

## MONITORING OF COAL MINING SUBSIDENCE BY HRSC-A DATA

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### ABSTRACT

Active deep hard coal mining in the Ruhrgebiet with significant subsidence movements leads to the development of large shallow basins on the ground surface. Due to legal requirements the German Coal Mining Company "Deutsche Steinkohle AG" (DSK) is obliged to make a prognosis and to forecast influences caused by current excavations. Important data needed are "Digital Terrain Models" (DTM), displacement maps, information on biotopes and the actual land-cover. The dynamic mining activities demand the updating of spatial information at regular times. Today these data are generated by methods of analytic photogrammetry and by manual fieldwork. With regard to effectiveness and economy DSK started to evaluate new methods of data acquisition and data processing by using digital photogrammetry and remote sensing techniques.

### 1 INTRODUCTION

The Ruhrgebiet in northwest Germany is one of the most densely populated areas in Europe. Traditionally, deep hard coal mining has been the motor of the economic growth in this region comprised between the rivers Ruhr in the South, Lippe in the North and Rhine in the West. In 1999 62.500 miners extracted 37,5 million tons of coal from seams of 0,6-4,5 m thickness at an average depth of about 1000 m.

Underground hard coal mining activities lead to surface impacts caused by subsidence movements (see Fig. 1). Longwall mining and room-and-pillar with retreat mining are high extraction mining techniques that cause the overburden to sag, thus creating a subsidence trough over active mine workings. The resultant surface impact is a large shallow depression or basin in the ground, which is usually circular or elliptical in shape, depending primarily on the geometry of the mine workings and the geological conditions. Local annual subsidence of several dm have to be expected. High demands are placed on planning and monitoring, because occurring effects may entail lasting changes and influences on the environment. To minimize these effects extensive environmental compatibility studies have to be performed and detailed prognosis have to be made.

Photogrammetric measurements and derived high resolution DTM are fundamental information to register the current topographic situation and to detect subsidence movements over time. These measurements are carried out with analytical stereoplotters and are highly accurate. However, manual measurement of a DTM is time consuming and cumbersome. Besides the impact on infrastructure it is important to register effects on different types of land-use, forestry and on the ecological situation of biotopes. Today detailed field surveys are carried out gathering current information on land-cover and biotopes. With regard of the large area (1.500 km<sup>2</sup>) that has to be monitored manual field work is very time consuming. Together with auxiliary data, describing e.g. the ground-water situation, photogrammetric measurements and the digitized field data are part of the "Geographic Information System" (GIS) set up by DSK [1]. The dynamic mining activities require an updating of the spatial information mentioned before at regular intervals. First investigations have been made by using multitemporal data. To evaluate the advantages of digital photogrammetry and remote sensing DSK carried out research studies to use new data sets. Within the framework of these research activities a test area was recorded with the HRSC-A camera [2] in May and simultaneously with the HRSC-A and the hyperspectral scanner HYMAP™ [3] in August 1998 [4].

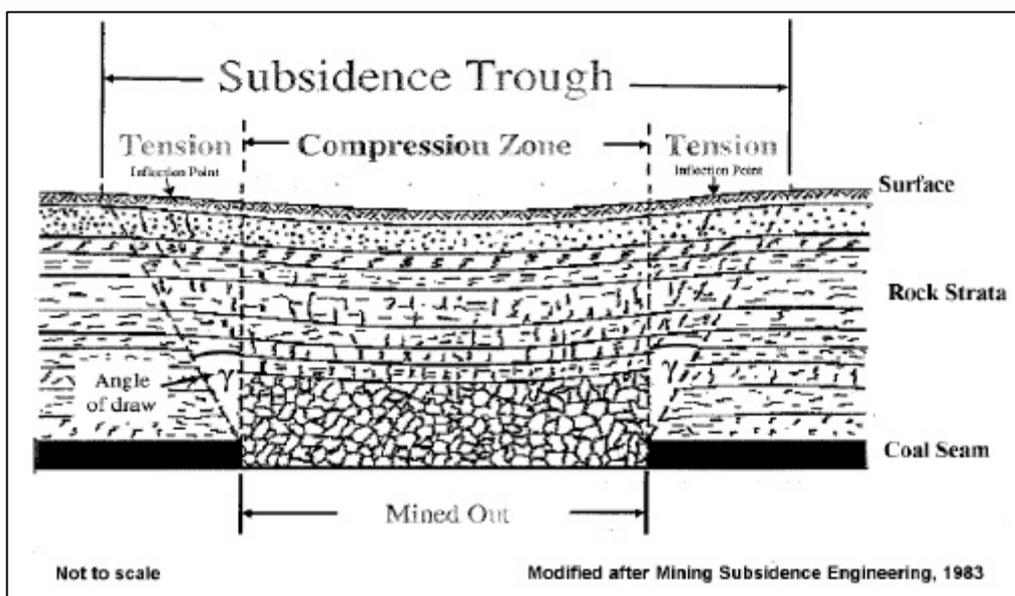


Fig. 1: Cross-section of subsidence trough

## 2 REFERENCE DATA

In March 1994 DSK generated a homogenous DTM over an area of approximately 300 km<sup>2</sup>. Based on aerial photographs with an image scale of 1:6.000, taken in March 1993, a 50 m grid mesh was measured and completed with recording breaklines down to distances of 1 m by analytical photogrammetric stereoplotters.

Mathematical models implementing geological and expected mining conditions are used to forecast subsidence movements for the influenced area of each mine site. Fig. 2 shows the 1m-contour lines for the "Calculation of Expected Subsidence" from 1993 to 2004.

As soon as details about the mining activities, location and the amount of extracted matter are known a more precise "Calculation of Subsidence" can be performed for a specific period. In Fig. 2 the calculated subsidence for the period from March 1993 to August 1998 is presented as color-slice.

A GPS-campaign was carried out in February 1999 to gather current ground-truth data of subsided areas. An area of 4 km<sup>2</sup> was recorded with more than 1700 points. With a point distance of 20 m sections with a total length of nearly 24 km along streets were measured. Additionally a parking lot area of 1,6 ha was covered with a 5 m grid (540 points).

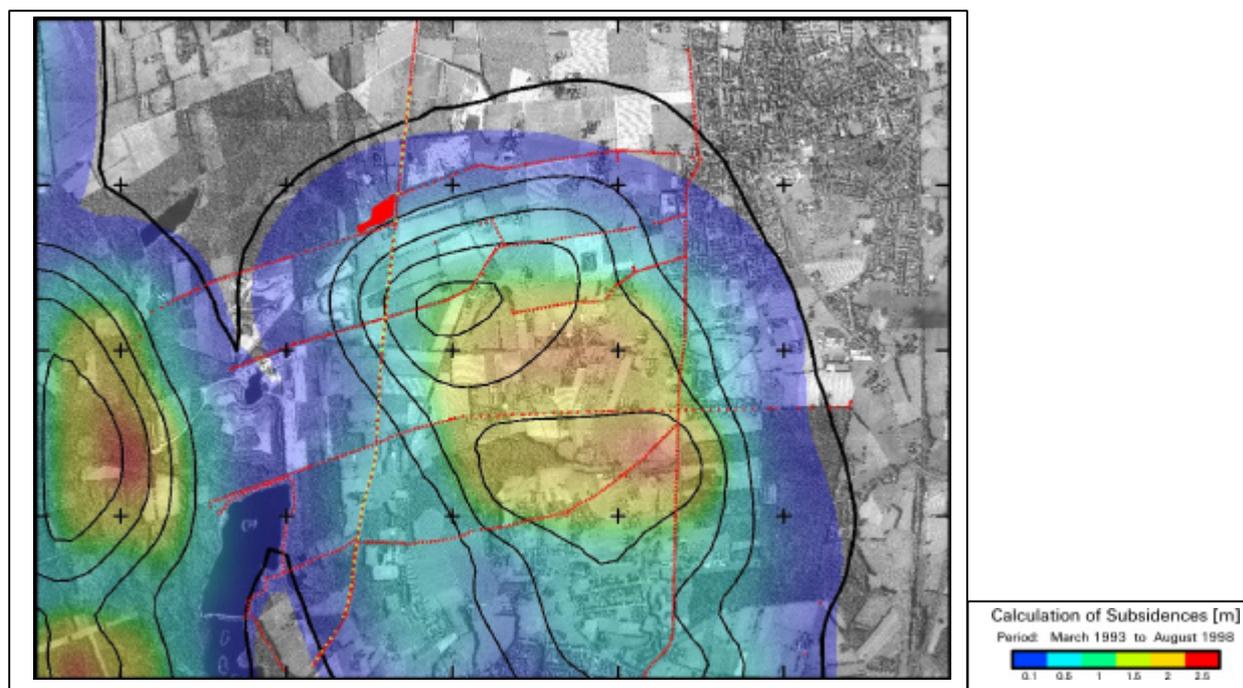


Fig. 2: HRSC-A orthoimage August 1998; "Calculation of Subsidence 1993-1998";  
 red: GPS-points 1999; yellow: levelling points;  
 black: 1 m-contour-lines "Calculation of Expected Subsidence 1993-2004"

The GPS measurement was performed by using one permanently registered point as local reference. The coordinates were calculated in postprocessing mode. To transform all GPS points to the Gauß–Krüger coordinate system ten ground control points located in stable areas were used. To control the transformation the SAPOS reference station in Essen at a distance of 16 km was considered. The standard deviation of the GPS points by number and percentage of points for each class is given in Tab. 1:

Class	Standard Deviation	Points	%
1	< 1 cm	1353	78,4
2	1 cm – 2 cm	191	11,1
3	2 cm – 3 cm	57	3,3
4	3 cm – 4 cm	21	1,2
5	4 cm – 5 cm	11	0,6
6	> 5 cm	93	5,4
Total		1726	100

Tab. 1: Standard deviation of GPS points

### 3 COMPARISON OF HRSC-A AND REFERENCE DATA

From the HRSC-A data a "Digital Elevation Model" (DEM) was generated by using five stereo-channels including two photometric channels to obtain redundant information of height data. The flown altitude of 3500 meters above ground level [agl] leads to a ground pixel size of 15 cm. The accuracy in height of the HRSC-A was determined to 0,05 thousandth of the flying height what results to  $\pm 20$  cm [5] and was confirmed by evaluations of both the DEM (May and August 1998) and versus the GPS-DTM'99 [6].

According to the flight campaign a land-use classification was carried out in August. The heights of both the HRSC-A DEM obviously show the different growth stage of the vegetation [4]. An investigation of the land-use revealed that about 40% of the area is covered by woods and 90% of the agricultural land-cover are grain- and cornfields.

The following investigations were performed using the photogrammetric DTM'93, the August-DEM of the HRSC-A camera and the "Calculation of Subsidence 1993-1998". The height differences between the photogrammetric DTM'93 and the HRSC-A DEM'98 are presented in Fig. 3. Within the shape of the contour lines a recent subsidence basin can be recognized south-east of the image center following the color slice from yellow, white, light blue to magenta. The disturbing influence of the vegetation can clearly be seen: forests appear in brown, settlements, bushes and refilled gravel excavation areas in red colors. Purple to black areas show the progression of current gravel excavations. Orange colors show corn fields for not affected regions while this crop is represented by light blue color within the subsidence trough.

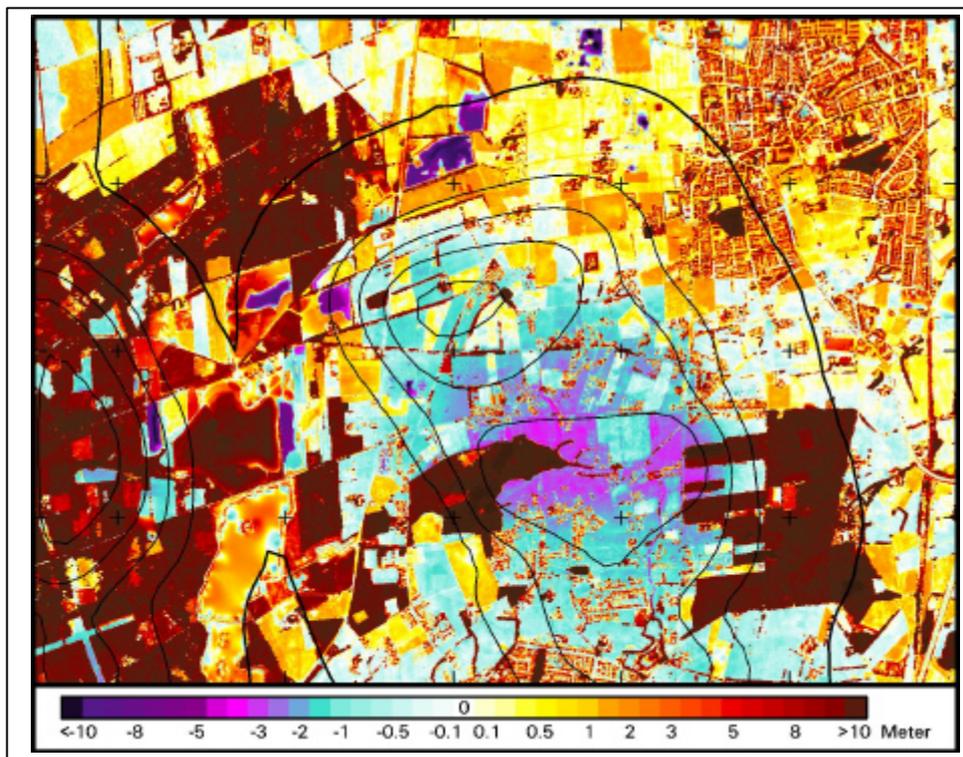


Fig. 3: Height difference between DTM (March 1993) and HRSC-A DEM (August 1998)

In summer 1998 a field survey was carried out to gather information on land-cover and biotopes. Using these results and the land-use classification acquired in 1995 the masks for forest land and corn fields could be created (see Fig. 4).

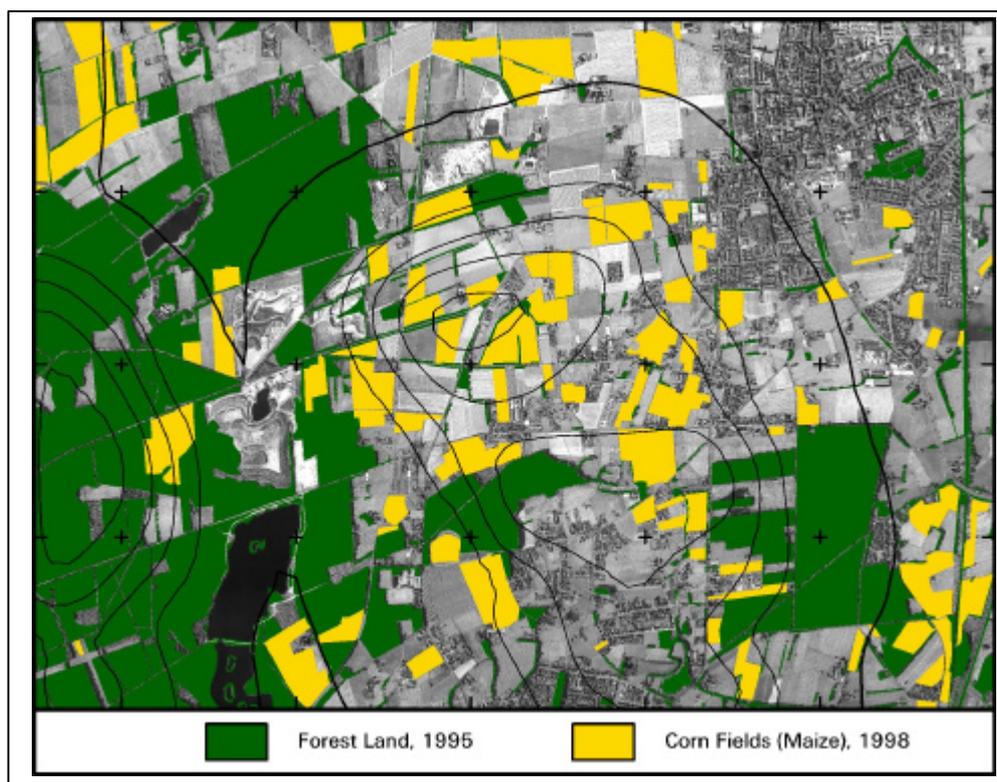


Fig. 4: Vegetation mask (forest land and maize)

The next step was to replace the forest land and corn fields by other height data:

- the vegetation mask was used to generate “no-data-areas” within the HRSC-A DEM’98
- the DTM’93 was updated and subsided to August 1998 with the “*Calculation of Subsidence 1993-1998*”
- the “no-data-areas” within DEM’98 were replaced with the heights of the subsided DTM’93
- the result is a “Digital Height Model” (DHM’93-98) that consists of two different and independent data sources.

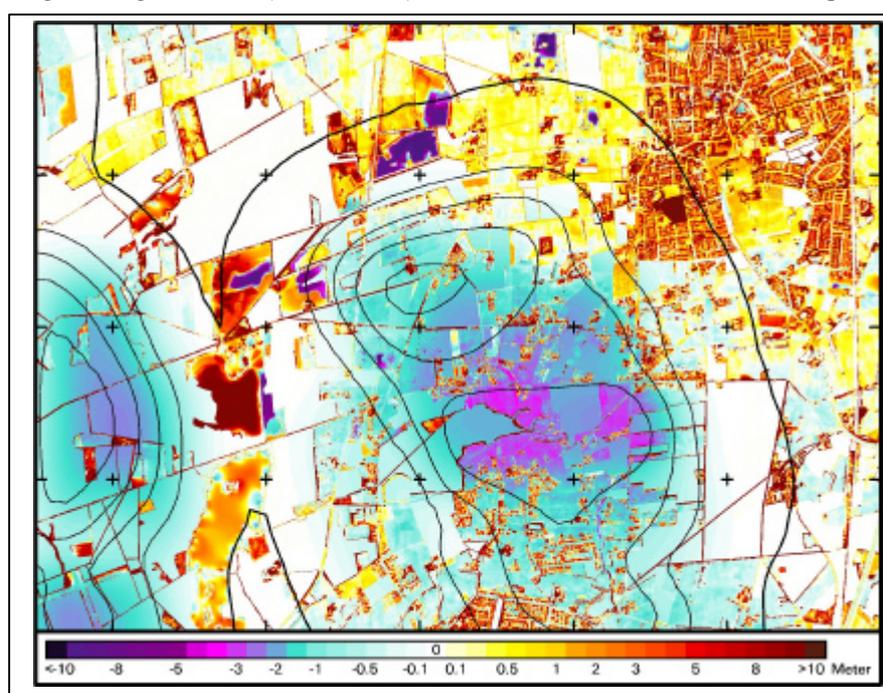


Fig. 5 Differences between DTM’93 and (HRSC-A DEM with subsided DTM’93)

To obtain an overview of the amount of calculated and occurred subsidence the differences between the created DHM'93-98 and the height situation in March 1993 (DTM'93, not-corrected) is shown in Fig. 5. White colors (no difference) appear in regions where no subsidence has been calculated or taken place.

This new generated height model contains unsteady areas depending on the boundaries of the masks that do not fit exactly with the edges of woods, large branches of big trees or avenues.

Within the subsidence trough large discrepancies of 1 m to 2 m between the calculated subsidence model and the measured HRSC-A data are obvious (see Fig. 5). The HRSC-A orthoimage in the right part of Fig. 6 shows a region of this basin where the vertical movement already led to an open water body in a flat depression. In this area two profiles were measured. The northern "Profile A" that lies within substituted forest land shows the movements of the "Calculation of Subsidence 1993-1998". The southern "Profile B" presents the measured amount of subsidence between the DTM'93 and the HRSC-A DEM'98. In the eastern parts both profiles show nearly the same amount of subsidence but in the western region the measured subsidence is up to 1 m larger than the calculated values.

Due to the expected accuracy of the calculated and the measured height models the comparison of both profiles leads to the assumption that in this case the DEM gathered by the HRSC-A camera is more accurate than the calculated subsidence model.

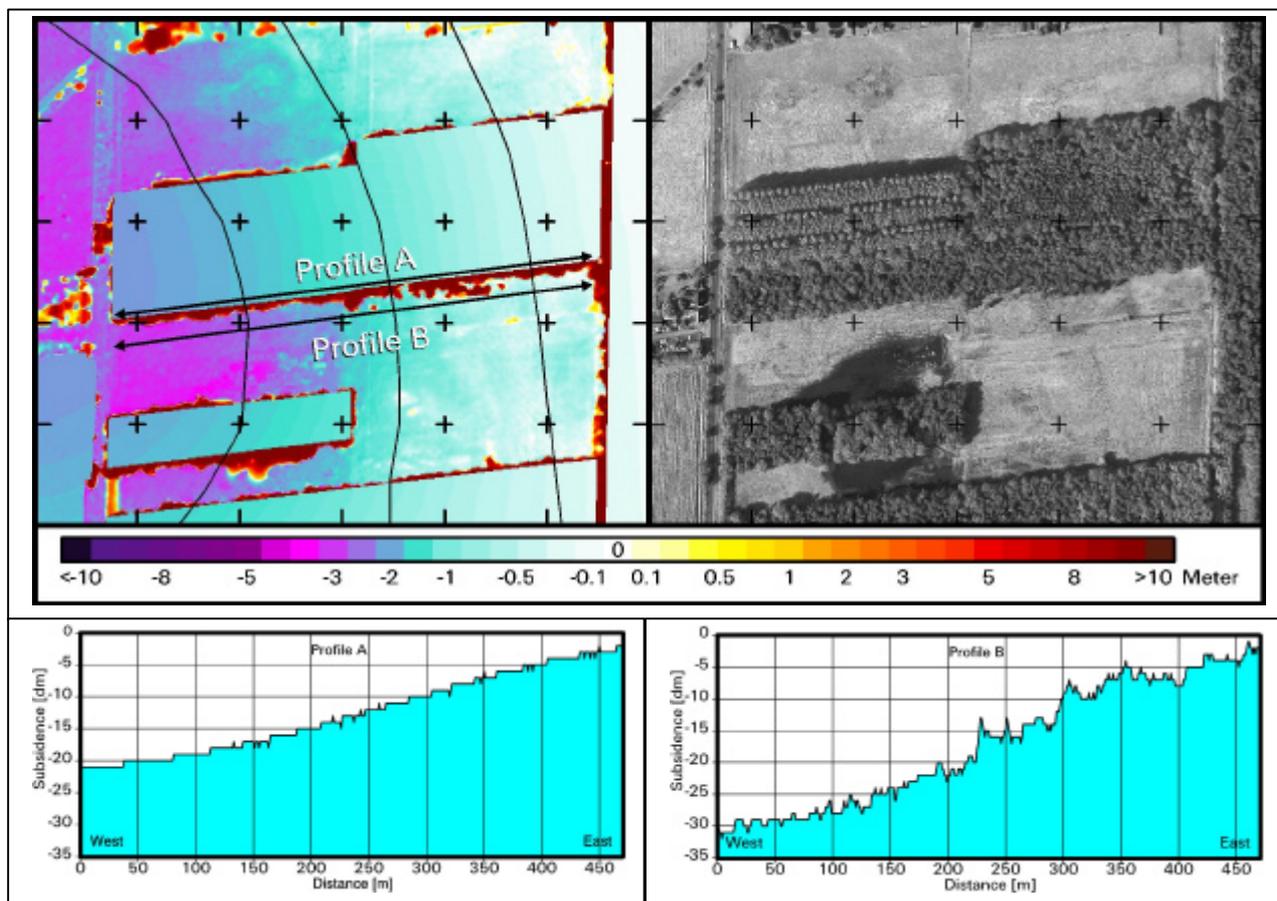


Fig. 6: HRSC-A orthoimage (upper right); DHM'93-98 (upper left) showing the location of height profiles "A" with calculated subsidence [dm] (lower left) and "B" with measured subsidence [dm] (lower right)

For the verification of this assumption the GPS-measurement (Feb. 1999) is used. In the period of five months between August 1998 and February 1999 a maximal subsidence of 10 cm can be assumed for areas with large movements. The location of the GPS points was used to build up a new data set containing the heights of GPS, of the subsided DTM'93 and of the HRSC-A DEM'98.

For this special region the difference between GPS measurements and HRSC-A DEM'98 lies between +30 cm and -30 cm for areas that are not disturbed by vegetation. The comparison of the GPS measurements with the calculated subsidence from March 1993 to August 1998 shows that the surface of the calculated model lies 50 cm to 150 cm above

the GPS heights (see Fig. 7). In this specific case it is clear that for planar and non-vegetated areas the HRSC-A DEM is more accurate than the subsidence calculations.

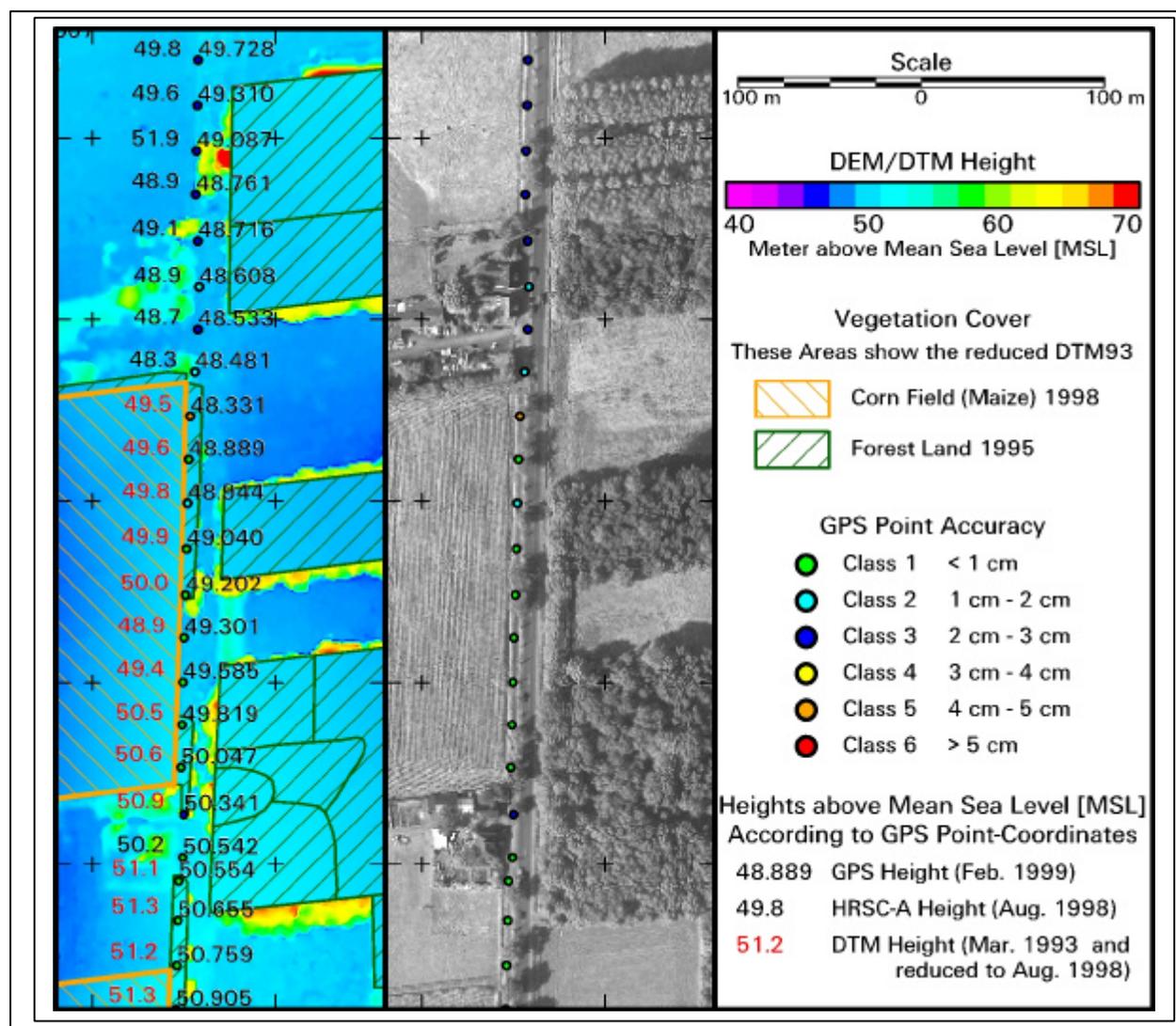


Fig. 7: Comparison of heights in GPS points (left): GPS-heights [mm], HRSC-A-DEM'98 [dm] and subsided DTM'93 [dm] (red); HRSC-A orthoimage with GPS point location and class (middle); legend (right)

#### 4 CONCLUSIONS

An accurate surveying method is necessary to monitor subsidence areas and to update given predictions. The analysis of different airborne scanner data permits the generation of high resolution DEM and the use of orthoimages for current land-cover data. Using multitemporal data analysis and integration of terrestrial data the determination of changes of the topographic situation can be performed. The results can be used to update the GIS. One step to gain more accurate data sets for the calculation of digital terrain models with a low influence of vegetation and small shadow-covered areas is a data acquisition at noon in the months of March and April. According to the evaluation the HRSC-A camera is suitable for multitemporal surveys to detect underground mining subsidence over longer periods for movements being larger than the system accuracy of  $\pm 20$  cm and to back and control currently used methods.

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