CHAPTER 29

NON-LINEAR WAVE-CURRENT INTERACTIONS IN THE SWADE RESEARCH PROGRAM.

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Abstract.

This publication gives an introduction to the SWADE experimental programme. It presents examples of results of directional ocean wave spectra in polar format obtained by the third generation met/ocean buoy WAVESCAN. Then focus is made on a new algorithm "CUWA" that simulates non-linear Stokes waves propagating through regions of strong surface current.

Introduction.

The surface wave dynamics experiment SWADE was initiated by the Office of Naval Research in U.S.A. as an accelerated research initiative. A large field experimental program was carried out in the fall of 1990 through the spring of 1991 offshore the coast of Virginia. The measurement systems and a team of investigators are funded by the U.S. Office of Naval Research and the National Aeronautics and Space Administration (NASA).

SWADE is concerned primarily with the evolution of the directional wave spectrum in both time and space, and the goal is to provide improved understanding of wind forcing and wave dissipation, and the effects of breaking waves on the air-sea coupling mechanisms. It is well known that this energy transport is strongly coupled to dissipation in breaking waves. Actually 33 % of momentum transferred from the wind to the large scale ocean current systems is due to wave breaking, LONGUET-HIGGINS (1969). Further a particular goal was to

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investigate the effects of waves on various airborne radar systems such as the surface contour radar (SCR), the remote ocean wave spectrometer (ROWS), and the synthetic aparture radar (SAR). Therefore it became very important in this experiment to have the best avaiable directional wave buoys to provide the sea surface truth, and make it possible to calibrate air-borne radar instruments. The company SEATEX from Trondheim in Norway funded the deployment of such a buoy.

Field Experiment.

The experiment was performed 100 nautical miles east of the coast of Virginia between Cape Hateras and Cape Cod. This was an area where the Gulf Stream developed large eddies or rings, and thus interacted strongly with the waves. Fig 1 shows the location of some of the instruments that were deployed in SWADE. Five directional wave buoys were selected for this task, among them the third generation WAVESCAN Met/ocean buoy from SEATEX in Norway. Also a large spar buoy was brought into the experiment but unfortunately the spar buoy was lost in a severe storm that occurred at the site in late october 1990. Therefore a SWATH-ship "FREDERICK G. CREED" from Canada was brought into the experiment. A SWATH is a small waterplane area twin hull catamaran. This ship was equipped with an array of wave gauges that permitted the ship to move to several positions on the site and measure the directional spectra there, see DONELAN et al. 1992. The comparison between directional spectra measured at sea and directional spectra measured with air-borne SAR-radars had a high priority. 5 airplanes from NASA, NADC,CRPE,CCRS and NRL participated, and during the most intensive measuring period, these aircrafts flew over the sea area with a SCR (Surface Contour radar), a ROWS (Radar Ocean Wave Spectrometer), a SAR (X- and C-band Side Looking Real Aperture Radar) and finally a 3-frequency SAR radar. During two intensive weeks not less than 41 flying missions were taken.

Fig 2 shows the site where the experiment took place, and Fig 3 and Fig 4 show examples of directional spectra obtained with the WAVESCAN buoy. The spectra are shown in polar format. Such a format was also used extensively in the Labrador Sea Extreme Waves Experiment LEWEX program, see BEAL (1990). After termination of the LEWEX-experimental program it was recommended by the 8 participating countries to use the polar format as an international standard for directional spectra in order to make practical applications more easy, in particular for ships navigating with access to forecasted directional wave spectra, see KJELDSEN (1990 c). Also comparisons with satellite and airborne directional wave spectra becomes

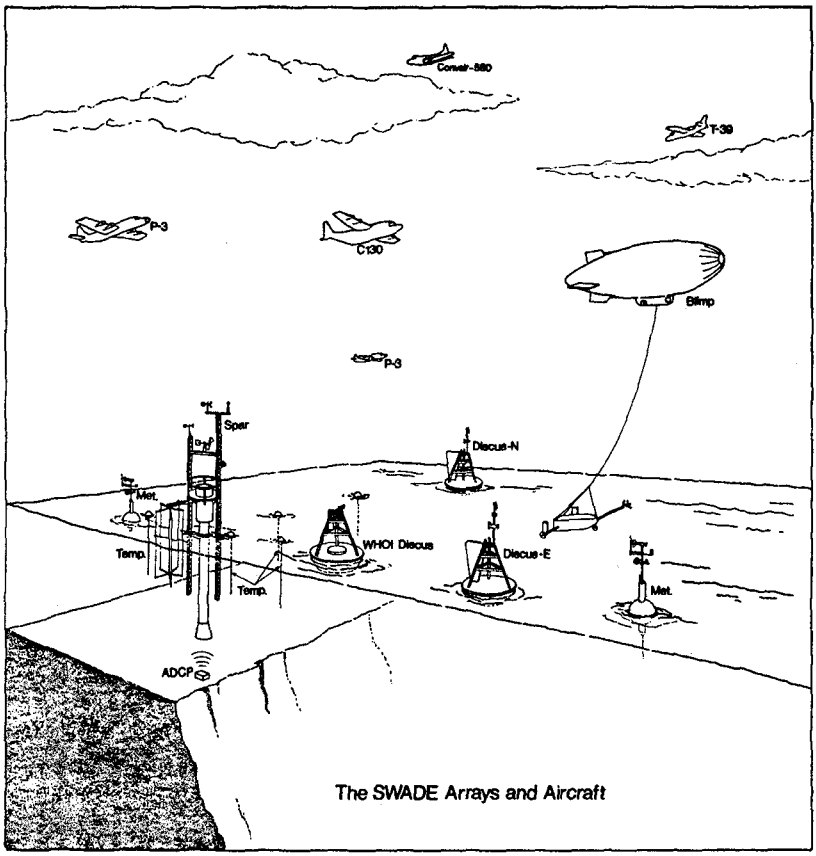

Fig. 1. The SWADE arrays and aircraft.
(From WELLER,DONELAN,BRISCOE,HUANG 1990.)

more convenient when all spectra are referenced to true North.

Fig 5 shows the increase in mean temperature on earth and in carbon dioxide in the period from 1860 to 1985. It is in particular in the two last decades that the carbon dioxide content in the atmosphere has a steep increase. Interaction between oceans and atmosphere are very important in this exchange of carbon dioxide and here the breaking waves plays an important role.

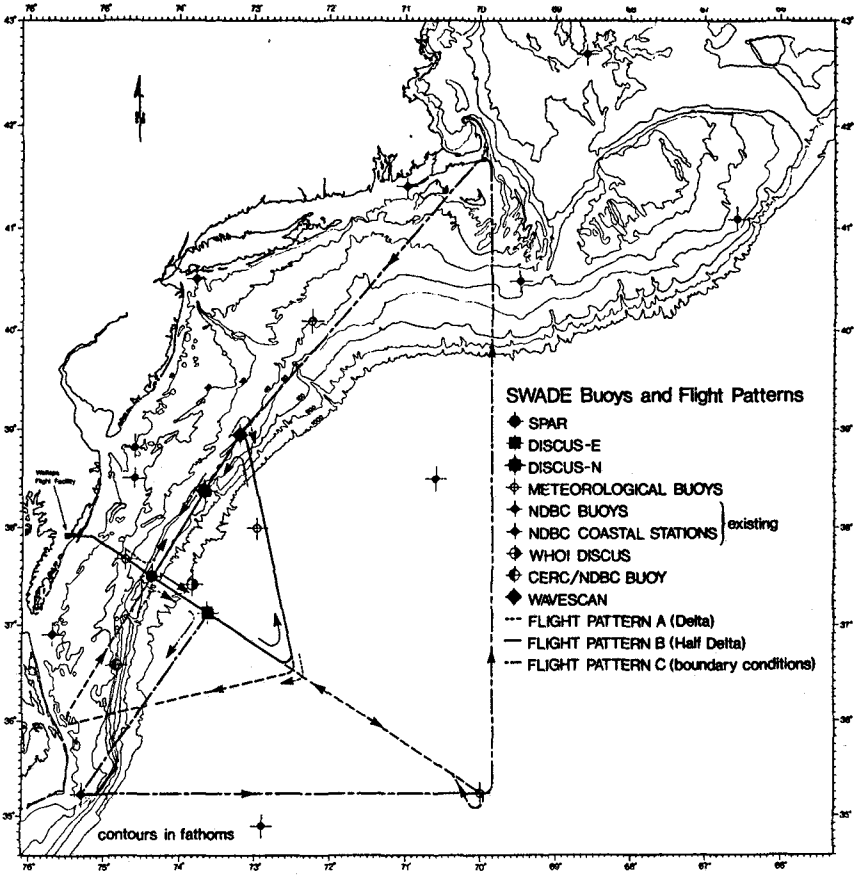

Fig. 2. SWADE buoys and flight patterns.
(From WELLER,DONELAN,BRISCOE,HUANG 1990.)

Fig 6 shows the third generation met/ocean WAVESCAN buoy. The WAVESCAN system consist of :

1. The met/ocean data buoy which automatically collects the raw data which is then processed onboard before transmission to the end user. A particular feature is the onboard wave directional analysis.

2. A telemetry system which can be used with satellite links and/or UHF radio links.

3. A data presentation system with RTscan software for communication, control and data presentation.

The data is avaiable to the end user in realtime from anywhere in the world's oceans. The system can make use of satellite systems, such as Service Argos, Inmarsat C, Meteosat or GOES, to provide the telemetry link. Locally, UHF radio may be used to provide a two way link to the shore based RTscan receiver/controller station. The data is organised and presented by the RTscan software which also provides the means to control and manage a network of buoys.
For further details see BARSTOW et al. (1991).

The buoy can be configured with sensors for :
- Wave characteristics, (heights, frequencies, directions).
- Wind speed and direction.
- Air temperature, pressure and humidity.
- Solar radiation.
- Current profile, velocity and direction.
- Water temperature.
- Dissolved oxygen.
- Ph-value.
- Salinity.
- Conductivity.
- Redox.

Fig 7 shows the WAVESCAN with an acoustic doppler current profiler,(ADCP) installed below. However this current meter is an additional option and it was not used in the SWADE experiment.
WAVESCAN was found to be the ideal buoy to use in connection with weather routing applications for ships.

Comparisons between results obtained with WAVESCAN and results obtained with SAR-radars.

It has been observed that directional ocean wave spectra obtained from wave buoys in some cases were wider than directional wave spectra obtained for the same situation with SAR-radars. A possible explanation is that the buoys are moving in the sea in yaw motion during data acquisition. However the WAVESCAN buoy was calibrated in a large wave calibration project WADIC performed at the EKOFISK field in Norway. Here an array with lasers were used to measure the directional wave spectrum. WAVESCAN calibration equations were then obtained in which yaw motion was eliminated, see ALLENDER et. al. (1989). The WAVESCAN buoy has therefore been used extensively as a key sensor, and used for comparisons both with airborne and with satellite-borne SAR-radars. This was in particular the case during the LEWEX experiment.

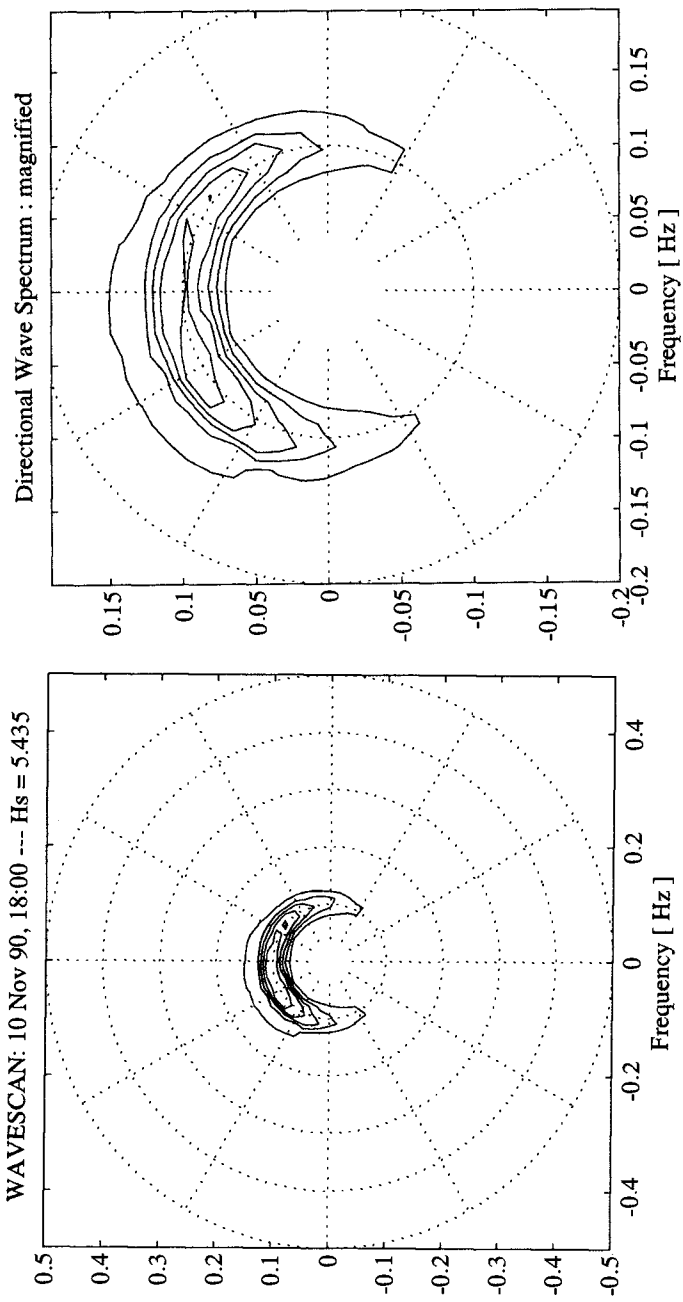

Fig. 3. Directional spectra in polar format obtained from the WAVESCAN Met/ocean buoy during the storm the 10th november 1990 at 1800.

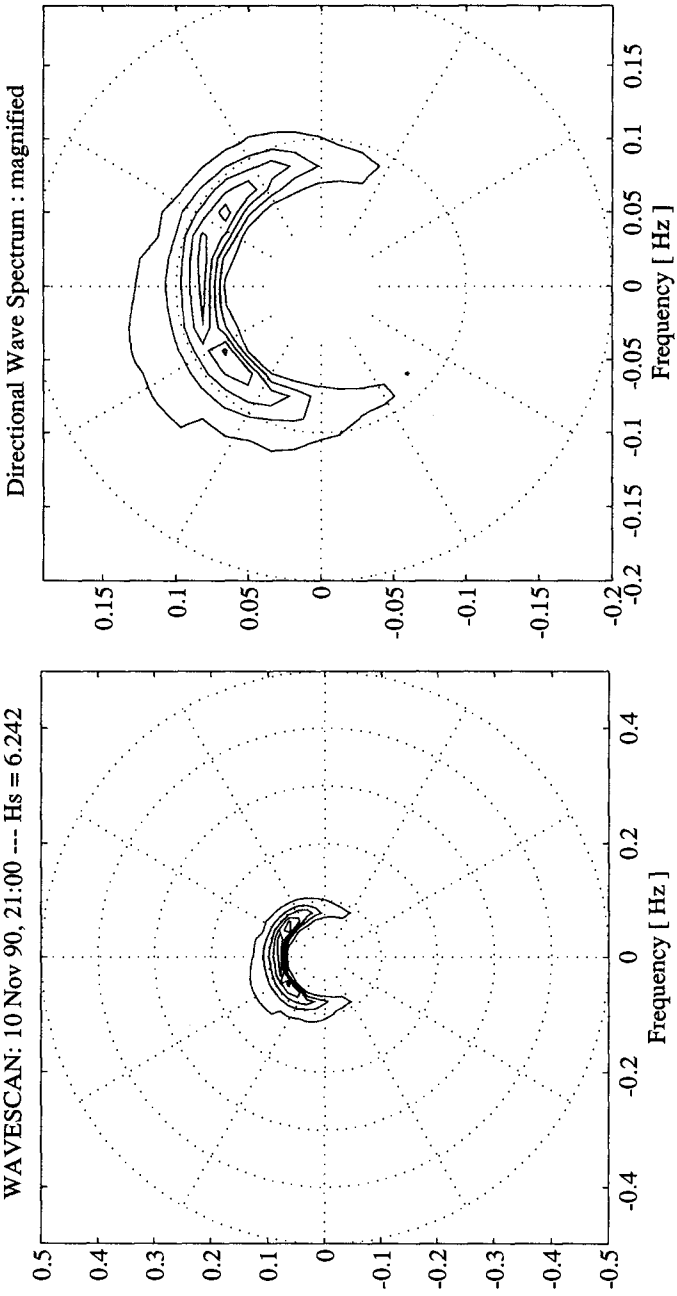

Fig. 4. Directional spectra in polar format obtained from the WAVESCAN Met/ocean buoy during the storm the 10th november 1990 at 2100.

There are various methods that can be used to derive the 3-dimensional spectra such as :

- The Fourier Series Expansion Method.
- The Maximum Likelyhood Method.
- The Maximum Entropy Method.
- The Variational Method.
- The Direct Integral Method.

An example of an algorithm used to derive directional spectra from the WAVESCAN buoy is given by KJELDSEN, KROGSTAD, OLSEN 1988.

The idea to use data from several directional buoys installed at the same position simultaneously in order to establish a statistical weighted directional spectrum to represent the best estimate to sea surface truth was used both in the WADIC and in the Labrador Sea Extreme Waves Experiment LEWEX, see KJELDSEN (1990 b).

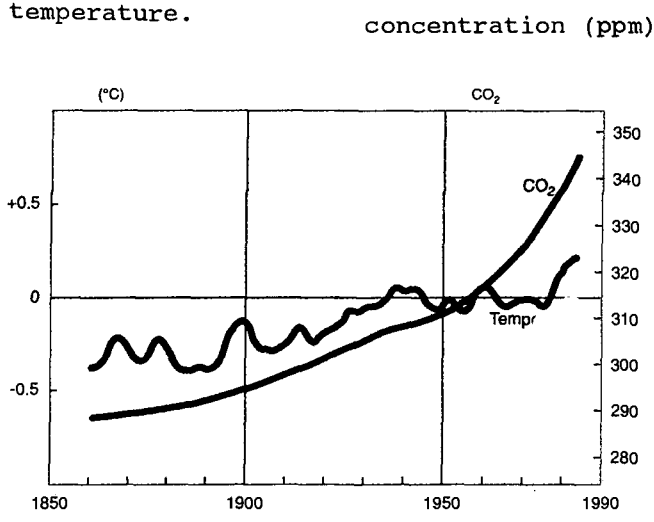

Fig. 5. Increase in mean temperature on earth and in content of carbon dioxide in the atmosphere (ppm) in the period from 1860 to 1985. (From WORLD RESOURCES INSTITUTE.)

Fig. 6. The Third Generation Met/ocean WAVESCAN buoy.

Fig. 7. An ADCP current meter installed below the WAVESCAN buoy.

Mathematical Algorithm.

Interaction between non-linear waves and strong surface currents such as the Gulf Stream is an important problem to consider with many practical applications. The Gulf Stream varies slowly in time and space and large vortex rings develop. In a study of waves on slowly varying currents it is natural to start with specifying the current field in space and time. However, in general, this is not possible. There is an ambiguity in the definition of still water when finite amplitude water waves propagate into the current. This is important because finite amplitude water waves often develop into breaking waves and thus the energy dissipation is governed by this non-linear wave-current interaction. The ambiguity is caused by the Stokes drift velocity. Thus superpostion of waves upon a current changes the current and its determination becomes part of the problem.

Let us consider the two equations that governs the problem. First we have the equation for the wave action flux B:

$$B=\frac{\rho g A^2 (U+C_g)}{2\sigma}$$

Here B is the wave action flux,
A the wave amplitude
U the surface current velocity
C_g the group velocity relative to the water
σ the intrinsic wave frequency
ρ the sea water density
g the gravity acceleration.

The cyclic wave frequency ω is given by the equation :

$$\omega = k(C+U) = \frac{g(C+U)}{C^2}$$

Here k is the wave number and
C is the phase velocity relative to the water.

Both the wave action flux and the cyclic wave frequency must be conserved. The problem can then be solved as two equations with two unknowns, namely the wave action and the surface current. When the equations are solved the following conditions must be taken into consideration. The non-linear dispersion relation for the waves is given by :

$$C^2=\frac{g}{k}(1+f(A^2k^2))$$

and the Stokes drift S is given by :

$$S=0.5*kA^2C$$

A new algorithm "CUWA"-(current-wave-interaction) is developed. Here a test simulation with non-linear Stokes waves propagating against a strong opposing current is considered.

Also a case with linear waves is simulated for comparison. However the linear theory is not valid in this case as the amplitude of the linear waves tends towards infinity.

The performed analysis showed that non-linear wave-current interactions are very important and deserves further attention. The research has many practical applications, such as forecasting of breaking waves, prediction of wave kinematics, pollution control and management of coastal areas and in particular navigation in coastal waters.

Further work.

There is a need not only to consider directional ocean wave spectra but also to analyse single waves. In particular measured extreme wave heights and wave groupiness should be analysed from the storm data obtained in november 1990.

Further results obtained from the algorithm "CUWA" should be compared with measurements obtained at positions where strong wave-current interactions have taken place.

An analysis of wave groups and single extreme waves has been initiated in other sea areas, see KJELDSEN (1989),KJELDSEN (1990 a) and KJELDSEN (1991).

Conclusions.

1. The final conclusions that are derived from the SWADE experimental programme will not be published by single scientists but will appear as a joint publication from all participants.
2. In nature it is often observed, that a current opposing the waves leads to a significant amount of whitecapping. The energy dissipation is then increased. It is nessessary to consider non-linear wave-current interaction computed by an algorithm such as "CUWA" in order to compute dissipation in breaking waves under such circumstances.
3. Directional ocean wave spectra obtained with the WAVESCAN buoy is calibrated against a laser array installed on a fixed platform. Thus movements of this particular buoy during data acquisition is eliminated. The WAVESCAN buoy has therefore been used extensively, in order to establish sea surface truth used in assesment of results with airborne SAR-radars.

Acknowledgement.

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