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Natural Hazards and Earth System Sciences
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Discussions

Interactive comment on "Recent land subsidence caused by the rapid urban development in the Hanoi urban region (Vietnam) using ALOS InSAR data" *by* V. K. Dang et al.

V. K. Dang et al.

dangvukhac@gmail.com

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First, we would like to thank the anonymous referee for his meaningful comments and the resulting constructive discussion, which helped to improve, we hope significantly, the paper. As a supplement, we proposed a revised version including changes according to his remarks but also to a data set of water level in the aquifers recently available, which appears indispensable to interpret our InSAR data.

1/ Comment 1: The reference Lin et al. (2011) is added into the text (line 3, P6157) and in the bibliography section (line 16, P6182). We replaced also the reference (Galloway

and Hoffmann, 2006) at line 8, P6157 by the new one (Galloway et al., 2000) and in the bibliography section (line 16, P6180)

2/ Comment 2: - We agreed and changed the 'geometric decorrelation' by "temporal decorrelation" (line 1, P6163) - We removed Fig. 2a-2b from the methodological section. We refer to these figures in the following section (3.2 Data), by adding the sentence at line 26, P6164: "In order to minimize both temporal and spatial decorrelation, the selected master image corresponds to the image acquired on 25 July 2009. Taking threshold of 2000 m and four years for spatial and temporal baselines respectively, Fig. 2a shows the 20 interferograms calculated with respect to this master image and Fig. 2b shows the 46 interferograms computed for the SB approach"

3/ Comment 3: We agreed with the reviewer regarding the un-clarity of this sentence. Avoiding to go into great details of the Stamps and Stamps/MTI methodology already intensely described in papers referred in our article (Hooper, 2004, 2008, 2010; Hopper et al., 2007), we chose to remove this sentence and modify the last paragraph of the methodology section (line 1-16, P6164): "In this paper, we follow the Multi-temporal InSAR method StaMPS/MTI developed by Hooper (2008) that combines InSAR PS method with SB method in order to extract the deformation signal at a larger number of pixels and to increase the signal-over-noise-ratio. The selection of PS pixels is performed firstly using PS approach developed by Hooper et al. (2007), and then, a second series of interferograms are processed using SB approach in order to identify distributed scatterers (DS) for which the filtered phase does not decorrelate significantly over short time period. Using the MT-InSAR method, the deformation signal is extracted at both the PS and DS pixels, that we call here Selected Pixels (SP), increasing the spatial coverage of signal and eventually contributing to a better phase unwrapping".

4/ Comment 4: According to the suggestion of the referee, we introduced the term 'Selected Pixels (SP)' for the pixels considered in this study and corresponding to the combination of both PS and DS pixels sets resulting from the PS and SB methods. For clarify, we include the term "SP" at line 14-15, P6164 with the sentence "Using the MT-InSAR method, the deformation signal is extracted at both the PS and DS pixels, that we call here Selected Pixels (SP)", but also over the whole manuscript with: Line 8, P6165; Line 12, P6165; Line 5, P6168; Line 8, P6172; Line 21, P6175; Fig. 5, P6190; Fig.6, P6192 (in the new version of manuscript, we have changed the sequence of the figures from Fig. 6)

5/ Comment 5: In figure 6b, we added vertical displacement time series for the block TT18B

6/ Comment 6: - For clarify, we change the title of this section at line 8, P6170 (5.2.1 Urban Sprawl), since it primarily focuses on the relation of the recent urban sprawl and spatial distribution of the subsidence. - The relation between vertical displacement and size/weight of the building is discussed in the section 5.3, where we explain that large heavy building are built with strong foundations down to 50-70 m below the topographic surface reaching Neogene geological layer. We add a sentence at line 23, P6175 "The 20 leveling measurements for CT2 building at Van Khe (Ha Dong) from October 2008 to September 2010 show a total value of -22.3 mm for vertical subsidence corresponding to an average of -0.97 mm/month (Diem et al., 2010)"

7/ Comment 7: For clarify and taking into account the new groundwater level data set, we replaced the sentence "where the groundwater piezometric head levels in Qp aquifer was located to -5 m in 2010 (Fig. 12). However this value reached -34 m.b.s.l. in 2006 in the same area (Winkela et al., 2010) due to the importation of surface water from Da River production plant at 60 km away from Hanoi in the June 2008" at line 19-23, P6173 with the new sentence: "where the groundwater piezometric head levels in Qp aquifer was located to -8.5 m b.s.l. in 2010 at observation well Q69 (Fig.12b). This value reached -4.3 m b.s.l. in 2006 in the same area (Nguyen and Nguyen, 2007)".

8/ Comment 8 and 9: The whole discussion related to seasonal variations is strengthened by the addition of the new data set of water level in the two aquifers. First we

modified the last sentence of the introduction at line 17-19, P6159: "(3) analyze these results with respect to several related parameters, being (i) the resistance of the shallow geological layers, (ii) the extend of the new urbanized areas built during these last decades and (iii) the ground water extraction taking into account the locations and the extraction rate of the water pumping plants, but also the water level within the main aquifers given by a recently available data set, corresponding to measurements at several observation wells during the 2006-2010 period collected by the Hanoi Center for Water Resources Planning and Investigation". Second, we presented six new graphics in Figure 12 showing the variations of groundwater level between at four places of urban areas (Figs 12b, 12c, 12d, 12e) and at three other locations in the outs-curt of the city center (Figs. 12f, 12g, 12h). Finally, we discussed our InSAR results at the light of these important data in the section 5.2.2 Ground Water Extraction at line 2-6, P6174 with: "In this area, the drinkable water is extracted from Qh aquifer through private shallow wells, and the presence of many factories with their proper wells could be a source to extract the groundwater from Qp aquifer, whose the extraction amount is impossible to estimate. "We compare our time series of the surface displacement with the evolution of the groundwater level in Qh aquifer and piezometric level of Qp aquifer measured by Hanoi Center for Water Resources Planning and Investigation during the period from 2006 to 2010 at 7 selected instrumented wells (Figs. 12): Q65 at Hoang Liet (Hoang Mai district), Q69 at Phu Lam (Ha Dong district), Q57 at Tan Lap in the north of Hoai Duc district, Q66 at Ngu Hiep in the south of Thanh Tri district, Q75 at Dong Mai (Ha Dong district), Q120 at Trau Quy (Gia Lam district), Q60 at An Thuong (Hoai Duc district). First, in order to understand the temporal evolution of these latter water levels, we look at the evolution of rainfall during the same period. We note that, for most of the wells, the variation of groundwater in aquifers follows the variations of rainfalls with clear seasonal fluctuations: rainy season (from May to September) or dry season (from October to April). We note particularly that the extreme rainfall on 31 October 2008 with more than 350 mm appears also in these water level time series, which indicates the water infiltration phenomenon (Fig. 12a). The correlation between the rain and the water levels in aquifers is especially clear in rural areas, where permeable surfaces are dominant and allow the natural recharge of these aquifers (Figs. 12f, 12g, 12h). Above the three wells with Q120, Q75 and Q60, very low deformation affects the ground surface with a largest vertical velocity of 12 mm.yr-1 at vicinity of the well Q120 (Fig. 3). In the newly urbanized villages such as the northern part of Hoai Duc district and the southern part of Thanh Tri district, the time evolution of the groundwater level of Qh aquifer shows clear seasonal variations in the Q57, Q66 wells (Figs. 12d, 12e). But the piezometric level in Qp aquifer is located at 5.0 m deeper than groundwater level in Qh aquifer and it changes from seasonal pattern to a linear decrease with a rate of 1.0 m.yr-1 starting from 2009. These areas are affected by the subsidence with a small rate ranging from 16.0 to 25.0 mm.yr-1 (Fig. 3). Regarding the urbanizing Ha Dong district, where our InSAR results show vertical rate of the ground deformation ranging from 45.0 to 60.0 mm.yr-1 (Fig. 3), the evolution of groundwater levels in both aquifers at Q69 well- located nearby the Ha Dong 2 production water plant (Fig. 11), does not show any seasonal variations. The water levels show a continuous lowering from 2006 at a mean rate of 1.0 m.yr-1 and 0.7 m.yr-1 for Qp and Qh respectively. However, it is important to note a clear acceleration of the water lowering from 2009 (Fig. 12b). In urbanized Hoang Mai district, the well Q65 is located in the margin of the largest subsiding area with a subsidence rate varying from 20.0 to 42.0 mm.yr-1 (Fig. 3). The evolution of the water level in the Qh aquifer remains constant over the time, when the piezometric level in Qp aquifer exhibits a complex time evolution with variations (Fig. 12c), but not as clear as for the wells Q75, Q120, Q60. The evolution of water levels in all observation wells clearly shows the acceleration of groundwater withdrawal in Qp aquifer, especially after the Hanoi's administrative regulation in May 2008 with the rising demands for water. The comparison of InSAR data with the data of water level in the aquifers suggests the important effect of the intense urbanization on the water resources. The development of impermeable coverage prevents the infiltration of precipitation for recharging of Qh aquifer and together with the drawdown of piezometric level in Qp aquifer due to pumping; this level of Qh aquifer could be also

lowered in the adjacent areas of water production plants".

10/ Comment 10: Indeed a correlation of the perpendicular baseline with time is often observed with ALOS data, which if present will result in residual phase and map into spurious deformation signal. The figure below (left) shows the temporal correlation of the perpendicular baseline for the dataset used in this study, the temporal correlation (coefficient = 0.263) is low over the time period of four years. In our study, we apply the DEM correction method described in Hooper et al., 2008, the DEM error map is shown in the second figure (right). Given the temporal distribution of perpendicular baseline (i.e. low temporal correlation, high temporal variability), a DEM error affecting the mean velocity map would also be visible in the DEM error map. We do not observe such DEM errors at the locations of observed surface deformation, and therefore are confident that our displacement estimates are not affected by DEM errors. We added a reference of (Gourmelen et al., 2007) at line 8 P6157 and we modified the article at line 19, P6164 as follow: "ALOS time-series analysis can suffer from residual DEM errors due to the frequent temporal correlation of the perpendicular baseline (Samsonov, 2010; Chen et al., 2013), however in our dataset the temporal correlation of the perpendicular baseline is low and the inversion for DEM error is robust due to the temporal variability of the perpendicular baseline; we observe no DEM errors in the region of surface deformation."

11/ Comment 11: Since we do not access to any absolute measurement, we need to adjust one set of data to the other one in order to compare the time evolution. To be more exact, we change the sentence "The third point of our InSAR time series was arbitrary located along the regression line of the leveling data" by "In order to adjust one set of data to the other one, we arbitrary position the regression line of the leveling data through the third point of our InSAR time series" - Using new sequence of some figures, the location of profile A-B in figure 8 is indicated on Fig. 7 or Fig.11

Reference: Chen, F., Lin, H., Zhou, W., Hong, T., and Wang, G.: Surface deformation detected by ALOS PALSAR small baseline SAR interferometry over permafrost environment of Beiluhe section, Tibet Plateau, China, Remote Sensing of Environment, 138, 10-18, 2013. Gourmelen, N., Amelung, F., Casu, F., Manzo, M. R., and Lanari, R.: Mining-related ground deformation in Crescent Valley, Nevada: Implications for sparse GPS networks, Geophys. Res. Lett., L09309, , 34, 9, doi: 10.1029/2007GL029427, 2007. Nguyen, T. H., and Nguyen, V. D.: 2006 Yearbook of groundwater resources at Vietnam's Northern Plain, Center for Water Investigation and Planning, Ha Noi, 314 pp., 2007. Samsonov, S.: Topographic Correction for ALOS PALSAR Interferometry, IEEE Geoscience and Remote Sensing Letters, 40, 7, 3020-3027, 2010.

Please also note the supplement to this comment:
http://www.nat-hazards-earth-syst-sci-discuss.net/1/C2486/2014/nhessd-1-C2486-2014-supplement.pdf

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., 1, 6155, 2013.

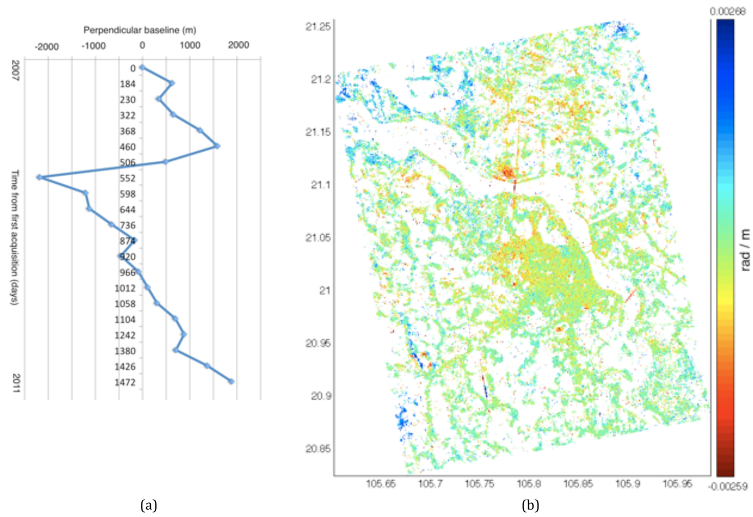

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Fig. 1.