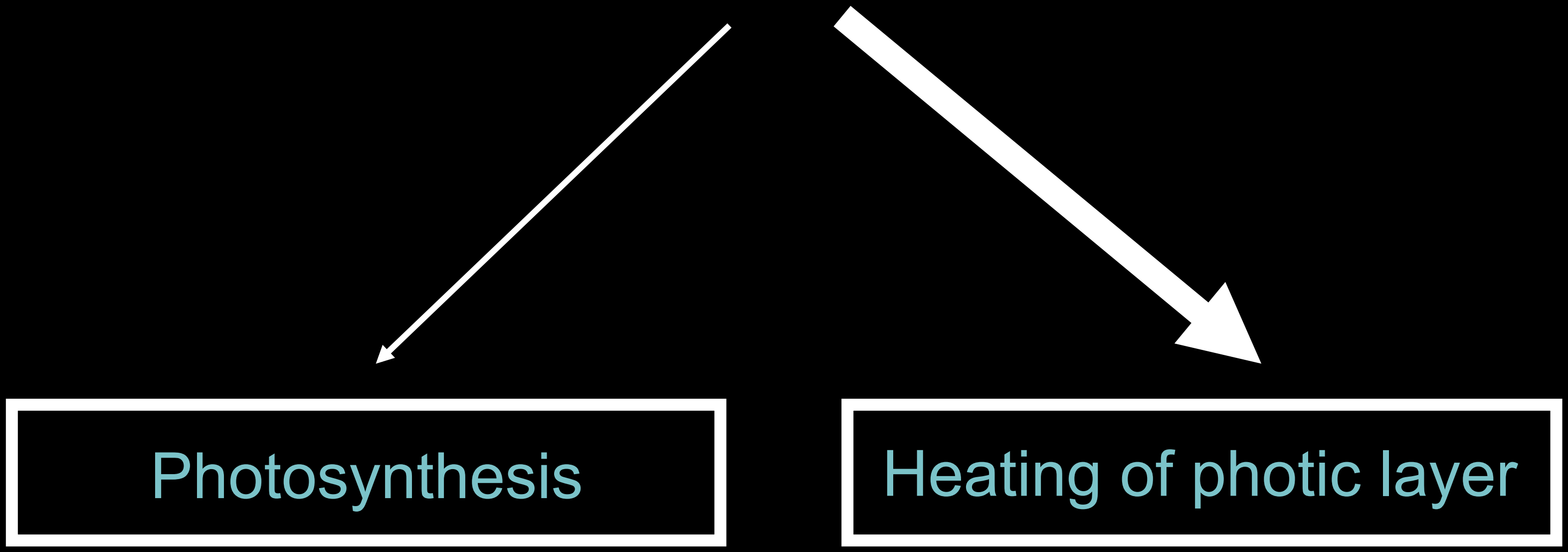
TIE-OHF and Ocean Colour: Final Meeting December 2017

Shubha Sathyendranth
Hayley Evers-King, Trevor Platt
Diane Knapett, Stephane Saux-Picart + OHF Team

Principal Fate of Light Absorbed by Phytoplankton

Thermal dissipation is the principal fate of energy absorbed by pigments, with a corresponding effect on the heat budget of ocean's upper layer

Dual Role for Light absorbed by Phytoplankton

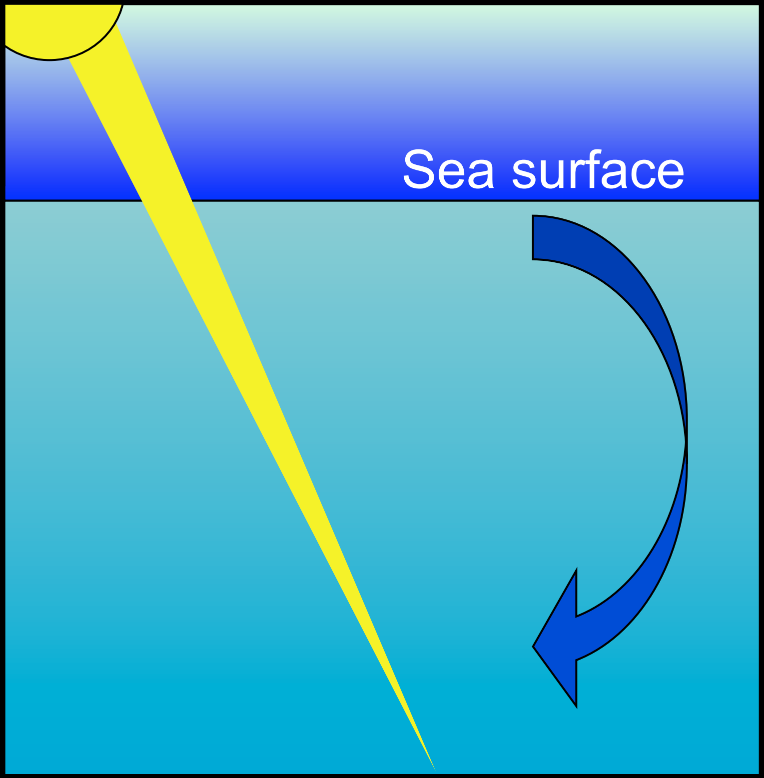


Photosynthesis

Heating of photic layer

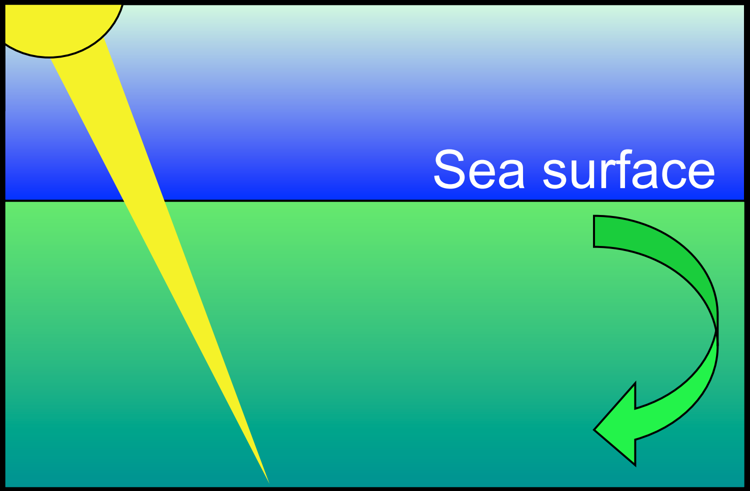
Diffuse attenuation coefficient *K* and mixed-layer depth

Low *K*



Deep photic layer
Favours deep mixed layer

High *K*



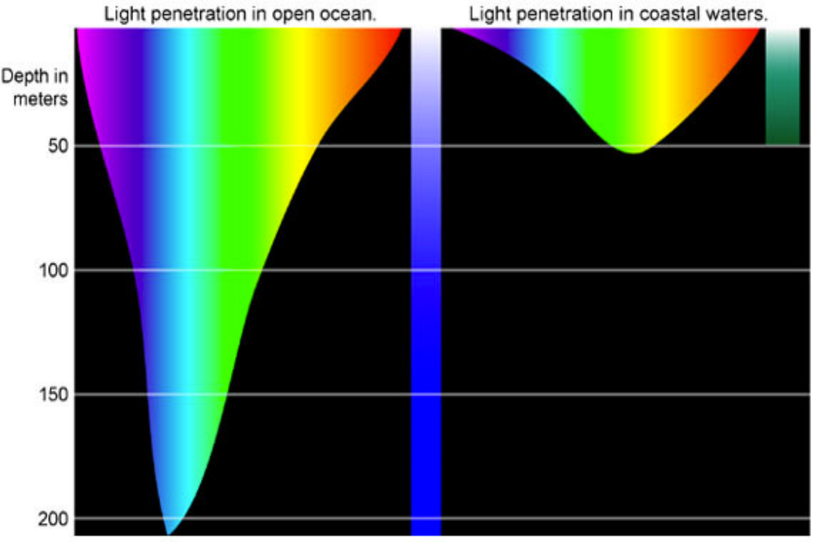
Shallow photic layer
Favours shallow mixed layer

Role of ocean colour in ocean heat budget and radiant fluxes

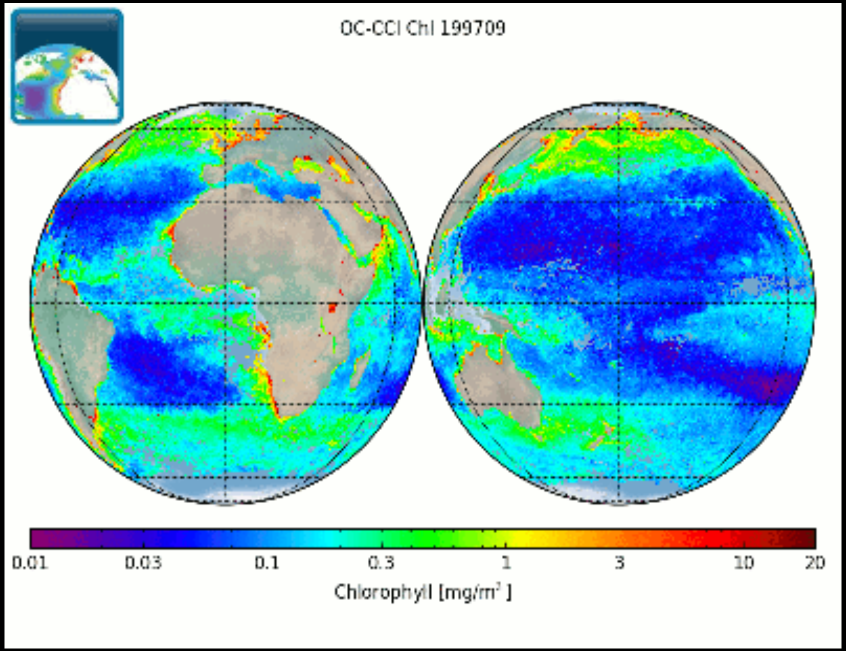
Attenuation is spectrally-dependent, according to the optical properties of substances present. In the open ocean, chlorophyll-a can be used to compute spectral light transmission.

We can use satellite-derived ocean-colour data e.g., OC-CCI for the computations.

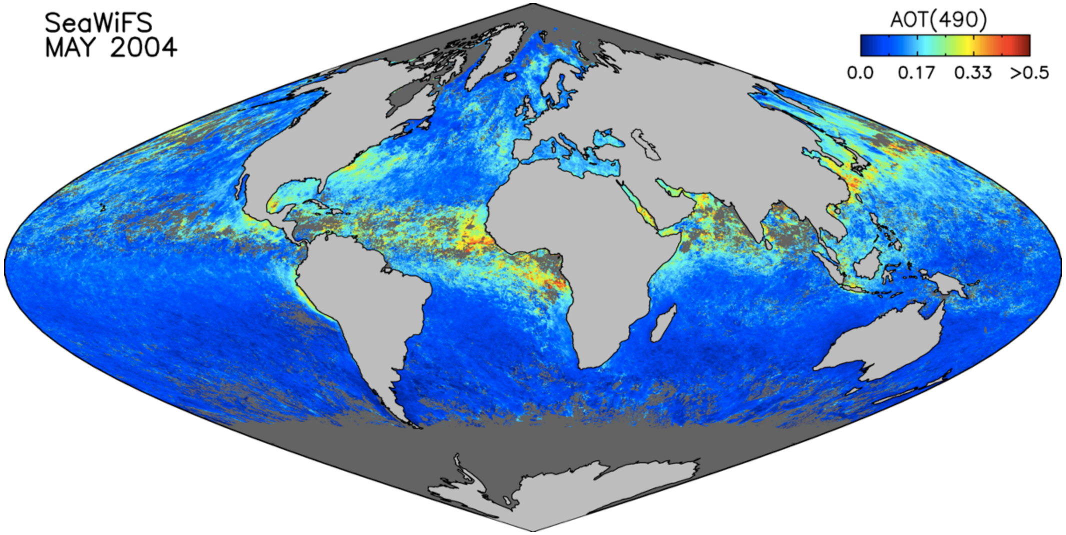
Chl-a 0.01 mg m^{-3} Chl-a 10 mg m^{-3}



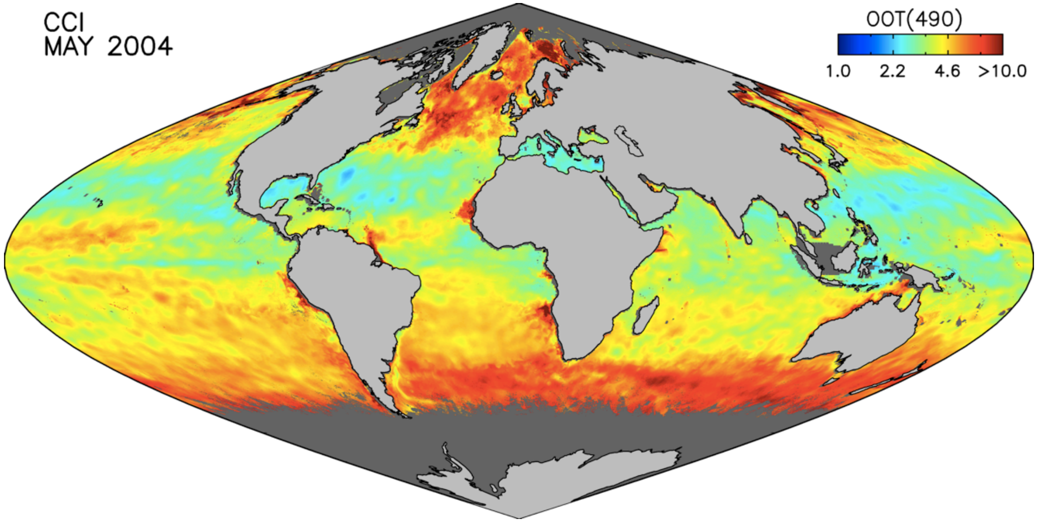
Light turns progerssively green at depth in the ocean, when Chl-a concentration increases.



Is the variability in optical thickness significant?



Aerosol Optical Thickness at 490 nm



Ocean Optical thickness at 490 nm for the mixed layer

Outline of Talk

1. Sensitivity – Turbulence Closure Model (GOTM)
2. Implementation using OC-CCI data
3. Future Directions

Sensitivity Analyses

Calculate irradiance attenuation profiles
Dependence on Chl-a
Dependence on sun zenith angle
Dependence on wavelength

↓

Fit exponential function to modelled irradiance profile

↓

Input attenuation coefficient to GOTM

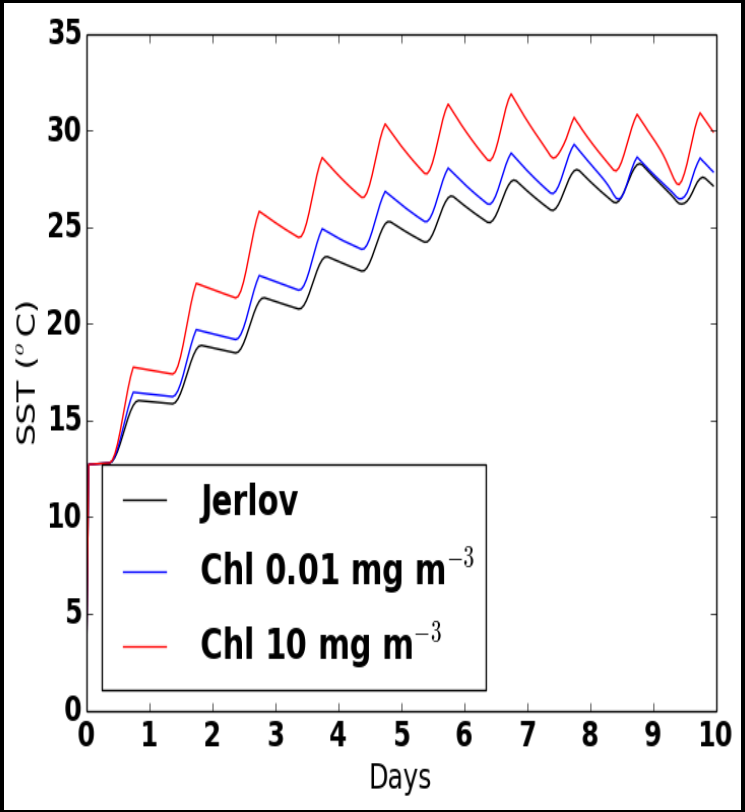
↓

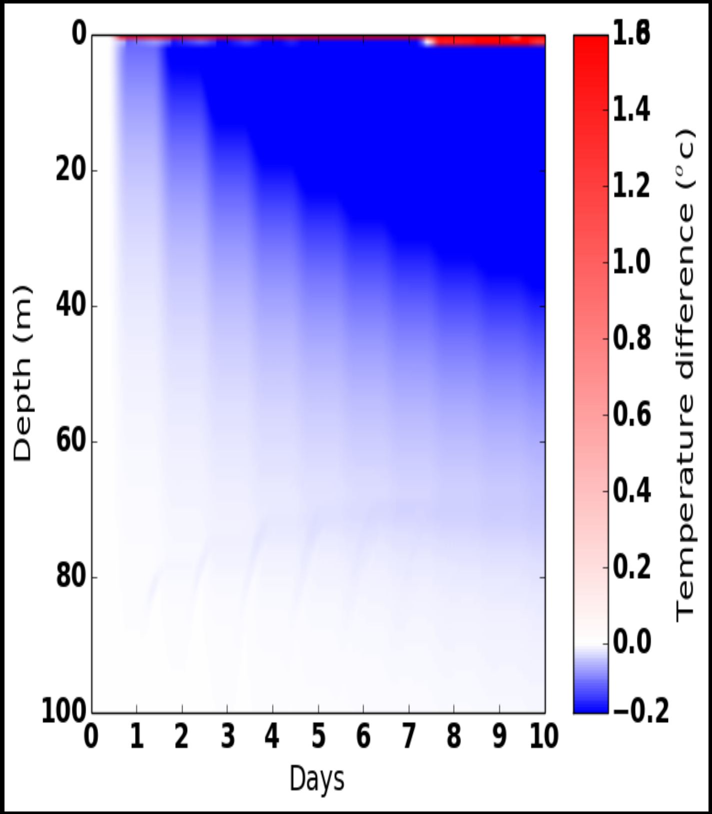
Sensitivity of SST and heat flux

1. Atmosphere-ocean optical model (350:700 nm):
    a. Based on Sathyendranath and Platt (1988), but
    b. Extended into the UV (400 – 350 nm)
    c. Updated phytoplankton components from Brewin et al. (2014).
    d. 4 different Chl-a concentrations (0.01, 0.1, 1, 10 mg m^{-3}).
    e. Compare with Jerlov water types.
2. Use to generate extinction files for GOTM runs.
3. Three different wind speeds (0.1, 5, 10 ms^{-1}).
4. High latitude and low latitude, winter and summer conditions (reflect choice of starting SST, humidity, air temp, sun zenith, day length).
5. Total of 60 model runs covering all combinations.

Sensitivity Analysis: Case 1

Low wind → shallow mixed layer
Low latitude, summer → high solar irradiance at sea surface
Impact of parameterisation of light penetration likely to be high
10 day run, hourly time steps

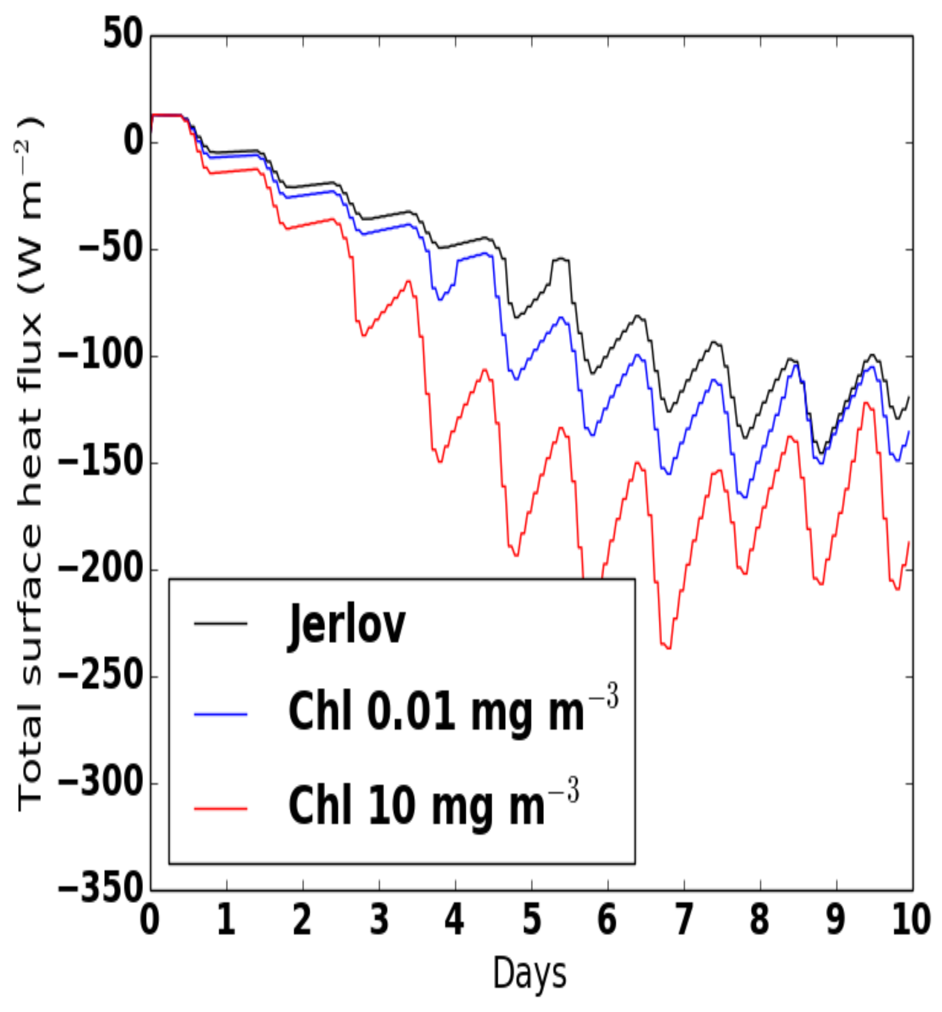


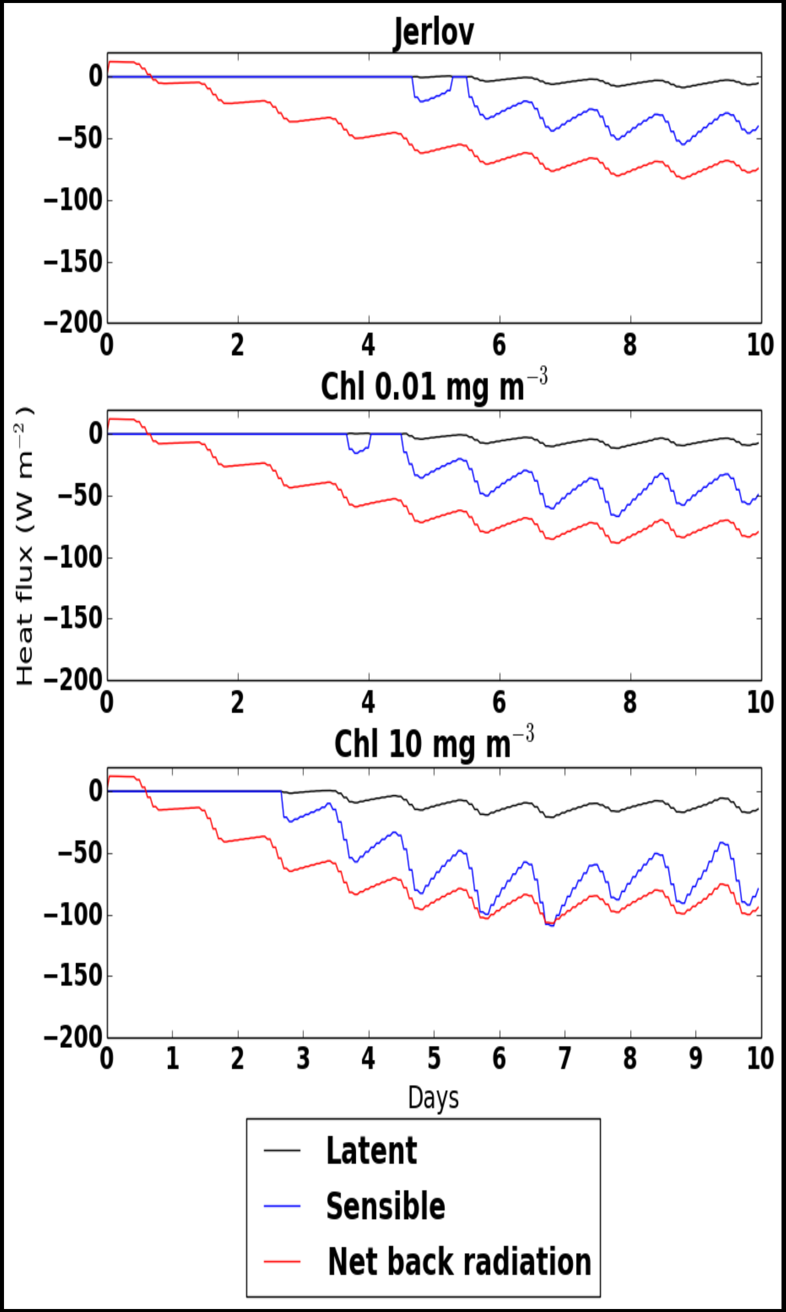


Outcome: SST increases (>1.5 °C) with Chl-a at surface. Cooling observed at depth (<0.2 °C)

Sensitivity Analysis: Case 1

Air temperature = 25 °C; Humidity = 70





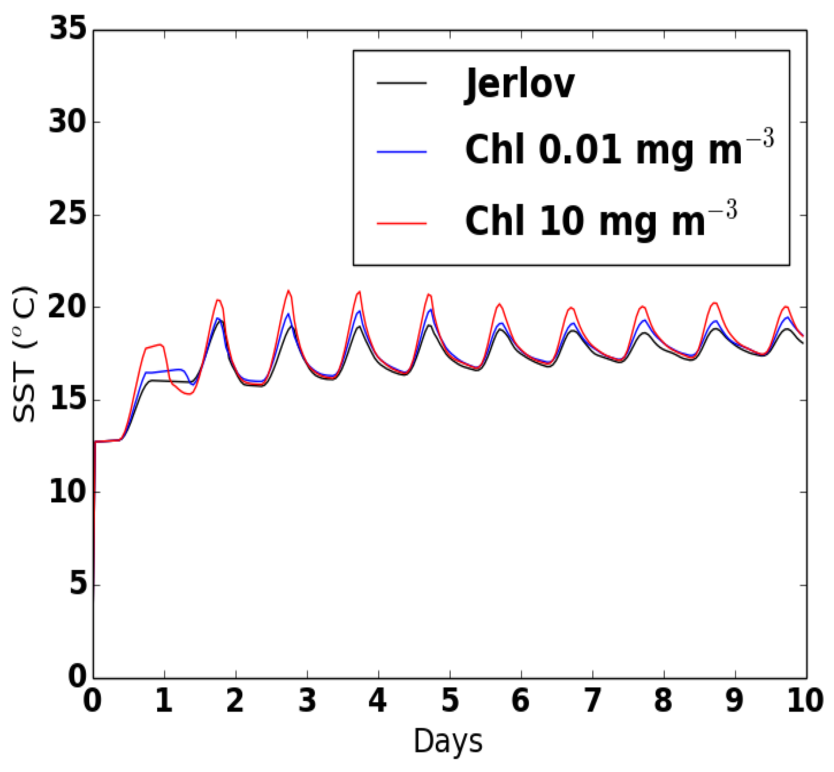
Max difference = 117 Wm^{-2}

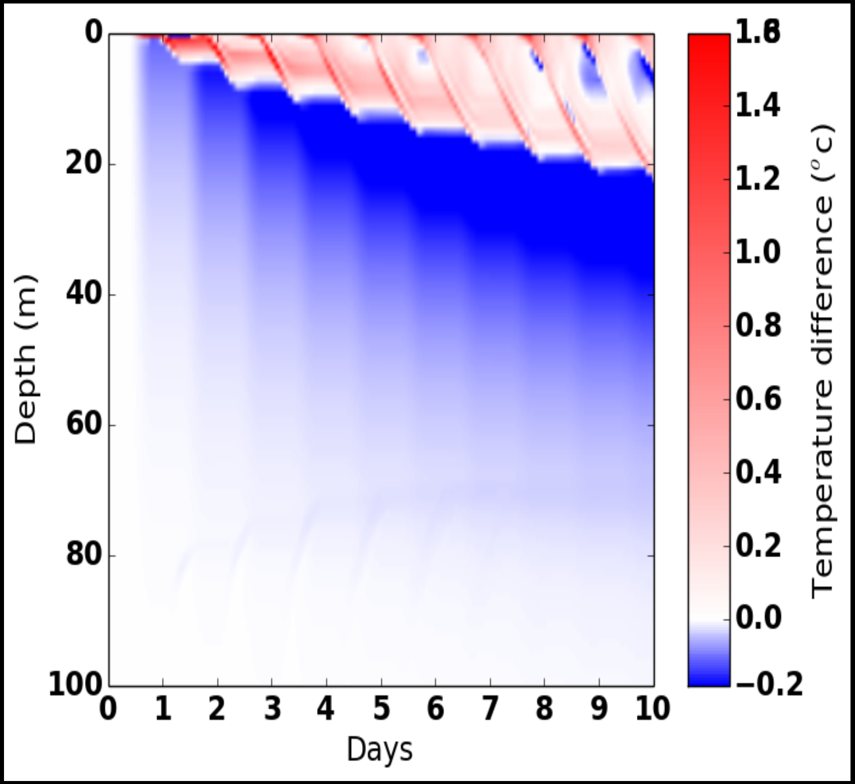
Sensitivity Analysis: Case 2

Medium wind ➔ deeper mixed layer

Low latitude, summer ➔ high solar irradiance at sea surface

10 day run, hourly time steps



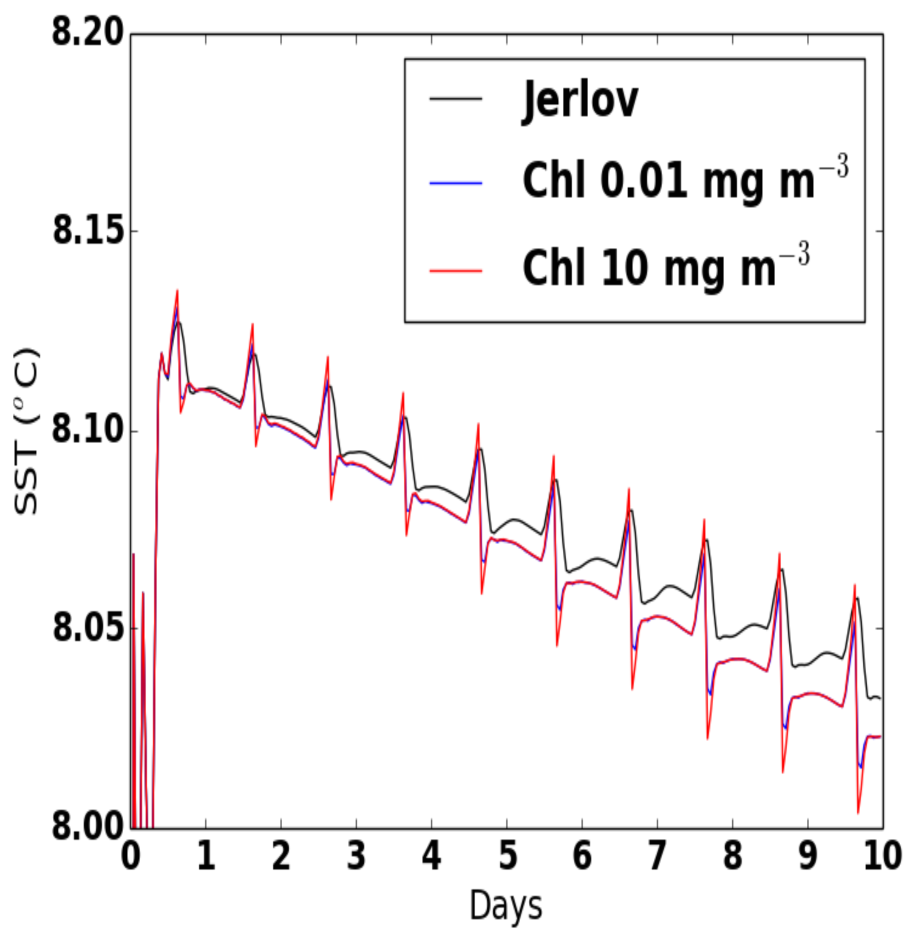


Outcome: Reduces sensitivity to optical variability. Surface warming mixed over the deeper mixed layer, and so reduces difference in SST. Subsurface cooling is reduced. Max difference in total HF of 40 Wm^{-2}.

Sensitivity Analysis: Case 3

- Low wind
- High latitude, winter.
  - Short daylength
  - Low surface irradiance

Outcome: Very small differences in heat flux (< 1 Wm^{-2}).

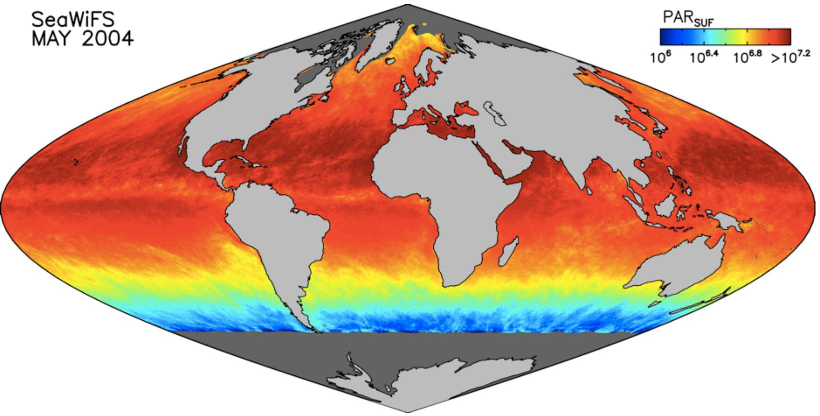


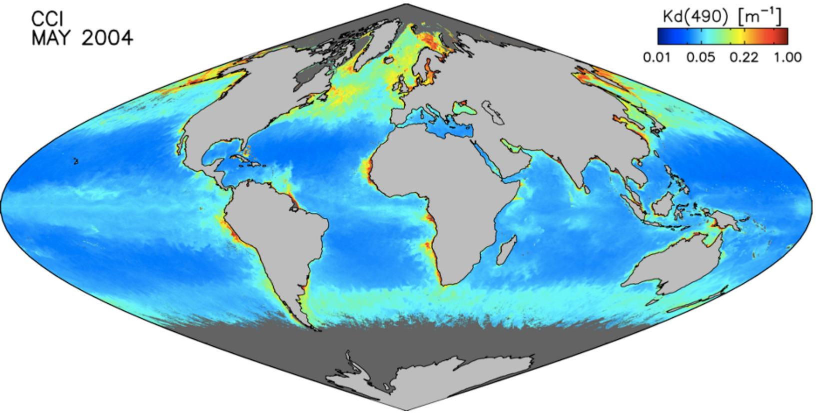
Satellite-data based calculations

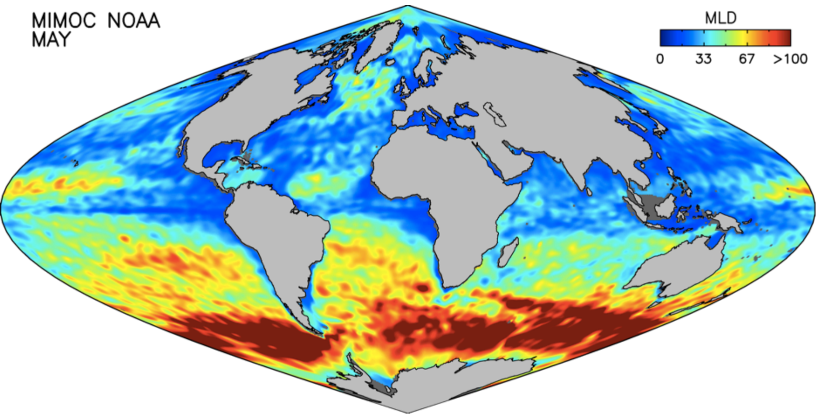
Using OC-CCI Chl-a as input

- Atmospheric-ocean spectral light transmission model (Sathyendranath and Platt 1988) modified with improved phytoplankton parameterisation (Brewin et al. 2015) used to calculate attenuation of solar radiation with depth in the ocean based on modelled surface irradiance, scaled to ocean-colour-derived solar irradiance in the UV and visible domains (350 – 700 nm).
- Extracts Irradiance (I_{MLD}) at Mixed Layer Depth (MIMOC data) or at 1% light level.
- Produce images of spectrally-integrated I_{MLD} for 1998-2005 at monthly time scales.

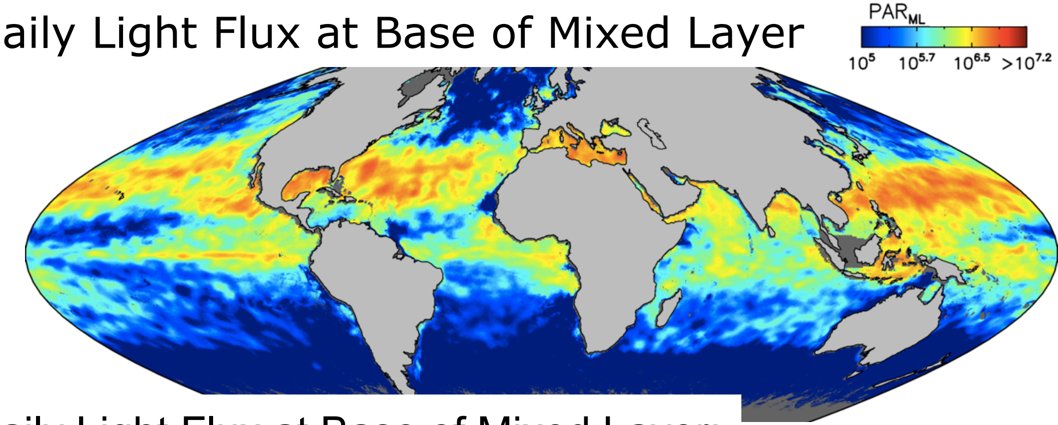
From Ocean-Colour to Energy Distribution in the Ocean



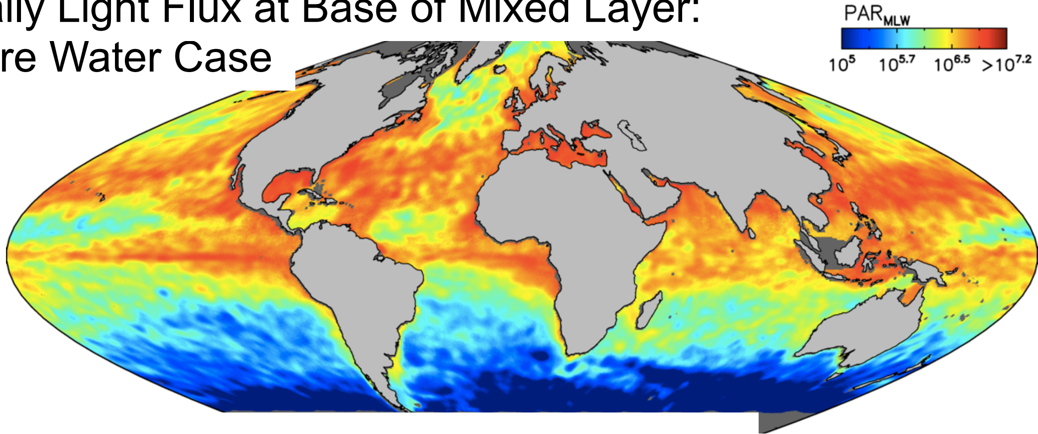




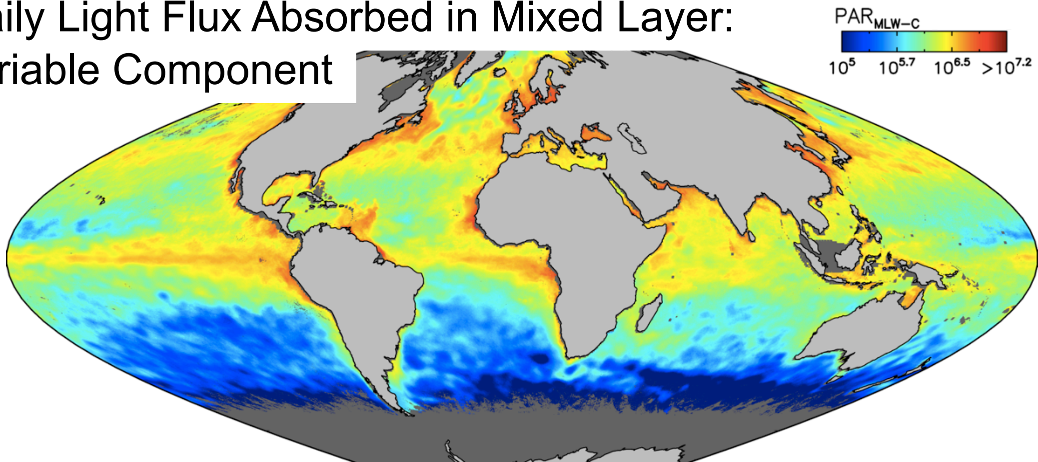
Daily Light Flux at Base of Mixed Layer



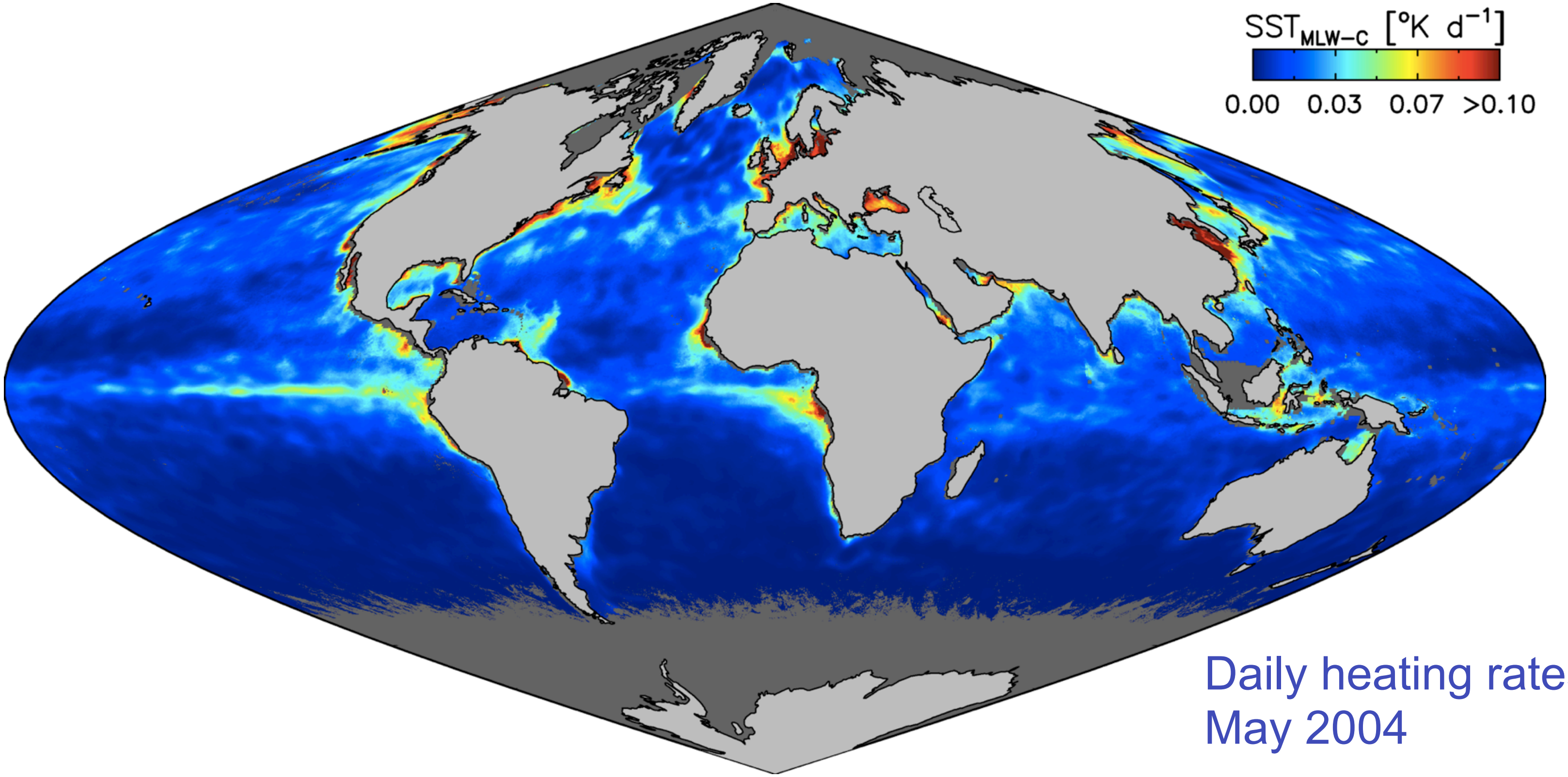
Daily Light Flux at Base of Mixed Layer: Pure Water Case



Daily Light Flux Absorbed in Mixed Layer: Variable Component



Optical Variability and Heating Rate

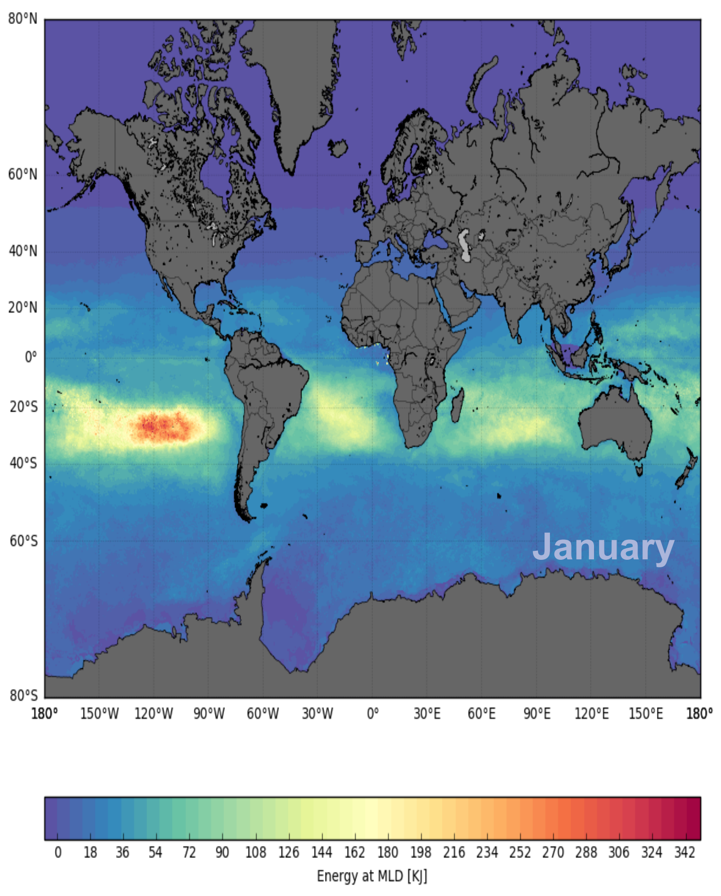


Daily heating rates
May 2004

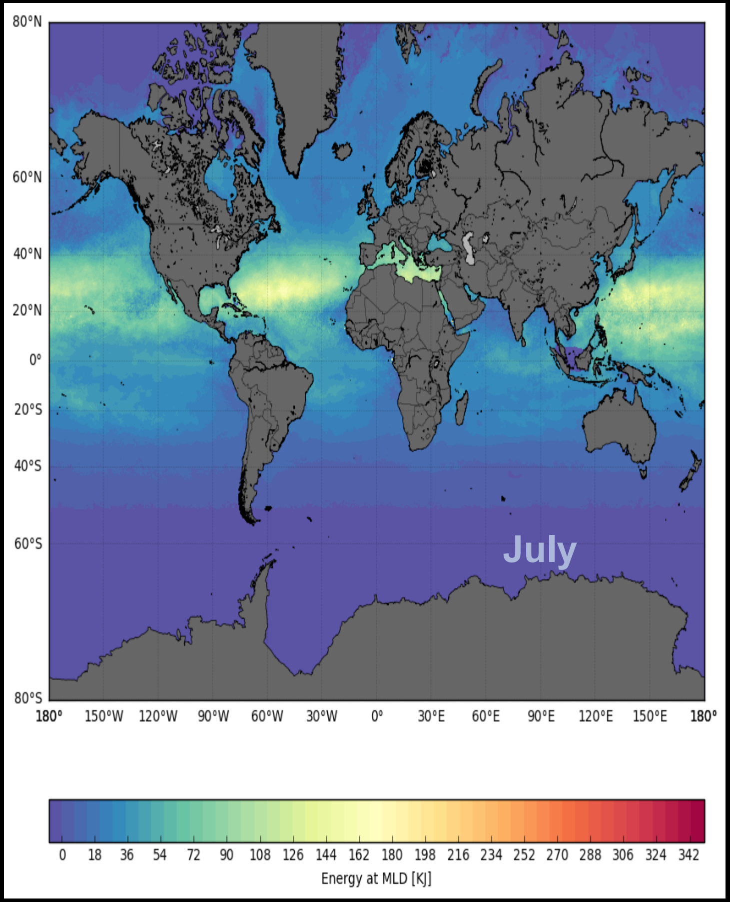
Variable component of heating of the mixed layer by the optical components of the sea (after the pure-water contribution has been removed).
How important is this for the ocean heat budget?

Data contribution to OHF Project

1. V2, 9km, monthly, 1998-2005
2. NetCDF files with Latitude, Longitude, Chl, MLD, PAR, $I_{(SURF)}$, $I_{(MLD)}$.

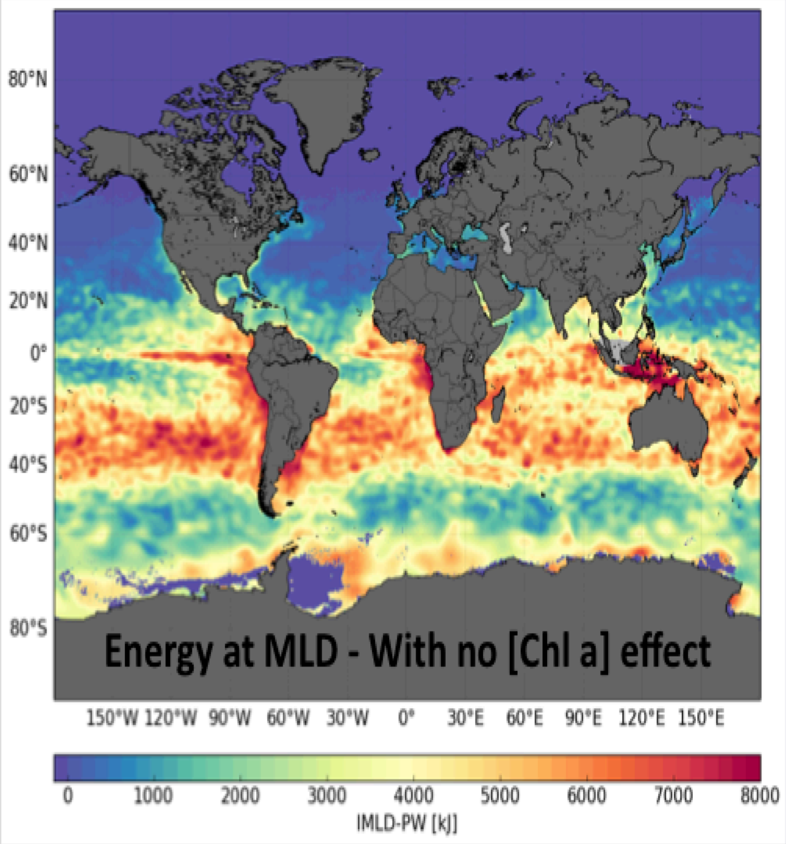


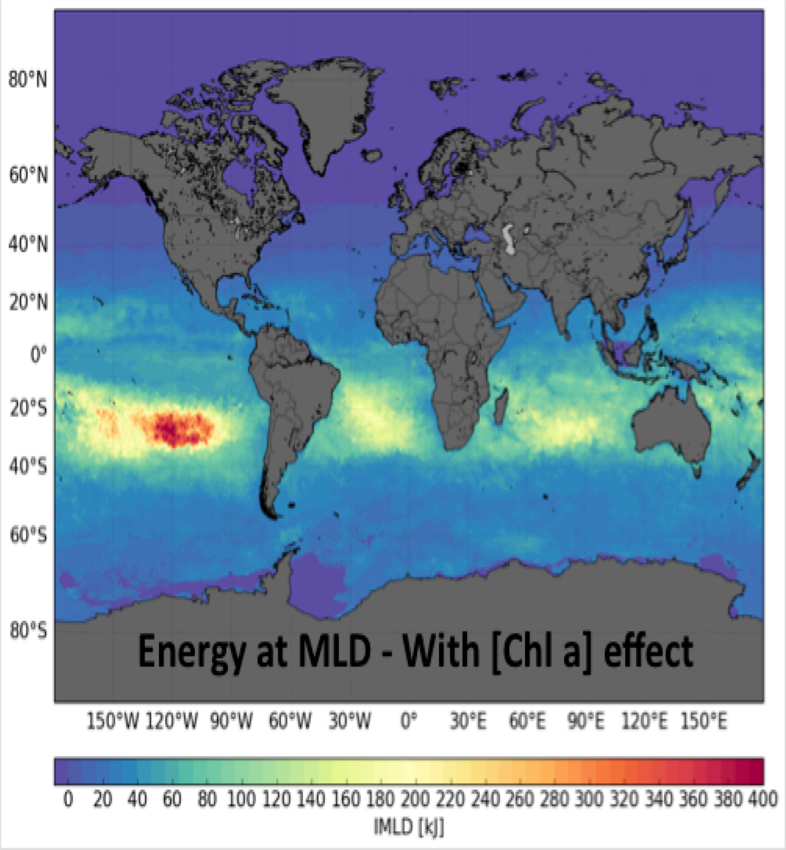
Energy at MLD (kJ)



Energy at MLD (kJ)

1. Can investigate impact of assumptions made about attenuation and how this impacts light penetration (e.g. in models/heat budgets).



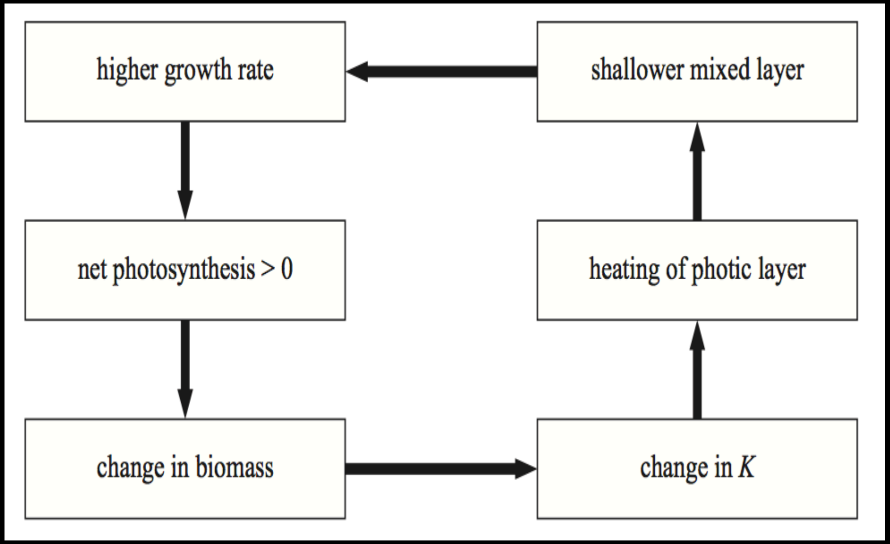


Summary

1. Sensitivity of heat flux as a result of optical variability is most substantial in low-wind, high-light scenarios, and depends on chlorophyll-a concentration. High wind and low light irradiance reduce sensitivity.
2. So effect of ocean optical thickness on upper-ocean dynamics is dependent on season and location.
3. Likely to be important at event scales associated, for example, with localised blooms.
4. Models could be used to understand variability at *in situ* sites (e.g., buoys).
5. Satellite products allow recording of variability in solar heating within, and below, mixed layer.

Further considerations

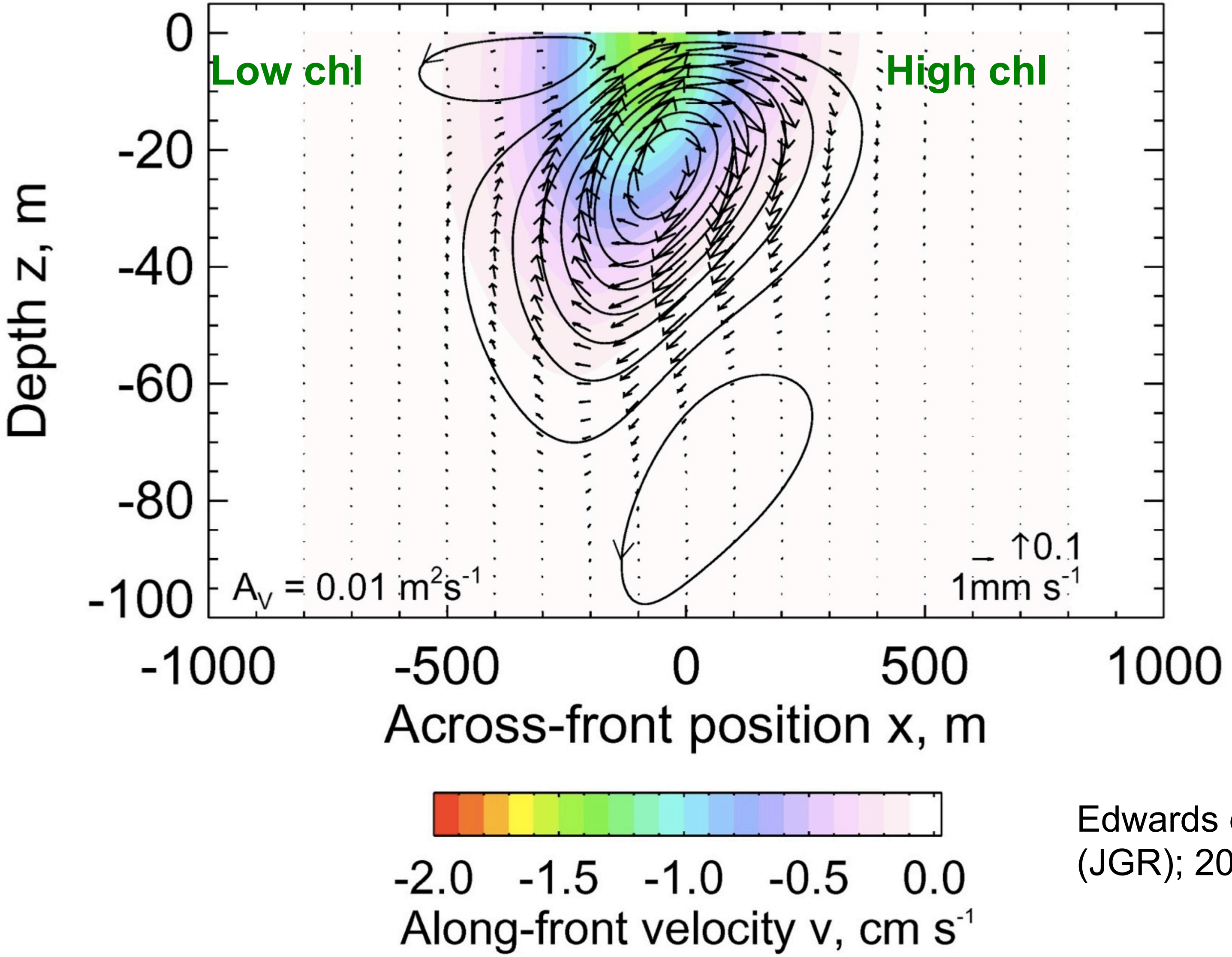
1. In the sensitivity analyses reported, turbulence closure model is not coupled with biology – so phytoplankton does not respond to changes in physical conditions
2. In many ecosystem models, including CMIP models, biology reacts to physics, there is no feedback
3. Nor have we explored impact on air temperature and vertical convection



Sathyendranath and Platt 2007

4. Effects of non-uniform Chl a vertical profile
   - Potential for local instability (Lewis *et al*. 1983). How important is it?
5. Attenuation more complex in case 2 waters.
6. Climate considerations: Until we explore the couplings and feedbacks between ECVs (ocean-atmosphere, physics-biology) we cannot hope to unravel implications of climate change for the Earth System and for life on Earth, as we know it.

Phytoplankton fronts and ocean circulation

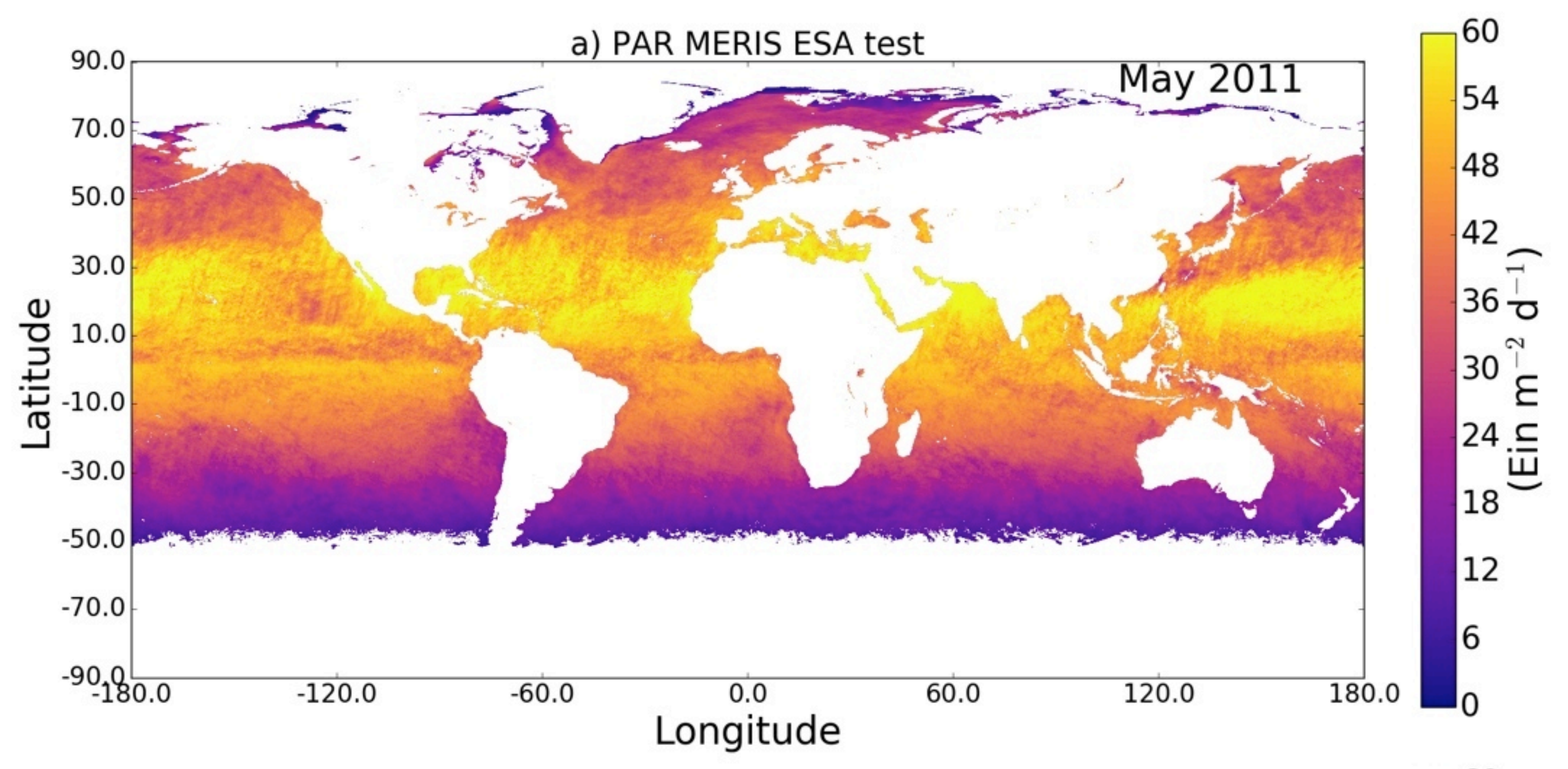


Edwards et al. 2001 (JGR); 2004 (JMS)

What are the effects of fronts and patterns in optical properties on ocean circulation? How can Earth observations help address such questions?

Do we have enough information now to take us to the next step:

Calculate ocean mixed layer or “mixing layer” from satellites?



We need climate-quality time series data on solar irradiance at the sea surface from satellites. ESA PPP project has produced very useful prototype. Continuity? Corresponding OLCI product?

- Changes heat flux (air T>SST).
- Max difference in total HF of 40 Wm^{-2}.

- Higher wind reduces the sensitivity to optical variability further.