# MAR650 Lecture 3: Global-Scale Physical-Biological Interaction Processes

**Thermocline Circulation:** principally exists in the upper few hundreds of meters and mainly driven by surface wind stress. It is also called "the wind-driven circulation" or "upper oceanic circulation".

**Thermohaline circulation:** prevails in the deep ocean and mainly driven by the buoyancy forcing associated with cooling (heated) by the cold (warm) air, and modified by sources and sinks of the fresh water. It is also called "the deep circulation" or "abyssal circulation".

**Observed currents:** a result of the combined effects of wind- and buoyancy-driven forcings.

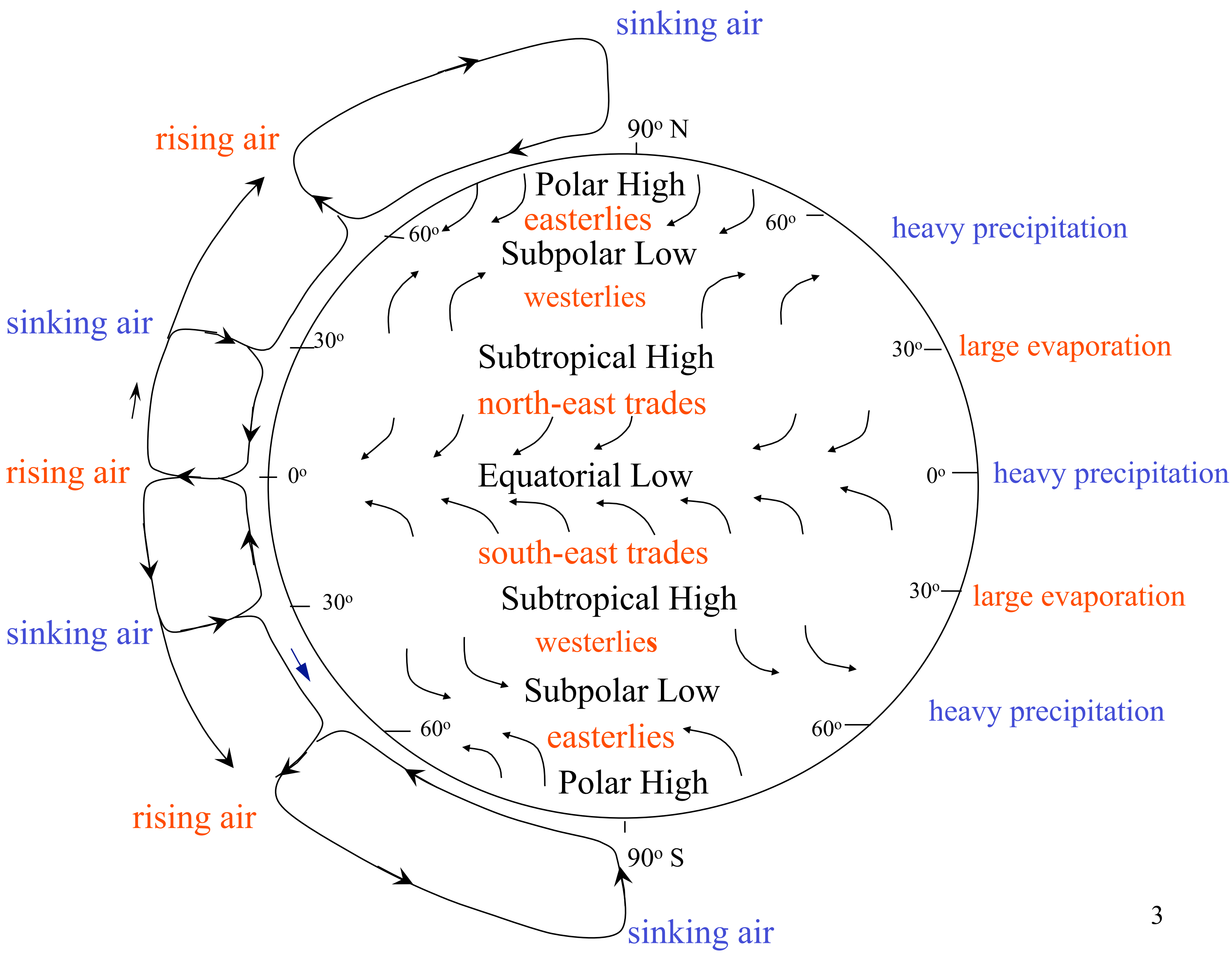
Biological observational evidences:

Euphotic layer ~ 200 m in the open ocean. Most of marine life are in the a few hundred meters' upper ocean;

DO and $CO_2$ cycles ~ related to the air-sea interaction at the sea surface

**Synoptic weather scale** → (related) Wind-driven circulations

Deep circulation mainly originates from the surface cooling and ices formation in the polar region, it is important to the climate-scale variation of global ocean nutrients and other chemical maters.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rising air
90° N
Polar High
easterlies
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heavy precipitation
Subpolar Low
westerlies
sinking air
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Subtropical High
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large evaporation
north-east trades
rising air
0°
Equatorial Low
0°
heavy precipitation
south-east trades
sinking air
30°
Subtropical High
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large evaporation
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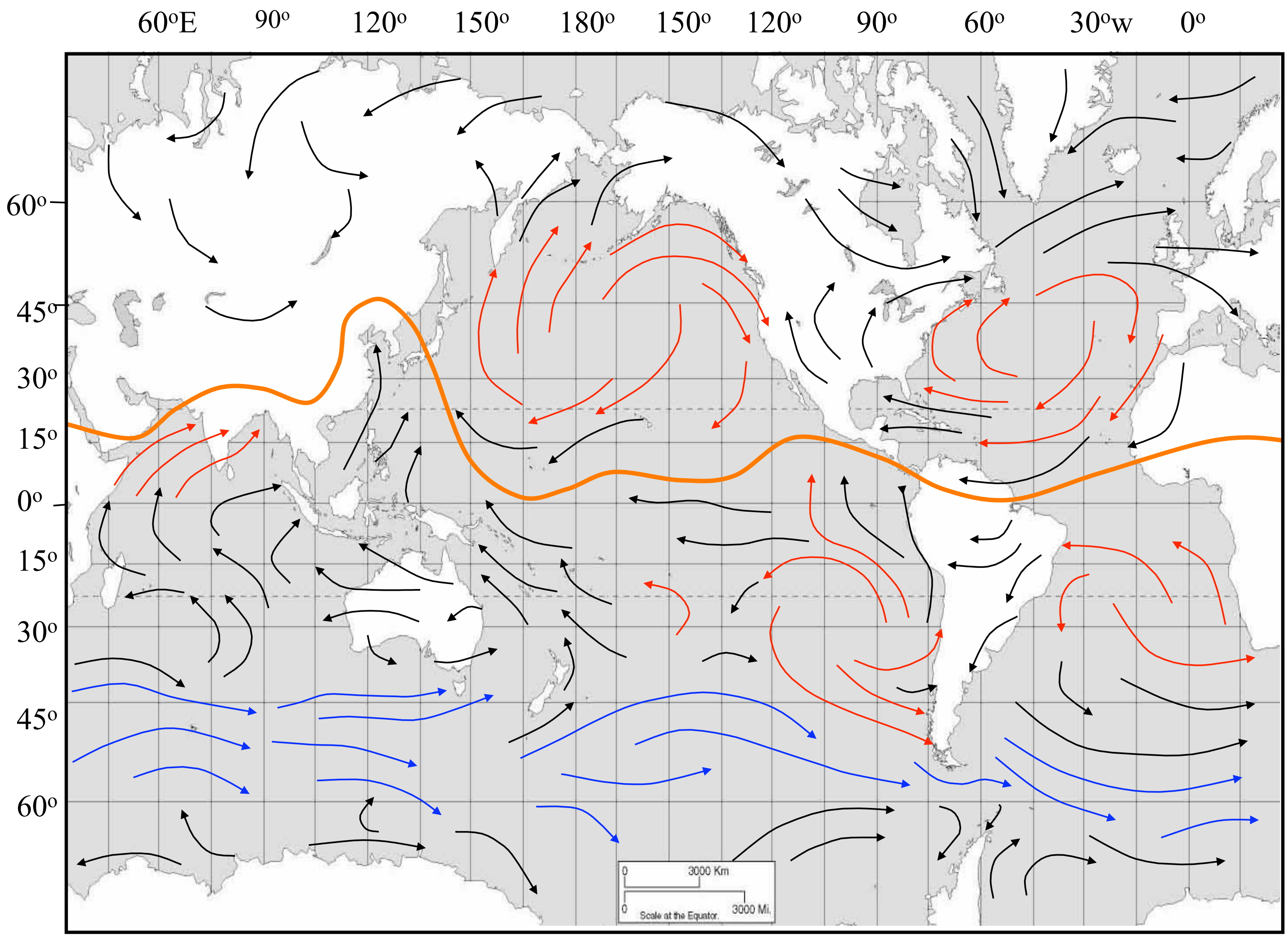
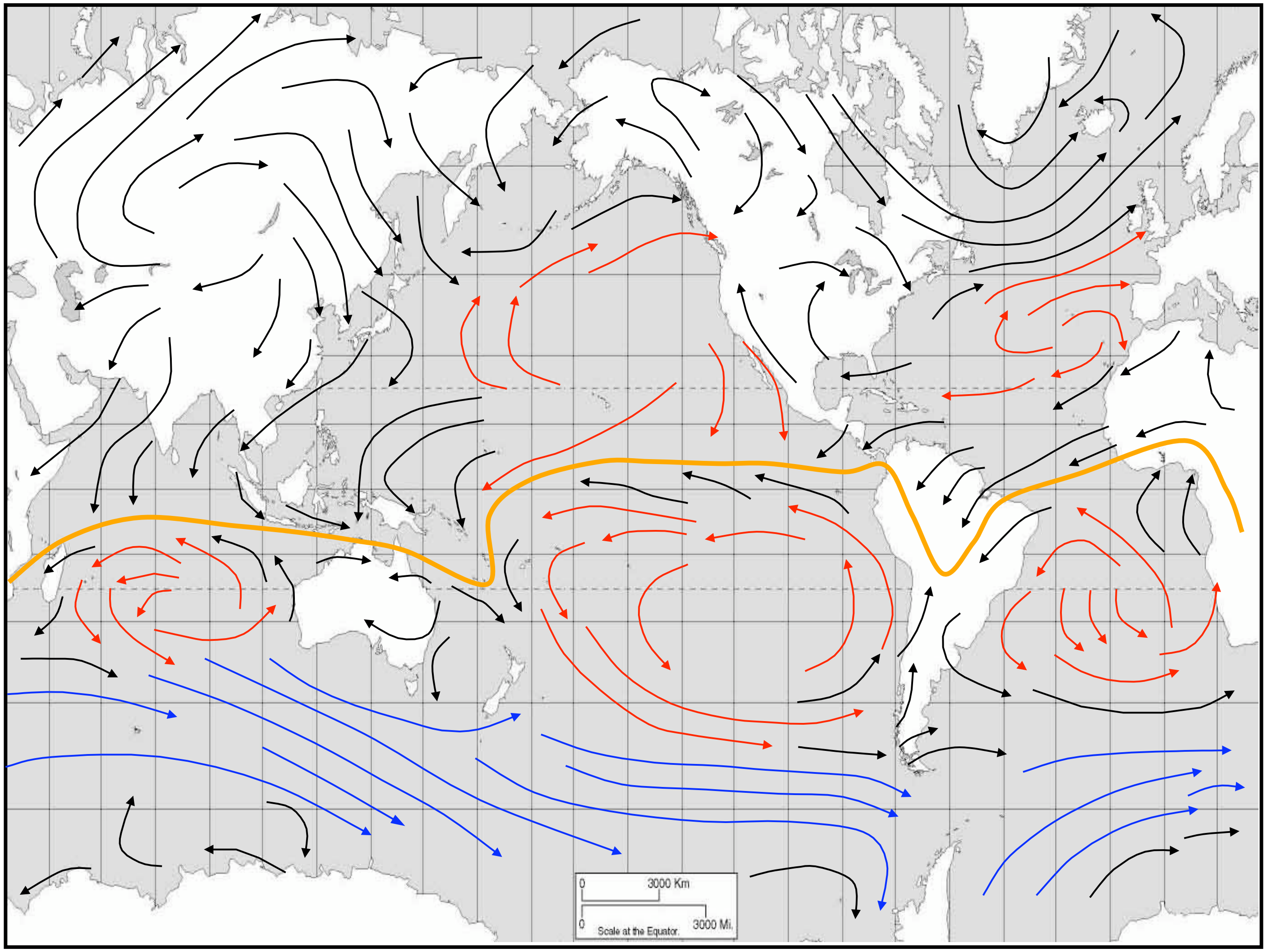
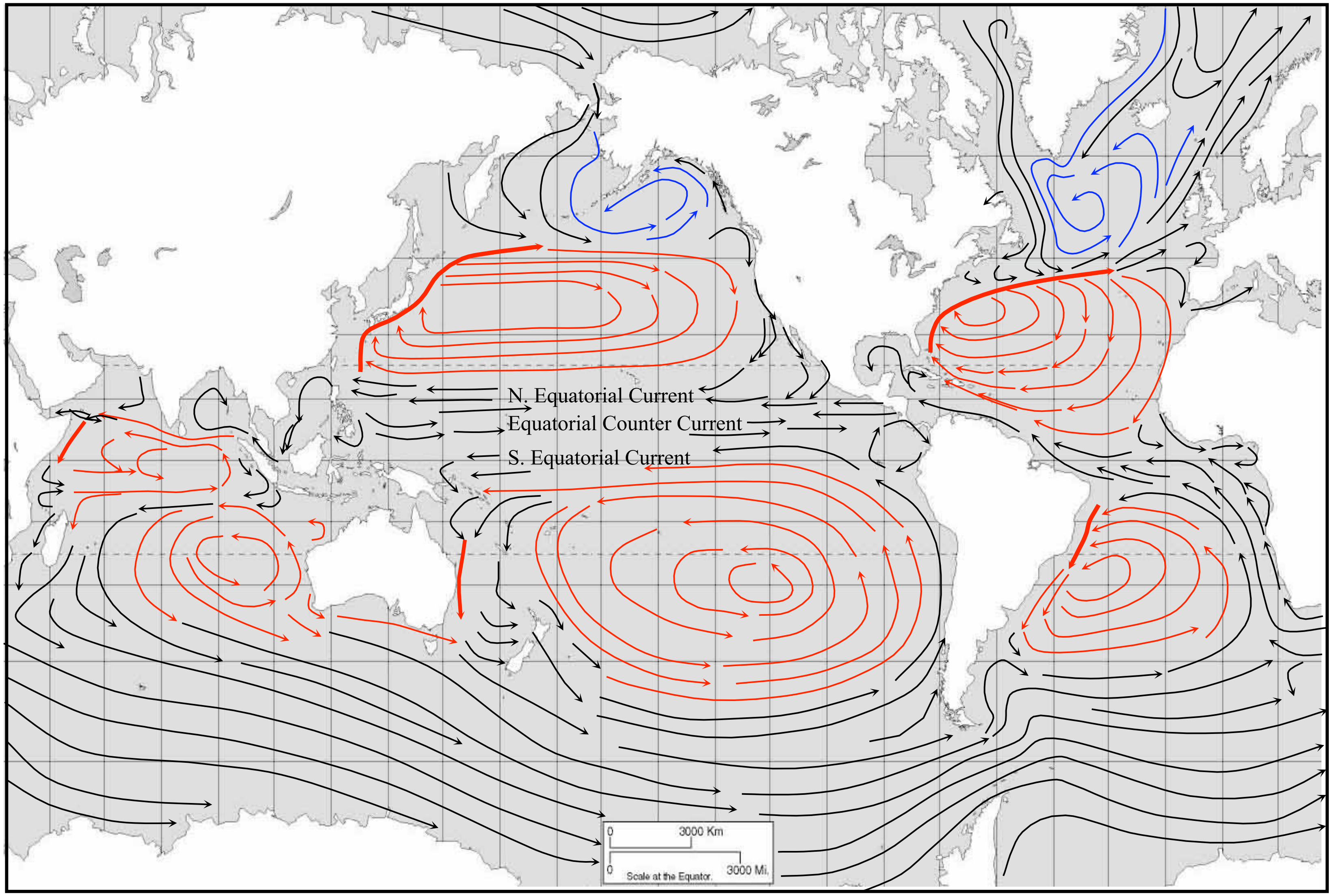



Wind Field on the northern hemisphere July

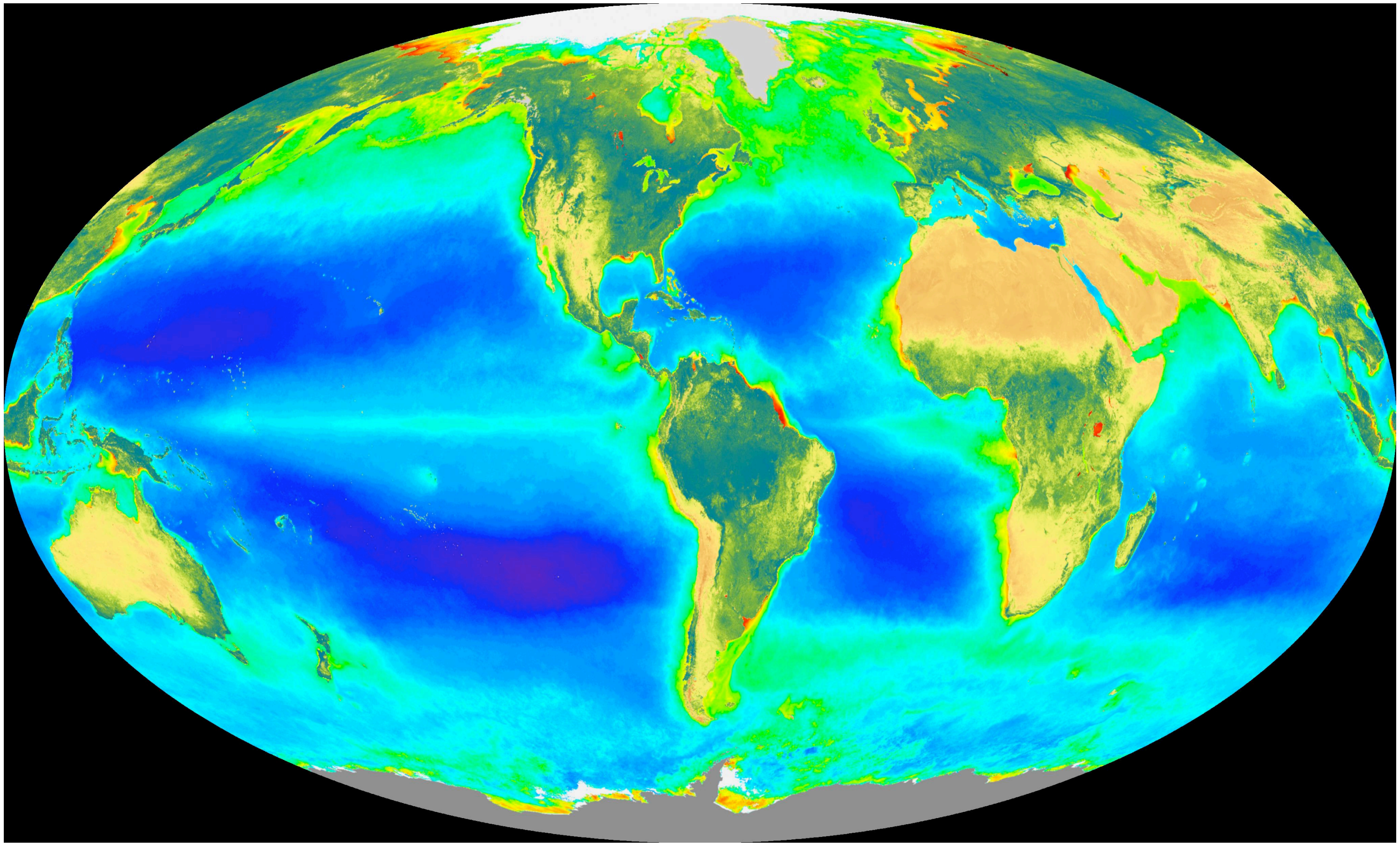



Wind field on the northern hemisphere January

# Wintertime upper layer circulation



# Global Distribution of Chl-a Concentration



Subpolar gyre: 15-150 mg/m$^2$

In the divergence zone near the equator: 15-30 mg/m$^2$

Subtropic gyre: 5-25 mg/m$^2$

**In the euphotic layer:**

In the subpolar gyre:

5~25 μg/L ($NO_3$), 0.1~0.5 g C/$m^2$ (primary production), 30~50 g/$m^2$ (zooplankton biomass)

In the subtropic gyre:

<0~5 μg/L ($NO_3$), <0.1 g C/$m^2$ (primary production), <7 g/$m^2$ (zooplankton biomass)

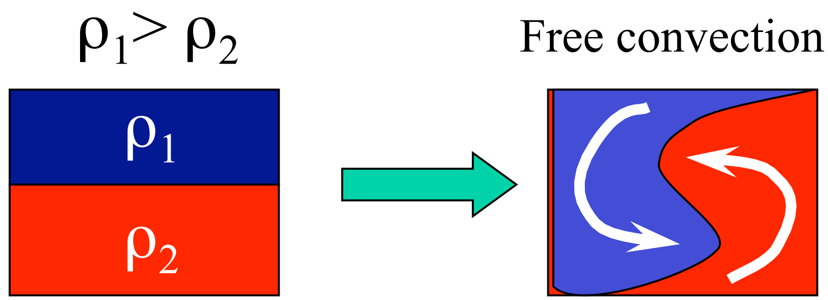
**In Ocean Biology**:

Call the Subtropic gyre region: **Biological Desert**

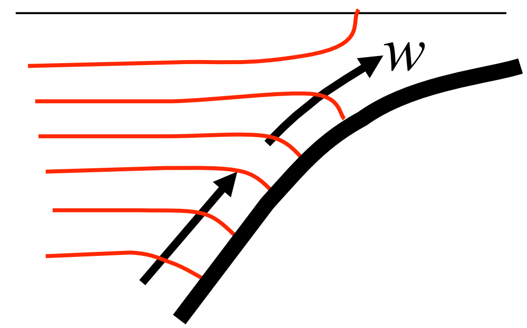
Question 1: What is physical and biological mechanism causing the formation of the biological desert in the subtropic gyre region?

Physical : Wind-driven anti-cyclonic circulation gyre, mixed layer/thermoclines, convection/advection, diffusion; eddy interactions,

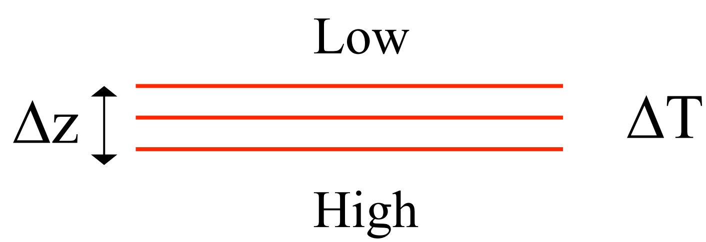
Biological: Nutrients




Convection: In the ocean, it usually refers to the free convection due to the buoyancy




Advection: In the ocean, it usually refers to the water transfer driven by currents



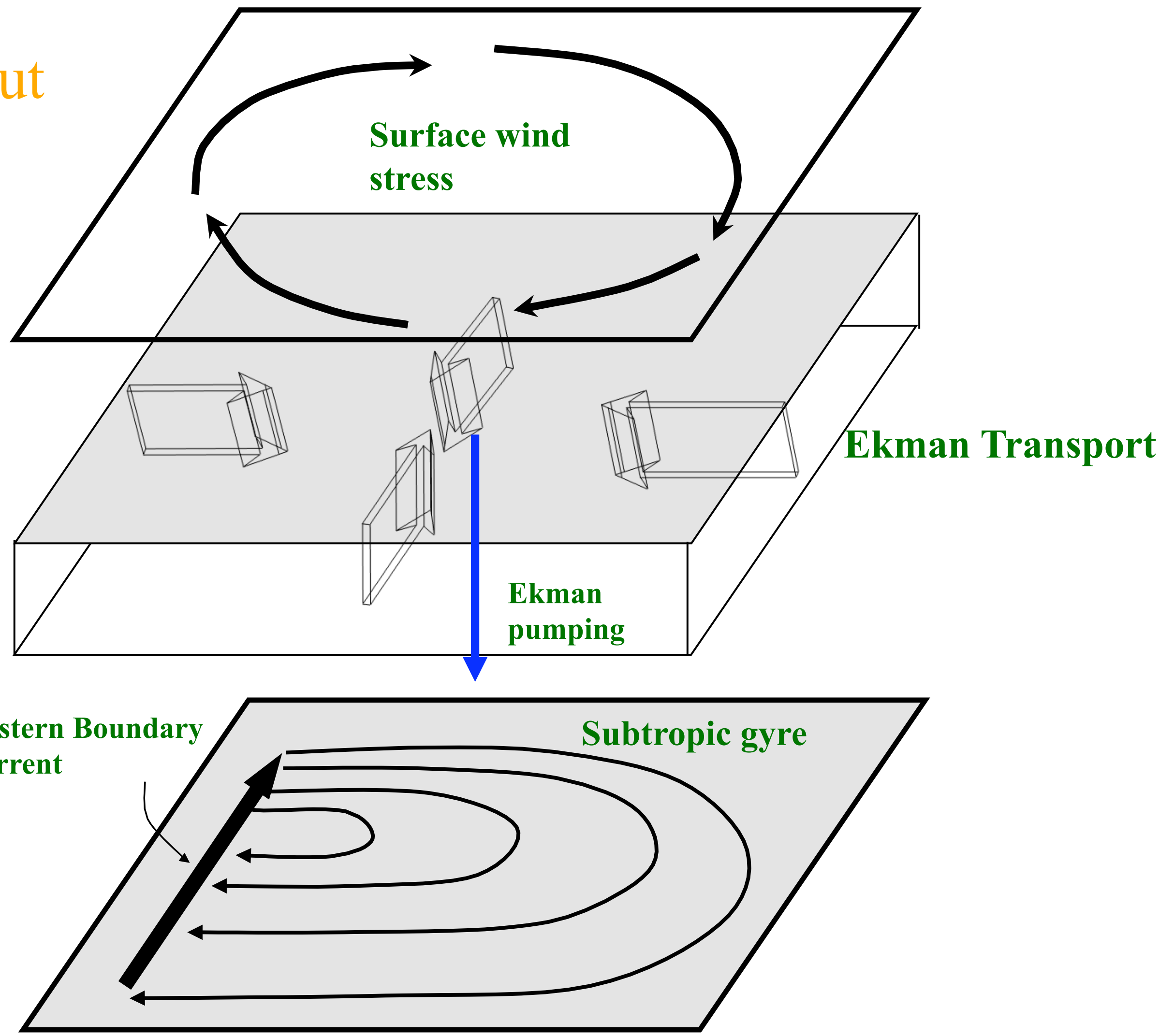

Diffusion: Turbulence-induced transfer of water property, such as temperature, salinity, nutrients, etc

$K_h$: The vertical diffusion coefficient, the diffusion flux: $K_h \, \Delta T / \Delta z$

Gradient

**Good light condition, mixed layer depth: 100-200 m in summer, 400 m in winter**

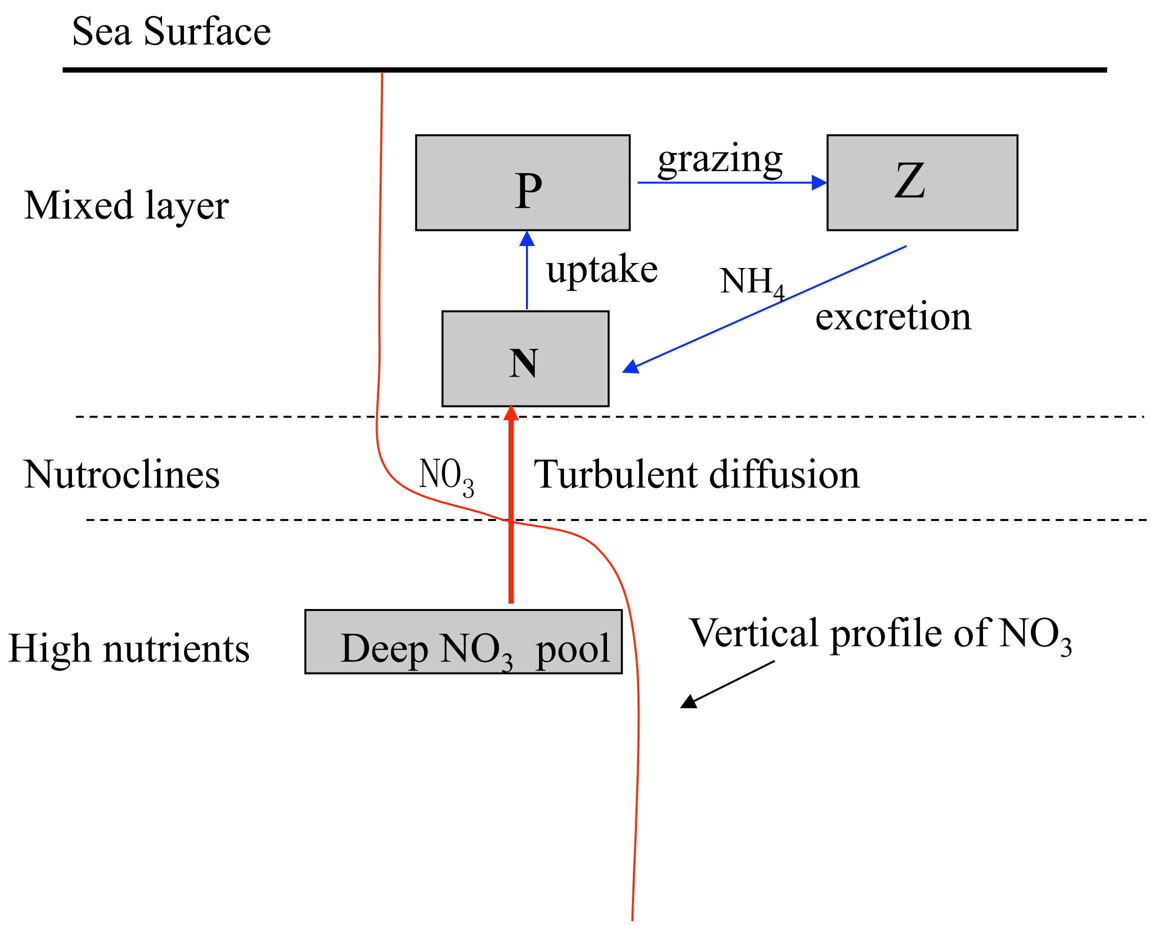
But




Limit the upward nutrient flux from the deep ocean to the euphotic layer

**Main Sources of nutrients' supply in the mixed layer**:

1) Nutrient recycling among the food web— a nutrients-phytoplankton-zooplankton system;
2) Upward flux through the thermoclines—turbulent diffusion and meso-or small scale eddy interaction.



Phytoplankton production is maintained through a new primary production (with a nutrient supply from a deep ocean: $NO_3$) and a regenerated production (with a nutrient supply from internal food web recycling: $NH_4$).

$$f = \frac{\text{Phytoplankton new production}}{\text{Phytoplankton new production} + \text{Phytoplankton regenerated production}}$$

In subtropic gyre *f*: 0.05~0.1, new production only account for 5%~10% of the total production, so that the new production is not enough to compensate the phytoplankton loss grazed by zooplankton: Therefore, when the phytoplankton biomass once become lower, this state could last for a long time.

Biological observational evidences show that the biological field in the subtropic region remains at the quasi-steady state:

Phytoplankton Production = Zooplankton Grazing

Once phytoplankton biomass is lower, zooplankton biomass will be lower, too.

## Quantitative estimation of the contribution of vertical diffusion:

King and Davol, 1979 and Lewis et al. (1986): based on nutrocline gradient

$$K_h \sim 0.3 \text{ cm}^2/\text{s} \sim 3\times 10^{-5} \text{ m}^2/\text{s}$$

Ledwell (1993): dye experiments over 5 months:

$$K_h \sim 0.11 \pm 0.02 \text{ cm}^2/\text{s} \sim 1.1\times 10^{-5} \pm 0.2\times 10^{-5} \text{ m}^2/\text{s}$$

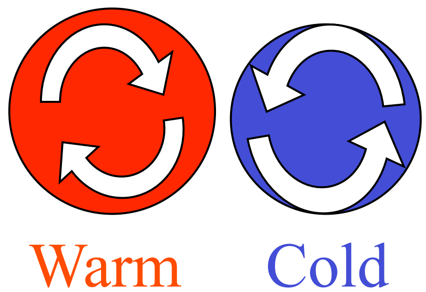
Ledwell’s estimation is much accurate. If we believe this value, then the upward nutrient flux through the nutroclines should be 3 times smaller than the value biological scientists thought in the70’s and 80’s.

**Therefore, the upward diffusion nutrient flux from a deep ocean is too weak to support the new production in the mixed layer in the subtropic gyre region.**

**Questions:**

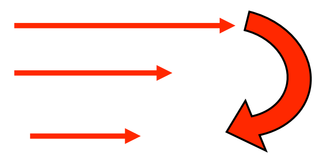
**What is another physical source for upward nutrient flux in the subtropic gyre region?**

Eddy interaction (McGillcuddy et al., Nature, 394, 263-265)

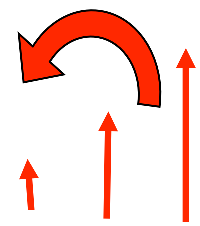



## Vorticity

$\zeta = \dfrac{\partial v}{\partial x} - \dfrac{\partial u}{\partial y}$ : Relative vorticity



$v = 0; \dfrac{\partial u}{\partial y} > 0; \zeta < 0$



$u = 0; \dfrac{\partial v}{\partial x} > 0; \zeta > 0$

$f = 2\Omega \sin\theta$ : Planetary vorticity caused by the earth rotation

$\dfrac{\zeta + f}{H}$ : Potential voricity. This voricity remains constant if no friction is considered.

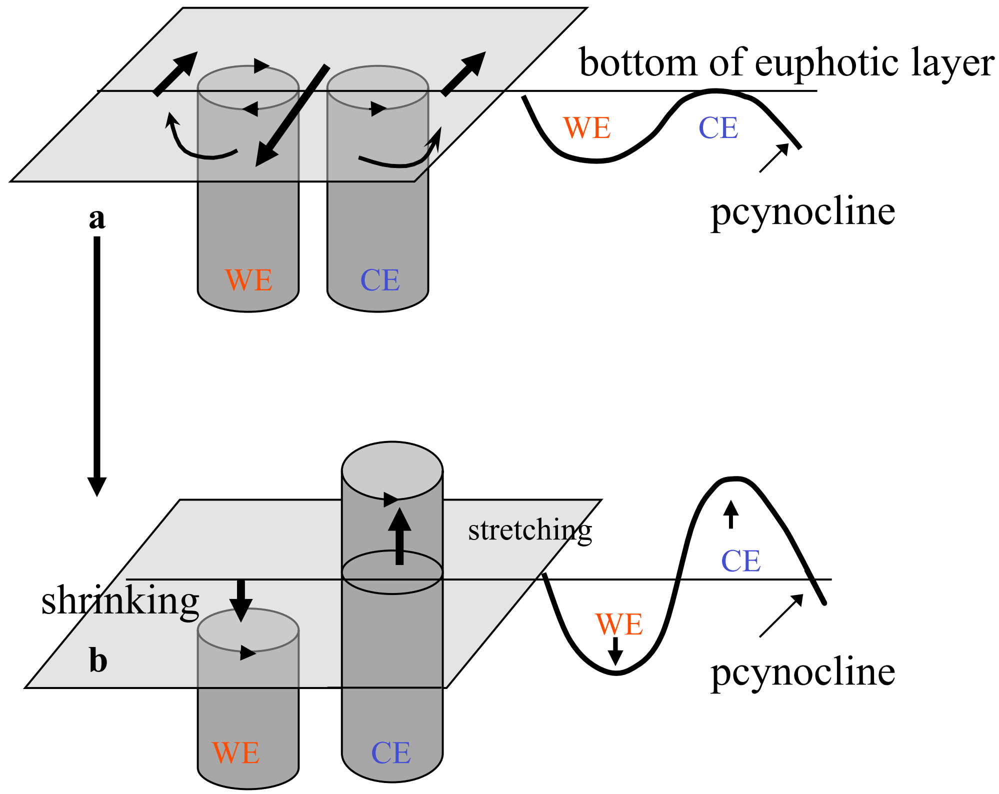
**Observational evidences:**

There are many small-or meso-scale cold-core and warm-core eddies: 10 ~100 km with a life time of 30 days.

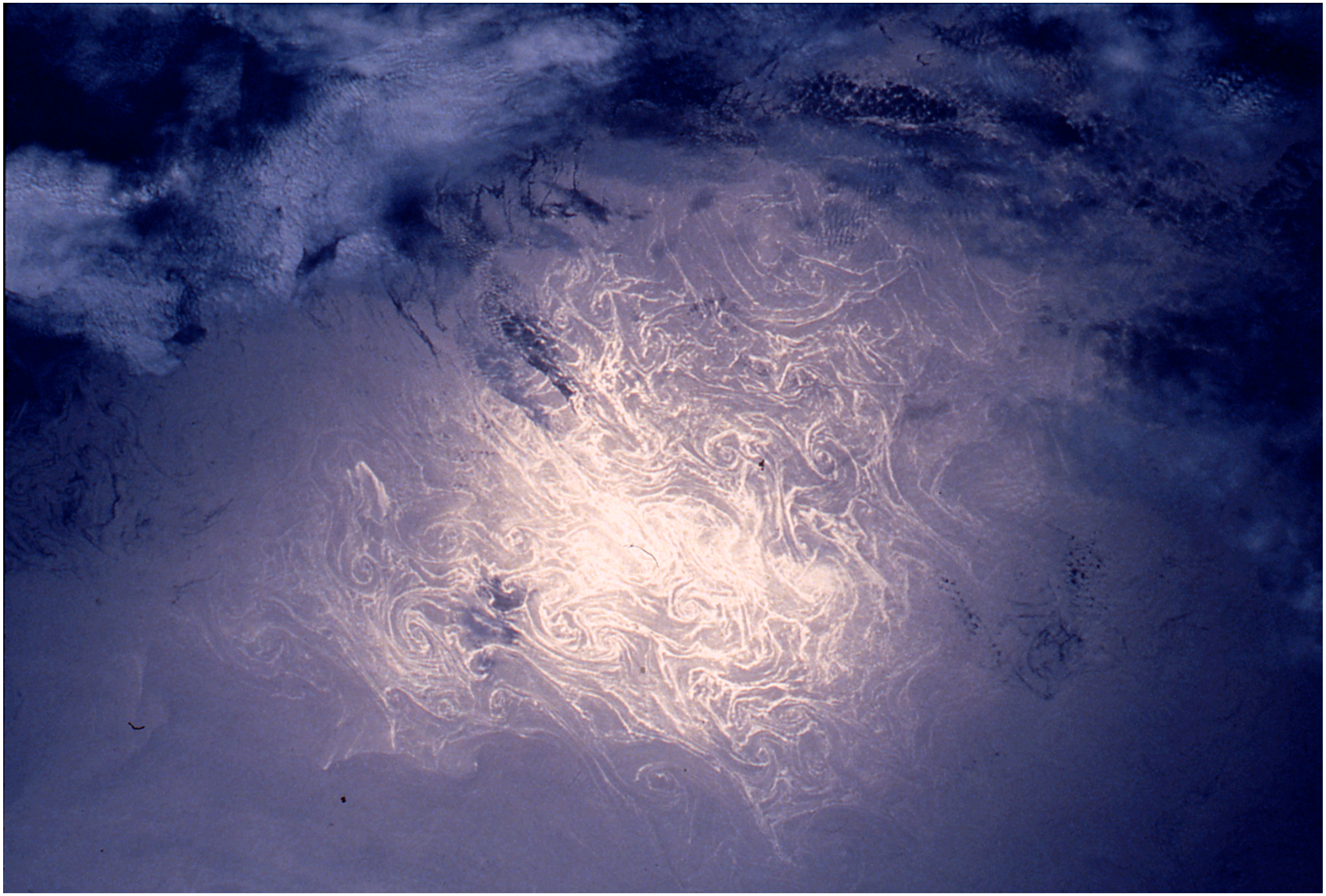
$$\frac{\zeta + f}{H} = \text{constant}$$

As $\zeta \nearrow$, H $\nearrow$ : stretching

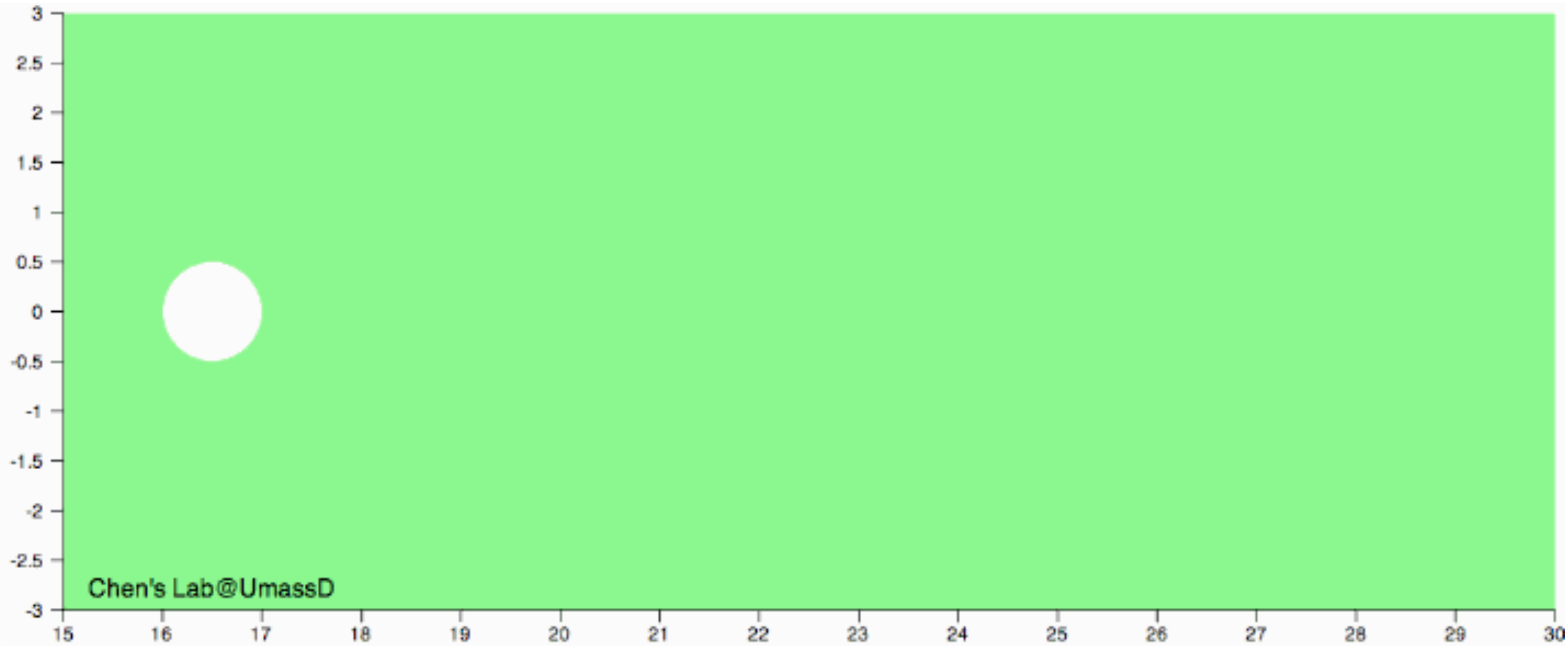
As $\zeta \searrow$, H $\searrow$ : shrinking



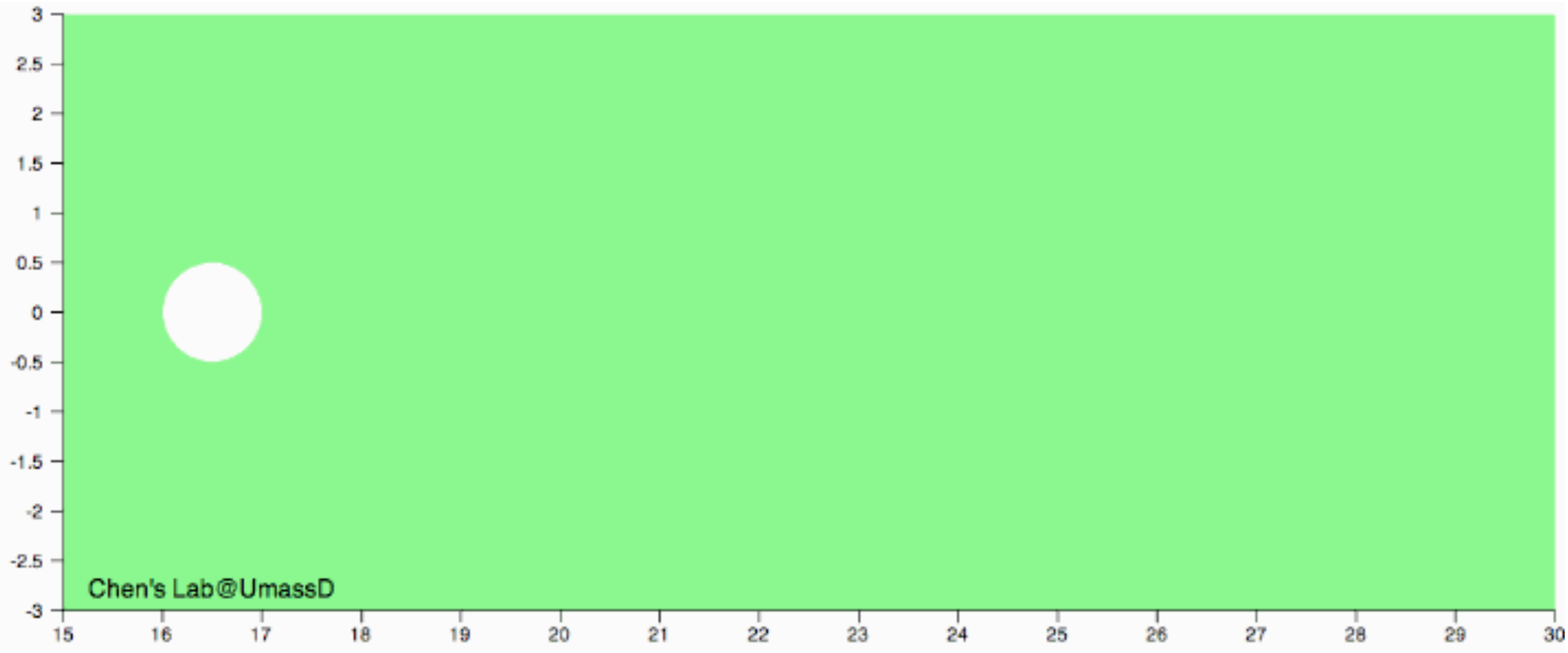

Vertical stretching scale >> 0.1 m/day (a downwelling vertical velocity scale caused by the wind vorticity).

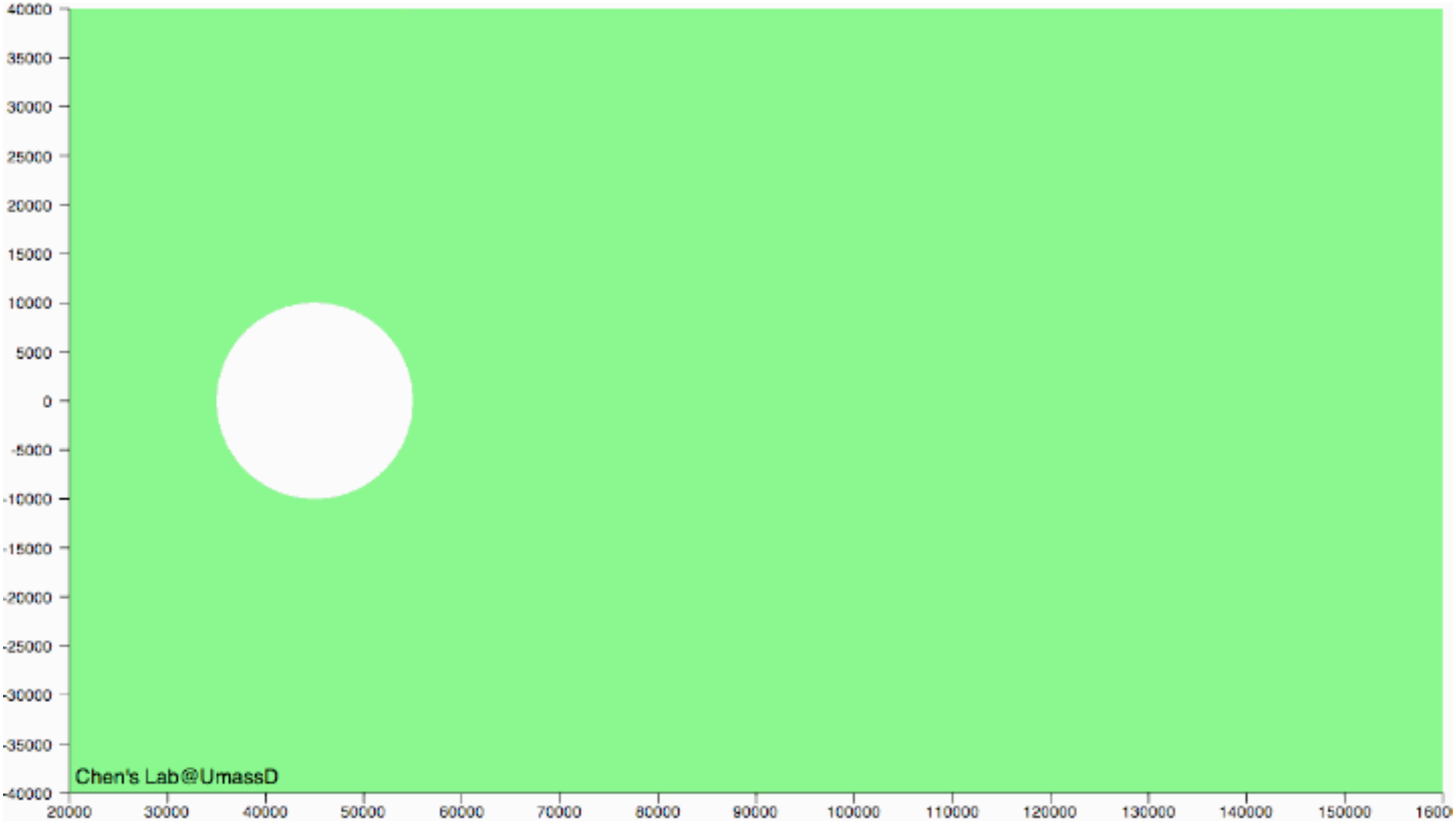


Under shear instability condition



Under the vortex condition

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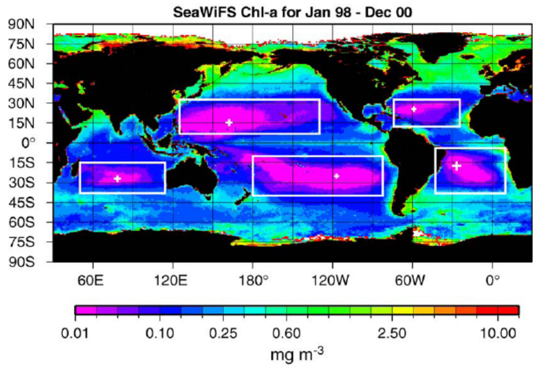
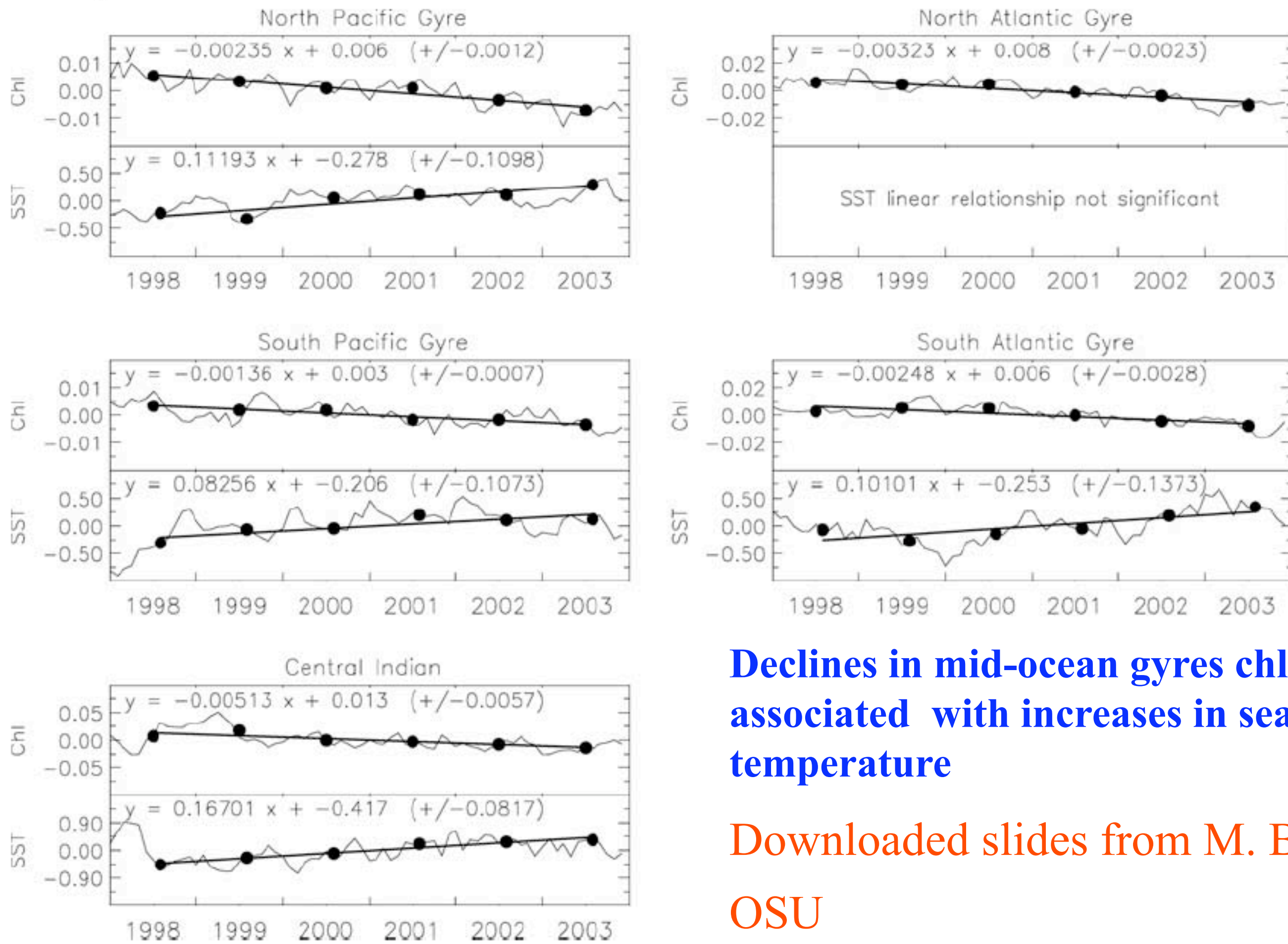



# Recent trends in global ocean chlorophyll

Watson W. Gregg
Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA
Nancy W. Casey
Science Systems and Applications, Inc., Lanham, Maryland, USA
Charles R. McClain
Laboratory for Hydrospheric Processes, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

GEOPHYSICAL RESEARCH LETTERS, VOL. 32, L03606, doi:10.1029/2004GL021808, 2005




**Declines in mid-ocean gyres chlorophyll associated with increases in sea surface temperature**

Downloaded slides from M. Berenfeld at OSU

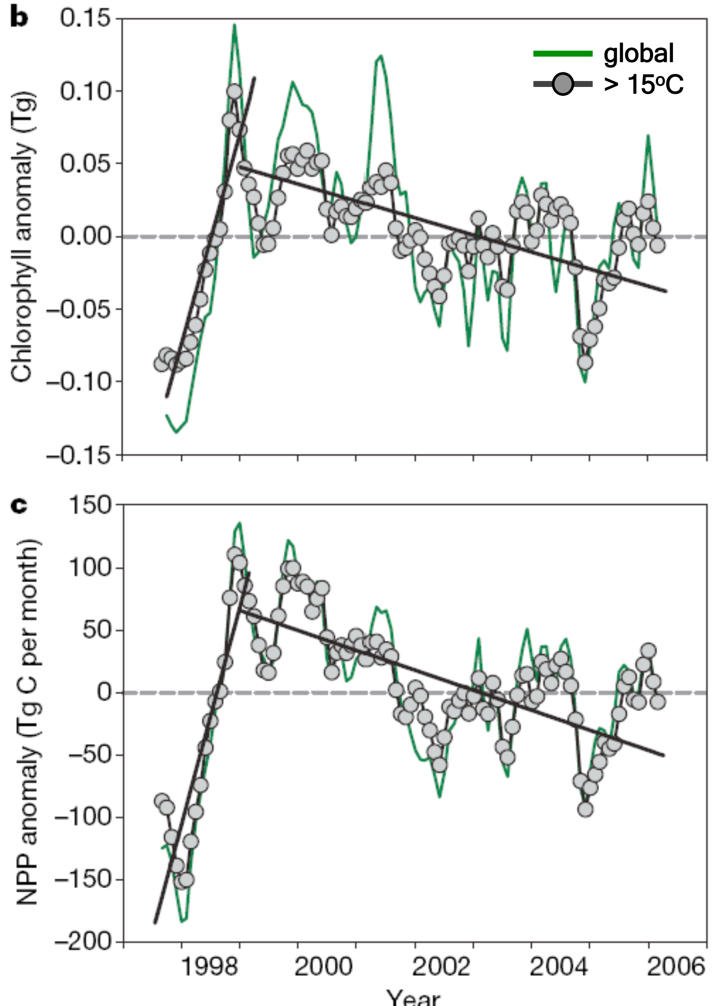


http://www.science.oregonstate.edu/ocean.productivity/highlights.php

# Climate-driven trends in contemporary ocean productivity

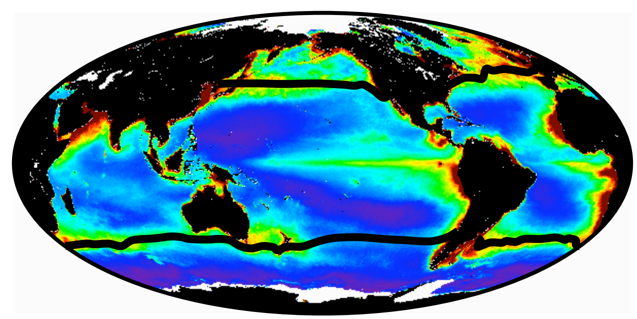
Michael J. Behrenfeld[1], Robert T. O'Malley[1], David A. Siegel[3], Charles R. McClain[4], Jorge L. Sarmiento[5], Gene C. Feldman[4], Allen J. Milligan[1], Paul G. Falkowski[6], Ricardo M. Letelier[2] & Emmanuel S. Boss[7]

7 December 2006 Vol. 444 Nature




## Tidbits

- Based on Vertically Generalized Production Model (VGPM)
- Initial increase = 1,930 TgC/yr
- Subsequent decrease = 190 TgC/yr
- Global trends dominated by changes in permanently stratified ocean regions (ann. ave. SST < 15°C)





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