**Central Valley Water Resources**

*Improving California Groundwater Assessments using GRACE and InSAR Datasets for Water Resource Management*

**Project Team**

***Project Team:***

Forrest Corcoran (Project Lead)

Marissa Dudek

James Kitchens

Patrick Saylor

***Advisors & Mentors:***

John T. Reager (NASA Jet Propulsion Laboratory, California Institute of Technology)

Zhen Liu (NASA Jet Propulsion Laboratory, California Institute of Technology)

Kyra Kim (NASA Jet Propulsion Laboratory, California Institute of Technology)

**Project Overview**

***Project Synopsis:*** This project used NASA’s Gravity Recovery and Climate Experiment (GRACE), Interferometric Synthetic Aperture Radar (InSAR), and in-situ data from groundwater monitoring wells and Geographic Positioning Systems (GPS) to determine groundwater depletion and land surface subsidence in California’s Central Valley. The Central Valley is one of the most productive agricultural regions in the world and relies heavily on groundwater for irrigation, particularly during major drought periods. These results served as reliable data for groundwater change and subsidence in sub-basins of the Central Valley where well and GPS data are sparse or unreliable.

***Abstract:***

California’s Central Valley is one of the most productive agricultural areas in the world, producing approximately $20 billion in crops annually. The recent California droughts of 2007-2010 and 2011-2017 resulted in increased groundwater pumping in the Central Valley to adequately irrigate farmland. Overdrafting of the Central Valley aquifer results in groundwater depletion, land subsidence, and permanent loss of groundwater storage. In 2014, depletion of groundwater led the state of California to enact the Sustainable Groundwater Management Act (SGMA), requiring critically overdrafted, high, and medium priority sub-basins to reach sustainable levels of groundwater pumping and recharge by 2042. SGMA allows local Groundwater Sustainability Agencies the authority to create Groundwater Sustainability Plans at the sub-basin level. To assist California’s Department of Water Resources, this project quantified groundwater change and land subsidence in Central Valley sub-basins with sparse or unreliable well and GPS data. This was done using NASA’s Gravity Recovery and Climate Experiment (GRACE), GRACE Follow-On (GRACE-FO), and interferograms derived from Sentinel-1 C-band Synthetic Aperture Radar (C-SAR) and Advanced Land Observing Satellite 2 (ALOS-2) Phased Array L-band Synthetic Aperture Radar 2 (PALSAR-2). Time series of the GRACE and InSAR data were compared with well and GPS data in data-dense sub-basins to determine the feasibility of these datasets for groundwater storage and subsidence monitoring. We found that GRACE and InSAR data are effective tools for determining groundwater change and land subsidence and can be used on their own to monitor sub-basins in the absence of well and GPS data.

***Keywords:***

remote sensing, groundwater, subsidence, GRACE, InSAR, time series

***National Application Area Addressed:*** Water Resources

***Study Location:*** Central Valley, CA

***Study Period:*** January 2003 to December 2019

***Community Concerns:***

* California’s Central Valley is one of the most productive agricultural regions in the world, producing $20 billion across 250 different crops annually and accounting for 17% of all United States irrigated agricultural land.
* Overdrafting of the Central Valley aquifer has led to groundwater depletion, land subsidence, and permanent loss of groundwater storage space.
* The current system of in-situ data collection varies in spatial and temporal continuity as well as reliability across the Central Valley, limiting actionable information needed to develop sustainability plans.

***Project Objectives:***

* Determine the feasibility of measuring groundwater storage change and land subsidence across the Central Valley using Earth observations
* Conduct a time series analysis of groundwater storage change and land subsidence for medium and high priority sub-basins
* Provide actionable data on groundwater storage change and land subsidence to the California Department of Water Resources (DWR) for sub-basins with sparse or unreliable in-situ data

**Partner Overview**

***Partner Organizations:***

|  |  |  |  |
| --- | --- | --- | --- |
| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **California Department of Water Resources, Southern Region Office** | Timothy Ross, Ph.D., Senior Engineering Geologist, SRO Section Lead; Jack Tung, Senior Engineering Geologist | End User | Yes |
| **California Department of Water Resources, North Central Region Office** | Bill Brewster, Senior Engineering Geologist, NCRO Section Lead | End User | Yes |
| **California Department of Water Resources, South Central Region Office** | Mike McKenzie, Senior Engineering Geologist; SCRO Section Lead | End User | Yes |
| **California State University, Los Angeles** | Charles Hays, Ph.D., Lecturer;  Jingjing Li, Ph.D., Assistant Professor | Collaborator | No |

***Decision-Making Practices & Policies:***

In 2014, California Governor Jerry Brown signed into law the Sustainable Groundwater Management Act (SGMA) in response to the depletion of groundwater and land subsidence caused by overdrafting of the Central Valley aquifer during one of the most intense droughts in California history, which lasted from December 27, 2011 to March 5, 2019. This legislation empowered local GSAs in high and medium priority sub-basins to enforce various measures with the goal of balancing aquifer pumping and recharge by 2042. The California Department of Water Resources (DWR) currently utilizes in-situ data from wells and GPS stations to confirm that GSAs are meeting the goals set by their sub-basin level GSPs. However, this data varies in spatial density and reliability from sub-basin to sub-basin.

***Project Benefit to End User:***

This project will provide groundwater storage change and land subsidence information to the California DWR in order to supplement the in-situ data currently in use. This information will be useful to the DWR in determining the compliance of medium and high priority GSAs with the SGMA legislation, particularly those in the outlying, rural sub-basins where in-situ data is scarce or unreliable.

**Earth Observations & End Products Overview**

***Earth Observations:***

|  |  |  |
| --- | --- | --- |
| **Platform & Sensor** | **Parameter** | **Use** |
| **GRACE-FO** | Groundwater storage | GRACE-FO data downscaled by Goddard Space Flight Center using the North American Land Data Assimilation System (NLDAS) will be used to measure groundwater storage changes. |
| **GRACE** | Groundwater storage | GRACE data downscaled by Goddard Space Flight Center using the North American Land Data Assimilation System (NLDAS) will be used to measure groundwater storage changes. |
| **Sentinel-1 C-SAR** | InSAR | Sentinel-1 C-SAR was used by JPL to create InSAR. This InSAR data will be used to measure land subsidence. |
| **ALOS-2 PALSAR-2** | InSAR | ALOS-2 PALSAR-2 was used by JPL to create InSAR data. This InSAR data will be used to measure land subsidence. |

***Ancillary Datasets:***

* US Geological Survey (USGS) National Water Information System (NWIS) – Dataset recording national groundwater levels over time used to demonstrate usefulness of GRACE dataset in quantifying groundwater storage
* USGS Groundwater Level – Dataset recording groundwater levels across the state of California used to demonstrate usefulness of GRACE dataset in quantifying groundwater storage
* California DWR Continuous and Periodic Groundwater Wells – Dataset recording groundwater levels across the state of California used to demonstrate usefulness of GRACE dataset in quantifying groundwater storage
* University Navigation Satellite Timing and Ranging Consortium (UNAVCO) GPS/Global Navigation Satellite System (GNSS) – Dataset recording continuous ground latitude, longitude, and elevation at a mm scale at various points across the world and used to demonstrate usefulness of InSAR dataset in quantifying land subsidence
* University of Nevada Reno (UNR) Geodetic Library GPS – Dataset recording continuous ground latitude, longitude, and elevation at a meter scale at various points across the world used to demonstrate usefulness of InSAR dataset in quantifying land subsidence

***Software & Scripting:***

* Esri ArcGIS Desktop 10.6 – Data manipulation and map production
* Esri ArcGIS Pro – Data manipulation and map production
* Quantum GIS 3.4 – Data manipulation and map production
* Python 3.7 – Data manipulation and visual creation

***End Products:***

|  |  |  |  |
| --- | --- | --- | --- |
| **End Products** | **Earth Observations Used** | **Partner Benefit & Use** | **Software Release Category** |
| **Groundwater Loss and Subsidence Maps** | GRACE  GRACE-FO  Sentinel-1 C-SAR  ALOS-2 PALSAR-2 | The partners can use the maps to contextualize groundwater storage and land subsidence change across the sub-basins. | I |
| **Time Series Analysis of Sub-basin Groundwater Loss and Subsidence** | GRACE  GRACE-FO  Sentinel-1 C-SAR  ALOS-2 PALSAR-2 | The partners can use the time series to contextualize the current trend in groundwater storage and land subsidence across the sub-basins. | I |
| **Visualization of In-situ and Remotely sensed Observations**  **(VIRGO)** | GRACE  GRACE-FO  Sentinel-1 C-SAR  ALOS-2 PALSAR-2 | The partners can use this software product to recreate the team’s analysis, incorporate new data as it becomes available, and visualize the results of the analysis. | III |

**Project Handoff Package**

***Transition Plan:*** The team provided the end products to the partners during a Week 9 virtual handoff meeting which included a detailed presentation of the team’s methods and findings.

***Software Release Plan:*** The partners have been informed of the waiting period associated with software release. Given that the 2019 annual reports for all GSAs were submitted shortly before the conclusion of this project, the partners anticipate the VIRGO tool will greatly improve their capacity to accurately monitor groundwater storage change and land subsidence leading up to the 2020 annual report.

***Team POC:*** Forrest Corcoran, fpcorcoran17@gmail.com

***Software Release POC:*** James Kitchens, kitchensjn@gmail.com

***Partner POC:*** Bill Brewster, Bill.Brewster@water.ca.gov

***Handoff Package:***

* Groundwater Loss and Subsidence Maps
* Time Series Analysis of Sub-basin Groundwater Loss and Subsidence
* VIRGO Software Package (following software release)
* Technical Report
* Poster
* Presentation

**References**

Amelung, F., Galloway, D. L., Bell, J. W., Zebker, H. A., & Laczniak, R. J. (1999). Sensing the ups and downs of Las Vegas: InSAR reveals structural control of land subsidence and aquifer-system deformation. *Geology*, *27*(6), 483-486.

Liu, Z., Liu, P., Massoud, E., Farr, T.G., Lundgren, P., & Famiglietti, J. S. (2019). Monitoring groundwater

change in California’s Central Valley using Sentinel-1 and GRACE observations. *Geosciences*, *9*(10),

436.

Miro, M., & Famiglietti, J. (2018). Downscaling GRACE remote sensing datasets to high-resolution groundwater storage change maps of California’s Central Valley. *Remote Sensing*, *10*(1), 143.

Sustainable Groundwater Management Act (2014). SB-1168 Groundwater (Pavely), AB-1739 Groundwater management (Dickinson), SB-1319 Groundwater (Pavely), State of California. Available at <https://water.ca.gov/Programs/Groundwater-Management/SGMA-Groundwater-Management>