SINGULAR WAVES, PROPAGATION AND PROGNOSIS

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Within the last years a high number of large ships has been lost. The causes of accidents are in many cases believed to be 'rogue waves'. These are individual waves of exceptional wave height or abnormal shape. To further investigate the properties of and forecasting abilities for low frequency wave fields, extreme individual waves and wave groups for both deep and shallow waters, the EU funds the project MaxWave within the 5th framework programme (EVK3-CT- 2000-00026). In addition this project deals with new design criteria considering the impact of rogue waves on ships and offshore constructions. The innovative part is the combination of new oceanographic knowledge and ocean wave data resources with new approaches to vessels, marine construction, design and operation. It addresses the needs of coastal engineers and port designers/operators in terms of influence and impacts of extreme waves. The main objective of MaxWave is to provide a quality-based metocean information product for the benefit of both high sea and coastal zone operating industry and authorities.

The project covers the following areas:

1. To confirm the existence of rogue waves and their risk of encounter. Existing measurements and hindcast modelling will be used to better understand the shape and impacts of extreme waves in relation with ship/offshore accidents. Modern measurement techniques will be exploited towards the recognition of extreme individual waves and their regional probability of occurrence.
2. To implement the improved knowledge of freak waves to modern ship design, by having involved the two marine communities of marine design and oceanography.
3. To develop forecast criteria for rogue waves with the aid of physical, mathematical statistical and deterministic wave model tests and by that to improve security for human life.
4. To disseminate and exploit the project results by the project members, covering the marine design/operation side, the wave science community, system providers and certifying institutions. A project advisory panel functions as an entrance to international bodies.

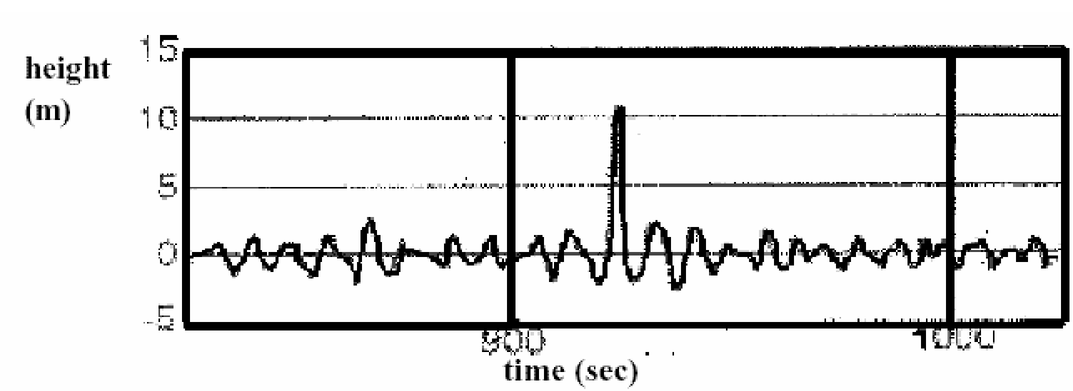

Fig 1: 200 sec Time series of wave height from the Gorm Field

Fig.1 shows a measured time series, which proves the existence of giant individual waves that are more than two times higher than the significant wave height. The large wave is a highly improbable event in a respective Rayleigh statistic.

Fig 2 shows a famous photograph of a white wall of water as an example of an individual abnormal wave. We can see on the following table 1 the partners of the project. There are three European Meteorological Offices, one Certifying Agency, one SME, three Universities and two large research facilities involved in the work.

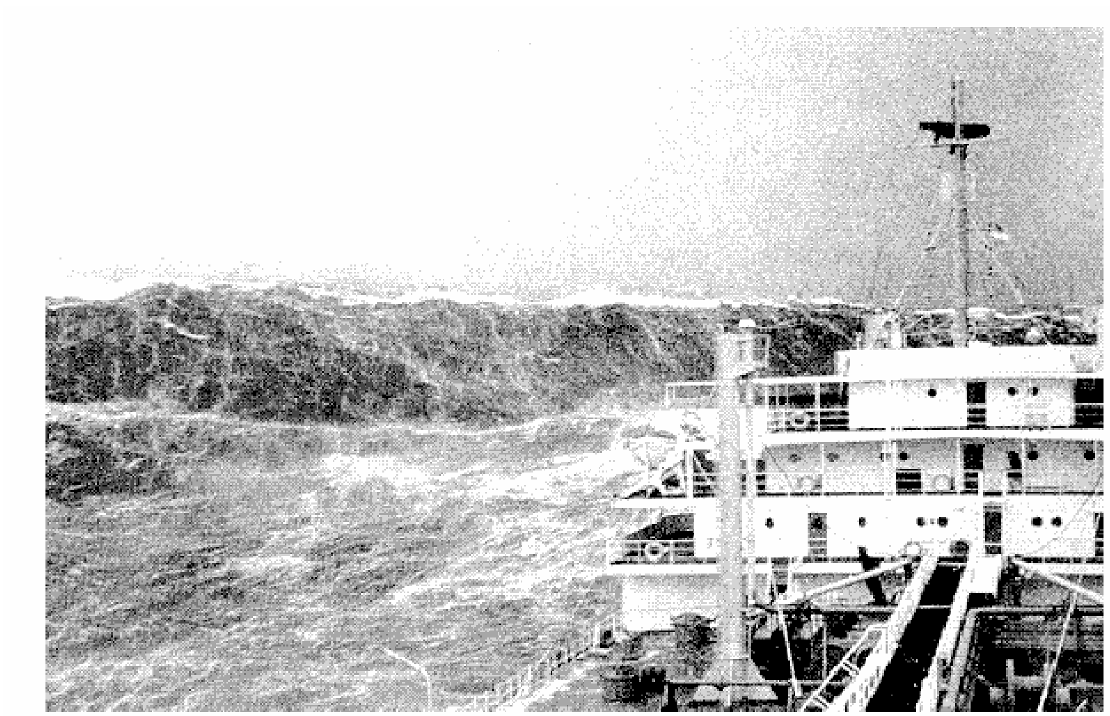

Fig 2: Giant wave in Bay of Biscay

Table 1: Partners of the project

- GKSS Research Center
- DNMI (Norwegian Met. Inst.)
- DLR (German space agency)
- UK Met. Office
- Instituto Superior Tecnologico
- Meteo France
- Ocean Waves
- K.U. Leuven
- Technical Univ. Berlin
- Det Norske Veritas

Meteo France is especially responsible for the improved warnings that should be given to the ships and to the offshore community. At present a warning to ships for rogue waves is only given by the South African weather service. For certain weather conditions, and for special behaviour of the Agulhas current, a warning is given for the east coast of South Africa. In this area well-documented cases of extreme individual waves had occurred in the past, and spectacular photographs of damaged ships are available (Fig 3 gives an example).

Fig 3: Giant wave impacts happen in the Agulhas current

The monster waves at the Agulhas current are explainable by the strong horizontal shear of the current, that causes refraction of the waves and this can lead to a focusing of wave energy if waves run opposite to the current direction as has been numerically shown in a paper by Lavrenov. Therefore one of the project activities was to measure the wave spectrum on a profile perpendicular to the Agulhas current axis. For that purpose a container ship was equipped with a WaMoS radar system, which is able to measure waves from a moving ship (Fig.4). As expected, when crossing the current, deviations in the directional spectrum of the waves were observed. This proves that the strength of the current is strong enough to cause refraction, which can lead to focusing of wave energy at certain locations, which are defined by the detailed velocity field within the Agulhas current. The wave data will be investigated for deviations in wave energy and in the statistics of single crest heights. Although the sea state was never higher than a significant wave height Hs=5 m deviations of wave statistics can be expected.

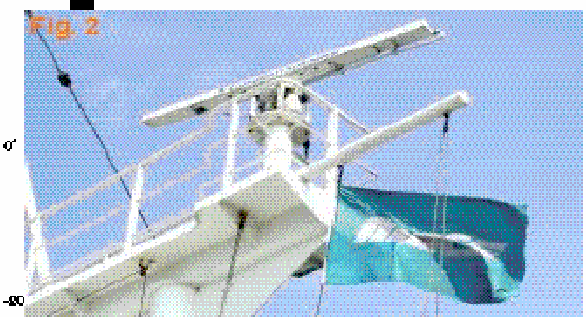

Fig 4: Voyage of container vessel Grey Fox equipped with ship radar

The ship measurements were also valuable for investigation of long swell forecasts that has been issued by the UK Met office, another partner in the project consortium. The UK Met Office especially takes care of hindcasts for monster waves reported in the past, and usually connected to damages for ships or for offshore platforms.

Hindcasts are also supported by measurements and respective analysis of directional wave data from the Ekofisk field by the DNMI from Norway. The DNMI has large experience for special wave forecasts for the especially sensible Ekofisk field and this experience will be exploited for the project aim to propose a warning service for areas of the ocean that are threatened by monster waves. First results seem to indicate that with the Ekofisk measurements as an input, monster waves may be predictable for areas as far as the Danish harbour Esbjerg.

Another way of looking for monster waves is by using space born synthetic aperture radar (SAR). The resolution of the radar satellites is strong enough to measure individual wave heights and this is consequently done by the MaxWave-partner DLR (German space agency). They use a product of the ERS satellites that is not routinely distributed by ESA, the so-called imagette mode that is used globally over the ocean every 200 km along the satellite track (Fig.5 gives an example of an imagette). From 3 weeks of satellite data (about 30.000 imagettes) it was possible to detect individual waves with extreme heights. One of the detected giant waves in a profile through the imagette is shown in Fig.6.

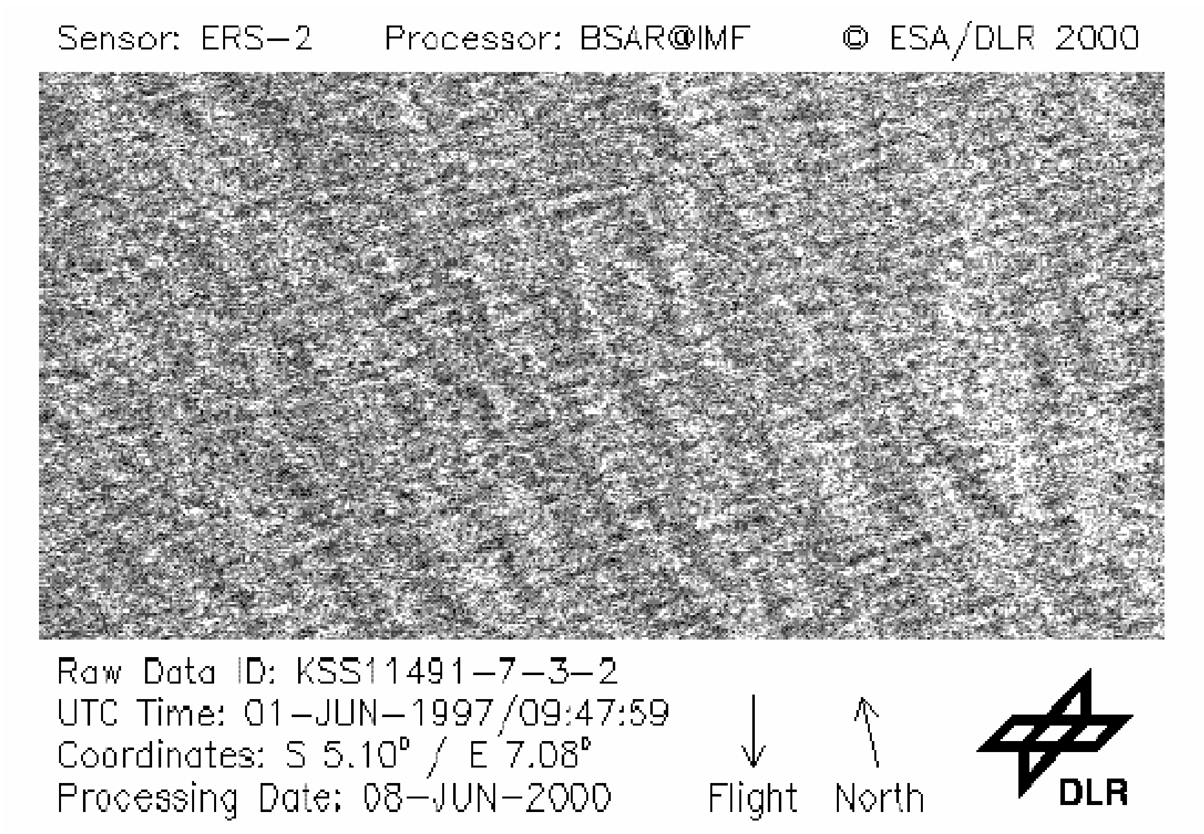

Fig 5: Example of an imagette from ERS-2

Similar methods to derive the individual wave heights, not merely the spectra, are applied to waves detected by ship radar by the MaxWave partner Ocean Waves, a KMU which develops and distributes the ship based WaMoS-wave radar.

The present design for ships, dependent on their stress by sea state, is surveyed by the classification agencies and within MaxWave it is taken care of by Norske Veritas. With their support the two partners Katholic University of Leuven and Instituto Superior Tecnico looked into the statistics of ship accidents due to bad weather, to get eventually a hint towards the spatial variability of dangerous sea states and possibly of extreme individual waves. The result for 5 years of North Atlantic weather is given in fig 7.

The ship designers in the project at partner IST also try with the help of these maps to derive parameters for seasonal or regional risks of ship voyages across the ocean.

At the Technical University in Berlin the task is to show in wave tanks the possibility to create wave groups of special shape and to study there impact on ships and structures (fig.8). It turned out that the creation of abnormal waves in a tank with a desired shape is feasible by superposition of waves with different frequencies. Historic wave events from which time series exist at fixed locations could be reproduced in the wave tank.

In the elapsed time of the project it became clear that the existence of large waves could be shown by mathematical-numerical methods, in wave tanks and by in situ measurements in the field. The open questions are the high frequency of occurrence and the dependency of this parameter on other environmental properties. Up to now only the

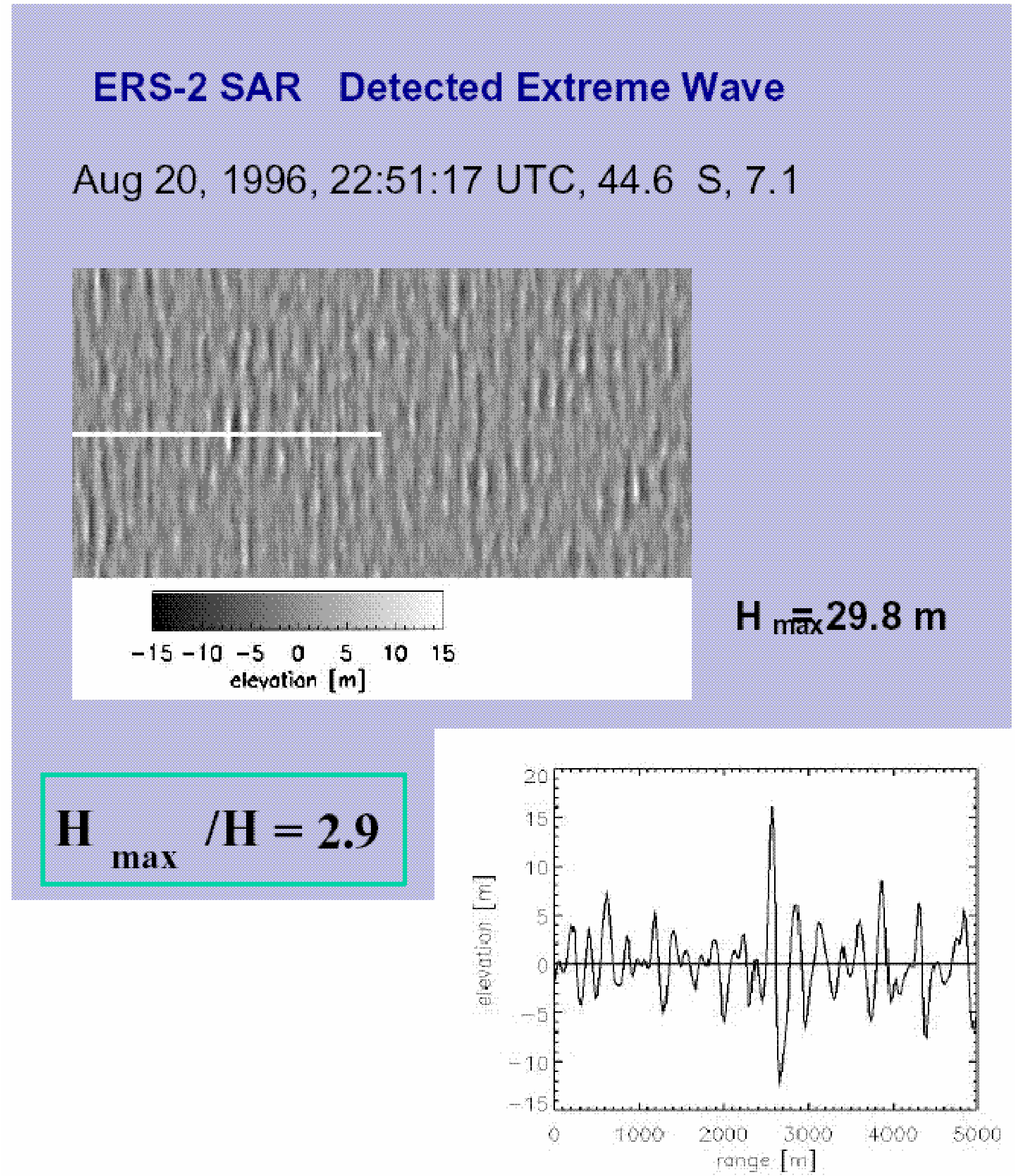

Fig. 6: Giant singular wave detected in imagette data of ERS-2 by DLR

triggering of monster waves by wave current interaction seems to be obvious. Since monster waves also occur outside of large oceanic current systems the investigation of generation mechanisms has to go on. We believe that a possible mechanism is the reduction of energy dissipation in vertically stratified water masses (by a vertical temperature or salinity gradient). Wave groups with longer wavelength would then reach deeper into the water column with their orbital motion and experience less dissipation by turbulent disturbances. This would lead to a stronger growth of the group than under normal circumstances possible, and would violate conventional wave statistics. A useful tool for the mathematical investigation of wave groups is the non-linear Schrödinger equation. The well-studied solutions are periodic wave groups (beat waves) that are often observed in 2-Hz-time series of wave records.

The challenge for the future is to identify solutions of the Schrödinger equation which are localized in space and non dispersive in time. A nice example for real existing wave groups with these properties are the waves generated by a moving ship.

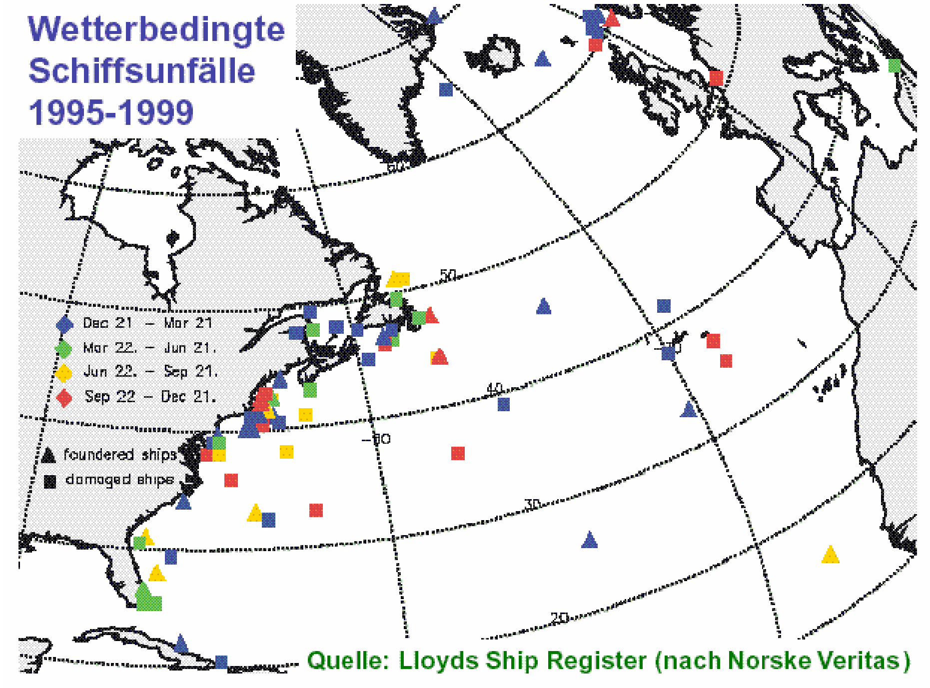

Fig. 7: Weather related ship accidents in the North Atlantic

Fig 8: Giant wave in a wave tank in Hannover

For the ship design there are lessons that could be learned from the vulnerability of the present ship design on the way to more endurable solutions. It is for instance obvious that the typical history of an accident is:

1. A huge wave destroys one window or more on the bridge.
2. The incoming water damages the electronics and leads to a stop of the engines.
3. The ship turns parallel to the sea crests and this leads to additional impact of sea state by increased roll angle and for instance destruction of additional windows with subsequent water inbrake.

For this scenario those ships are especially sensible, which have the bridge near to the bow, as is typical for tourist luxus liners (Fig.9).

Fig 9: Luxus liner Bremen, that encountered a giant wave in February 2001

To be reconsidered for ship design is also the fact that the wave climate tables used for ship design show different design waves than the respective tables for offshore platforms. The reasoning is, that ship captains, if possible, avoid areas with rough weather and therefore a modified wave climate can be used for ship design. This argument is not applicable, however, if the giant individual waves have to be taken into account in the design parameters, because they are not yet predictable in most areas of the ocean.

In summary, although the project has just finished the first half of its schedule, there are a number of results that recommend strongly to pay more attention to the space-time behaviour of ocean waves. Obviously not all of the information of a wave field is contained in the time or space average of the two dimensional spectrum.