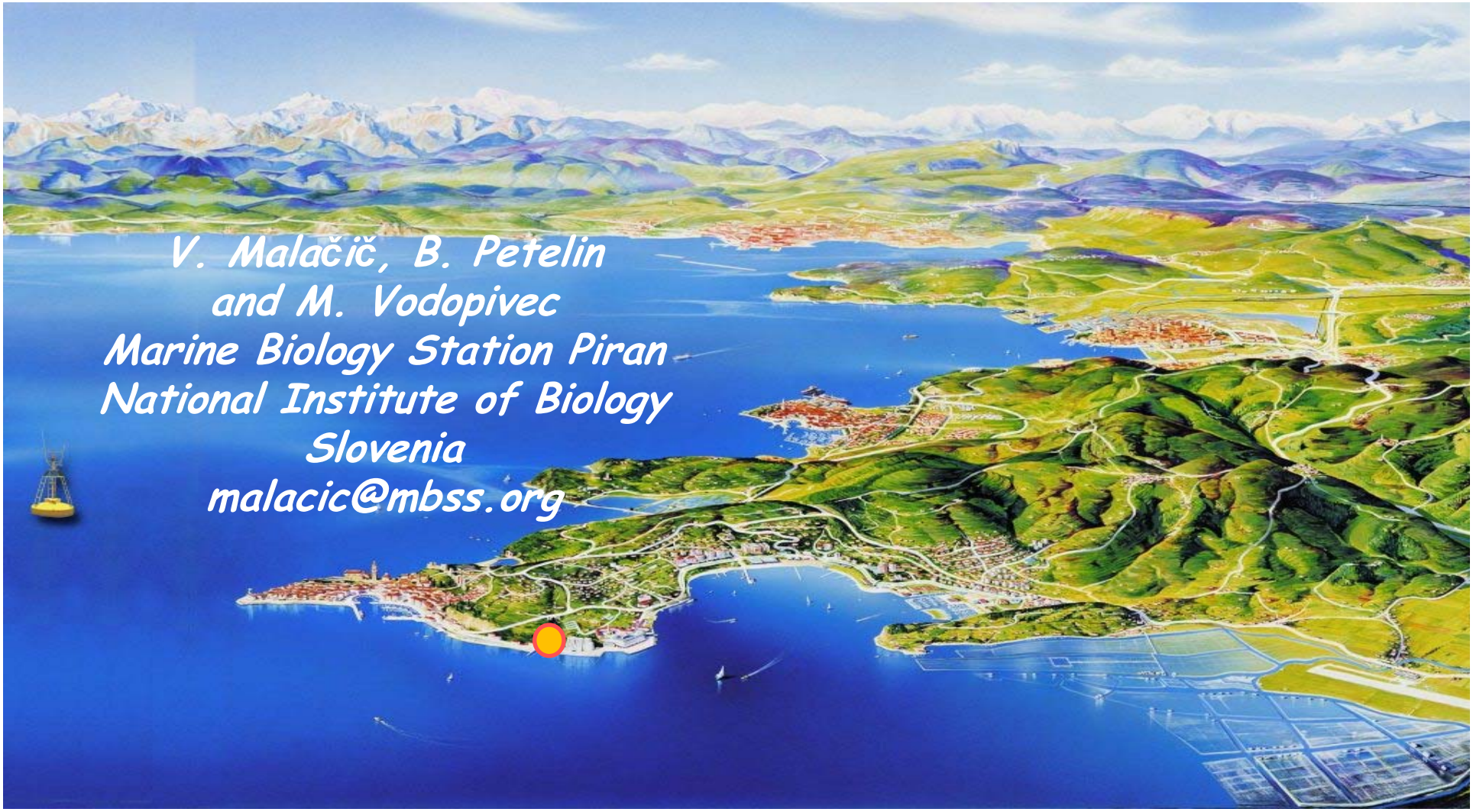
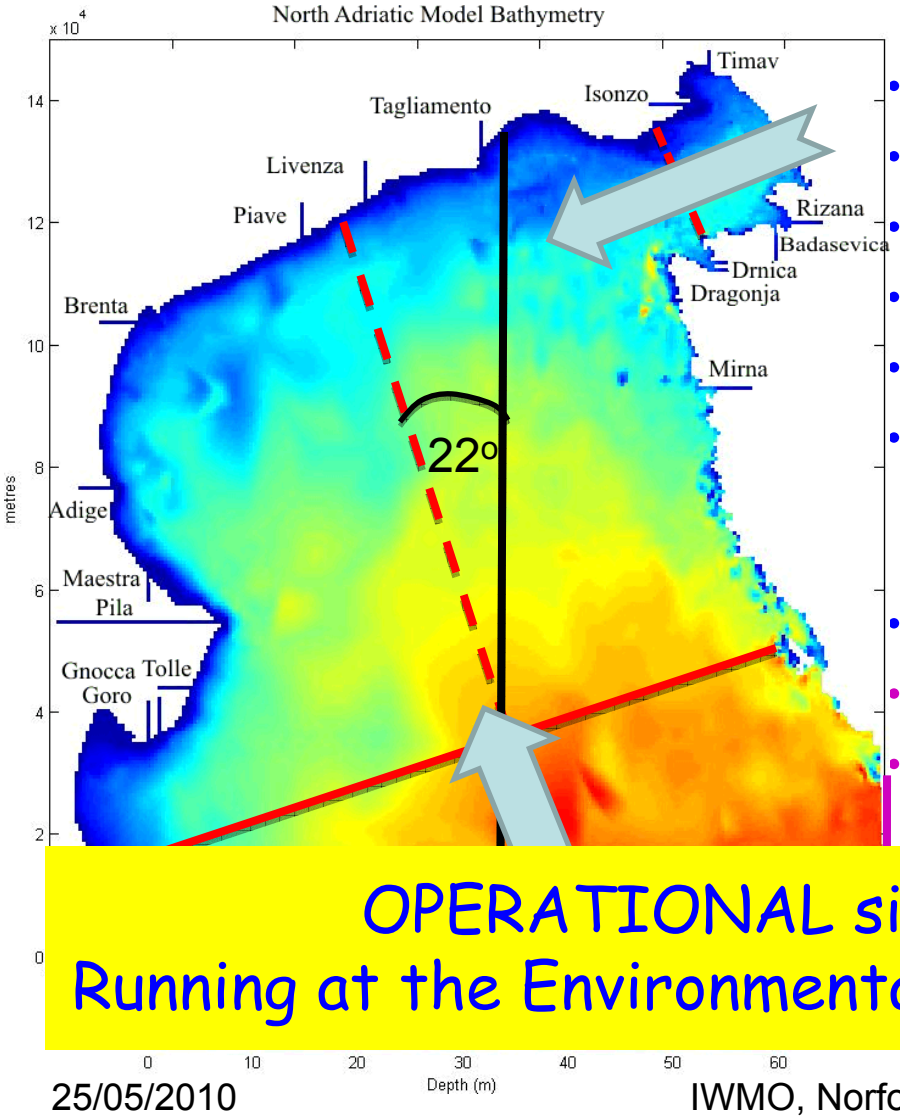
Circulation in widely open bays in northern Adriatic



V. Malačič, B. Petelin
and M. Vodopivec
Marine Biology Station Piran
National Institute of Biology
Slovenia
malacic@mbss.org


N45°30'
Croatia
Krk
Otok Cres
Otok Rab
Otok Pag
N44°30'
Београд
Belgrad
Marino
Bosnia and Herzegovina
Sarajevo
Сарајево
Serbia
Otok Murter
N43°30'
Otok Brac
Otok Hvar
Adriatic Sea
Montenegro
Podgorica
N42°30'
E 13°
E 15°
E 17°
E 19°
E 21°
South Adriatic Basin
N41°30'
Tiranë
Albania
Isola d'Ischia
Isola di Capri
N40°30'
N39°30'
Kerkyra
Ionian Sea
© 2010 Google

North Adriatic Princeton Ocean Model (NAPOM)



- 12.2^0 E - 13.91^0 E
- 44.478^0 N - 45.82^0 N
- No. cells 232 x 248 x 11
- Cells ~ 600 m x 600 m
- Depths: 2 m - 52.5 m
- 11 σ levels: 0,00, -0,06, -0.15, -0,26, -0,37, -0,48, -0,59, -0,70, -0,81, -0,91, -1,00, Eastern & southern OB
- Rectangular basin:
- 125±4 km (length) 94±3 km(width)
- Wind sirocco (jugo) along the basin

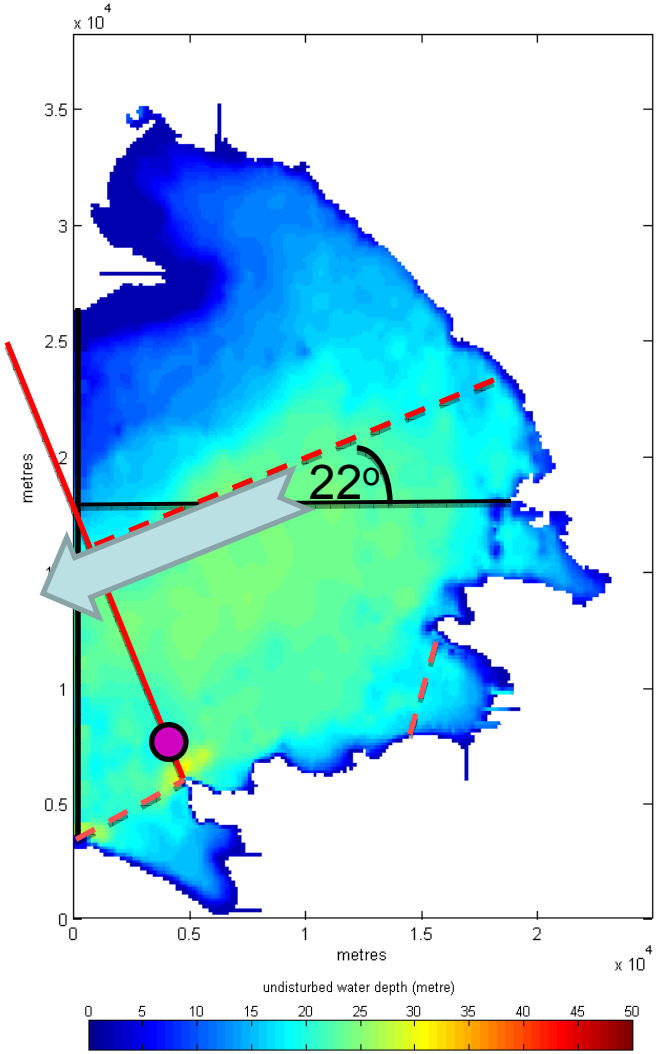
OPERATIONAL since December 2009
Running at the Environmental Agency of the R of Slovenia

Operational NAPOM inputs

Forcing	Source
Air pressure	Meteorological model ALADIN/SI: • model data supplier is Environmental Agency Of The Republic Of Slovenia (ARSO) •hourly data were interpolated from 9.5 km resolution of ALADIN/SI to 600 m resolution of NAPOM
Wind	
Solar radiation	
Upward heat flux	
Evaporation - precipitation	
River inflow	Monthly average river flow data: • Italian coast rivers - Raicich (1994) • Slovenian coast rivers – ARSO • Croatian coast rivers – Hydromet. Instof Croatia
Open Boundary Conditions + Tide	• AREG interannual non-tidal model from INGV, Bologna (daily averaged results of η, u, T and S with the resolution of ~2.5 km are interpolated to NAPOM open boudaries) • "AREG tide-only model", developed at NIB MBS Piran, Slovenia (tidal amplitudes and phases are interpolated to NAPOM open boundaries)

Gulf of Trieste (TSPOM)

TSPOM is nested into NAPOM

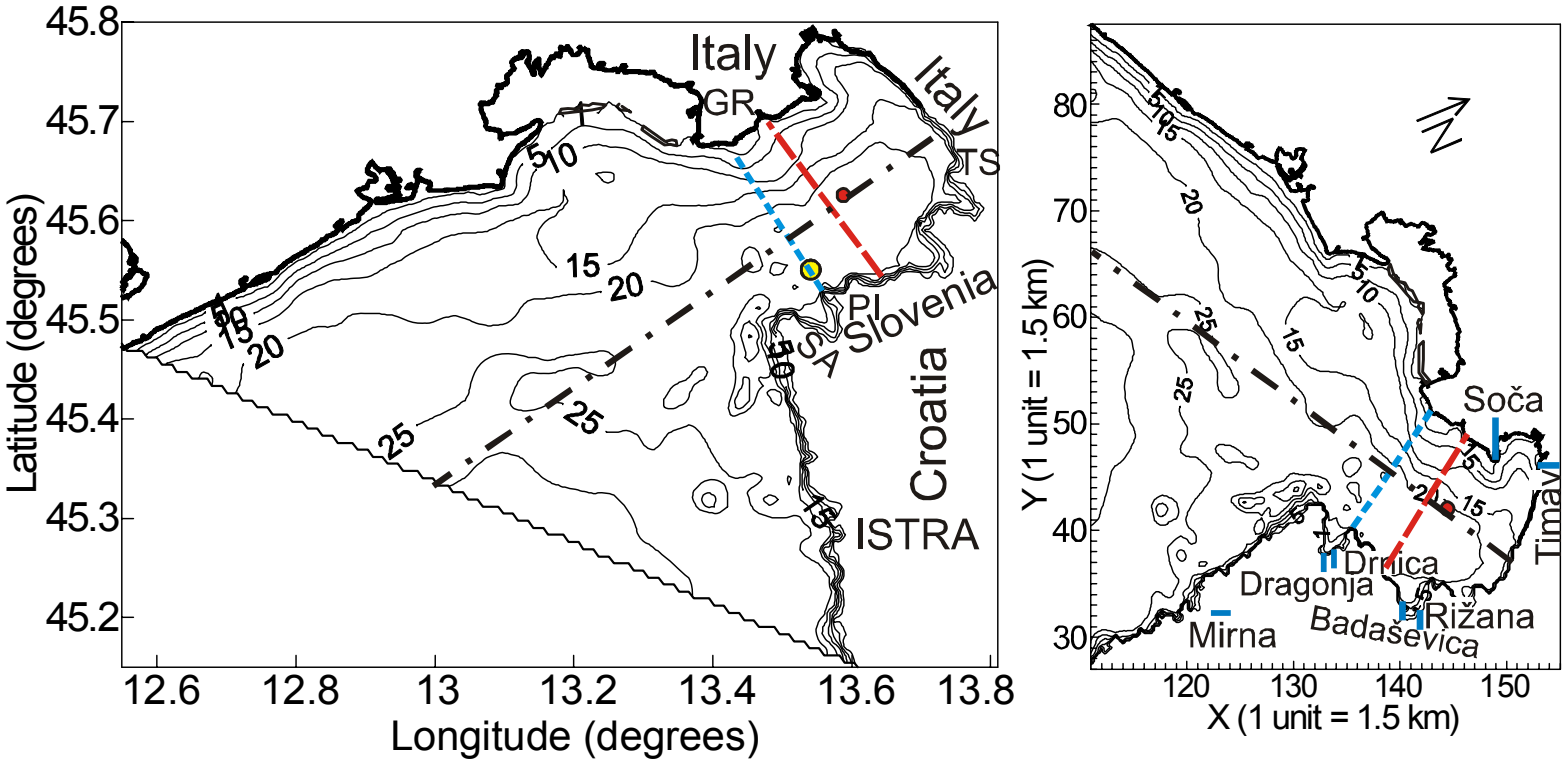


- 13.5029^0 E - 13.8212^0 E
- 45.4777^0 N - 45.8200^0 N
- No. cells: 176 x 256 x 11
- Cells ~ 150 m x 150 m
- Depths: 1 m - 34.2 m
- 11 σ levels: 0,00, -0,06, -0.15, -0,26, -0,37, -0,48, -0,59, -0,70, -0,81, -0,91, -1,00, western OB
- rectangular
- 21±2 km (length) 19±2 km (width)
- Wind bora (burja) along the basin

Bay of Koper
trapezoidal
3 km length,
4.75 km width

Bay of Piran
triangular
5.7 km length,
5 km width

Climatic circulation of the Gulf of Trieste

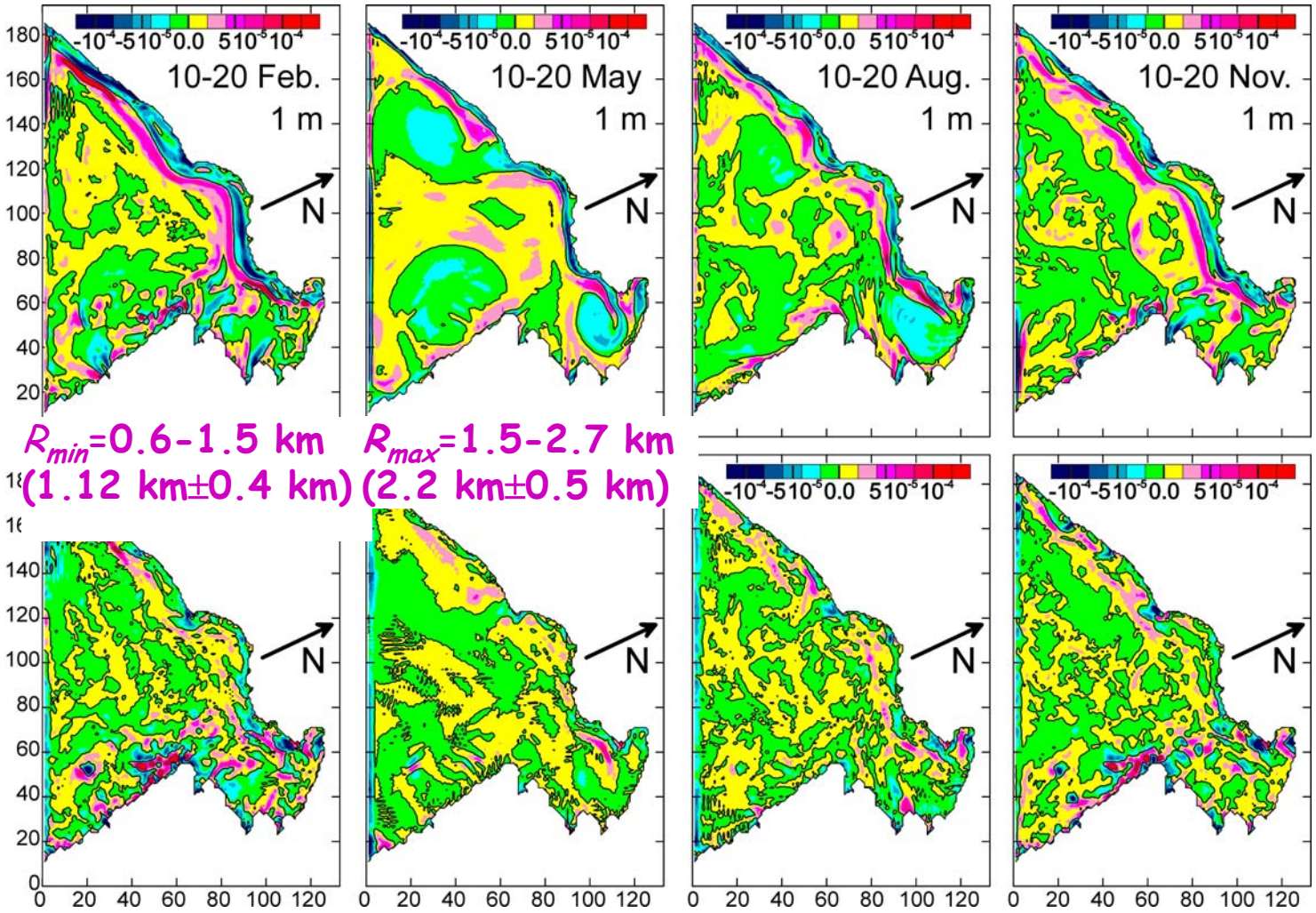


ACOAST model

ADRICOSM Project

Regional project (IT, CRO, SLO), coordinated by INGV in Bologna (N. Pinardi)

Climatic circulation of the Gulf



R_{min}=0.6-1.5 km (1.12 km±0.4 km)

R_{max}=1.5-2.7 km (2.2 km±0.5 km)

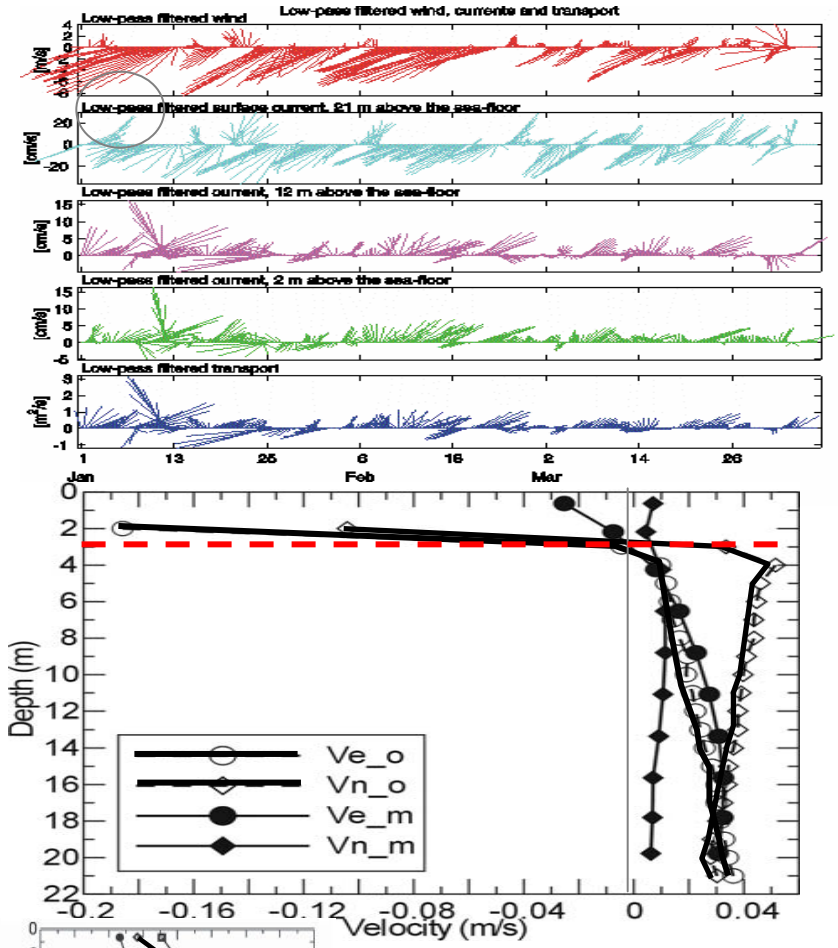
vorticity

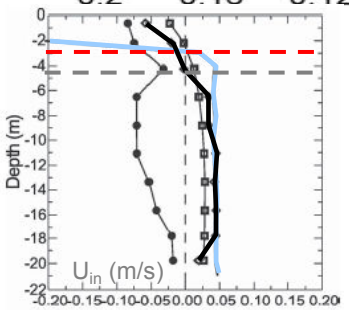
divergence

Malačič & Petelin JGR, 2009

Validation: with observations during winter 2002-03

'VIDA'
buoy.mbss.org'
Malačič & Petelin, 2006





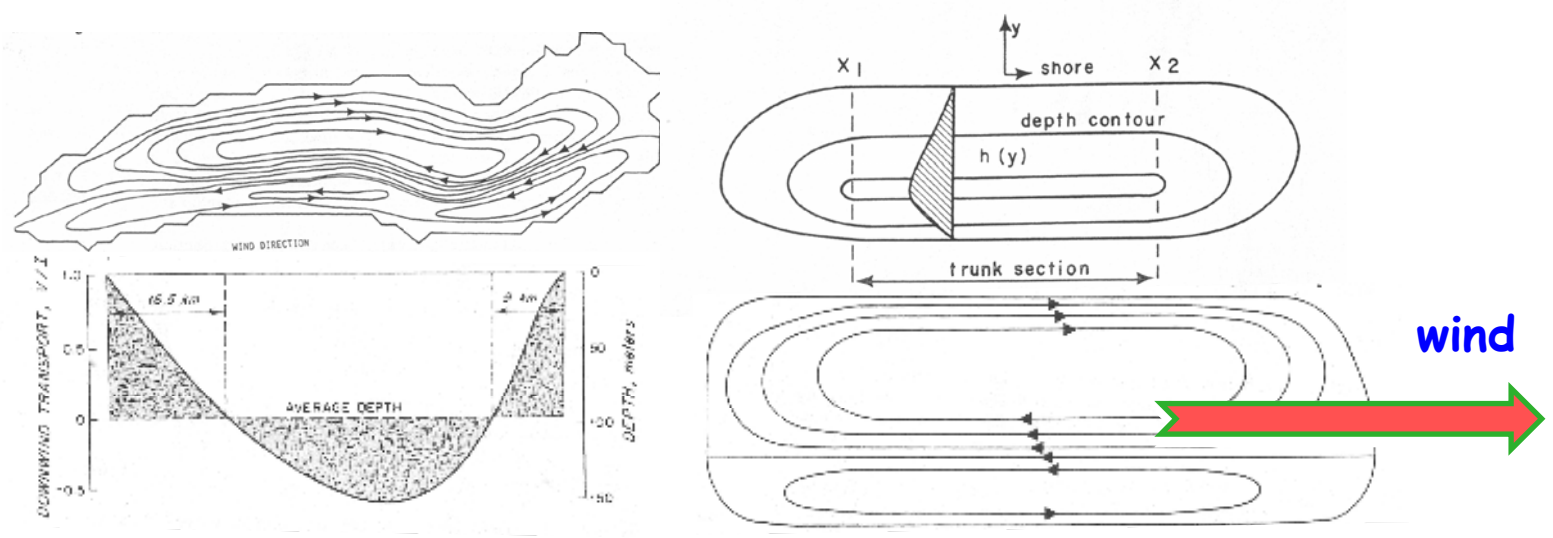
ADRICOSM

5-15 Jan 2003

$\langle U_w \rangle = 8.9 \pm 6.0$ m/s =>

$\tau = 1.36\ 10^{-4}\ m^2/s^2 = 8.7 * \tau_{mod}$

Transport theory for a 'trunk'



'for elongated basins': book of Csanady, G. T. 1982. Reidel

alongshore transport U, cross-shore V, $H(x,y)$; F = const., **Coriolis = 0**, frict. = 0, lin. $\partial U/\partial t = -g\,H\partial\eta/\partial x + F$; $\partial V/\partial t = -g\,H\partial\eta/\partial y$; $\partial U/\partial x + \partial V/\partial y = \partial\eta/\partial t$. Start from *rest* $\Rightarrow$ suppose: $U = At$; $V = Bt \Rightarrow A = -g\,H\partial\eta/\partial x + F$; $B = -g\,H\partial\eta/\partial y$; $\partial A/\partial x + \partial B/\partial y = 0$. Inside the trunk transport || isobaths $\Rightarrow B = 0 \Rightarrow \partial\eta/\partial y = 0$. No cross-trunk transport: $\int A\,dy = 0$ across the width $b \Rightarrow \partial\eta/\partial x = Fb/gS$; $S = \int H\,dy = 0 \Rightarrow$

$$U = Ft\,[1 - (Hb/S)] \Rightarrow \int U\,dt = [1 - (Hb/S)] \int F t\,dt \propto [1 - (H/H_{mean})]$$

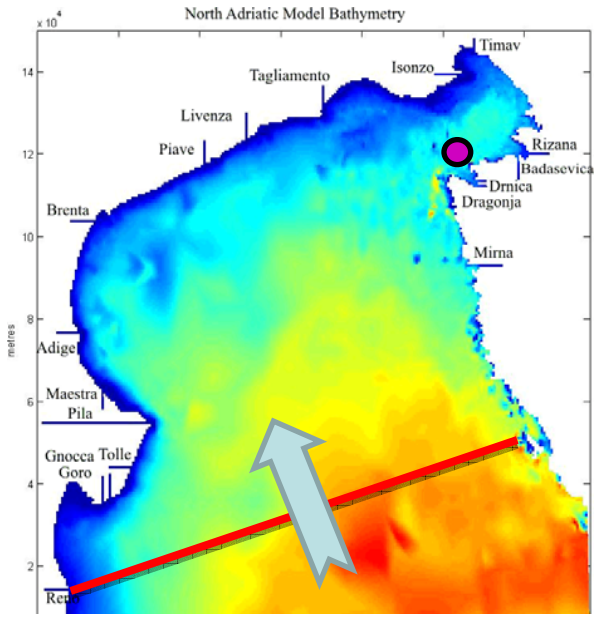
$\Rightarrow \langle U \rangle > 0$ or $\langle U \rangle < 0$ depending on $H > H_{mean} = S/b$, or $H < H_{mean}$.

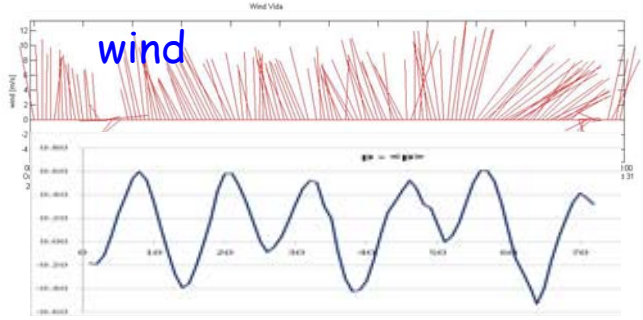
Near shores: $\langle U \rangle$ is along the wind; central part $\langle U \rangle$ opposes the wind.

NAPOM – Jugo

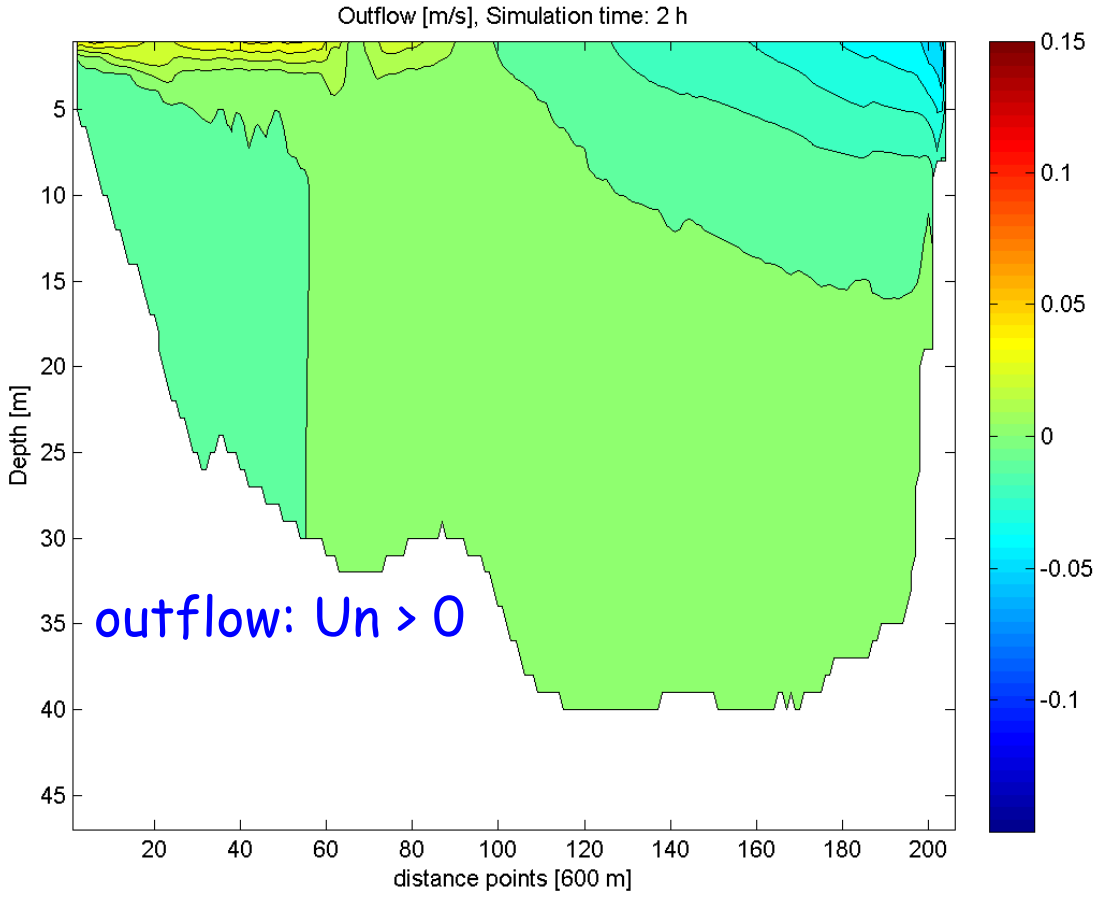
Weak stratification

JUGO: 28-30 Oct. 2008





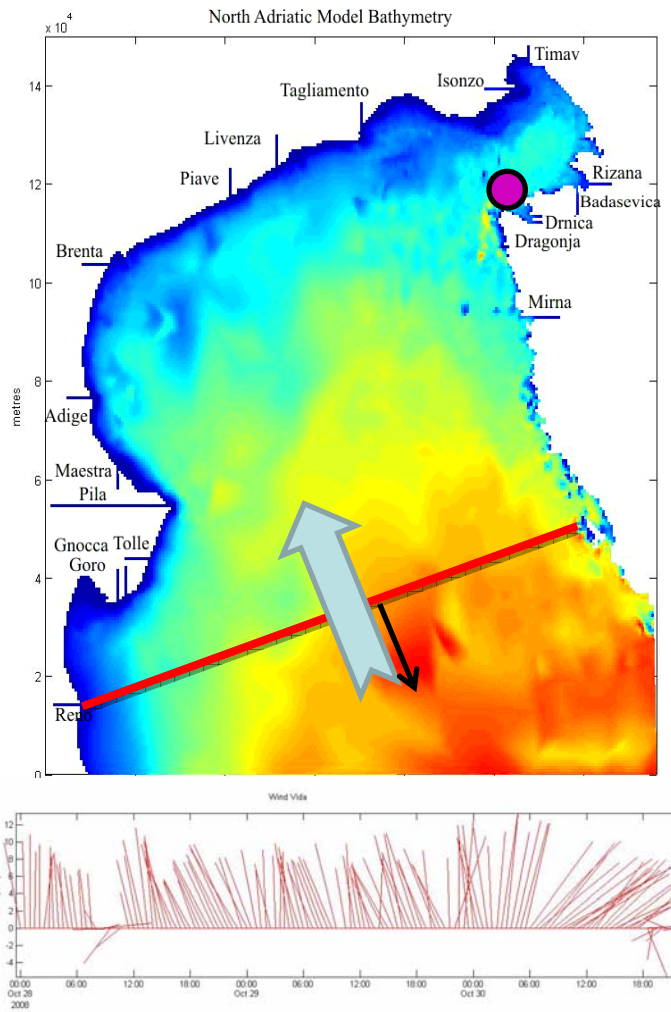
Buoy 'Vida'



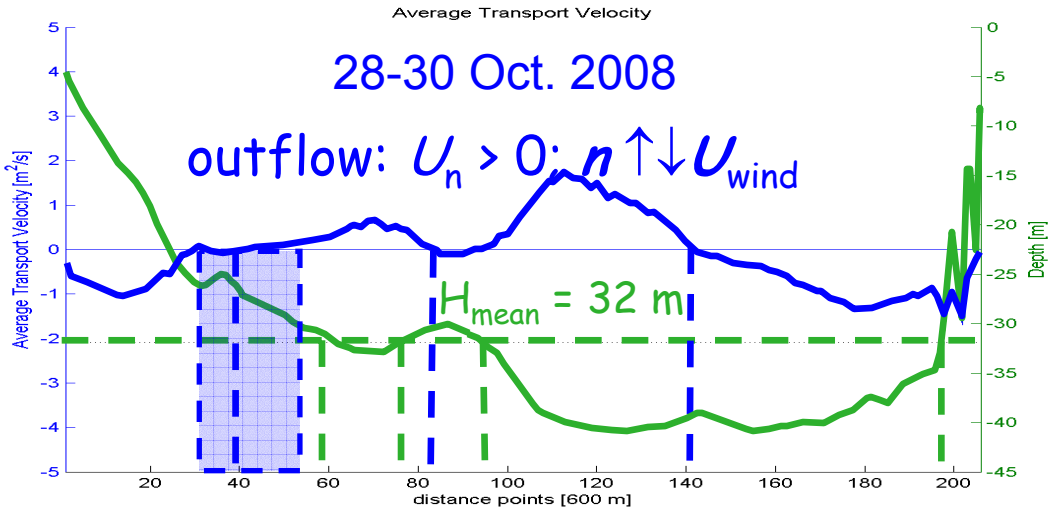
Transport across the northern Adriatic

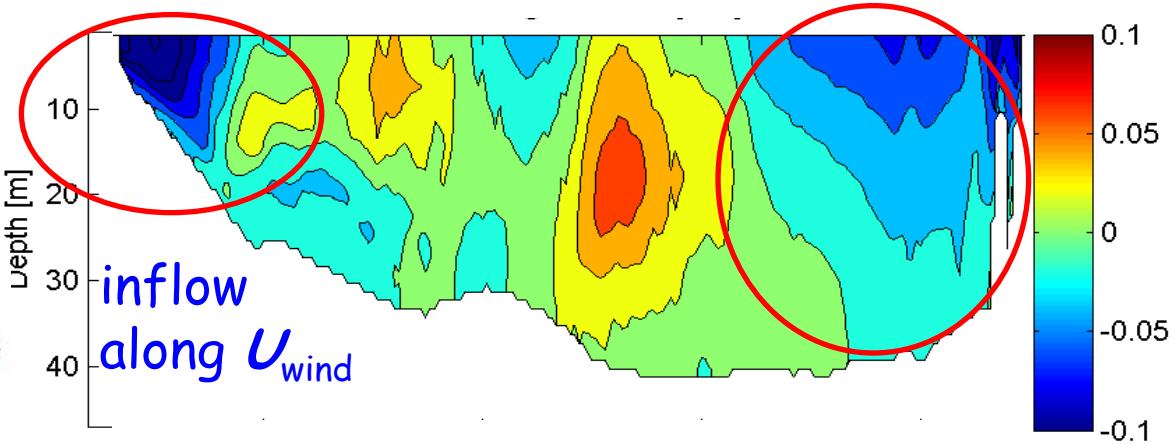
NAPOM – Jugo

Weak stratification



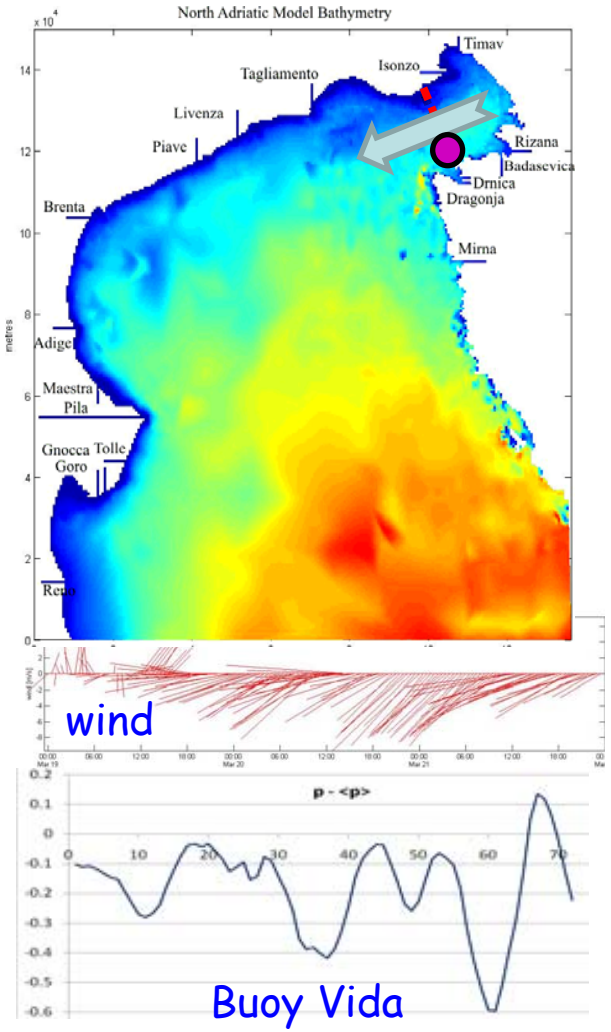
Wind at buoy Vida

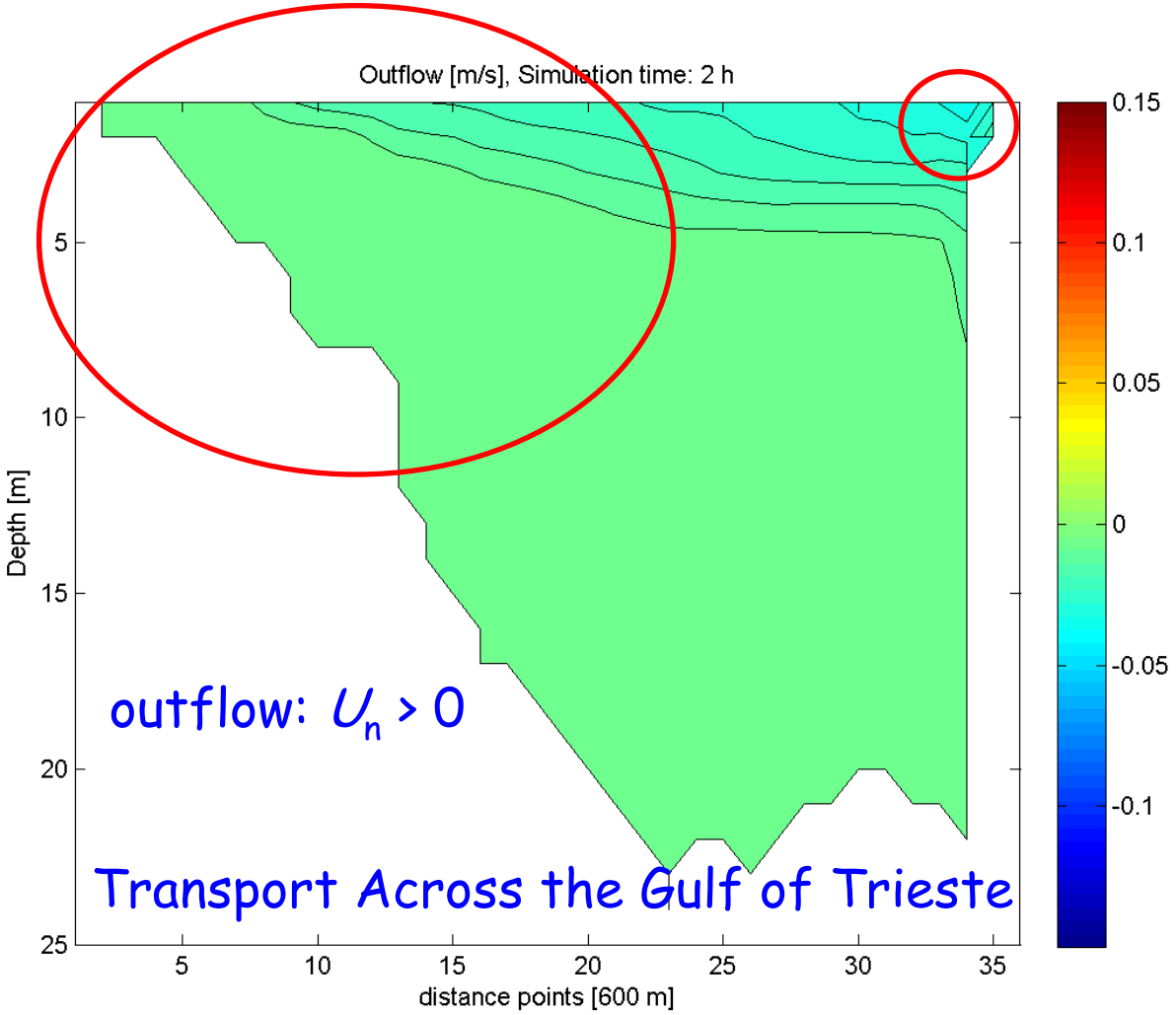




Transport across the north. Adriatic

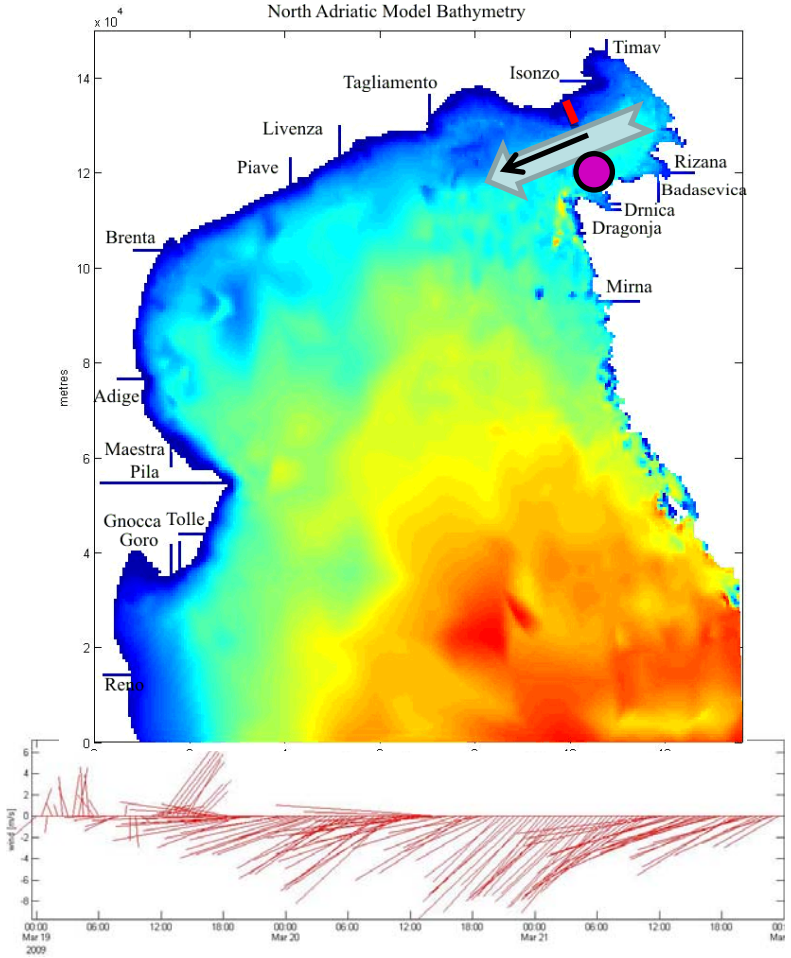
NAPOM – Bora wind, weak stratification



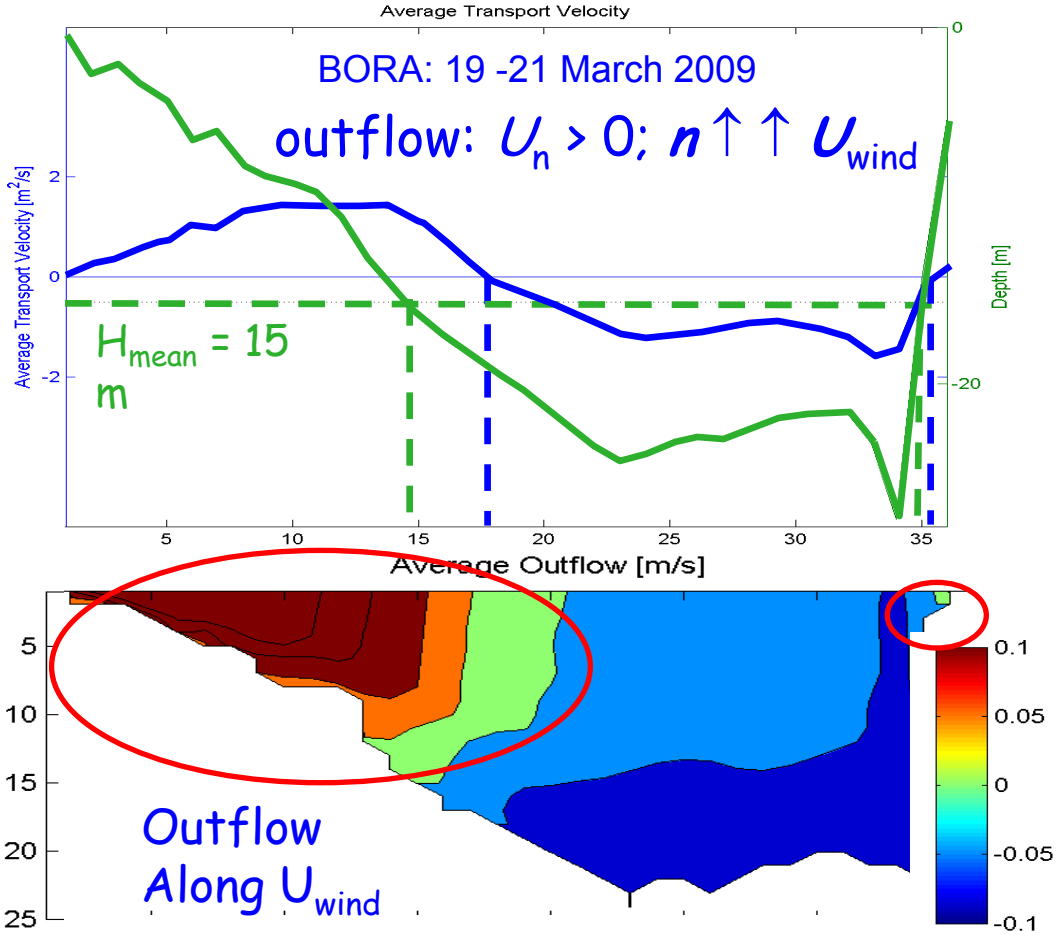


NAPOM – Bora wind

Weak stratification

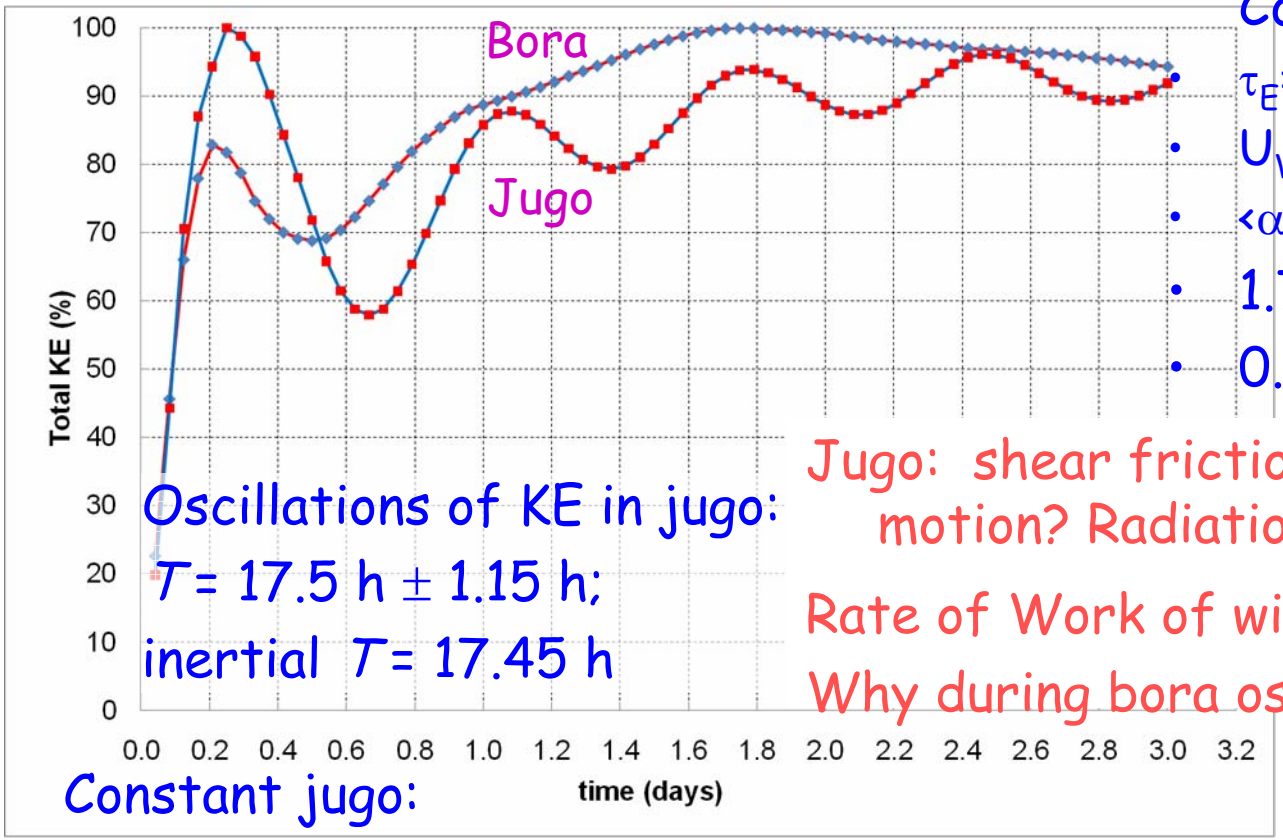


Wind at buoy Vida



Transport Across the Gulf of Trieste

NAPOM
Wind Setup - Total KE



Constant bora:

- τ_E=-0.25 m²/s², τ_N= 0.20m²/s²
- U_{WE}= -9.9 m/s, U_{WN} = -8.8m/s
- $\langle\alpha\rangle$ = 51.7⁰, Cd=0,002
- 1.7 days to max KE
- 0.5 days local min. of 70 %

Oscillations of KE in jugo:

T = 17.5 h ± 1.15 h;

inertial T = 17.45 h

Jugo: shear friction modulated by inertial motion? Radiation?

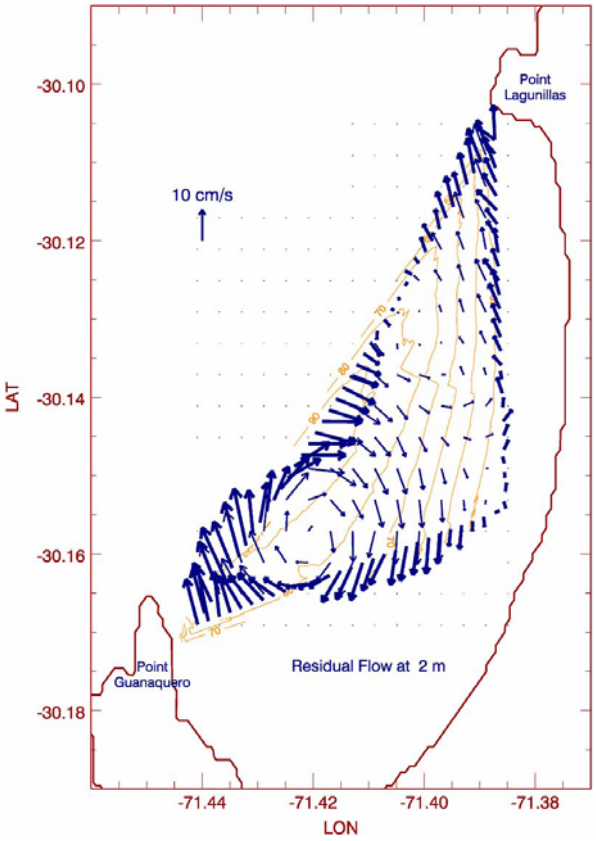
Rate of Work of wind $dA/dt = \rho\tau . u_S$

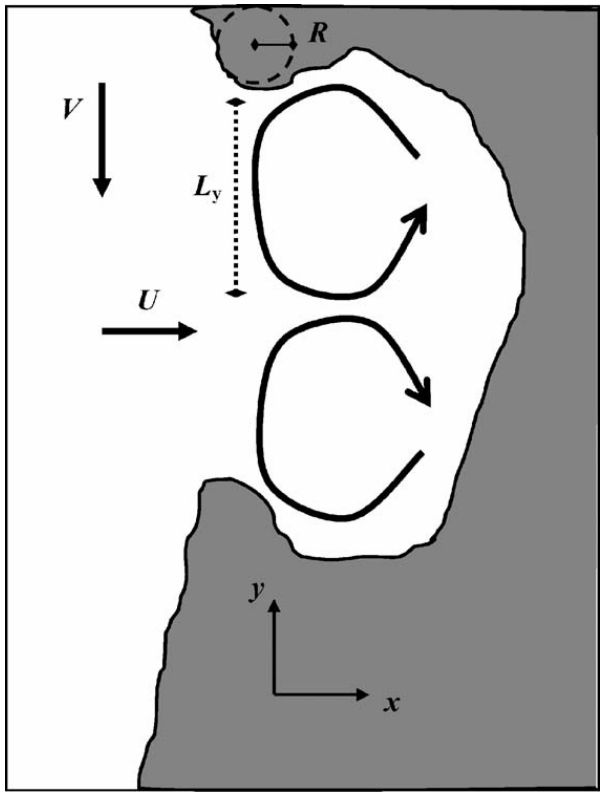
Why during bora oscillations are 'missing'?

Constant jugo:

- τ_E=-0.08 m²/s², τ_N=-0.23m²/s², (U_{WE}= -5.7 m/s U_W= 9.5 m/s)
- $\langle\alpha\rangle$ = 160⁰; 3 days to reach 90-95 % max KE, 0.7 days local min 58 %

Theory of residual circul. in bays





Valle-Levinson & Moraga-Opazo, 2006, CSR: Bipolar residual circulation in bays.

Linkage: alongshore flows *v* and cross-shore flows *u*:

$u\partial v/\partial x + v\partial v/\partial y = -g\,\partial\eta/\partial y$

$UV/R + V^2/L_y = g\,\Delta\eta/L_y$

R – curv. radius=crossshore scale; $U \sim \cong V$

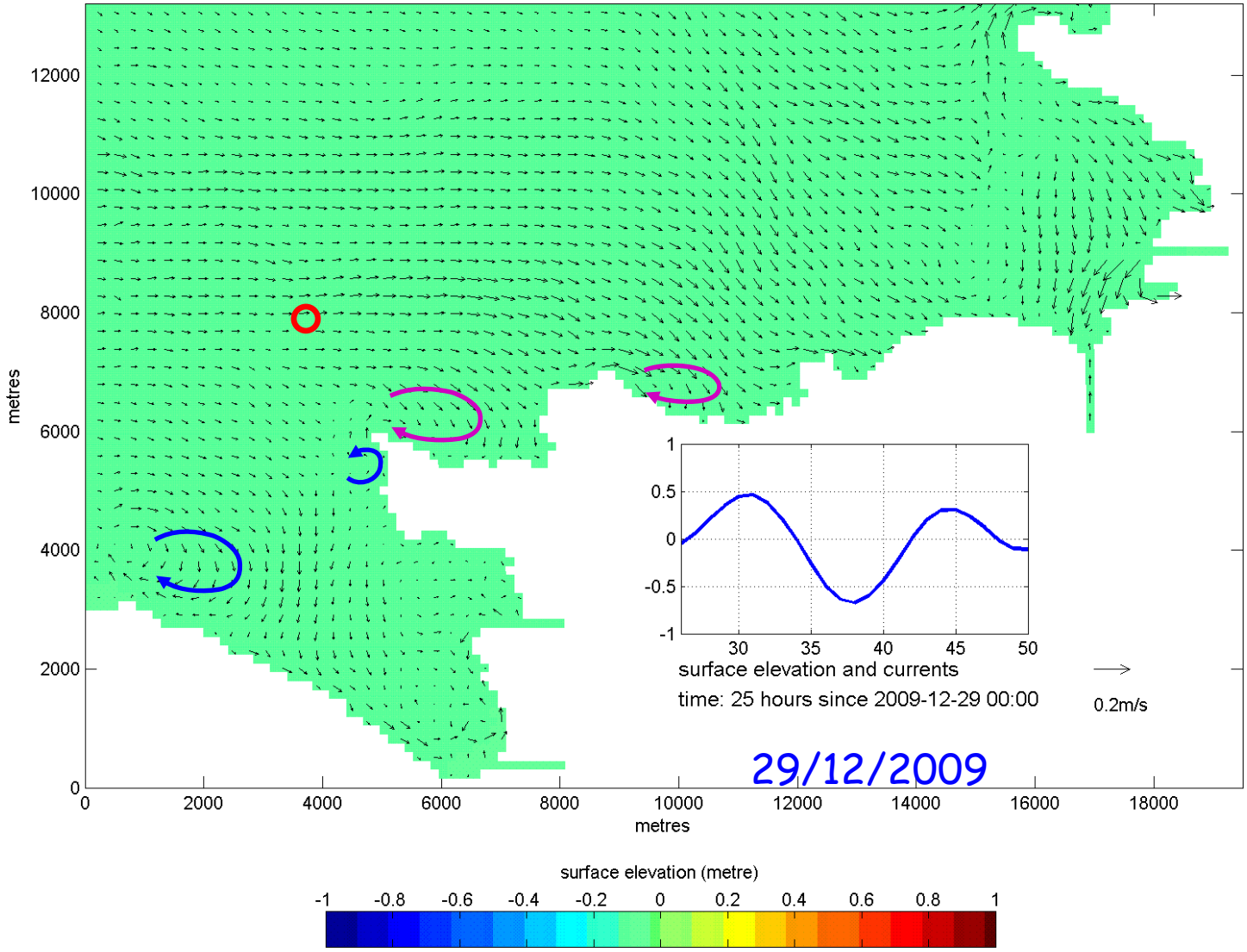
$L_y = R[g\,\Delta\eta/V^2 + 1]$

$L_y \sim 1/a_{cen}$;

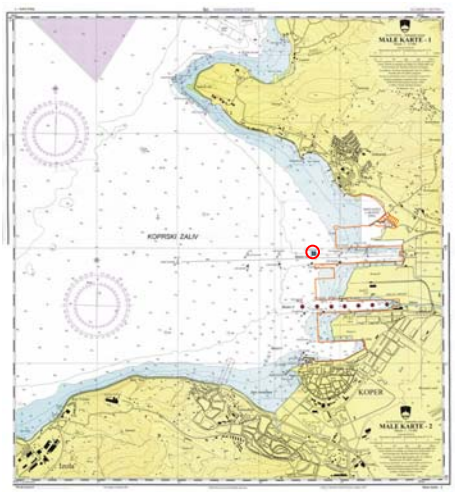
$a_{cen} = V^2/R$; $L_y \propto R$

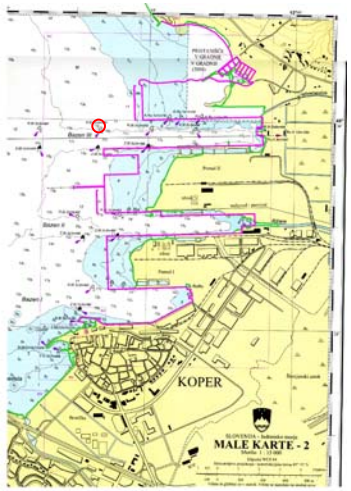
Typical tide, weak winds (< 3 m/s)

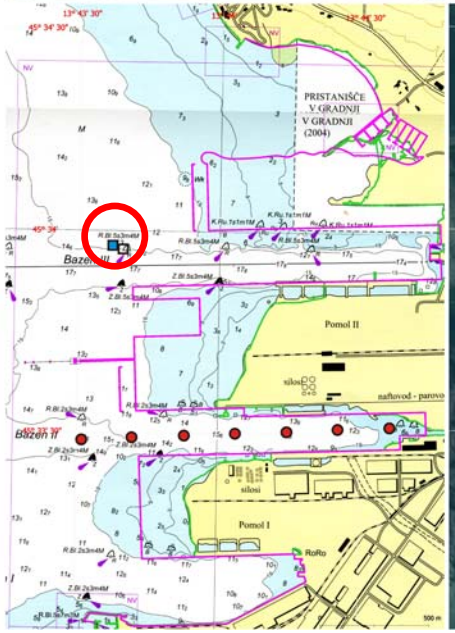
Weak stratification

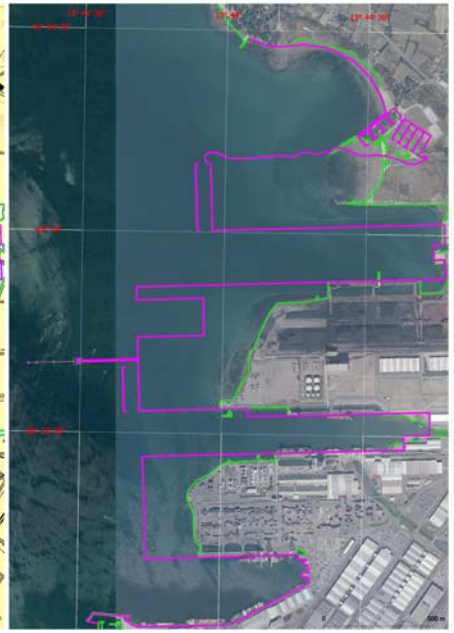


Current-meter observations in the Bay of Koper









13⁰ 43,6213' E

45⁰ 33,9638' N

One year measurements

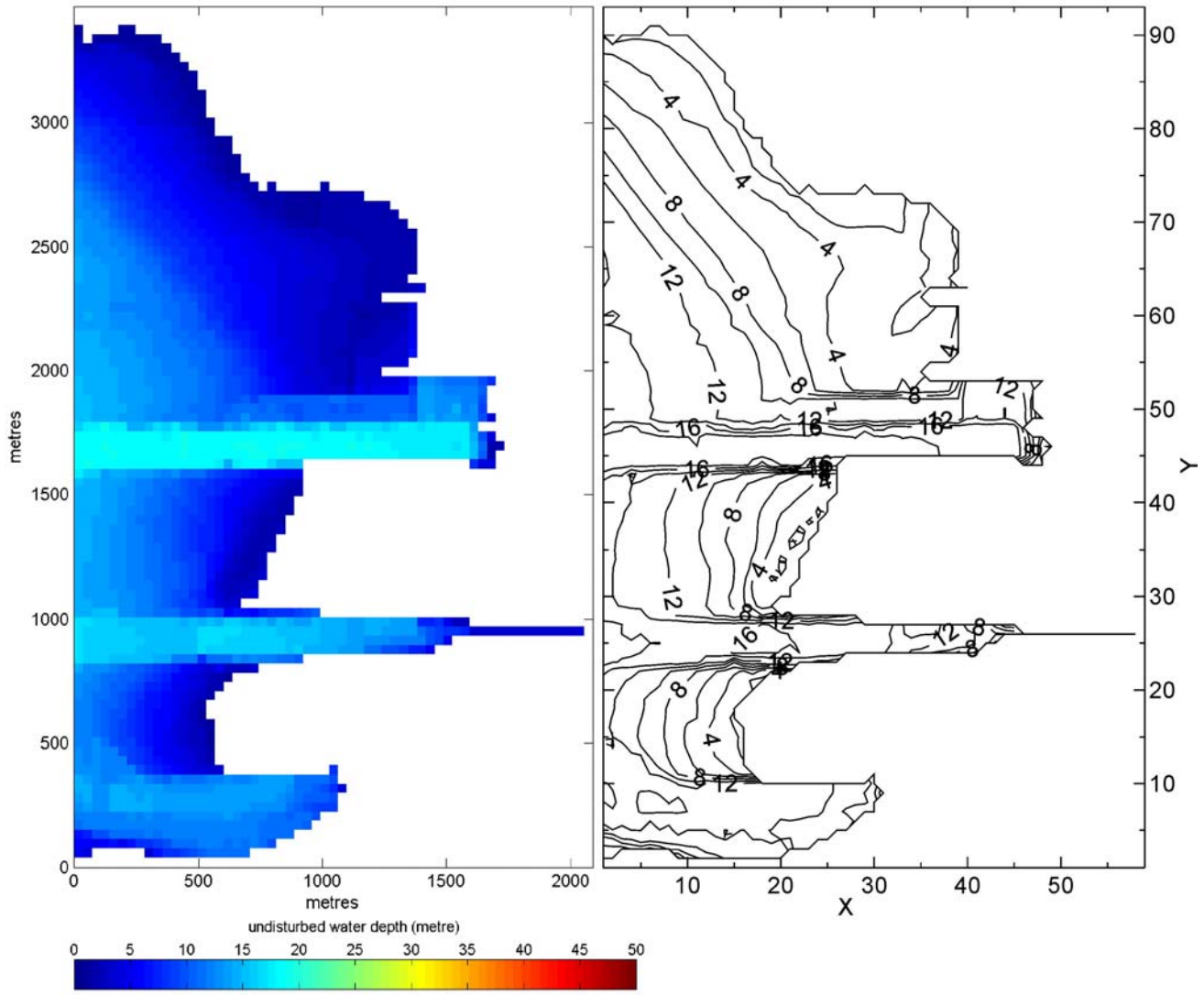
19. dec. 2008 – 28. apr. 2009

1. maj 2009 - 7. sep. 2009

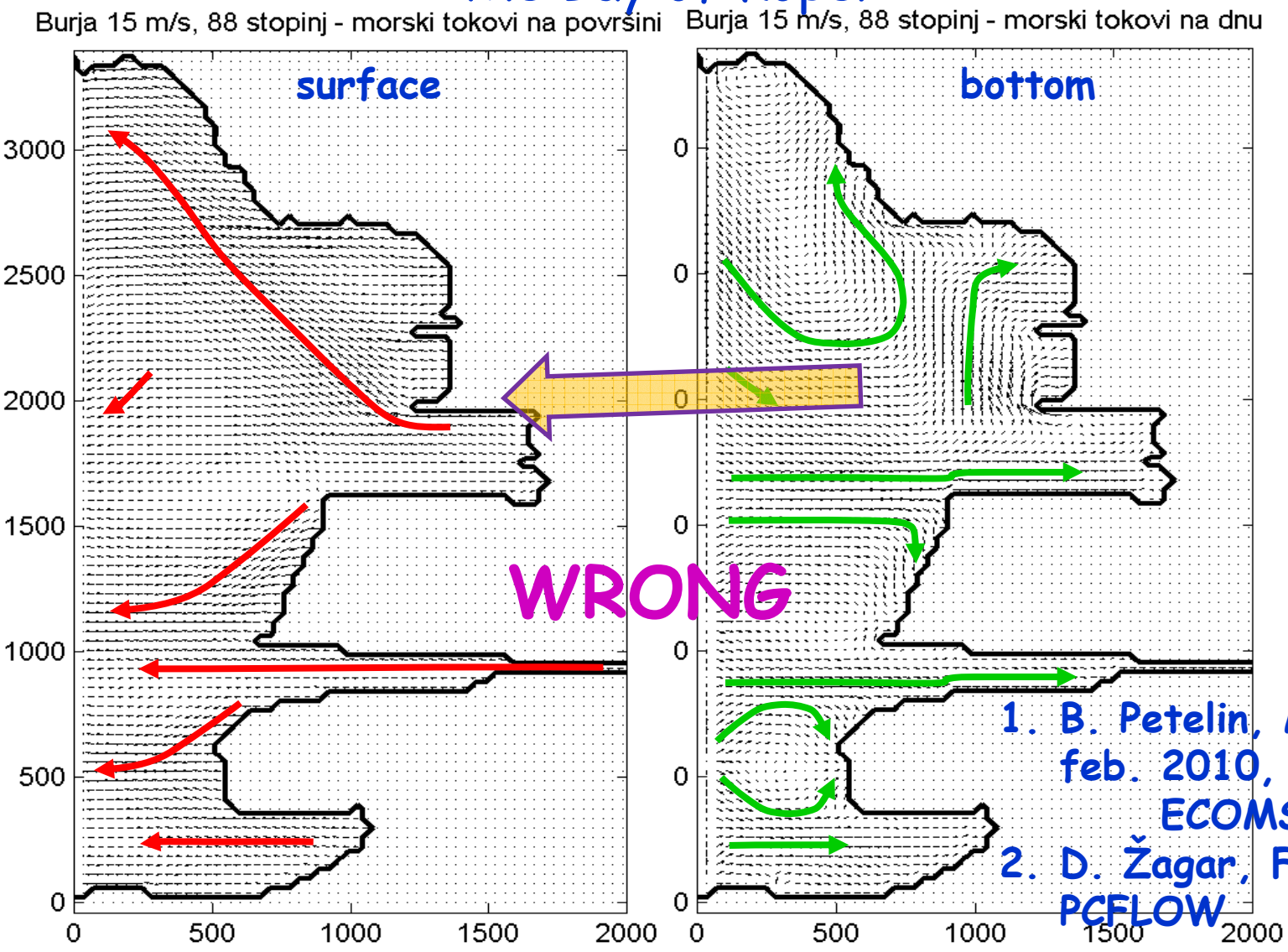
13. sep. 2009 - 21. dec. 2009

Ony nine days of data gaps

Inside the Bay of Koper – the Port of Koper

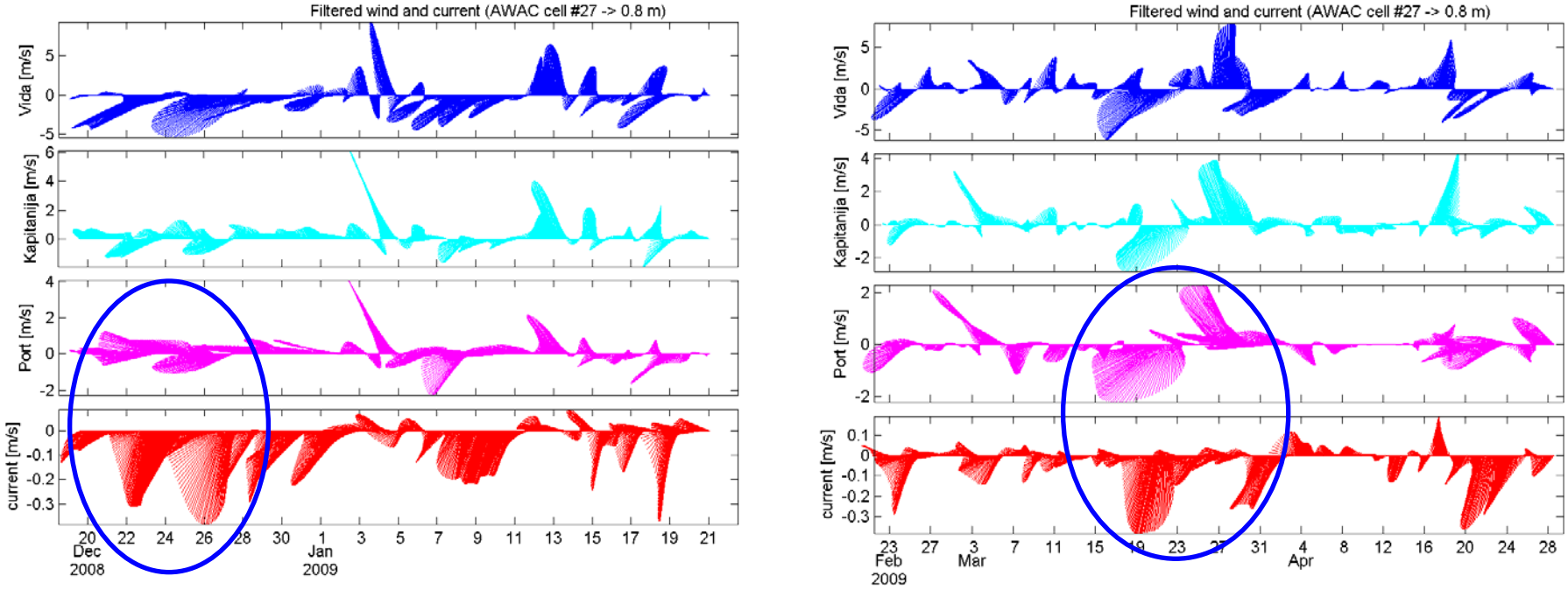


Simulation of the wind-driven circulation inside the Bay of Koper



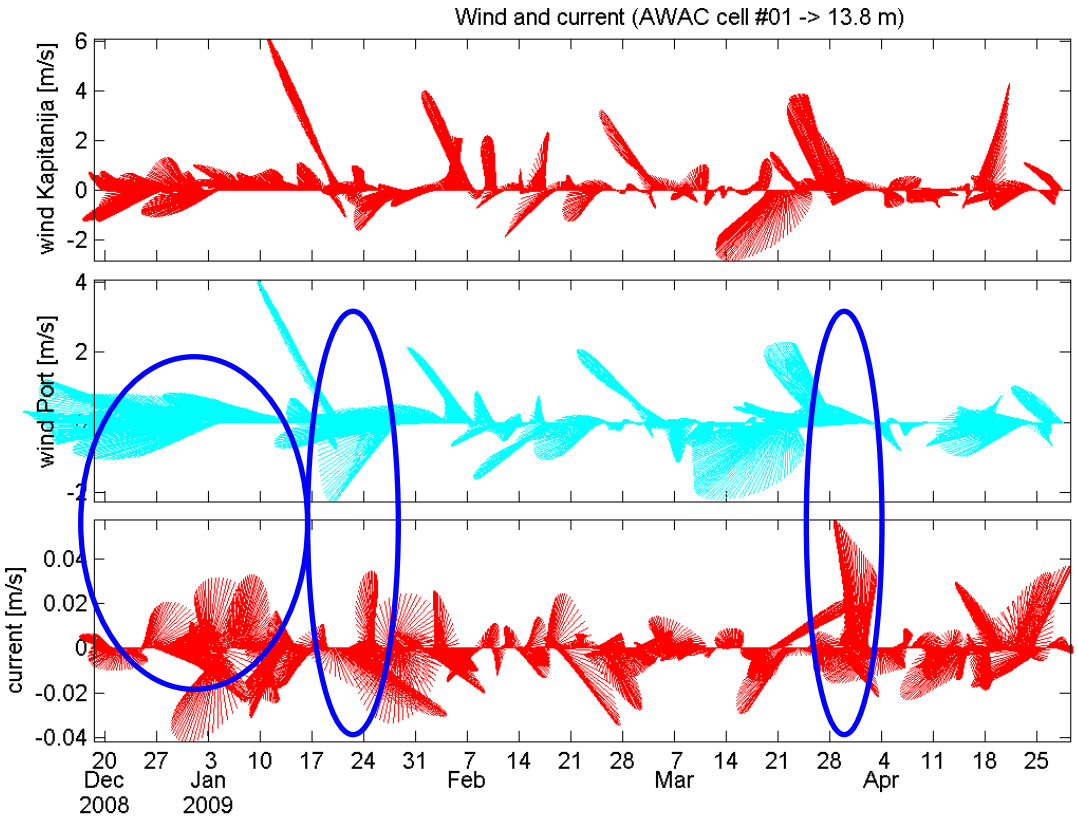
1. B. Petelin, MBP, feb. 2010, ECOMSED
2. D. Žagar, FGG PCFLOW

Current-meter observations in the Bay of Koper



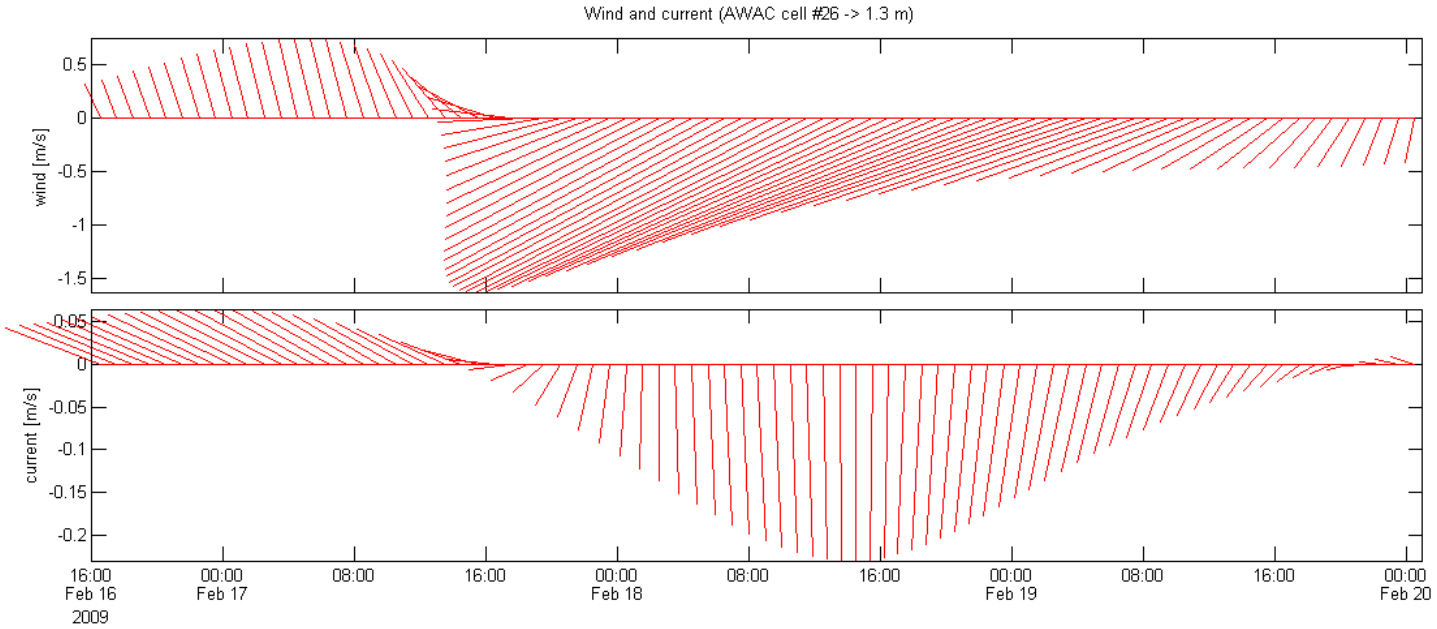
Filtered winds at ocean. buoy Vide (zgoraj), tidal gauge station in Koper ('Kapitanija'), inside the port of Koper ('Port') and surface current (depth 0.8m, red). 72 h low-pass filter applied (Pugh, 1982). Left Dec. 2008 –Feb. 2009, right Feb.-Apr. 2009.

Current-meter observations in the Bay of Koper



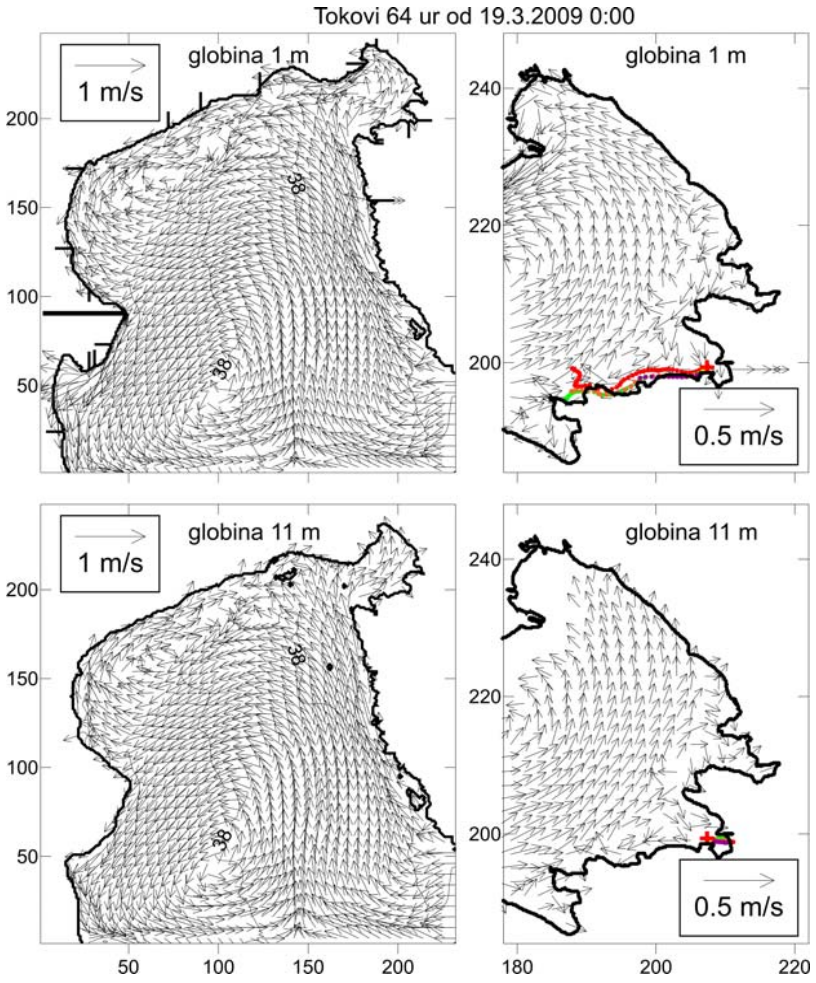
Winds at tidal gauge station in Koper (top, 'Kapitanija'), winds in the Port of Koper (middle,blue) and currents at depth 13.8m (below), near the floor.

Current-meter observations in the Bay of Koper

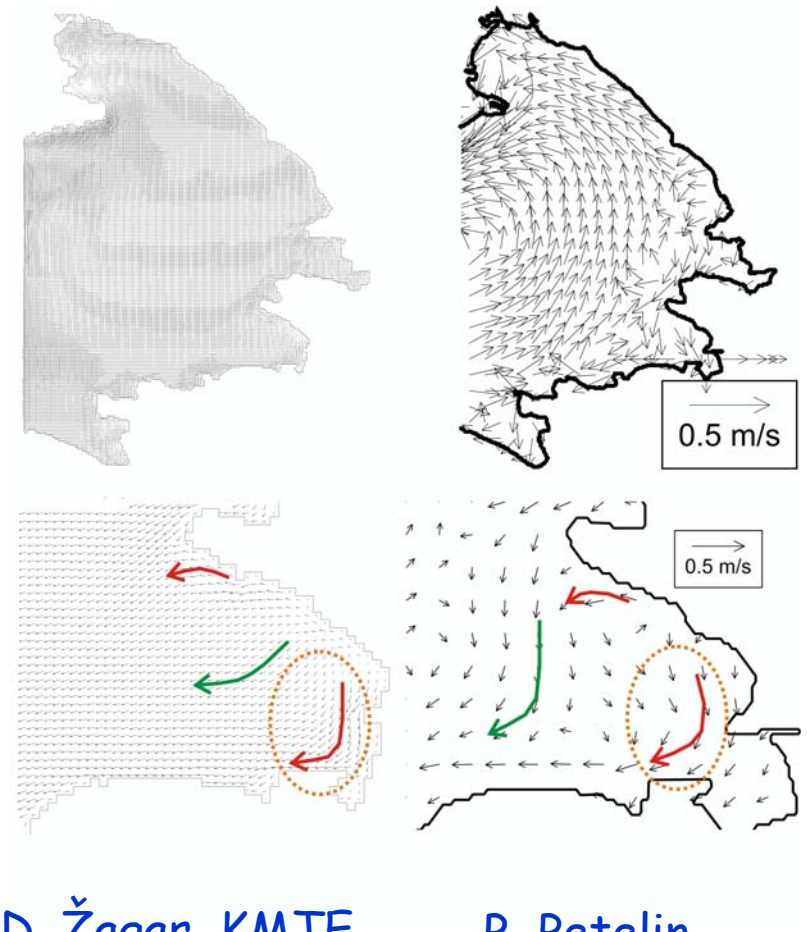


Winds in the Port of Koper (top) and surface current at the depth of 1,3 m (below).

Simulation of the wind-driven circulation in the northern Adriatic



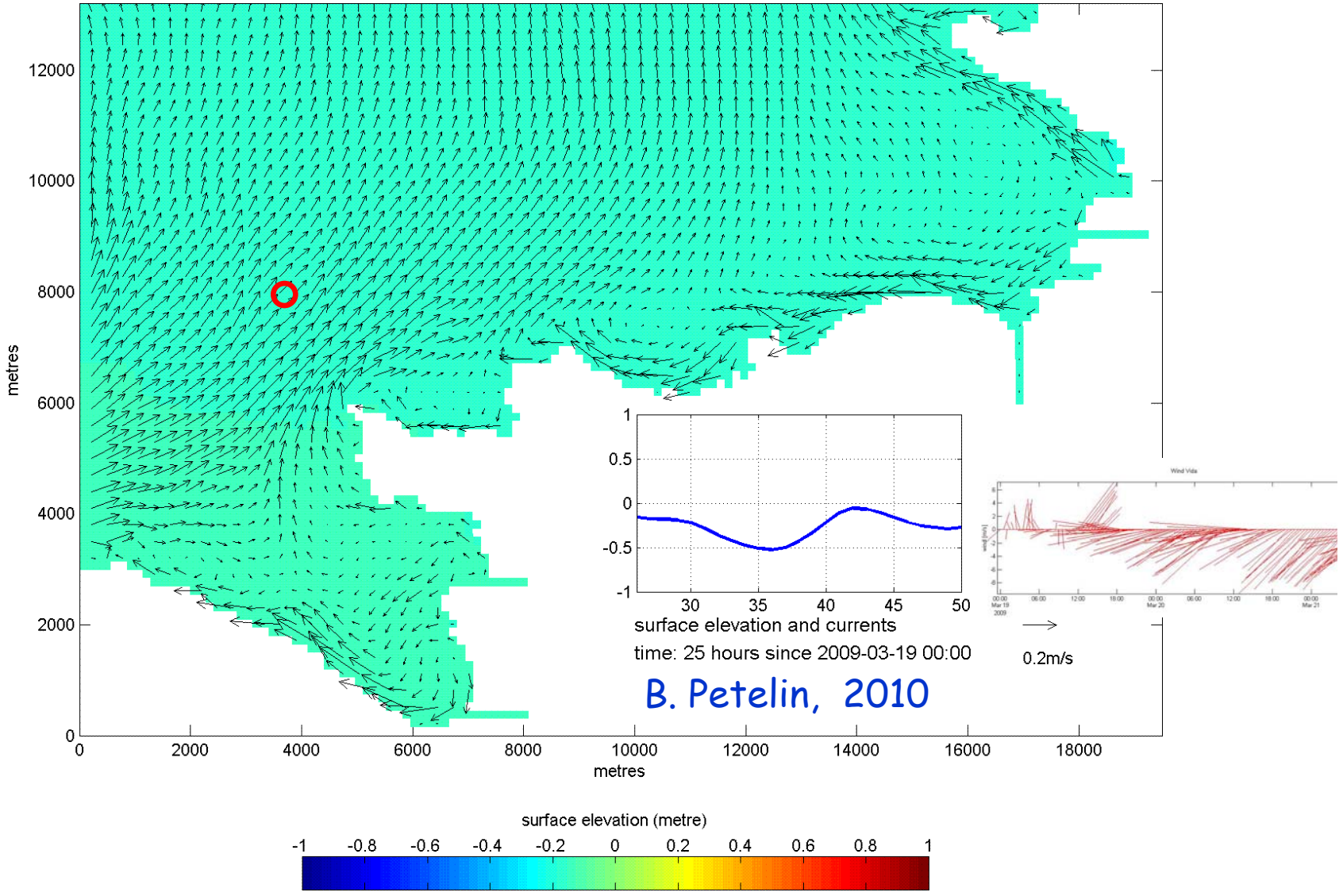
B. Petelin, MBP, 2010



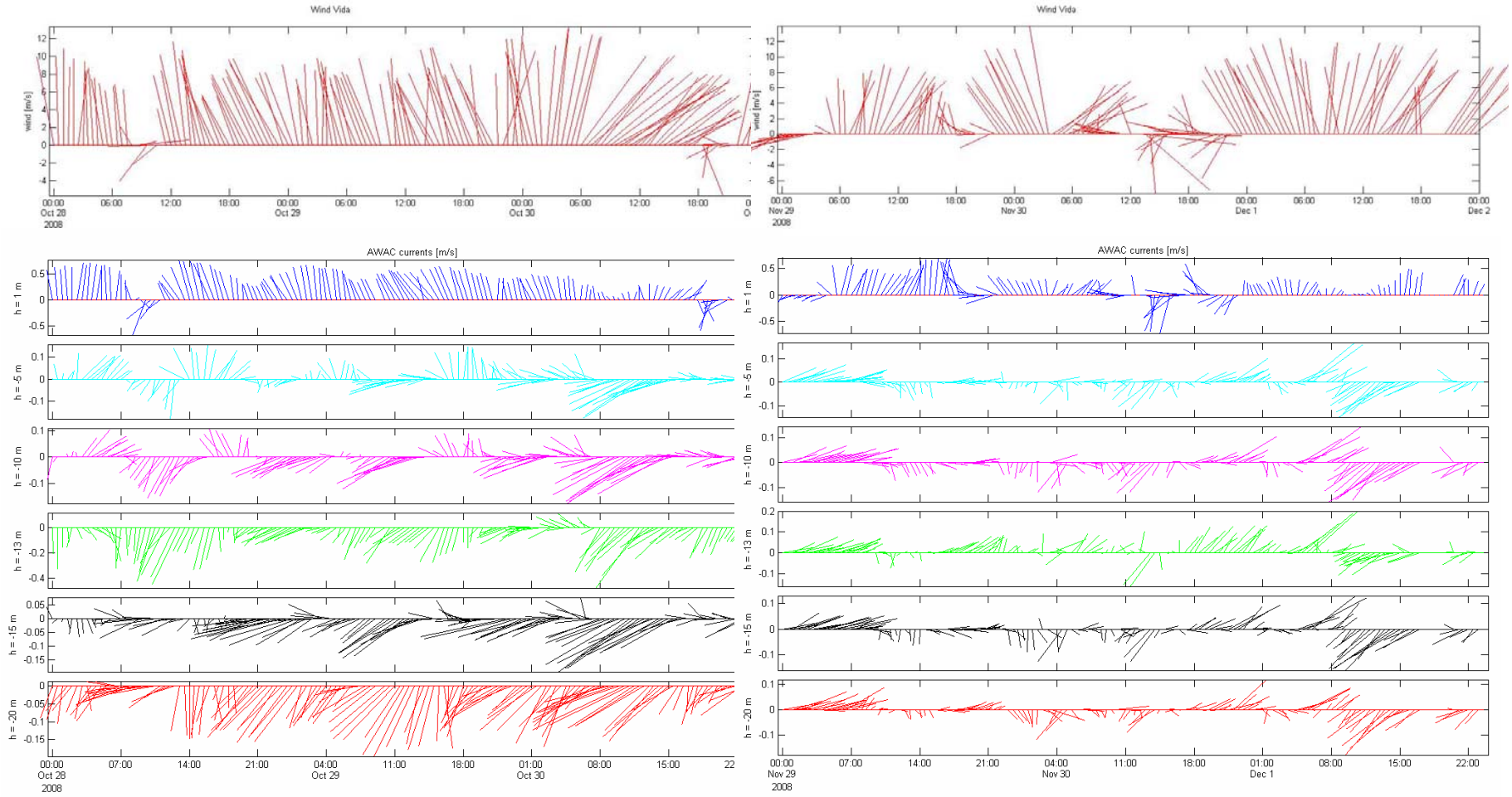
D. Žagar, KMTE, FGG, UNI-LJ, 2010

B. Petelin, MBP, 2010

TSPOM – Bora wind, weak stratification



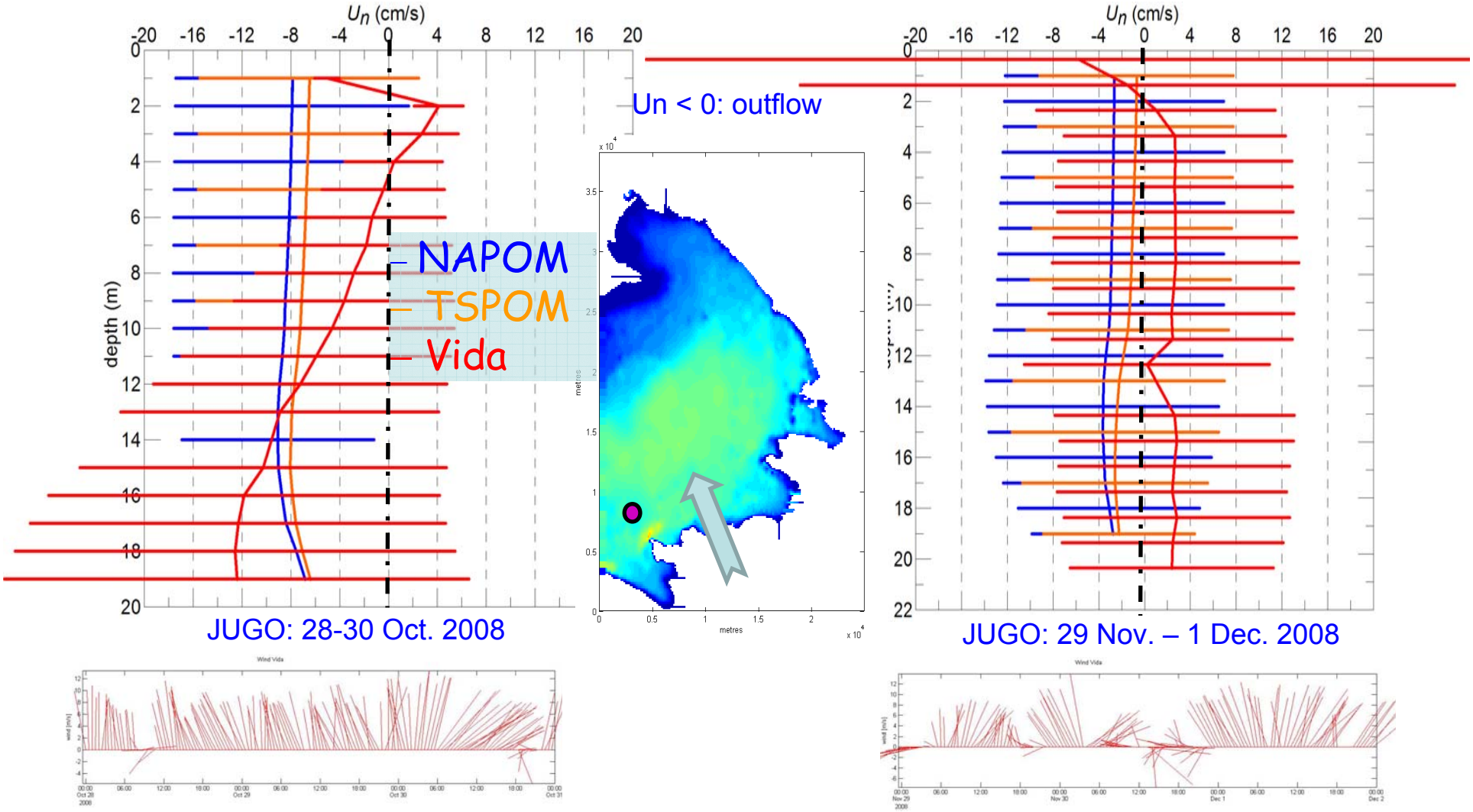
Buoy Vida



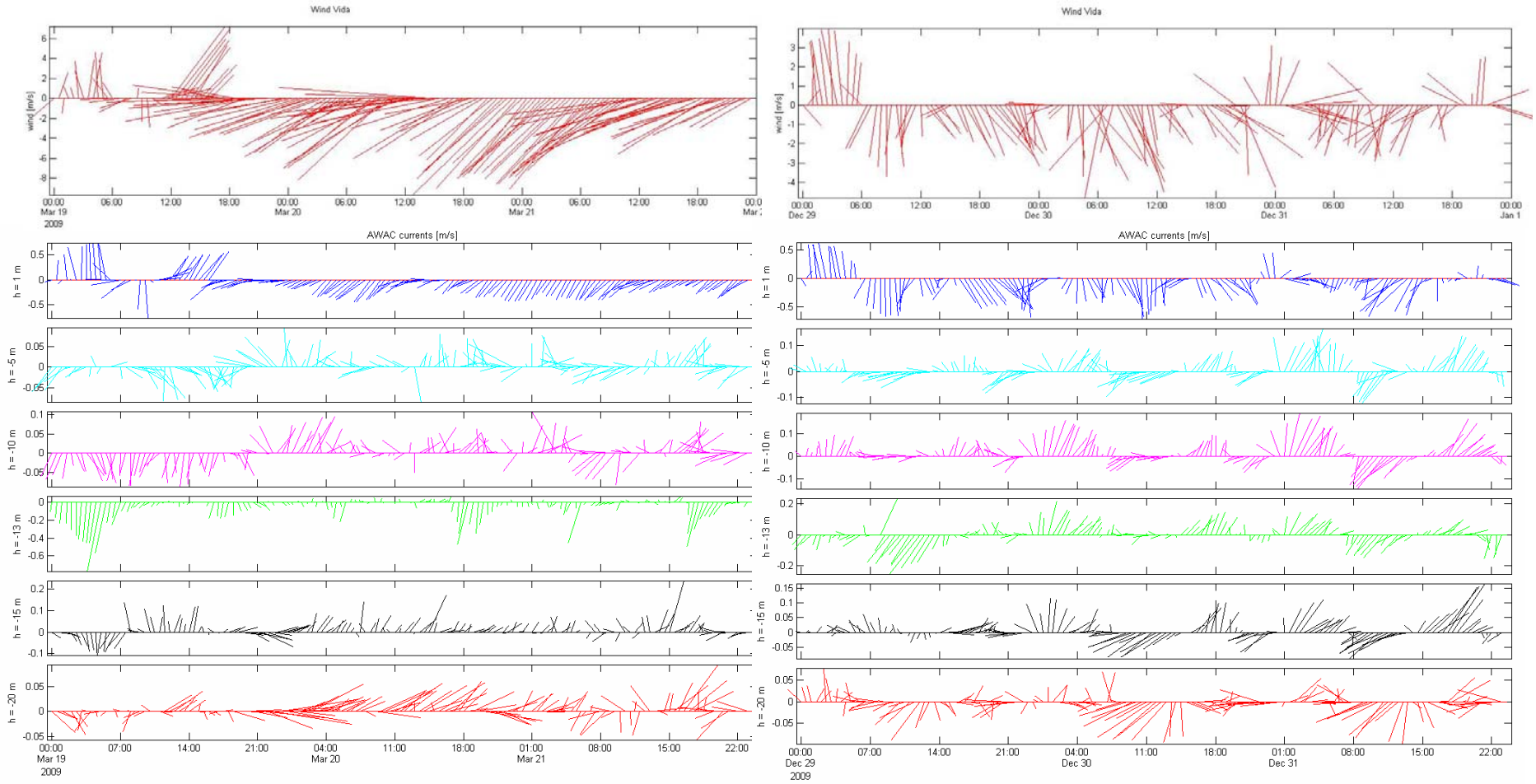
JUGO: 28-30 Oct. 2008

JUGO: 29 Nov. – 1 Dec. 2008

Validation - jugo



Buoy Vida - bora, tides

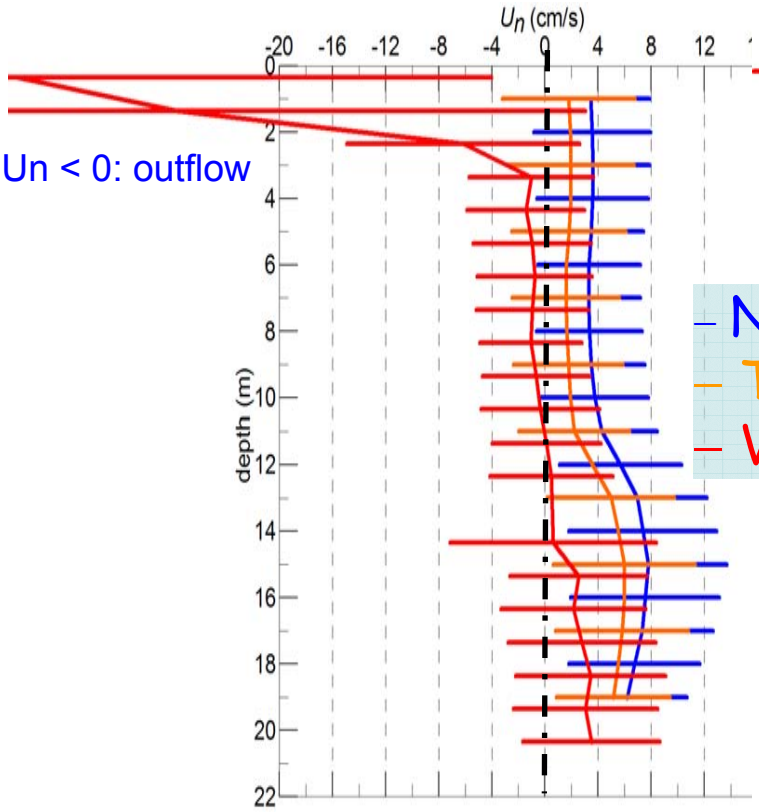


BORA: 19 -21 March 2009

Tides only: 29-31 Dec. 2009

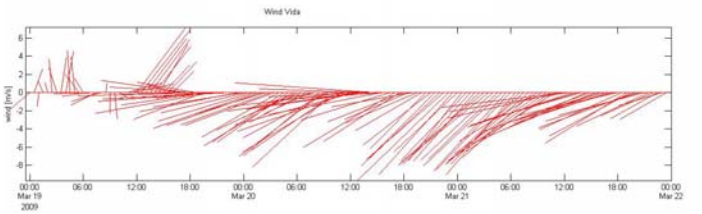
Validation – bora or tides

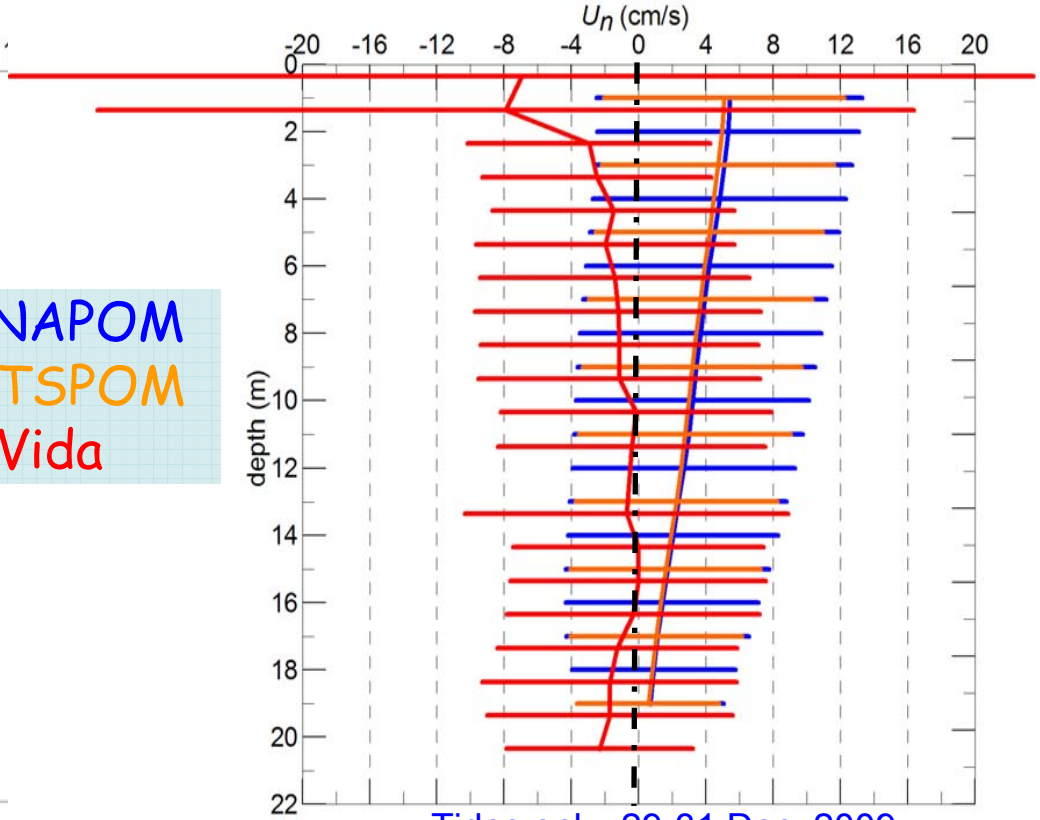
Un < 0: outflow



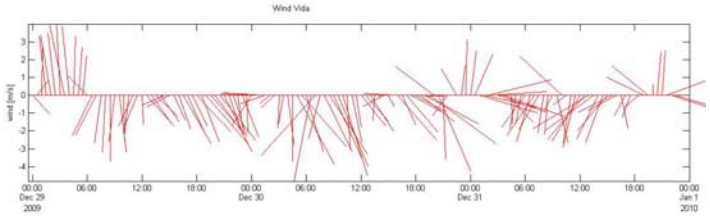
– NAPOM
– TSPOM
– Vida

BORA: 19 -21 March 2009





Tides only: 29-31 Dec. 2009



Conclusions

- Csanady (1982) theory of circulation under a sudden increase of wind along the elongated basin is roughly supported with the hindcast of wind-driven circulation . The assumption of Coriolis = 0 works better over the Gulf.

- Simulation of the bora wind-driven circulation only inside the small Bay of Koper is wrong. Wind driven circulation of the Gulf/northern Adriatic ➔southern current at the surface during the westward bora.

- Model fails to reproduce wind-driven curents at the place of a coastal buoy.

Further work

- Residual (tidal) circulation inside bays of Piran and Koper (tidal) ➔ are vortices scaled with the radius of curvature of promontories?

- Effect of horizontal viscosity (Smagorinsky) on currents around coastal buoy?

- Low-pass filtering on 'short' (synoptic) data sets instead of averaging

- Radiation of energy & vertical shear loss/gain of energy modulated with inertial period. Weak inertial signal during bora driving, why? (no horiz. shear of wind)

- Quantitative validation of southern wind-driven current inside the Bay of Koper

Initialization

o wih the fields of the operational model (INGV Bologna) of the Adriatic Sea

Nesting Boundary Conditions

o Elevation … elf(1,j)=elf2,j)

o Velocity 2D:

- $U_{nesting} > 0 \rightarrow U_{nested} = U_{nesting}$
- $U_{nesting} < 0 \rightarrow U_{nested} = U_{nesting}$*ratio-(SQRT(g/$H_{nested}$)*($EL_{nested}$-$EL_{nesting}$)

ratio = ($H_{nesting}$+$EL_{nesting}$)(H_{nested})+EL_{nested})

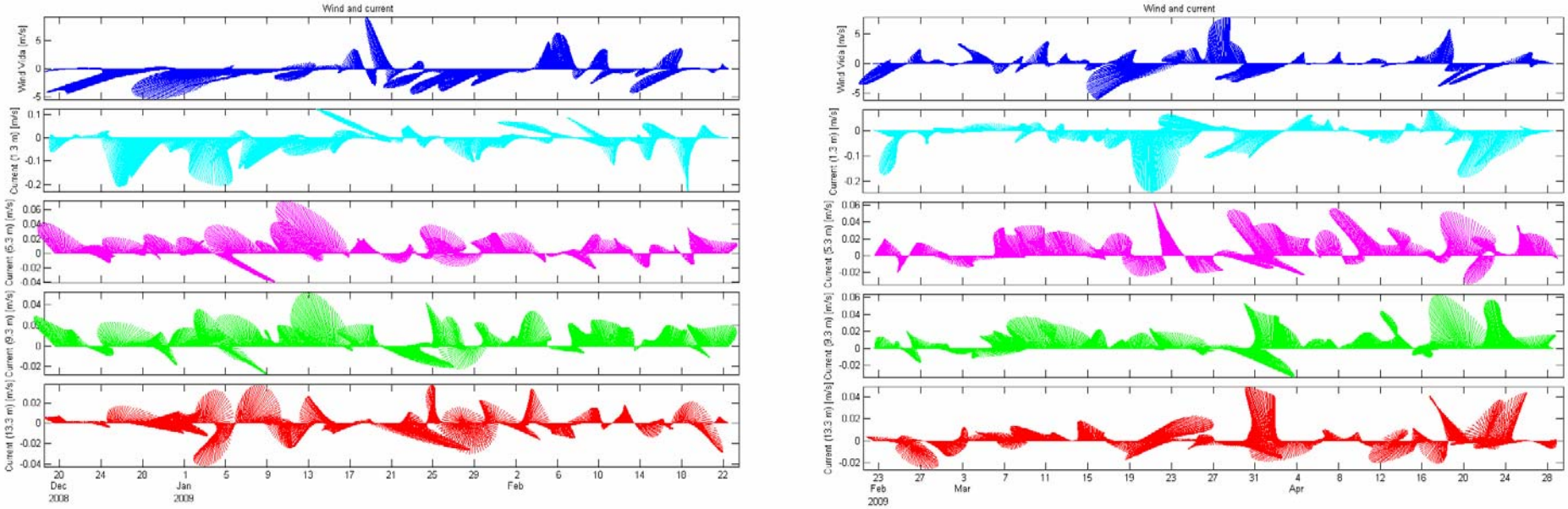
o Velocity 3D:

- Unested = Unesting
- Vnested = Vnesting

o T and S:

o POM manual…

Current-meter observations in the Bay of Koper



Filtered winds at ocean buoy Vida (top), and currents at depths 1,3 m, 5,3 m, 9,3 m in 13,3 m (below). Left: Dec. 2008-Feb. 2009, right Feb.-Apr. 2009