HIGH-RESOLUTION MAPPING OF FLUVIAL LANDFORM CHANGE IN ARID ENVIRONMENTS USING TERRASAR-X IMAGES

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1. INTRODUCTION

Satellite based radar interferometry is a powerful tool to detect change at the Earth's surface. Established change detection applications include the monitoring of slow changes due to land subsidence and landslide movement, and sudden changes induced by earthquakes [1]. However, only a limited number of publication deal with the monitoring of morphological change induced by erosion and sedimentation (for a review see [2]). One reason is the discrepancy between the process scale and the geometric resolution of the data available from civil space-borne SAR systems until recently. In June 2007 TerraSAR-X (TSX), Germany's first civil synthetic aperature radar (SAR) satellite was launched and starting in January 2008 external users where able to order TSX products [3]. A major advantage of TerraSAR-X is the high geometric resolution of the data acquired in High Resolution Spotlight (HS) mode. In the nominal 150 MHz bandwidth mode azimuth resolution is 1.1 m and range resolution 3.5 to 1.5 m depending on the incidence angle. In the experimental 300 MHz bandwidth mode the range resolution reaches even 1.8 to 0.75 m [4].

Recently, [5] demonstrated that the meter-scale ground resolution of TerraSAR-X nominal HS images (150 MHz) provides the opportunity to derive digital elevation models (DEM) with a 5-m-resolution representing landforms on the micro-relief scale, i.e. on the order of $10^0 – 10^4$ m^2 [6]. However, height precision of the derived DEM is not yet good enough to detect landform change on the micro-relief scale induced by small and frequently occurring erosion and sedimentation events. Following concepts used successfully in previous studies of land surface change in arid environments (e.g. [7], [8], [9]) the aim of this paper is to explore the high resolution detection of landform change induced by erosion and sedimentation using coherence as a proxy for landform stability and landform change, respectively.

2. STUDY AREA, MATERIAL, AND METHODS

The study area is located in the coastal desert of southern Peru, close to the town of Palpa (≈14.5°S/75.2°W, 400 km south of Lima). The climate of the coastal desert is hyper-arid with an average annual temperature of 22 °C, mean precipitation of 25 mm/yr, and a potential pan evaporation of 1600 mm/yr [3]. Vegetation and agriculture in the coastal desert is limited to the vicinity of rivers draining the Cordillera Occidental. The landform assemblage of the study area consists of three distinct landscape units: 1) stable, bare, and gently sloping bajada surfaces dissected by dry valleys; 2) broad valleys with intermittent rivers surrounded by arable land, orchards and settlements; and 3) steep bare and scree-covered mountains reaching heights of up to 450 m above the valley bottom. The morphodynamic regime of the landscape is characterized by continuous aeolian activity and fluvial activity during the rainfall and runoff season from December to April.

Within the framework of a TSX pre-launch proposal (grant no. GEO0258) 24 images were acquired from 4 study sites in the vicinity of Palpa representing different assemblages of the typical landforms of the coastal desert of Peru. However, here the discussion of the results will be restricted to the 6 images acquired with 150 MHz bandwidth, horizontal polarization and an incidence angle of 49.4 ° for the study side Palpa South (center position: 14.564°S / 75.205°W) between Oct. 2008 and Aug. 2009 (table 1).

Table 1: Temporal and estimated normal baseline of repeat-pass acquisitions for the study side Palpa South

Acquisition	08-10-12	09-03-26	09-08-05	09-08-16	09-08-27
08-10-01	11 d / 102 m	176 d / -22 m	308 d / -25 m	319 d / 100 m	330 d / 41 m
08-10-12		165 d / -124 m	297 d / -122 m	308 d / -2 m	319 d / -64 m
09-03-26			132 d / 17 m	143 d / 122 m	154 d / 63 m
09-08-05				11 d / 120 m	22 d / 64 m
09-08-16					11 d / -61 m

Interferometric analysis of the images was conducted using the software SARscape 4.2.001. Images were coregistered and flattened using the 90 m SRTM DEM [10] and multi-looked with a factor of 3 in azimuth and in range. Coherence was calculated from the filtered interferogram using the adaptive Goldstein filter.

3. CHANGE DETECTION USING COHERENCE

Analyzing the coherence of a single repeat-pass pair of TerraSAR-X HS images with a temporal baseline of 11 days acquired in October 2008 showed distinct differences in coherence (11-d-coherence: γ_{011}) for the three typical landscape units present in the study area [5]. The bare landscape units, i.e., the bajadas and the mountain areas, showed very high coherence with a median (Md) of 0.86 and 0.78, respectively. As compared to this the median of γ_{011} for the valley bottom is only 0.43. This is due to the presence of vegetation and agricultural activities on the irrigated fields in the valley bottom. Subsequent analysis of image pairs with short temporal baseline showed that this landscape unit dependent pattern is similar for all pairs with a 11 day temporal baseline.

The investigations of changes in coherence for image pairs with longer temporal baselines presented here, yield landscape unit specific trends of coherence (table 2). In the valley bottom coherence decreases from a mean = 0.5

Table 2: Mean, standard deviation and median of coherence for repeat-pass TerraSAR-X HS image pairs with varying temporal baseline for landscape units at the study side Palpa South (master acquisition: 08-10-01)

Acquisition	number of pixels	08-10-12 11 days	09-03-26 176 days	09-08-05 308 days	09-08-16 319 days	09-08-27 330 days
whole image	5878386	0.7±0.2 / 0.77	0.6±0.3 / 0.76	0.6±0.3 / 0.75	0.6±0.3 / 0.74	0.6±0.3 / 0.74
Valley bottom	1556800	0.5±0.2 / 0.45	0.2±0.1 / 0.22	0.2±0.1 / 0.21	0.2±0.1 / 0.21	0.2±0.1 / 0.21
Mountains	1838670	0.7±0.2 / 0.75	0.7±0.2 / 0.77	0.7±0.2 / 0.77	0.7±0.2 / 0.75	0.7±0.2 / 0.77
Bajadas	2439863	0.8±0.1 / 0.86	0.8±0.1 / 0.86	0.8±0.1 / 0.86	0.8±0.1 / 0.85	0.8±0.1 / 0.85

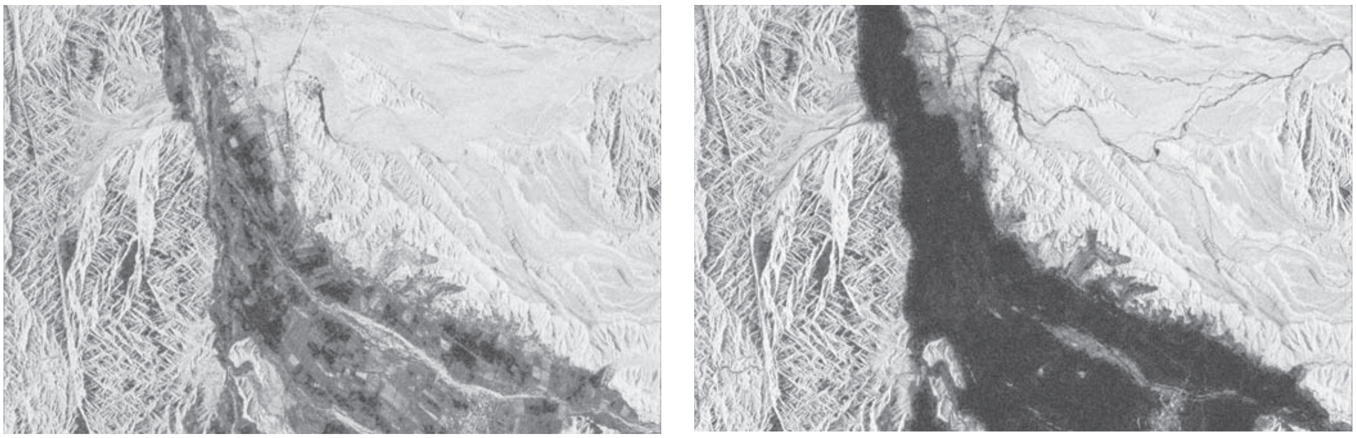

Fig. 1: Coherence of image pairs with 11 (left) and 330 (right) day temporal baseline for the study site Palpa South (center position: 14.564 S / 75.205 W). The V-shaped dark area in the center represents the valley bottom. To the left is the landscape unit mountains and to the right the bajadas. Elongated features in the valley bottom (left image) are dry braided river beds. The dark meandering features on the bajadas (right image) trace channels in the dry valley bottom where erosion and sedimentation occurred during a runoff event, most probably in Jan. 2009. (Data: DLR 2008 and 2009).

and a Md = 0.45 for γ_{011} to a mean = 0.2 and a Md = 0.22 for image pairs with a temporal baseline > 176 days. Considering the land use pattern in the valley bottom, the short wavelength used in the TerraSAR-X system and the fact that the period from October 2008 to March 2009 spans the rainfall and runoff season in the study area this trend was expected. However, for the landscape units with bare surfaces the statistical parameters (table 2) indicate little change in coherence even for a temporal baseline of 330 days. This can be interpreted as an indicator for overall stable conditions and the excellent performance of the TerraSAR-X system. The high coherence provides the opportunity to identify and delimit areas of change with high geometric resolution and to bracket the period when changes occurred. Comparing the two coherence images in figure 1 shows clear evidence of surface change in the bajada area (right image). Using additional information from the high resolution DEM and local knowledge indicates that the prominent dark linear features visible in the coherence images with 330 days temporal baseline (right image) trace channels in the wide dry valley bottom incised into the bajada surface.

These features appear for the first time in the coherence image with a 176 day temporal baseline (not shown) and can be attributed to a rainfall and runoff event in January 2009. Thus it is possible to effectively detect land surface change caused by erosion and sedimentation events using high resolution TerraSAR-X images even with discontinuous acquisition strategies requiring less resources. However, the landscape unit specific analysis demonstrates as well that this is only possible in regions where the backscatter is not disturbed by vegetation.

For the final abstract it is intended to expand this analysis to include all combinations of acquisitions, i.e. all temporal baselines.

5. REFERENCES

[1] H. A. Zebker, "Studying the Earth with interferometric radar," *IEEE Comput. Sci. Eng. Mag.,* vol. 2, pp. 52-60, May/Jun. 2000.

[2] A. Vrieling, "Satellite remote sensing for water erosion assessment: A review," *CATENA*, vol. 65, pp. 2-18, Jan. 2006.

[3] J. Mittermayer, B. Schättler, and M. Younis, "TerraSAR-X commissioning phase excecution summary," *IEEE Trans. Geosci. Remote Sens.,* vol. 48, no. 2, Feb. 2010. to be published. (doi: 10.1109/TGRS.2009.2026744, available online: 2009-10-06).

[4] T. Fritz and M. Eineder, Eds. (2009, Mar. 18). *TerraSAR-X Ground Segment Basic Product Specification Document, Issue 1.5, Doc.: TX-GS-DD-3302*. Available: http://www.dlr.de

[5] J. Baade, and C. C. Schmullius, "Interferometric microrelief sensing with TerraSAR-X – First results," *IEEE Trans. Geosci. Remote Sens.,* vol. 48, no. 2, Feb. 2010. to be published. (doi: 10.1109/TGRS.2009.2036720, available online: 2009-12-15).

[6] D. Barsch and G. Stäblein, "EDV gerechter Symbolschlüssel für die geomorphologische Detailaufnahme," *Berliner Geogr. Abh.*, vol. 30, pp. 63-78, 1978.

[7] U. Wegmüller, T. Strozzi, T. Farr, and C. L. Werner, "Arid land surface characterization with repeat-pass SAR Interferometry," *IEEE Trans. Geosci. Remote Sens.*, vol. 38, pp. 776-781, Mar. 2000.

[8] J. G. Liu, A. Black, H. Lee, H. Hanaizumi, and J. M. Moore, "Land surface change detection in a desert in Algeria using multi-temporal ERS SAR coherence images," *Int. J. Remote Sens.*, vol. 22, pp. 2463-2477, Sep. 2001.

[9] A. Lefort, M. Grippa, N. Walker, L. J. Stewart, and I. H. Woodhouse, "Change detection across the Nasca pampa using spaceborne SAR interferometry," *Int. J. Remote Sens.*, vol. 25, pp. 1799-1803, May 2004.

[10] USGS, "The Shuttle Radar Topography Mission, tile S15W076" Available: http://dds.cr.usgs.gov/srtm/version2_1/SRTM3/South_America/