End-to-end Framework for Future Inundation Scenarios of Coastal Cities with High Resolution Digital Surface Models

Eduard R. Heijkoop[1,2], Michael J. Willis[2,3], R. Steven Nerem[1,2], Kristy F. Tiampo[2]

[1]Colorado Center for Astrodynamics Research [2]Cooperative Institute for Research in Environmental Sciences [3]Dept of Geosciences, Virginia Tech

Eduard.Heijkoop@colorado.edu | 2023 CIRES Rendezvous

University of Colorado Boulder

CIRES

1. Background

Approximately 10% of the world's population lives close by the sea, and many of these people live in regions where sea level is rising faster than the global average rate. Additionally, knowledge of local infrastructure is often sparse and out of date. We use commercial WorldView stereo imagery to produce high resolution digital surface models [1], which we co-register to ICESat-2 geolocated photons for improved vertical accuracy.
We then combine these DSMs with AR6 projections of local sea level change and measurements of vertical land motion to estimate future risk of inundation due to sea level rise.

2. Filtering ICESat-2 for Co-registration of DSMs

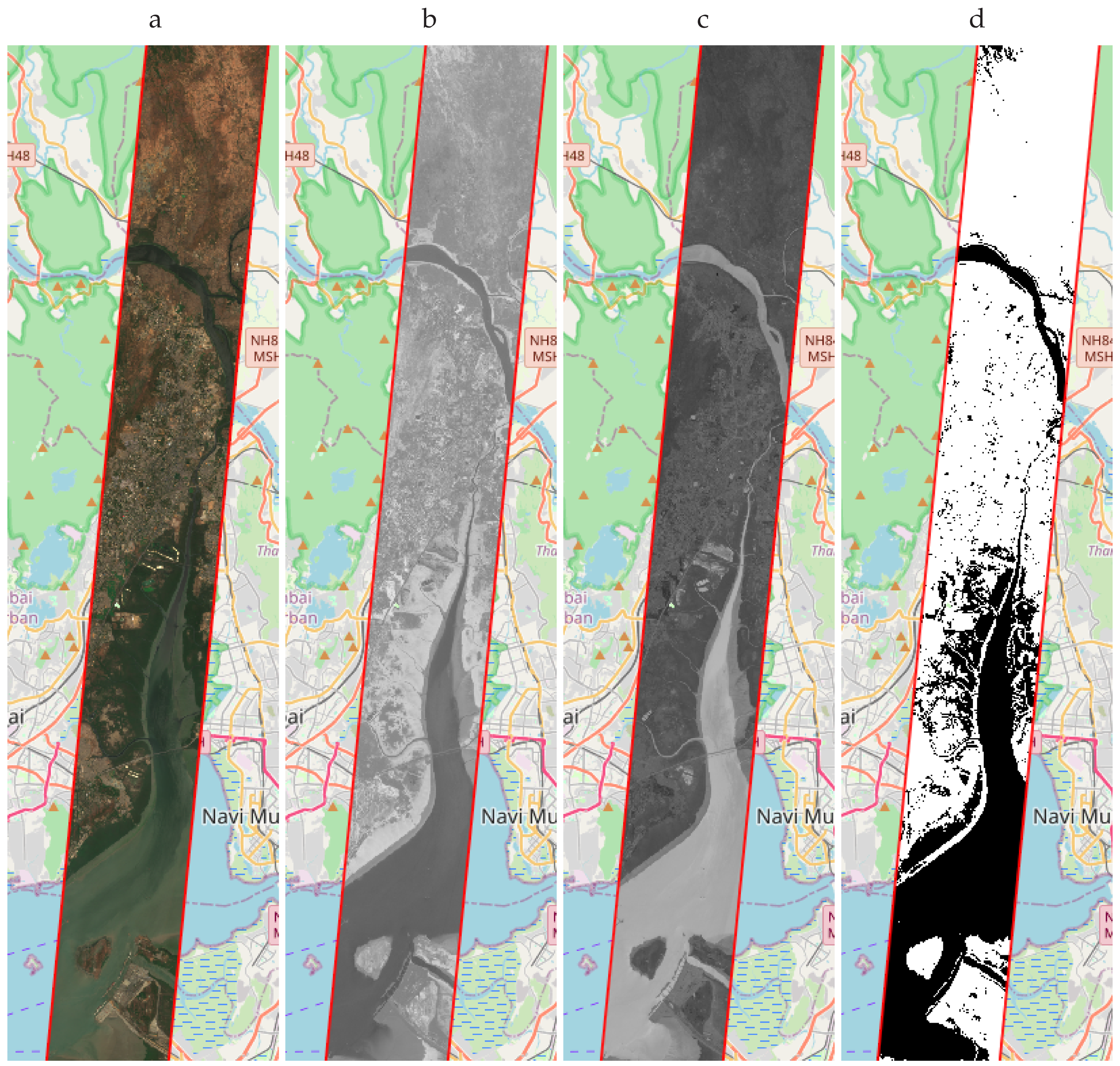

Figure 1: **a**. Sentinel-2 image (2019-03-14) over the extent of an ICESat-2 acquistion (2019-03-12) over Mumbai, India. The low temporal difference allows us to filter the ICESat-2 photons with the correct *in situ* conditions. **b**. Normalized Difference Vegetation Index (NDVI) obtained from the previous multispectral image. **c**. Augmented Normalized Difference Water Index (ANDWI) obtained from the same image. **d**. Mask obtained by thresholding the previous two indices, allowing for removal of ICESat-2 measurements over vegetation and surface water, which would otherwise increase the error with the digital surface model.

$$\text{NDVI} = \frac{\text{NIR} - \text{R}}{\text{NIR} + \text{R}} \tag{1}$$

$$\text{ANDWI} = \frac{\text{R} + \text{G} + \text{B} - \text{NIR} - \text{SWIR}_1 - \text{SWIR}_2}{\text{R} + \text{G} + \text{B} + \text{NIR} + \text{SWIR}_1 + \text{SWIR}_2} \tag{2}$$

Figures 1b and c show the NDVI and ANDWI over Mumbai, India, calculated with Equations (1) and (2), respectively. We use these indices to create a mask to filter out ICESat-2 photons over vegetated land and surface water, thereby improving the fit to the DSM.

3. Correcting DSMs with ICESat-2

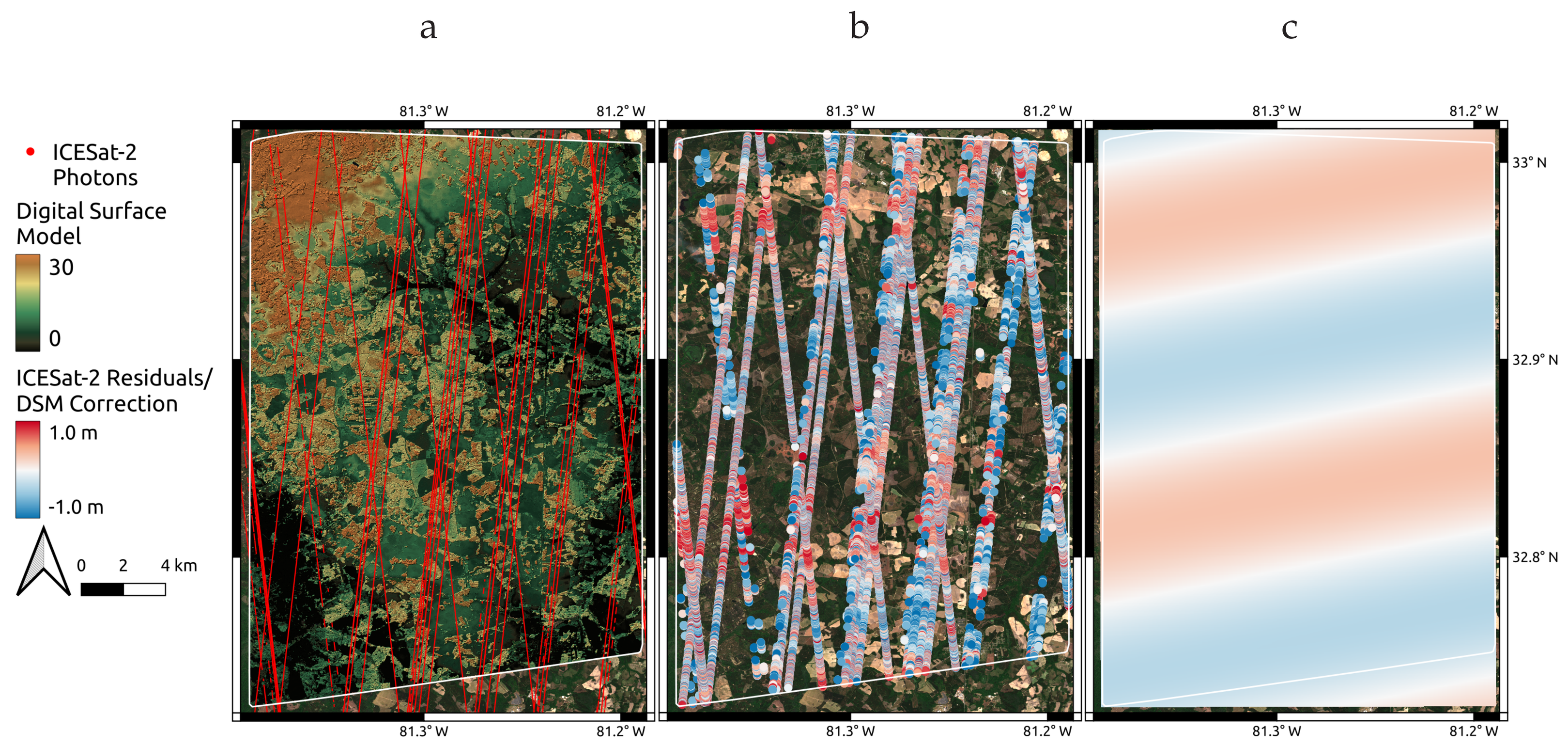

Figure 2: **a**. ICESat-2 coverage over the extent of a digital surface model near Savannah, Georgia. **b**. Remaining residuals after co-registration of the DSM to the ICESat-2 data. **c**. Surface fit to the residuals, which we use to correct the effect of jitter in our DSM.

After iteratively co-registering the DSM to the ICESat-2 photon cloud, we fit an oscillating surface to the residuals, shown in Figure 2, according to Equation (3).

$$\Delta h_{\text{jitter}} = A \sin\left(\frac{2\pi}{P}(y - y_0) + c\,(x - x_0)\right) k\frac{x}{x_0} \tag{3}$$

This reduces the RMSE w.r.t. ICESat-2 by approximately 10%, thereby improving the vertical accuracy of our DSMS, which is critical for inundation studies.

4. Projected Sea Level Rise

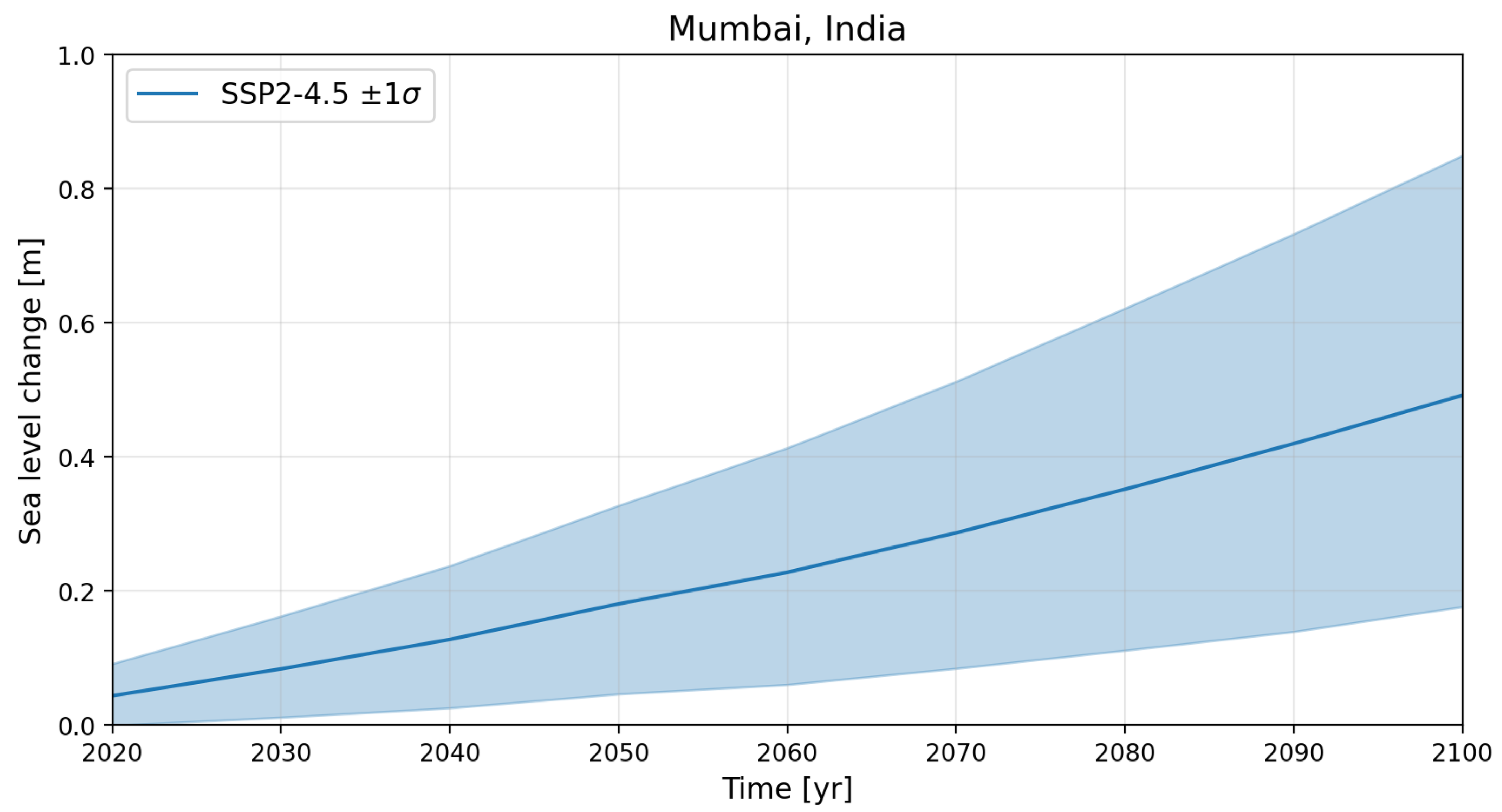

Figure 3: IPCC AR6 SSP2-4.5 projected sea level rise (w.r.t. 2005) off the coast of Mumbai, India between present day and the end of the century.

5. Results

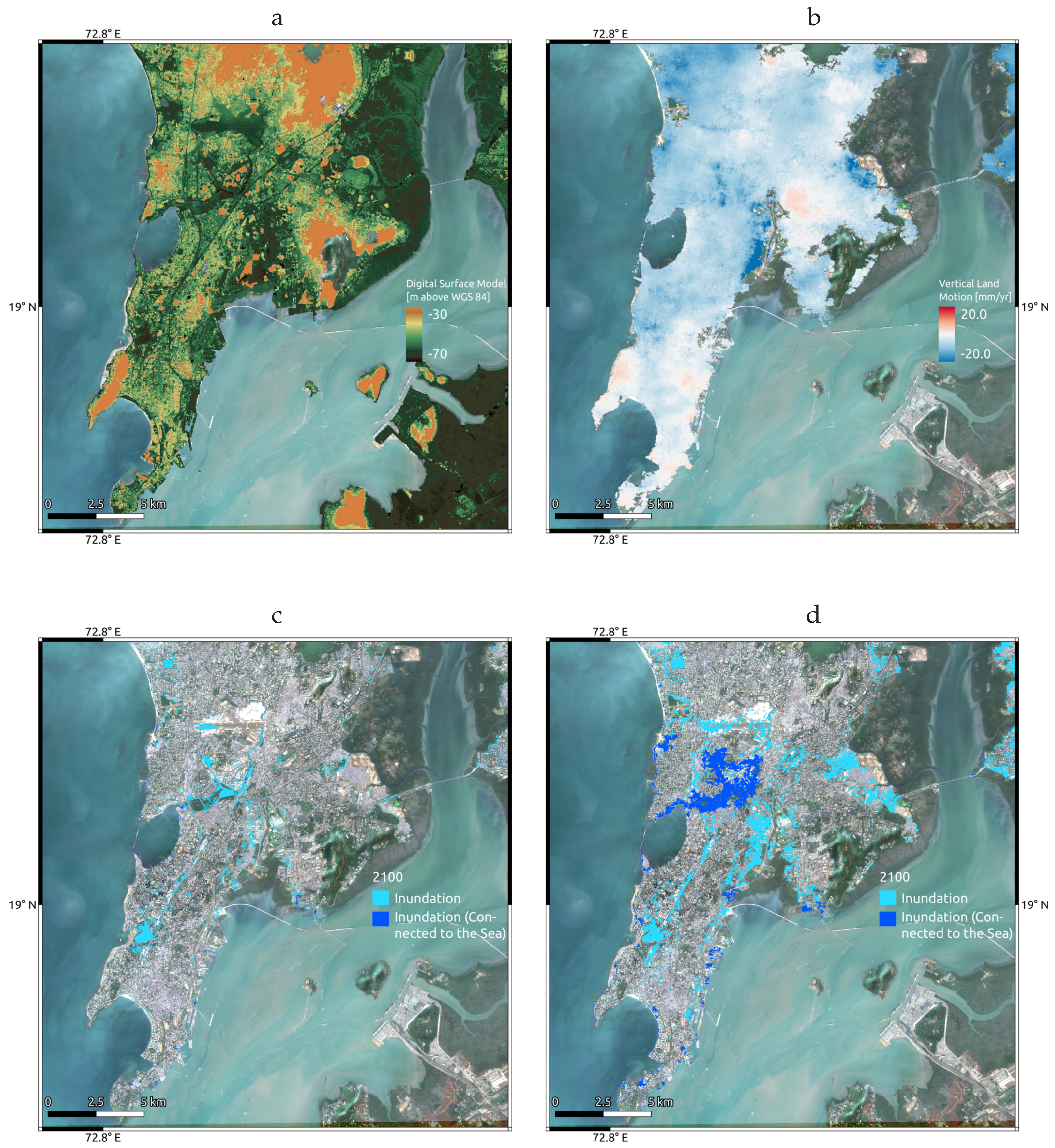

Figure 4: **a**. Digital surface model of Mumbai, India. **b**. Vertical land motion, derived from Sentinel-1 DInSAR. **c**. Projected inundation in 2100 using our DSM. **d**. Projected inundation in 2100 using SRTM.

We calculate inundated areas using Equation (4), propagating our DSM forward in time with vertical land motion rates derived from Sentinel-1 DInSAR.

$$I = \text{DSM}(t) < h_{\text{MSL}} + h_{\text{tide}} + h_{\text{SLR}} \tag{4}$$

6. References & Acknowledgements

[1] Noh, M. J., & Howat, I. M. (2015). Automated stereo-photogrammetric DEM generation at high latitudes: Surface Extraction with TIN-based Search-space Minimization (SETSM) validation and demonstration over glaciated regions. GIScience & remote sensing, 52(2), 198-217.
[2] Carrère, L., Lyard, F., Cancet, M., Guillot, A., & Picot, N. (2016, May). FES 2014, a new tidal model - Validation results and perspectives for improvements. In Proceedings of the ESA living planet symposium (pp. 9-13).
[3] Heijkoop, E. R., Willis, M., Nerem, R. S. & Tiampo, K. F. (2022, December). End-to-end Framework for Future Inundation Scenarios of Coastal Cities with High Resolution Digital Surface Models. In AGU Fall Meeting 2022. AGU.

This investigation was funded by the NASA Sea Level Change Team, the ICESat-2 Science Team and the IARPA Space-based Machine Automated Recognition Technique (SMART) contest.
Our DSMs are produced from DigitalGlobe stereo imagery, acquired through the NextView license.