Baseline studies North Sea wind farms: strategy of approach for flying birds

K.L. Krijgsveld
S.M.J. van Lieshout
H. Schekkerman
R. Lensink
M.J.M. Poot
S. Dirksen

Bureau Waardenburg bv
Adviseurs voor ecologie & milieu

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Bureau Waardenburg bv
Consultants for environment & ecology
P.O. Box 365, 4100 AJ Culemborg, The Netherlands
Tel. +31 345 51 27 10, Fax +31 345 51 98 49
E-mail wbb@buwa.nl Website www.buwa.nl

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commissioned by: National Institute for Coastal and Marine Management, The Hague
Picture frontpage: Oceanographic Company of the Netherlands (OCN)

14 July 2003
report 03-043

Status:	final report
Report:	03-043
Date of publication:	14 July 2003
Title:	Base line studies North Sea wind farms: strategy of approach for flying birds
Authors:	drs. K.L. Krijgsveld drs. S.M.J. van Lieshout drs. ing R. Lensink drs. H. Schekkerman drs. M.J.M. Poot drs. S. Dirksen
Number of pages incl. appendices:	50
Project nr:	02-145
Project manager:	drs. S. Dirksen
Name & address client:	National Institute for Coastal and Marine Managemant (RIKZ) P.O. Box 20907, 2500 EX Den Haag, Netherlands
Reference client:	Contract nr. RKZ-1268
Signed for publication:	head, sector Bird ecology drs. S. Dirksen
Initials:	S.D.

The Quality Management System of Bureau Waardenburg bv has been certified by CERTIKED according to ISO 9001.

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Consultants for environment & ecology

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Preface

The Dutch government has granted 'Noordzeewind' (Nuon Renewable Energy Projects and Shell Wind Energy) the possibility to build a wind farm consisting of 36 wind turbines off the coast of the Netherlands, near Egmond. This project serves to evaluate the economical, technical, ecological and social effects of offshore wind farms in general. To gather the knowledge which will result from this project, a Monitoring and Evaluation Program (MEP) has been developed. The knowledge gained by this project will be made available to all parties involved in the realisation of large-scale offshore wind farms. The study on ecological effects is coordinated by the National Institute of Coastal and Marine Management (RIKZ). Bureau Waardenburg and Alterra in cooperation have been commissioned by RIKZ to execute the base line study of effects on flight paths, flight altitudes and flux of migratory and non-migratory birds.

Here we present the study design of the first part of this study, in which the flight patterns of birds are determined in the reference situation before the construction of wind turbines has started. In this report we focus on the registration of bird movements. The study of flying birds will be mainly based on registration by radar. Visual observations will be carried out to obtain more detail in the radar information and to calibrate the radar registrations.

This plan has been conceptualised by Karen Krijgsveld, Suzan van Lieshout, Martin Poot, Rob Lensink and Sjoerd Dirksen from Bureau Waardenburg and Hans Schekkerman from Alterra. Mariska Harte, Hans van Zeijl and Hans Roberti from RIKZ and Walter van den Wittenboer from NOVEM supervised this project. Jeroen Brandjes put his night vision camera at our disposal.

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Summary

Bureau Waardenburg and Alterra in cooperation will study the effects of the Near Shore Wind Farm on flight paths, flight altitudes and flux of marine birds and non-marine migrating birds. In this publication we present the study design of the first part of this study, in which the flight patterns of birds are determined in the reference situation before the construction of wind turbines has started.

In chapter 1 we introduce the project by describing its background and the research goals. In chapter 2 we present the specific study aims; separated in fluxes, flight altitudes, and flight paths of birds. Subsequently we discuss which species of birds are of interest. In chapter 3 we give a brief overview of the methods that will be used to measure the flight patterns. These consist of three main components: radar observations, visual observations and ship-based observations on seaducks. In chapter 4 the methods and techniques that will be used are described in full detail. We start with a description of the study site and the location where measurements will be performed, and how we deal with spatial and temporal variation in flight patterns (§4.1). Secondly the radar equipment used for the observations is described (§4.2 and §4.3). This includes an elaboration on the techniques involved and on the necessities for calibration of echoes. In § 4.5 we describe the methods used to perform visual observations, and in §4.6 subsequently the methods to link the radar and visual observation in order to add species information to the radar signals. The chapter is concluded by discussing effects of environmental conditions and the ways to mobilise existent data on marine birds. Chapter 5 deals with the techniques used for data analysis. In Chapter 6 we summarize the research activities in a time frame.

1 Introduction

1.1 Background

In order to increase the supply of renewable energy in the Netherlands, the Dutch government has decided to support the construction of a near shore wind farm (NSW) of 36 turbines 10-15 km off the coast of Egmond, in the Netherlands. This project serves as a pilot study to build up knowledge and experience with the construction and exploitation of large-scale offshore wind farms. The knowledge gained with this project will be made available to those parties that are involved in the realisation of large-scale offshore wind farms. To collect this knowledge, an extensive Monitoring and Evaluation Program (MEP-NSW) has been designed in which the economical, technical, ecological and social effects of the NSW are gathered. Carrying out this MEP serves 'learning goals' for future wind farms further offshore as well as 'effect assessment goals' for the NSW itself.

Before building, research in the 'reference situation' will be carried out. As far as ecological topics are concerned, the National Institute for Coastal and Marine Management (RIKZ) is commissioning and supervising the projects. There are 6 topics (Lots 1-6), of which 5 and 6 are dealing with birds. Lot 5 (carried out by a consortium of Alterra and Bureau Waardenburg with CSR Consultancy as subcontractor) focuses on resident birds. Lot 6 (also carried out in co-operation between Bureau Waardenburg and Alterra) focuses exclusively on flying birds. Both (Lot 5 and Lot 6) are needed to make a full assessment of disturbance, barrier effects and collision risks of wind turbines in the coastal waters of the Dutch North Sea.

1.2 Outline of the study at hand

Derived from research results on land, the MEP requires bird research to enable an analysis on three types of possible effects on birds: collision of flying birds, disturbance of flight paths/barrier effects, disturbance of resting and/or feeding birds.

This project deals with the first two specific effects in relation to flight patterns; collision of flying birds and disturbance of flight paths/barrier effects. Flight patterns consist of the following three aspects which are the subject of study in this project; flux of birds, flight paths and flight altitudes. Knowledge of those is needed in order to be able to assess the first two effect types mentioned. The present 'reference situation' study involves the quantification of flight and behaviour patterns before construction of the NSW has started, and serves as a reference to which the situation during and after construction of the wind farm can be compared and evaluated (effect study). In this report we present the design of the observations of flight and behaviour patterns of birds in the reference situation.

1.3 Research goals

To determine what effects the NSW will have on birds, we need to quantify the following aspects of both marine birds and non-marine migrating birds in the reference situation at the NSW-site:

- Flux (intensity; numbers per time unit per surface area) of flying birds
- Altitudes of flying birds
- Flight paths of flying birds

Variation in these flight patterns caused by seasonal patterns, spring or autumn migration, day or night, and variation in weather conditions will also be determined. To cover this variation, the study of the reference situation will last a full year.

To study these aspects of flight patterns, we will use both radar and visual observations. Radar observations will give us detailed insight in the fluxes, flight altitudes and flight paths at sea, whereas the visual observations serve to identify species composition, behaviour and an independent dataset on flight patterns for calibration purposes. This reference study is designed in such a way that it allows us to link visual and radar observations and thus calibrate the radar observations.

In the second stage of the research program (when the wind turbines have been built) the three aspects mentioned before will be established both within and outside the park boundaries. This will be done in order to be able to compare the reference study with the study of effects and to quantify the effect of the wind farm. The chosen setup is comparable to a before/after BACI analysis. All species regularly flying within reach of the wind turbines may suffer effects from the wind farm, and thus all of these species will be included in the study. This means that both marine and non-marine migrating birds and resident marine birds are included in the study.

The research questions for the reference study can be summarised as:

- What are the fluxes, flight altitudes and flight paths of the species of birds that occur in the NSW area, 10-15 km out of the Dutch coast?
- How do the fluxes, flight altitudes and flight paths vary between seasons, spring and autumn migration, day and night, and under varying weather circumstances?

2 Study aims

In the light of the potential effects of wind farms on birds, which have been outlined in chapter 1, three aspects of flight patterns of birds are important: flight paths, fluxes and altitudes. To analyse the effects of the Near Shore Wind Farm on flying birds, we will start to establish the three aspects of flight patterns in the undisturbed reference situation, both for migrating non-marine and marine birds and for local marine birds. Based on this information, changes resulting from the presence of the Near Shore Wind Farm can be detected in the effect study in a later stage. In the following paragraphs, we describe these aspects of flight patterns as well as the species involved.

2.1 Flying birds in the air above near shore North Sea

2.1.1 Fluxes

Collision risk is the combination of actual number of victims and potential number of victims. The latter is the flux, or the number of birds per surface area per time unit. Measuring the flux of birds is therefore an important task. In relation to wind farms, not only flux is important, but also the altitudes at which all these birds are flying and the flight paths they use (see below). Furthermore, with detailed information from visual observations of the underlying species composition, the behaviour of the birds, and observations of factors affecting the number of birds passing, the ecological context of the flight patterns will be described.

The main variation in flux comes from migrating birds. Under influence of environmental conditions like wind or precipitation, the densities of birds passing an area during a period of time can vary immensely. The measurements need to cover this variation.

2.1.2 Flight altitudes

The flight altitude of a bird determines largely the extent to which it potentially can be affected by a wind turbine (or a wind farm). Birds generally fly at altitudes that lie within species-specific ranges. For many species however, these altitudes are not known. Flight altitudes of foraging marine species can be such that it puts them at risk from collision with the windmills.

Migrating birds that are flying over 300 m high may not be directly affected by the wind turbines at the NSW, but birds migrating at high levels occasionally come down under influence of e.g. bad weather or strong winds (Lensink *et al*, 1999). To evaluate the effects of the wind farm it is important to register the frequency with which this occurs.

2.1.3 Flight paths: directions in which birds are flying above the sea

Many birds fly to and from their nesting, resting and feeding areas on a daily basis, for which they follow more or less constant flight paths. At sea however, apart from birds breeding on the shore, daily flight paths are very much the result of drift by wind and tide, in combination with the (generally highly variable) locations of areas that are rich in food.

Wind also largely determines flight paths of migrating birds. The flight paths to be described in this study are therefore very much related to wind. In addition, the effects of a wind farm at sea are not limited to birds flying to and from their feeding grounds, but also include birds during their foraging activities.

2.2 Species of interest

To be able to evaluate whether significant effects on bird flight patterns will result from the construction and presence of the wind farm, we need to gather information on those species of birds that are relevant to the ecosystem of the North Sea. These species include marine birds as well as non-marine migrating birds. Marine birds are those bird species that are entirely or partially reliant upon the sea. They include local breeding birds foraging at sea, and migrating seabirds. Non-marine migrating birds include all other species flying over the study area mainly during the migration periods in spring and autumn, towards and from their breeding and wintering grounds. For the purpose of this study, all birds passing the study area in the North Sea and its immediate surroundings are included.

Both with visual and radar observations, all flying birds are registered and therefore all species and all individuals that fly in the vicinity of Meetpost Noordwijk. With the radars however, different species cannot be distinguished from each other without a detailed calibration of signal characteristics. Because of this, it is not known beforehand to what level species groups or species can be identified from the radar data. Calibration of the radars will answer the question to what extent species groups or species can be identified by radar, but given the large amount of signal characteristics and our experience thus far, we expect that signal-identification of a large number of species groups or species will be possible. Differentiation between migrating and local marine birds will also be based upon calibration of the signal characteristics.

Because some species groups or species have a higher ecological relevance than other, based on for instance abundance in the area and in respect to population size, the study of the reference situation will focus on the species listed in table 2.1. Those species are more or less abundant in the area of the wind farm during at least part of the year. Priorities in the discrimination of species are to distinguish terns from gulls, divers from seaducks and grebes, distinguish groups of migrating birds as swans, geese, diving or swimming ducks, thrushes, or small songbirds, and to be able to positively identify cormorants, gannets, gulls (as a group), common scoters, and alcids. At the end of the base line study we will be able to determine actual abundance of the various species (groups).

Table 2.1. *Overview of the species and groups of birds that will be studied, including the level to which identification is desired (whether this level is feasible, will be established in the course of the project).*

species or group	level
local and migrating marine birds	
cormorant	species
grebes	group
divers	group
alcids –guillemot, razorbill, puffin	group
gannet	species
sea ducks – scoter & eider	species
swimming ducks	group
shelduck	species
terns	group
large gulls & skuas	group
small gulls	group
fulmar & shearwaters	group
storm petrels	group
migrating birds	
swans	group
geese	group
diving ducks	group
dabbling ducks	group
waders	group
swift	species
larks	group
thrushes	group
crows	group
starling	species
small songbirds	group

3 Recording flight patterns: an outline of methods

To obtain a reliable and quantifiable impression of the flight patterns of birds in and around the study area, both visual and radar observations will be made of these patterns. Radar data provide the baseline, as radar will be operated continuously for one year, day and night. Visual data provide the necessary checks and additions in order to 'fill in' the general picture derived from radar with e.g. species information, and provide an independent second database on flight patterns of birds in which behavioural information is included. In this chapter the general methods chosen will be described briefly and related to the research.

3.1 Radar observations

To obtain information on flight patterns on a larger scale, for an extended period of time, and on diurnal as well as nocturnal flight movements, radar is the best available option. The choice for radar, and more specifically, marine surveillance radar, for bird flight observations has been motivated in the tender/project proposal and will not be repeated here.

Two types of radar-observations will be combined. One is the observation of flight paths, which is done using horizontal surveillance radar. This is standard radar as used on ships, which scans the horizontal area around the radar. With this radar, flight paths of birds flying through the radar beam are tracked and flight speed (ground speed) and direction are recorded. The second type of radar-observation is the observation of fluxes and flight altitudes. This is done using a similar type of radar, which is tilted vertically, and thus scans a vertical section of air. In this way, the flux can be measured by counting the number of birds that cross the radar beam during a fixed amount of time (10-15 min), and the altitude of the birds flying by can be measured by measuring the distance of the bird to the radar (corrected for the angle).

A system, called MARS XSP (Mobile Avian Radar System), provided by Geo Marine Inc. (Florida, US) will be used. The system has the desired combination of two radars, one in the horizontal plane for tracking flight paths and one in the vertical plane for flux and altitude measurements. These radars will continuously scan a large area above sea throughout the year, every day, both day and night, and automatically record all flight movements within this area. Thus the exact location, direction, speed, and altitude will be known of all echoes. The data recorded by radar will provide the principle dataset on flight patterns, which is far more extensive than the visual observations. In most weather conditions the radar has a much better detection compared to field observers, especially in the vertical plane.

However, the data coming in from the radar will not automatically be linked to a species of bird. It only logs individual echoes encountered with their characteristics. Thus, in order to be able to use these data, the echoes need to be linked to species groups or species during later analysis. In order to enable this type of analysis, a dataset will be built in which visual and radar observations are combined: 'groundtruthing' of radar echoes by observers determining species and other characteristics of echoes. As many radar signals as possible will be flagged and linked to a species of bird that was seen by simultaneously watching observers.

The capabilities of radar to monitor flight movements have been tested in earlier projects, among which are comparable offshore projects (Tulp *et al.* 1999b, Poot *et al*. 2001), as well as specifically developed field tests (Poot *et al.* 2000). It is clear that detection limitations exist with radars. However, our own experience thus far has been only with 12 kW radar. The Geo Marine radars used in our MARS XSP are more powerful (25 and 30 kW). Because of the higher power, but also because of the software developed by GMI for echo data processing, they have much better detection capacities and cover a larger range. The capacities of the Geo Marine radars will be calibrated extensively.

It will be impossible to positively identify every signal, but coupling the two methods (advanced radar and standardised visual observations) will cover the flight movements at sea more than adequately to identify main flight patterns and thus assess the risks of the future Near Shore Wind Farm.

3.2 Visual observations

With visual observations we will determine which species fly in the area, in what numbers, at what altitude range and in which direction. They will take place on a monthly basis for a restricted period of four to five consecutive days per month. This way a dataset will be built up of flight movements of all species present in the area, entirely based on visual observations. The main method used for these observations is the Panorama scan (§ 4.5.2). This is a technique developed by Lensink *et al.* (2000) to quantify bird numbers in different air layers. The technique ensures that birds are counted in the same area in a standardised way, and thus provides a reliable and independent data set of densities and flight patterns of birds with reliable information on species composition. The method relies strongly on the ability of observers to record birds in large distance classes to order to arrive at an estimate of absolute bird density.

These observations concern bird activities during daylight. At night the most important source of information will be the radar observations, but additional visual and other observations will be made by the researchers. For these, methods will need to be used that have not been determined at this point and will be tested during the coming months. Possibilities are summarised in § 4.5.1.

3.3 Flight patterns and altitudes of seaducks

In winter, seaducks occur in high concentrations in wintering areas at the North Sea, whereas outside these areas numbers are much lower. The exact location of wintering birds varies each year, depending on where the main feeding areas are (*Spisula* stocks). The Near Shore Wind Farm is located relatively close to a major seaduck (mainly common scoter) wintering area (Leopold 1996, Lindeboom 2002), and therefore possess a potential risk for the seaducks. To gain information on the flight patterns of the seaducks, the standard radar and visual observations will not suffice. Firstly because these observations will be made from a fixed position, and therefore have a relatively big chance not to be close enough to the changing locations of seaduck concentrations in a given year. Secondly, Meetpost Noordwijk, where all other observations will be carried out (see following chapter), is certainly too far away from areas where seaducks occur regularly. Because of these reasons, observations will be done from a ship. This will allow us to locate and approach concentrations of seaducks, after which the flight patterns of the seaducks can be studied. Because seaducks are active at night, radar observations on nocturnal flight patterns will be carried out. Visual observations will complement the radar observations at dusk and dawn, when major flight movements are likely to occur, as well as during daylight. Scoters are disturbed at large distances and fly off when a ship approaches. However, a recent study carried out on scoters north of Wales showed that when a ship is anchored and quiet, they do return to their feeding or resting grounds even when these are in close proximity of the ship (Poot *et al.*, in prep). Apart from scoters, other seaducks present in the area will be studied as well, along with flight patterns of other occurring species.

4 Study site, equipment and methods

In the sections below we discuss the location at which the measurements will be performed and how we deal with spatial and temporal variation (§4.1), as well as give a detailed description of the equipment and techniques that will be used to determine flight patterns of birds. This includes the radars and the techniques used therewith (§4.2 & 4.3), the visual observations (§4.4 & 4.5), the methods used to interpret the radar signals (§4.6), the ways in which variation in flight patterns due to environmental conditions are dealt with (§4.7), and how other available data will be used (§4.8 & 4.9).

4.1 Study area and observation posts

The NSW will be situated 10-15 km off the coast of Egmond and covers an area of approximately 100 km^2 (figure 4.1). Ideally, measurements of bird flight behaviour would take place close to the NSW-site and at the same distance from the coast, because these locations would be representative for the study site. Conditions like for instance water depth, water temperature and salinity as well as distance to the coast (van Gasteren *et al.* 2002) are likely to affect bird numbers, migrating patterns and flight behaviour. Observation posts that would be suitable from this point of view would be production platforms in the area. Because these platforms turned out not to be available to us, the choice is limited to a platform further away from NSW, Meetpost Noordwijk. This platform is situated at approximately the same distance from the coast as the NSW area. At this location all visual observations and radar observations can and will be carried out.

Meetpost Noordwijk
Research and monitoring platform 'Meetpost Noordwijk' is situated 9 km off the Dutch coast, near Noordwijk (figure 4.1). The platform is a station of the North Sea Monitoring Network, gathering hydro and meteo information from the North Sea. The platform is an excellent facility for performing experiments and testing equipment and materials in the marine environment. The platform counts 3 decks, the highest of which is 19 m above sea level (fig 4.2).

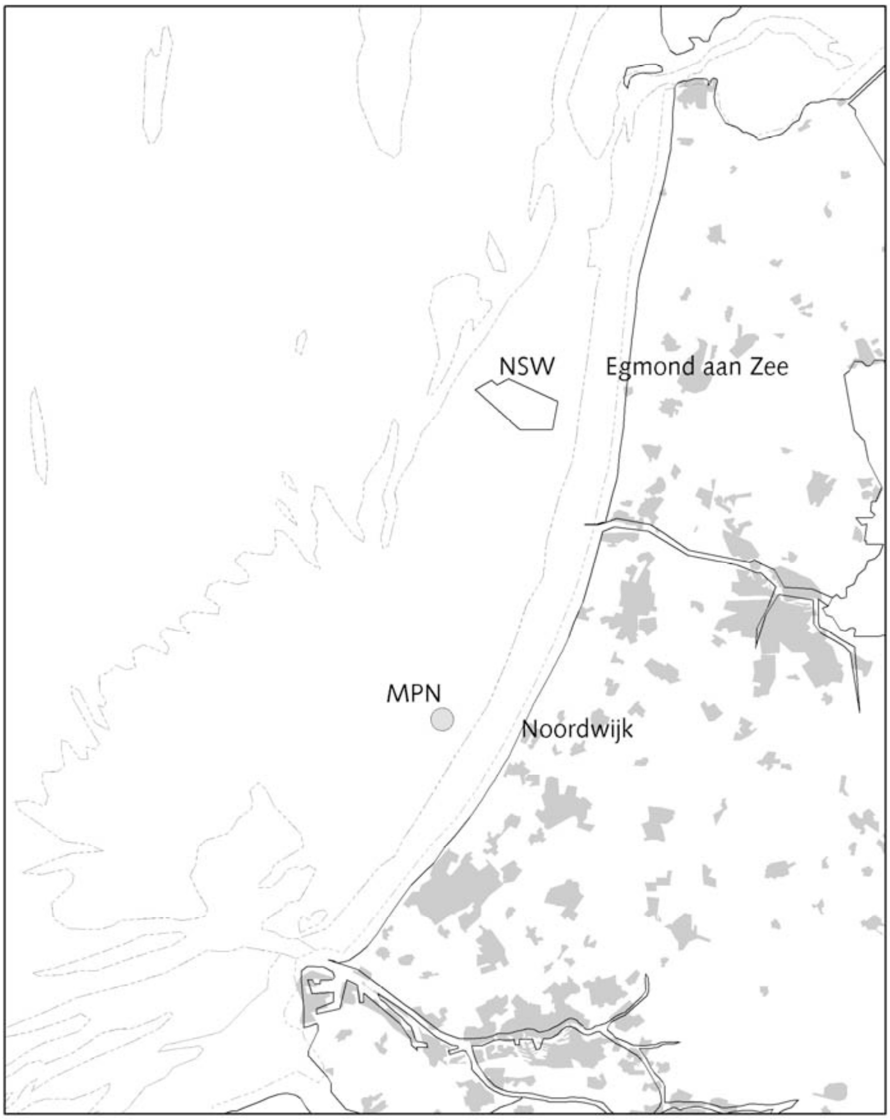

Figure 4.1 Location of the Near Shore Wind Farm (NSW) and of Meetpost Noordwijk where observations will be carried out.

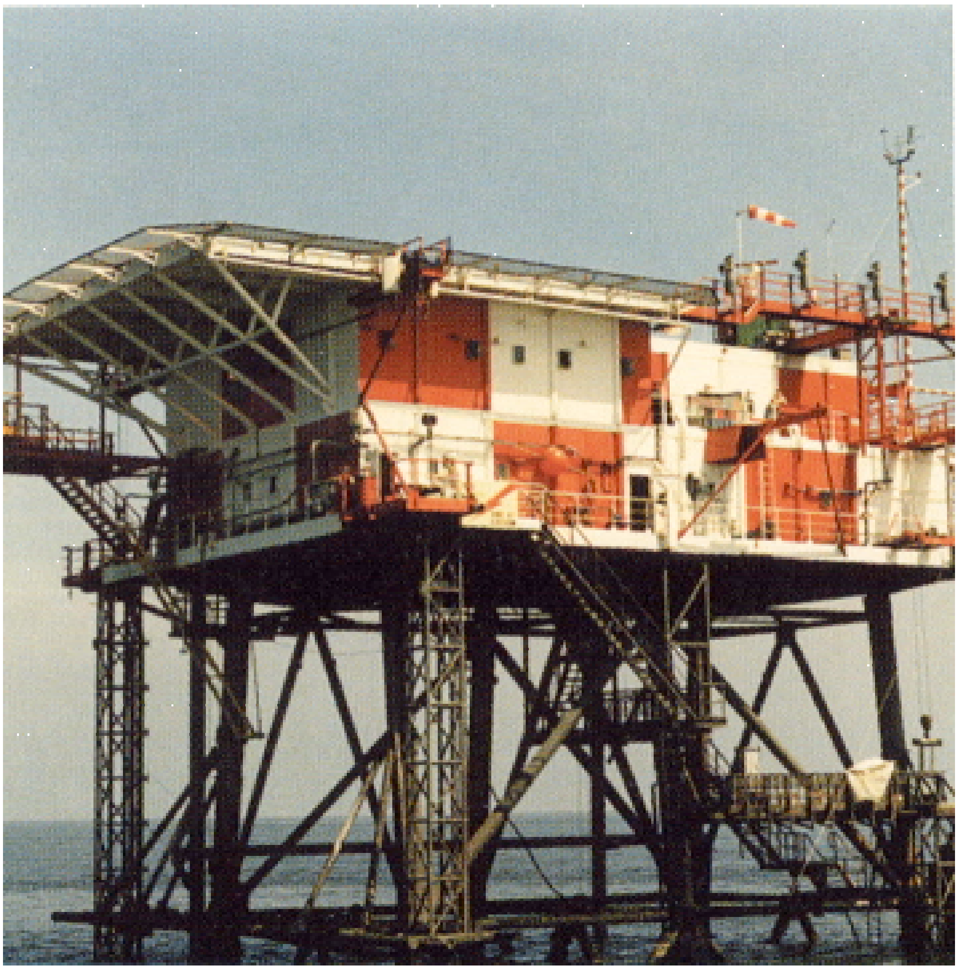

Figure 4.2 Picture of the research and monitoring platform Meetpost Noordwijk, which will be used as observation post in this study (source Oceanographic Company of the Netherlands).

Spatial and temporal variation in bird numbers

Because Meetpost Noordwijk is situated some 40 km to the south of the NSW-site and slightly closer to the coast, measurements of flight movements will need to be extrapolated to the conditions at the NSW-site.

The aspect that will show the highest amount of variation between the two sites will be the numbers of birds flying in the area (Poot *et al.* 2001). In the accompanying study on numbers and behaviour of birds (Lot 5), numbers of birds are counted in a large area in and outside the NSW-site. Data from the panorama scans give comparable information. Thus, the differences and similarities between the NSW site and the surroundings of Meetpost Noordwijk will become apparent. The data resulting from these counts will be used to correct measurements performed at Meetpost Noordwijk for the specific conditions at the NSW-site.

Flight paths and flight altitudes of local marine birds will be comparable between the two sites, since marine birds are highly mobile and cover an area far larger than the

NSW-site. Flight paths of migrating birds are determined to some extent by landmarks. The Afsluitdijk for instance is used by birds migrating to and from the north as such a landmark. Flight paths of migrating birds may therefore consistently follow specific routes. So north-south differences between Meetpost Noordwijk and the Near Shore Wind Farm area are likely to exist but can be identified and corrected for. For instance, available monitoring data on seabird migration can be used for this purpose.

As flight patterns vary considerably over a time scale, one year of observation in the reference situation will not be enough to obtain a good estimate of all flight patterns. The measurements in the reference situation at Meetpost Noordwijk will however be extended with observations for the effect study, during which Meetpost Noordwijk will remain to be used as observation post to study the reference situation. In addition, existent datasets will be explored to assess annual variation in bird numbers, on the basis of which the data from the study at hand can be evaluated. Possible relationships between flight patterns and annual and seasonal variation will be analyzed.

Shipbased observations on seaducks
The Orca 1, used by Lot 5 for ESAS transects, will also be used for the seaduck flight observations. It has two Furuno marine surveillance radars on board, both being X-band radar, which serve well to register flight movements of seaducks (Poot *et al*. in prep, observations on scoter flight patterns in Wales). One of these radars will be used for observations on movements (flight paths). An additional vertical radar (see §4.3) will be put on the ship for flight altitude measurements.

A vessel with S-band radar would be preferable. However, such a vessel is not available in The Netherlands in the size and price class feasible for this project. As seaducks are large enough to be seen with X-band radar in relatively good weather conditions, such a ship is not a strict requirement. Flexibility in planning the observations is required to be able to do the work in proper weather conditions, and this is agreed with the owner of the vessel chosen.

These observations will form an independent dataset, which will be analysed separately from the standard observations at Meetpost Noordwijk. The observation site will depend on the position of large scoter flocks in the winter 2003/2004.

4.2 MARS XSP

The MARS XSP is built around two Furuno radars as basic hardware:
1. 30 kW Furuno S-band radar for horizontal use (surveillance: flight patterns)
2. 25 kW Furuno X-band radar for vertical use (altitudes and fluxes)

The horizontal surveillance radar detects bird movements in a horizontal plane and will be used to record the flight patterns of birds (figure 4.3). The vertical radar detects bird movements in a vertical plane and will be used to measure flight altitude and flux (figure

4.4). Detailed (technical) specifications regarding the radars can be found in the appendix and at http://www.avianradar.com/mars.?p=mars.

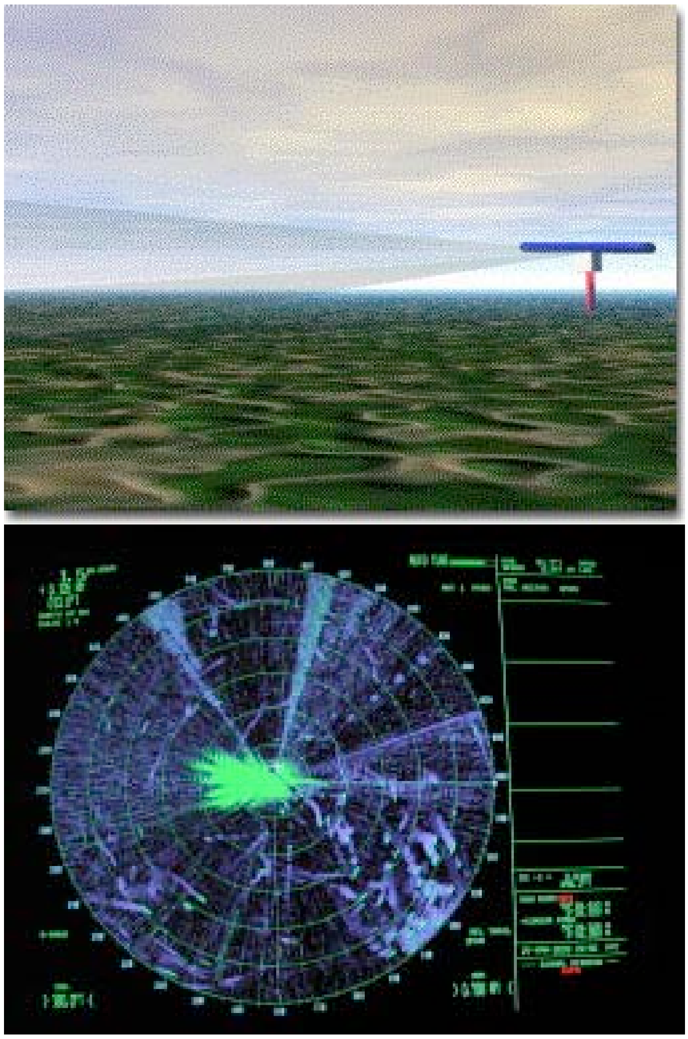

Figure 4.3 Top: Schematic overview of a surveillance radar scan in the horizontal plane (source: Geo-Marine website www.avianradar.com or www.geo-marine.com). Below: image of a 35 kW S-band surveillance radar showing gulls flying to the Welsh coast in the early morning (source: Bureau Waardenburg).

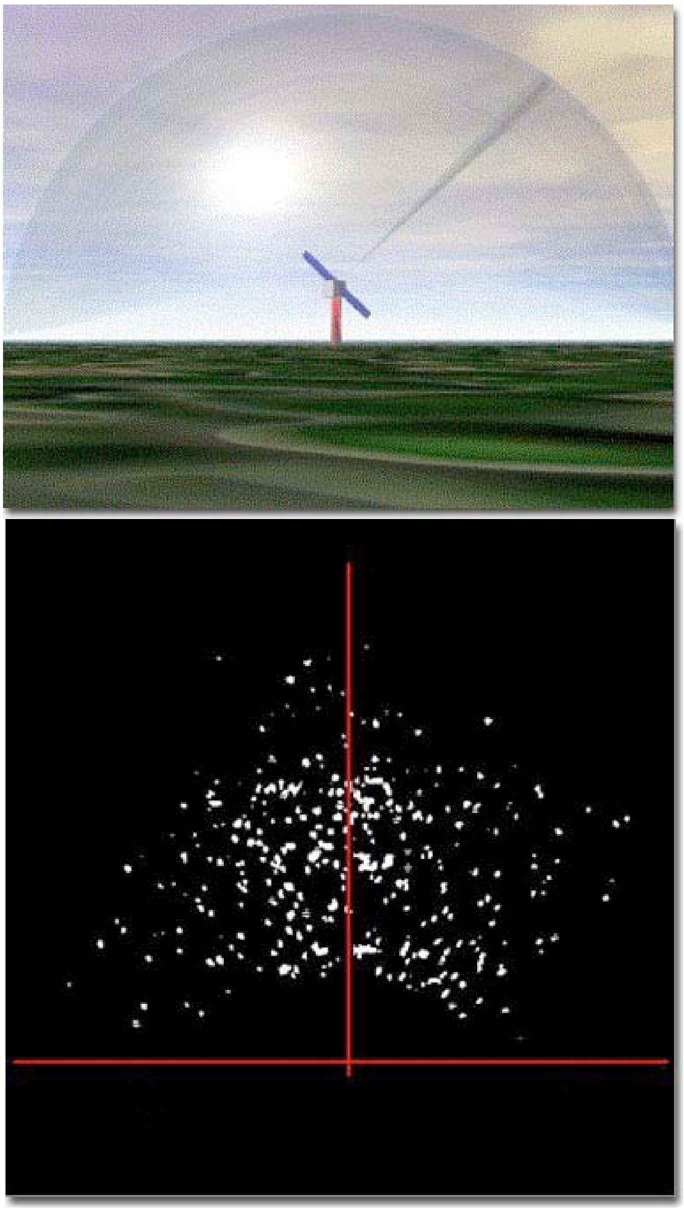

Figure 4.4 Top: Schematic overview of a radar scan in the vertical plane. Below: image of a 12 kW vertical X-band radar showing birds flying by at various altitudes. (source: Geo-Marine website www.avianradar.com or www.geo-marine.com)

Geo Marine has developed hardware and software allowing automatic registration of signals from flying birds and logging of these signals into a computer located on the platform. This system will allow us to monitor bird movements continuously (24 hours a day) throughout the year. The system is powerful, especially because of the specifically developed software, based on dynamic programming, and is capable to detect a signal from every bird down to finch size within a range of at least 2000 m. Larger birds are detected fully within a range of at least 4000 m (GMI pers. comm.). These distances however will vary with weather conditions. Detection probabilities will be measured during the study and under different environmental conditions (see also below). A large number of signal characteristics is logged as well, which can be used to help identify bird species. This is described in § 4.6.

Each signal will be registered together with information on, among others, exact time and x- and y-coordinates. This allows the datasets from the horizontal and vertical radar to be combined, by which means both flight path and altitude of a single characteristic will be known. The main goal of such a combination is to interpret the horizontal measurements in order to quantify the proportion of echoes detected at different altitudes. The datasets will be combined at the time of analysis.

X-band radar is more sensitive to loss of signal due to clutter from waves and precipitation than S-band radar, but S-band radar is less good for detecting small birds. S-band radar is chosen for horizontal use, in order to minimise loss by clutter. Larger birds (local marine birds) can be detected well with S-band radar. Detection loss of small species (songbirds) is higher, but the extent is currently unknown. This detection loss of songbirds on the horizontal radar is however not a major issue, since flight patterns of these species concern migration which will be detected with the vertical radar. In addition, signal loss with the S-band radar will be measured through comparisons with a horizontal X-band radar in good weather conditions (12 kW) and a comparison of the results of the vertical radar as described above. When using the X-band radar in vertical mode, the signal-loss due to clutter is restricted to the lower meters of the observation space and is therefore not an issue.

Within a range of 1500 m, visual observations are possible for most bird species (medium sized land birds up to large marine birds) (Lensink *et al.* 1998, 2000, Poot *et al.* 2000). This range is large enough to give a representative image of the flight movements in the area and to detect possible biases in bird numbers and flight behaviour caused by the platform. Data on flight patterns recorded by the horizontal radar may however be useful for example to analyse spatial differences in flight paths over a larger distance, as well as future effects of the NSW on flight paths in the effect study (and of Meetpost Noordwijk in the reference situation). Thus, data will be recorded with radar over the full distance of 5500 m, allowing a potential analysis over a larger range.

In figure 4.5 a schematic overview is given of the horizontal beam of the S-band radar. Figure 4.5.A depicts the position of the radar on top of the platform, with the shape of the theoretical radar beam (inner line; angle 25°) and the shape of the real or effective radar beam as can be calculated (van Moonen 1996 in: van Gasteren *et al.* 2002). The volume (both the range and the width) of the real radar beam is dependent on the size of the bird. Small species can be detected over a smaller range than larger species. The detection range for species of different sizes is depicted in the upper figure of 4.5.B. The actual range both in horizontal and in vertical direction is given in which birds are detected. For instance, if a robin can be detected only up to 500 m, the shape of the beam is similar to the shape depicted by the line that crosses the x-axis at 500 m. Thus, the area in which the robin will be detected is the area underneath this line. A larger species like a herring gull will be detected up to far larger distances, say 3000 m. The area where this bird will be detected by the radar, is the area underneath the line that crosses the x-axis at 3000 m. As a consequence, larger birds can be detected up to higher altitudes than smaller species. In the bottom graph of figure 4.5.B, a close-up is given of the detection ranges of the radar at short distance from the radar, depicting the area in which bird movements will not be detected.

With the vertically positioned X-band radar, detection capacities are higher but the shape of the detection range is similar. Thus, with the vertical radar, the detection range of a robin would be close to the range of the 1000 m line. Naturally, this would be 1000 m in the vertical direction rather than in the horizontal direction.

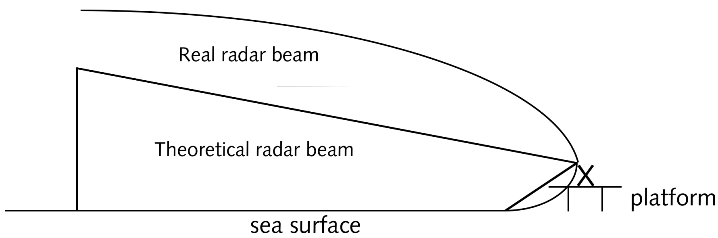

Figure 4.5.A. Schematic overview of the theoretical and the real or effective radar beam.

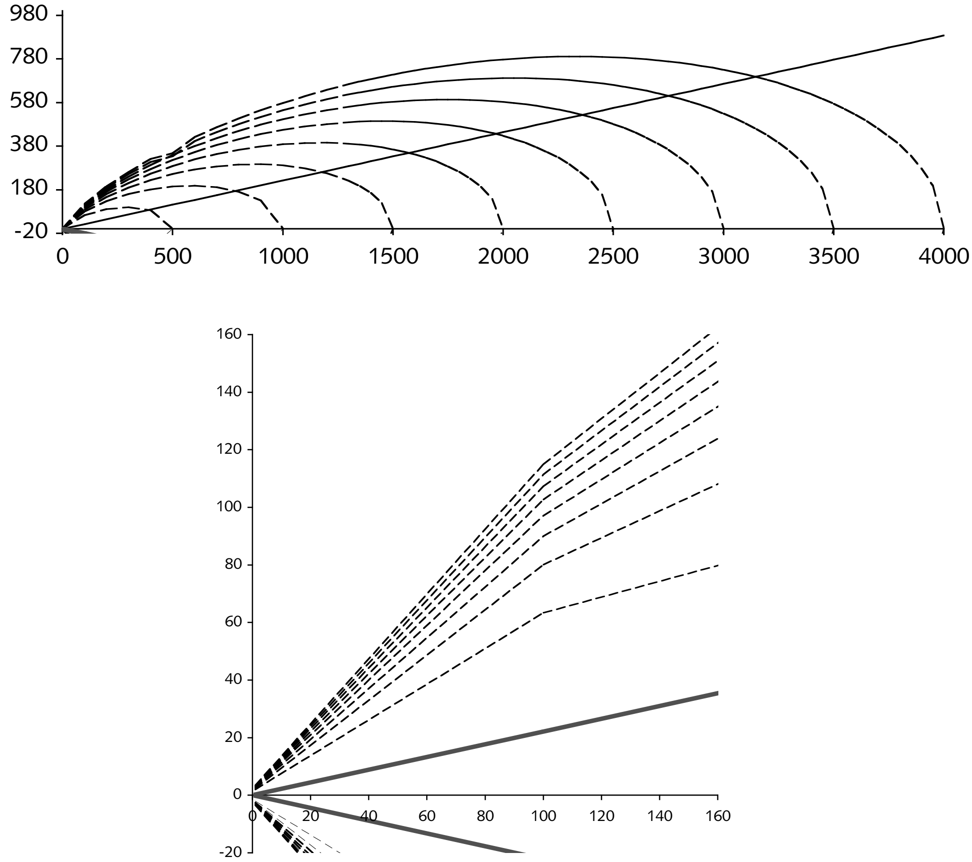

Figure 4.5.B. Schematic overviews of the detection ranges of the horizontal S-band radar. Imagine the radar to be positioned at the intersection point. Distances in meters. Top: The solid line indicates the theoretical radar beam volume according the average angle given by the manufacturer (25°). The dotted lines indicate effective radar beams according to different maximum detection ranges of different bird species groups (beam volumes calculated). The detection range increases with increasing size of the bird. Bottom: Close-up of the area closest to the radar with special reference to the gap of not covered air space by the radar close to the observation platform. Altitude of the radar is set to 0, the sea surface lies 20 m below this point. For further explanation see text.

Radar calibration

Before the Geo Marine radars can be deployed, they need to be tested and calibrated. There are four factors that need to be addressed specifically:

1. Detection loss related to heading of vertical radar relative to main flight direction
2. Clutter at low altitudes above sea
3. The attraction of the observation base as a landing platform for birds
4. A protocol for relating signal characteristics to species information by observers

1. *Detection loss*

   The direction in which a bird flies through the vertical radar beam may affect how well the signal is received. This is known to happen with the 10 and 12 kW radars (data Bureau Waardenburg). For instance, spoonbills and cormorants are of similar size, but spoonbills are picked up on radar far less than cormorants (own observations). Under what conditions this occurs (e.g., flight direction relative to radar orientation), and whether this occurs with the Geo Marine radars that are more powerful than the radars currently used for bird observations, needs to be tested. For this purpose four pilot-studies have been planned, which will be described in detail in a separate report on calibration of the Geo Marine radars:

   - Tests with the 12 kW-radar in combination with the Fly Catcher radar from the Royal Airforce, performed on land during nights with high occurence of migration; recently field work in the Peel has been carried out
   - Analysis by Geo Marine of existent data from the Geo Marine 25 KW X-band radars; currently in progress
   - Varying heading of the vertical radar (*i.e.*, position relative to the coast line) during observations at Meetpost Noordwijk in order to tackle a possible heading problem
   - Analyses of detection of different bird species close to the radar in relation to the relative small width of the radar beam and flight speed. However, radar echoes close to the platform are likely not be used in analysis due to the influence of the platform on flight patterns (see below in 3).
   - Determination of effective radar beam in relation to the distance from the radar for species groups of different sizes. Based on these analyses, a suitable distance will be selected over which to analyze the data.

2. *Clutter*

   Waves at sea cause a signal-disturbance called clutter. This phenomenon is common to all radars at sea. Within clutter, other signals are difficult to trace and therefore, detection of birds flying above sea may decrease. Of course the magnitude of this effect is dependent of the size of the waves and therefore weather-related. The magnitude of the problem is of course also dependent of the equipment used. MARS XSP has two features solving this problem in most circumstances. Firstly, for horizontal use an S-band is chosen. Because S-band radar has a larger wavelength, it is less sensitive to this type of clutter. This difference can easily be seen on any ship that has both S- and X-band radar on board. Secondly, the way the GMI-software is designed to select bird echoes, greatly enhances the detection capacity of the

equipment for birds: the dynamic programming is designed to record echoes within areas with clutter.
The vertical radar is, apart from the very lowest layer, insensitive to clutter from waves. Therefore, detection of the horizontal radar in different wave conditions can be checked by using vertical radar data from the air volumes covered by both radars, and during the day by visual observations.

3. *Attraction of the observation base as a landing platform for birds*
   Visual and radar observations will be analysed in order to determine at what distance flight patterns are influenced by the presence of Meetpost Noordwijk. Based on these analyses, a spatial window will be selected in which recorded echoes will be considered as observation base independent.

4. *Relating radar signal to species information*
   This aspect is discussed in § 4.6.

4.3 Additional radar use

For additional use on a ship (see § 4.1), two radars are available from our institutes:
- 12 kW Furuno FR 1510 X-band, for both horizontal and vertical use
- 10 kW Furuno FR 8111 X-band, for horizontal use

These radars do not have automatic registration, and therefore an observer has to record signals manually from the screen. The radars do allow an adequate registration of flight patterns (e.g., see Poot *et al*. 2002). These radars can be used on board of a ship in the study on seaduck flight behaviour. In addition, the ship's radar may be used to monitor flight paths, if this radar is stronger than our 10 kW radar and yields better images.

The radars mentioned here have been extensively tested and used in similar field research on seaducks (e.g. Spaans *et al.* 1998, Tulp *et al*. 1999a, b). Calibration/validation for using them in relation to the seaduck work in this project is therefore not necessary.

X-band radars are more sensitive to loss of signal due to sea-clutter and precipitation than S-band radars. Because of this, use of X band radar on board of the ship will be limited during periods with precipitation or during high seas. When using the X-band radar in vertical mode, the signal-loss due to clutter is restricted to the lower meters of the observation space.

4.4 Other equipment

For the observations the following equipment has been made available:
- 10□40 binoculars
- 30□/20-60□ telescopes and tripods
- two-way radios and other small electronic equipment

4.5 Methods used in observations

In the context of the development of wind farms offshore, information on flight movements is necessary both during day and night. Nocturnal flight activities however are most critical in relation to collision risks. Some species are mostly active at daytime (seabirds) whereas others are mostly active at night (migratory birds). However, for several species of seabirds it is not known at all whether they are active at night above sea. For these reasons, observations will be done 24 h a day.

4.5.1 Nocturnal observations

Radar

The most important source of information on nocturnal flight activities will be radar-observations. Since visual observations will be largely absent at night, nocturnal radar signals cannot be linked instantly to a visual observation of the species. Thus, the signals received by the radar will have to be interpreted at a later stage, using the linked information of diurnal visual and radar observations. Because the 25 and 30 kW radars yield a large quantity of signal characteristics, we anticipate that many of the birds flying at night can be identified to species or group level afterwards. This will be aided by the fact that observers who can detect major flight movements by eye and ear, will be present at the observation post at night as well as during daytime (for a period of 4 days each month). These observers, who are all trained ecologists, will develop an understanding of the bird activities, which will help to interpret patterns that are seen on radar (see 4.6. for linking radar and visual observations).

As signal-data of the radars are logged automatically on a computer, no observers need to be present during these observations. During the visual observations, one person will monitor the signals on the radar screen in order to link the visual observations with the radar observations. This is explained in further detail in paragraph 4.5.2

To record bird movements both vertically and horizontally, the radars will be set on their maximum ranges over which altitudes and flight paths will be recorded. Based on the calibration and validation tests, and dependent on the observation conditions (weather; waves, humidity/precipitation), in the stage of data analysis spatial windows will be selected in which good detection is achieved (see § 4.2). The spatial windows are necessary in order to counteract two types of artefacts at either sides of the outgoing radar beams, close to the radars and at the far end. The first one is the detection loss at far distances, especially for small birds, the second one is related to the fact that the observation base will attract birds as a landing platform, both local seabirds as well as migratory birds. Based on communication with GMI it is expected that the range at which good detection is achieved will be at least up to 4000 m for large to medium-sized birds. For small passerines this range is less, probably close to 2000 m. The range at which no or marginal influence of the observation base will be noticeable is unknown, but probably will be around 500 m. A study window of 500-2000/4000 m will be the likely set up in which reliable data of altitudes and flight paths will be analysed. However, no radar data will be excluded *a priori*.

Visual and alternative observations in the dark
In the dark, it will not be possible to conduct the standard visual observations in a similar way as during the day light hours. There are a number of options to conduct visual observations in the dark, apart from the radar observations. These are listed below. In addition, part of the observation periods will be planned around full moon (avoiding a bias), thus increasing the chance of being able to watch bird movements in the moon light.

- *Bird sounds*
  Observers present on the platform deck will be able to hear calls of birds, and these can serve as a means to identify the species. Both migrating and local birds may call. A group of scoters for instance produces clearly audible sounds with their wings, that can be heard both night and day. It is unknown to what extent birds will call and are audible at night over sea. Certainly not all species produce sounds, and this kind of observations may only be possible during very calm nights.
- *Light beam*
  A powerful light beam with a large angle from a search light may be used to establish nocturnal flight activity. Employing a schedule in which the beam is switched on at regular intervals for a fixed period of time (eg., 10 minutes every hour), flight activity can be registered by counting the number of birds flying through the light beam. Light sources are known to attract birds, but this effect seems to be absent or strongly reduced when the source of the light is hidden from view (Wiese *et al*. 2001). Deviations of flight routes towards or away from the light source will be evident from the radar-observations.
- *Other devices*
  We investigated the possibilities of using a passive infrared device or a night vision device. Both are unsuitable for this study due to limited possibilities (range, magnification, species identification) and/or costs.

4.5.2 Diurnal observations

Visual observations during the day (and night) will fill in the information on species composition and behaviour, in order to describe the ecological context of flight patterns above the studied part of the North Sea. Linking the visual observations with the recorded radar echoes is described in §4.6.

Visual observations
Standardised protocols will be used to register: species, number and direction of birds flying in the study area, estimated flight altitude and direction, size of the group, behaviour of the bird (e.g., migrating, foraging, scavenging etc), type of prey, associations with ecologically relevant variables and associations with human induced activities. These observations follow the ESAS-codes for behaviour as used in other

surveys (Camphuysen & Garthe 2001; downloadable from http://www.nioz.nl/en/deps/mee/projects/impress/publications.htm. Publication 2001.001).
These protocols are mainly for use in the Panorama-scans. For the calibration of radar-signals with observations, only a limited number of codes are relevant (flight direction and altitude). As many observations as possible will be linked 1 on 1 to radar observations (see §4.4).

Panorama-scans will be used to assess the species and the number of birds in the air as well as on the water in the area around the observation points. Panorama scans (see Lensink *et al.* 2000) are carried out by scanning the air and water in a 360° circle around the observer during a more or less fixed amount of time, using a pair of 10×40 binoculars. The distance up to which birds are included is 1500m. A search-image of which birds fly within or outside the 1500-m range will be built up during the counts, initially aided with a method in which a calliper is used and a calibration-curve using height of platform and observer and arm length of the observer (Heinemann 1981). Panorama-scans will be conducted every hour, lasting about 10 minutes per count.

Within the observation area of 1500m, most species are visible with binoculars. Only species smaller than starlings will be missed at distances over 500m. Therefore, distance classes to be used will be 500 and 1500m. This is based on field tests, in which field observers detected flying birds as well as experimental ball targets thrown in the air, under different weather conditions (Lensink *et al.* 1998, 2000). The observations are conducted with binoculars. An absolute estimate of bird density can be determined based on the known volume of the observation cone of the binoculars used, in combination with the recorded distance classes. Field tests in which the distance estimates of experienced field observers were compared with the measurements of sophisticated tracking radar have revealed that observers slightly tend to overestimate the distance of birds. This implies that bird densities based on visual observations tend to be underestimated. Based on the calibration tests available, corrections can be applied (Lensink *et al.* 1998, 2000, Poot *et al.* 2000).

These scans allow us to compare the density of flying birds according to observers and radar in a systematic way, during survey periods throughout the year, under different weather conditions, and during the entire light period of the day. In addition, visual observations give us the possibility to quantify the number of birds that is seen on radar but may not be detected visually, as well as the number of birds that fly low above the water and are possibly not picked up by radar due to wave clutter. Because the altitude up to which the air can be scanned is limited due to the angle of the binoculars (fig 4.6), those radar-data will have to be selected that match the altitude at which the panorama-scan data were recorded. With high waves, birds that fly low between the waves may be missed both with visual observations and with radar. Height of the waves will therefore be recorded as well.

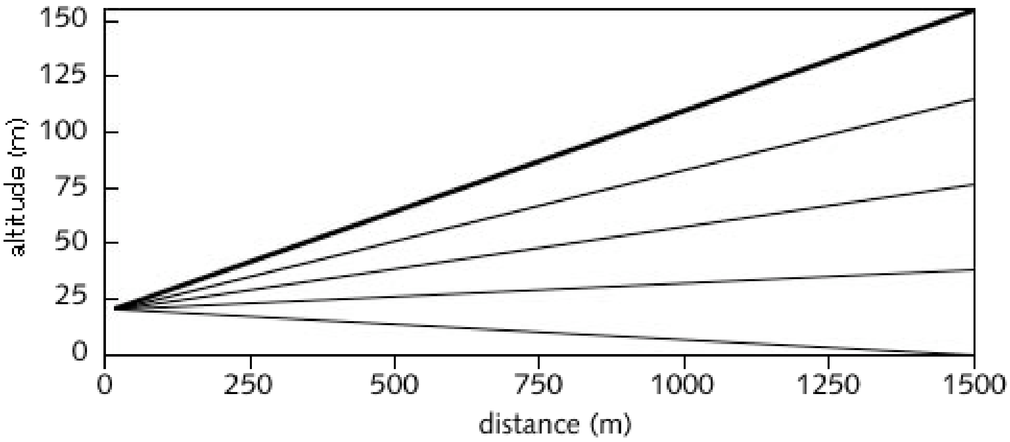

Figure 4.6 *Schematic view of the area of air covered with a Panorama-scan using a 10×40 pair of binoculars. With the water surface visible in the bottom part of the view, the maximum altitude at which birds are scanned is 155 m at 1500 m distance.*

4.6 Linking radar and visual observations

In order to identify the signals that are recorded with the radar, and to be able to make comparisons between the visual and the radar observations, simultaneous observations of birds need to be done with radar and with observers. Observers can identify the species, and simultaneously a person manning the radar can flag the signal which was identified by the observer to be a certain species. Thus, the characteristics of that signal are known to be of a certain species. This way, a large sample size can hopefully be built up per species. Identification of species from the signal characteristics alone will be a crucial factor in the effect studies.

Signal identification will be done by one-on-one linking of the visual observations and the radar observations. Through direct communication between field observers and radar-personnel, a visual sighting can be identified and flagged on the radar screen, *and vice versa* a radar signal of a bird can be located in the sky and identified.

These coupled observations will take place during all visual observations, for the entire duration of the reference study. This will result in a database of radar signals with the accompanying signal characteristics of which the bird species is known.

The two 25 and 30 kW radars from Geo Marine record a large quantity of signal–characteristics which can be used to identify which bird species belongs with the signal. These characteristics include speed (relative to ground surface), size (relative to distance), signal strength, reflectivity, etc. A list of all characteristics is given in table 4.1.

The signal characteristics can then be related to the species using regression techniques and multivariate analysis like Poscon (Engelmoer & Roselaar 1998; see Ch. 5).

Based on our current experience, it will be possible to identify a large amount of signals this way. During the observations it will become partly clear which signals belong to which species, but the exact extent to which this is possible will only be known after analysis of the data at the end of the reference study.

Table 4.1 List of the signal characteristics registered and logged by Geo Marine MARS XSP.

Horizontal radar	Vertical radar	Both
ID	ID	area
session number	session number	max segment
record date	record date	perimeter
scan number	scan number	orientation
ID number	ID number	ellipse major
track ID	track ID	ellipse minor
QA flags	QA flags	ellipse ratio
center X 1	center X 1	elongation
center Y 1	center Y 1	compactness
center X 2	center X 2	heywood
center Y 2	center Y 2	hyd radius
center X 3	center X 3	waddel disk
center Y 3	center Y 3	mean intercept
center X 4	center X 4	max intercept
center Y 4	center Y 4	type factor
latitude 1	heading	mean chord X
longitude 1	speed	mean chord Y
latitude 2	AGL Ft	reflectivity
longitude 2	ground track Ft	av reflectivity
latitude 3	target type	max reflectivity
longitude 3	target quality	min reflectivity
latitude 4		distance
longitude 4		bearing
heading		av center clutter
speed		max center clutter
target type		90% center clutter
		In clutter
		target center value

4.7 Interactions with Lot 5

In lot 5, data are being collected on numbers and behaviour of birds in a large area around the NSW-site, in combination with data on environmental conditions (see next §). These data will allow us to interpret data on flight patterns on a broader scale, and to extrapolate our data from the Meetpost Noordwijk area to the NSW-site. As lot 5 observations are already in progress and will not continue regularly beyond November 2004, there will be almost no overlap between the observations for lot 5 and lot 6. This will limit the degree to which comparisons can be made.
There is no dependency between the two lots in (the time available for) the use of a vessel.

4.8 Environmental data

Weather variables will affect the numbers of birds and their foraging and flight behaviour above sea, and will also affect possibilities for both radar and visual observations. Therefore it is necessary to monitor these factors during the observations and at Meetpost Noordwijk. At Meetpost Noordwijk, relevant weather data are available from a standard monitoring scheme. Rijkswaterstaat has indicated that these data can be made available for our project, but the details have to be arranged yet. A limited set of environmental data will be available from the study for lot 5, where a ship will sail regularly (5 periods of 5 days throughout the year) through the NSW-area, and from which data on water characteristics can be obtained.

Data on at least the following environmental factors are of interest:

- wind speed
- wind direction
- precipitation
- visibility
- air temperature
- water temperature
- salinity
- turbidity

For reasons of comparison and extrapolation to the site of NSW, comparable data from that site are desirable as well. From September 2003 a station will be operated in the wind farm site, where at least part of the data mentioned will be gathered routinely. in addition, the Dutch Meteorological Institute (KNMI) can provide basic weather data.

4.9 Mobilisation of all available basic and aggregated data

In our proposal we have argued that analysis of existing data will add to the knowledge needed to answer the questions of this project. This task will be carried out in the second

half of the study period. By then, we have our own field experience and the first analyses of our own field data.
Four other sources of data are available that can be used to put the results of this study into perspective of space and time and to direct additional analyses:

- year-round Flycatcher study at IJmuiden in 2000; describing basic patterns of migrating birds in the coastal zone (van Gasteren *et al*. 2000)
- database with 30 years sea watching observations along Dutch coast (Camphuysen & van Dijk 1983, Platteeuw *et al*. 1994)
- database with data on 20 years visible migration over land including the coastal zone (Lensink *et al.* 2002)
- database with observations of a few years sea watching from Meetpost Noordwijk (Centre for Seawatching (CvZ) unpublished)

After the start of Phase 2, we will contact the people involved and make arrangements for the necessary information/data to become available.

5 Data analysis

5.1 Assigning signals to species or species groups

The combined visual observations and radar observations of birds flying at Meetpost Noordwijk will result in a database in which each observation of a bird is coupled to a set of echo characteristics of that same bird. Of the most numerous species a large database of echo characteristics will become available. For species present in low numbers in the area of Meetpost Noordwijk during visual observations, the echo characteristics will be pooled at species group level. For each species a set of echo characteristics will be available that will partly be species specific, but that for another part will show similarities with echo characteristics of other species. To be able to identify a species(group) on the basis of echo characteristics alone, statistical analysis will be carried out to calculate the probability that a set of echo characteristics belongs to a given species.

First, consistency of the echo characteristics will be determined. Characteristics that show large variation for different individuals of a certain species, will be less useful as predictor variables. This analysis will give us insight in which characterisitics are the strongest determinants for species recognition.

Second, the dataset will be used to calculate the probability that a set of echo characteristics belongs to a given species. This requires a multivariate analysis. More specifically, a program called Poscon has been developed for similiar purposes by Engelmoer & Roselaar (1998), which meets our demands for analysis of echo characteristics, and which we will use to calculate probabilities. In short, in Poscon, echo characteristics are assigned to two or more groups or species of birds, and the probability is calculated that the characteristic belongs to that species or species group. Thus, we can identify characteristics or sets of characteristics that belong to a specific species (-group), and characteristics that can belong to several species (- groups).

Third, additional information on for instance presence or absence throughout the year can be used within Poscon to exclude species at specific periods, and thus increase the chance that a set of characters uniquely belongs to one species group or species.

5.2 Analysis of flight patterns

The data that will be collected with both visual and radar observations, will be processed (means and variation) and analysed to show relations between flight patterns (flight paths, altitudes, fluxes, flight speed) of birds and e.g., environmental conditions and seasonality, as well as other phenomena such as the presence of fishing vessels. Flight speeds are likely to vary with wind speeds, and the measured ground speeds and flight directions will therefore be related to wind speed and direction (yielding air speeds). Differences in patterns of migrating versus local birds will also be analysed.

The effect of changing weather conditions on for instance signal detection by the radar and distance at which birds are detected visually will be analysed once data are available. To avoid a bias in the data set due to for instance altered visibility, a correction factor will need to be included in the analysis of flight patterns.

These will be preliminary analyses, serving to identify patterns that can be of interest during the effect study. For the analyses we will use multiple regression techniques available in Genstat version 6.

5.3 Data storage

The data, both basic and processed, will be made available to others through Donar, the database of RWS. For this purpose a selection will be made of those data that are relevant. Which data to include and how to present these in Donar, will be decided in consultation with Donar managers, once data are available. In addition, the methods used for data analysis and the analysis-results will be delivered to Donar as well.

6 Time table

The following paragraph gives an overview of the timing of the measurements and the number of people involved, summarised in table 6.1.

Radar observations
After MARS XSP is installed and fully functional, radar observations will be conducted continuously, 24 h per day, for one year. As registration and storage of bird movements is fully automated, no people need to be present for these measurements. Functioning of radars and computers will be checked upon during the monthly visit for visual observations. Radar observations are planned to start in late July 2003. The second and third week of July will be used to install and test the systems.

Visual observations
Visual observations from Meetpost Noordwijk are planned each month (10-12 times a year in total), in part around full moon, for a period of four to five days with three people. These observations will be done simultaneously with the Lot 5-surveys in the months where Lot 5 will still have field surveys.

Seaduck observations
Observations on seaducks will be carried out twice with four people during two and a half days each in December and/or January when the number of ducks present is highest, and possibly in combination with or directly after Lot 5-surveys.

Table 6.1 Overview of timing and frequency of radar observations, visual observations, and observations on seaducks. d=days, p=people.

	Radar observations	Visual observations	Seaduck observations
June	preparations	preparations	
July	installation & calibration	trial run	
August	continuous	4/5 d – 3-4 p	
September	continuous	4/5 d – 3-4 p	
October	continuous	4/5 d – 3-4 p	
November	continuous	4/5 d – 3-4 p	
December	continuous	4/5 d – 3-4 p	2,5 d – 4 p
January	continuous	4/5 d – 3-4 p	2,5 d – 4 p
February	continuous	4/5 d – 3-4 p	
March	continuous	4/5 d – 3-4 p	
April	continuous	4/5 d – 3-4 p	
May	continuous	4/5 d – 3-4 p	
June	continuous	4/5 d – 3-4 p	
July	continuous	4/5 d – 3-4 p	

Delivery dates as mentioned in contract
Below, all important dates during Phase 2 and 3 of the project are summarised.

report on radar calibration*	4 weeks after start radar observations
first progress report	1 October 2003
second progress report	1 March2004
draft report Phase 2	16 July 2004
final report Phase 2	15 August 2004
draft final report Phase 3	8 October 2004

* Data files will be exchanged with Donar managers in order to create templates for datastorage of relevant data in Donar. Choices will be decided in consultation with Donar managers, once data are available.

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Appendices

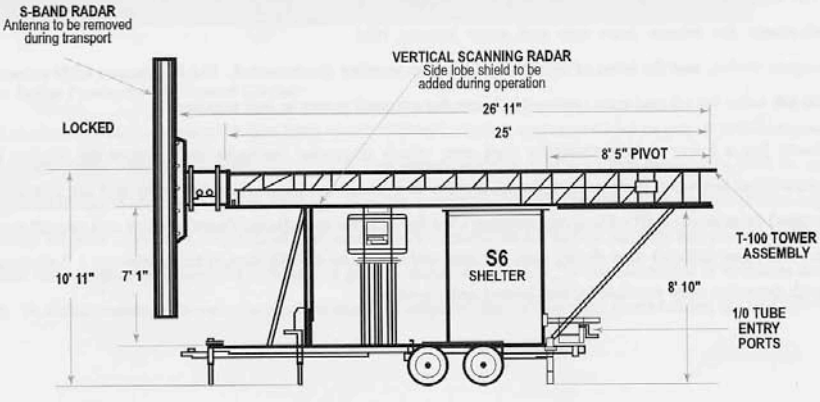
**(selection of pages of leaflet Geo-Marine, Inc.
Mobile Avian Radar System (MARS))**

AIRPORT MARS™ CONFIGURATION *MOBILE OR FIXED*

The Airport MARS™ trailer is typically supplied for commercial airports and high activity military applications. It features an 8 ft x 26 ft 11 in trailer with an air conditioned shelter with emergency backup forced air - cooling. The trailer is made from galvanized steel and aluminum for a long life with low maintenance requirements. The rest of the specification depends on the number of radars ordered with the system and the application. Fixed systems for realtime applications are hooked to local utilities for power supply. The radars and computers receive power through uninterruptible power supplies that provide about 10-15 minutes of power in the event of a power outage. A generator can be provided as an option for permanent or semipermanent installations if the client requires additional backup power for continuous monitoring in the event of a power outage. This option includes installation of an automatic switch to start the generator in the event of a power outage. Each radar on the trailer is fitted to a tower, which allows the radar to be elevated above the ground during operation and stowed while in transit. The trailer's shelter is painted to match local high visibility marking requirements for equipment on an airfield.

AIRPORT MARS™ TRAILER | SPECIFICATIONS

Trailer Length	26 ft 11 in
Trailer Width	8 ft
Trailer Height in transit	11 in
Trailer Height on site	Approx. 27 ft
Weight	5200 lbs max.
Brakes	12 v Electric
Tow Ball	2 5/16 in
AC Capacity	13500 BTU

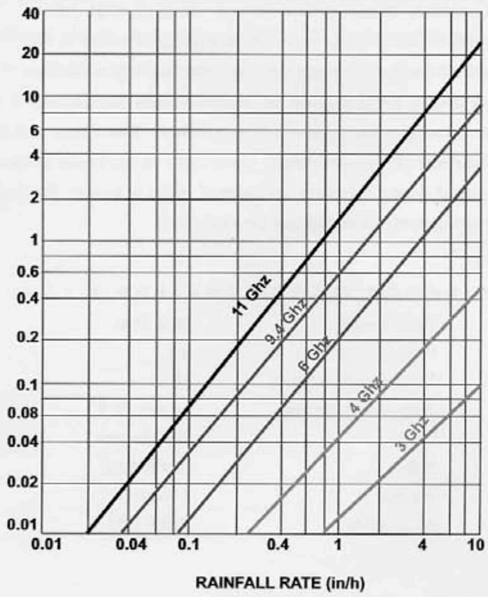


RADAR SYSTEM PERFORMANCE

The maximum range of detection of a bird target is a function of the power output of the radar, radar sensitivity, and size of the bird or flock of birds being monitored. Atmospheric targets such as rain, sleet, snow, smoke, and other particulates reduce the performance of all radars. Ground clutter can also degrade performance (ground clutter is processed out of radar images in the MARS system). Due to the many parameters involved, radar system performance modeling for a specific site is difficult to model without on-site data. To address this, GMI offers a simple solution for clients to evaluate a MARS unit for their application and assess local conditions. GMI both rents and leases MARS units to clients to evaluate the system and determine specific operating parameters before long term lease or purchase commitment.

Radar Performance in Rain and Snow

The graph *(right)* compares the theoretical performance of a radar at X-band, 9.4 GHz, in rain (blue line) and an S-band, 3 GHz, radar in rain (red line). Note that there is approximately 100 times more attenuation at X-band than at S-band for any given amount of rain. This is the reason why under most conditions VerCat™ X-band radar is unable to collect altitude data in precipitation. In the presence of heavy rain or other atmospheric conditions that swamp the radar display, the radar/computer is programmed to stop collecting data. The radar can usually continue to collect data in light rain or fog with slightly degraded performance due to attenuation of the signal. The more powerful 50 kW VerCat radar reduces to a small extent the effects of signal attenuation in the rain.

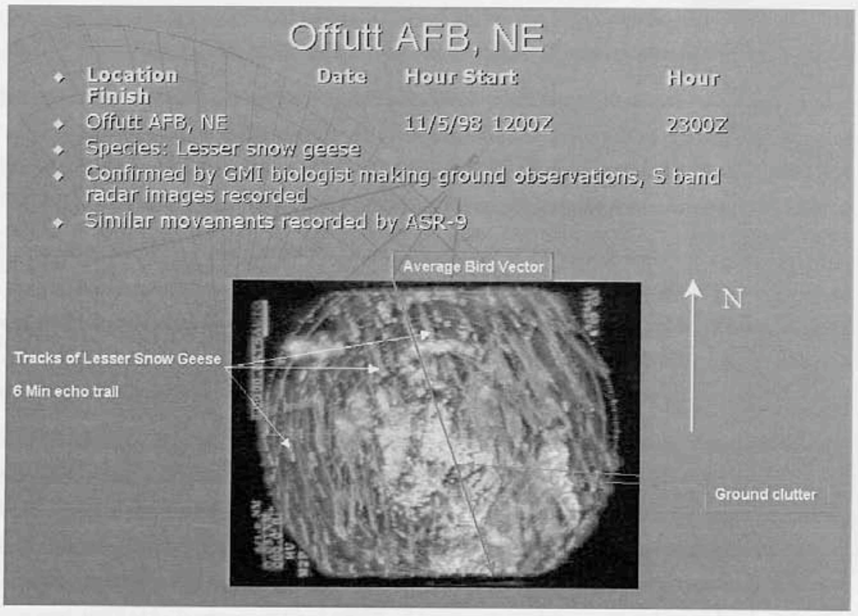


By contrast the S-band radar in combination with the radar computer interface exhibits good performance in the rain. The algorithms used in processing the S-band radar data eliminate the returns from rain and snow leaving bird targets visible, and the level of detection of birds in weather is attenuated. For this reason GMI recommends the use of a 60 kW radar for all real-time systems to boost the returned power in bad weather.

Snow has a lower radar reflectivity than rain, which attenuates the radar and clutters the display less than rain. As snowflakes transition from solid to liquid, there is an increase in radar reflectivity by up to 7 dB; however, when completely melted there is a 2-3 dB reflectivity increase over the original snowflake. Therefore bird and aircraft detection during snow are not more difficult than during rain. In rain and snow, the MARS should be considered a 2-dimensional radar system with detection only possible by the S-band radar system.

S-BAND SURVEILLANCE RADAR PERFORMANCE

The raw radar return image *(below)* shows the display of a 30 kW S-band MARS™ unit in operation at Offutt AFB, Nebraska, in November 1998. The range setting for the display is 6 nm or just over 11 km. The light blue lines indicate the path of flocks of 30–100 Lesser Snow Geese during the previous 6 minutes. The image confirms that a 30 kW radar in surveillance mode can detect flocks of 30+ geese at 6 nm. A 60 kW radar can achieve a 30%+ improvement on the range of detection achieved by a 30 kW surveillance radar. The radar display shows continuous tracks from one side of the radar display to the other. This 30 kW radar on this date was able to maintain detection of the larger flocks of geese (over 100 birds) to 22 nm or approximately 40 km. Smaller birds can be detected at shorter ranges. Typical data collection against smaller birds (small gulls and less) is conducted at 4 nm range setting and for larger birds at a 6 nm range setting.



Radar Performance in the Presence of Ground Clutter

GMI has developed a unique system to process the data from radars to detect, display, and record bird targets. It is this unique processing that eliminates clutter, classifies targets, and records data immediately to databases that establishes GMI as an internationally recognized leader in applied radar ornithology. The data generated from this innovative computer processing can be used immediately for pilot advisories, dispatch of bird control staff, or archived for further analysis and planning. The image *(above)* is a raw radar display and does not include any ground clutter suppression, so ground clutter is visible in the center of the display. To further enhance the radar beyond the standard output of the off-the-shelf marine radar, the MARS™

unit is interfaced to workstation personal computers (PCs) via a radar scan converter card. The MARS™ computer runs proprietary algorithms to remove the ground clutter and maintain the track of targets, even in ground clutter. This radar computer interface card allows the computer to capture data from the radar at a higher resolution and with greater dynamic range than the standard radar display. Once the PC captures the radar data, it is processed to remove remaining ground clutter returns. Four variations of the algorithm are currently available to optimize the ground clutter suppression to local conditions and custom, site-specific algorithms can be developed by GMI if required.

In clear air, a clutter map is made from multiple scans over a period of time. Each scan in the time series is compared to find the position and magnitude of returns from stationary objects in the radar's field of view. This map is then used to subtract from each radar scan the level of return of the ground clutter. Any bird target passing through an area of ground clutter is detectable as long as the ground clutter does not exceed the dynamic range of the radar/scan converter card. The scan converter card encodes the radar data at 12 bits or 4096 levels, giving the MARS™ units significantly greater dynamic range over current, comparable radar systems (typically processed at 4 or 8 bit levels).

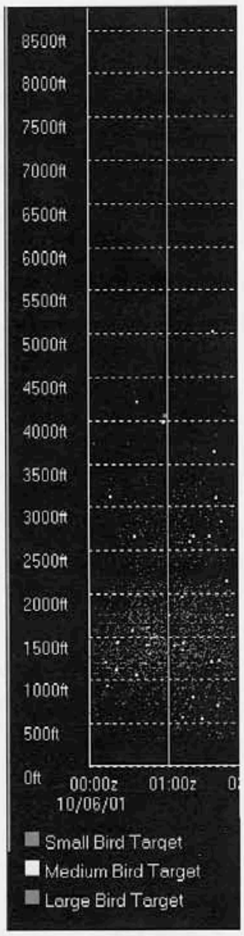
A target-tracking algorithm is used to find radar returns likely to be biological targets based on size, radar reflectivity and speed. The use of this algorithm to flag potential bird targets with clear symbols makes radar image interpretation by air traffic controllers much simpler than looking at just the raw radar returns. The target tracking algorithm helps to eliminate false alarms caused by interference or nonmoving targets not filtered out in the clutter map process.

The clutter map process is a secondary process to remove the ground clutter that was not already eliminated by the modifications made by GMI to the standard antenna arrays. The combination of antenna modifications, high dynamic range, clutter mapping, and target tracking provides a very effective solution to detecting birds with radar in high-clutter, terrestrial environments. Removing ground clutter returns from the radar display makes the display easier and quicker for the user to understand the information being presented.

The performance of the ground clutter suppression algorithms is dependent upon the intensity of local ground clutter and the types of targets being detected. No radar can see through objects such as buildings or terrain that can block the view of a bird target. Most airports provide a flat surface with few interruptions that generate only small amounts of clutter. The degree of clutter can vary depending on conditions - dew on grass is more reflective than dry grass, and vegetation such as trees blowing in the wind generates more dynamic clutter than under still conditions. If a target of interest is small compared to the variability of the local ground clutter conditions, it may not be detected. GMI operates the MARS™ units in a wide range of conditions in addition to airfields and landfills, which includes off-shore platforms in the Atlantic and mountainous areas in New Mexico. Small birds would not generally be detectable in the severe ground clutter of a mountainous region, but the system can detect aircraft and large birds under this circumstance. GMI's extensive experience and large base of operating data under a wide variety of site conditions allows GMI to select the best ground clutter algorithm type and settings for each customer's specific conditions.

VERTICAL *VERCAT MODE*
BIRD HEIGHT MEASUREMENT PERFORMANCE

It has historically been very difficult to demonstrate the performance of a radar to detect a bird. Theoretical calculations can be made from the power output of a radar, antenna gain and receiver sensitivity, and a simple model of the reflectivity of a bird; however, in practice a bird is a complex scatterer of radar energy and simple models fail to fully describe the actual performance a radar will achieve. To demonstrate the actual performance of the MARS units, GMI uses real data collected by the radar-detecting bird targets. The graph *(left)* shows data collected by one of GMI's MARS unit with a 25 kW VerCat radar. The graph clearly shows medium-sized birds (approximately the size of a small gull) to >5000 ft and a large bird (approximately the size of a goose) at 4000 ft. Large targets, such as a flock of geese can be seen at substantially higher altitudes due to there larger radar cross section. The VerCat radar can at close range/altitude detect small targets such as bats and birds such warblers. In a real-time airfield environment the 50 kW VerCat radar is designed to detect large flocks of (approx. 30) geese at a range of 3 km and at a height of 10,000 ft. These types of bird flocks impose the most serious potential for the loss of an aircraft. The use of a ground clutter reduction algorithm on the VerCat radar allows it to detect birds close to the surface of the earth, if a moving target is in direct line of site of the radar.

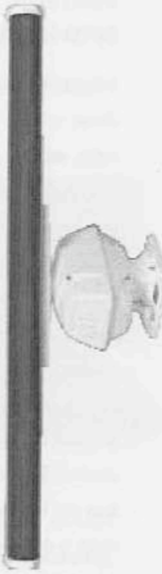


General Component Specifications

GMI offers a wide range of stock and custom component options. The following section presents technical and performance data on the base and high-end stock models for radars, computers, and various options. Each unit is custom configured from stock and/or custom components based on each specific customer's operational and budget requirements.

VERCAT™ RADAR *X-BAND (3 CM) FR1525M3 WITH 8 FT ANTENNA*

The FR1525M3 is the base VerCat™ radar and is offered on MARS™ units used to survey and collect data on bird activity. The VerCat™, vertical-scanning radar, is used for obtaining altitude data of birds passing over the area scanned by the radar. Typical peak power output is 25 kW and is used to measure altitude of bird movements up to 8500 ft and out to each side up to 1.5 nm (typically .75 nm). To find the height of bird targets passing through a study area, the antenna is normally oriented to scan perpendicular to the normal flight path of birds in the area. During migratory season this is generally an east-west scan.



The FR1525M3 is a modular, black-box radar consisting of a gearbox/transceiver, keyboard, and radar processor unit. This separation of functions creates maintenance costs that are dramatically lower than more traditional designs.

Each VerCat™ radar is configured with a custom-built antenna assembly designed by GMI to optimize bird detection and reduce the effects of ground clutter and sidelobe contamination to a minimum

X-BAND ANTENNA | SPECIFICATIONS

Radiator System	Slotted waveguide array	
Length	8 ft	
Beam width (H)	0.95°	
Beam Width (V)	20° - 40°	
Rotation Speed	24 rpm	
Antenna Gain	26.4 dB	
RF TRANSCEIVER		
Frequency		
X-band	9410 MHz, 9415 MHZ	
Output Power	25 kW	
PULSE LENGTH & PRR		
Range Scales	**P/L (μs)**	**PRR (Hz)**
0.125, 0.25	0.07	3000
0.5	0.07/0.15	3000
0.75, 1.5	2 from 0.07/0.15/0.3	3000/1500
3	2 from 0.15/0.3/0.5/0.7	3000/1500
6	2 from 0.3/0.5/0.7/1.2	1500/1000
12, 24	2 from 0.5/0.7/1.2	1000/600
IF Amplifier	Logarithmic, IF: 60 MHz, BW: 28/3 MHz	
Noise Figure	6 dB	
Power Supply		
AC USA	115 VAC, 50/60 Hz, 1 ø, 465 VA max.	

TRACSCAN™ RADAR *S-BAND (10 CM) FR1430DS WITH 9 FT ANTENNA*

The TracScan™ radar is used to obtain the ground track data of birds and aircraft moving through an area. Typical peak power output is 30 kW and is used to detect bird movement within a 4 or 6 nm range. The antenna scans 360 degrees from the surface to 25 degrees above the surface. Large birds can be detected out to a range of 12 nm and large flocks of geese have been detected as far away as 20 nm.

The FR1430DS is a modular, radar consisting of a gearbox/transceiver, keyboard, and radar processor unit. This separation of functions creates maintenance costs that are dramatically lower than more traditional designs.

Each TracScan™ radar is modified with custom-built antenna hardware designed by GMI to optimize bird detection in a terrestrial environment.

ANTENNA | SPECIFICATIONS

Radiator Type	Slotted waveguide array	
Length	9 ft	
Beam Width (H)	2.3°	
Beam Width (V)	25°	
Rotation Speed	24 rpm	
Antenna Gain	26.4 dB	
RF TRANSCEIVER		
Frequency		
S-band	3050 MHz +/- 30 MHz	
Output Power	30 kW	
PULSE LENGTH & PRR		
Range Scales	**P/L (µs)**	**PRR (Hz)**
0.25 to 0.5	0.08	1900
0.75	0.08/0.3	1900/1100
1.5	0.08/0.3/0.6	1900/1100/600
3	0.3/0.6	2200/1100
6, 12, 16, 24	0.6/1.2	1100/600
IF Amplifier	Logarithmic amplifier, IF 60 MHz bandwidth: 27 MHz (0.08/03 µs) 3 MHz (0.6/1.2 µs)	
Noise Figure	4 dB nominal	
Power Supply		
AC USA	110/230 VAC, 50/60 Hz, 1 ø	