Coastal Upwelling Features over Arabian Sea From ROMS-Model

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OUTLINE

- ✓ Introduction
- ✓ What is Upwelling
- ✓ Types of Upwelling
- ✓ What is the need to study the upwelling
- ✓ Which kind of models are appropriate for this study
- ✓ Upwelling Features from ROMS-Model

Introduction

- (Ekman,1905) deduced the fundamental dynamics of wind forced upwelling from looking at the deflection in the drift of icebergs.

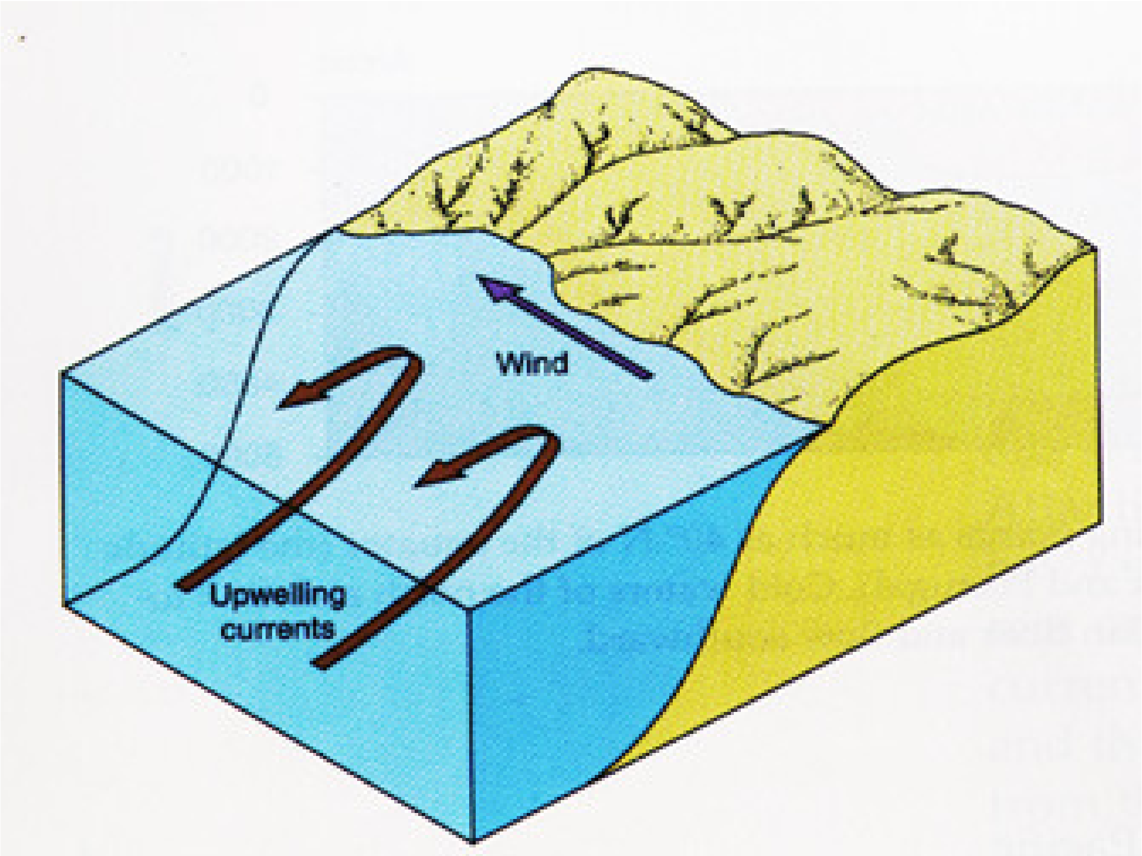
- A balance between wind frictional forcing at the sea surface and Coriolis forcing due to Earth's rotation explained the observed current deflection.

- Ocean upwelling is the ascending motion of deep cold and nutrient enriched water from subsurface layers resulting from horizontal divergence caused by Ekman offshore transport due to alongshore wind stress at the surface layers and convergence below. (Smith, 1968)

Mechanisms that create ocean upwelling

- Wind
- Coriolis Effect
- Ekman Transport

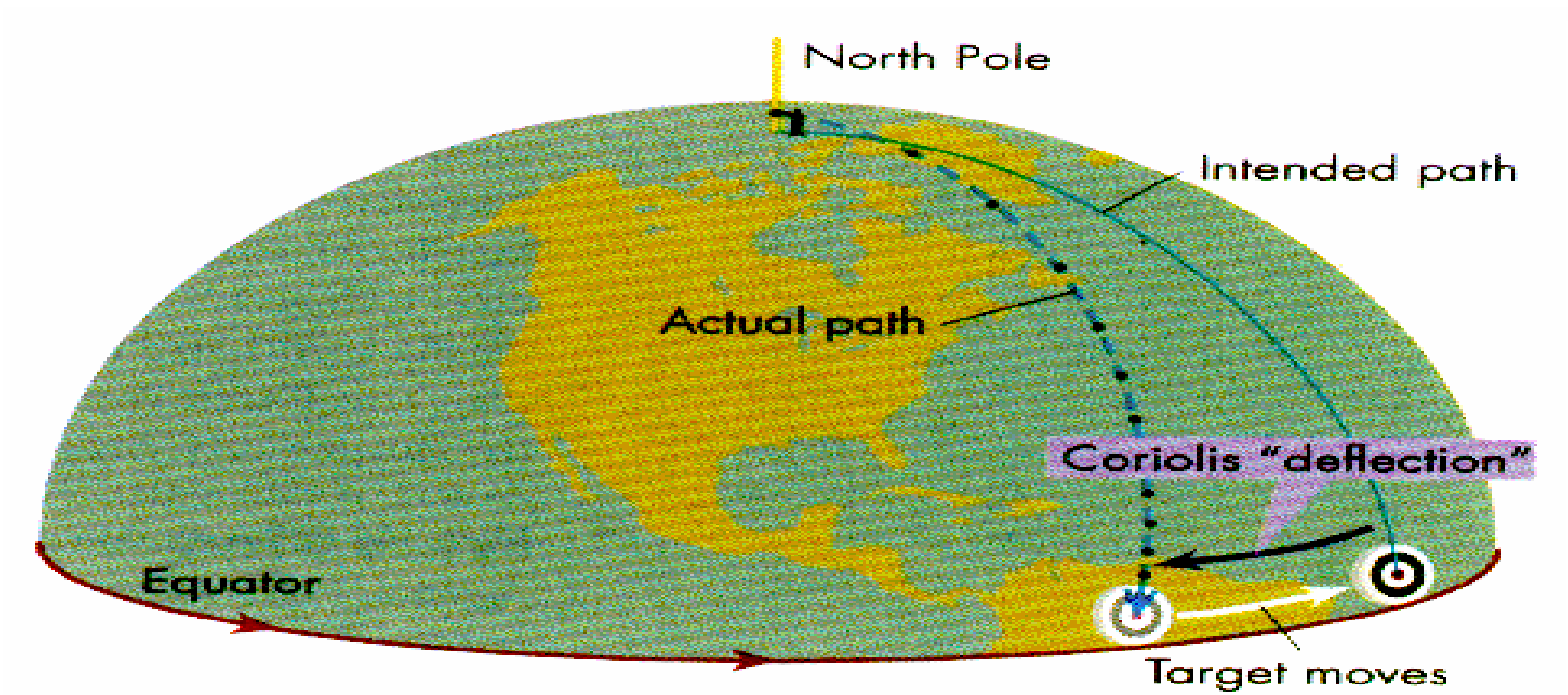
Upwelling refers to deep water that is brought to the surface.



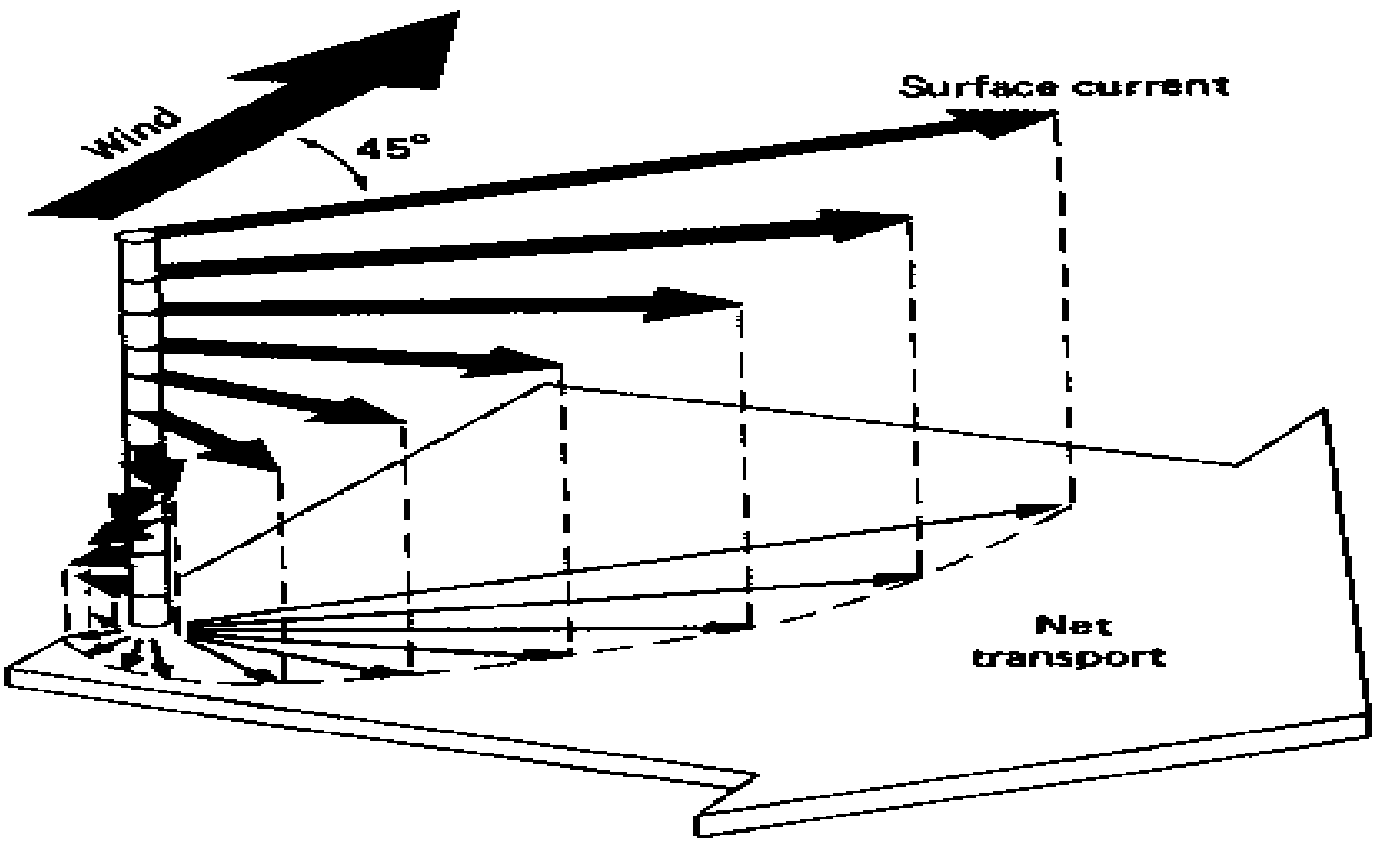
Areas of upwelling are created by surface winds that pull water away from an area. This deficit of water on the surface invites water to come up from deeper regions.

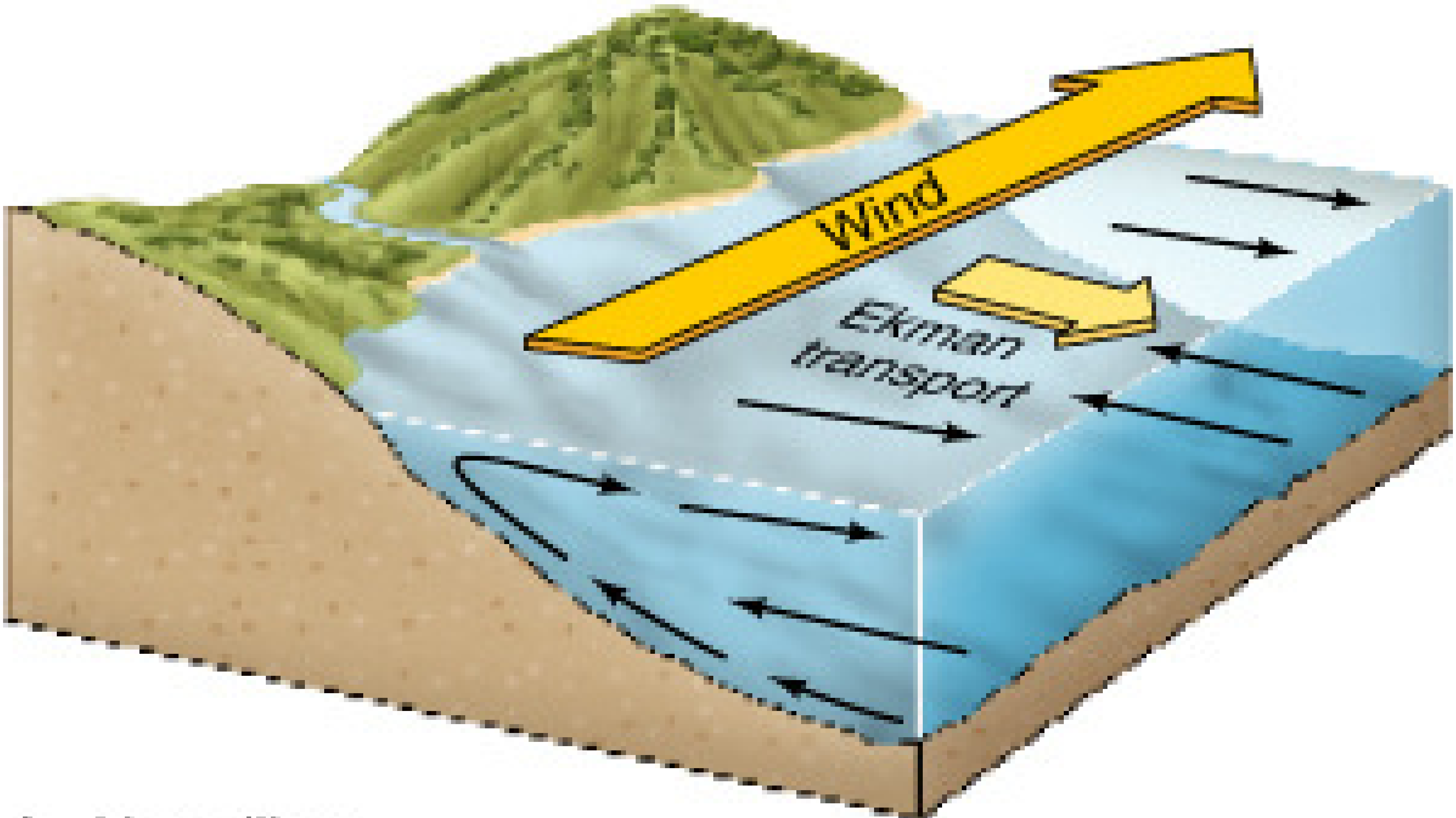
✓To understand upwelling, you must be familiar with how the Coriolis Force affects ocean surface currents.

The Coriolis Effect acts on moving water also. As water flows over the rotating earth, it appears to deflect to the right in the Northern Hemisphere and the left in the Southern.



Due to friction between the layers of water in the ocean and the Coriolis Effect, the net result of wind blowing across the surface of the water is transportation of a layer of water 90 degrees to the direction of the wind. This is known as Ekman Transport.

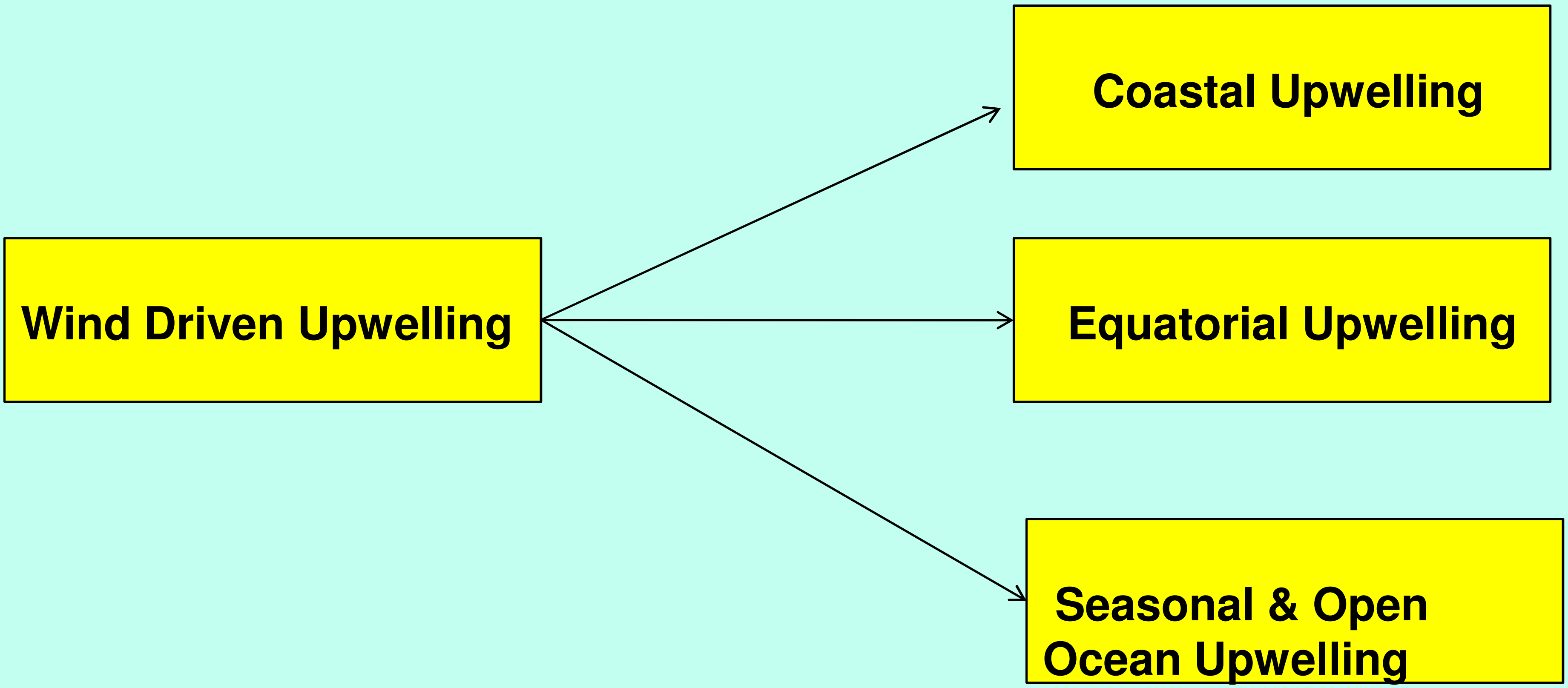




A. Upwelling

Upwelling Systems can be classified into 2 major categories:-

1. Wind Driven
   results from divergence in surface Ekman layer of the Ocean.
2. Dynamical
   results from the divergence in the upper Ocean (or) convergence in deeper water column caused by large scale current systems.



Effects of Upwelling

CAUSE – Nutrients are brought up to surface

EFFECTS:

- Phytoplankton & zooplankton thrive
- More food for fish and larger organisms
- Strong food webs and food chains

Reasons to study Upwelling

- Upwelled water is cooler and saltier than the original surface water, and typically has much greater concentrations of nutrients.

- . These nutrients support the base of the food chain phytoplankton

- The increased availability in upwelling regions results in high levels of primary productivity and thus fishery production. Approximately 25% of the total global marine fish catches come from five upwellings that occupy only 5% of the total ocean area

- Marine ecosystems in the ocean's eastern boundary currents generally have large fish stocks such as sardines and anchovies, and major populations of marine mammals and

ROMS Model configuration

• Domain	30^oS – 30^oN , 30^oE-120^oE
• Resolution	0.25^o X 0.25^o
• Vertical levels	20 Sigma levels
• Bathymetry	ETOPO2
• Initial condition	Levitus data – annual mean
• Open Boundary Condition	World ocean atlas(WOA-09)
• Surface Forcing	COADS Climatology - monthly

Upwelling Index

- The magnitude of offshore component of the Ekman Transport is considered as an indicator of the amount of water upwelled through the bottom of Ekman layer for balancing the dragged offshore transport.

  (Hart & Curri, 1960; Bakun 1973, Rayer 1981,Naidu 1999)

- Ekman Transport—

$$M_E = \frac{\tau}{f}$$

where- M_E = Ekman Transport [Kg./(m.sec)]

$\tau = \rho\, c_d\, V^2$ =Wind Stress [Kg./(m.sec^2)]

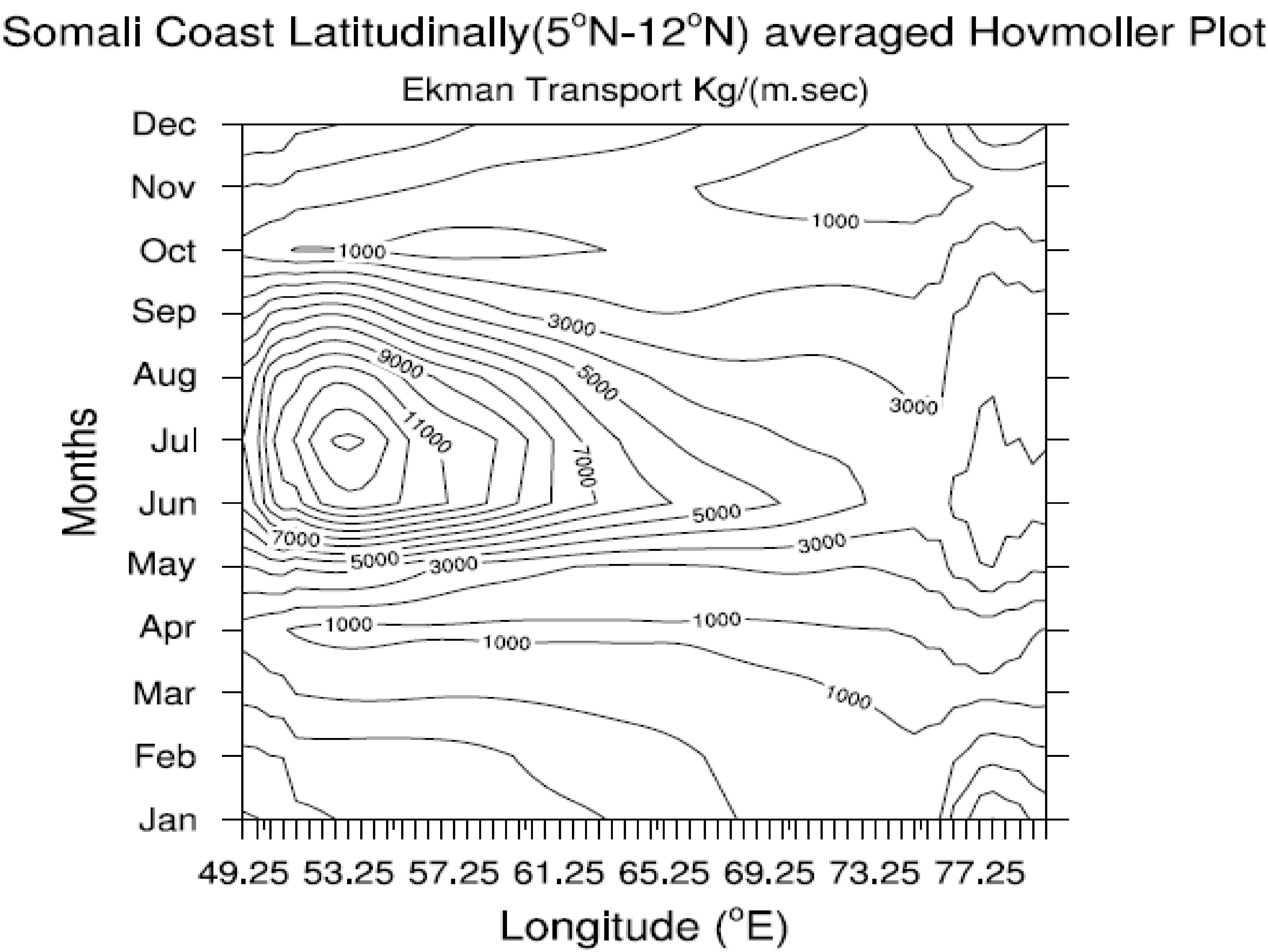
$f = 2\Omega \sin\emptyset$ = Coriolis Parameter [sec^{-1}]

ρ = Density of air = 1.175 [Kg./m^3]

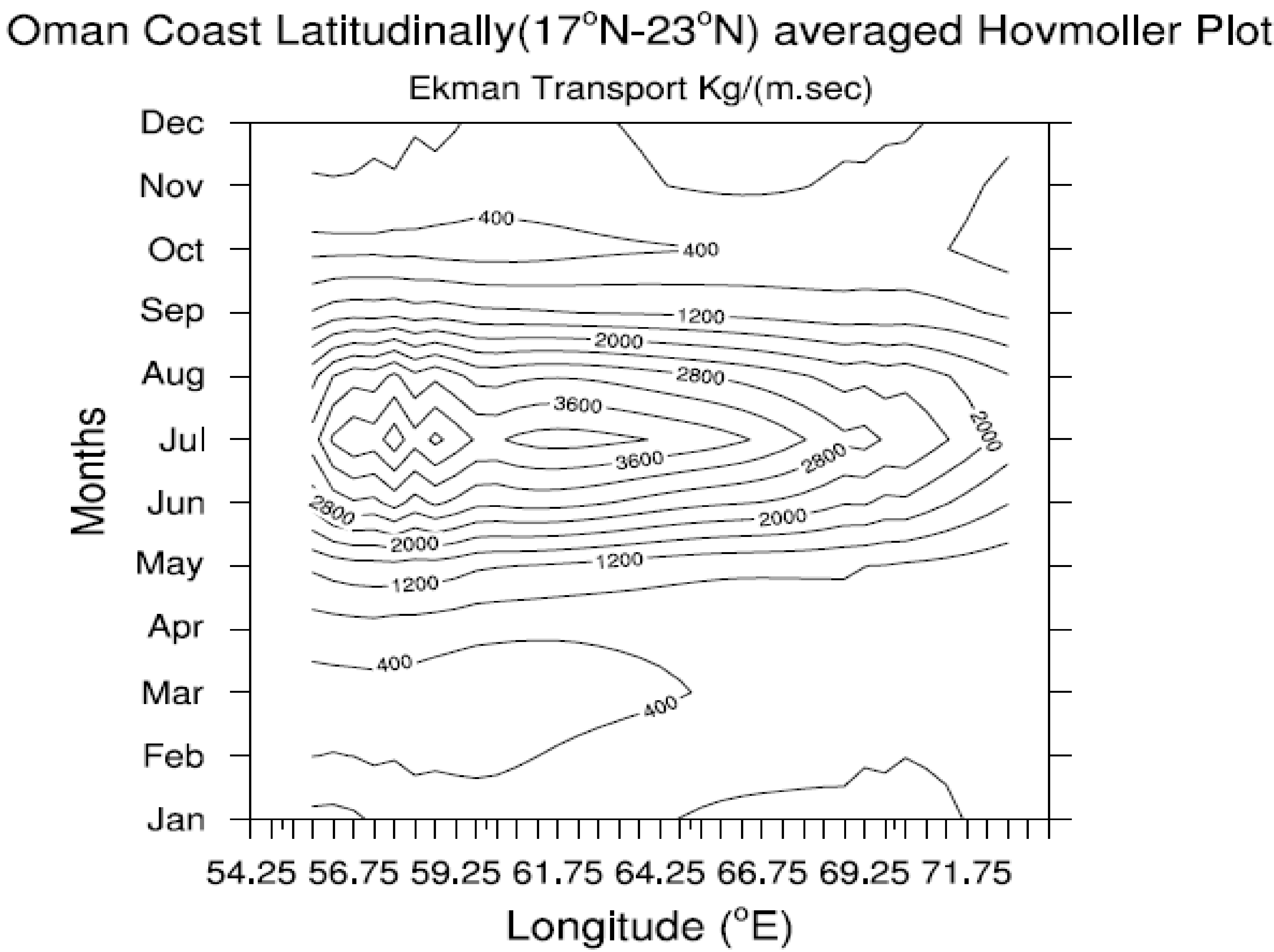
c_d **= DRAG COEFFICIENT = 0.0013**

V **= WIND SPEED (m/Sec)**

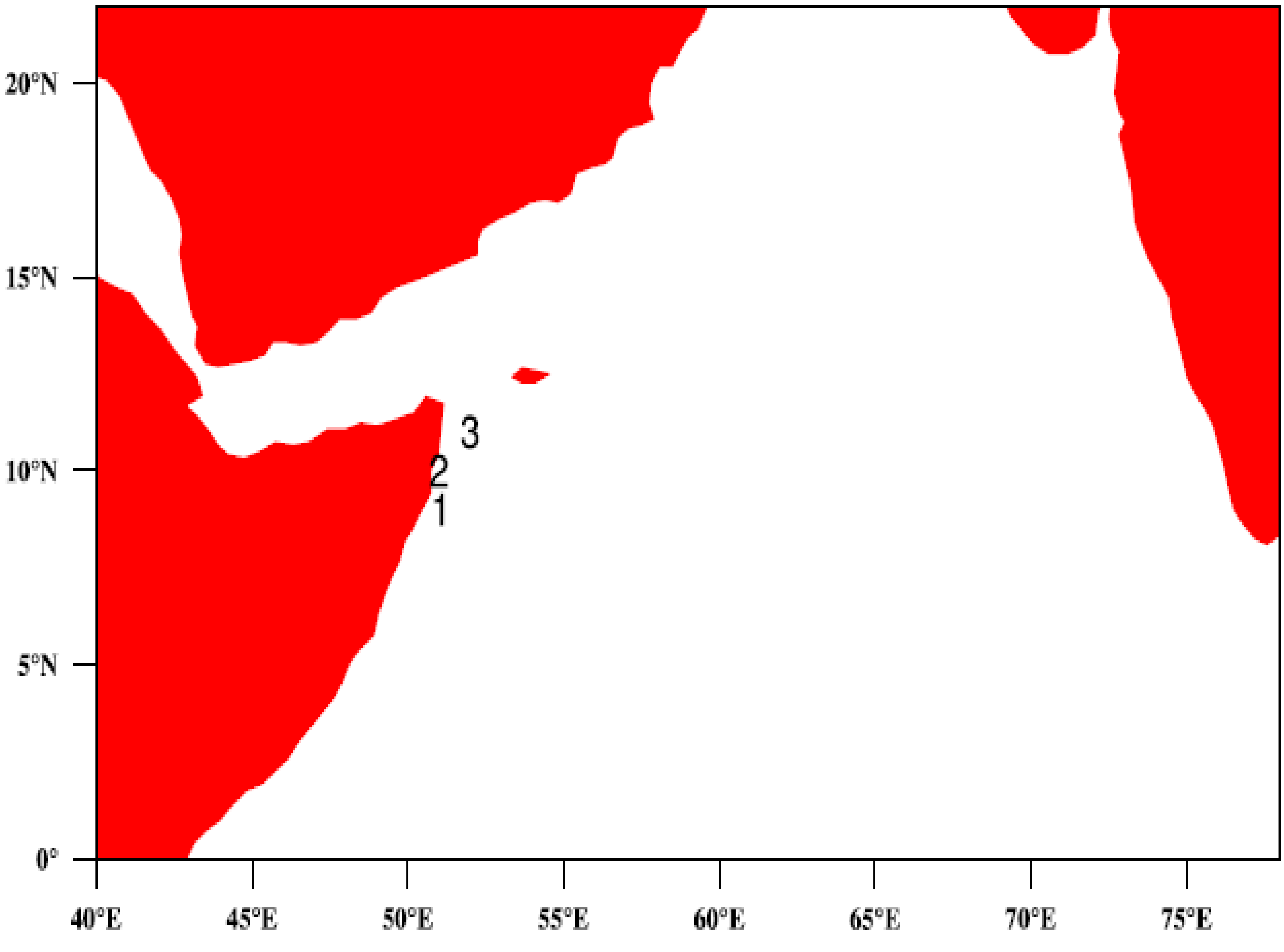
Ω **= ANGULAR FREQUENCY = 5.29 X 10-5 [/sec]**



Somali Coast Latitudinally(5°N-12°N) averaged Hovmoller Plot
Ekman Transport Kg/(m.sec)
Months
Dec
Nov
Oct
Sep
Aug
Jul
Jun
May
Apr
Mar
Feb
Jan
1000
3000
5000
7000
9000
11000
49.25
53.25
57.25
61.25
65.25
69.25
73.25
77.25
Longitude (°E)


Oman Coast Latitudinally(17°N-23°N) averaged Hovmoller Plot
Ekman Transport Kg/(m.sec)
Dec
Nov
Oct
Sep
Aug
Jul
Jun
May
Apr
Mar
Feb
Jan
Months
400
400
1200
2000
2800
3600
3600
2800
2000
2800
2000
2000
1200
1200
400
400
54.25 56.75 59.25 61.75 64.25 66.75 69.25 71.75
Longitude (°E)

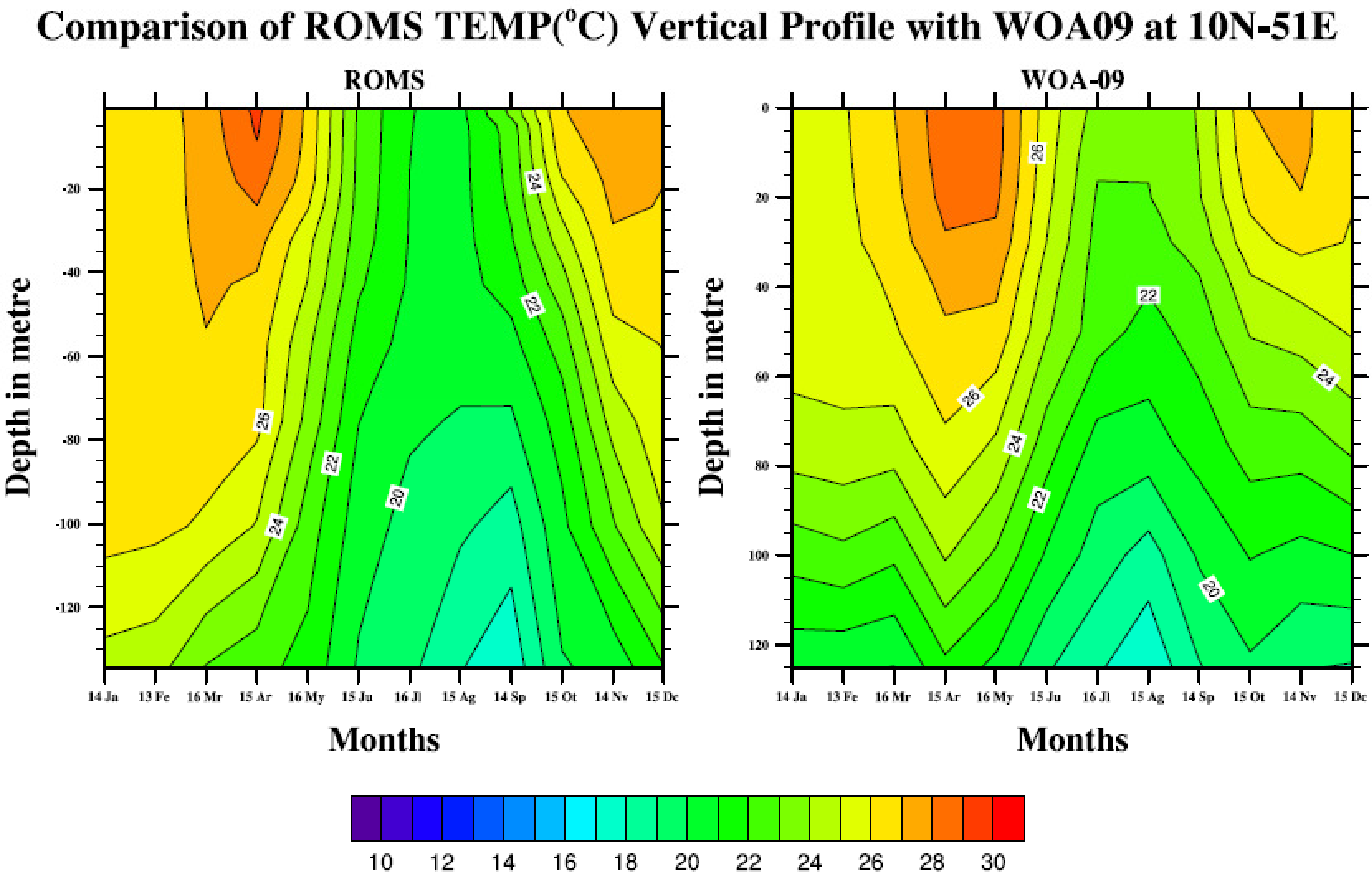
SOMALI COAST LOCATIONS



1) 9^0N-51^0E

2) 10^0N-51^0E

3) 11^0N-52^0E



Comparison of ROMS TEMP(°C) Vertical Profile with WOA09 at 10N-51E
ROMS
WOA-09
Depth in metre
Months
14 Ja
13 Fe
16 Mr
15 Ar
16 My
15 Ju
16 Jl
15 Ag
14 Sp
15 Ot
14 Nv
15 Dc
-20
-40
-60
-80
-100
-120
0
20
40
60
80
100
120
10
12
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18
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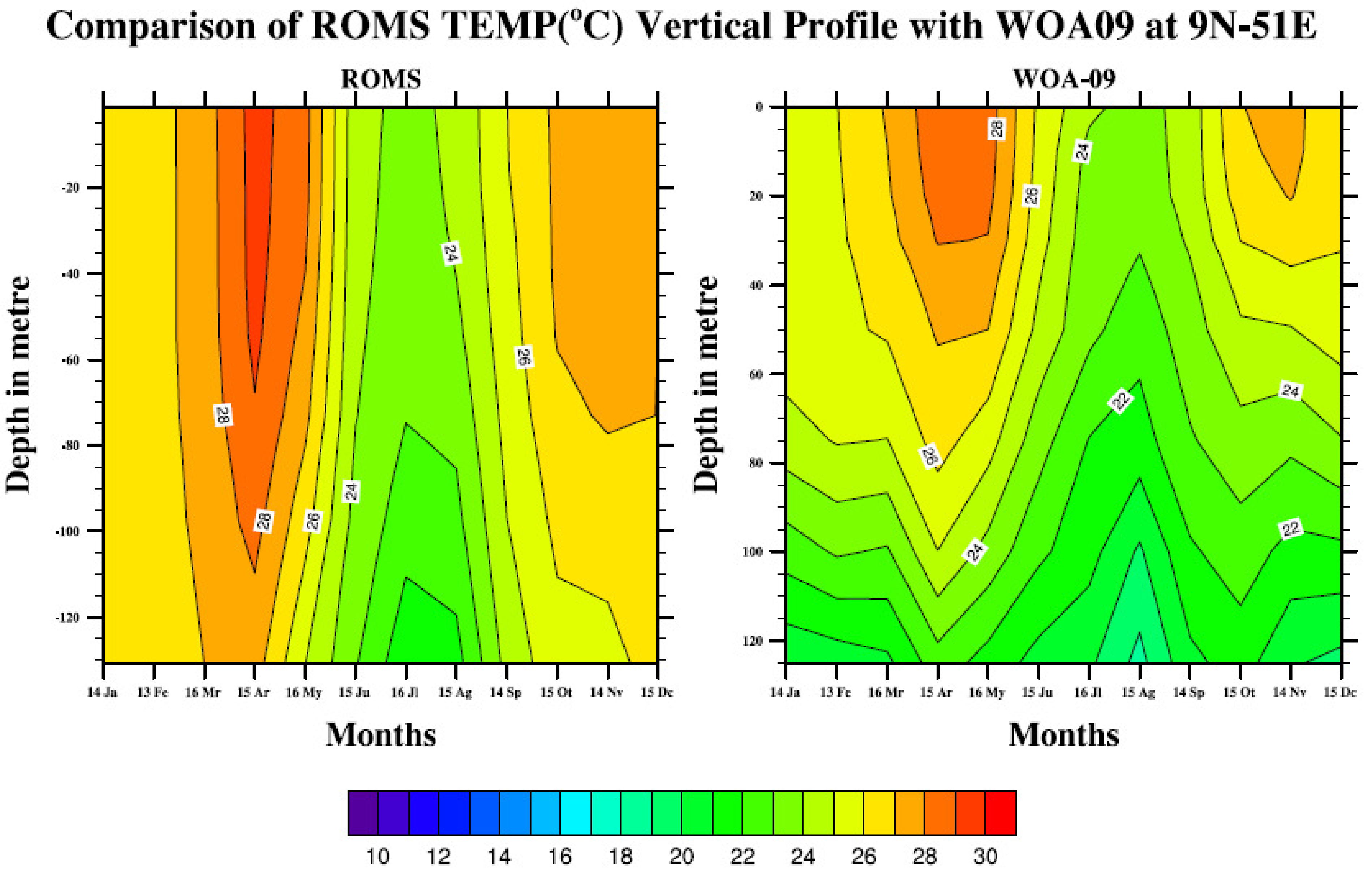
22
24
26
28
30



Comparison of ROMS TEMP(°C) Vertical Profile with WOA09 at 9N-51E
ROMS
WOA-09
Depth in metre
Months
14 Ja
13 Fe
16 Mr
15 Ar
16 My
15 Ju
16 Jl
15 Ag
14 Sp
15 Ot
14 Nv
15 Dc
-20
-40
-60
-80
-100
-120
0
20
40
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80
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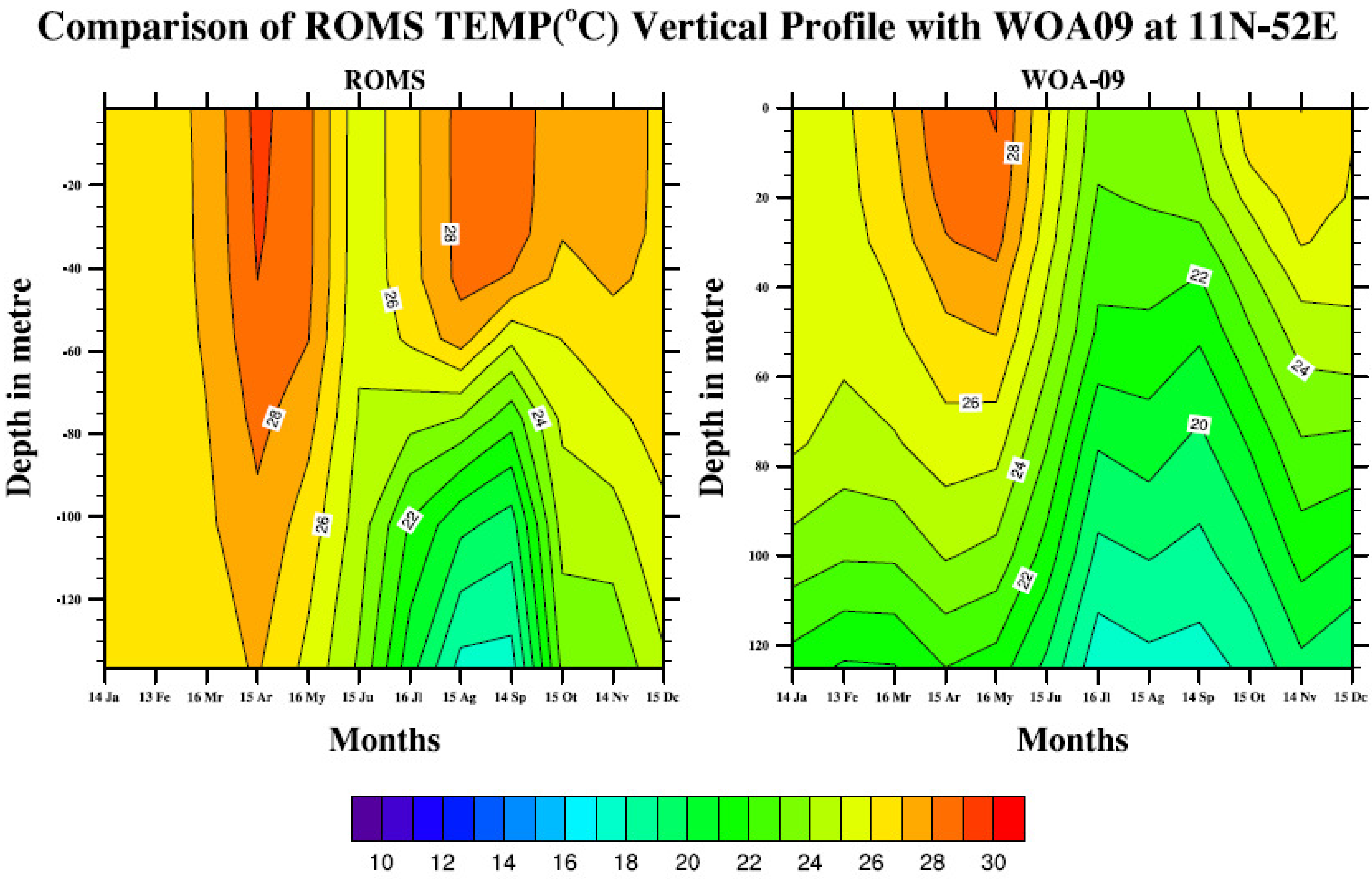
Comparison of ROMS TEMP(°C) Vertical Profile with WOA09 at 11N-52E
ROMS
WOA-09
Depth in metre
Months
14 Ja
13 Fe
16 Mr
15 Ar
16 My
15 Ju
16 Jl
15 Ag
14 Sp
15 Ot
14 Nv
15 Dc
-20
-40
-60
-80
-100
-120
0
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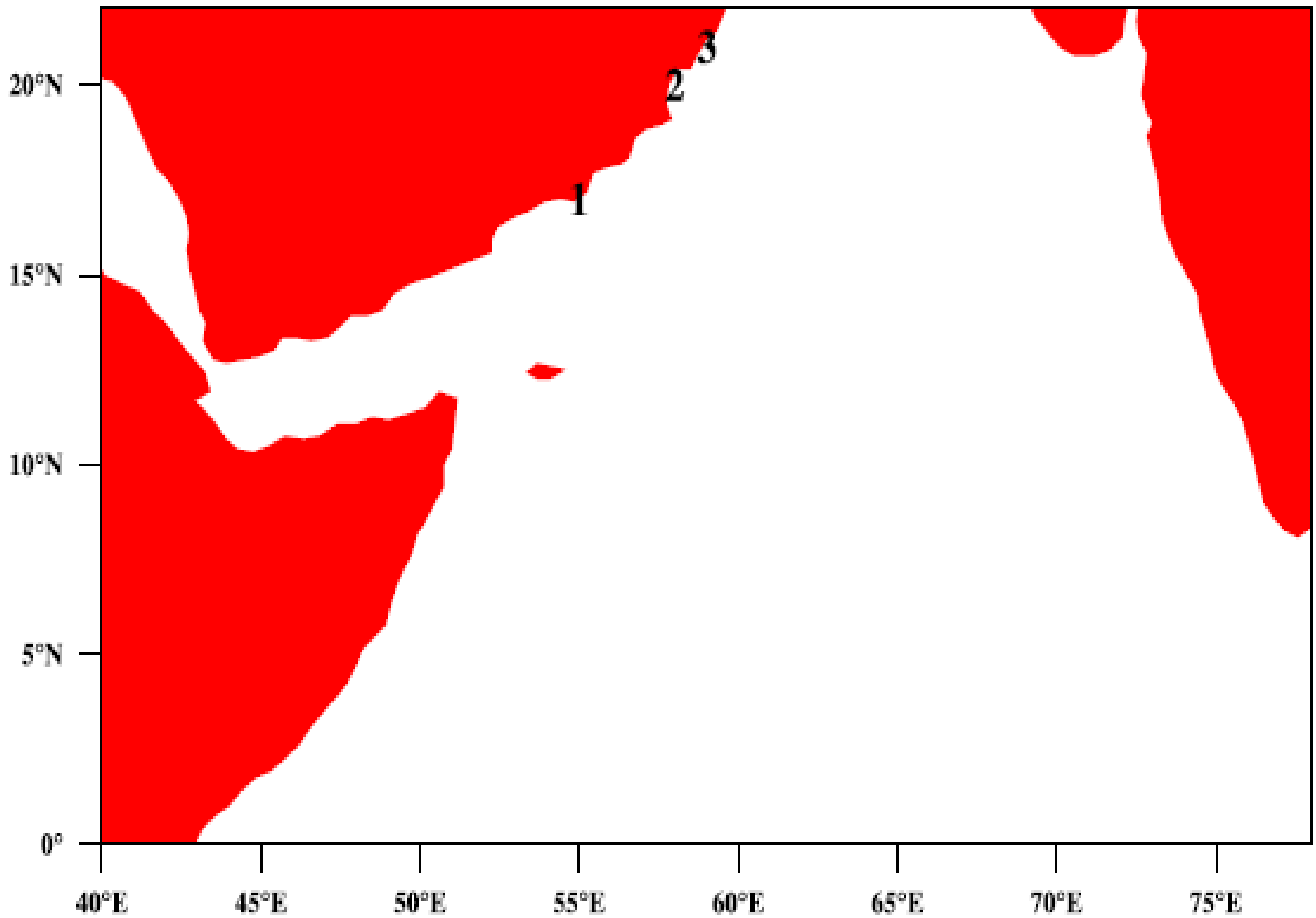
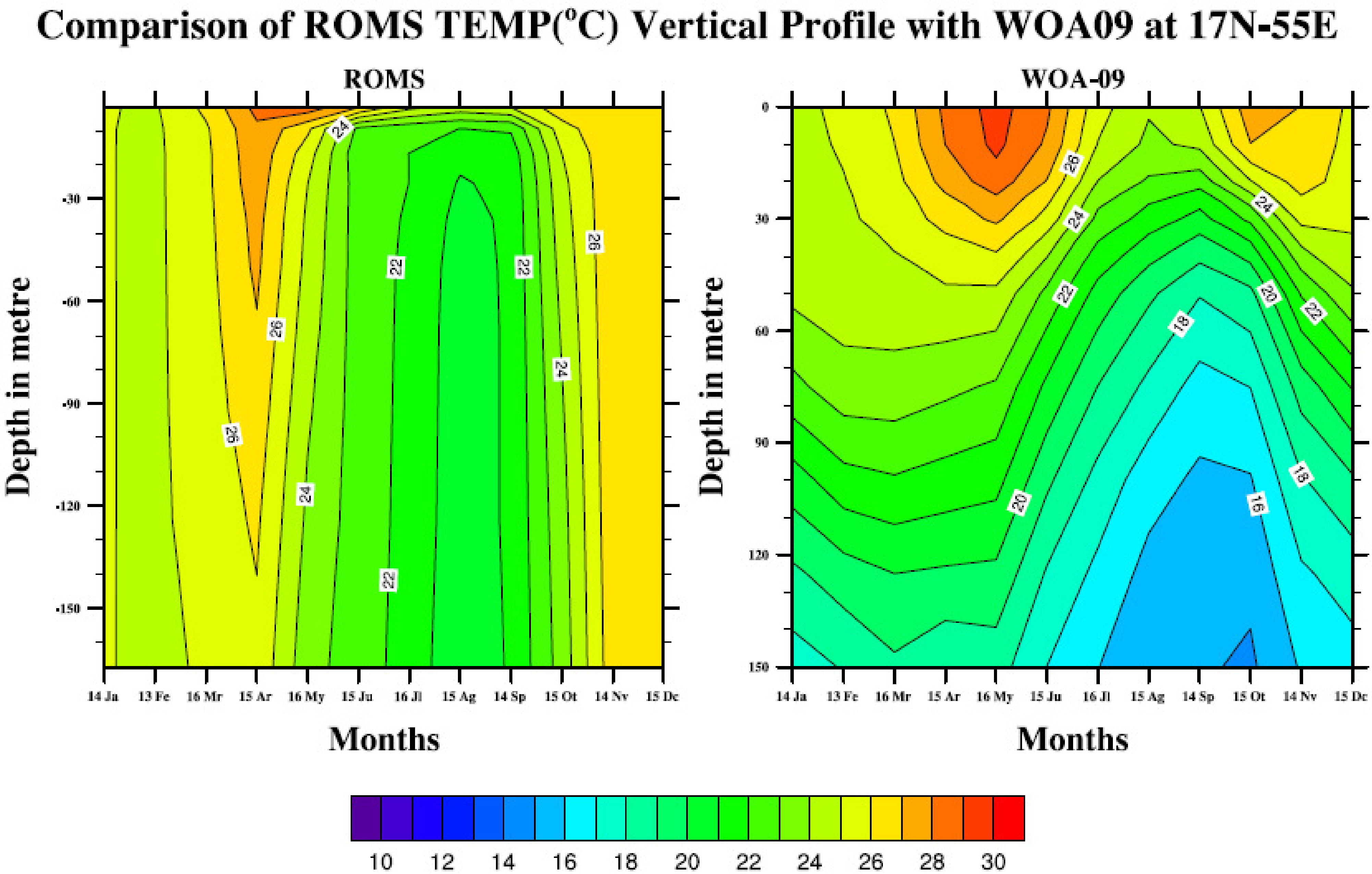
OMAN COAST LOCATIONS



1) 17^{0}N-55^{0}E

2) 20^{0}N-58^{0}E

3) 21^{0}N-51^{0}E


Comparison of ROMS TEMP(°C) Vertical Profile with WOA09 at 17N-55E
ROMS
WOA-09
Depth in metre
Months
14 Ja
13 Fe
16 Mr
15 Ar
16 My
15 Ju
16 Jl
15 Ag
14 Sp
15 Ot
14 Nv
15 Dc
-30
-60
-90
-120
-150
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30
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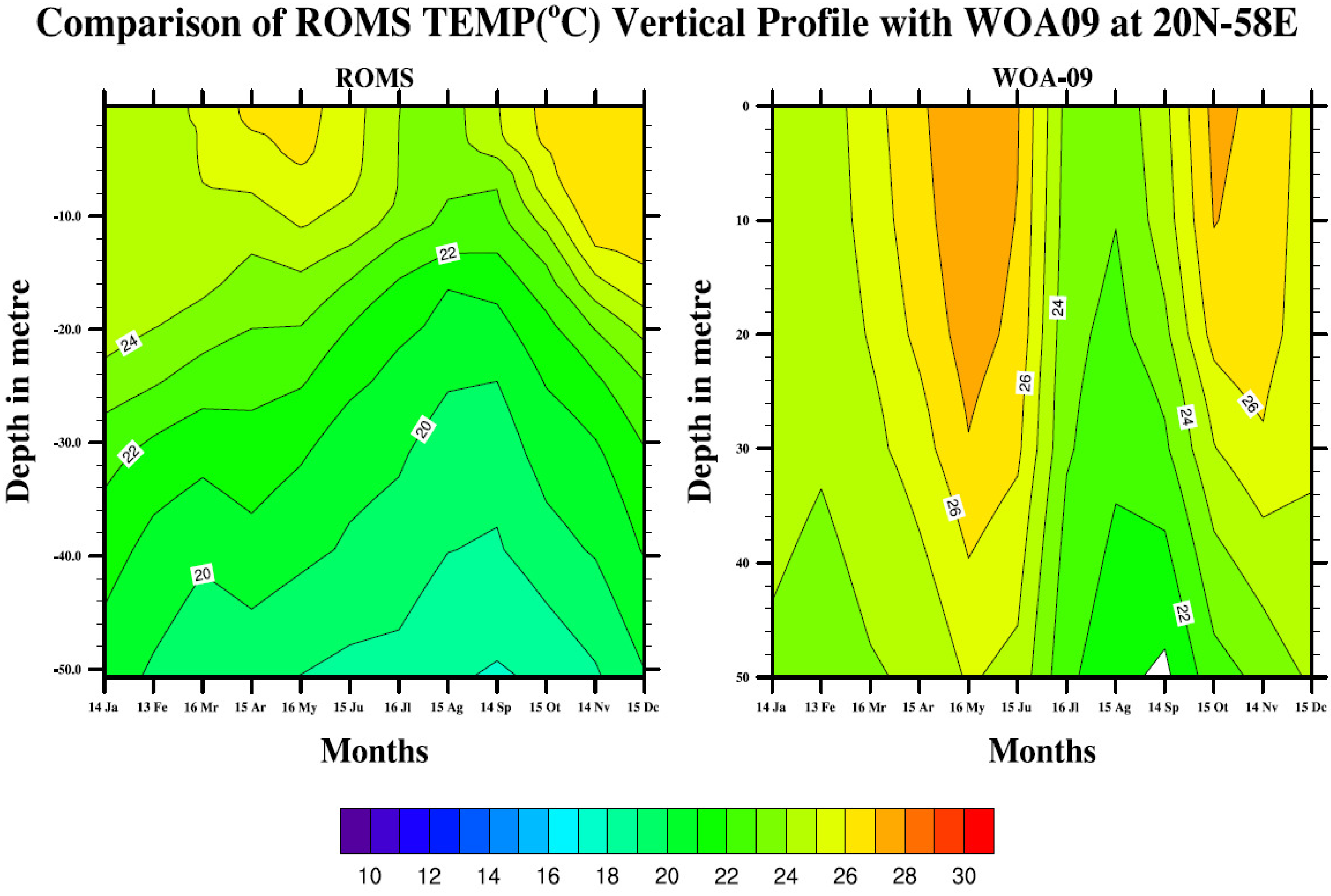
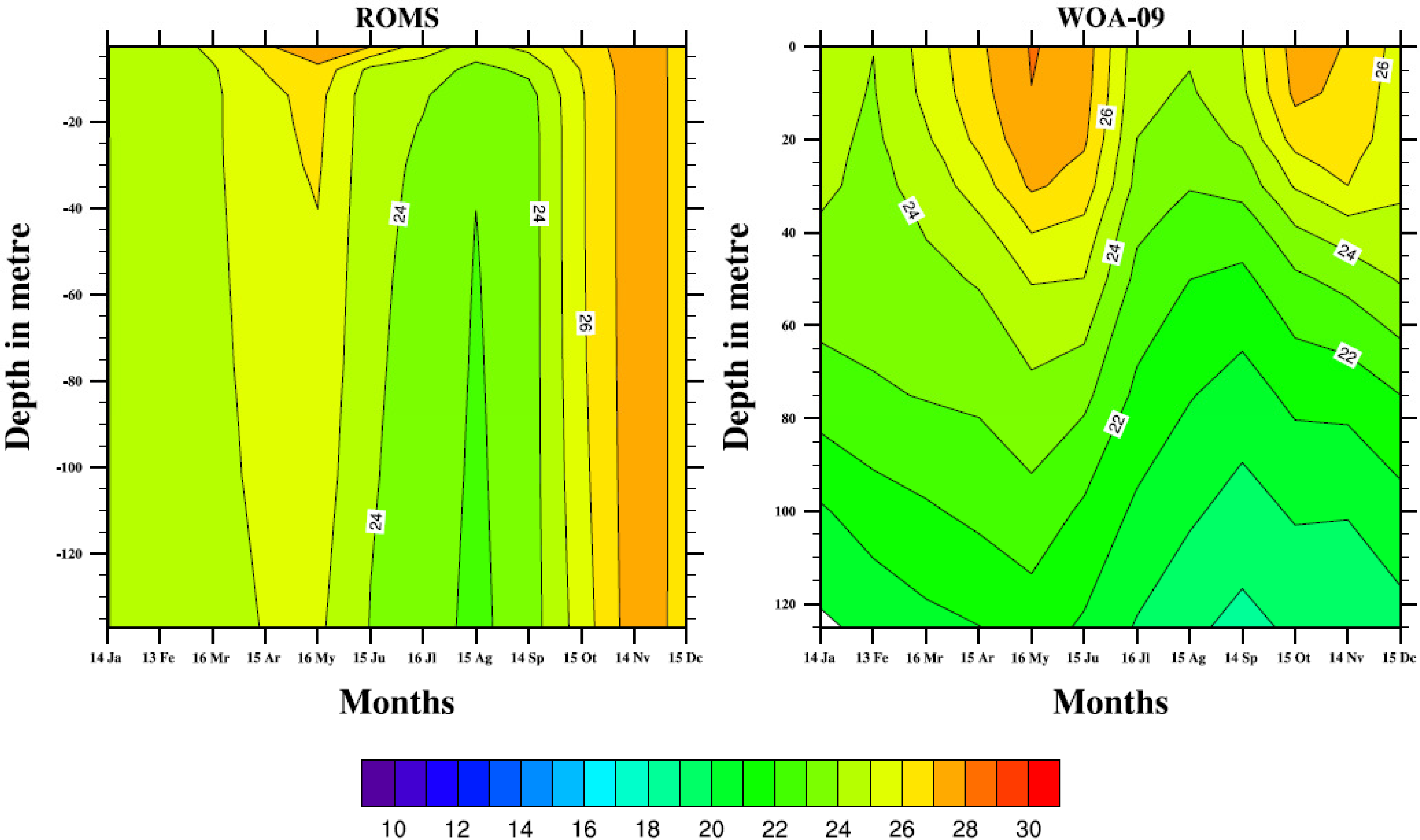


Comparison of ROMS TEMP(°C) Vertical Profile with WOA09 at 20N-58E
ROMS
WOA-09
Depth in metre
-10.0
-20.0
-30.0
-40.0
-50.0
0
10
20
30
40
50
14 Ja
13 Fe
16 Mr
15 Ar
16 My
15 Ju
16 Jl
15 Ag
14 Sp
15 Ot
14 Nv
15 Dc
Months
10
12
14
16
18
20
22
24
26
28
30

Comparison of ROMS TEMP(°C) Vertical Profile with WOA09 at 21N-59E



Conclusion

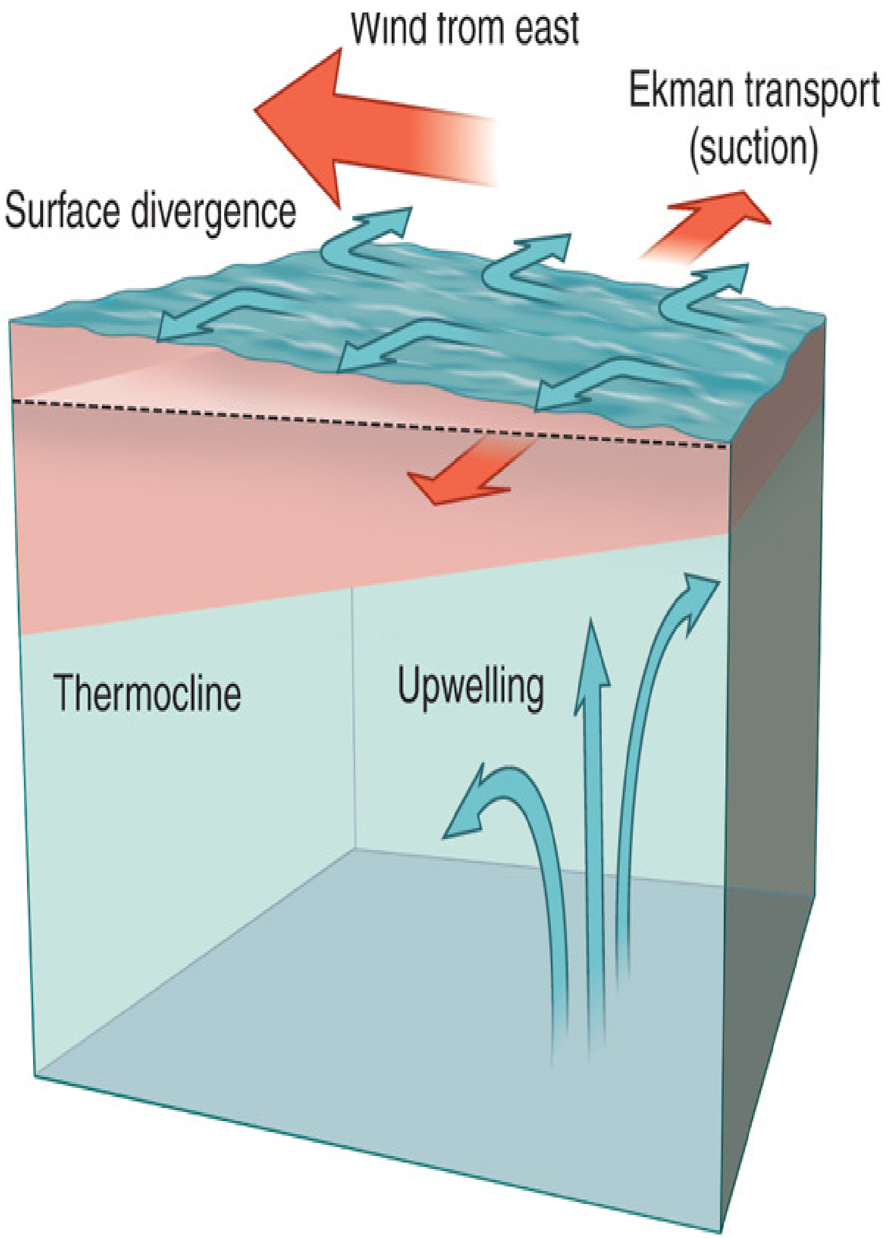
- The capability of a regional circulation model to simulate the upwelling features is assessed.

- Model is performing better over the Somali coast in comparison to Oman coast.

- The performance of the model can be improved by providing the higher vertical resolution and more realistic bathymetry.

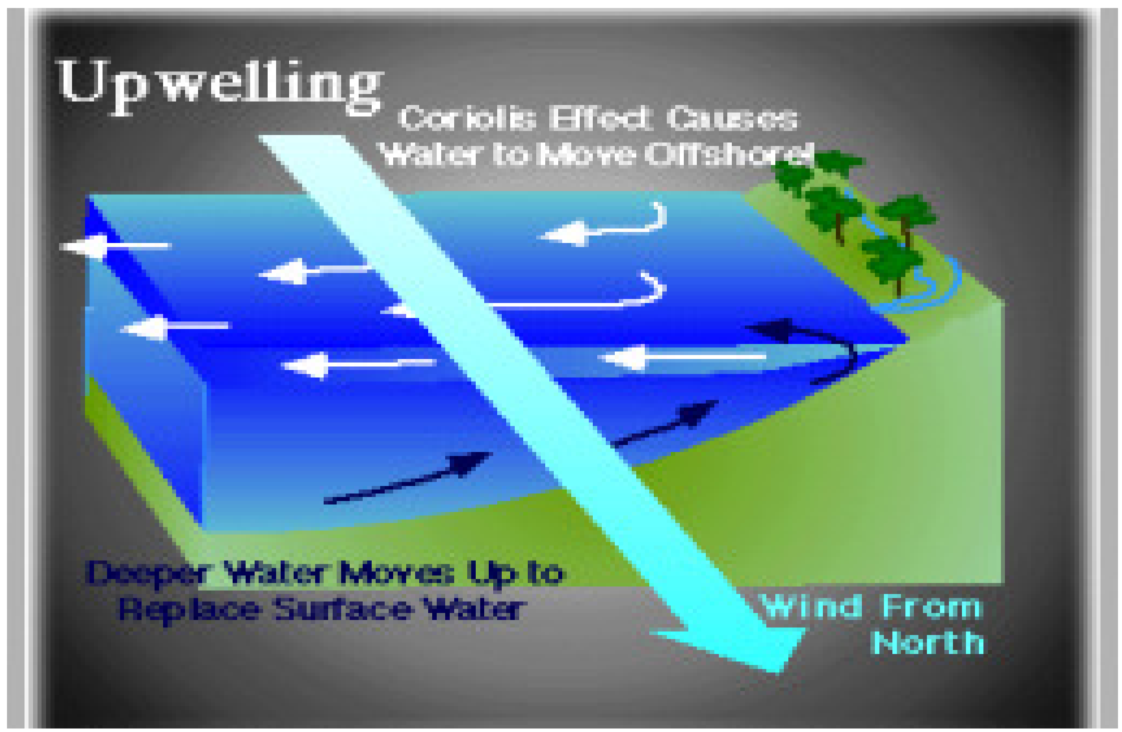
Thank You

Equatorial Upwelling



a.

Coastal Upwelling



Ekman Transport

Definition – term given for the 90 degree net transport of the surface layer due to wind forces and Coriolis Effect.

First investigated in 1902 by

Vaqn Walfrid Ekman

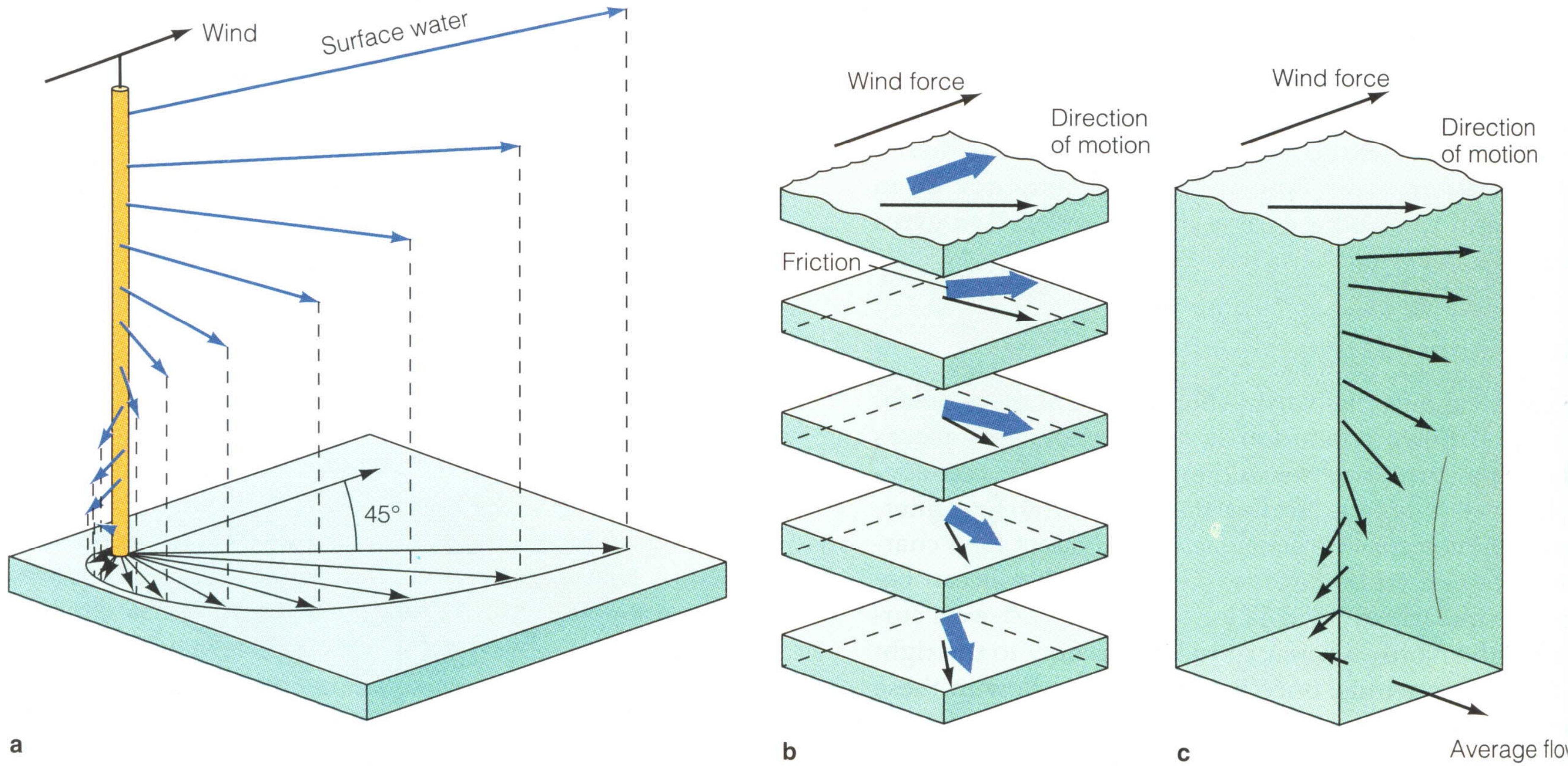
Ekman motion theory

- In the **northern hemisphere** this transport is at a **90 degree angle to the right** of the direction of the wind.
- In the **southern hemisphere** it occurs at a **90 degree angle to the left** of the direction of the wind.

Ekman Spiral – Model

plotting the water layers at various directions, speed and depth

Ekman Spiral Model



Upwelling

Definition – upward movement of the deeper, cooler waters toward the surface pushing surface waters away from the shore due to the Ekman Transport.

Description

Coriolis Effect moves water at right angles slightly right of the direction the wind is blowing resulting in surface currents pushing the surface waters offshore.

When surface waters are pushed offshore, water from below is drawn upward to replace them.

Caused by Waters Diverging away from a region.

Effects:-

Brings nutrient –rich waters to the surface encouraging seaweed and phytoplankton growth.

Moves drifting larvae long distances from their natural habitat affecting population stability.

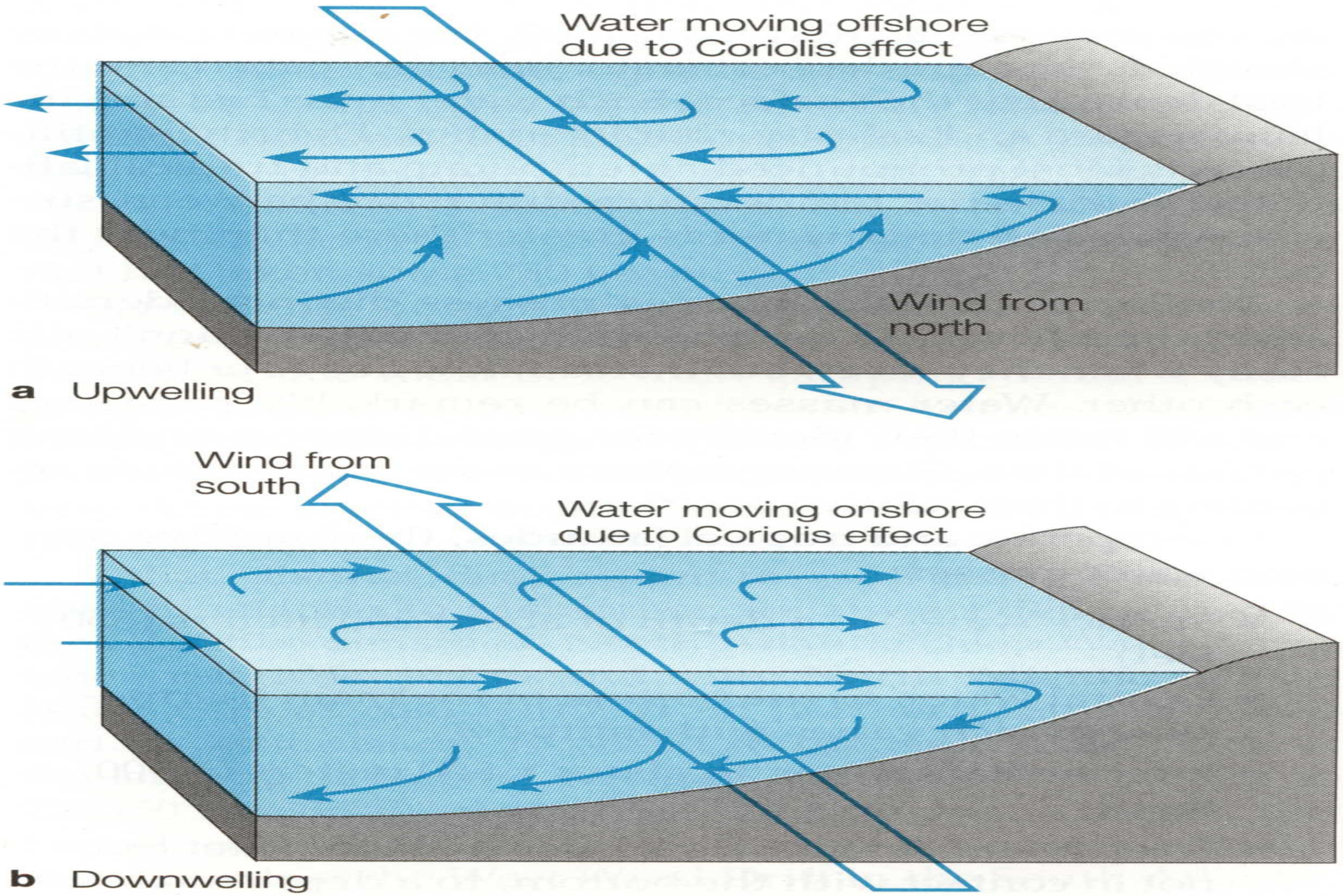
Downwelling

Definition – Surface waters move toward the shore due to Ekman Transport and sink to the bottom.

Remember: water is a fluid in constant motion; a change in the distribution of water in one area is accompanied by a compensating change in another area.

Caused by a Waters Converging toward a region.

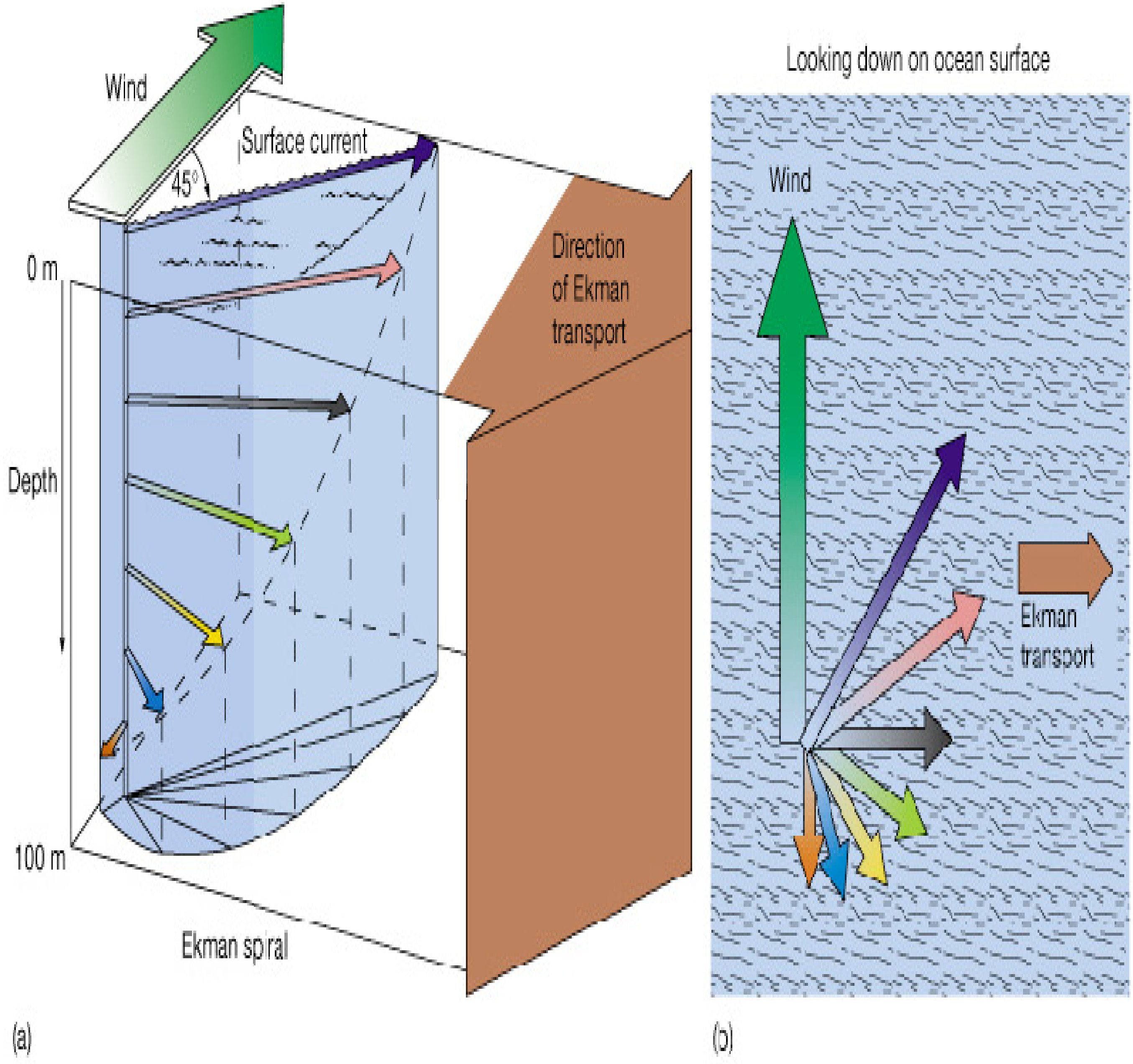
Upwelling and Downwelling Diagram



Ekman spiral

- **Ekman spiral** describes the speed and direction of flow of surface waters at various depths

- Factors:
  - Wind
  - Coriolis effect

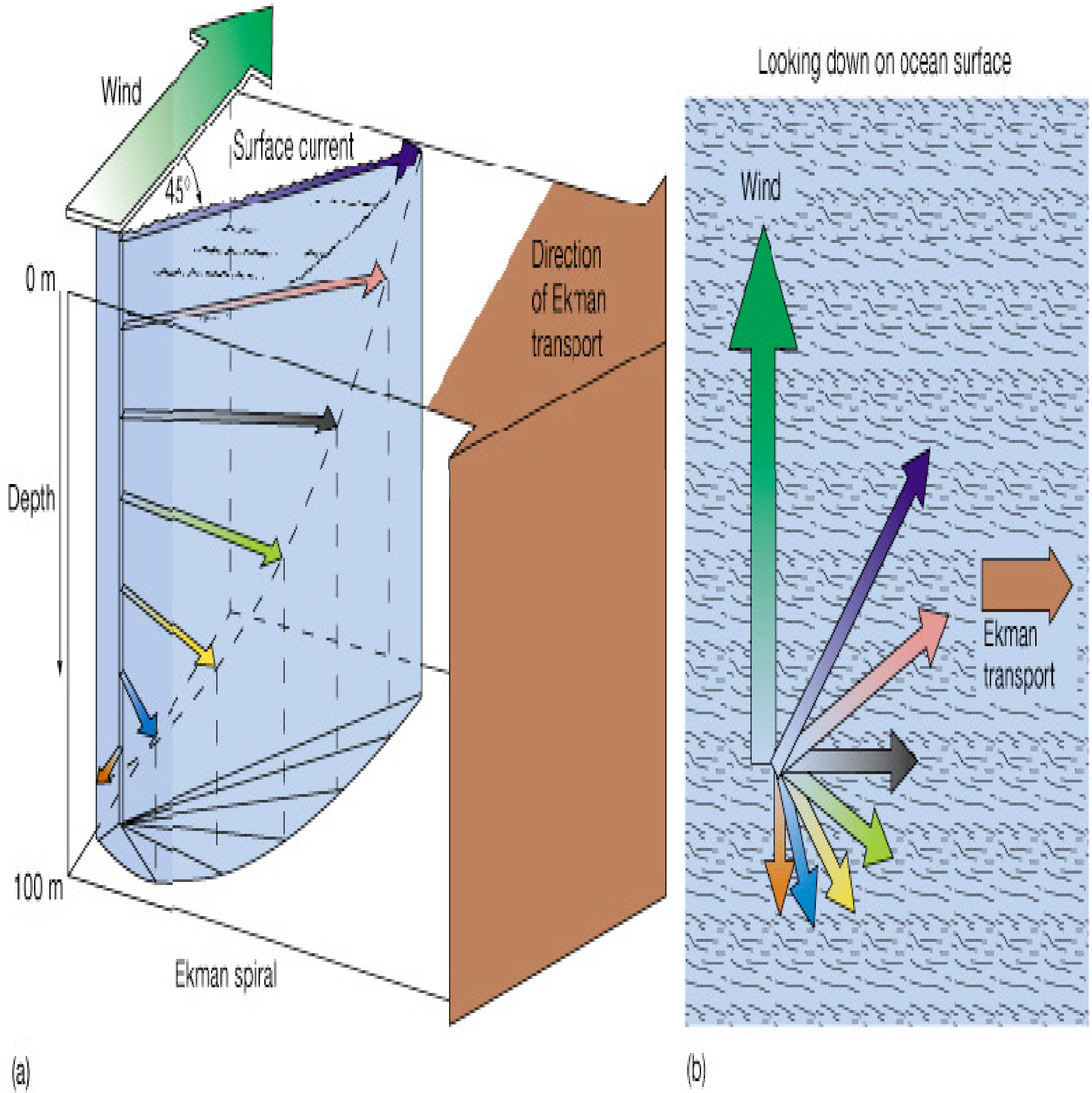


Ekman transport

- **Ekman transport**

  is the overall water movement due to Ekman spiral

- Ideal transport is 90º from the wind
- Transport direction depends on the hemisphere

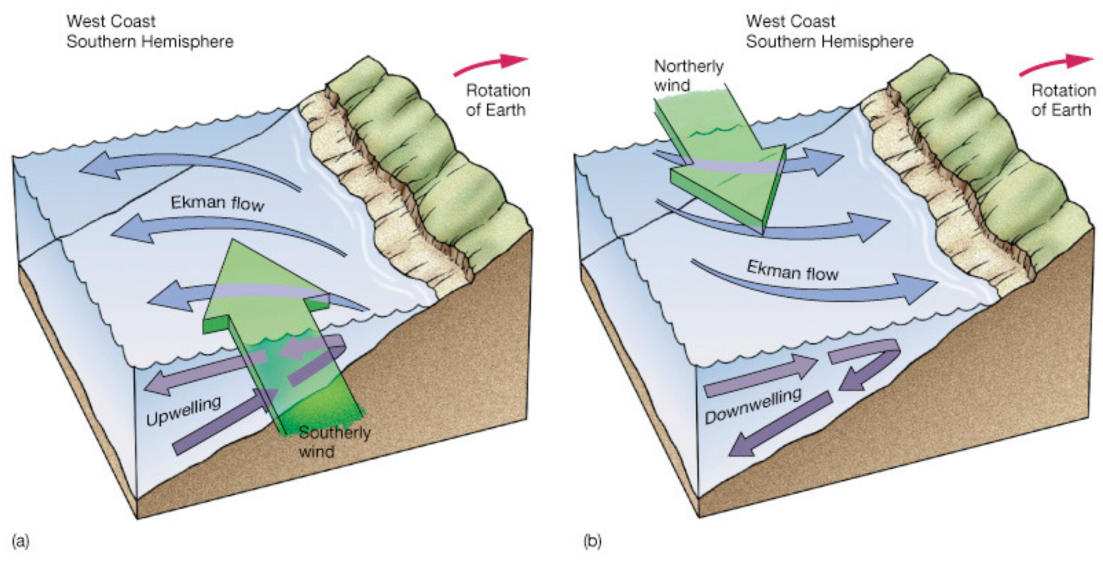


Upwelling and downwelling

- Vertical movement of water (□)
  - **Upwelling** = movement of deep water to surface
    - Hoists cold, nutrient-rich water to surface
    - Produces high productivities and abundant marine life
  - **Downwelling** = movement of surface water down
    - Moves warm, nutrient-depleted surface water down
    - Not associated with high productivities or abundant marine life

Coastal upwelling and downwelling

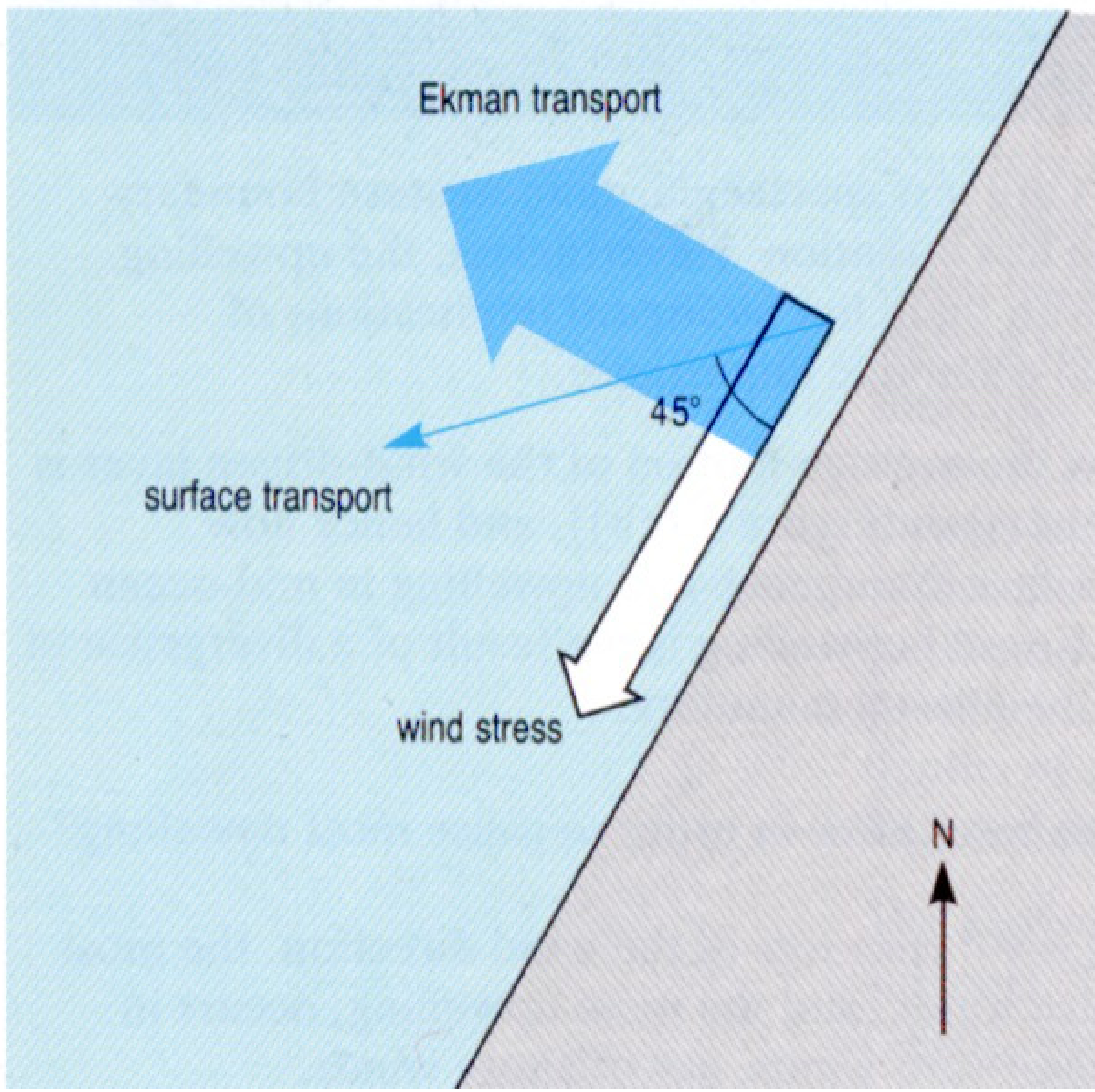
- Ekman transport moves surface water away from shore, producing upwelling
- Ekman transport moves surface water towards shore, producing downwelling



Coastal Upwelling

- Equatorward winds along a coastline lead to offshore Ekman transport
- Mass conservation requires these waters replaced by cold, denser waters
- Brings nutrients into surface waters creating bloom

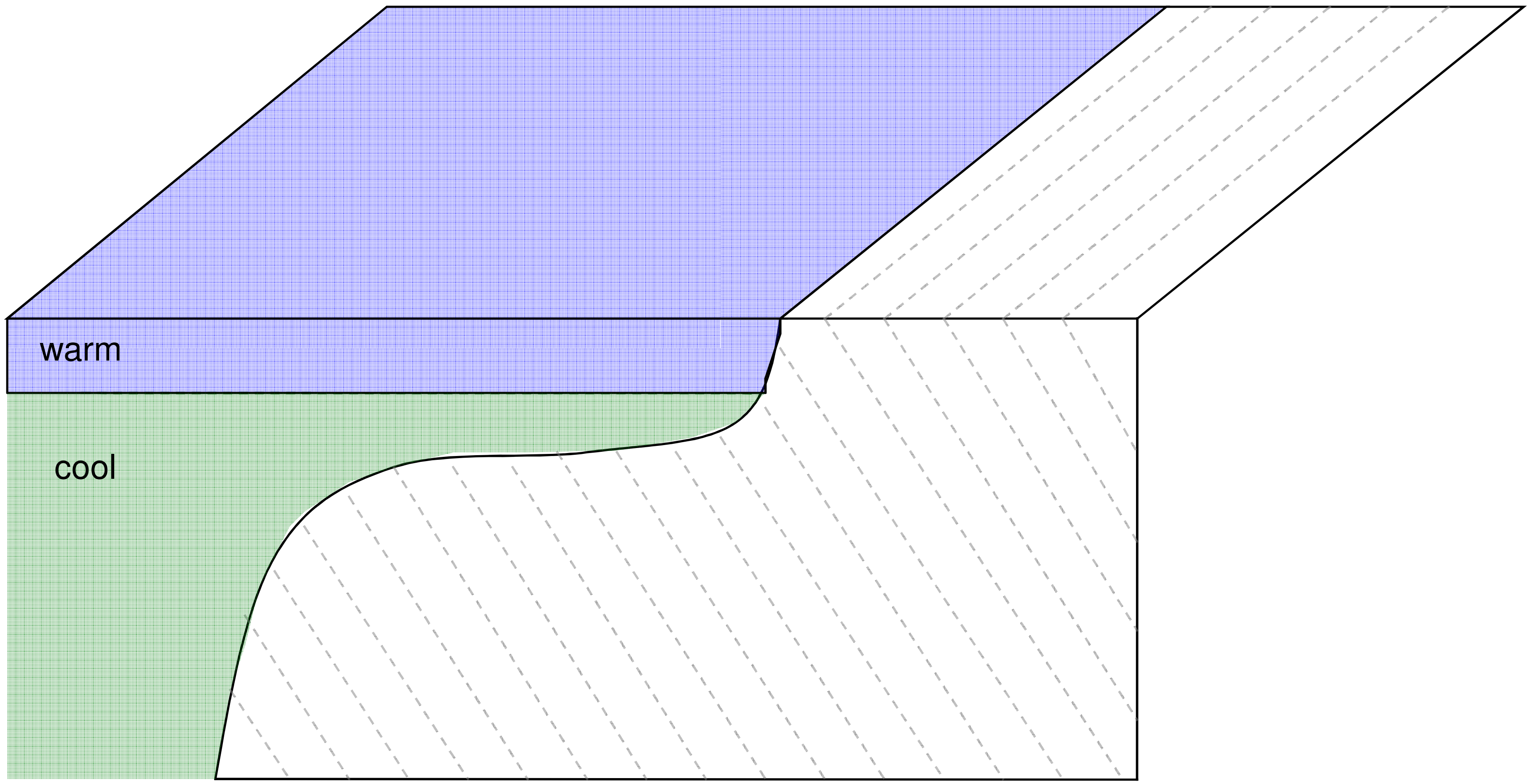
Coastal Upwelling



Review

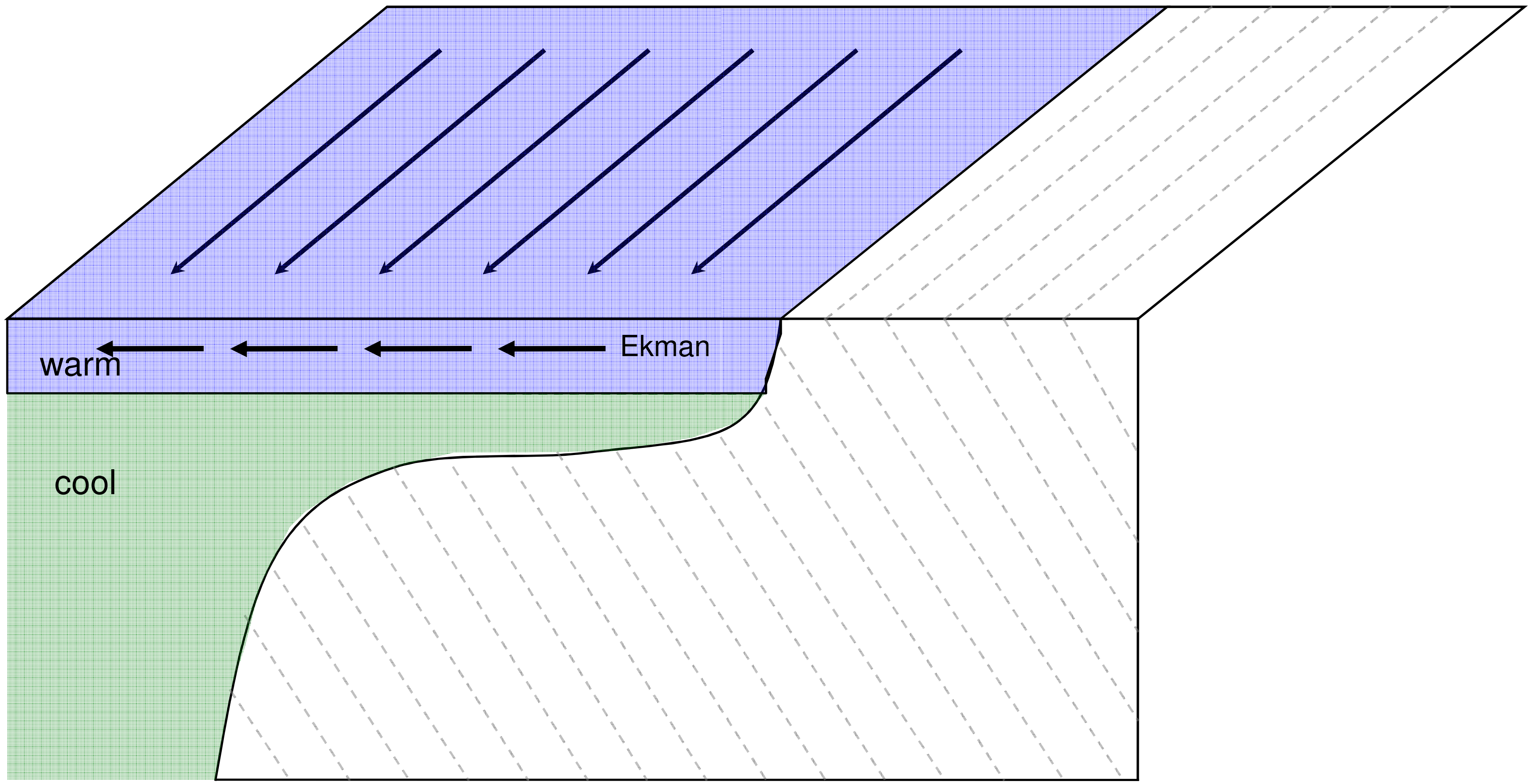
- Wind stress along coasts leads to divergence of surface Ekman transport
- This drives to coastal upwelling and forms a coastal jet
- This drives the productivity of eastern boundary currents
- Important for acidification of the coastal ocean

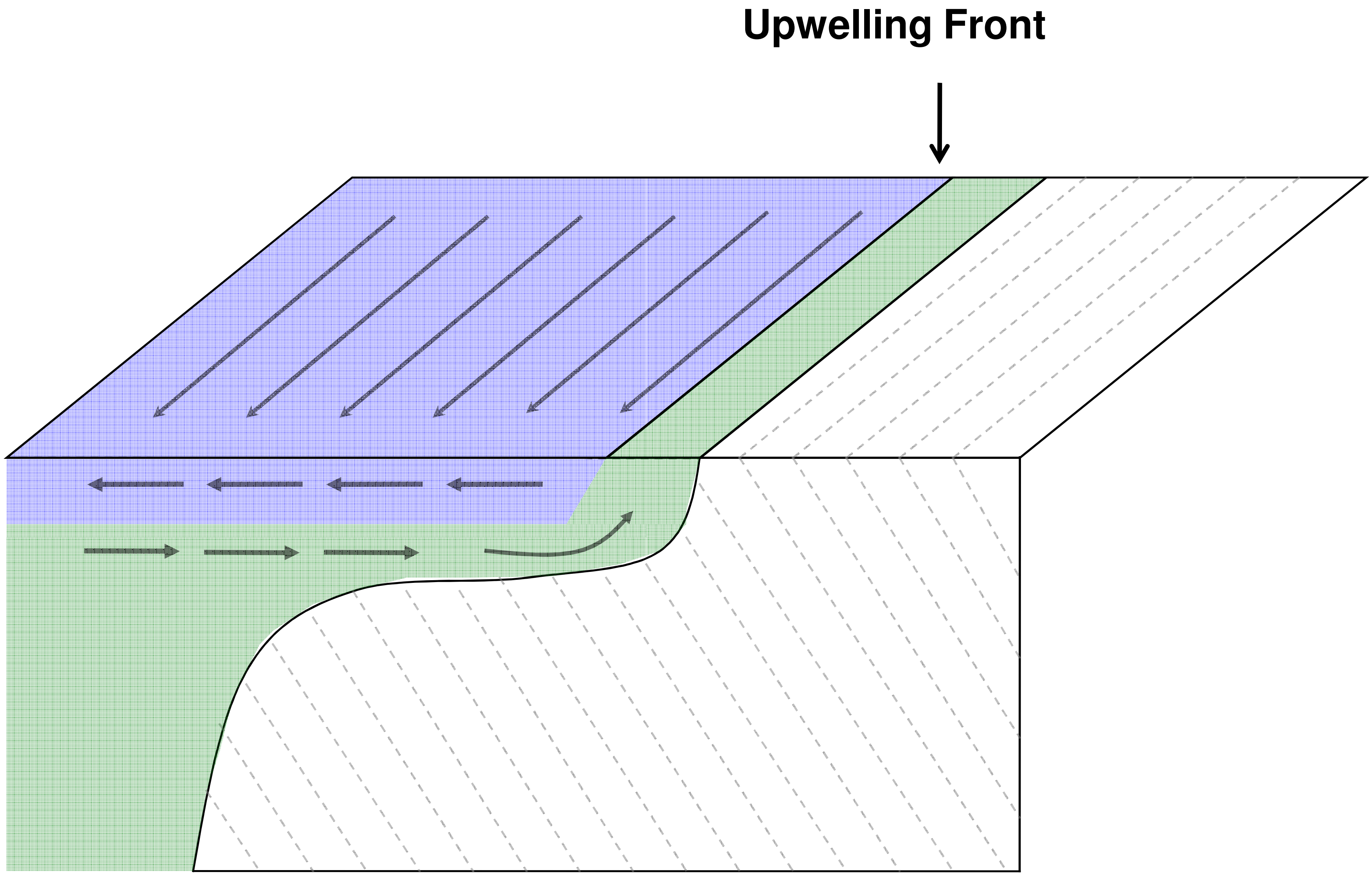
Consider a stratified coastal ocean



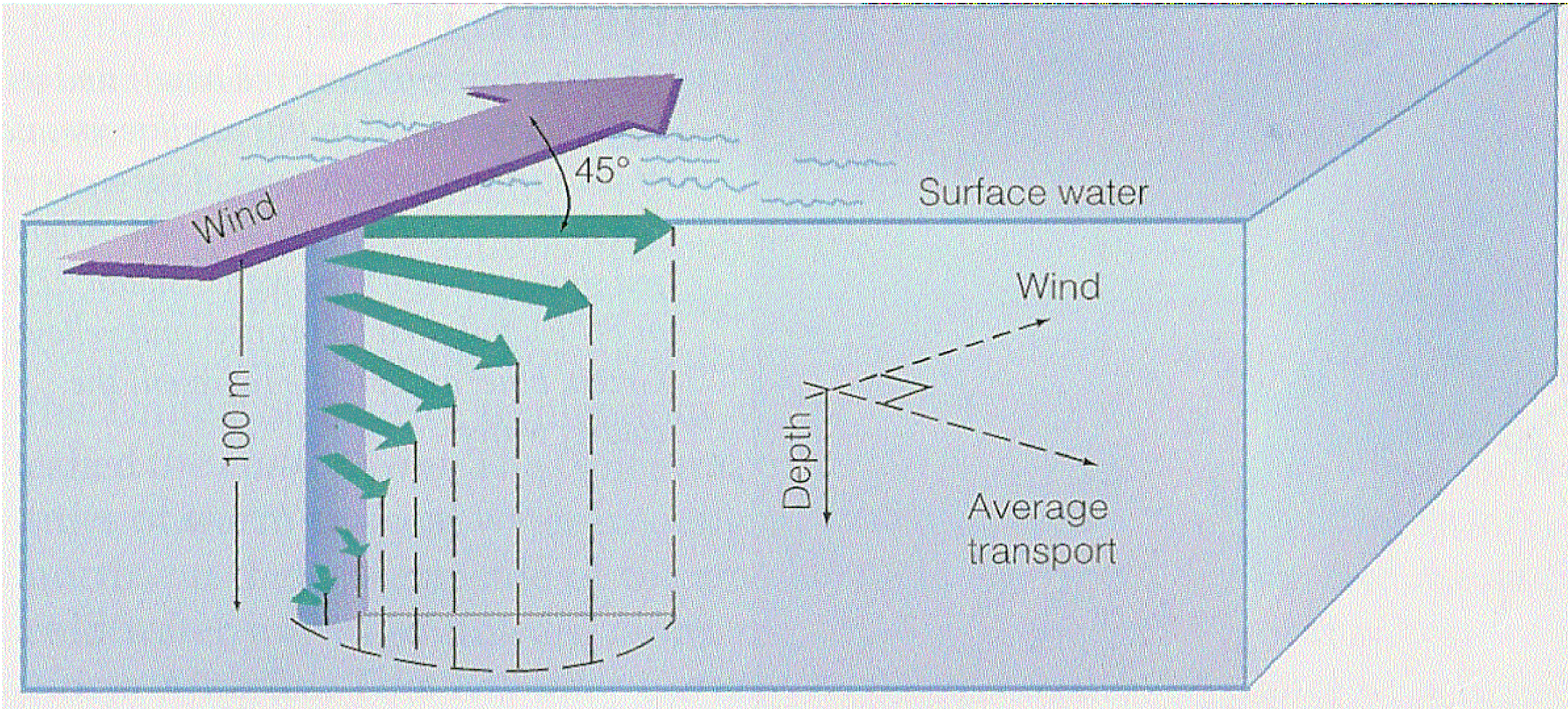
Northern hemisphere.

Upwelling Winds Drive Off-shore Flow in Surface Layer



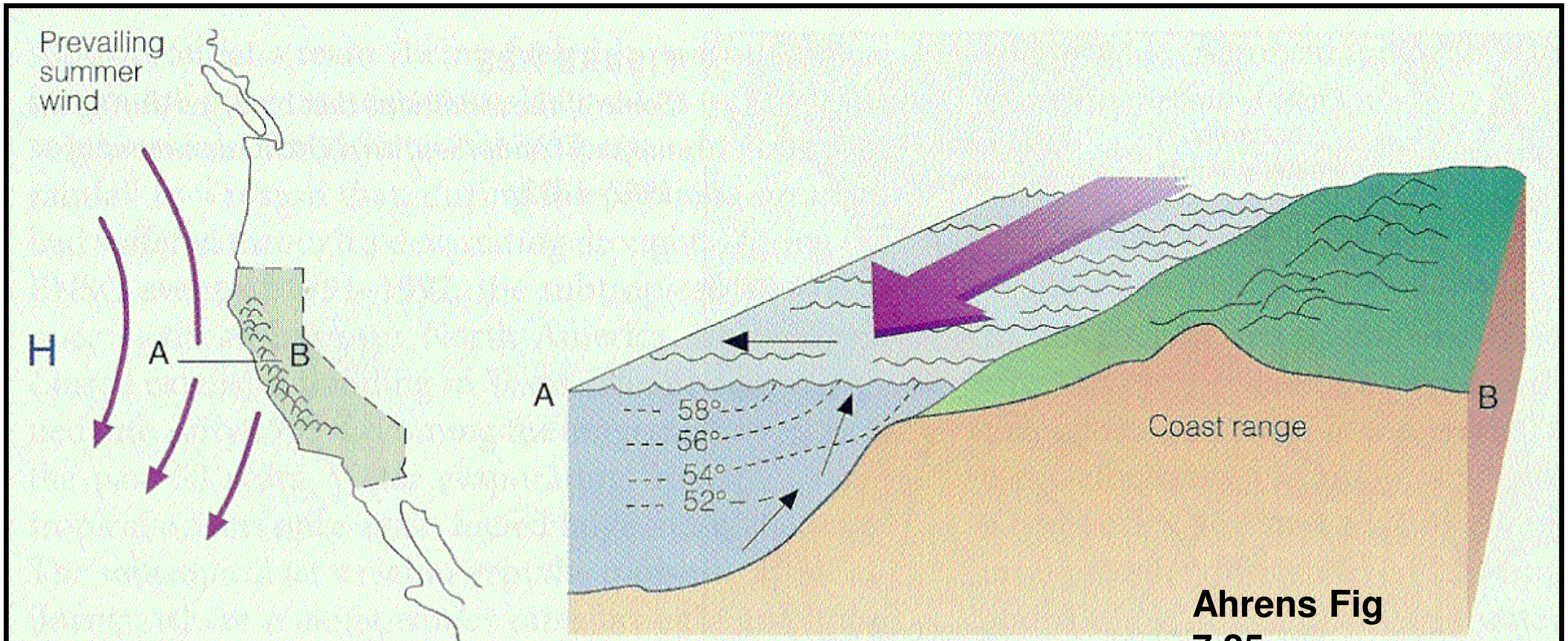

Upwelling Front

Ekman Spiral



Surface water moves 45° to the right of prevailing wind. Subsurface water moves at angles greater than 45°. Net transport of surface layer is 90° to the right. Coriolis force is responsible for the rightward rotation.

Upwelling from Alongshore Winds



Ahrens Fig 7.25

Wind pushes surface water southward. Coriolis force deflects water to the right. Cold water from below rises to surface. Fog persists over the cold water.

Surface wind stress

- Approaching sea surface, the geostrophic balance is broken, even for large scales.
- The major reason is the influences of the winds blowing over the sea surface, which causes the transfer of momentum (and energy) into the ocean through turbulent processes.
- The surface momentum flux into ocean is called the surface wind stress, which is the tangential force (in the direction of the wind) exerting on the ocean per unit area (Unit: Newton per square meter)
- The wind stress effect can be constructed as a boundary condition to the equation of motion as

$$\rho A_z \frac{\partial \vec{V}_H}{\partial z}\Big|_{z=0} = \vec{\tau}$$

Wind stress Calculation

- Direct measurement of wind stress is difficult.
- Wind stress is mostly derived from meteorological observations near the sea surface using the bulk formula with empirical parameters.
- The bulk formula for wind stress has the form

$$\tau = C_d \rho_a V V$$

Where ρ_a is air density (about 1.2 kg/m^3 at mid-latitudes), V (m/s), the wind speed at 10 meters above the sea surface, C_d, the empirical determined drag coefficient

Drag Coefficient C_d

• C_d is dimensionless, ranging from 0.001 to 0.0025 (A median value is about 0.0013). Its magnitude mainly depends on local wind stress and local stability.

• C_d Dependence on stability (air-sea temperature difference).

More important for light wind situation

For mid-latitude, the stability effect is usually small but in tropical and subtropical regions, it should be included.

• C_d Dependence on wind speed.

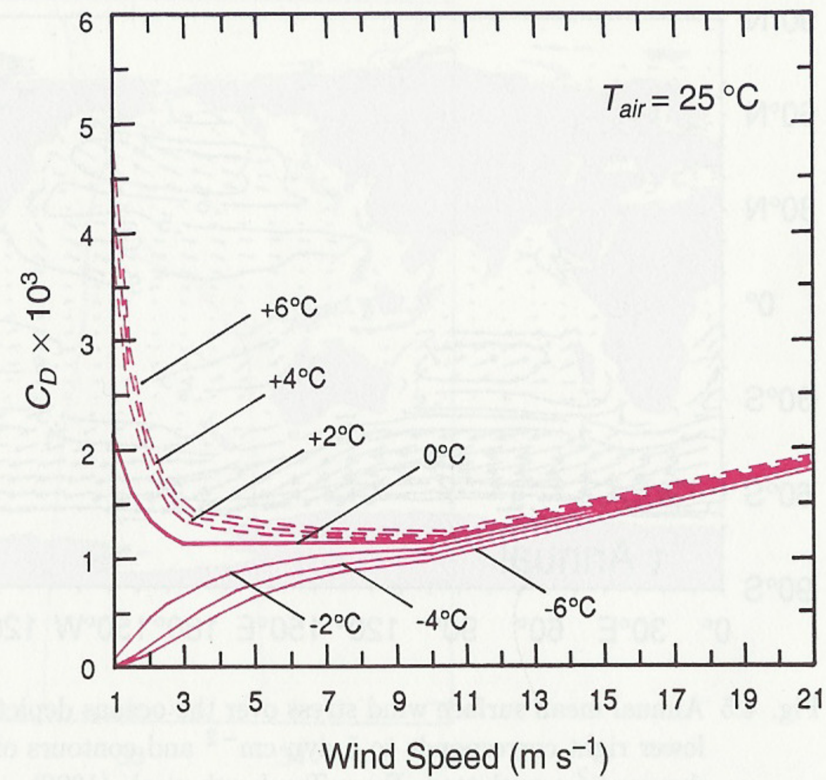


Fig. 4.6 The wind stress is computed from the wind speed, V, according to the formula $\tau = \rho_a C_D V \mathbf{v}$ and it is in the direction of the wind. Shown is the drag coefficient ($\times 10^3$), C_D , as a function of wind speed and atmospheric stability, as measured by the air–sea temperature differences, based on Large and Pond (1981), as given by Trenberth et al. (1989). Values are for an air temperature of 25°C and dashed lines indicate air less than sea temperatures (unstable).

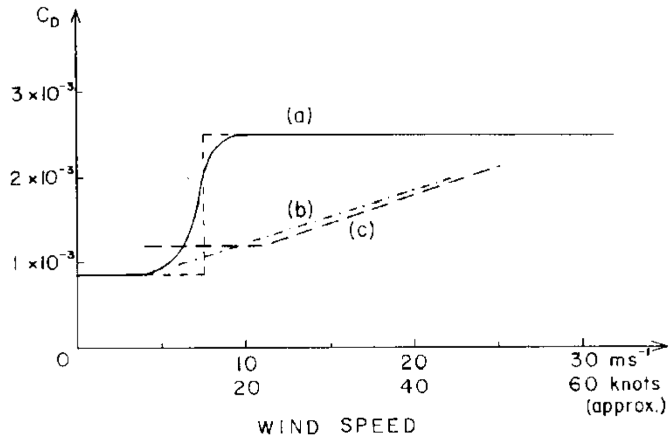


FIG. 9.14 *Form of drag coefficient (C_D) for wind over water as a function of wind speed: (a) as used for many calculations of wind-driven circulation; measured values for* 10 *m height for neutral stability by* (*b*) *Smith* (1980), (*c*) *Large and Pond* (1981).

C_d dependence on wind speed in neutral condition

Large uncertainty between estimates
(especially in low wind speed).

Lack data in high wind

Figure 7.1 Examples for the Drag Coefficient, C_{D10n} ,plotted as a function of wind speed, U_{10n}

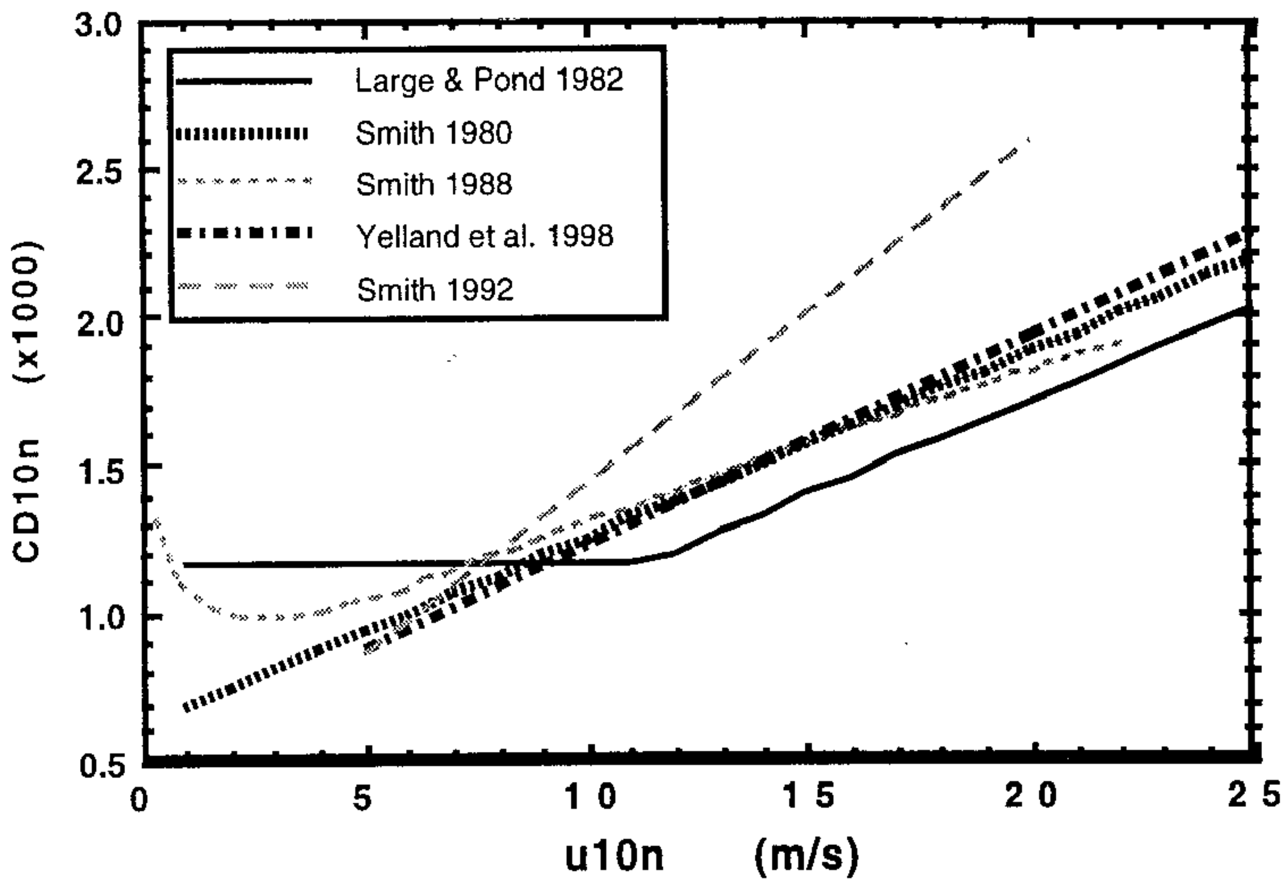
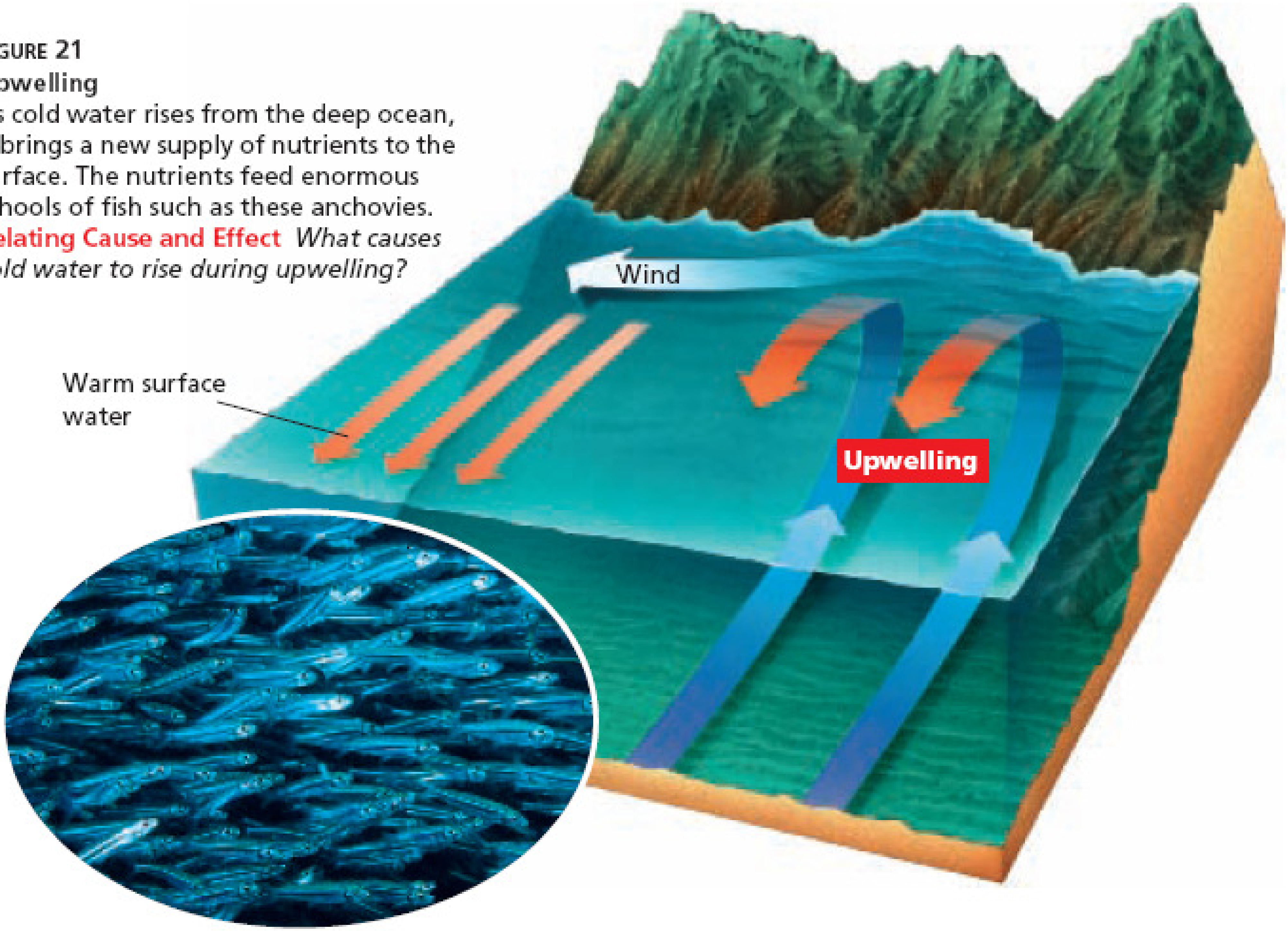
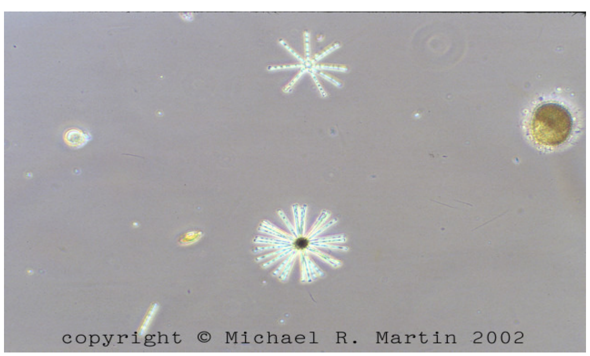


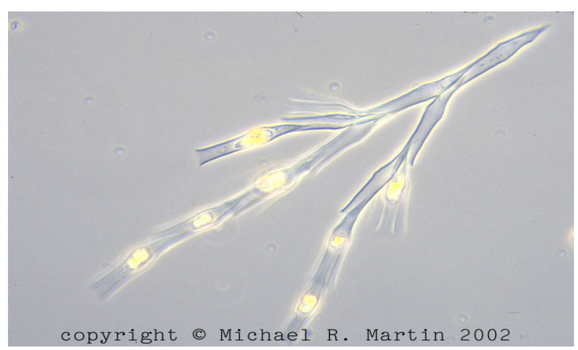
FIGURE 21
Upwelling
As cold water rises from the deep ocean, it brings a new supply of nutrients to the surface. The nutrients feed enormous schools of fish such as these anchovies.
Relating Cause and Effect *What causes cold water to rise during upwelling?*

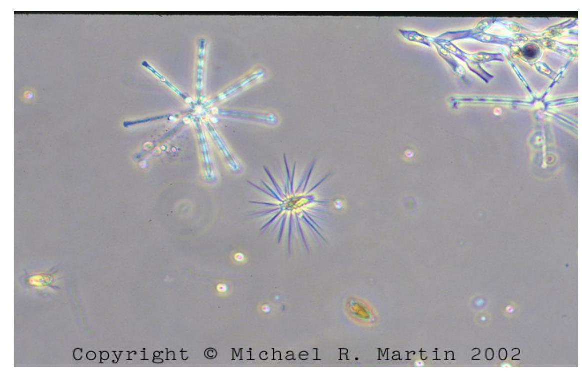


Upwelled water also contains nutrients (nitrate, phosphate, silicate) and dissolved gases (oxygen and carbon dioxide) that are not utilized at depth because of a lack of sunlight.

Now on the surface, these nutrients and gases help to fuel photosynthesis by small algae called phytoplankton.



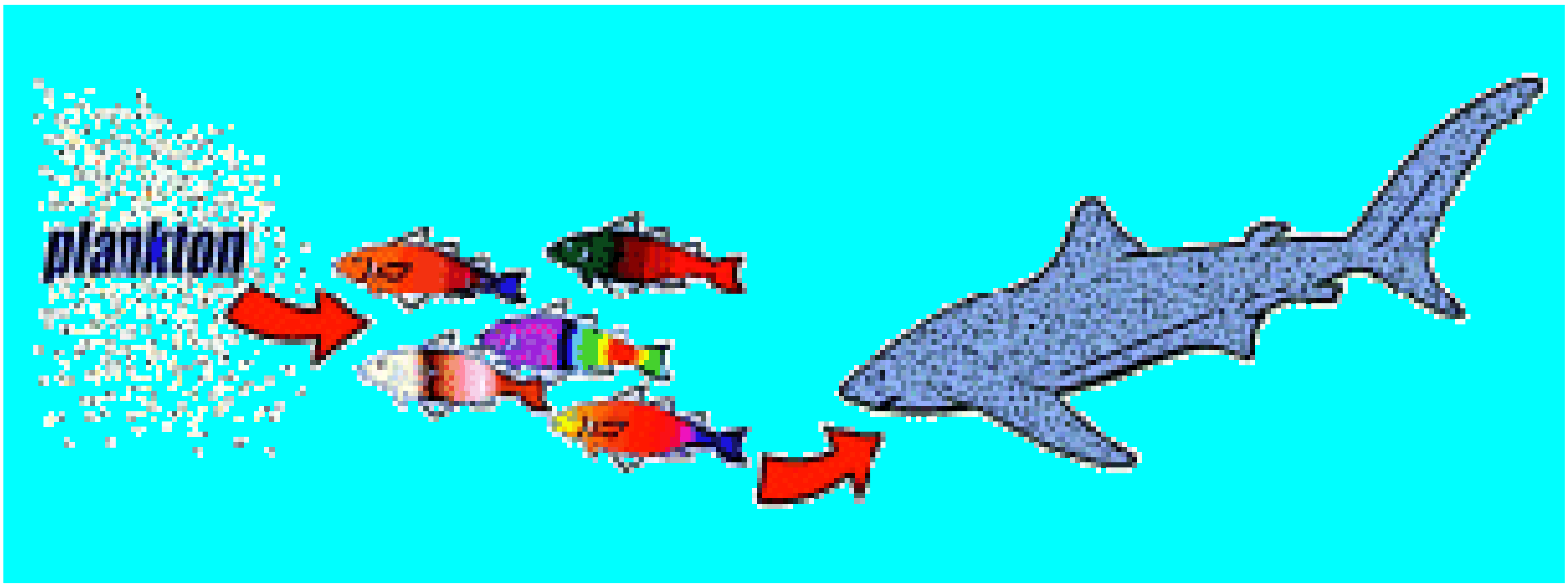




Ecological and Economic effects of upwelling:

- Upwelling leads to more phytoplankton
- More phytoplankton leads to more fish
- More fish lead to commercial fishing jobs and to more seafood

Phytoplankton come in many shapes and forms. Collectively they form the base of oceanic food webs.



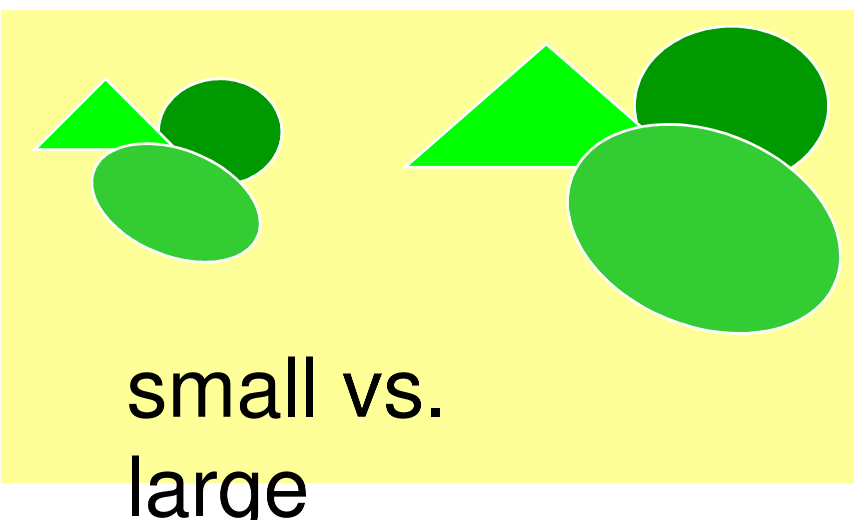
Without upwelling many of the world's fisheries would not thrive.

Even though upwelling areas account for only 1% of the ocean surface, they support 50% of the worlds fisheries.

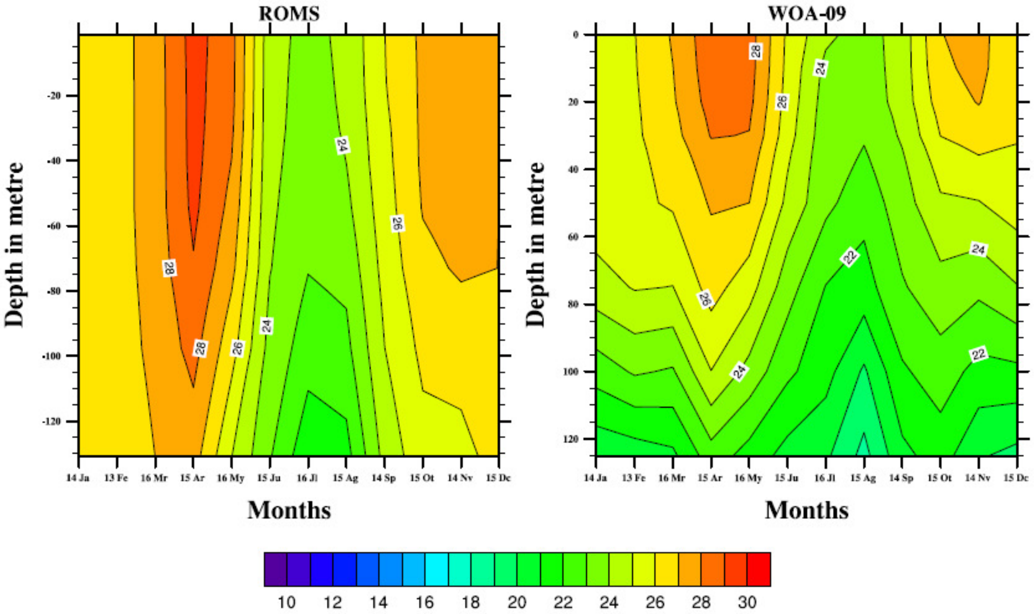
Productivity (phytoplankton growth) of an area is determined by the and the of upwelling.

- **Rate**

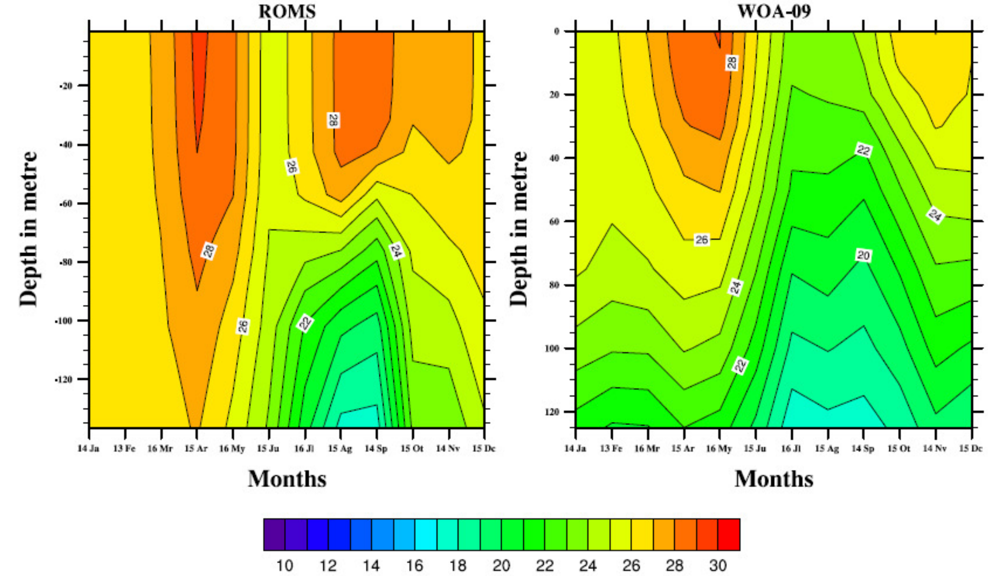
Duration of upwelling determines the total amount of phytoplankton.



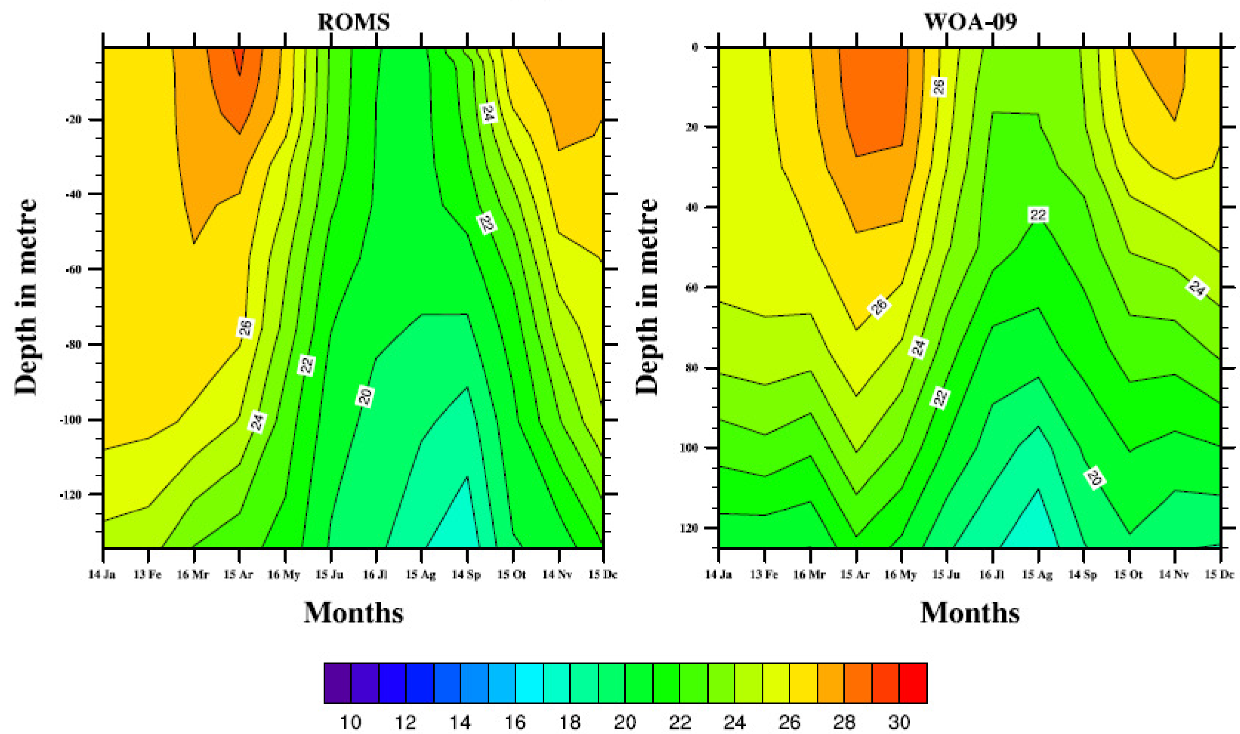
Comparison of ROMS TEMP(°C) Vertical Profile with WOA09 at 9N-51E

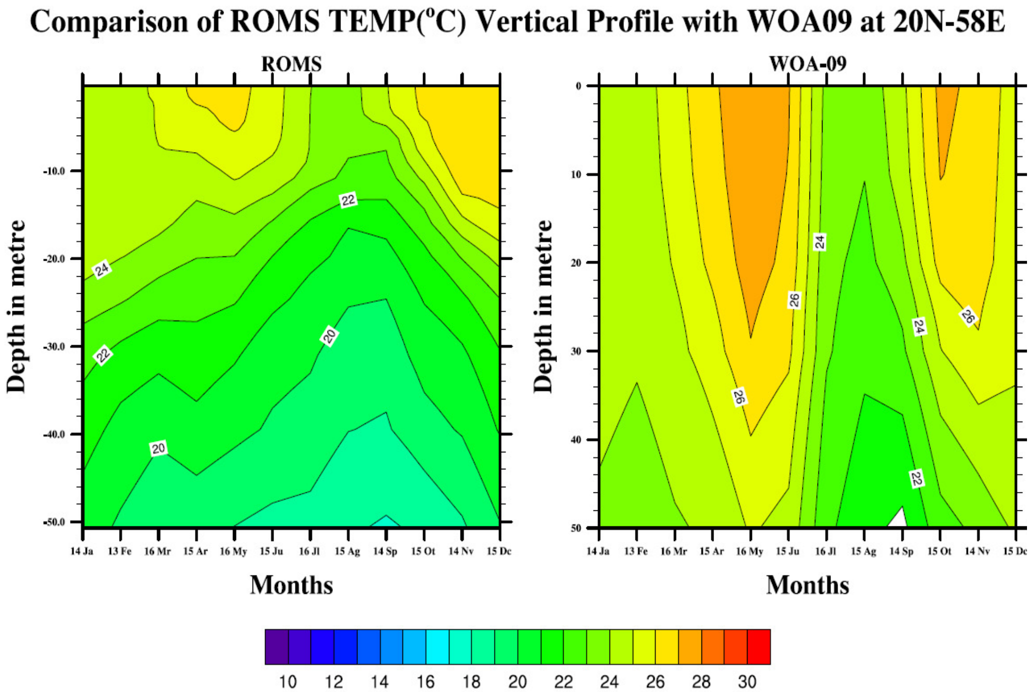


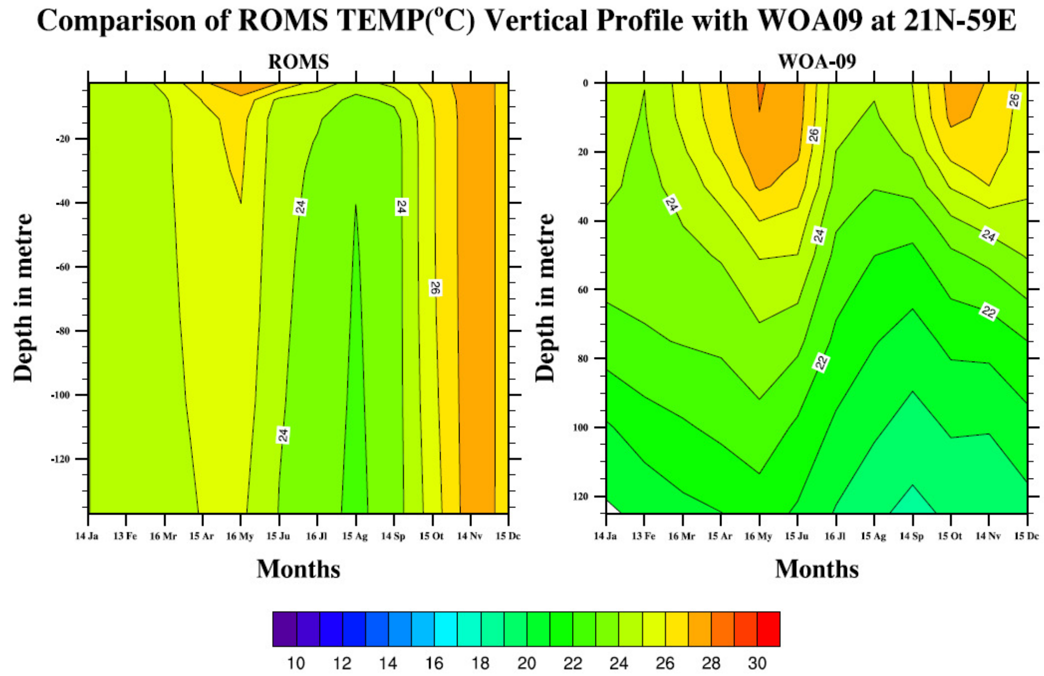
Comparison of ROMS TEMP(°C) Vertical Profile with WOA09 at 11N-52E

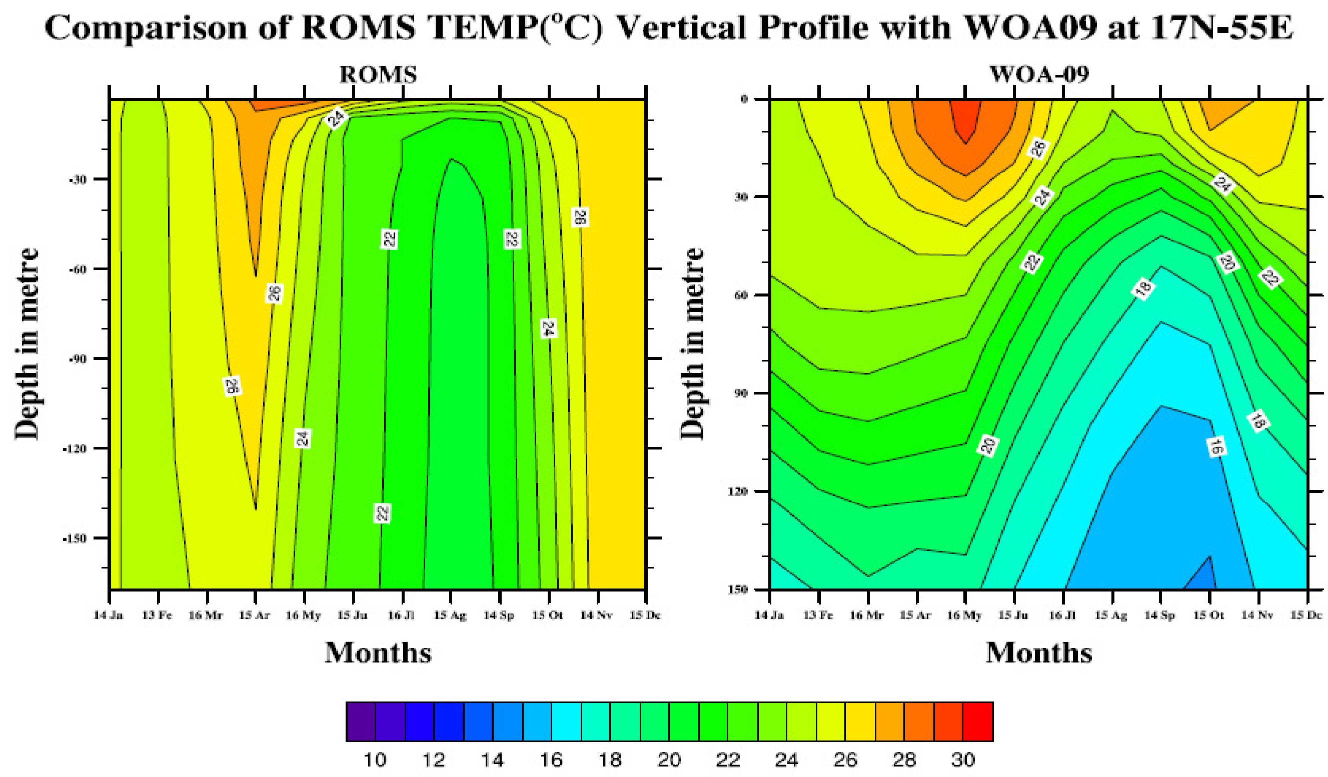


Comparison of ROMS TEMP(°C) Vertical Profile with WOA09 at 10N-51E




Comparison of ROMS TEMP(°C) Vertical Profile with WOA09 at 20N-58E
ROMS
WOA-09
Depth in metre
Months
14 Ja 13 Fe 16 Mr 15 Ar 16 My 15 Ju 16 Jl 15 Ag 14 Sp 15 Ot 14 Nv 15 Dc
-10.0 -20.0 -30.0 -40.0 -50.0
0 10 20 30 40 50
10 12 14 16 18 20 22 24 26 28 30


Comparison of ROMS TEMP(°C) Vertical Profile with WOA09 at 21N-59E
ROMS
WOA-09
Depth in metre
Months
14 Ja 13 Fe 16 Mr 15 Ar 16 My 15 Ju 16 Jl 15 Ag 14 Sp 15 Ot 14 Nv 15 Dc
-20 -40 -60 -80 -100 -120
0 20 40 60 80 100 120
10 12 14 16 18 20 22 24 26 28 30


Comparison of ROMS TEMP(°C) Vertical Profile with WOA09 at 17N-55E
ROMS
WOA-09
Depth in metre
Months
14 Ja 13 Fe 16 Mr 15 Ar 16 My 15 Ju 16 Jl 15 Ag 14 Sp 15 Ot 14 Nv 15 Dc
-30 -60 -90 -120 -150
0 30 60 90 120 150
10 12 14 16 18 20 22 24 26 28 30

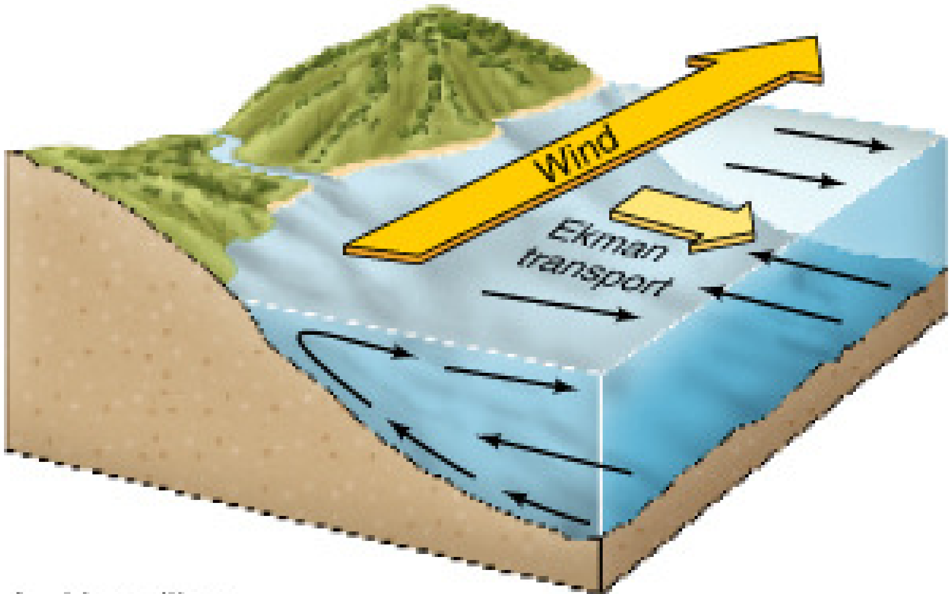
Reasons to study Upwelling

- Upwelled water is cooler and saltier than the original surface water, and typically has much greater concentrations of nutrients.

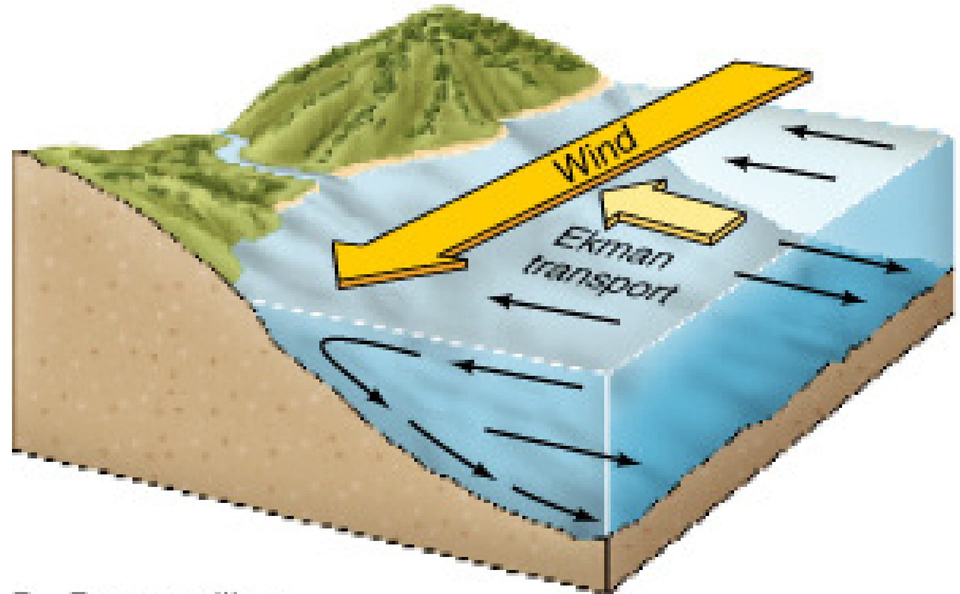
- . These nutrients support the base of the food chain phytoplankton

- The increased availability in upwelling regions results in high levels of primary productivity and thus fishery production. Approximately 25% of the total global marine fish catches come from five upwellings that occupy only 5% of the total ocean area

- Marine ecosystems in the ocean's eastern boundary currents generally have large fish stocks such as sardines and anchovies, and major populations of marine mammals and



A. Upwelling



B. Downwelling

- **Equator-ward winds on ocean eastern boundaries**
- **Pole-ward wind on ocean western boundaries**

- **Pole-ward winds on ocean eastern boundaries**
- **Equator-ward wind on ocean western boundaries**