MONITORING OF HARD COAL MINING SUBSIDENCE BY AIRBORNE HIGH RESOLUTION DIGITAL STEREO SCANNER DATA

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ABSTRACT
Due to legal requirements the German hard coal company "Deutsche Steinkohle AG" (DSK) is obliged by assessments on environmental impact to make a prognosis and to forecast influences caused by current excavations. Important data needed are "Digital Terrain Models" (DTM) which describe the topographic situation, information on biotopes and the actual land-cover. Today these data are generated by methods of analytical 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

Deep hard coal mining activities lead to influences caused by subsidence movements. The excavation at a depth of about 1000 m leads to the development of progressing subsidence basins on the earth surface. Local annual subsidence of several dm have to be expected. Therefore high demands to planning and monitoring are required because occurring effects may entail lasting changes and influences on the environment. To minimize those effects extensive environmental compatibility studies have to be performed and detailed prognosis have to be made.
Photogrammetric measurements and derivated high resolution DTM are fundamental information to register the current topographic situation and to detect subsidence movements over the time. These measurements done with analytical stereoplotters 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 done gathering current information on land-cover and biotope. In regard of the large area (1.500 km²) that has to be monitored manual field work is even 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. The dynamic mining activities demand to update 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 camera [1] in May 1998 and simultaneously with the HRSC and the HYMAP scanner [2] in August 1998.
The first case studies shown in this contribution were done to acquire the accuracy in height. These investigations can be assisted by using the HYMAP-data.

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2. REFERENCE DATA

In March 1994 DSK acquired a homogenous DTM over an area of approximately 300 km². Based on aerial photographs with an image scale of 1:6.000 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. 1 shows the 1m-contour lines for the *"Calculation of Expected Subsidence"* from 1993 to 2004.

When details about the mining activities, location and the amount of extracted matter are known a more precise *"Calculation of Subsidence"* can be performed, often backed by annual or biannual measurement of levelling networks.

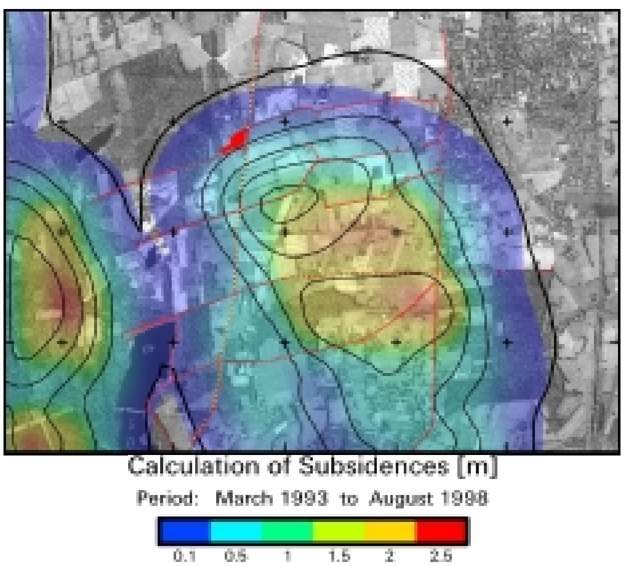

Fig. 1: HRSC-A ortho image (August 1998) and *"Calculation of Subsidence 1993–1998"*; overlay: red: GPS-points 1999, yellow: line levelling points, black: 1m-contour lines *"Calculation of Expected Subsidence 1993-2004"*.

A GPS-campaign was done in February 1999 to gather current ground-truth data of subsided areas. An area of 4 km² 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. Additional a parking lot area of 1,6 ha was covered with a 5 m grid mesh (540 points). This place is totally covered by both HRSC-A DEM and was even recorded by an aerial flight in March 1993. The same points measured by GPS were re-measured on an analytical stereoplotter using the aerial photographs from 1993.

All GPS points were transformed to the Gauß – Krüger coordinate system by using the SAPOS reference station no. 582 in Essen at a distance of 16 km. A classification for the accuracy of the GPS points is given in Tab. 1 by number and percentage of points for each class:

Class	Accuracy	Points	%
1	< 1 cm	1353	78,4
2	1cm – 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: Statistics for GPS measurement.

An impression of occured subsidence gives Fig. 2 showing the heights of the line levelling for the years 1992 to 1999 and the GPS-heights in 1999.
The inaccurate GPS points belong to "Class 6". The false heights depend upon the badly solved ambiguities of the GPS-signal.

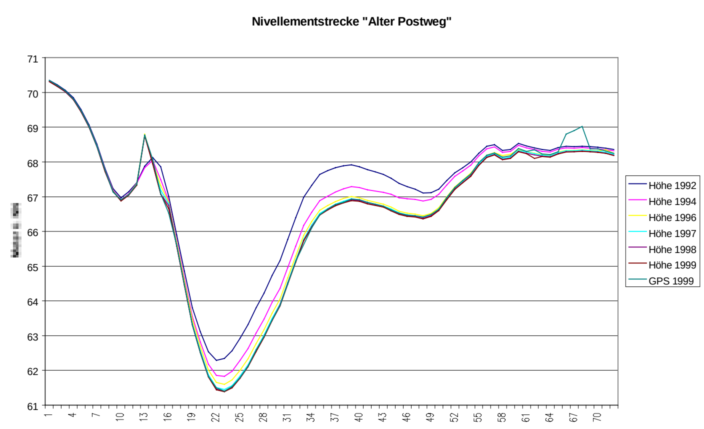

Fig. 2: Line levelling heights from1992 to 1999 and GPS-heights 1999.

3. COMPARISON OF HRSC-A AND REFERENCE DATA

The processing of the HRSC-A data was done by the generation of a ”Digital Elevation Model” (DEM) by using five stereo-channels additionally including two photometric channels to get 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 was determined to 0,05 thousandth what results to ±20 cm [3].

In 1998 the flight campaigns with the HRSC-A camera took place in May and August. For this reason the height data is affected by the growing vegetation and the comparison with the reference data is influenced by the different growth stage of forests, grain- and cornfields. A direct evaluation can only be done for fallow land, bare soil or pastureland. Nevertheless land subsidence of nearly 2.5 m in the long-term period from 1993 to 1998 can be recognized in Fig. 3:

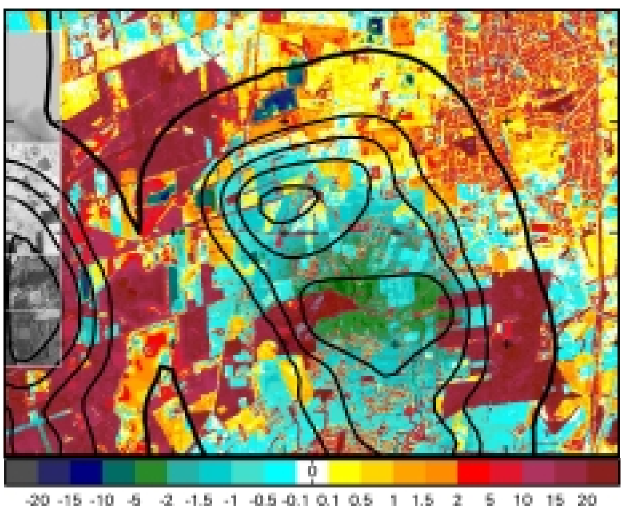

Fig. 3: Superimposition of Height Differences [m] (Analytical DTM 93 minus HRSC-A DEM 98) and HRSC-A data (left side); with an overlay of *“Calculation of Expected Subsidence 1993-2004”*.

The colored image contains the height differences in [m] between the HRSC-A DEM (August 1998) and the analytically measured DTM (March 1993). The left part of the image presents, from top to bottom, the analytical DTM from 1993, the HRSC-A DEM (May 1998), the HRSC-A DEM (August 1998), the HRSC-A ortho image (May 1998) and the HRSC-A ortho image taken in August 1998.
All image parts are overlaid by the 1m-contour lines *“Calculation of Expected Subsidence 1993-2004”*.

Compared with Fig. 1 the shape and amount of the subsidence is similar to *the “Calculation of Subsidence 1993 to 1998”*. Both data sources differ from the predicted model *“Calculation of Expected Subsidence 1993-2004”* in the same manner. If only fallow land and harvested fields are regarded the HRSC-A DEM and *“Calculation of Expected Subsidence 1993-2004”* show average differences of ±30 cm.

According to the flight campaign a coeval data recording of current land-use was performed in August. For this reason height differences can be assigned to land-use what can be seen in Fig. 4.
The differences of both the HRSC-A height data in August and May 1998 obviously show the different growth stage of the vegetation. The inquiry of the land-use revealed that nearly 90% of the agricultural land-use are grain- and cornfields. In May grain fields grew at a height of about 1.2 meters while the maize hardly reached 20 centimeters, but in August all grain fields were harvested and the corn has grown to a height of 1.8 meters.

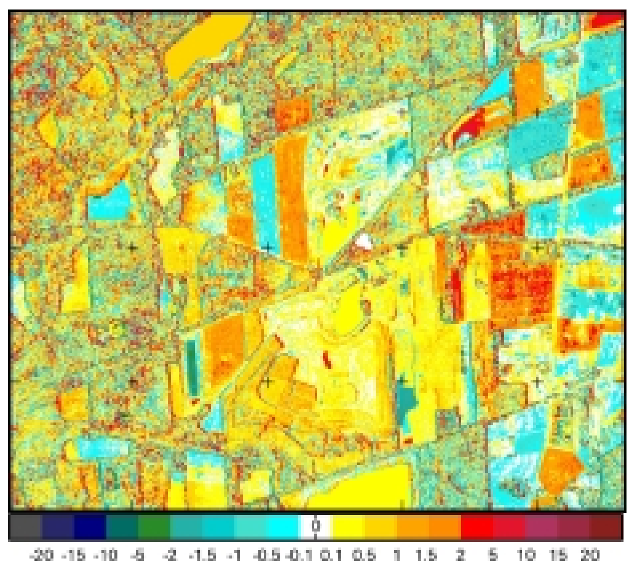

Fig. 4: Difference of HRSC-A DEM: (August minus May 1998), unit [m].

Harvested grain fields are situated under light blue-colored areas and the color-range from orange to red belongs to cornfields. Yellow colors appear at pastureland and on fallow land. Green and blue areas show the progression and dark-red colors the refilling of current gravel excavation areas.
The amount of differences on agricultural areas shows Tab. 2:

Vegetation cover	calculated differences in height
fallow fields	0 to +30 cm
pastureland/grassland	0 to -30 cm
corn	+50 to +150 cm
coniferous woods	+50 to +80 cm
harvested grain fields	0 to -130 cm

Tab. 2: Height differences of vegetation cover (Mai minus August 1998).

To estimate the accuracy of the HRSC camera the height data was examined for the area of a parking lot. The differences in height and the areas covered by parked cars are shown in Fig. 5. Regions only covered with asphalt are represented by differences from –20 cm to +20 cm corresponding to the system accuracy [3].

A repercussion to the height accuracy of HRSC-DEM can be seen over shadow areas of trees and woods (see Fig. 4 and 5). For the May-campaign data was recorded at 09:00 AM and for the August-campaign at 04:30 PM. In May the shadows lie in northwestern (blue colors) and in August in northeastern direction (dark-red colors). The differences up to more than 20 meters can be found in both elevation models and have to be carefully handled for further works on the DEM.

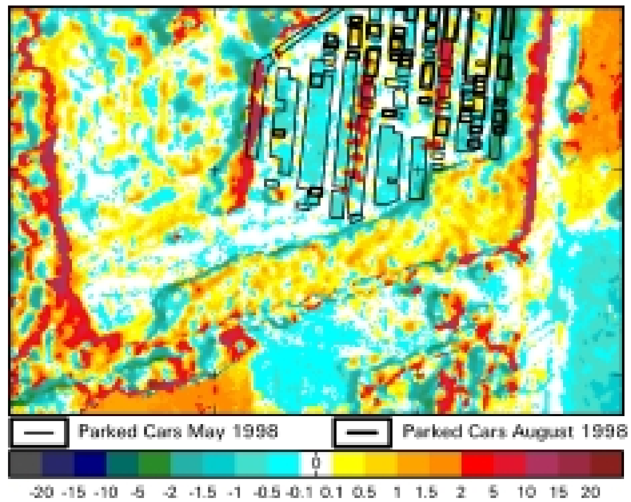

Fig. 5: Differences of HRSC-A DEM [m]: (August minus May 1998) and overlay with areas of parked cars in May and August 1998.

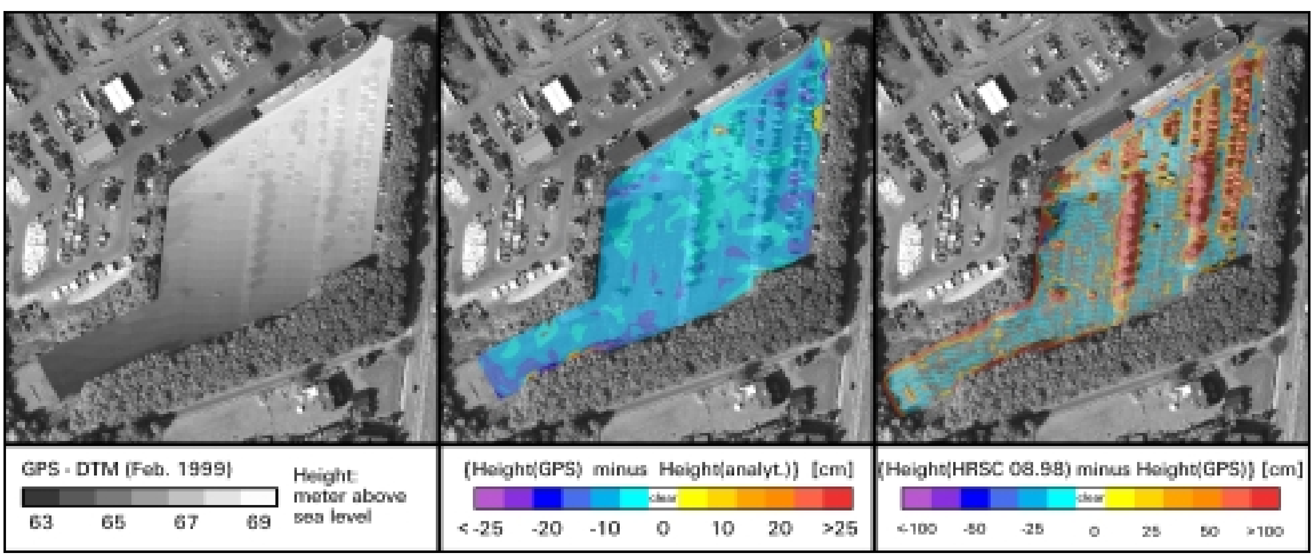

Fig. 6: DEM based on GPS-measurements 1999 (left), calculated differences between GPS measurements and analytical measurements 1993 (middle), calculated differences between HRSC-DEM and GPS measurements.

Furthermore 540 GPS points were measured on the parking lot area in February 1999. These GPS coordinates were used as a data set for a re-measurement by an analytical photogrammetric stereoplotter in two models from the aerial photographs taken in March 1993.

Fig. 6 shows the HRSC ortho image from August 1998 and translucent the GPS-DEM (left), the differences between GPS-DEM and the analytical DEM (middle) and the differences of the HRSC-DEM (August 1998) and the GPS DEM (right).

The comparison clearly indicates that the accuracy in height is nearly identical and within the precision of each used system. It can be recognised that the differences between GPS based DEM and the analytical DEM show an offset of – 5 cm to –10 cm in the northern and to –20 cm in the southern part. The amount of the differences indicates that the heights measured in 1999 are lower than in 1993. The distribution of the differences indicates effects to the surface caused by underground mining activities. The evaluation of the height data for the whole parking lot area was done with the program BLAN (University of Hanover) and leads to the results presented in Tab. 3. This comparison of corresponding GPS- and analytically measured DTM points results in a standard deviation lower than 10 cm but does not clearly show the different movements within the area.

Comparison	Standard Deviation S_z [m]	Systematic Part [m]	Standard Deviation without Systematic Part $S_{z'}$ [m]
GPS (99)–analyt. (93)	±0,078	-0,064	±0,045
HRSC 08. – 05.'99	±2,98	-0,82	±2,86

Tab. 3: BLAN Analysis

Fig. 7 shows the subsidence of the levelling points 1130 and 1160, located directly near the road easterly to the parking lot. Point no. 1130 lies near the northern and point no. 1160 near the southern margin of Fig. 6 at a distance of 200 meters to each other (see also Fig. 1).
In seven years levelling point 1130 sank about 18 cm and point 1160 was subsided with 32 cm. These amounts can be comprehended in Fig. 6 (middle).

The right part of Fig. 6 shows the comparison of the HRSC-DEM and the GPS based DTM. Differences from 0 to –25 cm in steady areas and values in the range of the accuracy of the HRSC were calculated. Differences from 0 to +1 m corresponding to the systematic part of –0.82 cm of the BLAN-Analysis– can be found at parked cars and even in areas cast by shadows. Values greater than +1 m can be found at and near trees.

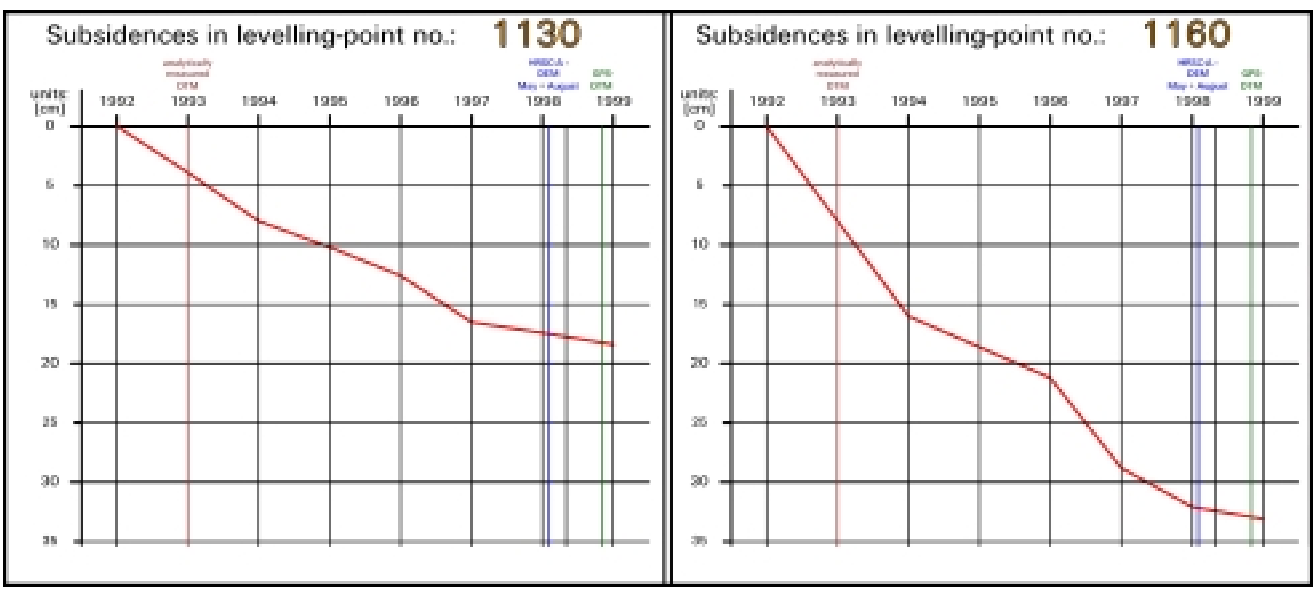

Fig. 7: Subsidence in levelling points no. 1130 and no. 1160 in the period from 1992 to 1999.

4. COMPARISON OF HRSC-A AND REFERENCE DATA

The main emphasis on the current investigations is laid upon the recording of the current land-use on large scale and the determination of occurring changes resulting from mining activities. The goal is the creation of fundamentals and exemplary data layer for an environmental monitoring system which shall comprise the analysis of remote sensing data as an important constituent [4].

The combined evaluation of HRSC-data and the hyperspectral scanner HYMAP contains a large potential even for the updating and revision of land-use maps as for the verification of the current land-cover.

The comparison of data acquired at different growth stages of the vegetation shows the possibility to discern vegetation areas of different growing conditions within one field with a single agricultural land-use. These differences may depend on the soil type, soil disturbances caused by the refilling of gravel excavations or a change of the soil moisture caused by mining subsidence [5] or subsurface drainage to maintain subsided agricultural areas.

The following example regards the changes of a cornfield and a barley field from May to August.

The upper row of Fig. 8 shows the HRSC ortho image (left) and DEM (middle) recorded May 14. 1998, the second row shows the same HRSC data for August 20. 1998. The DEM data contain a color-slice from blue to red for the heights between 62.5 and 66 meters above mean sea level [MSL]. A profile was measured for both elevation models (right images).

The lower row presents the georeferenced HYMAP image with the channel-combination 28-84-16 according to Landsat-TM 4-5-3.

Within this image three points were marked ("**o**") and with the knowledge of the corresponding heights in the HRSC-DEM the following assumption was made:

northern point: vital corn,
second point: soil,
southern point: corn, lower vitality.

And in fact, according to the assumption, the HYMAP-spectra purveyed (see Fig. 8, lowest row, right image):

northern point: vital corn
second point: soil
southern point: corn, lower vitality.

Further investigations will examine the potential of the combined HRSC- and HYMAP-data even for the generation of vegetation masks to eliminate the disturbing influence of forest areas and stocks of trees and for the verification of subsidence basins by increasing soil moisture.

5. CONCLUSION

An up-to-date surveillance is necessary to monitor effected areas and to update given predictions. The analysis of different airborne scanner data permits the generation of high resolution DEM and the derivation of current land-cover data. Utilizing multitemporal data analysis and integration of terrestrial data the determination on changes of the topographic situation can be performed. The results can be used to update the GIS.

According to the evaluation the HRSC seems to be suitable for multitemporal surveys to detect underground mining subsidence over longer periods for movements being larger than the system accuracy of ±20 cm. To gain more accurate data sets for the calculation of digital terrain models the same rules have be followed as for a campaign with normal photogrammetric cameras: data acquisition at noontime (small shadow-covered areas) in March/April with a low influence of vegetation.

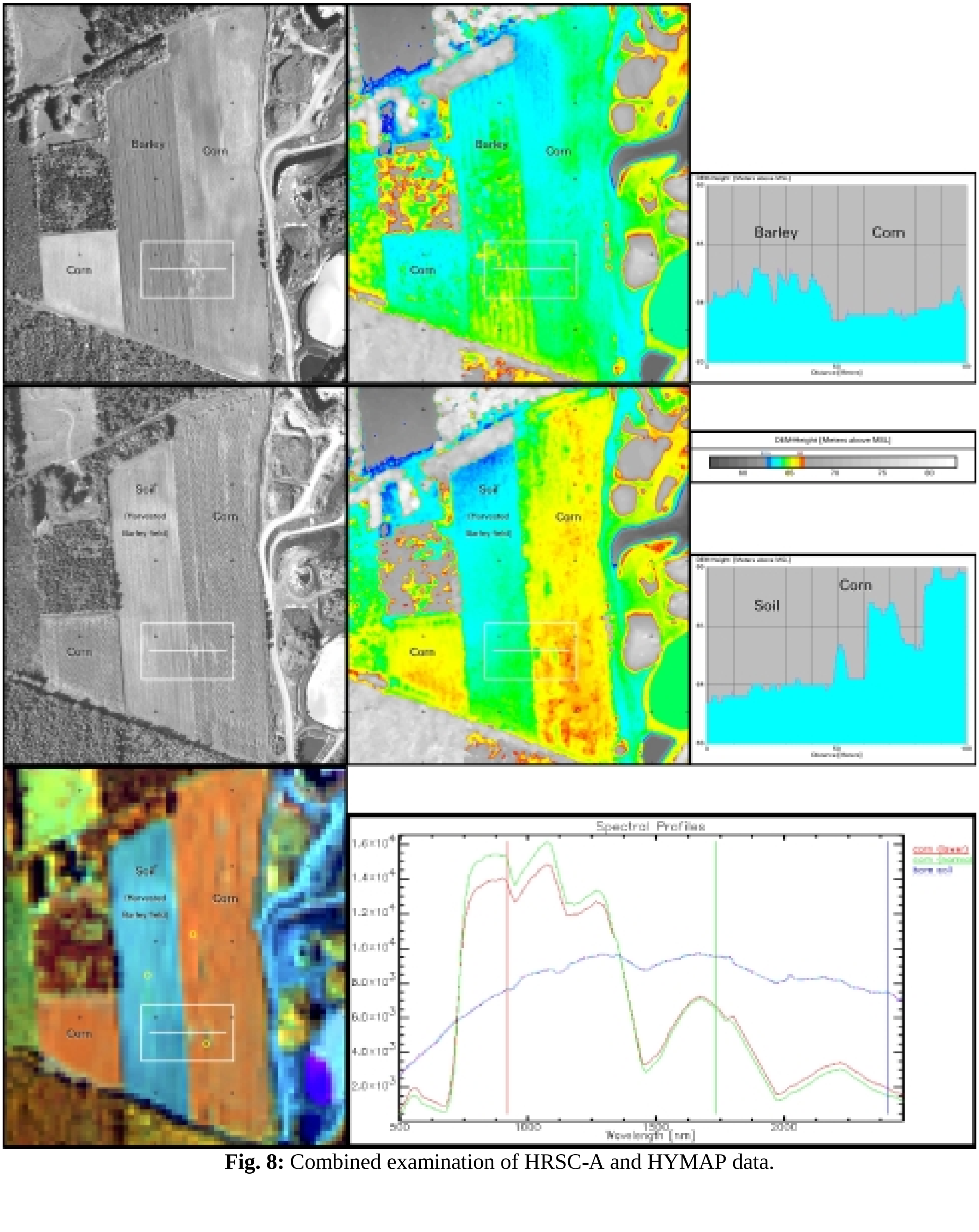

Fig. 8: Combined examination of HRSC-A and HYMAP data.

6. REFERENCES

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