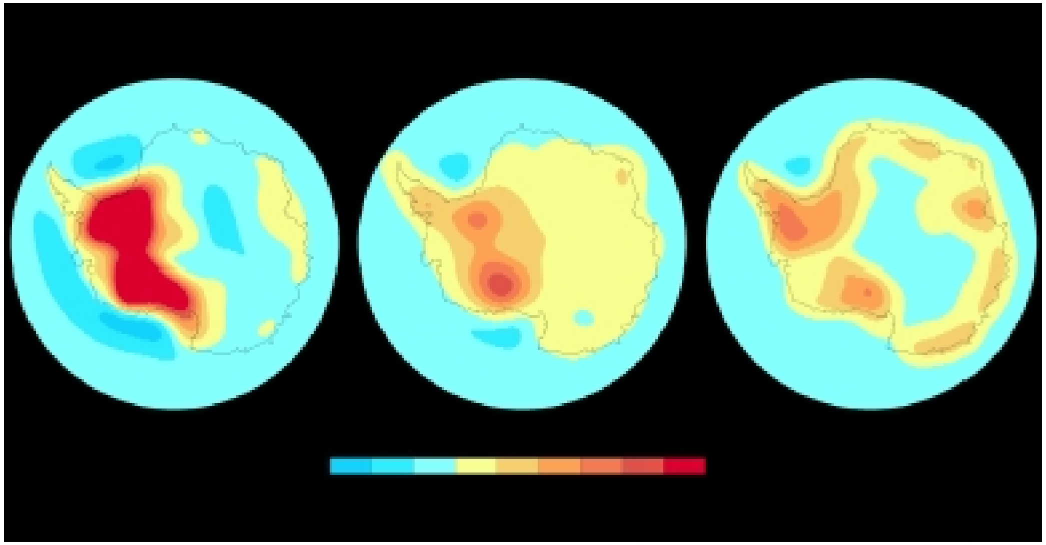
Tectonics – The View Forward

Integrated Physics Based Models Coupled to Observations

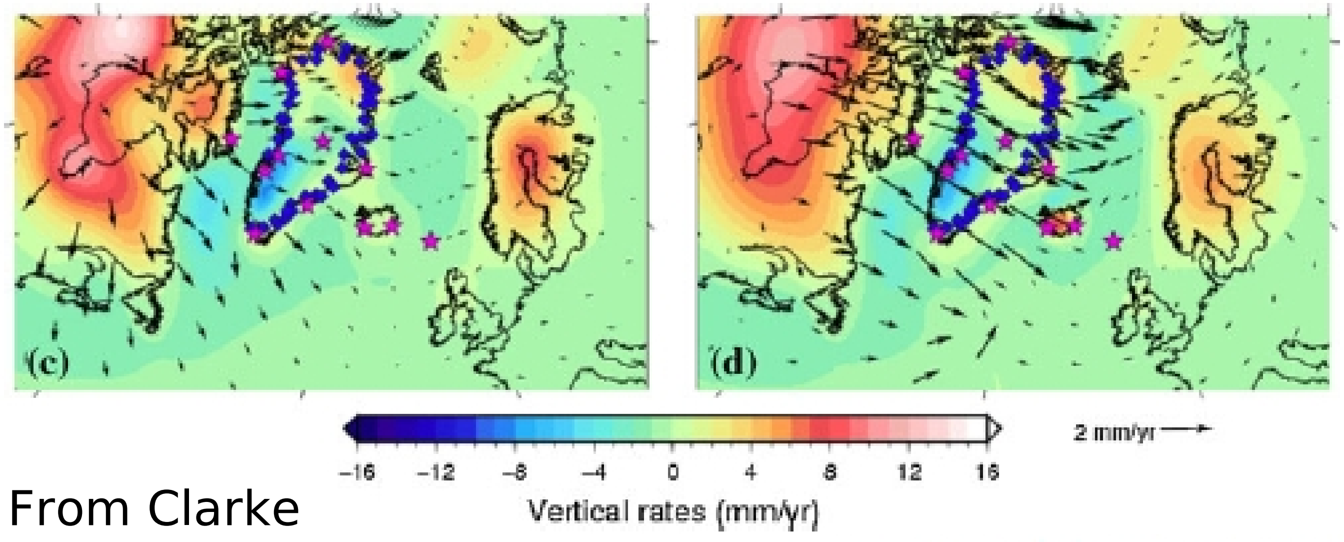
- Hydrologic
- Geodetic – GPS, GRACE, InSAR, absolute gravity
- Geodynamic – mantle convection, plate motions, loading response, GIA predictions, Sea level change
- Involves multiple spatial and temporal scales
- EARTH SYSTEM DYNAMICS

Confounding factors:
(2) Glacio-isostatic adjustment



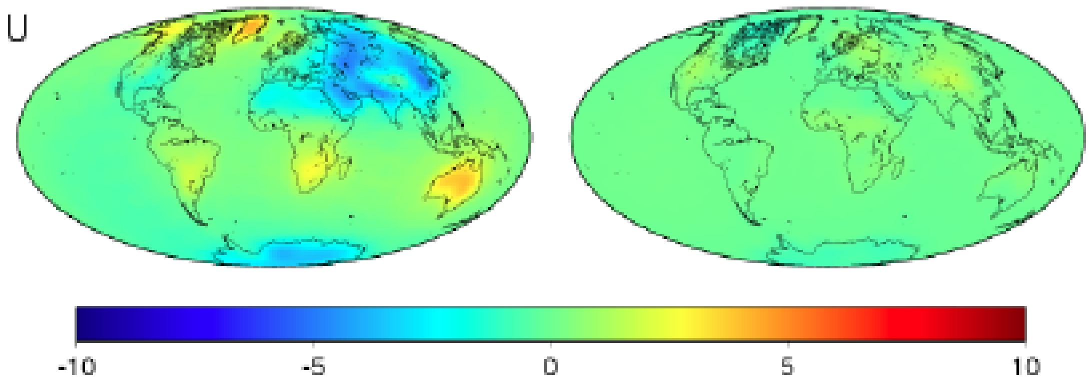
images: Matt King

King *et al.* (2010), *Surv. Geophys.*



From Clarke

Confounding factors:
(3) Atmosphere & Oceans



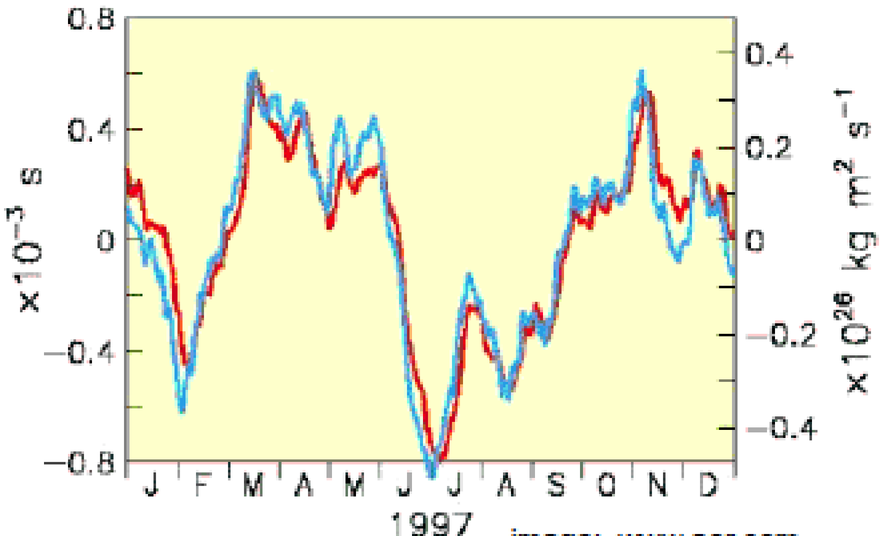
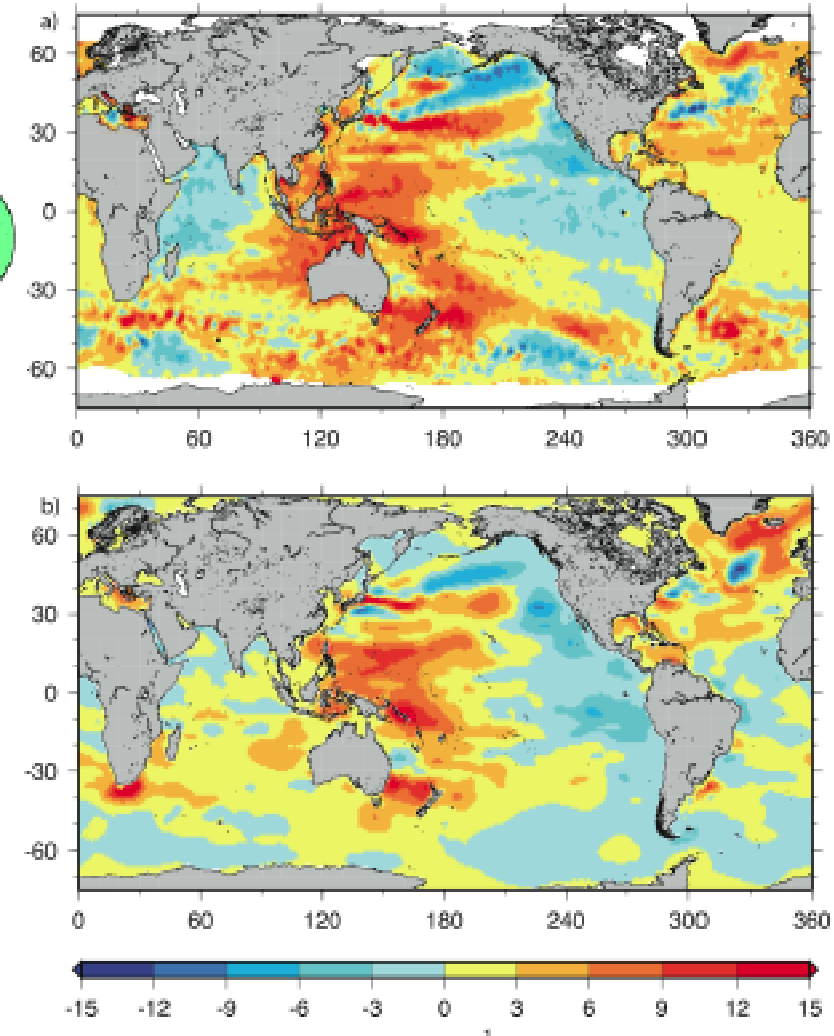


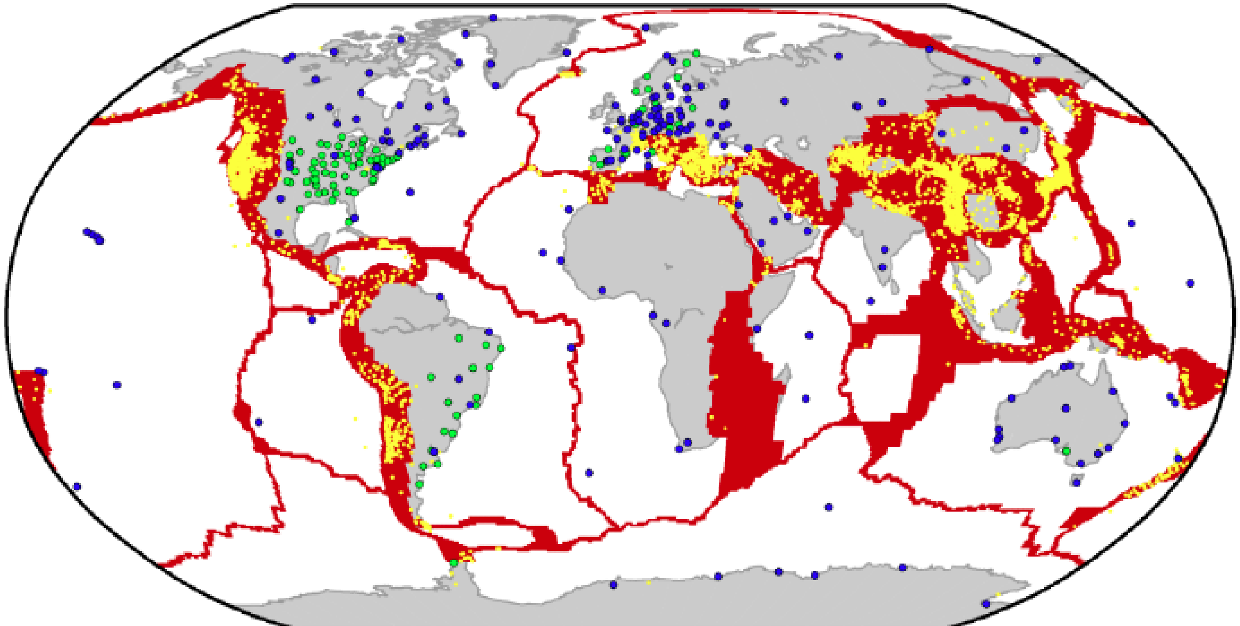
image: www.aer.com



IPCC (2007)

From Clarke

Confounding factors:
(1) Tectonics



From Clarke

image: David Lavallée, after Kreemer *et al.* (2006), *GRL*

Is it possible to have physics-based models that build on 3-D kinematics, seismology (tomography), history of subduction, convection, 3-D stresses, crust and mantle rheology?

Is it possible that models could also incorporate ice loading, hydrology, sea-level change?

Fully coupled models must accommodate a variety of temporal and spatial scales, will require precise geodetic techniques and accurate reference frame determination.

Tectonic Models

- Development of short term solid Earth models
  - Earthquake cycle
  - Rheology of the Earth
  - Time dependent deformation
  - Loading from sediments/ice (e.g., Sierra Nevada, SE USA, Antarctica, Greenland)

Tectonic Models

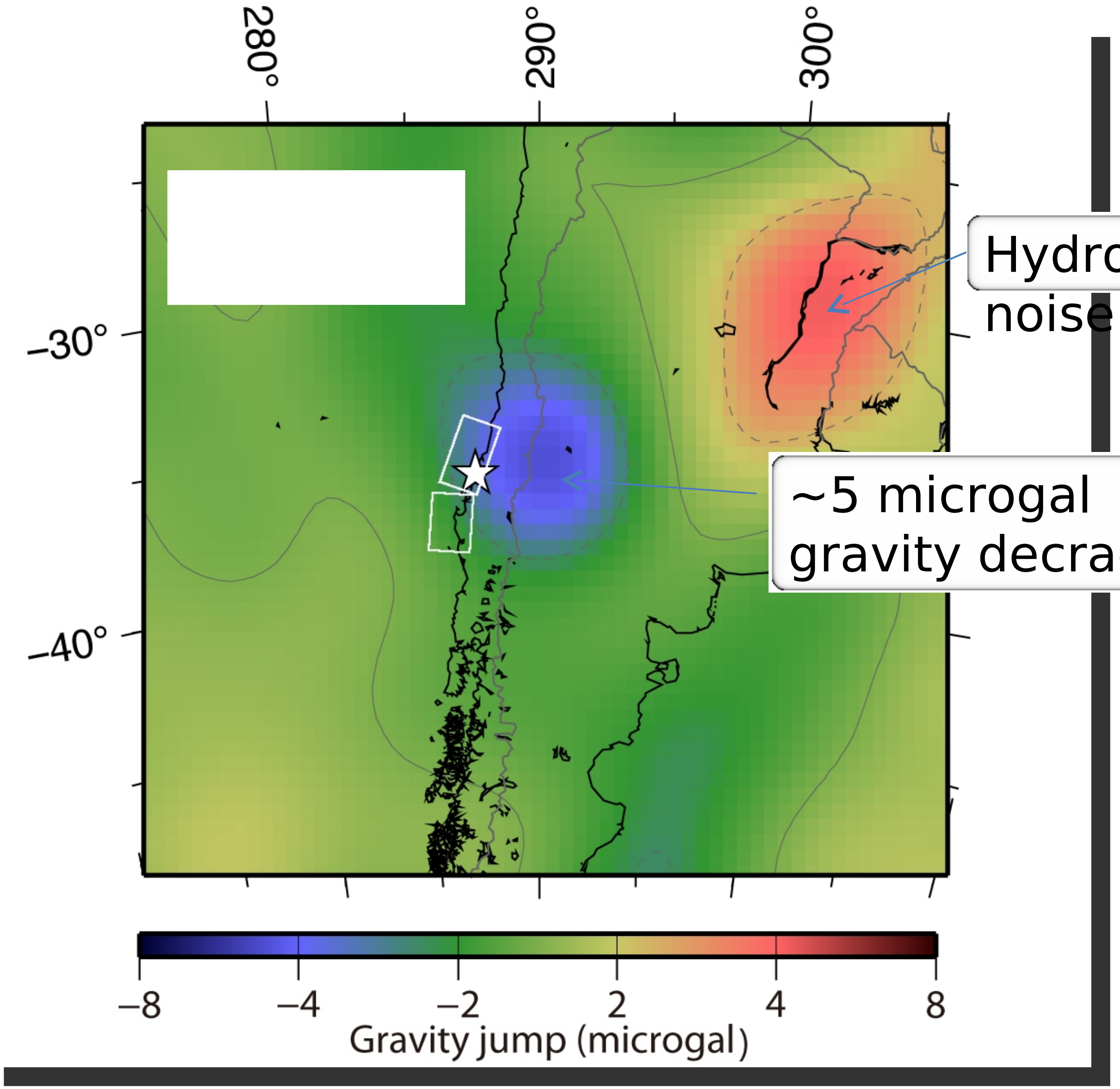
- Development of long-term dynamic models
  - Coupled physics of lithosphere/mantle interactions
  - Constrained by seismic observations, history of subduction, mineral physics, geologic constraints, plate motions
  - Radial and lateral rheology
  - Rheology estimates important for relating long -term deformation to shorter term measurements (GPS)
  - Provides an important boundary condition

Geodynamics/Geodesy/Hydrology/ Cryosphere

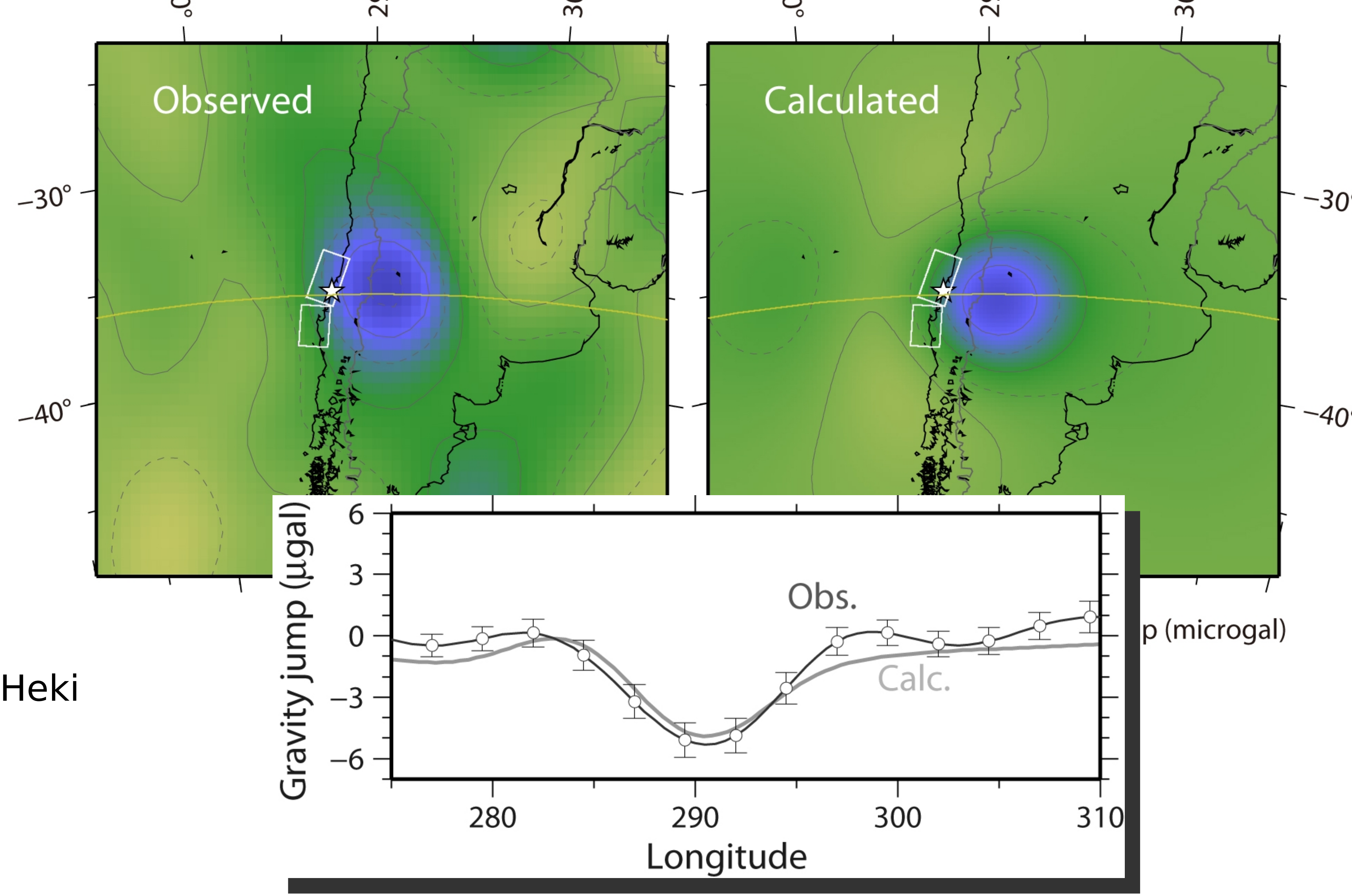
- Response to Earthquakes

Mapping the gravity jump : removing hydrological noises

Heki



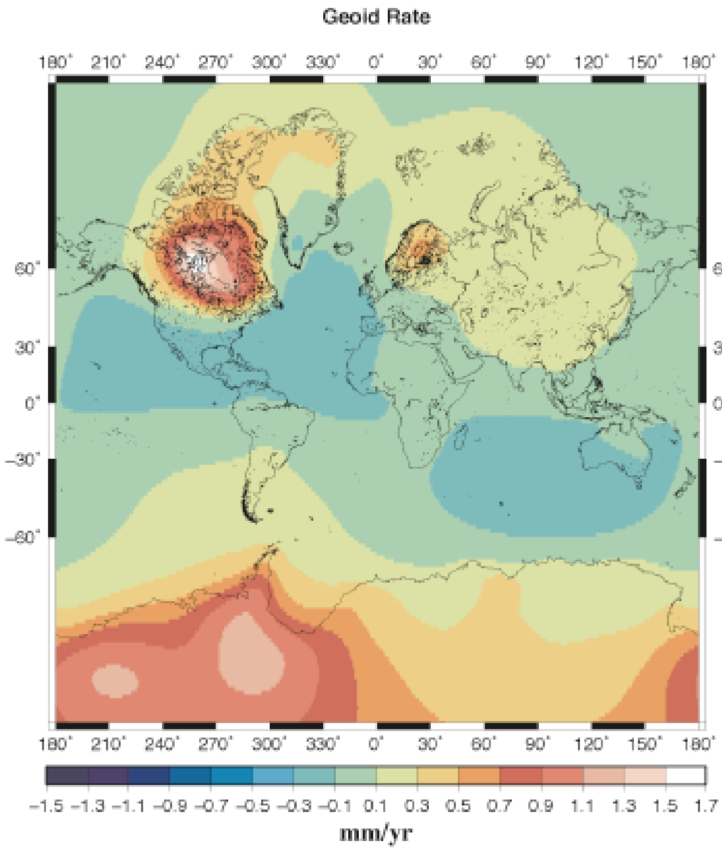
Coseismic gravity change : Obs. vs. Calc.



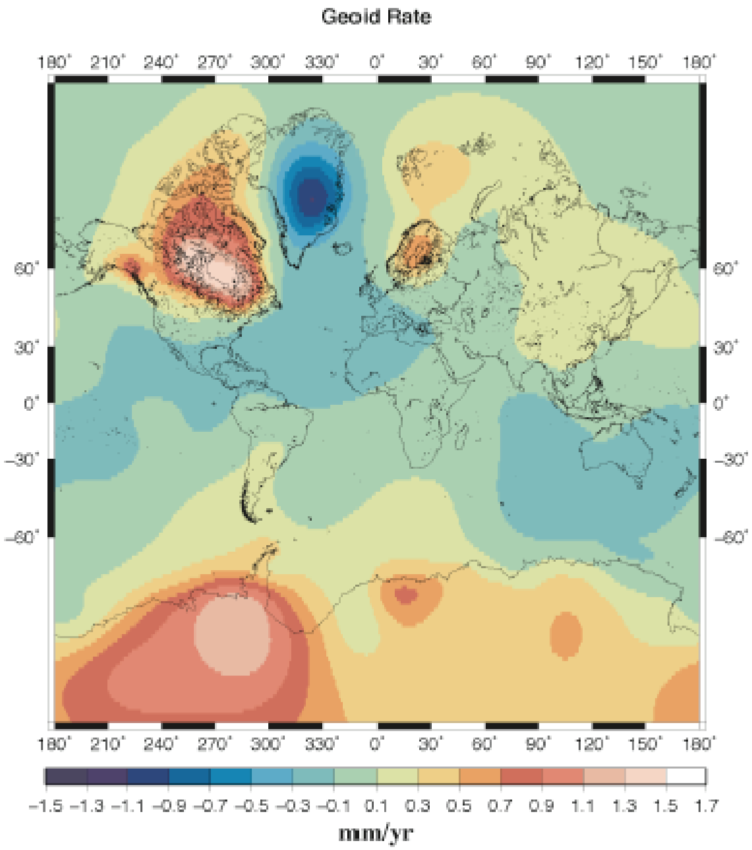
Heki

GIA and Physics Based Models

A Priori and Posteriori GIA Geoid Trend



ICE-5G/IJ2005/VM2



Inverted

Xiaoping Wu

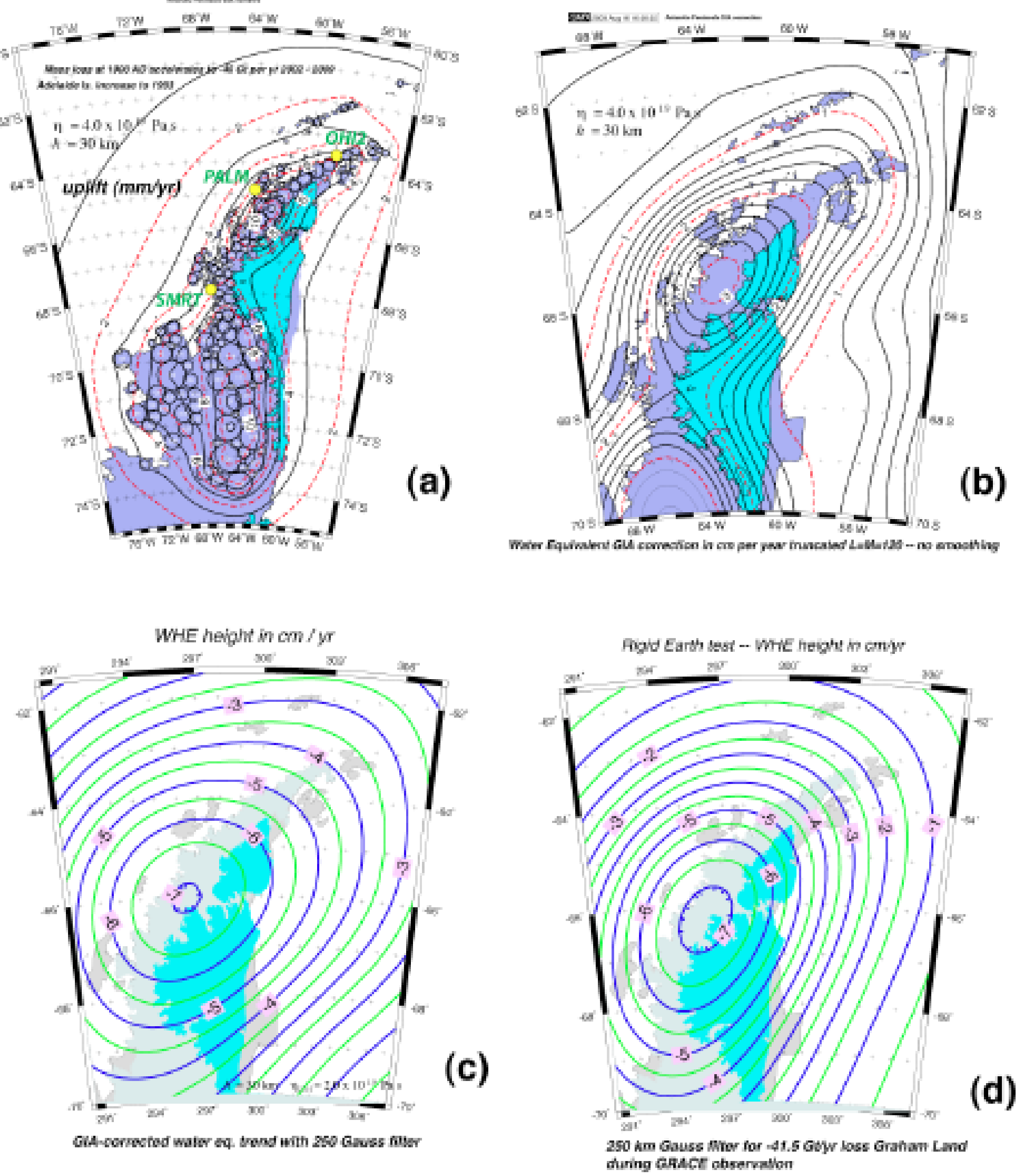
Signature Separation and Perspectives

- Global Kinematic:
  - Use fixed deglaciation areas and intrinsic dynamics
  - Successfully separates long-wavelength signatures
  - Fail to incorporate historical relative sea level data
  - Lack dual data coverage over ice sheet interiors
  - Cannot resolve ice history and Earth rheology
  - Full dynamics requires sea-level eqn solver with rev. rotational feedback
- Dynamic: Massive combination of all data

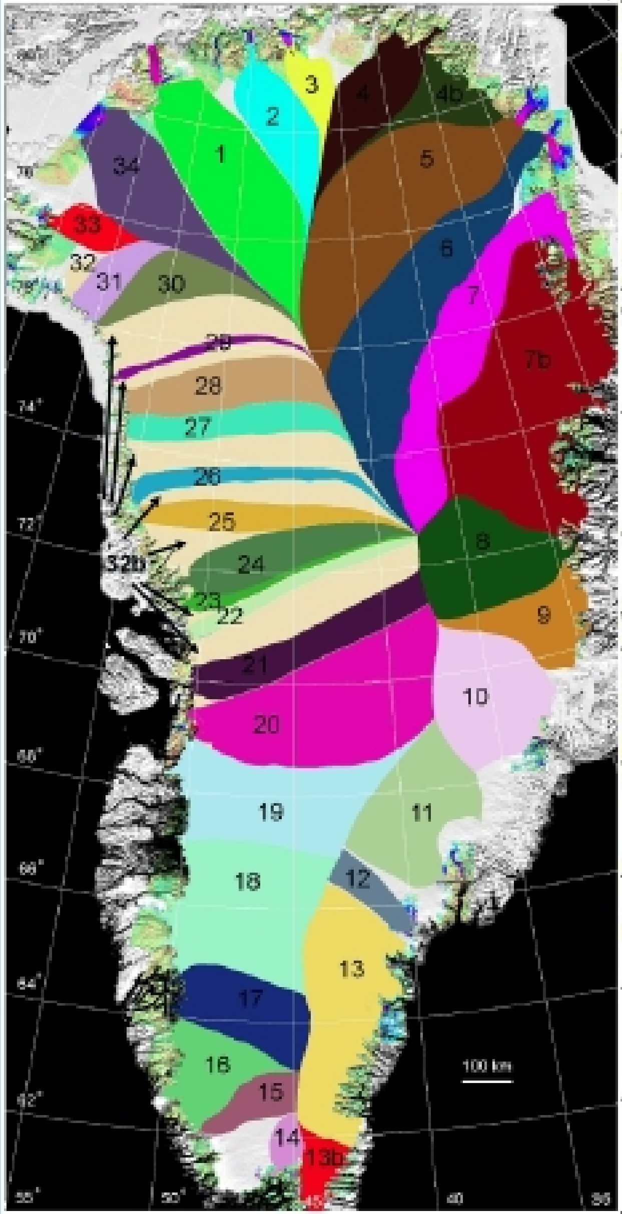
$$D = F(\dot{M}, M_{past}, H_L, \nu, \; .... \;)$$

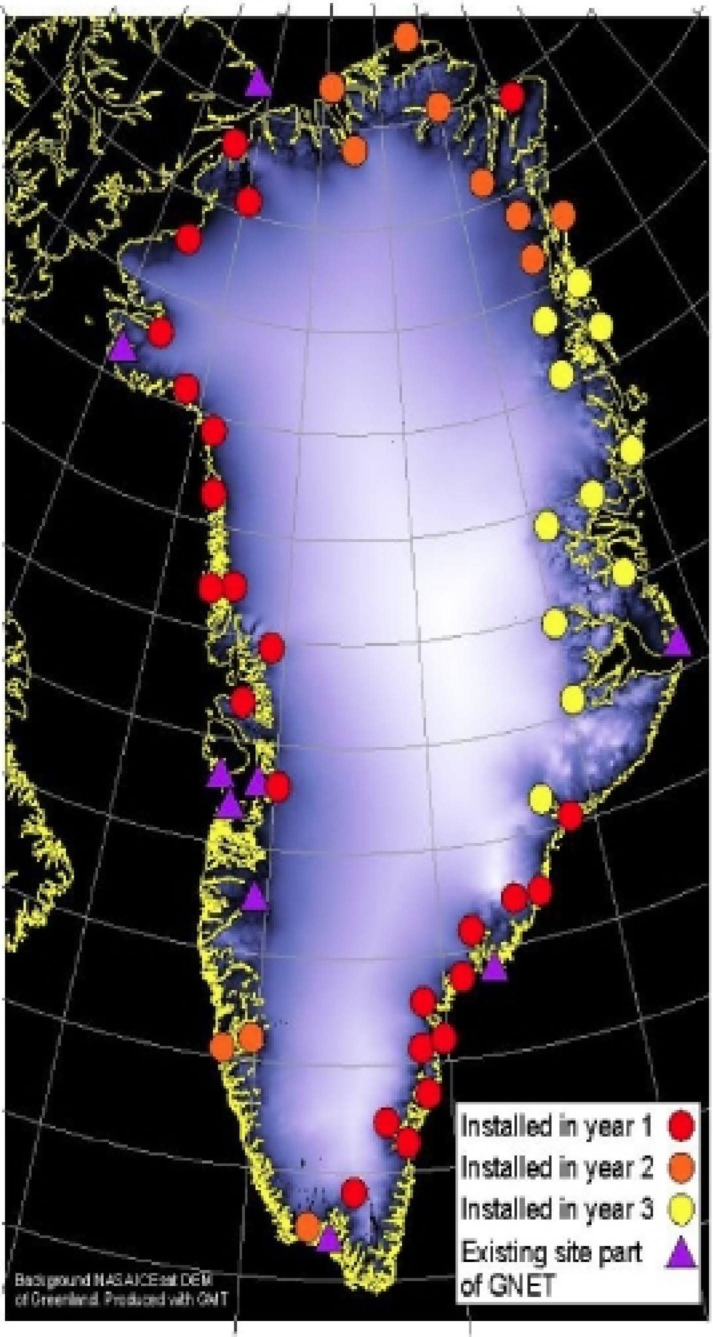
Xiaoping Wu

Sequence of iteration for Antarctic Peninsula



Ivans – combining GPS and GRACE + Physics based calculations





GNET:
will provide basin-by-basin view of ice health

Wdowinski and others

Accelerating uplift – fully physics- based models are needed

Regional Scale Models

GPS / Absolute Gravity Integration

5 AG – GPS sites

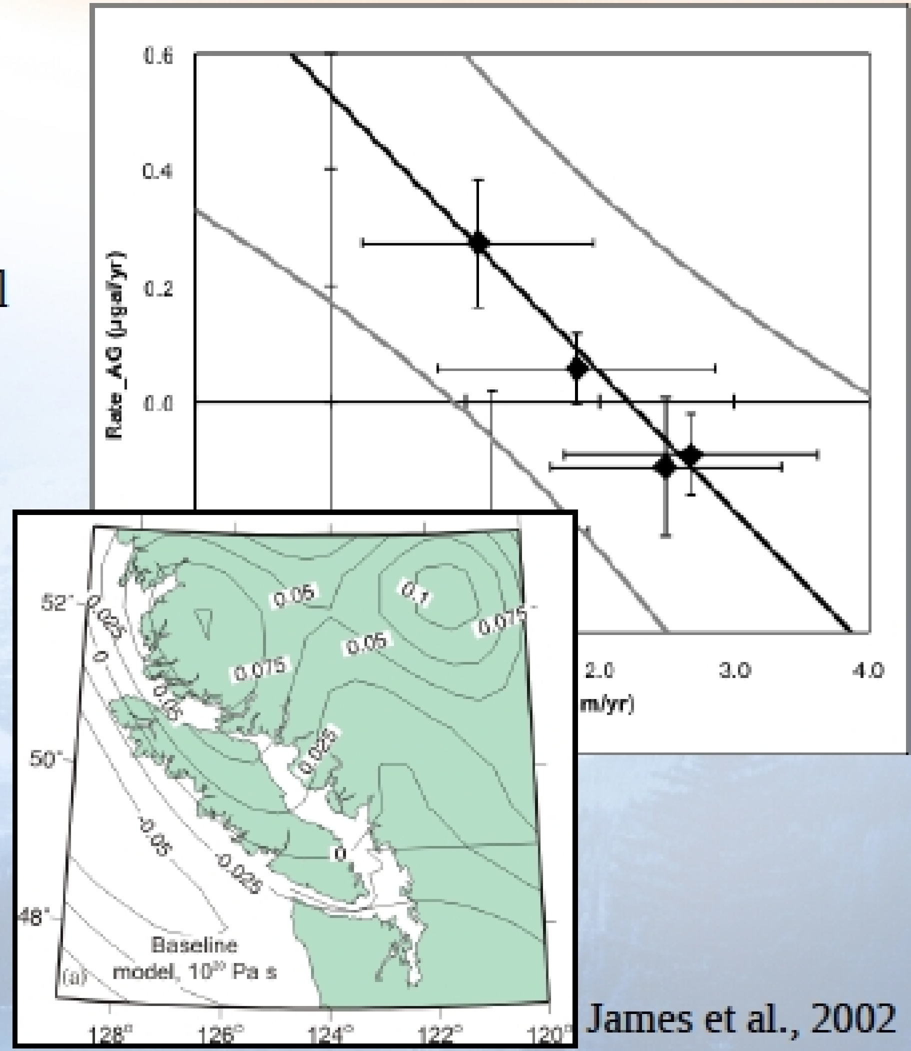
g/h ratio = -0.24 ± 0.13 μGal/mm

Consistent with subduction thrust theoretical value (-0.2 μGal/mm)

Consistent with no ongoing postglacial rebound due to low back-arc mantle viscosity (< 10^{20} Pa s)

>> Present-day PGR uplift rates less than 0.5 mm/yr

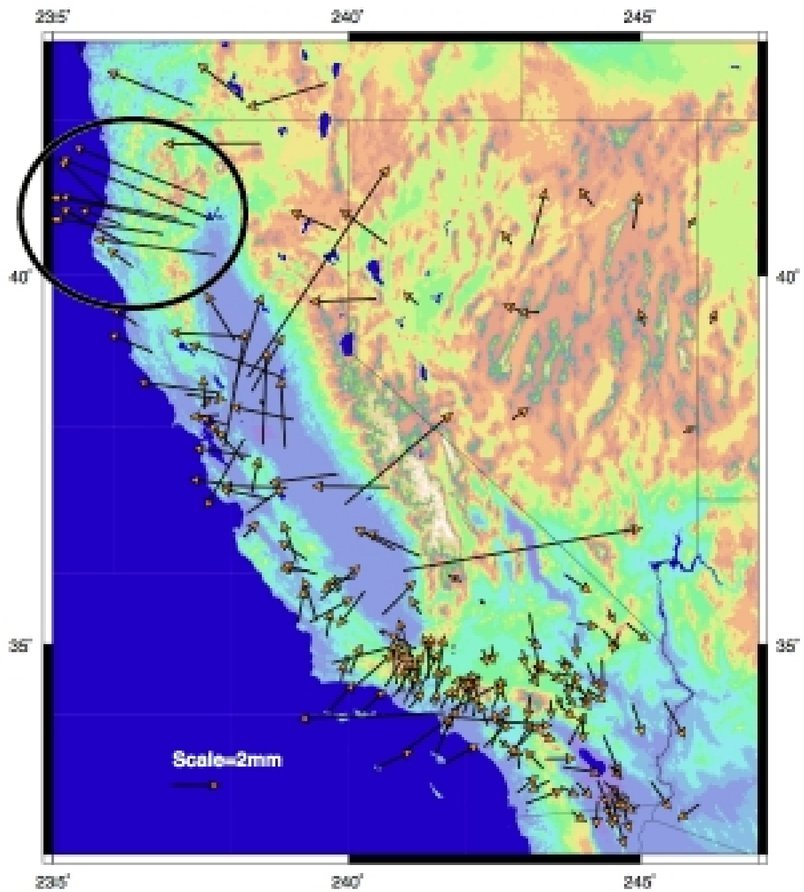
Mazzotti et al.

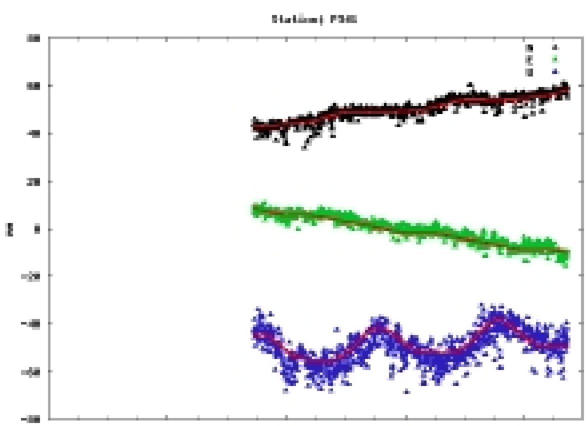


James et al., 2002

N. Calif. Peak in Oct.

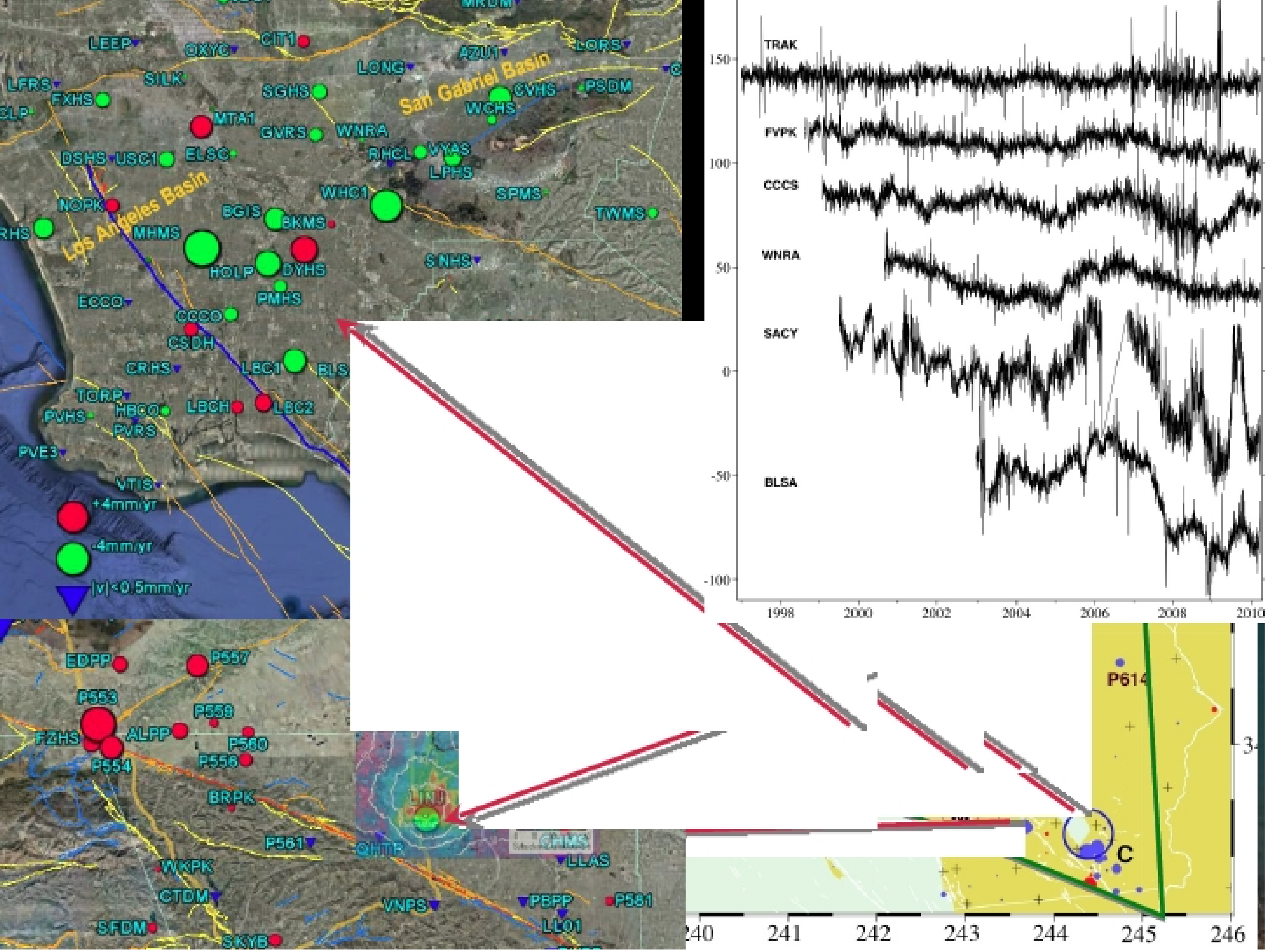
Annual Signal Phasor Plot





Meertens

- In order to measure tectonic mountain building (rates of <1mm/yr) we will need to be able to understand and model hydrologic loading effects


San Gabriel Basin
Los Angeles Basin
LEEP
OXYC
CIT1
AZU1
LORS
LFRS
SILK
LONG
FXHS
SGHS
CVHS
PSDM
MTA1
WCHS
GVRS
WNRA
DSHS
USC1
ELSC
RHCL
VYAS
LPHS
NOPK
WHC1
SPMS
BGIS
BKMS
TWMS
MHMS
HOLP
DYHS
SNHS
PMHS
ECCO
CCCO
CSDH
CRHS
LBC1
TORP
HBCO
LBCH
LBC2
PVHS
PVRS
PVE3
VTIS
+4mm/yr
-4mm/yr
|v|<0.5mm/yr
TRAK
FVPK
CCCS
SACY
BLSA
150
100
50
0
-50
-100
1998
2000
2002
2004
2006
2008
2010
EDPP
P557
P553
P558
FZHS
ALPP
P560
P554
P556
BRPK
P561
CHMS
QHTR
WKPK
LLAS
CTDM
VNPS
PBPP
P581
LL01
SFDM
SKYB
P614
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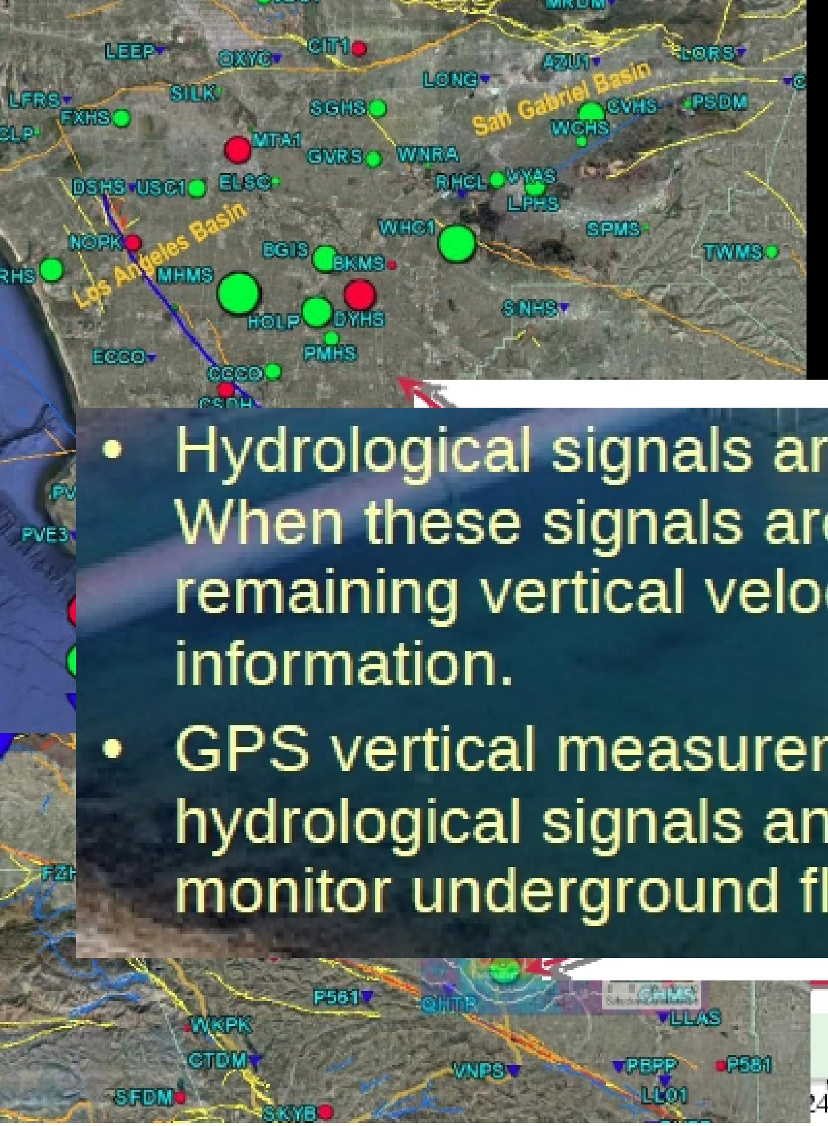
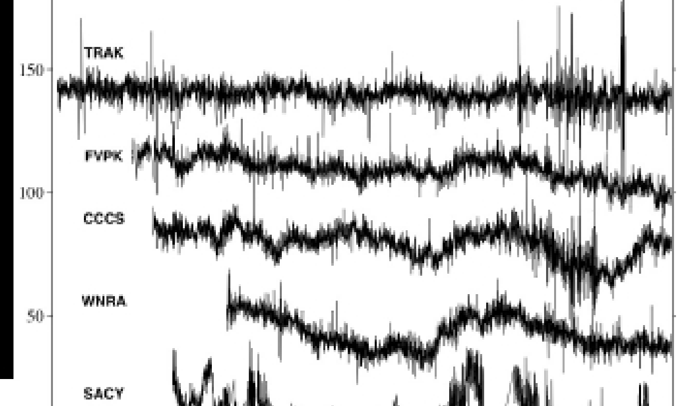
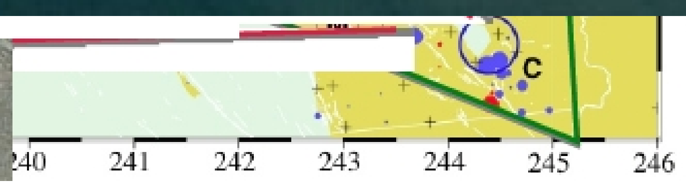
Dong et al.







- Hydrological signals are typically occur in isolated areas. When these signals are identified and subtracted, the remaining vertical velocity field could reveal tectonic information.
- GPS vertical measurements are very sensitive to hydrological signals and can provide effective means to monitor underground fluid variations.

Dong et al.

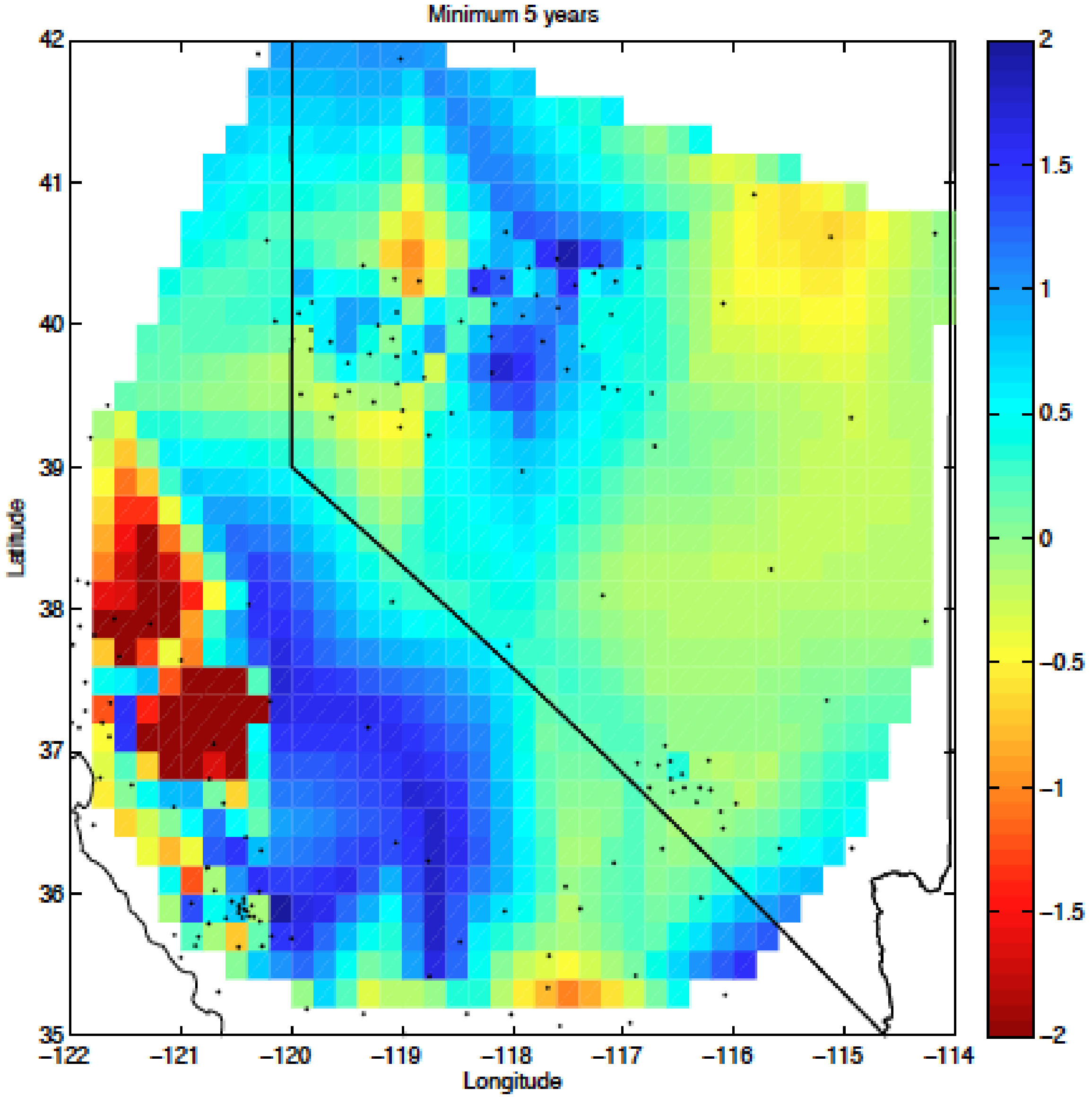
Analysis of Snowpack Reduction Impacts on California Groundwater Water Infrastructure Using DWR C2VSIM Model

C2VSIM - California Central Valley Simulation Model

Domain: 20,000 square miles

Miller

Vertical GPS Velocities Interpolated



- Time Series **5** years or longer
- Frame is GB09, similar to ITRF2005, but regionally filtered on scale of Great Basin.

We See:

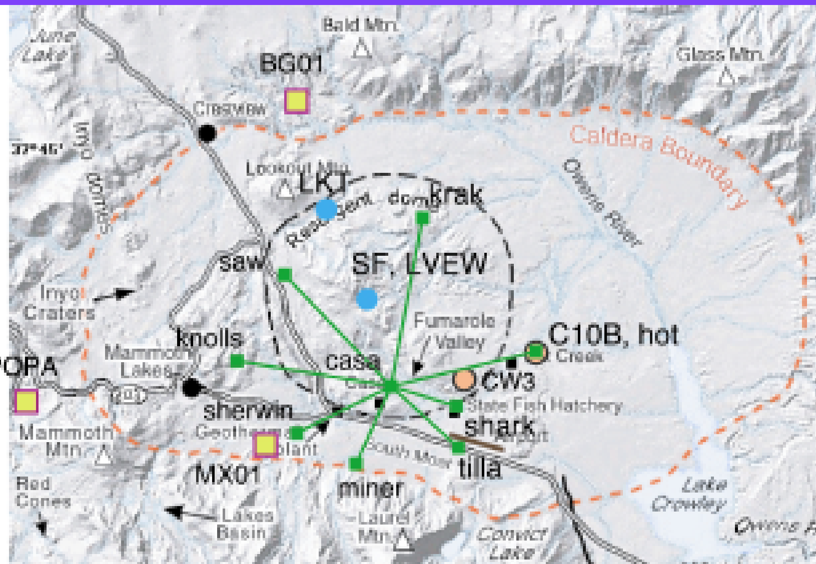
- Extremely stable eastern NV, RMS of ~0.2 mm/yr
- Larger uplift rates near Central Nevada Seismic Belt ~2 mm/yr
- Complexity in Walker Lane where crustal deformation rates are higher
- Generally upward rates on west slope of Sierra Nevada Range near 1 mm/yr

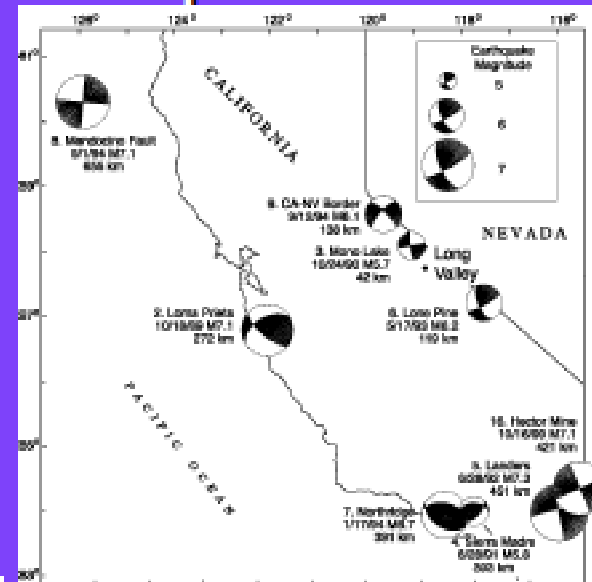
Rates similar to what others have shown (e.g. Fay et al., 2008; Bennett et al., 2009; Dong et al, 2009)

Hammond et al.

Earthquakes and far-field triggering

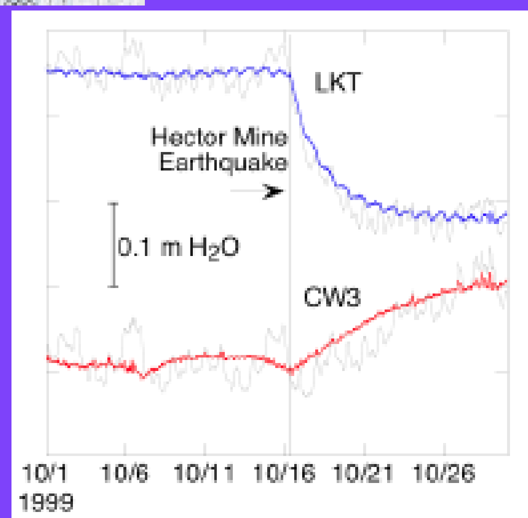
Fluid Pressure Changes at Long Valley Caldera from Distant Earthquakes





All earthquakes on map have produced similar fluid pressure changes

Fluid pressure increases in south moat thermal wells and decreases in non-thermal wells on and around the resurgent dome

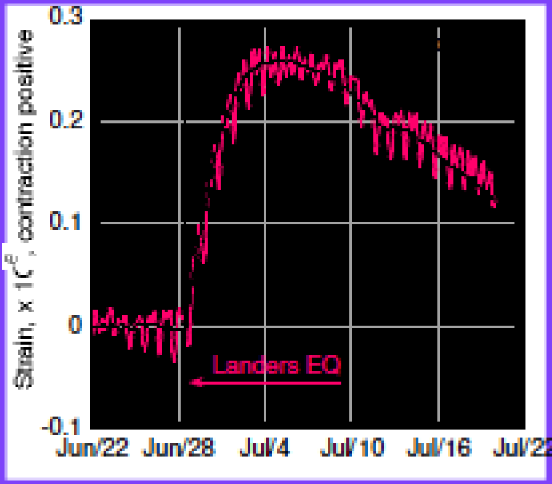


- Hypothesis: fluid-pressure decreases represent increments of dome inflation; increases represent triggered upflow of hot material beneath south moat (Roeloffs et al., JVGR 2003)
- But strain transients are not accounted for by these hypotheses…

Strain Changes Associated with Earthquakes

1992 Landers M7.3 450 km

Remotely triggered seismicity



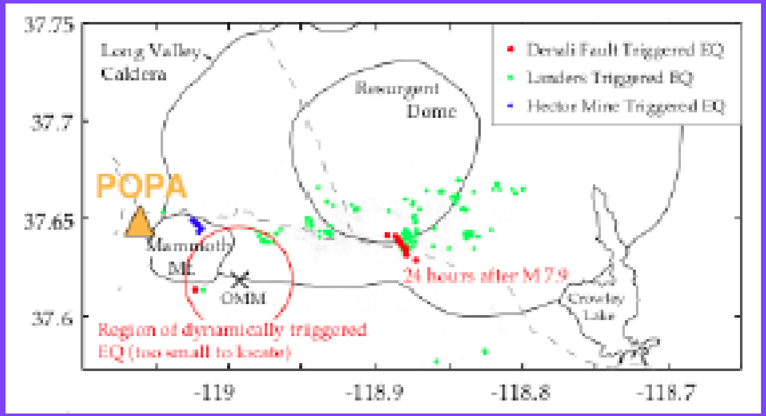
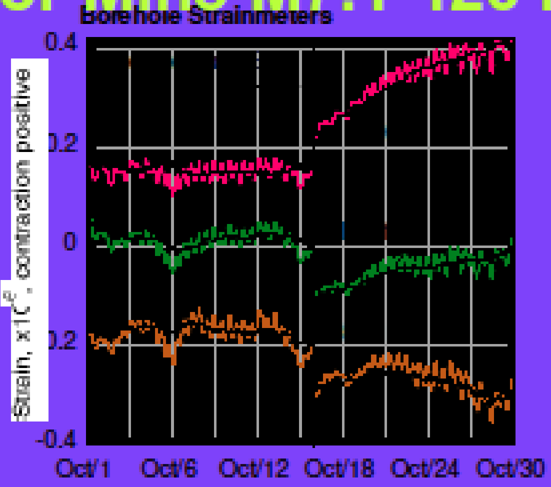


Figure by S. Prejean, USGS

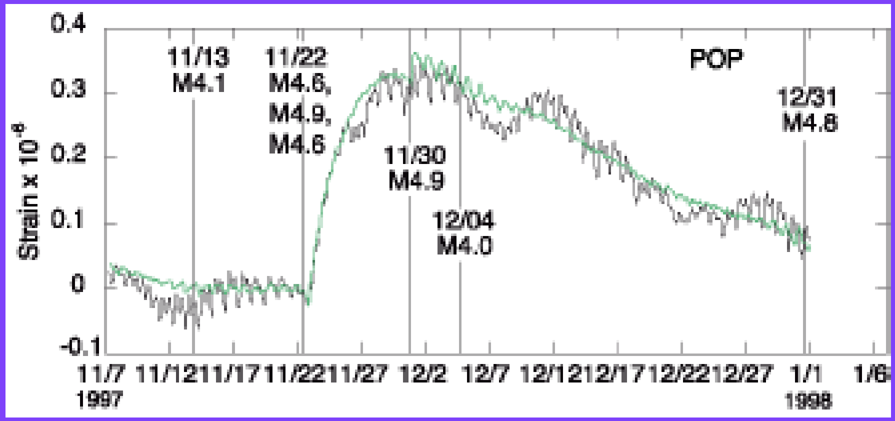
1999 Hector Mine M7.1 420 km

Remotely triggered seismicity



1997 South Moat Swarm

Possible intrusion beneath south moat



Summary

- Need solid geodetic/hydrologic infrastructure of space-based and land-based measurement
- Multidisciplinary research (physics-based) that couples across multiple spatial and temporal scales
- Rigorous multidisciplinary approaches have implications for sustainability, hazards, etc.

Questions posed in Peter Clarke's Presentation

Workshop questions

- How can we bridge the gap in spatial scales between regional/global and point/catchment measurements?

- How can we isolate long-term hydrological change from secular effects due to tectonics, GIA, etc?

- How can we improve measurement accuracy and robustness to seasonal and other artefacts?