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.

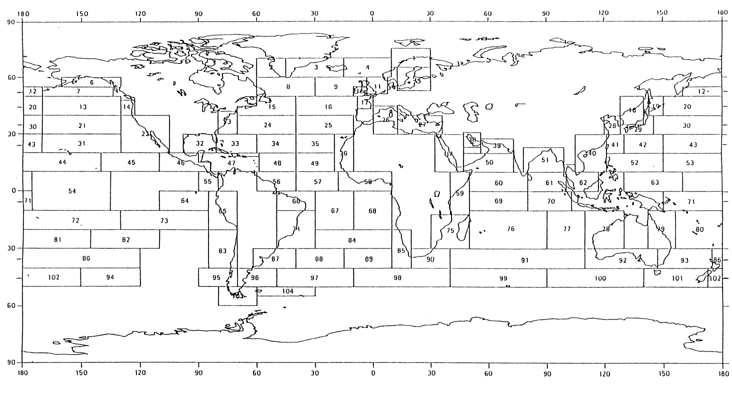


Figure 2.13. The Global Wave Statistics data grid.

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).

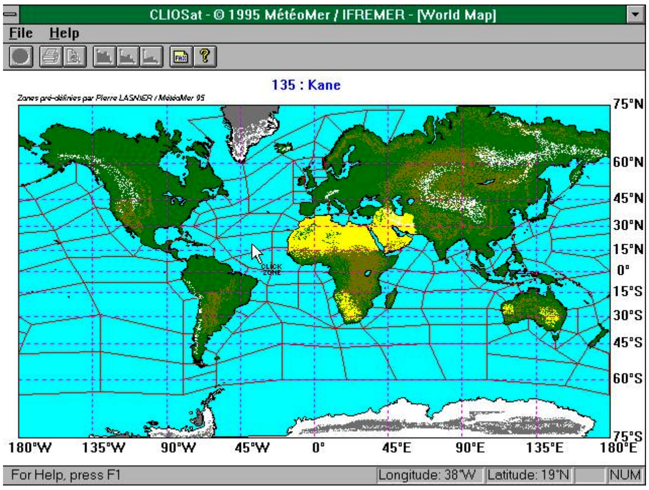


Figure 2.14 The Cliosat global data base

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.

	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.

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).

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).

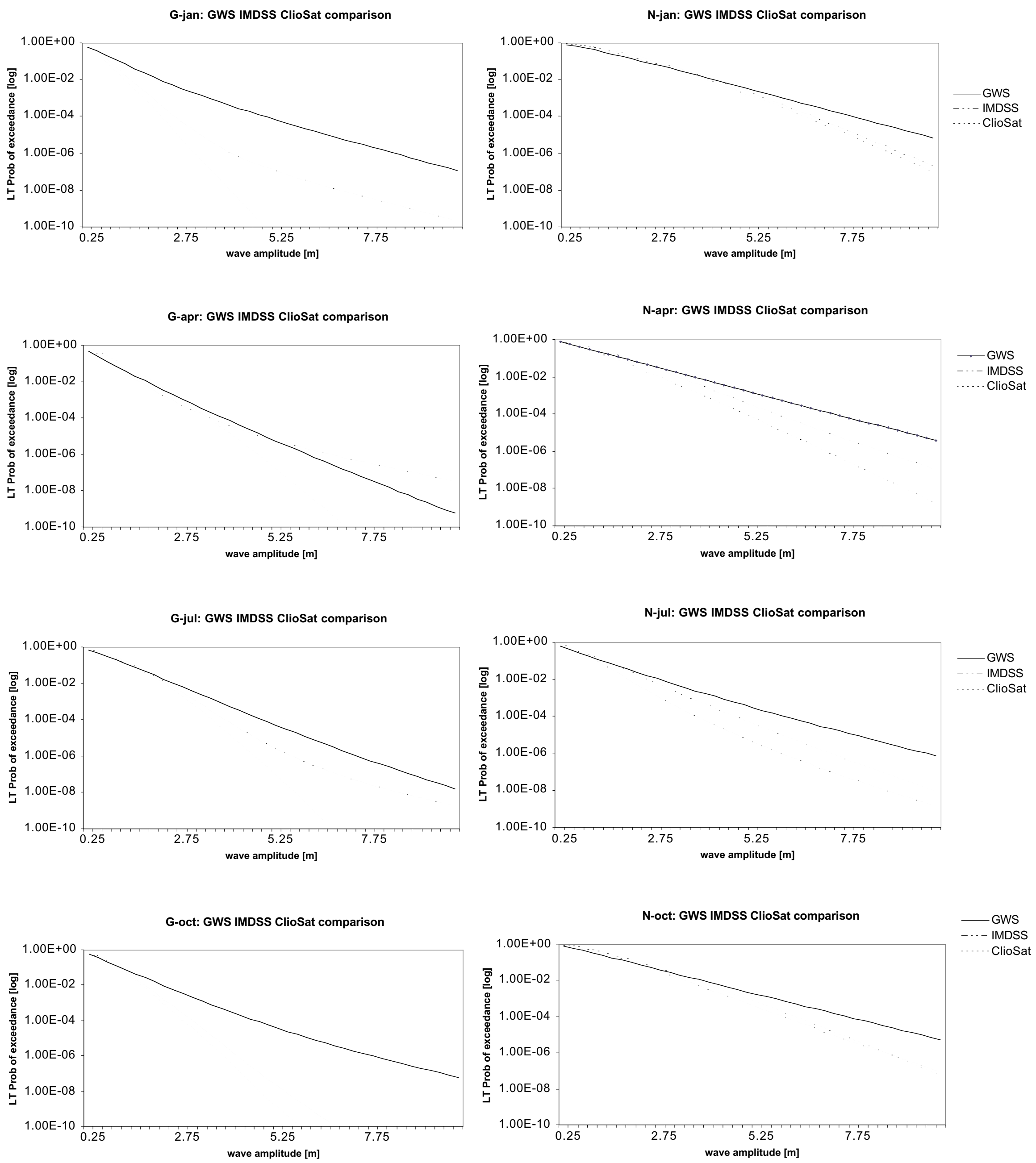


Figure 2.15 Exceedance probability charts derived from VAC from the GWS, IMDSS and Cliosat databases, for two routes: Colombo to Singapore (left —route G) and Hiroshima to San Francisco (right —route N). The probabilities have been calculated separately for each of four three-month seasons (the nominal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

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).

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.

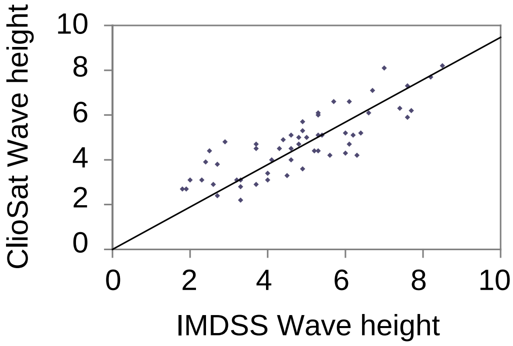


Figure 2.16 Scatter plot of Ha (maximum probable wave amplitude on voyage), as calculated from the Cliosat and IMDSS databases. 56 data points —one for each of four seasons on each of fourteen routes.

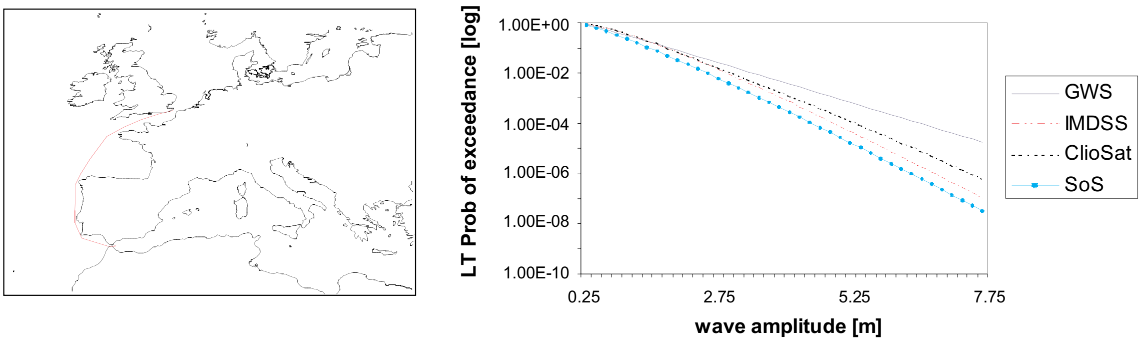


Figure 2.17 VAC output (as Log probability of exceedance for Ha) for the GWS, IMDSS, Cliosat and SOS (Wavsat) databases for the Dover to Gibraltar shipping route (left panel).

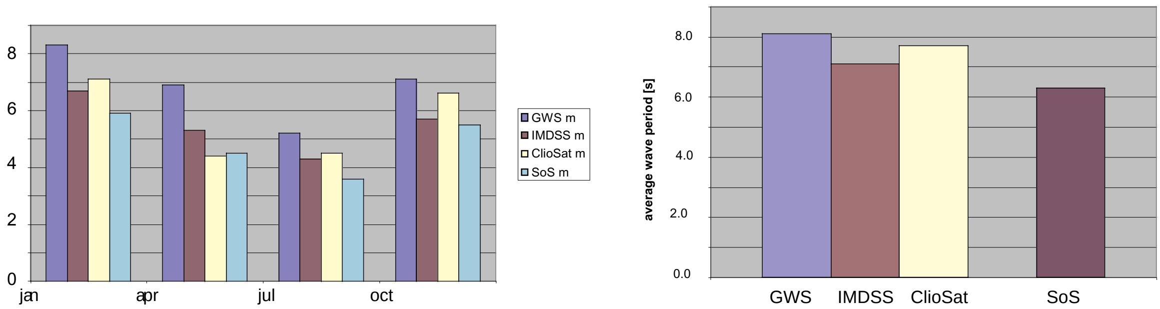


Figure 2.18. Histograms of VAC output for the Dover to Gibraltar route. Left - 2.18 Hs (for one voyage) for GWS, IMDSS, Cliosat and SOS (Wavsat) databases for the Dover to Gibraltar shipping route (left panel).

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.

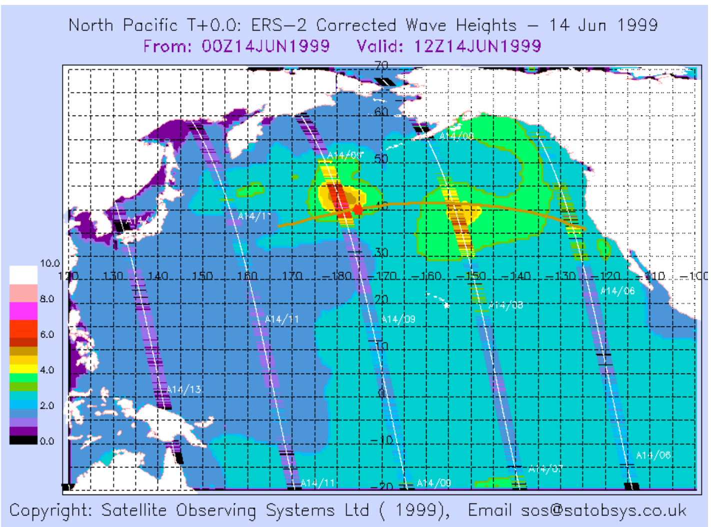
Review of Dockwise Express 20 Sea state alarm trial

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.

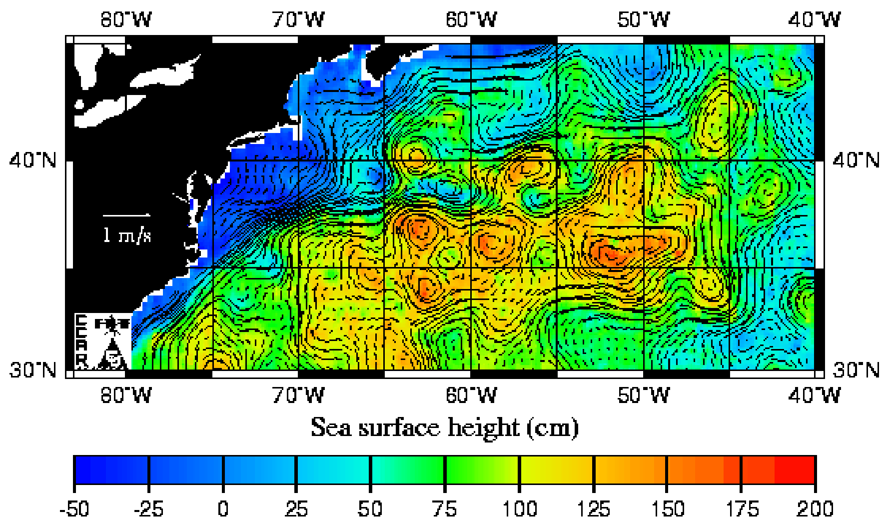
The purpose of this work package (WP5300) was to establish the present state of the art in the use of satellite data to monitor surface currents, to identify those systems which seem to offer the best opportunity for development into an operational system, and to establish the steps necessary to achieve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

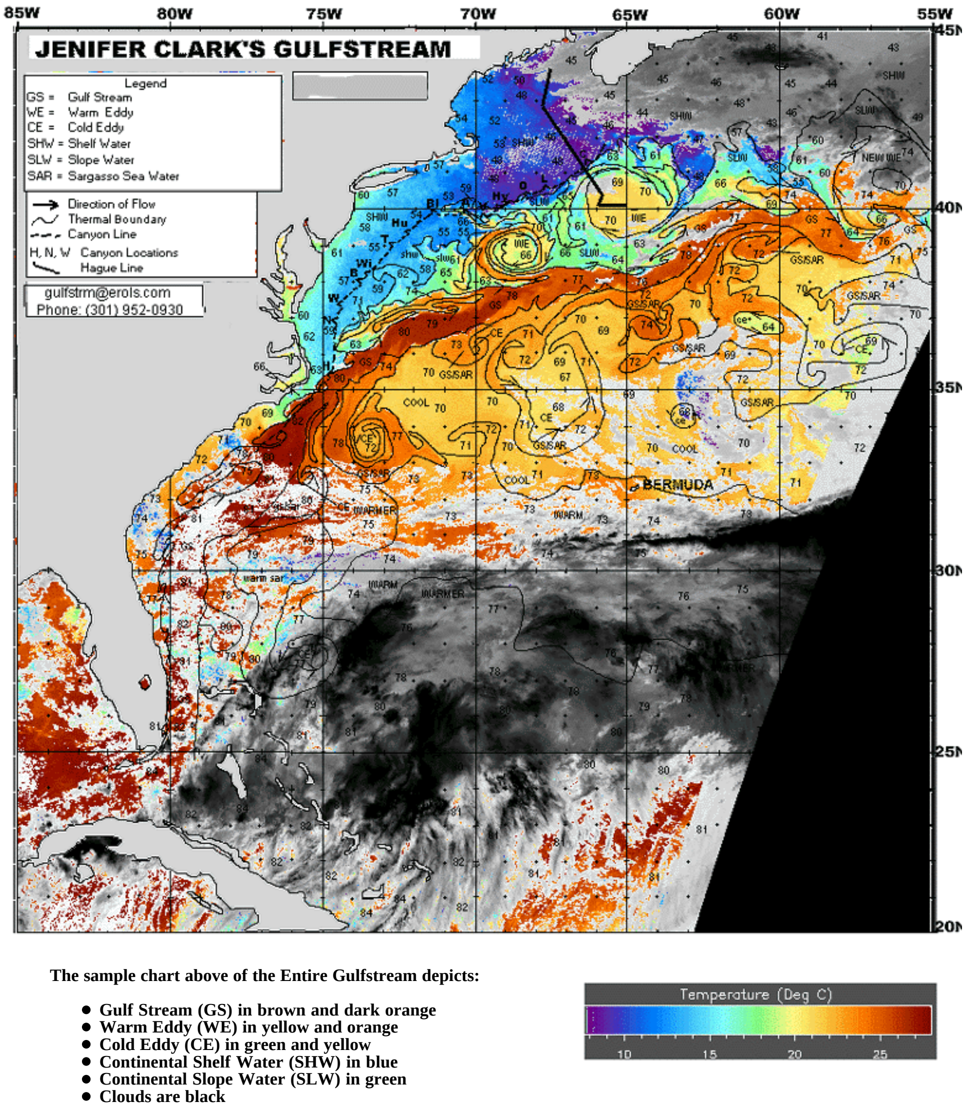


Figure 2.22 An example chart of the Gulf Stream off the eastern US coast, from "Jenifer Clark s Gulf Stream" service (JCG)

- **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.

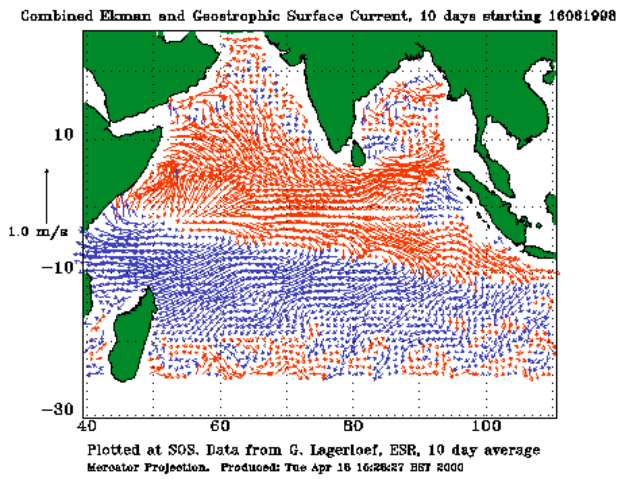
Case study

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).



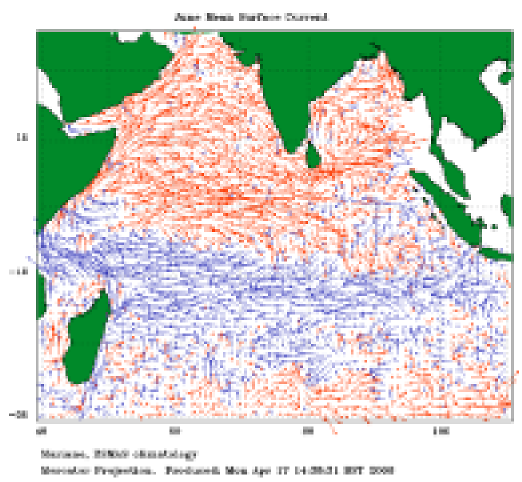


Figure 2.23 ESR (left) and RSMAS (right) surface current data for June; Red arrows indicate eastward flowing currents, blue arrows indicate westward flow

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.

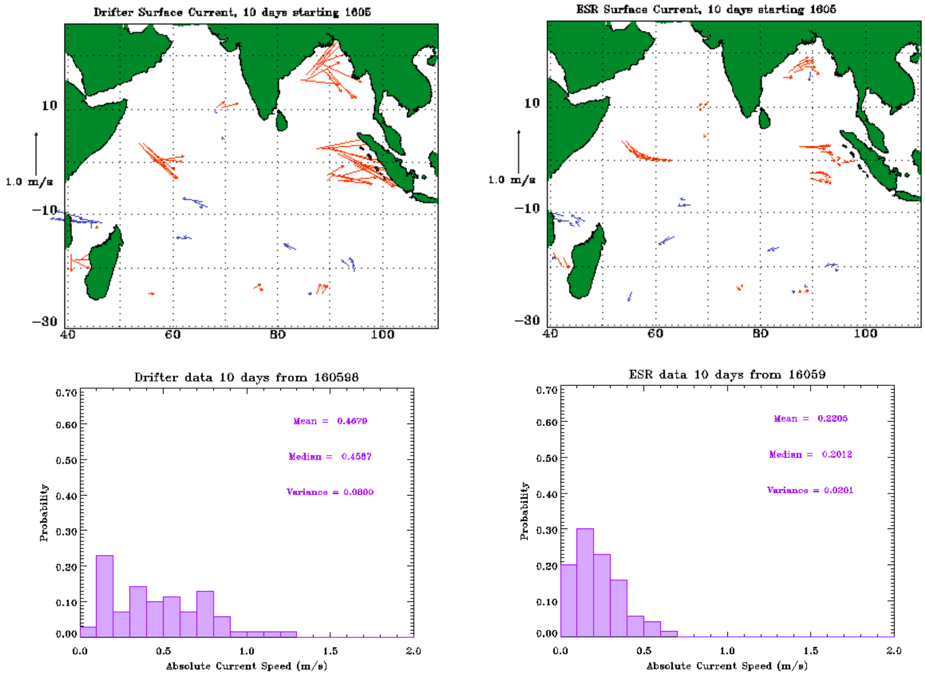


Figure 2.24 Drifting buoy (right) and ESR (left) surface current data for May/June. For this comparison ESR data were extracted only at the locations where buoy drift data were available. Bottom panels give histograms of speed distributions for these data.

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.

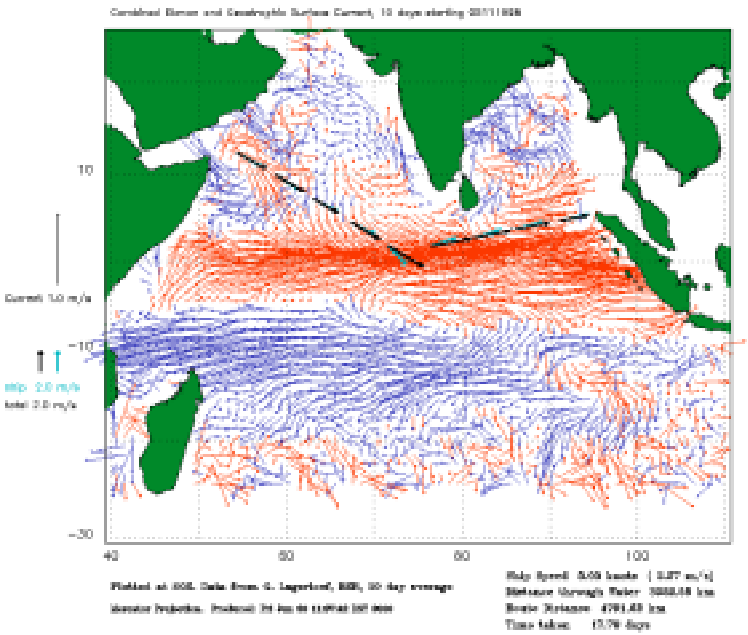


Figure 2.25. Ship routing trial for 05/11/98 (NE Monsoon). The ship (green) and combined ship and current vectors (black) are indicated by the heavy arrows. The underlying current fields are indicated by the red (east flowing) and blue (west flowing) arrows.

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.