TERRASAR-X TIME-SERIES APPLICATION TO INVESTI-
GATE AND MONITOR ANTHROPOGENIC EVENTS: THE
CASE STUDIES “KETZIN” AND “STAUFEN IM BREISGAU”

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ABSTRACT

Precise deformation monitoring associated with anthropogenic activities plays a key role for se-
curity aspects, damage control and implementing appropriate hazard mitigation measures. In
this study, we use observations from high-resolution TerraSAR-X imagery to investigate surface
deformation related to two case studies in Germany: the first one is the CO₂ storage pilot site in
Ketzin and the second one presents the remarkable local uplift in the historic city center of
Staufen im Breisgau. This paper presents the current state of work.

1 Introduction

Space-borne Interferometric Synthetic Aperture Radar (InSAR) time series analysis techniques such as the
Persistent Scatterer Interferometry (PSI) and the Small Baseline Subset (SBAS) method have proven
to be suitable tools to investigate and monitor surface displacements [1-2]. Compared to conventional geo-
detic techniques (GPS, leveling), SAR image-based methods provide a denser spatial sampling for retriev-
ing displacement information, especially in urban areas or sites with artificial facilities. As the temporal
sampling of measurements is based on the satellite’s revisit time, the repeated observation of a study area
has become possible within a few days with the new generation of high-resolution SAR sensors, such as
TerraSAR-X or COSMO-SkyMed. This is advanta-
geous compared to classical terrestrial surveys, which are time-consuming and laborious.

As the anthropogenic influence to the environment increases rapidly, a responsible handling is required
during and after each interaction, not only to prevent economic losses and casualties, but also to protect
ecological systems. Hence, InSAR observations can serve as a tool for detecting and monitoring surface
deformations that may be directly or indirectly linked to anthropogenic activities [3-4] or that occur in
populated regions [5]. Time series analysis can support the understanding of ongoing processes and the
surveillance of effectiveness of potential counteractive measures applied once the surface deformation
has been detected.

In this paper, we present the state of work of two case studies, for which we use SAR imagery to evaluate
surface deformations related to anthropogenic activities and populated areas. The first case represents a
study to assess surface deformation related to geological CO₂ storage and the second case deals with the
monitoring of an urban uplift that already has caused severe economic damages.

2 Geological CO₂ Storage at the
Ketzin Pilot Site

Close to Ketzin, 25 km west of Berlin, Germany’s
first onshore CO₂ storage project is in operation and,
since June 2008, 66,745 tons of CO₂ (4 August 2013)
have been injected into the reservoir in 630 m to
650 m depth. Compared to the large scale industrial
Carbon Capture and Storage (CCS) projects else-
where in the world (e.g. in a deep saline formation of
about ~1.8 km depth with injection rates of 1 Mt/year
at In Salah, Algeria [3,6]), the research activities at
the Ketzin pilot site do not aim at long-term injection
of large CO₂ volumes. The Ketzin project focuses on
the monitoring and prediction of CO₂ behavior in the
storage reservoir with a comprehensive scientific pro-
gram [7-8]. Against this background, the question
arises, whether InSAR can be used to assess potential
surface deformation in this specific case with low in-
jection rates of ~1,000 to 2,000 t/month.

Compared to the demonstrated InSAR applicability
for CO₂ storage monitoring at In Salah, the region
around Ketzin shows totally different environmental
conditions. Whereas, the In Salah site is located in a rocky desert with arid conditions [3], Ketzin is a humid and vegetated area, which needs to be considered in evaluating the usage of the InSAR techniques.

To support the space-based InSAR monitoring at the Ketzin pilot site, four corner reflectors were installed in March 2011 (see Figure 1), each close to the injection and observation wells.

2.1 Data

TerraSAR-X Stripmap imagery has been acquired since May 2009 in a descending track (relative orbit 78) with HH polarization and is expected to continue until September 2013, when the CO2 injection will have been stopped (August 2013) and the deconstruction of the injection plant will start. Although not recorded since the beginning of CO2 injection or even before, the data can be used to derive information about possible relative motions related to the geological CO2 storage.

As Figure 2 shows, the data is generally acquired regularly in the 11-days cycle of the TerraSAR-X revisit, except for a 12-weeks data lack between 3 July 2011 and 29 September 2011. The data gap interrupts the continuous time series processing by means of the Small Baselines Subset (SBAS) technique due to the temporal decorrelation related loss of coherence. Hence, the data is split into two sets for processing: one contains all images before and the second contains all images after the gap.

2.2 State of Work

Currently, work is in progress to process all data with both InSAR time series methods, PSI and SBAS as implemented in the StaMPS software [9] to also evaluate the level of information derived by those methods in context of the agricultural used region. Interferograms were generated by using DORIS (Delft object oriented radar interferometric software [10]).

The time series of the corner reflectors shall be compared with the available reservoir pressure data to investigate potential correlations.

3 Urban Uplift in Staufen im Breisgau

Within the historical city center of the small town Staufen im Breisgau, SW Germany, a remarkable urban uplift occurs, that was first recognized by visible cracks in the building walls end of 2007, then regularly measured by conventional leveling surveys since January 2008 and repeatedly observed with the TerraSAR-X satellite since July 2008. First Differential-InSAR based results were presented by Sass and Burbau [11] considering the TerraSAR-X Stripmap images from July 2008 and January 2009 showing the capability to extract deformation of several centimeters within the observation period in that urban area.

A continuation of the monitoring was assessed to be...
essential for observing the spatial extension and magnitude variations in time and to also relate subsurface processes and their changes to measurable surface deformations.

Severe damages at 269 buildings [12] were recorded (Figure 3) and the National Agency for Geology, Resources and Mining (LGRB) has started a comprehensive investigation [13-14]. The uplift is attributed to the disturbance of the hydro-geological system, presumably triggered by drilling activities for the heating and cooling of the city hall in September 2007. The drilling field is located next to this building. Spatial and temporal correlations with the drilling operation and observed damages have indicated a relationship. Explorations of the LGRB point out that the chemical reaction of calcium sulphate (Anhydrite) with groundwater to gypsum resulting in a volume increase has caused the surface deformation.

3.1 Data

The continuous TerraSAR-X acquisition of Staufen im Breisgau has started in July 2008 with two larger intervals of interruption in the winter to spring periods of 2012 and 2013 due to the TanDEM-X global Digital Elevation Model mission. Currently five years of Stripmap images in HH polarization recorded in an ascending track are available for the time series InSAR processing. Due to indications of horizontal motions as discussed in the LGRB reports [13-14] and in the analysis of first line-of-sight (LOS) results compared to leveling data by Lubitz et al. [15], additional images are acquired in a descending orbit since October 2012 to also discriminate between horizontal and vertical motion contributions.

3.2 Results & Discussion

Based on the SBAS time series investigation of the ascending SAR imagery from 22 July 2008 through 22 May 2011, Lubitz et al. [15] shows the capability of this technique to capture and monitor the deformation field in the city center of Staufen im Breisgau. The detected elliptical-shaped deformation field oriented in NE-SW direction reaches a cumulative LOS

Figure 3 Cracks in a building facade that is located in the area of deformation (picture by C. Lubitz, 23 August 2012).

Figure 4 Cumulative LOS displacement derived by using the SBAS technique as implemented in StaMPS for the observation period from 22 July 2008 through 22 May 2011 (Lubitz et al., 2013 [15]). The reference point to which the motion refers to is marked with a red star. The geothermal drilling field is highlighted with a yellow circle and the displacement contour lines for 1 cm, 10 cm, 20 cm and 30 cm are indicated.
uplift maximum of 33.5 cm within the observation period. The area of maximum uplift is located approximately 50 m north of the geothermal drilling field (Figure 4). The spatial extent of the uplift area agrees with the results of the leveling measurements, which are conducted by the Landratsamt Breisgau Hochschwarzwald, but the deformation border can be mapped at a higher level of detail by using the SBAS product due to the denser spatial sampling as compared to the leveling survey point network (not shown here).

Although the leveling results provide information on the vertical motion and the SBAS LOS results contain both horizontal and vertical displacement contributions, the temporal evolution of uplift is similar. Lubitz et al. [15] compared the time series of individual SBAS pixels with those of adjacent leveling points and found in both an approximately linear trend of the uplift rate until autumn 2009 followed by a period of decrease in the uplift rate that continued till the end of the observation period in May 2011. Among a variety of scenarios that have been discussed in detail in Lubitz et al. [15], this change seems to be reasonably caused by the performed counter measures, which are the sealing of the boreholes and the groundwater pumping to reduce the water inflow into the swellable strata. These activities have started in September and November 2009 and hence temporally coincide with the change in the uplift rate.

A closer look on the time series of the SBAS result and leveling measurements indicates magnitude discrepancies up to several centimeters that can be attributed to the additional horizontal motion contribution contained in the LOS SBAS result. Hence, the separation by additionally analyzing descending TerraSAR-X imagery is essential to first better evaluate the InSAR measurements compared to leveling and second to deepen the understanding of the ongoing processes.

### 3.3 Outlook

Albeit previous InSAR results presented in Lubitz et al. provide information on the spatial and temporal evolution of the urban uplift in Staufen im Breisgau, a consideration of the individual motion contributions, i.e. horizontal and vertical displacements, are required to enhance the understanding of the subsurface processes. Currently, work is in progress according to this task by taking into account the recently acquired descending images.

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### References


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