California Harmful Algae Risk Mapping (C-HARM) System

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[5]Scripps Institution of Oceanography
[6]NOAA CoastWatch
[7]NOAA National Ocean Service

C-HARM: Community needs, development, and operations

I. Rationale for a predictive capability for domoic acid

II. Development of the model tool

III. C-HARM demonstration and public web portal for end-users

IV. Assessing model performance (i.e. validation)

V. Crossing the “Valley of Death” to an operational environment; opportunities for development in other regions?

Why predict HABS in California?

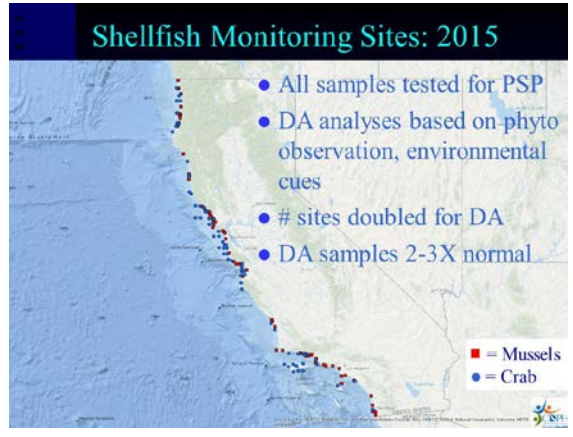
Lewitus et al. 2012

- Domoic acid (DA), from *Pseudo-nitzschia* blooms, is the **leading HAB issue on the U.S. West Coast….but is now expanding to the East Coast!**
- **Unprecedented West Coast-wide HAB of 2015 closed Dungeness Crab Fishery** for the season; contributed to **Unusual Mortality Events** of sensitive and protected species
- Shellfish growers, fishermen, and marine mammal rescue groups want an early warning system that will **enable mitigation efforts and resource management**

CA Dept of Public Health

<u>INITIAL BASELINE FOR MANAGEMENT/DECISION-MAKING</u>

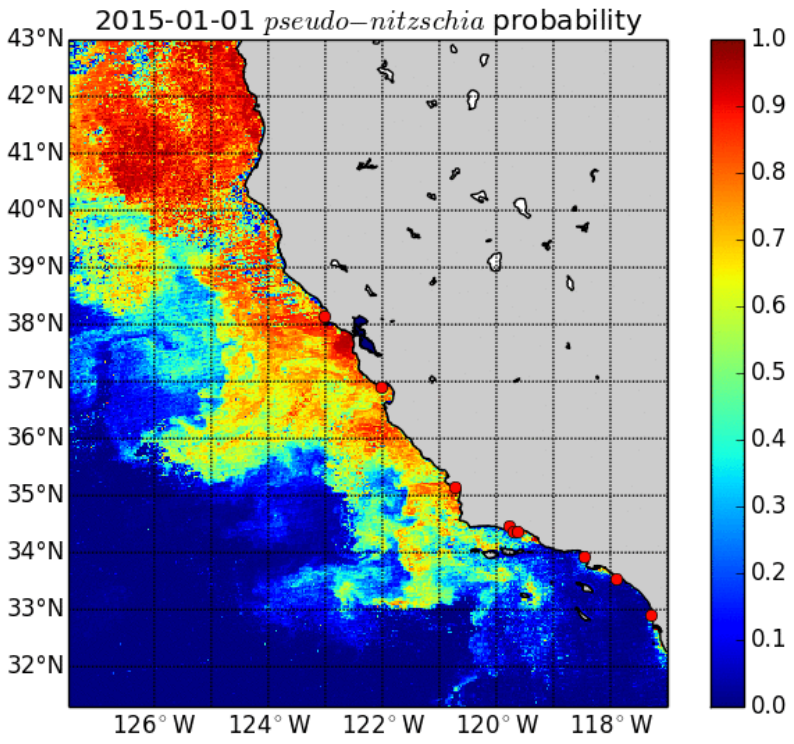
- CA Department of Public Health monitors for DA if the diatom is present at high abundance in the water
- Relies on fixed quarantine periods



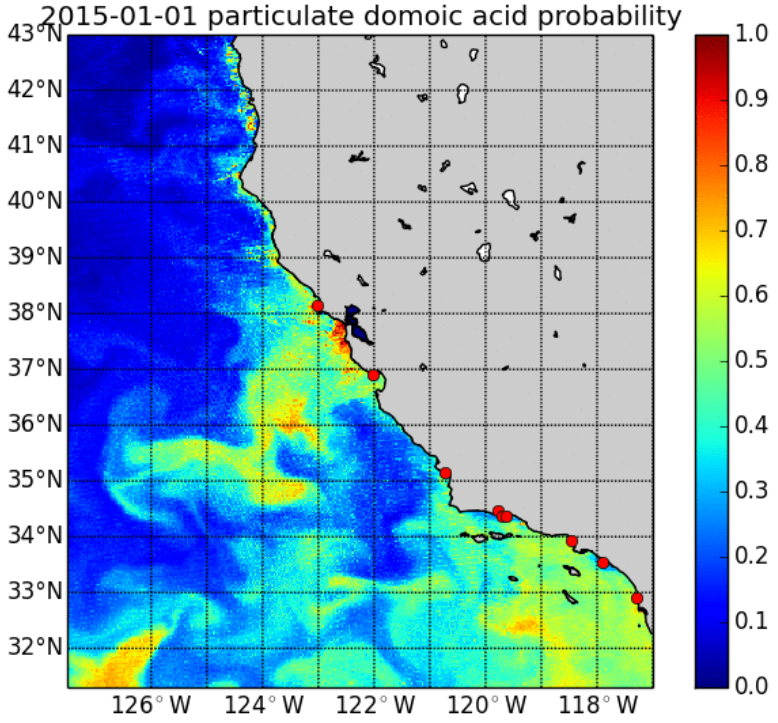
California Harmful Algae Risk Mapping System

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

Particulate Domoic Acid Nowcast



Particulate Domoic Acid Forecast



How did we conceive of and build the HAB model?

Lane et al. (2009)

• Monterey Bay; toxigenic *Pn* blooms

≥ 75% (blooms predicted)

Anderson et al. (2009, 2011)

• **Santa Barbara Channel, "Plumes & Blooms" Cruises for baseline data**

• *Pn* blooms

• ***Domoic Acid Toxin***

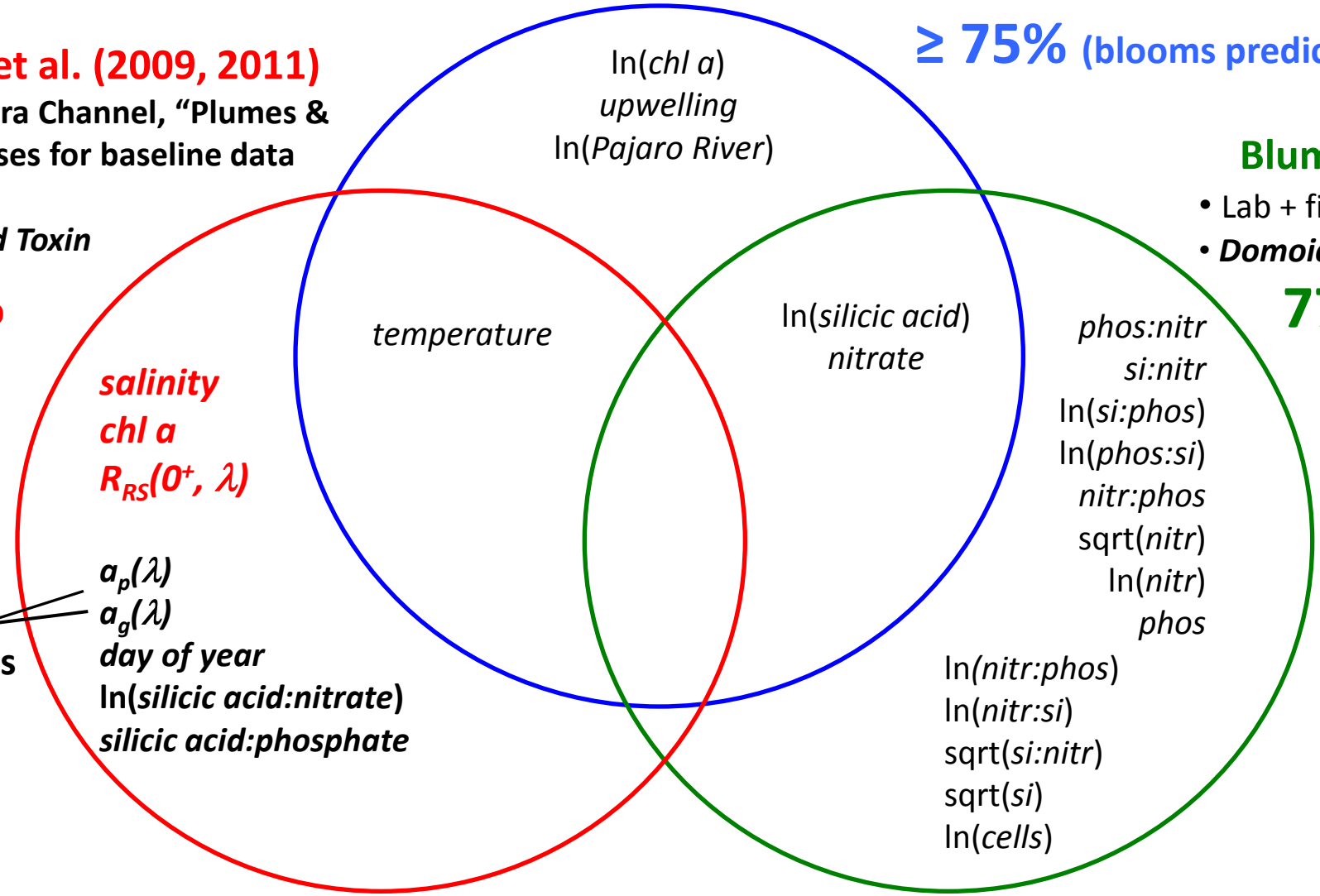
75%

Blum et al. (2006)

• Lab + field

• ***Domoic Acid* toxin**

77%



Absorption at various wavelengths

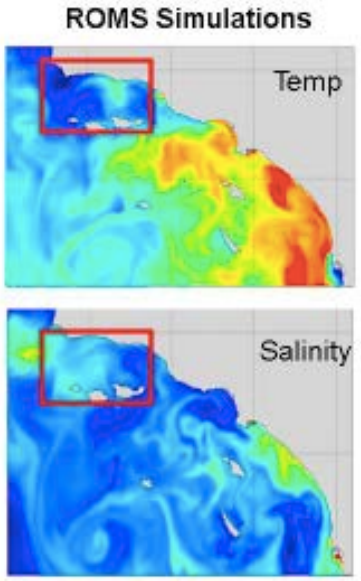
Generalized Linear Models – based on logic regression

HAB Variable (Threshold)	Best-fit Logistic GLM $P_{bloom} = e^{(\lambda)}/[e^{(\lambda)} + 1]$
Pseudo-nitzschia (10^4 cells mL^{-1})	λ= 17.0 – 6.18[R_{rs} (510/555)] – 0.237[**$Si(OH)_4$:(NO_3+NO_2)**] – 0.482(Month) – 0.225[**$Si(OH)_4$:PO_4**] – 1266[R_{rs} (510)]
DOMOIC ACID – pDA (500 ng L^{-1})	λ= -154.2 + 0.145[Chl] – 0.968[**$Si(OH)_4$:(NO_3)**] – 0.619(Temp) + 4.92(Sal) – 0.555(NO_3)
DOMOIC ACID – cDA (10 pg $cell^{-1}$)	λ= 10.7 – 0.618(Temp) – 0.659[**$Si(OH)_4$**]] – 767[R_{rs} (510)]

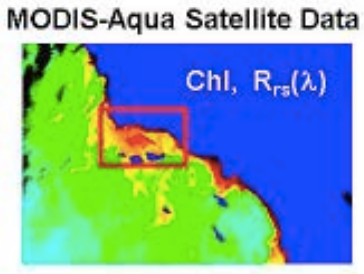
BUT….. we cannot easily acquire these nutrient data in real time or remotely
THUS… we cannot use these models for routine forecasting of DA event likelihood

ALTERNATIVE APPROACH: Build models using conditions that are related to nutrient physiology of organism but that can also be detected remotely

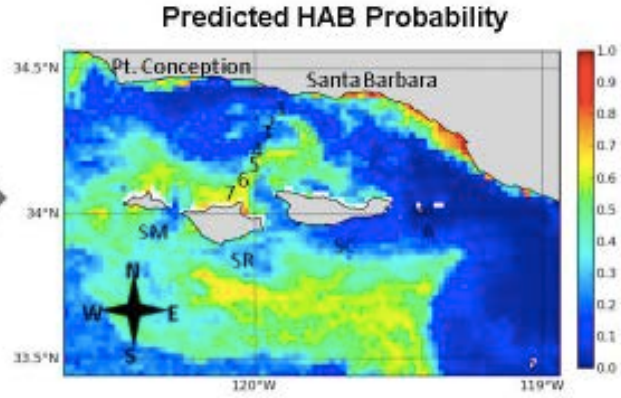
Regional Ocean Model System (ROMS) for physical parameters



VIIRS/Suomi NPP is now online!



Remote-Sensing HAB Model



HAB Variable (Threshold)	Best-fit Logistic GLM - **RS** $P_{bloom} = e^{(logit)}/[e^{(logit)} + 1]$
Pseudo-nitzschia (10^4 cells mL^{-1})	(i) logit = 8.54 - 10.84*[R_{rs} (510/555)] – 0.216*[Month] + 4.67*[R_{rs}(490/555)]
	(ii) logit = 5.32 - 2.87*[R_{rs} (490/555)] – 0.165*[Month]
pDA (500 ng L^{-1})	logit = -134.3 + 0.253[Chl] + 4.0*[Sal] – 502*[R_{rs} (555)]
cDA (10 pg $cell^{-1}$)	logit = -90.0 - 0.35*[Temp] – 666*[R_{rs} (555)] + 2.87*[Sal]

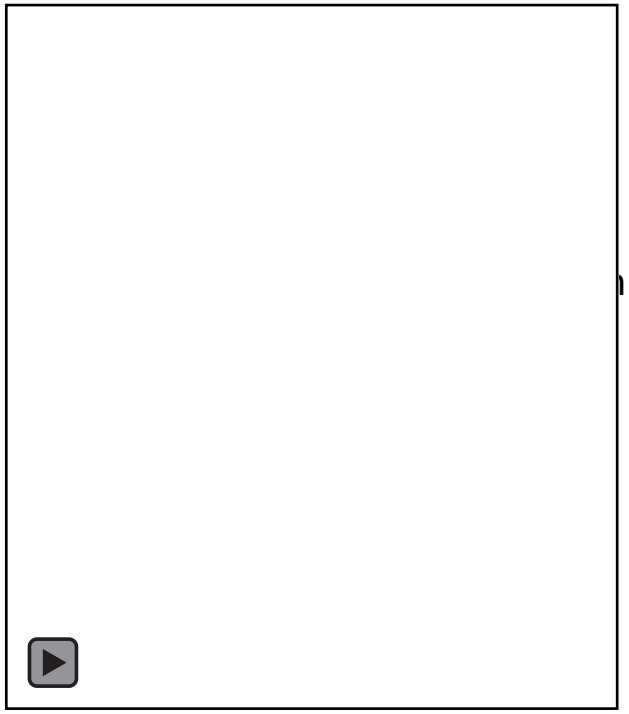
Remote Sensing Reflectance (at several wavelengths)
Salinity
Temperature
Chlorophyll

Nitrate
Phosphate
Silicic Acid

Anderson et al. 2011, Detecting toxic diatom blooms from ocean color and a regional ocean model. Geophysical Research Letters L04603

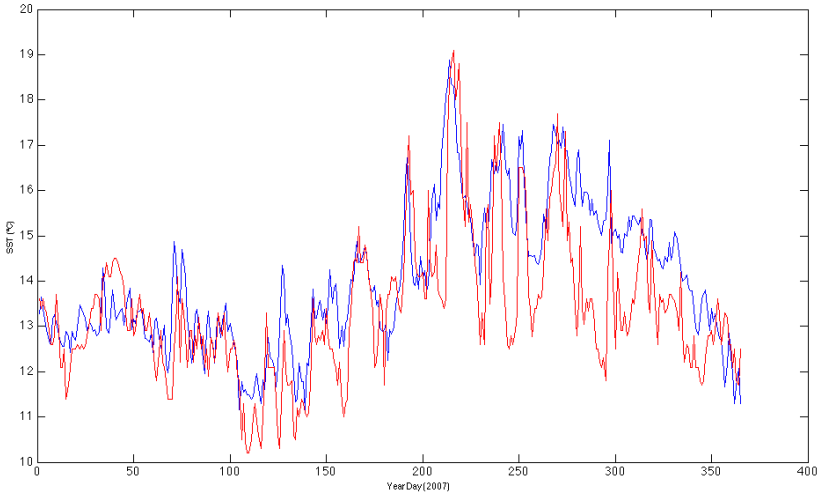
In order to run in near real-time, we have to deal with cloudy satellite imagery

Data Interpolating Empirical Orthogonal Functions (DINEOF)



Statistical reconstruction of satellite data solving spatial and temporal Empirical Orthogonal Functions simultaneously (Beckers & Rixen, 2003)

This is an open source method for statistically "filling" in gaps in the data, akin to Optimal Interpolation. Relies on the spatial variability inherent in the dataset for the time slice that you feed to the program.

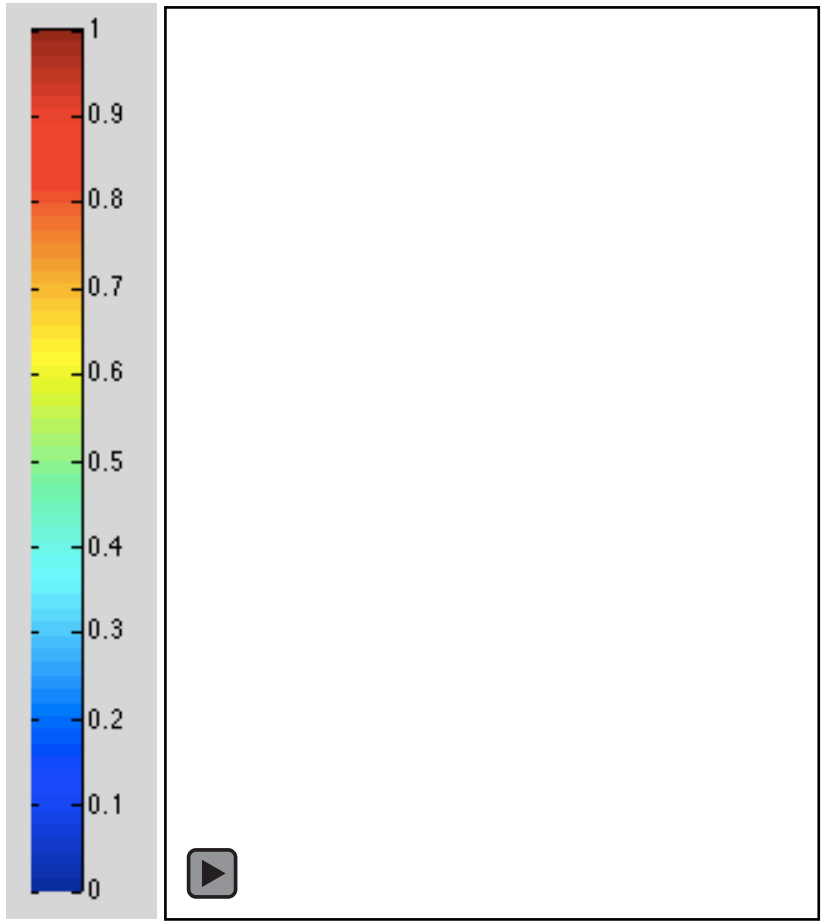


(NDBC 46054 West Santa Barbara)

Blue: MODISA DINEOF
Red: NDBC Buoy

- SST: R^2=0.9, RMSE (Root Mean Square Error) < 1°C, as good as Pathfinder AVHRR but daily!

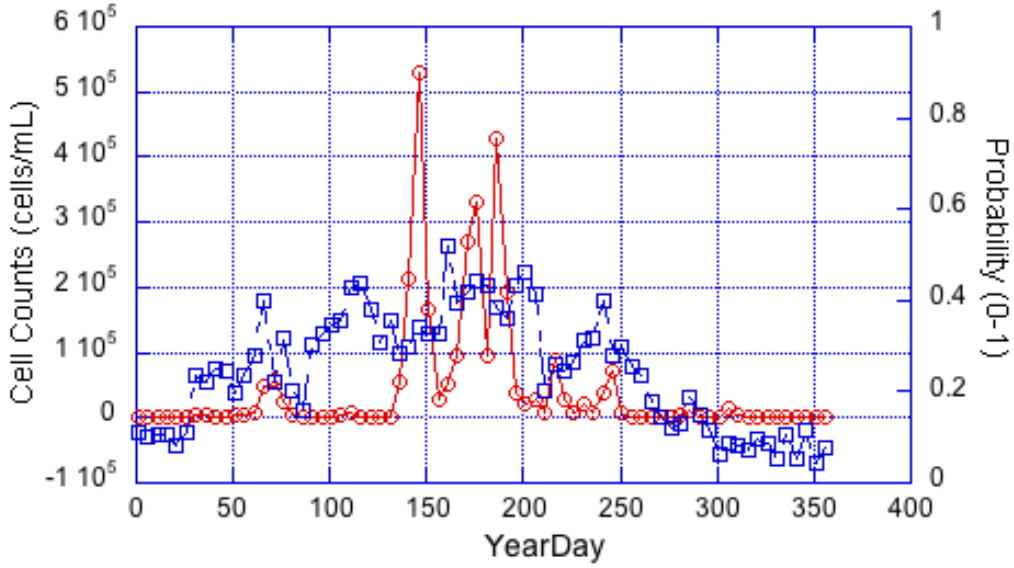
Hindcasting *Pseudo-nitzschia* Blooms



Probability (0-1) of *Pseudo-nitzschia*, 5-day intervals, 2009

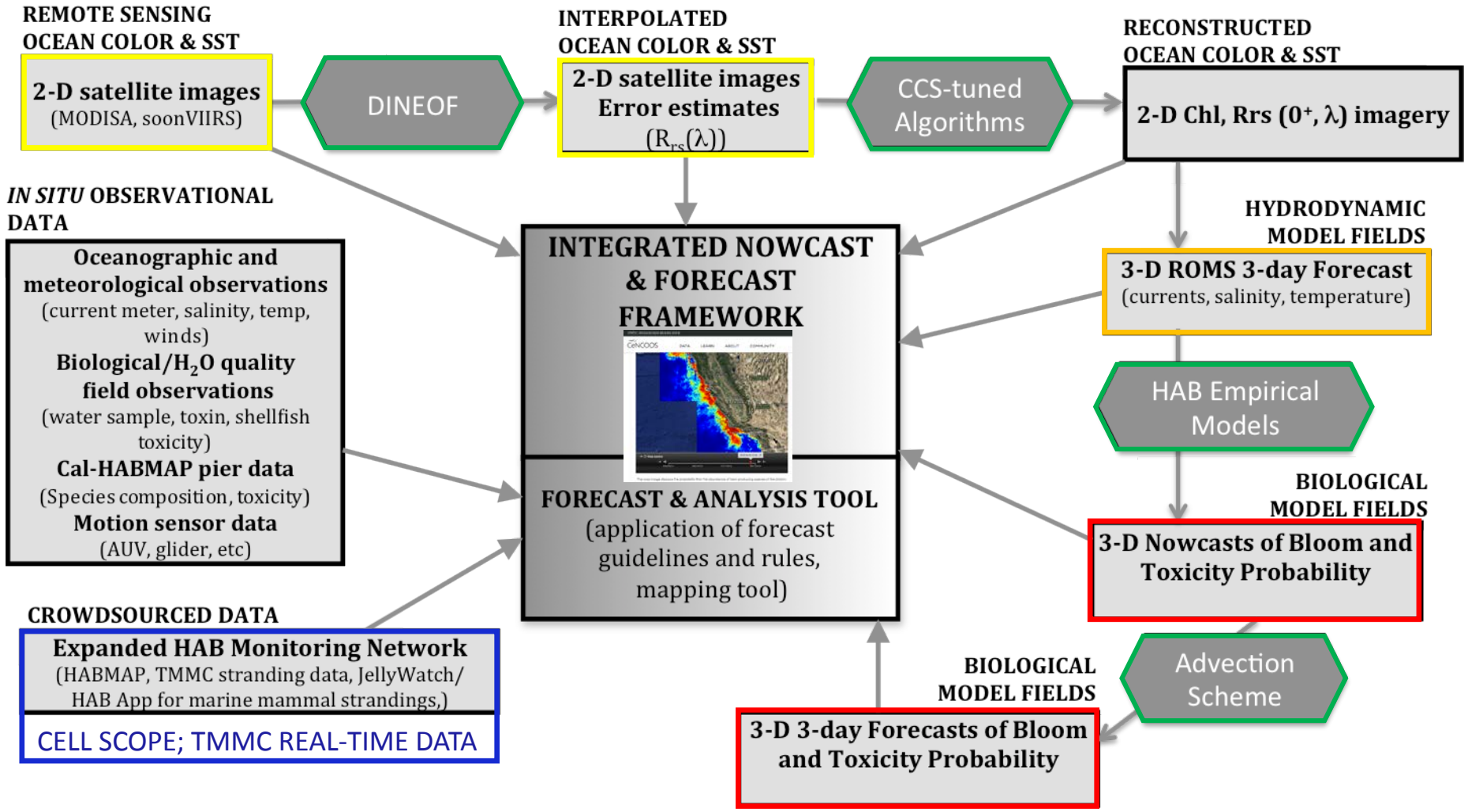
- Focus on 2009 (*Anderson et al. 2011*)
- DINEOF reconstruction at 5-day intervals

Red: Cell Counts
Blue: Predicted Probability



2009 Hindcast versus Cell Counts, Santa Barbara

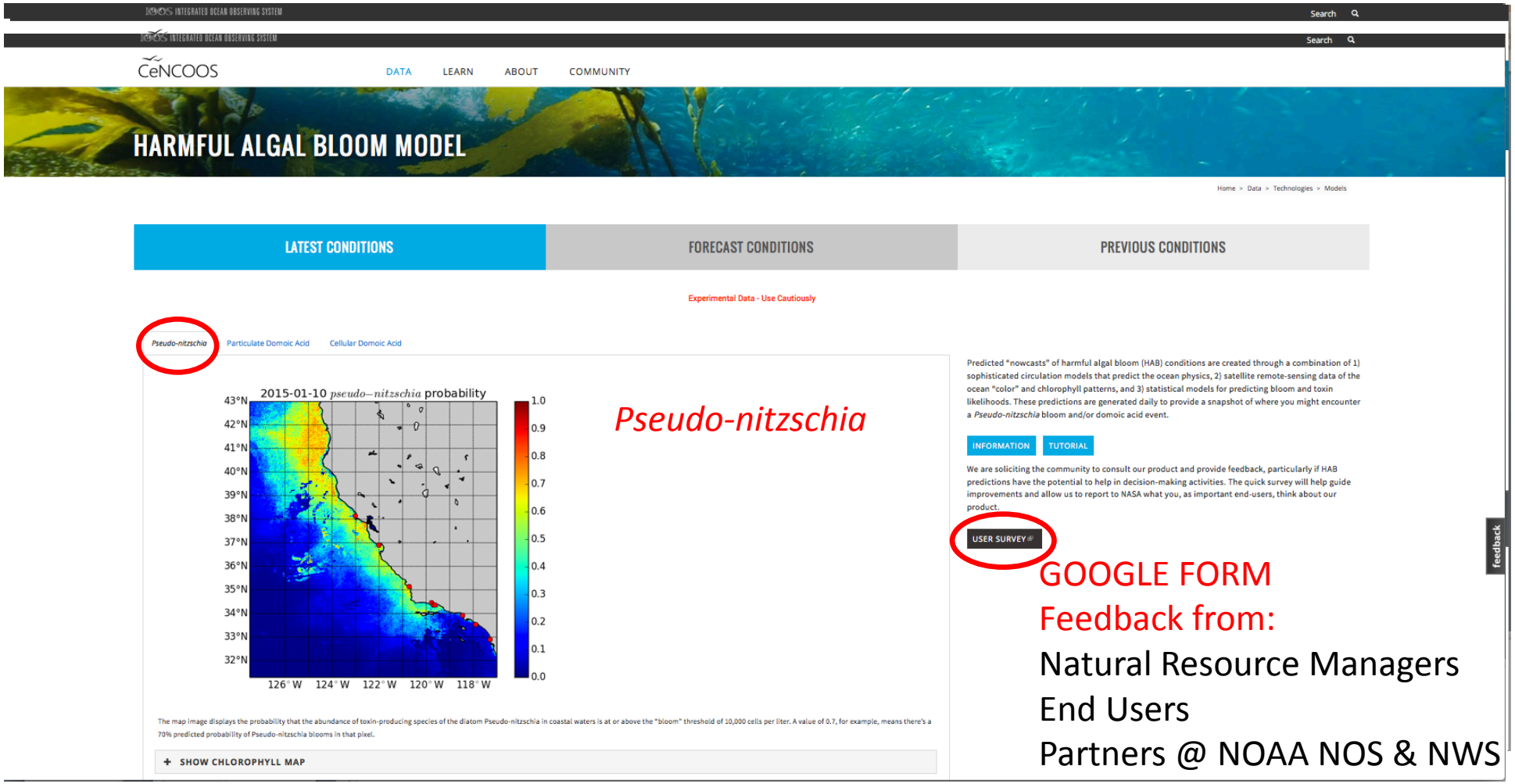
Workflow for the C-HARM Forecasting Tool



NASA Applied Sciences Program, Terrestrial Hydrology, Ocean Biology and Biogeochemistry Programs
"Ecological Forecasting for Conservation and Resource Management"
"Remote Sensing of Water Quality"

PUBLIC WEBSITE TO ENGAGE THE STAKEHOLDER COMMUNITY

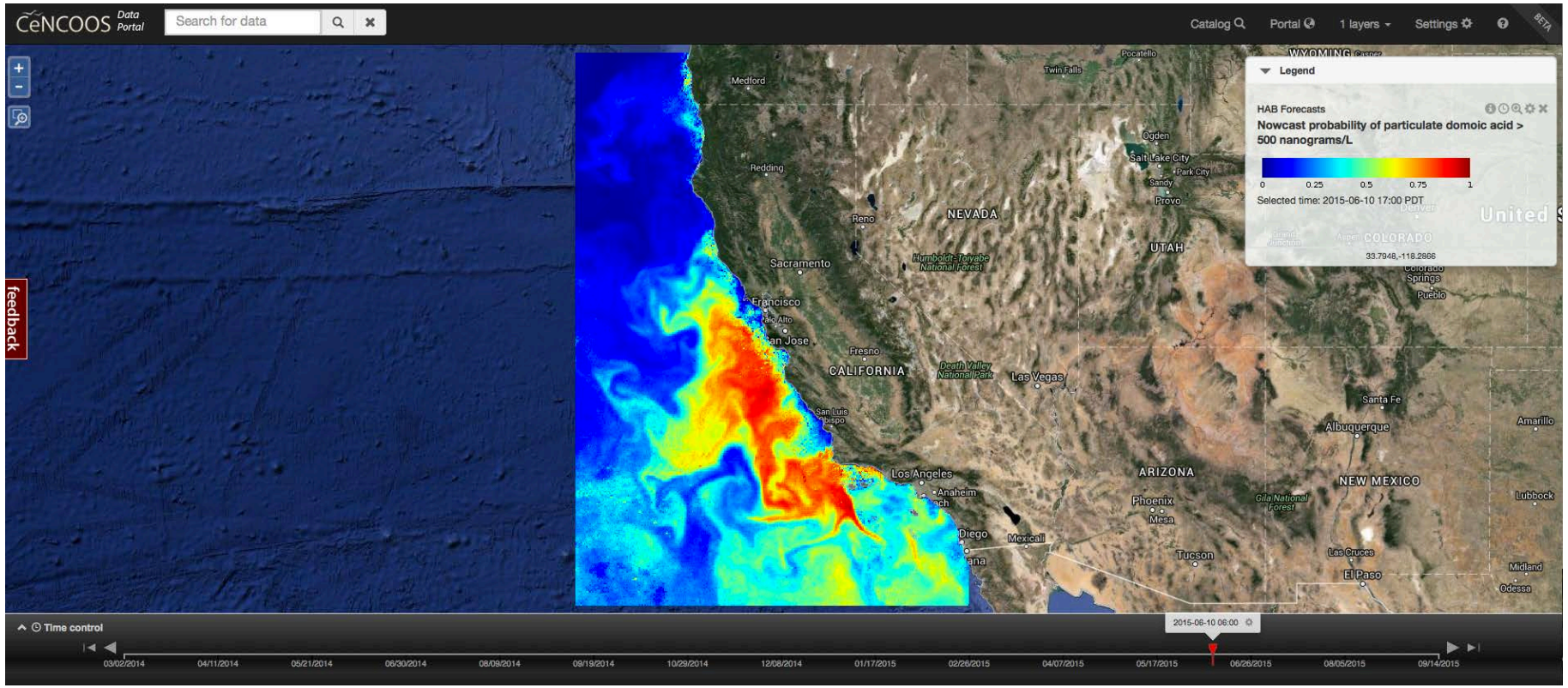
http://www.cencoos.org/data/models/habs/



GOOGLE FORM
Feedback from:
Natural Resource Managers
End Users
Partners @ NOAA NOS & NWS

Interactive CeNCOOS Data Portal “Previous Conditions”

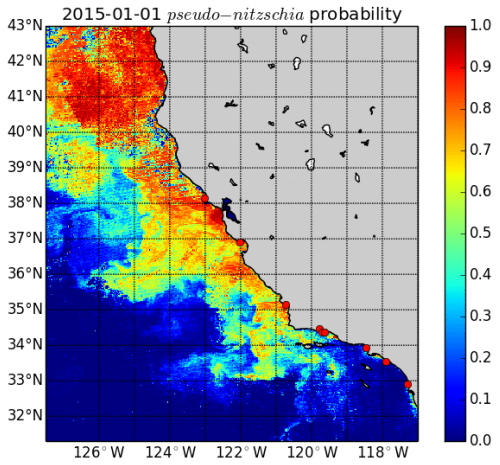
http://www.cencoos.org/data/models/habs/previous



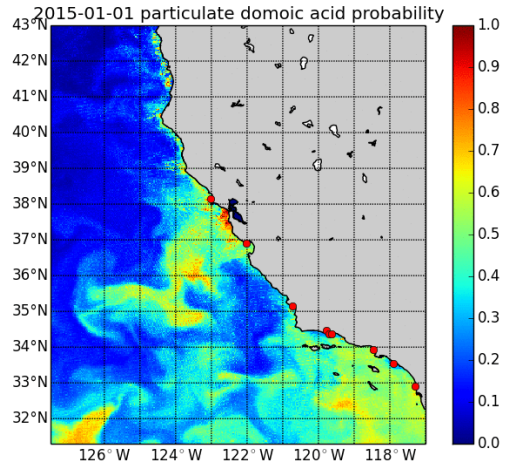
Interactive Data Portal C-HARM Nowcasts and 3-day Forecasts

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

Probability Maps

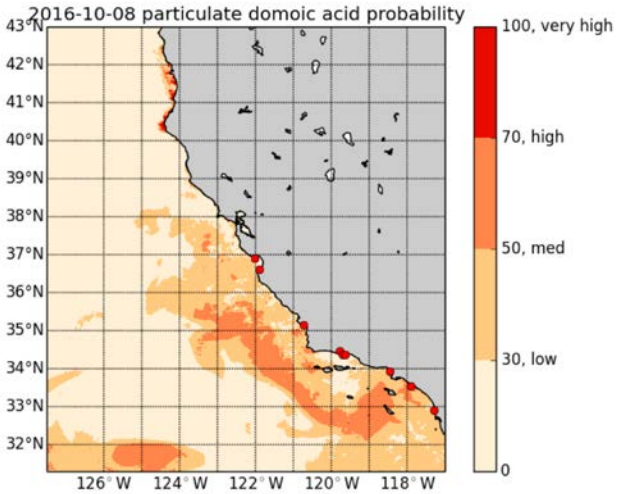


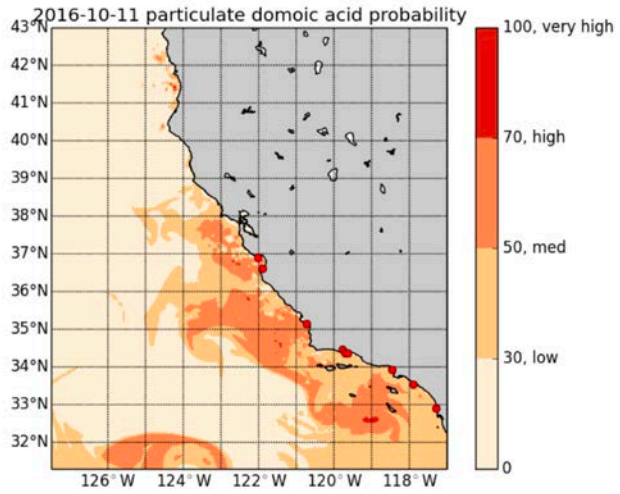
Particulate Domoic Acid Nowcast



Particulate Domoic Acid Forecast

Risk Maps based on stakeholder feedback





Testimonials from Shellfish Growers and Marine Mammal Rescue Centers

“As with every model I use, such as weather and wind and swell, I watch them to see how it applies to my local conditions, and then I determine my own degree of accuracy and apply them to making decisions about how I manage the farm. When a DA event occurs for me, I will be combing the models to see how it relates to my situation.”

– Bernard Friedman, Santa Barbara Mariculture Company, Santa Barbara, CA

"As the Medical Director of a southern California marine mammal rehabilitation center, I am always in need of current data concerning Domoic Acid blooms in southern California waters. We have been using these pictorial data to keep abreast of the seasonal trends in Domoic blooms that impact marine mammals in southern California waters. For the first time in 20 years we are able to verify Domoic Acid blooms in a timely fashion, that could result in moderate to severe pathologies and deaths in marine mammals in Orange County waters. **This is a classic example of 'fore-warned is fore-armed.'** We request that funding to this organization be continued to enable them to continue to produce such valuable data."

– Dr. Richard Evans, The Pacific Marine Mammal Center, Laguna Beach, CA

“There have been repeated calls for such capability at workshops and in publications from oceanographers, veterinarians, ecologists and public health officials, as these blooms have dramatic effects on marine mammal health as well as on the economy and human health.”

– Frances Gulland, Senior Scientist, The Marine Mammal Center, Sausalito, CA

Testimonials from Fishermen and Boaters


Photo: CA Fish and Wildlife

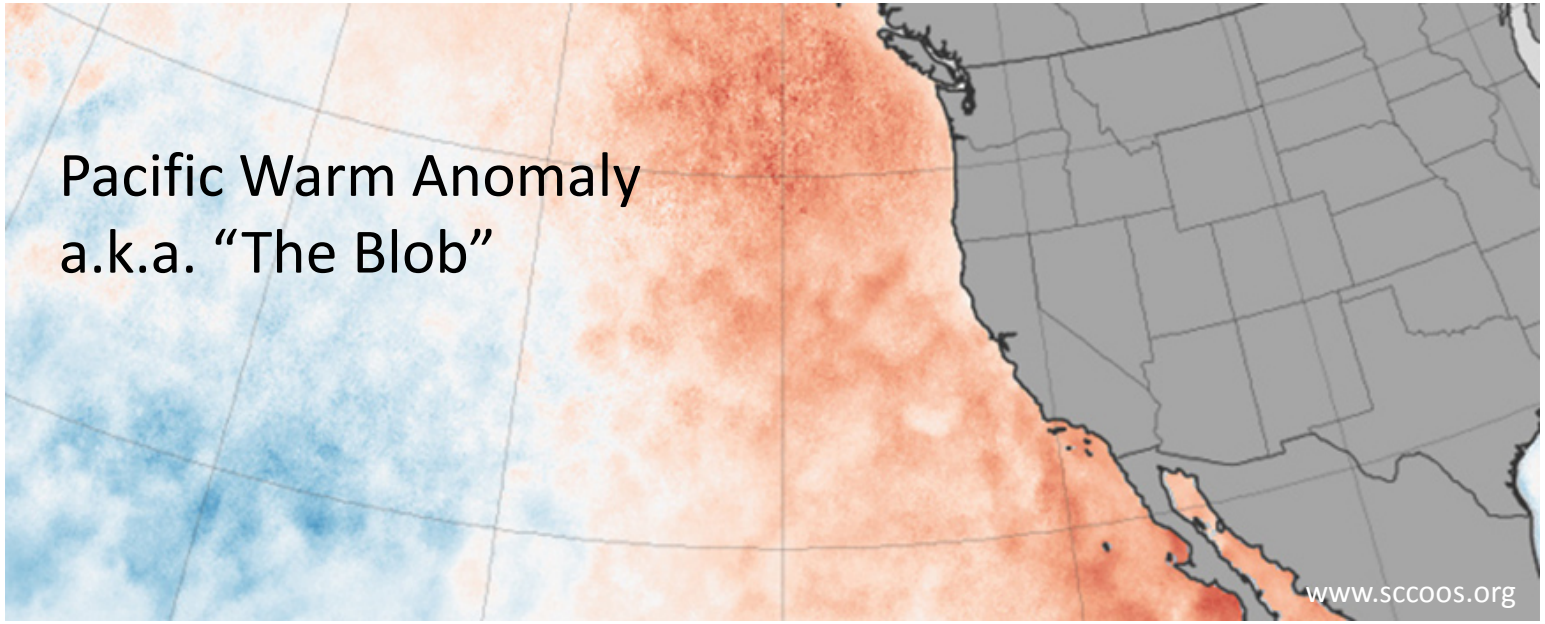
"As dungeness crab fishermen, we are following these models daily."

"As an off shore [*sic*] fisherman, this adds to the data I need to fish open water."

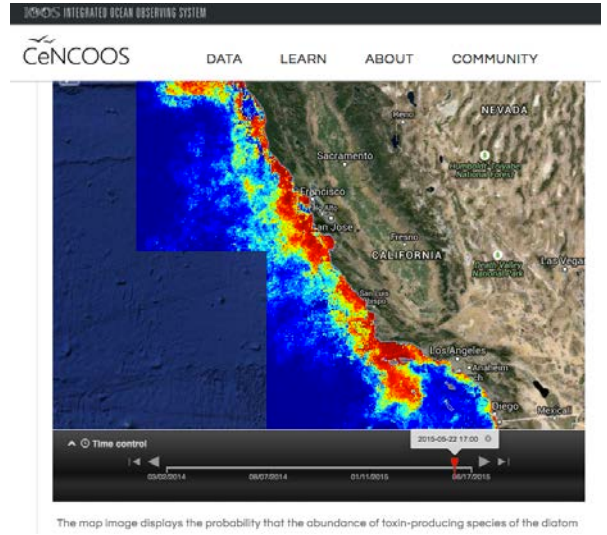
"I use these for kayaking and other outdoor recreation as well as to keep up with a generalized, and (when I am visiting here) specific understanding of what is going on from SF Bay, to the north and south. I started doing this because I live in east central IL, and kayak on rivers and Lake Michigan (itself an inland sea), and when I realized I could check the water quality, it made a big difference in when and where I go kayaking and/or deep water swimming." **-Aisha Sobh, concerned citizen**


Photo - http://kayakingcaldelta.blogspot.com

2015 BLOOM of DOOM associated with "The Blob"

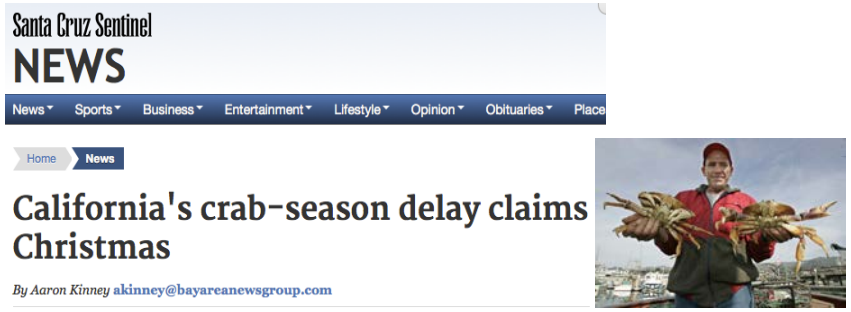


Pseudo-nitzschia C-HARM Map

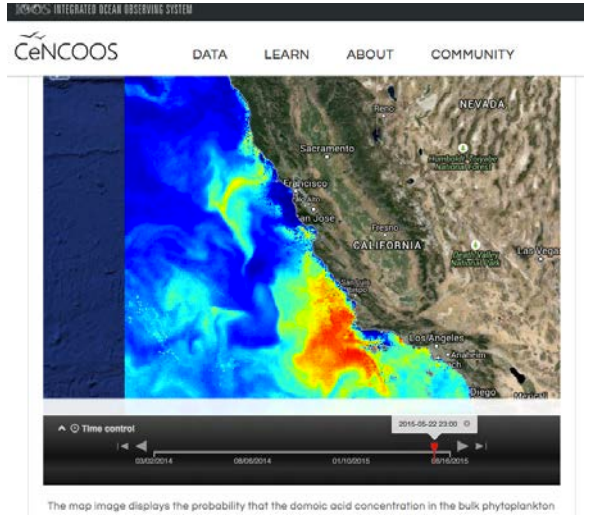


Unusual Mortality Event – includes 11 fin whales

Historic Dungeness Crab Closure!
Recreational and Commercial Harvests (Nov-May)



Domoic Acid C-HARM Map



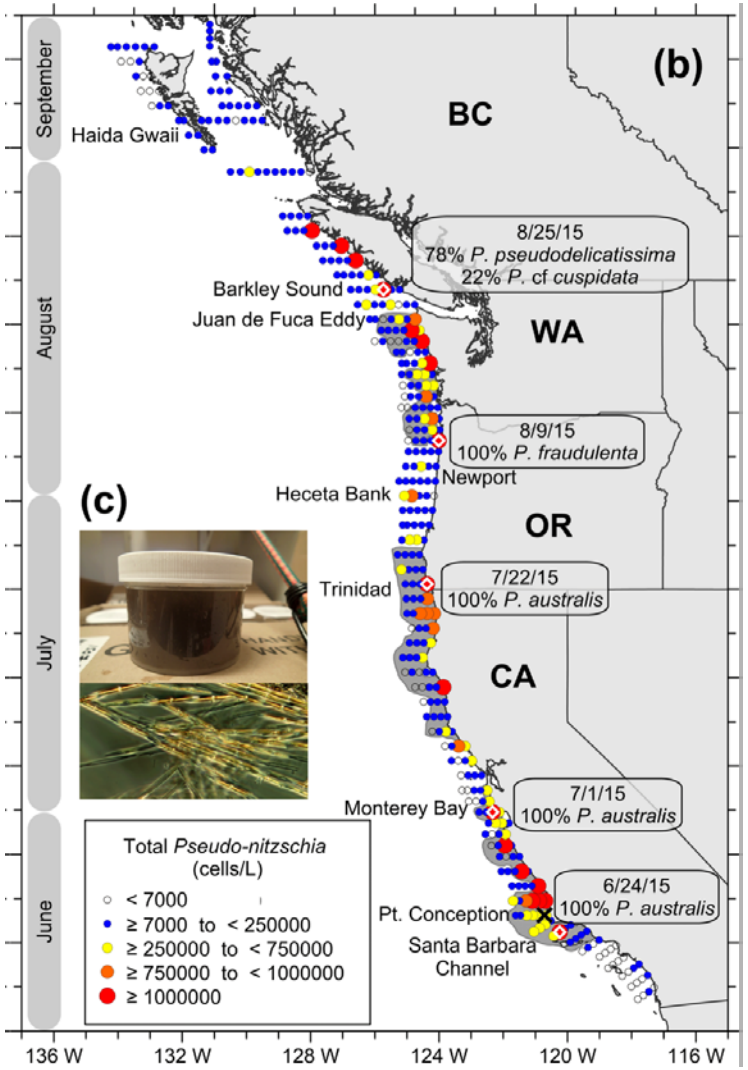
Geophysical Research Letters

RESEARCH LETTER
10.1002/2016GL070023

Special Section:
Midlatitude Marine Heatwaves: Forcing and Impacts

An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions

Ryan M. McCabe[1], Barbara M. Hickey[2], Raphael M. Kudela[3], Kathi A. Lefebvre[4], Nicolaus G. Adams[4], Brian D. Bill[4], Frances M. D. Gulland[5], Richard E. Thomson[6], William P. Cochlan[7], and Vera L. Trainer[4]

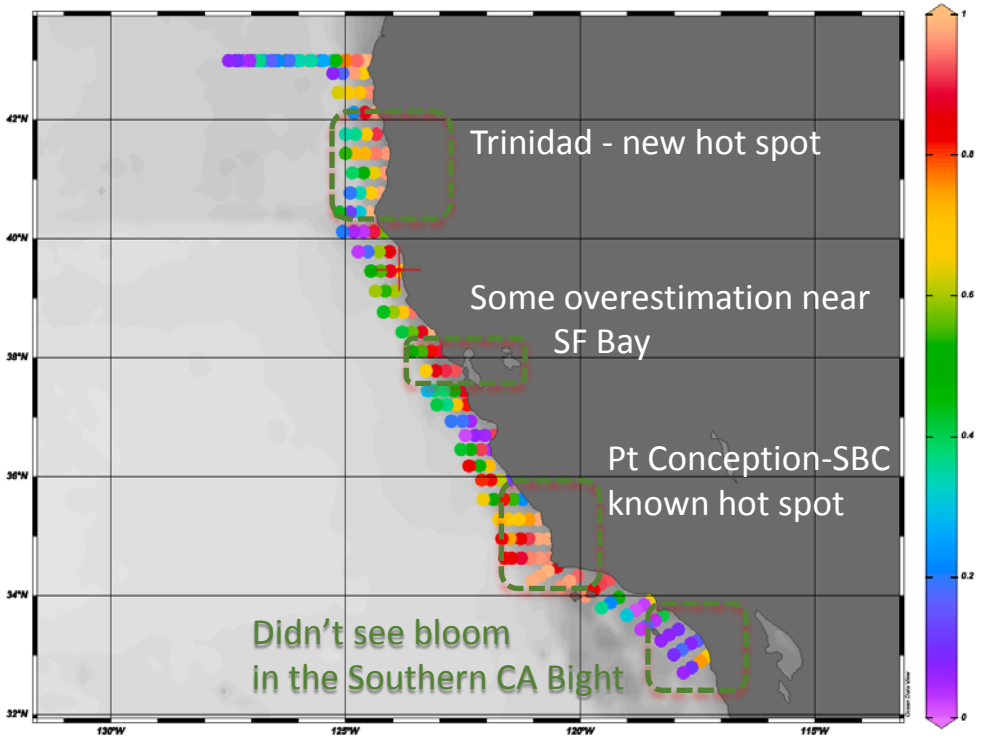


R/V Shimada NMFS Cruise-of-Opportunity

C-HARM ESTIMATES AT CRUISE STNS

Likelihood of a *Pseudo-nitzschia* bloom

64% Accuracy, 31% False Positives



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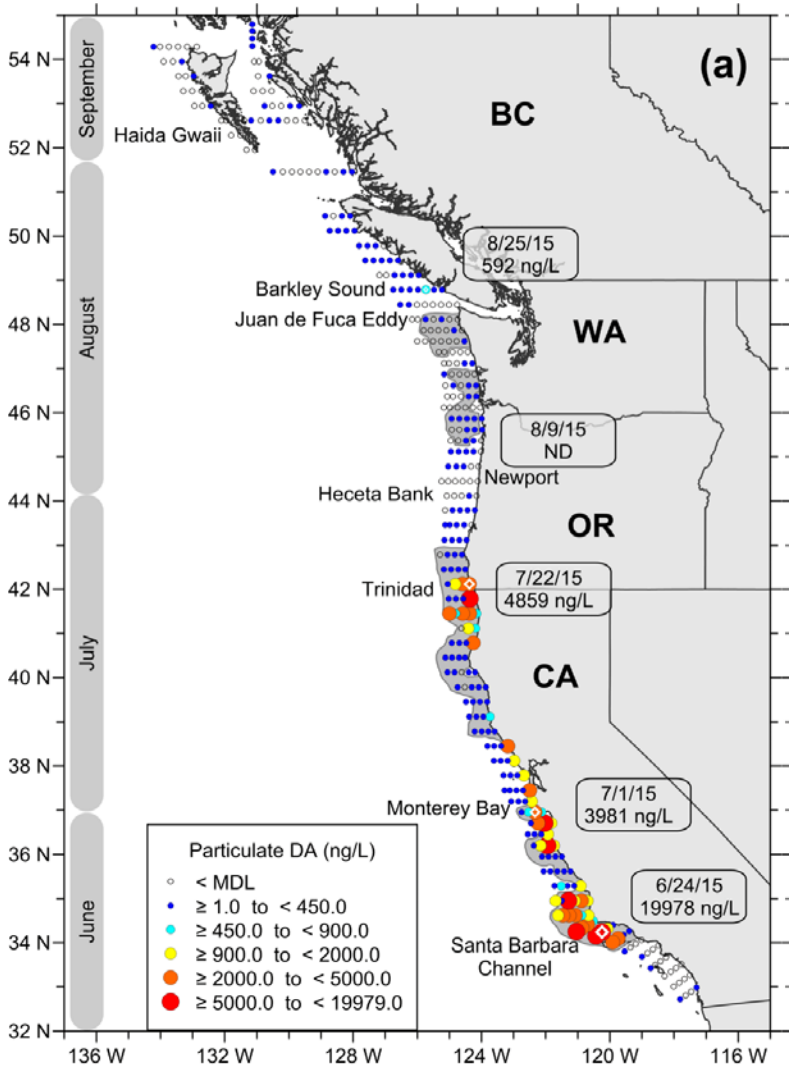
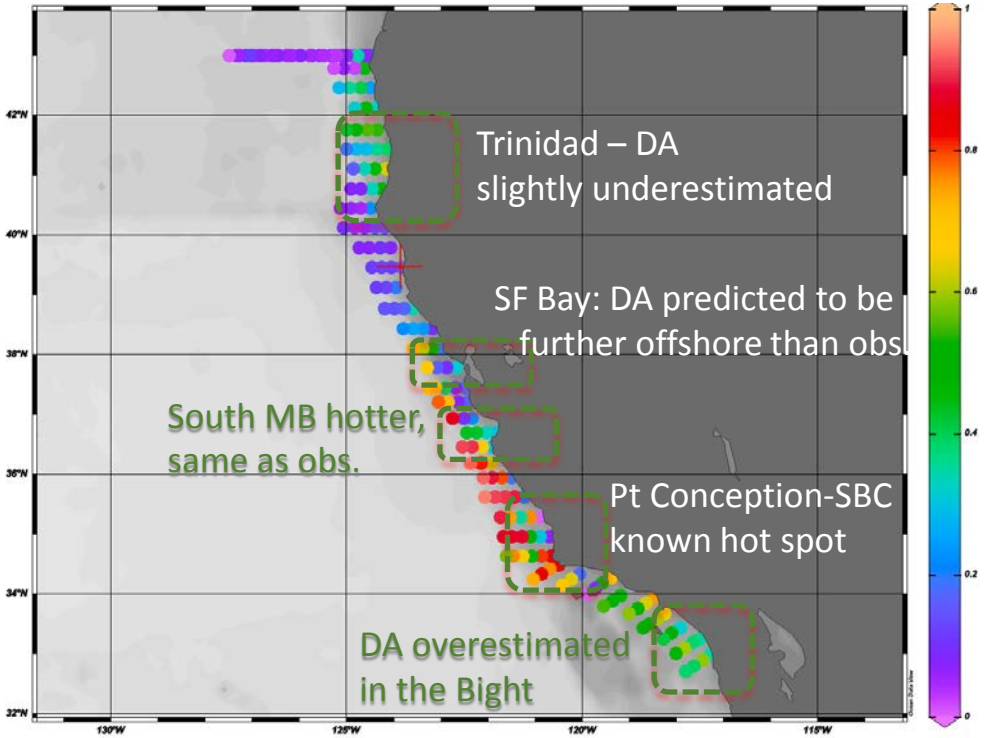


R/V Shimada NMFS Cruise-of-Opportunity

C-HARM ESTIMATES AT CRUISE STNS

Likelihood of elevated DA levels

71% Accuracy, 20% False Positives



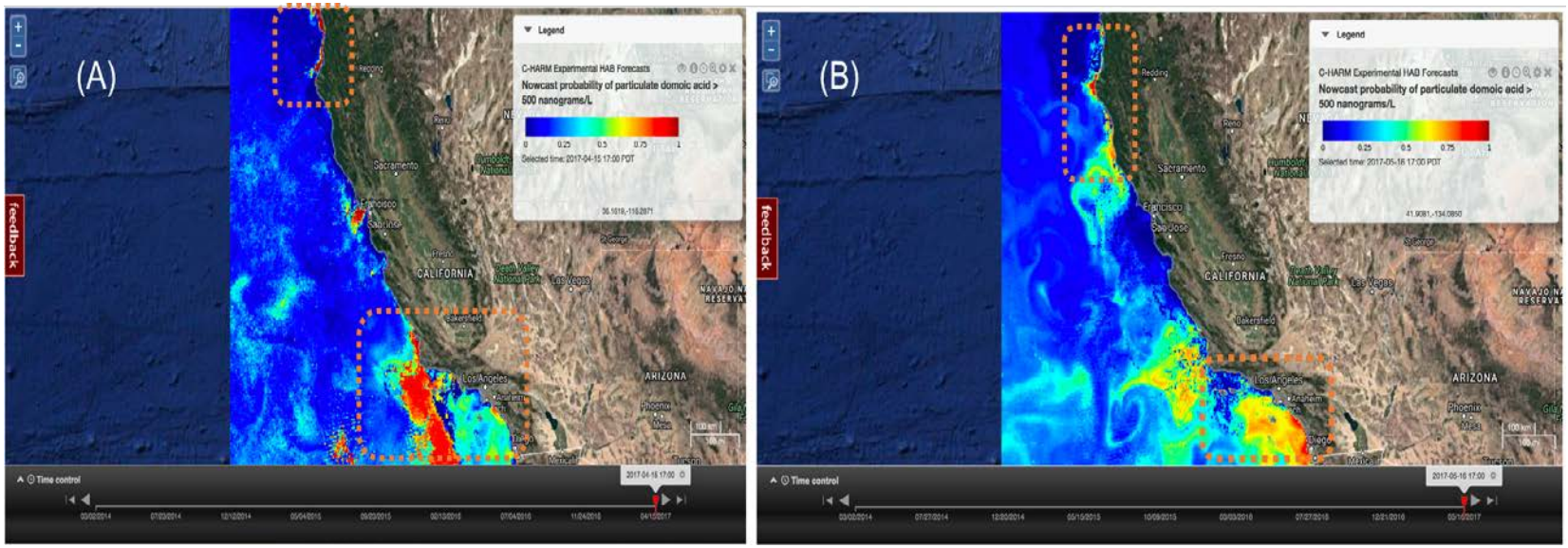
2017 – Extensive HAB in Southern California

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 and Ventura Counties

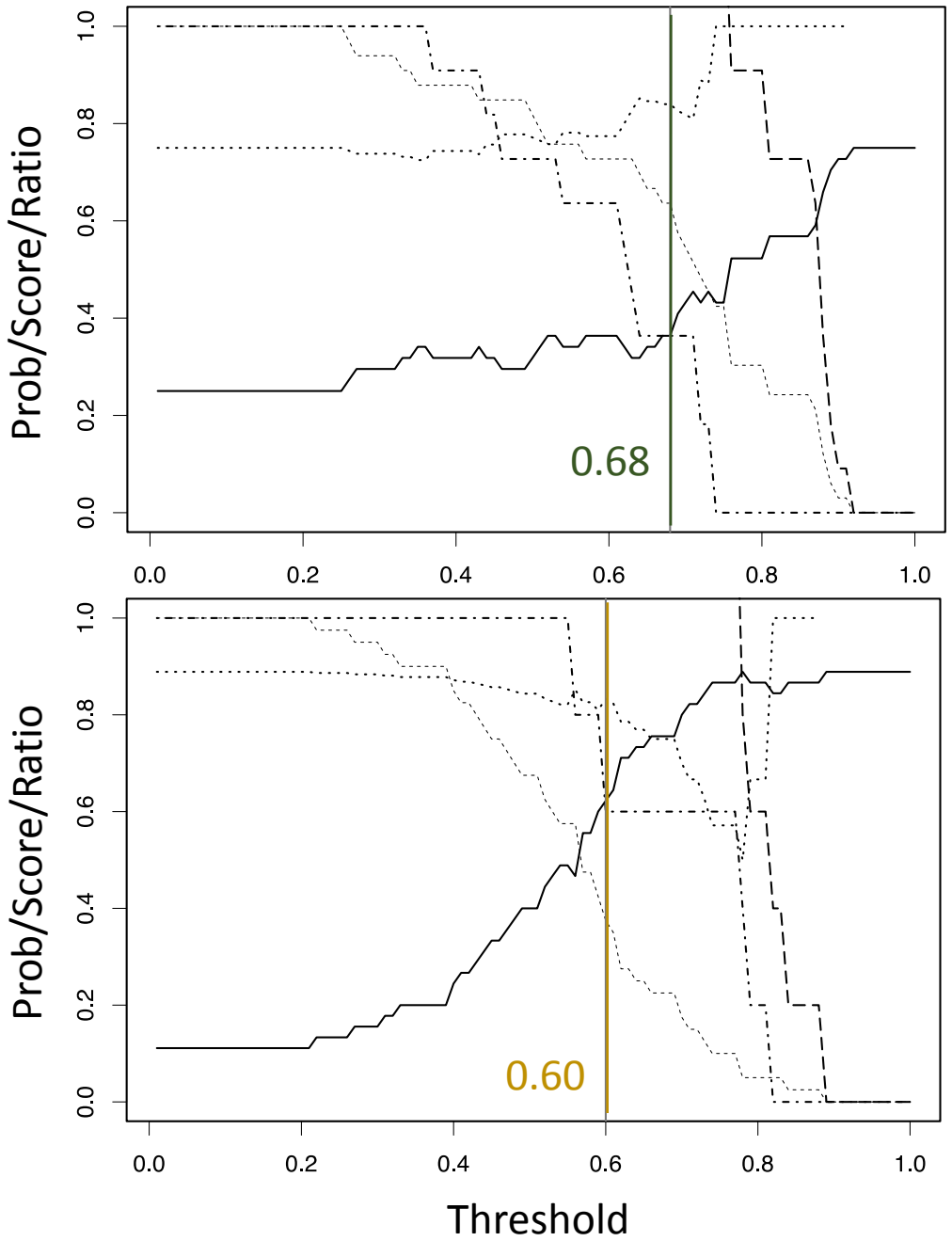


April 15 = HAB Onset

- 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



Contingency Plots to Assess Model Performance – Optimize Prob. Threshold

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

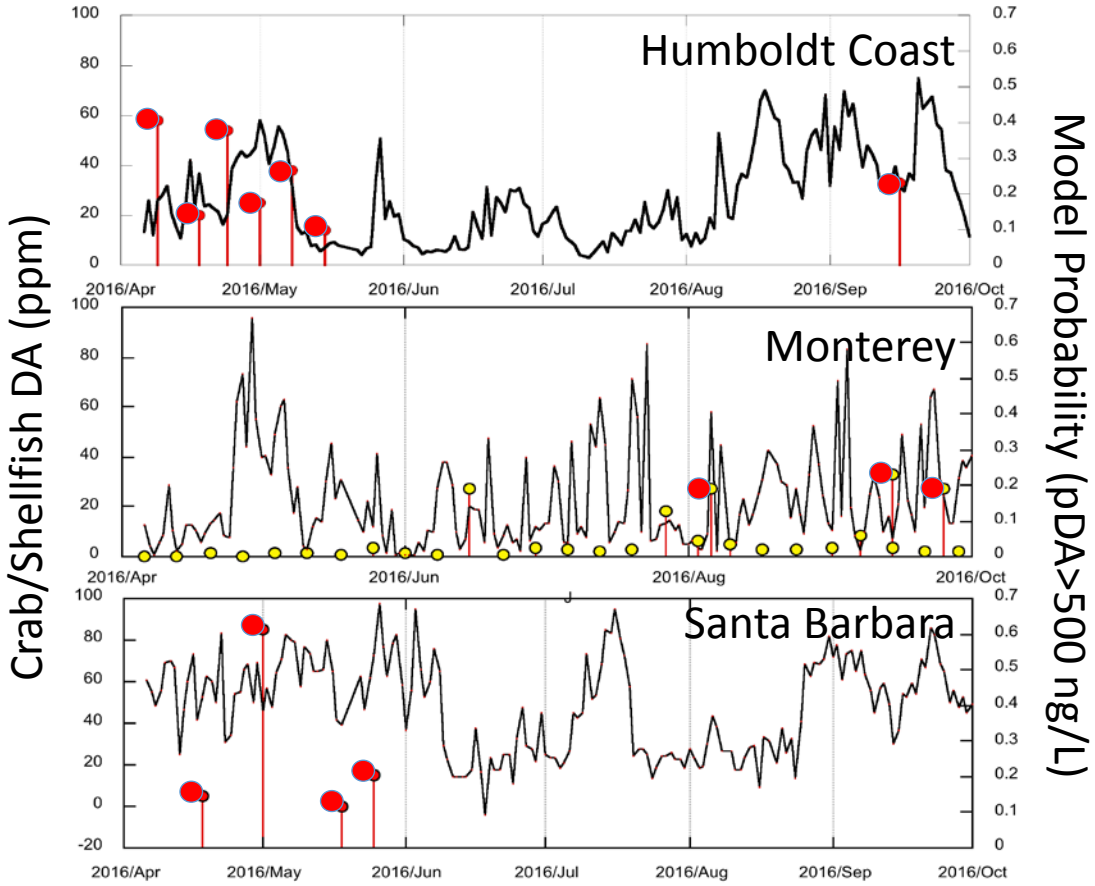
Domoic Acid at the SC Wharf *vs.* Nearest Model Pixel

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

Anderson et al. 2016, *Harmful Algae*

What does C-HARM tell us about shellfish toxicity?

2016 – Crab and Shellfish toxicity tracks nearshore model



Red=Crab, Yellow=Mussel

Crab Data from: http://www.cdph.ca.gov/healthinfo/pages/fdbdomoicacidinfo.aspx

REMOTE SENSING OCEAN COLOR & SST

Transition Development
CeNCOOS to NCCOS
Final Implementation
NOAA CoastWatch

MODISA TO VIIRS

DINEOF

RECONSTRUCTED OCEAN COLOR & SST

Transition Development
CeNCOOS to NCCOS
Final Implementation
NOAA CoastWatch

HYDRODYNAMIC MODEL FIELDS

Transition Development
RSS ROMS
Final Implementation
WCOFS at CSDL

DINEOF (FORECAST)

BIOLOGICAL MODEL FIELDS

Transition Development
CeNCOOS
Final Implementation
NWS WCOSS

Migrated to S4 Supercomputer in Jan 2016; ARL 7/8

IN SITU OBSERVATIONAL DATA

Transition Development
UCSC/CeNCOOS
Final Implementation
NCCOS/NOS CO-OPS*

CROWDSOURCED DATA

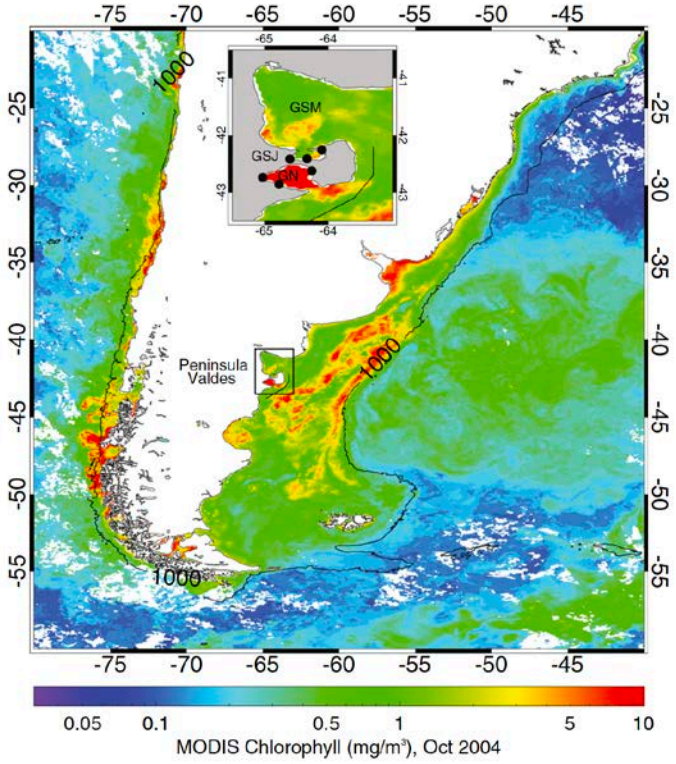
Transition Development
UCSC/CeNCOOS
Final Implementation
NCCOS/NOS CO-OPS*

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

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

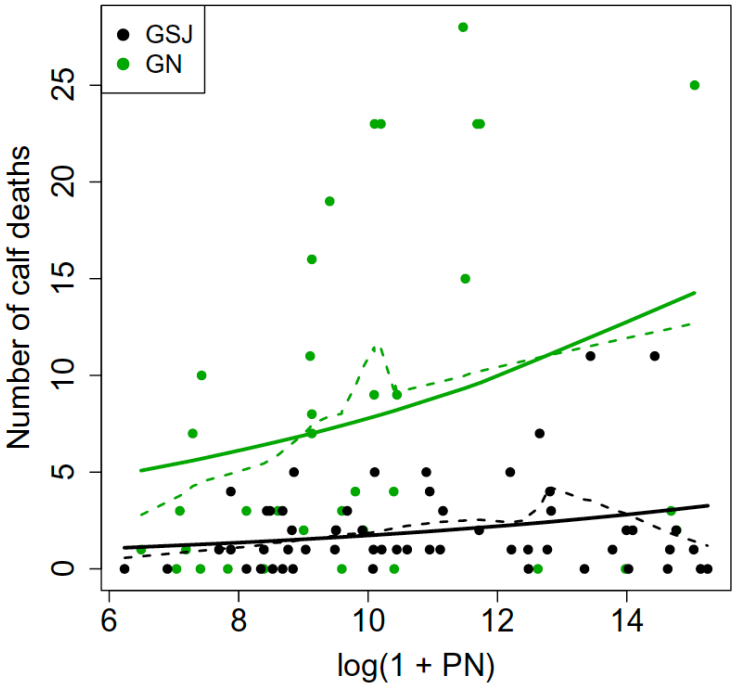
CeNCOOS = Central and Northern California Ocean Observing System
NCCOS = National Centers for Coastal Ocean Science
CSDL = Coast Survey Development Lab
RSS = Remote Sensing Solutions, Inc.

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

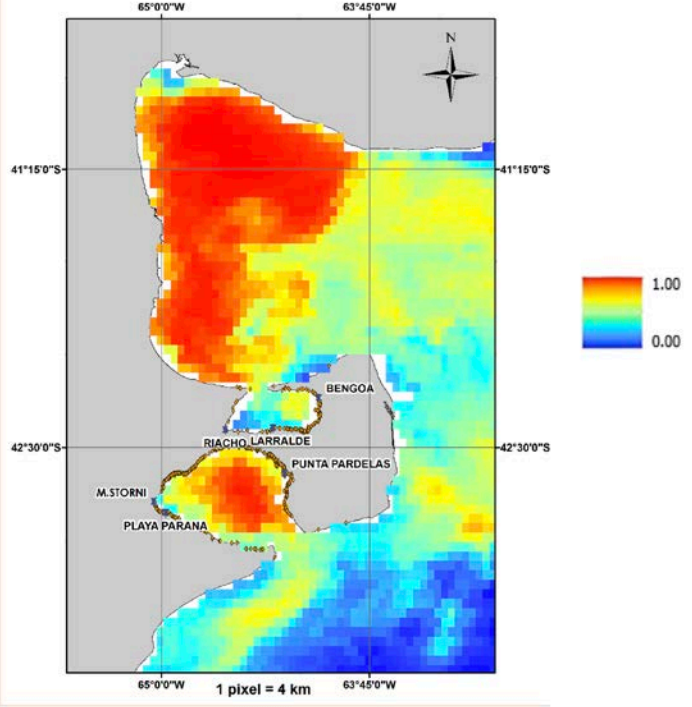


NASA DEVELOP Project

Peninsula Valdes, Argentina



Pseudo-nitzschia probability map (November 2006)



Wilson et al. (2016) Southern right whale (*Eubalaena australis*) calf mortality at Peninsula Valdes, Argentina: Are harmful algal blooms to blame? *Marine Mammal Science* 32(2)

Voelker, E., Morrow, J., Smith, T., (2014). Analyzing Harmful Algal Blooms in Southern Right Whale Habitat Using a Suite of Earth Observations. NASA DEVELOP Technical Paper.

Applied the C-HARM models to this region to assess the long-term relationship between mammal stranding events, HAB monitoring, and predicted HAB events

NASA Applied Sciences,
Ocean Biology and Biogeochemistry,
Energy and Water Cycle

NOAA MERHAB & ECOHAB
NCCOS

Many thanks to ARSET for this opportunity to share C-HARM with the community

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

New Position at SIO-SCCOOS
clrander@ucsd.edu