# Air-Sea $CO_2$ flux

Takahashi et al. 2009

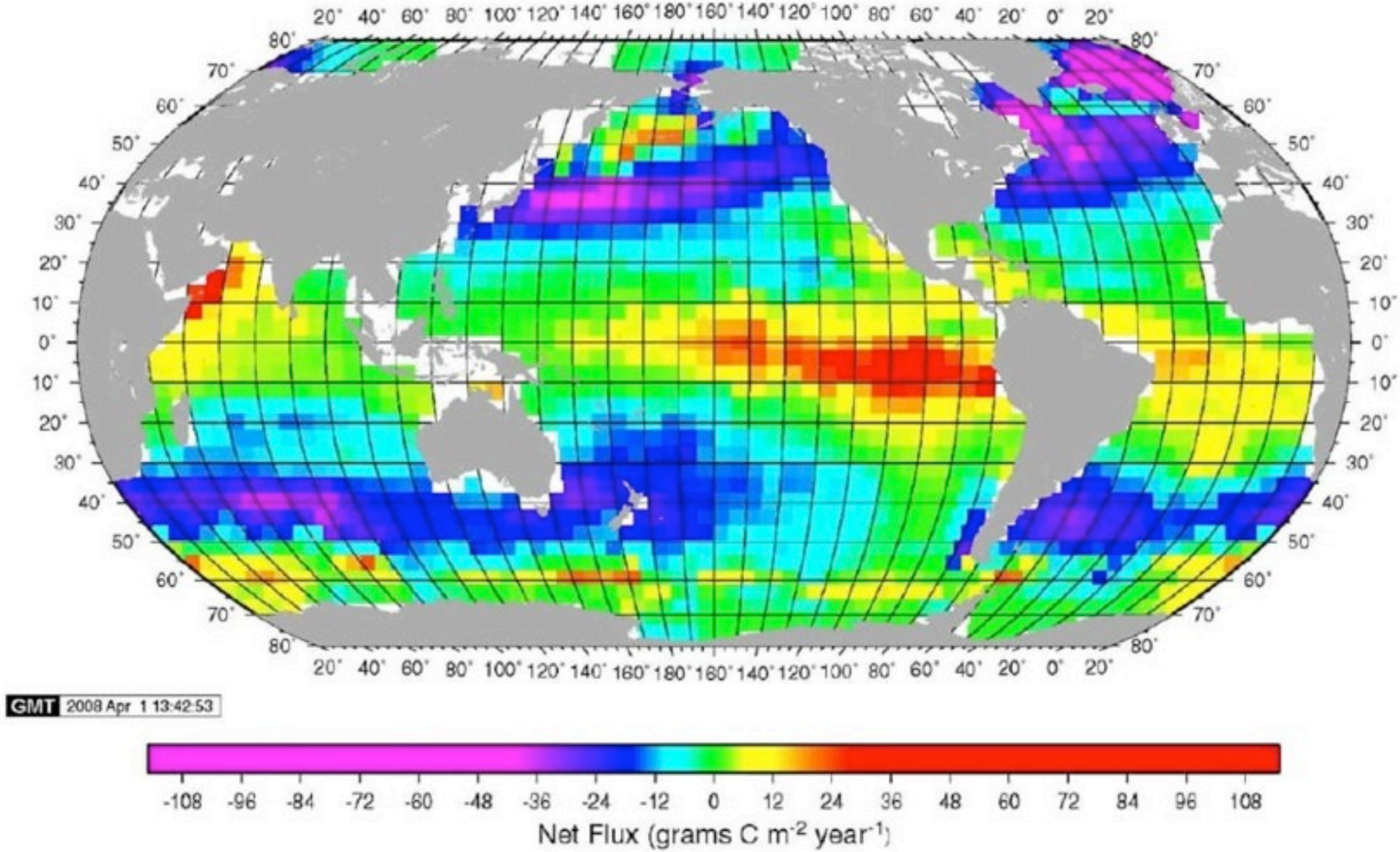
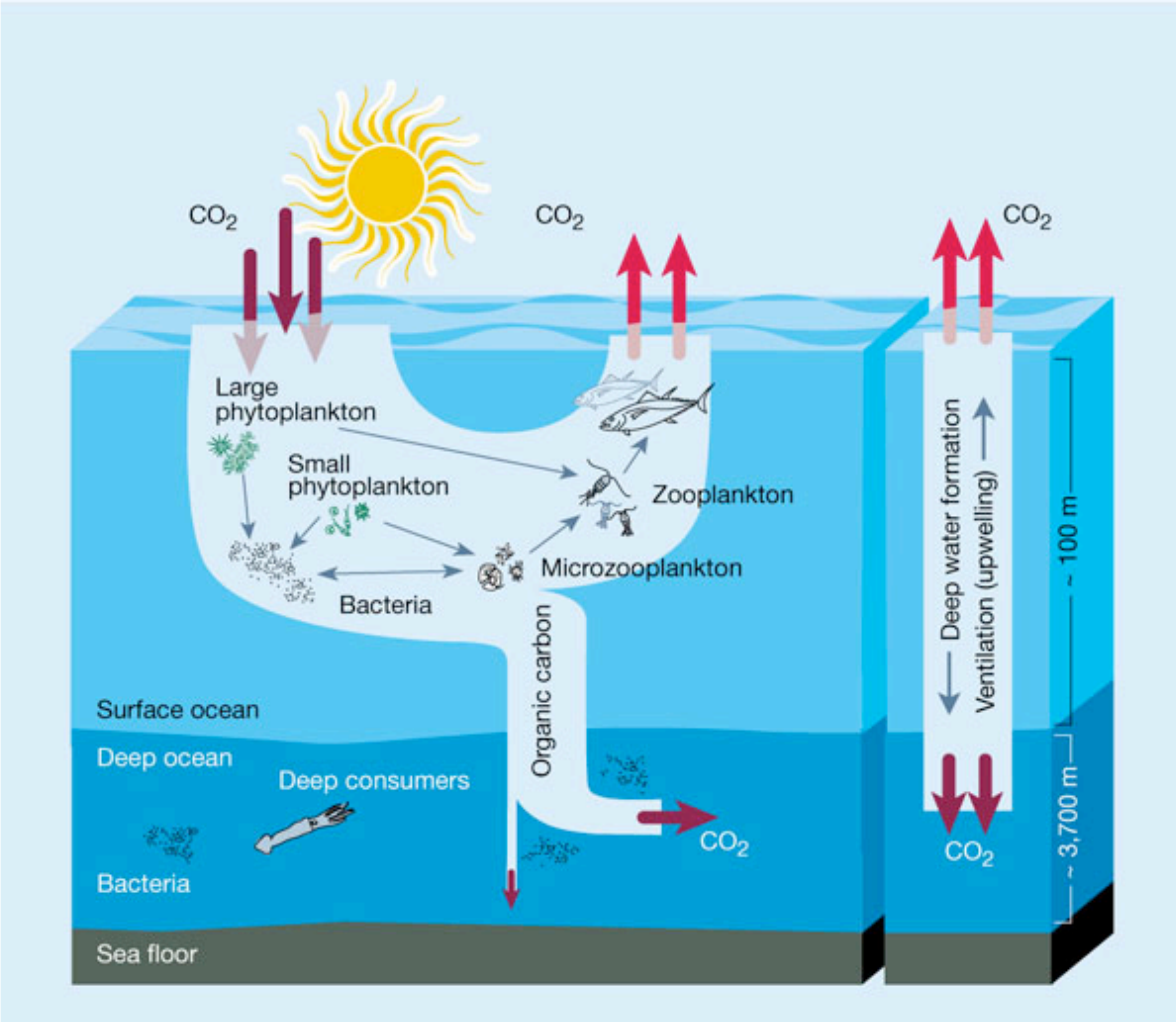
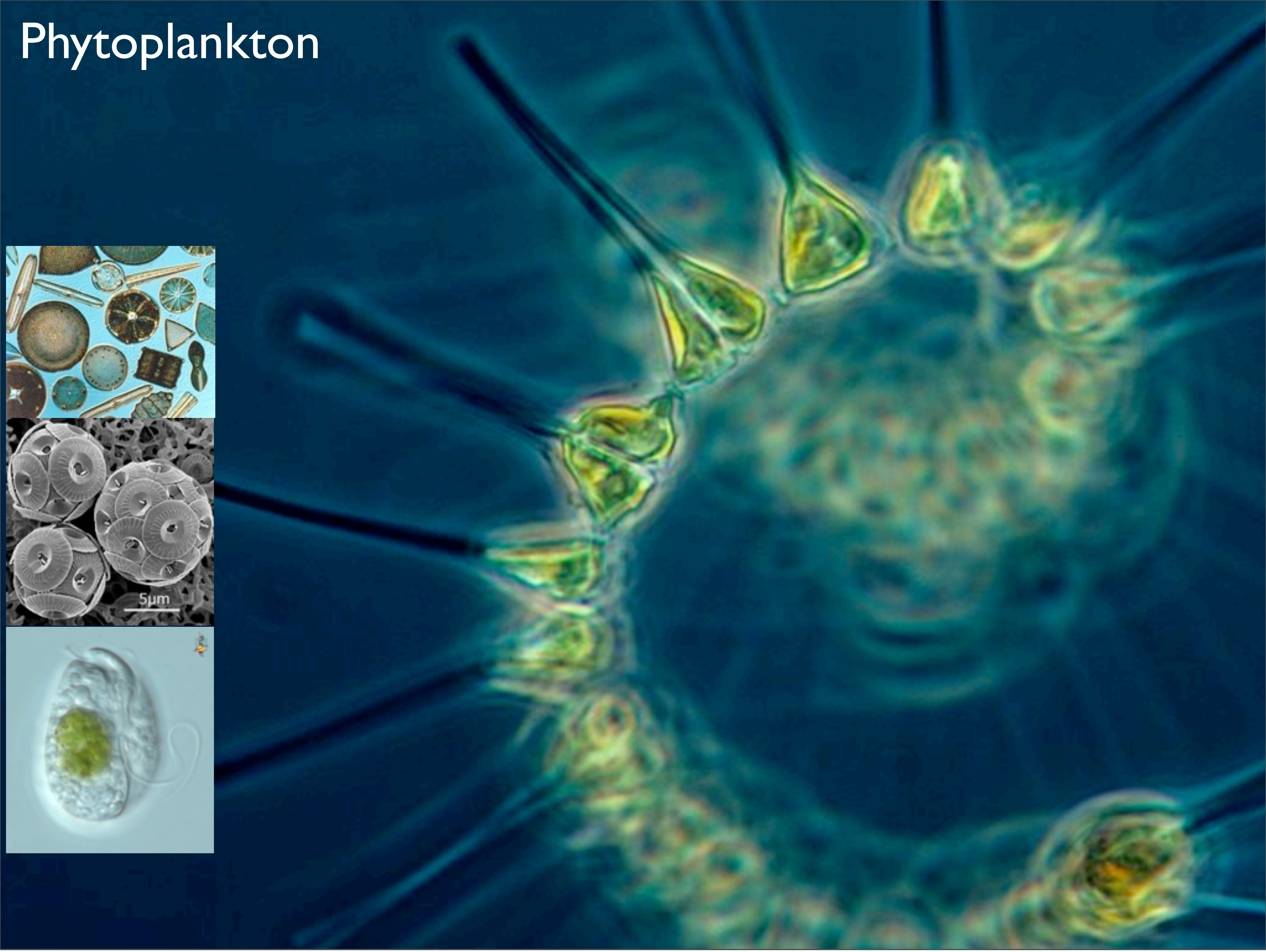


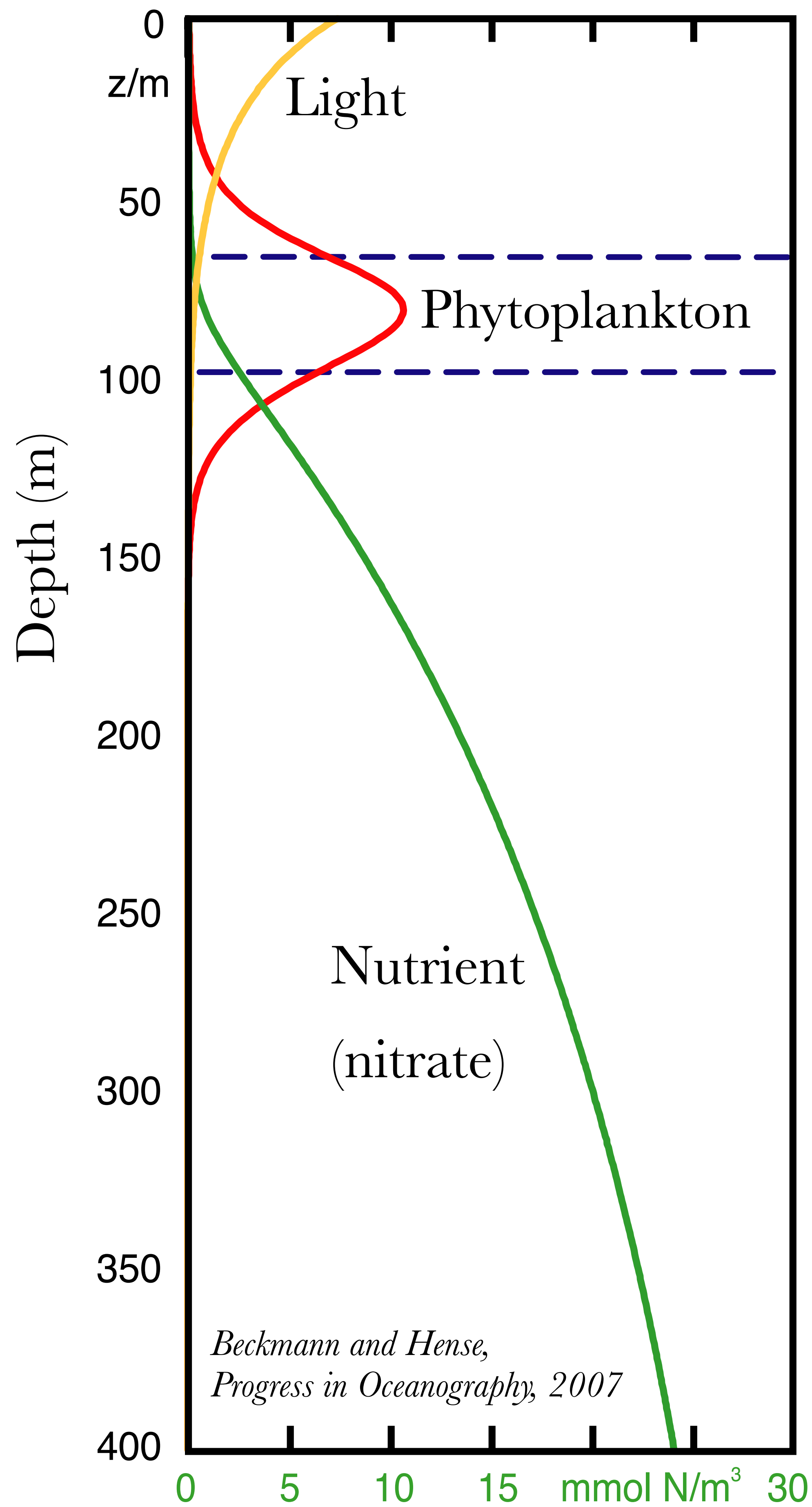

**Fig. 13.** Climatological mean annual sea–air $CO_2$ flux (g-C $m^{-2} yr^{-1}$) for the reference year 2000 (non-El Niño conditions). The map is based on 3.0 million surface water $pCO_2$ measurements obtained since 1970. Wind speed data from the 1979–2005 NCEP-DOE AMIP-II Reanalysis (R-2) and the gas transfer coefficient with a scaling factor of 0.26 (Eq. (8)) are used. This yields a net global air-to-sea flux of 1.42 Pg-C $y^{-1}$.

# Ocean carbon cycle



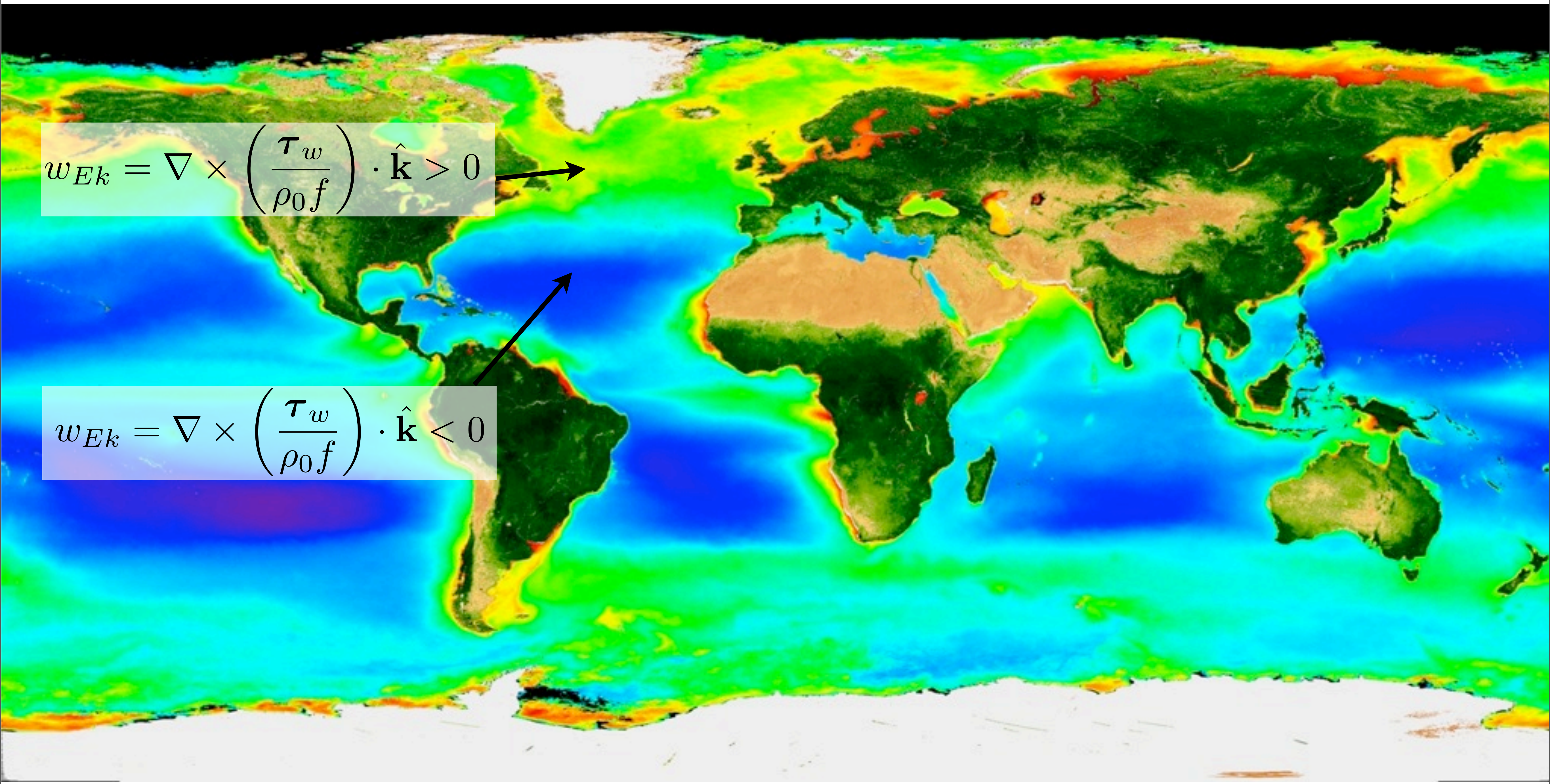
# Phytoplankton



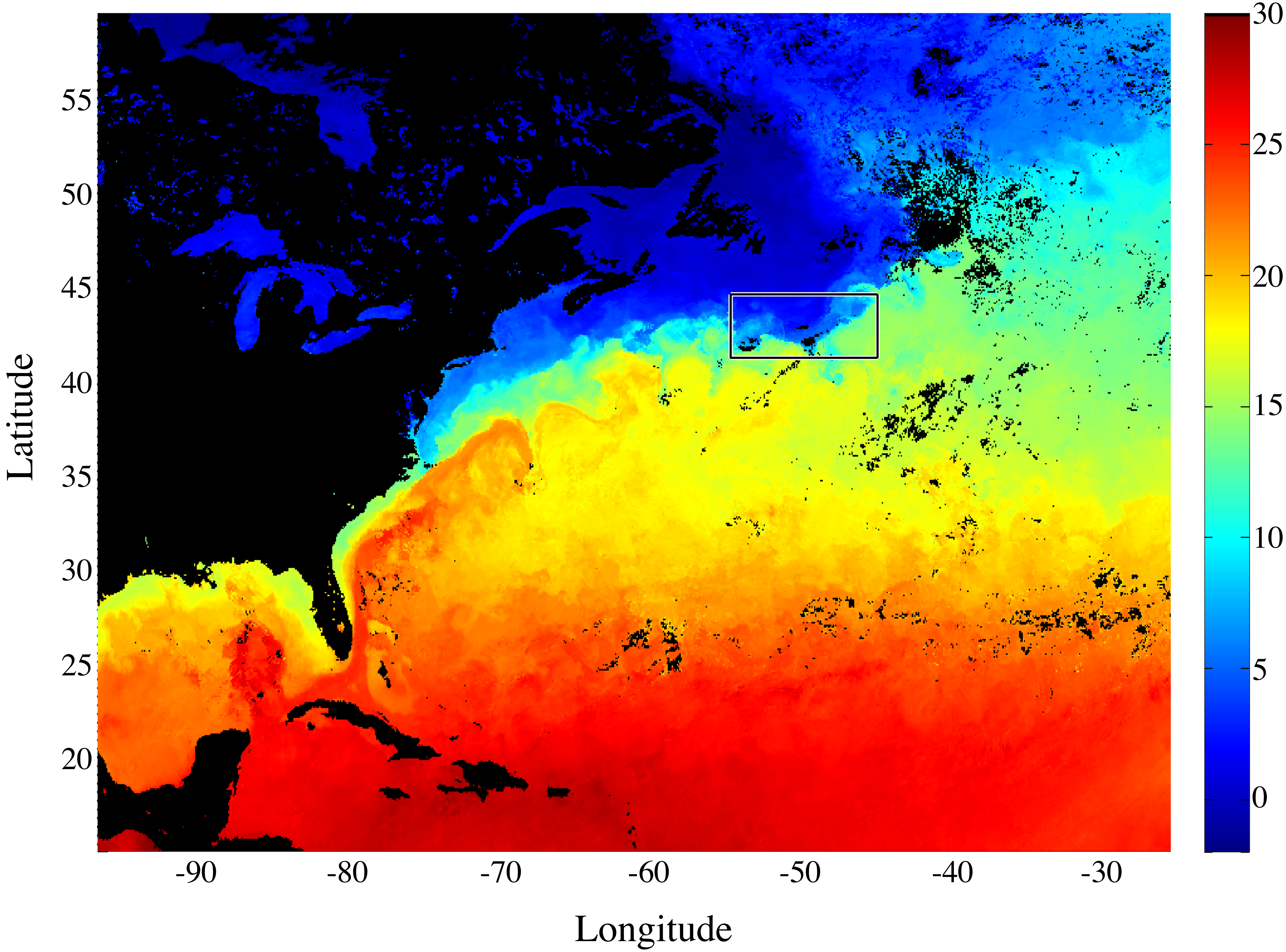


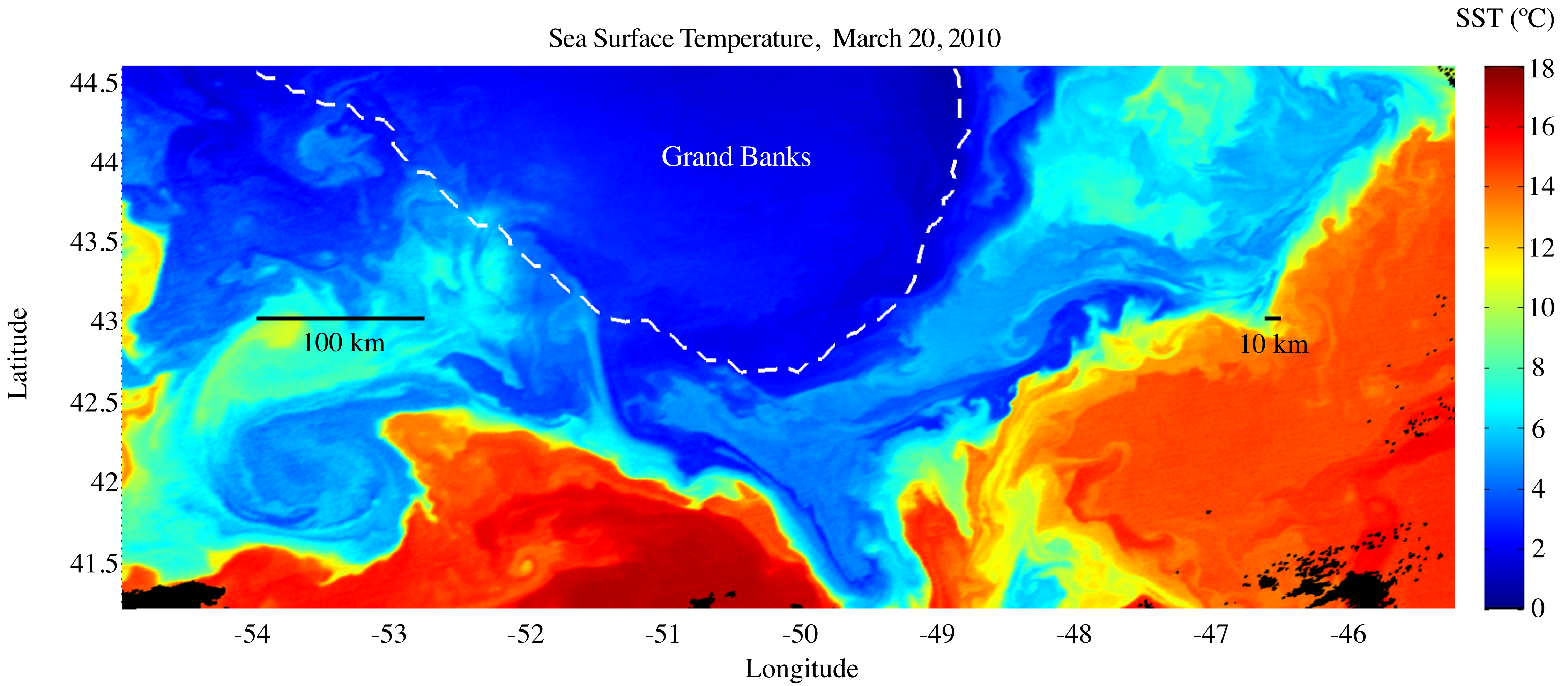

"deep chlorophyll maximum"

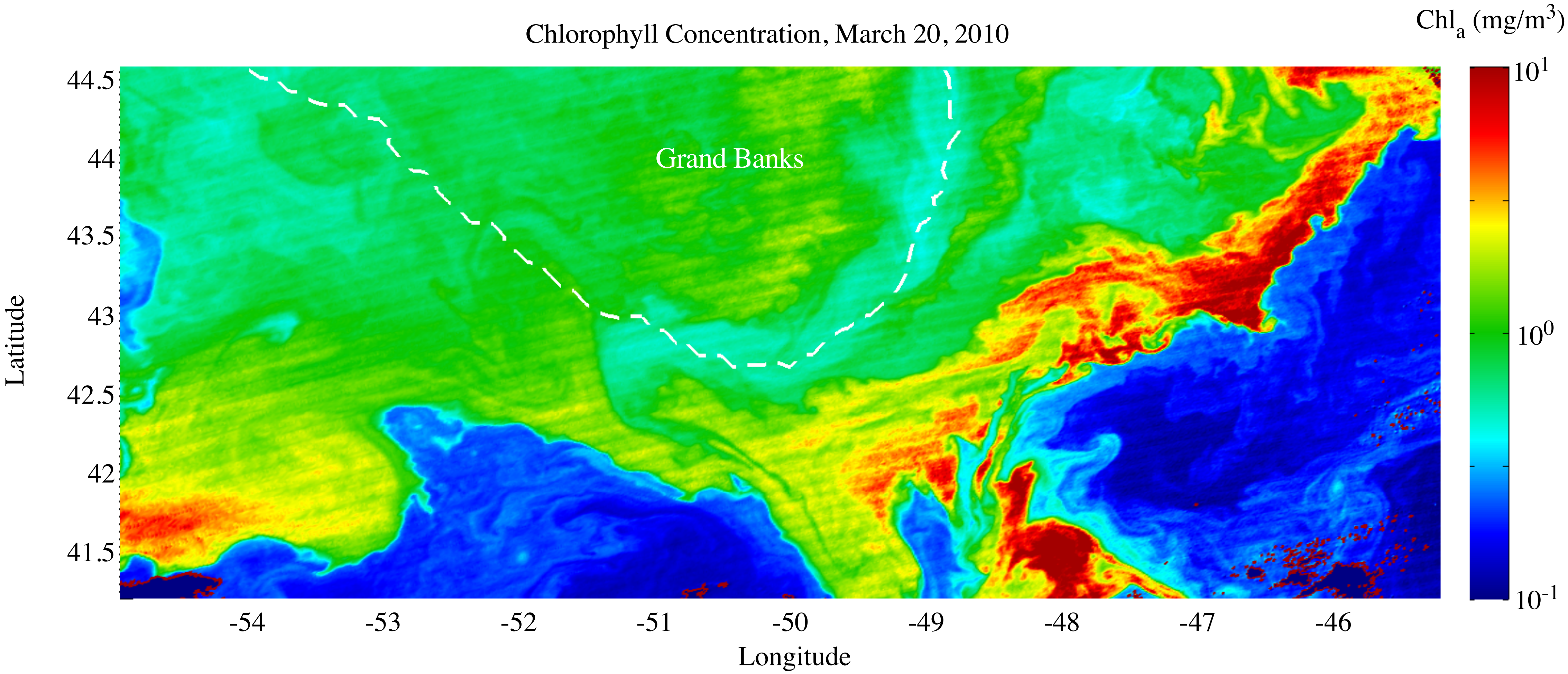
# Chlorophyll concentration



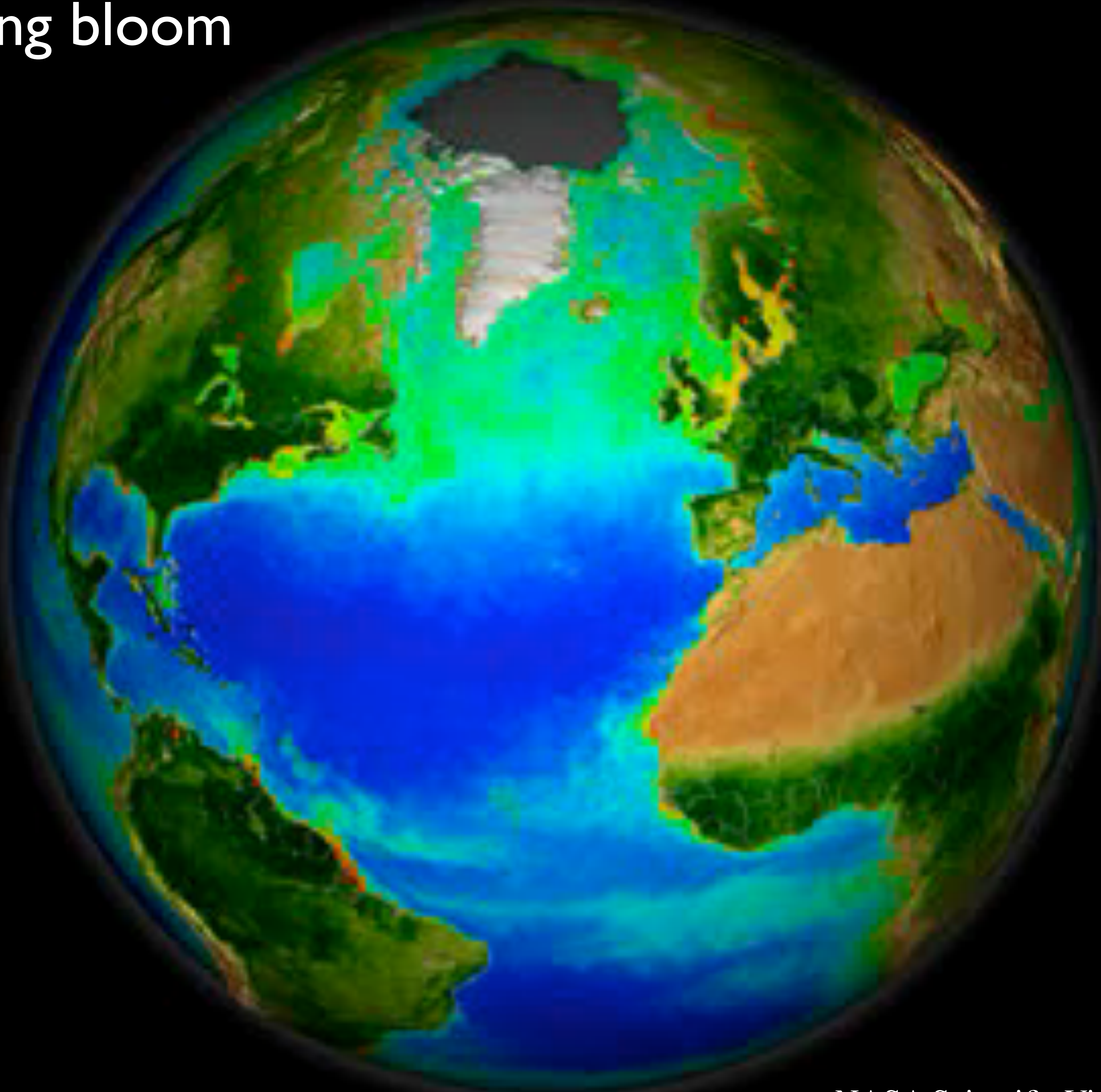
# Sea Surface Temperature (SST) (ºC), March 14-21, 2010




Sea Surface Temperature, March 20, 2010
SST (ºC)
Grand Banks
100 km
10 km
Latitude
Longitude
44.5
44
43.5
43
42.5
42
41.5
-54
-53
-52
-51
-50
-49
-48
-47
-46
18
16
14
12
10
8
6
4
2
0

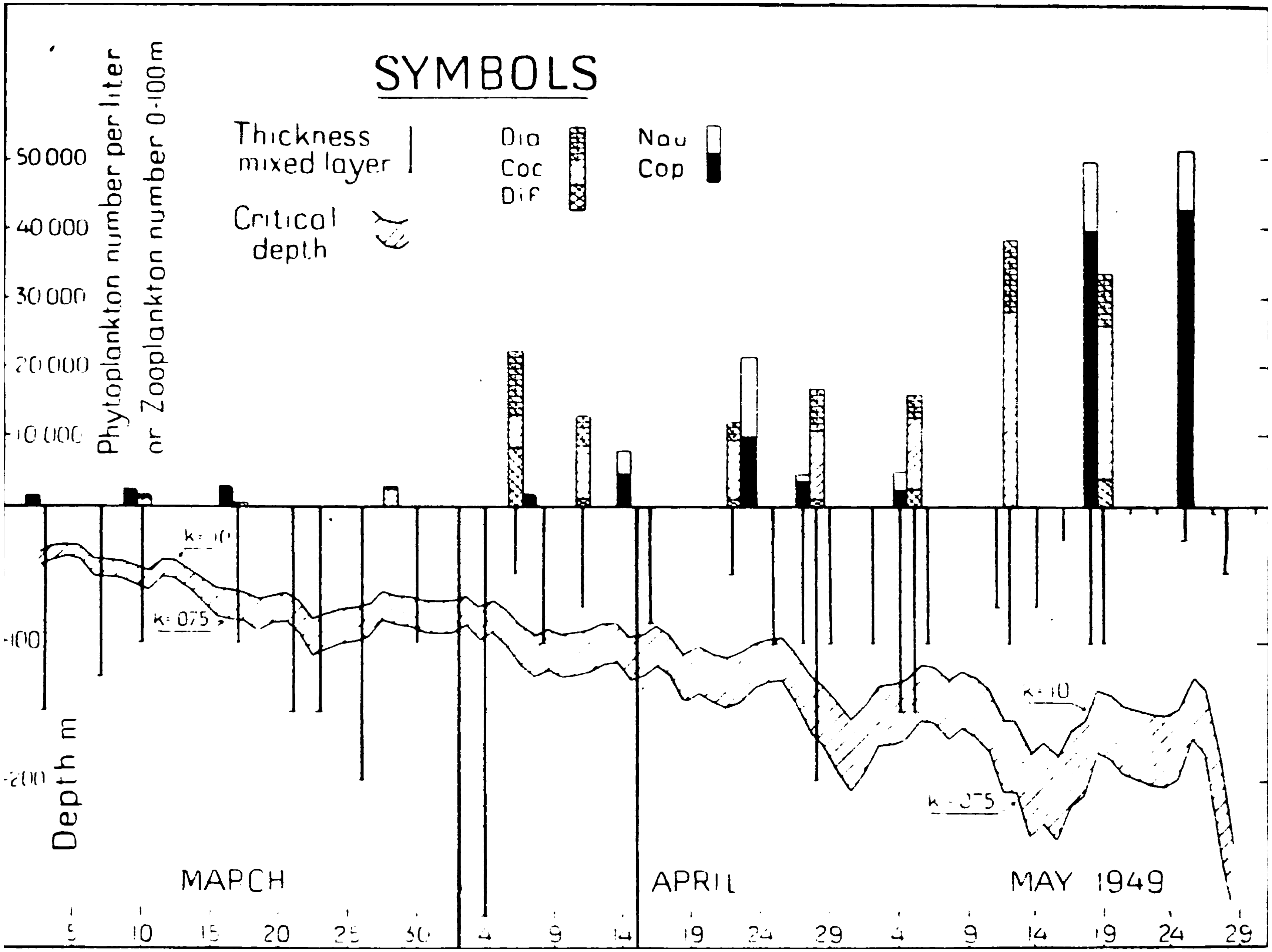

Chlorophyll Concentration, March 20, 2010
$Chl_a$ ($mg/m^3$)
Grand Banks
Latitude
Longitude
44.5
44
43.5
43
42.5
42
41.5
-54
-53
-52
-51
-50
-49
-48
-47
-46
$10^1$
$10^0$
$10^{-1}$

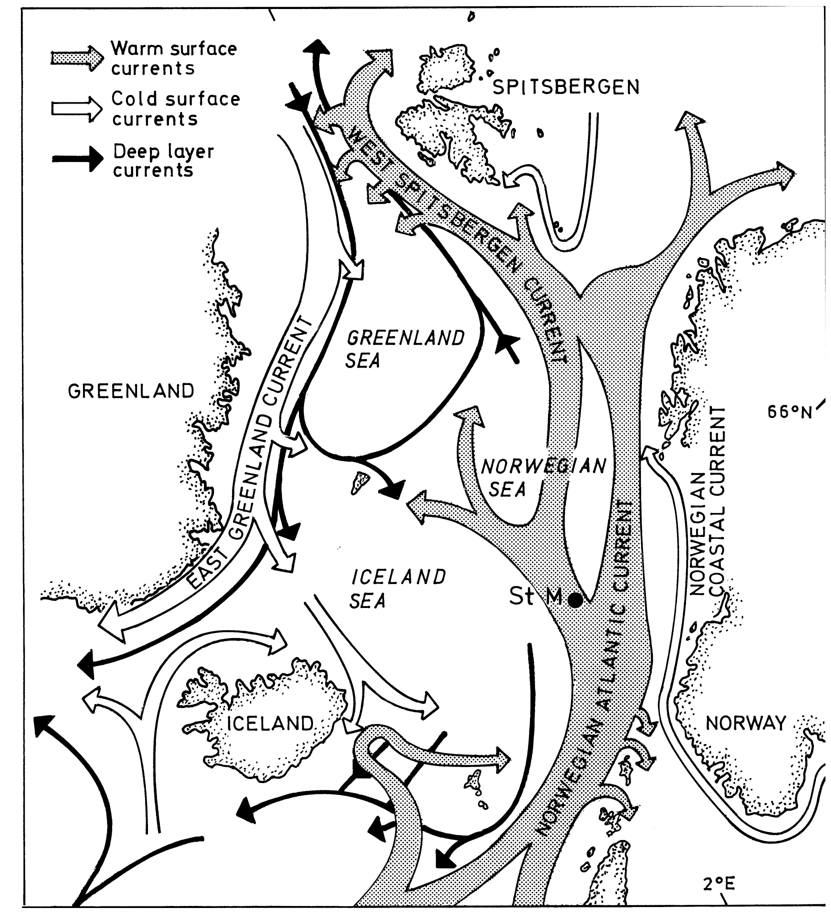
# Spring bloom



NASA Scientific Visualization Studio

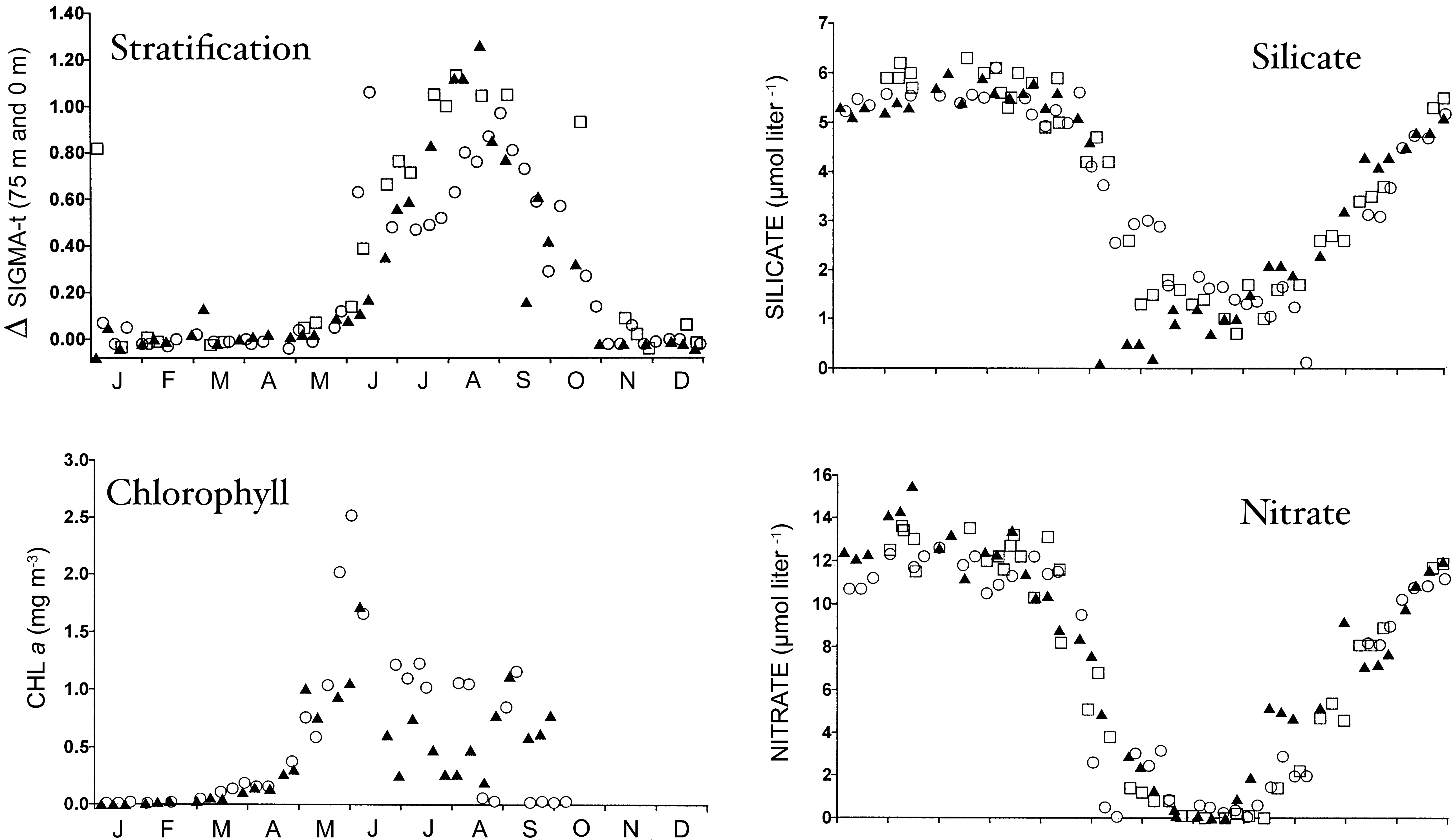
Sverdrup, H.U. 1953. On the conditions for the Vernal blooming of phytoplankton.




Dale et al. 1999

# Dale et al. 1999, Weather Station M (66°N, 2°E)



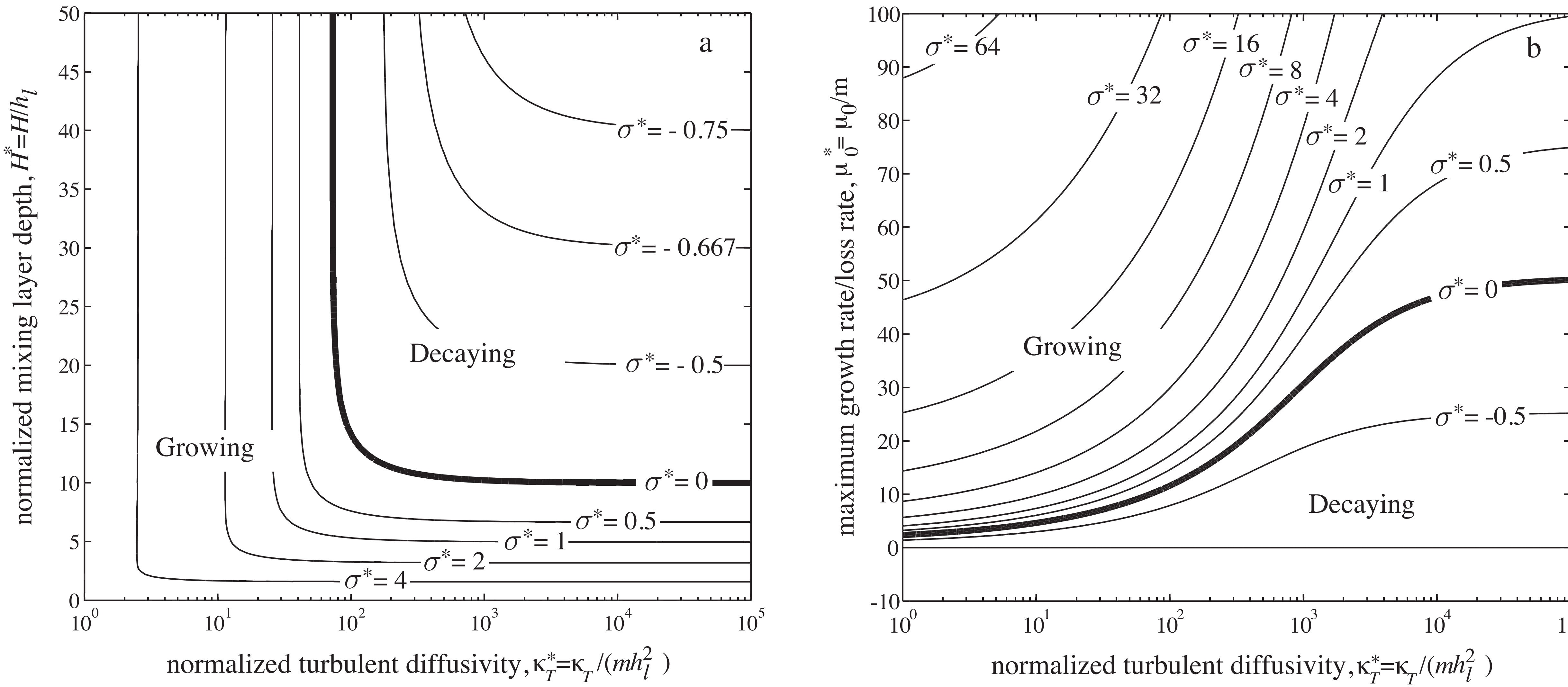



Fig. 3. Normalized maximum achieved growth rate, $\sigma^* = \sigma / m$, as a function of (a) the turbulent diffusivity, $\kappa_T^* = \kappa_T / m h_1^2$, and mixing-layer depth, $H^* = H / h_1$ for $\mu_0^* = \mu_0 / m = 10$, and (b) as a function of $\kappa_T^*$ and $\mu_0^*$ for $H^* = 50$. The achieved growth rate has been found by solving Eq. 2 with no flux boundary conditions at the surface ($z = 0$) and base of the mixing layer ($z = -H$).

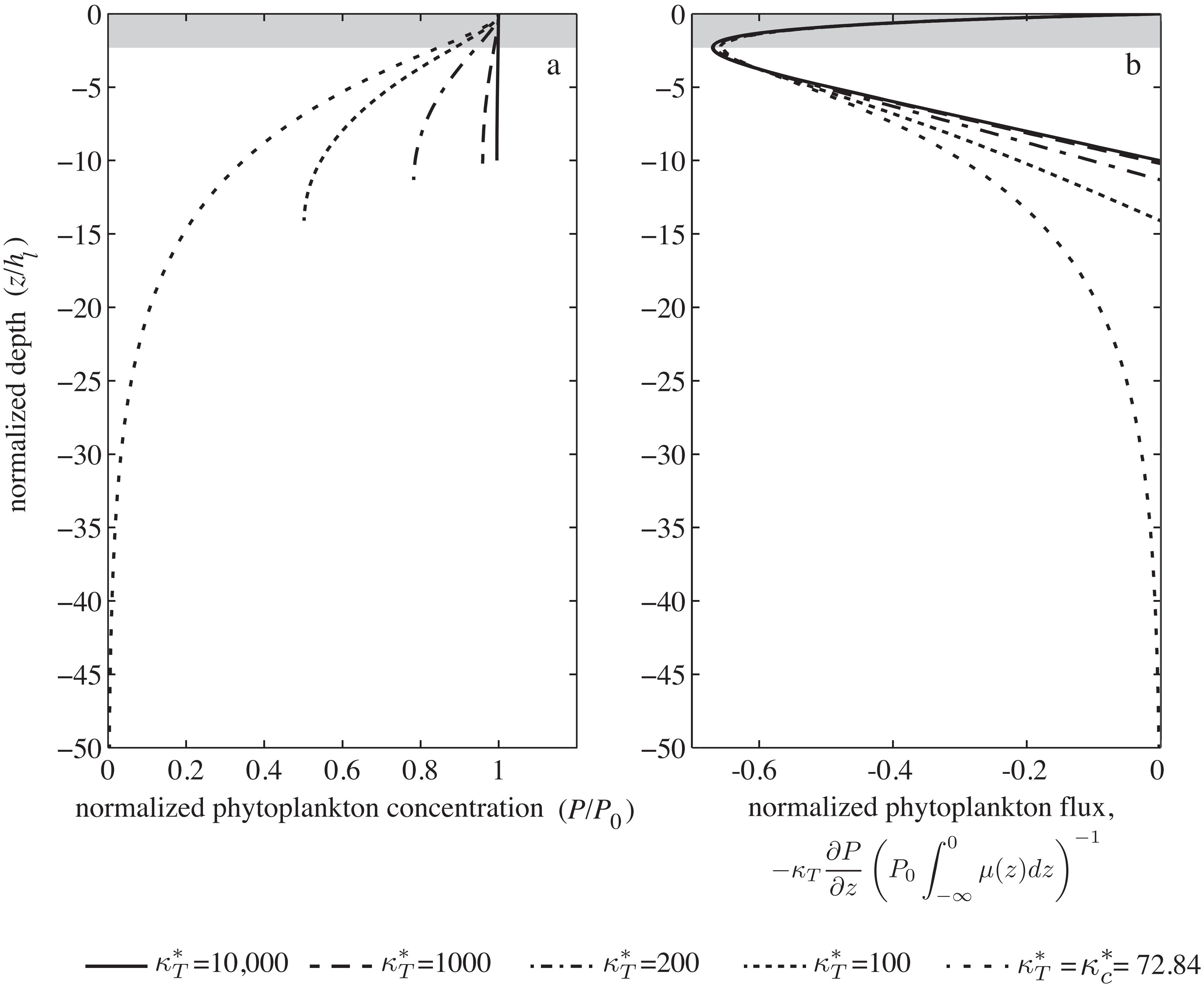


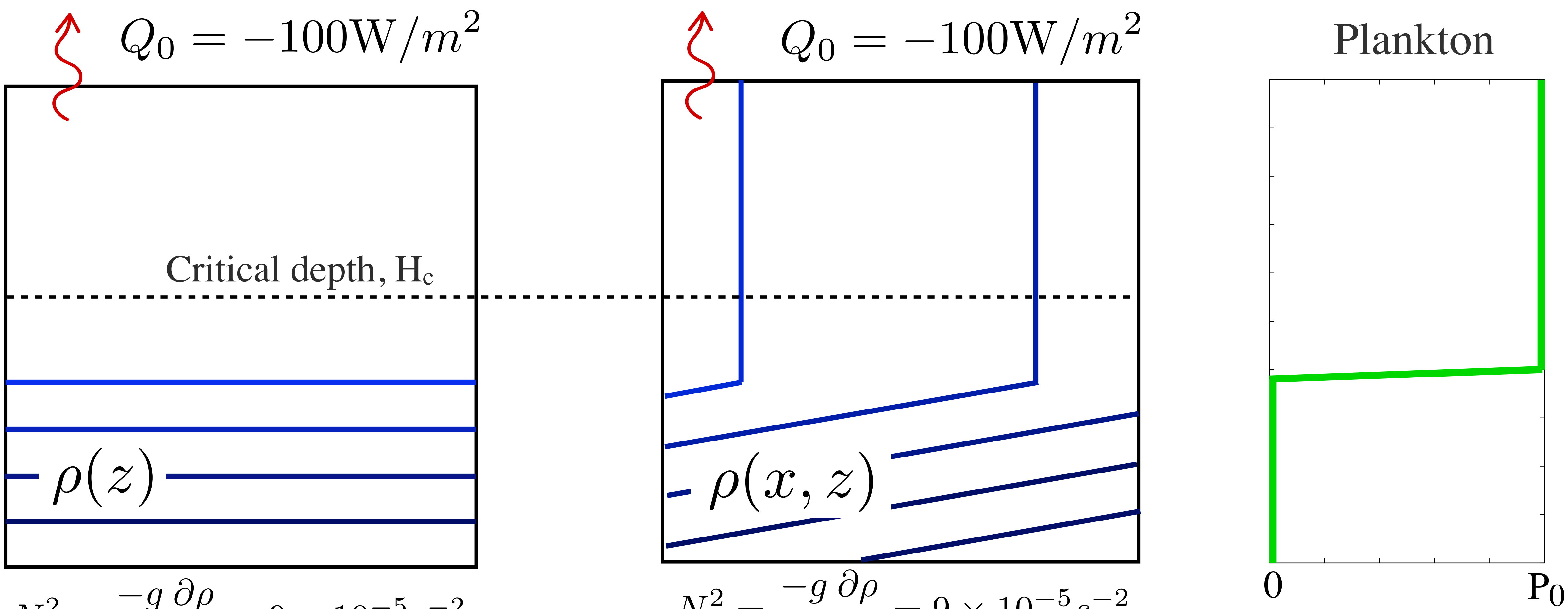

Fig. 4. (a) Vertical profiles of the nondimensional phytoplankton concentration from the analytical solution Eq. 37 with $\mu_0 = 1\ \mathrm{d}^{-1}$, $m = 0.1\ \mathrm{d}^{-1}$, and $\partial P / \partial z(z = 0) = 0$. (b) Profiles of the nondimensional turbulent phytoplankton flux.

Tuesday, March 12, 13

# Large-eddy simulations

Phytoplankton: $$\frac{\partial P}{\partial t} + \mathbf{u} \cdot \nabla P = \mu_0 e^{z/h_l} P - mP + (\kappa + \kappa_{SGS}) \nabla^2 P$$

Upright Convection | Slantwise Convection

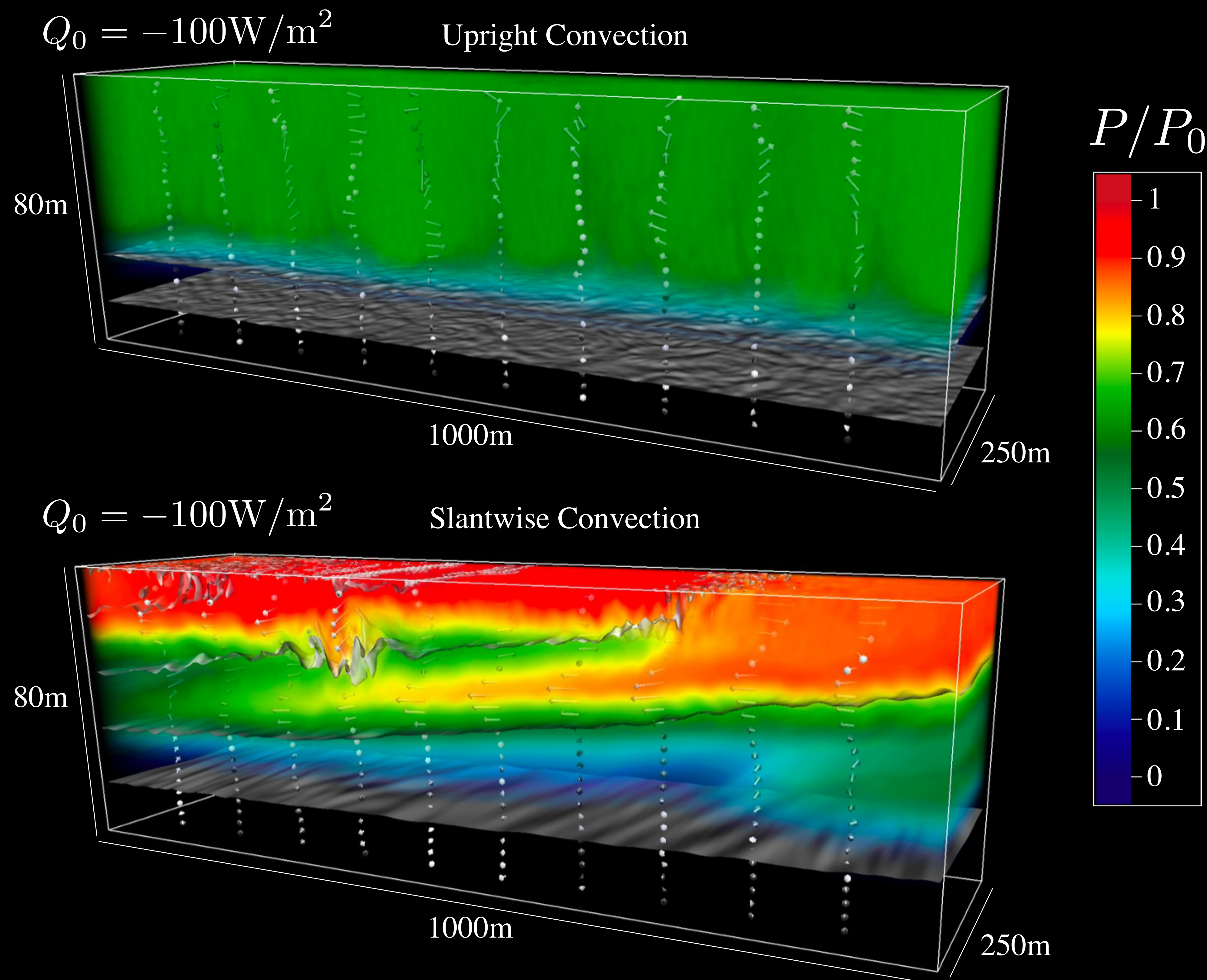



$$N^2 = \frac{-g}{\rho_0}\frac{\partial \rho}{\partial z} = 9 \times 10^{-5} s^{-2}$$

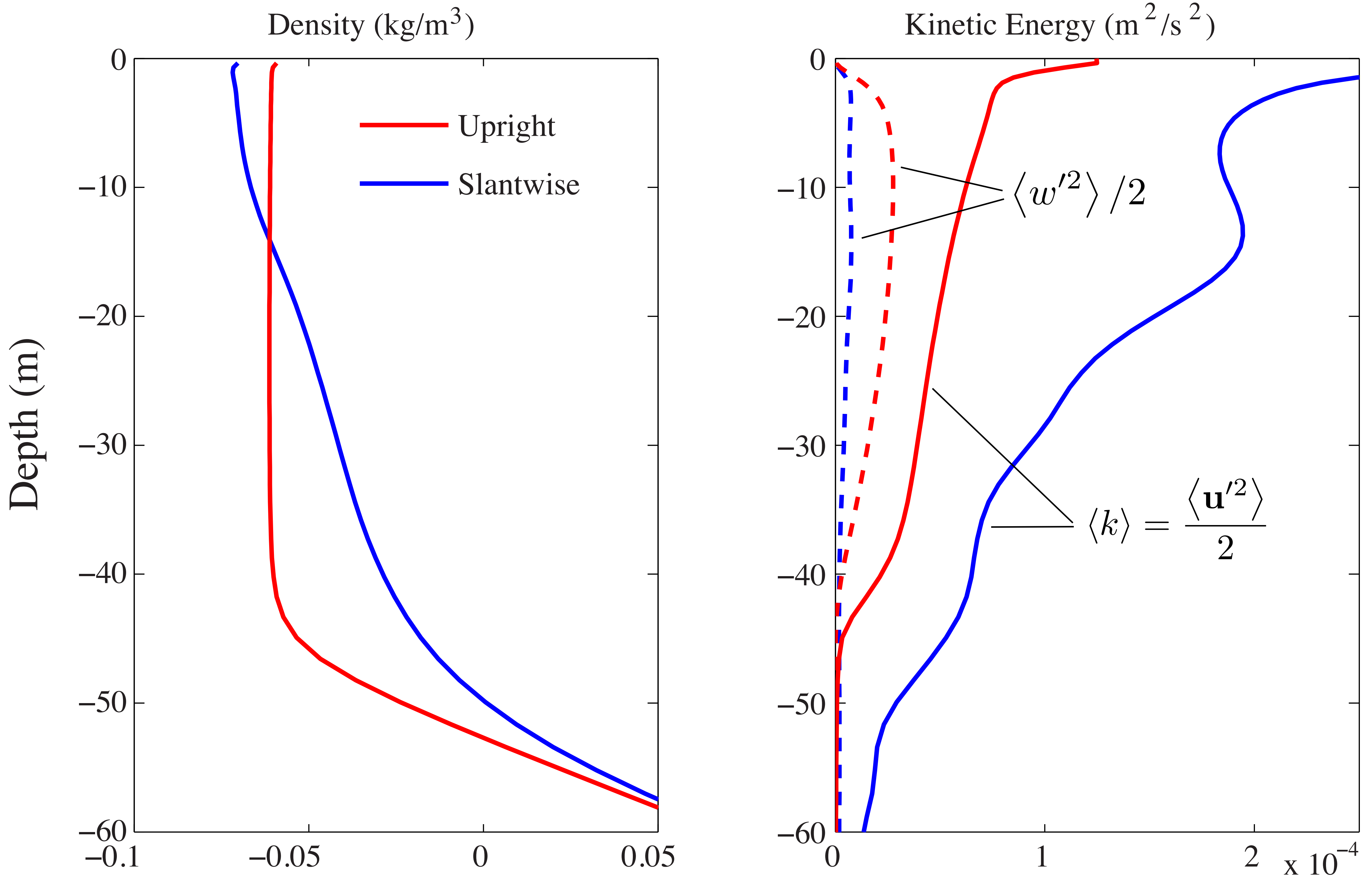
$$N^2 = \frac{-g}{\rho_0}\frac{\partial \rho}{\partial z} = 9 \times 10^{-5} s^{-2}$$

$$\Delta\theta/\Delta x \simeq 0.25^\circ \text{C/km}$$

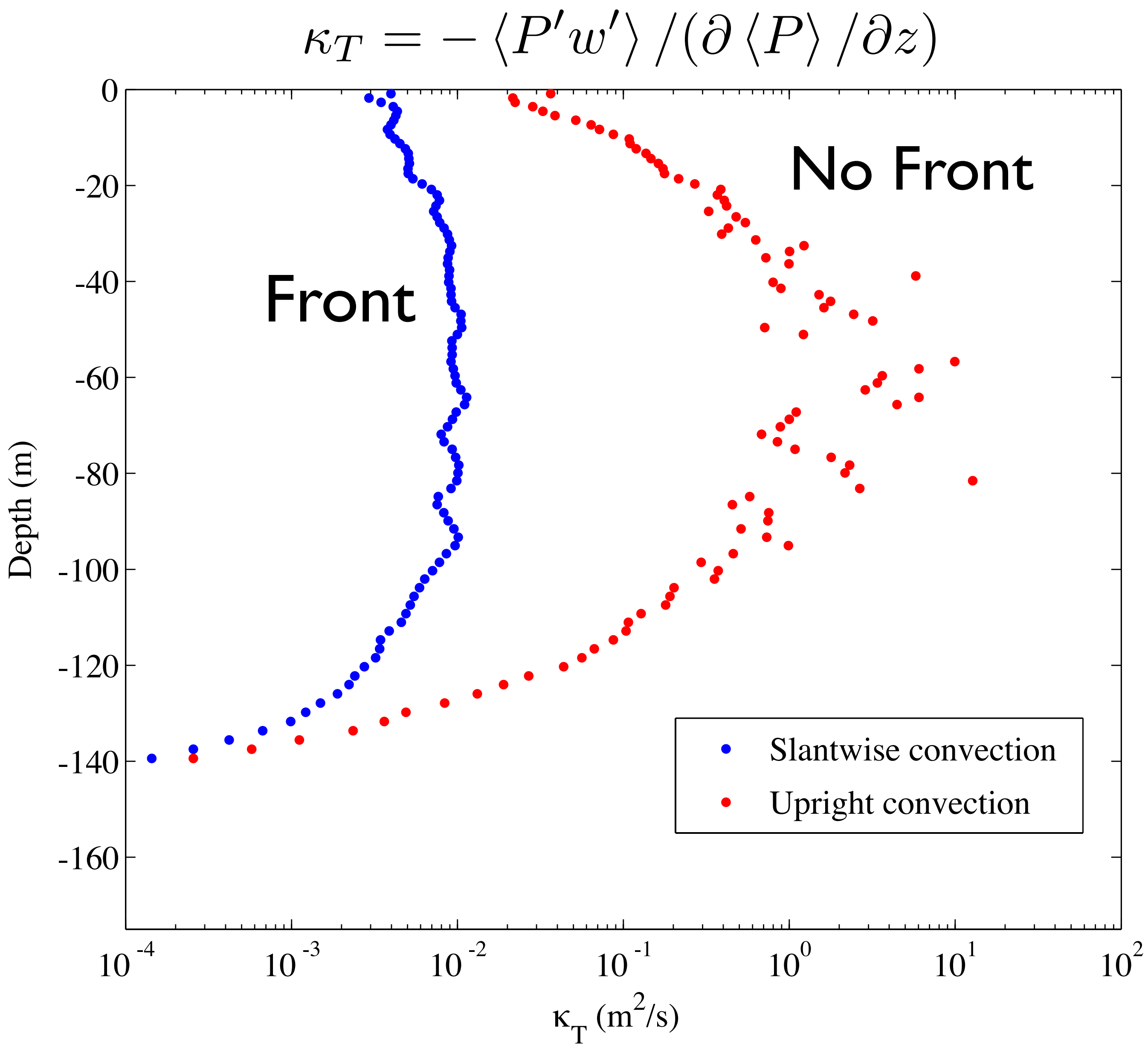
Taylor, J.R. and R. Ferrari (2011) GRL 38, L23601

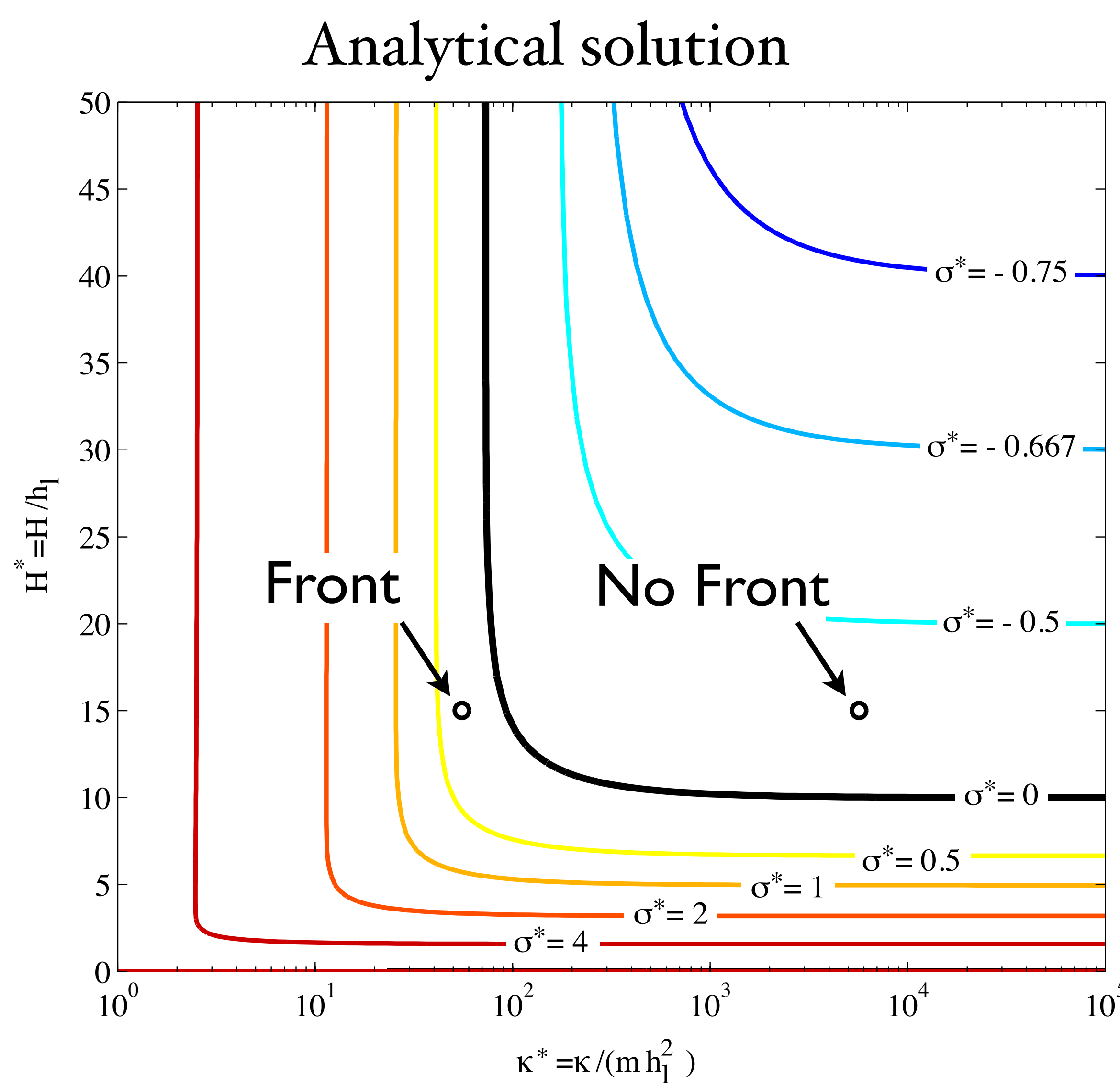


$Q_0 = -100\mathrm{W/m}^2$
Upright Convection
80m
1000m
250m
$Q_0 = -100\mathrm{W/m}^2$
Slantwise Convection
80m
1000m
250m
$P/P_0$
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0



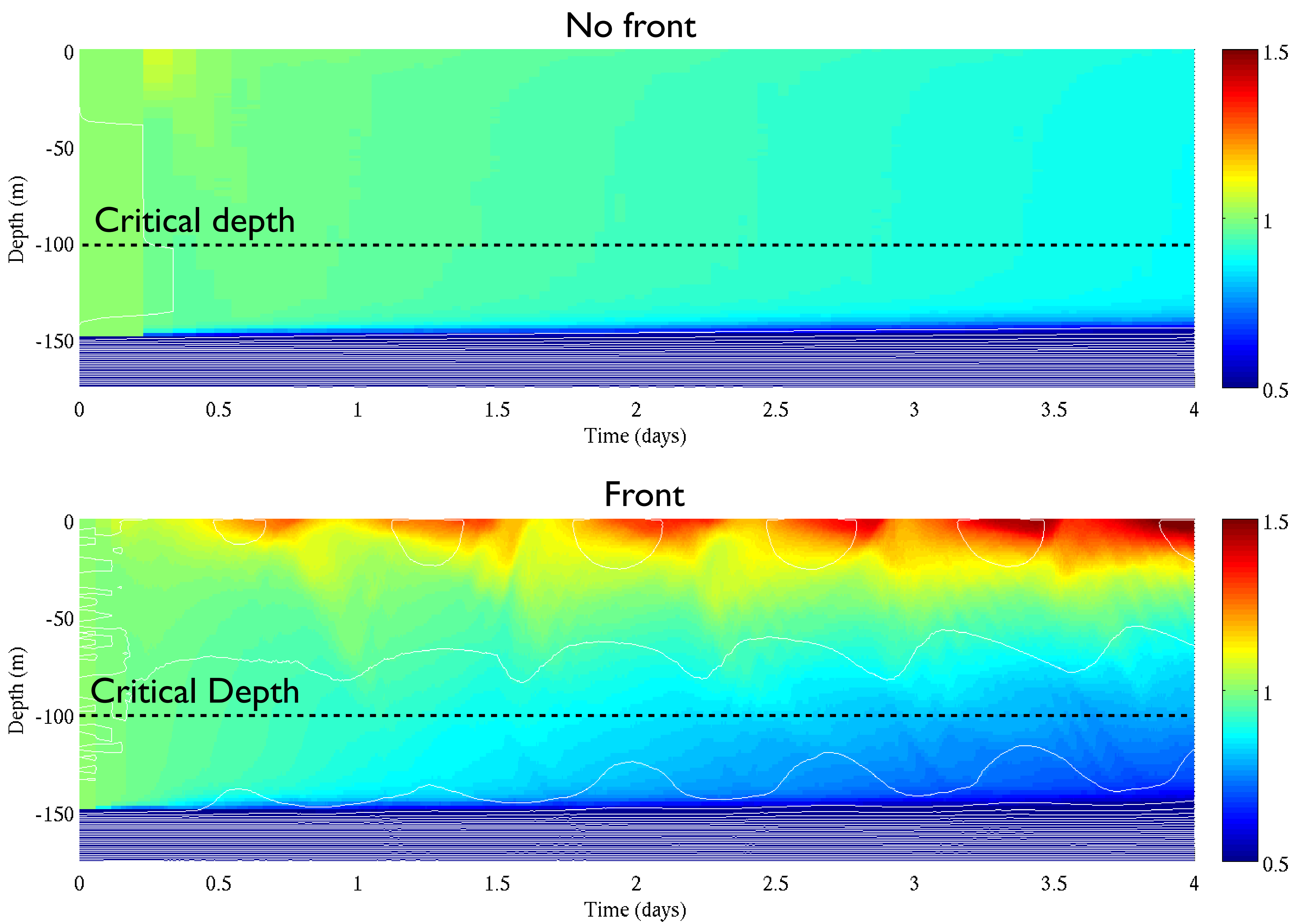
Density (kg/m3)
Upright
Slantwise
Depth (m)
0
−10
−20
−30
−40
−50
−60
−0.1
−0.05
0
0.05
Kinetic Energy (m 2/s 2)
⟨w′2⟩ /2
⟨k⟩ = ⟨u′2⟩/2
1
2
x 10−4

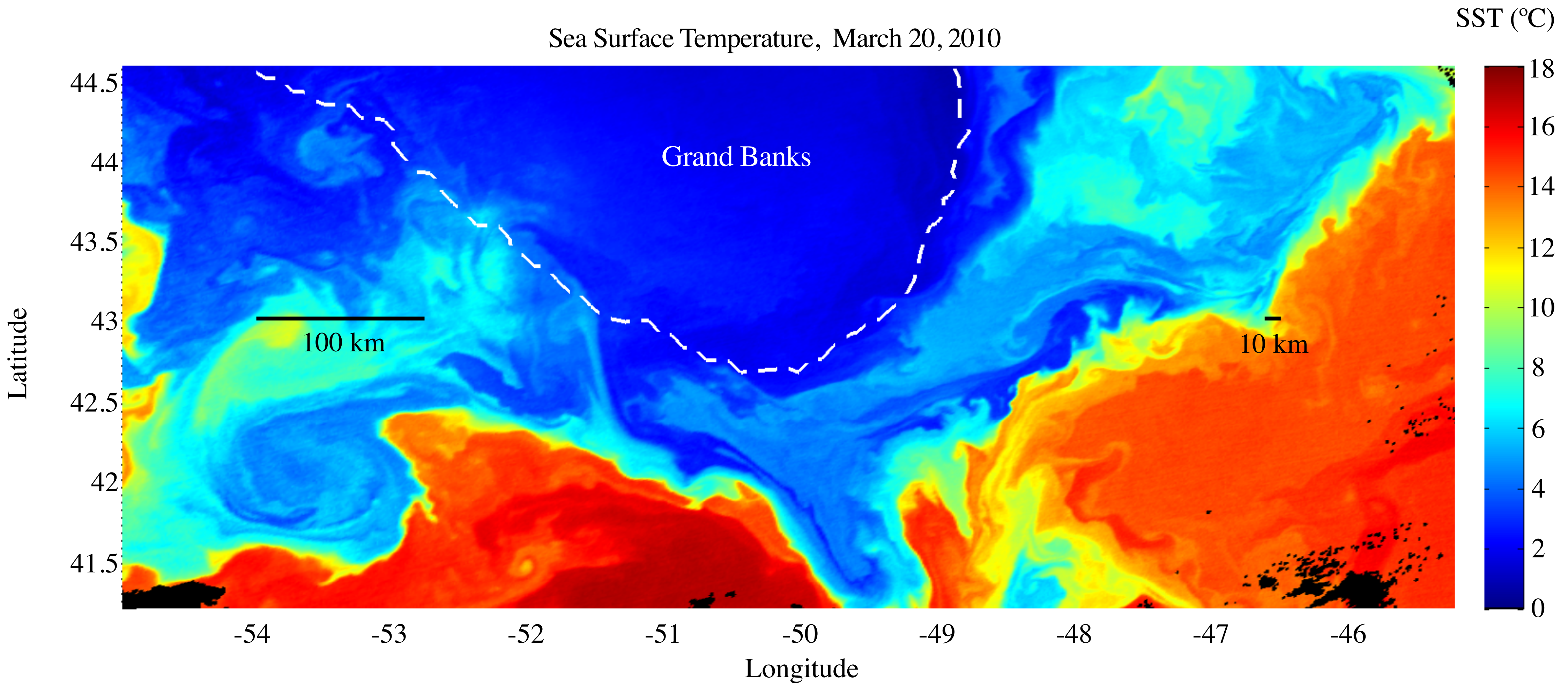


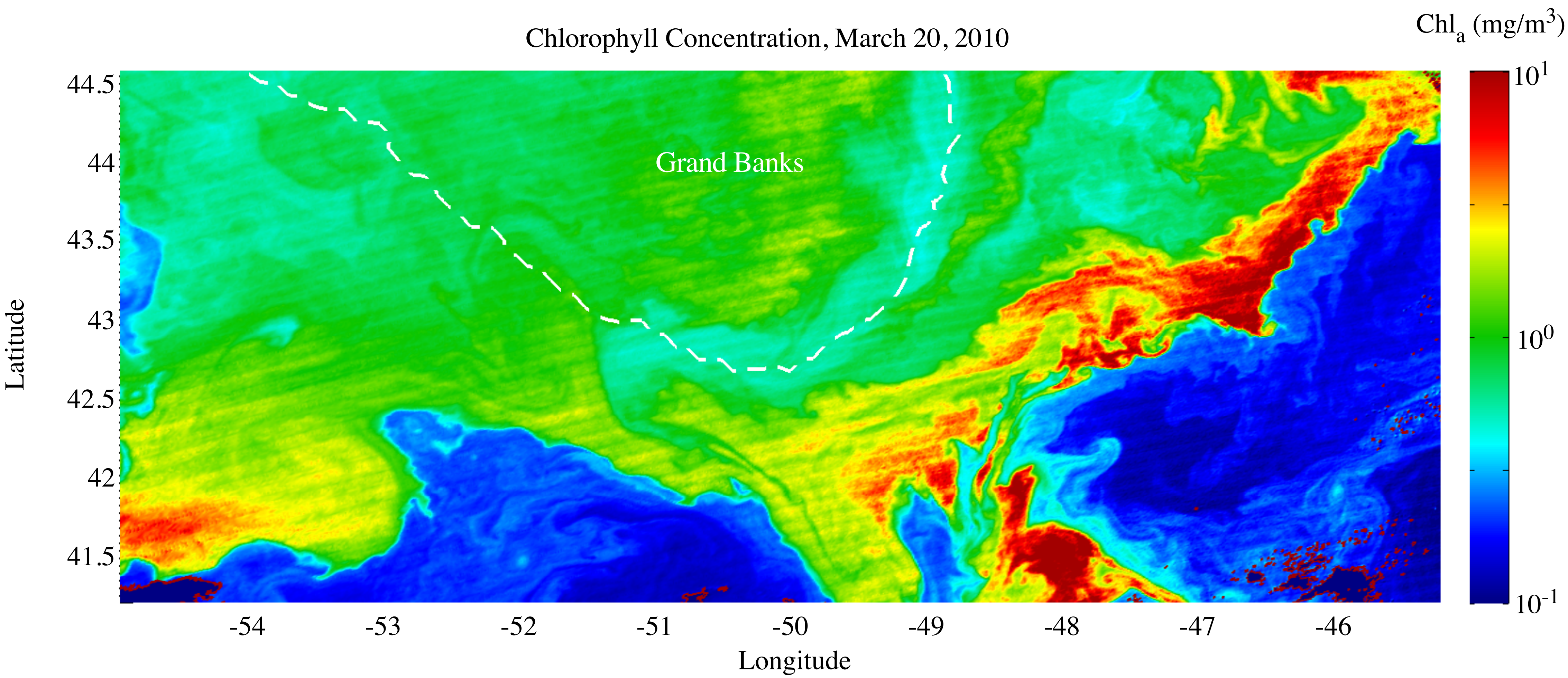




Fronts reduce vertical mixing, triggering phytoplankton bloom

# Mean phytoplankton concentration

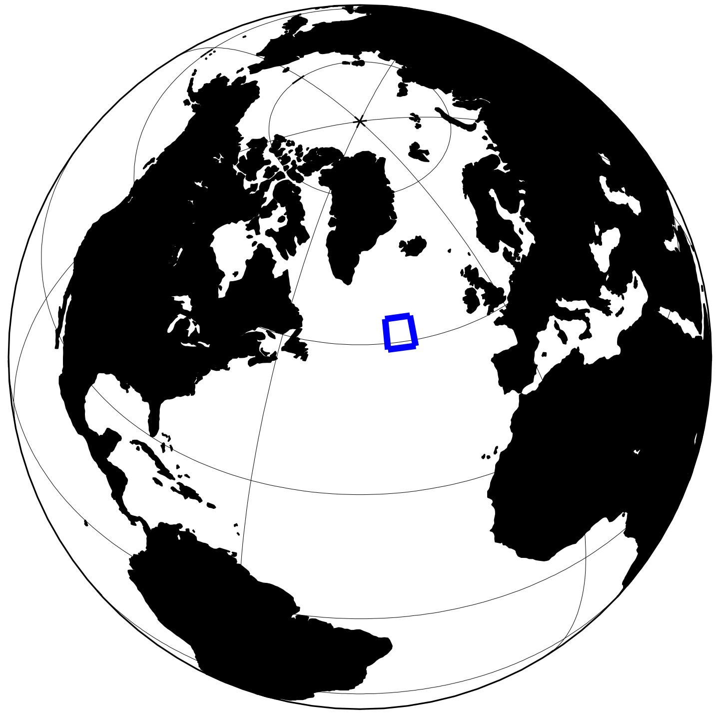



Sea Surface Temperature, March 20, 2010
SST (ºC)
Grand Banks
100 km
10 km
Latitude
Longitude
44.5
44
43.5
43
42.5
42
41.5
-54
-53
-52
-51
-50
-49
-48
-47
-46
18
16
14
12
10
8
6
4
2
0

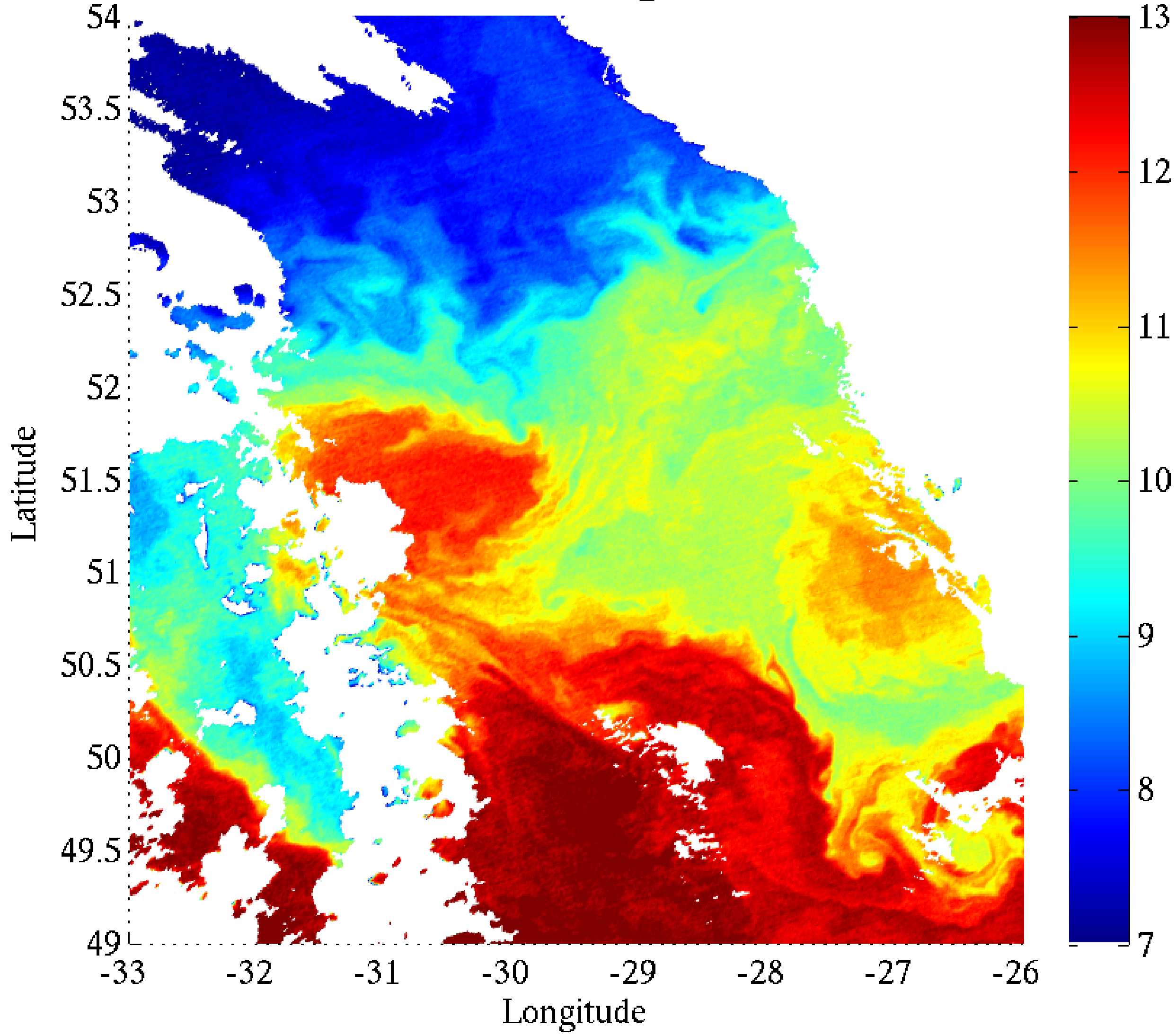

Chlorophyll Concentration, March 20, 2010
Chl$_a$ (mg/m$^3$)
Grand Banks
Latitude
Longitude
44.5
44
43.5
43
42.5
42
41.5
-54
-53
-52
-51
-50
-49
-48
-47
-46
$10^1$
$10^0$
$10^{-1}$

# Mid-winter bloom

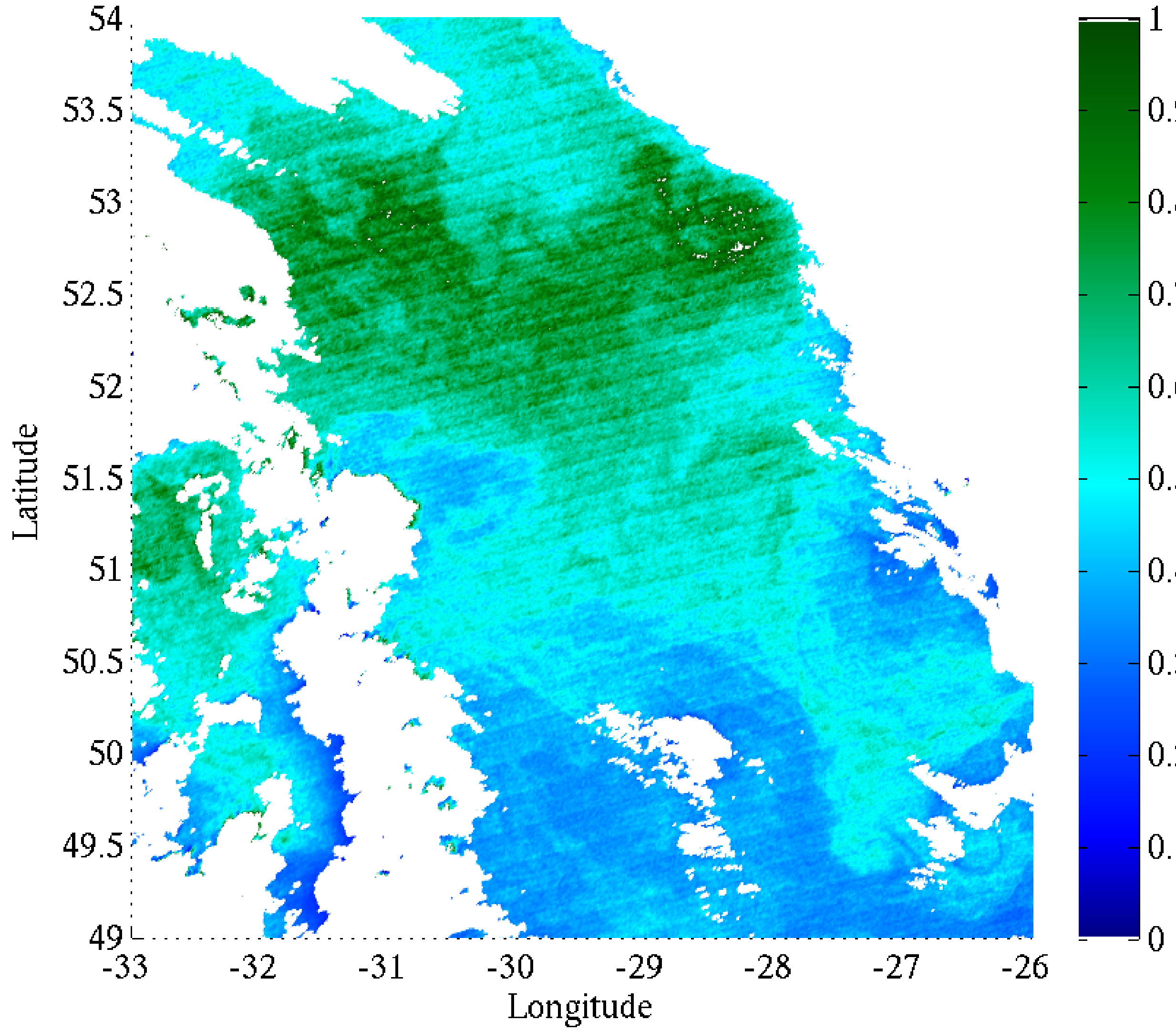
NASA MODIS Satellite
January 3, 2009



Sea surface temperature (°C)




Chlorophyll concentration ($mg/m^3$)



# MODIS Aqua September 19, 2008

Sea surface temperature | Chlorophyll concentration