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Advancing Water Resource Assessment with Insar Data and Subsidence Models

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Summary

Over the past three decades, Interferometric Synthetic Aperture Radar (InSAR) has grown from a tool for monitoring earthquakes and other massive signature deformation events to tracking the subtle, slow deformation processes associated with changes in groundwater storage. Improvements in time-series processing and noise reduction, as well as improved models of deformation, have enabled this advancement. InSAR has proven to be a valuable tool for characterizing elastic deformation in regions experiencing little long-term storage loss, as well as inelastic deformation in over-stressed aquifers.

Introduction

Rosemary Knight's research group has contributed to advancements in using InSAR to study groundwater systems. Starting in roughly 2010, her group began investigating the relationship of groundwater levels with InSAR-derived land deformation in the San Luis Valley, Colorado, ultimately developing a linear relationship between the two in elastically deforming regions (Reeves et al., 2011; Reeves et al., 2014; Chen et al., 2016; Chen et al., 2017). Some key findings from these studies were that InSAR could be used to temporally interpolate measurements of groundwater levels once calibrated to existing measurements, thus extending the record of groundwater levels; that there is typically a time lag on the order of several tens of days between changes in groundwater levels and ground deformation, due to the delayed drainage of clay layers; and that InSAR data over agricultural regions, where most deformation due to groundwater use occurs, can be greatly improved after identifying stable, coherent pixels along roads, buildings, and un-vegetated regions surrounding fields.

Next, her group evaluated the prevalence of inelastic deformation in the Central Valley of California, finding that the vast majority of subsidence occurring there was permanent (Smith et al., 2017). The approach developed in this paper made use of geologic and hydrologic datasets to determine how much of the aquifer was likely to be deforming, and whether inelastic or elastic processes better explained the observed deformation. One of the most significant contributions her group has made to the InSAR community is developing tools and models to integrate InSAR data with other near-surface geophysical datasets, such as airborne electromagnetic methods that provide information on subsurface structure (Smith and Knight, 2019). This approach enabled an improved understanding of where deformation was occurring in the subsurface, and also demonstrated that coupling electromagnetic and deformation models into a common inversion framework reduced uncertainty in both inversions. Coupling these datasets in process-based models allows for more robust groundwater evaluation and improved understanding of the mechanisms driving land subsidence.

Impact

Rosemary's group continues to study the complex processes driving land subsidence and relating them to groundwater systems and other geophysical datasets. In addition, her work has contributed to increased interest in using InSAR to study groundwater systems within the broader community. The following provides a non-comprehensive summary of some recent advances within the community to improve the capabilities of InSAR to study groundwater systems.

Zhang and Burbey (2016) demonstrated the utility of deformation data for improving groundwater model calibration. Alghamdi et al. (2020) and Boni et al. (2020) independently developed 3D groundwater flow and deformation models to improve aquifer characterization. Chaussard et al. (2014) and Chaussard and Farr (2019) built on the work of Reeves (2011) by using principal component analysis to isolate different components of the deformation signal and relate them to groundwater levels and aquifer properties.

Smith and Li (2021) developed an approach to account for elastic and inelastic deformation components in a process-based model with limited groundwater level data, advancing the use of InSAR for groundwater level characterization in inelastically deforming regions. Smith et al. (2021) also developed an approach to estimate the depth of deformation using nested wells. They also developed an approach to generalize subsidence processes and predict subsidence at a larger scale (western United States) than had been previously capable (Smith and Majumdar, 2021). Shirzaei et al. (2018) and Shirzaei et al. (2021) investigated the impact of land subsidence on relative sea level rise in coastal regions, finding that in many regions, coastal subsidence outpaces global sea level rise, adding to the threat of flooding and saltwater intrusion.

The timing of deformation can be driven by a number of factors, including delayed drainage of water from clays, groundwater pumping, and recharge. Recent investigations on the spatio-temporal patterns of deformation have shown that InSAR can be used to characterize recharge (Neely et al., 2021).

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Conclusions

Many challenges in using InSAR data to effectively study groundwater systems remain, particularly in integrating complex deformation processes more directly into groundwater models, producing high-quality InSAR data in regions with dense vegetation or large amounts of tropospheric water vapor, and detecting deformation signals from unconfined aquifers, which typically deform at a much lower magnitude than confined aquifers (Smith and Majumdar, 2021).

As technological advances and the launch of new satellites improve our ability to sense deformation of the earth with InSAR, the community is presented with new or more advanced tools to address these and other pressing challenges. The work and leadership of Rosemary Knight has improved the community's ability to address many of these issues, and helped to catalyze a new generation of scientists to tackle these challenges.

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