COMKISS WP5100

Comparison of wave databases and design methods for major shipping routes

Version 1.1

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Introduction

The aim of this report is to compare three databases (GWS, IMDSS and ClioSat) providing ocean parameters (wave height and wave period) when used in design methods.

The report consists of three main parts:

- The description of available databases, including a discussion of advantages and disadvantages
- The comparison of the databases when used in VAC program
- The description of different methods of design used by sea transportation industry.

1 Wind and wave databases

1.1 Introduction

There are several databases available for the design of transport and offshore installation works.

The following databases will be discussed:

- OWS
- GWS
- IMDSS
- ClioSat

Design waves will be compared for each database on the major shipping routes of the world. The pro's and con's of each database will be discussed.

1.2 Ship-Based Visual Observations

Visual observations of commercial ships are done all over the oceans and seas, and collected by eight meteorological organisms. The first observations were archived by British people in 1854. They have systematically been collected since 1961 according to the Resolution 35 of the Worldwide Meteorological Organisation.

These data have been analysed and compiled in statistics on geographical areas. Hogben and Lumb (1967) have published these statistics in atlases such as "Ocean Wave Statistics" and the more commonly used "Global Wave Statistics" by Hogben, Dawnka and Olliver (1986).

The correlation with buoy measurements shows considerable scatter. Therefore these measurements have to be carefully used. The wave period is especially difficult to assess. Consequently, periods are unreliable and uncorrelated.

Data from ship-based visual observations (known as VOS, Volunteer Observing Ships) have been analysed by Hogben and Lumb (1967) and first referred to as Ocean Wave Statistics (OWS). Hogben and Lumb compared the VOS archive with instrumented measurements and found substantial bias. Based on comparisons, Hogben and Lumb (1967) developed simple linear regression models to remove bias in the raw VOS data. This bias can be explained by the tendency of ships captains to avoid bad weather.

In 1986, the oil industry started using an improved version of OWS developed by Hogben et al. (1986) known as Global Wave Statistics (GWS). GWS was motivated in part by the realisation that OWS underestimates the probability of extreme waves (OWS underestimates buoy data by 20%, see reference 1), especially in regions with large amounts of swell energy (Hogben et al., 1986). GWS is based on an analysis of 55 million VOS observations collected from 1854 to 1984. To remove bias, an empirical correction was developed based on joint probability distributions between the wind and wave height. Hogben et al. (1986) labelled their correction technique "NMIMET". This allowed unrealistic estimates of the wave height to be eliminated from the database.

Periods in GWS do not come directly from visual assessments but are deduced from wave height distributions according to a "height-period" model.

GWS altlas consists of two databases: a worldwide database and a database for Europe. The worldwide database consists of 104 Marsden squares, the European database consists of 31 Marsden squares.

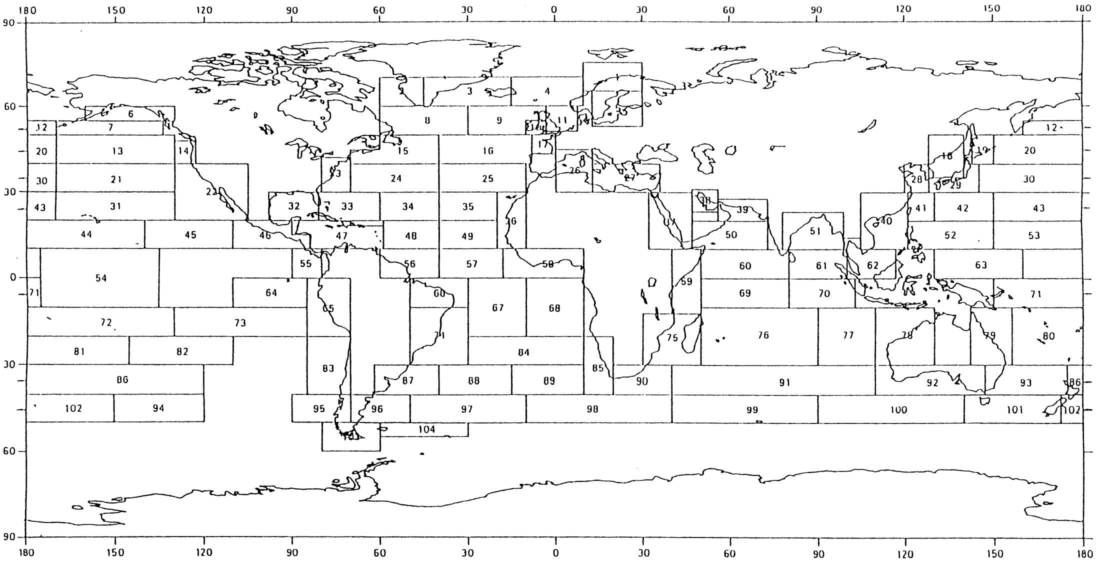


Figure 1 - GWS climatological areas

Each square contains seasonal and directional scatter diagrams. So in fact, the database contains for each season (4 + annual), for each direction (8 + all directions) for each area (31+104) scatter diagrams (6075).

Advantages

- Historical database: Gathering data from 1854 to 1984, ship-based observations remind a real historical database.
- Vast amount of data concentrated on major shipping routes: data are not homogeneously scattered, but are concentrated on major shipping routes. For the design of fixed structures OWS and GWS are consequently less suited.
- Avoidance of bad weather is included in the original OWS database.

Disadvantages

- Bad accuracy for periods assessments. Period data have been corrected by a meteorological model including a "height-period" joint distribution.
- Data are scarce or incoherent in large areas, which are not often crossed by shipping routes.

- Waves only: ship-based observations give information on waves only, there is no information on wind.
- Seasonal influences are not well modelled: no real good weather and no real bad weather are included in the database.

Conclusions

Since OWS scatterdiagrams are biased by the avoidance of bad weather, this database can give an indication of the effect of bad weather avoidance on ships motions.

GWS was extensively validated using instrumented observations. The comparisons for the northern oceans generally look good even in the tail of the distributions. The NMIMET correction clearly improved the comparison with data over that achieved with the uncorrected VOS data (labelled ‘raw data’ in the plots).

On the negative side, GWS has not been well validated along important routes in the southern oceans, Western Pacific, South China Sea, and low latitudes. This is largely because of the absence of instrumented data in these regions. The few comparisons are generally unimpressive.

Error statistics show substantial scatter, especially for the wave period.

1.3 Hindcast

Hindcast method consists in using historical wind databases. Swell climates are reproduced from meteorological wind maps. Swell assessment is based on wind speed, wind direction, his action time and fetch length.

The first methods are based on tables and formula (SMB and PNJ methods). These methods are not accurate ones: an error of 10% in assessing wind speed brings about errors of 45% on spectral energy and 22% on wave height.

IMDSS (Integrated Marine Decision Support System)

IMDSS is a forecast system developed by Oceanweather Inc. Following a number of highly successful regional implementations of the forecast system for specific offshore industry projects, the forecast system has been operational continuously since 1989 to provide global wind and sea state forecasting in support IMDSS operated as a joint venture with Ocean Systems Inc. of Oakland CA. Most recently, regional implementations of the IMDSS system, known as CYCLOPS (Tropical Cyclone Operational Prediction System) have combined high-resolution wind/sea state forecasts with probabilistic tropical cyclone track prediction.

This option is not used in VAC program and Monte-Carlo Simulation: in Monte-Carlo Simulation, a separate Hurricane database is called upon developed by ARGOSS b.v.

The IMDSS global wave statistics database covers the globe with 5926 gridpoints. The spatial grid is 2 ½ degrees in both longitude and latitude. The data is the result of an 4-year analysis of wind data.

Wave and wind data are archived in time and space. The directional wave spectra are archived by 12 parameters. Windfields are specified through reanalysis of surface pressure fields and use of enhanced ship report data files.

For VAC calculations these data are condensed to a wave database with 3-parameter scatter diagrams. No information on wind is available in this database.

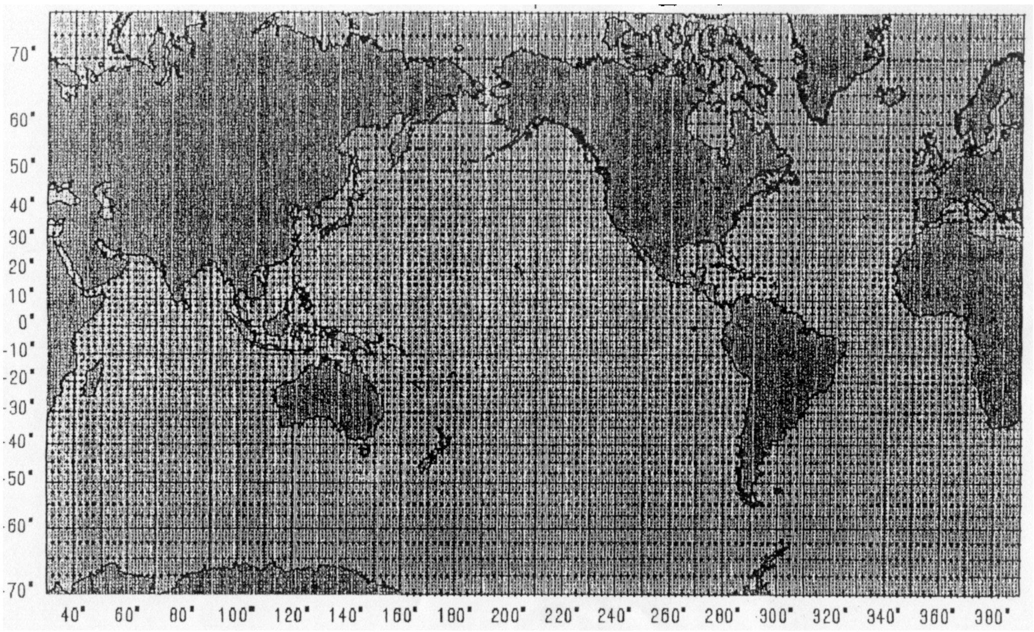


Figure 2 - IMDSS global spectra wave model grid

Each gridpoint has 45 normalised scatterdiagrams, first broken down into 5 categories: “all months and years” and 4 3-month seasons. Within each category there are 9 directionally stratified tables.

Advantages

- wave and wind data are archived; this makes it possible to model wind heel correctly
- persistence studies/good quality for MC Simulations
- 40-year time series
- three years with directional spectra
- grid size and time step for refined local studies
- also the forecasted weather is archived; this will make it possible to model weather routing and bad weather avoidance in design methods

- Tropical cyclones will be included in MCS by a separate worldwide cyclone database. This database contains historical tropical cyclones from 1970 until now

disadvantages

- accuracy limited for refined studies of extremes
- not suited to investigate climatological effects

conclusions:

- good quality for MC simulations / persistence studies
  refined local studies
- not good for refined studies of extremes, climatological changes
- suitable for fatigue analysis and reliability based transport/installation design
- suitable to model weather routing, short trip scenario's, installation procedures, weather avoidance, survival tactics, etc.

1.4 Satellite Observations

Satellite measurements have revolutionised for a decade investigation means in marine field: sensors of the moving satellites ERS2 and TOPEX / Poseidon offer now reliable characterisations of wind and sea conditions. They obtain parameters such as:

- Significant wave height and wind speed from TOPEX / Poseidon and ERS2 altimeters (one measurement every 7 km),
- Wind field (force and direction) from ERS2 scatterometer (one wind vector every 25 km on 500km-wide path to the right of the satellite track.
- Directional spectrum of wave height from the ERS2 Synthetic Aperture Radar in wave mode. Products are obtained every 200km to the right of the satellite track.
- Sea surface temperature from ERS2 infrared radiometer.

Active sensors transmit microwave pulses and measure the energy reflected by sea surface. The altimeter principle is based on specular reflection (wave slopes) while scatterometer and SAR principles are based on Bragg diffraction (wave ripples).

Satellite sensors accuracy now competes that achieved by conventional 'in situ' methods. The altimeter on Topex Poseidon measures its own height above the sea surface better than 5 cm and the average accuracy over one month is about 2 cm. The SAR radar has achieved a spatial resolution of about 25m. Changes in sea-surface temperature of a few tenths of a degree are detectable with ESA radiometer. And surface wind velocities over the sea can be measured over 50 km cells to an accuracy of about 2 m/s in speed and 20º in direction.

Satellite observations can be accessed either as raw data or from added value resellers such as Satellite Observation System (SOS), Oceanor or Meteomer & Ifremer. The corresponding products are:

- SOS: WAVSAT (climatologies).
- Meteomer & Ifremer: ClioSat (climatological atlas).
- *Oceanor: World Wave Atlas (climatological atlas).*
- *ARGOSS: Clams*

For operational purposes, one should definitely prefer validated and extracted values to the raw data, but the latter may be useful in the research phases of the development of new methods. SOS, Oceanor, and Meteomer & Ifremer provide climatological statistics for almost any oceanic area in the world, the only limitations are those of the operation of satellite altimeters in the vicinity of coasts. Meteomer & Ifremer and, to some extent, Oceanor, also provide the information in the form of an atlas with pre-defined areas, including additional information, derived from SAR and scatterometer products, on the directions of wind and waves, and on wave periods.

More details on these products can be found in Appendix A.
A comparison of the SOS database for the route Dover – Gibraltar can be found in Enclosure G.

Near Real Time

Sea transportation industry expects satellite observations to be an improvement in near real time assistance.

Indeed, products from altimeter measurements can be delivered within 24 hours at grid points. Meanwhile, near real time assistance require a complex development system, which can be hardly installed on a ship and only used by experts. Furthermore, near real time assistance is difficult to implement since a satellite cannot follow a ship track.

Ice

Satellites are particularly suitable for monitoring the Polar Regions where the weather can be inhospitable and the area enveloped in cloud or darkness for long periods of the year.

The two satellite-borne sensors, which provide information on ice conditions, are the Synthetic Aperture Radar and the altimeter. The imagery produced by SAR (on board of ERS 1&2 and Radarsat) is useful not only for the day-to-day operation of vessels, assisting them to find passages through ice, but can also be used to study the seasonal and inter-annual changes over polar ice-caps which may reflect changes brought about by global warming.

The altimeter carried by ERS 1&2 were specifically designed to track over ice surfaces. The difference in waveform - ocean to ice – can be used to track with good accuracy the edge of ice sheet.

Advantages

- With respect to conventional databases, satellite information presents the advantages of better quality/accuracy, especially in areas where there are few reliable field measurements that could be used to calibrate hindcast models. The statistical coverage (see figure in appendix A) is good compared to visual observations for regions where there are no main shipping routes.

- Previous comparisons consistently show that an altimeter measurement is nearly as accurate as a high-quality in situ instrument in the absence of heavy rain.

- Satellite data are gathered to smaller ocean areas than GWS data. Thus giving for these areas more accurate predictions. The satellite data provide also considerably more information (directional wave spectra, sea surface temperature) than the GWS data being this way applicable for wider forum of users.

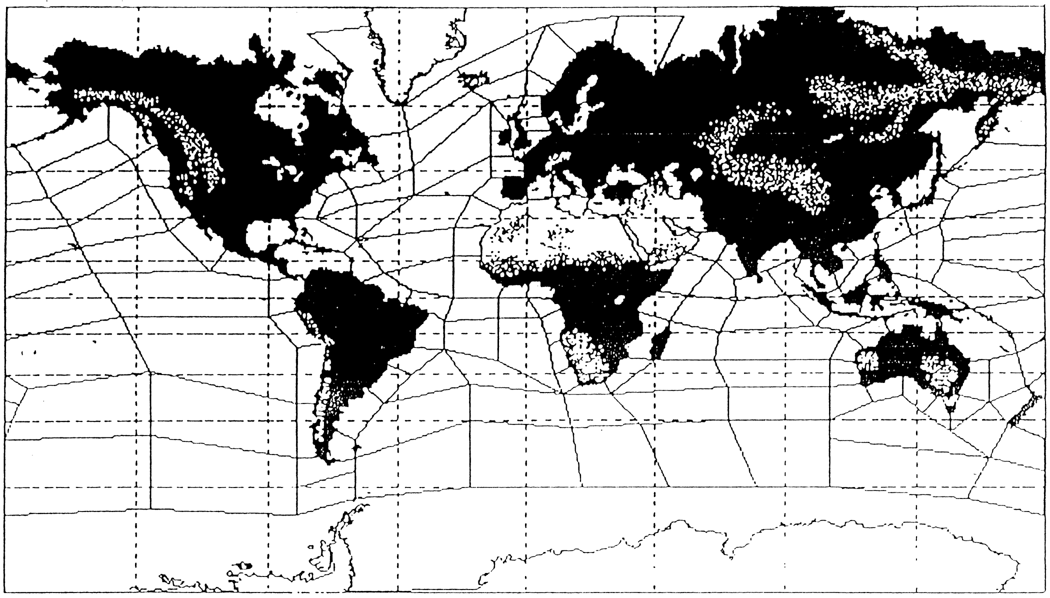


Figure 3 - ClioSat climatological areas

Disadvantages

- Satellite observations databases share 3 potential sources of error of concern to this application: interdecadal variations, sensor accuracy, and undersampling.

  - ✓ Interdecadal variations refer to natural variations in the storm severity that might occur over time scales of a decade or more. Since the satellite databases cover 7 years or less, they will miss longer-term variations.

  - ✓ Many investigators have studied altimeter sensor accuracy. They have found that satellite measurements can be corrected by a simple linear relationship in order to be consistent with weather buoys measurements. These results suggest an altimeter measurement is as accurate as a high-quality in situ sensor for most atmospheric conditions. Some questions remain concerning sensor accuracy in the presence of heavy rainfall such as is usually found in tropical cyclones: wave height and wind measurements are overestimated in the presence of heavy rainfall. Since heavy rainfall is inherent to tropical cyclones it follows that the satellite databases will tend to be have some artificially high waves in regions dominated by tropical cyclones.

- ✓ The last form of error, undersampling, was extensively studied by Cooper and Forristall. Undersampling of storms can result because satellites only revisit a site once every 10-35 days, and their tracks are separated by 100-200km. With this coarse sampling, the satellite may miss smaller storms like tropical cyclones since they have characteristics length and time scales as short as few hours and tens km. Reliable estimates of the 100-yr extremes can be calculated from the present satellite database for parts of the world where extremes are driven by extra-tropical storms and monsoons. That is because these storms occur frequently and have large characteristic length scales. Satellite undersampling could introduce serious errors in region where the extremes are dominated by tropical cyclones.

- The drawbacks of satellite observations stem from their discontinuous sampling in time and space. It is not possible to use them to construct exact histories of sea states at a given location or for a sailing ship.

  This thus rules out the possibility of using bootstrap methods, i.e. simulations using histories and introducing randomness by an arbitrary choice of the departure date, with satellite databases, unless some way can be found to extract from satellite data sufficient information on the underlying correlation structure in time and space of the sea states. Investigations will be undertaken in the COMKISS project to this aim, but in the meantime, only methods that do not take into account the history of the sea state succession can be used with satellite databases.

conclusions:

- good quality for climatological studies (except cyclones)
- not suitable for MC simulations
- not enough developed for near real time
- Suitable for ice

2 Comparison of databases on major shipping routes

2.1 Comparison method

The comparison between GWS, IMDSS and ClioSat databases is based on VAC calculation results. Fourteen routes were analysed in four seasons for each database.

The routes are chosen in order to be able to compare results with previous studies. Although the routes are on the Northern Hemisphere only, the results will give a good general impression of the IMDSS and ClioSat databases compared with the GWS database.

	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	Kaohsiung
I	Taiwan - Japan	Kaohsiung	Hiroshima
J	North Sea	Dover	Stavanger (NO)
K	North Atlantic Ocean	Halifax	Newcastle (UK)
L	Japan – Arabian Gulf	Hiroshima	Muscat
M	Germany – Arabian Gulf	Hamburg	Muscat
N	North Pacific Ocean	Hiroshima	San Francisco

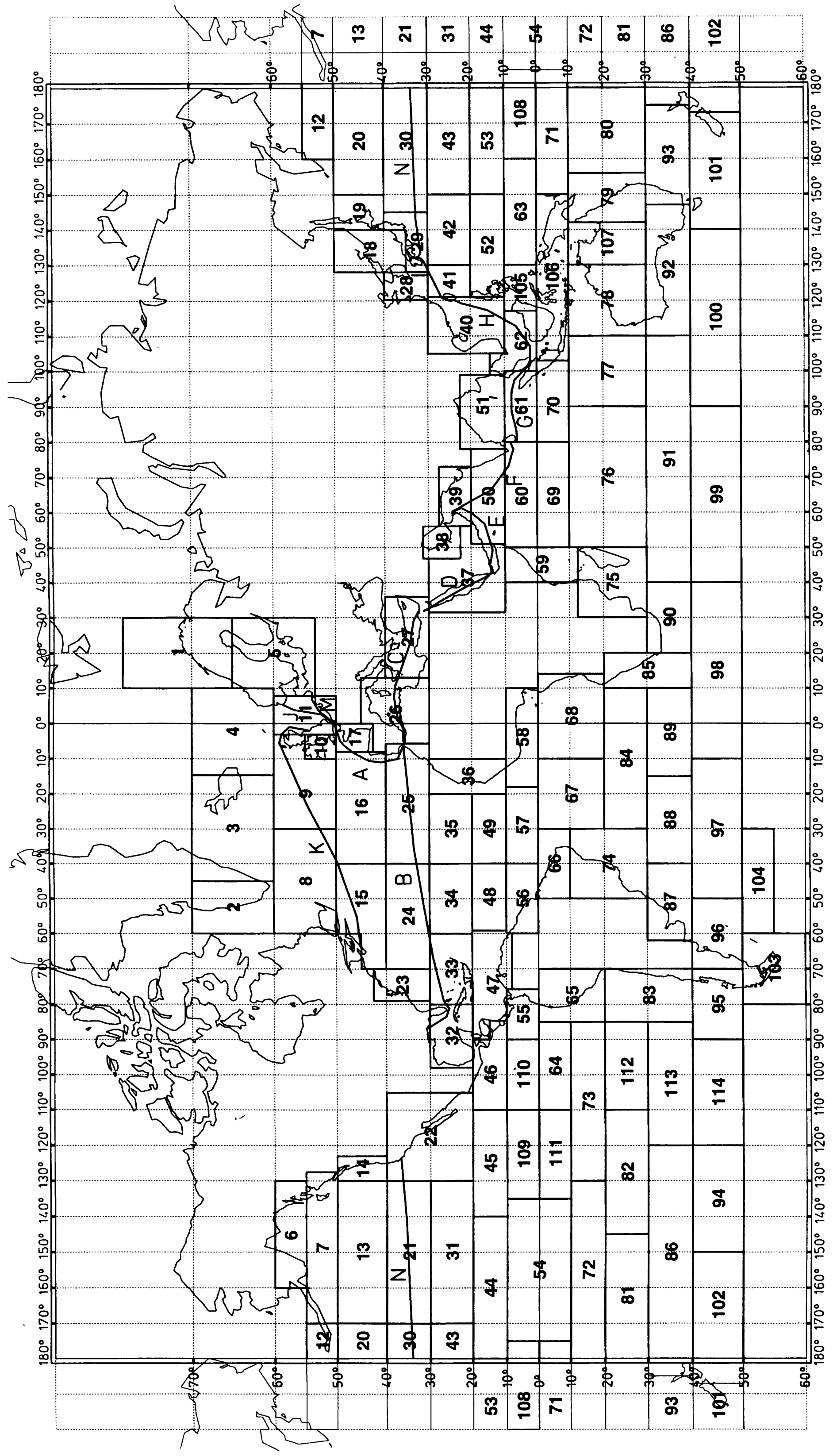


Figure 4 Major shipping routes

2.2 Results

The output of each VAC run has a distribution of the ‘waves as input’ which is given as wave amplitude versus probability. The 168 output files (14 voyages * 4 seasons * 3 databases) have been compared and graphs of the results are given in enclose D.

At the end of each VAC output file, a summary of wave height statistics for the total voyage is given. These values are also compared and given in enclose B.

The following table is a summary of the results for winter season:

Route	**GWS Ha**	**IMDSS Ha**	**ClioSat Ha**	**GWS Hs**	**IMDSS Hs**	**ClioSat Hs**	**GWS 1y-Hs**	**IMDSS 1y-Hs**	**ClioSat 1y-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

The following table is a summary of the results for summer season:

Route	**GWS Ha**	**IMDSS Ha**	**ClioSat Ha**	**GWS Hs**	**IMDSS Hs**	**ClioSat Hs**	**GWS 1y-Hs**	**IMDSS 1y-Hs**	**ClioSat 1y-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

3 Design methods

3.1 Introduction

The most important parameters in transport design are :

- Vessel characteristics:
    - Motion response
    - Stability
    - Strength
- Route characteristics:
    - Environmental conditions (wave, swell & wind climate)
    - Extreme events (tropical cyclones, etc.)
    - Existence of safe havens
    - Re-routing potential
- Weather avoidance:
    - Tactical decisions to avoid forecasted weather
    - Swift decisions to avoid imminent adverse vessel behaviour

Depending on the design method these parameters are modelled more or less accurately or not at all.

The four main categories of design methods may be ranked on basis of simplicity and on the amount of input required:

- The Rules of Thumb only take ship main particulars into account,
- Design Wave Method (short-term statistics) provides accelerations assuming a given sea state and models the ship's behaviour,
- Reliability based design methods (long-term statistics)
    1. Voyage Acceleration Climate (VAC): scatter diagrams calculations
    2. Monte Carlo Simulation (MCS): time step simulation

Reliability based design methods consist of the four following steps:

1. Determination of long term distribution of the extreme response of the vessel during an arbitrary storm: A storm consists of a succession of sea states, each with its associated wind condition. The most straightforward manner to determine the response behaviour in a particular sea state is, in principle, to perform a time domain simulation using a ship model. This has to be repeated for many different realisations of the same sea state, for all sea states in a storm and for all storm events in the database. By appropriate combination of the individual response distribution from each simulation the long-term distribution of the extreme response during an arbitrary storm can be determined.

2. Determination of the long-term distribution of the extreme response during the trip: The prior results are now combined with the probability that a storm will actually occur. This probability usually follows a Weibull distribution and defines the demand.

3. Determine the capability of the construction and seafastening. The capability is assumed to be normal distributed where mean and standard deviation depends on variation in weld-capacity continuity of strength etc.

4. Determine the probability of failure of the structure of the vessel on a given trip by subtracting demand from capability. The results of this step makes it possible to perform an economic risk evaluation and determine an environmental load level for structural design which meets a pre-defined reliability goal.

3.2 Rules 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 angles (20º for ships and 30º for barges) and pitching angles (7 to 10 degrees) associated with typical oscillation periods (the ship's natural rolling and pitching period) to obtain the transverse, longitudinal and vertical accelerations at the specified locations on board of the ship.

The simplicity of the method and the fast delivery of results remain its main advantages, but the ship response is not modelled.

3.3 Design Wave method

In a design wave method, the wave climate is taken into account. A design wave is determined for the trip. It can be the extreme value for the worst area, the extreme value for complete trip by combining scatter diagrams. For extreme values the most probable maximum on the trip or on ten trips can be used. Sometimes 1 year or 10 year return values are proposed by DNV and/or Noble Denton.

Advantage

- The simplicity of the model: few input are required and it is not time consuming with the modern calculation tools.

Disadvantages

- The wave climate is not modelled. Risk and exposure are unknown.
- The method does not model the probability of the design wave height, does not model the response of the vessel to the different wave periods.

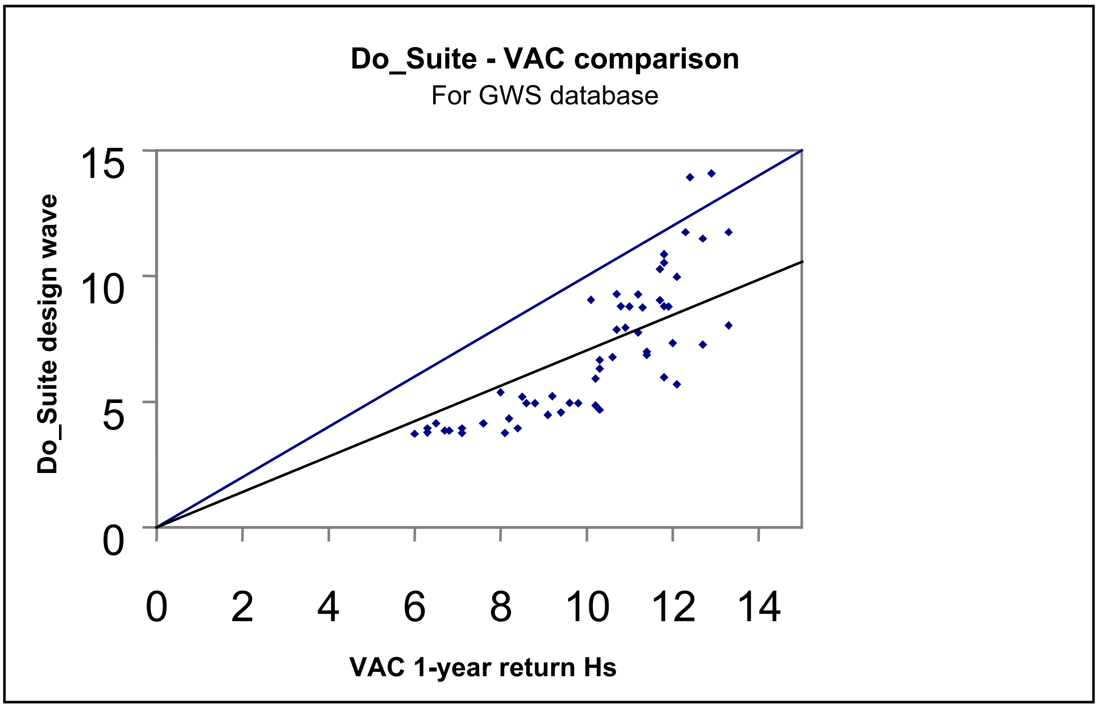
- Since the method does not make use of the complete motion climate for the trip, it cannot answer fatigue and risk exposure questions.
- Weather avoidance (weather routing) and exposure to the climate are not modelled.
- Extreme wind and wave conditions are assumed to act at the same time.

The disadvantages of the design wave method can be simply overcome by calculating the response to all sea states met during the trip since the calculation power of desktop PC's do not limit such calculations anymore.

Dockwise Design Wave Method program is called Do_Suite. Its theory and results are given in enclosures E and B. The method is based on the time spend in the worst area.

In the table below, you find a comparison between the Do_Suite design wave height and the most probable maximum Hs on a trip from VAC and the 1 year return Hs from GWS database.

	winter season				summer season			
	VAC			Do_Suite	VAC			Do_Suite
Route	Ha	Hs	1y_Hs	design wave	Ha	Hs	1y_Hs	design wave
A	9.75	8.3	13.3	11.75	6.76	5.2	9.2	5.23
B	9.68	8.7	11.8	10.87	7.12	5.8	8.6	4.95
C	8.65	6.4	11.4	6.87	5.4	3.9	7.1	3.75
D	5.57	4.1	7.6	4.14	4.6	3.3	6	3.73
E	4.76	3.4	6.5	4.14	8.59	6.7	11.7	9.04
F	4.76	3.6	6.3	3.94	8.53	7	11.2	9.27
G	6.31	4.8	8.5	5.2	5.88	5.1	8	5.38
H	8.15	6.4	10.7	7.87	7.32	5	9.6	4.96
I	8.27	6.4	11.4	6.99	8.41	5.6	11.8	5.97
J	8.67	5.7	13.3	8.04	6.25	3.7	9.4	4.57
K	10.19	9.4	12.9	14.08	8.06	6.8	10.3	6.32
L	8.83	7.1	10.3	6.66	9.19	7.6	10.7	9.28
M	10.33	8.5	12.3	11.75	8.83	6.9	10.1	9.05
N	10.16	9.4	12.4	13.93	8.44	7	10.2	5.92


Do_Suite - VAC comparison
For GWS database
Do_Suite design wave
15
10
5
0
0
2
4
6
8
10
12
14
VAC 1-year return Hs

3.4 VAC method (Voyage Acceleration Climate on a trip)

The motion climate method called Voyage Acceleration Climate (VAC) models the probability of all sea states (included storms) on a trip. A scatter diagram for the whole trip is constructed by weighting the scatter diagram in each climatological area or bins, for the time spend in that bin. This way the long-term distribution of the ship motions can be calculated by calculating the response to each sea state (storm) in the database.

This method therefore makes it possible to perform economic risk assessments, design to a pre-defined reliability goal and perform fatigue analysis.

The effect of ships routing and bad weather avoidance tactics by the ships crew can only be roughly approximated in this method. Wind and waves are un-correlated and therefore motions caused by extreme wind can only be combined with the extreme wave condition resulting in conservative assumptions.

Advantages:

- Economic risk assessments possible
- Design to a pre-defined reliability goal possible
- Fatigue analysis possible
- Databases available with sufficient duration

Disadvantages:

- Weather routing and bad weather avoidance can only be approximated
- Transports and installations with weather windows can only be approximated.
- Swell is not separately included
- Wind can only be modelled conservatively (separate non-correlated.)

More details about Voyage Acceleration Climate are given in enclosure F.

3.5 Monte-Carlo Simulation method (Randomly repeated trip simulation)

For this method a database has to be constructed that stores the wind and waves plus the forecast for each day.

Then a day is chosen on which a trip is started by throwing a dice. In 12 hr steps the trip is completed and the response to each sea state met is calculated. By repeating this exercise sufficiently often the long-term distribution of the motions can be constructed. Due to the availability of the weather forecast in the database also the effect of routing and bad weather avoidance can be modelled. This method is also suitable to model weather restricted operations. For example short trips and offshore installations with weather windows.

Advantages:

- Swell, wind and waves modelled
- Bad weather avoidance and bad weather tactics modelled
- Short trip and offshore installations with weather windows can be modelled:
- Economic risk evaluation possible
- fatigue analysis possible

Disadvantage:

- Very time consuming

4 Discussion of the results

4.1 General comments

- GWS results are approximately 30% higher than IMDSS and ClioSat results; this confirms previous studies.
- Previous studies also show that IMDSS and Cliosat data compare well in most of the cases.
- Comparison between IMDSS and ClioSat looks quite good regarding Ha and Hs values: ClioSat results are about 3% higher than IMDSS results.
  IMDSS-ClioSat comparison scatter graphs are given in enclosure C.
- ClioSat 1-year and 10-year return Hs are low (5% lower than IMDSS and 35-40% lower than GWS.) For transports these values are not meaningful.
- For route G in April, IMDSS results are inconsistent because the database is affected by a tropical cyclone that occurred in 1997. The short time coverage of the database makes it sensitive to extreme events.
- ClioSat results for route E and F in April are high compared with IMDSS results. On areas met by both routes, the two databases include data assessed during monsoon and which are not compiled over the same seasons (see the following paragraph)

4.2 Monsoon

Routes E and F are affected by the monsoon phenomenon. One can notice that IMDSS and ClioSat databases, which use to give approximately the same results, differ a lot for the month of April on both routes.

The monsoon effect on the sea state varies with months. On December, January and February, the monsoon is directed north-east, i.e. from shore to sea. That induces low values of wave height. On May, June, July, August and September, the monsoon is Southwest (from sea to shore), and brings about high values of wave height. There are two transit periods covering March and April months and October and November months.

GWS, IMDSS and ClioSat databases compile statistics over 4 3-month seasons. GWS seasons have been corrected for areas affected by monsoon, according to tropical cyclones that occurred also on these areas.

Tropical cyclones affect areas 39, 50, 60 and 61.

Finally, GWS and IMDSS seasons are most respective to monsoon periods than ClioSat seasons:

Comparison of season definition in monsoon areas for different databases:

	IMDSS	GWS for areas affected by monsoon			ClioSat
		Area 39	Area 50	Area 60	
Season 1	March April May	February March April May	April May	March April	January February March
Season 2	June July August	June July August	June July August September	May June July August September	April May June
Season 3	September October November	September October	October November	October November	July August September
Season 4	December January Februay	November December January	December January February March	December January February	October November December

March – April:	transition of monsoon
May - September:	South-West monsoon
Oktober – November:	transition of monsoon
December – February:	North-East monsoon

Besides tropical cyclones, others events such as typhoon and hurricane induce modifications in GWS seasons. Typhoons affect areas 20, 29, 30, 41, 42, 52, and 62, and hurricanes affect areas 22, 24, 32 and 33.

More interest has to be given for wave height assessments during monsoon than during events with short length scale (tropical cyclones, typhoons and hurricanes). Indeed, these events can be avoided whereas monsoon cannot. Thus, results have to be treated with care during monsoon in areas 39, 50 and 60. The best solution would be to use a monthly database for monsoon areas.

4.3 Conclusions

- GWS database is consistently high, IMDSS and ClioSat databases are basically good.
- Anomalies (such as tropical cyclones) due to short time coverage of IMDSS and ClioSat databases will be resolved by additional years of data and additional satellites.
- ClioSat can provide more information (wind force and direction, directional wave spectra) which could be used in design methods.

Bibliography

[1] AAGE C., ALLAN T.D., CARTER D.J.T., LINDGREN G., OLAGNON M., "Oceans from space", Satellite Uses: a Common Course for Engineering and Sea-conditions Studies, Brest, Ifremer, 1998, 166 pp.

[2] AALBERS A.B., LEENAARS C., "Two years of acceleration measurements on Dock Express heavy lift ships compared with predicted values from several design methods", Spring meetings of The Royal Institution Architects, 1987, paper 7, 13 pp.

[3] CARDONE V.J., COOPER C.K., SZABO D., "A hindcast study of the extreme wave climate of offshore West Africa (WAX)", Proc. 27th Annual Offshore Technology Conference, Houston, Texas, USA, 1-4 May 1995, pp. 439-451.

[4] HOEKSTRA R., " Engineering Guidelines and Criteria", Dockwise, Meer, May 1998, 60 pp.

[5] LEWIS E.V., "The motion of ships in waves", Extract of Principles of Naval Architecture, The Society of Naval Architects and Marine Engineers, 1967, pp. 607-717.

[6] QUADVLIEG F.H.H.A., AALBERS A.B., DALLINGA R.P., "Voyage Acceleration Climate: Functional specifications and Technical design", Maritime Research Institute of Netherlands, Wageningen, July 1998, 48 pp.

Enclosure A: ClioSat database

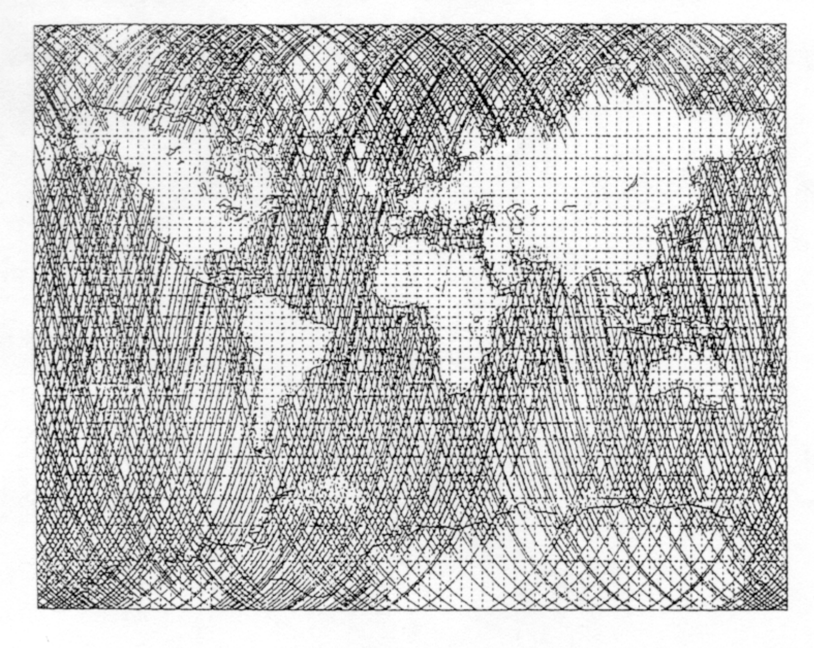


Figure 5 - spatial coverage of ERS 1&2: ground track during its 35-day cycle

ClioSat is a project by Ifremer and Meteomer (France), which is meant for developing satellite-based observations (wave and wind parameters) in order to prepare marine operations. Wave climates are presented on pre-defined bins, or on areas defined by the client, thanks to an on-line service.

Products

Products are available on 169 areas, and 4 quarters. They consist in:

- histograms
  - ✓ of waves (significant wave height Hs, peaks period Tp and peaks direction θp)
  - ✓ of wind (force ff and direction dd)
- diagrams of wave spectral parameters
  - ✓ Tp/θp, Tp/Hs, θp/Hs
  - ✓ Hs, Tz, main peak direction θpp, Hs/Tz, Hs/θpp
- wind diagrams (dd/ff)
- extreme values of significant wave height.

ClioSat sources

ClioSat statistics are provided by the databases of three satellites: GeoSat, ERS1 and Topex/Poseidon. Each satellite contribution is reported in the following table:

Product	Sensor	Satellite	Measurements time cover	Measurements period	Total number of data used in ClioSat
Hs histogram	altimeter	GeoSat, Topex Poseidon, ERS1	7 years	from nov 86 to oct 89 from dec 91 to jun 95	250 000 000
Extreme values of Hs	altimeter	Geosat, Topex Poseidon, ERS1	7 years	from nov 86 to oct 89 from dec 91 to jun 95	250 000 000
ff histogram	altimeter	Geosat, Topex Poseidon, ERS1	7 years	from nov 86 to oct 89 from dec 91 to jun 95	250 000 000
Tp histogram	SAR	ERS1	3,5 years	From dec 91 to jun 95	2 500 000
θp histogram	SAR	ERS1	3,5 years	From dec 91 to jun 95	2 500 000
(Hs/Tp) (Hs/θp) (Tp/θp) (Hs/Tz) (Hs/θpp) diagrams	SAR	ERS1	3,5 years	From dec 91 to jun 95	2 500 000
dd histogram	scatterometer	ERS1	3,5 years	From dec 91 to jun 95	270 000 000
(ff/dd) diagram	scatterometer	ERS1	3,5 years	From dec 91 to jun 95	270 000 000

Advantages of altimeter measurements

Altimeter sensors of satellites such as Geosat, ERS1, ERS2, and Topex, have provided significant wave height and wind forces measurements for 10 years. The advantages of such measurements are mainly their quality, the all-climate characteristic and a homogeneous worldwide density (one Hs measurement every 7 km and one spectrum every 200km).

These features induce:

- ✓ High time and space resolutions, allowing reliable climatologic characterisations of sights,
- ✓ Accurate determinations of storms, which is essential for a correct assessment of extreme values.

Furthermore, it is possible to complete offshore H_s^{max} measurements by combining them with periods and directions from metocean models, and transfer this information to specific coastal points.

Advantages of SAR “wave mode’ measurements

Wave height directional spectra from SAR “wave mode” measurements improve sights characterisations providing:

- ✓ Statistics: especially probability of “cross-seas”, “height-period-direction” joint distributions of sea state. These statistics are based on sea-states parameters whose quality, reliability, and density contrast with classic sources.
- ✓ Parameters of periods and directions combined with altimeter-measured H_s^{max}.

Moreover, corrected SAR product provide directional spectral information and might permit to fit the needs of several applications such as port roughness, analysis of sediment problems, storms reconstitution’s or dynamic and fatigue structures calculations.

Problems of the use of satellite data for sights characterisation

- Temporal sampling

One can wonder about the short time span of these measurements (about 10 years of altimeter measurements and 7 years of “wave mode” SAR products).
Meanwhile, this can be qualified by the following facts:

- ✓ The total number of data is systematically increasing, the number of satellites gets higher and higher. It might overcome the major disadvantage of temporal sampling: indeed, every satellite only comes back above a sight after several weeks (10 days for Topex Poseidon and 35 days for ERS), so that significant events such as exceptional storms may be missing.
- ✓ Satellite measurements homogeneously cover all oceans, and especially fill in areas where information was missing.
- ✓ Measurement quality (especially in storms conditions) is good. Satellite data over 5 years are more reliable than ship-based data over 20 years (missing or absurd during storms).

- Spatial discontinuity

The spatial density of SAR products (one product every 200 km) is low comparatively with altimeter information (every 7 km).
This has also to be qualified by:

- ✓ The possibility to obtain complete parameters by combining SAR product with altimeter measurements and metocean models.
- ✓ The existence of 7 years of measurements over areas where information was totally missing.

Example of scatter diagrams

The following scatter diagrams have been compiled for area Amazon (Gulf of Mexico) and for season 1 (January, February March).

Total	412	1027	493	26	0	0	0	0	0	0	0	0	
> 24 s		1											1
22-24 s		2											2
20-22 s		2	1										3
18-20 s		5	1										6
16-18 s	2	14	3										19
14-16 s	4	35	22	1									62
12-14 s	20	99	51	2									172
10-12 s	26	172	143	6									347
8-10 s	32	248	250	16									546
6-8 s	68	340	22	1									431
4-6 s	221	109											330
0-4 s	39												39
	0-1 m	1-2 m	2-3 m	3-4 m	4-5 m	5-6 m	6-7 m	7-8 m	8-9 m	9-10m	10-11m	> 11 m	Total

Figure 6 - Scatter diagram of Hs and periods of spectral peaks

Total	26	86	276	384	201	23	0	0	0	0	0	0	996
345-360		1	1	1									3
330-345													0
315-330													0
300-315													0
285-300													0
270-285													0
255-270													0
240-255													0
225-240													0
210-225													0
195-210													0
180-195													0
165-180													0
150-165													0
135-150													0
120-135			1										1
105-120		1	1	1									3
90-105		12	15	6	2	1							36
75-90		24	54	40	8	2							128
60-75		12	56	69	36	3							176
45-60		13	70	140	89	10							322
30-45		12	57	103	58	6							236
15-30		8	17	22	7	1							55
0-15		3	4	2	1								10
	0-3	3-5	5-7	7-9	9-11	11-13	13-15	15-17	17-19	19-21	21-23	>= 23	Total

The value given for the [0,3] class is estimated from the altimeter and reported in thousandths

Figure 7 - Scatter diagram of wind speed and direction

Enclosure B: Calculation results

Ha comparison

voyage	month	GWS	IMDSS	ClioSat
		m	m	m
A	jan	9.75	7.22	7.8
A	apr	8.56	5.83	4.9
A	jul	6.76	4.41	5.1
A	oct	8.64	6.44	7.2
B	jan	9.68	7.8	6.7
B	apr	9.31	6.31	5.1
B	jul	7.12	4.63	4.7
B	oct	8.97	6.8	6.3
C	jan	8.65	5.39	5.7
C	apr	7.8	4.86	5.2
C	jul	5.4	3.29	4.4
C	oct	7.94	4.78	5.5
D	jan	5.57	3.87	3.6
D	apr	5.31	3.19	3.6
D	jul	4.6	2.73	3.3
D	oct	5.11	3.13	3.3
E	jan	4.76	3.04	3.4
E	apr	6.18	3.1	5.6
E	jul	8.59	5.15	5.4
E	oct	4.96	3.83	3.6
F	jan	4.76	2.95	3
F	apr	6.1	2.98	5.7
F	jul	8.53	5.87	5.5
F	oct	5.23	3.2	3.6
G	jan	6.31	3.15	2.6
G	apr	4.82	4.56	4
G	jul	5.88	4.55	4
G	oct	5.83	3.48	3.2
H	jan	8.15	6.01	4.7
H	apr	6.95	4.41	4
H	jul	7.32	5.66	4.1
H	oct	8.37	5.98	5.3
I	jan	8.27	4.95	4.9
I	apr	7.03	3.9	3.5
I	jul	8.41	6.19	5.2
I	oct	8.61	6.76	4.9
J	jan	8.67	5.75	6.4
J	apr	7.86	4.99	5.1
J	jul	6.25	3.64	4.7
J	oct	8.32	4.95	6
K	jan	10.19	8.49	9.4
K	apr	9.87	8.11	6.7
K	jul	8.06	5.03	6
K	oct	9.27	7.06	8.7
L	jan	8.83	5.88	4.9
L	apr	7.63	5.07	5.8
L	jul	9.19	6.44	5.7
L	oct	9.13	6.88	5.6
M	jan	10.33	7.46	8
M	apr	9.24	6.07	5.9
M	jul	8.83	5.37	5.7
M	oct	9.39	6.62	7.4
N	jan	10.16	8.34	8.1
N	apr	9.69	7.62	6.4
N	jul	8.44	5.21	6.4
N	oct	9.96	7.59	7.7
mean		7.74178	5.30303	5.34285
minimum		4.6	2.73	2.6
maximum		10.33	8.49	9.4
st. deviation		1.69082	1.58141	1.51991

Most probable maximum Ha over 10 voyages

voyage	month	GWS	IMDSS	ClioSat
		m	m	m
A	jan	11.74	8.45	9.19
A	apr	10.46	7.16	5.75
A	jul	8.36	5.76	6.14
A	oct	10.58	7.69	8.48
B	jan	11.44	9.1	7.79
B	apr	11.18	7.48	6
B	jul	8.75	5.9	5.71
B	oct	10.78	8.31	7.41
C	jan	10.7	6.6	6.94
C	apr	9.86	6.08	6.42
C	jul	6.78	4.16	5.35
C	oct	9.95	5.89	6.67
D	jan	6.93	5.12	4.21
D	apr	6.64	3.91	4.33
D	jul	5.68	3.37	3.92
D	oct	6.38	3.89	3.89
E	jan	5.93	3.73	4.03
E	apr	8.02	3.8	6.86
E	jul	10.49	5.93	6.25
E	oct	6.23	4.8	4.36
F	jan	5.85	3.62	3.73
F	apr	7.94	3.62	6.91
F	jul	10.41	7.25	6.35
F	oct	6.52	3.92	4.43
G	jan	8.07	3.96	3.02
G	apr	5.95	6.3	4.66
G	jul	7.18	5.46	4.59
G	oct	7.47	4.08	3.75
H	jan	9.95	7.04	5.59
H	apr	8.85	5.71	4.76
H	jul	9.26	7.45	4.89
H	oct	10.3	7.41	6.4
I	jan	10.21	5.76	5.98
I	apr	8.82	4.57	4.2
I	jul	10.52	7.79	6.36
I	oct	10.62	8.94	5.84
J	jan	10.61	6.96	7.85
J	apr	10.02	6.07	6.42
J	jul	8.01	4.53	5.78
J	oct	10.44	5.94	7.54
K	jan	12.02	9.96	10.83
K	apr	11.77	9.79	7.84
K	jul	9.77	5.99	7.09
K	oct	11.09	8.39	10.07
L	jan	10.72	6.98	5.79
L	apr	9.46	7.11	7.01
L	jul	11.12	8.24	6.56
L	oct	11.12	9.04	6.66
M	jan	12.36	8.7	9.4
M	apr	11.19	7.39	7.12
M	jul	10.71	6.31	6.56
M	oct	11.36	7.87	8.66
N	jan	11.97	9.51	9.2
N	apr	11.55	9.04	7.43
N	jul	10.36	6.43	7.64
N	oct	11.87	8.93	8.88
mean		9.505714	6.485535	6.348035
minimum		5.68	3.37	3.02
maximum		12.36	9.96	10.83
st. deviation		1.927542	1.853846	1.745320

Hs comparison

voyage	month	GWS	IMDSS	ClioSat
		m	m	m
A	jan	8.3	6.7	7.1
A	apr	6.9	5.3	4.4
A	jul	5.2	4.3	4.5
A	oct	7.1	5.7	6.6
B	jan	8.7	7.4	6.3
B	apr	7.9	6.1	4.7
B	jul	5.8	4.6	4.5
B	oct	7.7	6.6	6.1
C	jan	6.4	4.6	5.1
C	apr	5.4	3.7	4.5
C	jul	3.9	2.4	3.9
C	oct	5.3	3.7	4.7
D	jan	4.1	2.3	3.1
D	apr	3.7	2	3.1
D	jul	3.3	1.8	2.7
D	oct	3.6	1.9	2.7
E	jan	3.4	2.6	2.9
E	apr	3.7	2.5	4.4
E	jul	6.7	4.8	4.7
E	oct	3.4	3.2	3.1
F	jan	3.6	2.7	2.4
F	apr	3.9	2.9	4.8
F	jul	7	6	5.2
F	oct	3.7	3.3	3.1
G	jan	4.8	3.3	2.2
G	apr	3.5	4	3.4
G	jul	5.1	4.9	3.6
G	oct	4.7	3.3	2.8
H	jan	6.4	6.3	4.2
H	apr	4.6	4	3.1
H	jul	5	4.5	3.3
H	oct	6.2	5.4	5.1
I	jan	6.4	4.6	4
I	apr	5.1	3.7	2.9
I	jul	5.6	5.2	4.4
I	oct	6.4	6	4.3
J	jan	5.7	5.3	5.1
J	apr	4.5	4.1	4
J	jul	3.7	2.7	3.8
J	oct	5.3	4.4	4.9
K	jan	9.4	8.5	8.2
K	apr	8.8	7.7	6.2
K	jul	6.8	4.9	5.7
K	oct	8.2	7	8.1
L	jan	7.1	5.6	4.2
L	apr	5.8	5	5
L	jul	7.6	6.4	5.2
L	oct	7.2	6.2	5.1
M	jan	8.5	6.1	6.6
M	apr	7.3	4.9	5.3
M	jul	6.9	4.8	5
M	oct	7.4	5.3	6.1
N	jan	9.4	8.2	7.7
N	apr	8.6	7.6	5.9
N	jul	7	5.3	6
N	oct	8.9	7.6	7.3
mean		6.0107	4.81964	4.7017
minimum		3.3	1.8	2.2
maximum		9.4	8.5	8.2
st. deviation		1.7900	1.70020	1.4641

1 year Hs comparison

voyage	month	GWS	IMDSS	ClioSat
		m	m	m
A	jan	13.3	9.2	9.7
A	apr	11.8	8.1	6.1
A	jul	9.2	7.3	6.5
A	oct	11.9	8.4	9.1
B	jan	11.8	9.3	7.7
B	apr	11.3	7.8	5.9
B	jul	8.6	6.5	5.8
B	oct	10.9	8.8	7.4
C	jan	11.4	7.2	7.5
C	apr	10.2	6.5	7.1
C	jul	7.1	4.6	5.8
C	oct	10.3	6.3	7
D	jan	7.6	5.4	4.4
D	apr	7.1	4	4.6
D	jul	6	3.4	4.1
D	oct	6.8	4	4.1
E	jan	6.5	4.4	4.4
E	apr	8.4	4.2	7.3
E	jul	11.7	6.6	6.6
E	oct	6.7	5.7	4.8
F	jan	6.3	4.2	3.9
F	apr	8.1	4.2	7.4
F	jul	11.2	7.9	6.6
F	oct	6.8	4.9	4.8
G	jan	8.5	5.1	3.1
G	apr	6.3	7.1	4.7
G	jul	8	7	4.7
G	oct	8.2	4.3	3.9
H	jan	10.7	8.5	6
H	apr	9.1	7	5.1
H	jul	9.6	8.1	5.1
H	oct	11.2	8.4	7.3
I	jan	11.4	6	6.5
I	apr	9.8	5	4.6
I	jul	11.8	8.8	7.4
I	oct	12	9.6	6.4
J	jan	13.3	8.5	9.2
J	apr	12.1	7	7.5
J	jul	9.4	5.4	6.8
J	oct	12.7	6.9	8.9
K	jan	12.9	10.6	11.1
K	apr	12.7	10.2	8
K	jul	10.3	6.7	7.5
K	oct	11.8	9	10.3
L	jan	10.3	7.3	5.6
L	apr	8.8	7.1	6.7
L	jul	10.7	8.5	6.5
L	oct	10.6	8.5	6.6
M	jan	12.3	8.4	8.8
M	apr	10.8	7	6.9
M	jul	10.1	6.8	6.3
M	oct	11	7.5	8.2
N	jan	12.4	9.7	9.1
N	apr	11.7	9.3	7.3
N	jul	10.2	6.9	7.7
N	oct	12.1	9.3	8.6
mean		10.067	7.04285	6.625
minimum		6	3.4	3.1
maximum		13.3	10.6	11.1
st. deviation		2.0627	1.82406	1.75273

10 year Hs comparison

voyage	month	GWS	IMDSS	ClioSat
		m	m	m
A	jan	15.4	10.1	10.6
A	apr	13.9	9.2	6.7
A	jul	11	8.6	7.3
A	oct	13.9	9.5	10.1
B	jan	13.7	10.4	8.4
B	apr	13.4	8.8	6.5
B	jul	10.4	7.7	6.6
B	oct	12.9	10	8.1
C	jan	13.9	8.4	8.7
C	apr	12.6	7.9	8.2
C	jul	8.7	5.7	6.7
C	oct	13	7.5	8
D	jan	9.2	6.9	4.9
D	apr	8.7	4.9	5.2
D	jul	7.2	4.1	4.7
D	oct	8.3	5	4.6
E	jan	7.8	5.2	4.9
E	apr	10.7	4.9	8.4
E	jul	13.8	7.3	7.3
E	oct	8.2	6.8	5.5
F	jan	7.5	4.8	4.6
F	apr	10.2	4.7	8.5
F	jul	13.1	8.6	7.1
F	oct	8.3	5.6	5.5
G	jan	10.2	5.9	3.4
G	apr	7.6	8.6	5.2
G	jul	9.3	7.8	5.1
G	oct	9.9	4.7	4.3
H	jan	12.7	9.4	6.7
H	apr	11.4	8.4	5.9
H	jul	11.9	9.9	5.8
H	oct	13.6	9.8	8.2
I	jan	13.5	6.6	7.4
I	apr	11.8	5.5	5.2
I	jul	14.6	10.3	8.5
I	oct	14.4	11.1	7.2
J	jan	16	9.5	10.5
J	apr	15.1	7.9	8.7
J	jul	11.5	6.3	7.8
J	oct	15.4	7.7	10.2
K	jan	14.6	11.6	12.2
K	apr	14.7	11.4	8.8
K	jul	12.1	7.5	8.4
K	oct	13.7	9.9	11.3
L	jan	12.4	8.5	6.4
L	apr	10.9	8.5	7.8
L	jul	12.9	9.9	7.3
L	oct	13	10	7.6
M	jan	15.1	9.9	10.2
M	apr	13.4	8.4	8
M	jul	12.4	8.1	7.2
M	oct	13.6	8.9	9.5
N	jan	14.2	10.5	9.9
N	apr	13.7	10.3	8.1
N	jul	12.2	7.8	8.7
N	oct	14.2	10.2	9.4
mean		12.1035	8.09642	7.464285
minimum		7.2	4.1	3.4
maximum		16	11.6	12.2
st. deviation		2.37830	1.98319	1.946225

Average voyage duration

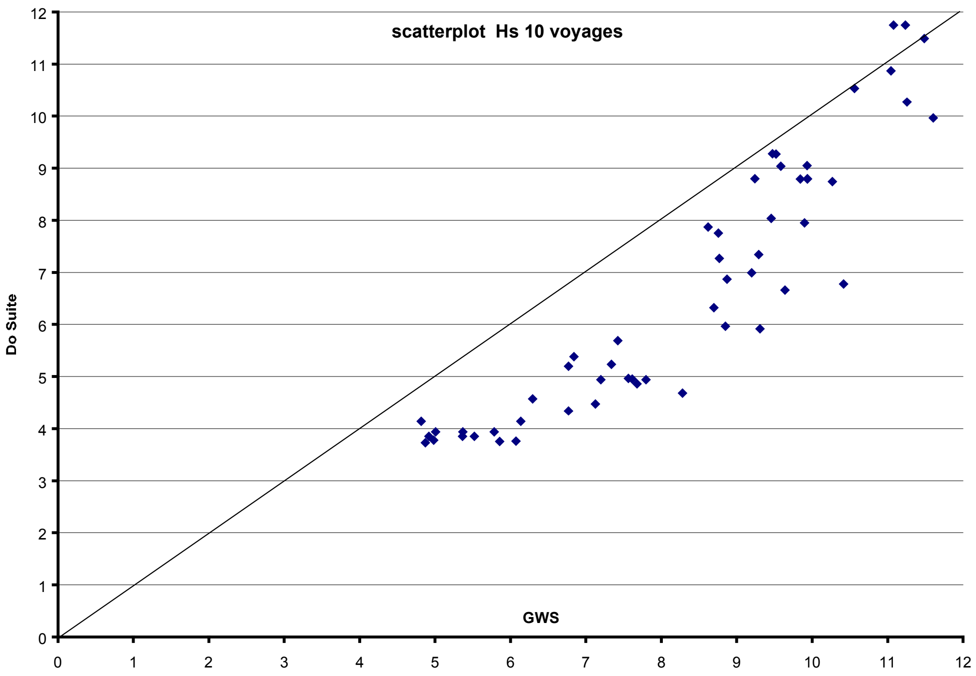
voyage	ETA	GWS	IMDSS	ClioSat
	days	days	days	days
A	3	3.9	3.9	3.6
B	13	14	13.6	12.5
C	6	5.6	5.4	5.7
D	4.5	3.9	3.8	3.7
E	5	3.6	3.5	3.7
F	7	4.9	4.8	4.8
G	5	4.7	4.6	4.8
H	5.5	5.1	5.3	4.6
I	5	3.5	3.5	2.8
J	2	1.6	1.6	1.6
K	11	8.7	8.5	8
L	22	17.5	17.3	17.3
M	22	18.2	17.9	17.5
N	15	15.5	15.3	16.2

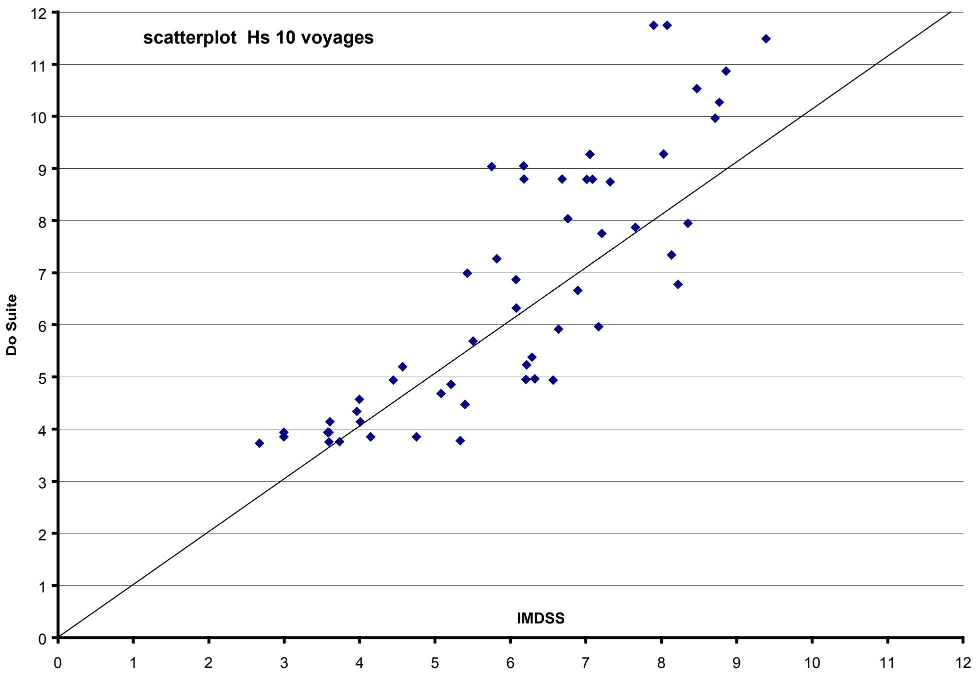
Do Suite results

voyage	month	voydur	design wave height	P(dw)
		hours	m	
A	jan	103.6	11.75	0.9896
A	apr	103.6	8.8	0.9827
A	jul	103.6	5.23	0.95
A	oct	103.6	8.79	0.9848
B	jan	381.6	10.87	0.9961
B	apr	381.6	8.74	0.993
B	jul	381.6	4.95	0.9723
B	oct	381.6	7.95	0.9918
C	jan	162.3	6.87	0.9814
C	apr	162.3	4.86	0.9578
C	jul	162.3	3.75	0.95
C	oct	162.3	4.68	0.9539
D	jan	115	4.14	0.95
D	apr	115	3.94	0.95
D	jul	115	3.73	0.95
D	oct	115	3.85	0.95
E	jan	105.9	4.14	0.95
E	apr	105.9	3.94	0.95
E	jul	105.9	9.04	0.9897
E	oct	105.9	3.85	0.95
F	jan	136.4	3.94	0.95
F	apr	136.4	3.76	0.95
F	jul	136.4	9.27	0.9909
F	oct	136.4	3.85	0.95
G	jan	137.2	5.2	0.95
G	apr	137.2	3.78	0.95
G	jul	137.2	5.38	0.9752
G	oct	137.2	4.34	0.95
H	jan	133.3	7.87	0.9883
H	apr	133.3	4.47	0.95
H	jul	133.3	4.96	0.962
H	oct	133.3	7.75	0.9869
I	jan	97.3	6.99	0.9802
I	apr	97.3	4.94	0.95
I	jul	97.3	5.97	0.95
I	oct	97.3	7.34	0.9802
J	jan	42.5	8.04	0.9794
J	apr	42.5	5.69	0.9583
J	jul	42.5	4.57	0.95
J	oct	42.5	7.27	0.9743
K	jan	249.3	14.08	0.9967
K	apr	249.3	11.49	0.994
K	jul	249.3	6.32	0.9836
K	oct	249.3	10.53	0.9951
L	jan	593.3	6.66	0.986
L	apr	593.3	4.94	0.95
L	jul	593.3	9.28	0.9909
L	oct	593.3	6.78	0.9701
M	jan	485.5	11.75	0.9896
M	apr	485.5	8.8	0.9827
M	jul	485.5	9.05	0.9898
M	oct	485.5	8.79	0.9848
N	jan	427.7	13.93	0.9979
N	apr	427.7	10.27	0.9962
N	jul	427.7	5.92	0.9855
N	oct	427.7	9.97	0.9959

Hs for 10 voyages comparison

voyage	month	GWS		IMDSS		DO Suite	
		voydur hrs	**Hs** 10 voyages	voydur hrs	**Hs** 10 voyages	voydur hrs	**design Hs**
A	jan	97.9	11.2	101.8	8.1	103.6	11.75
A	apr	93.3	9.2	89.8	6.7	103.6	8.80
A	jul	89.6	7.3	87.5	6.2	103.6	5.23
A	oct	93.9	9.8	94.2	7.1	103.6	8.79
B	jan	347.3	11.0	330.7	8.9	381.6	10.87
B	apr	336.4	10.3	324.7	7.3	381.6	8.74
B	jul	324.0	7.6	319.2	6.2	381.6	4.95
B	oct	335.4	9.9	327.8	8.4	381.6	7.95
C	jan	137.3	8.9	131.7	6.1	162.3	6.87
C	apr	134.5	7.7	131.2	5.2	162.3	4.86
C	jul	131.9	5.9	129.6	3.6	162.3	3.75
C	oct	133.9	8.3	130.6	5.1	162.3	4.68
D	jan	93.4	6.1	92.0	4.0	115.0	4.14
D	apr	92.9	5.4	91.3	3.0	115.0	3.94
D	jul	92.5	4.9	90.4	2.7	115.0	3.73
D	oct	92.7	5.4	91.4	3.0	115.0	3.85
E	jan	84.3	4.8	86.0	3.6	105.9	4.14
E	apr	84.4	5.8	83.8	3.6	105.9	3.94
E	jul	90.6	9.6	84.4	5.7	105.9	9.04
E	oct	84.2	4.9	84.3	4.8	105.9	3.85
F	jan	115.2	5.0	113.8	3.6	136.4	3.94
F	apr	115.0	6.1	113.4	3.7	136.4	3.76
F	jul	123.2	9.5	122.7	7.1	136.4	9.27
F	oct	115.1	5.5	114.6	4.1	136.4	3.85
G	jan	111.9	6.8	112.2	4.6	137.2	5.20
G	apr	110.6	5.0	110.4	5.3	137.2	3.78
G	jul	113.6	6.8	112.0	6.3	137.2	5.38
G	oct	111.9	6.8	110.3	4.0	137.2	4.34
H	jan	125.5	8.6	141.6	7.7	133.3	7.87
H	apr	119.8	7.1	121.7	5.4	133.3	4.47
H	jul	120.7	7.6	117.4	6.3	133.3	4.96
H	oct	123.7	8.8	127.7	7.2	133.3	7.75
I	jan	85.0	9.2	87.6	5.4	97.3	6.99
I	apr	81.9	7.2	83.2	4.4	97.3	4.94
I	jul	82.5	8.8	81.9	7.2	97.3	5.97
I	oct	84.5	9.3	87.6	8.1	97.3	7.34
J	jan	38.9	9.5	38.4	6.8	42.5	8.04
J	apr	37.4	7.4	37.6	5.5	42.5	5.69
J	jul	36.8	6.3	36.3	4.0	42.5	4.57
J	oct	38.5	8.8	37.5	5.8	42.5	7.27
K	jan	218.2	11.6	215.7	10.0	249.3	14.08
K	apr	210.6	11.5	206.3	9.4	249.3	11.49
K	jul	199.3	8.7	191.1	6.1	249.3	6.32
K	oct	207.0	10.6	205.4	8.5	249.3	10.53
L	jan	421.6	9.6	407.3	6.9	593.3	6.66
L	apr	411.8	7.8	408.4	6.6	593.3	4.94
L	jul	424.4	9.5	430.3	8.0	593.3	9.28
L	oct	419.3	10.4	410.9	8.2	593.3	6.78
M	jan	445.2	11.1	442.4	7.9	485.5	11.75
M	apr	435.8	9.9	425.8	6.2	485.5	8.80
M	jul	434.4	9.9	421.4	6.2	485.5	9.05
M	oct	436.1	9.9	431.0	7.0	485.5	8.79
N	jan	385.2	11.6	393.1	9.3	427.7	13.93
N	apr	371.6	11.3	367.2	8.8	427.7	10.27
N	jul	356.1	9.3	346.7	6.6	427.7	5.92
N	oct	374.3	11.6	364.0	8.7	427.7	9.97

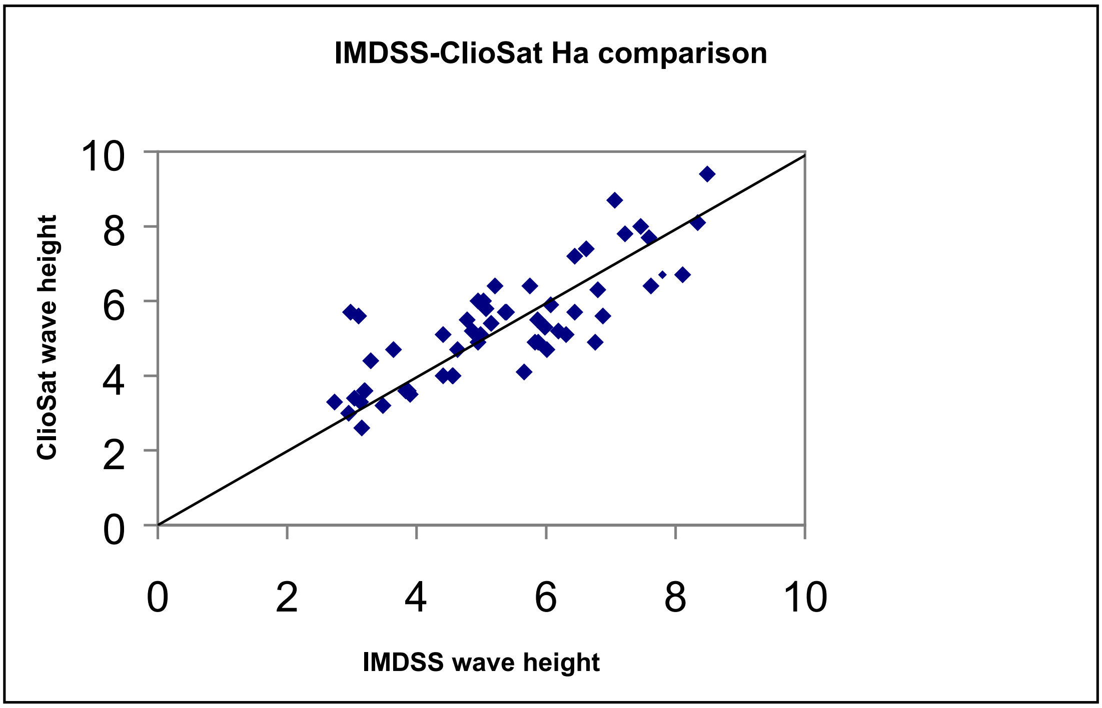

scatterplot Hs 10 voyages
Do Suite
GWS
0
1
2
3
4
5
6
7
8
9
10
11
12

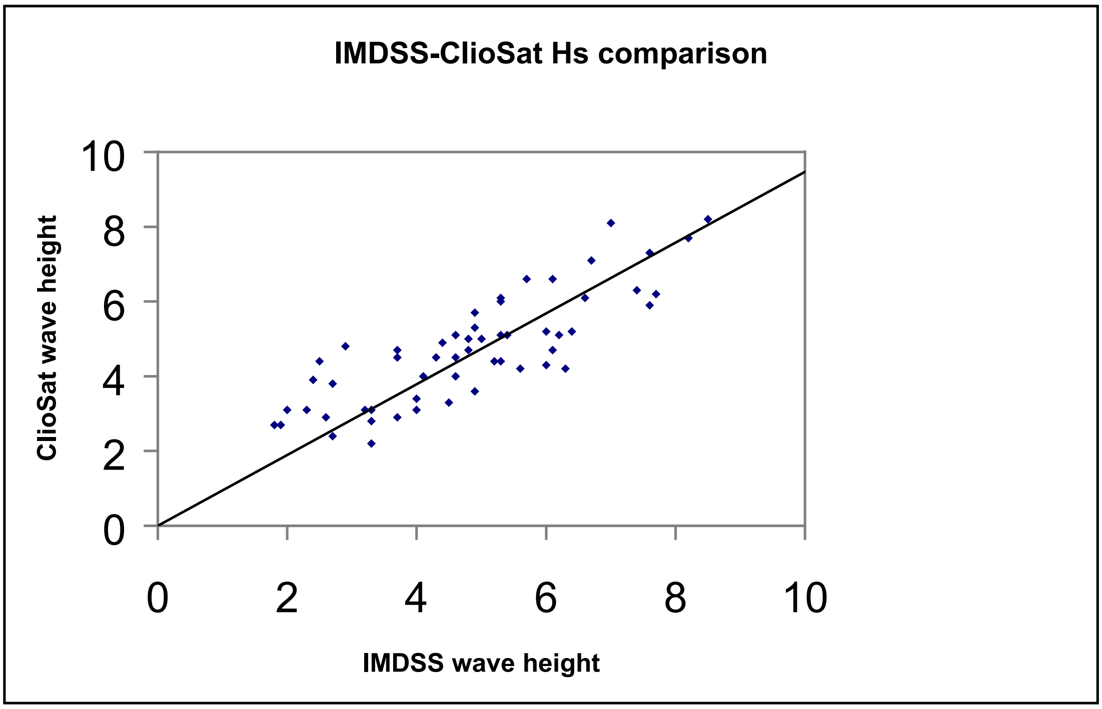

scatterplot Hs 10 voyages
Do Suite
IMDSS
0
1
2
3
4
5
6
7
8
9
10
11
12

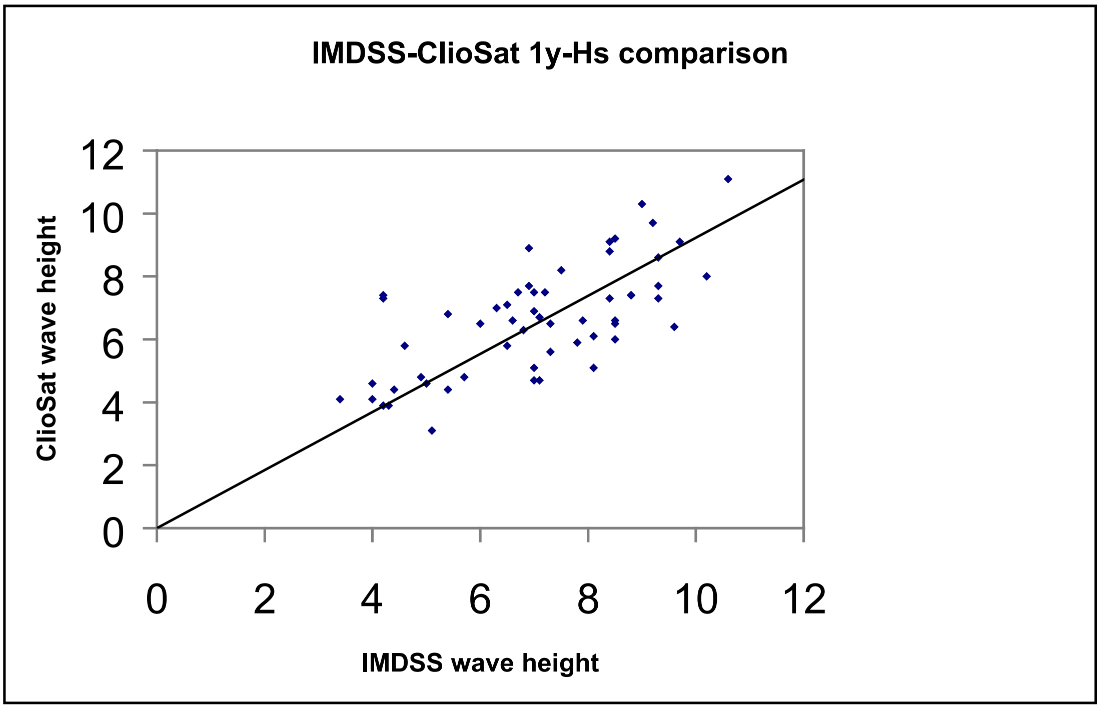
Enclosure C: scatter graphs for IMDSS-ClioSat comparison

On the following graphs, the bold line is the one which minimises the standard deviation. The closer to the thin line (45°-steep line) it is, the better the fit.

The IMDSS-ClioSat comparison looks very good, since the steepness of each bold line is very close to 1 in all cases (0.98 for Ha comparison, 1.01 for Hs comparison and 1.04 for 1-year return Hs).

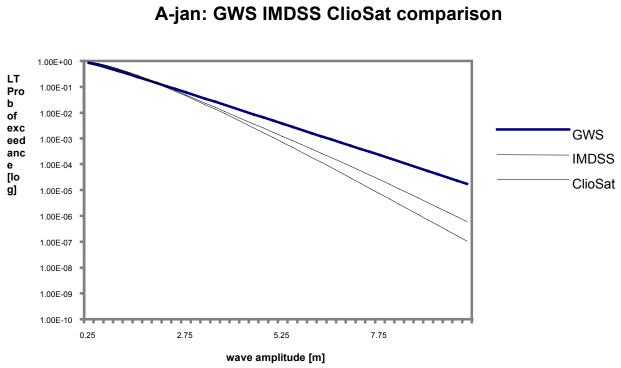


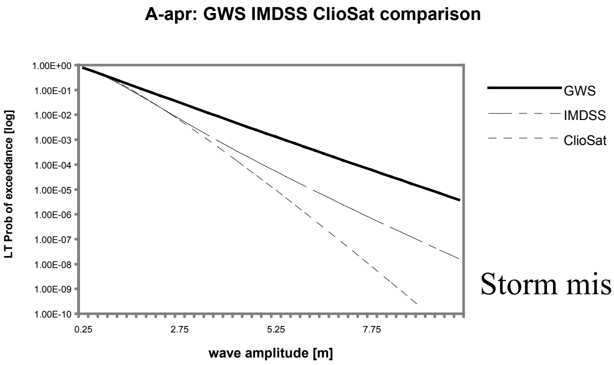

IMDSS-ClioSat Hs comparison
ClioSat wave height
IMDSS wave height
0
2
4
6
8
10
0
2
4
6
8
10


IMDSS-ClioSat 1y-Hs comparison
ClioSat wave height
IMDSS wave height
0
2
4
6
8
10
12
0
2
4
6
8
10
12

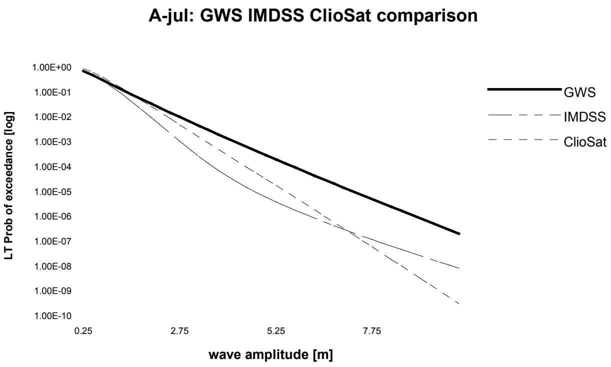
Enclosure D: GWS-IMDSS-ClioSat comparison graphs

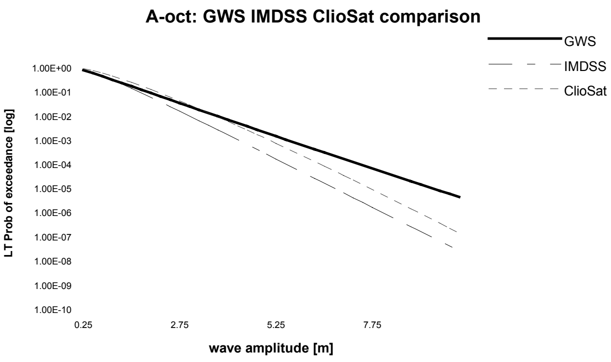
Route A: Dover – Gibraltar



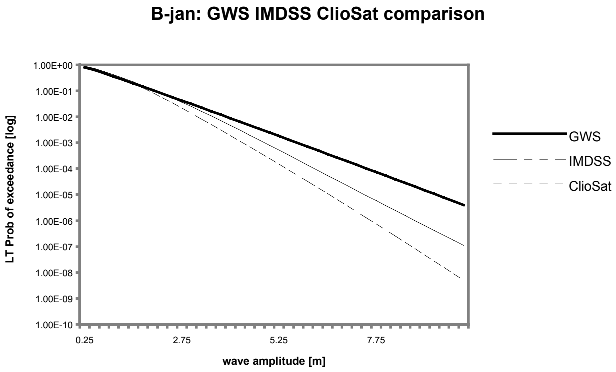


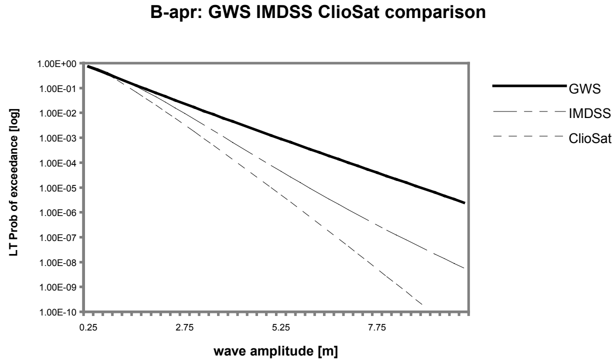
Storm missing in Cliosat??

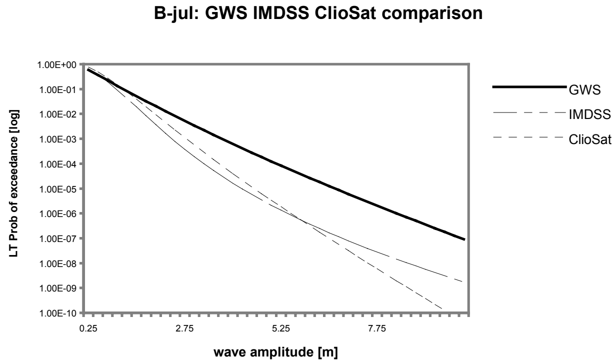


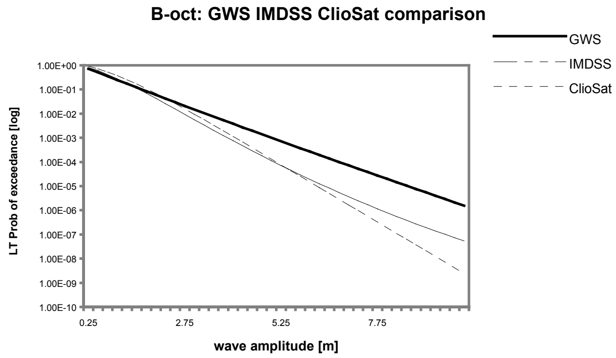


Route B: Gulf of Mexico - Gibraltar

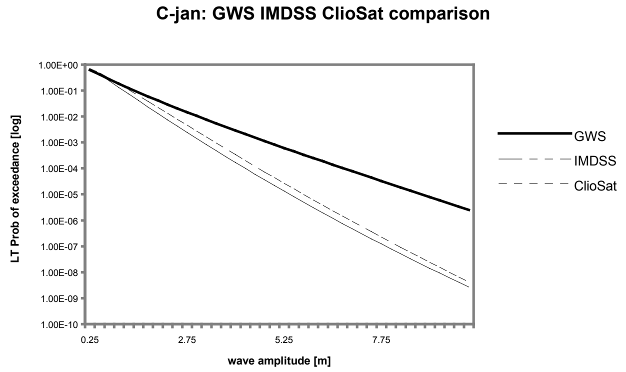


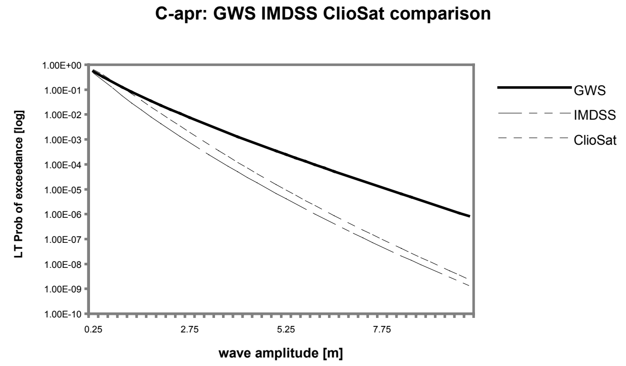


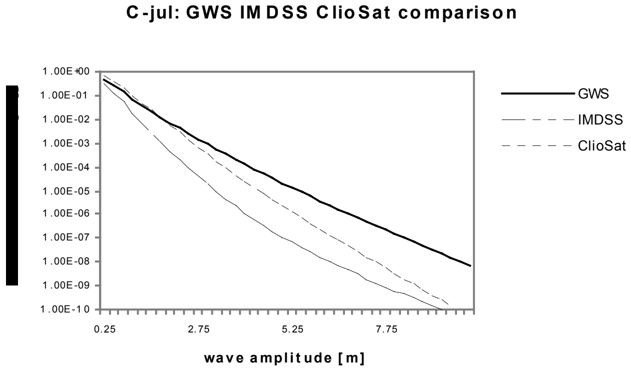


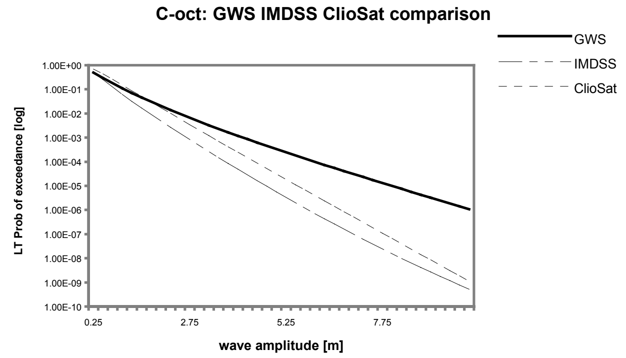


Route C: Gibraltar – Port Said

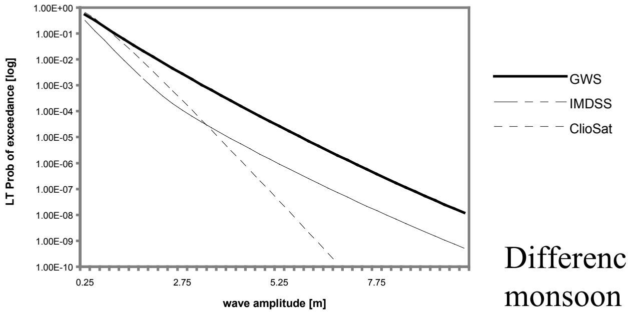




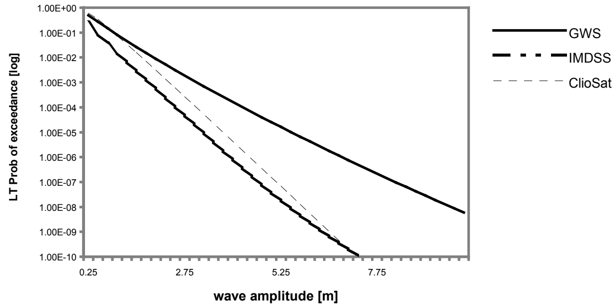


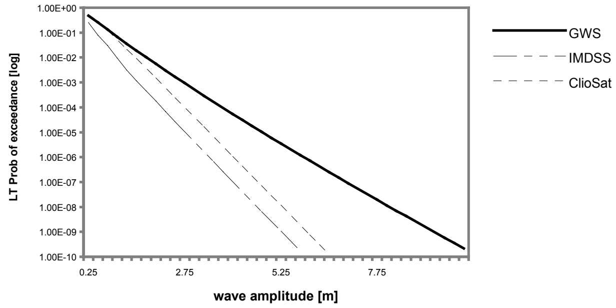


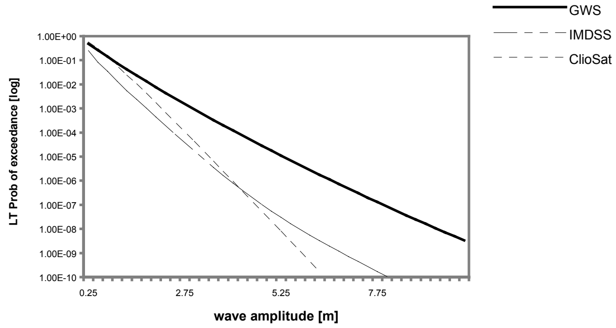
Route D: Suez - Aden


D-jan: GWS IMDSS ClioSat comparison

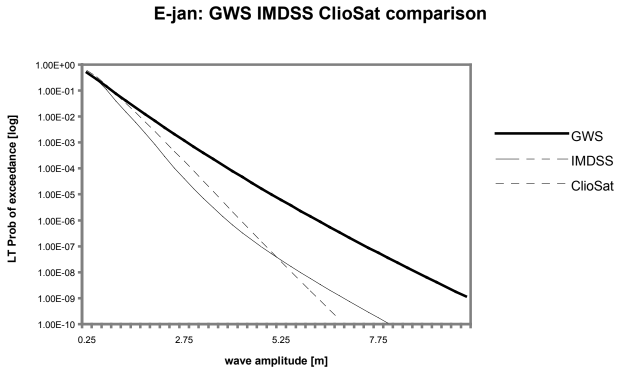
Difference in definition of monsoon month??

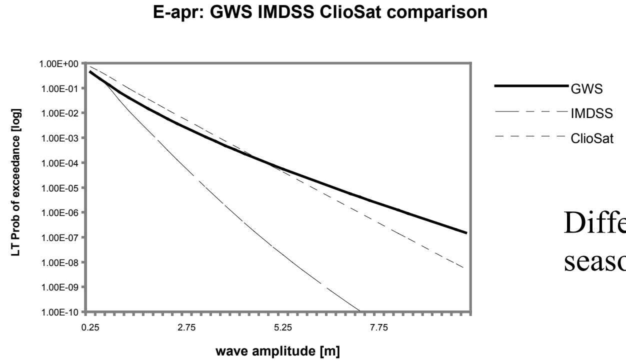

D-apr: GWS IMDSS ClioSat comparison


D-jul: GWS IMDSS ClioSat comparison

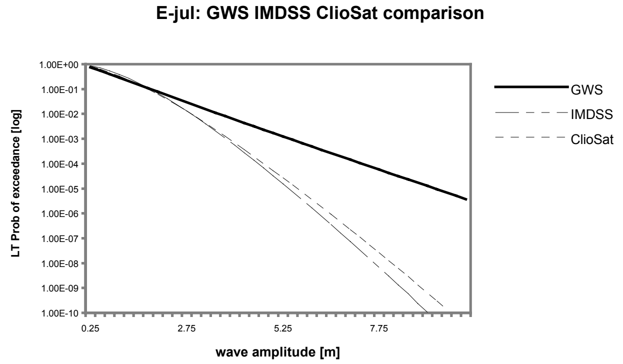

D-oct: GWS IMDSS ClioSat comparison

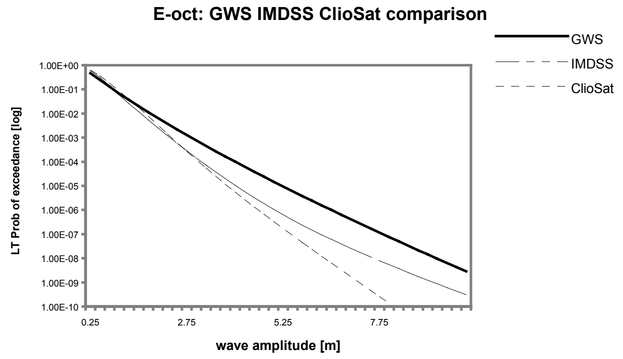
Route E: Aden Arabian Gulf


E-jan: GWS IMDSS ClioSat comparison


E-apr: GWS IMDSS ClioSat comparison

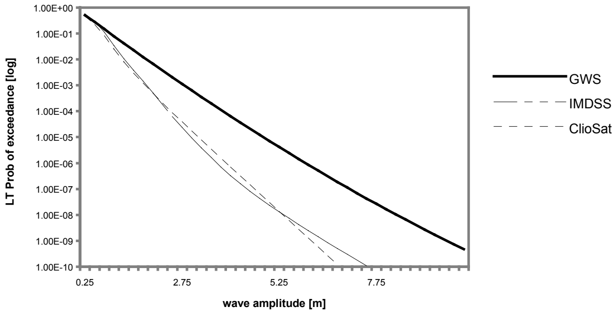
Different monsoon season??


E-jul: GWS IMDSS ClioSat comparison

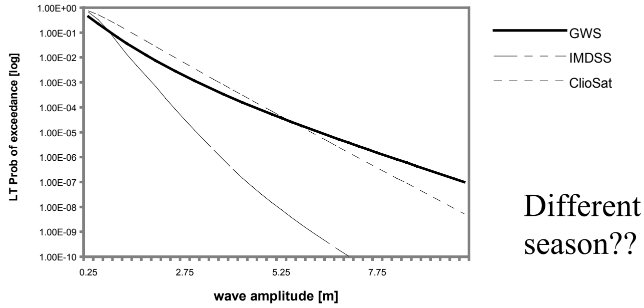

E-oct: GWS IMDSS ClioSat comparison

Route F: Arabian Gulf - Colombo

F-jan: GWS IMDSS ClioSat comparison

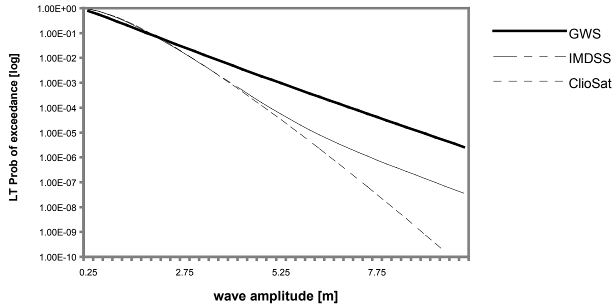


F-apr: GWS IMDSS ClioSat comparison

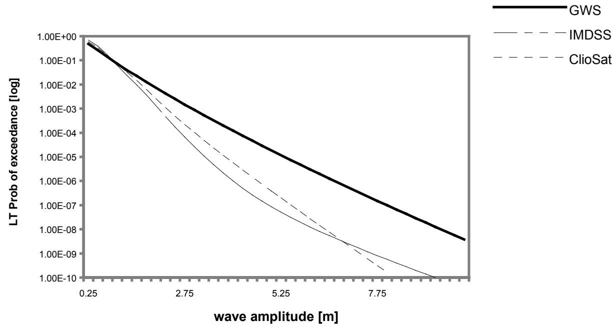


Different monsoon season??

F-jul: GWS IMDSS ClioSat comparison

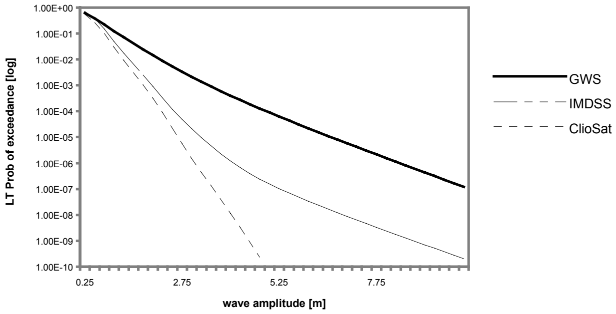


F-oct: GWS IMDSS ClioSat comparison

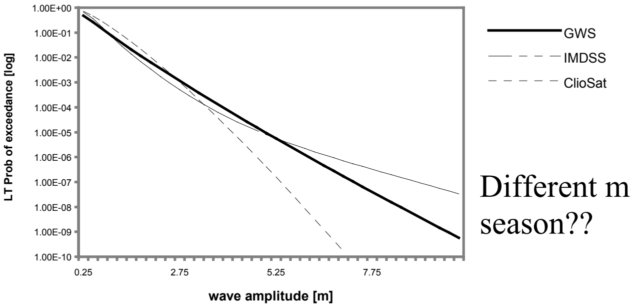


Route G: Colombo - Singapore

G-jan: GWS IMDSS ClioSat comparison

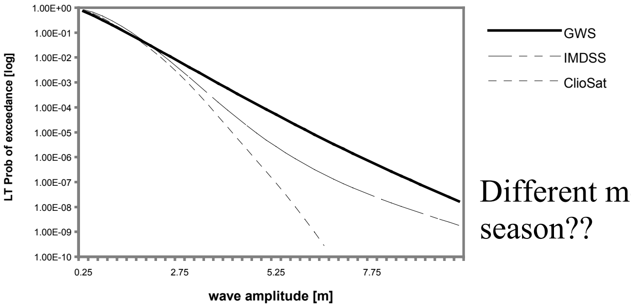


G-apr: GWS IMDSS ClioSat comparison



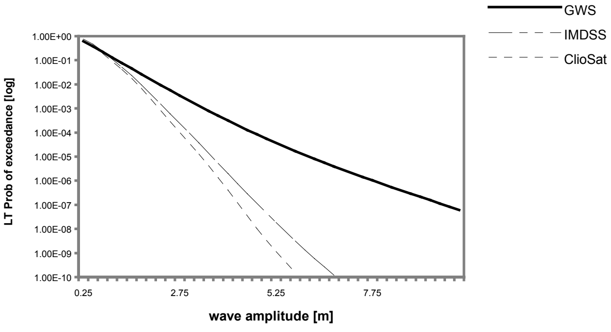
Different monsoon season??

G-jul: GWS IMDSS ClioSat comparison

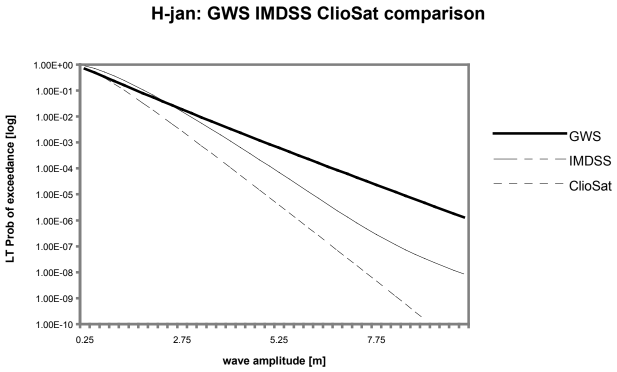


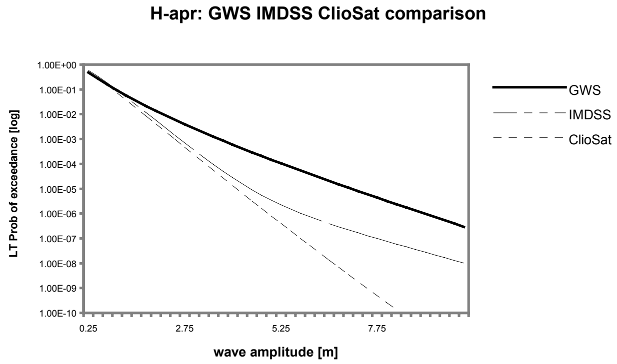
Different monsoon season??

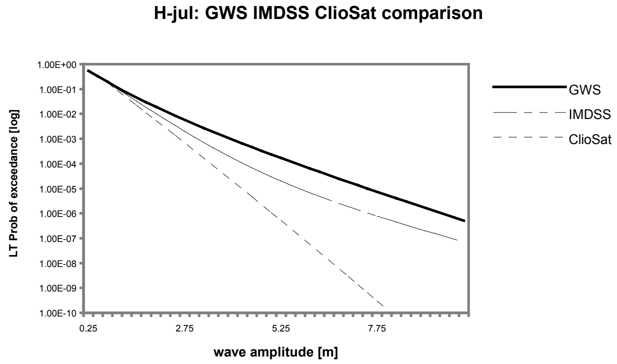
G-oct: GWS IMDSS ClioSat comparison

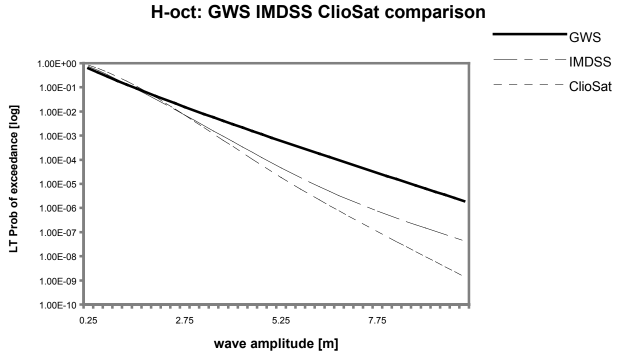


Route H: Singapore - Taiwan

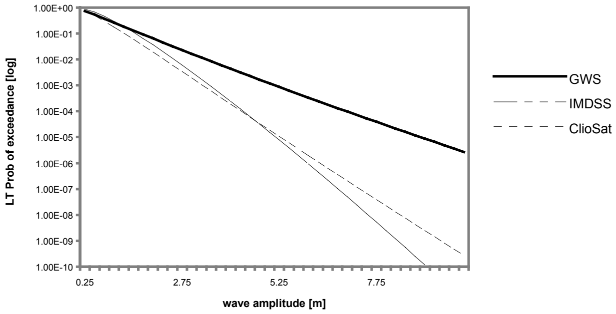

H-jan: GWS IMDSS ClioSat comparison

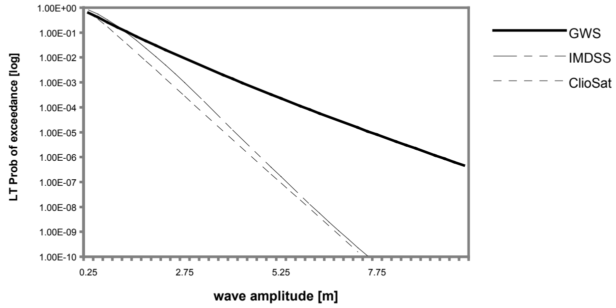

H-apr: GWS IMDSS ClioSat comparison

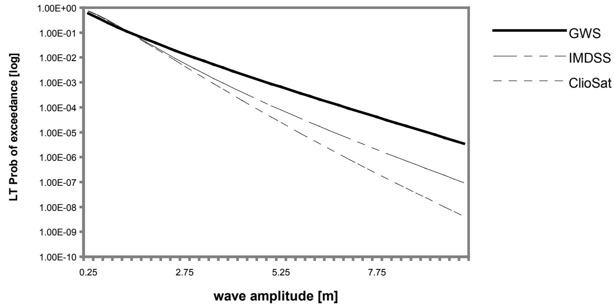

H-jul: GWS IMDSS ClioSat comparison

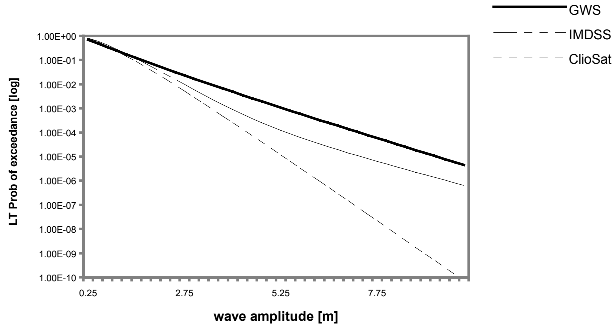

H-oct: GWS IMDSS ClioSat comparison

Route I: Taiwan - Japan

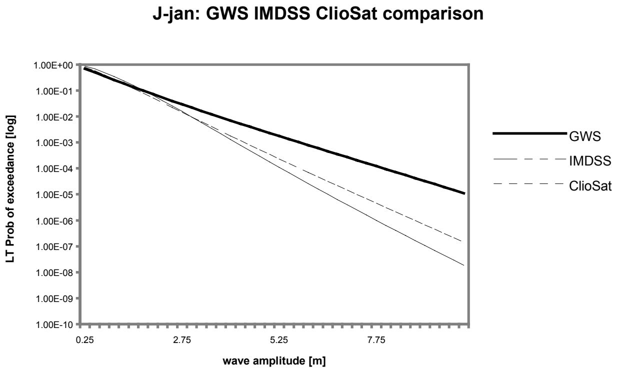

I-jan: GWS IMDSS ClioSat comparison

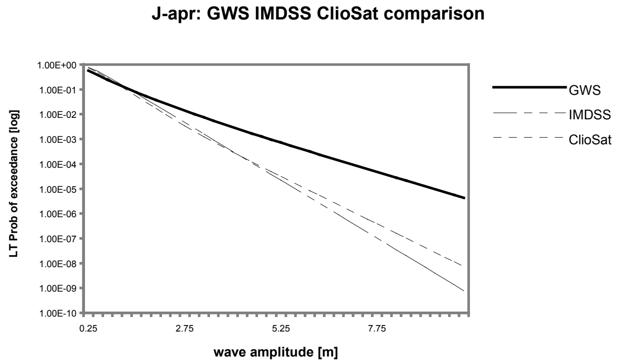

I-apr: GWS IMDSS ClioSat comparison

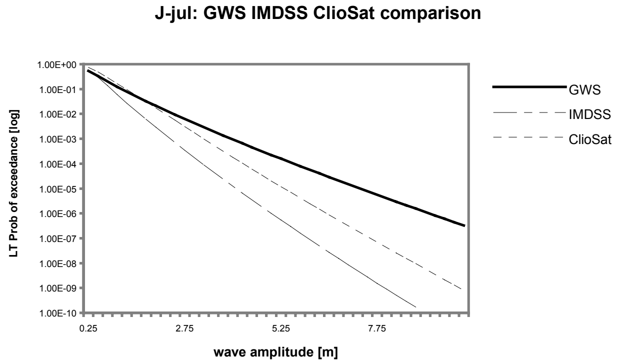

I-jul: GWS IMDSS ClioSat comparison

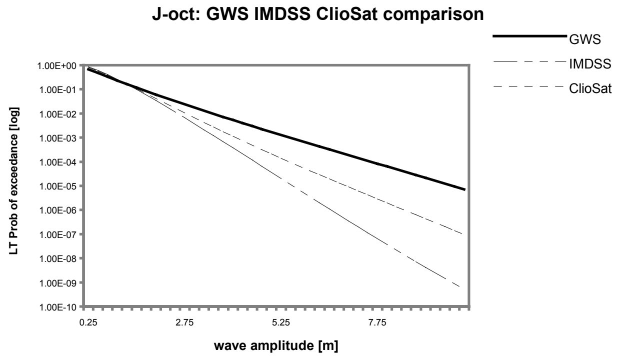

I-oct: GWS IMDSS ClioSat comparison

Route J: North Sea

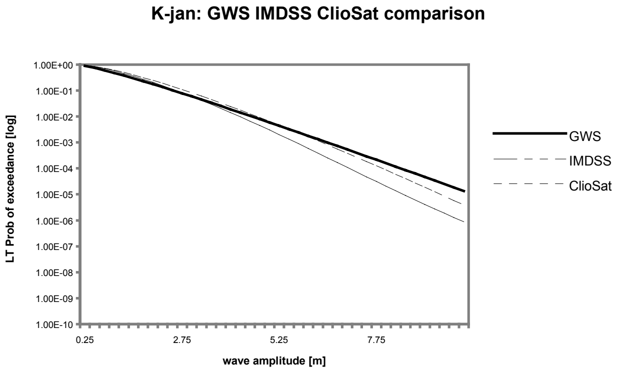


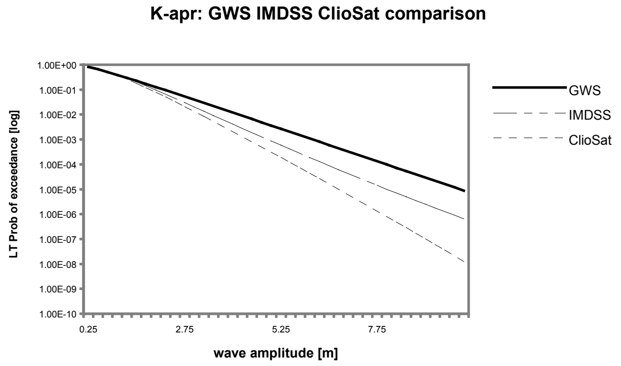


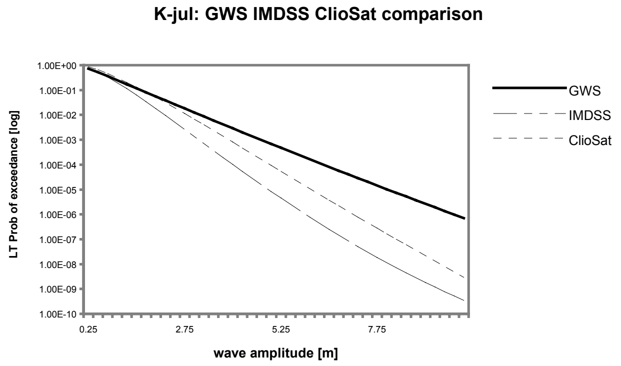


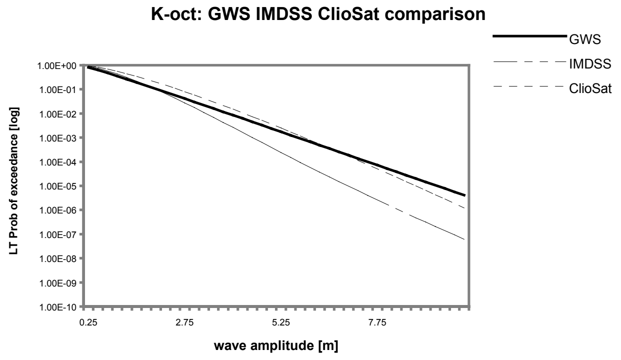


Route K: North Atlantic

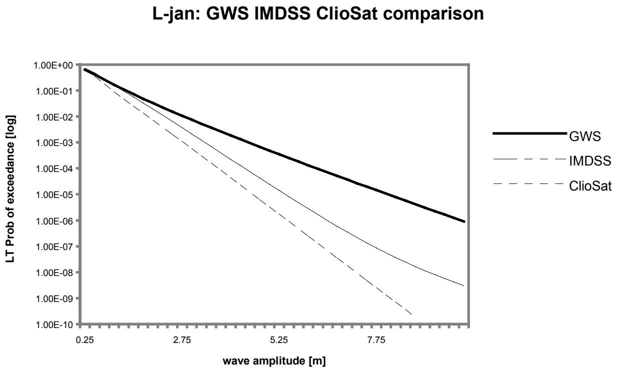


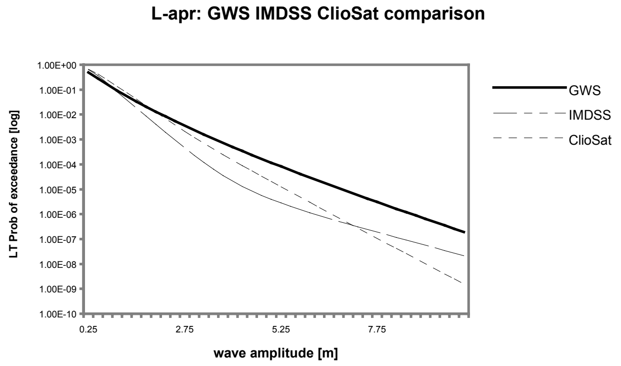


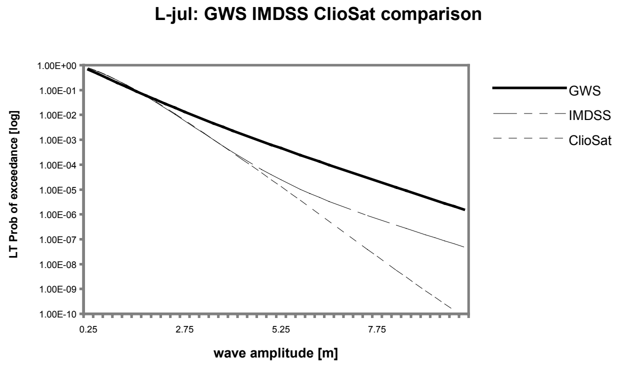


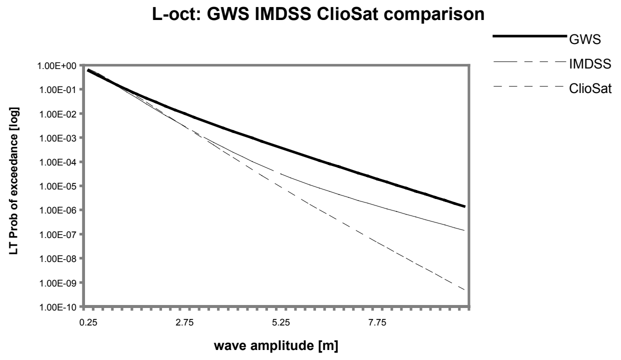


Route L: Hiroshima - Muscat



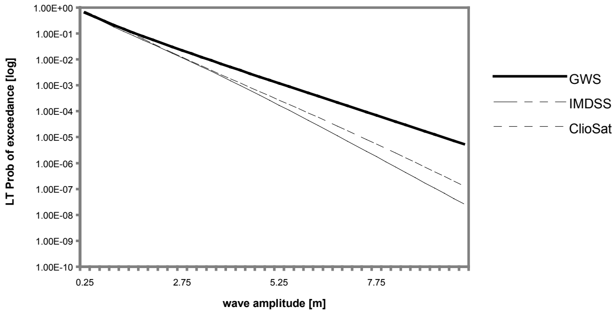




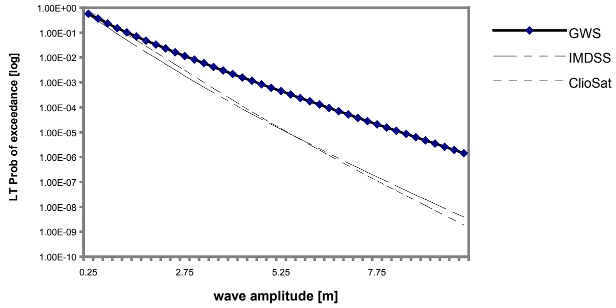


Route M: Germany – Arabian Gulf

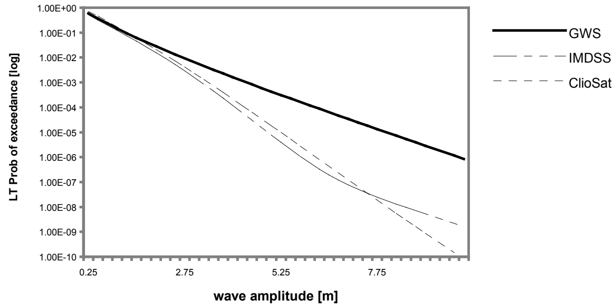
M-jan: GWS IMDSS ClioSat comparison



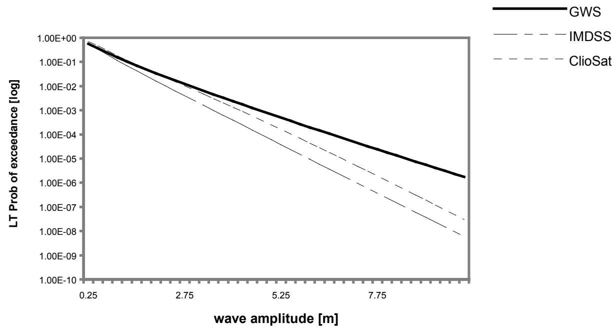
M-apr: GWS IMDSS ClioSat comparison



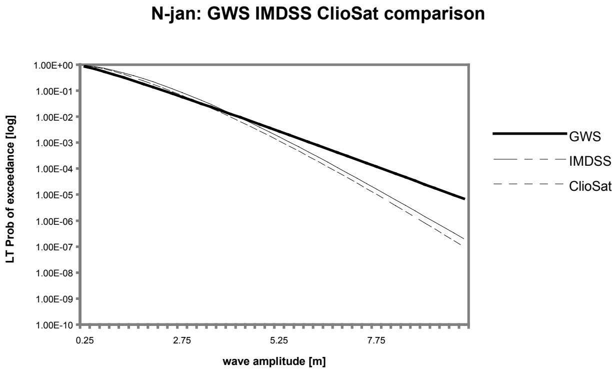
M-jul: GWS IMDSS ClioSat comparison

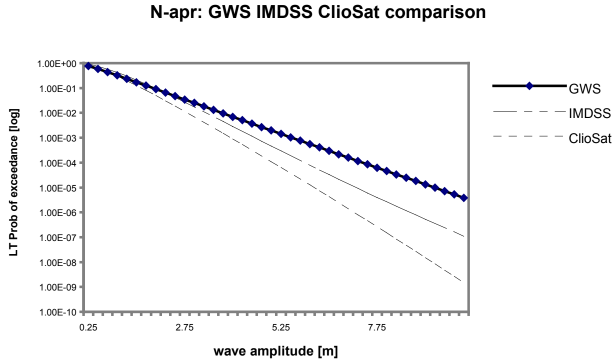


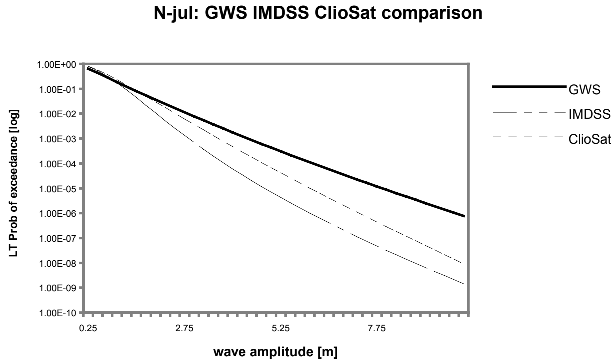
M-oct: GWS IMDSS ClioSat comparison

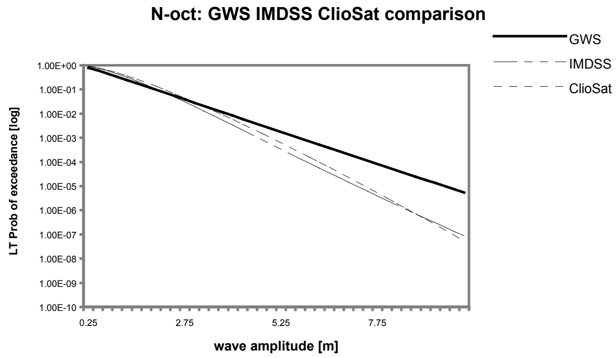


Route N: North Pacific









Enclosure E: Do-Suite Design Wave Method

The data is presented in terms of probability distributions of wave heights, periods and directions for the global selection of 104 sea areas of the Global Wave Statistics. From these available wave statistics, short term design sea states are derived with a maximum significant wave height which has a probability of exceedance of 5% (or 10% with routing). This probability is valid for the most severe area of the route.

After selecting the most severe area, the corresponding wave data is retrieved by means of a scatter diagram. Combining all the period classes results in the total distribution of "observed" wave height. Given this distribution a cumulative probability distribution can be determined, using Gumbel formula:

$P_i = \sqrt{}(m_i(m_i+k_i-1))/(n+1)$ where

n = total number of observations
m_i = number of the first obs. Within class i
k_i = number of obs. within class i

Given the transit time trough the area, the probability of exceedance of the individual "3-hour stationary storm" design wave height is calculated. An engineering approach is used to take the vessel's capability to avoid bad weather into account by reducing the number of 3 hour steps per area, with a factor which depends on the severity of the area. The probability of exceedance of the 3-hour design significant wave height is thus calculated as follows:

$P(H>H_{\text{sig 3 hours}}) = (1 - P(H>H_{\text{sig area}}))^{1/N}$ where

N = number of 3-hour transit periods through the area, corrected for the calm period
$P(H>H_{\text{sig area}})$ = 5% without weather routing or 10% with weather routing

The design probability of exceedance is fixed at 5%. In case weather routing is applied within a severe area, thus providing the ship with additional weather information, the P(design) is doubled to 10%.

Given the design wave height and the scatter diagram, 4 short term design sea states will be selected, consisting of a combination of design (or lower) significant wave height and 4 of the most probable wave periods.

Note that a mean wave period is calculated from GWS zero up-crossing periods:

$T_m = 1{,}087 * T_Z$

Enclosure F: VAC method

The VAC program represents a new procedure for the calculation of realistic values for the design loads for heavy lift and vulnerable cargo transports. Traditionally, design accelerations for ocean transports were calculated by the use of a so-called design wave. Now, a tool is produced which takes the motion climate during a complete voyage into account. During a voyage, a ship meets a variety of wind and wave conditions, called the wind and wave climate. The ship and the crew react on these wind and wave conditions. This results in a motion climate for that particular voyage. The most probable maximum load during the transport is derived from the motion climate and on the time actually spent at sea.

New in the VAC method are the following aspects:

1. The probability of all wave heights on the route with their range of different periods is taken into account. So, it is no longer necessary to select a design wave.
2. The effect of the actions of the crew can be taken into account by applying various scenarios. In this way, a much better fit is obtained between the actual motion climate as experienced and the calculated motion climate.
3. The effect on roll of water on deck can be taken into account. This is applicable for flat top barges only. The effect on the roll motions was already demonstrated in the Noble Denton Barge Research.

The program takes into account the non-linearity due to:

- Non-linear roll damping
- Involuntary speed loss in waves

Theory

The wave statistic input is given as a large database with a number of joint frequency distributions of sea states. The database can be issued from GWS, IMDSS or ClioSat, or any other database which can comply to the input format

Description of the voyage

For the description of the voyage, a list of waypoints should be supplied. A waypoint is a point where there is a change in course or there is a change of climatological area. Each part between waypoints is called a leg.

The voyage input file defines for each leg:

- The number of the climatological area where the leg is included
- The distance to be travelled
- The direction in degrees
- Month of the year the specific leg is sailed
- Current direction
- Current speed

The MARPLOT program can generate such a file when GWS or IMDSS database is used. The voyage description through ClioSat climatological areas can be done manually, since the bins differ from Marsden Squares of GWS database.

Most probable maximum Ha

The most probable maximum wave amplitude follows from the Weibull distribution of ‘waves as input’, by reading of at a probability level of 1/N, where N = Number of oscillations for the voyage duration, or at a probability of 1/νN for lower probabilities (where ν is a safety factor).

Most probable Hs for the voyage

The most probable significant wave height for the voyage is derived from the accumulated scatter diagram of the total voyage. This is the weighted sum of all scatter diagrams on the grid legs of the route. A Weibull fit to the cumulative Hs distribution is made and the most probable value is computed by assuming 3-hour sea states. Reading of at a probability level of N = Voyage duration / 3 gives the most probable Hs value.

1-year and 10-year return Hs values

Using the same accumulated scatter diagram and assuming 3-hour sea states, the 1 year and 10 year Hs values are computed by reading of the Weibull fit of Hs at N = (hours in 1 year) / 3 and N = (hours in 10 years) / 3 respectively.

Enclosure G: Comparison of SoS wave database for route Dover-Gibraltar

Comparison of SoS wave database for route Dover - Gibraltar

Report number:	R98101PB002
Revision:	1.1
Date:	12 july 2000
Author:	P.W.L. Brugghe Breeman Engineering and Services b.v.

Ordered by:	JIP COMKISS WP 5100

Preface

This report is prepared for JIP COMKISS work package 5100 ‘ Satellite Data Applied to Design Methods.’ Several JIP participants have contributed to this report. Especially Satellite Observing Systems (SoS) has put a lot of effort to comply to the required data format necessary for the calculations in the Voyage Acceleration Calculation program (VAC software.)
This report is an Annex of the main report for COMKISS work package 5100 titled ‘Comparison of wave databases and design methods for major shipping routes.’
A sub-set of the satellite wave database from Satellite Observing Systems (SoS U.K.) has been used to analyse the use of Satellite data for a transport from Dover to Gibraltar. The analysis was performed using the Voyage Acceleration Climate (VAC) program. It is a recent developed$^{1)}$ engineering tool to establish design criteria with the use of accumulated long term statistics for a simulated voyage with the use of wave scatterdiagrams.

The main report compares long term statistics for 14 routes on the Northern Hemisphere using several wave databases: GWS, IMDSS, ClioSat and an in-house Dockwise design method. This enclosure focuses only on the route from Dover to Gibraltar and compares results.

Revision	Date	Author	Comment
0.1	09 February 2000	PB	First issue
1.0	12 July 2000	PB	First handout
1.1	24 August 2000	PB	Minor changes

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1) VAC: Voyage Acceleration Climate, software developed by Maritime Research Institute Netherlands in Wageningen for Joint Industries Project VAC.

Contents

1 Introduction

The motion climate method called Voyage Acceleration Climate (VAC) models the probability of all sea states (included storms) on a trip. A scatter diagram for the whole trip is constructed by weighting the scatter diagram in each climatological area or bins, for the time spend in that bin. This way the long-term distribution of the ship motions can be calculated by calculating the response to each sea state (storm) in the database.

This method therefore makes it possible to perform economic risk assessments, design to a pre-defined reliability goal and perform fatigue analysis.

The effect of ships routing and bad weather avoidance by the ships crew can only be roughly approximated in this method. Wind and waves are uncorrelated and therefore motions caused by extreme wind can only be combined with the extreme wave condition resulting in conservative assumptions.

Advantages:

- Economic risk assessments possible
- Design to a pre-defined reliability goal possible
- Fatigue analysis possible
- Databases available with sufficient duration

Disadvantages:

- Weather routing and bad weather avoidance can only be approximated
- Transports and installations with weather windows cannot be modeled
- Swell is not separately included
- Wind can only be modeled conservatively

More details about Voyage Acceleration Climate are given in reference [2], [4] and [5].

2 Data description

The SoS data was re-formatted for the use in the VAC program. The scatterdiagrams based on significant waveheight and T_z were adapted to the output format used by the BMT [ref.1.]

- 45° directional stratification
- Season stratification
  - Annual
  - January – March
  - April – June
  - July – September
  - October – December
- 6 geographical area’s (bins)
- ASCII file format

SOS satellite data (for this exercise)

- contained only TOPEX data. October 1992 to January 1999
- Hs calibration
  Hs adjusted = HS Topex * 1.0523 - 0.0942
  (plus correction for drift after mid 1997 of minus 4mm per day)
- Tz is calculated from the altimeter backscatter and wave height, with a correction for wave age.
- SOS data cover October 1992 onwards, so should include the effect of some severe winters as well as calmer winters.

Cliosat satellite data (provided for the main report by Ifremer)

- include Geosat (1987-89) , ERS-1 (1991-95) and TOPEX (1992- ?).
- TOPEX calibration is:
  Hs adjusted = HS Topex * 1.10
  (i.e. the individual TOPEX values will be 5% plus 9.4 cm higher than SOS TOPEX values)

2.1 Scatterdiagram example

```
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1 316    0.000000    0.104037    0.201729    0.028915    0.005819    0.001083    0.000000    0.000000    0.000000    0.000000    0.000000
1 416    0.000000    0.000000    0.080475    0.142771    0.033847    0.007067    0.002361    0.000376    0.000000    0.000000    0.000000
1 516    0.000000    0.000000    0.000000    0.041471    0.090038    0.021216    0.004195    0.001293    0.000150    0.000000    0.000000
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1 116   21/10/1999 14:24:57 204 1   1  3 0 100.0000   3.5000    1.0000   11   0.5000    1.0000   15          0.0 360.0 ALL DIRECTIONS..
1 216    0.000309    0.010245    0.000247    0.000000    0.000000    0.000000    0.000000    0.000000    0.000000    0.000000    0.000000
1 316    0.000000    0.058014    0.109980    0.015861    0.002592    0.000494    0.000000    0.000000    0.000000    0.000000    0.000000
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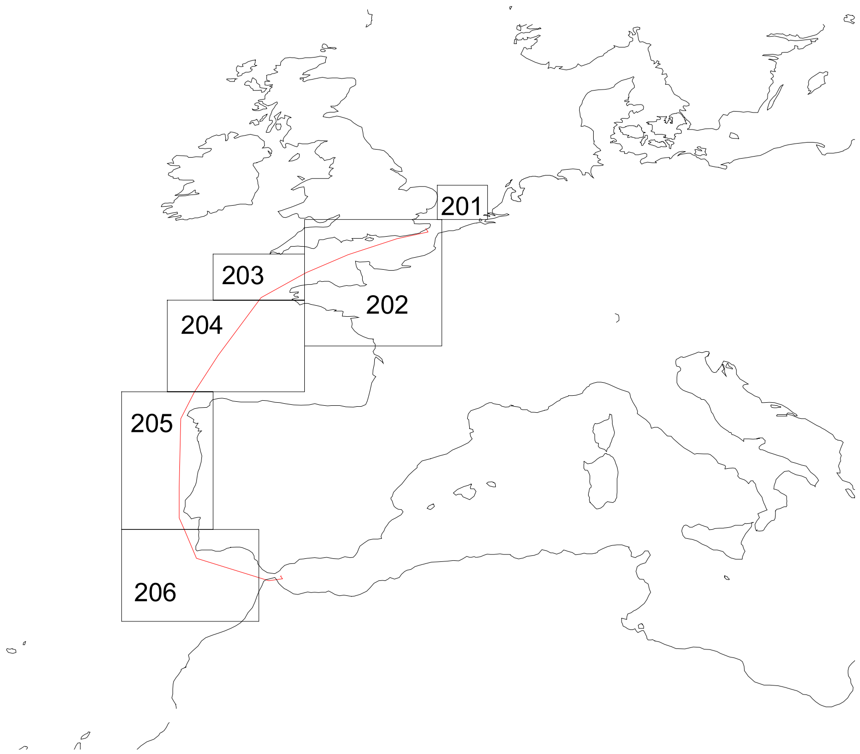
2.2 Area definition



2.3 Route

The route Dover to Gibraltar was used for comparison. Route definition, in legs from waypoint to waypoint, was handled by the VAC program using a geographical plotting program called MARPLOT. A legs are defined as a vector (course and distance) for each area.

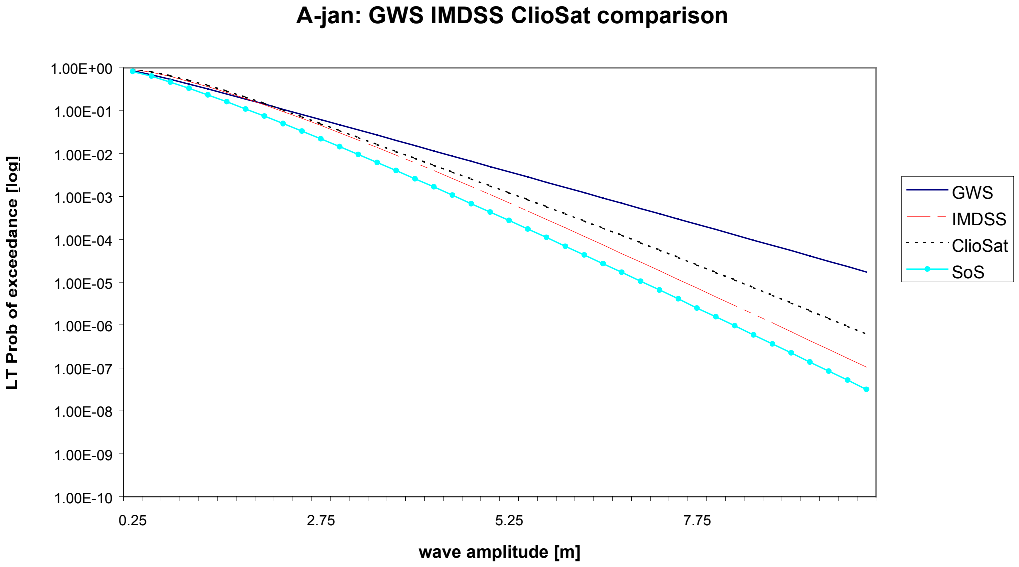
This route is referred to as route-A.

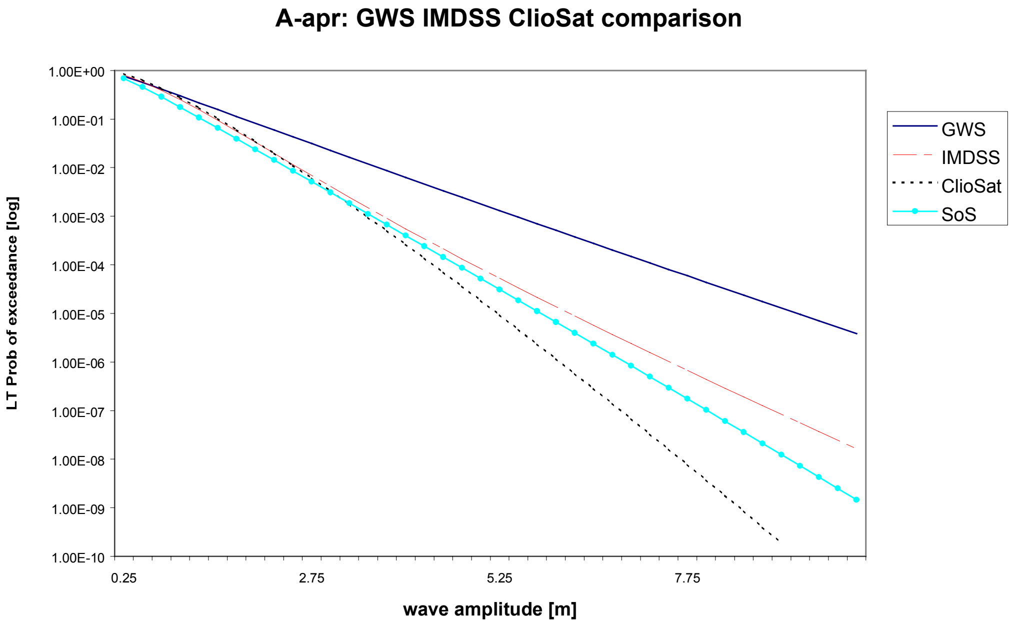
3 Results

Results is output data from the VAC program.

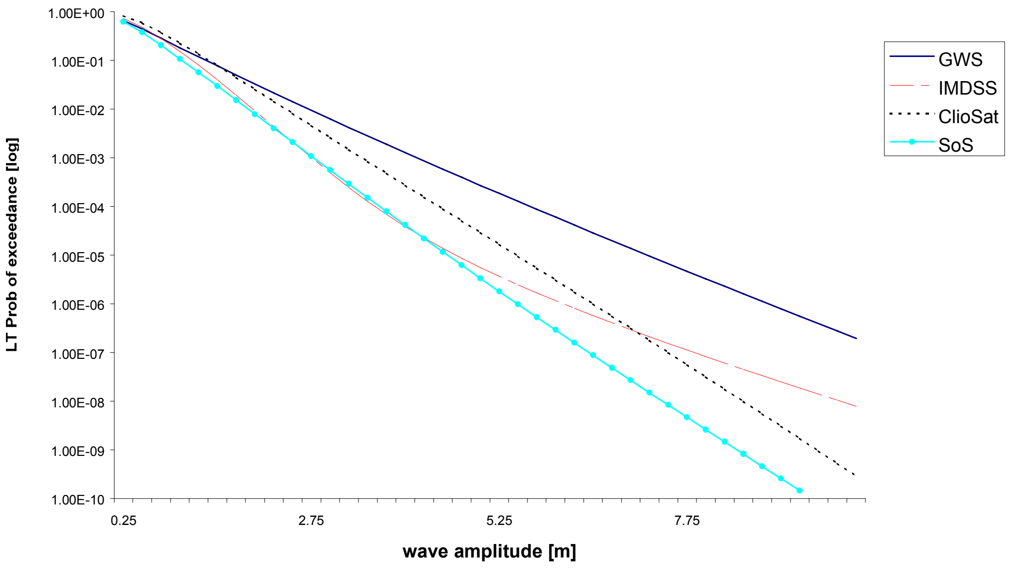
3.1 Waveheight amplitude

Shown is the long term probability of exceedance of a certain waveheight amplitude (H_a.)

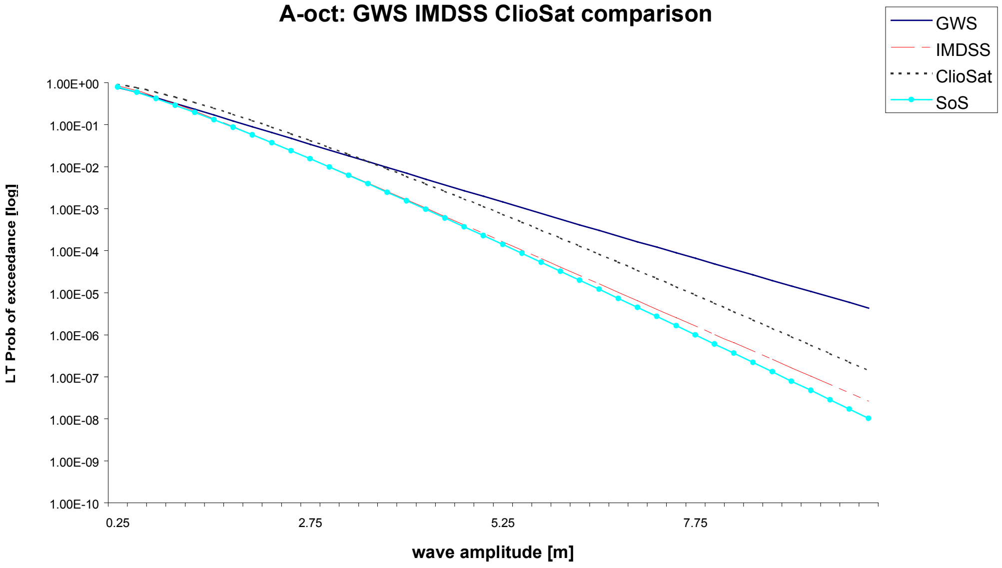




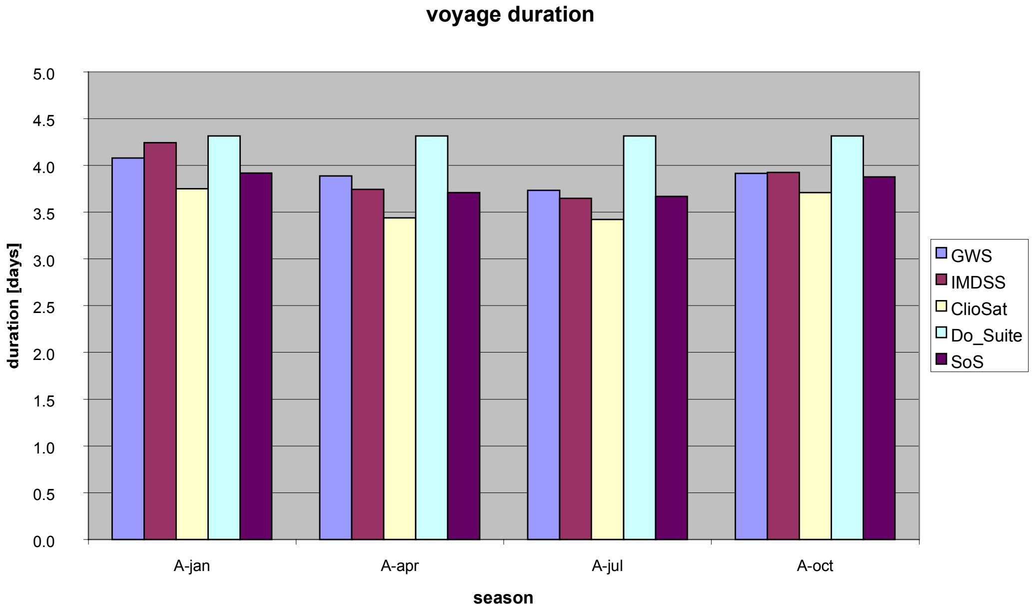
A-jul: GWS IMDSS ClioSat comparison



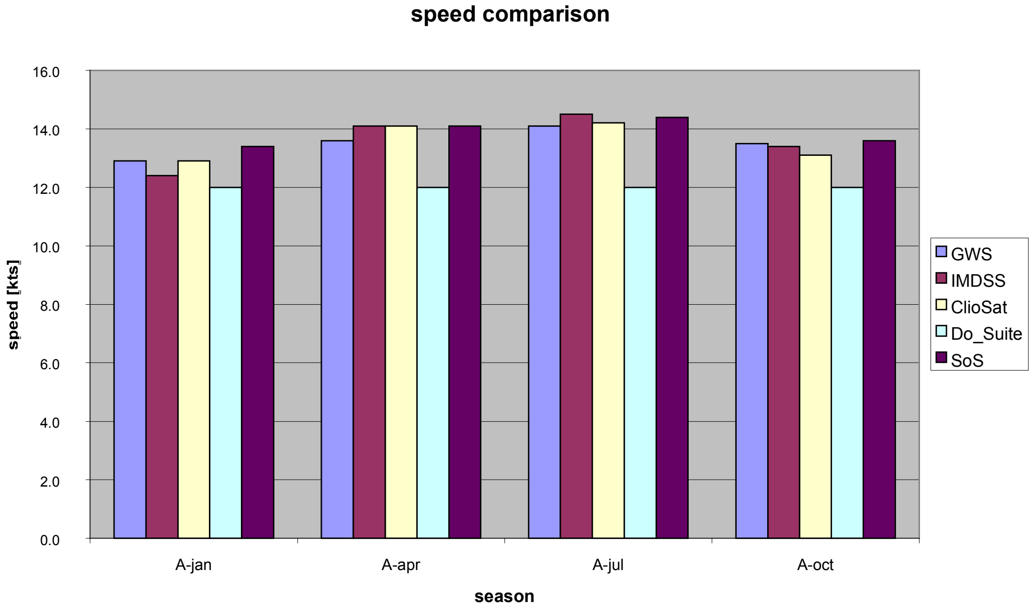
A-oct: GWS IMDSS ClioSat comparison



3.2 Voyage duration



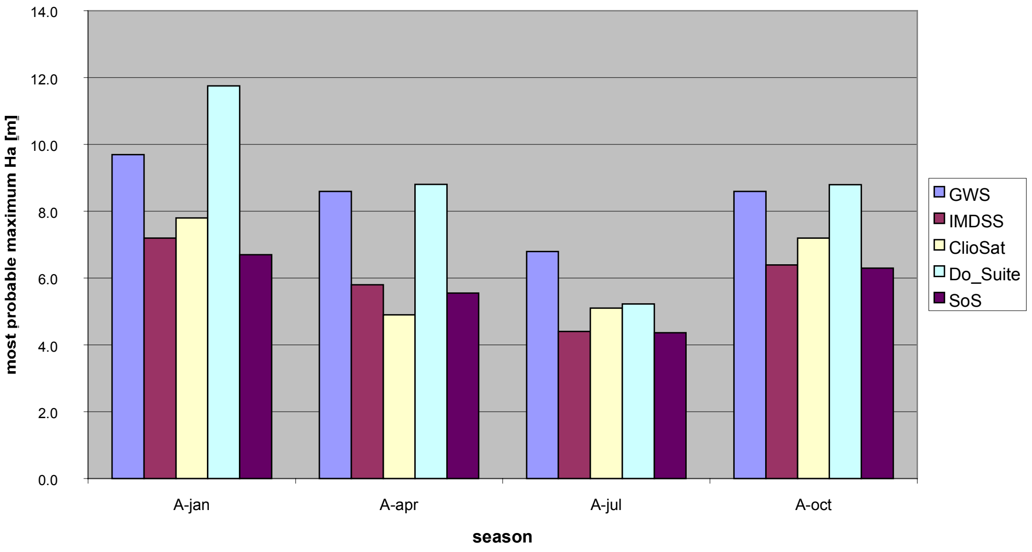
3.3 Transport speed during voyage



3.4 Most Probable Maximum Ha

This is the MprMax waveheight amplitude for the voyage duration

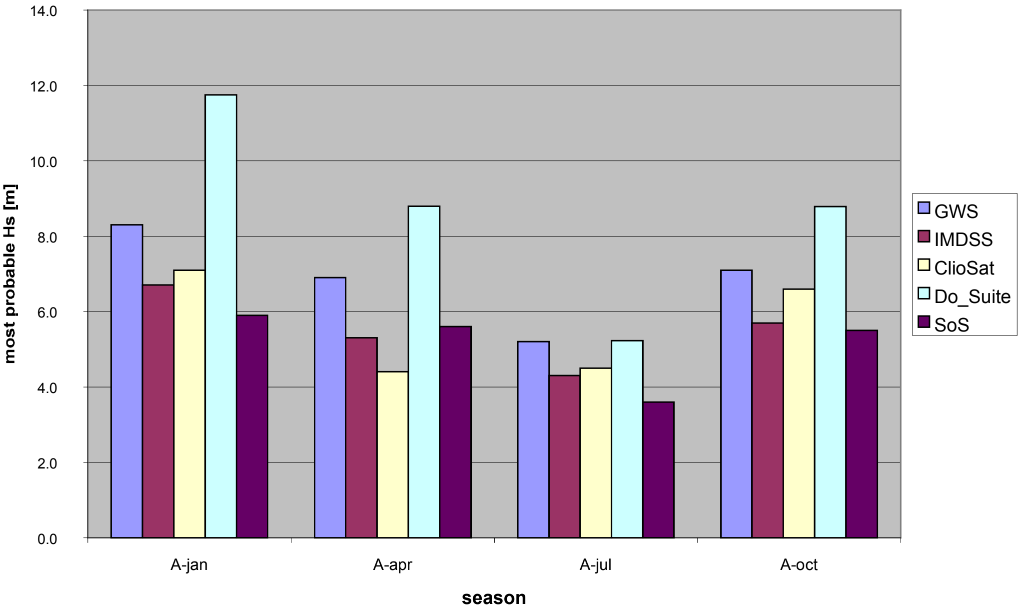
Ha comparison



3.5 Significant waveheight

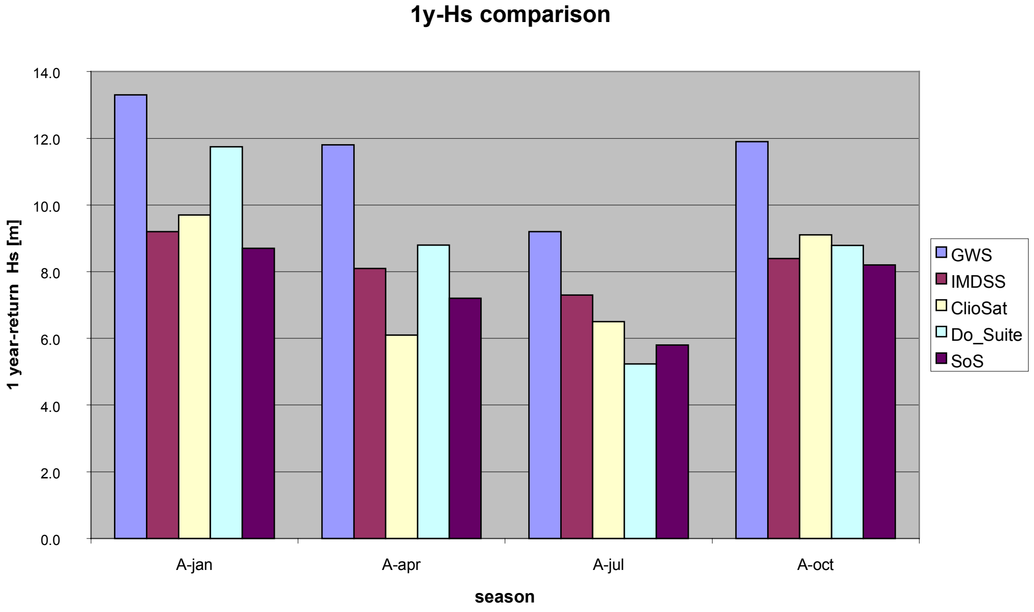
This is the significant waveheight for the voyage duration.

Hs comparison



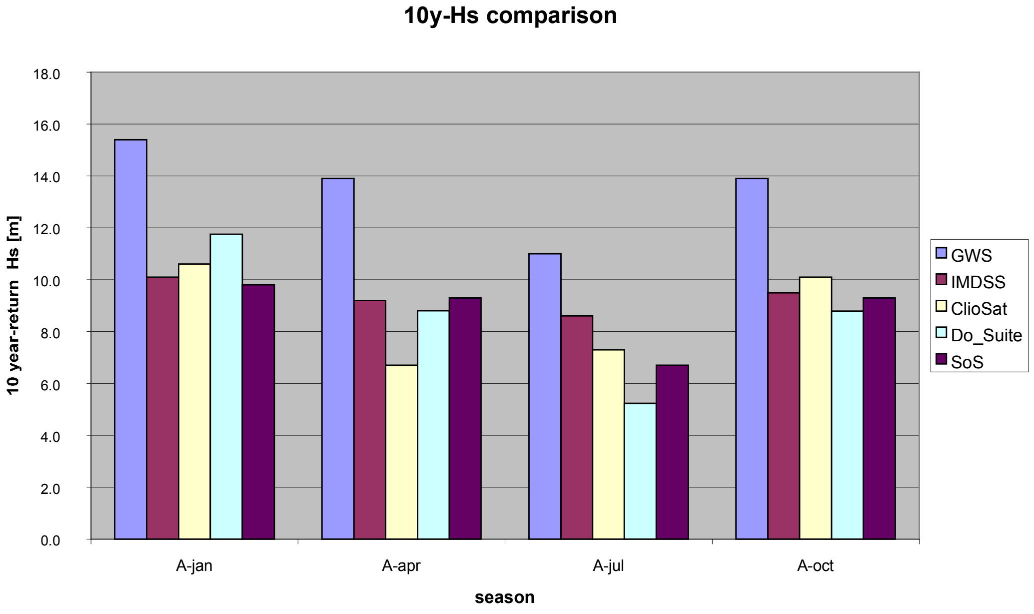
3.6 1 year Hs

This is the significant waveheight with a return period of 1 year.



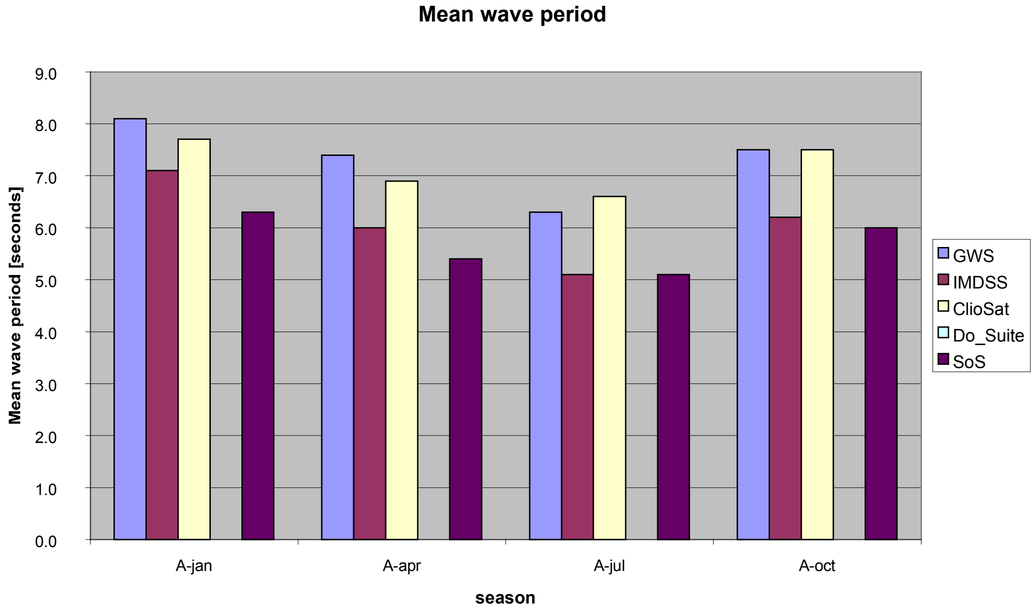
3.7 10 year Hs

This is the significant waveheight with a return period of 10 years.



3.8 Wave period

This is the men period for the waves encountered during the voyage.



3.9 Voyage summary

			GWS	IMDSS	ClioSat	Do_Suite	SoS
A-jan	voyage duration	days	4.1	4.2	3.8	4.3	3.9
	speed	kts	12.9	12.4	12.9	12.0	13.4
	most probable maximum Ha	m	9.7	7.2	7.8	11.8	6.7
	most prob max Ha over 10 voyages	m	15.4	10.1	10.6		
	average period waves as input	s	8.1	7.1	7.7		6.3
	Hs	m	8.3	6.7	7.1	11.8	5.9
	1 year Hs	m	13.3	9.2	9.7	11.8	8.7
	10 year Hs	m	15.4	10.1	10.6	11.8	9.8
A-apr	voyage duration	days	3.9	3.7	3.4	4.3	3.7
	speed	kts	13.6	14.1	14.1	12.0	14.1
	most probable maximum Ha	m	8.6	5.8	4.9	8.8	5.6
	most prob max Ha over 10 voyages	m	13.9	9.2	6.7		
	average period waves as input	s	7.4	6.0	6.9		5.4
	Hs	m	6.9	5.3	4.4	8.8	5.6
	1 year Hs	m	11.8	8.1	6.1	8.8	7.2
	10 year Hs	m	13.9	9.2	6.7	8.8	9.3
A-jul	voyage duration	days	3.7	3.6	3.4	4.3	3.7
	speed	kts	14.1	14.5	14.2	12.0	14.4
	most probable maximum Ha	m	6.8	4.4	5.1	5.2	4.4
	most prob max Ha over 10 voyages	m	11.0	8.6	7.3		
	average period waves as input	s	6.3	5.1	6.6		5.1
	Hs	m	5.2	4.3	4.5	5.2	3.6
	1 year Hs	m	9.2	7.3	6.5	5.2	5.8
	10 year Hs	m	11.0	8.6	7.3	5.2	6.7
A-oct	voyage duration	days	3.9	3.9	3.7	4.3	3.9
	speed	kts	13.5	13.4	13.1	12.0	13.6
	most probable maximum Ha	m	8.6	6.4	7.2	8.8	6.3
	most prob max Ha over 10 voyages	m	13.9	9.5	10.1		
	average period waves as input	s	7.5	6.2	7.5		6.0
	Hs	m	7.1	5.7	6.6	8.8	5.5
	1 year Hs	m	11.9	8.4	9.1	8.8	8.2
	10 year Hs	m	13.9	9.5	10.1	8.8	9.3

4 Conclusion

Satellite databases are relative new. This results in relative small databases regarding the number of samples. The sensitivity for single extremes is therefor high. Especially the route A from Dover to Gibraltar is close to land masses which causes data rejection due to land measurements.

In the probability of exceedance charts, the GWS / IMDSS / SOS relationship seems fairly constant - except in July where IMDSS has high probability of higher waves (possibly a bias from a single storm?). Cliosat lies between GWS and IMDSS expect for April , where it is lower than all data bases.
Significant Wave height (Hs).
GWS is always higher than the other data bases. IMDSS is always higher than SOS, SOS is usually lowest (except in April Cliosat is lowest). Cliosat is higher than IMDSS in Jan and Oct, but lower in April and July.

Wave periods.
SOS is lower periods in Jan and April than all others, but comparable to IMDSS in July and October

The differences in Cliosat and SOS significant wave heights are the periods of data in the data bases, calibration, and quality control.
Cliosat wave periods are from synthetic aperture radar, SOS from altimeter.

5 References

[1] Britisch Maritime Technology; ‘PC Global Wave Statistics user manual’; BMT Ltd, Middelsex U.K.;revision 1, October 1990

[2] QUADVLIEG F.H.H.A., AALBERS A.B., DALLINGA R.P., “Voyage Acceleration Climate: Functional specifications and Technical design”, Maritime Research Institute of Netherlands, Wageningen, July 1998, 48 pp.

[3] P.W.L. Brugghe, A.B. Aalbers; ‘IMDSS – GWS Comparison’;MARIN Wageningen; april 1999.

[4] A.B. Aalbers, C.E.J. Leenaars, F.H.H.A. Quadvlieg; ‘VAC: A Comprehensive Statistical Method for the Evaluation of Design Loads for Offshore Transport’;OTC paper No 8123; OTC may 1996.

[5] F.H.H.A. Quadvlieg, A.B. Aalbers, R.P. Dallinga, C.E.J. Leenaars; ‘ Voyage Acceleration Climate: A New Method to Come to Realistic Design Values for Ship Motions Based on the Full Motion Climate for a Particular Transport.’;MARIN Wageningen; Elsevier 1997.