Across-shelf surface transport and velocity structure on a coastal shelf directly influenced by estuarine outflow

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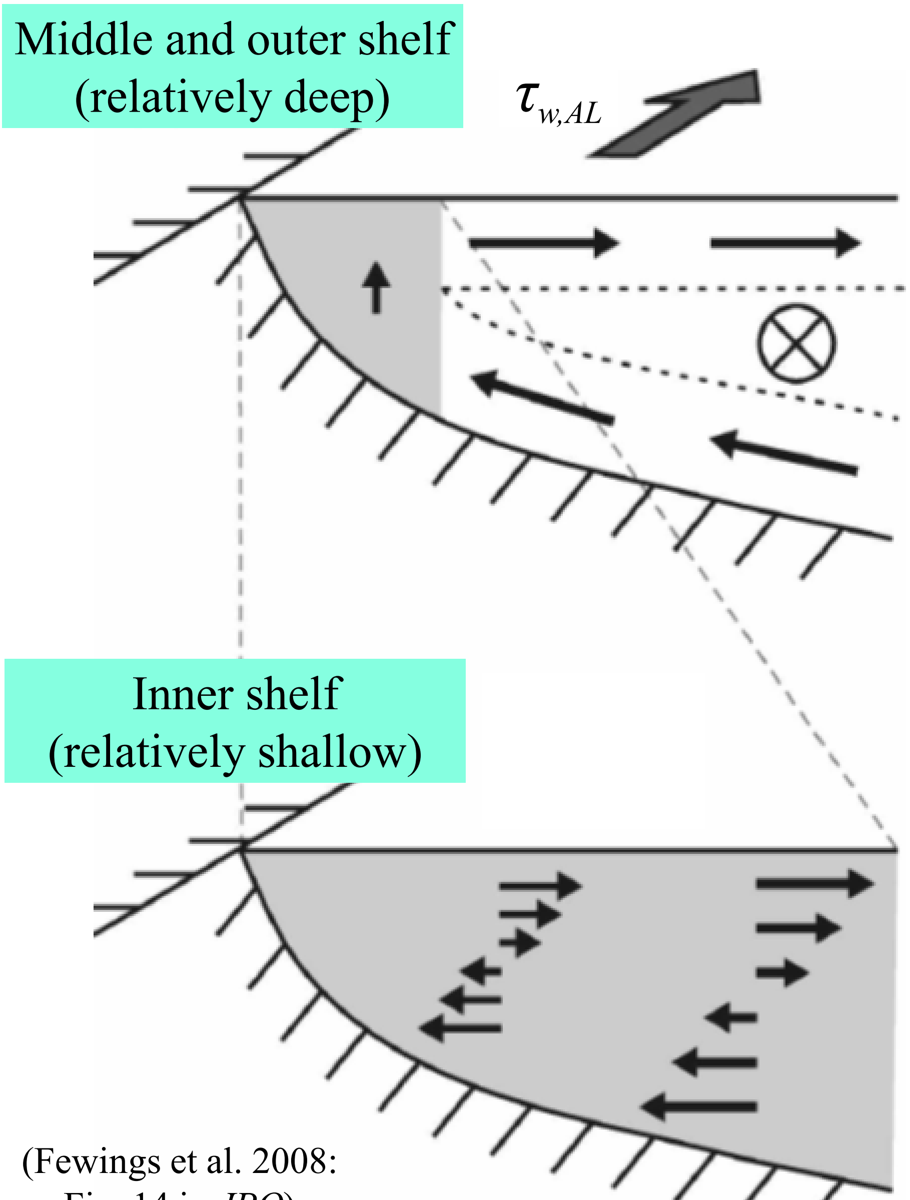
Outline

- Introduction
  : background and objective
- Data
- Across-shelf velocity structure and transport
  : Seasonal time scales
  : Synoptic time scales
- Summary



(Fewings et al. 2008: Fig. 14 in *JPO*)

Along-shelf wind ($\tau_{w,AL}$)-induced **Ekman** flow

: Two distinct surface and bottom boundary layers

: Main mechanism of driving across-shelf transport (T_{AC})

Overlapping (or interaction) of the surface and bottom boundary layers

: $\tau_{w,AL}$ may not be an effective driver of T_{AC} .

: $\tau_{w,AC}$ may become important.

- Factors affecting $\tau_{w,AL}$ ability to drive T_{AC} (**transport efficiency**)

: Those affecting turbulent diffusion of momentum (**vertical eddy viscosity**, $\boldsymbol{A}$) as it relates to Ekman boundary layer thickness ($\boldsymbol{\delta_E}$) = (2$\boldsymbol{A}$/f)$^{1/2}$ where f = Coriolis parameter

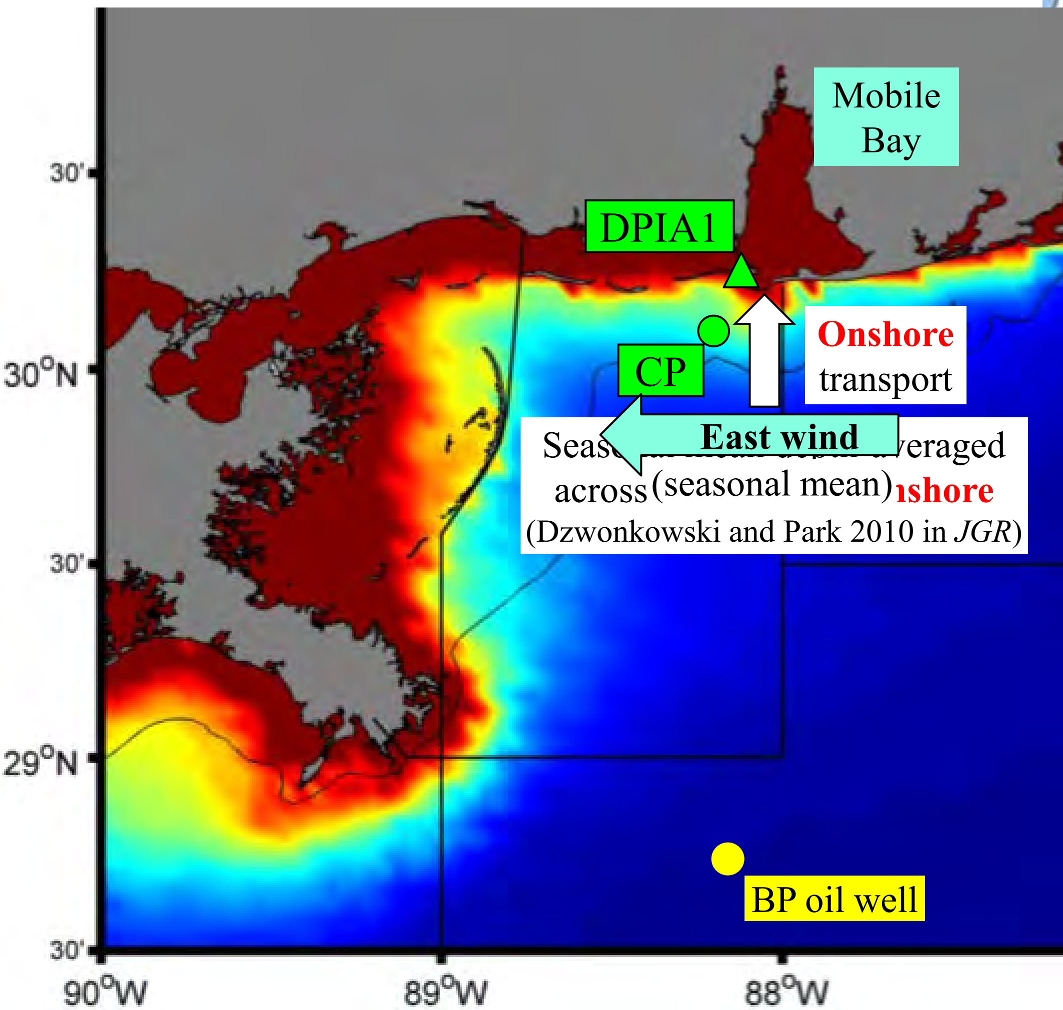
: Factors that reduce vertical mixing (e.g. **stratification**) decrease A and thus δ_E.
→ result in two distinct, separated surface and bottom boundary layers
→ $\tau_{w,AL}$-induced Ekman transport

: Factors that enhance vertical mixing (e.g. **wind stress**) increase A and thus δ_E.
→ promote overlapping of the surface and bottom boundary layers
→ decrease efficiency of Ekman transport and increase importance of $\tau_{w,AC}$ in driving T_{AC}

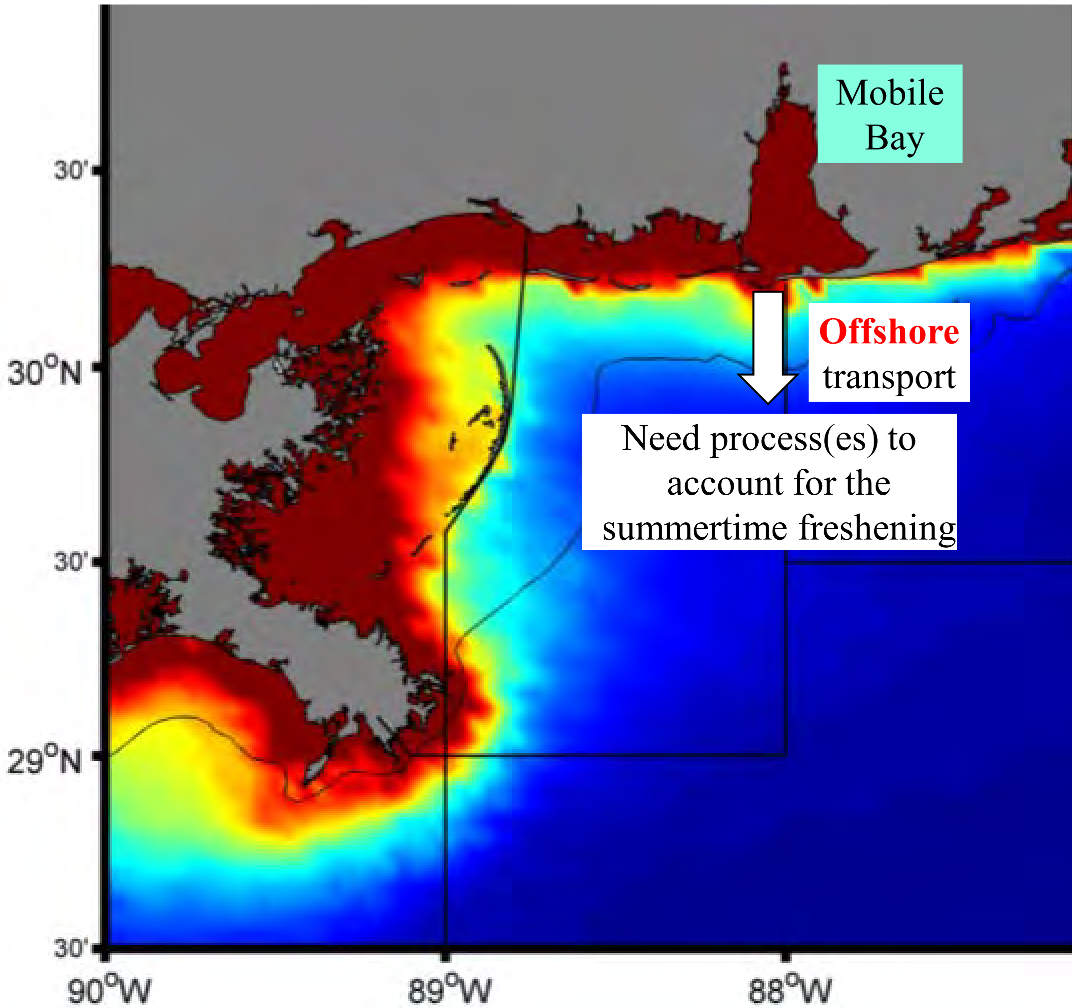
- Previous studies do not agree on

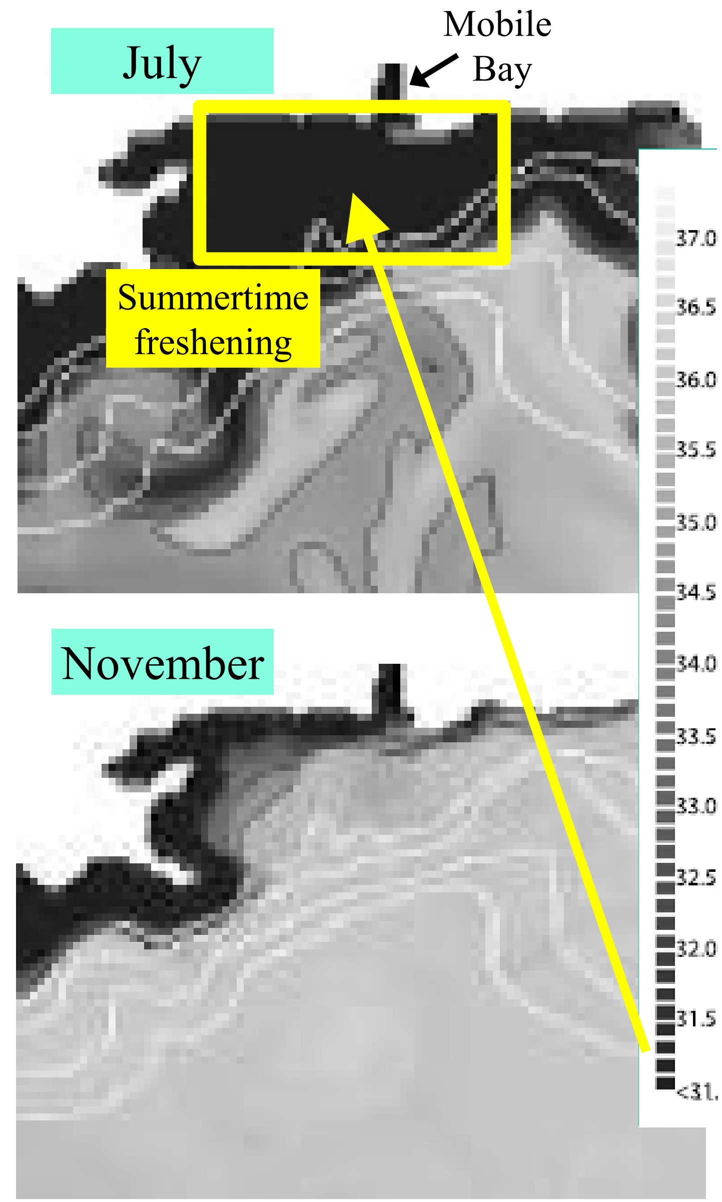
: Importance of stratification at event time scales (2-7 days)
: Relative importance between $\tau_{w,AL}$ and $\tau_{w,AC}$ at any given depth

➡ **Our target processes**


Mobile
Bay
DPIA1
Onshore
transport
CP
East wind
(seasonal mean)
Seas
veraged
across
ıshore
(Dzwonkowski and Park 2010 in *JGR*)
BP oil well
30'
30°N
30'
29°N
30'
90°W
89°W
88°W


WA
OR
CA
ID
MT
WY
NV
UT
CO
AZ
NM
ND
SD
NE
KS
OK
MN
IA
MO
AR
LA
WI
IL
MS
MI
IN
KY
TN
AL
OH
WV
VA
NC
SC
GA
FL
PA
NY
MEXICO
Gulf of Mexico
Atlanti
Ocea
CUBA
BELIZE
GUATEMALA





(Morey et al. 2003: Fig. 5 in *JGR*)

- Objective

: To investigate across-shelf transport processes on the inner shelf of northern Gulf of Mexico

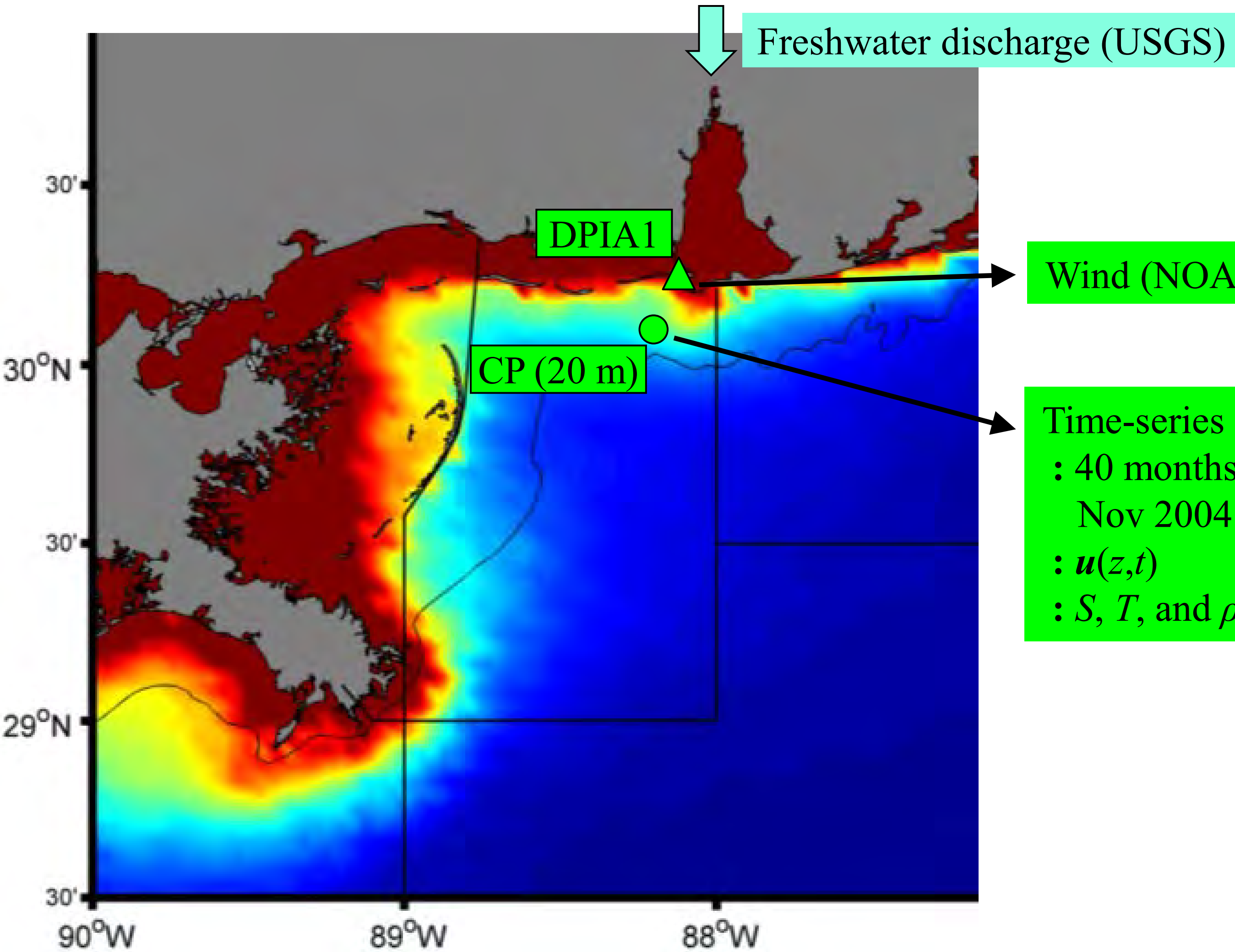
- Questions

1) Process(es) responsible for offshore surface transport, despite the predominant downwelling (and thus onshore transport) favorable east wind

2) Relative importance between along-shelf ($\tau_{w,AL}$) and across-shelf ($\tau_{w,AC}$) wind to across-shelf transport (T_{AC}) at any given depth

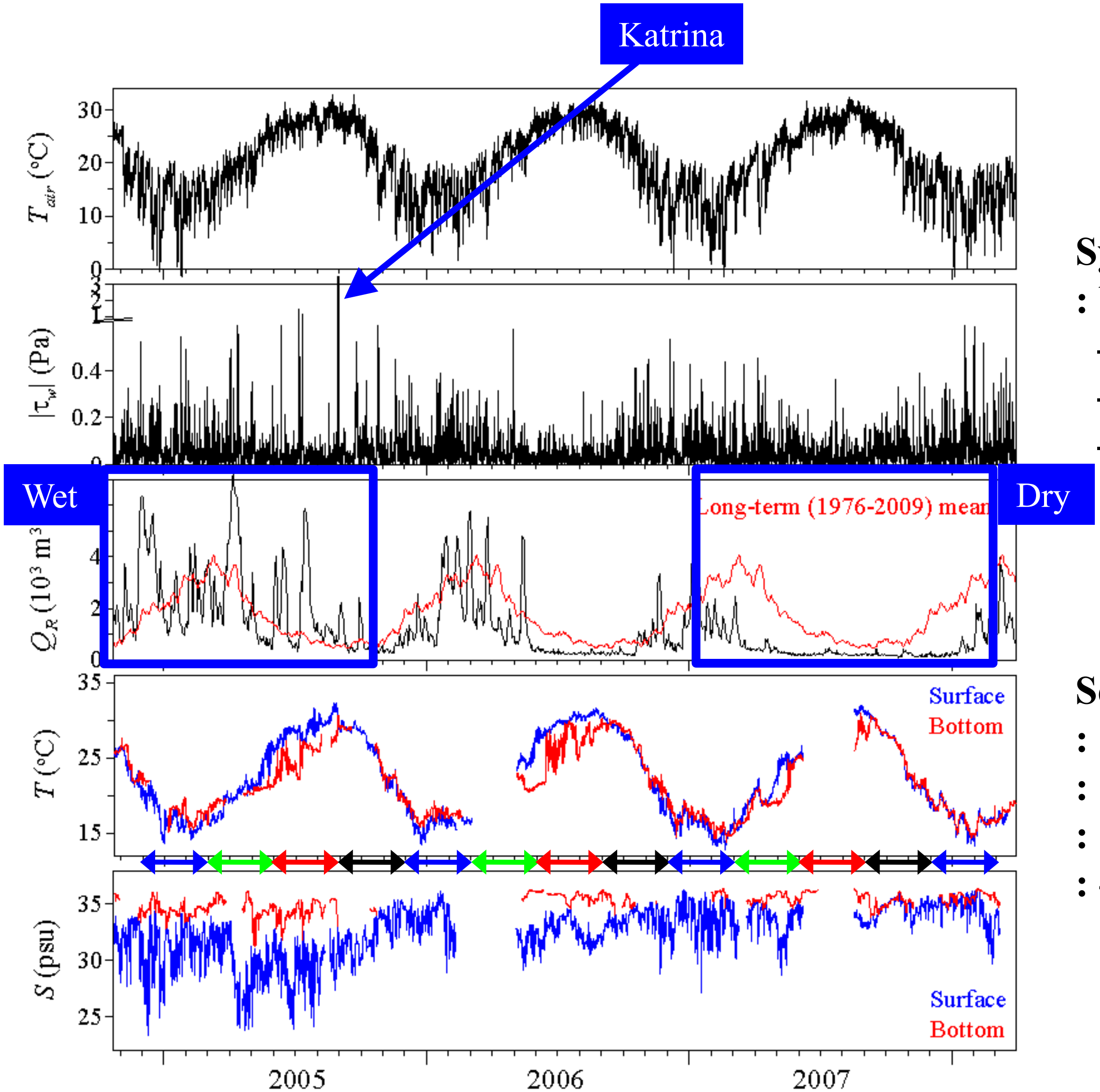
3) Modulating influence of wind stress and stratification on T_{AC}

- Data



Wind (NOAA)

Time-series data
: 40 months (3.33 years between Nov 2004 - Mar 2008)
: $\boldsymbol{u}(z,t)$
: S, T, and ρ at surface and bottom



Synoptic (event) scales

: binned data over a range of
- wind stress
- velocity shear
- stratification

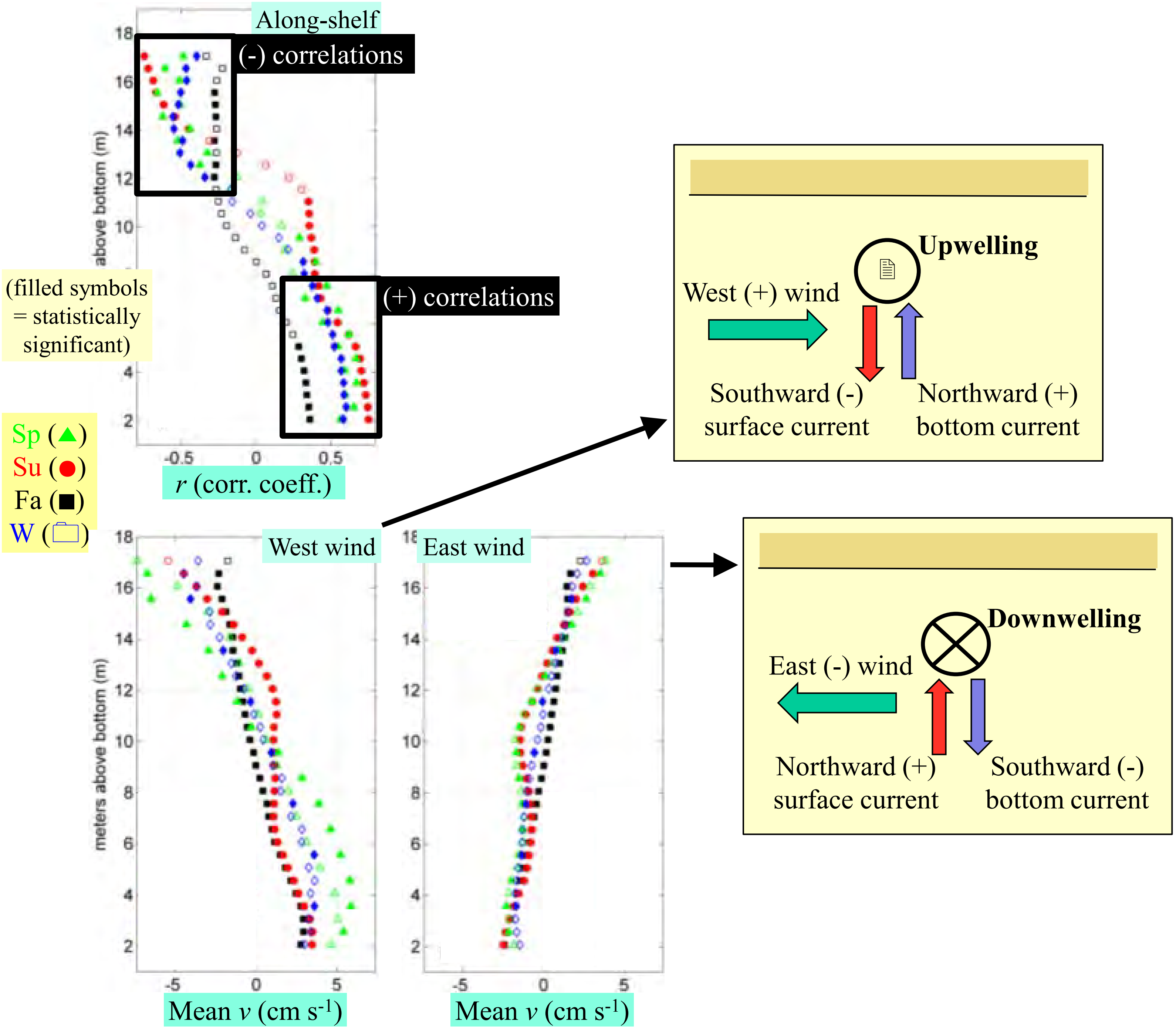
Seasonal scales

: 3 spring

: 3 summer

: 3 fall

: 4 winter seasons


Along-shelf
(-) correlations
(+) correlations
(filled symbols = statistically significant)
Sp (▲)
Su (●)
Fa (■)
W (□)
r (corr. coeff.)
meters above bottom (m)
West wind
East wind
Mean v (cm s-1)
Mean v (cm s-1)
Upwelling
West (+) wind
Southward (-) surface current
Northward (+) bottom current
Downwelling
East (-) wind
Northward (+) surface current
Southward (-) bottom current

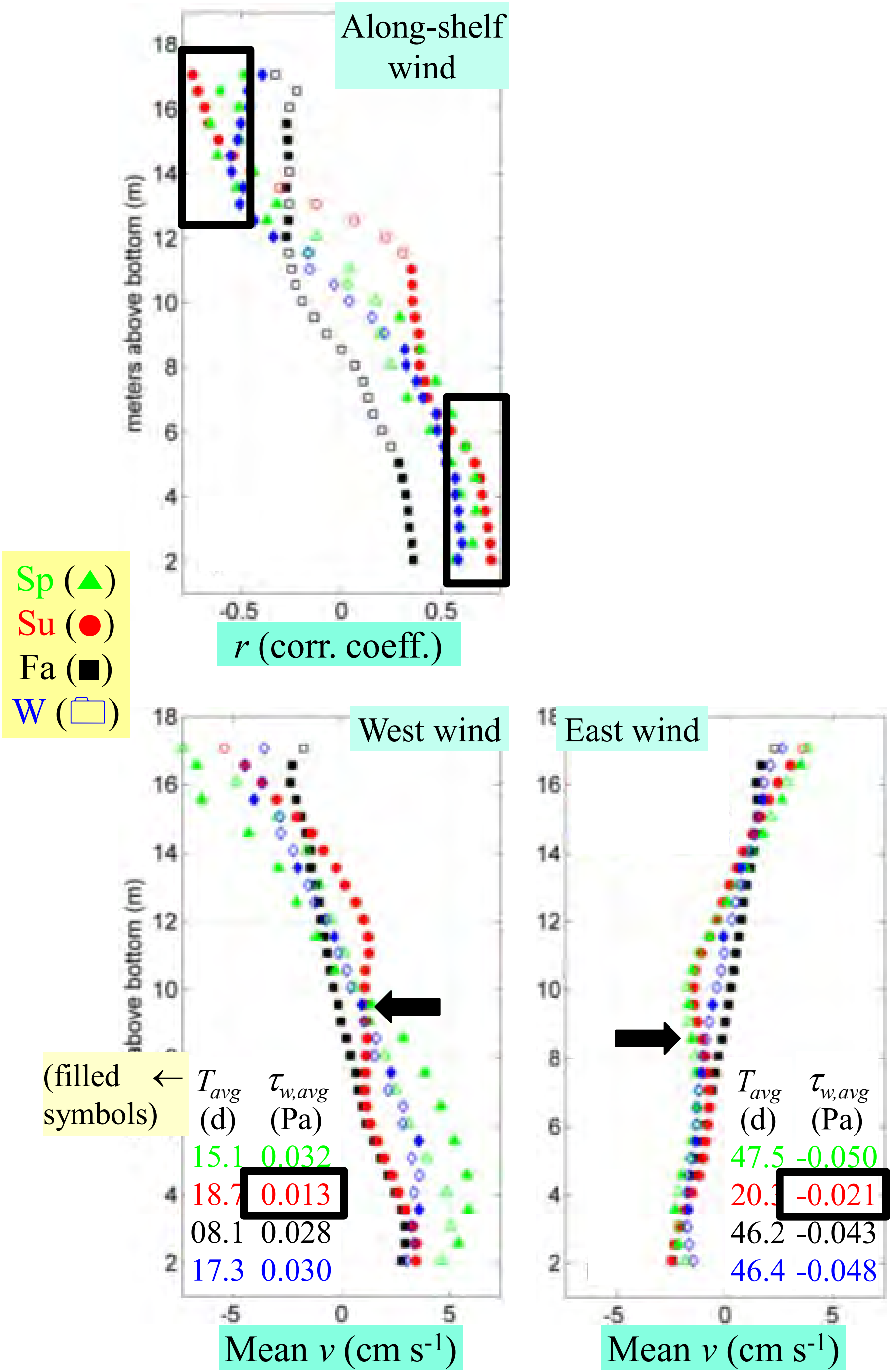


Table. Seasonal means.

Season	$\tau_{w,AL}$ (Pa)	$\tau_{w,AC}$ (Pa)	$\Delta\rho/D$ (kg m^{-4})
Spring 2005	-0.008	-0.004	0.26
2006	-0.010	0.007	0.29
2007	-0.021	-0.003	0.13
Summer 2005	-0.018	0.007	0.33
2006	-0.005	0.005	0.23
2007	-0.002	0.007	0.15
Fall 2005	-0.019	-0.028	0.09
2006	-0.014	-0.013	0.09
2007	-0.024	-0.023	0.03
Winter 2004-5	-0.013	-0.029	0.14
2005-6	-0.005	-0.021	-
2006-7	-0.012	-0.029	0.09
2007-7	-0.016	-0.026	0.06

Strongest magnitude response to wind stress (i.e. highest current speed per unit mean wind stress)

Table. Seasonal means.

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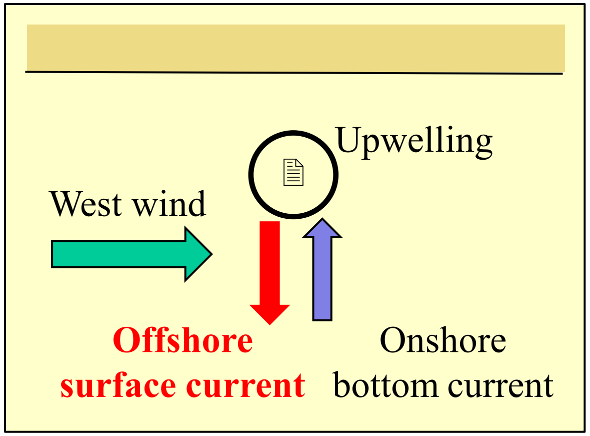

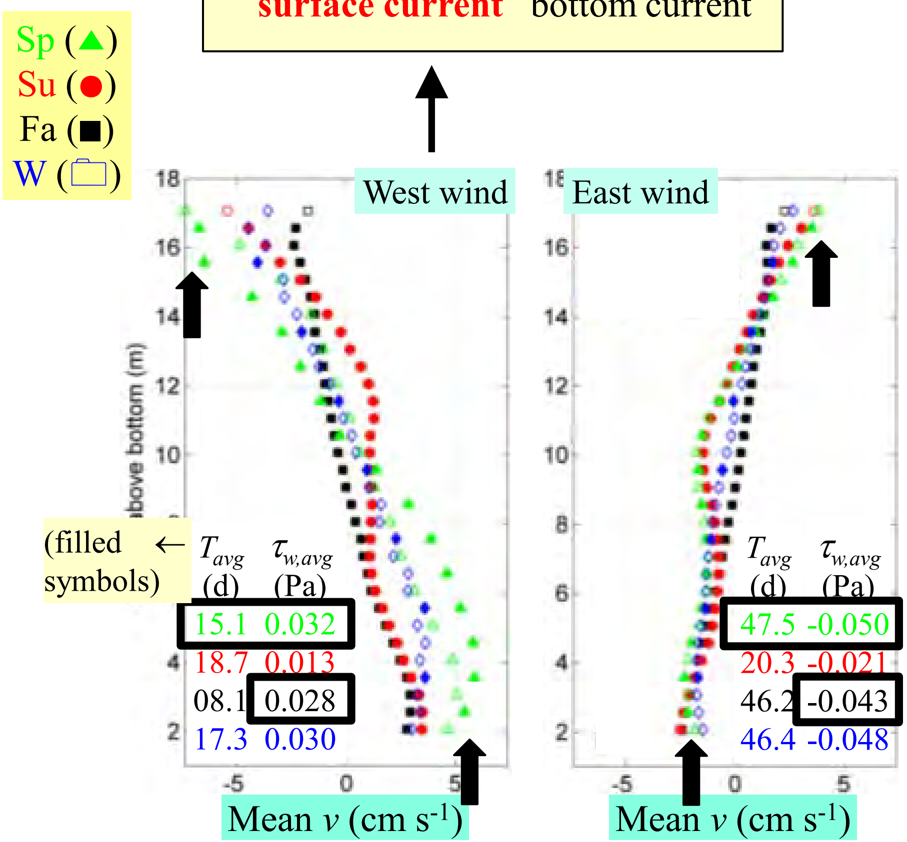

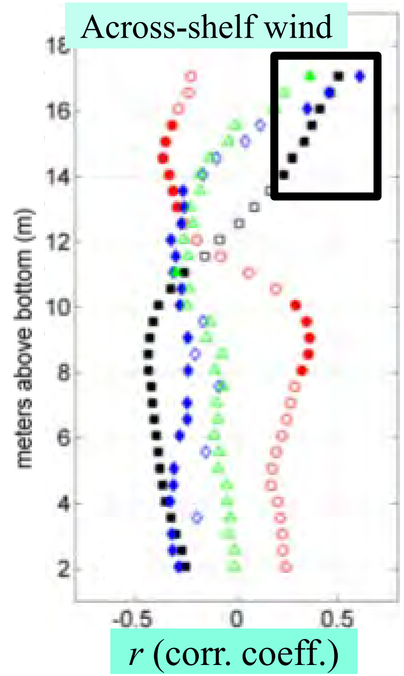

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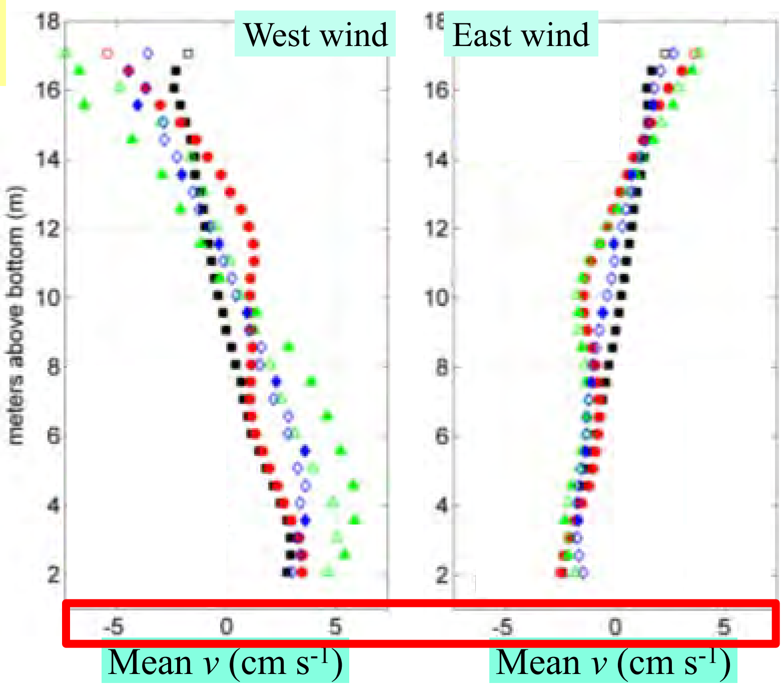
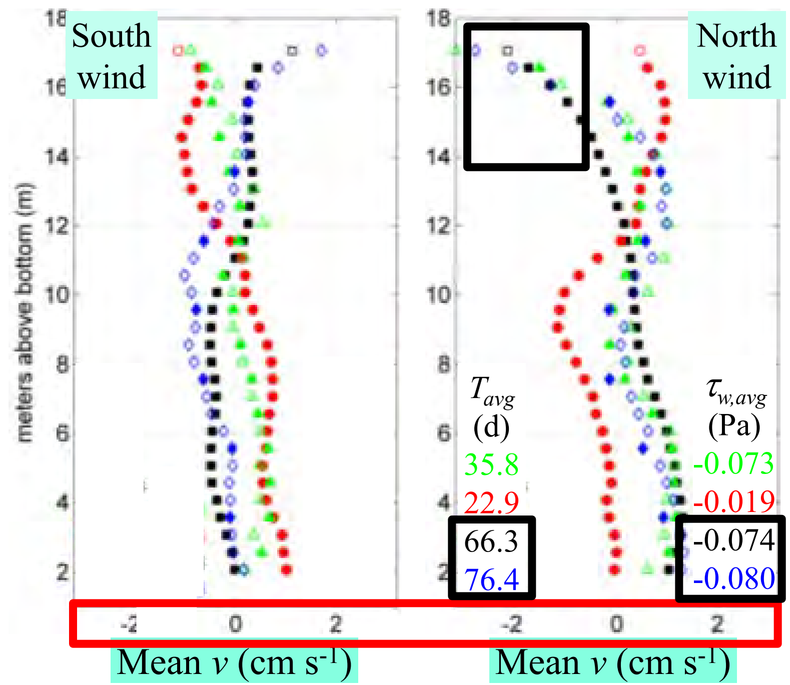
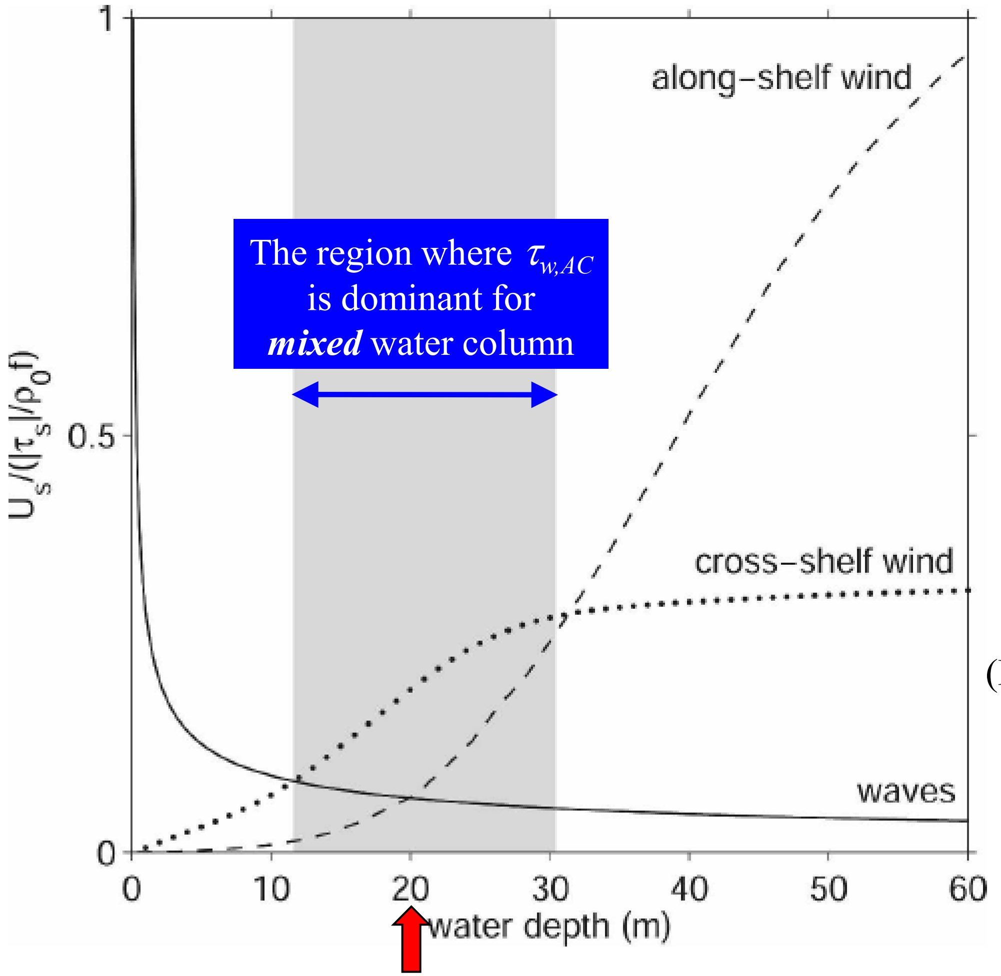
Sp (▲)
Su (●)
Fa (■)
W (◻)







(Fewings et al. 2008: Fig. 15 in *JPO*)

$\tau_{w,AL}$ still is more important than $\tau_{w,AC}$ for ***stratified*** water column.

Across-shelf surface transport

Depth-averaged across-shelf velocity

$$T_S(t) = \int_{\zeta}^{0} \left[v(z,t) - V(t) \right] \mathrm{d}z$$

1st zero-crossing depth

Across-shelf velocity component

vs.

$$T_E(t) = \frac{\tau_{w,AL}}{\rho f}$$

Along-shelf wind stress

Ekman transport

$$T_S(t) = a \cdot T_E(t) + b$$

Transport fraction

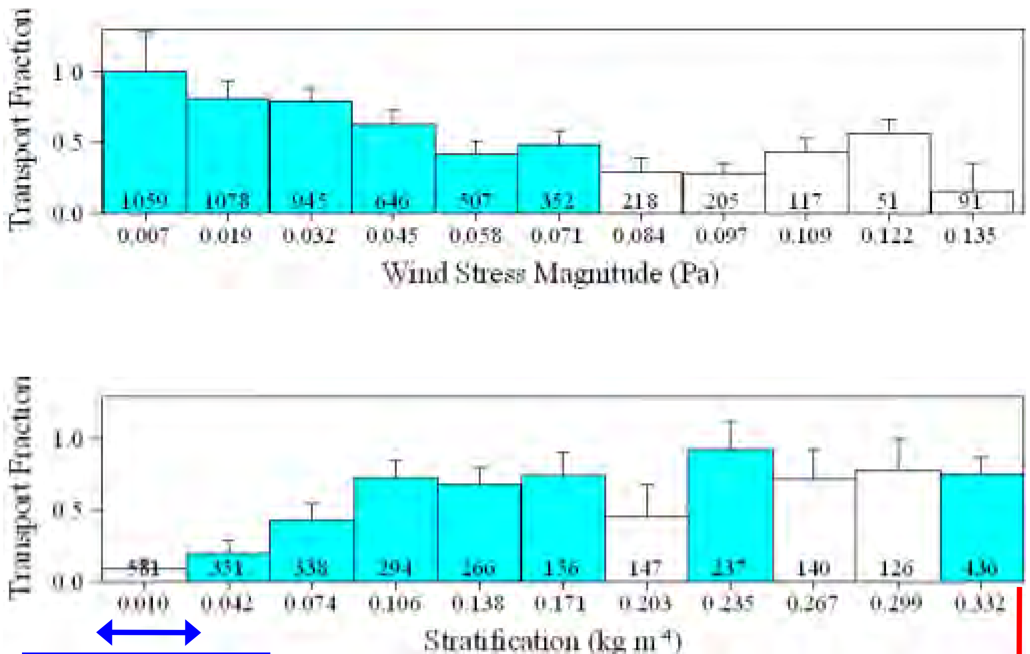
(the fraction of theoretical T_E realized in the observed T_S)

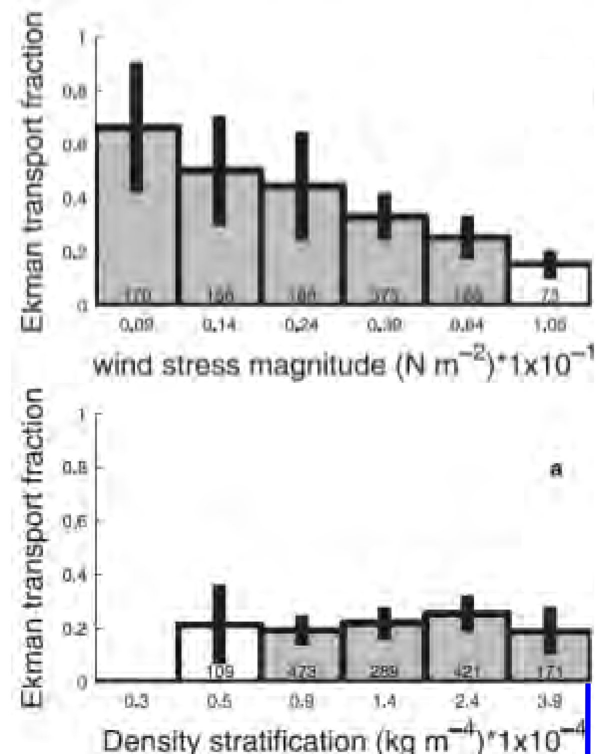
: The larger the transport fraction, the more efficient in using $\tau_{w,AL}$ energy in driving across-shelf transport.

Integer = number of data

Significantly correlated T_S and T_E

(Kirincich and Barth 2009: Fig. 9 in *JPO*)





0 - 0.04 kg m^{-4}

~ 0.5 kg m^{-4}

~ 0.04 kg m^{-4}

: As wind stress magnitude increases, A and thus δ_E increase.
→ promote overlapping of the surface and bottom boundary layers
→ reduce transport efficiency

: As stratification increases, A and thus δ_E decrease.
→ result in two distinct, separated surface and bottom boundary layers
→ enhance transport efficiency

- Questions

1) Process(es) responsible for ***offshore surface transport***, despite the predominant downwelling (and thus onshore transport) favorable east wind

: A strongly asymmetric response, favoring upwelling, to **along-shelf west** wind stress, particularly during spring and summer

: During fall and winter, response to **across-shelf north** wind stress (response may be weak, but such winds are frequent/strong and along-shelf wind is inefficient during these seasons)

2) Relative importance between *along-shelf* and *across-shelf* wind to across-shelf transport at any given depth

: For **stratified** water column, **along-shelf wind** still can be the more important at shallower depths (owing to the separation of boundary layers).

3) Modulating influence on *transport efficiency* of wind stress magnitude and stratification

: Transport efficiency increases with decreasing **wind stress magnitude** and increasing **stratification** (for **stratified** water column) at both seasonal and synoptic time scales.

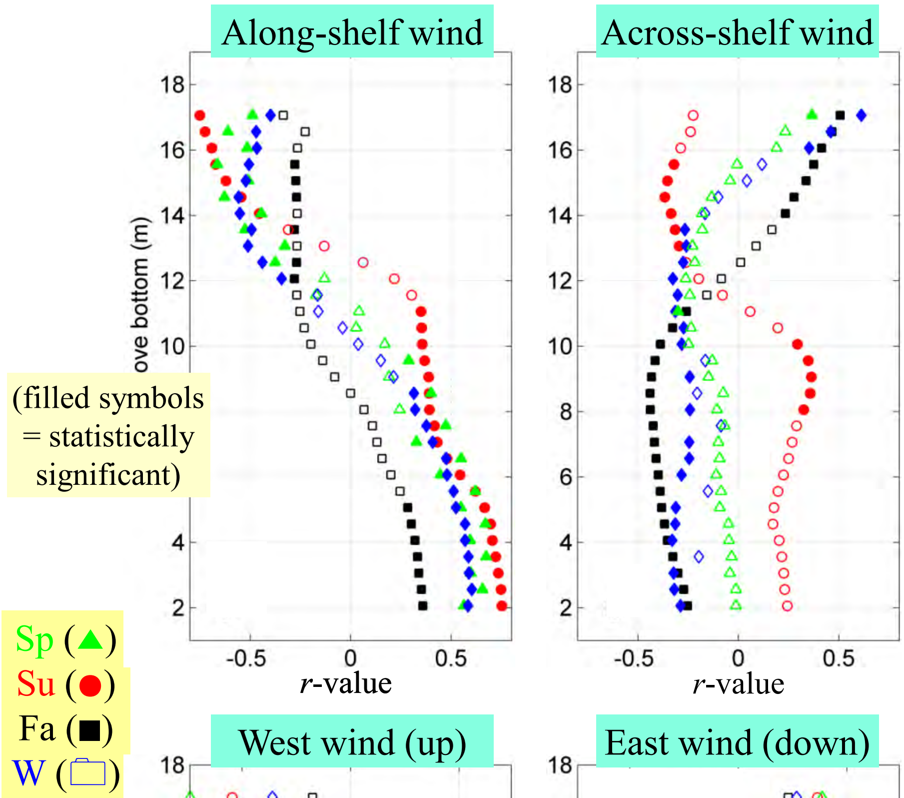
THANK YOU !!!

Questions / Comments ??

Table 1. Seasonal statistics for environmental conditions

Season	Wind Stress τ^w (Pa)			Stratification (kg m^{-4})		River Discharge (m^3 s^{-1})[a]
	Mean τ_{AL}^w	Mean τ_{AC}^w	SD of $\lvert\tau^w\rvert$	Mean	% Data[a]	
Spring						
2005	-0.008	-0.004	0.037	0.26	71	2758
2006	-0.010	0.007	0.048	0.29	20	1962
2007	-0.021	-0.003	0.042	0.13	77	561
Summer						
2005	-0.018	0.007	0.123	0.33	83	1876
2006	-0.005	0.005	0.017	0.23	93	292
2007	-0.002	0.007	0.017	0.15	19	207
Fall						
2005	-0.019	-0.028	0.065	0.09	7	649
2006	-0.014	-0.013	0.042	0.09	45	573
2007	-0.024	-0.023	0.038	0.03	72	195
Winter						
2004-05	-0.013	-0.029	0.050	0.14	100	2972
2005-06	-0.005	-0.021	0.042	-	-	1889
2006-07	-0.012	-0.029	0.043	0.09	22	1442
2007-08	-0.016	-0.026	0.046	0.06	64	517

[a] Discharge value with a 11-d lag, a lag time between the gauge stations and the study site (Dzwonkowski et al. 2011 in *CSR*)



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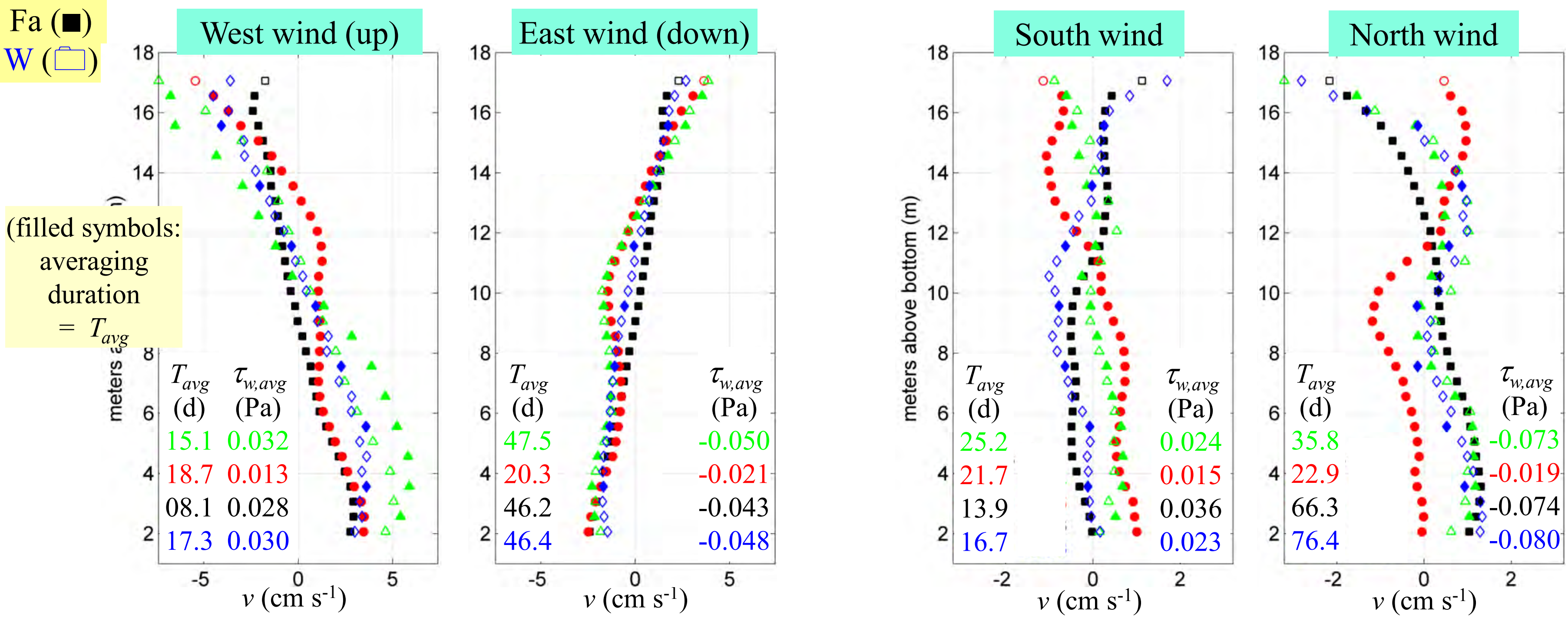
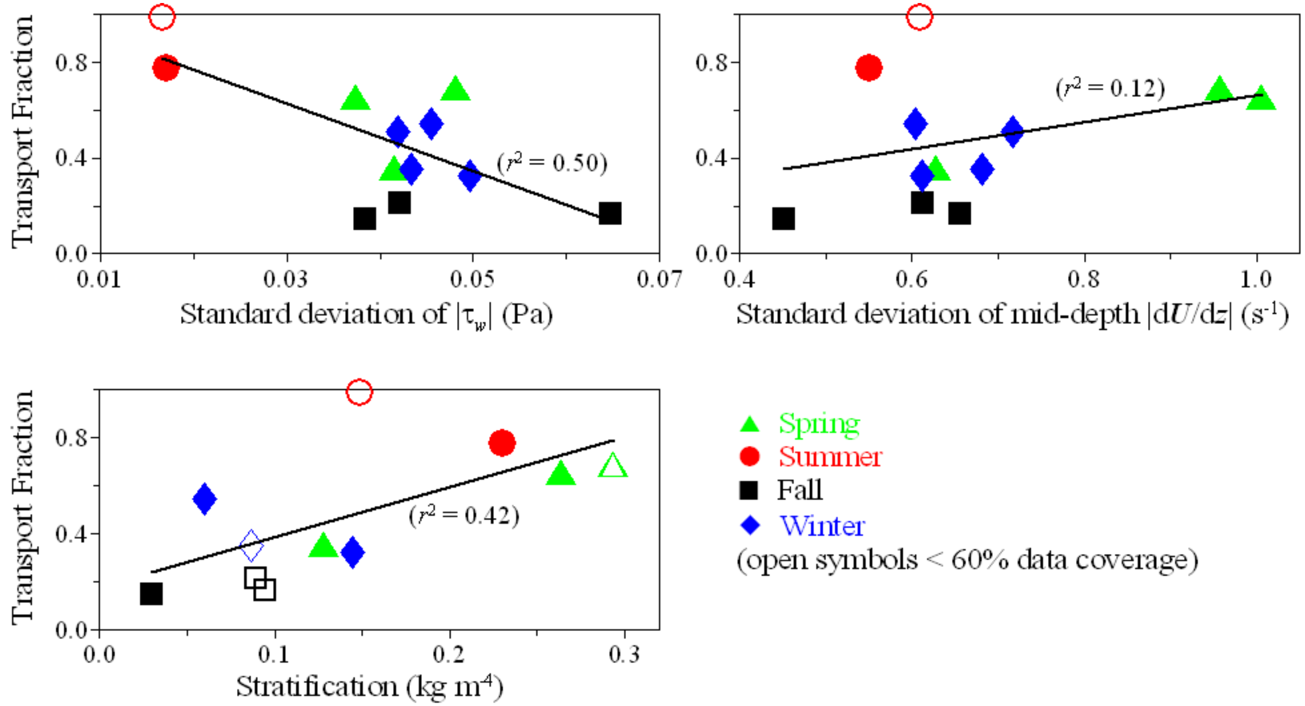
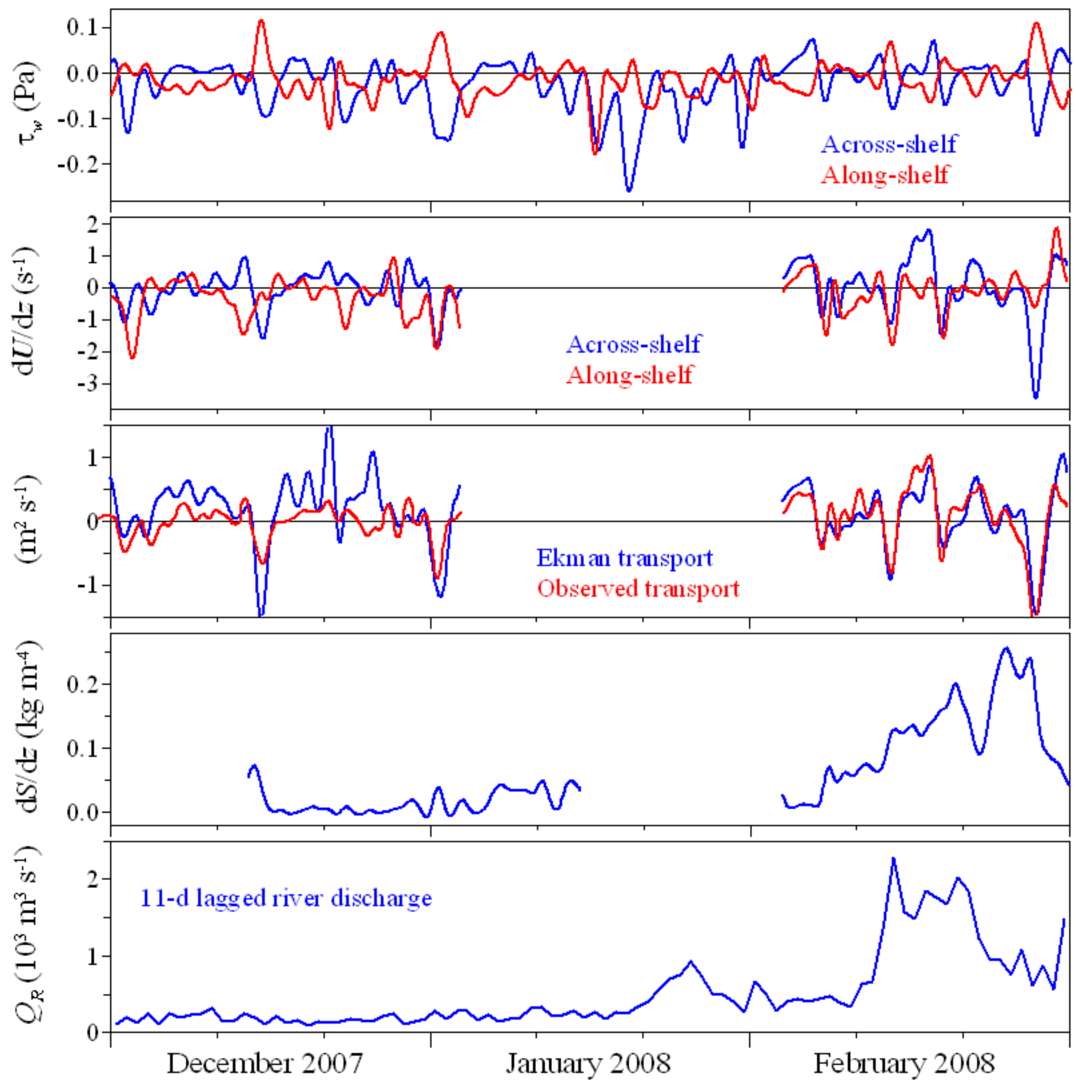
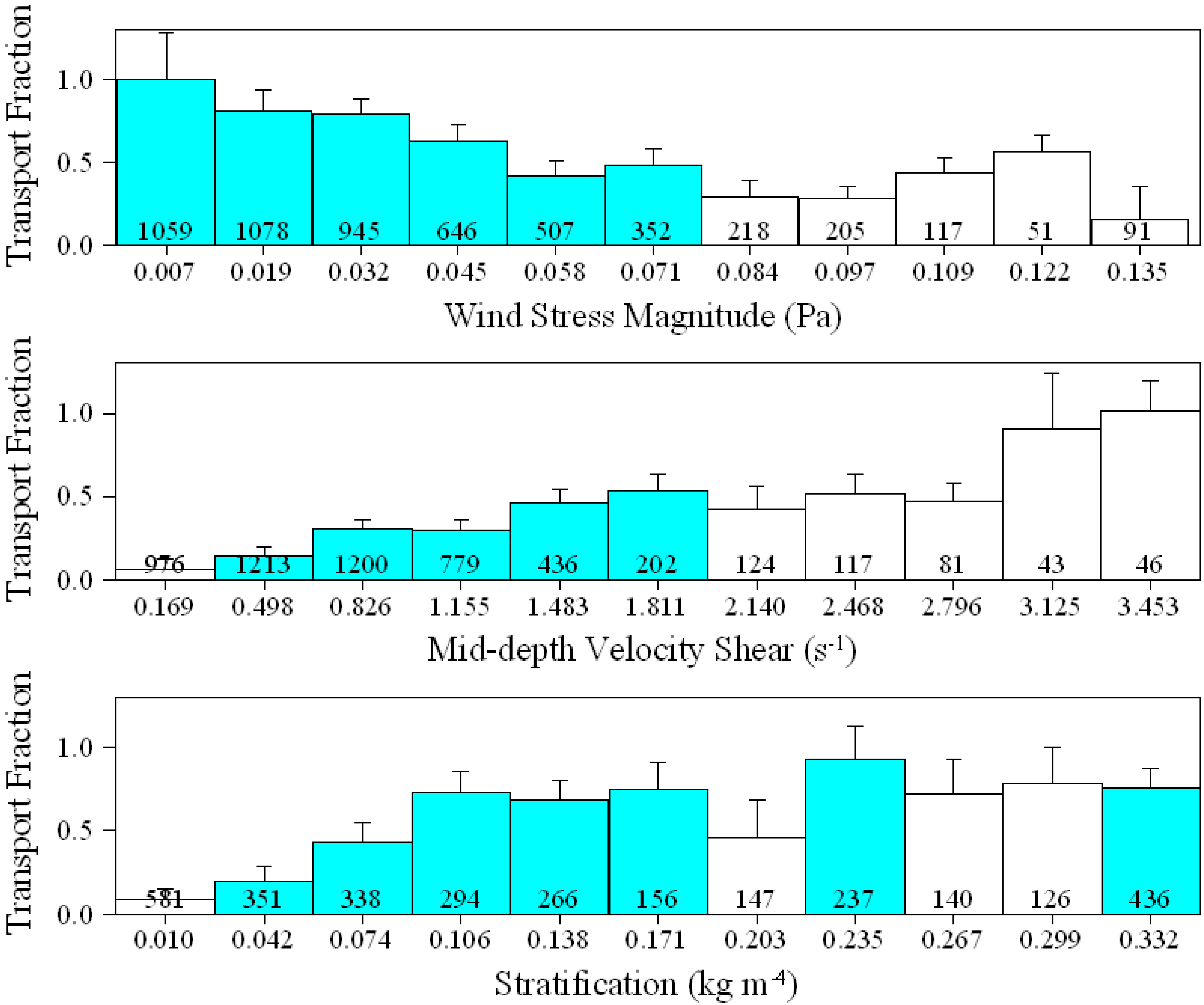




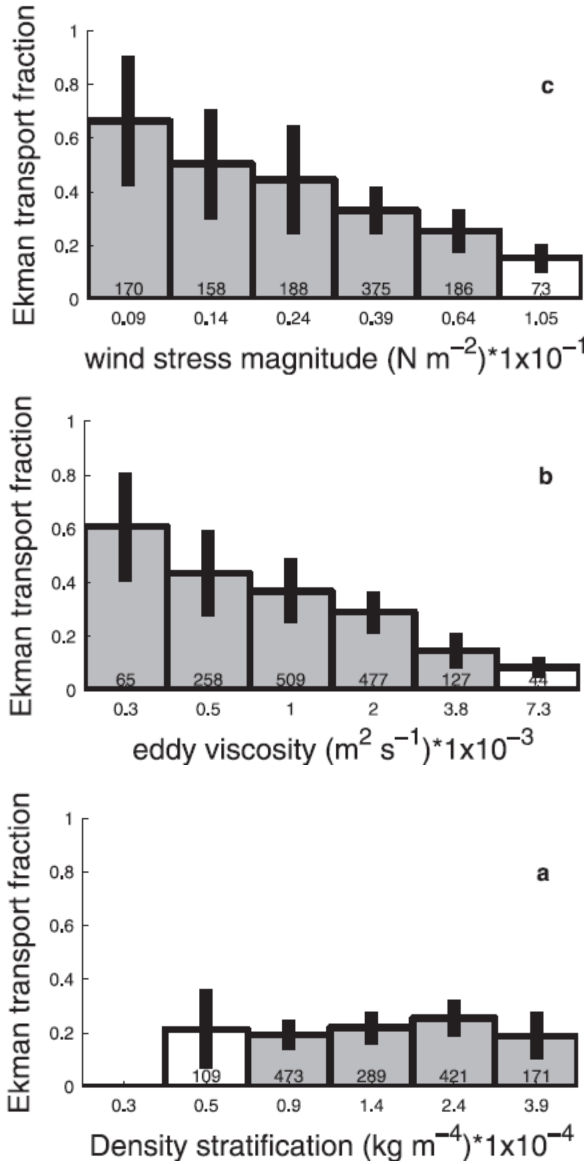
Transport Fraction
0.0
0.4
0.8
0.01
0.03
0.05
0.07
Standard deviation of |τw| (Pa)
(r2 = 0.50)
0.4
0.6
0.8
1.0
Standard deviation of mid-depth |dU/dz| (s-1)
(r2 = 0.12)
Transport Fraction
0.0
0.1
0.2
0.3
Stratification (kg m4)
(r2 = 0.42)
Spring
Summer
Fall
Winter
(open symbols < 60% data coverage)



0.1
0.0
-0.1
-0.2
τ_w (Pa)
Across-shelf
Along-shelf
2
1
0
-1
-2
-3
dU/dz (s-1)
Across-shelf
Along-shelf
1
0
-1
(m2 s-1)
Ekman transport
Observed transport
0.2
0.1
0.0
dS/dz (kg m-4)
2
1
0
Q_R (103 m3 s-1)
11-d lagged river discharge
December 2007
January 2008
February 2008



Transport Fraction
1.0
0.5
0.0
1059
1078
945
646
507
352
218
205
117
51
91
0.007
0.019
0.032
0.045
0.058
0.071
0.084
0.097
0.109
0.122
0.135
Wind Stress Magnitude (Pa)
Transport Fraction
1.0
0.5
0.0
976
1213
1200
779
436
202
124
117
81
43
46
0.169
0.498
0.826
1.155
1.483
1.811
2.140
2.468
2.796
3.125
3.453
Mid-depth Velocity Shear (s-1)
Transport Fraction
1.0
0.5
0.0
581
351
338
294
266
156
147
237
140
126
436
0.010
0.042
0.074
0.106
0.138
0.171
0.203
0.235
0.267
0.299
0.332
Stratification (kg m-4)



(Kirincich and Barth 2009:
Fig. 9 in *JPO*)

(max. stratification
~ 0.04 kg m^{-4})