IOC-IPHAB recommended procedures for automated and semi-automated HAB-monitoring and forecasting within the Global Ocean Observing System

About this document

At the VIIIth meeting of the International Panel on Harmful Algal Blooms, Intergovernmental Oceanographic Commission in Paris, France, a resolution about *Implementation of HAB monitoring within the Global Ocean Observing System* was made (resolution IPHAB-VIII.2). This was accepted by the IOC in 2007. The present document constitute the advice from the *IPHAB Task Team on HAB Observations and Forecasting Systems* to the *Global Ocean Observing System,* in particular to the Panel for Integrated Coastal Observations (PICO), a technical subcommittee of the GOOS Scientific Steering Committee.

Version history

Draft 1 of document
Distributed at the IOC-ICES-WGHABD in Galway, Ireland, 10-13 March, 2008

Draft 2 of document
Distributed at the GEOHAB SSC meeting in Annapolis, Maryland, USA, 10 April 2008

Draft 3b of document
Distributed to the *IPHAB Task Team on HAB Observations and Forecasting Systems* and the *IOC/ICES-WGHABD* 9 April 2009
Prepared by Bengt Karlson after advice from participants of the meeting of the ICES/IOC Working Group on Harmful Algal Bloom Dynamics, Punta Umbria, Spain, 30 March – 3 April, 2009

Version 1
20 April, 2009
Prepared by Bengt Karlson after advice from Task Team members.
Presented at IPHAB IX 23 April, 2009

Version 1.1 (this document)
Updated by Bengt Karlson after advice from IPHAB
Accepted by IPHAB IX 24 April, 2009

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Operational requirements
The procedures included are those that may produce results in near real time. A common definition for real time data is data that is accessible within 1 hour after measurement. This applies to many but not all methods included in this document. Data made available within 24 hours of measurement or later may also be useful for operational HAB observations and forecasts within the Global Ocean Observing System.

Acronyms and definitions
Adaptive sampling - an example of adaptive sampling is when water sampling is automatically triggered by a signal of high night-timechlorophyll fluorescence indicating a high biomass of algae.
GEOHAB = The Global Ecology and Oceanography of Harmful Algal Blooms, a SCOR/IPHAB programme
GOOS = The IOC programme Global Ocean Observing System
HAB = Harmful Algal Bloom
ICES = International Council for the Exploration of the Seas (North Atlantic)
IOC HAB Programme = The IOC Harmful Algal Bloom Programme
PICO = Panel for Integrated Coastal Observations, a technical subcommittee of the GOOS Scientific Steering Committee.
SCOR = Scientific Committee on Oceanic Research
WGHABD = ICES/IOC Working Group on Harmful Algal Bloom Dynamics

1 Harmful Algal Blooms

Most algal blooms are natural phenomena and cause no harm and indeed the growth of phytoplankton is the base of the major part of the marine food web. However, some algae are harmful and Harmful Algal Blooms (HABs) are of concern since they may affect human health, fisheries and aquaculture as well as large parts of marine ecosystems. Harmful algae include species that produce toxins that may accumulate through the food web starting with filter feeders (e.g. mussels). Fish killing species and species causing nuisance blooms (e.g. foam on beaches) are also included in the term harmful algae. Harmful effects of blooms of microalgae such as hypoxia due to eutrophication or upwelling resulting in high algal growth is also included. Some HABs have direct effects (clogging of filters) on industries such as desalination plants. It should be noted that most harmful algae only constitute a small part of the total phytoplankton biomass while they may still cause harm. A few hundred cells per litre of sea water may be enough to cause lethal toxicity in shellfish. The term low biomass blooms are used for these types of HABs in this document. Other harmful algae grow to high densities (e.g. several hundred thousand cells per litre or more) and the term high biomass blooms is used for these HABs. It should be noted that chlorophyll, which is a proxy for total phytoplankton biomass, is not an indicator for the presence of harmful algae.

2 Automated HAB-observations

2.1 Only some HABs can be monitored using automated techniques

2.2 There is value in monitoring for HAB species occurrence as well as for HAB-toxins/metabolites.

2.3 High biomass HABs with properties detectable using automated techniques (e.g. optical signatures) are good examples of cell detection. The following are examples of HABs that may be detected using optical signatures:
a) blooms of some filamentous cyanobacteria, e.g. *Nodularia spumigena* in the Baltic Sea
b) blooms of the fish killing dinoflagellate *Karenia mikimotoi* (e.g. in UK waters)
c) blooms of the dinoflagellate *Karenia brevis*, that form toxic blooms in the Gulf of Mexico.

2.4 Low biomass HABs can be detected in rare cases with optical techniques (e.g. automated image analyses of morphologically distinct species) but other less distinct forms require molecular techniques for cell detection.

2.5 Algal toxins can be measured in plankton or water samples using new analytical techniques, some of which are being miniaturised and automated.

2.6 Instruments for automated *in situ* cell and toxin detection are still under development and thus are not available commercially, although this will change within a few years.

2.7 The observing system should be designed to detect the HAB species that occur within a given region. No single system will work in all areas.

2.8 The observing system should be designed with sufficient spatial (horizontal and vertical) resolution to capture the time-space evolution of HABs and associated environmental conditions. This can best be accomplished with scientists who know the local oceanographic conditions such as stratification, currents, etc.

2.9 A combination of automated *in situ* measurements, remote sensing, automated sampling and adaptive sampling from research vessels is recommended for most circumstances.

2.10 Some HAB detecting systems require significant power and bandwidth. These will require cabled configurations and/or special hardware installations. In time these instruments will be miniaturized and easier to deploy but it is essential to deploy such instruments on test platforms at an early stage.

2.11 Some HABs develop in "hot spots" and in these cases HAB observing systems can be positioned there instead of attempting to achieve full areal coverage.

3 *In situ* systems

3.1 *In situ* systems include:

- 3.1.1 Sensors on buoys
- 3.1.2 Sensors on permanent structures, e.g. piles, wind mill masts, oil platforms and bridges
- 3.1.3 Sensors on AUV, autonomous underwater vehicles (gliders and powered vehicles)
- 3.1.4 Sensors on drifting profilers, e.g. Argo-type floats
- 3.1.5 Towed sensors, e.g. undulating oceanographic recorders
- 3.1.6 Sensors in flow-through systems on research vessels, voluntary observing ships (VOS), ships of opportunity etc. These systems, often called FerryBox-systems, only sample near surface water while many HABs are found deeper down.

3.2 Minimum set of parameters

- 3.2.1 Phytoplankton biomass proxy , i.e. night-time chlorophyll fluorescence
- 3.2.2 Turbidity
- 3.2.3 Salinity
- 3.2.4 Temperature
- 3.2.5 Specific HAB sensor if available (based on e.g. specific optical signature, molecular techniques or *in situ* flow cytometers with optical image analysis)

3.3 Sensors should be distributed in depth according to the local occurrence of HAB's.

- 3.3.1 In areas where HABs occur in sub surface layers sensors should be mounted on depth profiling platforms
- 3.3.2 Depth resolution for depth profiling platforms should be 25 cm or better, so as to be able to detect HABs aggregated in fine structures (fine layers).

3.4 Sampling frequency should be adapted to the spatial and temporal HAB-distribution in the area, if the HAB-species often occur in hot spots these should be monitored with greater temporal resolution.

- 3.4.1 Minimum frequency is once a day
- 3.4.2 Recommended frequency is every 1-3 hours
- 3.4.3 In FerryBox systems recommended horizontal frequency is 200 m or better.
- 3.4.4 Arrangements should be made for adaptive sampling triggered from data provided by *in situ* sensors.

3.5 Quality assurance and quality control of data collected should be documented

- 3.5.1 Reference water sampling and analyses of reference samples is an essential part of automated HAB-monitoring. Here follows some examples:
  a) Microscopy for cell counts and HAB species identification (also molecular methods may be

included)
b) Phytoplankton pigment analysis using laboratory fluorometry or spectrophotometry, ideally combined with High Performance Liquid Chromatography
c) Some automated instruments can archive samples for quality assurance.

3.6 All *in situ* instruments must include anti bio fouling measures adapted to local conditions and the deployment period. Anti bio fouling measures include

3.6.1 Copper shutters covering optical windows

3.6.2 Chlorination

3.6.3 Special coatings of optical windows

3.6.4 Automated cleaning/washing equipment in FerryBox and other flow through systems

3.6.5 Profiling platforms that spend most of their time in deep water with few fouling organisms

4 Optical techniques for observing HABs *in situ* include but are not limited to:

4.1 Fluorescence

Total phytoplankton biomass can be estimated using *in situ* instruments for measurement of chlorophyll a fluorescence, however quenching of chlorophyll a fluorescence e.g. by sun light should be taken into account and hence:
a) Use only measurements from night (at least 1 h after sunset and 1 h before sunrise)
b) Minimize quenching effect by allowing a period of darkness before measurement

4.1.1 Biomass of phycocyanin containing cyanobacteria can be estimated using *in situ* instruments for measurement of phycocyanin fluorescence. An example of a HAB-organism is *Nodularia spumigena* and other cyanobacteria that co-occur during blooms in the Baltic Sea.

4.1.2 Biomass of phycoerythrin containing organisms can be estimated using *in situ* instruments for measurement of phycoerythrin fluorescence HAB-organisms containing phycoerythrin include:
a) *Dinophysis* spp. (Diarrhetic Shellfish Toxins)
b) some cyanobacteria
c) the photosynthetic ciliate *Myrionecta rubra* (synonym *Mesodinium rubrum*) that is an optimum prey for *Dinophysis* spp. Blooms of *Myrionecta rubra* itself caused fish kills in the Bay of Fundy, Canada and elsewhere.

4.2 Absorption and scatterring

4.2.1 Example of a HAB-organism detectable using its absorption characteristics
a) *Karenia brevis* (Brevebuster)

b) *Phaeocystis* spp. (high chl, absorption over broad spectrum without scattering)

4.3 Automated image analysis in flow cytometers (e.g. FLOWCAM and FlowCytoBot) is useful for certain HAB-species with distinctive morphology.

5 Molecular methods for automated *in situ* identification of HAB-species

Molecular methods make it possible to identify and quantify HAB-organisms at the species or even at the strain level. Probes may also be directly targeted at genes controlling toxicity.

5.1 Molecular methods are being implemented in automated *in situ* laboratories. At least one system will be available commercially within a few years.

5.2 Both antibody and DNA-based methods must be verified with local populations of HAB-species

5.3 Many different types of molecular based assays are under development, ranging from quantitative PCR to sandwich hybridisation and surface plasmon resonance.

6 *In situ* sensors for detecting algal bloom physiological processes

These sensors do not give specific information about harmful algae but may contribute to the understanding of high biomass bloom dynamics. Bio fouling protection is essential as for all *in situ* sensors.

6.1 Oxygen sensors may give and indirect measure of photosynthetic activity minus respiration

Examples
a) Optode based oxygen sensor
b) Other oxygen sensors

6.2 Sensors for some specific fluorescence parameters may give information related to primary productivity

Examples:
a) Fast repetition rate fluorometers
b) Fluorometers aimed at fluorescence induction and relaxation

7 Remote sensing systems

Remote sensing systems for ocean colour estimate total phytoplankton chlorophyll-a in near surface water. In some cases, e.g. *Karenia brevis* in the Gulf of Mexico, a good "climatology" exists for HABs and their expression in the chlorophyll field. Many HABs occur deeper down and only a few HAB organisms have optical signatures detectable by remote sensing that can be used to differentiate them from phytoplankton in general. Detection using optical sensors on satellites is often restricted by cloud cover. Despite these limitations, remote sensing detection and monitoring of HABs may be very useful in some circumstances. The advantages are that remote sensing systems can observe over large areas on a regular basis and so can detect rapid increases in chlorophyll-a that can be targeted with *in situ* sampling. Remote sensing of currents and coastal upwelling/downwelling cycles through ocean colour, SST and altimetry observations can show how an algal bloom is advected, say, inshore or into neighbouring waters; these observations also provide valuable input to assimilate or update physical and / or ecosystem models. Remote sensing systems for HAB-observations include

7.1.1 Sensors on satellites

7.1.2 Airborne systems

7.1.3 In air observations from ships, buoys and masts

7.2 Parameters useful for HAB-observations from remote sensing include

7.2.1 Chlorophyll a

7.2.2 Turbidity

7.2.3 Some algae-group specific algorithms, e.g. for certain cyanobacteria

7.2.4 Sea Surface Temperature (SST), e.g. for detection of specific water masses and advection processes

7.3 Remote sensing systems should be combined with *in situ* systems to ensure that non surface blooms are included in observations

7.4 Quality assurance and quality control of data collected should be documented

7.4.1 reference measurements (sea truth) are an essential part of automated HAB-monitoring using remote sensing

7.4.2 a combination of reference measurements from automated *in situ* systems and reference sampling from ships is recommended

7.4.3 cell counts and identification of HAB-species using microscopy or molecular methods should be part of the quality control and assurance procedure

7.4.4 phytoplankton pigment analysis using laboratory fluorometry or spectrophotometry ideally combined with High Performance Liquid Chromatography may also be part of the quality control and assurance procedure

8 HAB-forecasting systems

Short term HAB forecasting models are most often driven (forced) by the same type of physical meteorological models that produce weather forecasts. The maximum length of these forecasts, often 5-10 days, also limit the range of HAB forecasts.This could be lengthened if observing systems could be placed in the (known) path of the bloom, upstream of the point of impact. To be able to model HAB development a basic requirement is that the HAB species possess properties that can be used to differentiate it from other phytoplankters. These properties must be described in mathematical terms. The existing HAB forecast models can be divided in three main types:

a) transport models, e.g. the use of drift models for prediction of movements of surface HABs
b) biogeochemical models for predicting some high biomass HABs
c) Lagrangian models ~ particle based models specifically designed for HAB-species

8.1 Forecasting systems should be combined with observation systems

8.2 Assimilation of data from observation systems is an integrated part in forecasting systems

8.3 Quality assurance and quality control of forecasts should be documented

8.3.1 Models
a) Equations and algorithms should be published scientifically
b) Computer program code should be documented
c) It is recommended that computer program code is made available to the scientific community as open source software.

8.3.2 Validation of model results
a) Reference measurements from *in situ* observation systems should be used for validation of forecasts. Skill assessments are essential.

9 HAB-warnings

Warnings must be based on best available knowledge, derived from a combination of observations, forecasts and expert knowledge.

10 GOOS Regional alliances identified for the first HAB observation and forecasting systems

One of the activities of the Task Team is to *identify regional locations where the first HAB observation and forecasting systems should be implemented.* A large part of the infrastructure needed should already be in place. The following is a list of GOOS regional alliances and the regional locations that the Task Team has identified:

10.1 EuroGOOS

10.1.1 BOOS - Baltic Sea Operational Oceanographic System
examples:
a) blooms of HAB-cyanobacteria

10.1.2 NOOS - North West Shelf Operational Oceanographic System
examples:
a) Skagerrak-Kattegat blooms of fish killing flagellates, e.g. *Pseudochattonella farcimen*.
b) Scottish waters with blooms of the fish killing dinoflagellate *Karenia mikimotoi*

10.1.3 IBI-ROOS - Iberia-Biscay-Ireland Regional Operational Oceanographic System
examples:
a) Blooms of *Dinophysis* spp. in Galician Rias, Irish waters and in the Bay of Biscay.
b) Blooms of *Karenia mikimotoi* in the Bay of Biscay and in Irish waters

10.2 Mediterranean GOOS
Northern Adriatic Sea

10.3 Black Sea GOOS – no regional location identified

10.4 NEAR - North-East Asian Regional-GOOS
Japan – Seto Inland Sea – several HAB species
Korea – blooms of *Cochlodinium polykrikoides*

10.5 PI-GOOS - Pacific Islands Global Ocean Observing System – no regional location identified

10.6 Indian Ocean GOOS – no regional location identified

10.7 IOCARIBE-GOOS - Global Ocean Observation system in the Caribbean Region – *Karenia brevis* blooms in the Gulf of Mexico.

10.8 GOOS-Africa

10.8.1 Benguela area
Example: High biomass blooms of dinoflagellates cause hypoxia resulting in mortalities of fish and shellfish

10.9 US GOOS

10.9.1 Gulf of Mexico Coastal Ocean Observing System (GCOOS)
Example: *Karenia brevis* blooms

10.9.2 North-eastern Regional Association Of Coastal Ocean Observing Systems (NERACOOS)
example:
a) *Alexandrium* blooms (PSP) in the Gulf of Maine and in the Bay of Fundy (Canada)

10.9.3 Northwest Association of Networked Ocean Observing Systems (NANOOS)
Example: Blooms of *Pseudo-nitzschia* (ASP) along the west coast of the North American continent.

10.10 SEA-GOOS - Southeast Asian GOOS – no regional location identified

10.11 OCEATLAN - Regional Alliance for the Upper Southwest and Tropical Atlantic – no regional location identified

10.12 GRASP - GOOS Regional Alliance for the South Pacific – no regional location identified