Εισαγωγή στην Ακουστική Ωκεανογραφία

Ο ήχος είναι ένα κύμα συμπιεστότητας (compressional wave) που διαδίδεται σε ένα χωρίο με ταχύτητα που εξαρτάται από το χωρίο διάδοσης.

Το νερό διαδίδει τον ήχο σε μεγάλες αποστάσεις.

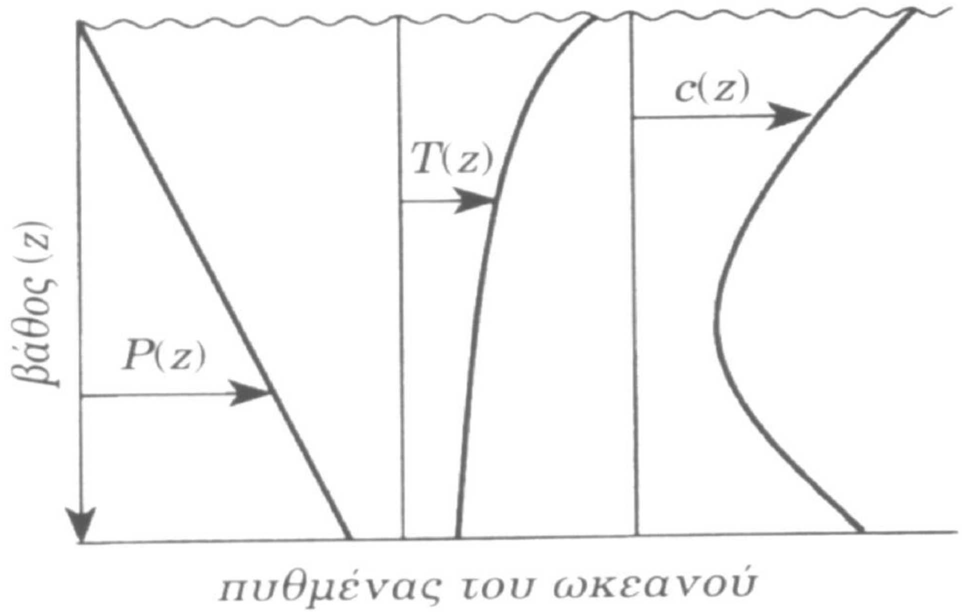
Ταχύτητα διάδοσης του ήχου στο νερό

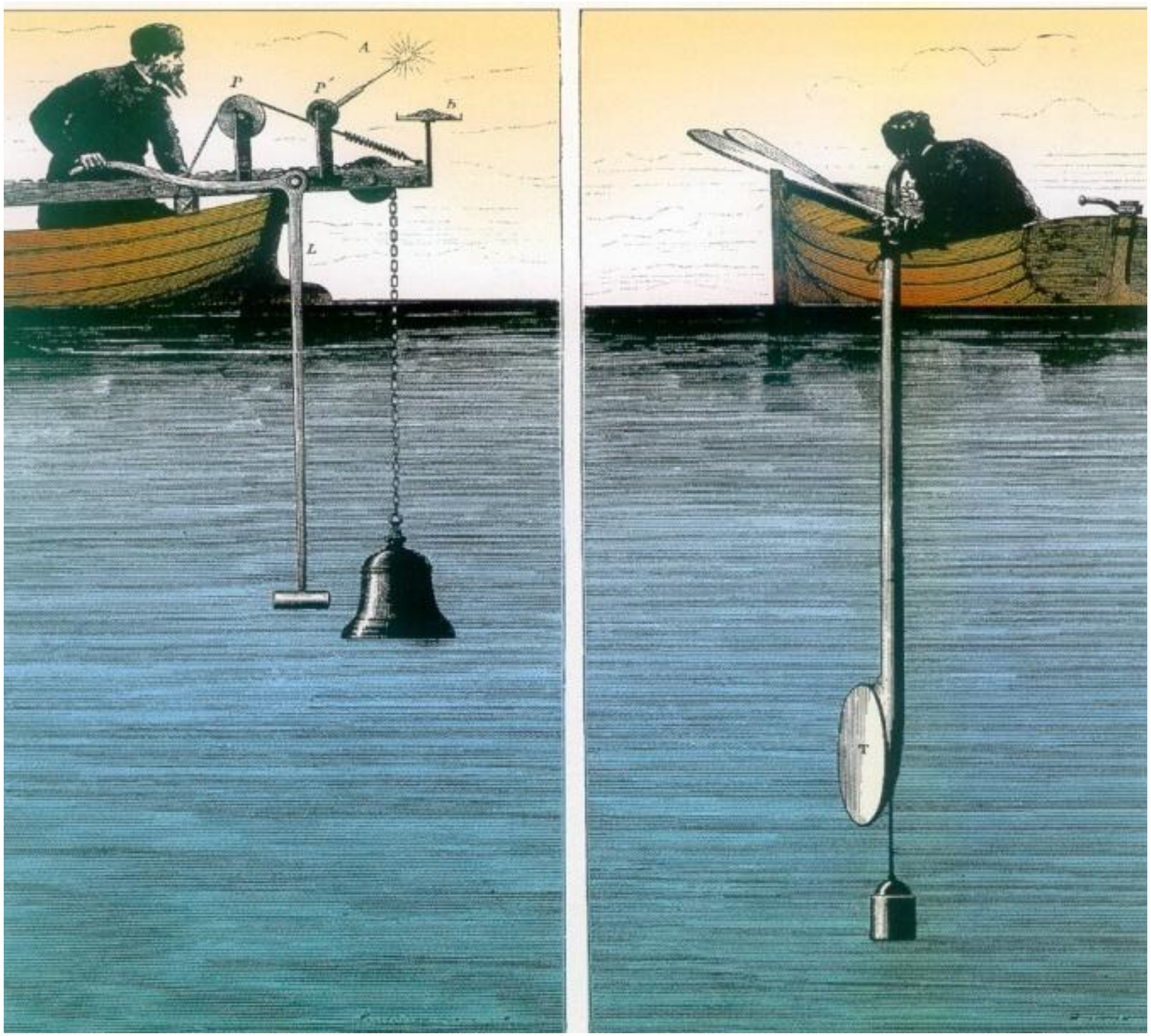
$$c=1449.2 +4.6\,T - 0{,}055\,T^2 + 0.00029\,T^3 + (1.34-0.010T)(S-35) + 0.016\,z$$

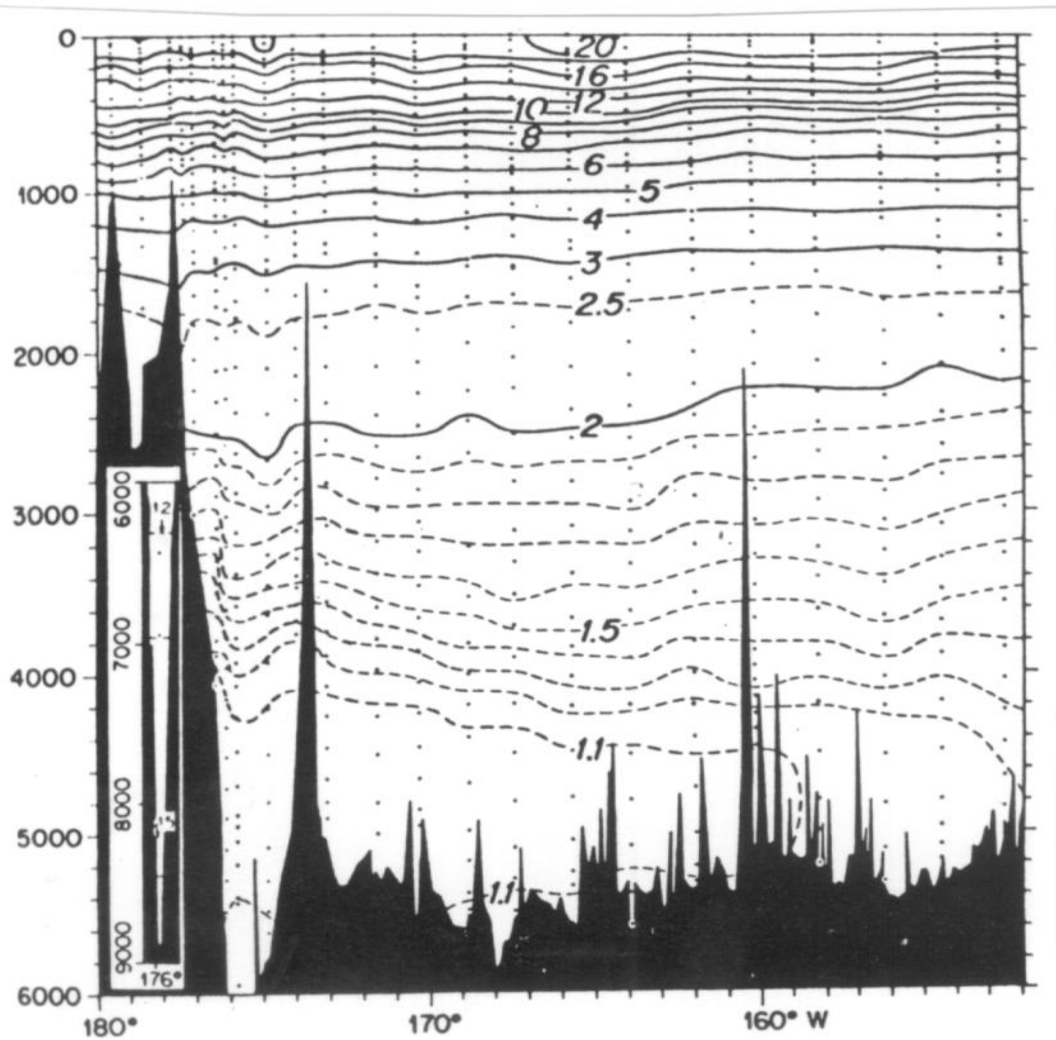
όπου c = ταχύτητα του ήχου (m/s)
T = θερμοκρασία (^oC)
S = αλατότητα (σε μέρη επί τοις χιλίοις)
z = βάθος (m)

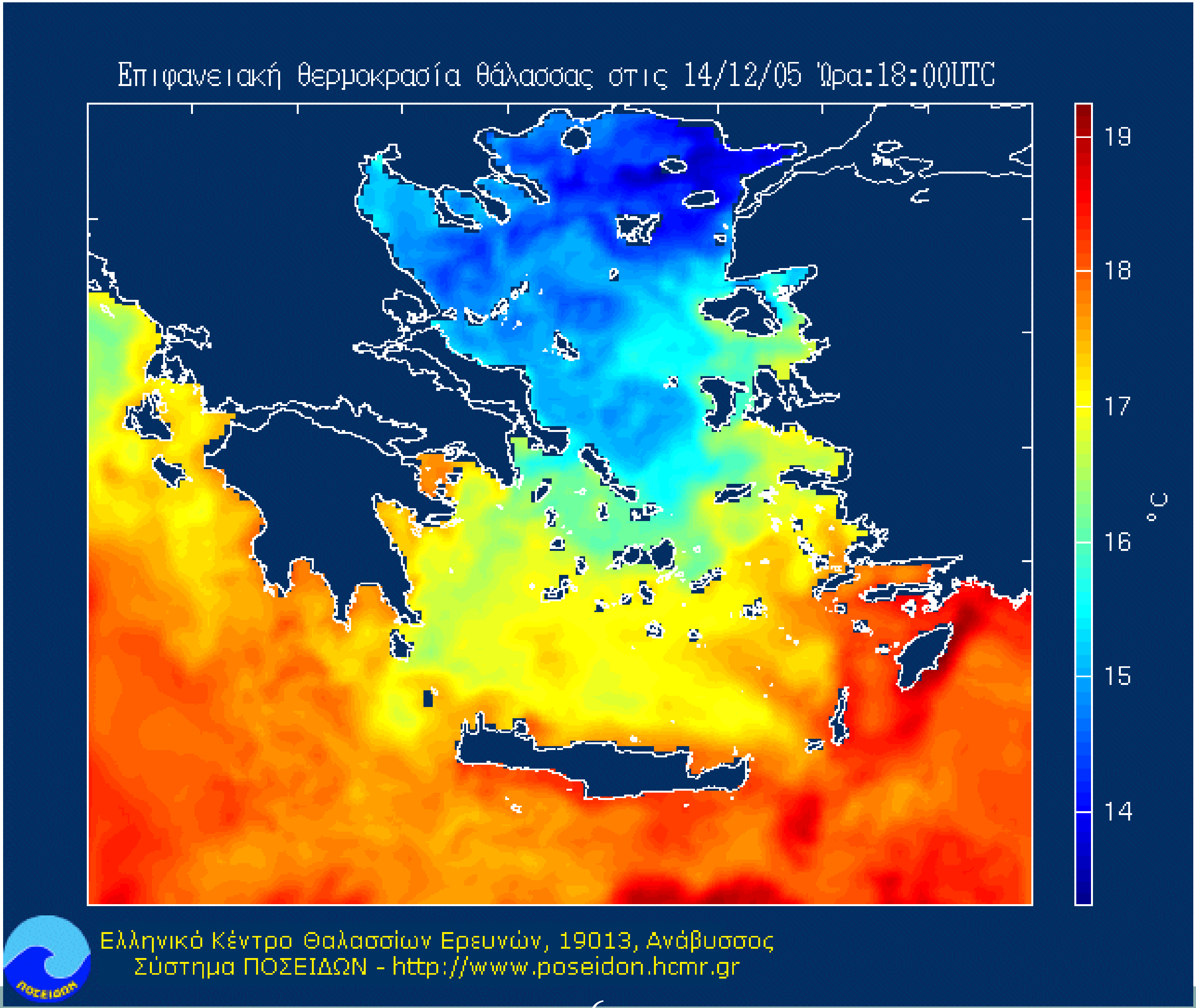
Η θερμοκρασία της θάλασσας και η πίεση μεταβάλλονται με το βάθος

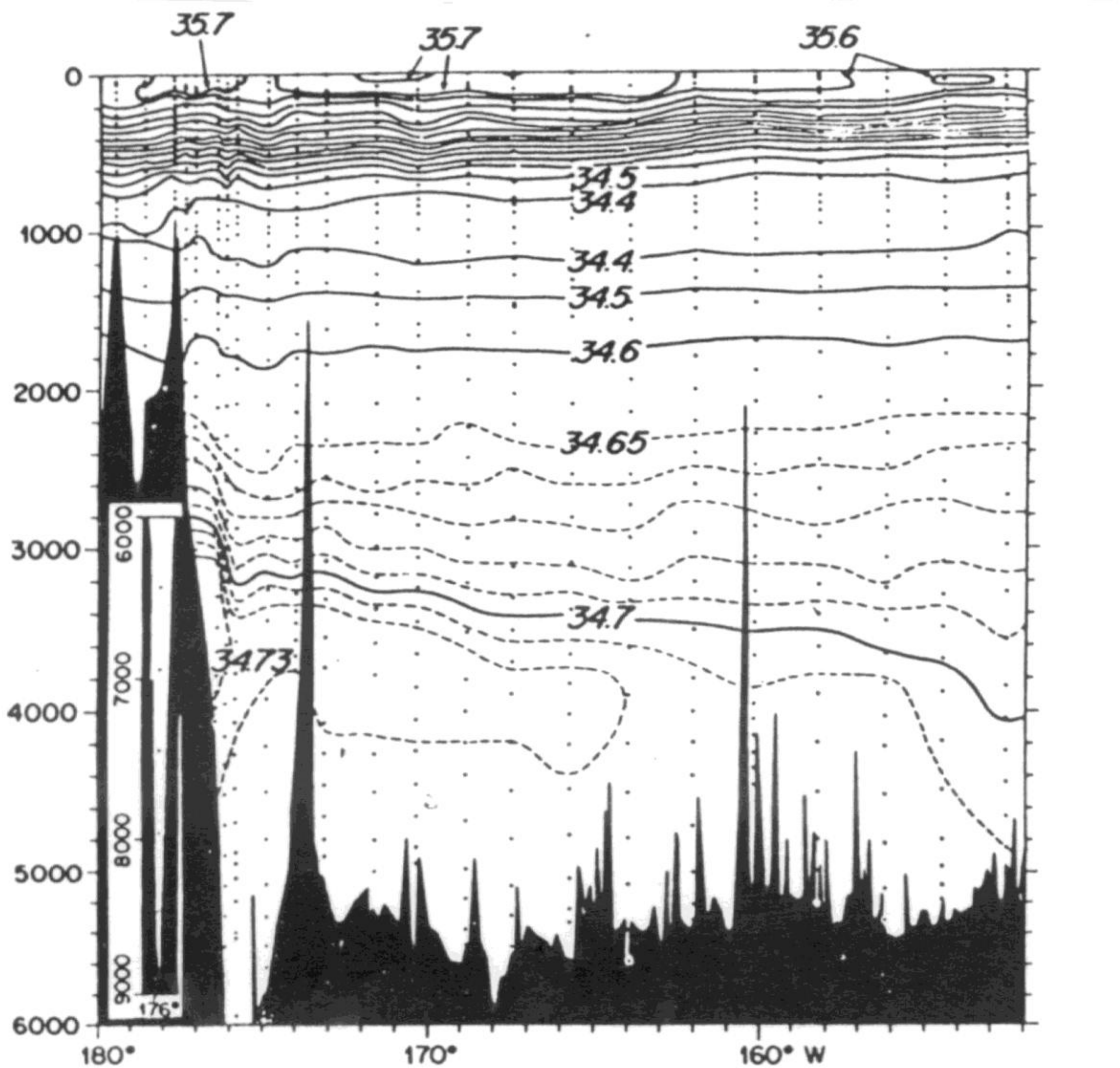
Η ταχύτητα διάδοσης εξαρτάται από τα μεγέθη αυτά και συνεπώς μεταβάλλεται με το βάθος

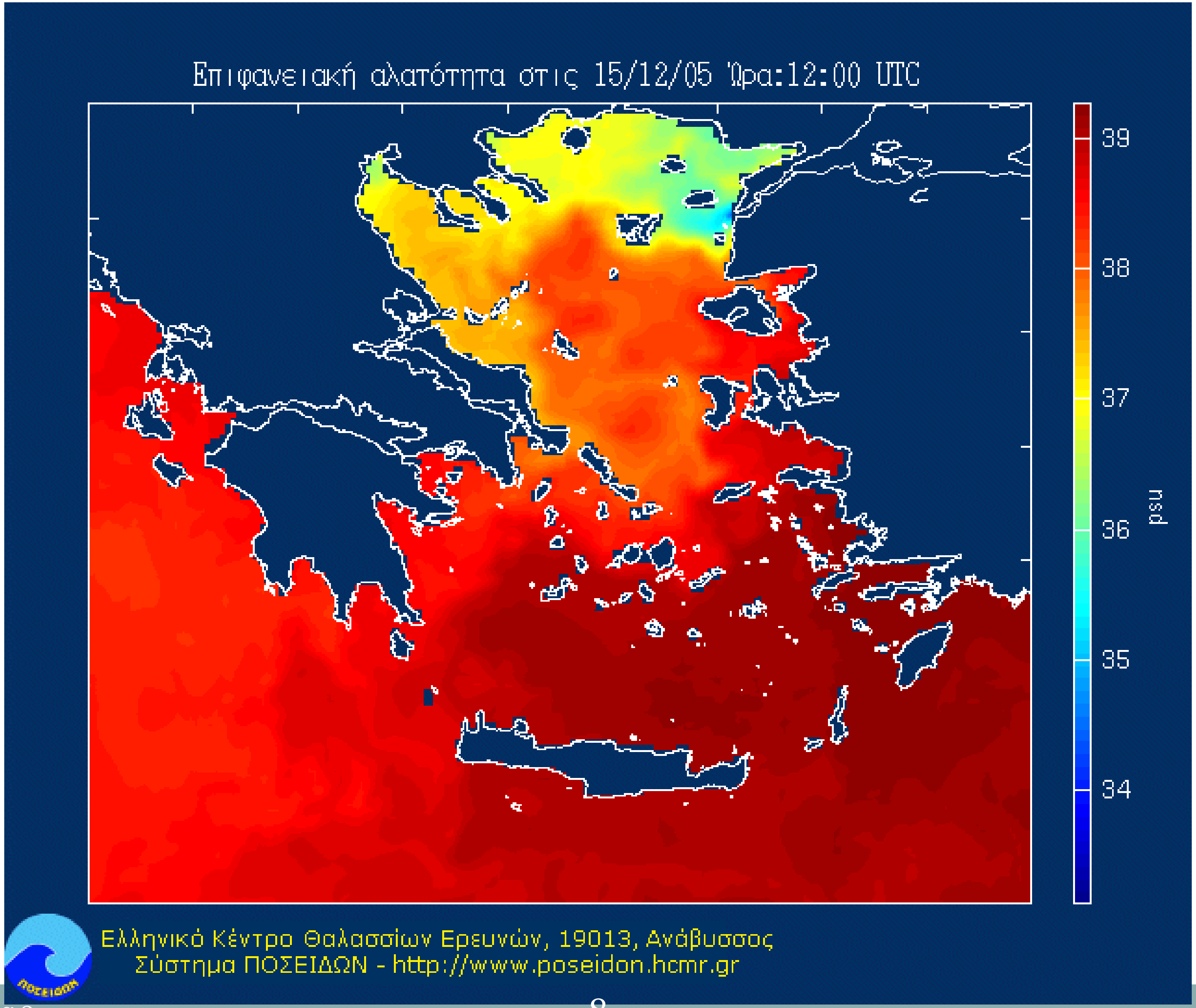


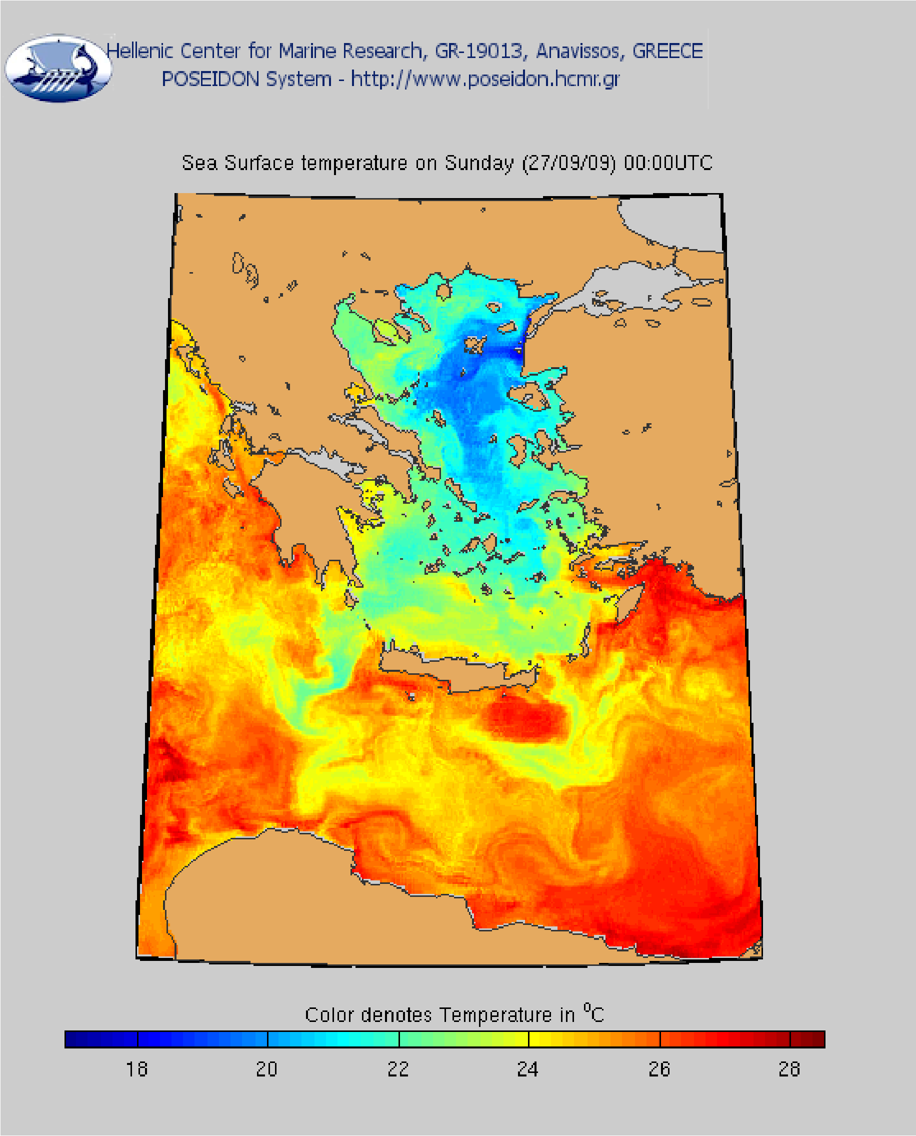

A
P
P'
b
L
T

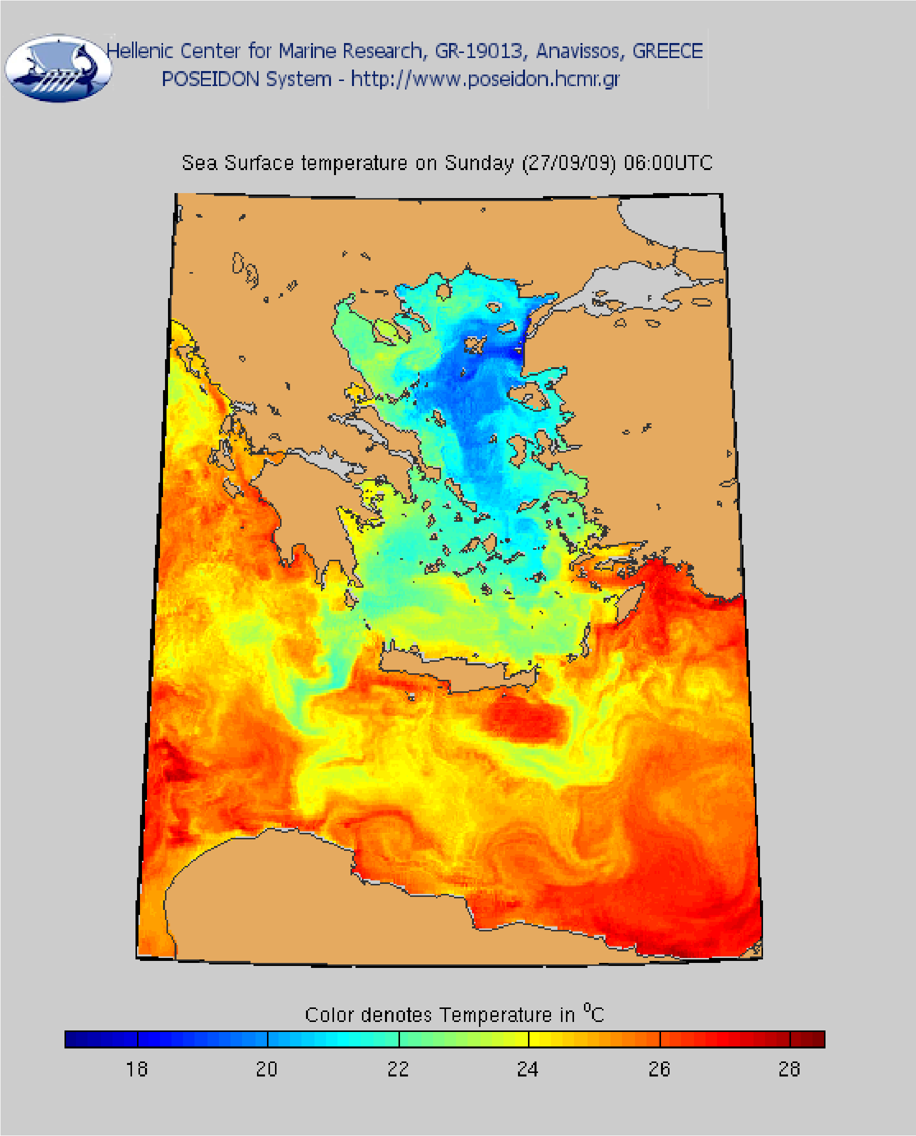

0
1000
2000
3000
4000
5000
6000
180°
170°
160° W
20
16
12
10
8
6
5
4
3
2.5
2
1.5
1.1
1.1
6000
7000
8000
9000
176°

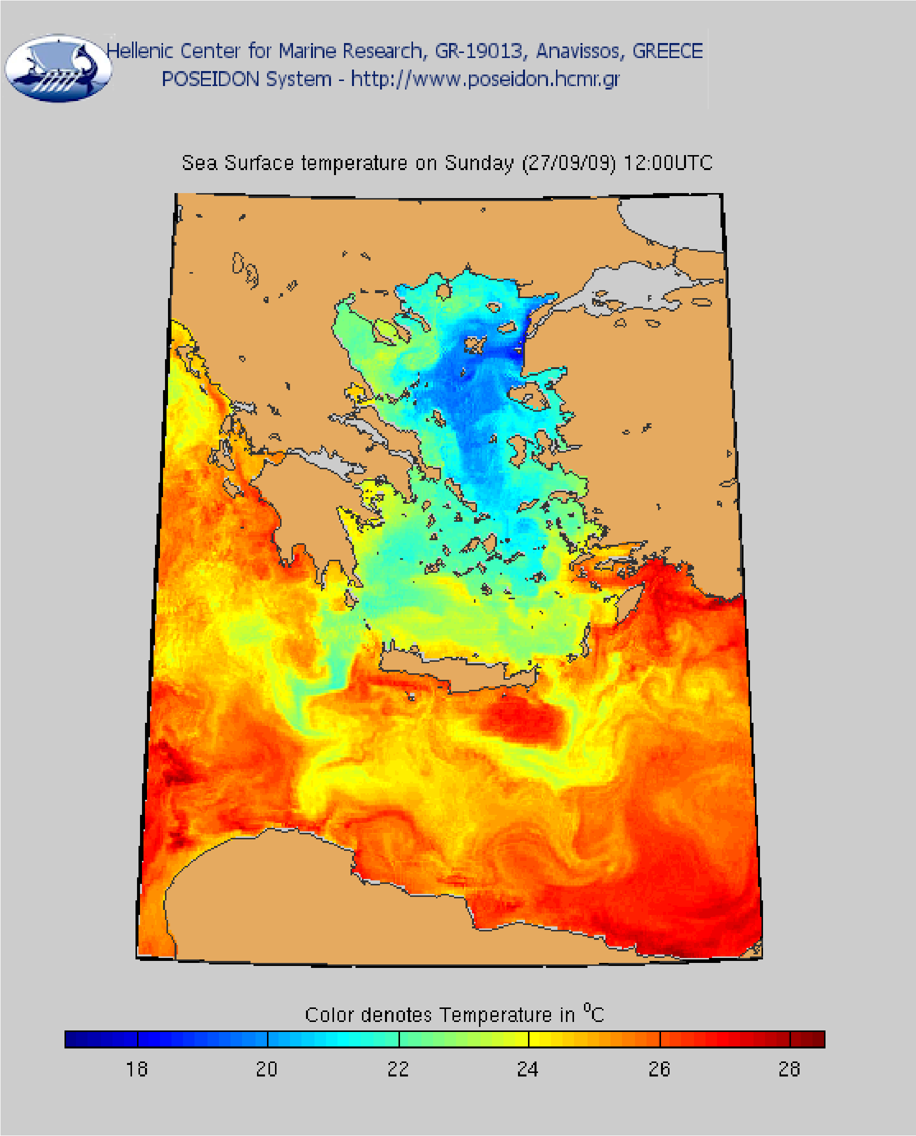

Επιφανειακή θερμοκρασία θάλασσας στις 14/12/05 Ώρα:18:00UTC
19
18
17
16
15
14
°C
Ελληνικό Κέντρο Θαλασσίων Ερευνών, 19013, Ανάβυσσος
Σύστημα ΠΟΣΕΙΔΩΝ - http://www.poseidon.hcmr.gr

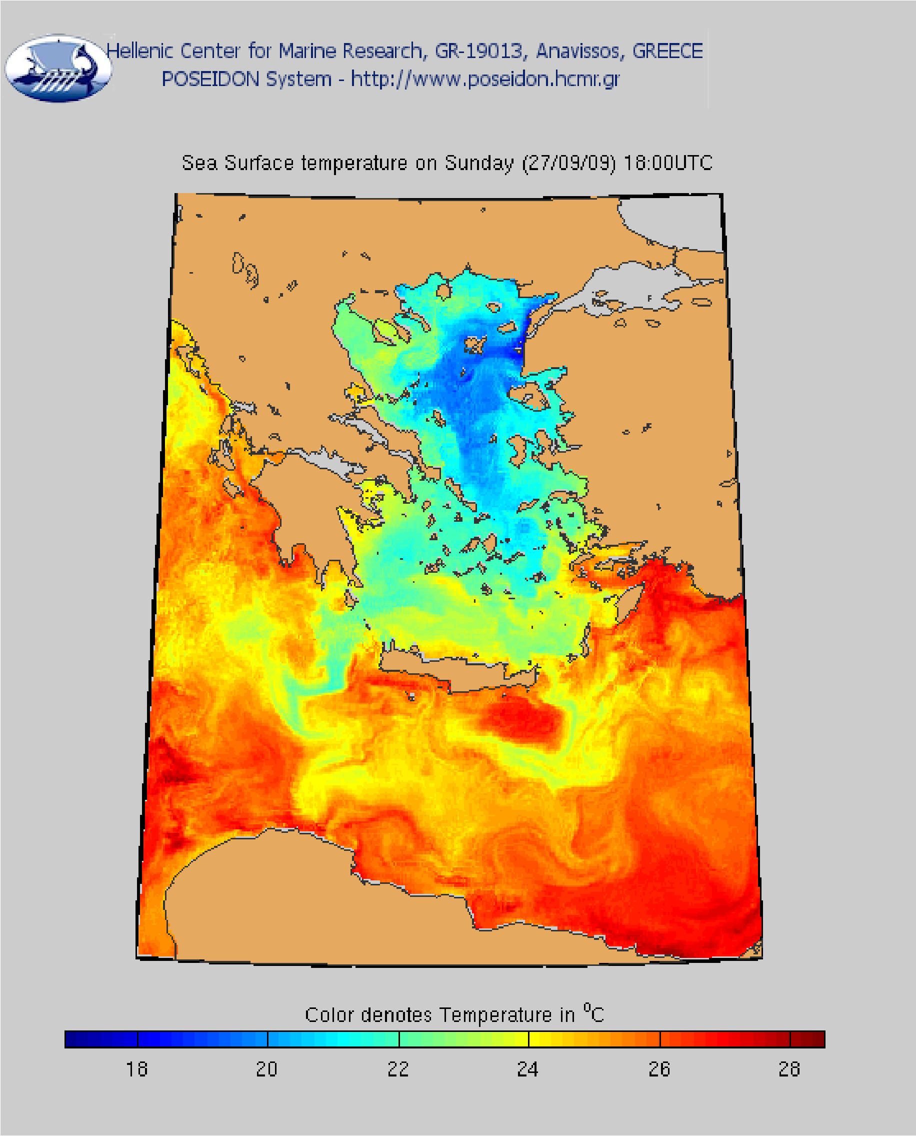

35.7
35.7
35.6
0
1000
2000
3000
4000
5000
6000
34.5
34.4
34.4
34.5
34.6
34.65
34.7
34.73
6000
7000
8000
9000
176°
180°
170°
160° W


Επιφανειακή αλατότητα στις 15/12/05 Ώρα:12:00 UTC
39
38
37
36
35
34
psu
Ελληνικό Κέντρο Θαλασσίων Ερευνών, 19013, Ανάβυσσος
Σύστημα ΠΟΣΕΙΔΩΝ - http://www.poseidon.hcmr.gr

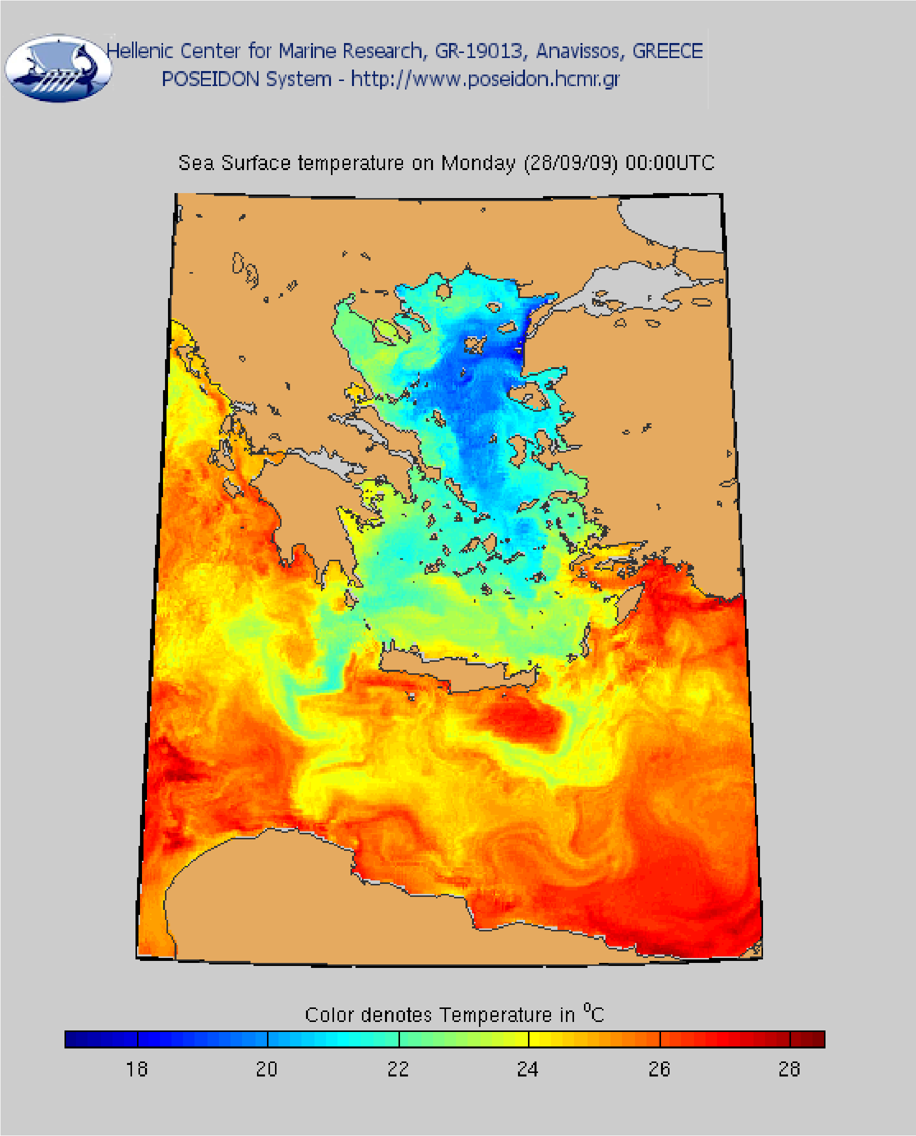

Hellenic Center for Marine Research, GR-19013, Anavissos, GREECE
POSEIDON System - http://www.poseidon.hcmr.gr
Sea Surface temperature on Sunday (27/09/09) 00:00UTC
Color denotes Temperature in °C
18
20
22
24
26
28


Hellenic Center for Marine Research, GR-19013, Anavissos, GREECE
POSEIDON System - http://www.poseidon.hcmr.gr
Sea Surface temperature on Sunday (27/09/09) 06:00UTC
Color denotes Temperature in °C
18
20
22
24
26
28

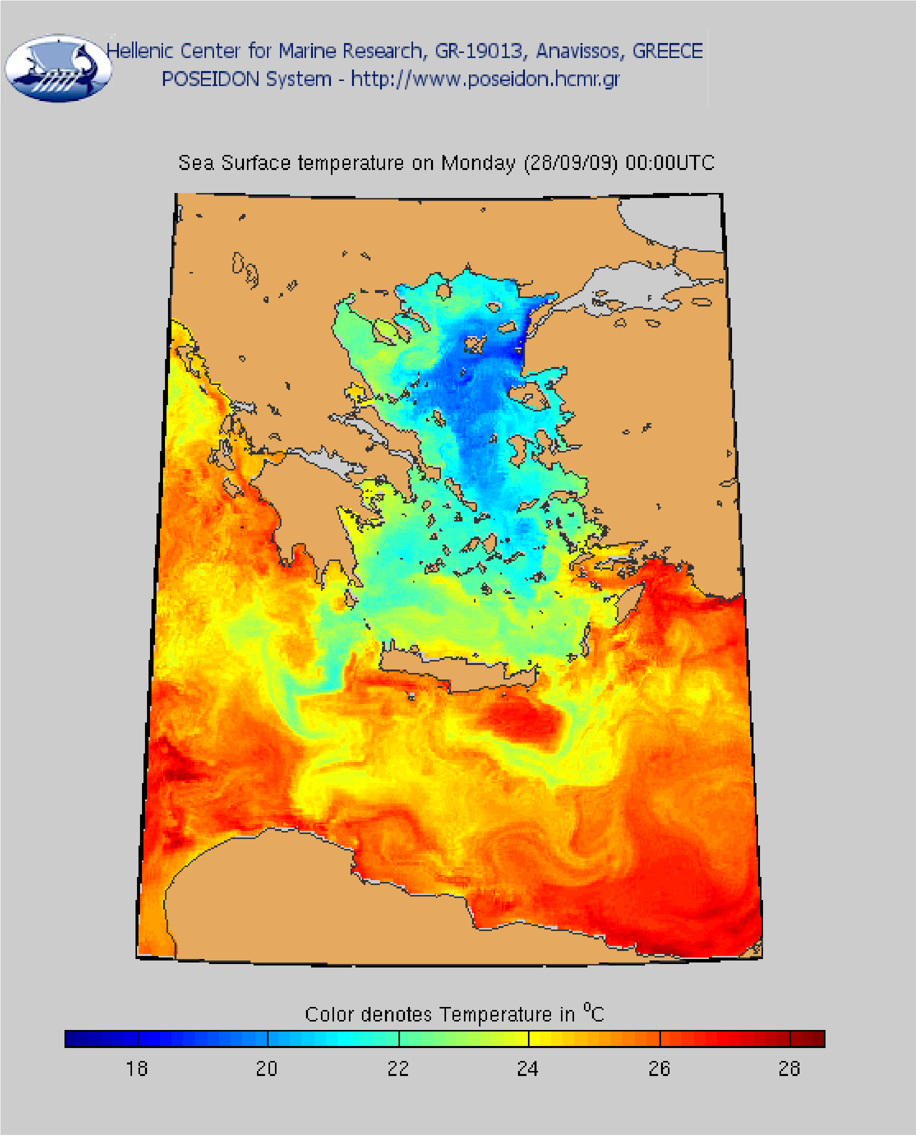

Hellenic Center for Marine Research, GR-19013, Anavissos, GREECE
POSEIDON System - http://www.poseidon.hcmr.gr
Sea Surface temperature on Sunday (27/09/09) 12:00UTC
Color denotes Temperature in °C
18
20
22
24
26
28



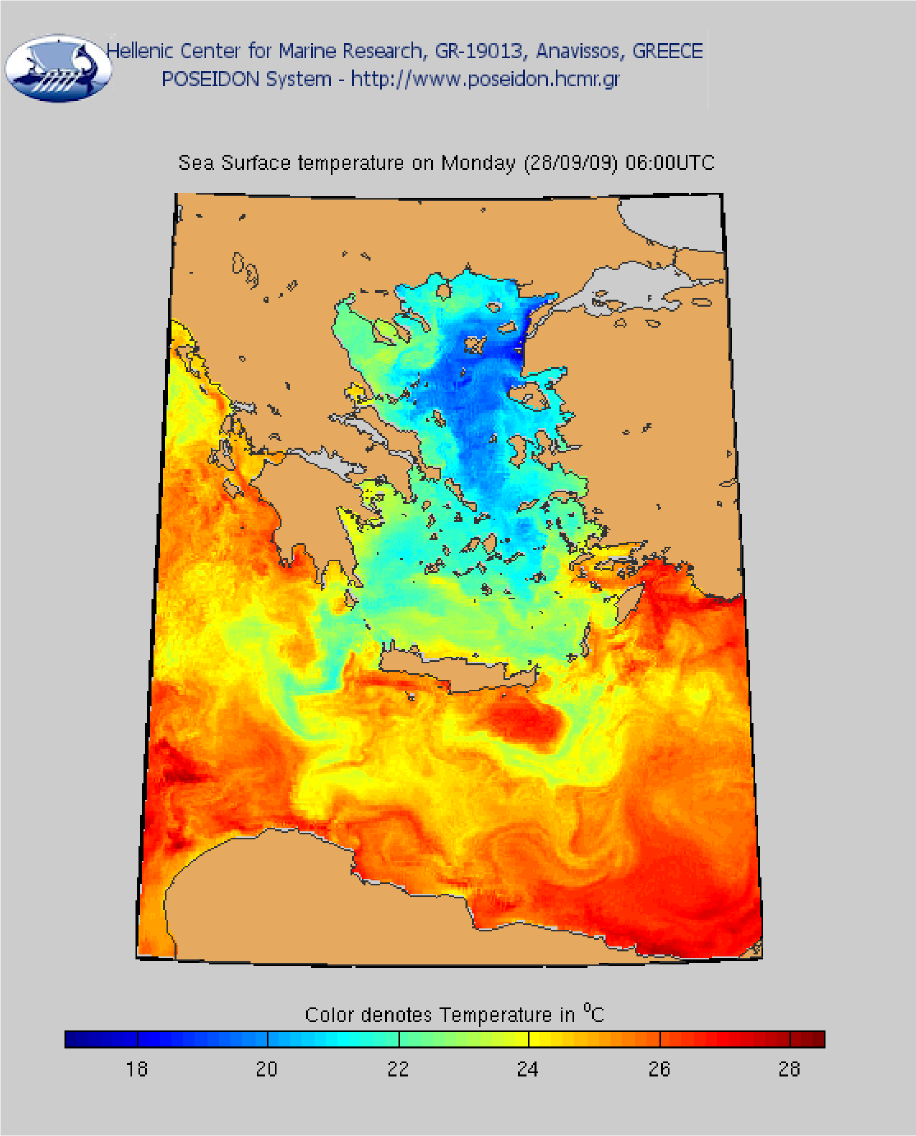
Hellenic Center for Marine Research, GR-19013, Anavissos, GREECE
POSEIDON System - http://www.poseidon.hcmr.gr
Sea Surface temperature on Sunday (27/09/09) 18:00UTC
Color denotes Temperature in °C
18
20
22
24
26
28



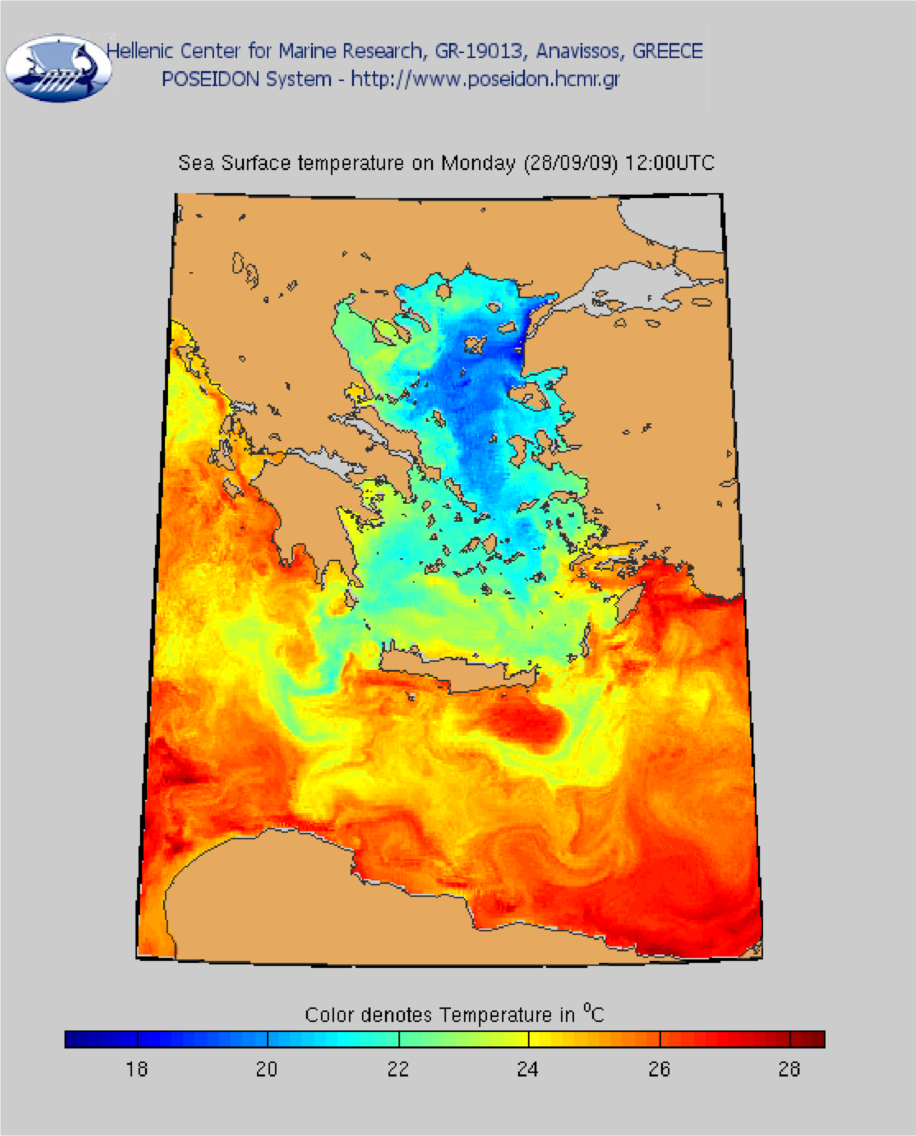
Hellenic Center for Marine Research, GR-19013, Anavissos, GREECE
POSEIDON System - http://www.poseidon.hcmr.gr
Sea Surface temperature on Monday (28/09/09) 00:00UTC
Color denotes Temperature in °C
18
20
22
24
26
28

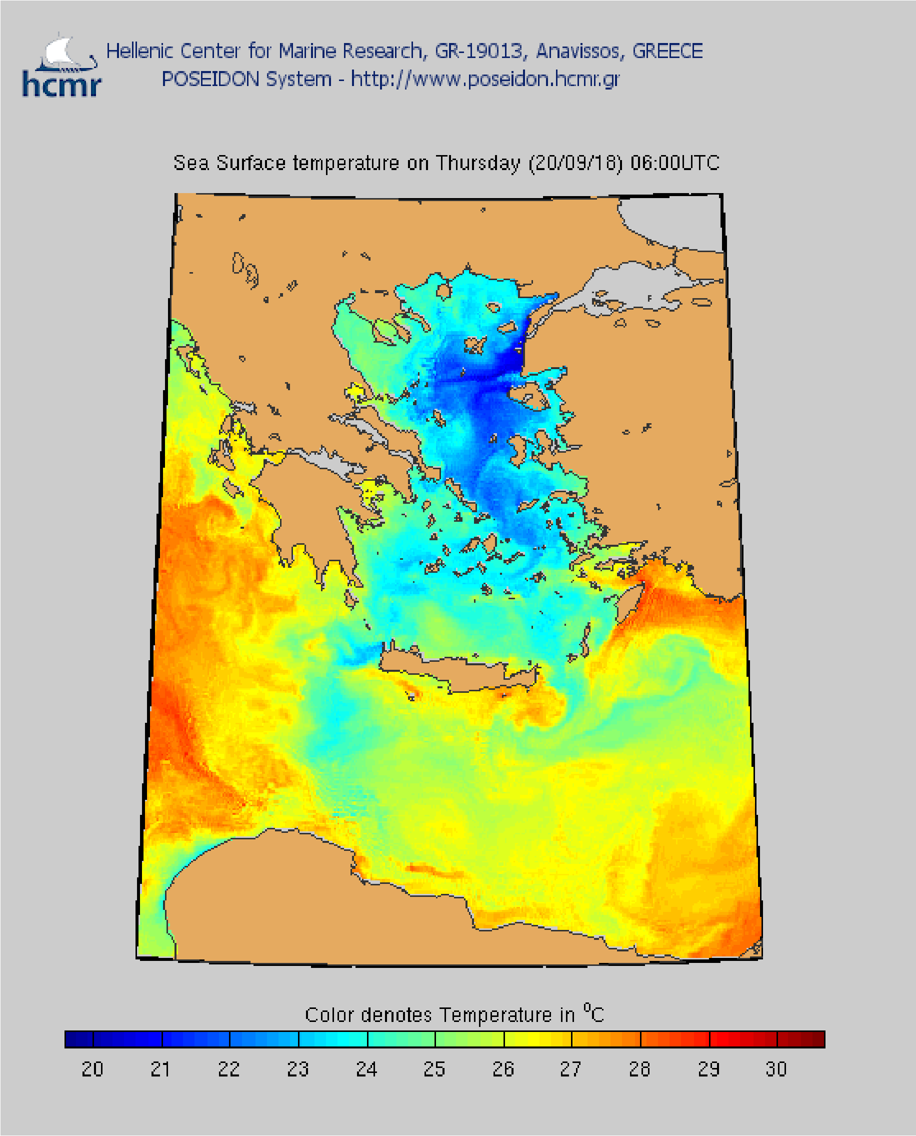


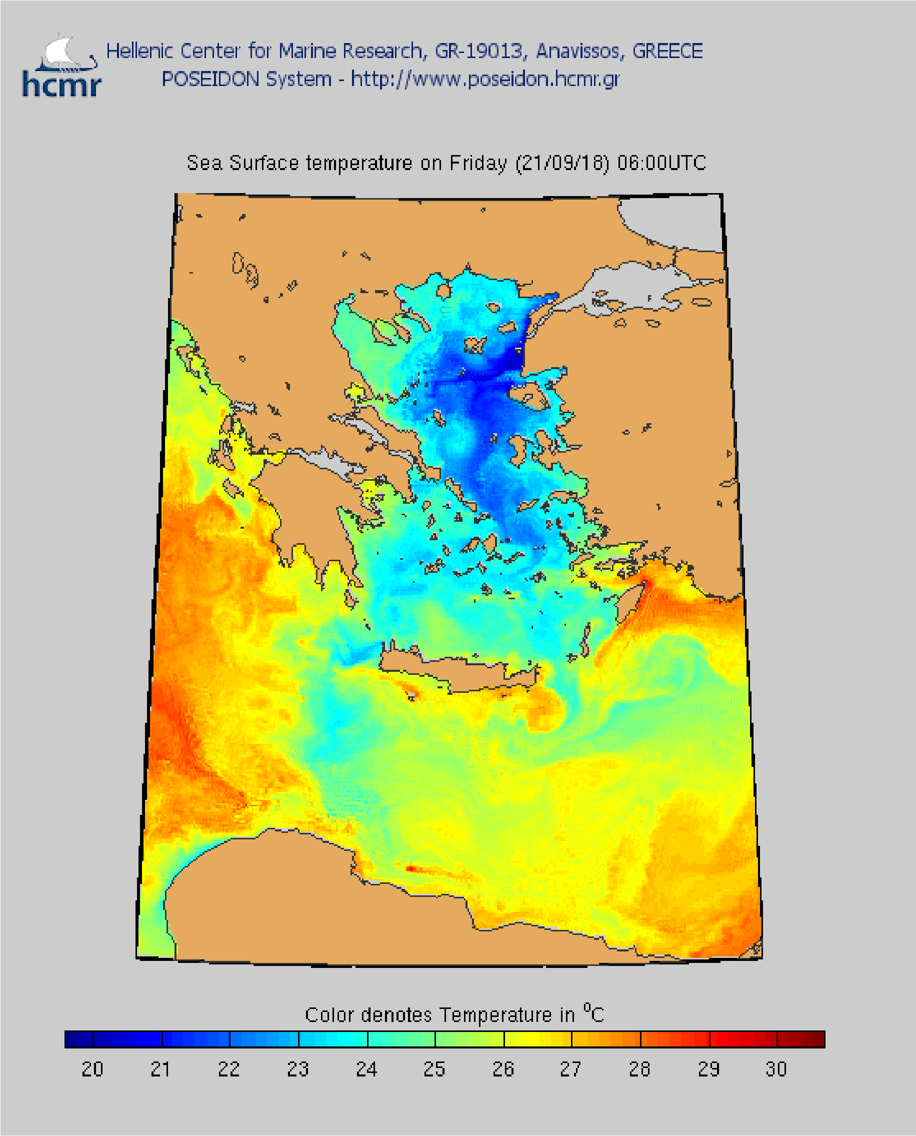
Hellenic Center for Marine Research, GR-19013, Anavissos, GREECE
POSEIDON System - http://www.poseidon.hcmr.gr
Sea Surface temperature on Monday (28/09/09) 00:00UTC
Color denotes Temperature in °C
18
20
22
24
26
28



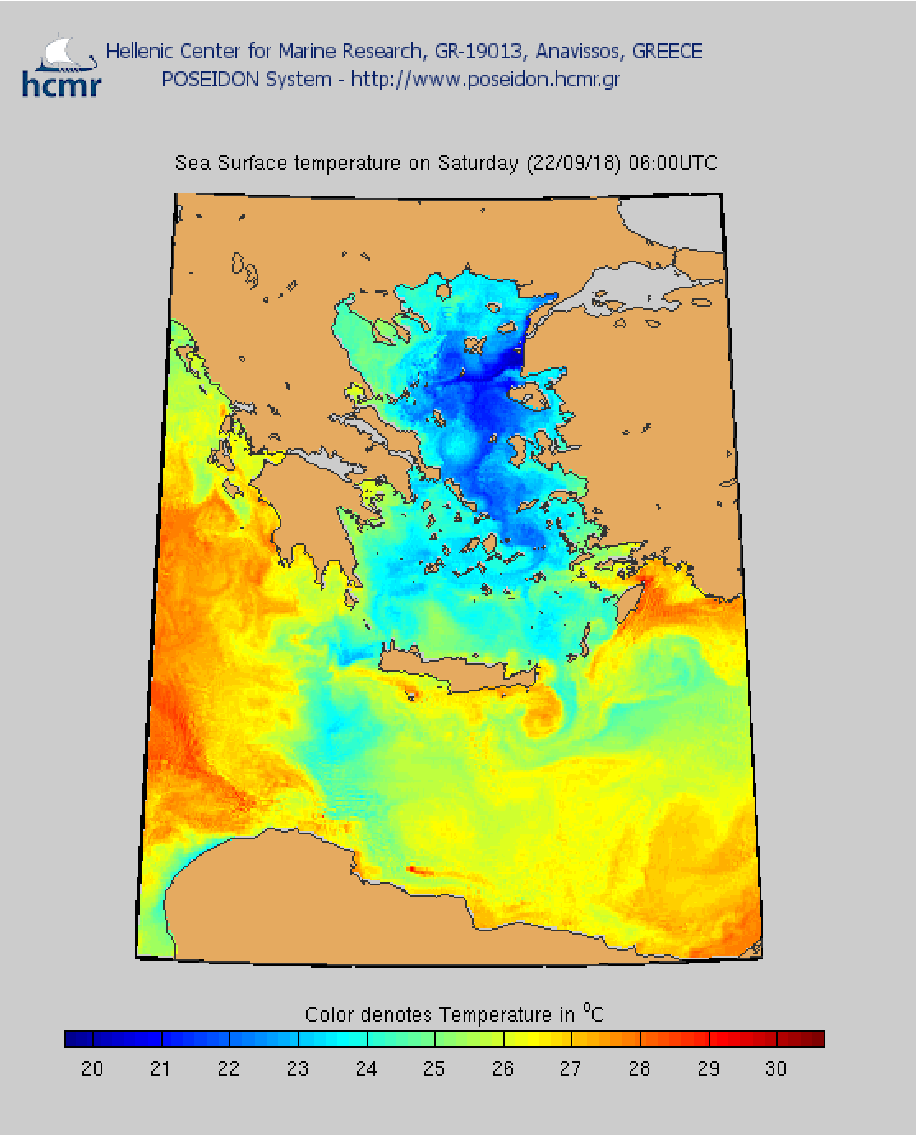
Hellenic Center for Marine Research, GR-19013, Anavissos, GREECE
POSEIDON System - http://www.poseidon.hcmr.gr
Sea Surface temperature on Monday (28/09/09) 06:00UTC
Color denotes Temperature in °C
18
20
22
24
26
28


Hellenic Center for Marine Research, GR-19013, Anavissos, GREECE
POSEIDON System - http://www.poseidon.hcmr.gr
Sea Surface temperature on Monday (28/09/09) 12:00UTC
Color denotes Temperature in °C
18
20
22
24
26
28

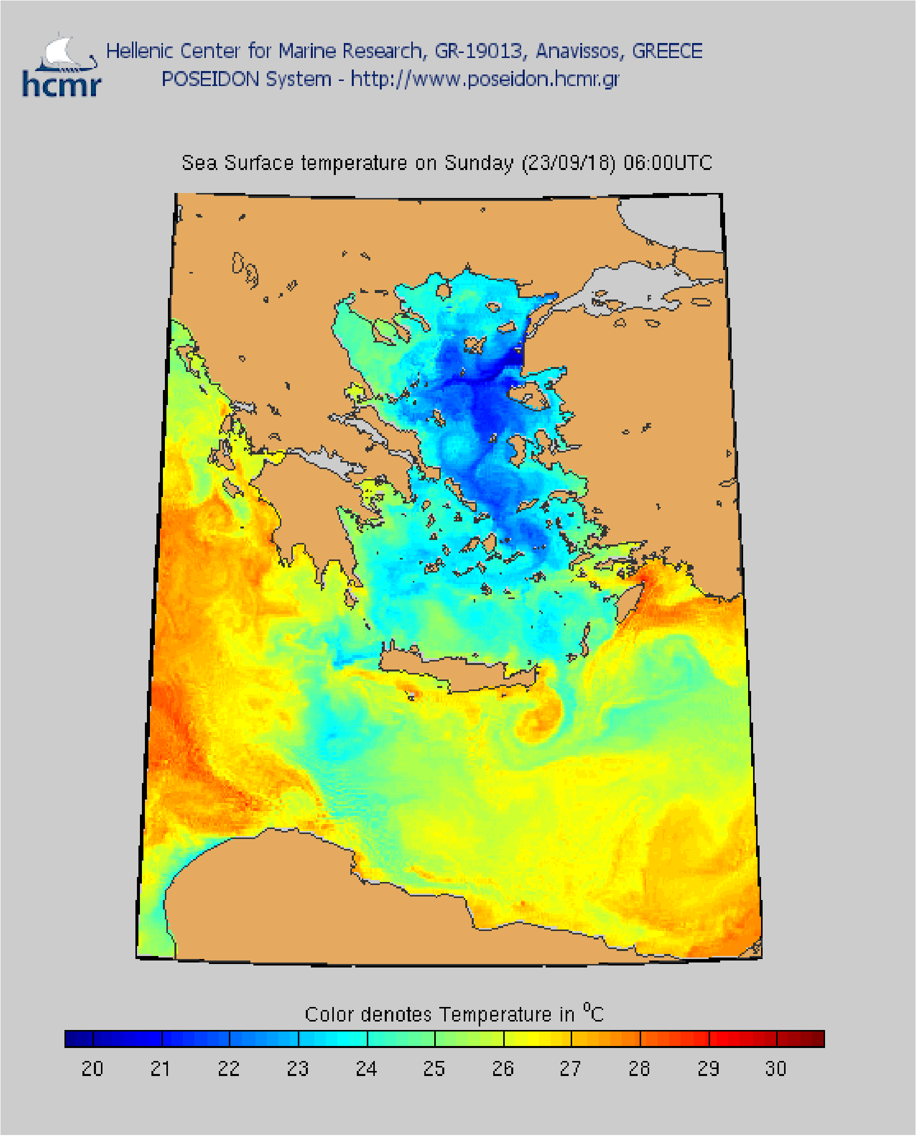

hcmr
Hellenic Center for Marine Research, GR-19013, Anavissos, GREECE
POSEIDON System - http://www.poseidon.hcmr.gr
Sea Surface temperature on Thursday (20/09/18) 06:00UTC
Color denotes Temperature in °C
20
21
22
23
24
25
26
27
28
29
30

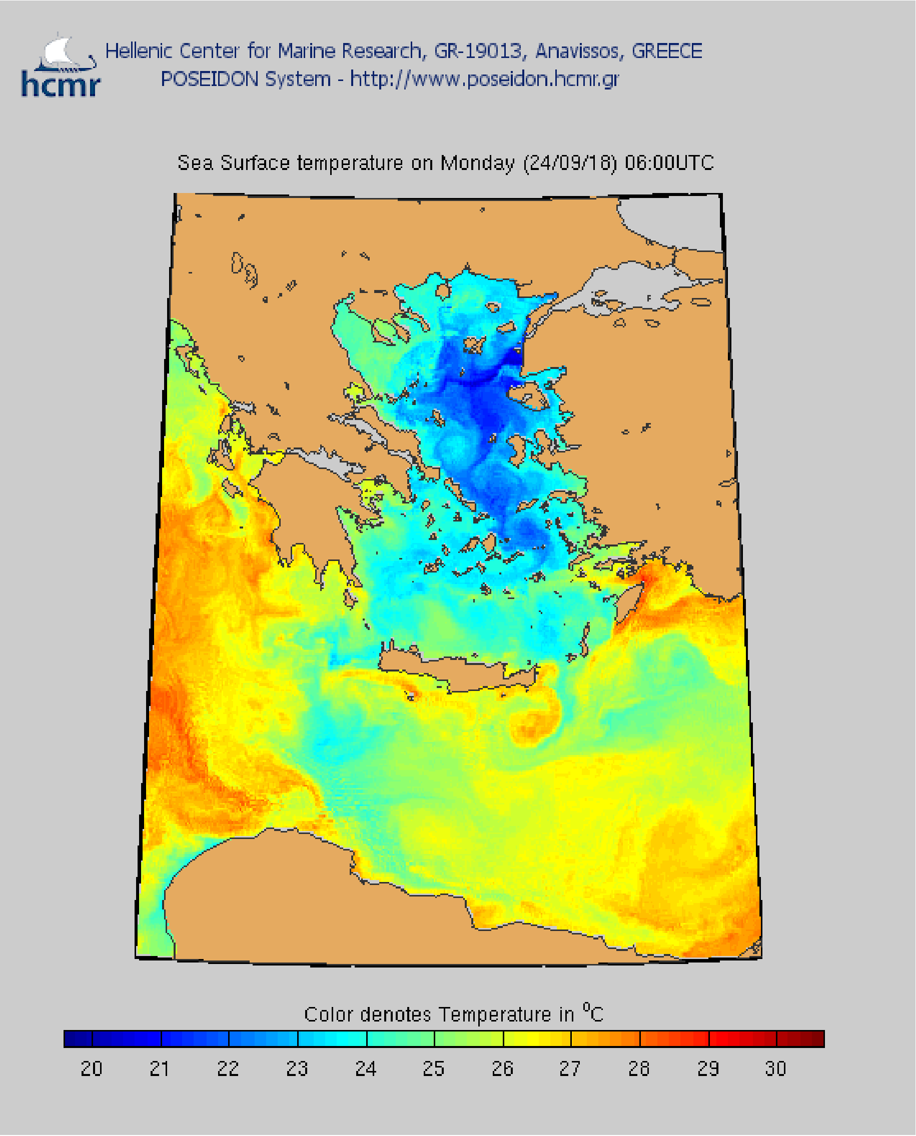


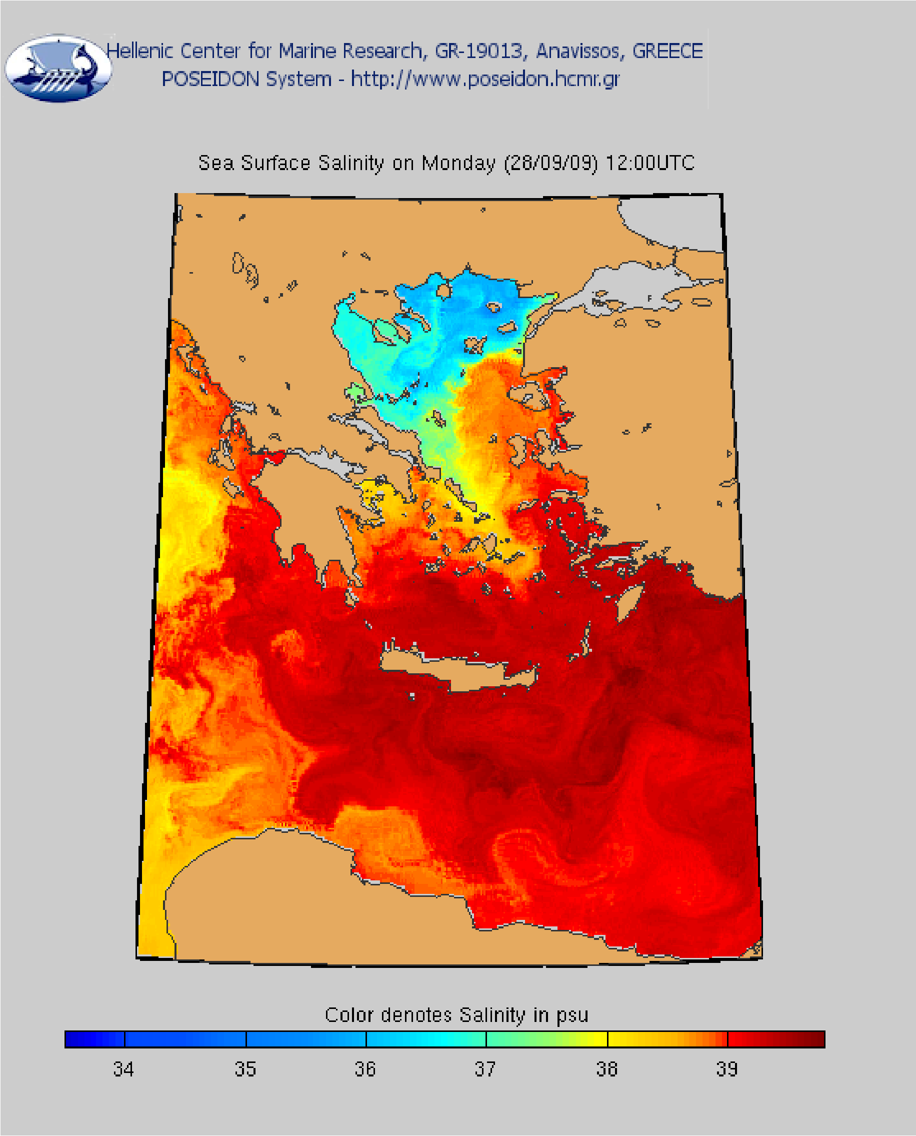
hcmr
Hellenic Center for Marine Research, GR-19013, Anavissos, GREECE
POSEIDON System - http://www.poseidon.hcmr.gr
Sea Surface temperature on Friday (21/09/18) 06:00UTC
Color denotes Temperature in °C
20
21
22
23
24
25
26
27
28
29
30

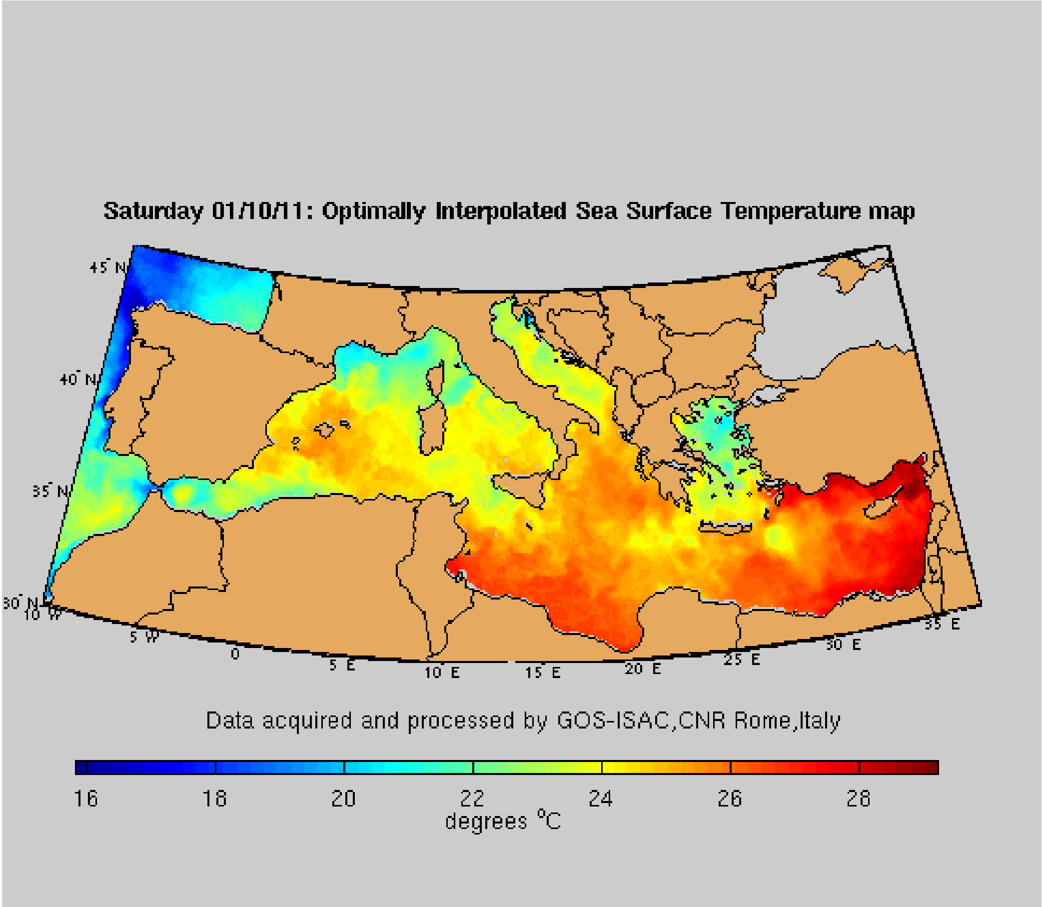


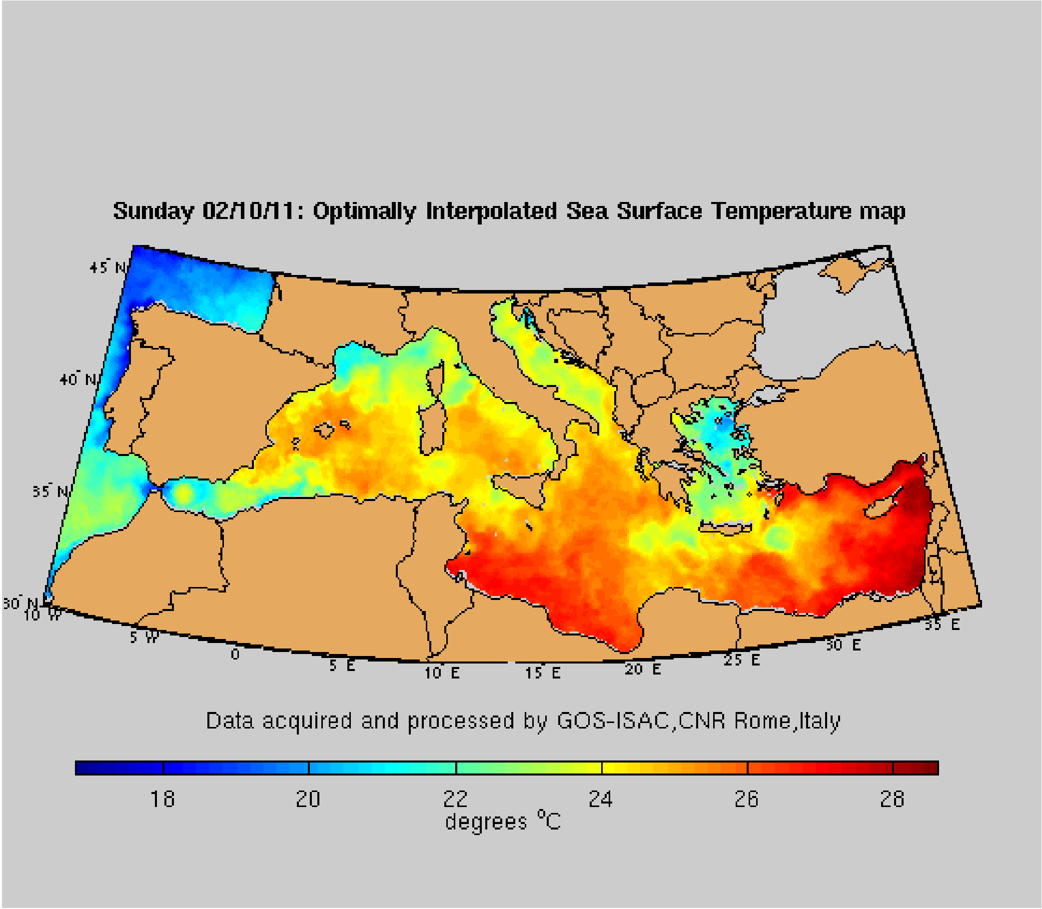
hcmr
Hellenic Center for Marine Research, GR-19013, Anavissos, GREECE
POSEIDON System - http://www.poseidon.hcmr.gr
Sea Surface temperature on Saturday (22/09/18) 06:00UTC
Color denotes Temperature in °C
20
21
22
23
24
25
26
27
28
29
30

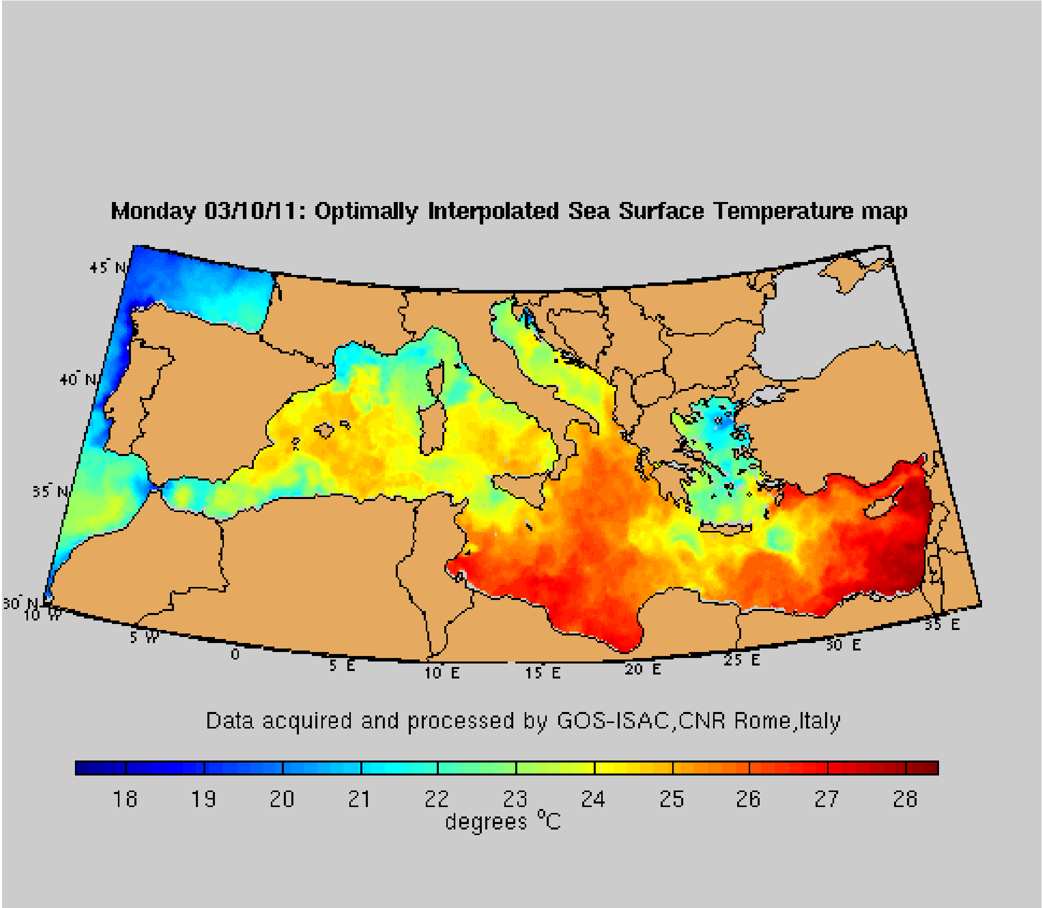

hcmr
Hellenic Center for Marine Research, GR-19013, Anavissos, GREECE
POSEIDON System - http://www.poseidon.hcmr.gr
Sea Surface temperature on Sunday (23/09/18) 06:00UTC
Color denotes Temperature in °C
20 21 22 23 24 25 26 27 28 29 30

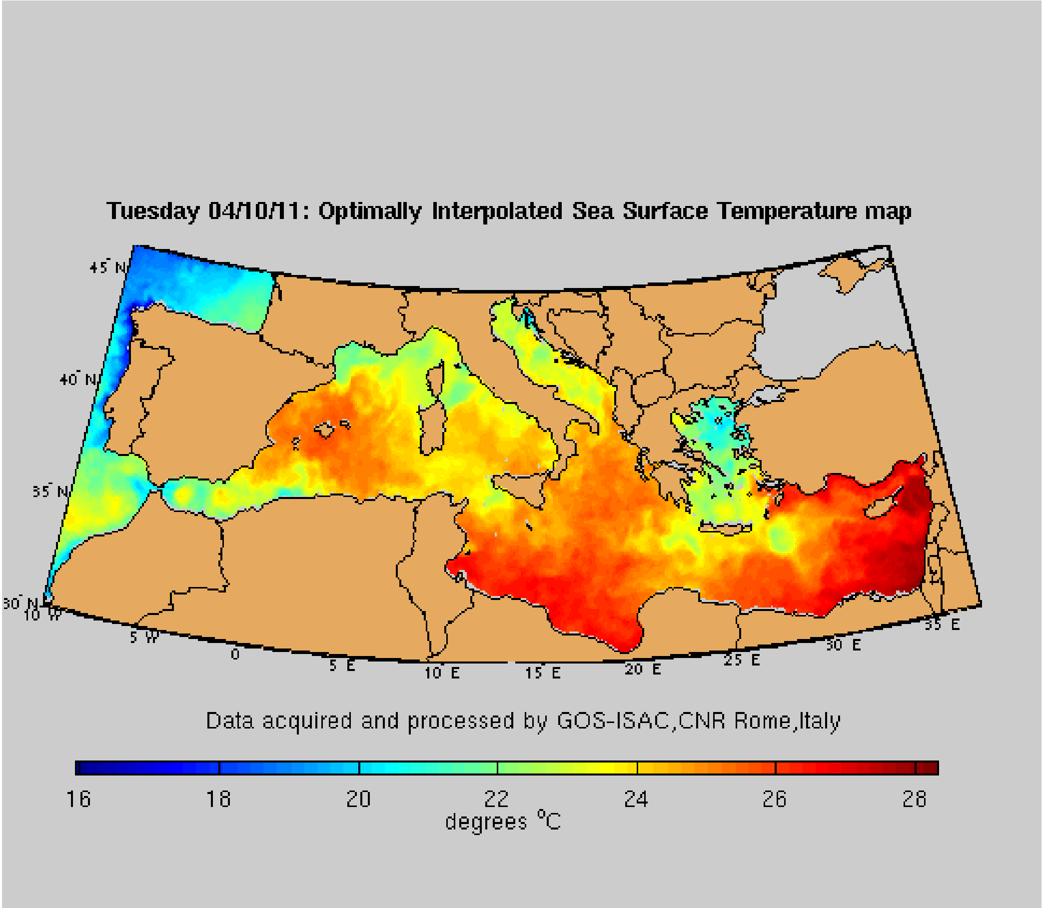

Hellenic Center for Marine Research, GR-19013, Anavissos, GREECE
POSEIDON System - http://www.poseidon.hcmr.gr
hcmr
Sea Surface temperature on Monday (24/09/18) 06:00UTC
Color denotes Temperature in °C
20
21
22
23
24
25
26
27
28
29
30

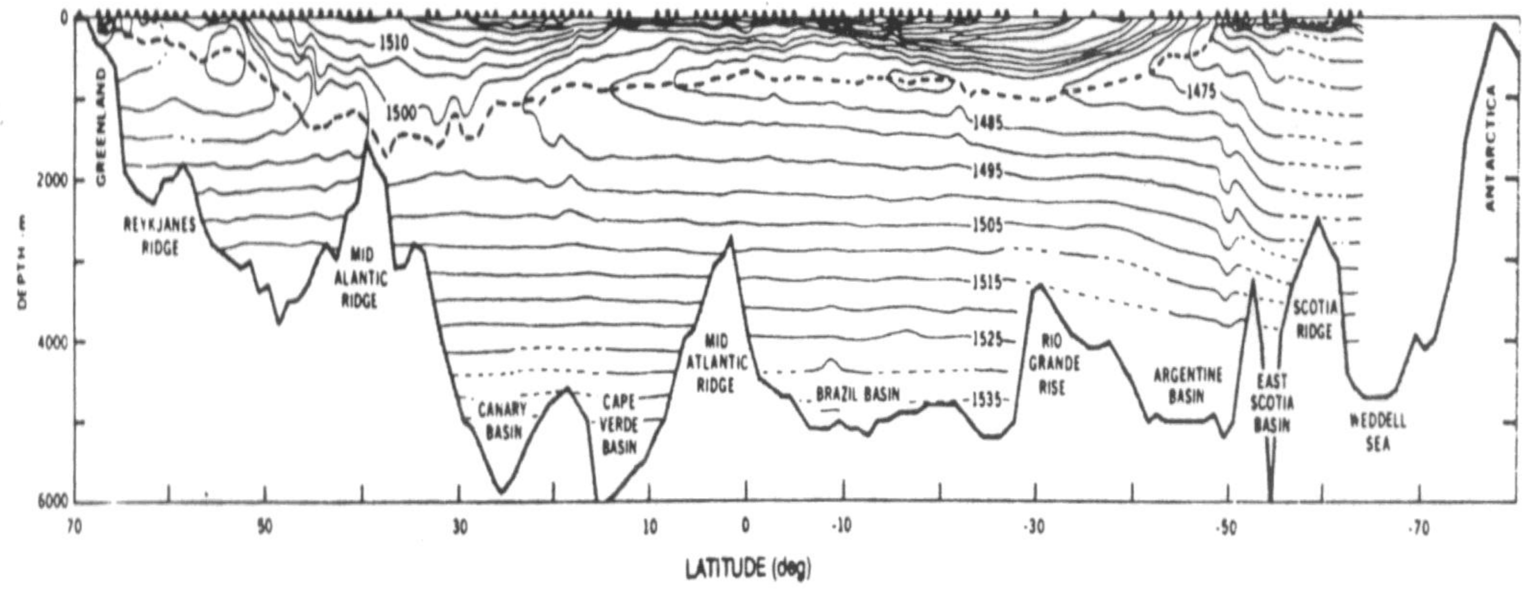

Hellenic Center for Marine Research, GR-19013, Anavissos, GREECE
POSEIDON System - http://www.poseidon.hcmr.gr
Sea Surface Salinity on Monday (28/09/09) 12:00UTC
Color denotes Salinity in psu
34
35
36
37
38
39

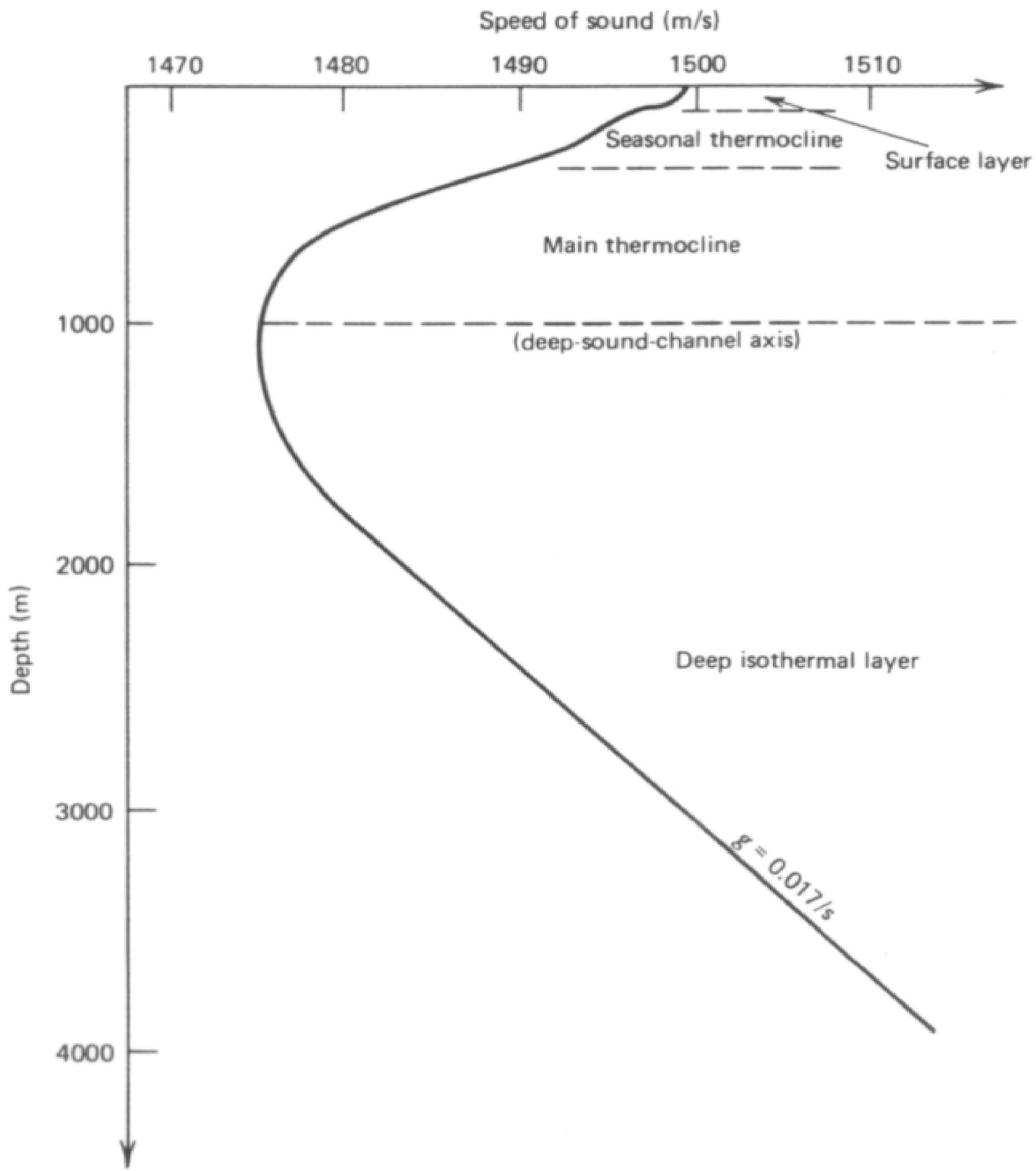

Saturday 01/10/11: Optimally Interpolated Sea Surface Temperature map
45 N
40 N
35 N
30 N
10 W
5 W
0
5 E
10 E
15 E
20 E
25 E
30 E
35 E
Data acquired and processed by GOS-ISAC,CNR Rome,Italy
16
18
20
22
24
26
28
degrees °C


Sunday 02/10/11: Optimally Interpolated Sea Surface Temperature map
45 N
40 N
35 N
30 N
10 W
5 W
0
5 E
10 E
15 E
20 E
25 E
30 E
35 E
Data acquired and processed by GOS-ISAC,CNR Rome,Italy
18
20
22
24
26
28
degrees °C

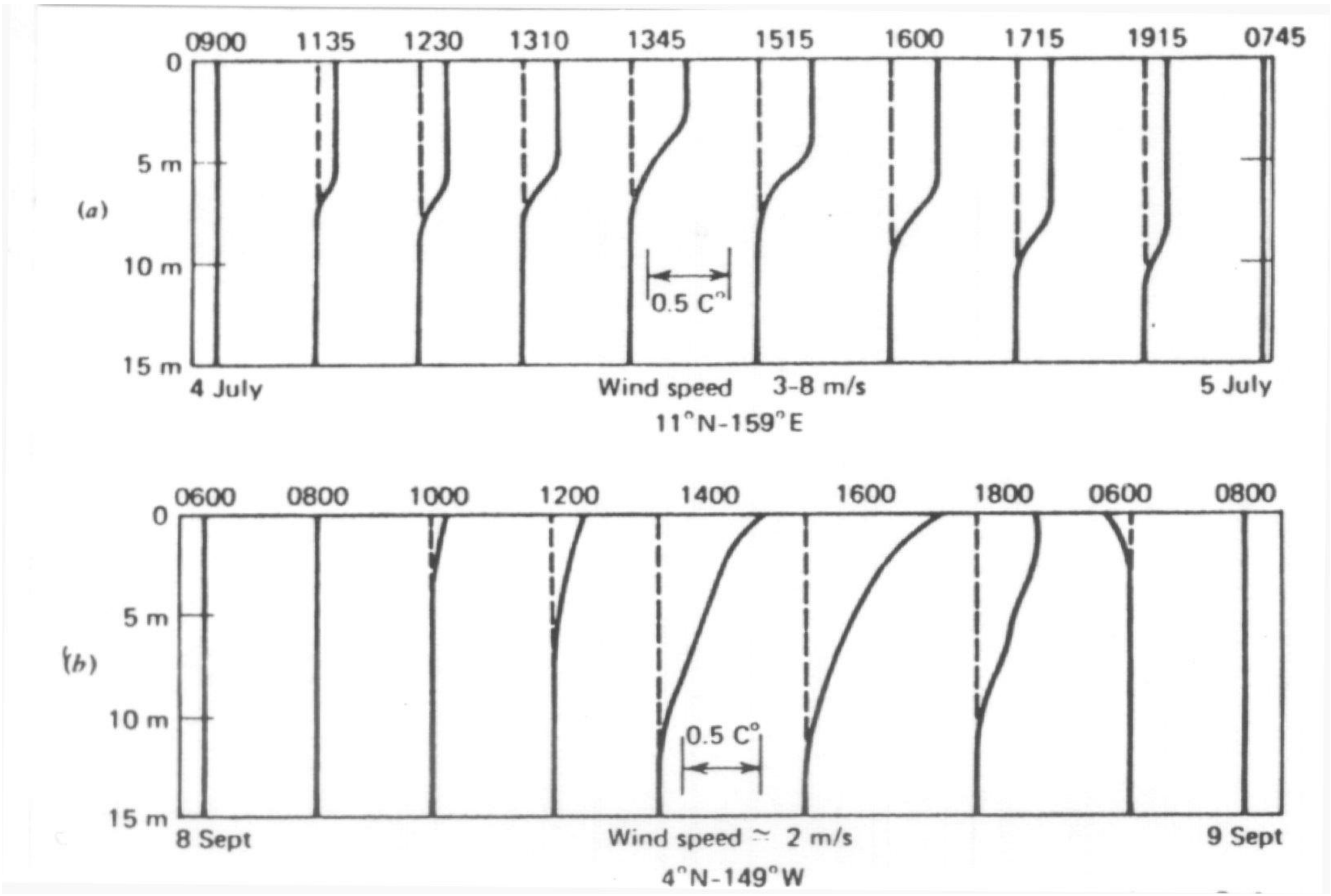

Monday 03/10/11: Optimally Interpolated Sea Surface Temperature map
45° N
40° N
35° N
30° N
10° W
5° W
0
5° E
10° E
15° E
20° E
25° E
30° E
35° E
Data acquired and processed by GOS-ISAC,CNR Rome,Italy
18
19
20
21
22
23
24
25
26
27
28
degrees °C


Tuesday 04/10/11: Optimally Interpolated Sea Surface Temperature map
45° N
40° N
35° N
30° N
10° W
5° W
0
5° E
10° E
15° E
20° E
25° E
30° E
35° E
Data acquired and processed by GOS-ISAC,CNR Rome,Italy
16
18
20
22
24
26
28
degrees °C


GREENLAND
REYKJANES RIDGE
MID ALANTIC RIDGE
CANARY BASIN
CAPE VERDE BASIN
MID ATLANTIC RIDGE
BRAZIL BASIN
RIO GRANDE RISE
ARGENTINE BASIN
EAST SCOTIA BASIN
SCOTIA RIDGE
WEDDELL SEA
ANTARCTICA
1510
1500
1475
1485
1495
1505
1515
1525
1535
DEPTH m
0
2000
4000
6000
70
50
30
10
0
-10
-30
-50
-70
LATITUDE (deg)



Speed of sound (m/s)
1470
1480
1490
1500
1510
Seasonal thermocline
Surface layer
Main thermocline
1000
(deep-sound-channel axis)
2000
Depth (m)
Deep isothermal layer
3000
g = 0.017/s
4000


0900
1135
1230
1310
1345
1515
1600
1715
1915
0745
0
5 m
(a)
10 m
15 m
0.5 C°
4 July
Wind speed 3-8 m/s
5 July
11°N-159°E
0600
0800
1000
1200
1400
1600
1800
0600
0800
0
5 m
(b)
10 m
15 m
0.5 C°
8 Sept
Wind speed ≃ 2 m/s
9 Sept
4°N-149°W

Κύματα Επιφανείας (Βαρύτητας και Επιφανειακής τάσης)

$$c = \sqrt{\frac{g}{k}}$$

όπου g είναι η επιτάχυνση της βαρύτητας = 9.8 m/s² και
k είναι ο «αριθμός κύματος» οριζόμενος ως

$$k = \omega / c$$

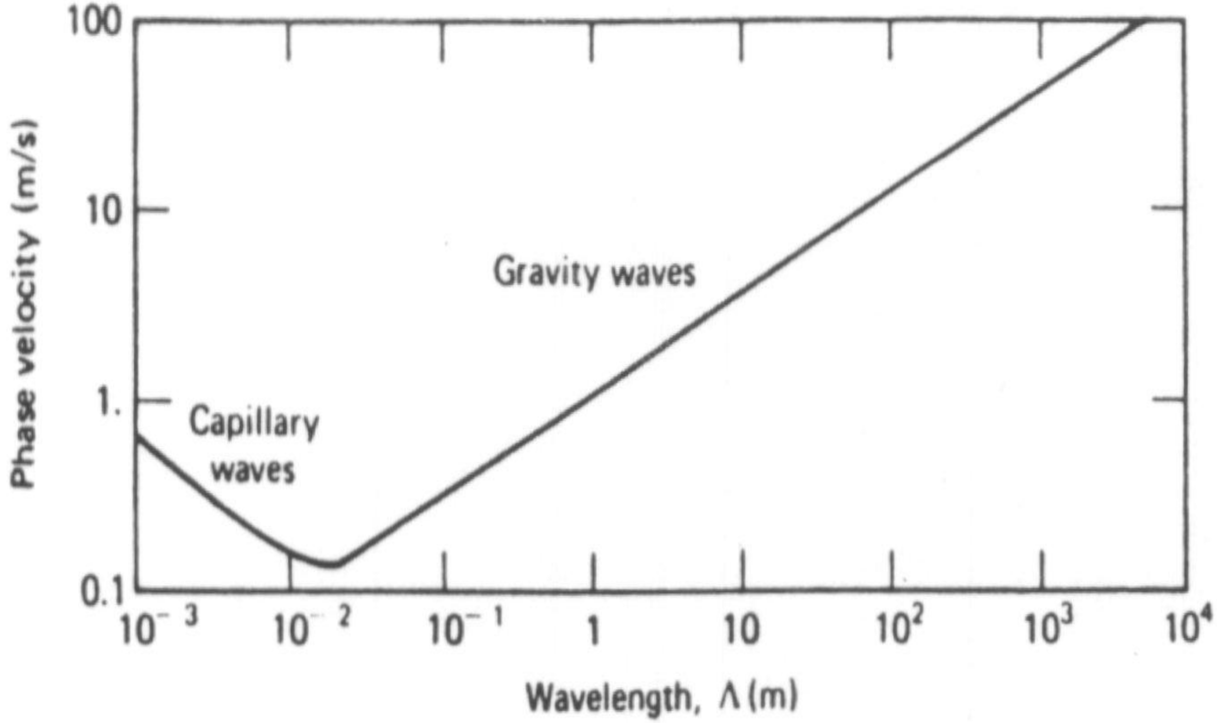
όπου ω είναι η κυκλική συχνότητα ($\omega = 2\pi f$)
f είναι η συχνότητα σε Hz

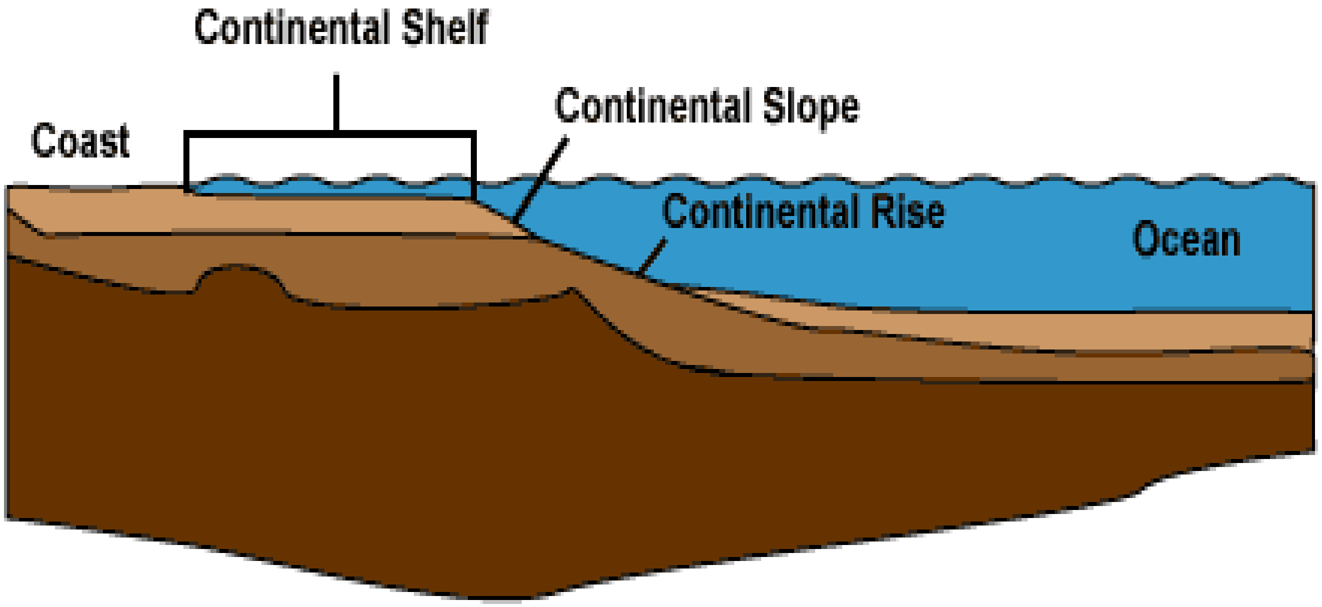
Στην περίπτωση που θεωρηθεί και η επιφανειακή τάση στον κυματισμό τότε η φασική ταχύτητα δίδεται από την σχέση

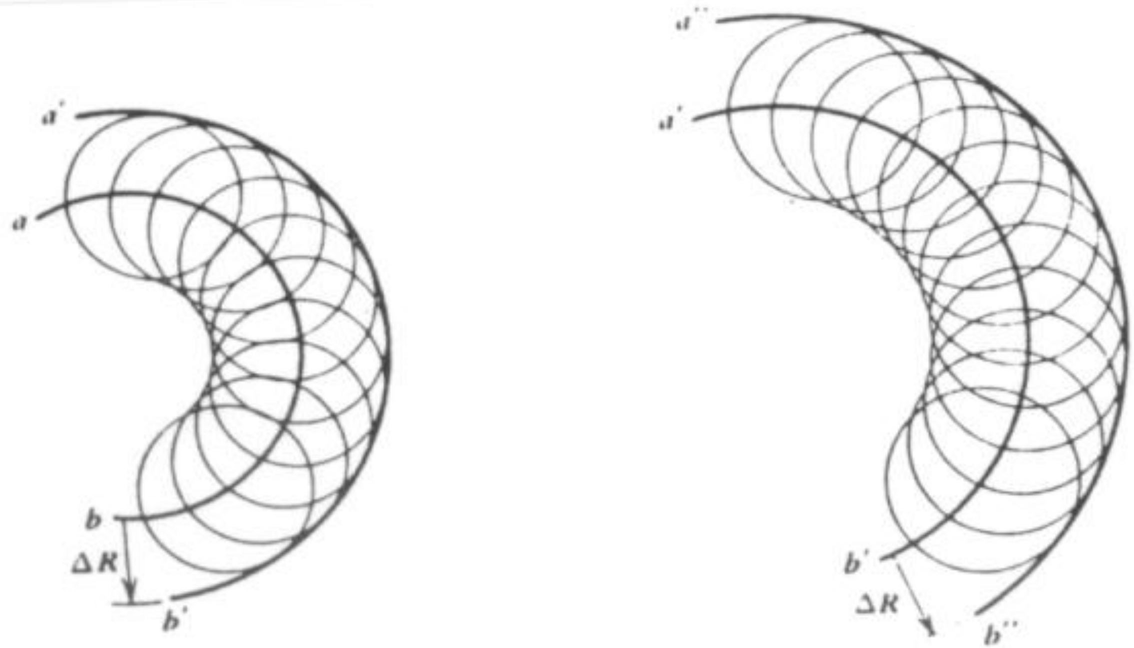
$$c = \sqrt{\frac{g}{k} + \frac{\sigma k}{\rho}}$$

όπου

σ είναι η επιφανειακή τάση (τυπική τιμή 7.4×10^{-2} N/m) και
ρ είναι η πυκνότητα του νερού (kg/m^3).


100
10
1.
0.1
Phase velocity (m/s)
Capillary waves
Gravity waves
10⁻³ 10⁻² 10⁻¹ 1 10 10² 10³ 10⁴
Wavelength, Λ (m)


Continental Shelf
Coast
Continental Slope
Continental Rise
Ocean

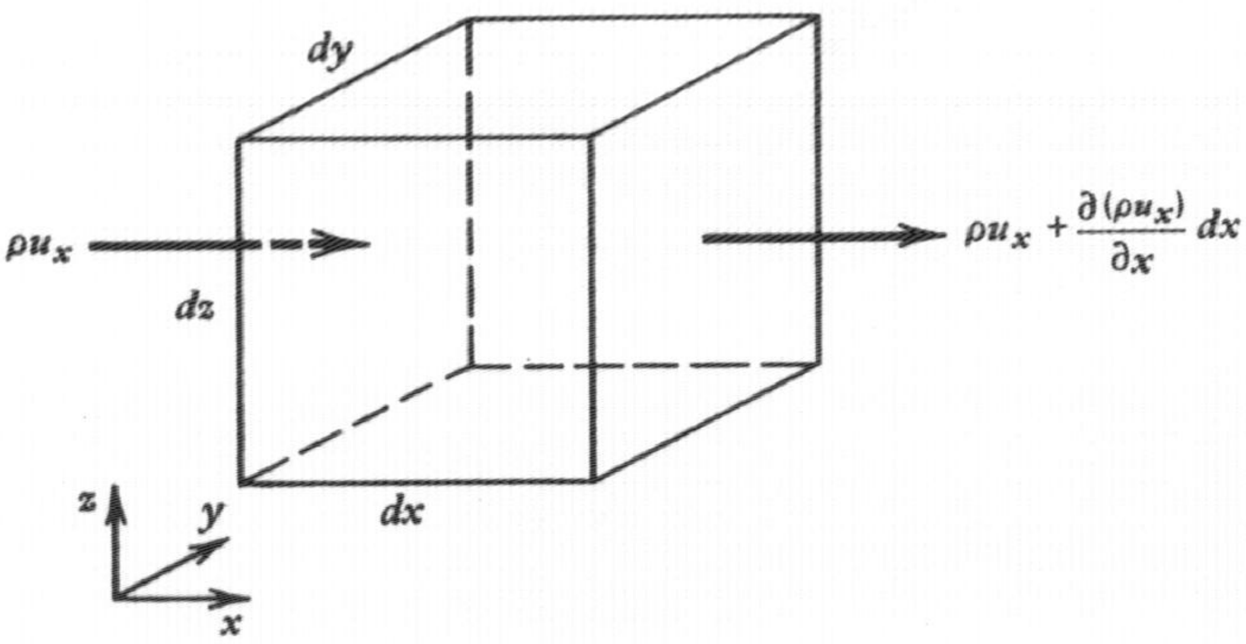

a'
a
b
ΔR
b'
a''
a'
b'
ΔR
b''

$$p = p(\vec{x}, t)$$

$$\rho = \rho(\vec{x}, t)$$

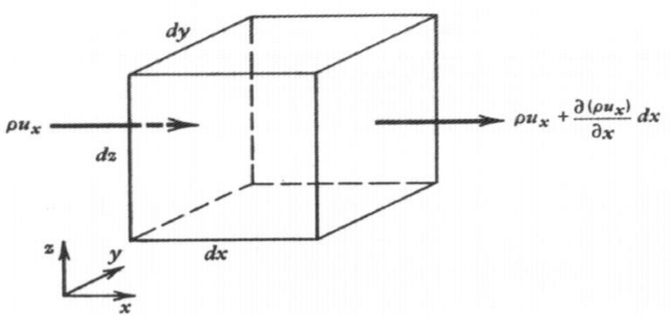
$$\vec{u} = \vec{u}(\vec{x}, t)$$

Ο ρυθμός ροής του υγρού δια μέσου του όγκου πρέπει να είναι ίσος με το ρυθμό αύξησης ή μείωσης της μάζας του ρευστού.



$$\{\rho u_x - [\rho u_x + \frac{\partial(\rho u_x)}{\partial x} dx]\} dy dz = -\frac{\partial(\rho u_x)}{\partial x} dV$$

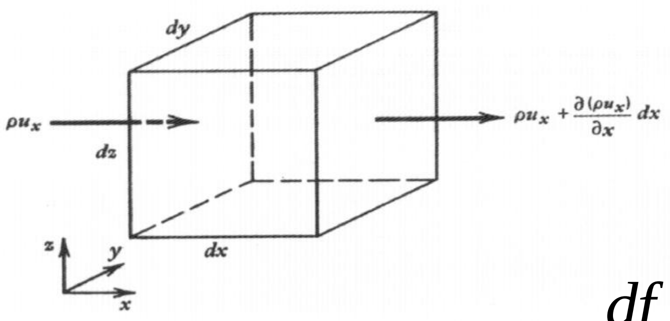
$$-[\frac{\partial(\rho u_x)}{\partial x} + \frac{\partial(\rho u_y)}{\partial y} + \frac{\partial(\rho u_z)}{\partial z}] dV = -[\nabla \cdot (\rho \vec{u})] dV$$



$$\frac{\partial \rho}{\partial t} dV.$$ Μεταβολή μάζας στη μονάδα του χρόνου

$$-[\nabla \cdot (\rho \vec{u})] = \frac{\partial \rho}{\partial t}$$

Εξίσωση συνέχειας



$$d\vec{f} = \vec{a}dm$$

$$df_x = [p - (p + \frac{\partial p}{\partial x}dx)]dydz = -\frac{\partial p}{\partial x}dV$$

$$d\vec{f} = -\nabla p dV$$

$$\vec{a}(x,y,z,t) = \lim_{dt \to 0} \frac{\vec{u}(x+u_x dt, y+u_y dt, z+u_z dt, t+dt) - \vec{u}(x,y,z,t)}{dt}$$

$$\vec{u} = (x+u_x dt, y+u_y dt, z+u_z dt, t+dt) =$$

$$\vec{u}(x,y,z,t) + \frac{\partial \vec{u}}{\partial t}dt + \frac{\partial \vec{u}}{\partial x}u_x dt + \frac{\partial \vec{u}}{\partial y}u_y dt + \frac{\partial \vec{u}}{\partial z}u_z dt$$

$$\vec{a}dm = -\nabla p dV$$

$$\vec{a} = \frac{\partial \vec{u}}{\partial t} + \frac{\partial \vec{u}}{\partial x}u_x + \frac{\partial \vec{u}}{\partial y}u_y + \frac{\partial \vec{u}}{\partial z}u_z$$

$$\vec{a} = \frac{\partial \vec{u}}{\partial t} + (\vec{u} \cdot \nabla)\vec{u} \qquad dm = \rho dV$$

$$-\nabla p = \rho\{\frac{\partial \vec{u}}{\partial t} + (\vec{u} \cdot \nabla)\vec{u}\}$$

Εξίσωση Euler

$$p = g(\rho)$$

Καταστατική Εξίσωση

$$\rho = \rho_0(\vec{x},t) + \varepsilon\rho_1(\vec{x},t)$$

$$p = p_0(\vec{x},t) + \varepsilon p_1(\vec{x},t)$$

$$\vec{u} = \vec{u}_0(\vec{x},t) + \varepsilon\vec{u}_1(\vec{x},t)$$

Εξισ. Συνέχειας

$$\frac{\partial(\rho_0 + \varepsilon\rho_1)}{\partial t} + \nabla \cdot \{(\rho_0 + \varepsilon\rho_1)(\vec{u}_0 + \varepsilon\vec{u}_1)\} = 0$$

$$\frac{\partial\rho_0}{\partial t} + \nabla \cdot \{\rho_0\vec{u}_0\} = 0$$

$$\frac{\partial\rho_1}{\partial t} + \nabla \cdot \{\rho_0\vec{u}_1 + \rho_1\vec{u}_0\} = 0$$

Εξισ. Συνέχειας $$\frac{\partial \rho_1}{\partial t} + \nabla \cdot \{\rho_0 \vec{u}_1\} = 0$$

Εξίσωση Euler $$-\nabla p_1 = \rho_0 \frac{\partial \vec{u}_1}{\partial t}$$

Καταστατική $$p_1 = \frac{\partial p_0}{\partial \rho_0} \rho_1$$

$$-\nabla^2 p_1 = \nabla \cdot (\rho_0 \frac{\partial \vec{u}_1}{\partial t})$$

$$\frac{\partial^2 \rho_1}{\partial t^2} + \nabla \cdot (\rho_0 \frac{\partial \vec{u}_1}{\partial t}) = 0$$

$$\Rightarrow \quad -\nabla^2 p_1 = -\frac{\partial^2 \rho_1}{\partial t^2}$$

Υποθέτουμε ότι $\vec{u}_0 = 0$

$$\rho_1 = p_1 \frac{1}{\dfrac{\partial p_0}{\partial \rho_0}}$$

$$\frac{\partial p_0}{\partial \rho_0} \equiv c^2$$

Θερμοδυναμικός Ορισμός Ταχύτητας

$$\nabla^2 p_1 = \frac{1}{c^2} \frac{\partial^2 p_1}{\partial t^2}$$

Κυματική Εξίσωση

$$\nabla^2 p_1 = \frac{1}{c^2}\frac{\partial^2 p_1}{\partial t^2}$$

$$p_1(\vec{x},t) = \overline{p}(\vec{x})T(t)$$

$$\overline{p}(\vec{x}) \equiv p(\vec{x})$$

$$T\nabla^2 p = \frac{1}{c^2}\, p\frac{d^2T}{dt^2}$$

$$\frac{c^2}{p}\nabla^2 p = \frac{1}{T}\frac{d^2T}{dt^2}$$

$$\frac{c^2}{p}\nabla^2 p = \frac{1}{T}\frac{d^2T}{dt^2} = -\omega^2$$

$$\nabla^2 p + \frac{\omega^2}{c^2}p = 0$$

$$\frac{d^2T}{dt^2} + \omega^2 T = 0$$

$$T = Ae^{i\omega t} + Be^{-i\omega t} \qquad T = A^{'}\cos(\omega t) + B^{'}\sin(\omega t)$$

$$T = e^{-i\omega t}$$

$$p_1(\vec{x},t) = \overline{p}(\vec{x})T(t)$$

$$p_1(\vec{x},t) = p(\vec{x})e^{-i\omega t}$$

$$\nabla^2 \equiv \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

$$\nabla^2 p + \frac{\omega^2}{c^2} p = 0$$

$$(\frac{\omega}{c})^2 = k^2 = k_x^2 + k_y^2 + k_z^2$$

$$p(x, y, z) = p_x(x) p_y(y) p_z(z)$$

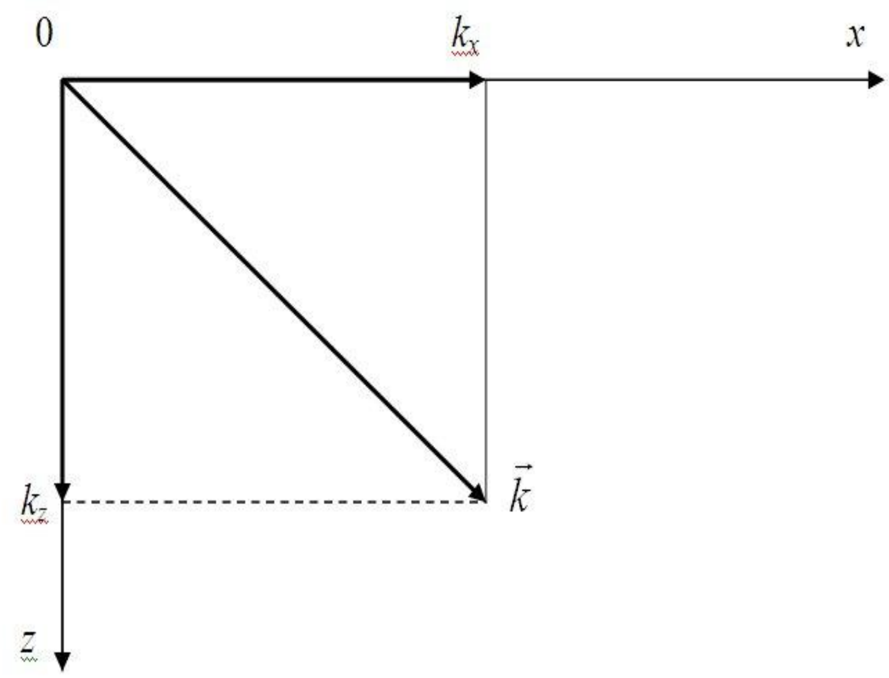
$$\frac{\partial^2 p_x}{\partial x^2} \cdot \frac{1}{p_x} + \frac{\partial^2 p_y}{\partial y^2} \cdot \frac{1}{p_y} + \frac{\partial^2 p_z}{\partial z^2} \cdot \frac{1}{p_z} + k_x^2 + k_y^2 + k_z^2 = 0$$

$$\frac{d^2 p_x}{dx^2} + k_x^2 p_x = 0 \qquad p_x(x) = A_1 e^{ik_x x} + A_2 e^{-ik_x x}$$

$$\frac{d^2 p_y}{dy^2} + k_y^2 p_y = 0 \qquad p_y(x) = B_1 e^{ik_y y} + B_2 e^{-ik_y y}$$

$$\frac{d^2 p_z}{dz^2} + k_z^2 p_z = 0 \qquad p_z(x) = C_1 e^{ik_z z} + C_2 e^{-ik_z z}$$

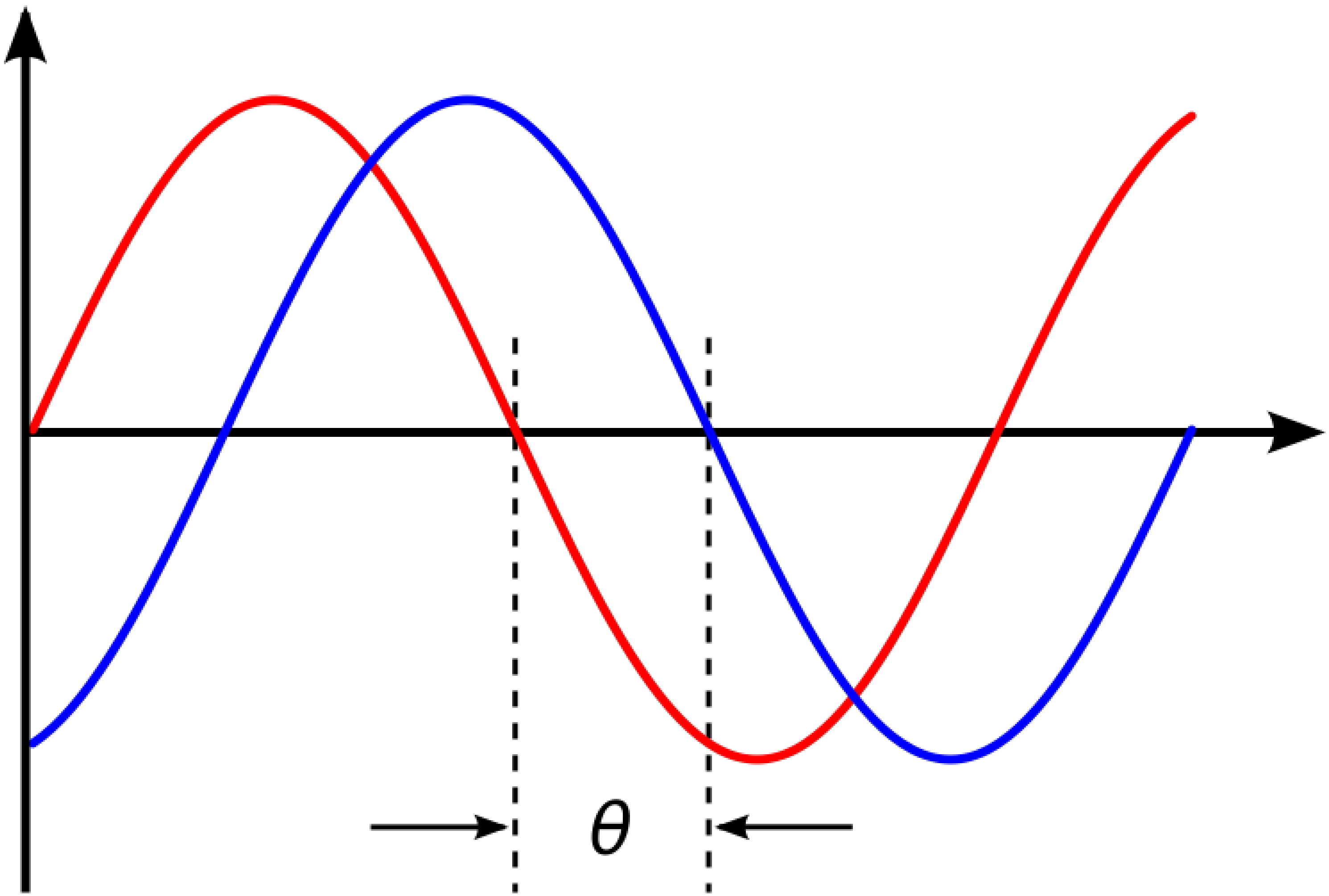
$$p_1(x,t) = p_x(x)e^{-i\omega t} = (A_1 e^{ik_x x} + A_2 e^{-ik_x x})e^{-i\omega t} = A_1 e^{i(k_x x - \omega t)} + A_2 e^{i(-k_x x - \omega t)}$$



$$p_1(x,y,z,t) = A_1 B_1 C_1 e^{i(k_x x + k_y y + k_z z - \omega t)}$$

$$p_1(x,y,z,t) = D e^{i(\vec{k}\cdot\vec{x} - \omega t)}$$

Μέτωπο κύματος : Γεωμετρικός τόπος σημείων σταθερής φάσης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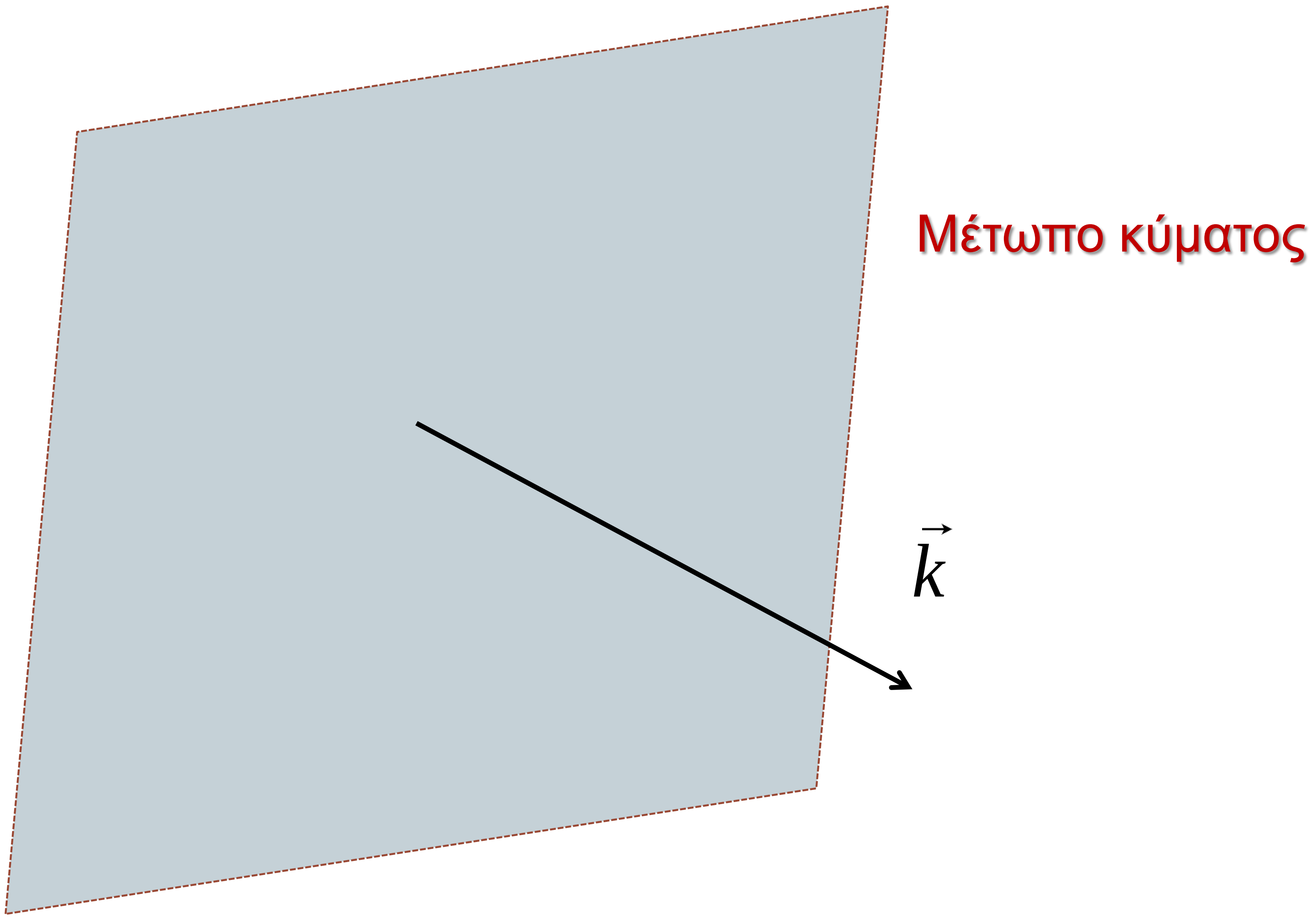
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