Progress in Multi-disciplinary Sensing in the 4-Dimensional Ocean

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Outline of Presentation

Review of the ocean sampling problem
Progress in ocean platforms
Advances in ocean sensors
Open ocean 4-D observational systems
Coastal ocean 4-D observational systems
Data assimilation
Thoughts on successful observing systems
Observational & Modeling Issues

1) Time-space ranges and resolution.
2) Sufficient variables to understand processes.
3) Synopticity

See video about scales: http://htwins.net/scale2/
Examples of Autonomous Sampling Platforms

- MOOS Mooring
- Spray Glider
- Slocum Glider
- Dorado AUV
- Aries UUV
- Remus AUV
Moorings, Bottom Tripods, Shore and Offshore Based Platforms

- HF Radars
- Satellites
- AUV's
- Gliders
- Moorings, Bottom Tripods, Shore and Offshore Based Platforms

Time Scales:
- 100 years
- 10 years
- 1 year
- 1 month
- 1 week
- 1 day
- Diurnal
- 1 hour
- 1 min
- 1 sec

Horizontal Spatial Scales:
- 1 mm
- 1 cm
- 1 dm
- 1 m
- 10 m
- 100 m
- 1 km
- 10 km
- 100 km
- 1,000 km
- 10,000 km

CLIMATE
- Decadal Oscillations/Fish Regime Shifts
- ENSO
- Seasonal MLD & Biomass Cycles
- Coastally Trapped Waves
- Synoptic Storms, River Outflows, & Sediment Resuspension

Ships
- Drifters
- Floats

Moorings
- Turbulent Patch Size
- Langmuir Cells
- Surface Waves

Satellites
- Fronts, Eddies & Filaments
- Phytoplankton Blooms
- Plankton Migration
- Inertial/Internal & Solitary Waves
- Internal Tides
- Surface Tides

AUV's
- Gliders
- Moorings
- Bottom Tripods
- Shore and Offshore Based Platforms

Molecular Processes
- Individual Movement

Mesoscale Phenomena
- Decadal Oscillations/Fish Regime Shifts
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- Mesoscale Phenomena
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Platform Progress: Atlantic Crossing via Glider, 2008


New Jersey to Spain in 221 days

4600 mi transit, 11,000 dives

1000 calls home

Glenn and Schofield, 2009

Next plan is for repeat of around the world voyage following the *HMS Challenger* expedition track made in 1872-76.
Path of Glider Scarlet Knight Glider – Note ocean features encountered

- Into Deep Water
- Cold Eddy
- Hurricane Bill
- Into Gulf Stream
- Warm Eddy
- Recovery
Satellite data and computer models were used to guide the Scarlet Knight through features.

Undergraduates and graduate students were major collaborators. Part of a curriculum to engage young scientists.
Examples of *in situ* optical measurement systems

**Key advances**

- Hyperspectral and CCD capabilities
- Multi-angle sensing
- Anti-biofouling methods
- Use of data for proxies
Examples of *in situ* chemical measurement systems

1. Nutrient analyzer: Al Hanson
2. pCO$_2$ analyzer: Chris Sabine
3. SEAS: Bob Byrne
4. Water sampler: Dave Karl
In situ electromechanical/fluidic system samples and concentrates microorganisms or particles

Automated molecular (i.e., DNA) probes
MEMS and Nanotechnology
Small size and weight
Low power requirements
0-20 m and 0-500 m ranges
Biofouling issues?

. RoyChaudhuri, et al., 2008
Open Ocean 4-Dimensional Multi-disciplinary sensing off Bermuda: A vision and progress
Some Big Picture Questions

What percent of global annual new primary production do eddies contribute (est. 10-50%)?

Do hurricanes and eddies lead to more or less CO$_2$ uptake by the ocean? Acidification?

How do hurricanes and eddies affect the ocean’s foodweb and ecosystems?

What would be the effects on hurricanes and eddies if global warming continues and *vice versa*?
Multi-Platform Approach
Bermuda Testbed Mooring

BTM
1994-2007

Also, HALE-ALOHA HOT site

Dickey et al., 2001
Tracks of Hurricanes
In North Atlantic

Black and Dickey, 2008

Since 1851

Since 1995
Events at the Bermuda Testbed Mooring Site

Dickey et al., 1998a,b, 2001a; McGillicuddy et al., 1998; McNeil et al., 1999; Zedler et al. 2002
Hurricane Fabian

- Worst hurricane to strike Bermuda since 1926, winds ~ 100 kts (50 m/s).
- 8 people died
- $300 M damage to Bermuda.
Ekman Spiral

Wind Vector

Ekman Transport Direction

Surface Current Direction

Northern Hemisphere Case
Data from BTM off Bermuda During Hurricane Fabian

Ekman Surface Currents 45° to right of wind vector
Ekman Transport 90° to right of wind vector

$U \text{ [cm/s]}$

$V \text{ [cm/s]}$
Current Response of Hurricane Fabian Using BTM’s ADCP

September 3 - 19, 2003 shows both Inertial motion & Ekman Spiral

1-hour ave.
3-m vert. bins

Dickey et al.
Radiance in a Dynamic Ocean (RaDyO)
Toward the Understanding and Prediction of Optical Variability Near the Ocean Surface

Tommy Dickey, UCSB
and RaDyO Investigators

Marlon Lewis
How can objects be ‘observed’ from above and below the sea surface?

Above- and below-surface images using RadCam on MASCOT – Images provided by Marlon Lewis’ group.
Examples of Related Interdisciplinary Problems

1. Prediction of underwater light field statistics given wave structure plus other factors (forward model-based).

2. Prediction of wave structure from subsurface light field statistics (inverse model).

3. Particle characterization with optics for remote sensing, photosynthesis, photo-oxidation, biogeochemistry, etc.


JGR Special Section 2011-2012
Processes and Factors Affecting Near Surface Optics

* Wind forcing and incident solar radiation
* Surface gravity and capillary waves
* Internal gravity waves
* Boundary layers on both sides of the interface
* Surfactants
* Whitecaps and bubbles
* Ocean circulation, water motion, turbulence
* Inherent and apparent optical properties
* Light absorption, scattering, polarization
* Radiative transfer at air-sea interface and within the water column
RaDyO Approaches

New Optical Technologies
Scales down to msec’s and mm’s
Large dynamic ranges
Multi-angle
Multi- and hyperspectral
Polarigraphic

Three Field Experiments

Physical & Optical Modeling
for Synthesis & Prediction
SB Channel with RaDyO Site and Other Platforms
Channel is ~40 X 100 km, max. depth up to ~600 m, ~170 m at site
Regional Setting for RaDyO SBC

SAR images, Ben Holt

Atmospheric and Oceanic Circulation Models by Carvalho, Chao, Dong, et al.
Evolution of Surface Currents

Libe Washburn’s HF Radar
1 day data on 1 km grid ave.; data assimilation model run by Yi Chao.

New eddy tracking algorithm
(Dong et al., 2012)
Multi-scale sampling 1sts
2-D slope field meas. cap.-
grav. waves w/ polarimeter.
IR anal. of μ-scale breaking.
Meas. detailed response of
underwater radiance to sfc.
Obs. wave field including
breaking at all scales.
3 Wind Regimes

Wind Speed From KM (Blue) and FLIP (red), mean values are calculated from KM data

Diurnal

Wind Speed Spectra (KM), Sept. 8-22, 2008

Wind Stress From KM (Blue) and FLIP (red), mean values are calculated from KM data

Wind Speed Spectra (FLIP), Sept. 13-23, 2008

OPL and Chris Zappa Data
KM ADCP Currents
MLD ~10-20 m (diurnal), then >20 m, and ~10 m.
Interfacial + near surface meas. to quantify microlayer and near surface processes including chemical and bubble effects (Vagle et al.) – obs. enhancement of part. conc. + increase in particle absorp. and scatt.
Right. MASCOT used for 1st comprehensive scattering (incl. 17 angles), absorption, CTD, and optical bubble observations. Also, linear polarization elements of VSF.

Left. Acoustic resonator used to measure bubble distributions in range of 5 - 100 microns in diam. Bubble plumes meas. under breaking waves.

Twardowski et al.

Vagle, Farmer, Czerski
HyperPro and Radcam

*Left.* Vertical profile of full radiance with 0.25 m resolution

*Right.* Resolve full radiance distr. at high freq.; $10^6$ dyn. range; both hemispheres

Marlon Lewis group
Right. Porcupine measures high intensity, msec scale flashes of 3000 W m\(^{-2}\) (over 10 times greater than ave.) spectrally.

Below. NPOL meas. full downwelling polarized spectral radiance distribution.

Ken Voss group

Dariusz Stramski group
Example fluctuations in downward irradiance measured with the Porcupine irradiance sensor (670 nm)

Time series for the normalized irradiance, $X(t) = \frac{E_d(t)}{<E_d>}$ in the open ocean south of the Hawaiian Islands on September 3, 2009 at 10:20 A.M. local time under variable sky conditions with intermittent cloud cover.

Depth $z = 1.7$ m, solar zenith angle $= 32^\circ$, wind speed $W = 10$ m s$^{-1}$, and the beam attenuation coefficient of seawater at 555 nm, $c(555) = 0.10$ m$^{-1}$.

*Darecki et al., 2011.*
ROMS Model
12.5 km (~20 mi) resol.
30 layers
12 Biol. variables
50-year spin-up

Real-time forcing: 1-day NCEP reanalysis 1950-2004
SGI Altix computer [2nd fastest]
(Yi Chao, JPL)

Modeling:
NRL
UCLA/JPL
Harvard

Time(year)
93 94 95 96 97 98 99 00 01 02 03 04

1.5 km
750 m
Interactive Modeling and Observations
Optimal Use of Data and Models via Melding

Measurement Meas. Error

Model Value Model Error

Data assimilation

Model Value Estimates Error Estimates Evaluations

Adaptive Sampling

Adaptive Modeling

Predictive or Retrospective

Based on Lermusiaux and Majumdro, 2003
Keys to Successful Observing Systems

Innovative technologies and modeling

Teaming with scientists in other fields + futurists

Breakthrough science results and sharing of data

Educational and outreach components

Multiple funding sources & long-term objectives

Dedicated leadership & teamwork
References

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Web: www.opl.ucsb.edu/Publications
email: tommy.dickey@opl.ucsb.edu.

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