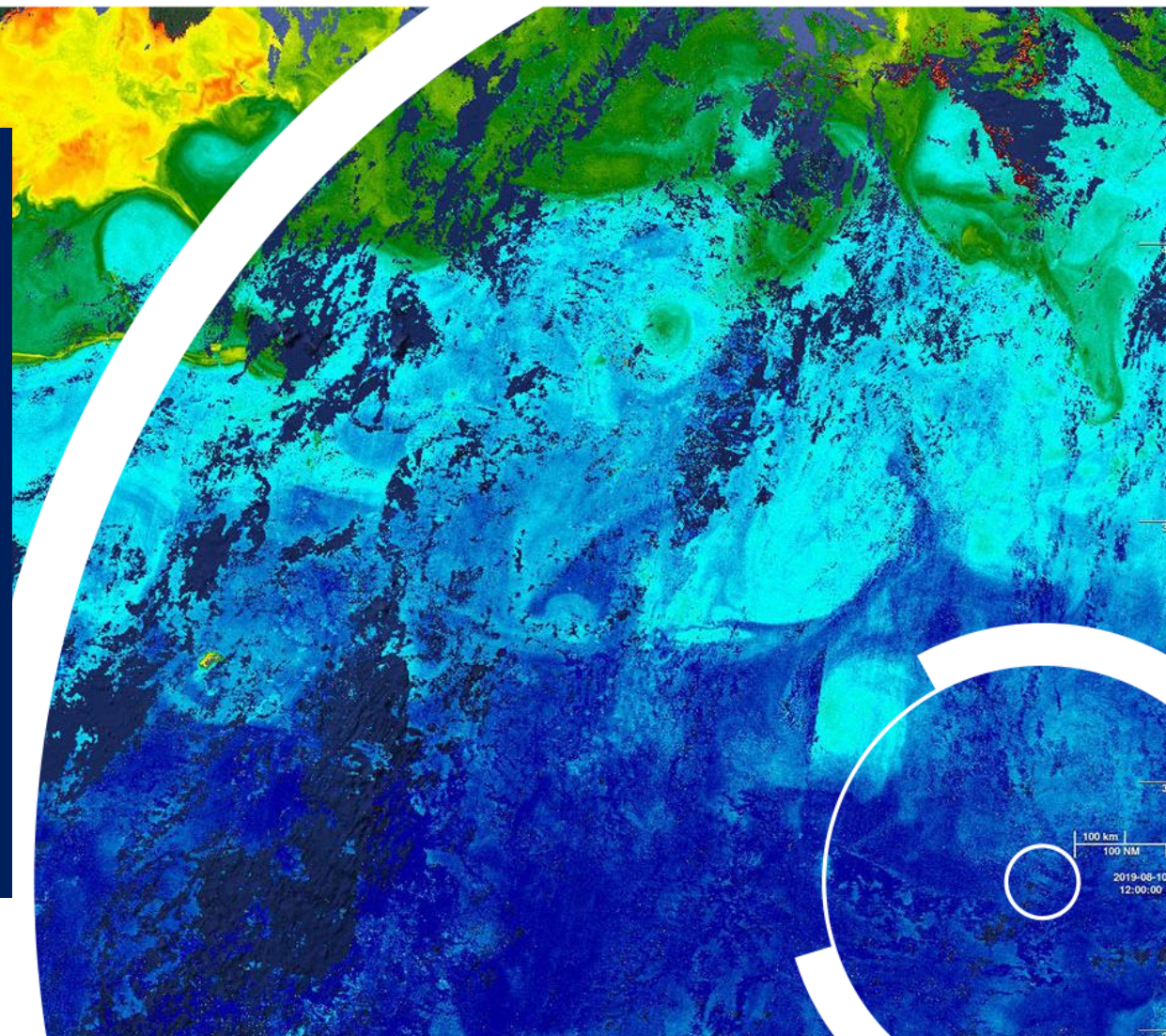


# Harmful Algal Blooms: challenges and opportunities for remote sensing

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*(\*with thanks and apologies to the wide community of people involved in HAB research, including Stewart Bernard, Raphael Kudela, Richard Stumpf, Mark Matthews, many many more!)*

*IOCCG Summer Lecture Series 2022*







# Who am I?

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What can I do to help people and planet?



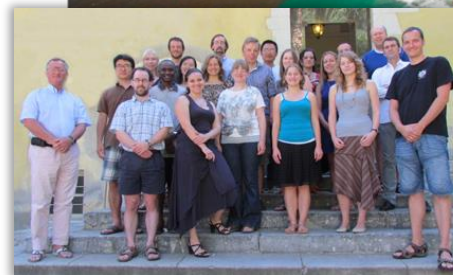
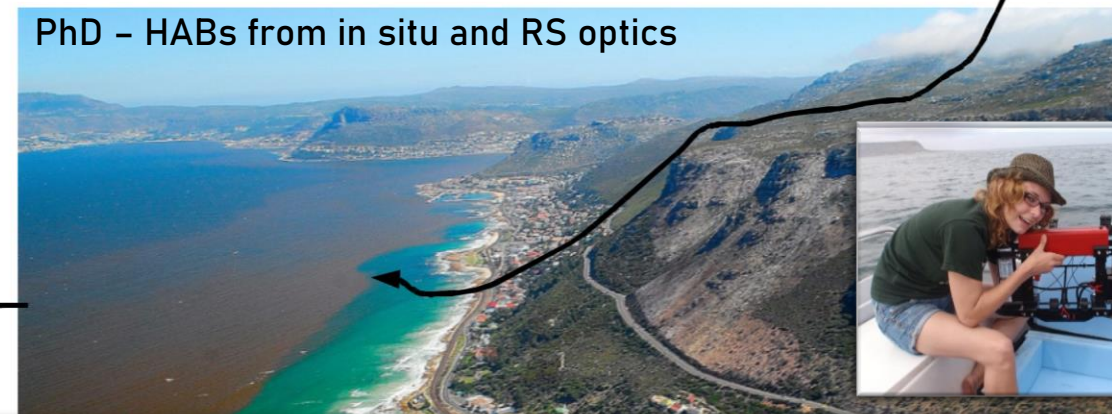
BSc. (hons)  
Environmental  
Science



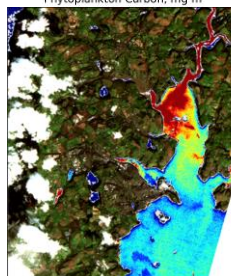
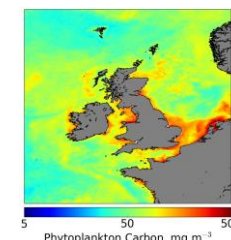
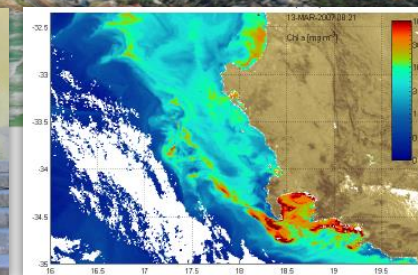
MSc. Oceanography



PhD – HABs from in situ and RS optics



IOCCG SLS 2012



Marine EO  
Scientist  
(PML)



Marine Applications  
Expert (EUMETSAT)





- What are HABs?
- What are the monitoring requirements?
- Challenges for remote sensing
- Examples of approaches
- Further ways to explore HAB remote sensing concepts



- “Bloom” itself is quite a loosely defined term (see Smayda et al., 2003)
- Important to think about this, particularly in terms of HABs because it relates to two key factors:
  - What impact they have?
  - How we are able to quantify them using metrics applied to data.
- Critical questions around relationships between harm and biomass (bloom typically related to increase in biomass).
- Timing and frequency also important considerations.

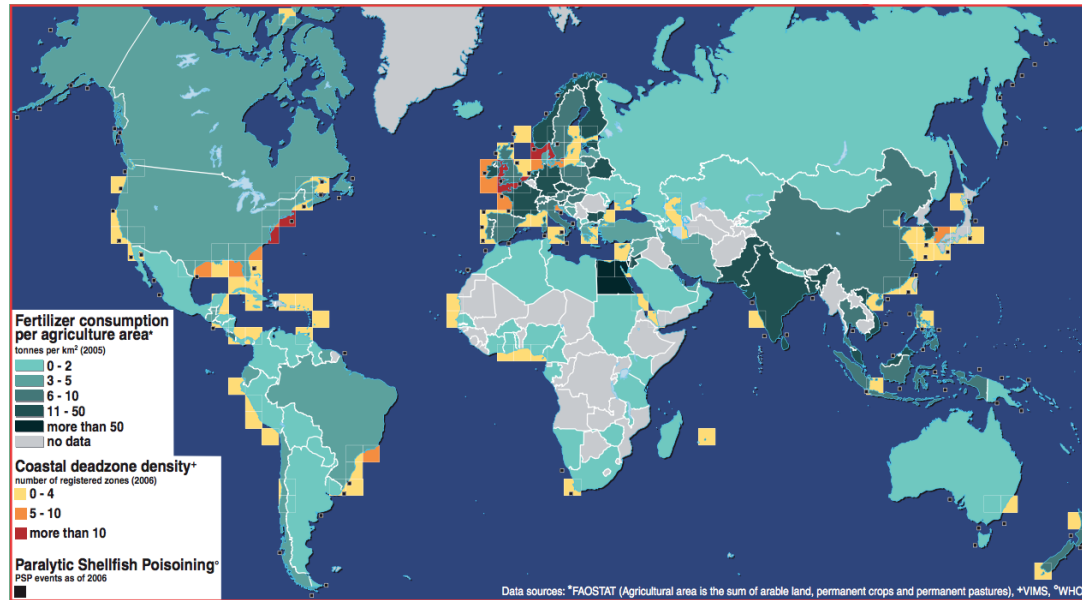


- “At least 8 different ways a bloom could be ‘Harmful’”
  - Starvation
  - Mechanical
  - Physical
  - Anoxia
  - $\text{NH}_4$  toxicity
  - Phycotoxins
  - Allelopathic (growth inhibition)
  - Ambush predation
- Generalise:
  - **Anoxic** (associated with high biomass)
  - **Toxic** (causing harm to humans, may not be biomass dependent)
  - **Ecological** (with some cross over)



- Spatio-temporal resolution
  - Often coastal so higher spatial resolution is beneficial
  - Temporal resolution need to be frequent, but long duration to investigate event scale but also place in wider context
- Capture characteristics that can link to impact:
  - High biomass
  - Types of species
    - What are we detecting?
      - Individual species?
      - Functional types?
      - Size structure?
      - Colour (see Dierssen et al., 2006)
  - Bloom formation/transport
    - Drivers (natural, unnatural?)

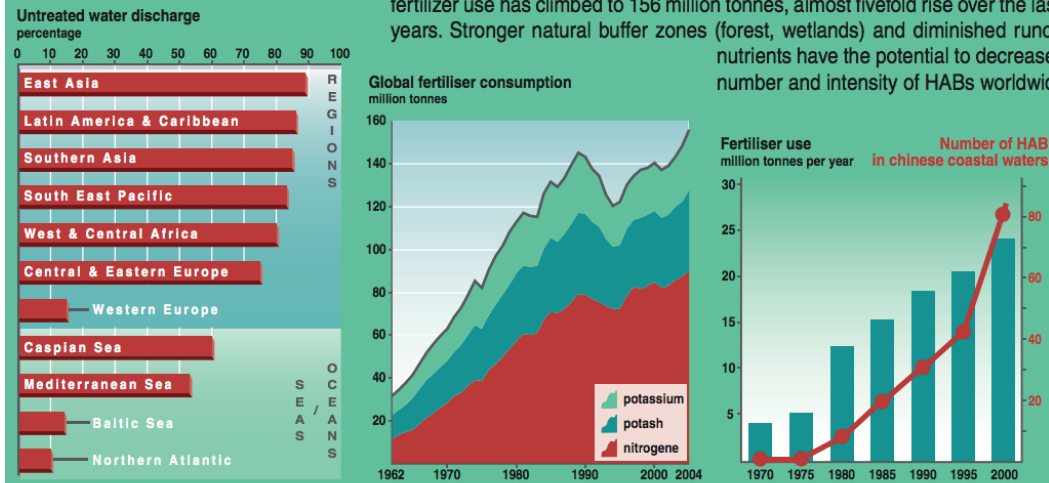




- Introduction of nutrients in to the marine environment from anthropogenic activities:
  - Sewage
  - Fertilisers

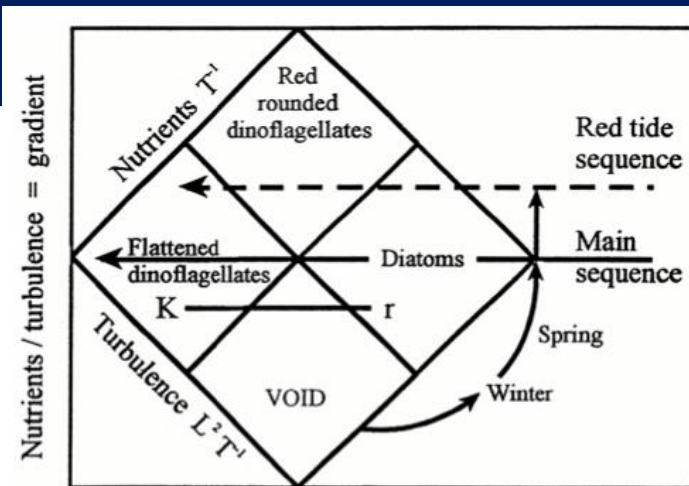
Marine water pollution has been identified as a factor in some HABs. Primary production, such as algal cell division, increases with eutrophication which is often fueled by untreated sewage water discharge. Notice on the graph how much water treatment needs improvement worldwide!

A link between the trends in fertilizer use and the number of red tides for Chinese coastal waters has been reported. Annual fertilizer use has climbed to 156 million tonnes, almost fivefold rise over the last 40 years. Stronger natural buffer zones (forest, wetlands) and diminished runoff of nutrients have the potential to decrease the number and intensity of HABs worldwide.



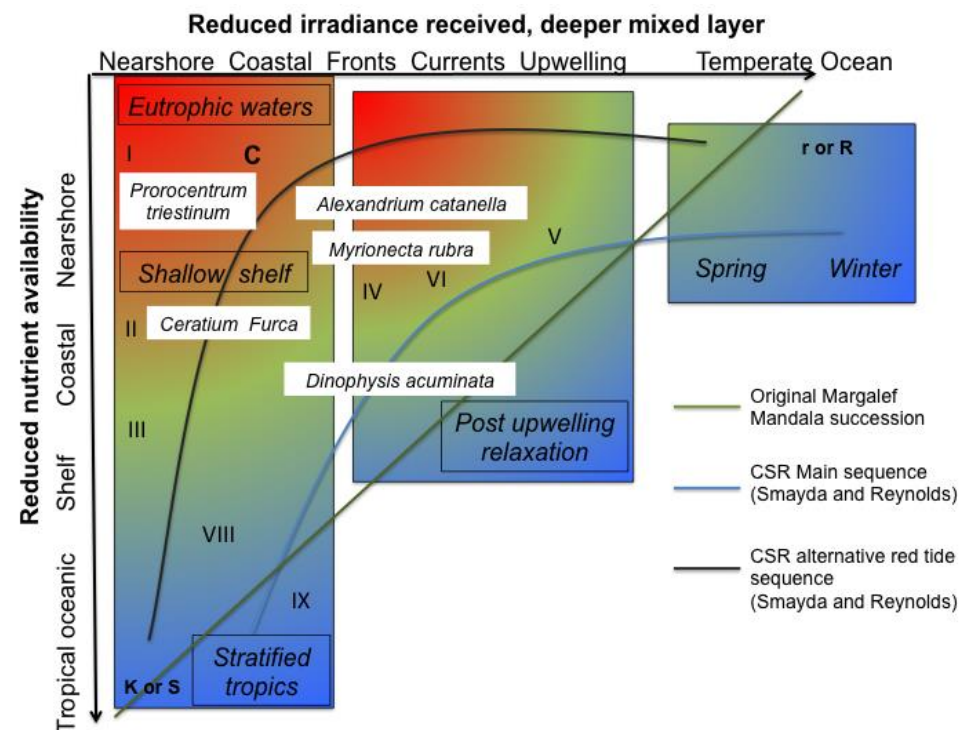
Data sources: The International Fertilizer Industry Association<sup>(1)</sup>, Earth Policy Institute<sup>(2)</sup>, UNEP 2006<sup>(3)</sup>, Smil 2001<sup>(4)</sup>, Zhang 1994<sup>(5)</sup>

- Introduction of nutrients in to the marine environment from natural forces:
  - Wind (upwelling)
- Balance between nutrient influx and stratification, and grazing pressure
- Species competition



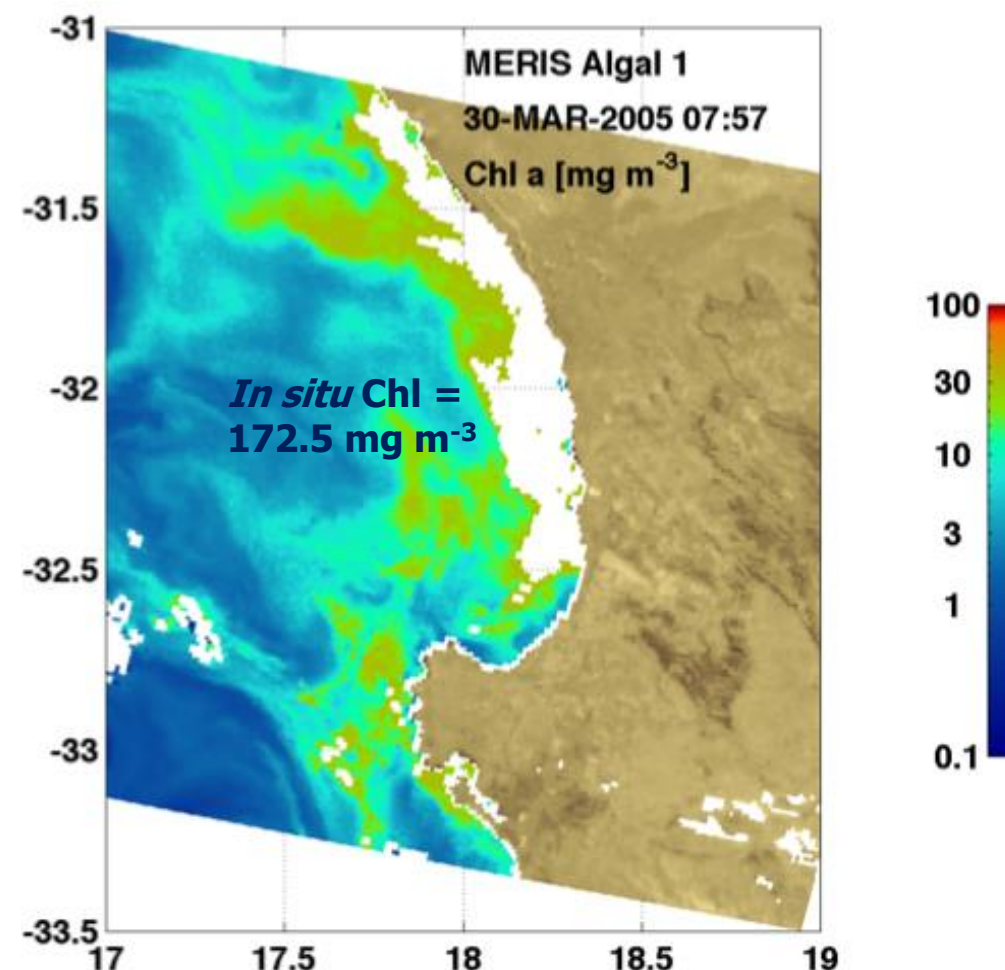
Nutrients x turbulence = productive potential

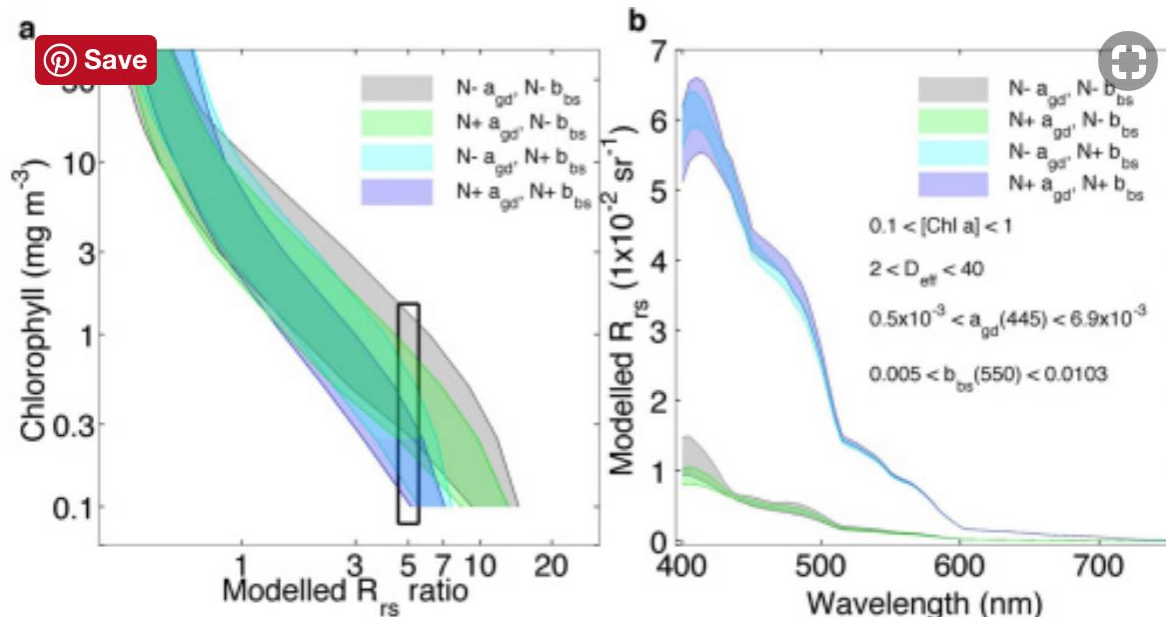
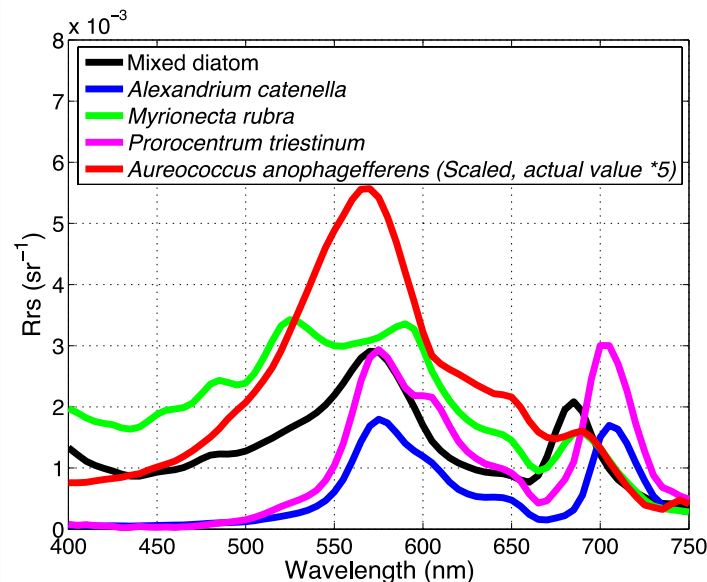
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- Balance between spatial/temporal resolution is challenging even with modern sensors
- Sensor sensitivity
  - Higher resolution land sensors not ideal for ocean waters (S2/L8)
- Coastal complexity
  - Atmospheric correction
  - Adjacency
  - Outside scope of standard [Chl] algorithms
  - Ambiguity...





- Spectral resolution/bandwidth/S:N – enough for species detection?
- Ambiguity:
  - In the ocean colour problem (multiple ways to make the same spectra) (see Defoin-Platel and Chami, 2007)
  - Sensitivity (see Evers-King et al., 2014)

Best approaches are likely to combine data:

- *In situ* monitoring
- Modelling

No 'one size fits all' solution

- For those interested in phytoplankton – HABs are probably one of the best natural circumstances to investigate their properties optically and from space!
- Many opportunities for synergistic RS techniques:
  - Understanding HAB formation through relationships with SST, wind, currents etc.
- Many benefits to be had:
  - Aquaculture is a growth industry
    - Huge losses (\$80 million from single event!)
  - Tourism/health
  - Commercial contexts



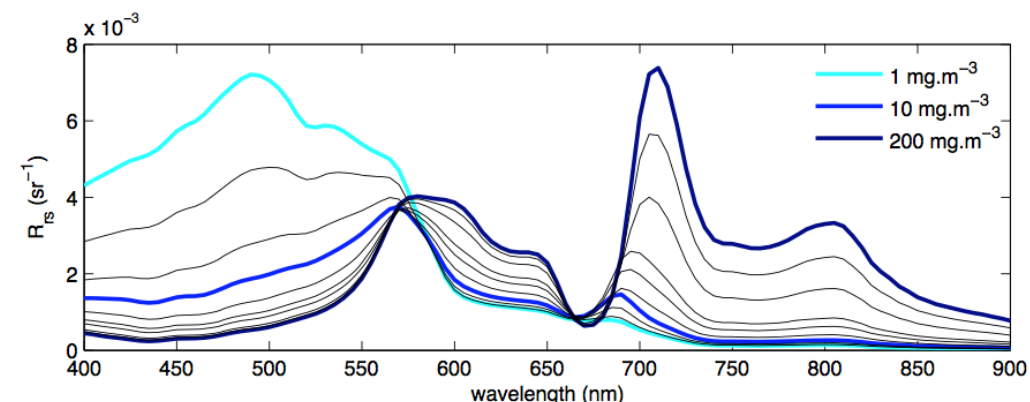
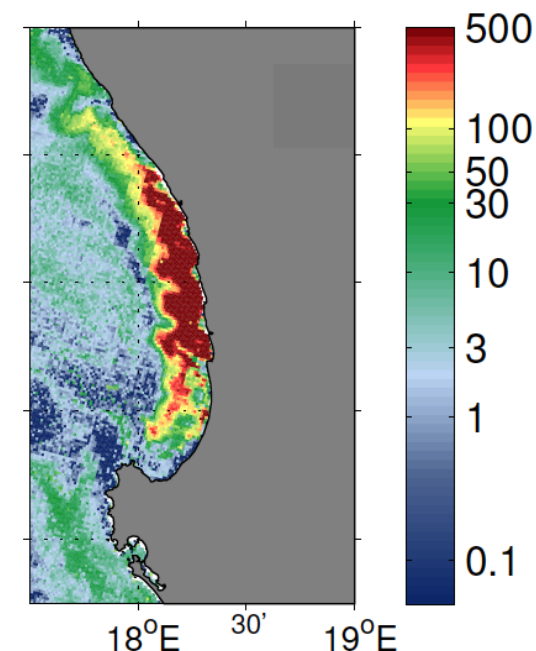


Target	Method	Reference
Biomass	Chlorophyll	Standard product
Chlorophyll fluorescence	Fluorescence line height (FLH), normalized fluorescence line height (nFLH)	Standard product
True-color image	Red-Green-Blue (RGB), Enhanced Red-Green-Blue (ERGB)	Standard Product
High biomass	Maximum chlorophyll index (MCI), Red band difference (RBD), maximum peak height (MPH)	Gower et al. 2005, Ryan et al. 2014; Amin et al. 2012; Matthews et al. 2012
High biomass	250 m band subtraction	Kahru et al. 2008
Floating Algae	Floating Algae Index (FAI)	Hu, 2009

See Kudela et al., 2017

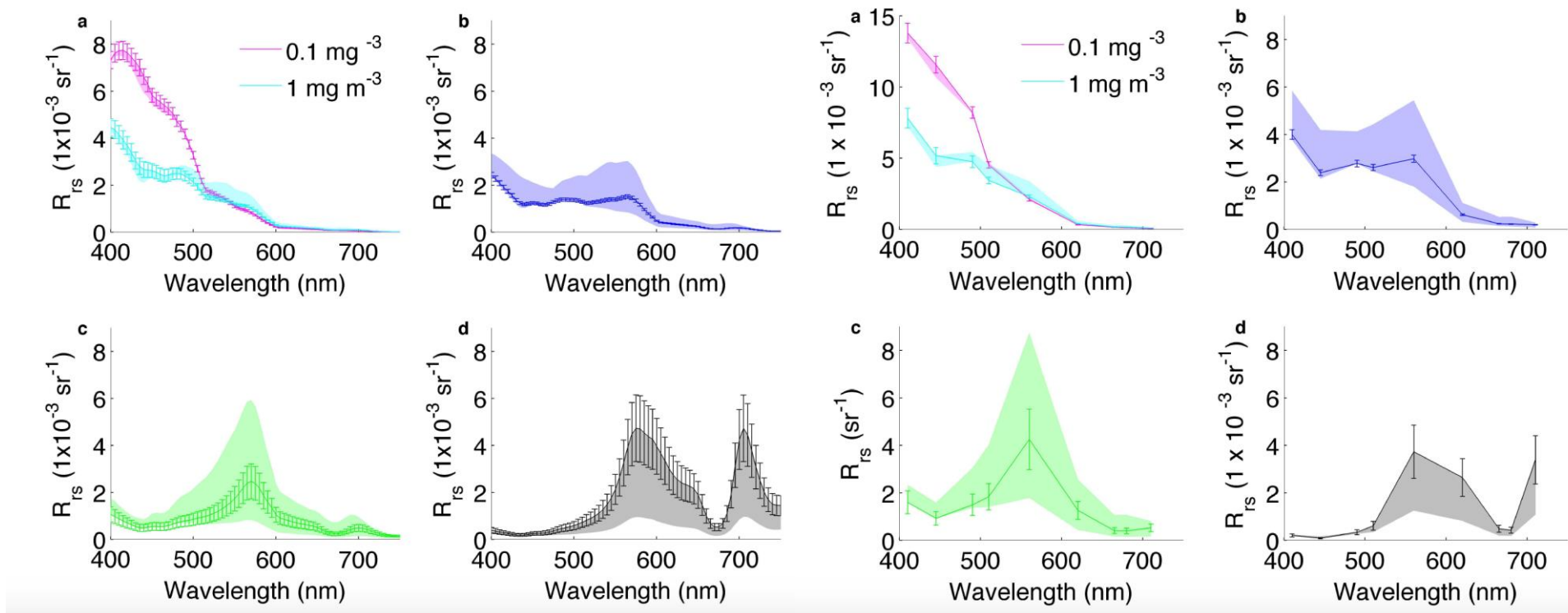
- Often use spectral shape rather than magnitude (reduce influence of acorr errors/need for it)
- Other approaches are semi-analytical with underlying assumptions (SIOPs etc) more suitable for these waters.

2nd April 2012



See Robertson et al., 2014

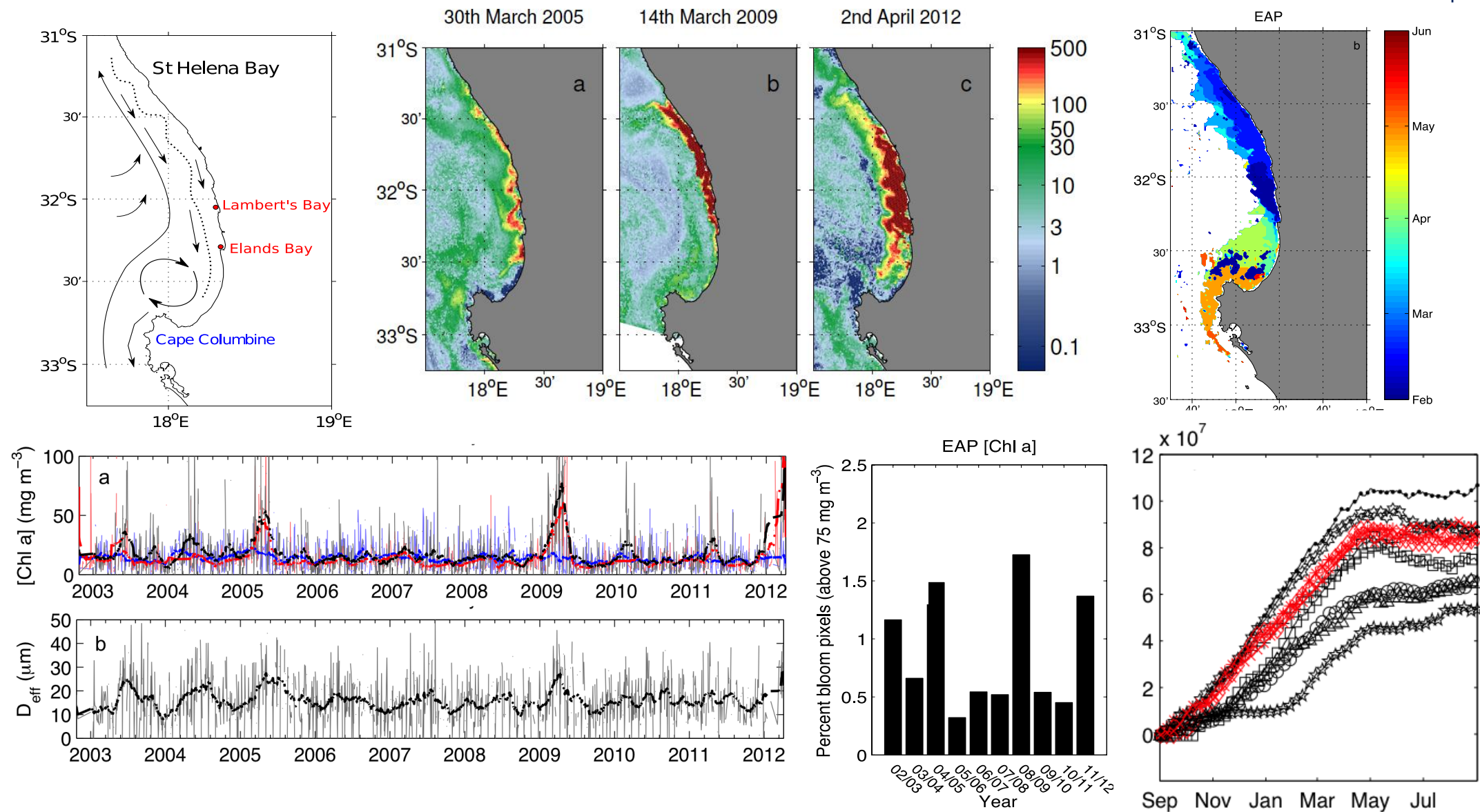
- Things to think about:
  - Assumptions in the models that underly the data...
  - Ambiguity – how distinct are the properties?
  - Relative sensitivity of the signal from the phytoplankton (and their characteristics) vs total IOP budget.
  - Error and uncertainty in your measurements (in situ or satellite)





# Examples of approaches: environmental dynamics

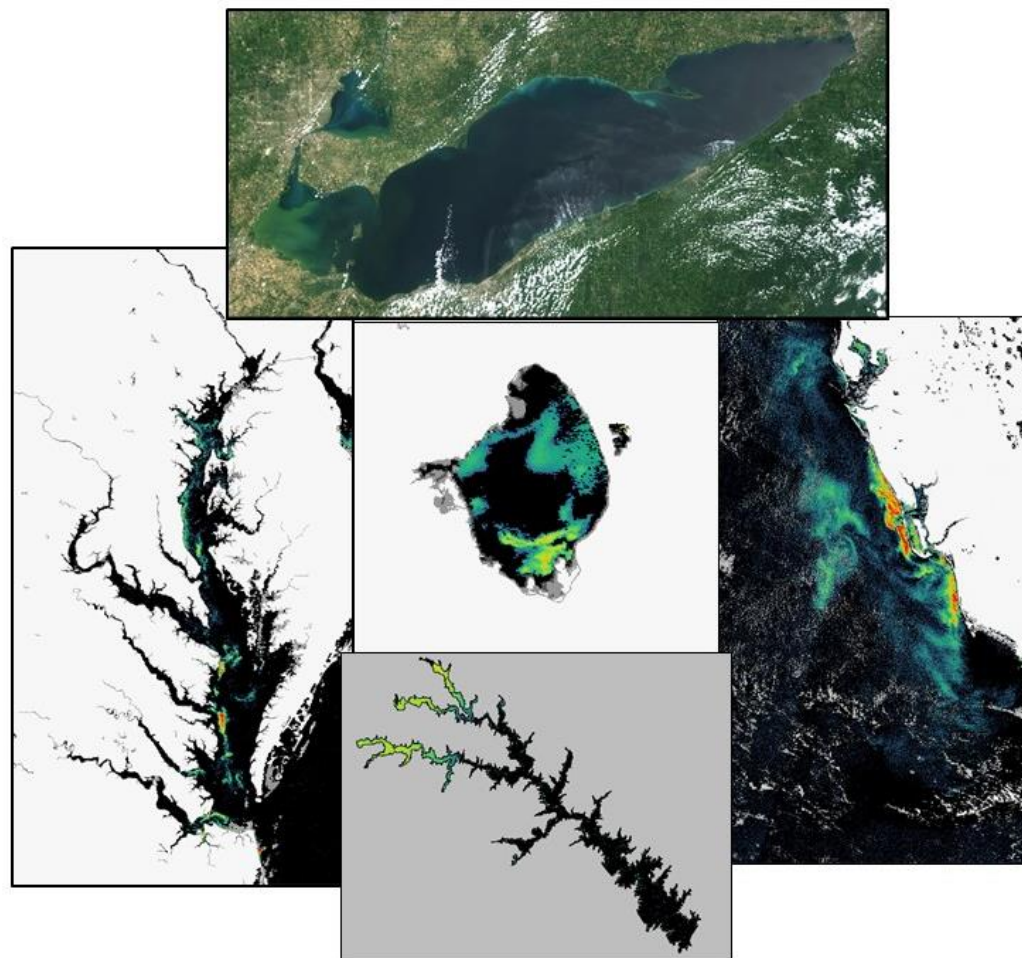
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# Examples of approaches: NOAA HAB services



- <https://oceanservice.noaa.gov/hazards/hab/>

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## Gulf of Mexico Harmful Algal Bloom Forecast

In the Gulf of Mexico, some harmful algal blooms are caused by the microscopic algae species *Karenia brevis*, commonly called red tide. *Karenia brevis* blooms can cause respiratory illness and eye irritation in humans. It can also kill marine life, and lead to shellfish closures. Blooms are often patchy, so impacts vary by beach and throughout the day. NCCOS monitors conditions daily and issues regular forecasts for red tide blooms in the Gulf of Mexico and East Coast of Florida. You can find the forecasts below, and up-to-date conditions here.

[Florida Forecast](#)

[Texas Forecast](#)

### Florida - Current Conditions

⚠️ There is no risk of respiratory irritation from *Karenia brevis* (red tide) at this time.



### Intensification Forecast

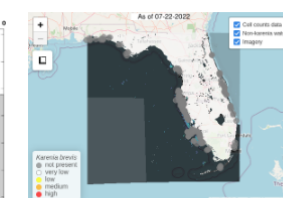
Model results estimating the likelihood of bloom initiation or intensification along the coast of Southwest Florida, due to an accumulation of cells at the coast.

[View Product](#)

### Respiratory Forecast

Modeled forecast of respiratory irritation at individual beach locations, based on field samples of *Karenia brevis* concentration, wind speed, and direction.

[View Product](#)



### Satellite Imagery

Current imagery from the Ocean Land Color Imager (OLCI) showing bloom location and extent.

[View Product](#)



### Beach Conditions Reporting System

Provides today's conditions at multiple beaches along the west coast of Florida, this includes



### State of Florida Observations

State of Florida (FWC-FWRI) bloom status updates and 8-day interactive map of statewide *K. brevis*



PROGRAMME OF  
THE EUROPEAN UNION

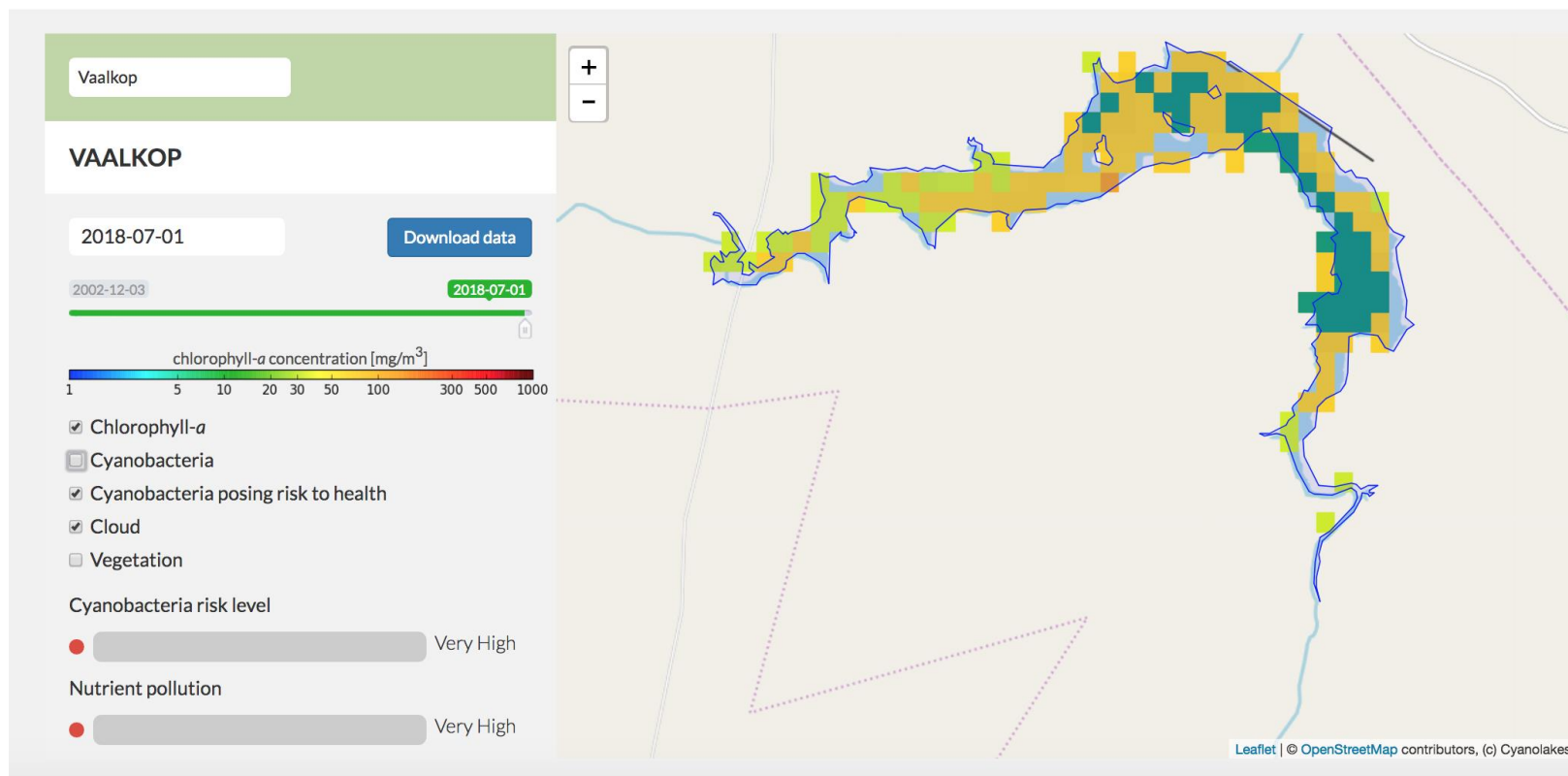


IMPLEMENTED BY EUMETSAT



# Examples of approaches: Cyanolakes

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For more information see: [www.cyanolakes.com](http://www.cyanolakes.com)  
and <https://cyanolakes.chpc.ac.za/>





# Examples of approaches: UK HAB bulletins and risk

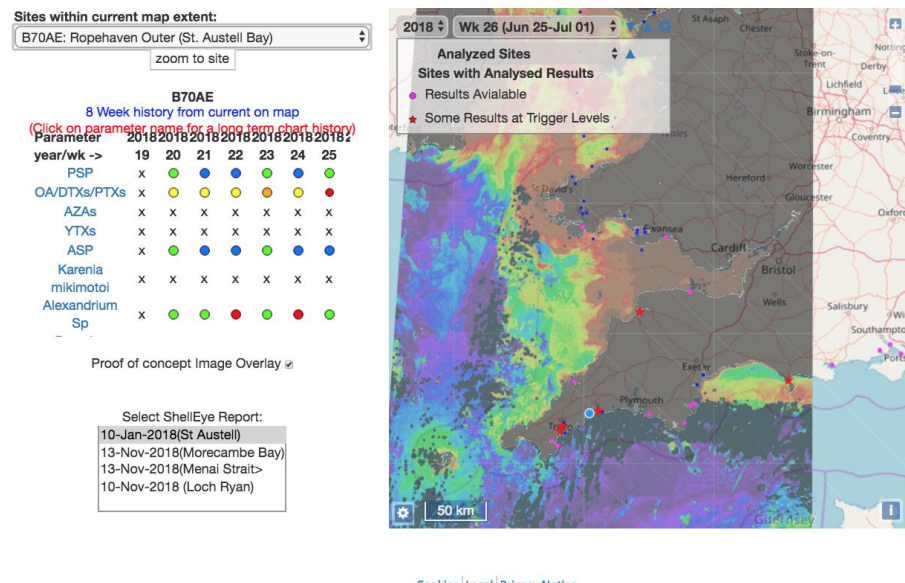
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## ShellEye Water Quality Event Map

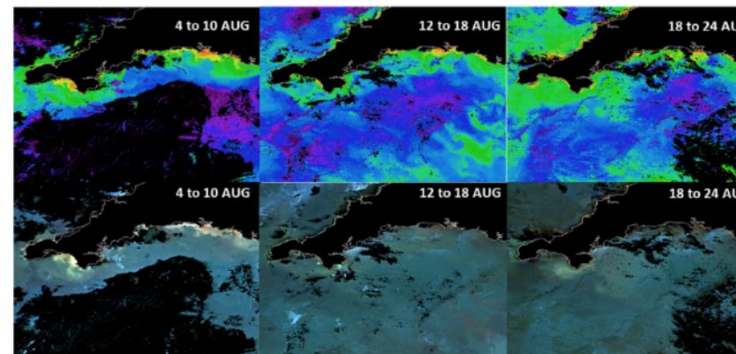
Welcome to the ShellEye Water Quality Event Map, providing data on harmful algal bloom events and microbiological hazards around the UK. Through this tool you can search water quality events by location, harmful algal bloom species, toxin or alert status.

We would very much value your feedback on this tool so please contact Kelly-Marie Davidson (ShellEye Communications Officer) at [kdav@pml.ac.uk](mailto:kdav@pml.ac.uk) to submit any comments you may have.

For further information about this tool or the developing ShellEye service in general, please contact Ruth Calder-Potts (ShellEye Project Manager) at [ruca@pml.ac.uk](mailto:ruca@pml.ac.uk).

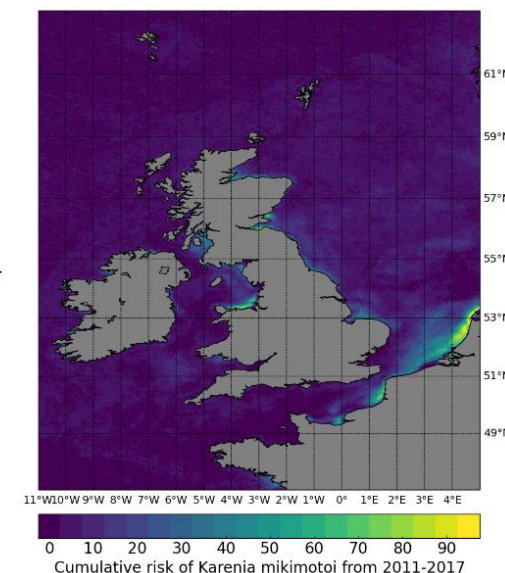
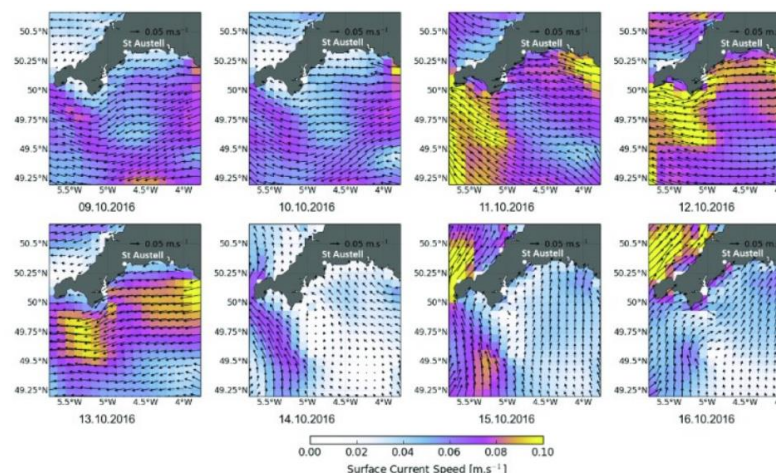


## Temporal evolution of the bloom



**Chlorophyll concentration (top):** showing the bloom growth and increase in concentration over the previous three weeks, since 4 August 2017.

**Enhanced ocean colour (bottom):** for the same dates.



PML/SAMS/CEFAS/UoEx collaborations

See [www.shelleye.org](http://www.shelleye.org) for more information





- A great natural laboratory for applied optics/RS research.
- Careful consideration needed of what it is you need to quantify as “HAB” (and indeed “bloom”) is a loose concept.
- Signal sensitivity and how this translates to measurements method is important.
- Good opportunity and gains to be made by combining approaches:
  - In situ/RS
  - Models for estimating risk

- Smayda et al., (2003): [https://aslopubs.onlinelibrary.wiley.com/doi/abs/10.4319/lo.1997.42.5\\_part\\_2.113](https://aslopubs.onlinelibrary.wiley.com/doi/abs/10.4319/lo.1997.42.5_part_2.113)
- Dierssen et al., (2006): <https://aslopubs.onlinelibrary.wiley.com/doi/abs/10.4319/lo.2006.51.6.2646>
- Defoin-Platel and Chami (2007): <https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2006JC003847>
- Evers-King et al., (2014): [https://www.osapublishing.org/DirectPDFAccess/B7BA5E7F-F0F7-5725-9294E1A837A0CC72\\_284439/oe-22-10-11536.pdf?da=1&id=284439&seq=0&mobile=no](https://www.osapublishing.org/DirectPDFAccess/B7BA5E7F-F0F7-5725-9294E1A837A0CC72_284439/oe-22-10-11536.pdf?da=1&id=284439&seq=0&mobile=no)
- Kudela et al., (2017): [https://www.researchgate.net/profile/Clarissa\\_Anderson/publication/323497462\\_Designing\\_an\\_observing\\_system\\_for\\_early\\_detection\\_of\\_harmful\\_algal\\_blooms/links/5a985693aca27214056d48ac/Designing-an-observing-system-for-early-detection-of-harmful-algal-blooms.pdf#page=118](https://www.researchgate.net/profile/Clarissa_Anderson/publication/323497462_Designing_an_observing_system_for_early_detection_of_harmful_algal_blooms/links/5a985693aca27214056d48ac/Designing-an-observing-system-for-early-detection-of-harmful-algal-blooms.pdf#page=118)
- Astoreca et al., (2009): <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2639444/>
- Kurekin et al., (2014): <https://www.ncbi.nlm.nih.gov/pubmed/28040105>
- Robertson Lain et al., (2014): <https://www.ncbi.nlm.nih.gov/pubmed/25090493>



- Exploring HABs from satellite ocean colour in SNAP:  
<https://drive.google.com/drive/folders/1Ds2CGp5q1ylKcM2emoxxPSW2fMgzTQFn?usp=sharing>
- Recent EUMETSAT case study with accompanying Jupyter Notebook <https://www.eumetsat.int/deoxygenation-impacts-marine-life-benguela>
- IOCCG report [https://ioccg.org/wp-content/uploads/2021/05/ioccg\\_report\\_20-habs-2021-web.pdf](https://ioccg.org/wp-content/uploads/2021/05/ioccg_report_20-habs-2021-web.pdf)





Thank you!  
Questions are welcome.