Crossing the “Valley of Death” with the California Harmful Algae Risk Mapping (C-HARM) System

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5 Step Process to Operations: Does it work?

I. Establish the need for a predictive capability

II. Demonstrate model readiness and feasibility

III. Continually conduct skill assessments *building on prior efforts in Anderson et al. 2009, 2011, 2016*

IV. Engage stakeholders and agency end-user early on

V. Cross the “Valley of Death” to operational environment
Why predict HABs in California?

• Domoic acid (from *Pseudo-nitzschia* blooms) is the *leading* HAB issue on the US West Coast

• Unprecedented West Coast-wide HAB of 2015 - closed Dungeness Crab Fishery for the season; contributed to *Unusual Mortality Events*

• Shellfish growers, fishermen, and marine mammal rescue groups want an early warning system that will *enable mitigation efforts and resource management*

**INITIAL BASELINE FOR DECISION-MAKING**

• CDPH monitors for DA if PN present in water
• Relies on fixed quarantine periods
California Harmful Algae Risk Mapping (C-HARM) System

II. APPLICATION READINESS

NASA Team Meeting

Anderson

REMOTE SENSING
OCEAN COLOR & SST
2-D satellite images (MODISA, soon VIIRS)

DINEOF

INTERPOLATED
OCEAN COLOR & SST
2-D satellite images
Error estimates
(R_{rs}(\lambda))

CCS-tuned Algorithms

RECONSTRUCTED
OCEAN COLOR & SST
2-D Chl, Rrs (0^+, \lambda) imagery

IN SITU OBSERVATIONAL DATA

Oceanographic and meteorological observations
(current meter, salinity, temp, winds)
Biological/H₂O quality field observations
(water sample, toxin, shellfish toxicity)
Cal-HABMAP pier data
(Species composition, toxicity)
Motion sensor data
(AUV, glider, etc)

CROWDSOURCED DATA

Expanded HAB Monitoring Network
(HABMAP, TMMC stranding data, JellyWatch/ HAB App for marine mammal strandings)

CELL SCOPE; TMMC REAL-TIME DATA

INTEGRATED NOWCAST & FORECAST FRAMEWORK

FORECAST & ANALYSIS TOOL
(application of forecast guidelines and rules, mapping tool)

HYDRODYNAMIC MODEL FIELDS
3-D ROMS 3-day Forecast
(currents, salinity, temperature)

HAB Empirical Models

3-D Nowcasts of Bloom and Toxicity Probability

BIOLOGICAL MODEL FIELDS

Advection Scheme

3-D 3-day Forecasts of Bloom and Toxicity Probability

NASA Applied Sciences Program, Terrestrial Hydrology, Ocean Biology and Biogeochemistry Programs
“Ecological Forecasting for Conservation and Resource Management”
“Remote Sensing of Water Quality”
Interactive Data Portal C-HARM Nowcasts and 3-day Forecasts

http://www.cencoos.org/data/models/habs/

Probability Maps

Risk Maps based on stakeholder feedback
Contingency Plots to Assess Model Performance – Optimize Prob. Threshold

*Pseudo-nitzschia* at the SC Wharf *vs.* Nearest Model Pixel

Domoic Acid at the SC Wharf *vs.* Nearest Model Pixel

Accuracy
- **POD**
- **FAR**
- **POFD**
- **BS** (bias score)

Anderson et al. 2016, *Harmful Algae*
**PN model** = coin flip? (AUC < 0.5)

**DA model** = Useful Model (AUC > 0.5)
An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions

**C-HARM ESTIMATES AT CRUISE STNS**

**Likelihood of a *Pseudo-nitzschia* bloom**

- **64% Accuracy, 31% False Positives**

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**R/V Shimada NMFS Cruise-of-Opportunity**

- **Trinidad - new hot spot**
- **Some overestimation near SF Bay**
- **Pt Conception-SBC known hot spot**
- **Didn’t see bloom in the Southern CA Bight**

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**Special Section:**
Midlatitude Marine Heatwaves: Forcing and Impacts

**RESEARCH LETTER**

10.1002/2016GL070023
An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions

R/V Shimada NMFS Cruise-of-Opportunity

C-HARM ESTIMATES AT CRUISE STNS

Likelihood of elevated DA Levels
71% Accuracy, 20% False Positives
2017 – Extensive HAB in Southern California

Sea Lions Suffering From Domoic Acid Poisoning, Laguna Beach Rescue Says

"In large concentrations, (the algae) produces neurotoxins that can destroy the brain," Pacific Marine Mammal Center said.

By Ashley Ludwig (Patch Staff) - April 11, 2017 12:23 pm ET

Broad Impacts: Animal Strandings/Death [Sea Lions, Elephant Seals, Guadalupe Fur Seals, Seabirds (Common Murres, Grebes, CA Brown Pelicans); Shellfish Advisories in Santa Barbara/Ventura Counties

April 15 = HAB Onset
• Offshore Event
• Low toxins measured at piers
• Animals stranding in large numbers

May 17 = HAB moves South & North
• More Impacts felt near San Diego
• HAB persists in Santa Barbara Channel
• Rock Crab fishery closed in Nor Cal
What does C-HARM tell us about shellfish toxicity?

2016 – Crab/Shellfish toxicity tracks nearshore model

Red=Crab, Yellow=Mussel
Crab Data from: http://www.cdph.ca.gov/healthinfo/pages/fdbdomoicacidinfo.aspx

New partners in Aquaculture 2016-2017

Greg Dale –
Coast Seafoods, Humboldt Bay

Kelly Stromberg –
Catalina Sea Ranch (first offshore site in U.S., San Pedro Bay)

Eric Bjorkstedt, Brian Tissot –
Humboldt State University

Jeff Anderson –
Northern Hydrology

Objectives:
• Collect paired shellfish/water toxins
• Create statistical model of shellfish toxicity
• Hydrological model of HB

Many thanks to NASA/Woody Turner for Stakeholder Engagement Funding
What does C-HARM tell us about shellfish toxicity?

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Many thanks to NASA/Woody Turner for Stakeholder Engagement Funding
CeNCOOS = Central and Northern California Ocean Observing System
NCCOS = National Centers for Coastal Ocean Science
CSDL = Coast Survey Development Lab
RSS = Remote Sensing Solutions, Inc.

MODISA TO VIIRS

DINEOF

INTEGRATED FORECAST FRAMEWORK
FORECAST & ANALYSIS TOOL
Transition Development
UCSC/CeNCOOS
Final Implementation
NCCOS/NOS CO-OPS*

NOAA NCCOS OPERATIONAL HAB MODELS
*GULF OF MEXICO
LAKE ERIE
GULF OF MAINE
CHESAPEAKE BAY
CALIFORNIA

WCOFS = West Coast Ocean Forecast System
WCOSS = Weather and Climate Operational Supercomputing System
CO-OPS = Center for Operational Oceanographic Products & Services

Migrated to S4 Supercomputer in Jan 2016; ARL 7/8
LESSONS LEARNED... so far

- Communicate early and often with partner agency/operational end-user
- Be prepared for leadership turnover at agency level
- Carefully document and annotate your model system
- Stay flexible - do not get wedded to one idea of a model’s “forever home”
- Continue R&D efforts - operational does not mean perfect
THANK YOU!

Terrestrial Hydrology & OBB
Jared Entin, Paula Bontempi
Applied Sciences Program
Woody Turner
Jay Skiles

http://www.cenkoos.org/data/models/habs
New Position at SIO-SCCOOS
crander@ucsd.edu
Empirical Habitat Models

Lane et al. (2009)
- Monterey Bay; toxigenic Pn blooms

≥ 75% (blooms predicted)

Anderson et al. (2009, 2011)
- Santa Barbara Channel
- Pn blooms
- Pn toxin

75%

Blum et al. (2006)
- Lab + field
- Pn toxin

77%

ln(silicic acid)
ln(phosphate)
ln(nitrate)
ln(chl a)
ln(upwelling)
ln(Pajaro River)
temperature

salinity
chl a
R_{RS}(0^+,\lambda)

a_p(\lambda)
a_g(\lambda)
day of year
ln(silicic acid:nitrate)
silicic acid:phosphate

ln(nitr:phos)
ln(nitr:si)
sqrt(si:nitr)
sqrt(si)
ln(cells)

ln(nitr:phos)
ln(nitr:si)
sqrt(si:nitr)
sqrt(si)
ln(cells)

ln(phos:nitr)
si:nitr
ln(si:phos)
ln(phos:si)
nitr:phos
sqrt(nitr)
ln(nitr)
phos
*3-km CA ROMS with 3D-Var (Yi Chao/CeNCOOS & SCCOOS)

Remote Sensing Reflectance
Salinity
Temperature
Chlorophyll
Nitrate
Phosphate
Silicic Acid

Anderson et al. 2011, Detecting diatom blooms from ocean color and a regional ocean model. Geophysical Research Letters L04603
The pDA model correlates well with central CA stranding peaks as early as 7 days before they occur...and with SPATT DA 9-12 days ahead.

Cross correlation functions for the nearest pixel corresponding with Santa Cruz Municipal Wharf. ARIMA was applied to time series prior to analysis to account for non-stationarity.

Anderson et al. 2016, Harmful Algae
2015 – Dungeness crab closures match climatological model
Data Interpolating of EOFs (DINEOF)

- Statistical reconstruction of satellite data solving spatial and temporal EOFs simultaneously (Beckers & Rixen, 2003)
- Can use covariance-matrices to solve for multiple linked datasets
- SST: $R^2=0.9$, RMSE < 1°C, as good as Pathfinder AVHRR but daily!

2007 SST Reconstruction (daily)

Blue: MODISA DINEOF
Red: NDBC Buoy

(NDBC 46054 West Santa Barbara)
Contingency Plots to Assess Model Performance - Optimize Prob. Threshold

Santa Cruz Wharf

A. All Stations – *Pseudo-nitzschia*

- **PN model** = coin flip? (AUC < 0.5)
- **DA model** = Useful Model (AUC > 0.5)

**Anderson et al. 2016, Harmful Algae**
Prep Satellite data (CoastWatch)

Download NASA OC data

Extract Chl, 488, 555 bands and make daily composite

Collect 180 days band data

Run EOF for each band

3 netCDF3 files: Chl, r488, r555
- 180 days data
- 180 days filled data
- lat, lon, time
- land mask
- 2.5 GB each (7.5 GB total)

Downsample to ROMS resolution

netCDF4 file
- 180 days filled Chl, r488, r555
- lat, lon, time
- land mask
- 300 MB (150 MB compressed)

Time to run: 3 x EOFs = 2.5 – 5 hrs

Archive Source data DINEOF results

Collect ROMS data (CeNCOOS, S4)

netCDF4 file
- 180 days salt
- 180 days temp
- lat, lon, time
- 150 MB

Time to run: 4 min / day

Nowcast (CeNCOOS, S4)

Run models:
- Pseudo-nitzschia (Pn)
- particulate domoic acid (pda)
- cellular domoic acid (cda)

Pn, cda, pda netCDF4 files
- 180 days data
- lat, lon, time
- 100 MB each

Maps Timeseries

Time to run: 5 minutes

Use in forecast script (next slide)
Forecast (CeNCOOS, S4)

- Run advection model using forecast u & v vectors
  - Using advection model results advect lastest filled Chl, 488, 555 forward 1, 2 & 3 days
  - Run EOF on advected Chl, 488, 555 (using 180 days of filled data)
  - Run pn, cda & pda models with forecast data

Maps, timeseries
  - Pn, cda, pda netCDF4 files
    - 3 days data
    - lat, lon, time
    - 2.5 MB each

3-day ROMS forecast
- u and v currents

Chl, r488, r555 .nc files
- 180 days filled data plus 3 advected days
- lat, lon, time
- land mask
- ROMS resolution
- 100 MB each

Same file as above except - 3 advected days are filled

3-day ROMS forecast
- lat, lon, time
- land mask
- ROMS resolution
- 100 MB each

Time to run total: 56 min
- Adv. model: 10 min
- Data advection & EOFs: 36 min
- Pn, cda, pda models: 5 min

From Prep Satellite data (last slide)
- netCDF4 file
  - 180 days filled Chl, r488, r555
  - lat, lon, time
  - land mask
  - 300 MB (150 MB compressed)
  - From CoastWatch

Last 180 day plus 3-day ROMS forecast
- salt,
- temp

From CoastWatch
- Last 180 day plus 3-day ROMS forecast
III. 2015 SKILL ASSESSMENT

OVERALL ACCURACY = 61% (7-day mean); 43% (daily matchups)

28% “Correct Negatives”
36% “False Alarms”
3% “Misses”
2015 Particulate Domoic Acid
Santa Cruz Wharf

OVERALL ACCURACY = 73%

70% “Correct Negatives”

24% “Misses”

3% “Hits”

3% “False Alarms”

MEASURED Particulate Domoic Acid (ug/L)

MODELED Particulate Domoic Acid Probability

NASA Team Meeting

III. 2015 SKILL ASSESSMENT

Anderson