关键词: SAR 干涉ometry, 下沉, 滑坡

ABSTRACT: 北部波希米亚煤田是一个有许多深矿和许多大露天矿的区域。这里的褐煤被开采。该区域并不稳定，然而，有许多城市和村庄位于该区域，可能受到采矿或采矿后活动的威胁。该区域通过 SAR 干涉ometry 技术进行制图。然而，该区域通过其他方法探索时是完全不一致的。另一方面，其他可能有变形的区域也被发现了。此外，SAR 干涉ometry 可以用于检测活跃的采矿区（DEM 变化）。

1 引言

有众多露天矿存在于波希米亚北部。一个约 20 公里 x 60 公里的区域几乎完全用于采矿活动。许多地质技术被用于监测地面运动和下沉。在该区域，既有露天矿又有深矿，造成下沉和滑坡。

有史以来，第一次使用传统的空间 SAR 干涉ometry 技术在该区域。然而，该方法的缺点是植被区域因其相干性丢失而无法使用。尽管只选择了冬季季节的数据，但许多区域是不一致的。

该区域不是地震的主体，它在短时间内造成大的变形。该区域的大部分是稳定的，然而，一些小区域可能缓慢地滑落或沉降。问题是检测这些区域，因为双程和三程干涉图象包含许多干扰影响，如 DEM 或轨道误差，甚至大气延迟。此外，最大的变形发生在湿季节，如春季或夏季，对于这些季节我们没有数据。

2 双程和三程干涉ometry

在常规干涉处理后，干涉图象包含地形对应的相位，以及变形对应的相位。为了提取变形相位，必须先去除地形相位。这可以通过两种基本方法实现：

- 两程干涉ometry，即使用外部 DEM 转换到干涉系统的相位，然后减去。
- 三程干涉ometry，即使用一个不同的干涉图象（假设不包含变形信号），重新标定到第一个干涉图象的坐标系统，然后减去。

有显著的差异在这些两种方法之间:
• in three-pass interferometry, both processed pairs have a common master; i.e. both interferograms are sampled in the same way and no shift or resampling must be performed before topography subtraction; in two-pass interferometry, the radarcoded DEM (using erroneous orbits) must be shifted in order to correspond to the interferogram;
• the resolution of the SRTM DEM is lower than that of the interferogram, i.e. the DEM must be interpolated;
• the DEM has no “decorrelated areas”, i.e. the phase of the radarcoded DEM is more reliable than the phase of the interferogram;
• in three-pass interferometry, the interferogram to be subtracted from the other must be unwrapped first; this may cause a significant error if it contains decorrelated areas.

3 SCENES USED

For detection of deformations, the following scenes were used:

1. ERS-1 scene acquired on March 7, 1999
2. ERS-2 scene acquired on March 8, 1999

These three scenes form three interferometric pairs:

• tandem pair, containing scenes 1 and 2 (temporal baseline is 1 day, perpendicular baseline is 110 m),
• defo 1 pair, containing scenes 2 and 3 (temporal baseline is 70 days, perpendicular baseline is 98 m),
• defo 2 pair, containing scenes 2 and 3 (temporal baseline is 69 days, perpendicular baseline is -16 m).

We also have another two scenes from years 2002-2003; however, we are not able to coregister these due to the large convergence of their orbits. In addition, we are not able to process some scene crops of the defo 2 interferogram, due to the same reason (the angle between the orbits is smaller for the defo 2 pair).

The tandem pair is not used for deformation monitoring, it is only used for subtraction of the topography of the deformation pairs. Its coherence is much better than that of the defo pairs.

The area of the northern-Bohemia coal basin is quite flat, however, the Ore Mountains form a part of the scene. We are only interested in relative changes with respect to the surroundings, and therefore we are not interested in global errors, such as phase-unwrapping errors.

4 RESULTS

4.1 Landsliding area

The area we know to landslide is located near the Chabařovice village. A lot of huge landslides were detected here by classical geodetic and geotechnical methods. Although the area looks well correlated in the tandem pair interferogram, it is almost completely decorrelated in the defo 1 and defo 2 pair interferograms (see Figure 1). Figure 2 contains a detrended crop of the differential interferograms (defo 1 - tandem pair, defo 2 - tandem pair). It can be seen that the area of interest itself (framed in Figure 1) does not contain significant (correlated) deformations; however, areas suspicious of deformation were found near to it.

The decorrelation may be caused by several effects. The vegetation is always the first. There is a high grass in the area; we assume that it does not disappear totally in the winter and a snowfall between the acquisitions of the two scenes (which is probable) may change its cover. In addition, the area is sloped in the flight direction of the satellite; however, radar interferometry only allows to map deformations in the direction perpendicular to the satellite flight. The landslides would...
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occur in the flight directions and landslides larger than few centimeters would always cause decorrelation in this direction (Hanssen, 2001).

4.2 Areas of subsidence

Unfortunately, results of deformation mapping out of the Chabařovice are unavailable, and therefore we have no data to compare our suspicious areas with. There are not only open mines in the Coal Basin, but also the deep mines, although much smaller in comparison to the open ones.

Figure 1. Landsliding area near Chabařovice. The coherence of the tandem (A), defo 1 (B) and defo 2 (C) pairs. The area of interest is framed.

Figure 2. Masked differential interferograms of the area near Chabařovice. In order for a pixel to be imaged, the product of the coherence of the tandem and particular defo pair (A - defo 1 pair, B - defo 2 pair) must be greater than 0.1 (low-coherent areas are pink-coloured). The areas suspicious of deformations are marked.

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Figure 3. An area suspicious of deformation near the village Břevny. There is an old deep mine here. (A - detrended masked interferogram (only pixels with the coherence product higher than 0.1 are imaged; B - coherence product image).
It is easier to detect subsidences than to detect landslides, because they usually do not cause the change in the cover, i.e. reflectivity, and the phase is changed more homogeneously throughout the place imaged into one pixel.

4.3 Other influences

The phase does not need to be corrupted by deformations. In figure 5, there are many sharp-edged areas with a different phase than their surroundings. We assume these areas to be agricultural fields, farmed in a different way at the time between the acquisition of the two scenes.

4.4 DEM errors

Figure 6 shows an area where the DEM does not correspond to the reality. The SRTM DEM was acquired in 2000, i.e. approximately one year after the acquisition of the processed scenes. Although no deformations can be seen in the image (the topo pair is processed here) the DEM error can be seen clearly. However, the accuracy of the evaluated DEM error is in the order of tens of meters.

If evaluating a deformation pair, i.e. a pair which may contain a deformation in addition to topography, the DEM error can be erroneously assumed to be deformations. However, that is no possibility to recognize this effect, except for processing the three-pass interferogram at the same time.
5 CONCLUSIONS

Some areas suspicious for deformations (subsidence) have been found. We hope that more scenes will allow us to see the deformations more clearly and in more areas because the Northern-Bohemian Coal Basin is unstable as a whole. More data will be requested from ESA this summer. However, it is very difficult to map landslides, especially such huge ones as occur in the Chabafiovice area (mapped by classical methods). In addition, landslides often occur in non-urban areas where they do not cause a human danger. On the other hand, the subsidences, which are easier to map with radar interferometry, occur often in urban areas.

Some artifacts are caused by imperfect coregistration of the interferogram with the DEM (2-pass case). This may be solved by using a shorter baseline (if possible) or by an automatic coregistration of the DEM with the interferogram, which is being prepared.

We will soon see the comparison of the interferometry results with mining maps which is now performed.

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