Land Subsidence in Bangladesh

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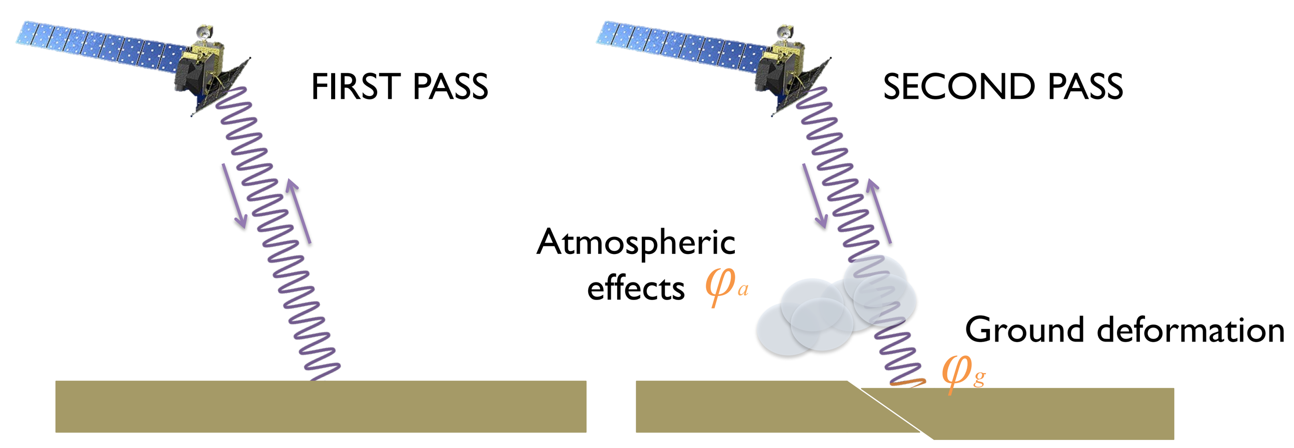
A delta under pressure

The Ganges-Brahmaputra Delta is formed by the confluence of the Ganges, Brahmaputra and Meghna Rivers, which together drain nearly two million square kilometers of Nepal, Bhutan, China (Tibet), India and Bangladesh [Kuehl et al., 2005]. Under pristine conditions, the large sediment supply of the this river system can compensate for both slow sea-level rise and natural land subsidence. The same may not be true for populated areas, however. Sluice gates and clay embankments throughout the delta have resulted in a 37% reduction in the number of distributary channels and may have reduced sedimentation [Syvitski et al., 2009]. It is therefore necessary to quantify the vertical dynamics of the delta with a high degree of precision, in order to identify areas of high compaction and subsidence, facilitate infrastructure and flood-management decisions, and shed light on the controls of vertical motion in a complex setting under pressure from rapid population growth. To that end, this study reconstructs subsidence rates in the eastern portion of the delta, covering more than 10,000 km^2 at a high spatial resolution of 100 m. The map was produced using Interferometric Synthetic Aperture Radar (InSAR) covering the period 2007 to 2011.

Measuring deformation with InSAR

Fig 1. Two – pass interferometric SAR (InSAR) utilizes the phase changes between repeat passes of a satellite-mounted Synthetic Aperture Radar (SAR) to measure ground deformation with mm-scale accuracy, if other factors remain the same (e.g. water vapor).



ALOS PALSAR					MODIS	
Date	Acquisition time (UTC)	Orbit	Mode	Frames	Acquisition time (UTC)	Precipitable water (cm)
2007 Dec 20	16:31:18	10147	FBS	450/460	16:50:00	1.5
2008 Feb 04	16:30:48	10818	FBS	450/460	17:00:00	2
2008 Mar 21	16:30:09	11489	FBS	450/460	15:35:00	3.5
2008 Dec 22	16:31:37	15515	FBS	450/460	19:35:00	2.5
2009 Feb 06	16:32:14	16186	FBS	450/460	17:00:00	1.5
2009 Dec 25	16:33:55	20883	FBS	450/460	16:50:00	1.5
2010 Feb 09	16:33:46	21554	FBS	450/460	17:00:00	2.5
2010 Dec 28	16:29:57	26251	FBS	450/460	16:50:00	2
2011 Feb 12	16:29:00	26992	FBS	450/460	17:00:00	2.5

Table 1. We control for all factors that can induce phase change – the most important factor is water vapor. I restrict the radar data to the driest days using MODIS L2 water vapor products.

Fig 2 (below). The nine SAR images were combined to produce 30 interferograms, or phase-change maps.

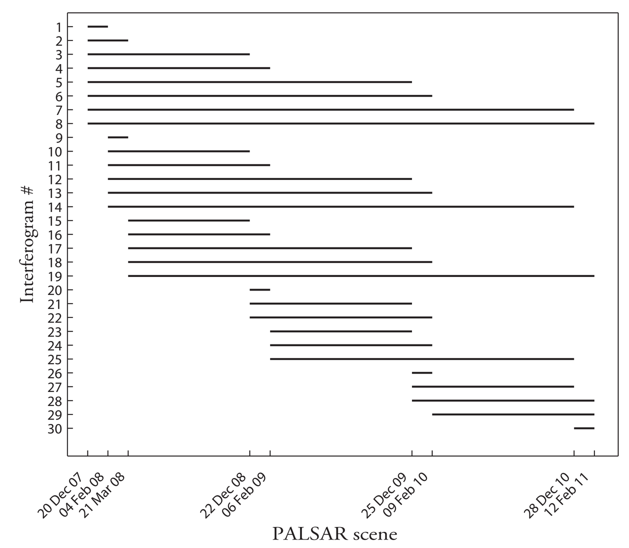
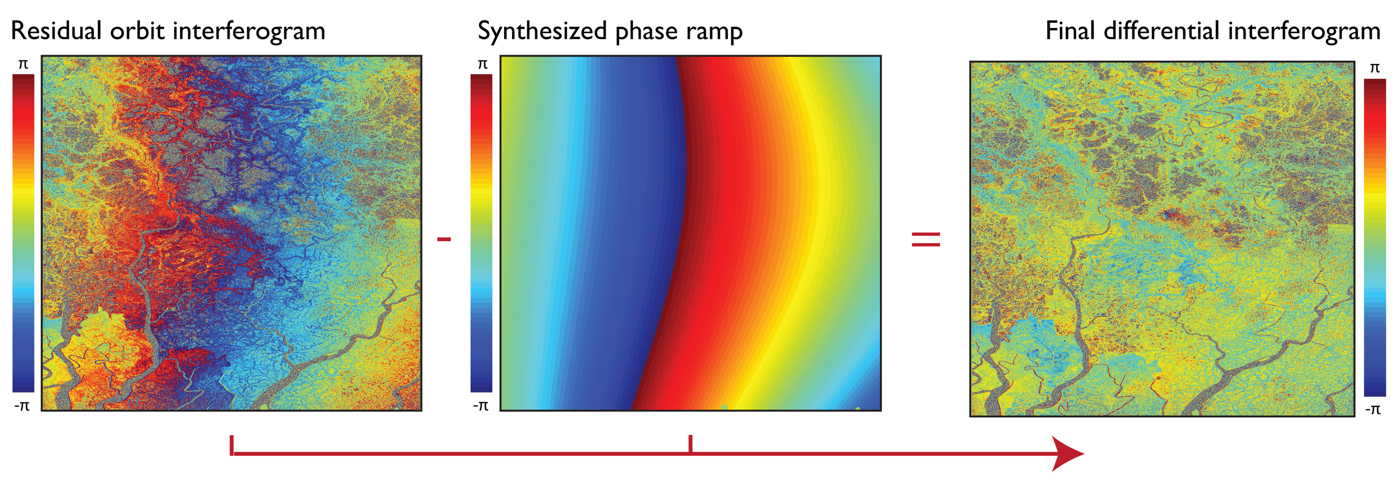


Fig 3. Orbital phase-ramp corrections make broad signals impossible to measure.



The Ganges-Brahmaputra Delta

Fig 4. The Ganges-Brahmaputra system drains most of the Himalayas and has built the largest delta in the world.

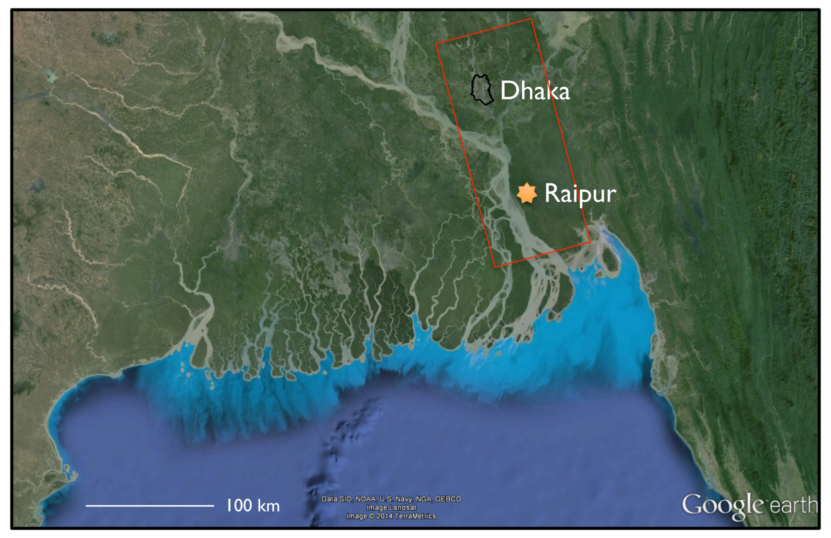


Fig 5. Red box indicates the study area; black outline shows the Dhaka metropolitan area. Star shows GPS device in Raipur used for calibration.

Challenges for InSAR close to the shore

Figs 6 & 7 (above): Dense vegetation at the shore can prevent the radar from reflecting off of the surface.

Fig 8 (right): hand-packed clay dikes may compact for years after construction, yielding false subsidence measurements. *Photo credit: Irina Overeem*

Subsidence rates in the delta range from 0 – 18+ mm/y

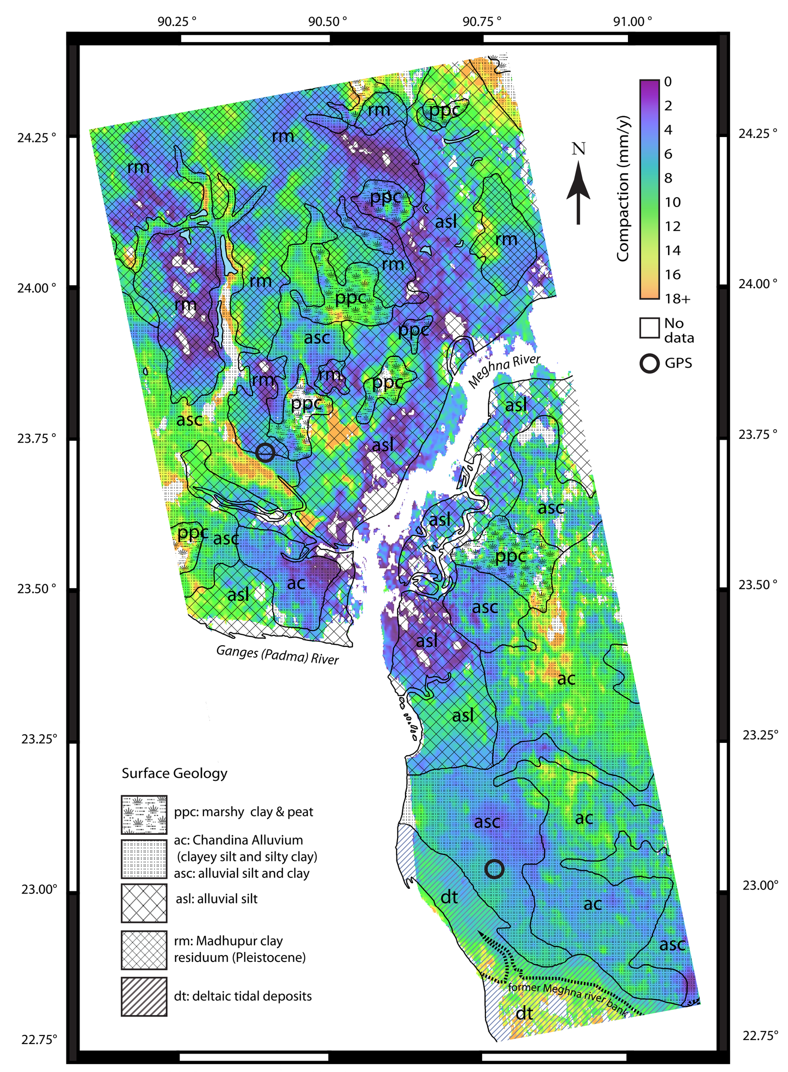


Fig 9 (left): InSAR-derived average subsidence rates show loose correspondence with surface geology and may reflect subsurface features.

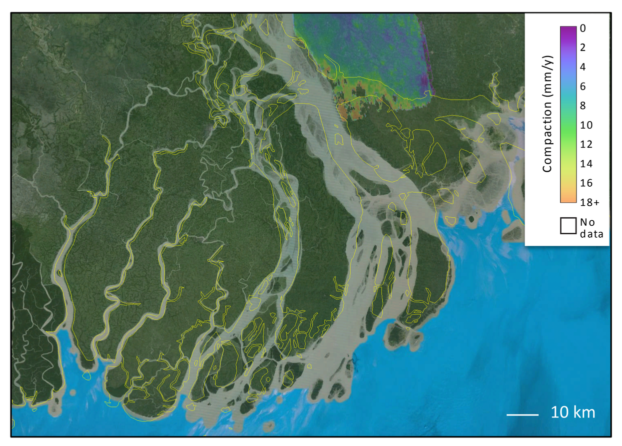


Fig 10. The coastline from 1944 shows a branch of the Meghna that filled with sediment during the 1950 Assam Earthquake. This newly deposited sediment is rapidly compacting; InSAR captured the boundary.

Subsidence in Dhaka: 0–10 mm/y

Fig 11. The Dhaka metro area is home to > 17 million people whose groundwater usage lowers the water table by 2.5 m/y. We therefore expected InSAR to show a cone of depression with highest subsidence in the city center. A GPS device (center) anchored on the roof of the geology building at the University of Dhaka provided a validation source for the InSAR measurements, which were calibrated with a second GPS device located 100 km away in the cityof Raipur. *Photo credits: Irina Overeem; Stephanie Higgins*

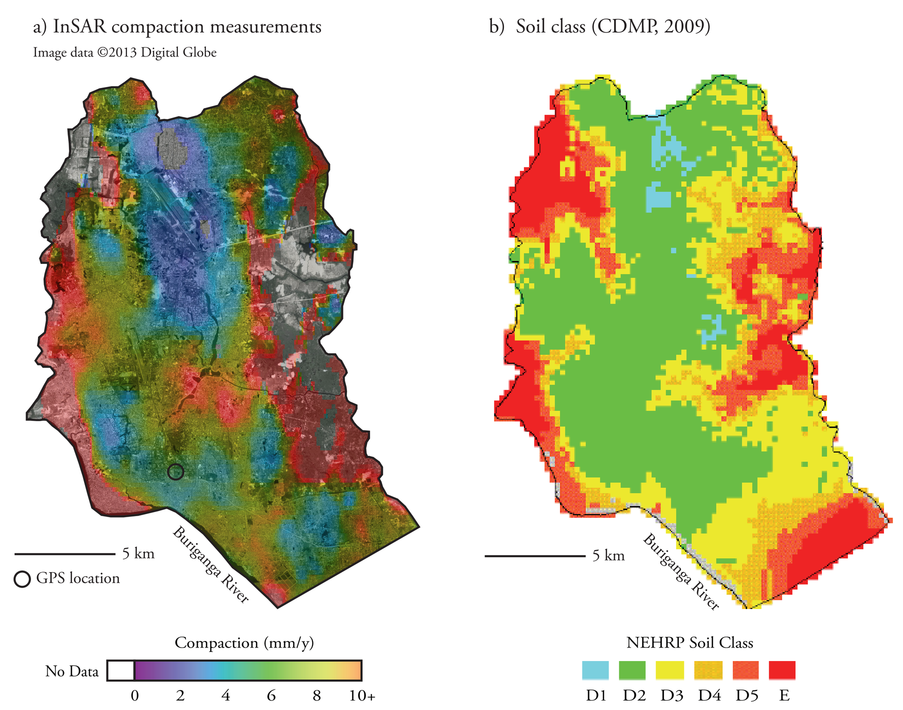
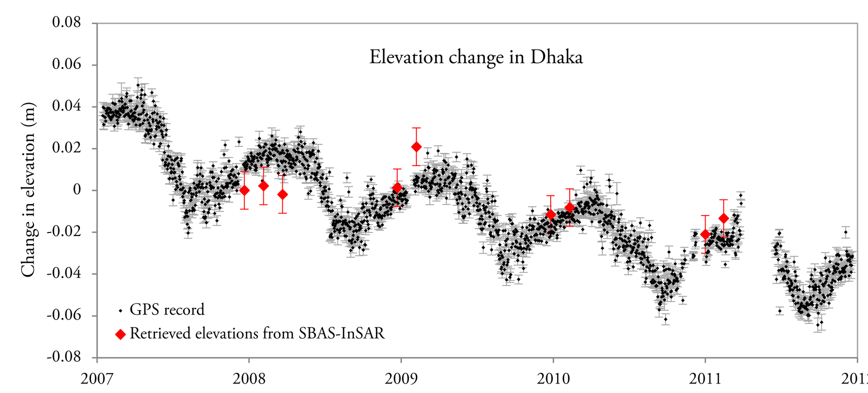


Fig 12. In fact, subsidence rates in Dhaka show strong correlation with surface soil class. Stiffer soils (red & orange) are compacting less quickly while looser soils (yellow, green and blue) are compacting more quickly. This suggests that the Pleistocene consolidated clays that characterize much of the region are mitigating the impacts of Dhaka's extreme groundwater usage.

Fig 13. The InSAR retrieval agrees well with the GPS record from the roof of the Geology building at the University of Dhaka. Note the annual fluctuations, which are due to flexure of the entire delta under the weight of annual monsoon floodwaters.



References

Higgins, S., Overeem, I., Syvitski, J. P. M., Steckler, M. S., Akhter, S. H., and Seeber, L., (2014), InSAR measurements of compaction and subsidence in the Ganges-Brahmaputra Delta, Bangladesh, Journal of Geophysical Research Earth Surface, *in press.*

Kuehl, S. A., Allison, M. A., Goodbred, S. L., and Kudrass, H., (2005), The Ganges-Brahmaputra Delta, in *River Deltas – Concepts, Models, and Examples, Special Publication No. 83,* edited by L. Giosan and J. Bhattacharya, pp. 413-424, Society for Sedimentary Geology (SEPM).

Syvitski, J. P. M., Kettner, A. J., Overeem, I., Hutton, E. W. H., Hannon, M. T., Brakenridge, G. R., Day, J., Vorosmarty, C., Saito, Y., Giosan, L., and Nicholls, R. J., (2009), Sinking deltas due to human activities, Nature Geoscience, 1, 173-176.

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