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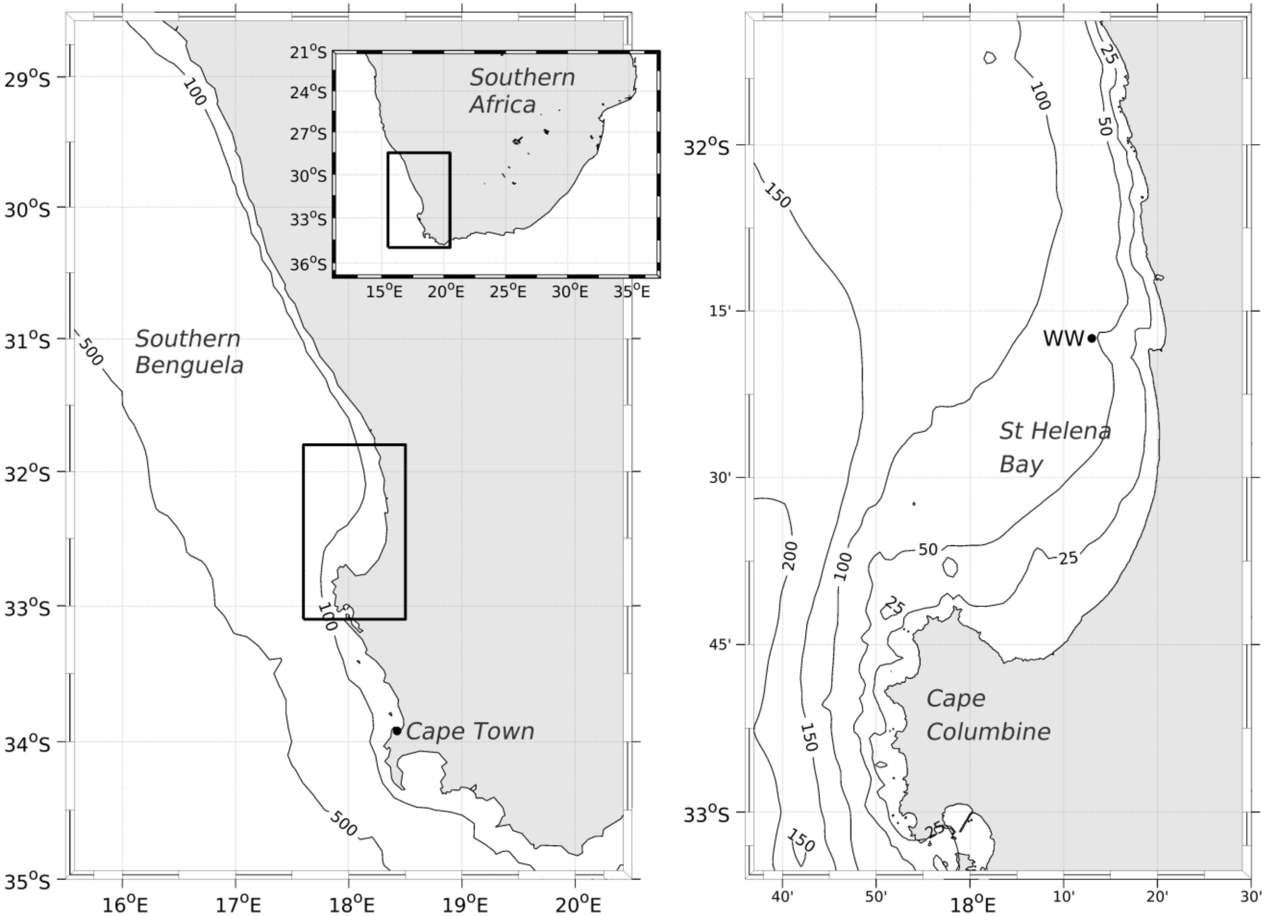
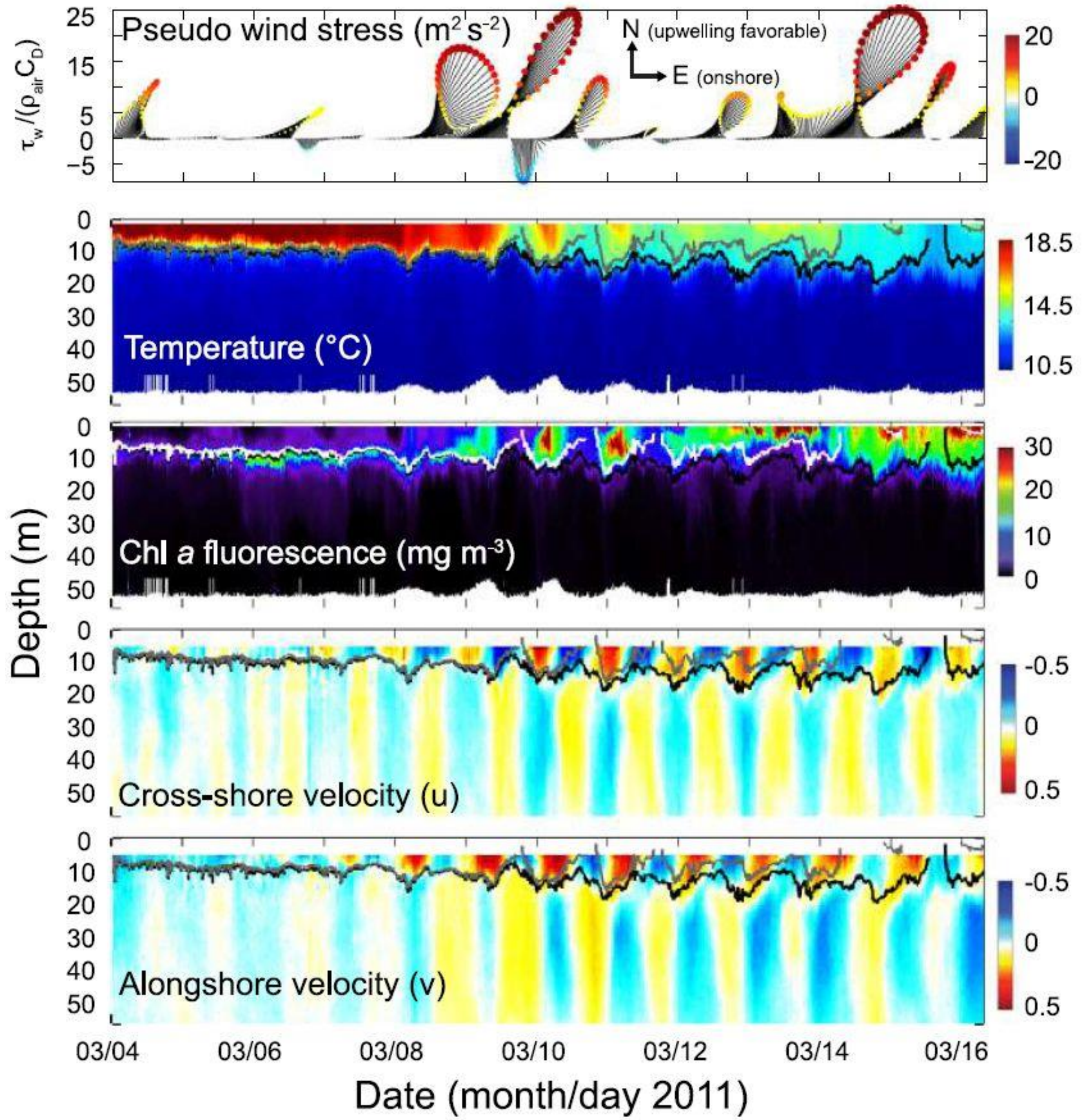
The influence of diurnal winds on phytoplankton dynamics in a coastal upwelling system off southwestern Africa

Andrew J. Lucas [a,*], Grant C. Pitcher [b,c], Trevor A. Probyn [b], Raphael M. Kudela [d]





JGR Oceans

RESEARCH ARTICLE

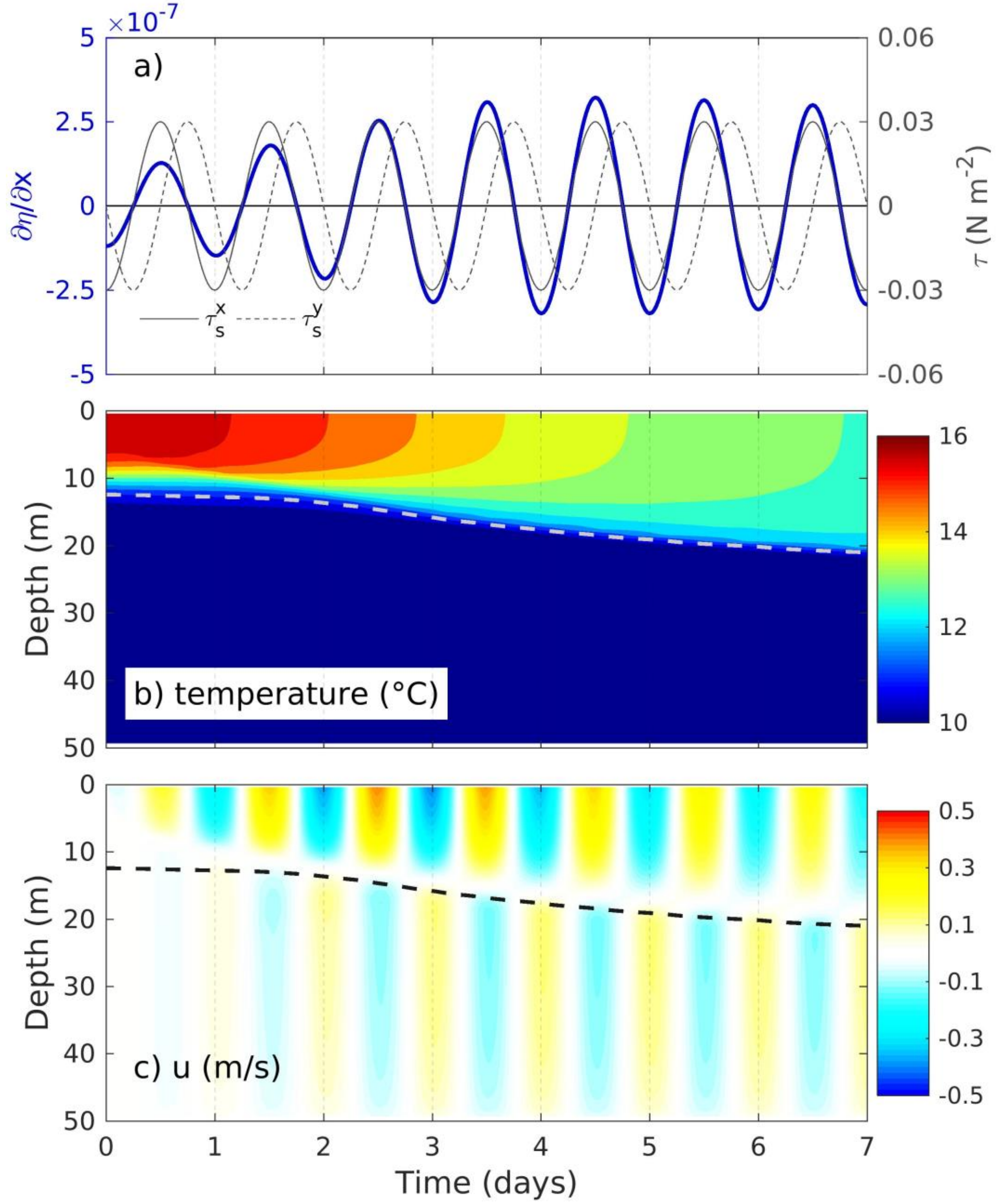
10.1029/2020JC016208

Enhanced Vertical Mixing in Coastal Upwelling Systems Driven by Diurnal-Inertial Resonance: Numerical Experiments

Giles Fearon[1,3], Steven Herbette[1,2], Jennifer Veitch[3,4], Gildas Cambon[2], Andrew J. Lucas[5], Florian Lemarié[6], and Marcello Vichi[1,7]

CROCO 1D model

- Anti-cyclonic rotating wind stress with diurnal frequency and constant amplitude τ^{ac0}
- Horizontal surface elevation gradient forcing ($\frac{d\eta}{dx}$) to ensure zero cross-shore barotropic flow
- Latitude (ϕ) =30˚S ($f=2\Omega\sin\phi=1$ day^{-1})
- water depth = 50 m
- Bottom temperature = 10˚C
- Surface temperature = 16˚C
- Thermocline (dotted line) approximated by 11˚C isotherm
- Zero surface radiation



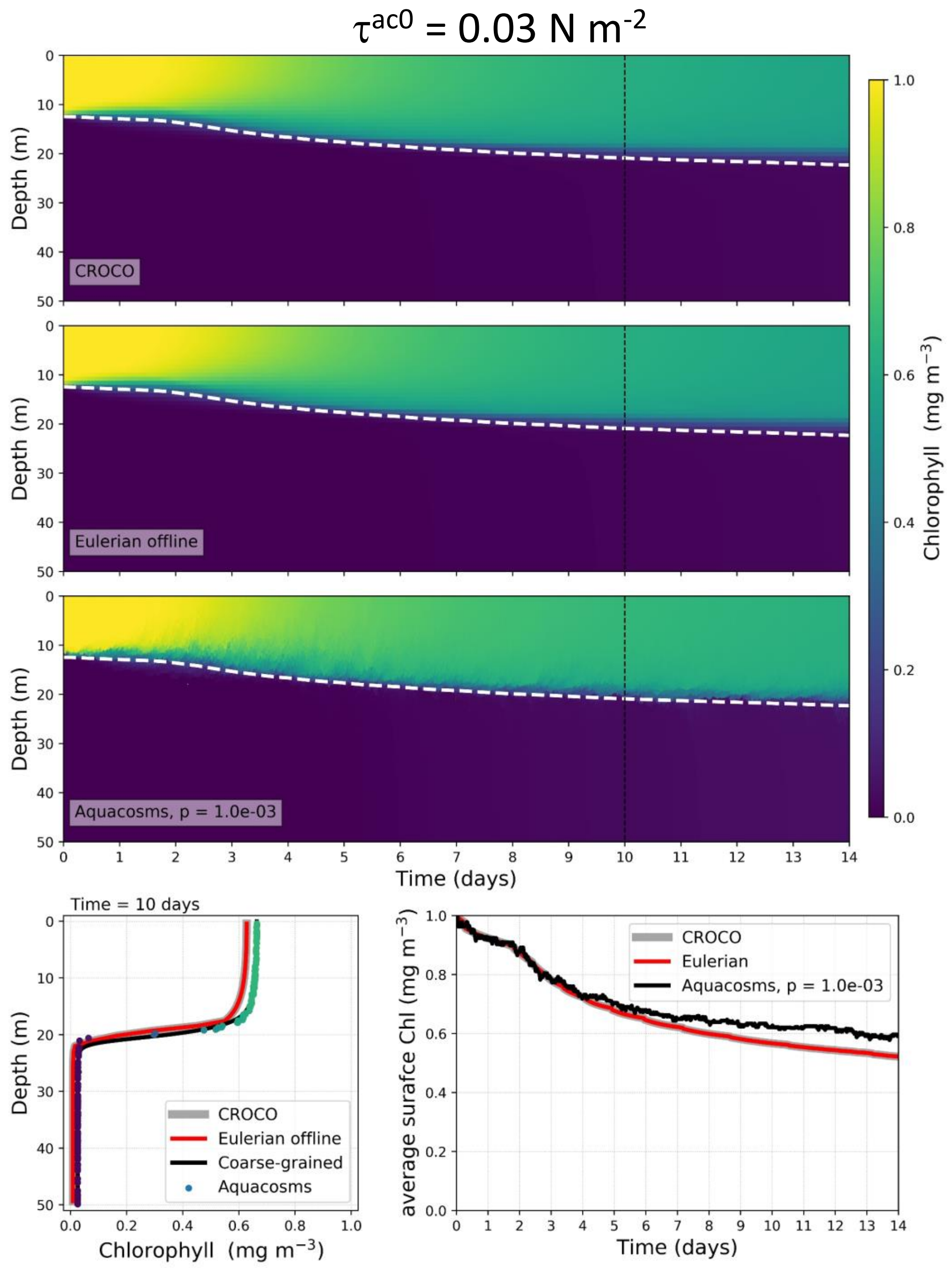
No Reactions

Initial Chl condition – 1 mg m^{-3} in surface layer, 0 mg m^{-3} in subsurface

$$\frac{\partial C}{\partial t} = \kappa \frac{\partial^2 C}{\partial z^2}$$

C = phytoplankton concentration (mg m^{-3})
κ = diffusivity (m^2 s^{-1})

Aquacosm model settings:
dt = 5 s
Npts = 200
radius = 10 m
p = 10^{-3}
Random walk method = ‘Milstein’



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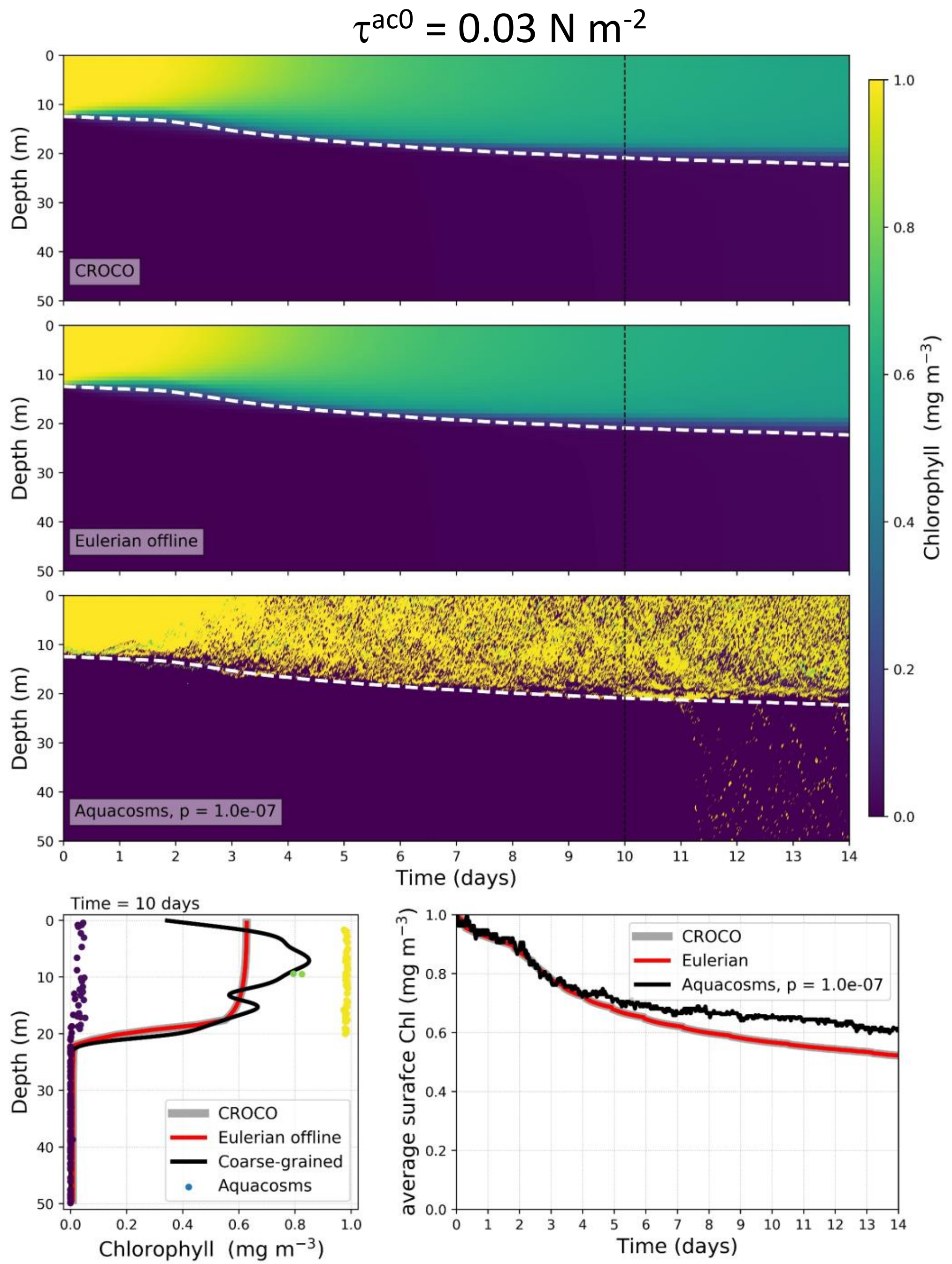
C = phytoplankton concentration (mg m^{-3})
κ = diffusivity (m^2 s^{-1})

Aquacosm model settings:
dt = 5 s
Npts = 200
radius = 10 m
p = 10^{-7}
Random walk method = 'Milstein'



Sverdrup

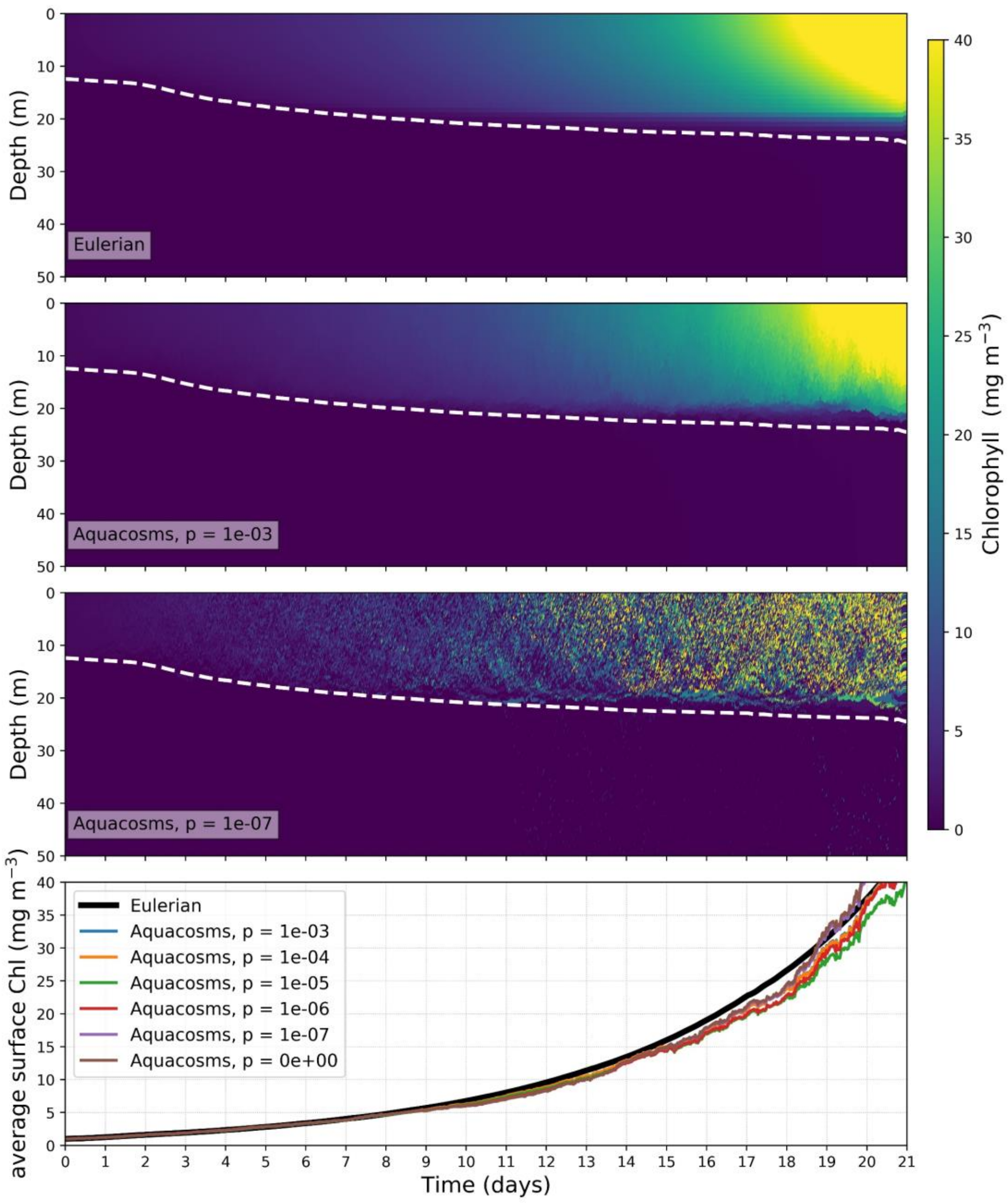
Initial Chl condition – 1 mg m^{-3} in surface layer, 0 mg m^{-3} in subsurface

$$\frac{\partial C}{\partial t} = \left(re^{-z\lambda} - \mu\right)C + \kappa\frac{\partial^2 C}{\partial z^2}$$

C = phytoplankton concentration (mg m^{-3})
r = maximum photosynthetic rate (1/day)
λ = light decay (m^{-1})
μ = respiration rate (1/day)
κ = diffusivity (m^2 s^{-1})

Model settings:
r = 1 days^{-1}
λ = 1/5 m^{-1}
μ = 0.1 days^{-1}

τ^{ac0} = 0.03 N m^{-2}



Sverdrup with carrying capacity

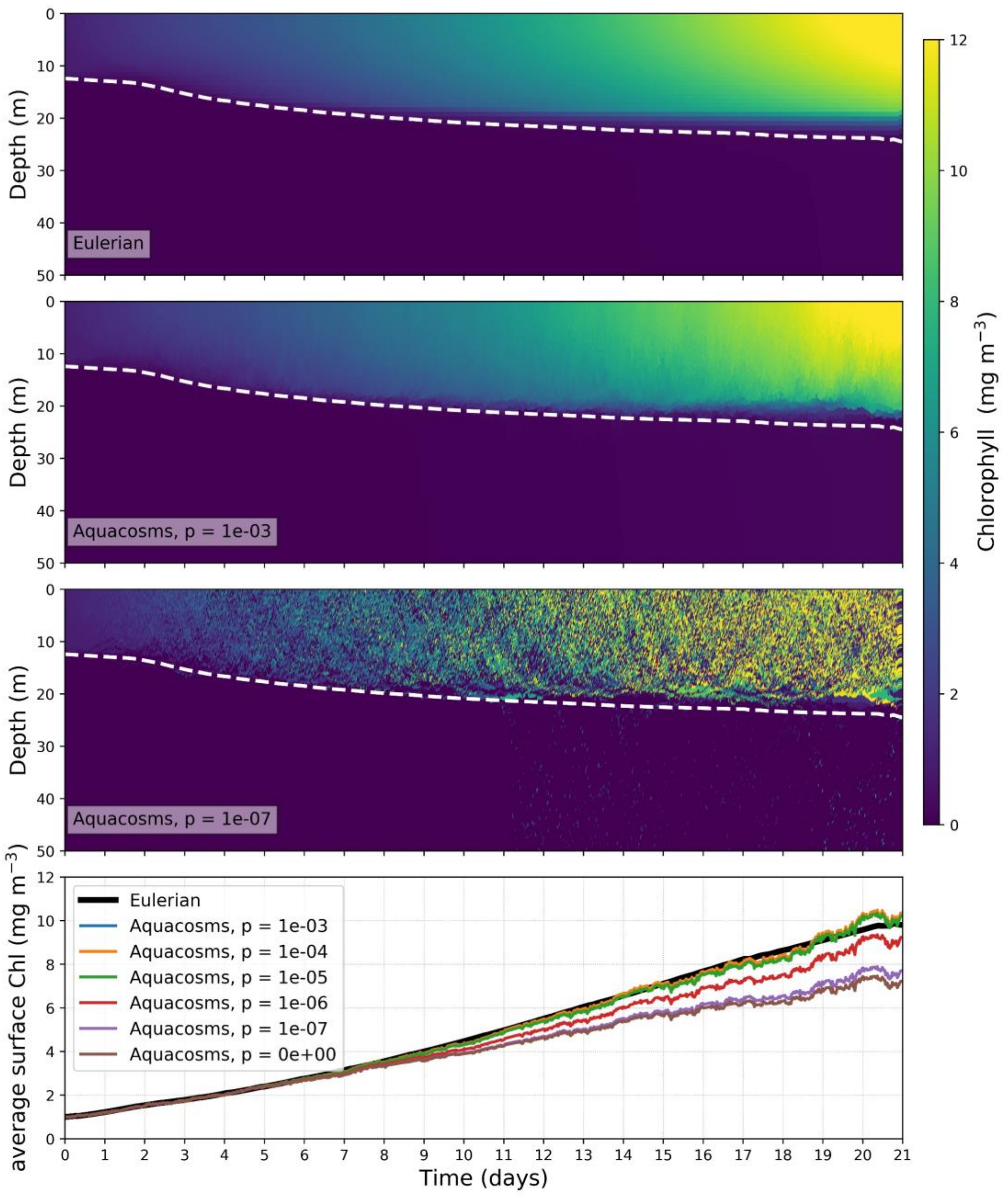
Initial Chl condition – 1 mg m^{-3} in surface layer, 0 mg m^{-3} in subsurface

$$\frac{\partial C}{\partial t} = (re^{-z\lambda} - \mu)\left(1 - \frac{C}{K}\right)C + \kappa\frac{\partial^2 C}{\partial z^2}$$

C = phytoplankton concentration (mg m^{-3})
r = maximum photosynthetic rate (1/day)
λ = light decay (m^{-1})
μ = respiration rate (1/day)
κ = diffusivity (m^2 s^{-1})
K = carrying capacity (mg m^{-3})

Model settings:
r = 1 days^{-1}
λ = 1/5 m^{-1}
μ = 0.1 days^{-1}
K = 20 mg m^{-3}

τ^{ac0} = 0.03 N m^{-2}



BioShading_onlyC

Initial Chl (L) condition – 1 mg m^{-3} in surface layer, 0 mg m^{-3} in subsurface.
Initial Carbon (C) = L / θ_{chl}

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left(\kappa(z,t)\frac{\partial C}{\partial z}\right) + \dot{C}.$$

where $\dot{C} = rf^E C - bC - \dfrac{aC^2}{C_h + C}$

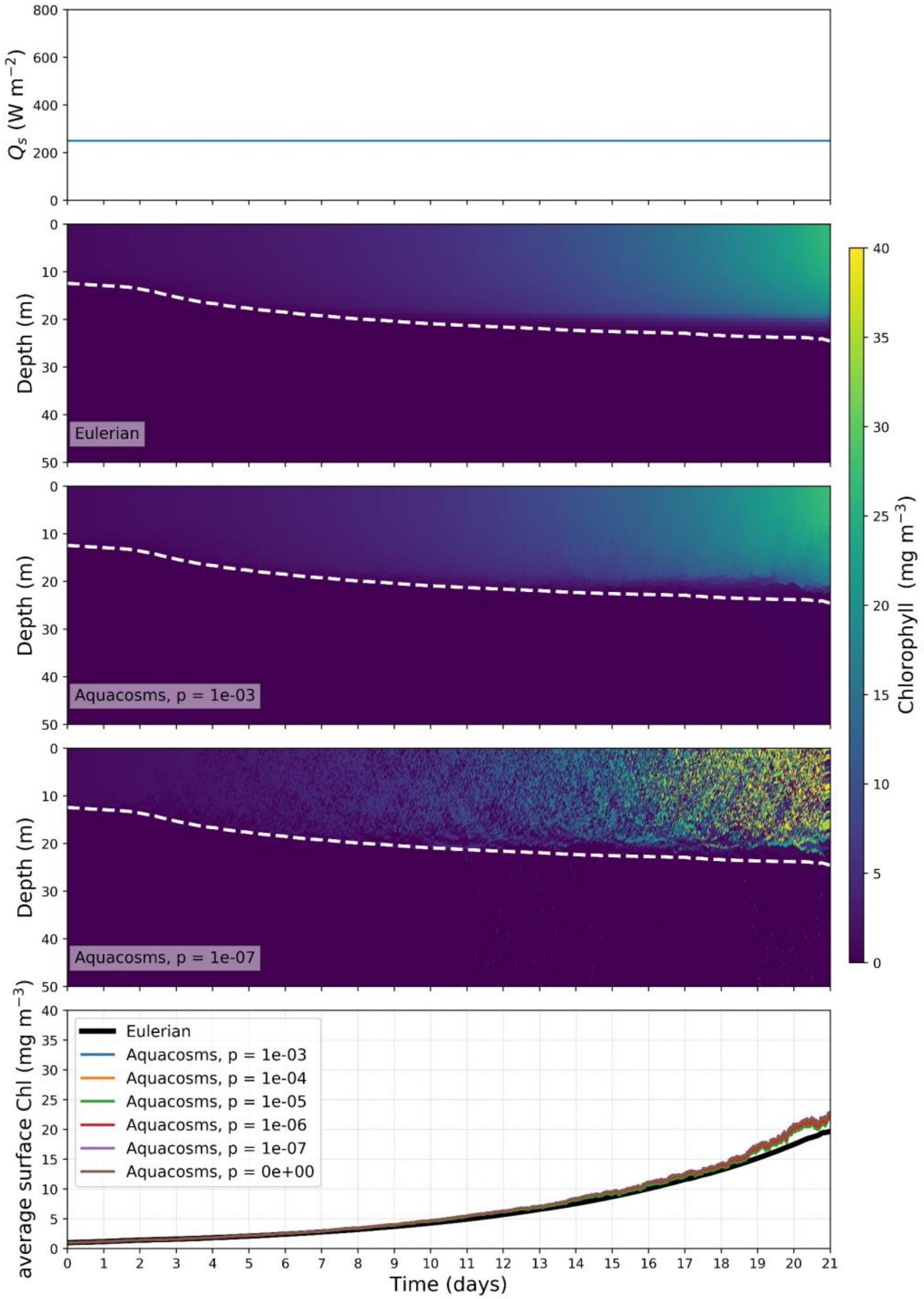
where $f^E = 1 - \exp\left(-\dfrac{\alpha E_{PAR}}{r}\theta_{chl}\right)$

where $E_{PAR}(z) = \varepsilon_{PAR}\ Q_S\, e^{\lambda_w z + \int_z^0 \lambda_{bio}(z')dz'}$

where $\lambda_{bio} = cL$, $L = \theta_{chl} C$

Model settings:
θ_{chl} = 0.017
r = 0.5 days^{-1}
λ_w = 1/5 m^{-1} (as per Sverdrup experiments)
c = 0 m^2 mg chl^{-1} (i.e. no bioshading)
b = 0.16 days^{-1}
a = 0.1 days^{-1}

τ^{ac0} = 0.03 N m^{-2}



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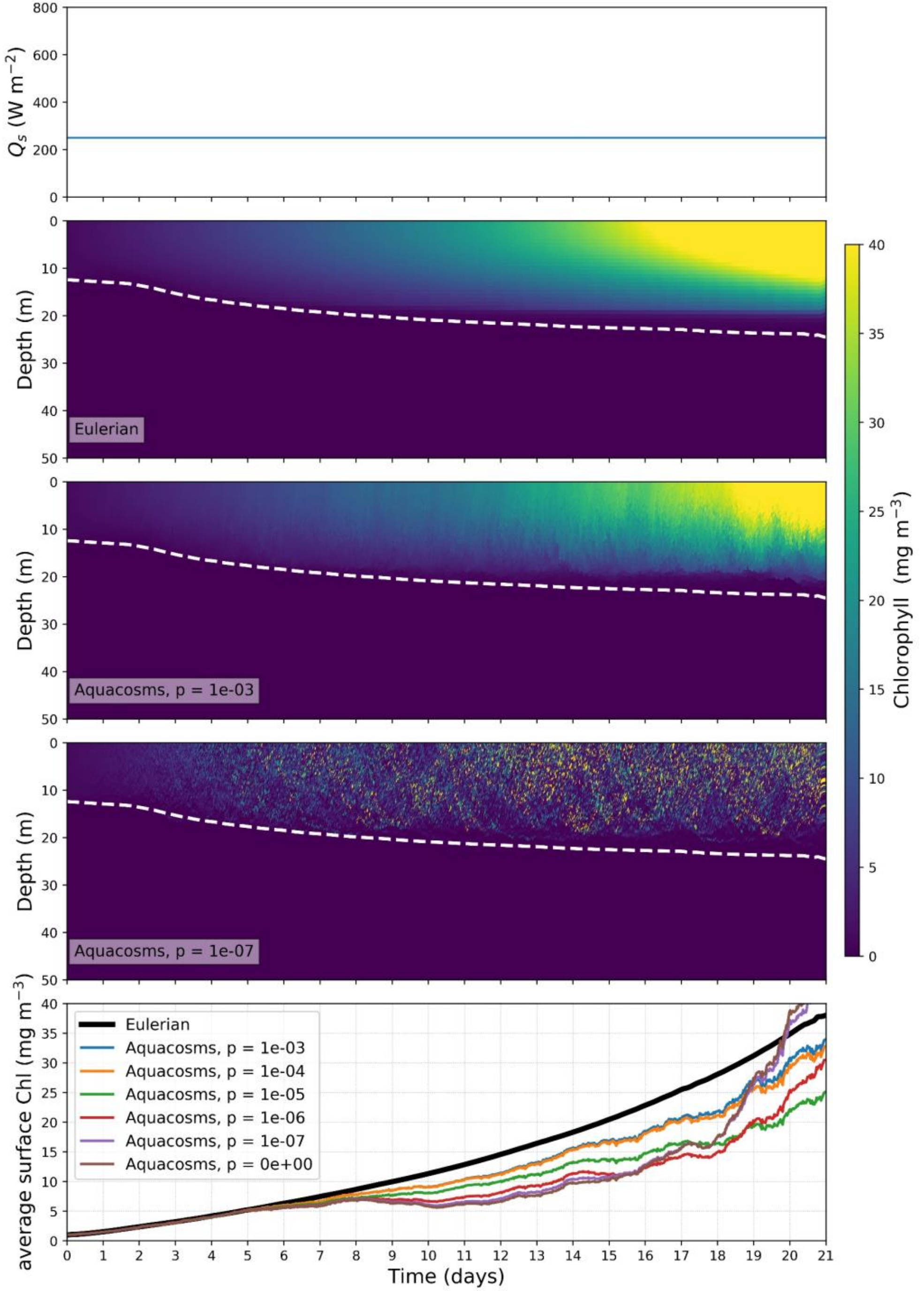
where $\lambda_{bio} = cL$, $L = \theta_{chl}C$

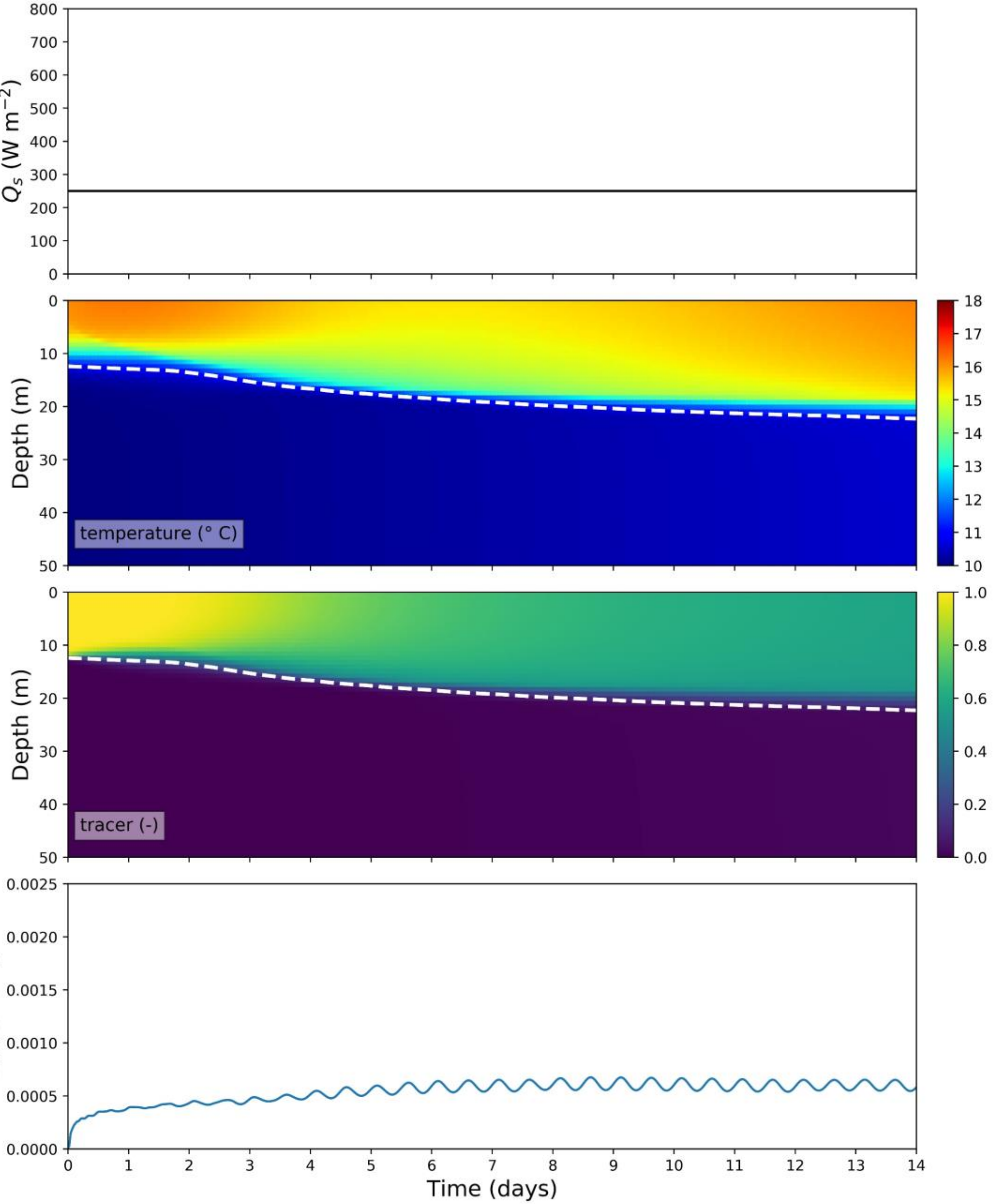
Model settings:
θ_{chl} = 0.017
r = 2 days^{-1}
λ_w = 1/5 m^{-1} (as per Sverdrup experiments)
c = 0 m^2 mg chl^{-1} (i.e. no bioshading)
b = 0.16 days^{-1}
a = 1 days^{-1}

τ^{ac0} = 0.03 N m^{-2}

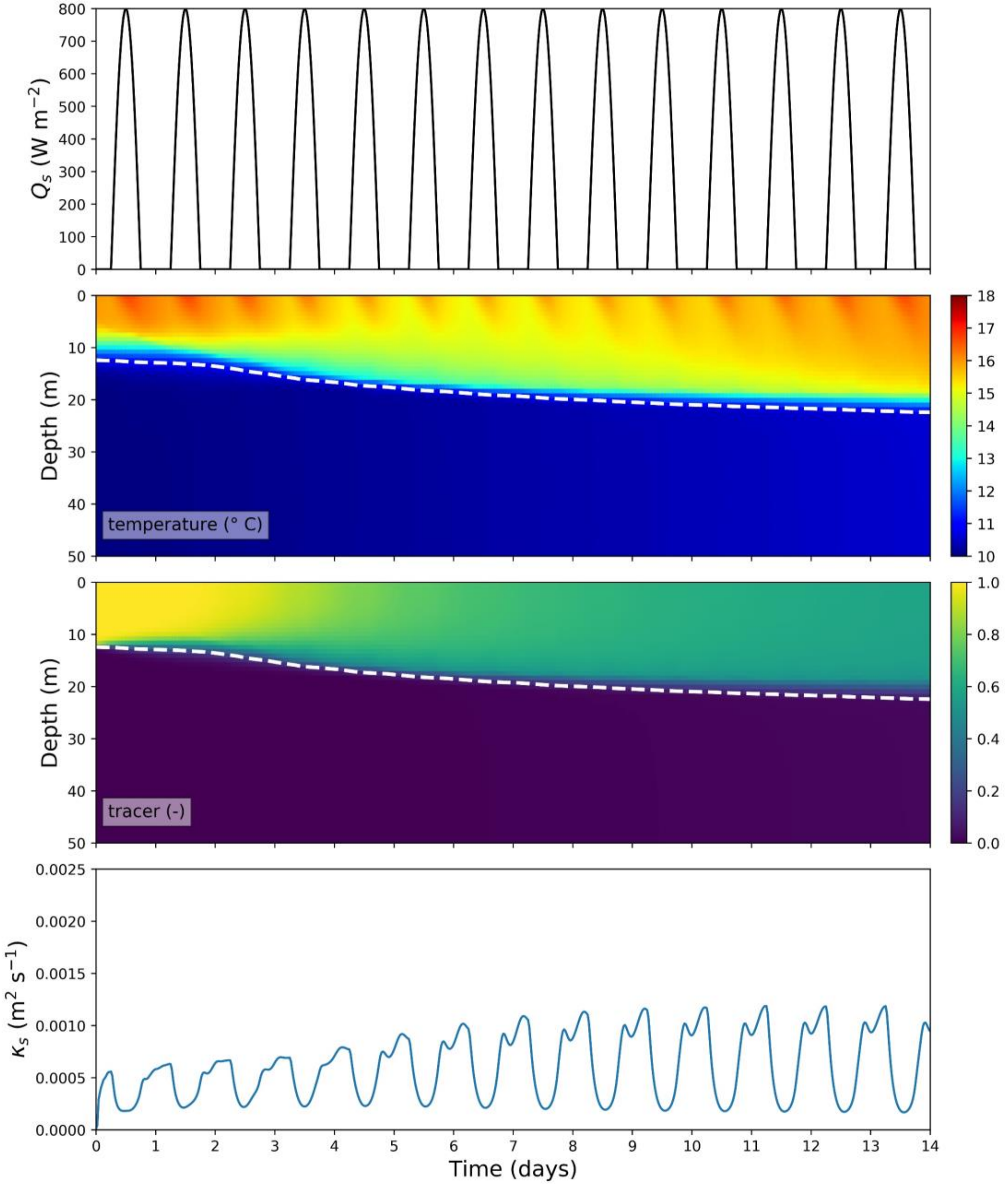


Impact of diurnal surface heat fluxes

τ^{ac0} = 0.03 N m^{-2}, τ^{mean} = 0 N m^{-2}

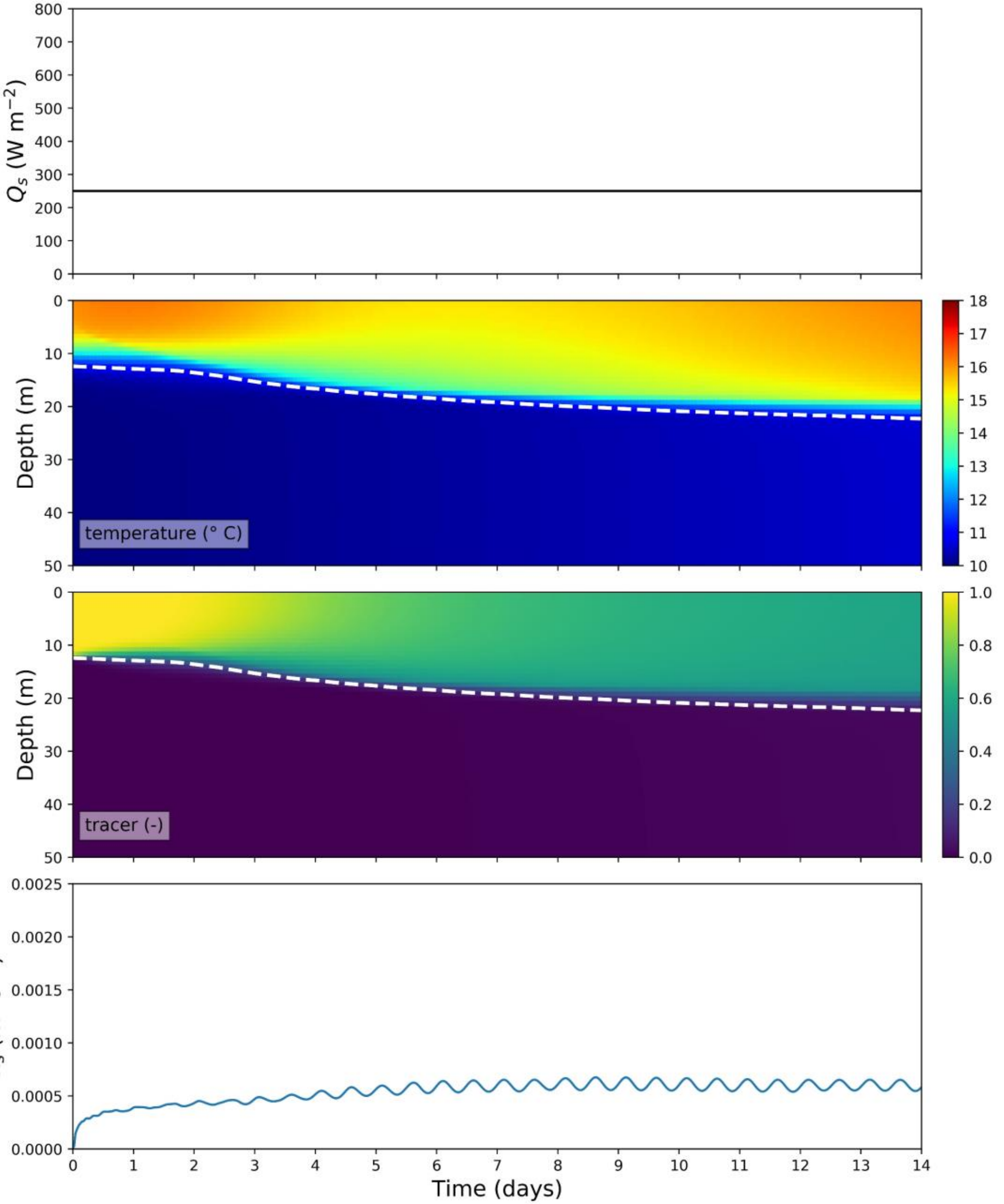


τ^{ac0} = 0.03 N m^{-2}, τ^{mean} = 0 N m^{-2}

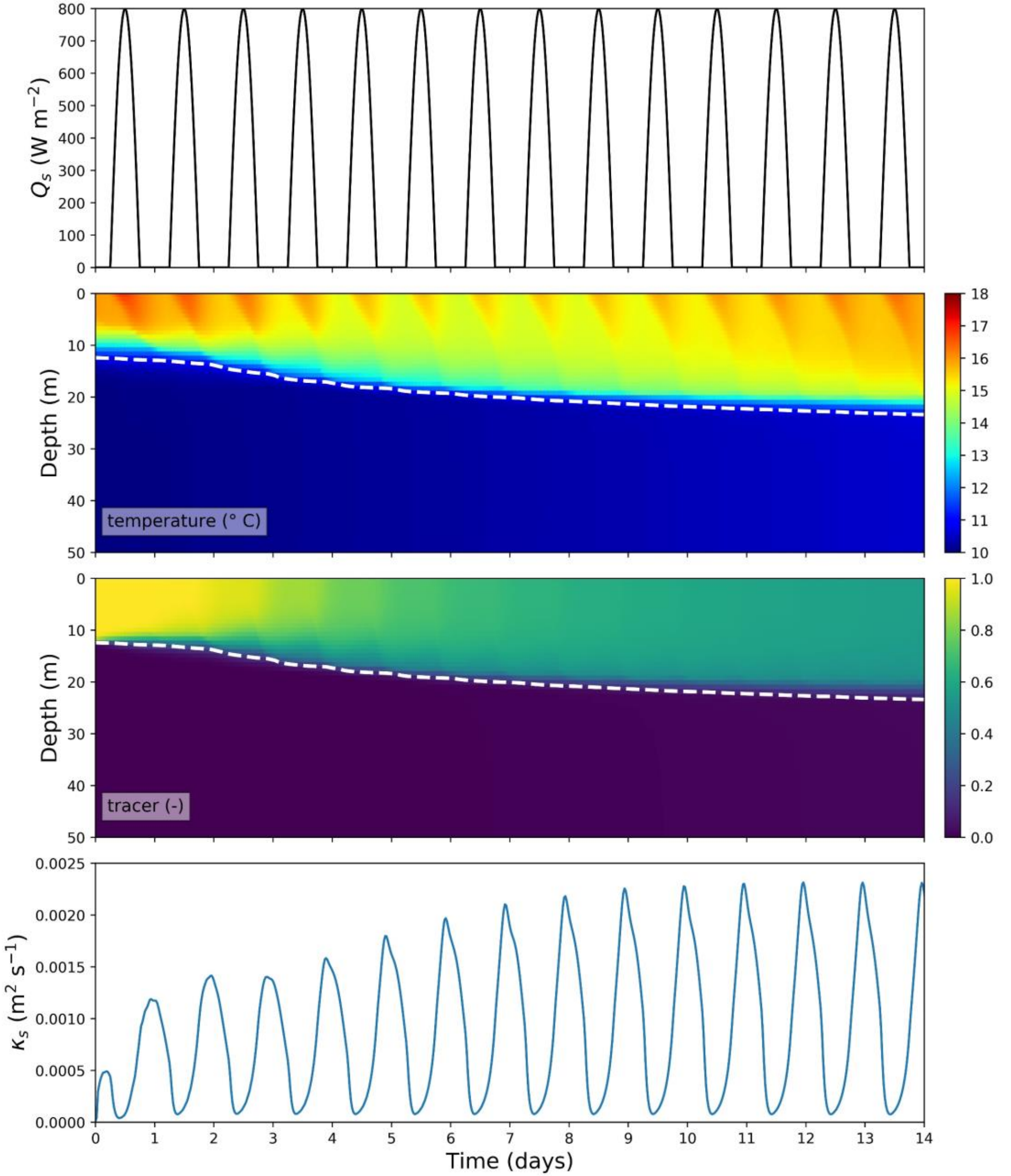


Impact of diurnal surface heat fluxes and a mean alongshore wind stress

τ^{ac0} = 0.03 N m^{-2}, τ^{mean} = 0 N m^{-2}



τ^{ac0} = 0.03 N m^{-2}, τ^{mean} = 0.05 N m^{-2}



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Model settings:
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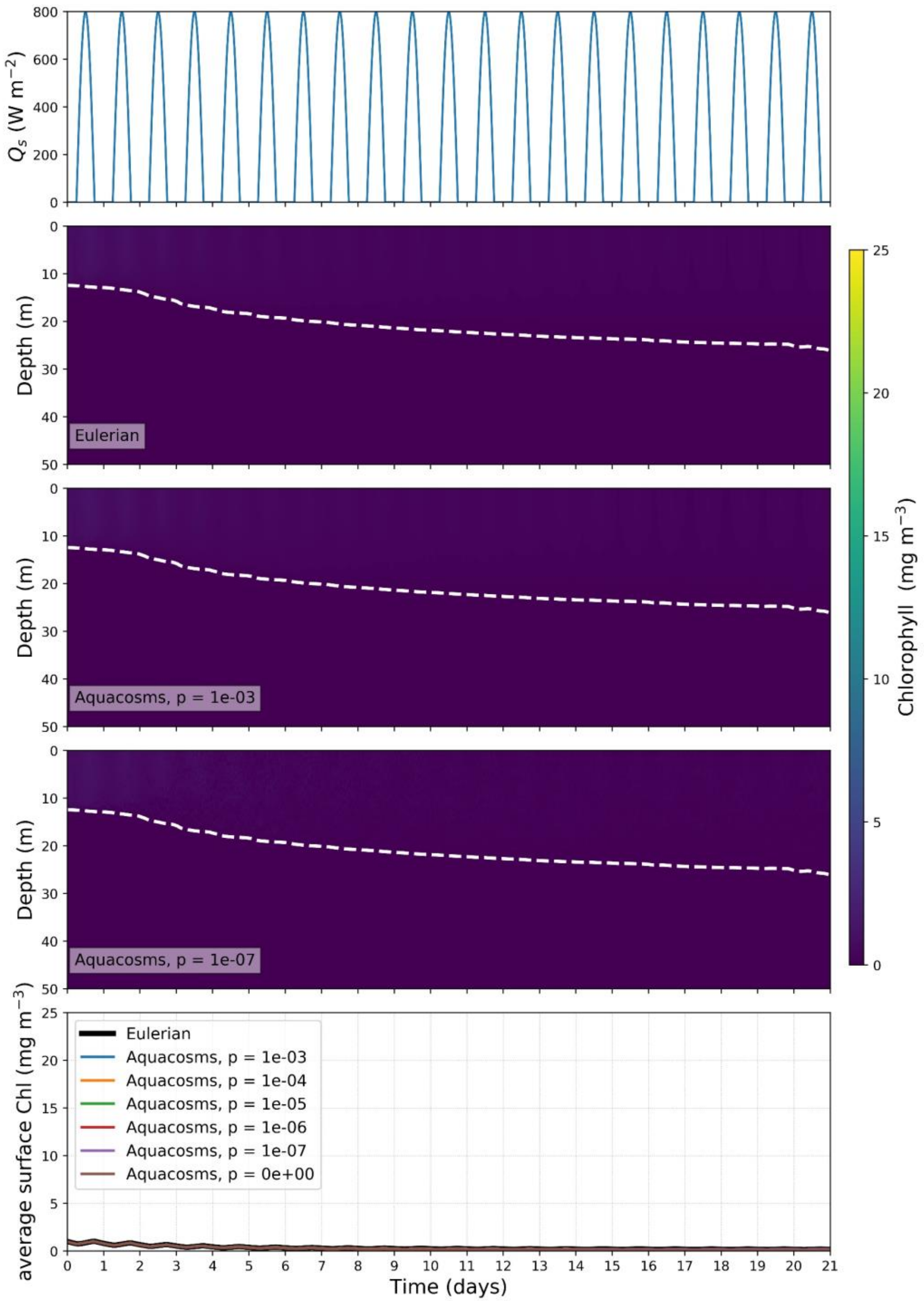
a = 1 days^{-1}

τ^{ac0} = 0.03 N m^{-2}, τ^{mean} = 0.05 N m^{-2}



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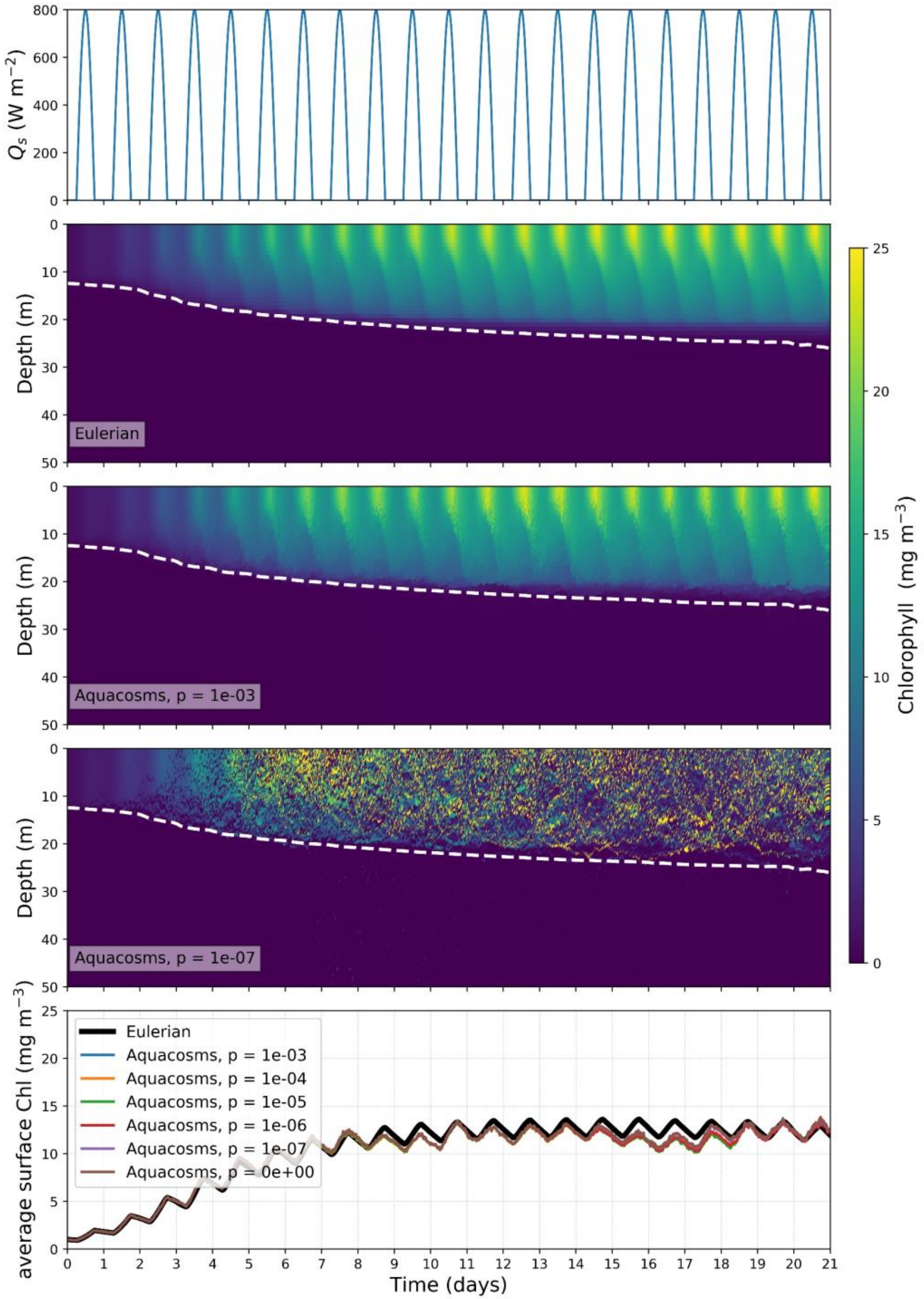
where $E_{PAR}(z) = \varepsilon_{PAR}\ Q_S\, e^{\lambda_w z + \int_z^0 \lambda_{bio}(z')dz'}$

where $\lambda_{bio} = cL$, $L = \theta_{chl} C$

Model settings:
θ_{chl} = 0.017
r = 2 days^{-1}
λ_w = 1/23 m^{-1} (clear water)
c = 0.03 m^{2} mg chl^{-1} (i.e. including bioshading)
b = 0.16 days^{-1}
a = 0.1 days^{-1}

τ^{ac0} = 0.03 N m^{-2}, τ^{mean} = 0.05 N m^{-2}



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b = 0.16 days^{-1}
a = 0.1 days^{-1}

$$\varepsilon = \frac{R\ell^2}{\kappa_s}$$

where ℓ =thermocline depth (maybe better to use euphotic depth?)
$R = \dot{C}/C$, averaged over ℓ
κ_s =κ averaged over ℓ