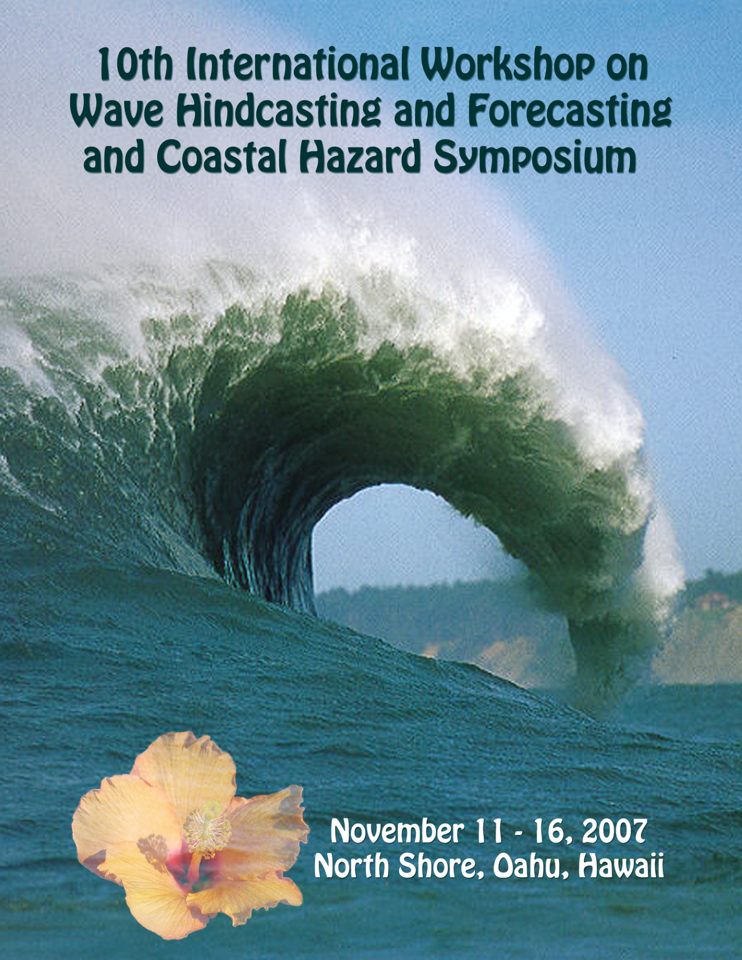
10th International Workshop on Wave Hindcasting and Forecasting and Coastal Hazard Symposium



November 11 - 16, 2007
North Shore, Oahu, Hawaii

ABSTRACTS

10th INTERNATIONAL WORKSHOP ON WAVE HINDCASTING AND FORECASTING AND COASTAL HAZARD SYMPOSIUM

NORTH SHORE, OAHU, HAWAII
NOVEMBER 11 – 16, 2007

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10th International Workshop on Wave Hindcasting and Forecasting
&
Coastal Hazard Symposium
North Shore, Hawaii, November 11-16, 2007

FINAL PROGRAM
Sunday, November 11

4:00 – 6:00 p.m. **Workshop Registration Desk Open**

6:00 – 7:30 p.m. **Icebreaker**

5:00 p.m. **Poster Display**

P1 ***Blended Global High Resolution Sea Surface Forcing Parameters for Numerical Ocean Modeling;*** **Huai-Min Zhang, Richard W. Reynolds, Lei Shi, & John J. Bates**

P2 ***Overview of the Operational Marine Forecast and Warning Products at the Ocean Prediction Center and the National Hurricane Center;*** **Christopher Burr, Hugh Cobb, Mark Willis, Martin C. Nelson, Robert Berg, David Feit, Scott Prosise, and David Mills**

P3 ***Corrupted Quickscat Data and Resultant Erroneous Wave Watch III Output.*** **Robert Burke & Patrick Caldwell**

P4 ***Prototyping Fine-Resolution Operational Wave Forecasts for the Northwest Atlantic.*** **Will Perrie, Bash Toulany, Peter Smith & Yongcun Hu**

P5 ***Breaking of Nonlinear Two-Dimensional Waves in Deep Water.*** **Alexander Babanin, Dmitry Chalikov, Ian R. Young & Ivan Savelyev**

P6 ***Estimation of Plunging Surf Spectra from Remotely Measured Infrasound.*** **Joseph Park, Milton Garces & David Fee**

P7 ***Interannual Variability & Predictability of Summertime Significant Wave Heights in the Western North Pacific.*** **Wataru Sasaki & Toshiyuki Hibiya**

P8 ***Nonlinear Unidirectional & Directional Spectra in Currituck Sound Time Series.*** **Al R. Osborne**

P9 ***High Accuracy Ocean Surface Winds from SAR Imagery.*** **Will Perrie & Hui Shen**

P10 ***Spectral Density Composite for Aiding Hawaiian Southern Shore Surf Forecasts.*** **Patrick Caldwell**

P11 ***Effect of Wind Resolution on Spectral Wave Modeling in the Hawaii Region.*** **Justin Stopa, Demont Hansen & Kwok Fai Cheung**

P12 ***Wind Sea & Swell Delineation for Numerical Wave Modeling.*** **Barbara Tracy, Eve Marie Devaliere, Troy Nicolini, Hendrik Tolman & Jeffrey L. Hanson**

P13 ***Future Exploitation of In-Situ Wave Measurements at Station Mike.*** **Margaret Yelland, K. Bjorheim, C. Gommenginger, R.W. Pascall & B.I. Moat**

P14 ***Assessing Extreme Storm Intensity by Combining Storm Power with Surge*****; Heidi P. Moritz & Hans R. Moritz**

P15 ***Pacific Land Ocean Typhoon (PILOT) Update.*** **C. Pollock, S. Boc, A. Garcia, M. Merrifield, A-C Pequignet, J. Becker, J. Aucan, O. Vetter, T. Hilmer, K-F. Cheung, J. Goo, P. Quiroga & Y. Wu**

P16 ***A Study of Ocean Waves at Fisherman's Wharf, Victoria Harbour.*** **David B. Fissel, Jianhua Jiang & Dave Billenness**

P17 ***Spectral Wave Modeling of Swell Transformations in Indigenous Marshallese Navigation*****; J. Genz, J. Aucan, B. Finney, M. Merrifield**

P18 ***Deployment of an RDCP600 to Measure Directional Wave Spectra in Open and Marginal Ice Zones*****; Oceana Francis-Chythlook & David Atkinson**

P19 ***Wind Waves Numerical Simulation : Hurricane Dean Case Study;*** **J. Antonio Salinas, Roberto Padilla-Hernandez & Fernando Oropeza**

P20 ***US Army Corps of Engineers Wave and Current Data Collection Activities in the Hawaiian Islands: 2005 – 2007*****; Jessica Podoski, Thomas Smith, Kent Hathaway & Stanley Boc**

Monday, November 12

8:00 a.m.	**Welcome and Hawaiian Blessing**
	Session A: Coastal Waves I **Chair: Al Osborne**
8:20 a.m.	**A1. Three & Four Wave Exact Resonance Interactions in the Flat Bottom Boussinesq Equations;** ***Miguel Onorato, Al Osborne, Donald Resio & Peter Janssen***
8:40 a.m.	**A2. Modeling Nonlinear Random Wave Propagation Over Cohesive Sediments;** ***James M. Kaihatu, Alexandru Sheremet & Steve Su***
9:00 a.m.	**A3. Coupled Wave and Sediment Dynamics on Atchafalaya Shelf, Louisiana, US;** ***Alexandru Sheremet, S. Jaramillo & M. A. Allison***
9:20 a.m.	**A4. Bottom Friction in Nearshore Wave Models;** ***Jane McKee Smith & Alison Sleath Grzegorzewski***
9:40 a.m.	**A5. Wave Transformation Modeling with Bottom Friction Applied to Southeast Oahu Reefs;** ***Mary A. Cialone & Jane M. Smith***
10:00 a.m.	**BREAK**
	Session B: Coastal Waves II **Chair: Tom Smith**
10:15 a.m.	**B1. Hindcasting of Waves and Wave Loads on Dutch Wadden Sea Defenses;** ***Ap van Dongeren, Jacco Groeneweg, Gerbrant van Vledder & Andre van der Westhuijsen***
10:35 a.m.	**B2. Sea Surface Elevation Maps Obtained with a Nautical X-Band Radar – Examples from WaMoS II Stations;** ***Katrin Hessner & Konstanze Reichert***
10:55 a.m.	**B3. Operational Implementation of a Multi-Grid Wave Forecasting System; Arun Chawla, Degui Cao, Vera Gerald Todd Spindler & Hendrik Tolman**
11:15 a.m.	**B4. Components of Storm-Induced Water Level Along the Coastal Margin and Related Effects on the Nearshore Wave Environment.** ***Hans R. Moritz & Heidi P. Moritz***
11:35 a.m.	**B5. Occurrence of Coinciding High Surf and Tides Along the North Shore of Oahu, Hawaii;** ***Patrick Caldwell, Jerome P. Aucan & Christopher P. Kontoes***
11:55 p.m.	**LUNCH**
	Session C: Wave Dissipation **Chair: Peter Janssen**
1:25 p.m.	**C1. Spectral Dissipation Term for Wave Forecast Models, Experimental Study;** ***Alexander Babanin and Ian Young***

1:45 p.m.	C2. Implementation of New Experimental Input/Dissipation Terms for Modeling Spectral Evolution of Wind Waves; ***Alexander Babanin***, *Kakha Tsagareli, Ian Young & David Walker*
2:05 p.m.	C3. The Performance of the WAM4.5 Based on a Revised Formulation of the Whitecapping Dissipation and on Limiting the Drag Coefficient in Hurricane Type Wind Forcing; ***Roop Lalbeharry*** *& Serge Desjardins*
2:25 p.m.	C4. Dissipation due to Wave Breaking; ***V.E. Zakharov***, *F. Dias, A.I. Dyachenko & A. O. Prokofiev*
2:45 p.m.	BREAK

Session D: MORPHOS
Chair: Robert Jensen

3:00 p.m.	D1. Methodology and Results for Nearshore Wave Simulation in a Coupled Hydrodynamic and Wave Model System to Evaluate Storm Surge in Coastal Louisiana; ***Christopher Bender*** *& Jane McKee Smith*
3:20 p.m.	D2. Realtime Wave and Surge Modeling with High Resolution Atmospheric Model Coupling; ***Patrick Welsh***
3:40 p.m.	D3. Evaluation of Wave Model Performance in a North Carolina Test Bed; ***Eve-Marie Devaliere***, *Jeff Hanson & Rick Leuttich*
4:00 p.m.	D4. MORPHOS: Advancing Coastal Process Research and Modeling; ***Jeffrey L. Hanson***, *Donald T. Resio & Rob Wallace*
4:20 p.m.	D5. Modeling Hurricane Impacts on Beaches, Dunes & Barrier Islands; ***Dano Roelvink***, *Ad Reniers, Ap van Dongeren, Jaap van Thiel de Vries, Jamie Lescinski & Dirk-Jan Walstra*
4:40 p.m.	D6. Investigating Scales of Nearshore Morphology Modeling; ***Bradley D. Johnson***

Tuesday, November 13

Session E: Climate Change
Chair: David Levinson

8:00 a.m.	E1. The MSC Beaufort Sea Wind and Wave Reanalysis; ***V.R. Swail***, *V.J. Cardone, M. Ferguson, D.J. Gummer & A.T. Cox*
8:20 a.m.	E2. A High-Resolution Hindcast Study for the North Sea, the Norwegian Sea & the Barents Sea; ***Magnar Reistad***, *Oyvind Breivik & Hilde Haakenstad*
8:40 a.m.	E3. Characteristics of Wind Wave Periods, Lenghts and Steepness from Vos Data Over the Global World Ocean and in the Offshore Regions; ***Sergey Gulev*** *& Vika Grigorieva*
9:00 a.m.	E4. Dynamical Versus Statistical Downscaling Approaches for Projecting Ocean Wave Heights; ***Xiaolan L. Wang*** *& Val R. Swail*
9:20 a.m.	E5. Wind, Wave and Storm Surge Hindcasts & Scenarios and Related Coastal & Offshore Applications: The CoastDat Data Set at the GKSS Institute for Coastal Research; ***Ralf Weisse***, *Ulrich Callies, Heinz Gunther, Hans von Storch, Frauke Feser, Katja Woth, Iris Grabemann & Andreas Pluess*
9:40 a.m.	BREAK

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Session F: Improved Physics / Measurements for Prediction
Chair: George Forristal

9:55 a.m.	F1. The Back Effect of Breaking Waves on Adverse Currents; ***Chris Garrett***
10:15 a.m.	F2. Experimental Justification of Weakly Turbulent Nature of Growing Wind Seas; ***S.I. Badulin****, A.V. Babanin, D. Resio, V.E. Zakharov*
10:35 a.m.	F3. The High-Frequency Range of Wind Wave Spectra and Implications for Wave Breaking; ***Donald T. Resio*** *& Charles E. Long*
10:55 a.m.	F4. Coupling Alongshore Variations in Wave Energy to Beach Morphologic Change Using the SWAN Wave Model at Ocean Beach, San Francisco, CA; ***Jodi Eshleman****, Patrick L. Barnard, Li H. Erikson & Daniel M. Hanes*
11:15 a.m.	F5. Hurricane Wave and Surge Computations: Deficiencies & Research Needs; ***Joannes Westerink,*** *J. Smith, V. Cardone, A. Cox, D. Resio, R. Jensen, T. Wamsley & B. Ebersole*
11:35 a.m.	LUNCH

Session G: Wave Prediction – Tropical
Chair: Vince Cardone

1:05 p.m.	G1. Modeling Wind-Waves & Currents under Tropical Cyclone Forcing: Benchmarking of WAVEWATCH III and MECO Models for Selected Storms in NW Australia and in the Gulf of Mexico; ***Jose-Henrique Alves*** *& Michael P. Garvey*
1:25 p.m.	G2. North Atlantic Wind Waves of 2005 Hurricane Season – Prediction vs. Observation; ***Hendrik L. Tolman*** *& Yung Y. Chao*
1:45 p.m.	G3. To Blend of Not To Blend: In the Pursuit of Finding an Operational Way to Give Hurricane Characteristics to the CMC Forecast Wind Field; ***S. Desjardins****, R. Lalbeharry, H. Ritchie, & A. Macafee*
2:05 p.m.	G4. Comparing Hindcasts with Wave Measurements from Hurricane Lili, Ivan, Katrina & Rita; ***George Z. Forristall***
2:25 p.m.	G5. Forecast Error Analysis During Hurricane Katrina Using the NOPP Real-Time Prediction System for Tropical Cyclones; ***Hans C. Graber****, Andrew Cox, Robert E. Jensen, Don Slinn, Scott Hagan, Robert Weaver, Neil Williams, Geoffrey Samules & Vincent Cardone*
2:45 p.m.	BREAK

Session H: Model Verificatons
Chair: Val Swail

3:00 p.m.	H1. Inter-Comparison of Operational Wave Forecasting Systems; ***Jean-Raymond Bidlot,*** *Jian-Guo Li, Paul Wittmann, Manon Fauchon, Hsuan Chen, Jean-Michel Lefevre, Thomas Bruns, Diana Greenslade, Fabrice Ardhuin, Nadao Kohno, Sanwook Park & Marta Gomez*
3:20 p.m.	H2. Development of Spatial Inter-Comparison Within the Operational Wave Forecast Verification Exchange; ***Adrian Hines****, Jean-Michel Lefevre & Dave Poulter*
3:40 p.m.	H3. Using Altimeter Data to Validate & Develop Wave Models; ***Hendrik Tolman***

4:00 p.m.	**H4. Validation & Application of Jason-1 and Envisat Significant Wave Heights;** ***Tom Durrant & Diana Greenslade***
4:20 p.m.	**H5. Updates to WAM CY 4.5+;** ***Robert E. Jensen, H. Gunther & P. Janssen***
4:40 p.m.	**H6. Consensus Forecasts of Integrated Wave Parameters;** ***Diana Greenslade, Tom Durrant & Frank Woodcock***

Wednesday, November 14

Session I: Estimation of Coastal Hazards I
Chair: Jessica Podoski

8:00 a.m.	**I1. Hindcasting Winds, Waves & Storm Surge for Hurricane Katrina;** ***Joannes Westerink***
8:20 a.m.	**I2. Hindcasting Winds, Waves & Storm Surge for Hurricane Rita;** ***Casey Dietrich, J. Smith, J. Westerink, J. Atkinson, S. Bunya, R. Jensen, V. Cardone, A. Cox, H. Westerink, R. Luettich & C. Dawson***
8:40 a.m.	**I3. Representation of Vegetation on the Wind Boundary Layer and Surface Bottom Friction;** ***John Atkinson***
9:00 a.m.	**I4. High Performance Computing to Resolve Propagation and Advection Dominated Multi-Scale Multi-Process Physics;** ***Clint Dawson, E. Kubatko & J. Westerink***
9:20 a.m.	**I5. The Influence of Barrier Islands and Lower Plaquemines Parish Mississippi River Levees on Waves and Storm Surge in Southern Louisiana;** ***Wiebe de Jong & Hugh Roberts***
9:40 a.m.	**BREAK**

Session J: Estimation of Coastal Hazards II
Chair: Darryl Hatheway

9:55 a.m.	**J1. Comparison of Emperical Methods and a Boussinesq-Type Wave Model for Predicting Overtopping of Coastal Structures;** ***Patrick J. Lynett, Don Resio & Mathijs van Ledden***
10:15 a.m.	**J2. Louisiana Chenier Plain Regional Hydrodynamic, Salinity & Hydrologic Numerical Models;** ***Ehab Meselhe, Robert Miller & Jeanne Arceneaux***
10:35 a.m.	**J3. Numerical Surge Modeling of Coastal Restoration Features;** ***Ty Wamsley***
10:55 a.m.	**J4. Probabilistic Design Methods for Levee & Floodwall Design;** ***Mathijs van Ledden, Pat Lynett, Don Resio & Nancy Powell***
11:15 a.m.	**J5. Implications of the Spectral Shape of Wave Conditions for Engineering Design & Coastal Hazard Assessment – Evidence from the English Channel;** ***Andrew Bradbury, Travis Mason, Tim Poate & Tamzin Palmer***
11:35 a.m.	**LUNCH**

Session K: Estimation of Coastal Hazards III
Chair: Dr. H. Das

1:05 p.m.	**K1. Performance of the JPM and EST Methods in Storm Surge Studies; *David Divoky* & *Don Resio***
1:25 p.m.	**K2. Hurricane Surge Classification for Risk Assessment Along the Gulf of Mexico Coastline; *Jennifer L. Irish* & *Donald T. Resio***
1:45 p.m.	**K3. The Evaluation of Storm Surge Hazard in Coastal Mississippi & Louisiana; *Alan Niedoroda, D. Resio, D. Divoky, R. Lowe, L. Charles, H. Das & C. Reed***
2:05 p.m.	**K4. Time Dependent Wave Setup During Hurricanes on the Mississippi Coast; *Don Slinn, A.W. Niedoroda, R.G. Dean, H. Das, R. Weaver, C. Reed & J. Smith***
2:25 p.m.	**K5. Approaches for the Efficient Probabilistic Calculation of Surge Hazard; *Gabriel Toro***
2:45 p.m.	**BREAK**

Session L: Climate Variation & Coastal Hazards
Chair: John J. Marra

3:00 p.m.	**L1. Is There a Discernible Anthropogenic Impact on Atlantic Hurricane Activity; *Thomas R. Knutson***
3:20 p.m.	**L2. Extra-Tropical Cyclones in a Warming Climate: Observational Evidence of Trends in Frequencies and Intensities in the North Pacific, North Atlantic & Great Lakes Regions; *David Levinson* & *Peter Bromirski***
3:40 p.m.	**L3. Extreme Still Water Levels; *Sofia Caires, Ferdinand Diermanse, Douwe Dillingh & Reimer de Graaff***
4:00 p.m.	**L4. An Overview of Different Methods for Assessing Historical Hurricane Frequency and Potential Risk for the Gulf of Mexico Coast; *David Levinson, Trevor Wallis & Mike Squires***
4:20 p.m.	**L5. The Modern Predictability of the 1966 Big Venice Flood; *Luigi Cavaleri, Luciana Bertotti & Roberto Buizza***
6:00 p.m.	**RECEPTION**
6:45 p.m.	**LUAU**

Thursday, November 15

Session M: Tropical Meteorology
Chair: Mark Powell

8:00 a.m.	***M1.* Tropical Cyclone Atmospheric Forcing for Ocean Response Models: Approaches & Issues; *Vincent Cardone* & *Andy Cox***
8:20 a.m.	**M2. Specification of Tropical Cyclone Parameters from Aircraft Reconnaissance; *Andrew Cox* & Vincent Cardone**

8:40 a.m.	**M3. CBLAST Program of Coupled High Resolution Hurricane Models; *Shuyi Chen***
9:00 a.m.	**M4. Realistic Simulations of Intense Hurricanes with the NCEP/NCAR WRF Modeling System; *Chris Davis & Greg Holland***
9:20 a.m.	**M5. New Findings on Hurricane Intensity, Wind Field Extent & Surface Drag Coefficient Behavior; *Mark Powell***
9:40 a.m.	**M6. Uncertainty in Population Properties of North Atlantic Tropical Cyclones; *Peter Vickery***
10:00 a.m.	**BREAK**

Session N: Extreme Waves
Chair: Miguel Onorato

10:15 a.m.	**N1. The "Voyager" Storm in the Mediterranean Sea; *Luigi Cavaleri & Luciana Bertotti***
10:35 a.m.	**N2. Are "Unexpected" Waves as Important as Rogue Waves? *Johannes Gemmrich & Chris Garrett***
10:55 a.m.	**N3. Extension of the ECMWF Freak Wave Warning System to 2 Dimensional Propagation; *Peter Janssen, Nobuhito Mori & Miguel Onorato***
11:15 a.m.	**N4. Freak Wave Prediction from Spectra; *Nobuhito Mori, Peter Janssen & Miguel Onorato***
11:35 a.m.	**N5. Modeling Rogue Waves in Fully Directional Sea States; *Al Osborne***
11:55 a.m.	**N6. Evolution of Random Directional Wave and Rogue Wave Occurrence; *Takuji Waseda & Takeshi Kinoshita***
12:15 p.m.	**N7. Freak Waves as a Result of Modulational Instability; *Vladimir Zakharov & A. Dyachenko***
12:35 p.m.	**WORKSHOP ENDS FOR THE DAY**

Friday, November 16

Session O: Island Inundation
Chair: Stan Boc

8:00 a.m.	**O1. Predicting Wave Conditions in a Coral Embayment from Offshore Directional Spectral Model Input; *Ron Hoeke & Curt Storlazzi***
8:20 a.m.	**O2. Phase-Resolving Simulation of Wave Evolution Over a Shallow Reef; *Patrick Lynett***
8:40 a.m.	**O3. Waves and Water Level Collected During the Pacific Island Land Ocean Typhoon Experiment; *Mark Merrifield, A-C Pequignet, J. Becker, J. Aucan, O. Vetter, T. Hilmer, S. Boc, C. Pollock, K.-F. Cheung, J. Goo, P. Quiroga & Y. Wu***
9:00 a.m.	**O4. Wave Energy Budget for Pacific Island Nearshore Environments; *Anne-Christine Pequignet, Janet M. Becker & Mark A. Merrifield***
9:20 a.m.	**O5. Combined Wind and Waves Over a Reef; *Alejandro Sanchez, Jane Smith, Zeki Demirbilek & Stan Boc***
9:40 a.m.	**BREAK**

Session Q: Wave Model Applications for Coastal Hazards
Chair: Alex Sheremet

9:55 a.m.	**Q1. Estimation of Probable Maximum Wave Height in the Sea Areas around Japan Based on Simulations of Typhoon and Depression (Storm) Generated Waves;** ***Masataka Yamaguchi, Hirokazu Nonaka & Yoshio Hatada***
10:15 a.m.	**Q2. Diagnosing the Large Swell Event Associated with the Extratropical Transition of Hurricane Florence (2006);** ***Mark C. Willis***
10:35 a.m.	**Q3. The Improvement of JMA Operational Wave Models;** ***Toshiharu Tauchi***
10:55 a.m.	**Q4. The 2007 Release of WAVEWATCH;** ***Hendrik Tolman***
11:15 a.m.	**Q5. Numerical Aspects and Source Term Analysis of Wave Modeling in a Tidal Inlet;** ***Gerbrant van Vledder, Jacco Groeneweg, Andre van der Westhuijsen & Ap van Dongeren***
11:35 a.m.	**BREAK (Setup for Working Lunch)**

Working Lunch – Box Lunches Provided

Session R: Model Improvements
Chair: Jeff Hanson

12:05 p.m	**R1. Numerical Investigations for the Applicability of SRIAM Method as a New Non-Linear Energy Transfer Function;** ***Hitoshi Tamura, Takuji Waseda, Yasumasa Miyazawa & Kousei Komatsu***
12:25 p.m.	**R2. A Two-Scale Approximation for Nonlinear Energy Transfers in Observed Wave Spectra;** ***Will Perrie & Donald Resio***
12:45 p.m.	**R3. Operationalisation of the TSA Method for the Computation of Non-Linear Four-Wave Interactions in Third-Generation Wave Models;** ***Gerbrant van Vledder***
13:05 p.m.	**Closing Remarks / Closing Ceremony**

BLENDED GLOBAL HIGH RESOLUTION SEA SURFACE FORCING PARAMETERS FOR NUMERICAL OCEAN MODELING

Huai-Min Zhang, Richard W. Reynolds, Lei Shi, and John J. Bates
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Phone: 828-271-4090

Advances in understanding the coupled air-sea system and modeling of the ocean and atmosphere demand increasingly higher resolution data. Observationally and for higher resolution, blending of observations from multiple platforms (constellation of satellites, ships and buoys, etc) is desirable. In this paper, we describe the development of such blended sea surface products for wind, water and air temperatures and humidity.

Sea surface wind speed has been observed by one satellite in the mid 1987 and gradually increased to six or more satellites by mid 2002. Our sampling study showed that on a global 0.25° grid, blended products with temporal resolutions of 6-hours, 12-hours and daily have become feasible since mid 2002, mid 1995 and January 1991, respectively. A uniform blending was processed using a near Gaussian 3-D interpolation, and blended products are available in resolutions of 6-hourly, daily and monthly, all from July 1987 to present. Wind direction has been observed from fewer satellites, thus the directions are taken from the NCEP Re-analysis 2, which is operationally updated.

The widely used Reynolds Optimum Interpolation SST analysis has been improved with higher resolutions (daily and 0.25°). The improvements use both infrared and microwave satellite data that are bias-corrected by in-situ observations for the period 1985 – present. The new versions provide very significant improvements in terms of resolving ocean features such as the meandering of the Gulf Stream, the Agulhas Current, the equatorial jets and other fronts.

The Ta and Qa retrievals are from the AMSU sounder onboard the NOAA satellites. Retrieval algorithms are developed using the neural network approach. Using the 2002 one-year collocated satellite and in-situ data, the RMSE for Ta is ~ 1.94°C.

Further details can be obtained from http://www.ncdc.noaa.gov/oa/satellite.html.

OVERVIEW OF THE OPERATIONAL MARINE FORECAST AND WARNING PRODUCTS PRODUCED AT THE OCEAN PREDICTION CENTER AND THE NATIONAL HURRICANE CENTER

Christopher Burr, Hugh Cobb, Martin Nelson, Mark Willis,
David Feit, Scott Prosise, David Mills & Robert Berg

The nearly 40 operational marine forecasters working at the National Weather Service's Ocean Prediction Center and the National Hurricane Center issue about 250 products (text and graphical) per day. The Area of Responsibility covers nearly all of the open oceanic waters over the Atlantic (including the Gulf of Mexico and Caribbean) north of the equator and a vast area over the Pacific. These products include text High Seas and Offshore Waters Forecasts and graphical Surface Analyses, Sea State and wind/wave charts, Surface Progs, Peak Wave Period charts, and a Tropical Cyclone Danger Area chart. The customers are diverse and include recreational boaters, commercial fishing, cruise ships, and trans-oceanic cargo vessels. This poster highlights some of the products the two offices issue, the enhanced synergy at both centers, tools and techniques used by the forecasters, and future products and services including producing high resolution grids.

CORRUPTED QUICKSCAT DATA AND RESULTANT ERRONEOUS WAVE WATCH III OUTPUT

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On Tuesday March 13th 2007, the largest northwest swell of the season reached the Hawaiian islands resulting in warning level surf exceeding 25 feet. Prior to 18Z Sunday March 11th 2007, global weather and wave models were doing a good job in handling the storm which produced the swell.

A Quickscat pass centered over the storm around 18Z on the 11th had significant errors in the wind field primarily with wind direction. Due to lack of any ship or surface data in the area, the Quickscat winds were used in the 18Z GFS model initialization. The result was a much weaker low and an unrepresentative wind field. The GFS input to the Wave Watch III model resulted in much lower seas in the fetch area aimed at Hawaii. Forecasters at WFO Honolulu were quick to pick up on this erroneous output and reverted to previous model output for swell and surf forecasts associated with the approaching wave train. This study shows the continued need for quality control of input data into the GFS and Wave Watch III models. Introduction of erroneous data can cause significant errors in the resulting forecasts of winds and waves.

PROTOTYPING FINE-RESOLUTION OPERATIONAL WAVE FORECASTS FOR THE NORTHWEST ATLANTIC

Will Perrie, Bash Toulany, Peter Smith and Yongcun Hu

Bedford Institute of Oceanography
1 Challenger Dr.
Dartmouth, Nova Scotia, Canada

We describe a wave forecast system for fine-resolution wave forecasts for Lunenburg Bay, Nova Scotia, the site of an interdisciplinary marine environmental prediction project for the Atlantic Coastal Region.

This five-year project has involved the extensive collaboration of Dalhousie University, the Meteorological Service of Canada and Bedford Institute of Oceanography to develop a real-time atmosphere-ocean observing system for Lunenburg Bay, with observations to guide and test the marine coastal prediction system in an examination of marine environmental phenomena important on daily to weekly time scales, including: waves, surface winds, sea breezes, fog, coastal upwelling, and circulation and ecosystem dynamics in coastal embayments. This project is leading to significantly improved knowledge and understanding of: (i) how the coupled ocean/atmosphere system works in the Atlantic sector; (ii) how ecological processes can be incorporated into realistic physical models; (iii) how the predictive skill of interdisciplinary coupled atmosphere/shelf/bay models varies on time scales of days to weeks; and (iv) what the consequences of episodic phenomena including extreme weather events are. It is resulting in coupled atmosphere/ocean/wave models and techniques that will be suitable for adaptation by national government agencies, and it is producing improved numerical models for describing and forecasting coastal ocean physical and biological conditions. These advances contribute to the detection and prediction of change in coastal environments due to human activities and climate change.

The wave forecast system has been extensively calibrated in studies of hurricane Juan, which made landfall in Halifax as a category 2 hurricane on September 29, 2003. The model system consists of 5 nested grids ranging from a bay-scale grid with very high resolution of 1 km, to a North Atlantic grid with resolution 0.5^{o}. Nested implementations of SWAN (v.40.31) are used for the inner-most very fine- and fine-resolution grids. These grids are driven at their boundaries by nested implementations of WAVEWATCH-III (v.2.22; denoted WW3) for three higher level (i.e. progressively coarser) model grids. Wave model results are compared to *in situ* surface buoys and ADCP wave data in near-real time, and results are displayed online. The wave model system is driven by a nested multi-grid weather forecast system constructed by the Meteorological Service of Canada with high resolution 2.5 km winds to drive the corresponding Lunenburg Bay wave and ocean models. The wave model system has been used to investigate the influence of finite depth topography and storm structure on surface waves, in accordance with recent field and modeling campaigns.

BREAKING OF NONLINEAR TWO-DIMENSIONAL WAVES IN DEEP WATER

Alexander Babanin, Dmitry Chalikov, Ian R. Young, Ivan Savelyev*

The causes of breaking of deep-water two-dimensional waves are studied. Evolution of initially monochromatic steep waves to the point of breaking was first investigated by means of the fully nonlinear Chalikov-Sheinin model. Individual wave steepness is found to be the single most important parameter which determines whether the wave will break immediately, never break or take a finite number of wave lengths to break. If the wind forcing is superimposed, it can alter the wave-breaking dependences, but these effects appear to be of secondary importance.

The results were subsequently verified and elaborated in a laboratory experiment. The experiment demonstrated good qualitative agreement with the numerical simulations and consequently the breaking dependences were quantified.

Since the location of breaking onset, which occurs as a result of the natural evolution of nonlinear wave trains can thus be controlled, properties of incipient breakers were measured. It was found that the breaking will occur once the wave reaches the Stokes limiting steepness.

Potential applications to field conditions are also discussed.

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10TH INTERNATIONAL WORKSHOP ON WAVE HINDCASTING
AND FORECASTING & COASTAL HAZARD ASSESSMENT,
North Shore, Hawaii, November 11-16, 2007

Estimation of Plunging Surf Spectra from Remotely Measured Infrasound

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Abstract

Plunging surf is a known generator of atmospheric infrasound, though the mechanisms have not been clearly identified. Acoustic radiation spectra computed by a model based on dynamic, collective bubble oscillations created by demise of the initially entrained air pocket are compared to data collected at Polihale, on the island of Kauai. Agreement indicates that collective bubble oscillations are a contributor to infrasound for medium-to-large scale (<5m) plunging waves. Primary model parameters include the breaking wave spectrum, which depends on seafloor geometry, and the characteristic scale of the bubble clouds. A nonlinear state estimator is applied to invert the model, and produce estimates of the breaking wave spectra given remotely sensed infrasound. The breaking wave distributions can then be used to infer seafloor morphology and bubble plume scales. Lamarre & Melville [1] found that dissipation of breaking wave energy by air entrainment against buoyancy can account for up to 50% of the dissipated energy. With an estimate of the incident wave energy spectrum and entrained air volumes, the wave energy dissipated in breaking might be estimated. The residual could provide an estimate of the wave energy available for runup on the shore.

[1] Lamarre E., Melville, W. K., Air entrainment and dissipation in breaking waves, Nature, 351, 469-472, 1991

INTERANNUAL VARIABILITY AND PREDICTABILITY OF SUMMERTIME SIGNIFICANT WAVE HEIGHTS IN THE WESTERN NORTH PACIFIC

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We propose and validate a linear regression model which enables us to predict the summer (June–August) mean of the monthly 90th percentile of significant wave heights (H90) in the western North Pacific (WNP). The most prevailing interannual variability of H90 is identified by applying an Empirical Orthogonal Function analysis to H90 obtained from the ERA-40 wave reanalysis as well as from the optimally interpolated TOPEX/Poseidon (OITP) wave data. It is found that the increase of H90 is correlated with cyclonic circulation in the WNP which links with warm SST anomalies in the Niño-3.4 region. We adopt zonal wind anomaly averaged over the region 5°N–15°N, 130°E–160°E (U10N) as a predictor of the first principal component (PC1) of H90, since U10N is closely correlated with the PC1 of H90. It is revealed that regression models obtained from two different wave datasets are nearly identical. The predictability of the regression model is assessed in terms of the reduction of the root-mean-square (rms) errors between H90 and the reconstructed data. The predictor is found to be successful in reducing the rms errors by up to 40% for the ERA-40 wave reanalysis and by up to 70% for the OITP wave data within the latitudinal band 10°N–25°N, though rms errors exceeding 0.3 m still remain, particularly in the East China Sea.

NONLINEAR UNIDIRECTIONAL AND DIRECTIONAL SPECTRA IN CURRITUCK SOUND TIME SERIES

A. R. Osborne

Currituck Sound time series have been analyzed to determine their nonlinear directional spectra. Spectral representations in terms of multidimensional Fourier series for both unidirectional and directional sea states are addressed. A surprising result is that low frequency motions in the data correspond to the long-wave regime characteristic of the Korteweg-deVries equation while the main peak of the spectrum constitutes a regime characteristic of the nonlinear Schroedinger equation. In the low frequency regime we find that the spectral components can be characterized as a “soliton gas”, i.e. one in which the wave components are essentially all solitons. These results have important implications on the transfer of energy to low frequency motions from high frequency waves in shallow water regions. Some estimates as to how this energy transfer occurs are made based upon the nonlinear spectral analysis approach. Another important result of our analysis is the discovery of rogue wave modes near the main peak of the spectrum. This work has been jointly conduced with Miguel Onorato, Chuck Long and Don Resio.

HIGH ACCURACY OCEAN SURFACE WINDS FROM SAR IMAGERY

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Recent progress on the remote sensing of ocean surface winds suggests that Synthetic Aperture Radar (SAR) is capable of giving valuable measurements of ocean surface winds with high spatial resolution and high accuracy. We have been focusing on wind retrieval from SAR images for low- to- moderate wind conditions, as well as under high wind conditions, such as hurricanes. Two new methods have been developed, one is the gradient method (GM), which focuses on low-to-moderate wind retrievals [He et al., 2005; Perrie et al., 2006; Shen et al., 2006], the other is a new algorithm for hurricane winds [Shen et al., 2006, 2007]. Both methods can potentially be implemented in automatic wind retrieval systems from SAR, with no dependence on external wind information, which is important for operational applications.

Our recent studies suggest that atmospheric boundary layer stabilities have impact on the accuracy of ocean surface wind retrieval from SAR images. Since the widely used geophysical model function (GMF) for ocean wind retrieval from SAR was developed based on 10-m neutral stability wind database, the wind retrieved directly from SAR images differs from the actual wind under real ABL (Atmospheric Boundary Layer) conditions. Several SAR images with various ABL stabilities are studied, and retrieved winds are compared by in-situ measured buoy winds. We show that the ABL stability and height difference between SAR retrieved winds and in-situ measurements have direct influence on the retrieved SAR winds. A method to calibrate the influence of ABL stabilities is introduced. The calibrated winds are shown to improve the SAR-derived ocean surface winds (for instable ABL conditions) by up to about 10%, which is potentially important for related studies of ocean waves. (Perrie et al. 2007).

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SPECTRAL DENSITY COMPOSITE FOR AIDING HAWAIIAN SOUTHERN SHORE SURF FORECASTS

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Extra-tropical cyclones in the southern hemisphere create surf on southern shores of the Hawaiian Islands. A small percentage of episodes create hazardous conditions at harbor entrances, dangerous near shore currents, and if combined with a spring high tide, high shoreline run-up. The National Weather Service in Honolulu issues high surf advisories when heights are above the high season average and high surf warnings for exceptionally large episodes. The issuance of a warning sets into motion actions for the civil defense, select transportation and commercial sectors, and water safety personnel. Thus, the forecasters need strong evidence prior to making the call. One of the most important tools used for fine tuning a surf forecast is buoy data. Wave sensors of a buoy on the equator about 1300 nm south-southeast of Oahu provide roughly a two-day lead while a network of three buoys spread east to west within 17-19^{o}N south of the main Hawaiian Islands gives roughly a one-quarter to one-half day fore warning. To better understand the potential magnitude of an imminent swell, the spectral density as a function of wave frequency (period) is analyzed. This study creates a composite signature for the spectral density based on historic cases of surf categorized by magnitude. The composites can be used as a guideline to forecasters as future events unfold.

EFFECT OF WIND RESOLUTION ON SPECTRAL WAVE MODELING IN THE HAWAII REGION

Justin Stopa, Demont Hansen, and Kwok Fai Cheung

The state of Hawaii is affected by significant swells throughout the year. NOAA NDBC operates four buoys in the Hawaii region which provide useful deep water wave data to Hawaii's residents. In addition, UH operates two buoys on Oahu's North and East shores that provide nearshore wave conditions. The third generation wave model WaveWatch3 (WW3) is employed to provide complete coverage of the Hawaiian Islands.

A global WW3 (version 2.22) was setup up identically to NOAA's operation model and is forced with the Global Forecast System (GFS) winds. Then spectral wave conditions were provided into a smaller Hawaii domain which covers the entire state. Hawaii WW3 is forced with interpolated GFS winds. In addition, another Hawaii WW3 is forced with winds from the UH Meteorology department's fifth generation mesoscale model (MM5). Interpolated GFS winds are not able to pick up the small scale wind perturbations, and localized wind patterns. Since the local trade-winds can generate significant swells, it is imperative that an adequate wind field is used to force Hawaii WW3.

A two week case study, March 17 to April 2, 2005 was chosen based on its local wind characteristics and global wave characteristics. This period represents two important features: 1) calm local winds coupled with a significant ground swell and 2) strong local winds which generated a wind swell coupled with a significant ground swell. First differences in the wind field were quantified comparing MM5 and interpolated GFS. Next a wave analysis is completed comparing Hawaii WW3 forced with interpolated GFS and Hawaii WW3 forced with MM5. In conclusion, the procedures in this study to hindcast wave events can be implemented to forecast waves in the future.

WIND SEA AND SWELL DELINEATION FOR NUMERICAL WAVE MODELING

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Hendrik Tolman, NWS NCEP
Barbara Tracy, USACE Coastal and Hydraulics Lab

The US Army Corps of Engineers has partnered with the National Weather Service to develop efficient tools for the separation of wind sea and swell system information from numerical wave model output. A new FORTRAN partitioning algorithm uses watershed delineation technology to isolate peak domains in directional wave spectra. The algorithm has suitable efficiency to be operated over regional to global-scale domains. This allows the wave height, period, direction and spread statistics from individual wave components to be saved from every computational grid point in a numerical wave modeling application. A wind forcing ratio is introduced to facilitate classification of wave systems as either wind sea, swell or mixed. The resulting algorithm is now part of an operational SWAN application developed by the Eureka Weather Forecasting Office and has also been tested with all NCEP WAVEWATCH III grids. Continuing work is focused on developing efficient wave component clustering tools for visualizing the temporal and spatial evolution of wave systems across ocean basins.

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FUTURE EXPLOITATION OF IN-SITU WAVE MEASUREMENTS AT STATION MIKE

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As part of a UK-SOLAS (Surface Ocean-Lower Atmosphere Study) project the National Oceanography Centre (NOCS) has instrumented the Norwegian weather ship *Polarfront* with the directional wave radar "WAVEX". This system complements the *Polarfront's* existing ship borne wave recorder which was installed by the Norwegian Meteorological Institute in 1978. The *Polarfront* and its predecessors have occupied Station Mike (66 degrees N, 2 degrees E) all year round for nearly 60 years. NOCS also equipped the ship with digital cameras and the autonomous air-sea flux system "AutoFlux". The NOCS systems were installed in September 2006 and will operate continuously for at least 3 years. Project information and real-time data from the ship can be found via http://www.noc.soton.ac.uk/ooc/CRUISES/HiWASE/index.php . The sea-state dataset being obtained on the *Polorfront* is unparalleled in that the SBWR provides reliable wave height data but no directional information, whereas the wave radar provides excellent directional wave spectra but infers wave heights indirectly. It is believed that, until now, the two systems have never been deployed together for more than brief periods. On *Polorfront* the two systems provide very comprehensive information on sea state, in a region of the world's oceans which experience a wide range of conditions (eg. 3-hourly significant wave heights of 15.5 m in November 2001). The main research aim of the project is the parameterisation of the air-sea fluxes, including wind stress, in terms of wind speed, sea state, etc. However, the wave data set being collected has potential uses which fall outside the project aims and we would welcome proposals for collaboration from members of the remote sensing and modeling communities. Here we describe initial results which show that the two wave systems agree reasonably well for wave period, but that significant wave heights from the WAVEX are over estimated in the presence of swell.

ASSESSING EXTREME STORM INTENSITY BY COMBINING STORM POWER WITH SURGE NEWPORT, OREGON, USA

Heidi P. Moritz[1] and Hans R. Moritz

In a 2004 extremal wave height analysis, the full period of record for 4 NDBC buoys along the Oregon and Washington coasts was used to identify the design wave height variability along the Pacific Northwest coastline. Projected 100 year wave heights were similar for all buoys at around 12 m with the exception of the Newport buoy which exhibited a 100 year wave height projection of 3.4 m higher at 15.8 m. A 2006 analysis built on the earlier analysis to develop a storm power history for one of the four NDBC buoys, 46029 – Columbia River Buoy. The present analysis proposes to conduct a similar storm power history analysis for the Newport buoy, 46050. Also located at Newport is a NOAA water level observation station (South Beach) which has been in operation since 1967. Hourly water level differentials from tides will be used to calculate magnitude and duration of surge during the identified storm events. Total surge intensity measured in meter-hours (Pope, 2007) will also be calculated.

Data used in this investigation spans the years of available NDBC buoy data at 46050 (1991 to 2007). Storm power is evaluated using the theoretical wave power calculation **($P_o=1/2E_oC_o$) x storm duration**. The variability of storm direction with storm power will also be presented. A comparison of storm power results will be made between the Newport and Columbia River locations to see if storm power results differ as significantly as design wave height values. A potential storm intensity scale will combine storm power and storm surge. Figure 1a shows extremal wave analysis results for the four NDBC buoys. Figure 1b identifies the locations of the NDBC buoys and the South Beach water level station. Figure 2 illustrates storm power results for the Columbia River buoy.

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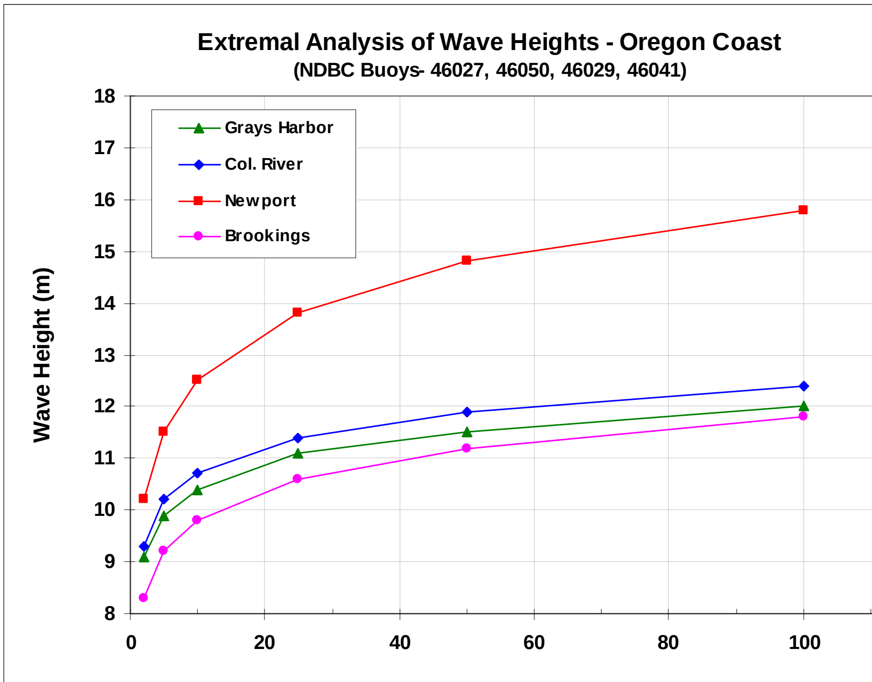

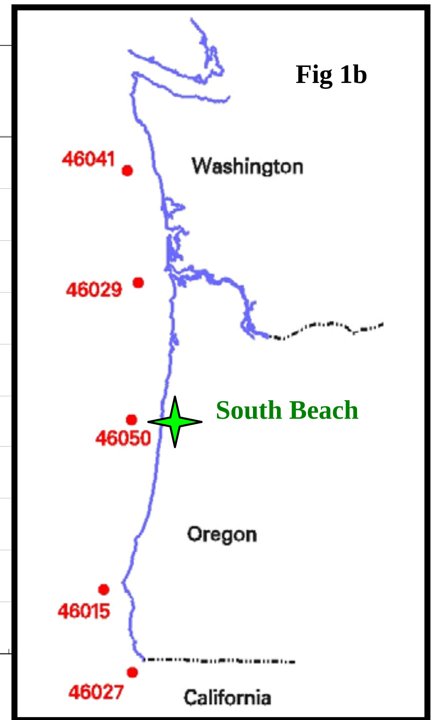

Figure 1a (Moritz, 2004)

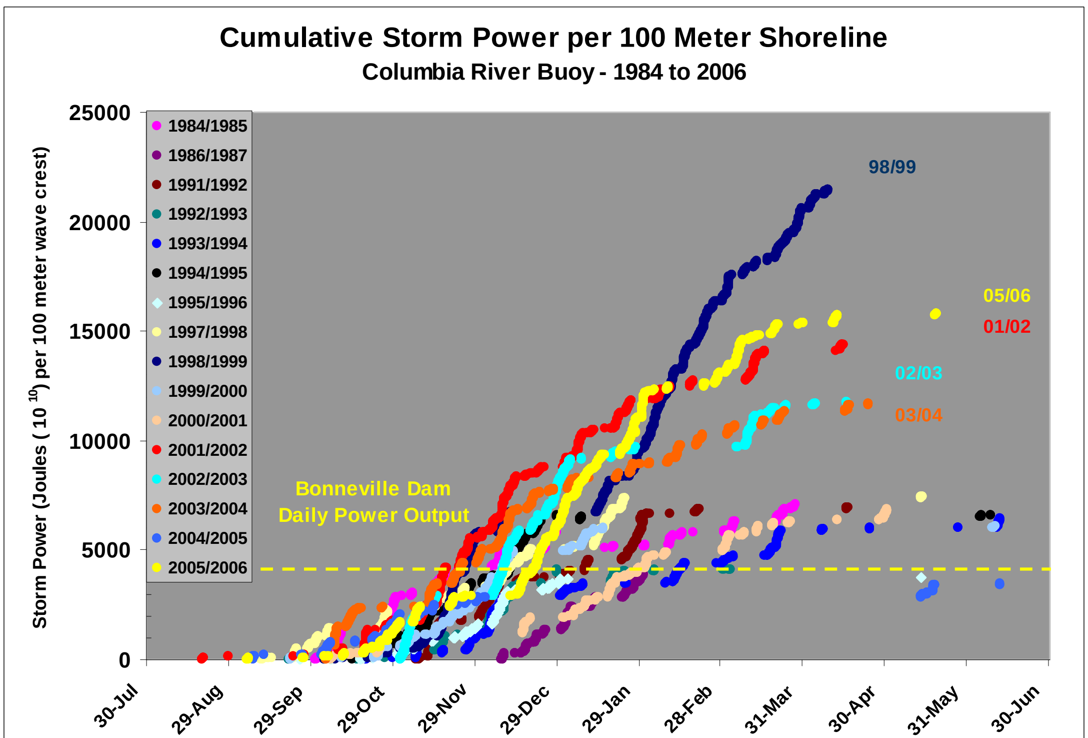

Figure 2

PACIFIC ISLAND LAND OCEAN TYPHOON (PILOT) EXPERIMENT AND TYPHOON MAN-YI GUAM

C. Pollock, S. Boc, A. Garcia, M.A. Merrifield, A-C. Pequignet, J.Becker, J. Aucan, O.Vetter, T.Hilmer, K-F. Cheung, J.Goo, P.Quiroga, Y.Wu

The PILOT program sponsored by the US Army Corps of Engineers is designed to acquire the data necessary to depict and better understand the physics of the wave–reef interaction. Field laboratories have been established on the islands of Guam, Saipan and Oahu. Guam was selected primarily because it is affected by an average of three tropical cyclones annually. In addition, it offers a favorable physical and logistical setting to study the required processes. Data collection is accomplished by the use of a nearby deep-water directional wave buoy, a coastal water-level and meteorological station, shallow water wave gages on the reef flat, and a laser-based bathymetric survey.

Typhoon Man-Yi passed within 200 nautical miles of south of Guam as a tropical storm during the period of 8 – 10 July 2007. This storm produced significant wave heights of 11.8 meters at the deep-water directional wave gage at the Ipan site. This poster will present the wave data collected over the reef platform and the deep water waves from Typhoon Man-Yi.

A STUDY OF OCEAN WAVES AT FISHERMAN'S WHARF, VICTORIA HARBOUR

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A sequence of very strong wind events on the south coast of British Columbia in December 2006 resulted in some wave damage to the Fisherman's Wharf facility in Victoria Harbour. A hindcast wave modeling study was carried out using the SWAN model to provide quantitative wave information for input to consideration of a breakwater or wave attenuation system built adjacent to the Victoria Harbour facility. The wave study addressed the regional wave conditions in eastern Juan de Fuca Strait to provide open boundary input to a high resolution (10 m horizontal grid) of Victoria Harbour. The high resolution wave model provided computed wind wave generation, current-wave interaction, refraction, diffraction as well as attenuation due to the Fisherman's Wharf floating docks. The model was calibrated and verified for two periods of large wave events measured in March 1976 with wave data available from two temporary Fisheries and Oceans Canada wave stations operated simultaneously in Victoria Harbour. The results from these two cases showed good agreement with independent observations at the innermost wave station located to the west of Fisherman's Wharf. Two cases of very large wave events, which occurred in March 1977 and December 2006, were then simulated using the model. In the first case, observations, with a maximum H_s of 0.9 m, were available near the Harbour entrance. At Fisherman's Wharf, the H_s wave heights were always less than 0.40 m on its seaward edge. For the second case of December 12 – 15, 2006 very large wind speeds peaking over 40 knots in Victoria Harbour generated very large waves. The wave model predicted maximum H_s wave heights of 0.46 m early on December 15 at the seaward edge of Fisherman's Wharf.

SPECTRAL WAVE MODELING OF SWELL TRANSFORMATIONS IN INDIGENOUS MARSHALLESE NAVIGATION

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Indigenous navigators in the Republic of the Marshall Islands developed an elaborate system of guiding their canoes among low lying coral atolls by sensing through sight and feel how the atolls transform swell and currents. One of the few surviving elders with navigational knowledge recently called for a concerted effort to revive indigenous navigation and voyaging. He envisioned that a wave model of the salient swell conditions would complement his indigenous concepts, as well as help to preserve the knowledge and serve as a pedagogical tool for a future navigation school. His initiative developed into a collaborative project among University of Hawaii-Manoa anthropologists and oceanographers, additional Marshallese elders and *Waan Aelon in Majel* (Canoes of the Marshall Islands), a community organization devoted to the revival of canoe building and sailing. The oceanographic component of the project involved gathering wave displacement data from buoy deployments at various locations around and between several atolls, analyzing satellite imagery and simulating swell transformations. In the poster, we examine the indigenous Marshallese concepts of the ocean through a spectral wave model of swell transformations salient for navigation. The wave model articulates strongly with an indigenous concept involving refraction and diffraction in the atoll's wave shadow. Several other indigenous concepts, however, cannot currently be explained.

DEPLOYMENT OF AN RDCP600 TO MEASURE DIRECTIONAL WAVE SPECTRA IN OPEN AND MARGINAL ICE ZONES

Oceana Francis-Chythlook and David Atkinson

Our study examines swell propagation through marginal ice zones. To study this observational, a bottom-mounted Aanderaa RDCP600 has been deployed for one year which will allow for observations during open water and ice cover-up. The instrument was deployed on July 2007 on the Chukchi Sea shelf at a 20 meter depth to measure wave height and direction, along with other wave parameters. The relatively shallow depth of the instrument allows for an acoustic based wave measurement which is needed to measure wave direction. The acoustic based waves are sampled at a 2 Hz rate for 15 minutes every 2 hours. This sampling rate is designed to target longer wave periods. There are currently no known directional wave datasets in the Arctic that have had yearlong deployments. The RDCP wave data will be incorporated into a regional wave model which will contain a new sea ice component. This paper reviews the instrument, its deployment, and its anticipated employment to support the wave modeling.

WIND WAVES NUMERICAL SIMULATION: HURRICANE DEAN CASE STUDY.

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The wind waves associated to Hurricane Dean (august 2007) are examined using the atmospheric model MM5 and SWAN wave model. The system (MM5-SWAN) has been implemented as operational wave forecasting at the Mexican Institute for Water Technology. Results are compared against measurements at buoy No. 42056 (NDBC-NOAA) placed at the Caribbean Sea. Comparisons presented in this study will provide an assessment of the wave forecast system during hurricane conditions.

US ARMY CORPS OF ENGINEERS WAVE AND CURRENT DATA COLLECTION ACTIVITIES IN THE HAWAIIAN ISLANDS: 2005-2007

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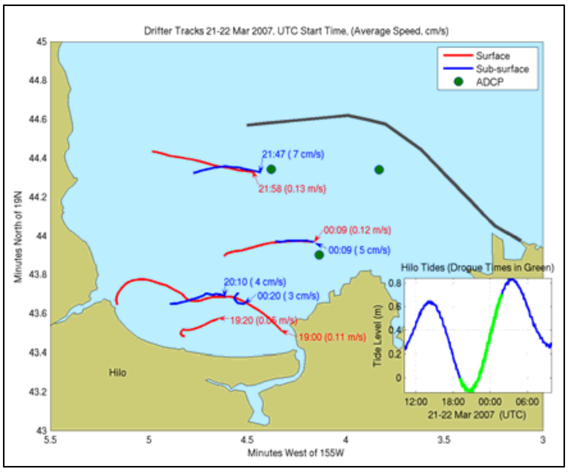
Coastal processes in and around the Hawaiian Islands involve many varied and interrelated features such as complex reef bathymetry, wave transformation over reefs, island wave sheltering, and a highly variable and seasonally dependent wave climate. In order to further understand these processes and incorporate this knowledge into practical coastal engineering applications such as coastal structure design, sediment management and water quality studies, the US Army Corps of Engineer's Honolulu District and Engineering Research and Development Center, with support from the University of Hawaii, have undertaken several wave and current data collection efforts in recent years.

This poster will present an overview of three data collection efforts in the Hawaiian Islands, including collection methods, results, and applications to project planning and design. Wave gages, current profilers, and current drogues have been deployed at various locations in Southeast Oahu as part of USACE's Regional Sediment Management Program (2005), in Hilo Bay as part of the County of Hawaii's Hilo Bay Water Quality Study (2007), and in Waikiki as part of the City and County of Honolulu's Natatorium War Memorial Study (2007).

Deployment of sub-surface current drogue at Hilo Bay



Plot of Current Drogue Track in Hilo Bay

Frame-mounted Acoustic Doppler Current Profiler for Southeast Oahu Data Collection

Natatorium War Memorial at Waikiki (Diamond Head in Background)

THREE AND FOUR WAVE EXACT RESONANCE INTERACTIONS IN THE FLAT BOTTOM BOUSSINESQ EQUATIONS

M. ONORATO, A. OSBORNE, D. RESIO, P. JANSSEN

We study the nonlinear transfer of energy in the quadratic Boussinesq equations in flat bottom conditions. By writing the equations in wave action variables we first show that exact three wave resonant interactions are possible when two wave numbers are very close to each other. The result is the generation of a long free wave. Using then the method of the multiple scales, we derive a shallow water version of the Zakharov equation. For broad spectra, a four wave standard kinetic equation is derived, allowing for exact four wave resonant interactions. For such equation, using dimensional arguments, a power law solution corresponding to a constant flux of energy is found. We confirm such results by direct numerical simulations of the Boussinesq equations. Low frequency components of experimental data taken from Currituck Sound (NC) confirm our theoretical and numerical results. The relation between the Boussinesq kinetic equation and the Hasselmann equation in arbitrary depth is discussed.

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MODELING NONLINEAR RANDOM WAVE PROPAGATION OVER COHESIVE SEDIMENTS

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The damping of wave energy by cohesive bottom sediments has been long observed. However, the effect of mud-induced dampening on the details of wave-wave interaction is still unclear. Measurements of random waves propagating over mud showed unexpected damping of short wave frequencies (Sheremet and Stone 2003), which was later ascribed to subharmonic interactions exacerbated by low frequency damping due to mud (Sheremet et al. 2005).

Recently, Kaihatu et al. (2007) developed a model for propagating nonlinear waves over viscous mud, using the thin-layer viscous fluid dissipation mechanism of Ng (2000). Kaihatu et al. (2007) limited themselves to permanent form waves over a flat bottom in order to look closely at the detail of wave dissipation and the effect on the nonlinear interactions. In this study, we expand on this to look at the effect of mud on the evolution of random wave spectra. We intend to look at some synthetic cases of random wave propagation, including surf zone propagation, and investigate the characteristics of wave nonlinearity of the result using third moments and bispectra. Preliminary results indicate that wave skewness, for example, tends to be affected more by the presence of mud than wave asymmetry. We will also compare the model to wave attenuation data taken over the Atchafalaya Shelf in Louisiana.

COUPLED WAVE AND SEDIMENT DYNAMICS ON ATCHAFALAYA SHELF, LOUISIANA, US

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Water and cohesive sediment dynamics are monitored in the first 1 meter above the bottom, as part of an ONR-funded study of the characteristics of lutocline and fluid mud formation and their effects on wave propagation in muddy coastal environments. The experiment site selected for this study is the muddy inner shelf (less than 20 m water depth) fronting Atchafalaya Bay, Louisiana. The observation system is composed of two tripod-based instrument clusters including fiber-optic spectrometer (FOS), acoustic backscatter sensor (ABS), upward-looking ADCP, pressure and optical backscatterance sensors (OBS), and downward-looking PC-ADP. The tripods have been deployed at various locations on the topset and foreset region of the muddy subaqueous delta of the Atchafalaya River, to examine cross- and/or along-shelf wave evolution and sediment state variability under a variety of hydrodynamic forcing conditions. Deployment timing and instrument data collection is focused upon examining the primary wave events that impact this section of the coast--winter cold fronts and tropical cyclones.

BOTTOM FRICTION IN NEARSHORE WAVE MODELS

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Bottom friction has been used in nearshore wave models to represent a number of processes, including wave damping by vegetation, coral reefs, and mud. Bottom friction has also been used as a calibration knob without consideration of bottom type and realistic ranges of coefficients. Two friction formulations have been implemented into the nearshore spectral wave model STWAVE (Smith et al. 2001, Smith and Sherlock 2007): JONSWAP and Mannings n. This paper will provide evaluations of the STWAVE dissipation using several data sets and show example results evaluating coastal restoration alternatives in southern Louisiana.

References:

Smith, J. M., Sherlock, A. R., and Resio, D. T. 2001. "STWAVE: Steady-State Spectral Wave Model, User's Guide for STWAVE Version 3.0," ERDC/CHL SR-01-01, U.S. Army Engineer Research and Development Center, Vicksburg, MS, 80 pp.

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WAVE TRANSFORMATION MODELING WITH BOTTOM FRICTION APPLIED TO SOUTHEAST OAHU REEFS

Mary A. Cialone and Jane M. Smith

The purpose of the modeling study for the Southeast Oahu Regional Sediment Management demonstration project was for the Engineer Research and Development Center, Coastal and Hydraulics Laboratory to provide the Honolulu District with a tool for understanding wave transformation and nearshore circulation in the study area (Mokapu Point to Makapuu Point). The significant reef system in the region was a particular challenge for modeling wave transformation, therefore the Corps' widely-used wave model, STWAVE, was enhanced to include the effect of bottom friction. Development of a bottom friction capability in stwave was completed and first applied to the extensive reefs in the Southeast Oahu study area. Application of this model capability to a specific site requires validation to field data. Field (wave) data was collected both seaward and landward of the Southeast Oahu reef for comparison to model results.

A single friction value can be applied to the entire stwave domain or a range of friction values can be applied on a cell-by-cell basis. In the initial application, 134 wave conditions first simulated without bottom friction were repeated with the revised STWAVE, applying a bottom friction coefficient typical for reefs of 0.05 over the entire model domain. A comparison of wave heights at one nearshore location was made. With the inclusion of bottom friction, wave height at the nearshore location ranges from 53 to 85% of the previous results that did not include bottom friction. On average, the wave height was 71% of the without bottom friction value at the selected location. Waves from the northeast refract slightly (1 deg) less with the inclusion of bottom friction. Waves from the east-southeast refract slightly (1 deg) more with the inclusion of bottom friction. Additional model applications with variable bottom friction were made for the field data collection time period and model results were compared to field data.

“Hindcasting of waves and wave loads on Dutch Wadden Sea defenses”

Abstract Wave-workshop

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The SBW-Wadden Sea (Strength and Loads on Sea Defenses in the Dutch Tidal Inlet “Wadden” Sea) project which is commissioned by the Dept. of Public Works has the objective to improve the SWAN wave model so that consistent and reliable HBC (Hydraulic Boundary Conditions) for the sea dikes around the Wadden Sea can be computed, and thus the state of sea defenses can be assessed.

The starting point of the project is the observation that there is uncertainty concerning the quality of the present HBCs in the Wadden Sea. This is because there was insufficient confidence in the SWAN wave model (initially mainly regarding the swell penetration) to produce reliable boundary conditions in the Wadden Sea. The lack of confidence is due to the fact that the Wadden Sea is a very complex area where many physical processes occur and where strong spatial variations in the model inputs (bathymetry, wind, currents) exist.

In the project extensive hindcasts of the Amelander Zeegat (in the Dutch part of the Wadden Sea) and Norderneyer Seegat (in the German part) for a variety of storms were performed and compared to field data, which were acquired with a unique and large array of directional wave buoys in the last few years.

The studies show that the SWAN model performs relatively well, but with degrading performance further into the Wadden Sea. The model also shows some swell penetration over the tidal flats, but not in the channels where the buoys were located. This points to a lack of sufficient data, a problem which has been remedied by adjusting and extending the Amelander Zeegat measurement gauge program. The results and measurements also show that, while the ebb tidal delta (due to depth-limited breaking) is a phenomenal wave energy dissipator, the relatively (to the offshore conditions) small amount of energy that does penetrate may be large relative to the processes inside the domain, where local wave growth, wave-current interactions and depth-limited breaking also take place.

SWAN shows important shortcomings compared to buoy measurements due to the wave model inputs of bathymetry, offshore wave boundary conditions (under extreme conditions), tidal currents, and local wind forcing. These effects are all illustrated and addressed in the paper, with possible remedies and directions for future research. The successful validation of SWAN with the field data in such a complex area will add further confidence to the use of the model elsewhere where less wave data may be available.

A concurrently-submitted paper will address the numerical effects of SWAN modelling in the same area (Van Vledder et al.)

Sea surface elevation maps obtained with a nautical X-Band radar – Examples from WaMoS II stations

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The Wave Monitoring System WaMoS II was developed for real time measurements of directional ocean wave spectra. It has been used in recent years to monitor the sea state from fixed moored platforms, coastal areas andmoving vessels.

WaMoS II uses the 'sea clutter' information which contains the backscatter of the microwaves of the sea surface. By analysing the radar backscatter the directional wave spectra from the sea surface are obtained in real time. From there all spectral sea state parameters such as significant wave height, peak period, and peak direction both for wind sea and swell are derived.

In addition to the spectral wave parameters, WaMoS II can derive series of 2 d-sea surface elevation maps. The WaMoS II surface map sequences allow to investigate the properties of individual waves in time and space. The used inversion algorithm allows to determine amplitude and phase of each partial wave of the wave spectrum. This algorithm, which is under development for the last 5 years was applied to a number of different data sets. Several parameters can be derives from the sea surface elevation maps that give a better understanding of the individual wave structure. For example studies on the observed maximal wave heights can be carried out for different wave scenarios. Interesting aspects are the temporal evolution of the ratio between occurring maximal and significant wave heights during a developing storm.
Initially the development of the algorithms was started with special emphasis on 'extreme waves'. The need to better understand the nature and the probability of occurrence of such events led to a range of ongoing R&D studies. Mostly those applications are of interest for ship applications with the aim to predict the ship movements over varying temporal scales. Most of the development work is initially tested for fixed stations. In November 2006 an interesting wave event caused some damage on a platform in the Southern North Sea. WaMoS II radar raw data from this platform will be presented, giving an impression of those area covering measurements that allow for looking at the evolution of waves in space and time.

OPERATIONAL IMPLEMENTATION OF A MULTI-GRID WAVE FORECASTING SYSTEM

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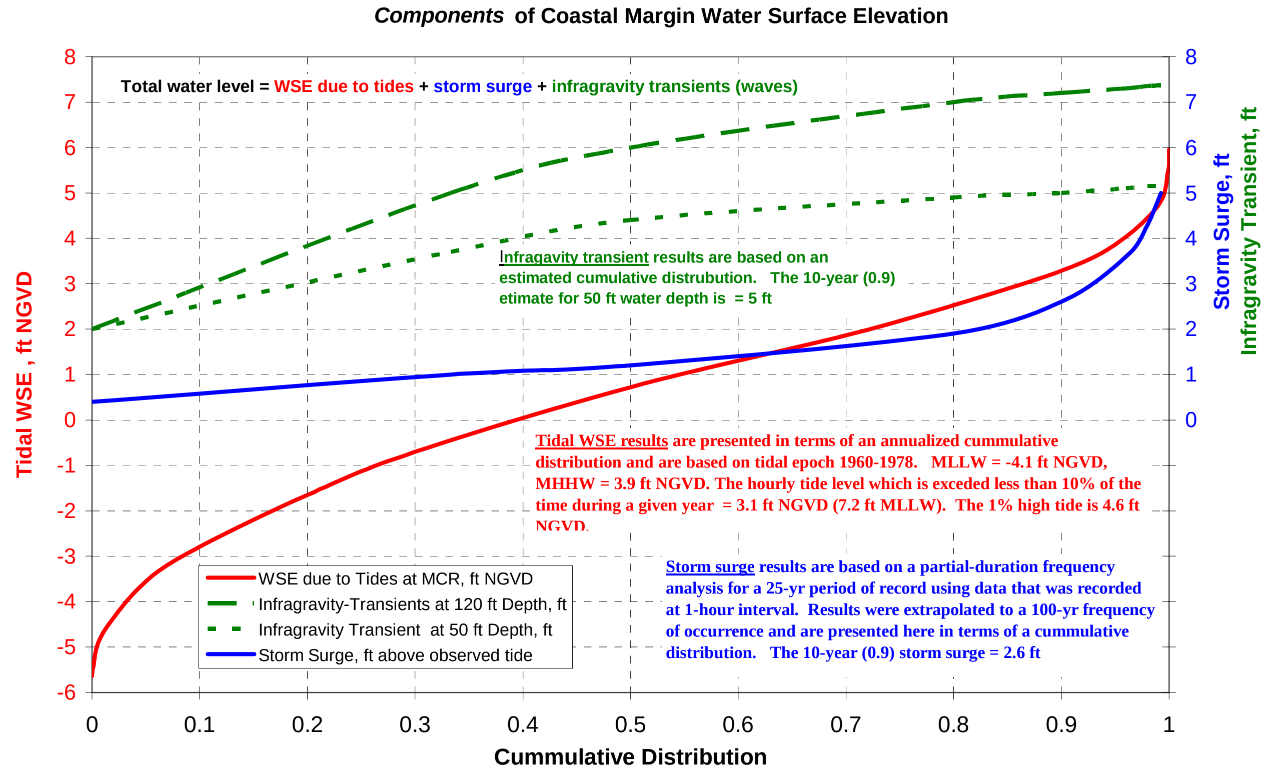
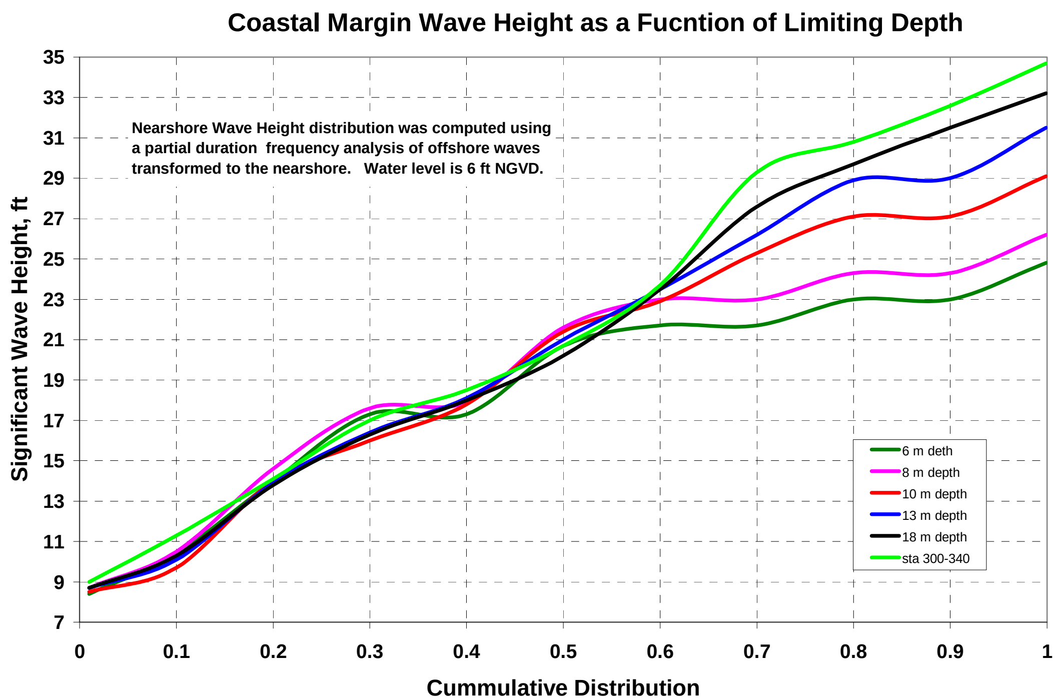
A new operational multi-grid wave forecasting system is presently being implemented at the National Center for Environmental Prediction using the third release of WAVEWATCH III. This model replaces three of the six wave models that currently make up the NOAA WAVEWATCH III operational model suite – the regional Alaskan Waters (AKW) model, the regional Western North Atlantic (WNA) model and the regional Eastern North Pacific (ENP) model. The system was developed to take advantage of new features in the third release of WAVEWATCH III, in particular the two-way nesting between grids of different resolution and carving out selected areas of the computational domain. These features allow us to increase the spatial model resolution without adding to the computational cost. The system consists of eight grids at different resolutions that have been developed to provide Weather Forecast Offices (WFOs) of the National Weather Service (NWS) and the different centers of NCEP with gridded model guidance of suitable resolution for all areas where they have the responsibility to provide gridded forcast products. The eight different grids are : a global (30 minute) grid, four regional (10 minute) grids for the Eastern Pacific, Alaska, US West Coast and US East Coast, and 3 coastal (4 minute) grids for the US East Coast, US West Coast (including the islands of Hawaii) and Alaska. As in the previous models the forecasts are provided four times a day at 0000, 0600, 1200 and 1800 hours. Each cycle starts with a 9 hour hindcast and extends out to 180 hours (as opposed to the previous 6 hours hindcast and extension out to 126 hours). Products include both point and field outputs. Field output data is stored in GRIB2 format which packs data more efficiently than the earlier GRIB1 format. Apart from the standard mean wave parameters, the field output also includes the parameters of the partitioned wave spectra. Partitioning can be carried out to an arbitrary number of components but is currently limited to three: wind-wave component, primary and secondary swells.

COMPONENTS OF STORM-INDUCED WATER LEVEL ALONG THE COASTAL MARGIN AND RELATED EFFECTS ON THE NEARSHORE WAVE ENVIRONMENT

Hans R. Moritz and Heidi P. Moritz

Many aspects of maritime and coastal margin activity demand reliable description of the nearshore wave environment, which is contingent upon the accurate representation of wave transformation phenomena along the coastal margin. The degree to which storm waves impact a coastal margin is prescribed by the regional/local wave climate, nearshore bathymetry, and water level. In conditions where waves are depth limited, water level plays a significant role in controlling the depth limited wave height. A higher water level will allow larger depth-limited waves to affect a given shallow water location. This means that the total water depth (d) may have a pronounced affect on the design wave climate affecting a given nearshore location or coastal structure. For given water depth (d), the height of a depth-limited wave can generally range between 0.4d to 1.2d. Total water depth (d) is defined by: the reference water depth (bathymetry) + tide elevation + storm surge + other transient effects (Δη). The reference water depth (bathymetry), tide elevation, and storm surge are parameters normally prescribed (or estimated) to define total water depth (d), when assessing coastal engineering design elements, assessing coastal hazards, or analyzing shoreline evolution. Rarely are "other transient -Δη" effects considered when defining a total water depth (d). But what if the "other transient effects, Δη" are equivalent to the tidal excursion or storm surge, and Δη was not considered when calculating total water level? This paper will investigate the occurrence of nearshore water level transients due to storm wave activity and the related consequences of not including "transient effects" when estimating important coastal engineering design parameters such as: depth limited wave height, shore face run-up/swash excursion, overtopping on coastal structures, wave force loading, and sediment transport/scour. Figure 1-2 illustrates the components of water level along the Pacific Northwest Coastal margin and the effect of total water depth upon wave height along a coastal
inlet.





TOP Figure (1). Components of water level along the costal margin. A transient water level along the shore's edge can be raised by 1-2 m within a time-span of 30 seconds and persist for a period of 1 to 4 minutes. BOTTOM Figure (2). Computed wave height along a coastal inlet based on variation in areal position and depth contour. A transient change in water level of 2 meters would have considerable effect on the above the nearshore wave environment.

OCCURRENCE OF COINCIDING HIGH SURF AND TIDES ALONG THE NORTH SHORE OF OAHU, HAWAII

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The wash of waves upon terrestrial coastal zones along the north shore of Oahu has an annual cycle with the maximum during the boreal winter high surf season. An understanding of the variability of the wave wash is important for coastal planning, safety, transportation, and property protection. The landward extent of the wash increases with increasing surf size and tidal height. This study analyses historic wave data, predicted tides, and sea level records to determine how often and for what duration in hours do high surf and tides coincide categorized by thresholds of surf and tidal height. The Hawaii Department of Transportation has logged reports of days when wave wash debris was cleared from the coastal highway and the National Weather Service Storm Data publications note incidents of coastal property damage by waves. This information is studied to help define the thresholds for significant wave wash episodes.

SPECTRAL DISSIPATION TERM FOR WAVE FORECAST MODELS, EXPERIMENTAL STUDY

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A field experimental study of wave energy dissipation is presented. The experiment was conducted at Lake George, Australia and allowed simultaneous measurements of the source functions in a broad range of conditions, including extreme wind-wave circumstances. Results revealed new physical mechanisms in the processes of spectral dissipation of wave energy, which are presently not accounted for in wave forecast models. The spectral dissipation was measured for the first time. Frequency distributions both for the wave breaking probability and breaking severity were obtained. The breaking of waves at a particular frequency was demonstrated to cause energy damping in a broad spectral band above that frequency, and thus causes a cumulative dissipative effect for waves of smaller scales. At the small scales (high frequencies), this cumulative dissipation appears to dominate compared to direct wave-breaking dissipation. It was found that at moderate winds the dissipation is fully determined by the wave spectrum whereas at strong winds it is also a function of the wind speed. This result indicates that at extreme wind-forcing conditions a significant part of the extra energy flux is dissipated locally rather than being available for enhancing the wave growth. The new spectral dissipation function also accommodates the threshold wave-breaking behaviour discovered earlier. The dissipation term is parameterised and the new parameterisation is presented in a form suitable for spectral wave models.

IMPLEMENTATION OF NEW EXPERIMENTAL INPUT/DISSIPATION TERMS FOR MODELLING SPECTRAL EVOLUTION OF WIND WAVES

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Numerical simulations of the wind-wave spectrum are conducted on the basis of new wind input and wave dissipation functions obtained in the Lake George field experiment. The experiment allowed simultaneous measurements of the source functions in a broad range of conditions, including extreme wind-wave circumstances.
Results revealed new physical mechanisms in the processes of spectral input/dissipation of wave energy, which are presently not accounted for in wave forecast models. These results were parameterised as source terms in a form suitable for spectral wave models. The simulations were conducted by means of the two-dimensional research WAVETIME model (Gerbrant van Vledder) with an exact solution for the nonlinear term. Physical constraints were imposed on the source functions in terms of the known experimental dependences for the total wind-wave momentum flux. Enforcing the constraints in the course of wave spectrum evolution allowed fine tuning of experimental parameters of the new input and dissipation functions. The resulting time-limited evolution of integral, spectral and directional wave properties, based on implementation of the new physically-justified source/sink terms and constraints, is then analysed. Good agreement of the simulated evolution with known experimental dependences is demonstrated.

THE PERFORMANCE OF THE WAM4.5 BASED ON A REVISED FORMULATION OF THE WHITECAPPING DISSIPATION AND ON LIMITING THE DRAG COEFFICIENT IN HURRICANE TYPE WIND FORCING

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Operational weather prediction models have often shown weaknesses in their ability to simulate the development and track of tropical storms to the level of detail necessary for accurate wind estimates in the vicinity of such storms. To improve the surface wind field in the shorter term winds from the MSC GEM weather prediction model are blended with the CHC parametric hurricane wind model called SLOSH. The unblended and blended winds are used to force the WAM4.5 in a one-way coupled model system. Studies have indicated that the drag coefficient is unsaturated in hurricane type wind forcing and this leads to unrealistic wave height prediction in the areas of maximum winds in the vicinity of the hurricane centre. A revised formulation of the whitecapping dissipation source term as implemented at ECMWF is used in this study to give a more realistic interaction between windsea and swell. Results from wave simulations of hurricanes Wilma, Juan and possible hurricanes from the 2007 hurricane season will be presented based on unblended and unblended winds, with and without drag coefficient capping and with and without revised formulation of the whitecapping dissipation.

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ON DISSIPATION DUE TO WAVE BREAKING

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The question about the function dissipation S_{diss} modeling loss of wave energy due to wave breaking is one of the most important in Physical Oceanography. Anyone who wants to develop a reliable model of wave dissipation needs realistic model of S_{diss}. Meanwhile, little is known about S_{diss} so far. No artificial theory of wave breaking is created and experimental data on S_{diss} are scarce. The most advanced experiments of Banner, Babanin and Young show that the wave-breaking is a threshold-type phenomenon, governed in the first approximation by the single parameter: average wave steepness μ. In this talk we report the results of our numerical experiments on modeling of S_{diss} in the "Computational wave tank". We solved exact Euler equations for incompressible deep fluid with free surface using combination of conformal mapping to the lower half-plane and the spectral code. The equations were equipped with artificial hyper viscosity arresting the wave-breaking on some acceptable level. We created an initial data in the form of propagating standing waves and followed their evolution during long period of time of 10^5 initial periods. By measuring of the energy loss rate, we are able to find S_{diss}. Our preliminary results are the following:

1. S_{diss} depends dramatically on μ. If $\mu \approx 0.06$, S_{diss} is negligibly small. If $\mu \approx 0.12$, wave breaking is the dominating effect and S_{diss} is large. Dissipation due to wave breaking is the threshold effect.

2. S_{diss} depends essentially on wave number. The long waves suppress more short waves.

3. Model of S_{diss} used in operational models WAM3 and WAVEWATCH are too crude. For moderate steepness $0.06 \le \mu \le 0.08$ they overestimate dissipation in the area of spectral peak at least by the order of magnitude.

METHODOLOGY AND RESULTS FOR NEARSHORE WAVE SIMULATION IN A COUPLED HYDRODYNAMIC AND WAVE MODEL SYSTEM TO EVALUATE STORM SURGE IN COASTAL LOUISIANA

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To update and improve coastal storm surge estimate in coastal Louisiana, a modeling study was conducted that included wind modeling, Gulf of Mexico- and regional-scale wave modeling, surge modeling, and nearshore wave modeling (including one-way and, for nearshore waves and surge, two-way interactions). The modeling effort required relatively high resolution nearshore wave modeling with STWAVE (Smith et al. 2001, Smith and Sherlock 2007) to define the coastal features and accurately resolve the nearshore wave setup. The spatial extent of the grids captured the inundation limits of the simulated storms and allowed grid manipulation to evaluate coastal restoration and management alternatives. The variability and intensity of the storm forcing required a robust system to develop the offshore waves as input to the STWAVE grids and to couple the nearshore waves and the hydrodynamic model (ADCIRC). Nesting into regional offshore wave models (WAM), multiple STWAVE grids with 200-m resolution simulated nearshore waves. At each of 93 time-steps, STWAVE simulated the nearshore waves with input from WAM (offshore waves) and ADCIRC (wind and surge). Interpolation of the gradients of radiation stress from STWAVE onto the ADCIRC mesh allowed development of the spatial and temporal variation of wave setup within each STWAVE grid. The study domain (predominance of low-lying coastal marshes), the intensity of hurricane forcing, and model execution on several multi-node super computers led to several advancements in the STWAVE model. These advancements include a new bottom-friction algorithm, variable surge and wind input capability, efficient model codes suitable for parallel computing application, and several pre- and post-processing applications. After a brief discussion on the coupled hydrodynamic and wave modeling system, this paper will provide details on the STWAVE advancements developed during the study. Presentation of STWAVE results will demonstrate the effects of various storm parameters on the resultant waves and water levels (wave setup).

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Smith, J. M., Sherlock, A. R., and Resio, D. T. 2001. "STWAVE: Steady-State Spectral Wave Model, User's Guide for STWAVE Version 3.0," ERDC/CHL SR-01-01, U.S. Army Engineer Research and Development Center, Vicksburg, MS, 80 pp.

Smith, J. M., and Sherlock, A. R. 2007. "Full-Plane STWAVE with Bottom Friction: II. Model Overview," ERDC TN-SWWRP, U.S. Army Engineer Research and Development Center, Vicksburg, MS, 13 pp.

REALTIME WAVE AND SURGE MODELING WITH HIGH RESOLUTION ATMOSPHERIC MODEL COUPLING

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Historically, wave and surge forecasts have either been based on synoptic scale wind fields in realtime, or high-resolution wind fields in the hindcast mode. Recent verification of high resolution wind fields from the Weather Research and Forecast (WRF) Model have shown superior skill over the synoptic model forecasts in Florida (Bogenschutz 2004). The science now exists to couple these improved forecasts directly to our coastal ocean and wave forecast models in realtime; the remaining problems are primarily in the realm of the computer science and architechture.

UNF AWIS Lab will port and configuration the USACE code for STWAVE to the IBM P5 processor and multi-processor configuration of the UNF High Performance Computing Cluster (HPCC) which is running the high resolution Weather Research and Forecast Model. The WRF model provides a highly variable wind field to drive the coastal and estuarine waters rather than the more smoothly variant synoptic fields. Computation of the wave field and surface height will be on a on a finite element grid of data points, output at hourly time intervals with inland resolution to near 25 meters for Northeast Florida. Single and two-way coupling of the wave field will be attempted and compared (see Funakoshi and Hagen 2006).

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EVALUATION OF WAVE MODEL PERFORMANCE IN A NORTH CAROLINA TEST BED

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Rick Leuttich
University of North Carolina/Institute of Marine Sciences

An instrumented model test bed, set up in coastal North Carolina, is employed to evaluate the performance of a regional SWAN application. The test bed includes an extensive ground-truth data archive, populated by wind and wave observing assets operated by the US Army Corps of Engineers Field Research Facility (USACE FRF), Coastal Ocean Research and Monitoring Program (CORMP), National Ocean Service, SouthEast U.S. Atlantic Coastal Ocean Observing System (SEACOOS) and the National Data Buoy Center. The observations are compared to model predictions using the new Automated Model Evaluation System (AutoMEDS). This system performs both temporal correlation and quantile-quantile regressions to compute error statistics and evaluate model performance at the wind-sea and swell component level. The techniques are applied to assess the performance of an operational SWAN hindcast that has been in operation at USACE FRF since January 2007. The results are used to identify hindcast strengths and weaknesses and guide future developments.

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MORPHOS: ADVANCING COASTAL PROCESS RESEARCH AND MODELING

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Don Resio, USACE Coastal and Hydraulics Laboratory
Rob Wallace, USACE Coastal and Hydraulics Laboratory

Environmental risks along U.S. coasts have risen remarkably over past decades, and in particular the 2004-2005 hurricane events have exposed significant deficiencies in our ability to access coastal risk. Reliable, physics-based models for predicting winds, waves, currents, water levels, and the coastal response during extreme storms has emerged as a critical need that must be met in order to fulfill important Corps' mission needs. The Modeling of Relevant Physics of Systems for Estimating Risk (MORPHOS-ER) project is the path the Corps is taking to achieve these goals within the System Wide Water Resources Program (SWWRP). MORHPOS focuses on modeling nearshore coastal response during hurricanes and other large storms. Equal emphasis is given to the development of accurate, physics-based models of storm characteristics, winds, waves, currents, water levels within storms, inundation and beach response. MORPHOS will provide a systems approach for solving general problems related to coastal risk. This work has a multi-agency significance with on-going partnerships currently established with NOAA, Office of Naval Research, U.S. Geological Survey and FEMA.

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MODELING HURRICANE IMPACTS ON BEACHES, DUNES AND BARRIER ISLANDS

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The devastating effects of hurricanes on low-lying sandy coasts, especially during the 2004 and 2005 seasons have pointed at an urgent need to be able to assess the vulnerability of coastal areas and (re-)design coastal protection for future events, but also to evaluate the performance of existing coastal protection projects compared to 'do-nothing' scenarios. In order to address such questions the Morphos-3D project was initiated. This project brings together models, modelers and data on hurricane winds, storm surges, wave generation and nearshore processes (wave breaking, surf and swash zone processes, dune erosion, overwashing and breaching). For modeling the nearshore processes a new public domain model, 'XBeach', was developed and will continue to be validated and improved. The XBeach model can be used as stand-alone model for small-scale (project-scale) coastal applications, but will also be used within the Morphos model system, where it will be driven by boundary conditions provided by the wind, wave and surge models and its main output to be transferred back will be the time-varying bathymetry and possibly discharges over breached barrier island sections. The model solves coupled 2DH equations for wave propagation, flow, sediment transport and bottom changes, for varying (spectral) wave and flow boundary conditions. It resolves the wave-group and infragravity time scales, which are responsible for most of the swash and overwash motions, which thus can be modeled explicitly. The model has already been validated against extensive large-scale flume data sets including short and long wave distributions, return flow, orbital velocities, concentrations and profile change during dune erosion events. An essential part is an avalanching mechanism which allows a surprisingly accurate description of the evolution of the upper profile and dune face. Next steps that will be reported at the workshop include field validation for hurricane impacts ranging from dune scarping to full breaching.

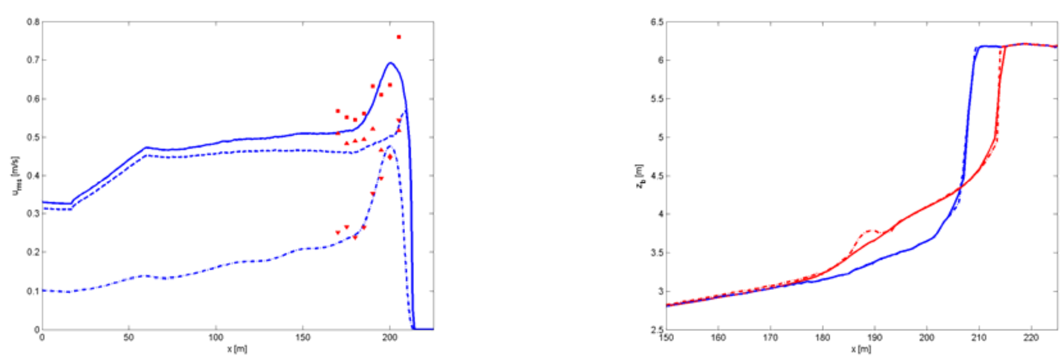

Figure 1. Left: measured and computed LF, HF and total rms orbital velocities ; Right: Initial (blue), measured (red dashed) and computed (red drawn) profile evolution for large-scale dune erosion test.

Investigating scales of nearshore morphology modeling

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The present tools for predicting shoreline and beach-face change rely on assumptions that simplify the problem and render a tractable computational exercise for an otherwise unimaginably complex problem. This limitation makes the present models applicable in simple cases but relies heavily on site-specific empirical parameters and can predict result in gross error for conditions beyond the calibration range such as severe storm events. Recent improvements in understanding of sediment transport may provide improvements to the morphology models, but the vast separation in modeled time and length scales has not been bridged. The present effort uses a new large-scale data set of beach profile change and dune retreat with over-wash as a context for investigating the effectiveness of modeling technologies at differing scales. For instance, a system using process-based high-fidelity results as part of a morphology modeling framework will be compared with the existing empirical technologies in terms of computational effort and skill in predicting the laboratory data.

Preference is for a paper presentation.

THE MSC BEAUFORT SEA WIND AND WAVE REANALYSIS

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Following the highly successful AES40 and MSC50 long-term wind and wave climatologies, the MSC Beaufort project applied many of the same hindcast analysis techniques to the Canadian Beaufort Sea to produce a 20+ year climatology spanning the period 1985-2005. Intensive reanalysis of the winds in the strong storm population which drives the extreme wave conditions was performed, along with statistical corrections applied to the NCEP/NRA winds using measurements to better hindcast the operational "day-to-day" wind climate. Weekly dynamic updates of ice edge information for wave modeling were based on high-resolution Canadian Ice Center data. Application of OWI 3rd generation wave model was made on a 28km grid covering much of the open waters of the Arctic and nested to ~5 km grid within the Canadian Beaufort. Extensive validation using a series of MEDS wave measurements in water depths from 11 to 87m water depth was performed. An online wind and wave atlas for the Beaufort Sea is also in production.

A HIGH-RESOLUTION HINDCAST STUDY FOR THE NORTH SEA, THE NORWEGIAN SEA AND THE BARENTS SEA

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The Norwegian Meteorological Institute has recently embarked on the construction of a new high-resolution hindcast archive to dynamically scale down the ECMWF ERA40 archive for the atmosphere and the wave field. The archive will begin to resolve the polar low activity found in the Norwegian Sea and the Barents Sea, known to be important for the wind and wave statistics in the arctic region.

The atmosphere is modelled using a regional model, HIRLAM10, with a lateral resolution of 10km and 40 vertical levels. The domain includes the North Sea, parts of the North Atlantic, the Norwegian Sea, the Greenland Sea and the Barents Sea. Initial values and boundary values are taken from ERA40 data. HIRLAM10 fields are relaxed towards ERA40 fields in the boundary zone the. A digital filter is applied to maintain some of the large scale features of the ERA40 fields. Sea surface temperature and sea ice data are updated at least weekly.

The wave model WAM is applied for the same area and with the same horizontal resolution as HIRLAM10. The 10km WAM model is nested in a 50km model covering most of the North Atlantic. Input to the WAM model is 10m wind from HIRLAM10 for the nested (10km) model and from ERA40 for the coarse (50km) model, and sea ice data. A new nesting scheme is applied, allowing the nested model to have a resolution and grid orientation that is independent of the outer grid.

The outcome of the project will be a three-hourly set of atmospheric data, e.g., wind, air pressure, air temperature, humidity and precipitation as well as wave parameters for all grid points. Two-dimensional wave spectra are stored for selected grid points. The new hindcast archive will cover the ERA40 period, September 1957 – August 2002. The project will be completed early 2009.

In this paper preliminary results will be shown. Model results will be evaluated using observations of atmospheric parameters and the wave field.

CHARACTERISTICS OF WIND WAVE PERIODS, LENGHTS AND STTEPNESS FROM VOS DATA OVER THE GLOBAL WORLD OCEAN AND IN THE OFFSHORE REGIONS.

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In this work we extend the analysis of Voluntary Observing Ship (VOS) visual data about wind waves to the estimation of periods, and, thus, geometry of wind waves. Analysis of periods, especially in the context of climate variability is much more difficult compared to the analysis of wind wave heights, because visual estimates of wind wave periods are much more uncertain and more rare than height estimates. Quantitative estimation of wind wave periods requires specific corrections and a precise quality control. We used in our analysis visual wave observations from the ICOADS archive of marine meteorological variables, covering the period form 1885 to 2006. Information about directional characteristics of wind waves and wind wave periods was used in the first step for the period 1970-2006, for which the observational practices and code systems are well documented. Global climatology of directional characteristics of wind wave periods, wave lengths and steepness has been developed afterwards with a higher resolution in the off-sore regions compared to open ocean regions. The longest average wind waves of more than 100 m are identified in the northeastern Pacific, although the largest wave age, accounting for both wave periods and wind component in the wave direction, has been found in the North Atlantic. Joint analysis of the wind period characteristics and wind height estimates in form of 2-dimensional distributions allowed to quantitatively estimate interannual to interdecadal changes in the wind wave steepness. In both North Atlantic and North Pacific wind seal steepness experienced upward changes during the last several decades, ranging from 3 to 8% per decade. Taking into account generally growing wind sea height, this implies a disproportional change of wind sea heights and periods. To take into account this phenomenon in the estimation of extreme wind seas, we performed the analysis of wave extremes accounting for the steepness characteristics as well. Statistics of the steepest extreme waves provide a basis for identification of the most dangerous extreme waves which may not necessarily be associated with the highest waves, but with the steepest ones. For this purpose a new set of extreme wave indices, based on the characteristics of steepness was introduced and quantitative estimates were derived for the open ocean regions and off-shore regions. Pilot estimates of wave-age-based and wave-steepness-based wind stress also available from a new generation processing of VOS data will be presented.

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DYNAMICAL VERSUS STATISTICAL DOWNSCALING APPROACHES FOR PROJECTING OCEAN WAVE HEIGHTS

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This study compares statistical projections of ocean wave heights (seasonal means and extremes) with the corresponding dynamical projections obtained from running a state-of-the-art wave model (ODGP-3G). Both the statistical and dynamical projections are based on the same projections of the atmosphere (sea level pressure and surface wind fields) as simulated by the Canadian coupled climate model CGCM2 with the IPCC IS92a forcing scenario for three 20-year periods (1975-94, 2040-59, 2080-99).

WIND, WAVE AND STORM SURGE HINDCASTS AND SCENARIOS AND RELATED COASTAL AND OFFSHORE APPLICATIONS: THE COASTDAT DATA SET AT THE GKSS INSTITUTE FOR COASTAL RESEARCH

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The coastDat data set is a compilation of coastal analyses and scenarios for the future from various sources. It contains no direct measurements but results from numerical models that have been driven either by observed data in order to achieve the best possible representation of observed past conditions or by climate change scenarios for the near future. Contrary to direct measurements which are often rare and incomplete, coastDat offers a unique combination of consistent atmospheric, oceanic, sea state and other parameters at high spatial and temporal detail, even for places and variables for which no measurements have been made. In addition, coastal scenarios for the near-future are available which complement the numerical analyses of past conditions.

The backbones of coastDat are regional wind, wave and storm surge hindcast and scenarios mainly for the North Sea and the Baltic Sea. We will discuss the methodology to derive these data, their quality and limitations in comparison with observations. Long-term changes in the wind, wave and storm surge climate will be discussed and potential future changes will be assessed. We will conclude with a number of coastal and offshore applications of coastDat demonstrating some of the potentials of the data set in hazard assessment. Examples will comprise applications of coastDat in ship design, oil risk modelling and assessment, and the construction and operation of offshore wind farms.

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The Back Effect of Breaking Waves on Adverse Currents.

The effect of currents on surface waves is described by wave action conservation, with a modification to allow for wave dissipation. The back effect of the waves on the total mean flow can be expressed in terms of radiation stress divergence, but part of this force just drives the changing Stokes drift of the waves. Subtracting this, the back effect of the waves on the underlying mean flow can be described in terms of the wave vortex force, surface sources and sinks allowing for volume flux exchange between waves and mean flow, and a term describing the way in which damped waves transfer momentum to the mean flow. An explicit form for this extra term is derived on the assumption that wave steepness is constrained not to exceed a critical value. Application to the case of waves breaking on an adverse current is described, with the prediction of secondary circulations in the underlying flow.

On experimental justification of weakly turbulent nature of growing wind seas

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A comprehensive set of more than 20 dependencies of wave height variance (mean energy) and wave frequencies on fetch, obtained over almost 50 years of field observations, is analyzed. Quantitative conformance with asymptotic weakly turbulent law of wind wave growth is demonstrated for approximately half of these dependencies. This asymptotic law is based on hypothesis of leading role of nonlinear transfer as compared with wave input and dissipation. Hence, the experimental results can be considered as a justification of this hypothesis.

The proposed wave growth law links total wave energy to total net wave input. For conventional power-law approximations of wind wave growth it gives a family of possible dependencies and relationships between corresponding exponents and pre-exponents. Available wind-wave data are analyzed thoroughly to fix possible physical ground of deviations of the resulting dependencies from these theoretical relationships.

THE HIGH-FREQUENCY RANGE OF WIND WAVE SPECTRA AND IMPLICATIONS FOR WAVE BREAKING

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Detailed analyses of wind wave spectra have shown that the high-frequency region of these spectra consistently deviates from an equilibrium-range form $(k^{-5/2})$ to a k^{-3} form. The location of the "break-point" from the characteristic equilibrium range form to the alternative form appears consistent with kinematic constraints imposed by the horizontal component of the orbital velocity within the wave field. In this context, the flux of energy into the high frequencies is balanced by irregular wave breaking, which predominately occurs near the crests of the largest individual waves within the wave field. This leads to a very different source term balance within the spectrum than posed by the assumption that significant wave breaking is widely distributed throughout the spectrum. Radiation stresses, critical in the generation of coastal storm surges, can be markedly affected (increased) by this change in the frequency location (phase speeds) of the breaking waves.

COUPLING ALONGSHORE VARIATIONS IN WAVE ENERGY TO BEACH MORPHOLOGIC CHANGE USING THE SWAN WAVE MODEL AT OCEAN BEACH, SAN FRANCISCO, CA

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The San Francisco Bight in central California is a challenging location to accurately predict waves based on deep water measurements due to complex offshore bathymetry, high energy wave conditions, and tidal flows associated with the San Francisco Bay estuary. Nearshore wave predictions are further complicated by a north-south trending coastline and prevailing northwest incident wave angles that refract over the massive ebb tidal delta (~ 150 km2) at the mouth of San Francisco Bay before reaching Ocean Beach. More than 50 three-dimensional beach surveys have been conducted from 2004 through 2007 to quantify the morphologic beach response both seasonally and to individual large swell events. The field measurements and wave modeling indicate that the shape of the ebb tidal delta exerts a first order control on the location of persistent onshore erosion. The southern portion of the beach contains a persistent erosional section that threatens valuable public infrastructure and recreational beach use. As part of the U.S. Geological Survey San Francisco Bight Coastal Processes Study, instruments were deployed in summer 2005 and winter 2006 at several locations in the nearshore region and on the outer ebb tidal delta to help characterize alongshore gradients in wave conditions and wave transformation across the delta for variable offshore forcing conditions. These measurements were used to calibrate and validate a SWAN model for the region, forced by buoy measurements in deep water. Model results generally underestimate wave energy, but show strong gradients in wave energy along the shoreline that are highly dependent on incident wave angle. This is likely due to the variable focusing, dissipation, and refraction as waves from different angles transform over the ebb tidal delta.

HURRICANE WAVE AND SURGE COMPUTATIONS: DIFICIENCIES & RESEARCH NEEDS

Joannes Westerink & Jane McKee Smith

ABSTRACT NOT AVAILABLE

Modelling wind-waves and currents under tropical cyclone forcing: benchmarking of WAVEWATCH III and MECO models for selected storms in NW Australia and in the Gulf of Mexico

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The WAVEWATCH III and MECO models are the basis of numerical hindcasts of wind-waves and currents generated under tropical cyclone forcing for several met-ocean and engineering design applications at MetOcean Engineers, including environmental monitoring, seismic surveillance, exploratory drilling and preliminary/final design of offshore and coastal structures. Taking advantage of the wealth of tropical storm data publicly available for severe Gulf of Mexico hurricanes, and of the extensive database of measurements conducted by MetOcean Engineers in the NW Australian region during severe tropical cyclones, the performance of alternative hindcasts generated using WAVEWATCH III and MECO are critically assessed. Wave and current hindcasts are generated with two alternative methodologies for Gulf of Mexico hurricanes, using both wind and pressure fields specified by HRD/NOAA surface wind analyses and by the MetOcean Engineers method, which is based on a parametric representation of winds estimated using NHC/NOAA best-track data. Field data collected during NW Australian tropical cyclones are used to investigate the sensitivity of wave and current hindcasts to uncertainties in the parametric wind model parameters, and also to assess the impact to model performance of changing available WAVEWATCH III physics packages, for wind forcing and wave dissipation. The effects of blending tropical cyclone wind fields with environmental flows, and a preliminary evaluation of the impacts of wave-current model coupling are also explored.

NORTH ATLANTIC WIND WAVES OF 2005 HURRICANE SEASON – PREDICTION VS. OBSERVATION –

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Unprecedented numbers of tropical storms and hurricanes occurred in the North Atlantic and the Gulf of Mexico in 2005. There was a record of 27 named tropical storms, of which 15 were hurricanes with one of them to be the most intense hurricane on record for the Atlantic (Hurricane Katrina). Many of these storms/hurricanes have created enormous high waves disastrous to the coastal areas. In this study, we analyze relevant wind fields and wave patterns and validate model predicted wave conditions against available NDBC buoy measurements. Model predictions are obtained from two operational regional wave models – WNA (the Western North Atlantic wave model) and NAH (the North Atlantic Hurricane wave model). The WNA model is driven solely with wind forecasts from NCEP/GFS (the Global Forecast System for atmosphere) available at 3-h intervals. Wind fields used to drive the NAH wave model, on the other hand, are obtained by blending GFS wind fields with high-resolution wind fields generated hourly by the GFDL (Geophysical Fluid Dynamics Laboratory) hurricane model. We first identify measured waves with a storm or storms that caused the wave height to raise higher than 2 m in time series so that waves generated by other than the tropical storms (e.g. the middle latitude storms) are excluded. The procedure involves measured and predicted time series of wind speed, wind direction, significant wave height, and spectral peak period. Spectral component waves and moving sequences of the significant wave steepness derived from the model are also used in the procedure of identification. We then construct the frequency distribution and correlation of difference (errors) between predicted and measured peak wave heights and the time of occurrence. The preliminary result shows that the error in the wave height is less than 20% and the time lag is within 5 hour for both models. The cluster of wave height error for the Atlantic Basin is more concentrated than that of the semi-closed Gulf Basin while the contrary is true for the time lag. The NAH and WNA models, in general, provide comparable predictions. However, near the occurrence of maximum wave height, NAH yields better agreement with observation than WNA.

TO BLEND OR NOT TO BLEND: IN THE PURSUIT OF FINDING AN OPERATIONAL WAY TO GIVE HURRICANE CHARACTERISTICS TO THE CMC FORECAST WIND FIELD

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As presented at the last workshop, an operational blending process between the Regional GEM forecast surface field and parametric hurricane wind and pressure fields is in continuous development. The blending is done through a system called SWIM (Surface Wind Interpolator and Modifier). SWIM is connected through a coupled system to a wave or a surge model which receives the modified wind and pressure fields when the hurricane blending process is activated.

In cases when the atmospheric model already simulates a significant surface vortex as its representation of the hurricane, two questions arise: how to blend, and to what extent. In this paper an environmental weight based on the surface geostrophic vorticity is applied to take into consideration the current representation of the hurricane by the atmospheric model. The methodology leads to an automated decision maker on the degree of blending, which may result in no blending being applied, as demonstrated in Hurricane Wilma. The use of the surface geostrophic vorticity as a predictor of the extent of the blending zone is also presented.

Some results of past cases, and of the forthcoming 2007 hurricane season, will be presented at this Workshop.

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COMPARING HINDCASTS WITH WAVE MEASUREMENTS FROM HURRICANES LILI, IVAN, KATRINA AND RITA

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Oceanweather wave hindcasts were compared to measurements in Hurricanes Lili, Ivan, Katrina and Rita. Data from the National Data Buoy Center, the Naval Research Laboratory, and oil industry platforms was available for the work. The bias between simultaneous hindcast and measured significant wave heights was -0.11 m for wave heights greater than 6 m. The scatter index was 0.15. These statistics show that the overall quality of the hindcasts in these extreme storms is at least as good as in other high quality hindcasts. The peak wave heights of 15.96 m in Ivan and 16.91 m in Katrina at Buoy 42040 were however underestimated by the hindcasts. There appears to be no real reason to doubt these measurements. An even higher significant wave height of 17.9 m was reported from the NRL pressure measurements. We believe that this value was inflated by amplification of high frequency noise from the pressure transducer, and a better estimate of the true maximum is 15.5 m. Estimates of the maximum probable wave height in a storm give an integrated measure of the strength of the storm and eliminate sampling variability from the measurements. The agreement between the estimated maxima from the hindcasts and measurements is about the same as the agreement between the time series. The industry measurements include continuous records at high sample rates. Zero downcrossing wave and crest heights from those measurements agree well with the short term distributions commonly used in offshore design studies.

FORECAST ERROR ANALYSIS DURING HURRICANE KATRINA USING THE NOPP REAL-TIME PREDICTION SYSTEM FOR TROPICAL CYCLONES

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The long-term goal of the NOPP project is to provide accurate estimates of winds and waves using an operational forecasting system. The largest errors in forecasting of tropical cyclone parameters still emanate from uncertainties in the track and intensity forecast. Since the NOPP system utilizes the official track and intensity forecast from the National Hurricane Center (NHC), we examine the magnitude of the track error and subsequent impact on the wind and wave fields as well as storm surge along the coastline. To establish baseline parameters of uncertainty we will use the official, analyzed, post-storm track and intensities for Hurricane Katrina (2005) from the NHC. This hindcast run of winds, waves and surge will be used to establish the accuracy of the NOPP system. The forecast runs from the NOPP system during Hurricane Katrina will be used to estimate track errors as a function of the Katrina life cycle. This set of runs will also be examined to derive what portion of the wind, wave and surge uncertainties at buoy and coastal stations are caused by the track error.

We will also assess the track error uncertainties with the mean parameters from the ensemble runs of alternate forecast tracks.

INTER-COMPARISON OF OPERATIONAL WAVE FORECASTING SYSTEMS

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A routine inter-comparison of wave model forecast verification data was first established in 1995 to provide a mechanism for benchmarking and assuring the quality of wave forecast model products that contribute to applications, such as safety of life at sea, ship routing, and, in general, the Global Maritime Distress and Safety System GMDSS.

This original inter-comparison was developed around the exchange of model forecast data at an agreed list of moored buoy sites at which instrumented observations of significant wave height, wave period and wind speed are available over the WMO GTS. The exchange has expanded from its original five centres to its current twelve. All centres actively contribute data on a routine basis.

The JCOMM Expert Team on Wind Waves and Storm Surges, during its first meeting (ETWS-I, Halifax, Canada, June 2003) noted the value of the exchange, and endorsed the further expansion of the scheme to include other wave forecast systems. At the ETWS-II meeting (Geneva, March 2007), it was agreed that this activity should continue. It was also recognised that it should also be made more visible.

The earlier results were first presented ten years ago during WAVES97. It is now opportune to review what has been achieved so far. Improvements in wave forecasting are clearly visible. At the same time, from the slow, yet steady increase in available wave observations, the inter-comparison has extended to more locations. Finally, it is hoped that the current results will motivate participants to discuss possible new avenues for extending this inter-comparison. It is hoped that this activity will motivate further improvements in the quality level of operational wave forecasts with clear benefit to the safety at sea.

DEVELOPMENT OF SPATIAL INTERCOMPARISON WITHIN THE OPERATIONAL WAVE FORECAST VERIFICATION EXCHANGE

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The routine intercomparison of wave model forecast verification data that has been underway since 1995 has been developed around the exchange of model forecast data at an agreed list of moored buoy sites at which instrumented observations of significant wave height, wave period and wind speed are available. This exchange of data has proven invaluable, with a large number of centres now participating.

In considering the future development of the exchange the JCOMM Expert Team on Wind Waves and Storm Surges identified potential benefits in extending the exchange to include intercomparison of spatial fields from the model forecasts.

Techniques have been developed within the sea surface temperature (SST) community that allow the spatial intercomparison of model products alongside satellite observations, and collocated in situ observations. A sophisticated system of this nature has been developed within the GODAE High Resolution SST Pilot Project, based upon the concept of the High Resolution Diagnostic Data Set (HR-DDS).

The HR-DDS consists of a collection of small areas over which model, satellite and in situ data are presented together to allow straightforward comparison of spatial data over these selected areas. The data used in the HR-DDS can be delivered from multiple sources, are collated at a single centre, and are subsequently accessible via a map-based web interface. The HR-DDS approach is a complementary method to the validation statistics that potentially adds to the understanding of the differences in performance between forecast systems.

This paper will present an initial demonstration of the application of the HR-DDS system to wave model forecast verification, and will describe the potential for extension of the system to provide additional functionality and hence further insight into the performance of the operational wave forecast systems.

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USING ALTIMETER DATA TO VALIDATE & DEVELOP WAVE MODELS

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ABSTRACT NOT AVAILABLE

VALIDATION AND APPLICATION OF JASON-1 AND ENVISAT SIGNIFICANT WAVE HEIGHTS

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In this work, significant wave height (SWH) data from altimeters onboard Jason-1 and Envisat is validated against in-situ buoy data from the NDBC and MEDS buoy networks. Data covers a period of 3 years for Envisat and over 4 years for Jason-1. Co-location criteria of 50 km and 30 minutes yield 3452 and 2157 co-location for Jason-1 and Envisat respectively.

Jason-1 is found to be in no need of correction, performing well throughout the range of wave heights, though is notably noisier than Envisat. An overall rms difference between Jason-1 and buoy data of 0.229 m is found. Envisat is overestimating low SWH and underestimating high. A linear correction reduces the rms by 8%, from 0.219 m to 0.202 m. A systematic difference in the SWH being reported by MEDS and NDBC buoy networks is noted. Using the altimeter data as a common reference, it is estimated that MEDS buoys are underestimating SWH relative to NDBC buoys by about 10%.

These corrected altimeter data are then used to perform a global assessment of AUSWAM, a version of the WAM model run operationally at the Australian Bureau of Meteorology.

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UPDATES TO WAM CY 4.5 +

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From the final release of WAM Cycle 4 (Komen et al. 1994), there have been numerous changes and upgrades. These modifications have been made not only in terms of the architecture (Standard FORTRAN 95), a modular and dynamic allocation paradigm. It also significantly reduces the I/O burden of boundary interpolation, and incorporates auxiliary routines into one source code. The application of WAM Cycle 4.5.+ can also be extended for shallow-water simulations with the inclusion of depth induced breaking mechanisms. New dissipation source term specification suggested by Bidlot, et al. (2007) has significantly improved the reliability of operational wave predictions at ECMWF. Single and multi-processor versions are now available and actively used at weather prediction centers reducing the computational load on forecasting capabilities. Lastly the breakthrough work in the air-sea exchange between waves and winds, along data assimilation of the extensive satellite based altimetry estimates have brought significant gains in the operability of WAM.

This paper will describe these updates and through examples demonstrating the versatility and improved waves estimates based on the documented improvements of WAM Cycle 4.5+ .

CONSENSUS FORECASTS OF INTEGRATED WAVE PARAMETERS

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The Operational Consensus Forecast (OCF) scheme uses past performance to bias-correct and combine numerical forecasts to produce an improved forecast at locations where recent observations are available. This technique was applied to 24-hour forecasts of Significant Wave Height from a limited set of models in the Australian region in Woodcock and Greenslade (2007). The results showed that a "composite of composites", in which wave models with highly correlated errors are combined before being included in a performance weighted bias-corrected forecast can outperform the best bias-corrected individual model. In the present work, this study will be extended to include models from other forecasting centres (e.g. ECMWF, Meteo-France, FNMOC). In addition, other forecast parameters such as peak period, other forecast periods and an expanded set of observation locations will be considered

Woodcock, F. and D. J. M. Greenslade: 2007. Consensus of Numerical Model Forecasts of Significant Wave Heights, *Wea. and Forecasting*, in press.

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HINDCASTING WINDS, WAVES & STORM SURGE FOR HURRICANE KATRINA

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ABSTRACT NOT AVAILABLE

HINDCASTING WINDS, WAVES, AND STORM SURGE FOR HURRICANE RITA

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Hurricane Rita was one of three major hurricanes in the Gulf of Mexico during the 2005 season. Hurricane Rita tracked across the Gulf from the southeast to the northwest and made landfall near Sabine Pass and the border between the states of Louisiana and Texas. A modeling system has been developed that simulates hurricane winds, wind-waves, storm surge, tides and river flow in this complex region. This is accomplished by defining a domain and computational resolution appropriate for the relevant processes, specifying realistic boundary conditions, and implementing accurate, robust, and highly parallel unstructured grid algorithms for the long wave current/storm surge/tide model and nested structured grid algorithms for the wind-wave models. A basin to channel scale implementation of the ADCIRC continuous Galerkin unstructured grid hydrodynamic model has been developed to compute the long wave circulation in the region. The associated grid resolves features down to 30 meters and contains 2.17 million nodes and has a solution computed at every second during the simulation.

Modeled results show that the overland flooding in southwestern Louisiana was extensive, that the hurricane winds created significant water velocities in the Gulf of Mexico before the hurricane made landfall, and that a significant amount of surge was created near New Orleans, far from where Hurricane Rita made landfall. There was 7 to 9 ft of surge on the east bank of New Orleans and Lake Pontchartrain despite the fact that Hurricane Rita made landfall over 250 miles away. In southwestern Louisiana, the maximum surge elevation was about 15 feet at the coastline south of Calcasieu Lake. However, significant storm flood elevations occurred in other parts of the region, including the Lake Charles area north of Calcasieu Lake, the north edge of Vermilion Bay, and even along the highway levees to the southeast of New Orleans. In contrast, the maximum velocities occurred in localized regions within defined channels, such as Sabine Pass, the Calcasieu Shipping Channel, and even the exchanges between Lake Pontchartrain and Lake Borgne.

A detailed validation analysis is also presented. Two sources of measured data were used; one was a set of high-water marks obtained from FEMA and the URS Corporation, and one was a set of hydrographs published by the USGS. ADCIRC does an excellent job of matching the high-water marks and hydrographs, with the exception of regions where the model does not contain a sufficient level of geographic and grid resolution. The validation analysis suggests that a higher level of resolution is needed in various regions to better define flooding conduits and the associated topographic and raised features.

REPRESENTATION OF VEGETATION ON THE WIND BOUNDARY LAYER AND SURFACE BOTTOM FRICTION

John Atkinson

The coupled application of the Adcirc and Stwave computer models has recently received significant attention for accurately forecasting the extent of hurricane storm surge inundation. It is desired to apply the coupled models to predict storm surge over vast reaches of coastline for which fine spatial details of Manning-n roughness values and wind roughness coefficients need to be obtained for very large regions of the coastal plain. In an effort to increase accuracy and improve efficiency, new techniques have been pioneered to compute the relevant parameters from geo-referenced land-use maps. The land-use data sets identify spatial variations in degree and kind of vegetated and developed regions. The strategy for extracting the required data and filtering the information to the appropriate computational grid scale are described. Simulations of tides and hurricane hindcasts are presented to demonstrate the impact of the improved roughness coefficients on the computed response.

HIGH PERFORMANCE COMPUTING TO RESOLVE PROPAGATION AND ADVECTION-DOMINATED MULTI-SCALE MULTI-PROCESS PHYSICS

Authors:
Clint Dawson, Ethan Kubatko and Joannes Westerink

One of the challenges in coastal hazards modeling is capturing inland propagation and advection-dominated flow at multiple scales. Algorithms are required which allow for the capture of sub-grid features, are adaptive in space and time, and stable across a wide-range of flow scales. Our group has been investigating high resolution discontinuous Galerkin methods for modeling such processes. These types of algorithms have several interesting features: one can build physics into the models through so-called numerical fluxes, they are locally and globally mass conserving, and they allow for the use of adaptivity in both mesh and polynomial order. They are also quite local computationally and thus lend themselves to implementation on massively parallel architectures. In this talk, we will briefly discuss the discontinuous Galerkin formulation, and give several numerical results for both model problems and field applications. We will also discuss the parallel scaling of the method and demonstrate that it can actually outperform traditional finite element methods on large-scale parallel computers.

THE INFLUENCE OF BARRIER ISLANDS AND LOWER PLAQUEMINES PARISH MISSISSIPPI RIVER LEVEES ON WAVES AND STORM SURGE IN SOUTHERN LOUISIANA

Wiebe de Jong & Hugh Roberts

ABSTRACT NOT AVAILABLE

COMPARISON OF EMPIRICAL METHODS AND A BOUSSINESQ-TYPE WAVE MODEL FOR PREDICTING OVERTOPPING OF COASTAL STRUCTURES

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Empirical overtopping equations, based on numerous experimental datasets, are the standard method for estimating overtopping rates during engineering design. These methods are restricted to the experimental parameter space on which they are founded, and extensions to "real" foreshore profiles can be cumbersome. During recent levee design studies along the Gulf of Mexico coast, a detailed-hydrodynamic modeling component was introduced to understand and quantify the uncertainties of using empirical methods for irregular reaches. Using a Boussinesq-type wave model, which is a phase-resolving hydrodynamic model including dispersive, nonlinear, and turbulence effects, it was found that empirical methods are still very useful, but great care must be taken during application to non-idealized reach profiles. Specifically, the effect on the overtopping rate due to nearshore wave evolution, such as wave decay and interaction with shallow bottom features, and due to specific wave properties, such as nonlinearity, skewness, and asymmetry, will be discussed.

LOUISIANA CHENIER PLAIN REGIONAL HYDRODYNAMIC, SALINITY AND HYDROLOGIC NUMERICAL MODELS

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The Louisiana Chenier Plain encompasses the coastal zone and marshes from Freshwater Bayou west of Vermilion Bay to Sabine Lake near the Texas-Louisiana border. Over the years, man-made changes to the regional circulation patterns have caused documented land loss, increased salinities, marsh deterioration, impacts on seasonal inundation patterns and drainage potentials, and greater vulnerability to storm surges. Alterations include the construction of several large and deep artificial ship channels, numerous dredged access canals to enhance navigation, the Gulf Intracoastal Waterway, and Louisiana Highways 82 and 27 impacting the natural hydrology of the marsh. A coupled one-and two-dimensional hydrodynamic and salinity transport model was developed for the Chenier Plain along the southwestern Louisiana coast to gain an understanding of the regional hydrology and circulation patterns. The model consists of a dynamically-linked system of channels, open water areas and marshes covering an area greater than 4,200 square miles. The natural and man-made system of inland waterways and structures, including 128 channels spanning across 870 miles, are represented through the one-dimensional model MIKE11. The channels and bayous are connected to a 500m x 500m MIKE21 grid representing the marshes, lakes and near-shore Gulf of Mexico using MIKE FLOOD. The numerical model has been calibrated and validated using water-level and salinity data and through velocity field measurements. It is noteworthy that the model incorporates real-time hydraulic structure operations. Statistical analyses demonstrate the model's applicability in studying the effect of altered hydrology and changes to the circulation patterns within the system on a daily or monthly time scale. The validated model will be used as a tool to evaluate proposed restoration and hurricane protection strategies. In addition, a watershed hydrology MIKE SHE model was developed for the area extending from the Gulf Intracoastal Waterway northward to Leesville, LA encompassing an area of roughly 6,500 square miles. This physically-based model consists of over 1,500 miles of streams linked to a 500m x 500m grid representing the land topography and storage areas. This model was calibrated against existing stage and discharge data and subsequently used to examine the system response to 50% of the 100-year probable maximum precipitation. The hydrologic model will be used to design drainage facilities for a variety of proposed Category 5 protection levee alignments. Additionally, the model will be used to study the drainage impact for upstream areas during the 100-year flood event as a consequence of each proposed levee alignment. Given overtopping rates and the rainfall accumulations for a Category 5 hurricane scenario, the model will also be used to predict stage, overland flow, and river discharge resulting from the proposed comprehensive levee protection system.

NUMERICAL SURGE MODELING OF COASTAL RESTORATION FEATURES

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Topography, landscape features, and vegetation have the potential to reduce storm surge elevations. Land elevations greater than the storm surge elevation provide a physical barrier to the surge. Landscape features (e.g., ridges and barrier islands) and vegetation (e.g., maritime forests and wetlands) below the surge elevation have the potential to create friction and slow the forward speed of the storm surge. The purpose of this paper is to discuss how coastal landscape features are presently represented in the ADCIRC model, identify areas of improvement, and assess the potential of coastal features for reducing storm surge for hurricanes with varying intensity. The friction formulations in the model that impact surge and sensitivity of the model to various parameters used to represent landscape features will be discussed. Methods for modifying the grid and model inputs to represent alternative landscape configurations will be introduced. Surge results for base conditions and alternative future degraded and restored coastal landscapes will be presented and analyzed. Recommendations on where in the landscape restoration activities may be most beneficial will be presented. The impact of coastal landscape features on surge propagation is a relatively new application for surge models an area of active research that suffers from a lack of quality data. A field data collection effort undertaken to acquire much needed data will be introduced.

PROBABILISTIC DESIGN METHOD FOR LEVEE AND FLOODWALL DESIGN

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The current FEMA and USACE guideline says that *"the levee height at the coast should be equal to the 1% water level plus the 1% wave height or the maximum runup whichever is greater plus 1ft"*. The extra 1 ft of freeboard accounts for uncertainties in the various hydraulic variables. A disadvantage of this approach is that the uncertainty in the various variables is likely not be constant but is a function of the uncertainties in water level and wave characteristics at a specific location amongst others. This paper presents a simple probabilistic design method that explicitly takes into account the uncertainties in the design parameters. For this purpose, the uncertainty in the design parameters (runup, overtopping rate) are explicitly computed using Monte Carlo Simulations (MCS). Several applications of levee and flood wall designs in the New Orleans area will be presented to show the differences between the current guideline and the new approach. It appears that the new approach results in significantly higher or lower design levee heights depending on the errors in the water level and wave characteristics. The differences show that the new approach is a useful tool to take uncertainties explicitly into account.

IMPLICATIONS OF THE SPECTRAL SHAPE OF WAVE CONDITIONS FOR ENGINEERING DESIGN AND COASTAL HAZARD ASSESSMENT - EVIDENCE FROM THE ENGLISH CHANNEL

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Probabilistic coastal hazard assessments and design methodologies for coastal engineering structures, and in particular beaches, are based typically upon extreme storm event wave conditions of defined return period. Such conditions are usually estimated by extrapolation of long time-series of integrated parameter output produced from hindcast models or wave measurements (e.g. Hs, Tz, □). A coupled programme of nearshore wave measurement, wave hindcasting, and measurements of beach response to extreme storm events in the English Channel, has identified some beach responses that are not characterized well by the integrated parameters. Closer examination of the measured wave data has suggested that the unexpected beach responses appear to be related to the spectral characteristics of the storm events. Wave conditions characterized by a bi-modal distribution of wave period appear to produce more damaging conditions than is suggested by empirical models which are based only on integrated parameters. In some instances the spectral characteristics are further complicated by bi-directional conditions.

Output from various wave models (e.g. EMCWF, WAM and Metoffice 2nd generation model) also provides varying methods of definition of integrated parameters. Differences in characteristics have been noted, between measurements from a nearshore wave-buoy network and hindcast models, particularly for more extreme events. Significant variability of spectral characteristics has been observed, when comparing hindcast models with nearshore wave measurements.

Analysis of spectral records from the buoys off the south coast of England indicates that the wave climate is frequently bi-modal, with clearly defined swell and wind wave components. Under these circumstances use of the integrated parameter output produced by hindcast models may be misleading and full spectral output can be valuable. Although the integrated parameters are usually the only wave parameters used in conventional coastal engineering empirical design formulae, the spectral shape may be of some design significance, particularly when considering wave run-up, breaching and overtopping. Reliable methods of incorporation of spectral descriptions in design methods are also required therefore.

PERFORMANCE OF THE JPM AND EST METHODS IN STORM SURGE STUDIES

David Divoky[1], Donald T. Resio[2]

There are two major approaches to the determination of storm surge frequencies: the Joint Probability Method (JPM) and the Empirical Simulation Technique (EST). Both approaches have been used in surge studies by federal agencies including NOAA, the US Army Corps of Engineers, and the Federal Emergency Management Agency. The methods are fundamentally different: EST is an historical approach based on the actual storms observed within a region, while JPM is a synthetic approach based upon hypothetical storms constructed in accordance with the regional climatology.

Numerous arguments have been advanced regarding the relative strengths and weakness of these two approaches, and it is probable that EST should be preferred in some applications, while JPM might prove superior in others. The present work was undertaken to clarify these issues, focusing on the problem of surge from hurricanes. Hurricane surge within a region is noteworthy for both its sporadic nature and its relatively large spatial gradients, and so poses a difficult problem of local sample variation. The regional characteristics of surge from northeasters, on the other hand, are significantly different and so might pose a different set of challenges for the analyst.

The general scheme of the present study was, first, to postulate, *a priori*, a true description of the local hurricanes from nature's hidden point of view, and then to construct hypothetical records of successions of storms and their corresponding coastal responses (covering a range of record lengths commonly available in practice). This was done for conditions consistent with those observed along the northern Gulf of Mexico. Each synthetic record generated in this way was analyzed using both the JPM and EST approaches, and the inferred surge frequencies were compared with the true values derived from the *a priori* distributions. This procedure was repeated a large number of times in order to determine both mean performance and the inherent variability of the estimates. A number of simplifications and idealizations were made in order to allow very large numbers of simulations as well as the exploration of alternate *a priori* realities. For example, the synthetic storms representing nature were defined parametrically in a conventional way, annual occurrence rate was assumed to be Poisson, idealized straight shorelines were adopted, a simple functional proxy was used for surge (no hydrodynamic simulations were done), and so forth. Nature's *a priori* distributions were defined with varying degrees of correlation among the defining storm parameters, with characteristics chosen to adequately cover the range of realistic possibilities, and with appropriate geographic variability. EST evaluations were made using both its original entirely-historical approach, and the more recent variation involving hypothetical track translation. The JPM evaluation of each simulated record required preliminary estimation of nature's unknown parameter distributions, before proceeding to construction of the corresponding storm simulation set. A simple JPM approach requiring a large number of simulations was adopted, rather than a refined optimum-sampling approach. The study findings are presented in a series of summary tables, along with a discussion of conclusions and suggested guidance.

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HURRICANE SURGE CLASSIFICATION FOR THE GULF OF MEXICO COASTLINE

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Over the last quarter-century, hurricane surge has been assumed to be primarily function of maximum storm wind speed as might be estimated from the Saffir-Simpson Hurricane Scale. However, Hurricane Katrina demonstrated that wind speed alone cannot reliably describe surge. This presentation will show that storm size plays an important role in surge generation, particularly for very intense storms making landfall in mildly-sloping regions. Prior to Hurricane Katrina, the historical hurricane record evidenced no clear correlation between surge and storm size, and consequently little attention was given to the role of size in surge generation. In this study, the hydrodynamic model ADCIRC was employed simulate storm surge at the coastline for a series of idealized scenarios. The numerical results were used to classify surge at the coastline as a function of meteorological parameters, including storm size, and regional geographic conditions. The resulting classification compares well with observations. It was found during this study that, for a given intensity, surge varies by as much as thirty percent over a reasonable range of storm sizes. These findings clearly demonstrate that storm size must be considered when estimating surge, particularly when predicting socioeconomic and flood risk.

THE EVALUATION OF STORM SURGE HAZARD IN COASTAL MISSISSIPPI & LOUISIANA

A. Niedoroda[1], D. Resio[2] , D. Divoky[3], R. Lowe 4, L. Charles[4], H. Das[1], C. Reed[1]

The tremendous destruction along the central Gulf Coast of the United States caused by Hurricanes Katrina and Rita (2005) was the major impetus for development of improved methods to assess storm surge risk. Both the U.S. Army Corps of Engineers (Corps) and the Federal Emergency Management Agency (FEMA) assembled teams of experts to carry out this work. The two teams had overlapping memberships and worked in close coordination so that conceptually similar methods, independently implemented, were employed. The FEMA team focused on coastal Mississippi; the Corps team worked primarily on Louisiana, but also carried out a separate Mississippi project.

These storm surge projects incorporated the best available technology. The high-quality tropical storm data that has been available since the initiation of Hurricane-Hunter aircraft missions was emphasized. This data has steadily improved as data buoys, satellites and other instrument systems have been deployed. A combination of numerical models of all the important processes was employed including ADCIRC, WAM, PBL, STWAVE, SWAN and SLOSH. . In order to establish statistics of surge elevation, both teams adopted an optimum-sampling implementation of the Joint Probability Method (JPM-OS).

An important aspect of these projects was the use of many new methods either adapted from recent work in other disciplines (eg. the offshore industry) or newly developed during the course of the work. Extensive tests of these methods and proof-of-concept demonstrations were performed, establishing confidence in the validity of both the techniques and the findings.

In this paper, we present an overview of the methodologies developed by the Corps and FEMA teams. Each of the major components of the studies is described and points of similarity and differences of approach are highlighted. Most differences were of minor detail, but some involved fundamental methods with important impact on the computational structure of the analyses. Despite these differences, the findings were in excellent agreement, validating the common conceptual approach.

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TIME DEPENDENT WAVE SETUP DURING HURRICANES ON THE MISSISSIPPI COAST

D.N. Slinn, A.W. Niedoroda, R.G. Dean, H. Das, R. Weaver, C. Reed, J. Smith

In recent decades several large hurricanes have impacted the Mississippi coast, including Hurricanes Camille (1969), Betsy (1964), Georges (1998), and Katrina (2005). Storm surge models, such as ADCIRC, have considerable skill at hindcasting and forecasting the storm surge levels. In many hurricane simulations wave setup contributes on the order of a meter to the surge. surge level..

For an uncomplicated beach and nearshore profile, steady state conditions and where wave dissipation is controlled exclusively by depth limited breaking, wave set-up η_o, is proportional to the offshore wave breaker height H_o with η_o / H_o = 0.1 to 0.2. The actual value depends on the assumed breaker coefficient $\kappa = H_s / h$ where H_s is the significant wave height and h is the water depth. This ratio usually ranges between about 0.4 and 0.6 for different wave spectra and bottom slopes.

Waves in major hurricanes generally have maximum heights of 10-20 meters at the peak of the storm. Accordingly the expectation of wave setup along the Mississippi coast during large hurricanes on the order of 1.0 to 4.0 m. In coupled wave and surge simulations with numerical models, however, the contribution to the total storm surge has been closer to 0.5 m; approximately a factor of 4 lower than expected.

In this paper we present a probable explanation for this observation. There appear to be three independent contributing factors. First, wave transformation across the shelf is affected by steepness limited breaking in intermediate depth water. The significant wave heights decrease from amplitudes of approximately 20 meters to approximately 10 meters due to steepness-limited breaking. This happens before depth limited breaking begins to play an important role. The response of the setup caused by wave height decay in deeper water is much less than if the waves had broken nearer to shore in shallow water. Second, there are important time-dependent effects. Mississippi has a chain of barrier islands located approximately 15 kilometers offshore. The largest hurricane waves break in the surf zone outside the barrier islands and the setup they produce outside the islands pours water into the sound between the islands and the mainland. The rate of filling of water into the sound is not sufficiently rapid to produce near steady-state conditions over the entire zone of breaking waves. Therefore, the total wave setup does not reach the coast within the finite duration of the hurricane passage. The third significant factor in producing relatively low contributions to the total storm surge from the wave setup is that the value of κ = 0.4, that can be inferred from coastal wave simulations with the SWAN or STWAVE model, is at the low end of the typical range. In the steady-state theory the total setup depends on κ^2. In large storms the surf zone expands far offshore and the 'effective' bottom slope becomes less than 1/100. Such gentle bottom slopes are associated with small values of κ.

Hence, these three contributing factors, are sufficient within the modeling system to produce surprisingly low values for the wave setup in Mississippi. We present results of simulations and theory supporting these interpretations.

APPROACHES FOR THE EFFICIENT PROBABILISTIC CALCULATION OF SURGE HAZARD

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The Joint-Probability Method (JPM) for the evaluation of surge hazard combines the probabilistic characterization of the hurricane climatology in the region with a numerical model for surge generated by a hurricane, given its characteristics. Mathematically, the annual probability that the surge elevation η exceeds a certain value *h* may be written in the following form:

$$P[\eta_{\max(1\,yr)} > h] = \lambda \int_{\underline{x}} f_{\underline{X}}(\underline{x}) P[\eta > h \mid \underline{x}] d\underline{x}$$

where λ is the annual rate of storms, the random vector $\underline{X}$ represents storm characteristics (ΔP, Rmax, forward velocity, landfall location relative to the site, storm heading, etc.), $f_{\underline{X}}(\underline{x})$ represents the associated probability density function, and $P[\eta > h \mid \underline{x}]$ is the probability that a storm with characteristics $\underline{x}$ will generate an *H* greater than our value of interest *h.* Evaluation of $P[\eta > h \mid \underline{x}]$ involves one surge calculation $\eta(\underline{x})$, and often involves consideration of modeling error and of other factors not explicitly included in $\underline{X}$. This integral is evaluated for multiple values of h, generating a *hazard curve,* and then the curve is searched to identify the value of h associated with return periods of interest.

These calculations present practical problems because they involve evaluation of an integral over many dimensions (often 4 our more) and because each evaluation of $P[\eta > h \mid \underline{x}]$ involves expensive meteorological and hydrodynamical calculations to determine $\eta(\underline{x})$ for one artificial storm.

This paper discusses and compares a number of approaches for these calculations. One approach represents $P[\eta > h \mid \underline{x}]$ as a random function with certain correlation properties and uses this representation to approximate the integral above as a weighted sum over a discrete number of optimally selected "artificial storms" $\underline{x}_i$. Other approaches develop a deterministic or random-function approximation for $\eta(\underline{x})$, using results obtained for a carefully selected, limited number of artificial storms, and then use this approximation to evaluate the integral above.

IS THERE A DISCERNIBLE ANTHROPOGENIC IMPACT ON ATLANTIC HURRICANE ACTIVITY?

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There is currently evidence both for and against the existence of a discernible anthropogenic impact on Atlantic hurricane activity. Published evidence is reviewed, and new results relevant to this issue are presented. Emanuel's (pers. comm. 2007) Power Dissipation Index, including a correction for overestimated intensities in the 1950s and 60s, shows unprecedented high values in recent decades in the context of the past ~60 yr, and correlates remarkably well with low-frequency tropical Atlantic SST variations. Tropical Atlantic SSTs have increased over the past century, and we believe that anthropogenic forcing and internal climate variability have both likely made a discernible contribution to the strong warming since 1970. A limitation of Emanuel's index is that during the pre-satellite era (pre-1965), aircraft reconnaissance did not fully cover the basin, increasing uncertainty in PDI during that period. Also, the index does not extend back to the late 1800s and early 1900s, when Atlantic SSTs were apparently ~0.7C cooler than at present. Landsea (EOS, 2007) uses landfalling statistics to infer no significant increase in basin-wide tropical storm counts since 1900. His conclusion is based on trends computed between pairs of active or inactive epochs in the series. U.S. landfalling hurricane activity (frequency and PDI) show no increasing trend over the past century or so; hurricane counts have a slight negative trend since 1878. However, Landsea's critical assumption of a constant landfalling fraction over time limits confidence in this assessment. Holland and Webster (Phil. Trans. R. Soc. A 2007) examine relationships between numbers of all Atlantic named storms and hurricanes, minor hurricanes, and major hurricanes, and conclude that tropical cyclone and hurricane counts have increased dramatically during the past century, related to the rise in tropical Atlantic SSTs. While one might presume that hurricanes and major hurricanes are less likely to have been missed in pre-satellite years than tropical storms, their key assumption that the existing HURDAT data accurately portrays long-term basin-wide statistics for hurricanes and major hurricanes requires further substantiation. In addition, while raw (unadjusted) basin-wide hurricane counts show a significant rising trend beginning in years 1881, 1891, …, 1921, the trend is no longer significant if one begins in 1851, 1861, or 1871 (R. Smith, pers. comm. 2007). We use historical Atlantic ship track and storm track data to estimate the expected number of missing tropical storms each year in the pre-satellite era (1878-1965). After adjustment, the storm counts covary with tropical SSTs on multi-decadal time scales, but their long-term trend (1878-2006) is weaker than the trend in similarly normalized SSTs (though both are nominally positive). The linear trend in adjusted storm counts for 1900-2006 is strongly positive (+4.2 storms/century) and highly significant according to three tests which attempt to account for serial correlation. However, this trend begins near a local minimum in the time series and ends with the recent high activity, perhaps exaggerating the significance of the trend. The trend beginning from 1878 is weakly positive, and not statistically significant with p~0.3.

While we generally prefer using as long a series as possible to assess trends, the uncertainty in the late 1800s is larger than that during the 1900s—an important caveat on the results using the earlier start date. The results also suggest that the average duration of Atlantic tropical cyclones has decreased for reasons as yet unexplained. Tropical cyclone occurrence rates appear to have decreased in the western part of the basin (consistent with declining U.S. landfalling hurricane counts) but may have increased slightly in the central and eastern basin, suggesting a structural change such as shifts in storm tracks. Important assumptions of our methodology, such as that all landfalling storms since 1878 which were not seen by ships were detected and reported upon landfall, will require further investigation. We have developed a new regional modeling framework designed specifically for dynamical downscaling of Atlantic hurricane activity. The non-hydrostatic model has a grid spacing of 18km and is run without convective parameterization, but with internal spectral nudging toward observed large-scale (basin wavenumbers 0-2) atmospheric conditions from reanalyses. The model simulates the observed rise in Atlantic hurricane activity (numbers, Accumulated Cyclone Energy (ACE), Power Dissipation Index (PDI), etc.) over the period 1980-2006 fairly realistically, as well as ENSO-related interannual variations in hurricane counts. Annual simulated hurricane counts from a two-member ensemble correlate with observed counts at r=0.86. The model does not simulate hurricanes as intense as those observed, with minimum central pressures of ~937 hPa and maximum surface winds of ~47 m/s being the most intense simulated in these experiments. To explore possible impacts of future climate warming on Atlantic hurricane activity, we are re-running the 1980-2006 seasons, keeping the interannual to multidecadal variations unchanged, but altering the August-October mean climate according to changes simulated by an 18-member ensemble of AR4 climate models (years 2080-2099, A1B emission scenario). The warmer climate state features enhanced Atlantic SSTs, and also enhanced vertical wind shear across the Caribbean (Vecchi and Soden, GRL 2007). A key assumption of this approach is that the 18-model ensemble-mean climate change is the best available projection of future climate change in the Atlantic. Some of the models show little increase in wind shear, or even a decrease, and thus there will be considerable uncertainty associated with the hurricane frequency results, which will require further exploration. Results from our simulations will be presented at the meeting. Based on the available evidence, we cannot yet conclude with high confidence that anthropogenic forcing has caused a discernible anthropogenic influence on hurricane activity to date.

Collaborators on this work at GFDL include: Gabriel Vecchi, Joe Sirutis, Steve Garner, Isaac Held, and Bob Tuleya.

EXTRA-TROPICAL CYCLONES IN A WARMING CLIMATE: OBSERVATIONAL EVIDENCE OF TRENDS IN FREQUENCIES AND INTENSITIES IN THE NORTH PACIFIC, NORTH ATLANTIC, AND GREAT LAKES REGIONS.

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Studies of changes in extra-tropical cyclones and associated frontal systems have focused on cyclo-genesis locations, and the resulting storm tracks, frequencies, and intensities, as well as their coastal impacts. The primary constraint on these studies has been the limited period of record available that has the best observational coverage for reanalysis efforts and verification of results, with most research focused on the latter half of the 20th century. In addition to studies using reanalysis data, other longer-term studies of the variability of storms have typically used wave or water level measurements as proxies for storm frequency and intensity.

Based on reanalysis data, numerous recent articles have documented changes in extra-tropical cyclone activity in response to a warming climate. Specifically, a significant pole-ward shift of the storm track in both the North Pacific and North Atlantic Ocean basins has been diagnosed by a number of recent studies that have shown a decrease in the observed frequencies in mid-latitudes, and a corresponding increase in activity in high-latitudes. In contrast, there have been only a few studies that have analyzed the long-term frequencies and intensities of extra-tropical cyclones over North America, and specifically in the Great Lakes region. Evidence for observed changes in extra-tropical cyclones in each of these regions will be presented, along with new Pacific and Atlantic buoy wave analyses that shed light on the statistical significance of trends in cyclone frequency and intensity.

Observed trends in extra-tropical cyclones are directly related to the amplitude and distribution of wave energy measured by offshore ocean buoys, which has significant implications for coastal storm hazards. Changes in long period (>12 sec), intermediate period (6-12 sec), and short period (<6 sec) components in the wave-energy spectra permit inferences regarding the change over time of the paths of the extra-tropical storms, as well as their intensities and resulting wave energies. Recent results that show the combined observations from several buoys in the eastern North Pacific support a progressive northward shift of the dominant Pacific storm tracks to higher latitudes.

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EXTREME STILL WATER LEVELS

Sofia Caires, Ferdinand Diermanse, Douwe Dillingh and Reimer de Graaff.

Still water level (SWL) is the level that the sea surface (at a given point and time) would assume in the absence of wind waves. SWLs are influenced by astronomical and meteorological effects. The estimation of extremes of the SWL, required in metocean studies, is not straightforward. One of the main problems it faces is the inhomogeneity, sparsity and scarcity of the data. Moreover, it is not clear which modelling approach is appropriate for estimating the extremes.

The following approaches are currently used:

1. Extreme value analysis of the SWLs.
2. Estimation of extreme water levels from the convolution of the extremal distribution of the surge (or that of a non synchronous difference between SWL and tide) with the empirical distribution of tidal levels. Compared to 1., this is thought to make better use of the data, and of the sometimes complete tidal information.
3. Estimation of extreme surge levels from extreme weather conditions (winds and atmospheric pressures) and computation of pessimistic or conservative SWL estimates by adding the Highest Astronomical Tide to them.

The purpose of this study is to assess approaches 1. and 2. and to provide guidelines as to which should be used in a given situation. In each of them, two different extreme value analysis methods will be considered: the peaks-over-threshold and annual maxima methods. Using the results of our analyses with approach 2. we shall also provide indications about the tidal level that should be used in approach 3.

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“AN OVERVIEW OF DIFFERENT METHODS FOR ASSESSING HISTORICAL HURRICANE FREQUENCY AND POTENTIAL RISK FOR THE GULF OF MEXICO COAST”

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Significant public interest has been focused on the potential risk related to hurricanes along the Gulf of Mexico coast since the devastating impacts from hurricane Katrina in 2005. This paper and presentation will provide an overview of two different methods of analyzing hurricane data in order to determine their historical frequencies and assess their probable risk of occurrence for the coastal regions of the Gulf of Mexico. A number of issues will be addressed related to determining the appropriate period of record and offshore extent for each analysis method. In addition, statistical techniques for determining extremes related to the central pressure data from Gulf Coast hurricanes, as well as specific applications of Generalized Extreme Value (GEV) theory for calculating hurricane return periods will be evaluated. Finally, a frequency analysis of the historical inland extent of tropical storm and hurricane force wind speeds will also be covered.

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10th International Workshop on Wave Hindcasting and Forecasting

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Coastal Hazards Assessment

The modern predictability of the 1966 big Venice flood

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Abstract

In November 1966 Venice suffered its worst historical storm, when high waves and a large storm surge pushed the sea level on the coast and within the lagoon at heights never recorded before. At the time there was only a limited warning of the forthcoming event, and the local population was totally unprepared to face the consequences.

We have asked ourselves if, should a similar event happen again, we would be able to issue a timely forecast. To answer this question we have hindcast the storm using the data available at the time, but with modern technology, i.e. using the present oceanographic and meteorological models and the presently available computer power. On top of this, we have issued virtual forecasts, i.e. we have run the models in forecast mode starting from the different situations existing on the various days before the storm (the 4th of November).

The results have been extremely enlightening. It turns out that the first warning of an exceptional storm could have been issued, with modern technology, since six days before the storm. From October 30 onward there would have been also a correct quantification and timing of the surge in the town.

This result is very promising for the present capabilities. Given the enormous amount of data presently available, orders of magnitudes larger than forty years ago, we derive that at least the same order of predictability is to be expected today for large significant storms.

TROPICAL CYCLONE ATMOSPHERIC FORCING FOR OCEAN RESPONSE MODELS: APPROACHES AND ISSUES

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AND

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THE SPECIFICATION OF TROPICAL CYCLONE ATMOSPHERIC FORCING FOR OCEAN RESPONSE MODELS IS DESCRIBED WITH EMPHASIS ON METHODS THAT ARE CURRENTLY ACTIVELY APPLIED IN BASINS RICH IN IN-SITU, AIRBORNE AND REMOTELY SENSED METEOROLOGICAL DATA. FIVE ALTERNATIVE WIND FIELDS DEVELOPED FOR GULF OF MEXICO HURRICANE KATRINA (2005) ARE APPLIED WITH A THIRD GENERATION WAVE MODEL TO HIGHLIGHT THE SENSITIVITY OF PREDICTIONS OF INTEGRATED PROPERTIES OF THE WAVE SPECTRUM TO THE WIND FIELDS, INCLUDING A PRELIMINARY ASSESSMENT OF THE SENSITIVITY OF INNER CORE PEAK SEA STATES TO HIGH FREQUENCY TEMPORAL CHANGES IN THE WIND FORCING. WE EMPHASIZE APPROACHES AND CRITICAL ISSUES THAT WILL BE ADDRESSED AT THIS CONFERENCE IN MORE DETAIL WITHIN PAPERS IN THE SPECIAL SESSION ON TROPICAL METEOROLOGY.

SPECIFICATION OF TROPICAL CYCLONE PARAMETERS FROM AIRCRAFT RECONNAISSANCE

Andrew T. Cox and Vincent J. Cardone
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This paper describes the development and application of a workstation which is used to determine and track in time the parameter sets required to drive a Tropical Planetary Boundary Layer (TropPBL) model. These inputs include easily obtainable parameters such as central pressure and track as well as the scale pressure radius (related to the radius of maximum winds) and so-called Holland's *B* parameter which controls the peakedness of the wind and pressure profile. Preliminary analysis and validation of storm systems with double exponential wind and pressure profiles will be presented and discussed as part of the on-going work to revisit and assess the physics of the TropPBL model.

CBLAST PROGRAM OF COUPLED HIGH RESOLUTION HURRICANE MODELS

Shuyi Chen

ABSTRACT NOT AVAILABLE

REALISTIC SIMULATIONS OF INTENSE HURRICANES WITH THE NCEP/NCAR WRF MODELING SYSTEM

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The Weather Research and Forecasting model is a non-hydrostatic mesoscale model designed for simulation and prediction of fine-scale atmospheric phenomena, emphasizing horizontal grid lengths of a few kilometers or less. The Advanced Hurricane WRF (AHW) is a derivative of the Advanced Research WRF model which maintains a moving nested grid system that allows local resolution of roughly 1 km, making it ideal for the prediction of the multiple length scales present in hurricanes ranging from the scale of outflow (1000 km or more) to the width of the eye wall (10 km).

During the past four Atlantic hurricane seasons, the AHW model was run in real time and in retrospective mode to produce forecasts of hurricane track, intensity and structure out to five days lead time. During the 2004 and 2005 hurricane seasons, AHW performed comparably to operational models using an innermost nest of 4 km grid spacing, with evidence of improved intensity forecasts beyond 1.5 days during the 2005 season. During 2006, a second nest of 1.33 km grid spacing was added to resolve the eye wall of storms. In 2007, a mixed-layer ocean model was added to provide a feedback of mixing-induced sea-surface cooling to the atmosphere.

The focus of this talk will be on the prediction of the structure of the wind field in a variety of storms including Katrina and Wilma from 2005, and Dean, Felix and Karen from 2007. The sensitivity of maximum wind will be investigated for changes in air-sea exchange coefficients and upper-ocean feedback. Other metrics of the wind distribution, such as the radius of maximum wind and integrated kinetic energy, are also evaluated. In the case of hurricane Dean, these metrics illustrate that the AHW realistically changes the vortex size and handles the collapse of the core at landfall, but does not replicate the fluctuations associated with eye-wall replacement cycles. The simulations from 2007 also indicate a relatively lower predictability of cyclones initialized in their earliest stages of formation compared with more mature depressions.

NEW FINDINGS ON HURRICANE INTENSITY, WIND FIELD EXTENT, AND SURFACE DRAG COEFFICIENT BEHAVIOR

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Analysis of several years of measurements from relatively new sensors are changing our views of hurricane intensity, the radial extent of the surface wind field, and the behavior of the surface drag coefficient in extreme winds. When communicating hurricane awareness, it is important not to focus primarily on the Saffir-Simpson Category or storm intensity (the maximum wind speed). Storm size is also important. Integrated kinetic energy represents a framework that captures the physical process of ocean surface stress forcing waves and surge while also taking into account structural wind loading and the spatial coverage of the wind. Surface wind measurements from GPS dropsondes and the Stepped Frequency Microwave Radiometer (SFMR), when compared to maximum flight-level winds, suggest that current operational methods used to estimate maximum winds in mature hurricanes are biased high by 10% in all but the strongest (Cat 5) storms. Standardization and real-time objective analysis methods applied to measurements from diverse observation platforms tend to result in radial wind field extent estimates that exceed those conducted operationally. Recent research conducted at Penn State suggests that the extent of tropical storm force wind radii is underestimated operationally by ~ 15%. Analysis of hundreds of GPS dropsonde profiles suggest that after an initial increase with winds up to hurricane force, the surface drag coefficient decreases with wind speed. Examination of radial variation of the drag coefficient indicates that smaller drag values are found at distances closer (< 30 km) to the storm center where little variation with wind speed is noted. Farther from the storm center, the initial increase followed by a decrease behavior is found. Dividing these outer data further by storm relative azimuth the increase-then-decrease behavior was most evident in the front left sector where the winds flow across the primary storm-generated swell.

UNCERTAINTY IN POPULATION PROPERTIES OF NORTH ATLANTIC TROPICAL CYCLONES

Peter Vickery

ABSTRACT NOT AVAILABLE

10th International Workshop on Wave Hindcasting and Forecasting

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Coastal Hazards Assessment

The "Voyager" storm in the Mediterranean Sea

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Abstract

On February 14, 2005 a severe mistral storm caused substantial damage to the cruiser "Voyager" between Balearic Islands and Sardinia. At the time it was reported that an exceptionally high wave, 14 m high, had smashed the windows of the control cabin and flooded the control system. After a few hours the onboard personnel managed to restart one engine and the ship limped in the storm towards the closest harbour.

As mistral storms are rather frequent in the area, we were puzzled by the reported figures, also because the storm did not seem to be so exceptional to put in danger a large cruiser. Hence we have hindcast the storm, making use of all the available sources of data. This included a pass of the Jason satellite happened at practically the time of the accident. The ECMWF wind fields were validated and corrected on the base of the QuikSCAT scatterometer.

A careful use of all these source and the related comparison with the model results suggests that the scatterometer winds can be slightly overestimated in the Mediterranean Sea. At the opposite the altimeter wind speeds are generally underestimated.

The wave hindcast suggested significant wave heights up to 10 metres in the area of the accident. This implies that the reported 14 m high waves were not exceptional. Therefore, consistently with the geometry of the cruiser, we have hypothesised that it was a 14 metre crest that hit the ship and caused the damage. For both the above cases and on the base of theory and previous laboratory experiments, we have evaluated the probability of such heights, taking also into account the nonlinearities in the field, hence the likelihood of freak waves.

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Are "unexpected" waves as important as rogue waves?

Rogue waves have received considerable scientific attention in recent years. They are commonly defined as waves with height $H \geq 2.2 H_s$, where H_s is the significant wave height. Linear superposition of random wave components leads to a Rayleigh distribution of wave heights, and it is expected that one in about 16000 waves (or one wave every two days for a ten second wave period) is larger than $2.2 H_s$. We suggest that the "unexpectedness" of large waves is also of great concern to ships and beachcombers. In linear simulations we examine the probability of a wave being β times larger than any of the preceding *N* dominant waves. We derive the frequency of such waves as a function of β and *N* for various wave spectral shapes. To give one example, in developing seas the likelihood of a wave twice the size of any wave within the preceding 22 dominant wave periods (β = 2, *N* = 22) is as high as that for a classical rogue wave. In addition, the occurrence of "unexpected" waves in surface elevation records from various locations in the NE Pacific is examined.

Extension of the ECMWF freak wave warning system to 2 dimensional propagation.

Peter A.E.M. Janssen, Nobuhito Mori, and Miguel Onorato

Abstract

Wave forecasting is about forecasting the mean sea state, as reflected by the ocean wave spectrum, and for quite some time it was thought that it was not possible to make statements about extreme events. Recently, it has been shown, however, how to relate fluctuations around the mean sea state to the wave spectrum. Therefore, when the wave spectrum is known the probability distribution function (pdf) of the sea surface elevation can be determined. The tails of the pdf give vital information on the occurrence of extreme events such as freak waves.

Based on the above approach, a first, one-dimensional version of a freak wave warning system has been introduced at ECMWF at the end of 2003. Here, we will discuss its important extension to two-dimensional propagation.

FREAK WAVE PREDICTION FROM SPECTRA

Nobuhito Mori, Peter A.E.M. Janssen, and Miguel Onorato

The last decade freak waves have become an important topic both engineering and science society. The freak wave is sometimes featured by a single and steep crest giving severe damage to offshore structures and ships. Freak wave studies have been started in the late 80's and the high-order nonlinear effects on the freak waves were discussed in the early 90's. After that, Janssen (2004) formulated the analytical relationship between spectral shape and the kurtosis of the surface elevation. This result has the potential to summarize previous freak wave studies such as the nonlinear interactions, spectral profiles and etc.

The purpose of this study is to investigate the relationship between the spectrum shape and occurrence probability of freak waves through the nonlinear four-wave interactions for freak wave prediction system. The wave height and maximum wave height distributions are formulated as a function of kurtosis by the non-Gaussian theory. The theory of wave height distribution and the occurrence probabilities of freak waves will be compared with laboratory experiments.

MODELING ROGUE WAVES IN FULLY DIRECTIONAL SEA STATES

A. R. Osborne

Rogue waves in directional sea states are addressed from physical, mathematical and numerical points of view. We conduct numerical simulations based upon the extended nonlinear Schroedinger equation in 2+1 dimensions (x, y, t). The simulations are conducted with fully nonlinear multidimensional Fourier series and include the presence of unstable modes, a kind of rogue wave, in the spectrum. By selecting the initial conditions to correspond to a wide range of directional spectra, we show how one can actually control the presence of rogue wave activity in a selected sea state. One limit of the theory allows one to excite all possible rogue modes in a sea state in order to simulate what we refer to as a rogue sea. These numerical results are compared to the analysis of Currituck Sound data, discussed elsewhere in this meeting.

This work has been jointly conduced with Miguel Onorato, Chuck Long and Don Resio.

EVOLUTION OF RANDOM DIRECTIONAL WAVE AND ROGUE WAVE OCCURRENCE

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The probability of extreme waves exceeding twice the significant wave height (i.e. the rogue waves), is suggested to be a function of wave steepness and frequency bandwidth. The combined parameter is named the "Benjamin-Feir" index suggesting that the non-resonant wave-wave interaction (or the Benjamin-Feir instability in some cases) is responsible for the increased rogue wave occurrence. However, recent studies suggest that the non-resonant wave-wave interaction is suppressed by the directionality of the wave spectrum. Preliminary study suggested that for a given steepness and frequency bandwidth, the Kurtosis (and hence the probability of the rogue wave) rapidly decreases as the spectrum broadens (Waseda, 9th Wave WS). In this report, we will present results from the additional experiment conducted using the directional wave maker located at one end of a rectangular basin (50m long, 10 m wide, 5 m deep, Kinoshita lab IIS). The experimental parameters cover ranges of directional spreading (unidirectional to broad), steepness, and frequency bandwidth with a conventional JONSWAP-Mitsuyasu type spectrum. Other directional distributions such as the observed one by Hwang & Wang (2001) and bimodal distribution were studied as well. The results will be discussed isolating effects of strong nonlinearity (i.e. wave breaking), relative significance of bound waves and instability, and effects of discretization of the spectrum. In particular, the spectral downshifting due to wave breaking plays an important role in the increase of the Kurtosis. Implication of these findings to the rogue wave prediction utilizing 3rd generation wave models will be discussed as well.

FREAK WAVES AS A RESULT OF MODULATION INSTABILITY

By V.E.Zakharov and A.I. Dyachenko

This is widely recognized that formation of freak waves is a result of development of the modulation instability. However, an analytical theory of this fundamental phenomenon is not properly developed yet. All existing theories exploit envelop-type equations which fail in the most crucial moment of the extreme wave appearance. By the use the conformal mapping technique we developed an efficient numerical code for solution of the Euler equation for potential flow of ideal deep fluid with free surface. The code makes possible to study instability of arbitrary steep Stokes waves. We show that Stokes waves with steepness close to limiting are badly unstable and the most dangerous instability is doubling of the period.. Due to this instability the steep Stokes waves cannot be used as structural units for modeling of the ocean surface. They break up and loose their energy in a time comparable with their period. Instability of gentle-sloping wave leads to formation of envelop soliton gas. Solitons merge and finally create a very steep instable soliton which generates the freak wave.

At the moment we are developing the code, making possible to follow formation of freak waves from stochastic weakly nonlinear wave spectra modeling a real sea.

Predicting wave conditions in a coral embayment from offshore directional spectral model input

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A host of watershed and coastal management concerns at Hanalei Bay, Kauai, has prompted a concerted effort to gain better understanding of circulation and water quality within the bay through fine scale numerical modeling. Hanalei Bay contains morphologically diverse areas of fringing reef, reef flats, and both fine and course grained sediment. Because the microtidal conditions and the bay's exposure to North Pacific swell, waves are potentially the most important single driver of nearshore circulation during much of the year. We examine methods of estimating surface gravity wave input at the boundaries of a coastal numerical model of the bay, as well as wave propagation, shoaling, and breaking within the model. Specifically, comparisons are made between: a) results using directional spectral input and parameterized input, and b) results using "standard" hydraulic roughness schemes for sediment, higher homogenous values for coral reefs, and spatially varying values derived from measurements of rugosity. These results are compared with *in situ* observations at a number of locations within the bay. Preliminary results indicate the importance of using directional spectral input at the offshore boundary and spatially heterogeneous roughness grids in the coastal model.

PHASE-RESOLVING SIMULATION OF WAVE EVOLUTION OVER A SHALLOW REEF

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In this presentation, a new set of experimental measurements for wind waves propagating over a reef will be compared with two different numerical models. The experiments, performed in a large basin, are driven by unidirectional or directional spectra, and provide insight into the three dimensionality of wave propagation over a reef. To compare with the experimental data and to provide additional insight into this problem, numerical simulations will recreate the experiments. Two models will be used: a depth-integrated Boussinesq-type model and a Reynolds-Averaged Navier-Stokes (RANS) model. The Boussinesq model yields rapid predictions and can simulate the directional spectra cases, while the RANS provides detailed data on the breaking, turbulence, and vertical hydrodynamic structure of the wave field. The overall accuracy and practicality of the Boussinesq model for this type problem will be discussed, as well as, through comparisons with the RANS, the consequences of needing a depth-integrated breaking and turbulence model.

WAVE AND WATER LEVEL OBSERVATIONS COLLECTED DURING THE PACIFIC ISLAND LAND OCEAN TYPHOON (PILOT) EXPERIMENT

M. A. Merrifield, A-C Pequignet, J. Becker, J. Aucan, O. Vetter, T. Hilmer, S. Boc, C. Pollock, K.-F. Cheung, J. Goo, P. Quiroga, Y. Wu

The PILOT project, sponsored by the Army Corps of Engineers, included field experiments at fringing reefs to determine the factors leading to storm-driven inundation at prototypical Pacific Island shorelines. Wave runup and setup are examined for two fringing reef morphologies: the shallow and smooth reef platform at Ipan, Guam, and the considerably rougher platform at Mokuleia, Hawaii. The coastal runup and setup at each site are examined as a function of offshore wave conditions and water level over the reef, primarily associated with the tide. Numerical simulations from a suite of spectral and phase resolving models are compared with the observations. Of particular interest are conditions at Ipan Reef associated with Typhoon Man-Li which passed 200 nm to the south of the site causing peak offshore significant wave heights of 7m.

Wave energy budget for Pacific island nearshore environments

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Abstract

The Pacific Island Land-Ocean Typhoon experiment (PILOT) is being carried out to develop a better understanding of coastal inundation and flooding along island shorelines due to storm waves and elevated sea levels associated with typhoons. Cross-shore arrays of single pressure sensors, collocated pressure sensors and acoustic current meters were deployed across Ipan reef, Guam, Mokuleia and Waimea Bay, Hawaii. These data are used to estimate reflection, transmission, and dissipation of wave energy over a range of frequency bands for the steep and complex bathymetry of the study sites. The effects on the energy budget of reef porosity and partial reflections are assessed to determine the amount of the energy available at the shoreline for inundation and flooding.

COMBINED WIND AND WAVES OVER A REEF

Alejandro Sánchez
Jane Smith
Zeki Demirbilek
Stan Boc

Wave heights over wide and shallow reefs such as those found on the south-east coast of the Pacific Island of Guam are essentially depth-limited, making the accurate estimation of reef ponding and wind and wave setup vital to the accurate prediction of breaking wave heights, wave run-up and inundation. This paper describes a comparison of wave and water level measurements obtained in a two-dimensional wind-wave flume model of a fringing reef type profile with numerical model results and previous empirical and analytical relationships for wind and wave setup, ponding and wave run-up. A brief description of the test facility, instrumentation, test conditions, numerical models, and empirical and analytical relations is provided. The reef profile is representative of the south-east coast of the Pacific Island of Guam and consists of a composite slope, reef face, wide reef flat and a constant slop beach. Laboratory test cases consist of 83 combinations of waves, winds and water levels covering typical to extreme conditions found at the Island of Guam. Numerical simulations of the lab test were performed using the steady-state spectral wave model STWAVE coupled with a depth-averaged circulation model ADCIRC for model validation and calibration. Model results show good comparisons of both water levels and wave heights for storm conditions with maximum errors of approximately 20%, but results deteriorate with decreasing water levels over the reef flat. Empirical and analytical formulas show good comparisons with measured reef ponding, but do not compare well with wave run-up.

ESTIMATION OF PROBABLE MAXIMUM WAVE HEIGHT IN THE SEA AREAS AROUND JAPAN BASED ON SIMULATIONS OF TYPHOON- AND DEPRESSION(STORM)-GENERATED WAVES

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This paper presents an estimate of probable maximum (significant) wave height (PMWH) generated by typhoons and extratropical cyclones(depressions) in the Northwestern Pacific Ocean and the Japan Sea. Typhoons and depressions are generated over a period of 100,000 years using a Monte-Carlo simulation model, and the wind and wave computations are conducted for each of a large number of selected intense typhoons and depressions. The analyses show that the typhoon-generated PMWH exceeds 26 m in a sea area near Shikoku Island facing the Pacific Ocean and that the depression-generated PMWH is above 26 m in an eastern sea area far from East Japan. Those PMWHs are 10 to 13 m greater than the maximum wave heights generated by historical typhoons and depressions in the recent decades. A similar feature can be found in the Japan Sea.

DIAGNOSING THE LARGE SWELL EVENT ASSOCIATED WITH THE EXTRATROPICAL TRANSITION OF HURRICANE FLORENCE (2006)

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Accurate wave forecasts are imperative for both offshore and coastal safety and economics. Recurving tropical cyclones present a significant challenge to the operational marine forecaster not only due to complex meteorological and oceanographic processes, but also through overall public perception. Category 1 Hurricane Florence was a large tropical cyclone that recurved over the Western Atlantic 10-13 September 2006. Florence became an extratropical low early on 13 September about 420 n mi south-southwest of Cape Race, Newfoundland. The storm was not a direct threat to the United States during its tropical lifetime. However, as Florence transitioned to an extratropical low it interacted with a strong area of high pressure over Eastern Canada. This interaction produced an expanding wind field creating a significant fetch of gale to storm force N to NE winds off the Eastern Seaboard. The significant fetch produced a prolonged, long period swell event for both the offshore and coastal waters of the western North Atlantic that led to high surf, rip currents, coastal flooding, significant beach erosion, and at least two deaths. Both deaths were reported in Volusia County, Florida on 14 September and 16 September which was after Florence had completed its extratropical transition and was moving out to sea. In addition to a discussion regarding the challenges of effectively informing the public during these events, a detailed case study and wave model verification results are presented.

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THE IMPROVEMENT OF JMA OPERATIONAL WAVE MODELS

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The Japan Meteorological Agency (JMA) has been operating 2 wave models for ocean wave prediction. One is the global wave model (GWM) and the other is the coastal wave model around Japan (CWM).

These models are categorized into third generation wave model and composed of prognostic equation of wave spectra. The physical processes are developed at the Meteorological Research Institute (MRI)-JMA, so called MRI-III.

Major update of MRI-III was introduced in May 2007. Main improvements at this version-up are described below.

・Improvement of physical processes (especially in dissipation term).

・Increase of spatial resolution: 0.5 degrees both in latitude and longitude for GWM and 0.05 degrees for CWM.

・Increase of wave spectral resolution: 36 azimuthal directions.

The model prediction shows better correspondence with the measurement than the previous model, especially in the oceans of the Southern Hemisphere. These updates will lead to more accurate marine weather services and enhanced safety and efficiency of shipping, small craft and maritime industries.

THE 2007 RELEASE OF WAVEWATCH

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For nearly decade, the WAVEWATCH III wind wave model has been used world wide for wave hindcasting, forecasting and research. Most widely used is the second release of the model, dating from 2002. The public release of the third version of the model is scheduled to coincide with its operational implementation at NOAA/NCEP in September 2007. The present paper describes new features in the 2007 model release.

The main development effort for the third release of WAVEWATCH III has gone into the development of two-way nesting techniques. To facilitate this, a new data structure was designed that allows for the storage of an arbitrary number of model grids in a single program. Furthermore, two-way nesting techniques have been developed for grids with systematically increasing or decreasing resolutions, as well as techniques to provide the proper data exchange for overlapping grids with similar grid resolutions. This has resulted in so-called mosaic approach to modeling, where an arbitrary number of grids with arbitrary resolutions are treated as a single model with full interaction between all grids.

Additional developments in the wave model include the capability to carve out arbitrarily shaped computational domains from conventional structured grids, wetting and drying of grid cells, alternative source term parameterizations and additional parameterizations for surf-zone physics. The capabilities of the new model features will be illustrated with idealized and real-world applications.

Finally, ongoing and future development plans for WAVEWATCH III will be discussed, including the planned open-source approach to joined development of WAVEWATCH III by a loosely organized team of developers inside and outside of NOAA.

"Numerical aspects and source term analysis of wave modeling in a tidal inlet"

Abstract Wave-workshop

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In the framework of the SBW-Wadden Sea (Strength and Loads on Sea Defenses in the Dutch "Wadden" Sea) project (Van Dongeren et al., 2007) an in-depth study was performed to find the best modelling approach with the SWAN model to hindcast storm waves in a tidal inlet. The first part of this study comprised of an analysis of the requirements to the computational grids and numerical settings. The second part focused on the role of the physical processes when North Sea storm waves penetrate into the Wadden Sea.

SWAN is often used in combination with the WAQUA flow model. Since this model uses non-uniform grids, the requirements to non-uniform grid for wave modelling were investigated. This led to simple rules to generate non-uniform grids aiming at an optimal distribution of grid points. These rules were applied to make dedicated non-uniform wave model grid for the tidal inlet of Ameland, thus saving a considerable amount of points compared to regular grids with a constant spacing.

SWAN uses an iterative procedure to solve the action balance equation. Tests were carried out to come up with generally applicable and robust convergence criteria. These tests showed that the convergence behaviour differs not only per wave parameter (wave height, wave period and mean wave direction), but also per geographical area. This information was subsequently used to improve the convergence behaviour of SWAN.

An important aspect of improving any wave model is to pinpoint the sources of prediction errors. Therefore hindcast studies of storms in the tidal inlet of Ameland were carried out. Modelling problems were identified by a careful comparison of measured and computed spectra, but also by analyzing the spatial distribution of the magnitude of the physical processes as modelled in SWAN. The latter provided insight in the relative importance (according to SWAN) of source terms in the entire domain. In addition, the spatial distribution of some non-dimensional parameters was investigated. These investigations showed that depth-limited wave breaking and triad interactions are dominant in the shallow areas of the tidal inlet, whereas the 'deep-water' source terms dominate in the shallow Waddensea. Of special interest was the propagation of swell waves through the tidal inlet, which seem to propagate over the tidal flats. The analysis of the non-dimensional parameters showed that in some areas SWAN is applied outside its assumed range of applicability.

The results of this study revealed a number of weak points in the modelling of waves in a tidal inlet and many suggestions for model improvements and model forcing were formulated.

A concurrently-submitted paper will address the overall scope of the SWAN modelling and a comparison against measurements in the same area (Van Dongeren et al.)

Numerical investigations for the applicability of SRIAM method as a new non-linear energy transfer function

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The aim of the WAVE-JCOPE project is to establish a realistic high resolution coupled wave-current prediction model in the Kuroshio region. To improve the estimation of the wave spectra, we have implemented the SRIAM method (Komatsu and Masuda, 1996) for efficient and accurate computation of the non-linear energy transfer function (Snl). In the 9th wave workshop, authors indicated that the spatial distribution of significant wave height induced by wave-current interaction is considerably different between the two computations with SRIAM and Discrete Interaction Approximation (DIA) non-linear energy transfer function implemented in the WAVEWATCH III. This discrepancy is caused by the inadequate use of semi-implicit integration scheme with SRIAM, which was originally used for the DIA. So, we first discuss the numerical integration scheme suitable for SRIAM. Second, we examine basic properties of SRIAM method for duration- and fetch-limited wave growth. Finally, to demonstrate the effect of non-linear transfer on wave-current interaction, numerical experiment of wave refraction by shear current was conducted with only the non-linear energy transfer function effective in the source terms. Incident wave (JONSWAP spectrum with $\cos^4\theta$ directional spreading) is set to propagate against an ocean current. The spatial distribution of wave height and the focal points near the center of current for SRIAM and DIA are approximately consistent with each other, contrary to the previous report. However, spectral profiles are considerably different for the two cases. One obvious difference is that the spectral spreading calculated by SRIAM is clearly narrower than that calculated by DIA. Moreover, we definitely found, in the case of SRIAM computation, that the wave refraction is weakened by the self-stabilization effect of non-linear energy transfer function.

A TWO-SCALE APPROXIMATION FOR NONLINEAR ENERGY TRANSFERS IN OBSERVED WAVE SPECTRA

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We recently derived and presented a new method for estimating the transfer rates in wind wave, based on a two-scale approximation (TSA) to the full Boltzman integral (FBI) for quadruplet wave-wave interactions. In that presentation, the TSA method was tested for idealized spectral data. In this paper, we focus on observed wave spectral from field measurements. Comparisons are given of TSA, the full Boltzman integral, FBI, and the Discrete Interaction Approximation (DIA) which is presently used in almost all operational wave forecast models, using data collected in Currituck Sound, and in open ocean conditions. The latter data include directional waverider observations off the Field Research Facility at Duck North Carolina during hurricane Wilma in 2005. These comparisons show that TSA compares favorably with FBI, and that it is a notable improvement over the DIA.

"Operationalisation of the TSA method for the computation of non-linear four-wave interactions in third-generation wave models"

Abstract Wave-workshop November 2007

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The speed-up of computation of the non-linear four-wave interactions in discrete spectral wave models is the subject of many studies. A full computation of these interactions involves the solution of a six-fold integral along a 3-dimensional manifold in wave-number space. Due to these requirements the exact computation of these interactions is not feasible for inclusion in operational wave models. It is for this reason that many approximate methods have been developed of which the Discrete Interaction Approximation is the most famous.

Recently, Resio and Perrie (2007) developed a two-scale method to compute these interactions. This method, referred to as the TSA method, splits an arbitrary spectrum in a parametric part and a residual part. Substitution of these two spectra in the formulation of the Boltzmann integral results in a number of cross-terms in the action density product term. The terms related to the parametric part can be pre-computed exactly using the WRT method, whereas part of the remaining cross-terms are used as correction terms to come up with a good approximation to the full integral. One of the most important benefits of this hybrid method is that it uses a database of precomputed exact transfer rates and that the method uses the same number of degrees of freedom as the discrete spectrum for which these interactions are computed.

Resio and Perrie (2007) have shown that the TSA method provides a fast and accurate method to compute the non-linear four-wave interactions for a wide range of academic and measured spectra. The next step in the development of the TSA method is to explore its capability in operational wave models and to determine optimal modelling choices in the core of the TSA method. To that end the TSA method has been rewritten in subroutine form such that it can be build in existing operational third generation wave model like WAM, ST-WAVE, WAVEWATCH and SWAN.

This paper describes the set-up of the operational TSA method with special attention to the separation of an arbitrary spectrum in two parts, the efficient handling of the pre-computed databases of exact non-linear transfer rates. Next, the experience of the TSA method in operational applications, such as growth curves and field cases is discussed.

Resio, D.T., and W. Perrie, 2007: A two-scale approximation for efficient representation of nonliner energy transfer in a wind wave spectrum. Part 1: Theoretical Development. Submitted to JPO.