FFI RAPPORT

AN AUTOMATIC STATION FOR MEASUREMENT OF METEOROLOGICAL PARAMETERS AND THERMAL SIGNATURES

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OLSEN Frode Berg

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Bjarne Haugstad
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8) ABSTRACT

Two measuring stations have been established - the purpose being to collect comprehensive databases of thermal signatures of background elements together with the prevailing meteorological conditions. The databases have primarily been used as a foundation in developing models for simulation of thermal signatures of natural backgrounds and for vehicles.
The stations are built up by two different systems: one with a calibrated thermal camera for radiometric measurements, and one with a number of meteorological sensors - i e sensors for recording relevant parameters which are influencing the thermal signatures of backgrounds and objects. That includes air temperatures and humidity, long and short wave radiation (in and out), wind speeds and directions, precipitation (rain and snow), and finally underground temperatures. Both stations are remotely controlled from FFI via telephone lines, and it is possible to transfer the collected data from the stations to FFI over the same lines.
At each measuring site 3-4 thermal images are automatically recorded every 15 minutes and every 5 minutes over 50 meteorological parameters are recorded.
The stations have been operating successfully over long periods of time, and they have proved to fulfil the purpose of delivering confident meteorological information and radiometric data of backgrounds and objects.

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CONTENTS

AN AUTOMATIC STATION FOR MEASUREMENT OF METEOROLOGICAL PARAMETERS AND THERMAL SIGNATURES

1 PURPOSE

Two measuring stations have been established – the purpose being to collect comprehensive databases of thermal signatures of background elements together with the prevailing meteorological conditions. The databases have primarily been used in FFI project 775, which was aimed at developing models for simulation of thermal signatures for natural backgrounds and for vehicles (1). Both models should be based on real meteorological data and they were to be calibrated against real thermal images – descriptions of the models are being reported in (2) and (3) respectively.

The stations are built up by two different systems: one with a calibrated thermal camera and one with a number of meteorological sensors – i e sensors for recording relevant parameters which are influencing the thermal signatures of backgrounds and objects. The high frequency of measurements over longer periods of time required that the stations were fully automatic. A complete set of sensors was borrowed from our German co-operating institution FGAN-FOM (Forschungsgesellschaft für Angevantes Naturwissenschaften – Forschungsinstitut für Optik und Mustererkennung).

The present report describes the construction of the stations with all their sensors, data handling and transmission to FFI, and the final data bases used for modelling.

2 MEASURING SITES

2.1 Locations in Norway

In order to obtain a database as comprehensive as possible, extreme weather conditions over long periods of time had to be included. A study of the climate in Norway indicated three possibilities: Northern Norway (cold), western coast (wet and windy), and Southeastern Norway (warm and dry) as illustrated in figure 2.1.

Other important factors for choosing locations were the presence of a variety of background elements within a limited area, and the necessary infrastructure like housing for some of the instrumentation, electricity supply, and telephone lines. All these requirements were fulfilled at the air bases at Bardufoss (in the North), Ørland (at the western coast), and Rygge (in the South) – “encircled” in figure 2.1. Additional advantages by choosing air bases were that the measuring stations were located within a fenced area and close to official weather stations.

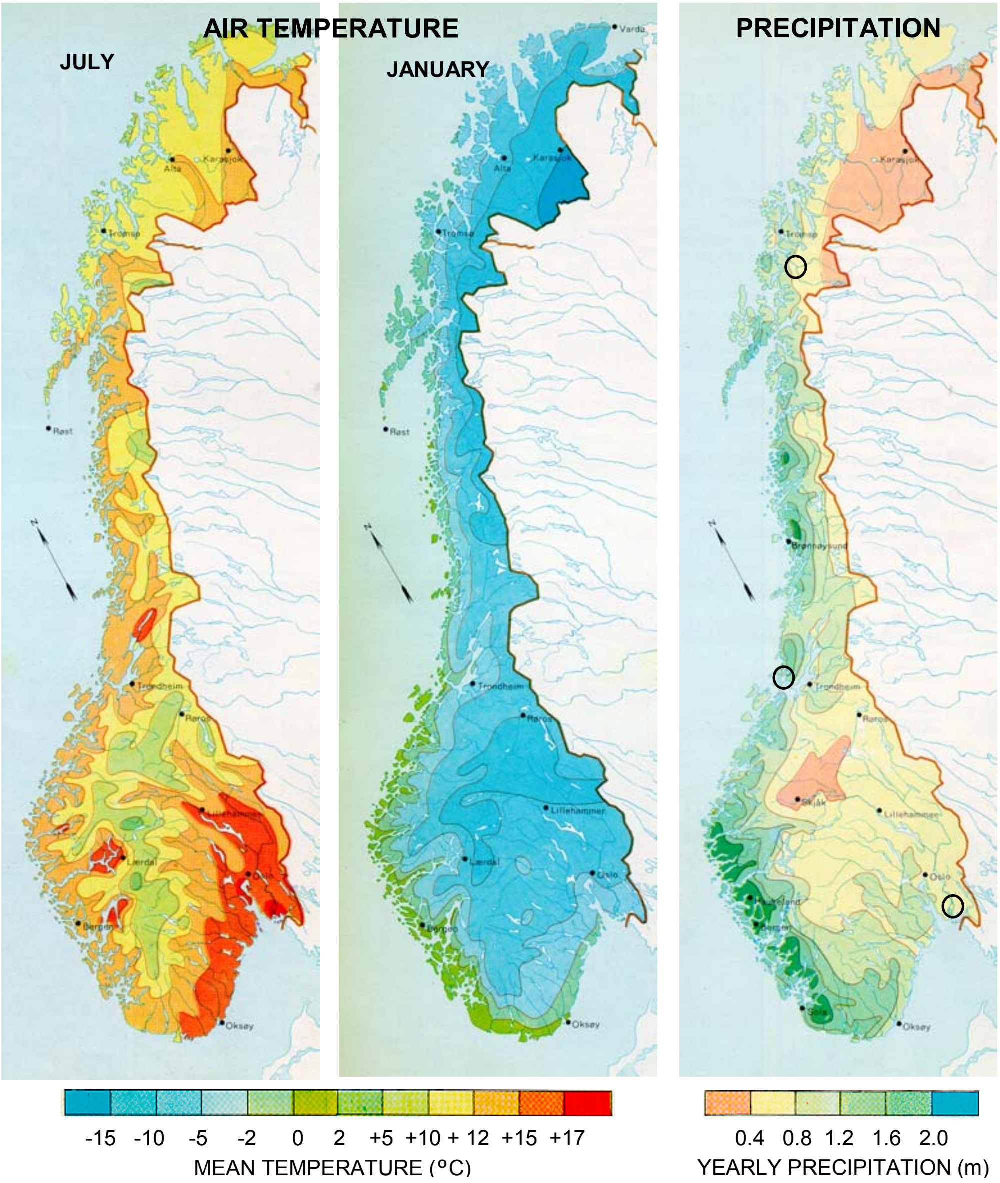


Figure 2.1 *Air temperature for summer and winter and yearly precipitation in Norway*
(Climate maps: © J W Cappelen Forlag a.s)
The circles indicate the measuring stations, - their exact positions being:

Bardufoss:	*69° 3'N, 18°34'E,*	*100 m above sea level*			
Ørland:	*63°43'N, 9°38'E,*	*20 m*	"	"	"
Rygge:	*59°24'N, 10°43'E,*	*55 m*	"	"	"

Three locations had now to be served by only two measuring stations. It was therefore decided that one should be operated permanently at Bardufoss while the other should be transferred between Ørland and Rygge: Ørland during winter and Rygge during summer. This would result in measurement sites in the following climate:

Bardufoss:	Cold winter, polar night – Warm summer, midnight sun
Ørland:	Wet and very windy winter
Rygge:	Warm, dry summer

Ørland is in fact very windy during the winter months. The wind force at Ørland is normally 6 Beaufort (10.8 m/s) or above in more that 60% of the days in each of the months October to March, while this occurs in less than 15% of the days at Rygge and Bardufoss.

2.2 Description of sites

At the air stations were chosen fairly open measuring sites to avoid shadowing of the background elements. At all sites there were erected two masts, one for meteorological instruments and one for two cameras: one thermal camera for measuring of thermal radiation and one video camera. This means that only the instruments have to be transferred between Rygge and Ørland while the masts remained at the stations. At the sites the camera masts were positioned so that the field of view from the cameras was away from the sun, i e the cameras were looking mainly towards the north.

The background elements found at the sites were coniferous and deciduous trees, scrubs and heather, grass, gravel roads, rock, etc. In figure 2.2 are shown pictures of two of the areas as taken from the camera mast. The sites also included parking places for measuring thermal signatures of vehicles.

Figure 2.2 Pictures taken from the camera mast at Bardufoss (top) and Rygge. Fields of view of the thermal camera (1 to 3 and 6) are given for Rygge. The meteorology mast and precipitation sensor can be clearly seen.

Some of the instruments require room climate for operating – for instance a PC. Housing requirements were solved differently at the three stations: in a warmed air defence shelter at Rygge, in a building at Ørland, and in a caravan acquired specially for the purpose at Bardufoss (figure 2.3).

Figure 2.3 The caravan at Bardufoss with the camera mast and camera housing
To the right is shown the working station within the caravan

The distances from the thermal camera to the background elements to be measured vary from 30 to 70 m at Rygge, 20 to 60 m at Bardufoss, and 10 to 50 m at Ørland. Except for rainfall conditions, the thermal transmission will very seldom be influencing the radiometric measurements at such short distances.

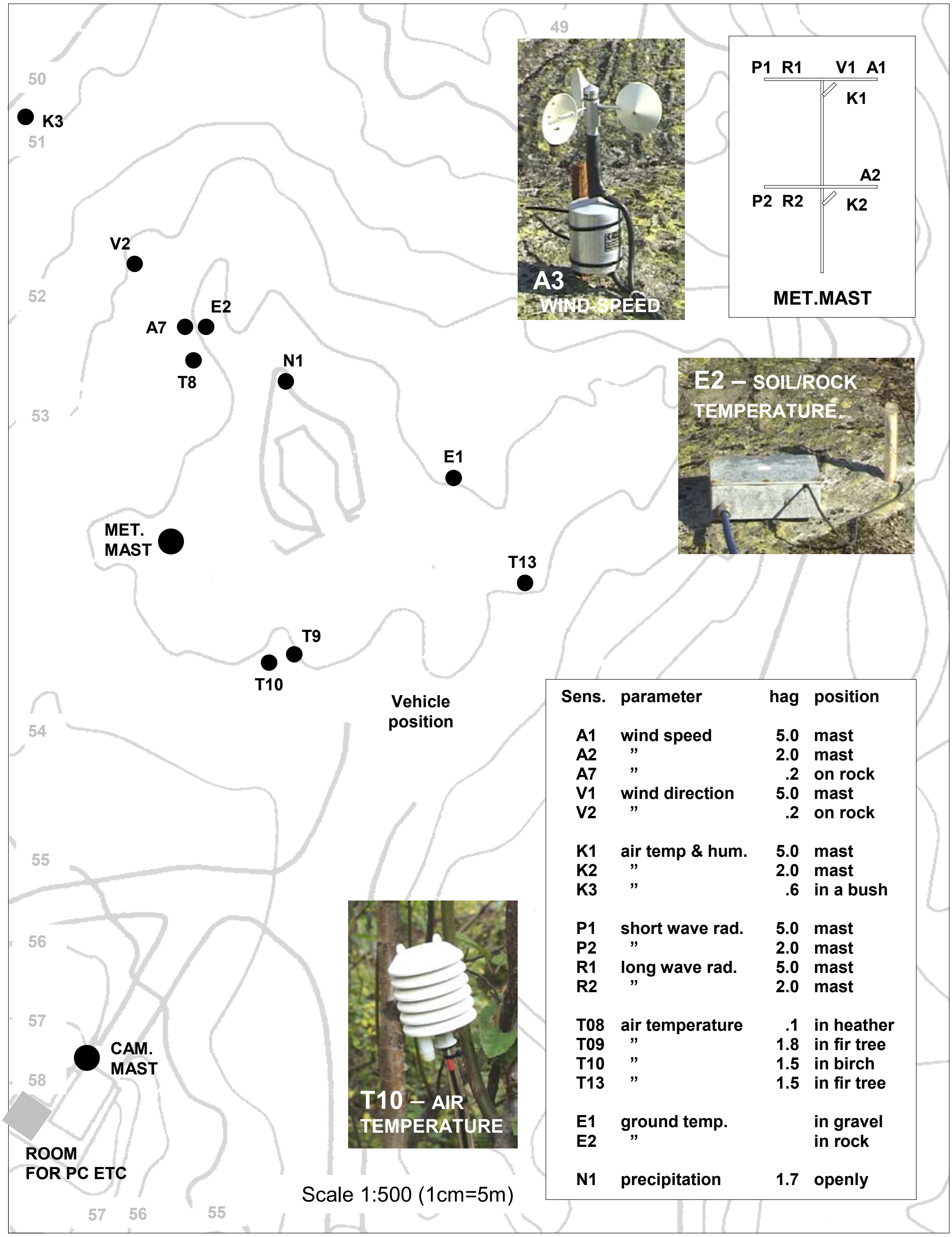
The measuring station at Bardufoss can also be used for long distance measurements as can be seen from figure 2.3. By turning the camera towards an easterly direction, background elements like woods at different distances, moor, bog, and cropland can be measured. By such measurements the atmospheric transmission of thermal radiation has to be taken into account.

3 MEASURING METEOROLOGICAL PARAMETERS

3.1 Sensors

The measuring sites are built up in principally the same way with two masts (meteorology and camera), housing for computers, and sensors mounted in the masts and among the background elements. As an example is shown the site at Rygge – figure 3.1. The positions of the two masts are given, and seen in connection with the photo in figure 2.2 the positions of the sensors relative to the background elements can be found.

In figure 3.1 is already presented the sensors of the measuring stations. All meteorological parameters that are considered to have any influence upon the thermal signatures of backgrounds and objects were measured. That includes air temperature and humidity, long



Sens.	parameter	hag	position
A1	wind speed	5.0	mast
A2	”	2.0	mast
A7	”	.2	on rock
V1	wind direction	5.0	mast
V2	”	.2	on rock
K1	air temp & hum.	5.0	mast
K2	”	2.0	mast
K3	”	.6	in a bush
P1	short wave rad.	5.0	mast
P2	”	2.0	mast
R1	long wave rad.	5.0	mast
R2	”	2.0	mast
T08	air temperature	.1	in heather
T09	”	1.8	in fir tree
T10	”	1.5	in birch
T13	”	1.5	in fir tree
E1	ground temp.		in gravel
E2	”		in rock
N1	precipitation	1.7	openly

Figure 3.1 *Sensor positions at Rygge*
All sensors are listed in the table with a description of their positions and their heights (in m) above ground (hag). Pictures of some of the sensors are shown.

and short wave radiation (in and out), wind speed and direction, and finally precipitation (both snow and rain). Additionally the temperature in the ground was measured. There may be some differences in the number of sensor from site to site. However, all sites had a specially constructed mast with meteorological instruments as depicted in figure 3.2.

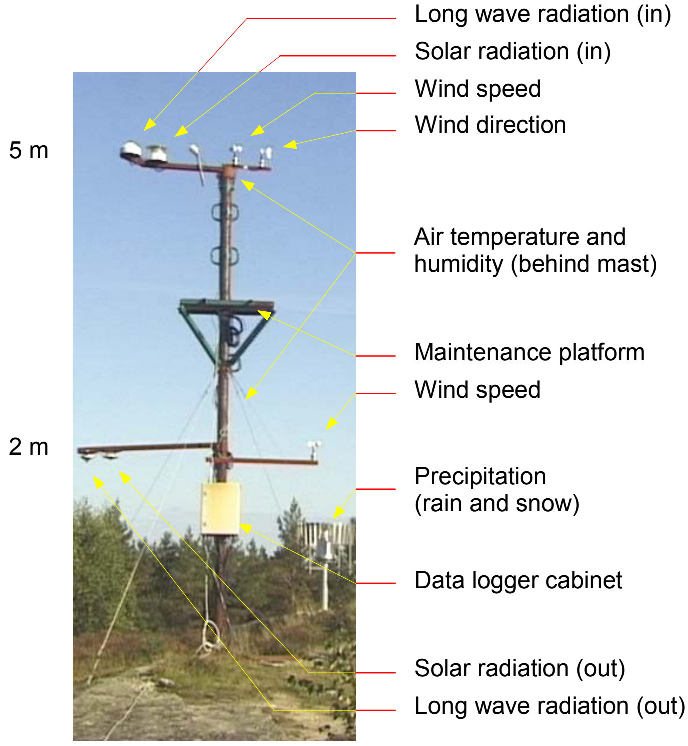


Figure 3.2 Mast with meteorological instruments. Precipitation sensor in the background

The air temperature, air humidity, and wind speed were measured at two heights above ground: 2 and 5 m (figure 3.2). The variation with height for these parameters necessitated measuring them at ground level in some places, and the air temperature was also measured within trees and bushes as indicated in figure 3.1. Even the wind direction was measured at ground level.

Nearly all meteorological instruments are standard instruments: the make, type and specifications are given in appendix A. A special sensor was constructed to measure the temperature in the ground at 5 different depths: 2, 10, 20, 30 and 50 cm below surface (see figure 3.1 and description in the appendix).

3.2 Data logging and transmission

All sensors are connected to a Campbell Scientific CR10X data logger. The logger is equipped with three multiplexers (external units) in order to obtain enough input channels. The logger with peripheral instrumentation and a GSM module are mounted in a weather tight cabinet on the meteorological mast (figure 3.3). In the cabinet is also a battery with charger. The capacity of the battery makes it possible to run the station for a couple of weeks in cases of line power cut (220V). For more sunny parts of the world, the station might be run by the power from solar cell panels.

The data logger is programmed to read data from the sensors 2 times per minute. From calibration curves the data are converted to the usual units for temperature, wind speed, etc.

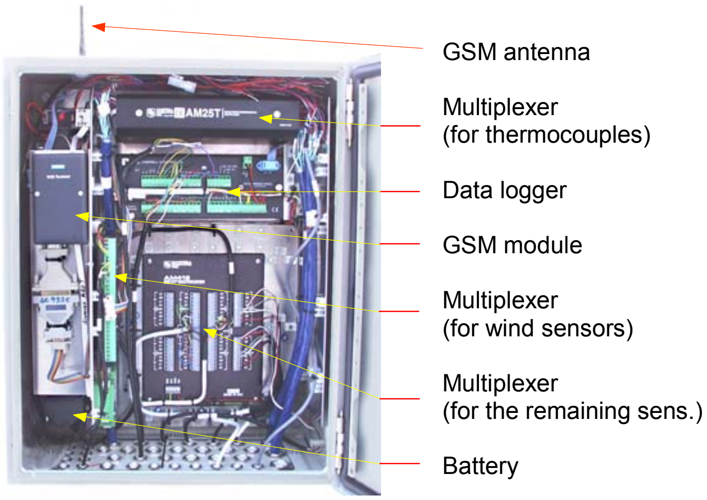


Figure 3.3 Data logger cabinet with its contents

Mean values of the last 10 measurements from every sensor are stored in the memory of the logger every 5 minutes.

The capacity of the local memory is restricted to take data for just a few days. Data is therefore transmitted several times a week to FFI over telephone via the GSM module. (For areas with inferior GSM coverage, it is possible to use ordinary telephone lines.) The GSM line makes it possible to read the instruments in near real time from FFI (figure 3.4). It is also possible to control the condition of the sensors and to re-programme the data logger from FFI. A detailed description of data logging and transmission can be found in (4).

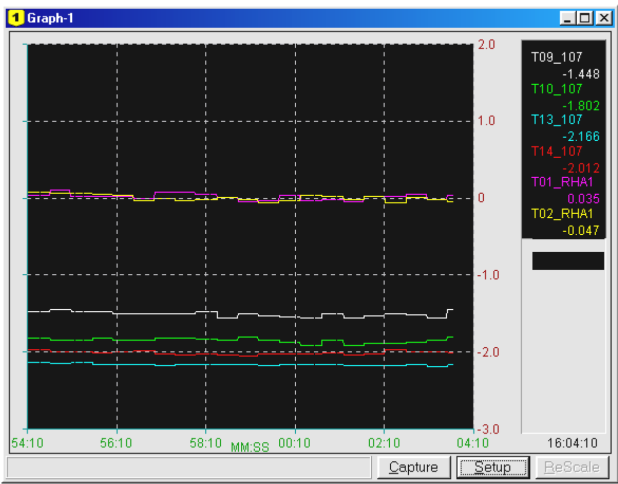


Figure 3.4 The recordings from six different temperature sensors at Rygge as read in near real time at FFI.

4 MEASURING THERMAL SIGNATURES

4.1 Thermal camera

At the top of the camera mast is a calibrated thermal camera (8-12μm) that is used for imaging the site with its background elements. The calibrated camera makes it possible to read the apparent temperature for each pixel in the images. By averaging all pixel values for a certain background element, the apparent temperature for that element can be found; and by taking the results from a series of images, the variation with time can be established.

The camera is mounted in a weather tight housing on a Computar PT10 pan/tilt head at the top of the camera mast. For cold days (below 5 ^{o}C) the housing is heated by a thermostat regulated heater element, and a fan draws the warmed air past the cameras. Each time an image is to be taken a door opens automatically as shown in figure 4.1. The system is pre-programmed to record images in fixed directions every 15 minutes. The scenes recorded by the camera at Rygge can be seen from figure 2.2, and examples of thermal images are given in figure 4.2.

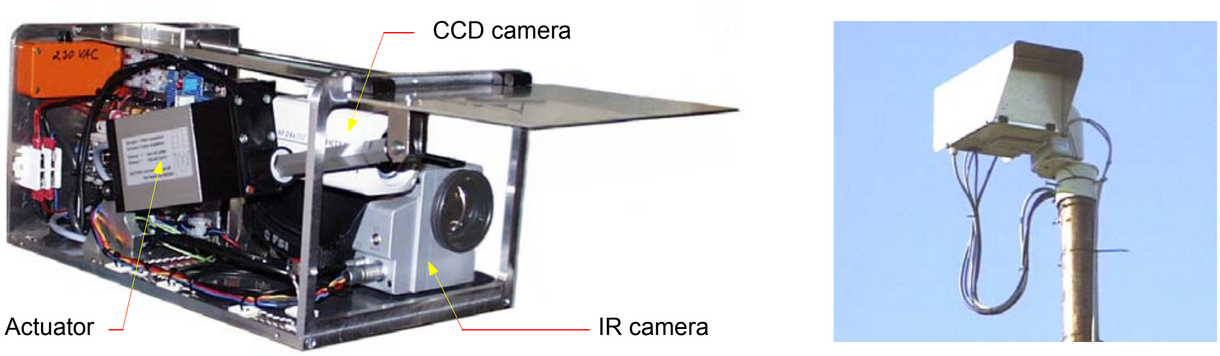


Figure 4.1 *The camera housing without cover with open door (left) and in the mast (right)*
To the left can be seen some of the electronics, the cameras, and the actuator which opens the door.
The housing also contains a CCD camera for visual images. These are used for obtaining a general view of the scene: cloud shadows, snow on the ground, etc
Specifications for the cameras are given in the appendix B.

When measuring thermal signatures of a vehicle, the system is programmed to record images of the vehicle in its position – field of view marked 6 in figure 2.2. In order to obtain the real surface temperature of the vehicle, a number of thermocouples (type “T”) are glued to the most interesting parts of the vehicle. The thermocouples are connected to the meteorological system and read every 5 minutes as described earlier.

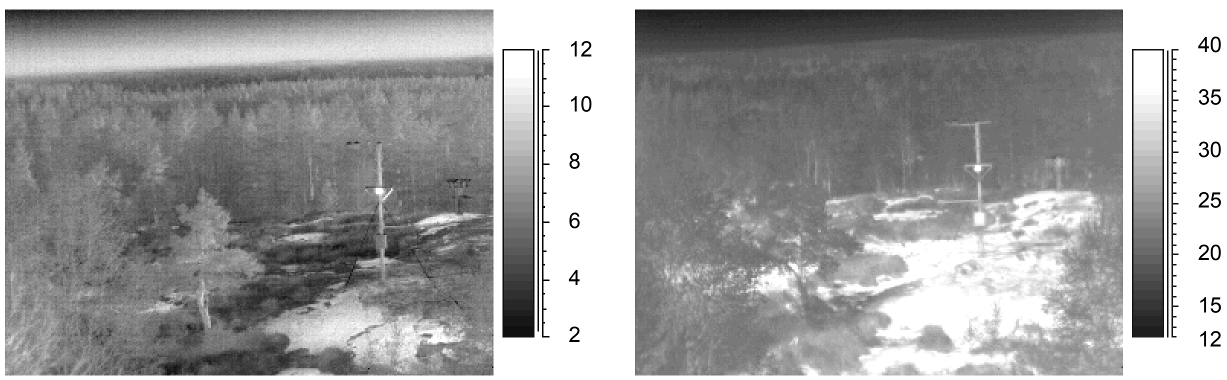


Figure 4.2 *Thermal images from Rygge 12 May 2001 at 0545 and 1545 hours.*
Temperature scales (in ^{o}C) are given to the right of each image.
Photo of the imaged scene can be seen in figure 2.2.
The hot spot in the middle of the mast is a position reference.

4.2 Camera control

Both cameras and the pan/tilt head are connected to a local computer (PC). A special programme, ImageSequencer, is made for controlling both pan/tilt head and cameras. Every 15 minutes the housing door is opened, the cameras are steered in pre-programmed directions (see figure 2.2), and images are recorded from both cameras – all in a pre-programmed sequence. A video monitor by the computer (see figure 2.3) facilitates the adjusting of the cameras, and it can be used for controlling the recording sequences.

Most functions of the thermal camera can be controlled from the computer via a PCMCIA adapter. This is, however, not the case for the main switch. Problems arise after power cuts: the thermal camera does not restart automatically. To solve this problem a mechanical system based on a computer-controlled actuator was constructed to mechanically switch on the camera.

The CCD camera permits remote control of the focal length (12X optical zoom), the focus, the aperture, and the shutter. With the intention to run the station as automatically as possible, it was decided to set the camera in an automatic mode for focus and aperture.

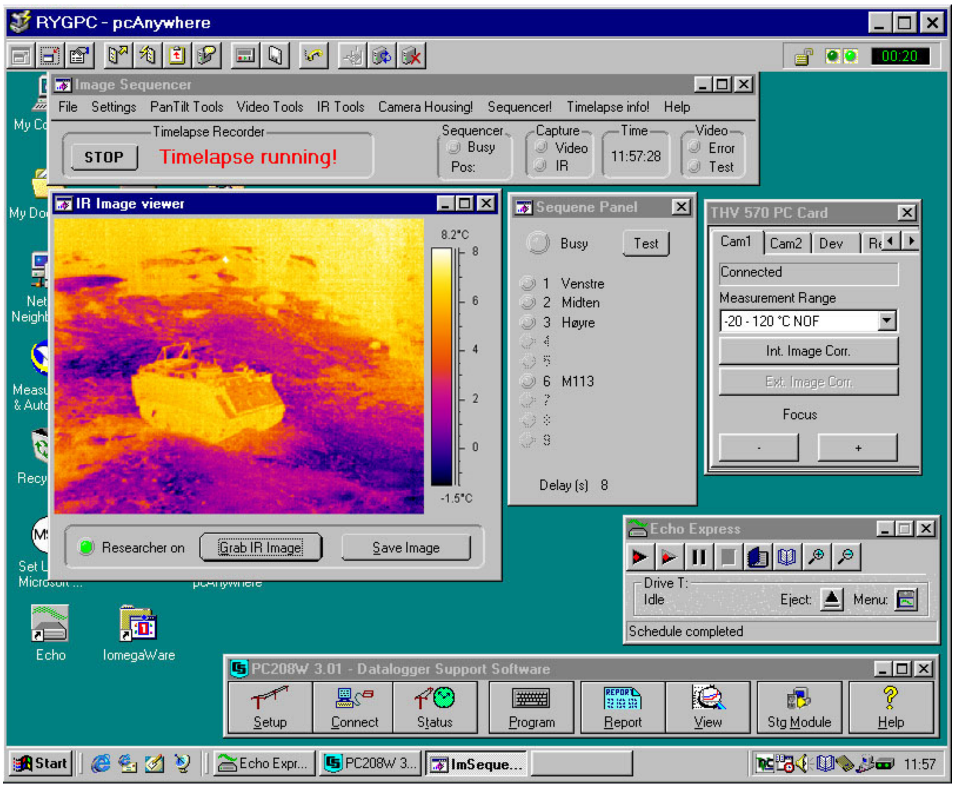
A large effort was put into making the programme and station as self-supported as possible. There are routines for correcting most of the errors that may occur. Such corrections are logged in a special file. And if the computer stops responding (is hanging), the operator at FFI can re-set the computer via telephone.

An error occurs from time to time in the function that chooses camera direction – it may stop. To be able to correct such errors a function based on pattern recognition is built into the programme. If the first and last image of a sequence is identical, the programme automatically re-sets the steering of the camera.

By a remote control programme, PcAnywhere, it is possible for the operator at FFI to take command over the computer via telephone. In this case the programme transmits the whole display from the computer at the measuring site to the computer at FFI (figure 4.3). This option is used for controlling that the station is working properly and also for making changes in the programme – for instance changing camera directions. Over this connection it is also possible to transfer single images and the computer log file. In the log file the programme lists problems and errors that may have occurred.

4.3 Image transmission

The imagery is stored on the hard disc of the local computer. To prevent loss of data in case of hard disc crash, the imagery is copied automatically to a back-up tape twice a day. The capacity of the tape permits storing imagery for several months. The size of the imagery is prohibitive for allowing transmission over telephone line, and the tape has therefore to be brought physically to FFI.



Figur 4.3 PC display for camera control as transferred from Rygge to FFI.

4.4 Lining up images for temperature measurements

Inaccuracies in the pan/tilt head and a little swaying of the mast causes the direction of the thermal camera to vary somewhat from one sequence to another. That means that the same image pixel position does not necessarily record the radiation from the same point in the scene from one image to another, as can clearly be seen from figure 4.2. Lining up the images is therefore required, and for this purpose some hot position references were installed in the area.

Covered up halogen lamps have been used as hot spot references. The lifetime of the lamps is, however, restricted, and the frequent changing of lamps is not consistent with the autonomy of the measuring station. The halogen lamps are therefore being substituted with 20x30 cm heating foils.

A special computer programme has been made for reading and lining up the thermal images. Two different methods are used:

1 by advanced pattern recognition (based on the programme library IMAQ-Vision from National Instruments), and
2 by searching for rectangular areas with high temperature (the hot spot references).

The last method will in most cases be successful, as the hot references are usually the hottest areas in the images. For images without any hot spot (burnt out lamps, power cuts) the first method is applied. All images have been analysed in this way, and the offsets are stored with their corresponding images in a final data bank.

Another data programme has been made to calculate mean temperatures with standard deviations and max/min values for given regions in the terrain. Such regions have to be manually defined in one of the images. Based on the results from the lining up of the images, the programme finds the same physical regions in other images and does the temperature calculations. The results are stored with the corresponding images in the data bank. This makes it possible to study how the temperature of background elements or objects varies with time as illustrated in figure 4.4.

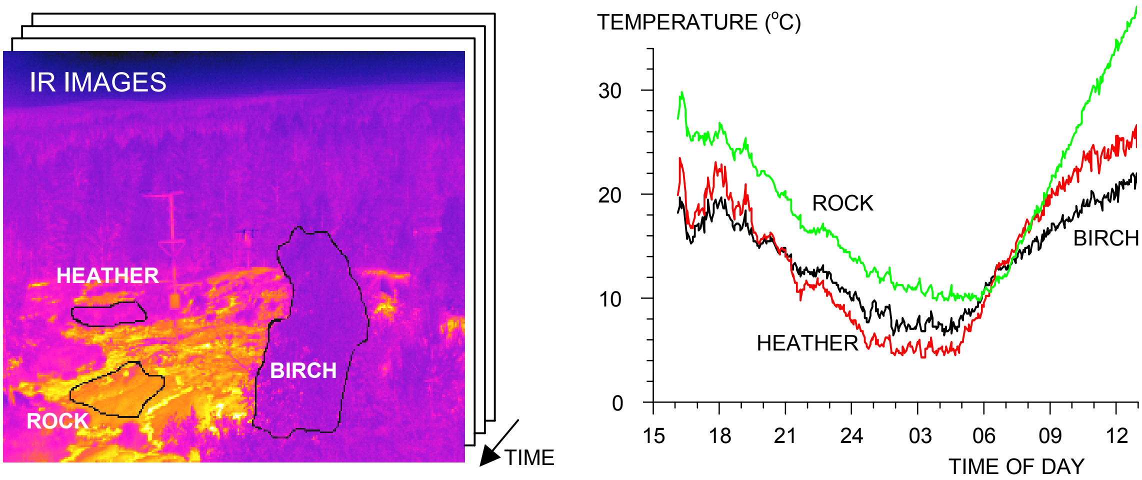


Figure 4.4 Lined up IR images used for studying temperature variation with time. The defined areas of background elements in the image shown can be re-found in all the stacked images, and the calculated mean temperatures are presented to the right.

5 DATA BANK

A data bank with one database for each measuring station is established at FFI (6). All meteorological measurements and all images are stored in these databases. The meteorological sensors result in more than 50 readings every 5 minutes, which means ca 15 000 data points per day. The camera records 3-5 images every 15 minutes, which results in nearly 400 thermal images à 158 kB per day. The same number of images comes from the CCD camera, although they are only about one-third in size.

The database for Rygge, which has been operating more or less continuously since November 2000, contains more than one million data points, about 110 000 thermal images, and the same number of CCD images. It is possible in an easy way to search for recordings from a given sensor for a given time interval – and for given camera directions. It is also possible to search for mean temperatures for terrain regions where such values have been calculated.

For each meteorological sensor acceptance intervals are defined. For values outside these intervals the recordings are ignored. This may for instance occur when the actual sensor has been disconnected from the data logger.

6 SUMMARY

Two nearly identical automatic measuring stations have been constructed. They have been operating successfully over long periods of time, and they have proved to fulfil the purpose of delivering confident meteorological information and radiometric data of backgrounds and objects. Some minor modifications are, however, necessary in order to increase the operating reliability of the stations.

A huge amount of data is already stored in a data bank, and the data will be used for further analysis and as a foundation for modelling of thermal signatures of backgrounds and objects. However, additional data is required – especially for more extreme weather conditions.

The stations have also proved to be useful for studying thermal camouflage systems, and it is planned to use them as proving stations for such studies.

APPENDIX

A METEOROLOGICAL INSTRUMENTS

A.1 Thermometers (air temperature)

Make: Cambpell Scientific, Ltd
Type: 107 Temperature Probe
Characteristics:
Precision thermistor in a water-resistant probe with solar radiation shield T351-RS (figure 3.1).
Thermal constant: 60 s (in air at 1m/s)
Linarisation errors:

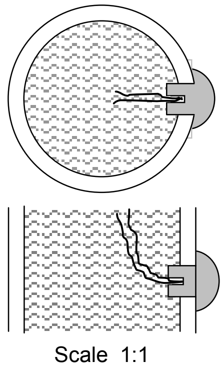
Range °C	Error °C
-40 to +56	< ± 1.0
-38 to +52	< ± 0.5
-23 to +48	< ± 0.1

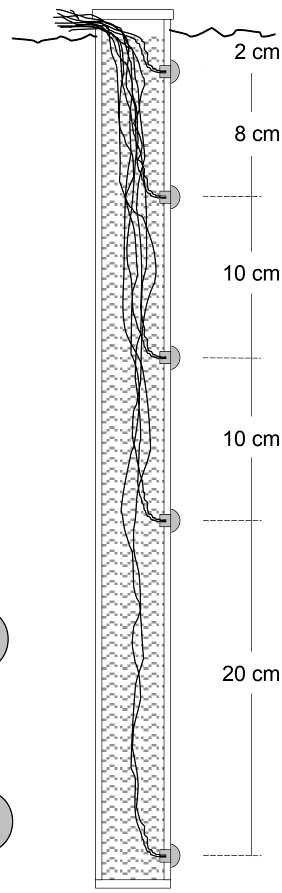
A.2 Thermometers (ground temperature)

Make: FFI
Type: Homemade
Characteristics:
Five thermocouples mounted in a watertight extruded plastic tube at depths 2, 10, 20, 30, and 50 cm. In order to obtain the best possible thermal contact with the ground material, the thermo-couples are welded into drilled holes in copper nails as shown. Finally the tube is filled with a thermal insulating material.
The tube is put in a drilled hole in the ground in such a way that the heads of the copper nails have good thermal contact with the ground material, and the narrow space between the tube and ground is filled with fine-grained sand. (Figure 3.1)
Thermocouple characteristics:

Type:	T (Copper-Constantan) (Cu – Cu/Ni)
Lead diameter:	0.2 mm
Lead insulation:	Teflon
Temperature range:	-40 to +125 °C
Accuracy:	± 0.5 °C

The same type of thermocouples is used for measuring object temperatures.





A.3 Combined Hygrometer and Thermometer

Two types of combined instruments with about identical specifications have been used:

	Instrument 1 (FFI)	**Instrument 2** (FGAN-FOM)
Make:	Delta-T Devices Ltd	Skye Instruments Ltd
Type:	RHA1	SKH 2011

Characteristics – Hygrometer:

Relative humidity sensor: cracked chromium oxide, which alters capacitance with changes in relative humidity.

Measurement range: 0 to 100% RH
Operating temperature: -30 to +70^{o}C (limits -40 to +140^{o}C)
Linearity deviation: typically 2.5% RH between 10 and 90% RH
Accuracy: < 2% RH (-30 to +70^{o}C), including electronics
Time response: typically 10s between 10 and 75% RH for 90% of the step
Hysteresis: < 5% RH
Power requirement: 5-15V DC, 2 mA

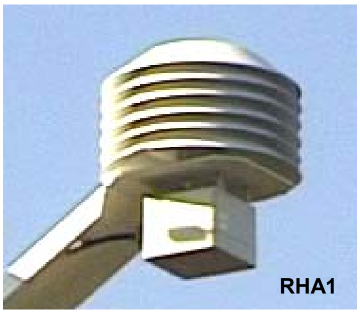
Characteristics – Thermometer:

Varnish and epoxy coated 2k thermistor

Accuracy:

Range ^{o}C	Error ^{o}C
0 to +80	< ± 1.0
-20 to +80	< ± 0.13

Drift: typically < 0.02 ^{o}C per 8 years



A.4 Wetness sensor

Make: Campbell Scientific, Ltd
Type: 237

Characteristics:

The sensor consists of a rigid epoxy circuit board (75x60 mm) with interlacing gold-plated copper fingers, the space between the fingers being 0.25 mm. Condensation and rain on the sensor lowers the resistance between the fingers, which is measured by the data logger.

A.5 Anemometers

Make: Vector Instruments
Type: A100R

Characteristics:

Mercury switched counting of the revolutions of a 3-cup rotor (figure 3.1).

Threshold: 0.2 m/s
Max speed: > 75 m/s
Accuracy: 1% of reading (10 to 55 m/s) – 2% of reading (> 55 m/s)
Calibration: 0.8 revolutions per m nominal
Temperature range: -30 to +70^{o}C

A.6 Windvanes

Make: Vector Instruments
Type: W200P
Characteristics:
Precision wire-wound potentiometer as a shaft angle transducer.

Threshold:	0.6 m/s
Max wind speed:	> 75 m/s
Accuracy:	3° in steady winds > 5 m/s
Range:	360° mechanical angle, full-circle continuous rotation allowed
Temperature range:	-50 to +70°C

A.7 Precipitation Gauge

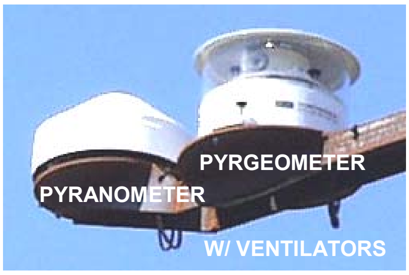
Make: Geonor AS
Type: T-200B
Characteristics:
Weighting a collecting bucket by a vibrating wire sensor. A thin oil film prevents evaporation, and for freezing weather a mixture of ethylene-glycol and methane is added.

Opening:	200 cm^2
Capacity:	0-600 mm (12 l bucket)
Sensitivity:	0.1 mm
Accuracy:	0.1% of full scale
Repeatability:	0.1 mm
Temperature range:	-25 to +70°C (depending of amount of anti-freeze additive)

A.8 Pyranometers

Make: Kipp & Zonen
Type: CM 21
Characteristics:
A 100-thermocouple sensor imprinted on a thick substrate, housed under K5 glass domes. On the upward looking instrument is mounted a heated ventilator type CV2.

Spectral range:	305-2800 nm (50% points) 335-2200 nm (95% points)
Irradiance:	0 – 1400 Wm^{-2} (max 4000 Wm^{-2})
Viewing angle:	2 π sr
Response time:	5 s (for 95% response)
Directional response:	± 10 Wm^{-2} (for beam radiation)
Non-stability:	± 0.5 % per year
Non-linearity:	± 0.25 %
Temperature response:	± 1 % (–20 to +50 °C relative to 20 °C)
Receiver paint:	Carbon black



Glass domes: Schott K5 optical glass 2 mm thick, 30 mm and 50 mm outer diameter

A.9 Pyrgeometers

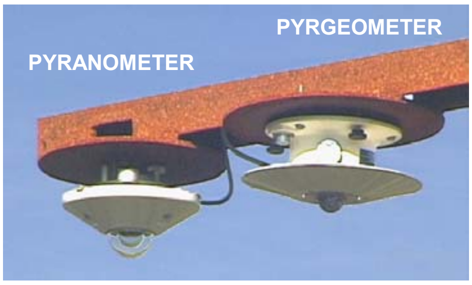
Make: The Eppley Laboratory, Inc.

Type: PIR (Precision Infrared Radiometer)

Characteristics:

Thermopile with temperature compensation and compensation for emitted radiation.
On the upward looking instrument is mounted a heated ventilator type VEN.
The pyrgeometer is mounted next to the pyranometer in such a way that the sensors are at the same horizontal level.

Spectral range:	3.5-50 µm
Temp. dependence:	± 2 %, -20 to 40 °C (nominal)
Linearity:	± 1 %, 0 to 700 Wm^{-2}
Response time:	2 s (i/e signal)
Cosine response:	< 5 % from normalization, insignificant for a diffuse source
Orientation:	no effect on instrument performance
Calibration:	blackbody reference



B CAMERAS

B.1 Thermal Camera

Two nearly identical thermal cameras have been used. The only difference between them lies within parts of the software.

	Camera 1 (FFI)	**Camera 2** (FGAN-FOM)
Make:	FLIR Instruments	Agema Systems
Type:	ThermaCAM PM 595	Thermovison 570

Characteristics:

Calibrated thermal camera used as a radiometer (figure 4.1)

Spectral range:	7.5-13 µm
Detector:	Focal plane array (FPA) uncooled microbolometer 320 x 240 pixels
Image frequency:	50 Hz non-interlaced
Field of view:	24^o x 18^o
Spatial resolution:	1.3 mrad (IFOV)
Thermal sensitivity:	0.1^oC at 30^oC
Operating temperature:	-15 to $+50^oC$

B.2 CCD Camera

Make: Hitachi
Type: VK-C77E
Characteristics:
This is a colour video camera that is used for taking still images of the scene.

Image sensor:	interline ¼" CCD type
Scanning system:	2:1 interlaced
Scanning frequency:	50 Hz vertical
Effective pixels:	752 x 582
Horizontal resolution:	> 460 TV lines
Lens:	F1.6, f = 4-48 mm
Zoom:	12x optical plus additional 2x digital
Sensitivity:	6 lux
White balance:	auto/manual – here: auto
Iris and focus control:	auto/manual – here: auto
Operating temperature:	0 to +40^{o}C

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