The Drought In California: How A Satellite Named GRACE Is Helping To Watch Our Groundwater

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Second only to glaciers, groundwater is the most readily available source of fresh water for homeowners, businesses and cities. Therefore, it is important to protect sources of groundwater from over pumping. Unregulated, over pumping of groundwater has impacted the State of California's energy budget, environment and led to increased disputes between homeowners and city governments. As a result, satellites like the Gravity Recovery and Climate Experiment (GRACE) and GPS stations have become important to monitoring groundwater level when holding users accountable has been difficult.

Since 2013, the prolonged drought in the Western United States has contributed to 240 Gigatons of groundwater lost, or equal to the annual mass loss of the Greenland ice sheet (Borsa, Agnew & Cayan, 2019). In 2019, a team of Geophysicists from the Scripps Institution of

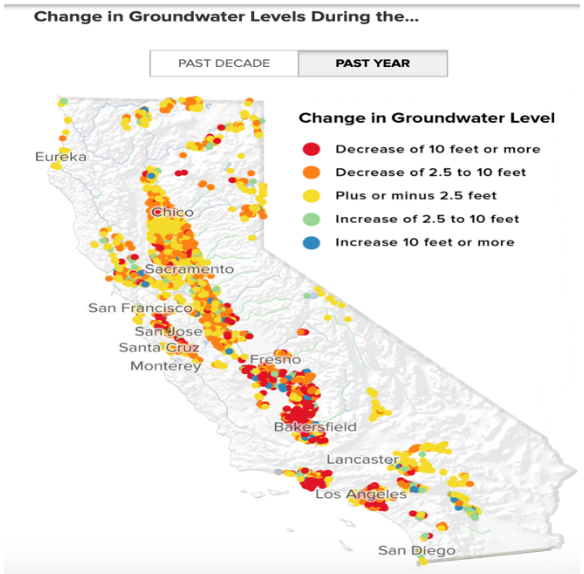


Figure 1: The Central Valley of California, "The Salad Bowl of the World" also suffers from the greatest land subsidence in the whole state.

Oceanography analyzed data collected from GRACE in order to monitor the uplift in the Western United States caused by the drought. Their overall determination was that In California's mountains the uplift is 15 millimeters, whereas the median uplift across the entire western region is five millimeters (Borsa, Agnew & Cayan, 2019).

GRACE works like the camera on an IPhone. Just like when you sweep an

IPhone to take a panoramic picture, GRACE sweeps through an orbit to take a picture of a spot on Earth. Like the Iphone in this analogy, the size of the detector on the satellite is small (only 10 meters), but by lengthening the orbit or "sweep", the resolution of the spot on the ground increases.

However, that's where the analogy ends. While a camera captures light bouncing off its subject, GRACE shoots radar down to the surface and measures how far the waves traveled before they bounced back to its sensors. Also, unlike taking a panoramic picture, the satellite does not sweep through a larger orbit to squeeze more surface into the "picture." It sweeps through a larger orbit to increase the size of its aperture, like the "shutter" of a camera if we still want to stick to the camera analogy.

By sweeping radar signals over a five kilometer orbit with our ten meter satellite, the a spot on the Earth's surface now has a spatial resolution of 20 meters instead of five kilometers. The technique of radar and "sweeping", known as Interferometric Synthetic Aperture Radar (inSAR), can measure the height of the ground by comparing the time it takes for radar signals to bounce off the surface of the earth. However, like other methods to measure data on groundwater, GRACE has its limitations. The current spatial resolution is not wide enough to be useful to enforcement agencies. Using GRACE, data was obtained using radar with an ability to get higher resolutions of 200 km (Borsa, Agnew & Cayan, 2019).

Once the data is recorded, changes in differences in height are turned into ripples of color on a graph called an "interferogram." The direction of color changes over the ripples, as shown in Figure 2, indicates whether the ground has risen or fallen. Interferograms are not often perfect though. Even though inSAR has the advantage that radar can penetrate through cloud cover, surface weather like snow pack, flooding or even vegetation can create the appearance of static on the interferogram. This is why some regions like the Sierra Nevada are difficult to get clear interferograms because of seasonal snow that obscures radar.

Data from GPS stations was used to get better local resolution of aquifers within a local area. These GPS stations are buried several meters in sturdy rock so that "poroelastic effects" or measurements in height due to moist soil, don't skew the data. The data was then corrected using the Seasonal Trend Loess (STL) method, which is a type of mathematical analysis using

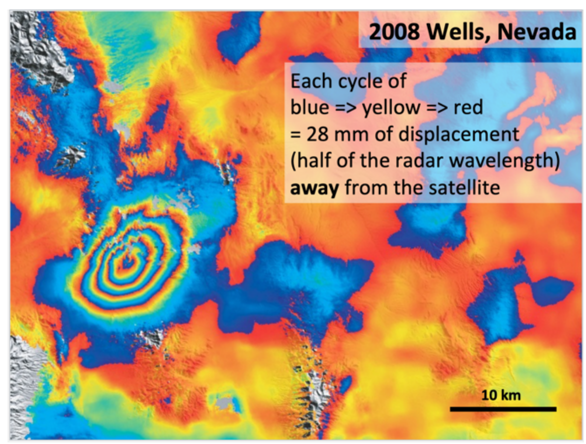


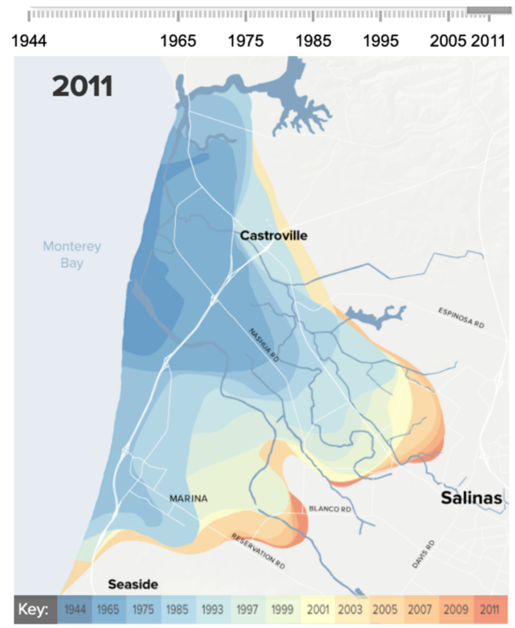
Figure 2: Example of an interferogram used for earthquake fault zones. Interferograms can also be used to show land rising and falling from groundwater over pumping.

Green's function to process signals having some noise or unwanted signal mixed in. The STL method takes the signal measured at the GPS sensors and separates it into the three signals representing the noise and a signal of interest to the person analyzing the data.

Corrections were made to the GPS data including Seasonal Trend Loess Method, a signal processing method that takes signal as shifts in height from the GPS stations and reduces it to the three sources on the surface of the Earth that are contributing to the surface deformation: Seasonality, Trend and Loess (Borsa, Agnew and Cayan). The other method And the latter

Good monitoring of groundwater levels using inSAR and enforcement can result in some aquifers being recharged (Borsa, Agnew & Cayan, 2019). Although, GPS stations can provide a lot of detail for small local areas, they cannot provide as high detail for larger areas. Borsa's study used a "checkerboard test" to measure the spatial resolution at 200 to 300 kilometers (Borsa, Agnew & Cayan, 2019).

Satellite data from GRACE has also been used to make recommendations for groundwater management. However, due to the limitations of tools for groundwater measurement, including GRACE available and reliable data is difficult to find in most regions in general, but



Source: Monterey County Water Resources Agency

Figure 3: : Over pumping of aquifers can lead to salt water intrusion. The most common solution is to create a fresh water wall (Moran, Choy and Sanchez, 2014).

"even in highly developed agricultural areas, such as the Central Valley of California" groundwater users are not required to provide data of their well use (Vasco, Farr, Jeanne, Doughty & Nico 2019). To date, domestic, business and government users of water wells are not required to provide records of groundwater usage to public agencies and the resolution of GRACE is not yet wide enough to provide enforceable data for these agencies (Vasco, Farr, Jeanne, Doughty & Nico 2019).

The severe drought and over pumping of aquifers has led to increased conflicts between businesses and city governments (Moran, Choy & Sanchez, 2014). According to the California Public Utilities Commission, the State energy budget for pumping groundwater during summer has exceeded that of the State Water Project, Central Valley Project and Colorado River Aqueduct combined. Over pumping in the Monterey Bay has seen saltwater intrude farther inland. (Moran, Choy & Sanchez, 2014).

By taking steps to diversify water sources, regulating new wells and monitoring with inSAR, city governments that have cooperated with recommendations for groundwater management have reduced or halted losses in groundwater (Moran, Choy & Sanchez, 2014). Between 1934 and 1967, land in the Santa Clara Valley had dropped 13 feet due to over pumping, and after supplementing water demand to include surface water and monitoring they halted the subsidence of their land (Moran, Choy & Sanchez, 2019). However, it's important to keep in mind that not all aquifers can recharge within a human time-frame.

If recommendations for groundwater management are ignored, prolonged droughts combined with bad management will lead to worsened water quality and reliability. Aquifers that have been over pumped have measured increased concentrations of nitrates, synthetics, salts and petroleum products that have forced governments to shut wells down (Borsa, Agnew & Cayan, 2019). If actions are not taken, quality and access to groundwater will decrease, as aquifers may not be able to be recharged within a human timescale.

Groundwater represents our second largest source of freshwater besides glaciers. Therefore, protecting it is vital for businesses, communities and agriculture. Satellites, like NASA's GRACE use radar techniques like inSAR to survey groundwater by detecting changes in surface level. While GRACE and other tools for monitoring groundwater have their limitations, hopefully future satellite designs will improve on the spatial resolution needed to provide public agencies data that is enforceable and makes users accountable.

Citations

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