ORGANIC CARBON DEPOSITION IN GYRE VERSUS EDDY OCEANS

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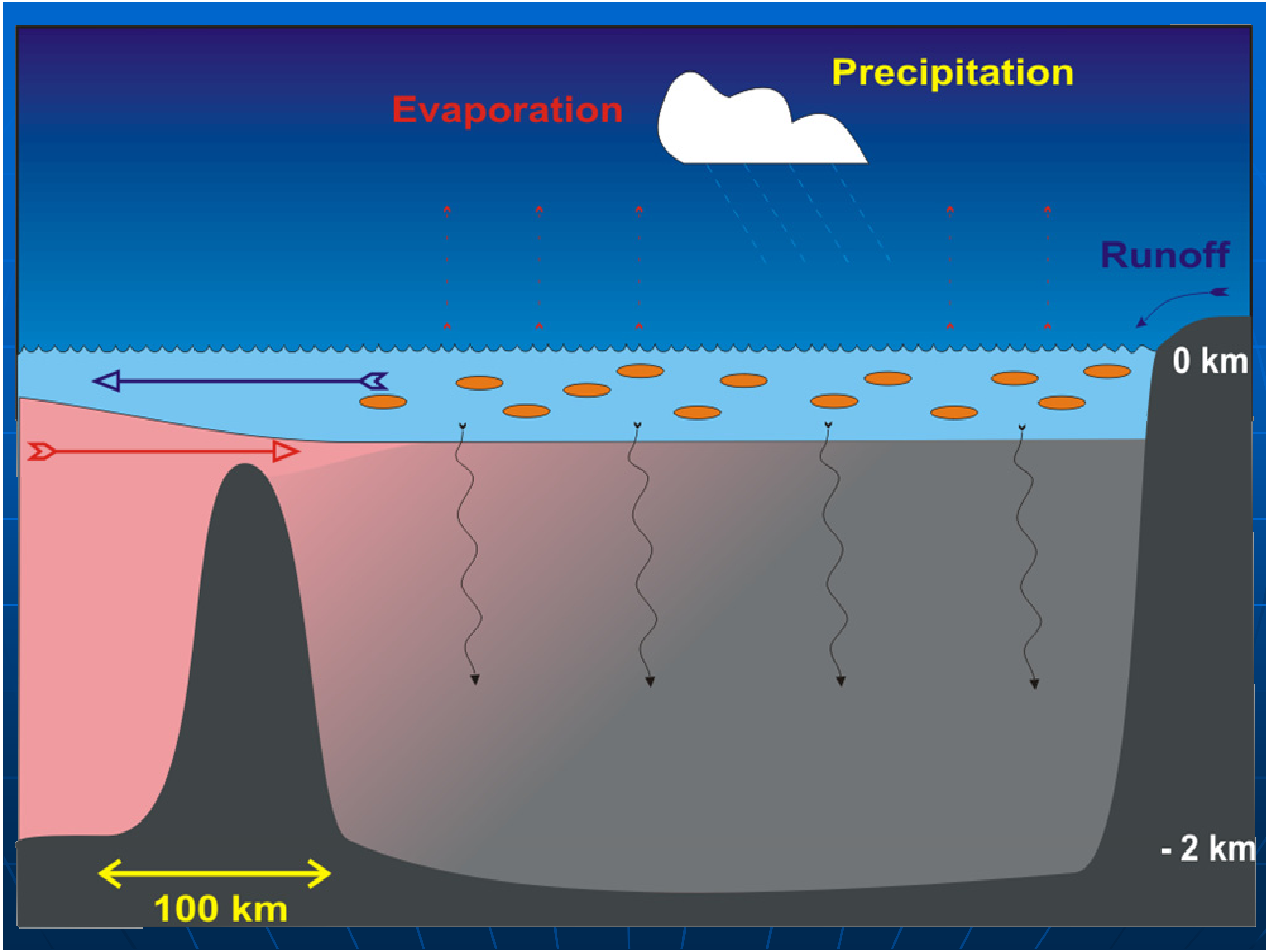
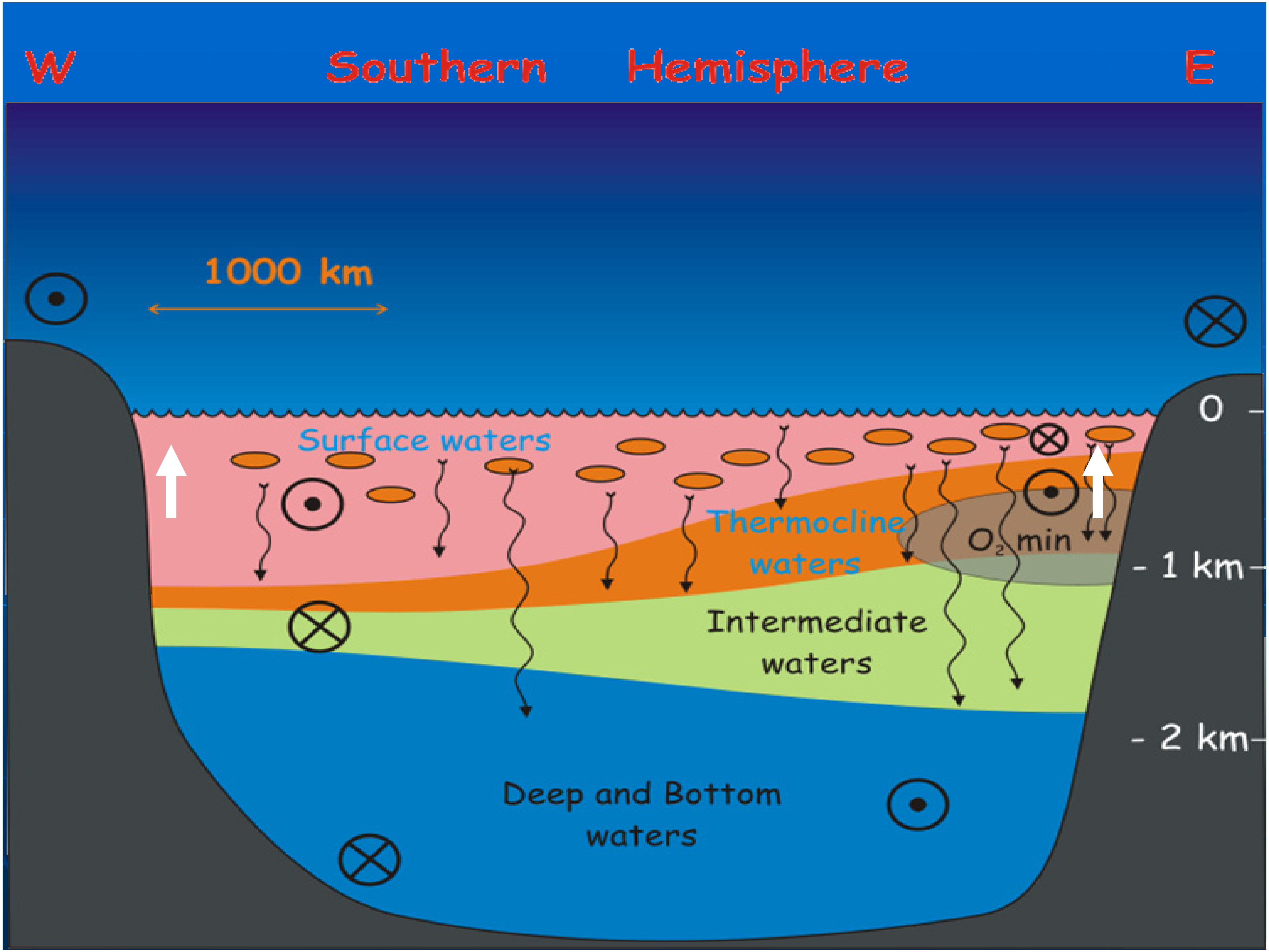


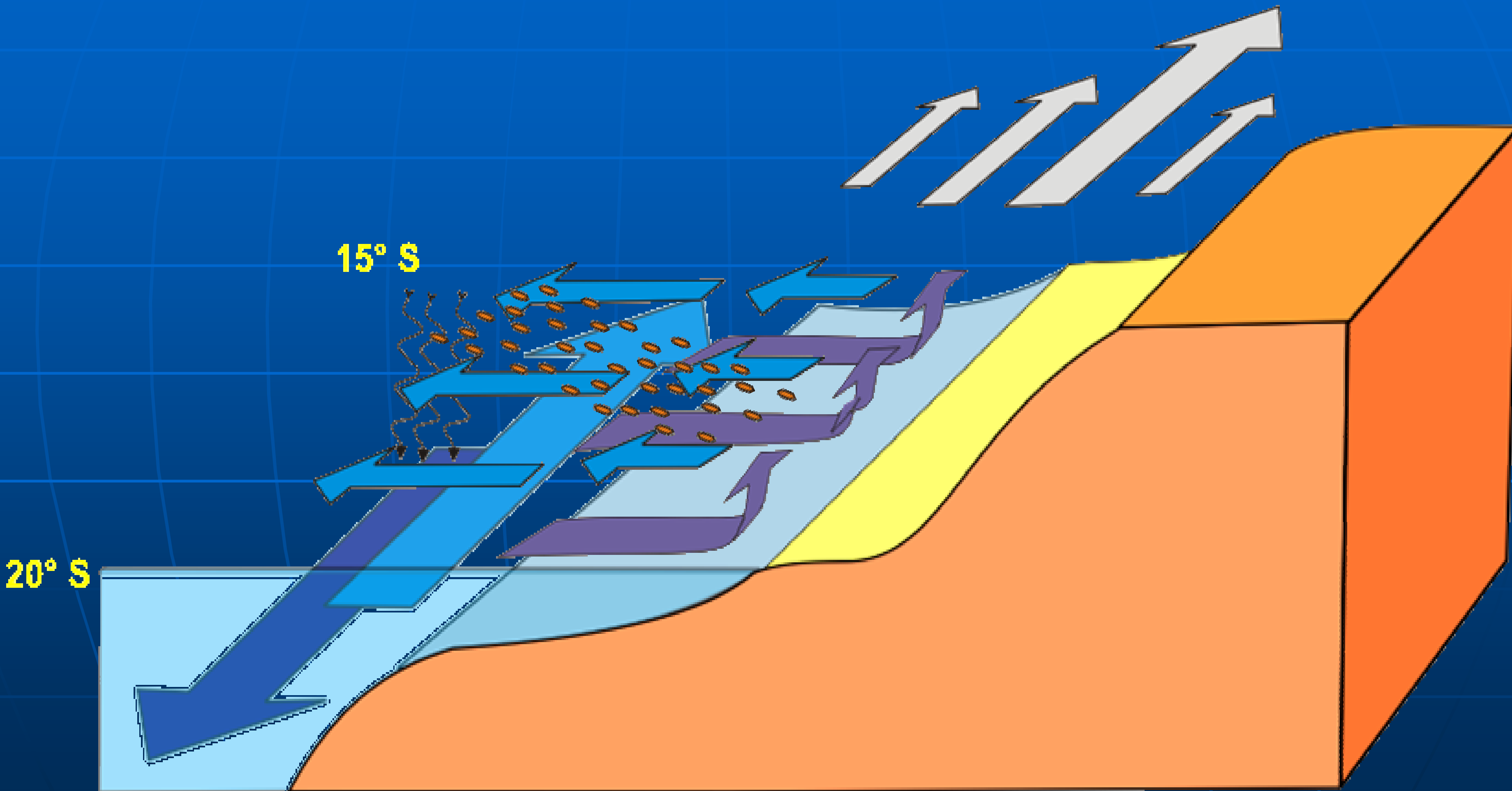
Precipitation
Evaporation
Runoff
0 km
- 2 km
100 km

- The Black Sea model requires a very strong positive fresh water balance
- Nutrients are supplied from land along with the fresh water

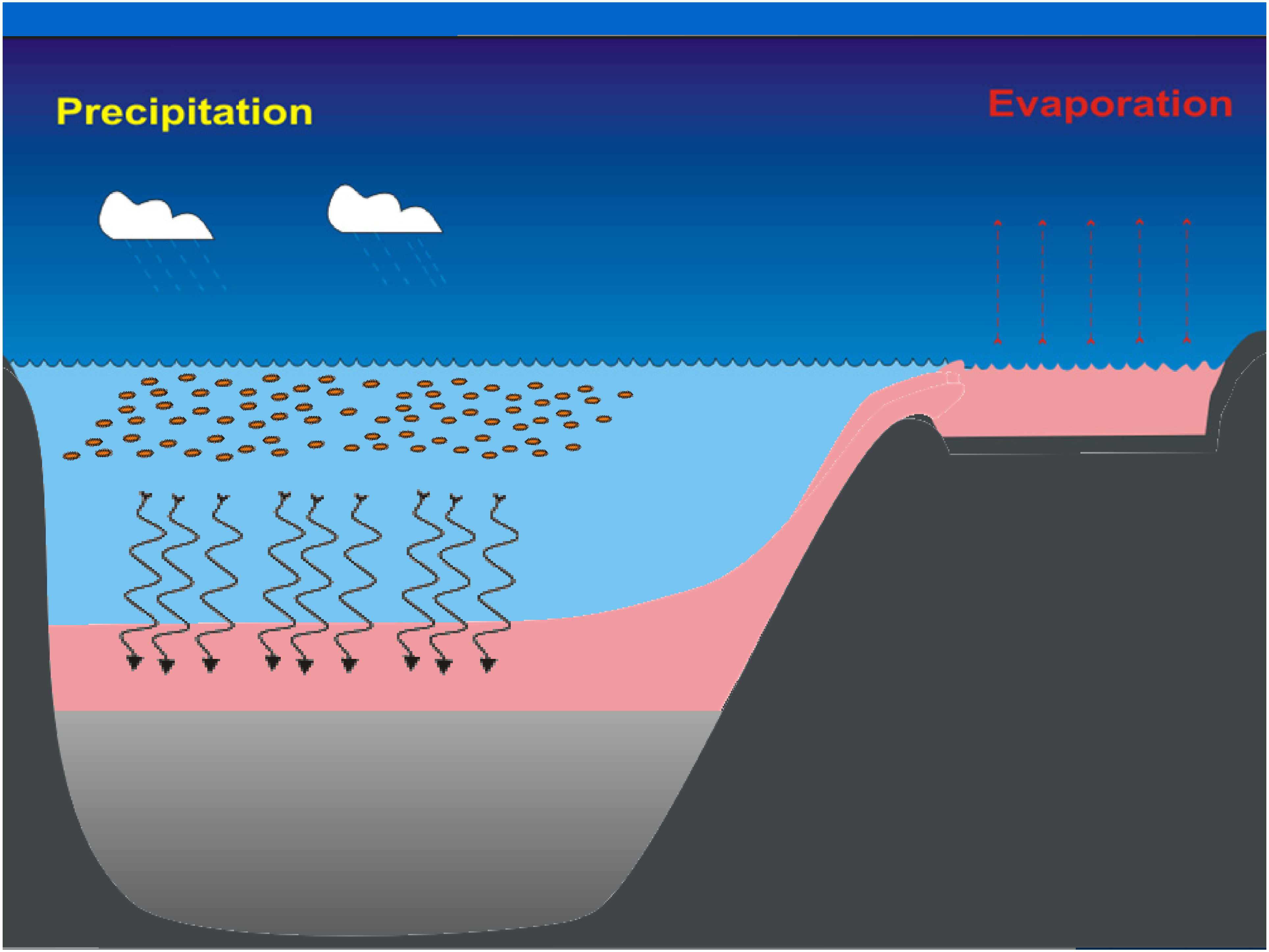


W
Southern Hemisphere
E
1000 km
Surface waters
Thermocline waters
O_2 min
Intermediate waters
Deep and Bottom waters
0
1 km
2 km

How the Benguela coastal upwelling system feeds on itself



- The Oxygen Minimum model requires special conditions such that it can feed on itself
- Nutrients are trapped in a localized recycling system


Precipitation
Evaporation

All of these models involve nutrient traps

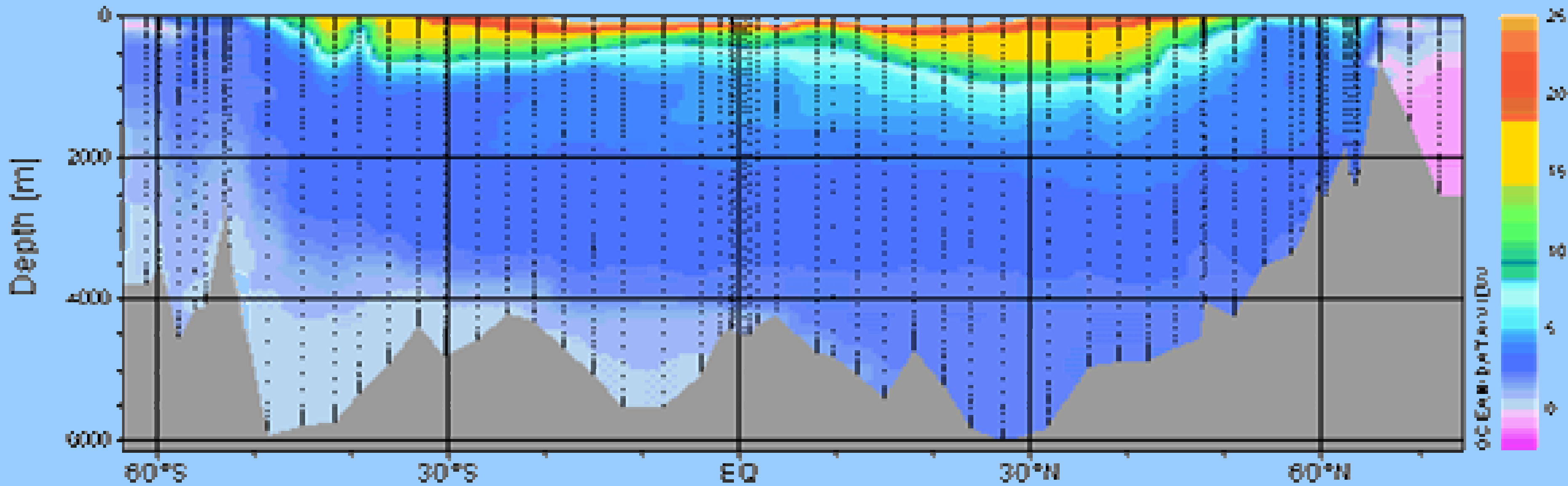
How do they behave in the context of a change in the structure of the ocean?

From gyre (modern – “ice house”)

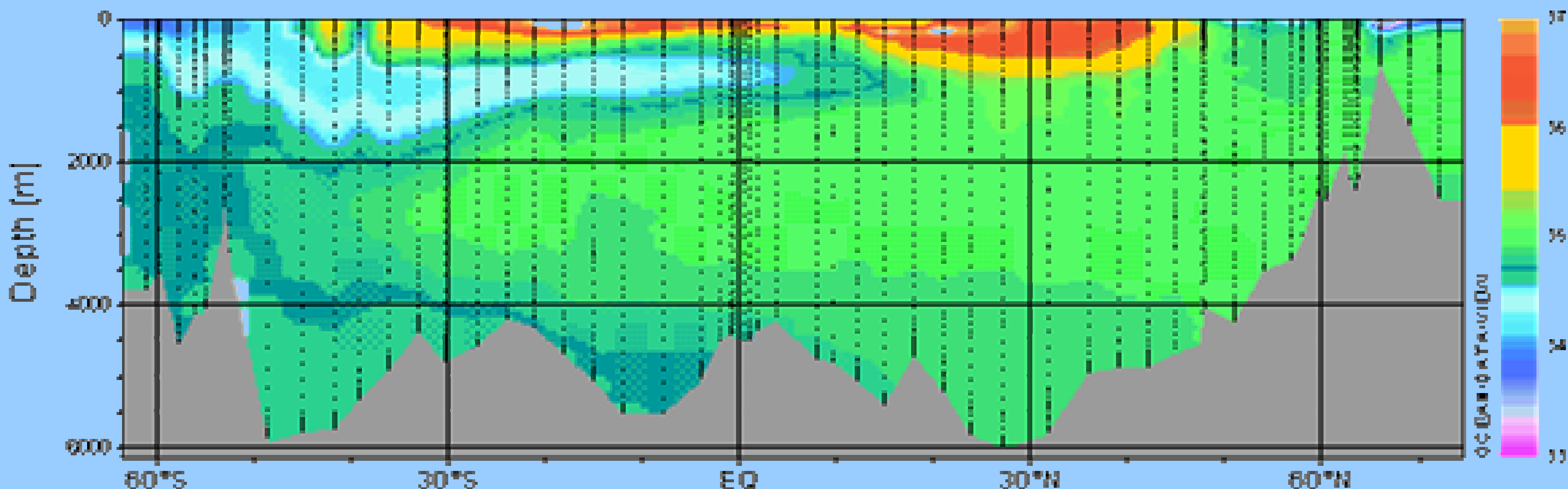
To eddy (warm – “greenhouse”)

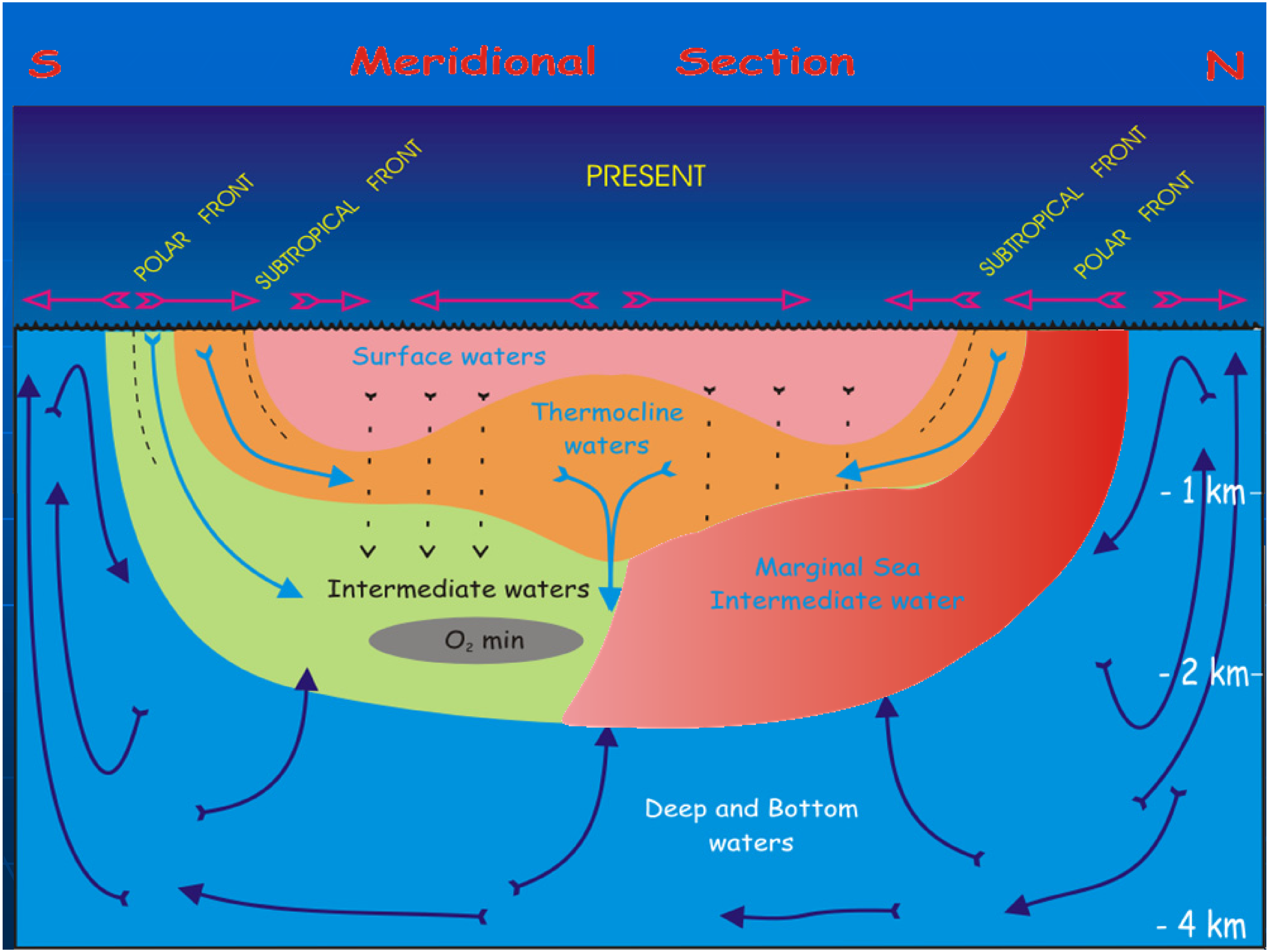
Ocean

Temperature [°C]

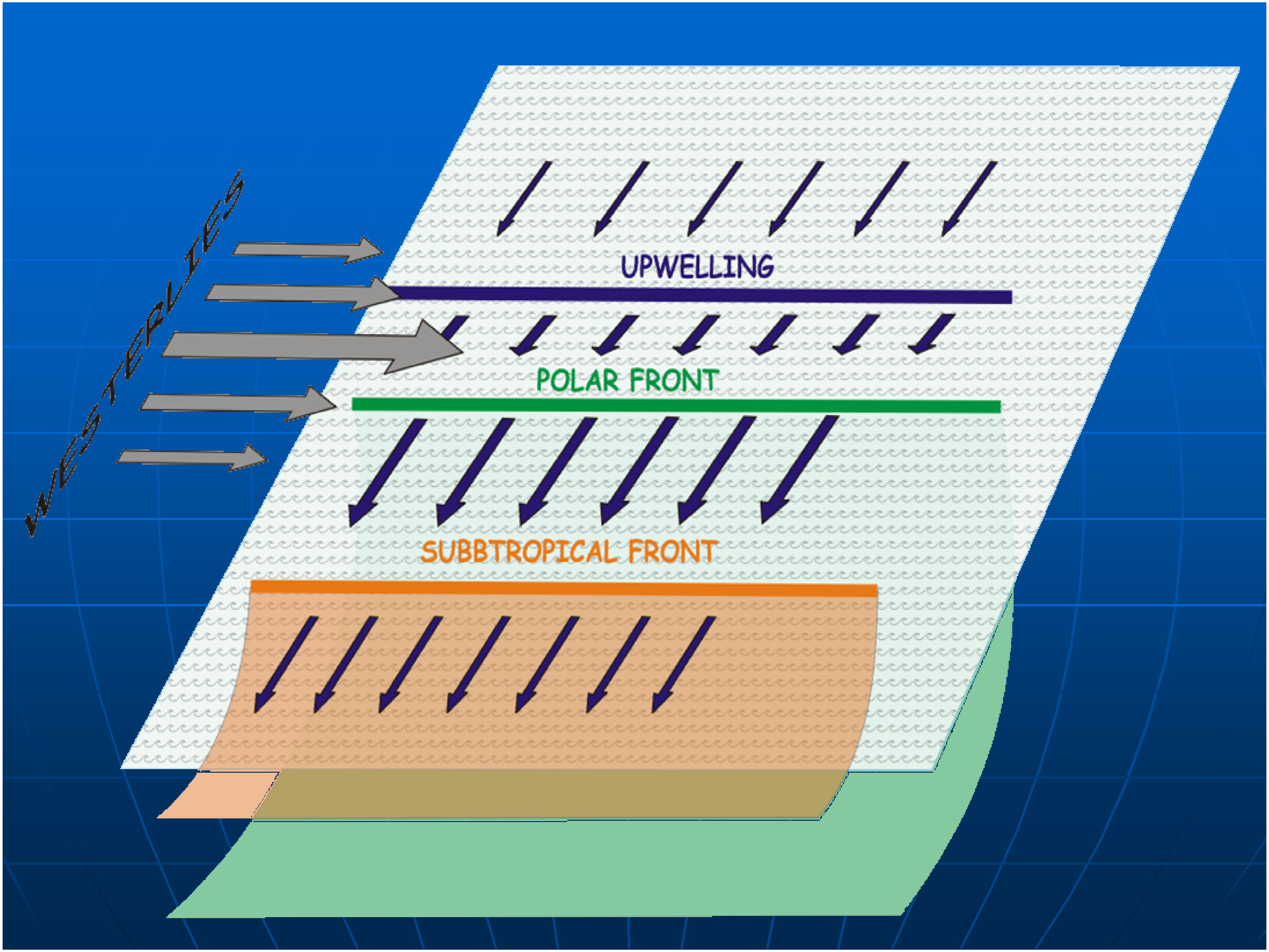


Salinity [psu]



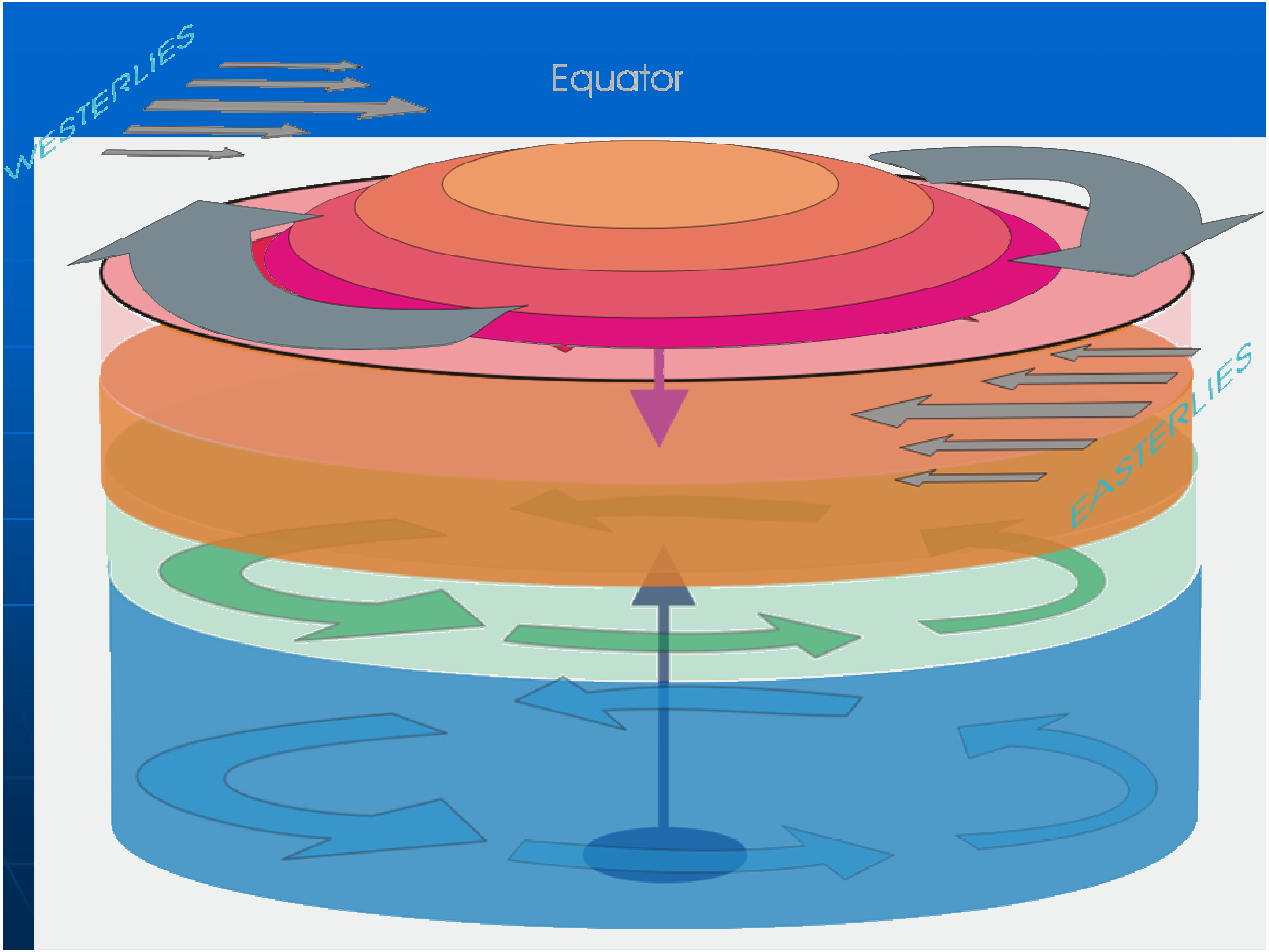


S
Meridional Section
N
PRESENT
POLAR FRONT
SUBTROPICAL FRONT
SUBTROPICAL FRONT
POLAR FRONT
Surface waters
Thermocline waters
Intermediate waters
O_2 min
Marginal Sea Intermediate water
Deep and Bottom waters
- 1 km
- 2 km
- 4 km

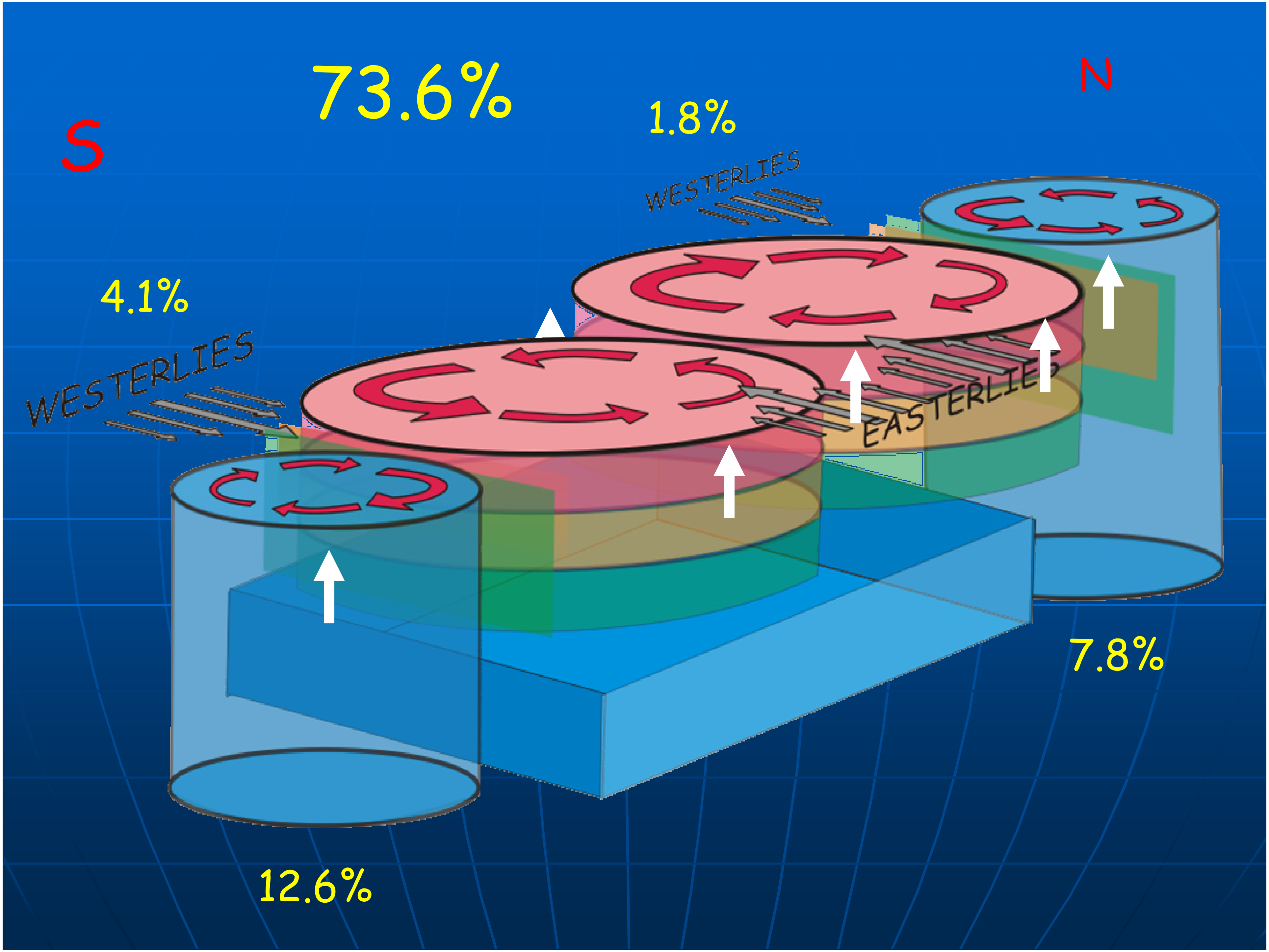

WESTERLIES
UPWELLING
POLAR FRONT
SUBBTROPICAL FRONT

The structure of the modern ocean depends on …

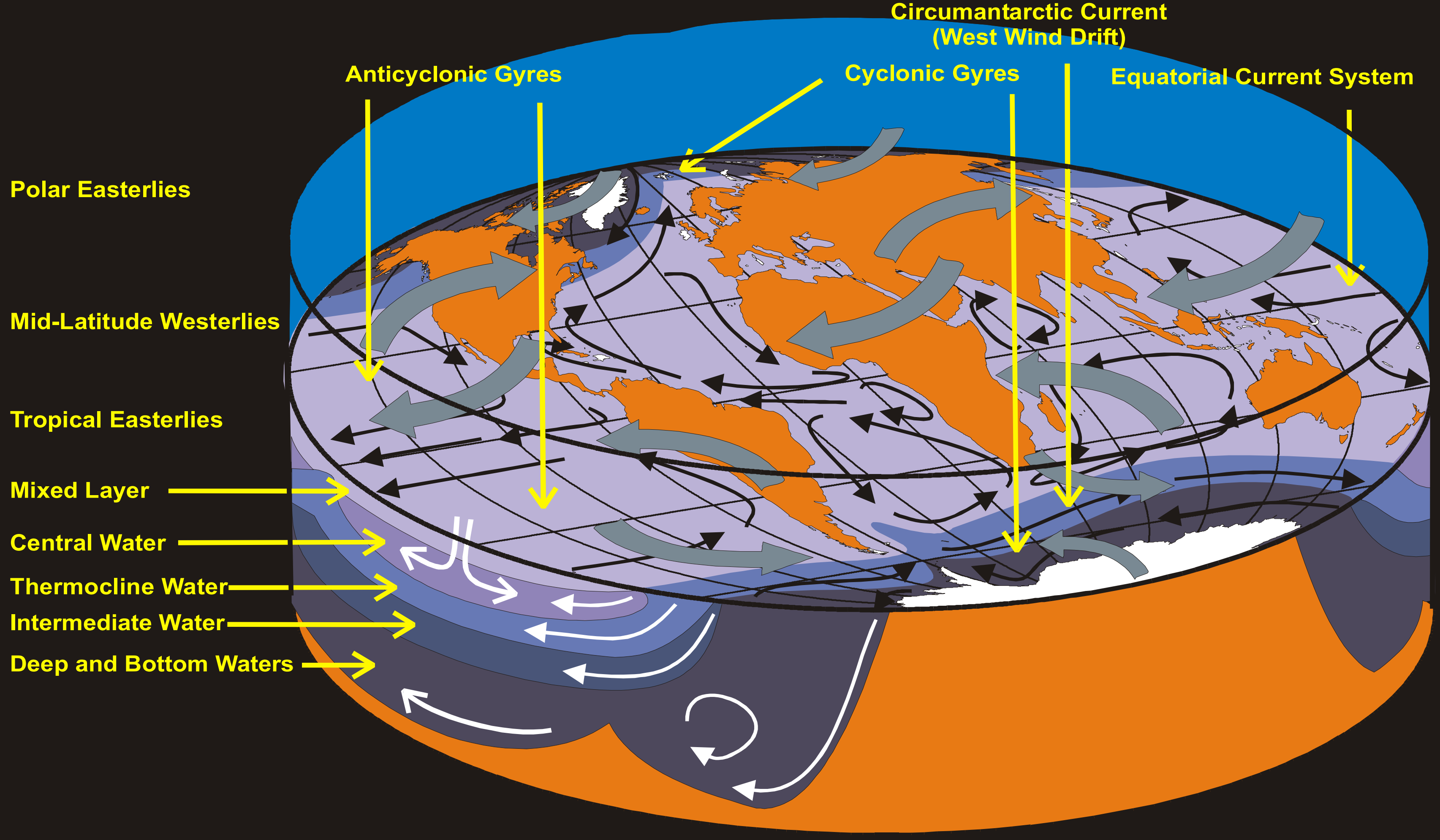
- Ocean frontal systems that define and supply the oceanic pycnocline
- The ocean fronts are forced by steady westerly winds centered on 45° latitude
- The steady westerly winds are forced by permanent atmospheric high pressure at the poles
- High pressure at the poles is forced by polar ice



Equator
WESTERLIES
EASTERLIES


73.6%
S
N
1.8%
4.1%
WESTERLIES
WESTERLIES
EASTERLIES
7.8%
12.6%

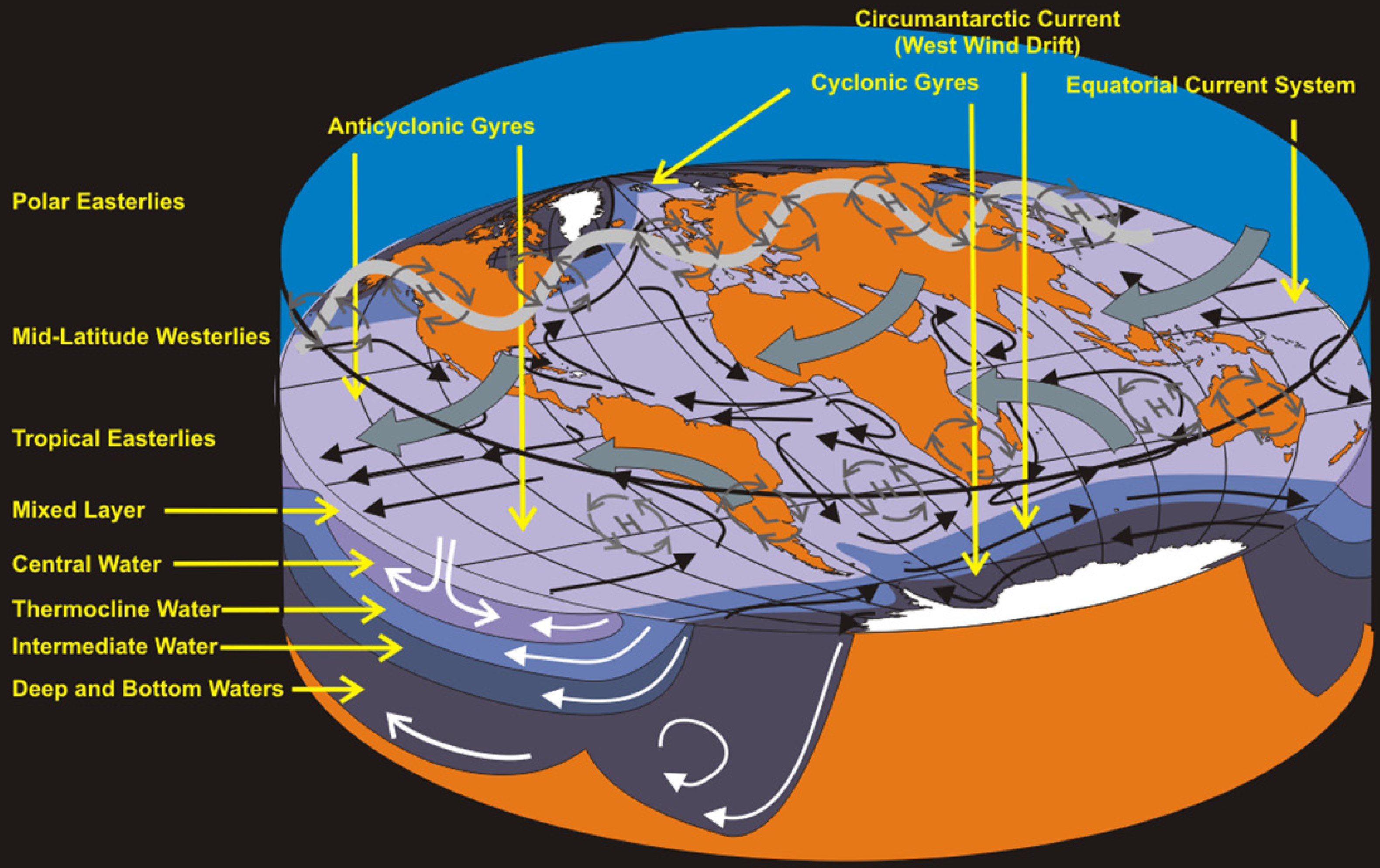
Low latitude stratification with anticyclonic gyres vs. high latitude convection with cyclonic gyres



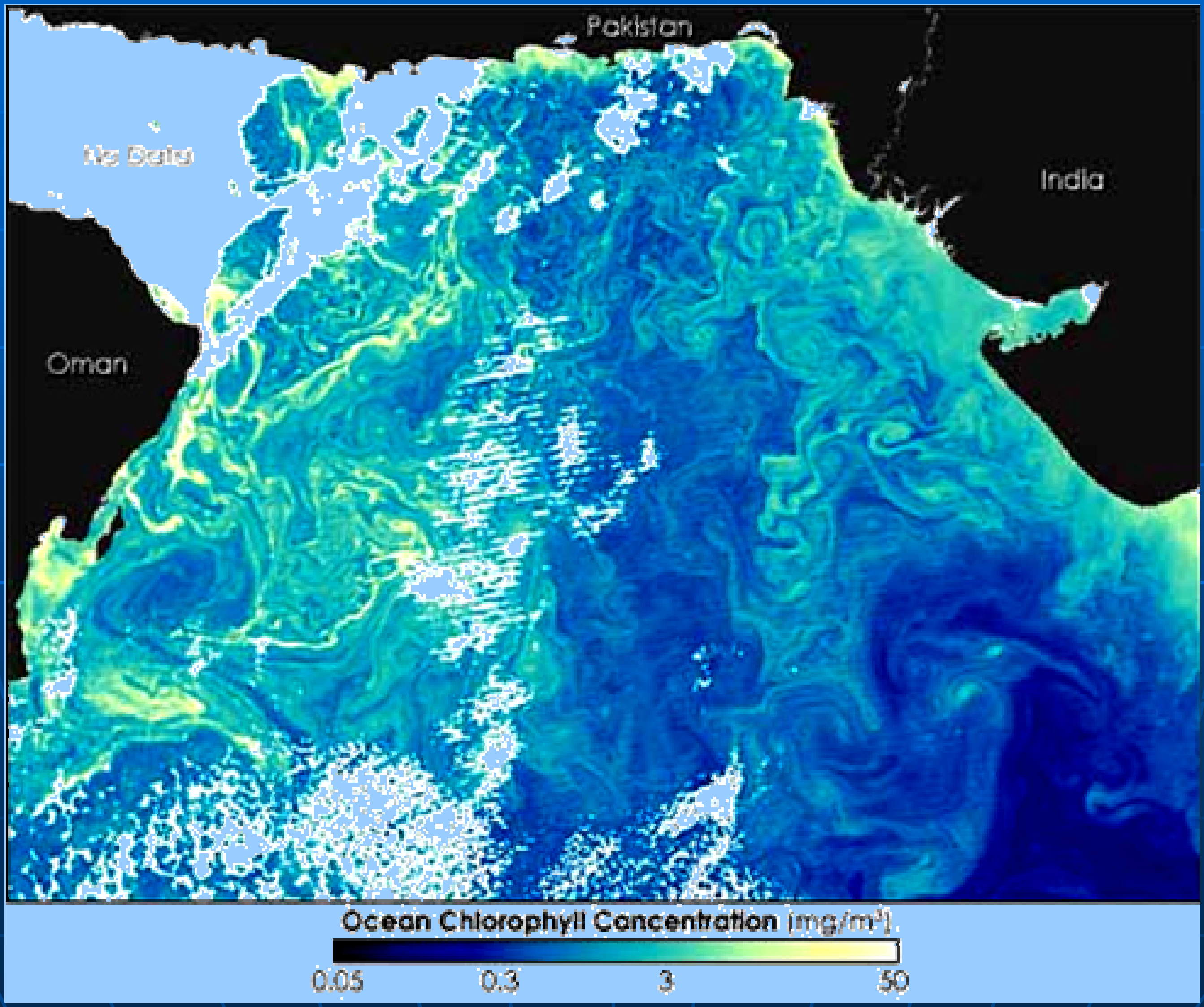
This "highly organized" ocean circulation is the integral of forcing by the weather over a decade or two

The shorter term circulation is controlled by eddies generated by weather events

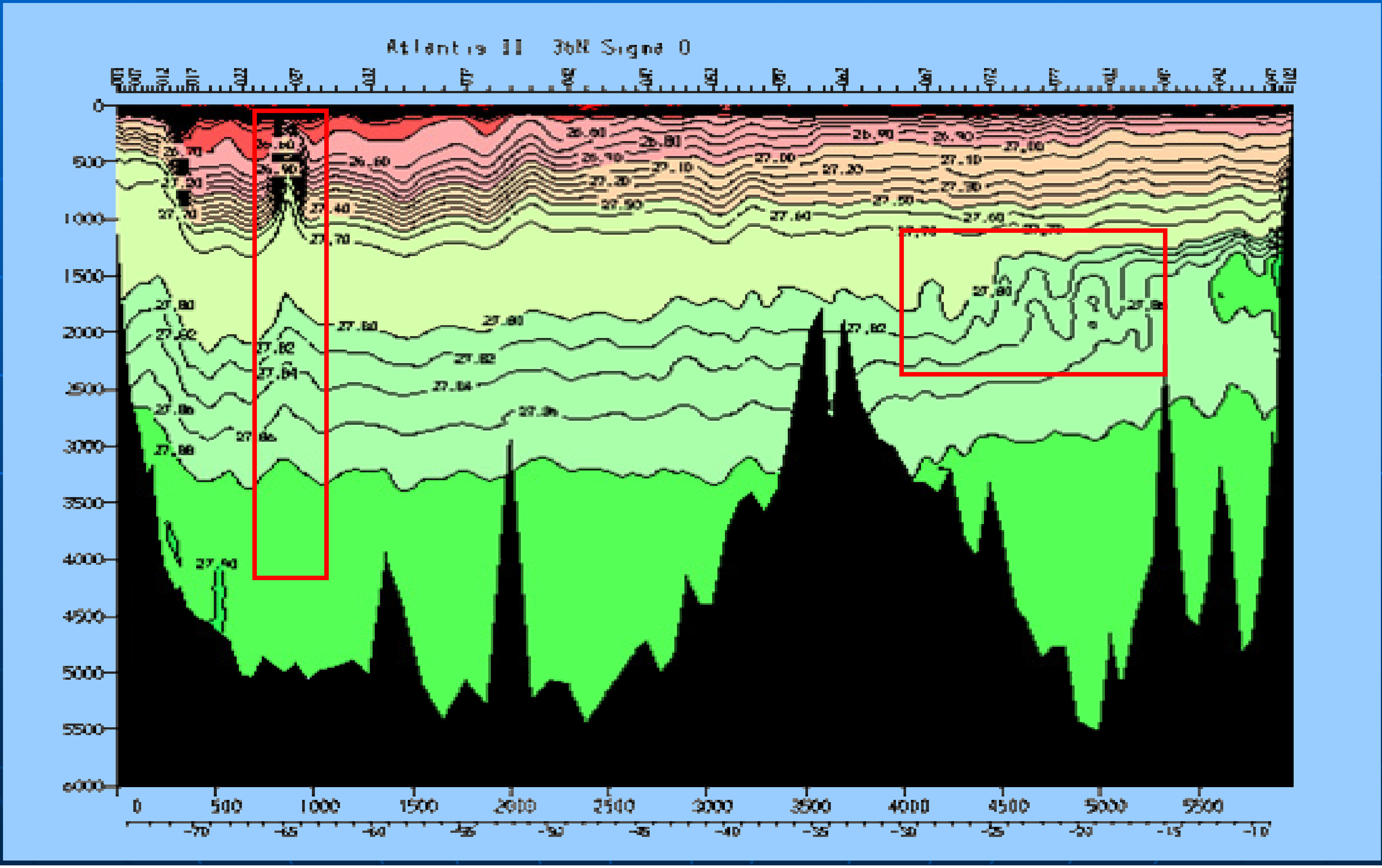
Add the complexity of moving high and low pressure systems locked to the planetary waves of the jet stream (NH) and the more stable Walker Circulation (SH)



Variable winds combine with bathymetry to produce mesoscale ocean eddies today



A detailed density section across the North Atlantic W – E at 36°N



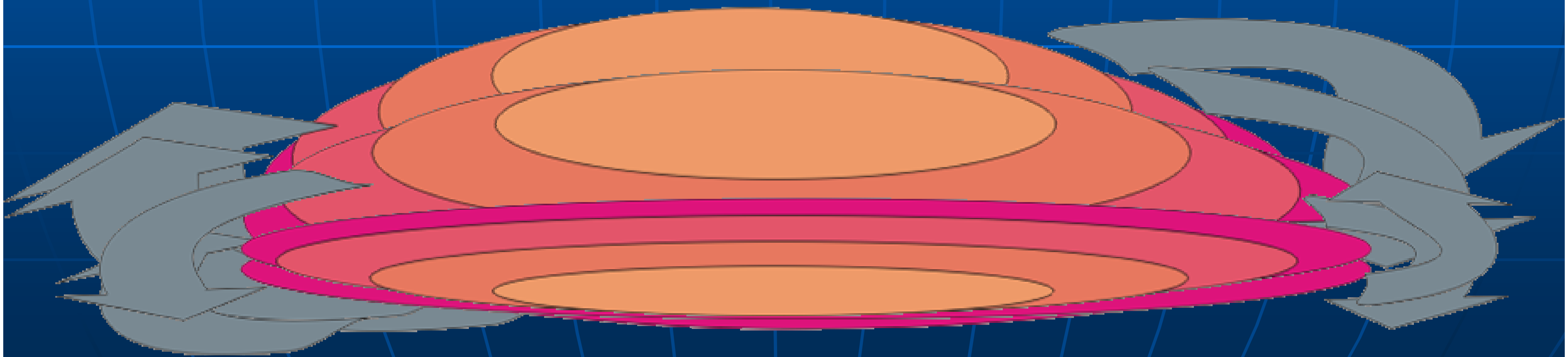
However, without polar ice …

- The polar pressure systens reverse with the seasons
- Because the equatorial low remains constant, each hemisphere alternates between three and two cell atmospheric circulation
- The westerly winds require a polar high and are seasonal
- The subropical/polar frontal systems are at best seasonal
- The well defined structure of the modern ocean disappears

But remember this anticyclonic gyre dome?

It is forced up 2m by the winds, but evaporation at 30° removes 1m – net height 1m

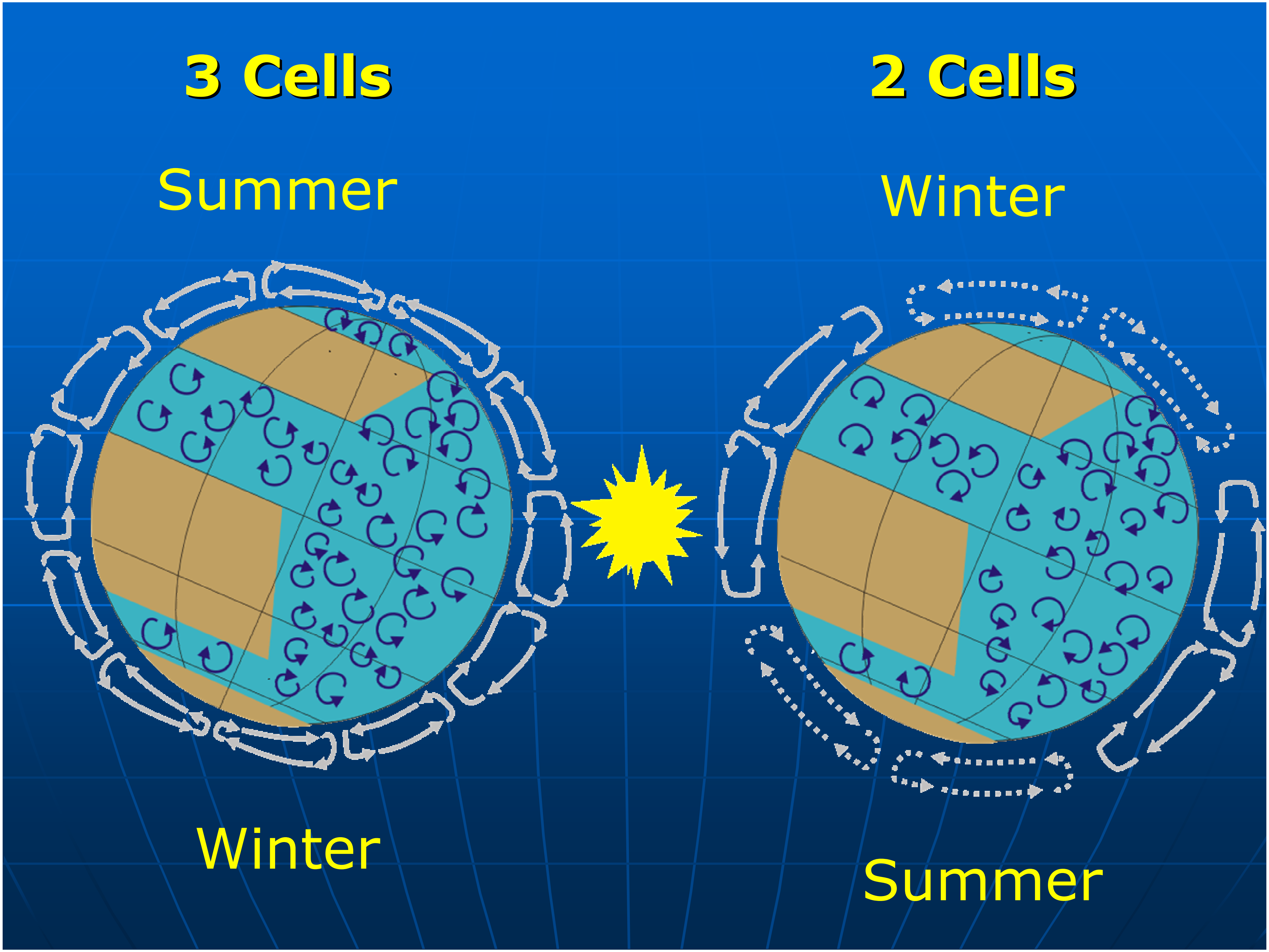
As the winds forcing decreases, the evaporation increases – and …



And even worse

- During much of its history the Earth has had land at one pole and water at the other
- The water pole has a high in summer and low in winter
- The land pole has a high in winter and low in summer
- Both poles have high pressures and low pressures at the same time !

- A CONDITION UNIQUE IN OUR SOLAR SYSTEM


3 Cells
2 Cells
Summer
Winter
Winter
Summer

The result

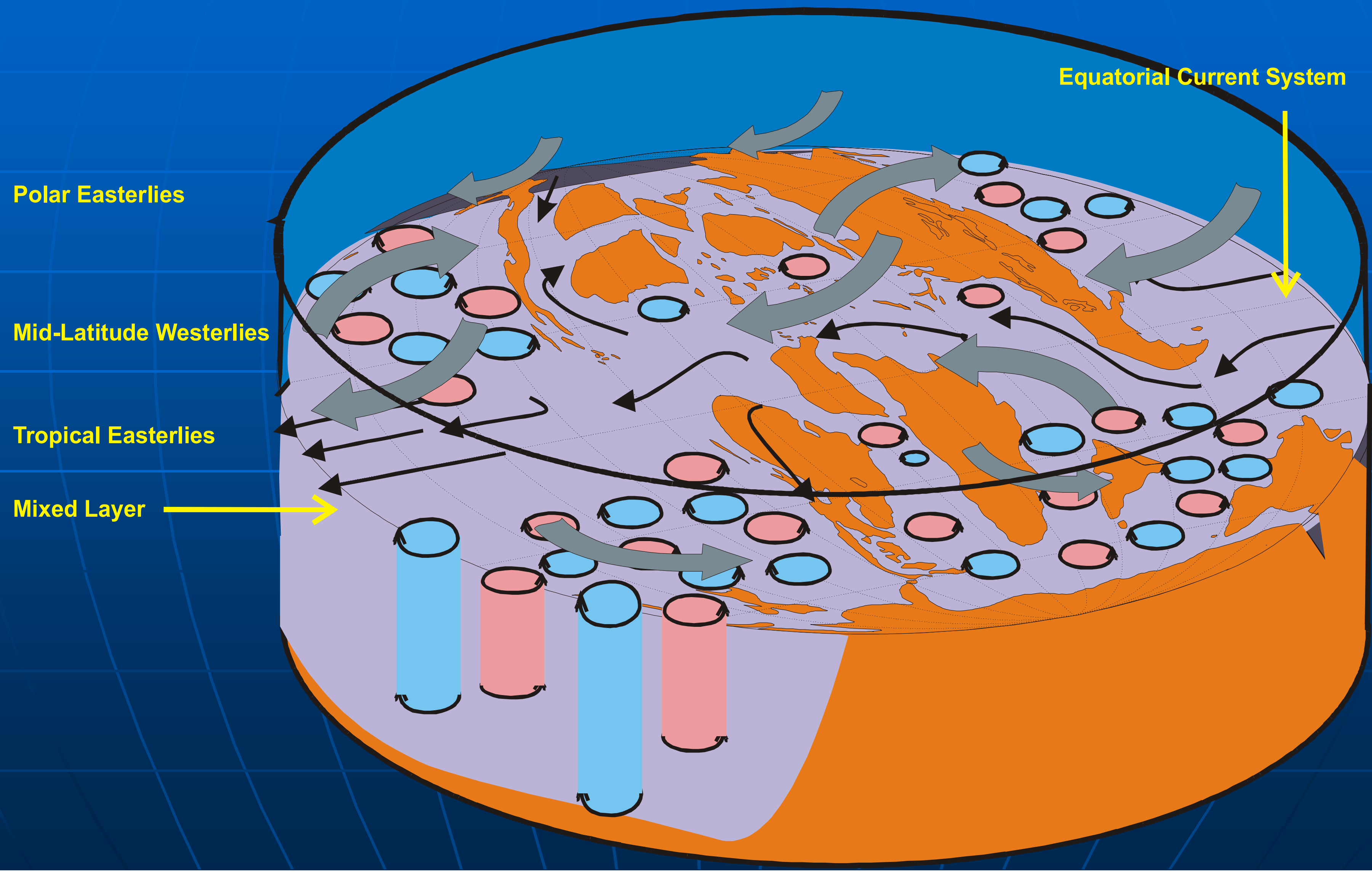
- No subtropical/polar frontal systems to bar heat transport to the poles
- No well-defined tropical/subtropical anticyclonic gyres
- No well-defined thermocline to separate surface and deep ocean
- No well-defined sources for deep water
- And an unstable chaotic climate producing

AN OCEAN FILLED WITH TRANSIENT EDDIES

Whereas the modern gyres are forced by the winds and only respond to bathymetry in shallow water

Eddies are generated by transient weather events and are steered by the bottom topography

Early Cretaceous circulation might have looked like this

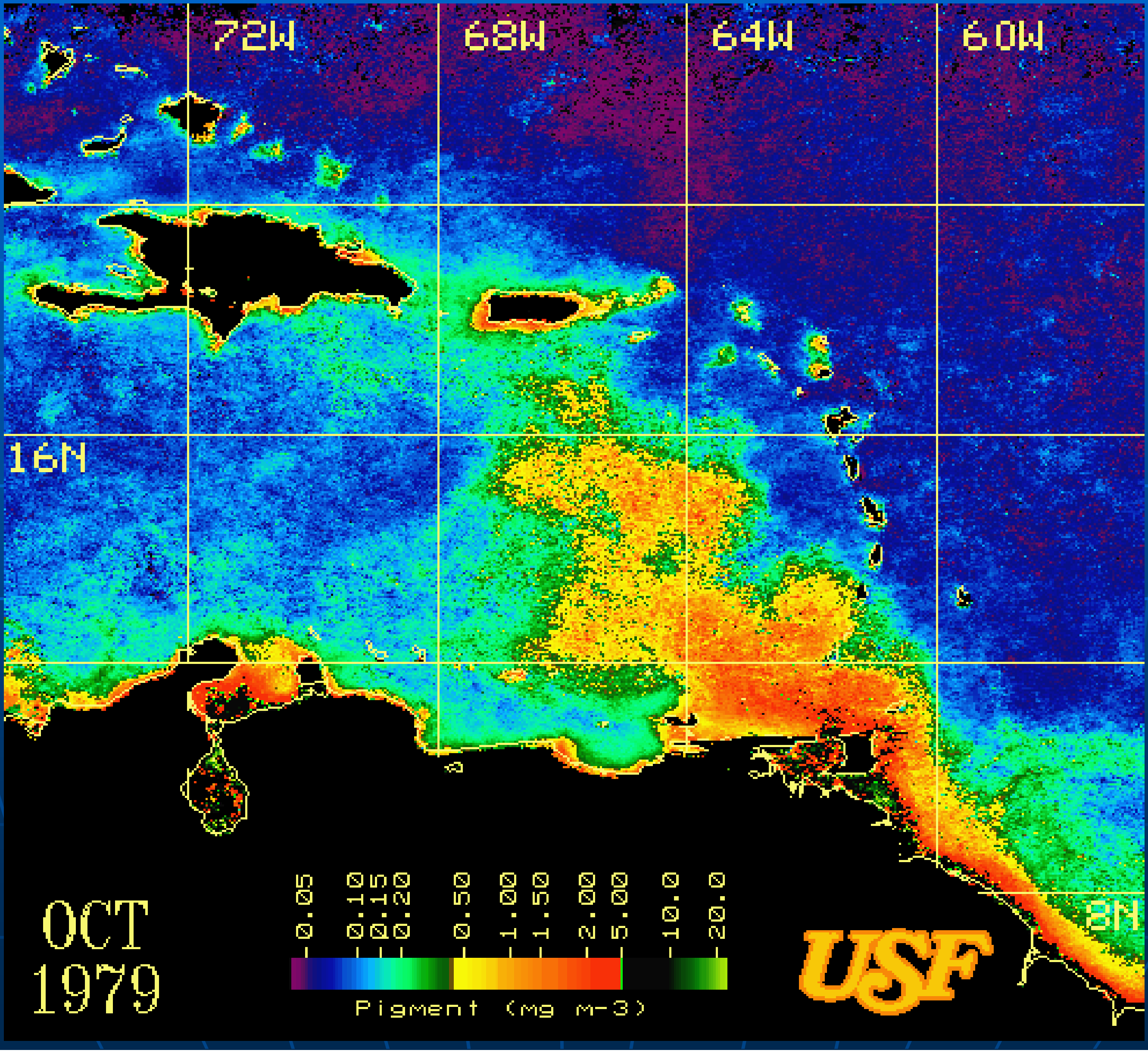


Comparing icehouse and greenhouse ocean density structure

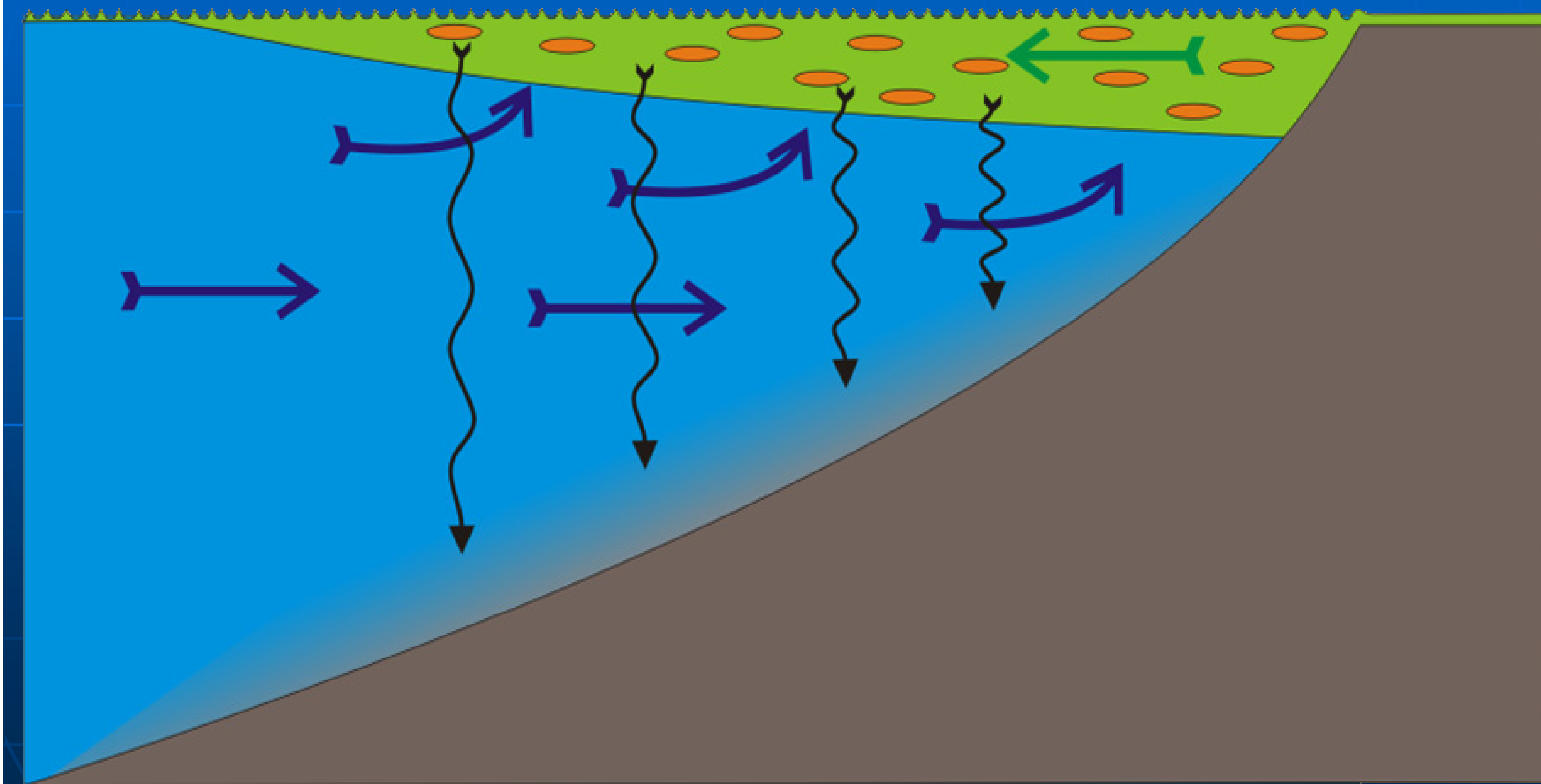
What about the sites of upwelling?

- The Equatorial upwelling systems , forced by easterly winds, persists (e.g. Cretaceous of Venezuela)
- The general convective upwelling, limited today to the polar regions (e.g. diatom ooze bands), becomes more widespread regionally but much less intense
- The mid-latitude coastal upwelling along the eastern margins of ocean basins (e.g. Monterey Fm. analogs) disappears

River plumes can be quite large



River plumes would be especially effective in an eddy ocean



Coastal upwelling doesn't work well because …

The eddy-ocean concept can explain why

- Eocene diatomaceous deposits can be widespread in the middle of the central North Atlantic
- Early Cretaceous oceanic black shales can have both local and widespread – possibly global – distributions
- Older ophiolites have pillow lavas overlain by dark shales

The eddy-ocean concept also suggests that

- On an Earth without bipolar ice petroleum source beds may have formed in ways and at places different from what we would expect by analogy with modern Corg deposits