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Innovation in meteorology for maritime navigation

WAVE SPECTAL DATA IN SHIP WEATHER ROUTING

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October 23th, 2013

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Introduction

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Weather routing and ship guidance are essential in the navigation both to ensure safe passages and to achieve the target required by the ship mission.

To provide reliable weather predictions is the first essential step towards the development of an efficient weather routing system integrated in the navigation procedures.

On-board software for route selection combined with remote advice and guidance from ashore weather service offices allow to avoid weather hazard ensuring the autonomy of the captains in the decision making process.

Wrong prediction in ship behaviour, even if conservative, can lead to dangerous situations.

Meteo-marine data sources

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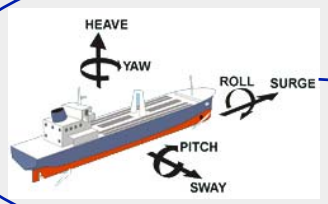
Main sources which provide a complete description of the sea-state in term of directional spectra:

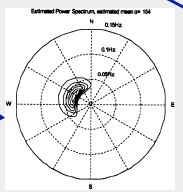
Direct measurements

Third generation numerical models

X-band radars

Wave spectra from ship motion





Meteo-marine data sources

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THIRD GENERATION NUMERICAL MODELS

Modern phase averaging models predict the spatial and temporal evolution of the directional spectrum solving the equation:

$$\frac{\partial F}{\partial t} + C_g \cdot \nabla F = S_{tot}$$

where the source term S_{tot} represent, in deep water the summation of atmospheric inputs, dissipation and quadruplet nonlinear interactions.

- WAM
- WW3
- SWAN (nearshore)

Meteo-marine data sources

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Example of hindcast database:

- ECMWF re-analysis (ERA15, ERA40, ERA-interim) – worldwide
- NCEP/NCAR reanalysis – worldwide
- HYPOCAST – European seas
- Regional hindcast (NORA10 – Northern European seas)

Example of forecast services:

- ECMWF – WAM
- NOAA – WW3
- National and regional institutes of meteorology

Meteo-marine data sources

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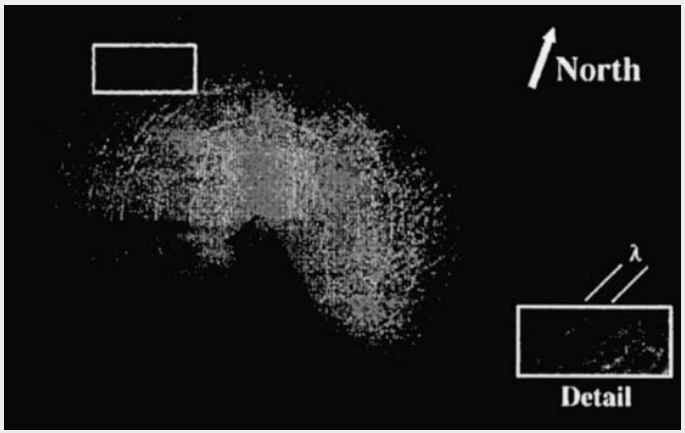
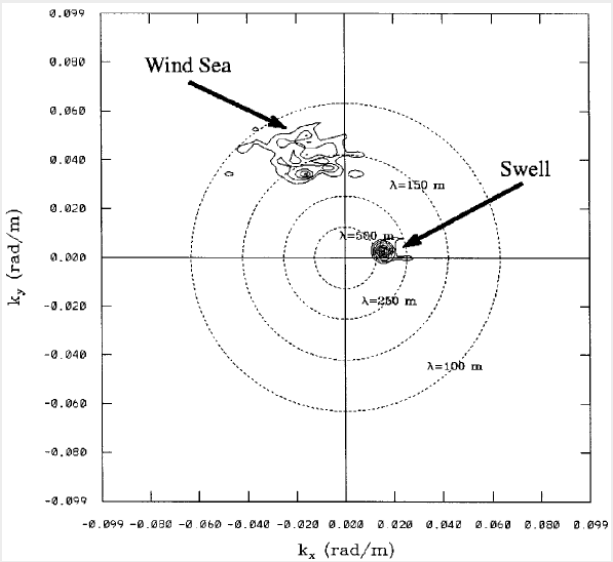
Nautical radar

Sea clutter



Directional wave spectra



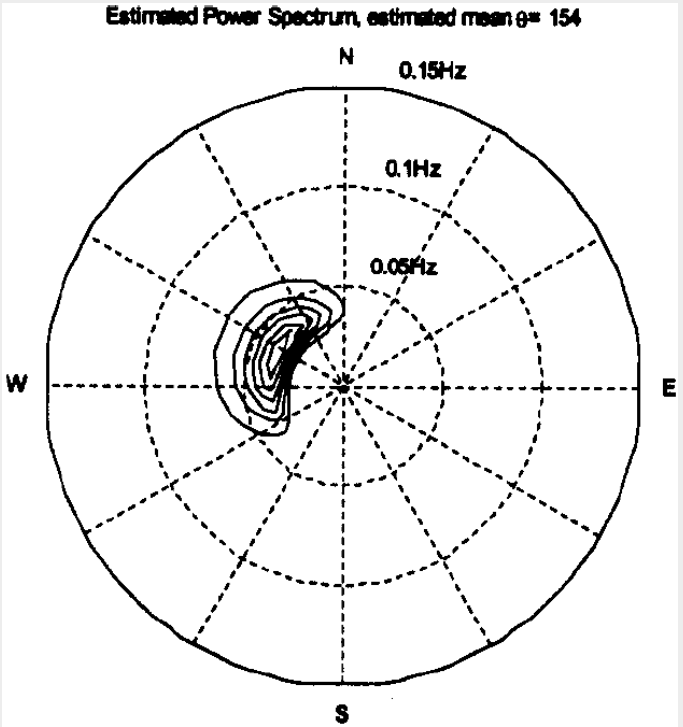
Meteo-marine data sources

WAVE SPECTRA FROM SHIP MOTIONS

Ship motions is so correlated with wave spectra that the inverse process can be made, calculating the spectra from the motions provided by common motion sensors.

The main limits are:

- not circular symmetry
- low pass filter effect



Source: Pascoal et al. (2007)

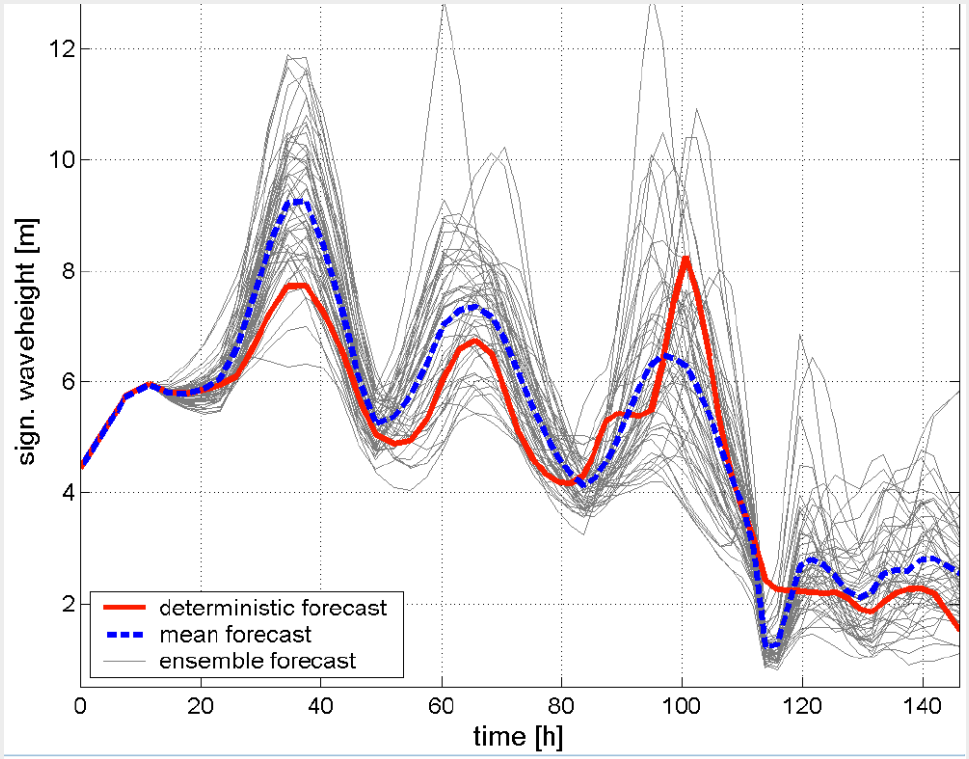
Meteo-marine data sources

Best approach:
mix “man-machine” ensemble forecast

Forecasts from
various forecast centres

Quality-control
by experienced forecasters

Quantification of uncertainties



Source: Hinnenthal (2008)

Meteo-marine data sources

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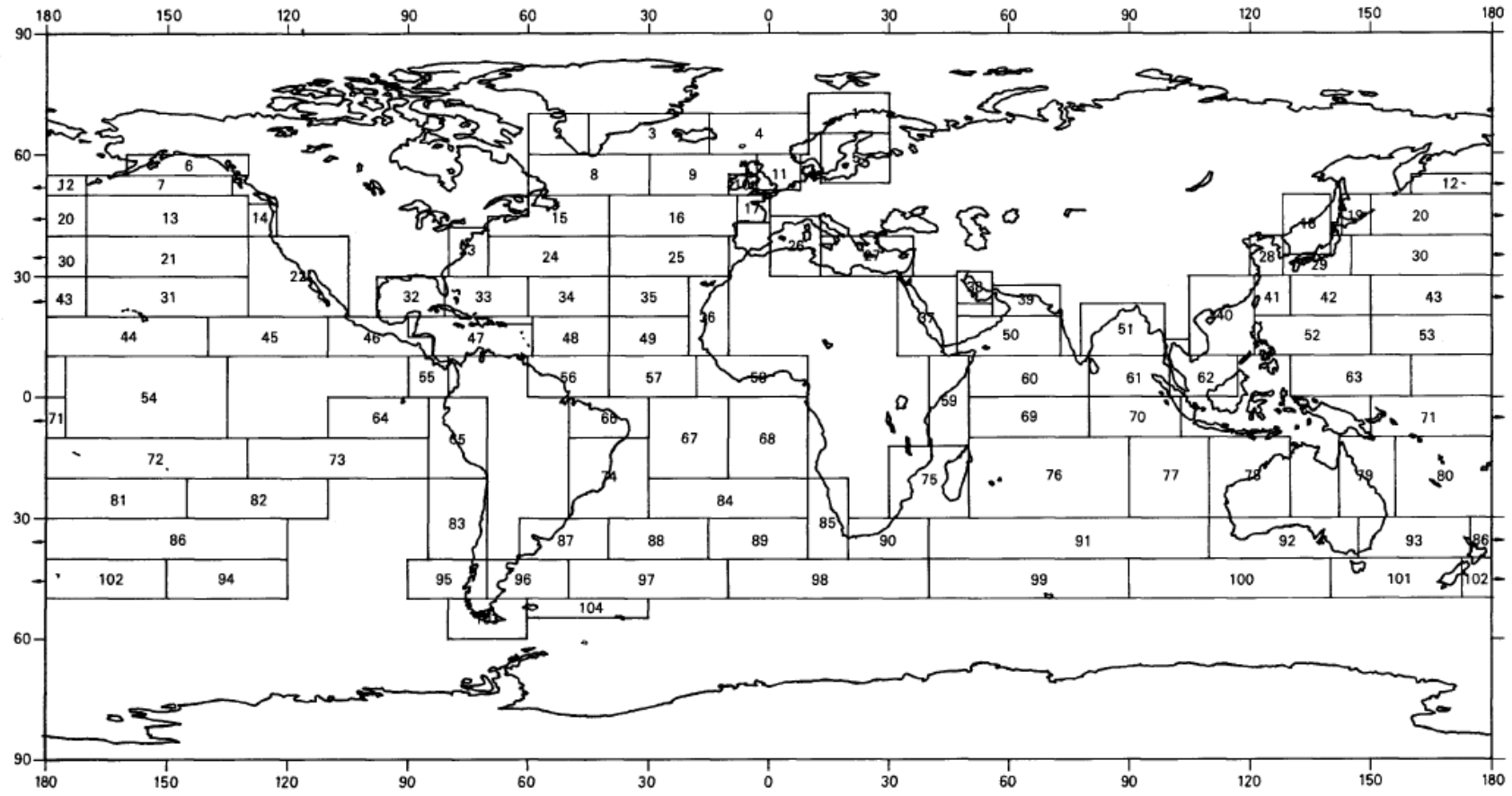
Ocean wave statistic, giving probability of occurrence of a certain sea-state in terms of H_S and T_P, are traditionally used to evaluate operability and plan route schedules and fleet management.



Source: Hogben et al. (1986)

Meteo-marine data sources

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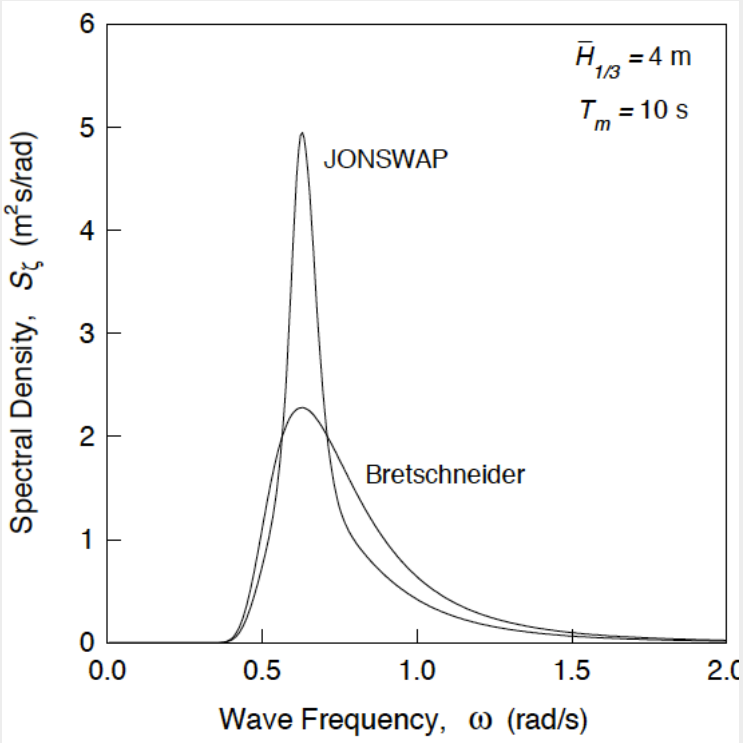
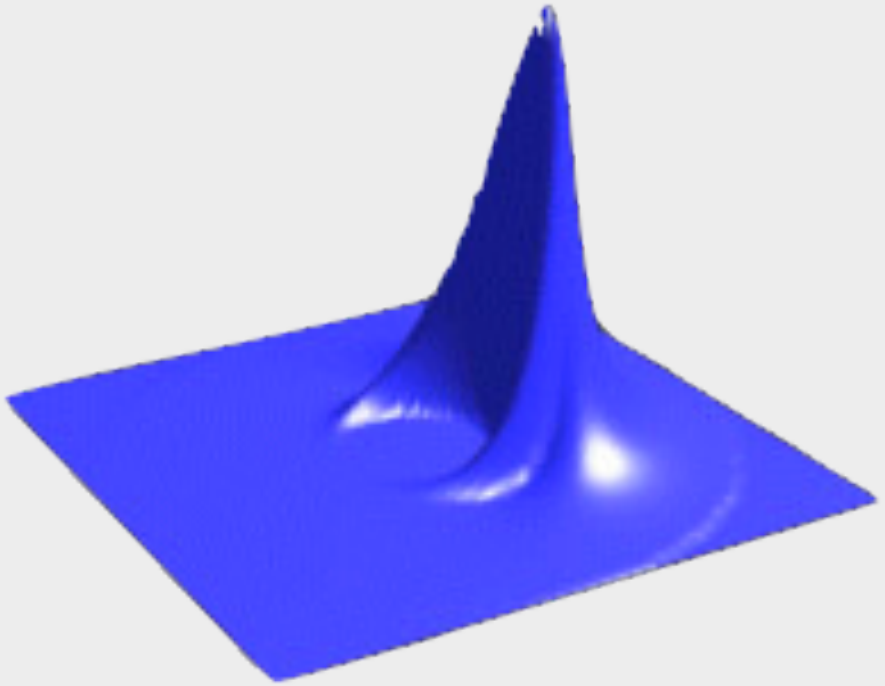
The traditional parametric representations of the wave spectra which are used in naval engineering and routing are uni-modal and unidirectional.
Seldom the short crest is simulated by a symmetrical cosine function.





Meteo-marine data sources

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BUT…

Meteo-marine data sources

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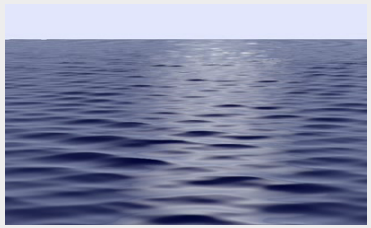
wind sea



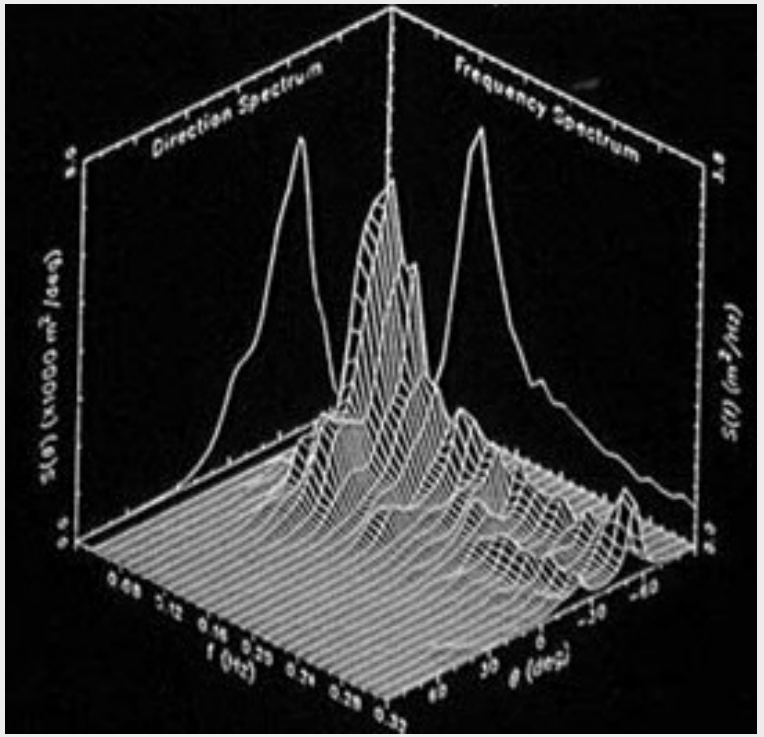
swell

u_α

u_α

c_p

c_p



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Meteo-marine data sources

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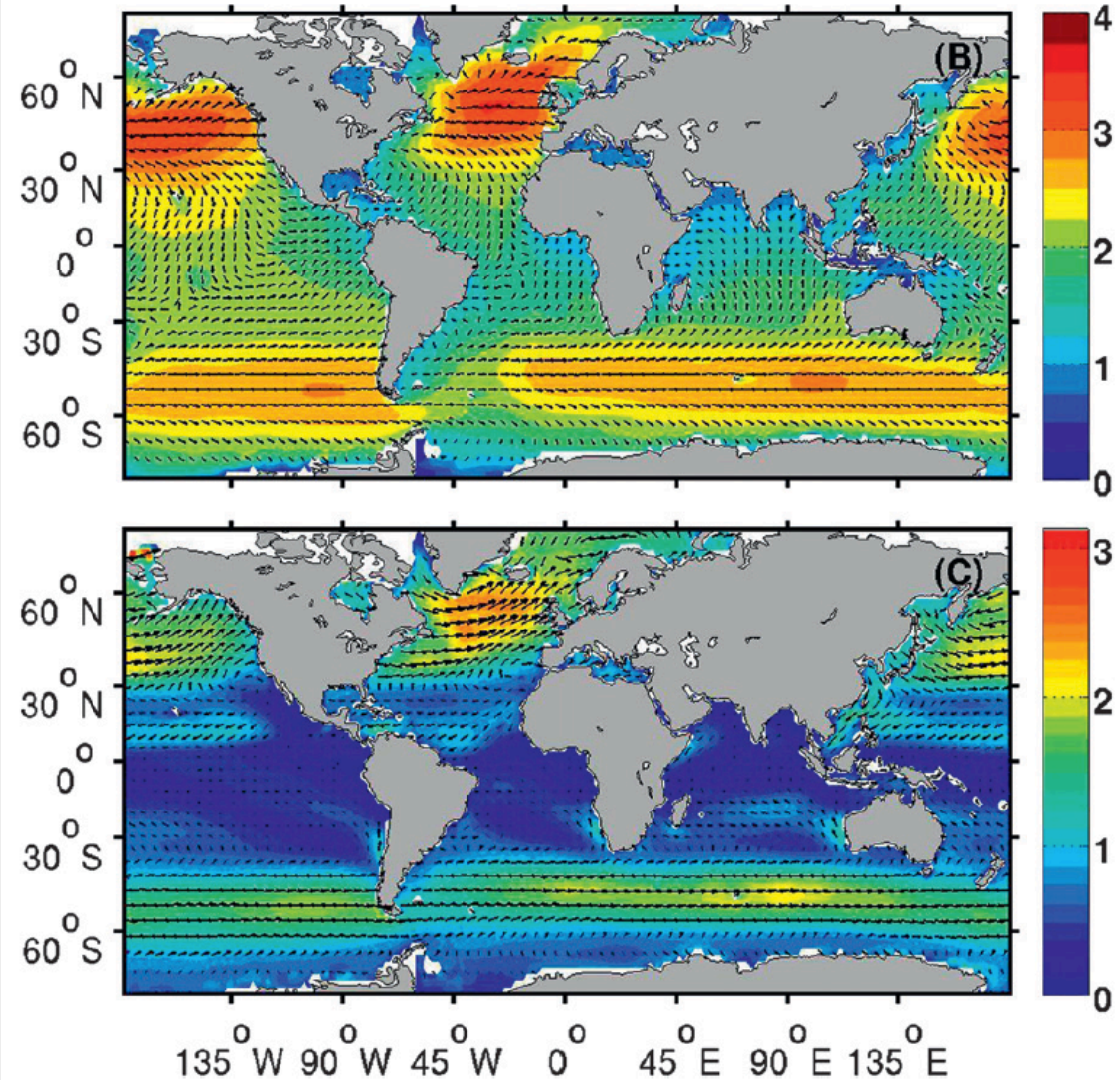
Sea surface is always a mix of wind sea and swell waves.



Source: Semedo et al. (2011)

Ship motions

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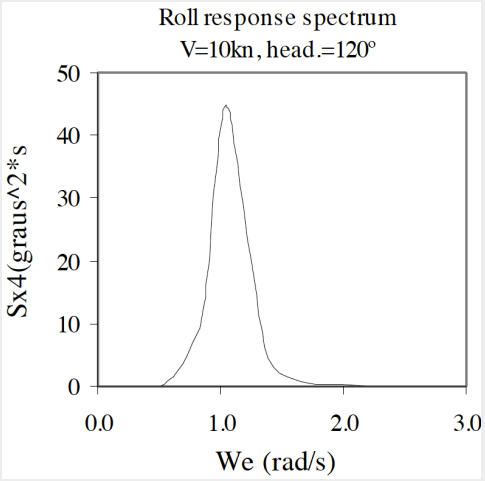
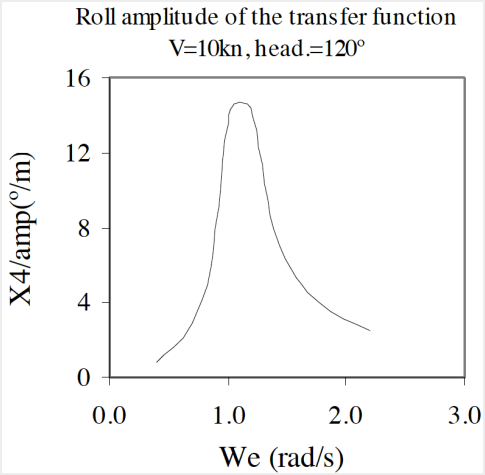
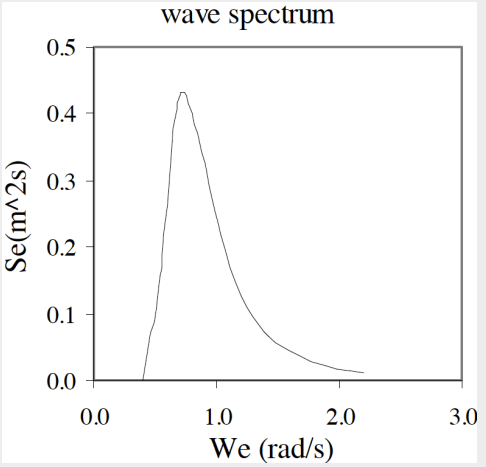
For the j[th] motion, the ship response spectrum can be calculated from the wave spectrum, knowing the relative transfer function as:

$$S_j(\omega,\beta) = [\ X_j/a(\omega,\beta)\ ]^2 * S_\zeta(\omega)$$







Ship motions

The accurate knowledge of the frequency distribution of the exiting forces is vital.

Preliminary assessment of natural periods:

- Heave : $T_{\xi 3} \approx 2.5 \sqrt{T}$
- Roll : $T_{\xi 4} \approx 0.73 * B/\sqrt{GM_T}$
- Pitch : $T_{\xi 5} \approx \begin{cases} 2.5 \sqrt{T} \\ 0.70 * L/\sqrt{GM_L} \end{cases}$

Warning of resonance

Ship motions

Dangerous situation in adverse weather – IMO

In the MSC circular 1228 the following dangerous conditions are highlighted:

- Surf-riding and broaching-to: long waves in following or quartering seas
- Wave crest amidships: $\lambda = 0.6 \div 2.3\ L$
- Synchronous rolling motion: $T_E = T_R$
- Parametric roll motions: $T_E \approx T_R$ or $T_E \approx 0.5\ T_R$

All of those hazards are strictly dependent on the wave frequency.
Their avoidance is being included in the newest weather routing software.

Ship weather routing

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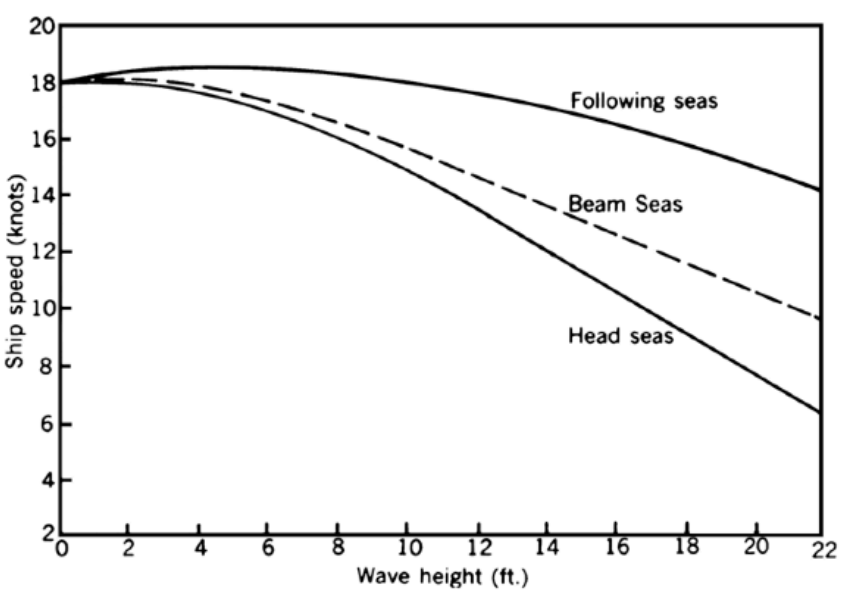
Traditional weather routing services are based on storm avoidance

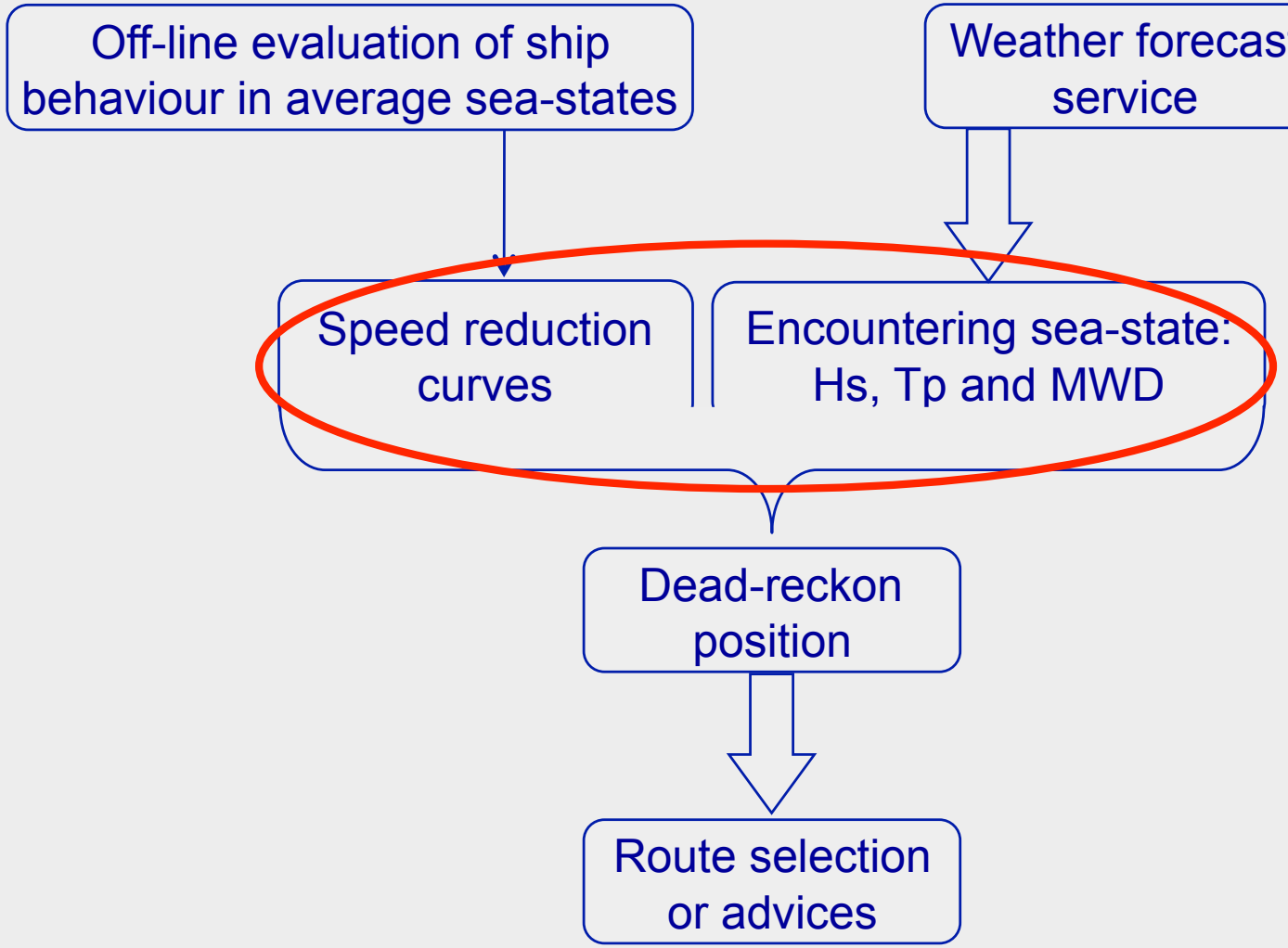
Ship performances are assessed by speed reduction curves

Fuel consumption is estimated based on mean tonnes per day



Sea-state can be simply describe through its energy content and mean direction

Ship weather routing



Ship weather routing

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Reasons of such a simplistic method

- First generation wave models neglected non-linear wave interactions in the source term
- Spectral prediction was not enough accurate and reliable
- Parametric description of sea-state dramatically reduced the required amount of data
- Storing and transmition are simplified

Ship weather routing

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Added resistance is one of the parameters which is most affected by the use of real or approximated spectrum

Using parametric spectra added resistance is generally overestimated

Local minima are not detected

Wrong estimation of speed reduction

Erroneous ship dead-reckoned position

Routing software do not exploit favourable combinations of speed and heading

It may lead to dangerous situation or unnecessary diversions

Route is not optimized

A conservative approach is not acceptable

Ship weather routing

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Wave periods are averaged if a parametric description of spectra is used

Energy distribution in frequency is approximated and neglects local peaks

Dangerous situations are strictly dependent on combination of natural period of motion and wave period

Surf-riding,
parametric rolling motion
and special stressing condition for ship structures cannot be predicted.

Ship weather routing

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More than 5000 containers are lost every year

Over 40% of the worldwide liner service vessels arrive one or more days behind the schedule.

An outdated weather routing technology based on storm avoidance and speed reduction curves is no sufficient.

Detailed ship performances and loading condition must be taken into account as well as an accurate description of the sea-state

Ship weather routing

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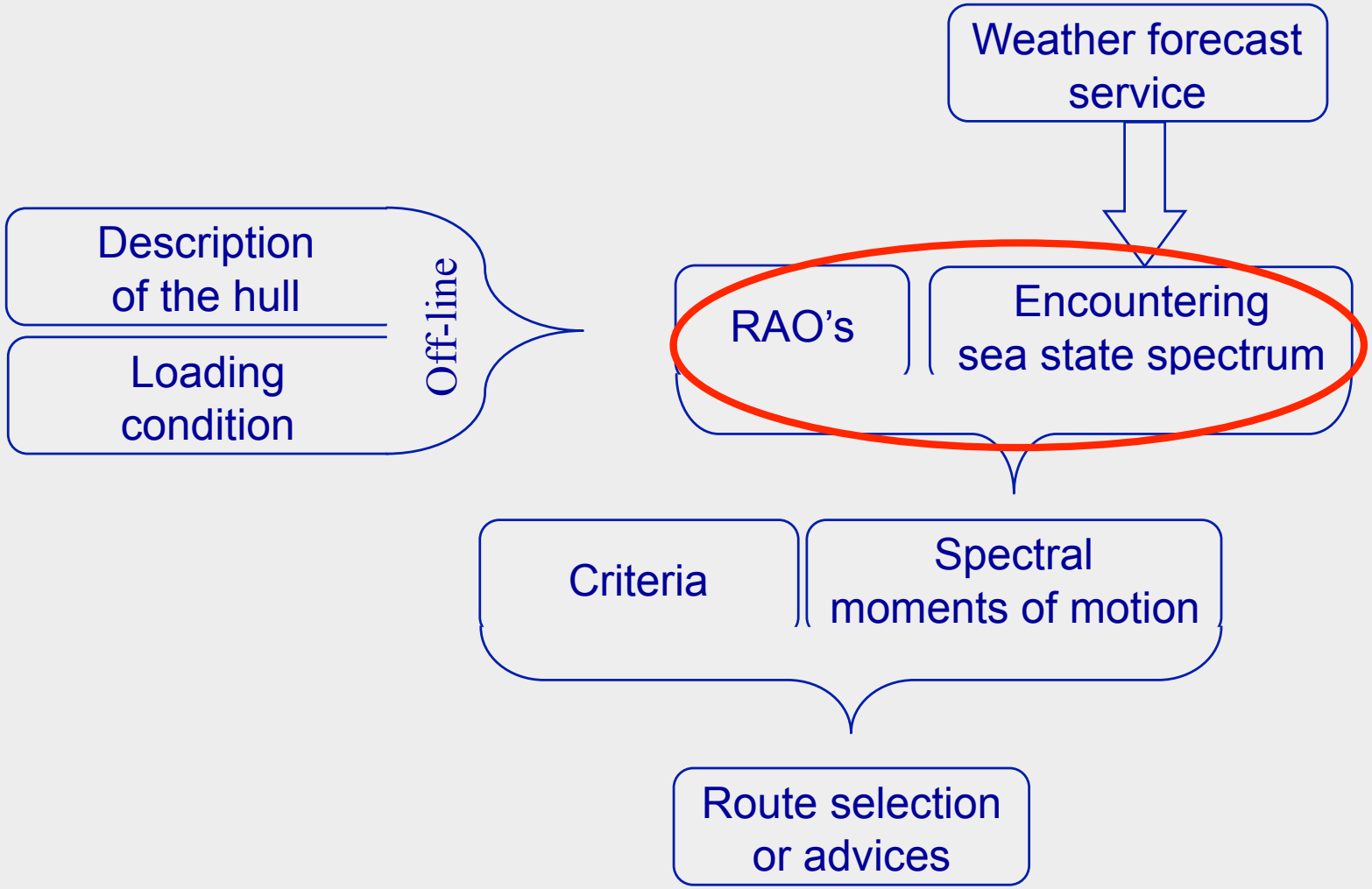
Technical improvements to be exploited:

New satellite communications are making possible the transmission of larger amounts of data than possible through traditional radio messages, a development which supports systems using on-board analysis to evaluate and select the route.

Only during the last few years, the computing power of a desktop PC has been able to run such a computationally intensive programs in less than a minute as part of onboard software to provide sea-keeping guidance and safe operating limits.

Modern third generation spectral wave models provide high quality prediction, if fed with reliable weather forecast.

Ship weather routing



Ship weather routing

Intrinsic multi-objective optimization:

- time of arrival (ship speed)
- safety
- consumption
- comfort
- …

Weather influences all of the optimization parameters. An accurate and reliable forecast also in terms of wave frequency and direction is vital.

Thanks to the increasing computational potentialities, genetic algorithms and dynamic programming are more and more preferred to solve this multi-objective problem, the main advantages are that they do not require an “all comprehensive” cost function and allow the detection of all the “optimal” routes, which can be ranked in function of the required strategy.

Guidance

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1/3 of the ships using track ship routing receive operational or weather-dependent change while underway

Route selection process must be repeated in navigation fed by updated weather data

It is recommended to be assisted by an ashore service centre

Guidance

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Human-factor-included ship guidance

Captains tends to act in accordance with the sea-keeping effects

If slamming, acceleration, green water etc occur to frequently, ship is slow down or it change heading

But sea-keeping and stability features often have opposite.

Guidance

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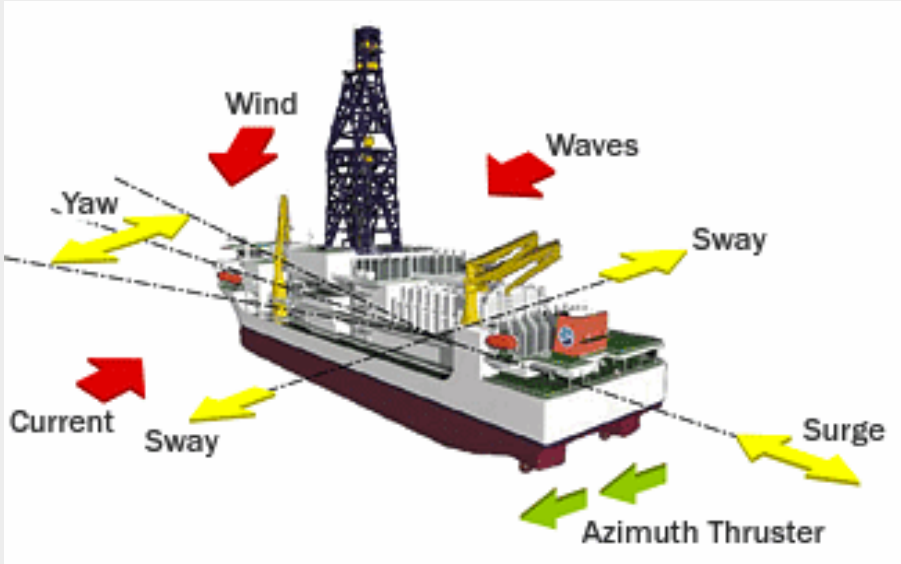
Offshore extreme operations

Researches aimed at using the directional wave spectra from x-band navigation radar to predict the incoming wave profile are being carried on. Extreme off-shore operations may remarkably increase the working hours and reduce the risk preventing motions which might compromise the mission.



Voyage optimization

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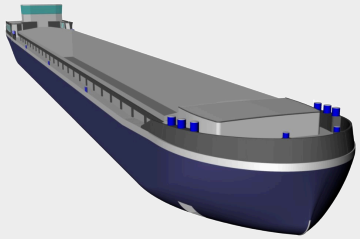
MUCH MORE THAN A SIMPLE WEATHER ROUTING SYSTEM

Voyage optimization

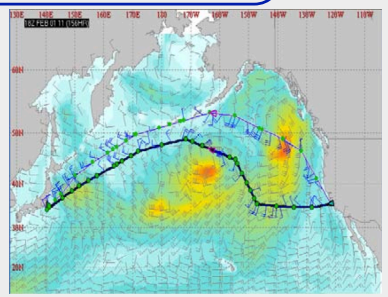


Ship design

Ship life

Fleet planning

Route selection



Conclusions

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Prediction of ship responses and drift forces differs if real or standard parametric wave spectra are adopted

Traditional weather routing system are not able to ensure safe and properly multi-objective optimized passages

Computation and communications capability increased a lot in last years ensuring transmission, storing and elaboration of a large amount of data

Improved skills of NWP and III generation wave models guarantee reliable forecasting

New concept of weather routing system are recommended in order to predict in details ship behavior in seaways

Weather should influence every aspect of the naval engineering: design, logistic, navigation

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Thank you for the attention

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October 23rd, 2013