

# **SURFACE WATER WAVES**

**13-31 August 2001**

**Report from the organisers: S.E. Belcher, T.J. Bridges & S.G. Sajjadi**

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## **Scientific Background**

Of all the various types of fluid wave motion that occur in nature, surface water waves are not only the most easily observed but of great practical importance because of their impact on coastal and offshore structures and ship dynamics, their implication for sediment transport and coastal morphology and their overall effect on the energy and momentum exchange between the atmosphere and oceans. There has been no shortage of motivation for a theoretical description of water waves, and the problem has attracted the attention of mathematicians across the whole spectrum from applied to pure mathematics.

Since the work of Stokes and his contemporaries in the nineteenth century, there has been significant advance in the theoretical understanding of water waves. The end of the twentieth century is a convenient time to assess the accomplishments in the theoretical study of water waves, and identify key new directions for the twenty-first century.

For the programme on surface water waves, the organisers identified two main areas of fundamental importance to water waves that build on results of the twentieth century and pose great theoretical challenges into the next century. The topics are non-linear three-dimensional waves, and interactions of wind, waves and turbulence. With multi-scale resolution now possible using the latest computers, there is a potential for significant advances in the semi-analytical and numerical aspects of 3D waves including prediction and study of qualitative aspects that heretofore have not even been predicted. Secondly, recent developments of mathematical theory of non-linear and breaking waves and of the unsteady critical layer effects when the wind drives waves have pointed the way to a new body of theory for wind-wave interaction. Experimental data is beginning to be available to discriminate between and contribute to the conflicting theories.

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## **Structure of the Programme**

The three-week programme was possibly the longest duration focussed academic meeting on water waves in history, and the participation was global with representatives attending from Australia, USA, France, Canada, Germany, Ukraine, Russia, Portugal, Italy, Denmark, Netherlands, Israel, India, Estonia, Greece, Mexico, Sweden, and the UK. A complete list of short and long stay participants can be found on the INI SWW webpage.

The first two weeks of the programme had a bi-polar structure, with formal talks in a workshop setting blended in with large time gaps for informal discussion groups, and in the third week, the time was structured by Euroconference format.

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## Workshops

In the first two weeks there were 6 focussed sessions. Each of these sessions took place in the afternoon, leaving 6 mornings and 4 full-days for discussion groups. The main formal events in the first two weeks are listed below. Each of these events has a webpage with talk titles, programme and other information and links can be found on the INI SWW webpage.

· Opening Day Talks (Monday):

Opening day focussed on "Challenges", with talks by leading experts in meteorology, oceanography, air-sea interaction and wave breaking discussing major open problems. The speakers were P.A.E.M. Janssen (ECMWF), D.H. Peregrine (Bristol), J. Gunson (UK Meto), J. Wolf (POL) and S.A. Thorpe (SOTON), and the session chair was J.C.R. Hunt (UCL).

· BRIMS Day (Tuesday):

This programme was sponsored by the Hewlett Packard BRIMS research facility in Bristol. The theme was "New Developments in the study of Water Waves". The speakers were M.S. Longuet Higgins (San Diego), J.L. Bona (Texas), F. Dias (Ecole Normale Superieure), W.K. Melville (San Diego), H. Segur (Colorado) and J.M. Vandenbroeck (East Anglia), and the session chair was S.E. Belcher (Reading).

· Methodology versus Rigour (Wednesday):

In this special session there were only two speakers: Professor K. Kirchgaessner (Stuttgart) and Professor C.C. Mei (MIT). Both methodology and rigour have played important roles in the development of the theory of water waves, and these two talks, by leading proponents of each view, contrasted these two approaches to theory. This session was chaired by J.L. Bona(Texas).

· LMS Spitalfields Day (Thursday):

The London Mathematical Society sponsored a day devoted to "Mathematics of Water Waves". This session included speakers from North America, the Netherlands, France, Germany and the UK. The speakers were W. Craig (McMaster), E. van Groesen (Twente), G. Iooss (Nice), G. Schneider (Bayreuth), and J.F. Toland (Bath). The organizer and Chair of the session was T.J. Bridges (Surrey).

· Geometry, Oceanography and Overview (Friday):

This Friday afternoon session included talks from three different angles: D.D. Holm (Los Alamos) talked about geometric formulation of shallow water models, M. Banner (New South Wales) talked about recent developments in wave breaking, V. Shrira (Keele) talked about three-dimensional horseshoe patterns on the ocean surface. The session was chaired by C.C. Mei (MIT).

· Overview Session (Friday):

On Friday afternoon at 4:30, J.C.R. Hunt (UCL) gave an overview of the accomplishments of the week, and gave some insight into what directions the programme might consider in weeks two and three. Some of the ideas emanating from this discussion session will appear in the scientific writeup of the programme.

· Wind, Wave and Turbulence Day (Wednesday, 22nd August):

This session concentrated on interaction issues: wind-wave, wave-wave and wave-turbulence interaction. At the end of this session there was a joint lecture between the Water Waves

Programme and the Integrable systems program given by P.J. Olver (Minnesota). The main WWT speakers were D. Nicholls (Notre Dame), V. Shrira (Keele), G. Caulliez (Marseille), T. Hara (Rhode Island), V. Kudryavtsev (Ukraine) and M.A.C. Teixeira (Lisboa). The Chair and organizer of this session was S.E. Belcher (Reading).

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## EU Conference

Week three, beginning Tuesday August 28 (Monday, 27th August was a bank-holiday), was full conference mode, with over 50 additional participants arriving. For this conference additional funding was received from the EU in the form of an EU Conference grant.

The range and depth of the lectures was extraordinary. Topics included theory and observation of breaking waves, statistical aspects of the sea surface, remote sensing, interaction of random waves, three-dimensionality of wave breaking, extreme and freak waves, violent waves and impact phenomena, effect of driving and dissipation, sea drag, mechanisms for wind forcing of waves, large scale modelling, standing waves, stability of solitary waves, solitary waves on deep water, dimension breaking of waves, existence of three-dimensional solitary waves, new developments in Boussinesq models, hexagonal and other surface patterns, three-dimensional patterns, short-crested waves, flow over topography, interface modelling, interaction of waves with longitudinal vortices, wave turbulence, and spectral modelling.

Highlights of the first day included the opening talk by Professor V.E. Zakharov (Landau Institute) who gave an overview of the progress in his group over the past few years on water wave problems, and the special Institute Lecture on Tuesday evening by Professor A.D.D. Craik (St Andrews) on the history of theoretical developments on water waves in the 19th Century during the time of George Stokes. (An expanded version of this talk will appear in the proceedings of the Wind-over-Water meeting.)

Day two of the EU conference had 11 30 minute talks in two sessions, with the morning session on wind-wave interaction and the afternoon session on solitary waves. On Day three, there were 11 30 minute talks in two sessions, with the morning session on "Three-dimensional water wave patterns" and the afternoon session on "Wave- wind- vortex- and turbulence--wave interaction". The conference dinner, on Thursday evening, was held at Christ's College Dining Hall, where M.S. Longuet-Higgins read out a poem written by Keith Moffatt in honour of "Theoretical and Applied Mechanics Day".

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## Satellite Meeting: the Wind-over-Wave Conference

This conference was held immediately after the INI programme at Churchill College, Cambridge, and sponsored by the IMA. It is the second conference on wind-over-waves, following the successful first meeting held at the University of Salford in 1997. Sessions addressed air-sea interaction, ocean wave dynamics and forecasting, breaking waves, wave turbulence interactions and Langmuir circulations. The Programme committee for this conference was S.E. Belcher, T.J. Bridges, J.C.R. Hunt and S.G. Sajjadi. The list of invited speakers was J. Battjes (Delft), T.J. Bridges (Surrey), M.S. Longuet-Higgins (San Diego), V. Makin (KNMI, Netherlands), W.K. Melville (San Diego). The programme had ten sessions each with a mixture of invited and contributed talks. The complete programme can be found on the web at: <http://www.maths.surrey.ac.uk/personal/st/T.Bridges/WOW.html>

In addition to the plenary lectures, there were over 20 contributed lectures on a wide range of topics. On Tuesday evening, a dinner was held in the Churchill College Dining Hall in honour of the 60th birthday of Julian Hunt.

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## Outcome and Achievements

One of the most interesting outcomes of the programme was the enthusiastic interaction between researchers working primarily on physical aspects of water wave theory and those working on strictly theoretical constructs. Another disciplinary divide which was opened up is the statistical viewpoint versus the deterministic viewpoint. The bipolar -- three-dimensionality and wave-interaction -- starting point of the programme rapidly developed into a list of five areas identified for future emphasis. An excellent indication of the volume of activity at the programme is the "wrap-up session".

On the last day of the Surface Water Wave programme, a wrap-up discussion session, chaired by Professor Michael Banner (New South Wales), was held. It engaged the audience with a concentrated discussion lasting more than 3 hours -- although only 90 minutes had been planned! The five main themes which emerged from the programme and an overview of some of the future issues raised in the discussion are highlighted below.

- Statistical wave evolution models: planning for the next generation SWE model; extending the current range of validity; modelling nonlinear spectral transfer mechanisms; modelling wind input forcing, and dissipation.
- Fundamental mathematical questions: development of new model equations with three-dimensionality; testing of model equations using dynamical systems and functional analysis; methods for the initial value problem; role of "spatial dynamics"; new theories for large amplitude deterministic or statistical representations.
- 3D patterns and coherent structures: the level of detail of ocean waves that can be represented mathematically; role of solitary waves and envelopes for 3D waves; role of vorticity; horseshoe patterns as coherent structures; role of nonlinearity in wave group dynamics; Langmuir cells; mathematics of inhomogeneity.
- Wave breaking in deep water: role of directionality; influence of underlying shear; models for predicting onset and strength of breaking; relating statistics to dissipation; development of model equations for 3D wave breaking; deterministic breaking versus statistical analysis; need a model or paradigm for post-breaking of waves.
- Extreme waves in oceanography: identification of the underlying mechanisms; role of refraction by sub-mesoscale currents; methods for prediction; cause of occurrence rate; role of nonlinearity; spatio-temporal statistics of extremes; acceptable definition for freak waves.

The two main sources of publication are the Wind-over-Wave proceedings and a scientific overview by the organisers. The WOW meeting will have a traditional conference proceedings, and due to the close association of the WOW meeting with the INI programme, manuscripts from the INI programme participants have been invited as well. The volume is edited by S.G. Sajjadi and J.C.R. Hunt, and it is expected to be published in Summer 2002. An article on the WOW meeting has appeared in the Spring 2002 issue of *Mathematics Today*, published by the IMA.

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