TEST OF A NEW ONBOARD SHIPROUTEING SYSTEM

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ABSTRACT

ERS–1 SAR wave mode spectra are assimilated into the third generation wave model WAM and the improved wave forecasts are then used for a new onboard shiprouteing system.
The forecast wave spectra are partitioned into their dominant windsea and swell components (significant wave heights, directions and periods). These parameters together with the wind fields are transmitted every twentyfour hours to the ship. A route optimization is performed onboard using a Bellmann algorithm
The shiprouteing system was succesfully tested onboard the Hapag Lloyd container ship BONN EXPRESS during a north Atlantic and Pacific crossing. Optimal routes of fuel consumption, for a ten day ECMWF weather forecast and, as reference, the analyzed fields are shown and compared to recommendations of the German Seewetteramt and the actual route of the ship.
Optimal routes in respect to fuel saving, speed and safety are intercompared.
Further application as well as transfer to routine operation is discussed.

1. INTRODUCTION

Important progress in wave analysis and forecasting was achieved by the development of the third generation wave model WAM (WAMDI, 1989). However, results are still limited by the errors in the wind fields, due partly to insufficient sea surface wind data for assimilation in atmospheric models.
Since the launch of ocean observing satellites global coverage of sea surface winds has improved and in addition wave data, like the significant wave height from the Altimeter and 2d wave spectra measured by the Synthetic Aperture Radar (SAR), have become available in real time. Therefore, wave modellers have become interested in wave data assimilation to improve model results and also correct the wind fields from wave field corrections. In a combined wind and wave data assimilation scheme these analysed winds can then be used as input into atmospheric models. Improved wave forecasting is of great value for coastal warning and shiprouteing systems as well as for off shore operations, while improved wave analysis yields improved wave statistics, needed for example to determine the wave forces in the design of ocean and coastal structures.

The two–dimensional instantaneous ocean–wave images of the SAR clearly contain valuable information on the full two–dimensional wave spectrum, the basic function completely characterizing the local sea state. However, because of nonlinear imaging effects due to motions of the sea surface the SAR spectra are distorted, and in addition the propagation direction of the waves can only be determined with standard imaging techniques within 180 degree ambiguity (Hasselmann et al 1990) .
The derivation of a closed nonlinear integral expression describing the mapping of an ocean wave spectrum into a SAR spectrum has enabled the operational implementation of an iterative inversion technique for retrieving ocean wave spectra from SAR spectra (Hasselmann and Hasselmann 1991). The algorithm is based on the minimization of a cost function, using a WAM wave model spectrum as a first guess. It has since been extended to yield smooth, calibrated SAR retrieved spectra by Brüning et al. (1993) and Hasselmann and Brüning (1994).
In recent years several simple schemes have been developed to assimilate significant wave height data from the altimeter into wave models (Thomas et al, 1988, Janssen et al, 1989, Lionello et al, 1990 , Lionello et al 1994,

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Günther, 1992).
To correct the 2d wave spectrum from wave height information only, these schemes used either second generation wave models, which prescribe the shape of a wind–sea spectrum, or had to introduce additional assumptions regarding the spectral shape in adjusting the energy level of the spectrum.
These difficulties are due to inadequate information in the assimilation of the full wave spectrum retrieved from the SAR spectra.
The inversion of SAR wave mode spectra and an assimilation scheme for 2D wave spectra for the WAModel including wind corrections, is described in Heimbach, (this issue). An alternative wind correction method based on a Greens function approach is presented in Bauer, (this issue).

2. OPTIMAL SHIP ROUTES

Interest in optimizing ship routes by minimizing fuel consumption received a strong impetus during the oil crisis of 1972, a detailed discussion can be found in Soeding (1989).
In general, the shiprouteing problem is the task of determining an optimal ship route which, for given weather conditions, minimizes some cost function J, dependent on fuel consumption, ship safety, time of arrival and other factors. Thus:

$$J(\mathbf{x}, \mathbf{v}, t_a) = \int_{t_s}^{t_a} F_c(\mathbf{x}, \mathbf{v}, \mathbf{par})\, dt + \alpha_{arr} F_{arr}(T, t_a)$$

$$\mathbf{v}(t) = \frac{d\mathbf{x}}{dt} \quad \text{ship velocity}$$

$$\mathbf{x}(t_s) = \mathbf{x}_s, \quad \mathbf{x}(t_a) = \mathbf{x}_a \quad \text{coordinates of start , arrival}$$

$F_c(\mathbf{x}, \mathbf{v})$ cost function for fuel, engine damage and hazards

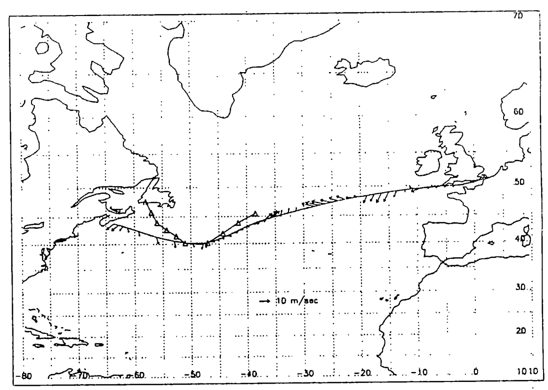
$F_{arr}(T, t_a)$ cost function for untimely arrival
T planned time of arrival

The fuel component of the cost function is evaluated for a given ship by a Holtrop–Mennen algorithm (1982), using tables of resistance depending on ship speed at given weather conditions from the Hamburger Schiffbau Versuchsanstalt (HSVA, Boese et al. 1974). To the fuel cost function penalty terms for possible engine damage and hazard areas are added with appropriate weights.
The optimization problem is solved using a Bellman type optimization algorithm (Bellman 1967).
The algorithm was implemented on a PC onboard the Hapag Lloyd Container ship BONN EXPRESS and tested during four voyages across the Atlantic and Pacific. Further information on the system and the test conditions are given in Frembgen, (this issue).
The procedure for route optimization was as follows:
The ten day ECMWF wind and wave forecast was formatted by the German Marine Weather Service (SWA) and daily transmitted to the ship via INMARSAT. In the North Atlantic, an ice warning boundary was also transmitted. The optimization was calculated onboard, with the aid of a graphical user interface.
Simultaniously, the German Marine Weather Service provided independent recommendations via telex, fax or phone.

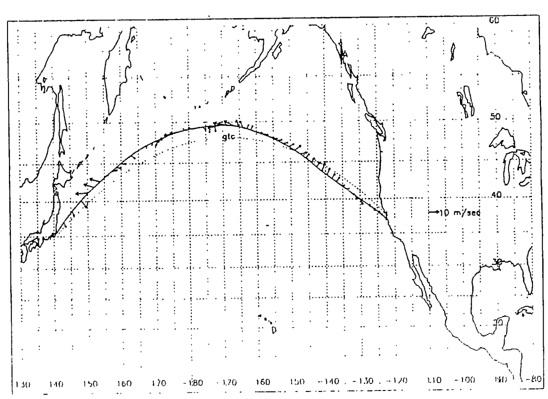
3. TEST VOYAGES

The system was successfully tested onboard the Hapag Lloyd container ship BONN EXPRESS during the following four voyage transects:

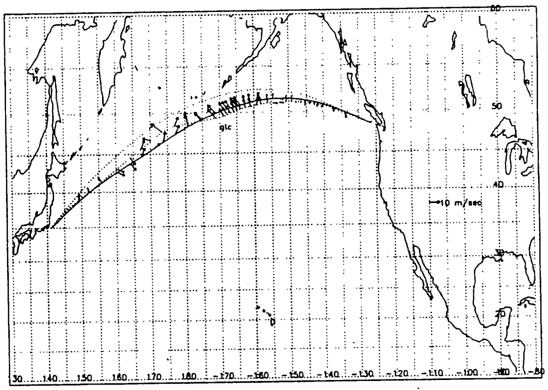
1) Thamesport – Halifax, sailing 10.05.95, 6 UTC;
weather conditions:
mainly easterly winds Beaufort force 5 to 6, highest sea states 3 to 4 meters
The most southward occurrence of icebergs was 40N 50W.



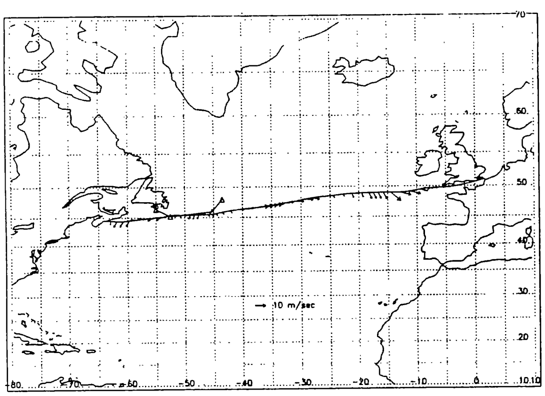
2) Oakland – Yokohama, sailing 4.06.95, 22 UTC;
weather conditions:
in the beginning southerly winds around Beaufort force 7, later turning east , then north; highest sea states 4 meters



3) Yokohama – Seattle, sailing 29.6.95, 18 UTC;
weather conditions:
winds turning from southwest , south to northwest during the voyage, up to Beaufort force 5; highest sea states 3 meters



4) Halifax – Antwerpen, sailing 28.6.95 6 UTC;
weather conditions:
winds initially north to east force 4, later west to southwest up to Beaufort force 6, highest sea states 3m ;
The most southward occurrence of icebergs was 45N 50W



The figures show the four journeys, the optimal route calculated by the optimization system and the wind and ice conditions encountered during the passage.
Due to the relatively weak wind conditions and low sea states, the potential fuel savings on the optimal routes did not exceed 1%, if compared with the shortest navigable routes.
However, the optimization system proved to be useful even under summertime weather conditions:
The system automatically evaluates shortest navigable routes in presence of icebergs.

On the passage to Yokohama the master did not follow the calculated optimal route sligtly north of the great circle, but spent an additional 6% of fuel by going via the Aleutes.
Additional information on the performance of the route optimization system is given in Frembgen, (this issue).

4. ROUTE COMPARISONS

Most benefit from a route optimization can be expected in heavy weather conditions, of course.
As the weather conditions were very calm during the test voyages, comparisons of the route optimization system with the recommendations of the German Marine Weather Service (SWA) and between fore– and hindcasts are given on virtual passages for different weather situations in November and December 94.
Fig. 2 shows an ensemble of daily optimal westbound hindcast routes calculated by SWA for November 94. Two classes of optimal routes can be distinguished, depending on the variability of storm tracks. The high frequency of southern routes reflects a nothward shift of the Aleutian low, not allowing to cruise along routes close to, or north of the great circle.

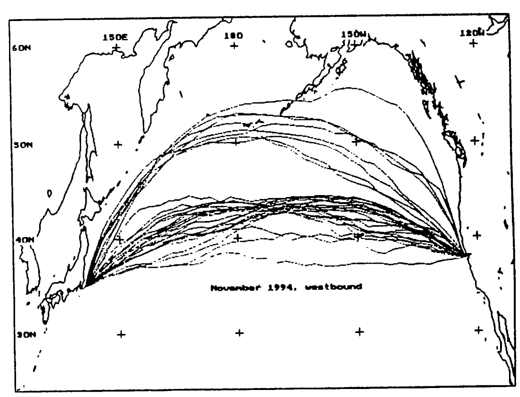


Figure 2 Statistic of optimal routes for November 1994

When comparing the SWA recommended routes with the optimized routes of the present system, in all cases routes of the same classes were recommended by both systems, although routes may differ in detail. Figure 3 shows for example a comparison for a Pacific passage starting on the 20.11.95.
Figure 4 compares fore– and hindcast fuel optimized routes for the same period of time.
After 4 days the fore – and hindcast weather differ substantially , with the result that the optimal forecast route is situated further northward.

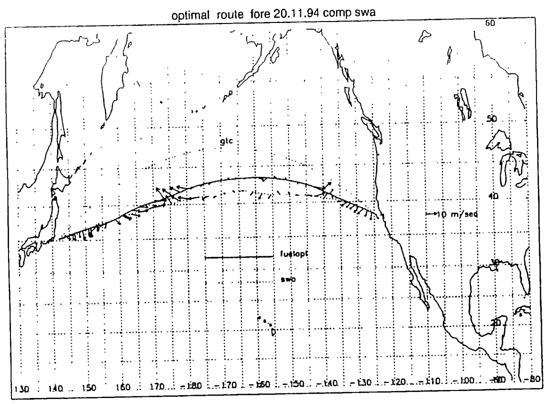


Figure 3 Comparison of SWA recommended route and route of the present system

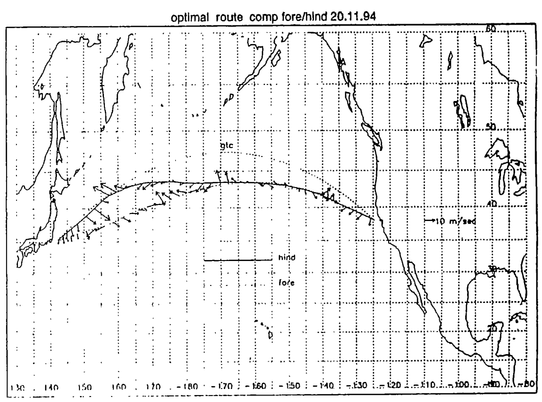


Figure 4 Comparison of fore– and hindcast route

Figure 5 shows a crossing of the Pacific starting on the 5.12.95 during very severe weather conditions. The colors show sea state in one meter contour spacing. In the gulf of Alaska waves higher than 15m are encountered. The yellow line shows the great circle route. Loss of ship or severe damage is possible on this course. The red route is the fuel optimized route, avoiding the severe storm to the south, later turning north, avoiding storms on the great circle. The green route is a second minimum of the optimization, much longer than the red route but safer.
In this case it would seem to be too high a risk to choose the fuel optimal route, since the weather forecast could turn out to be incorrect, the severe storm in the Gulf of Alaska moving southward faster or even intensifying.

5. CONCLUSIONS

The succesful test of an onboard optimization system has provided a bundle of experience and new ideas. Developers are therefore encouraged to integrate onboard shiprouteing into operational shore–based weather information systems. For ship operators an onboard system will soon turn out to be a profitable tool, not only avoiding hazards, but also reducing fuel consumption by an average of 5%.
The value of the system should improve with improved medium range weather and wave forecasts resulting from ERS–1/2 wind and wave data assimilation in operational forecast models.

6. REFERENCES

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Figure 5 Oakland – Yokohama, sailing 5.12.95
colors show waveheight in 1m contour spacing