SUPPLEMENTARY FILE

Surface Subsidence in Urbanized Coastal Areas: PSI Methods Based on Sentinel-1 for Ho Chi Minh City

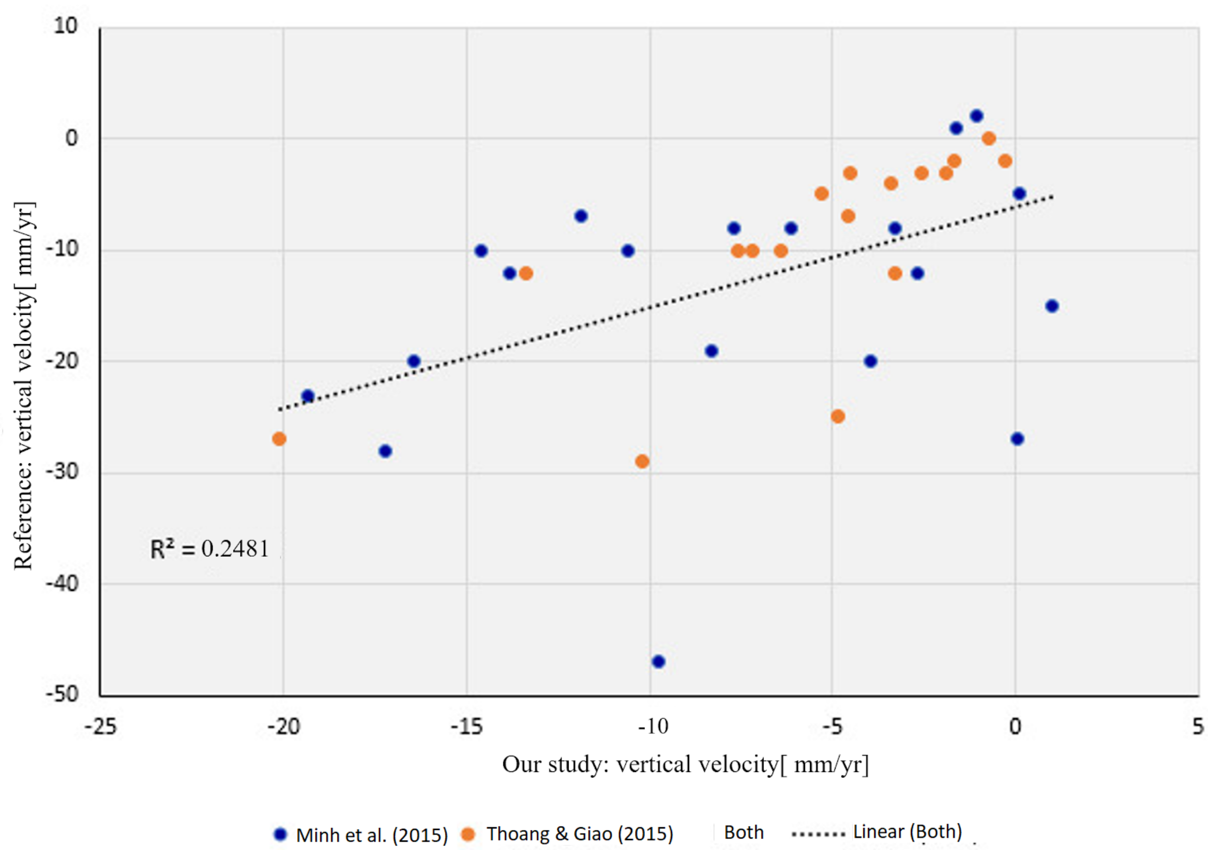

FIGURE S1: Vertical velocities of reference points for validation proxy

Ideally, leveling data would be available and leveraged, however that was not feasible for this study considering that we were made aware that many of the leveling stations had actually subsided themselves and new ones have recently been commissioned within and after the period of study. We identify the lack of leveling data as a shortcoming of the study, and as an indirect measure of confidence, we used the reference points from the studies of Minh et al. (2015) and Thoang and Giao (2015), as depicted above for the evaluation of our results. These points allow us to show and calculate the overall agreement, despite the different source and temporal reference.

The figure shows the agreement of subsidence rates retrieved from the validation data of the two studies (y axis) with our measurements at these locations (x axis). The overall coefficient of determination is 0.248, but the two studies strongly differ in this regard: The reference data of Minh et al. (2015) (blue dots) consist of 19 route leveling measurements from the south of the center (circles in Figure 2) and result in a coefficient of determination of R^2=0.12. This is mostly caused by strong underestimations of subsidence rates in the west of the study area (Figure 2). In turn the reference data of Thoang and Giao (2015) (orange dots) were retrieved from a one-dimensional Finite Element (FEM) consolidation model based on data from 2006 to 2010, and resulted in clearly higher agreement with our data of R^2=0.53). Both reference datasets together result in an R^2 of 0.248 mostly indicating a general underestimation of subsidence rates in our study.

- Minh, D. H. T., Van Trung, L., & Toan, T. L. (2015): Mapping ground subsidence phenomena in Ho Chi Minh City through the radar interferometry technique using ALOS PALSAR data. *Remote Sensing*, *7*(7), 8543-8562.
- Thoang, T. T., & Giao, P. H. (2015): Subsurface characterization and prediction of land subsidence for HCM City, Vietnam. *Engineering Geology*, *199*, 107-124.

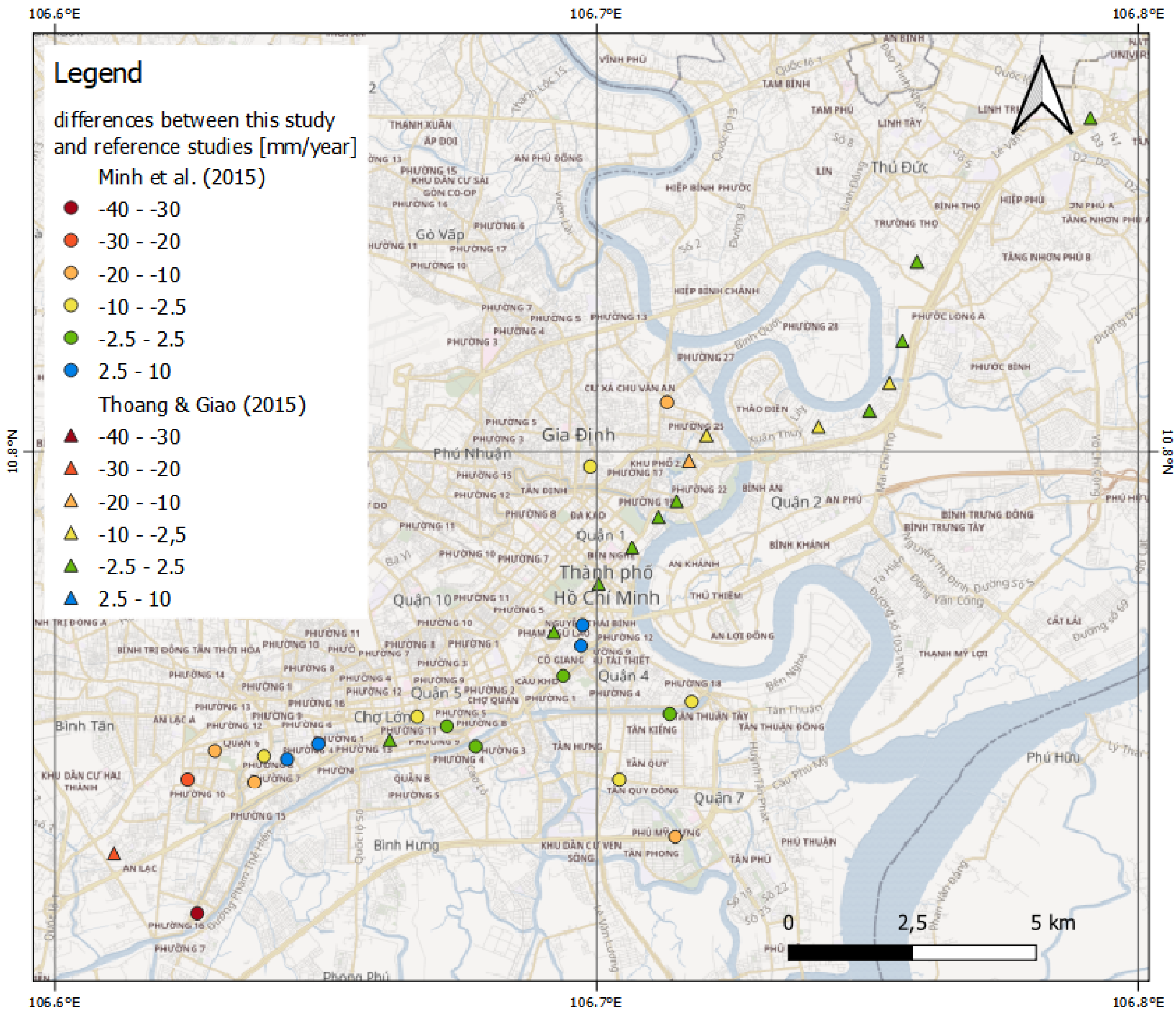

FIGURE S2: Spatial distribution of reference points

This figure shows the spatial distribution of the reference points which were used as a proxy for validation (Figure 1), as well as their absolute differences (mm per year) to the results of our study. The colors indicate that the reference data indicated stronger subsidence as in our study in most of the cases. However, the majority of the deviation was within +/- 2.5 mm per year. Only the areas in the southwest show stronger discrepancies larger than -20 mm / year. Note that the referenced studies were conducted leveraging data from 2010 and prior. Due to the nearly decade long gap between the time frames, some differences in the spatial distribution are to be expected between our study and the referenced studies. Yet, still there is consistency between our study and the reference studies, most notably in regions which are known to have relatively stable formations such as in district 1.

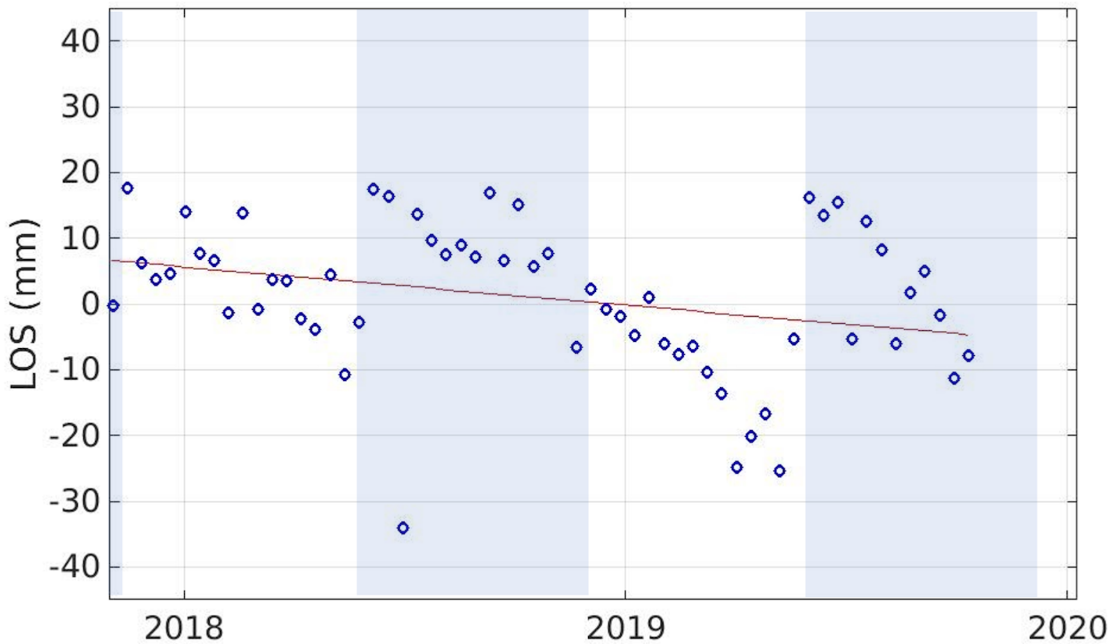

FIGURE S3: Temporal analysis in District 8- an area of rapid subsidence

Temporal analysis indicates that some of the high subsidence rates were lost or inaccurate due to such significant subsidence in the transition from the wet season to dry season (see the annual, not seasonal, trend pattern in the figure below of this particular area of D8) that the deformation signal exceeded that which can be measured given the wavelength and revisit of Sentinel-1. Note that the wet seasons are elucidated by the blue bars in this figure. If this error was a result of atmospheric signal, we would expect to see a significant difference in noise between the wet season and the dry season. As mentioned in our paper, the maximum differential deformation for Sentinel-1 compared to ALOS, which used in previous studies, is ~11.7 mm/day (or 1.4 cm/12 day interval) and ~12.8 mm/day (or 5.89 cm/46 day interval) respectively (Crosetto et al., 2016, Zhou et al., 2009). Additionally, the ALOS data used in previous studies is known to have the significant disadvantage of ionospheric influence on the interferometric phase (more than 20 times stronger than in C band), of which ionospheric influence is much less predictable than atmospheric influence (Chapin et al., 2006). Conversely, the tropospheric-induced error is known to be much more significant in the other suggested data sources mentioned previously, namely TerraSAR and COSMO-SkyMed (Fornaro et al., 2014).

- Crosetto, M., Monserrat, O., Cuevas-González, M., Devanthéry, N., & Crippa, B. (2016): Persistent scatterer interferometry: A review. *ISPRS Journal of Photogrammetry and Remote Sensing*, *115*, 78-89.
- Zhou, X., Chang, N. B., & Li, S. (2009): Applications of SAR interferometry in earth and environmental science research. *Sensors*, *9*(3), 1876-1912.
- Chapin, E., Chan, S. F., Chapman, B. D., Chen, C. W., Martin, J. M., Michel, T. R., & Rosen, P. A. (2006, April). Impact of the ionosphere on an L-band space based radar. In *2006 IEEE Conference on Radar* (pp. 1-8).
- Fornaro, G., & Pascazio, V. (2014). SAR interferometry and tomography: Theory and applications. In *Academic Press Library in Signal Processing* (Vol. 2, pp. 1043-1117). Elsevier.

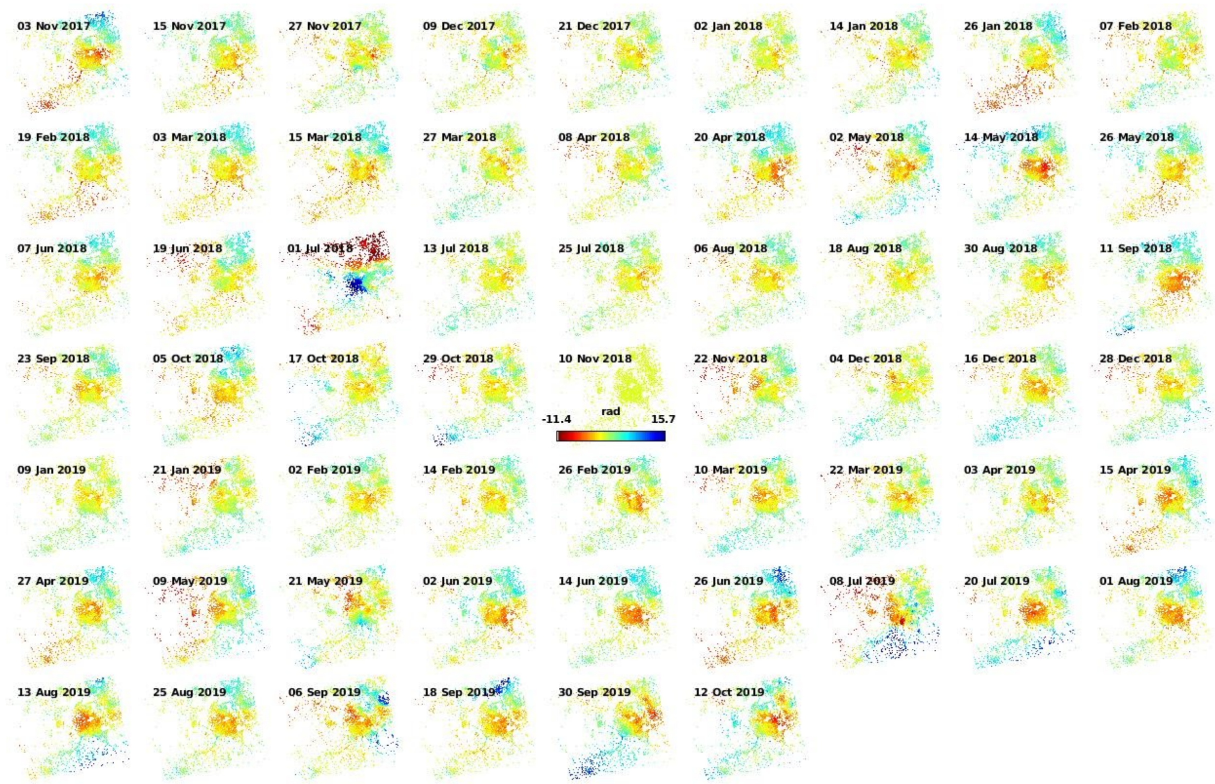

FIGURE S4: Interferograms of unwrapped phases.

This figure shows the interferograms of all descending image pairs used in this study. It illustrates that the unwrapped phases are primarily consistent with the observed data. Moreover, the few faulty interferograms that are accounted for do not superimpose the overall pattern and we decided not to exclude them from the analysis to maintain the consistent 12-day intervals between consecutive images. In all time-series plots, the phase signal from 01-Jul-2018 can clearly be identified as an outlier which deviates from the overall trend, but without impacting its slope or direction.