Turkish Straits System Joining Seas and Continents: A Grand Challenge for Oceanography

İstanbul, 03 May 2016

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REGION

Seas of the Old World

SYSTEM

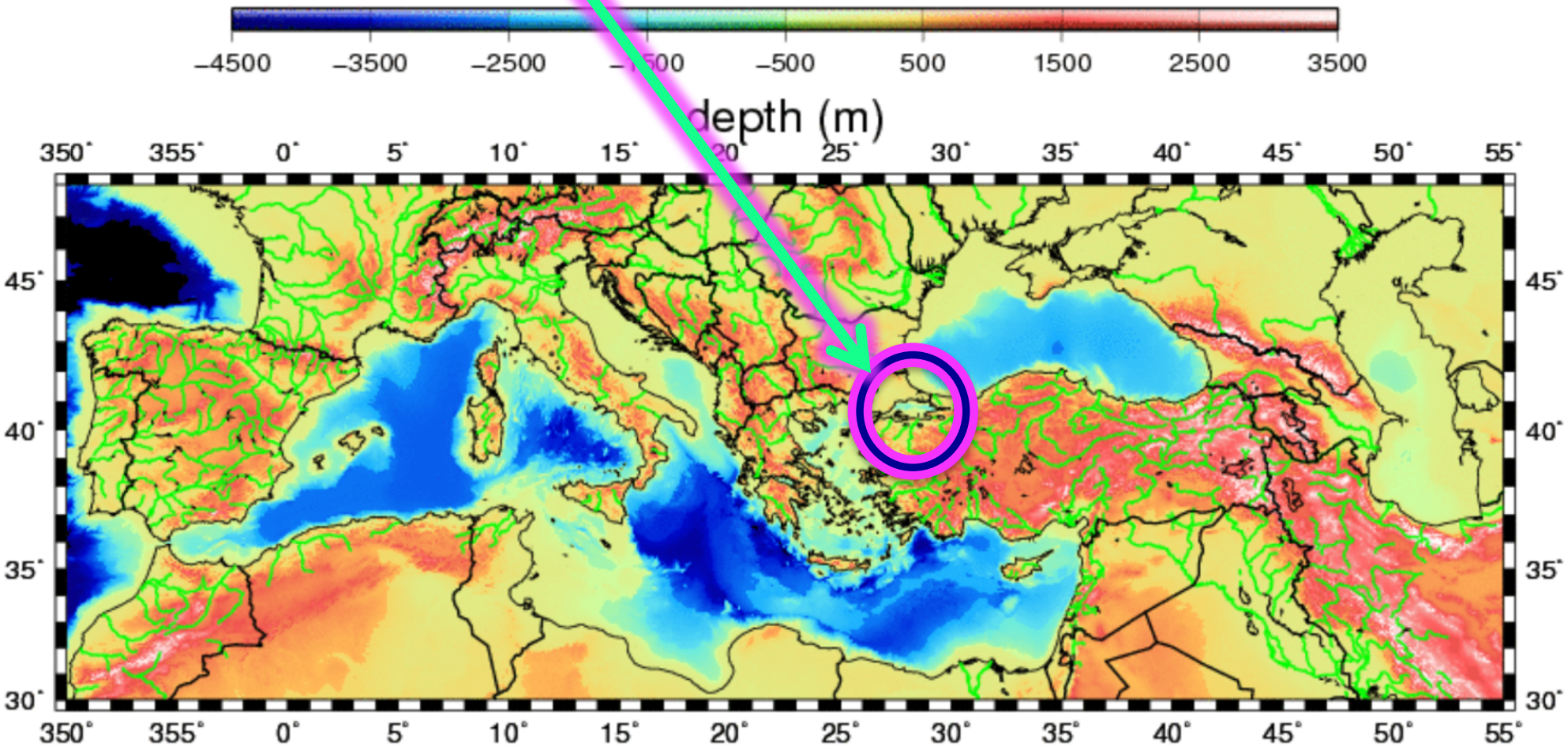
Turkish Straits System

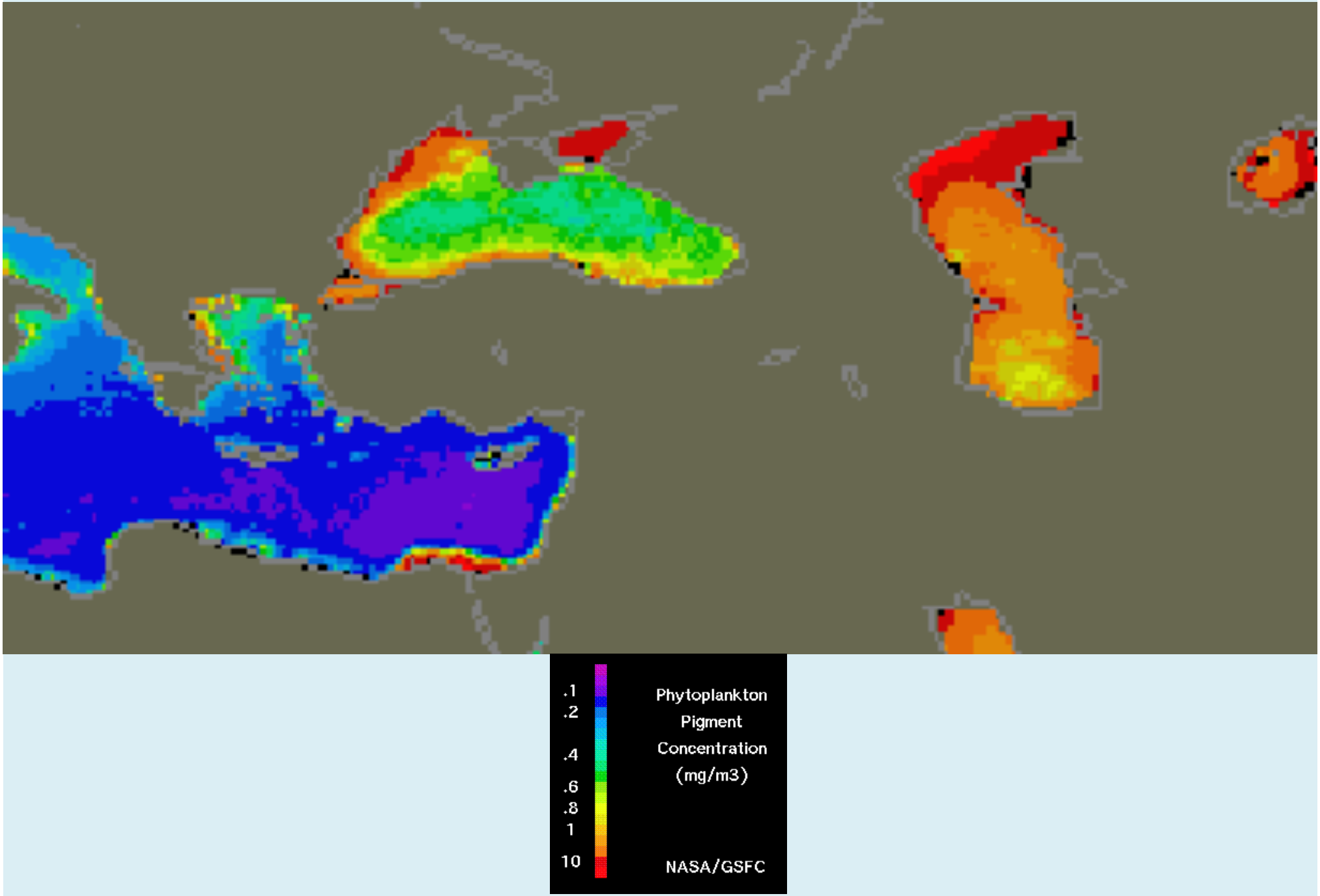
At the center stage of climate change

“Seas of the Old World”

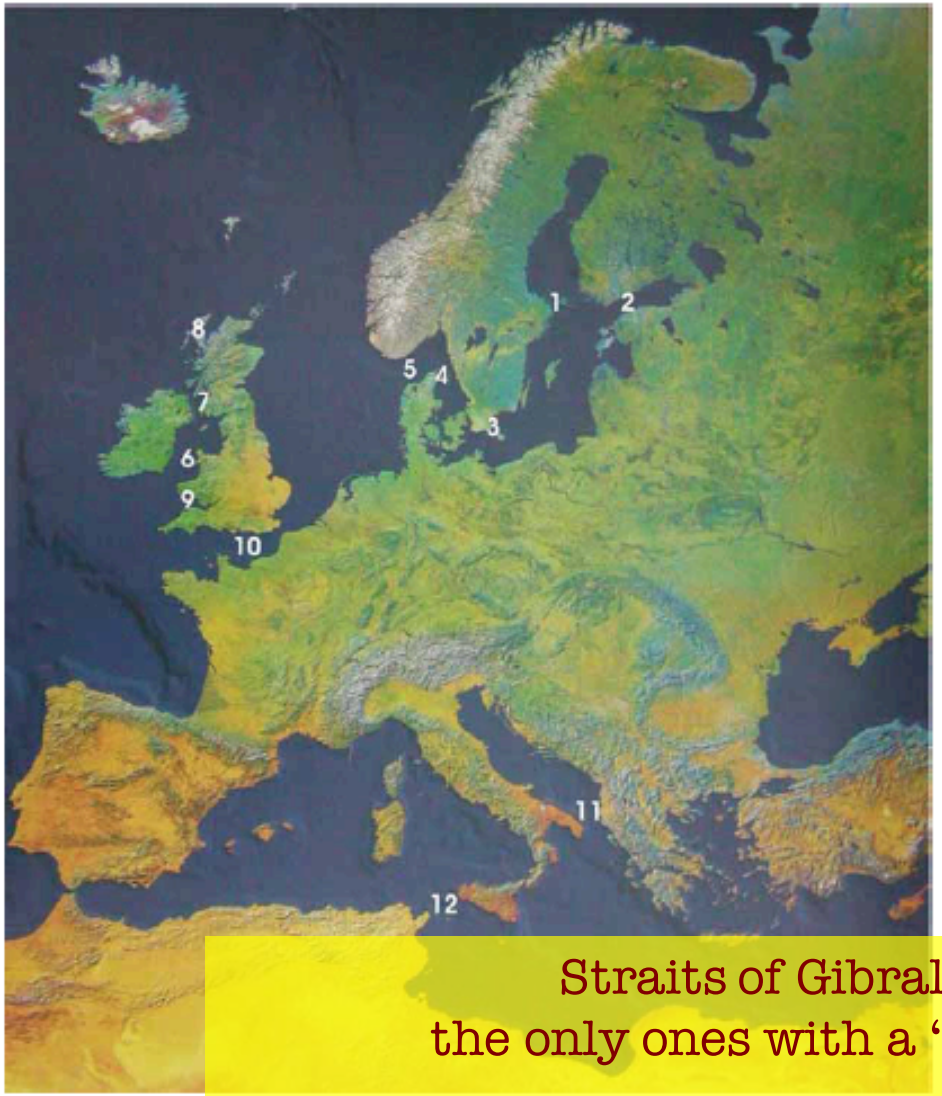
Turkish Straits System

at the center




.1
.2
.4
.6
.8
1
10
Phytoplankton
Pigment
Concentration
(mg/m3)
NASA/GSFC

Wide Straits in Europe *Narrow*



Straits of Gibraltar and Bosphorus are
the only ones with a 'maximal exchange' regime !

Northern Europe
-01- Södra Kvarken (*Finland / Sweden*)
-02- Gulf of Suomenlahti (*Estonia / Finland*)
-03- Bornholm (*Denmark / Sweden*)
-04- Kattegat (*Denmark / Sweden*)
-05- Skagerak (*Denmark / Norway*)
-06- St Georges Channel (*UK / Ireland*)
-07- North Channel (*UK*)
-08- The Minch & Little Minch (*UK*)
-09- Bristol Channel (*UK*)
-10- English Channel (La Manche) (*UK / France*)

Southern Europe
-11- Strait of Otranto (*Albania / Italy*)
-12- Strait of Sicily (*Italy / Tunisia*)

Figure 1a STRAITS, European wide

Northern Europe

-01- Skiftet (*Finland*)
-02- Store Belt & Lille Belt (*Denmark*)
-03- Kalmasund (*Sweden*)
-04- Kadet Rinne (*Denmark / Germany*)
-05- Fehmarnbelt (*Denmark / Germany*)
-06- The Sound (*Denmark / Sweden*)
-07- Strait of Dover (France / *UK*)

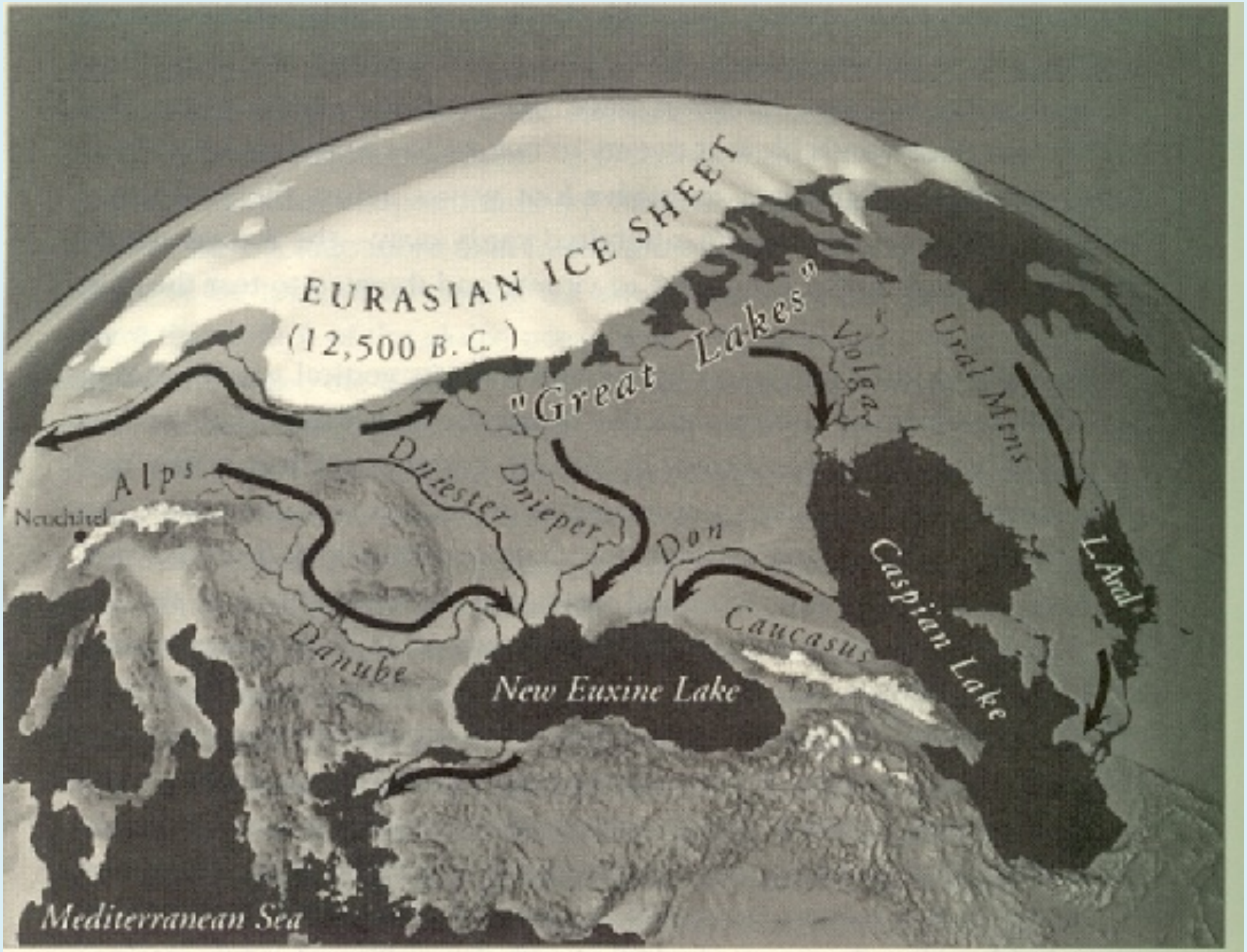
Southern Europe

-08- Strait of Messina (*Italy*)
-09- Strait of Bonifacio (*France / Italy*)
-10- Strait of Gibraltar (*Morocco / Spain*)
-11- Entrance Gulf of Corinth (*Greece*)
-12- TSS Bosporus, Marmara, Dardanelles (*Turkey*)

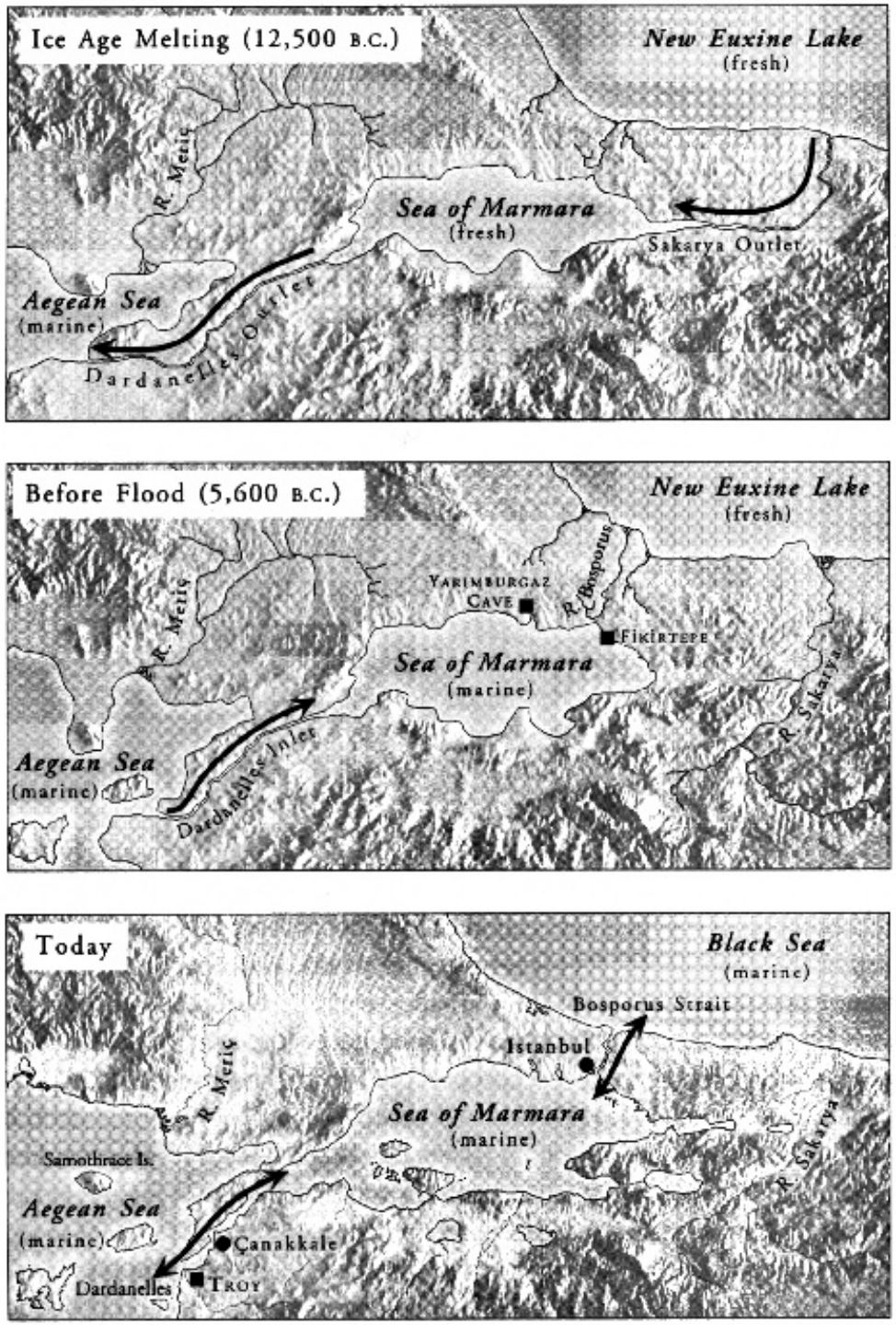
Figure 1b STRAITS, European narrow sea

Black Sea and Eurasian water cycle:
Closed basin fed by continental runoff
balanced by the Turkish Straits System

The Catchment Area - Black Sea Drainage Basin



The path of meltwater delivered from the Eurasian ice sheet beginning around 12,500 B.C.


Ice Age Melting (12,500 B.C.)
New Euxine Lake
(fresh)
R. Meriç
Sea of Marmara
(fresh)
Sakarya Outlet
Aegean Sea
(marine)
Dardanelles Outlet
Before Flood (5,600 B.C.)
New Euxine Lake
(fresh)
Yarımburgaz
Cave
R. Bosporus
Fikirtepe
R. Meriç
Sea of Marmara
(marine)
R. Sakarya
Aegean Sea
(marine)
Dardanelles Inlet
Today
Black Sea
(marine)
Bosporus Strait
Istanbul
R. Meriç
Sea of Marmara
(marine)
R. Sakarya
Samothrace Is.
Aegean Sea
(marine)
Çanakkale
Troy
Dardanelles

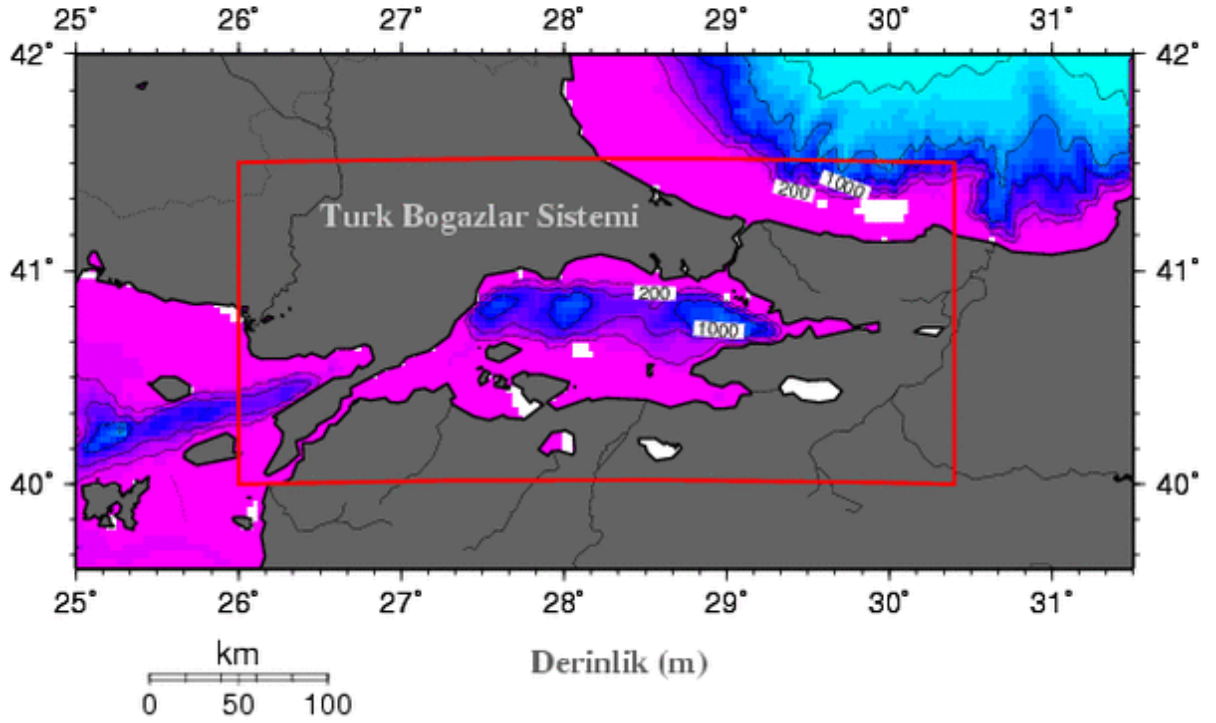
SEA STRAITS

BOSPHORUS AND DARDANELLES STRAITS IN PARTICULAR

Sea straits constitute complex, high-energy physical environments with rapid currents, hydraulic transitions, stratification and turbulence, and are controlled strongly by geometric constraints, often creating complex multi-scale interactions influencing the states of the interconnected basins. A wide range of coupled motions at scales extending from short-term to climatic co-exist and interact in sea straits and their adjacent basins.

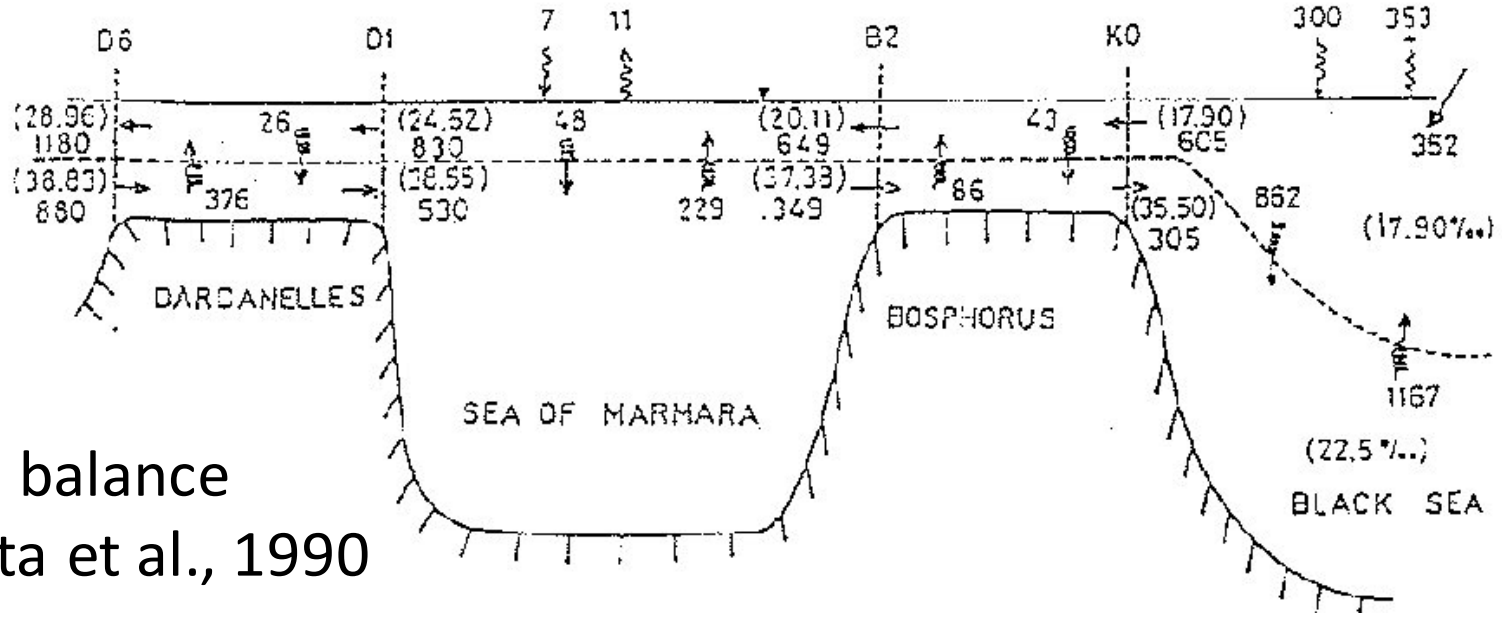
deep bathymetry adjoining wide shelf areas, interconnected by straits, canyons

Economic, Strategic importance



Major traffic route

Oil transport



Water balance
Ünlüata et al., 1990

TURKISH STRAITS SYSTEM

ROLE:
DARDANELLES AND BOSPHORUS STRAITS
AND MARMARA SEA
coupling of Mediterranean and Black Seas

PASSAGEWAY AND CHOKE POINT:
the meeting place of
Mediterranean and Black Sea waters,
land and sea-based traffic,
fault lines, earthquakes, pollution,
migrating fish, birds and people

needs services at the maximum level !

Turkish Straits System
Interaction with adjacent Seas

Forcing from (adjacent basins) :
- sea level
- barometric pressure
- wind setup
- water balance R+P-E

Time scales:
Bosphorus: Transit time < 1/2 day
Dardanelles: Transit time ~ few days
Black Sea: residence time 1-5yr for CIL, >2000yr for bottom
Marmara Sea: residence time 3mo for upper, 6-12yr for lower layer
Mediterranean: residence time ~100 yr
Forcing: < daily - multidecadal

SCIENTIFIC HISTORY

denizbilim'in (oceanography) baharı:

Seyir ve haritacılık'ta gelişmeler:
Cristoforo Colombo - Chios 1474 - Amerika 1492
Isolario – orta çağların coğrafyacı ve gezginleri
Piri Reis 1465 - 1554 – Akdeniz ve Hint Okyanusu seyahatleri
gelgitler ile ay hareketleri ilişkisi - 'Bahriye' – 1526
Galileo (1564-1642) – gelgitleri güneşle ilişkilendiriyor – 1632
Isaac Newton (1642-1727) gelgit - ay ilişkisi / bilimsel teori - 1686
Luigi Ferdinando Marsili (1658-1730) – İstanbul Boğazı'nda ilk bilimsel buluşlar – oşinografi'nin başlangıcı !

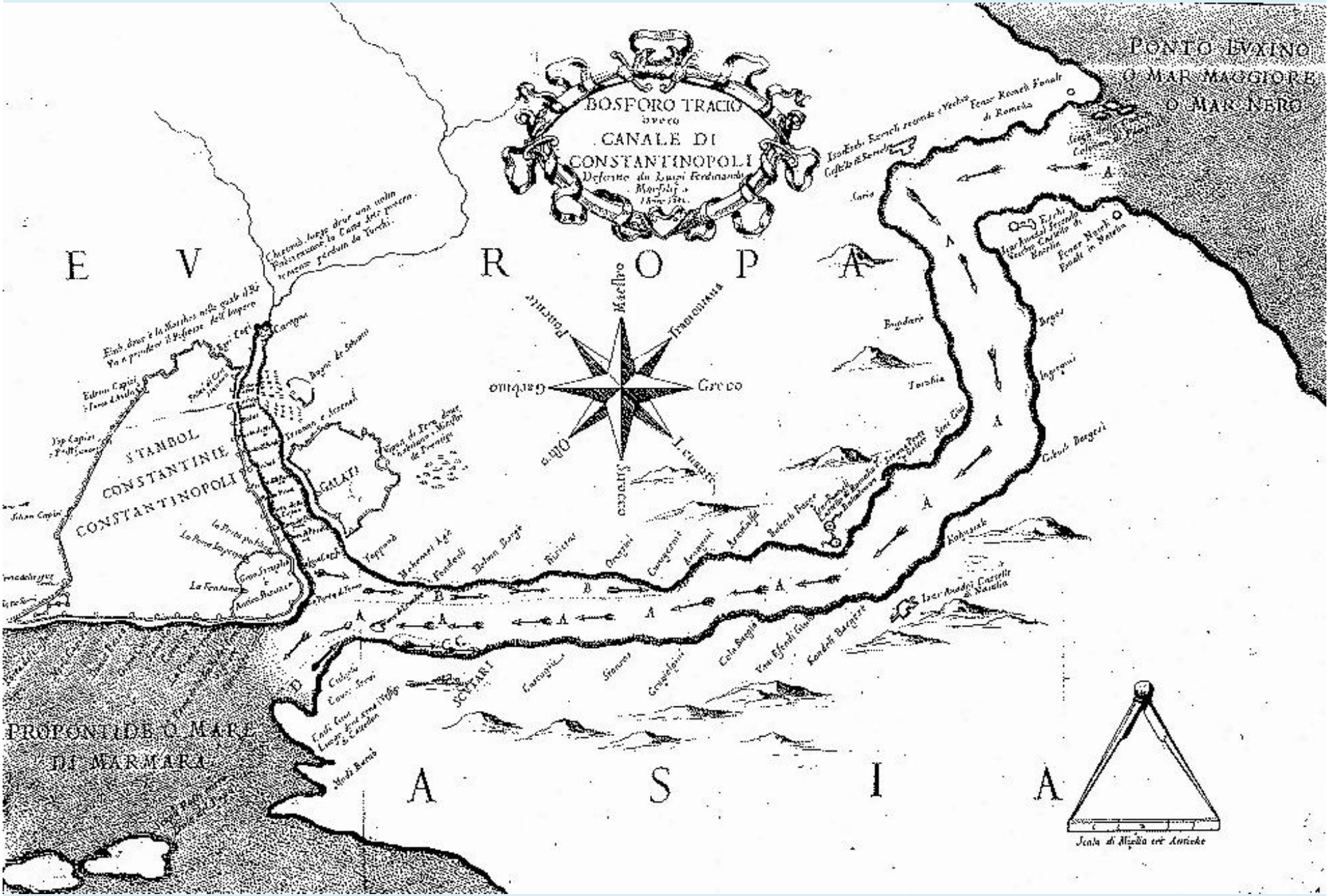
İstanbul Boğazı - Bosphorus:

Luigi Ferdinando Marsili (1658-1730)
Bosphorus - 'Osservazioni intorno al Bosforo Tracio' – 1681

Spratt 1870, Wharton 1872, Makaroff, 1881, Magnaghi 1882,
Gueydon 1886, Spindler 1894, Nielsen 1910, Merz 1917,
Möller 1928
Ulyott, Ilgaz, Pektaş 1943-1956
Defant 1961, Carruthers 1963, Özturgut 1964, Bogdanova 1961

OSSERVAZIONI
INTORNO
AL
BOSFORO TRACIO
OVERO
CANALE DI CONSTANTINOPOLI
Rappresentate in Lettera
ALLA SACRA REAL MAESTA
DI
CRISTINA
REGINA DI SVEZIA
DA
LVIGI FERDINANDO
MARSILII.

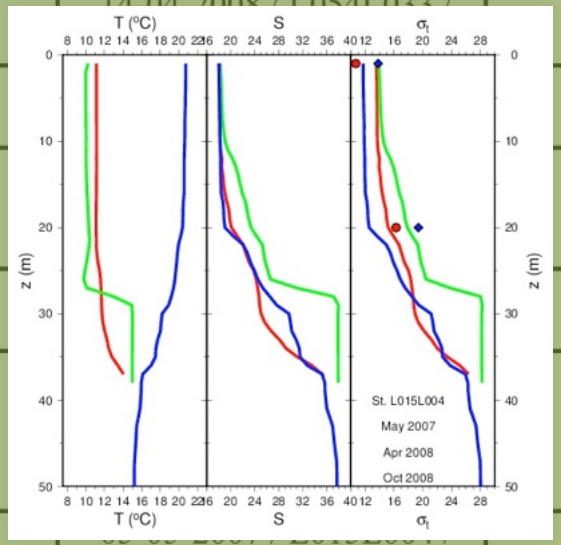
In Roma, Per Nicolò Angelo Tinassi 1681.
Con Licenza de' Superiori.


BOSFORO TRACIO
ovvero
CANALE DI
CONSTANTINOPOLI
Descritto da Luigi Ferdinando
Marsigli
EVROPA
PONTO EVXINO
O MAR MAGGIORE
O MAR NERO
STAMBOL
CONSTANTINIE
CONSTANTINOPOLI
GALATI
PROPONTIDE O MARE
DI MARMARA
ASIA
Scala di Miglia ore Antiche

L. F. Marsili

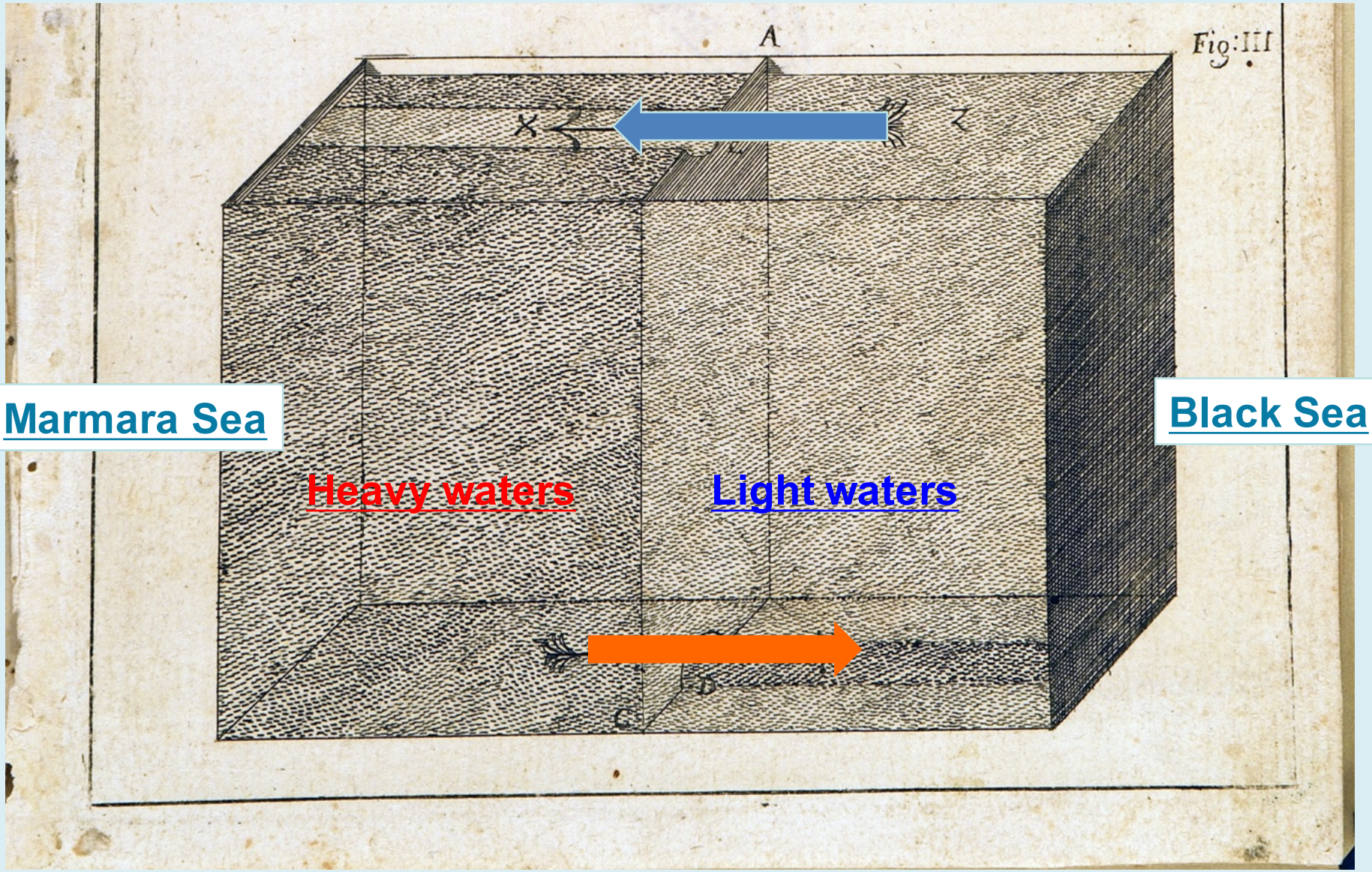
Denizsuyu yoğunluk ölçümleri

Name of Location (A)	Station date (B)	Weight of rings (C)	Best reconstructed (D)	Date / station of observation / coordinates of R/V BİLİM (SESAME)	Present day density (E)
area : as in Marsili (1681) : current	dd-mm-yyyy	[grains]	[kg m^{-3}]	dd-mm-yyyy / station number / latitude - longitude	[kg m^{-3}]
1. Aegean: entran of "Smirne" : İzm		5.5	1027.3		1028.6
2. Aegean: "Lem from "Dardanelli" Lemnos		1.5	1025.1	01-10-2008 / J57I011 / 3957.002,N,02601.190,E	1022.7
3. Dardanelles: "S "Abido" : Nara Pa		1.5	1019.5	01-10-2008 / K125I262 / 4012.466,N,02626.405,E	1017.4
4. Sea of Marmara Marmara Ereğlisi		69	1018.1	03-10-2008 / L00K03 / 4059.995,N,02803.011,E	1016.6
5. Bosphorus: "toppana" : Tophane (cannon foundry) north of the Golden Horn	22-02-1680	64.5	1015.6	14-04-2008 / L015L004 / 4101.717,N,02900.601,E	1013.5
6. Bosphorus: "castello nuoi" : Rumelihisarı	02-02-1680	64.5	1015.6	14-04-2008 / L054L033 /	1013.9
7. Golden Horn : Bosphorus: "terzana" : Tersane (shipyard)	10-04-1680	46.75	1005.6		-
8. Golden Horn : "Caragaz": "kara ağız ?" (Kağıthane stream mouth)	10-04-1680	58.125	1012.1		-
9. Golden Horn : "Caragaz" (after rain)	10-04-1680	54.05	1009.8		-
10: Bosphorus: "due Fanali alla bocca del Mar Nero" : Fener (lighthouses) section at Black Sea entrance of Bosphorus	04-08-1680	56.25	1011.0		1011.7
11. Bosphorus: "Bisectas" : Beşiktaş (surface)	28-06-1680	61.75	1013.8	4101.717,N,02900.601,E	1013.0
12. Bosphorus: Beşiktaş (deep)	28-06-1680	71.75	1019.4	"	1014.3



Rameli Hissari
Zingir Tasci
Saat
Romilio
Vilio castello
Vilio castello
novo castello
Cingir Tas
Oerke Tasci
Fener Burnu
Carbace Limani
CARA DEN.
MARE
Carbacie Burnu
Fener Anatoli
Poiraz Limani
Rameli Hissari
Zingir Tasci
Saat
Dibindan acar.
i.e. A fundo fluit
i.e. mola è regione promo.
(distans) Sesqui

Roma'da ilk laboratuvar deneyi (1681)



L. F. Marsili 1658 – 1730

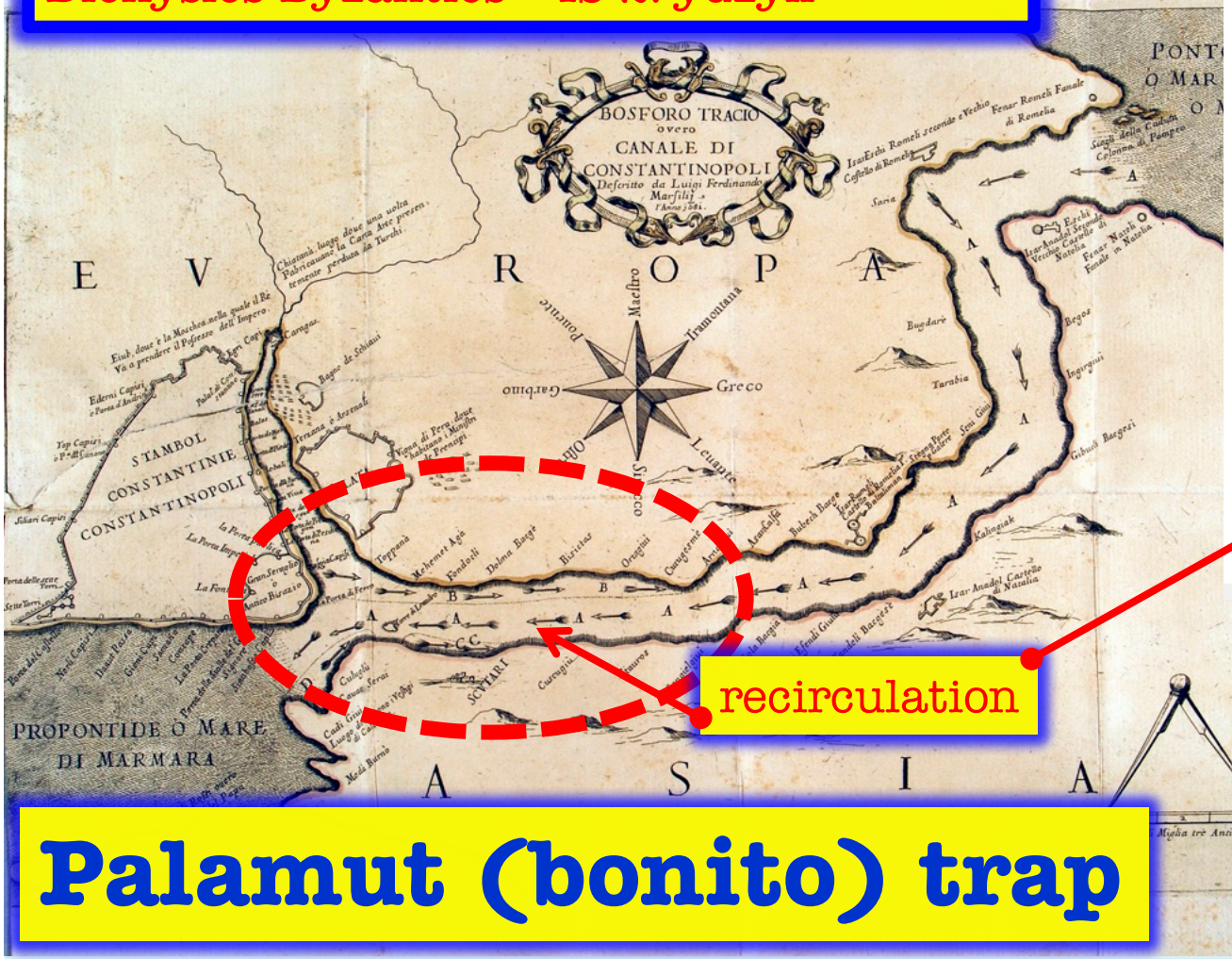
Marsili, L. F. (1681).
Osservazioni Intorno al Bosforo Tracio overo Canale di Constantinopoli

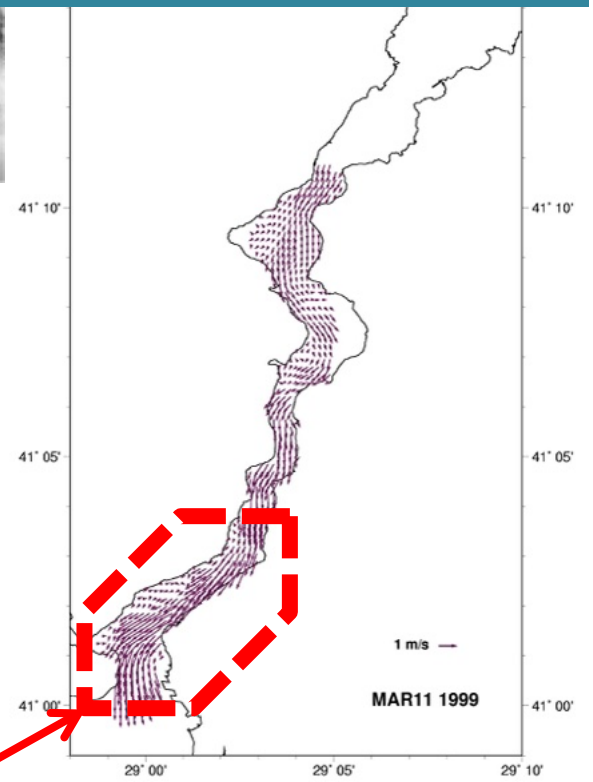
Keras – Haliç – Golden Horn

Petri Gyllii (1561). *De Bosporo Thracio*

Dionysios Byzantios - İS 2. yüzyıl

İstanbul'da binyıllar süren İmparatorlukların Ekonomik dayanağı !





recirculation

Palamut (bonito) trap

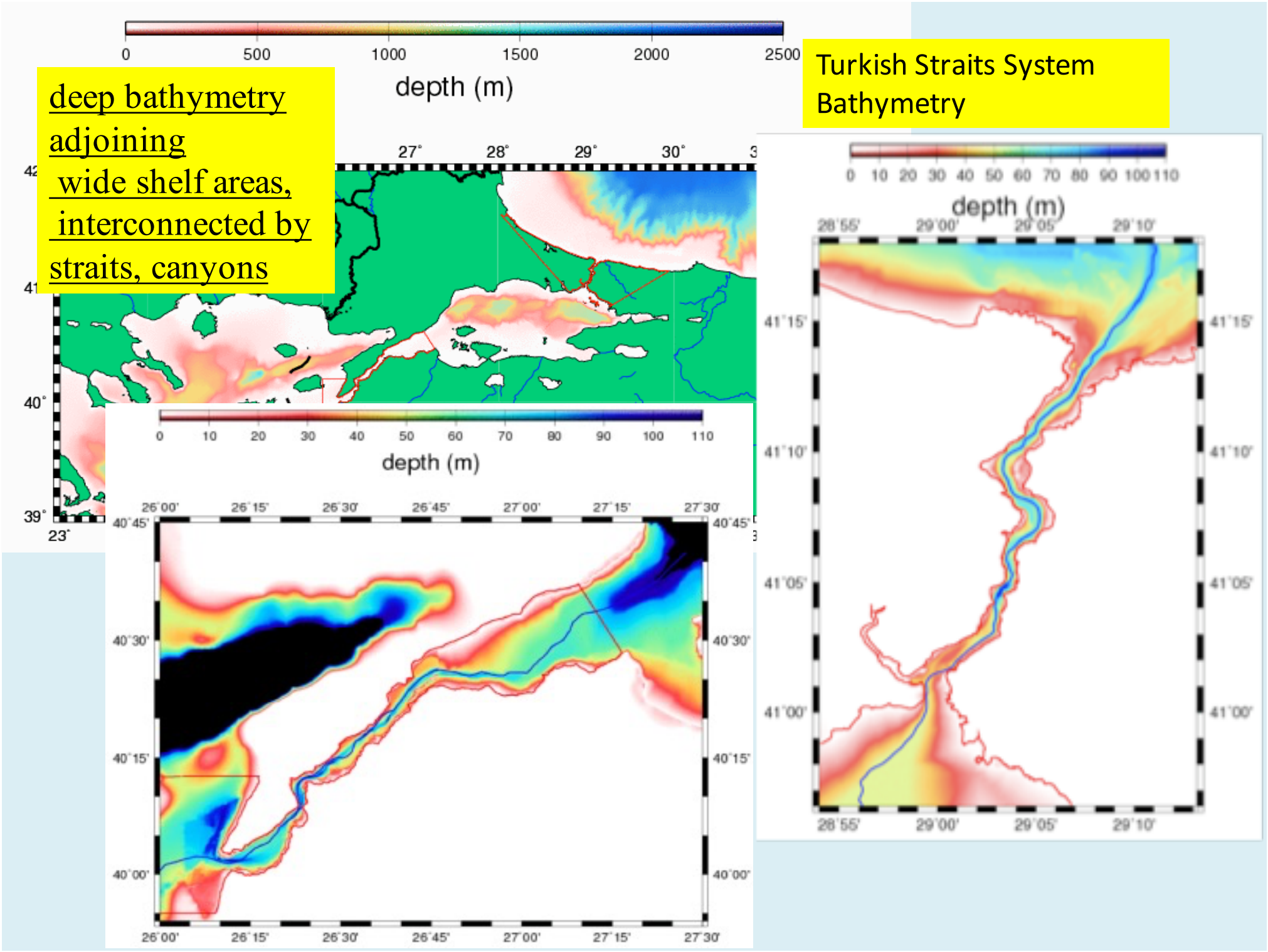
Bosphorus surface currents

ADCP measurements

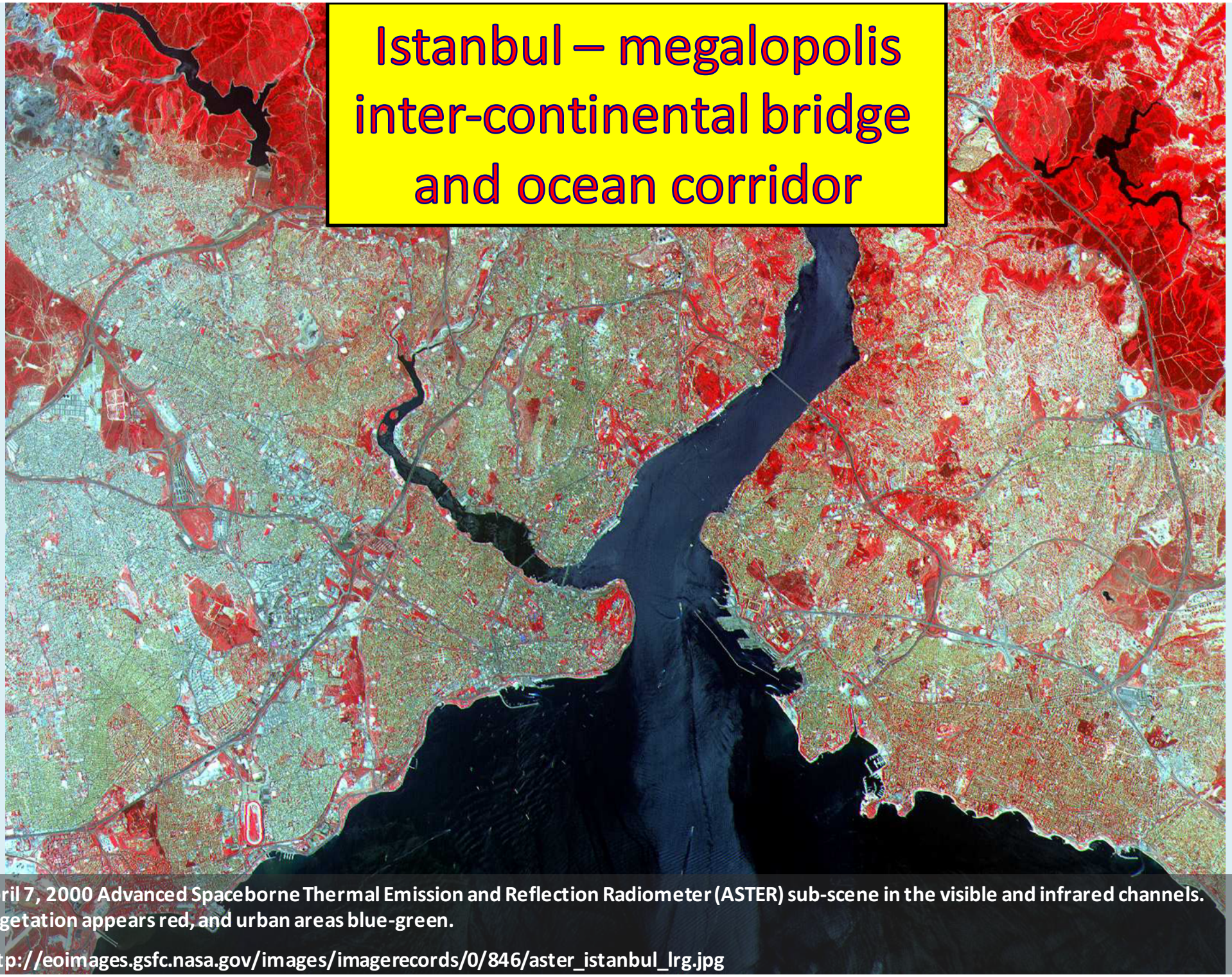
ODTÜ-DBE, 1999

Turkish Straits System
Türk Boğazlar Sistemi

System Properties
and
Risks

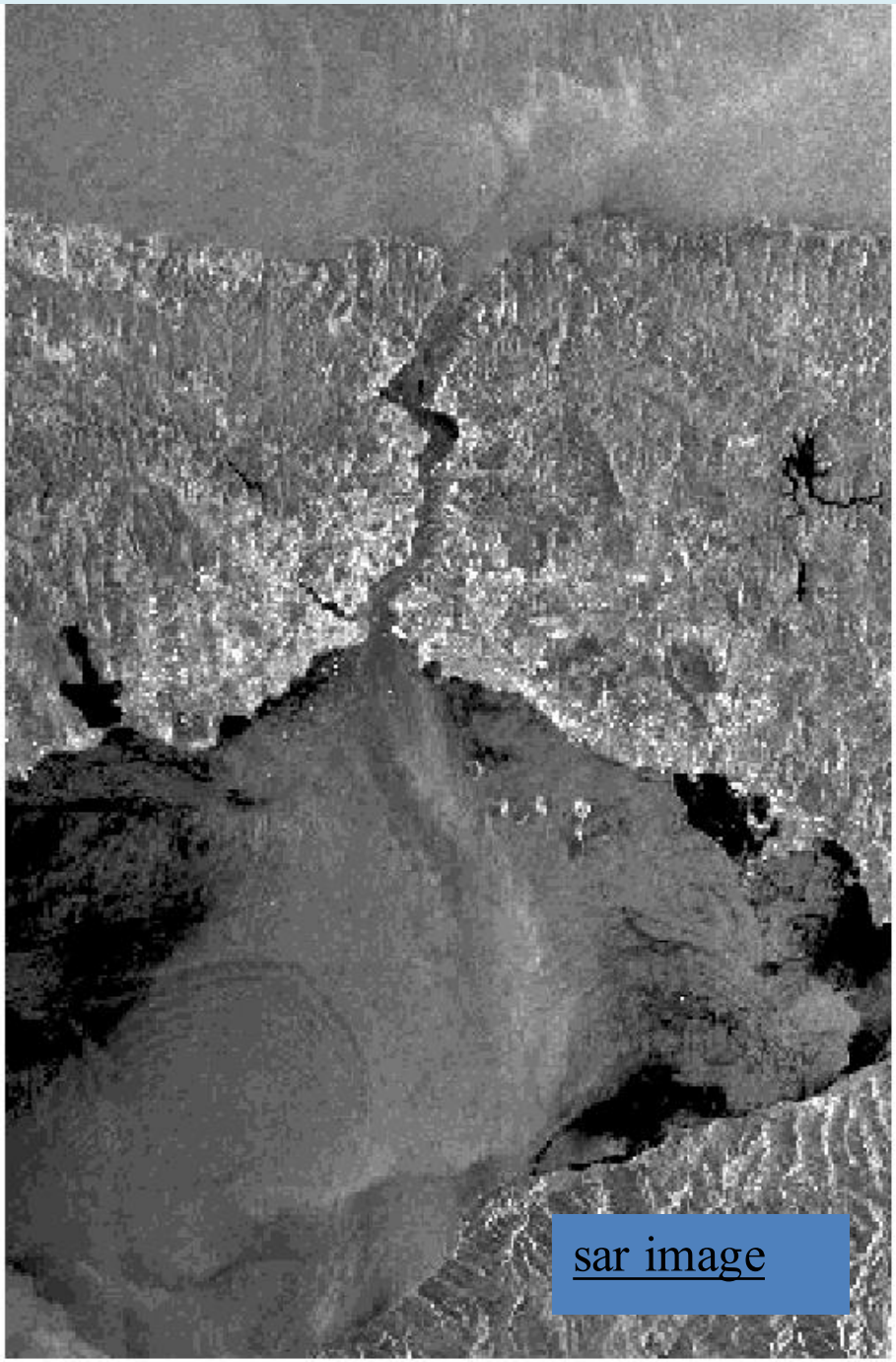

0 500 1000 1500 2000 2500
depth (m)
deep bathymetry adjoining wide shelf areas, interconnected by straits, canyons
Turkish Straits System Bathymetry
27° 28° 29° 30°
42
41
40°
39°
23°
0 10 20 30 40 50 60 70 80 90 100 110
depth (m)
26°00' 26°15' 26°30' 26°45' 27°00' 27°15' 27°30'
40°45'
40°30'
40°15'
40°00'
0 10 20 30 40 50 60 70 80 90 100 110
depth (m)
28°55' 29°00' 29°05' 29°10'
41°15'
41°10'
41°05'
41°00'

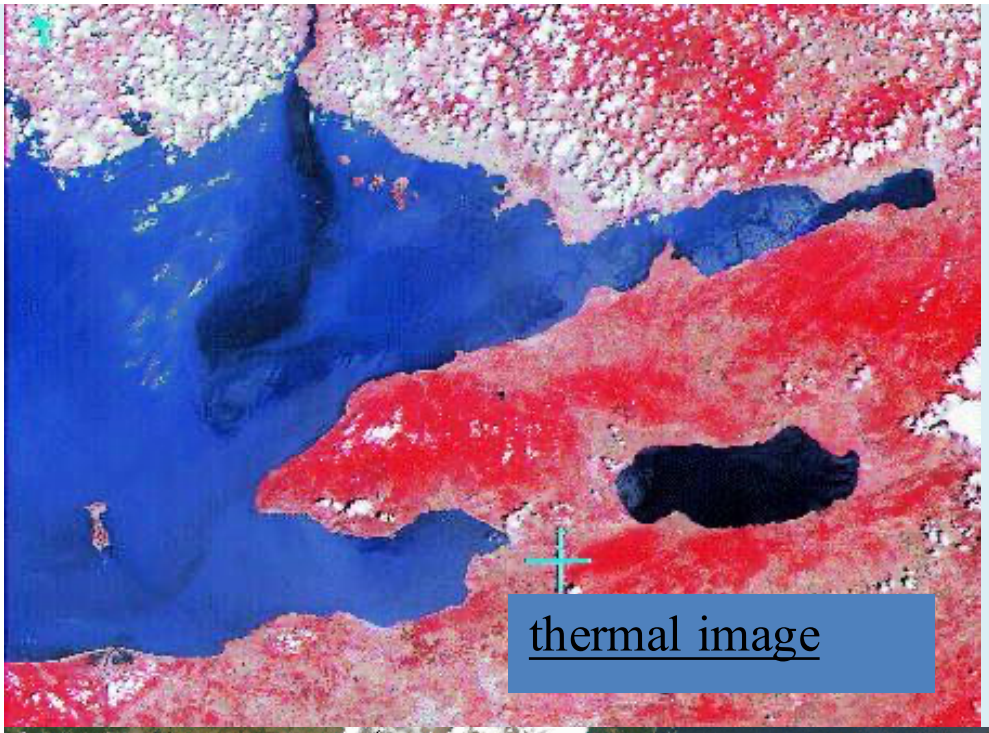
Istanbul – megalopolis inter-continental bridge and ocean corridor

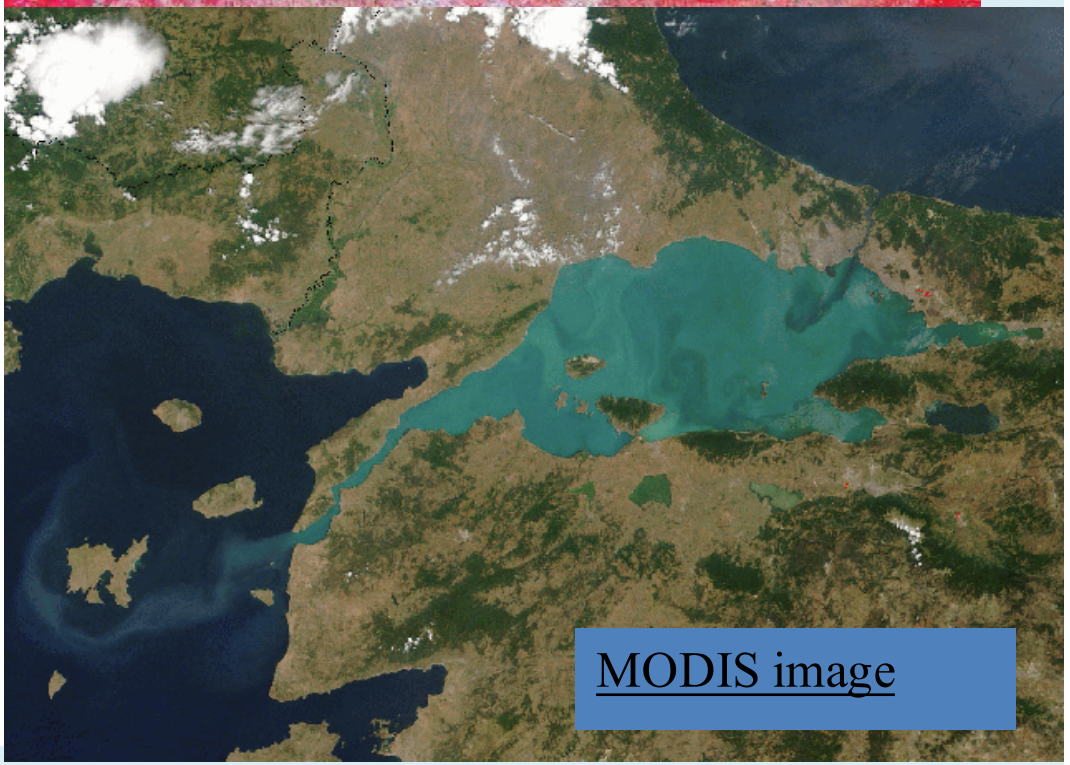


April 7, 2000 Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sub-scene in the visible and infrared channels. Vegetation appears red, and urban areas blue-green.

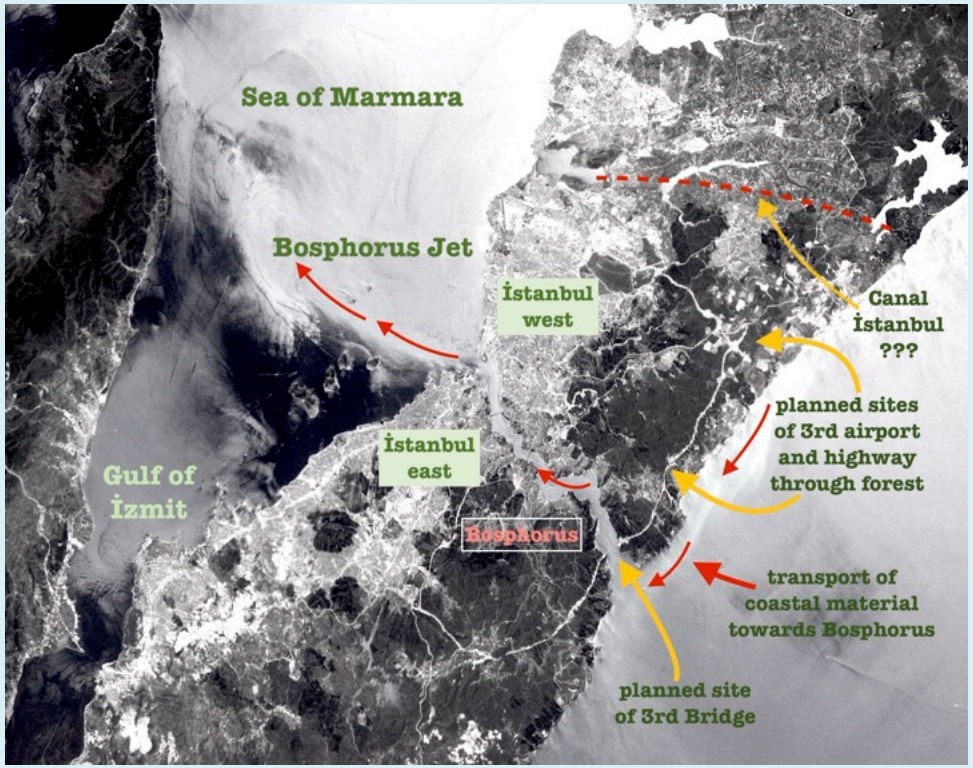
http://eoimages.gsfc.nasa.gov/images/imagerecords/0/846/aster_istanbul_lrg.jpg


sar image

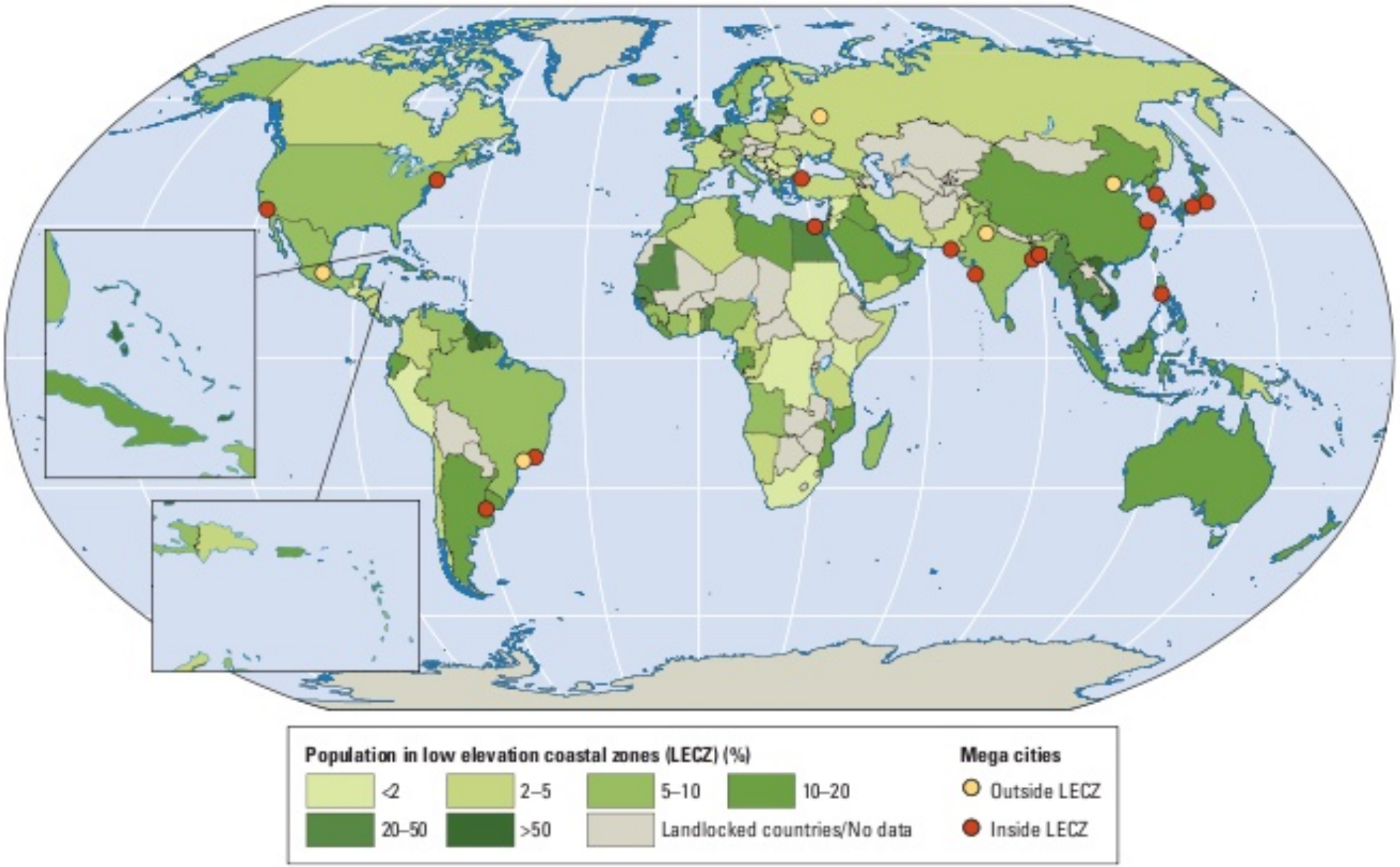

thermal image


MODIS image

Turkish Straits captured by ISS astronaut Samantha Cristoforetti on June 9, 2015
https://twitter.com/astrosamantha/status/608197918395400192

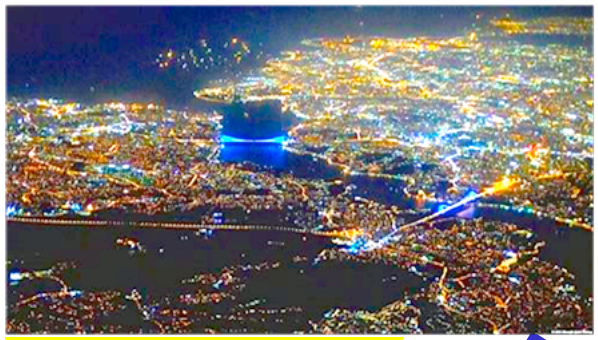


Map 2.1 At risk: Population and megacities concentrate in low-elevation coastal zones threatened by sea level rise and storm surges



megalopolis İstanbul

'yeni İstanbul'
nüfus patlaması !



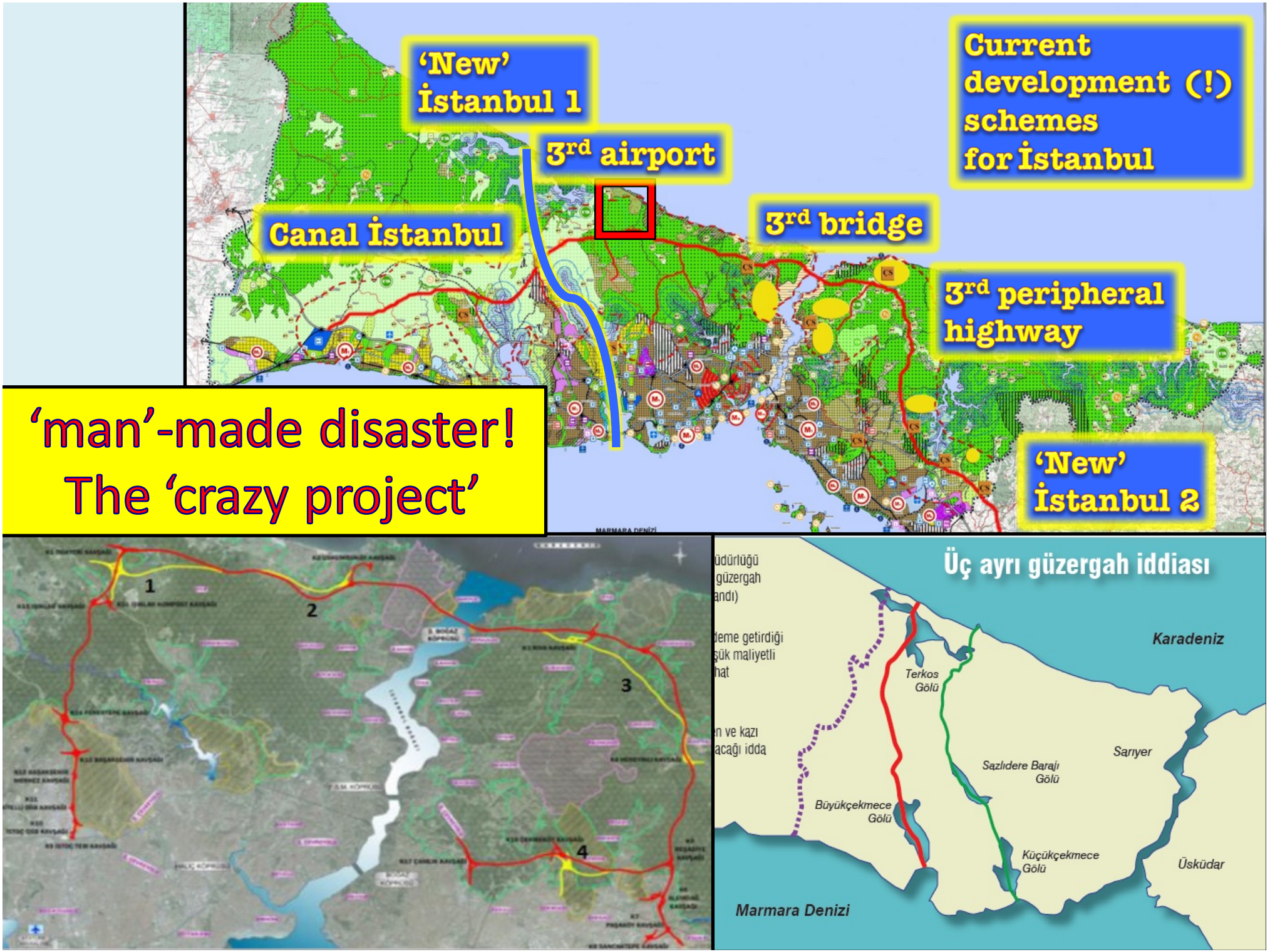
Star wars !

Şimdi !

1960

year

population (x10^6)


'New' İstanbul 1
3rd airport
Current development (!) schemes for İstanbul
Canal İstanbul
3rd bridge
3rd peripheral highway
'New' İstanbul 2
'man'-made disaster!
The 'crazy project'
1
2
3
4
Üç ayrı güzergah iddiası
Karadeniz
Terkos Gölü
Sarıyer
Sazlıdere Barajı Gölü
Büyükçekmece Gölü
Küçükçekmece Gölü
Üsküdar
Marmara Denizi

Accidents and marine pollution risks

Global Chokepoints and Oil Routes

millions of barrels per day | Risk of mines | Navigation Challenge | Risk of piracy/attacks

Heavy traffic poses challenge for oil tankers in the straits

6th Fleet

2.9 Turkish Straits

Most of the oil passing through the Straits of Hormuz goes to Japan, India and China

7th Fleet

2nd Fleet

3rd Fleet

Straits of Hormuz

Suez Canal 4.5

5th Fleet

17

Highly susceptible to piracy and tanker attacks

Bab el-Mandab 3.3

Panama Canal 0.8

Most of the oil that passes through the canal is headed for the U.S.

15.2 Straits of Malacca

U.S. naval presence increased in this area under the Obama administration

Less than 10% of Persian Gulf oil goes to the U.S.

Source: U.S. Energy Information Administration

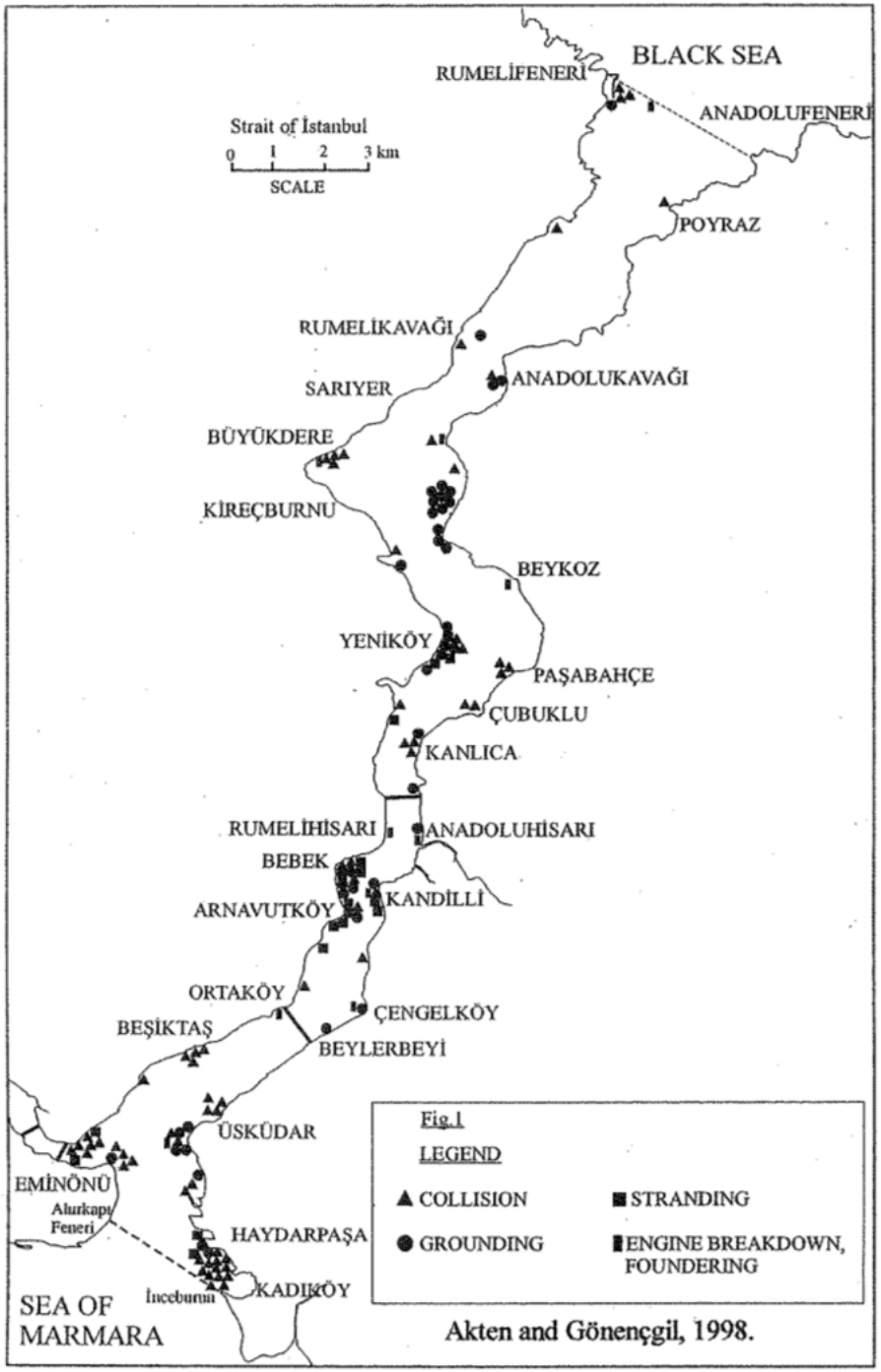


Fig. 1. Strait of Istanbul casualty chart

Shipping Casualties in the Bosphorus

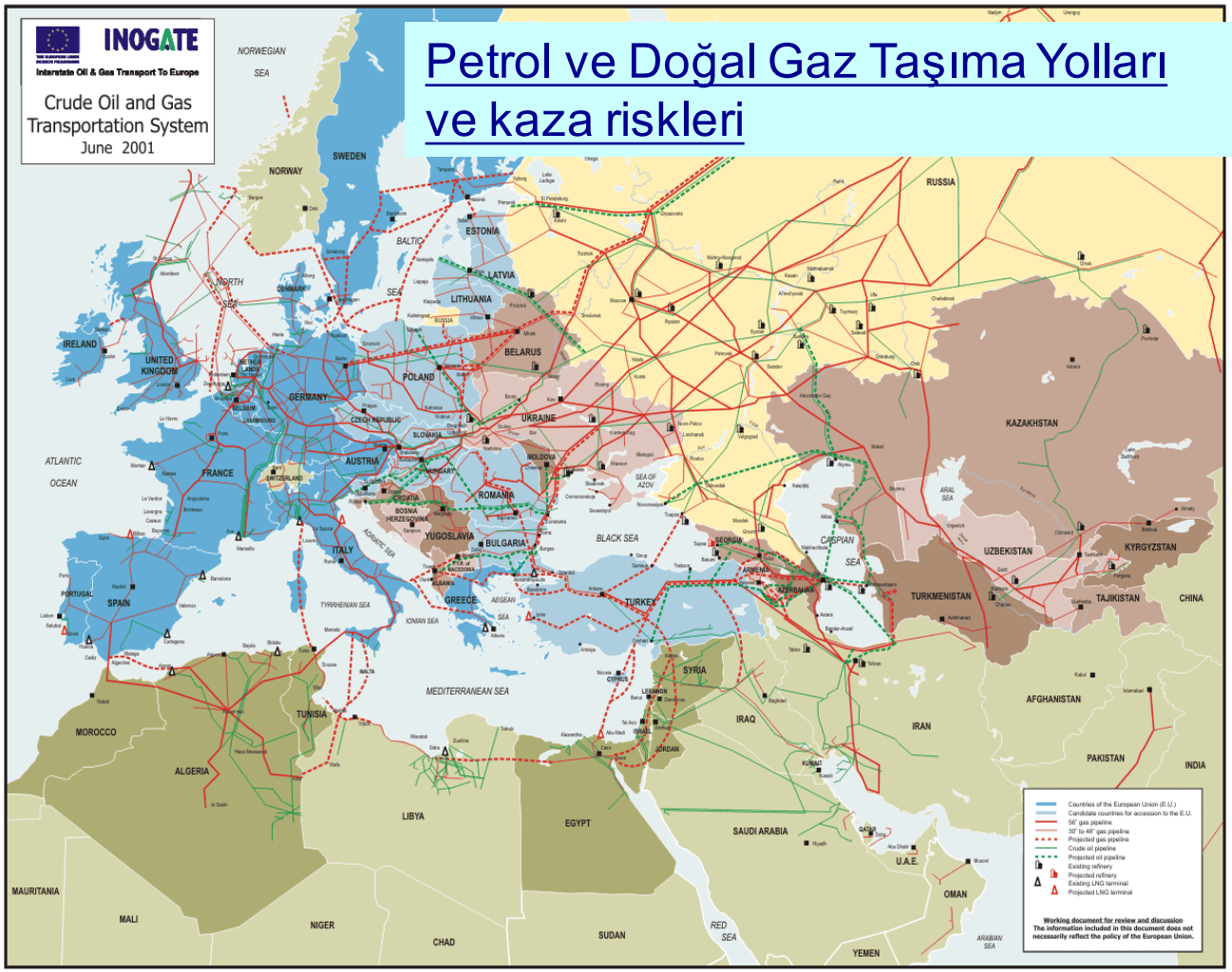
Akten & Gönençgil, 1998

21. Yüzyılda artan riskler

ENERJİ YOLLARI
DENİZ TAŞIMACILIĞI
SANAYİLEŞME
DENİZ KİRLİLİĞİ
  DENİZ KAZALARI
  PETROL YAYILIMI
  KİMYASAL YAYILIMI
  ÇÖP BİRİKİMİ
ÖTROFİKASYON
BİYOÇEŞİTLİLİK KAYBI
SU ALTI SES KİRLENMESİ
EEZ BELİRLEME
BESİN KAYNAKLARI

Gereken:
BİLGİ TOPLUMU
BİLGİ EKONOMİSİ
olmak

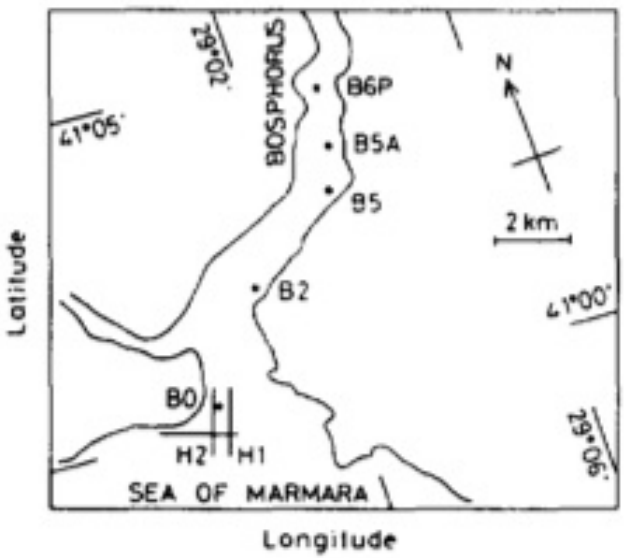
Petrol ve Doğal Gaz Taşıma Yolları ve kaza riskleri



Independenta
1979

POLLUTION RISKS

Waste disposal system dye studies and measurements, Özsoy et al, 1995; Beşiktepe et al., 1994, Beşiktepe et al., 1995



ocation of the Ahirkapı sewage pipeline. The ship trac
mentioned in the text are overlapped.

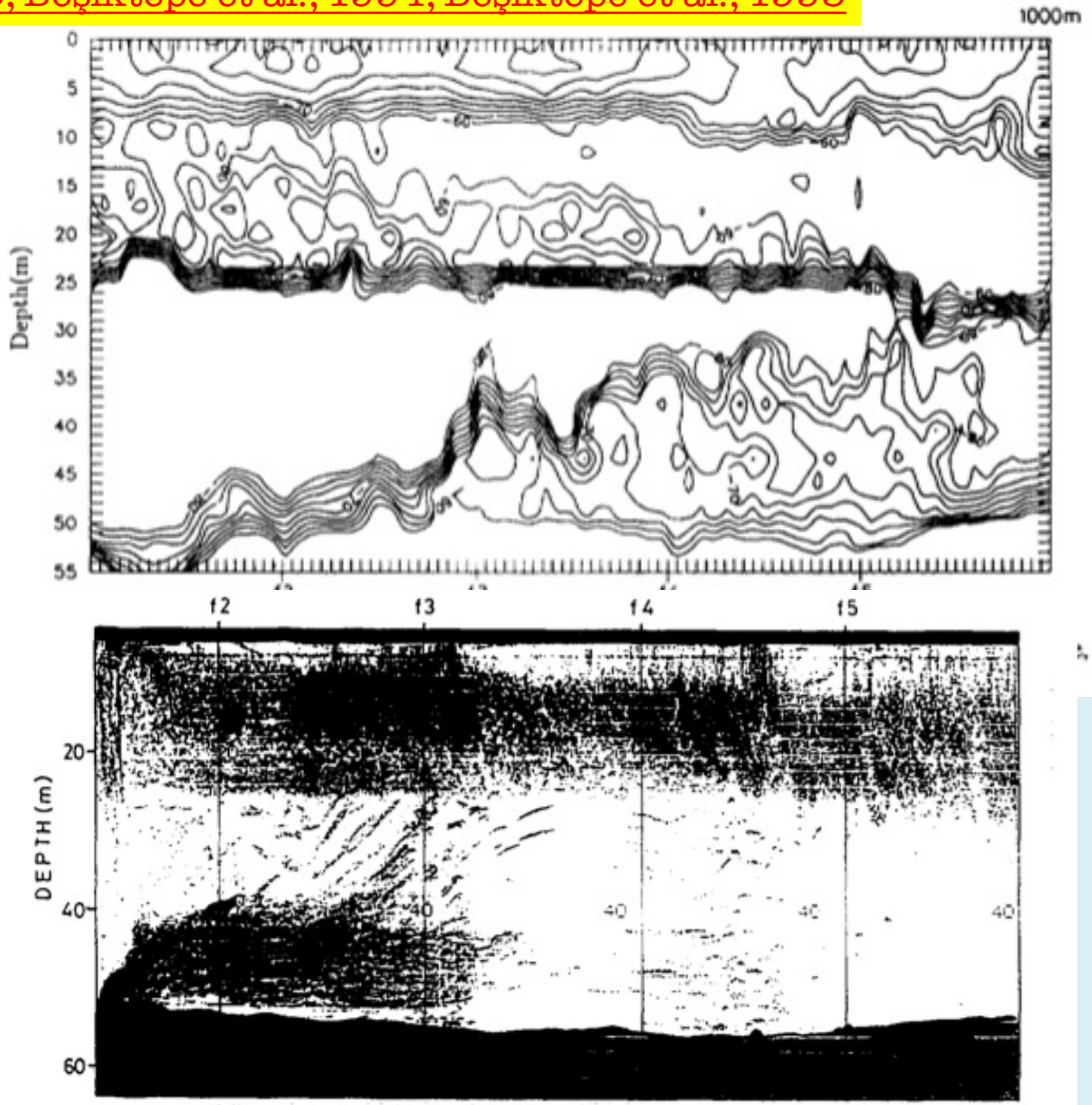


Figure 3a. Echo sounder record along section 1 across Ahirkapi diffuser pipeline, 18 May 1992.

İSKİ Waste water disposal system dye studies
Özsoy et al, 1995
R/V BİLİM ve R/V Arar
works!

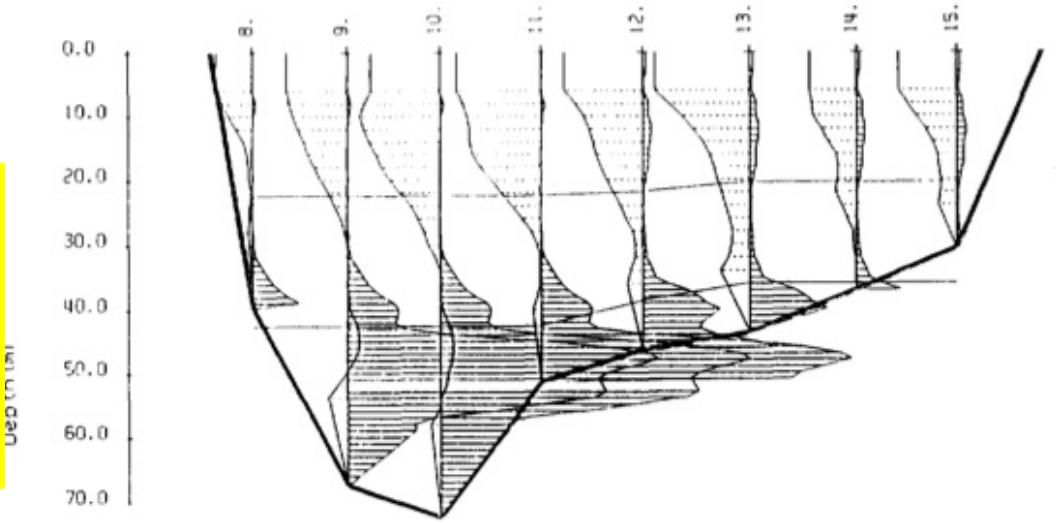


Figure 3. Flux calculations at Section B5, 5 March 1993, 14:22. The dye concentration and normal velocity profiles are depicted in solid and dotted lines respectively at every sample depth.

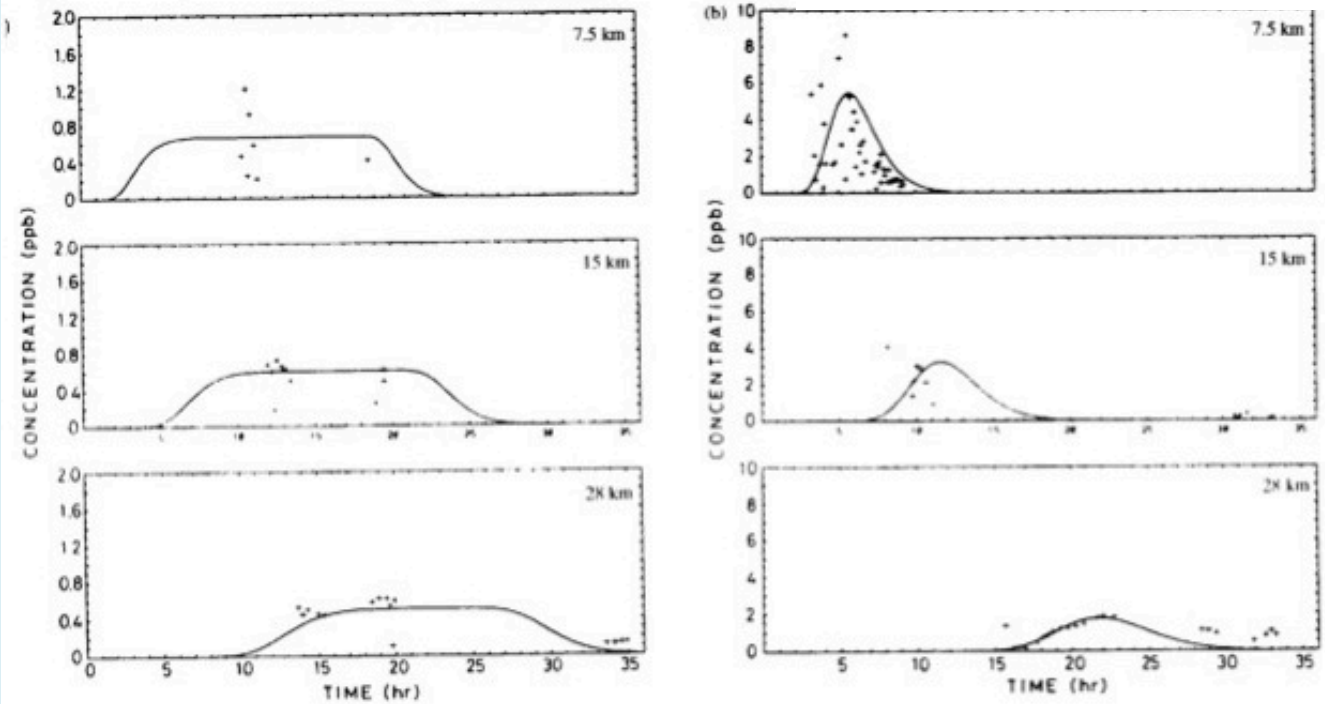
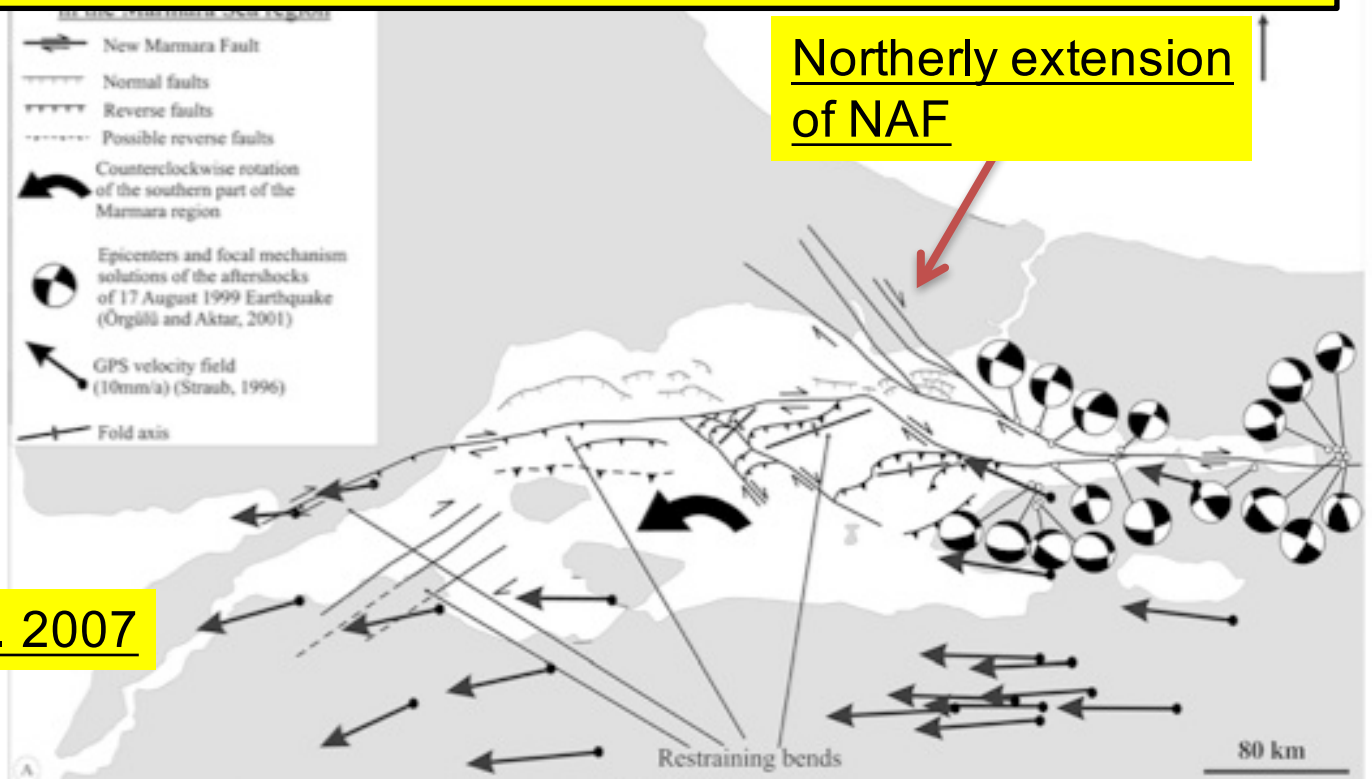


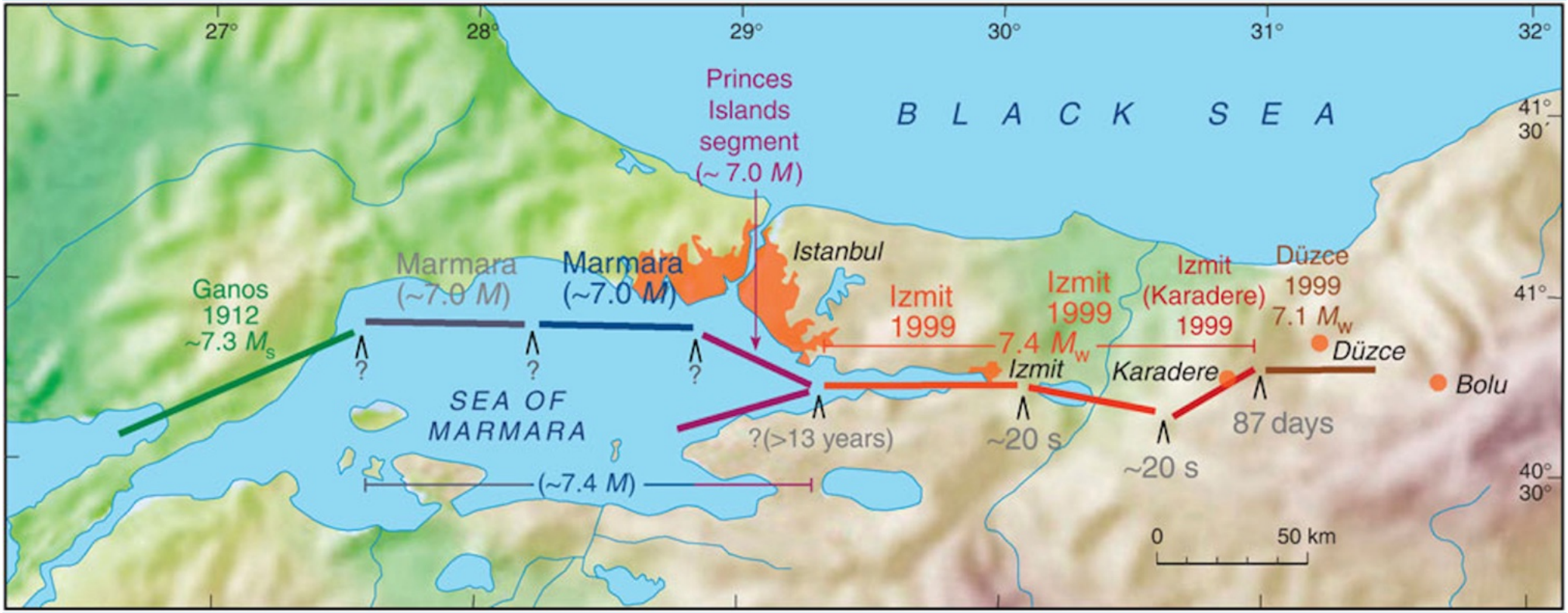
Figure 2. Lower layer average Rhodamine-B (c_3) at different locations along the Bosphorus, after (a) continuous dye release, September 1992, and (b) instantaneous release, March 1993. Data points are measurements, and the solid lines in the three consecutive plots respectively are the predicted concentrations at the 7.5 km, 15 km and 28 km distances from the source (in the vicinity of stations B5, B8 and B15 respectively).

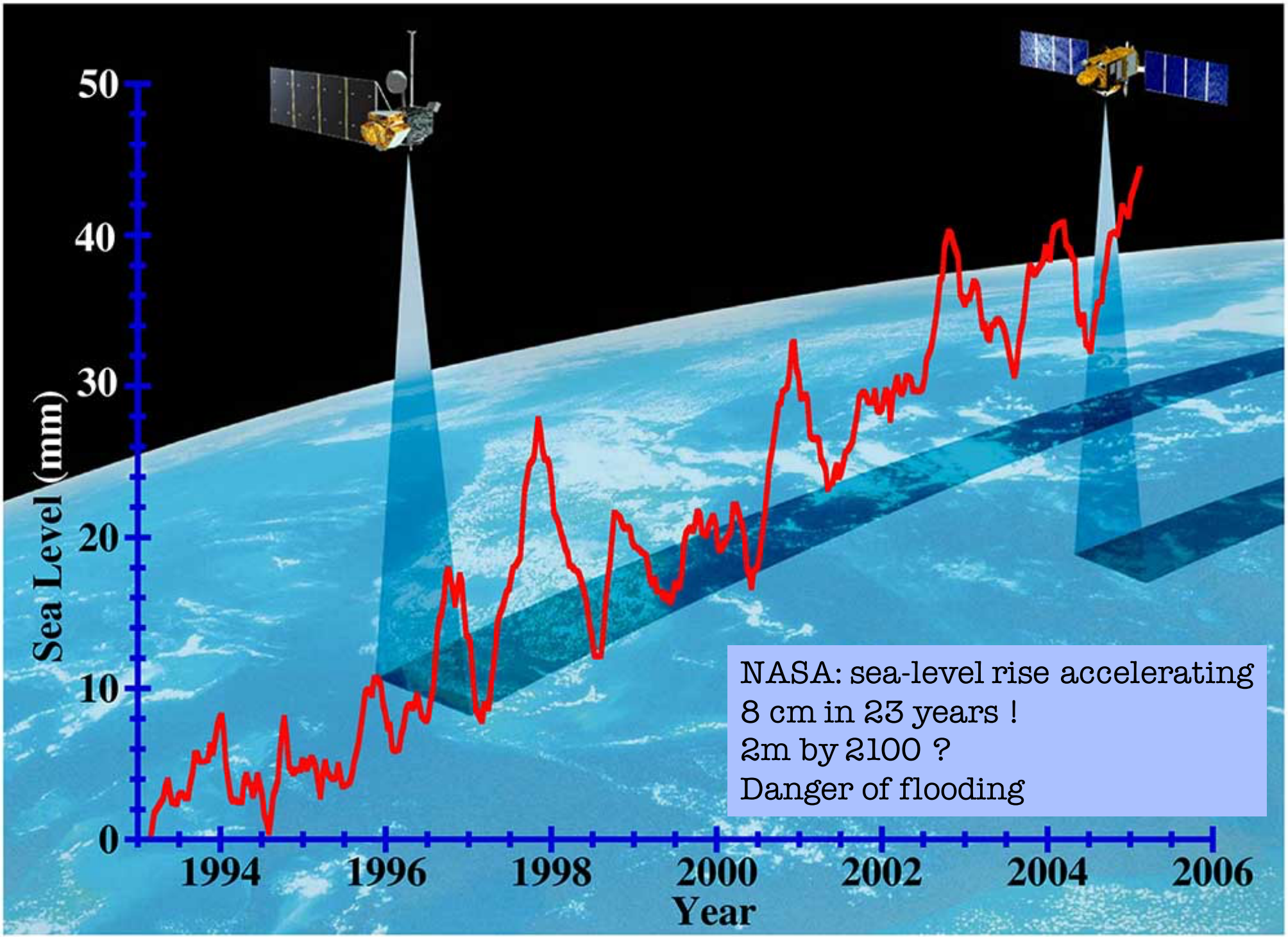
Earthquake risks – 1999 eartquake disaster

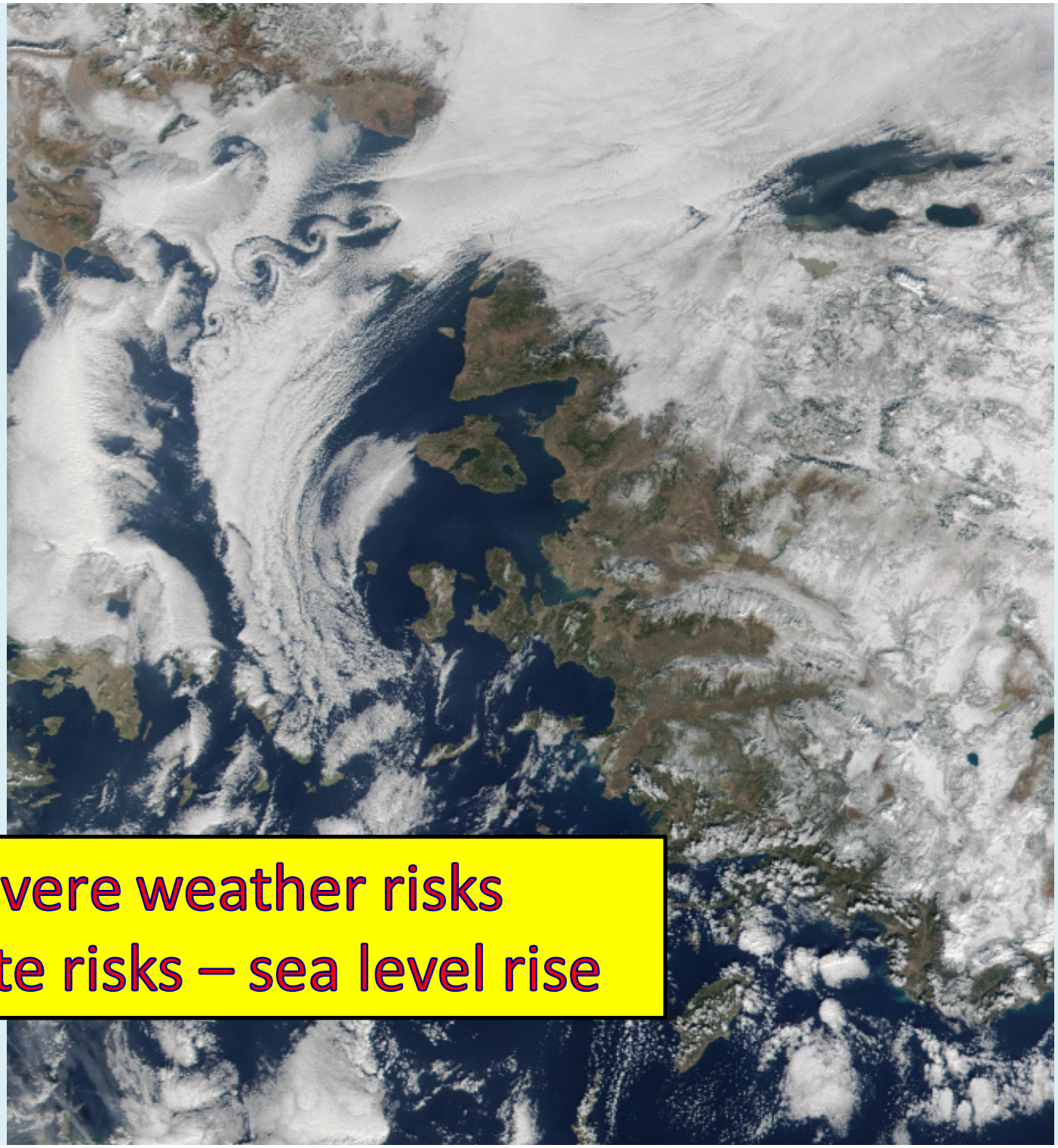
solutions (Örgülü and Aktar 2001), and GPS velocity fields (Straub 1996) in the Marmara region. **B** Fault map of the Marmara Sea, based on multi-beam bathymetric and seismic data. The *bold lines* show the New Marmara Fault and the reverse faults controlled by the New Marmara Fault. The *thin lines* show the normal faults of the initial Marmara Basin



Gökaşan et al. 2007


27°
28°
29°
30°
31°
32°
41° 30′
41°
40° 30°
B L A C K S E A
Princes Islands segment (~ 7.0 M)
Istanbul
Ganos 1912 ~7.3 M_s
Marmara (~7.0 M)
Marmara (~7.0 M)
SEA OF MARMARA
(~7.4 M)
?(>13 years)
Izmit 1999
Izmit 1999 7.4 M_w
Izmit
~20 s
Izmit (Karadere) 1999
Karadere
~20 s
Düzce 1999 7.1 M_w
Düzce
87 days
Bolu
0
50 km

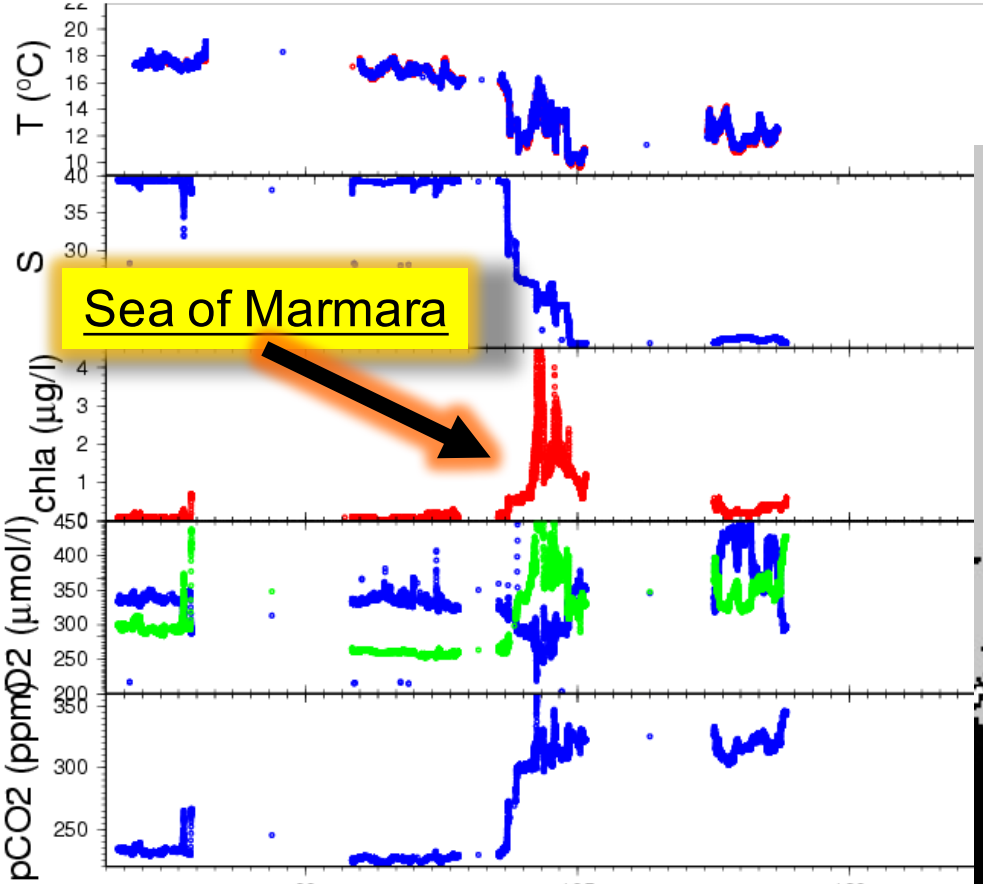

50
40
30
20
10
0
Sea Level (mm)
1994
1996
1998
2000
2002
2004
2006
Year
NASA: sea-level rise accelerating
8 cm in 23 years !
2m by 2100 ?
Danger of flooding



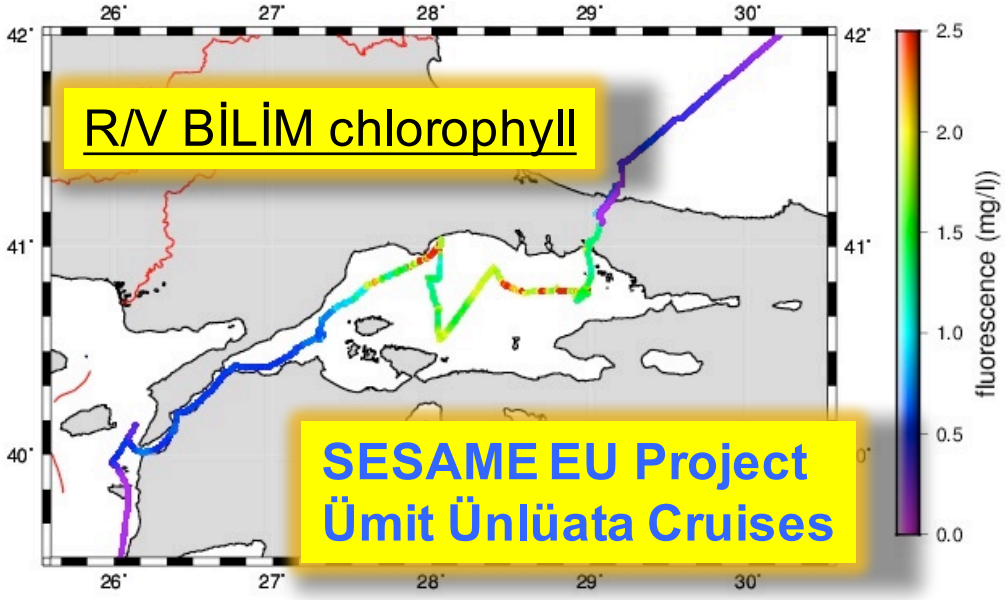
Severe weather risks

Climate risks – sea level rise

Marine ecosystem risks

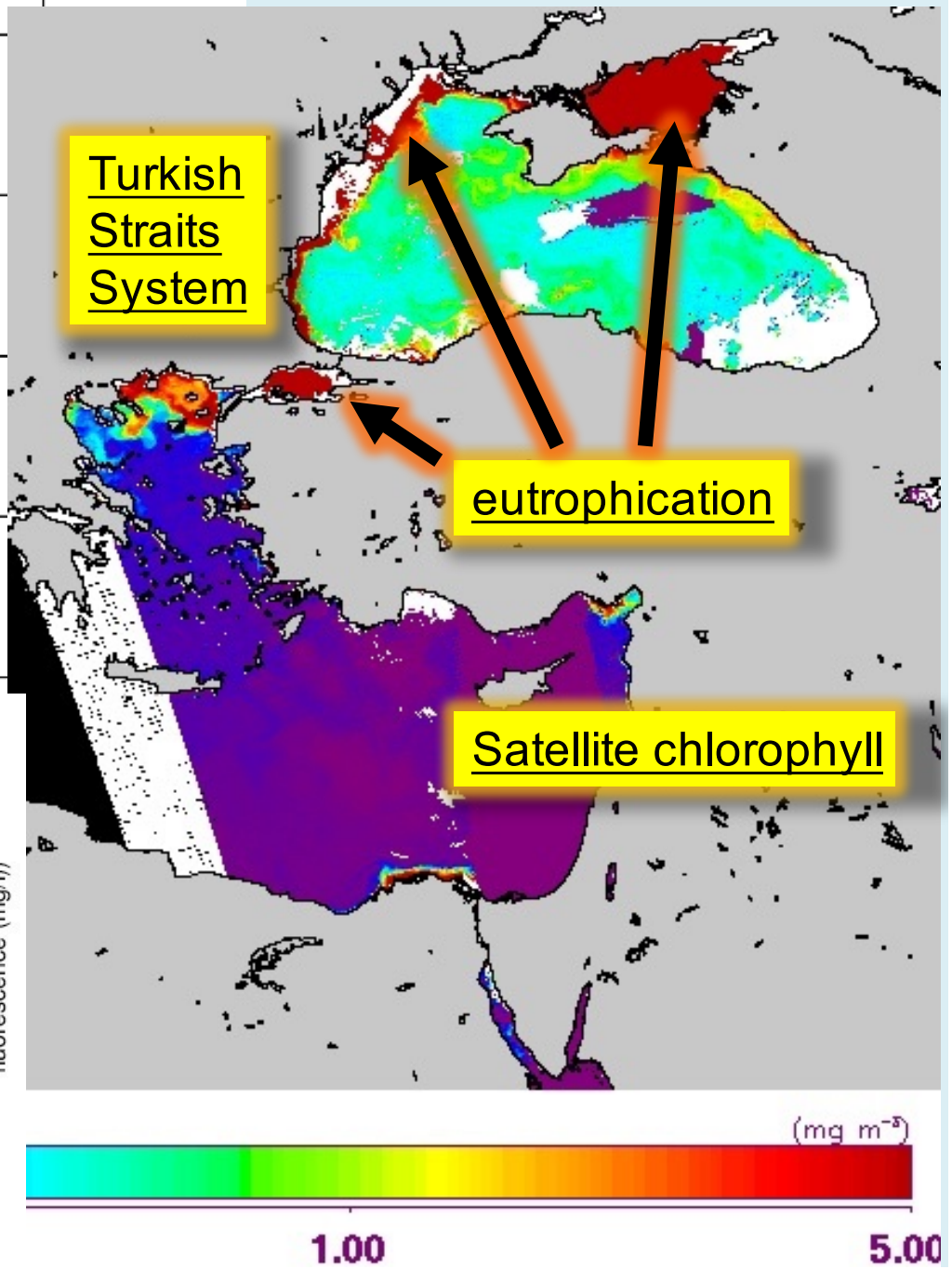


Sea of Marmara



R/V BİLİM chlorophyll

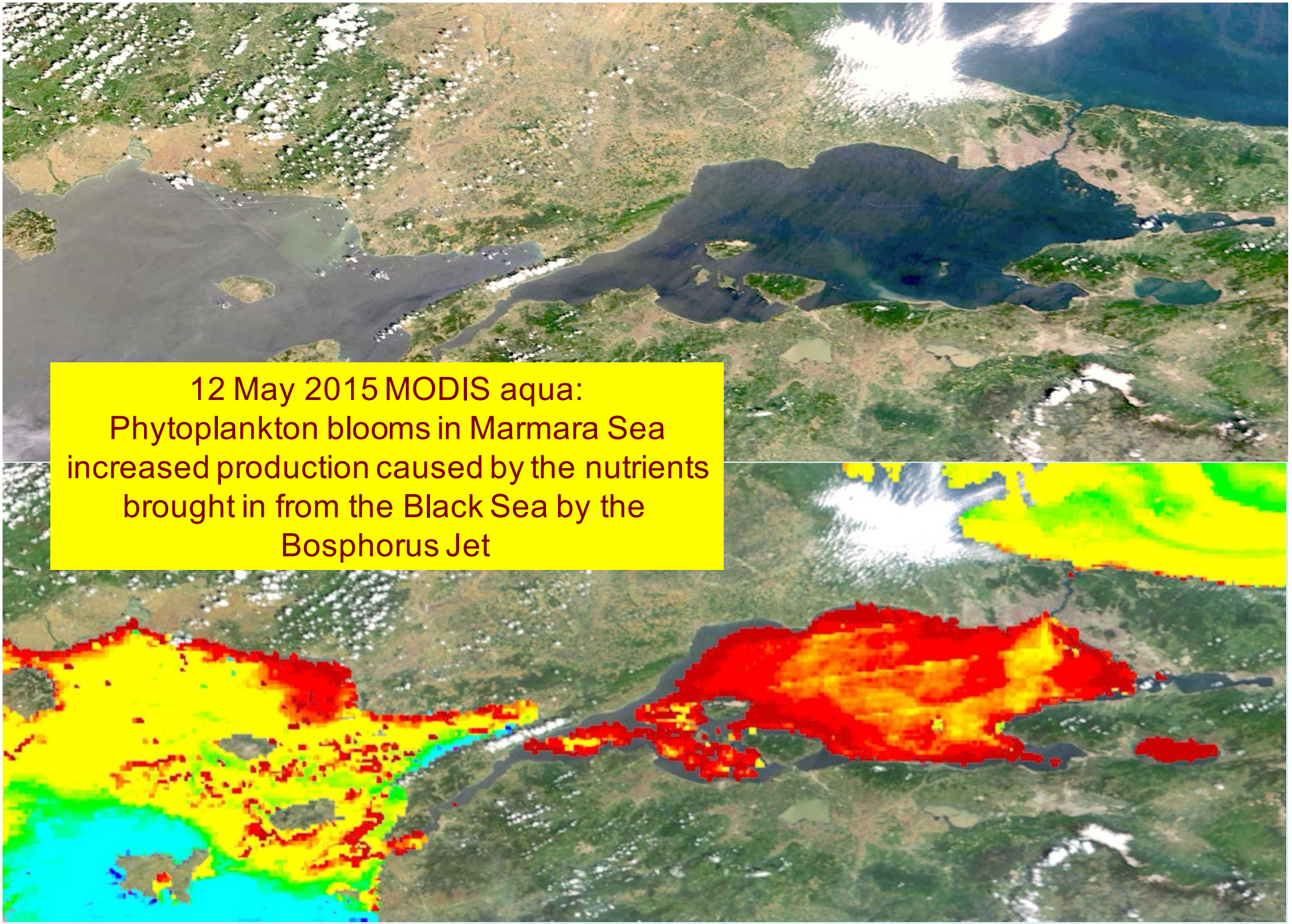
SESAME EU Project
Ümit Ünlüata Cruises



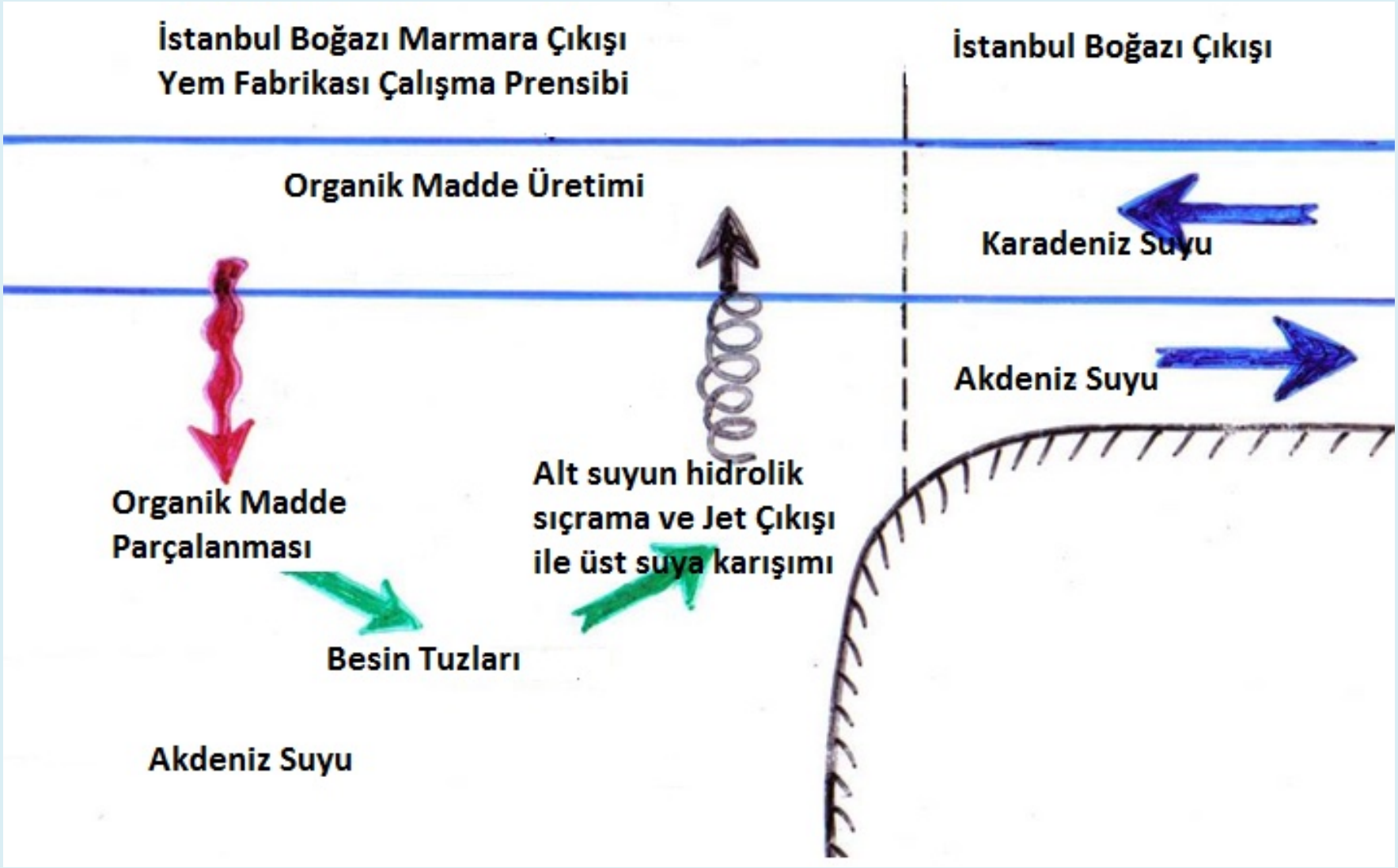
Turkish Straits System

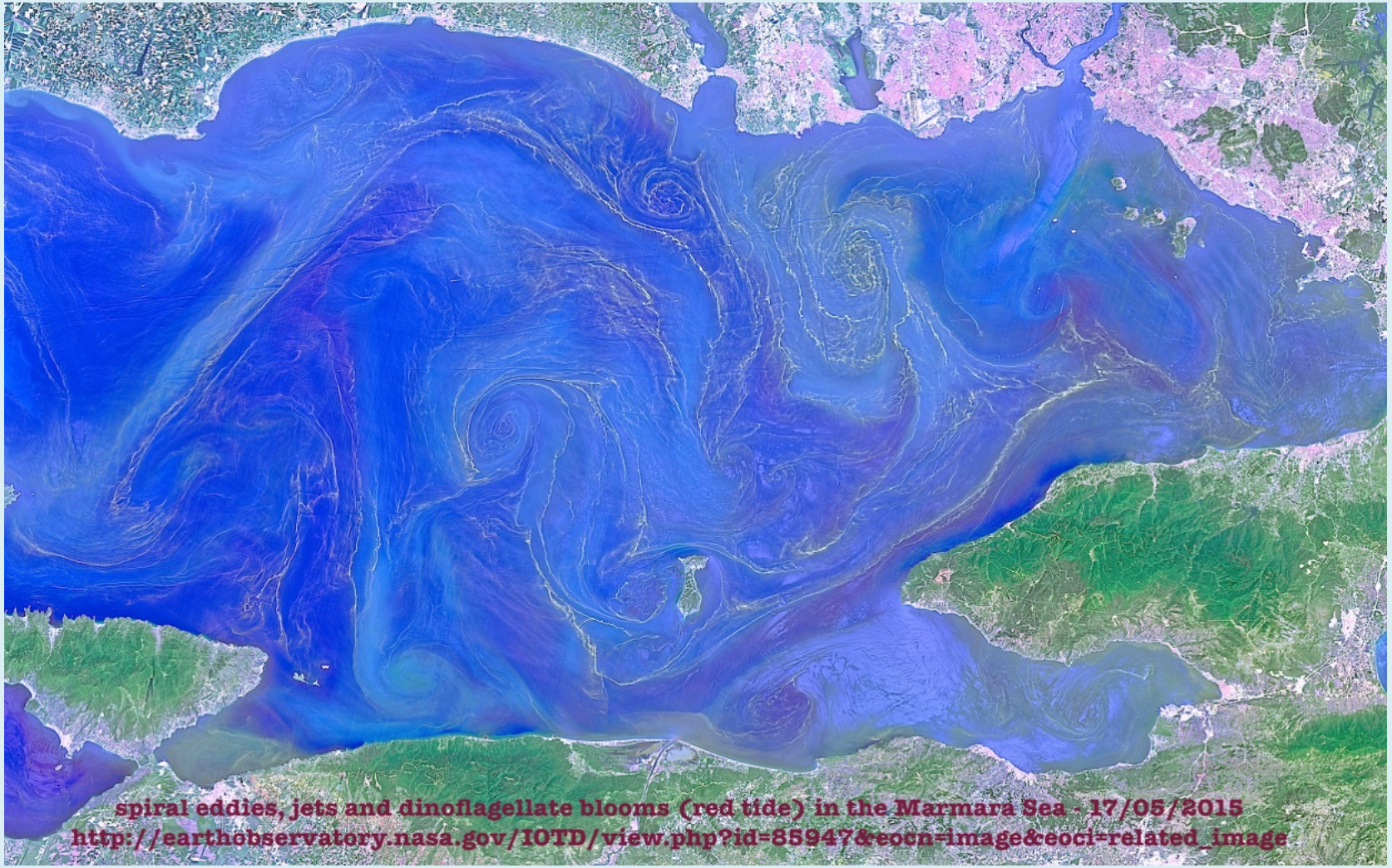
eutrophication

Satellite chlorophyll


12 May 2015 MODIS aqua:
Phytoplankton blooms in Marmara Sea
increased production caused by the nutrients
brought in from the Black Sea by the
Bosphorus Jet

Fertilizer factory producing organic matter for Marmara Sea: http://www.havadantozdan.com/cilgin-proje-neden-olmaz/





17 May 2015 satellite image of red tide (or harmful algal bloom, HAB)
(http://earthobservatory.nasa.gov/IOTD/view.php?id=85947&eocn=image&eoci=moreiotd)

http://www.milliyet.com.tr/marmara-iste-boyle-oluyor-gundem-2061522/

Turkish Strait System Background: Surface Circulation

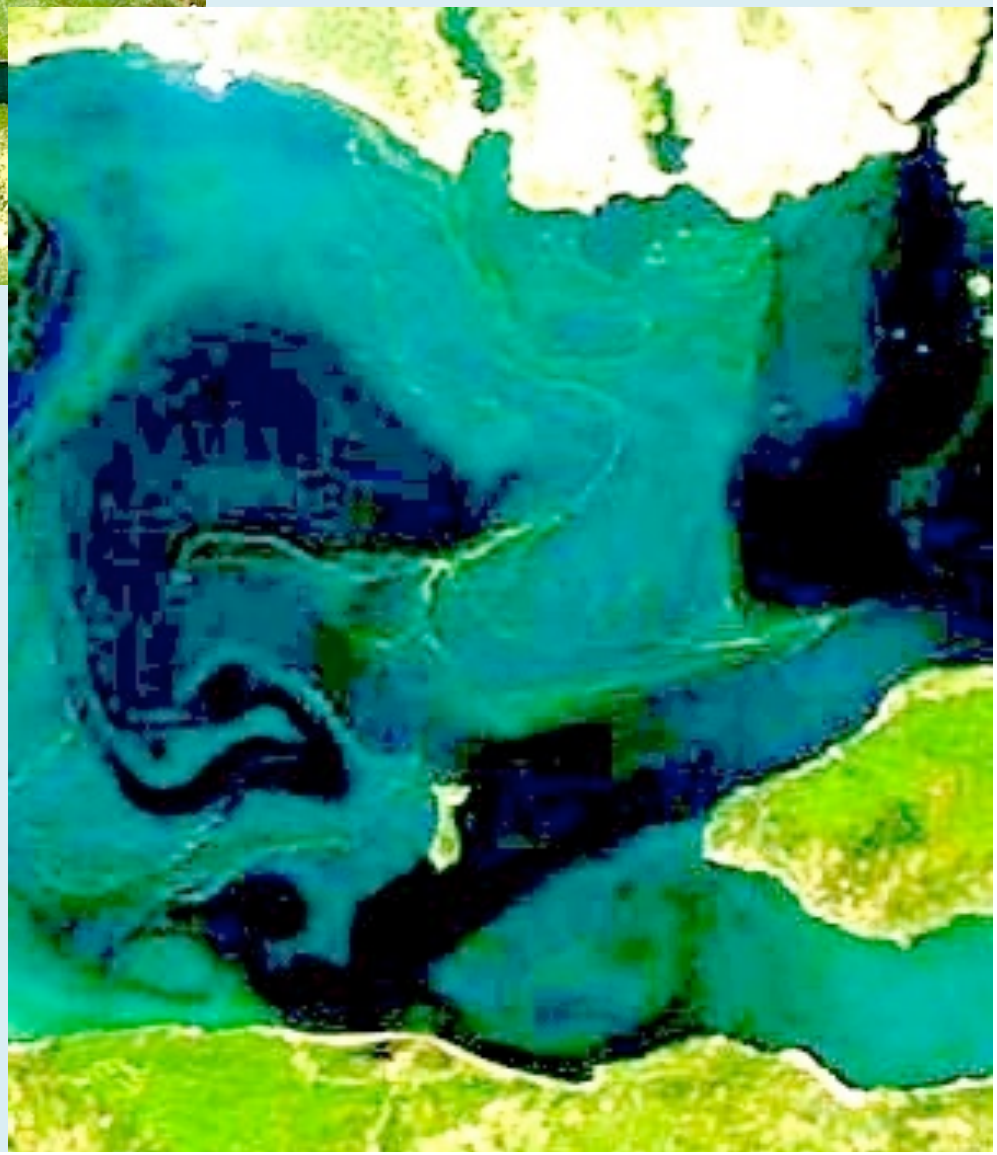
26 April 2013

27 April 2013

Turkish Strait System Background: Surface Circulation

29 April 2013

Toxic Algae
HAB
Harmful Algae Bloom



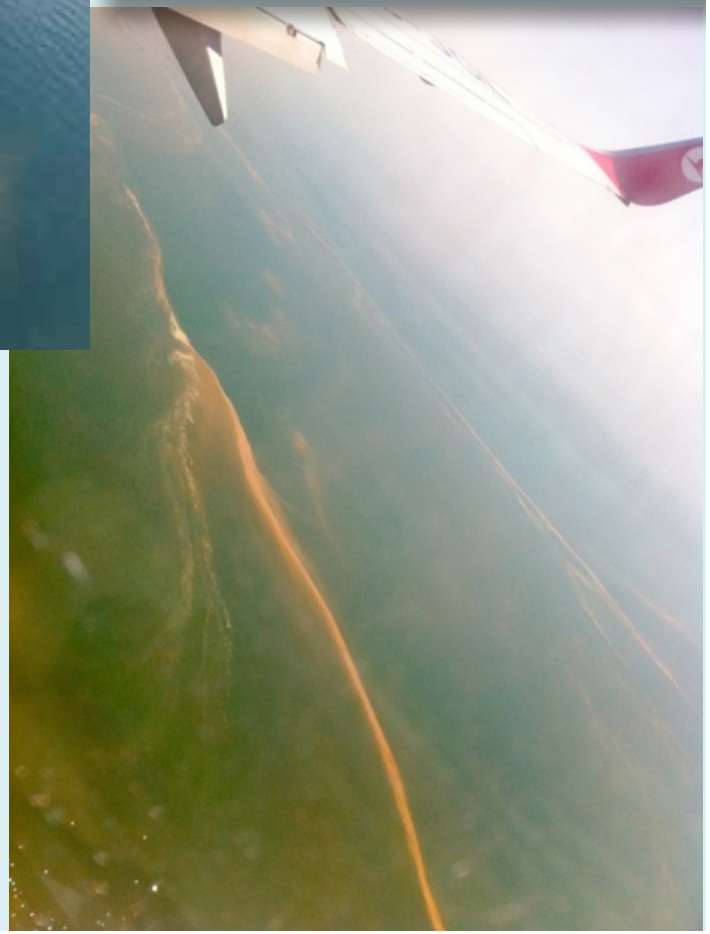
25 April 2013 MODIS satellite ocean colour images

Silent death of a small internal sea neigboring to large marine basins!

Marmara Sea
Toxic Algae Blooms
HAB:
Harmful Algae Bloom

24 April 2013 news Milliyet daily
Toxic algae bloom near Tekirdağ
http://gundem.milliyet.com.tr/marmara-da-korkutan-tablo/gundem/gundemdetay/24.04.2013/1697729/default.htm

Flight over Marmara Sea 28 Nisan 2013 (Photo: Dr. Bettina Fach, IMS-METU).



Mediterranisation of Black Sea ?

Alien species

GFCM studies and reviews No: 85, 2010

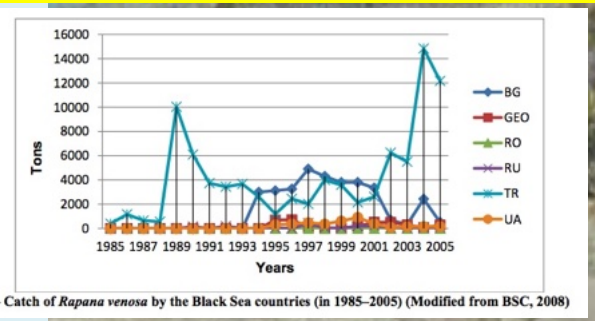


Figure 6 – Catch of *Rapana venosa* by the Black Sea countries (in 1985–2005) (Modified from BSC, 2008)

Experimental results

Turkish Straits System
Interaction with adjacent Seas

Forcing from (adjacent basins) :
- sea level
- barometric pressure
- wind setup
- water balance R+P-E

Time scales:
Bosphorus: Transit time < 1/2 day
Dardanelles: Transit time ~ few days
Black Sea: residence time 1-5yr for CIL, >2000yr for bottom
Marmara Sea: residence time 3mo for upper, 6-12yr for lower layer
Mediterranean: residence time ~100 yr
Forcing: < daily - multidecadal

Oşinografi gözlem sistemleri

Araştırma gemilerinden elde edilen veriler

1954-2001
örnekleme istasyonları
kırmızı: R/V BİLİM - IMS-METU

R/V BİLİM

Su seviyesi, meteoroloji,
Deniz suyu özellikleri
Kıyısal istasyonları:
9 + 5 + 3 = 17
kıyısal istasyon:

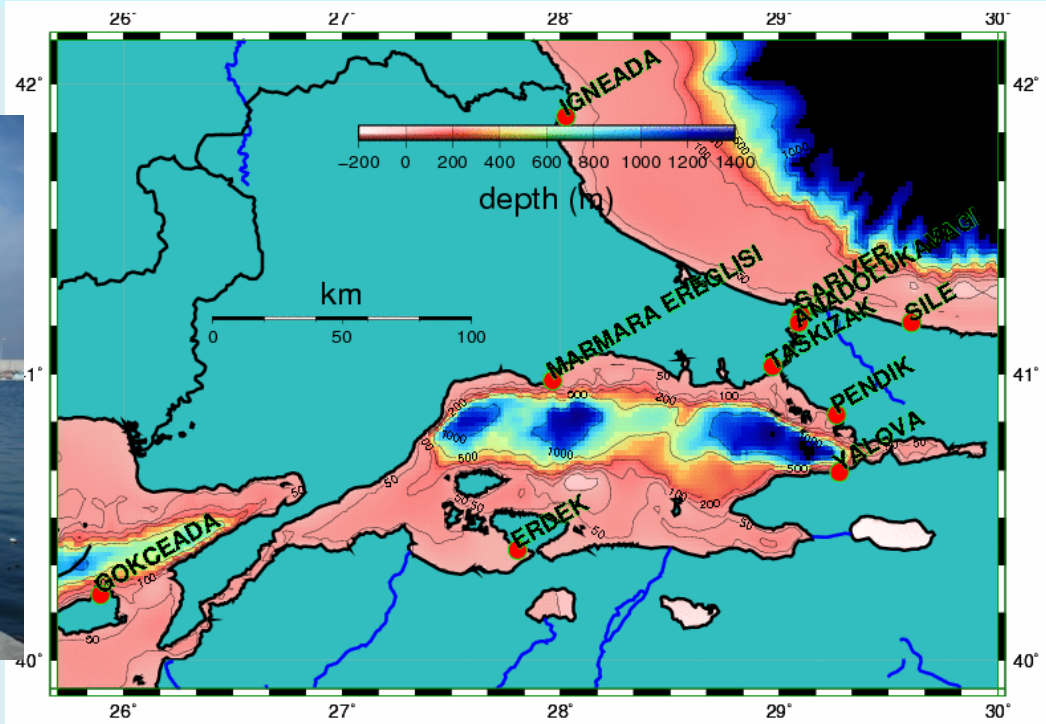
İğneada
Şile

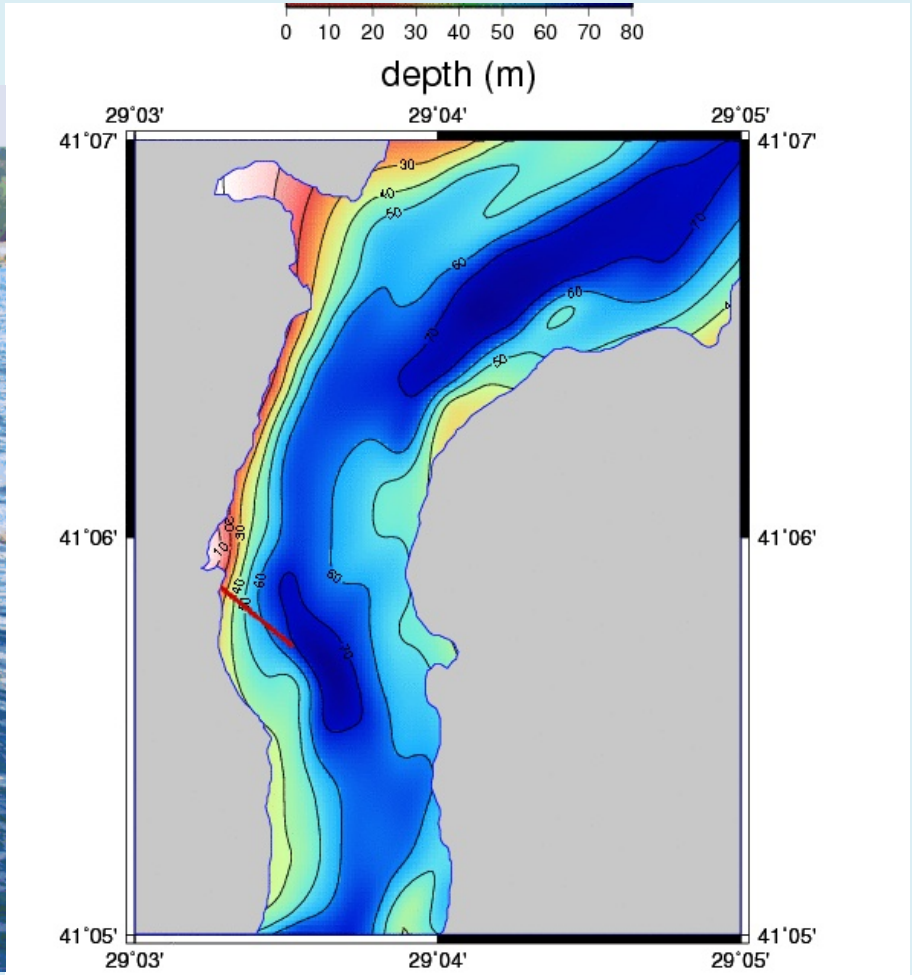
Sarıyer
Anadolukavağı
Haliç

Pendik
Yalova
Marmara Ereğlisi
Erdek
Gökçeada

Aksaz
Bozyazı
Taşucu
Erdemli
İskenderun

Girne
Magosa

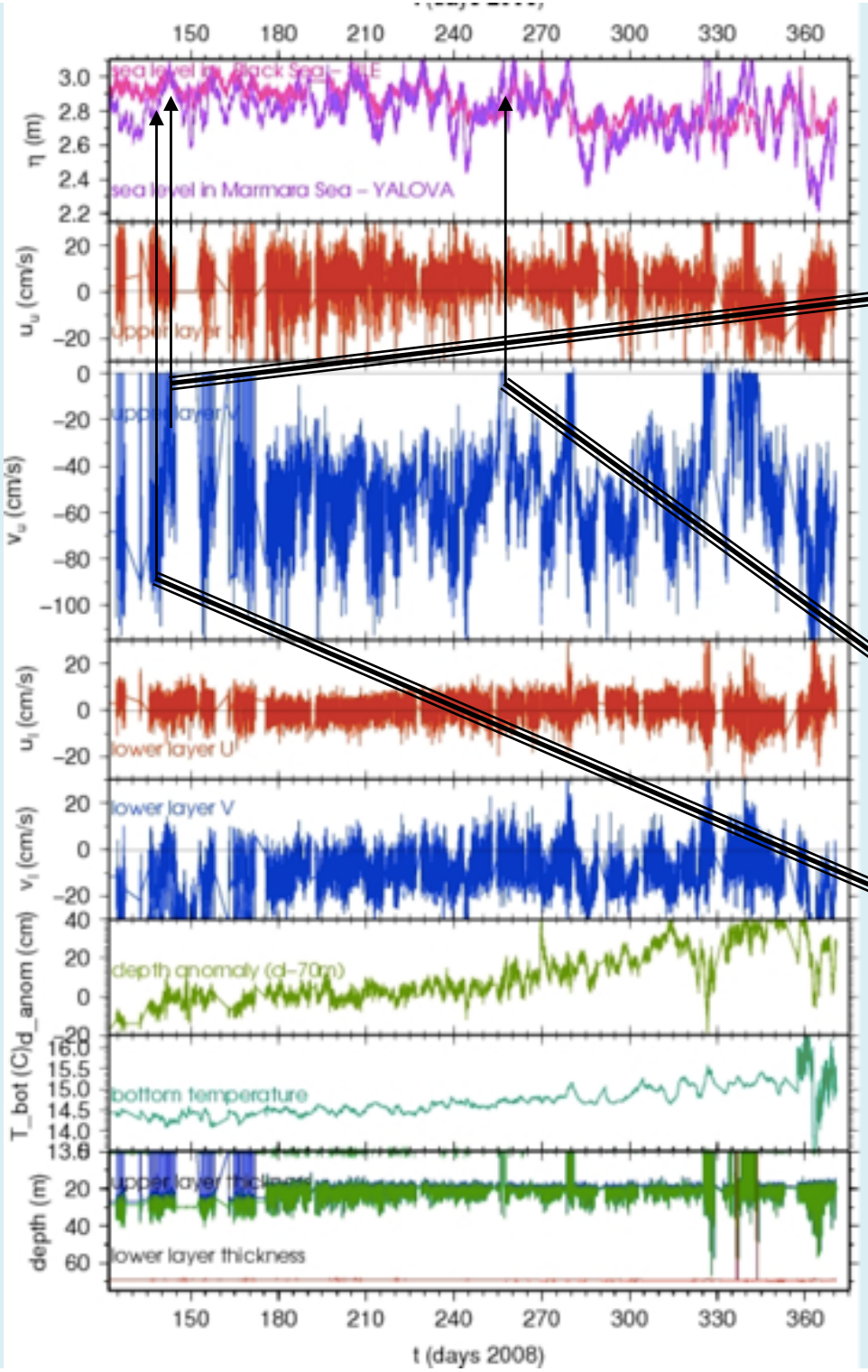


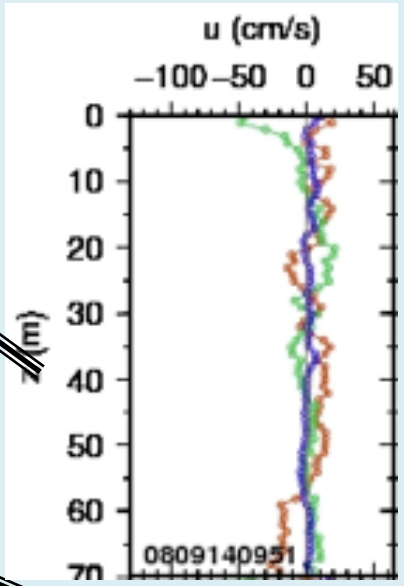


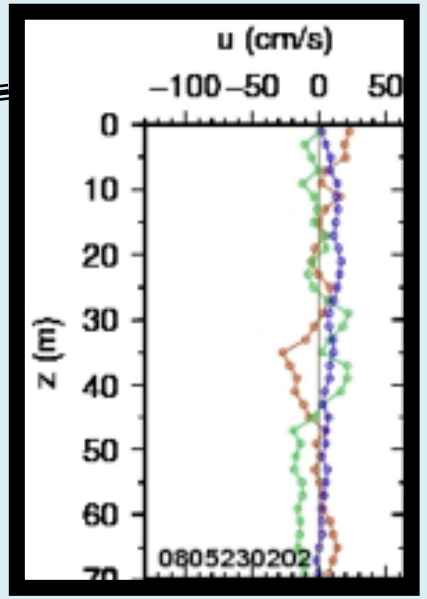
cabled ADCP system

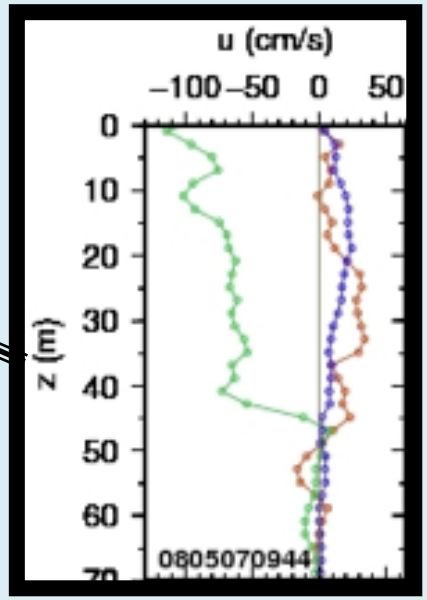
real-time measurements

Üst tabaka akımının “tıkanması”



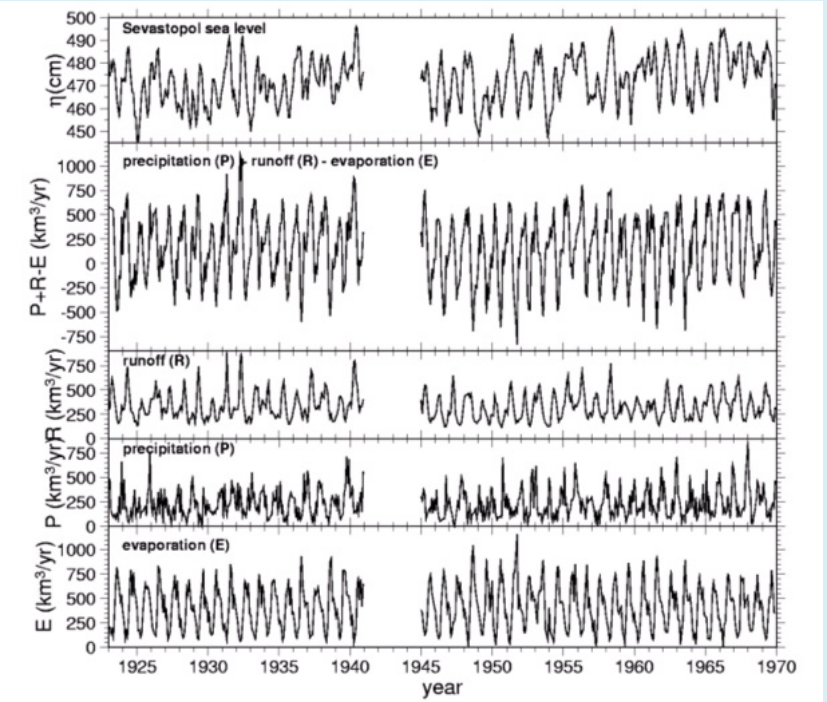


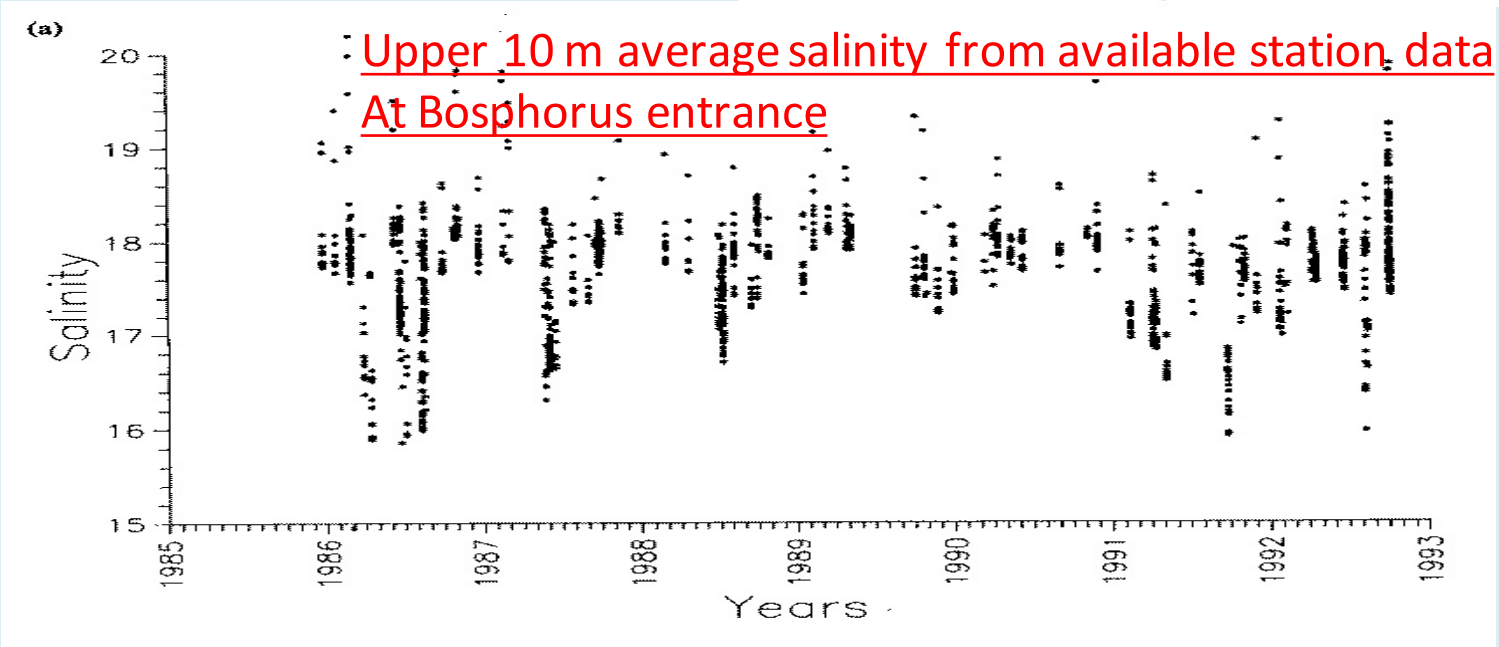




Physical complexity

Seasonal and interannual variability in Black Sea water budget





Upper 10 m average salinity from available station data At Bosphorus entrance

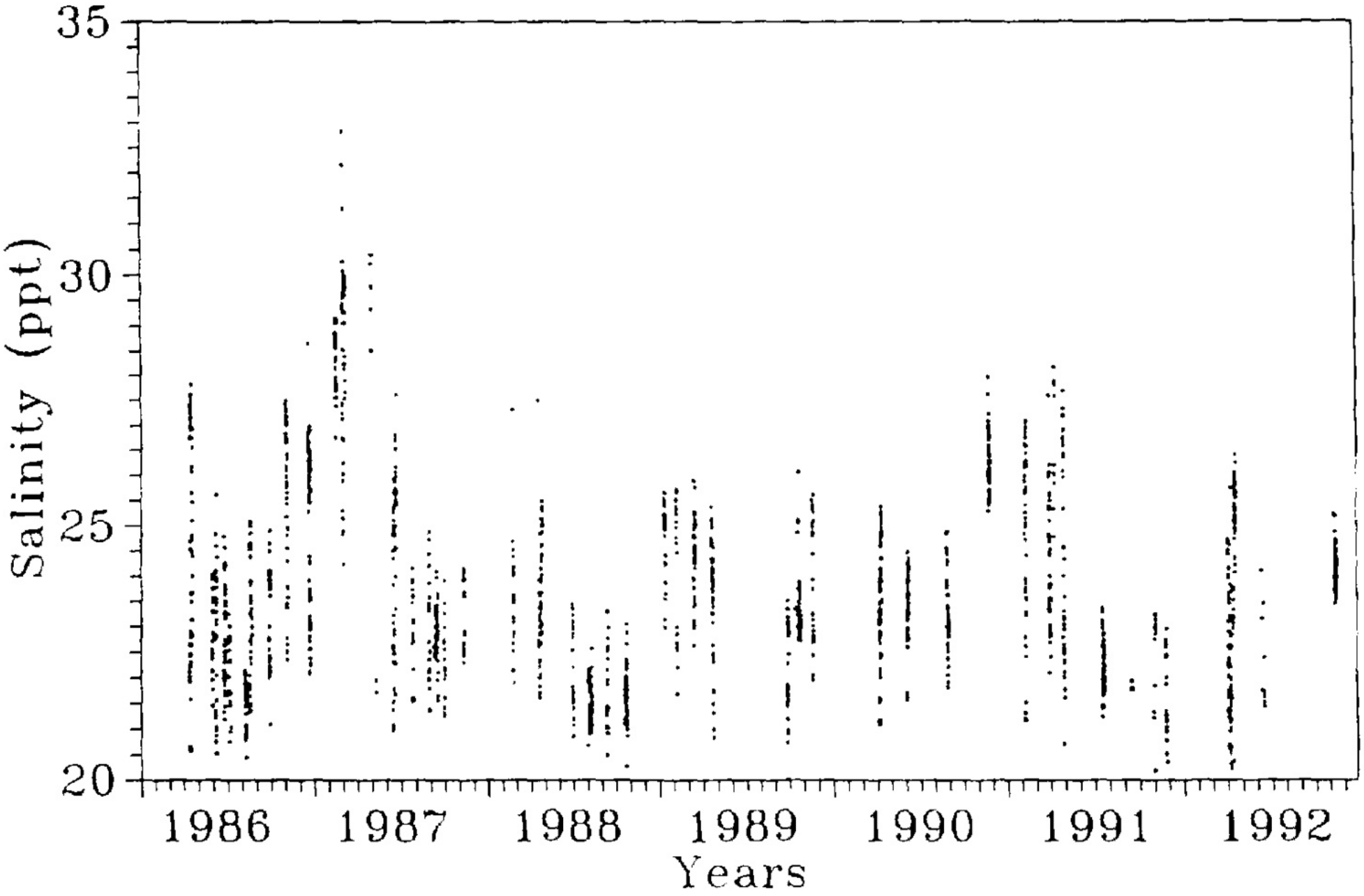
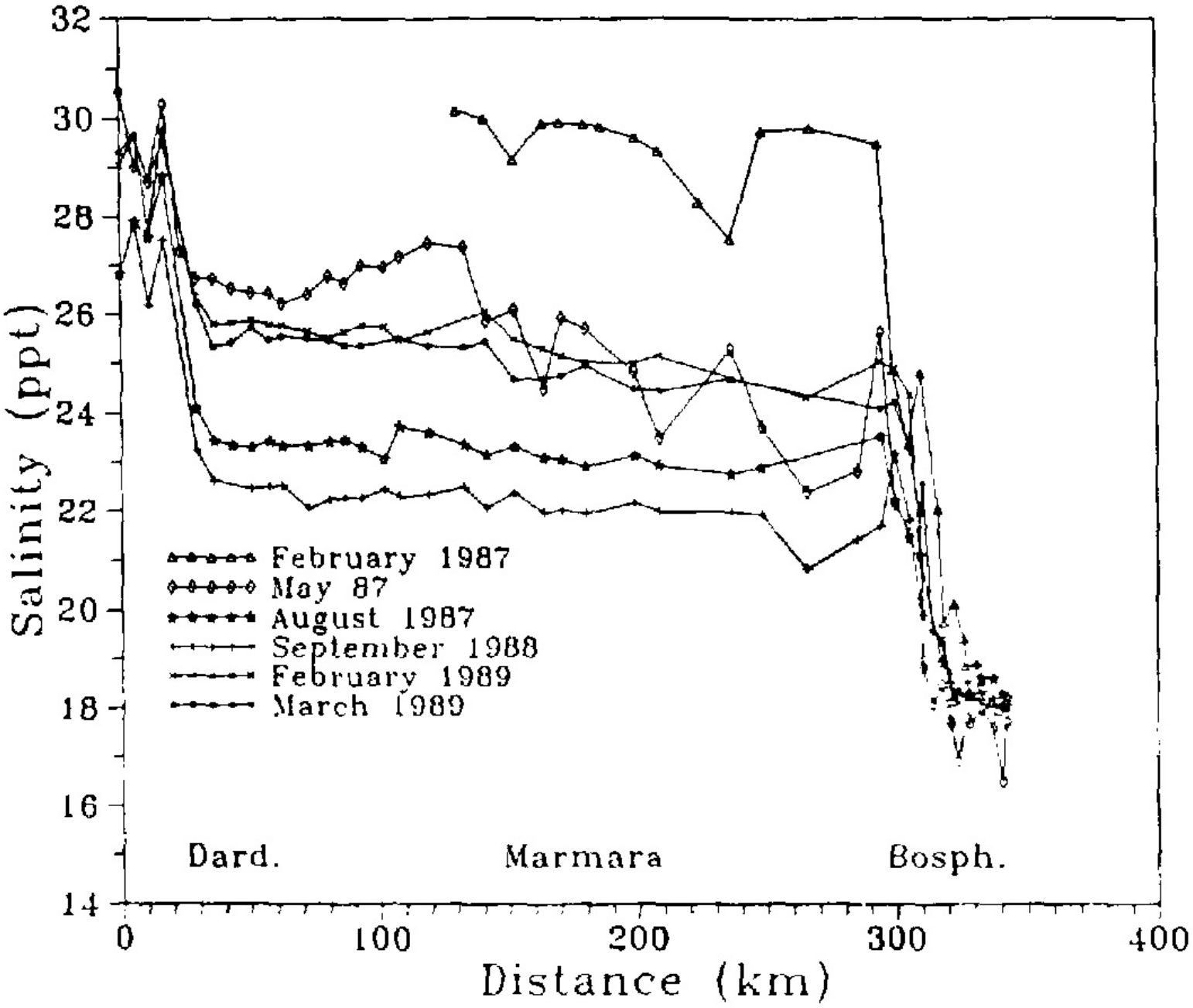
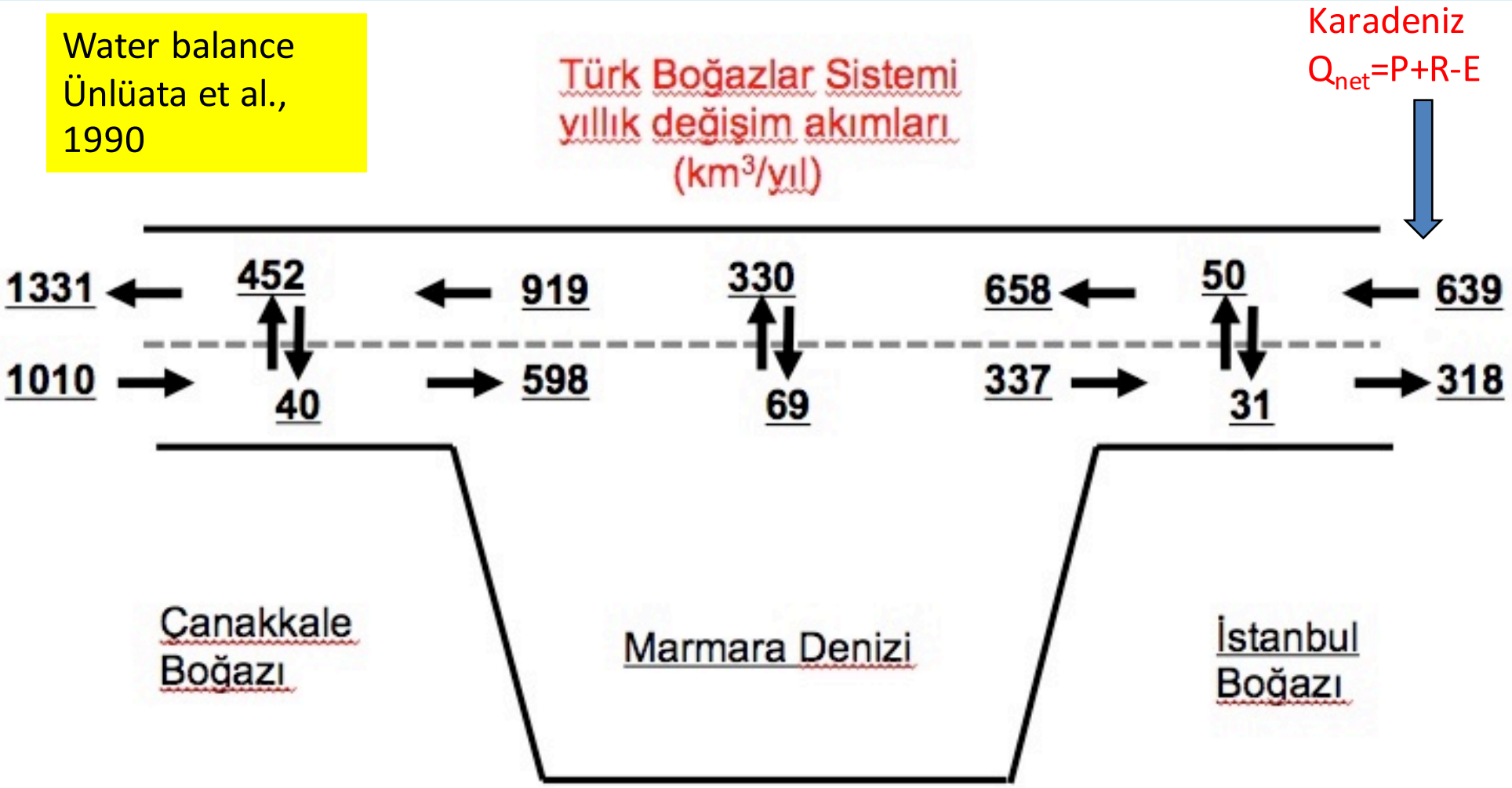


FIG.12. Surface salinity measurements (upper 10m average during the course of the measurements in the Marmara Sea. Each data point corresponds to a hydrographic station occupied in the basin.



Upper layer averaged salinity distribution along the main axis of the Turkish Straits System for different months.

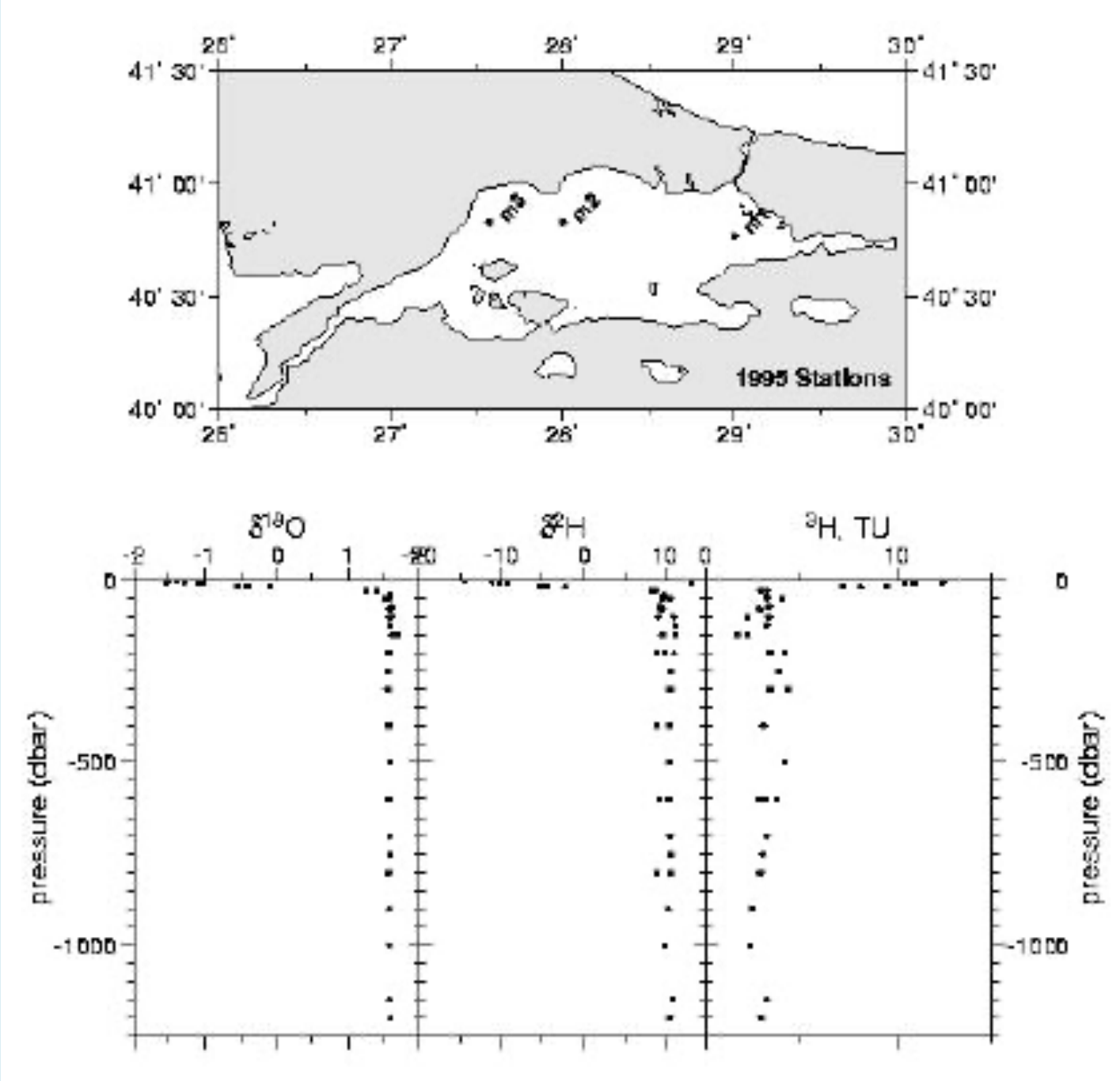
Water balance
Ünlüata et al., 1990



Bosphorus salinity ratio: $S_2/S_1 = 38.5 / 18 \approx 2$

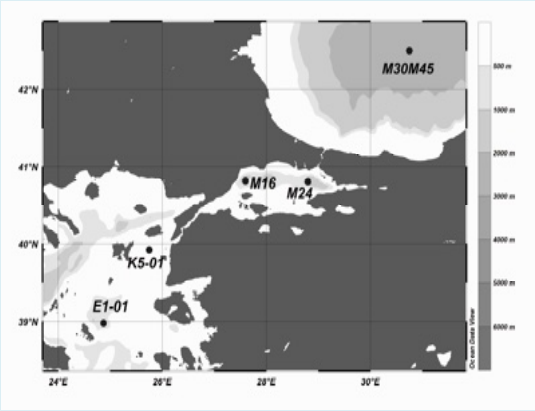
Mass conservation: $Q_1/Q_2 = 658 / 337 \approx 2$

average mass conservationi $S_1 Q_1 = S_2 Q_2$

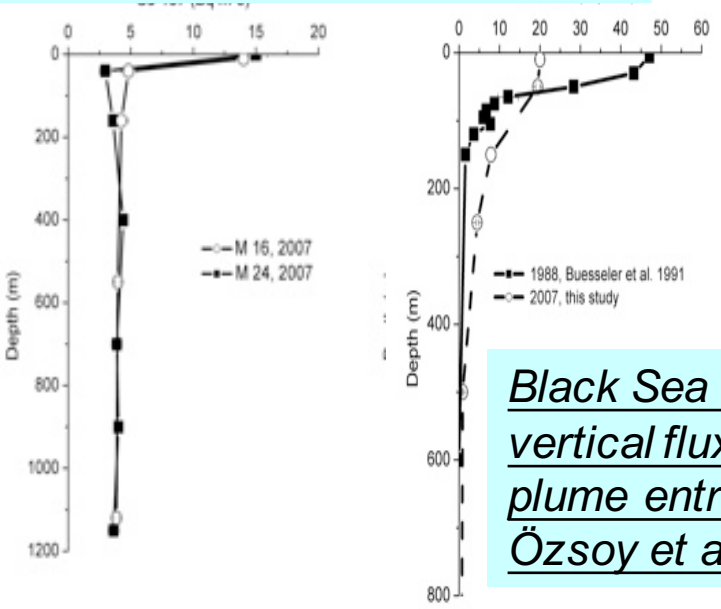


O-18, deuterium ve tritium profiles in the Marmara Sea (Rank et al., 1998).

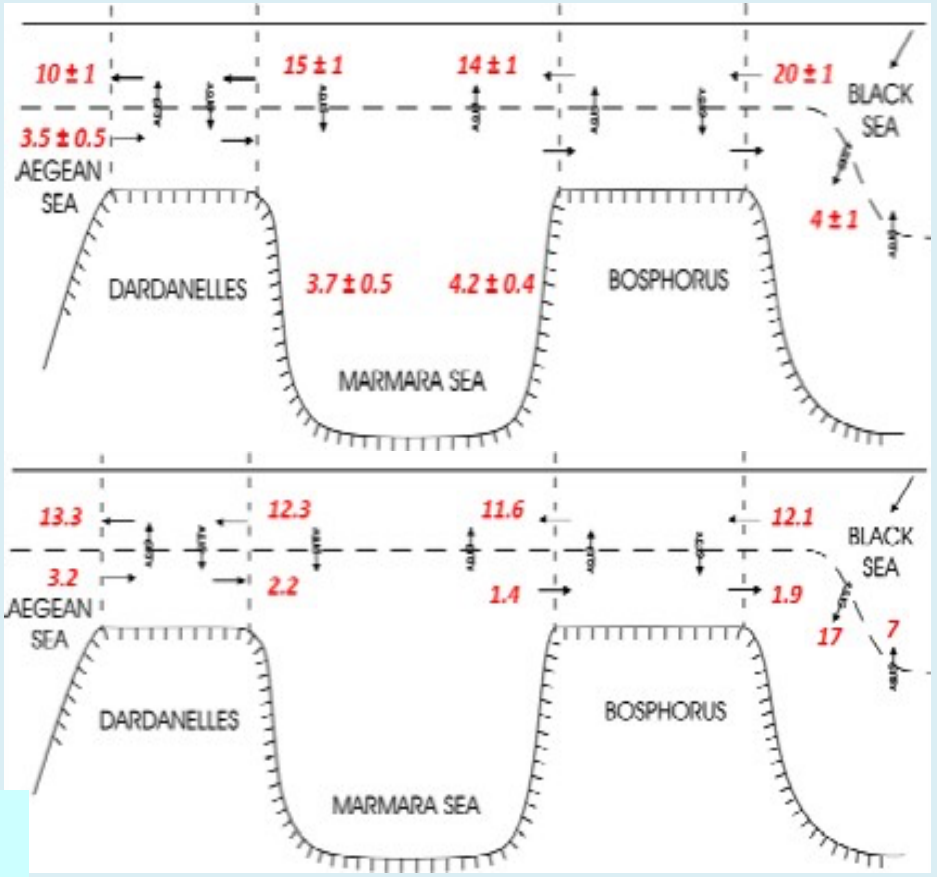
Tracers - Turkish Straits System and Black Sea



^{137}Cs vertical profiles in the Marmara Sea and Black Sea



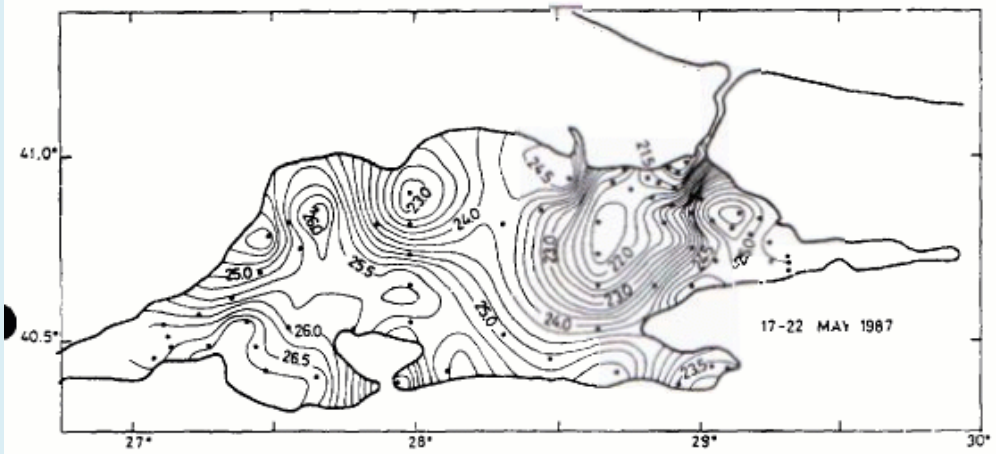
Concentration and fluxes of ^{137}Cs in the Turkish Straits System (10^{12} bq y^{-1})



Black Sea vertical fluxes by plume entrainment Özsoy et al., 1994

Volume fluxes based on Beşiktepe et al., 1994

Beşiktepe et al., 1993



Surface salınity and dynamic height (Beşiktepe et al. 1994)

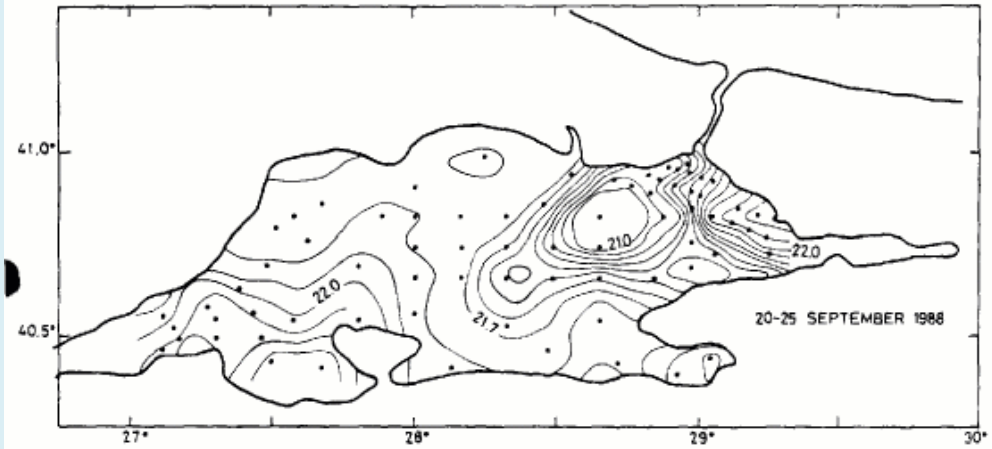


FIG.9. Distribution of surface salinity in the Marmara Sea for (a) May 1987 (b) September 1988.

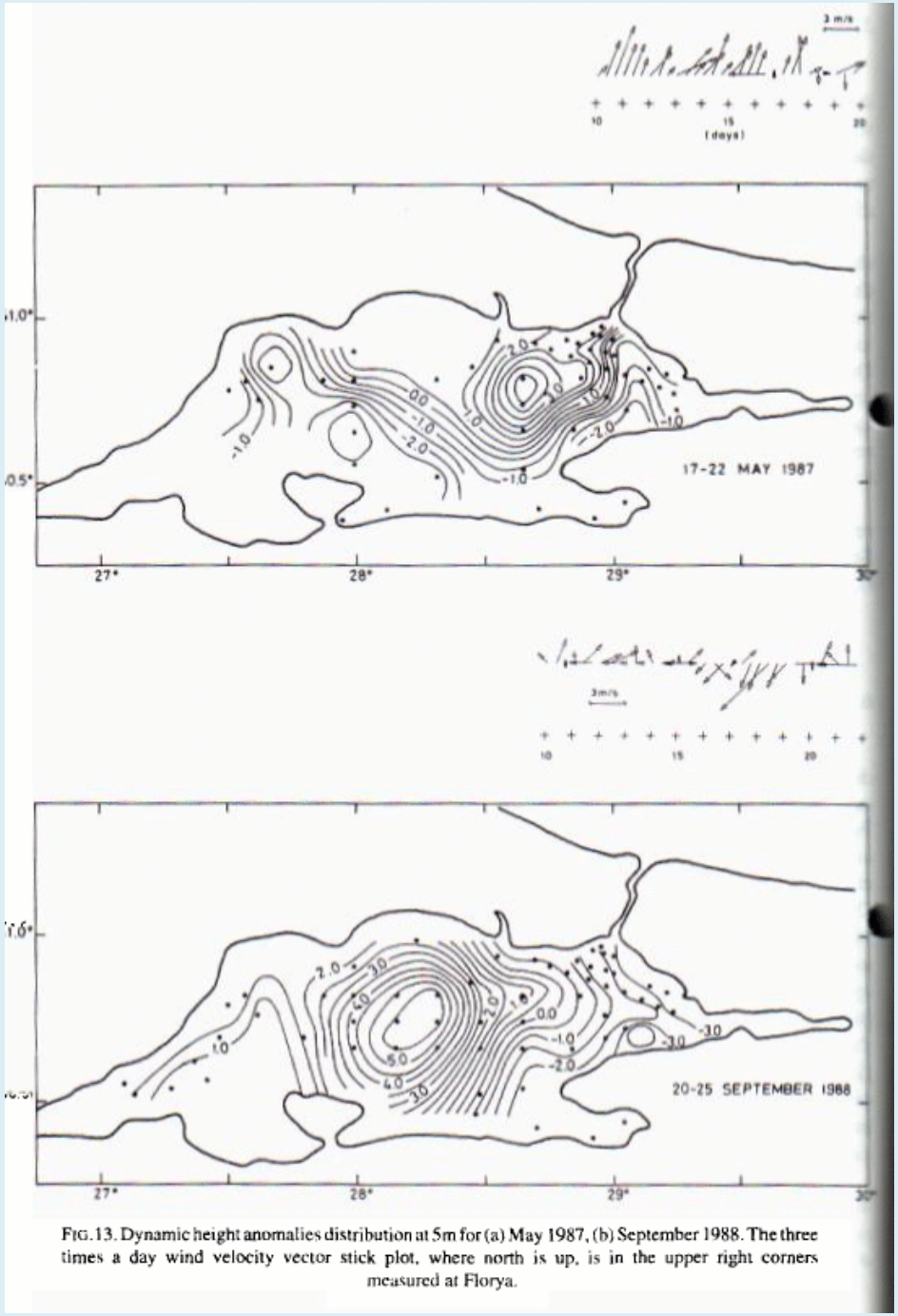
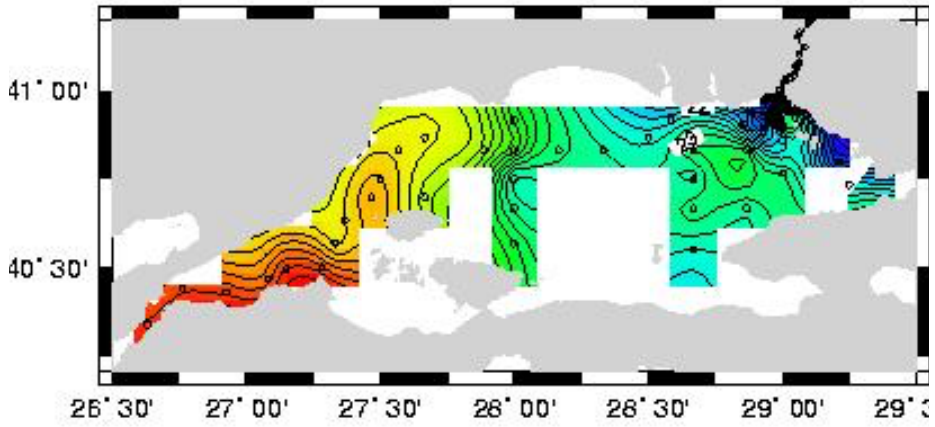
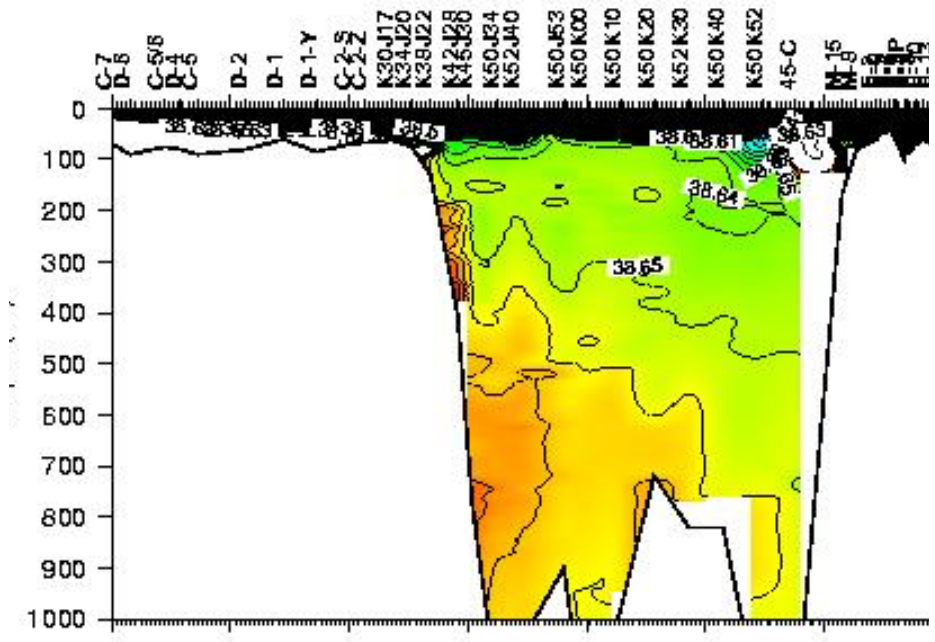
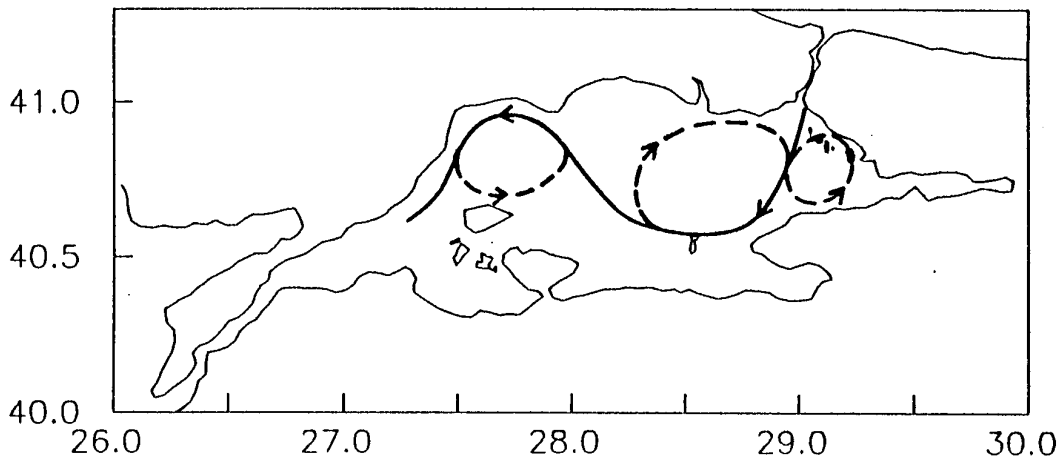


FIG.13. Dynamic height anomalies distribution at 5m for (a) May 1987, (b) September 1988. The three times a day wind velocity vector stick plot, where north is up, is in the upper right corners measured at Florya.





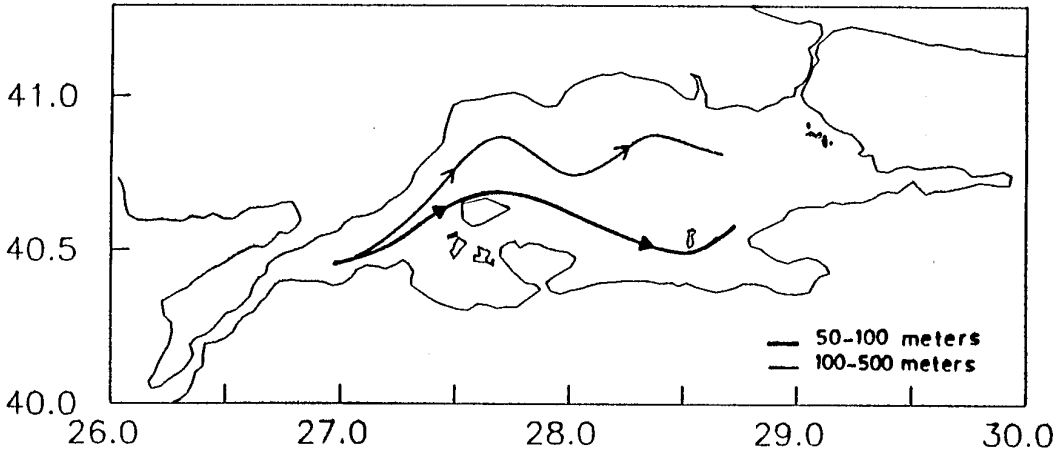
Salinity, April 1995
(Beşiktepe, 2000)

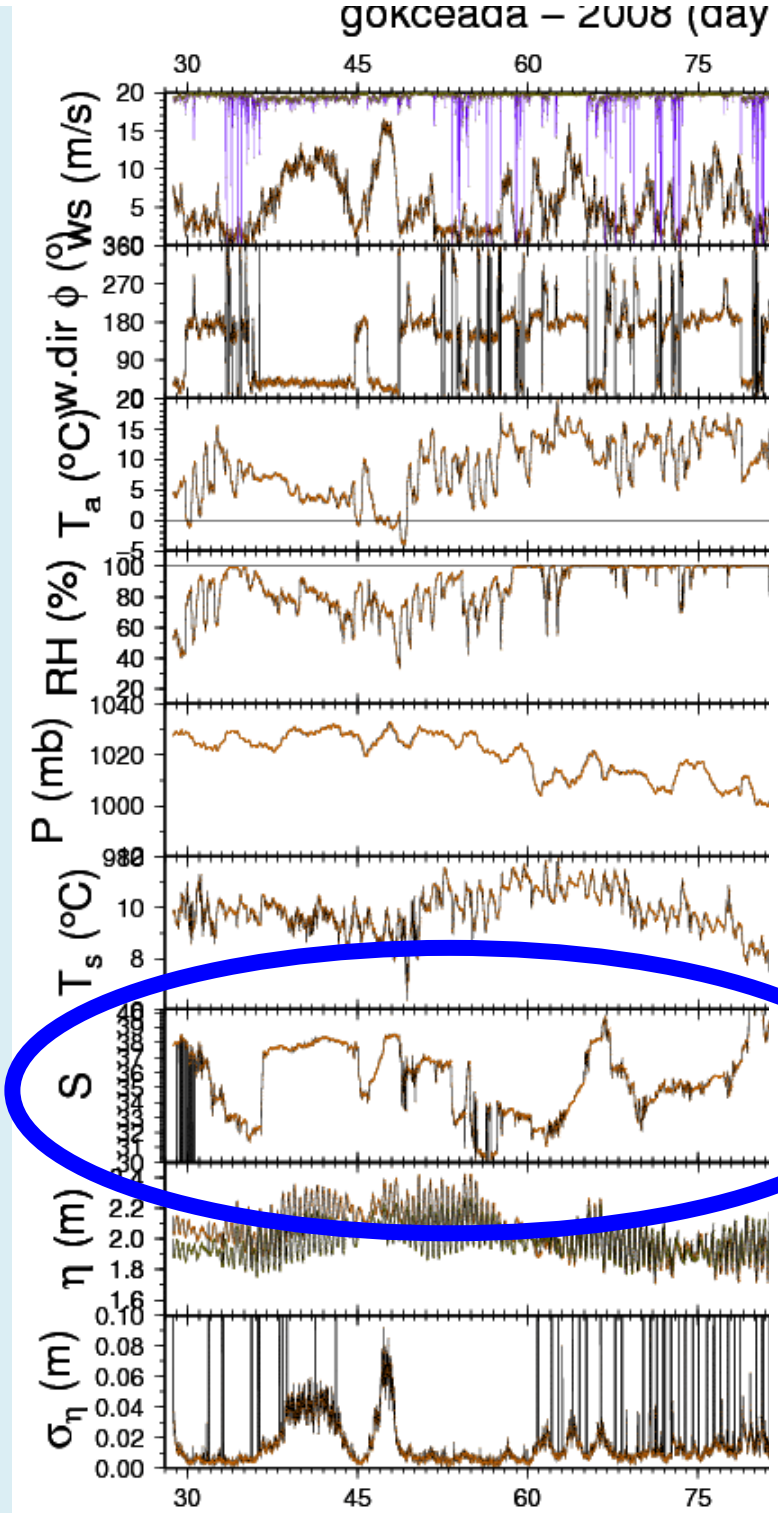


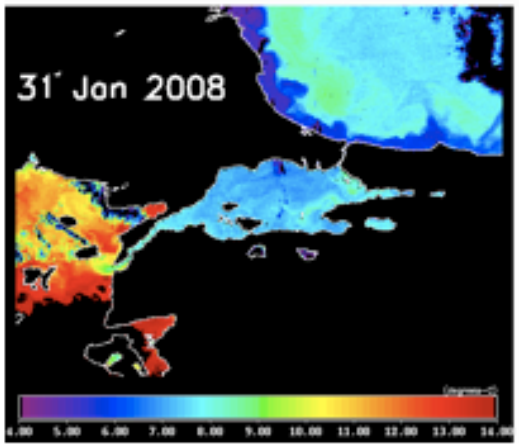
upper layer circulation

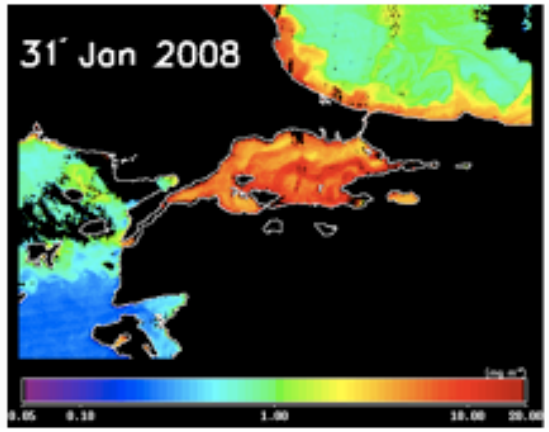
(Beşiktepe et al. 1994)

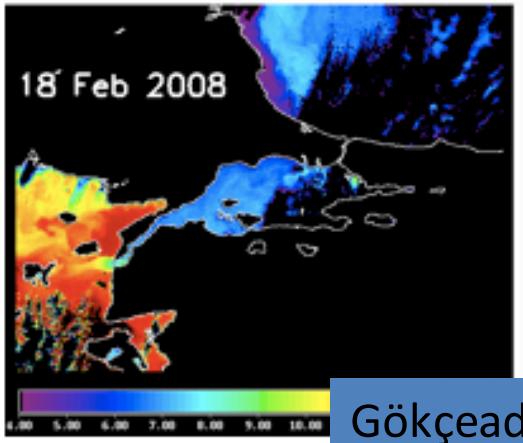
lower layer circulation

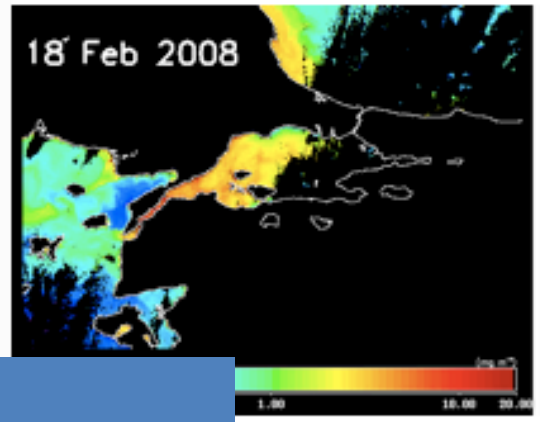




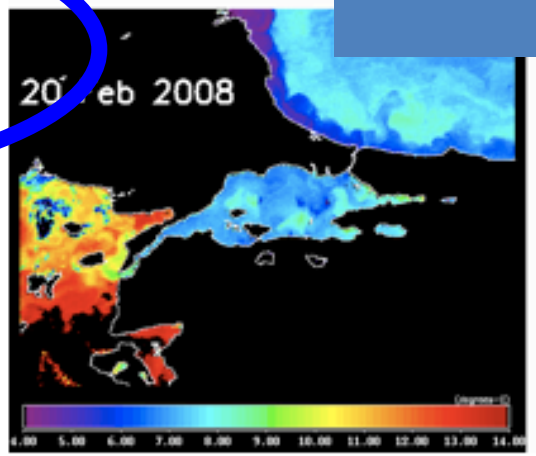


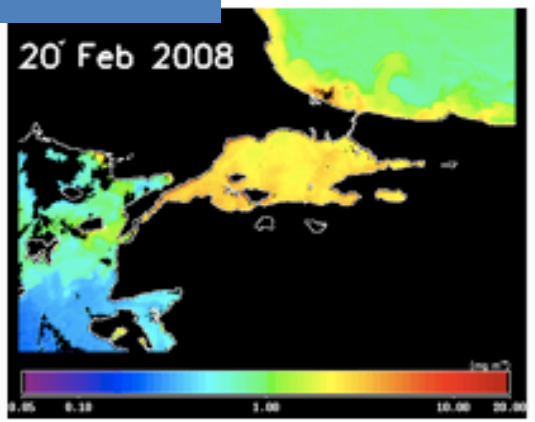




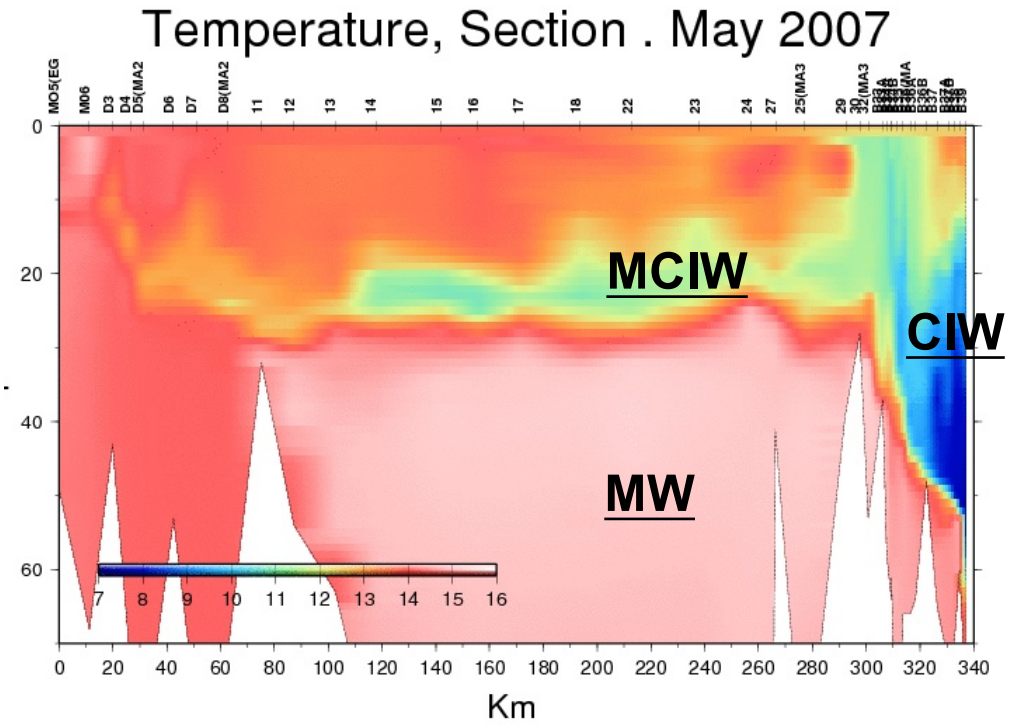


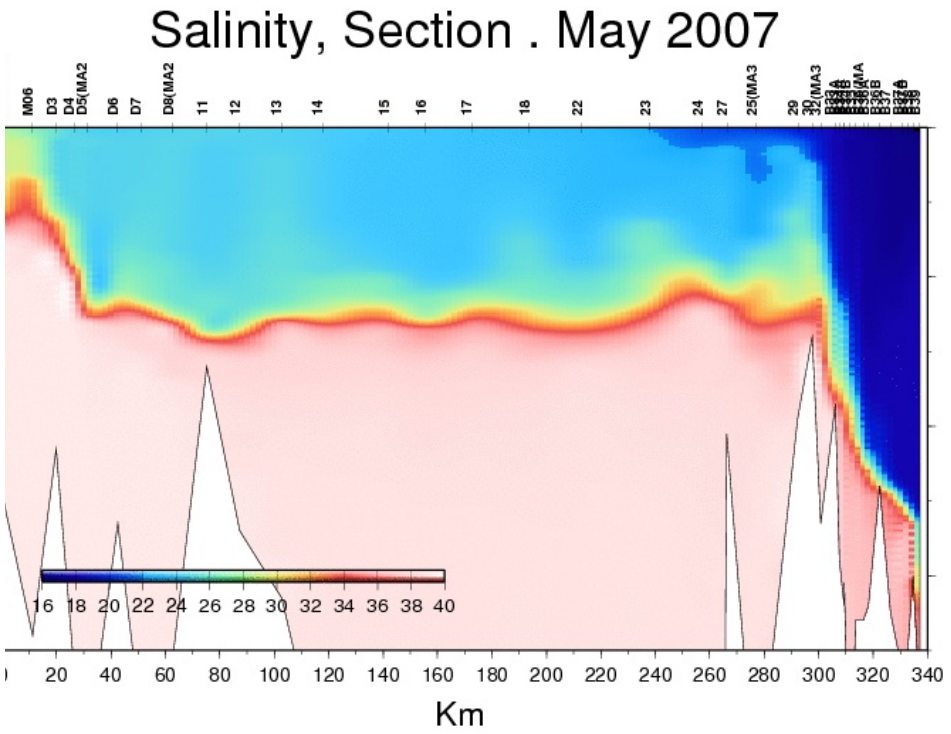
Gökçeada
Coastal station



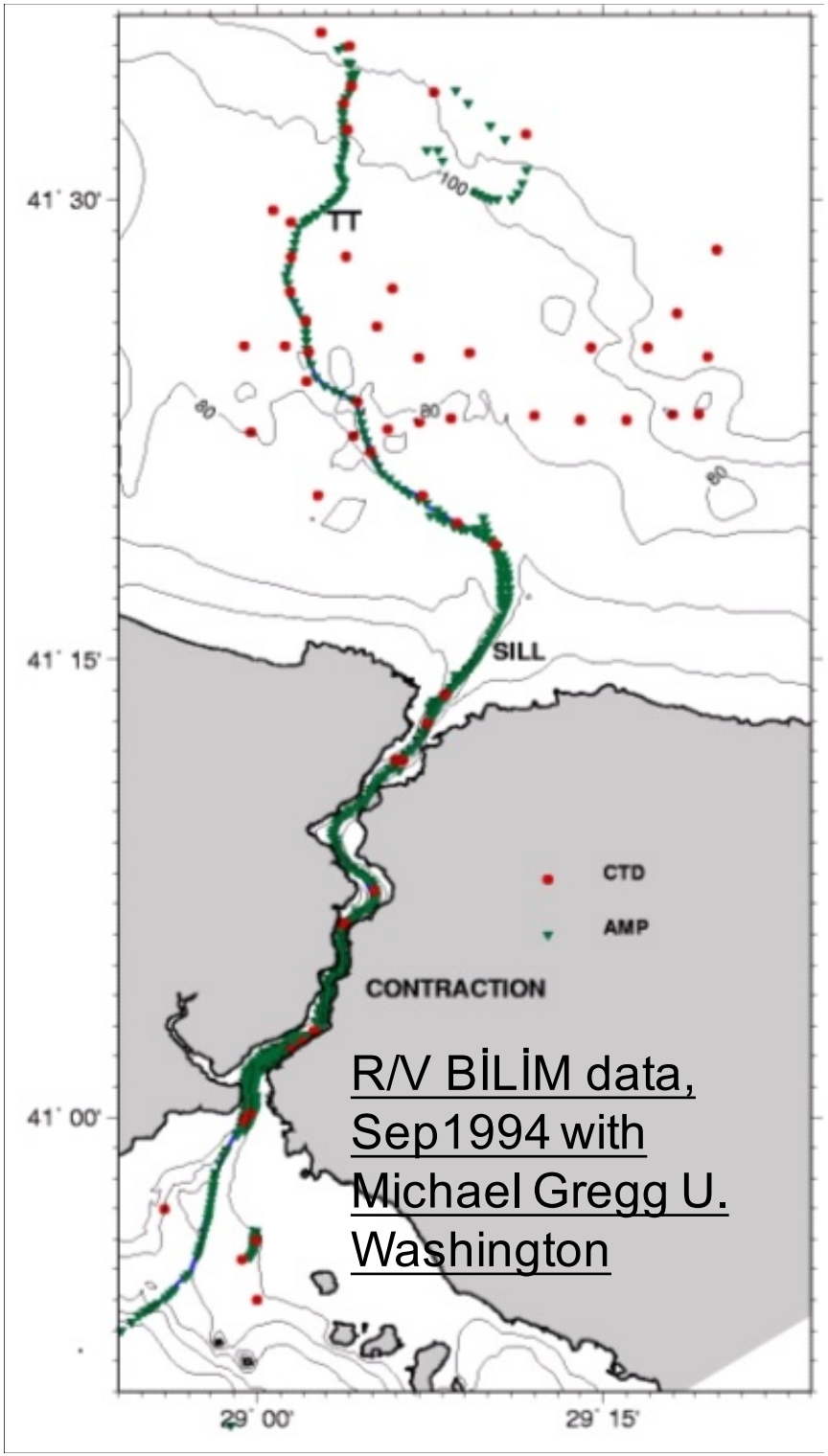


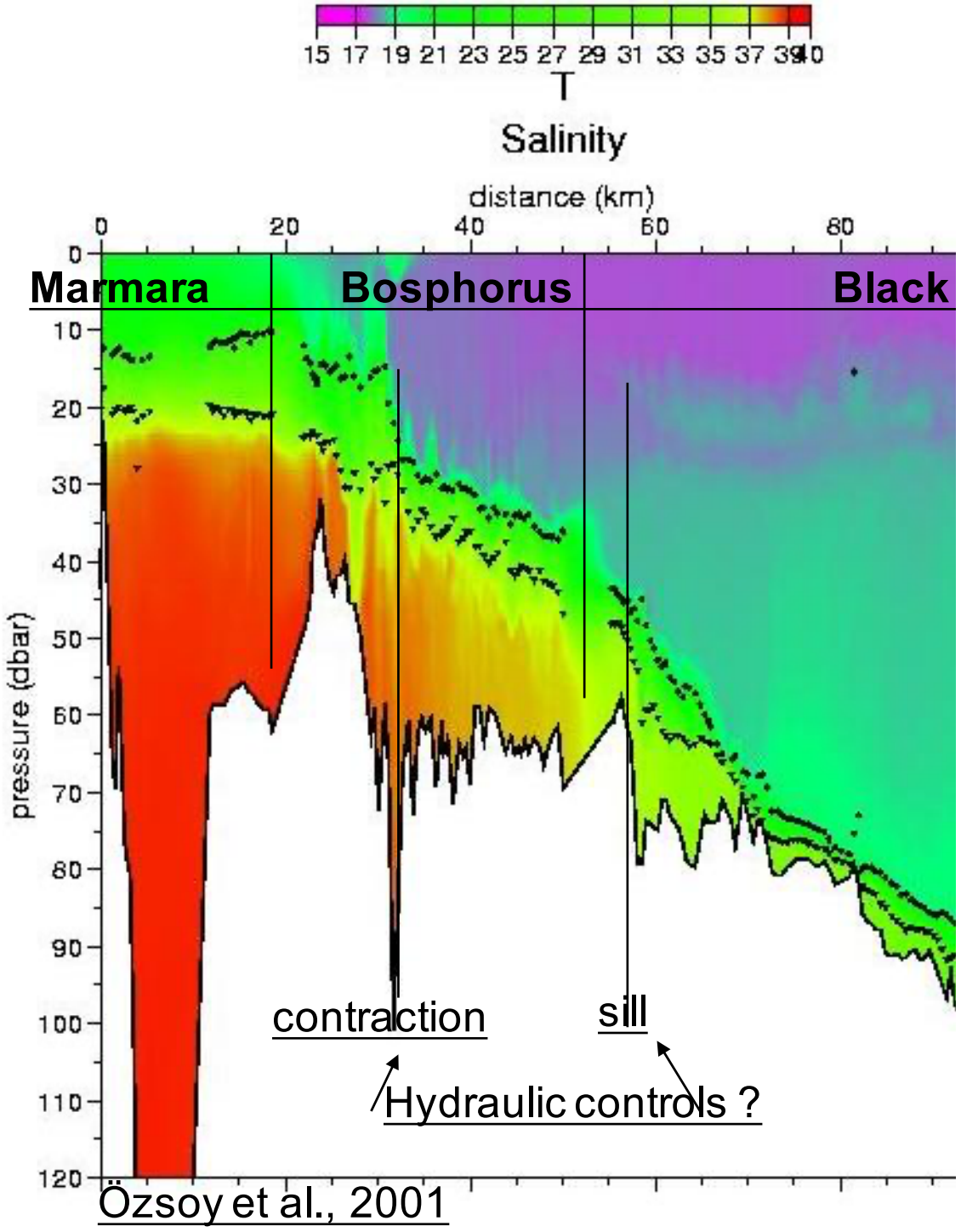
Turkish Straits System and northern Aegean Sea exchange

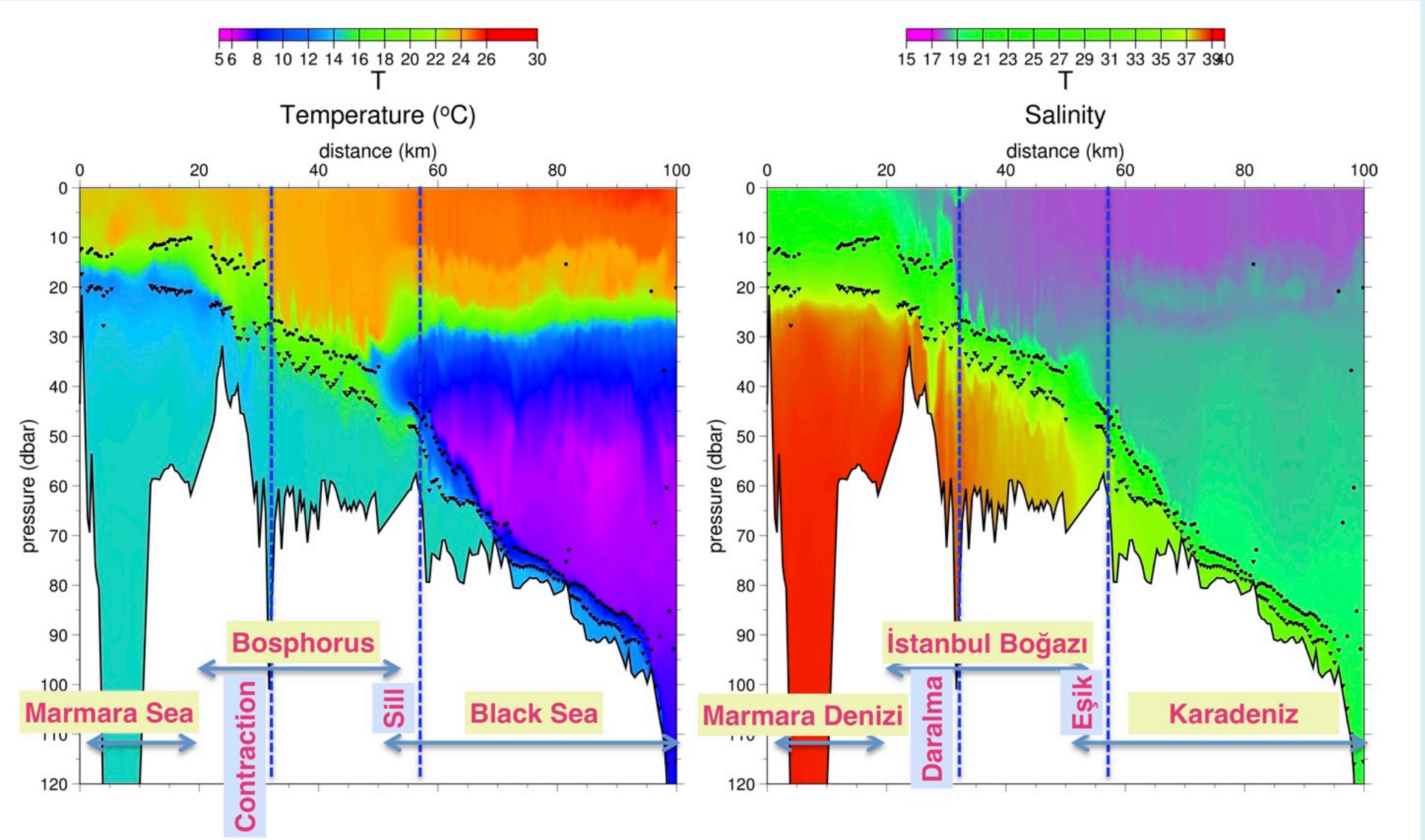




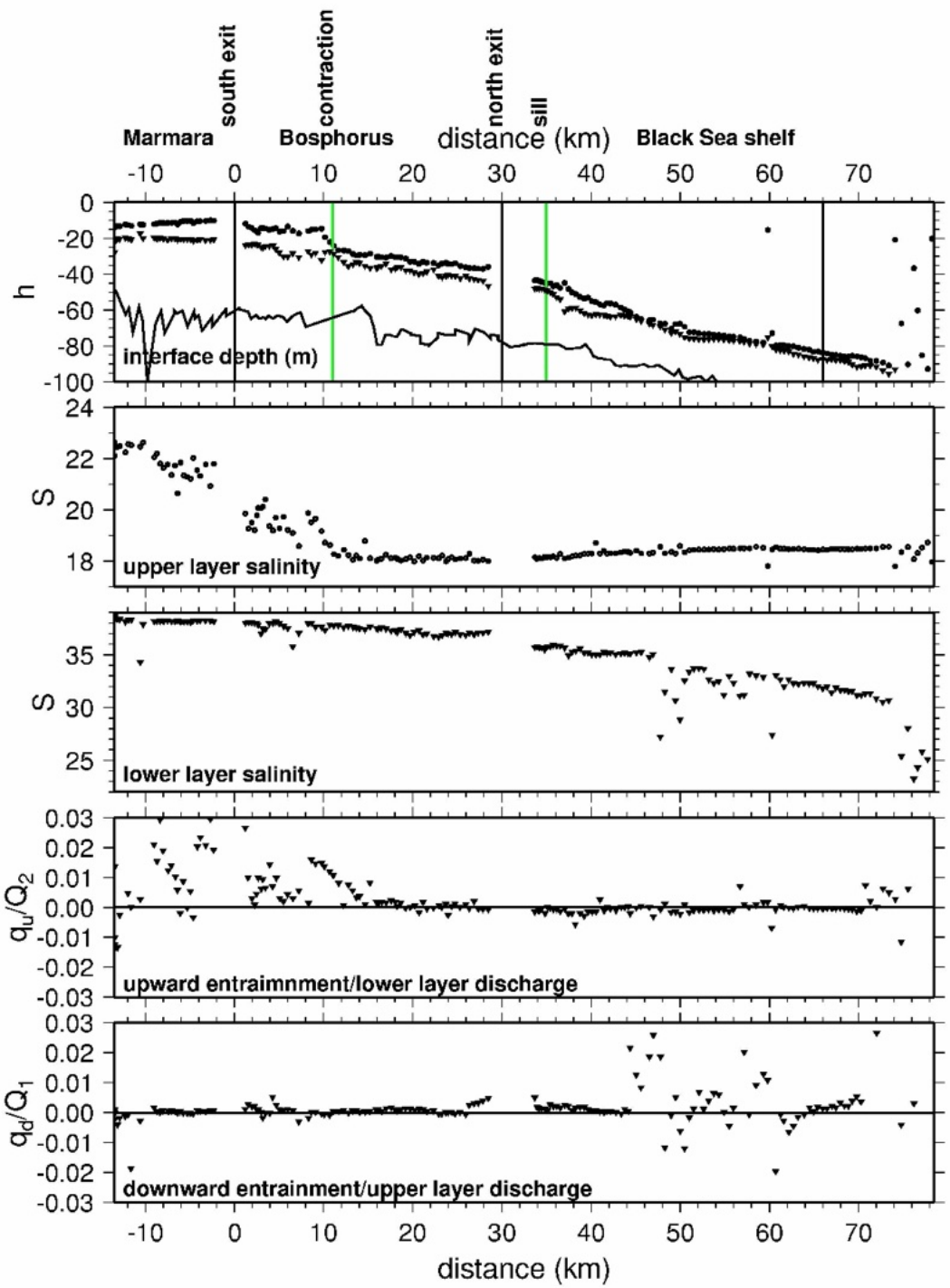
Dardanelles Strait **Marmara Sea** **Bosphorus Strait** **Black Sea**


41° 30'
41° 15'
41° 00'
29° 00'
29° 15'
100
80
80
80
SILL
CTD
AMP
CONTRACTION
R/V BİLİM data,
Sep1994 with
Michael Gregg U.
Washington

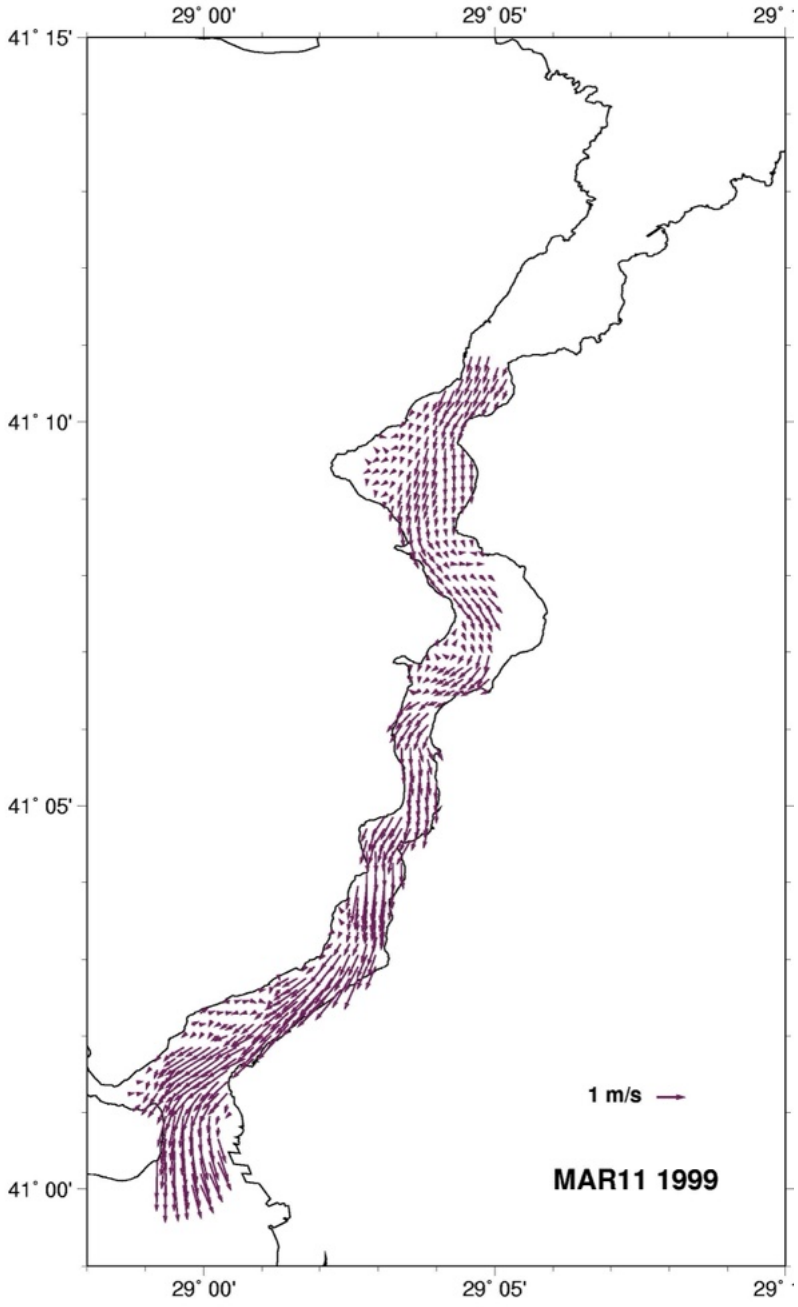

15 17 19 21 23 25 27 29 31 33 35 37 39 40
T
Salinity
distance (km)
0
20
40
60
80
Marmara
Bosphorus
Black
pressure (dbar)
0
10
20
30
40
50
60
70
80
90
100
110
120
contraction
sill
Hydraulic controls ?
Özsoy et al., 2001

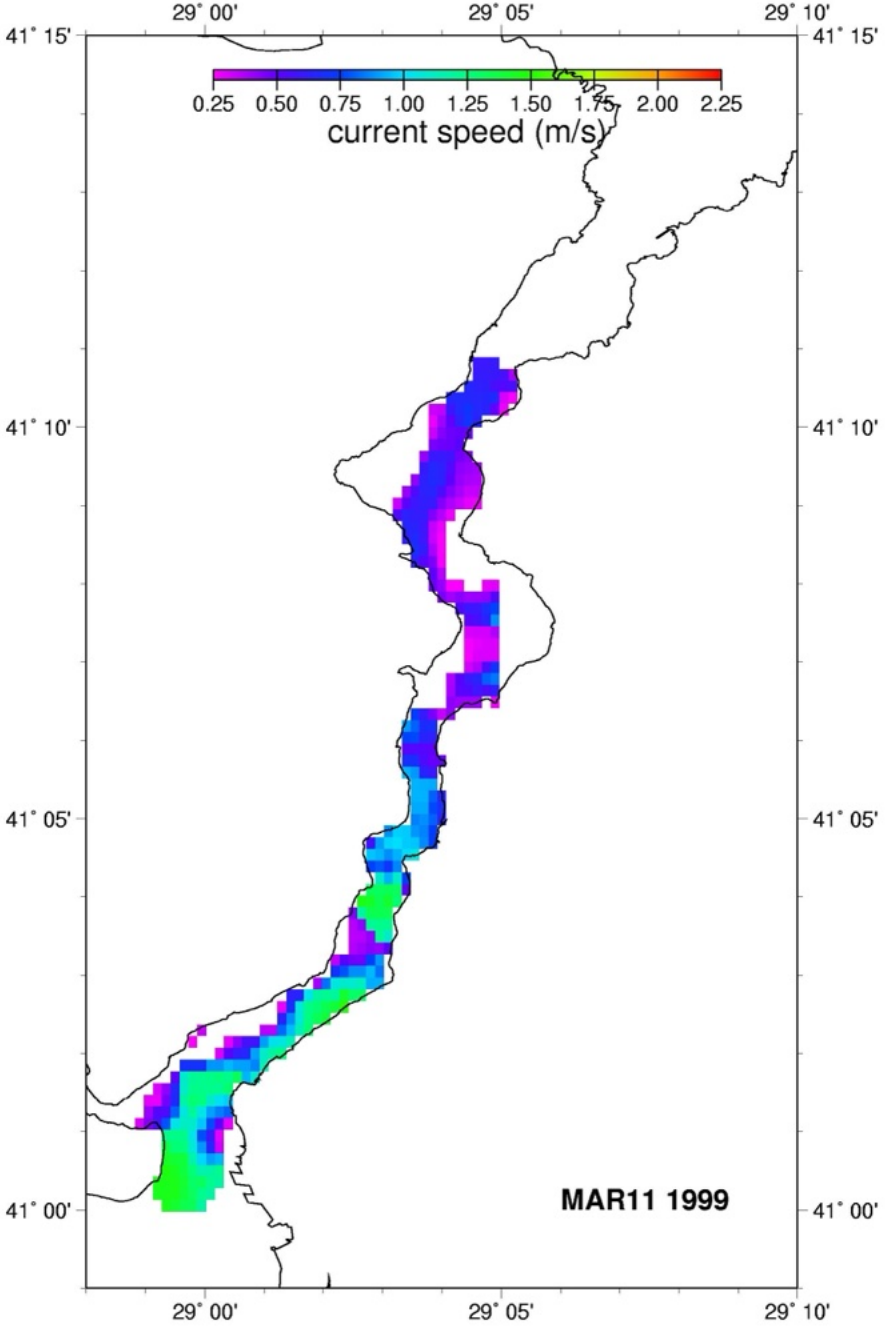


Measurements in the Bosphorus (1994)
Gregg et al., 1999; Gregg and özsoy, 1999, 2002



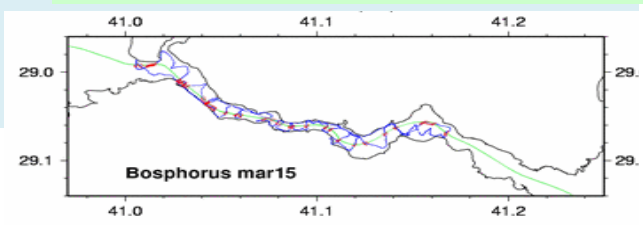
Entrainment fluxes

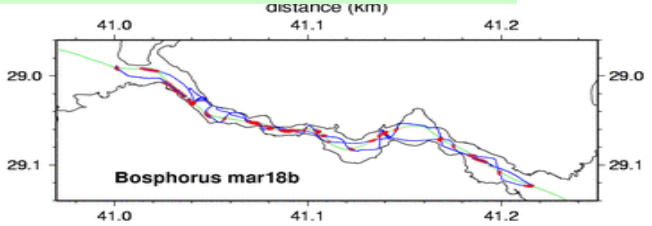

29° 00'
29° 05'
29°
41° 15'
41° 10'
41° 05'
41° 00'
1 m/s
MAR11 1999

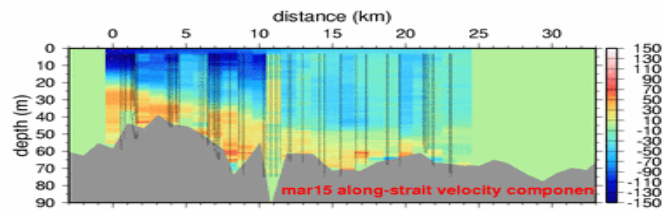

29° 00'
29° 05'
29° 10'
41° 15'
41° 10'
41° 05'
41° 00'
0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25
current speed (m/s)
MAR11 1999

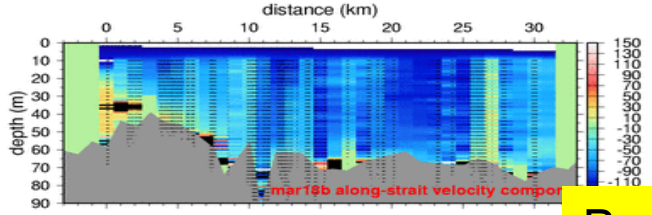
normal lower layer blocked

blocking of layered flows
In the Bosphorus
Events that influence
the circulation

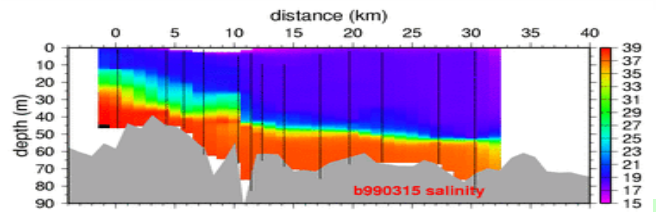


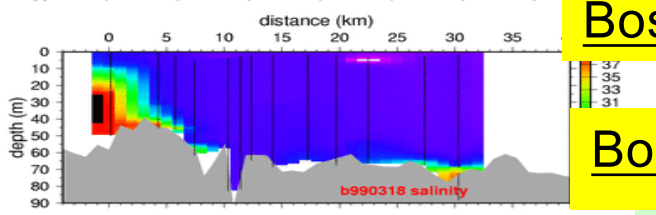






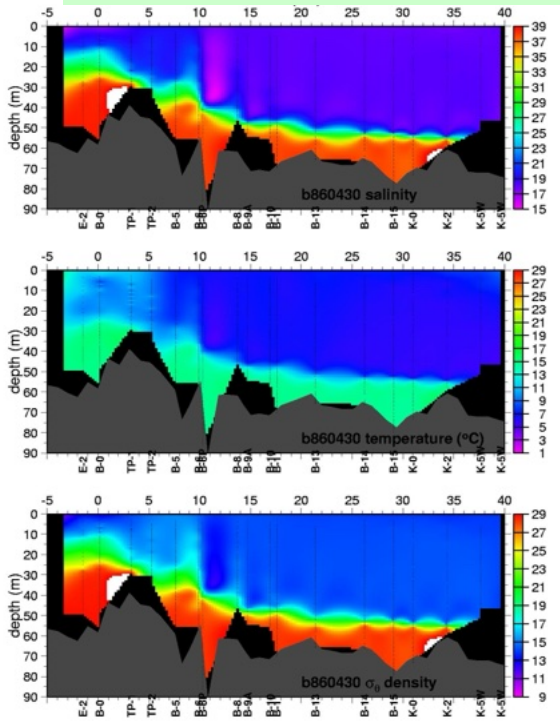
Bosphorus ADCP measurements

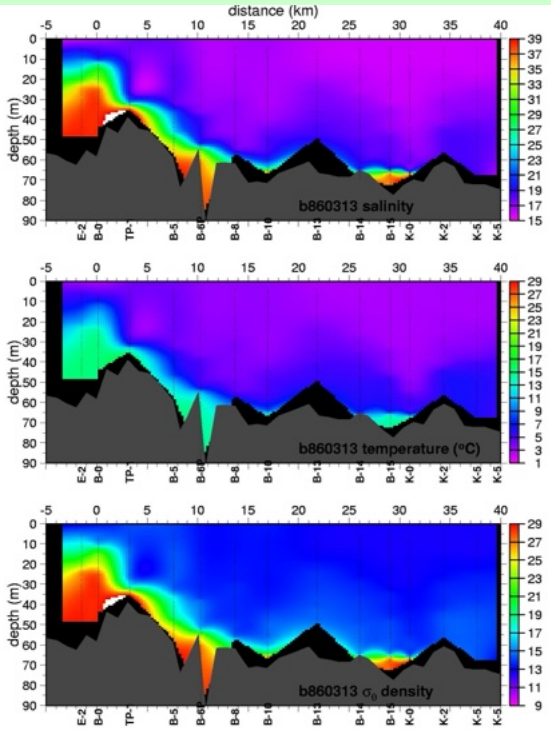


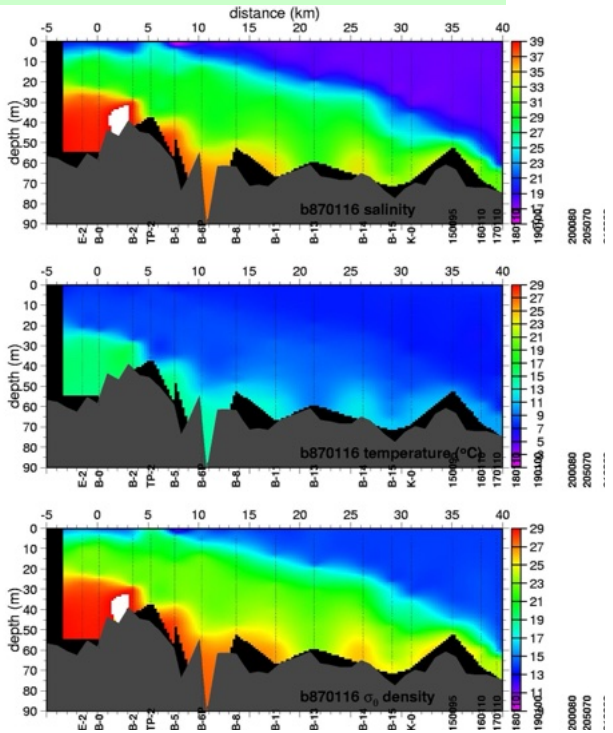


Bosphorus CTD measurements

normal lower layer blocked upper layer blocked



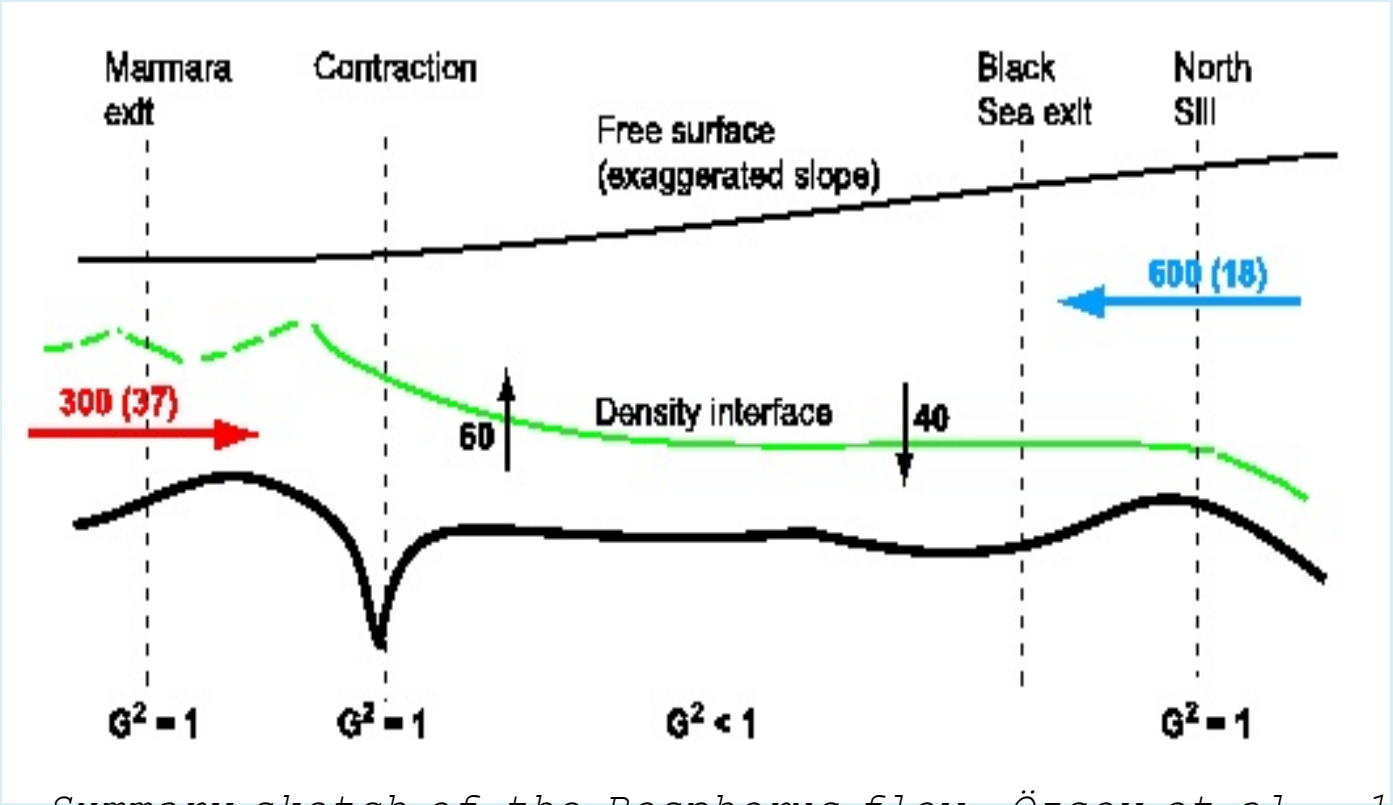




MAXIMAL EXCHANGE THEORY

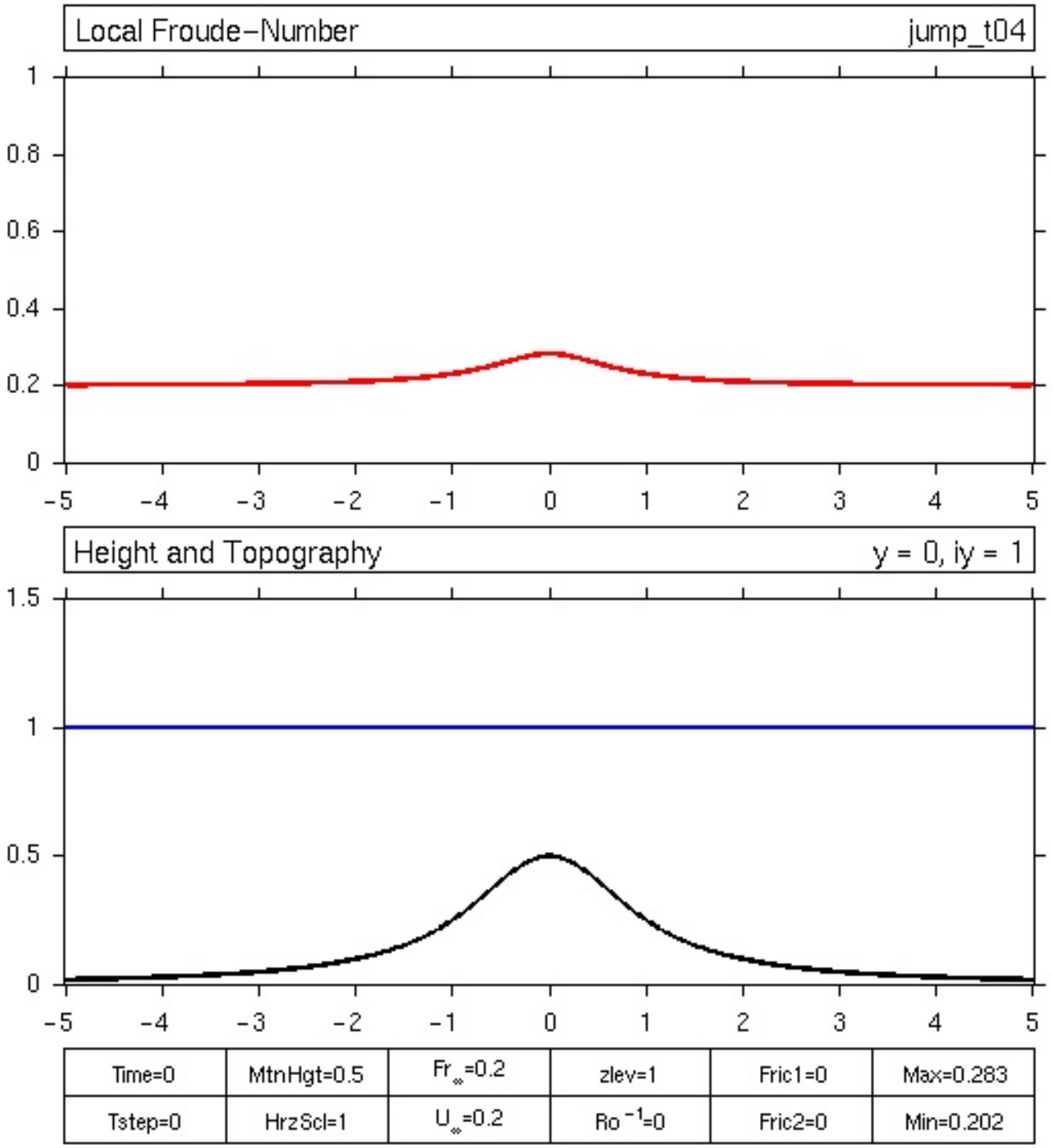
for a two-layer flow

$$F_i^2 = \frac{u_i^2}{g' h_i}, \qquad g' = g\frac{\varrho_2 - \varrho_1}{\varrho_2} \qquad G^2 = F_1^2 + F_2^2 = 1.$$



Summary sketch of the Bosphorus flow, Özsoy et al., 1998

If two topographic controls exist at north sill and the contraction, there is a unique solution fully determined by the strait. And the exchange is as greater as it can be.


Local Froude−Number
jump_t04
1
0.8
0.6
0.4
0.2
0
−5
−4
−3
−2
−1
0
1
2
3
4
5
Height and Topography
y = 0, iy = 1
1.5
1
0.5
0
Time=0
MtnHgt=0.5
Fr∞=0.2
zlev=1
Fric1=0
Max=0.283
Tstep=0
HrzScl=1
U∞=0.2
Ro−1=0
Fric2=0
Min=0.202

Composite Froude Number
Analogue of Mach Number in aerodynamics

$$G^2 = F_1^2 + F_2^2 = \frac{U_1^2}{g' h_1} + \frac{U_2^2}{g' h_2} = 1 \qquad \text{(Eq. 3.13)}$$

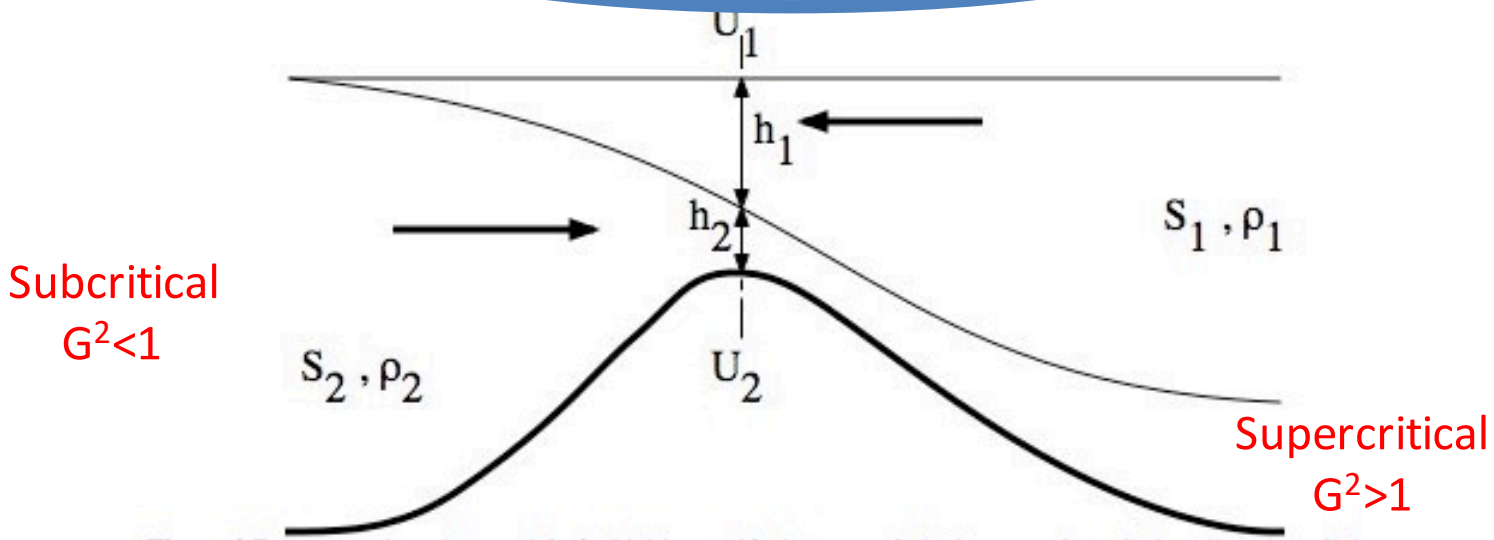


Figure 3.7. A general section model of a highly stratified estuary. Q_j is the water flow, S_j describes the salinity over the j-th border (Tomczak, 1998.)

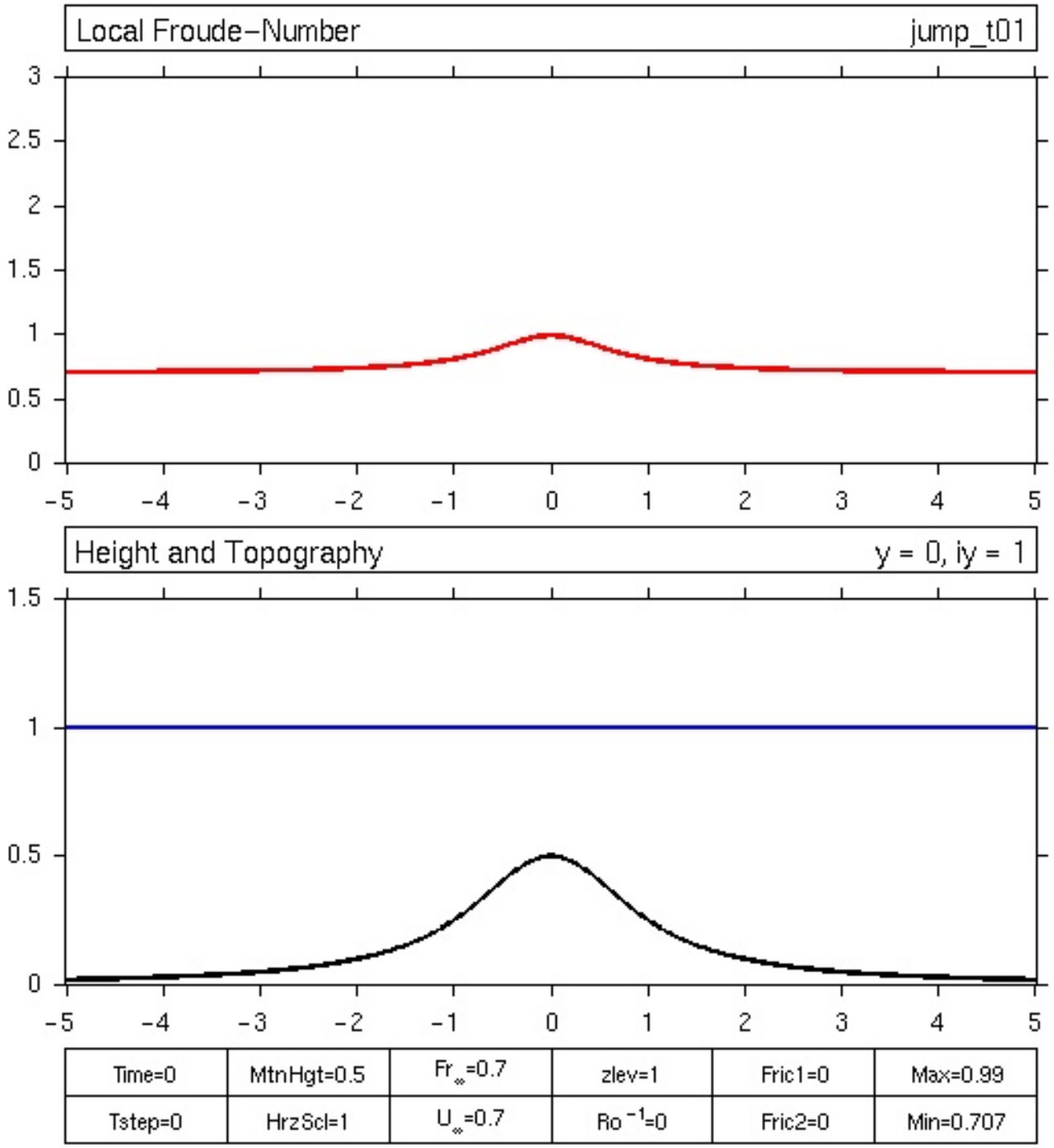
where $g' = g\Delta\varrho / \varrho = g(S_2\text{-}S_1) / S_2\,\varrho$ is the reduced gravity and U_1 and U_2 are the velocities in each layer. The situation is shown in Figure 3.7 and is usually applicable to fjord-like estuaries.

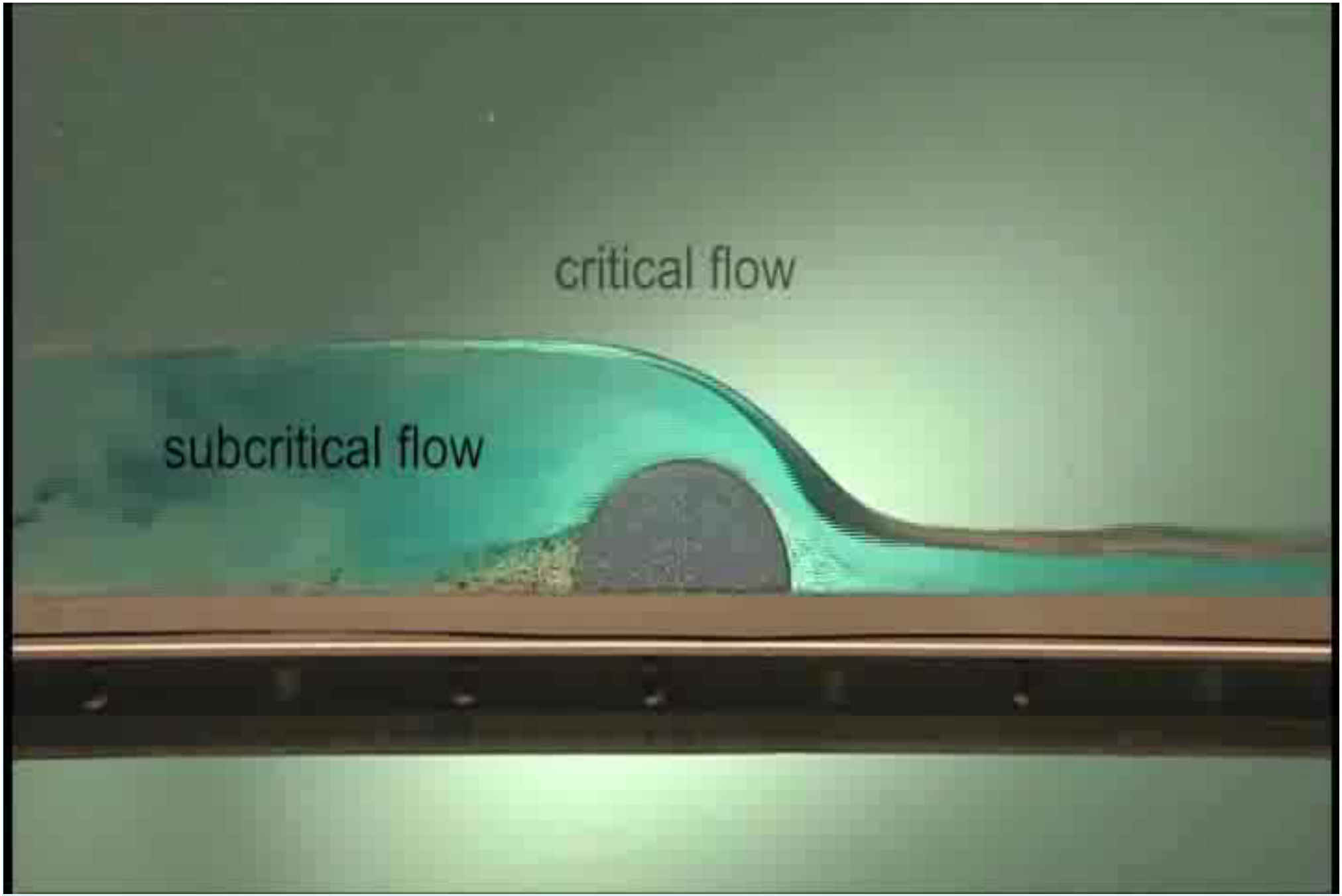
The sill has a width B and depth H, the freshwater inflow to the estuary is Q_f. Setting $u_1h_1 = q_1 = Q_1/B$, $u_2h_2 = q_2 = Q_2/B$ and $q_f = Q_f/B$ and defining the relative layer thickness as

$$h_1 = (1-\eta)H;\ \ h_2 = \eta H \qquad \text{(Eq. 3.14)}$$

gives together with Eq. 3.13 the dynamic sill condition i terms of q.

$$\frac{q_1^2}{(1-\eta)^3} + \frac{q_2^2}{\eta^3} = g' H^3 \qquad \text{(Eq. 3.15)}$$

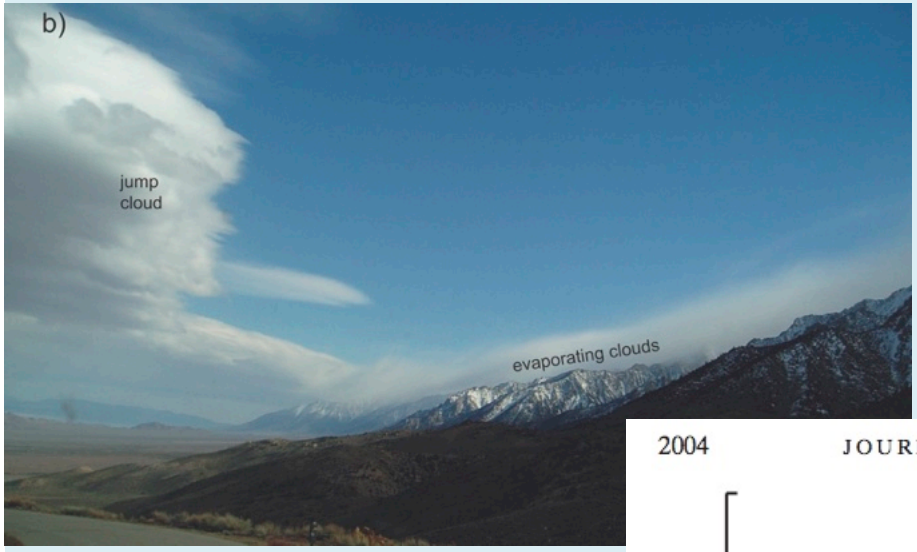

Local Froude–Number
jump_t01
3
2.5
2
1.5
1
0.5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
Height and Topography
y = 0, iy = 1
1.5
1
0.5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
Time=0
MtnHgt=0.5
Fr∞=0.7
zlev=1
Fric1=0
Max=0.99
Tstep=0
HrzScl=1
U∞=0.7
Ro⁻¹=0
Fric2=0
Min=0.707


critical flow
subcritical flow

Hydraulic jump in boat’s wake

Circular hydraulic jump in kitchen sink

Armi and Mayr, 2011, J. Appl. Met. Clim.
The Descending Stratified Flow and Internal Hydraulic Jump
In the Lee of the Sierras



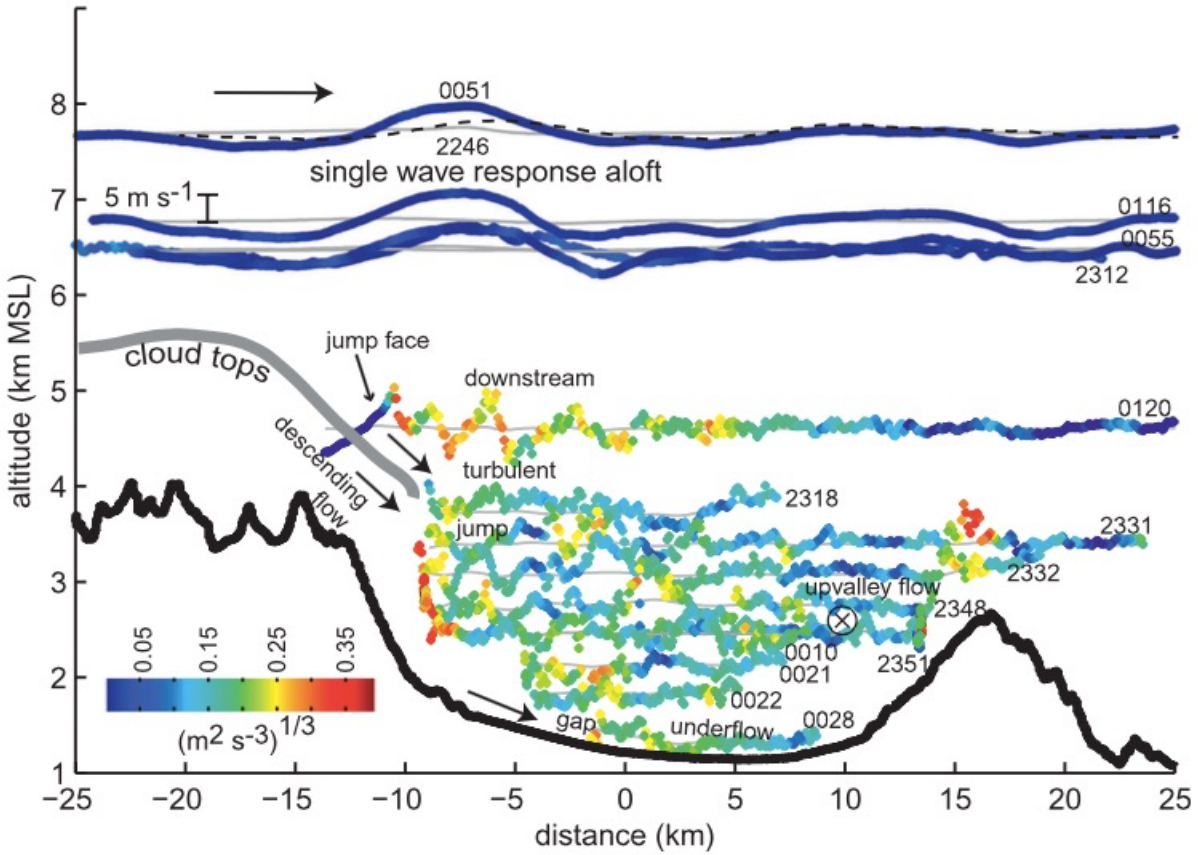


FIG. 10. Vertical cross section of King Air aircraft data approximately from west to east: vertical wind speed (m s^{-1}) is shown as lines oscillating around aircraft tracks and color coded with the u component of the turbulent dissipation rate [color bar; $(m^2\ s^{-3})^{1/3}$]. The early leg at 7.7 km is dashed for clarity.

Hydraulic jump in boat’s wake


© Mark Van Coller/Solent

Straits Modeling

Bosphorus and Dardanelles

Barbary Macaques

The Flow of Atlantic Water Through the Strait of Gibraltar

DAVID M. FARMER and LAURENCE ARMI

The Flow of Mediterranean Water Through the Strait of Gibraltar

LAURENCE ARMI and DAVID M. FARMER

1988

DEDICATION

This work is dedicated to our friends, the Barbary Apes, who for centuries have observed the Strait of Gibraltar from their home on the Rock, and to our other stern critics and colleagues.

Ilıcak and Armi, 2011

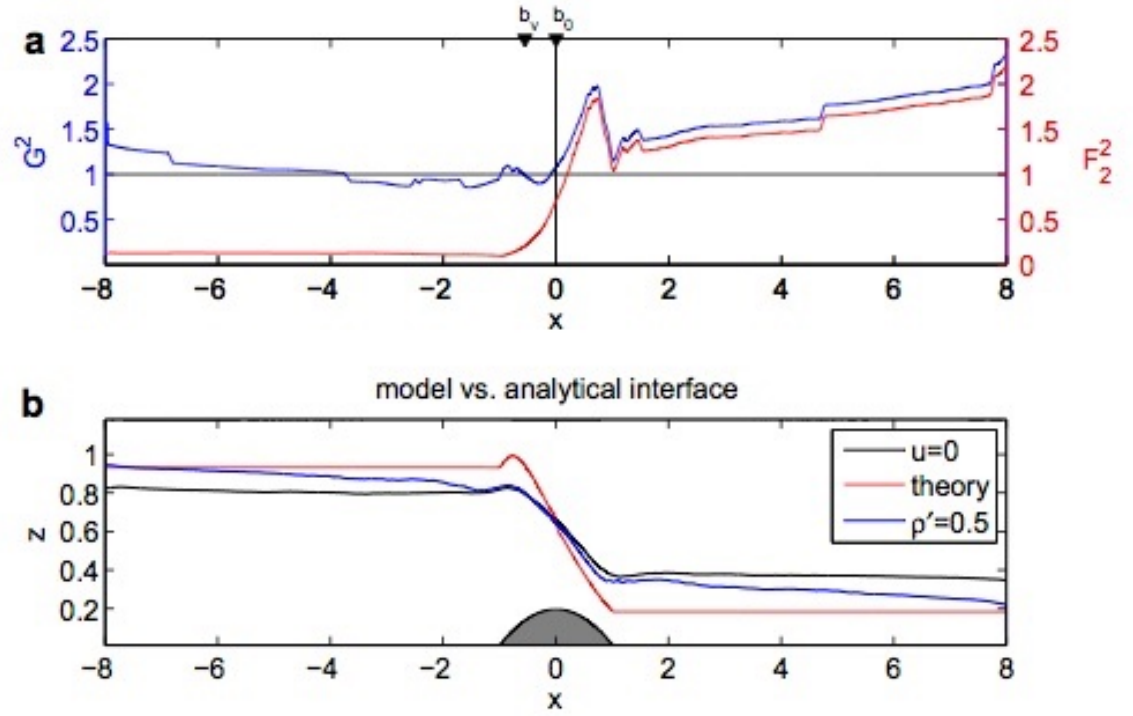


Fig. 7. (a) G^2 and F_2^2 for *geom*1, location of the virtual control is shown with an arrow. (b) Analytical and modeled interface heights for *geom*1.

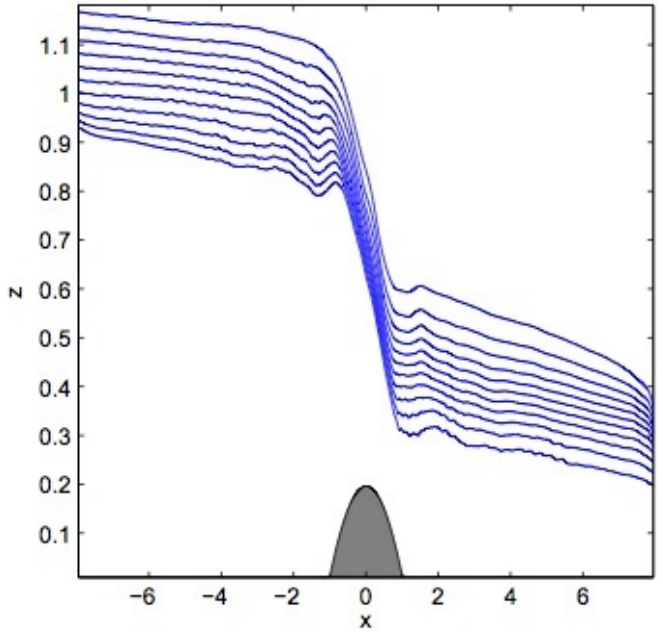


Fig. 6. Time-averaged density field for *geom*1. Contour interval is every 0.05 between $\rho' = 0.25$ and $\rho' = 0.55$.

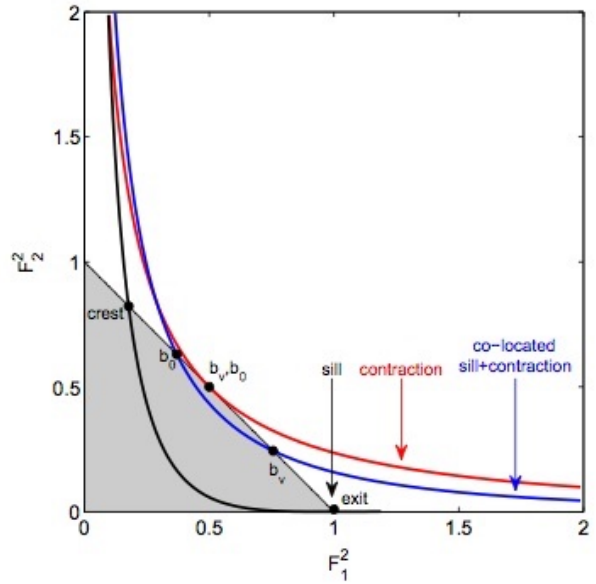
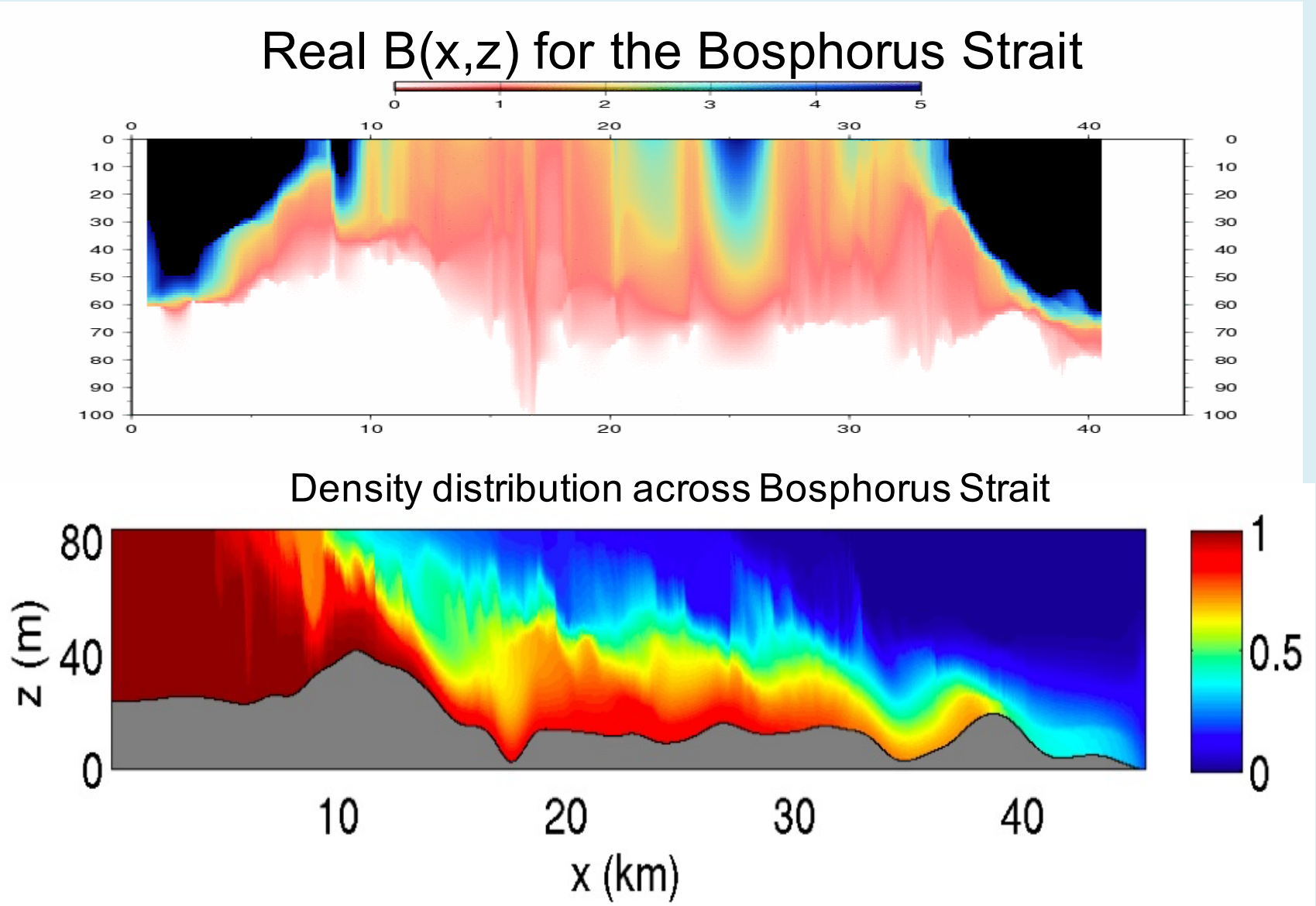
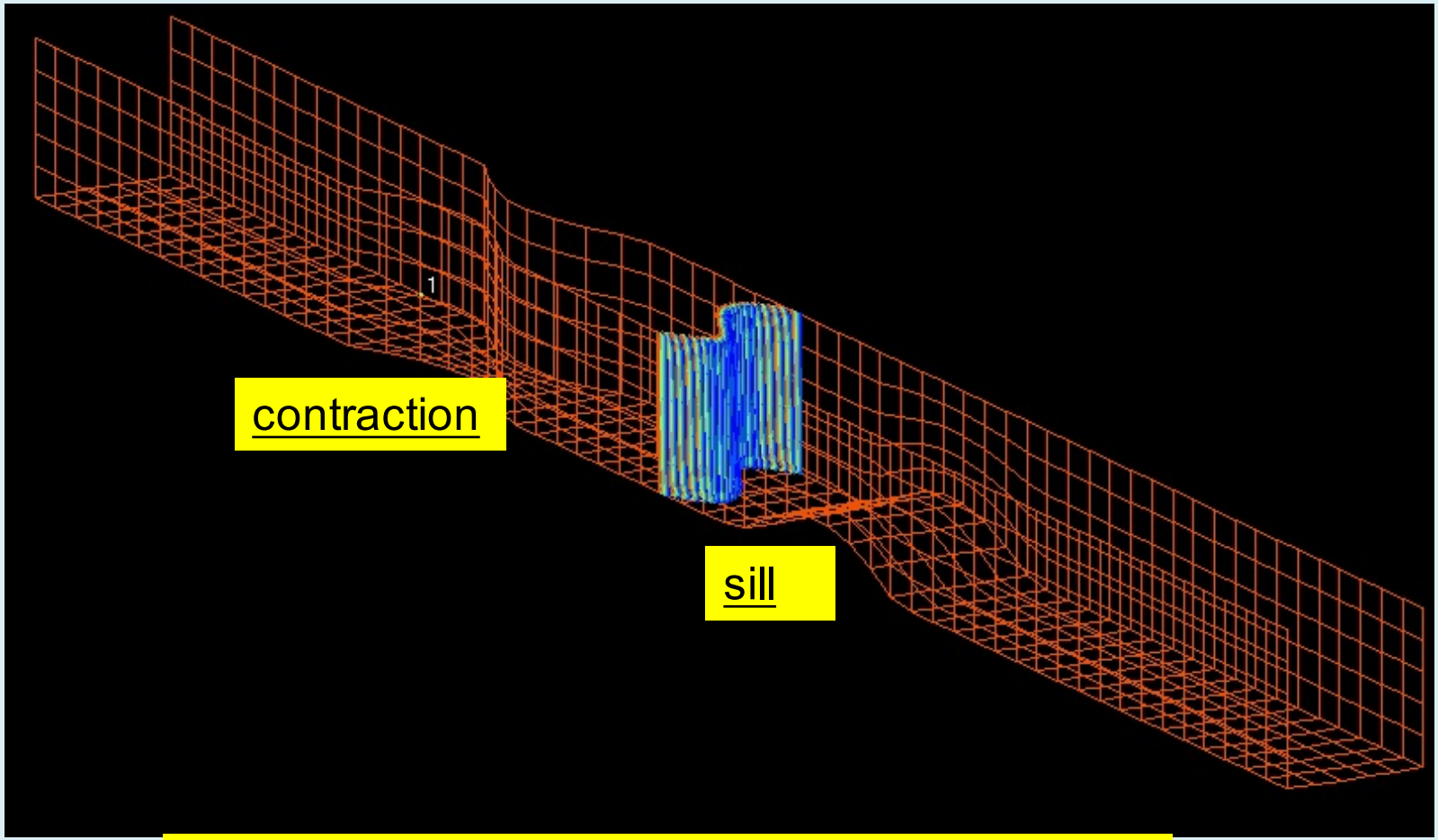


Fig. 2. Froude number plane for maximal exchange ($q_r = 1$) for different geometries. The subcritical region is shaded. In the sill case, the control points are at the crest and exit of the channel. In the contraction case, virtual and topographic controls (b_v,b_0) coincide at the narrow. In the co-located sill and contraction case, virtual control (b_v) is on the dense side of the topographic control (b_0).



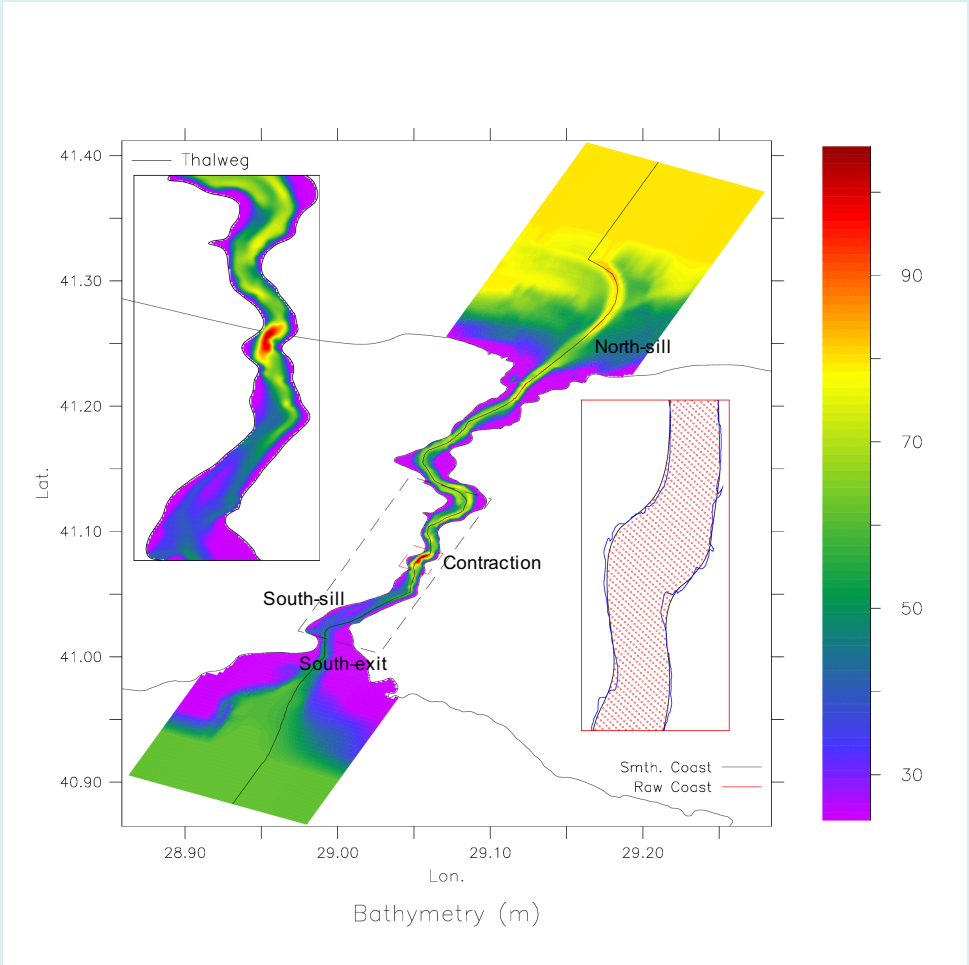
Ilıcak, Özgökmen, Özsoy, Fischer, 2009. Non-hydrostatic Modeling of Exchange Flows Across Complex Geometries, Submitted - Ocean Modelling



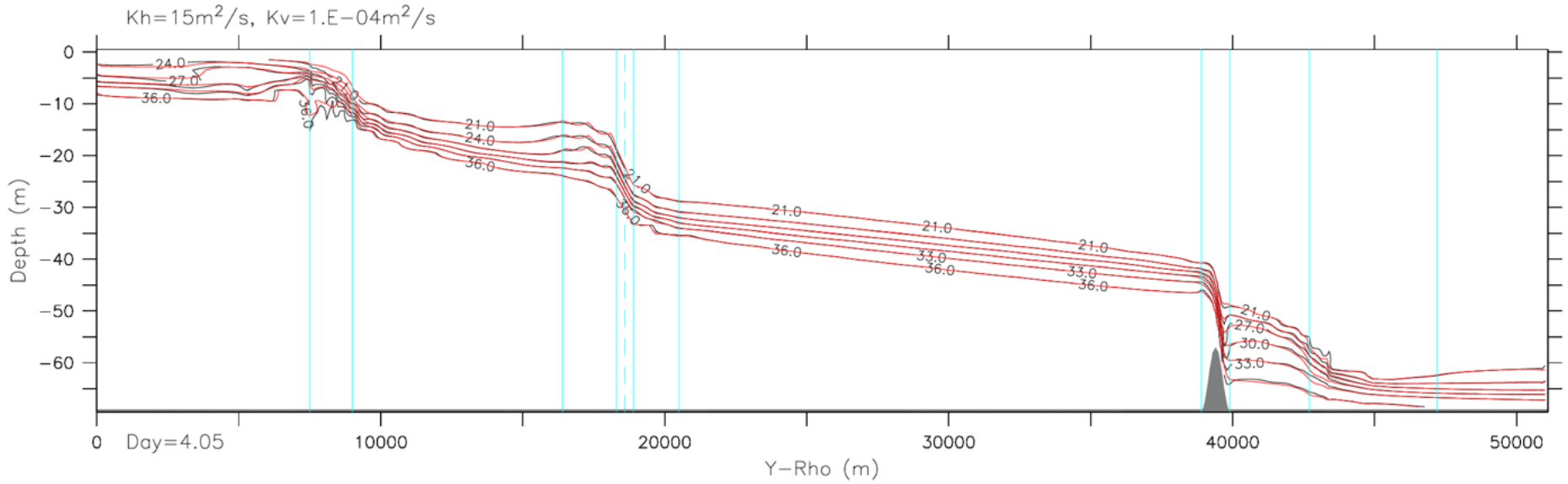
Simulation of idealized hydraulic controls
(contraction and sill)
Idealized Bosphorus Strait
Tamay Özgökmen (RSMAS, University ofMiami)

ROMS OCEAN MODEL
BOSPHORUS

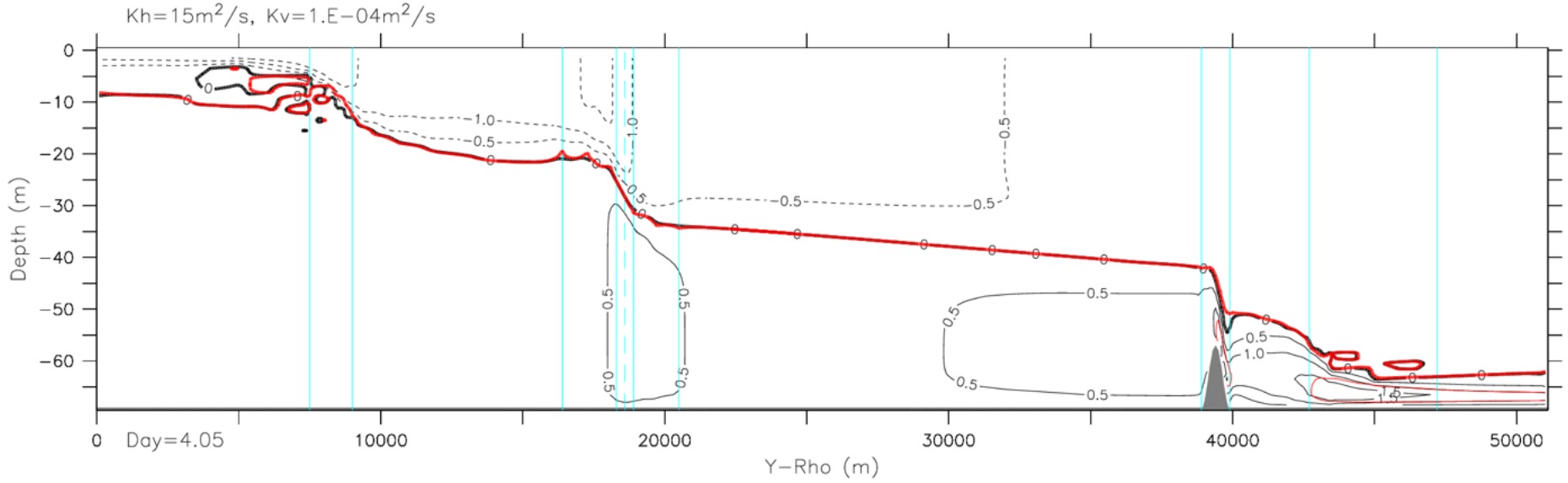
MODEL CONFIGURATION



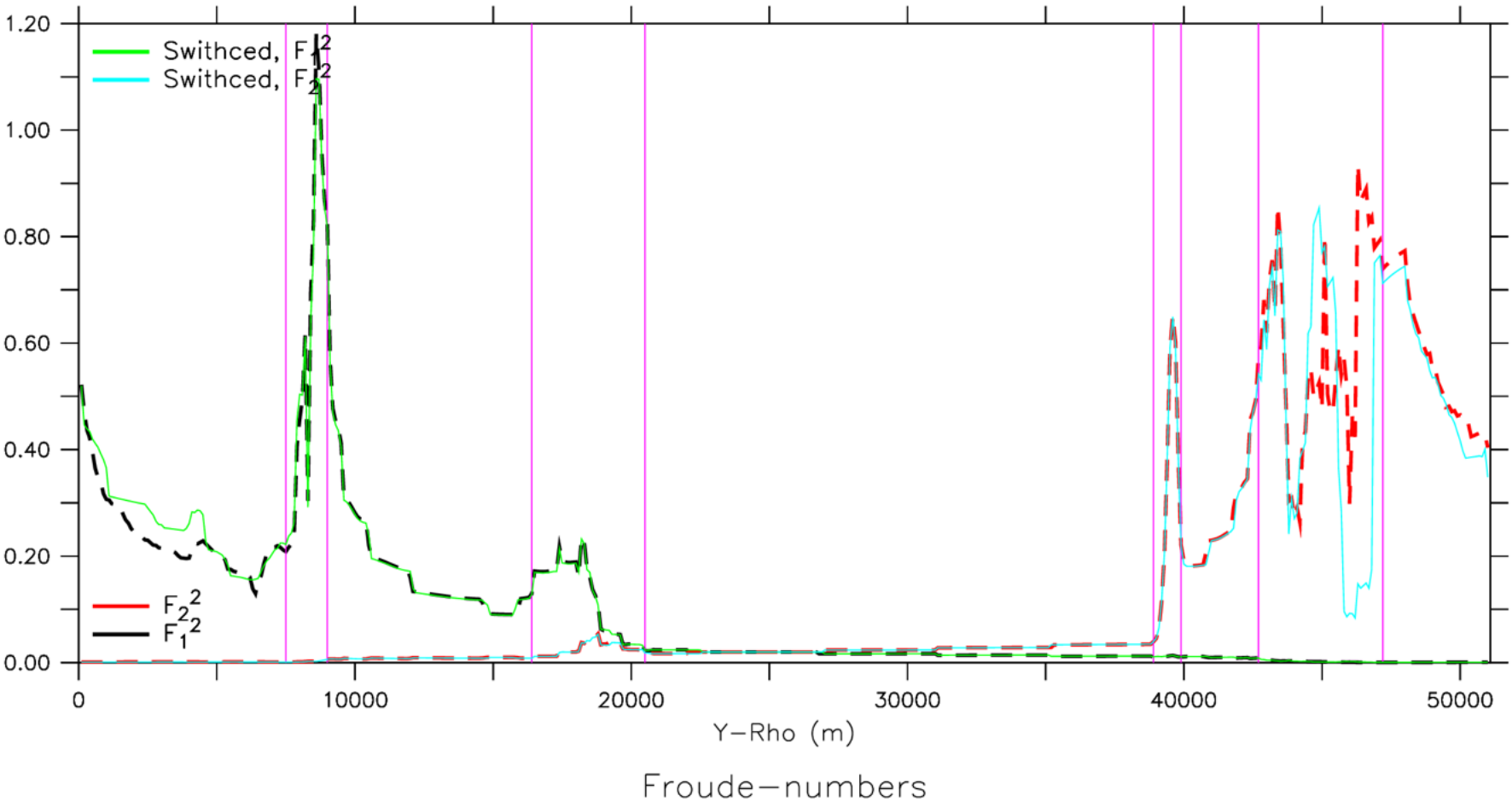
- Irregular coastline and highly variable bathymetry
- Heterogenous structure
- Complex 3d physical interactions
- Demand of high resolution
- In the past: simplified models due to limited computer resources



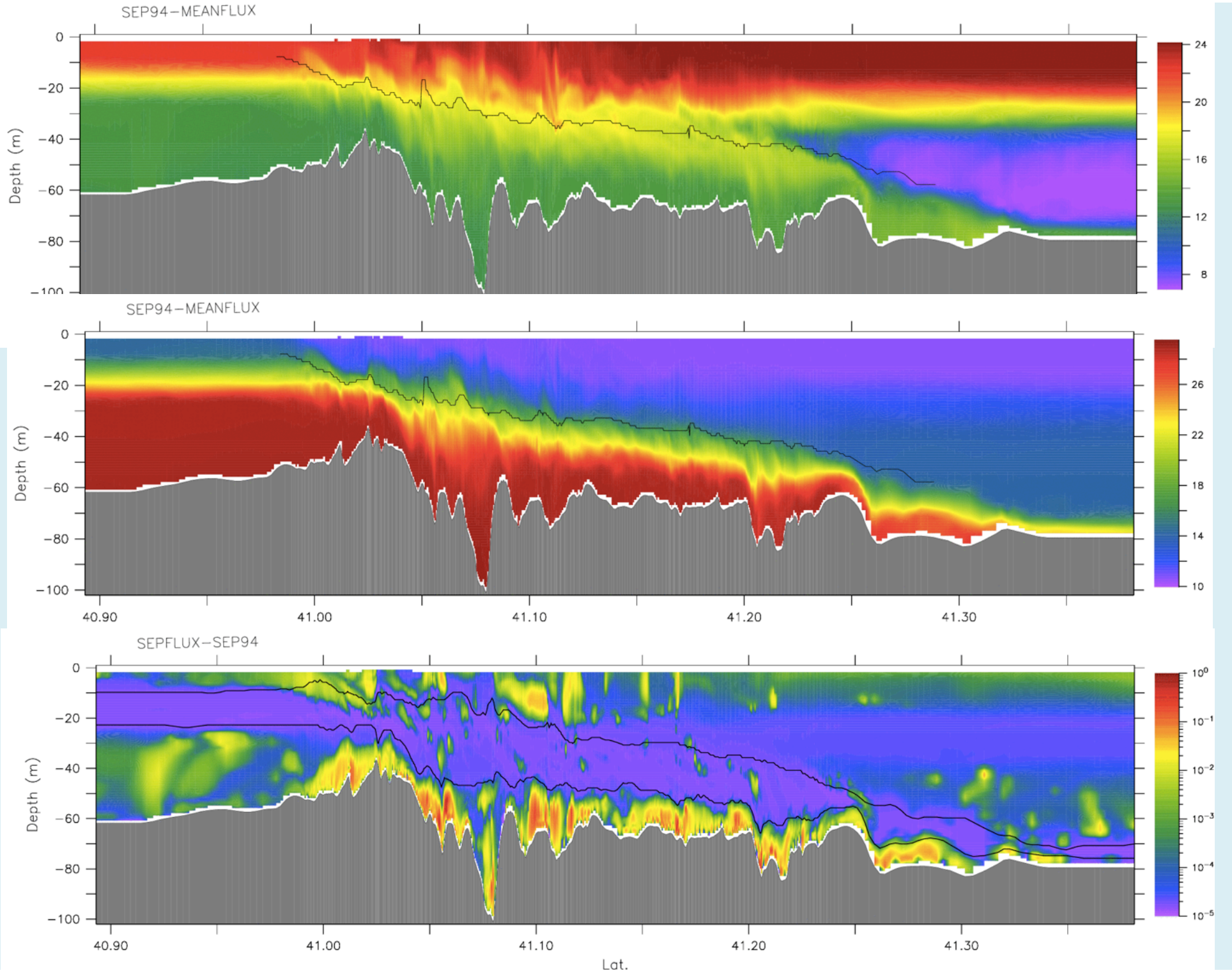
Along-channel Salinity

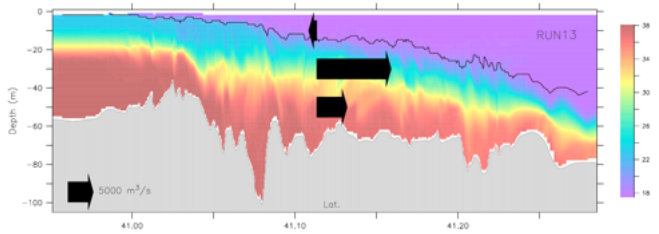


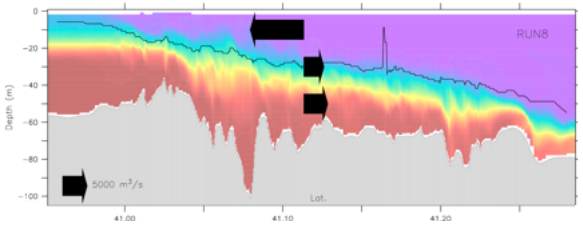
Along-channel V-Vel. (m/s)

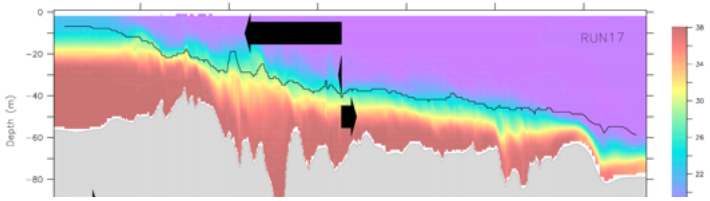


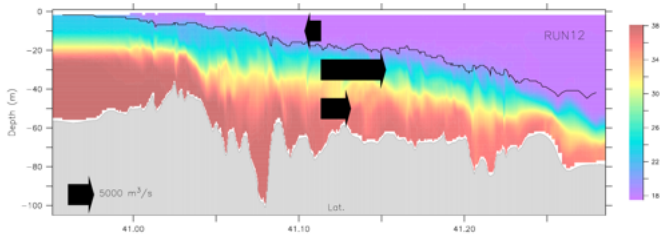
Froude–numbers

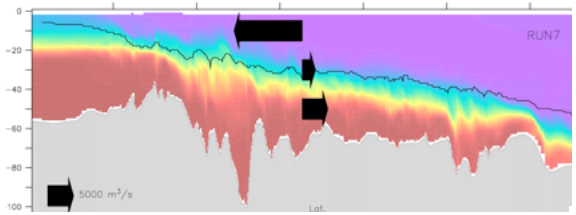

SEP94−MEANFLUX
Depth (m)
0
−20
−40
−60
−80
−100
24
20
16
12
8
SEP94−MEANFLUX
Depth (m)
0
−20
−40
−60
−80
−100
26
22
18
14
10
40.90
41.00
41.10
41.20
41.30
SEPFLUX−SEP94
Depth (m)
0
−20
−40
−60
−80
−100
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
40.90
41.00
41.10
41.20
41.30
Lat.

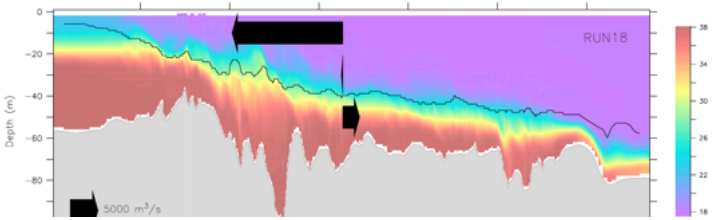

RUN13
Depth (m)
5000 m³/s
Lat.
41.00
41.10
41.20

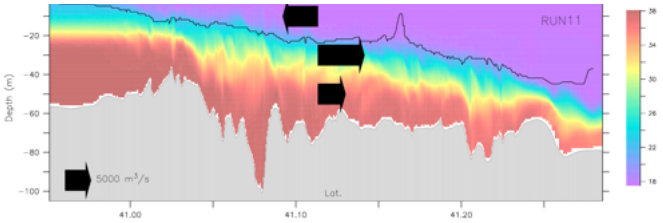

RUN8
Depth (m)
5000 m³/s
Lat.
41.00
41.10
41.20

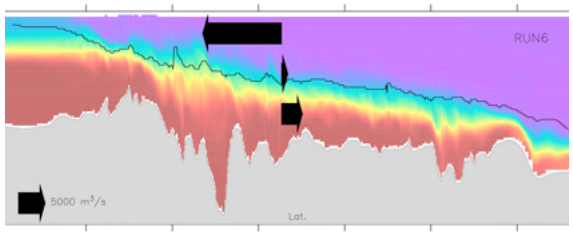

RUN17
Depth (m)

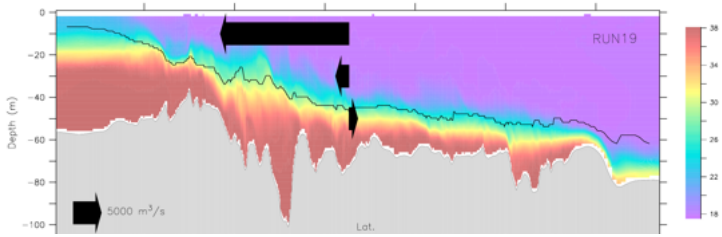

RUN12
Depth (m)
5000 m³/s
Lat.
41.00
41.10
41.20

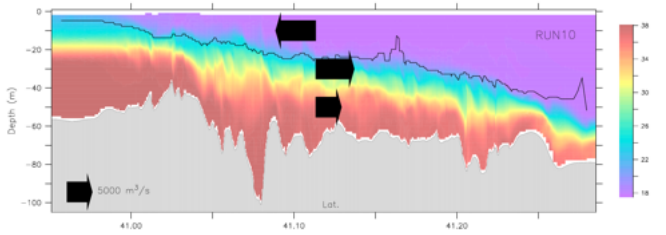

RUN7
Depth (m)
5000 m³/s
Lat.

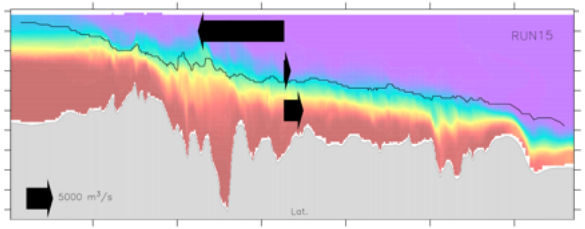

RUN18
Depth (m)
5000 m³/s

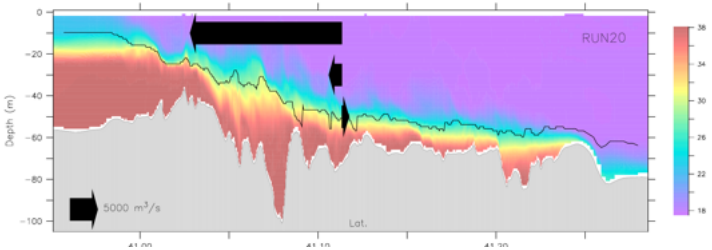

RUN11
Depth (m)
5000 m³/s
Lat.
41.00
41.10
41.20

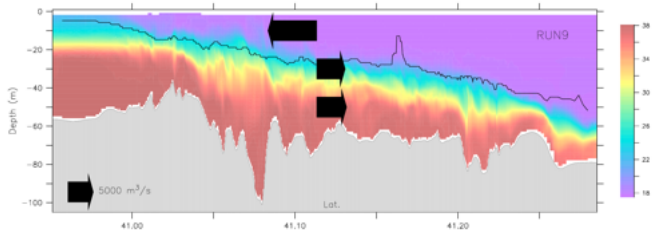

RUN6
5000 m³/s
Lat.

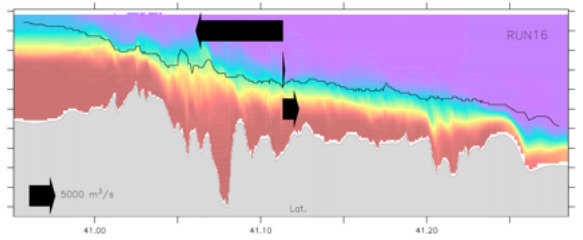

RUN19
Depth (m)
5000 m³/s
Lat.

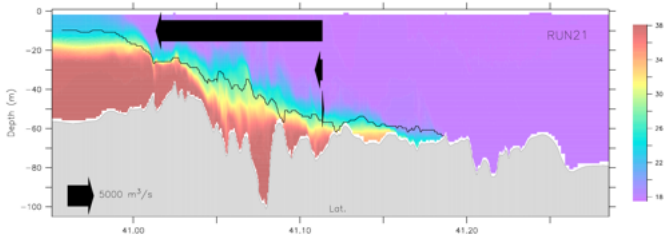

RUN10
Depth (m)
5000 m³/s
Lat.
41.00
41.10
41.20


RUN15
5000 m³/s
Lat.
41.00
41.10
41.20

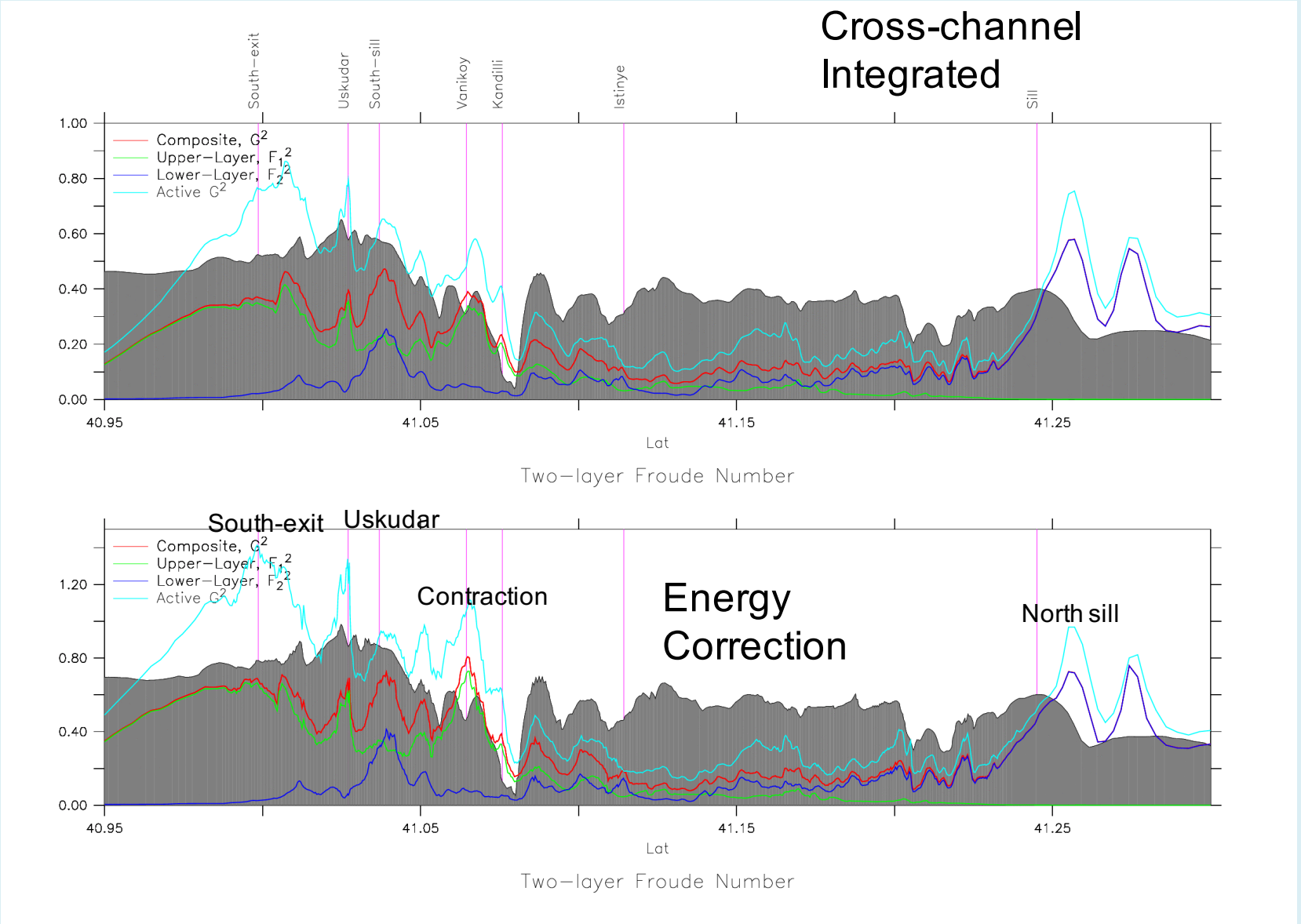

RUN20
Depth (m)
5000 m³/s
Lat.


RUN9
Depth (m)
5000 m³/s
Lat.
41.00
41.10
41.20


RUN16
5000 m³/s
Lat.
41.00
41.10
41.20

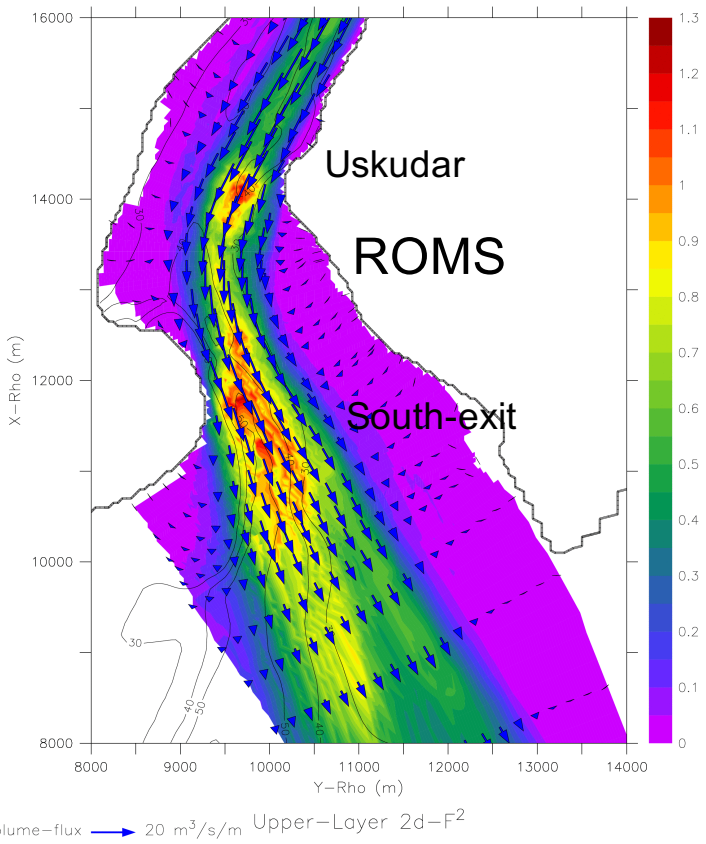

RUN21
Depth (m)
5000 m³/s
Lat.
41.00
41.10
41.20

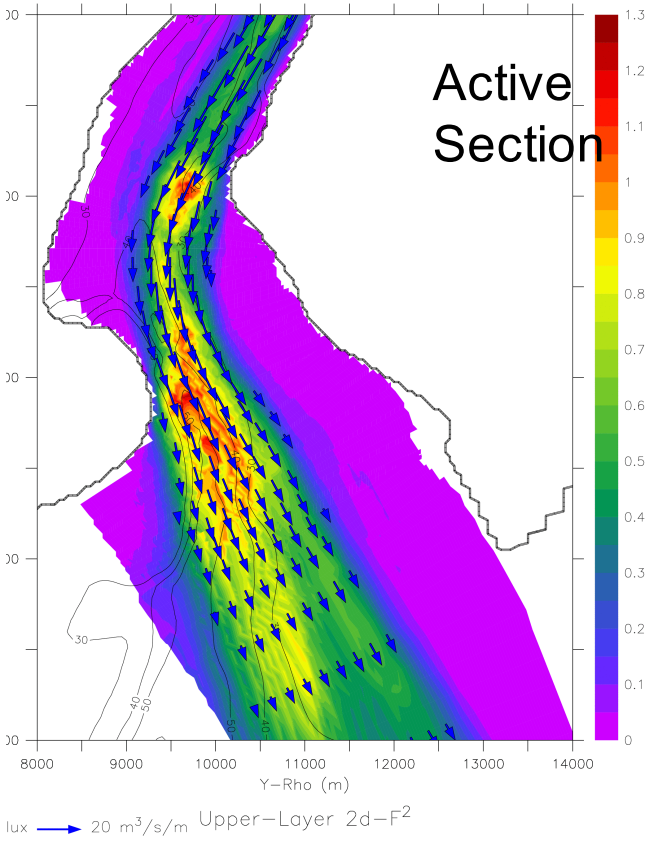
TWO-LAYER FROUDE-NUMBER

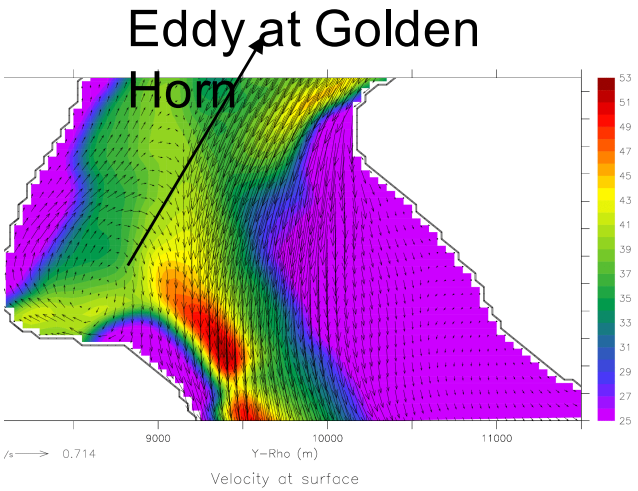


TWO-LAYER FROUDE-NUMBER

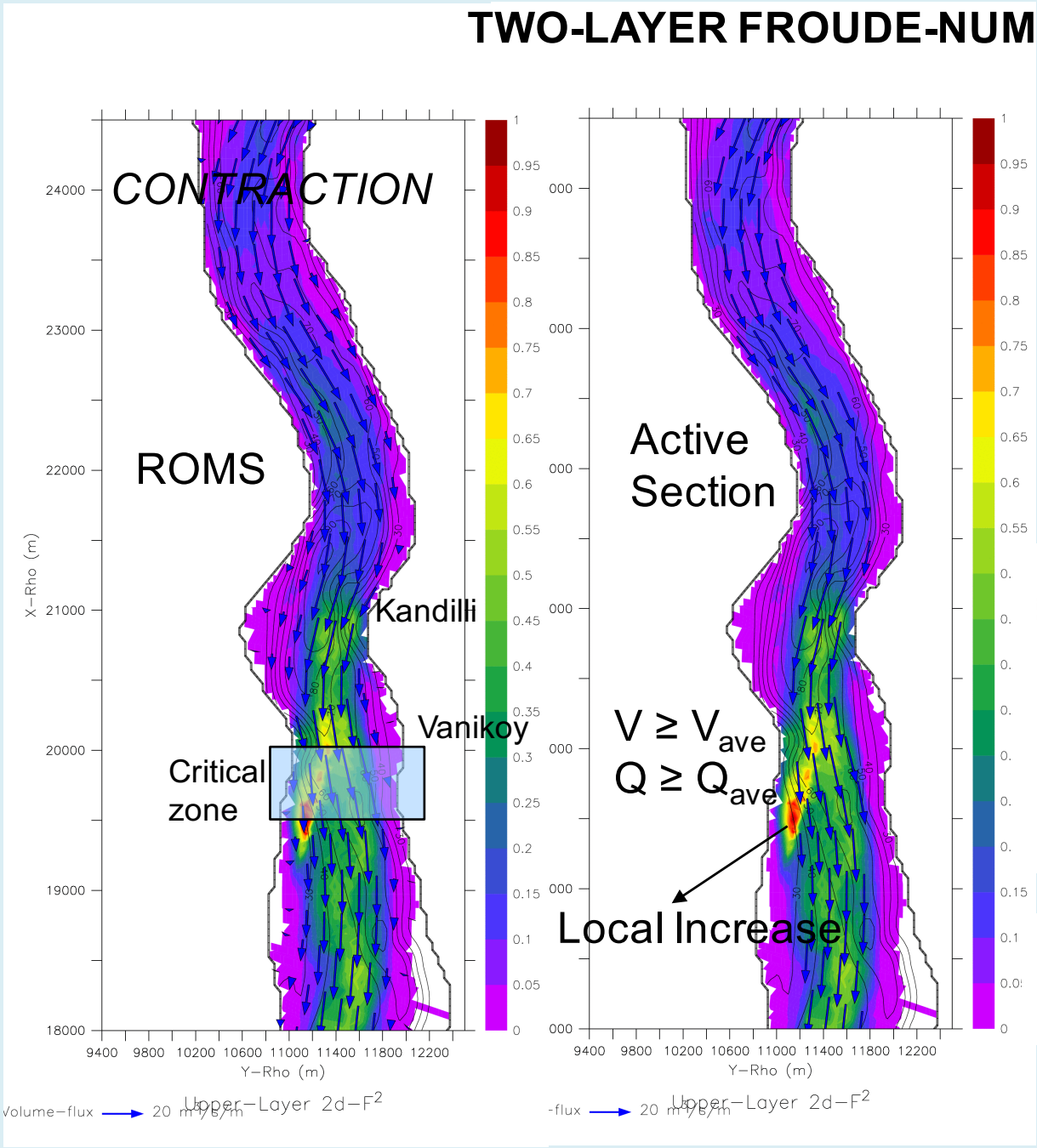
SOUTH-EXIT





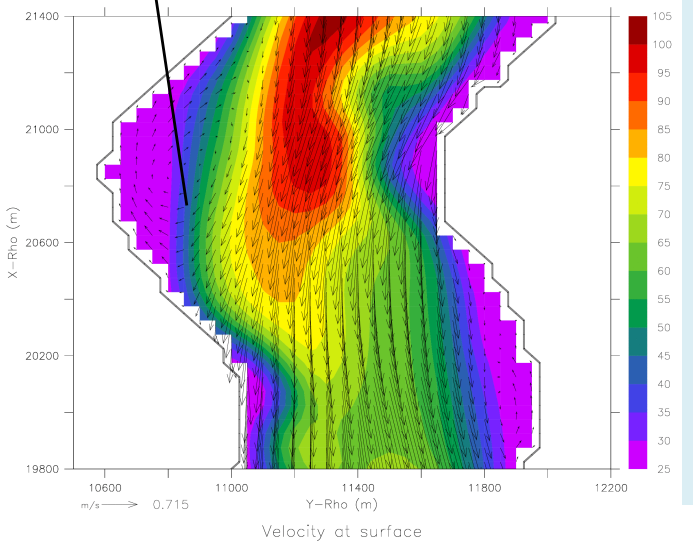


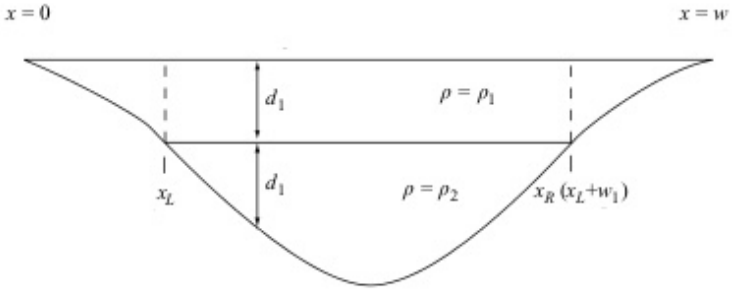
TWO-LAYER FROUDE-NUMBER



Recirculation

Eddy at the Contraction



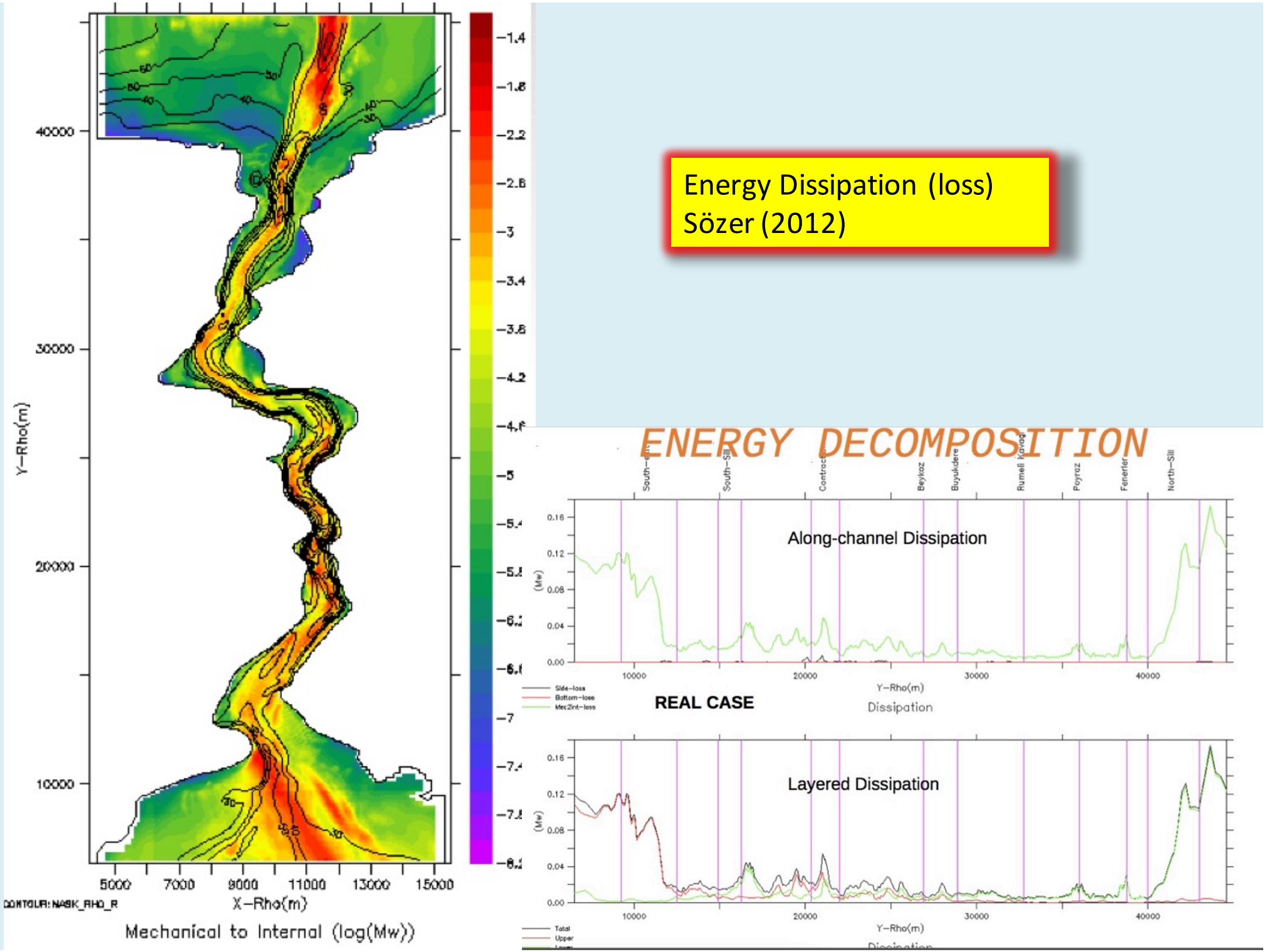


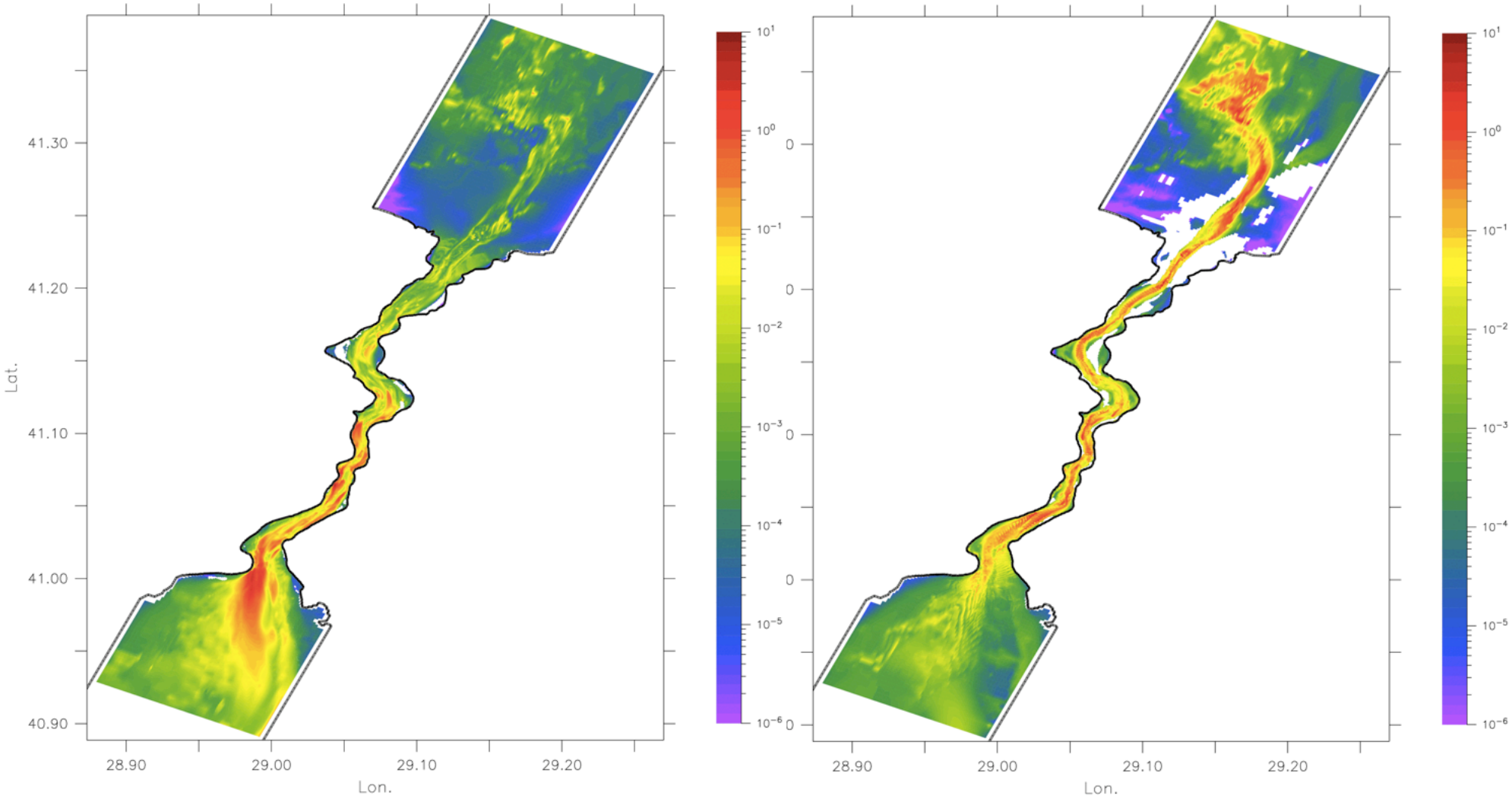
Transverse variation in velocit

$$G_w^2 = \frac{1}{\frac{1}{w_I}\int_0^w \frac{g' D_1}{V_1^2}\mathrm{d}x} + \frac{1}{\frac{1}{w_I}\int_{x_L}^{x_R} \frac{g' D_2}{V_2^2}\mathrm{d}x} = 1.$$

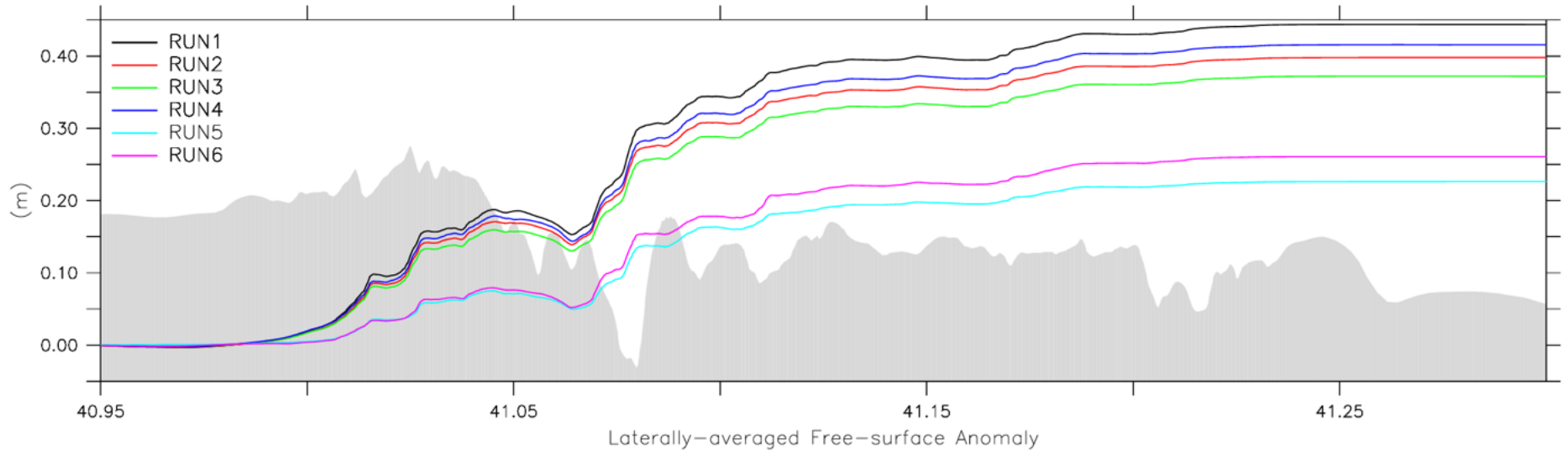
* Pratt 2008

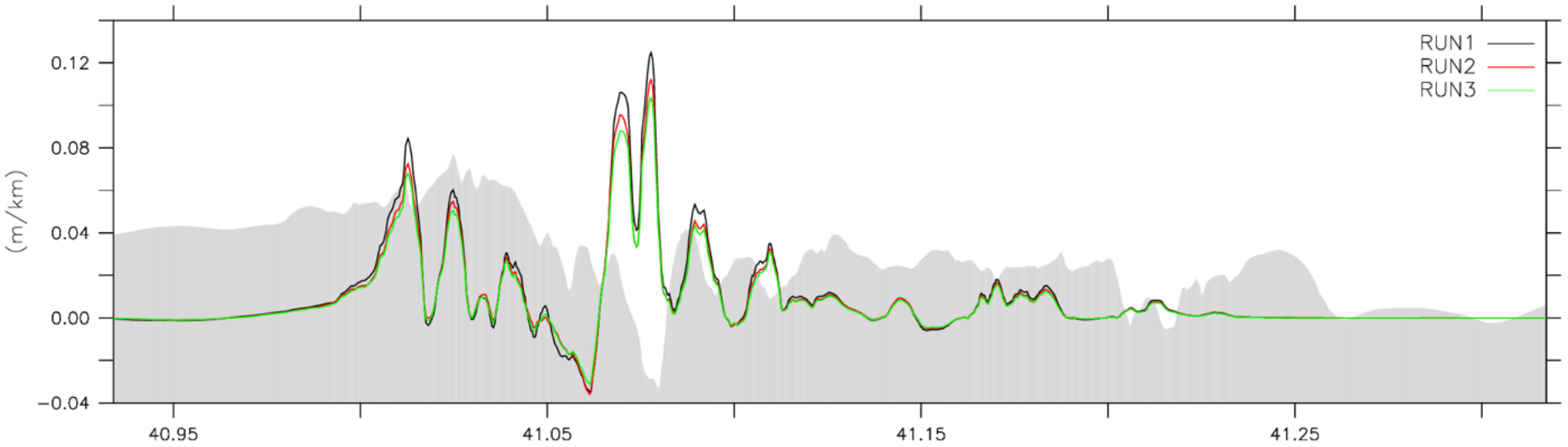
Energy Dissipation (loss)
Sözer (2012)



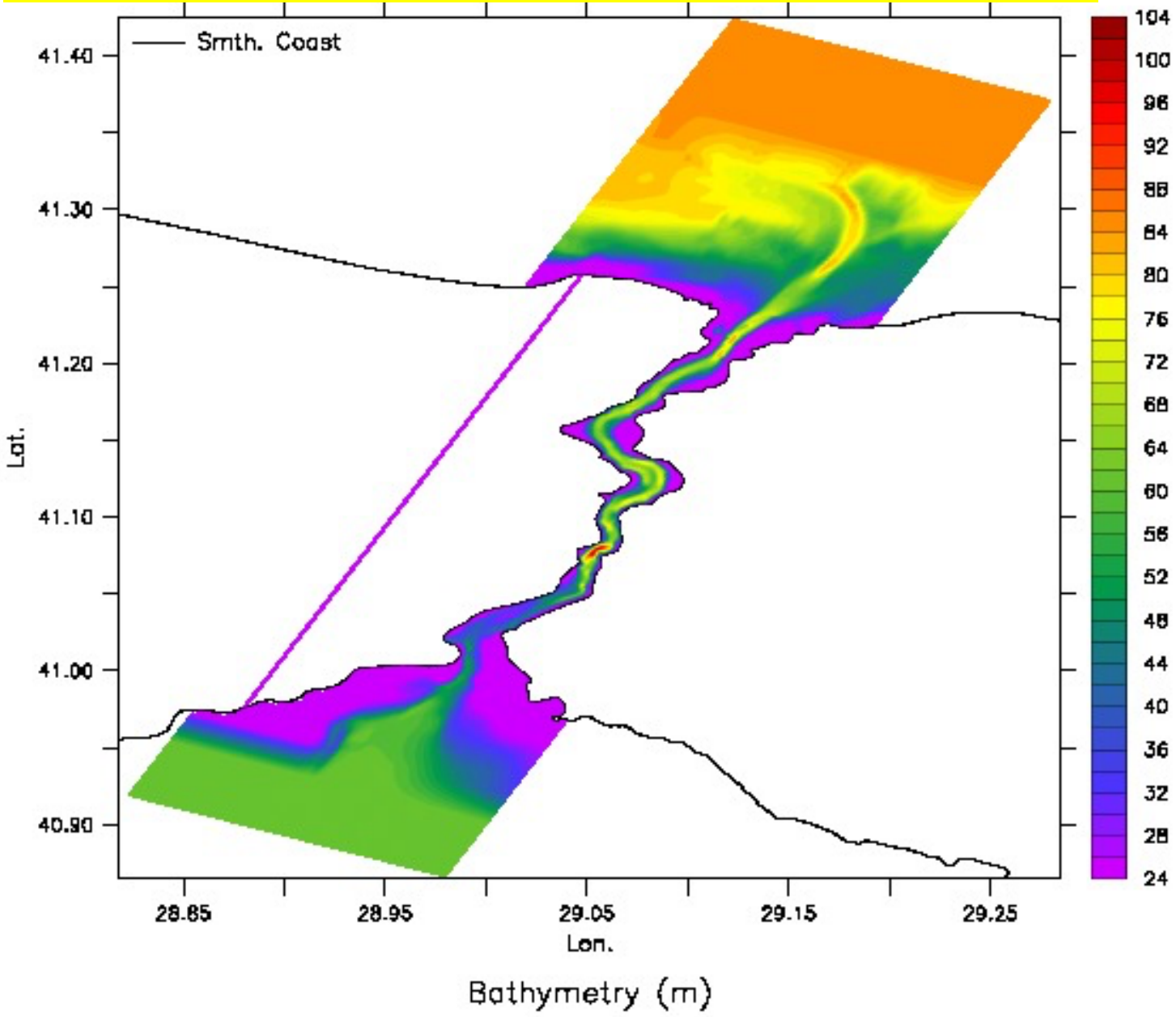


Horizontal distribution of mechanical energy dissipation (W/m^2) in the (a) upper and (b) lower layers


RUN1
RUN2
RUN3
RUN4
RUN5
RUN6
0.40
0.30
0.20
0.10
0.00
(m)
40.95
41.05
41.15
41.25
Laterally−averaged Free−surface Anomaly

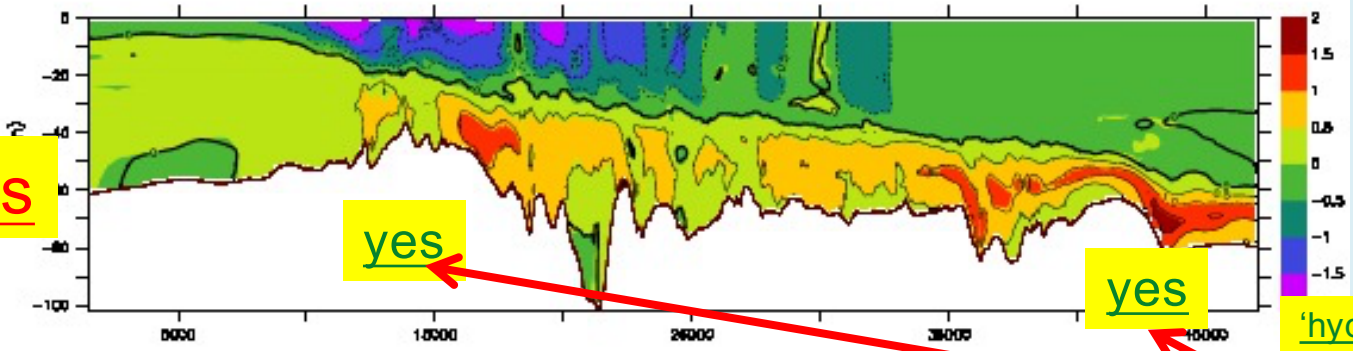

RUN1
RUN2
RUN3
0.12
0.08
0.04
0.00
−0.04
(m/km)
40.95
41.05
41.15
41.25
Laterally−averaged Free−surface Slope

Bosphorus and prototype Canal İstanbul coupled model predictions (Sözer, 2013)



Bosphorus and Canal İstanbul currents (Sözer, 2013)

Bosphorus



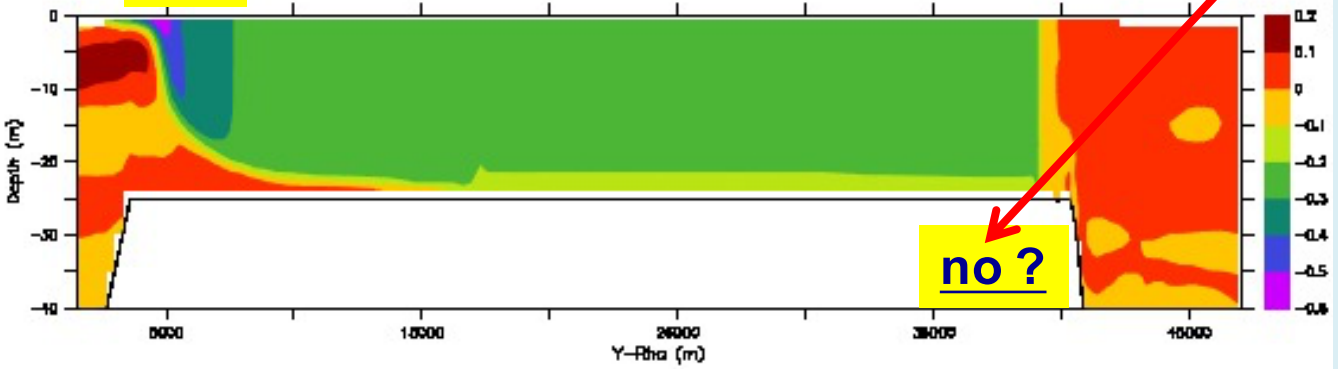
yes

yes

'hydraulic jump' !

yes

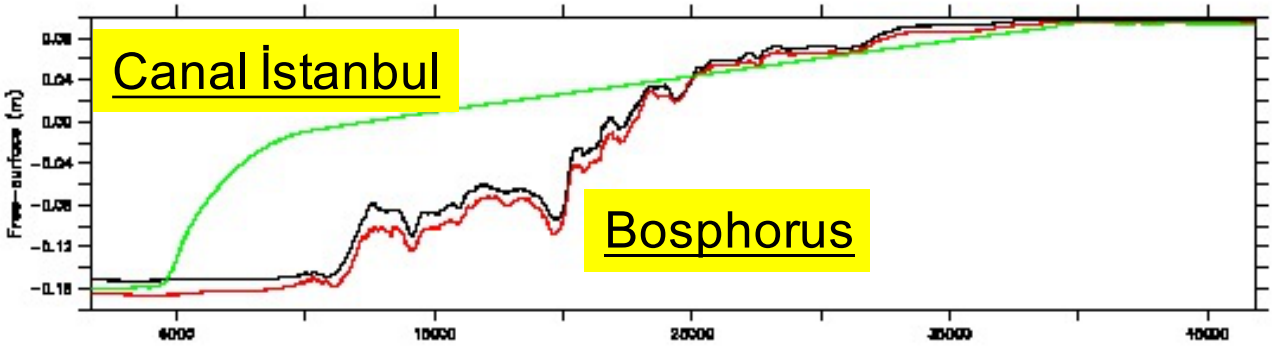
Canal İstanbul



no ?

Sea level variation between Black Sea and the Marmara

Marmara Sea



Canal İstanbul

Bosphorus

Black Sea

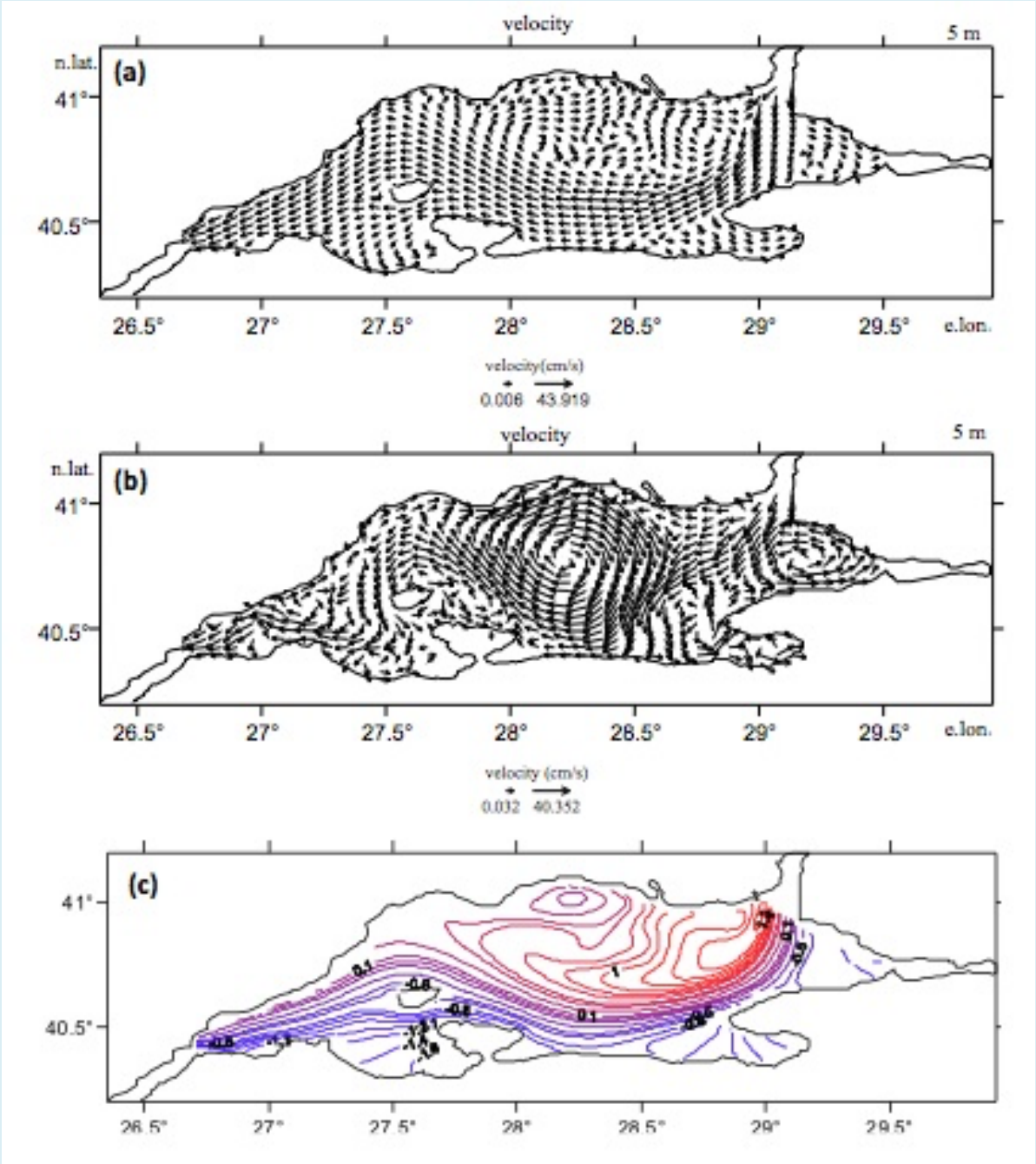
Results from various coupled simulations of Canal İstanbul and Bosphorus

Increase in average flux resulting from the addition of Canal İstanbul is about ~4%
amounting to 600 – 800 m^3/s
BUT CARRYING BLACK SEA WATER!

Like a medium size river added
to the influx entering the Marmara Sea:
e.g.
Sakarya river (Black Sea): 200 m^3/s
Nile River (Mediterranean): 1000 m^3/s

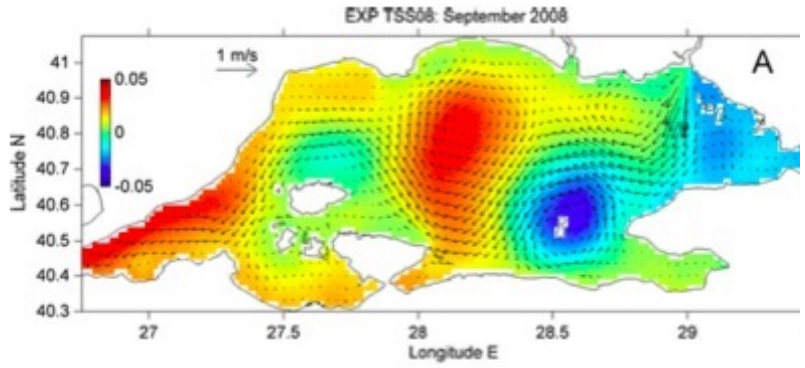
Marmara Sea Modeling

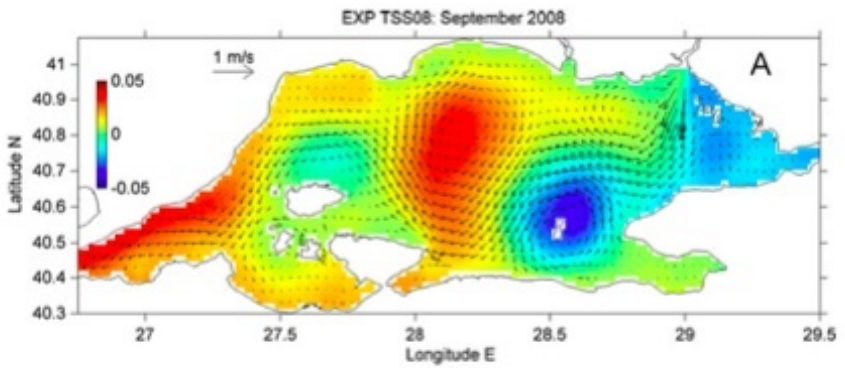
Demyshev and Dovgaya, MHI
20 year integration !

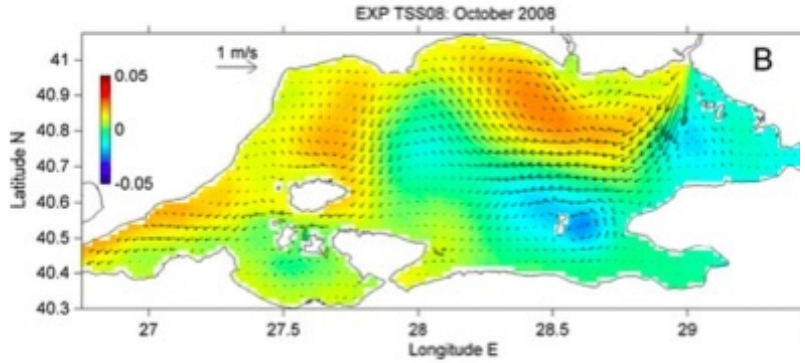


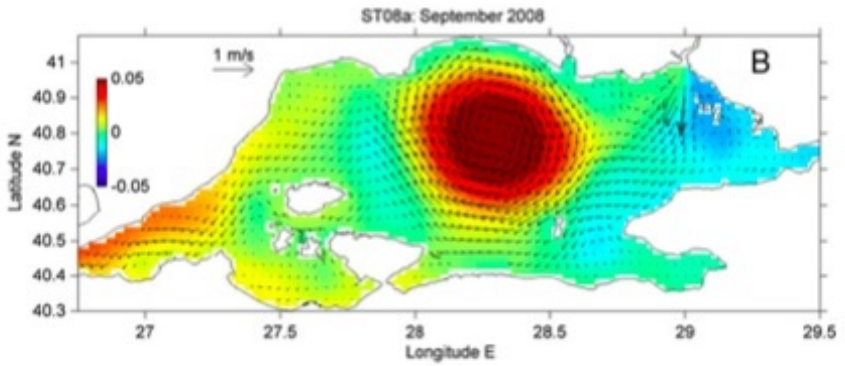
Without wind

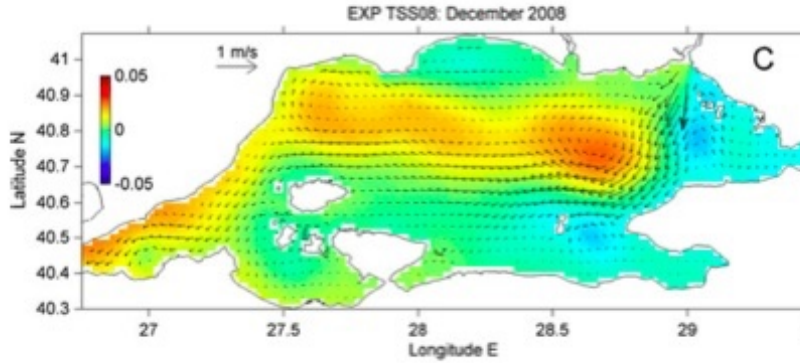
With wind

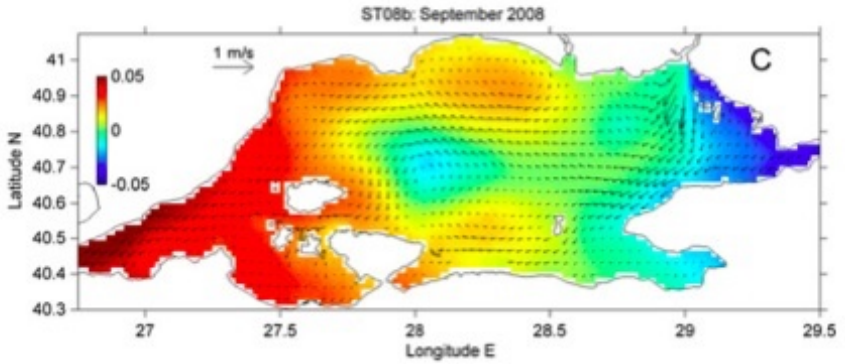


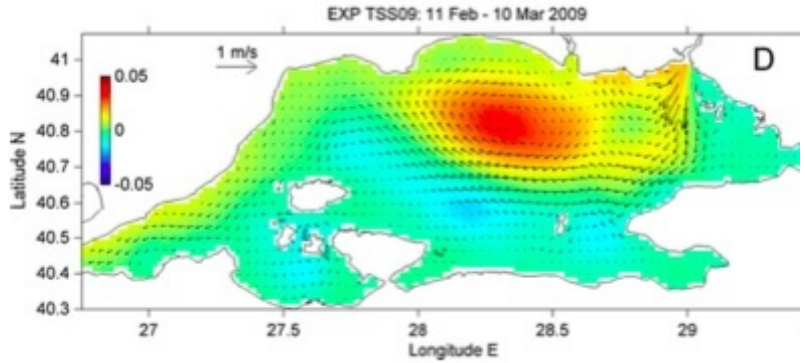


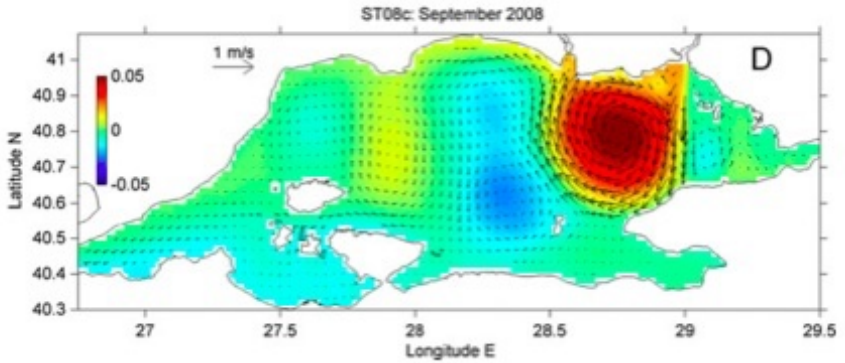






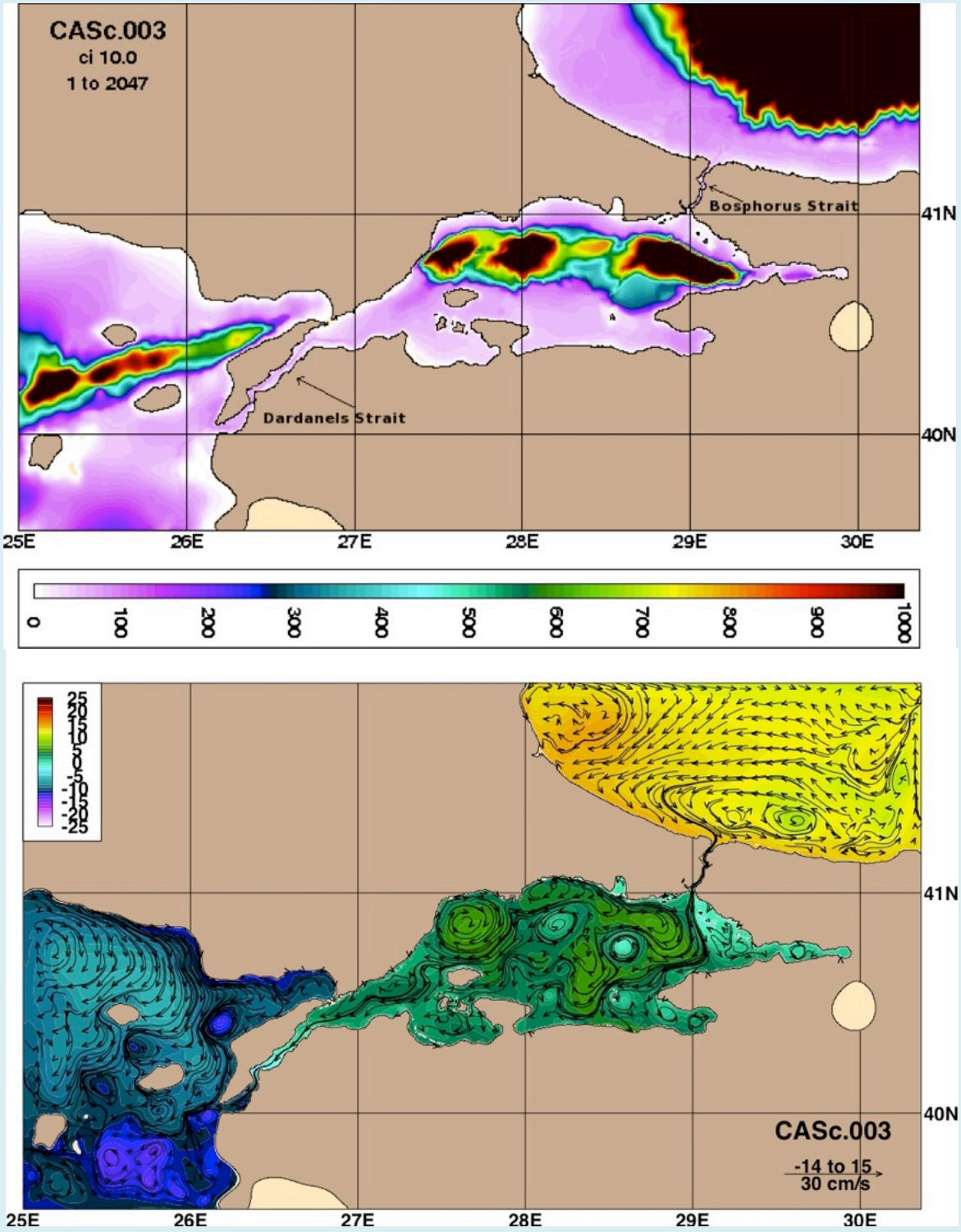




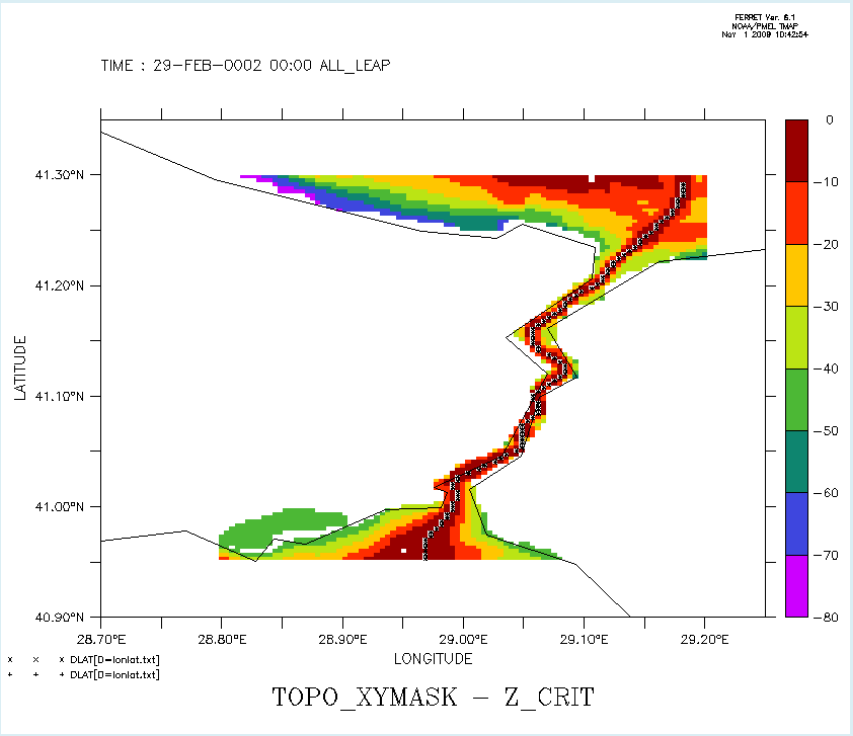


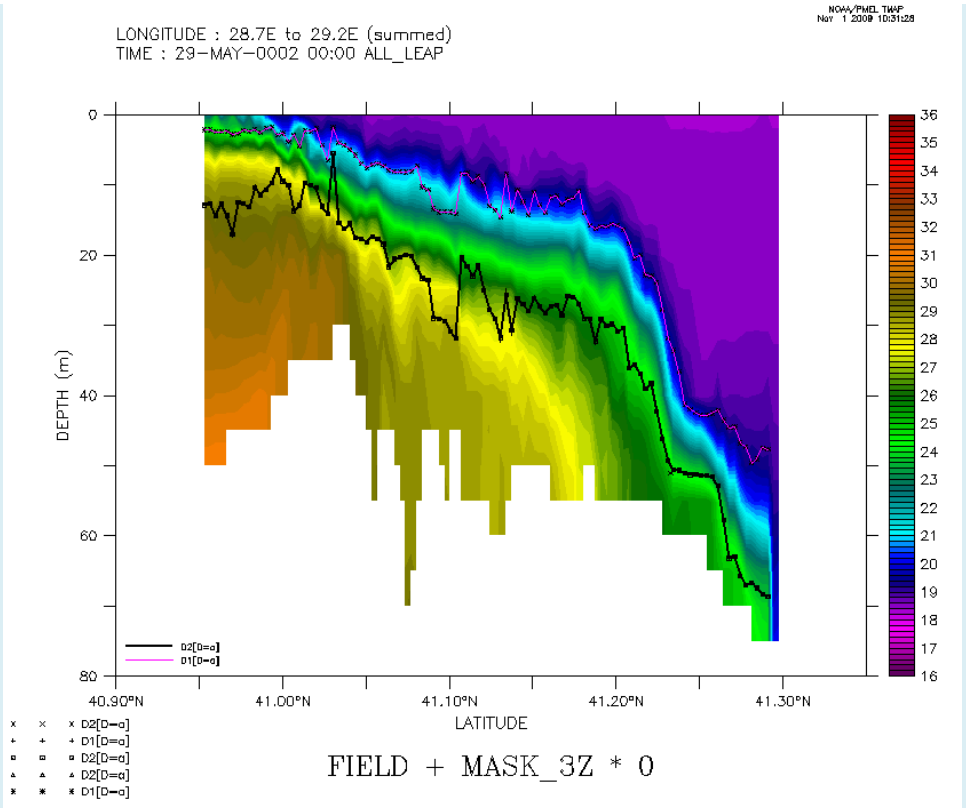
Chiggiato et al. 2012

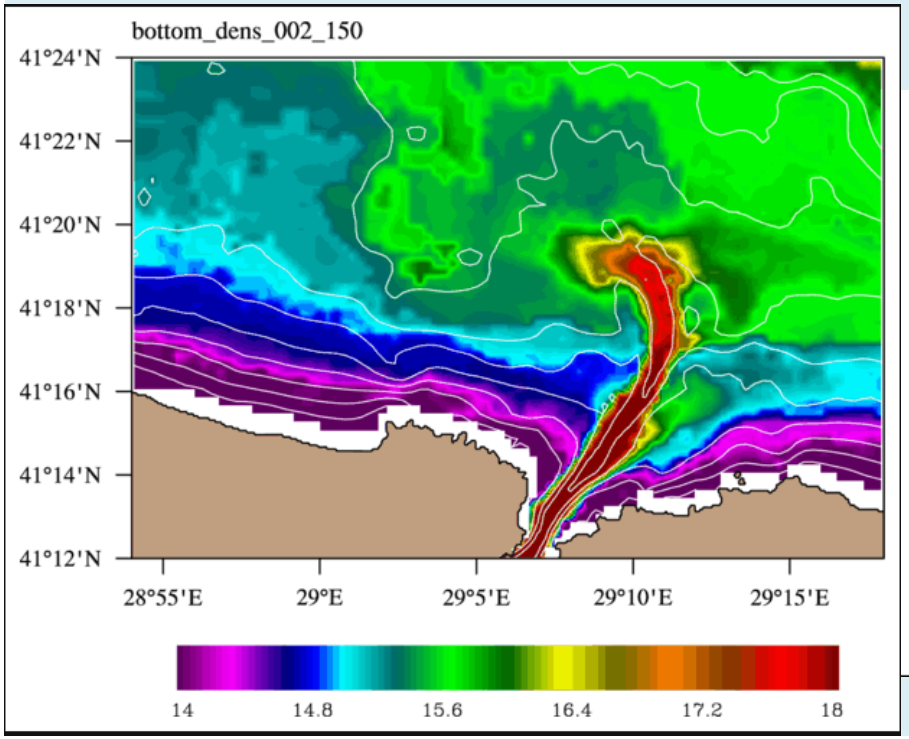
Turkish Straits System Modeling



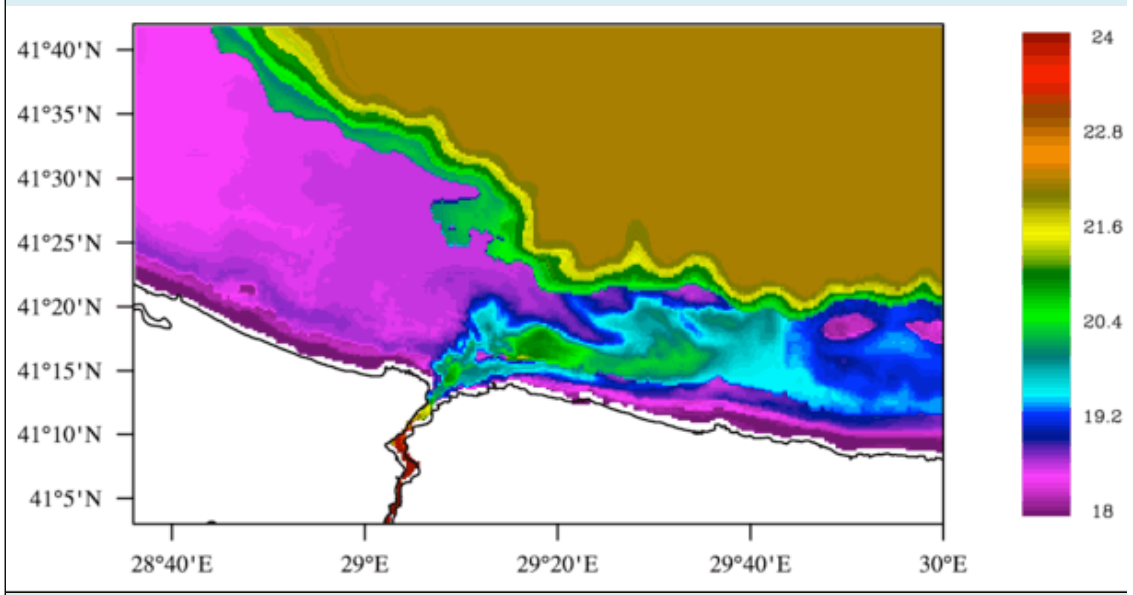
Murat Gündüz, 2009







Murat Gündüz, Hycom



Inter-Basin Coupling with a Turkish Straits System Model

Aimed by
MyOcean – MyOcean2 Projects
Copernicus Service

Development:
11-12 July 2012, İstanbul:
Research And Development Initiative For Advanced Modeling of The Turkish Straits System: Physics, Modeling Issues and Strategy
Had important suggestions for TSS modeling:

- Need for high resolution, HPC
- Coupling challenge
- Closing the water budget
- Unknowns, adaptive strategy
- Need for proper parameterizations
- Role in improving adjacent seas forecasts
- Identification of important processes
- Identification of data to be used

1st things 1st:

Turkish Straits **!=** Marmara Sea

It has to be called Turkish Straits System (TSS)

- Marmara Sea can not even be singly described, let alone forecasted, without the two Straits !
- inter-basin coupling is the ultimate motive and it can not be achieved without the straits !

The TSS is a very special, fragile system of great complexity despite its small size. It is not the typical piece of an ocean and the approach is non-standard !

- The TSS is a crucible of nonlinear, highly stratified, turbulent, high energy flows that are often outside the predictive capabilities of current models
- Forecasting of TSS is a **grand challenge in terms of prediction,** that must be based on most up-to-date science and models
- Problem is **HUGE**: 3.5 millon nodes in FEOM
  7.0 million nodes in MITgcm

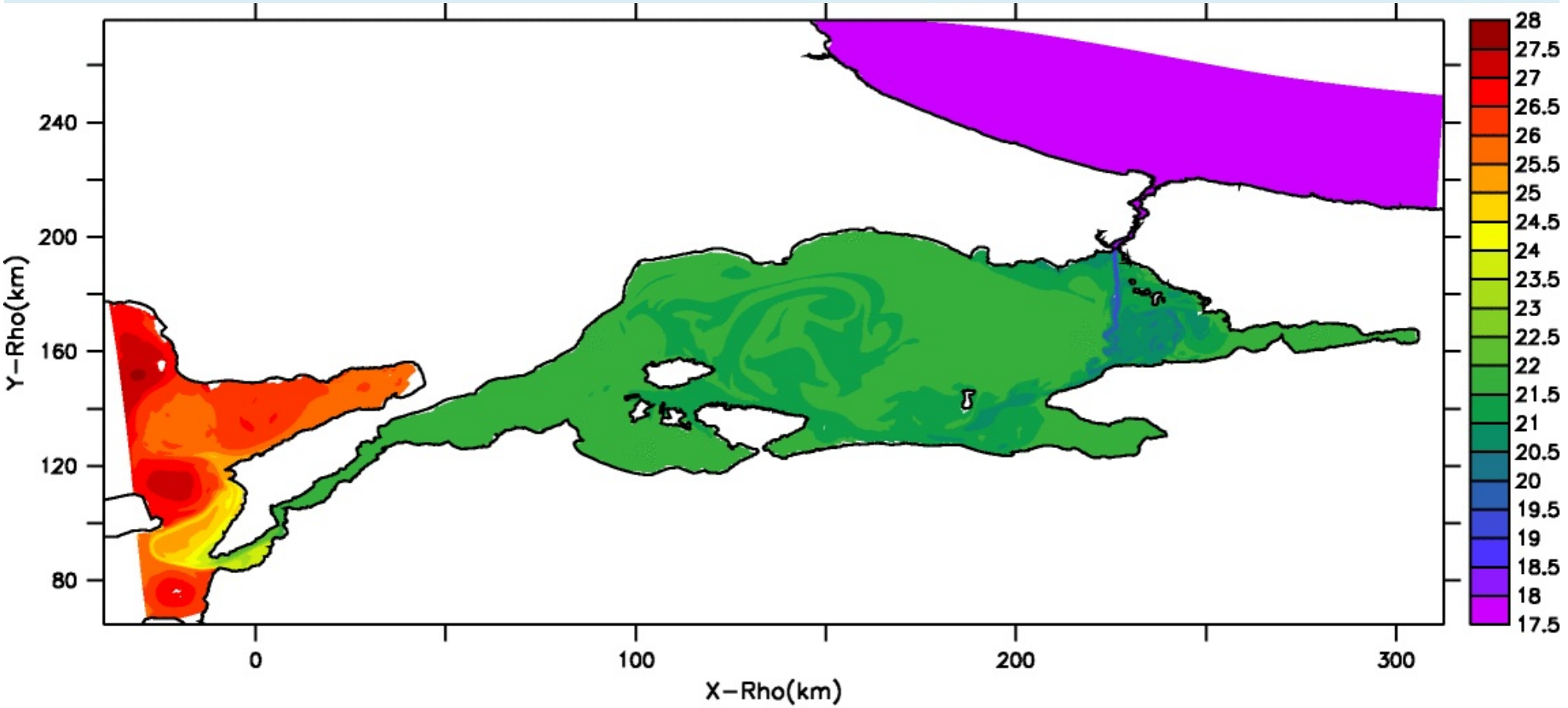
Development:

- Synergistic experimental programs and modeling development (last 30 years, peaked in last 5 years) taking on the grand challenge
- Continued rearing of TSS modeling with multiple objectives (TÜBİTAK, IntenC, BMBF, Helmholtz Foundation, Italian FM, PRACE)
- Development and testing of four different models (HyCOM, ROMS, MITgcm, FEOM) applied to TSS

Prospects for COPERNICUS:

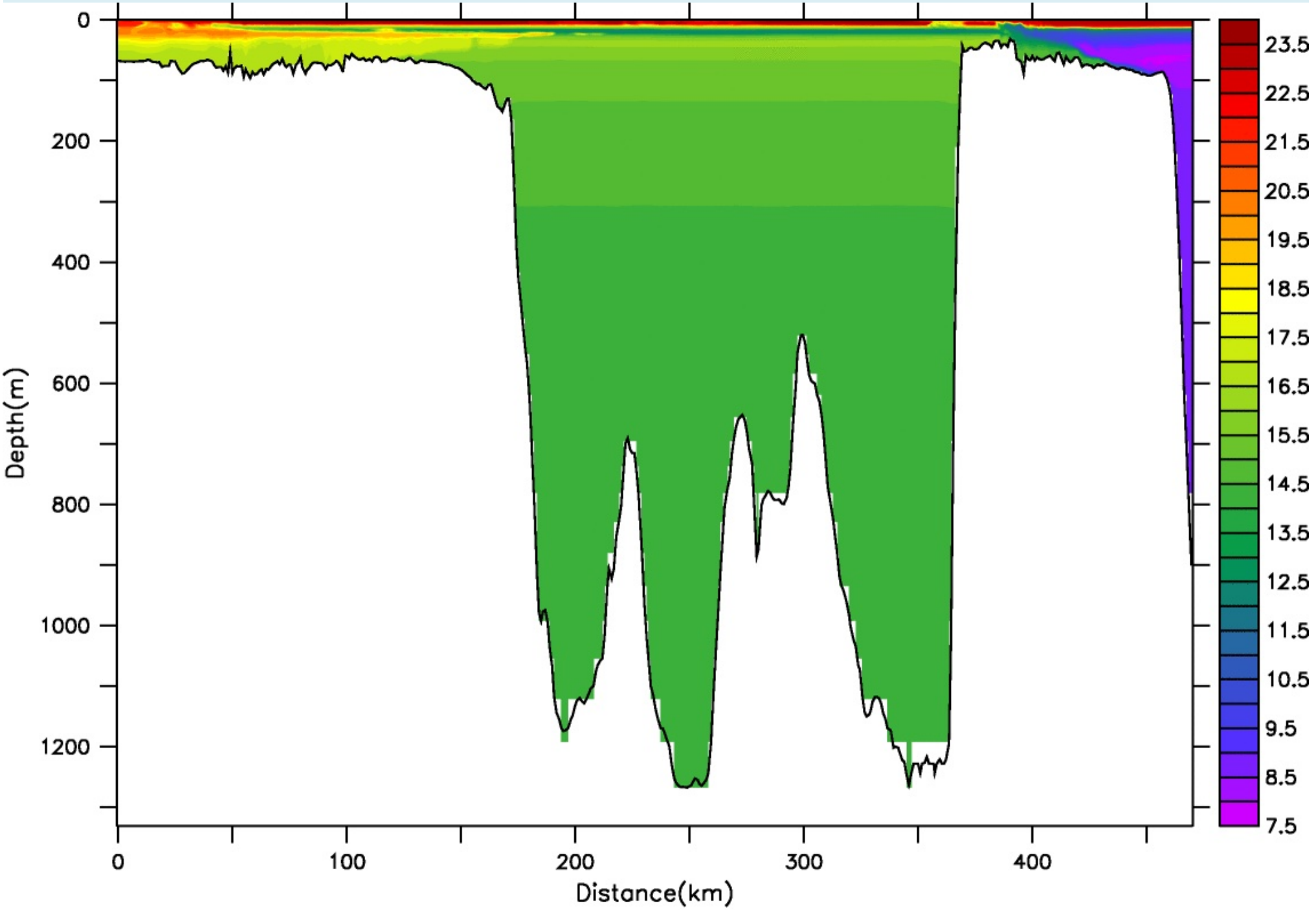
- Being 'almost there' does not necessarily imply smooth transition to operation
- Straits being well represented has helped surmount major problems
- Present ad-hoc solution for the coupling challenge
- Closing the Black Sea water budget is essential
- May need adjustments in parameterizations
- Will improve adjacent seas forecasts by producing lateral fluxes to them
- Will enable ad-hoc operational marine service
- Without the knowledge and data base of IMS-METU the goal can not be achieved
- Back-up service envisioned

Gianmaria Sannino (ENEA), Adil Sözer, Emin Özsoy (ODTÜ-DBE)
TURBO / DEEP (TÜBİTAK Italian Foreign Ministry Bilateral Project
Supported by the EU initiative PRACE
(Partnership for Advanced Computing in Europe) for supercomputing

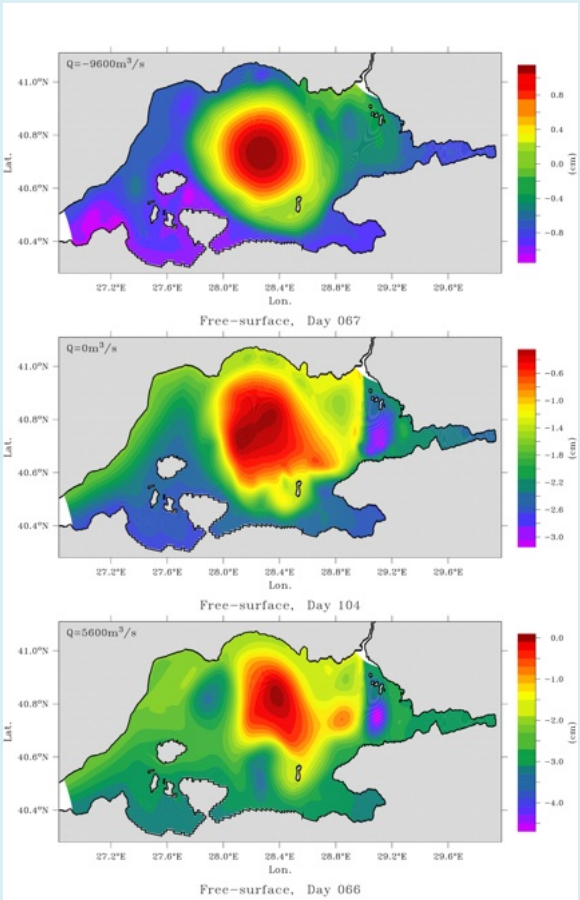


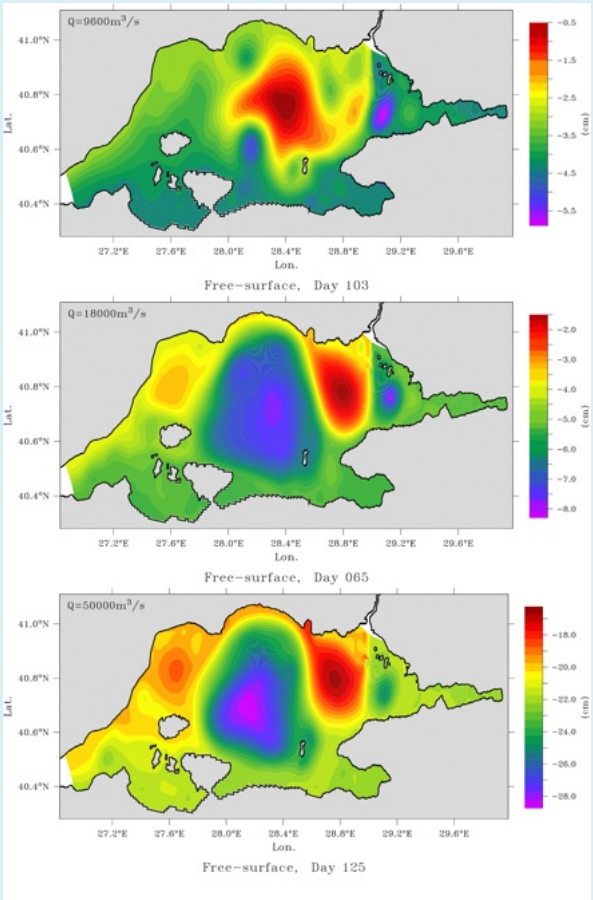
Salt, Z=−5.4m, Day=035.00

MITgcm non-hydrostatic model (curvilinear variable grid)
Δx = 35-500m, Δy = 60-1000m, Grid Size = 2184*648*72

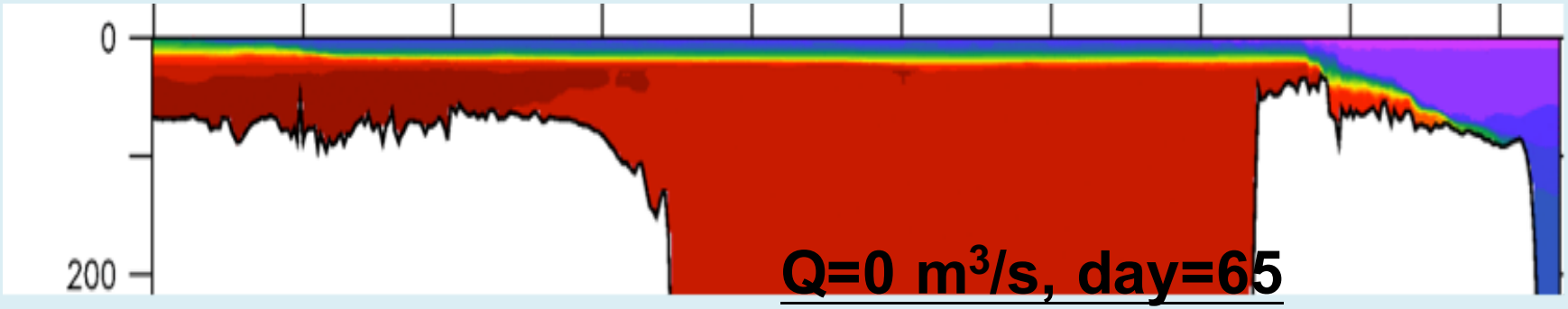

0
200
400
600
800
1000
1200
Depth(m)
0
100
200
300
400
Distance(km)
23.5
22.5
21.5
20.5
19.5
18.5
17.5
16.5
15.5
14.5
13.5
12.5
11.5
10.5
9.5
8.5
7.5

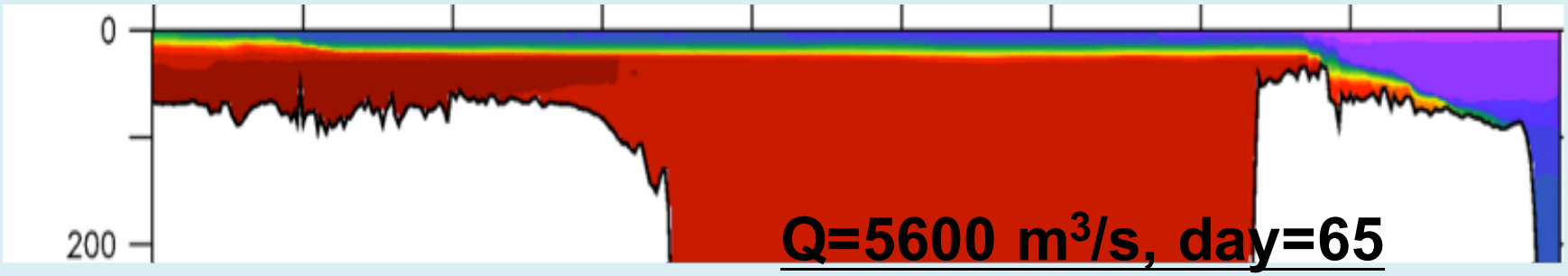
Temp, Day=35

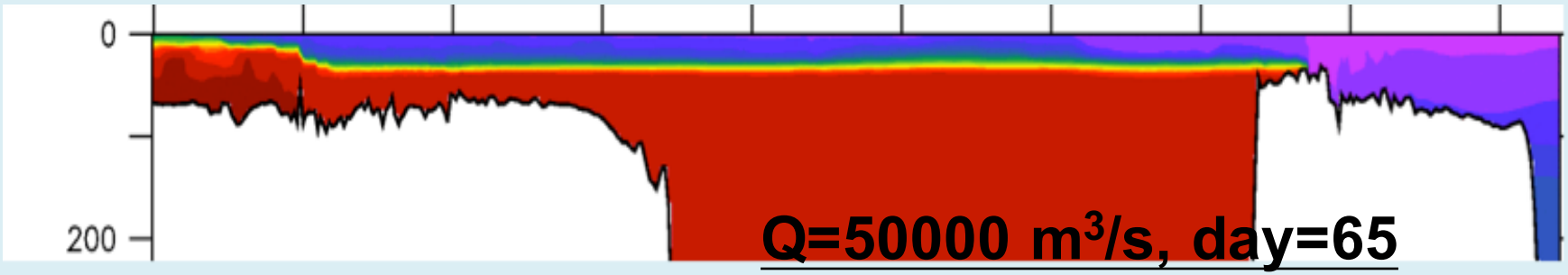

Q=−9600m³/s
Free−surface, Day 067
Q=0m³/s
Free−surface, Day 104
Q=5600m³/s
Free−surface, Day 066
Lat.
Lon.
(cm)

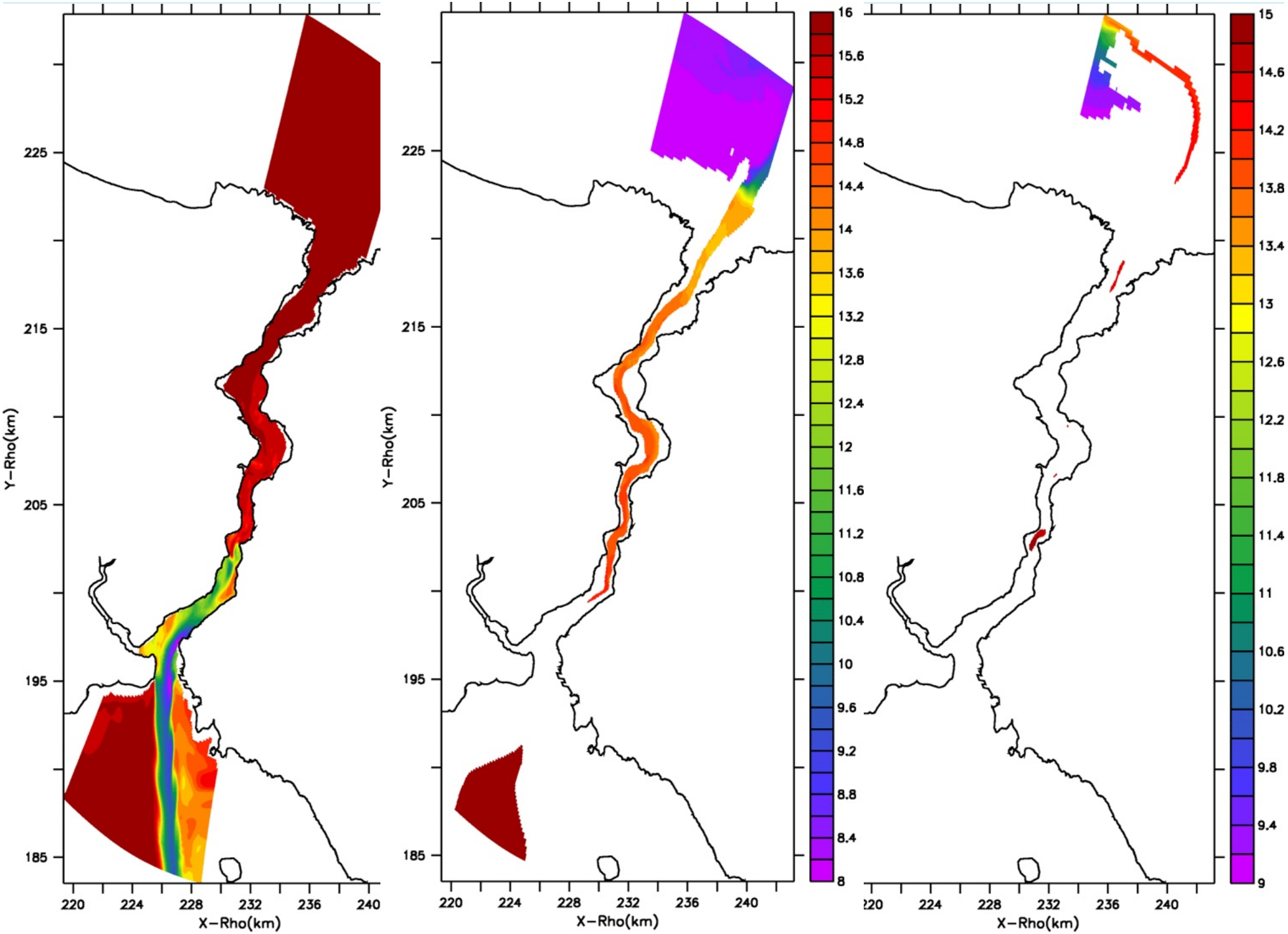

Q=9600m³/s
Free−surface, Day 103
Q=18000m³/s
Free−surface, Day 065
Q=50000m³/s
Free−surface, Day 125
Lat.
Lon.
(cm)

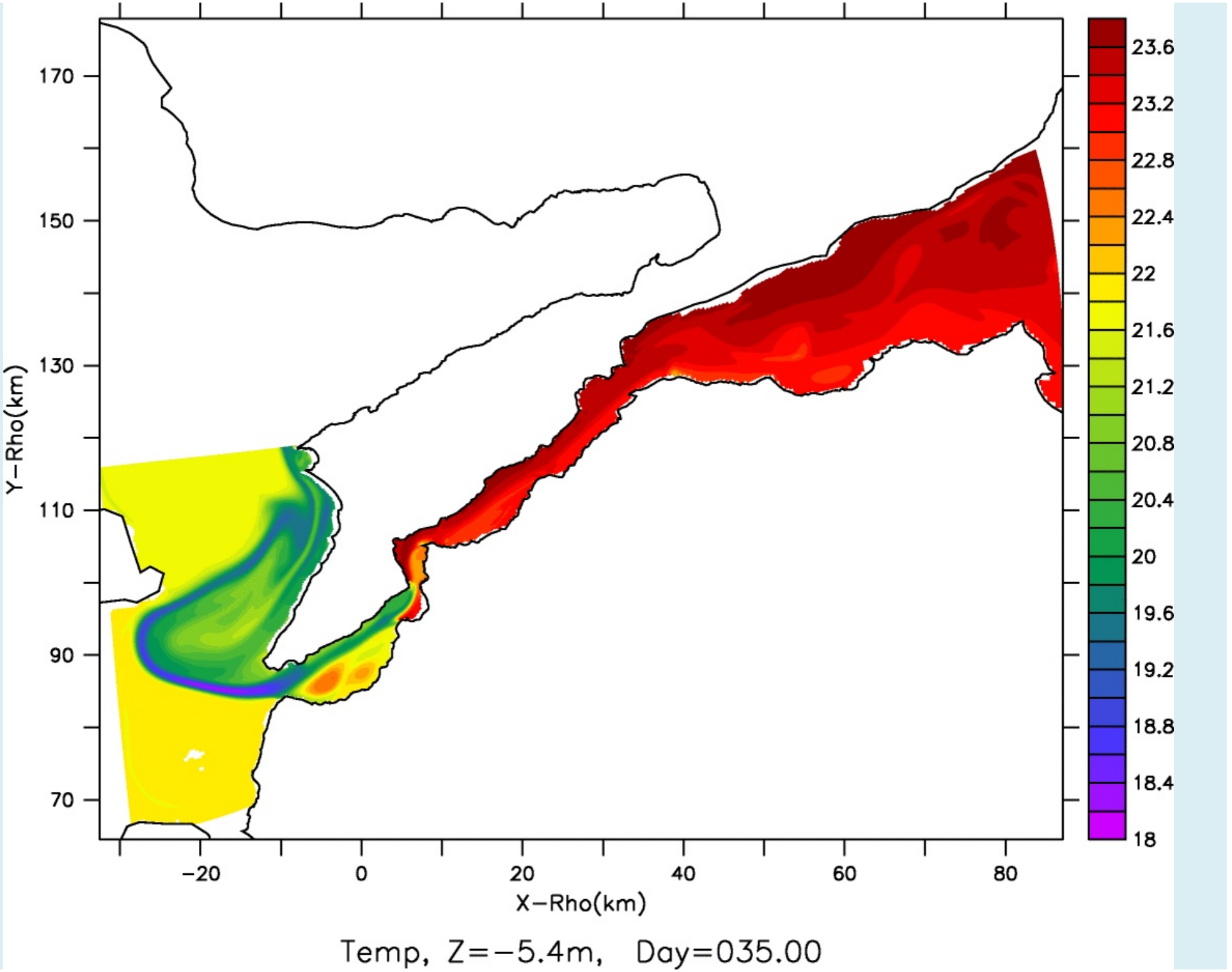
MITgcm TSS model: TSS cross-section salinity field

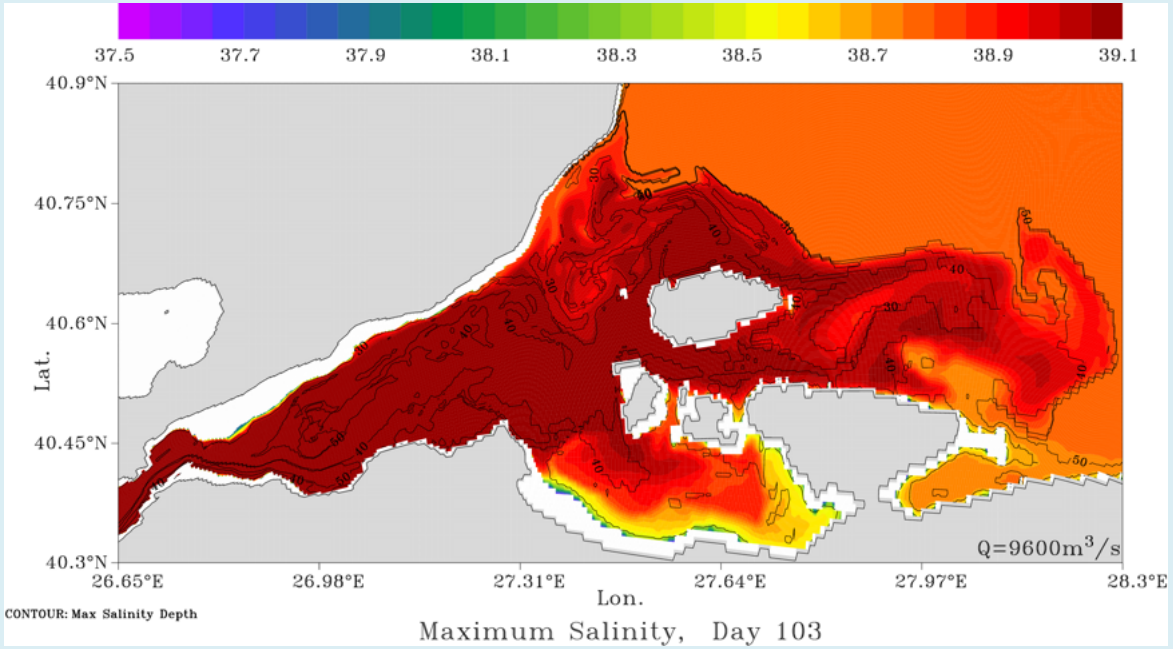




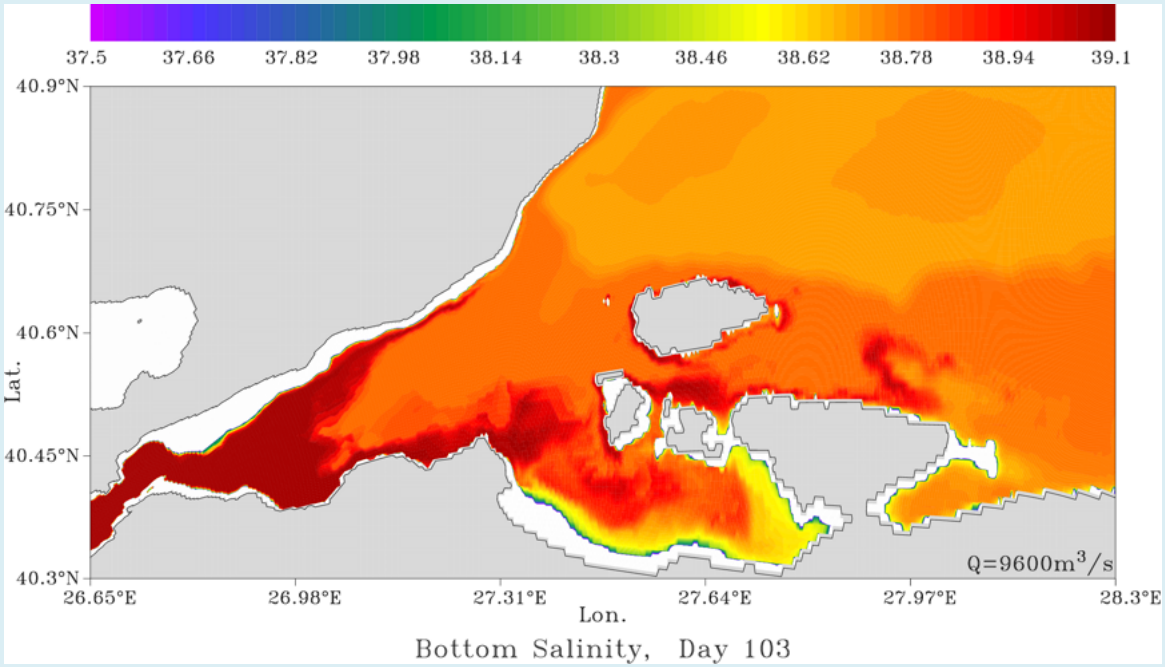



Y-Rho(km)
225
215
205
195
185
220
224
228
232
236
240
X-Rho(km)
16
15.6
15.2
14.8
14.4
14
13.6
13.2
12.8
12.4
12
11.6
11.2
10.8
10.4
10
9.6
9.2
8.8
8.4
8
15
14.6
14.2
13.8
13.4
13
12.6
12.2
11.8
11.4
11
10.6
10.2
9.8
9.4
9
Temp, Z=-5.4m, Day=035.0
Temp, Z=-51m, Day=035.00
Temp, Z=-73.9m, Day=035.00

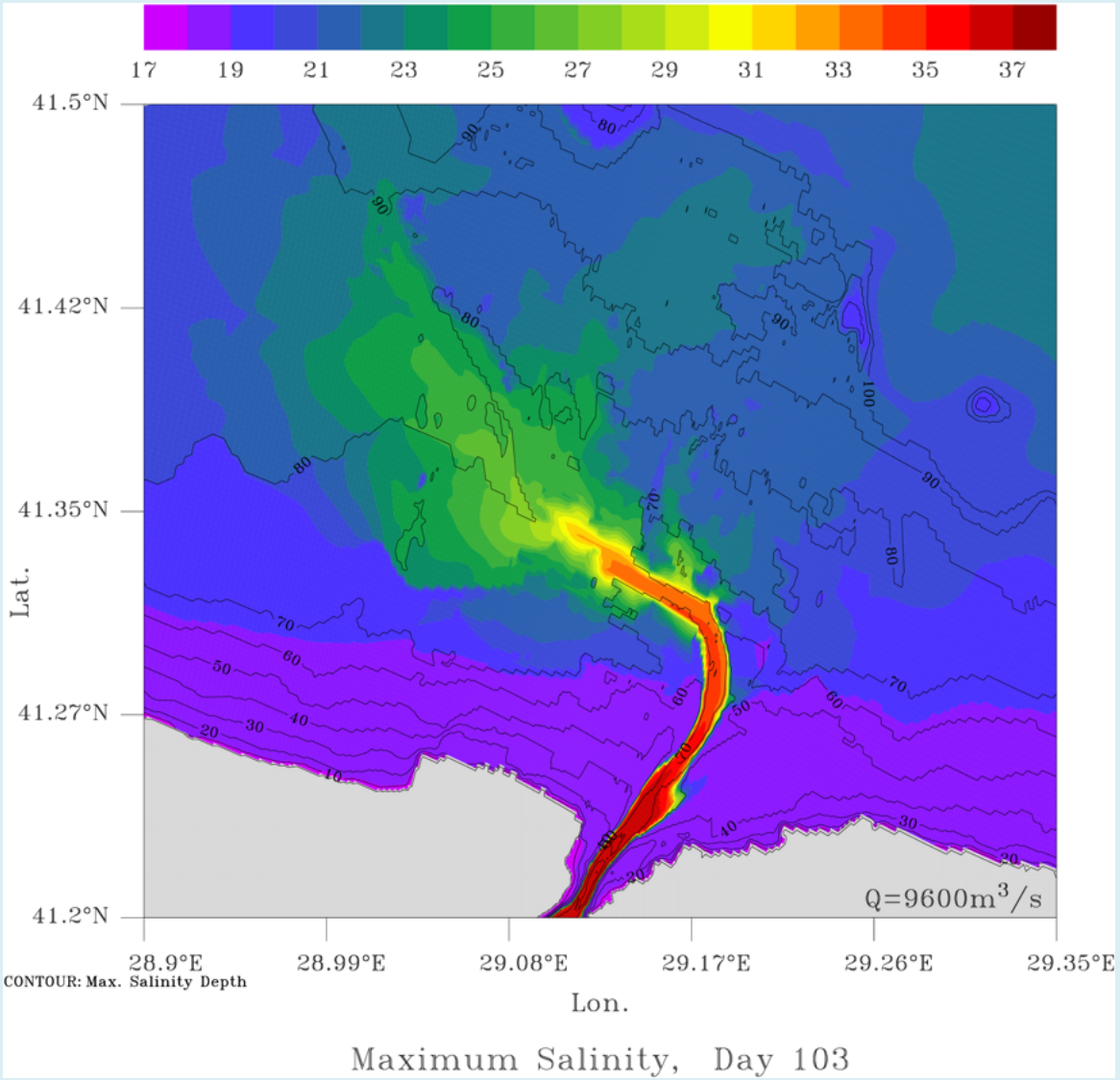

170
150
130
110
90
70
Y−Rho(km)
−20
0
20
40
60
80
X−Rho(km)
23.6
23.2
22.8
22.4
22
21.6
21.2
20.8
20.4
20
19.6
19.2
18.8
18.4
18
Temp, Z=−5.4m, Day=035.00

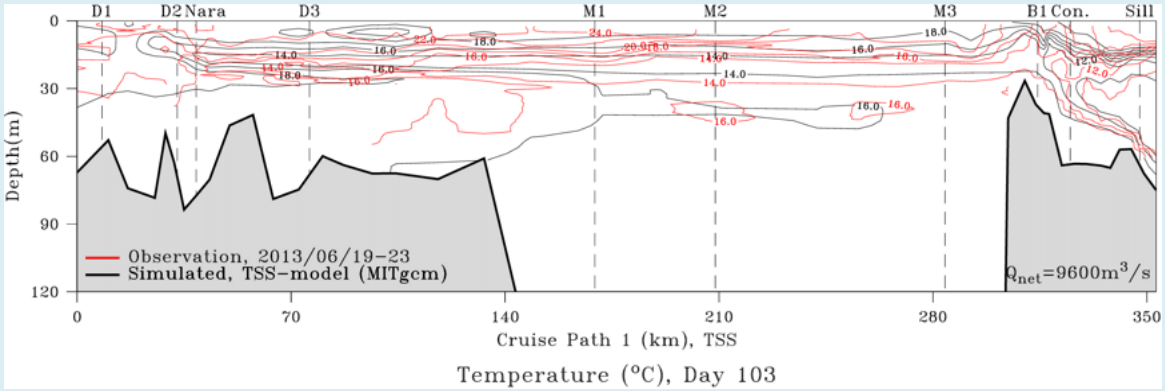


Maximum Salinity, Day 103

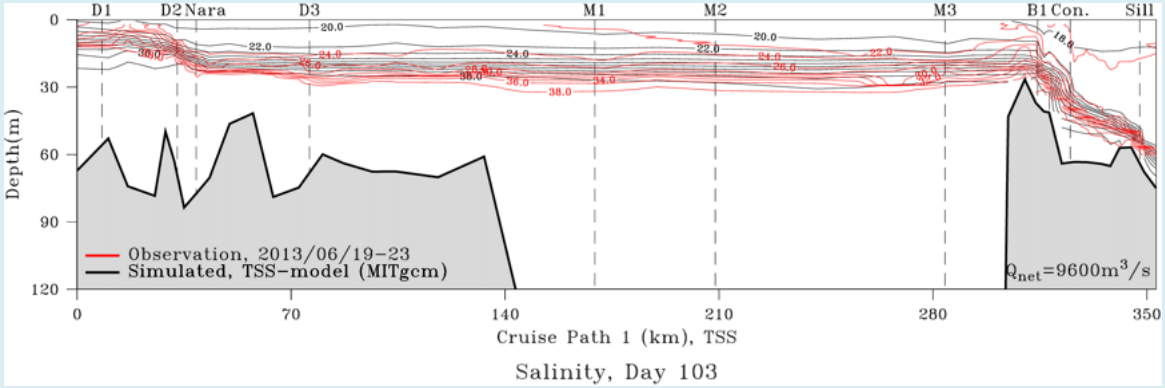


Bottom Salinity, Day 103

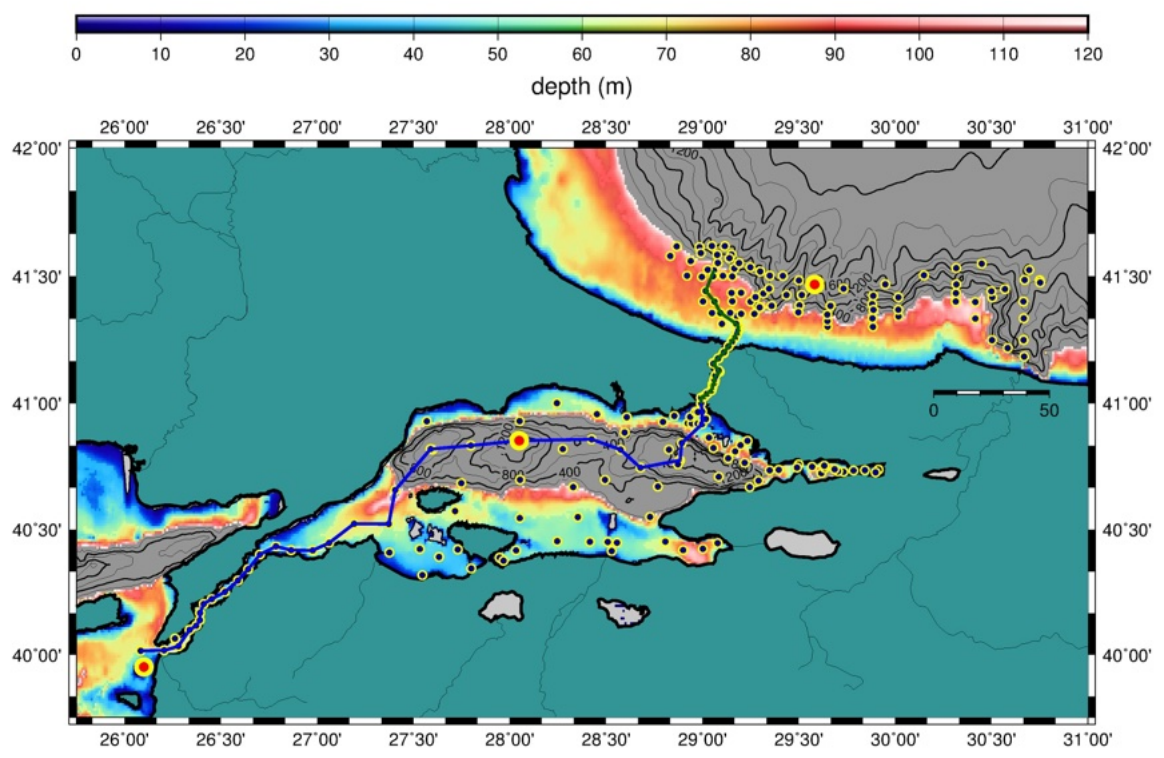

17
19
21
23
25
27
29
31
33
35
37
41.5°N
41.42°N
41.35°N
41.27°N
41.2°N
Lat.
28.9°E
28.99°E
29.08°E
29.17°E
29.26°E
29.35°E
Lon.
Q=9600m3/s
CONTOUR: Max. Salinity Depth
Maximum Salinity, Day 103

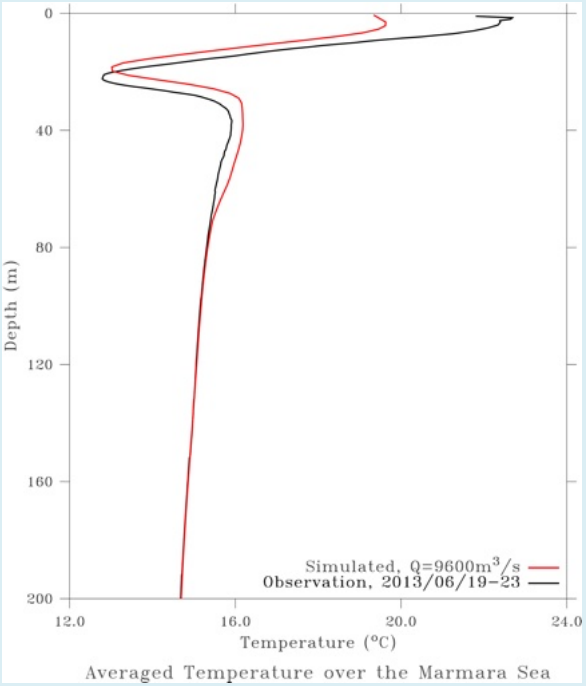


Temperature (°C), Day 103

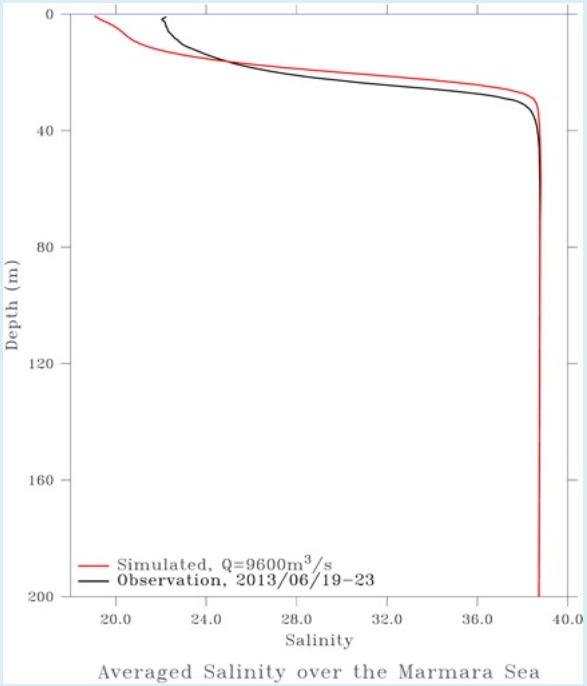


Salinity, Day 103

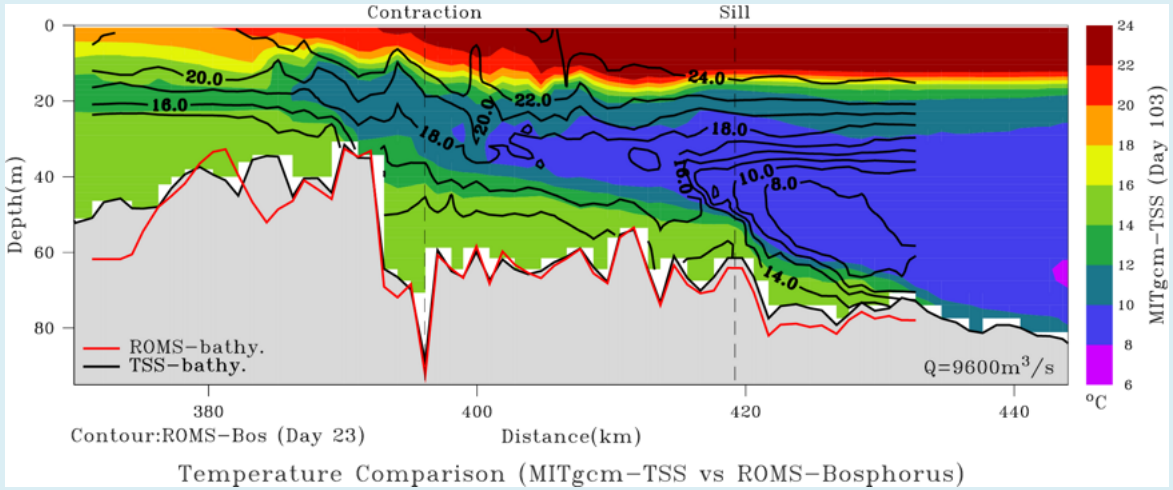




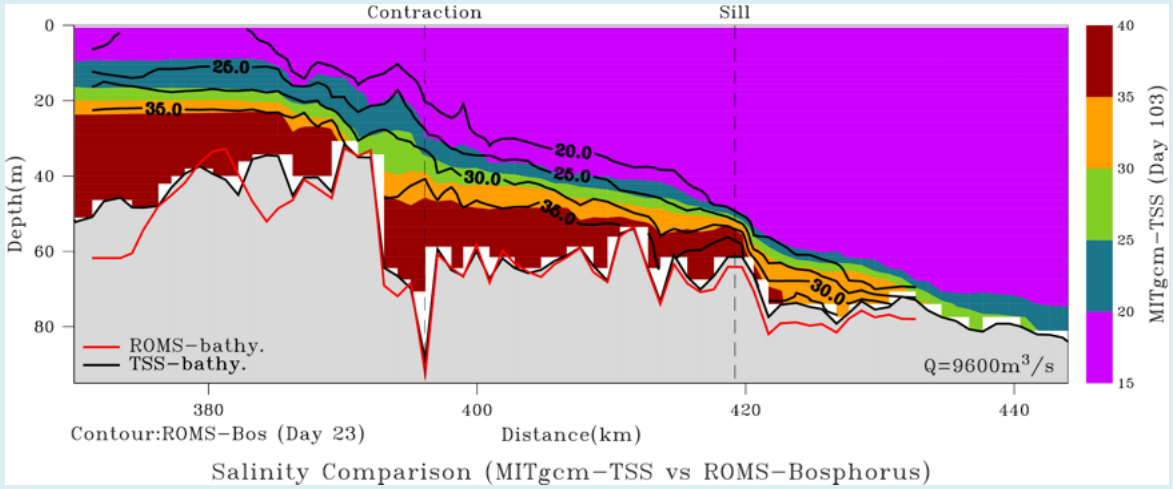
Averaged Temperature over the Marmara Sea



Averaged Salinity over the Marmara Sea



Temperature Comparison (MITgcm−TSS vs ROMS−Bosphorus)



Salinity Comparison (MITgcm−TSS vs ROMS−Bosphorus)

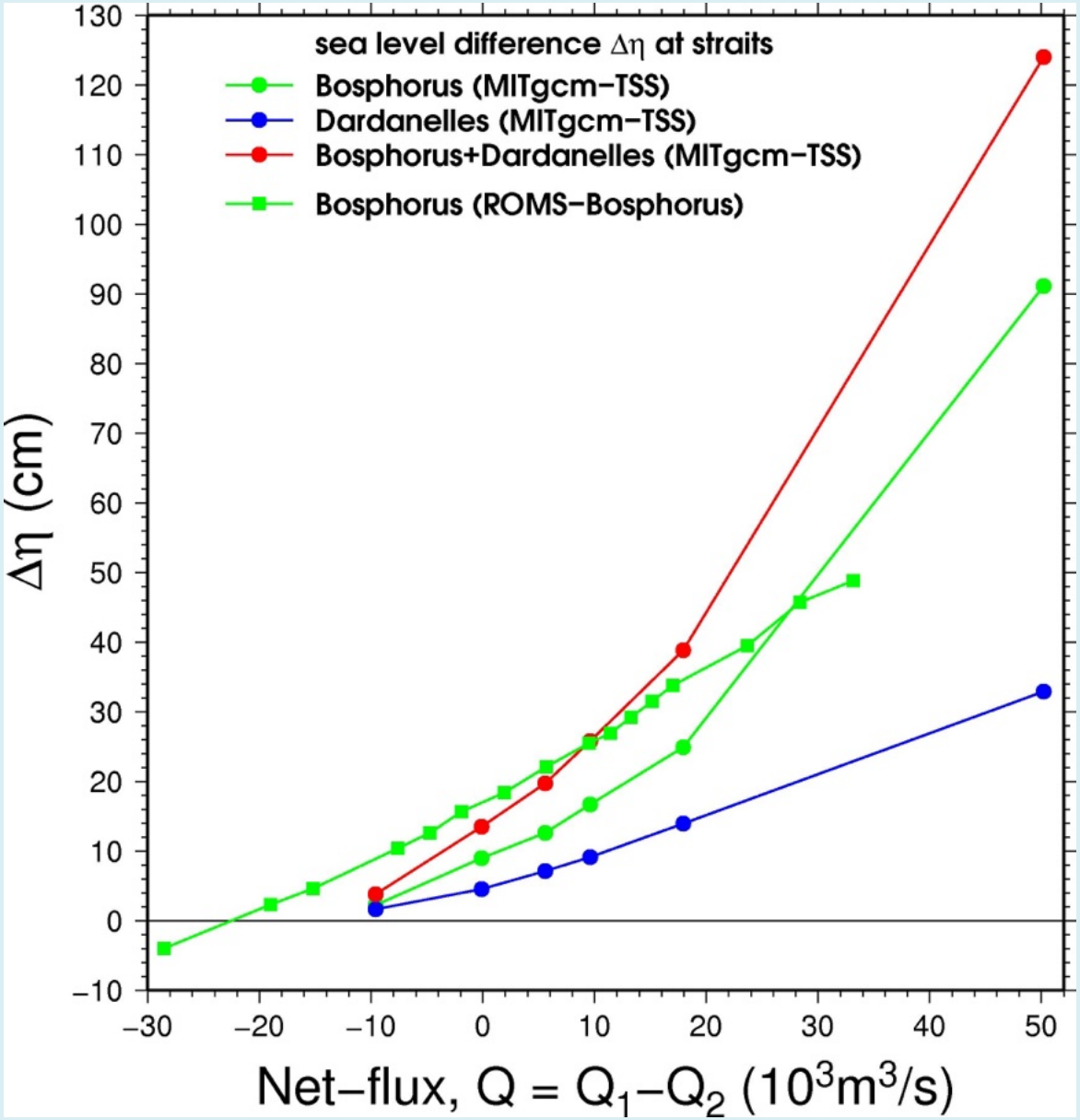

sea level difference Δη at straits
Bosphorus (MITgcm−TSS)
Dardanelles (MITgcm−TSS)
Bosphorus+Dardanelles (MITgcm−TSS)
Bosphorus (ROMS−Bosphorus)
Δη (cm)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−10
−30
−20
−10
0
10
20
30
40
50
Net−flux, Q = Q1−Q2 (10^3 m^3/s)

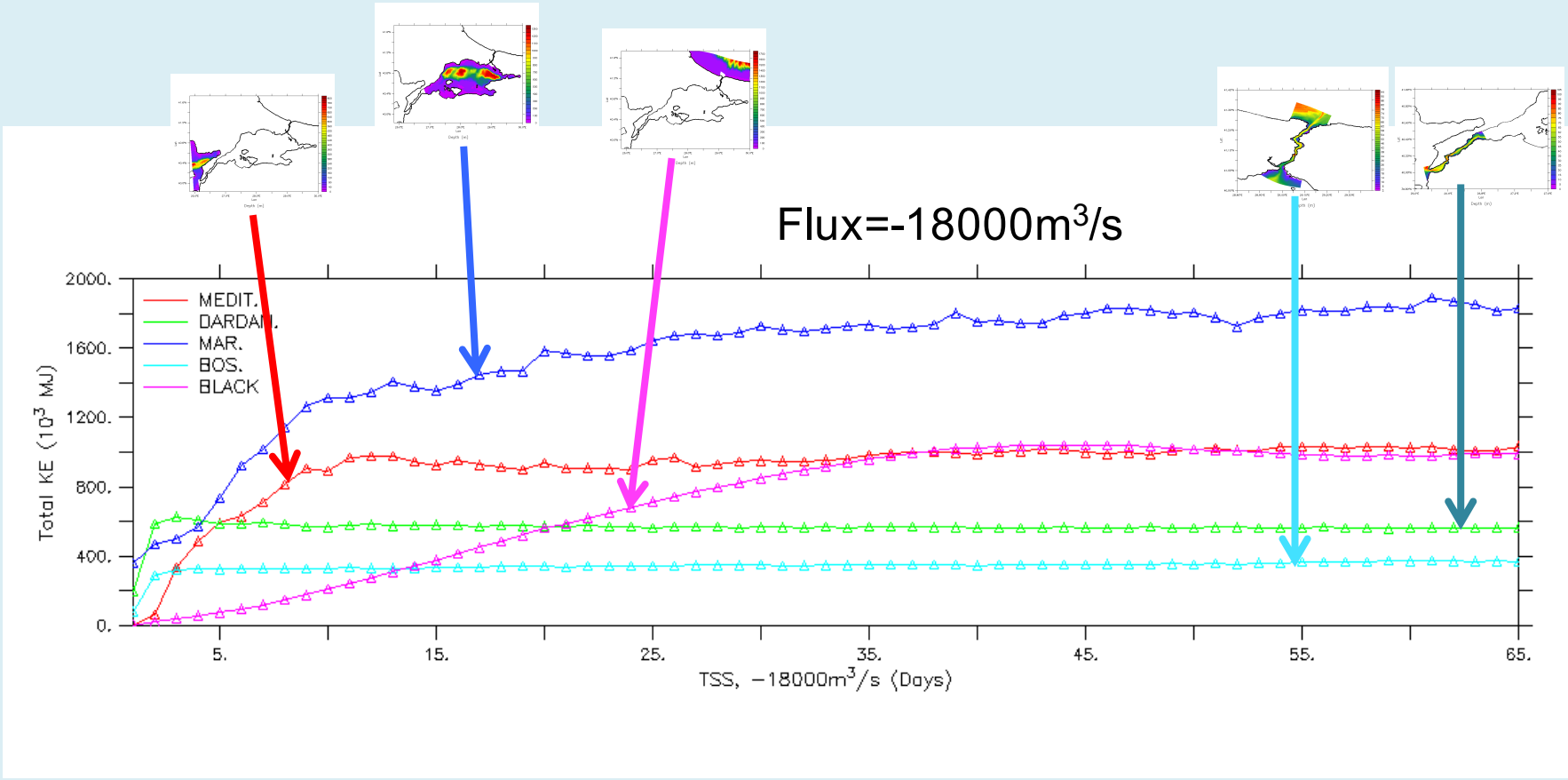
Table 1. LAYER AND TOTAL FLUXES AT STRAITS

Net flux Q (m^3/s)	Bosphorus (TSS) (m^3/s)		Dardanelles (TSS) (m^3/s)		Bosphorus (ROMS) (m^3/s)	
	upper	lower	upper	lower	upper	lower
	Q_1	Q_2	Q_1	Q_2	Q_1	Q_2
-9600	1900	11500	3500	13100	6800	16400
0	6950	6950	8750	8750	12200	12200
5600	9950	4550	13200	7600	15400	9800
9600	13000	3400	15800	6200	17800	8200
18000	19200	1200	22100	4100	23600	5600
50000	50100	100	52700	2700	-	-

Table 2. SEA LEVEL DIFFERENCE VERSUS NET FLUX AT STRAITS

Net flux Q (m^3/s)	Bosphorus (TSS) sea level difference $\Delta\eta$ (cm)	Dardanelles (TSS) sea level difference $\Delta\eta$ (cm)	Bosphorus (ROMS) sea level difference $\Delta\eta$ (cm)
-9600	2.2	1.6	8.9
0	9.0	4.5	16.9
5600	12.6	7.1	22.0
9600	16.7	9.1	25.6
18000	24.9	13.9	34.6
50000	91.1	32.9	-

MITgcm TSS model: kinetic energy



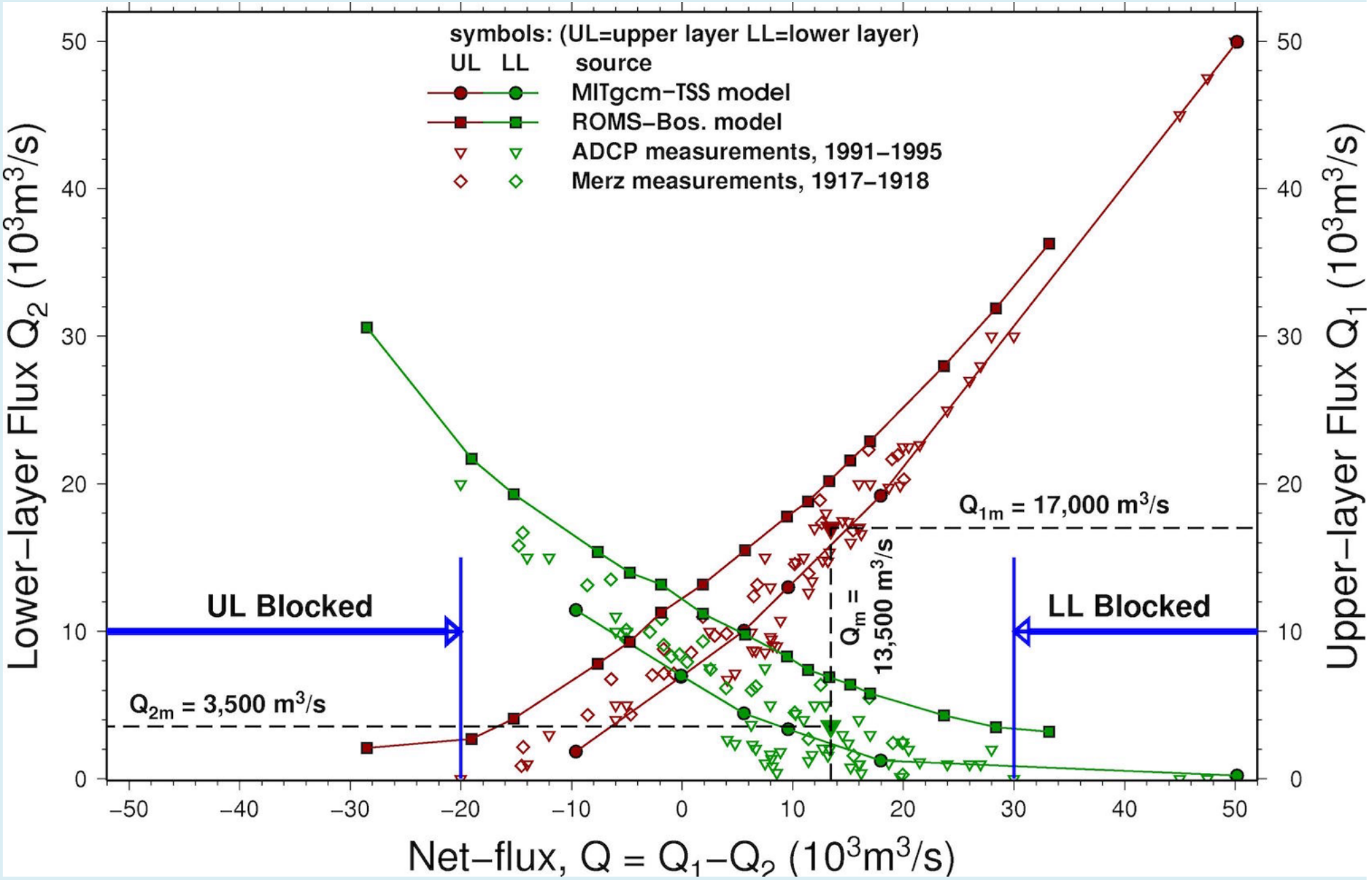
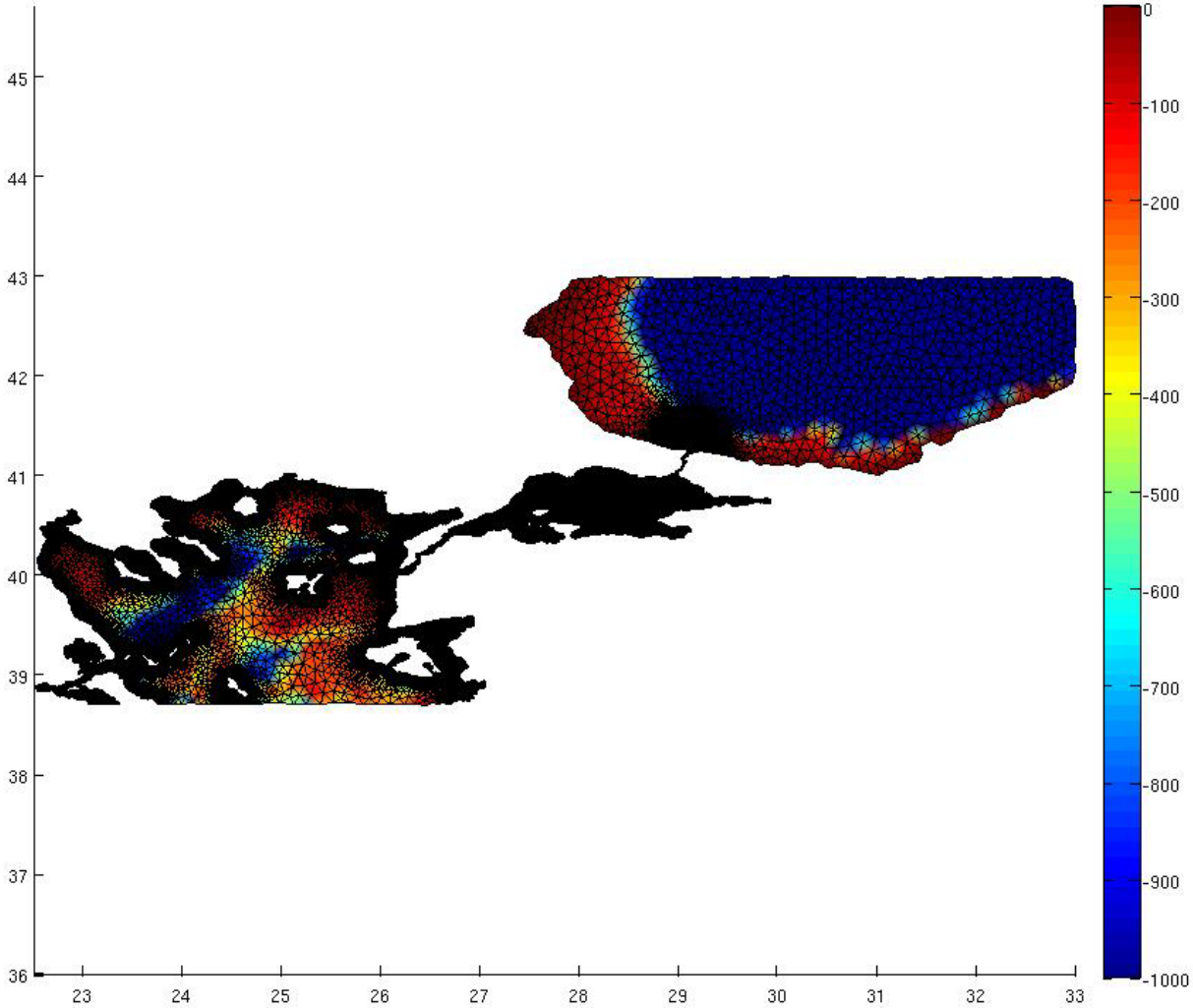

symbols: (UL=upper layer LL=lower layer)
UL LL source
MITgcm–TSS model
ROMS–Bos. model
ADCP measurements, 1991–1995
Merz measurements, 1917–1918
Lower–layer Flux Q_2 ($10^3 m^3/s$)
Upper–layer Flux Q_1 ($10^3 m^3/s$)
Net–flux, $Q = Q_1 – Q_2$ ($10^3 m^3/s$)
Q_{1m} = 17,000 m^3/s
Q_{2m} = 3,500 m^3/s
Q_m = 13,500 m^3/s
UL Blocked
LL Blocked
50
40
30
20
10
0
–50
–40
–30
–20
–10
0
10
20
30
40
50

Table 1. SEA LEVEL DIFFERENCE AT STRAITS AS A FUNCTION OF NET FLUX

Net flux Q (m^3/s)	Bosphorus (TSS) sea level difference $\Delta\eta$ (cm)	Dardanelles (TSS) sea level difference $\Delta\eta$ (cm)	Bosphorus (ROMS) sea level difference $\Delta\eta$ (cm)
-9600	2	1.5	-
0	8	5	14
5600	10	7	18
9600	14	11	22
18000	22	16	30
50000	85	32	-

FEOM Model Gürses et al. 2016

Horizontal Discretization



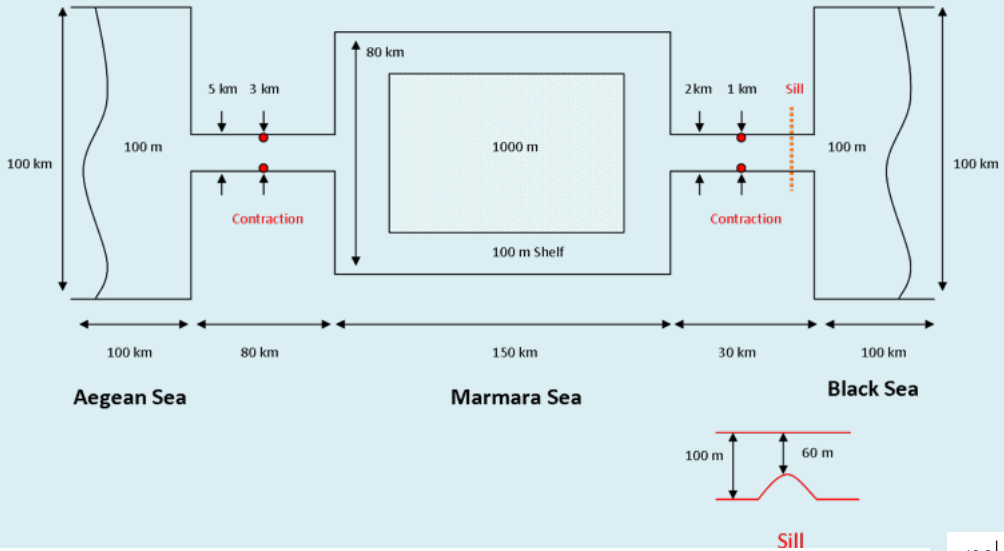
Number of nodes:

	FESOM G1	FESOM G2
2d-nodes	75000	100000
3d-nodes	~3 mil	~5 mil

Resolution:

	FESOM G1	FESOM G2
BOS	65 m	50 m
DAR	100 m	100 m
MAR	2 km	1 km
BS/AS	12 km	5 km

Ideal Test Case



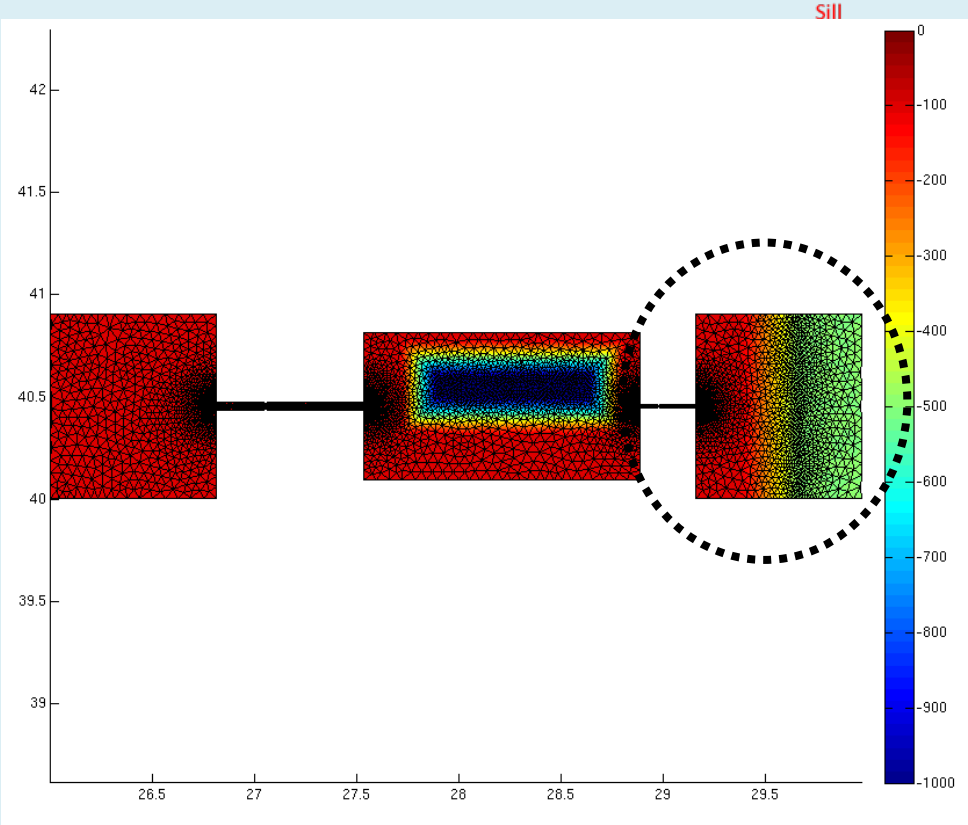
Sill

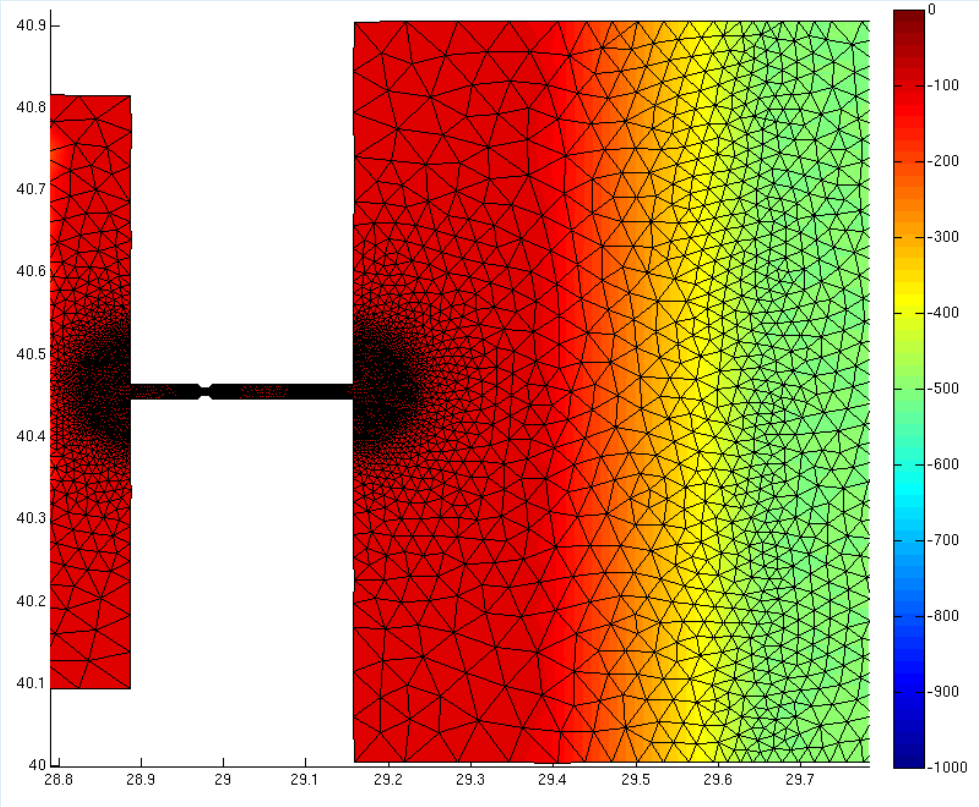
Number of Surface Nodes: 11418

Number of Surface Elements: 21820

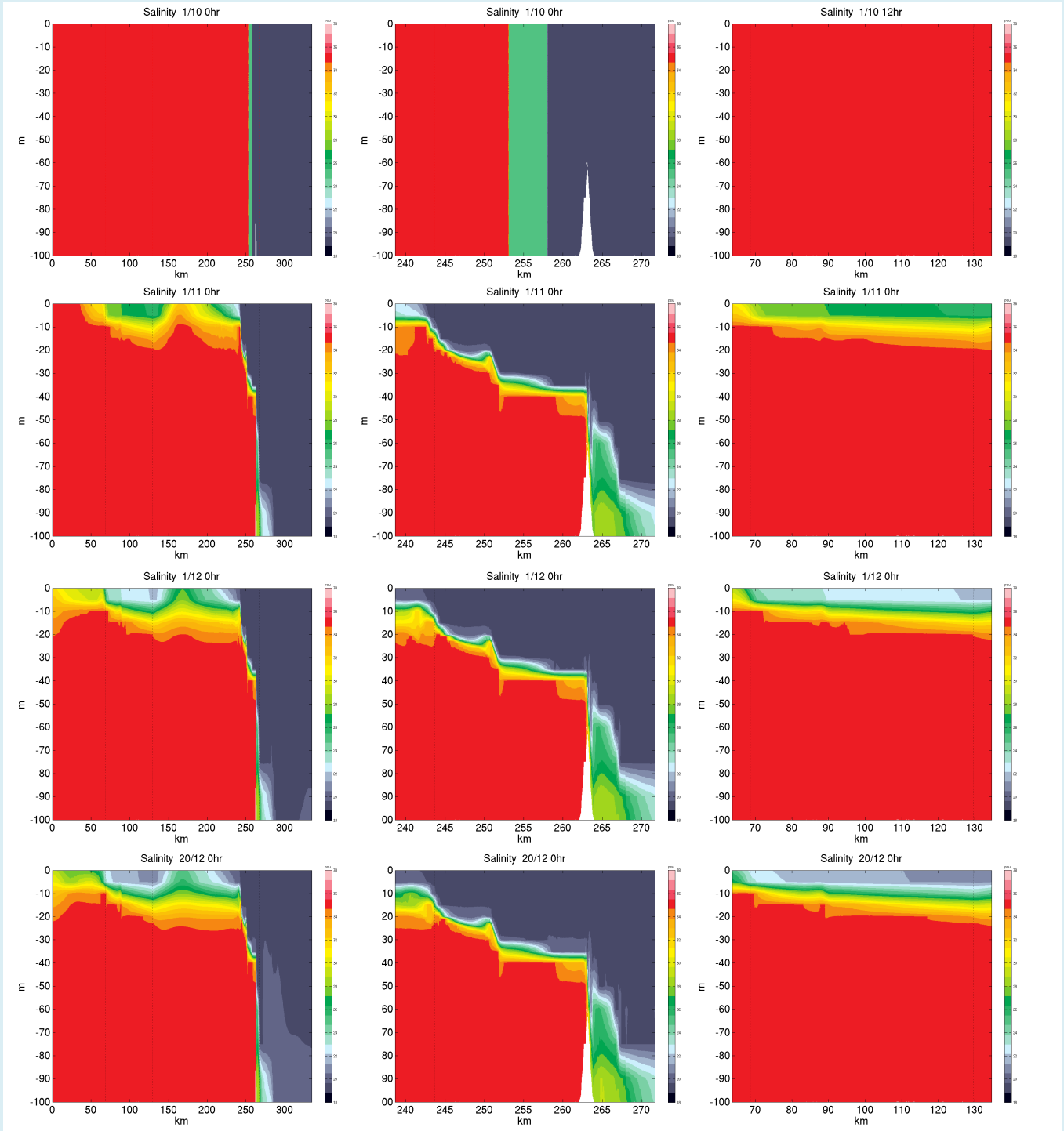
Number of Vertical Levels: 29

Time Step = 20 s. (5 s.)

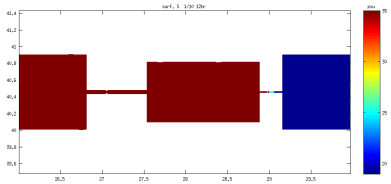


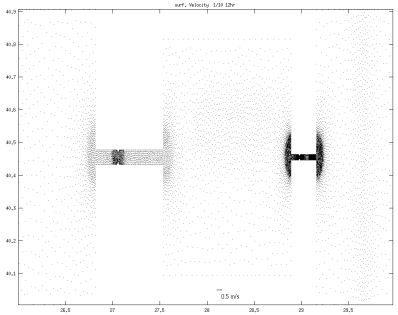


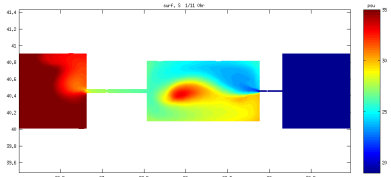
TNoL6

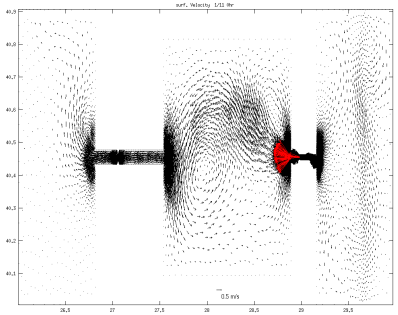

EAST-WEST SECTION
BOSPHORUS
DARDANELLES
Salinity 1/10 0hr
Salinity 1/10 0hr
Salinity 1/10 12hr
Salinity 1/11 0hr
Salinity 1/11 0hr
Salinity 1/11 0hr
Salinity 1/12 0hr
Salinity 1/12 0hr
Salinity 1/12 0hr
Salinity 20/12 0hr
Salinity 20/12 0hr
Salinity 20/12 0hr
m
km

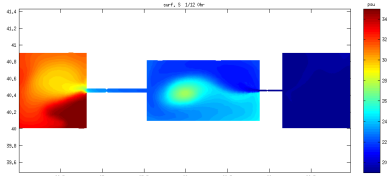
SURFACE

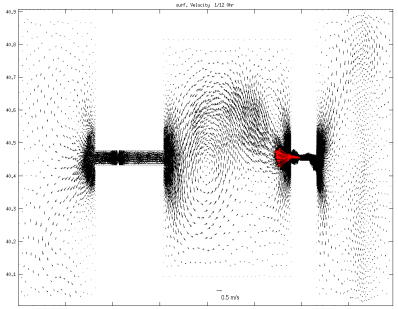


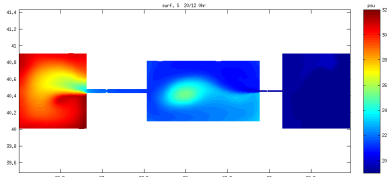


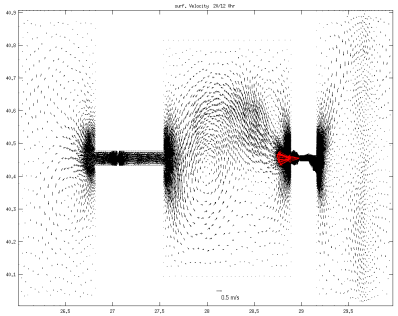




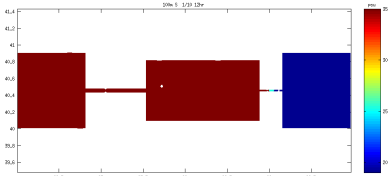


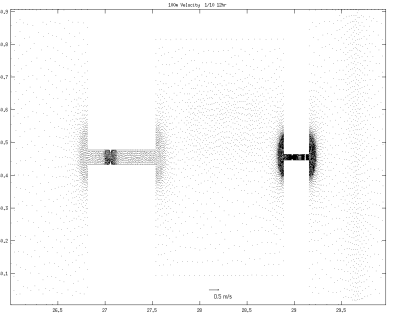


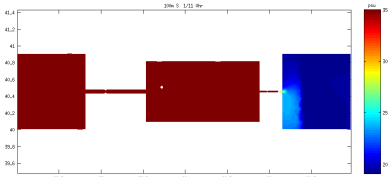


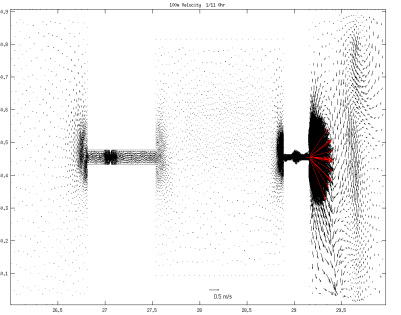


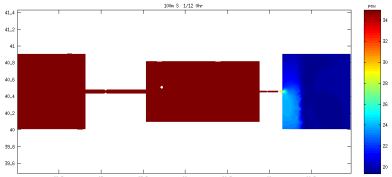
100 m.

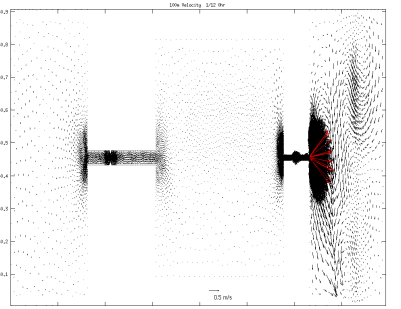


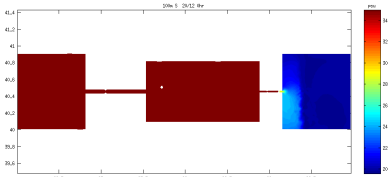


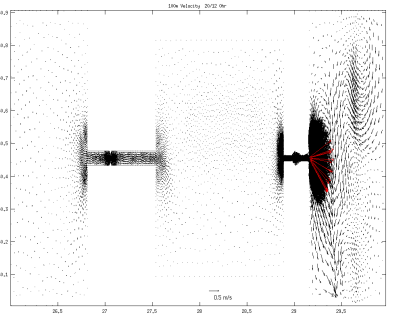




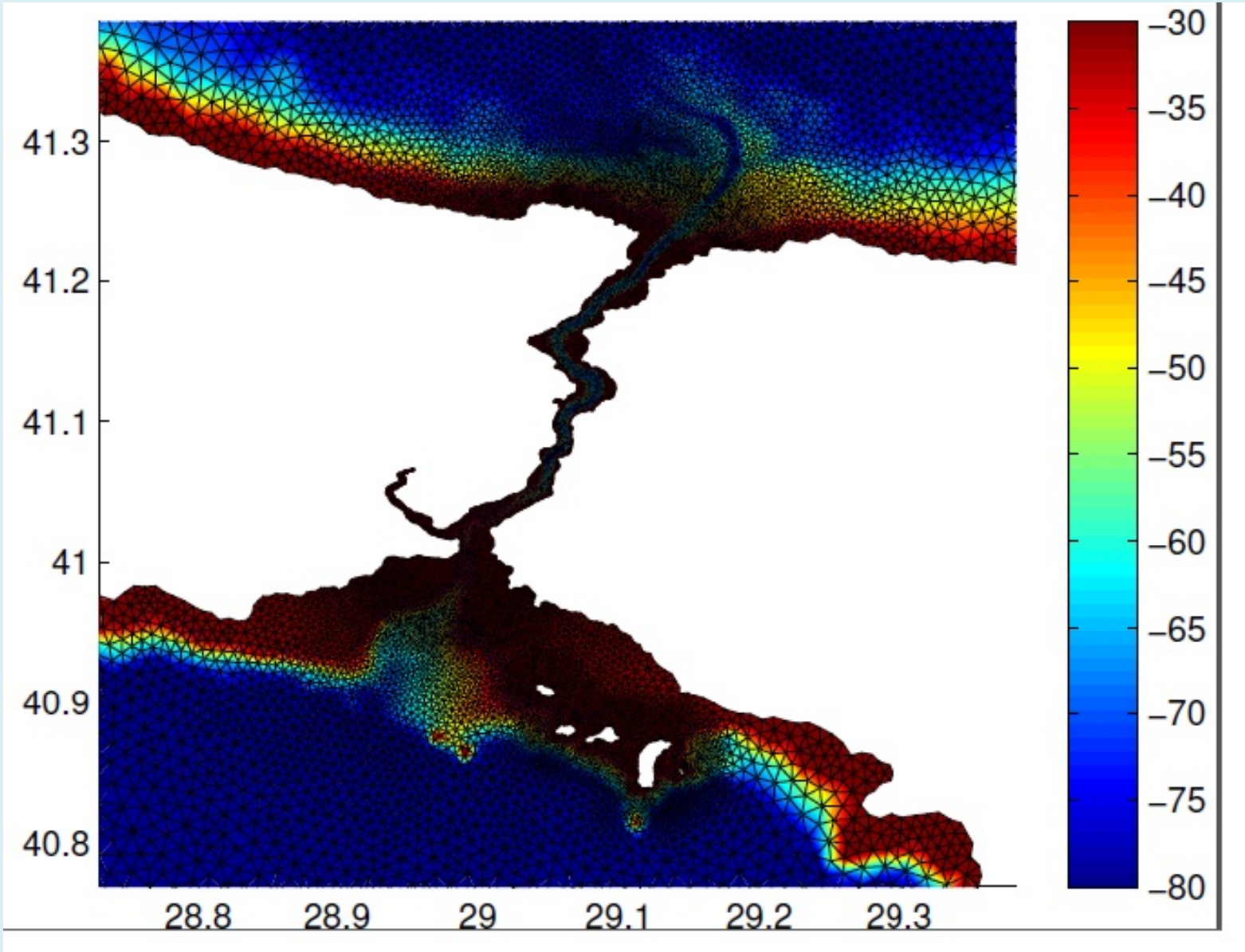


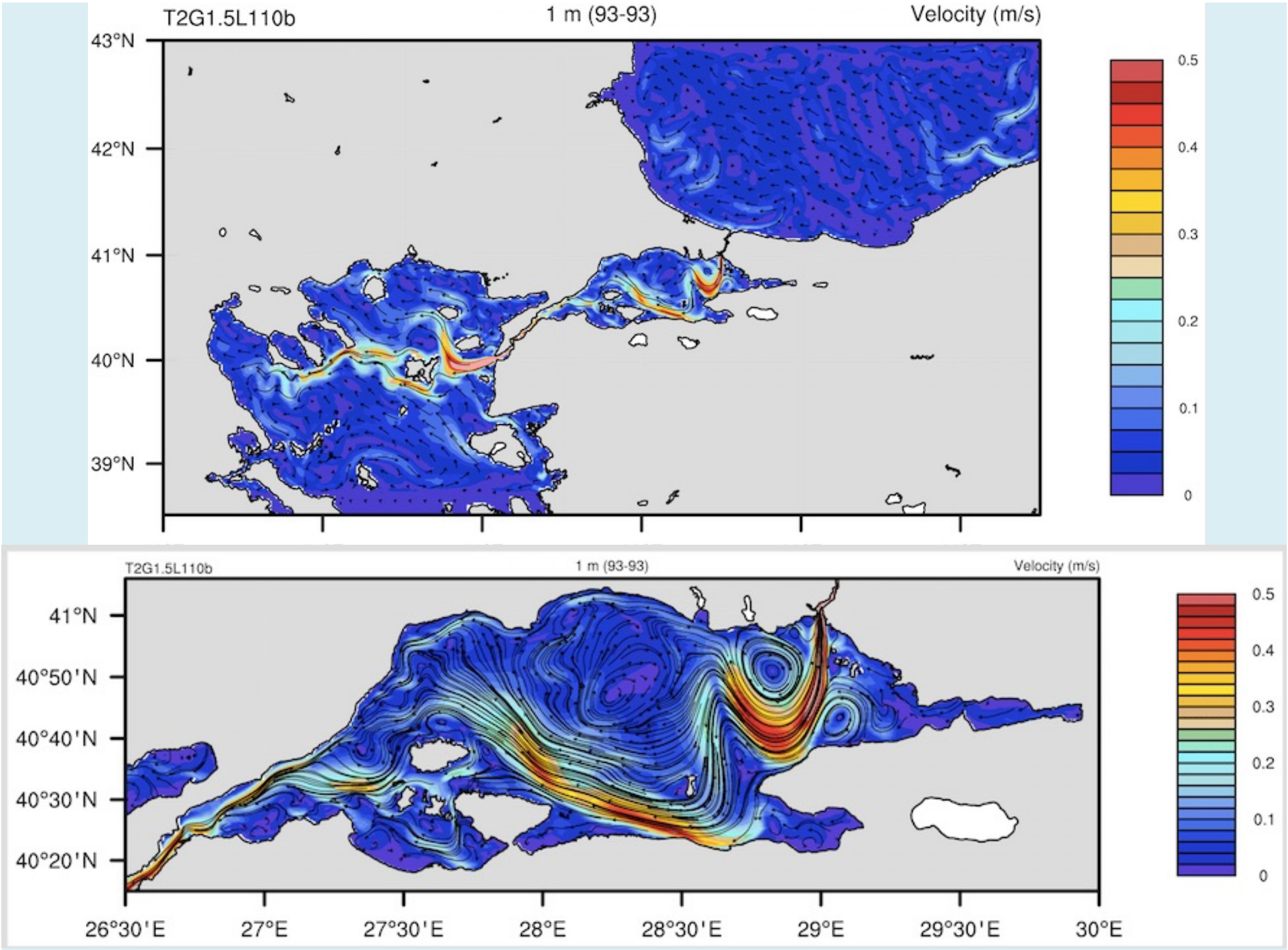


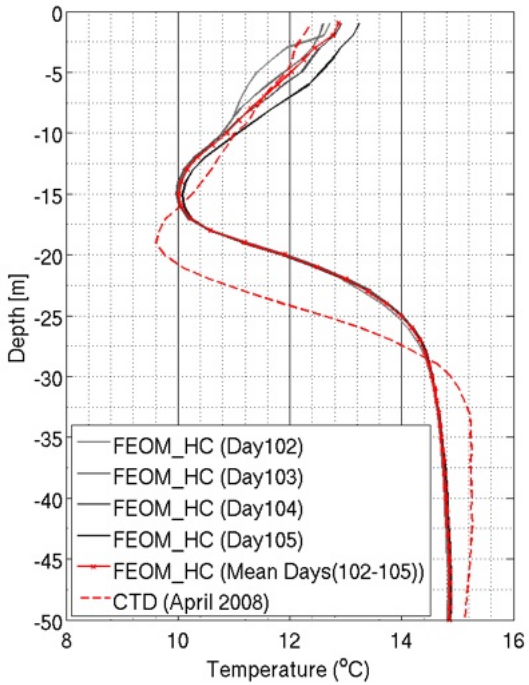




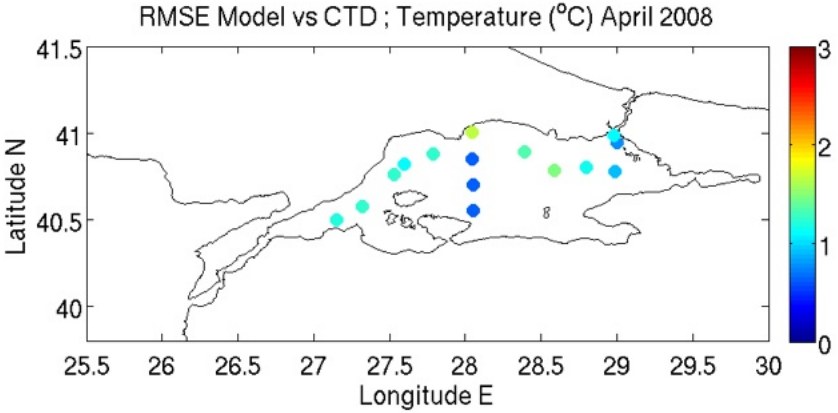
Model

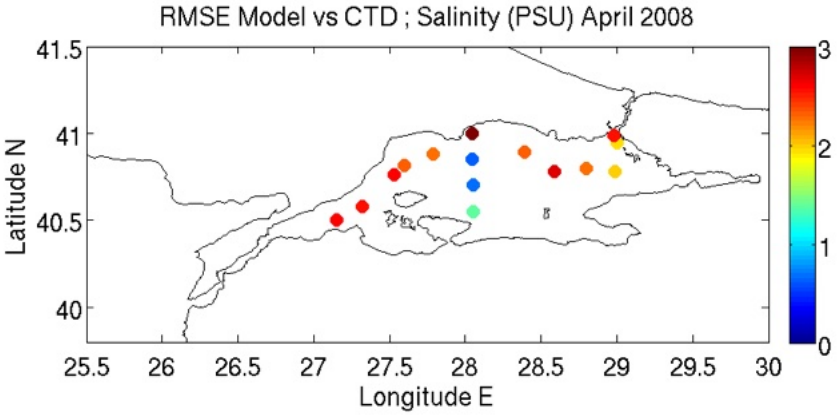

41.3
41.2
41.1
41
40.9
40.8
28.8
28.9
29
29.1
29.2
29.3
−30
−35
−40
−45
−50
−55
−60
−65
−70
−75
−80

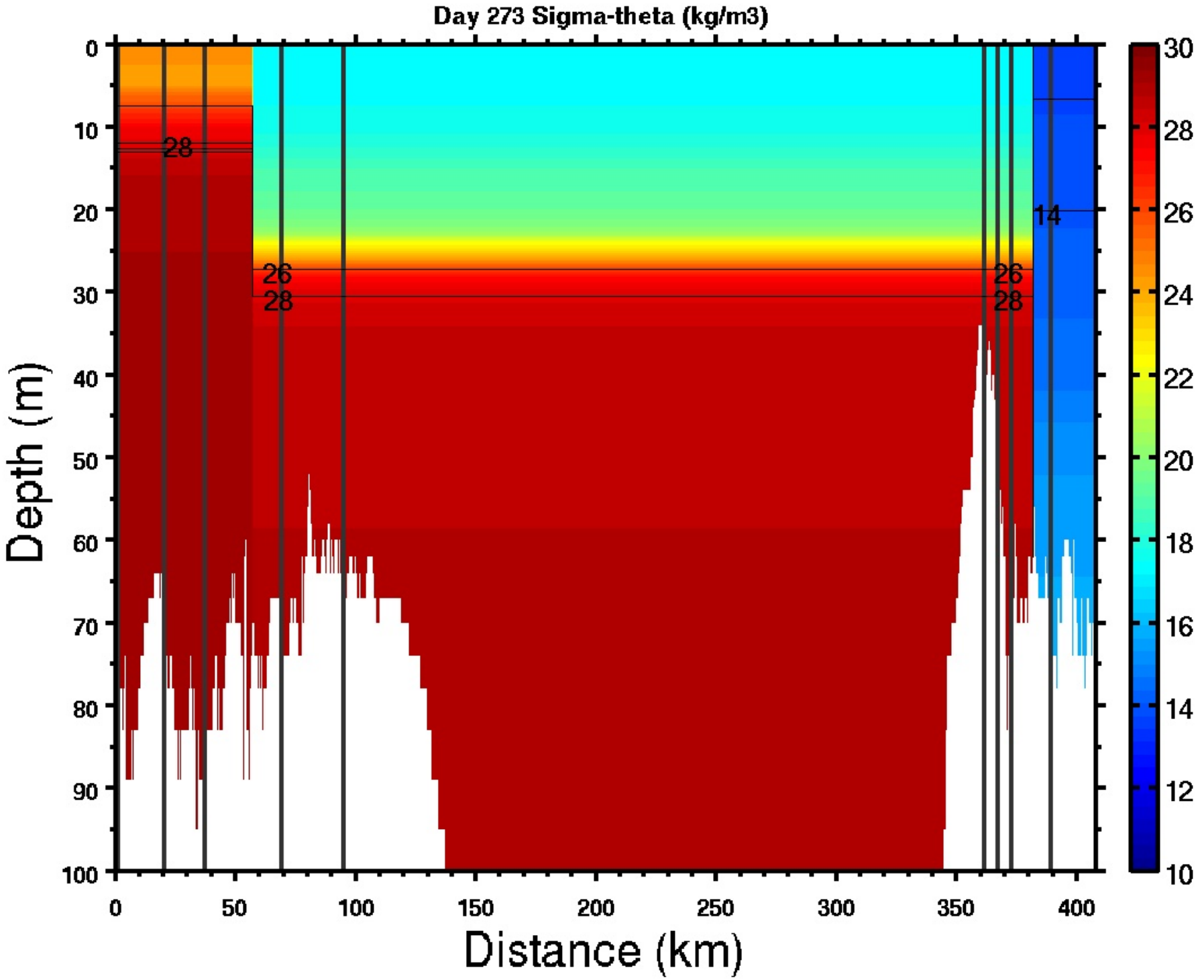

T2G1.5L110b
1 m (93-93)
Velocity (m/s)
43°N
42°N
41°N
40°N
39°N
0.5
0.4
0.3
0.2
0.1
0
T2G1.5L110b
1 m (93-93)
Velocity (m/s)
41°N
40°50'N
40°40'N
40°30'N
40°20'N
26°30'E
27°E
27°30'E
28°E
28°30'E
29°E
29°30'E
30°E
0.5
0.4
0.3
0.2
0.1
0

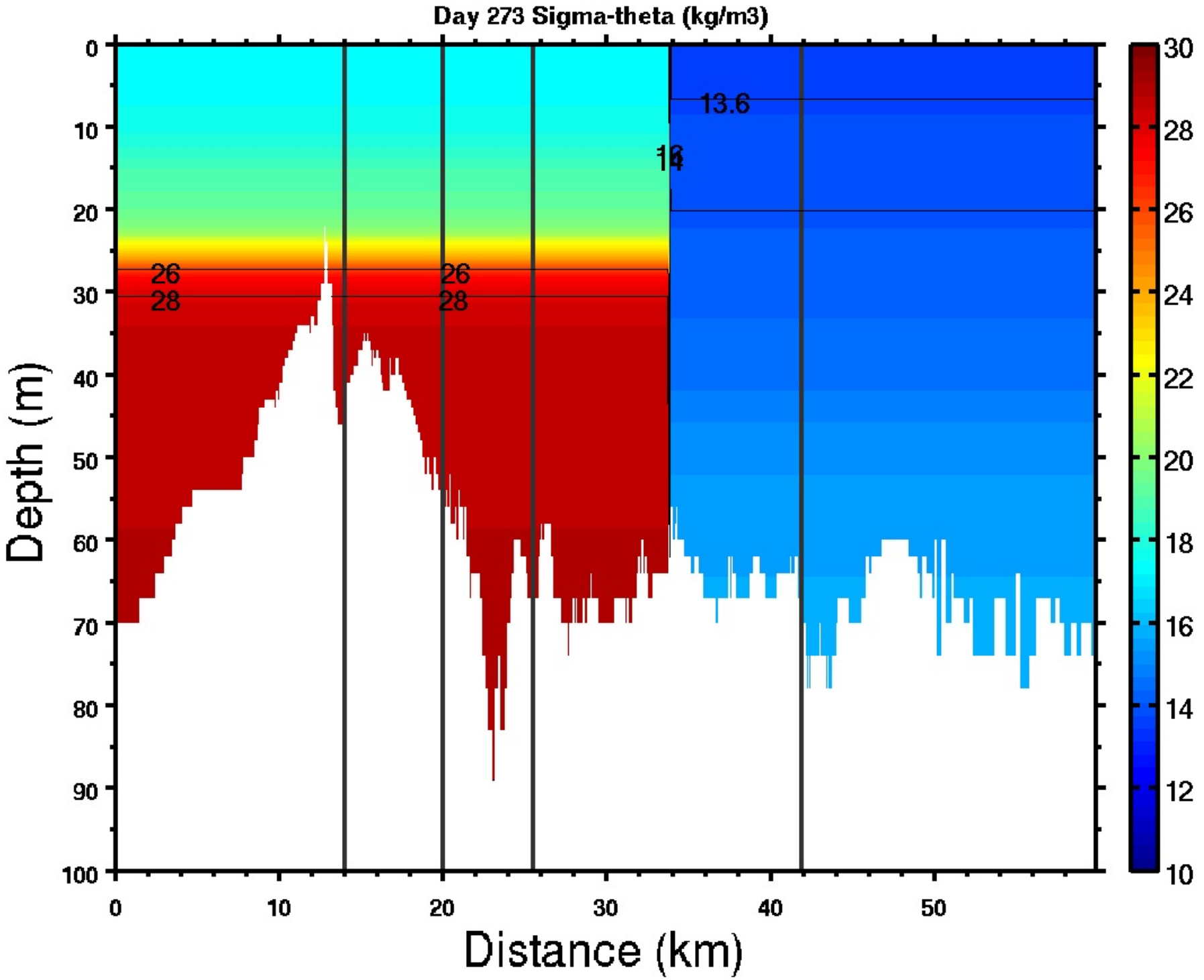

Depth [m]
Temperature (°C)
FEOM_HC (Day102)
FEOM_HC (Day103)
FEOM_HC (Day104)
FEOM_HC (Day105)
FEOM_HC (Mean Days(102-105))
CTD (April 2008)


Salinity (psu)

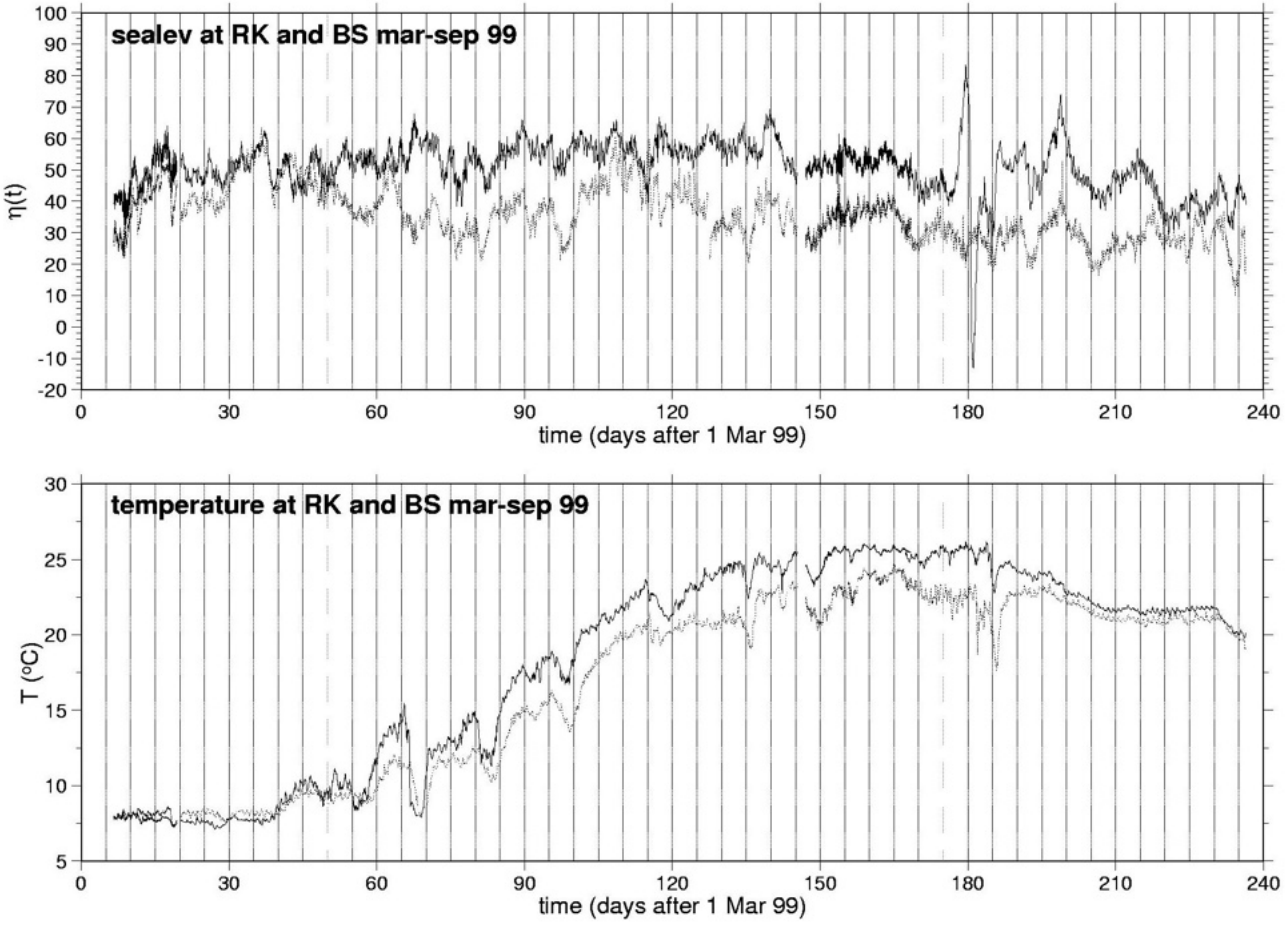

RMSE Model vs CTD ; Temperature (°C) April 2008
Latitude N
Longitude E


RMSE Model vs CTD ; Salinity (PSU) April 2008
Latitude N
Longitude E

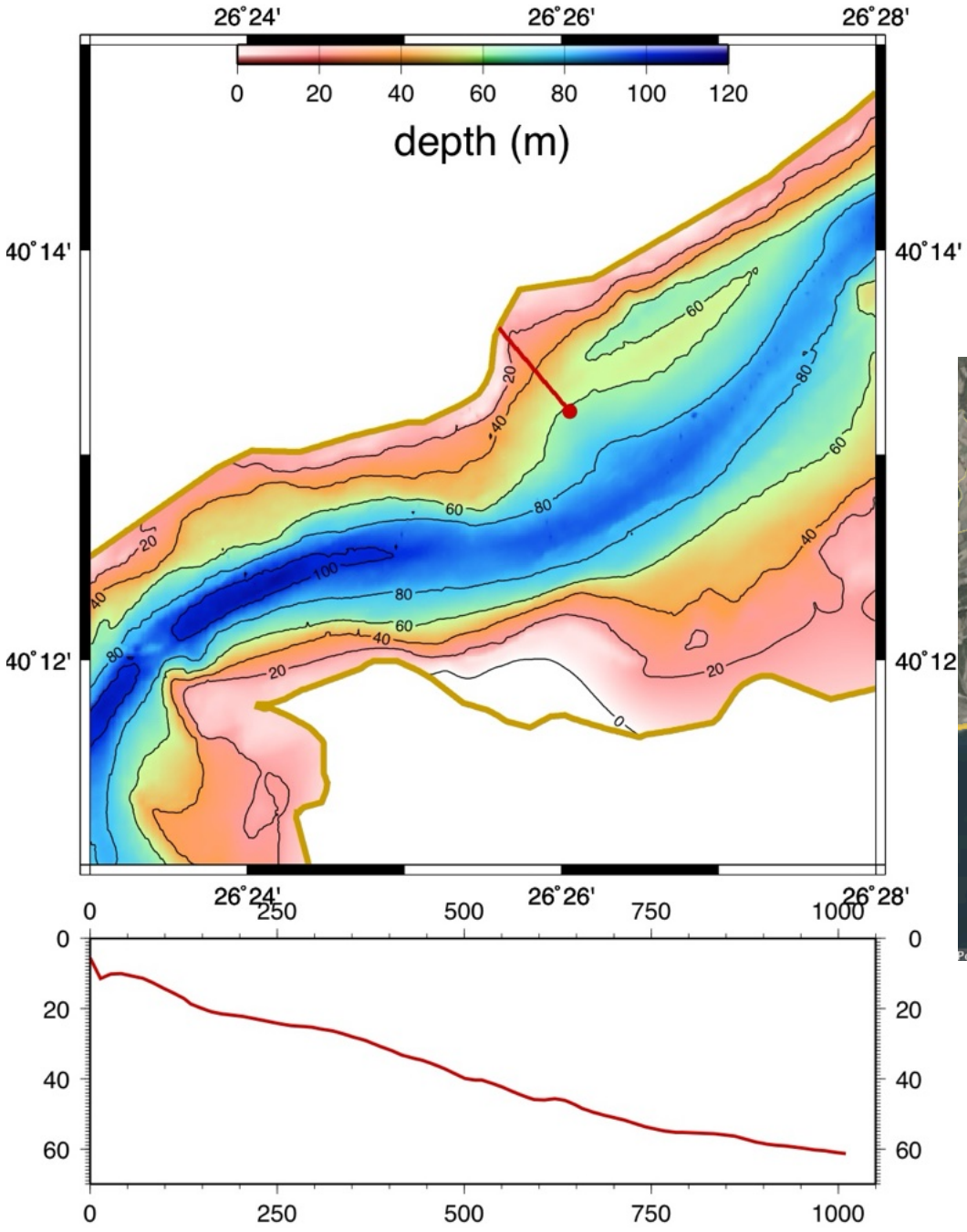

Day 273 Sigma-theta (kg/m3)
Depth (m)
Distance (km)
0
10
20
30
40
50
60
70
80
90
100
0
50
100
150
200
250
300
350
400
28
26
28
26
28
14
30
28
26
24
22
20
18
16
14
12
10

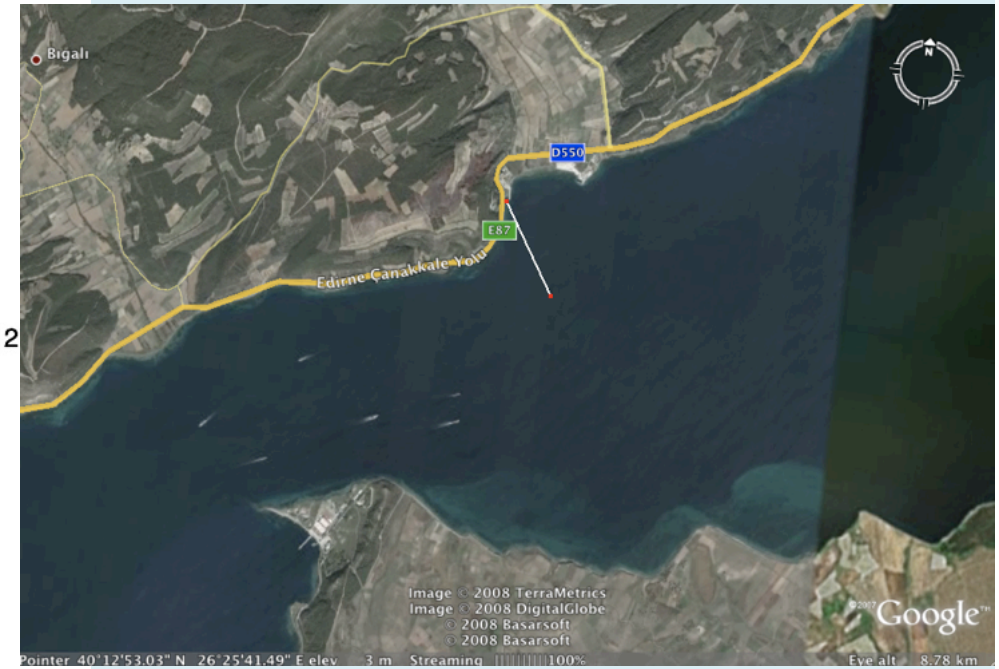

Day 273 Sigma-theta (kg/m3)
Depth (m)
Distance (km)
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50
13.6
14
26
28
26
28
30
28
26
24
22
20
18
16
14
12
10

work not concluded


sealev at RK and BS mar-sep 99
η(t)
time (days after 1 Mar 99)
temperature at RK and BS mar-sep 99
T (°C)
time (days after 1 Mar 99)

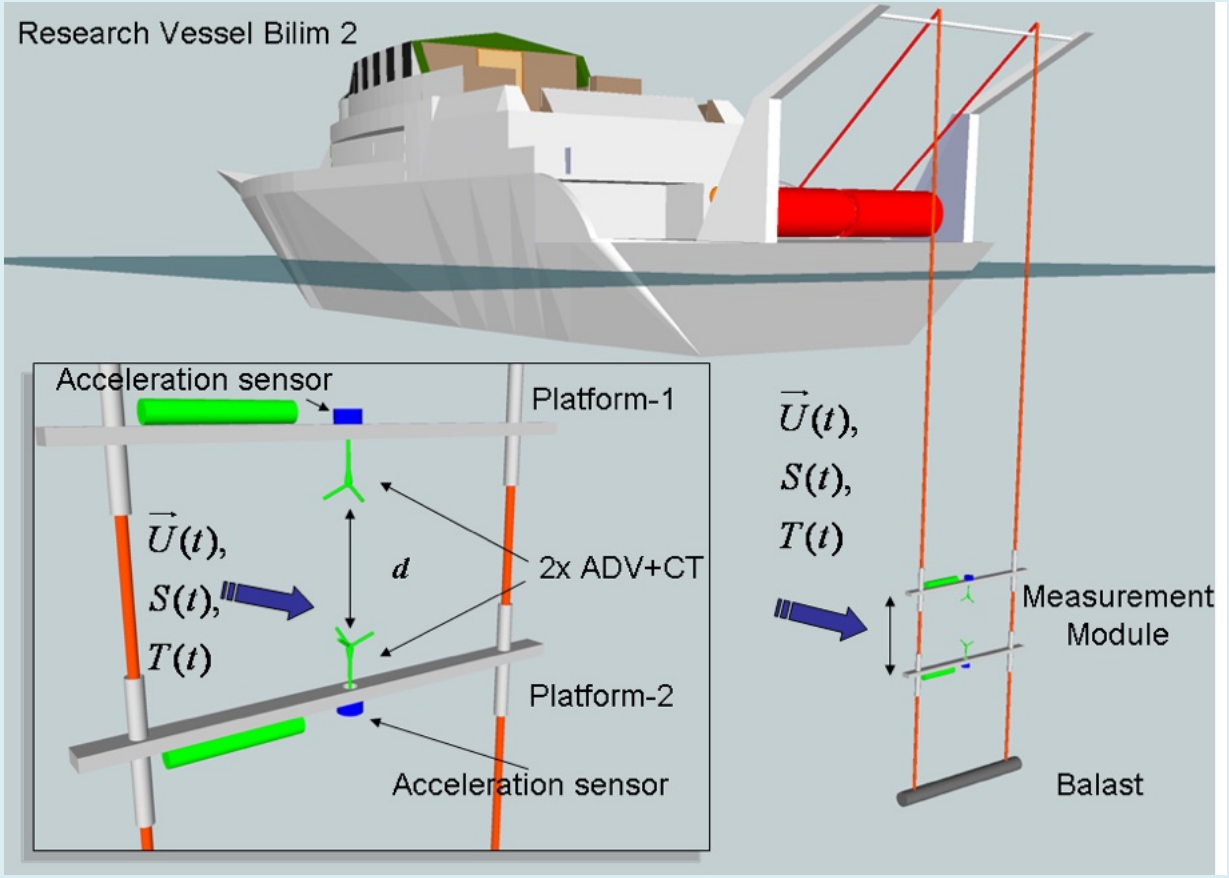
Çanakkale Boğazı ADCP





Çanakkale ve İstanbul Boğazları besin, klorofil ve plankton örnekleyicileri

Concept of measurements



- Compass
- Acceleration (linear+rotational)
- Tilt angle

	Spectrum	Two-point correlations (Structure fuctions)	Auto correlation	Length scales
Velocity (3C)	✓	✓	✓	Longitudinal & transverse
Temperature	✓	✓	✓	Longitudinal
Salinity	✓	✓	✓	Longitudinal

Emin Özsoy, Özgür Ertunç,
Çağatay Köksoy,
Hermann Lienhart

TÜBİTAK – BMBF
İkili İşbirliği Araştırma Projesi

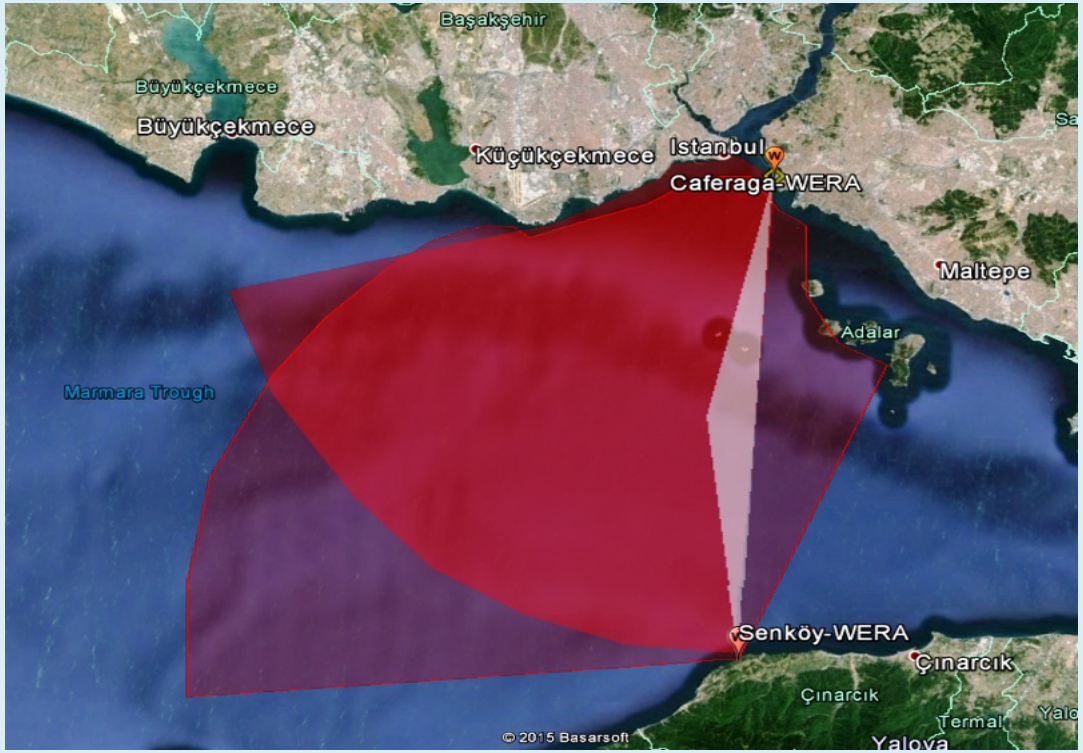
İstanbul Boğazı'nda
Yüksek Reynolds Sayılarında
Türbülanslı Karışım

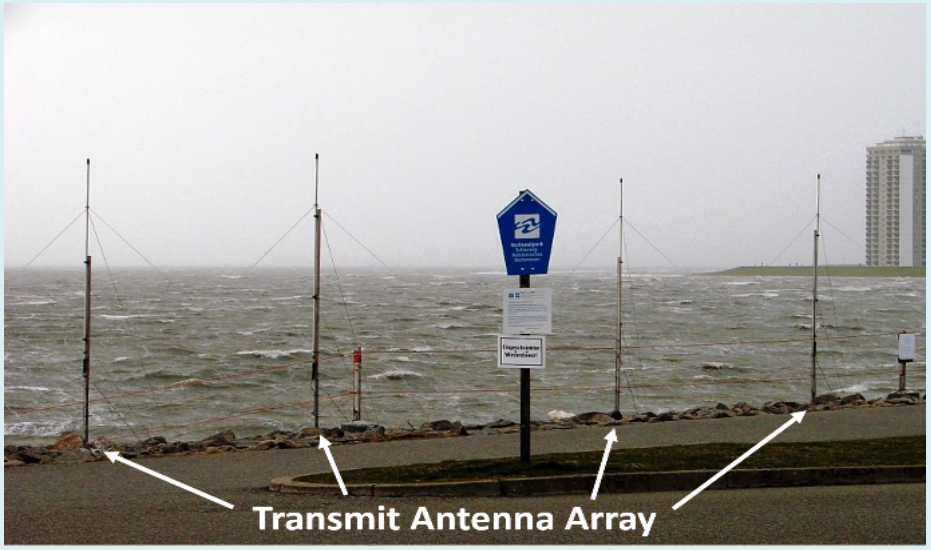
Sergi ve Katılım:

2014 Türk-Alman Araştırma,
Eğitim ve İnovasyon Yılı
Açılış Etkinliği

"Science Bridging Nations"
Türk Alman Uygulamalı
Ortak Projeleri Sergisi

23 Ocak 2014, Berlin


Başakşehir
Büyükçekmece
Büyükçekmece
Küçükçekmece
Istanbul
Caferaga-WERA
Maltepe
Adalar
Marmara Trough
Senköy-WERA
Çınarcık
Çınarcık
Termal
Yalova
© 2015 Basarsoft


Transmit Antenna Array


WERA Container
Receive Antenna Array
Walking Pedestrians