The International Workshop on Wave Hindcasting and Forecasting and the Coastal Hazards Symposium

Øyvind Breivik† Val Swail‡ Alexander V Babanin§ Kevin Horsburgh¶

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Abstract

Following the 13th International Workshop on Wave Hindcasting and Forecasting and 4th Coastal Hazards Symposium in October 2013 in Banff, Canada, a topical collection has appeared in recent issues of Ocean Dynamics. Here we give a brief overview of the history of the conference since its inception in 1986 and of the progress made in the fields of wind-generated ocean waves and the modelling of coastal hazards before we summarize the main results of the papers that have appeared in the topical collection.

Keywords: Wave modelling, wave hindcasting, wave measurements, wave theory, coastal hazards, storm surges, water level forecasting.

1 History of the Workshop

The first International Workshop on Wave Hindcasting and Forecasting was held in Halifax, Nova Scotia, Canada in September 1986. Since then, 12 more workshops have been organized, joined in 2007 by the Coastal Hazards Symposium.

Wave forecasting and its close relative wave hindcasting (distinguished from reanalyses by the absence of assimilated data) have undergone dramatic changes since the early days of the workshop. Back then the now common third generation (3-G) wave models where the model spectrum evolves freely through nonlinear interaction had only recently been developed (SWAMP, 1985; Hasselmann et al., 1988). The workshop intended to bring hands-on users of wave data in contact with the leading theoreticians and modellers of the day. In this it succeeded, and a number of important projects were born out of contacts established at the conference where the oil and gas producers in particular could specify what their needs were. As such the workshop helped anchor the wave modellers, usually people with a penchant for theoretical musings, to practical problems facing users who had to weather storms in some of the windiest places on earth.

Although the precise nature of the research has changed significantly over the past 28 years, the primary objectives of the workshop have remained essentially the same, namely to

- provide a forum for the exchange of ideas and information related to wind and wave hindcasting and forecasting, including modelling, measurement and past and future states of the climate
- coordinate ongoing research and development initiatives

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‡Corresponding author. E-mail: oyvind.breivik@met.no; ORCID Author ID: 0000-0002-2900-8458. Norwegian Meteorological Institute, Alleg 70, NO-5007 Bergen, Norway
§Climate Research Division, Environment Canada, Toronto, Canada
¶Swinburne University of Technology, Australia
¶National Oceanography Centre, Liverpool, UK
• discuss priorities for future research and development

The period around the time of the initial workshop was a very exciting one for wave modelling, forecasting and hindcasting. The WAM model (Hasselmann et al., 1988) was in the process of becoming the first community wave model, arising out of the SWAMP program (SWAMP, 1985) and the plethora of wave models which existed in the early 1980s. The advent of these sophisticated third-generation models, and the rapidly increasing computing capabilities of numerical weather prediction centres, led to the increased use of numerical wave models in operational forecasting.

With time more centres began using these models for their operational programs, and an international wave forecast comparison project was established, coordinated by The European Centre for Medium-Range Weather Forecasts (ECMWF), to evaluate forecast performance and identify areas of potential improvement (Bidlot et al., 2002). At the same time, hindcasting was becoming the accepted basis for developing wave climatology in general, and particularly for developing the basis for offshore design criteria. Due to the limitations of computing power and the lack of suitable historical wind fields, these early hindcasts covered only the most extreme storms in a limited area of the ocean. They were thus a far cry from today’s decades-long, global wave hindcasts forced with atmospheric reanalyses. Yet at the time these hindcasts took a Herculean effort in terms of computing and through the meticulous preparation of suitable wind fields.

An important alliance was formed in 2006, when the workshop was first co-sponsored by the WMO-IOC Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM). Subsequently, and following the very successful JCOMM Scientific and Technical Symposium on Storm Surges in October 2007 in South Korea, a symposium on hazard assessment in coastal areas was established, and later held jointly with the Wave Workshop. This has provided an excellent opportunity for cross-pollination of ideas between wave and storm surge prediction.

While the primary focus of the workshop was, and remains, wave hindcasting and forecasting, what makes this workshop unique is the treatment of the end-to-end research issues associated with ocean waves, from the basic research on wave physics to the ultimate use of the products. The topics have thus ranged from research and operational aspects of wave and storm surge hindcasting and forecasting, regional hindcasts, storm surge climatology, data collection and instrumentation, data assimilation, wave-current interaction, wave-ice interaction, shallow-water and nearshore effects, wind fields for wave hindcasting or forecasting, extremal analysis, as well as past and future climate trends and variability.

Over the past 30 years the Wave Workshop has presented the results of many innovative and groundbreaking studies, introduced new national and international initiatives, and induced a large number of collaborative research efforts on all aspects of wave research, including measurements, modelling, forecasting and validation, as well as wave climate including historical trends and future projections. It would be impossible to list all of those here, and we would risk omitting many important interactions. However, a few noteworthy examples are described in the following paragraphs. On a popular note, the 10th Wave Workshop is well described in Chapter 8 of the popular-science book The Wave by Casey (2010). We also remind the reader that the proceedings of all workshops are available online at http://www.waveworkshop.org.

The initial Wave Workshop (WW-1) had three particularly noteworthy presentations. Komen and Zambresky (1986) described the development of the landmark WAM model (Hasselmann et al., 1988), the first 3-G spectral wave model. The model resulted from a major international collaboration led by Klaus Hasselmann following the Sea Wave Modelling Project (SWAMP, 1985) which had demonstrated large discrepancies in the fauna of wave models in use at the time. Its presentation at WW-1 served to broaden the community even further. WW-1 also saw two landmark presentations related to wave hindcasting and its use for structural design. Francis (1986) described the North European Storm Study (NESS), which was the first effort to construct a long-term climatology of extreme wave events based on selected storms for an ocean basin. At the same time, Sverre Haver reported on the adequacy of hindcast data for structural design, illustrating the industry’s move towards hindcasting as the basis for design criteria instead of
relying solely on measurements.

The second Wave Workshop (WW-2) boasted an entire session (Cardone et al., 1989a,b; Szabo et al., 1989a,b; Bolen et al., 1989) on wave hindcasting of extreme storms for the development and evaluation of the wave criteria for the design of the gravity-based production platform at Hibernia, on the Grand Banks of Newfoundland. This was the first time that the industry’s design procedures had been published in such a forum.

WW-3 saw the introduction of data assimilation methods in wind wave modelling (Burgers et al., 1992) and a coupled wind-wave data assimilation system by Las Heras and Janssen (1992). WW-3 also saw a presentation of “Hindcasting waves using a coupled wave-tide-surge model” by Wu and Flather (1992), which would be an early precursor to work done in later years on coastal inundation, incorporating wave, tide and surge components.

Two significant results were reported at WW-4. The presentation “The WASA project: changing storm and wave climate in the northeast Atlantic and adjacent seas?” (WASA Group, 1995a,b) described a continuous hindcast archive as well as a hindcast of selected storms forced with archived operational wind fields for the northeast Atlantic, and a comprehensive climate trend analysis. Cox et al. (1995) introduced “An interactive objective kinematic analysis system” as an efficient way to incorporate manual kinematic analysis of surface wind fields into background fields from numerical weather prediction products. This technique yields a much better representation of the highest winds in a storm, and thus also of the most extreme wave conditions which drive design criteria. This approach has been refined over time, and remains the most effective method to capture the highest sea states in a hindcast, even with the advent of high quality reanalyses as evaluated later by Caires et al. (2004).

WW-5 was very noteworthy for the introduction of the first continuous wind-wave hindcast forced with reanalysis winds. Cox and Swail (2001) and Swail and Cox (2000) respectively described the evaluation of the marine surface wind product from the National Center for Environmental Prediction (NCEP) reanalysis (Kalnay et al., 1996) and the application of those forcing fields, including the kinematic wind analysis previously developed, to produce a long-term North Atlantic wave hindcast. On the wave modelling side, WW-5 saw the presentation of the third-generation SWAN wave model (Booij et al., 1999; Ris et al., 1999). The end users continued to be well represented in this forum, as illustrated by the presentation on “Wave Hindcasting and Forecasting: Their Role in Ensuring the Safety of Personnel Involved in Offshore Oil and Gas Exploitation” by Smith (1998).

WW-6 introduced the rapidly expanding research topic of non-linear wave phenomena, particularly with respect to rogue or freak waves described in the presentation “Nonlinear dynamics of rogue waves” by Osborne et al. (2000).

WW-7 introduced several new concepts. Swail et al. (2002) showed the first attempts to describe not only the past trends of the wave climate from a reanalysis, but also future projections based on statistical downscaling methods for an entire ocean basin, the North Atlantic. Thomas and Swail (2002); Thomas et al. (2005) demonstrated the importance of homogenisation of historical wave measurements for removing spurious trends due to changes in hull type, sensor and processing methods. Also, Gulev et al. (2002) demonstrated that, while visual wave observations had long been considered to be a barely adequate estimate of the wave climatology on a global or regional basis, it was still possible to derive more sophisticated information from them (see also Gulev et al. 2003; Gulev and Grigorieva 2004). Following up on some of the research on rogue waves, Gunson and Magnusson (2002) presented an approach for investigating conditions for rogue wave events using a global spectral wave model. Not least among the key presentations at WW-7 was the introduction of the 2002 release of WaveWatch-III (Tolman et al., 2002).

WW-8 saw the wave climate trend and future projection research advance to the identification of climate change signal and uncertainty (Wang et al., 2004). The usefulness of satellite wind fields for wave hindcasting, in particular from QuikScat, was highlighted by Cardone et al. (2004). Scatterometers in general, and QuikScat in particular, have proven to be an unparalleled resource for both wave hindcasting and forecasting. Another key area of development in
the modelling realm was described by Banner et al. (2004), on forecasting of breaking waves during storms.

WW-9 described the first ever detection of human influence on trends of North Atlantic Ocean wave heights and atmospheric storminess (Wang, 2006; Wang and Swail, 2006). This workshop also saw a focus on extreme waves, with the presentation on extreme waves in the ECMWF operational wave forecasting system (Bidlot et al., 2006). Grigorieva and Gulev (2006) also extended their previous work on wave observations from voluntary observing ships (VOS) to show their utility for extreme waves worldwide and their changes over the past 50 years.

At WW-10, Bidlot et al. (2007) and Hines et al. (2007) described advances in the JCOMM Wave Forecast Verification Project, a routine inter-comparison of wave model forecast verification data to provide a mechanism for benchmarking and assuring the quality of wave forecast model products, which had been formalized as a JCOMM activity at the first session of the JCOMM Expert Team on Waves and Surges in 2003, and was subsequently described in a JCOMM Technical Report by Bidlot and Holt (2006). The project now includes 17 centres, many running global wave forecast systems, with different wave models, different wind forcing, and different model configurations. The goal is to continue to add new participants, including regional participants (where appropriate), and to expand the scope of the intercomparison as feasible. This includes validation against satellite altimeter observations but also comparing spectra as well as utilizing techniques for comparing against measurements spatially separated from the model grid point. Here it is pertinent to mention in particular the triple-colligation technique pioneered by Caires and Sterl (2003) and later used by Janssen et al. (2007) and Abdalla et al. (2011) for random error estimation in altimeter wind and wave products. Extreme wave prediction was also a focus of this workshop, with advances in freak wave prediction from spectra described by Mori et al. (2007), and the extension of the ECMWF freak wave warning system to two-dimensional propagation (ECMWF, 2013).

WW-11 saw advances in the understanding of wave measurements. Swail et al. (2009) described a philosophy for continuous wave measurement and evaluation as presented to the Oceanobs’09 conference, and the development of a JCOMM Pilot Project on Wave measurement Evaluation and Test (WET). Bender et al. (2003) presented evidence showing very large potential overestimates of wave height measurements in buoys with a simple 1-D accelerometer due to heeling of the hull. Mark Hemer introduced the joint JCOMM and World Climate Research Programme (WCRP) Coordinated Ocean Wave Climate Projections (COWCLIP) initiative, which is looking at potential future changes to the wave climate (see Hemer et al. 2012 for an overview of COWCLIP). On the wave forecasting side, Banner and Morison (2009) described new methods for incorporating breaking wave predictions into spectral wave forecasting models (see also Banner and Morison 2010). An entire session was devoted to the emerging forecast activity of ensemble wave predictions, including those of the MetOffice, ECMWF, Meteo-France, NCEP and Environment Canada.

At WW-12 the recently developed NCEP Climate Forecast System Reanalysis (CFSR) was presented (Chawla et al., 2013). This data set entails a coupled reanalysis of the atmospheric, oceanic, sea-ice and land data from 1979 through 2010, and a reforecast run with this reanalysis (Saha et al., 2010). This reanalysis has much higher horizontal and vertical resolution than the Global and the North American Reanalysis. In keeping with the end-to-end scope of the workshop, Carrasco et al. (2011) investigated the potential for ensemble wave forecasts of weather windows with the requirements of offshore operations in mind. In particular, the issue was addressed as to whether the emerging probabilistic forecast approach is (always) better than a deterministic one, and whether probabilistic decisions are best based on ensemble mean or probability threshold.
2 The 13th Workshop

The 13th International Workshop on Wave Hindcasting and Forecasting and the 4th Coastal Hazards Symposium was held in Banff, Canada from 27 October to 1 November, 2013. The workshop had more than 90 participants who gave over 75 presentations and displayed 18 posters.

In addition to the selection of papers from WW-13 submitted for this special issue of Ocean Dynamics, there were several keynote presentations. In view of the recent increased interest in the Arctic, two papers were particularly noteworthy. Bidlot et al. (2014) described a new approach to inclusion of sea ice attenuation in an operational wave model (as opposed to the standard operational approach at ECMWF to consider 30% ice concentration and above as land and spectra set to zero, see also Doble and Bidlot 2013). As well, Salisbury et al. (2014) described the implications of ice cover on storm surge dynamics in the Beaufort Sea. An important new initiative of WMO, the Coastal Inundation Forecasting Demonstration Project (CIFDP), combining flood forecasting due to storm surge, ocean waves, tides and river runoff, was introduced by Lee et al. (2014).

In addition to the general sessions, each workshop has had a theme session. For WW-13 this theme session targeted the JCOMM priority area “Forecasting Dangerous Sea States”. Topics included theoretical, numerical, laboratory or operational applications dealing with forecasting of hazardous wave conditions such as crossing seas, unusually steep waves, rapidly developing seas and rogue waves. In addition to the main topic the sessions spanned a wide range of topics, among those wave measurements, operational wave and storm surge forecasts, hindcasting, advances in wave and storm surge modelling, coastal impact and a special session on COWCLIP (see Hemer et al. 2012, 2013).

Forecasting dangerous sea states is a diverse topic since what is dangerous to one vessel or platform may be harmless to another. This was reflected by the large number of presentations ranging from studies of the impact of rogue waves on marine structures (Bitner-Gregersen and Toffoli, 2014) to theoretical investigations into the generation of extreme waves from interactions between fully nonlinear 2D surface waves (Chalikov et al., 2014). A similar model was used by Babanin et al. (2014) to investigate the interaction of wave components that are very close in wavenumber space, and it was found that the interactions between wave components seemingly break down when the separation in wavenumber space becomes very small. This was taken as evidence of a “corpuscular” nature of water waves, i.e., that there is an inherent discreteness to the Fourier spectrum of waves.

In situ measurement of waves remains the main source of “ground truth” for assessing the quality of wave models, both for hindcasting and for operational forecasts. The vexing issue of what exactly buoys measure, especially in high seas, remains a challenge some 60 years after the first wave spectra were measured using capacitance wire recorders (Tucker and Charnock, 1955; Burling, 1955). Waseda et al. (2014) demonstrated that buoys originally meant for meteorological measurements or tsunami monitoring can be equipped with GPS sensors and provide reliable wave measurements in remote deep-water locations. Observations from tropical cyclones showed evidence of nonlinearities in the orbital motion of the highest waves in the centre of wave groups. This is of interest when studying the behaviour of freak waves. Collins et al. (2014) remind us that wave buoys normally report only integrated parameters. This is insufficient for investigating the extremal behaviour of individual waves (rogue waves) but understandable in light of the low bandwidth and limited storage of traditional wave measuring devices in remote locations. However, Collins et al. (2014) demonstrate that by also reporting the maximum wave height and the total number of waves per record, valuable information about the occurrence of extreme waves can be gleaned from properly tilt-corrected wave buoys.

Bitner-Gregersen and Magnusson (2014) investigated the intrinsic sampling variability of the most frequently used wave-height and wave-period scales, namely significant wave height and zero-crossing wave period, by varying the recording intervals of 2 Hz time series from a wave buoy and a downward looking laser in the central North Sea. It is argued that sampling
variability from wave measurements is greater than from models because of natural long-term trends in the field and due to non-stationary changes of weather conditions. Standard deviations of significant wave height and zero-crossing wave period are compared with observations and show similar trends. The sampling variability is higher in wave height than in wave period, but both increase as the height and period grow. It is also noted that the JONSWAP spectrum (Hasselmann et al., 1973) gives higher variability than the Pierson-Moskowitz spectrum (Pierson and Moskowitz, 1964).

Remote sensing of ocean waves by microwave radar is a relatively well-understood process where Bragg scattering from short gravity-capillary waves, which in turn are modulated by the presence of longer gravity waves, allow a spectrum to be estimated (Wright, 1968; Keller and Wright, 1975; Phillips, 1988). Although the relative energy of the ocean wave spectrum may be estimated quite precisely, establishing the absolute energy level may be a harder task. Ewans et al. (2014) have carefully analyzed the principles behind the measurement technique and long time series of observations from radars operated by Shell. The conclusion is that the radars compare remarkably well to Wavec buoys in the vicinity of three platforms in the North Sea as well as one in the Norwegian Sea. The observations are stratified by direction to analyze the shielding from the platform, but only small reductions are found in directions where shielding may be expected. Gibson et al. (2014) investigated field measurements of wave height and crest elevation from Saab WaveRadar instruments mounted on eight fixed jacket platforms and a Datawell Directional Waverider buoy during a severe storm in the North Sea. The storm generated seas which peaked well in excess of the 100-year significant wave height for that region. The authors also identify 19 freak-wave events. They found that the significant steepness and spectral bandwidth during the storm remain almost constant. Consequently, there is little change in the commonly applied design wave height and crest elevation probability distributions during the storm. Whilst the bulk of the recorded data was in good agreement with the theoretical distributions, it was demonstrated that when the wind speed exceeded 25 m s$^{-1}$, the measured crest elevation lay above the second-order Forristall wave crest distribution (Forristall, 2000). The authors postulate that this could be due to the modulational instability of the waves due to both the wind forcing and/or their steepness or local wind input to large waves. Lund et al. (2014) noted that the strength of the surface wave signal in marine X-band radar images strongly depends on range and azimuth, i.e. the angle between antenna look and peak wave direction. The field of view is typically partially obstructed, e.g. due to the coastline or ship superstructures, which may result in an increased variability or error associated with estimated wave parameters. Using reference data from a nearby Datawell Waverider buoy off the California coast, the authors quantified the dependency of the radar-based two-dimensional wave spectrum and parameters on range and azimuth and proposed and evaluated empirical methods to remove the dependency. In a related study Hessner et al. (2014) demonstrated the large amount of information that can be gathered in coastal locations through the use of high resolution remote sensing techniques. High resolution wave, current and water depth fields derived by marine X-band radar were presented for a coastal region of extreme tidal currents in the presence of inhomogeneous bathymetry at the south coast of New Zealand’s North Island. The sea state data provides a spatial representation of coastal effects like wave shoaling and refraction forced by bathymetry and current interaction. The near-surface current measurements about 3 km off the coast show expected tidal current pattern, in agreement with currents from RiCOM, a hydrodynamic model. The observed current field also captured small-scale features caused by the influence of the local bathymetry.

The modelling and forecasting of storm surges was the subject of three sessions. An emerging theme is probabilistic forecasting of water level using ensembles of wind and pressure fields. A number of operational ensemble forecast systems are already in place around the world (Flowerdew et al., 2009; de Vries, 2009; Flowerdew et al., 2010, 2013). Mel and Lionello (2014) presented results from an ensemble for the Adriatic Sea forced by ECMWF wind and pressure fields. In a three-month period in 2010 the model was found to have a good spread-error ratio and the ensemble mean is found to outperform deterministic forecasts. Hence the ensemble
serves both to forecast the uncertainty as well as improve the central forecast. Etala et al. (2015) report advances in storm surge forecasting for the Argentinian coast. Using a Local Ensemble Transform Kalman Filter (LETKF), water level from in situ gauges and satellite altimetry is assimilated into a high-resolution 20-member ensemble storm surge model. The improvement on the inner part of the shelf is significant, and demonstrates quite clearly the value of using satellite altimetry for storm surge forecast systems.

The design criteria of offshore installations are critically sensitive to the highest waves encountered in a storm. Bitner-Gregersen and Toffoli (2014) investigated the occurrence of rogue sea states and the consequences for marine structures in a session on design criteria. They looked in detail at crossing sea states where rogue waves are likely to occur. This is done on the basis of a hindcast with the the WAM model, combined with numerical simulations in the physical space by means of the Higher Order Spectral Method. It is concluded that the 40-degree separation of two wave systems is where the largest waves can be expected.

The 100-year return values of significant wave height and 10-m wind speed are important parameters for the estimation of the load and fatigue on offshore installations. A new method for estimating return values from very large ensembles of archived forecasts at long lead times was presented by Breivik et al. (2014a). Nine years of archived 10-day forecasts consisting of 51 members from the ECMWF ensemble were used to produce global maps of return values for 10-m wind speed and significant wave height. The method was previously used to explore wave height return values in the North Atlantic (Breivik et al., 2013).

The session on operational wave forecasting saw the public release of the fourth WAVEWATCH III version (the model development was previously described in WW-12, see also Tolman et al., 2013). One of the contributions to the new WAVEWATCH III version is the option of running on a spherical multiple-cell grid which allows regions of various resolution to be handled in a single model integration. Li and Saulter (2014) present a global implementation at resolutions of 25, 12 and 6 km and find that the performance compares favourably with the UK Met Office regional wave forecasts.

The session on wave climate trend and variability saw a number of papers exploring new methods to tease out the trends of the past and future wave climate. Aarnes et al. (2015) presented a detailed analysis of the trends in wave height and marine wind speed from ERA-Interim (Dee et al., 2011). They found that the trend at analysis time is contaminated by changes to the observation network. This is particularly problematic for wave height since the wave model relies solely on altimeter observations. There is an abrupt change in the mean wave height in 1991 when the ERS-1 satellite was launched. 10-day forecasts starting at 00 and 12 UTC are part of the ERA-Interim reanalysis runs, and it was found that a lead time of 48 hours gave a more realistic trend in both wave height and wind speed. Vanem (2014) used a Bayesian spatiotemporal analysis on the NORA10 hindcast (Reistad et al., 2011; Aarnes et al., 2012; Breivik et al., 2013) to investigate the trends present in the hindcast. The trends were found to be weaker than those found using a similar method on the C-ERA-40 data set (Caires and Sterl, 2005), which is a statistical adjustment of the ERA-40 reanalysis (Uppala et al., 2005). Paris et al. (2014) compared the trends in wave height for the Bay of Biscay from a number of coarse resolution reanalyses and hindcasts to their recently completed high-resolution hindcast BOBWA-10kH (Charles et al., 2012). They find that the regional forecast slightly overestimates the wave height in the Bay of Biscay whilst ERA-Interim and C-ERA-40 tends to underestimate slightly. The trends appear to be broadly similar. In a similar study, Grabemann et al. (2014) used a consistent approach to analyze a set of ten wave climate projections to estimate the possible impact of anthropogenic climate change on mean and extreme wave conditions in the North Sea (see also Groll et al., 2014). They found that though the spatial patterns and the magnitude of the climate change signals vary, some robust features among the ten projections emerge: mean and severe wave heights tend to increase in the eastern parts of the North Sea towards the end of the twenty-first century in most projections, but the magnitude of the increase in extreme waves varies by several decimeters between the projections. For the western parts of the North Sea more than half of
the projections suggest a decrease in mean and extreme wave heights. They conclude that the influence of the emission scenario on the climate change signal seems to be less important, and that the transient projections show strong multi-decadal fluctuations, and changes towards the end of the twenty-first century might partly be associated with internal variability rather than with systematic changes.

Pérez et al. (2014) presented a diagnostic method for analyzing the origin and travel time of wave systems for a given location, known as “Evaluation of Source and Travel-time of wave Energy reaching a Local Area” (ESTELA). The method allows the characterization of the area of influence for a particular location. The method is capable of characterizing the wave energy and travel time in that area and relies on a global scale analysis using both geographically and physically based criteria. The geographic criteria rely on the assumption that deep water waves travel along great circle paths. This limits the area of influence by neglecting energy that cannot reach a target point, as its path is blocked by land. In a companion paper, Camus et al. (2014) described a method for identifying optimal predictors when investigating which indices to use for assessing the local wave climate. The method is based on a statistical model that relates significant wave height to the sea level pressure. The predictor is composed of a local and a regional part, representing windsea and swell, respectively. The spatial domain of the predictor is determined using the ESTELA technique.

Several regional hindcasts have appeared recently, and the session on wave hindcasts at this workshop saw the presentation of a truly high-resolution hindcast for Irish waters. Gallagher et al. (2014) employed an unstructured grid varying in resolution from about 250 m nearshore to about 10 km offshore with ERA-Interim as boundary conditions. Semedo et al. (2015) investigated the swell climate in the Nordic Seas as it is represented by the NORA10 hindcast (Reistad et al., 2011). They found that swell is dominant more than 50% of the time even in the relatively sheltered Barents Sea during the winter months. During summer months, the swell prevalence rises to about 90% in the Norwegian Sea. Only in the semi-enclosed North Sea did the winter-time swell prevalence drop below 50%. Large changes in the wintertime atmospheric circulation over the North Atlantic during the period had an impact on the wave heights in the eastern North Atlantic mid to high latitudes. Decadal trends of total significant wave height in the Nordic Seas are mostly due to contribution of swell and to the changes in wave propagation. Carrasco et al. (2014) investigated the global wave drift climate, i.e., the geographical distribution of the surface Stokes drift velocity and the Stokes mass transport, using ERA-40 (Uppala et al., 2005). The study shows that in most of the oceanic basins the global surface Stokes drift is chiefly driven by the local wind sea while its vertically integrated transport is mainly swell-driven. Ponce de Léon and Soares (2015) calculated the Benjamin-Feir index (Janssen, 2003) from a wave model integration forced with winds from the CFSR reanalysis (Saha et al., 2010) to investigate the presence of extreme sea states in North Atlantic extratropical storms.

The COWCLIP session on the future wave climate was the second of its kind. There is still a debate about the cost-benefit ratio of adding dynamical wave models to future coupled model intercomparison project climate integrations (CMIP). In the meantime, a few estimates of the impact of waves on the climate system are starting to appear. In this session Fan and Griffies (2014) presented coupled climate simulations of the impact of wave-induced Langmuir turbulence (Skyllingstad and Denbo, 1995; McWilliams et al., 1997; Teixeira and Belcher, 2002; Polton and Belcher, 2007; Grant and Belcher, 2009; Belcher et al., 2012) and turbulence from non-breaking waves (Qiao et al., 2004; Babanin and Haus, 2009; Qiao et al., 2010). This is an important topic for both climate modelling as well as coupled models on seasonal and shorter scales as it has implications for how the ocean surface boundary layer (OSBL) warms.

The 22 articles in the topical collection provide a snapshot more than a complete overview of the current state of the field. We hope that by putting together this topical collection we provide a starting point for new workers in the field as well as a body of references of what has been published earlier. The Wave Workshop will continue its bi-annual progress, and exciting times lie ahead as wave modellers and ocean modellers take the first tentative steps toward each other
by introducing effects of the wave field on the ocean surface boundary layer in full-fledged coupled models of the atmosphere-wave-ocean system (Babanin et al., 2009; Janssen et al., 2013; Fan and Griffies, 2014; Breivik et al., 2015). The effect of the sea state on the climate system is still relatively uncharted territory, but it appears increasingly likely that the enhanced mixing through wave breaking (Craig and Banner, 1994) and Langmuir turbulence (McWilliams et al., 1997; Grant and Belcher, 2009; Belcher et al., 2012) together with the Coriolis-Stokes forcing (Hasselmann, 1970; Weber, 1983; Jenkins, 1987; McWilliams and Restrepo, 1999; Polton et al., 2005; Breivik et al., 2014a) have a profound effect on the mixing in the upper ocean. This in turn has a direct feedback effect on the climate system through the heat fluxes between ocean and atmosphere. But there is also another way through which waves affect the climate system, namely the increased (or reduced) roughness on the sea surface. This was explored by Janssen (1989, 1991) and later implemented in the coupled atmosphere-wave forecast system at ECMWF in 1998 (Janssen, 2004). The increased roughness affects the evolution of low pressures in the extratropics, but there is also evidence of the opposite in swell-dominated areas (Semedo et al., 2009). Finally, the role of waves in the marginal ice zone is beginning to be better understood. Doble and Bidlot (2013) and Kohout et al. (2014) show the dramatic reach of storms in ice-covered waters through measurements of wave activity more than 100 km from the ice edge. Waves probably play an important role in breaking up the ice in the marginal ice zone, causing the ice to melt more rapidly. But waves are also affected by the presence of sea ice as its presence changes the fetch, and it seems clear that only coupled models incorporating both an active ice model with wave break up and a wave model which can model the sea state in areas with moderately high sea ice concentration can hope to realistically capture this interaction. We look forward to seeing presentations on these and other topics relating to the modelling of ocean waves in future workshops, the first of which is to be held in Key West, Florida, in November 2015.

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http://www.waveworkshop.org

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