FFI RAPPORT

USE OF COMMERCIAL AERIAL PHOTOGRAPHY AND SATELLITE IMAGES DURING EXERCISE "STRONG RESOLVE"

BJERKE Pål

FFI/RAPPORT-2004/01361

USE OF COMMERCIAL AERIAL PHOTOGRAPHY AND SATELLITE IMAGES DURING EXERCISE "STRONG RESOLVE"

BJERKE Pål

FFI/RAPPORT-2004/01361

FORSVARETS FORSKNINGSINSTITUTT
Norwegian Defence Research Establishment
P O Box 25, NO-2027 Kjeller, Norway

FORSVARETS FORSKNINGSINSTITUTT (FFI)
Norwegian Defence Research Establishment

P O BOX 25
N0-2027 KJELLER, NORWAY

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE
(when data entered)

REPORT DOCUMENTATION PAGE

1) PUBL/REPORT NUMBER	2) SECURITY CLASSIFICATION	3) NUMBER OF PAGES
FFI/RAPPORT-2004/01361	UNCLASSIFIED	53
1a) PROJECT REFERENCE	2a) DECLASSIFICATION/DOWNGRADING SCHEDULE	
FFI-III/839/1	-	

4) TITLE

USE OF COMMERCIAL AERIAL PHOTOGRAPHY AND SATELLITE IMAGES DURING EXERCISE "STRONG RESOLVE"

5) NAMES OF AUTHOR(S) IN FULL (surname first)

BJERKE Pål

6) DISTRIBUTION STATEMENT

Approved for public release. Distribution unlimited. (Offentlig tilgjengelig)

7) INDEXING TERMS

	IN ENGLISH:		IN NORWEGIAN:
a)	Satellite imagery	a)	Satellittbilder
b)	Aerial photography	b)	Flyfoto
c)	Remote Sensing	c)	Fjernmåling
d)	3D-modelling	d)	3D-modellering
e)		e)	

THESAURUS REFERENCE:

8) ABSTRACT

Elevated sensors with imaging capabilities have been used by the military for approximately 150 years. Cameras onboard balloons, airplanes and satellites have given information of vital importance to different nations through the years. For the last 30 years, images from commercial optical satellites have been available and used by nations not able to have their own photo satellite.

At FFI there have been projects on investigating military use of commercial optical satellite images since 1989. The first satellite investigated was SPOT with a resolution of 10 meters, suitable to analyse infrastructure. In 1999 the IKONOS satellite with a resolution of 1 meter was launched into orbit, and objects of the size of a car were detected. In 2001 the commercial optical satellite QUICKBIRD became operational with a resolution of 0.6 meters, after the American congress introduced a new lower limit of resolution of 0.5 meters.

For the exercise Strong Resolve 2002, aerial images in different resolutions down to 10 cm were obtained. These were investigated for use in planning. Satellite images from both IKONOS and QUICKBIRD were ordered to be taken while the exercise was held. The images were later used to investigate the ability to detect military units participating in the exercise.

9) DATE	AUTHORIZED BY This page only	POSITION
2004-04-20	Johnny Bardal	Director

ISBN-82-464-0823-2

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE
(when data entered)

CONTENTS

USE OF COMMERCIAL AERIAL PHOTOGRAPHY AND SATELLITE IMAGES DURING EXERCISE "STRONG RESOLVE"

1 INTRODUCTION

Imaging from above has been a source of information for the military for many years. From the early days by using balloons, then airplanes, and so through the last 40 years the use of satellites. The changeover from aerial photos to satellite images, gave new opportunities in military surveillance when limited access areas could no more be prevented from being photographed.

The photo satellites with the best resolution are reserved for the largest nations, both because of the cost and the advanced technology. American authorities however opened in 1993 up for sales of optical satellite images with resolution down to 1 meter, and further on in 2001 they moved the limit to 0.5 meters. Images with such a good resolution could reveal objects and infrastructure of a military sensible kind, and will by some people be considered to be beyond the limits of necessary security.

During the last 20–30 years, imagery has moved gradually from film/paper to the computer screen. The digital manipulation of the imagery has greatly increased the possibility to extract and utilize the information. This especially applies to comparing and putting together information from different maps and imagery (data fusion). Another popular technique involves use of elevation models for 3 dimensional visualisation.

FFI has been working with optical imagery from commercial satellites for more than 12 years. The activity includes evaluating and developing the information from the imagery with the purpose to cover military needs. The access of commercial optical satellites with still better resolution is the prime reason for the continuing work. The information within the images has increased, and an extended number of users can potentially use the information. Commercial satellite images do not today cover the need for near real-time imagery. The reason is mainly the ordering and delivery time, which can be days and weeks.

The typical military use of images from commercial optical satellites is planning and surveillance. For planning purposes, the use of imagery can often give information more accurate and fresher than most maps available. For surveillance purposes images from above can be taken on a regularly basis to study changes in e g installations and infrastructure.

During exercise Strong Resolve 2002 one wished to evaluate the importance of higher resolution of the imagery to cover the information needs from the military. Satellite imagery was taken during the exercise. The evaluation of these images is the main object of this report.

The imagery was ordered in grey scale, which better suits the conditions with winter and snow. Also, aerial imagery with resolution down to 10 cm to evaluate imagery for planning.

2 EARLY WORK

FFI started in 1989 work on evaluating commercial optical satellite images for military use. At the time media showed commercial satellite images from military bases in Soviet. The first images taken from LANDSAT 5, had a resolution of 30 meters (1984), while images taken from SPOT had a resolution of 10 meters (1986). The infrastructure of military bases was clearly visible.

When starting, the main thing was to build competence in the field. At the same time SPOT satellite images were bought for training purposes. Imagery were both from military bases at Kola as well as from near-by places in Norway in order to be familiar with the motive of the imagery.

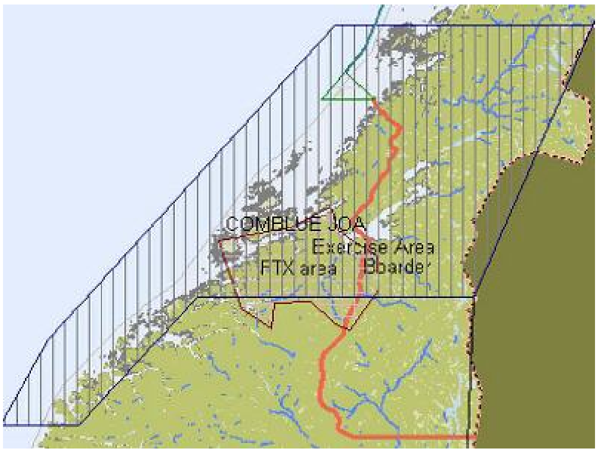
At the time, little or no software for manipulating satellite images was available, making the need for developing our own software. Through the 90's a program for administration and manipulating satellite images was made (DIMAS), and is still in use. Further, we developed algorithms for calculating elevations from SPOT stereo imagery. At the same time, we also developed methods for detecting and identification of objects. The moderate resolution of 10 meters restricted the work to study infrastructure and objects like roads and buildings [1].

In 1993 US authorities gave permission for sales of imagery from commercial optical photo satellites with a resolution of 1 meter. Several satellite operators advertised planning of new satellites that should cover the resolution of 1 meter. FFI then started a new project in 1997-1998 that among other things had the purpose of evaluating the military use of those new satellites to come [2].

It took some years to get the first commercial 1-meter satellite in orbit. The reasons were both technical and economical problems, in addition to launch failures (EARLYBIRD and IKONOS 1). On the September 24 1999, the IKONOS 2 at last went into orbit (IKONOS 2 is later referred to as just IKONOS). It was now of interest to study the possibilities of the new imagery, and in the years 2000-2001 FFI analysed IKONOS imagery. Satellite maps were produced, and they were warmly welcomed by the military users. It was also found that light and shadows were of great importance in process of interpreting the imagery. The work was presented in a report in 2001 [3].

3 PLANNING

When coming to the NATO exercise Strong Resolve 2002 (SR2002), it was decided that FFI should test the use of aerial photos and satellite imagery. The exercise was conducted in March 2002, and took place in the central part of Norway, as shown in figure 3-1.



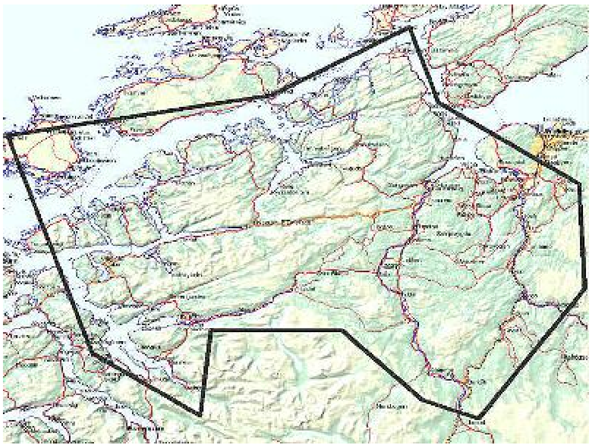


Figure 3-1 Map of the exercise Strong Resolve 2002. Left the total exercise area, and right the area of the land battle.

Several things were tested. At the time,the commercial photo satellite QUICKBIRD had recently been available with a resolution of 0.62 meters, and it was desirable to be familiar with its potential. A comparison between QUICKBIRD and IKONOS, with a resolution of 1 meter, was planned. Ordering imagery from both satellites also increased the possibility to get at least one successful image from the exercise. Getting cloud free imagery from that area in the middle of March is limited.

To order imagery, it was necessary to know where interesting activity of the exercise would take place and at what time. Interesting activity means fighting units doing their job with their normal equipment. This was rather difficult since the exercise plans were limited to the exercise planning group, and the fact that the exercise was so free that it was unsure where the units would be at the time. With assistance from FKS (Defence Headquarter South), an area between Rindal and Storås was selected for the period from March 10. to March 15. (the satellite operators wanted a timeslot of 5 days).

It was also of interest to look at image resolutions from 50 cm, which is the limit for commercial satellite imagery, down to 10 cm, which is assumed available from military satellites. This was accomplished by ordering aerial photography in different resolution from within the exercise area.

Our main contact at FKS was the Target and Photo intelligence section. The word target is meant as installations of tactical importance, which if destroyed could give a military advantage. Examples are bridges, harbours, airports, industry etc. The targets are part of the infrastructure, and are chosen in peacetime. Before the exercise FFI was given the identity of several targets. For the last years a 3 dimensional visualising program has been in use at the FFI. This 3D-program was used to visualise the targets to check if this could give advantage over the “flat” imagery.

4 AERIAL PHOTOGRAPHY

Aerial photography has existed for nearly 100 years, and is primarily used for cartography and area planning. Another use is construction of elevations by comparing imagery of the same area taken from different angels (stereo pairs). Even if aerial photography is used as raw material for constructing maps, the imagery itself might be useful when it comes to details. There will always be limits for when to use photography and when to use a map. The map gives a simple representation of an area, with well known symbols and a limited level of details, making it easy to read. The imagery however shows the complex reality of the smallest detail, but with no help to interpret what is seen. For some military applications, like targeting, a combination of photography and map will give the best result. The map used to place the target in the terrain, and imagery to assess the function and vulnerability of the target.

Aerial photography is usually divided in vertical and oblique imaging. Vertical imaging represents the earth in a way that somewhat removes the understanding of elevation. It gives although a very good description of the relationship of objects in the horizontal plane, and is well suited for map production. Oblique imaging gives imagery that is difficult to measure on. The perspective view, however, gives a better 3 dimensional understanding of the motive, and is well suited for analysis and identification of objects.

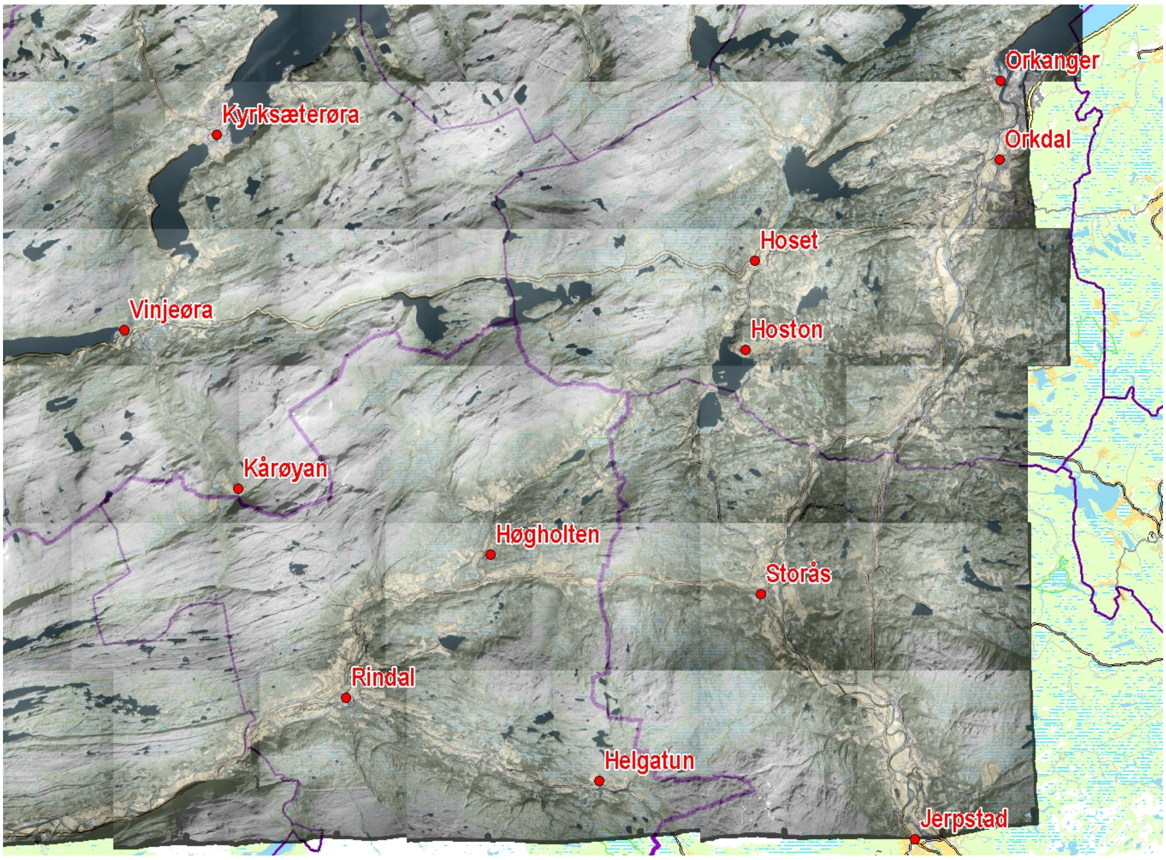
The use of aerial photos is connected to how old the photos are. For some types of planning tasks, even photos several years of age are useful, if the infrastructure has not been changed. However, several uses of the photos have strict demands on the age of the photos. In cases like intelligence and Battle Damage Assessment (BDA), the photos should be as fresh as possible. Only the transport and the processing of the images should give the images age, in the vicinity of 1 hour or less.

Aerial photos are seldom useful in their original form. Most often the imagery must be geometrically corrected, and in several cases the information from the imagery will be used in cartographic products. This is a task well suited for computers, and it is therefore necessary to have the imagery represented in an electronic form, readable for the computer. This is done through a scanning process, measuring the intensity values of the picture elements (pixels). All aerial photos used in this project are in electronic form.

The Royal Norwegian Air Force shut down their only photo squadron the autumn of 1979. Since then the military have used allied aircrafts to cover their needs for aerial photos over Norwegian areas. The use of aerial photos seems to have been reduced. This has also resulted in less experienced photo interpreters. The aerial photos in military archives today are from selected areas, and have varying age. Most of the imagery covers specific areas and objects, and does not continuously cover any larger area. Objects are commonly photographed both vertically and oblique. In this project all the imagery was vertical since different photos should be compared and had to be in a certain coordinate system. The imagery had to be rather new to insure that the infrastructure was unchanged. The imagery was acquired from commercial aerial photo operators.

4.1 AQUIRING AERIAL PHOTOGRAPHS

Since the project could not afford to have the area photographed, we had to see what was available in the archives of the commercial aerial photo operators. During the first contact with the operators, Fjellanger Widerøe A/S [4] and Fotonor A/S [11], we asked for information about the imagery taken the last 5 years within the area of land battle (see figure 3-1). From Fjellanger Widerøe A/S imagery was available from 1999 covering most of the exercise area. The imagery was black/white, and was taken from a height giving a scale of 1:40.000. With a scanning density of 14 µm this gives a resolution of approx 50 cm. This is a suitable resolution to investigate, since this is exactly the legal limit for resolution of commercial satellite imagery. At the same time it was possible to cover large parts of the exercise area in a reasonable way, both regarding to price and memory (see table 4-1). The Military Geographic cell at The Weaponry School of the Engineers (VSIV) that planed to participate in the exercise, and use the imagery as well, but needed a larger coverage. It was found that older imagery was available at the Central Archive for Vertical Imagery. This archive contains every vertical image more than 5 years of age. Today the archive has more than 2 million aerial



Figur 4-1 Coverage of the exercise area with aerial photos with resolution of 50 cm (Copyright Fjellanger-Widerøe A/S)

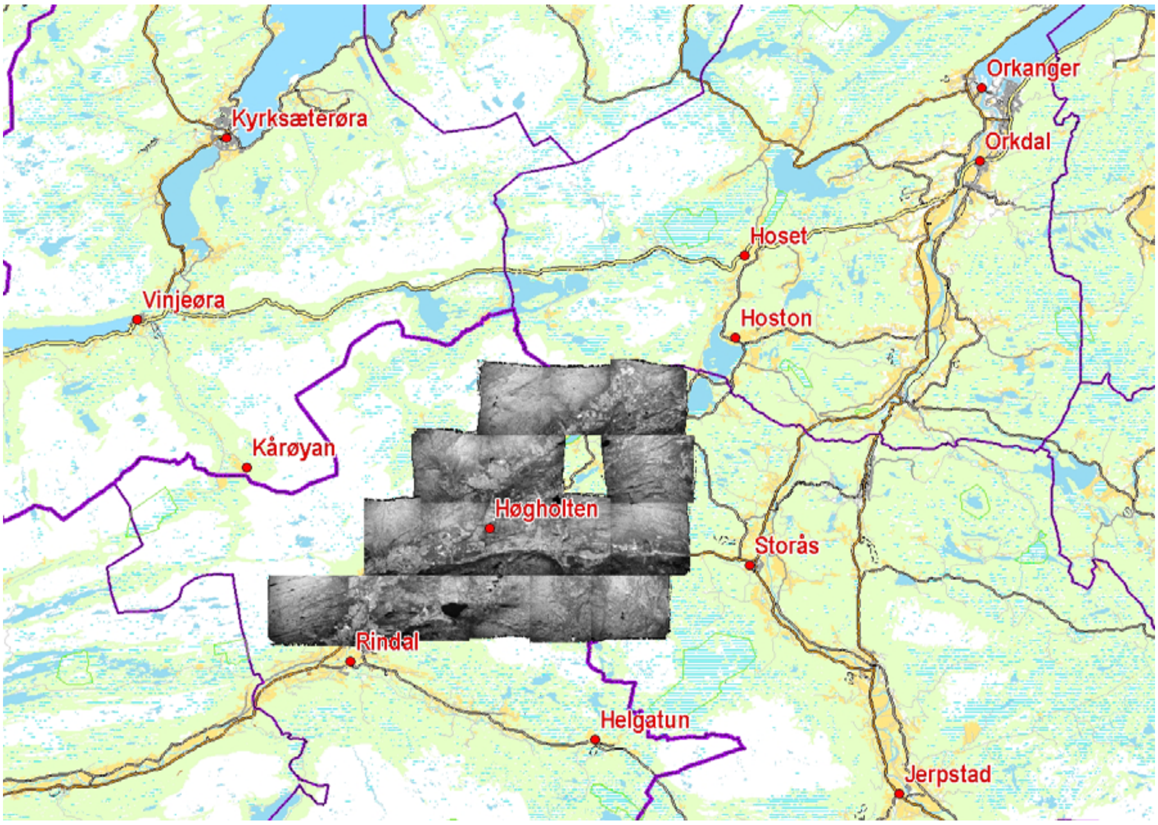


Figure 4-2 Coverage of the exercise area with aerial photos with resolution of 25 cm (Copyright Fotonor A/S)

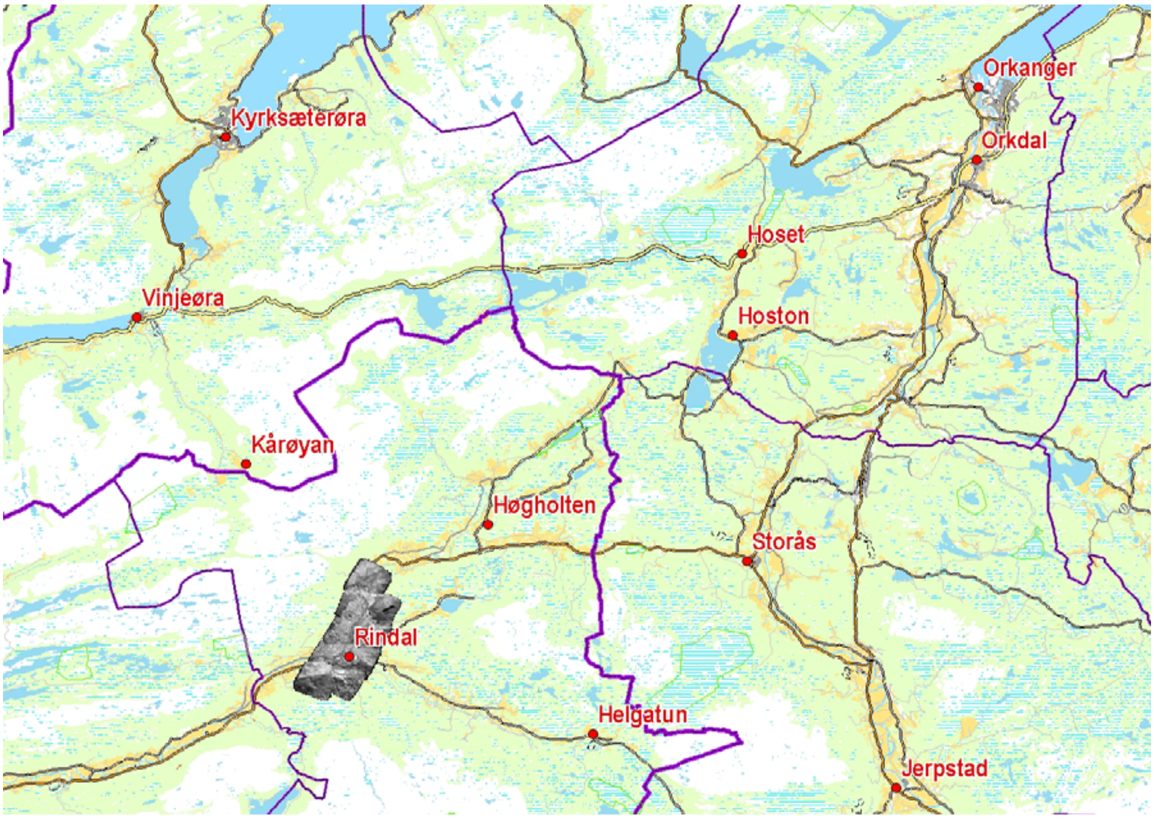


Figure 4-3 Coverage of the exercise area with aerial photos with resolution of 10 cm (Copyright Fotonor A/S)

Coverage	Year	Scale	Scan density [µm]	Resolution [cm]	# of images	Area [km^2]	Memory [GB]	Price [NKO]
Land battle area	1988/91/98	1:40.000	14	56.0	77	3500	11.0	26.000
Area of Rindal.	1999	1:18.100	14	25.34	18	225	3.3	8.300
The centre of Rindal	1999	1:8.000	14	11.2	9	18	2.7	4.500

Table 4-1 Survey of obtained imagery

photos back from 1930. In this archive we found the imagery wanted by VSIV from 1988 and 1999. The total coverage of the 50 cm imagery is shown in figure 4-1.

It was also a goal to study imagery with resolution better than what was available from commercial satellites. From Fotonor A/S it was found imagery over the Rindal area from 1999. These images had been taken from a height giving a scale of 1:18.000 and 1:8.000. With a scan density of 14 µm those images had a resolution of 25 cm and 10 cm. By having a common coverage of an area with 50 cm, 25 cm and 10 cm imagery, there was a good opportunity to study the significance of resolution for the detection and identification of objects on the ground. A resolution of 10 cm is supposed to be near the limit of what is possible on military satellites Figure 4-2 and 4-3 shows the coverage of aerial photos with resolution of 25 cm and 10 cm

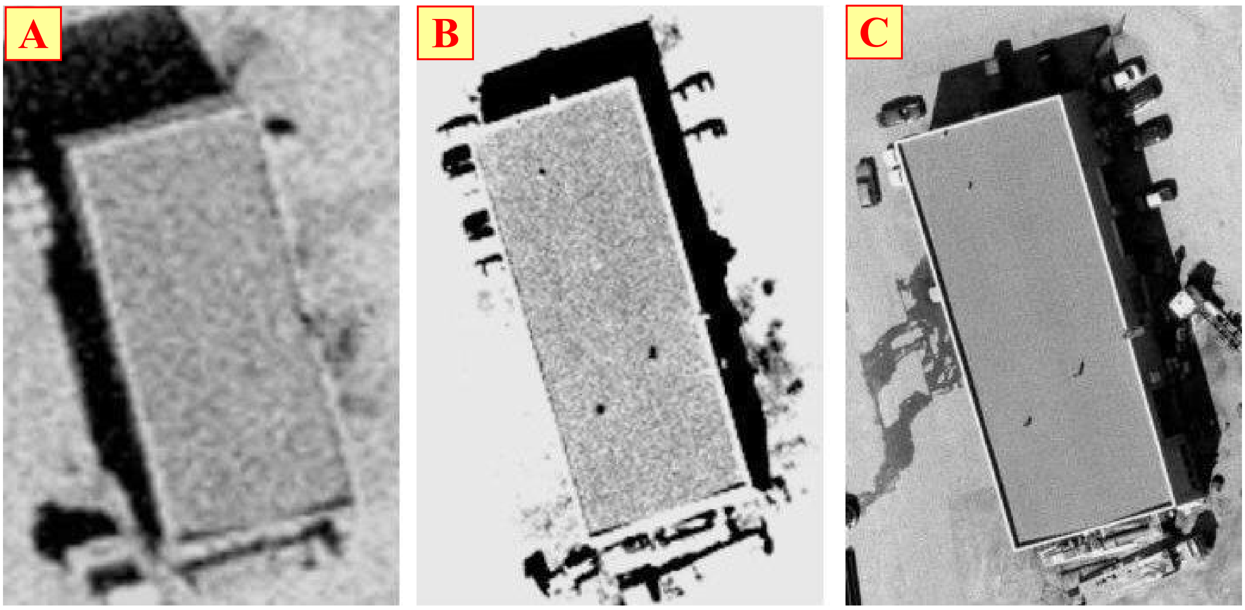


Figure 4-4   Comparison of imagery with different resolution

A) 50 cm (Copyright Fjellanger Widerøe A/S)

B) 25 cm (Copyright Fotonor A/S)

C) 10 cm (Copyright Fotonor A/S)

It is obvious that better resolution gives finer details in the imagery. What is possible to detect when resolution changes is not that intuitive. Figure 4-4 shows aerial photos of a building with cars around it. In the 50 cm image the cars are detectable, but not clear enough to give a safe classification. The form of the cars is clearer in the 25 cm image, but first in the 10 cm image it is possible to give a certain classification. The ventilation hatches on the roof of the building are also good examples of how details emerge as the resolution gets better. In chapter 7 there is another example on how the certainty of object classification varies with the resolution.

4.2 The cost of aerial photographs

The calculation of the price of aerial photos is a complicated process involving several factors. Besides the flight to the area of photographing and the photographing itself, the operator has expensive equipment to maintain. For all photo missions there is a starting fee to get to the photographing area in the range of 10.000 NOK. The photographing is done in stripes and is paid by the distance in the range of 400 NOK pr km. The length of the stripes is dependent on several factors. If stereo-pairs are needed, that is a pair of images used for calculating terrain height, the images need to be taken with an overlap of 60 % between every image in the stripe, and an overlap of 30% between the stripes. This will practically double the number of stripe-km compared to a single coverage of the area. The wanted scale will decide which height the imagery will be taken from, and affect the width of the stripes. A larger scale will give narrower stripes. Further, the choice of camera (filmformat) will affect the width of the stripes. Next there will be a choice of greyscale or colour imagery, type of paper or perhaps scanning of the imagery. Geometric correction of the imagery is not included in the price. A GPS precise positioning of the aircraft is available at an extra cost.

If large areas are to be photographed, the total price can be considerably reduced since the photographing can be more effective, and the operator offers rebates. Likewise the price will be reduced if the ordering of photographing comes early, before the photo season starts. This will give the operator better opportunity to plan, and the photographing can be more efficiently combined with other orders.

4.3 Geometric correction

Aerial photos are normally delivered on film or (photo) paper. The images show how the earth looks like through the camera, but has no reference to any coordinate system as for example degrees latitude and longitude as used on maps. To make a reference to numbered positions like a map coordinate system, the imagery has to go through a geometric correction. This means in practice to find points in the mage that can be given a unique reference value. This correction is done today with the help of a computer using the scanned version of the image as an input. Computer programs are made especially for this process. On aerial photos marking on the edges (fiducial points) are giving reference to the physical size of the film. In the cameras calibration report will give the exact distance between the fiducial points as well as the focal distance of the lens. This information is necessary to make the geometrical correction. Further the terrain model of the area being photographed has to be known, as well as a positioning reference like a map. The points used as reference must be clear, and have a geometry that will make it possible to position with high accuracy. The correction can't be better than the accuracy of the reference itself. Usually maps are used as reference even if they don't have the precision required. The reason is that reference points with high precision are costly and time consuming to get. It is important that the image is clearly marked with the level of precision that is used.

Geometric correction of imagery can take time, and puts demands on how accurate the operator shall work. Even if the task is done by the computer, it is the operator that chooses the points to use as reference. The price of geometric correction is high. In this project we had the means (programs) to do it, and wanted to get some experience in doing the correction ourselves. At FFI a computer program for image processing, ERDAS, was bought in the spring of 2000. The program is specialized in processing aerial photos, and has a function for geometric correction. As mentioned above, such a program needs the camera parameters as well as a terrain model and a reference that in our case was a vector map. The operator then has to find points in the image that can also be found in the map. Figure 4-5 shows a screen dump of ERDAS in the module for geometric correction. On the left of the screen we have the satellite image to be corrected. On the right the reference is shown, a vector map in scale 1:50.000 (N50). Numbered red circles on both the image and on the map mark points that go together. In the lower part of the image, a table show all the points with their position, height and an error-value. The error-value gives indication on how well each point is coordinated with the total image.

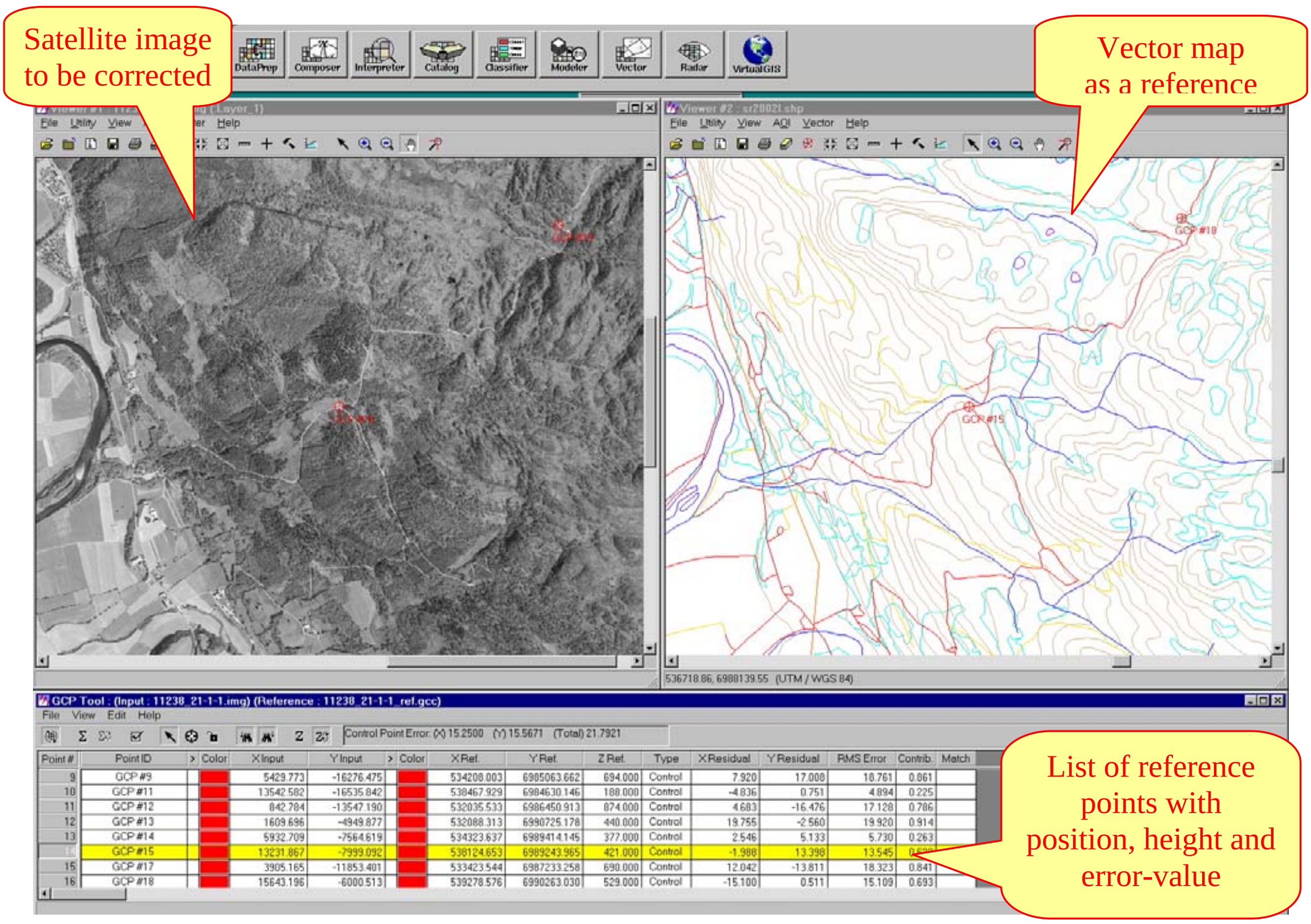


Figure 4-5   Screen dump from program for geometric correction of aerial photos (ERDAS)

It was found that by picking 25 well defined points evenly spaced in the image, a satisfying correction of the image was achieved. However, it was not always easy to find points in the image that had a reference to the map. The themes in the map that were most easily found in the image, with the geometry giving the best precision, were chosen. The best themes to use were roads and lakes. It is reasonable that roads are good references with their simple manmade geometry. It did happen, however, that woods along the roads could throw shadows, making the road more diffuse as a reference point. Small bays and headlands make good points in lakes. Varying water level could however make uncertainties. Small lakes might even change their form due to change in water level. As mentioned earlier a terrain model is used as a reference for elevations (DTED) having an uncertainty of 10 to 20 meters. If an edge of a lake is used as a point, the level of the water will be more precise from the map than from the terrain model. In the computer program there is a possibility to override the height from the terrain model with one that can be written in as a single value. Rivers are surprisingly difficult to spot in the image. The reason, is that the woods and bushes near the river and their shadows make the river a part of the surroundings.

Experience from correcting imagery during this exercise, tell us that the average error of the correction is comparable to the precision of the reference material. The aerial photos that were corrected with 1:50.000 scaled maps, had an uncertainty of 10- 20 meters. Maps with scale 1:50.000, have an uncertainty of 20 meters on the ground, and 10 meters in height.

4.4 3 dimensional modelling / visualisation

It is fully accepted that we describe our three dimensional world in two dimensions, like we do in maps. The third dimension can be described through contour lines, colour coding or shading. The images can then be said to be 3 dimensionally correct, but only from one certain position and viewing angle. By use of computers and electronic versions of images and maps, it is possible to simulate imagery from arbitrary positions and angles. The terrain and the objects in the image must then be modelled in 3 dimensions. For the terrain, there exist terrain models with varying resolution and coverage. For the low resolution models, with scale from 1:250.000 and less, terrain models are available for the whole world. Better terrain models only exists for small areas of the world. Manmade objects like buildings and industry are seldom to be found in 3 dimensional maps. Maps in larger scales can have the outline of larger buildings, but will not show the form and height of them. The GIS computer program ArcView makes it possible to generate simple 3 dimensional objects, where the outlines can be copied from images. Height, form and surface can be chosen in the program. The heights of the objects are seldom known, but can be calculated from the shadows and the sun angle. 3 dimensional modelling of terrain and infrastructure has the purpose of giving a better understanding of the area shown relative to height. A 3 dimensional description of images of lower scale can be made from a simple terrain model. For larger scales, also buildings, plants and so on, will have to be modelled. This is quite expensive and time consuming, and should be carefully considered against the advantages in its use.

FMGT is presently developing at terrain model for Norway based on 1:50.000 maps. The model is part of the American format DTED [5], and at precision level 2. It already exists a DTED level 1 model of the world.

4.4.1 Examples from Strong Resolve 2002

From the Targeting section at FKS, FFI was informed about the targets to be used during the exercise. Some of these targets were chosen to be presented in a 3 dimensional visualization. Figure 4-6 shows one of the examples where the target is two bridges south west of Rindal centre. Part A in the upper part of the figure shows an aerial photo with a resolution of 10 cm. Part B shows he perspective view using a coloured terrain model. To increase the reality, the aerial photo is draped upon the terrain model, as shown in part C. Even if the terrain has its elevation, the buildings will lie “flat” in the image. Some buildings were then given an appropriate outline and a height, represented as blocks. The colour and the light angle could be chosen from the program. Part D shows the result. Some other themes like roads and waters were also vectorised as lines and areas, and given colour. This is in fact a start of synthesising the real world into 3 dimensions. Full reality is however very difficult to achieve.

The 3 dimensional representation was positively commented by the targeting section. The aerial photos, which were 3 years old, were supposed to be too old to be used for analysing the targets.

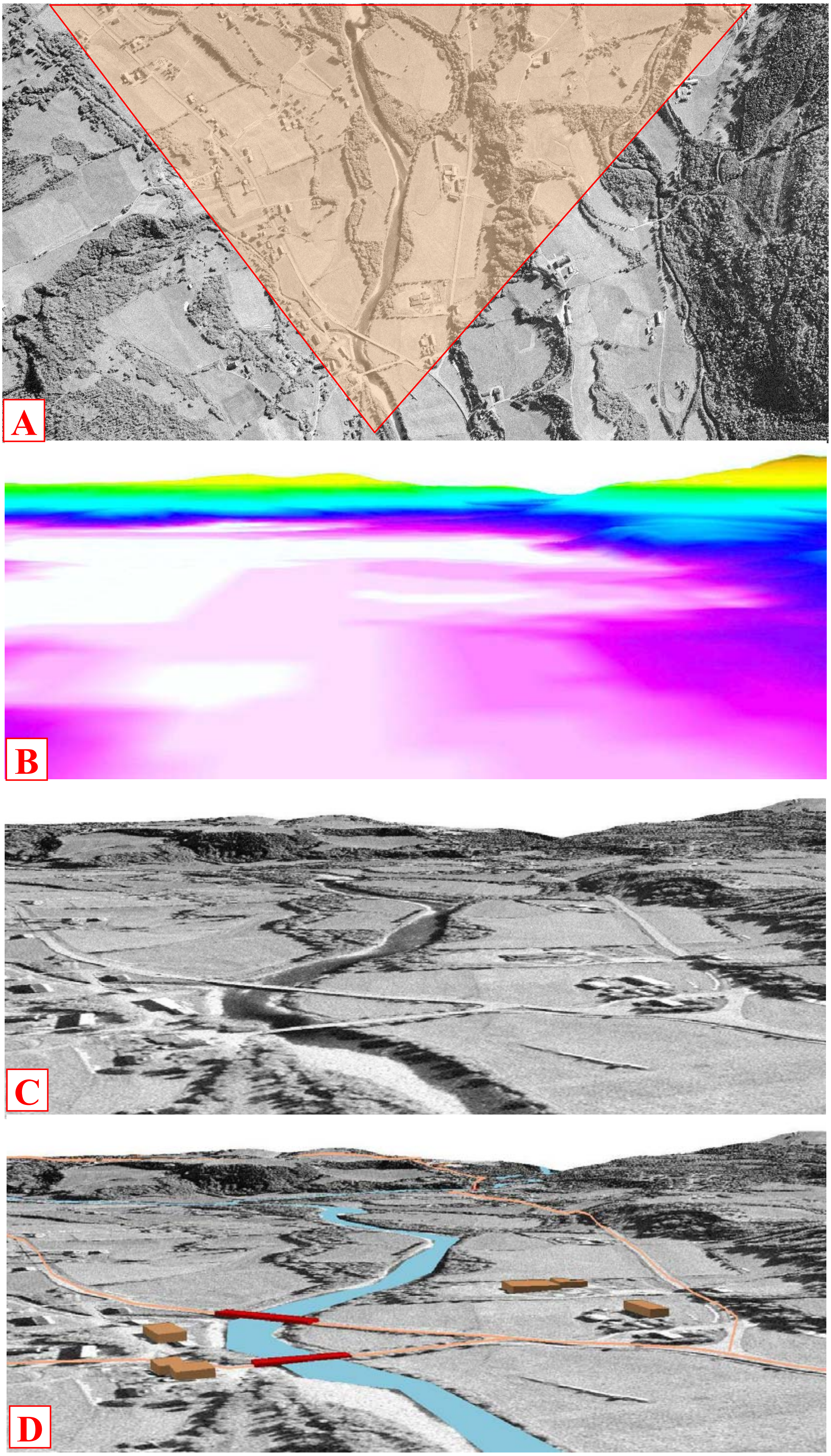


Figure 4-6   3 dimensional visualisation

5 SATELITE IMAGES

As mentioned earlier, FFI has since 1989 followed the developing of commercial photo satellites for possible use in the military. Earlier projects at FFI have evaluated commercial photo satellites including IKONOS with a resolution of 1 meter. This work will look at the use of satellite imagery to describe the area of the military exercise, and to investigate the possibility to detect troops and military activity. In addition to IKONOS, imagery from a new photo satellite, QUICKBIRD, with resolution of 60 cm will be evaluated.

Time and place for taking the image was chosen by the help of planning officers at FKS, who had knowledge about the content and development of the exercise. The image was planned to cover the area between Rindal and Storås. Both satellite operators wanted a time window of minimum 5 days for the taking of the image. The time window was chosen from Sunday March 10 to Friday March 15.

5.1 Ordering satellite images

Even if the investigation of satellite images mainly is concerned with the information in the image, the way of ordering the image is well worth being accustomed to. Here we give some points about ordering forms, payment conditions, delivery times and the handling of the satellite operators.

5.1.1 IKONOS

IKONOS was launched September 24 1999 as the first commercial satellite with a resolution of 1 meter. IKONOS imagery has been investigated by FFI as part of project 763 NEXTSAT in 2000/01 [3]. The imagery was then obtained directly from SpaceImaging in USA (SI-US) [8], but we were later asked to use the newly established European headquarter in Ankara, Turkey (SI-EU) next time we ordered.

Recording parameters for the IKONOS image						
	Camera angle		Sun angle		# of pixels	
Image part	Azimuth	Elevation	Azimuth	Elevation	Column	Row
1	349.5300	60.90939	175.8398	24.13356	12348	7175
2	318.1512	70.49675	176.1939	24.14396	12387	7195
3	269.7371	69.67103	176.5449	24.15315	2425	7134
Time of recording : March 13 2002 at 11:17 GMT						

Table 5-1 Recording parameters for the IKONOS image

The IKONOS image was put together from 3 smaller images taken close in time with only seconds in time difference. The satellite had however moved 100’s of km between each image, like figure 5-1 shows.

Already 2 days after the recording, a quick look of the image was available. Figure 5-2 shows the total image taken. This image was a little bigger than what was ordered, which is marked as a red rectangle. FFI received the image a week after the recording. This is shorter delivery time than experienced earlier.

The quality of the image is good considering the large contrast because of the snow covered terrain. There is now sign of clouds or snow in the image.

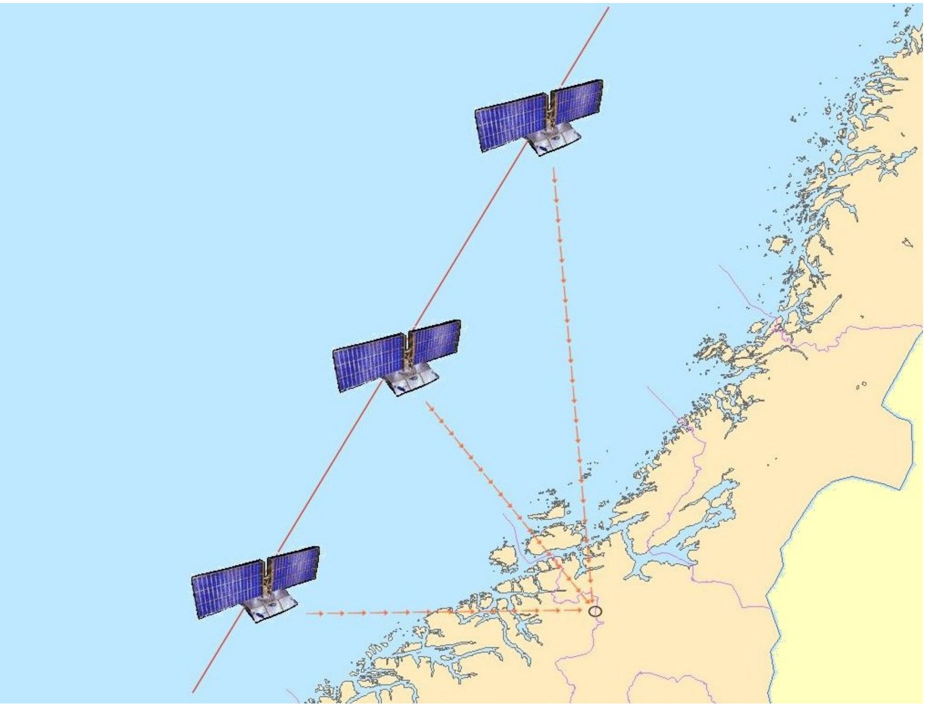


Figure 5-1 Time of imaging for the IKONOS image

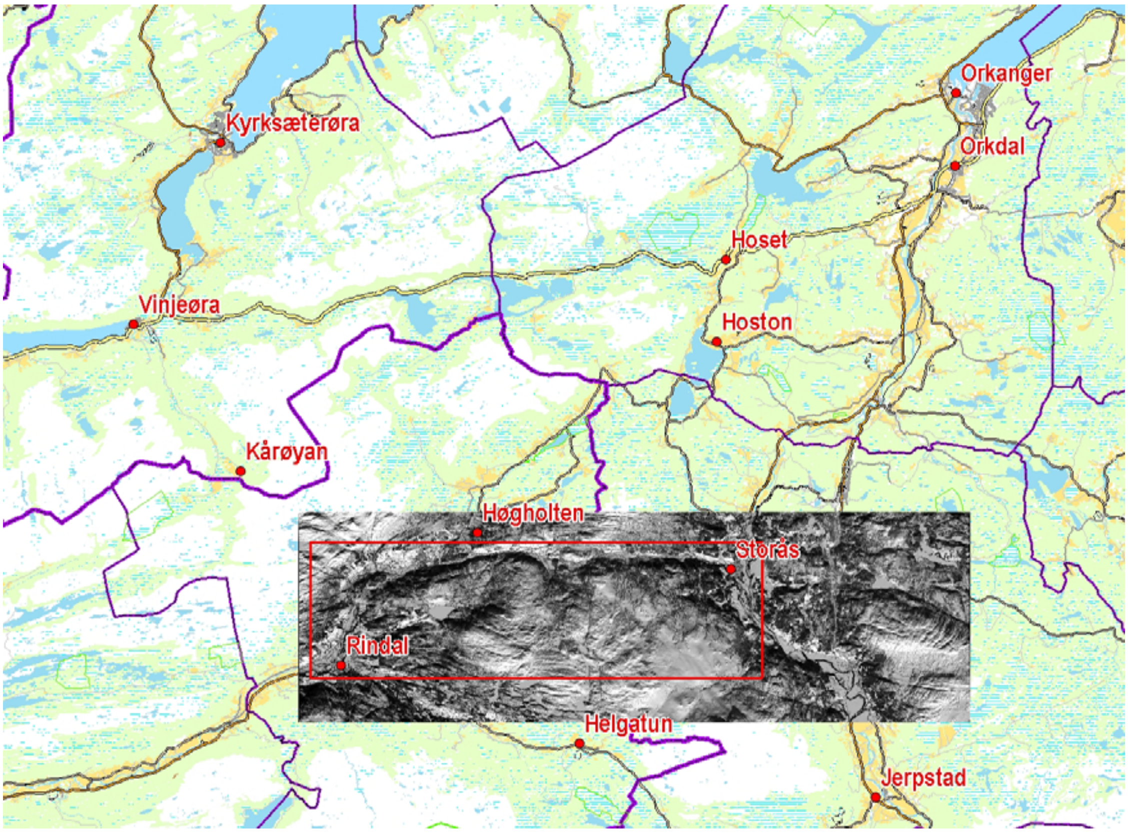


Figure 5-2 IKONOS image coverage. The image shows the total while the red rectangle shows the part that was ordered and received

(Copyright SpaceImaging)

5.1.2 QUICKBIRD

QUICKBIRD came in orbit October 18 2001, and is operated by the American firm Digital Globe [9]. It is really the second QUICKBIRD since their first attempt to launch the satellite failed. Originally QUICKBIRD was planned with a resolution of 1 meter, which was the legal limit at the time of planning. In the spring of 2001, however, the American government allowed satellite imagery with resolution down to 0.5 meters. As a result the operator chose to change the orbit height from 600 km to 450 km, giving a best resolution of 62 cm.

Ordinary sales of QUCKBIRD imagery started autumn 2002, but the operator Digital Globe, accepted the order. Their European agent is EurImage [10], located in Rome, Italy. EurImage represent most commercial photo satellites for sale in Europe.

To achieve a time window for the recording of 7 days, we had to order a "priority tasking" costing 50 % more.

Later we were informed that the image was so big that it had to be split up in 2 sub images. The first sub image was taken on March 10, but was not useable because of clouds. The last sub image was taken on March 14 with no clouds. This sub image covered areas we originally did not order, but since military units were in the area, it was decided to buy the complete sub image. Figure 5-3 shows the image from QUICKBID. The originally ordered area is like the one ordered for IKONOS as shown as a red rectangle if figure 5-2.

Before receiving the QUICKBRD image, we were warned that snow and ice had reflected the sunlight and saturated the sensors in certain areas. We were told the effect only was visible in the upper left part of the image. Since this part of the image only contains mountains, we accepted the image. When receiving the image, however, the saturation effect was visible in spots all over the image. After complaining, Digital Globe accepted to let us keep the image for free.

The image was received 3 weeks after it was taken. A quick look of the image was however transferred to FFI in an E-mail even in the afternoon the day the image was taken. In principle it could have been the original image.

Recording parameters for the QUICKBIRD image						
Image part	Camera angle		Sun angle		# of pixels	
	Azimuth	Elevation	Azimuth	Elevation	Column	Row
1	23.957	65.7019	167.847	23.9989	23339	22800
Time of recording : March 14. 2002 at 10:47 GMT						

Table 5-2 Recording parameters for the QUICKBIRD image

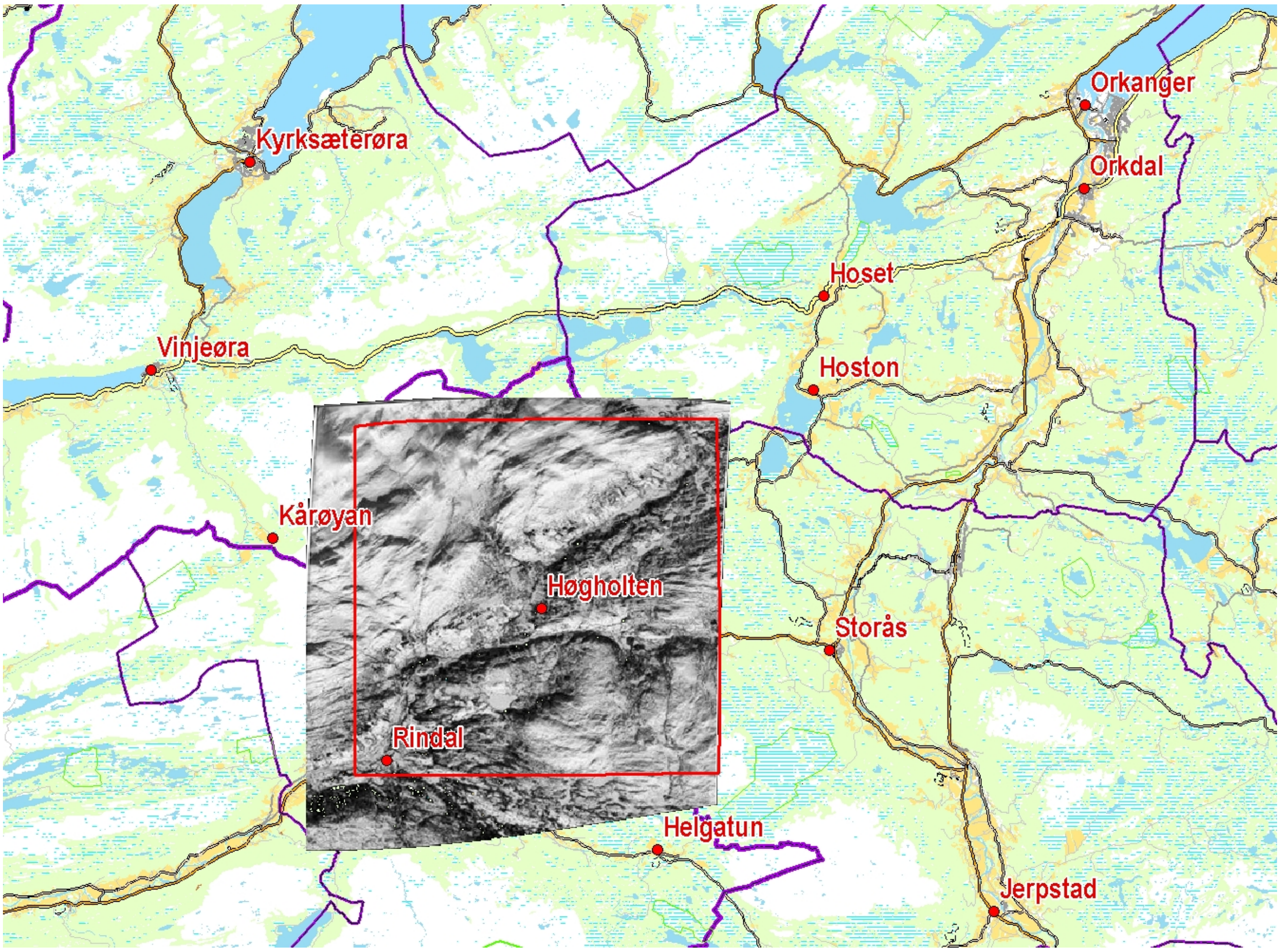


Figure 5-3 QUICKBIRD area cover. The red rectangle shows the received image.

(Copyright DigitalGlobe)

5.2 Prices on satellite imagery

Comparing prices on satellite imagery (pr km^2) *by My 2002*				
Satellite	Pancromatic	Multispectral	Pan sharpened	Bundle (Pan + MS)
IKONOS 1)	$ 25.00	$ 18.00	$ 27.50	$ 37.50
QUICKBIRD 2)	$ 22.50	$ 25.00	$ 30.00	$ 30.00
1) Min image area 100 km^2. Added fee on orders on new imagery less than 60 days ahead of recording : $ 3000 + 20 % add to the price pr km^2-prisene. 2) Min image area 64 km^2 on new orders., and 25 km^2 from archive. No extra fee for new imagery compared to archive imagery.				

Table 5-3 Comparing prices on satellite imagery

The 2 satellite operators have different ways to calculate their price. Common for both is that the price increases with the area covered. The price will be as shown in table 5-3. This table is valid for imagery with the simplest geometric correction (25 meter CE90). Both operators offer several levels of geometric correction with accordingly higher prices. The prices in the table are for use f the imagery within an organization or firm.

5.3 Examples from Strong Resolve 2002

When the satellite imagery was received, work started on analysing the information. The information within the image can be divided in infrastructure and military objects being part of the exercise. Evaluation of IKONOS imagery has been done earlier at FFI [3], but not with the ground covered in snow. The imagery, being taken early in the year, has lower sun angle and longer shadows than found in earlier work.

As a guide to find military units in the imagery, situation briefs held during the exercise were used. Figure 5-4 shows a situation view over the Rindal area taken from a brief held on Thursday March 14. The blue symbols indicate the BLUE forces, while the red symbols indicate the LIME forces. We will not go in detail with the scenario or the fighting units, just show the situation map as a tool we used to spot units on the imagery.

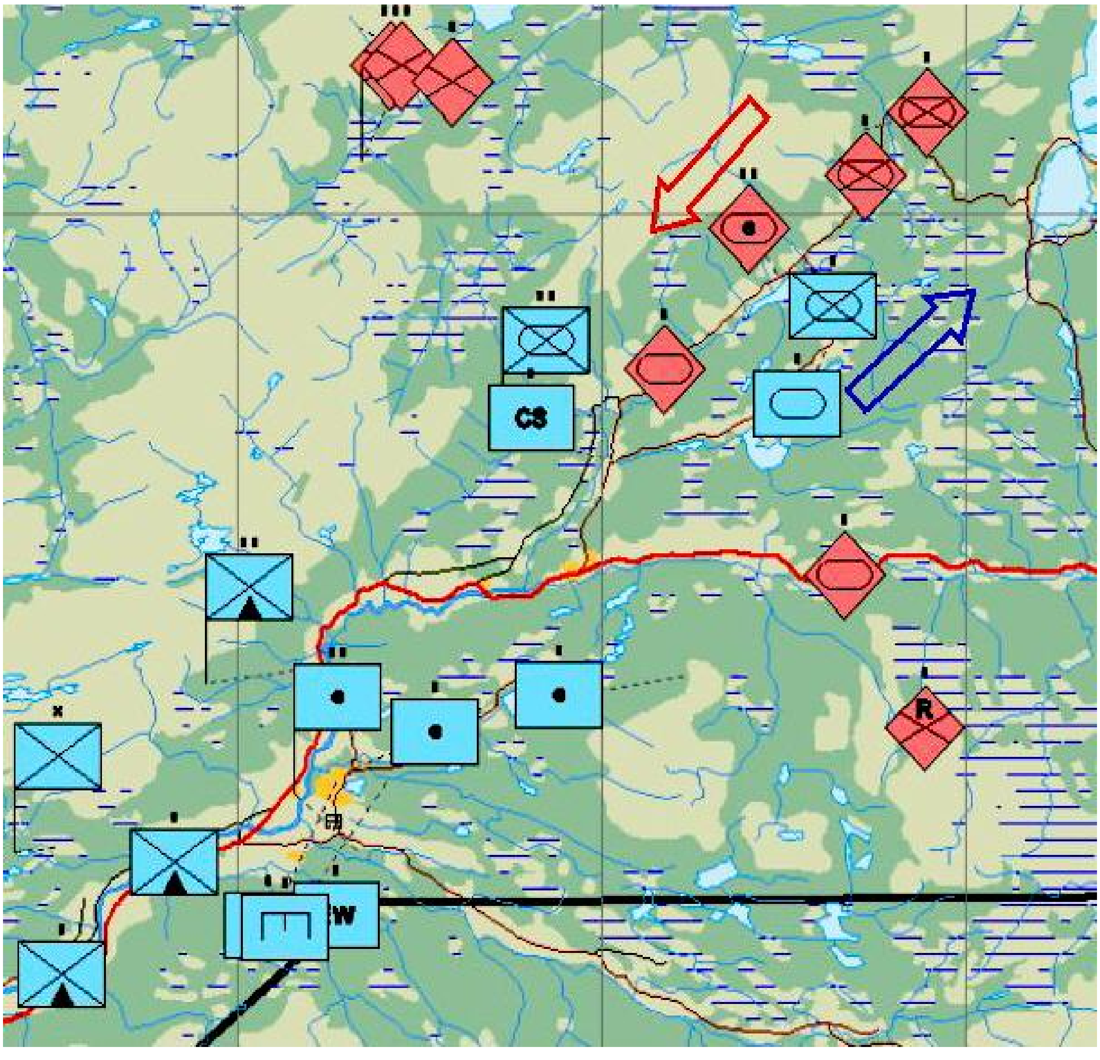


Figure 5-4 Situation map from the exercise in the area of Rindal given by the FKS on Thursday March 14.

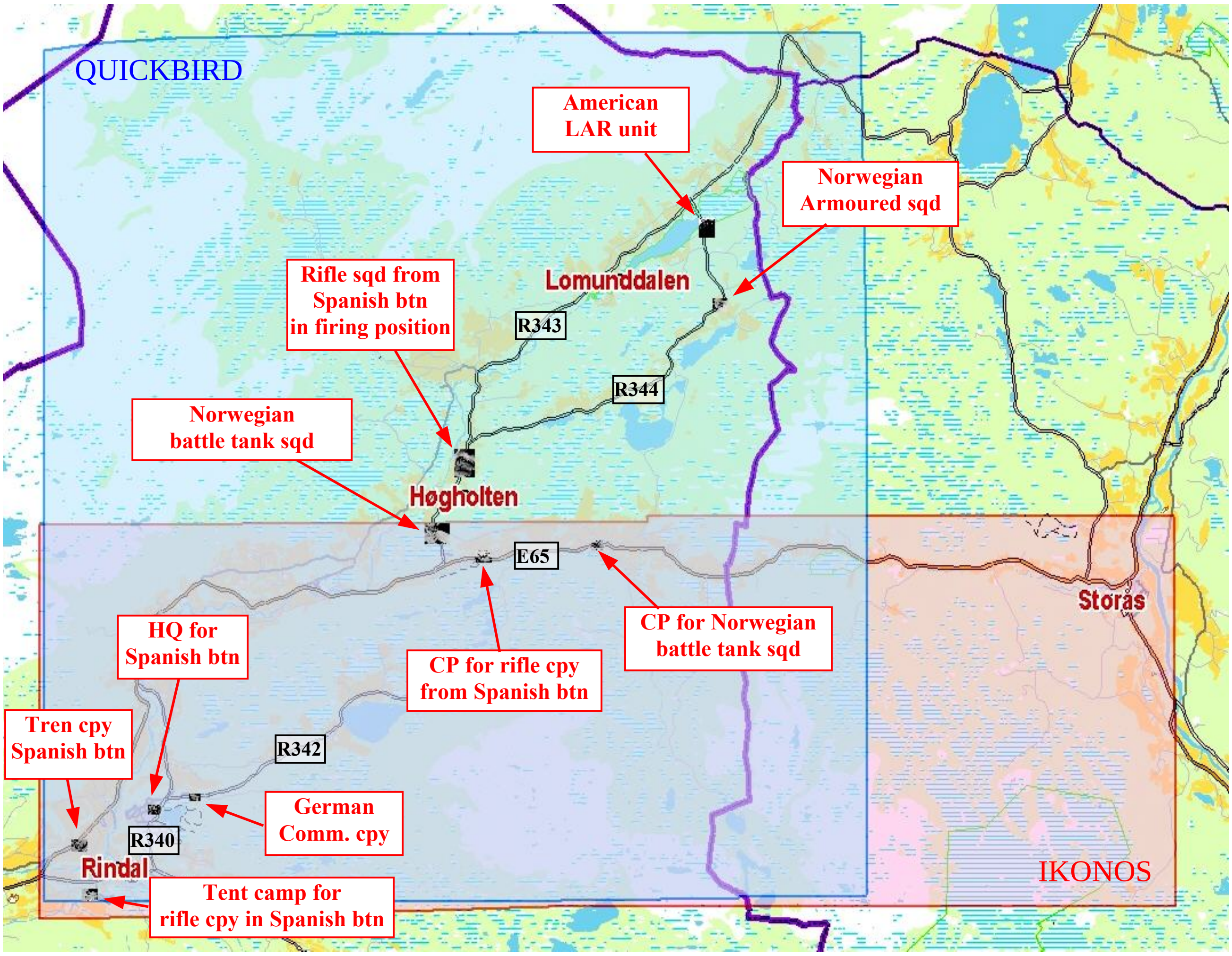


Figure 5-5 Overview of area cover from the satellite images and naming of some military units positions.

The main thing to look for in the imagery was military activity. There were a number of tracks in the snow from belt driven vehicles. Often the tracks were old, and the vehicles had disappeared. Vehicles were spotted when they appeared in fairly open areas. Headquarters and tent camps were mixed with the infrastructure, and were harder to detect. Figure 5-5 shows an overview of the 10 image segments discussed in this report, and what type of unit in the image.

Aerial photos of the area from 1999, were used as aid for analysing the imagery. The point was to use these photos as a reference on what was a part of the permanent infrastructure.

In addition, photos had been taken along the main roads. These had been taken from a vehicle driving along the road, and showed both the road and some of the surroundings. An image was taken every 20 meters. The imagery was acquired from the Norwegian Road Administration that used the imagery to control the surface of the road. The project was named ALFRED, and such imagery used in this report will be referred to as ALFRED-imagery.

The largest military unit within the coverage of the imagery was a Spanish infantry battalion. The battalion was part of the BLUE forces, and had its headquarter and supporting units in the area of Rindal centre. Their task was to prevent the LIME forces to move eastwards along the highway E-65, and from northeast along highway 343 through the Lomund valley. The battalion had 2 rifle companies equipped with tracked vehicles and snow scooters.

A Norwegian armoured squadron belonging to BLUE forces attacked through the Lomund valley. The squadron from the Dragon regiment at Rena, consisted of 2 squadrons of Leopard 1A5 battle tanks, 2 squadrons of CV90 infantry fighting vehicles and 1 squadron of NM142 combat vehicles. These vehicles, probably more than 20, were in the area south of the road crossing between highway 344 and highway 343.

A compound unit from the LIME side was on the way south on highway 343. It is difficult to identify the separate units, but both a squadron of battle tanks and a squadron of armoured vehicles, both from the armoured battalion at Setermoen/Bardufoss, were in the area. In addition an American unit of Light Armoured Reconnaissance (LAR) was present in the area.

On the axis from west to east on the highway E-65 a battle tank squadron from the Norwegian armoured battalion, normally located at Setermoen/Bardufoss, was operating for the LIME forces. They had been fighting a Spanish unit, and taken position in the road crossing between the highway E-65 and highway 343.

During the investigation of the imagery, a Norwegian liaison officer to the Spanish infantry battalion was available. The armoured squadron at Rena also was helpful to identify their unit in the imagery, and so was also the armoured battalion at Setermoen/Bardufoss.

All the georeferenced imagery in this report is oriented with north pointing upwards. On both satellite images the sun was shining almost from the south. The QUICKBIRD image is taken almost straight from north, while the IKONOS mage is taken from north/northwest. To increase the 3 dimensional impression, it can be better to watch the imagery from the sensors position.

5.3.1 Headquarter of the Spanish battalion

The largest unit within the area of the imagery was a Spanish infantry battalion. The unit belonged to the BLUE forces, and was stationed in the area around Rindal centre. Rindal is an intersection in the east-west connection in the area, and the Spanish unit had the task to prevent the enemy to pass through. Their headquarters was placed at a sports ground in Rindal, which they shared with an American unit.

Figure 5-7 shows the satellite imagery of the headquarters. Vehicles are parked in the east-west direction on the east side of the sports ground. The shadow of each vehicle is cast on the next, and the vehicles are difficult to count. The QUICKBIRD image is however more readable, giving a contour of the vehicles against the shadow. This is not possible to see in the IKONOS image.

On the northern side of the sports ground there are 3 tents with the tip in the north-south direction. The tip shows in the shadow on the snow, but are more clearly in the QUIKBIRD image than the IKONOS image. Fig 5-6 shows the type of tent.

On the satellite images the sports ground is partly covered with shadows from the trees in the south of the sports ground. In figure 5-8 there is an aerial photo of the sports ground from 1999. In this case the sun is high on the sky, showing most of the sports ground with no shadows.

It is worth while to notice some obvious differences between the summer and winter images. The summer images show grey scale values from the characteristics of the ground, and all the objects are affected by light and shadow. On the winter images, the surface is white because of the snow so the objects can be projected on the ground giving a 3 dimensional kind of visualization.

Figure 5-6 Tent used by the Spanish battalion

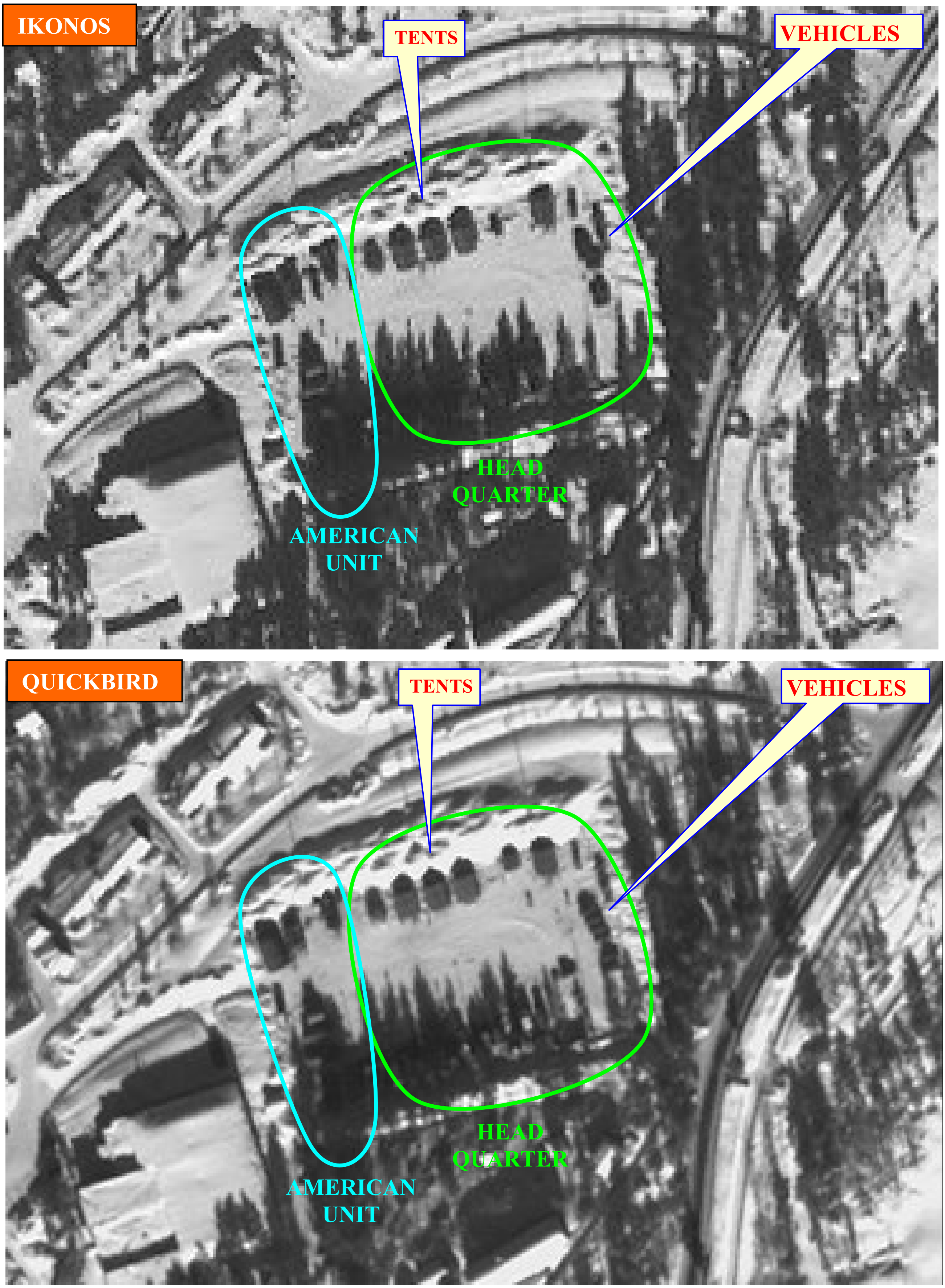


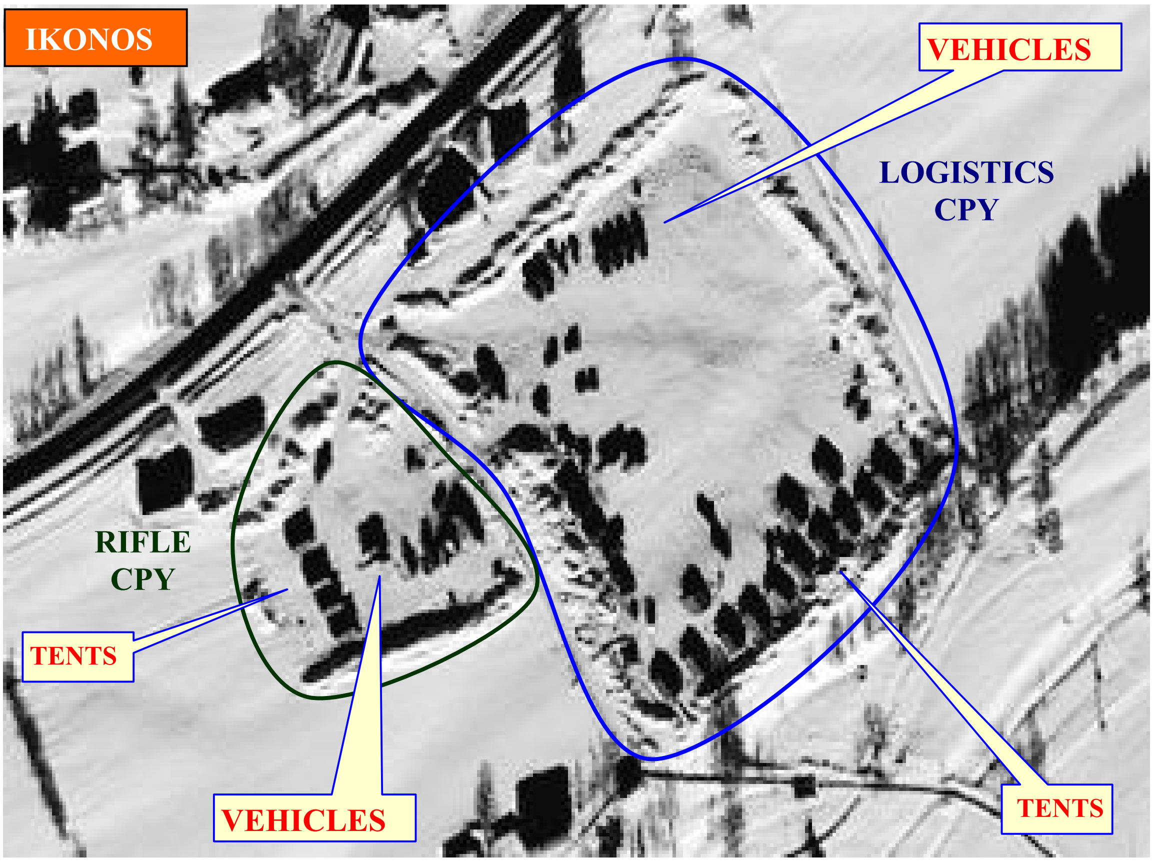
Figure 5-7 Image segment showing the head quarter of the Spanish infantry battalion (IKONOS : Copyright SpaceImaging / QUICKBIRD : Copyright DigitalGlobe)

Figure 5-8 Aerial photo from 1999 of the sports ground used at command post for the Spanish battalion (Copyright Fotonor A/S)

5.3.2 Spanish battalion logistics area

The Spanish infantry battalion had put its logitics unit together with a rifle company west of Rindal centre. The satellite image of the area is shown in figure 5-9. The camp was on a field cleared of snow. At the logistics unit we registered 13 larger tents and ca 20 vehicles (tracked vehicles, trucks) on an area of 90 x 120 m2. The rifle company had 4 larger tents, and an unknown number of vehicles in an area of 50 x 50 m2

The area was at first not detected since the tents and vehicles became part of the surroundings. An aerial photo of the area from 1999 is shown in figure 5-10. By comparing the images, it became clear that the area was a field. Since it was a military exercise in the neighbourhood, we guessed that the field was settled by a military group rather than a Tivoli, a market or being a storage area for containers. The liaison officer of the Spanish battalion later confirmed the camp.



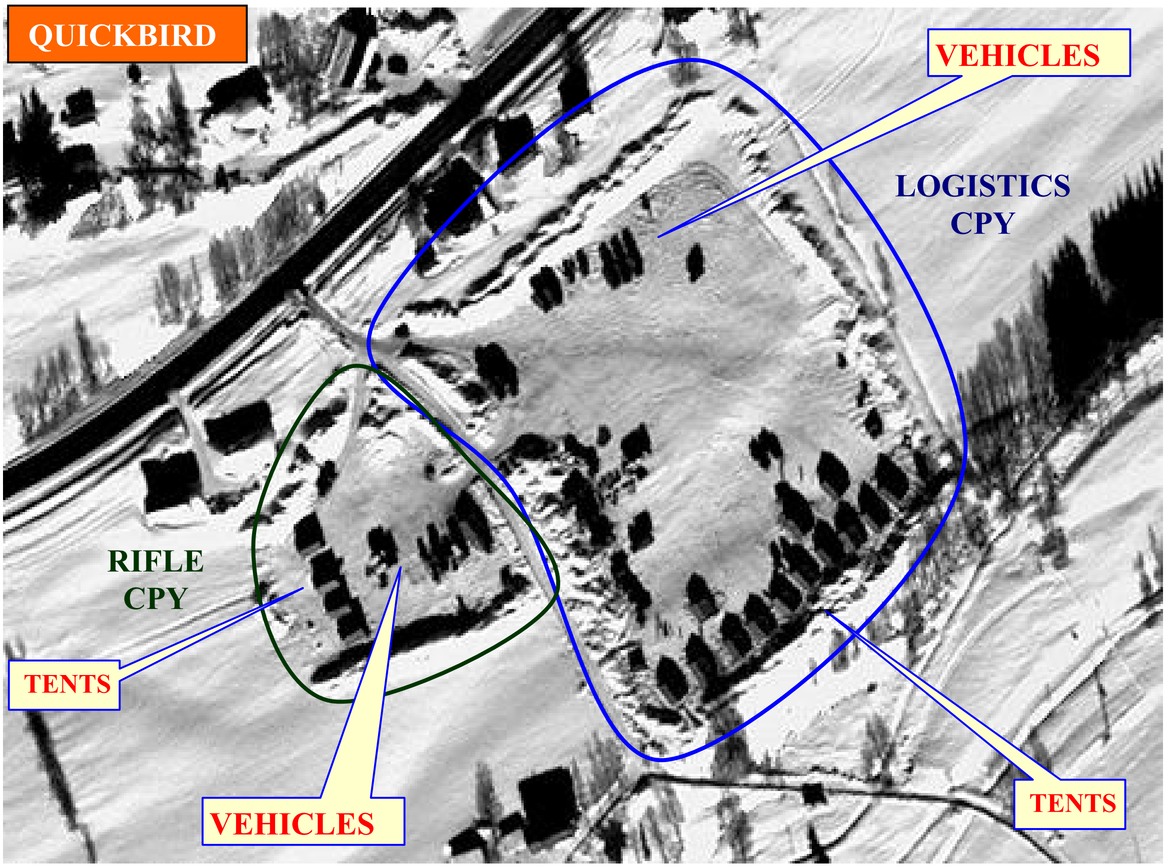


Figure 5-9 Camp for the logistics company and rifle company, both belonging to the Spanish infantry battalion

(IKONOS : Copyright SpaceImaging / QUICKBIRD : Copyright DigitalGlobe)

Figure 5-10 Aerial photo from 1999 of the field used as barrack yard for logistics- and rifle company of the Spanish battalion (Copyright Fotonor A/S)

5.3.3 Camp for rifle company in Spanish battalion

The Spanish infantry battalion had a tent camp for its rifle company south of Rindal. This is shown in figure 5-11. The camp consisted of 7 larger tents, which were measured to 7 x 5 m2. We were later told that the tents were only for sleeping, and that the unit in daytime went into positions northwards. The camp measured 50 x 50 m2.

The tents were not detected until the liaison officer pointed out the place. There are several signs of military activity in the area. Tracks in the snow outside the tents show that they are in use. The tents, however, look like huts that are common in the area. From the aerial photo in figure 5-12, it is seen that no huts are present, but that it is building activity. The placement of the tents make them a part of the surroundings, and hard to find.

The house straight north of the tents can be misunderstood regarding the 3 dimensional understanding. The lower part of the house with 4 windows, is part of a slanting roof, and not a wall. It is probably the windows that contribute to the misinterpretation.

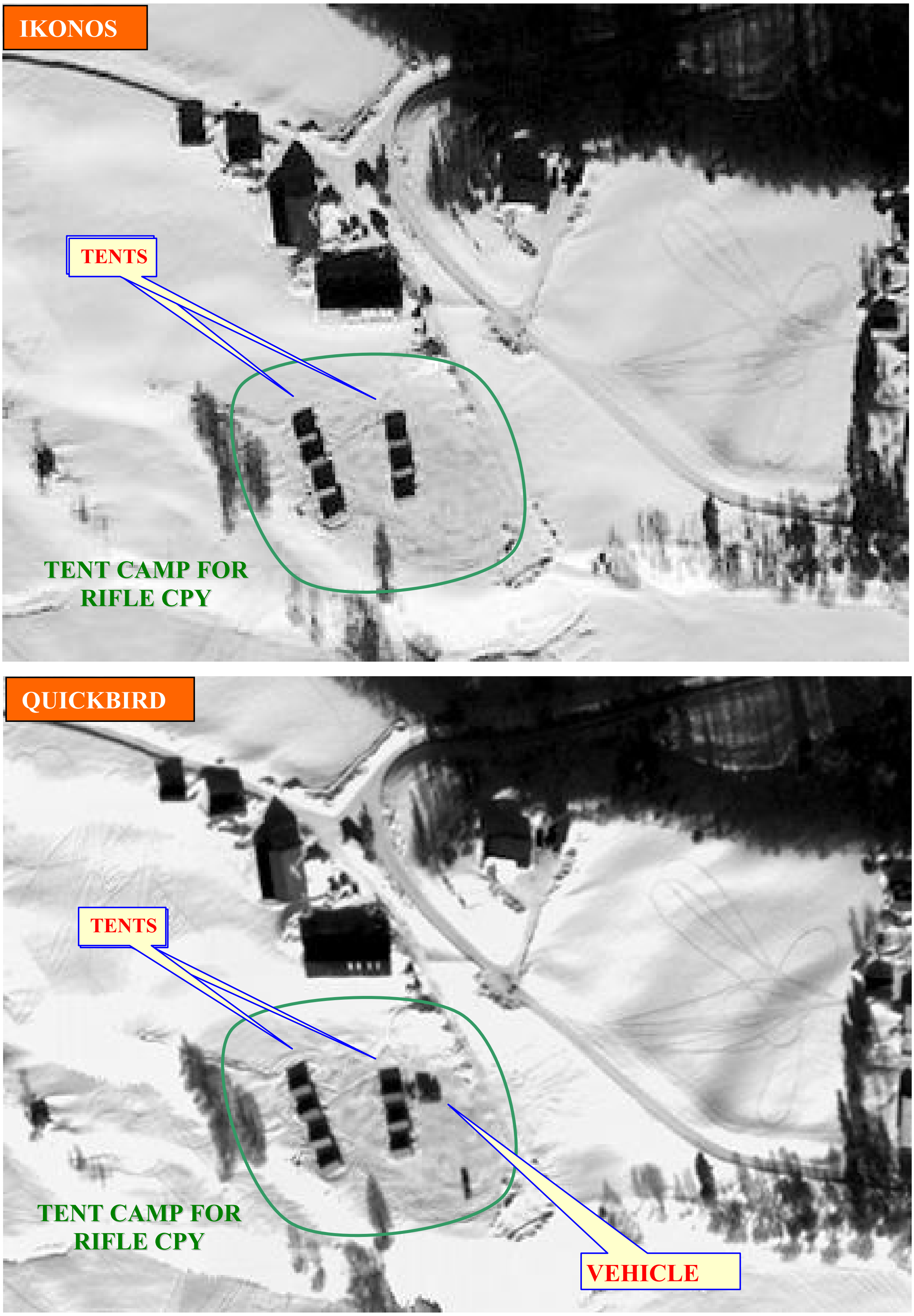


Figure 5-11 Barrack yard for rifle company in Spanish battalion

(IKONOS : Copyright SpaceImaging / QUICKBIRD : Copyright DigitalGlobe)

Figure 5-12 Aerial photo from 1999 of barrack yard of rifle company of Spanish battalion (Copyright Fotonor A/S)

5.3.4 Defence position for rifle unit from the Spanish battalion

A rifle unit from the Spanish battalion was in position along highway 343 south in Lomund valley. The defence position was divided in 2 groups near a farm, as shown in figure 5-13. The group south of the farm consisted of 5 firing positions, while the group north of the farm consisted of 10 firing positions. The firing positions were on a line with approximately 15 meters between each. It is not possible to see the number of men in each position, or if the positions are armed at all at the time of photographing.

Between the positions, and from the positions to the road, are tracks in the snow. It is not possible to decide if the tracks are from snow scooters or walking soldiers (possibly using snow shoes).

The image in figure 5-13 is a good example of how combination of snow and long shadows make contrasts that makes clear signs of activity that barely should be detectable with regard to the resolution of the image.

Figure 5-14 is an aerial photo from 1999 showing the same area, in addition to 2 ALFRED images taken south and north along the road. The ALFRED images show the slope of the terrain not visible in the vertical imagery.

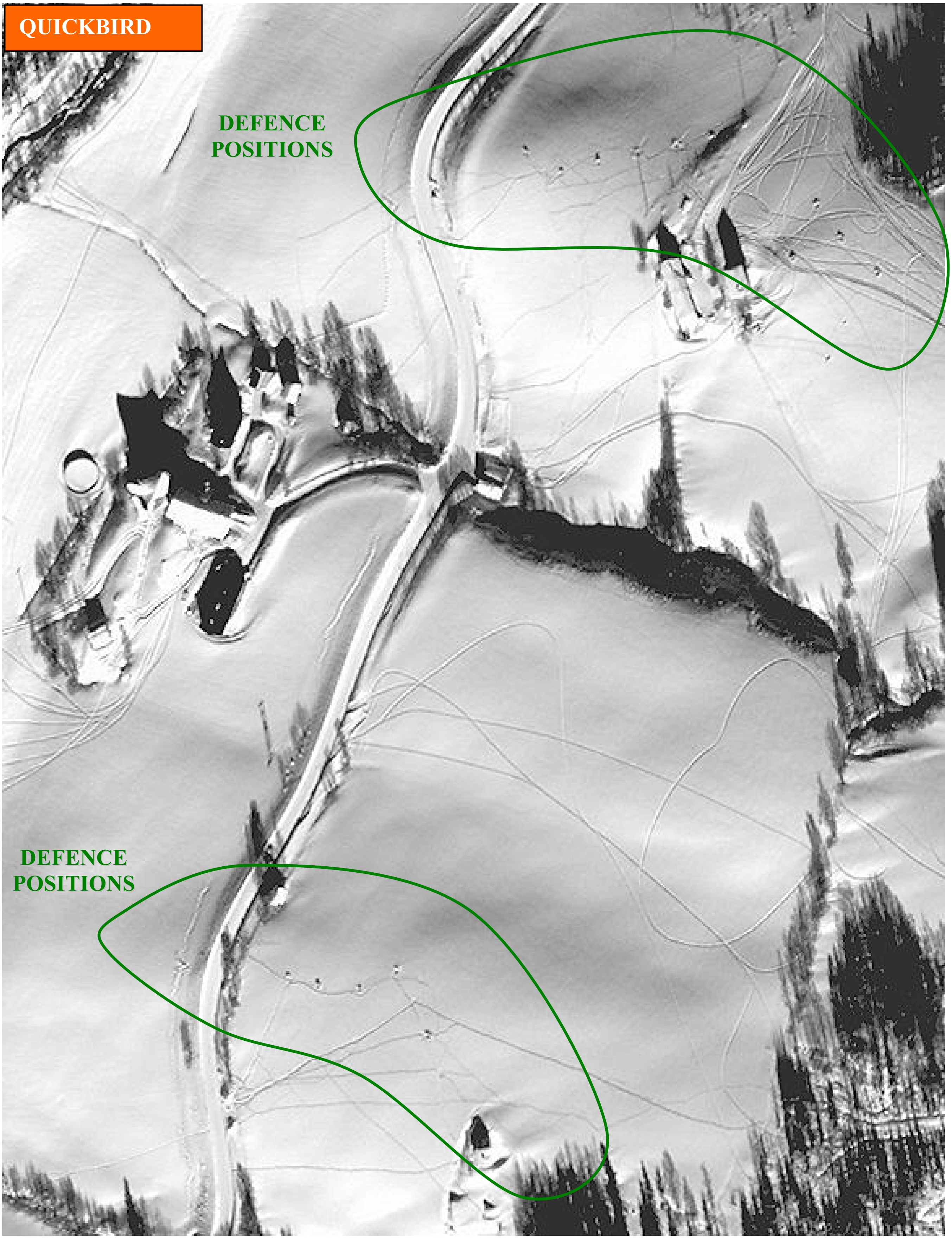


Figure 5-13 Defence positions of rifle squadron of the Spanish battalion
(Copyright DigitalGlobe)

Figure 5-14 Area for Spanish rifle squadron from an aerial photo (1999), and ALFRED images

(Flyfoto : Copyright Fotonor A/S / ALFRED Copyright Statens veivesen)

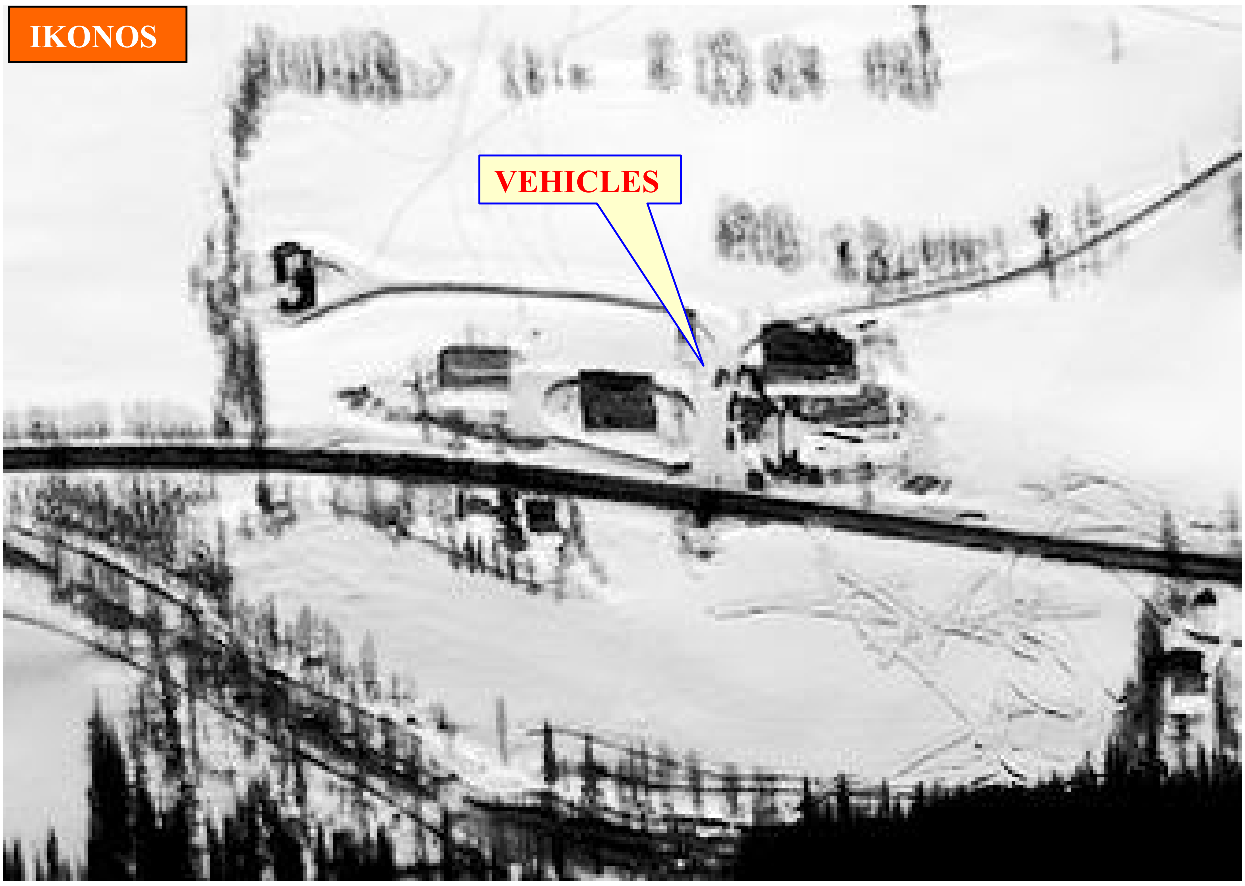


Figure 5-15 Command post for the rifle company of the Spanish battalion (Copyright SpaceImaging)

5.3.5 Command post for the rifle company of the Spanish battalion

A rifle company from the Spanish battalion had its command post at Upper Rindal along the highway E-65. Figure 5-15 shows the satellite images of the area. Outside the building are 10-15 vehicles parked.

The number of vehicles is much higher than in the aerial photo in figure 5-16. This should perhaps alert an experienced photo interpreter.

The command post was later pointed out for us by the Norwegian battle tank squadron that had passed the command post several times during the exercise.

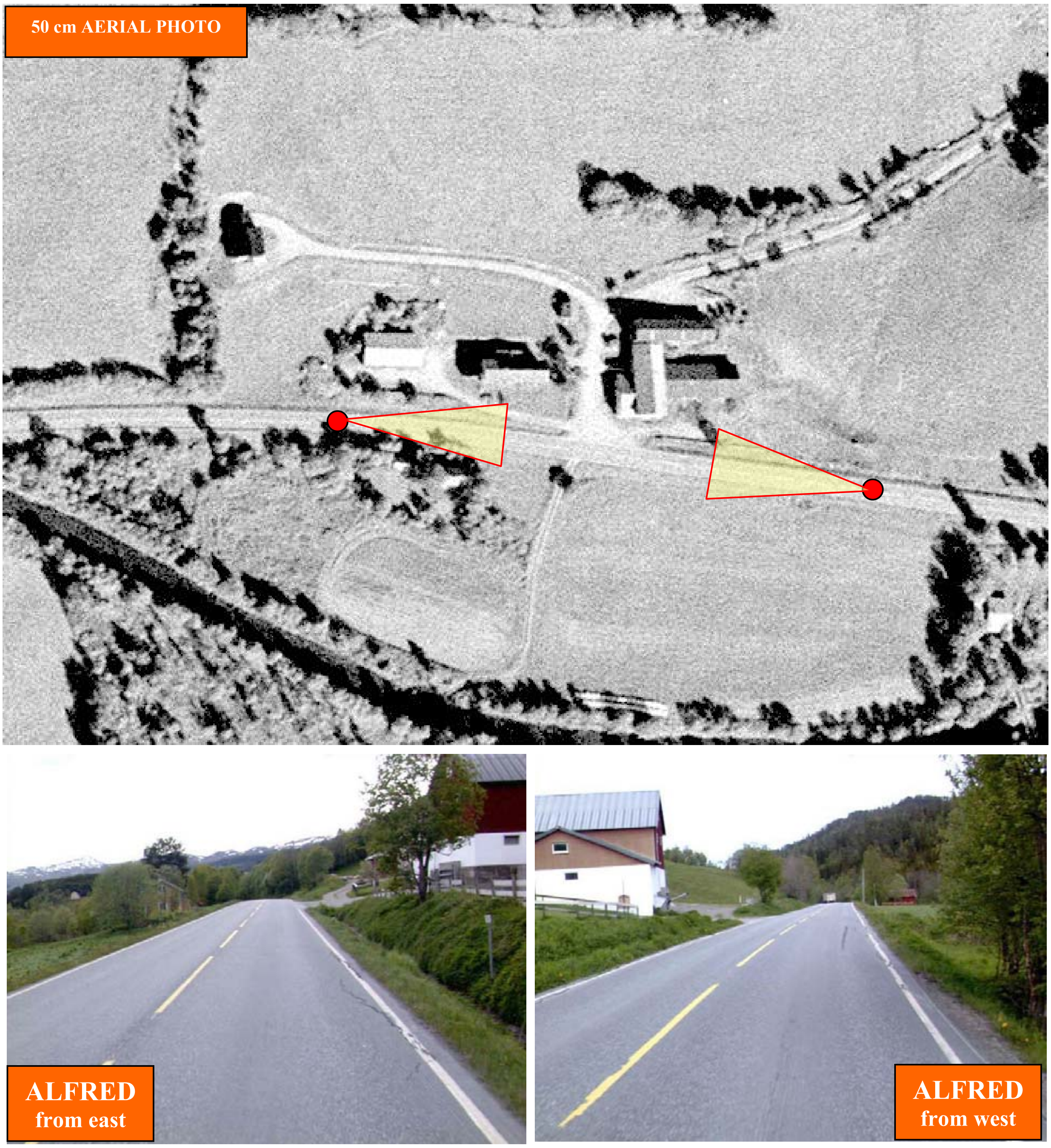


Figure 5-16 Area for Spanish rifle squadron seen from aerial photo (1999), and ALFRED images

(Flyfoto : Copyright Fjellanger Widerøe A/S / ALFRED Copyright Statens veivesen)

5.3.6 German communications company

North-east of Rindal and south of highway 342, a German communications company had its camp as shown in figure 5-18. The camp covered a 100 x 100 m2 area of a field with woods on both sides. Only the most southern half of the field was used. The other part of the field might have been used by other units earlier. The camp consisted of larger tents in the south-west corner. From 2 smaller antennas in the south-east corner there could be a camouflaged tent. A larger antenna is clearly visible, and was measured to a height of 22 meters from the knowledge of the sun angles and the camera angle.

The image in figure 5-18 clearly shows the difference in resolution of the IKONOS and QUICKBIRD imagery. In the same image segment the QUICKBIRD image shows a nearly smooth grey level transition, while the IKONOS image clearly shows single pixels. The increased resolution is however difficult to use get more information out of the image.

The vehicles in the image are parked with the longitudinal direction nearly parallel to the sunlight. The low sun angle produces long shadows from the vehicles. The width of the vehicles is easy to measure (uncertainty corresponds to pixel resolution), while shadow creates problems in measuring the length of the vehicles. For some vehicles the contour is as dark as the shadow, while for other vehicles there are lighter areas as a superstructure.

The uncertainty in measuring length from the image is shown in figure 5-17 which shows the shadow from two different types of Hummer. For a sun angle of 24º the shadow will be cast a meter longer when the vehicle has a superstructure. This will cause problems when geometric size is used for identification.

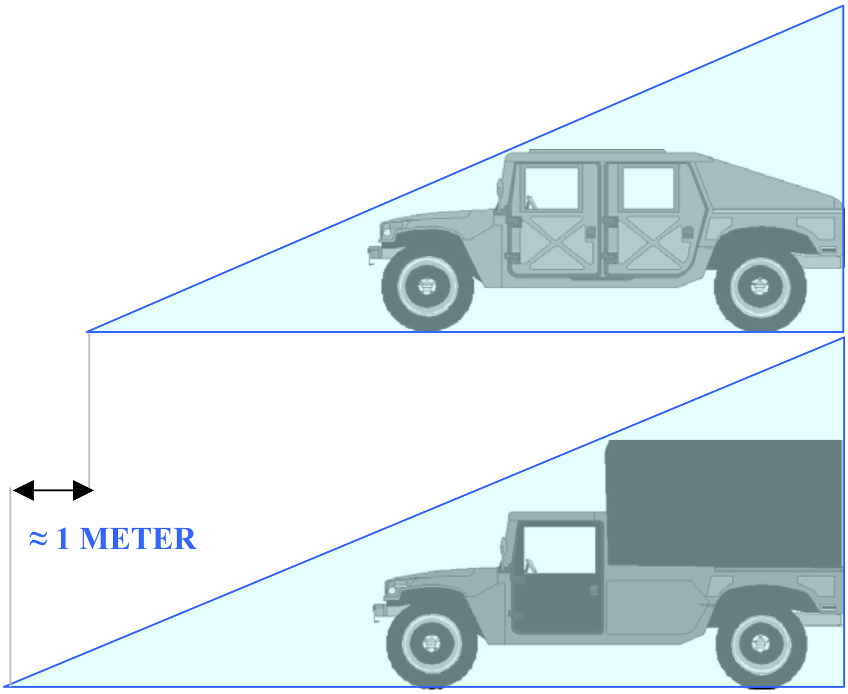
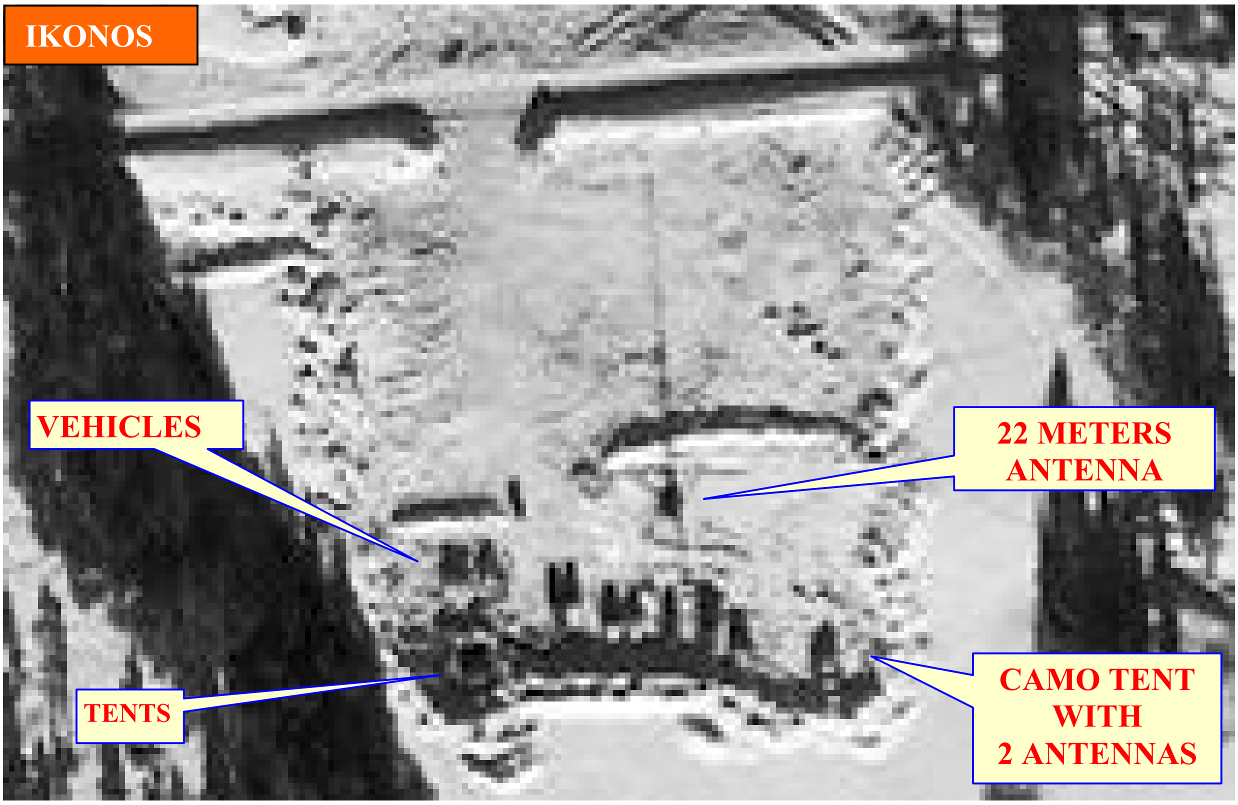


Figure 5-17 Comparison of the shadow of 2 Hummer with different superstructure for 24^{O} sun angle



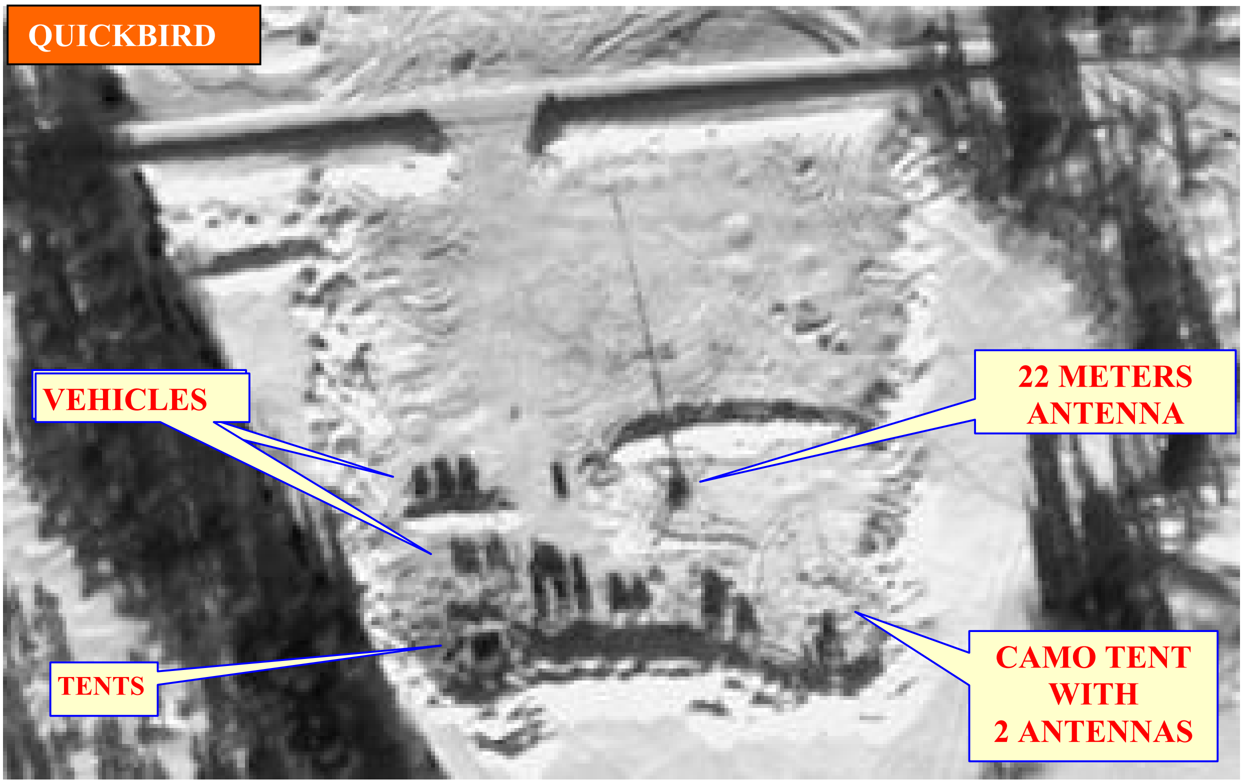


Figure 5-18 German communications company

(IKONOS : Copyright SpaceImaging / QUICKBIRD : Copyright DigitalGlobe)

Figure 5-19 Area for German communications seen on a an aerial photo (1999) and ALFRED images

(Flyfoto : Copyright Fotonor A/S / ALFRED Copyright Statens veivesen)

Figure 5-19 shows an aerial photo from 1999 covering the same area. Without this photo it would be difficult to verify that the camp area really was an open field. The ALFRED imagery did supplement in giving an understanding of the terrain.

5.3.7 Norwegian armoured squadron

An armoured squadron belonging to the Dragon regiment at Rena, attacked along highway 344 northwards Lomund valley. The squadron belonged to the BLUE forces, and consisted of 2 battle tank units with 8 Leopard 1A5, 2 armoured units with 8 CV90 and 1 armoured unit with 4 NM-142. In figure 5-21 almost half the squadron is seen at some farm houses. The rest of the squadron is along the highway 344.

Figure 5-20 Vehicles used by the Norwegian battle tank squadron

Figure 5-20 shows images of the vehicles used by the armoured squadron. Even if they look quite different in a high resolution image with a perspective view, they are certainly not easy to distinguish on the satellite image in figure 5-21. The identification is very uncertain, and is based on a combination of the contour of the objects and what the personnel from the armoured squadron seem to remember from the exercise. An aerial photo from 1998 together with ALFRED images from the area are shown in figure 5-22. They helped as a reference on what objects were parts of the farm.

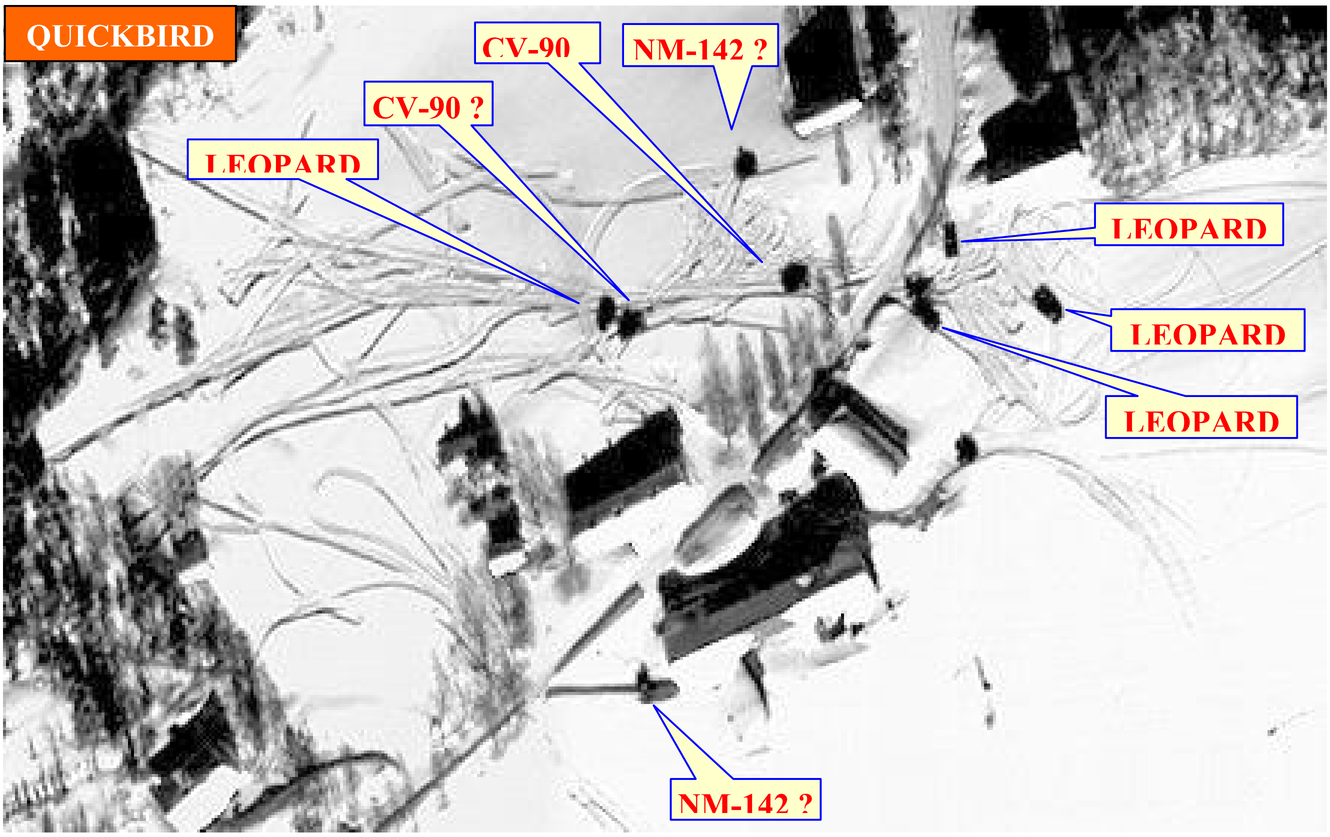


Figure 5-21 Norwegian battle tank squadron *(Copyright DigitalGlobe)*

Figure 5-22 Area for Norwegian battle tank squadron from an aerial photo (1999) and ALFRED images

(Flyfoto : Copyright Fjellanger Widerøe A/S / ALFRED Copyright Statens

5.3.8 American Light Armoured Reconnaissance (LAR) unit

The image dynamics has increased since the first commercial photo satellites (LANDSAT and SPOT) with 256 intensity levels, compared to commercial photo satellites of today (IKONOS and QUICKBIRD) with 2048 levels. This increases the possibility of detecting objects in shadows. A good example is in figure 5-23 showing 9 vehicles of which 6 is in shadows. It is uncertain which outfit these vehicles belong to, but an American LAR unit is the most probable according to personnel from different units within the area. Figure 5-24 shows an aerial photo from the same area in 1998 and 2 ALFRED images.

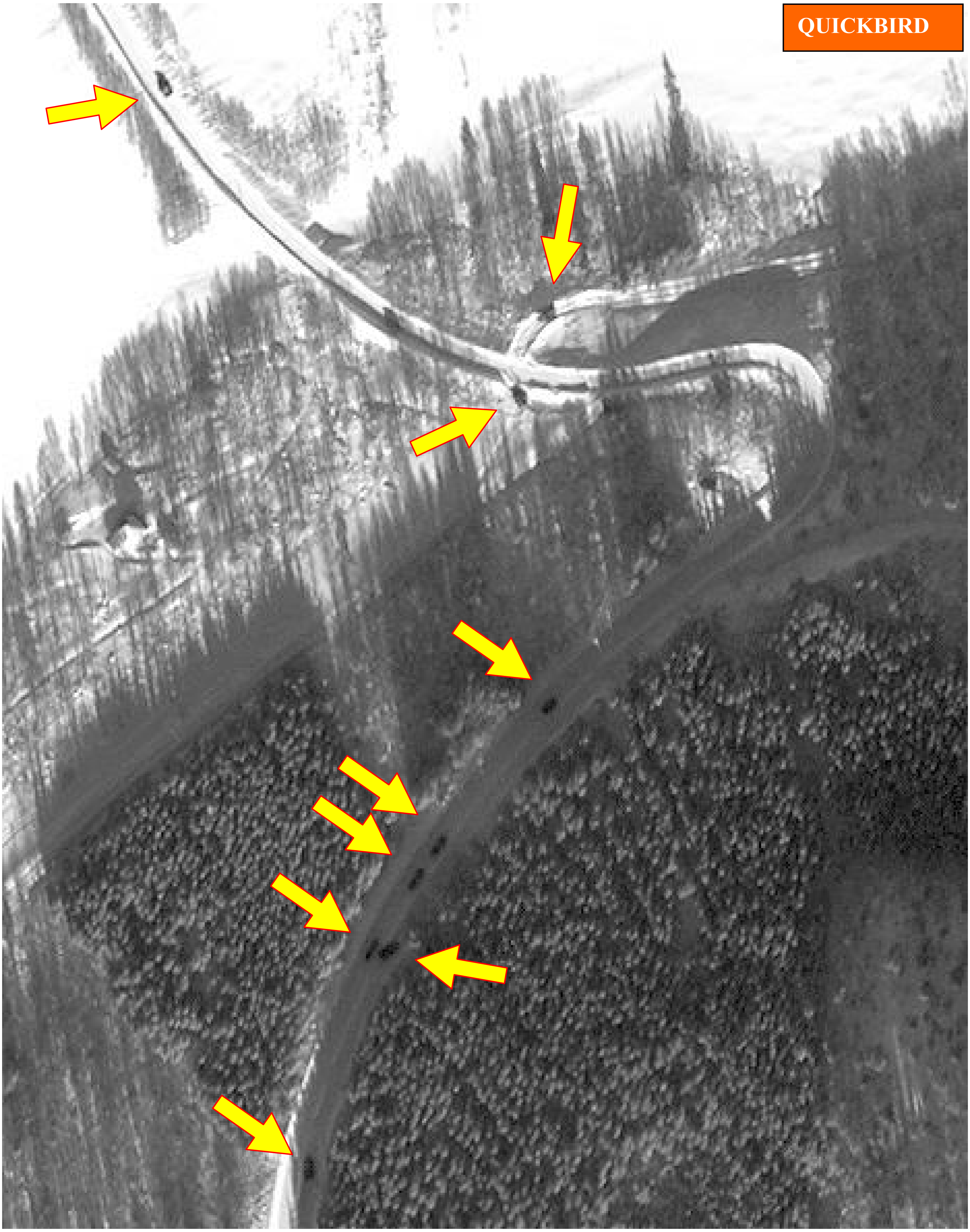


Figure 5-23   American LAR unit. The arrows point at vehicles.   (Copyright DigitalGlobe)

Figure 5-24 Area for Norwegian battle tank from an aerial photo (1999), and ALFRED images

(Flyfoto : Copyright Fjellanger Widerøe A/S / ALFRED Copyright Statens veivesen)

5.3.9 Armoured squadron no 2 in position

The Norwegian armoured squadron no 2 from the armoured battalion in Bardufoss belonged to LIME. They went along the highway E-65 toards Upper Rindal with their Leopard 1A5. In figure 5-25 there are images of highway 343 south of the highway E-65. On the IKONOS image, 3 battle tanks are in position, while on the QUICKBIRD taken the day after, only one battle tank is seen. Several battle tanks were seen on the satellite image in figure 5-25.

The battle tanks in figure 5-25 were pretty easy to find. The tracks in the terrain were obvious, and in this case the battle tanks were in the end of the tracks. To identify Leopard battle tanks is more difficult. The only way of identification is to use the length/width measurements. We know however that no civilian would drive into the 2 meters deep snow, so this leaves the military vehicles. As mentioned earlier the long shadows make it difficult to see the contour of the vehicle. The Leopard and CV90 has approximately the same size, and it was finally personnel from the battle tank squadron that identified them.

Figure 5-25 shows an aerial photo of the same area from the summer of 1998, together with ALFRED images. Again the aerial image was valuable as a reference. The ALFRED images shows that the field has a slight slope.

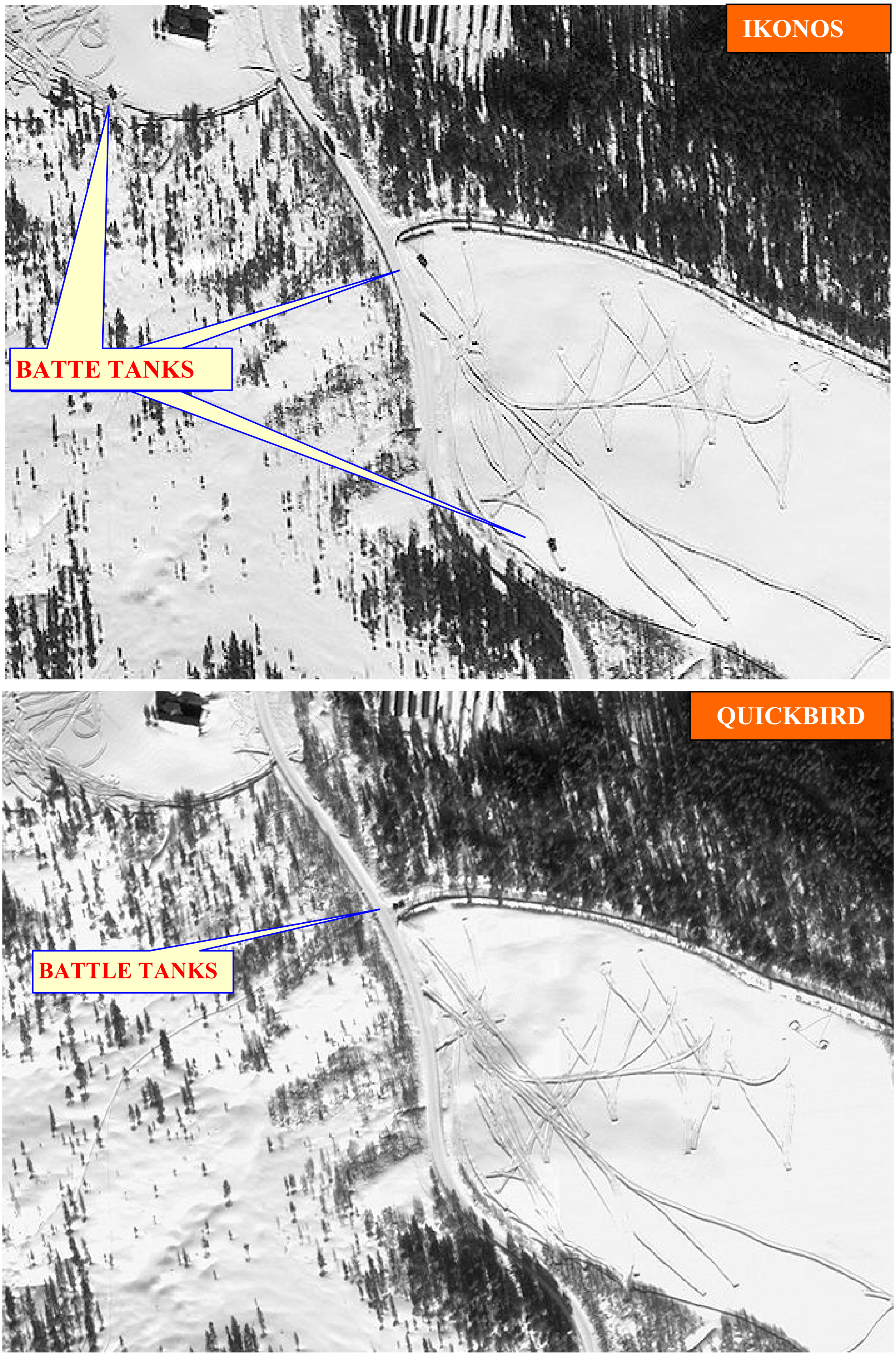


Figure 5-25   Battle tanks from the Norwegian squadron in positions

(IKONOS: Copyright SpaceImaging / QUICKBIRD : Copyright DigitalGlobe)

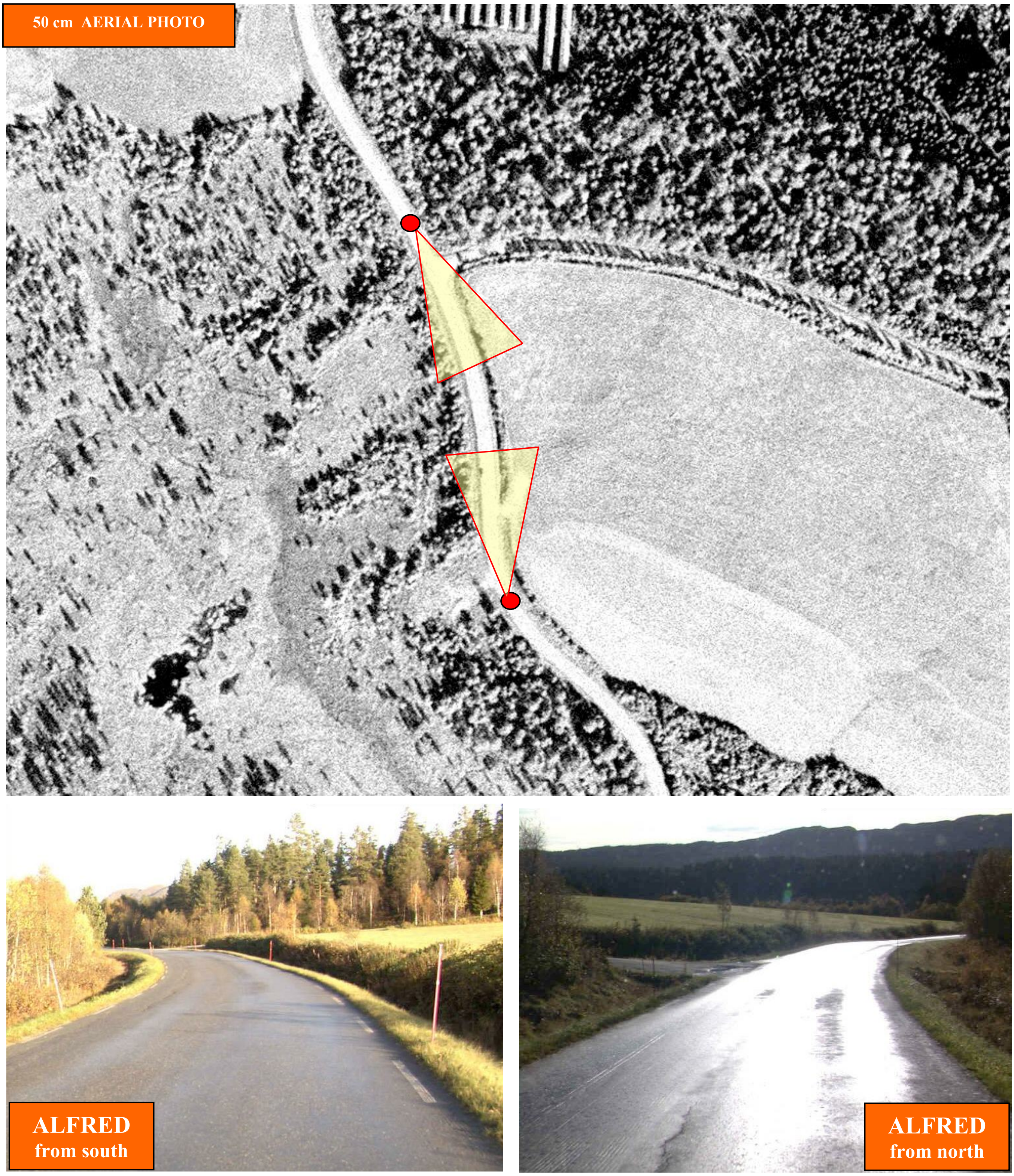


Figure 5-26 Area of Norwegian battle tanks seen from aerial photo (1998), and ALFRED images.

(Flyfoto : Copyright Fjellanger Widerøe A/S / ALFRED Copyright Statens veivesen)

5.3.10 Command post for battle tank squadron no 2

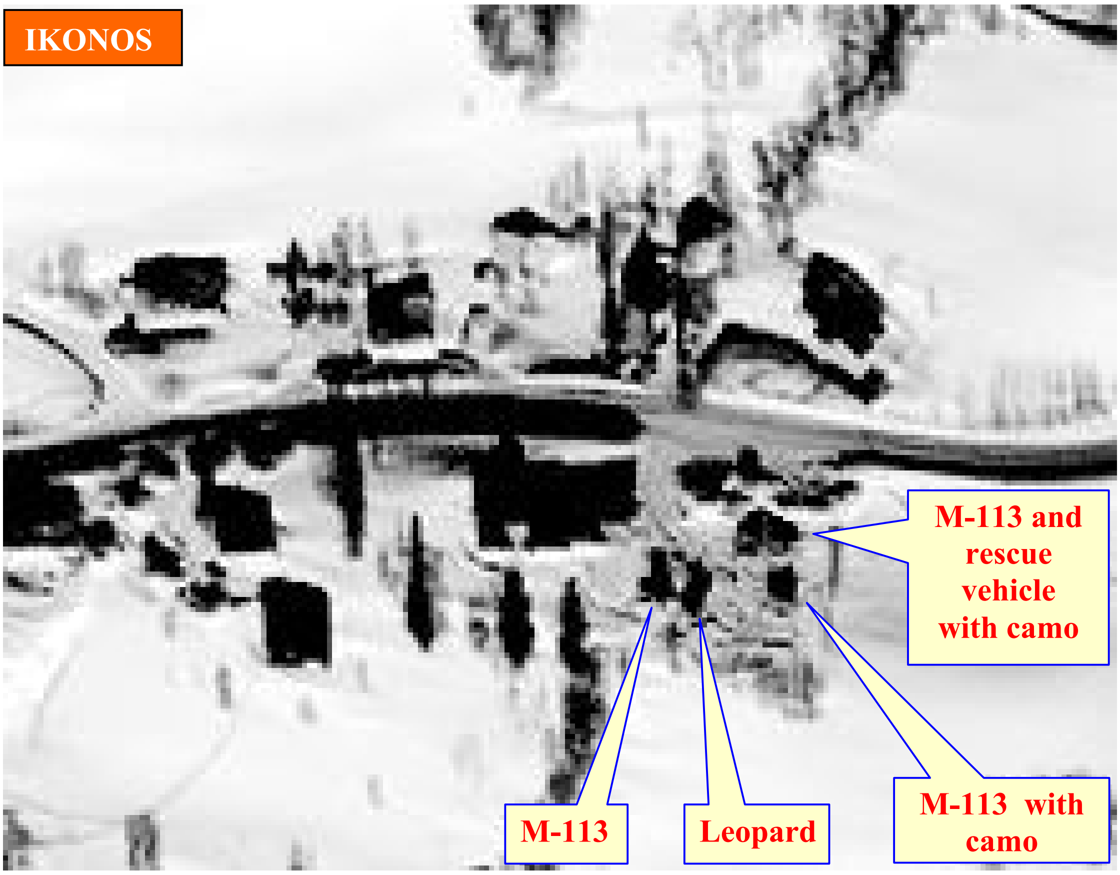


Figure 5-27 Command post of the Norwegian battle tank squadron (Copyright SpaceImaging)

The battle tank squadron had their command post along the highway E-65 at Upper Rindal. An assembly house was used for the purpose. The vehicles were parked in the open space next to the building. When the IKONOS image was taken, the 3 M-113 armoured personnel vehicles, 1 rescue vehicle and 1 Leopard battle tank were present (figure 5-27). The QUICKBIRD image was not readable in this area.

The command post was impossible to identify without additional information. There was clearly activity in the area, and the snow was greyer than in the surroundings. This is however a description which could suit several civilian activities along the road.

The detailed description of figure 5-27 was done by personnel of the battle tank squadron.

Figure 5-28 shows an aerial photo from 1998 covering the same area. From the ALFRED imagery, the space in front of the building seems to be a parking lot.

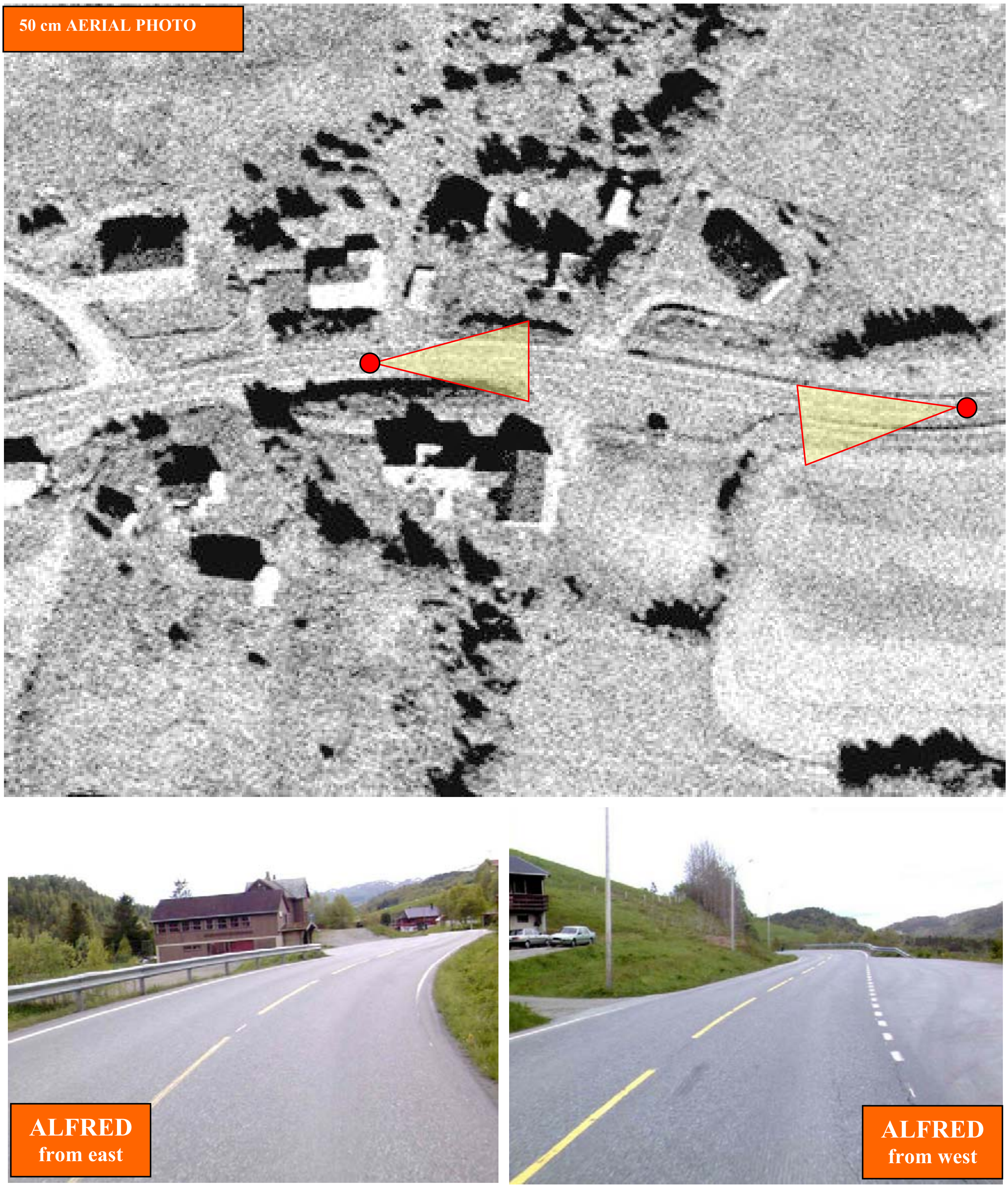


Figure 5-28 Command post of the Norwegian battle tank squadron from aerial photos (1998), and ALFRED images

(Flyfoto : Copyright Fjellanger Widerøe A/S / ALFRED Copyright Statens veivesen)

6 AERIAL PHOTOS VS SATELLITE IMAGERY

Images from aeroplanes and satellites have a lot in common, but there are also certain differences.

The largest principal difference is the unique possibility of the satellite to take pictures in areas with restricted access. Until today it is not known that any nation has tried to prevent photographing from satellite even if the information is known to be very revealing. Aerial photography is normally restricted to taking pictures over own territory, and even there the government will control that the information will not reveal anything that could harm home security.

Satellite imagery is more expensive than aerial photos. The main reason is the price of the satellite, and the management of it. Satellites have a global scope, and needs a system to download and distribute the imagery. This gives a big market, but at the same time demands resources to effectively sell the imagery.

A satellite can typically photograph an arbitrary point on the globe every 2-3 day all year long. If one had permission to take aerial photos, there would have been some planning before the images could be taken. Imagery from satellite can be taken more “spontaneous” than from aeroplanes, since the camera always will be on its way to the target.

For imaging over own controlled area where aerial photographing is possible, this will be preferred. The main reason is the high price of satellite imagery. From the demand of minimum image area from the operator, a satellite image will today cost more than 2.500 Euros. For this amount of money it is possible to have an aerial photo where ever in Norway with maximum priority. If you want to cover a larger area, aerial photography will be almost 10 times cheaper than satellite imagery.

Another advantage with aerial photography is image resolution. It is often necessary with a resolution better than 50 cm that is limit for commercial satellite imagery.

Satellite imagery has its strength when all its advantages can be used at the same time. A military task where this is fulfilled is when:

- Regularly surveillance by means of imaging (e g weekly)
- An area of limited size (e g a base)
- Relatively good resolution (e g 50 cm)
- Relatively cheap (e g 3-4.000 NOK pr image)
- Over time as an subscription (e g on a yearly base)

Such a concept should be attractive both to the satellite operator and the surveiller.

7 VISITTING FKS / JHQ NORTH DURING SR2002

During the exercise we met several units working at FKS. As a guest at the targeting branch, we could participate as observers in the meetings held.

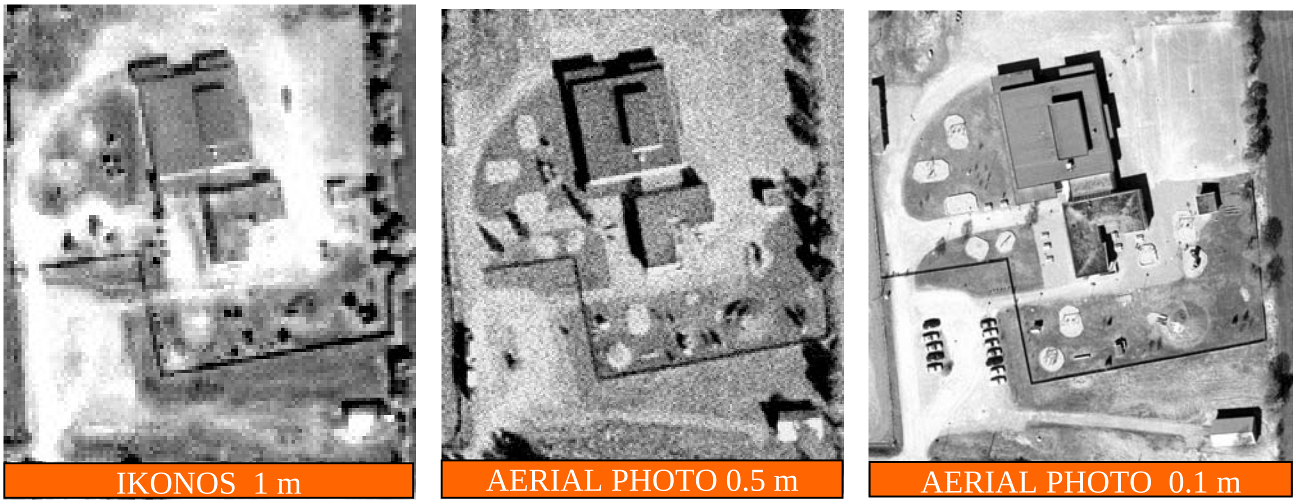


Figure 7-1 Comparison of image resolution

In one of the meetings, Joint Target Nomination Board (JNTB), FFI was able to present its activities during the exercise. We showed aerial images in varying resolutions. In one example there was an image of a bridge and a building close by. The bridge was on the target list. To reduce the possibility of collateral damage it was desired to identify the function of the building. Figure 7-1 shows the building in 3 different resolutions. The resolution had to be as good as 10 cm to identify the building as a kindergarten. Figure 7-2 shows a section of the image with the play apparatus that was the key to the identification.

Figure 7-2
Necessary image resolution to identify the kindergarten

8 SUMMING UP

- You might be lucky and get cloud free satellite images over Central Norway in the middle of March.
- Commercial optical satellites are now taking pictures with a resolution of 60 cm, and it is legal to sell satellite images with a resolution of 50 cm.
- The improvement in resolution from 1 meter to 60 cm is visible, but gives little new information.
- Images with resolution from 60 cm to 1 meter in resolution detect lighter vehicles and equipment. A safe identification though is hard without any other information.
- Snow and low sun angle gives shadows and contrasts which is both positive and negative in analysing images. The advantage is that small objects can be seen in the image even if they are so small that they should not be detectable. The disadvantage is that long shadows make it difficult to see the contour of objects.
- Tracks in the snow from vehicles are very revealing.
- It should be rather easy to use trees and shadows to avoid being seen from above.
- Aerial photos taken in advance were useful for several reasons.
- For some military operations it is necessary to use near real time imaging. The Norwegian defence has no systems to cover such a demand.
- 3 dimensional visualisation of terrain and infrastructure gives a better understanding of an area.

9 CONCLUSION

An improved image resolution in satellite images from 1 meter to 60 cm, has little influence on identifying objects in the images. Even for larger vehicles, like battle tanks, it is only the contour that can contribute to identification.

Satellite imagery showed clearly that snow covered areas made any movements outside roads very visible through the tracks in the snow. It was correspondingly obvious that woods effectively prevented insight in ground activity.

The low angled sun made shadows long. This resulted in that small objects normally not visible were detected because of the shadow. The long shadows made it further difficult to determine the contour of objects since the transition between the shadow and the object itself was unclear. Objects close together throw shadow on each other in a way that they could not be separated.

Images taken in advance with high resolution (≤ 0.5 meter pixel size), can be useful as supplement to maps for planning purposes. For some tasks, however, it is only real time imagery from the ongoing battle that is useful. The military does not have any imaging system today that can cover these needs.

There are still groups in the military whom are not sufficiently aware of the possibilities to use aerial photos and satellite imagery as help in planning military operations. It would seem useful to visit such groups and demonstrate the usefulness of such imagery.

List of litterature

[1] Bjerke Pål, Heggen Hanne Marit, Viken Kjell
”Kartlegging v h a SPOT”,
1997, FFI-RAPPORT-97/02005, Forsvarets Forskningsinstitutt

[2] Bjerke Pål
”Militær bruk av bilder fra kommersielle optiske fotosatellitter”,
1998, FFI-RAPPORT-98/04501, Forsvarets Forskningsinstitutt

[3] Bjerke Pål
”Evaluering av høyoppløselige optiske bilder fra IKONOS satellitten”,
2001, FFI-RAPPORT-2001/05750, Forsvarets Forskningsinstitutt
[BEGRENSET]

[4] http://www.fw.no/flyfoto/

[5] http://www.nima.mil/publications/specs/printed/89020b/89020b.pdf

[6] Baker John, O'Connell Kevin M, Williamson Ray A
“Commercial Observation Satellites”
RAND / ASPRS 2001

[7] http://carterraonline.spaceimaging.com/cgi-bin/Carterra/phtml/login.phtml
(for å nå arkivet, må en la seg registrere, og få et brukernavn og passord)

[8] http://www.spaceimaging.com

[9] http://www.digitalglobe.com

[10] http://www.eurimage.com

[11] http://www.fotonor.no