EUMETSAT

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Harmful Algal Blooms: challenges and opportunities for remote sensing

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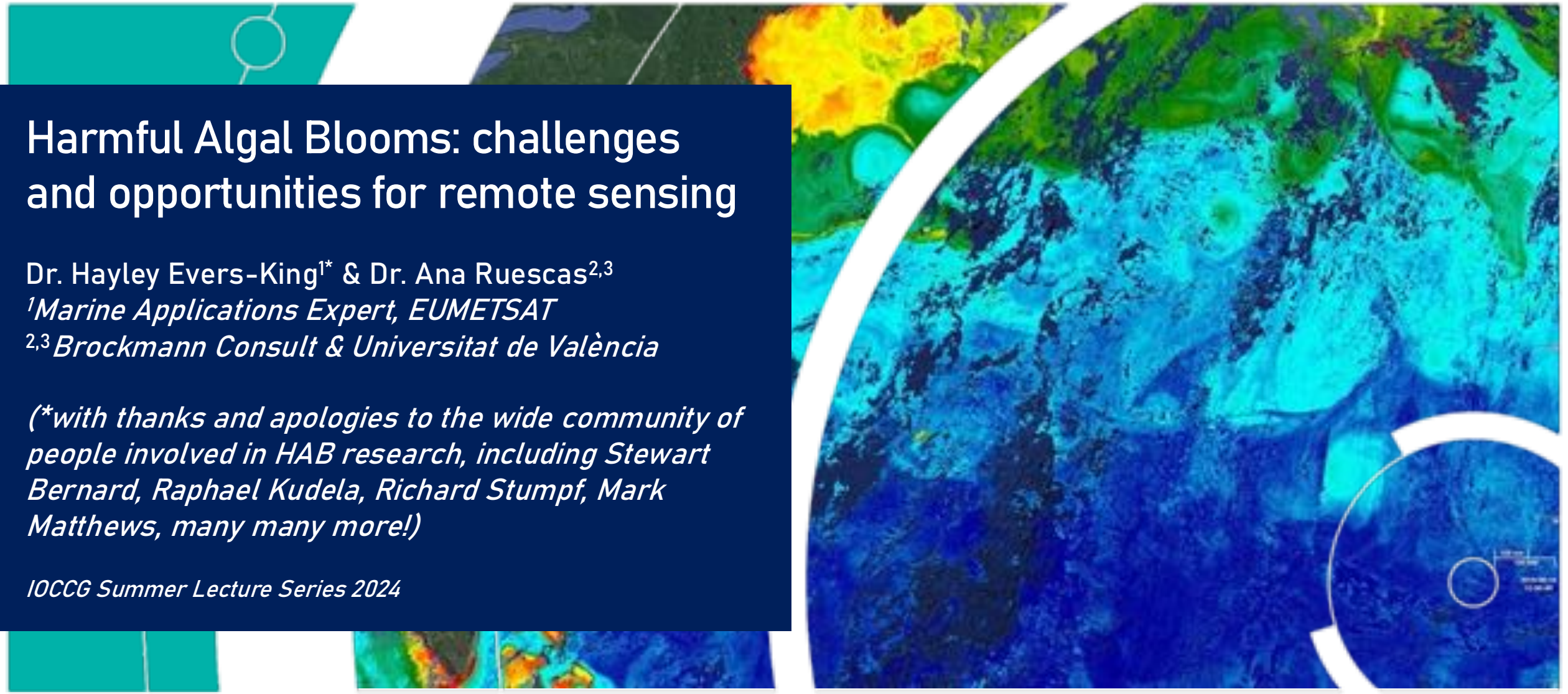
*(*with thanks and apologies to the wide community of people involved in HAB research, including Stewart Bernard, Raphael Kudela, Richard Stumpf, Mark Matthews, many many more!)*

IOCCG Summer Lecture Series 2024



Agenda

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

Harmful Algal Blooms

- "Bloom" itself is quite a loosely defined term (see Smayda et al., 2003)

  "An algal bloom or algae bloom is a rapid increase or aggregation in the algae population of freshwater or marine water systems and is often identified by water discolouration of their pigments."

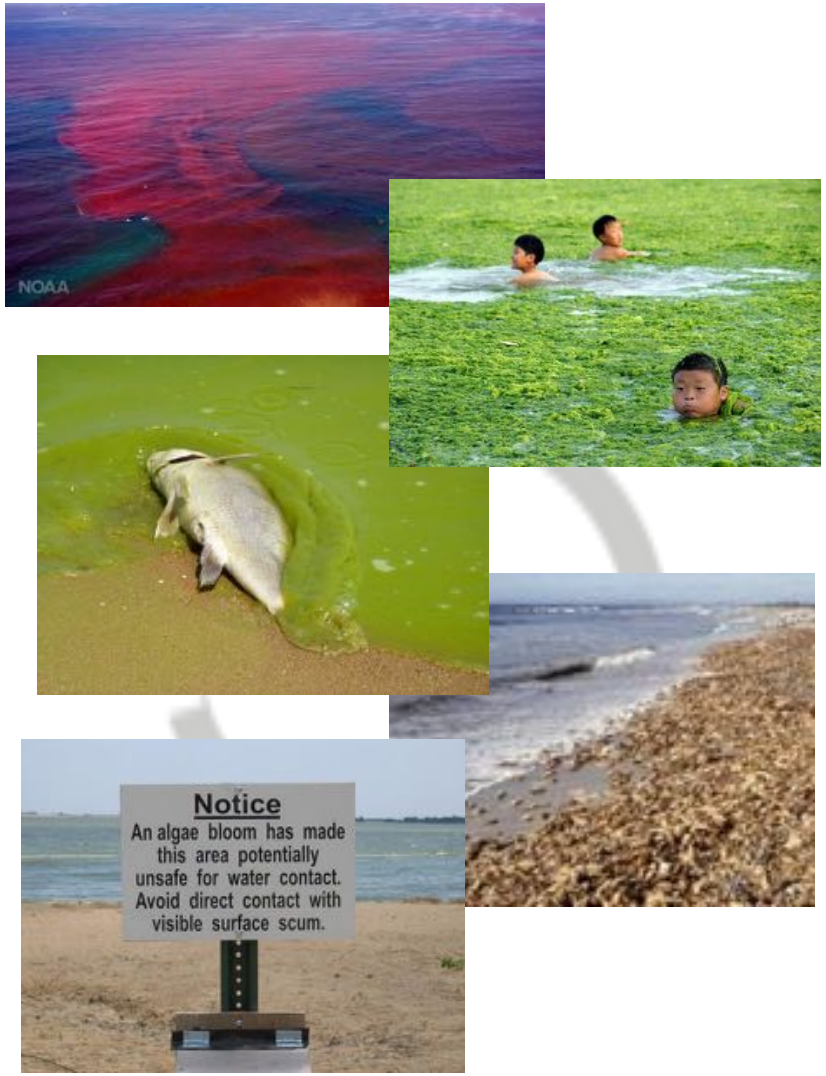
- Important to think about this, particularly in terms of HABs because it relates to two key factors:
  - What impact they have?
  - How we are able to quantify them using metrics applied to data.

- Critical questions around relationships between harm and biomass (bloom typically related to increase in biomass).

- Timing and frequency also important considerations.

Impacts of Harmful Algal Blooms

- "At least 8 different ways a bloom could be 'Harmful'"
  - Starvation
  - Mechanical
  - Physical
  - Anoxia
  - 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)

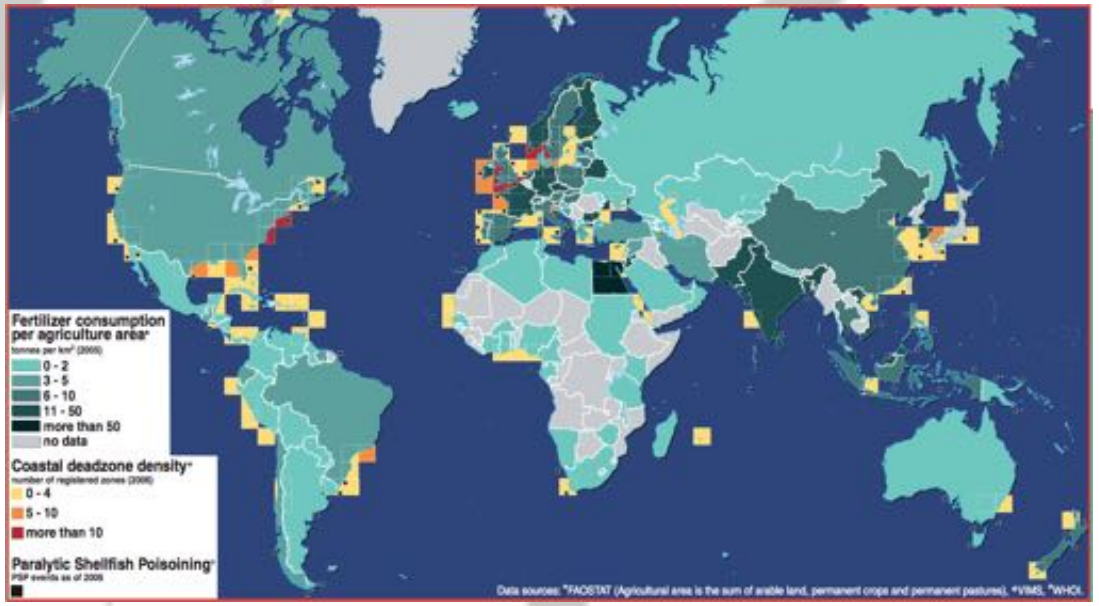


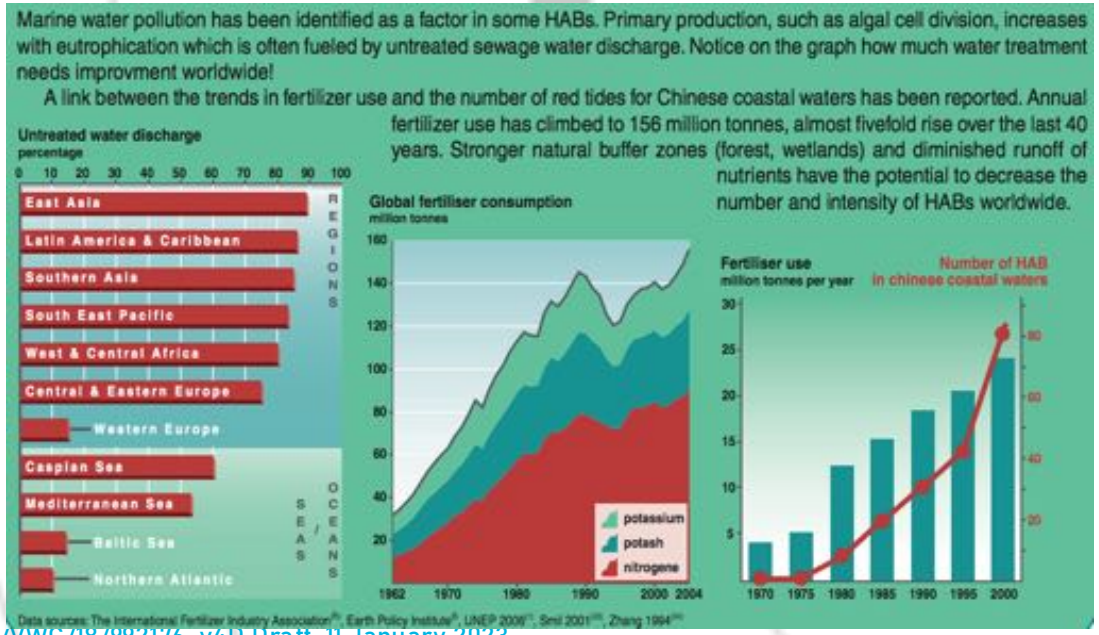
Monitoring requirements for HABs

- 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?)

What drives HABs?...

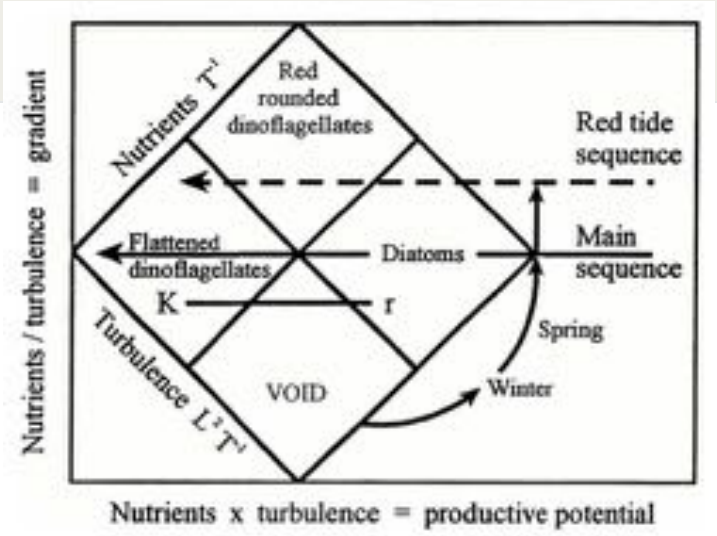


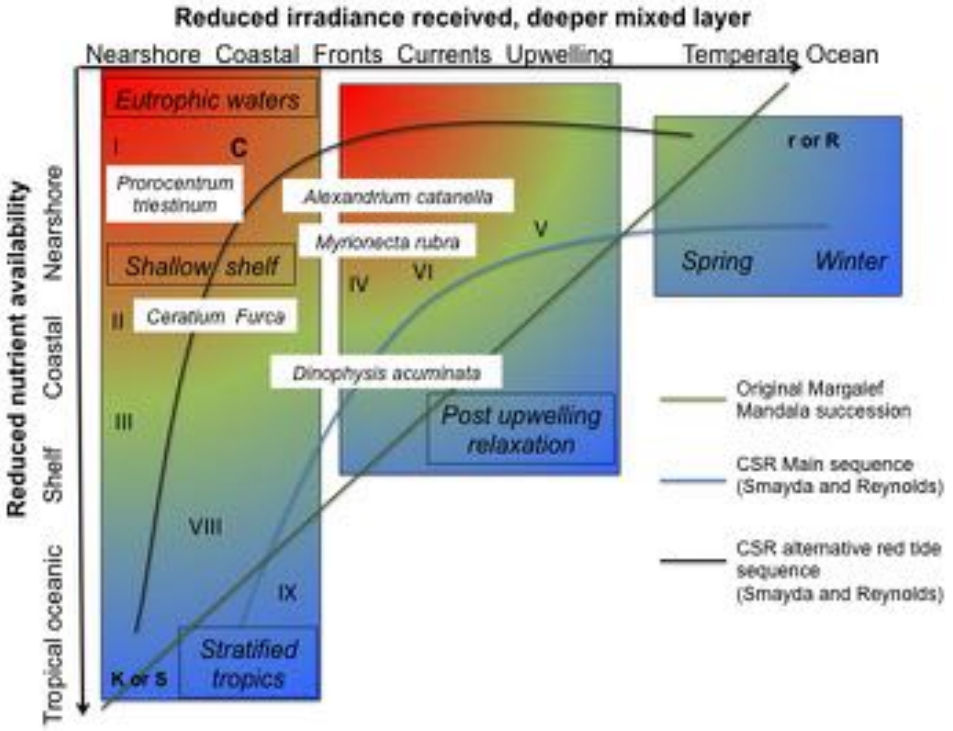


- Introduction of nutrients in to the marine environment from anthropogenic activities:
  - Sewage
  - Fertilisers

What drives HABs?

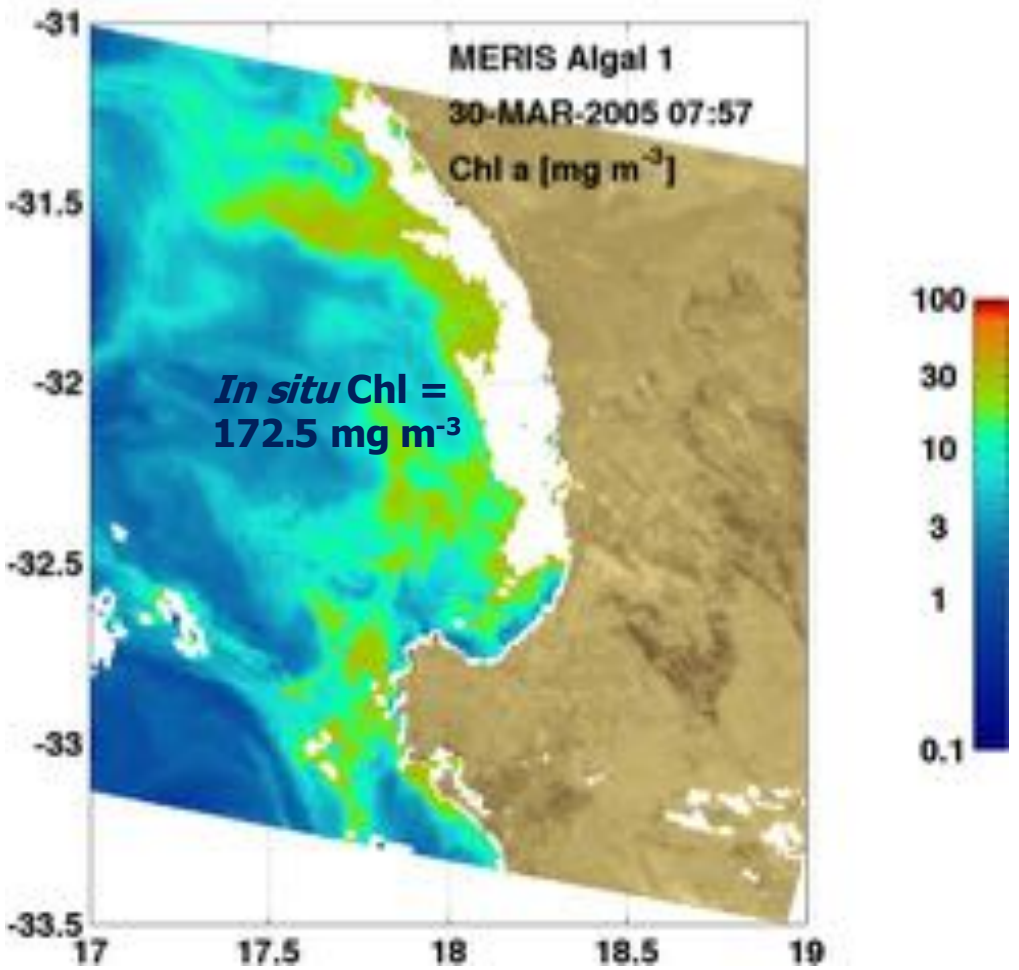
- Introduction of nutrients into the marine environment from natural forces:
  - Wind (upwelling)
- Balance between nutrient influx and stratification, and grazing pressure
- Species competition



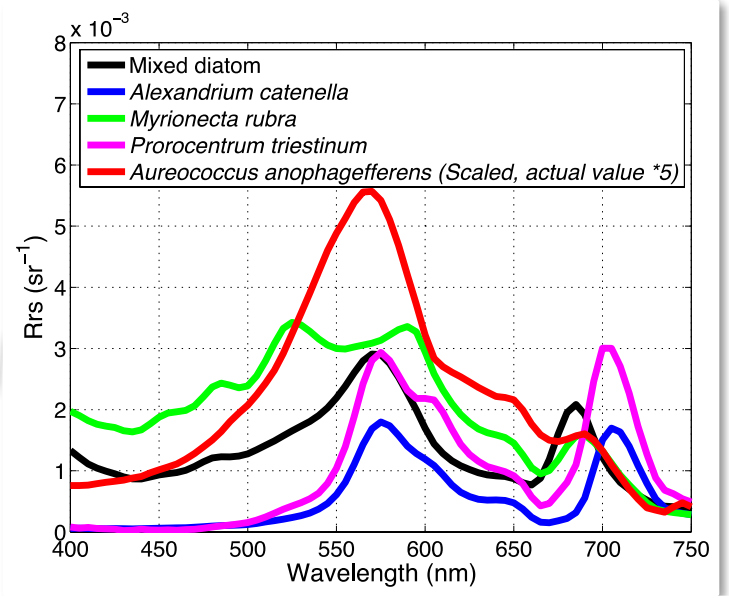


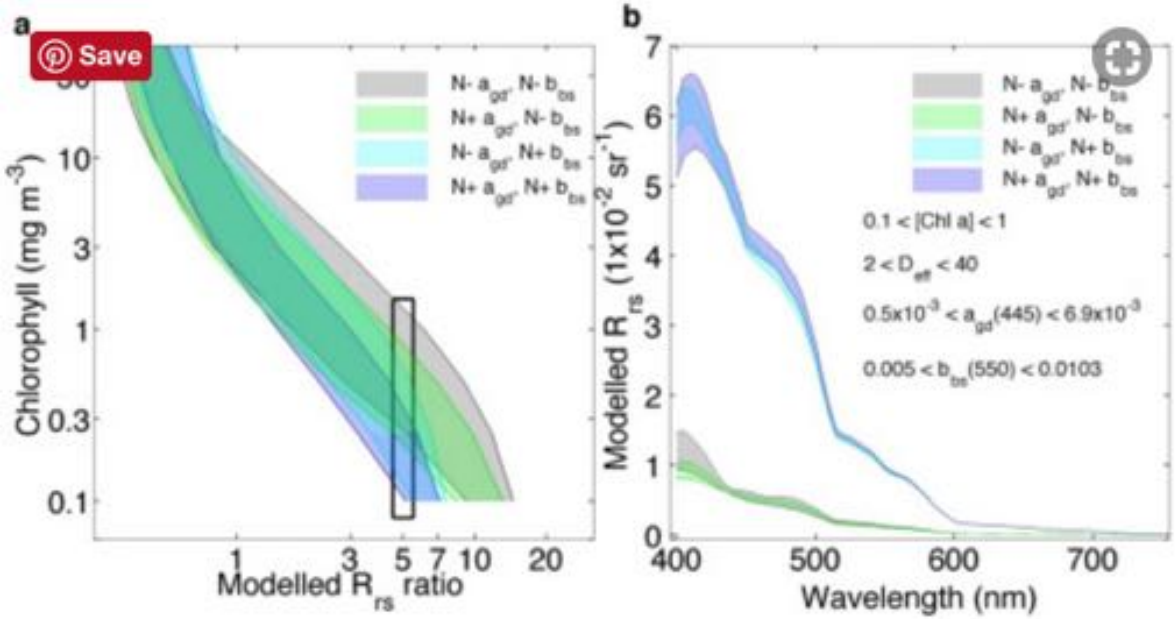
Challenges for remote sensing (general)

- 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…



Challenges for remote sensing (specific)





- 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

Opportunities from HABs research

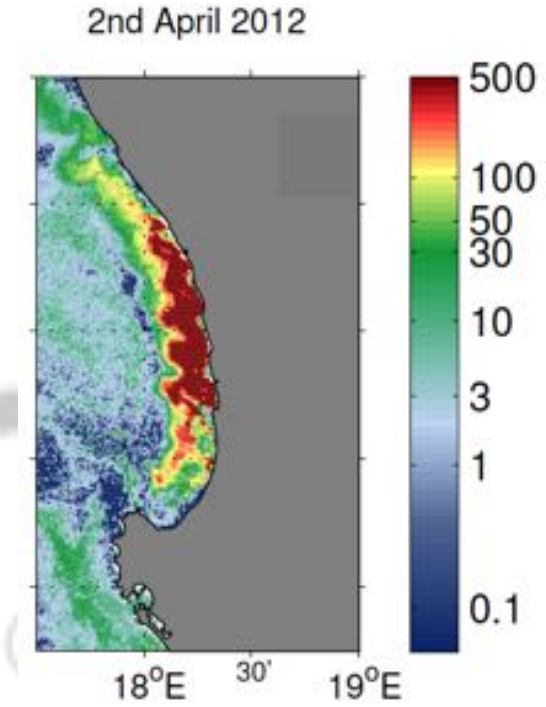
- For those interested in phytoplankton – HABs are probably one of the best natural circumstances to investigate their properties optically and from space!
- Many opportunities for synergistic RS techniques:
  - Understanding HAB formation through relationships with SST, wind, currents etc.
- Many benefits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

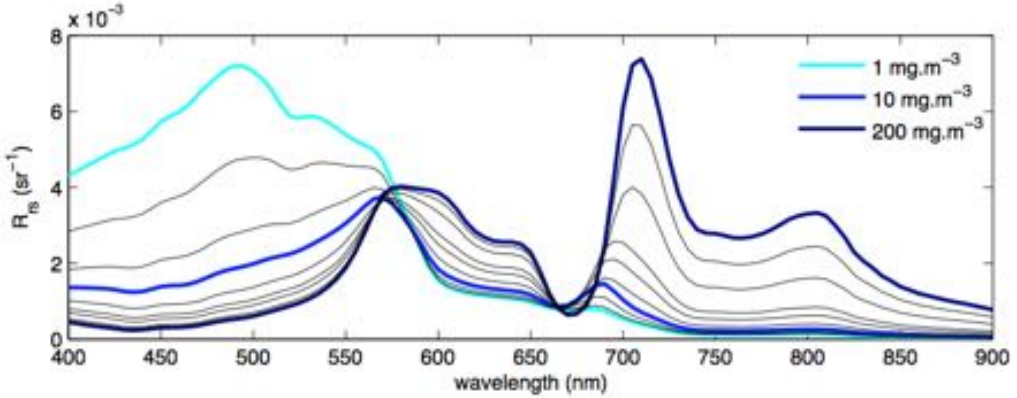
Examples of approaches: high biomass algorithms

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.



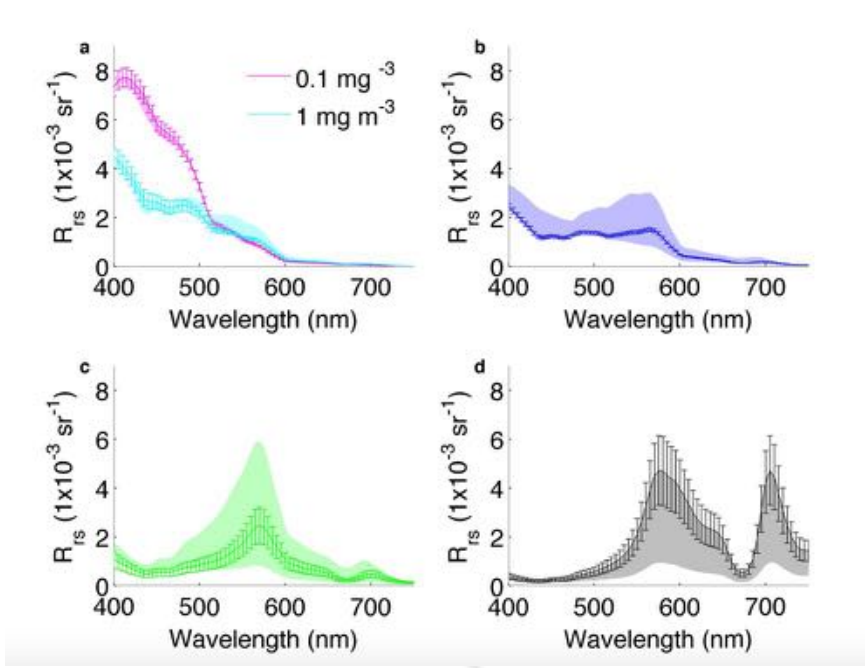


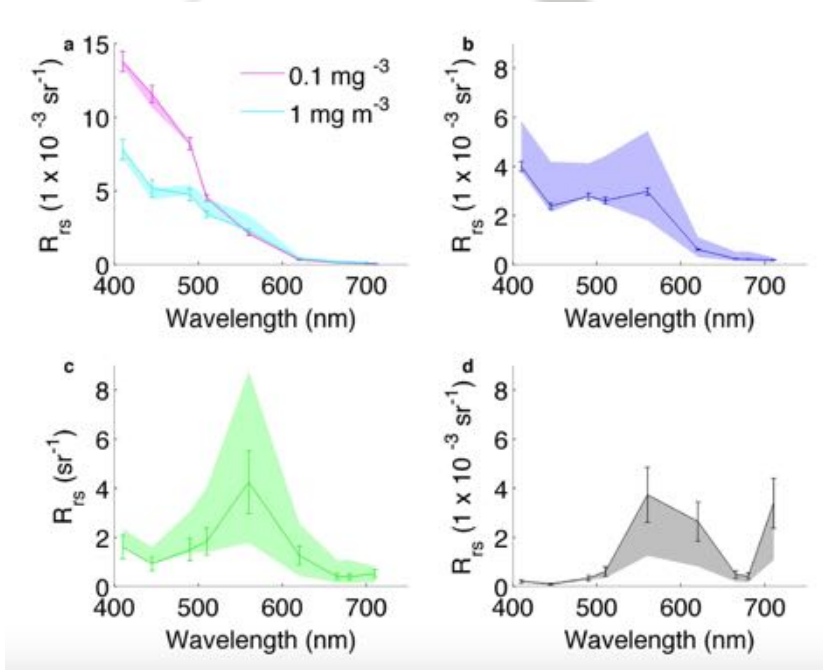
See Robertson Lain et al., 2014

Examples of approaches: species detection

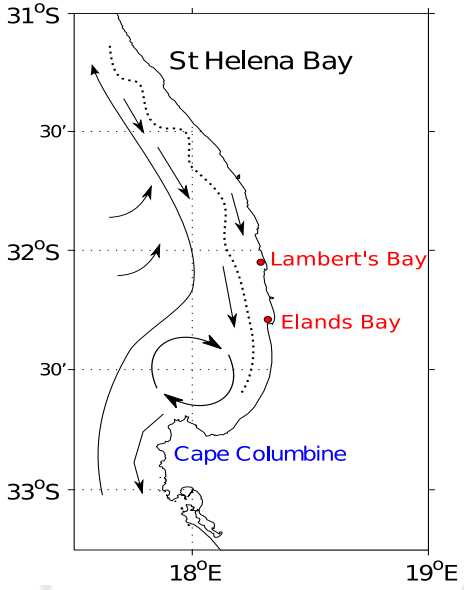
Things to think about:

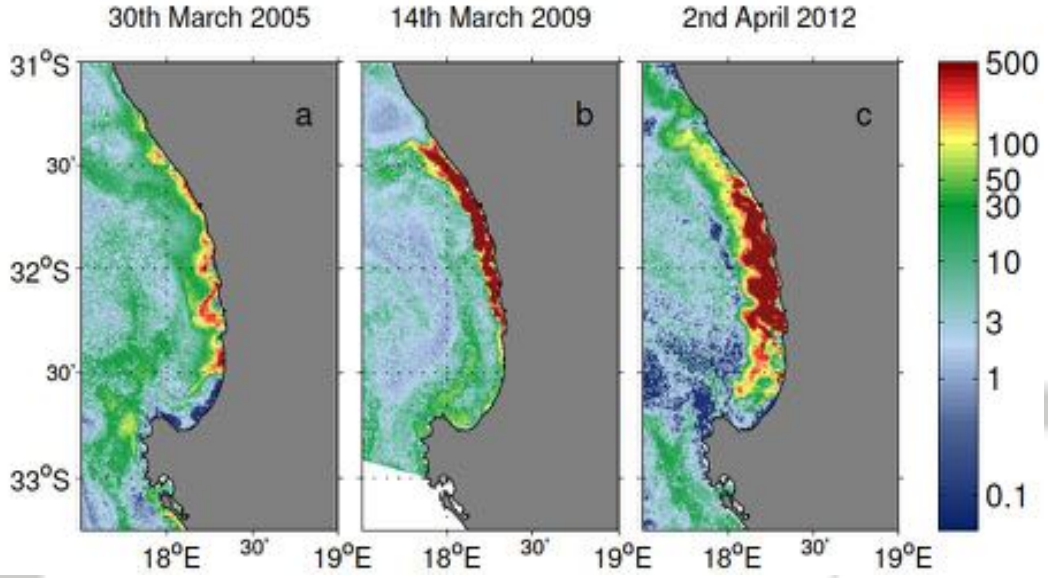
- Assumptions in the models that underly the data…
- Ambiguity – how distinct are the properties you want to look at?
- How much the biomass has to be before you can see a particular pigment related peak or a change in cell size?
- How big the change in cell size must be before you can detect a change in the signal?
- Prospect: generate models with diff. sizes and types to see how the signal is affected (much more signal with higher biomass)
- Error and uncertainty in your measurements (in situ or satellite)

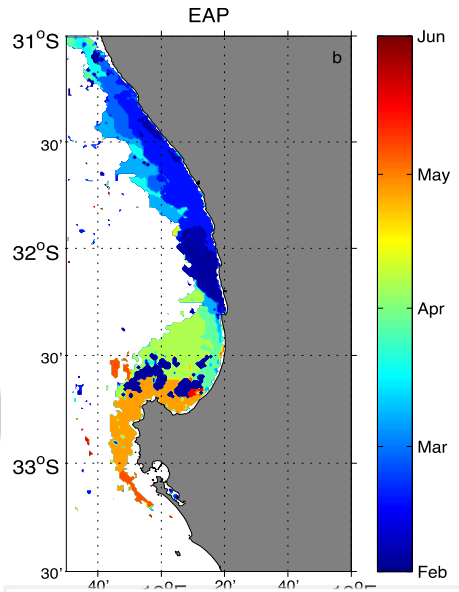


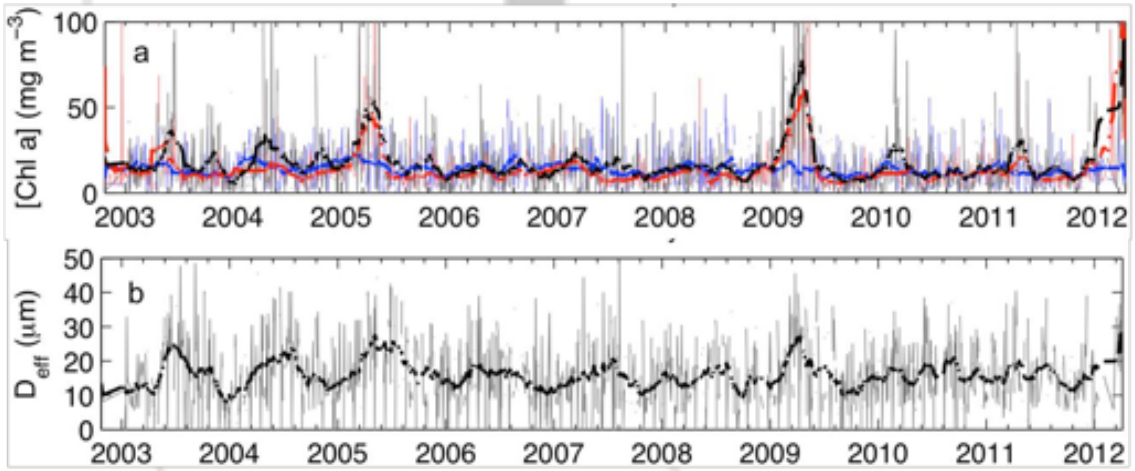


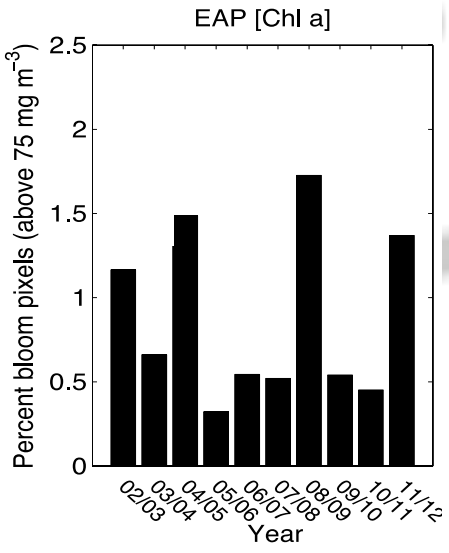
Examples of approaches: environmental dynamics

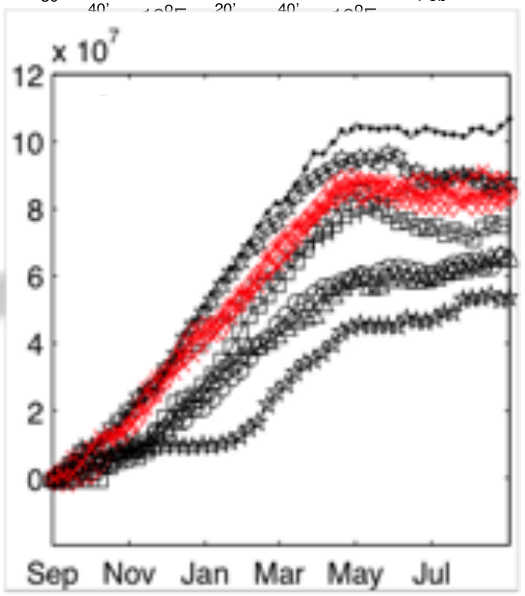




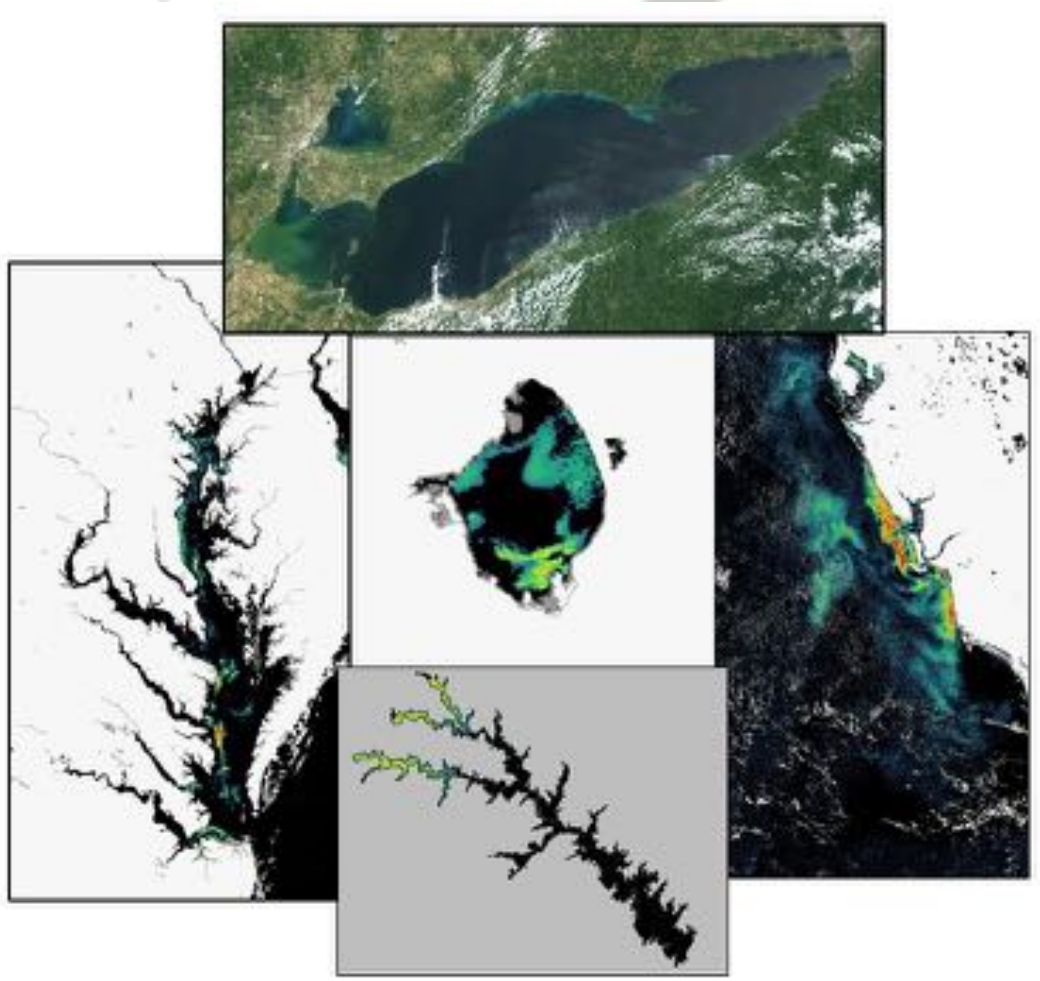


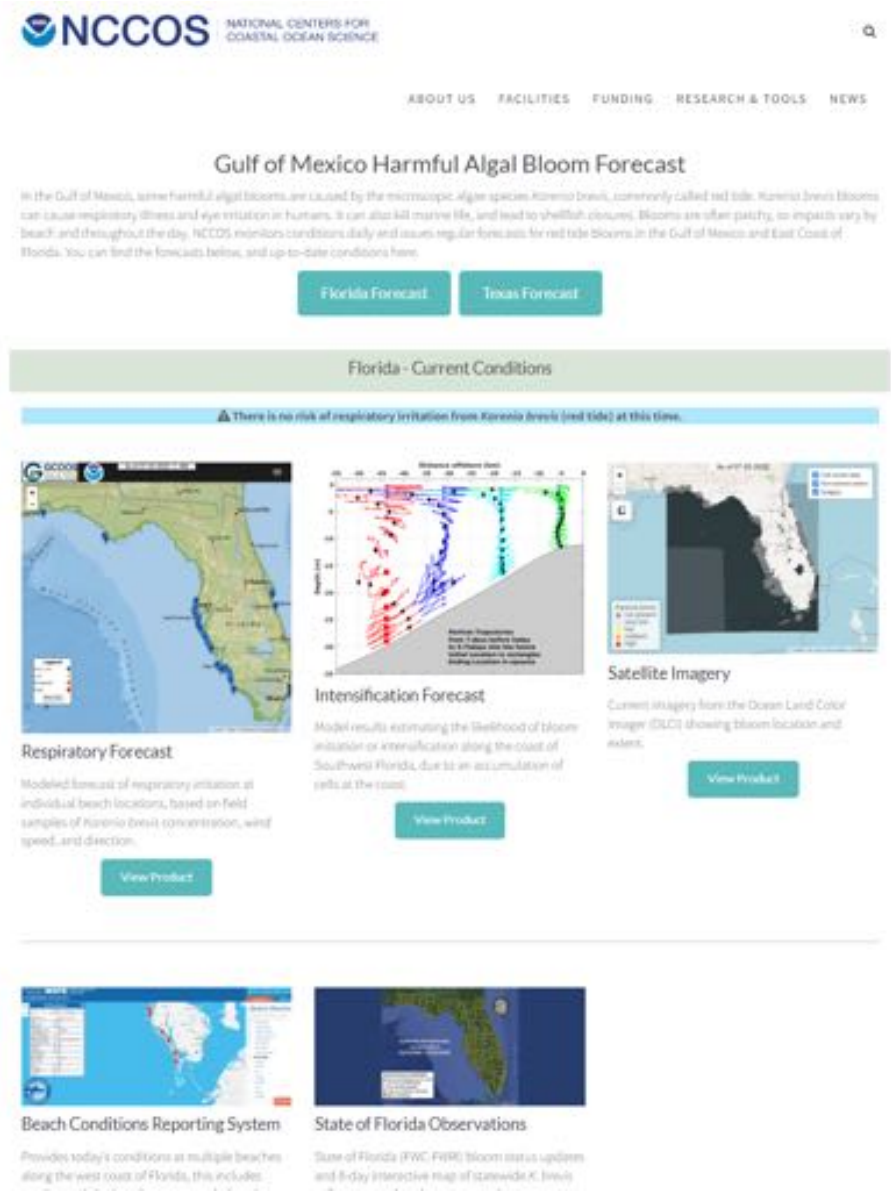






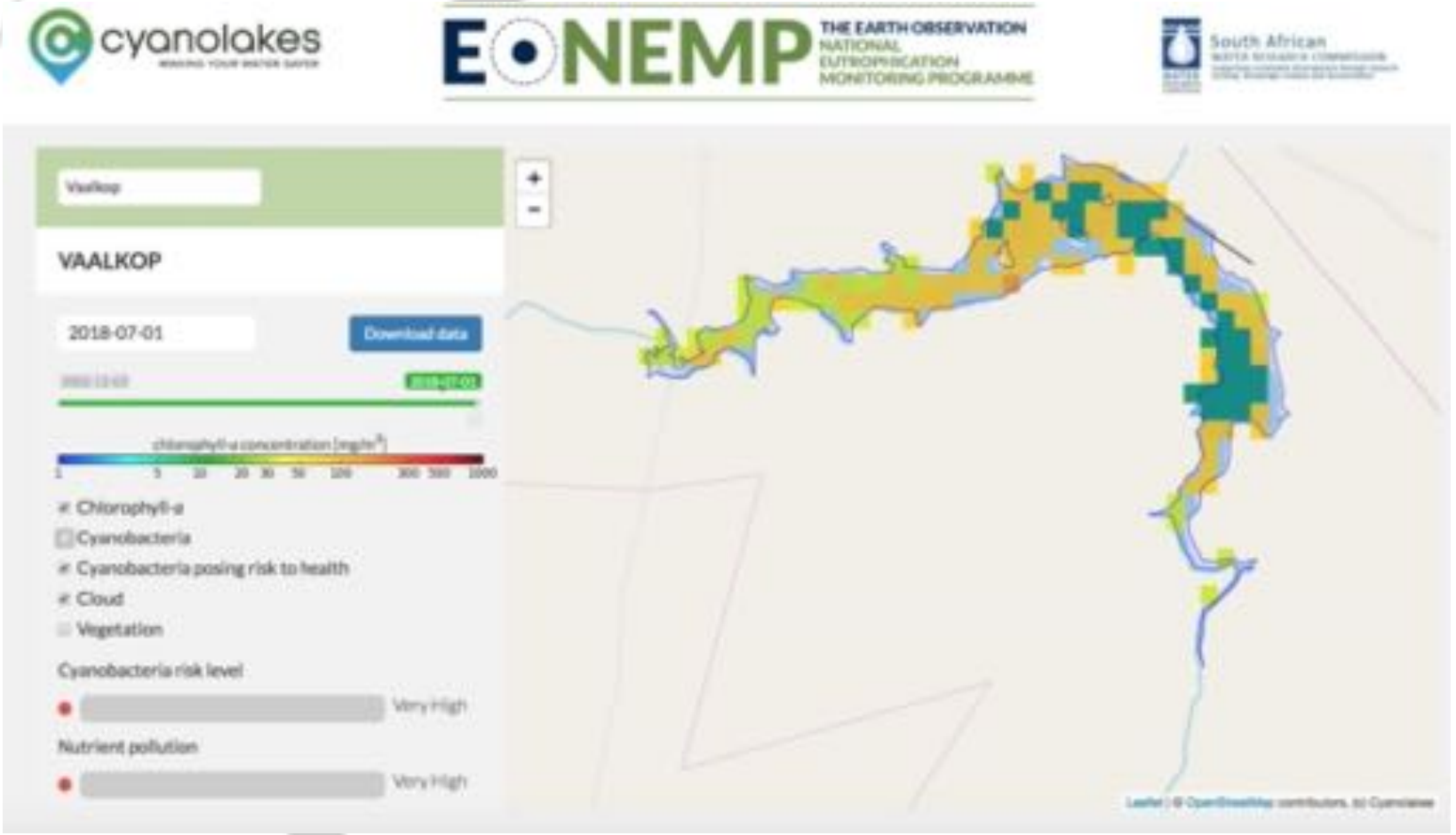
Examples of approaches: NOAA HAB services





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

Examples of approaches: Cyanolakes

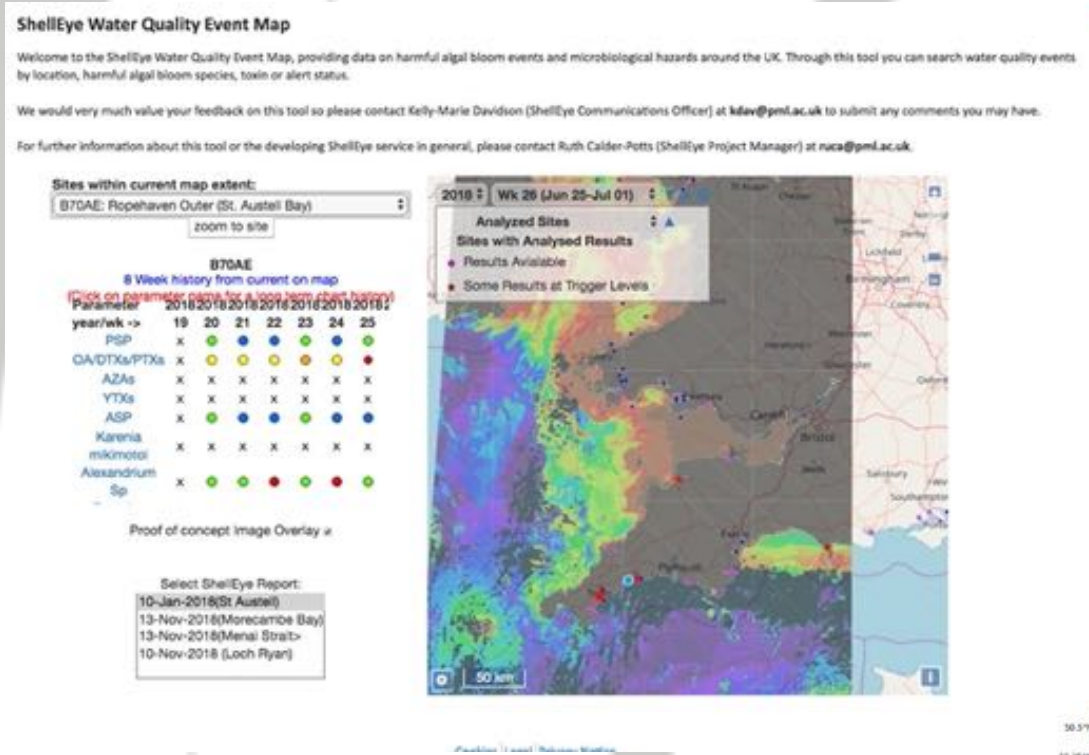


For more information see: www.cyanolakes.com

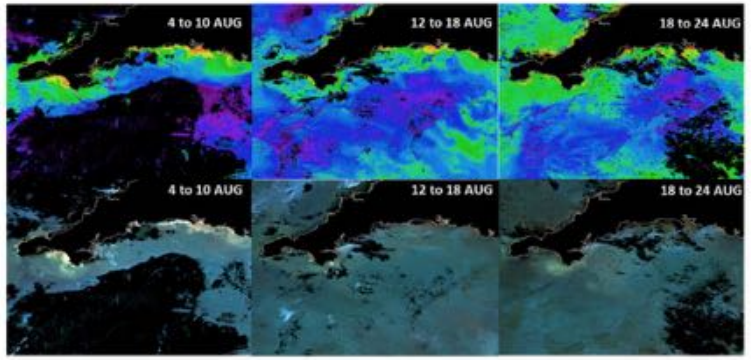
and https://cyanolakes.chpc.ac.za/

Examples of approaches: CyanoAlert

Examples of approaches: UK HAB bulletins and risk

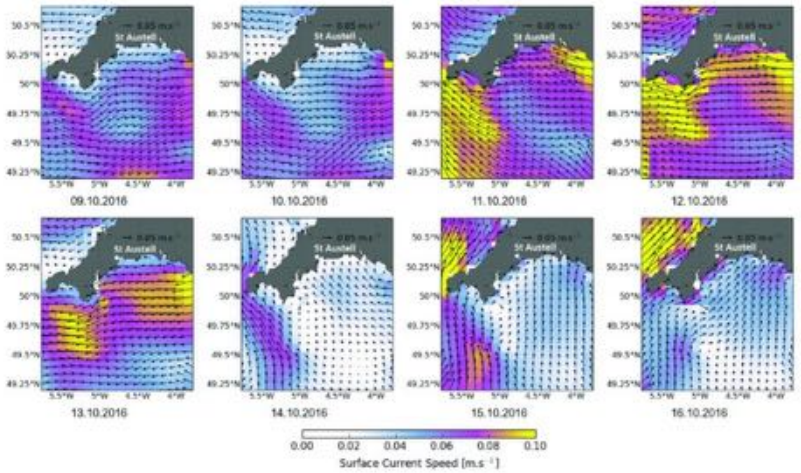


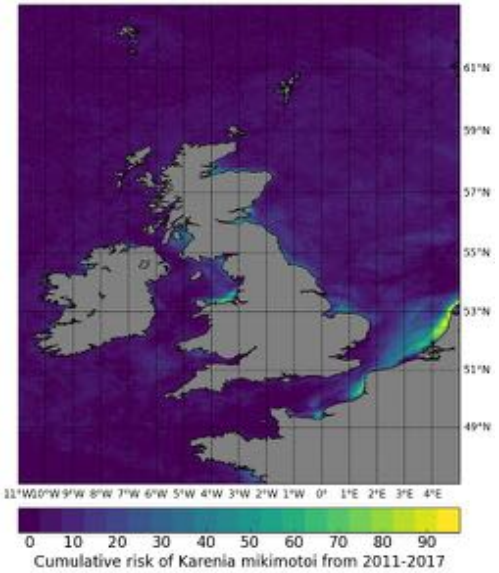
Temporal evolution of the bloom



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 for more information

HABs: Take home messages

- 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

References

- Smayda et al., (2003): 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
- 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
- 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

Further ways to explore HABs remote sensing concepts

- Exploring HABs from satellite ocean colour in SNAP: https://drive.google.com/drive/folders/1Ds2CGp5q1ylKcM2emoxxPSW2fMgzTQFn?usp=sharing
- EUMETSAT case study with accompanying Jupyter Notebook--->Open to cooperation to publish new case studies!! https://www.eumetsat.int/deoxygenation-impacts-marine-life-benguela
- Blooms in Europe and Africa:
  - https://user.eumetsat.int/resources/case-studies/viewing-algal-blooms-in-european-seas-during-summer-2024
  - https://user.eumetsat.int/resources/case-studies/south-african-algal-blooms
- IOCCG report https://ioccg.org/wp-content/uploads/2021/05/ioccg_report_20-habs-2021-web.pdf
- We are preparing two new Application User Guides that will be uploaded to the EUMESAT User portal early next year.
- https://user.eumetsat.int/data/themes/marine/water-quality

Hands-on 1:

Investigating cyanobacterial algal blooms in the Baltic Sea

Data used

Dataset	EUMETSAT collection ID	EUMETSAT collection description	WEkEO dataset ID	WEkEO description	Copernicus Marine Data Store product ID	Copernicus Marine product description
Sentinel-3 OLCI level-1b full resolution	EO:EUM:DAT:0409	Description	EO:EUM:DAT:SENTINEL-3:OL_1_EFR___	Description	-	-
Sentinel-3 OLCI level-2 full resolution	EO:EUM:DAT:0407	Description	EO:EUM:DAT:SENTINEL-3:OL_2_WFR___	Description	-	-
Baltic Sea Multiyear Ocean Colour Plankton, Reflectances and Transparency L3 daily observations	-	-	OCEANCOLOUR_BAL_BGC_L3_MY_009_133	Description	OCEANCOLOUR_BAL_BGC_L3_MY_009_133	Description

https://gitlab.eumetsat.int/eumetlab/oceans/ocean-training/applications/ocean-case-studies/-/blob/main/Case_studies/Water_quality/Algal_blooms/Algal_blooms_baltic_2023.ipynb

Thank you!

Questions are welcome.