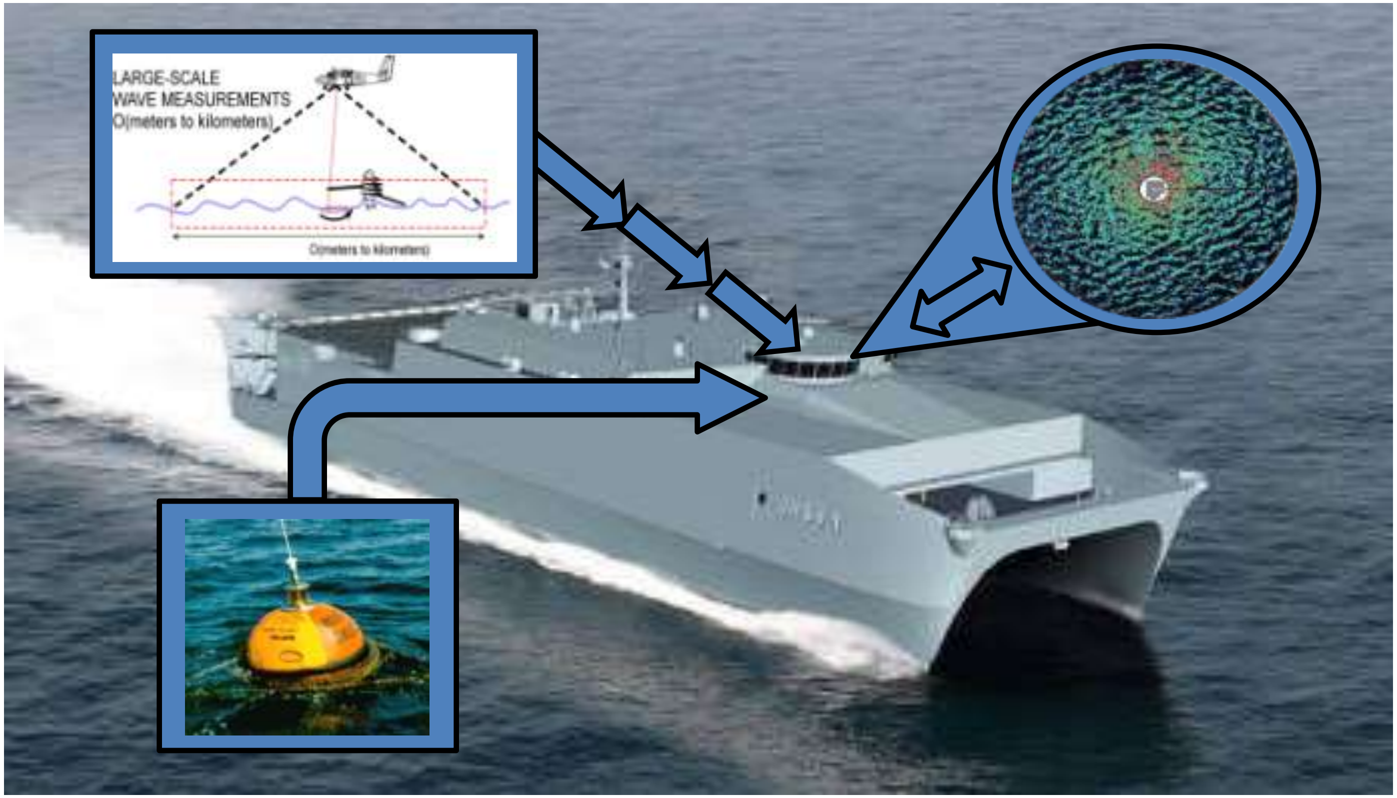
Note: These slides are for informational purposes only; the information herein does not supersede that in the BAA, and should be considered a supplemental resource only.

The BAA is to be considered the primary resource for information and guidance with respect to proposal development.

Environmental and Ship Motion Forecasting (ESMF)



Dr. Paul Hess
Program Officer, ONR 331

Enabling S&T Investments

Multidisciplinary University Research Initiative (MURI) (ONR Code 33, 6.1): Real-time Sensing, Prediction, And Response To Evolving Nonlinear Wave Fields

Objective:

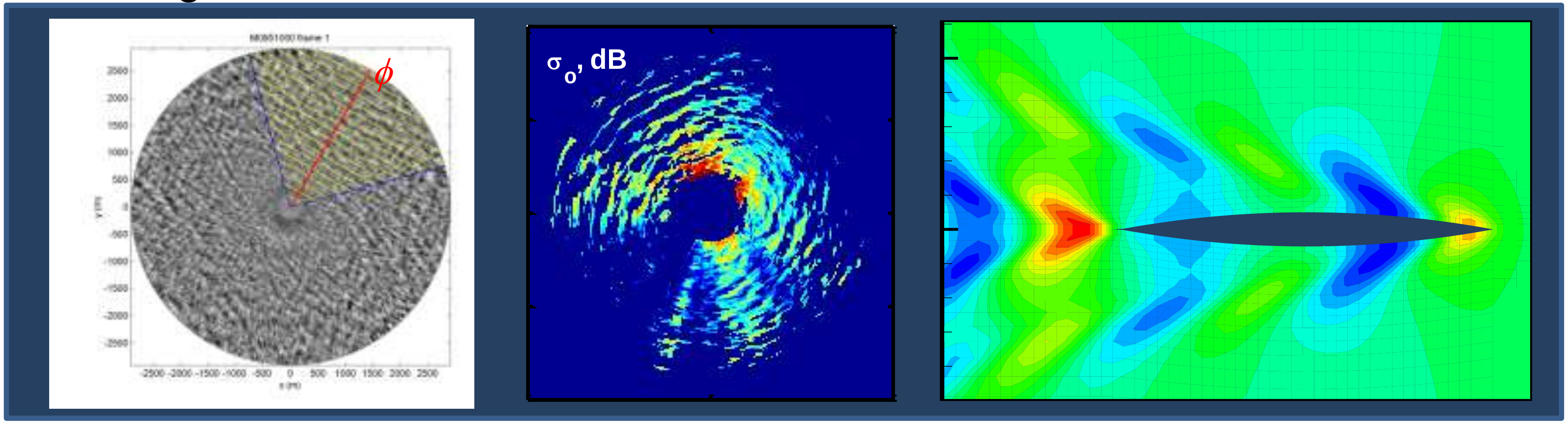
Advance the foundations of:

- Radar measurement of ocean waves,
- Prediction of nonlinear wavefields,
- Prediction of ship motions, and
- Optimal control in a wavefield

– all toward an integrated, real-time capability for intelligent, safe maneuvering.

Technical Approach:

- Derive theory of radar-wave interactions, including coherent returns
- Develop theory of nonlinear wavefields given limited (radar) data input
- Construct fast prediction method for ship motions in an extreme seaway
- Adapt optimal control theory to motions
- Demonstrate techniques at sea



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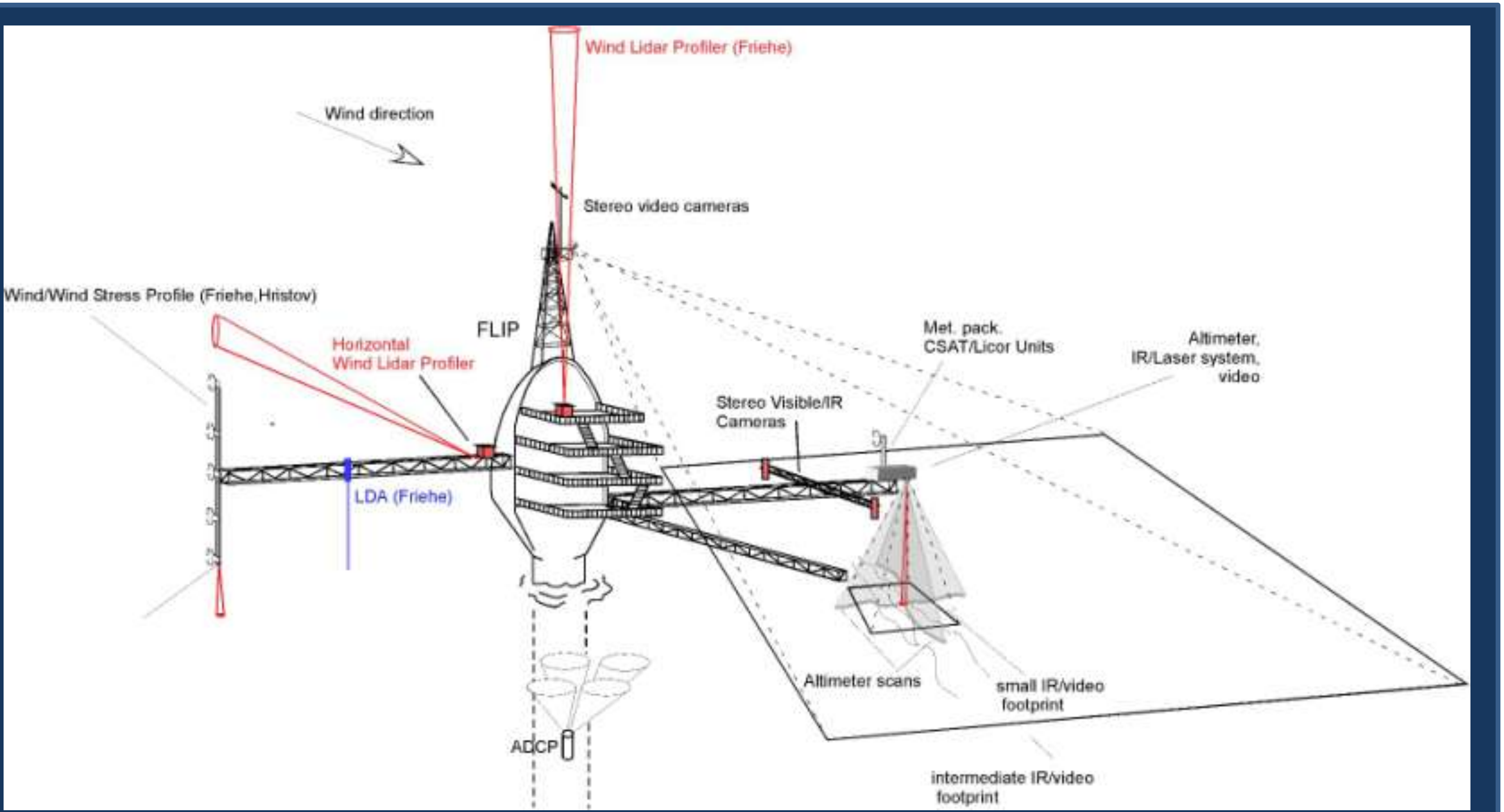
Enabling S&T Investments

- The research in the different areas is closely integrated since each area requires input from the preceding area.
- The research is being conducted by 13 faculty members at 4 different universities
  - University of Michigan, lead school
  - Applied Physics Laboratory at the University of Washington
  - New Jersey Institute of Technology
  - Ohio State University

High-Resolution (Hi-Res) Departmental Research Initiative (DRI): Surface Waves, Wave Breaking and Current Measurements from Platforms



Scripps FLIP Ship

Hi-Res DRI: Surface Waves, Wave Breaking and Current Measurements from Platforms

Measurements from FLIP

Wave:
- Laser Wave Gauge
-Microwave/Ultrasonic Wave Gauge
- Scanning Laser Altimeter
- Visible/IR Stereo imagery
- Acoustic e.g. Wave ADCP
- X Band Radar (e.g. WaMos)
- Polarimetric camera

Wind:
- Ultrasonic anemometer
- Wind LIDAR profilers

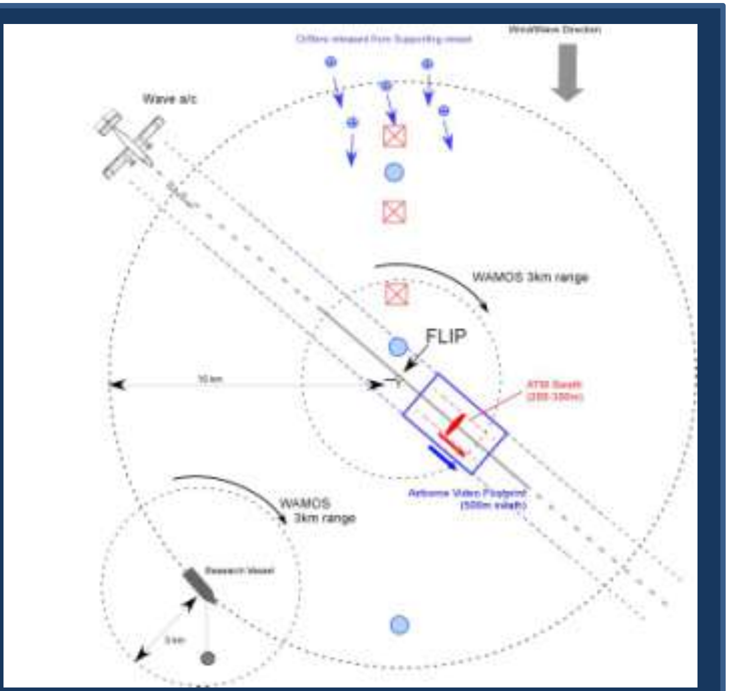
Current
- Acoustic (e.g. ADCP)
- X-band radar (e.g. WaMoS)

In-Situ Buoy Measurement:

- Waverider
- Scripps mini-buoy

Airborne Measurement:
- NASA ATM Topographic Mapper
- Riegl Laser Altimeter
- Dual 11Mpx Camera system (12bit)
- GPS/IMU (LN200 based)

- FLIP
- Buoys
- Airborne
- Support Vessel



International Efforts

- **European Union: Joint Industry Project**
- Similar goals to ESMF program:
  - Wave elevation/spectrum
    - Ocean Waves: X-band radar, WaMoS II
  - Wave propagation model
    - TU-Delft: Linear model, 2-D validation tests
    - UiO: Nonlinear model
    - MARIN: Wave propagation model tests
  - Ship Motions Model
    - TU-Delft, MARIN, OceanWaves
- Results:
  - Predicted quiescent periods up to 2 min in advance
  - “Good enough” for crane operators, not good enough for any feed forward capability

Technical Risks

Top Technical Risks	Description
Total System Integration	The system-of-systems will need to integrate a number of different technology areas across a set of common, open architecture interfaces. The system will need to run quickly and at a high level of accuracy, with high reliability and availability.
Remote wave field sensing	The wave field sensing technologies will need to be of high enough fidelity to provide wave propagation and ship motion algorithms with highly accurate wavefield data. Any error introduced by the sensors will be compounded through the wave propagation and ship motion estimates.
Wave propagation/Ship motion modeling	These tasks are computationally intensive, and will need to run real-time or faster than real-time for this system to meet the goals of the FNC.
Operator Guidance (OG)/Decision Support System (DSS)	An OG/DSS system combining high-level wavefield measurements translated into ship motion estimates has never been developed beyond low TRL levels. Data management and updating strategies will be critical.

Wave and Wind Field Sensing

Environmental Sensors

- **Sensors:** Integration of a sensor system to provide real-time estimates of the temporal and spatial ***wave*** and ***wind fields***. Properties of interest include wind speed and direction, standard wave parameters (Hs, Tp), directional wave spectrum, and complete phase-resolved wavefield measurements.

Caveats

This presentation should not be viewed as an endorsement of any of the technologies, and in fact should not be interpreted as being inclusive of all possible applicable technologies.

The information presented herein was obtained from a number of publicly available sources and though I neglected the detailed attribution of the information presented, this information is available. Also, while the work is not mine, any errors in the presentation are mine.

Wind Measurement

Wind Sensors

- Cup and Windmill Anemometers
- Sonic Anemometers
- Laser Doppler Anemometers
- Wind LiDARs

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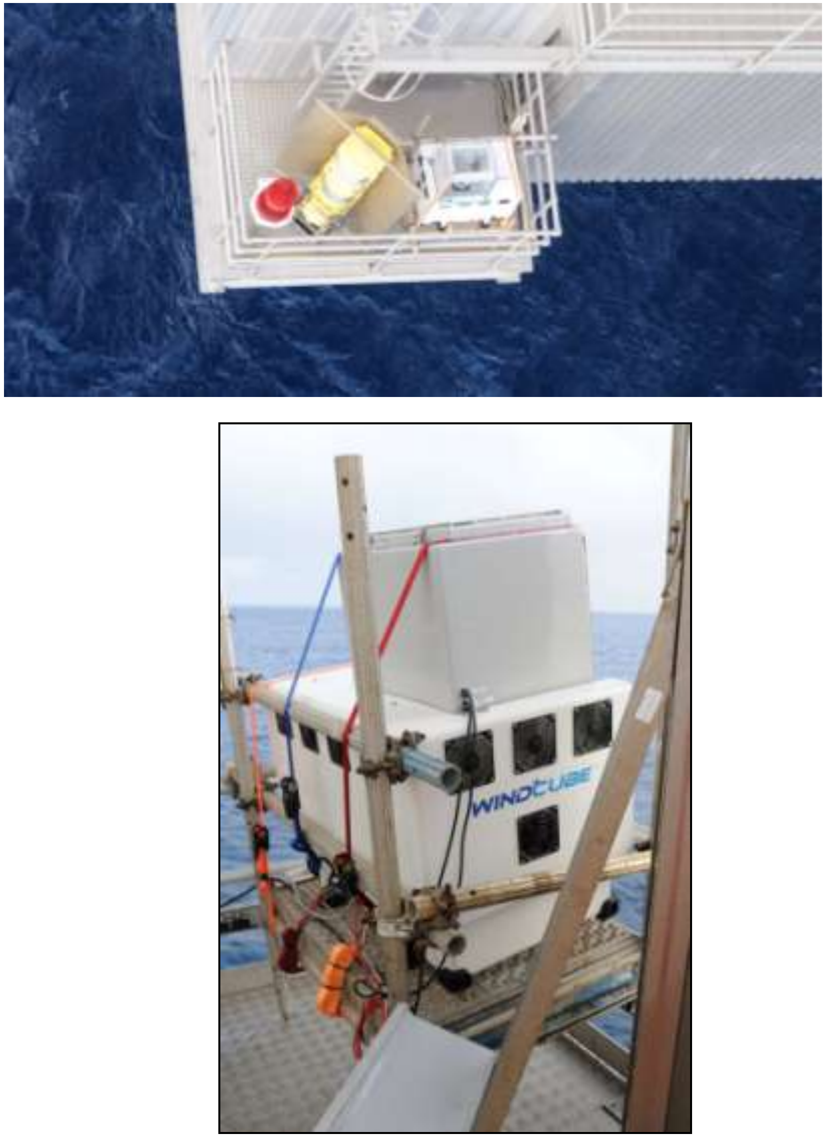
Wind LiDAR

Wind LiDAR profiler

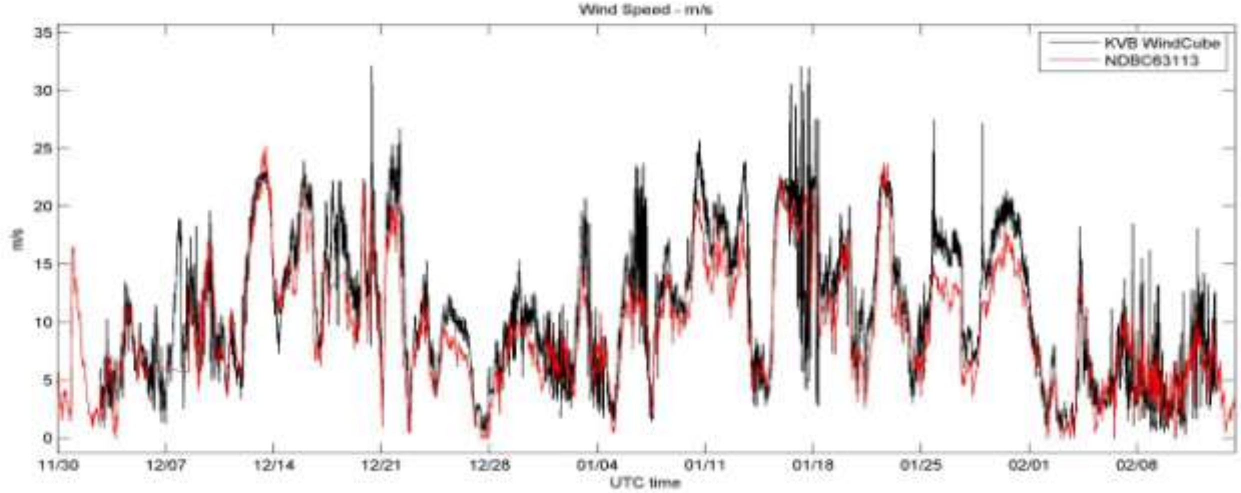
Modified Leosphere Windcube
With computer controlled mirror (two rotating stages)

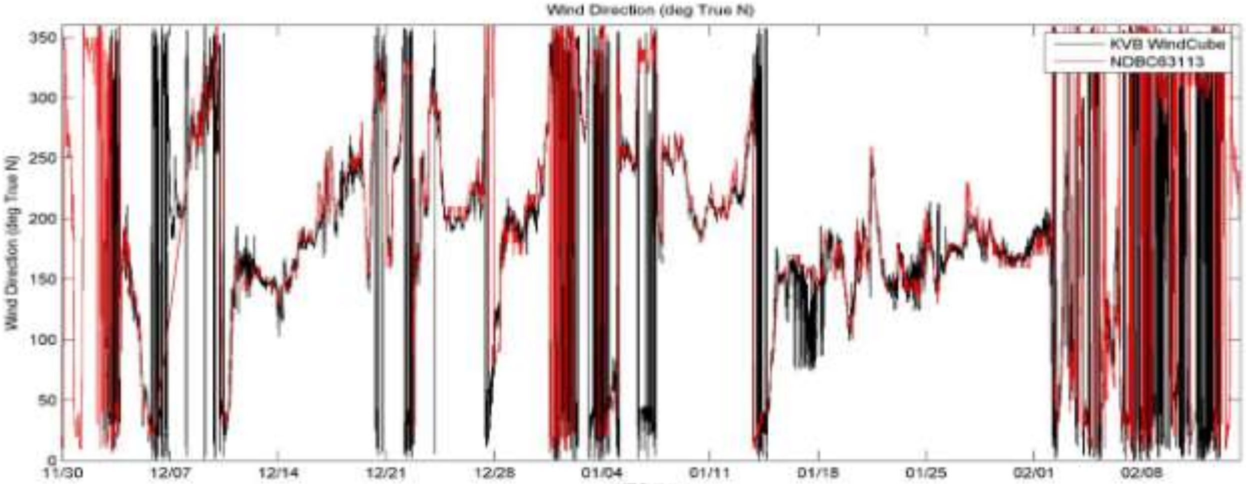


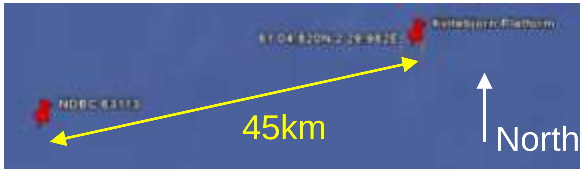
Wind LiDAR

Wind LiDAR profiler – Comparison with NDBC station

WindCube Measurements 120m away from platform







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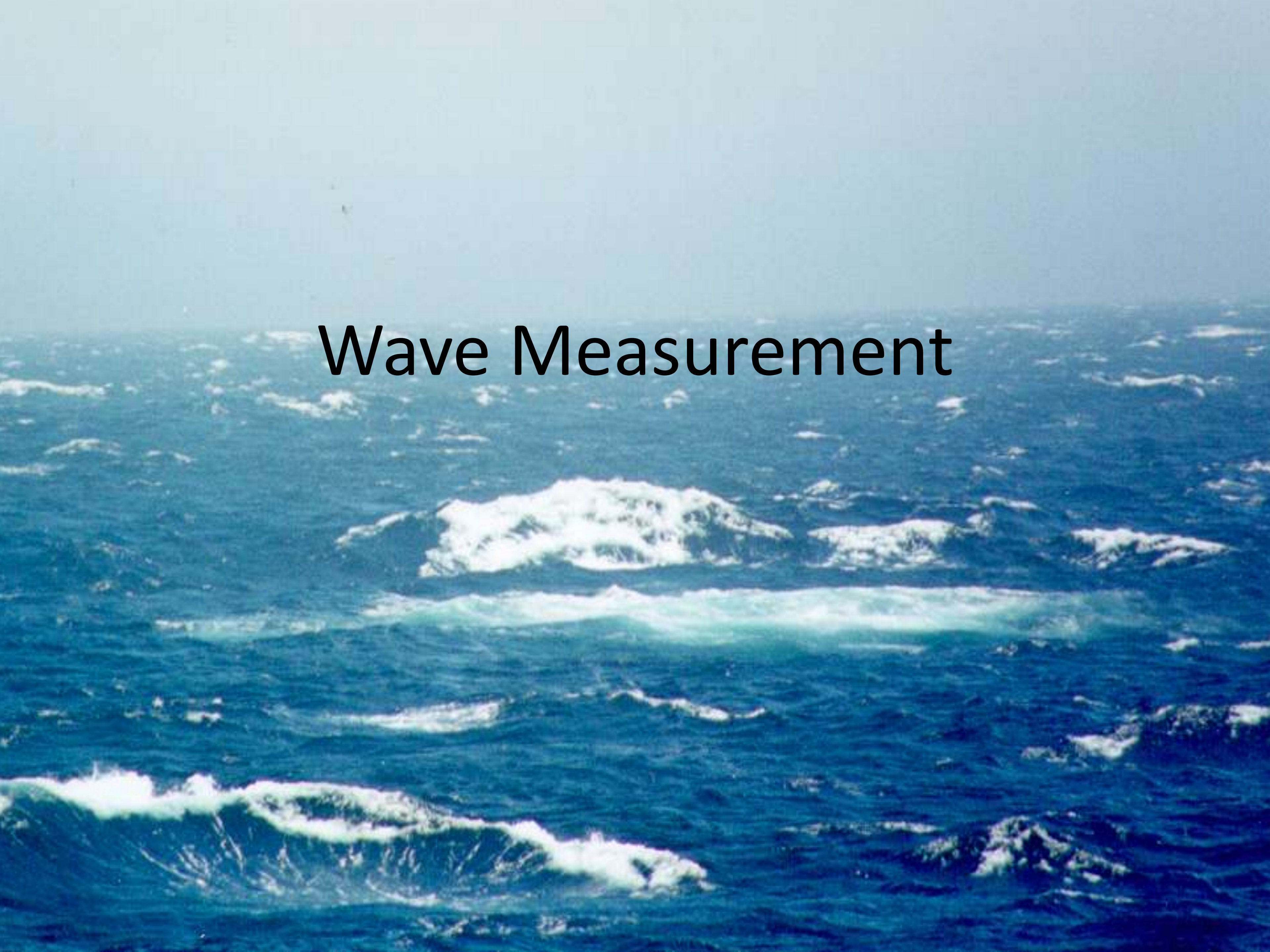
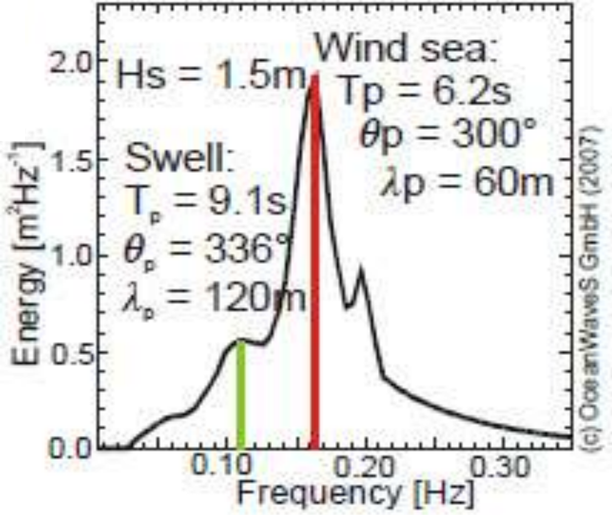
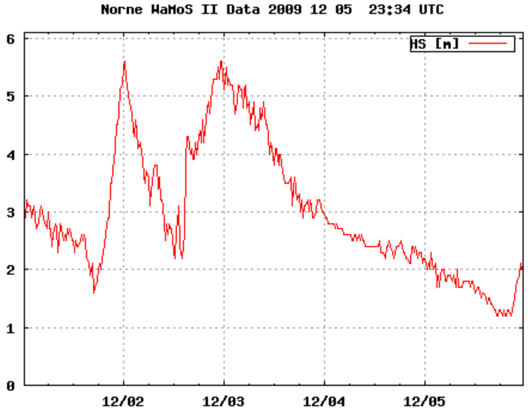


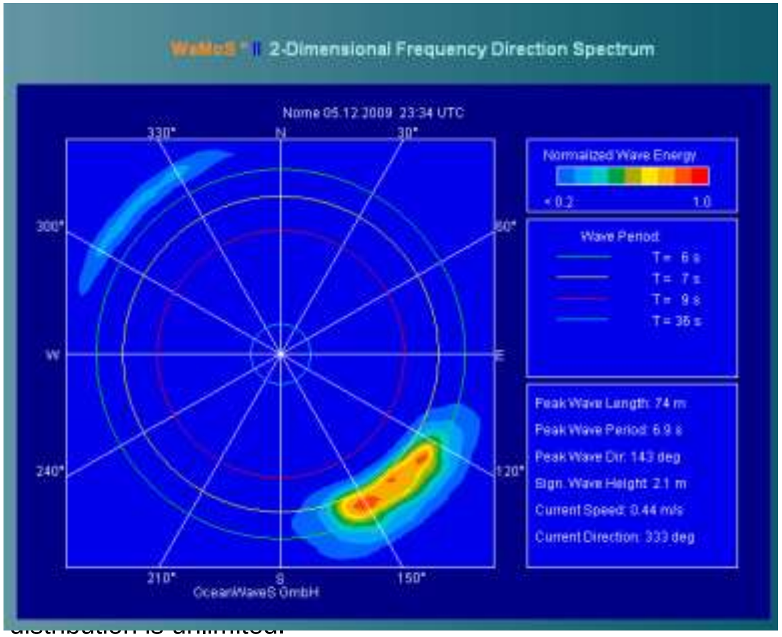
Wave Measurement

Sea State

Top Sea State 3	Top Sea State 4	Top Sea State 5	Mean Sea State 6	Mean Sea State 7	Mean Sea State 8
$H_{1/3}$ = 1.25 m	$H_{1/3}$ = 2.50 m	$H_{1/3}$ = 4.00 m	$H_{1/3}$ = 5.00 m	$H_{1/3}$ = 7.50 m	$H_{1/3}$ = 11.50 m
T_{MP} = 7.5 s	T_{MP} = 8.8 s	T_{MP} = 9.7 s	T_{MP} = 12.4 s	T_{MP} = 15.0 s	T_{MP} = 16.4 s





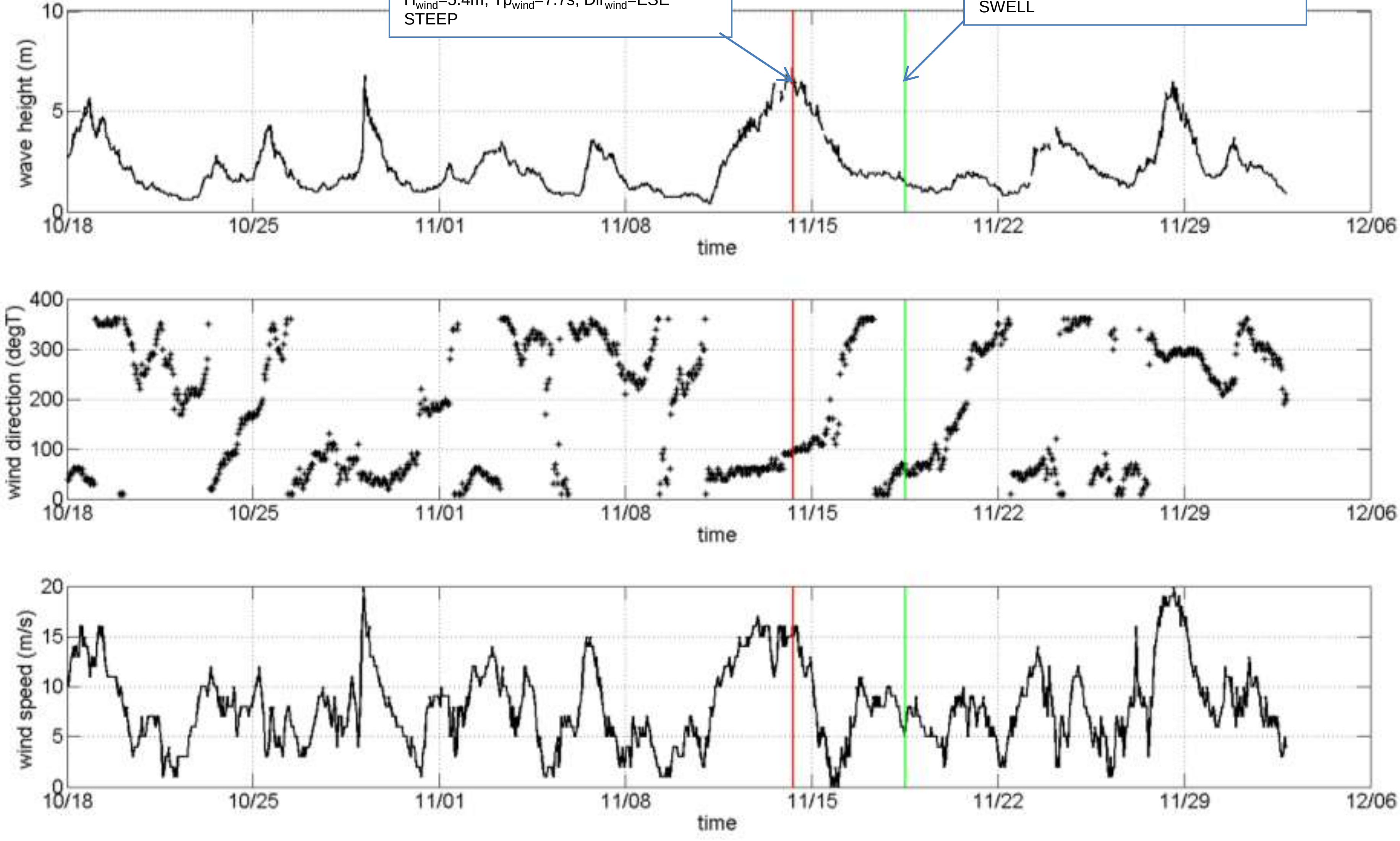


- A sea state is characterized by statistics, including the wave height, period, and power spectrum.

- The sea state ***varies with time***, as the wind conditions or swell conditions change.

- Typically, records of ***one hundred to a thousand wave-periods*** are used to determine the wave statistics

Sample Data



11/14 0700 GMT, SS7
H_s=7.2m, T_p=11s, T_{avg}=8.7s
H_{swell}=4.8m, Tp_{swell}=11.4s, Dir_{swell}=ESE
H_{wind}=5.4m, Tp_{wind}=7.7s, Dir_{wind}=ESE
STEEP

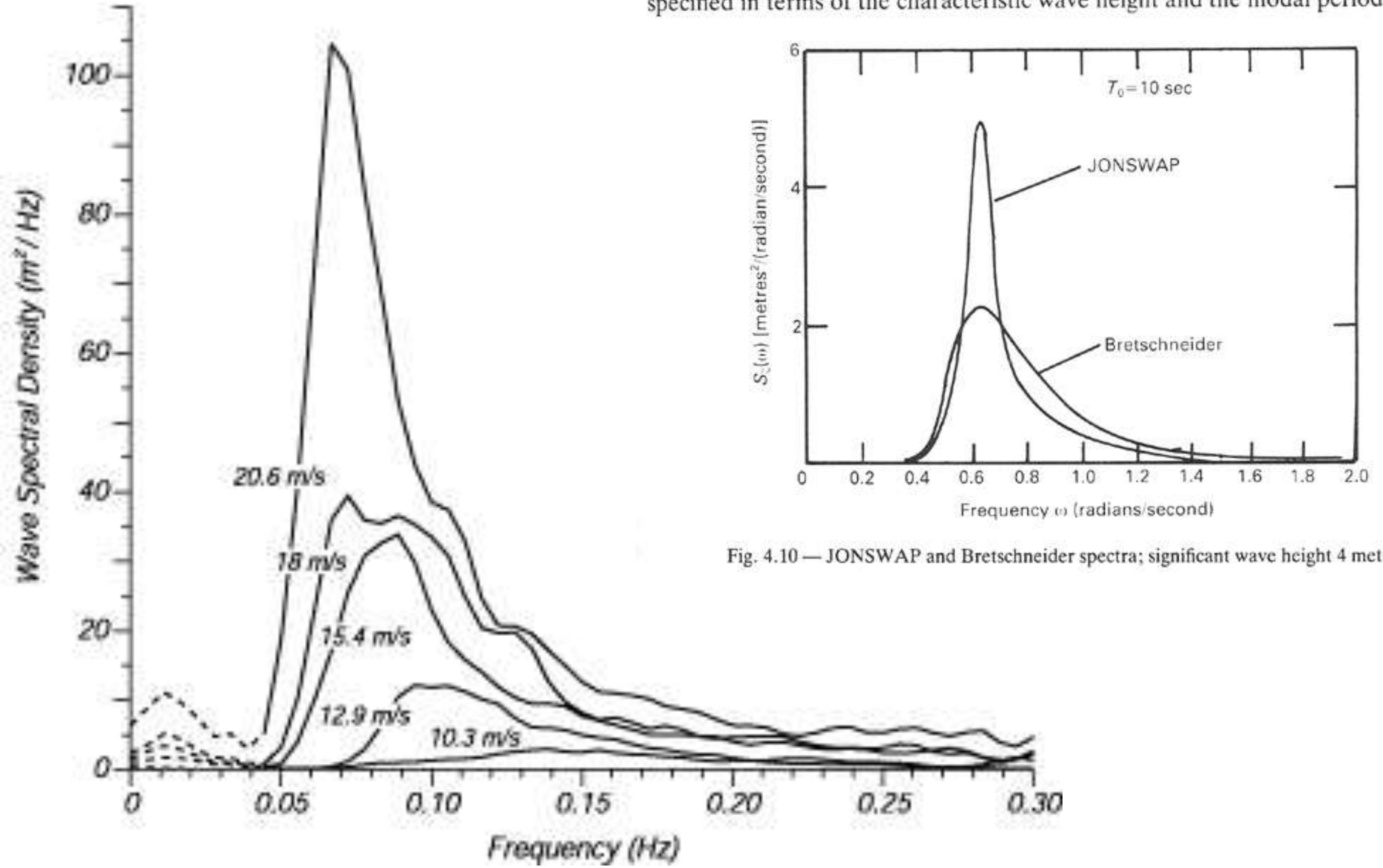
11/18 1400 GMT, SS4
H_s=1.3m, T_p=10s, T_{avg}=5.6s
H_{swell}=1.0m, Tp_{swell}=10s, Dir_{swell}=ESE
H_{wind}=0.9m, Tp_{wind}=5.9s, Dir_{wind}=NE
SWELL

NDBC Buoy 44008, 54NM southeast of Nantucket

Wave Spectra

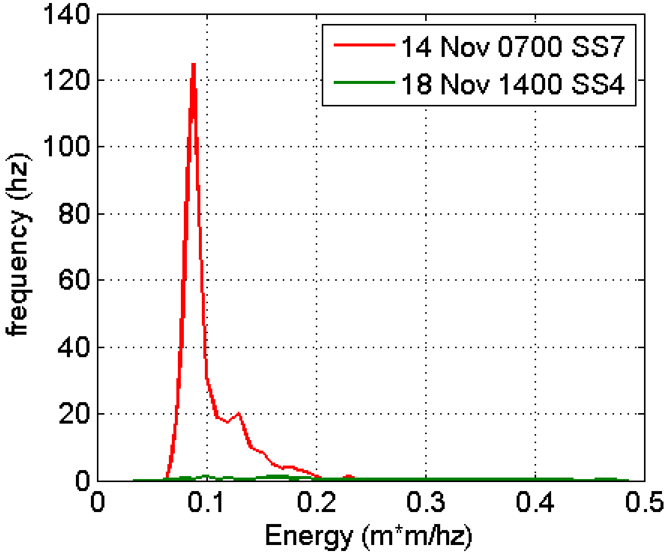
The JONSWAP spectrum is thus a distortion of the Bretschneider spectrum specified in terms of the characteristic wave height and the modal period. Fig. 4.10

Fig. 4.10 — JONSWAP and Bretschneider spectra; significant wave height 4 metres.

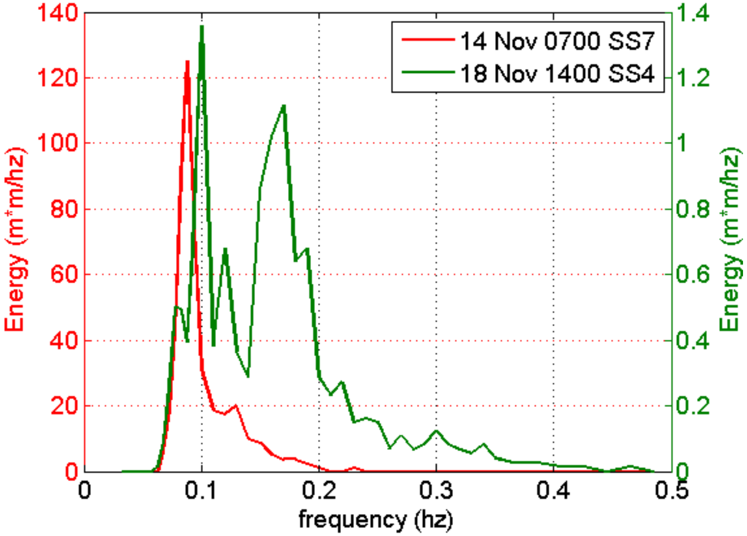


Wave spectra of a fully developed sea for different wind speeds according to Moskowitz (1964)

Wave Spectra



SS7 and SS4 from Buoy 44008 with same y-axis scales

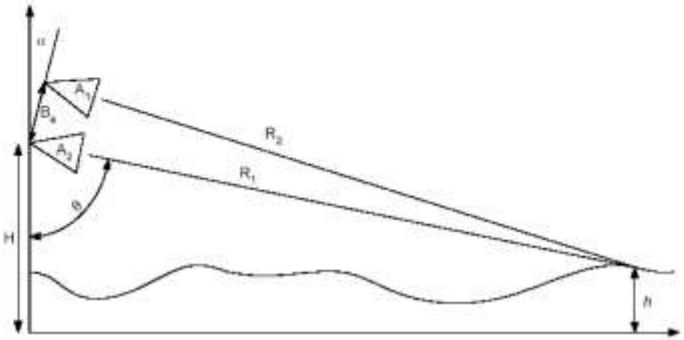


SS7 and SS4 from Buoy 44008 with different y-axis scales

Radar based Systems

Radar Interferometers

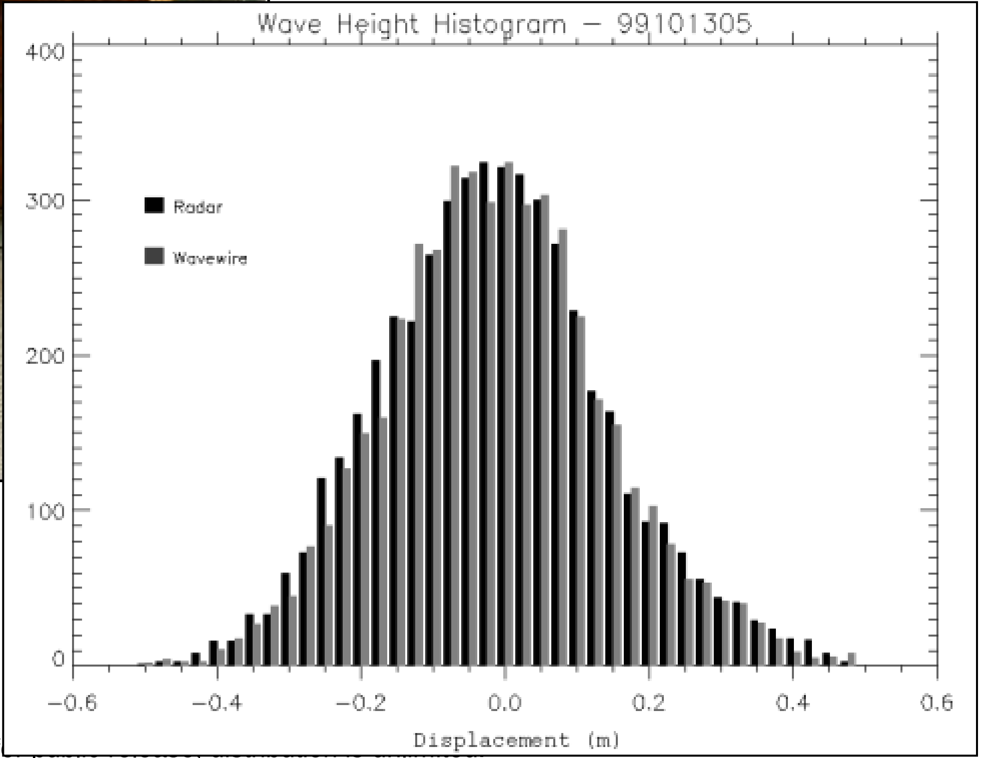
- Applications:
  - “Long” term ship navigation using wave-field prediction
  - Short term ship navigation (reaction navigation)
- Application requirements:
  - Range of detectable ocean wavelength, wave height and slope
  - Radius of coverage
  - Data update rate



- Technical constraints:
  - Feasibility of the mechanical design
  - Effects of boat motion
  - Expected range of pitch and roll for which the system must compensate

FOPAIR: Interferometer Mode

FOPAIR - Focused Phased Array Imaging Radar



HF Radar Systems

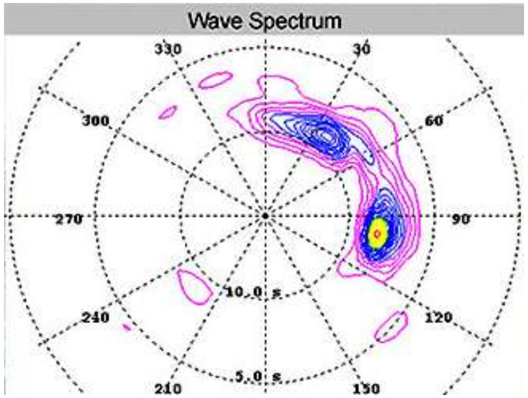
HF Current Mapping Radar

Navigation Radars

There a number (few) commercial systems utilizing marine navigation radar systems.

- WaMos II – Developed by GKSS, commercialized by OceanWaves (Germany)
- Wavex – Developed by MIROS A/S (Norway)

- Signal processor interface to standard marine navigation radar
- Provides integral wave parameters (Hs, Period, Wavelength)
- Provides frequency and wavenumber directional spectra
- Non-Doppler (***empirically based retrieval, local cal. required***)



Nonlinear Imaging Process

X-band backscatter from a wind roughened surface is modulated by several processes

1. HYDRODYNAMIC MODULATION: Longer gravity waves modulate the backscatter as they propagate beneath the capillary waves
2. TILT MODULATION: Modulation due to changes in the incidence angle of the electromagnetic waves along the long wave slope
3. SHADOWING: Higher waves block intermediate and small waves at grazing incidence
4. BREAKING: Breaking waves lead to sea spikes

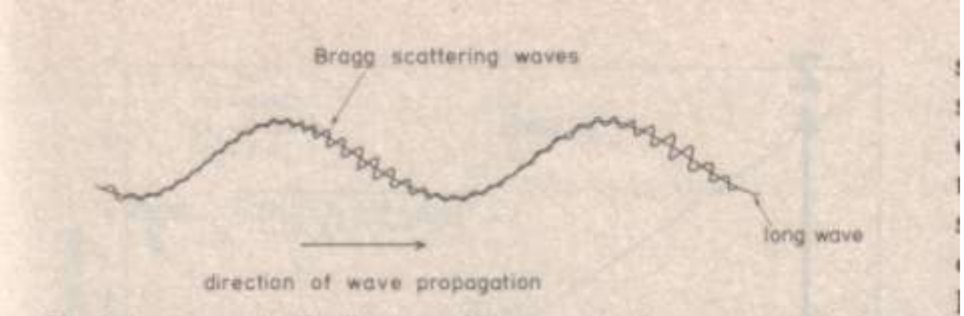
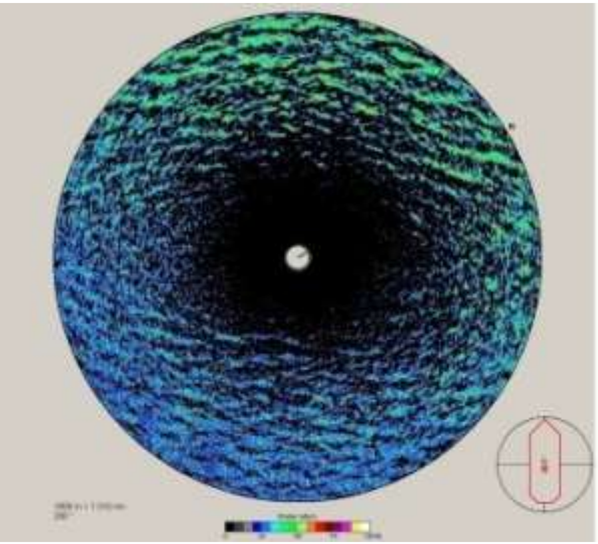


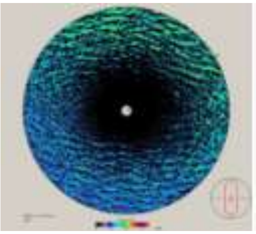
Fig. 2. Asymmetric distribution of Bragg scattering waves on the long wave due to hydrodynamic interactions.

(Alpers et al., 1981)

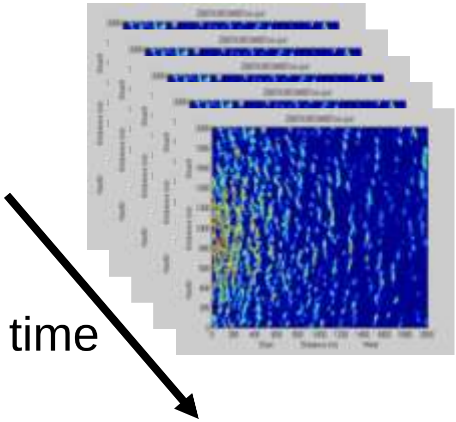


Navigation Radars

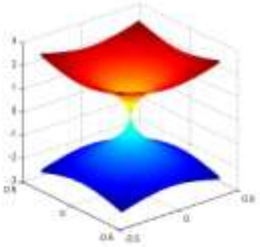
Basic Approach for Inverting X-band Backscatter for Surface Waves



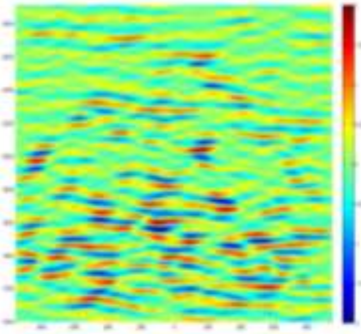
Backscatter



time



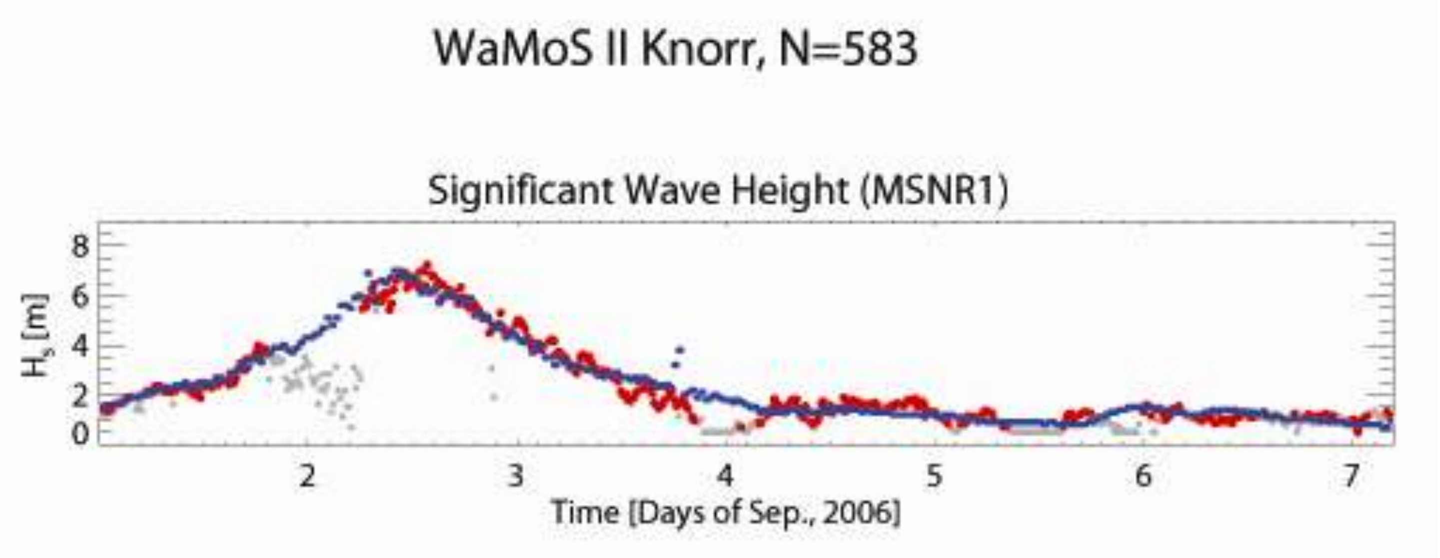
Passband filter based upon dispersion relation



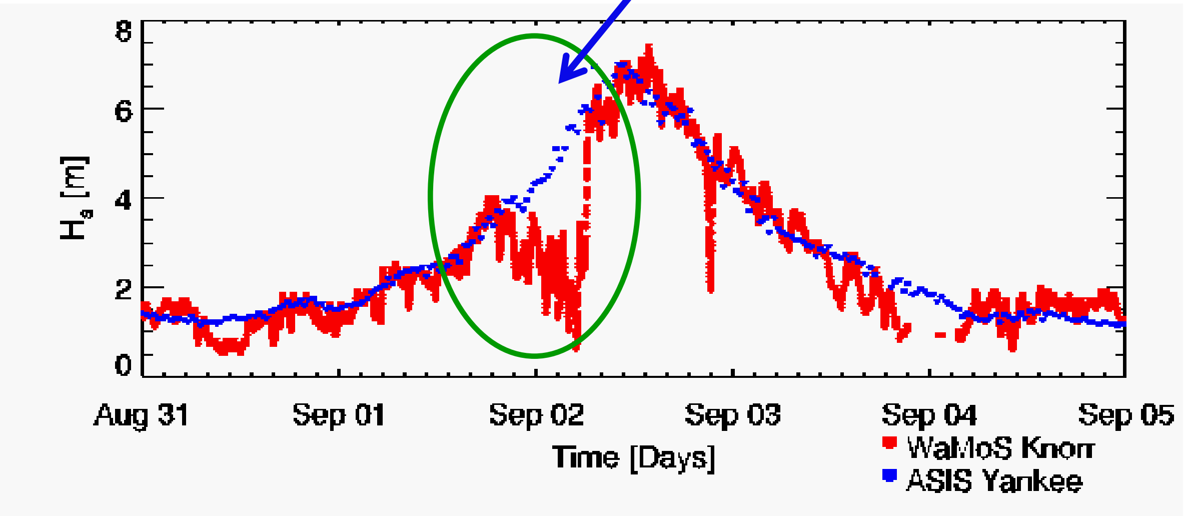
Invert filtered record, apply MTF, scale variance to HS

(Young et al 1985, Seemann et al 1995, 1997, Borge et al 2000, 2004)

Navigation Radars - Issues



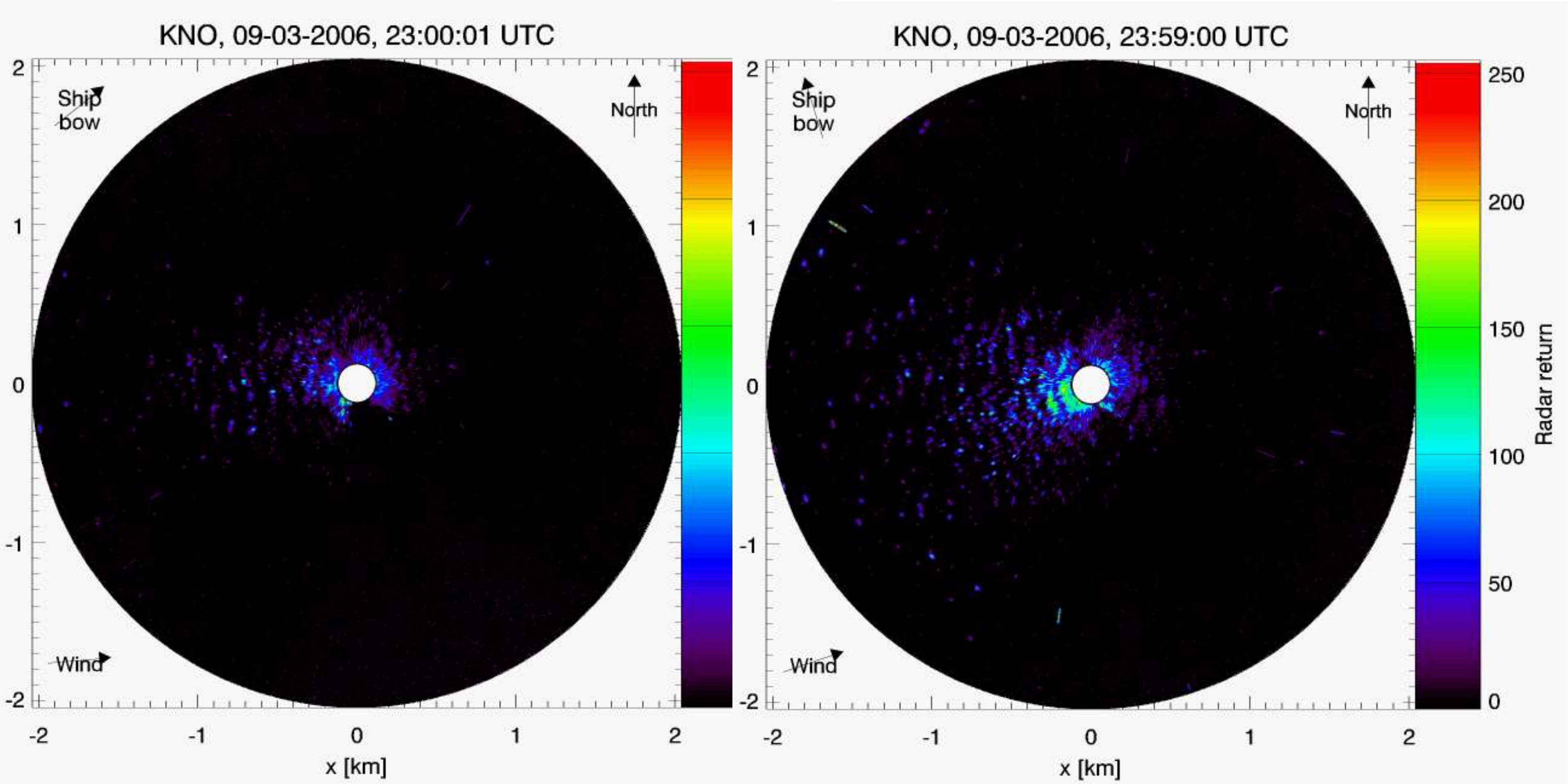
Rain changes the surface roughness and hence the backscatter from radar



Contamination by rain

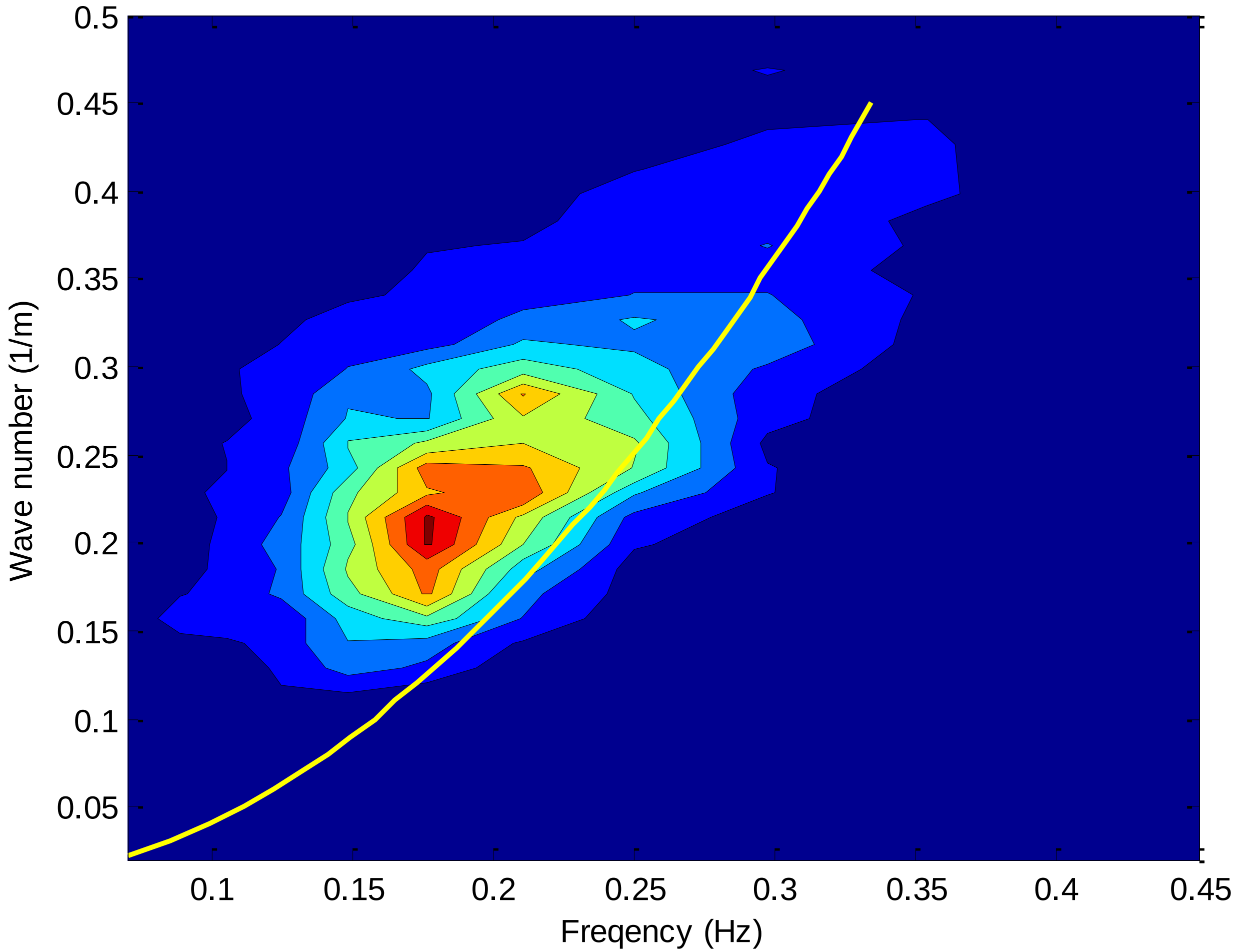
Navigation Radars - Issues

Radar Backscatter in Low Winds (~3m/s)



Swell still visible in a narrow window upwind, but not in other areas. Total wave height estimates may still be biased too low.

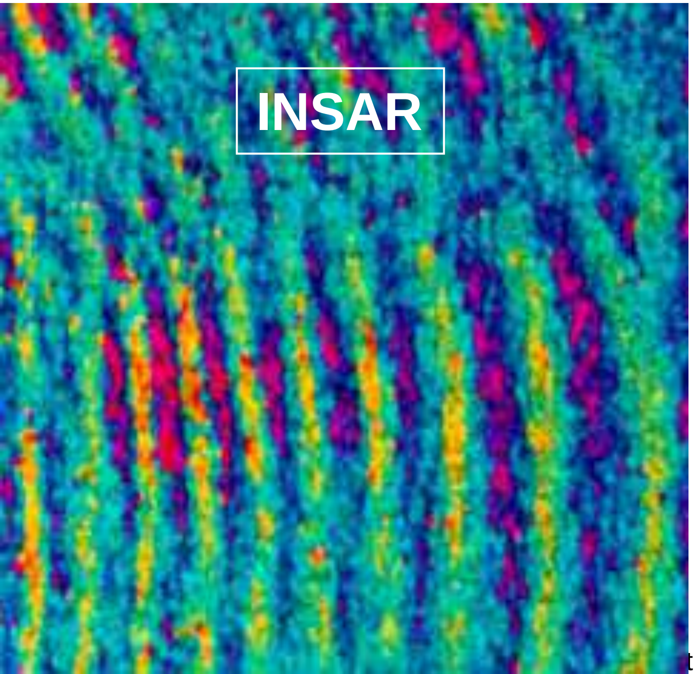
Navigation Radars - Issues

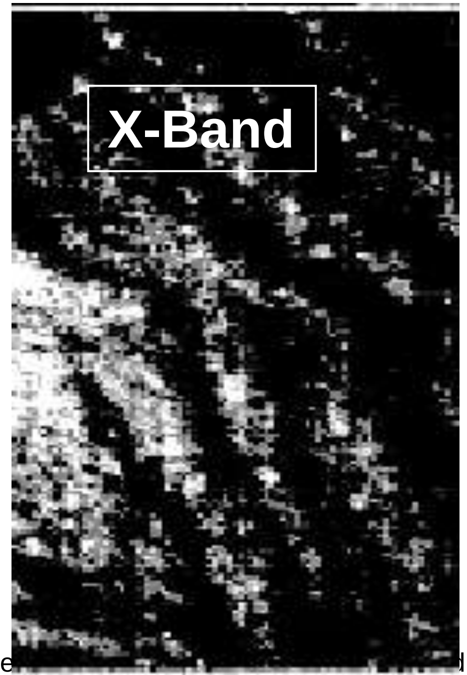


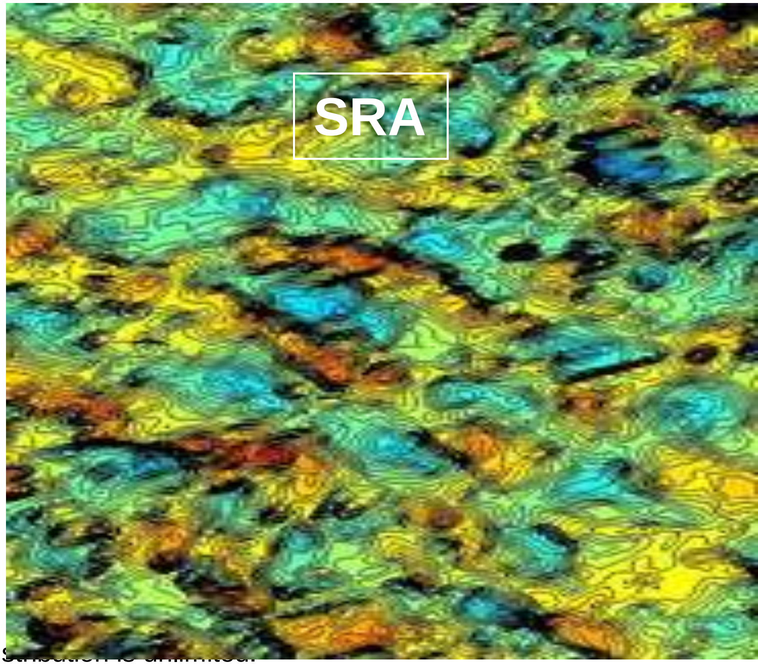
Doppler shift due to ~65 cm/s current

Imaging Radars

- **Coherent Instrumentation Radar**
- **Interferometric Synthetic Aperture Radar (INSAR)**
- **Scanning Radar Altimeter (SRA)**



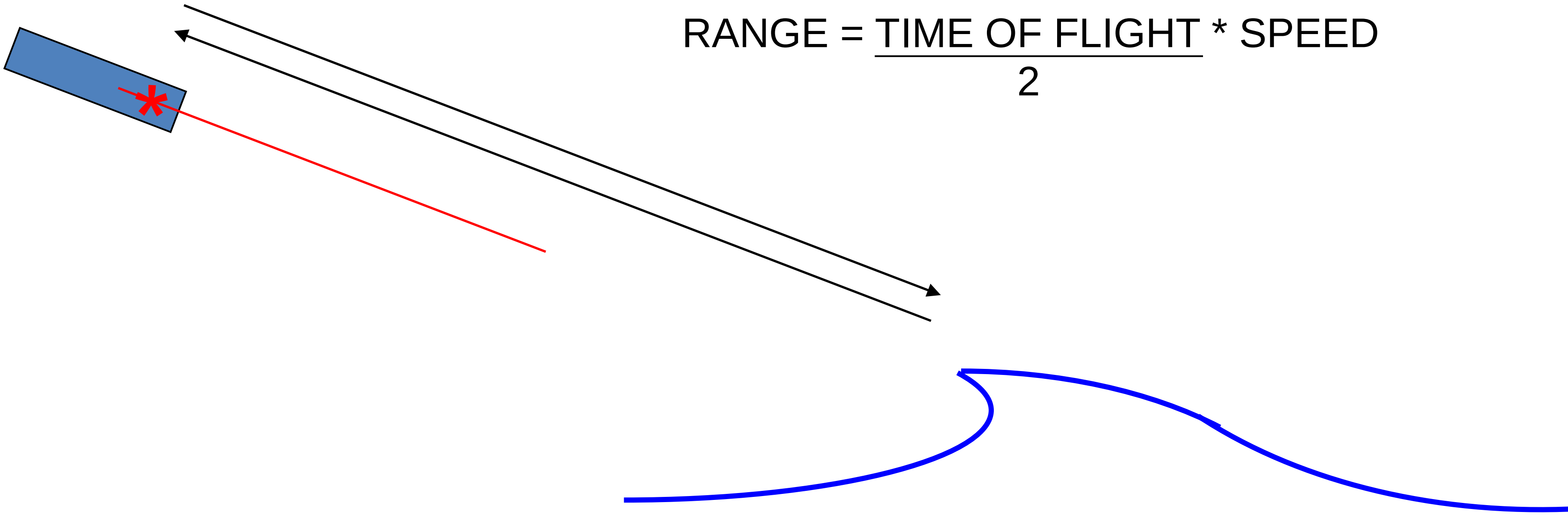




LiDAR based Systems

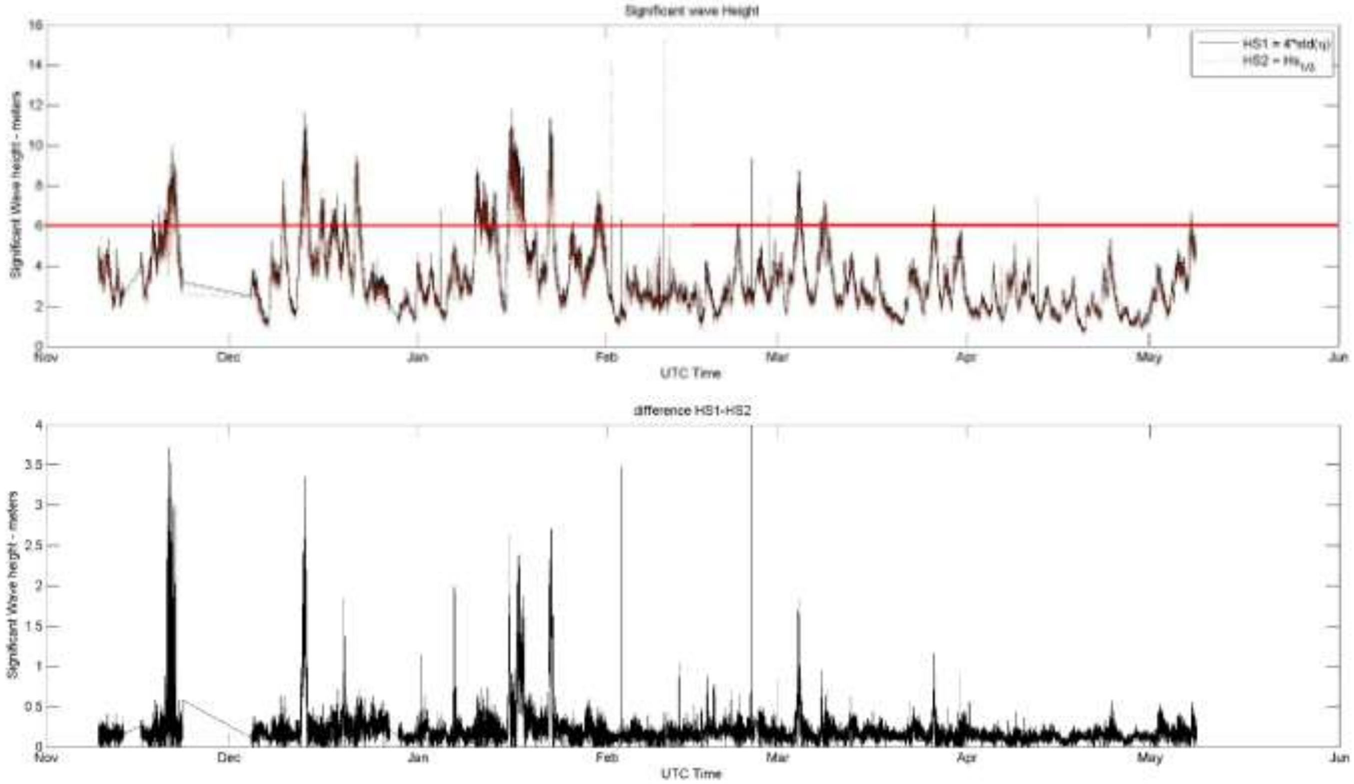
LiDAR

Light Detection And Ranging (LiDAR) is essentially a Radar system that uses ***laser light*** in place of the radar’s radio frequency (RF) for ranging



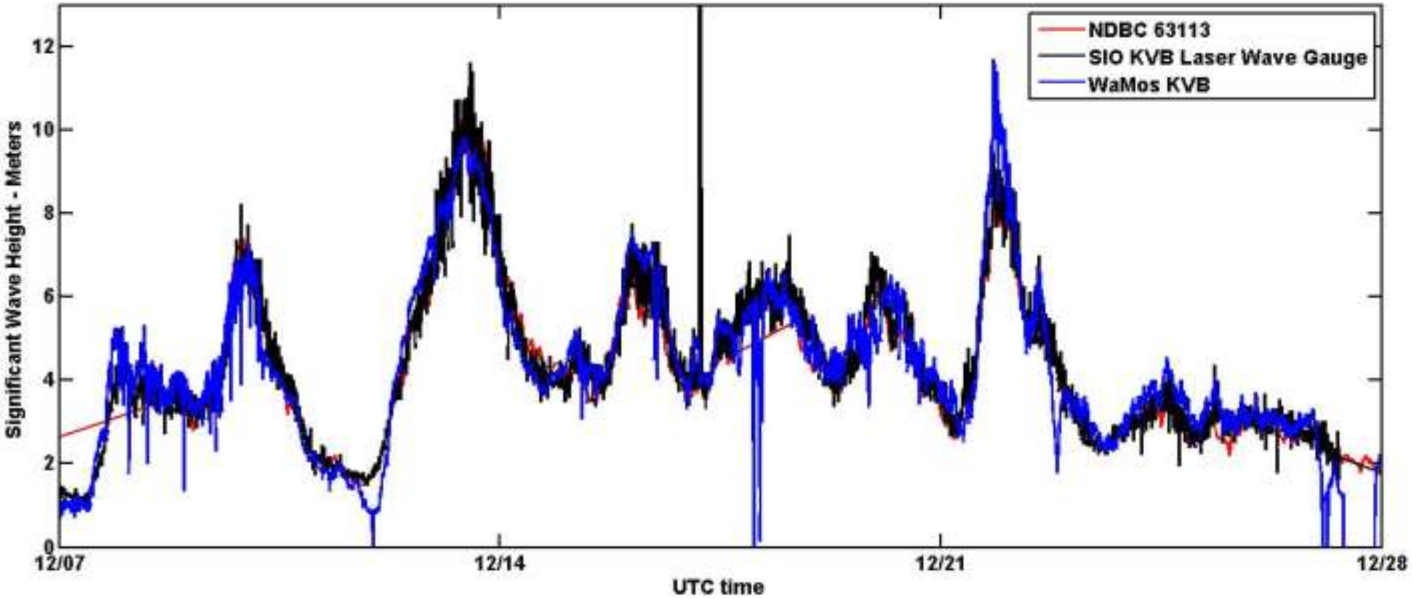
$$\text{RANGE} = \frac{\text{TIME OF FLIGHT}}{2} * \text{SPEED}$$

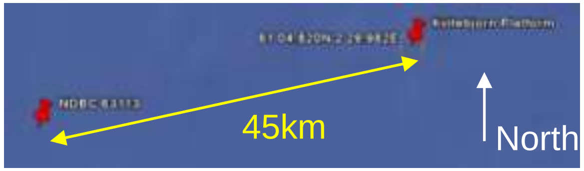
SIO Laser Wave Gauge – Overview (10min average)



LiDAR

WaMoS II System – Comparison with Laser Wave Gauge and NDBC Station 63113

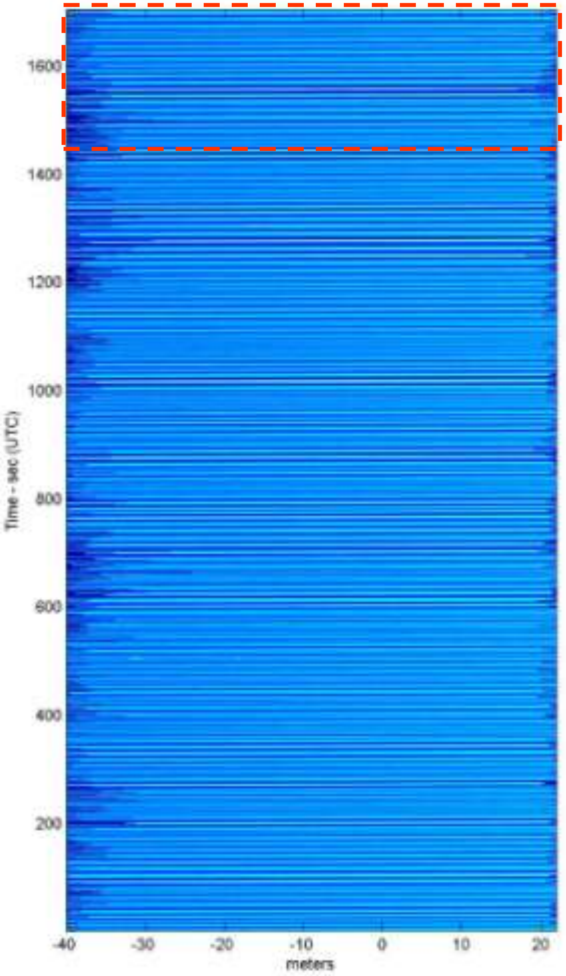




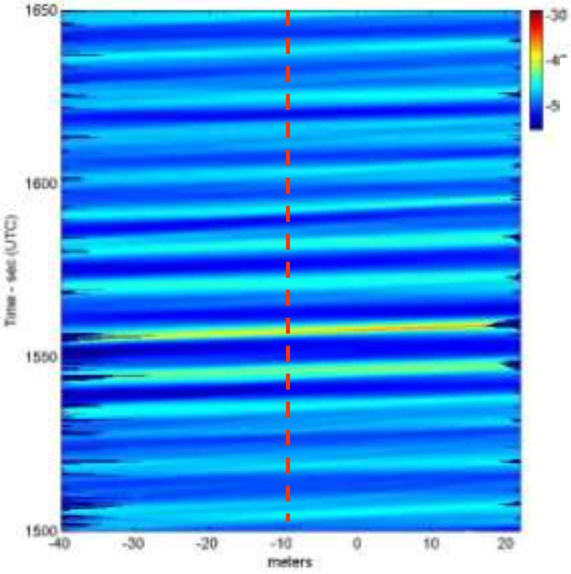
LiDAR

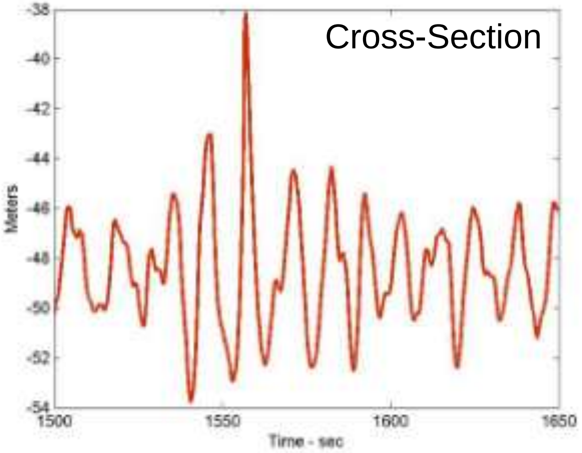
Scanning Laser Altimeter – Riegl Q240i

Wave Elevation Profile



Wave Elevation Profile

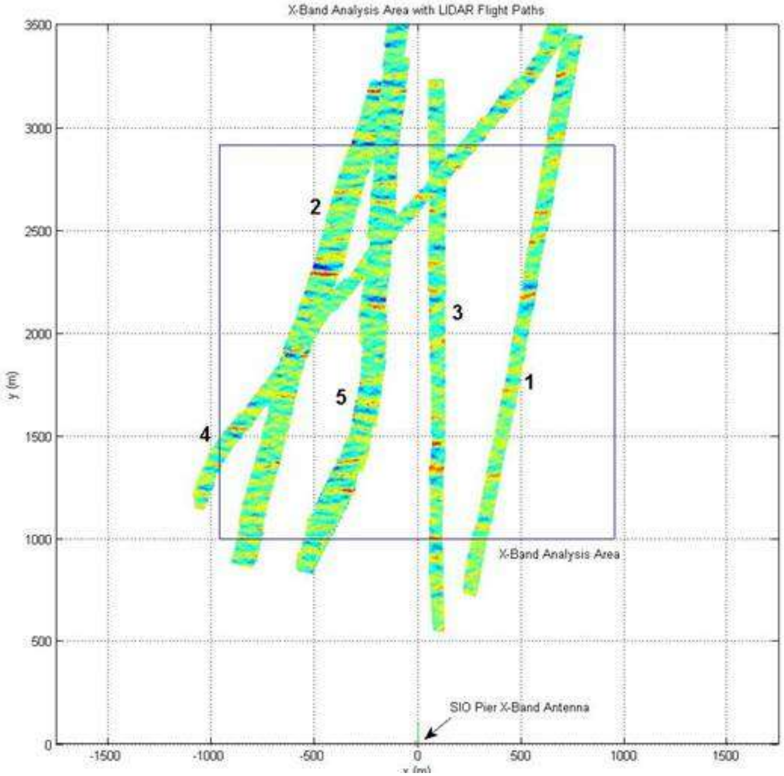


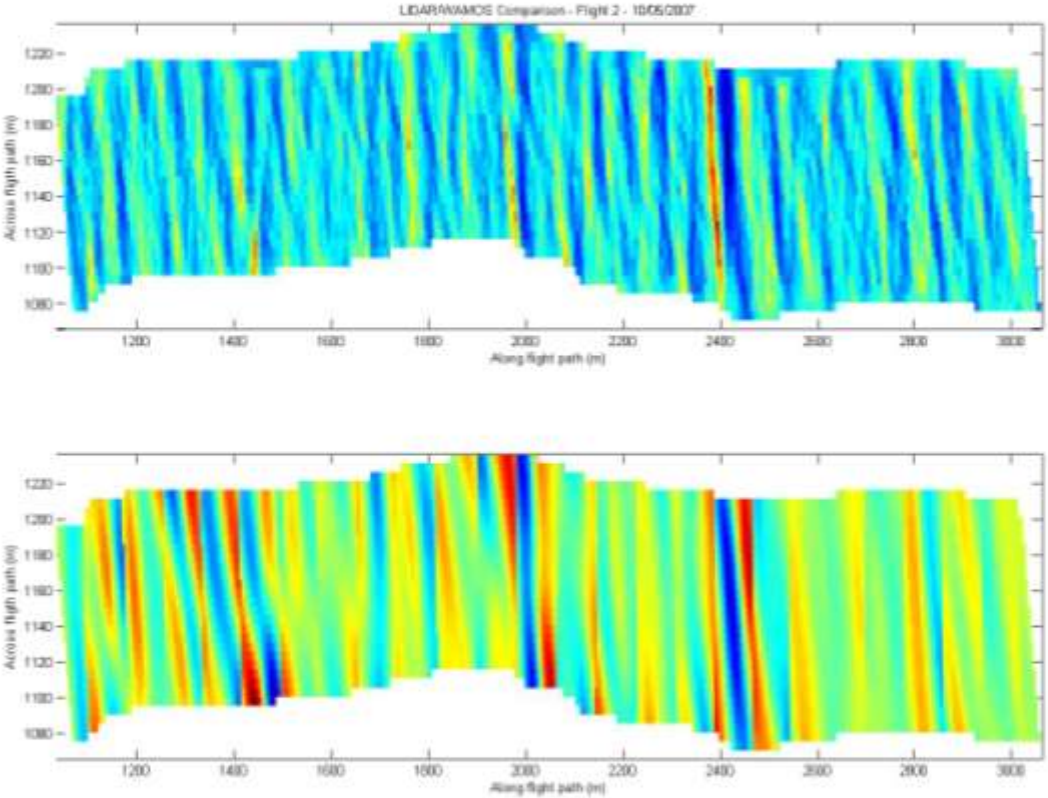


01/17/2009 17:00 UTC Wind Speed ~ 20m/s Hs = 7m

LiDAR Comparison to WaMoS Radar System

(Melville, Lenain, Reineman)



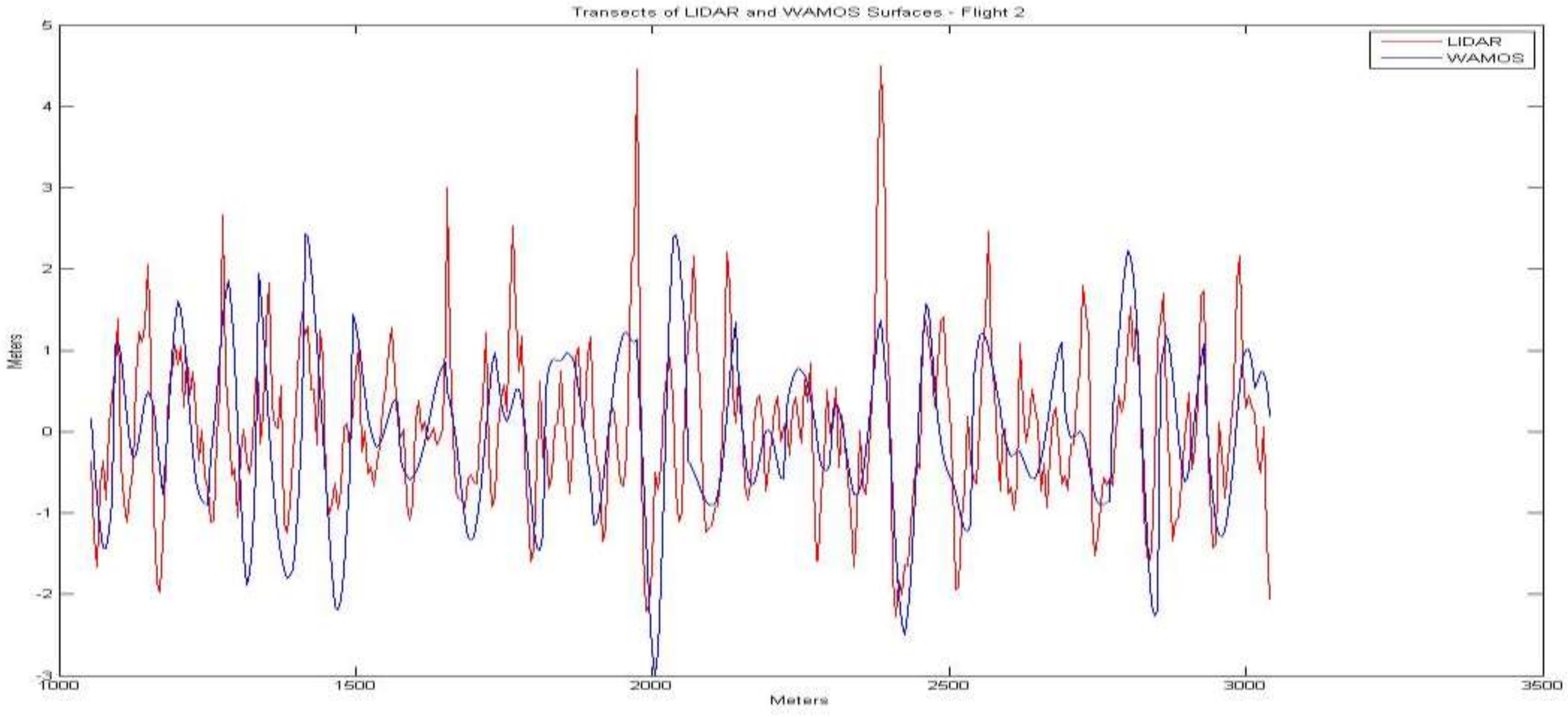


Along Flt Path 2

LiDAR - Airborne

LIDAR Comparison to WaMoS Radar System

(Melville, Lenain, Reineman)

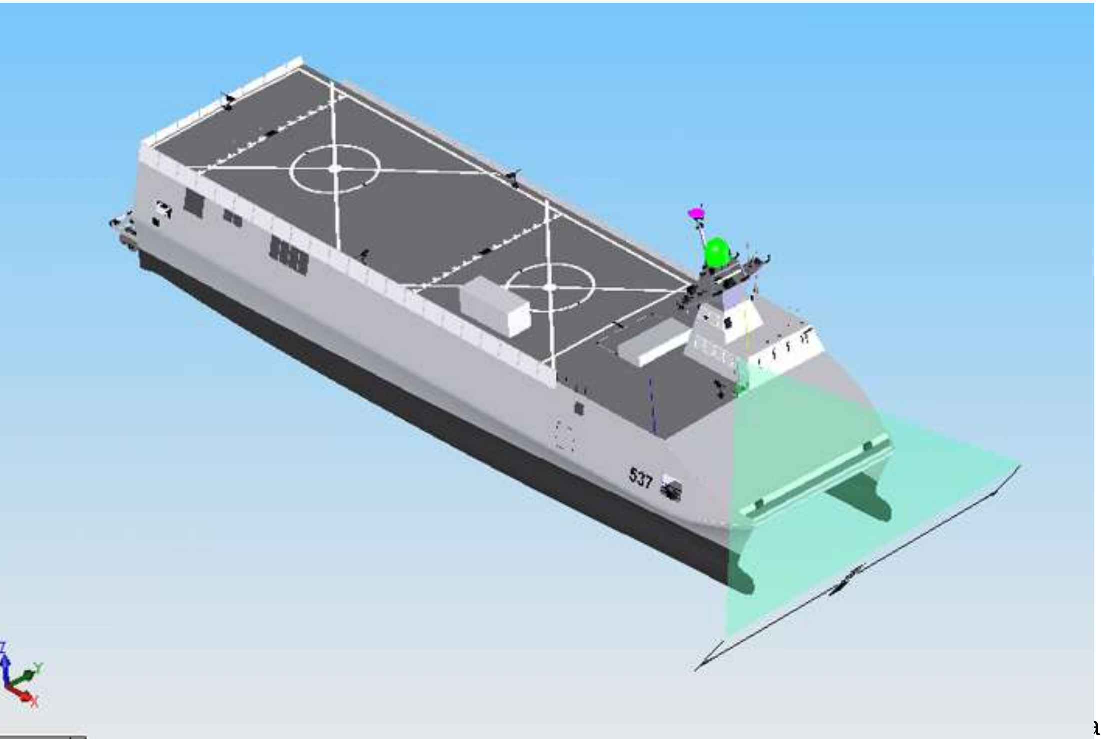


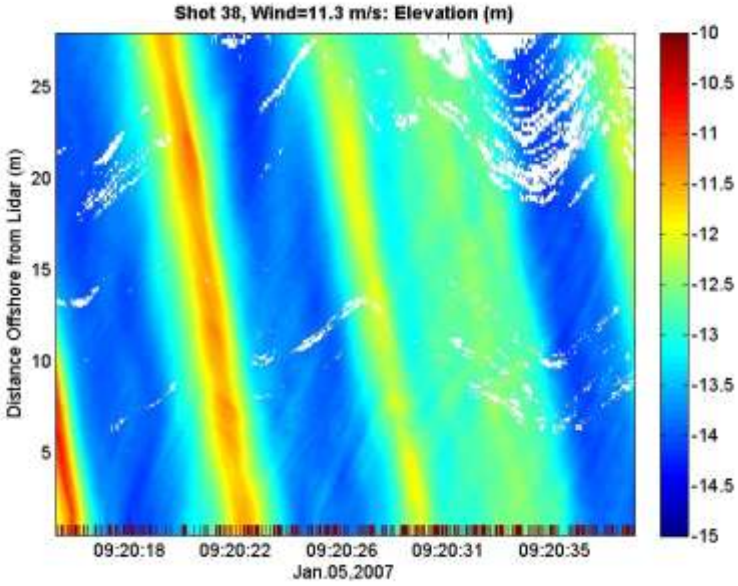
Transect Comparison
Taken Down the Middle of the Flight Path 2

LiDAR - Shipboard

Ship-based LiDAR Measurements

- **Tower Mounted LiDAR System**
- **Independent measurement of wavefield using LIDAR**
- **Time-synchronized 6 DOF measurements of vessel motions**





LiDAR - Issues

Eye-Safety

- Laser measurements can be significantly impacted by eye safety.

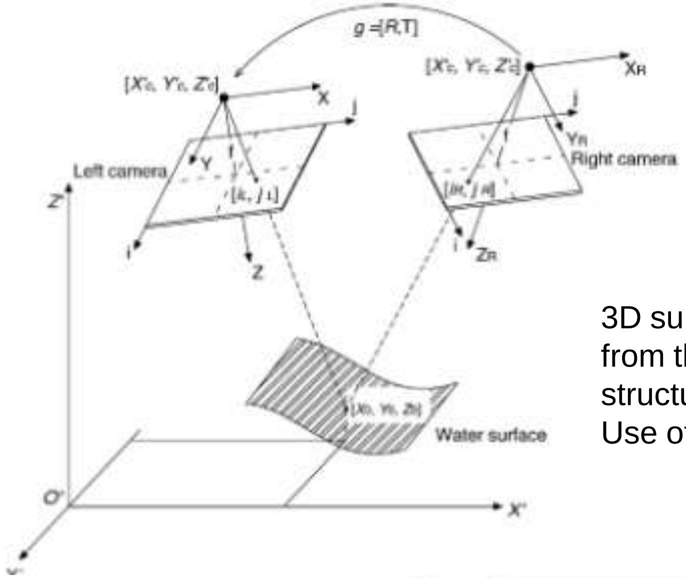
- Since five inch binoculars are routinely used aboard ships, the ***Navy has very restrictive laser safety requirements***. In addition, Navy ships often operate in international coastal waters where they can viewed by observers using either binoculars and telescopes.

- Thus any laser routinely used on a Navy ship (ie not part of combat operations) must be safe for a wide range of viewing scenarios.

Stereo Imaging

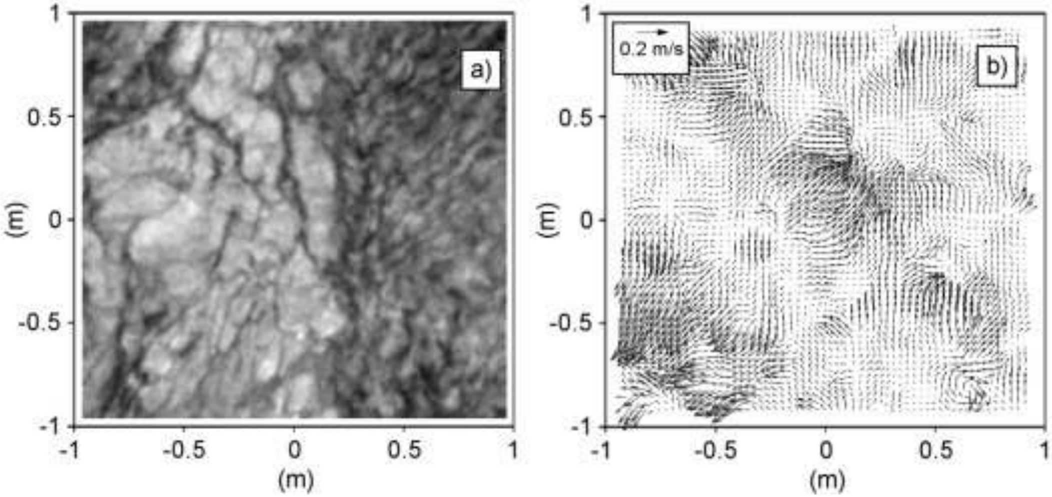
Stereo Imaging

Stereo Infrared/Visible Imagery – 3D surface measurements

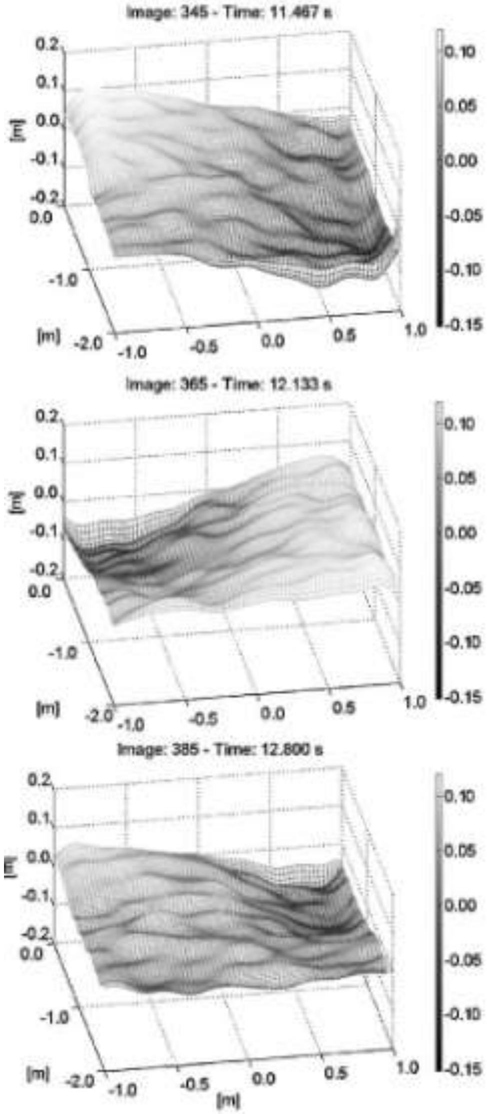


3D surface retrieval (night and day) from the Surface Temperature structures

Use of two LWIR Cameras



Sample IR image and corresponding velocity derived from PIV analysis

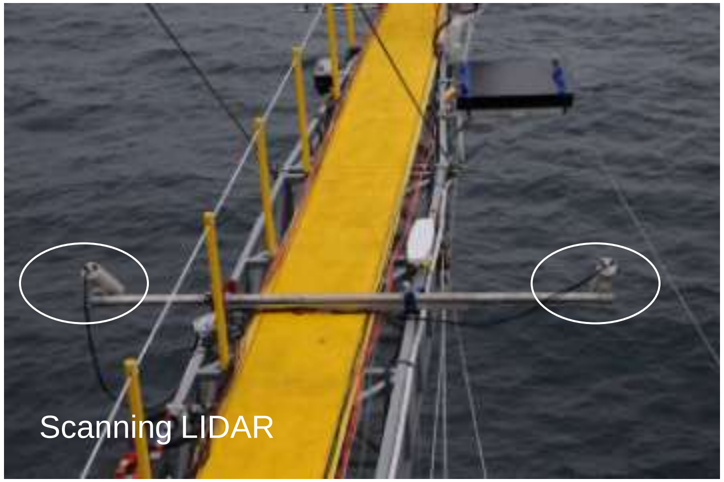


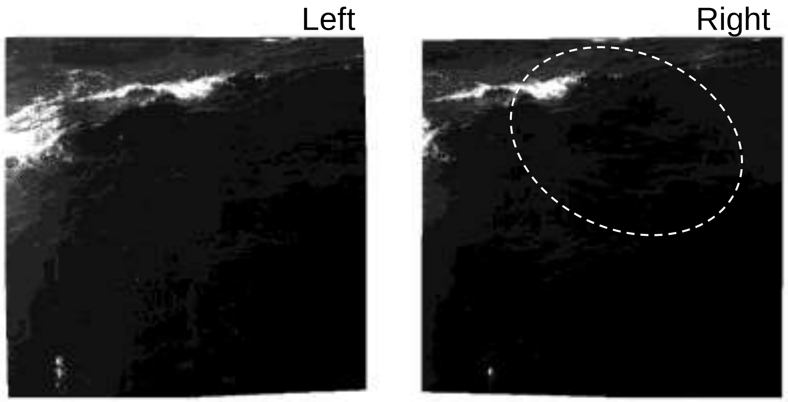
Sample 3D surface retrieval using Visible imagery

Stereo Imaging

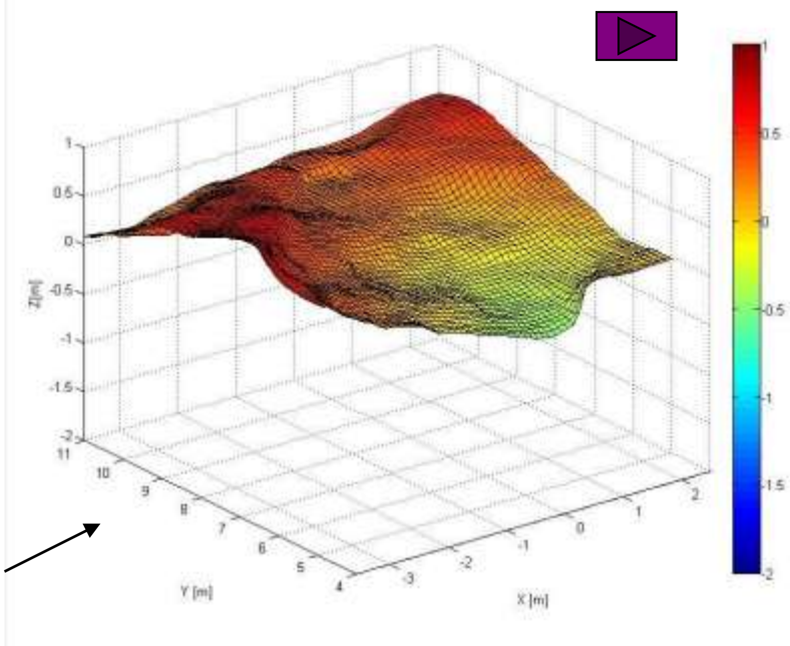
RaDyO Santa Barbara Channel Experiment
Stereo Imaging System

Two 4Mpx cameras mounted on the Starboard boom (10Hz), collocated with a scanning LIDAR





19/09/2008 23:03:85.5 UTC



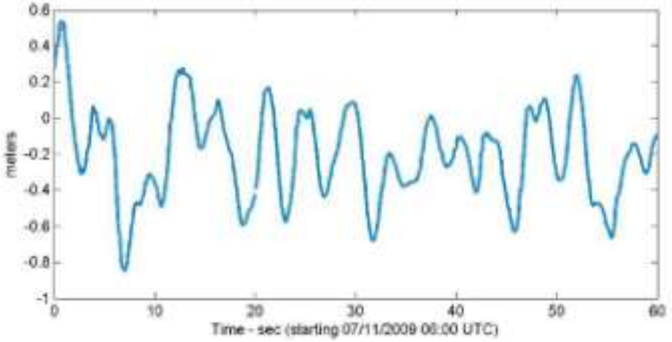
19/09/2008 23:03:85.5 UTC

Stereo Imaging

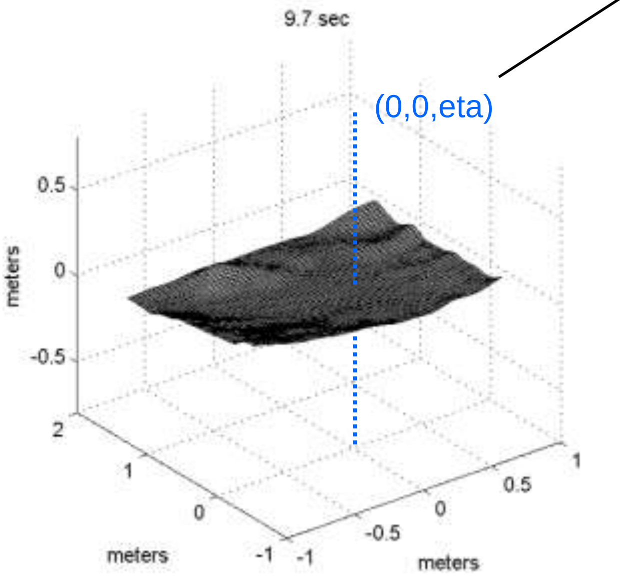
Stereo IR Imaging – HiRes July 2009 Cruise (Preliminary)

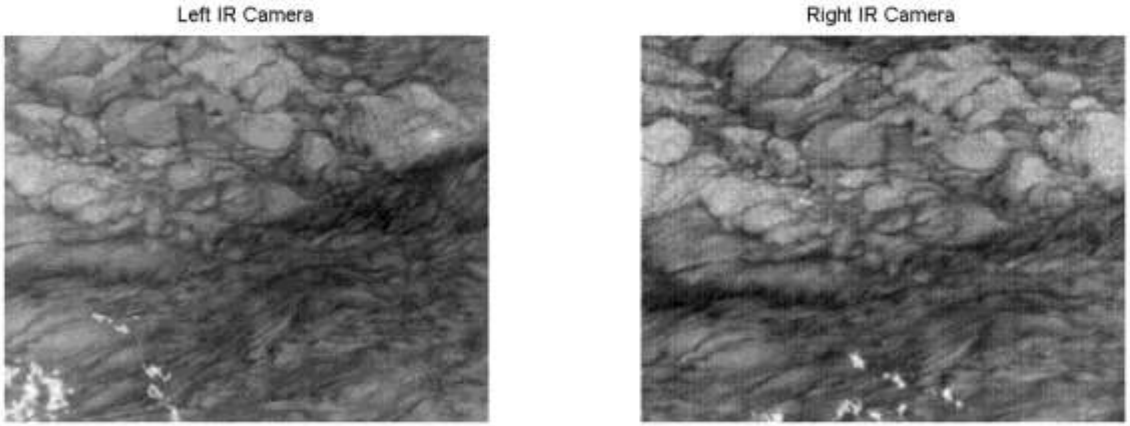
Courtesy of Melville, K. SIO-UCSD

Wave Elevation measured at x=0m,y=0m



Movie




Left IR Camera

Right IR Camera

Wind Speed ~2-3m/s

Stereo Imaging - Shipboard

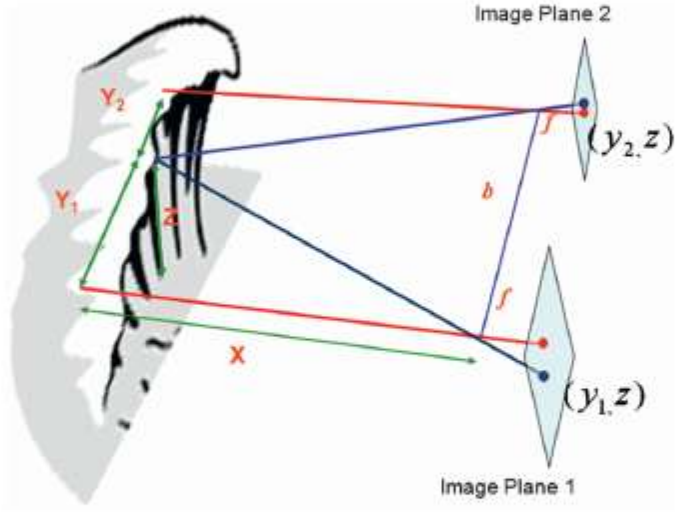


FIG. 2. Stereo imaging geometry.

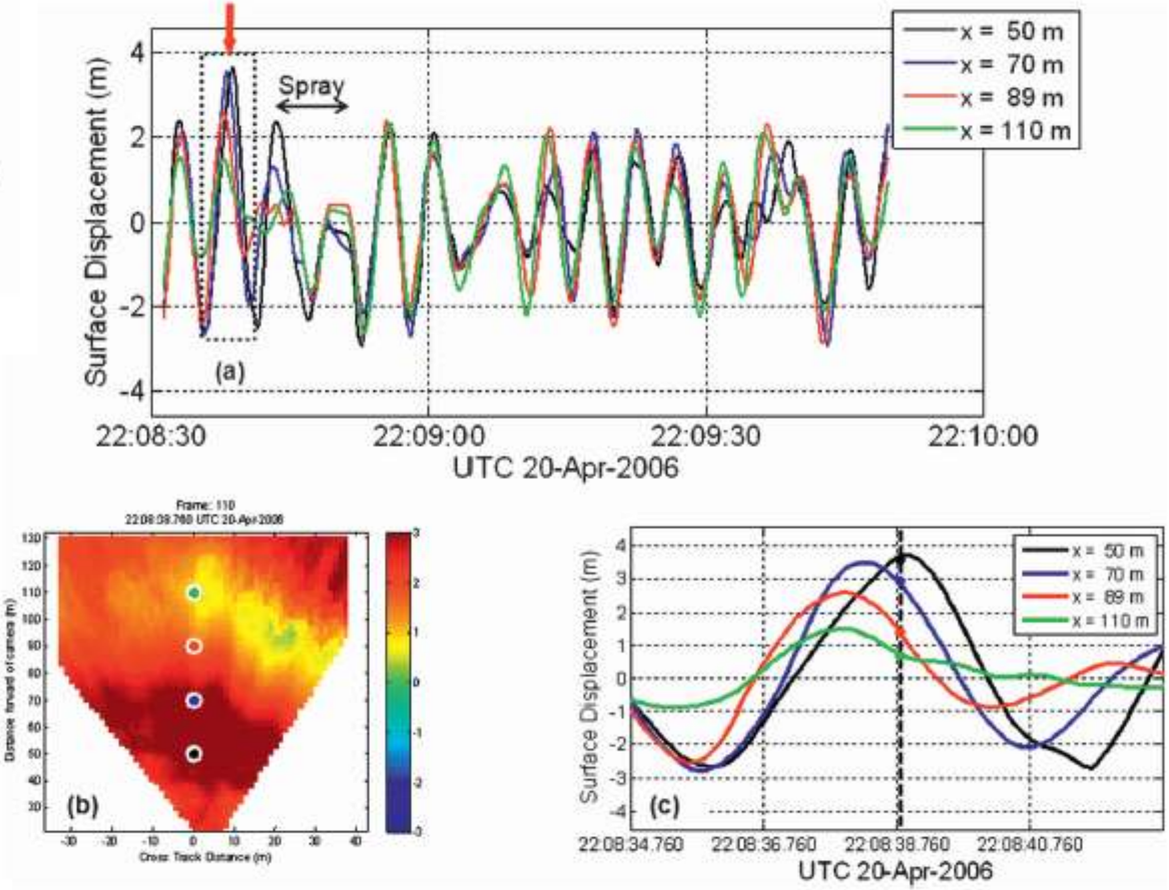


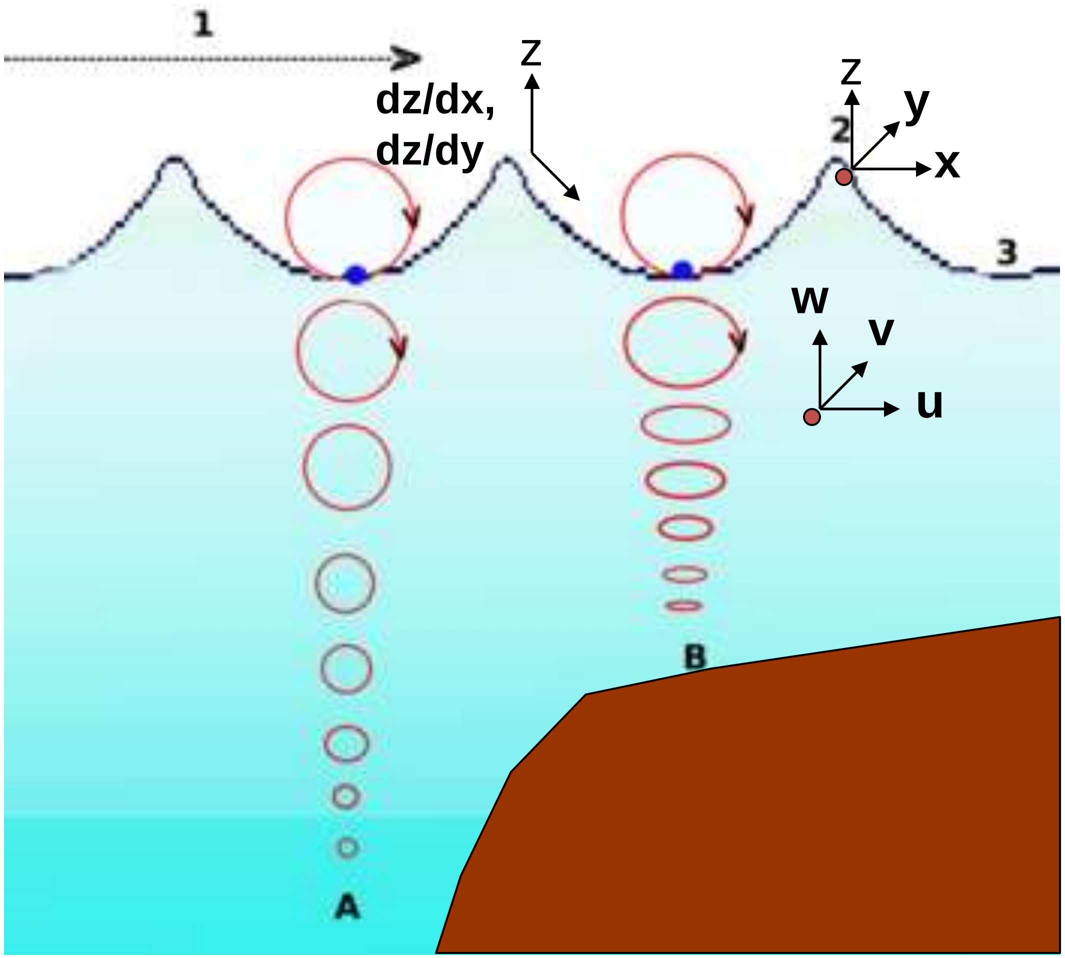
FIG. 12. Wave field variation across S-O image: (a) time series at four along-track locations at $y = 0$; (b) locations of data in one image of sequence, shown by red arrow in (a); and (c) enlargement of large, slamming wave [slam 5; box in (a)].

Brandt, A. et al, 2010

Wave Buoys

Wave Buoys

The Basics: Estimating the Motion of a Sea Surface Particle



The Big 3

X, Y, Z

Pressure Sensors
Accelerometers
Tilt sensors
Angular Rate Sensors
Acoustic Sensors
Radar
Lidar

Wave Buoys

Datawell Directional Waverider Buoys

MarkIII accelerometer buoy

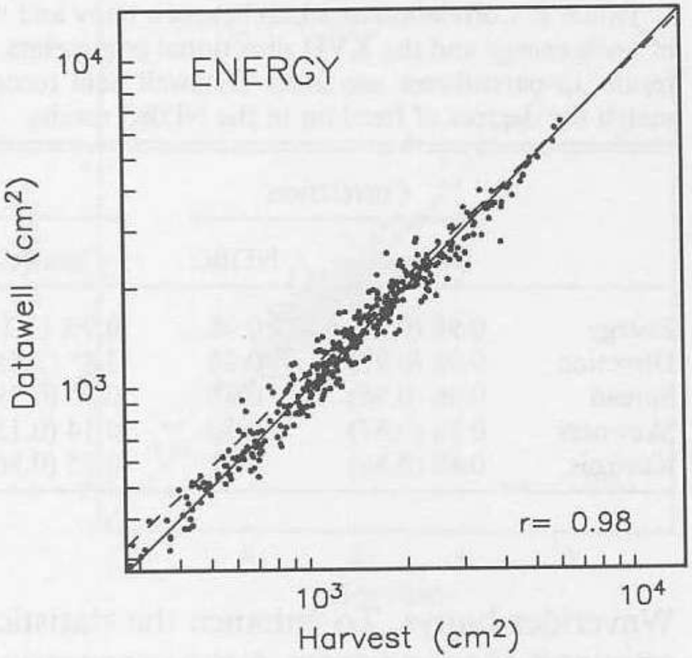
- Measures x-y-z displacements with 3-component Hippy accelerometer package
- Moored 0.9 m diameter buoy
- Mature technology, accuracy well established
- Expensive

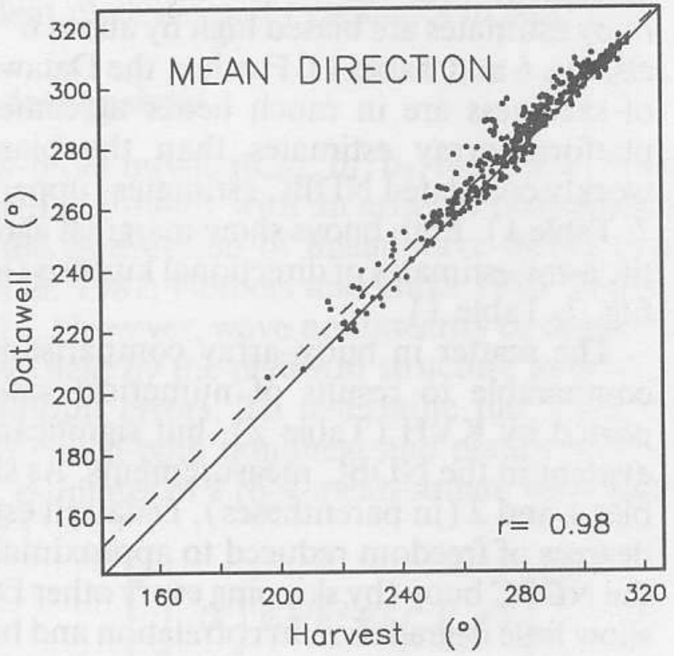
DWR-G GPS buoy

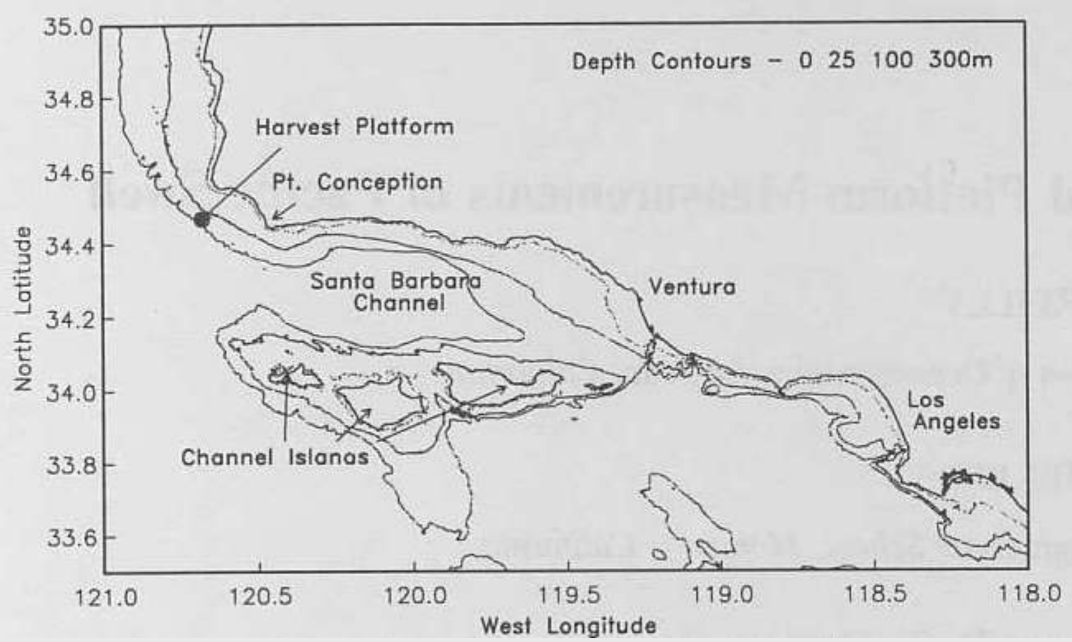
- Measures x-y-z displacements from Doppler shift in GPS signal
- Moored (0.9 or 0.7 m diameter) or free drifting (0.4 m diameter)
- Newer technology, accuracy/reliability not as well established
- Less expensive

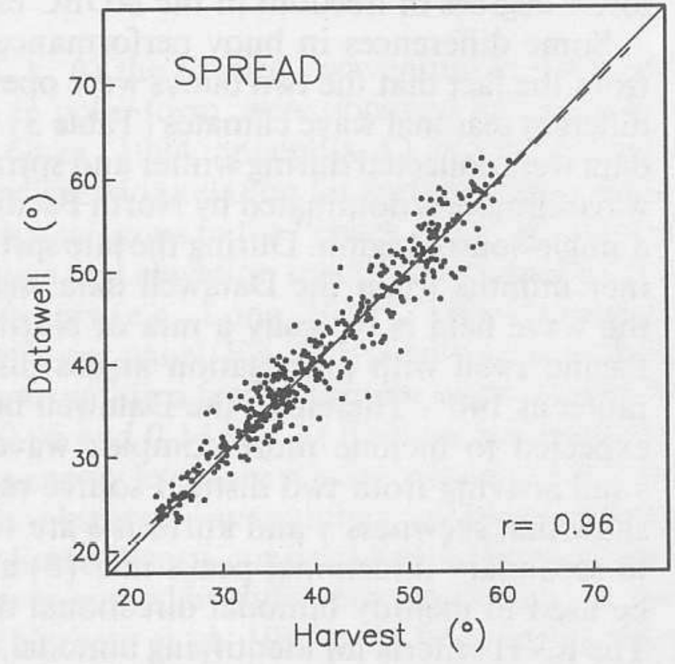
A comparison of directional buoy and fixed platform measurements of pacific swell.

O'Reilly, W. C., T. H. C. Herbers, R. J. Seymour and R. T. Guza, 1996: *J. Atmos. Oceanic Technol.*, 13(1), 231-238.



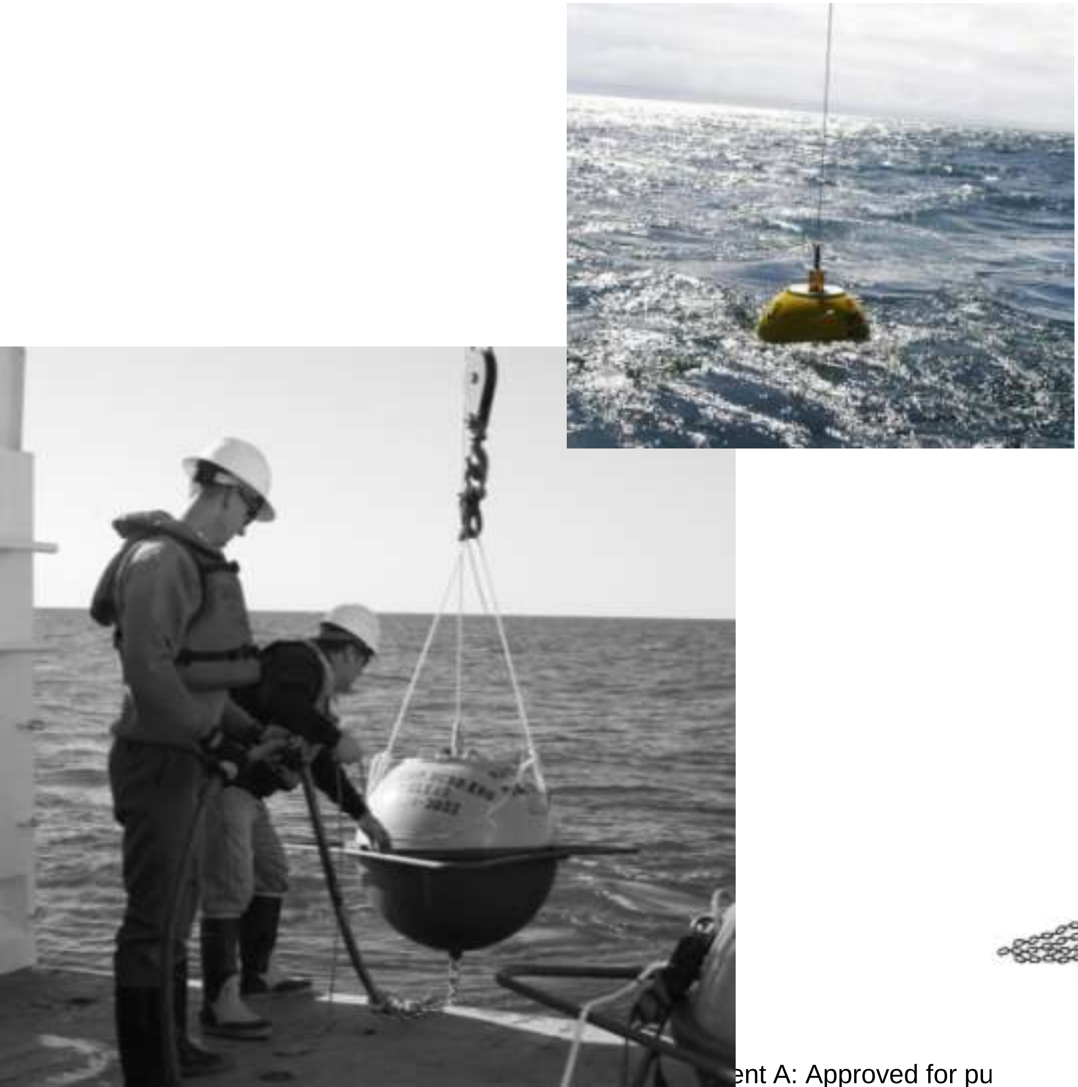






Wave Buoys

Moored Buoys



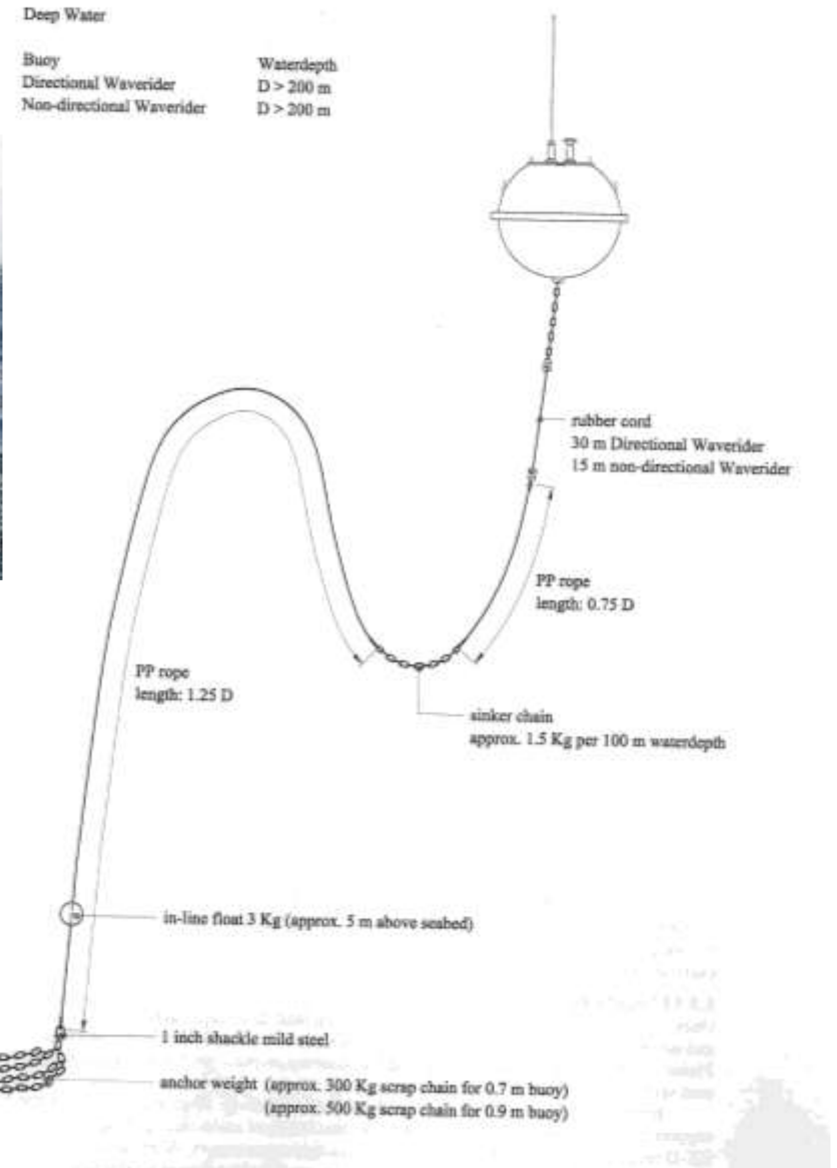
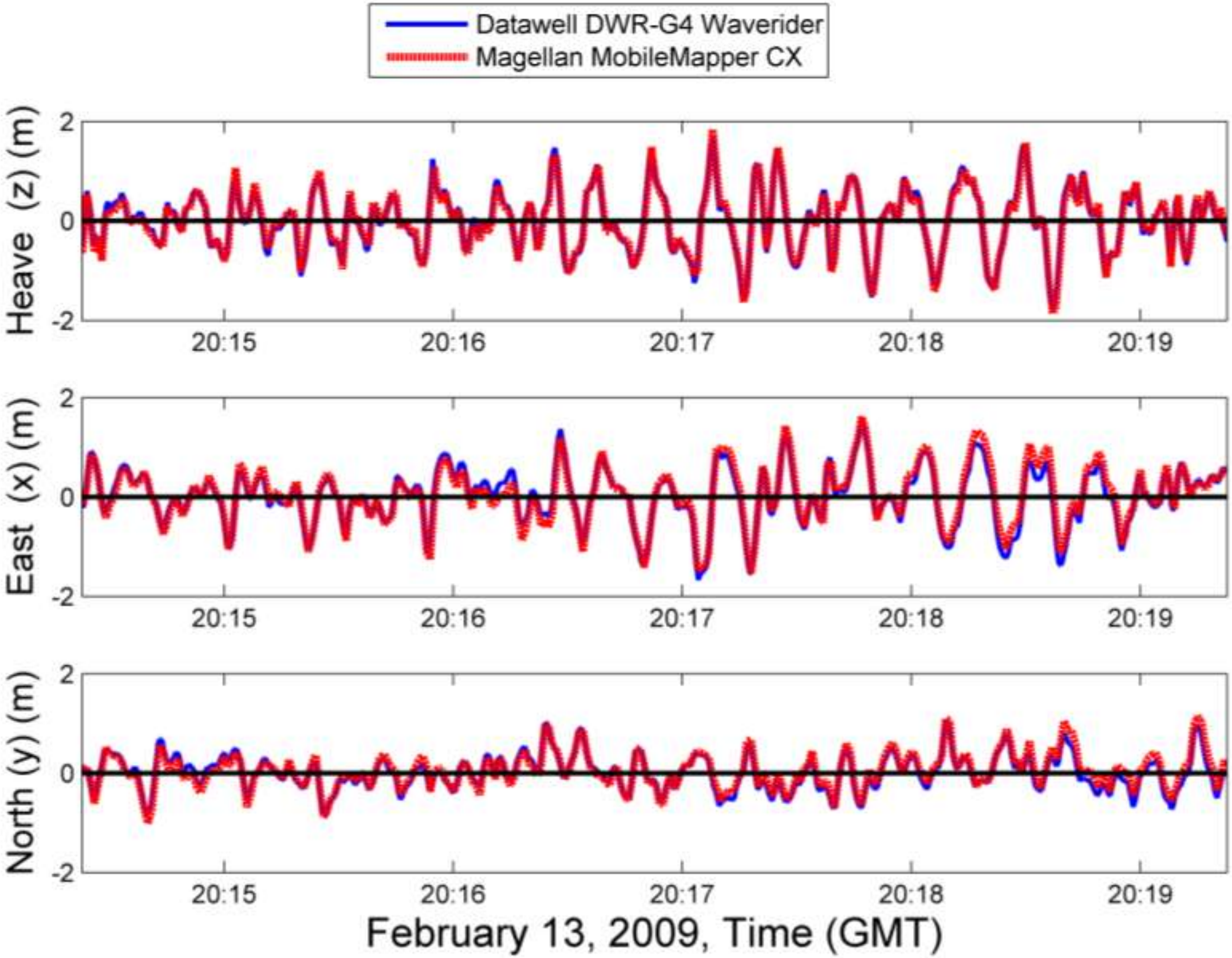


Figure 5.8.7(e) Mooringline layout for the (Directional) Waverider.

Wave Buoys



Datawell DWR-G4 Waverider
Magellan MobileMapper CX
Heave (z) (m)
East (x) (m)
North (y) (m)
2
0
-2
20:15
20:16
20:17
20:18
20:19
February 13, 2009, Time (GMT)

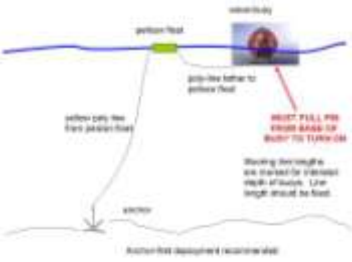
Wave Buoys

“Miniature Wave Buoys”: Eric Terrill, SCRIPPS

Miniature Wave Buoy

- Designed for free drifting, rapid deployment. Mooring design being tested and evaluated.
- 14 day reporting capability. Wave messaging 2x/hour. Position information every 10 minutes.
- Standard wave parameters reported (Hs, Tp) and 64pt directional wave spectrum reported in Wavegram. 9 band wave spectrum computed and reported via web.
- Data access and plotting through web. ASCII data download for plotting in excel.
- Wavegram message forwarding to forecasters via email.
- Small form factor: 8” sphere.
- Powered by 9 alkaline D-cell batteries. No HAZMAT shipping.
- Designed for simple deployment – single switch operation. No specialized software or computers at the forecaster end of the system.

Mooring components and shipping container.

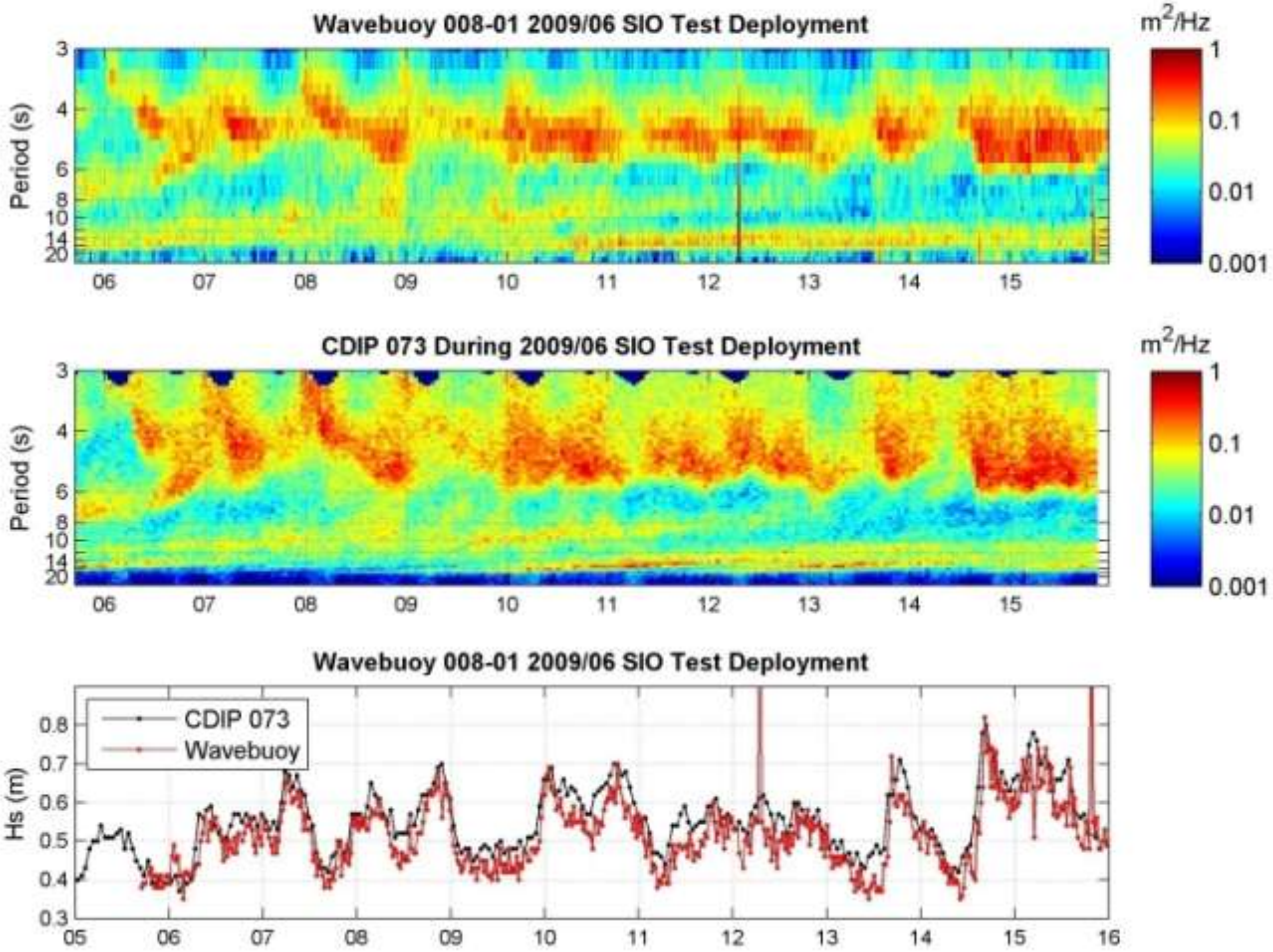


Mooring diagram.

Coastal Observing R&D Center
Marine Physical Laboratory, Scripps Institution of Oceanography
Eric Terrill (eterrill@ucsd.edu)

Wave Buoys

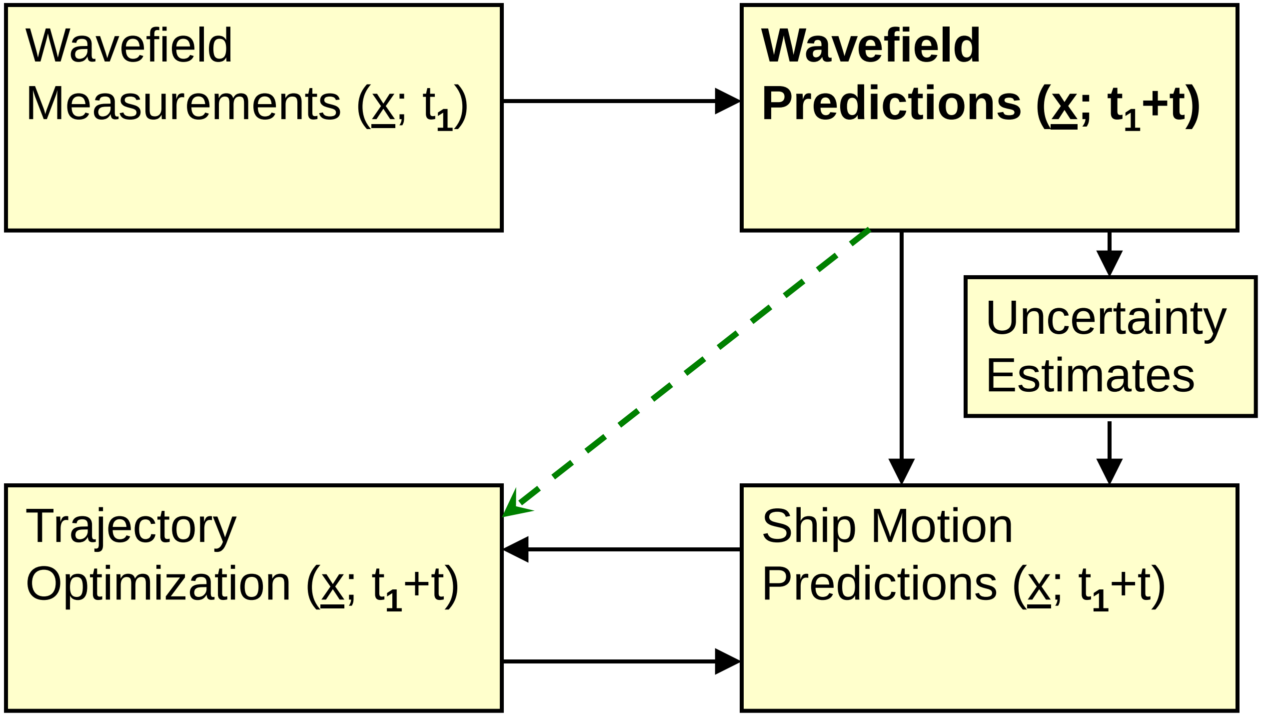
Miniature Wave Buoy
JUNE 09 Scripps Pier Validation Test



Wave and Wind Field Propagation

Wave Propagation

Elements



Wavefield Measurements ($\underline{x}$; t_1)

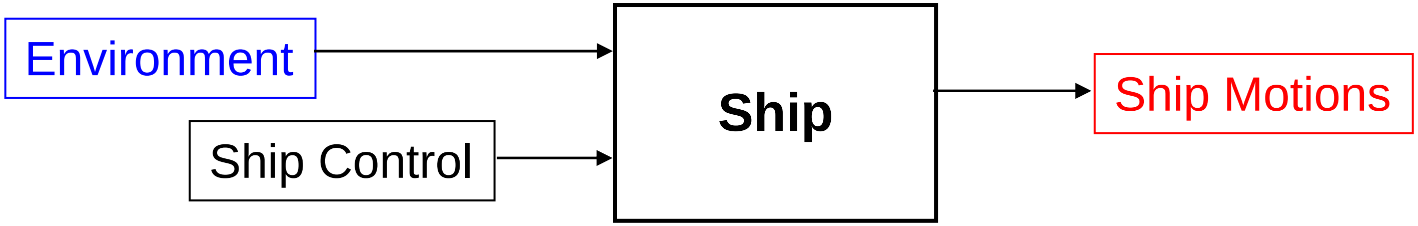
Wavefield Predictions ($\underline{x}$; t_1+t)

Uncertainty Estimates

Trajectory Optimization ($\underline{x}$; t_1+t)

Ship Motion Predictions ($\underline{x}$; t_1+t)

Wavefield Prediction



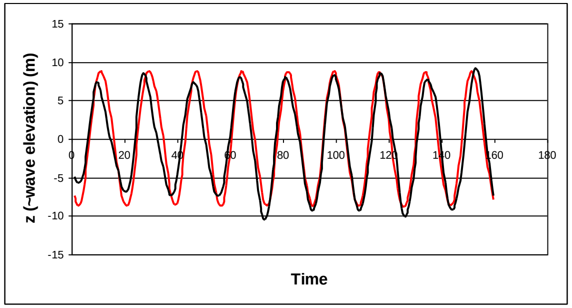
Environment

Ship Control

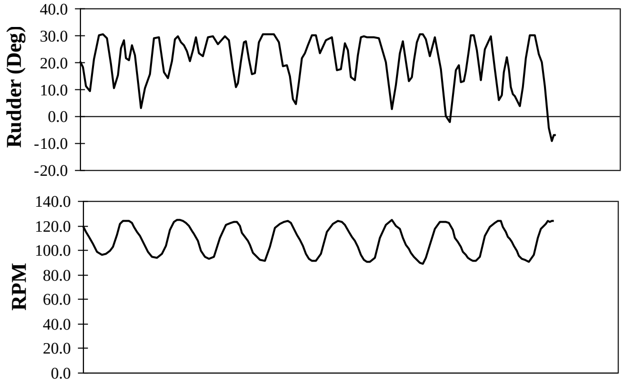
Ship

Ship Motions

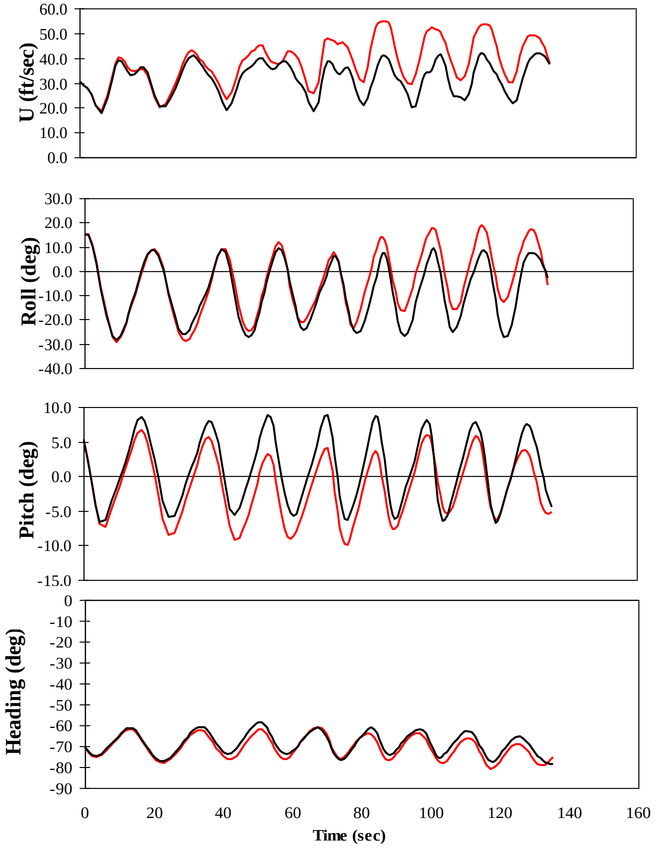
Wave Elevation at Ship – Measured, Calculated



Ship Controls – Rudder, Propeller RPM



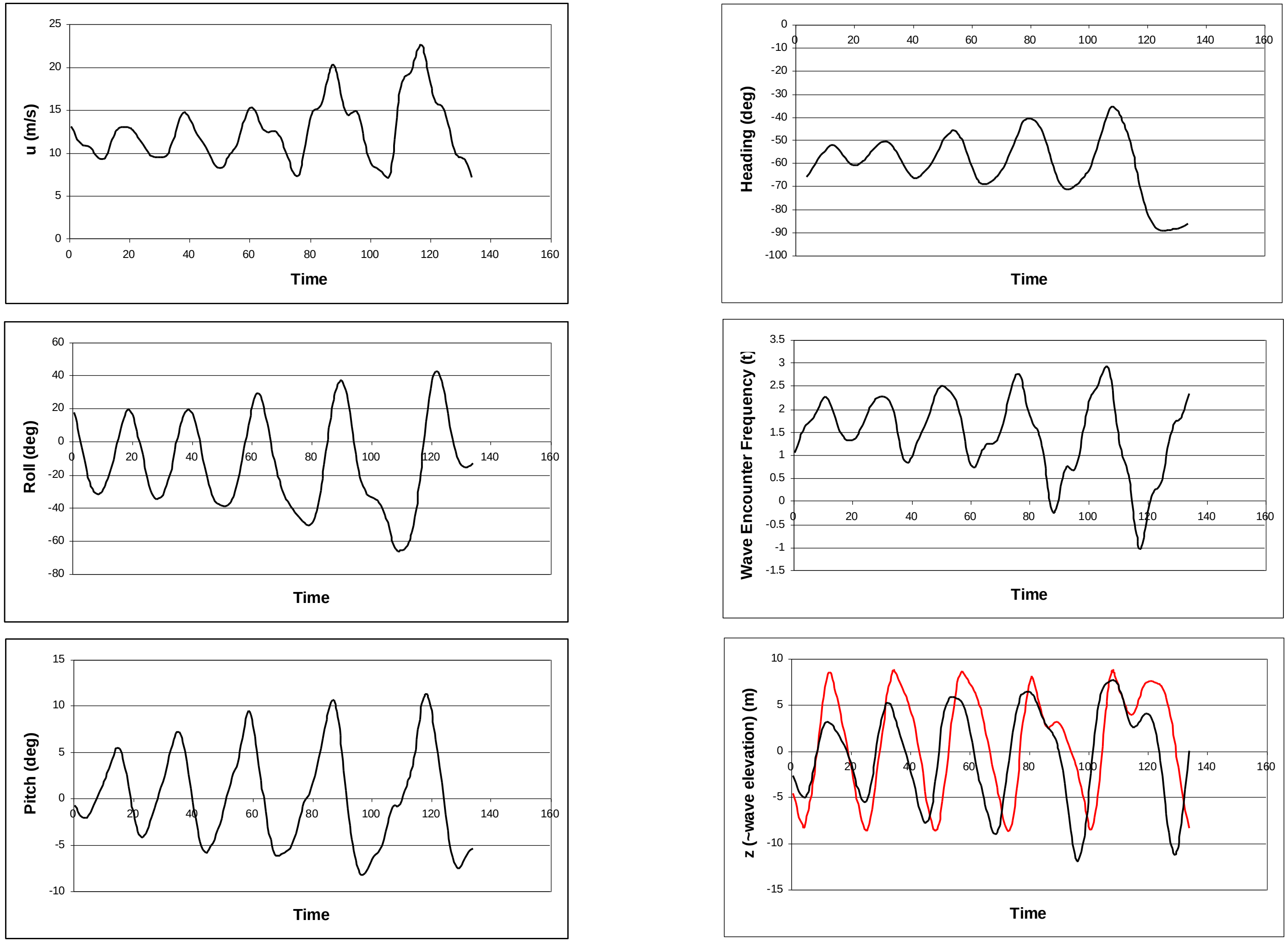
Measured Black – Predicted Red



Wavefield Prediction

ESMF

Do the inverse problem – Issue: how do you propagate this forward and what happens when conditions change



- **Black Measured/Calculated**
- **Red Calculated Ideal Wave Elevation**

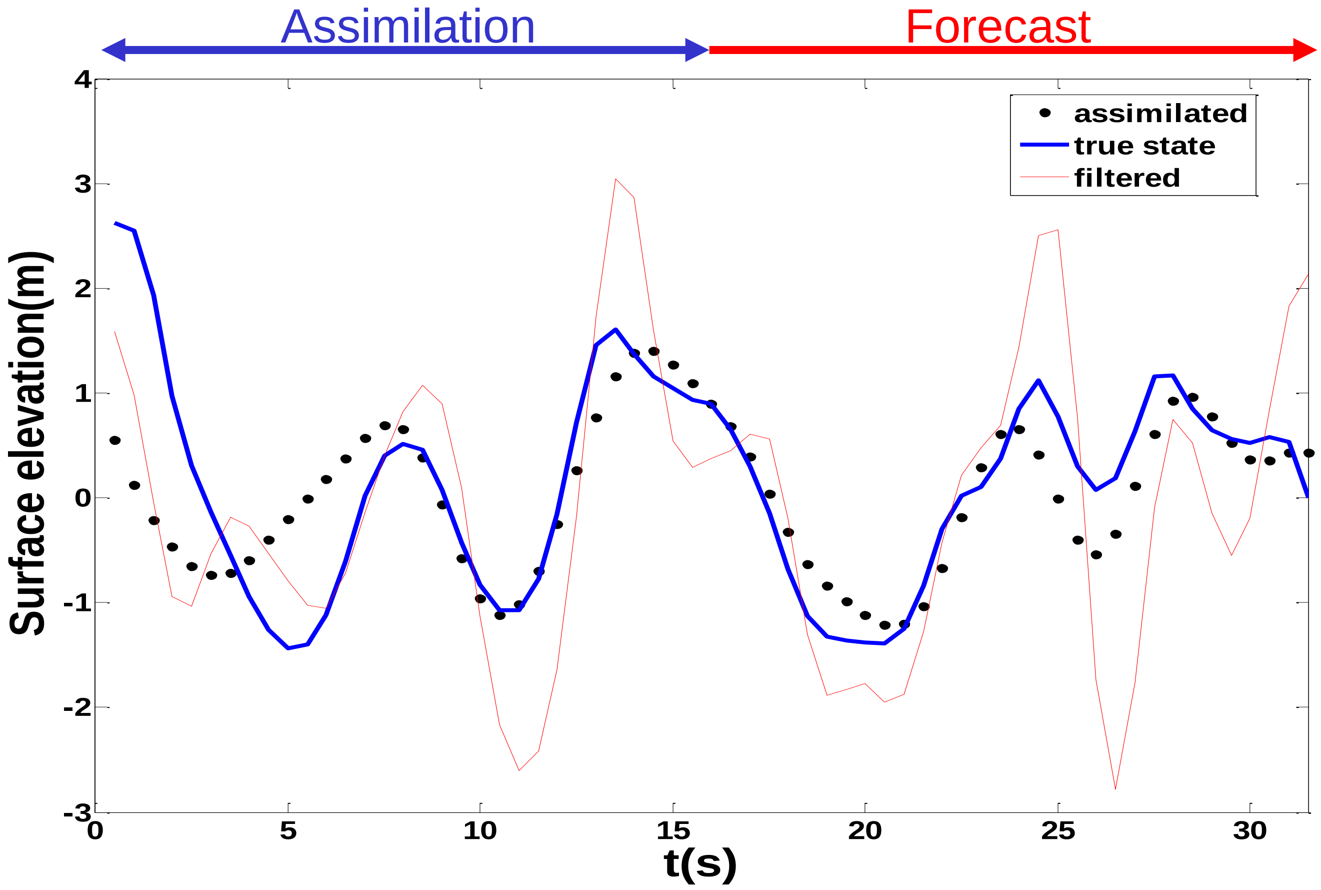
Wave Propagation

Add sensor data-

- Linear propagation
- Nonlinear propgation

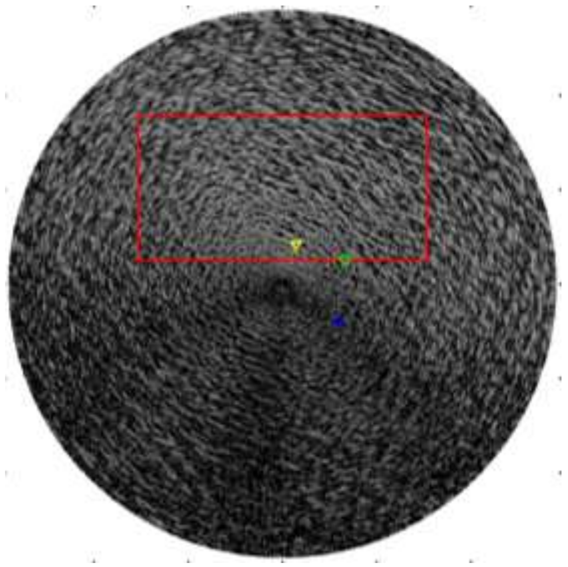
Wave Propagation

Ability to Forecast with Filtered Radar Data used as “Observation” (x=L/2)



Wave Propagation

Data Assimilation Problem

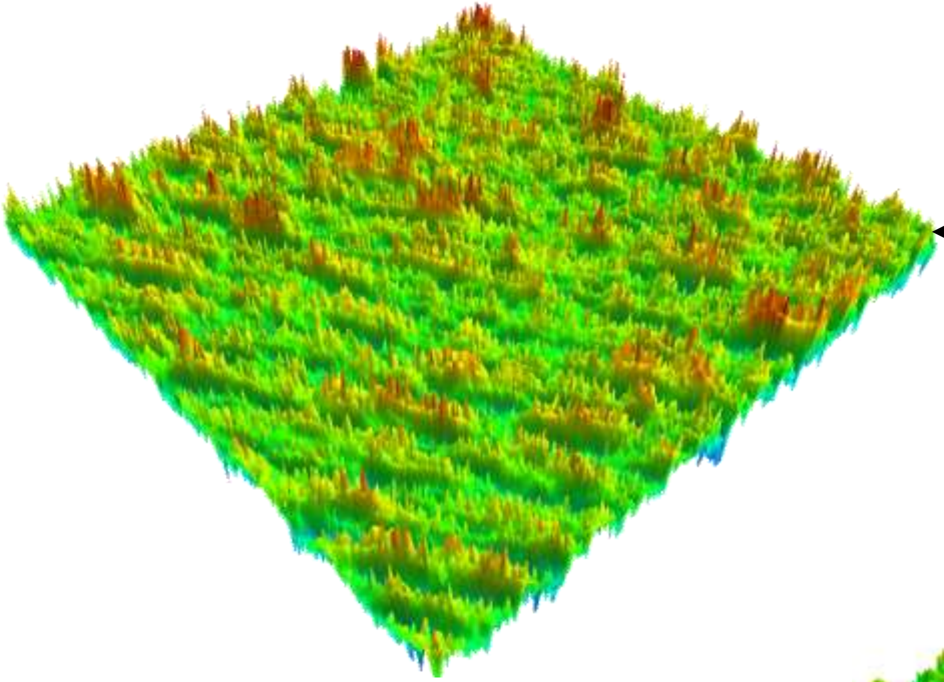


- Given a sequence of radar images, determine optimal initial wave field that minimizes differences between model predictions and radar observations over assimilation interval

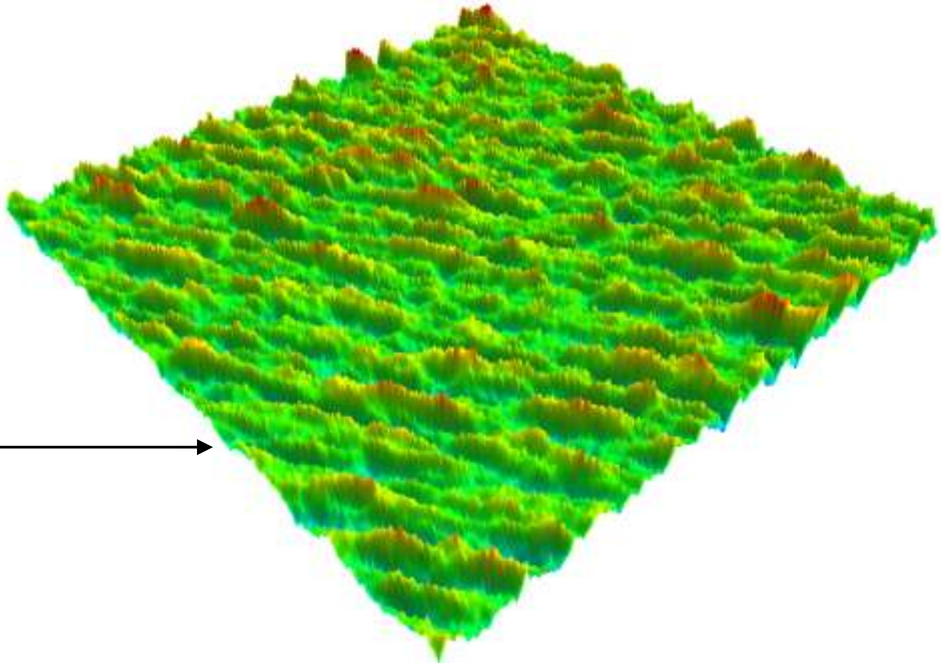
$$J(\eta_0(\mathbf{x});\cdots)=\sum_{j=1}^{N_{obs}}\iint\left[\eta_{pred}(\mathbf{x},t_j)-\eta_{obs}(\mathbf{x},t_j)\right]^2 d\mathbf{x}$$

- Use optimal initial condition to forecast nonlinear evolution of wave field

Wave Propagation



Initial condition with 50% Gaussian Noise

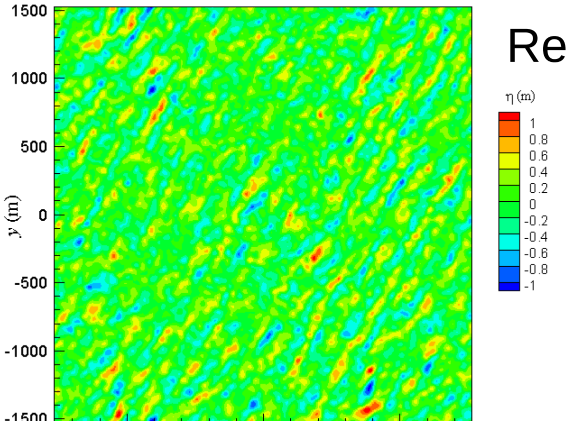


Recovered initial condition after data assimilation

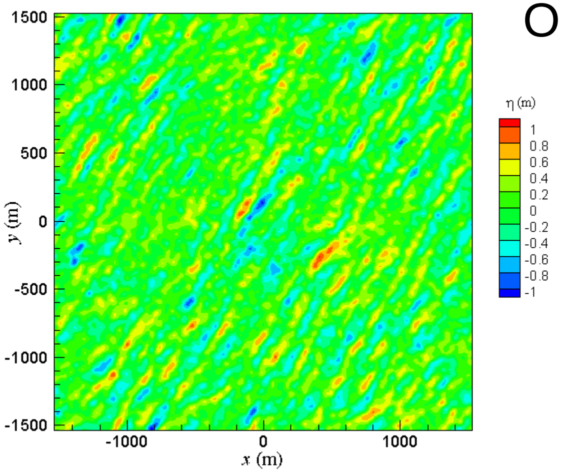
Distribution Statement A: Approved for public release; distribution is unlimited.

Wave Propagation

Alaska Experiments: Retrieved and optimized surface elevation maps for the April 8 @15:00 UTC



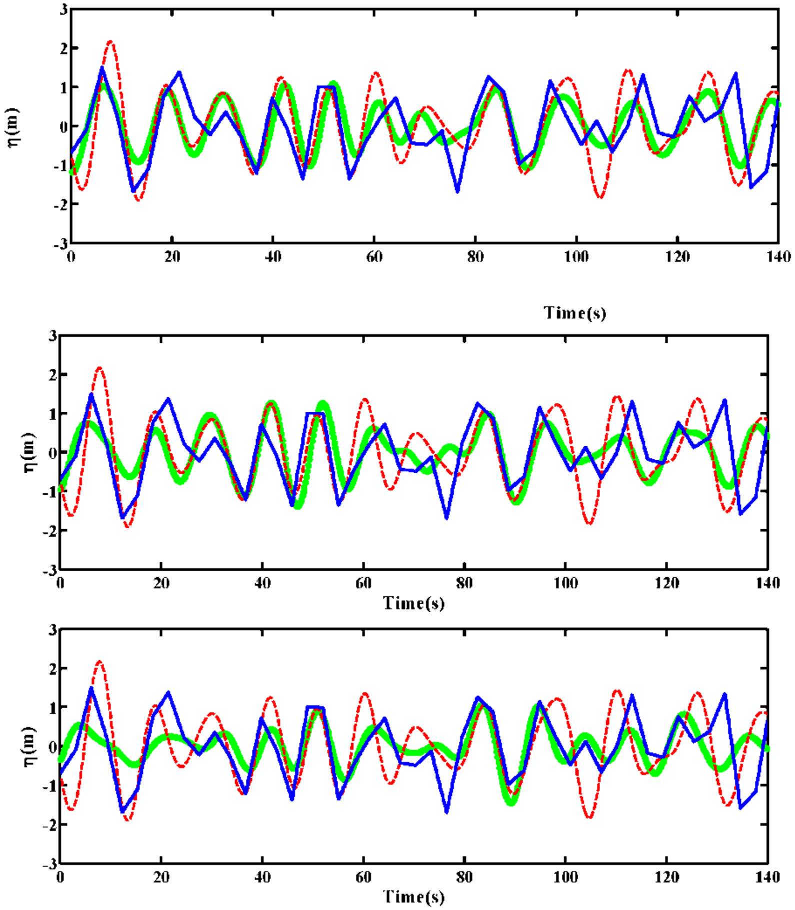
Retrieved



Optimized

Comparison of Model Predictions with Radar Measurements @ x=L/4,y=-L/4

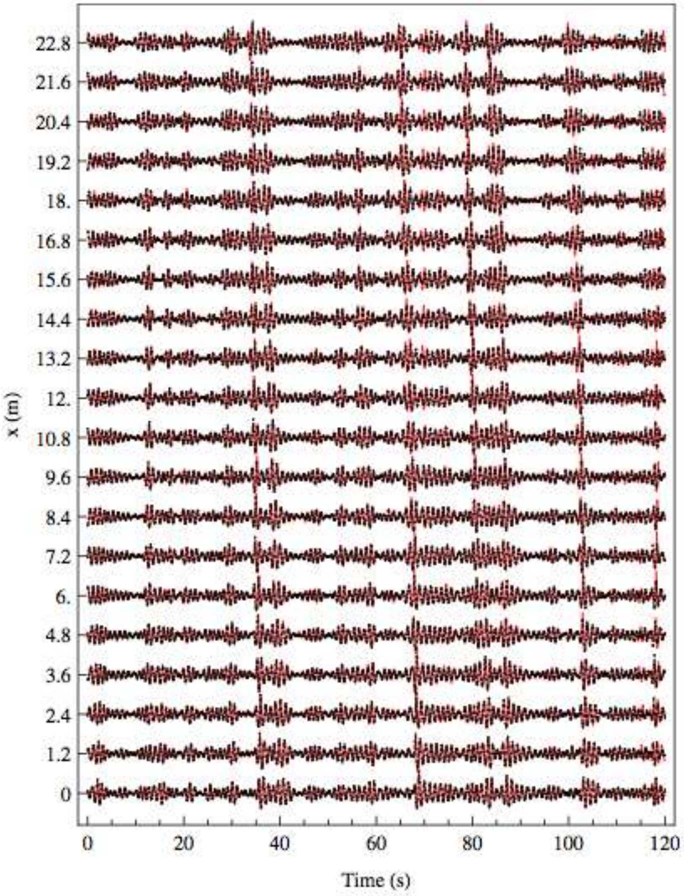
Assimilation Forecast



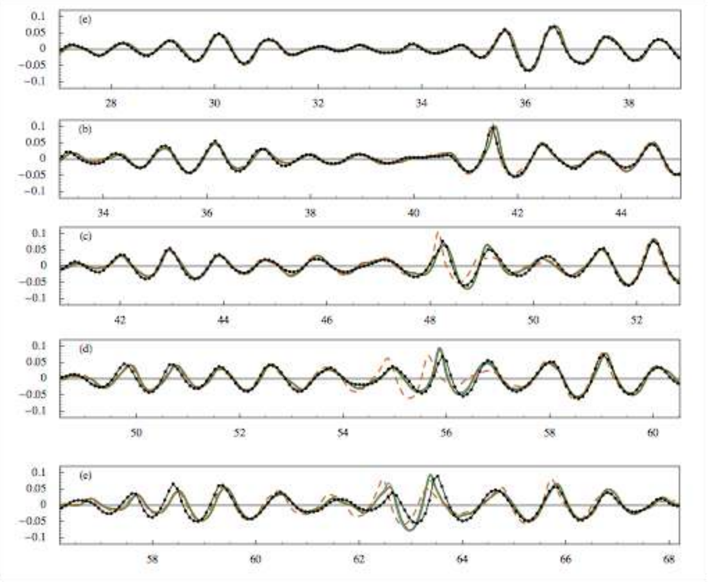
Blue=radar, Red = No assimilation, Green = Assimilated

Wave prediction and validation

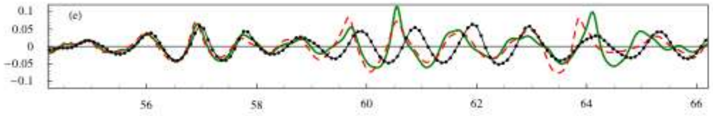
Comparison of numerical solutions with experiments



in the absence of wave breaking



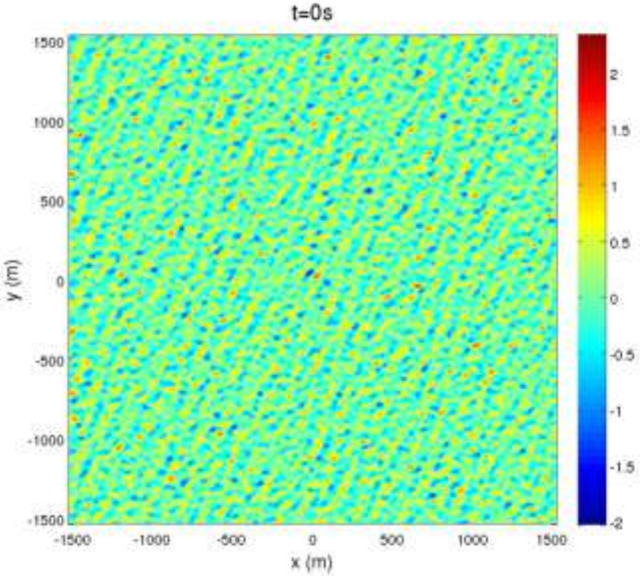
in the presence of wave breaking



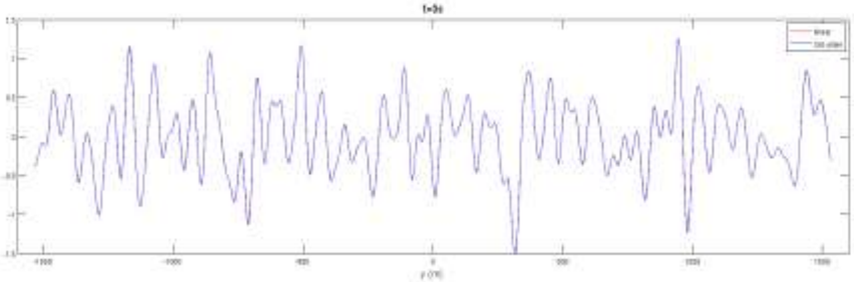
Choi, NJIT

Wave Propagation

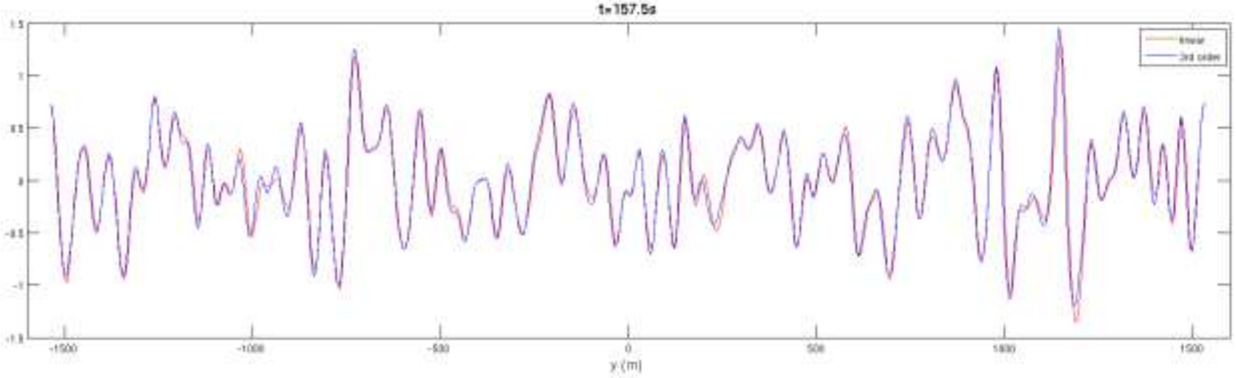
Comparison with field experiments



at t=0 s



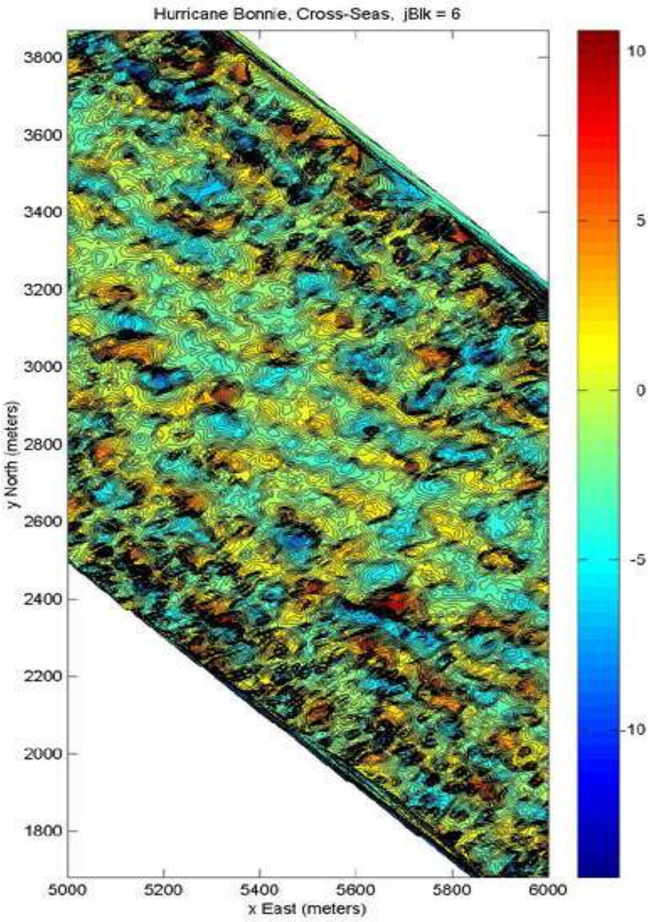
linear versus nonlinear



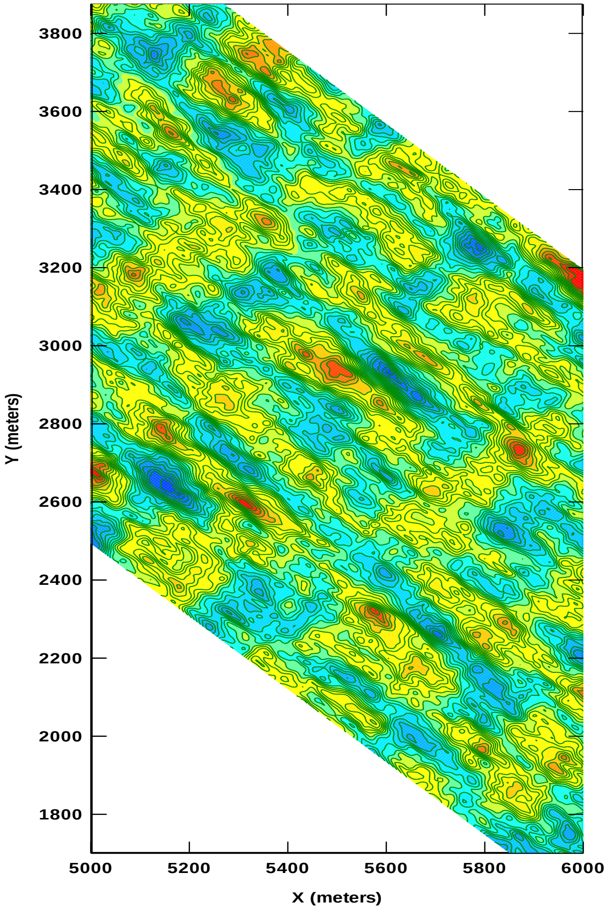
at t=157.5 s

Wave Propagation

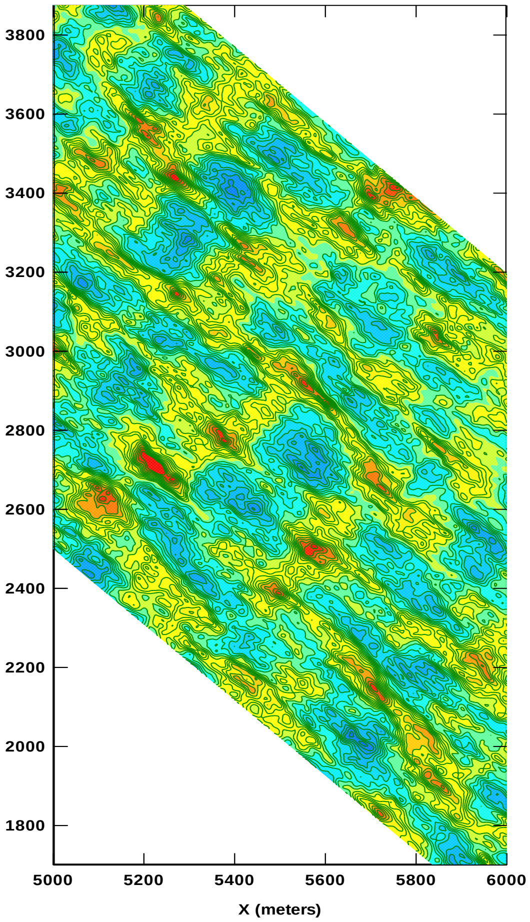
Nonlinear Models to Reconstruct and Forecast Wave Field Evolution



Scanning Radar Altimeter data



Reconstructed wave field



Wave field after 30 minutes of nonlinear evolution

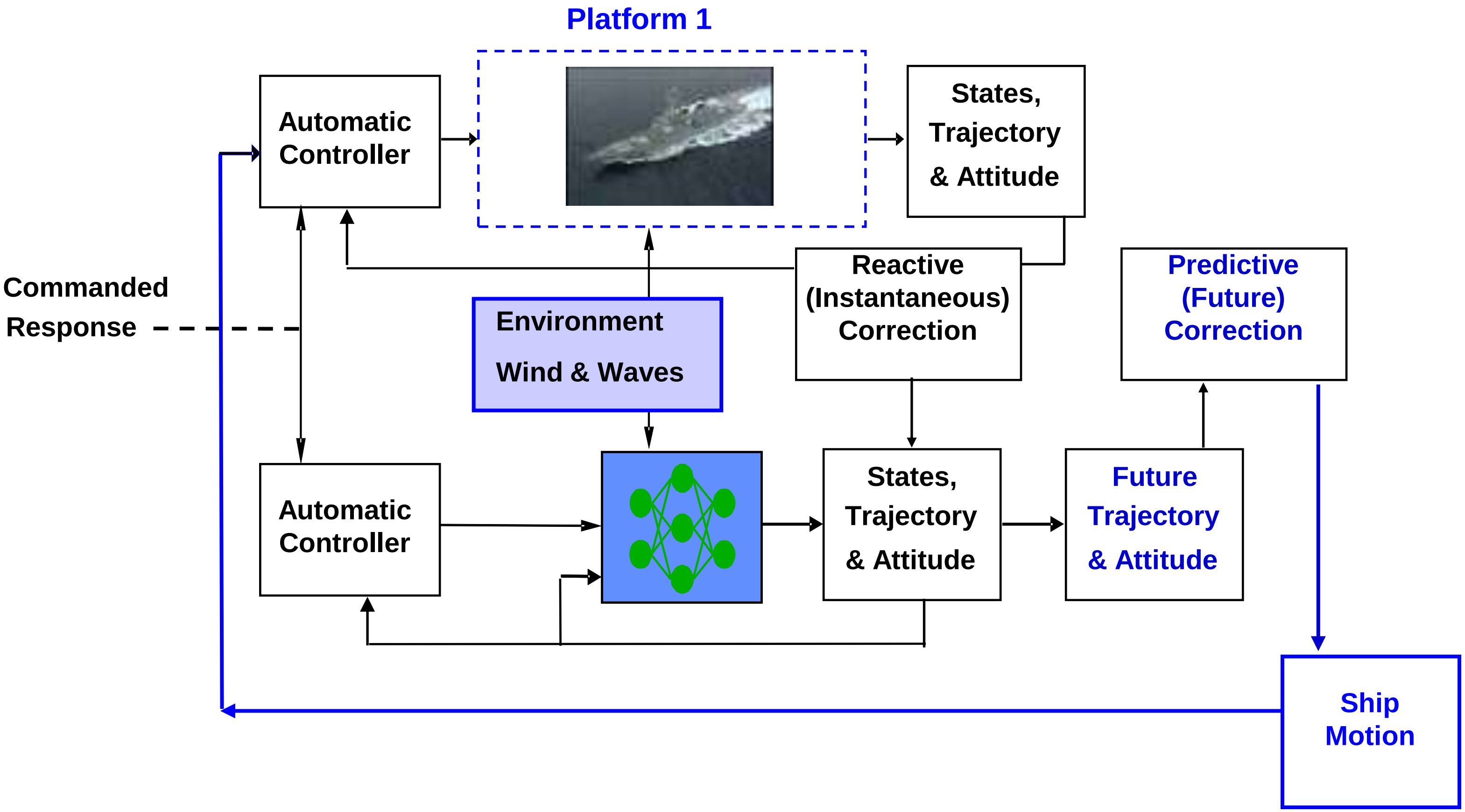
Ship-Motion Prediction

Ship-Motion Prediction

- Available Tools and Methods
  - Data measurements (e.g. Ship As a Wave Buoy (SAWB) approaches)
  - Physics-based modeling using simulation codes
  - Neural Network based models
  - Others?
- Forecasting Approaches
  - Real-time predictions
  - Pre-computed data base
- Considerations
  - Input data requirements
  - Necessary complexity
  - Speed vs. accuracy

Ship-Motion Prediction

- General Approach



Code Capabilities

Environment	Configurations
Irregular Waves	Number of Bodies
Regular Waves	Multihull Vessels
Wind - Speed, Direction	Arbitrary Body-to-Body Alignment
Current - Speed, Direction	Surface Effect Ships
Finite water depth	ACV's (fully skirted)
	Motion Control Systems

Hydrodynamics	Non-Hydrodynamic Factors
Forward Speed/ High Speed	Mooring System Forces on Bodies
Propulsor/thruster forces	Fender Forces and Dynamics on Bodies
Time domain/frequency domain	Ramp Forces and Structural Dynamics on Bodies
Wave shadowing effects on motions	Autopilot/Dynamic Positioning
Appendage Forces	Simulate overtaking scenarios
Free surface non-linearity	
Body non-linearity	
Drift forces	
Ship Degrees of Freedom	

Categorization of Codes

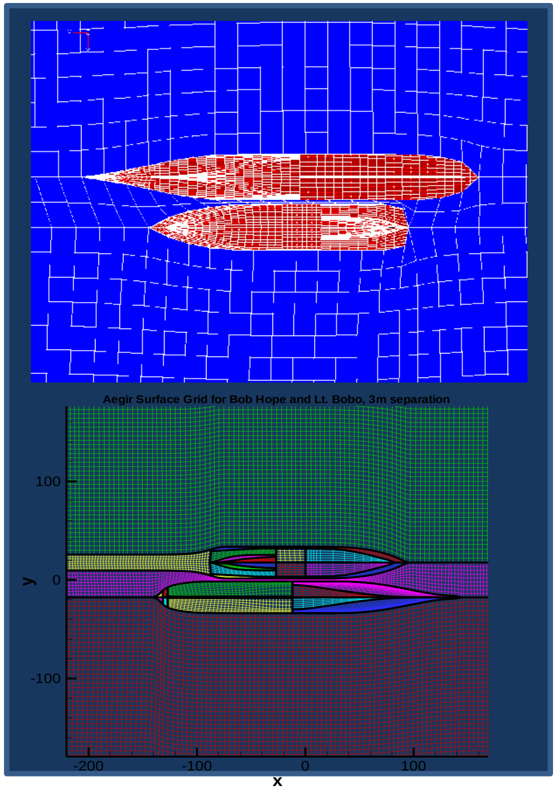
- Time domain tools based on externally computed impulse response functions
  - Frequency domain seakeeping
  - Empirical maneuvering forces
  - Steady flow interactions
- Time domain / Frequency domain tools based on zero-speed free surface Green’s function
- Time domain Rankine panel methods
- Frequency domain tools based on zero speed Green’s function
- RANS

Potential Issues with Codes

- Time-step size
- Panel grid on hull
- Resonant waves in the gap between two vessels
- Length of run, removal of transients when selecting time sequence for harmonic analysis
- Methods based on free surface Green’s function
  - Frequency spacing used for impulse response function calculation
  - Irregular frequencies
- Rankine Panel methods
  - Sensitivity to free surface grid

Multi-body Simulation Codes

- Multi-Vessel Ship Motion Prediction Codes Evaluation Study (2006-2008)
  - NSWCCD Seakeeping Division (Andy Silver, Mike Hughes, Rielly Conrad, SangSoo Lee, John O’Dea, Joe Klamo)
  - Sea Basing Application
  - Codes selected for evaluation
    - CSC MVS
    - D&P MVTDS
    - AQWA
    - LAMP-Multi
    - Aegir
    - DRDC Canada ShipMo3D



Available: Silver, et al. NSWCCD Hydro Dept. Report NSWCCD-50-TR-2008/070

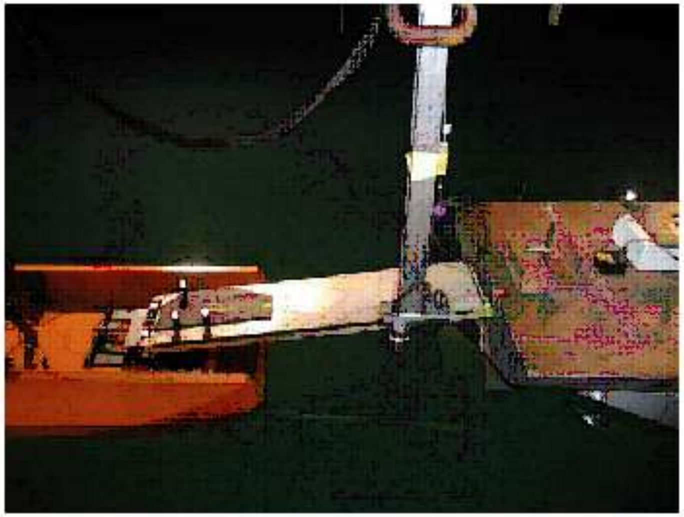
Example Model Test Run

HOPE and BOBO 33 meters spacing, head seas (180°), 16 kts, regular waves (2.5 m, 0.5 rad/s full scale)

Multi-body Simulation Codes

- SES Motion Prediction Codes Evaluation Study Evaluation for T-Craft (2009-)
  - NSWCCD Seakeeping Division (Andy Silver, Mike Hughes, Rielly Conrad, SangSoo Lee, John O’Dea, Dave Wundrow)
  - Sea Basing Application
  - Codes selected for evaluation
    - WAMIT
    - AQWA
    - MOSES
    - LAMP-Multi
    - Aegir

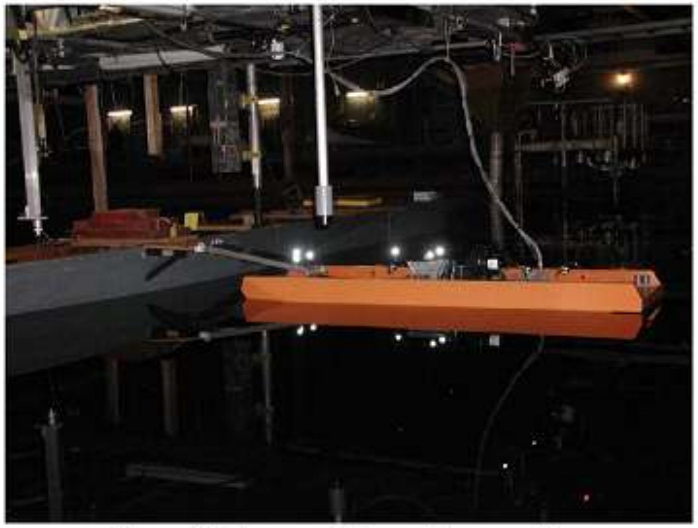
NSWCCD LMSR and T-Craft Test



Tandem Configuration with ramp

Tandem Hinged Connection

Side-by-Side 15 foot separation



Med-Moor Configuration

NSWCCD Model Test

Ship-Motion Prediction

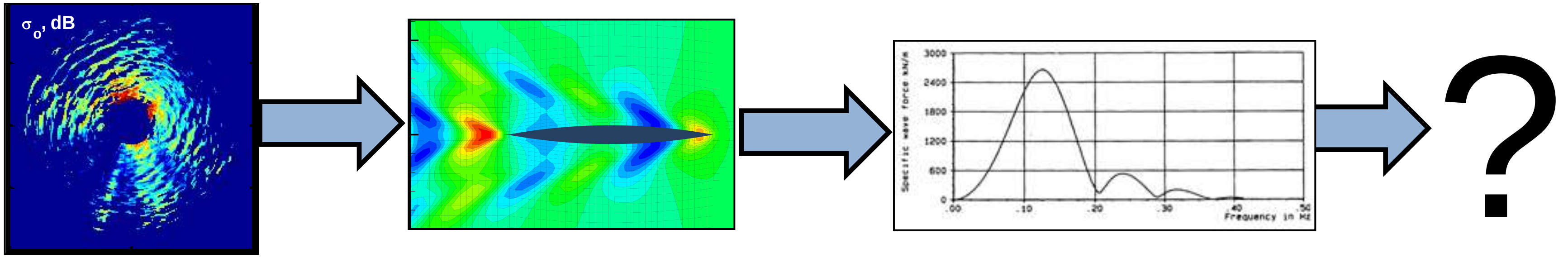
- What is the best approach?
- Depends on:
  - – Operational condition(s)
    - Ship(s) type and size
    - Speed and heaving
    - Specific function
  - – Environment
    - Wind-wave conditions
    - What input data is available
  - – Forecast duration

Decision Support System and Operator Guidance (DSS & OG)

DSS/OG

Decision Support Systems (DSS) and Operator Guidance (OG)

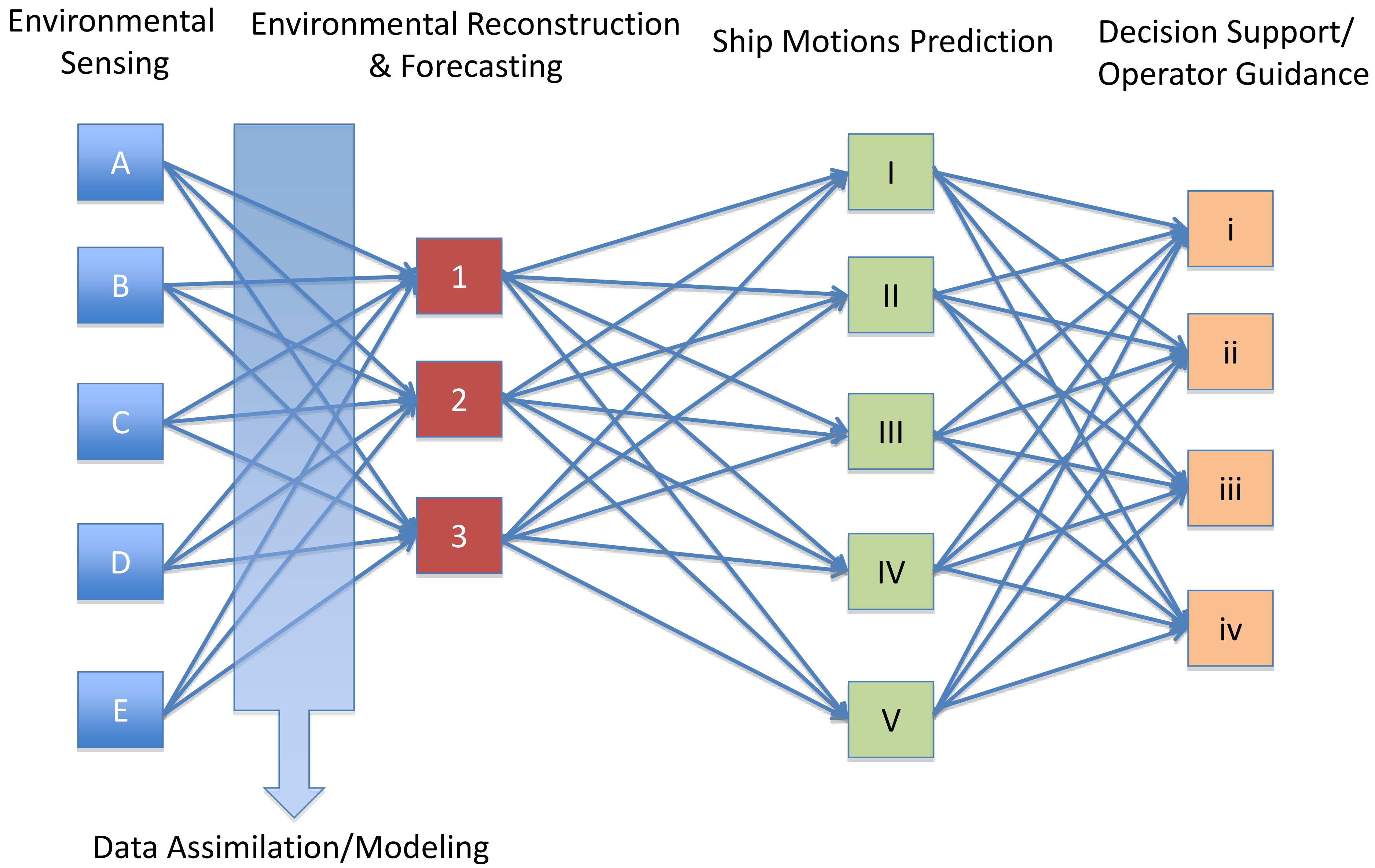
- We have the wavefield/ship motions data:
  - Is the data good enough (accuracy, resolution, availability) for DSS/OG?
  - How do we integrate it?
- We have integrated data: how do we convey the results to the operators in a meaningful way?



DSS/OG

- **Synthesis: How do we connect the pieces (sensors→wave models→ship motions)**
  - Each technology component feeds the next-coupled system
  - How do similar components (e.g. multiple sensors) talk to each other: which one takes precedent?
  - Inputs and outputs are **important**
  - Errors propagate from sensors to models (which already have errors ‘built-in’)

DSS/OG



Environmental Sensing

Environmental Reconstruction & Forecasting

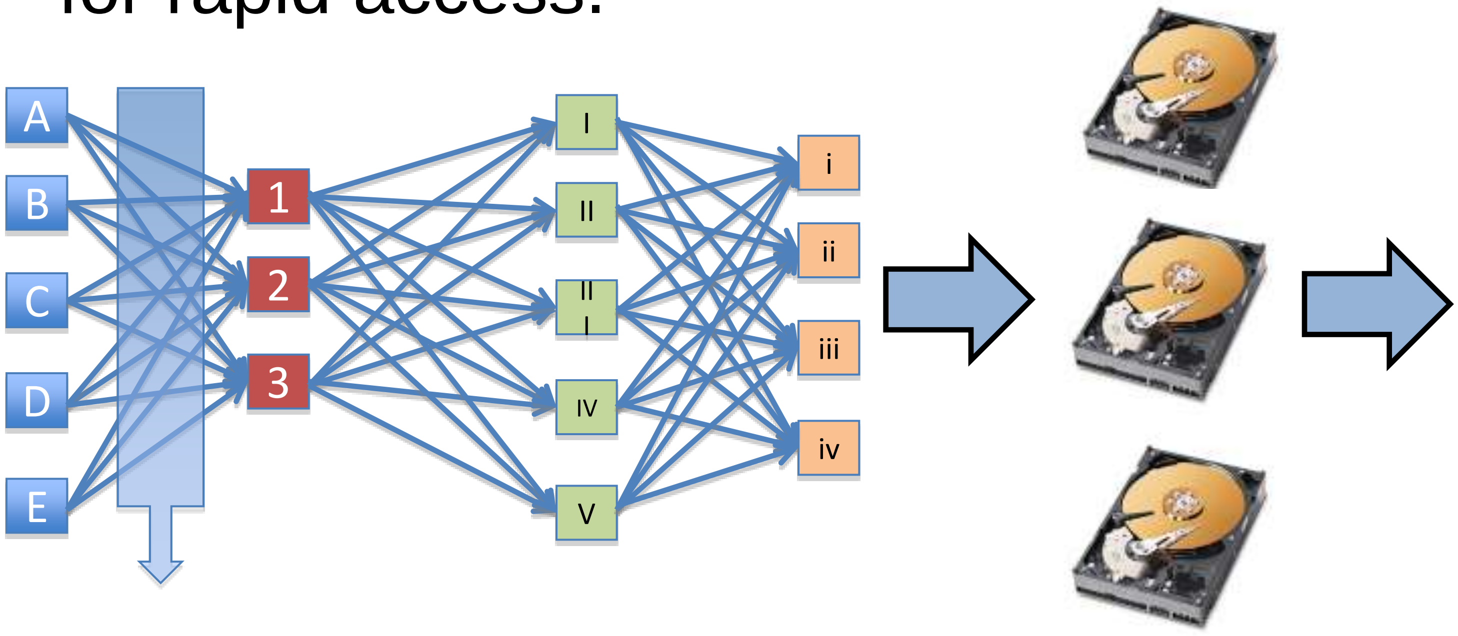
Ship Motions Prediction

Decision Support/ Operator Guidance

Data Assimilation/Modeling

DSS/OG

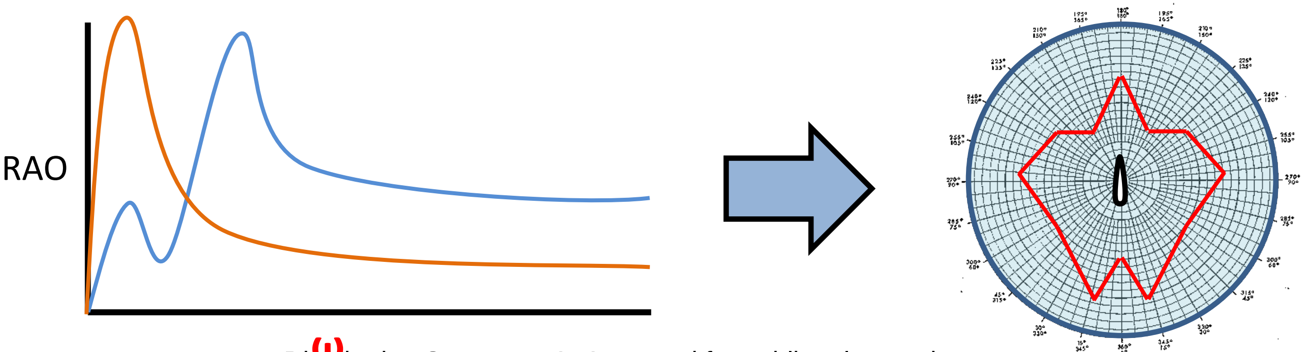
- Management: How do we cope with data overload?
  - With the possibility of multiple sensor platforms, multiple wave models, and multiple ship motion models, how do we store and organize the data for rapid access.



What we need, when we need it!

DSS/OG

- Real-time vs. Pre-Computed
  - Computational demand for computing real-time
    - Linear vs. Non-linear: Former is computationally fast, but what do you lose in accuracy? Latter is computationally demanding, but do we need a nonlinear model for lower sea states?
  - Can we use pre-computed results?
    - Can a pre-computed database of motions that’s ship specific and geographically (time, season, conditions) specific?
    - Time domain vs. frequency-domain approaches?

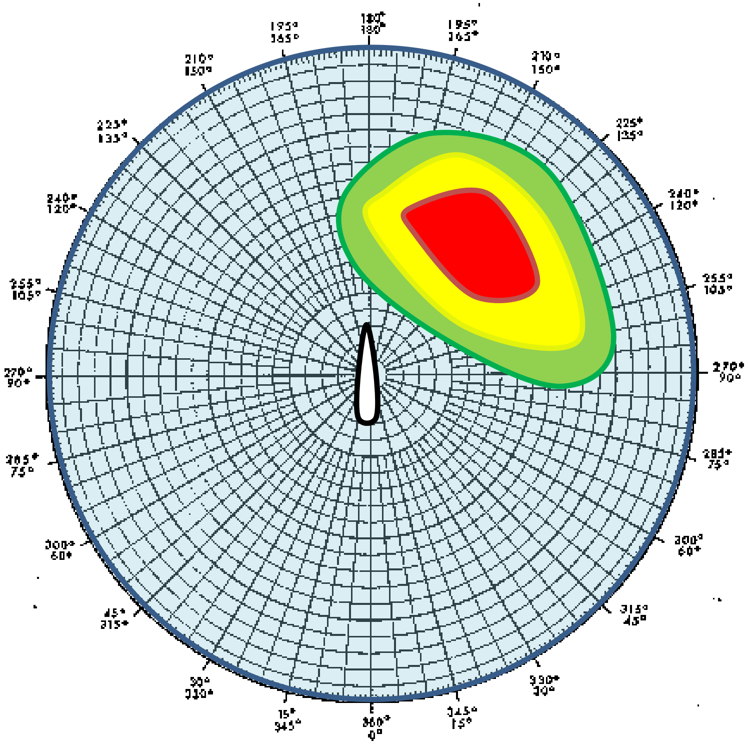


DSS/OG

- How do we communicate our results to the operator?
  - Critical question to be answered. Data is worthless if not conveyed properly (in a useful manner) to the shipboard operators→ Must turn **information** into actionable **knowledge**
  - What level should the DSS/OG communicate to?
    - Ship's Bridge: Do we communicate the information to the top and let them disseminate it to the operators on the deck?
    - Ship's Crew: Do we provide guidance to the crew on the deck doing the actual operation?
    - Answer is probably **both,** but how do we do so?
    - How will the system architecture impact these approaches?
  - How often/fast can the DSS/OG be updated?

DSS/OG

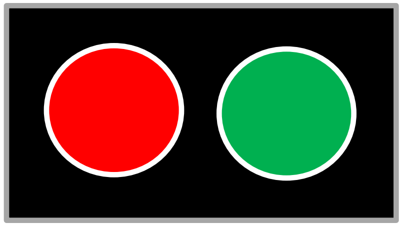
- How do we communicate our results to the operator?
  - Polar plot?



This may **<u>not</u>** be the final answer- what other methods of communication exist? Which are ost efficient?

DSS/OG

- How do we communicate our results to the operator?



  - – Go/No-Go indicator
    - Simple indicator for operators on deck and ship drivers.
    - Perhaps too simple for bridge crew- differing levels of fidelity for differing levels of operators and/or conditions.

Crane Operations

LCAC Operations

Ramp/Lighterage Operations

DSS/OG

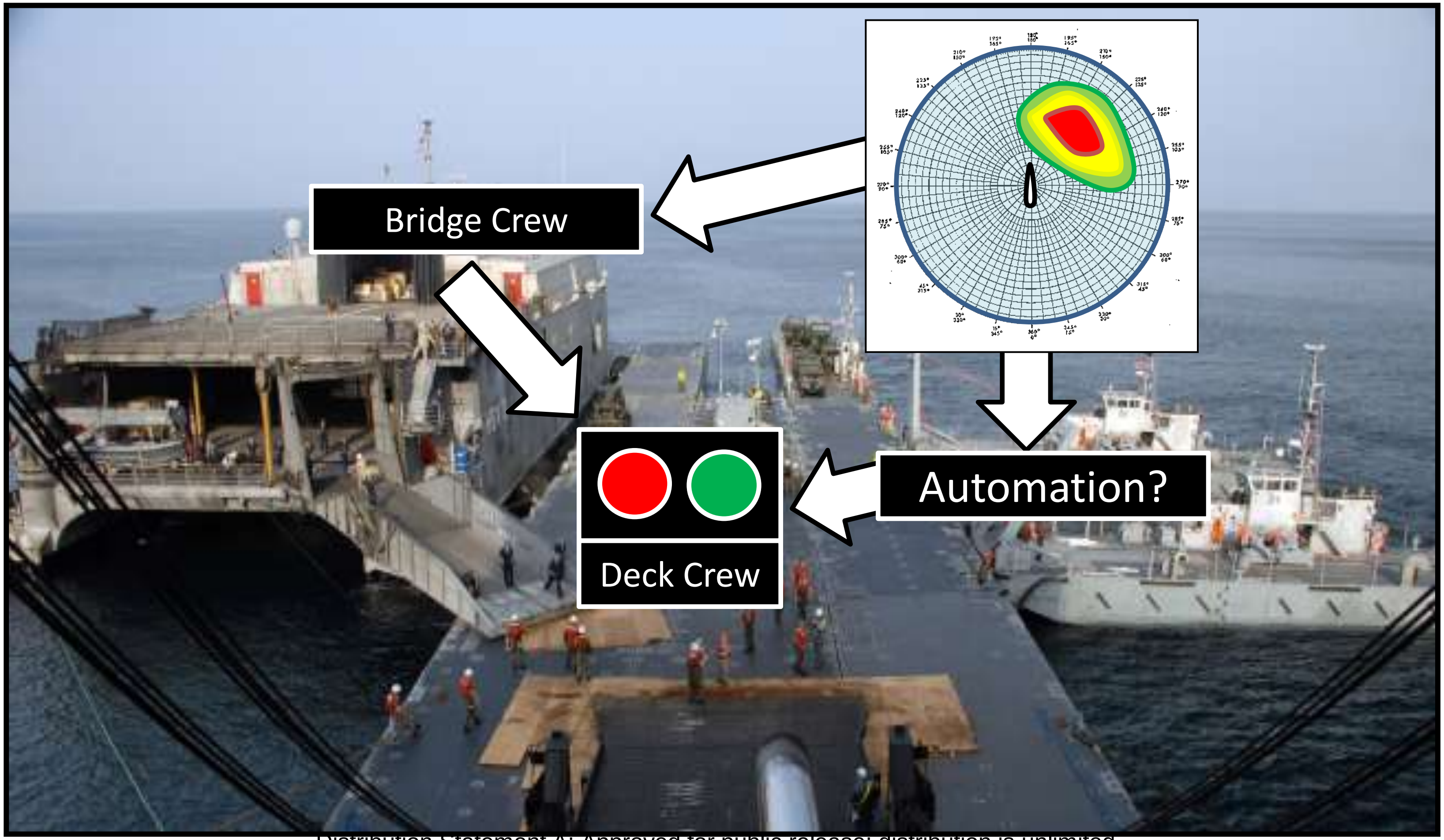
- How do we communicate our results to the operator?
  - What other approaches exist to convey our information to the operators outside of polar plots and simple Go/No-Go indicators?
  - “Visual Display of Quantitative Information”
    - Outside-the-box thinking on operator guidance Graphical User Interfaces (GUIs).
    - How can we leverage advancements in computational power and graphics to produce novel (and useful!) GUIs.
    - Simple vs. Complex: Must maintain a balance that best conveys information to the operator(s)

DSS/OG

- Automated Control vs. Man-in-the-loop
  - How much control should we take out of the hands of the operators?
    - Automation is obviously faster, but generally more reactive
    - How much control do operators desire→goes back to the type of GUI developed.
      - Go/No-Go indicators could be automated or controlled from bridge
      - Based on more detailed wavefield/ship motions information
    - Should different approaches be used for different operational conditions

DSS/OG

- Automated Control vs. Man-in-the-loop
  - – How much control can/should we take out of the hands of the operators?



Bridge Crew

Deck Crew

Automation?

DSS/OG

- Training
  - – Whichever type of system is implemented, there should be a focus on the degree of training required for the operators.
  - – GUI and system design will dictate depth of required training
    - Complicated system may require very brief ship/waves theory class. Not necessarily bad, just one more consideration in the trade-space of guidance system design.
    - Better theory training may result in sailors trusting system vs. “black-box” set of indicators.
    - For complex bridge-based system, training in a simulated environment may improve response time for operation

DSS/OG

- The “-ilities”
  - A high level of maintainability, availability, and particularly **reliability** will dictate level of operator’s trust in system.

✓ Sensors
Wave Models
Ship Motions
Operator Guidance

✗ Unreliable

=

- An unreliable system will result in the operators either turning it off or ignoring it.

DSS/OG

- Conclusions
  - We are not trying to suggest a particular solution, but rather pose some questions we feel need to be answered for this system to be successfu
  - We want ideas for operator guidance and decision support that fall outside of current practice.
  - Polar plots, Go/No-Go indicators: these are the easy solutions. What else?
  - There have been both commercial and international joint industry project efforts previously to work on OG/DSS system design. A good start, but we need to field a functional integrated system by FY15.

DSS/OG

- EU Advanced Decision Support System for Ship Design, Operation, and Training (ADOPT) Project

“The aim of the project is the integration of all organizational, procedural, operational, technological, environmental and human related factors concerning safety at sea through out the entire vessel life cycle.

http://adopt.rtdproject.net/

- Ship-To-Ship-Ops (STSOps) Project: Research Council of Norway

“The project objective is to develop new knowledge and new tools for studies of complex ship-to-ship operations. The final work package uses operational experience as an input to studies of future operational guidance tools for ship-to-ship operations.”

http://www.sintef.no/Projectweb/STSOps/