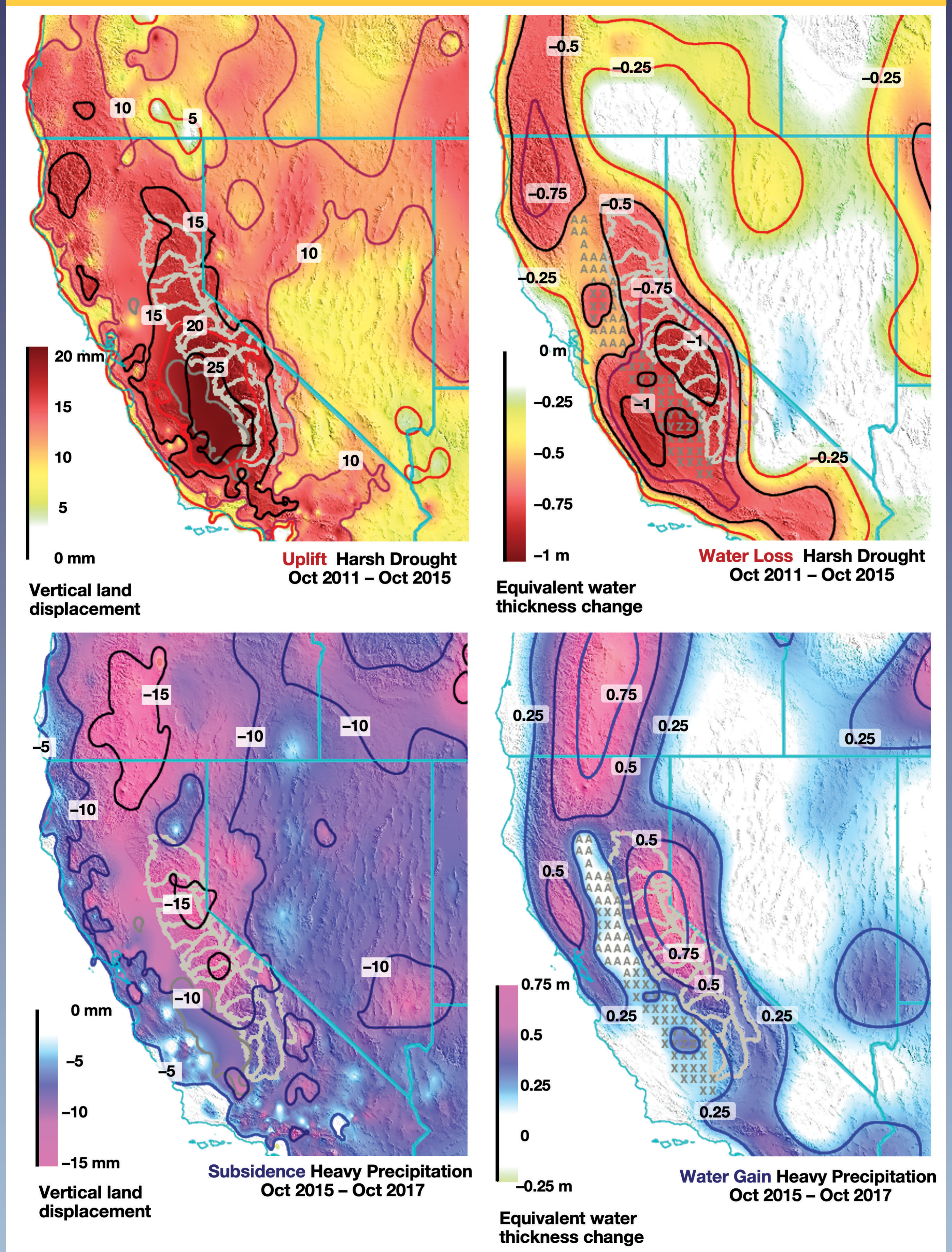
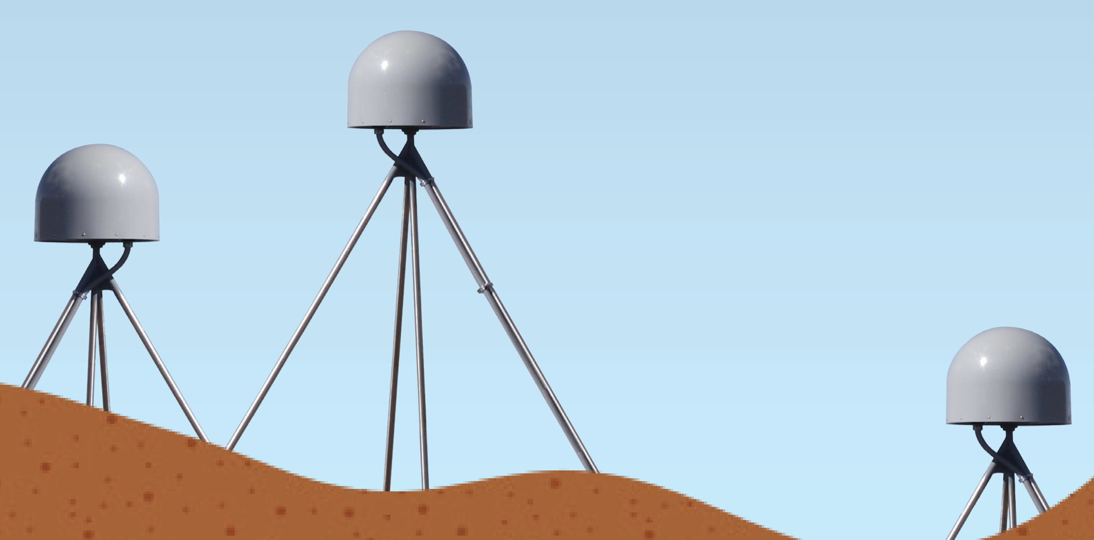
Monitoring Groundwater with Geodesy

GPS

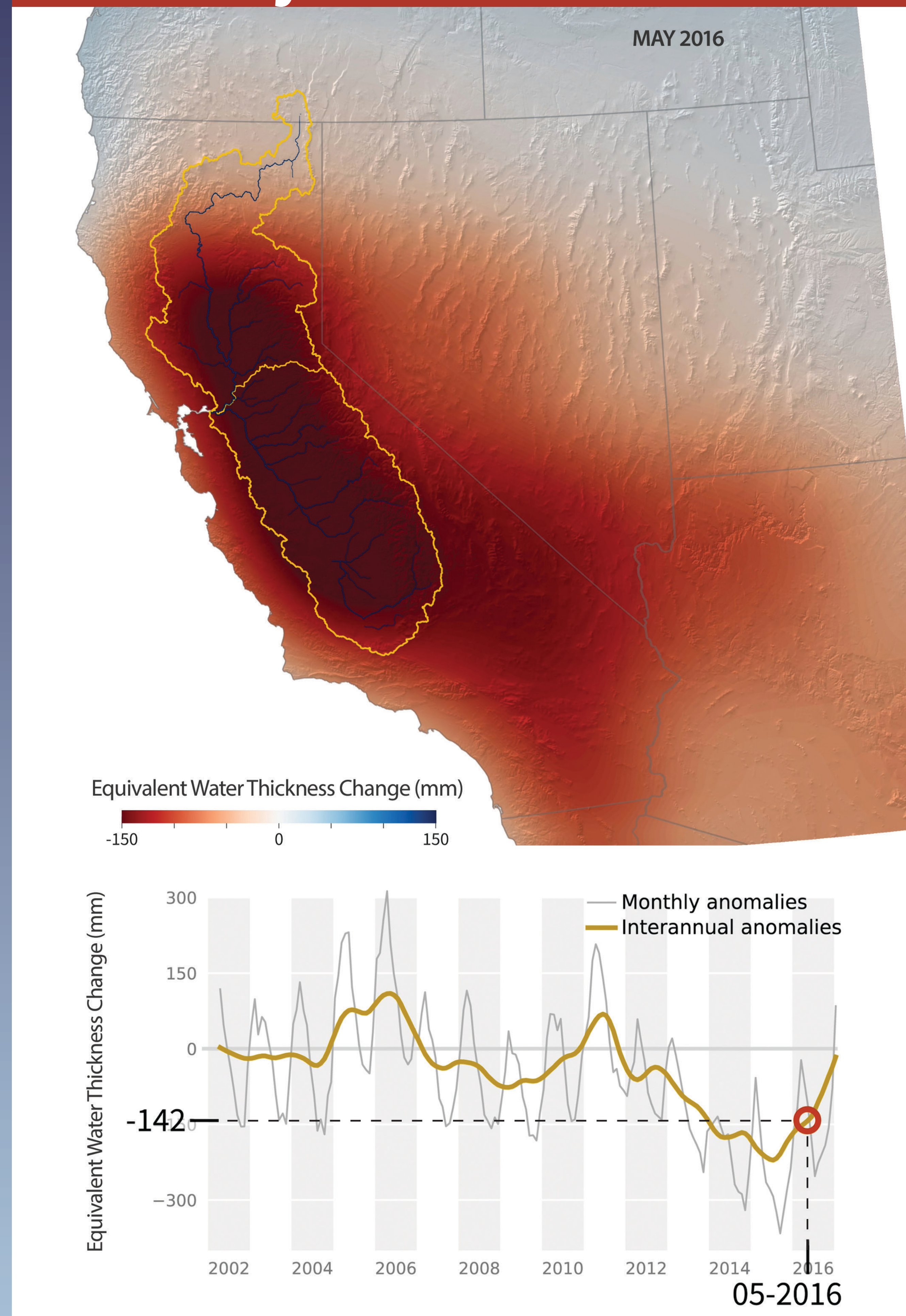


High-precision **Global Positioning System** stations can measure location far more exactly than your phone. As the ground beneath them moves, they are sensitive enough to detect changes of less than 1 millimeter per year! They measure vertical movement in addition to horizontal, which means they can also monitor groundwater.

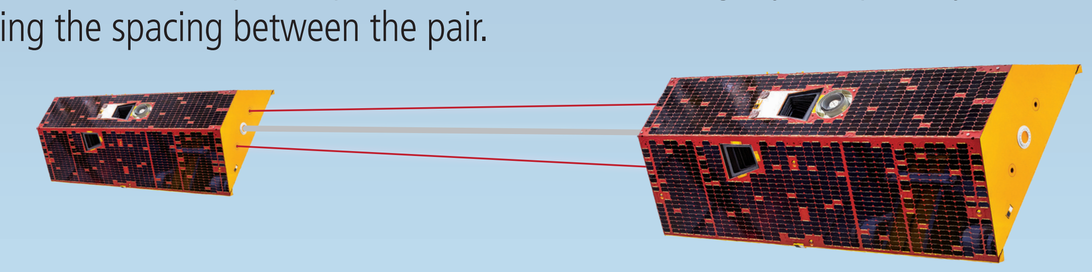
That's because the added weight of extra water actually compresses the bedrock of Earth's crust, causing the surface to drop slightly. (This is called "subsidence.") The surface bounces back up when the water disappears—during the dry season or during a longer drought. In this example, we can see measured bedrock movement (L) and the corresponding groundwater change (R) during a multi-year drought and during a period with above-average precipitation.



Gravity

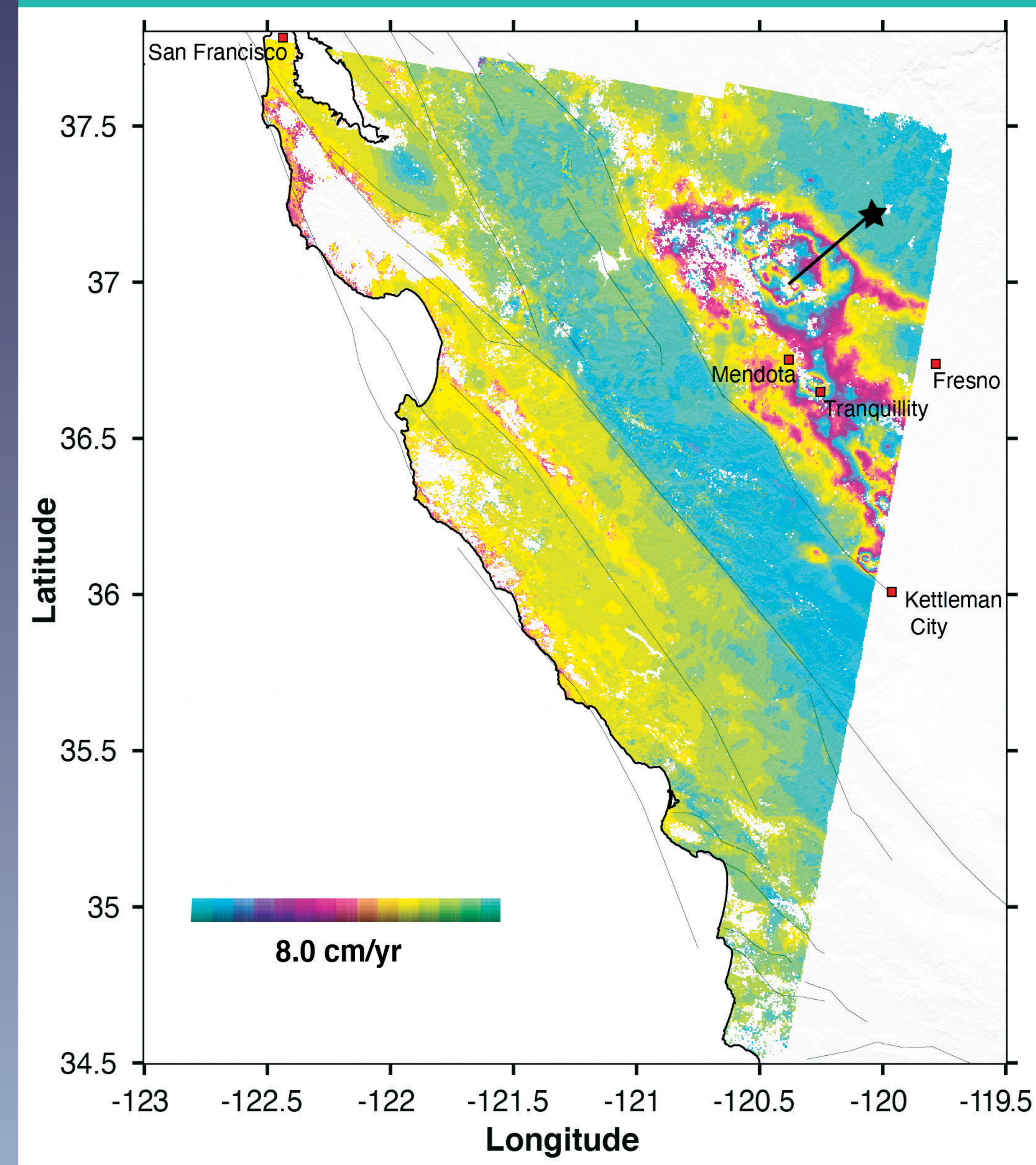


NASA's GRACE *(Gravity Recovery and Climate Experiment)* mission is actually a pair of satellites that fly in formation, precisely measuring the spacing between them. Earth's gravitational pull is not uniform because of variations in the mass of material—whether bedrock or water or glacial ice—below you in any given location. These variations cause the satellites to speed up or slow down ever so slightly, temporarily increasing or decreasing the spacing between the pair.

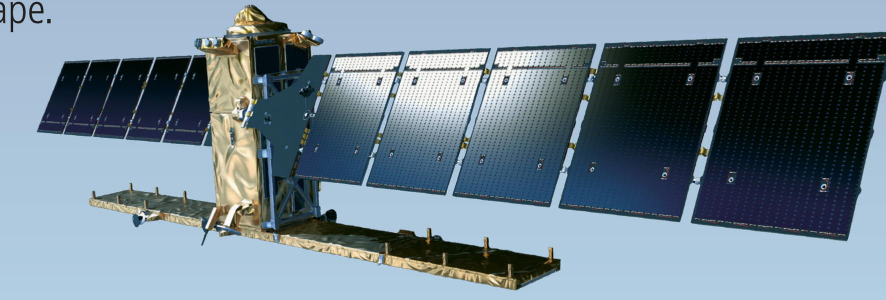


This allows the **GRACE** mission to measure changes in mass over time as a glacier melts or as groundwater is depleted. In the map above, we see the results of the first GRACE mission (which was replaced by GRACE-FO in 2018) measuring the change in groundwater over time for the area of California outlined in yellow. This particular map shows how dry the area was in May 2016 after the drought shown in the GPS maps.

InSAR



InSAR stands for *"Interferometric Synthetic Aperture Radar."* Satellites bounce radar signals off the surface of the Earth and use the delay in the signal's return to measure distance extremely precisely. This technique produces a high-resolution 3D map of the surface that shows every hill and valley. By comparing all the 3D maps made by multiple passes of a satellite, like the European Space Agency's **Sentinel-1A** satellite shown here, we can see if anything has moved or changed shape.



In this example, we see surface changes for a portion of California between 2015 and 2017. In places like California's Central Valley, overuse of groundwater causes the surface to drop in elevation slightly. This occurs because water occupies the tiny spaces between particles of sediment, helping to keep the particles separated. When water is removed, the sediment is able to compact together more tightly, occupying less overall space.

InSAR maps often use a unique rainbow color scheme that helps highlight small differences. Rather than each color representing a specific number, the scale shows that 8 centimeters of subsidence is represented by a complete sequence of colors as your eye moves across the map. If you follow the line from the black star on the map, you'll cross three repetitions of the rainbow to a location that experienced about 24 centimeters per year of subsidence—the largest movement in this area.

What is Geodesy?

Geodesy is the science of the Earth's shape, measuring changes in its surface, gravitational field, and rotation. These measurements help us do things like detect earthquakes, study plate tectonics, track shrinking glaciers, monitor landslides, and even help to keep self-driving cars on the road.

To watch a short video that animates and explains all this in a little more detail, scan this QR code with your phone or search "measuring drought GPS" on YouTube!

NSF NASA GAGE National Science Foundation's Geodetic Facility for the Advancement of Geoscience UNAVCO