Physical Interactions between Continental Discharges and Coastal Ocean: An Attempt of Brief Review

by Peter O. Zavialov, Shirshov Institute of Oceanology

Baltiysk, Russia, July 2, 2008

A part of the material used in this talk was prepared by:

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Peter Makkaveyev

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Outline

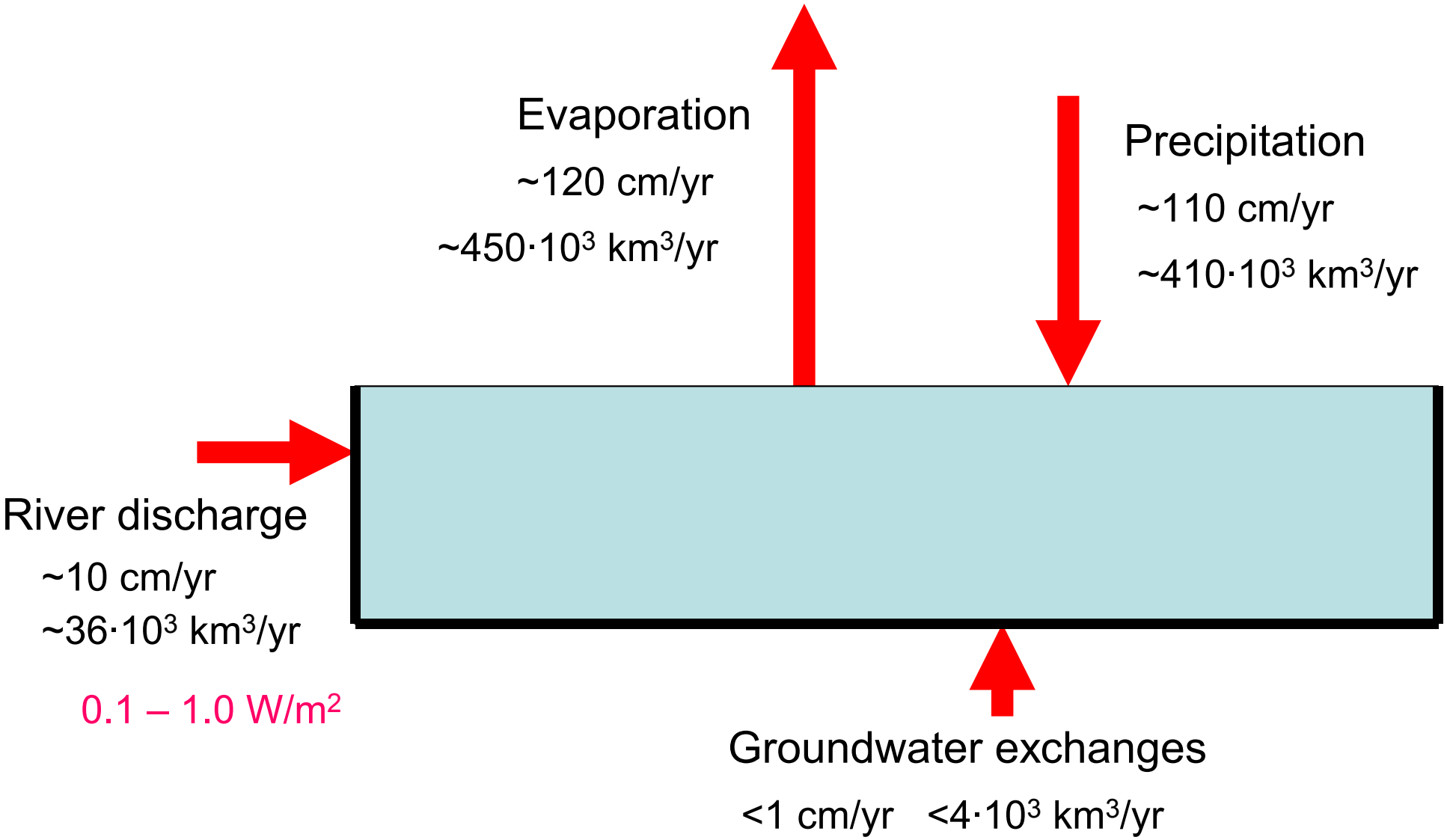
1. Water budget of the ocean and the seas. Coast as a *permeable* lateral boundary of the ocean
2. How do river discharges modulate 3D structure and variability of the ocean?
3. A “zoo” of river plumes, and their amazing properties
4. Physics behind: free plumes, plumes with bottom friction, wind-dragged plumes
5. Some specific issues: river discharges as potential source of

   5.1) internal waves in non-tidal basins, and

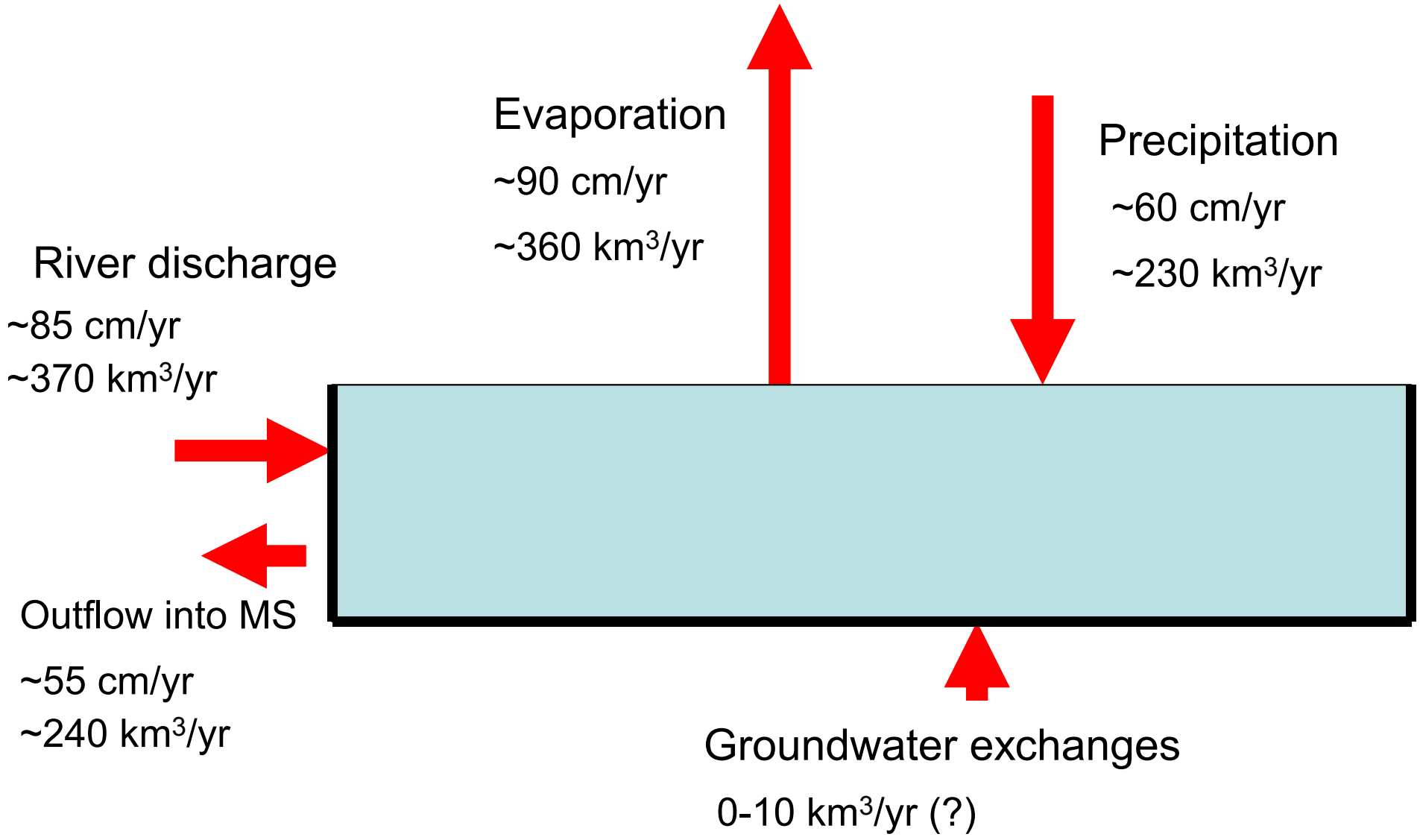
   5.2) vorticity on shelves

   (illustrated by data recently collected in the Black Sea)
6. Conclusions

Water budget of the ocean

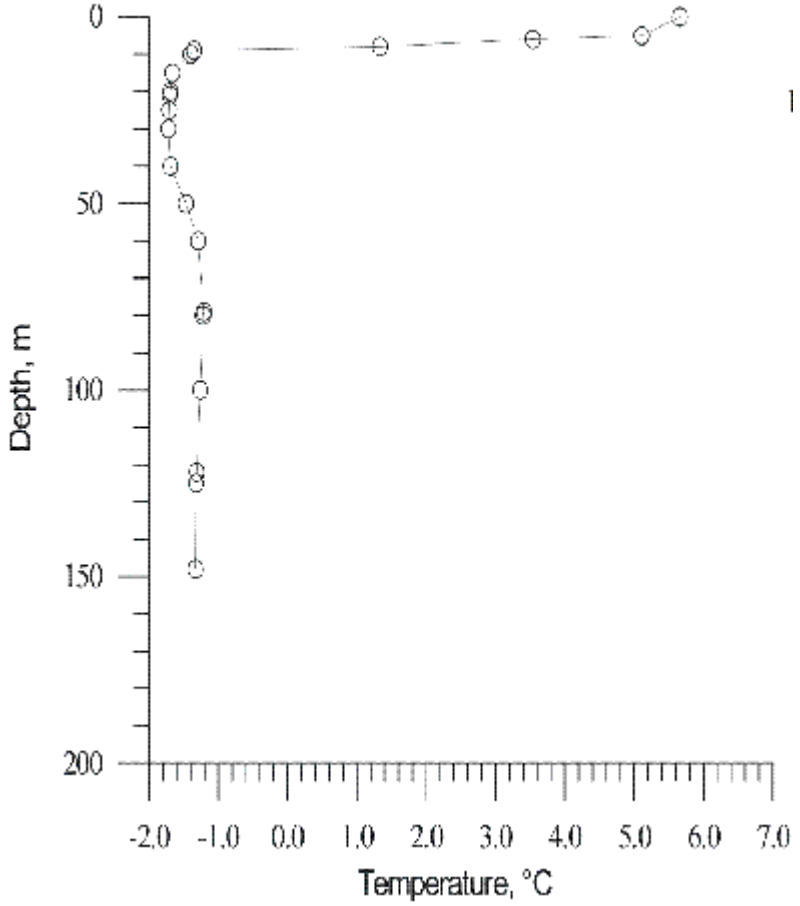


Water budget of the Black Sea

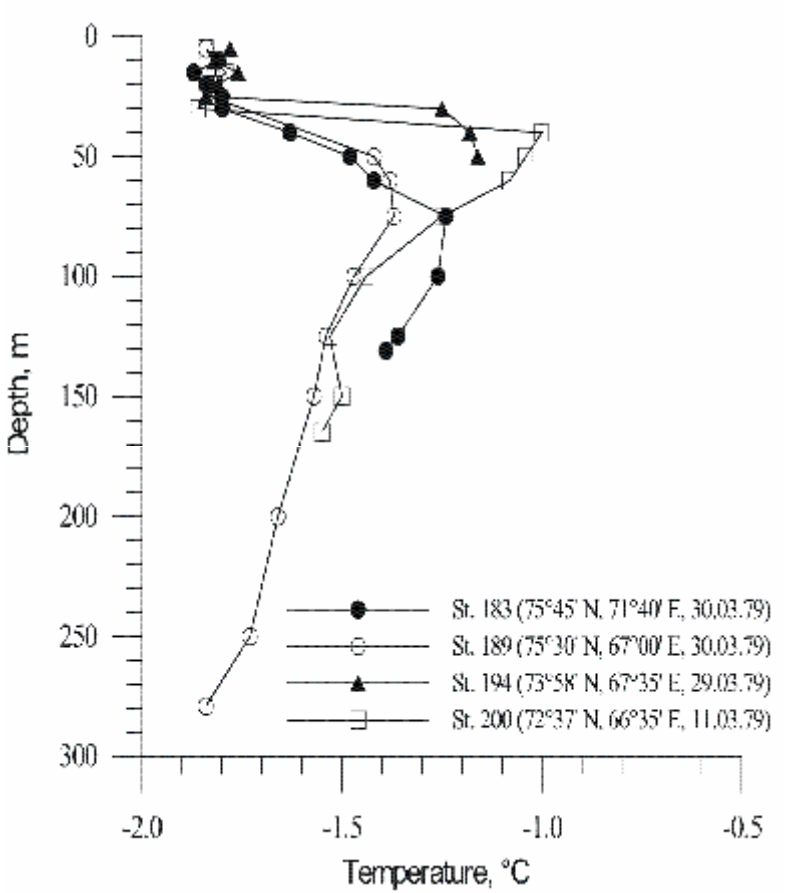


Kara Sea

[Pivovarov et al., JGR, 2003]



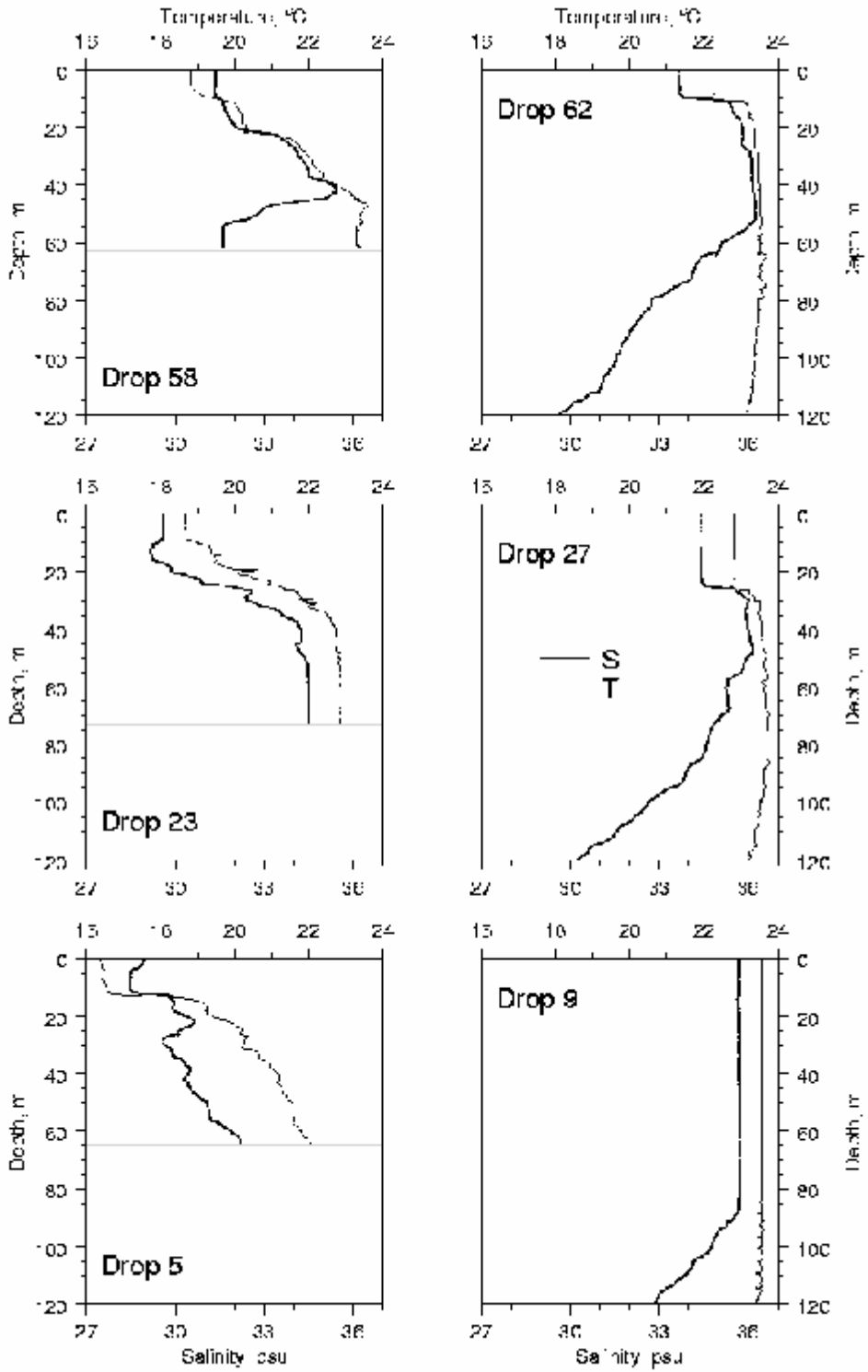
Summer



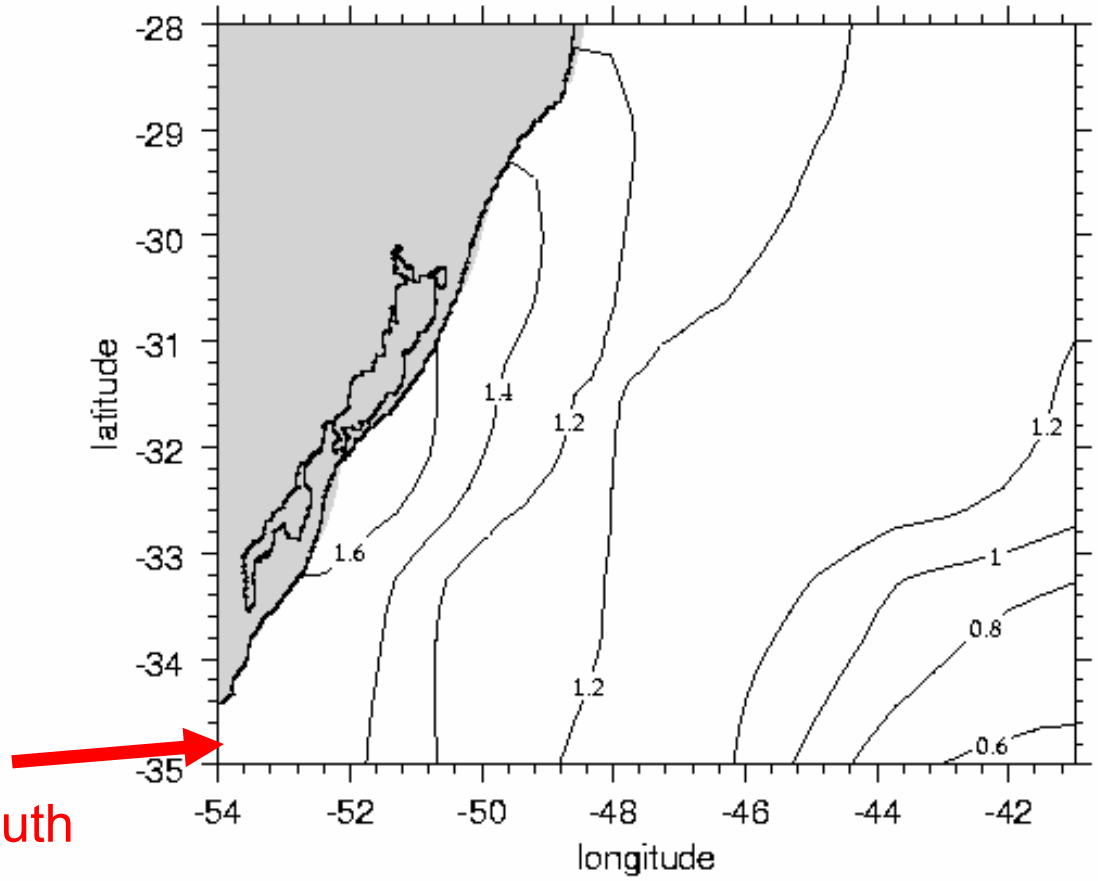
Winter

Southwest Atlantic

[Zavialov et al., GRL, 2004]



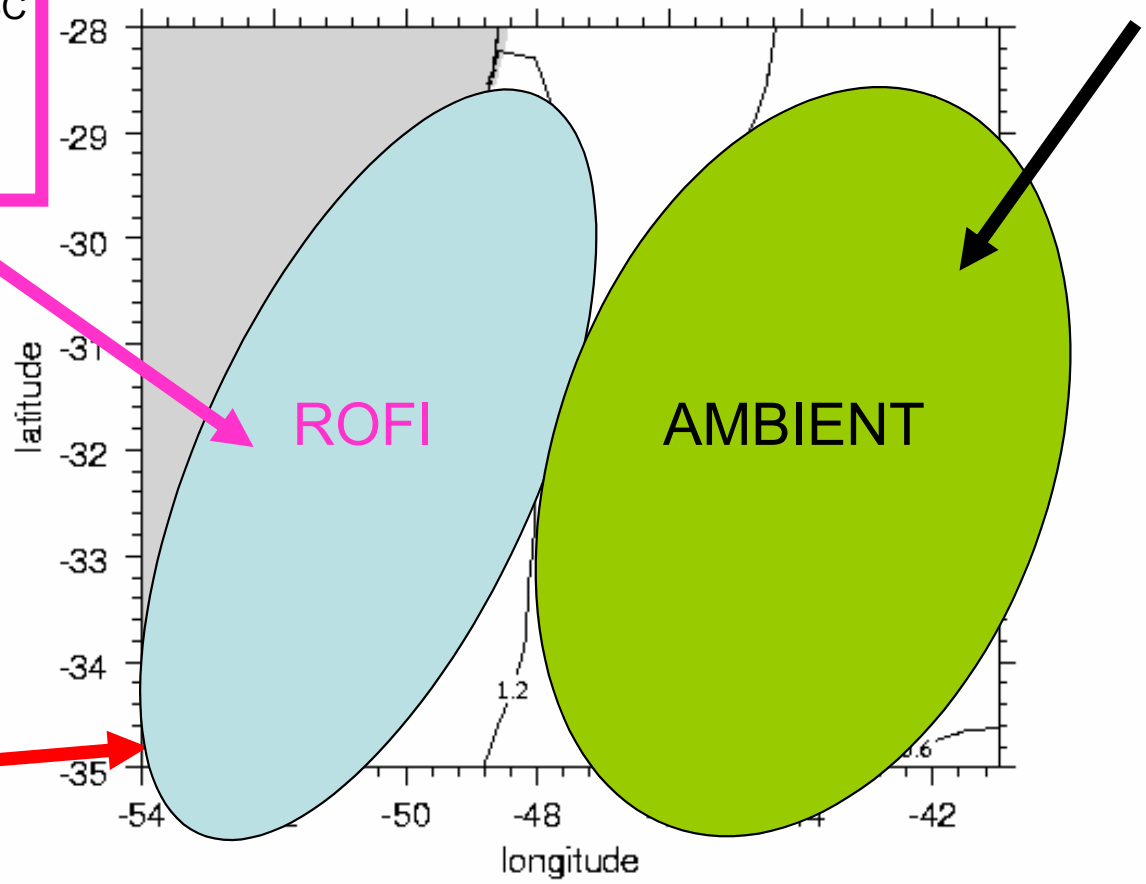
Southwest Atlantic ocean



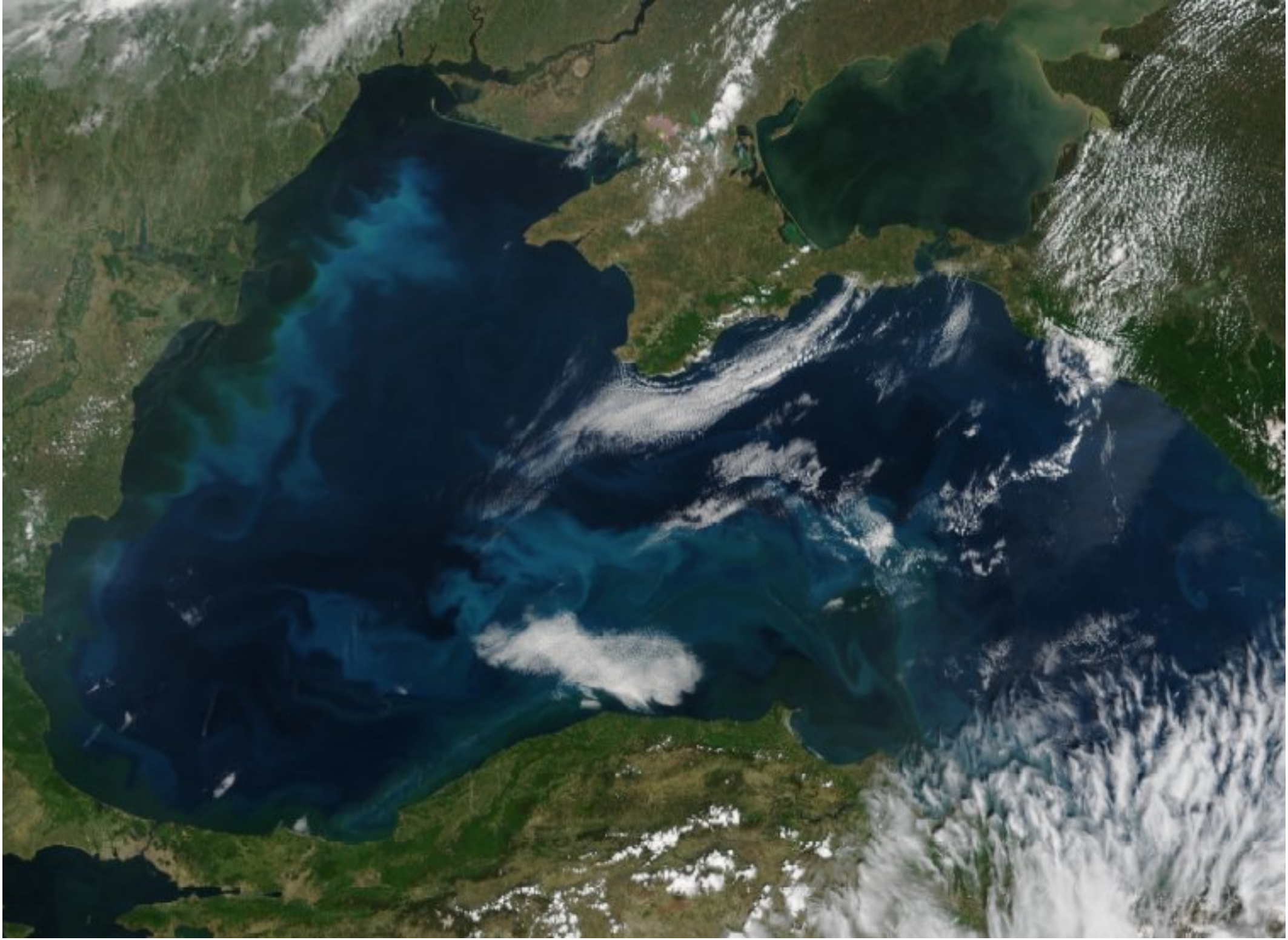
La-Plata mouth

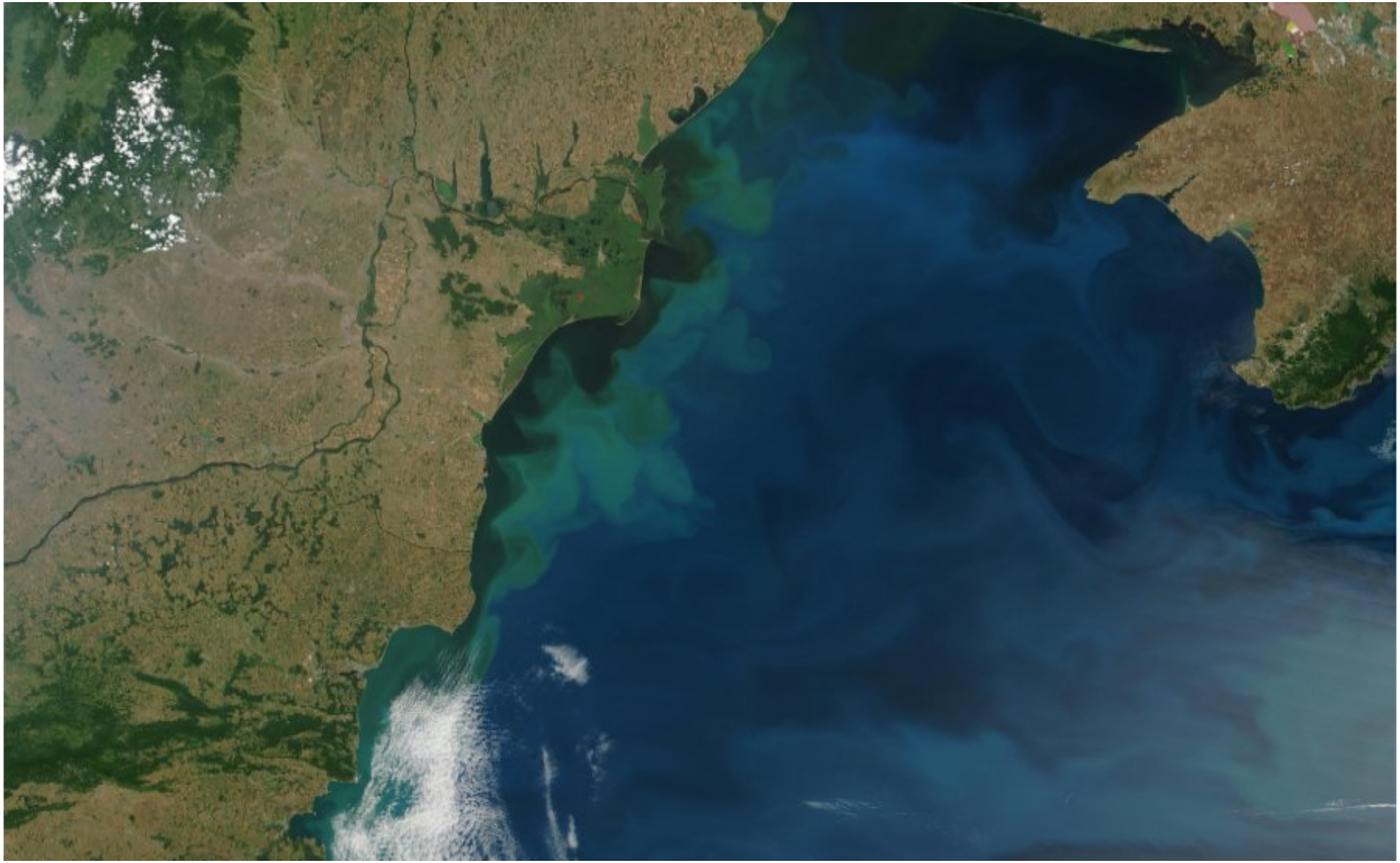
Seasonal SST range: up to 10C
Higher harmonics: up to 40%
Secular trend: up to 1.6C/100 yr
Overall SST variability: up to 2.3C
Diurnal SST range: up to 1.2C
Net flow direction: north
Convection: no

Seasonal SST range: 4-6C
Higher harmonics: less than 10%
Secular trend: up to 0.5C/100 yr
Overall SST variability: about 1C
Diurnal SST range: ~0.2C
Net flow direction: south
Convection: yes



[Zavialov et al., 1996-2000]






ТУАПСЕ
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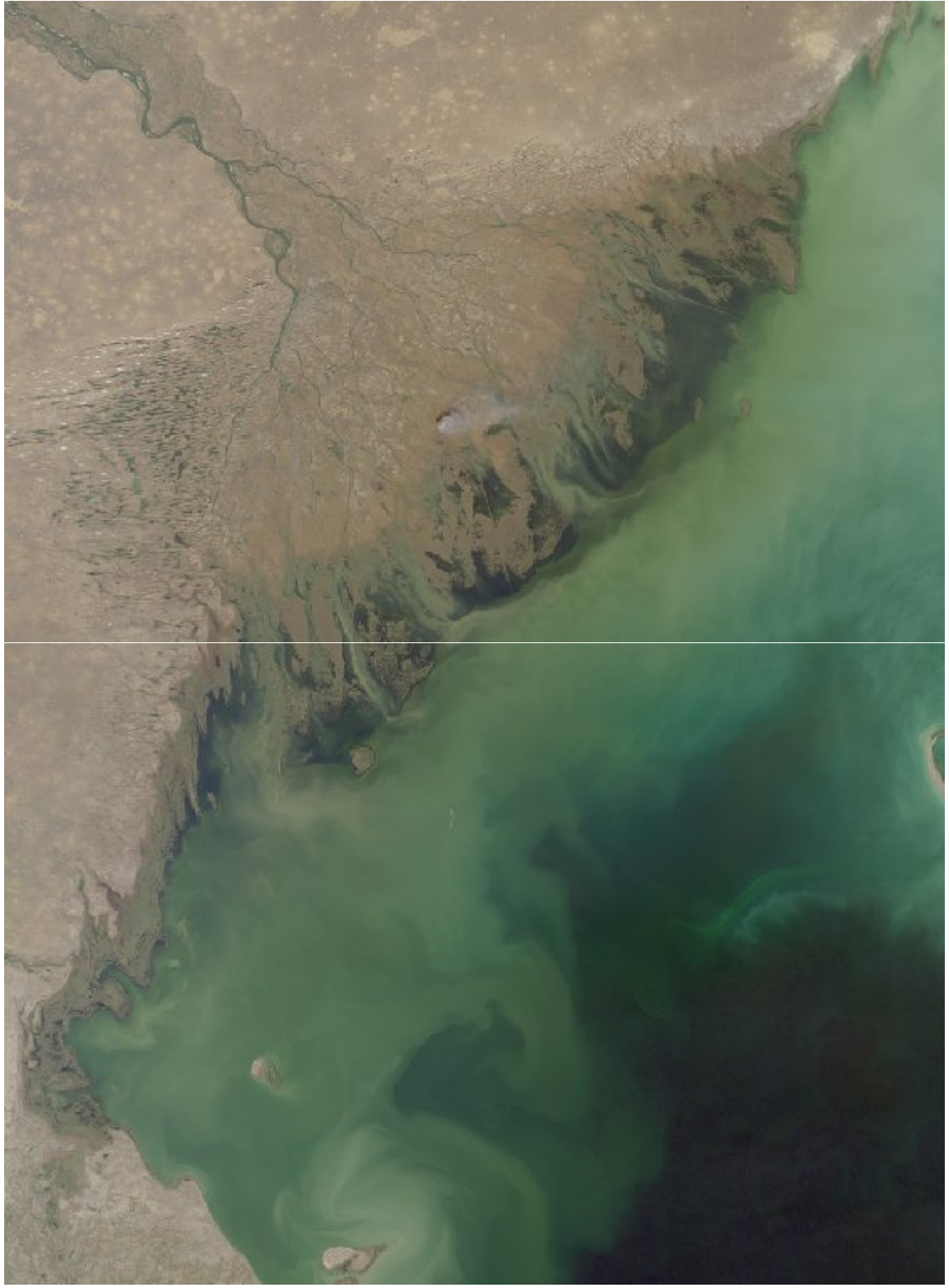
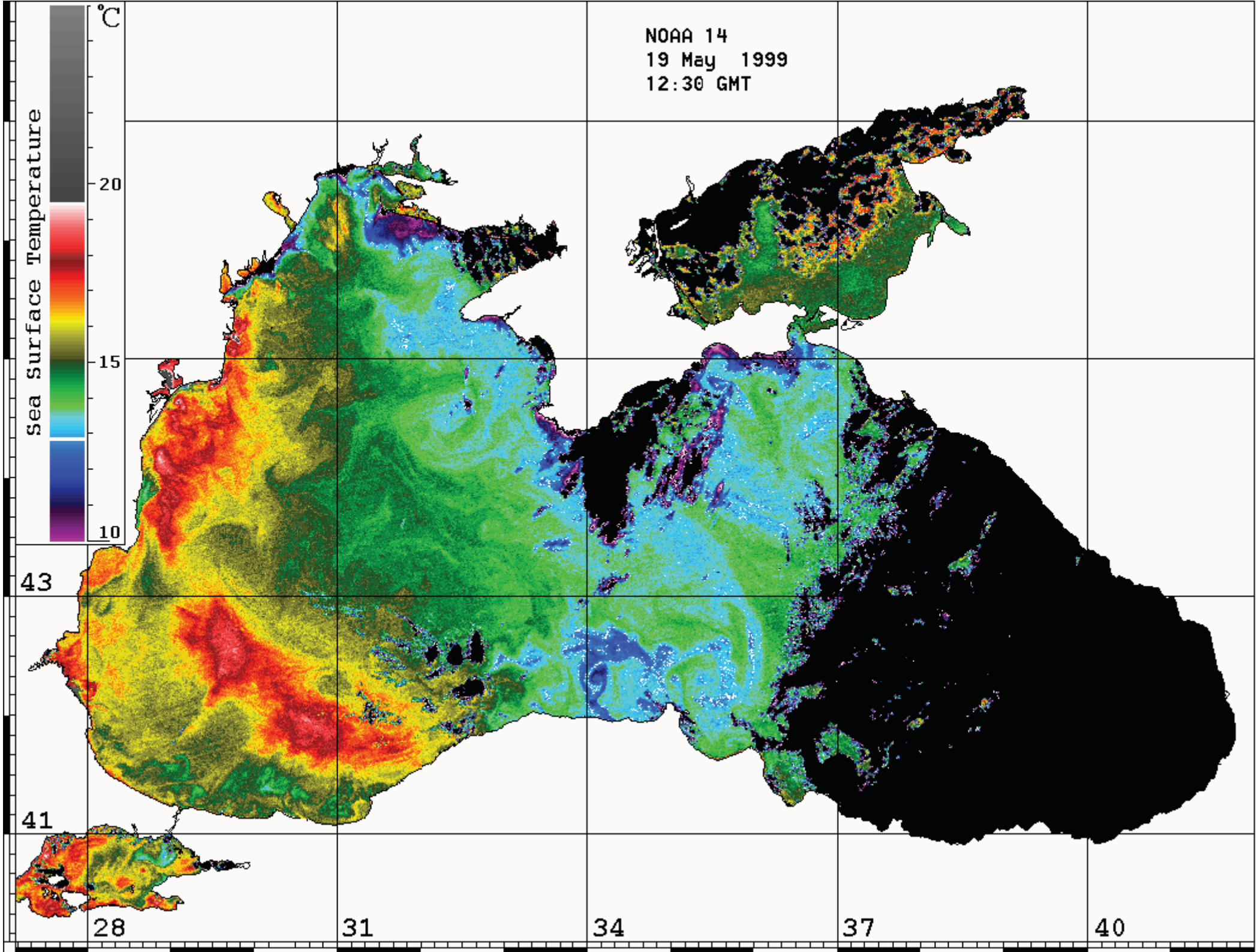
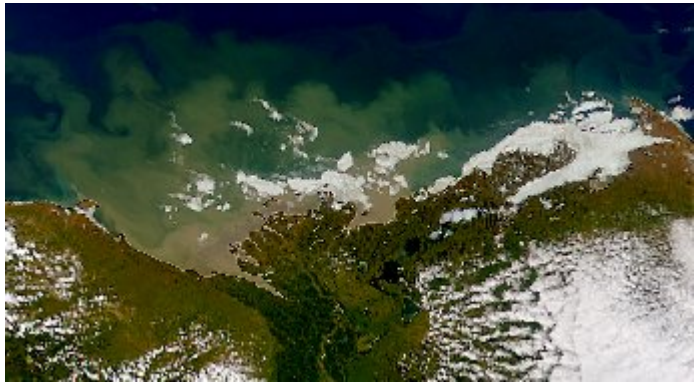
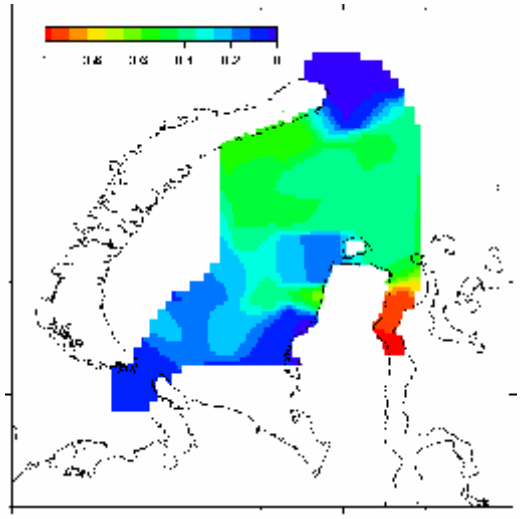
АДЛЕ




NOAA 14
19 May 1999
12:30 GMT
Sea Surface Temperature
°C
20
15
10
43
41
28
31
34
37
40

Typical shapes of river plumes

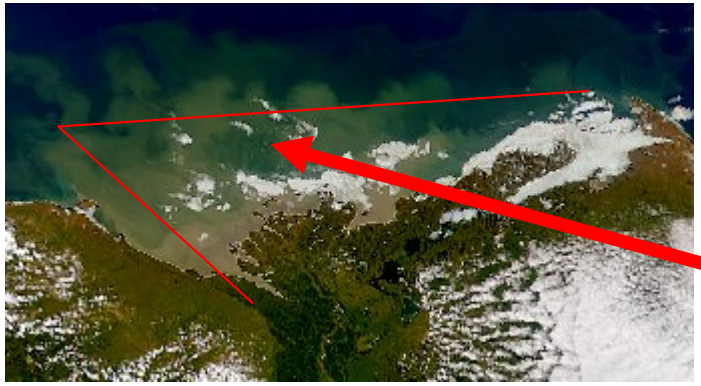




Typical shapes of river plumes

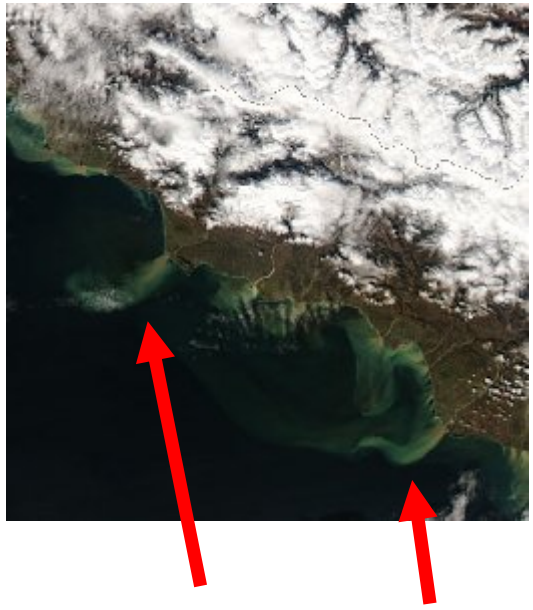
«пузырь»

bulge



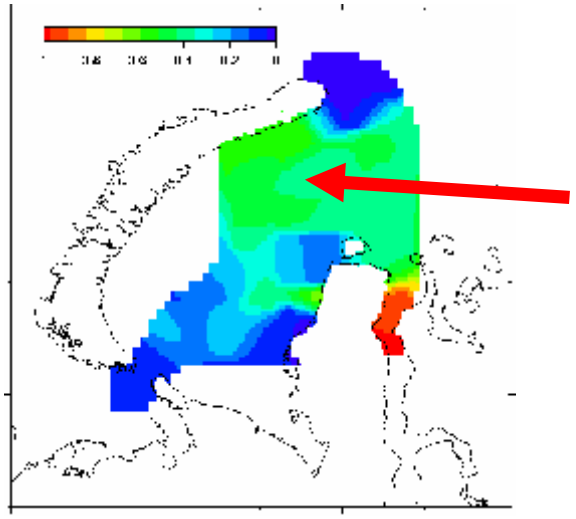
«язык»

tongue



«струя»

jet



«линза»

lens

Momentum equations

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + fv + \frac{\partial}{\partial z}A_z\frac{\partial u}{\partial z}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial y} - fu + \frac{\partial}{\partial z}A_z\frac{\partial v}{\partial z}$$

$$\frac{\partial p}{\partial z} = \rho g$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + fv + \frac{\partial}{\partial z}A_z\frac{\partial u}{\partial z}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial y} - fu + \frac{\partial}{\partial z}A_z\frac{\partial v}{\partial z}$$

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$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial y} - fu + \frac{\partial}{\partial z}A_z\frac{\partial v}{\partial z}$$

$$\frac{\partial p}{\partial z} = \rho g$$

$$\cancel{\frac{\partial u}{\partial t}} + u\cancel{\frac{\partial u}{\partial x}} + v\cancel{\frac{\partial u}{\partial y}} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + fv + \frac{\partial}{\partial z}A_z\frac{\partial u}{\partial z}$$

$$\cancel{\frac{\partial v}{\partial t}} + u\cancel{\frac{\partial v}{\partial x}} + v\cancel{\frac{\partial v}{\partial y}} = -\frac{1}{\rho}\frac{\partial p}{\partial y} - fu + \frac{\partial}{\partial z}A_z\frac{\partial v}{\partial z}$$

$$\frac{\partial p}{\partial z} = \rho g$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + fv + \frac{\partial}{\partial z}A_z\frac{\partial u}{\partial z}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial y} - fu + \frac{\partial}{\partial z}A_z\frac{\partial v}{\partial z}$$

$$\frac{\partial p}{\partial z} = \rho g$$

Momentum equations

$$fu = \frac{1}{\rho}\frac{\partial p}{\partial y}$$

Geostrophic balance

$$\frac{\partial p}{\partial z} = \rho g$$

Hydrostatic balance

Momentum equations

$$fu = \frac{1}{\rho}\frac{\partial p}{\partial y}$$

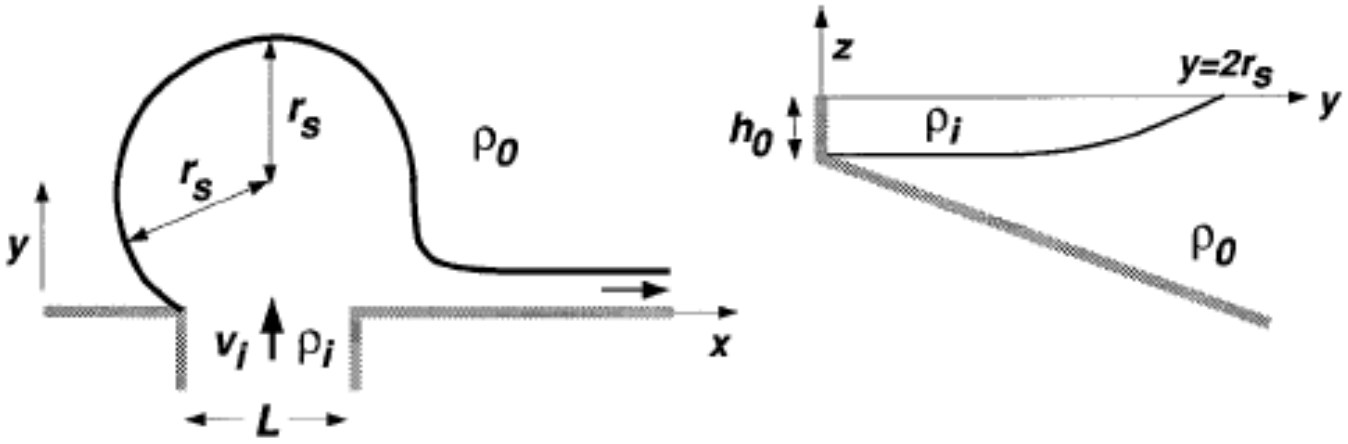
$$\frac{\partial p}{\partial z} = \rho g$$

↓↓

$$\boxed{\frac{\partial u}{\partial z} = \frac{g}{\rho f}\frac{\partial \rho}{\partial y}}$$

«Thermal wind equation»

“Surface-advected plume”



Scaling relations

$$\frac{\partial u}{\partial z} = \frac{g}{\rho f}\frac{\partial \rho}{\partial y} \sim \frac{g\dfrac{\Delta\rho}{\rho}}{fL_d}$$

$$\frac{U_d}{H} \sim \frac{g'}{fL_d}$$

$$H \sim \frac{U_d fL_d}{g'}$$

Scaling relations

$$\frac{\partial u}{\partial z} = \frac{g}{\rho f}\frac{\partial \rho}{\partial y} \sim \frac{g\dfrac{\Delta\rho}{\rho}}{fL_d}$$

$$\frac{U_d}{H} \sim \frac{g'}{fL_d}$$

For “small” rivers,

$H \sim 1$ м

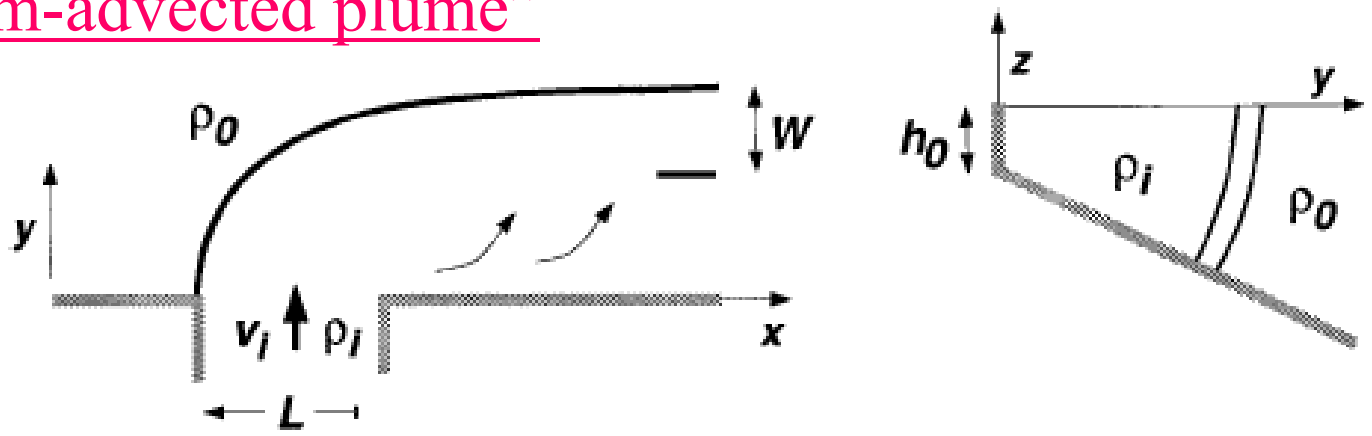
$$H \sim \frac{U_d fL_d}{g'}$$

For “big” rivers,

$H \sim 10$ м

What if bottom friction is there?

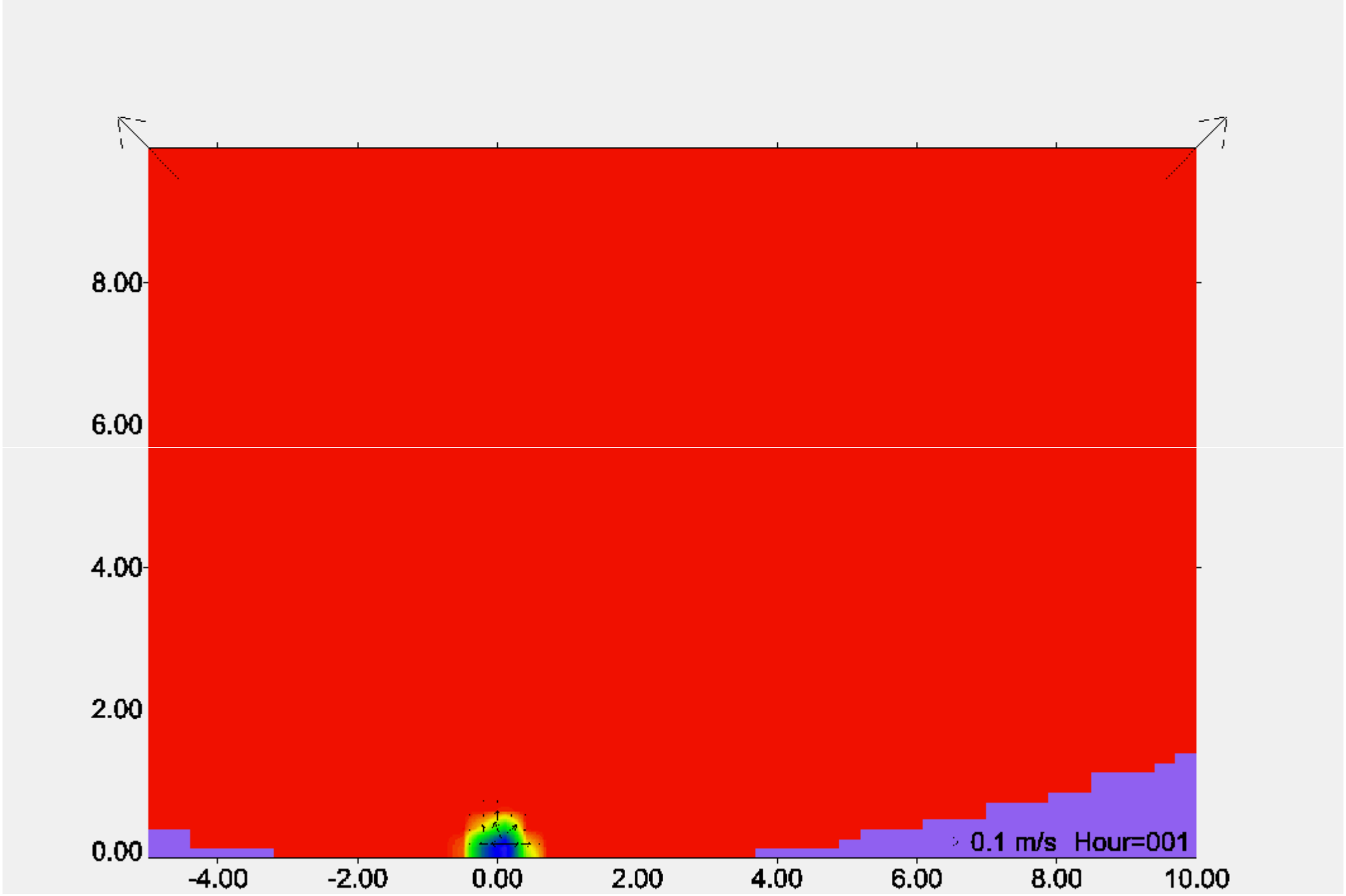
"Bottom-advected plume"

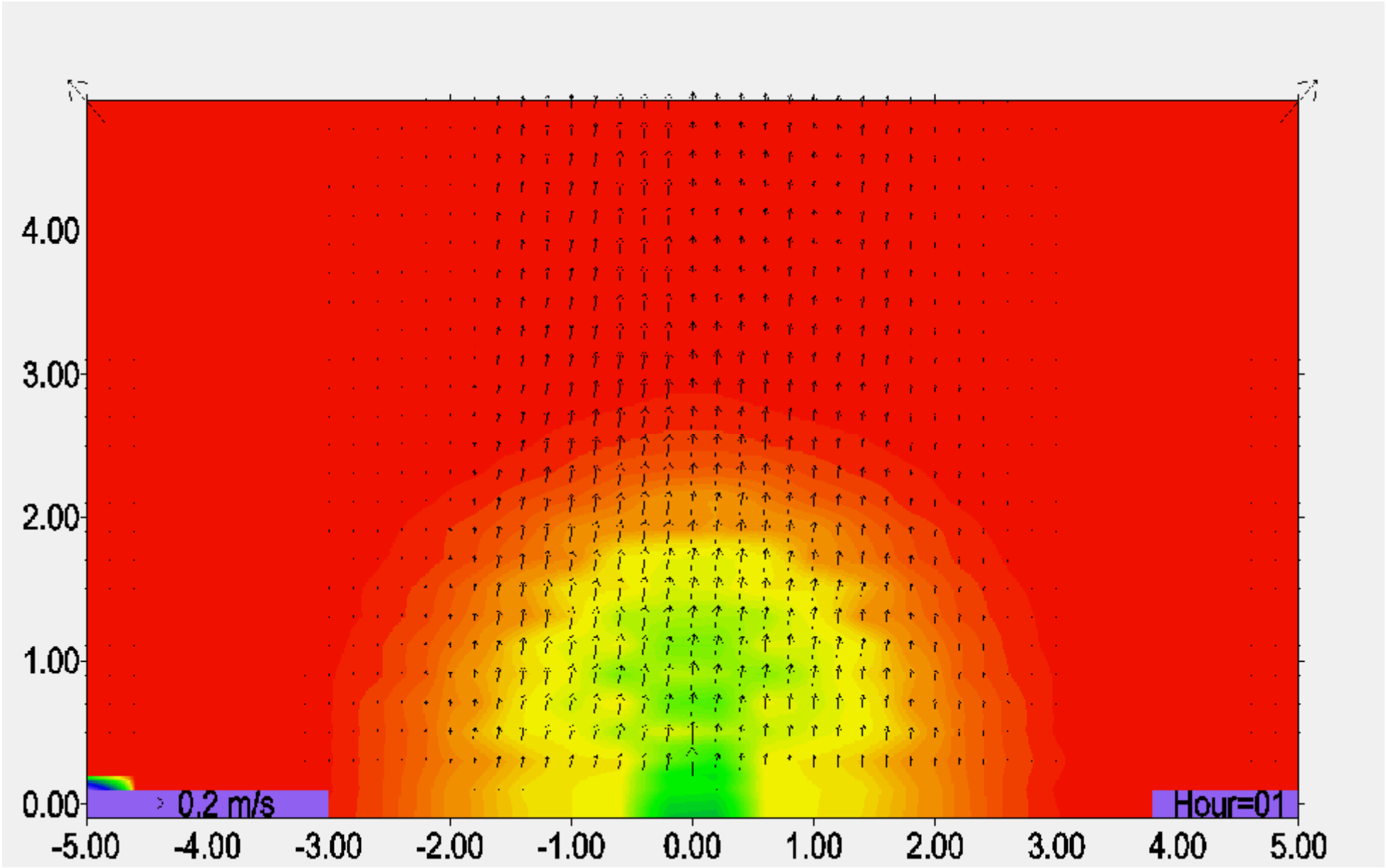


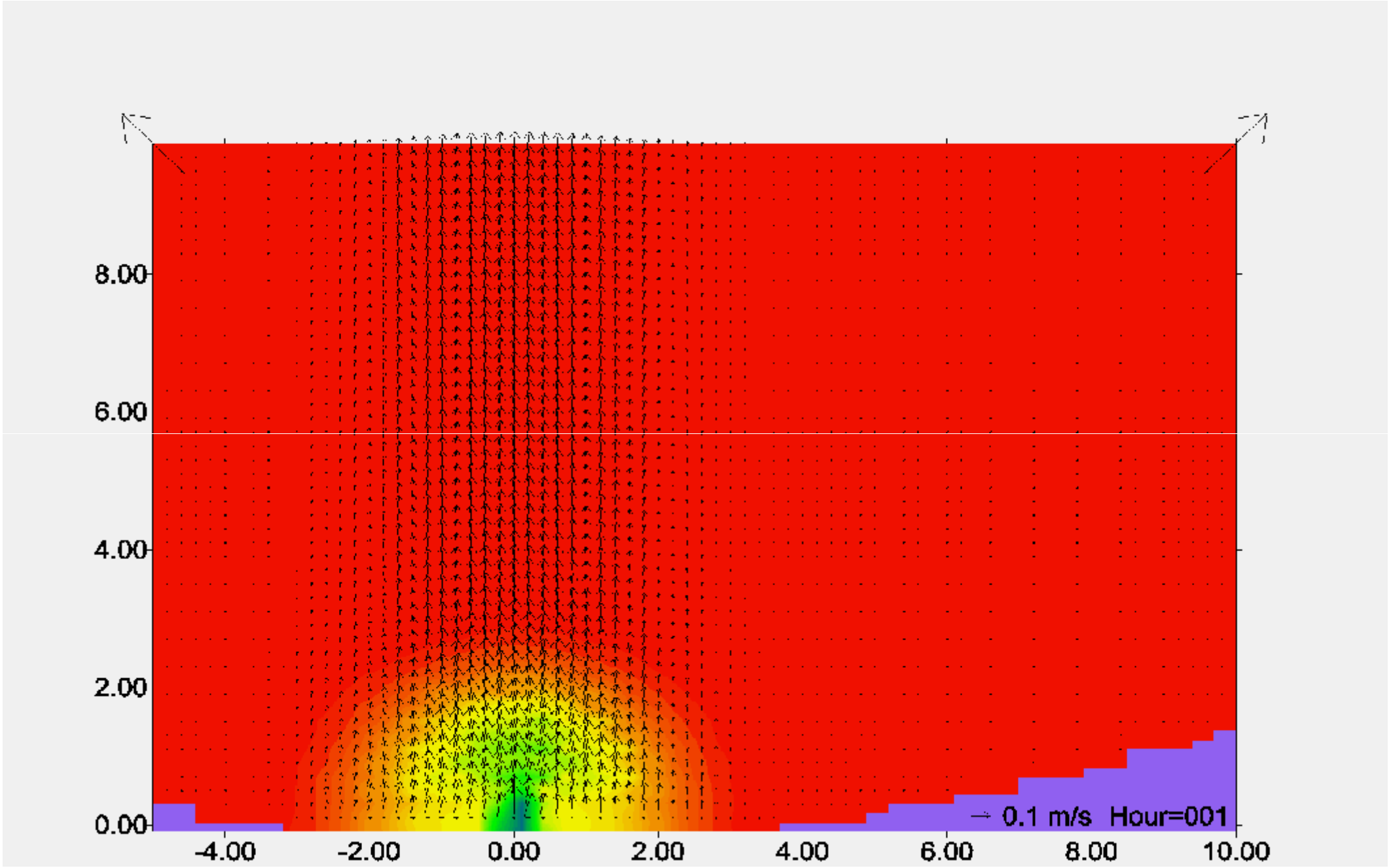
[Yankovsky and Chapman, JPO, 1997]

What if wind is there?

(POM simulations by [Zhurbas and Zavialov])


8.00
6.00
4.00
2.00
0.00
-4.00
-2.00
0.00
2.00
4.00
6.00
8.00
10.00
0.1 m/s Hour=001


4.00
3.00
2.00
1.00
0.00
-5.00
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
> 0.2 m/s
Hour=01


8.00
6.00
4.00
2.00
0.00
-4.00
-2.00
0.00
2.00
4.00
6.00
8.00
10.00
0.1 m/s Hour=001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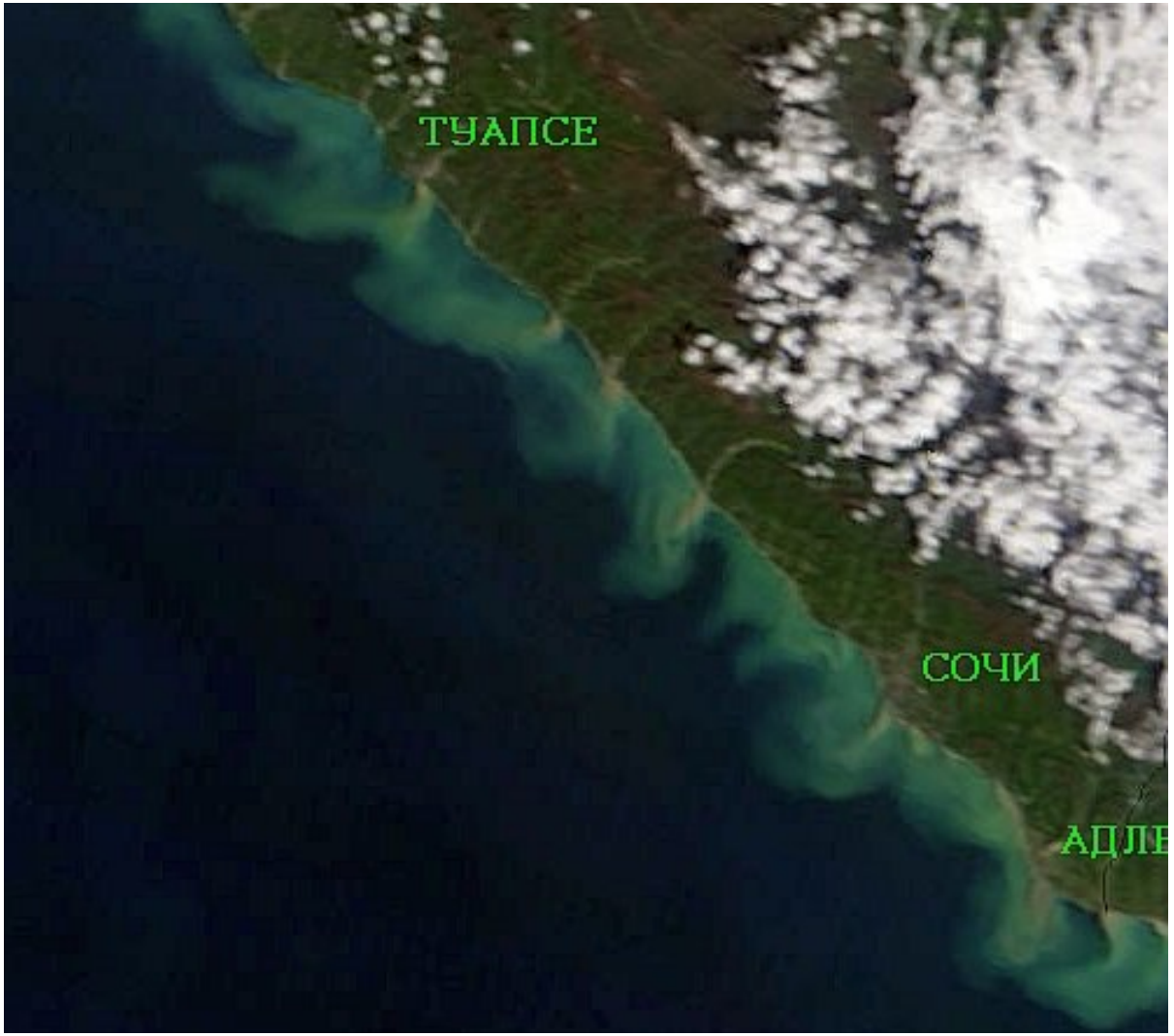
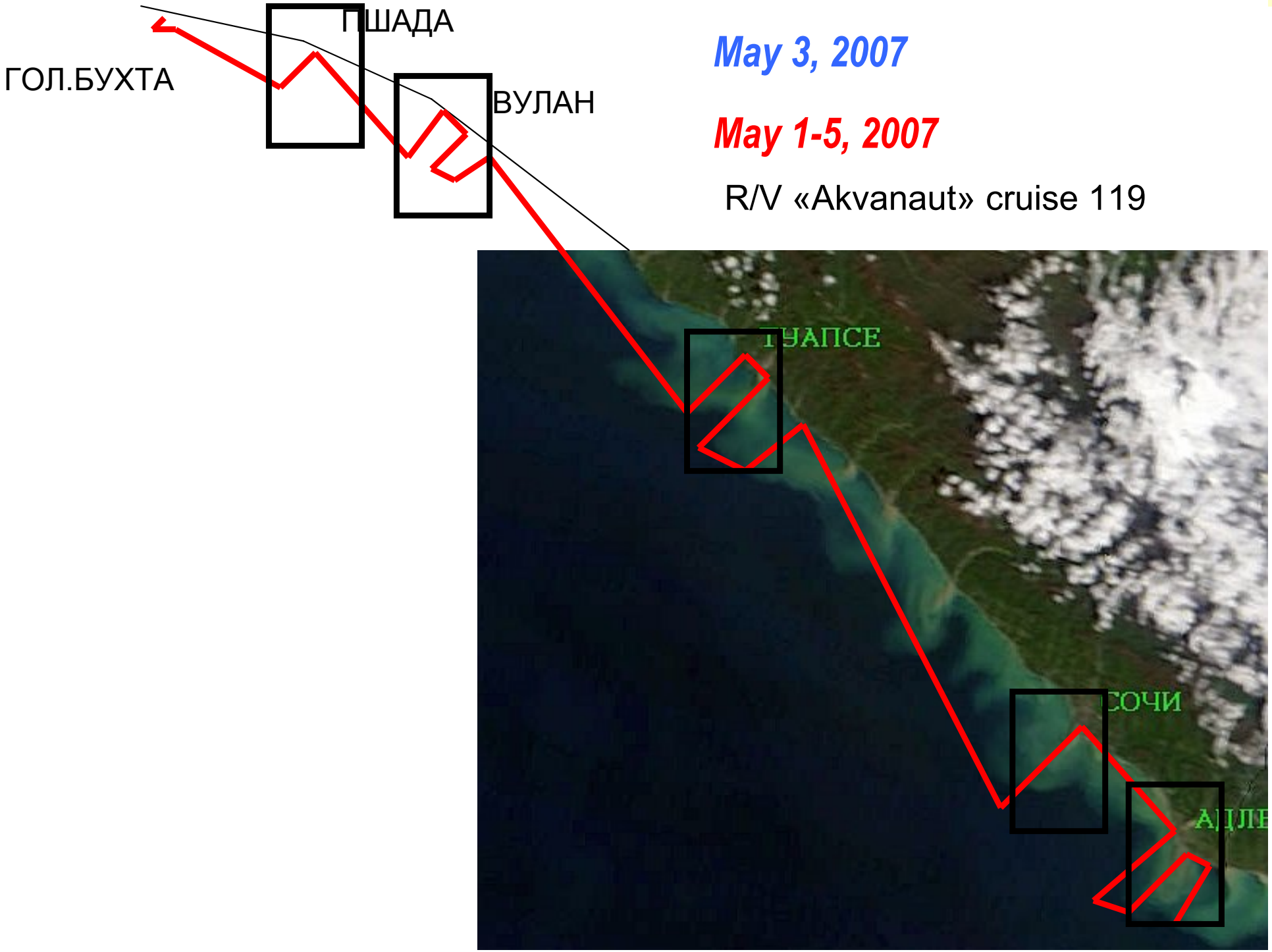
При использовании этой карты -
обязательна ссылка на источник
Украина
Одесса
56
200
Румыния
Азовское
море
30
Керчь
Евпатория
Коктебель
Феодосия
Россия
Анапа
Симферополь
Судак
Алушта
Севастополь
Ялта
7
Геленджик
Лазаревское
Дагомыс
Красная
поляна
Сочи
Адлер
2
0.3
Черное море
Болгария
Грузия
38
Турция
46

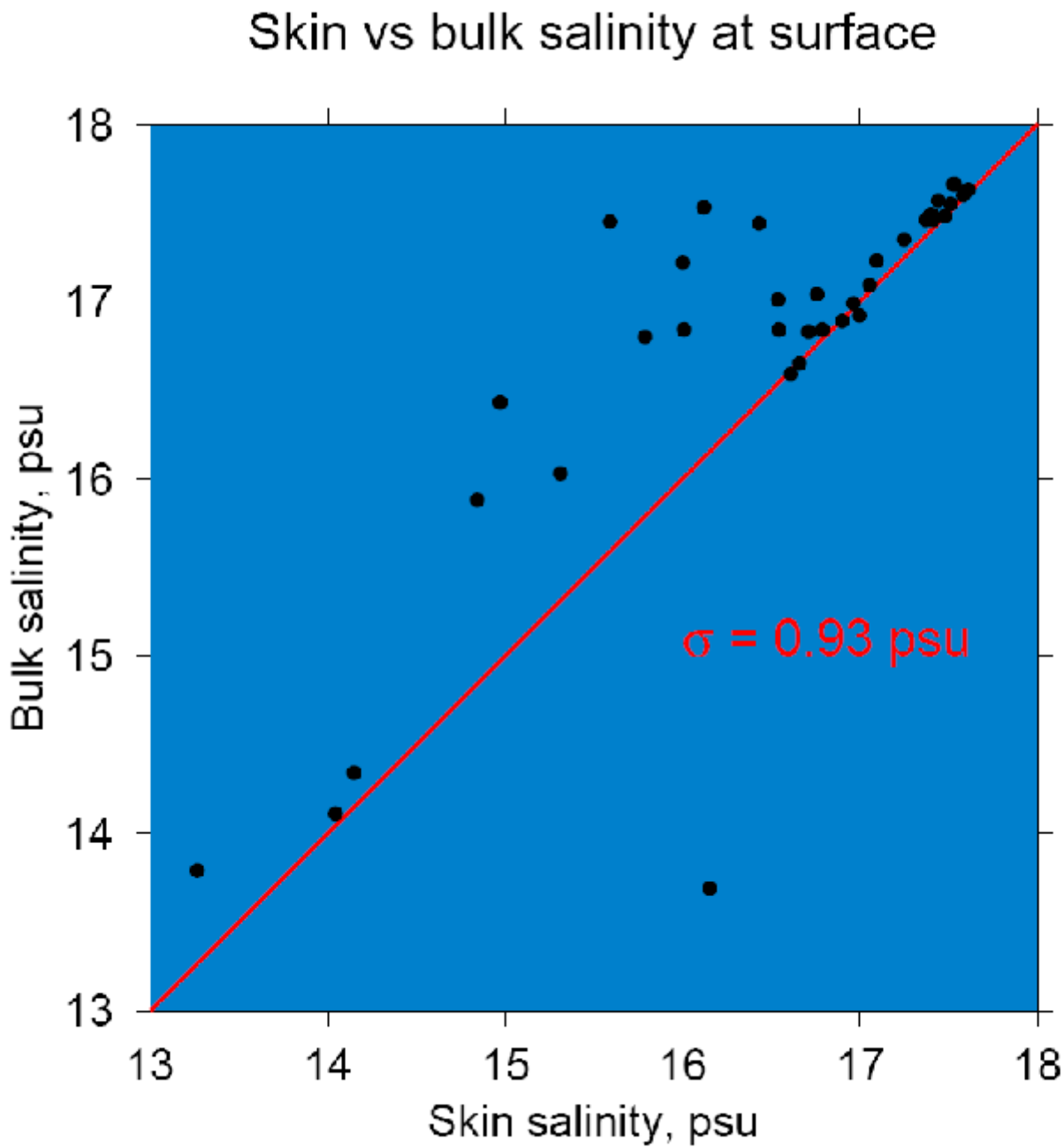
River	Q, m^3/s
Mezyb	3.9
Pshada	9.8
Vulan	6.4
Tuapse	12.8
Sochi	16.1
Mzymta	49.5

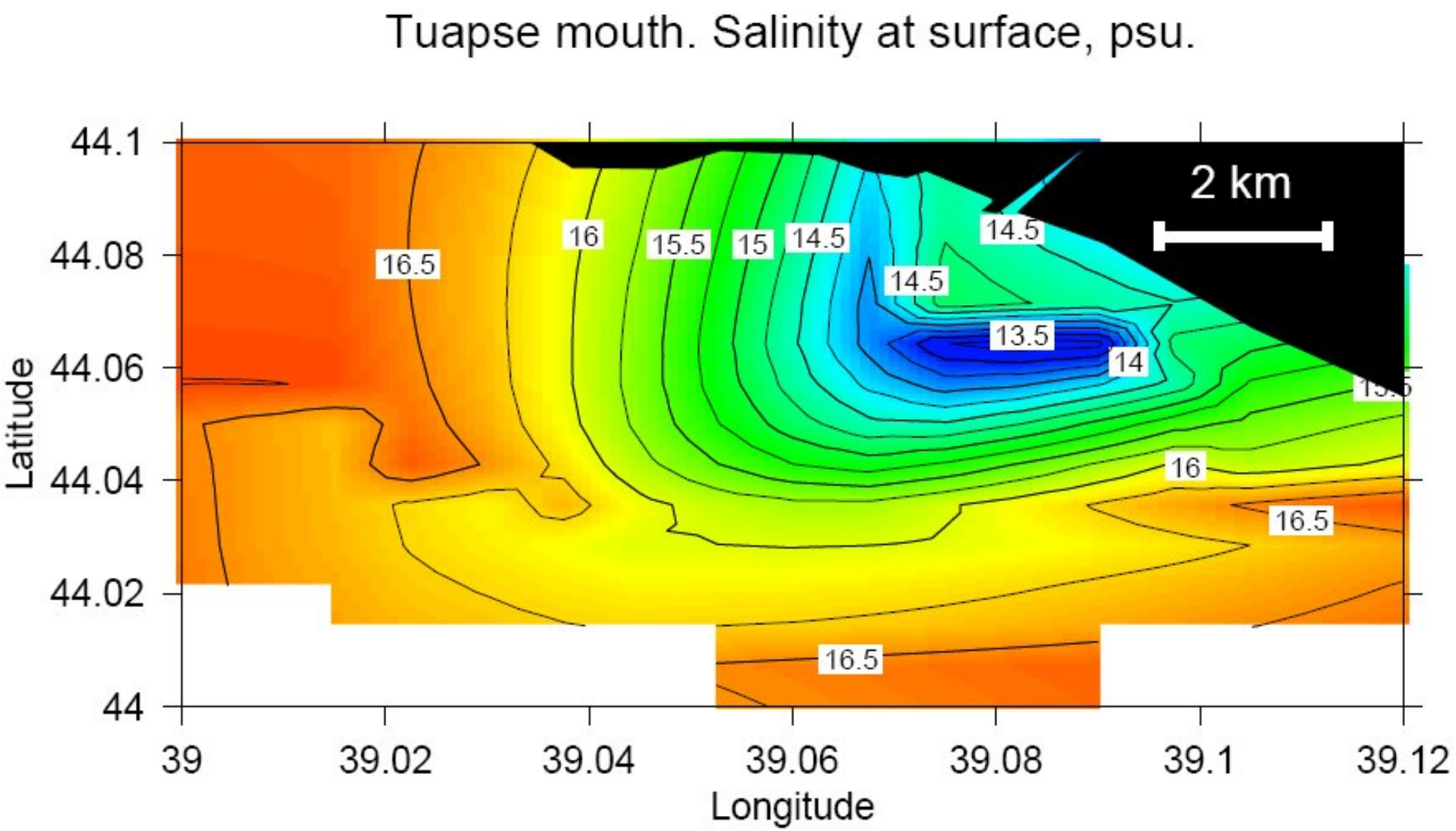
May 3, 2007

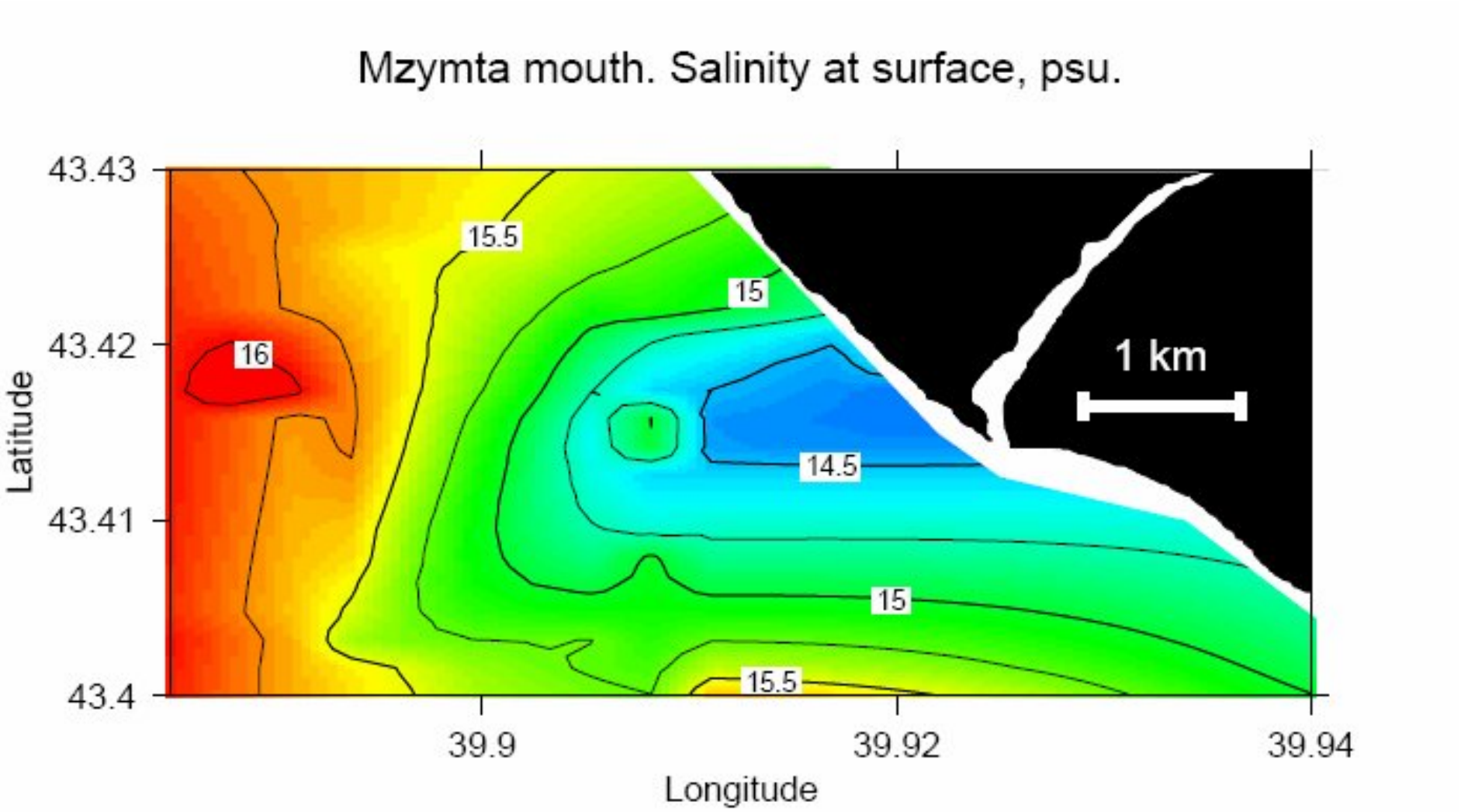


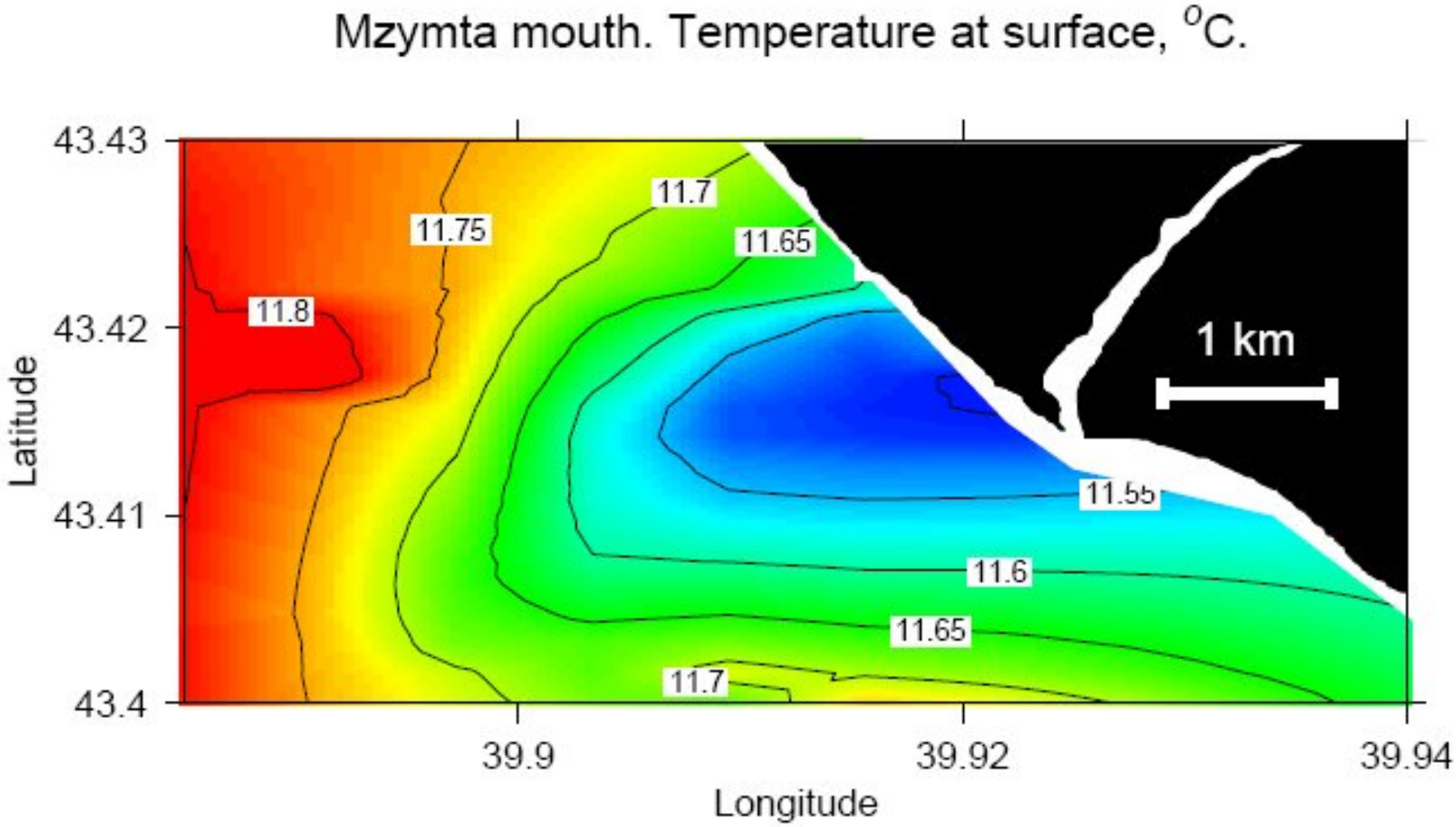

ГОЛ.БУХТА
ПШАДА
ВУЛАН
May 3, 2007
May 1-5, 2007
R/V «Akvanaut» cruise 119
ТУАПСЕ
СОЧИ


FRESH WATER

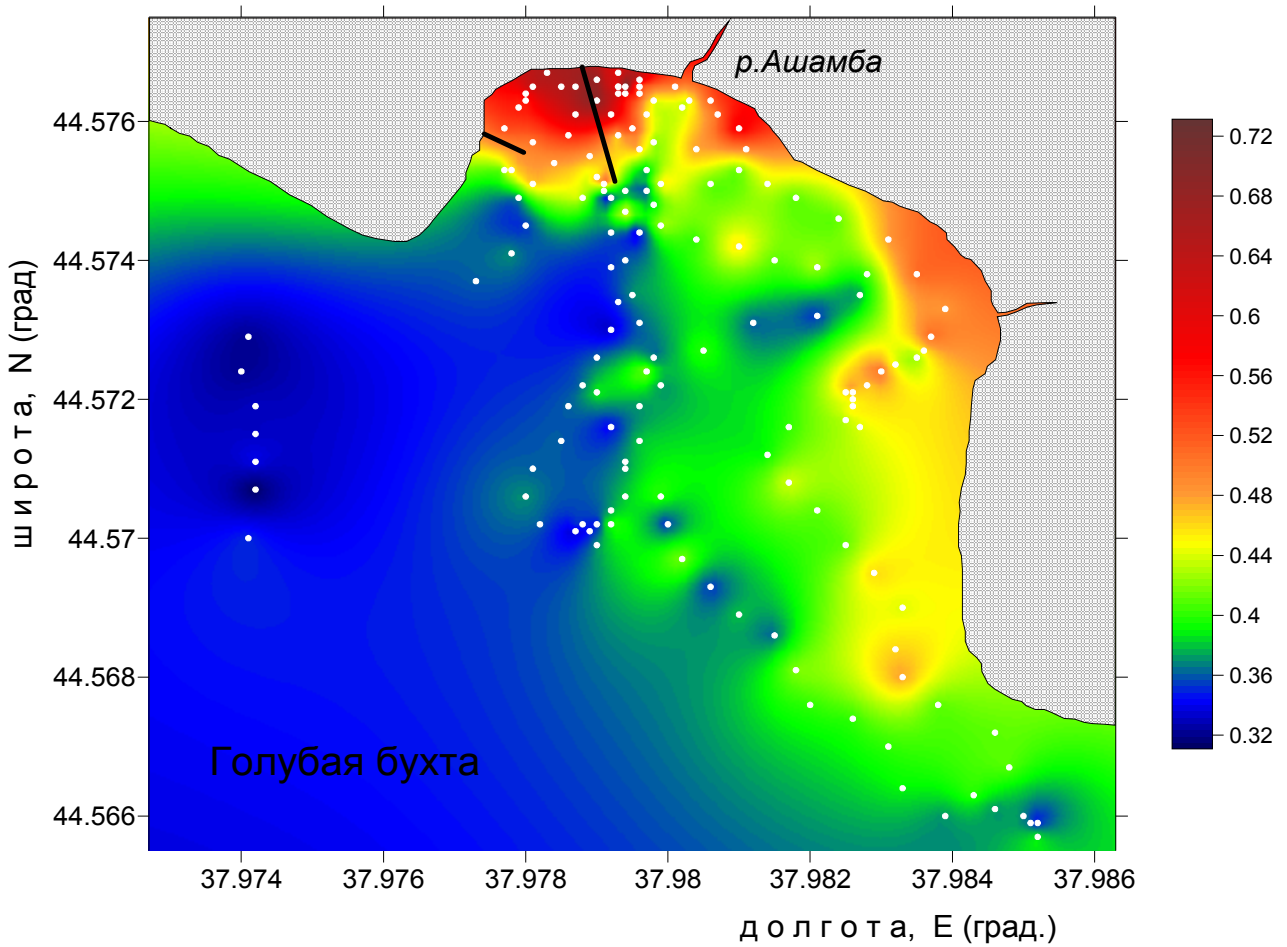

Skin vs bulk salinity at surface
Bulk salinity, psu
Skin salinity, psu
18
17
16
15
14
13
13
14
15
16
17
18
σ = 0.93 psu


Tuapse mouth. Salinity at surface, psu.
2 km
16.5
16
15.5
15
14.5
14.5
14.5
13.5
14
16
16.5
16.5
44.1
44.08
44.06
44.04
44.02
44
Latitude
39
39.02
39.04
39.06
39.08
39.1
39.12
Longitude


Mzymta mouth. Salinity at surface, psu.
43.43
43.42
43.41
43.4
Latitude
39.9
39.92
39.94
Longitude
15.5
15
16
14.5
15
15.5
1 km

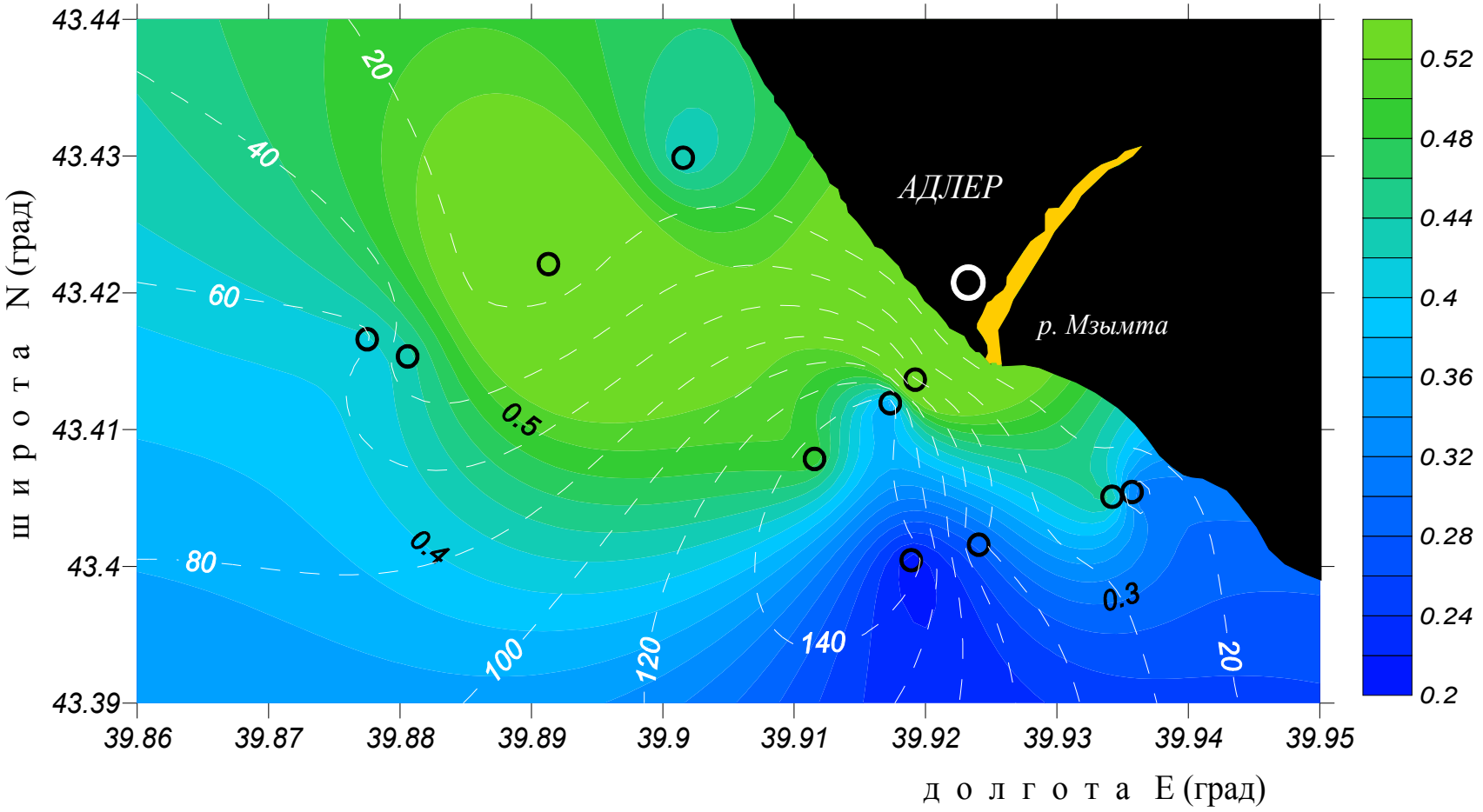

Mzymta mouth. Temperature at surface, °C.
43.43
43.42
43.41
43.4
Latitude
39.9
39.92
39.94
Longitude
11.8
11.75
11.7
11.65
11.55
11.6
11.65
11.7
1 km

“Yellow matter” near Ashamba mouth



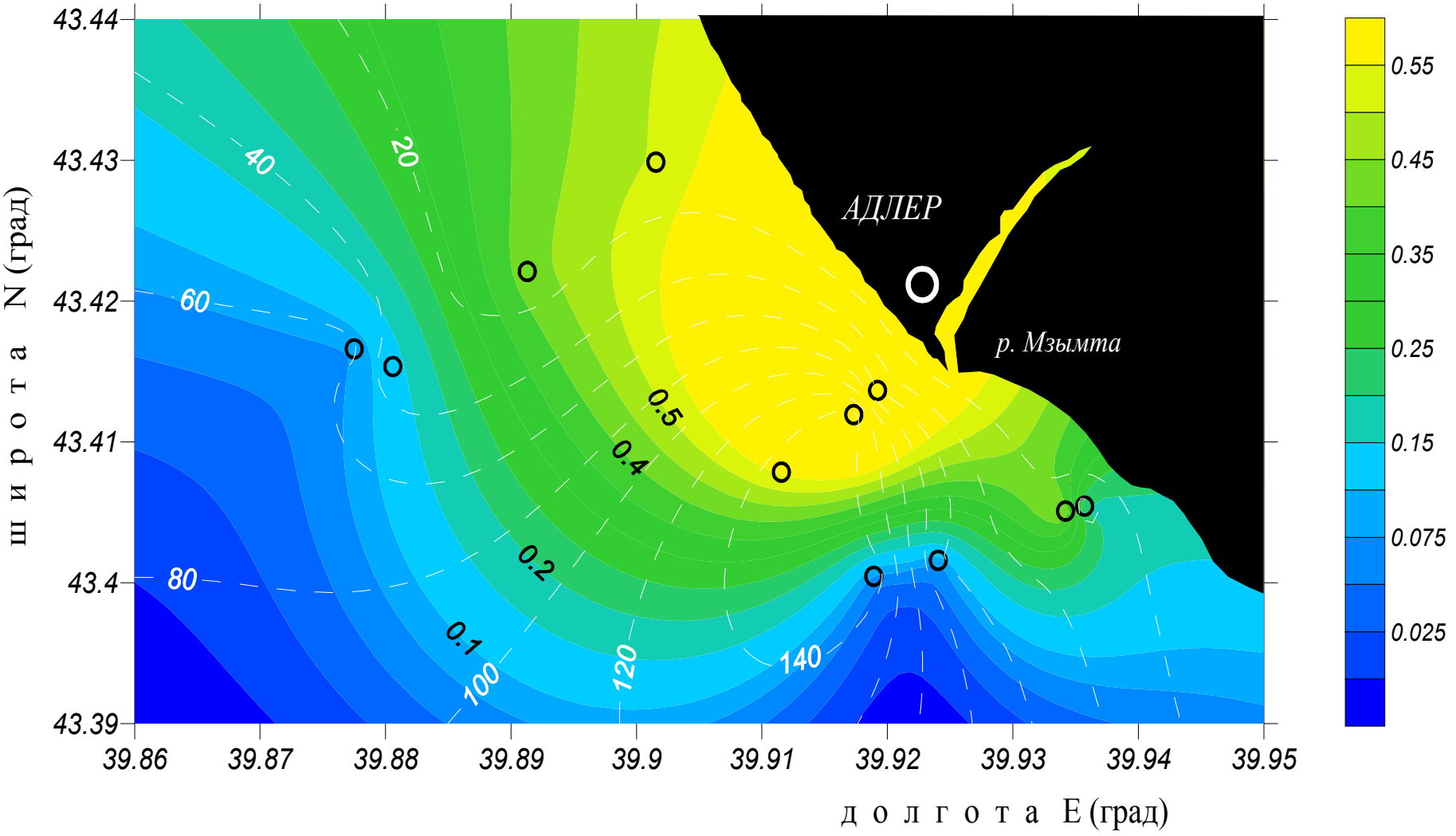
Распределение растворенного "желтого вещества" в поверхностном слое (усл. ед.)

Chlorophyll near Mzymta mouth



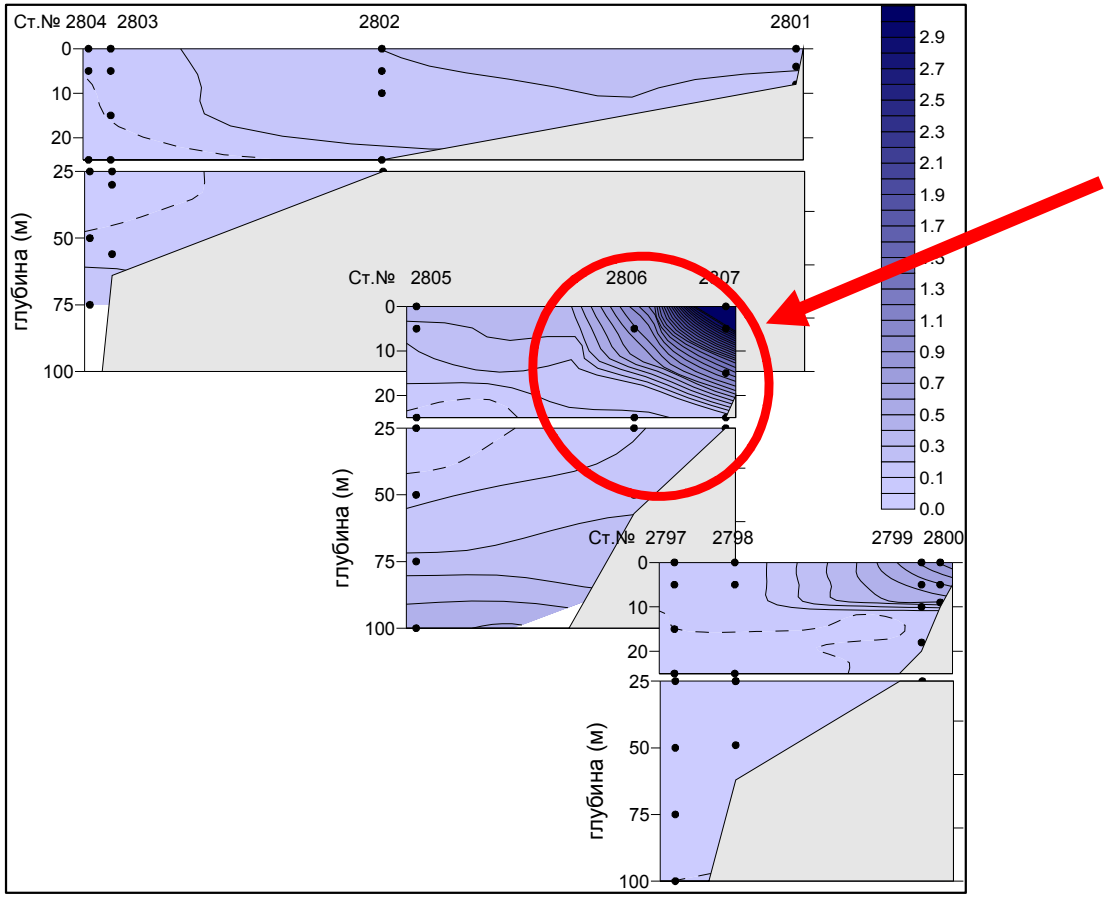
Хлорофилл на 0 м (мг/м ^{3})

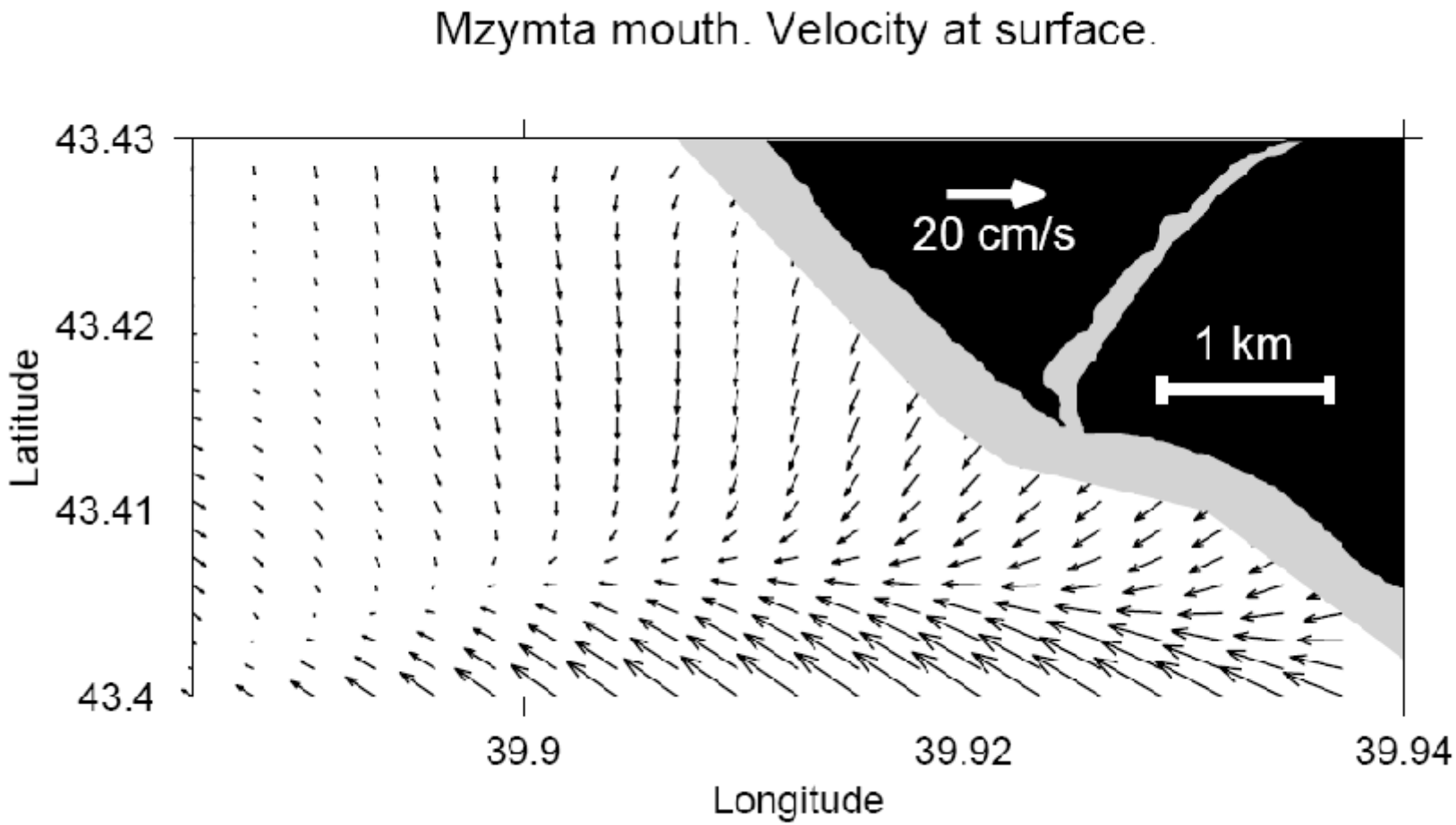
Suspended matter near Mzymta mouth

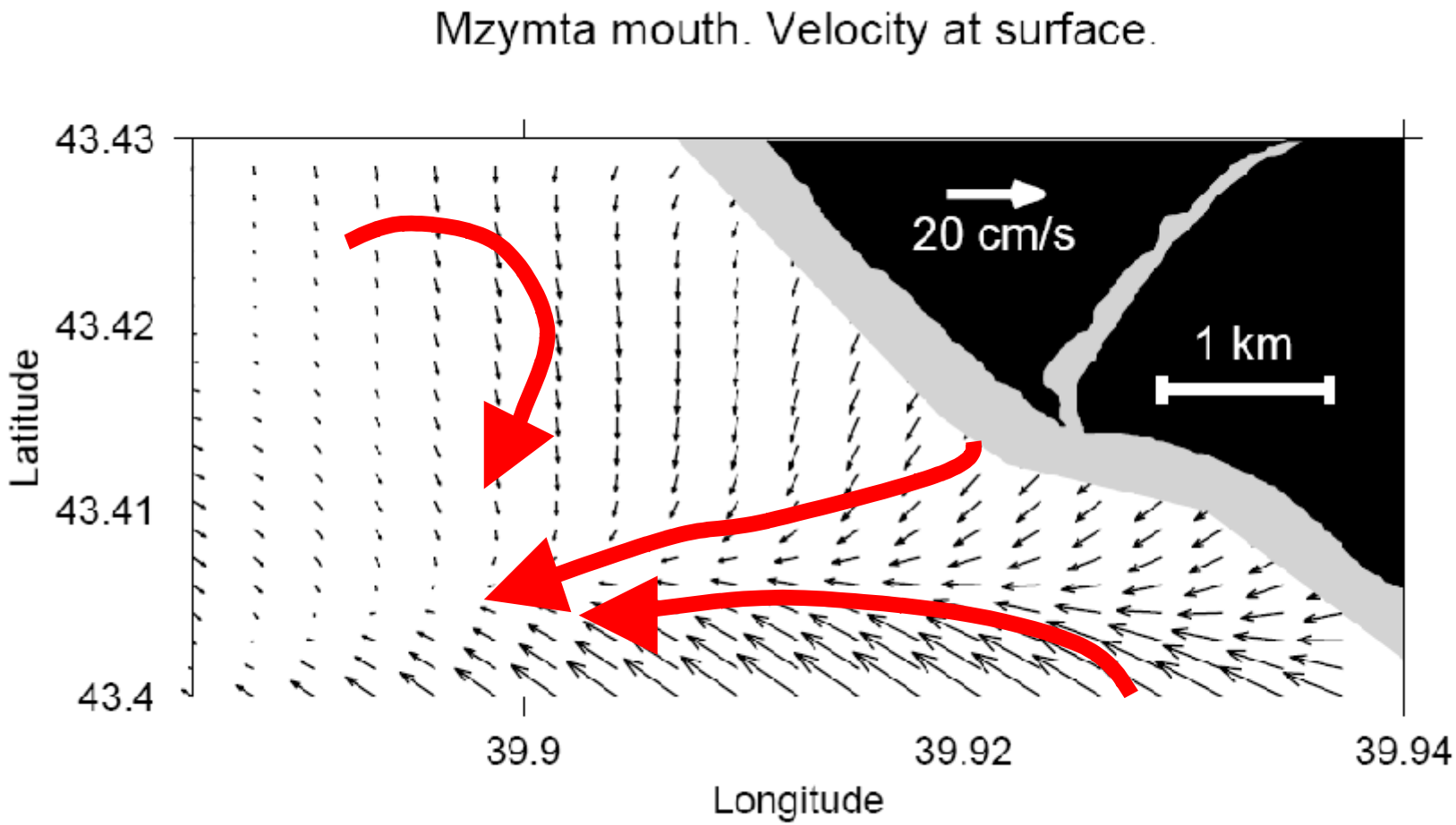


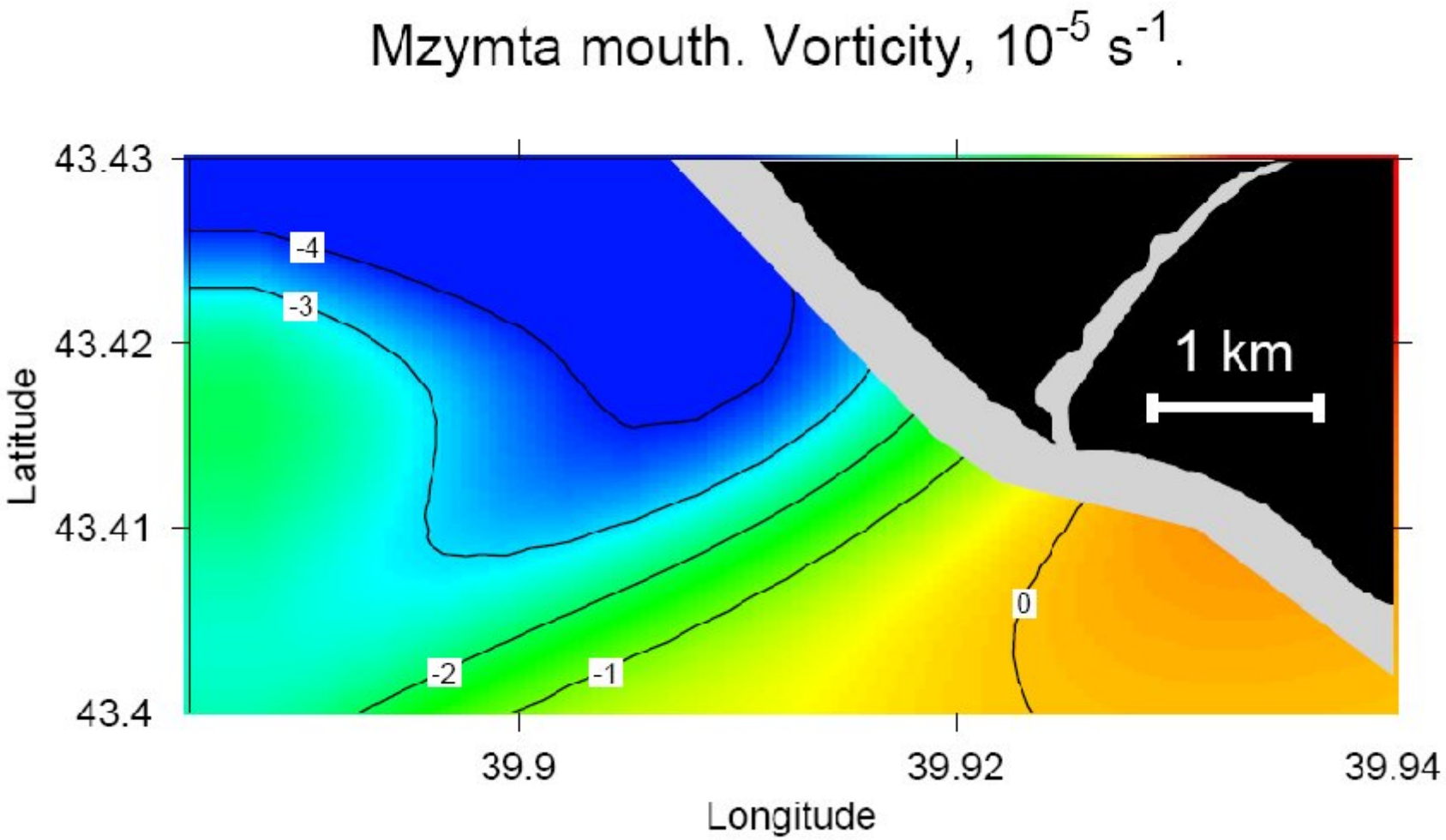
Органическая взвесь на 0 м (а440фд, 1/м)

Non-organic P near Mzymta mouth

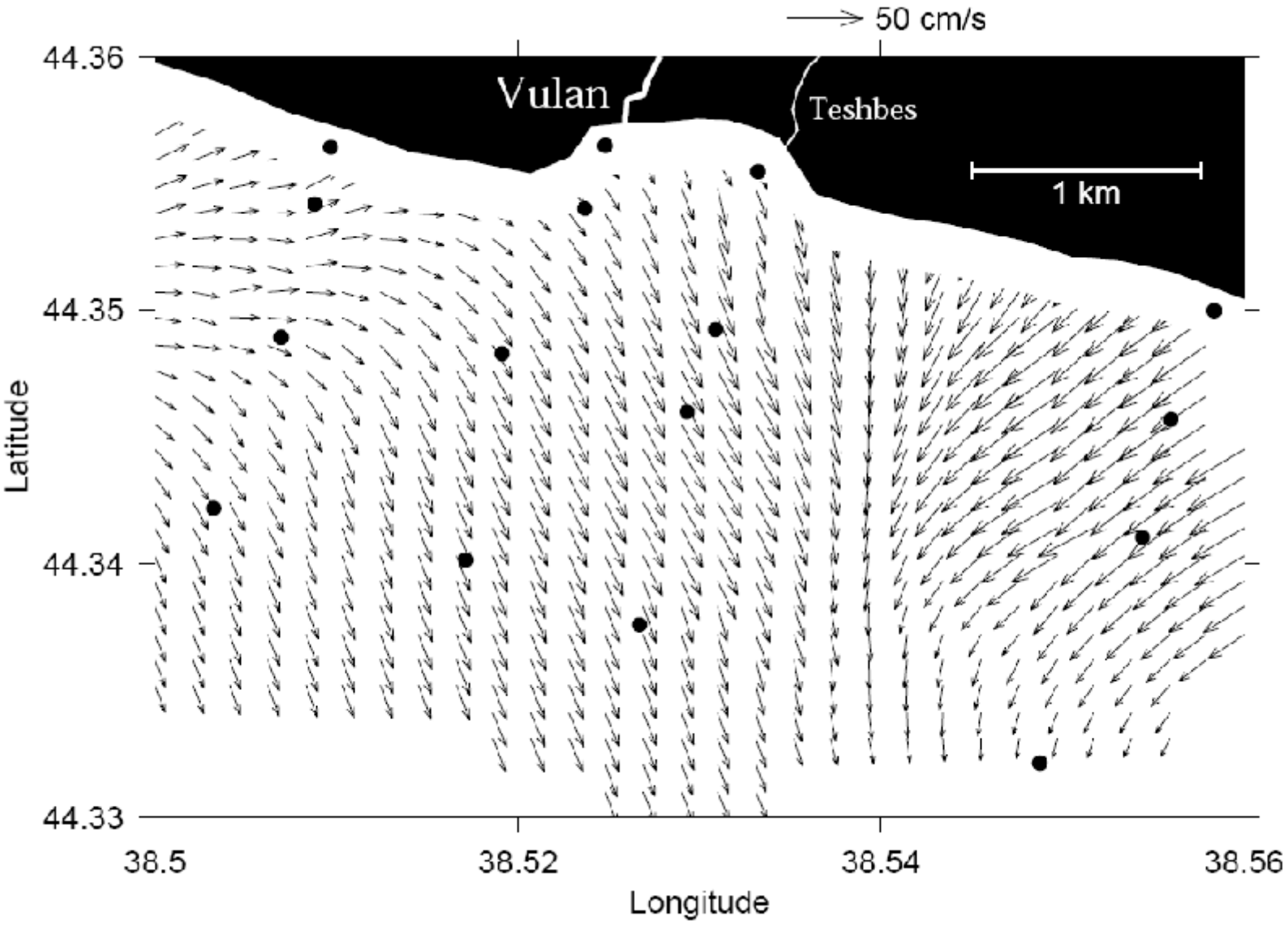


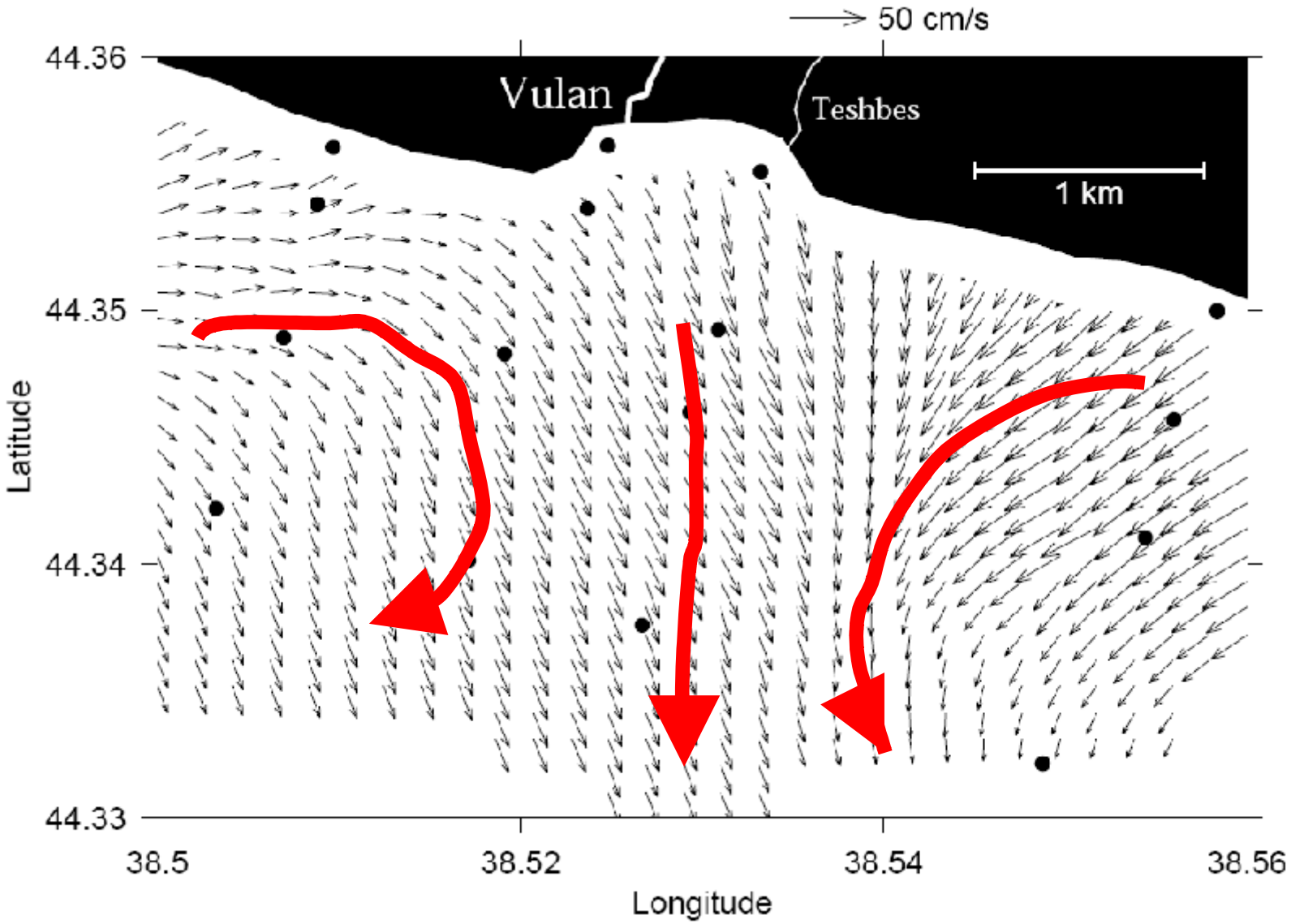

Mzymta mouth. Velocity at surface.
43.43
43.42
43.41
43.4
Latitude
20 cm/s
1 km
39.9
39.92
39.94
Longitude

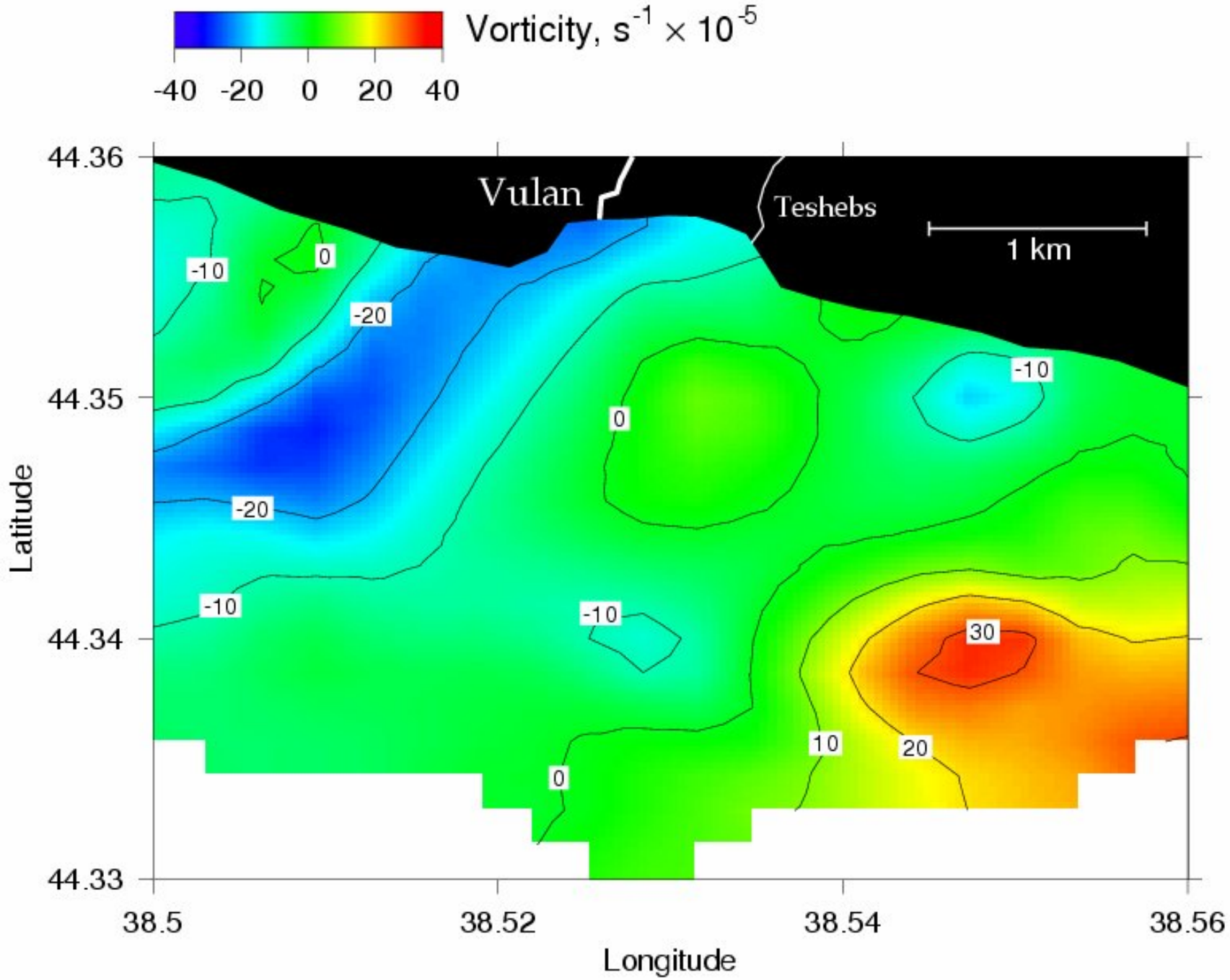

Mzymta mouth. Velocity at surface.
43.43
43.42
43.41
43.4
Latitude
20 cm/s
1 km
39.9
39.92
39.94
Longitude

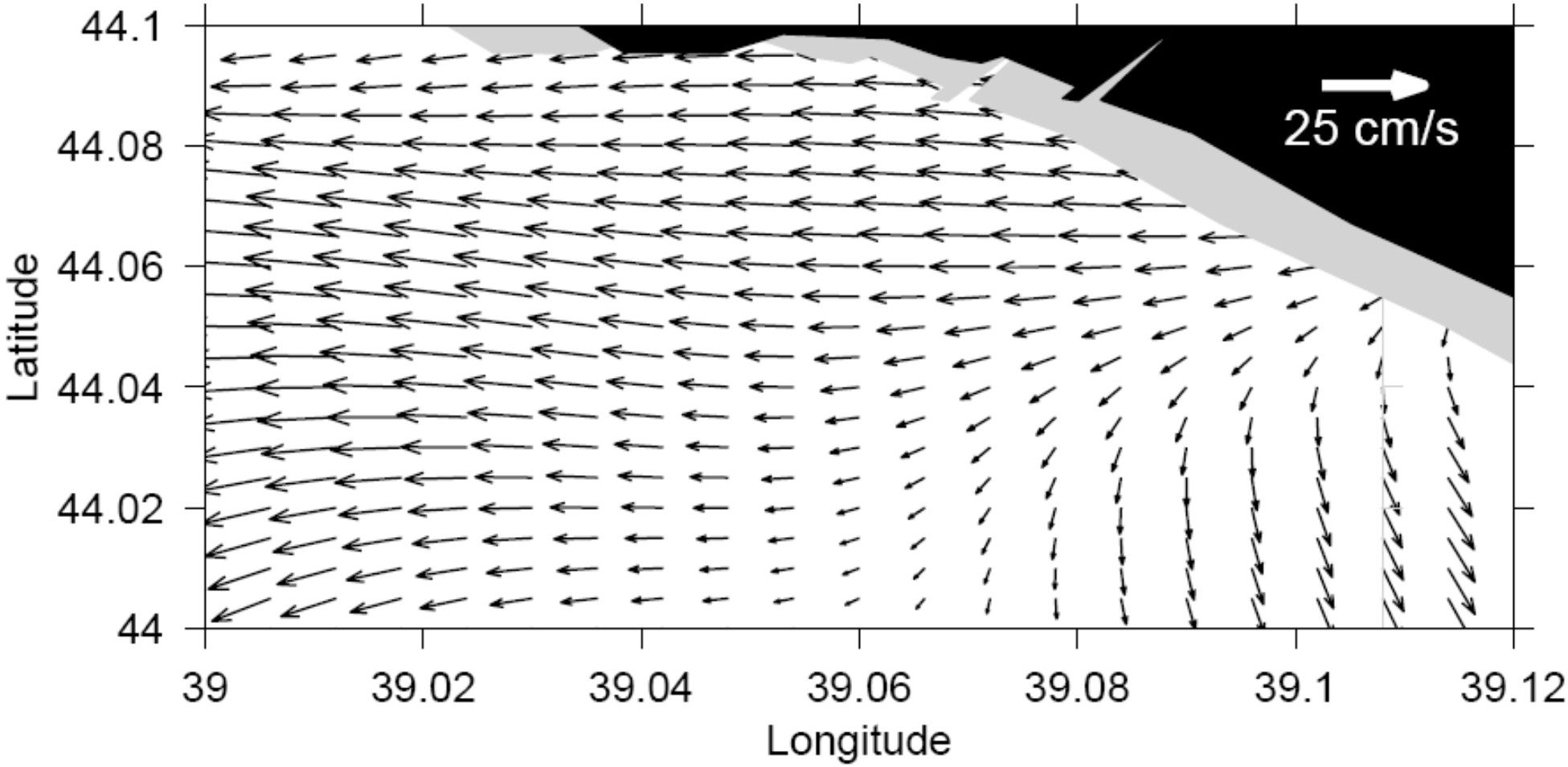

Mzymta mouth. Vorticity, 10-5 s-1.
43.43
43.42
43.41
43.4
Latitude
-4
-3
-2
-1
0
1 km
39.9
39.92
39.94
Longitude

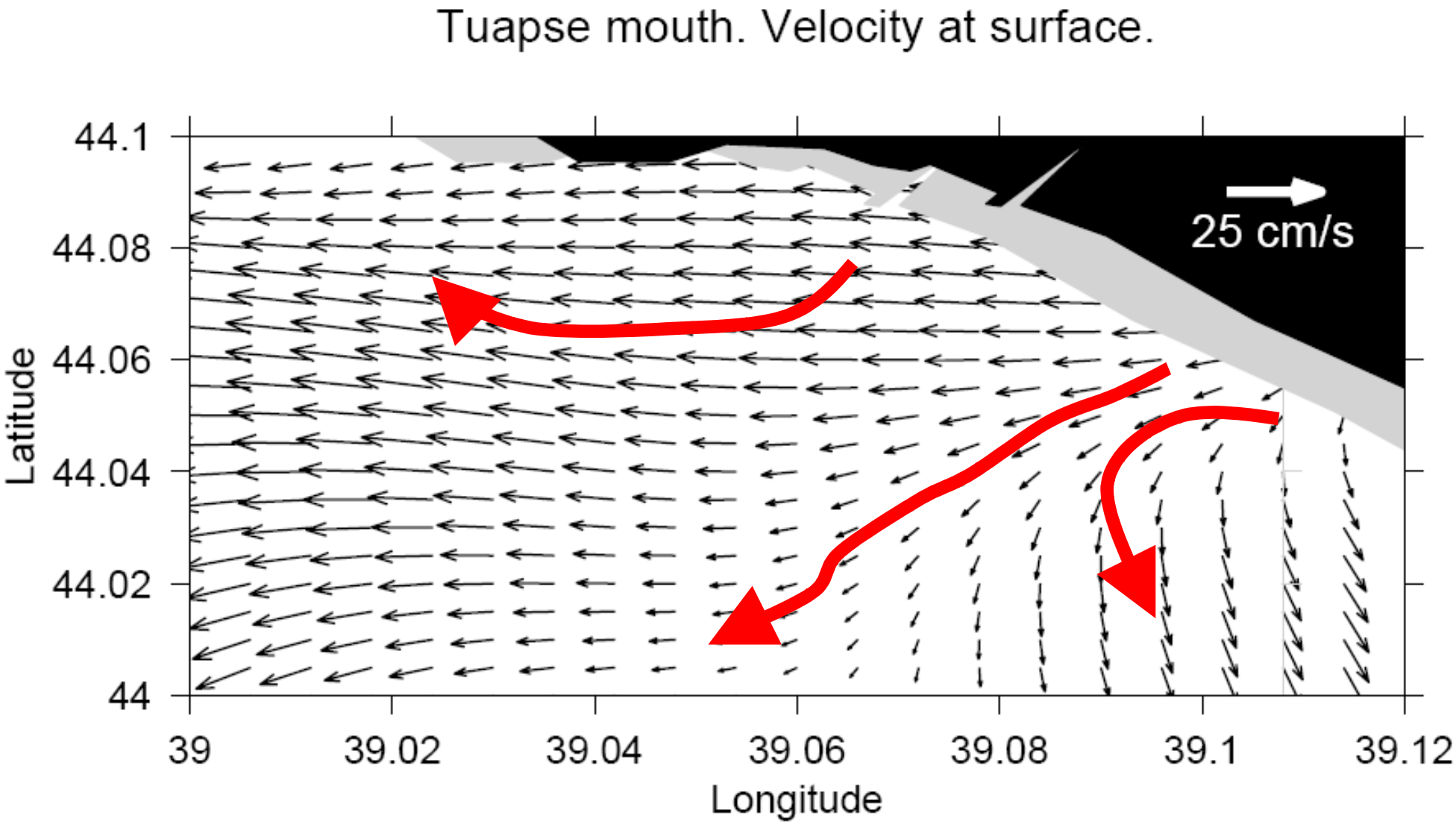
Velocity near Vulan mouth
7/06/2006



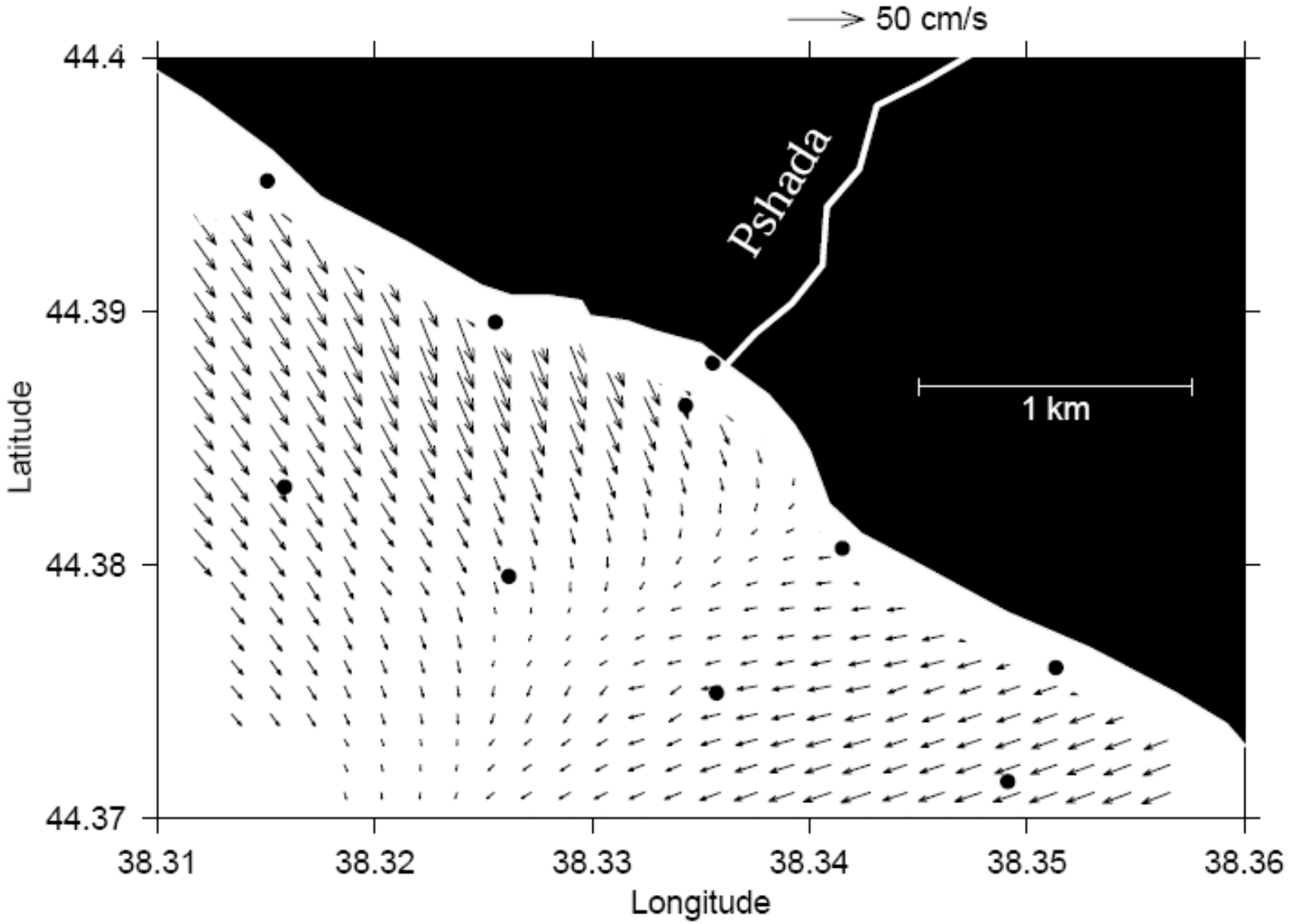

50 cm/s
Vulan
Teshbes
1 km
44.36
44.35
44.34
44.33
Latitude
38.5
38.52
38.54
38.56
Longitude


Vorticity, s-1 × 10-5
-40 -20 0 20 40
Vulan
Teshebs
1 km
-10
0
-20
-10
0
-20
-10
-10
30
10
20
0
44.36
44.35
44.34
44.33
Latitude
38.5
38.52
38.54
38.56
Longitude

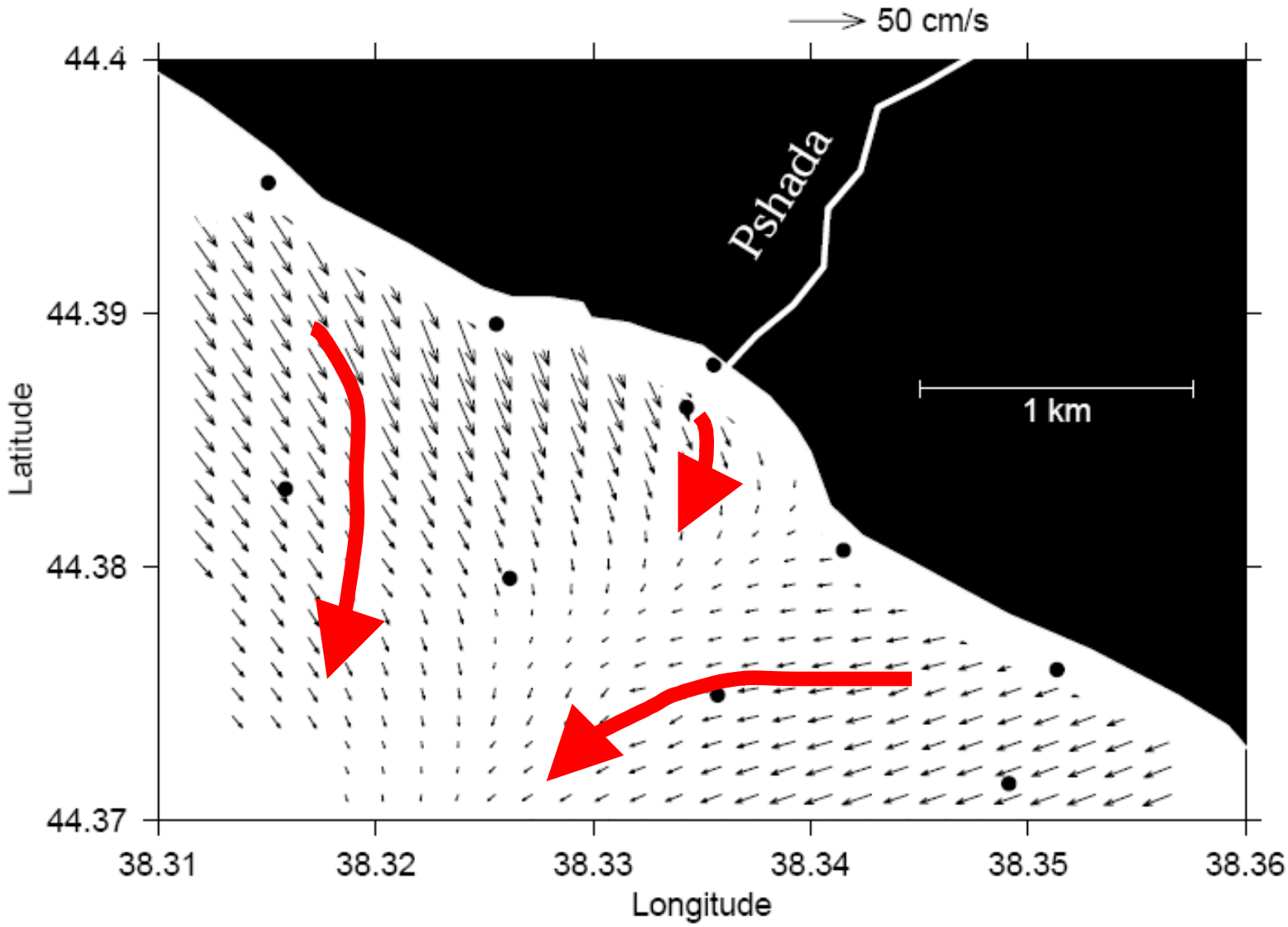

Tuapse mouth. Velocity at surface.
25 cm/s
Latitude
Longitude
44.1
44.08
44.06
44.04
44.02
44
39
39.02
39.04
39.06
39.08
39.1
39.12


Tuapse mouth. Velocity at surface.
25 cm/s
Latitude
44.1
44.08
44.06
44.04
44.02
44
39
39.02
39.04
39.06
39.08
39.1
39.12
Longitude

Течения у устья р.Пшада
2/06/2006

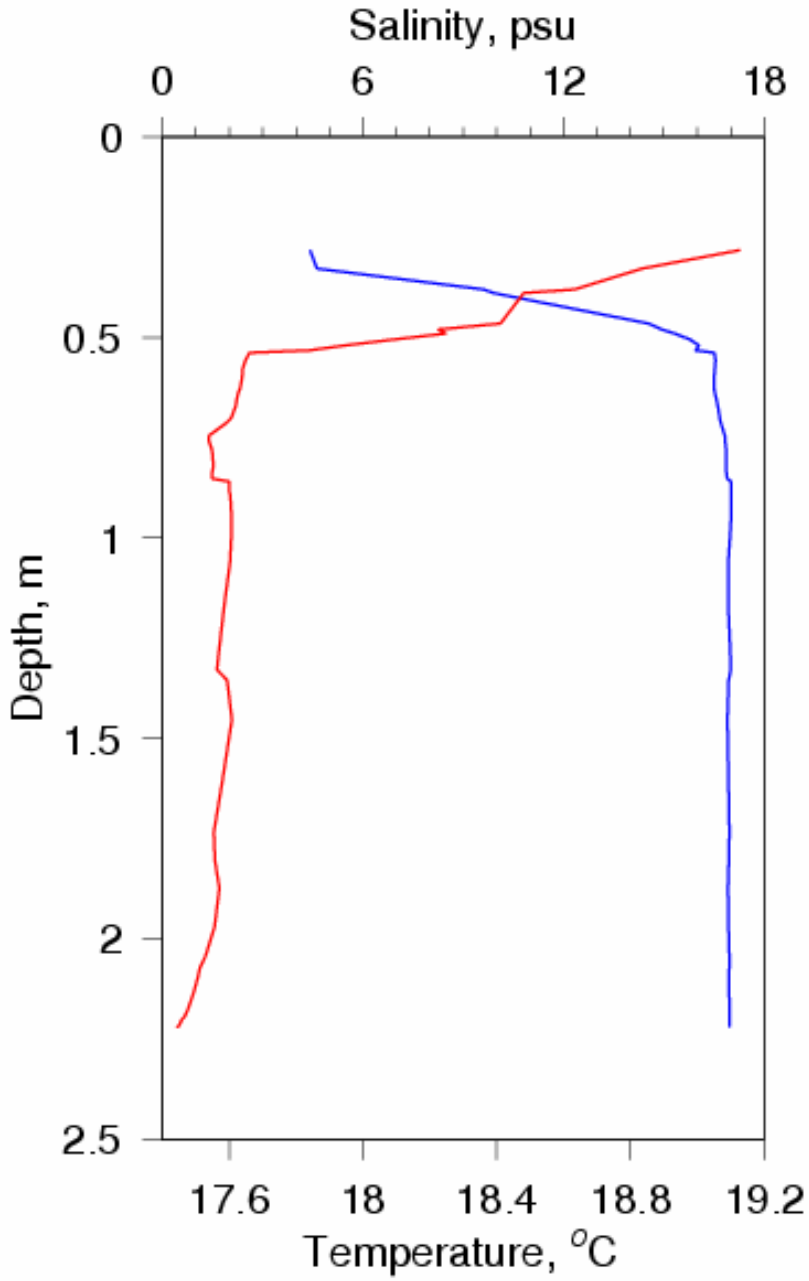


Течения у устья р.Пшада
2/06/2006



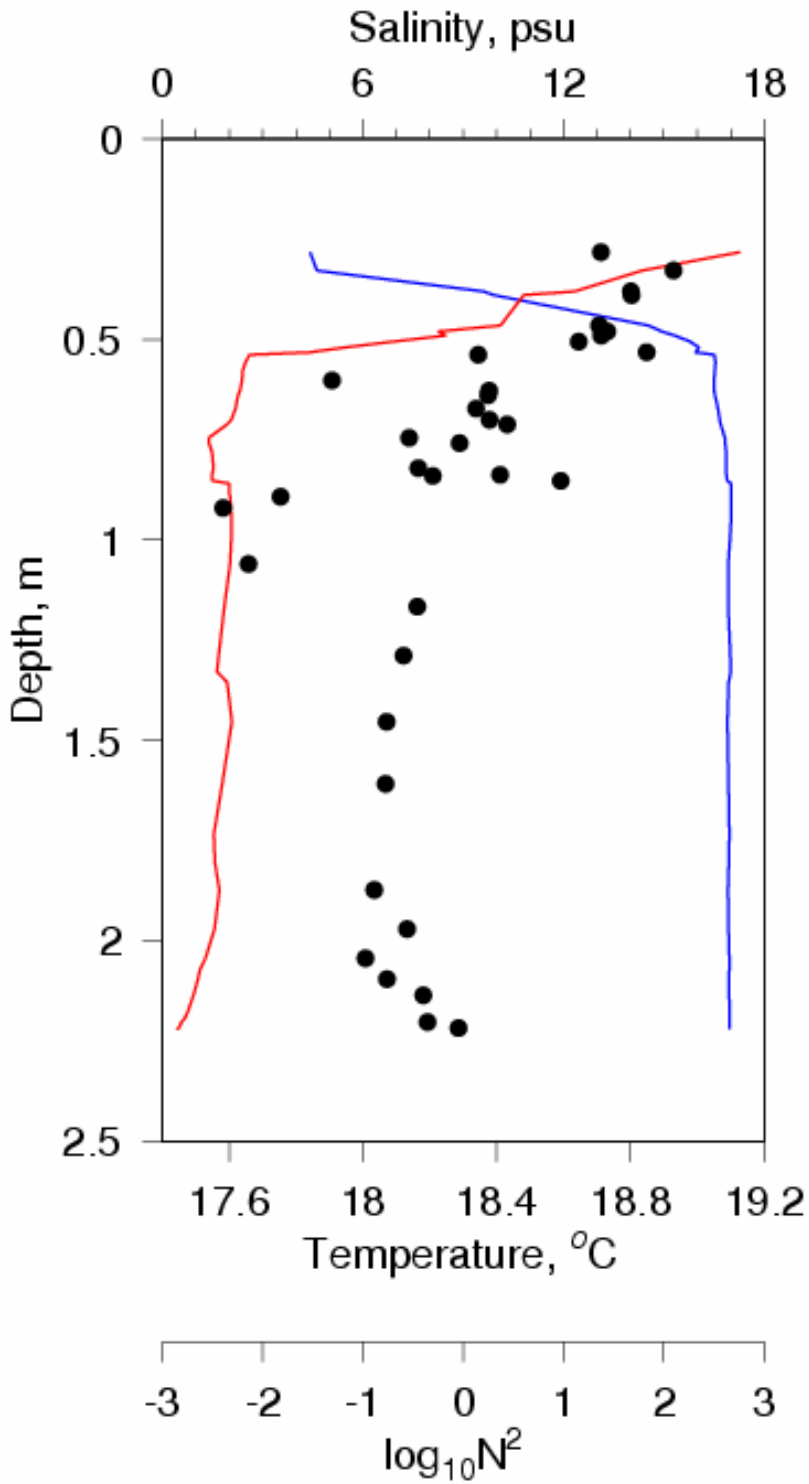
Вулан:

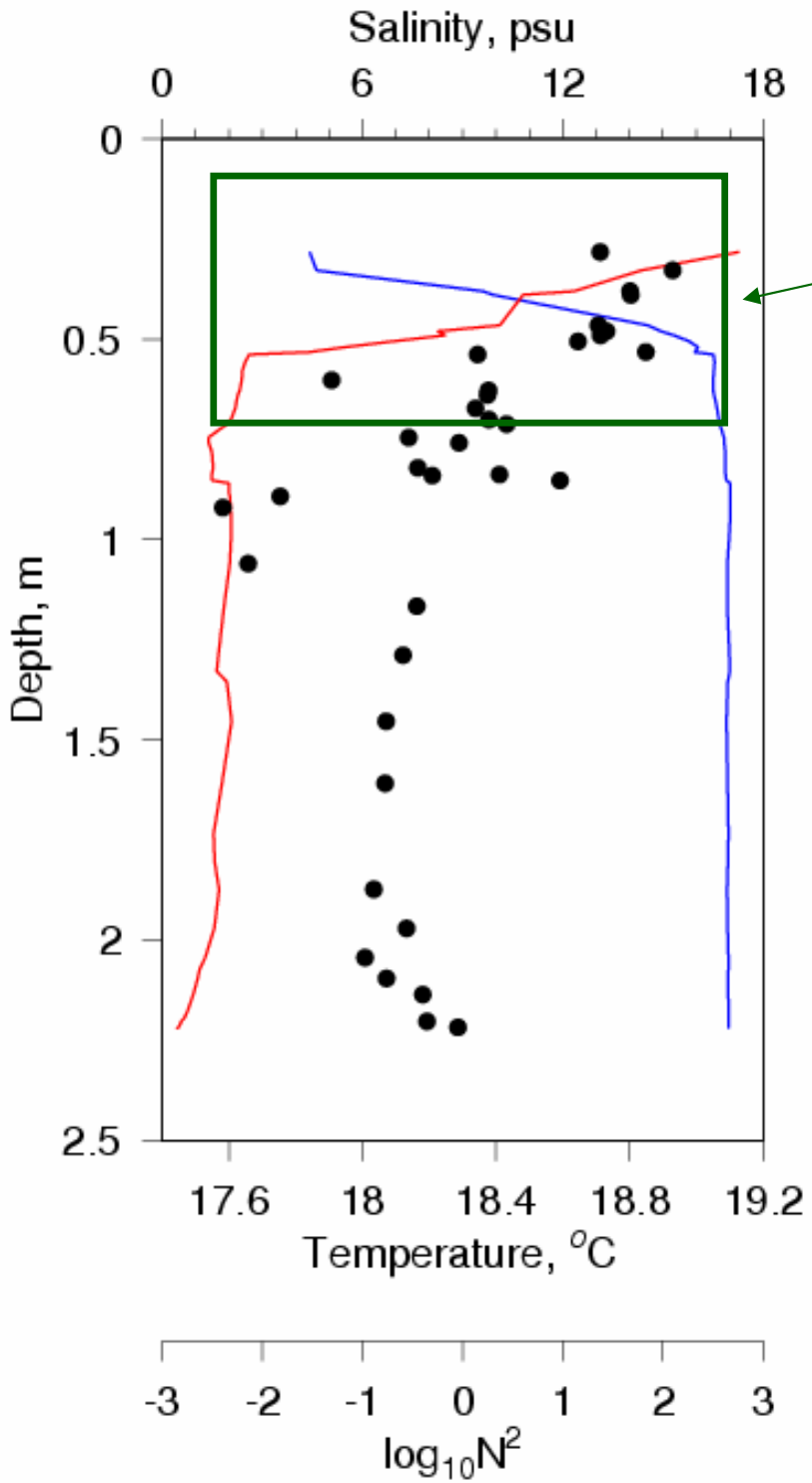
температура,
соленость



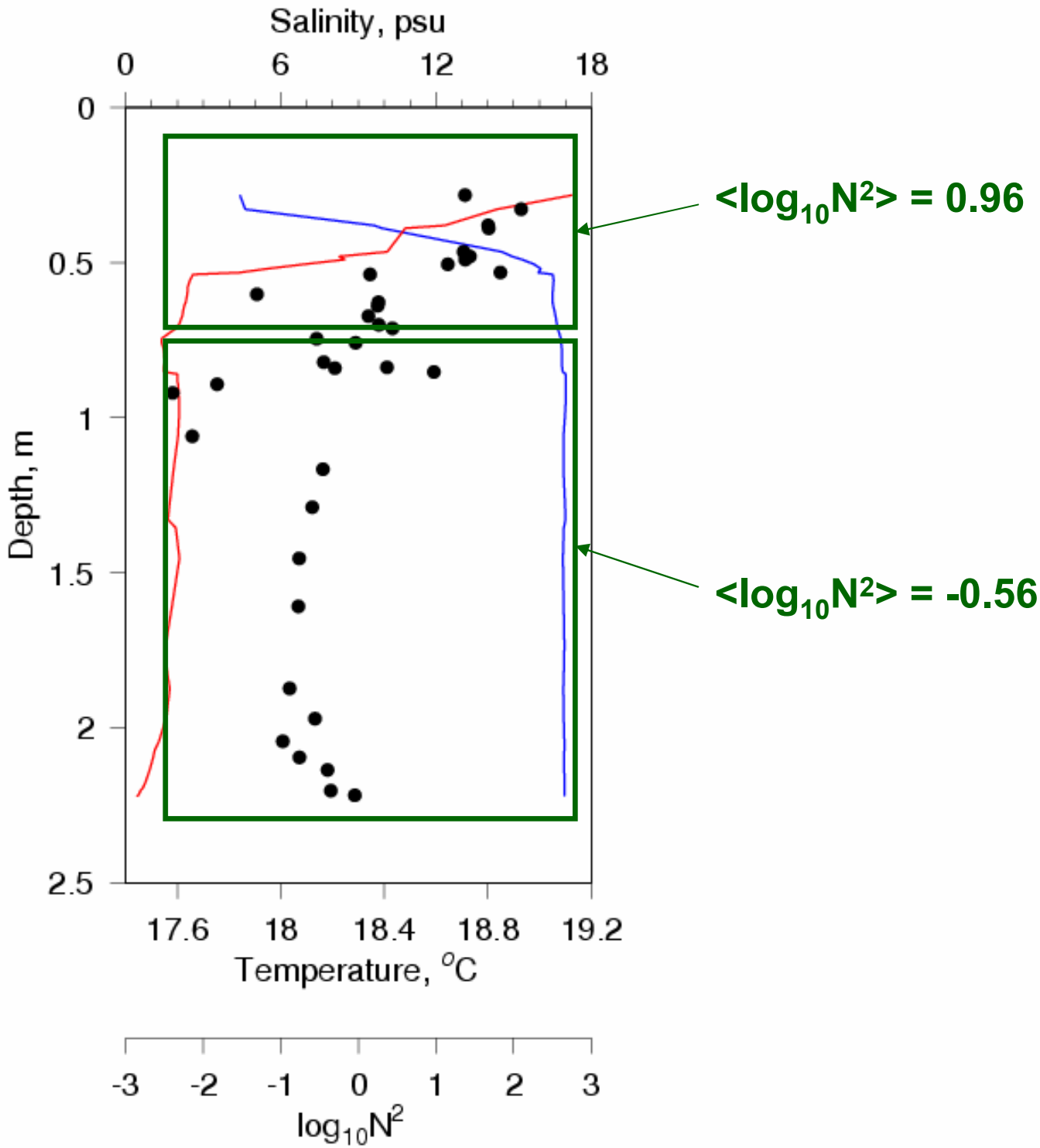
Вулан:

температура,
соленость,
частота
плавучести





$\langle \log_{10} N^2 \rangle = 0.96$


Salinity, psu
0
6
12
18
0
0.5
1
1.5
2
2.5
Depth, m
17.6
18
18.4
18.8
19.2
Temperature, °C
-3
-2
-1
0
1
2
3
log10N2
<log10N2> = 0.96
<log10N2> = -0.56

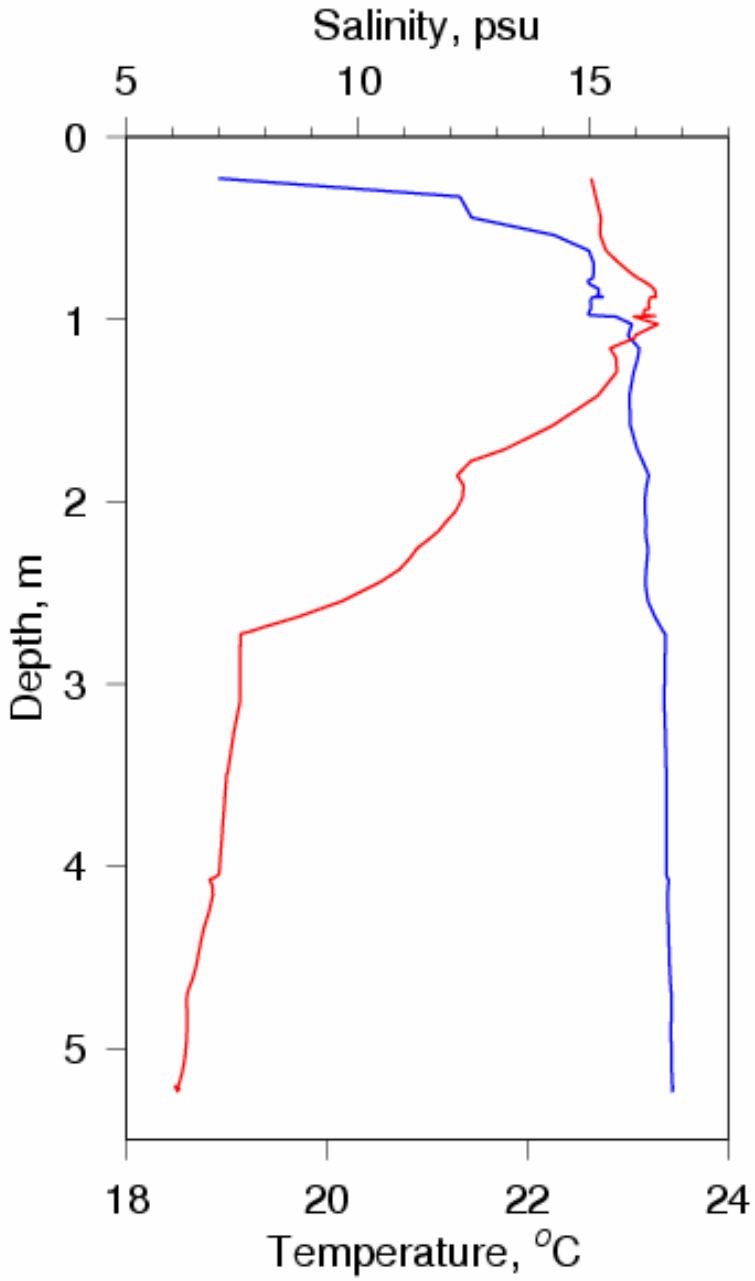
$$A_v \sim \varepsilon / N^2$$

[e.g., *Gregg*, 1984]

⇉ *Within this model, eddy viscosity at the bottom edge of Vulan plume was reduced by a factor of* **33** compared with that in the ambient waters

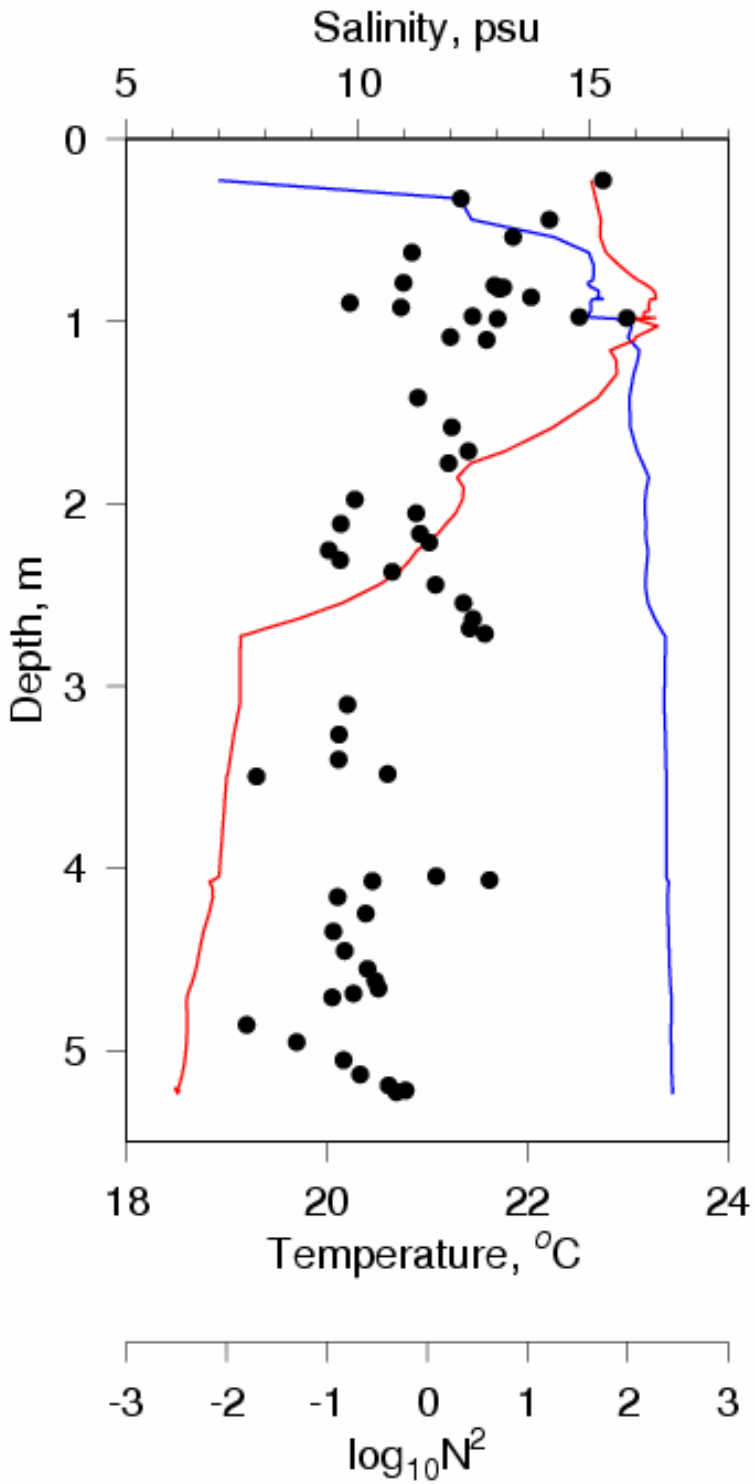
Пшада:

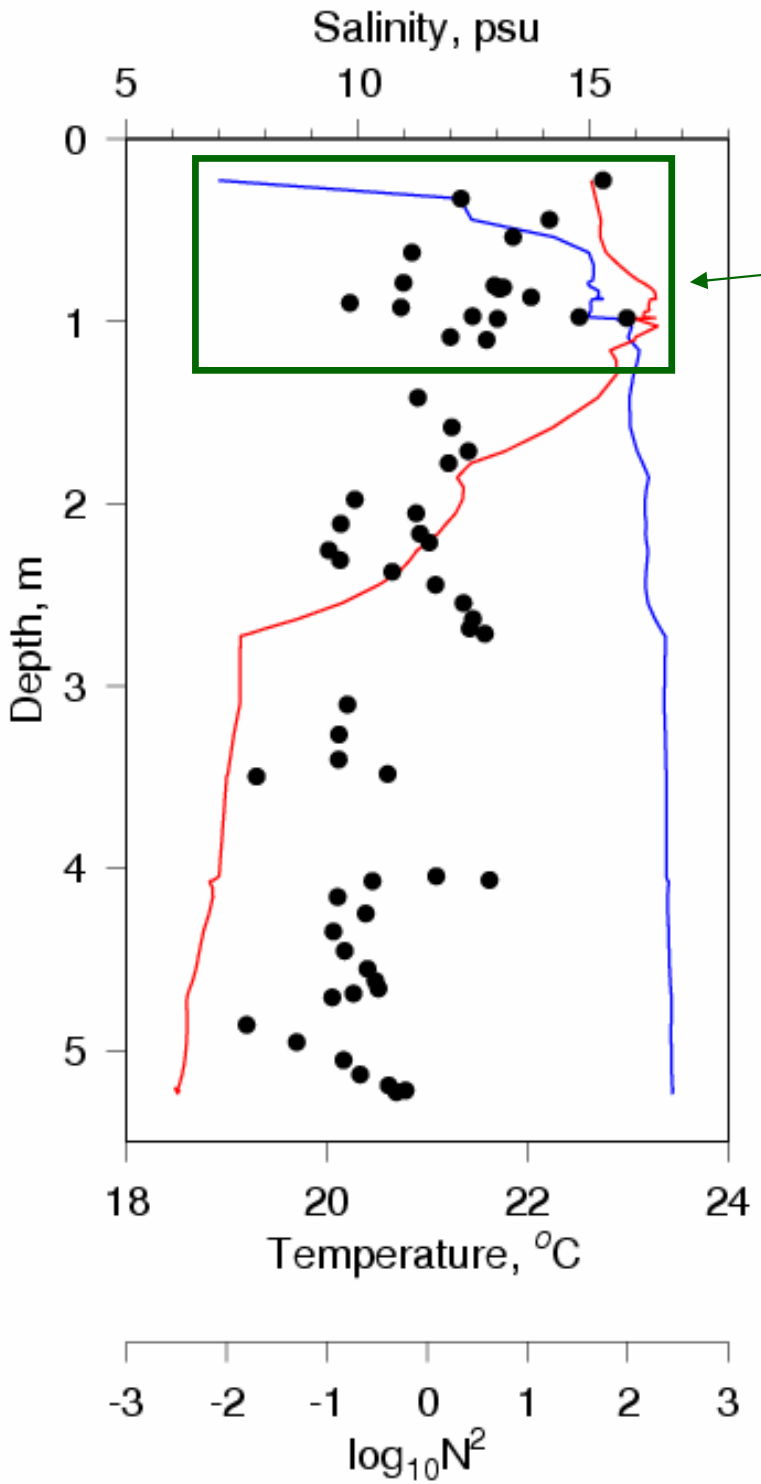
температура,
соленость



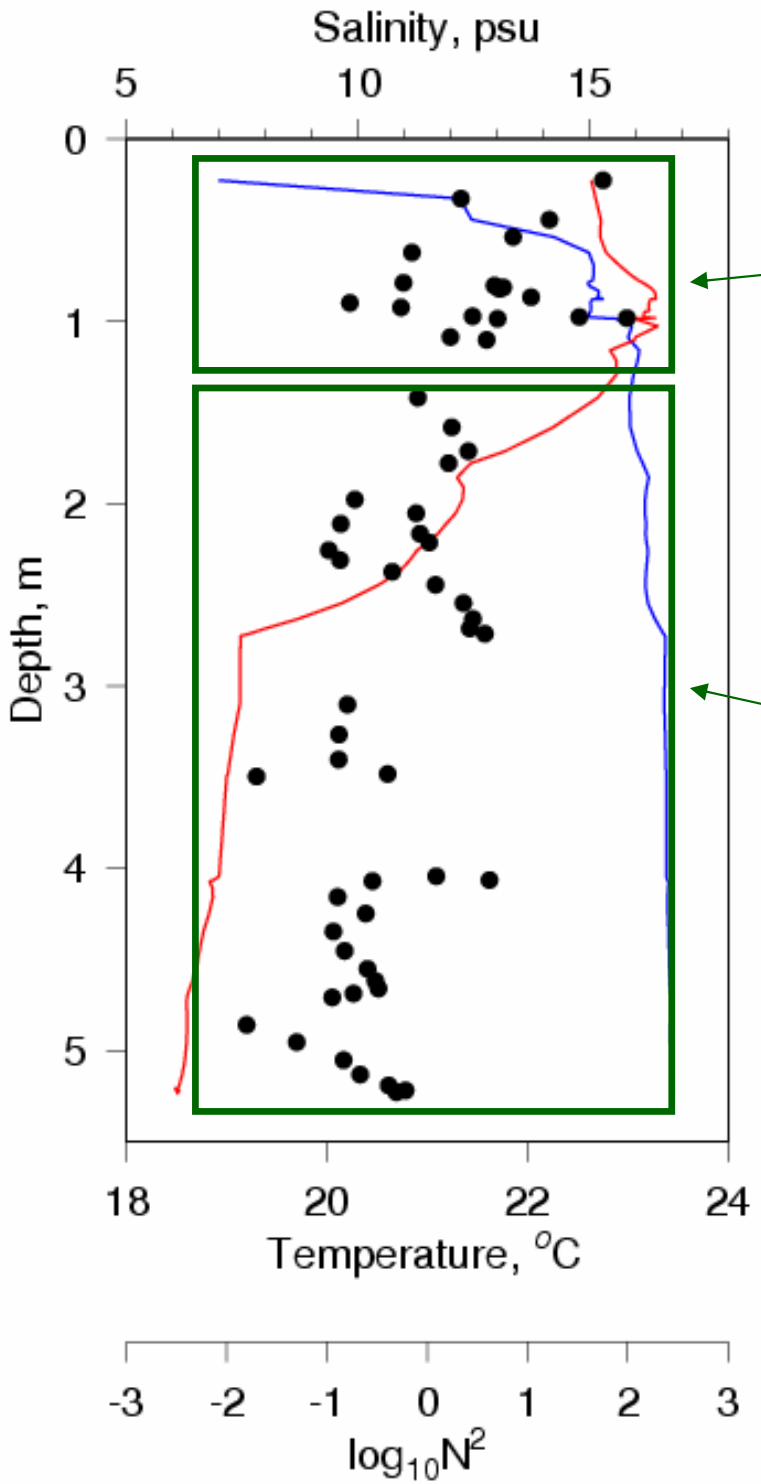
Пшада:

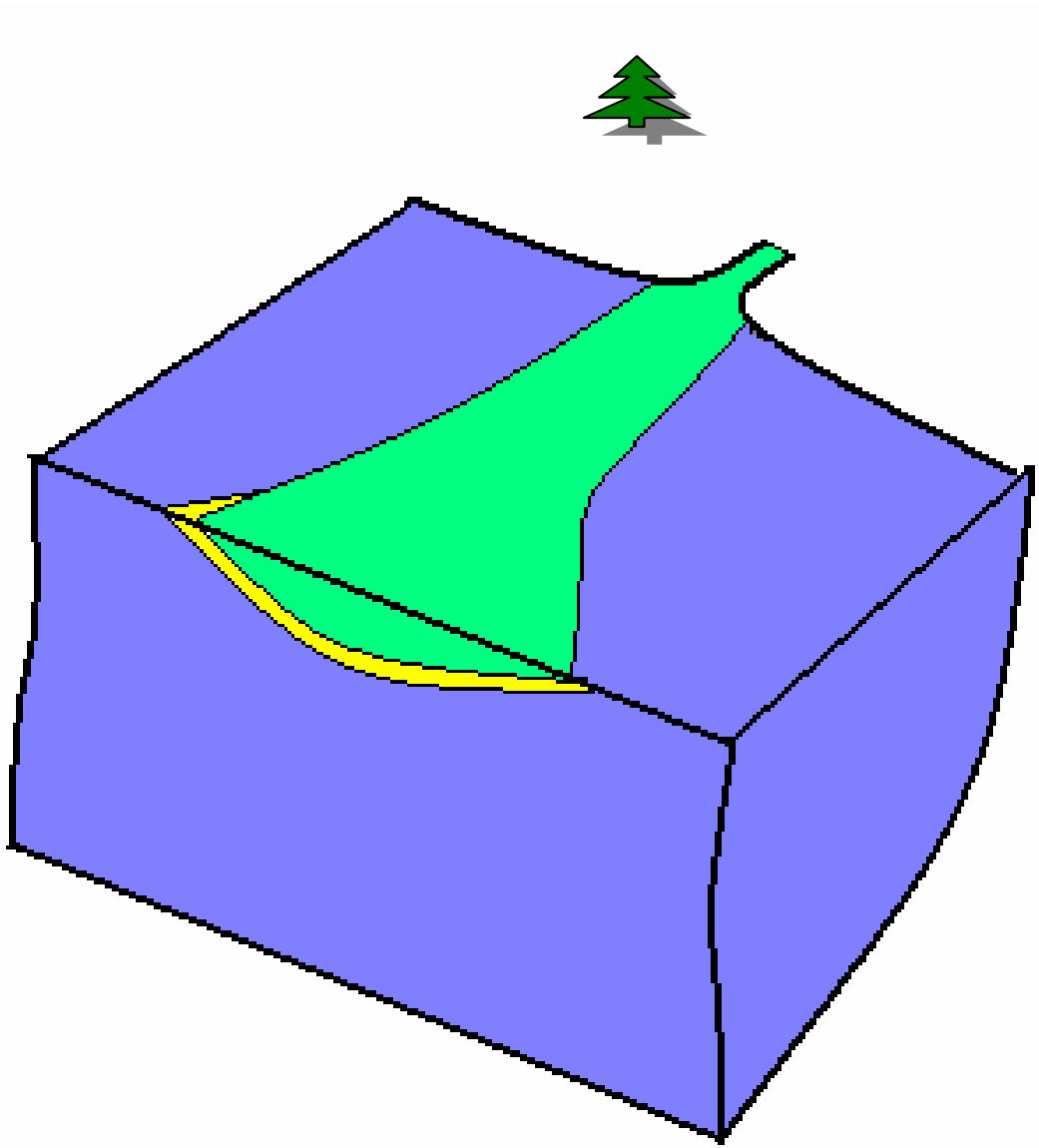
температура,
соленость,
частота
плавучести

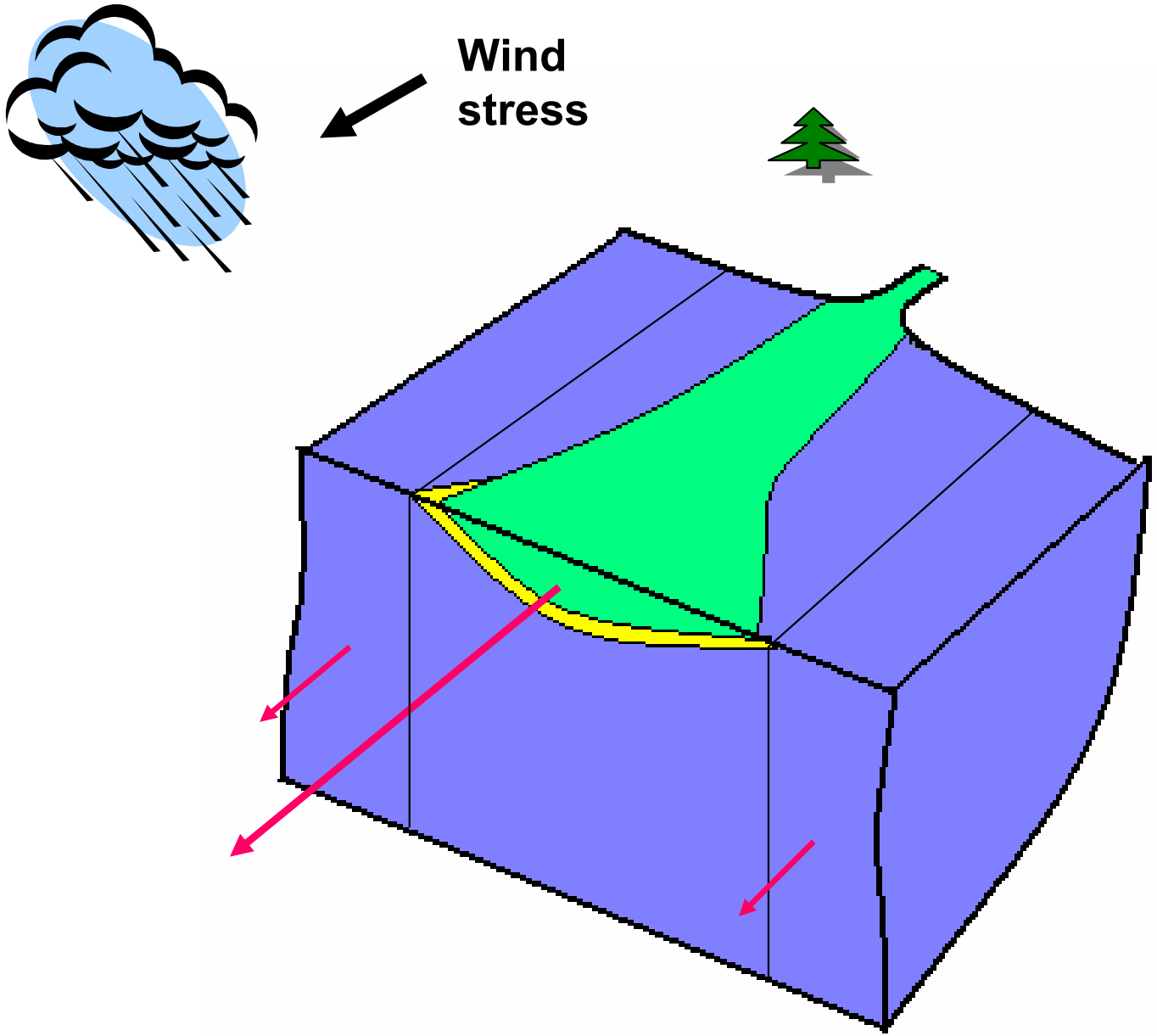


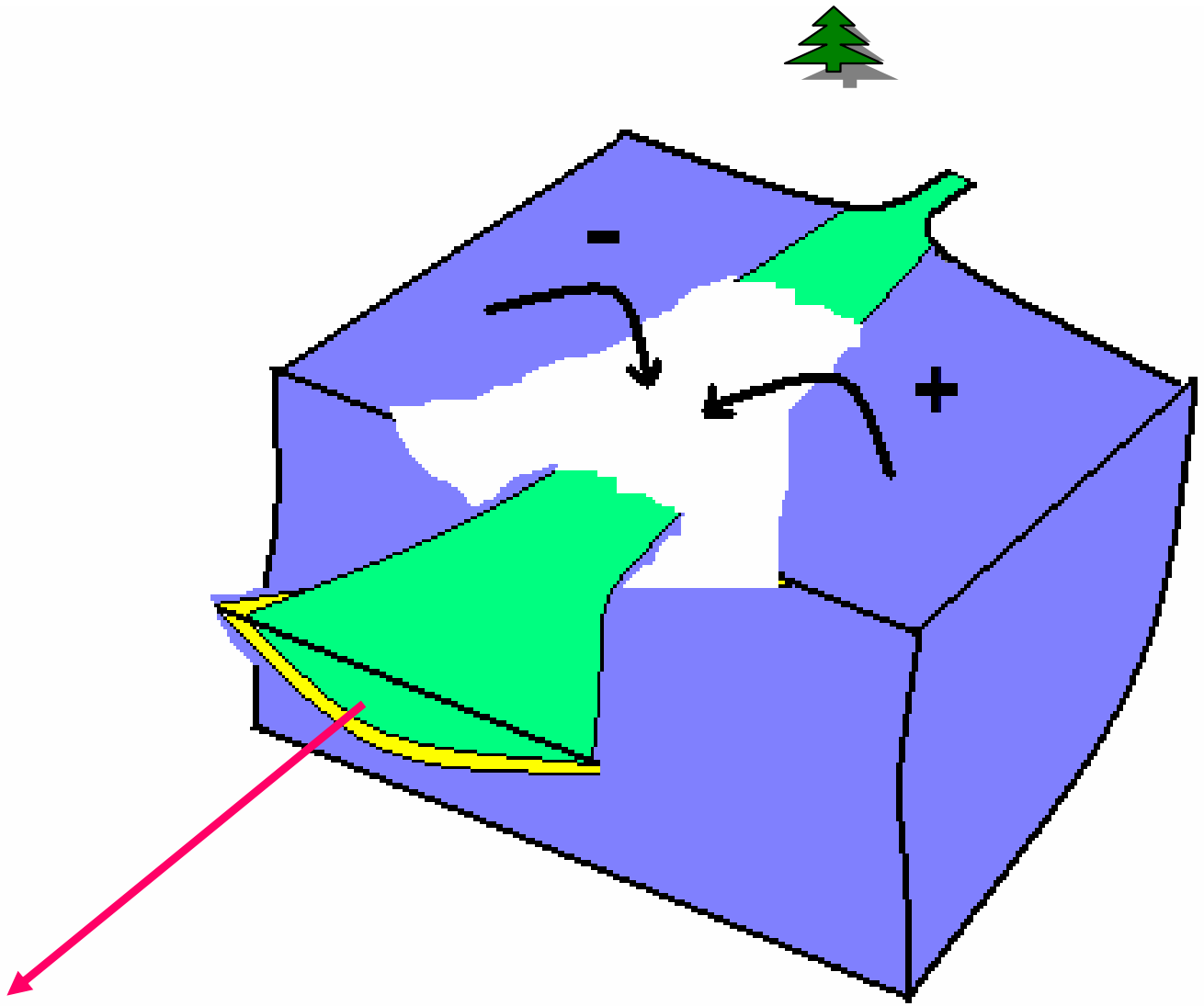


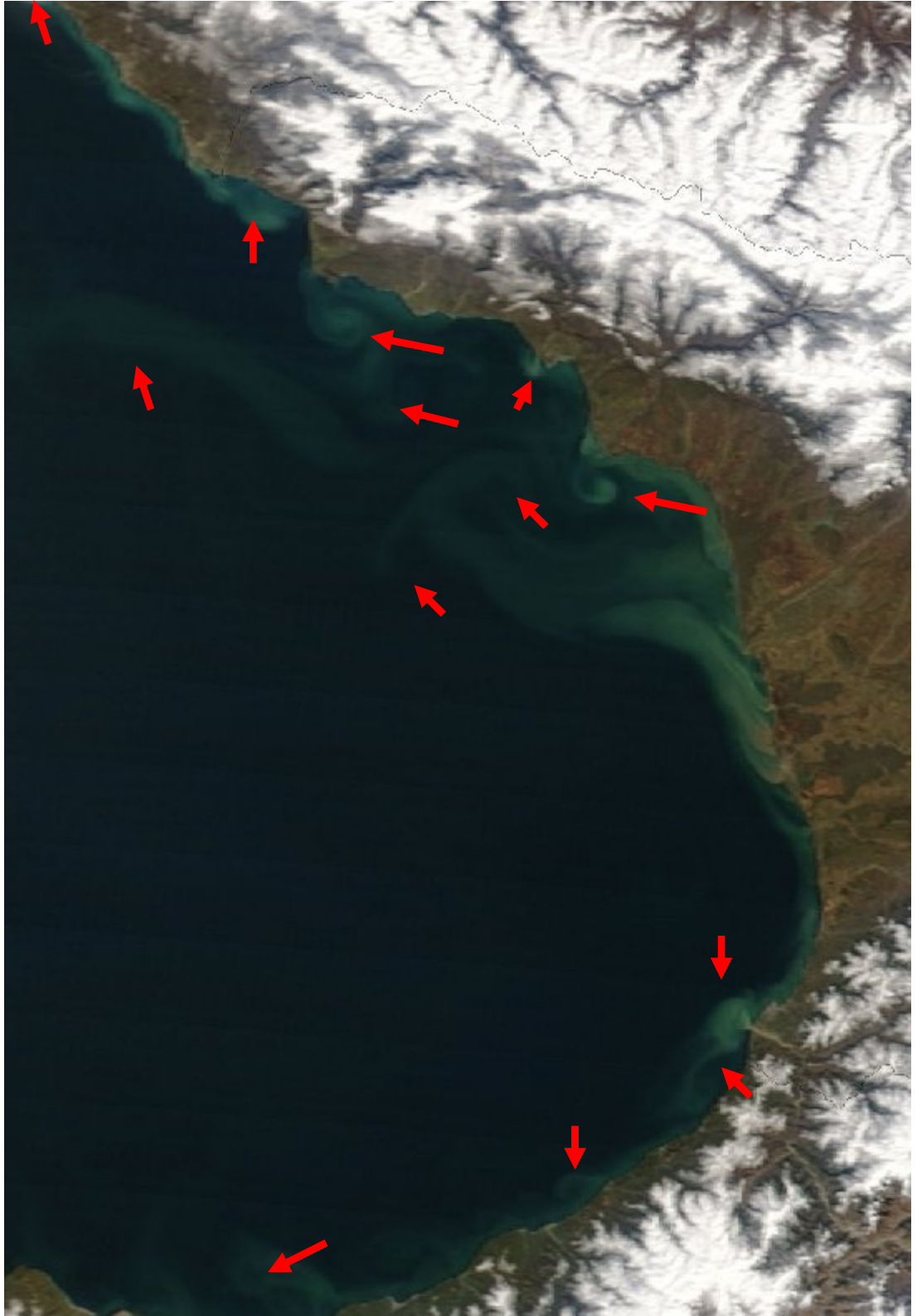
$\langle \log_{10} N^2 \rangle = 0.66$

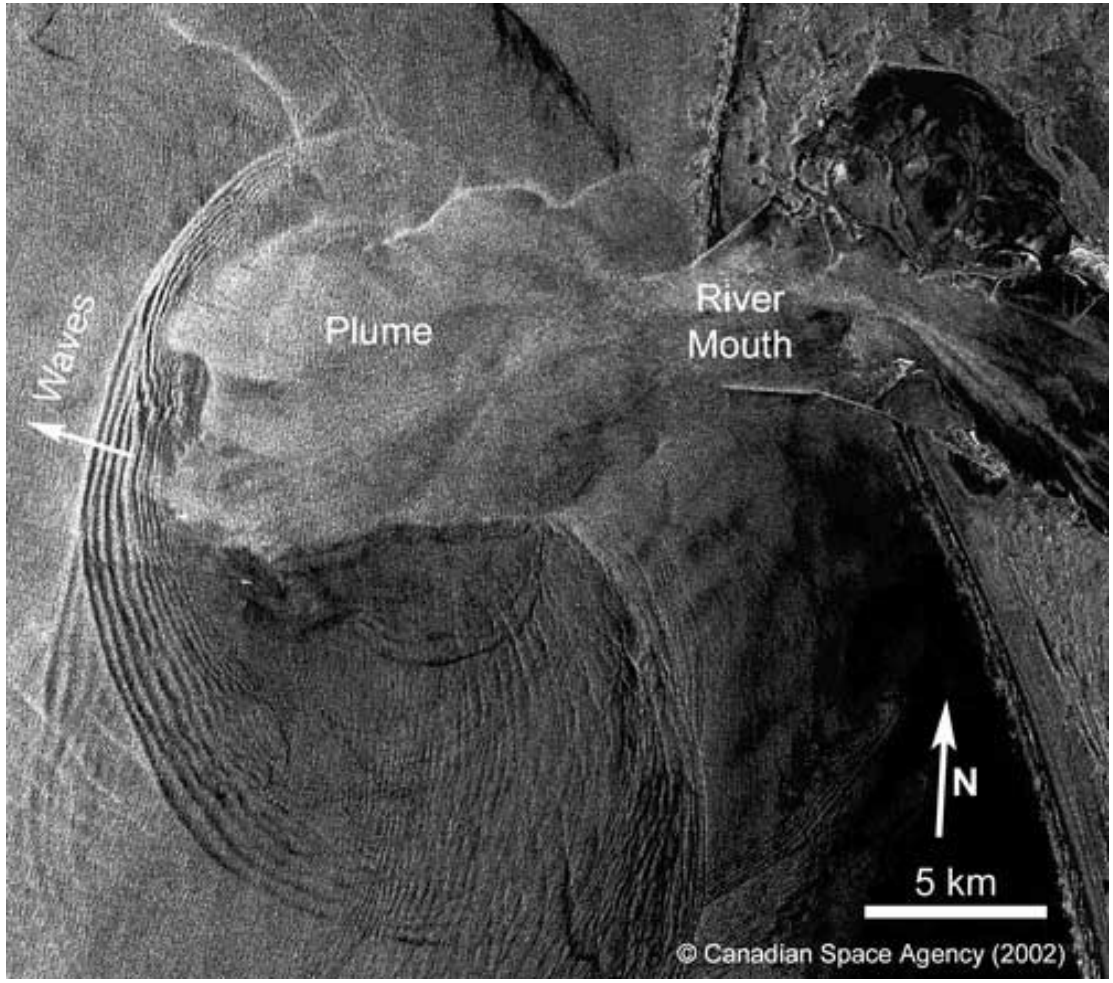

Salinity, psu
5
10
15
0
1
2
3
4
5
Depth, m
18
20
22
24
Temperature, °C
-3
-2
-1
0
1
2
3
log10N2
<log10N2> = 0.66
<log10N2> = -0.40



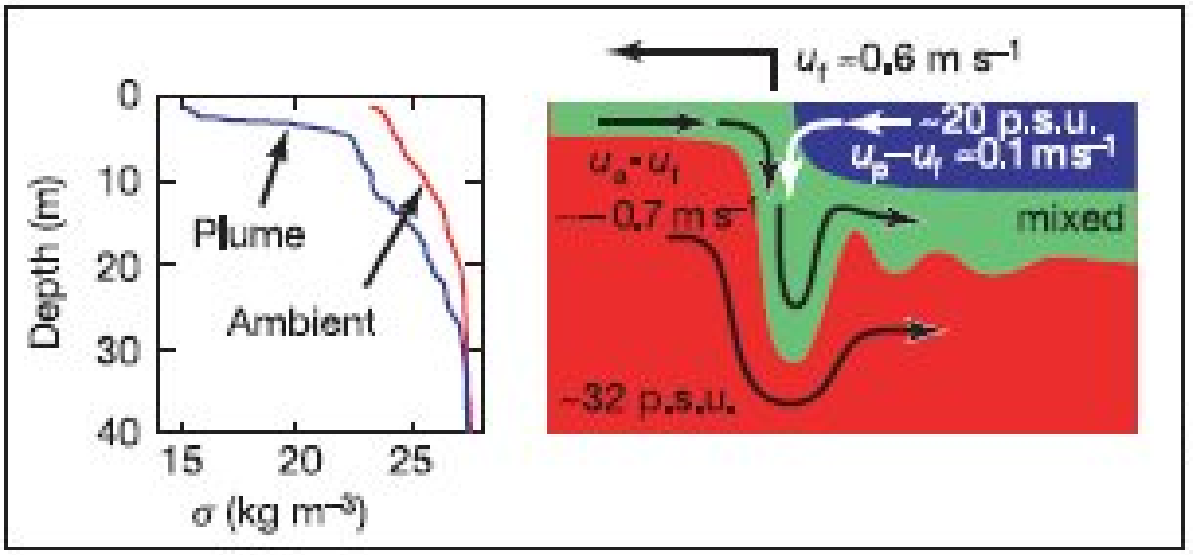

Wind
stress





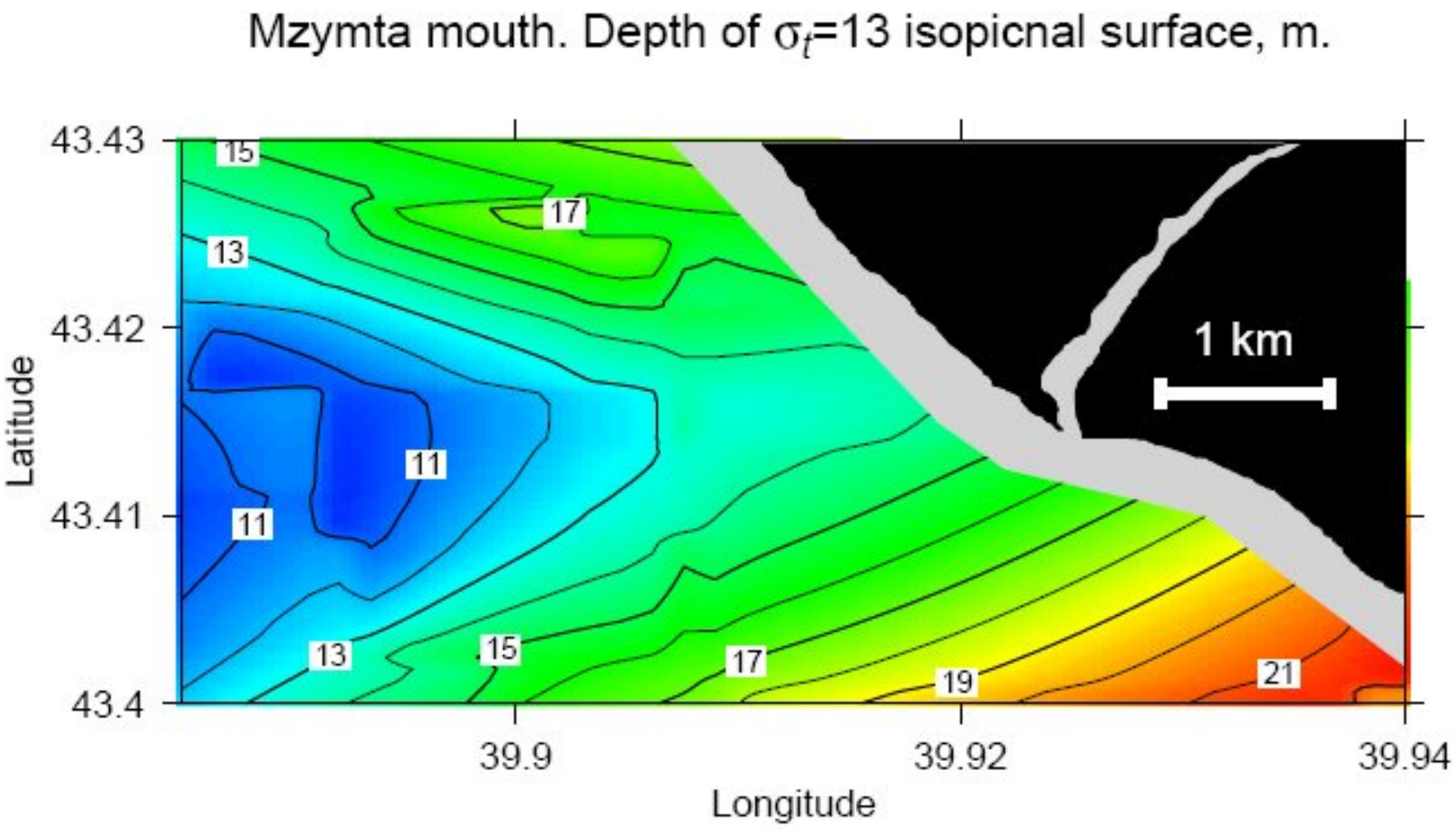


[Nash and Moum, Nature, 2005]

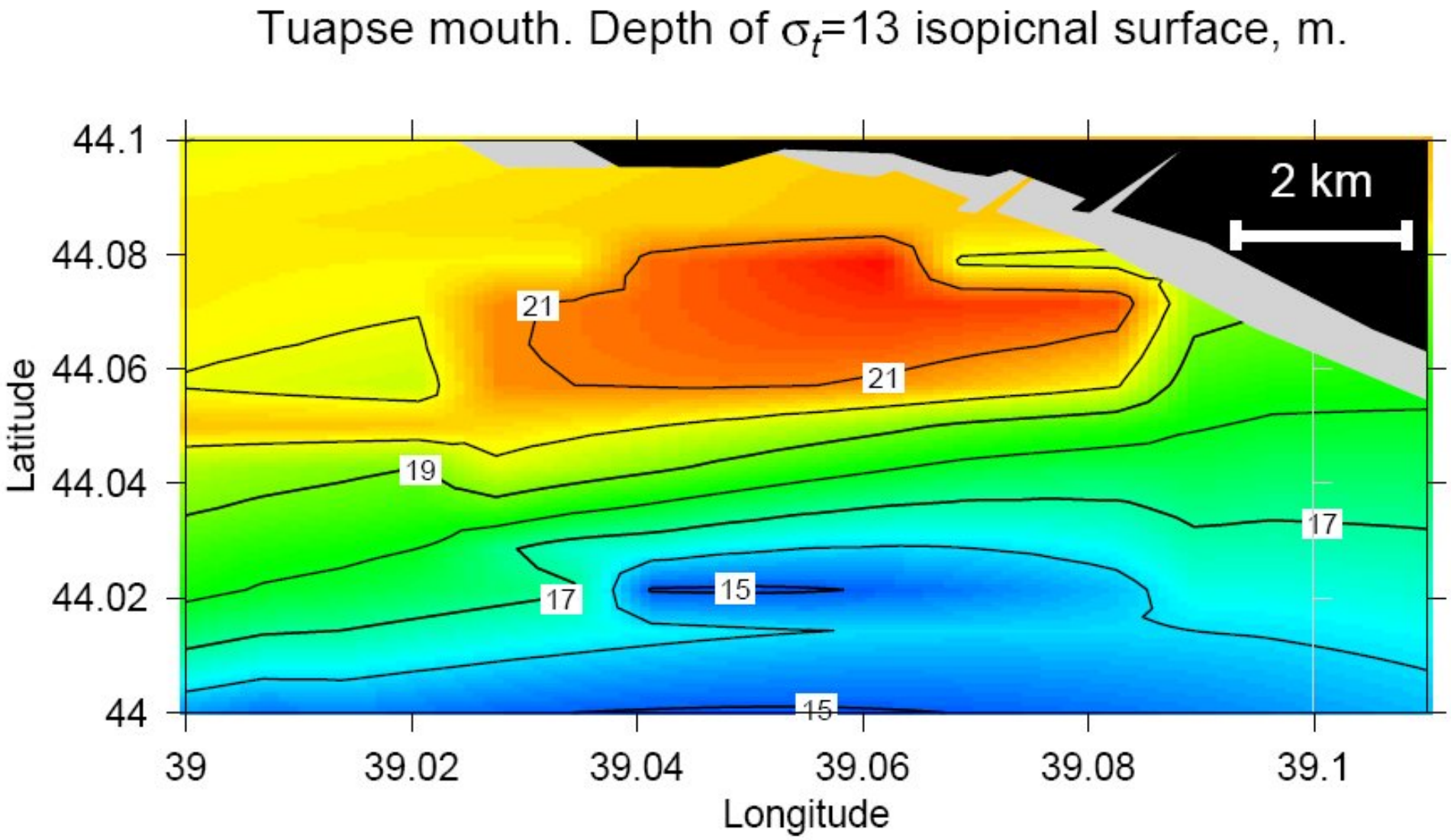


[Nash and Moum, Nature, 2005]

Hint of internal waves activity? Mzymta mouth



Hint of internal waves activity? Tuapse mouth



Тезисы (1): *(My apologies to those not reading Russian!)*

- К побережью материка следует относиться, как к *проницаемой* боковой границе океана, потоки тепла и пресной воды через которую могут быть сопоставимы с потоками на границе океан-атмосфера (по крайней мере, для отдельных регионов).

- Речные плюмажи являются повсеместно распространенным в океане и важным явлением. В зависимости от характера стока, батиметрии и ветрового воздействия они могут иметь форму локализованного «пятна», вытянутой вдоль берега протяженной (иногда на тысячи километров!) полосы, струйного течения в направлении от берега, либо отделившейся от устья линзы.

- Сток рек формирует особый тип термохалинной структуры на обширных акваториях и эффективно “модулирует” изменчивость океана в разных масштабах - от суточного до векового.

Тезисы (2):

- Влияние стока не сводится к простому «алгебраическому» обмену свойствами между речной и морской водой. Более важен динамический механизм влияния, связанный с подавлением перемешивания под опресненным поверхностным слоем

- Переменные во времени стоковые плюмажи являются генераторами внутренних волн на шельфе. Этот механизм может быть особенно важным в неприливных акваториях, таких как ЧМ и БМ

- Предположительно, стоковые плюмажи даже небольших рек при ветровом воздействии могут выступать также в качестве своеобразных «триггеров» генерации завихренности на шельфе

Тезисы (3):

- Стоком малых рек российского побережья ЧМ отнюдь не следует пренебрегать. По крайней мере в период весеннего половодья он оказывает отчетливое влияние на термохалинные и гидрохимические поля, а также динамику течений, в пространственных масштабах, сопоставимых с шириной шельфа.

- Стоки рек российского побережья ЧМ западнее Туапсе и восточнее Туапсе резко отличаются друг от друга по гидрохимическим параметрам и свойствам переносимой взвеси

THANK YOU!