COMKISS

Conveying Metocean Knowledge Improvements on to Shipping Safety

Final report

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1. INTRODUCTION

1.1 Objectives

The acronym COMKISS stands for COnveying Met-ocean Knowledge Into Shipping Safety. However the project objectives were somewhat wider than this description might imply.

The main objective of the COMKISS was:

- *to demonstrate to major segments of the European marine transport industry the benefits of integrating satellite-derived information on sea state with more conventional methods.*

A secondary objective lay in the method of demonstration. Since the project involved close co-operation of industrial partners from beginning to end, their endorsement of the usefulness of satellite data counts much more than any claim made by EO value-added companies. Separate demonstration modules have been created to record the separate tasks and chronicle the improvements made through the introduction of satellite-derived information where it was not used before. Thus COMKISS had a secondary objective:

- *to raise awareness of the usefulness of satellite data in increasing the safety and overall efficiency of shipping operations (by using EWSE as the channel for communicating progress.)*[1]

COMKISS aimed to demonstrate the extent to which the introduction of space-derived information on sea-state into three major marine operations would benefit their daily activities. The objective was to bring about a change of attitude, not by convincing operators to use EO data where it is inappropriate, but to demonstrate that space-derived information can at the very least act as a control on the quality of the data they presently depend on and, at best, replace it.

Three main offshore industry sectors were selected for the study, chosen because of their previous lack of exposure to satellite data. These were: ***ship design and certification,*** the ***transport of very large loads*** such as dock cranes and offshore platforms, and the operation of ***high speed craft***.

COMKISS was a two year programme, with ambitious goals. Within the general objective of demonstrating marine applications of satellite data to the offshore industry were eight individual applications studies — aimed at testingthe potential benefit, in terms of improvements to safety and economy, of specific applications of satellite data. These applications fell into two general categories: provision of ***near real-time*** data to operational offshore activities, and application of ***climatological databases*** for planning and design. This report lays out how far these ambitious aims have been satisfied, and indicates where further work is required.

1.2 Context

Europe s maritime heritage

Over many centuries Europe s close involvement with the seas which surround it has been fundamental to its prosperity. Europe s economic development is inextricably linked to its seafaring heritage; today over 90% of its external trade and nearly 30% of its internal trade is carried by sea. Maritime industries across Europe employ over 2.5 million people.

The sea still represents a real hazard, however, and mariners retain a healthy respect for its sudden changes of mood. Despite the most modern technological advances, the number of vessels of over 500 tonnes that are claimed *every year* by the sea remains at a remarkably constant 150 - over a third in weather-related incidents. Delays and damage to ships are relatively common, and large financial losses are incurred each year.

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[1] *During the period since the COMKISS proposal was submitted EWSE has been replaced by INFEO (http://www.infeo.org). At the same time the COMKISS team agreed that the Demonstration Module structure within INFEO was too restrictive to allow a good representation of the COMKISS applications studies. Hence new format DMs have been placed at the IFREMER web site (http://www.ifremer.fr/metocean/shipping/shipping.htm).*

The paradox that shipping is the most environmentally friendly transport system, yet potentially the most dangerous, is recognised by the Commission. A Maritime Task Force was established by the EC to help the European maritime industry rise to this challenge. It was designed to provide a marine focus to individual European programmes - including Industrial Materials & Technologies (IMT), Information Technologies, Transport, Telematics, Marine Science, Fishing & Aquaculture, and Energy.

Satellite Measurements of Sea State

Sensors for measuring the state of the sea in terms of surface wind speed and direction, and the height, direction and period of waves, have been employed from satellites for over 20 years. It was first demonstrated by Seasat, in 1978, that a suite of microwave sensors that included a Synthetic Aperture Radar (SAR), a wind scatterometer, and a radar altimeter could estimate these parameters to useful accuracies from polar-orbiting satellites.

In the case of the scatterometer, wind speed can be measured to – 2m/s and direction to 020¡. The altimeter provides estimates of significant wave height (equal approximately to the height of the highest third of waves) to – 0.5m. It can also measure wind speed but not direction along the satellite s track. The SAR, with a spatial resolution of around 30m, provides images of surface waves from which the direction and period (wavelength) of wave trains can be extracted provided care is taken to allow for non-linear distortions. The SAR on ERS-2 operates a wave mode which produces 5 x 5km imagettes of surface wave fields at 200km intervals around the globe.

Since 1985, when the US Navy launched the radar altimeter satellite Geosat, there has been an almost continuous string of scientific satellites which have provided global measurements of sea state. ERS-1 was launched by the European Space Agency (ESA) in 1991, carrying an altimeter, scatterometer and SAR (amongst other instrumentation), and was followed by its (similarly instrumented) successor ERS-2 in 1995. In addition the USA and France launched the TOPEX/Poseidon altimeter satellite in 1992, primarily to monitor small changes in ocean circulation. Both TOPEX/Poseidon and ERS-2 operate to this day. A follow-on to the US Navy s Geosat was launched early in 1998 but has experienced early teething problems, and has only recently been accepted by the US Navy (November 2000). More missions are to follow. In February 2001 the successor to TOPEX/Poseidon, JASON, is scheduled for launch, and in June 2001 ESA plan to launch ENVISAT. In the meantime global directional wind field measurements are now provided by the US scatterometer mission QuikScat.

These satellite missions have provided observations which, subject to proper quality control, validation and calibration, have been archived into a global database from which statistics on wave behaviour can be extracted. However, each of these missions has scientific (and technical) rather than operational goals. Thus the sampling regimes are selected to study scientific problems of major interest rather than ensure that measurements are provided at a sufficient spatial and temporal density to provide useful operational information to offshore operators.

We should also note that a number of radar imaging satellites (such as RADARSAT), which have the potential to provide seastate information are also now operational. However, data from these latter satellites have not been included in COMKISS applications studies.

Wave Models

Another significant activity, which equals the emergence of satellites in the speed of its development, has been the improvements to wind/wave models made possible by modern computer technology, and by advances in the understanding of the physics of ocean waves.

Most numerical models provide deterministic predictions and hindcasts. Such results are difficult to use by the industry, which in any case wants to know the probability that reality will divert from the prediction by a given extent. Some agencies are now developing new techniques to establish the uncertainty in deterministic forecasts, though the use of ensemble forecasts (Janssen, 2000). In addition, through the theoretical developments carried out from COMKISS at the

University of L nd (Baxenavi et al, 2000a and 2000b), we have seen how direct use of satellite measurements in stochastic models can enable the calculation of risk probabilities that may then be used in the decision making process, whether at the design stage or in NRT (Near Real Time).

Summary

The objective of the project was to investigate the combined use of satellite data and wave models, not to advocate one against the other. The output of a model, no matter how sophisticated, can only be as good as the quality of the input data, which may be sparse in some areas. The satellite data therefore represents a valuable check on the model outputs. Models can provide estimates of those wave parameters which are difficult to measure reliably from satellites (for example period and direction, especially at wavelengths less than 100m).

To provide near real-time information to assist in the day-to-day planning of maritime operations represents a formidable challenge. The simple reason is that even if a higher degree of co-ordination between the separate missions can be introduced, the number of spacecraft will still fall short the ideal requirement to match the rate of change of sea-state in any one area. One of the objectives of COMKISS is to establish the coverage required by end-users.

COMKISS set out to identify applications where satellite data could have a positive impact, but is not yet exploited fully, and to inform the offshore industry of the capabilities of these data.

1.3 The Partnership

There were six partners in the COMKISS programme, including a strong end-user representation covering three sectors of the offshore marine industry. The two industrial full partners, ***Dockwise*** (a Belgian company specialising in the transport of unusually large loads) and ***Bureau Veritas*** (a major shipping design and certification organisation), guided the investigations in their own area of interest and adjudicated the results. A further unfunded partner, ***Corsica Ferries*** (which operates fast ferries between France, Corsica and Italy), co-operated on a voluntary basis allowing an important analysis of High Speed Craft operations. There were four scientific partners: ***IFREMER***, the French national marine research organisation; the Department of Mathematics and Statistics at the ***University of L nd***, specialists in wave statistics; ***Optimer***, an engineering Metocean studies company; and ***Satellite Observing Systems***, a leading EO value-added company specialising in providing satellite-derived marine information. The partners responsibilities within the COMKISS project are given below:

- Project Manager, Wave Statistics — **University of L nd**, Sweden,
- Project Co-ordinator, Wave climate databases — **Satellite Observing Systems**, UK
- Science Partner, MetOcean Analyses — **IFREMER** (MetOcean Group), France
- Science Partner, MetOcean Analyses — **OPTIMER**, France
- End User Partner, Large load transportation — **Dockwise**, Belgium
- End User Partner, Ship Design / Certification — **Bureau Veritas**, France
- External End User, High Speed Passenger Ferries — **Corsica Ferries**, France

The consortium brought together to carry out this programme represents a very well-balanced mix of marine industries, European national interests, research/university experience in the measurement and behaviour of surface waves, and EO value-added companies specialising in the marine environment. The programme of work adheres to the CEO philosophy of being driven not by the EO data providers but by the industrial partners actively engaged in marine commerce.

2. WORK ACHIEVED

In this chapter all aspects of the technical work are presented. The first two sections provide an overview, and a discussion of user requirements. Sections 2.3 — 2.5 detail thework carried out and provide individual conclusions and recommendations following from each work package. Section 2.6 lists the formal project deliverables. Combined conclusions and recommendations are given in Chapter 3.

2.1 Overview

The technical work for COMKISS was separated into three individual work packages, according to the client organisation involved. Table 2.1 indicates all the Work Packages in COMKISS, the three technical Work Packages are highlighted: WP3000, Ship Design (Bureau Veritas); WP4000, High Speed Craft (Corsica Ferries); WP5000 Unconventional Transportation (Dockwise).

Work package	Responsible partner
WP1000: Project Management	University of L nd, Georg Lindgren
WP2000: Project Definition	Satellite Observing Systems, David Cotton
WP3000: Ship Design	**Bureau Veritas, Guy Parmentier**
WP4000: High speed craft	**OPTIMER, Raymond Nerzic**
WP5000: Unconventional transportation	**Dockwise, Cees Leenaars**
WP6000: Demonstration Modules	IFREMER, Michel Olagnon
WP7000: Validation, Verification, Exploitation	Satellite Observing Systems, David Cotton

- **Table 2.1 — COMKISS Work Packages, and responsible partners.**

Work Packages 1000 and 2000 were concerned with Project Management and Project Definition. Work Package 6000 concerned the preparation of Demonstration Modules, and was performed by IFREMER. The Demonstration Modules were seen as a very important part of the COMKISS project in that, in addition to satisfying part of the requirement to disseminate the COMKISS results, it was intended that they would be available to potential industrial users to enable them to verify the circumstances under which satellite data can generate real benefits to their own maritime activities. WP7000 (Validation, Verification, Exploitation) is also important. This activity brings together of the results from WP3000, 4000 and 5000 to form coherent and specific recommendations: for future developments to optimise effective use of satellite EO data, and for disseminating advice so that industrial users are made aware of the capabilities of presently available data sets.

2.2 User Views and Practice, and Project Requirements

It was important to first ascertain the current practices and requirements of the three users involved in COMKISS. This enabled the team to define the applications to be developed and tested. After the three user representatives had identified their most important expectations on the project, some compromises had to be made to economise with time and money available for archive data. Whilst the work packages of the project that were originally designed for the three types of users remained, some modifications to individual work packages were made. These aspects of the project development are reported fully in the COMKISS User Requirements document (COMKISS 1999a) and in the Revised Technical Annex (COMKISS 1999b).

The user views and requirements, as discussed within the project, are presented below.

2.2.1 WP3000 Ship Design

Within COMKISS, Bureau Veritas represented the ship certification sector, and presented requirements both on regular shipping operations and on High-Speed ferries.

For conventional shipping certification, wave models and ship response functions based on Global Wave Statistics (BMT, 1990) are used to assess the fatigue life on critical parts of a ship s hull.

Bureau Veritas has observed unexpectedly large damage on ships at certain routes in the Mediterranean. These could be attributed to inaccuracies in the database, and it was thought advantageous for future certification strategies to find out if more accurate wave statistics, with directional information, can be extracted from the satellite archives.

Also related to fatigue is the topic of *fail safe construction*. Much of the fatigue loading on a ship s hull is experienced during loading and unloading in port. Inspection for fatigue cracks is routine, but it might happen that a ship leaves port with an undetected crack. This can still be safe, provided that no long period of rough sea-states is experienced during a crossing. Bureau Veritas wanted to know if satellite archives provide sufficient information on the frequency of long spells of rough (and smooth) sea-states along selected routes where this type of safety risk may occur.

The certification industry also has a strong interest in better rules for the certification of High-Speed craft and ferries. These requirements are presented in Section 2.2.2.

The summarised requirements from the ship certification sector are given in Box 1:

Box 1: Requirements from Bureau Veritas

A long regular ship route should be selected for which an extensive database on ship performance exists and for which a satellite metocean database can be obtained. The ship response models used in the certification process should be combined with metocean data and the results compared to those obtained using the Global Wave Statistics database (BMT, 1990). If deviations are detected it proves that the more detailed information from satellite data are useful in design and certification.

A new procedure is needed to assess the possibility of fatigue crack growth during an ocean crossing of specified duration. Investigations should therefore be made to see if satellite data could provide reliable statistics on persistence of severe wave conditions during the crossing period. The requirement of BV is that the project should demonstrate to what extent this could be done with present or future wave surveying satellites.

2.2.2 WP4000 High Speed Craft (HSC)

The interests of the HSC industry have been formulated both by the HSC operator Corsica Ferries (CF) and by Bureau Veritas (BV).

Certification of HSC

BV wished to investigate use of satellite derived data in making early assessments of conditions encountered by HSC during normal operation. They receive measurements of ship stresses and estimates of sea-state from operators. These measurements may then be used in setting sea-state dependent rules for the operation of these craft.

In particular, BV has carried out HSC trials in the Mediterranean (S of Nice) in June 1998. Ship stress measurements are available, and BV wished to see if improved estimates of actual sea state information, directional wave spectra if possible, might effect assessments, which consider possible modifications to models and maybe also to ship design.

Operational aspect of HSC

CF identified their specific need for near real-time wave height and direction information from satellites. CF co-operates with M t o France on forecasts of wave conditions on their routes in the Mediterranean.

Data are required in near real-time and as forecasts for short term (less than two hours and up to 24 hours). The usual metocean data requirements for Corsica Ferries are: an assessment of the accuracy of the forecast from M t o France (Aix en Provence).; information about the evolution of the sea state.; warning of possible severe conditions; advice on clear weather windows.

There were possible problems associated with the Corsica Ferry routes, because of the high temporal and spatial variability in conditions around Corsica and the local enhancement of winds due to topography. Hence it was thought that satellite data alone may have limited impact, and that some combination with high-resolution local models may be required.

The Corsica Ferry routes are Nice/Bastia, Nice/Calvi, Savona/Bastia, Civitavecchia/Golfo Aranci. The most critical locations are around Cap Corse, and at the Eastern End of the Straits of Bonifacio.

The user requirements for HSC are summarised in Box 2.

Box 2: Requirements from HSC

The most important issue for the High-Speed craft sector is to see if satellite information can be made available with sufficiently high resolution in Near real-time to decrease downtime on scheduled routes due to limits on sea state criteria. Satellite data can only assist meteorological predictions. The study should reveal the sampling interval needed for the satellite data to be useful in that assistance.

Ship response models for high-speed craft are presently developed for sea state models with direction dependent specification. CF (and BV) wanted to know how the use of a satellite directional wave database for the Mediterranean could help to compare actual measured stress levels on board ship with predicted stress levels.

2.2.3 WP5000 Unconventional transportation

Dockwise has two main operational modes for predicting/responding to environmental conditions. The first is an office-based system which is used to run a risk evaluation for proposed operations by running Monte-Carlo simulations of the operations through an archive of environmental parameters. The second mode is an on-board system that provides route and decision making support, and monitors conditions en-route.

We first consider the office-based system. The use of Monte-Carlo simulations is an important feature of Dockwise s procedures. Rather than extracting a single set of predicted/expected climate conditions for a given route, multiple model runs of the proposed operation are made through the archived climate data, incrementing by date/location so that statistics of loads/stresses/exceedances can be generated and failure probabilities (e.g.) assessed.

The COMKISS programme complements the SAFETRANS project, of which Dockwise is a partner, and whose main aim is to reduce risk during transport and offshore installation. However, some key items are not included in the SAFETRANS programme, i.e.

- The ability to analyse, after the event, the exact conditions at the time of an operation.
- The development of a package to predict movements and stresses on board a ship during planned operations.

Dockwise identified further areas where improvements were desirable:

- Improved accuracy in forecasts, to aid short term planning.
- Improved information for (semi-) enclosed seas where model data are often unreliable (e.g Black Sea, Caspian Sea, Philippines, Indonesia). They currently use global statistics derived from models (covering a period of 5 years). They were interested to compare these global statistics with those derived from satellite data.

In summary, Dockwise hoped to assess the potential improvement that could be achieved over existing practices through the application of satellite data, as summarised in Box 3.

Box 3 Requirements for Transportation of Unusual Loads

Design database. Currently Dockwise uses a database from Oceanweather Inc. (Connecticut, USA). Would satellite data be more reliable/accurate?

Near Real Time Data. They need a better description of the wave field during operations.

Surface Currents. Could satellite data be used to improve or modify the available information on surface currents? For instance could satellite data provide time variability to add to the steady state maps that are already available?

With regard to the 2nd mode of operation (the ship-bases system), the specific requirement is to assess whether satellite data can improve the accuracy of forecasts fed into the on-board systems. Different opinions have been expressed.

On one hand it was argued that it would be preferable to improve a single source of information sent to shipmasters. On the other hand it was suggested that it would be better to provide the satellite-derived information separately to enable a decision to be made after comparing the two sets of information

2.2.4 Summary

Common application themes emerge from the user requirements, Box 4.

Box 4: Summarised, combined requirements of satellite data from COMKISS End-Users

Trials of satellite derived wave climate databases over routes and periods specified by the COMKISS client partners. How do satellite derived databases compare to other databases? Can they provide reliable information where more conventional sources fail?

The need for near real-time measurements for all 3 Work Packages, and, for each, an assessment of the usefulness of the fast delivery data stream of ERS-2 and other near real-time data. Forecasts can be inaccurate, and modern operations (e.g. cable laying, heavy lifts offshore, high-speed craft) can have precise operational limits. More accurate forecasts with a heavy emphasis on measured data are seen as highly desirable. However, is the density of satellite measurements sufficient to provide a useful service?

Improved reconstruction of the sea-state that prevailed during classification and certification trials. This will involve the best use of satellite archives and wind/wave models. The latter may be more appropriate for actual hindcasts at the time and place of the trials. Are satellite data preferable to gridded output from long term historical re-analysis models?

Can other useful parameters be derived (e.g. surface currents) by combining satellite data from various sources?

In the next three sections, 2.3 —2.5, we consider separately the work carried out for the technical work packages, WP3000 (Ship Design), WP4000 (High Speed Craft), and WP5000 (Transport of Unusual Loads).

2.3 WP3000 Ship Design

2.3.1 Introduction

The aim of this work package was to demonstrate the possibility of improving the definition of loads in the design rules from the better knowledge of sea states provided by satellite observation. Three main domains where such improvement may be expected have been considered; each was addressed by an individual sub work package. The first, WP3100 —*Checking Design Criteria* - deals with long term behaviour of the ship structure on an actual trading route (Rotterdam to Trieste). The second, WP3200 — *Fail Safe Calculations* - addresses a fail safe requirement. As an example, a gas carrier in normal condition should not experience any cracks in the ship s structure. Nevertheless, if for any reason some cracks should occur, of a sufficient size to be clearly identifiable, it should be possible to demonstrate that the ship can continue and safely reach a harbour where it can be repaired. Satellite altimeter data for the Rotterdam to Boston route were used for this study. The final case, addressed by WP3300 —*Satellite information for High Speed Craft Trials* - investigates the possibility of using satellite data to speed up the procedure of post voyage or vessel trials analysis. This could be achieved by providing, in near real-time, measurements of the actual sea states corresponding to the stress responses recorded on board the vessel. This would allow a sea state by sea state calibration of loads rather than an averaged life calibration of loads.

2.3.2 WP3100 Checking Design Criteria for Long Term Loads

In this task we examined how it is possible to improve damage prediction from satellite data. In particular we were interested in the route from Rotterdam to Trieste, Figure 2.1. Satellite altimeter significant wave height and wave period data from TOPEX (1992-1999) were employed in this study.

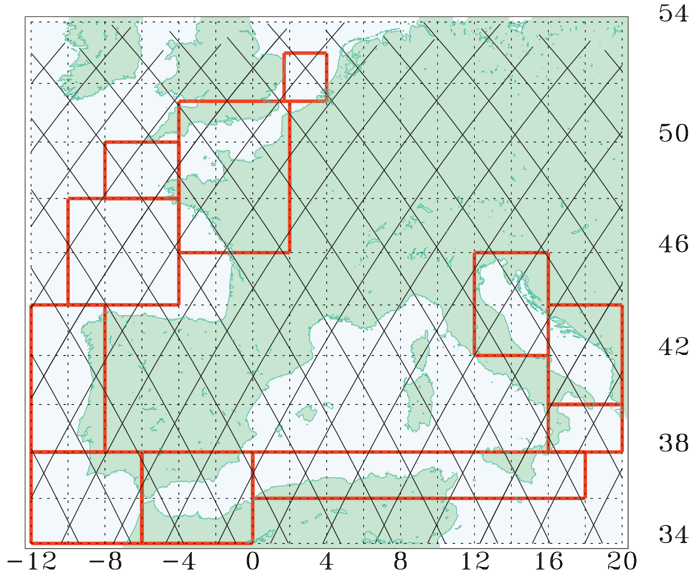


Figure 2.1 Areas (red boxes) selected for satellite data extraction along the Rotterdam to Trieste Route. The diagonal black lines indicate the location of TOPEX altimeter data. Each track is repeated once every ten days.

Damage prediction is currently carried out by classification societies using one of two approaches: rules calculations or direct approach calculations. The first technique (rules calculation) does not lend itself easily to modification in order to include new types of data. This is because the procedures are rigidly defined, and rely a great deal on learnt design experience. Also the loading cases in these procedures are too simplified to easily make use of data from satellite observation. However, and in contrast, the direct calculation procedure is better suited to modification. A standard procedure under this method would involve the following steps:

- A mission profile is determined for the ship, defining the expected life of the ship in a given area with a given heading, speed and loading.
- Area specific scatter diagrams are created. They provide the frequency of sea states expected to be encountered by the ship as defined by Hs (significant wave height) Tma (mean wave period), and heading.
- A shape of the wave spectrum is assumed. Generally for North Atlantic Ocean a Pierson Moskowitz, (Pierson and Moskowitz, 1964) is assumed.
- The damage corresponding to each short term interval is calculated, and then accumulated over the full life of the ship.

This procedure (see figure 2.2) is able to take into account information which can update and improve the determination of sea states, including (if available) data on wave energy distribution versus the frequency and the heading. Thus the direct calculations approach has been selected for use in COMKISS.

However, available satellite data do not directly match the input requirements for these procedures. Thus, in order to make progress, it was first necessary to identify and develop suitable statistical theory, and to establish databases of appropriate derived parameters. Sections 2.3.5 (*Development of a Theoretical Basis*) and 2.3.6 (*Statistical Analysis of Satellite Data*) provide brief descriptions of this work. Readers are referred to the original reports for more detail (Baxenavi et al., 2000a and 2000b).

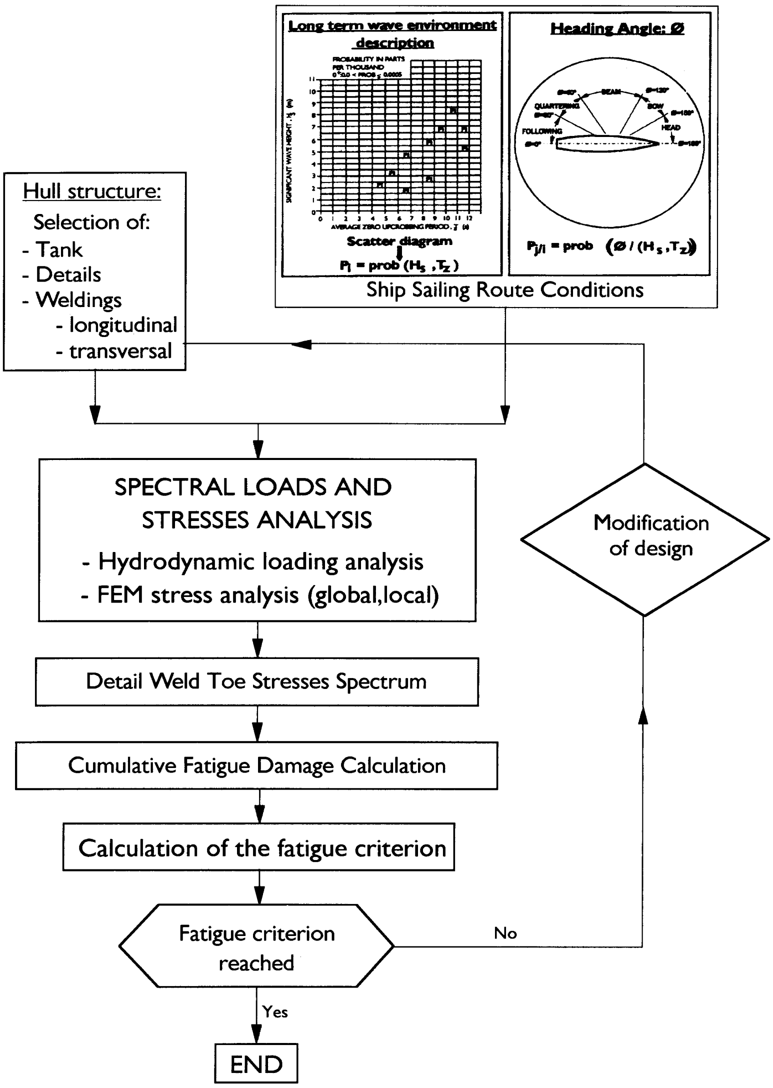


Figure 2.2 Direct Calculation Fatigue Analysis Procedure Flow Chart.

2.3.3 WP 3200 Fail Safe Calculations

Until now there has been no generally accepted methodology to check the safety of a ship with a leakage. The failure mechanism is well known and deals with the mechanics of fracture. i.e. crack propagation until brittle fracture condition is reached. The main problem is to define a realistic loading history corresponding to the period of time between the detection of the leakage and the arrival to a place where the ship may be unloaded and repaired. In this task we planned:

- to define a methodology to obtain a set of typical loading history taking the expected correlation between the successive sea states due to the persistence of storms.
- to ascertain if satellite observations may provide data that fit the above model, and so provide to the designer reliable data to carry out his/her verification check on an actual gas carrier. The designer would apply a fracture mechanics tools currently used in Bureau Veritas to establish the structure strength against crack propagation after a leakage.

Together these stages would also demonstrate the applicability of the methodology. This study required a statistical analysis and processing of satellite data which involved the construction of a time referenced data set. This is described in Section 2.3.6 (*Statistical analysis of satellite data*). TOPEX altimeter significant wave height and wave period data covering the North Atlantic route from Rotterdam to Boston (USA) were used in this study (Figure 2.3)

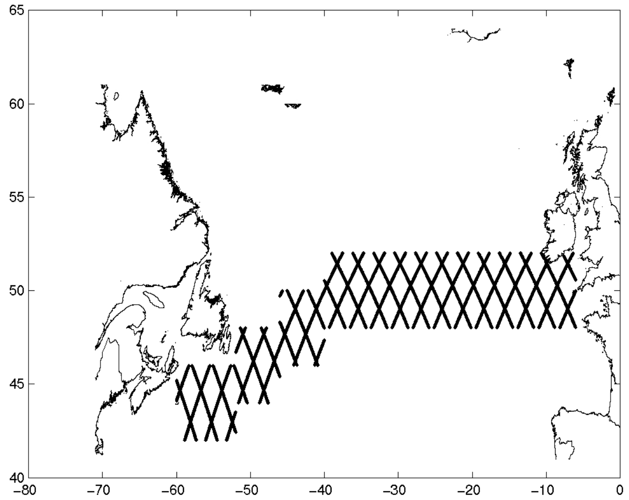


Figure 2.3 Satellite data coverage (from the TOPEX/Poseidon altimeter satellite) over the Rotterdam to Boston (USA) route.

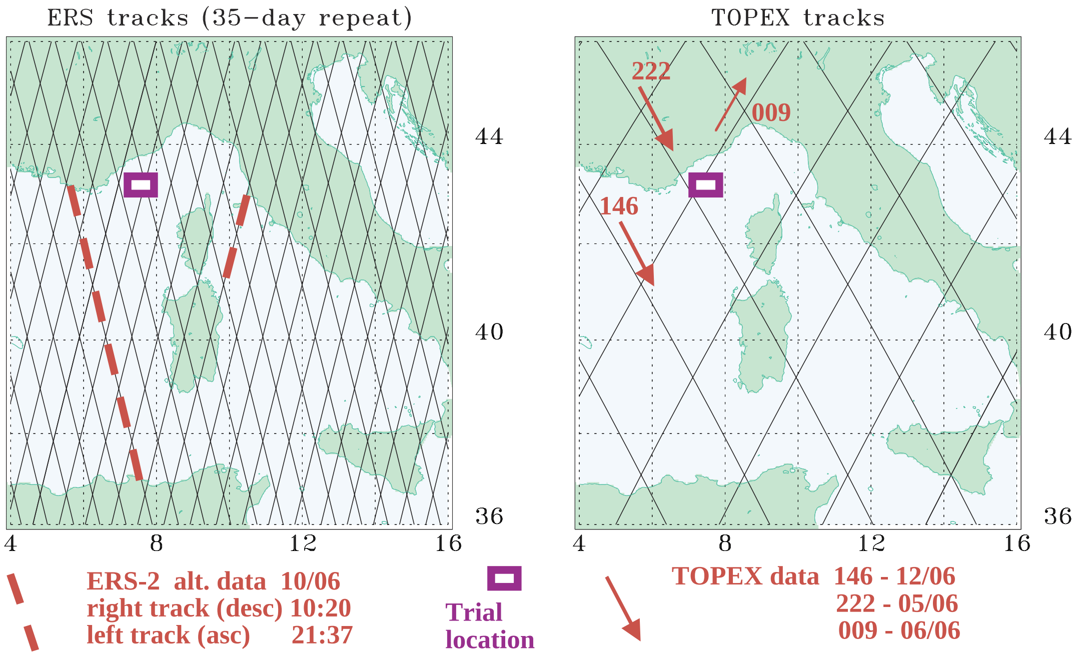


Figure 2.4. Location of Bureau Veritas High Speed Craft trials in the Mediterranean Sea, and of nearest altimeter data (left, ERS-2; right TOPEX) at the time of trials in June 1998.

2.3.4 WP3300 Near Real Time Data

For a new concept of ship such as a HSC, it is important for a designer and a classification society to know if the current design tools remain applicable or if new techniques should be developed to determine the best ship structure. For this task we investigated whether the satellite data could provide the relevant information to enable calibration of the hydrodynamic calculation using actual measured sea states.

HSC on the BV register are monitored and regularly provide the authorities with information concerning the stress history used for ultimate strength and fatigue damage accumulation. The process of rules loads calibration could be improved by the knowledge of actual sea state corresponding to stress and acceleration records. A period from May to August 1999 was selected for this study. The region of interest was a small area to the south of Nice where HSC trials normally take place (Figure 2.4). The aim was to use the available satellite data as input to hydrodynamic calculations and compare the statistics of resulting stresses and accelerations with those derived directly from measurements on the craft.

2.3.5 Development of a Theoretical Basis for Vessel Responses

This section briefly describes a study carried out at the University of L nd to support WP3000. Readers are referred to the full report, Baxenavi et al. (2000a).

The Problem

Let us consider a ship which is undertaking voyages over a certain relatively long period of time. The loads she experiences and consequently her responses to these loads are random and thus are best analysed by reliable statistical methods. Clearly, from the engineering point of view, it is most important to find an accurate approach to study the extreme events occurring during the period under investigation. The principal methodological challenge in this problem is that there are several different sources of random variability. They are directly related to temporal-spatial scale within which one considers the sea surface. Yet, conditions occurring on the sea surface are changing continuously in time and in space, and the randomness is different in different scales and thus different methods should be chosen depending on the scale. If necessary, calculations should be made at different scales, and the separate results then combined together.

Although much of the relevant theory has appeared previously in the literature, this is, as far as we know, the first attempt to establish a consistent methodological framework. We expect that this new framework will prove helpful for future advances in research on these topics.

General Description

We consider the following three different scale threshold levels. First, there is randomness related to short-time variability of the sea surface in time intervals measured in minutes or, at most, a few hours, and in a restricted region in which the weather conditions appear to be the same (Figure 2.5, top left). Another level of variability is due to the change of the sea states, as a consequence of changes of weather conditions occurring within several hours or even several days (Figure 2.5, top right). Local conditions may also be different to those in distant regions of the sea. Finally, there is a stochastic variability of different journeys which are undertaken at different times of year and possibly along different routes (e.g. Figure 2.5 bottom left and bottom right). Of course, these are only few of many possible factors and the complete analysis would be extremely complex, if possible at all. In these notes we focus on these factors which are most important for the statistical properties of extreme waves (or responses). However, the proposed methods can be also applied to studies of arbitrary, not only extreme, waves.

Applications and Present Methodology

In various practical problems, for example in safety considerations, it is important to determine the probability that the response - for instance the heave amplitude, or the acceleration at a given location of a ship, or the stress in a given member - exceeds some critical level over some time interval (one voyage, the duration of a storm, the lifetime of the vessel).

The conventional method is presently to oversimplify the problem, assuming that the random influencing variables are uncorrelated and of known simple distributions, and/or to use Monte Carlo type simulations of numerous potential histories for the time interval of interest, and accept the statistics of their results as a valid basis for the safety assessment.

New Developments

Satellite measurements provide data at time intervals such that the conventional method of history reconstruction cannot be used with them. Baxenavi et al., (2000a) sets the definitions and theory for methods that rely on parameters that may be estimated from the satellite measurements.

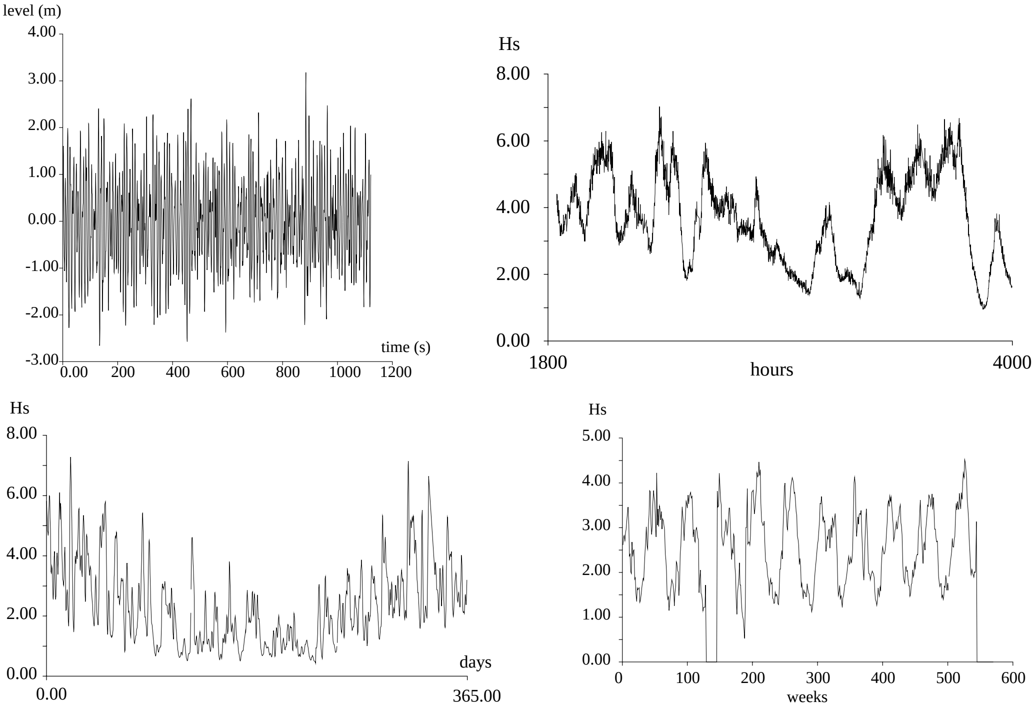


Figure 2.5 Wave height records over different periods. Top left : 17 minute record of a 4 m significant wave height (Hs) sea state. Top right one month record of Hs, Bottom left 1 year record of Hs, bottom right, 11 year record of Hs.

In Baxenavi et al., (2000a) a number concepts are defined and discussed:

Sea state and its duration; Route, as a time-indexed trajectory, and as an unknown variable apart from its end-points; Response Process, on the basis of a conditional Gaussian model.; Periods of stationarity.; Distributions of response and probabilities of exceedances; Crossing intensity and oscillations density functions.; Height of the crest of an oscillation; Distribution of rainflow cycles; Poisson approximation for the number and probability of exceedances; Connection of route segments; Estimation of probabilities.

Conclusions and Recommendations

The conclusions and recommendations coming from this theoretical study are summarised in Box 5.

Box 5: Conclusions and Recommendations from Baxenavi et al., 2000a.

The theoretical statistical bases have been established to allow analysis and estimation of response level exceedance and of rainflow damage accumulation experienced by a vessel.

Baxenavi at el., (2000a) raise many questions. The most important issues are the validation of the assumptions, and the practical estimation of the parameters used in the theoretical formulae. Such practical estimation should not be limited to satellite data, but should of course consider them as one of the potential sources of information.

Safety assessment needs to be understood in a stochastic manner. This is not yet current practice everywhere, but the models presented here are essentially stochastic, and they are a compelling stage in the process, all the more if satellite data are to be used.

Collaborative research actions should be able to shed light on the ways to solve the problem of extracting information on the time-histories of sea state processes from the almost instantaneous space lines of the orbital path.

2.3.6 A Statistical Analysis of Satellite Wave Data in the Mediterranean and the North Atlantic Ocean.

This section presents a summary of a second study carried out at the University of L nd to support WP3000. In this study satellite altimeter significant wave height and wave period data for the Mediterranean Sea (Rotterdam —Trieste) and North Atlantic Ocean (Rotterdam — Boston) were processed to create the data sets that were necessary to address the problem posed by Bureau Veritas. Again, readers are referred to the original report, Baxenavi et al., 2000b.

Statement of the Problem and Approach

This study addressed the design rules in shipbuilding. Conventional strength criteria for ships are based on a description of loads that is independent of actual ship service and corresponds to worst sea conditions expected over a period of 20 years. Knowledge of actual sea conditions would allow the demonstration of the capacity of a ship designed for a specific service.

A second topic is to investigate the possible spatial structure of the wave climate, in particular the dependence structure over extended areas, in order to make possible the estimation of the fail-safe properties of ocean crossings, and in particular to find the distribution of the worst wave conditions over a fixed period of time, typically 10-15 days.

The study was broken into two parts. A Mediterranean and Eastern Atlantic route Trieste-Rotterdam (Figure 2.1) was chosen for the design rules and a Northern Atlantic route Rotterdam-Boston (Figure 2.3) for the fail-safe part.

The two routes are not only different from a meteorological point of view, but they are also monitored by the satellite passages in quite two different ways. Much of the Trieste-Rotterdam route, in particular the Adriatic part near Trieste, lies rather close to the coast, and there are many missing or unreliable data. The Atlantic data are rather more reliable and stable. The parameters for the statistical distributions in the wave characteristics are of course different and vary along the routes, with small and regular variations in the Atlantic, and larger ones in the Mediterranean.

Applications and Present Methodology

Fatigue is one of the most important criteria in the design of ships. Estimation of the fatigue loading can be significantly improved if precise climate information, including seasonal trends, can be made available all along the route. The fail-safe condition would correspond for instance to avoidance of the risk that a crack in a LPG carrier, undetected at the inspection before sailing, would propagate to full ruin during a single, extremely severe, voyage of 10 to 15 days.

The conventional method, fatigue assessment by direct calculation, is based on the partitioning of the oceans in the areas of the Global Waves Statistics atlas (BMT, 1990), and on a combination of the corresponding Hs-Tz scatter diagrams with weights corresponding to the probability of presence of the ship in each area.

Due to the wide geographical extent of the areas, this method does not describe precisely the climate of routes, and the averaging of conditions over areas where strong climate gradients exist may lead to severe over- or under-estimation of the actual fatigue damage.

Moreover, the method is unable to provide any realistic estimation of the probability and the nature of the most severe conditions on a given route.

New Developments

Satellite altimeter measurements of significant wave height, Hs, give an opportunity to refine the estimation of the distribution of sea states, both in space and by season. In this study, TOPEX-Poseidon data provided by the SOS WAVSAT archives were used to this end. Time was separated between summer and winter months, and space in square bins of about 2 by 2 degrees. The following procedure was then applied:

- Reconstruction of missing values in each track
- Fit of a parametric (log-normal) distribution to the observations in each bin.

- Validation of the processing method.
- Parameterisation of the distributions with respect to the position on the route.
- Computation of overall damage distribution for voyages along that route.

Figure 2.6 provides representations of (winter) Hs data along the Rotterdam —Trieste route, as derived for this COMKISS study. The top two panels give the mean of log(Hs), and the 10% Hs quantile estimated directly from the satellite data. The bottom panel gives the 10% Hs quantile derived from a log-normal model generated from reconstructed data. The small difference between these latter two figures (not shown here) indicates that the model form is acceptable. In this form, these data are now suitably organised for fatigue calculations.

A different procedure was required for the consideration of the North Atlantic data, because the short term duration and geographical extent of storms was an important factor. Thus the altimeter Hs values were used to generate upcrossing statistics (e.g. the frequency with which a certain significant wave height threshold is crossed in a km). Figure 2.7 presents such data for the central section of the North Atlantic in winter.

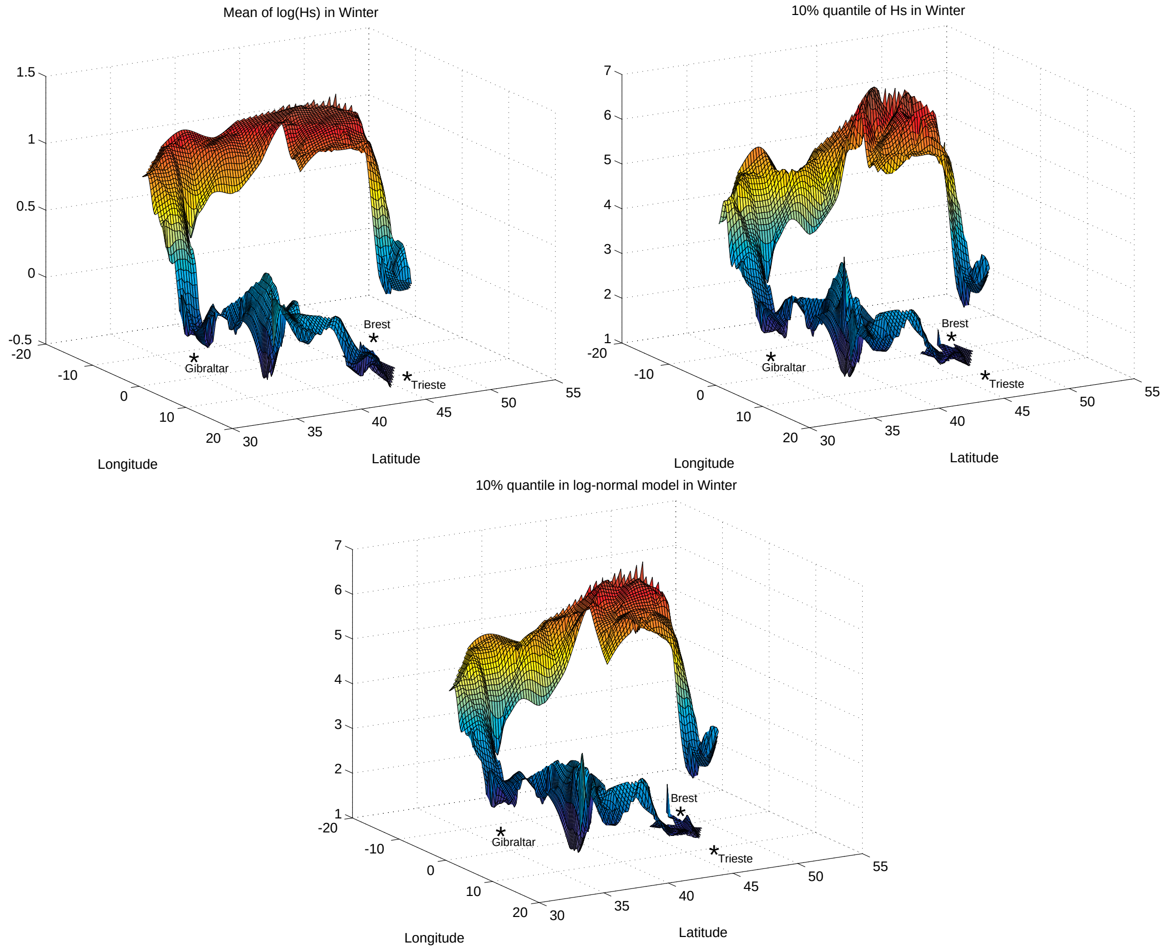


Figure 2.6 Analysis of satellite altimeter significant wave height data along the Rotterdam — Trieste route. Top left — Mean of log(Hs)for winter, Top Right- Estimated 10% Hs quantile for winter, Bottom —10% Hs quantile from a log-normal model generated from reconstructed data.

Analysis of the Example

This experiment was a good demonstration that the probability density function of Hs and Tz could be modelled along a given route, and the parameters of the model may be estimated from satellite data.

However, for a given voyage, the sea states that are encountered are correlated in a manner that cannot be straightforwardly estimated from satellite measurements. This is the reason for the definition of the problem described in section 2.3.5.

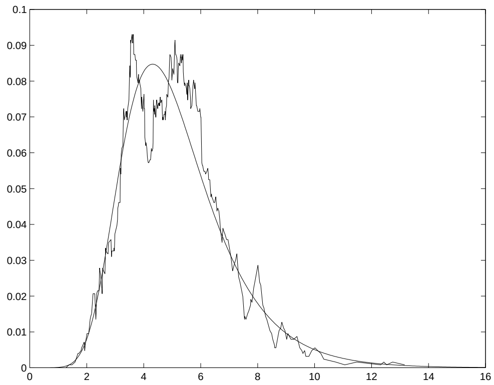


Figure 2.7 Probability of upcrossing a Hs threshold in winter, for the mid section of the Rotterdam — Boston route (North Atlantic). A Gumbel distribution has been fitted.

Conclusion and Recommendations

It is important for the user to recognise that fail safe conditions (and fatigue over a single voyage, for sea-fastening for instance) need to be understood in a stochastic manner. This condition is necessary because satellite data does not directly provide sea state histories that could be used for more deterministic approaches.

Based on this work, it was concluded that it should become possible in the future to consider the correlation of the sea-states that are encountered along a given route in a single voyage. Also, the service providers should soon be able to give directly height-period, or even damage distributions for a simple transfer model, for a given route instead of asking the user to combine local information.

Conclusions and recommendations are summarised in Box 6.

Box 6. Conclusions and recommendations from Baxenavi et al., 2000b

Conclusions:

- Joint probability density functions of wave height and period can be accurately estimated on a given route for a given season from satellite data.
- The estimation is robust, and provides a higher resolution than the climatological atlases.
- These pdfs can be transformed to the damage increment distributions that are of primary interest to design and risk assessment.

Recommended research actions:

- Provide a clear statement of the problem for the correlated conditions encountered in a single voyage.

4. Improve the model of the probability density function of the overall fatigue damage cumulated during one voyage along a given route.

2.3.7 WP3000 Results — End User Perspective

WP3100 Checking Design Criteria for Long Term Loads

From the satellite observations it was possible to obtain a useful and accurate description in space of the wave height statistic parameter. Unfortunately, unless design techniques are also altered, this improvement in the description of the wave amplitude cannot on its own provide an immediate improvement in the determination of the ship fatigue damage. This is because the stress equivalent level for fatigue damage estimation depends not only on the wave height, but also on ship (relative) heading, wave period and ship speed. The ship s speed and route are usually well defined and available for this study. However, the wave direction and periods were not available, and are essential for fatigue calculations as presently constructed.

WP3200 Fail Safe Calculations

Establishing a methodology

A storm model has been proposed to describe the sequence of sea states along the route of a ship. This model involves parameters that allow the user to adjust the intensity and the duration of the storm, and, if necessary, can allow an asymmetry between the periods of increasing intensity and decreasing intensity.

Can satellite observation provide adequate data?

The duration of a typical storm may be estimated as between 4 to 8 days. The mean interval of time between two consecutive satellite observations is close to 10 days. So, without recourse to other data sources (e.g. hindcasts), it was not possible to validate the statistical model of storm versus actual sea data.

Application to actual gas carrier

Due to the lack of information on the actual sequence of sea state conditions it has not been possible to determine a set of reference loading history that could be used to determine the worst case that a gas carrier could encounter on a period of 15 days. So, with present data density, satellite data cannot be used to carry out a fatigue calculation to establish fail safe conditions.

WP3300 Near Real Time

Over a 3 month period we have found very few satellite observations which coincided with the dates of sea trials. Only on 4 days during this time did the dates and locations of satellite data correspond to those of the HSC trials carried out in an area of the Mediterranean Sea between Nice and Corsica (Figure 2.4). Due to variability in the local sea conditions it is very difficult to extrapolate the satellite observation from one location to another, and the sea conditions vary quickly from an hour to another. At the end we identified only one case where the satellite track crossed the ship route within one hour. Thus, for similar reasons as before we cannot directly use the satellite observation to determine the stress and acceleration response of the HSC. However, we did have the opportunity to compare the satellite measured Hs with that recorded in the vessel Logbook. It was found that:

- The logbook indicated an Hs between 1.5 m to 2m when the satellite data indicated 1.3 m
- the logbook provides the wave direction whereas the satellite altimeter data do not.
- the logbook provides an estimate of wave period.
- The safnav which recorded the acceleration and stresses corresponding to the bending moment provides an indication of the period of the acceleration and bending moment.

The wave period was estimated from the ship s forward speed and heading. This provided an estimate for Tma in the range 4 to 7 seconds. Unfortunately, this range corresponds to a large variation of response of the ship in pitch acceleration and in bending moment. It was concluded that the calculation used in the dimensioning of the ship structure is probably conservative, as expected, but we were unable to measure the degree of overestimation of the loads on the ship.

2.3.8 WP3000 Potential Benefits

As the situation stands (regarding satellite data availability) no immediate real benefits may be expected from satellite observations unless there is a willingness to modify design procedures. If data coverage can be improved, i.e. if the ship could obtain continuous information in a localised area which provide an accurate representation of sailing conditions, then important benefits may be expected.

WP3100 Checking Design Criteria for Long Term Loads

Two aspects of this procedure may benefit from improved wave data provision. First, more accurate and reliable data could allow more economical designs by decreasing the uncertainty on the design loads. The second aspect has to do with inspection and maintenance planning.

Sea conditions can be quickly varying, particularly in coastal waters, according to the geographic position. A refined description of sea states involving the actual directional spectrum (i.e. wave energy density versus frequency and direction) representative of an area over a few square kilometres may help particularly in checking design rules and tools. This would in turn allow the calibration of the design criteria which were originally based on feedback from on board the vessel. This type of analysis would require a history of sea states in all areas covered by the ship during its lifetime.

Satellite data may be in competition with or may complement ship-borne monitoring and measurement recording. With knowledge of actual sea conditions experienced on voyage, a procedure involving hydrodynamic and structural calculations can generate an estimate of accumulated damage. This information, together with information from ship-borne stress transducers, may help the ship owners and classification society to schedule the inspection and/or maintenance of the ship, and establish the risk of delaying a scheduled visit if trading requirements make the disposability of the ship important.

It is clear that this possibility assumes that:

- The ship-owner could have available the wave spectral density versus the frequency and direction in a wavelength range between (at least) 10 m to 1000 m.
- That this spectrum be representative of actual sea conditions and not subjected to the errors that can occur in hindcast model output.

WP3200 Fail Safe Calculations

The project has demonstrated that up until now there has been no objective data to evaluate the worst load history on a ship on a period of time of 15 days .

It is clear that a raw Monte-Carlo process does not describe the actual loading process as it neglects the interactions between consecutive sea states. Also data sets based on historical ship records are not sufficiently reliable to provide anything other than a mean value .

This worst case information is necessary, from a statistical point of view, to allow the continuing operation of certain categories of ship. Also, an observation every 3 hours (full wave spectrum) could drastically improve the design of ship to allow survival after a first failure.

Clearly, an expectation of an accurate, measured, three hourly time series everywhere on any given ship route is unrealistic. Hindcast data provide one solution to this problem. Otherwise, the work of Baxenavi et al., 2000b suggests that the processes are stochastic, and provide a statistical basis for an alternative formulation of the problem.

WP3300 Near Real Time

The High Speed Craft can only operate under a specified limit of wave height. Currently the estimated wave height, which determines whether the craft will set out on its voyage, is based on specific analysis of a forecaster who provides the expected sea state over the next few hours. Due to a lack of direct information of the local conditions, the actual sea states encountered by a High Speed Craft navigating in narrow seas like Mediterranean Sea are rarely known precisely. If knowledge of the actual conditions can be acquired then a more accurate definition of acceptable limits of wave conditions may be derived, and safety factors could be more precisely specified. This would require a continuous knowledge of the local sea conditions or at least the knowledge of the sea conditions at the time and location where the ship is navigating. If this type of knowledge were available it might be possible to define ship specific allowable sea state conditions, which will depend upon wave height, direction and period, as well as shape and size of ship.

2.3.9 WP3000 End User Recommendations

Satellite wave data, as currently available, require improvements to be useful in ship structure design, as outlined below.

Type of Data

For ship design, a measurement of wave height is not sufficient. Calculation of loads are carried out from an assumed power spectrum of the wave versus frequency and direction. To be really applicable to ship design, satellite data should provide sufficient parameters to allow an estimation of the wave power spectrum over the full range of wave frequencies. There remains a question as to whether SAR wave spectra data are sufficiently accurate for this purpose (not tested within COMKISS).

Area described

In coastal navigation or closed seas the sea states depend significantly upon interaction with the nearby land topography. Information averaged over an area is not sufficient as:

- For ultimate strength the designer needs information on the worst sea condition, i.e. to decrease the uncertainty on the scatter of sea states encountered by the ship.
- Fatigue depends on the wave amplitude in a non-linear way. If a mean value is used in calculations, it may lead to an underestimate of the fatigue load on the ship.

- ***Frequency of observations***

To be effective, particularly with regard to the fail safe conditions and the near real-time requirements, data are required with a much higher spatial frequency. Certainly less than one day, and ideally every three hours.

Long term calculation

If ships are designed for world-wide operation, the designer needs only a sufficient number of observation to be representative of a mean operation condition, whilst allowing for an estimate the uncertainty around this mean mission profile . An important question is: Can the satellite observations be competitive with other type of observation for coastal navigation?

Fail safe

To be effective any data source should be able to provide information on the evolution of consecutive sea states. A typical storm duration may be about 4 days, and the typical persistence time of a given sea state may be estimated at around 3 hours. Therefore the designer should have information regarding the worst possible sequence of 3 hourly sea states during 15 days. This analysis is most relevant for deep sea navigation, and so precisely located information is probably not too important, although time regularity is very important.

Near Real Time

To be effective the satellite should be able to provide information at the immediate location and time where the ship may be sailing.

- ***Reliability of data***

The estimation of fatigue strength is very sensitive to the stress amplitude, which in turn depends upon the accuracy of the wave data. Within the COMKISS studies Bureau Veritas found some discrepancies between the satellite measurements and the logbook observations. Without a third reference source, one cannot be certain which data set provides the more accurate estimate of conditions.

2.4 WP4000 High Speed Passenger Craft

2.4.1 WP4100 HSC Requirement for Near Real Time Data

Introduction

A major problem in the management of High Speed Crafts (HSC) is their vulnerability to rough seas. In the operational case analysed for the COMKISS project (sea crossings between France, or Italy, and Corsica) we were advised that the HSCs operated by Corsica Ferries are able to sail in comfortable conditions for passengers in sea states with significant wave heights less than 4°metres. This limit was set in accordance with regulations from Certification Authorities and confirmed by Corsica Ferries experience.

Hence, the operational problem is to receive accurate advanced knowledge of sea states that will be encountered in future crossings. From a commercial perspective, the ferry company must be able to inform all its passengers with enough advance notice that the HSC crossing will not be possible because of weather conditions. When this is the case, passengers are transferred to conventional ferries. If the marine weather forecast underestimates the sea conditions, and if very rough seas are encountered, the ship will sail slowly, the journey will be uncomfortable and the passengers dissatisfied, with commercial consequences. On the contrary, if the weather forecast overestimates the conditions, the ferry company will cancel the HSC crossing, which in fact would have been possible; again having commercial consequences.

To face these problems, ferry companies are asking for an improvement in the weather forecasts, based on more reliable observations of sea conditions in the marine area where they operate. This requirement has been analysed in the COMKISS project with particular emphasis on the improvement that could result from a better application of satellite observations on a near real-time basis. The full Work Package report is provided as annex to this final report (Nerzic, 2000)

The analysis was based on Corsica Ferries 1999 summer season (May to September). The routes operated by Corsica Ferries are between Nice (France) and Bastia or Calvi (Corsica), and between Savona (Italy) and Bastia (see Figure 2.8).

Corsica Ferries provided the COMKISS project with data from marine weather forecasts prepared by M t o France and with ship observations during crossings that are summarized in figure 2.9. Satellite Observing Systems provided satellite data for the analyses.

During this period (May — Sept 1999), there were some occurrences of severeweather conditions, with winds up to Beaufort 7/8 and waves up to 4m (the local operational limit of HSC). In one occasion a severe storm was not accurately predicted, causing some trouble in Corsica Ferries operations.

Satellite Data and Weather Forecast

Satellite measurements of sea state and wind over the Corsica Ferries routes were used to assess sea conditions on selected occasions during its operating season. Unfortunately coverage of ERS-2 scatterometer (measuring wind fields) and SAR wave mode data (providing images of sea states) is poor in the Mediterranean, and no data were available in the Corsica region for summer 1999. This poor coverage follows partly from the fact that the ERS-2 SAR is often switched out of its wave and scatterometer modes over the Mediterranean. In any case, the numerous islands in the Mediterranean mean that even when the scatterometer is switched on, valid ocean returns are rarely received on all three of the scatterometer antennas. In the latter case further off-line processing is necessary to retrieve valid wind data, and although a scheme has been developed, these data were not available to COMKISS for 1999. SAR image data were not considered, because the COMKISS budget could not allow extra purchase of these data.

Thus only altimeter data have been extracted. Satellite Observing Systems has extracted wind speed and significant wave height data from ERS-2 and TOPEX, for the months of May to September, for all data within 40¡-45¡N, 6¡-12¡E (Carter, 1999). The ERS-2 data were retrieved from the fast delivery data streams, and so had not undergone any post processing by the designated processing facilities. This can mean that certain aspects of quality control were not carried out and some doubtful data may remain in the data stream. All satellite data were calibrated or corrected according to conversion formulas given in WP4000 final report (Nerzic, 2000).

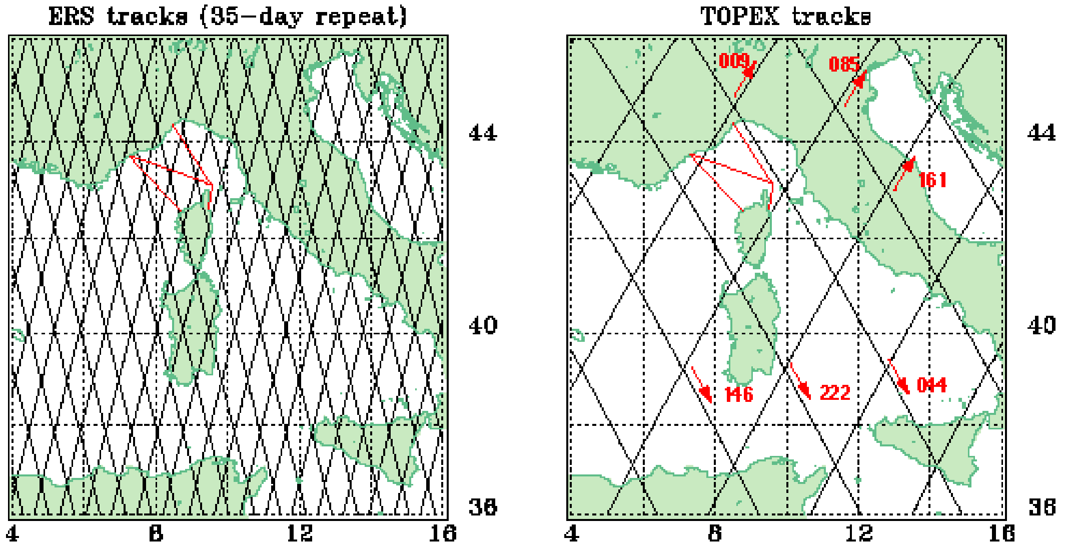


Figure 2.8 ERS-2 and TOPEX tracks (black lines) over Corsica Ferry routes (red lines): Nice to Calvi/Bastia, Savona to Bastia.

M t o France routinely provided weather forecasts to Corsica Ferries. Forecast data were derived from an analysis of meteorological conditions collected by M t o France and from the application of forecast / hindcast models. The meteorological conditions were collected in particular from the ECMWF atmospheric model and from meteorological stations along the Mediterranean coast. Also available were offshore data, such as the marine weather buoy deployed in deep water off Nice. The main models used by M t o France were a wind model for the European area (Arp ge) and a wave model for the Mediterranean Sea (VagMed). The data issued from the models were analysed further by meteorologists from the Aix-en-Provence office of M t o France and then dispatched to Corsica Ferries.

For operational purposes, and also to ensure safe sailing conditions, the company used the marine weather forecast dispatched in the morning (6H30) and in the afternoon (17H30). These very short time forecast data are the most useful data for routine operations. However when bad weather is predicted, with several days notice, the forecast information is of prime importance for planning purposes (for passages by HSC *and* conventional ships). Reports warning of severe weather conditions, occasionally issued by the meteorological office, are also essential for safety reasons; sometimes, bad weather can be predicted only a few hours before it develops in the Mediterranean Sea. In such case, a rapid dissemination of information to all ships in the affected area is essential.

In addition to weather forecast bulletins, Corsica Ferries also uses information from other sources, coastal land stations and other ships crossing in the area. Despite this, there remains a clear demand from HSC operators for more information on weather conditions on a near real-time basis, particularly when sea conditions are changing rapidly.

A summary of morning forecast data and observed weather conditions along the routes is presented in Figure 2.9. In the first analysis of weather forecasts for the Nice —Corsica area, a comparison between predicted and observed data was carried out. An initial overview suggested that predicted wind and wave conditions were generally consistent with ship observations. But a more detailed analysis indicated that during calm wind and wave conditions forecasts generally overestimated, while during severe conditions they sometimes slightly underestimated. This was verified by a regression analysis, which also showed a quite large scatter. The tendency of wave models to underestimate high waves, and overestimate low waves is known to be a common problem (e.g. Sterl et al., 1998).

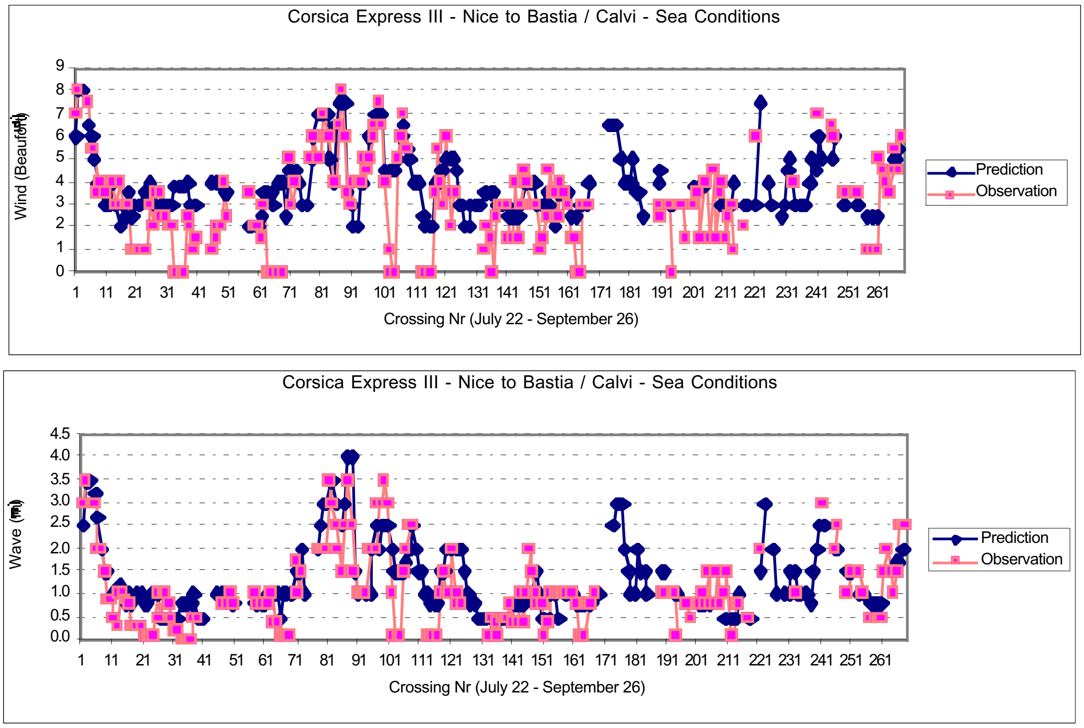


Figure 2.9 Weather forecast and observations on Nice - Corsica routes. Top —wind speed, Beaufort scale. Bottom significant wave height, Hs in m.

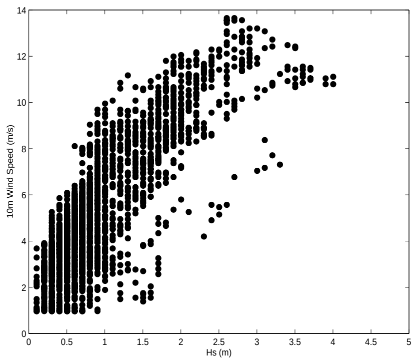


Figure 2.10 Wind — wave scatter diagram from satellite observations

In addition, a basic analysis of wind and wave conditions recorded from satellites in the Nice — Corsica area (cf. Figure 2.10.) indicated a generally good correlation between local wind and significant wave height. But the plot also showed some data that did not have the same properties as the rest of the data: see the data points with wind speeds between 4 and 8 m/s and significant wave height between 2.3 and 3.5m in the lower right of the figure.

Further analysis revealed that these data were recorded on May°21/22, when Corsica Ferries reported divergences between the weather forecast and actually observed marine conditions. The particular weather conditions during this period were investigated in greater detail and it was found that rather unusual weather conditions were experienced during this period, with strong wind gradients and rapid changes in meteorological conditions.

Potential Benefits and Recommendations

The analysis of wind and sea conditions experienced by Corsica Ferries on Nice-Corsica crossings during their 1999 operational season, in relation with weather forecast and with satellite observations, led to some useful conclusions regarding possible improvements of weather coverage for operations by High Speed Craft. It should be noted however that, considering the limited available information on sea condition forecasts, and the lack of in situ wave measurements, some conclusions should have to be confirmed with reference to data from other sources.

First, the analysis showed some limitations on the accuracy of weather forecast in this area of the Mediterranean Sea, where local conditions can influence weather and sea states, and rapid changes from mild to severe weather conditions can occur. This inadequacy is clearly connected to the limited number of observations and measurements of wind and sea conditions in the area, and to the quite low resolution of weather forecast models. These issues are particularly important when one considers the rapid and local changes of weather in the area.

However, the input of satellite observations is too limited at present to contribute to improvements in weather forecast performance. This is because satellite coverage is too sparse, with measurements (for altimeter data) limited to narrow tracks. However, if satellite coverage was widely extended, and if satellite data were transmitted to weather forecast offices in near real-time, this would certainly result in significant improvement in local weather analyses.

Also, if satellite coverage was significantly extended, and if wind and sea observations were transmitted to HSC operators in near real-time, this would give the operators complementary information to aid in decision making with regard to HSC crossings in critical situations, for instance for decisions of whether or not to cancel crossings.

Box 7 summarises the HSC requirements for near real-time data

Box 7. High Speed Craft requirements for near real-time data

More data on actual wind and sea conditions in their operational area.

More reliable weather forecasts.

A network that would dispatch all available information (land and ship observations, coastal and open sea measurements, satellite observations, weather forecast) on a near real-time basis.

2.4.2 WP4200 HSC Performance Related to Wave Conditions

Introduction

Another important aspect of the operation of High Speed Crafts, with respect to metocean conditions, is their behaviour in rough seas. To understand and predict their behaviour, we must satisfy two requirements, to have a detailed characterisation of sea states and an accurate model of ship response to sea conditions. The main objectives of the analysis of HSC performance are to improve the safety of HSC, from a refined characterisation of sea states and to control ship behaviour with respect to passenger comfort.

As pointed out in section 2.4.1, the main sources for sea state characterisation are hindcast models and satellite observations, in addition to in situ measurements which are available only at few locations.

In the COMKISS project, the HSC performance was investigated in relation to satellite data and available hindcast data, based from the lessons drawn from Corsica Ferries experience in the operation of Nice —Corsica routes. Other maritime areas where HSC are operating (English Channel / Manche, Irish Sea, Baltic) have been considered also in the investigation, with the objective of taking account of the sensitivity of HSC performance against different climatologies.

HSC Response to Sea Conditions

The main HSC response parameters that have to be considered for the study of HSC behaviour at sea can be summarized in three categories as follows:

- Accelerations in the 6 degrees of freedom (heave, pitch, roll, sway, surge, yaw), that are of main importance for passenger comfort. Because of the particular behaviour of HSC at sea, compared to conventional ships, these parameters have to be analysed very carefully.

- Ship motions in the same 6 degrees of freedom, which are particularly important for ship manoeuvrability.
- Strains in all structural parts, that are of prime importance to ensure its structural strength.

These parameters are studied and calculated by naval architects and engineers, on the basis of specified local sea conditions in the area of operation, and in relation to the specified HSC performance (operational speed, etc.) These studies then lead to the analysis of operational limits, taking account of passenger comfort and ship behaviour. In the Nice-Corsica area, the limit was set to Hs°=°4m.

For these studies, the following information was requested:

- *Metocean conditions in the area of operation*

Statistics and extreme values of the following metocean parameters over the whole area are needed: wind speed and direction; current speed and direction; tide (when relevant); directional wave spectra.

Among these parameters, the most important are those related to wave conditions, which are of prime importance with respect to accelerations, motions and strains. In general, there are few data on directional wave spectra, and wave data are usually limited to statistics of significant wave height, associated wave period and wave direction,

When available, more detailed wave characteristics such as wave spectral shape, directional spreading and information on crossed seas are also of importance for refined engineering studies.

- *Information on High Speed Craft Performance.*

In particular, information on HSC operational speed and maximum speed, and vessel heading together with relative wave direction, are required.

Specific metocean analyses of HSC maritime routes are necessary in general, and are of particular importance when sea conditions are variable along the route. This is often the case for HSC routes because of local effects near coasts. In the specific case of Nice-Corsica route, there are at least three different areas, one close to Nice which experiences land influences, another in open sea (the area known as Balagne) and a third one near Cap Corse, with specific sea conditions related to the local relief. Detailed analysis of sea conditions along Nice-Corsica route, as well as other HSC routes, would require detailed wind and wave data that were not available. Consequently, only large scale sea conditions from satellite observations were considered.

Climatology Statistics for HSC Performance Studies

Wind speed, significant wave height and period (Davies et al., 1997) can be derived from altimeter data for sea climatology of any maritime area. Other parameters (directional and spectral data) have to be acquired from other satellite instruments such as wind scatterometer and SAR wave mode, from wind and wave hindcast models, or from site measurements.

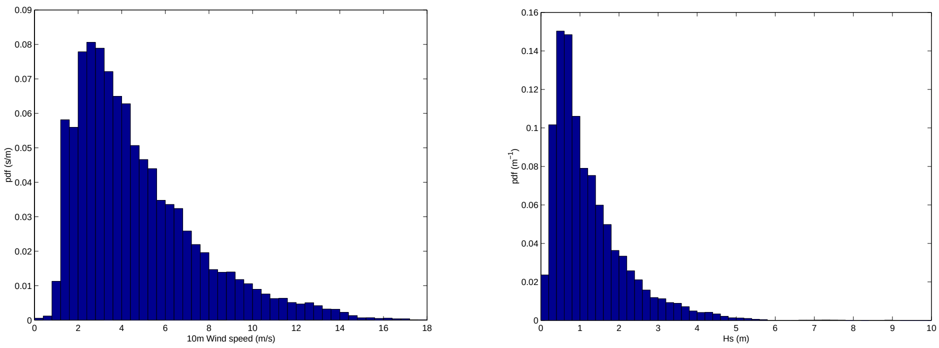


Figure 2.11 Histograms of wind speed and significant wave height from altimeter data

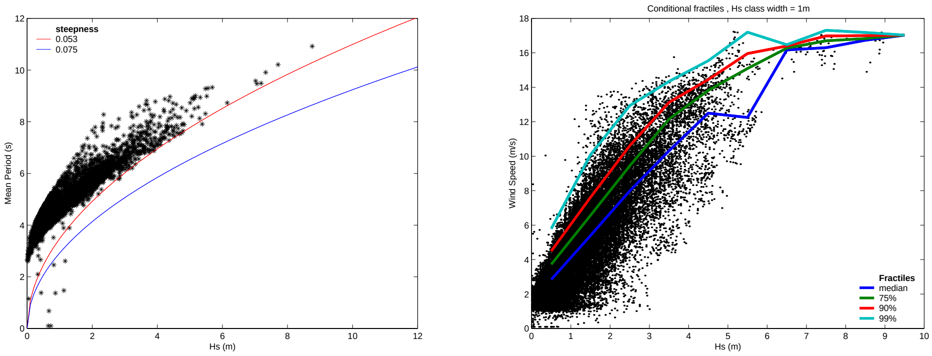


Figure 2.12 Scatter diagrams of significant wave height and wind speed / mean wave period in Nice-Corsica area, from satellite altimeter data

For the Nice-Corsica routes, only altimeter data were available. For the present study, the TOPEX and Poseidon altimeter significant wave height (Hs) wind speed (U10) data, together with an estimate of zero upcrossing wave period (Tz) have been extracted from archived data. Data, covering the period October 1992 to December 1998, have been extracted within the region 40¡-45¡N and 6¡-12¡E. The data are presented in Figures 2.11 (raw histograms of U10 and Hs) and 2.12 (scatter diagram of Hs-Tm in relation with 2 steepness curves, and diagrams of Hs-U10, with conditional fractiles).

The satellite data characterize the local climatology in terms of wind speed, significant wave height and mean wave period, with their correlations. A main advantage of satellite data is that they now cover a relatively long period (over 10 years), which is of evident interest from a statistical point of view, providing information about the interannual variability of wind and sea conditions. However, it must be considered that because satellite coverage is infrequent, peak storm conditions are often not observed and, therefore, wind and sea statistics may not adequately represent these severe conditions.

In addition, it has to be considered that statistics of altimeter data are prepared generally for large maritime areas which would normally be expected to have somewhat different climatologies. In particular, wave conditions are significantly different in open seas and in coastal areas. Also there is evidence that the altimeter may underestimate wind speed (by up to 30%) in semi-enclosed and enclosed seas (Cotton 1999a and 1999b). Therefore, satellite observations must be carefully analysed before an accurate climatology can be derived.

Hindcast data provide an alternative or a complementary source, because hindcast models can produce long time series of wind and sea parameters over large areas. However, although we were able to collect wind fields from ECMWF for COMKISS , we could not easily (and inexpensively) gain equivalent access to wave fields. This indicates that it is not easy to build a local wind and sea climatology from hindcast data for HSC performance studies.

However, there is no difficulty in deriving the wind and sea parameters, mentioned above as required for modelling HSC performance, from hindcast results. This is because hindcast models are able to produce wind speed and direction parameters as well as directional wave spectra parameters over any maritime area. In addition, tide and current parameters can also be computed from models.

But, beside the availability of hindcast data from suppliers, there are also some limitations in the use of hindcast data for HSC performance studies. The wind fields from ECMWF for the Nice-Corsica area have a grid size of 1.125¡ x 1.125¡, and a time step of 6 hours. This grid scale is too coarse to represent the spatial variations and rapid changes of wind and sea conditions that are known to occur in the area. In addition, hindcast models also have some limitations, particularly when used in semi-enclosed or in enclosed seas. This is because the physics involved in the meteorological and oceanographic phenomena are very complex. A recommendation from COMKISS is to use available observations to calibrate and validate hindcast models.

A third source of wind and sea data are surface observations, in three categories:

- observations from land stations,
- ship observations
- site measurements, on land and coastal stations or from buoys.

Land and ship observations are very useful for maritime operation management, because they can be dispatched very rapidly. Such systems are used routinely by HSC operators for decision making.

However, for the purpose of climatological statistics, the accuracy of the visual observations is not, in general, good. Therefore, the observations used for climatological studies are often limited to meteorological measurements from land stations and to wave measurements from wave buoys.

When available, local measurements are of prime importance. Even if they do represent only a local climatology, and even if the duration of site measurements is often limited to a few years, they are the most reliable information. Therefore, when they are used to calibrate or validate other sources such as satellite observations or hindcast data, they contribute to improvements in their reliability.

When climatological statistics are available over an operational area, as a minimum requirement the following statistical data are necessary:

- monthly directional distributions of wind speed (U10) over the area,
- monthly directional distributions of significant wave height (Hs) over the area,
- joint distributions of significant wave height and peak energy period (Hs-Tp),
- typical directional wave spectra, if available.

Then, the HSC performance can be analysed, on a monthly basis if necessary, in relation to operational limits on acceleration, motion or strain. In particular, for instance, this can result in estimates of stand-by duration for bad weather conditions, on a monthly basis.

Potential Benefits and Recommendations

Because HSC are highly sensitive to rough sea conditions, with respect to ship behaviour and hence passenger comfort (of prime consideration), it is of major importance to evaluate their performance in any maritime area where they may operate.

HSC are much more sensitive to sea conditions than conventional ships, which are able to operate safely in rougher seas. HSC behaviour is more sensitive to certain wave properties, such as wave length, directional spreading, crossed seas, all of which must be considered in relation to the HSC heading relative to wave direction. Therefore, for safety reasons and for operational reasons (for example for stand-by estimates), precise local climatology statistics are necessary to estimate HSC performance with accuracy.

From the analysis carried out in COMKISS project, we conclude that the use of hindcast data and satellite observations, validated with site measurements when available, would allow for the development of adequate climatological statistics for HSC performance analyses. There are some remaining limitations that could be overcome with refined hindcast models, with more satellite observations and with more site measurements.

2.5 WP5000 Transportation of Unusual Loads

Dockwise are experts in the trans-ocean transport of unconventional loads (cranes, offshore deck modules, giant hulls, etc.). Their operations can be slow moving and often involve very large loads, so they are more sensitive than conventional shipping operations to adverse sea state conditions and local surface currents. Reliable, accurate, and up to date information is therefore a necessity, for economic and safety reasons. For COMKISS WP5000 we considered three applications of satellite data:

- The need for accurate wave climate databases to ensure reliable design and planning of sensitive operations.
- The need for reliably accurate real-time wave information and the best possible forecast to aid operational decisions.
- The possible use of satellite data to provide regular updates on ocean surface currents.

Applications studies were carried out in each of these three areas and are discussed in separate sections below.

2.5.1 WP5100 Satellite Data Applied to Design Methods for Marine Operations

Introduction

The design of marine transport and offshore installations requires the input of accurate wave and wind conditions, which have to be extracted from an appropriate climate database. Since 1854, visual observations of commercial ships have been collected and compiled into databases. Recent developments, through hindcasts on one hand, and satellite measurements on the other hand, have led to significantly improved climatologies. This market sector perhaps represents the most successful commercial exploitation of satellite sea state data to date, with climate products available from a number of sources.

The various available wave climate databases are significantly different in presentation, and sometimes in contents. The WP5100 study considered the use of GWS (empirically corrected ship observations), IMDSS (hindcast) and ClioSat and WAVSAT (both derived from satellite measurements) databases for design of voyages on the major shipping routes of the world. The aim was to provide recommendations for the best strategy for those who want to use them. Readers are referred to the full report, Leenaars et al, (2000) for more detail.

In the rest of this section 2.5.1, we present an overview of Design Methods , as applied by ocean transporters such as Dockwise, and then we present and compare four different wave climate databases using a software tool known as VAC (Voyage Acceleration Climate). This comparison was carried out by Dockwise, with some support from IFREMER. Finally we present conclusions from the user (Dockwise) perspective.

Design Methods Overview

Heavy lift ocean transports and offshore operations require detailed calculations to design a transport or offshore installation. Realistic values for the loads, which work on both vessel and cargo, have to be determined.

In the chain of design three aspects have to be modelled:

- The wind & wave climate on the route.
- The vessel response to the wind and wave climate.
- The weather avoiding actions by crew .

The vessel behaviour can be modelled by tank-test or numerical calculations. The environmental parameters which the vessel is likely to meet during the voyage are retrieved from databases.

Traditional design methods choose a certain *design wave* (height and period) from the area with the worst environment. Nowadays a more detailed description of the environmental parameters is required since clients want to know the risk and exposure involved in such an operation and would like to analyse possible damage due to fatigue.

The vessel s crew always try to avoid adverse conditions. Thus bad weather areas are avoided, and in case the vessel behaviour exceeds certain criteria, measures are taken to minimise the motions. However, this type of avoidance behaviour is not implicitly incorporated in today s design methods.

The following design methods procedures are in common use:

The “Rule of Thumb”

For many years, classification societies have used very simple formulae to determine accelerations on board, irrespective of the design sea conditions. These formulae make use of characteristic rolling and pitching extreme angles associated with the ship’s natural periods to obtain accelerations at the specified locations on board the ship. The advantages of this method are its simplicity, and its ability to deliver results quickly. However, ships responses to actual sea state conditions are not modelled.

Design Wave Methods

The design wave method takes into account the wave climate, in the sense that a single design wave is determined for the entire voyage. This could be the extreme value for the worst area, or the extreme value for a complete route by combining scatter diagrams, and may have a return period of 1 or more trips or years ([perhaps up to 10). Again this technique is relatively simple to apply, and results can be obtained quickly, without the need of significant computing power. However a number of important aspects are not modelled (exposure to wave climate, the probability of occurrence of the design wave height, the response of the vessel to different wave periods). Also, questions regarding fatigue, risk and exposure cannot be answered.

Reliability based design methods

Reliability based methods are much more comprehensive and take into account all consequences of different wave climates at each stage along the planned route. The extreme response of the vessel to arbitrary storms is modelled, the probability of occurrence of severe storms is modelled, the capability of construction and sea-fastenings are tested, and the probability of structural failure is established. These techniques are very thorough, but can be very computer intensive and time consuming. Two different methodologies, Voyage Acceleration Climate (VAC) and Monte Carlo Simulation (MCS) are discussed below:

Voyage Acceleration Climate (VAC). (Aalbers and Leenaars, 1987, and Quadvlieg et al., 1998)

The Voyage Acceleration Climate (VAC) response method models the distribution of all sea states during a trip. A distribution is computed by weighting the distribution of each climatological area along the route by the time spent in that area. A complete response distribution is then computed, which is then used for the design with respect to reliability objectives or fatigue. This technique gives a very full assessment for most aspects of voyage risk, (possibility of fatigue, environmental damage), however it is only able to approximate bad weather avoidance, and the use of weather windows . Further the effect of swell is not separately calculated

Monte Carlo Simulation (MCS).

In this method, a full historical database of measured (or simulated) wind and waves conditions is used. A date of departure is drawn at random in the history for the season of interest, and the voyage is simulated in 12 hours steps, including decisions of routing and bad weather avoidance. For each sea state, the response of the ship is calculated. Gathering the results for all random selections, a good estimate of the response distribution is obtained. This is possibly the most thorough method of all —allowing the simulation of bad weather avoidance and use of weather windows. The main disadvantage is that it can be very time consuming and computer intensive.

Description of Wave Climate Databases

Visual observations of winds and waves by commercial ships have been archived for a century and a half, and became systematic following a resolution of the WMO in 1961. The most well-known compilations of these observations are the OWS (Ocean Wave Statistics, Hogben & Lumb, 1967) and the more recent Global Wave Statistics (GWS, Dacunha and Hogben, 1989) which empirically corrects for biases that were identified in the earlier OWS. The main advantages of GWS°/ OWS are the length of the collection period and their suitability to shipping applications, because they incorporate the effect of bad weather avoidance and are well-documented for the major shipping routes. The main drawbacks are the lack of information outside the main routes, the poor accuracy for wave periods (poorly estimated even by experienced observers), the lack of wind information, and some deficiencies in seasonal representation and in reporting extremes.

Hindcasts compute wave heights from historical wind databases. The computer codes which simulate the physical wave processes have reached a good level of maturity, but errors and uncertainties in the input wind fields are amplified by this process, as wave heights are roughly proportional to the square of the wind speed. The quality of the results is thus often impaired by the lack of accuracy or of validation of the wind data, especially for regions where few observations are available, such as in most of the southern hemisphere. The main advantages of hindcasts are that they provide world-wide, long-duration histories of waves. The main drawbacks are that they are proprietary and costly, that they depend on the personal skills of the analysts who verified and corrected the wind fields, and that they have limited accuracy in extreme conditions. However, it should be noted that the availability of satellite scatterometer measurements of winds during the last decade has significantly improved the accuracy of the wind field. Cotton et al., (2000) compare three types of wave climatology: one derived from visually observed ship data, one from a 15 year hindcast and one from satellite altimeter data. They show that the visually observed data tend to overestimate low waves and underestimate high waves, as do the hindcast model output (though to a lesser extent). Interestingly, they also found that the hindcast and visually observed climatologies show different patterns of long term trends in the North Atlantic. The altimeter data do not, as yet, provide a long enough time series to consider decadal patterns of variability.

In comparison to conventional databases, satellite information brings in the advantages of better quality°and accuracy, especially in areas where there are few reliable field measurements to calibrate hindcast models. They can also provide a more detailed characterisation of sea conditions (directional spectra, sea surface temperature), and complete global coverage (for instance GWS provides no coverage in the seas off West Africa). The drawbacks result from the difficulties in finding automatic quality control methods that can both process the huge amounts of available data, and yet intelligently eliminate non-ocean effects such as rainfall. Also the length of record, though now over 10 years, is still too short to take into account long-term variability or decadal trends. In addition, sampling is an issue as satellites may under-sample small and fast moving storms such as tropical cyclones. Finally, it is not possible to reconstruct histories for use in Monte Carlo simulations because of the sparseness of the time-space sampling.

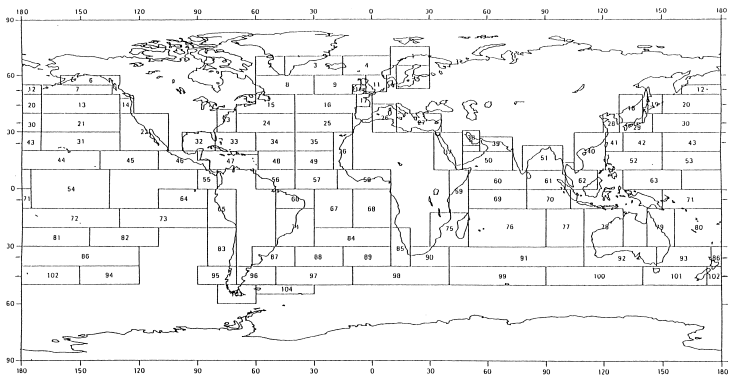


Figure 2.13. The Global Wave Statistics data grid.

Four databases were used in WP5100:

Global Wave Statistics – GWS (Dacunha and Hogben, 1989):

This database is derived from empirically corrected ship visual observations. The GWS global atlas is divided into 104 Marsden squares (Figure 2.13). For each square (four) seasonal and (eight) directional scatter diagrams are available. The GWS data base has some known defects, but is popular and still widely used. In particular GWS contains no wind data, and has poor coverage in the Southern Hemisphere. Further, the database grid squares are very large, and so cannot allow for local variability, and the data base may be biased against bad weather (which the ships providing the data naturally tend to avoid).

IMDSS (Integrated Marine Decision Support System) – OceanWeather.

The IMDSS database is derived from a global wave model hindcast output, generated from a 40 years re-analysis wind field. For the IMDSS global climatology, the grid is 2.5¡ x 2.5¡. Directional wave spectra are available, represented by 12 parameters. Each gridpoint has 45 normalised scatter diagrams, under 5 time categories (long time average, four three-month seasons) and 9 directions. For other purposes all the forecast data are also separately archived and available (useful for Monte Carlo simulations).

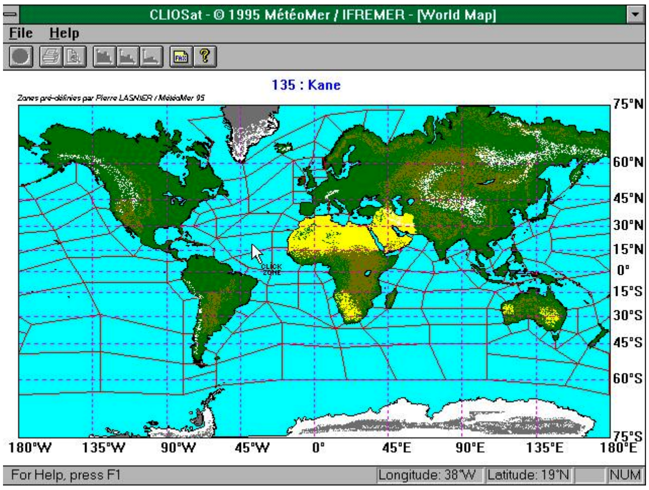


Figure 2.14 The Cliosat global data base

Cliosat - Meteomer.

The Cliosat database is derived from satellite altimeter measurements (wave height and wind speed), SAR measurements (swell wave period, height and direction), and scatterometer wind speed and direction data. The global data base is divided into 169 so-called climatologically consistent regions (Figure 2.14). Seasonally divided scatter diagrams of directional wave data are available for each region.

WAVSAT – Satellite Observing Systems

The WAVSAT data base is designed for detailed regional studies and is not ideally configured for easy access for global scale calculations. WAVSAT contains a geographically ordered archive (in 2¡ x 2¡ squares) of rigorously quality controlled and calibrated satellite altimeter wind speed and significant wave height data, at the original measurement resolution (1 measurement per second, representing 5-10 km average along track). Thus, although the data base contains a higher level of detail, more preparation is required to extract data along a given ship route, and WAVSAT data were only included in comparisons for one of the fourteen routes in the study (route A, Dover to Gibraltar). Cooper (1997) assessed the WAVSAT and GWS databases for tows in SE Asia.

Other satellite derived sea state climatologies are available from OCEANOR (Norway), and ARGOSS (The Netherlands).

Comparison of Wave Climate Databases

GWS, IMDSS, Cliosat on 14 Northern Hemisphere Routes

Fourteen major world shipping routes were selected for the comparison (Table 2.2). The SOS WAVSAT database was only considered for Route A (Dover- Gibraltar). All the selected routes were northern hemisphere routes, and it could be argued that this will favour databases relying on in situ observations (OWS, GWS) and possibly hindcast derived databases (IMDSS) as the input wind data to these are preferably distributed in the northern hemisphere. In contrast, satellite data are evenly distributed across the all regions (north and south hemispheres) and these data should be equally accurate everywhere.

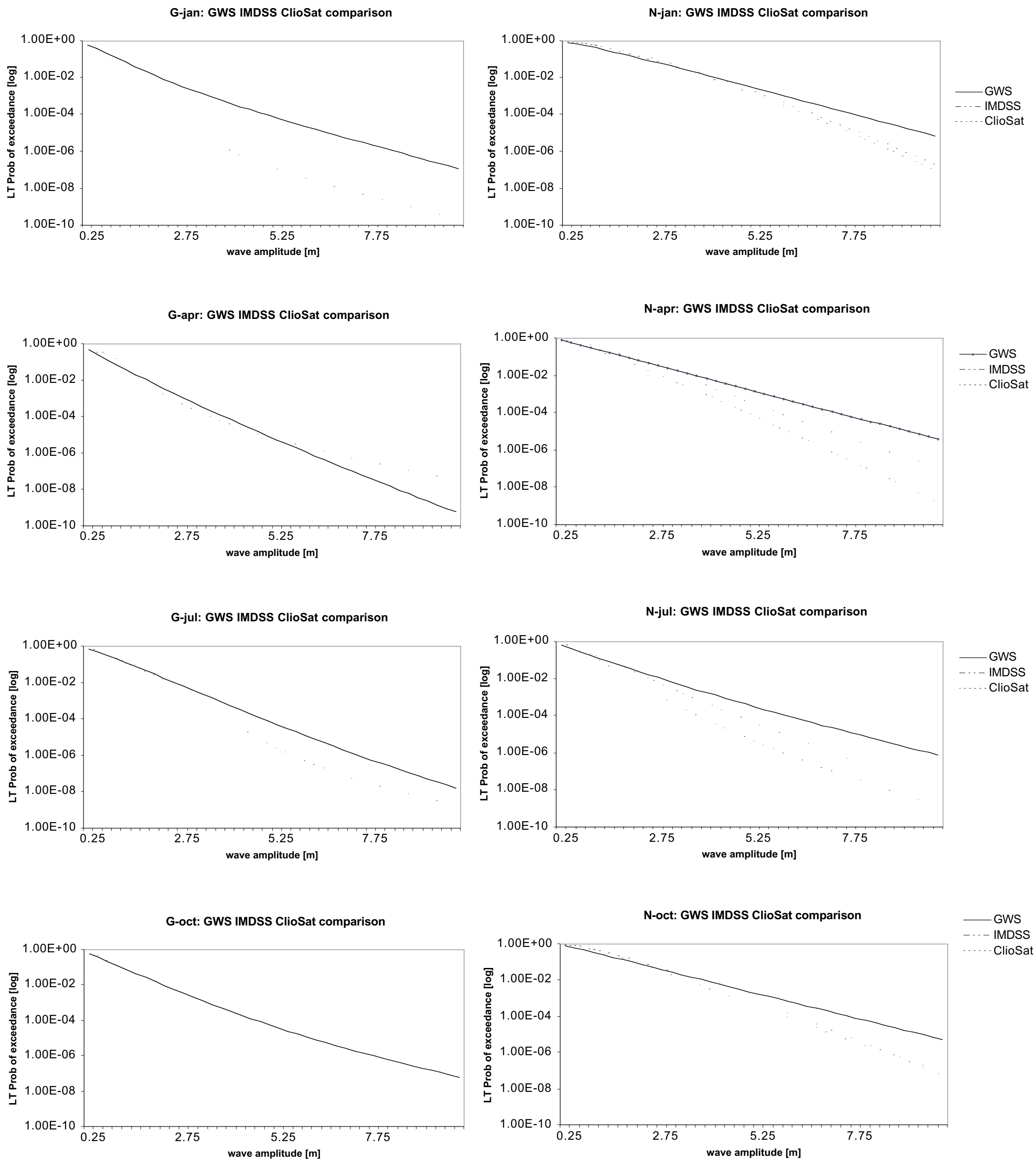


Figure 2.15 Exceedance probability charts derived from VAC from the GWS, IMDSS and Cliosat databases, for two routes: Colombo to Singapore (left —route G) and Hiroshima to San Francisco (right —route N). The probabilities have been calculated separately for each of four three-month seasons (the nominal start month is indicated).

The VAC package was used to calculate a range of wave amplitude probabilities for each grid square along the selected route, and then these probabilities were integrated along the route, weighted according to the elapsed time the vessel spent in each grid square. This procedure was carried out for each of four seasons. Figure 2.15 shows the VAC output expressed as a probability of exceedance of maximum wave amplitude on voyage, Ha. For route G (Colombo to Singapore) we can observe that GWS consistently gives higher probabilities of larger waves. It is also apparent that there are significant divergences between the results from the three databases. GWS and IMDSS agree better in the seasons beginning an April and July (central two left-hand panels of Figure 2.15), but IMDSS and Cliosat agree better in the seasons beginning in January and October (top and bottom panels, left-hand side of Figure 2.15).

	route	departure	arrival
A	English Channel — Gibraltar	Dover	Gibraltar
B	Gulf of Mexico — Gibraltar	New Orleans	Gibraltar
C	Gibraltar — Port Said	Gibraltar	Port Said
D	Suez — Aden	Suez	Aden
E	Aden — Arabian Gulf	Aden	Muscat
F	Arabian Gulf — Colombo	Muscat	Colombo
G	Colombo — Singapore	Colombo	Singapore
H	Singapore — Taiwan	Singapore	Kaoshiung
I	Taiwan — Japan	Kaoshiung	Hiroshima
J	North Sea	Dover	Stavanger (NO)
K	North Atlantic Ocean	Halifax (US)	Newcastle (UK)
L	Japan — Arabian Gulf	Hiroshima	Muscat
M	Germany —Arabian Gulf	Hamburg	Muscat
N	North Pacific Ocean	Hiroshima	San Francisco

Table 2.2 The fourteen routes over which the wave climate databases were compared in COMKISS WP5100.

Route	GWS Ha	IMDSS Ha	ClioSat Ha	GWS Hs	IMDSS Hs	ClioSat Hs	GWS 1yr Hs	IMDSS 1y Hs	Cliosat 1yr Hs
A	9.75	7.22	7.8	8.3	6.7	7.1	13.3	9.2	9.7
B	9.68	7.8	6.7	8.7	7.4	6.3	11.8	9.3	7.7
C	8.65	5.39	5.7	6.4	4.6	5.1	11.4	7.2	7.5
D	5.57	3.87	3.6	4.1	2.3	3.1	7.6	5.4	4.4
E	4.76	3.04	3.4	3.4	2.6	2.9	6.5	4.4	4.4
F	4.76	2.95	3.0	3.6	2.7	2.4	6.3	4.2	3.9
G	6.31	3.15	2.6	4.8	3.3	2.2	8.5	5.1	3.1
H	8.15	6.01	4.7	6.4	6.3	4.2	10.7	8.5	6.0
I	8.27	4.95	4.9	6.4	4.6	4.0	11.4	6.0	6.5
J	8.67	5.75	6.4	5.7	5.3	5.1	13.3	8.5	9.2
K	10.19	8.49	9.4	9.4	8.5	8.2	12.9	10.6	11.1
L	8.83	5.88	4.9	7.1	5.6	4.2	10.3	7.3	5.6
M	10.33	7.46	8.0	8.5	6.1	6.6	12.3	8.4	8.8
N	10.16	8.34	8.1	9.4	8.2	7.7	12.4	9.7	9.1

Table 2.3 Summary of VAC results for the GWS, IMDSS and ClioSat climatologies for the winter season. Ha: most probable maximum wave amplitude on voyage; Hs: most probable maximum Hs on voyage; 1yr Hs: 1 yr return value of Hs (winter data only) on route).

Route	GWS Ha	IMDSS Ha	ClioSat Ha	GWS Hs	IMDSS Hs	ClioSat Hs	GWS 1yr Hs	IMDSS 1y Hs	Cliosat 1yr Hs
A	6.76	4.41	5.1	5.2	4.3	4.5	9.2	7.3	6.5
B	7.12	4.63	4.7	5.8	4.6	4.5	8.6	6.5	5.8
C	5.40	3.29	4.4	3.9	2.4	3.9	7.1	4.6	5.8
D	4.60	2.73	3.3	3.3	1.8	2.7	6.0	3.4	4.1
E	8.59	5.15	5.4	6.7	4.8	4.7	11.7	6.6	6.6
F	8.53	5.87	5.5	7.0	6.0	5.2	11.2	7.9	6.6
G	5.88	4.55	4.0	5.1	4.9	3.6	8.0	7.0	4.7
H	7.32	5.66	4.1	5.0	4.5	3.3	9.6	8.1	5.1
I	8.41	6.19	5.2	5.6	5.2	4.4	11.8	8.8	7.4
J	6.25	3.64	4.7	3.7	2.7	3.8	9.4	5.4	6.8
K	8.06	5.03	6.0	6.8	4.9	5.7	10.3	6.7	7.5
L	9.19	6.44	5.7	7.6	6.4	5.2	10.7	8.5	6.5
M	8.83	5.37	5.7	6.9	4.8	5.0	10.1	6.8	6.3
N	8.44	5.21	6.4	7.0	5.3	6.0	10.2	6.9	7.7

Table 2.4 Summary of VAC results for the GWS, IMDSS and ClioSat climatologies for the summer season. Ha —Most probable maximum wave amplitude on voyage; Hs - Most probable maximum Hs on voyage; 1yr Hs —1 yr return value of Hs (summer data only) on route).

It is thought that these differences may occur because the seasons as represented in the databases actually contain different months. The GWS data base is altered so the seasons coincide with the expected monsoon seasons. The results agree better for route N (Hiroshima to San Francisco), although GWS still provides higher expectations of larger waves. The Cliosat and IMDSS databases agree particularly well for the winter half of the year (seasons beginning in January and October (top and bottom panels, right-hand side of Figure 2.15).

Tables 2.3 and 2.4 summarise the comparison results for all fourteen routes for the winter and summer seasons respectively.

These tables confirm that some aspects of our observations for routes G and N hold true for most of the other routes. Thus, GWS is found to give a higher probability of bigger waves on every route. By and large, IMDSS and Cliosat agree fairly well, though there are exceptions (for instance route G during the months April to September). Figure 2.16 is a scatter plot of Cliosat against IMDSS Ha as calculated for each route and season. This confirms that, on average, there is no large bias between these two data sets. Exceedance probability diagrams and tabulated results for all routes are available in Leenaars et al., (2000).

GWS, IMDSS, Cliosat and Wavsat: Route A, Dover to Gibraltar

An extra comparison using the VAC package was carried out for the Dover to Gibraltar route, this time including data from the SOS Wavsat database (including an experimental wave period parameter derived from the altimeter measurements). Figure 2.17 show the VAC results for January to March (for GWS, IMDSS, Cliosat and Wavsat). Again GWS gives the highest probability of bigger waves, SOS-Wavsat gives the lowest, although the difference between Wavsat (marked SOS), IMDSS and Cliosat is small. These results are fairly representative for the whole year, though Cliosat gives the lowest waves for the season starting in April (Figure 2.18, left panel). The right hand panel of Figure 2.18 gives the annual average wave period. The experiment altimeter wave period (SOS) seems slightly low with respect to GWS, IMDSS and Cliosat, which are otherwise in quite good agreement. The reader is again referred to Leenaars et al., (2000) for full details.

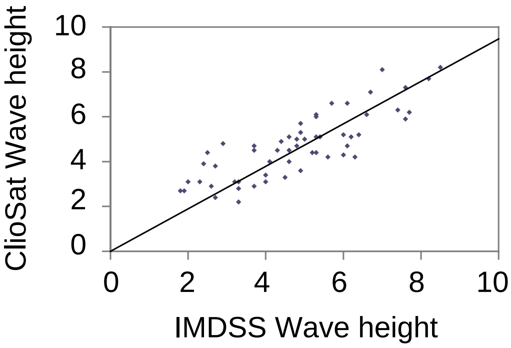


Figure 2.16 Scatter plot of Ha (maximum probable wave amplitude on voyage), as calculated from the Cliosat and IMDSS databases. 56 data points —one for each of four seasons on each of fourteen routes.

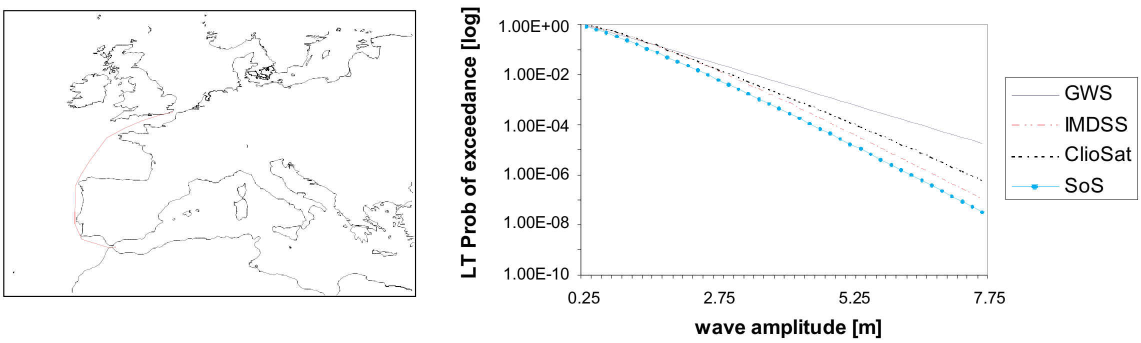
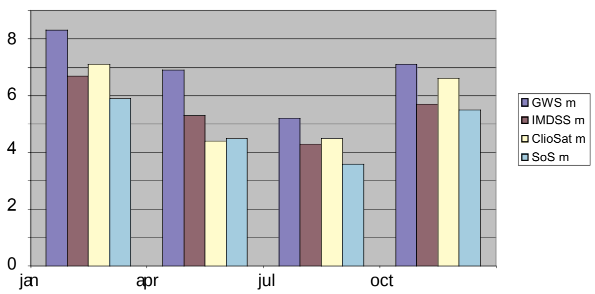


Figure 2.17 VAC output (as Log probability of exceedance for Ha) for the GWS, IMDSS, Cliosat and SOS (Wavsat) databases for the Dover to Gibraltar shipping route (left panel).



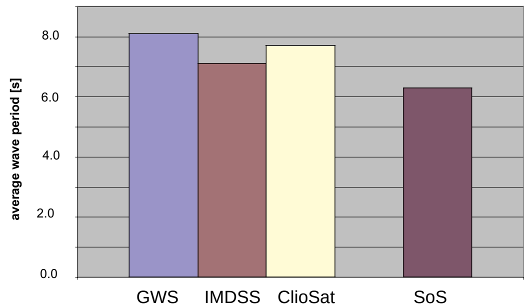


Figure 2.18. Histograms of VAC output for the Dover to Gibraltar route. Left - 2.18 Hs (for one voyage) for GWS, IMDSS, Cliosat and SOS (Wavsat) databases for the Dover to Gibraltar shipping route (left panel).

Conclusions of the wave database comparison

The GWS database consistently gives higher waves (by about 30%), than the IMDSS and ClioSat (and SOS-Wavsat) databases, which are normally in good agreement.

Areas affected by cyclones give different results for IMDSS and Cliosat. This is probably because the databases cover relatively short time periods and may contain different numbers of such events. This anomaly should diminish as databases cover longer periods of time. Differences were noted between databases because of different representation of the monsoon season (i.e. different months were included).

The input data used in the GWS database covers a longer period than the IMDSS and Cliosat, and so should have a better representation of cyclones. ClioSat can provide more information (wind force and direction, directional wave spectra) which could be used in design methods.

Box 8 lists the recommendations following from the database comparison.

Box 8. Recommendations following the comparison of wave climate databases.

For further research

- Determine how to provide "best estimates" of climatologies, blending the various sources of data.
- Refine seasonal discretisation to suit local phenomena such as monsoons.

To making the data more accessible:

- Building statistics along a route should be made a much more straightforward task.
- There is still a need to increase confidence in terms of the quality control and reliability assessment of satellite data.

However, it is noted that the continued collection of satellite data will automatically increase the reliability of climatological databases.

2.5.2 WP5200 On Board Decision Support System

Introduction

Tow-outs of large structures, deck matings, laying of submarine telecommunication cables or of pipelines have to be carried out offshore in all the oceans of the world. The ships and barges dedicated to this type of operation have operational limits, usually about 4 to 5 m Hs. Advance notice of, say, six hours, in case of worsening of the sea conditions allows time for a smooth shut down of the operation, enabling a quick resumption when the weather improves. If the vessel is taken unprepared, the end of the cable or of the pipe has to be dropped in such a manner that the restart will be lengthy and costly. Of course, decisions based on false alarms may also prove very costly.

The problem is thus to increase, at low cost, the reliability of the forecast information that is available on-board for making decisions in case of sea conditions close to the operational limits. The regularly available weather forecasts have a number of shortcomings:

- On most occasions the forecast is accurate, however when differences are found between the forecast and available observations, these differences do not appear to be processed into the next issues of forecasts. Thus, a local update / improvement of the forecast must be judged onboard.
- The forecasts do not provide detailed information for the exact position, date and time of the vessel.

An onboard decision support system could predict the motion behaviour of a vessel, based upon the following input information :

- A dedicated weather forecast.
- Real-time measured ship motions.
- Measured wind/wave conditions and visual observations
- Satellite observations can widen the area of measured wave climate around the vessel and thus give an early warning for adverse conditions which might not be reflected in the weather forecast.

In 1998, with CEO/JRC support, Satellite Observing Systems carried out a Product Marketing and Development study for a Sea State Alarm Service (contract 14036-1998-06 F1PC ISP GB), see Jolly, (1999). This project finished in January 1999. Under COMKISS, further SSA trials were carried out on a Dockwise vessel.

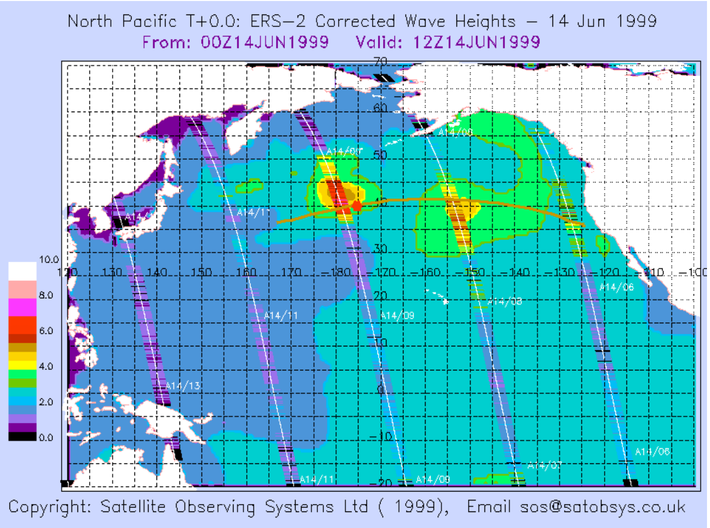
Review of Dockwise Express 20 Sea state alarm trial

Background

During May 1999 to July 1999 a Sea State Alarm (SSA) trial was conducted onboard a sub-sea telephone cable installation vessel on a project from San Francisco towards Guam in the Northern Pacific. Cable laying is an unconventional procedure which is limited by seastate and cannot deviate from its intended track.

The vessel, Dockwise Express 20 (Figure 2.19), was equipped to receive dedicated forecasts as well as the public forecasts broadcast via the regular nautical frequencies. Operations such as cable laying are usually supported by extensive weather forecast provision: weather fax, NAVTEX, SAT-C broadcasts, and also dedicated forecasts from an international forecast provider. Most of these forecasts are available on a 6 hourly basis. It should be noted that regular weather services like Navtex, weather telex via SATCOM-C, weather fax, are free of charge, and that it is compulsory to have all the necessary equipment on board. Dedicated weather services cost a few hundred Euros per week, **excluding communications costs**. A SATCOM-A, B or mini-M may be necessary, and not all vessels are equipped to receive internet e-mail.

Figure 2.19 The Dockwise Cable Laying Vessel, Dock Express 20.



SSA Warning 12Z 12.6.99

Data just received from the satellite indicate that the forecast is seriously in error regarding the storm just to the NE of your location.

Forecast wave heights of around 5.0m are actually approaching 7.0m

Summary from 09Z 12.6.99
(average over 75km intervals beneath the satellite)

(White, ascending track on image)

Time(Z)	Long	Lat	Wind	Wave
09:19:22	-169.99	41.73	17.68	4.67
09:19:37	-170.30	42.65	18.16	5.62
09:19:41	-170.39	42.88	18.65	6.58
09:19:51	-170.59	43.46	18.74	6.92
09:20:08	-170.94	44.43	16.90	6.48
09:20:15	-171.11	44.89	15.44	5.50
09:20:28	-171.39	45.63	13.89	4.74

Figure 2.20. Sea state alarm image for 14 June 1999, and email text warning issued 2 days earlier. A significant discrepancy (underestimate) between wave model and satellite measured significant wave height can be seen at 40¡N, 170¡W, close to the vessel s location (indicated by red dot). The continuous brown line indicates the great circle cable route.

Methodology

The objectives of the trial were to test the usefulness of the SSA service, and to collect suggestions and improvements from user feedback. During the trial the vessel received (by email) a twice daily map of the area of interest with the 12h forecasted wave heights and the measured wave height received from satellites. This was presented in a clear colour, graphical format, file size was about 44 Kbytes. In addition, e-mail warnings were sent when wave heights in excess of specified limits were detected, to give the ship s master early warning.

Figure 2.20 shows the image e-mailed to Dockwise Express 20 on 14 June 1999, together with an earlier e-mail which warned of nearby severe conditions. The storm to the NE of the ship’s location on 12.6.99 had already passed the ship by, and the corresponding warning was thus not sufficiently timely to change any decision on board. Had it reached the ship earlier, the warning of 14.6.99 would have fully demonstrated the value of the satellite data correction to the forecast. However, because of the time and distance separating satellite measurements, and of the procedure requiring the ship s officers to poll a mailbox in order to retrieve the map, the crew were already fully aware of the actual wave heights when they retrieved the satellite corrections. However, this experience does highlight the potential value of such a system, should it be possible to improve data coverage and delivery time.

From a consideration of the charts transmitted throughout the voyage, it was apparent that the wave model seemed to underestimate high wave heights, and overestimate calmer sea-states, a model tendency which has been reported before (Sterl et al., 1998, and Cotton et al., 2000).

This experiment was thus a good demonstration of the validity of the principles used, and provided a strong encouragement to act upon the practical defects in an operational follow-up.

Conclusions

A detailed assessment of the trials was provided by the Dockwise officers and shore based staff, in discussion with the service providers, Satellite Observing Systems. The conclusions were encouraging (Box 9), and led Dockwise to suggest the COMKIAS proposal, discussed later. We should also note that further SSA trials (outside COMKISS) have been carried out by STASCO in the North Atlantic, the Indian Ocean and the China Seas. STASCO formed similar positive conclusions, which are covered by those outlined in Box 9.

Box 9. User assessment of Sea State Alarm Trials

Data were considered correct, measurements close to vessel position were accurate.

Graphical presentation is clear, the best option is to cover a large area of interest.

No operational decisions were made on basis of SSA data. This conclusion is based on the fact that route deviations are not possible.

SSA warnings should be sent by FAX as soon as they are available; vessel s officers can then call up the image data.

Data were used to confirm other weather forecasts.

The wave model (forecast) was seen to overestimate the lower sea states and under estimate higher sea states. Discrepancies of over 2m were recorded, which were apparently not corrected in succeeding forecasts. Therefore the wave forecast was often neglected and other forecasts used instead.

SSA gave early warning to unpredicted adverse weather conditions.

Size of data ~44 KB was considered reasonable, especially when compared to the international forecast provider's data (200 - 270 KB).

The Galaxy Singapore-Halifax Voyage

From August to October 1998 a transport of a jack-up drilling rig took place from Singapore to Halifax (Canada). Due to the very long, fully erected, with 200 m high legs, the voyage could not use the Suez Canal and had to sail via the Cape of Good Hope. In addition, accurate sea state information and forecasts were of special importance. For this voyage the Galaxy was equipped with a motion measurement box and a bow wave radar. Signals from the bow radar were corrected for local bow motions which were derived from the motion measurement box.

As part of WP5200, and after the completion of the voyage, satellite data within 500 km of the ship s track were compared to on-board measurements. The intention was to establish whether satellite data could contribute to onboard decisions and to post-voyage analyses.

There were nine occasions when the satellite passes were close to the vessel s position. When the significant wave height was 3-4 m the on-board and satellite measurements compared well. Above that level the onboard measurements were higher than satellite measurements. It is thought that this was caused by a wrong correction on the measured (onboard) wave height signal with relation to the ship s motion. Such an error would be highly dependent upon ship type and loading conditions. The experience of this analysis confirms that all wave height measurements need careful treatment. However, it was again clear that the lack of a dense satellite ground path is a major drawback when using satellite data for analyses.

WP 5200 Conclusions and Recommendations for Further Actions

A number of research actions, and operational improvements were recommended, Box 10.

Box 10. WP5200 Recommendations

Provide a single, consistent map by blending ship and satellite data into predictions.

Extend application from open sea to nearshore and to closed seas.

Include measured wind speed/direction and wave direction/period.

Subdivide wave data into sea and swell if feasible.

Increase satellite density, in order that warnings are timely. - Launch of constellations of satellites, as proposed in the GANDER (Jolly et al., 2000, Zheng, 1999), or PLEIADES (see www links) projects.

Establish better transmission schemes from land to ship.

It is important to note that ship owners will not pay separately for services which they see as being overlapping. Thus the SSA service does not, as it stands, represent a replacement for the regular forecast services. However, it is suggested that other segments of the marine industry could strongly benefit from such services. In addition to the cable- and pipe-laying applications, a service such as SSA would be relevant to oceanographic campaigns, where submersibles or instruments are operated from an oceanographic vessel, to salvage operations for wrecks, or to offloading from offshore oil production facilities. In general, any operation where a limit is set on operability with respect to sea state and where it is undesirable or impossible to sail away, can benefit from such a service, improving the reliability of the forecasts of wave heights, wind speeds, or ship responses.

2.5.3 WP5300 - Detection of Surface Currents

Introduction

Slow moving transports, and stationary offshore operations involving floating platforms with connected deep water systems can be severely affected by ocean surface currents. Satellite measurements offer the potential capability of providing near real-time current information which could improve operational safety and contribute to significant savings of time (and hence fuel) on trans-oceanic routes. Accurate forecasts of ocean surface currents would find useful applications in: unconventional transports at sea, sensitive offshore operations, sailboat racing, boat deliveries, and offshore fishing.

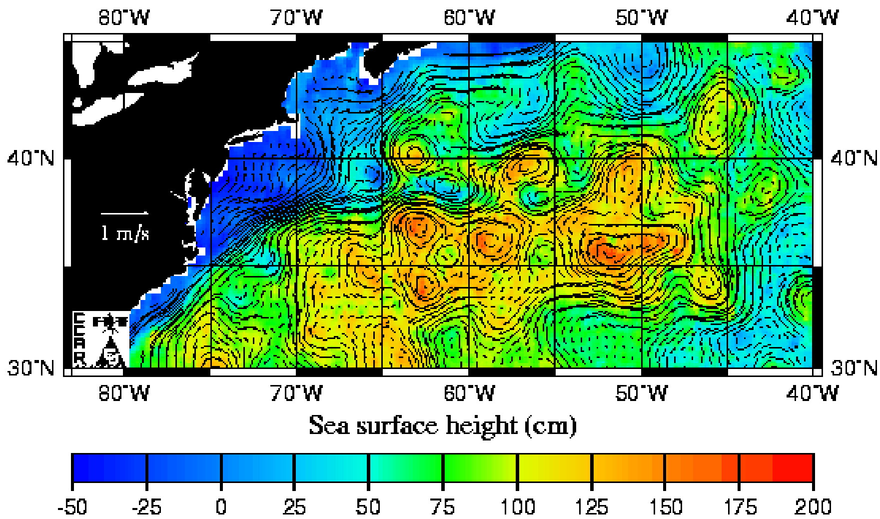
The purpose of this work package (WP5300) was to establish the present state of the art in the use of satellite data to monitor surface currents, to identify those systems which seem to offer the best opportunity for development into an operational system, and to establish the steps necessary to achieve such an operational system.

It seems that the priorities of the academic organisations who have developed the methodologies presented here have been to investigate transport (of heat, energy, salinity) and circulation on a time averaged basis. Thus operational knowledge of short term variability (time scales of less than a month) may not be regarded as important as the longer term picture, except perhaps to establish the scales and general nature of short term variability. The need that COMKISS is investigating is a very different one. The requirement in principle is for accurate, short term, information on the location of strong surface currents so that vessels can be routed to avoid or take advantage of them. However, the structure of surface ocean currents is rarely simple. The strongest currents contain loops and whirls and routinely spin off eddies. The relevant time and space scales depend very much on the variability of the current —thus the best solution is most likely to be an intelligent system which would input the (predicted) current structure of the region to be traversed and then work out the optimum route. Figure 2.21 provides a graphic example of the problem for the Gulf Stream / North Atlantic Drift. If data were presented in this form to a ship s master he/she would find it very difficult to decide how to act upon it. However, an intelligent ship routing system should be able to calculate an optimum route.

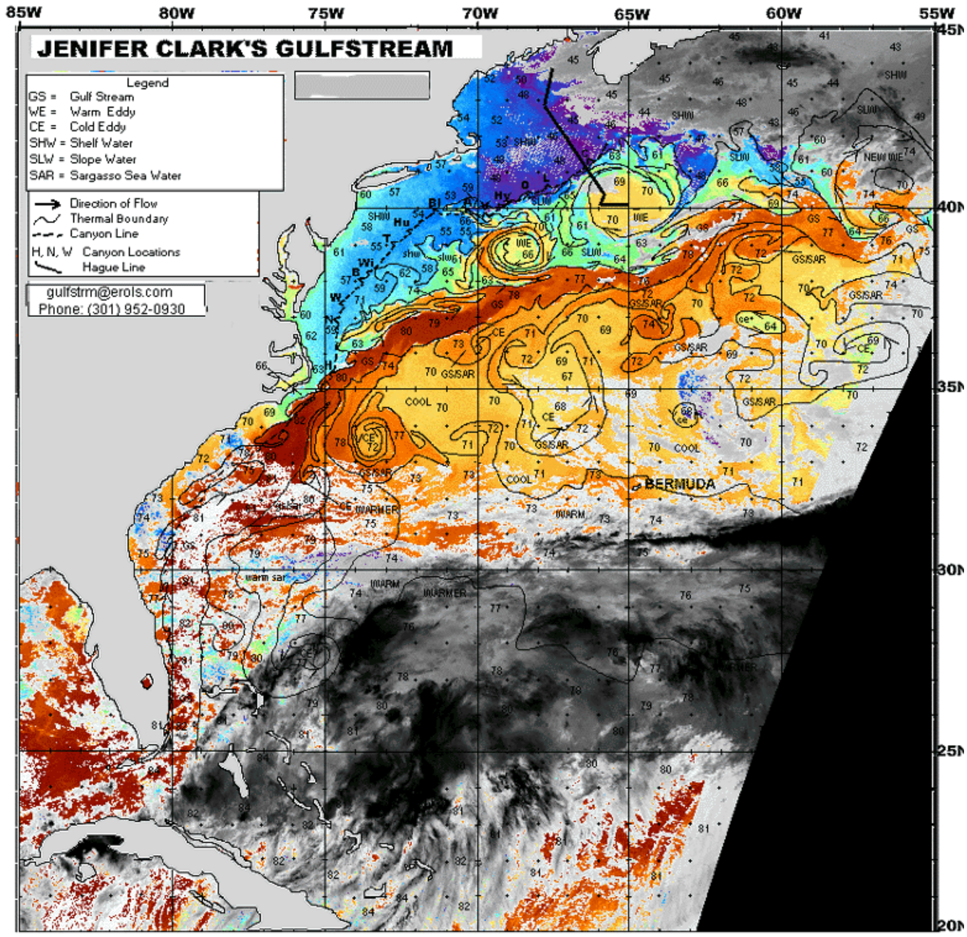
Satellite Sources of Surface Current Information

There are number of data sources from which near real-time surface current information of potential use for routing purposes can be derived. The main options are:

- **Satellite altimeter sea surface height**: Provides derived (geostrophic) surface current magnitude and direction information. Figure 2.21 provides an example of a sea surface height anomaly field from CCAR (Center for Astrodynamics Research, University of Colorado), from which current variability can be inferred.
- **Satellite radar backscatter measurements (altimeter, scatterometer, SAR)**: Can indicate the location of boundaries of current systems.
- **Satellite radiometer sea surface temperature and ocean colour data**: Can provide proxy "tracer" information of surface current systems. This technique needs hto be supported by an *a priori* knowledge of the current patterns.



- **Figure 2.21 Sea surface height anomaly (from long term mean) from satellite altimeter data (TOPEX and ERS-2) for a 10 day period starting 16/08/1999.**



The sample chart above of the Entire Gulfstream depicts:

- **Gulf Stream (GS) in brown and dark orange**
- **Warm Eddy (WE) in yellow and orange**
- **Cold Eddy (CE) in green and yellow**
- **Continental Shelf Water (SHW) in blue**
- **Continental Slope Water (SLW) in green**
- **Clouds are black**

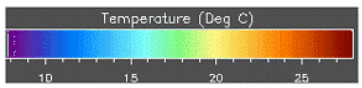


Figure 2.22 An example chart of the Gulf Stream off the eastern US coast, from "Jenifer Clark s Gulf Stream" service (JCG)

- **Scatterometer wind vectors**: Used to derive wind driven circulation (Ekman drift).
- **Large scale, or local, ocean circulation models**: Requiring assimilation of satellite height data (see the first option).

State of the Art - Commercial and Academic Current Prediction Systems - Presently Available

OceanRoutes is a major ship routing company with offices around the world. We understand that its ship routing system uses satellite data to provide twice weekly updates in highly dynamic regions (Gulf Stream, Kuroshio). These updates are added to background currents which are derived from monthly climatologies. In addition, wind driven currents in storms are addressed in ship speed down calculations .Another, specialised, commercial system which makes use of satellite information is "Jenifer Clark's Gulfstream" (hereafter JCG). See Figure 2.22 for an example chart. The service was initially established for ocean yacht racing, but has found customers in other markets (ocean tows, tankers) who have reported useful accuracy. JCG makes use of Sea Surface Temperature (SST) and Sea Surface Height (SSH) analyses (Figure 2.21) which are freely available on US academic web sites.

Lagerloef et al., (1999), describe a technique which combines geostrophic velocities derived from altimeter sea surface height data and Ekman drift velocities derived from scatterometer wind fields.

The French MERCATOR project (Dandin et al., 1999) has ambitious aims to implement a high resolution global ocean circulation model, which will assimilate satellite and in situ data, and aims to be operational within the next year or so. Results from the *Clipper* prototype are however leaving many potential users sceptical that the desired definition and accuracy can be achieved, and hence doubtful whether these models can be used for purposes outside their main aim of medium and long-term climate modelling.

From Stennis Space Centre, the US military runs an experimental Real Time North Pacific Ocean nowcast/Forecast system, based on a 0.25¡ resolution circulation model, with assimilation of altimeter and AVHRR sea surface temperature data.

Case study

Within COMKISS we wished to compare a satellite derived near real-time data set with a multi-year climatology, so that we could investigate the potential added commercial benefits offered by near real-time data. The North Indian Ocean was selected for this study, in particular the shipping route from Aden to Singapore. This study comprised two parts, a validation of the near real-time data set against a climatology and drifting buoy data, and a trial ship routing exercise.

The "near real-time" data set (hereafter referred to as "ESR") was provided by Dr Lagerloef, of Earth and Space Research, Seattle, and the climatological data set (referred to as "RSMAS") by Dr. Mariano of the Rosenstiel School of Marine and Atmospheric Science, Miami (Mariano et al., 1995). The ESR data set was provided as a series of 1¡ x 1¡ gridded data sets, each covering ten days (covering the period May 1998 to May 1999). The RSMAS climatology, derived from ship drift information, was provided on a 1¡ x 1¡ grid as climatological monthly averages. In addition, drifting buoy data were downloaded from the USA PODAAC web site, to enable a comparison with some directly measured data. Coverage of this data set within a specified time period is limited, but this comparison did provide some useful indications of accuracy.

Results of Data Comparison

The climatology and real-time data set both showed the expected seasonal current features related to the NE Monsoon (December - March) and the SW Monsoon (June —September). During the NE Monsoon, there is the westward North Equatorial Current between the equator and 8¡N, with an eastward flowing equatorial counter-current to the south (between 0¡ and 8¡ S), and another westward flowing current, the South Equatorial current south of this (between 8¡S and 25¡S). During the SW monsoon the flow to the north of the equator is reversed such that almost the entire flow north of 8¡S is eastward (see figure 2.23).

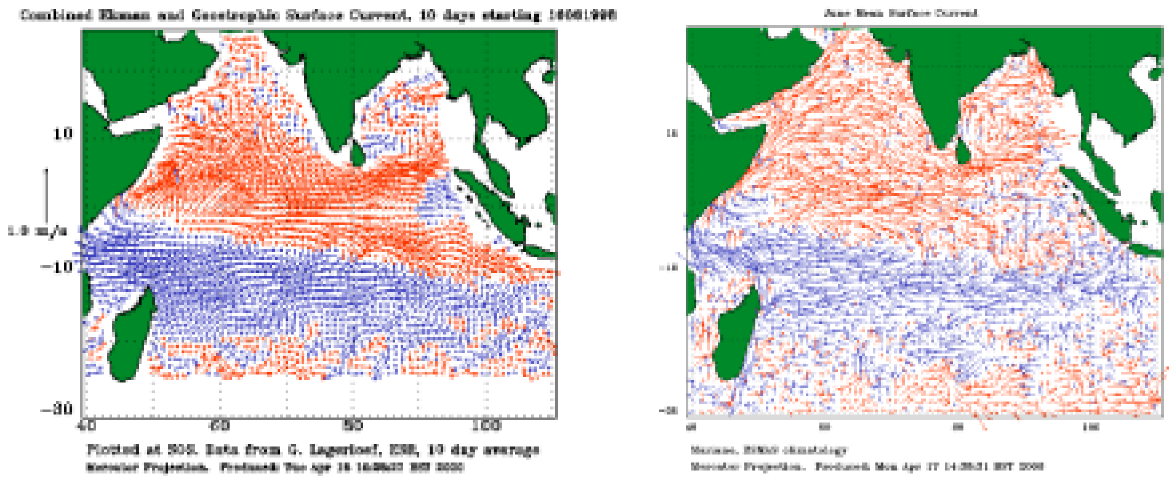


Figure 2.23 ESR (left) and RSMAS (right) surface current data for June; Red arrows indicate eastward flowing currents, blue arrows indicate westward flow

However, whilst there are clear similarities, there are also evident differences between the two data sets.

- In general, the current speeds in the RSMAS data are much larger than those in the ESR data. However, the size of this bias is not consistent between various regions within the Indian Ocean.
- The RSMAS data are noisier in both speed and direction.
- The ESR near real-time data are able to represent transient, but strong, current features, which the long term climatology cannot. See for instance the eddy off the coast of Somalia (0.0¡N, 50¡E) in Figure 2.25.

We then compared the ESR data with the drifting buoy data (Figure 2.24). From this, and other comparisons it became clear that although the ESR data gave a good representation of the directions of surface currents, it underestimated speeds significantly, in some cases giving current speeds only half of those found in the drift data.

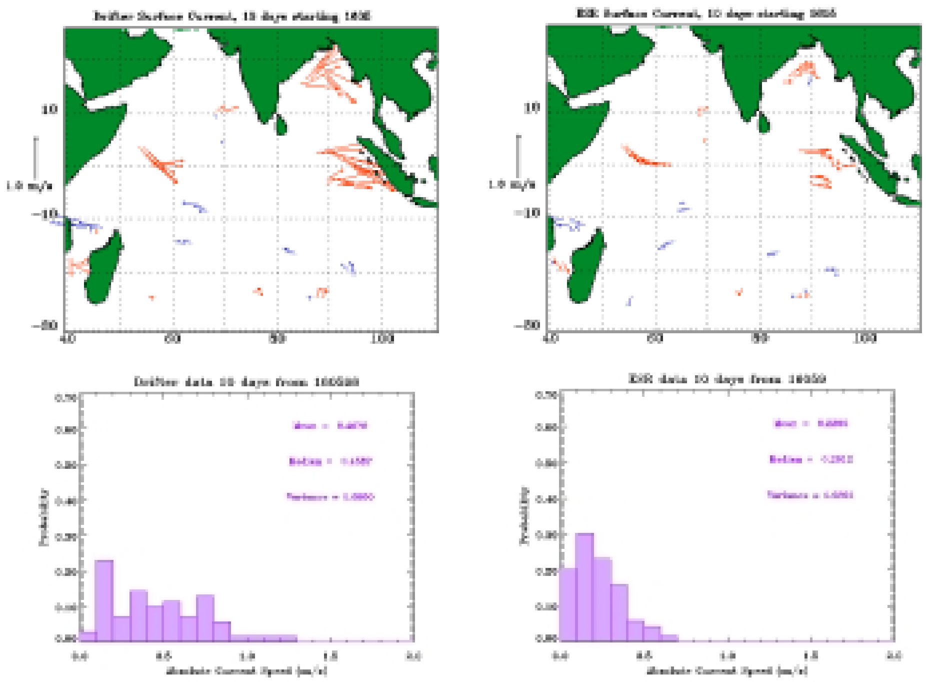


Figure 2.24 Drifting buoy (right) and ESR (left) surface current data for May/June. For this comparison ESR data were extracted only at the locations where buoy drift data were available. Bottom panels give histograms of speed distributions for these data.

Ship Routing Trial

Methodology

In the ship routing trial for WP5300, the travel time for a vessel travelling at 5, 10 and 20 knots along the Singapore-Aden route was calculated. This calculation included the effect of surface current according to the ESR data set (not corrected for the underestimates revealed above). The "nominal" route ran from Socotra (12¡36'N 53¡59'E) to Banda Aceh (5¡30'N 95¡20'E) passing to the south of the Maldive Islands (at 1¡N, 73¡E). The active routing did not make use of a routing algorithm (the trial was restricted by time and available funds) but simply consisted of a subjective visual analysis, the aim being to achieve an approximate measure of the possible savings in time. Four test journeys were analysed, at different times of the year when different current regimes hold sway. Table 2.5 summarises the results and Figure 2.25 illustrates the case for the 10 day period beginning 05/11/98.

Results

The results were perhaps disappointing. They indicated that routing, involving deviation away from the "nominal" route to take advantage of stronger current flows, increased journey times in all but one case (NE Monsoon, ship speed 5 knots, Table 2.5). However, one should recall that the ESR current speeds are suspected to be low. If these currents speeds were increased, more reductions in journey times might have been achieved.

Season	date	Ship speed	Time saving (routed —unrouted)	Total Journey Time
SW Monsoon onset	16/05/98	5 knots 10 knots 20 knots	+0.10 day +0.23 day +0.19 day	19.3 days 10.2 days 5.2 days
SW Monsoon	26/06/98		*Routed and unrouted tracks identical*	
NE Monsoon onset	26/10/98	5 knots 10 knots 20 knots	+0.65 day +0.59 day +0.37 day	19.6 days 10.2 days 5.2 days
NE Monsoon	05/11/98	5 knots 10 knots 20 knots	-0.26 day +0.30 day +0.25 day	22.9 days 11.1 days 5.5 days

Table 2.5. Results of trial ship routing using ESR near real-time surface currents.

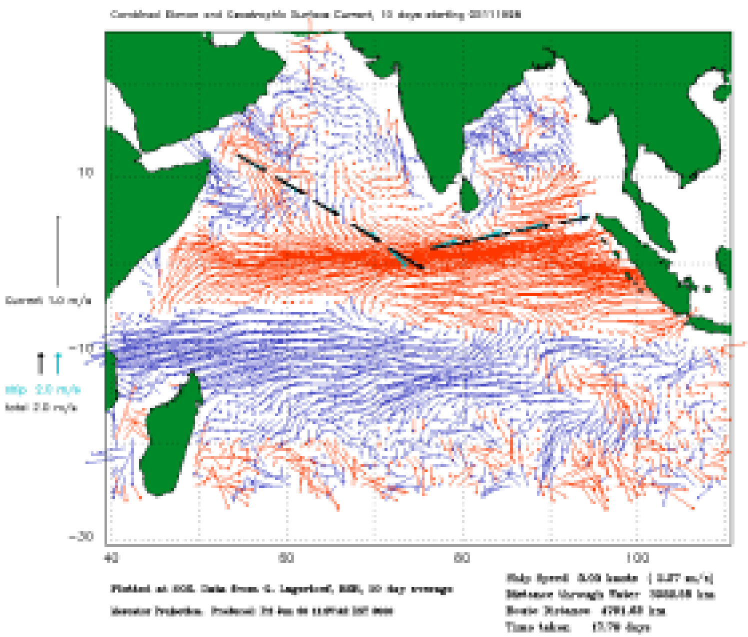


Figure 2.25. Ship routing trial for 05/11/98 (NE Monsoon). The ship (green) and combined ship and current vectors (black) are indicated by the heavy arrows. The underlying current fields are indicated by the red (east flowing) and blue (west flowing) arrows.

Conclusions

Significant differences were found between a satellite derived near real-time surface current data set and a longer term climatology. The climatology data were found to much noisier than the real-time data, with higher current speeds. Subsequent comparison against drifting buoy data suggested that the real-time surface currents speeds were much too low.

It was possible to identify significant (and genuine) current features, such as meso-scale eddies and local gyre systems, in the ESR near real-time data set (many examples in Figure 2.25) which cannot be represented by a multi-year climatology.

In the Indian Ocean, current strengths were only locally large (Somali current ~4 kn during SW monsoon), and so routing may not have a large impact. In fact only on one occasion in the WP5300 trial was a time saving achieved. If the near real-time current speeds were increased, as the comparison with drifter data suggested they should be, then routing would have a greater effect. In particular routing may be most useful in the environs of significant gyres (such as the eddy system offshore Somalia), or to give accurate indication of the onset of monsoon related circulation patterns. Also a gridded current data set would enable accurate prediction of journey times which would help with port arrangements.

Other observations were that AVHRR sea surface temperature data would add higher temporal and spatial resolution, and that a larger scale trial may make a good applications study.

WP5300 - Surface Currents Recommendations

If a commercially viable system, of interest to offshore users is to be realised, it is necessary to demonstrate that worthwhile cost savings can be realised. Thus we recommend a market survey and cost benefit analysis, which (if the results were encouraging) would precede an applications development programme, see Box 11

Box 11. Recommendations for development of an operational surface current application

Market Study to define a commercially viable system (if possible), including: preliminary market study, cost benefit assessment, outline system specification (for instance, data service only, or fully integrated ship advice system), delivery mechanisms.

Application Development, to develop, trial and cost an operational near real-time surface current data service. The study would need to include the following steps: secure end-user(s) as partner(s), define end-user requirements, define initial technique and data set requirements, generate initial data set and carry out detailed comparisons with climatology as presently used in routing operations, modify data processing techniques as necessary, define service specifications, carry out full scale operational trial including transmission of data to offshore operation, review trial, cost various options of a fully operational service.

In addition, there may be an opportunity to develop a more complete intelligent advice system, ship or office based.

It is expected that continued collection of satellite data will automatically increase the reliability of climatological databases in the future.

2.5.4 WP5000 Conclusions

Potential benefits

Satellites could provide a vast amount of environmental data containing oceanographic parameters, of potential value to vessel operators. A dense spatial coverage and short processing time are necessary if these data are to be used to make operational decisions. Fast delivery of the satellite data enables a quality improvement of the short-range model-based weather forecast.

For transport design, high quality satellite data (wind-wave and swell spectra plus simultaneous wind information) would enable the designer to narrow the margin of uncertainty. This could then allow the transport of some loads previously not feasible using traditional design methods, whilst otherwise increasing reliability and enhancing safety. Data should cover sufficiently long periods at close intervals in time and space, to ensure that rare events (like tropical storms) are captured.

When using near real-time satellite data for operational decisions the financial benefits for transports are difficult to fix. Offshore operations would significantly benefit by better short-range forecasts. Therefore the nowcast has to be complemented and integrated with a forecast. These data have to presented in a way suitable for the decision makers on board.

A good near real-time forecast service could save up to 5 days a year on average per ship (large container/ tanker / heavy load transport). This is equivalent to $100,000 — $150,000 USper ship per year. In addition, the reduction in consequential damage (due to increased safety) could easily add up to several hundred millions of dollars. Therefore the insurance companies and cargo owners stand to benefit financially the most from an improved service.

Recommendations

Shipping safety requires a vast amount of accurate environmental data in order to establish design loads. Data acquisition by satellite allows a homogenous data structure in time and space. In order to be able to represent properly seasonal variability it is necessary to stratify the statistics in weeks rather than months, or even worse, four pre-determined seasons (as is presently the case). Therefore, more long-term and high spatial density measurements are necessary in order to improve upon the shortcomings of the satellite data-sets presently available.

An overlap of services is to be avoided, therefore close co-operation of satellite data providers and forecasting offices is required. Ideally the user should not be confronted with two data sources. Instead, at an early stage the data should be merged and so supplement each other.

State-of-the-art calculation and simulation methods require a detailed description of sea-state. This then in turn generates a requirement for more detailed parameters, such as the separation of wind-waves and swell. Indeed, ideally all significant swell components should be represented.

2.6 COMKISS Deliverables

The foregoing sections of this chapter provided details on the scientific and technical aspects of the work carried out under Work Packages 3000, 4000, and 5000. Table 2.6 lists the formal project deliverables, as defined in the Technical Annex, revision 1, and in the final column details how they were achieved.

There were no significant departures from the revised work plan, as detailed in the COMKISS Technical Annex Rev. 1 (provided as an annex to this report).

Work Package	**Partner**	**Initial Due Date (from 1st Tech. Ann.)**	**Description**	**Delivery Details and Reference (below)**
1000	UL	T_1 09/1998	Project Management Plan	**Formal Report provided to Commission : 09/98** Project Management Plan (WP1100) and Quality Management Plan (WP1300), G. Lindgren, University of Lund, *September 1998*.
1000	UL	T_2 09/1998	Quality Plan	
2000	SOS	T_3 11/1998	User Requirement Document	**Formal Report provided to Commission: 12/98:** COMKISS User Requirement Document, G. Lindgren (University of Lund), *December 1998.*
2000	SOS	T_3 11/1998	Revised Programme	**Internal Project Documents: 12/98, 07/99** COMKISS Work Programme Update D. Cotton, Satellite Observing Systems, *December, 1998.* COMKISS Project Status Review, D. Cotton. Satellite Observing Systems, *July, 1999.* **Formal Report provided to Commission: 05/99** COMKISS Technical Annex Revision 1, University of Lund, *May 1999*
2000	UL	T_3 11/1998	Guidelines for WP3000-5000	**Internal Project Document: 12/98** COMKISS Work Programme Update D. Cotton, Satellite Observing Systems *December, 1998*
1000	UL	T_6 02/1999	Cost Statement	1st COMKISS Cost Statements, *March 1999*
1000	UL	T_{12} 08/1999	Annual Report	**Formal Report provided to Commission, 10/99 :** COMKISS Annual Report, , University of Lund, *October 1999*
1000	UL	T_{12} 08/1999	Cost Statement	2nd COMKISS Cost Statements, *Sept. 19999*
1000	UL	T_{18} 02/2000	Cost Statement	3rd COMKISS Cost Statements, *March 2000*
3000	BV	T_{18} 02/2000	Application Report: Ship Design/Certification	**Internal Final Report, 10/2000** Ship Design and Certification Final Report, G. Parmentier (Bureau Veritas), *October 2000*.
4000	IF	T_{18} 02/2000	Application Report: High Speed Craft	**Internal Final Report*: 09/2000*** High Speed Passenger Craft Final Report, R. Nerzic (Optimer) and M. Prevosto (IFREMER), *September 2000.*
5000	DW	T_{18} 02/2000	Application Report: Unconventional Loads	**Internal Final Report*: 10/2000.*** WP5000 TransOcean Transport / Heavy Lift, P. Brugghe (Breeman Engineering) Cees Leenaars (Dockwise) *October 2000*
6000	IF	T_{21} 05/2000	Demonstration Modules	**Web pages completed: *10/2000*** WP6000 Demonstration Modules — on line at http://www.ifremer.fr/metocean/shipping/shipping.htm *October 2000*
1000	UL	T_{24} 08/2000	Cost Statement	4th and summary COMKISS Cost Statements, *in preparation 12/2000:*
7000	UL	T_{24} 08/2000	Final Report	**In preparation (12/2000)*:*** WP7000 Technology Implementation Plan and Final Report.

Table 2.6 Table of Deliverables —based on Table in Technical Annex Review 1 (T_0 = 08/1998)

3 CONCLUSIONS AND FUTURE STEPS

The Chapter 3 Structure is as follows:

3.1 Summary of Results and User Recommendations

3.1.1 Introduction

In section 3.1 we summarise the COMKISS recommendations for making best use of ocean remote sensing data, both through the enhancement of existing applications and through the development of new applications. As we have noted before, the types of applications fall into three categories: Near real-time data, wave climate databases, and provision of surface current information. We will discuss the recommendations separately for each of these categories, and present the possible ways of making progress in satisfying the recommendations. First, however, we make a brief presentation of the joint COMKISS / OGP (international association of Oil and Gas Producers) Met Ocean Committee workshop, held at the Total Fina Elf Offices in Paris in October 2000.

3.1.2 COMKISS/ OGP workshop

Although the commercial partners of COMKISS represented a good cross-section of offshore users of MetOcean data, the COMKISS team was especially pleased to be able to hold a workshop with members of the SAFETRANS JIP (Joint Industry Programme) of the OGP MetOcean Committee. This allowed a presentation of the COMKISS programme to a number of influential and experienced representatives of the offshore oil and gas production industry. It was to allow this workshop to take place within the COMKISS programme that a two month extension was granted to the COMKISS Work Programme. The workshop programme and minutes are provided as an annex to this final report. We summarise the (informal) conclusions here in Box 12. These conclusions represent a synthesis of opinion, gained from discussions during and following the workshop. The should not be taken to represent the formal view of the OGP MetOcean Committee, as no such formal opinion was agreed (or sought).

Box 12. Recommendations from the COMKISS / OGP workshop.

- A high priority is separate information on swell and sea.
- Good presentation to ensure that ships officers will make use of a service is essential. The data can be of the highest quality, but if they are not presented in an accessible form, then they will not be used.
- Satellite data are useful to the industry, **but** satellites by themselves do not solve any problems, and even more, the satellite data, when they come out of the space agencies, still require significant efforts before they can be used
- Oil industry buys metocean services from providers, they do not develop them in-house, and funding can only be expected for a project which addresses a consensus view on risk assessment and safety criteria. . It should be noted that space agencies should not expect funding support from the industry for the launch of additional satellites.

3.1.3 Near Real Time Data

Requirements

Boxes 7 and 10 gave the user requirements for near real-time data. Many offshore users are finding that they have a requirement for higher accuracy sea state forecasts than are provided by the present sources. Problems are encountered when unexpectedly severe conditions occur. Many forecast sources now have an impressive reliability, but the few occasions when they fail are often during severe events when the consequences are the most serious. It is perhaps surprising that it is difficult to find statistics on the level of reliability with which particularly severe conditions are predicted. Thus we have added a further recommendation (see Table 2.6) for a study (independent of the forecast providers) to investigate the accuracy of sea state forecasts, specifically with regard to their ability to forecast the location and severity of wave fields associated with storms.

There are clear requirements, from all sectors, for a higher density of measurements (in time and space) and for reliable measurements of wave direction and wave period at all wavelengths. The spatial and temporal density requirements vary with the region and the type of craft. Thus trans-ocean shipping are rarely subject to sudden and localised changes in weather and sea state, whereas high speed craft in sheltered seas experience, and are much more sensitive to, a higher level of small scale variability. In the former case six hourly updates, based on a 1 degree global grid, would be satisfactory. In the latter case, at least three hourly updates should be available, and measurements should be available at a resolution to match local variability (< 10 km in coastal regions). These improved data sources would need to be backed up by a network that would dispatch all available information (land and ship observations, coastal and open sea measurements, satellite observations) on a near real-time basis, and must be completed with wave forecasts to avoid overlapping / double services. Table 2.6 summarises the recommended further work to develop and improve near real-time applications of satellite ocean data.

Ref.	What	Who ?	How
NRT 1	Ensure nowcast is consistent with reliable observations.	Academia, Research Institutes	Provide "exact" merging methods of measurements with nowcasts
NRT 2	Provide easy access to near real-time satellite data.	Satellite data providers and resellers, Forecasting Offices	Merge satellite information transmission with that of regular forecasts.
NRT 3	Improve temporal and spatial resolution by at least one order of magnitude.	Government Agencies, and public private partnerships	Launch and operate more ocean observing satellites
NRT 4	Simplify and improve methods to make information available on-board	Government Agencies	NRT delivery of relevant information to value-added resellers that the end-users may then poll
NRT 5	High resolution information in coastal waters	Research institutes, resellers	Merging of satellite (and other) measurements with high resolution local wave models.
NRT 6	Assess ability of wave models to forecast severe sea state conditions	Academia, Research Institutes	Compare (satellite) measurements of storm conditions with forecasts.

Table 2.6 Recommendations of further work to optimise use of Near Real-time Satellite MetOcean data.

Potential benefits

When using near real-time satellite data for operational decisions, the financial benefits are difficult to quantify precisely. This is partly due to the lack of precise information on forecast accuracy of the severe conditions which results in damage or delay, and partly because of the lack of detailed information on the actual commercial cost of such damage and delay. These costs will often be spread across several cost centres of a commercial operation, including such areas as maintenance, insurance, and fuel.

However, we can make a rough estimate. Let us say that, for offshore use, a good near real-time forecast service could save up to 5 days a year on average per ship. At an estimated 20 —30,000 Euro per day, this would come to 100 —150,000 Euro per ship per year. In addition, the reduction in consequential damage could easily build up to several hundred millions of dollars. In fact it could be argued that the insurance companies and cargo owners stand to benefit most from an improved service.

For coastal use, the financial benefits are perhaps even less easy to quantify, because we can add to the above factors the rather less tangible consequences of passenger confidence. However, if we assume 500 passengers each paying 100 Euro per passage, a single cancelled crossing will cost the company 50,000 Euro in lost revenue.

It is known that commercial organisations currently pay of the order of 50 Euros per day per vessel for metocean and routing services. The current combined shipping and oil industry ocean fleet numbers roughly 40,000 vessels. So if we assume, for the purposes of a rough costs estimation, 250 operating days per annum, and a charge of 10 Euros per day for a new metocean daily service, we come to a market value of the order of 100 million Euro per year, in this sector only (not including passenger transport, the military, or the small craft sector). Market studies suggest that one can reasonably expect a 10% market penetration, so we have a final potential market sum of 10 million Euro per year (in the commercial large ship and oil and gas sectors(Stephens, 1999).

In terms of environmental clean up costs, we understand that the expenditure of Total Fina Elf, following the Erika disaster off the coast of Britanny has recently exceeded 500 million Euros. Expenditure by public bodies can be reasonably supposed to be at least equal to this. Thus, if it is assumed that improved sea-state information can reduce the number of incidents such as the Erika, the potential benefits to society run to billions of Euro.

3.1.4 Wave Climate Databases

Recommendations

Box 8 detailed the recommendations on improvements to wave climate databases. The requirements for wave climate databases are well established. For conventional design studies, scatter diagrams of directional wind and wave spectra are required, on a gridded monthly basis. Existing conventional databases provide these with varying degree of geographic and temporal resolution. For some applications (especially coastal) this resolution is not satisfactory. New methods based on Monte-Carlo simulations require a time ordered, gridded, archived hindcast database, to allow multiple calculations of voyages along a given route.

First, we consider applications of more conventional design methods to databases which provide gridded sea state climatologies which are assumed to be consistent year on year. We have seen in Chapter 2 that satellite data can be used to generate joint probability density functions of wave height and period. We have further seen that the estimation is robust, and is at least equal in definition to that which climatological atlases can provide, although a longer time series of data would be preferable. These are the reasons why this sector has already seen the development of a number of commercial satellite based wave climate atlases. However, these new atlases based on satellite derived data have not completely replaced atlases based on data from other sources. It was therefore important to establish where the satellite derived atlases could not match the performance of others. It seemed that the main problems were to do with accessibility (or flexibility). Often database designs were too rigid to allow new procedures to be applied.

Directional and spectral information are also of vital importance. Although SAR data have been available for nearly 10 years, there is still an apparent lack of confidence in the wave parameters derived from this instrument.

Now we consider the applications where time ordered data are desired, for instance the fail-safe calculations of Bureau Veritas, or the Monte Carlo design methods.

We saw in the fail-safe studies for Bureau Veritas that data were required to provide information on the evolution of the consecutive sea states, so that information with time regularity was very important. Databases containing archived output from hindcast models can provide this information, on their own satellite data cannot. This provided the incentive for the research activities based at the University of L nd, which developed a very important and useful basis for understanding the (stochastic) nature of statistics necessary for calculating fail-safe conditions, particularly when neatly arranged time ordered data are not available.

We were also confronted with the need to provide improved reconstruction of the sea-state that prevailed during classification and certification trials. We suggest such applications must involve the combined use of satellite archives and wind/wave models.

We also noted that alternative ways of dealing with some of these problems were available. For instance it would be possible, and in some instances desirable, to generate a satellite based equivalent of the time ordered hindcast archives through some intelligent combination with hindcast models. However, we argued that safety assessments should be approached in a stochastic manner. This is not yet current practice everywhere, but models were developed which were built upon such an understanding, and allowed the more direct use of satellite data.

Ref.	What	Who ?	How
WC 1	Provide time-histories, and/or alternative techniques to Monte-Carlo simulations	Academia, Research Institutes	Characterize the sea state temporal and spatial process, and give methods to estimate the corresponding parameters
WC 2	Provide detailed spectral and directional information on sea states	Academia, Research Institutes	Improve processing algorithms (note that altimeter periods are of great use).
		Government Agencies	More accessible, and better coverage of, satellite derived directional wave products
WC 3	Simplify access to satellite data, have formats suitable for industry applications	Government Agencies	Better organisation of archive databases
		Satellite data providers and resellers	Improve extraction and compilation methods, go one or several steps beyond climatological atlases.

Table 2.7 Recommendations of further work to develop the use of climate databases holding satellite MetOcean data.

Table 2.7 summarises the recommendations for development of climate database applications.

Potential benefits

Satellites are able to provide a vast amount of environmental data containing oceanographic parameters, which is useful to vessel operators. They can provide measured data at a much higher spatial and temporal resolution than was previously possible. These data are of reliable quality in all areas of the ocean, and are not biased towards any particular type of conditions.

High quality satellite wind and wave spectral data can enable the development of more precise design techniques, perhaps allowing overseas transports which were previously not feasible, but certainly allowing better estimates of safety margins.

It is again difficult to put a price on these developments. Conventional wave climate databases do not command a high price, perhaps a few thousands of Euro. More, the volume of such sales is not large. However, databases which allow the development of more accurate design techniques, or improved estimates of safety may be able to command a higher price. This may be particularly so in the light of recent incidents (Erika, Ievoli Sun - http://www.ifremer.fr/com/ievolisun/), which as we have seen can cost the public purse and private companies billions of Euro. Shipping safety is coming under the spotlight again, and it seems that new legislation is under consideration.

3.1.5 Surface Currents

Recommendations

- Box 11 summarised the conclusions and recommendations of the surface currents study. It was found that there was certainly scope for satellite data to provide a near real-time service which would represent a significant improvement to that presently available. However, some of the necessary processing techniques are not yet well enough developed for such a service to be created at the present time. Thus, some further background development is required.

Ref.	What	Who ?	How
SC 1	Market Study	Sponsored Consultancy project	Define commercial system, including: preliminary market study, cost benefit assessment, outline system specification delivery mechanisms
SC 2	Application Development	Joint programme, with industry and academia	Develop, trial and cost an operational near real-time surface current data service.

Table 2.8 Recommendations of further work to develop the use of satellite MetOcean data in provision of surface current information

Potential Benefits

If a commercially viable system of interest to offshore users is to be realized, it is necessary to demonstrate that worthwhile cost savings can be realised. In addition, there may be an opportunity to develop a more complete intelligent advice system, ship or office based.

Savings would be realised through reduced journey time (or reduced ship speed), resulting in a saving of fuel, or, with improved accurate knowledge of expected voyage duration, more efficient use of expensive port facilities. Fuel is a major component in the costs of ocean transport, and potential savings are significant. For example if improved surface current information allowed a moderate 0.5 knot improvement on an average 10 knot speed over a 2000 NM voyage, the journey time would be reduced by10 hours. Assuming an average fuel consumption of 30 tonnes per day, consumption would be reduced by 12.5 tonnes. For slower or larger vessels the savings could be even more significant. Port facilities are highly priced, and so any unused quayside time is an expensive and unnecessary cost.

3.2 Potential Solutions to Offshore User Requirements

3.2.1 Introduction

It was never the purpose of COMKISS to suggest that satellite data could, or should, completely supersede other metocean data sources. The aim was rather to identify how best use could be made of these new data sources which are now available, and to indicate what new developments would have the best impact on offshore activities. Thus within this section we explore the ways in which the expressed desires and recommendations of offshore operators can be met best.

The foregoing pages of this report have revealed the large potential that exists for the better use of satellite data. However, it can be argued that the various modes of metocean data provision and application have not changed sufficiently to enable commercial users to take best advantage of these new data sources. Until now, use of satellite data has largely been limited to assimilation into existing (or modified) wave forecast models, or to the development of climatological databases for use in design techniques which have not markedly changed. We suggest that a more innovative approach should be encouraged, which may suggest the adoption of new design and forecast methods.

We will first discuss the general techniques that are available, before moving on to consider in more detail how each recommendation might be met. Broadly speaking there are four ways of making more use of satellite data:

- Improved processing of existing data sets, to present them in a form which is more accessible to the non-expert user, or to generate secondary parameters which are of interest.
- Merging of satellite data with other data or model output.
- The launch of new satellite systems, targeted specifically at operational use.
- The development of new statistical techniques for use in design methods, which will enable the more direct use of satellite data.

We discuss each of these in more detail below.

Improved Data Processing

Satellite data sets currently provided by the centres appointed as distributors by the space agencies (AVISO, CERSAT) are rarely in a form accessible to the non-specialist user. This is because the data centres seem to concentrate in providing the data in a form suitable for academic studies. Thus the role being taken up by value added companies (often SME s) is to interpret and process the data into a form more suitable to industry users. The wave climate databases of OCEANOR, ARGOSS, Meteomer, and Satellite Observing Systems represent such an activity. However, we suggest that there is scope for more activities in this area. One suggestion from users has been that it should be possible to query databases on line, and request information in a specific desired format.

An example of value added services is provided by Jenifer Clark s Gulfstream . Here a number of different types of satellite data have been processed into higher level data sets by academic organisations, and are then freely available on web sites. However, a further level of interpretation and merging is required before a product of use to the non-expert user is generated (sea surface current maps).

Thus the extra processing can be quite sophisticated (the generation of maps of geostrophic sea surface current variability from altimeter range data), or almost trivial (the bringing together of a few different sources of freely available information). However, they each perform a service in making the data accessible to the inexpert offshore user.

Data sets currently not well used are image data of all kinds (SAR, ocean colour, SST). These data sets require intensive processing, often with subjective human intervention. This is because the image contains information from a mix of influences which can interact in complex ways (see for example Topliss et al., 1994). To date it has proved difficult to develop generic processing schemes to enable the extraction of selected geophysical (e.g. sea state) parameters. An extra barrier to the routine exploitation of long time series of image data is the high cost of individual scenes.

New Merging Techniques

For short term sea state forecasting, the major part of the offshore industry continues to rely on existing suppliers of data. These include, or are based on products supplied by, the national meteorological agencies. These large agencies often seem to be unwilling to be innovative with regard to the inclusion of new data sets into their forecast or database systems. Often the only use they make of satellite data is in the validation of existing models or through assimilation into modified forecast models. As satellite data now represent by far the largest single source of measured ocean data, this situation does not seem to the COMKISS partners to represent the best use of satellite data.

In particular the COMKISS end-users have expressed that sea state model nowcasts should be consistent with reliable measured data. Their officers wish to know the very best estimate of local conditions and cannot understand why once a model has assimilated some measured data it can continue to be inaccurate at the point of assimilation. In particular they lose faith in forecasts once the nowcasts have been seen to be wrong (even only once). In contrast, they are able to place extra faith in information that includes reliable direct measurements. Thus one of the major recommendations of COMKISS is that new techniques for combining satellite measured data with wave nowcasts and forecasts should be developed. The principle is that reliable measured data should be used to generate the nowcast wave field at regular synoptic periods. This renewed nowcast is then used as the starting point for each new forecast. The development of this technique, currently applied in a number of geophysical disciplines (including seismology), lies at the heart of the COMKIAS proposal, outlined later in this chapter (Section 3.3.1)

The COMKIAS proposal is aimed at offshore use. However, models and satellite data can also be usefully merged to provide climate and real-time information close to the coast. We have explained that satellite altimeters by themselves cannot provide information close to the coast. SAR image data could in principle provide information close to the coast, but as we have noted, processing schemes have not yet been developed which can successfully, and automatically, extract the information on waves that may in principle be available. At present the best way forward is provided by the combination of satellite data and wave models. In a UK study, JERICHO, Cotton et al., (1999) demonstrate how shallow water wave models can use satellite measurements as boundary conditions to derive wave climate information close to the coast. However, they found that the wave models had to be set up anew at each new coastal location, where local in-situ data were required to allow suitable adjustments to model parameters. Once the models were setup, historical satellite measurements could be used to generate a longer term climatology. In a similar vein, a European study, EUROWAVES (Cavaleri et al., 1999), proposes a technique to provide wave climate information based this time on a generic application of the SWAN wave model (Ris et al., 1999), the boundary conditions being provided by the larger grid ECMWF wave model, verified against satellite and other measured data sources.

New Satellite Systems

Up to now, satellite missions providing oceanographic data have been driven by the requirement to satisfy academically defined scientific goals, or the need to prove and develop new technology. Although the data sets they have produced have been shown to have a wide range of applications, with one exception, the missions have not been designed to have a long term operational remit. This exception is the US NOAA TIROS (advanced Television InfraRed Observation Satellites) series, which carry the AVHRR (Advanced Very High Resolution Radiometer) instrument to map sea surface temperature, in operation since 1978, (Vasquez et al., 1995). More recently there has been a move to provide operational provision of ocean winds, through satellite-borne radar scatterometers. However, one could not yet regard this provision as operational. Also, because until now it has been relatively expensive to build and launch a satellite, there has been a tendency to build in a high level of redundancy and place a lot of instrumentation on a single platform. This increases the costs of satellite missions, so that ENVISAT will cost an estimated 3 billion Euro. There is now a move to cheaper, smaller satellites (Zheng, 1999). Such satellites, so called micro-satellites, may weigh 100kg rather than many 1000s kg, they require much less power and may be built and launched for millions, instead of billions, of Euro. We suggest that this type of satellite, with their much lower cost, will provide the most likely option for operational provision of EO data over the ocean.

New Statistical Techniques

As a result of the studies carried out at the University of L nd for WP3000, we propose this fourth option. Existing design method techniques have been developed to work with the form of data that has been most widely available until now. That is gridded climatological databases, or archived wave hindcasts. Satellite data provide the most prolific source of measured data, and it is suggested that that new techniques should be developed to make use of these data. Thus the techniques proposed by Baxenavi et al., (2000a) and (2000b) recognise the essentially stochastic nature of sea state forces, and make use of satellite data to provide random samples of sea state. It is clear that further development is required. In particular the techniques should be expanded to make use of directional and wavelength information (e.g. from Synthetic Aperture Radar). However, we believe that these studies provide a valuable step towards the development of new design method techniques.

3.2.2 Near Real Time Data

There are 6 main recommendations (Table 2.6) for Near Real Time Applications

NRT 1 Remove Nowcast Discrepancies

The need here is to develop new merging techniques to combined a higher volume of measured data with output from wave models (see above discussion). Here the measured data will be used to define the current state, rather than as a means to adjust a model defined state. Some new research is required here, and so we have suggested that academic and research institutes are involved in some developmental studies and trial applications. The development of these new techniques forms part of the COMKIAS proposal, which will be presented briefly in Section 3.3.1

NRT 2 Provision of Satellite Information with Regular Forecasts

One problem for users of forecasts is that they cannot know the reliability of individual forecasts. One way of dealing with this problem is to provide actual measured information along with the nowcast from which the forecast is obtained, then the user can himself judge the accuracy of the model prediction. This tends to increase faith of the user in the service provider. The Satellite Observing System s Sea State Alarm service provides an example of such a service.

NRT 3 Improve Temporal and Spatial Information.

It seems clear that the only way to provide better *data* coverage is through an increase in the number of satellites providing data. The radar altimeter is the least expensive (and the most accurate) instrument which measures waves from space. However, it makes a measurement in a narrow beam (5-10 km wide) directly under the satellite.

It is relatively simple to calculate the coverage that a series of such satellites can provide. A satellite on a near polar orbit at heights of 600-800 km will complete about 14 orbits a day, taking roughly 100 minutes (1.67 hours) to complete each orbit. Thus adjacent tracks are separated by about 25¡ at the equator. Each orbit contains an ascending and a descending pass, on opposite sides of the earth, thus satellites in a single orbital plane will provide 12 hourly coverage of any given region. If a measurement is to be available within 200 km of any location at 6 hourly intervals (a specification suggested by offshore users), the maximum track separation must be 400km (or roughly 4¡ at the equator). Thus there should be 6 satellites within each orbital plane. If 6 hourly coverage is desired, this requires a further 6 operational satellites launched into a second plane, offset from the first by close to 90¡. Thus a total of 12 operational satellites would be required to provide the requested service. The GANDER proposal (see section 3.3.1) has shown how such a service could be provided, through the use of relatively inexpensive microsatellites.

In 2001 two new satellites with wave measuring radar will be launched, ENVISAT, and JASON. Both will have near real-time data capability. However, even with two satellites, sampling will be sparse. According to the above calculations the best coverage we can hope for is tracks 12.5¡ apart (1375 km), with 12 hourly coverage. Nonetheless this will double the availability of near real-time data. It is planned that COMKIAS and Sea State Alarm will carry out trials to test the added benefit.

Swath measuring instruments potentially provide better coverage. For instance the US Quickscat radar scatterometer provides measurements over a 1800 km swath width and generates 90% global coverage every day. However, at present there are no swath-type satellite instruments that are able to provide wave measurements. The French SWIMSAT proposal, being developed by CETP (Hauser, 2000) proposes such an instrument (again see section 3.3.1).

NRT 4 Simplify and improve methods to make information available on board

An important recommendation is that all satellite missions which generate potentially useful metocean data should have a near real-time data provision facility, allowing a delay of 3 hours or less between the time of measurement and the dissemination of the data to users. These data should be (electronically) available to meteorological agencies and to value added companies who can then ensure easy access to end-users

NRT 5 High Resolution Coastal Information

We have already shown that 12 or more satellites carrying radar altimeters would be required to supply the suggested offshore coverage (measurements within 200 km every six hours). The coastal requirements are even more restricting (~10 km every three hours), implying a requirement of 60 satellites in each of four planes — 240, all told. Thus it is not realistic toexpect that satellite altimeter data can meet the coastal data requirements. The present state of the art scatterometers (e.g. Quikscat) provide wind fields with a daily coverage at 25 km resolution, and so we could not get wind fields at the necessary resolution from even these instruments. Finally there are SAR image data. These data have been seen to provide highly detailed information of wind wave variability near the coast (see e.g. Alpers et al, 1998). However, even if the already noted processing and cost problems can be overcome, coverage is again limited. The ERS-2 SAR has a swath width of 100 km (giving a latitudinal coverage of 2800 km per day, so one such satellite would take approximately 15 days to provide complete global coverage.

Therefore in the short term the best option is likely to involve the use of high resolution regional models, merged with remotely sensed data where they are available.

The ability of HF wave radar to measure ocean waves has been demonstrated by a number of researchers (see. e.g Wyatt 1999). Other developments have demonstrated how a modified ship s X-band radar can measure local wave fields (Reichert et al., 1999). A combination of these measurements with local wave models (validated by in situ data) should be able to provide a more reliable service in coastal waters.

NRT 6 Investigate Accuracy of Forecasts in Critical Conditions

When planning the development of a new forecast system, it is important to know how much one can hope to improve on existing sources, so as to be able to assess the potential value of an improved system. Thus it is necessary to have a good understanding of how well the existing forecasts perform in critical situations, those conditions under which most losses occur offshore. Most forecasts assessments that are publicly available seem to provide overall statistics, which indicate good performance in general terms, but they do not provide a focussed assessment of severe conditions, when one may expect that it is most difficult to provide accurate forecasts. We thus recommend an independent study to assess the performance of wave model forecasts during storm events.

3.2.3 Wave Climate Databases

There are 5 main recommendations (Table 2.7) for Wave Climate applications

WC 1 Provide Time Histories, or alternatives to Monte Carlo Simulations

Because of the incomplete sampling of global wave fields, gridded time histories can only be provided when measurements and model hindcasts are combined. At present satellite data are used to validate the hindcast data locally, and are not included as an intrinsic part of such databases (see e.g Cox et al, 2000). It is suggested that better use could be made of the satellite data. The new data merging techniques we have suggested in response to recommendation NRT 1, could be used in the generation of a new series of hindcasts to provide an alternative hindcast archive — one which contained an exact representation of reliable measured data.

We have already addressed the need for industry to consider new techniques for design methods, which are better suited to the measured data that are available. Baxenavi et al., (2000a and 2000b) provide a starting point for such developments, but more work is required.

Both these aspects would require a combination of academic / research institutes, with direction provided by a co-operating end-user.

WC 2 Better Provision of Spectral and Directional Information

Directional and spectral information are of a high priority for offshore users. However, although such parameters are available from SAR wave mode products, and these parameters are included in climate databases and wave model assimilation schemes, SAR wave data have yet to gain the widespread acceptance that altimeter data now have.

We suggest that a problem lies within the processing and distribution of wave mode data by the ESA appointed distribution agency. For a new data set to become accepted by a group of users the data must first be easily accessible. Even a moderately low cost on new data sets can make them unattractive, when the potential benefits are uncertain. It could be argued, with strong justification, that altimeter data would not have gained such wide acceptance if thousands of Euro had been charged for the use of the global Geosat and TOPEX altimeter data sets. In addition there is an apparent confusion about the best processing scheme to apply to SAR wave mode data, perhaps stemming from the need to apply a wave model based first guess in the interpretation of wave spectra.

For ERS SAR wave mode data to be better and more widely used, we suggest that they should be re-issued, with processing based on a well regarded algorithm, at a price set only to cover distribution costs. The schemes for distribution of ENVISAT wave mode data are currently being established. We would again suggest that anything above a simple distribution cost price will limit the potential user community to expert academic groups.

WC 3 Simplify Access to Satellite Data / Improve Extraction and Compilation Methods

It is well known to all users of satellite data that in the majority of cases it is easier and quicker to retrieve data from US databases than European databases. With this ease of access to US databases, any extra charges or difficulties placed in the way of accessing data from other sources simply result in these other data not being used. We believe therefore that the agencies responsible for data distribution must maker greater attempts to make the data sets more accessible and should be adequately funded to do this. Otherwise European researchers and value added industries are placed at a disadvantage with regard to their competitors/colleagues in the US.

If some of the initial data processing and cost burden is lifted from the value added industries, then they will be better placed to invest in the development of more sophisticated data extraction and compilation tools for use by their customers.

3.2.4 Surface Current Applications

There are 2 main recommendations (Table 2.8) for Surface Current applications. They could be brought together under a single Applications Development programme.

SC 1 Market Study

It seems likely that there is scope for better use of satellite data with regard to provision of surface current data. However, the size of a potential market for such products is not well defined. There is also a need to establish end user requirements and to determine service specifications and delivery mechanisms. A short-term market study would define the value of the potential market and establish the commercial viability of a new satellite based surface current prediction system. In addition the survey would help to determine whether a system should be limited to a data service, or included as part of a more comprehensive ship advice system.

SC 2 Application Development

There are scientific and technical problems to be overcome. We have seen that present techniques need further development and improved validation. There is also a need to investigate ways to blend information from various data sources.

Such a study would require a partnership between research institutes, value added companies and a commercial end-user (either a shipping company or a routing company). A first stage would develop and refine the processing techniques used to generate the near real-time current data sets, and would be followed by a full scale operational trial including transmission of data to an offshore operation. Finally, after a review of the trial various options of a fully operational service would be investigated.

3.3 Dissemination and Exploitation

Exploitation of the COMKISS results has already commenced, through the highly successful COMKISS/OGP workshop. It is intended and hoped that this connection between the OGP and researchers with expertise in the use of satellite data will continue, at least in an informal way. Further routes of exploitation are planned through proposals for joint research or applications development programmes, for funding under various mechanisms. In addition we highlight some proposals for new satellite missions, which could provide improved operational coverage.

Other exploitation will take place through the distribution of copies of the COMKISS final report and other material, and through presentations at appropriate forums, such as workshops and industry discussion meetings.

3.3.1 Proposals /Applications

COMKIAS (Conveying Metocean Knowledge into an Advisory System)

COMKIAS is an innovative proposal to develop and test a pre-market advanced marine on-board advisory system. The COMKIAS system will combine on-board load measurements with on-board and remote sea state data (including near real-time satellite data) and high quality forecasts, to generate advisory information for vessel operation and planning. A two stage, three year, programme is proposed. An initial development stage includes a market study and the development of key components of the prototype advice system, including the development of new techniques to merge satellite data and models. The second, implementation stage will assemble a prototype COMKIAS system and carry out trials on selected end-user offshore operations. Thus the COMKIAS programme will address a number of the key recommendations from COMKISS (NRT1, NRT2, and NRT4). The COMKIAS proposal was initiated by one of the COMKISS end-users, Dockwise, and builds on some experience within the Joint Industry Project SAFETRANS. The COMKIAS partnership now includes SEMA, Ecole de Mines, IFREMER, Dockwise, University of L nd, OPTIMER, and Satellite Observing Systems. The team was advised that the COMKIAS proposal did not fit well into the key activities being addressed by Framework V, so the intention is to seek EUREKA status and look for industry sponsorship.

SEAROUTES

SEAROUTES is a Framework V proposal, now accepted, in the Growth programme. SEAROUTES is led by the Technical University of Berlin and was initiated quite independently of the COMKISS work, but embraces a number of the recommendations that have come from COMKISS (NRT 2, NRT 4 and NRT 6). The SEAROUTES proposal aims to develop an advanced decision support system for ship routing based on full-scale ship-specific responses, and improved sea and weather forecasts including synoptic, high resolution near real-time satellite data. The project is particularly directed at high speed craft for which new response models will be developed. One of the key aspects is the use of near real-time satellite data, although they will be used in a relatively conventional way —assimilated into the ECMWF wave model. However, the accuracy of these forecasts under critical conditions will be examined.

SEAROUTES has 10 partners (including Satellite Observing Systems), with a mix off industrial and academic partners. It will commence in January 2001, and run for three years.

GANDER

The GANDER programme proposes the launch of a constellation of microsatellites, each carrying a wave measuring radar altimeter. Detailed technical studies have shown that a micro-satellite platform could carry such a radar on a 100kg platform providing 50W of power (Jolly et al, 2000). A constellation of 5 such GANDER satellites could be built and launched for approximately 40 Million Euro. It has been shown that, to ensure a continuous service, some redundancy is necessary and failure must be allowed for. Thus a constellation of 16 would be required to provide the ideal coverage recommended by the COMKISS offshore users, requiring 12 operational satellites (see section 3.2.2 recommendation NRT 3). Such a system would cost commensurately more although there would be some savings through the benefits of bulk production. Altimeter data rates are low, so the ground segment of the operation would be relatively simple to establish, and could be based largely on existing infrastructure. It is intended that the GANDER system will be a complete end-to-end ship advice system, providing forecasts and nowcasts to the bridge from the GANDER central office. It would incorporate wave models through the new merging techniques recommended by COMKISS. Thus GANDER addresses all the NRT recommendations under NRT (1-5), except NRT 6 (coastal information). Although a detailed market study (Stephens, 2000) has demonstrated that a GANDER system could be economically self supporting, substantial initial start up funding is required, some years before revenue starts to flow. Thus it would be difficult to gain adequate investment purely from the private sector, and some initial support from public funds will be necessary.

SWIMSAT(Hauser, 2000)

SWIMSAT is a proposal, under preparation at the French Laboratory CETP (Centre d tudes des Environnements Terrestre et Plan taires, for a satellite mission carrying a real aperture wave measuring radar, for submission as one of the European Space Agency s Earth Explorer Opportunity Missions. The radar will make directional wave measurements along a ~200km swath, providing directional spectra at 15¡ resolution in wavelengths from 50-500m. SWIMSAT thus addresses recommendation WC 2, and if it operates a near real-time data delivery system, could also address recommendations NRT 1, 2, 3 and 5.

AltiKa (Vincent et al., 2000)

AltiKa is a project within the French space agency (CNES) to build a Ka band satellite altimeter, possibly to be launched as a partner to JASON-2. Moving to Ka band (a higher frequency than Ku band) allows a lower power altimeter, with a smaller antenna, and so allows the possibility of a dual frequency altimeter on a microsatellite platform. However, the higher frequency also renders the radar signal more vulnerable to attenuation by atmospheric liquid water. Note that, in contrast to the purely wind/wave measuring basic GANDER design, AltiKa will be a range measuring and wave measuring altimeter. In consequence it is also a higher cost satellite.

GAMBLE

GAMBLE is a proposal for Thematic Network under Framework V. The proposal, currently under review, is led by CNES and Satellite Observing Systems. The intention is to build a co-operative network of all major altimeter experts in Europe to ensure that complementarity of proposed altimeter missions is exploited to the full. Satellite altimeter missions approved and under consideration are ENVISAT, JASON (Escudier et al. 2000), GANDER, Altika (Vincent et al, 2000), and SWIMSAT (Hauser, 2000). Under the GAMBLE proposal a number of themed workshops will take in expert opinion to advise on the specification of new missions, and on the joint processing of data from different missions.

Surface Currents

Satellite Observing Systems intends to generate a proposal for an applications development project, in partnership with a major ship routing company and an end-user company. The proposal will take into account the COMKISS recommendations, but is presently in the early stages of development.

3.3.2 Workshops, Space Agencies, and Other Opportunities

COMKISS OGP workshop

The joint COMKISS /OGP workshop has already been discussed, and further details are provided in an annex to this report. It is intended that the workshop will open a dialogue between the COMKISS partners and the OGP Metocean committee. The Final COMKISS report will be distributed to members of this committee.

European Space Agency

We were grateful for ESA s participation in the COMKISS /OGP workshop in the person of Jerome Benveniste, from ESA/ESRIN. The COMKISS final report will be provided to key people within ESRIN, who are responsible for the exploitation of EO data, with an invitation for feedback and discussion. Satellite Observing Systems hopes to present COMKISS results at the first post launch ENVISAT symposium.

CNES (Centre National d Etudes Spatiales), and AVISO

The COMKISS final report will be provided to key people within CNES and the distribution agency AVISO, again with an invitation for feedback and discussion. Satellite Observing Systems is a member of the JASON Science Working Team, and aims to present COMKISS results at the post launch JASON SWT in October 2001.

Other Opportunities

All COMKISS partners will aim to present COMKISS results at appropriate industrial and scientific meetings in the coming year. A full distribution list is being drawn up and will be available to the EC scientific officer

3.3.3 COMKISS Material for Dissemination

COMKISS material available for dissemination in early 2001 will include:

- The full final COMKISS report plus annexes.
- All COMKISS scientific papers and technical reports:

Baxenavi A., K. Podg rski, and I. Rychlik, Distributions of Responses experienced by a vessel, 23 pp, September 2000.

Baxenavi A., G. Lindgren, I. Rychlik, and L. Tual, A statistical analysis of satellite data of wave parameters in the Mediterranean and Northern Atlantic Ocean , 31 pp, September 2000.

Cotton P. D., 2000, Final Report for WP5300, Surface Currents from Satellite Measurements, Technical report for COMKISS , Godalming, UK, June 2000.

Leenaars C., S. Louazal, and P. Brugghe, 2000, Comparison of wave databases and design methods for major shipping routes, COMKISS WP5100 Scientific Report, 77 pp, July 2000.

Nerzic N., and M. J. C. Prevosto, 2000, *COMKISS Project — WP4000 High Speed Passenger Craft°— Final Report*, Optimepublished Technical report for COMKISS , Brest, France., 45 pp, October 2000.

- The COMKISS web site: http://www.maths.lth.se/matstat/staff/georg/comkiss
- The COMKISS Demonstration Modules at http://www.ifremer.fr/metocean/shipping/shipping.htm
- The COMKISS Executive Summary report
- A CD containing all the above. Documents in pdf format, other information as HTML.

3.4 Meeting Project Objectives

In the COMKISS proposal and Technical Annex, the principal project objective was defined as:

To demonstrate to major segments of the European marine transport industry the benefits of integrating satellite derived information on sea state with the more conventional methods used by them at present.

We believe that, with this final report and the dissemination of the material listed above, this primary aim has been amply fulfilled. In the later stages of COMKISS, the joint OGP / COMKISS workshop provided an ideal opportunity to demonstrate applications of satellite data to an informed and powerful group of users. In the end, what was perhaps anticipated as a one-way demonstration of applications has very definitely developed into a two way process. Whilst the industrial partners within COMKISS have been fully involved in the testing of some trial applications, and have accepted the value of satellite data in a range of applications, they have provided important feedback to the scientific partners of their needs from wind and wave data sources. Thus, the scientific partners of COMKISS have learned some valuable lessons on the methods and needs of end-users, and many of the recommendations coming at the end of the COMKISS project are directed at data providers, rather than data users. We can thus add a rider to the primary objective:

To communicate to value adders, research institutes and space agencies the operational requirements of offshore end-users for sea state data.

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- AVISO and ESA for access to data from TOPEX / Poseidon and ERS-1 and ERS-2 data.

Glossary

Altika A proposal within CNES for a Ka band altimeter satellite.
ATSR Along Track Scanning Radiometer — satellite instrument to measure surface temperature
AVHRR Advanced Very High Resolution Radiometer — satellite instrument to measure surface temperature
AVISO Archivage, Validation, et Interpetation des donnees des Satellites Oceanographiques. Distribution agency for TOPEX and other altimetry data, part of CNES.
BMT British Maritime Technology.
BV Bureau Veritas.
CCAR Centre for Astrodynamics Research, University of Colorado
CEO Centre for Earth Observation, based at JRC.
CETP Centre d tudes des Environnements Terrestre et Plan taire.
CF Corsica Ferries.
ClioSat A satellite derived wave climate database from Meteomer.
CNES Centre National d Etudes Spatiales.
COMKIAS Conveying Metocean Knowledge Information into an Advisory System — A proposal to develop and test a complete ship based advisory system.
DM Demonstration Module
EC European Community
ECMWF European Centre for Medium Range Weather Forecasting.
ENVISAT An ESA Earth Observing satellite to be launched in June 2001
EO Earth Observation
ERS-1 ESA Remote Sensing satellite, 1991-1996.
ERS-2 ESA Remote Sensing satellite (follow-on to ERS-1), launched in 1995 and currently operational.
ESA European Space Agency.
ESR Earth Science Research , Seattle, USA
EUROWAVES A European Framework IV project, led by OCEANOR.
EWSE European Web Server Exchange — now replaced by INFEO.
GAMBLE Global Altimeter Measurements By Leading Europeans, A Framework V proposal from Satellite Observing Systems and CNES.
GANDER A proposal for a constellation of wave measuring micro-satellites.
Geosat US Navy altimeter satellite, 1984-90.
GWS Global Wave Statistics, a development from OWS.
Hs Significant Wave Height.
HSC High Speed Craft.
IMDSS Integrated Marine Decision Support System (a hindcast derived wave climate database from OceanWeather Inc.)
INFEO Information on Earth Observation, web site developed by CEO.
JASON US /French altiemter satellite, follow-on to TOPEX, to be launched in February 2001
JIP Joint Industry Programme.
JRC The EC Joint Research Centre, Ispra, Italy.
MCS Monte Carlo Simulation..
NOAA National Oceanic and Atmospheric Administration.
NRT Near Real Time.
OGP International Association of Oil and Gas Producers.
OWS Ocean Waves Statistics. An early wave climate database, derived from visual observations, from BMT
PODAAC Physical Oceanography Distributed Active Archive Centre, USA.

Poseidon Solid state radar altimeter, operating on the TOPEX platform.

Quikscat A US wind measuring scatterometer satellite, currently operational.

RSMAS Rosenstiel School of Marine and Atmospheric Science

SAR Synthetic Aperture Radar.

SEAROUTES Framework V proposal in the Growth programme, to develop a decision support system for fast ocean vessels.

SEASAT Earth Observing Satellite, launched in 1978.

SSA Sea State Alarm ,a demonstration fast delivery service from Satellite Observing Systems

SST Sea Surface Temperature.

STASCO Shell International Trading and Shipping Company Ltd.

SWAN A third generation shallow water wave model.

SWIMSAT A proposal for a real aperture radar wave measuring satellite.

TIROS advanced Television InfraRed Observation Satellites. A series of NOAA satellites from 1978 onwards, carrying AVHRR instruments.

TOPEX US / French altimeter satellite, launched in 1992 and still operational.

VAC Voyage Acceleration Climate, software used as part of office based design method.

Wavsat A satellite derived wave climate database from Satellite Observing Systems.

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WWW Links

ARGOSS Wave Cliimate Database: http://www.waveclimate.com/

AVISO http://sirius-ci.cst.cnes.fr:8090/HTML/information/general/welcome.html

Bureau Veritas: http://www.bureauveritas.com/

CCAR: http://www-ccar.colorado.edu/

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Corsica Ferries: http://www.corsica-ferries.fr/index_en.html

Dockwise: http://www.dockwise.be

GANDER: http://www.satobsys.co.uk/GANDER/webpages/ganhome.html

IFREMER: http://www.ifremer.fr

INFEO: http://www.infeo.org

Jenifer Clark s Gulfstream: http://users.erols.com/gulfstrm/

LagerLoef Earth Science Research, Seattle:: (http://www.esr.org.lagerloef/sfcV/sfcV.html)

OCEANOR World Wave Atlas: http://www.oceanor.no/wwa/

OceanWeather: http://www.oceanweather.com/

OGP (The International Association of Oil and Gas Producers:
http://www.ogp.org.uk/index.html

PLEIADES: http://www-projet.cst.cnes.fr:8060/PLEIADES/Fr/index.html

PODAAC: http://podaac-www.jpl.nasa.gov/

RSMAS: http://www.rsmas.miami.edu/

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(http://www7320.nrlssc.navy.mil/npacnfs_www/NPACNFS.html)

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ANNEXES

1. Internal Project Notes

1.1 Notes on Participation of Corsica Ferries, *P.D. Cotton, June 2000, 1 page.*

1.2 Notes Regarding Final Meeting *P.D. Cotton, October 2000, 1 page.*

1.3 Letter Confirming Conclusion of Scientific Work *P.D. Cotton, October 2000, 1 page.*

1.4 Letter Detailing Completion of Project Deliverables *P.D. Cotton, October 2000, 1 page.*

2. COMKISS / OGP Workshop Agenda and Report,

P.D. Cotton and M. Olagnon, October 2000, 2 pages, Notes for internal project distribution

3. Project Deliverables

3.1 Project Management and Quality Plan (WP1000) *G. Lindgren, 4 pp, September 1998*

3.2 First six month Progress Report *COMKISS Project Team, 4 pp, February 1999*

3.3 Technical Annex rev1 *COMKISS Project Team, 39 pp, May 1999*

3.4 User Requirement Document (WP2000) *G. Lindgren,, 4 pp, May 1999*

3.5 First Annual Report *COMKISS Project Team, 27 pp, October 1999*

3.6 Six Month Progress Report *COMKISS Project Team, 6 pp, February 2000*

3.7 Final Project Report *COMKISS Project Team, December 2000*

3.8 Technical Implementation Plan *COMKISS Project Team, December 2000*

4 Scientific Publications and Scientific / Technical Reports

4.1 Distributions of Responses experienced by a vessel, *A. Baxenavi, K. Podg rski, and I. Rychlik, COMKISS Scientific Report, 23 pp, September 2000.*

4.2 A statistical analysis of satellite data of wave parameters in the Mediterranean and Northern Atlantic Ocean *A. Baxenavi, G. Lindgren, I. Rychlik, and L. Tual, COMKISS Scientific Report, 31 pp, September 2000.*

4.3 Comparison of wave databases and design methods for major shipping routes *C. Leenaars, S. Louazal, and P. Brugghe, COMKISS Scientific Report, 77 pp, July 2000.*

4.4 High Speed Passenger Craft — COMKISS WP4000 Final report *R. Nerzic and M. Prevosto, COMKISS Scientific Report, 45 pp, October 2000.*

5 COMKISS Project Web Page and Demonstration Modules

6 COMKISS Dissemination Material