Ocean Colour Remote Sensing
Technology Requirements for a Radiative Transfer Approach

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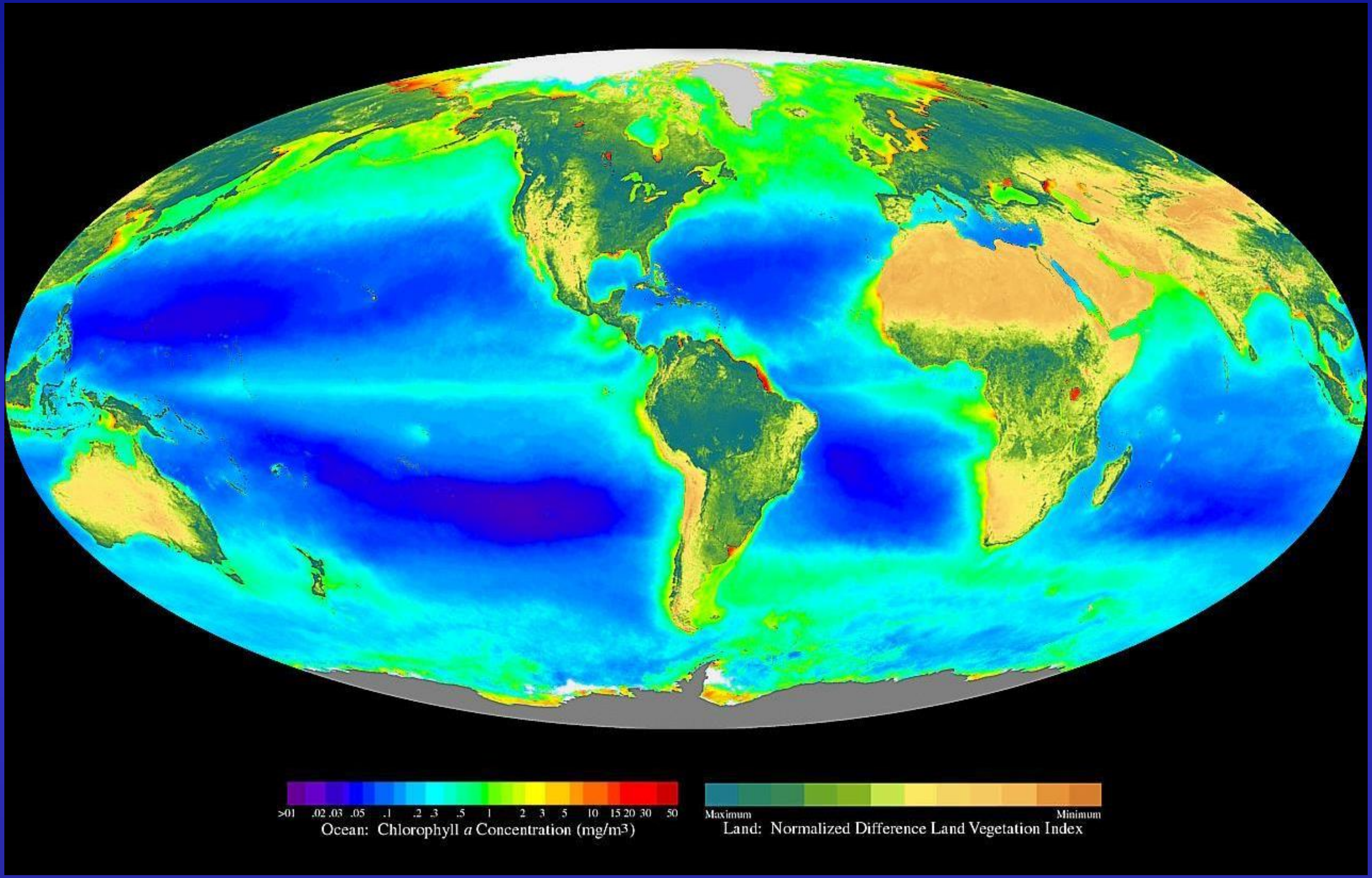
Ocean Colour Remote Sensing: Global Dynamics



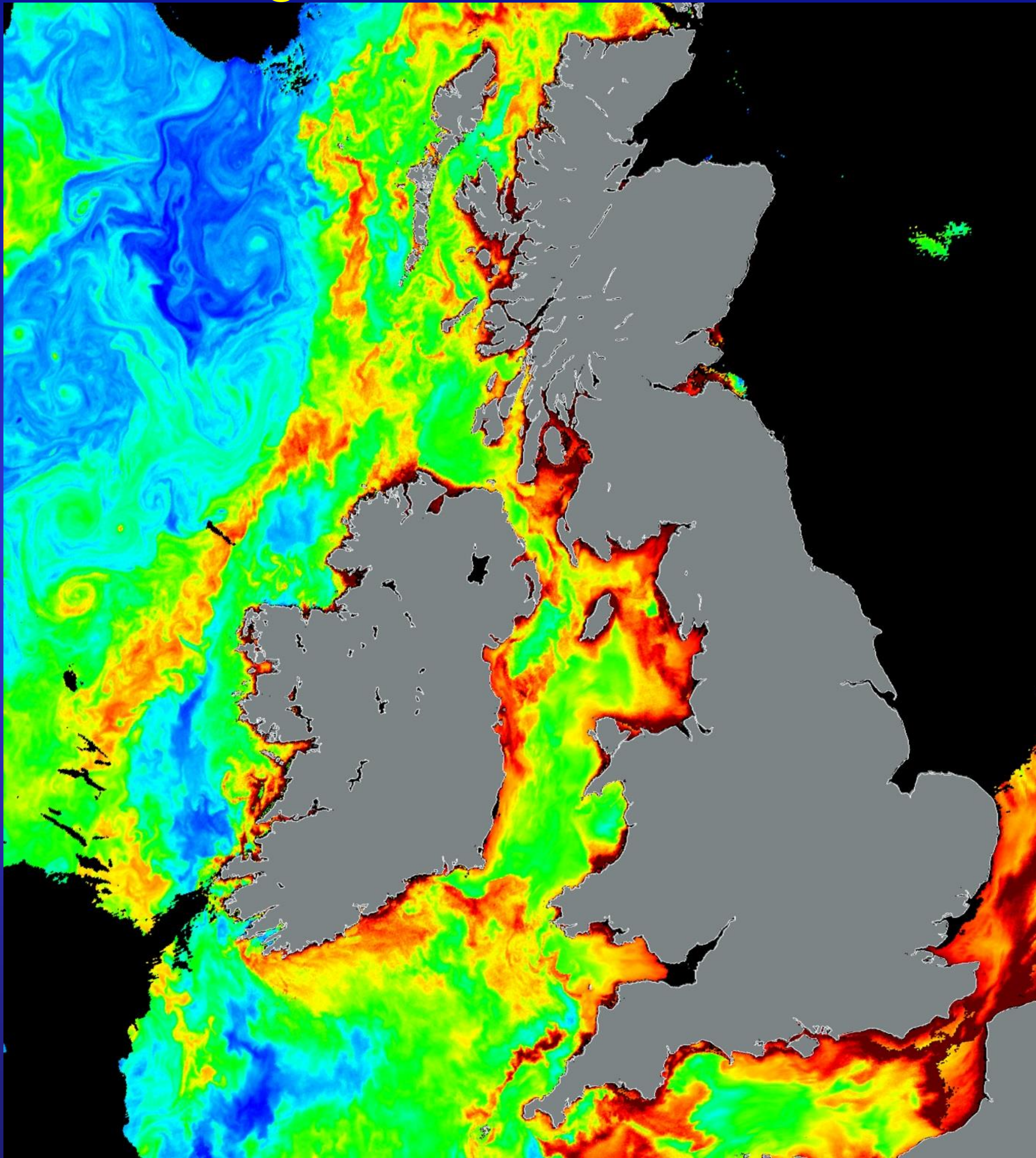
- Continuous daily global coverage since 1997 via multiple missions.
- Climate relevant data set – Essential Global Climate Variable.
- Uniquely sensitive to biological materials in surface layer of ocean.
- Also sensitive to sediment and dissolved organics in coastal waters.

Ocean Colour Remote Sensing: Products

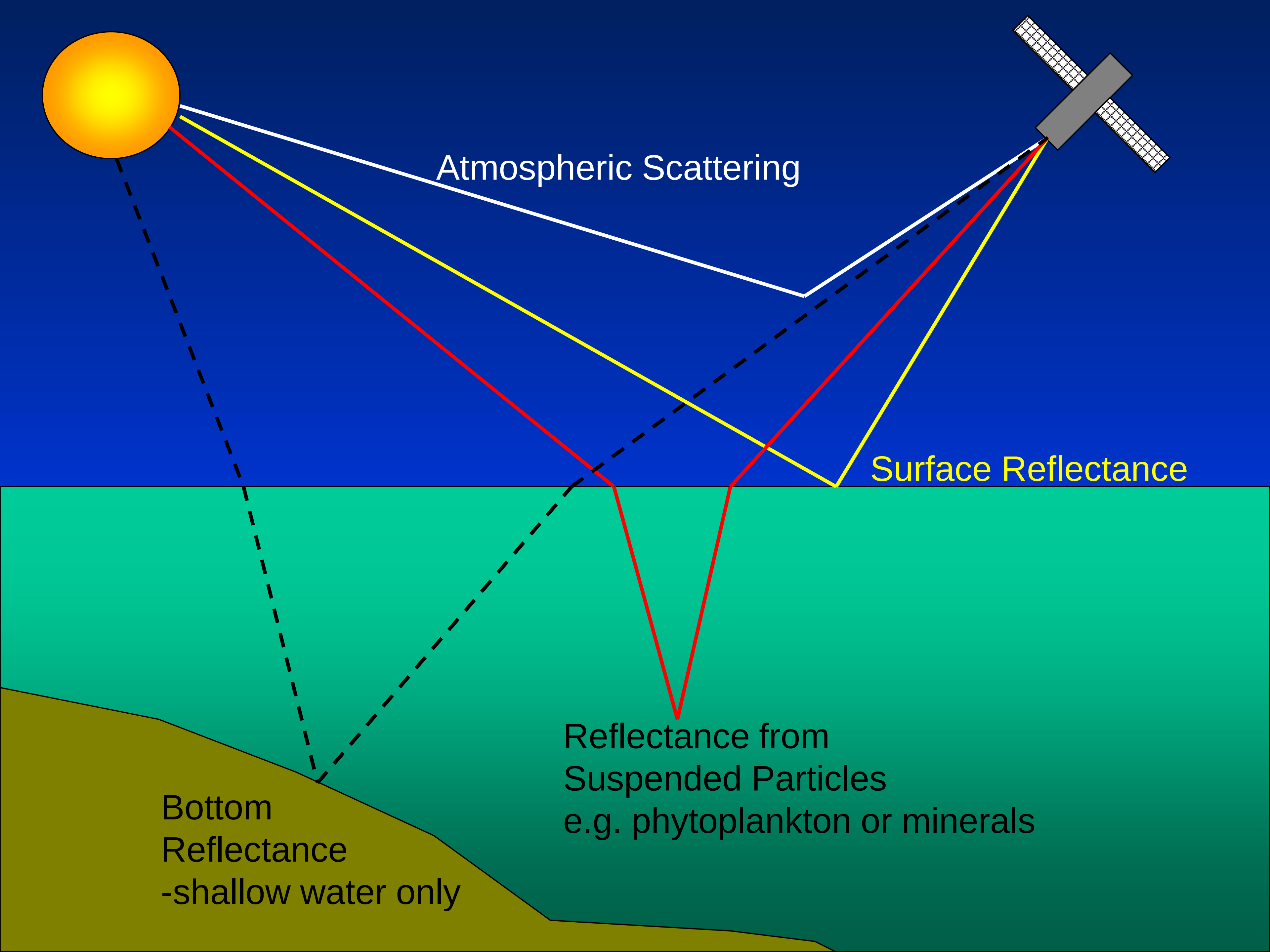
High level products derived from reflectance data using variety of numerical methods.

Products include:

Chlorophyll
Turbidity (sediment)
Attenuation
Optical properties
Sea surface temperature
Euphotic depth…

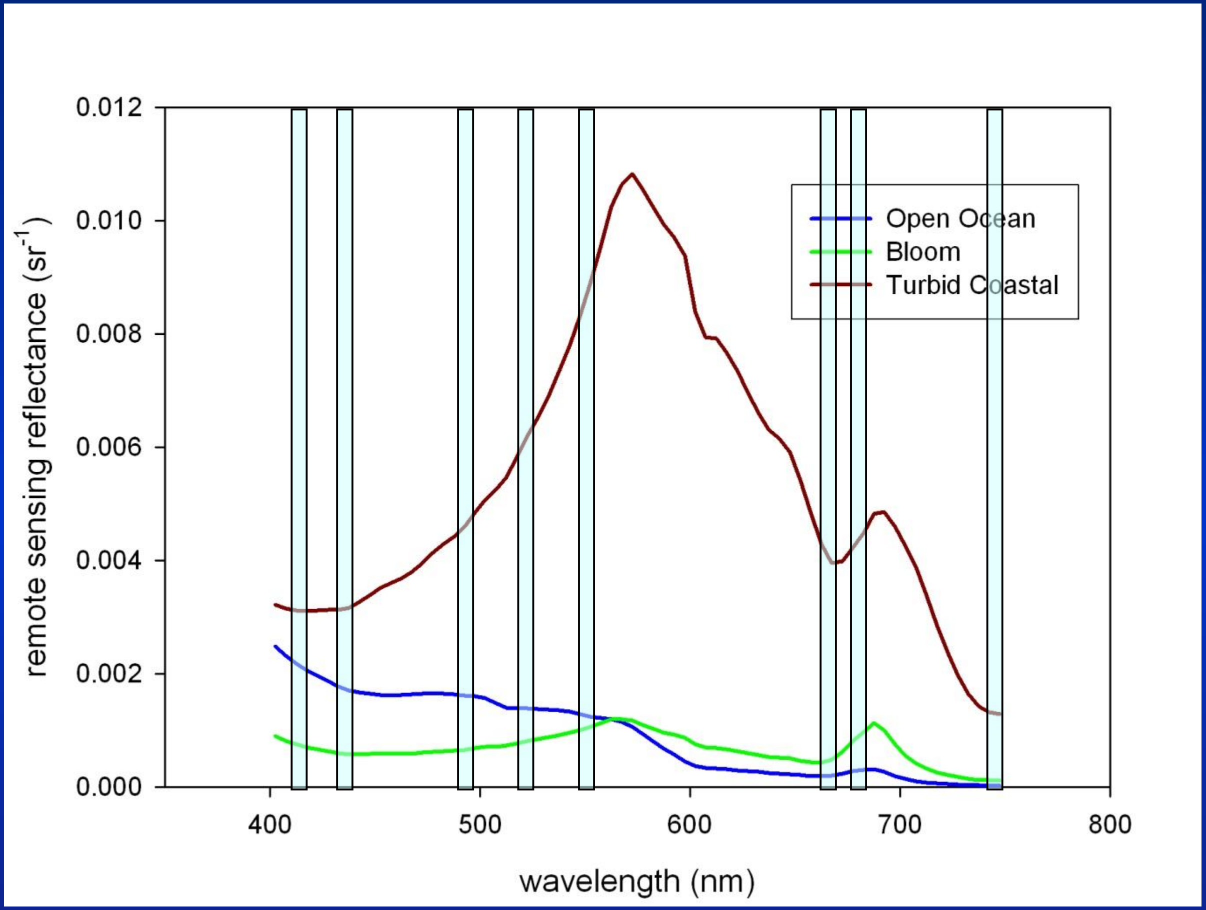


Ocean colour remote sensing: background



Atmospheric Scattering
Surface Reflectance
Reflectance from
Suspended Particles
e.g. phytoplankton or minerals
Bottom
Reflectance
-shallow water only

Ocean Colour Remote Sensing: Reflectance Spectra



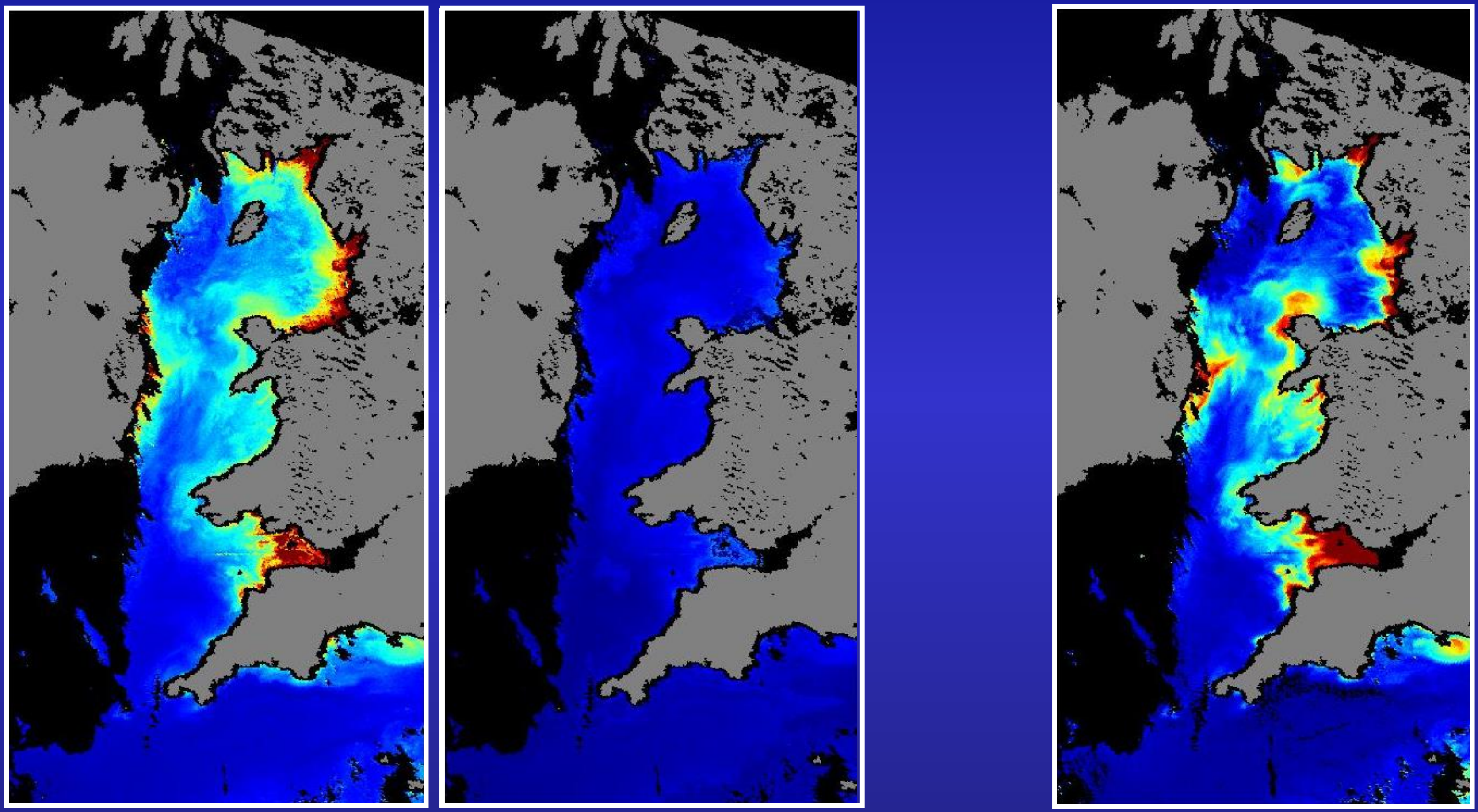
MODIS wavebands

Water colour depends on concentration of optically active constituents: water, phytoplankton (algae), dissolved organics, minerals (sediment)

Ocean colour products *derived* from atmosphere-corrected reflectance signals

Ocean Colour Remote Sensing: Algorithm Development and Validation

Chlorophyll a (mg m^{-3})   Mineral Suspended Solids (mg l^{-1})



NASA Algorithm   Tuned Algorithm   New Algorithm

Standard chlorophyll algorithm performs poorly in coastal waters in January due to resuspended sediment linked to winter mixing.

McKee et al. Estuarine, Coastal and Shelf Sci. 73: 827-834, 2007.

Algorithm development:
a radiative transfer approach

Algorithm development: radiative transfer approach

Use radiative transfer model to simulate water leaving reflectance spectra.

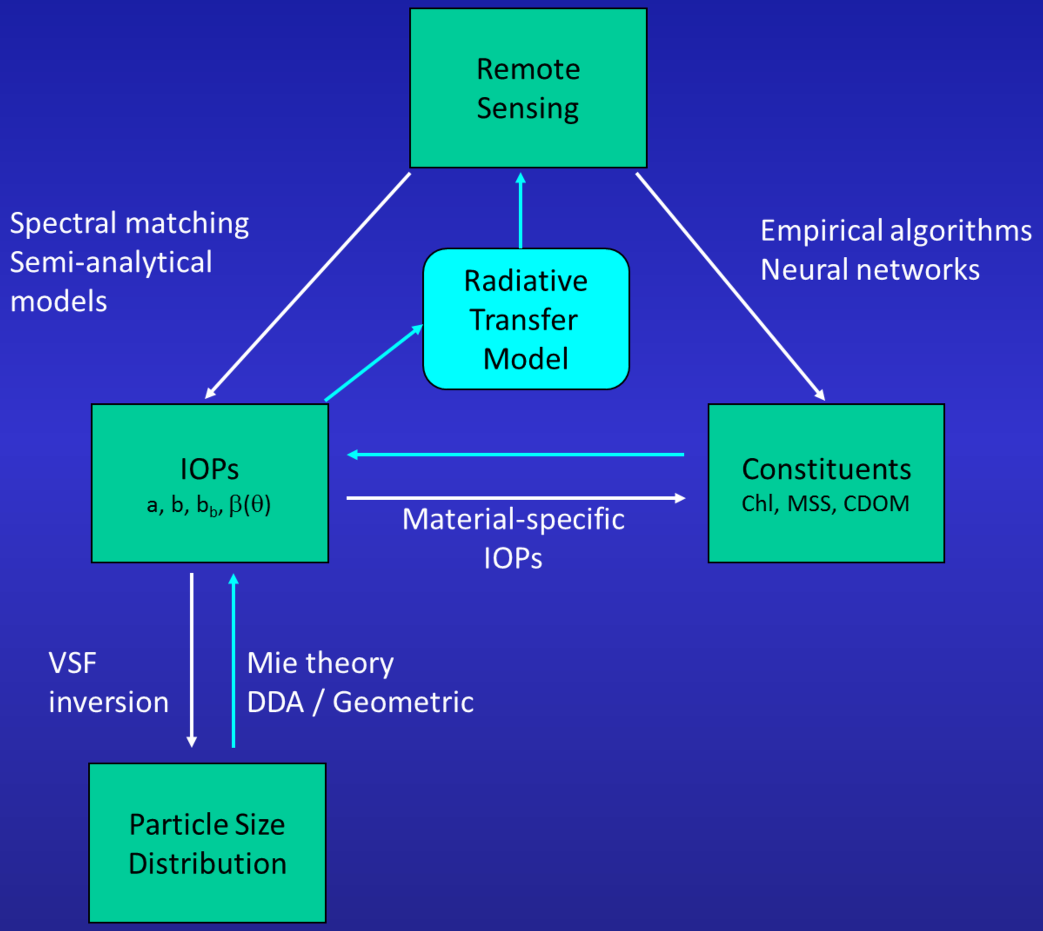
Requires knowledge of Inherent Optical Properties:

absorption	a
scattering	b
backscattering	b_b
VSF	$\beta(\theta)$

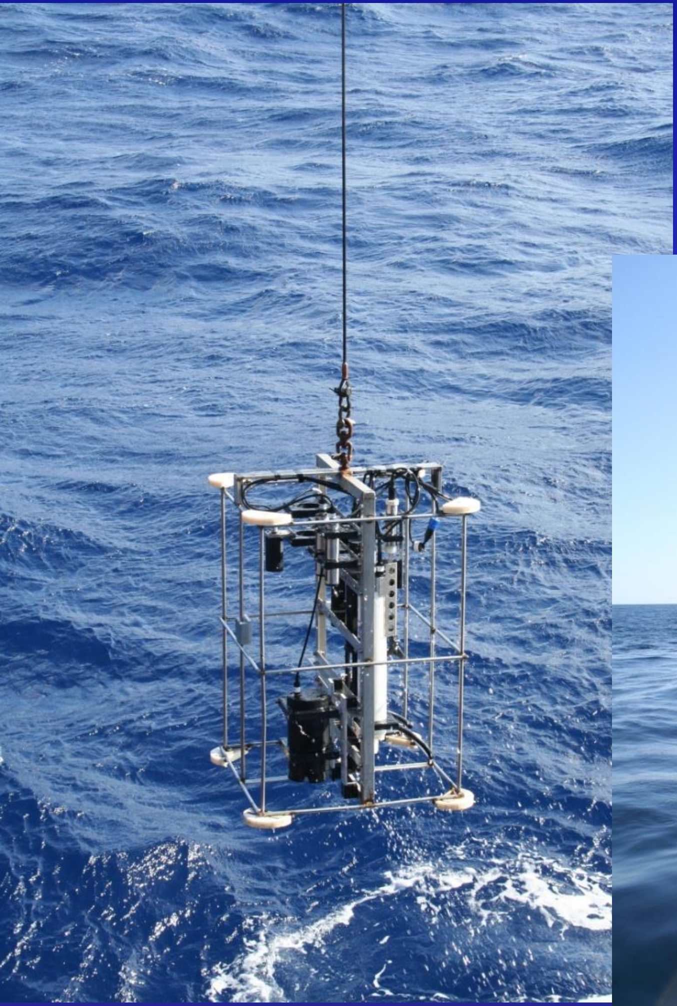
Can model wide variety of concentration combinations.

Systematic exploration of parameter space.

Test range of algorithms…

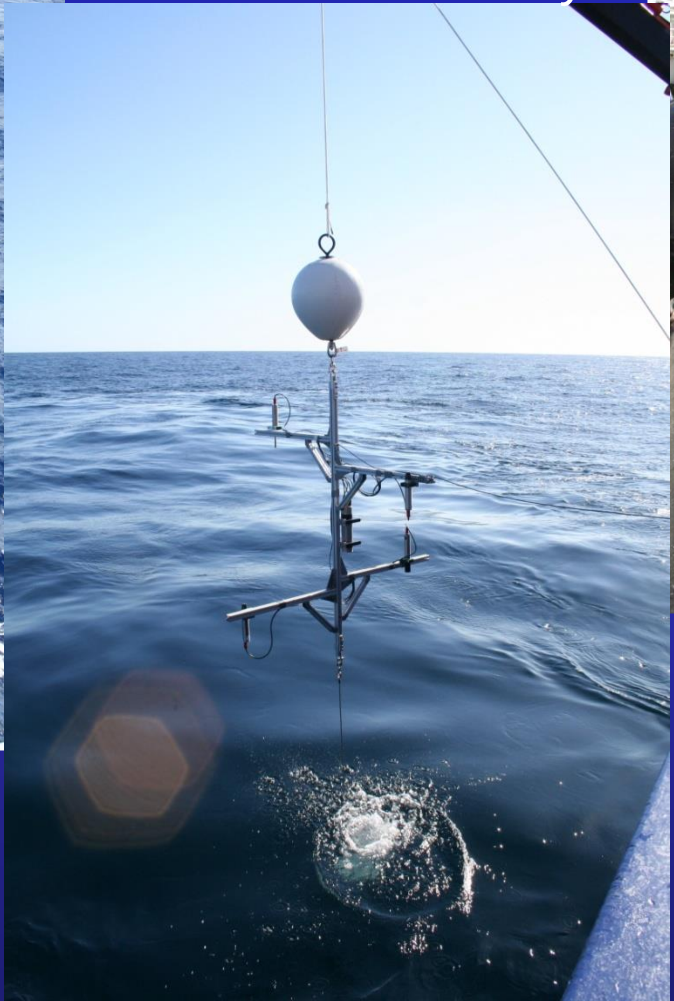


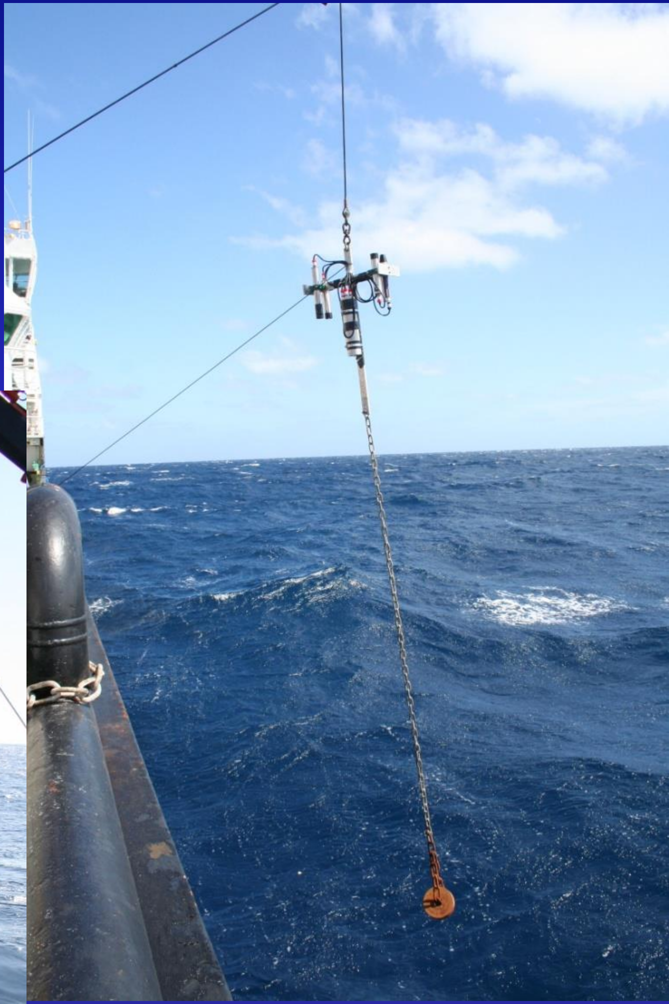
In Situ Optical Measurements



IOP Profiles

Surface Radiometry

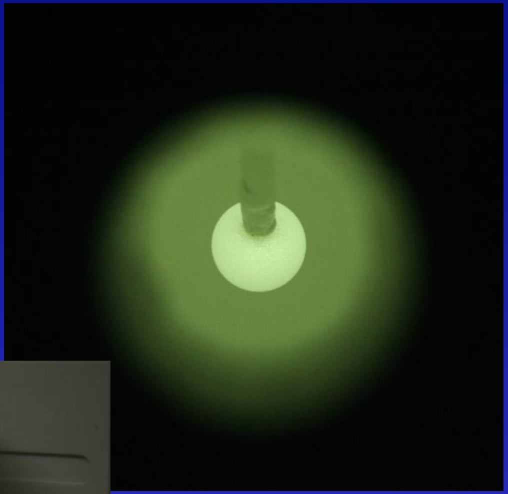


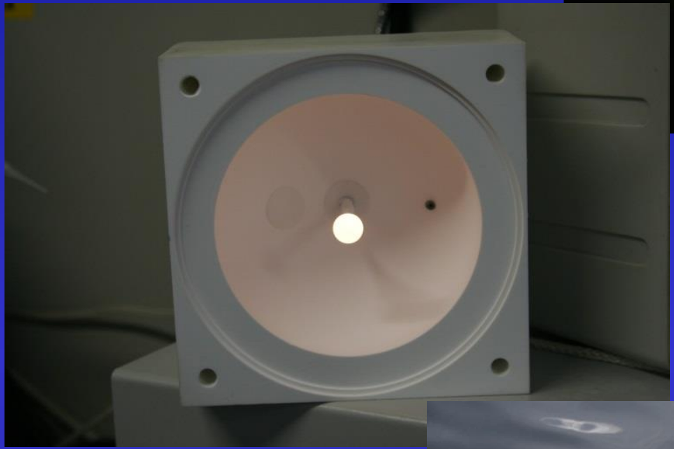


Radiometry Profiles

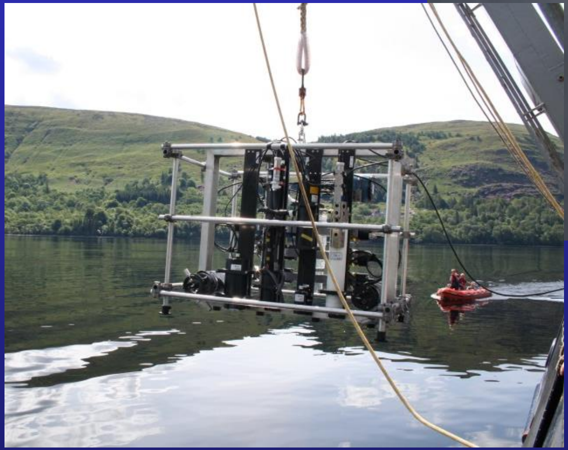
Inherent Optical Properties: New Solutions and New Technology

- Radiative transfer approach demands accurate IOPs.
- Developing new corrections for existing instrumentation e.g. WETLabs ac-9.
- Working with international partners to further develop PSICAM technology.
- Exploiting innovations in quantum optics to develop new transmissometery solution.





PSICAM with HZG, Germany



In situ IOPs and sampling

Algorithm development: radiative transfer approach

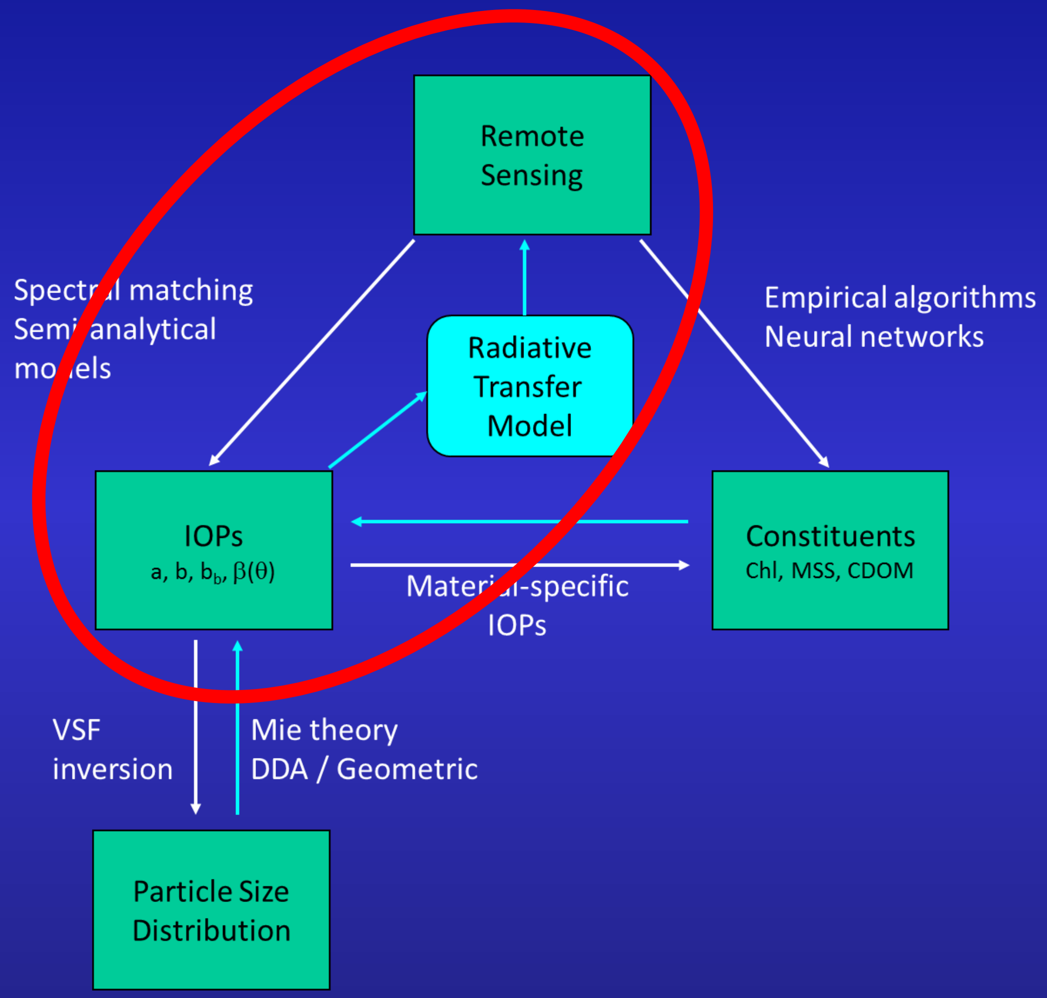
Data quality is critical.

IOP measurements are ALL subject to significant, systematic errors.

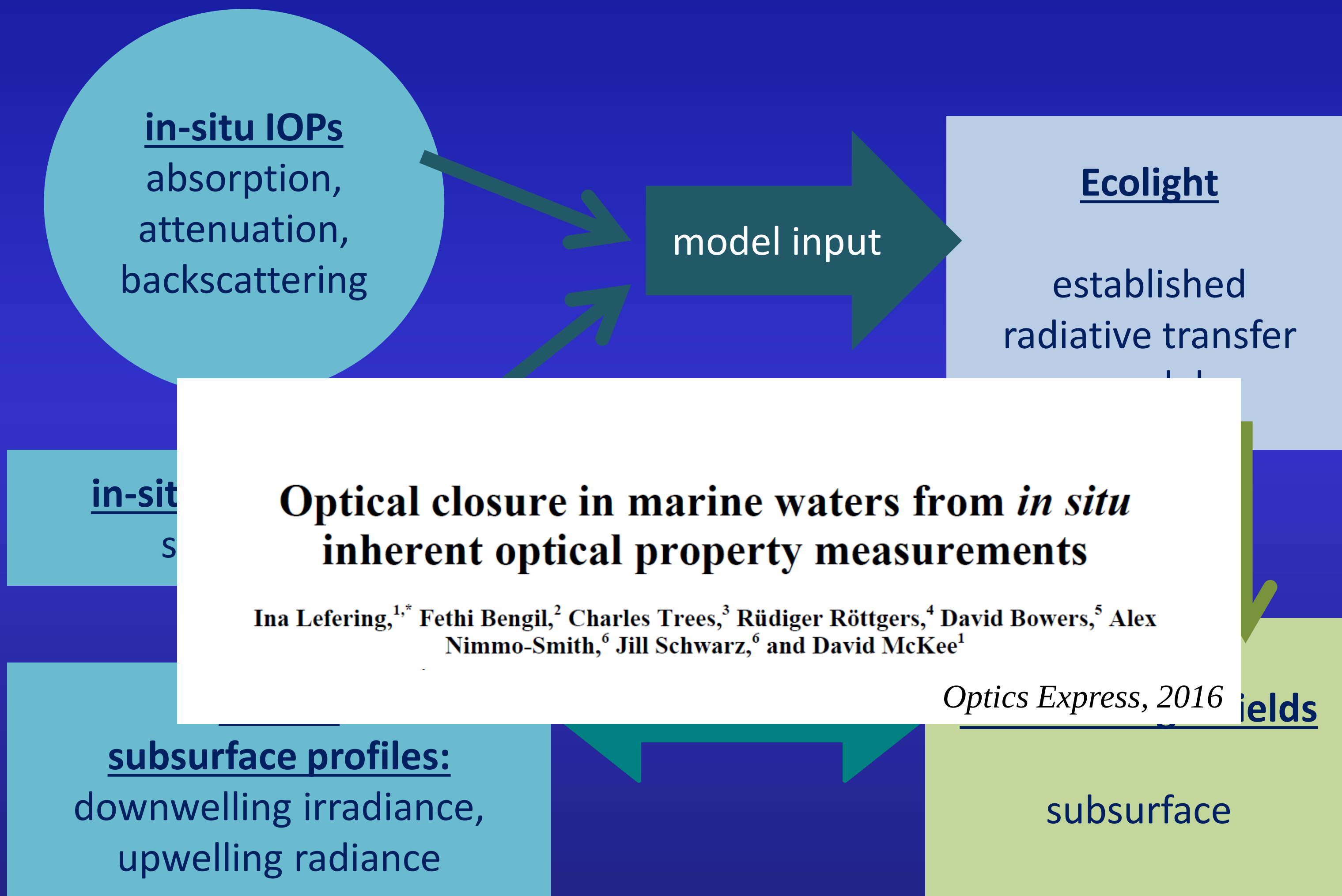
Need to establish ability to achieve optical closure between modelled and measured radiometry.

Going to compare modelled radiometry with in situ measurements.

Using Ecolight RT simulations.



Optical closure



Field work - sampling

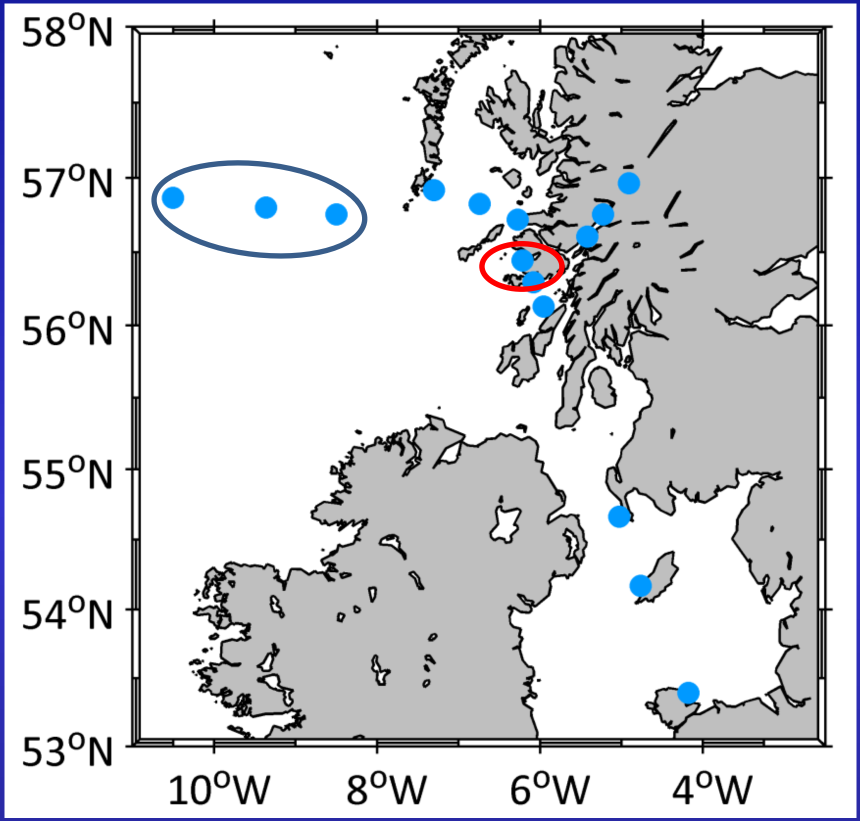
- Data collected June 2012
- Optically different water types

  mainly case 2 coastal waters,

  some clear blue stations

  and a coccolithophore bloom

- Collecting state of the art IOPs
- Testing new scattering correction approaches



Modelled light field parameters

2 products derived from underwater radiometric measurements:

Radiance reflectance, R_L

- proxy for remote sensing reflectance
- at first measured depth, z_{min}
- strong spectral signal

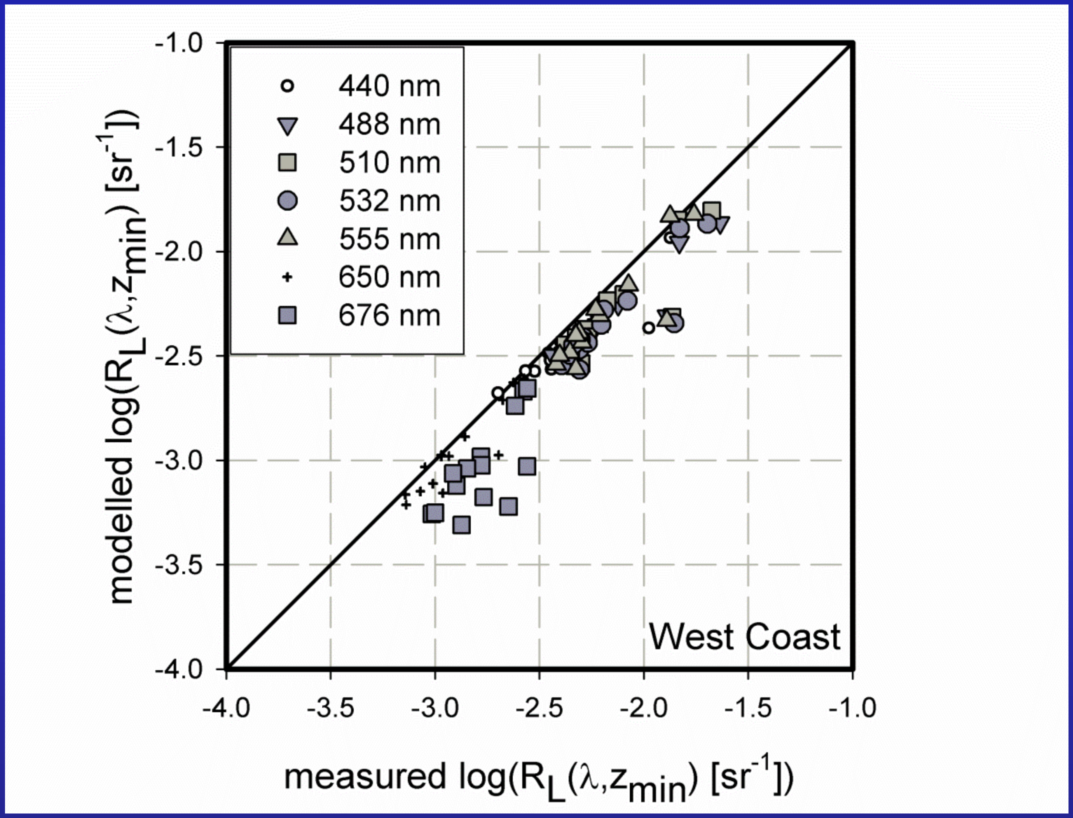
$$R_L(\lambda, z_{min}) = \frac{L_u(\lambda, z_{min})}{E_d(\lambda, z_{min})}$$

Photosynthetically available radiation (PAR)

- input for primary production and ecosystem models
- depth profiles
- less sensitive to wavelength artefacts

$$PAR = \sum_{400}^{700} (E_d(\lambda)\Delta\lambda)$$

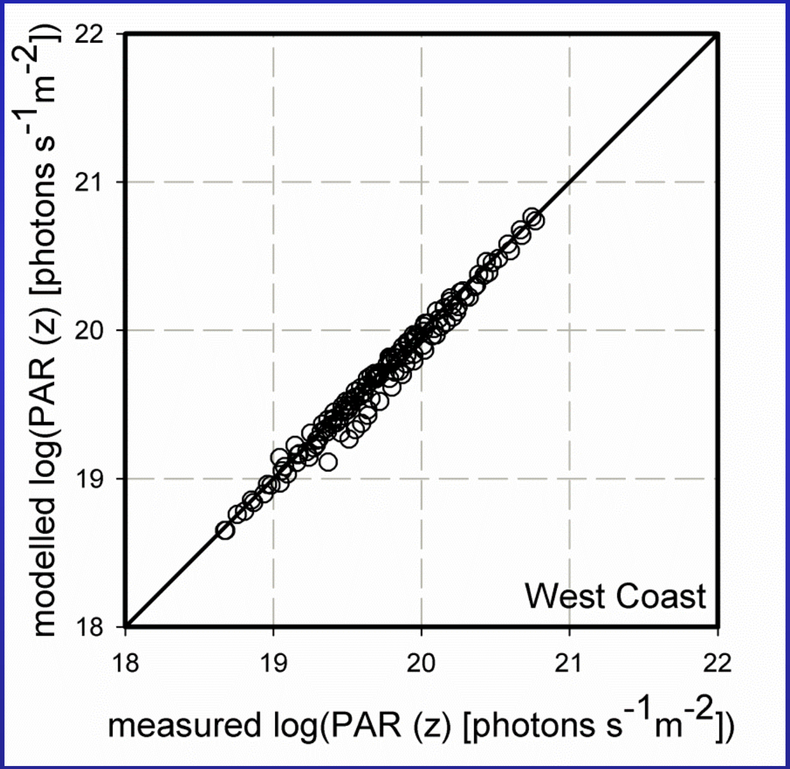
Remote sensing products



- Modelled and measured radiance reflectance RMSE 24%
- Model tends to underestimate R_L
- Potential limitations for assimilation / validation schemes for remote sensing and physical-ecosystem models

Photosynthetically Available Radiation, PAR

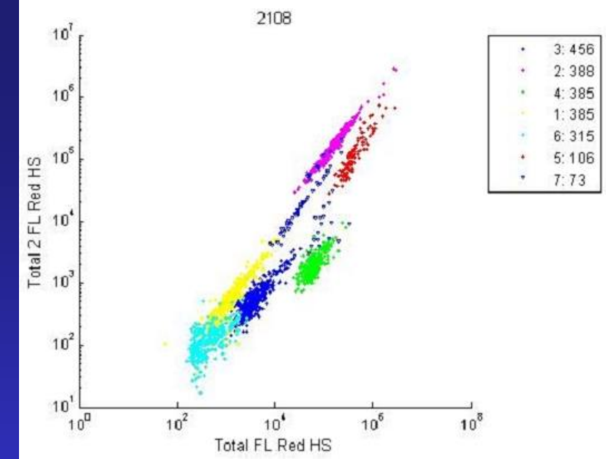
- strong correlation between measured and modelled PAR (max. measured depth = 30 m)
- low spread RMS%E = 15%
- deviation from 1:1 naturally increases with depth
- very encouraging for coupled bio-optical ecosystem modelling

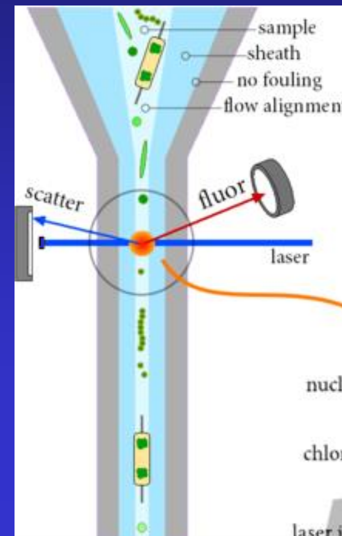


In situ IOP data quality

- Good (?) level of optical closure observed for in situ profiles / most stations.
- Limited closure with surface reflectance might be boundary conditions e.g. surface structures.
- Poor quality closure in coccolithophore bloom and more turbid waters points to continuing issues with backscattering / VSF data.
- Backscattering / spectral VSF technology probably currently limiting factors.
- Also need to consider uncertainties in the radiometry data.

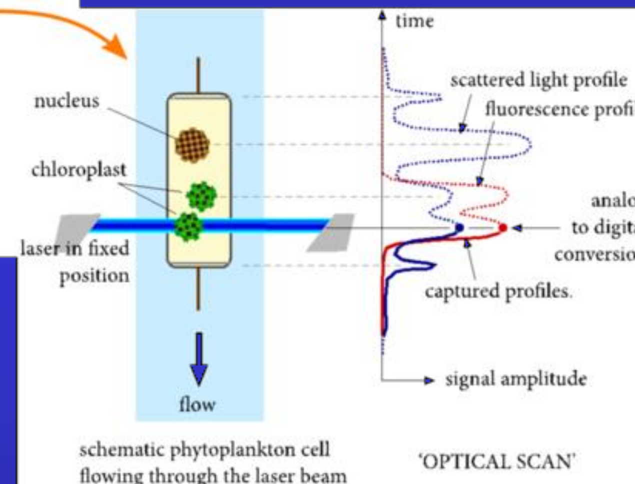
Future Directions:
In Situ Flow Cytometry

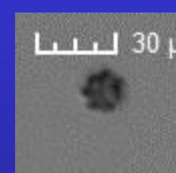


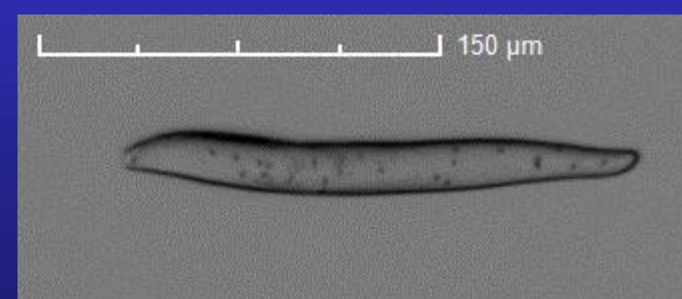


Cytosub submersible flow cytometer.

- Includes imaging capability.
- Particle characterisation (ref index).
- Particle size distribution (wide range).
- Link to IOPs via optical modelling.
- Taxonomic classification.

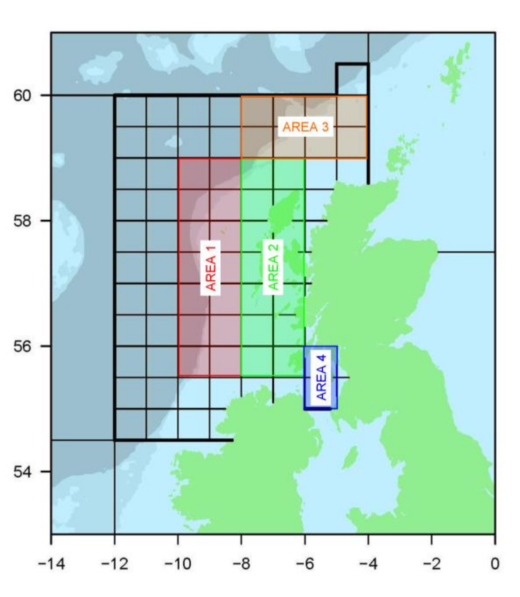


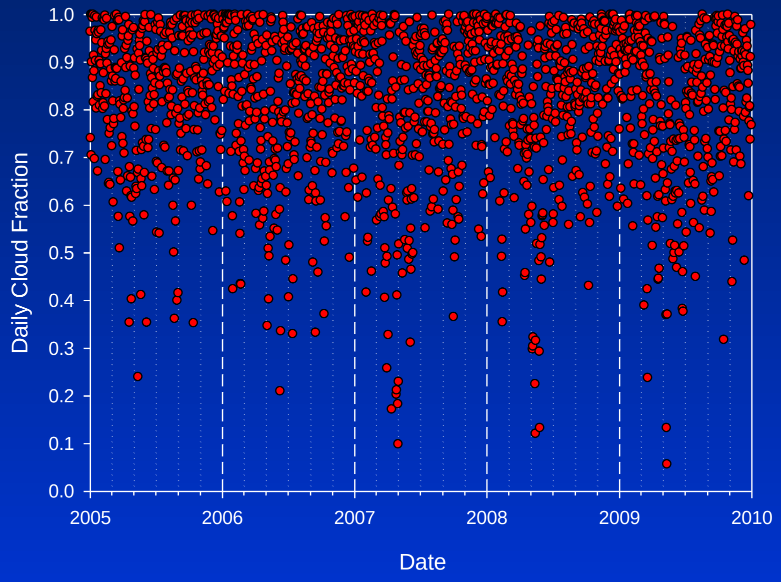




Ocean colour : other limiting factors…

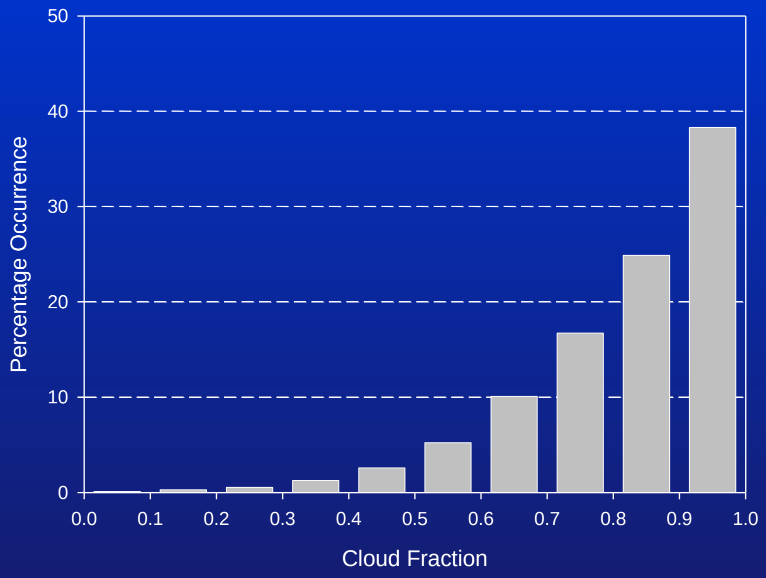
OCRS Limitations: West Coast Cloud Cover





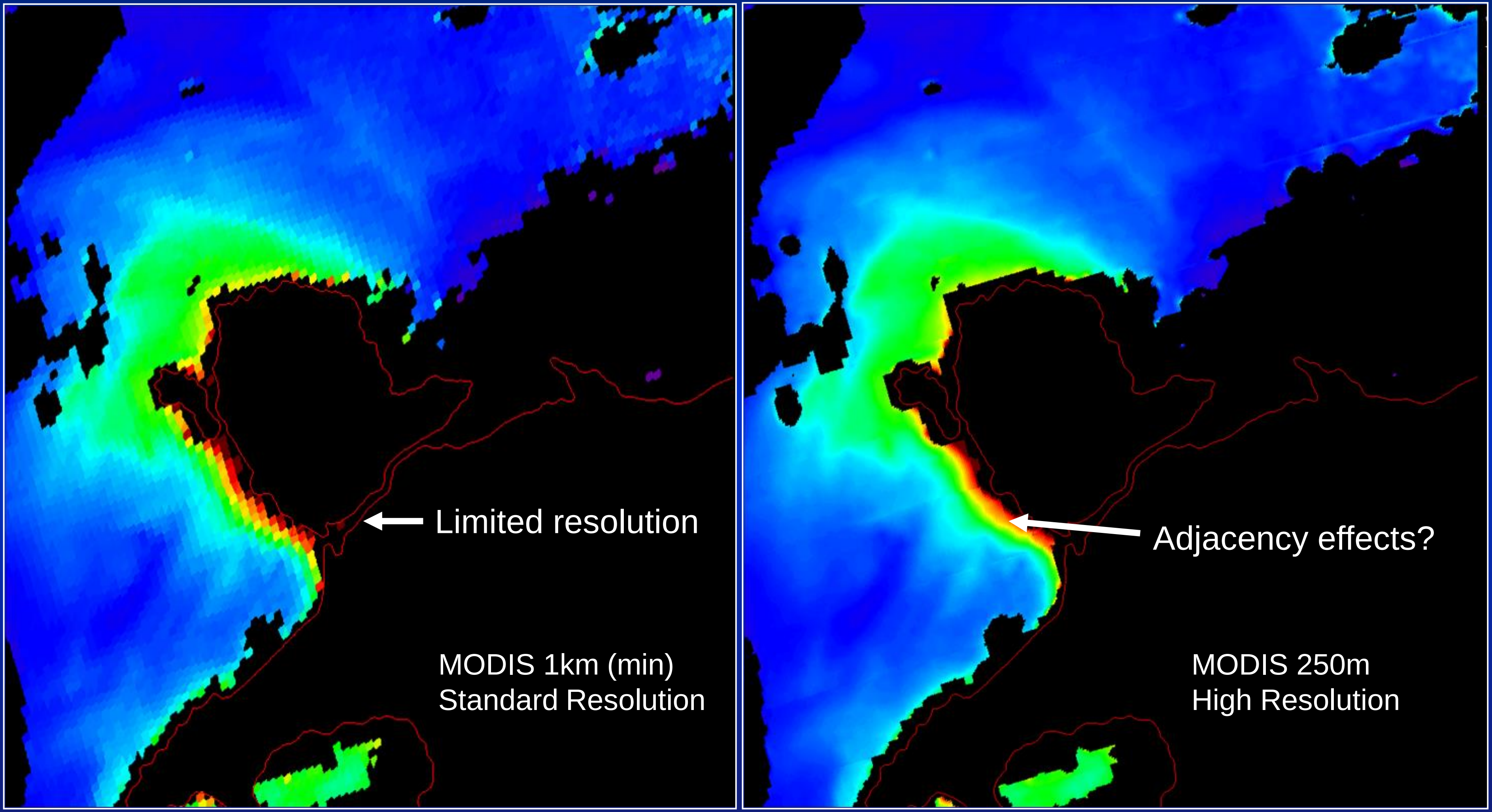
Cloud Cover:

NE Atlantic – more than 50% cloud cover in 95% of passes



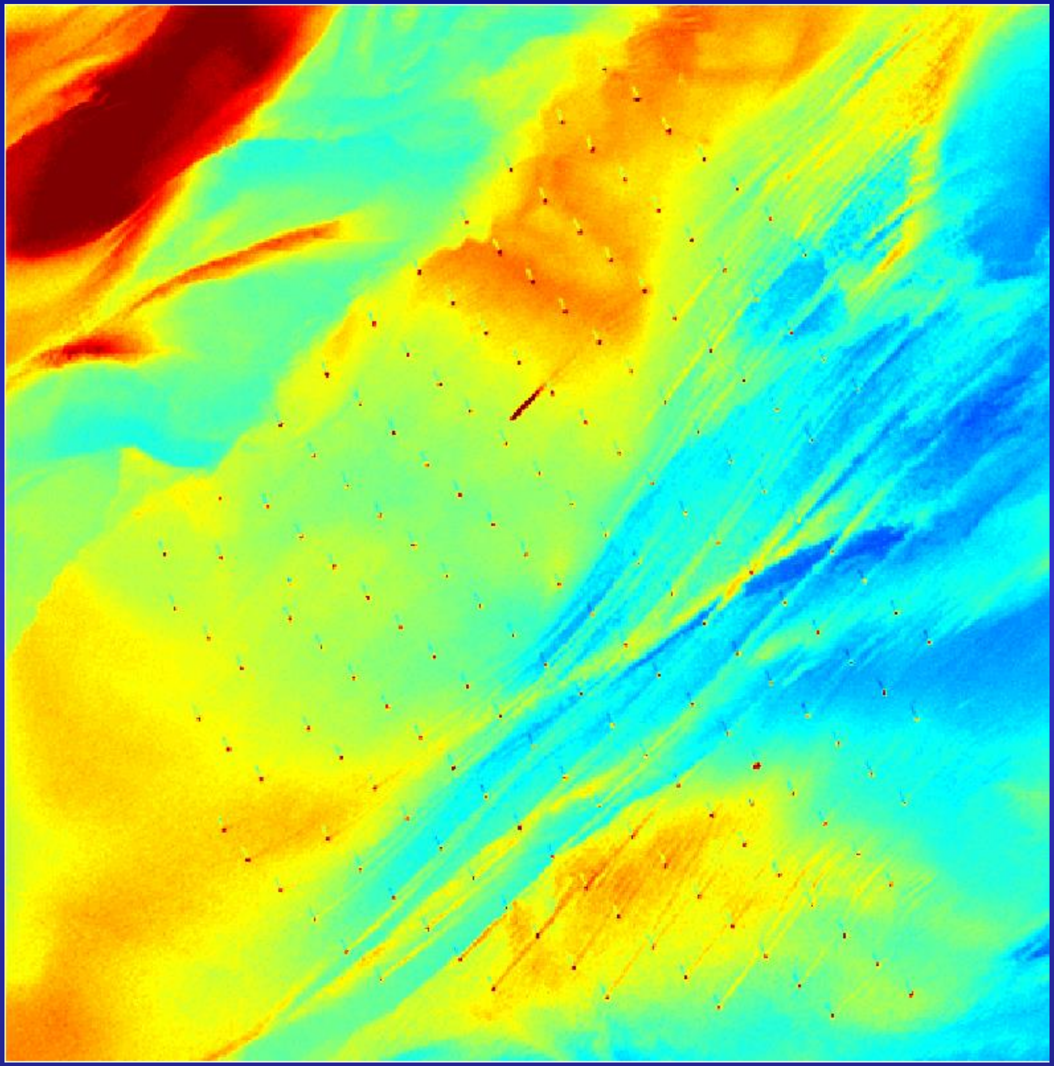
Bailey et al. (2011) The West of Scotland Marine Ecosystem: A Review of Scientific Knowledge

Spatial Resolution and Adjacency Effects



Recent and emerging developments

Landsat 8: High Resolution Imagery

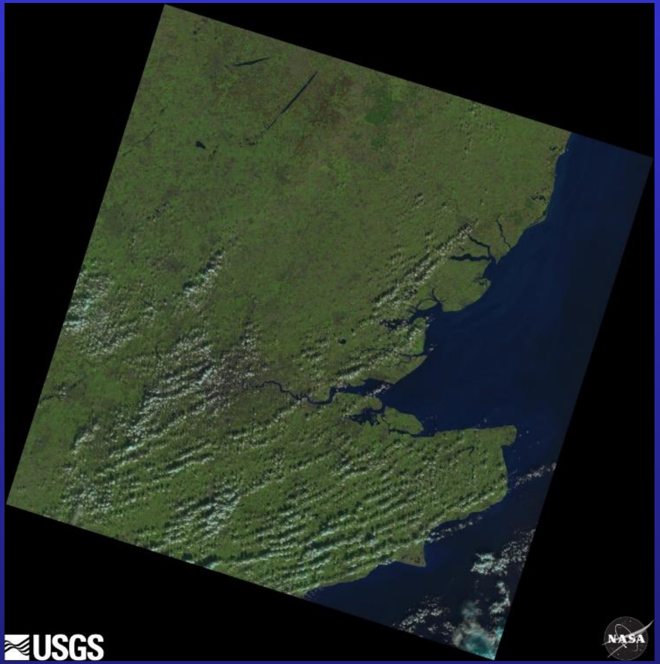


Turbid Plumes from London Array wind farm turbine pilings

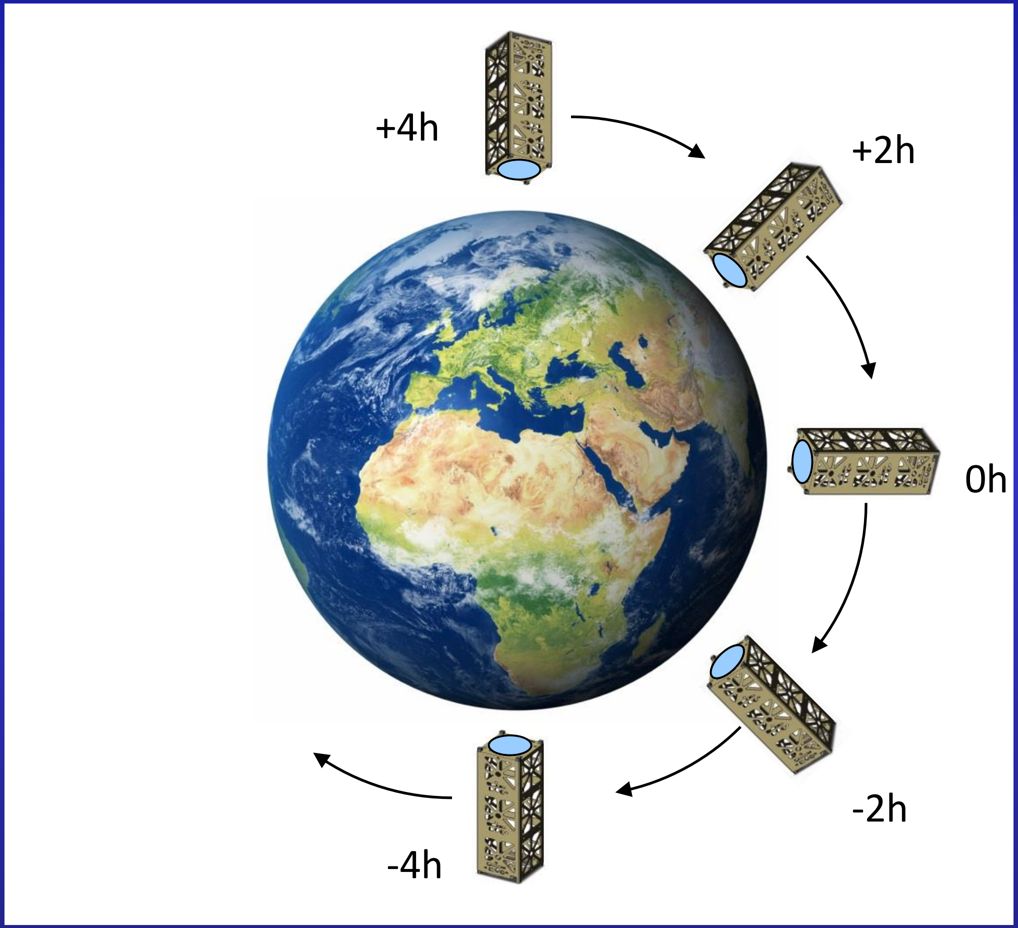
Landsat 8 provides useful spectral information at very high spatial resolution.

BUT repeat visit frequency is very low (16 days).

Limited use for operational monitoring.



Ocean Colour Remote Sensing: CubeSats



Increase repeat frequency using constellation of small, cheap EO CubeSats.

Sensors tailored to user requirements.

Launch costs vastly reduced.

SeaHawk sensor being developed by GSFC / Clyde Space team.

New imaging technologies being developed e.g. single pixel cameras.

Conclusions

- Data quality essential – performance of standard algorithms in optically complex coastal waters often limited.
- Need to understand current data quality limits and impact on model performance.
- Development of new sensing platforms e.g. remotely piloted aircraft, CubeSats will transform operational applications.
- Data validation for European shelf waters requires substantial further effort.
- Ocean colour remote sensing has potential to support important industries: marine renewables, aquaculture, fishing…
- Support for policymakers and demonstrating compliance with environmental legislation.

Thanks!

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http://bcp.phys.strath.ac.uk/marine/