Linking Observations and Modeling In Coastal Ocean Observing Systems

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Data Assimilation in Support of Coastal Ocean Observing Systems (CIOSS, 2007)
Linking Observationalists and Modelers With Coastal Ocean Observing Systems

courtesy of John Bane (UNC)
Physical Oceanographers and the Coastal Ocean

courtesy of John Bane (UNC)
Coastal Oceanographers

Physicists!
Outline

• Some definitions
• Time series are great!
• Satellite data are great!
• Revealing the depths
• Subsurface interannual variability in the CCS
• Spatially intensive time series
• IOOS
• The ORION program

courtesy of John Bane (UNC)
Webster’s Dictionary:

“observatory – A building equipped for observation of natural phenomena, as in meteorology, magnetism, or astronomy.”

ocean observatory – an array of ocean and atmosphere sensors on a variety of platforms used together with models by a team of scientists, technicians and students

observatory science – “science” is what we do!

observing system – observatory plus models; near real-time; often used in operational 24/7/365 context of Ocean.US

Observatories are “laboratories” for experimentation and allow interplay between observationalists and modelers. They enable:

- 4D view of atmosphere, ocean, topography
- Long time series, hence more degrees of freedom
- Full-season coverage and the capture of “events”
- Interactive and adaptive sampling
- Generation and testing of new scientific hypotheses
- Development of new technologies
Scientific Insights from Coastal Observatories

- atmosphere
- ocean circulation
- ocean ecosystem
- sediment/shore topography

Observations

Modeling

Theory

Society
Heard ‘round the Data Assimilation Workshop

- “space and time scales are short”
- “no substitute for data”
- “if you data assimilate, it doesn’t matter how bad the BCs/ICs are”
- “I/we don’t know”
- “long time series are great!”
- “it’s a good idea to conserve mass”
- “the ocean is grid free”
- “models aren’t good enough to do X”
- “observations aren’t good enough to test the models”
- “what do we need more to make the model fit data”

- “yeah, but what have you learned new about the ocean?”
An ocean observatory

TAO/TRITON Array

wind speed, direction/humidity
temperature/pressure/precipitation
short wave radiation

Conductivity/Temperature
Current meter

CT

CT

CT

CT

CT

CT

CT

CT

CT

CT

CTD

CTD

CTD
El Nino/La Nina

An ocean observatory

low sea level = cold  high sea level = warm
A coastal ocean observatory circa 1981-1982

Fig. 3. A three-dimensional schematic of the final CODE 2 moored array which returned usable data. Current meter locations are identified by solid circles, meteorological buoys are shown by buoys, the temperature-conductivity chain is shown by open circles, the bottom stress instrumentation is shown by bisected triangles and rectangles, bottom pressure and temperature recorders are shown by asterisks and coastal meteorological stations are shown by open squares. A bottom-moored Doppler acoustic profiling current meter (DAPCM) was deployed at C4. The NCAR Queen Air and R/V Wecoma were used for all aircraft and most shipboard survey work respectively, in CODE 1 and 2.
Coastal Ocean Observing
circa 2007
Time series are great!

Huyer and Smith (1978)
Satellite data are great!

Castelao et al. (2006)
Submesoscale is gonna be tough to observe!

Barth (1994)

20-km wavelength
1-day e-folding fast propagation
35 cm/s
20 m/day vertical velocity

Need some clever Lagrangian techniques

Barth (1994)

Figure 1. (a) Satellite infrared sea surface temperature (°C) from June 2, 1992, off Oregon. (b) SST anomalies (°C).
Revealing the depths
Coastal Ocean Data Assimilation (DA) System
Oregon Shelf, Summer 2001

Data Assimilation: Model + Data = Optimized Solution (3D+Time)

analysis of BML variability

Kurapov et al. (2005)
Use Princeton Ocean Model (POM)

350 x 220 km, Periodic domain, $\Delta x \sim 2$ km, 45 vertical $\sigma$-layers

Forcing: alongshore wind stress, heat flux

Kurapov et al. (2005)
Data assimilation:

-sequential, optimal interpolation (OI)

\[ v_{t-\Delta t}^a \xrightarrow{\text{POM}} v_t^f, \]

\[ v_{t}^{a} = v_t^{f} + G(\text{obs}_t - Hv_t^{f}) \]

Time-invariant gain matrix [Kurapov et al. JGR, 2004]
matrix matching observations to state vector

-incremental approach

-correction only to \(u\):

-correction term is present in momentum equations

-however, equations for \(T, S, q^2, q^{2l}\) are dynamically balanced (which facilitates their term balance analysis)

Kurapov et al. (2005)
Effects of DA: improvement in near-bottom currents

alongshore velocity at NH10 mooring [Kosro]

b) $v$, NH10, 10 m

c) $v$, NH10, 66 m

model-data corr.: 0.52 (no DA) $\rightarrow$ 0.83 (DA)

rms error: 8.1 (no DA) $\rightarrow$ 4.4 cm s$^{-1}$ (DA)

Kurapov et al. (2005)
Near-bottom horizontal currents and density (days 146-237):

- 5 cm s$^{-1}$ lat, N lon, W

bathymetric contours are 50, 100, and 200 m

- mid-shelf – large bottom stress, inner-shelf – low bottom stress

Rightarrow an area of increased bottom stress curl

Kurapov et al. (2005)
Spatial and temporal variability of BML thickness on the mid-Oregon shelf

BML thickness $\delta_B = \text{distance from bottom, over which } \sigma_0 \text{ is decreased by } 0.0006 \text{ kg m}^{-3}$ from its bottom value [Moum et al., 2004]

Kurapov et al. (2005)
**Hypothesis:** Upwelling jet flowing over a wider part of the Oregon shelf creates conditions for Ekman pumping near bottom

Surface current (days 146-191), shades: $\sigma_0 = 24, 25 \text{ kg m}^{-3}$

Pumping velocity:

$$w_p = \frac{k \cdot \text{curl} \tau_B}{\rho_o f},$$

where $\tau_B$ is the bottom stress

- a BBL effect on the vertical velocity at the top of BBL

Kurapov et al. (2005)
Areas of larger $w_p$ match closely those of larger BML thickness

Kurapov et al. (2005)
Vertical sections (44.11N) on 19 August 2001

Barth et al. (2005)
Light attenuation in BBL

BBL thickness

Barth et al. (2005)
What about interannual variability in CCS subsurface structure?

Subarctic Invasion in 2002

Freeland et al. (2003)
Enhanced nutrient flux increased production over the California Current System as a whole

Figure 2. Nutrient concentrations (μM) versus salinity for station NH-25 along the Newport line from 1998–2002.

Wheeler et al. 2003
Anomalously low DO sourcewater led to hypoxia over the shelf

Grantham et al. (2004)
Interannual variability – The 2002 Subarctic water invasion
• significant fish and Dungeness crab die-offs

Normal Inner-Shelf Rockfish Community

July 2002

Grantham et al. (2004)
Spatially extensive time series

Autonomous underwater vehicle gliders

OSU coastal glider group
  Jack Barth, Kipp Shearman, Anatoli Erofeev,
  Tristan Peery (graduate student), Jesse Steele (undergrad)
  REU summer students
Newport Line
- 90 km cross-shelf
- Strong currents (50+ cm/s)
- Scary bathymetry
- Historical Observations

OSU Glider Operations

Newport Line
- April – Dec 2006
- 197 glider-days
- 4236 km
- 56 sections
- 16,438 profiles

Umpqua River Line
- Summer 2007
Glider bob end of line GPS fix:
(44°37'N, 124°7.241'W)

0.2 m/s

Temperature (°C)
Salinity (PSU)
Dissolved Oxygen (mL/L)
Chlorophyll fluorometer (μg/L)
CDOM fluorometer (ppbL)
Backscatter (mL/L)
Salinity (PSU), Depth: 0-10m, April 5 - December 17 2006

Columbia River Plume
Hypoxia can affect large sections of the Oregon continental shelf
IOOS Regional Associations

AOOS - Alaska Ocean Observing System

CeNCOOS

Southern California Coastal Ocean Observing System

PacIOOS

GCOOS

CarIOOS

GLOS - Great Lakes Observing System

GoMOOS - Mid-Atlantic Coastal Ocean Observing Regional Association

Macoora
Okay, here’s the audience participation part

• How many of you belong/participate in your local OOS?

• How many of you help in deciding where and what to measure?

• How many of you put model output on a public-access web portal?

• How many of you get asked about local ocean-related issues? For example,
  • pollution
  • hypoxia
  • climate change
  • search and rescue?

We all need to be relevant and active!
Modelers can help decide what to observe!

Who knows what the “consensus” observational variables are for IOOS?

T, S, pressure, velocity, wind speed, T-air

What about surface radiation?
What about high-resolution pressure and turbulence?

The biological list is long:
• chlorophyll fluorescence
• dissolved oxygen
• nitrate
• Colored Dissolved Organic Matter (CDOM)
• light backscatter
• acoustic backscatter
• genomic, proteomic, transcriptomic, …
ORION

Location: Celestial Equator (visible in both Northern and Southern Hemispheres)

Coordinates:
Right Ascension: 05h
Declination: -05°

Source: Greek mythology, Arab, ancient Indian & Egyptian

The story behind the name: The pattern in the constellation Orion was recognized as a human figure by many ancient cultures. Orion's position on the Celestial Equator makes it visible all over our planet.
Ocean Research Interactive Observatory Networks (ORION)

Ocean Observatory Initiative (OOI)
NSF Major Research Equipment and Facilities Construction (MREFC)
In the President’s FY08 budget
$300+ million over 6 years
Includes fixed infrastructure, sensors, mobile platforms,
cyberinfrastructure, education and outreach
Does not include $ for Operations and Maintenance
estimated to ramp up to $50M (in 2007 dollars) by 2013 ($30M)
Does not include explicit $ for modeling, although …

Everyone involved with the program thinks
modeling is important!
Ocean Research Interactive Observatory Networks (ORION)
Ocean Research Interactive Observatory Networks (ORION)

How can modeling become better integrated?

• formal participation in ORION advisory structure

• through individual and group proposals to the OCE core

• through the Implementing Organizations which will build the system (a strong argument can be made for OSSEs to design arrays and autonomous platform sampling)

• community pressure on and advise to NSF OCE by groups like this!

• creative application of efforts funded by other agencies: NOPP is an excellent example!

IOOS is becoming more “real”