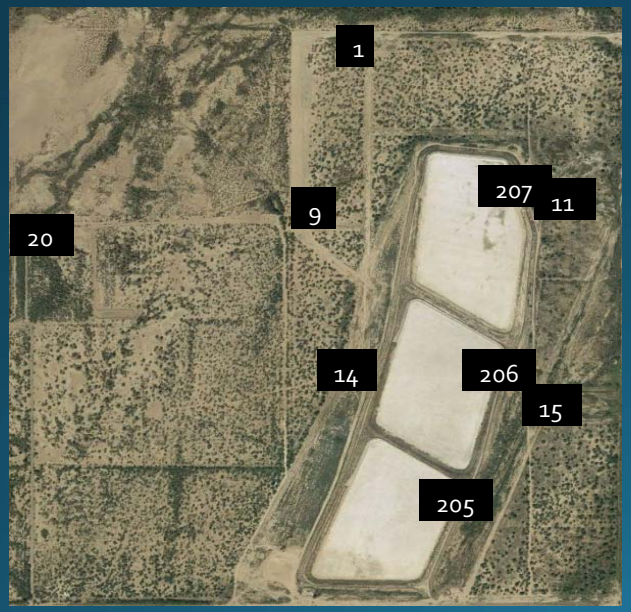
Gravity change follows infiltration cycles closely

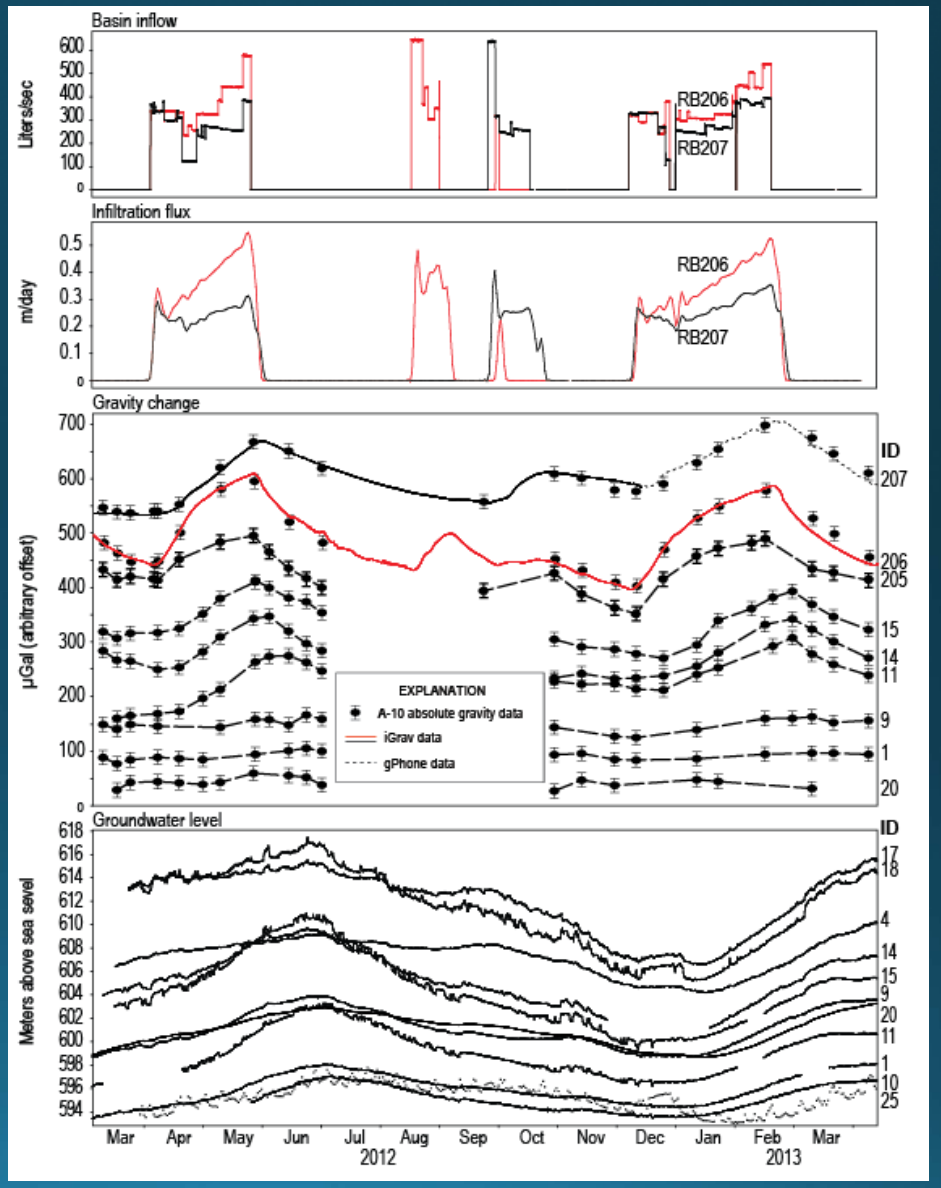
Water levels change all together; match total infiltration

Not much long-term storage accumulation/steady-state conditions/water is moving efficiently to the regional aquifer

A-10 and continuous records match well

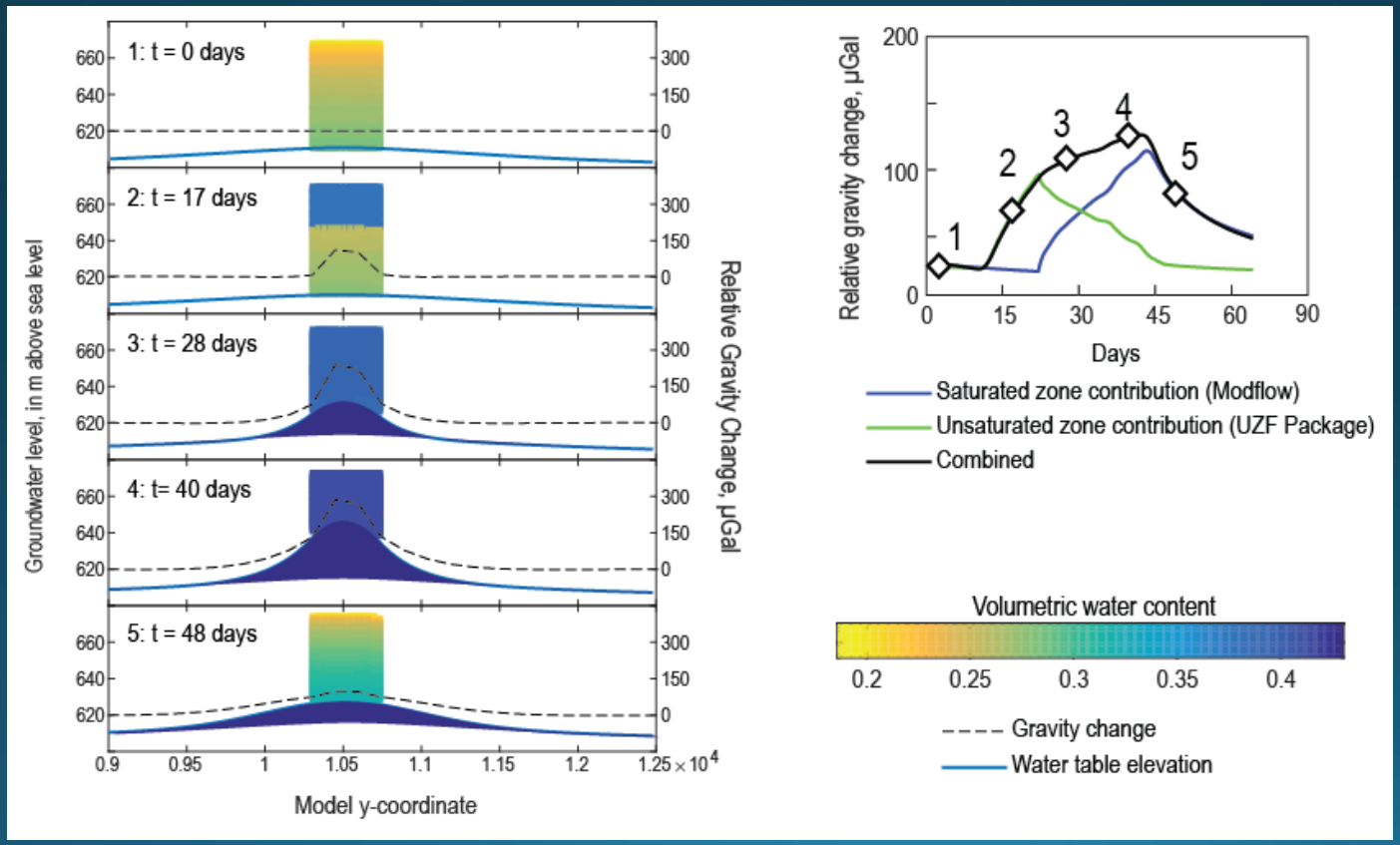
Unavoidable data gaps in A-10 record





Groundwater-flow modeling

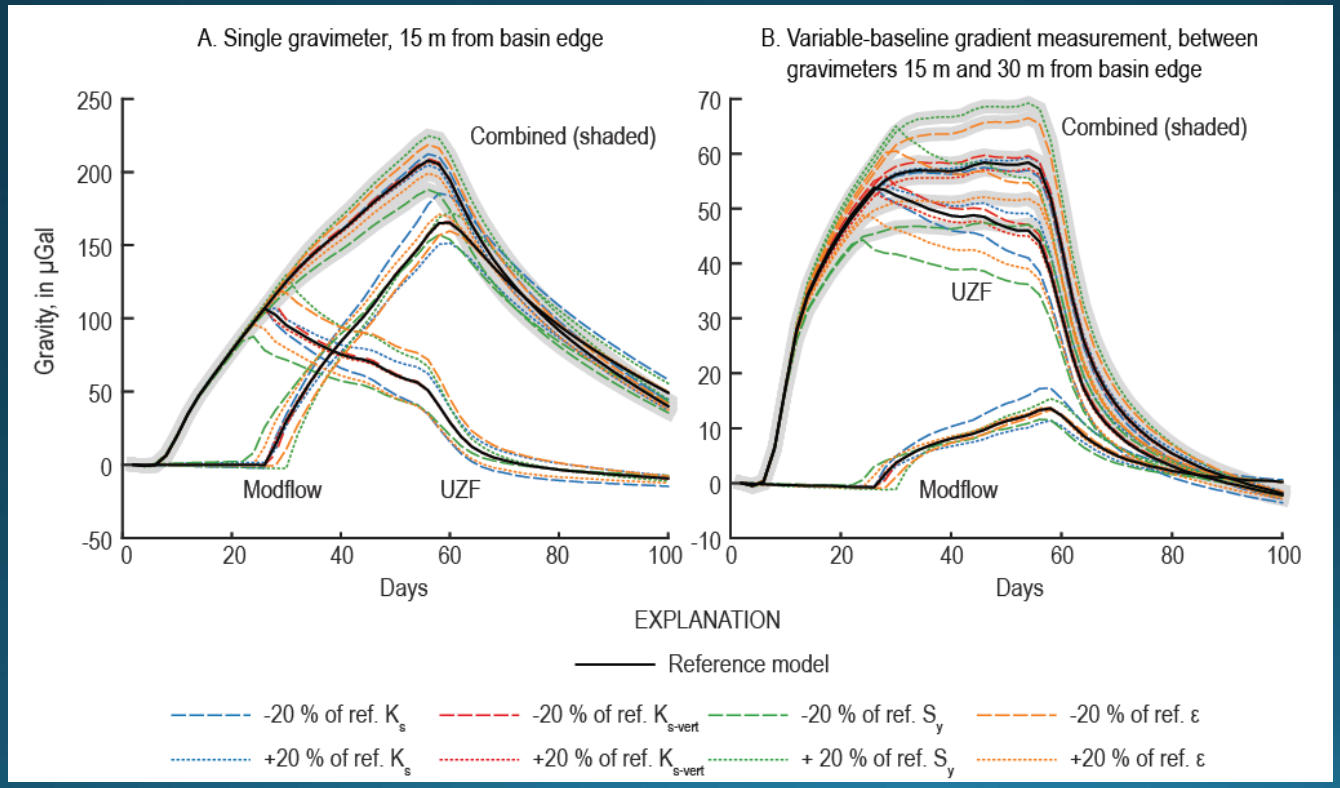
MODFLOW with the "UZF" unsaturated-flow package



(Water Resources Research, 2016)

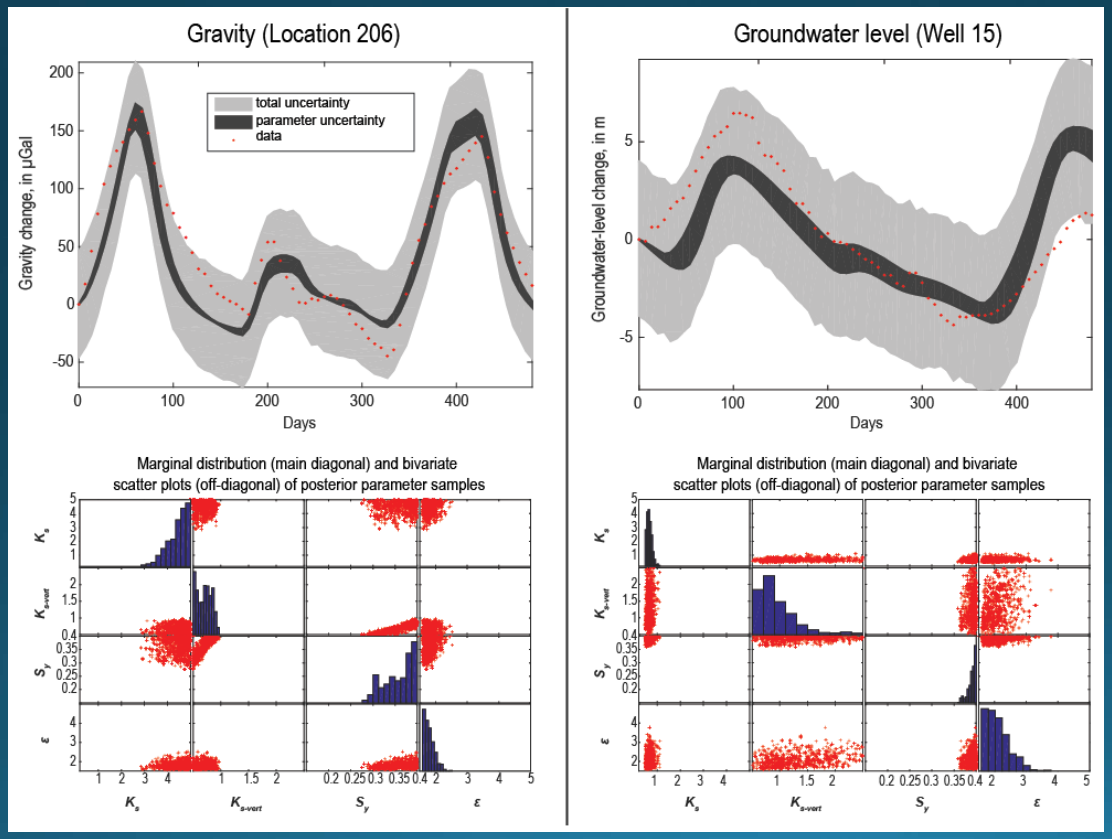
Groundwater-flow modeling

Simulated gravity sensitivity to parameter variation



Groundwater-flow modeling

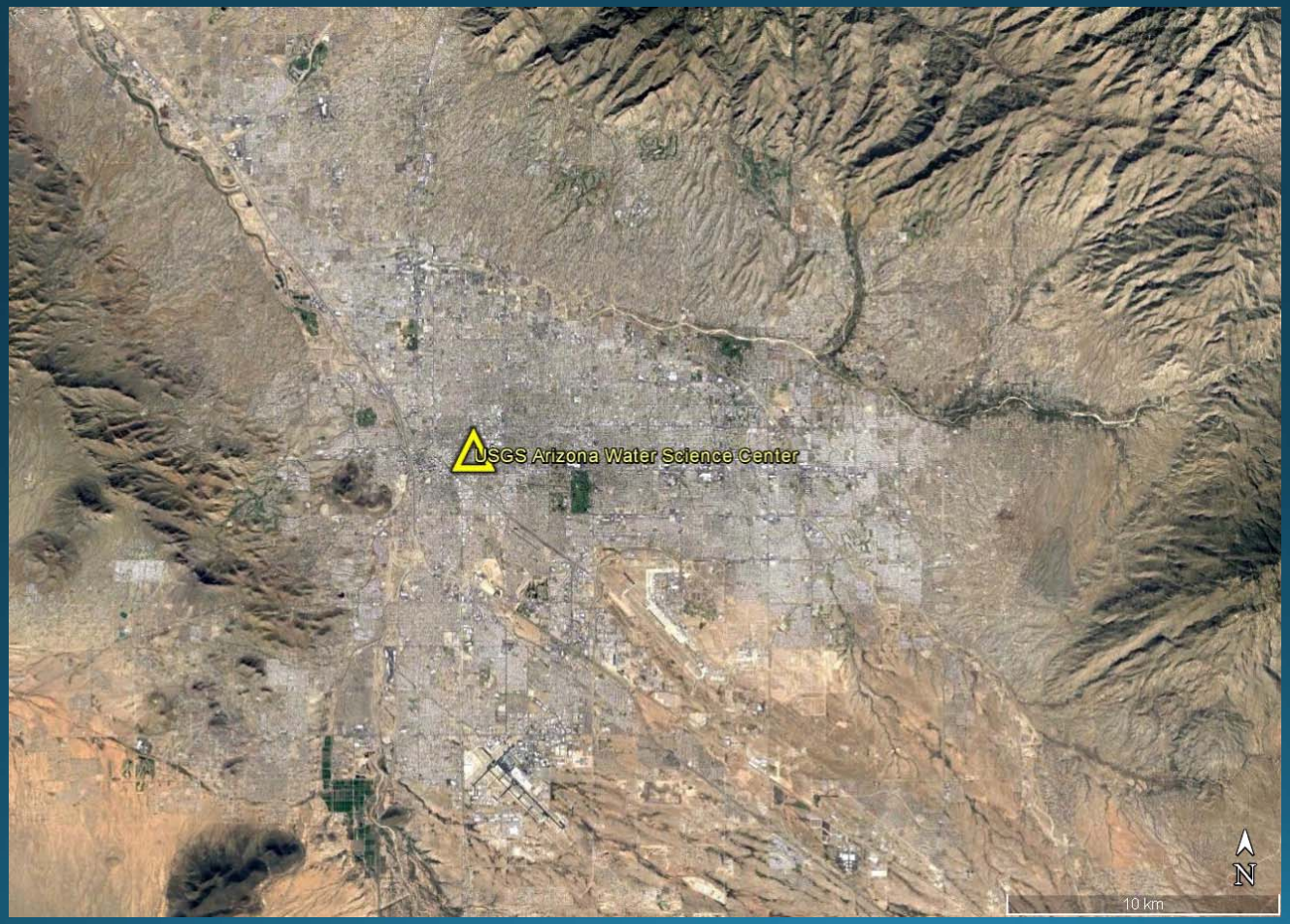
Predicted parameter values



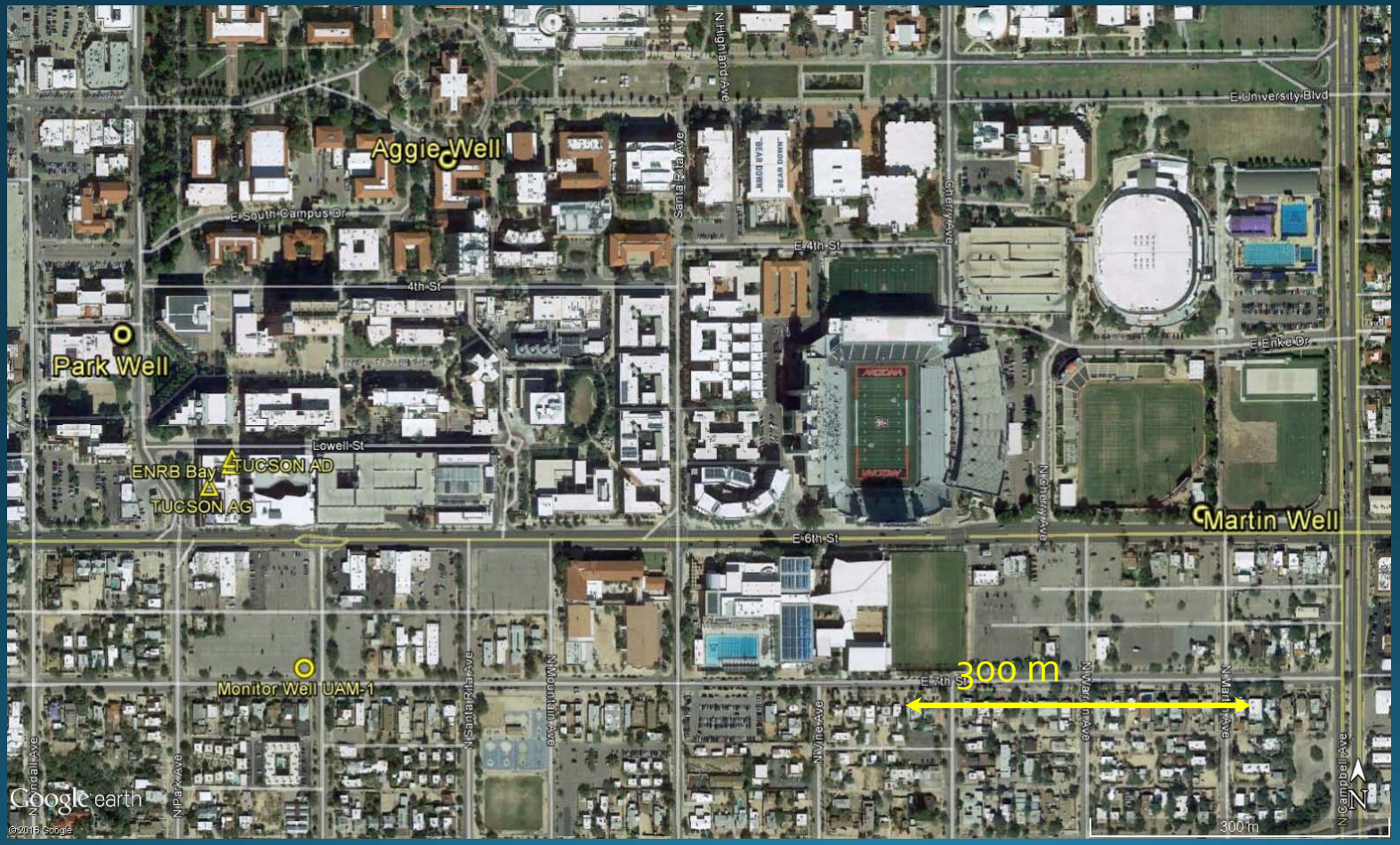
Case study: Artificial recharge

- For a signal this large, measurement is easy
  - A-10, iGrav, gPhone all provide similar information
- Continuous gravity data provide information about:
  - Steady-state performance of the facility (storage is not accumulating)
  - Groundwater-model parameters
- Relative-gravity data were useful for qualitative interpretation
- Because infiltration rates are so high, gravity data (i.e., a better groundwater model) aren't necessarily that useful.
- Groundwater-level data are bad for model calibration because they reflect basin-wide processes that aren't simulated by the model

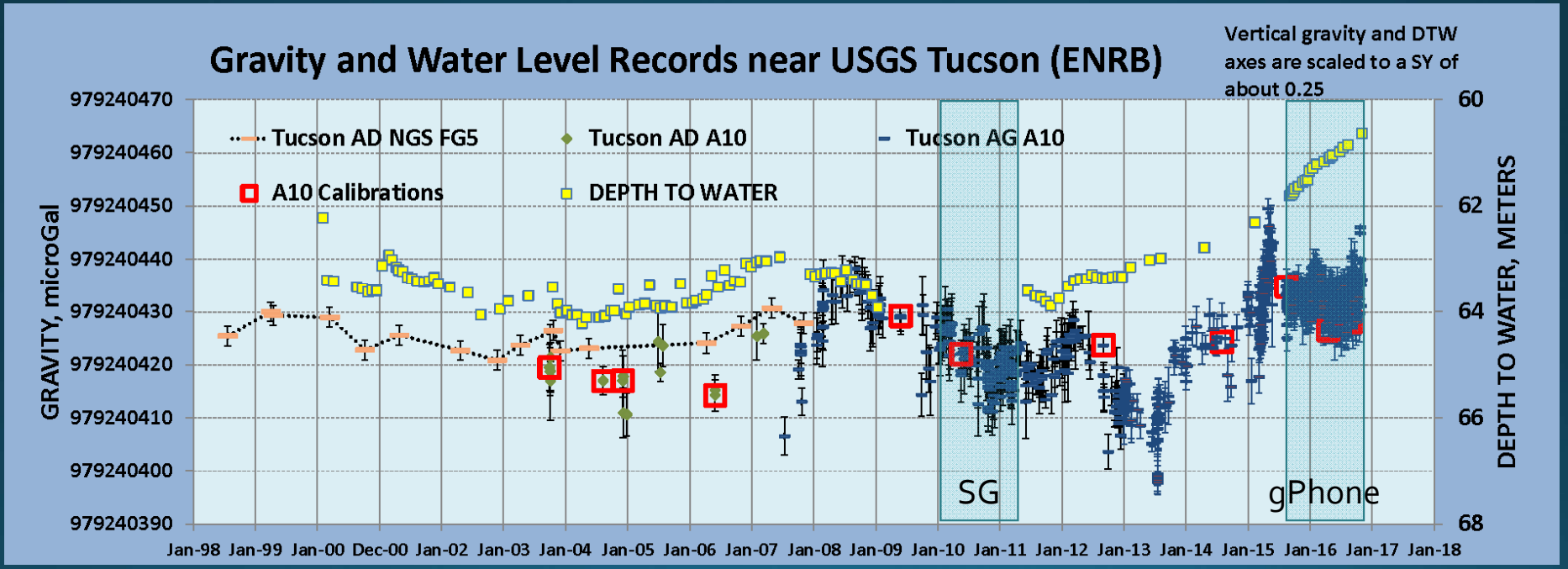
Case study: Groundwater pumping



Case study: Groundwater pumping

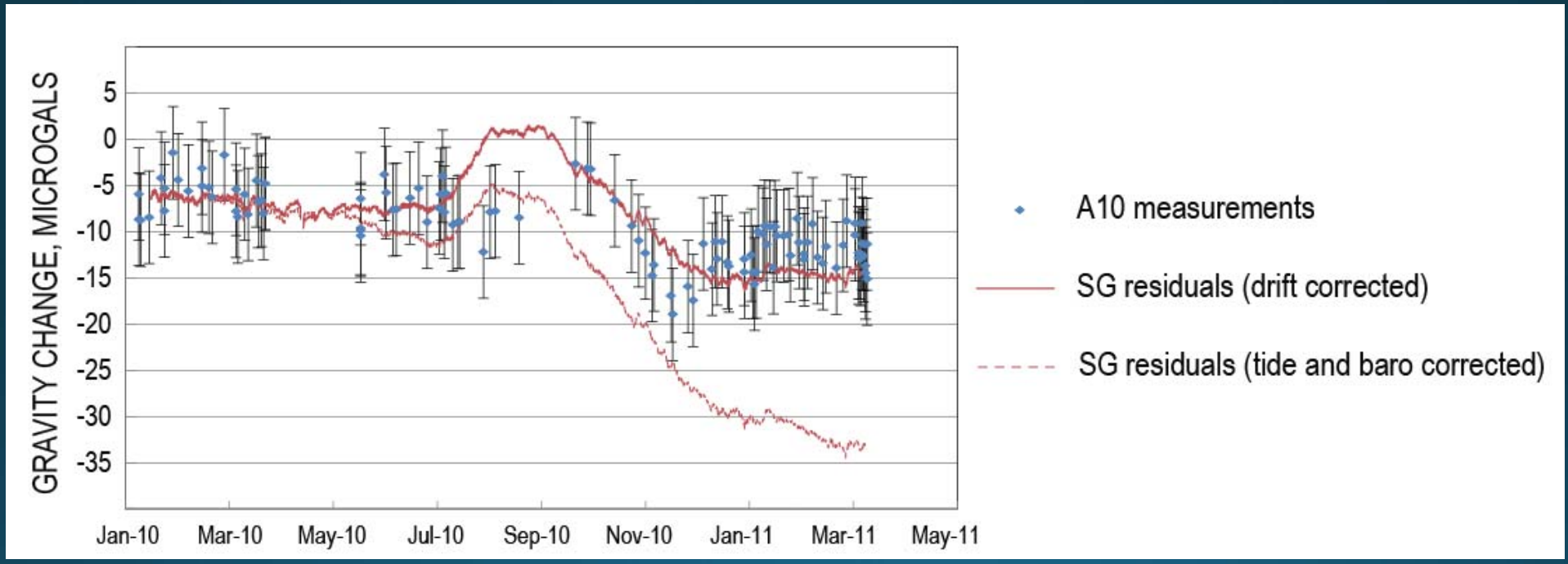


Long-term gravity record



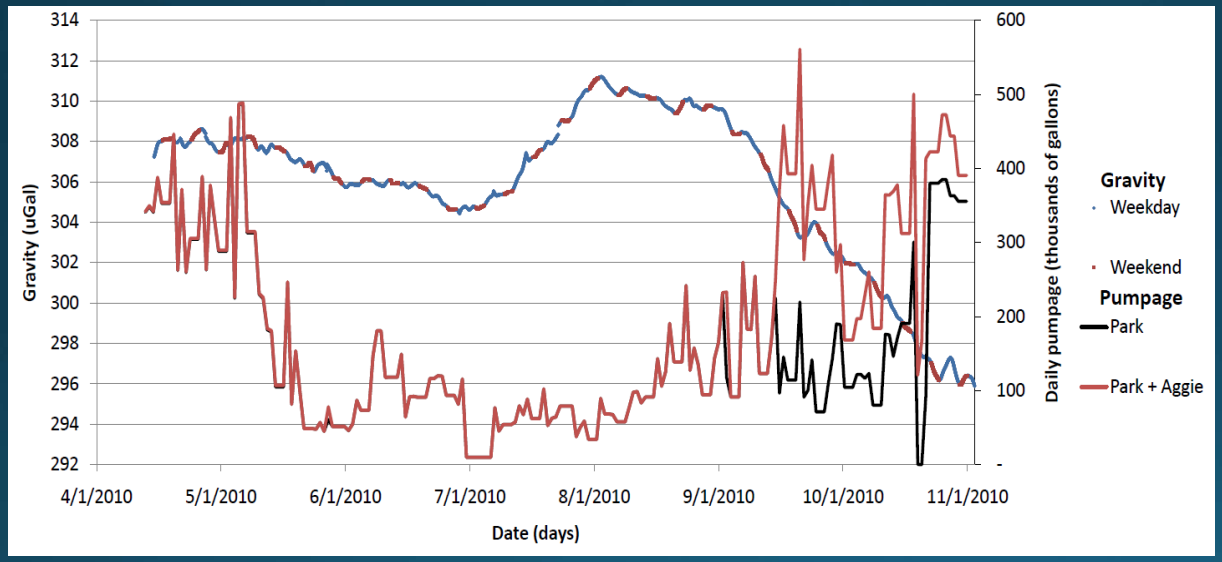
Attempt 1: OSG-047

Attempt 1: A-10/SG disagreement



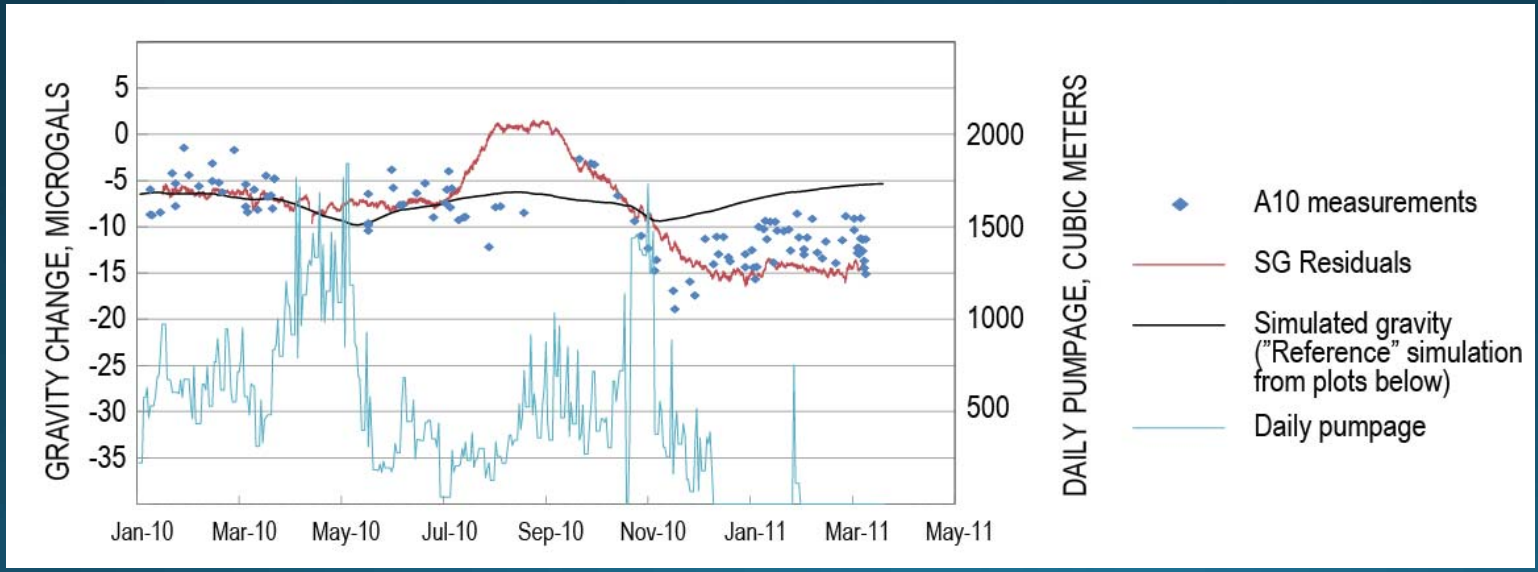
Attempt 1: OSG

The timing of gravity changes correlates with pumping



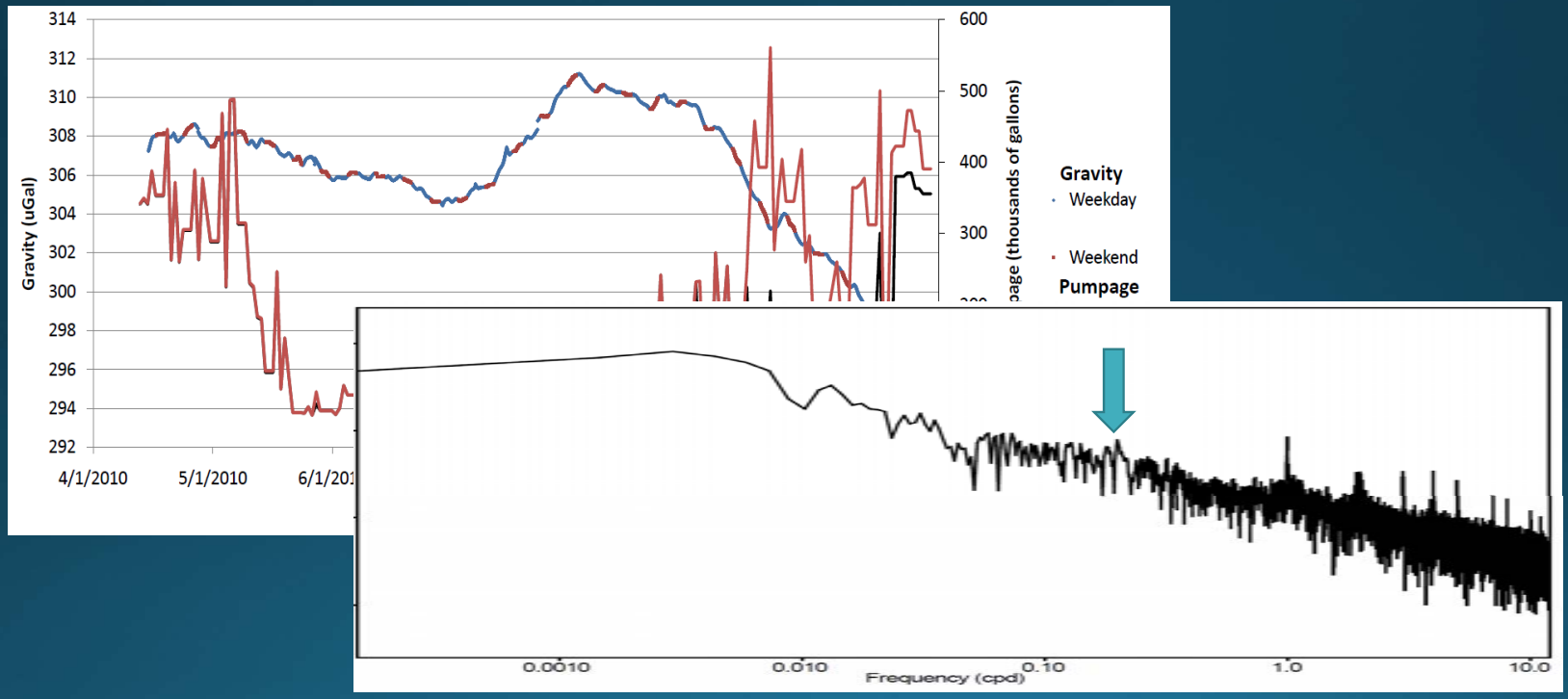
Attempt 1: OSG

A simple groundwater-flow model was unable to simulate the magnitude of gravity changes



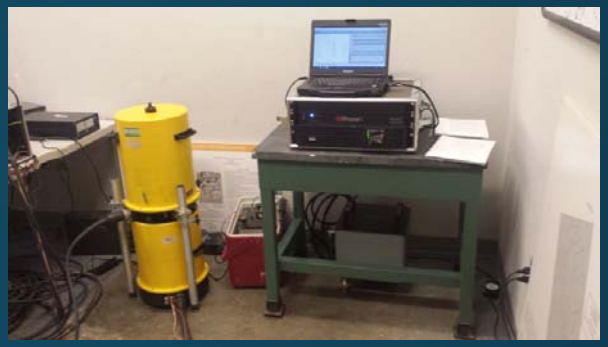
Attempt 1: OSG

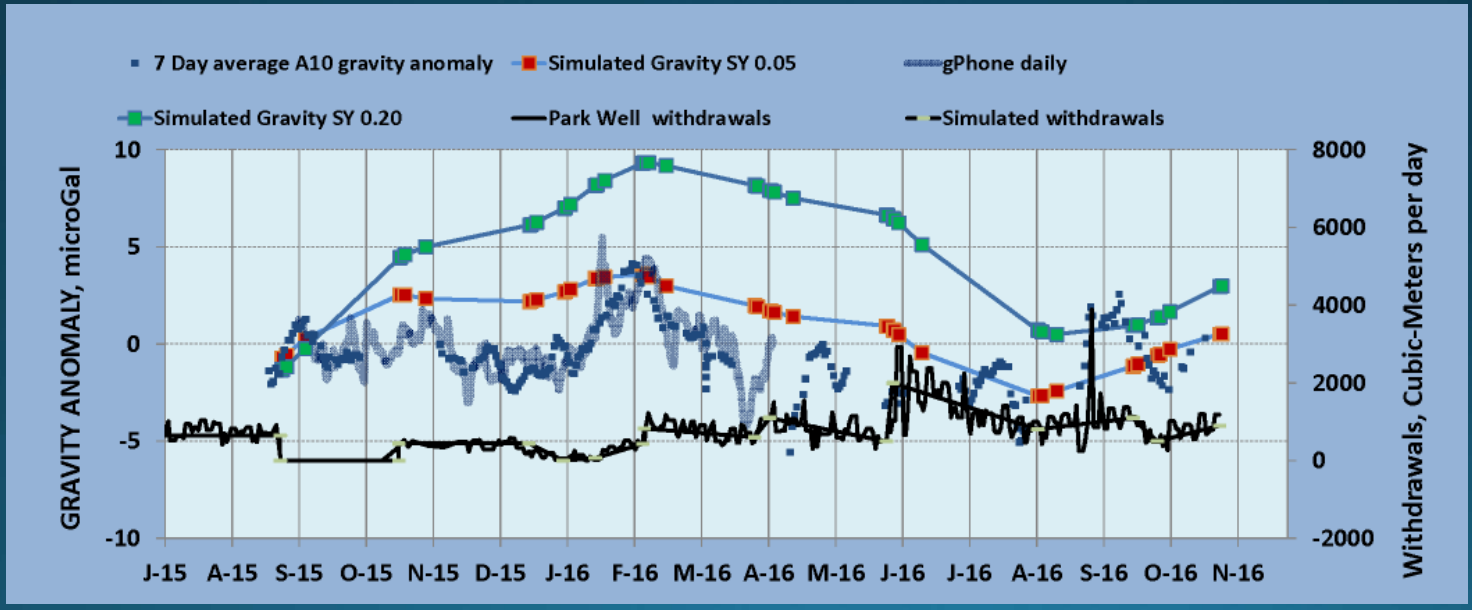
- Weekly signal (0.143 cpd): from pumping?



Attempt 2: gPhoneX

- MODFLOW Superposition (Change) Model
- 50 m grid 200X200
- 7 layers well connected vertically
- Unconfined upper layer
- Added regional linear rate of WL rise based on records
- Added recharge from streamflow infiltration
- Tested many Transmissivity and Specific Yield combinations





Conclusion

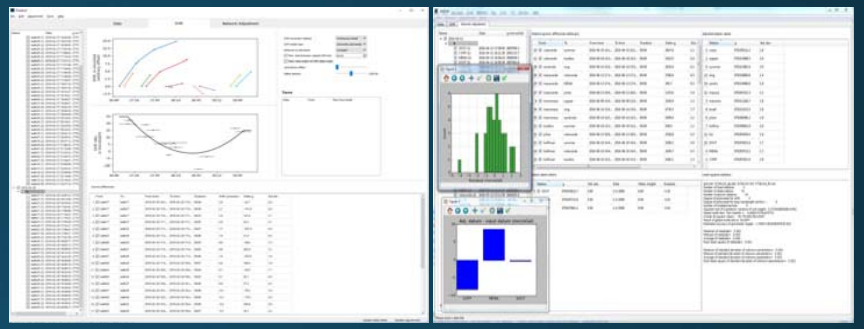
For both case studies, 1-dimensional admittance-factor corrections for groundwater are insufficient.

To account for the hydrology signal, a three-dimensional groundwater-flow model is required.

It would be impossible to adequately correct for the hydrology signal through measurement of hydrologic changes alone.

USGS Southwest Gravity Program

- A-10 absolute meter, 3 Burris meters, 3 L&R meters plus occasional SG and/or gPhone meters
  - ~ 3,800 A-10 measurements 2005-2018
- Funding is from cooperators, not the U.S. Government
- Primarily hybrid A-10/relative surveys
- GSadjust software
  - Interactive drift correction
  - Iterative least-squares adjustment
  - https://github.com/jkennedy-usgs/sgp-gsadjust
- Southwest Gravity Program website:
  - http://go.usa.gov/xqBnQ
- Absolute-gravity processing scripts (GitHub)
- COSMOS soil moisture monitoring – removing near-surface changes to more accurately measure deeper changes
- jkennedy@usgs.gov



Discussion

- Are short (1 year or less) projects useful to include in IGETS? What about those with very large hydrology signals? Is there a minimal useful length of record?
- A service (e.g., IGETS) that provides site-specific tide models from continuous data would be very useful for the hydrology community
- Continuous meters are necessary for many hydrology studies, but they are likely to be deployed for short durations.
- Gravity is the ultimate hydrogeophysical method, but…
- Applications of gravity data for hydrology studies are still limited by instrumentation – too much electricity, too expensive, too fragile, etc.