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# Land subsidence in Liaohe River Delta, China due to oil and gas withdrawal, measured from multi-geometry InSAR data

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Liaohe River Delta (LRD) is one of the major centers for hydrocarbon production, agriculture, and fisheries in Northeastern China. Liaohe Oilfield, located in the deltaic region, is China's third-largest oilfield with an annual production capacity of 10 million tons of crude oil and 800 million $m^3$ of natural gas. Since its operation in 1970, Liaohe Oilfield had produced more than 480 million tons of crude oil and 88 billion $m^3$ of natural gas by the end of 2019.

Pore pressure drawdown due to oil/gas production has resulted in reservoir compaction and surface subsidence above the reservoir. This compaction and subsidence can cause significant damages to production and surface facilities. Main concerns are related to low-lying coastal areas in the context of eustatic sea-level rise (SLR), where land subsidence contributes to relative SLR and exacerbates flooding hazards. In addition, regional and local land subsidence have combined with global SLR to cause wetland loss in the LRD.

Our main aim in this study is to investigate time-dependent land subsidence induced by reservoir depletion in LRD, by analyzing Synthetic Aperture Radar (SAR) images from Sentinel-1 satellite. We retrieved vertical land subsidence and horizontal displacements through processing and merging multi-geometry images from two ascending and two descending tracks covering the area over the 2017 to 2021 time span. We observed significant local subsidence features in several active production oilfields, and the areal extent of subsidence is basically consistent with the spatial extent of production wells. The most prominent subsidence is occurring in the Shuguang oilfield. Due to reservoir depletion, it forms a land subsidence bowl in an elliptical shape with a major axis of ~6.3 km and a minor axis of ~3.2 km, and the maximum subsidence rate is exceeding 230 mm/yr. Because of the large depth $D$ relative to the areal extent $L$, that is, a relatively small ratio $L/D$, the displacement field caused by oil production is three-dimensional. An inward, symmetrical, east-west horizontal movement was observed around the subsidence bowl in Shuguang oilfield, with an average eastward movement rate of ~40 mm/yr and an average westward rate of ~30 mm/yr. This three-dimensional deformation is well reproduced by a cylindrical reservoir compaction/subsidence model.

In September 2021, a storm surge accompanied by heavy rainfall caused water levels to rise by 50-130 cm in Liaodong Bay, resulting in extreme flooding in oilfields along the coast. The most severe flooding hazard was occurring in the Shuguang oilfield with the highest land subsidence rate. Our new InSAR-derived surface subsidence associated with the oilfield operations raises the question of the potential impact of land subsidence on the flood severity. This work highlights the

importance of incorporating reservoir depletion-induced subsidence into flood management to ensure the security of the oil and gas industry along the coastal regions.