Monitoring and Nowcasting of Harmful Algal Blooms

Richard P. Stumpf
NOAA, National Ocean Service

reported HAB occurrences worldwide

Image from whoi.edu/redtide
Key Contributors

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Karenia brevis, Florida, Photo. R. Stumpf NOAA
Distribution of some major HAB toxic events
(does not include cyanobacterial blooms in coasts and lakes)

Amnesiac Shellfish Poisoning

Paralytic Shellfish Poisoning

Neurotoxic Shellfish Poisoning

Diarrhetic Shellfish Poisoning

From www.whoi.edu/redtide
Impacts of Harmful Algal Blooms

• Molluscan shellfish losses
• Fish kills (threat to aquaculture)
• Protected species, e.g., manatees, whales
• Tourism
• Public health (respiratory, swimming)
• US $1 billion in loss over 10 years
• $1 Billion industries at risk in east Asia & Europe
What is a “Bloom”?

For “normal algae”, a bloom is an increase in concentration or higher than normal.

For harmful/toxic algae, a bloom is a concentration that causes harm.

“A species does not have to achieve high biomass, or high population densities to be in a bloom state” (Smayda, 1997)

“Red tide” is inaccurate. Deadly toxicity in shellfish is possible at a few thousand cells/L (e.g. *Alexandrium fundyense*, *Dinophysis*)
Outline: Monitoring and Nowcasting of Harmful Algal Blooms (HABs)

Problem: What is the distribution of the HAB: the “HAB Field”?

• Solution, part 1: combine obs methods & technologies

• Solution, part 2: combine the obs with models

• Skill Assessment to identify weaknesses

Ultimate objective: to solve management/public problem, not to use new technology.
Why are HABs difficult to map? They are patchy. An extremely dense patch of *Karenia brevis* (toxic dinoflagellate) Gulf of Mexico

Credit: Paul Schmidt
Patchiness even with best observations

Baltic, 2005, cyanobacteria, commonly estimated from satellite.

This bloom missed west Öland beaches, Tourism crisis, source E. Graneli
Satellite challenge, clouds (and ambiguous classifications)

- Yellow indicates potential HAB, eastern Gulf of Mexico, 2005, worst event in 30 years
  
  - Aug 12
  - 2005 Aug 13
  - Aug 14

- Cloudy area interpreted using “persistence” (from a previous day)
- Ambiguous algorithm, requires manual correction
Locating a HAB, sampling problem (Florida)

Even an excellent program has limited resolution

- A week of sampling in FL, source: FWRI database, research.myfwc.com

Oversimplified: If you need data every day at every 1 km, then you will need to sample at least 1 day at every 1 km.

Stumpf et al., JMS, 2009

16 samples in a county (60 km) in a week cannot resolve finer than 26 km of coast per day
Vertical patchiness:
Thin Layer issue, especially *Dinophysis*,
Resolvable with absorption measurements, provided the layer can be found. Major issue in European

Gentien et al., 2005
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Solution: Find Technologies that work and integrate the observations
NOAA HAB Forecast System
Gulf of Mexico

- Observations
  - (satellite imagery, buoys, field samples, respiratory irritation)

- Model output
  - (heuristic, empirical)

- Synthesis and Analysis

- A harmful algal bloom has been identified in patches from southern Lee to central Collier County. Patchy very low impacts are possible from southern Lee County to central Collier County today through Thursday. No other impacts are expected.

- Conditions Report (public)

- HAB Bulletin (managers)

- http://tidesandcurrents.noaa.gov/hab/
• Observations from the public

Solution: Find technologies that work and integrate them

www.helcom.fi

• Ships of opportunity

• Remote sensing

• Modeling

• Research vessels

• Analyses and research

• Coast guards
Data types: all technologies are needed

- **Mobile Sampling Systems (people, ships, gliders)**
  - **Pro:** targeted, flexible, reconnaissance, speed and accuracy. Can be moved to where the HAB event is taking place; Quantify severity of HAB at targeted location. Provide sub-surface measurements (gliders), rapid assessment at beaches
  - **Con:** Limited offshore. Logistical difficulty (mobilizing people, gear), temporal frequency depends on people.

- **Satellite (and aircraft) Remote Sensing**
  - **Pro:** Geographic coverage. Provide broad area coverage not available from other means (up to 10K sample locations per day for SW Florida)
  - **Con:** Ambiguous algorithms, need analysis *with environmental data; objective rules.* Need verifying in situ sampling for HAB presence and concentration; can’t yet measure currents or salinity effectively; impacted by cloudiness
    - Aircraft methods are not standardized

- **Fixed Sampling Systems (piers, buoys)**
  - **Pro:** Can provide continuous data in all weather conditions, day and night
  - **Con:** Detection only at a site and for “pure” HABs (<10 sample locations per day)
After 2005 crisis on Öland, Sweden, a volunteer optical technique was implemented. Eyes, filters, digital cameras, internet and shipping of critical samples.
Location: Sweden
Experimental study
MISS ALGA (Granéli et al)

- Volunteer-based
- Quick assessment of water color
- Analysis of follow-up
- Addresses critical sites
- hik.se/hab

MISS ALGA
Algrapporter from Öland and Kalmar
Here, you find information about the alga situation on the beaches on Öland and in Kalmar. Miss alga is a part in a pilot project there voluntary "Algsparser" sample takes the different beaches. New samples are taken each day and the alga reports be updated of researchers the wide college in Kalmar. Click on that beach you want to know more about.

The three colours (green, yellow, red) refers only to the amount poisonous cat hair algae.
You can also few information via:
Telephone: 0480 - 44 60 10
Mobile: mobil.hik.se

LATEST NYTT
Now, the daily reporting is finished (2006-08-15)
for this season. The future 2 weeks happen updating about alga occurrence a gang in the week.

Badtemperaturerna (2006-08-14)
The temperature is measured kl 6.30-8.00. During the day, temperature with least 2 degrees increases celsius.

Aerial photos (2006-08-09)
Now, you can look on aerial photos (31/7, 7/8) from your favourite beaches on Öland!
Location: Sweden experimental study
MISS ALGA (Granéli et al)

- Volunteer-based
- Samples every three days for more detail, and accuracy assessment
Ships of opportunity with real-time data transfer, e.g., Alg@line in Baltic.  www.fimr.fi/en
Monitoring with AUV (glider), patrol a transect for days or weeks, data return in hours. Kirkpatrick et al.

Temperature

Salinity

K. brevis presence

More offshore

Increased onshore

Depth 35 m

35 km

Sep 30 – Oct 02

Oct 02-03

Stumpf et al., Venice Ocean Obs 2009
Fixed sensors (example, Brevebuster in Florida)

- Designed waveguide absorption meter as "Brevebuster" (Kirkpatrick et al.)
- Deployed on mooring and on AUV (Slocum gliders)

Karenia brevis absent

Karenia brevis present

Karenia brevis absent

Kirkpatrick et al.

Graph generated at 13:46:33 01/04/2006
Coastal Zone Color Scanner, Nov 14, 1978, one month after launch

Field documented (by coincidence) “Red Tide” HAB of *Karenia brevis* (then *Gymnodinium breve*)

Demonstrated the potential value of ocean color (Used by Steidinger and Haddad, 1981)

But chlorophyll concentration is insufficient.
Remote sensing:
Blooms as a change in concentration, combined with other rules (seasonality, location, shape, previous data)

HAB located with satellite, field data, and ruled-based (heuristic) model.
SeaWiFS data.

(Tomlinson et al., 2008)
MERIS, additional bands provide analysis of intense blooms

- Bloom negative
- “Positive Cyan Index”
- No Bloom
- “Negative Cyan Index”

Wynne et al., 2008
More specific algorithms are possible with new sensors: *Microcystis* (coastal & lakes) MERIS imagery using spectral shape algorithm (Wynne et al., 2008).

Bloom concentrating rapidly

Lake Erie, USA

2008 MERIS data
### Some HABs evaluated with remote sensing

<table>
<thead>
<tr>
<th>HAB Species</th>
<th>Region</th>
<th>Sensing Type</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pseudo-nitzschia spp.</em></td>
<td>Upwelling regions</td>
<td>SST, chlorophyll</td>
<td>ASP, variable</td>
</tr>
<tr>
<td><em>Karenia brevis</em></td>
<td>Gulf of Mexico</td>
<td>Chlorophyll, optical ratio, absorption spectra</td>
<td>NSP, respiratory, fish toxin</td>
</tr>
<tr>
<td><em>Karenia mikimotoi</em></td>
<td>Coastal ocean (Hong Kong, Ireland, New Zealand)</td>
<td>SST chlorophyll</td>
<td>NSP</td>
</tr>
<tr>
<td><em>Gymnodinium catenatum</em></td>
<td>Estuaries, coastal ocean, upwelling</td>
<td>SST chlorophyll</td>
<td>PSP</td>
</tr>
<tr>
<td><em>Alexandrium spp.</em></td>
<td>Coastal ocean (Gulf of Maine, Gulf of Alaska)</td>
<td>SST</td>
<td>PSP</td>
</tr>
<tr>
<td><em>Gonyaulax</em></td>
<td>Upwelling regions</td>
<td>Chlorophyll, possible UV absorption</td>
<td>Fish toxin</td>
</tr>
<tr>
<td><em>Cochlodinium</em></td>
<td>Coastal ocean (British Columbia, Korea)</td>
<td>SST, color</td>
<td>Shellfish toxin</td>
</tr>
<tr>
<td><em>Nodularia, Microcystis</em></td>
<td>Enclosed Brackish</td>
<td>Color</td>
<td>Hepatotoxin</td>
</tr>
</tbody>
</table>

### Other major HABs not clearly monitored with remote sensing

| Dinophysis              | Ireland, Portugal, Norway                   | Maybe SST However optical in situ | Shellfish toxin                                 |
• Algal maps

• Combining information from:
  
  • Visual observations by trained volunteers
  • Coast guard observations from airplanes
  • Data from ships of opportunity
  • Remote sensing data

Fleming-Lehtinen et al.
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These are different types of models

Numeric, transport or ecological / population (McGillicuddy et al., Gulf of Maine)

Heuristic, rule-based, with numeric models as input, Stumpf et al., Gulf of Mexico

Other, numeric with a statistical model for probability (likelihood) fields; Baltic, European HABES, Chesapeake Bay
Particles moved with modeled currents, and reformed to concentration

11Sep 2008
MERIS converted to particles

15Sep modeled with 11Sep observed

15Sep modeled as concentration

Wynne et al.
**Alexandrium Population Dynamics Model**

- Cyst Dist. (# / cm^2)
- Endogenous Clock
- Germ. rate (% / day)

- Growth (per day)

\[ \text{Growth} = \min \left( f(PAR), g(T,S) \right) \]

- Upward swimming 10 m/day

- “Mortality” = 0.1 per day

McGillicuddy, Anderson et al.
Example 3-D Transport, (hydrodynamic + population)
Running from initial conditions. Gulf of Maine
McGillicuddy, He, Anderson et al.
Ecological Models

- 3-D Hydrodynamic/Ecological
  - e.g. Gulf of Maine model, has ecological initiation from cysts (then used as a transport model)
  - No optics (cannot see *Alexandrium*)

3-D: Norway monocoze model for flagellates
  - *(Chatonella*, however not useful for major *Alexandrium* and *Dinophysis*)

- Heuristic (expert “fuzzy” logic)
  - e.g. EU HABES project (*Alexandrium* inputs)
Bluegreen algae situation in July 2006

Fleming-Lehtinen et al.
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• **Skill Assessment to identify weaknesses**
Skill Assessment:
Identifies areas for investigation. **What is the forecast resolution?**

*Karenia brevis*: Respiratory impact, evaluated by lifeguards listening for coughing, data transmitted by Blackberry.

<table>
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<th>County-wide Forecast of moderate/high respiratory impact</th>
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<tr>
<td>Correct County-wide (at least one beach)</td>
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<td>Correct against individual reports from 6 beaches</td>
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</table>

Kirkpatrick: coolgate.mote.org/beachconditions

Stumpf et al., 2008, J.Marine Systems
Gulf of Maine: Quantitative skill evaluation: Resolution again

<table>
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<tr>
<th>Averaging</th>
<th>$r^2$ (mod,obs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cruise by Cruise</td>
<td>0.68</td>
</tr>
<tr>
<td>100 km scales</td>
<td>0.49</td>
</tr>
<tr>
<td>50 km scales</td>
<td>0.31</td>
</tr>
<tr>
<td>25 km scales</td>
<td>0.23</td>
</tr>
<tr>
<td>10 km scales</td>
<td>0.17</td>
</tr>
<tr>
<td>Point-to-Point</td>
<td>0.10</td>
</tr>
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</table>

- $r^2 = 1 - \text{var(misfits)}/\text{var(observations)}$.

• 1993 RMRP surveys

• Stock et al. (2005)
Why is the difference?

Patchiness, and lack of resolution on the initialization, difficulty of assimilating data (in Gulf of Maine)

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<td>Correct County-wide (at least one beach)</td>
<td>73%</td>
</tr>
<tr>
<td>Correct against individual reports from 6 beaches</td>
<td>21%</td>
</tr>
</tbody>
</table>

Credit: Paul Schmidt
Data Problems

Nowcasts, Forecasts depend as much on the HAB field as on the model

• Modeled transport should allow for ensembles of
  – Interpreted HAB fields
  – probability fields

- Aug 20 modeled from Aug 14 MERIS
- Aug 20 modeled from Aug 17 MERIS
- Aug 20 Observed from MERIS
- 20 Aug MERIS with NOAA analysis
Nowcasts and forecasts need data and model integration for HAB locations.

- **Problem:** Determine the HAB “field” (distribution)
  - Better nowcasts and forecasts need better resolution observations

- **Solution:** Combine all technologies, from ancient to modern
  - Solve the problem, not use the most exciting technology

- **Solution:** Data assimilation needed,
  - Integration needed for HAB fields, currently all methods require expert analysis.
  - Ensemble initialization needed to determine uncertainty in HAB forecast

- **Forecast skill assessment:** identify weaknesses

- **Ultimate objective:** to solve management/public problem, not to use new technology.