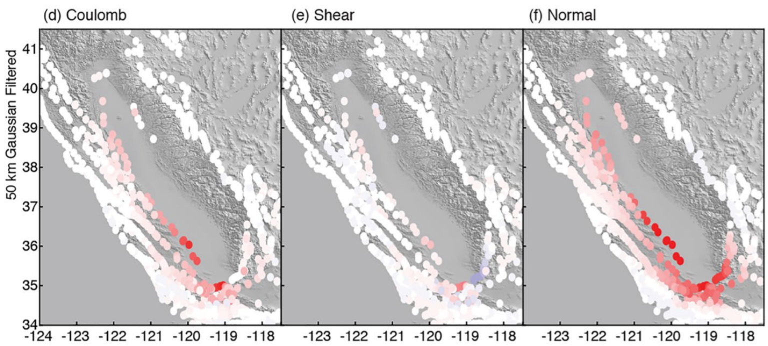
CSQ-34 Summary

Question	Knowledge Advancement Objectives	Geophysical Observables	Measurement Requirements	Tools & Models	Policies / Benefits
How do active faults respond to stress perturbations associated with the water cycle, and what are the relative contributions of climate extremes and human activities ?	A) Quantify and locate changes in groundwater storage at daily to weekly timescales and high spatial resolution, as well as the associated spatial variations of aquifer storage parameters. Discriminate these deep water mass changes from those of the shallow hydrological components.	• Ground deformation derived from GNSS measurements to constrain regional-scale water loads (from the elastic deformation response) • High-resolution ground deformations from InSAR to constrain local groundwater level variations • Gravity to constrain total water mass • Data on soil moisture, surface water levels	• Daily to weekly timescales • High spatial resolution • Multi-satellite missions can help improve the gravity recovery	Models of elastic and poro-elastic deformations of the solid Earth under a water load	Improved seismic hazard assessment from improved understanding of earthquake nucleation processes
	B) Estimate crustal deformations and stress field perturbations due to groundwater and shallow water mass changes, and assess the impact on the seismicity. Compare results in contexts of extreme climatic events, or in areas subject to human pumping.	• Knowledge on surface and deep water loads derived from the previous objective • Ground deformations due to water loads observed from GNSS and InSAR • Seismicity		Models of elastic and poro-elastic deformations of the solid Earth under a water load Knowledge on the distribution of faults Ability to calculate stress variations	

CSQ-34 Narrative

Changes in the water mass at the Earth's surface generate small variations in the crustal stress field from local to regional scales. Despite their small amplitude, it has been proposed that these changes could modulate seismicity, by affecting the state of stress on active faults and pore fluid pressure at depth (e.g. Craig et al. 2017). A number of studies have provided support for this hypothesis, such as those focussing on seasonal variations in the rate of seismicity (Johnson et al., 2017). Studying earthquakes modulation by water loads actually provides a natural laboratory to explore the effects of specific stress perturbations on faults and better understand earthquakes nucleation processes. Note that in active tectonic environments such as plate boundaries, changes in the stress field induced by hydrological loads are much smaller than the secular rates of stress accumulation due to tectonic processes, but the situation may be different within continental interiors, where the secular tectonic stresses are smaller. Current efforts aim at a better estimation of the groundwater contribution to the total water mass change, by combining different types of geodetic observations (e.g. Carlson et al., 2020). Indeed, this groundwater contribution may be under-estimated in GPS-based water load models, resulting in an under-estimation of the non-tectonic crustal stress. Its accurate quantification and location is crucial to better describe the forces that modulate seismicity, the contributions of human pumping activities and climate extremes, and their influence on the seismic hazard.



Stress field perturbation along faults in California from total groundwater loss during the 2007–2010 drought. Red color : 1-1.5 kPa stress change (Carlson et al., 2020).

References

Carlson, G., Shirzaei, M., Werth, S., Zhai, G. and Ojha, C. (2020). Seasonal and long-term groundwater unloading in the Central Valley modifies crustal stress, *Journal of Geophysical Research: Solid Earth*, 125, e2019JB018490.

Craig, T., Chanard, K., Calais, E. (2017). Hydrologically-driven crustal stresses and seismicity in the New Madrid Seismic Zone, *Nature Communications*, 8, 2143.

Johnson, C.W., Fu, Y. and Bürgmann, R. (2017). Seasonal water storage, stress modulation, and California seismicity, *Science*, 356, 1161-1164.