SCIENTIFIC REPORTS

OPEN

Time-varying land subsidence detected by radar altimetry: California, Taiwan and north China

Received: 04 November 2015
Accepted: 31 May 2016
Published: 21 June 2016

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Contemporary applications of radar altimetry include sea-level rise, ocean circulation, marine gravity, and icesheet elevation change. Unlike InSAR and GNSS, which are widely used to map surface deformation, altimetry is neither reliant on highly temporally-correlated ground features nor as limited by the available spatial coverage, and can provide long-term temporal subsidence monitoring capability. Here we use multi-mission radar altimetry with an approximately 23 year data-span to quantify land subsidence in cropland areas. Subsidence rates from TOPEX/POSEIDON, JASON-1, ENVISAT, and JASON-2 during 1992–2015 show time-varying trends with respect to displacement over time in California's San Joaquin Valley and central Taiwan, possibly related to changes in land use, climatic conditions (drought) and regulatory measures affecting groundwater use. Near Hanford, California, subsidence rates reach 18 cm yr^{-1} with a cumulative subsidence of 206 cm, which potentially could adversely affect operations of the planned California High-Speed Rail. The maximum subsidence rate in central Taiwan is 8 cm yr^{-1}. Radar altimetry also reveals time-varying subsidence in the North China Plain consistent with the declines of groundwater storage and existing water infrastructure detected by the Gravity Recovery And Climate Experiment (GRACE) satellites, with rates reaching 20 cm yr^{-1} and cumulative subsidence as much as 155 cm.

Land subsidence is caused by natural and/or anthropogenic processes including subsurface fluid extraction, underground mining, drainage of organic soils, sediment compaction/load in coastal regions, and permafrost degradation[1,2]. Globally, in regions with irrigated agriculture and rapid population growth, groundwater extraction typically is the principal cause of subsidence[1,3,4]. Subsidence is a hazard that increases flood risk, causes damages to man-made structures and cultural heritages in low-lying regions, exacerbates sea level rise in coastal regions, and results in significant socio-economic distress[1,5]. Standard tools for monitoring subsidence are precision leveling, Global Navigation Satellite System (GNSS), interferometric synthetic aperture radar (InSAR) and borehole extensometers[1,4,6]. Satellite gravimetry from the Gravity Recovery And Climate Experiment (GRACE[7]) can deduce groundwater mass changes at a coarse spatial resolution (350 km or greater). Currently, a large percentage of lands including croplands is threatened by subsidence, erosion and desertification which are affecting global food safety[8]. By 2050, an estimated two billion more people will need to be fed, increasing demand on agricultural land use for improved rates of food production[9]. For irrigated croplands dependent solely on groundwater or on the conjunctive use of surface water and groundwater, high rates of groundwater extraction can lead to unsustainable cropland practices owing to groundwater depletion. These practices can result in undesirable effects including irreversible aquifer-system compaction and land subsidence in susceptible aquifer systems, which can be exacerbated during droughts[1,2,10].

This study explores the use of satellite radar altimetry for improved monitoring of subsidence in three irrigated cropland areas: California's San Joaquin Valley (SJV), central Taiwan (CT), and the North China Plain

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