Combining Sentinel-1A/B InSAR and high-resolution topography in the study of coastal megacities

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Today, the joint phenomena of rapid urbanization and population growth has resulted in an increase in the number of cities of over 10 million inhabitants, or megacities, worldwide. While western megacities such as Los Angeles have been relatively stable in recent years, the developing world saw an increase from two to thirteen between 1975 and 2000 (http://www.igbp.net). In 2011, sixteen of the 23 global cities that fell into that category were coastal (UN-DESA 2012). Their growth is often coupled with unplanned urbanization and sprawl, with important effects on coastlines, demographics and ecosystems (Angel et al. 2011; Allison et al., 2016). The associated risk is exacerbated by anthropogenic coastal subsidence processes and sea-level rise due to climate change, potentially increasing inundation, flooding, storm surges and infrastructure damage. Ground deformation phenomena, either uplift and/or subsidence, can arise from volcanic and tectonic processes, hydrocarbon exploitation, groundwater pumping and shallow compaction of sediments, particularly along coastal deltas. A better understanding of the processes affecting coastal megacities can be achieved through the combination of satellite and ground-based measurements. Here we combine both high-resolution topography, in the form of optical digital surface models (DSMs), and differential interferometric synthetic aperture radar (DInSAR), to better characterize the effects of local and regional subsidence, coastal erosion, sea-level rise and urbanization in several megacities from around the developing world. DInSAR time series from Sentinel-1A/B images, coregistered to high-resolution DSMs, are used to constrain local and regional ground deformation, while those same DSMs can be used to better model inundation due to sea level rise.

High-resolution DSMs and DInSAR

Recent work suggests that high-resolution DSMs not only can provide important information for improved flood mapping and extent (Amante, 2018), they also can have been shown to improve pixel recovery in DInSAR processing in areas of moderate-to-high topography, thereby improving coherence and phase unwrapping and, ultimately, surface deformation estimates (McKee, Gonzalez and Tiampo, submitted, 2018).

Figure 1, below, shows a comparison of DInSAR results, for a 24-day time period (October 16 to November 9, 2017) using DSMs at different resolutions for a low-relief megacity, Mumbai, India. On the top are shown coherence plots (yellow is high coherence, blue is low), below are shown line-of-sight range increase. The yellow areas are the city of Mumbai itself. Resolution increases from left to right, as noted. The 30 m DSM is a Shuttle Radar Topography Mission (SRTM) DSM (https://gdex.cr.usgs.gov/gdex/); the 2 m optical DSM was created from Digital Globe optical images acquired for a NASA Sea-Level Rise project; the 10 m DSM was upsampled from the 2 m DSM.

Note that while the LOS signal is a function of atmospheric moisture (monsoonal) and the total amplitude is irrelevant, the coverage, pattern and amplitude of the fringes increases with increasing resolution, even in coastal city with relatively flat topography.

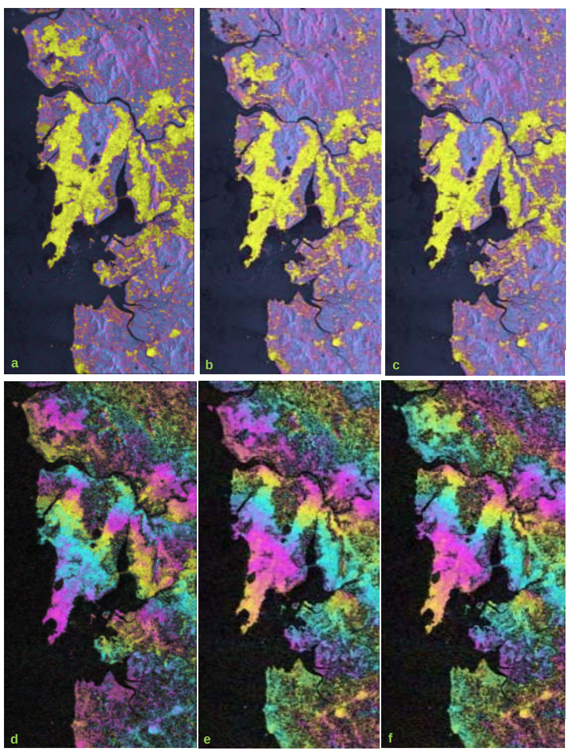


Fig. 1: Coherence (top) for DInSAR images for the time period October 16 to November 9, 2017, processed with DSMs at a) 30 m, b) 10 m and c) 2 m resolution. DInSAR LOS range change (bottom) for the same image pair, processed with d) 30 m, e) 10 m and f) 2 m DSM resolution.

Mumbai, India: DInSAR

Here we downloaded 72 Sentinel-1A/B SAR SLC (Single Look Complex) images acquired between February 2017 and January 2020 over the city of Mumbai from the Alaskan Satellite Facility (ASF) and processed all possible pairs using GAMMA software (Wegmüller et al., 2015), removing topography with the 2 m DSM. Below are shown two DInSAR image pairs from the 373 resulting pairs.

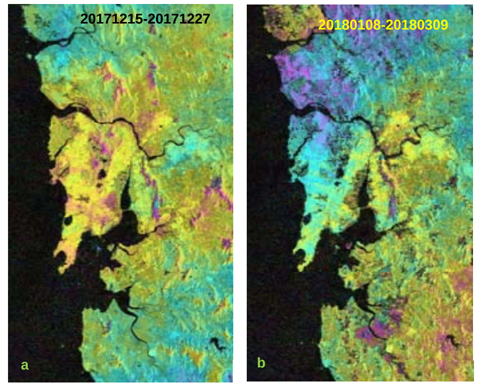


Fig. 2: DInSAR LOS displacements for Mumbai, India over a period of approximately a) 12 days and b) 48 days. Here, purple is stable, and yellow represents a maximum range increase of ~2 cm.

We selected 149 pairs with good coherence between February 2017 and January 2020 for input into a DInSAR time series using the MSBAS method (Samsonov and d'Oreye, 2012). The resulting analysis produces a map of the average velocity and individual time series at every point with good coherence. The resulting velocity map, in meters/year, is shown below, along with the time series at three locations. The reference location is shown by a purple star, a lava bedrock ridge in the city downtown. Note the persistent subsidence, relative to that point, that reaches 3 cm/year in the marshes surrounding the inlet to the east.

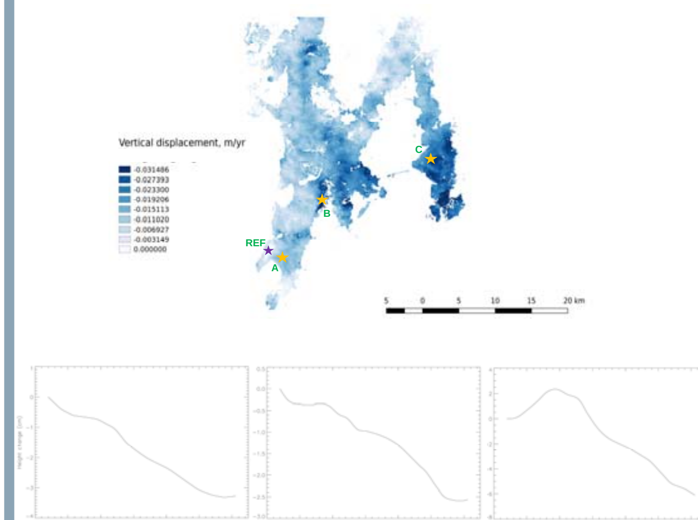
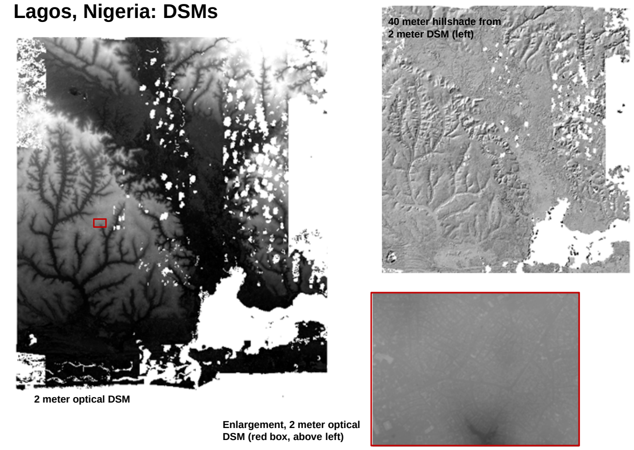


Fig. 3: a) Vertical displacement at Mumbai, India, February 2017 through January 2020. Motion is referenced to the purple star (REF). b) Time series at A (yellow star); c) Time series at B (yellow star); d) Time series at C (yellow star).

Lagos, Nigeria: DSMs



Lagos, Nigeria: DInSAR

For this study, we downloaded 7 Sentinel-1A and 1B SAR SLC images over the city of Lagos from ASF and again processed all possible pairs, although only for the F2 subswath, again removing topography with a 2 m Digital Globe optical DSM. Original images were acquired between December 2017 and September 2018. In the two images shown below, range increase, or subsidence, reaches a maximum rate of almost ~2 cm/year in regions along the low-lying coast.

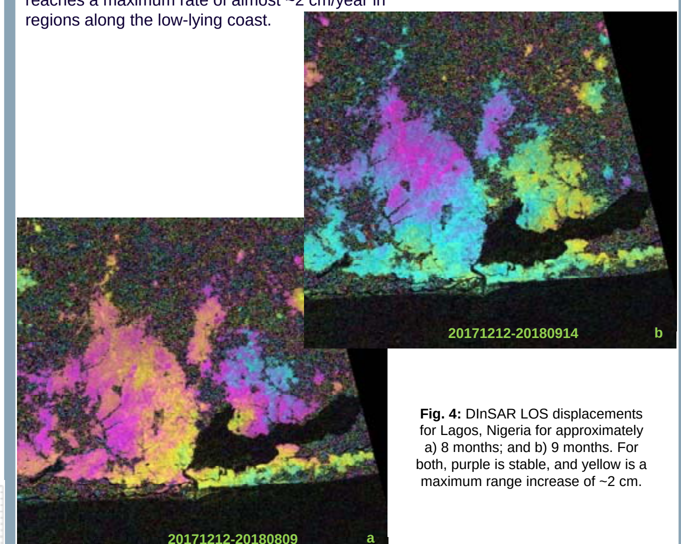


Fig. 4: DInSAR LOS displacements for Lagos, Nigeria for approximately a) 8 months; and b) 9 months. For both, purple is stable, and yellow is a maximum range increase of ~2 cm.

CONCLUSIONS & FUTURE WORK

- High-resolution DSMs can improve coherence, pixel recovery and fringe unwrapping in DInSAR images even in regions of relatively low topographic relief.
- Sentinel-1A/B data produces consistent, coherent DInSAR results over long temporal baselines in these coastal cities.
- Early results suggest that there is ongoing subsidence in both Lagos and Mumbai.
- Future work includes time series over these regions and other megacities.

ACKNOWLEDGEMENTS

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