The Influence of **Biology** on Physics **in the Oceanic Boundary Layer**

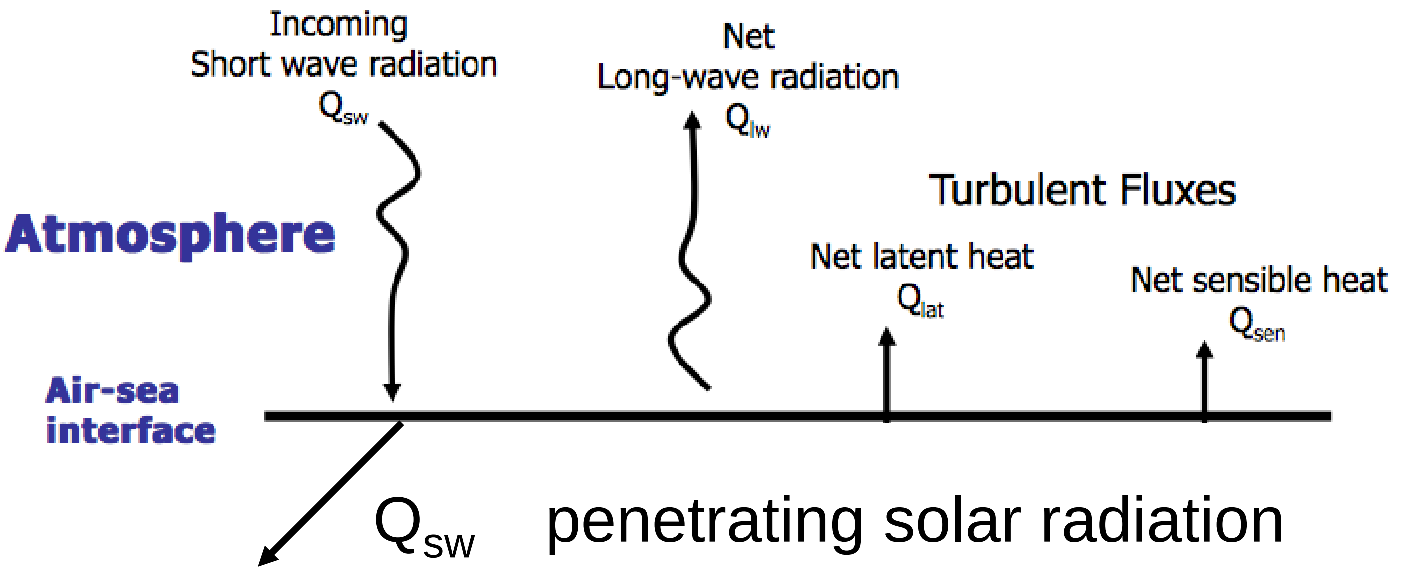
Carter Ohlmann

Earth Research Institute, University of California, Santa Barbara, CA 93106

Goals

- Demonstrate role of phytoplankton on ocean heating, thermal structure and mixing.
- Show ocean radiant heating parameterizations should depend on biology.

Air-sea heat exchange



$$Q_{net} = Q_{sw} + Q_{lw} + Q_{lat} + Q_{sen} + Q_{adv}$$

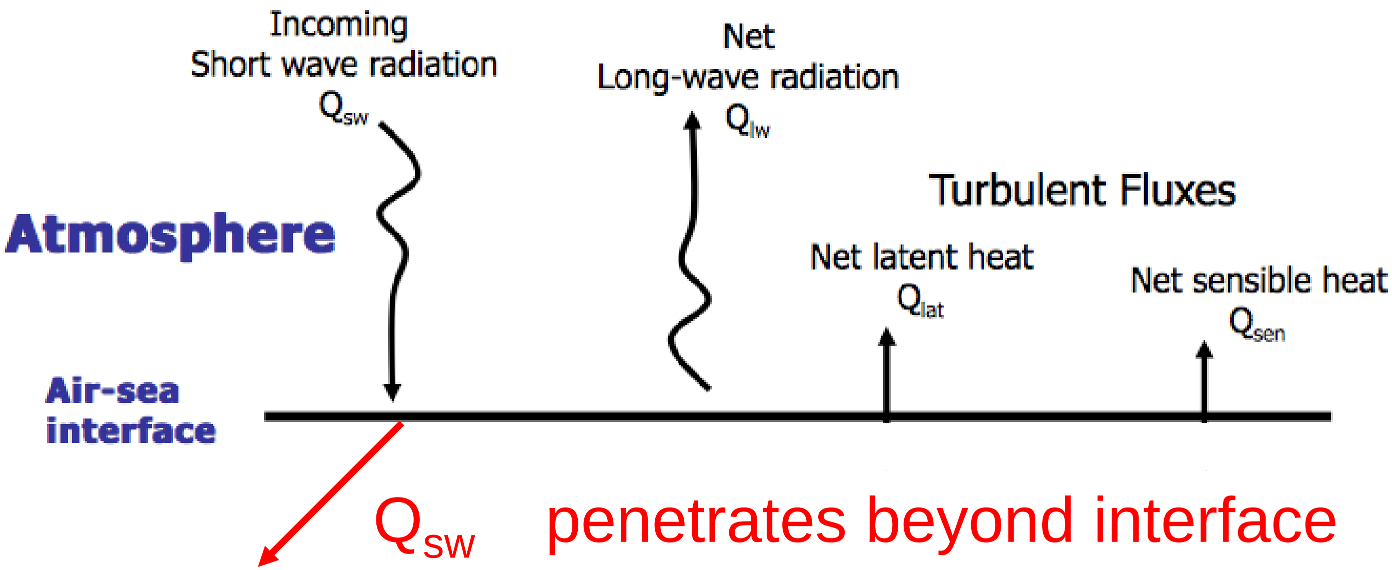
Q_{sw} -- shortwave radiation (30 – 260 W m^{-2})

Q_{lw} -- longwave radiation (-60 – -30 W m^{-2})

Q_{lat}-- latent heat flux (-130 – -10 W m^{-2})

Q_{sen}-- sensible heat flux (-40 – 0 W m^{-2})

Air-sea heat exchange



$$Q_{net} = Q_{sw} + Q_{lw} + Q_{lat} + Q_{sen} + Q_{adv}$$

Q_{sw} -- shortwave radiation (30 – 260 W m^{-2}) generally largest term

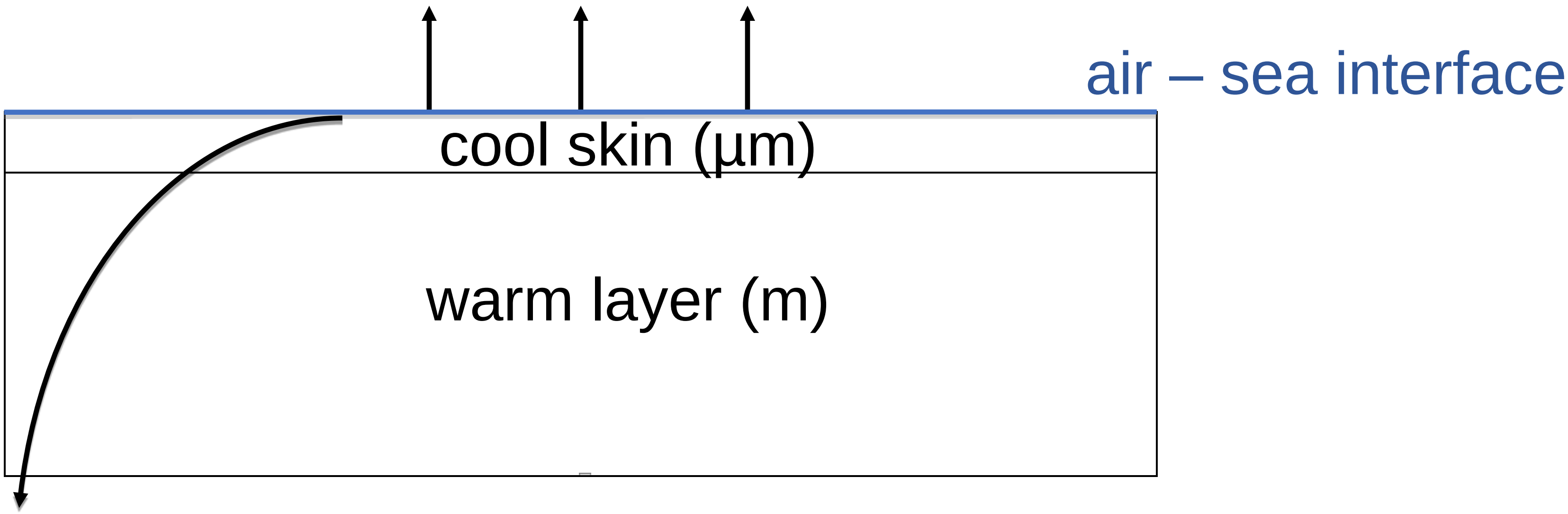
Q_{lw} -- longwave radiation (-60 – -30 W m^{-2})

Q_{lat} -- latent heat flux (-130 – -10 W m^{-2})

Q_{sen} -- sensible heat flux (-40 – 0 W m^{-2})

Air-sea heat exchange: resulting b.l. structure

$$Q_{net} = Q_{sw} + Q_{lw} + Q_{lat} + Q_{sen} + Q_{adv}$$

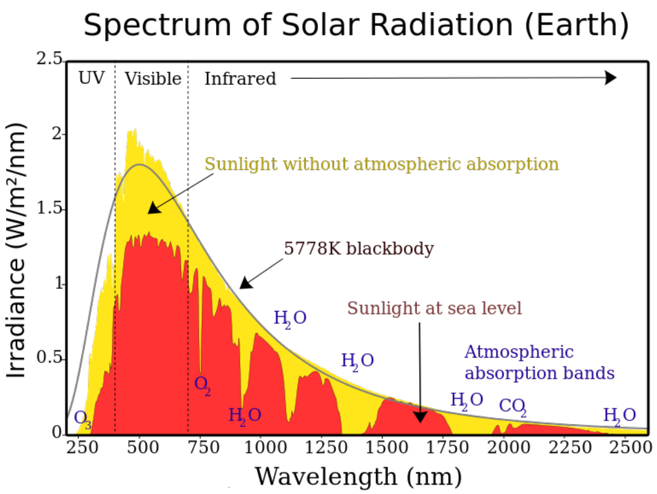


JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 101, NO. C1, PAGES 1295–1308, JANUARY 15, 1996

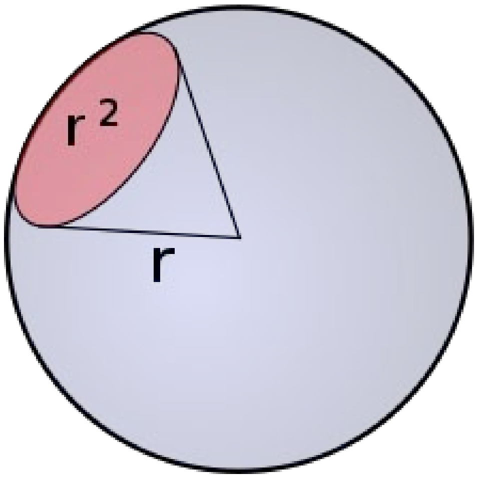
Cool-skin and warm-layer effects on sea surface temperature

C. W. Fairall,[1] E. F. Bradley,[2] J. S. Godfrey,[3] G. A. Wick,[4] J. B. Edson,[5]
and G. S. Young[6]

In-water radiative transfer theory



spectral dependence (λ; nm)



directional dependence (θ, ϕ; steradian)

$$\cos\theta \frac{dL(z,\theta,\phi,\lambda)}{dz} = -c(z,\lambda)L(z,\theta,\phi,\lambda) + \int_0^{2\pi}\int_0^{\pi} L(z,\theta',\phi',\lambda)\beta(z;\theta',\phi' \rightarrow \theta,\phi;\lambda)\sin\theta' d\theta' d\phi' + \Sigma(z,\theta,\phi,\lambda)\ .$$

L is spectral radiance (W m^{-2} sr^{-1} nm^{-1})

In-water radiative transfer theory

$$\cos\theta \frac{dL(z,\theta,\phi,\lambda)}{dz} = -c(z,\lambda)L(z,\theta,\phi,\lambda) + \int_0^{2\pi}\int_0^{\pi} L(z,\theta',\phi',\lambda)\beta(z;\theta',\phi' \rightarrow \theta,\phi;\lambda)\sin\theta' d\theta' d\phi' + \Sigma(z,\theta,\phi,\lambda)\ .$$

L is spectral radiance (W m^{-2} sr^{-1} nm^{-1}), or radiance (W m^{-2} sr^{-1})

c is attenuation = absorption + scattering

β is volume scattering function

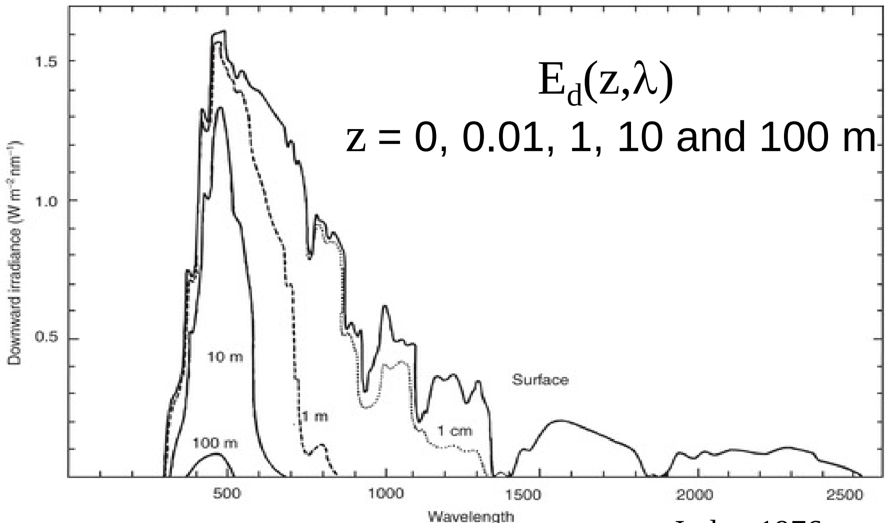
} depend on biology

RT equation solved numerically using: Monte Carlo methods, invariant imbedding, discrete ordinates.

Irradiance, E_d, is all energy traveling in downward direction

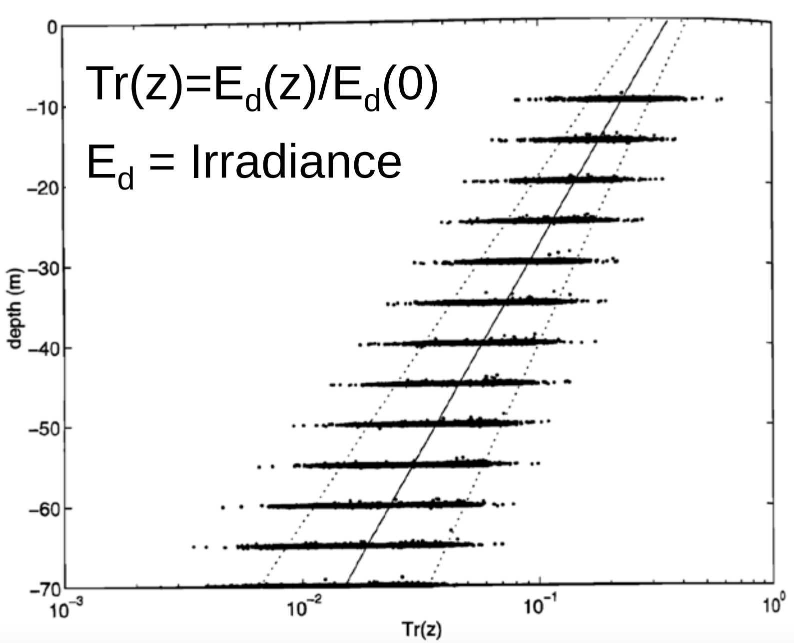
$$E_d(z,\lambda) = \int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi/2} L(z,\theta,\phi,\lambda)\left|\cos\theta\right| \sin\theta d\theta\, d\phi$$

In-water solar transmission



Jerlov 1976

- attenuation depends on λ
- spectrum narrows with depth
- $E_d(1\text{ m}, \lambda > 750\text{ nm}) = 0$
- only “blue” light at z =100 m

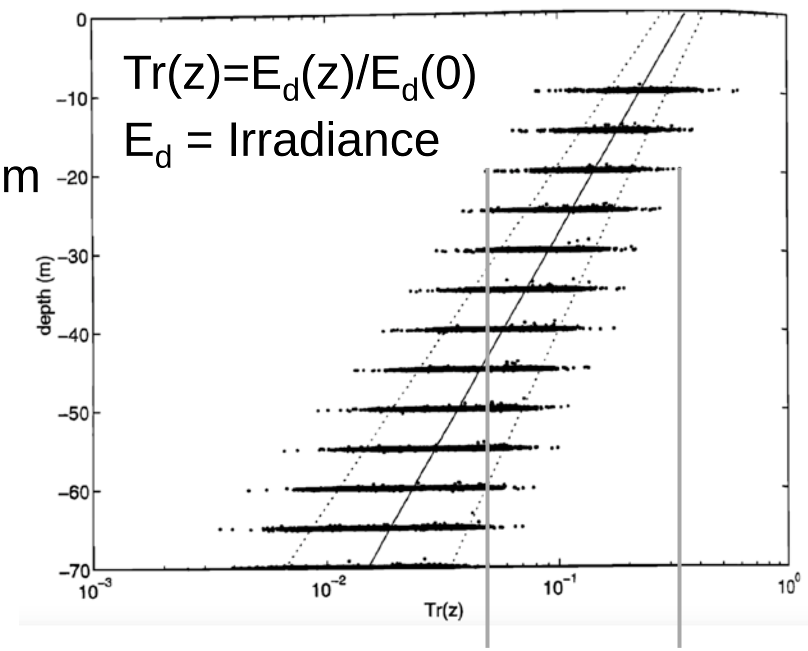


Tr(z) is fraction of surface irradiance at depth after spectral integration and normalization.

In-water solar transmission

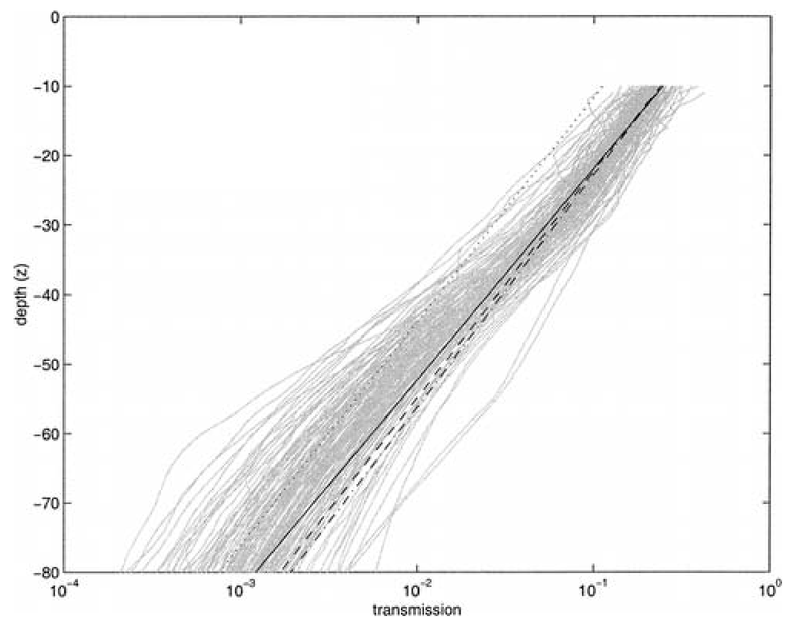
- Phytoplankton need sunlight to grow
- Vertical distribution of radiant heating affects stratification/mixing

variability in solar flux divergence depends on biology



Fraction of surface irradiance at depth

Ohlmann et al. 1998 *JGR*



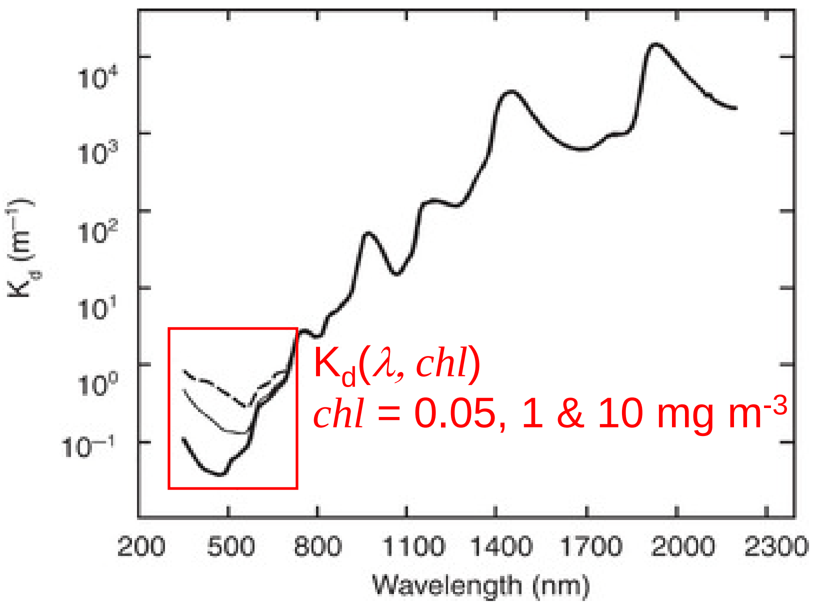
Ohlmann 2003 *J. Climate*

Parameterizing in-water solar transmission

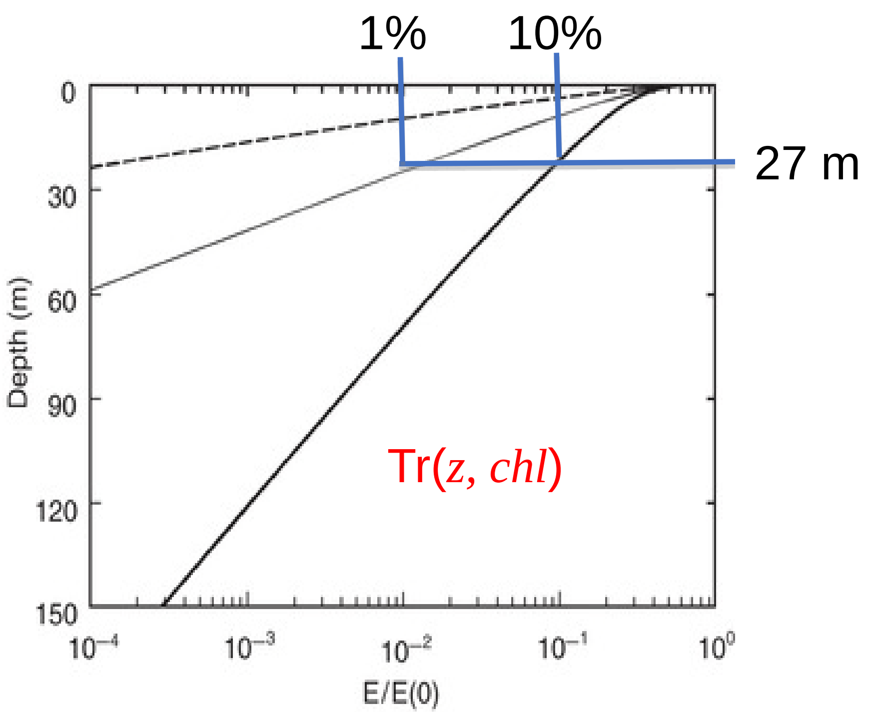
Define spectral diffuse attenuation coefficient

$$K_d(z,\lambda) = \frac{d \ln E_d(z,\lambda)}{dz}$$

; can define $K_d(\lambda, water)$ and $K_d(\lambda, chl)$



phytoplankton influence at λ < 800 nm



chl = 0.05, 1 & 10 mg m^{-3}

Kuo *et al.* (1993)

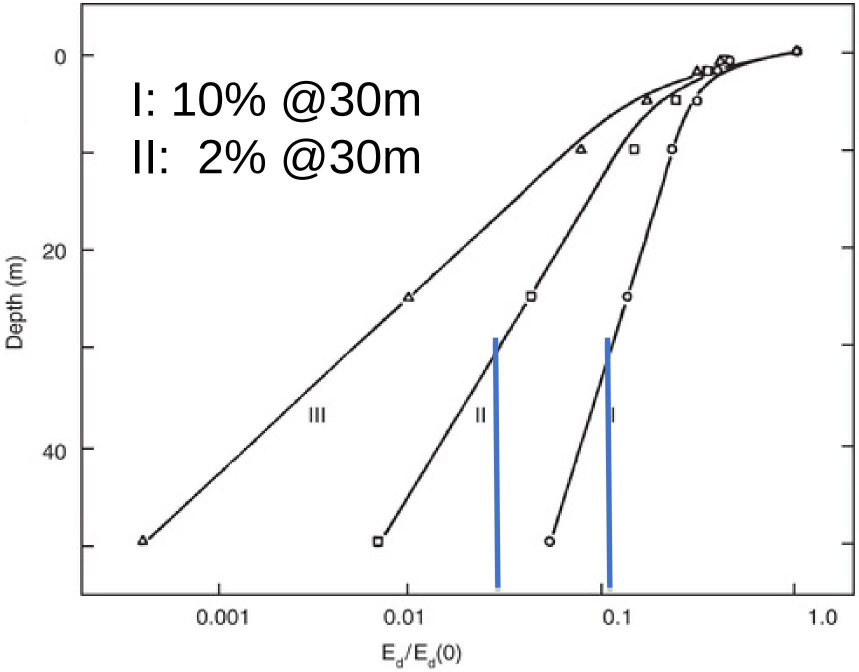
Parameterizing in-water solar transmission

$$K_d(z,\lambda) = \frac{d \ln E_d(z,\lambda)}{dz}$$

$$E_d(z) = E_d(0) \sum_i A_i \exp(-B_i z)$$

A_i and B_i parameters related to Jerlov water type (Jerlov 1976)

varying optical properties or "color" of water



Tr(z) for Jerlov water types I, II, and III.

Parameterizing in-water solar transmission

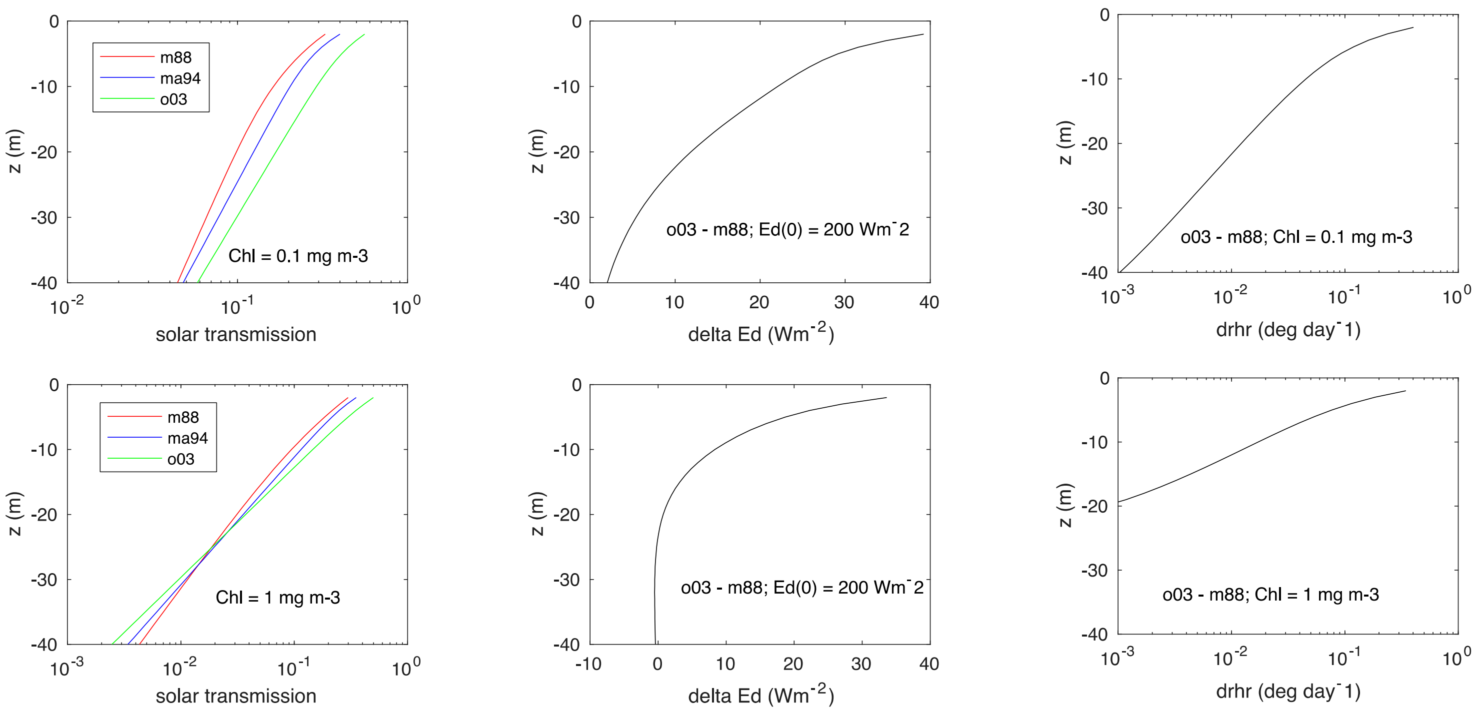
$$E_d(z) = E_d(0) \sum_i A_i \exp(-B_i z)$$

State-of-the-art parameterizations relate A_i and B_i to chlorophyll conc.

Morel (1988): Based on $K_d(chl)$

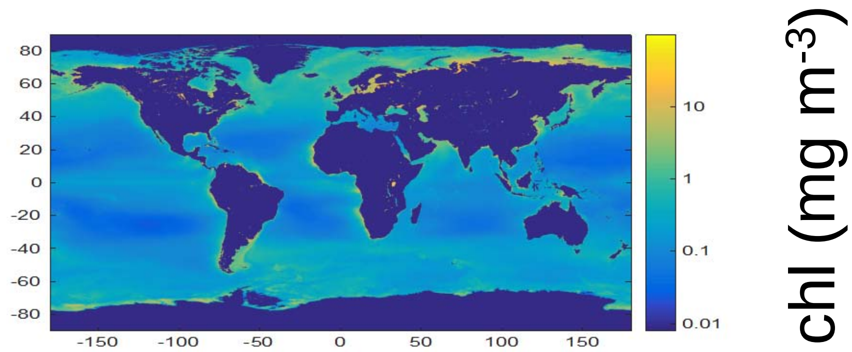
Morel and Antoine (1994): Partitions $E_d(0)$ into spectral regions

Ohlmann (2003): Purely empirical, computationally simple



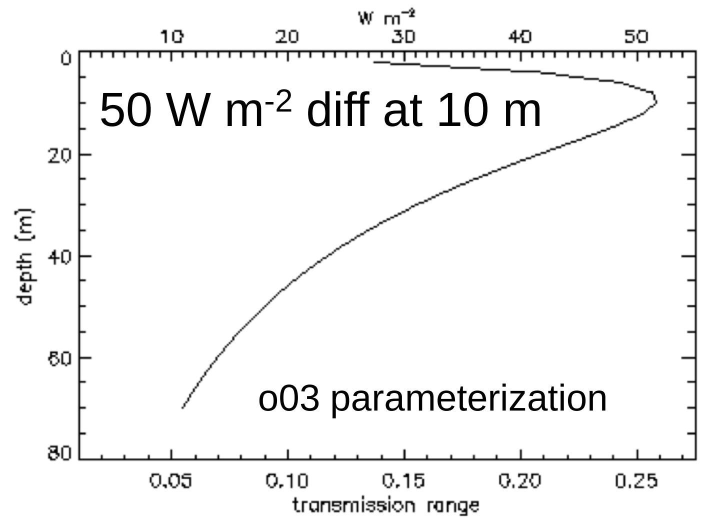
Three Tr(z) parameterizations and their difference in flux and heating rate.

Biological impact on Tr(z) and $E_d(z)$



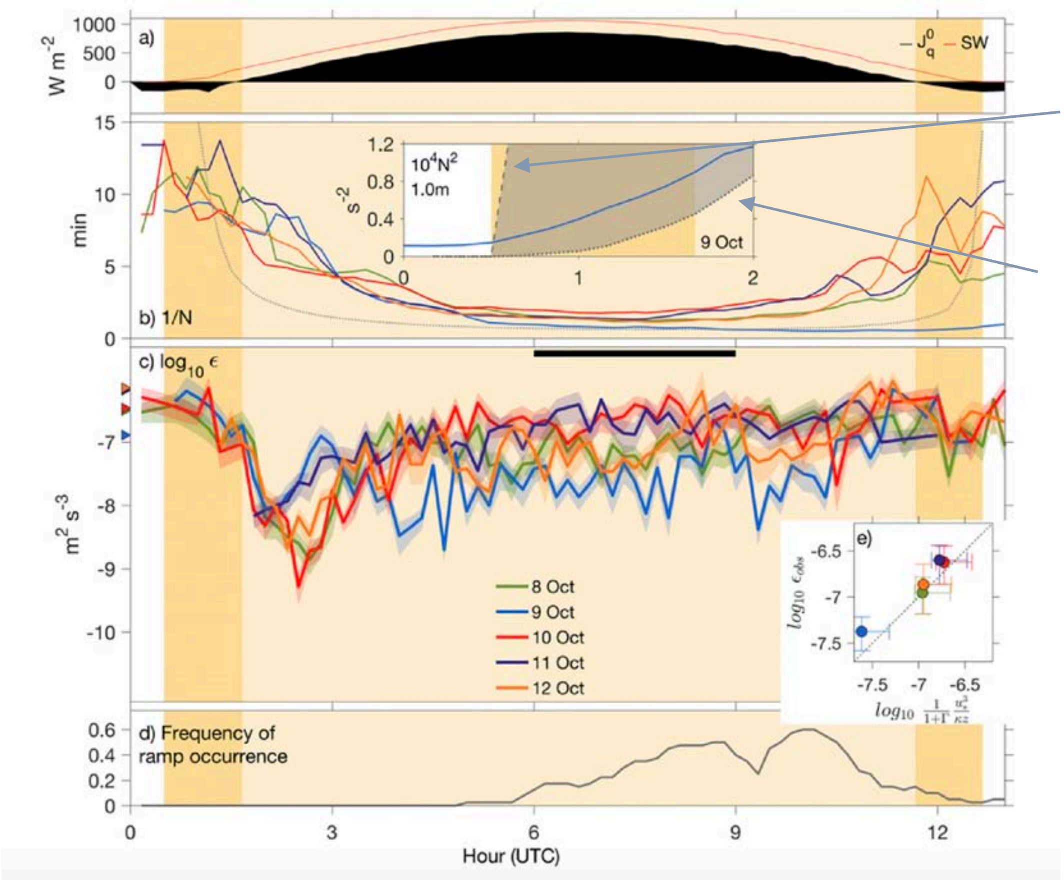
Mean (2002 – 2018) chlorophyll concentration from MODIS-Aqua.

Tr(z,chl=0.01) - Tr(z,chl=3.0)



delta Tr(z,chl) between chl = 0.01 and 3 mg m^{-3}. Also expressed as $E_d(z)$ for $E_d(0)$ = 200 W m^{-2}.

Why does solar transmission matter?



N^2 from:

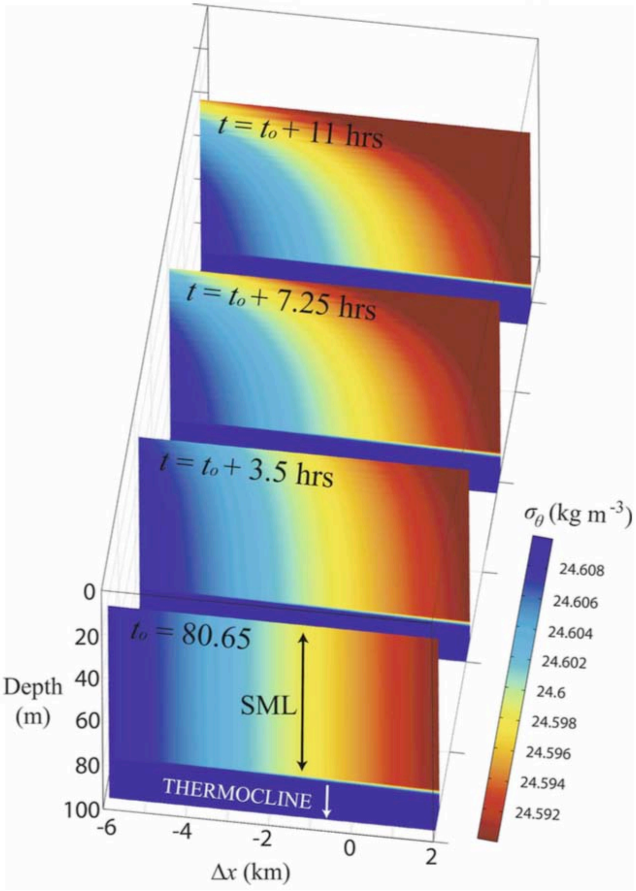
Jerlov water type

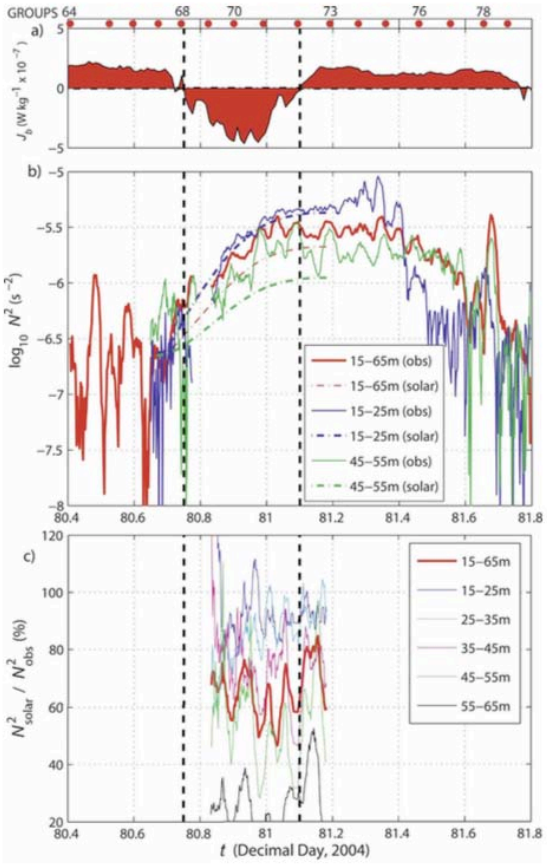
observations

chl concentration

Diurnal cycling in warm layer. Solar flux divergence initially suppresses ε by two orders of magnitude. Then shear associated with a w.l. jet increases ε until balanced by buoyancy. Figure from Moulin et al. 2017.

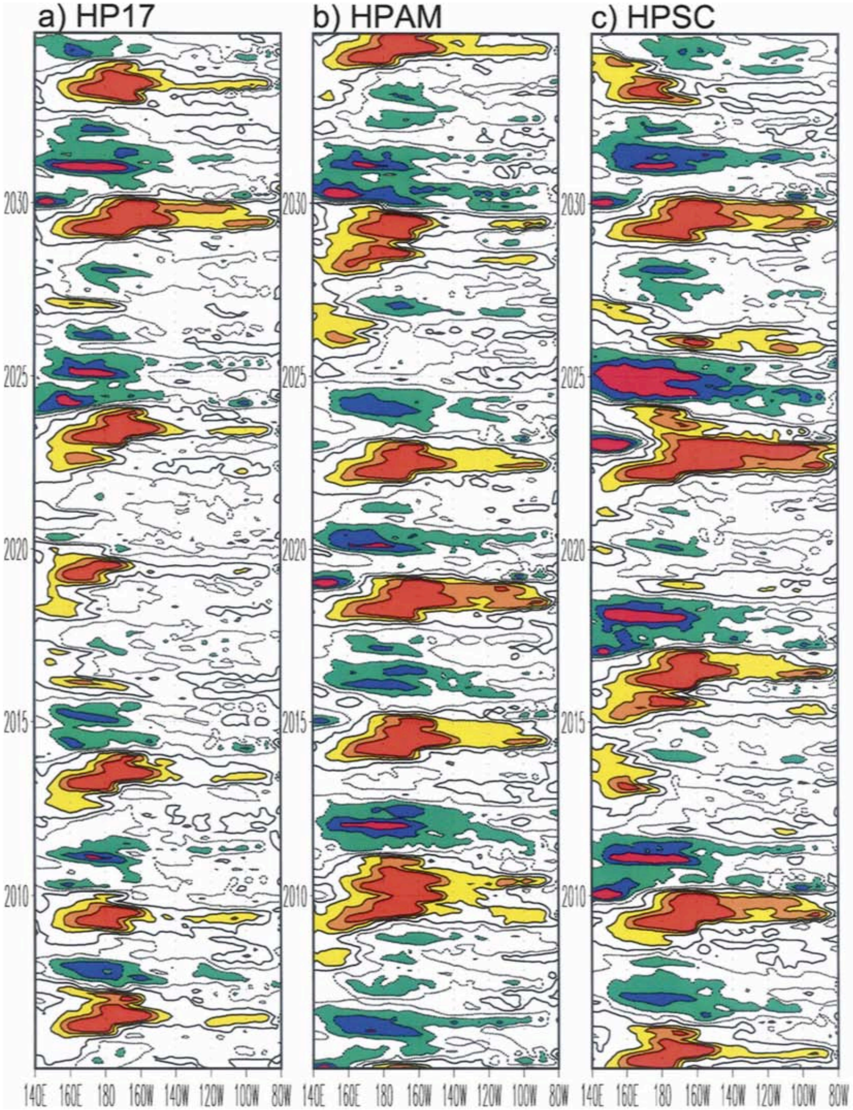
Why does solar transmission matter?





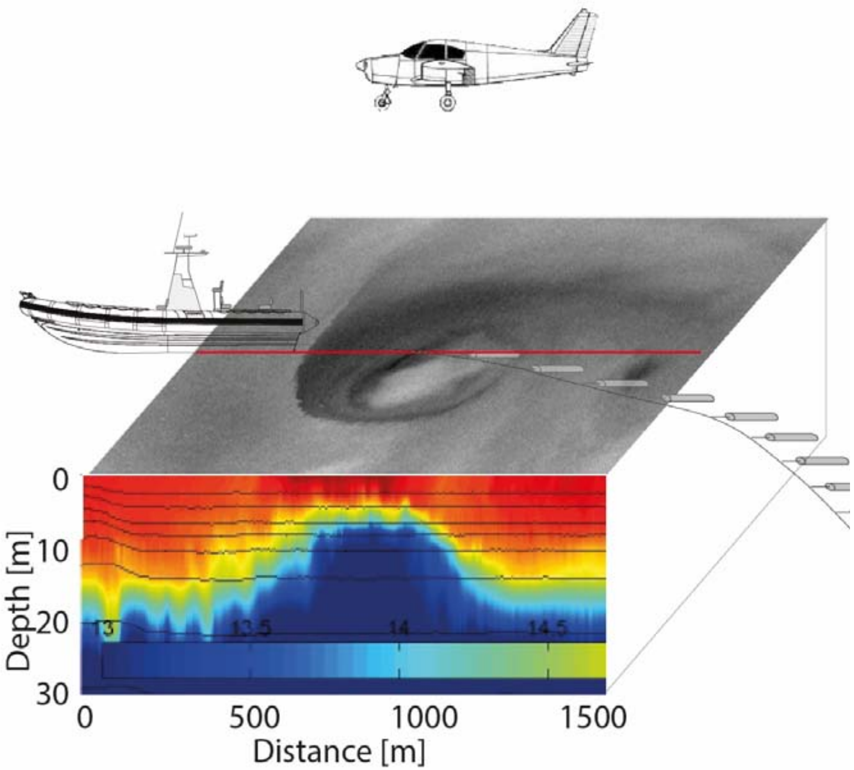
Evolution of horizontal density gradient (t=0) to solar heating after 3.5, 7.25, and 11 hours (left). Figure gives the appearance of dynamics (gravitational slumping) through solar heating alone. More than 80% of observed N^2 is attributable to solar heating in top 25 m. Figures from Hosegood et al. 2008.

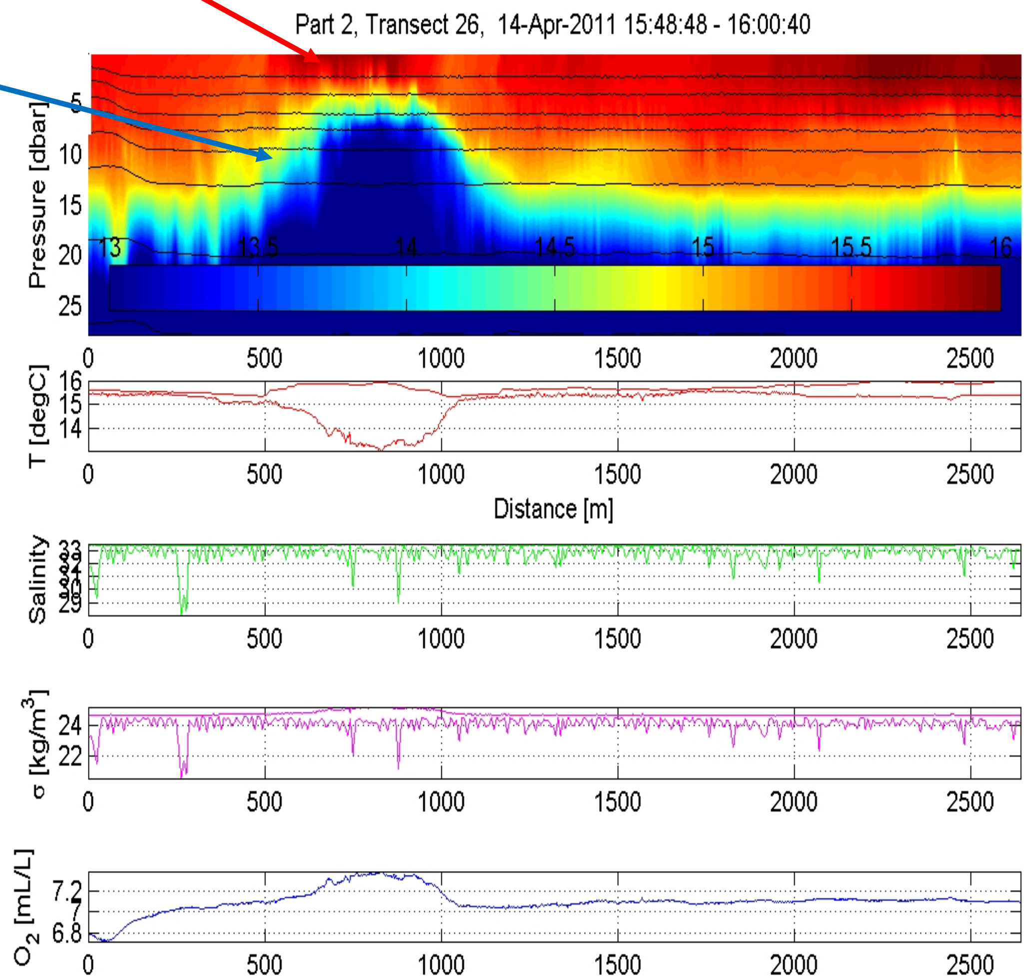
Why does solar transmission matter?



Equatorial (2°S - 2°N) SST anomalies from simulations with arbitrary solar transmission (left), annual mean chl-based solar transmission (middle), and seasonal cycle chl-based solar transmission (right). Contours are every 0.5°C. Figure from Ballabrera-Poy et al. 2007.

Cold Eddy with Warm Surface Expression





Is biology (elevated chl) enhancing near-surface heating?

Summary

- Variations in upper ocean biomass (chl) can influence ocean thermal structure and mixing.
- Chlorophyll-based parameterizations of solar transmission exist.
- Decades of global chlorophyll concentration data are available.
- The sensitivity of upper ocean dynamics to biologically-forced variations in solar heating should be revisited.