Surface circulation in Block Island Sound and Adjacent Areas

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Acknowledgements:

Chris Kincaid, Rob Pockalny, Dong-Ping Wang,
Dan Codiga, Jim O'Donnell.

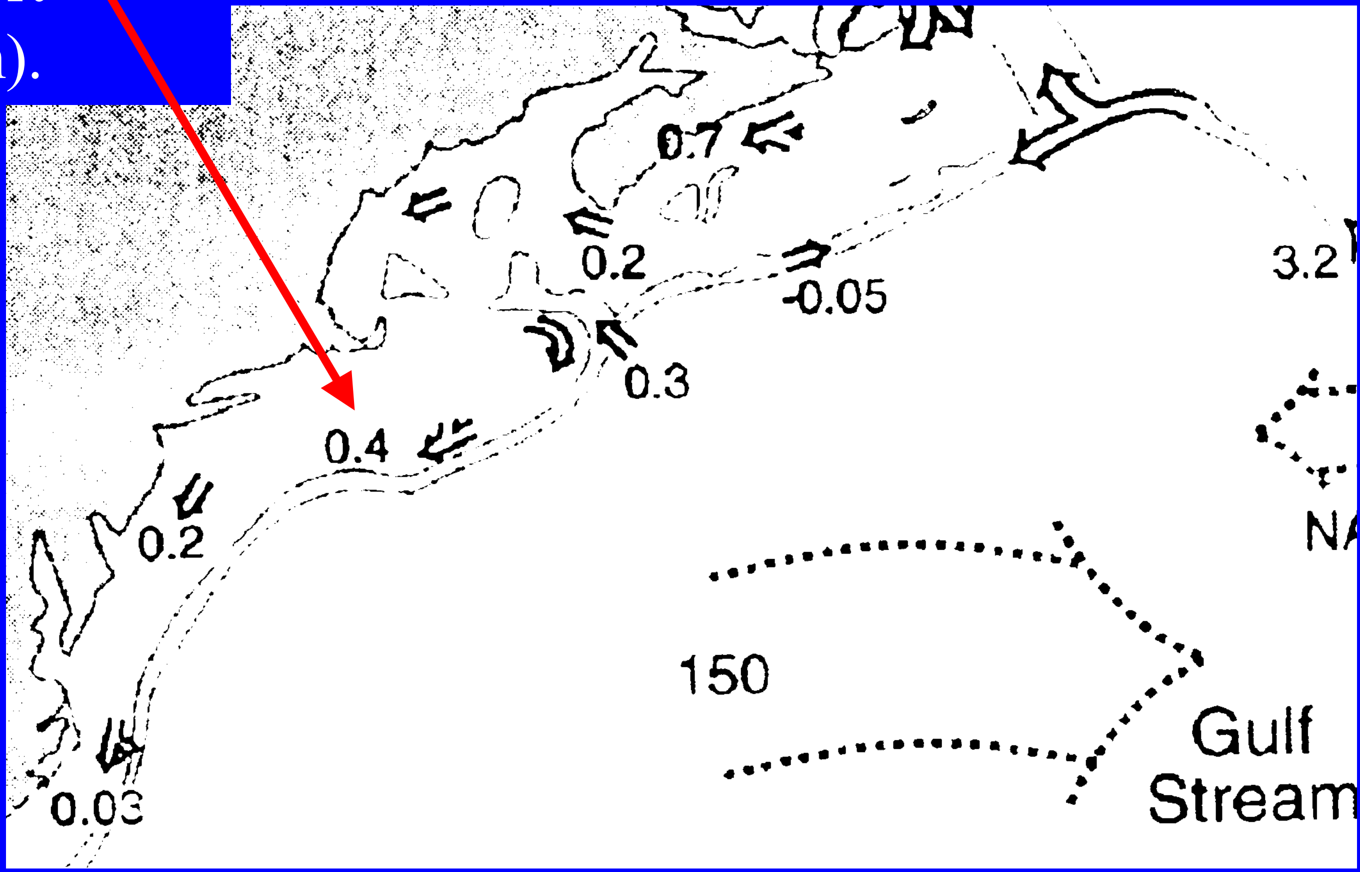
Objectives of Talk

- Provide remote sensing overview of surface currents with focus on the interaction between the Long Island Sound outflow and the coastal ocean circulation.
- Describe seasonal cycle in surface circulation.
- Suggest coastal current connectivity of Block Island and Rhode Island Sounds.

Northeast US Coast Shelf Circulation

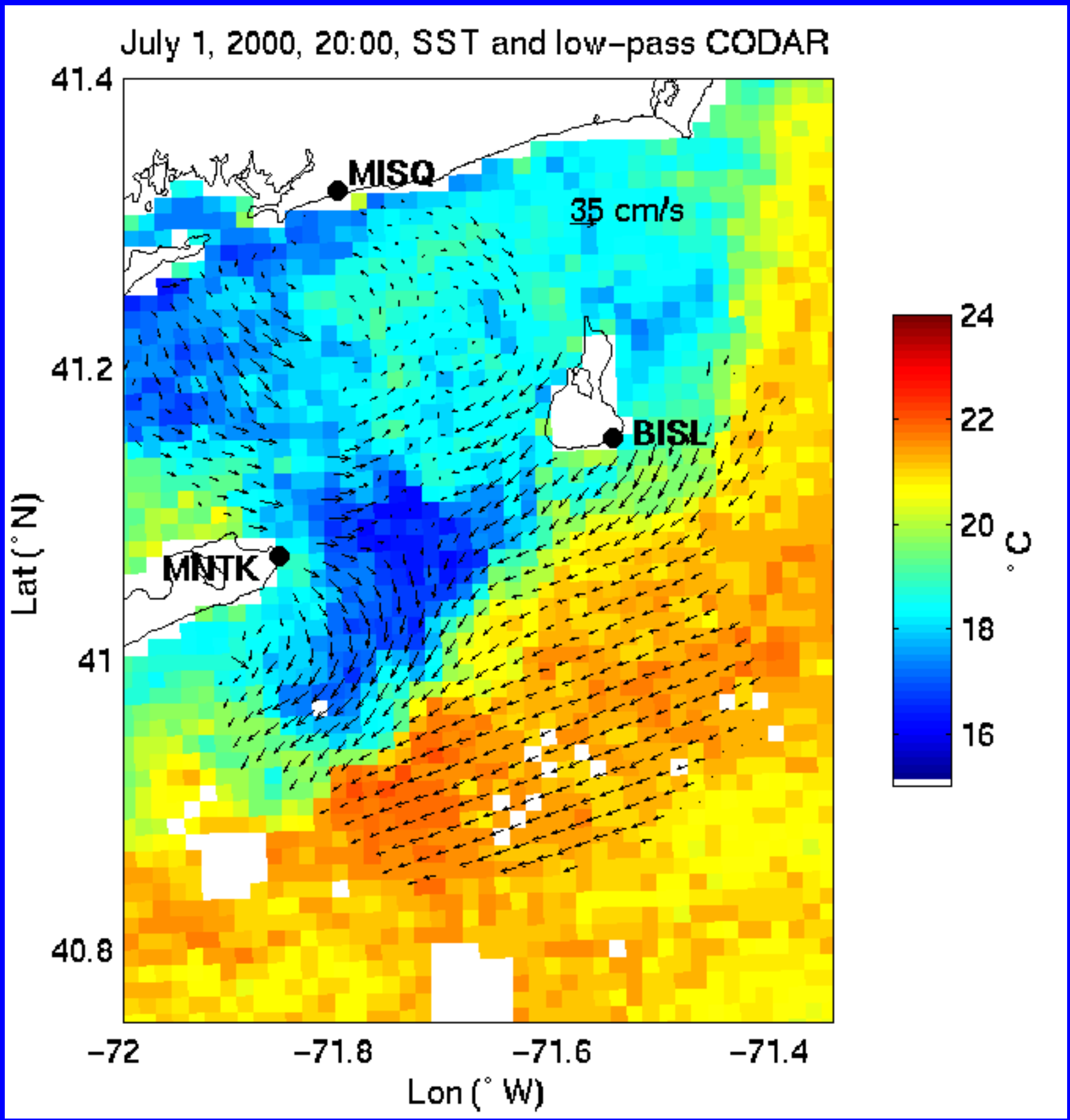
Beardsley *et al.* (1985),
Nantucket Shoals Flux Exp:
No seasonal transport
variability (h > 40m).

Annual Mean Transport (Sv)



From Loder *et al.*,1998

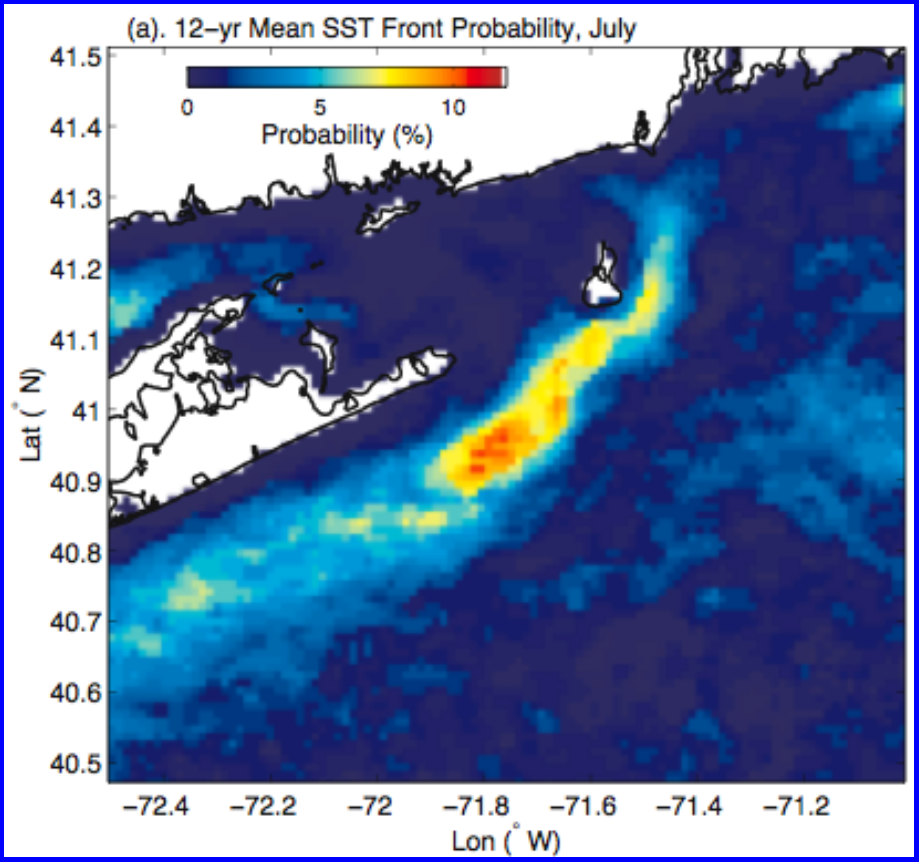
Summertime Sea Surface Temperature Structure in BIS and Vicinity



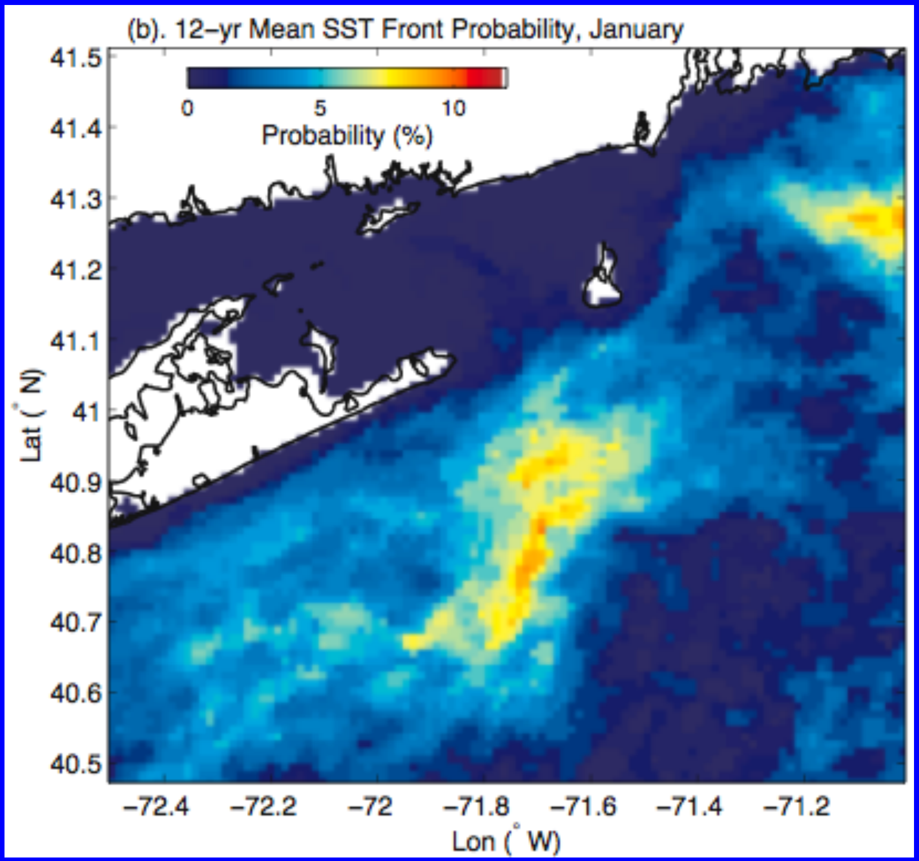
SST Front Probability

Averaged over 1985-1996

July



January



Summer:

Frontal zone narrow.

Suggests relatively stable front.

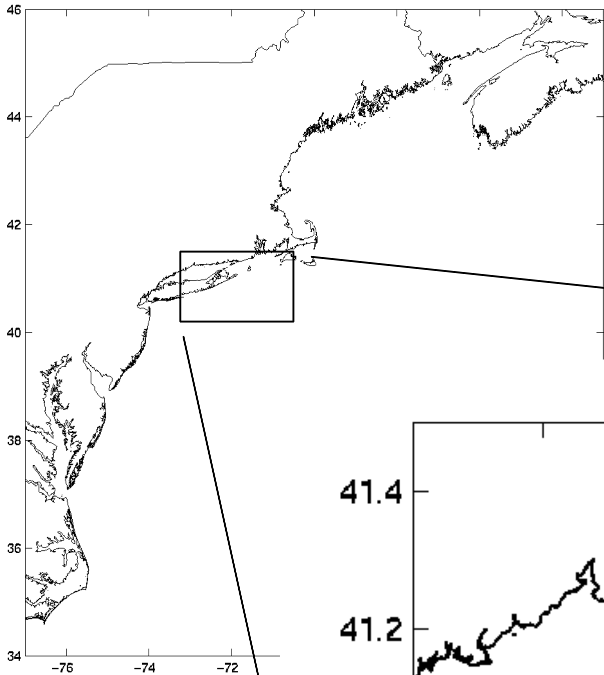
Winter:

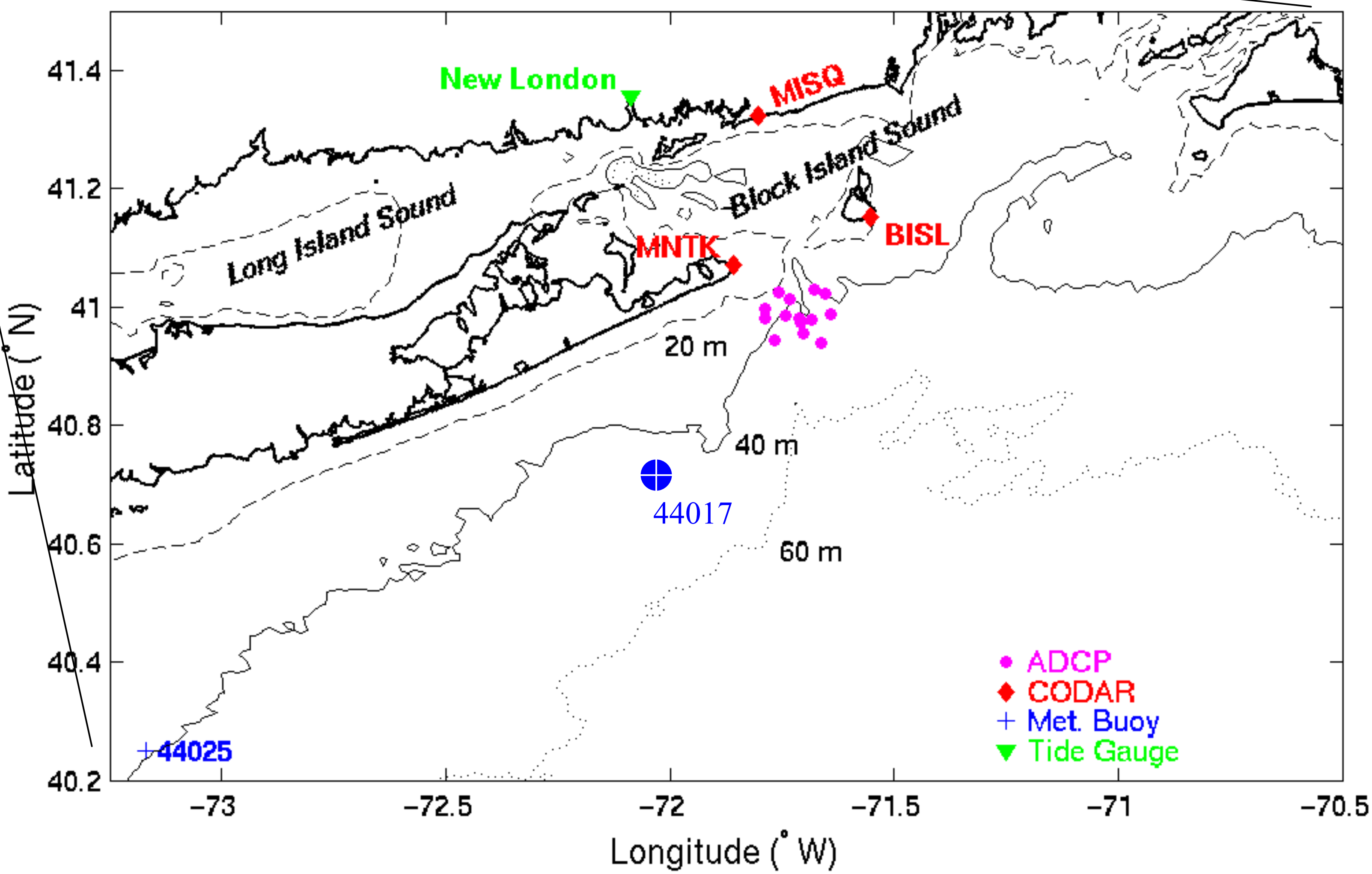
Frontal zone broad, diffuse.

Suggests front is variable.

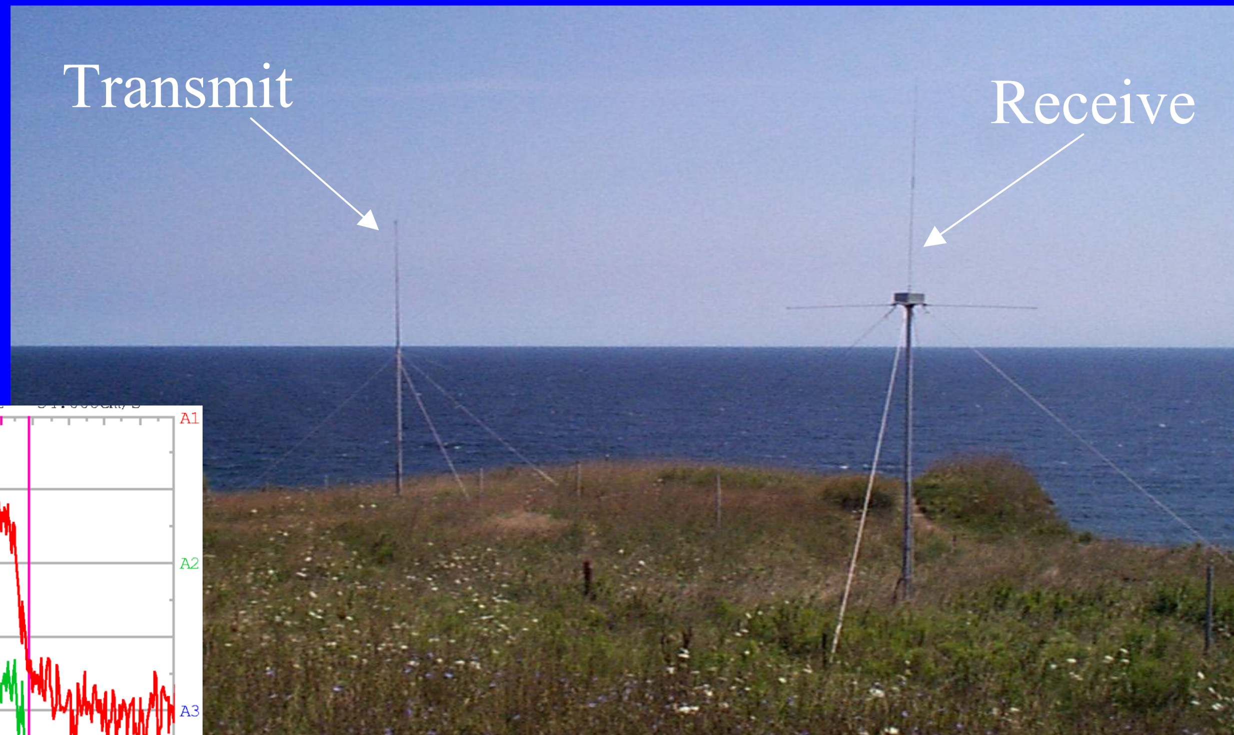
F.R.O.N.T. CODAR

3-site Surface current mapping system operated since 2000.

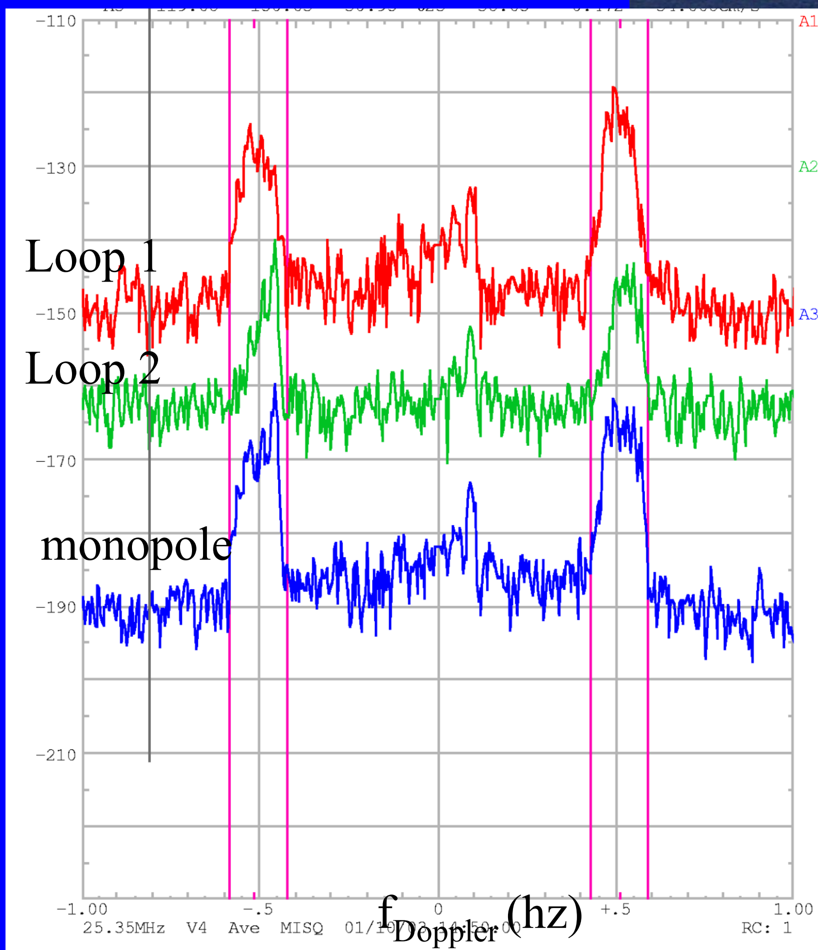




CODAR
Direction Finding



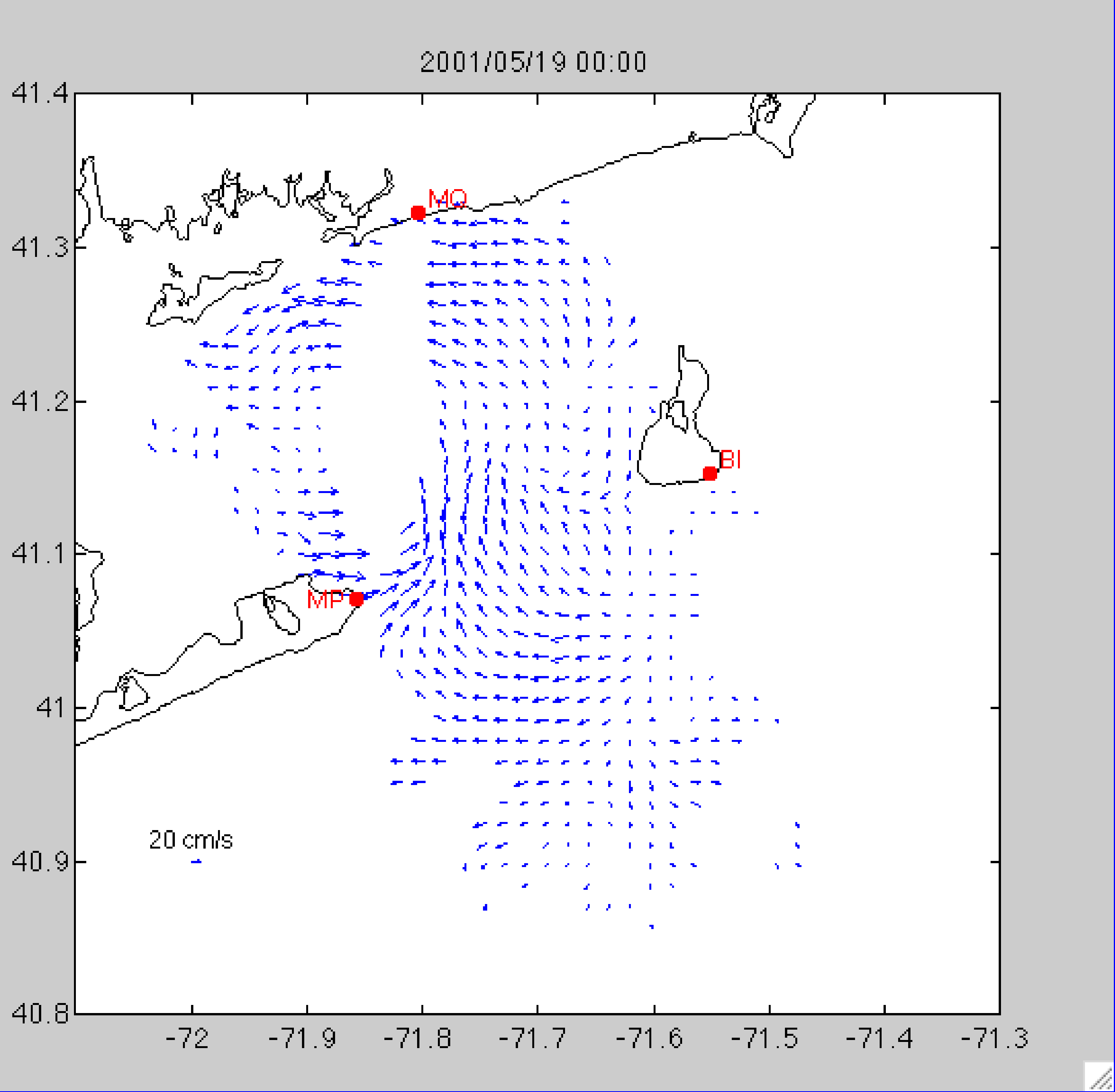
Doppler Spectra



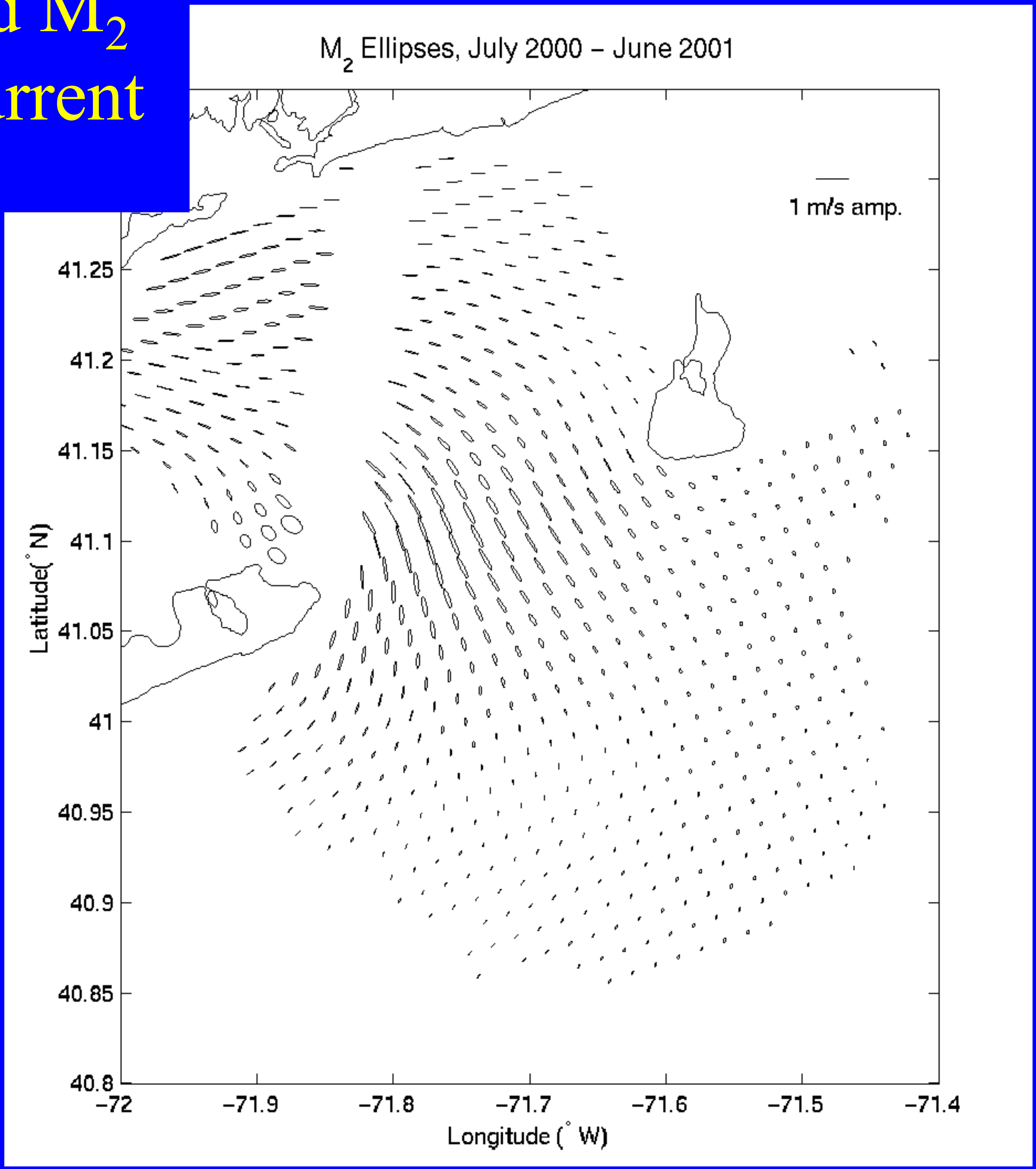
•Hourly surface current maps

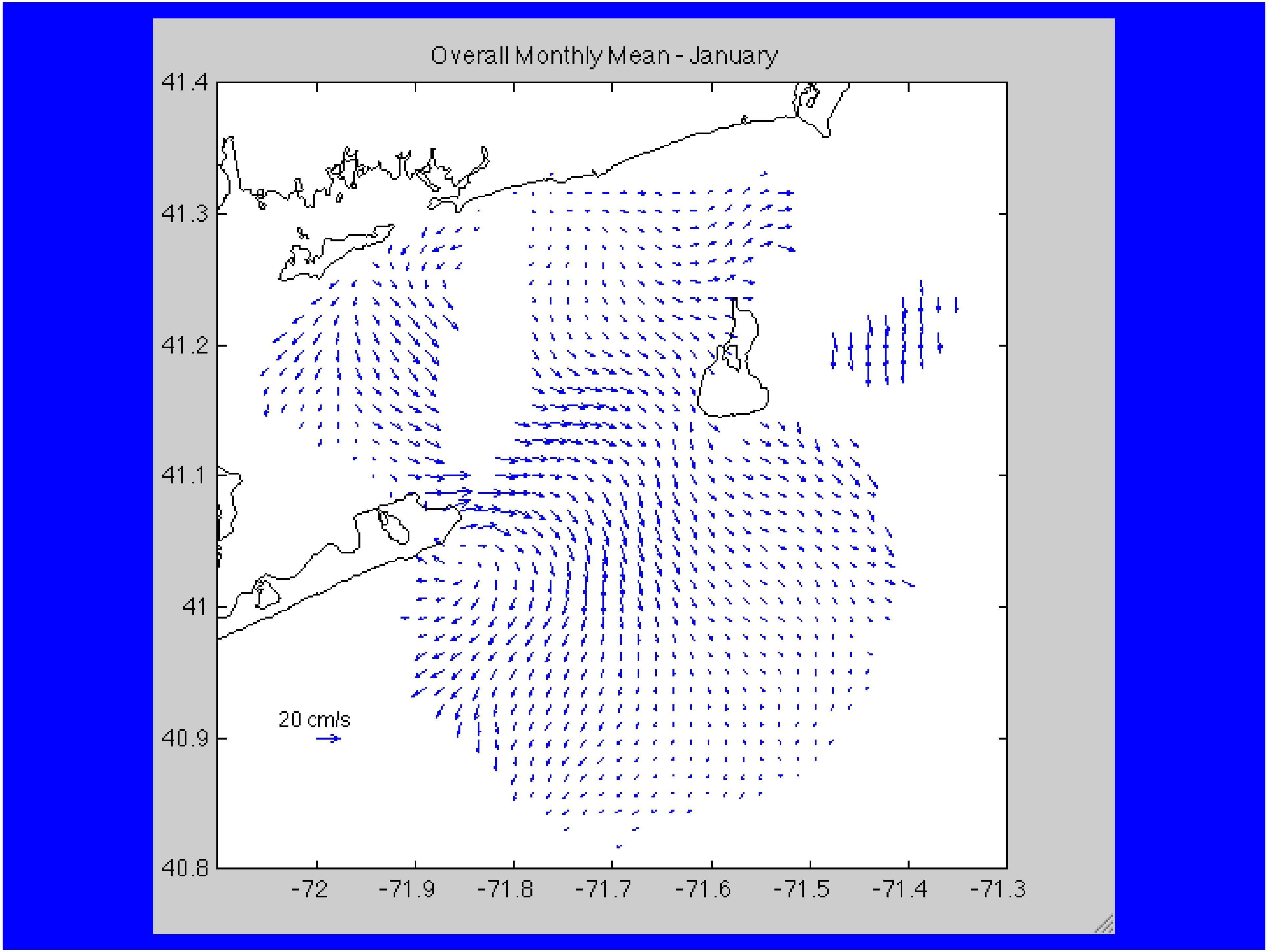
•Approximately 8 years of observations

•Spatial resolution ~2 km.



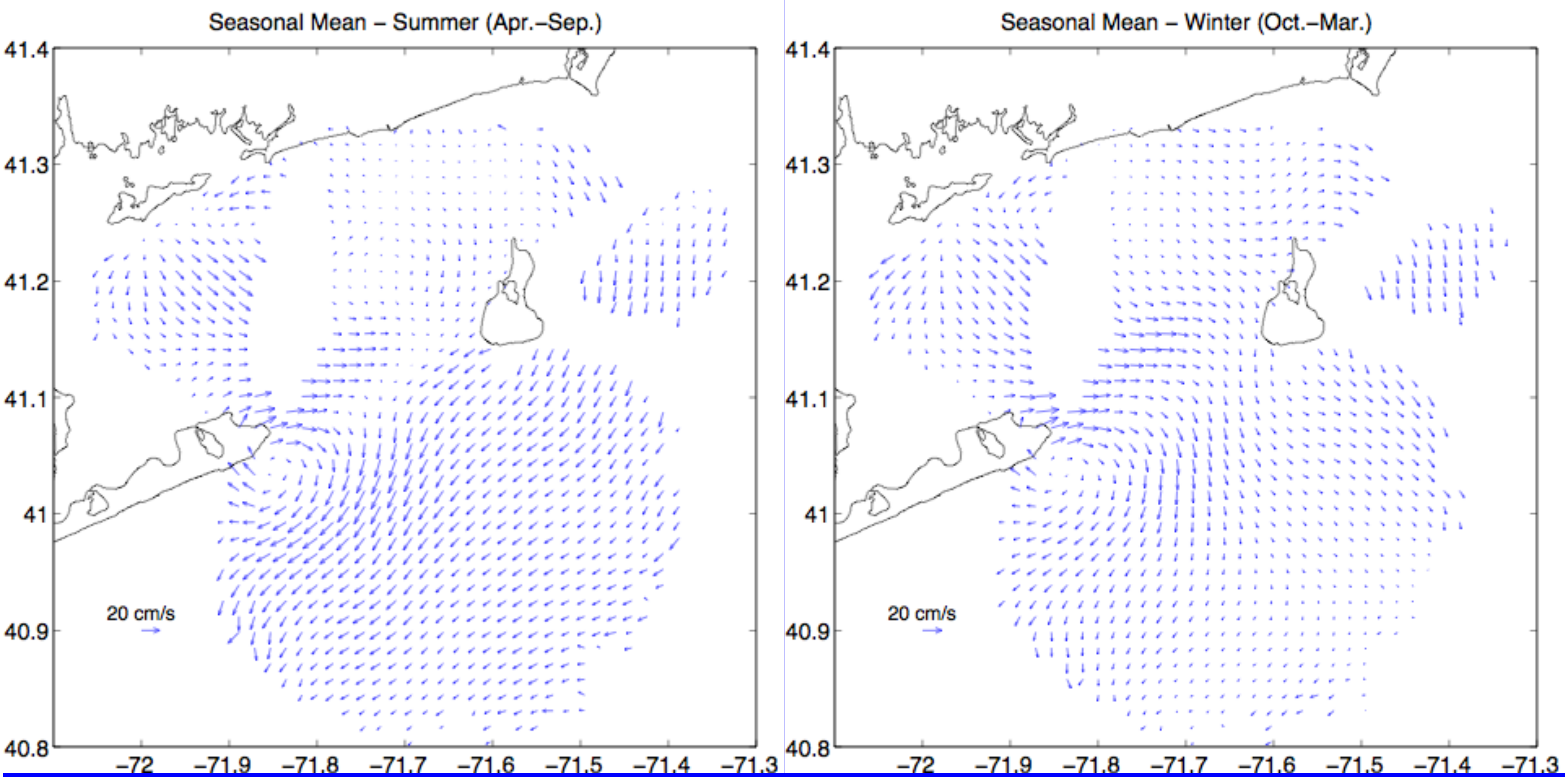
CODAR-derived M_2 Surface Tidal Current Ellipses




Overall Monthly Mean - January
41.4
41.3
41.2
41.1
41
40.9
40.8
-72
-71.9
-71.8
-71.7
-71.6
-71.5
-71.4
-71.3
20 cm/s

Seasonal Mean Surface Currents

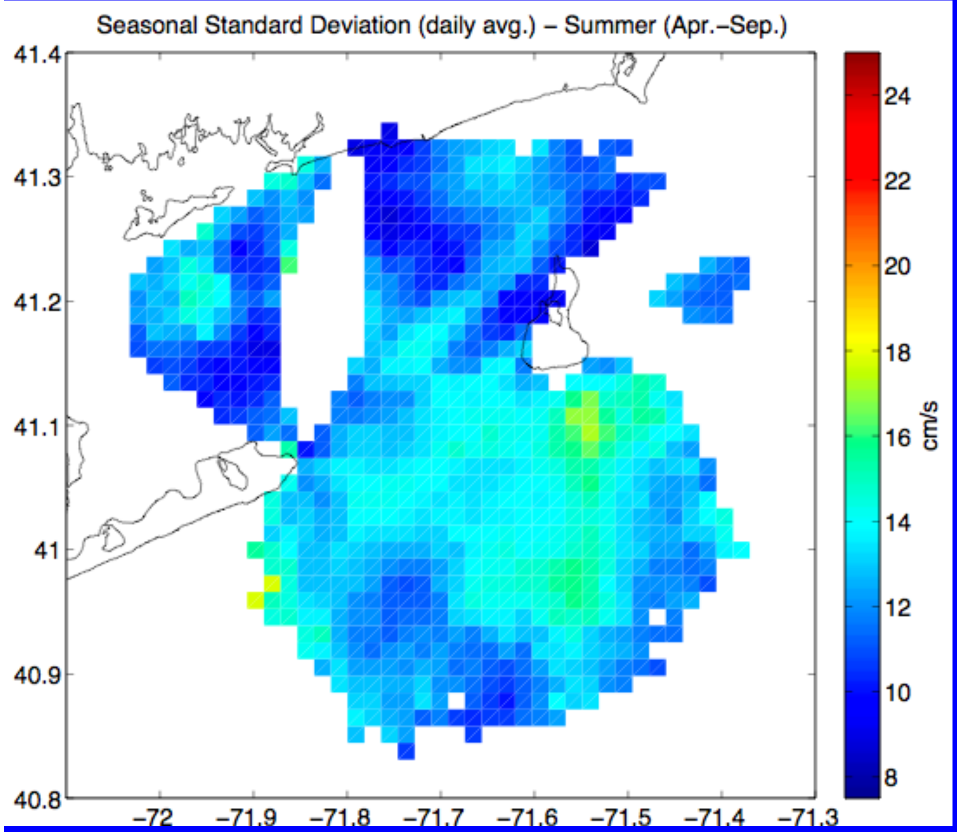
summer winter



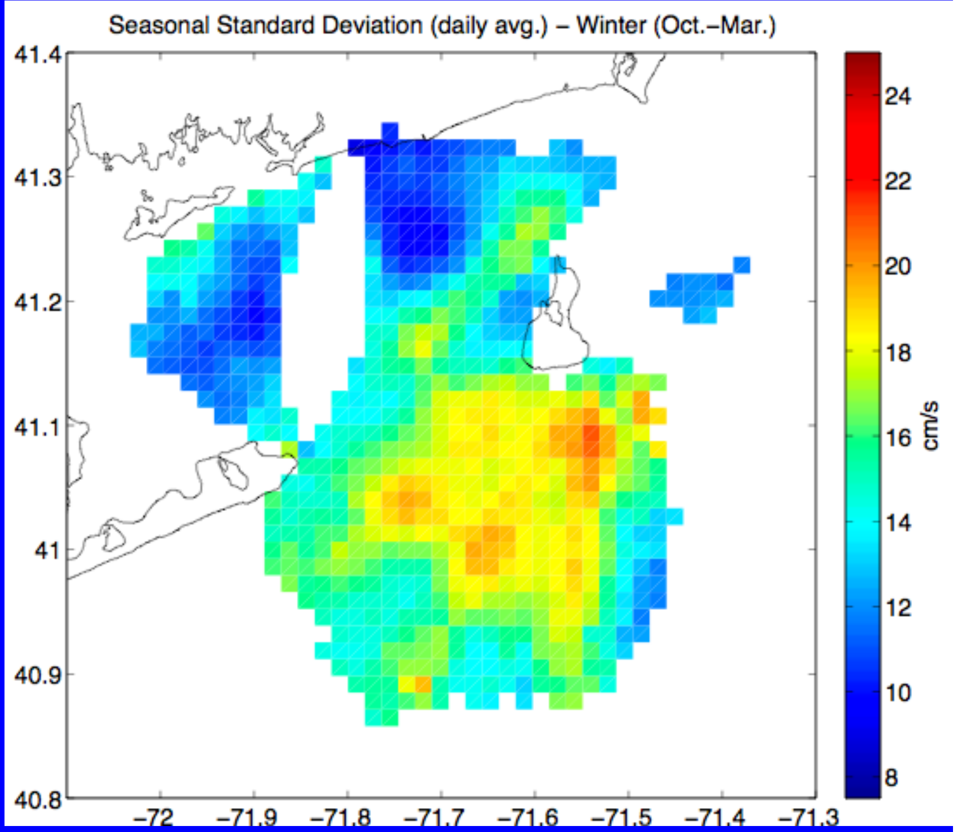
Summer: strong southwestward jet.
Winter: weak along-shelf flow.

Surface Current Standard Deviation (Seasonal)

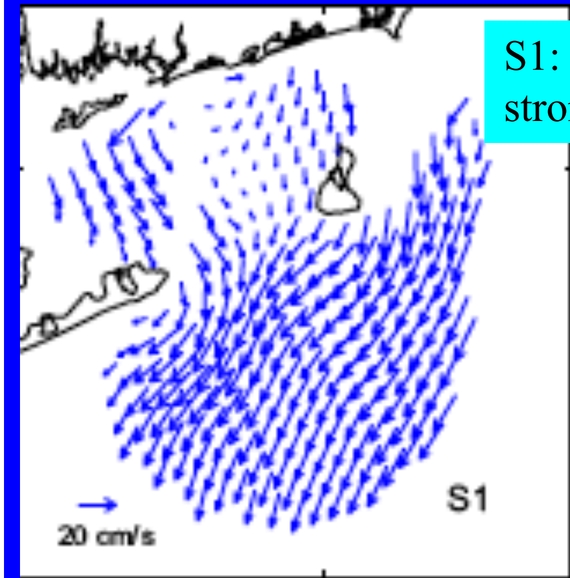
summer



winter

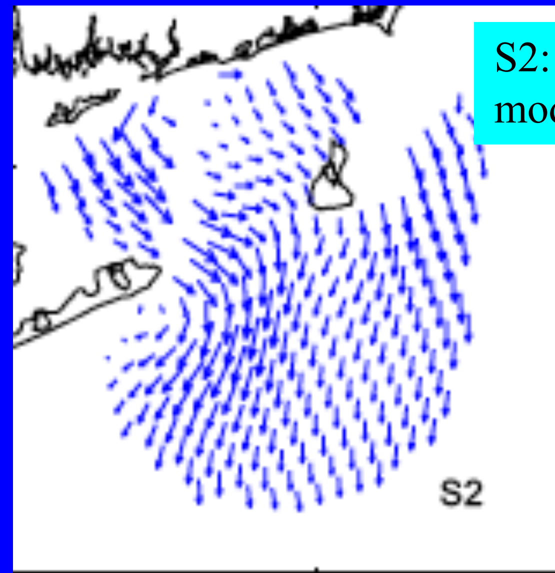


Summer Surface Current Patterns



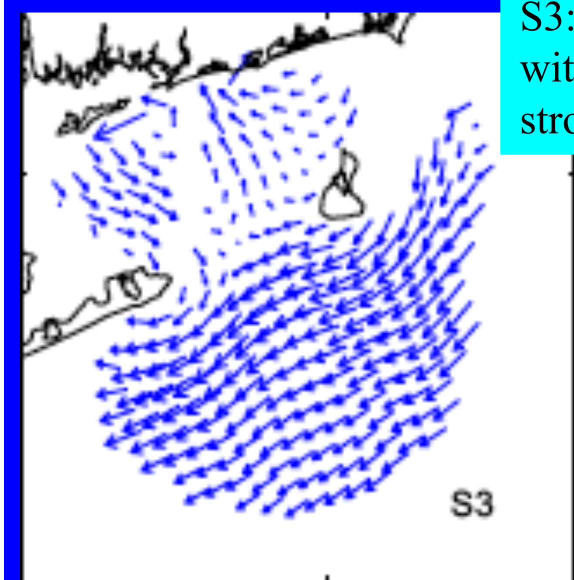
S1: Strong LIS outflow, strong coastal current

22%



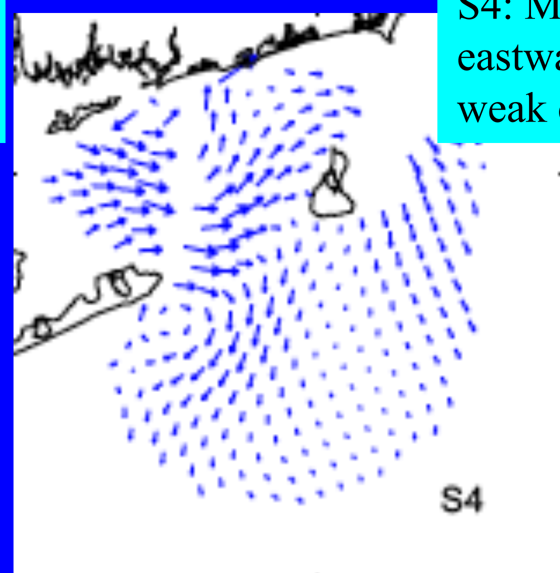
S2: Strong LIS outflow, moderate coastal current

24%



S3: Moderate LIS outflow with BIS recirculation, strong coastal current

28%

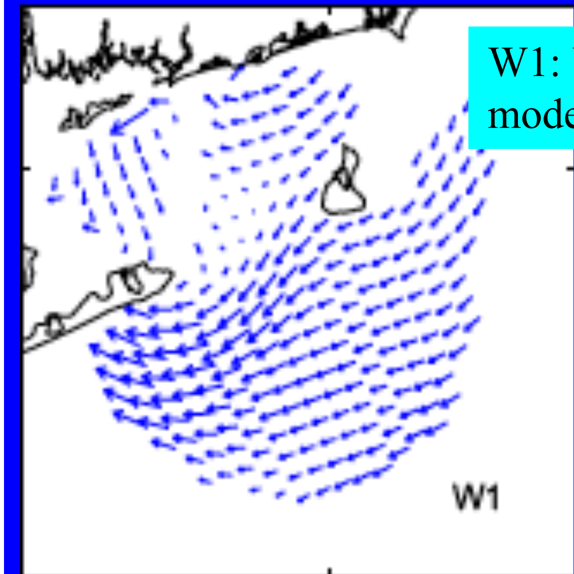


S4: Moderate LIS outflow, eastward BIS flow, weak coastal current

26%

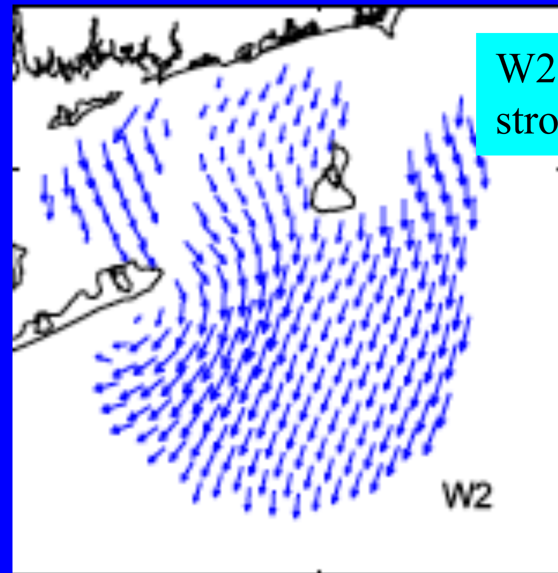
From Mau et al. ECSS 2007

Winter Surface Current Patterns



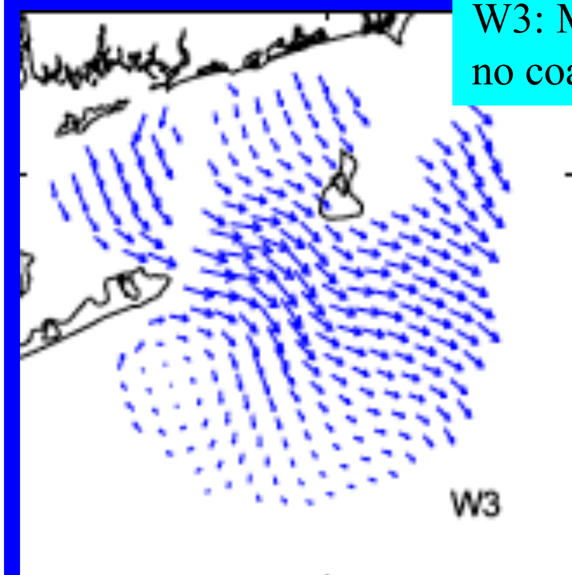
W1: Weak LIS outflow, moderate coastal current

23%



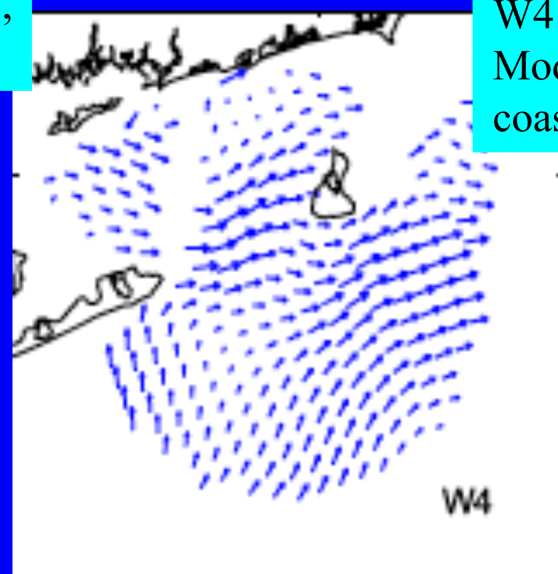
W2: Moderate LIS outflow, strong coastal current

26%



W3: Moderate LIS outflow, no coastal current

19%



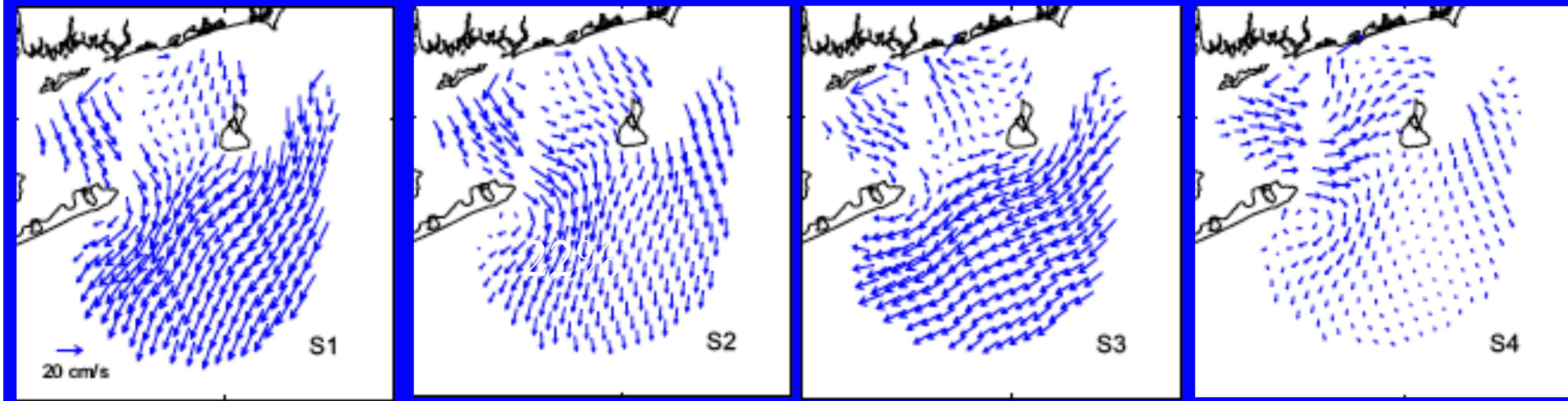
W4: Weak LIS outflow, Moderate NORTHWARD coastal current

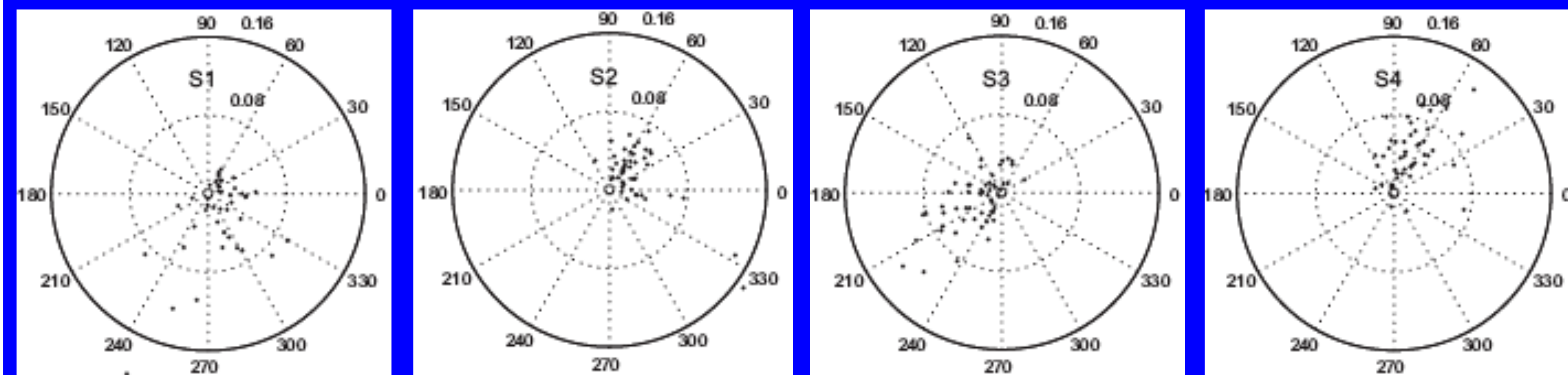
32%

From Mau et al.
ECSS 2007

Summer Current Patterns in Response to Wind

From Mau et al.
ECSS 2007





Southeastward wind

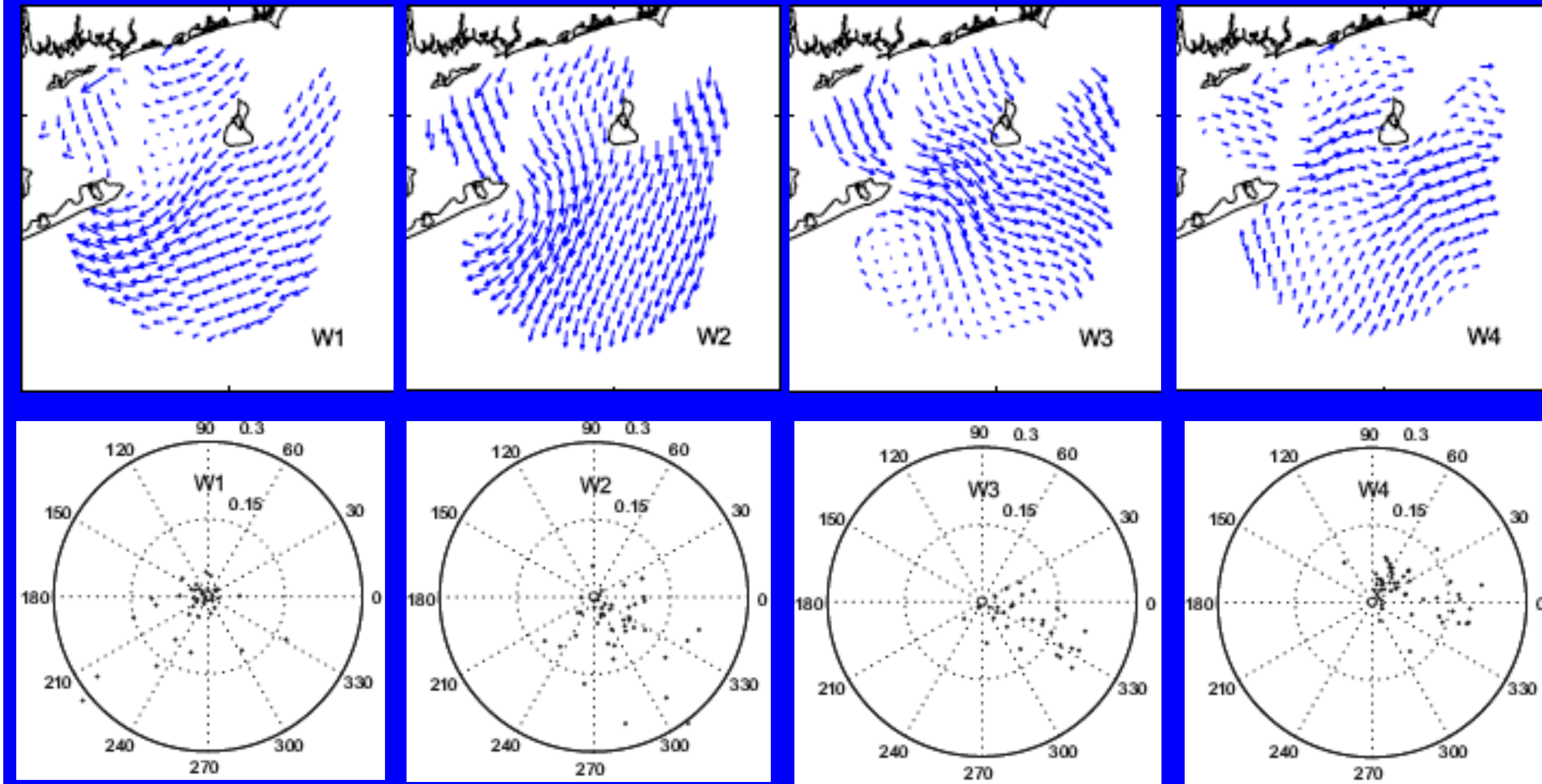
Northeastward wind

West-southwestward wind

North-Northeastward wind

Winter Current Patterns in Response to Wind

From Mau et al.
ECSS 2007



Southwestward winds

South-Southeastward winds

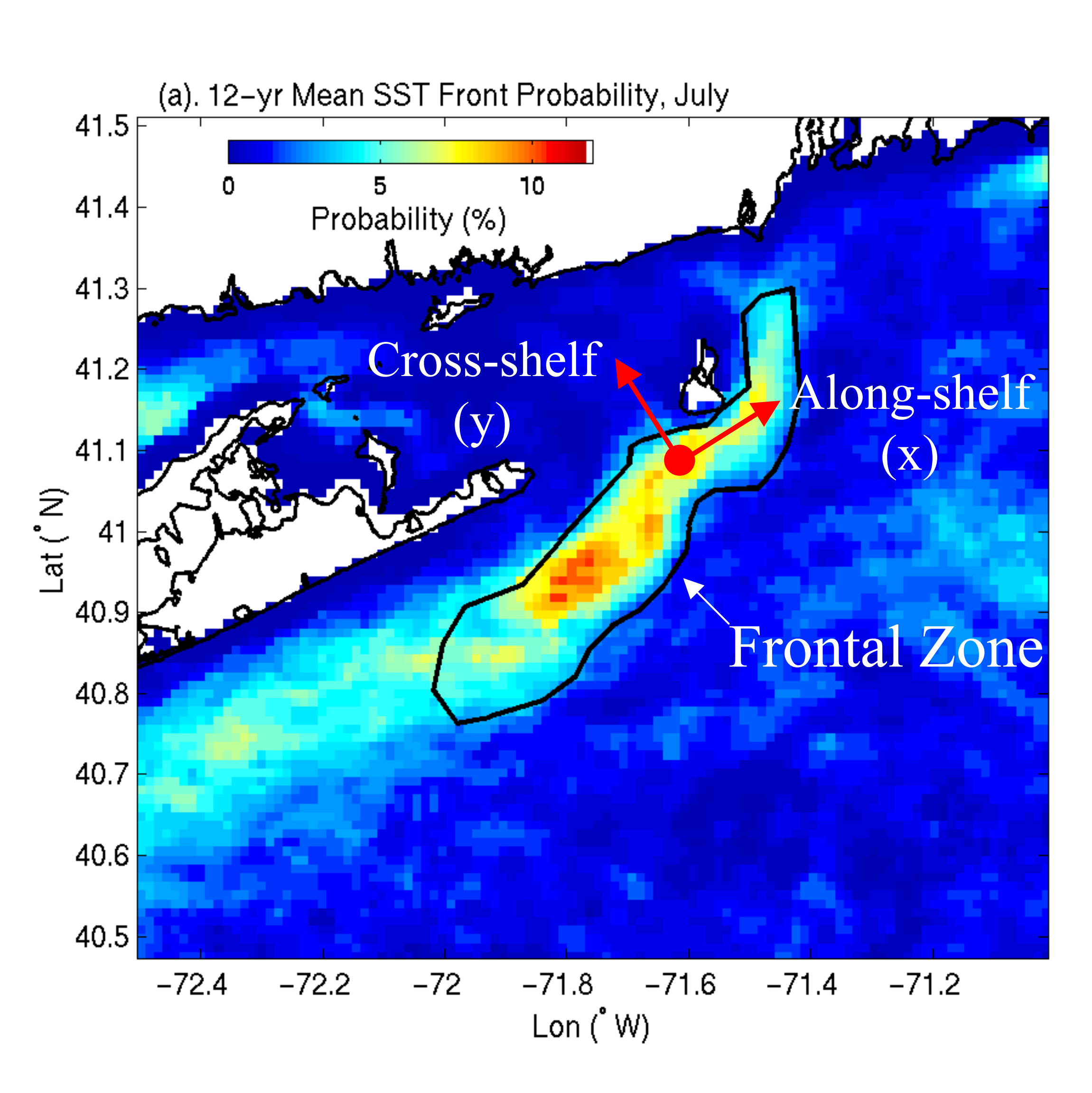
East-Southeastward winds

Eastward winds

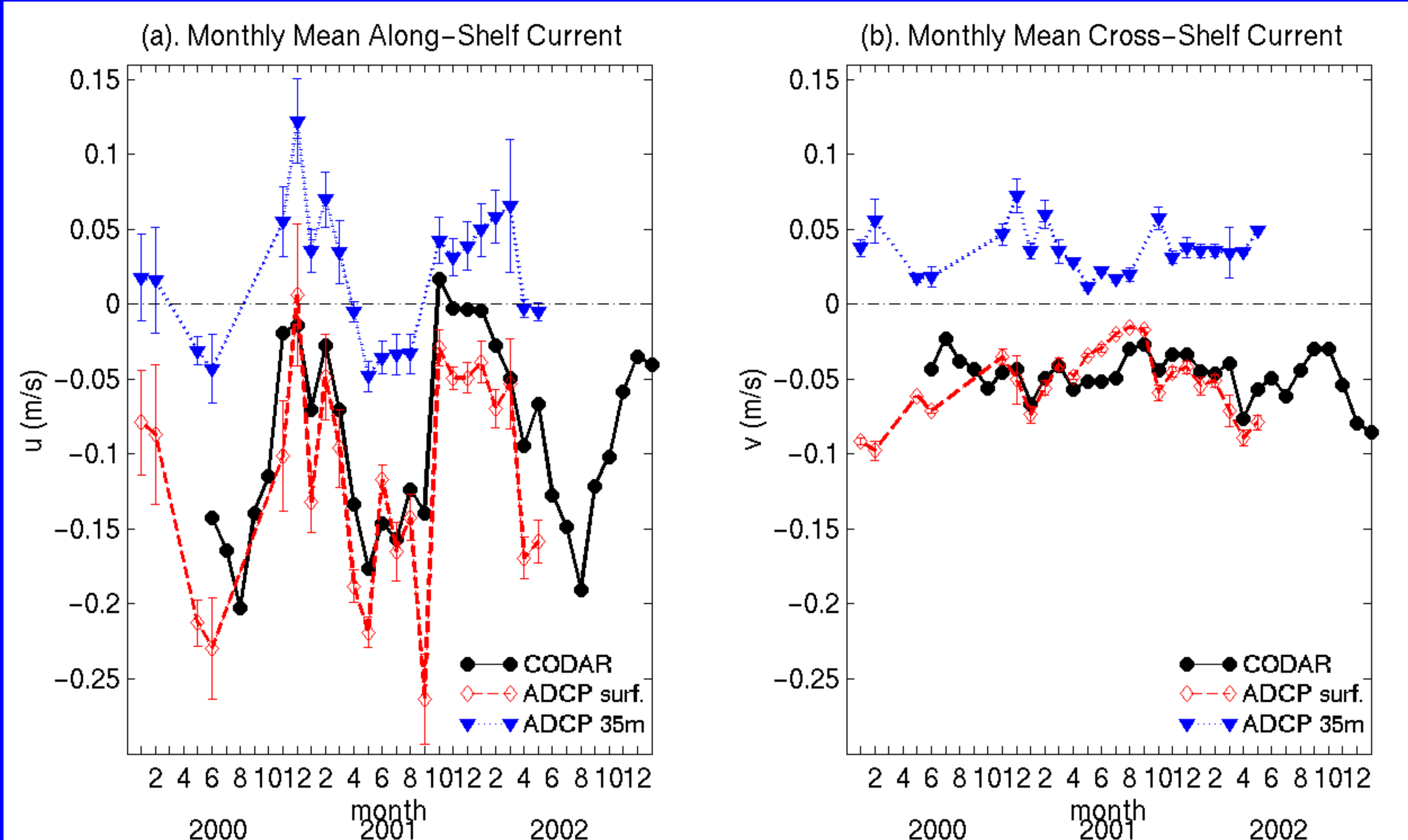
Velocity Averaging

Average CODAR and ADCP currents on **monthly** basis and spatially over frontal zone.

Along-shelf direction:
57.5°True
(average principal axis direction within frontal zone)

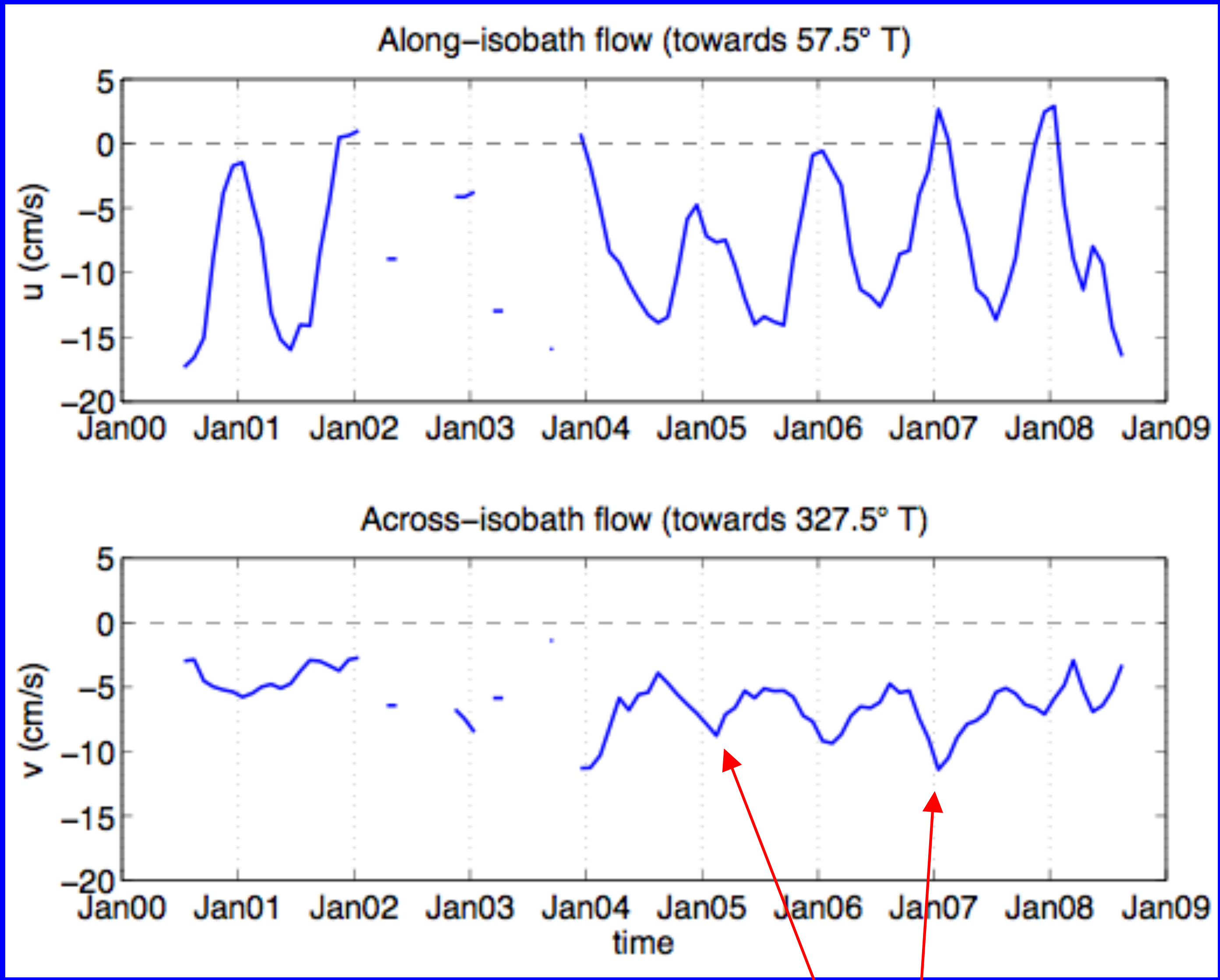


Seasonal Current Variability in Frontal Zone



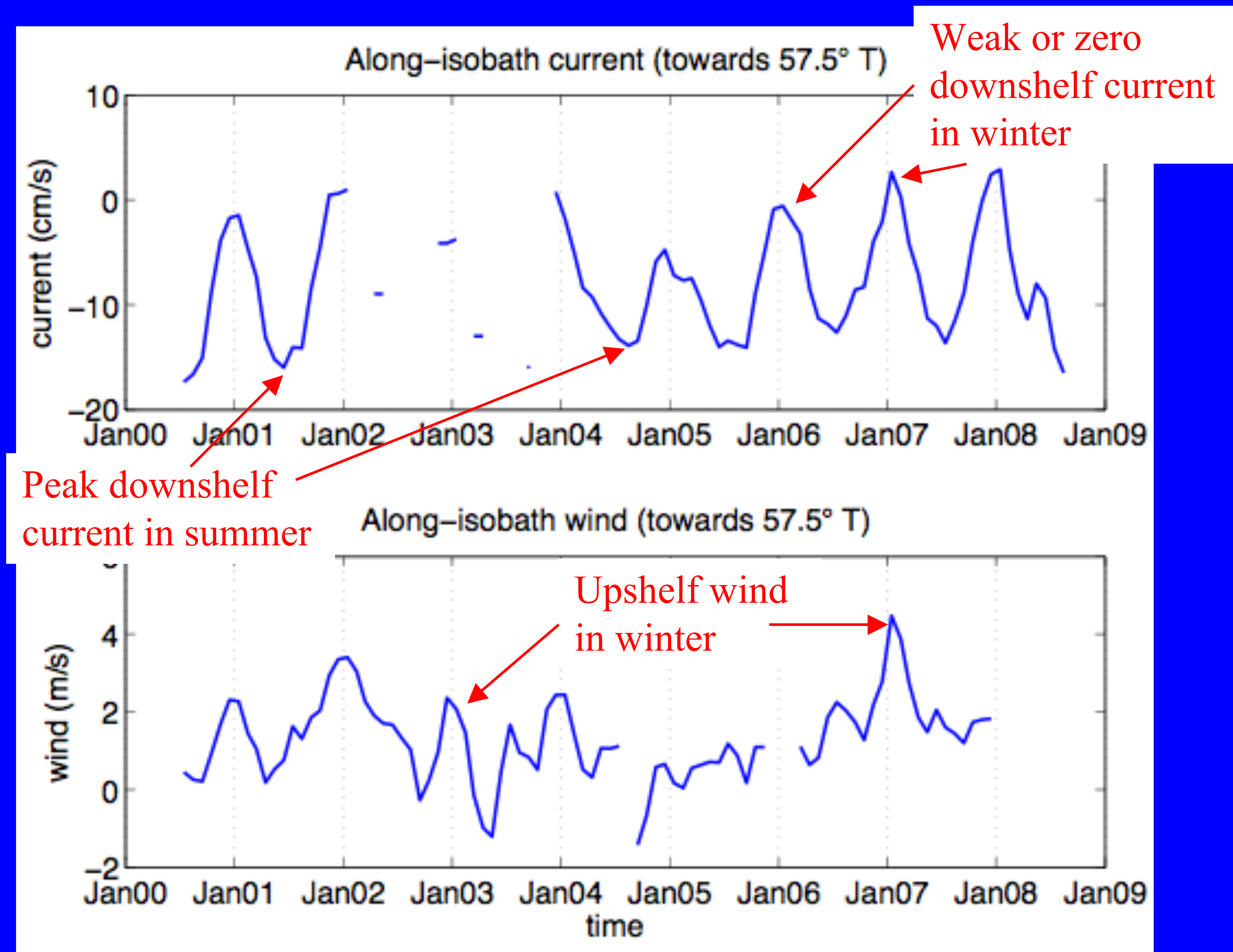
From: Ullman and Codiga, 2004.

Long-term view (2000-2008)

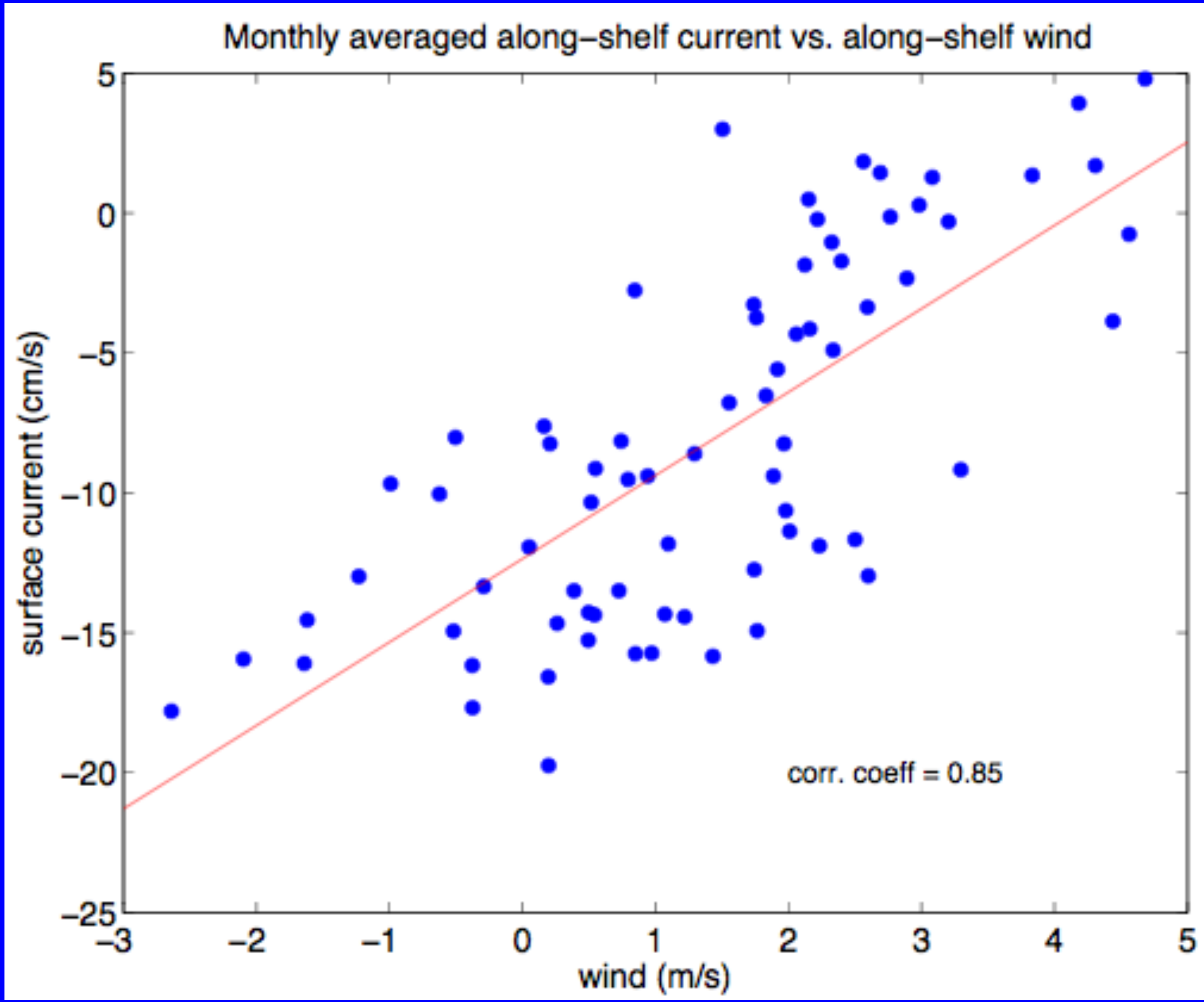


Cross-isobath component: strongest offshore in winter.

Relation to wind

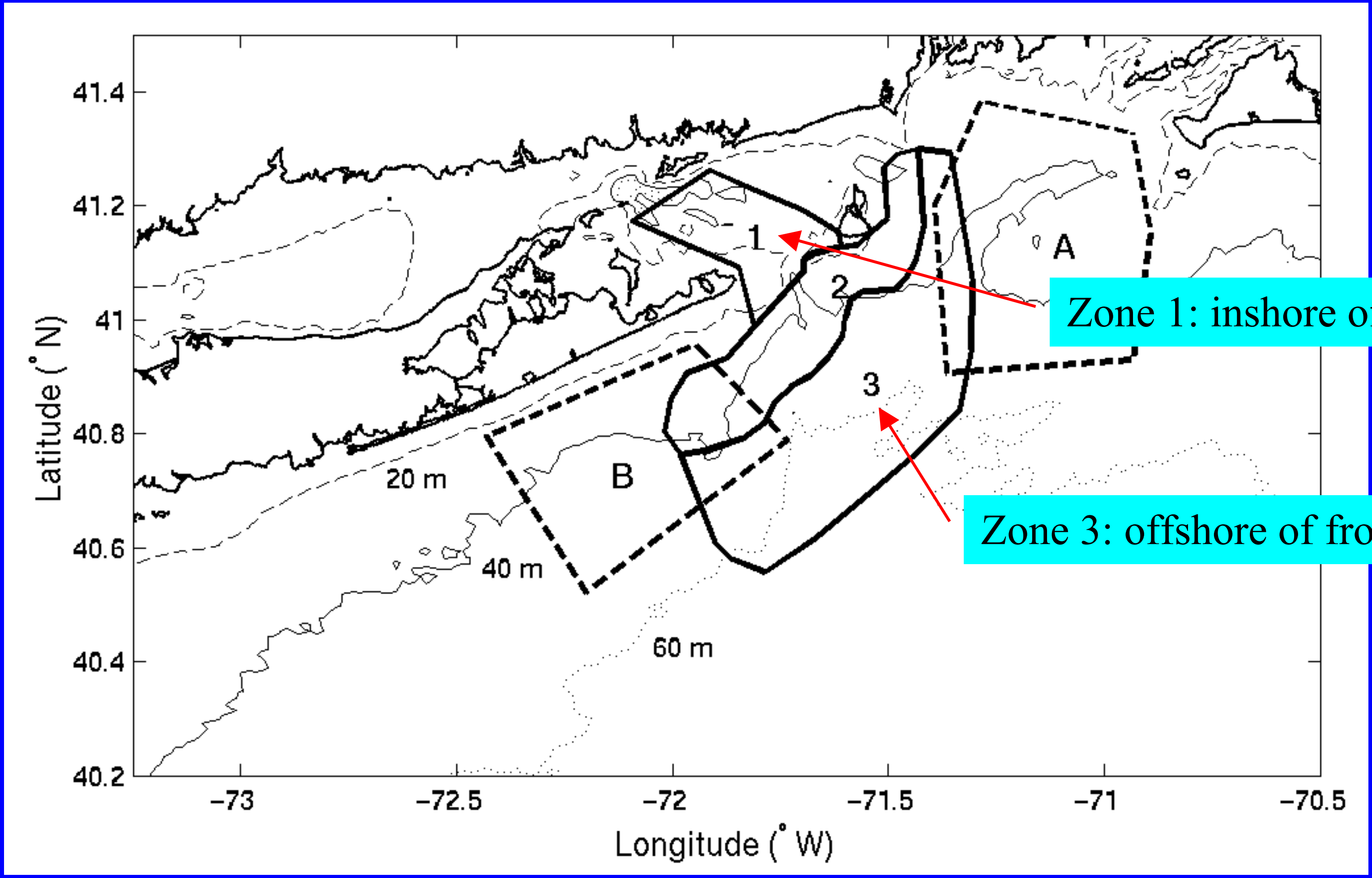


Relation to wind



Monthly Climatological Hydrography

Averaged all available hydrographic casts from World Ocean Database (1998) and FRONT cruises by month and within zones defined here.

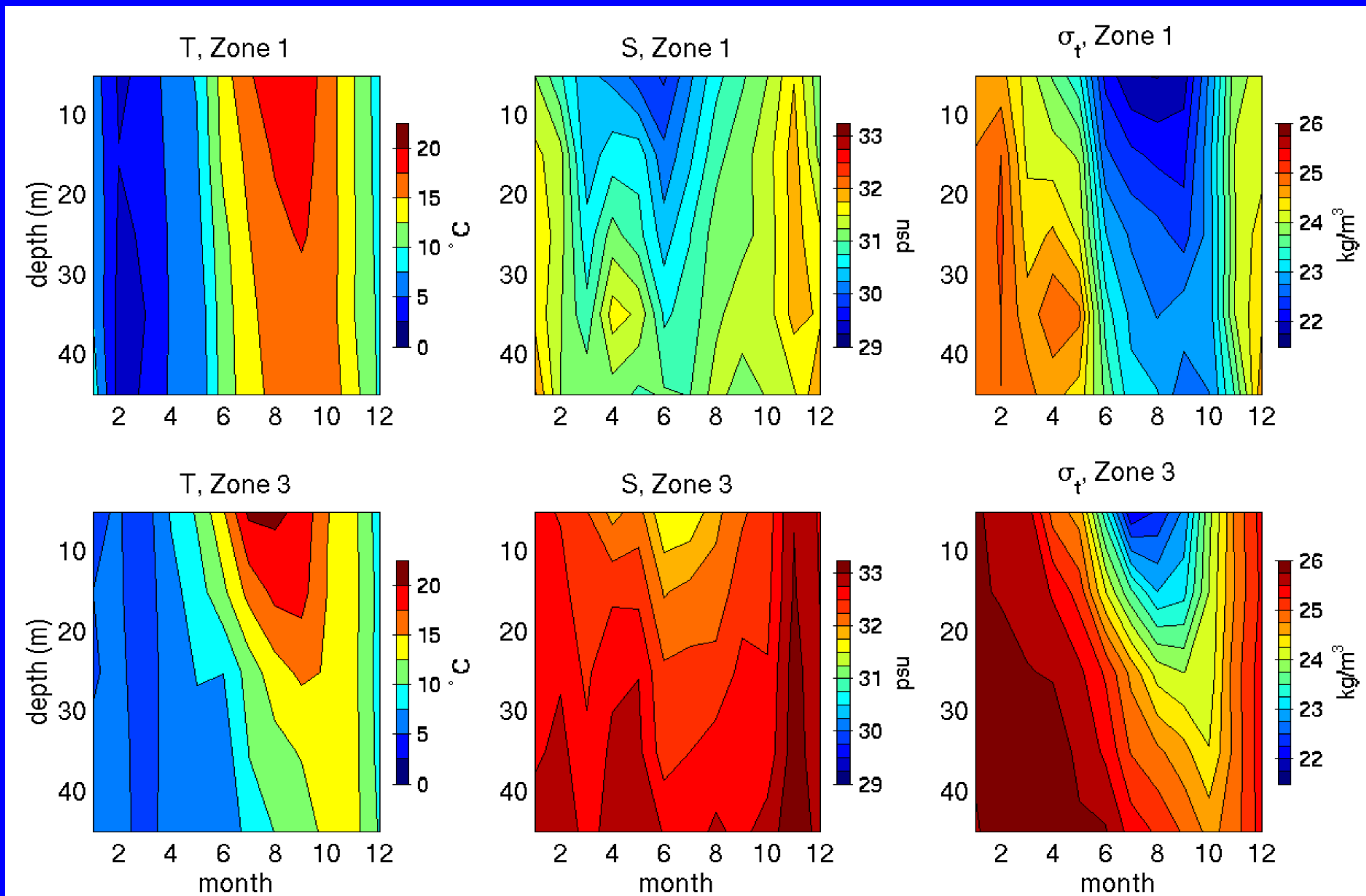


Zone 1: inshore of front/jet

Zone 3: offshore of front/jet

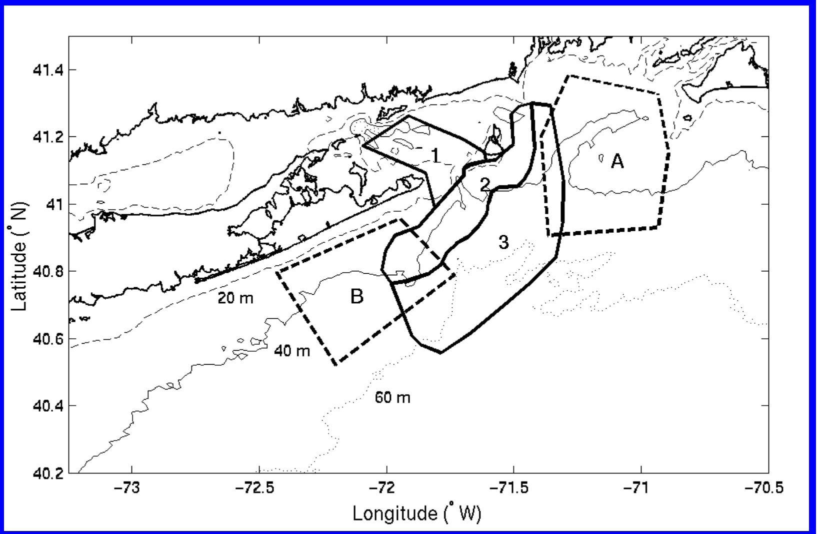
Monthly Climatological Hydrography

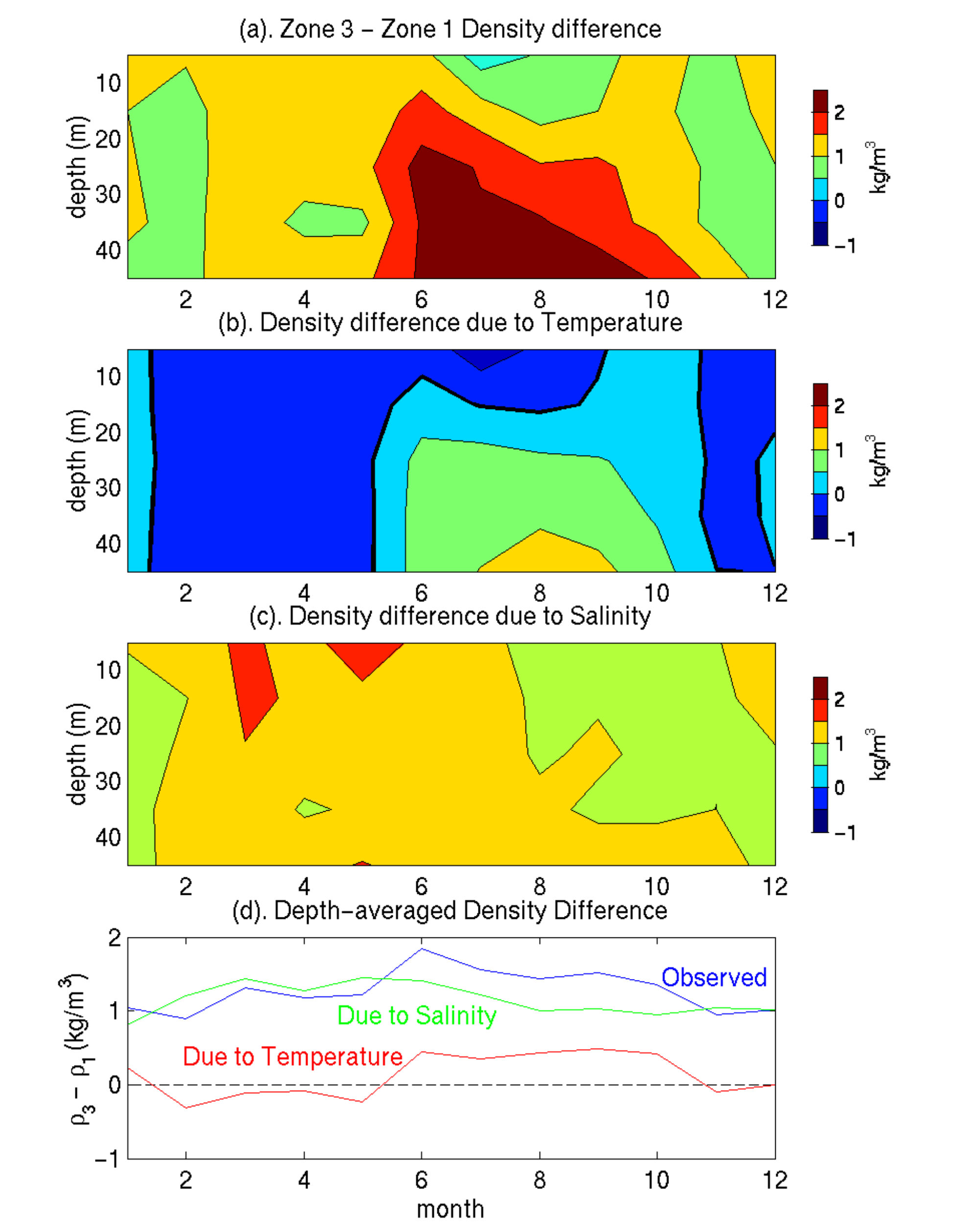
Temp. | Salinity | Sigma-t



From: Ullman and Codiga, 2004.

Zone 3 – Zone 1 Density Difference





•Cross-shelf density gradient dominated by effects of salinity.

•Effects of temperature become relatively more important in summer.

From: Ullman and Codiga, 2004.

Depth and Tidally Averaged Momentum Balance

Decompose velocity into tidally averaged (u,v) and tidal (U,V) components:

$$(u^*, v^*) = (u, v) + (U, V)$$

Overbar denotes depth average:

$$\overline{u} = \frac{1}{H}\int_{-H}^{0} u \cdot dz$$

Brackets denote tidal average:

$$u = \langle u^* \rangle = \frac{1}{T}\int_{0}^{T} u^* \cdot dt$$

$$\frac{\partial \overline{u}}{\partial t} = f \cdot \overline{v} - \frac{1}{\rho_0 H}\int_{-H}^{0} \frac{\partial P}{\partial x} \cdot dz + \frac{\tau_{sx}}{H} - \frac{\tau_{bx}}{H} - \left\langle \overline{U}\frac{\partial \overline{U}}{\partial x} + \overline{V}\frac{\partial \overline{U}}{\partial y} \right\rangle \cong 0$$

$$\frac{\partial \overline{v}}{\partial t} = -f \cdot \overline{u} - \frac{1}{\rho_0 H}\int_{-H}^{0} \frac{\partial P}{\partial y} \cdot dz + \frac{\tau_{sy}}{H} - \frac{\tau_{by}}{H} - \left\langle \overline{U}\frac{\partial \overline{V}}{\partial x} + \overline{V}\frac{\partial \overline{V}}{\partial y} \right\rangle \cong 0$$

Local accel. (negligible)

Coriolis

Pressure Grad.

Wind Stress

Bottom Stress

Tidal Stress

Separating Steric and Non-Steric Pressure Gradient Components

Density anomaly: $\varepsilon = \dfrac{(\rho - \rho_0)}{\rho_0}$

Horizontal pressure gradient at depth z: $\dfrac{1}{\rho_0}\dfrac{\partial P}{\partial y} = g\dfrac{\partial \eta}{\partial y} + g\dfrac{\partial}{\partial y}\int_z^0 \varepsilon \cdot dz'$ (1)

Define surface steric height relative to z=-H_m: $\eta_S = -\int_{-H_m}^0 \varepsilon \cdot dz'$

Then: $g\dfrac{\partial \eta_s}{\partial y} + g\dfrac{\partial}{\partial y}\int_{-H_m}^0 \varepsilon \cdot dz' = 0$ (2)

Subtracting (2) from the RHS of (1) gives: $\dfrac{1}{\rho_0}\dfrac{\partial P}{\partial y} = g\dfrac{\partial \eta_{NS}}{\partial y} - g\dfrac{\partial}{\partial y}\int_{-H_m}^z \varepsilon \cdot dz'$

Non-Steric **Steric**

where $\eta_{NS} = \eta - \eta_S$ is the surface departure from the steric setup level.

Terms in Depth-Averaged Momentum Balance

Coriolis

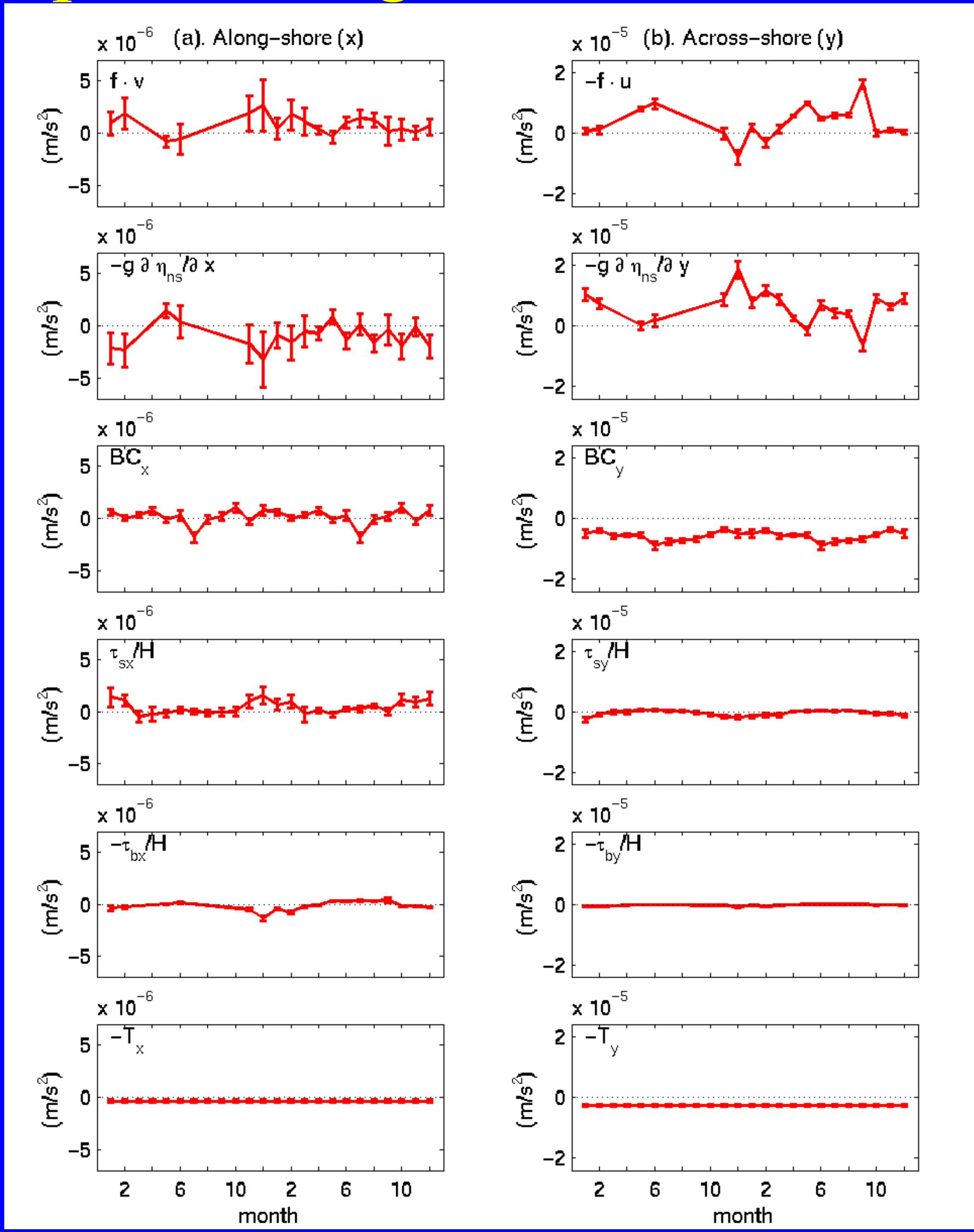
Non-steric P.G. (residual)

Steric P.G.

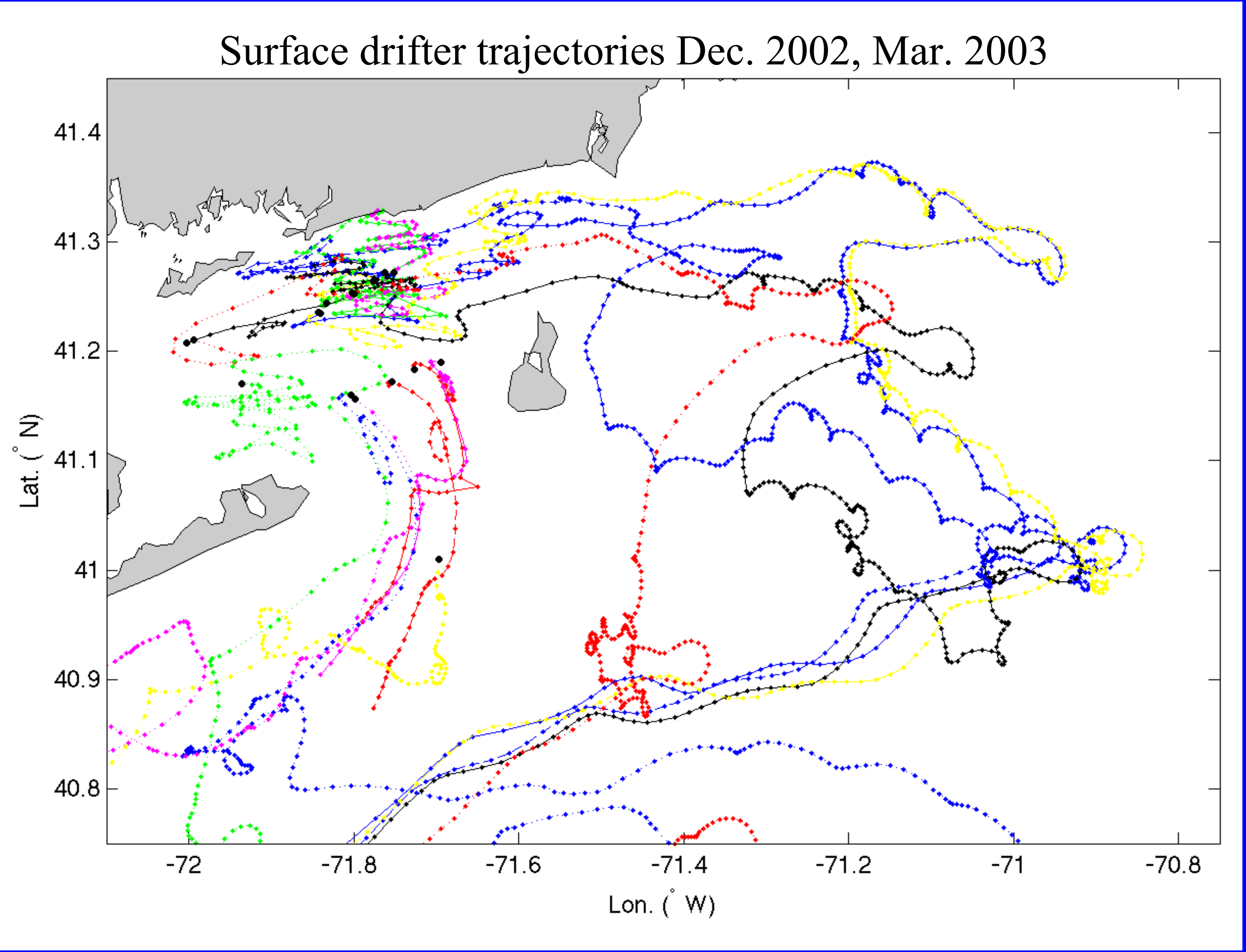
Wind Stress

Bottom Stress

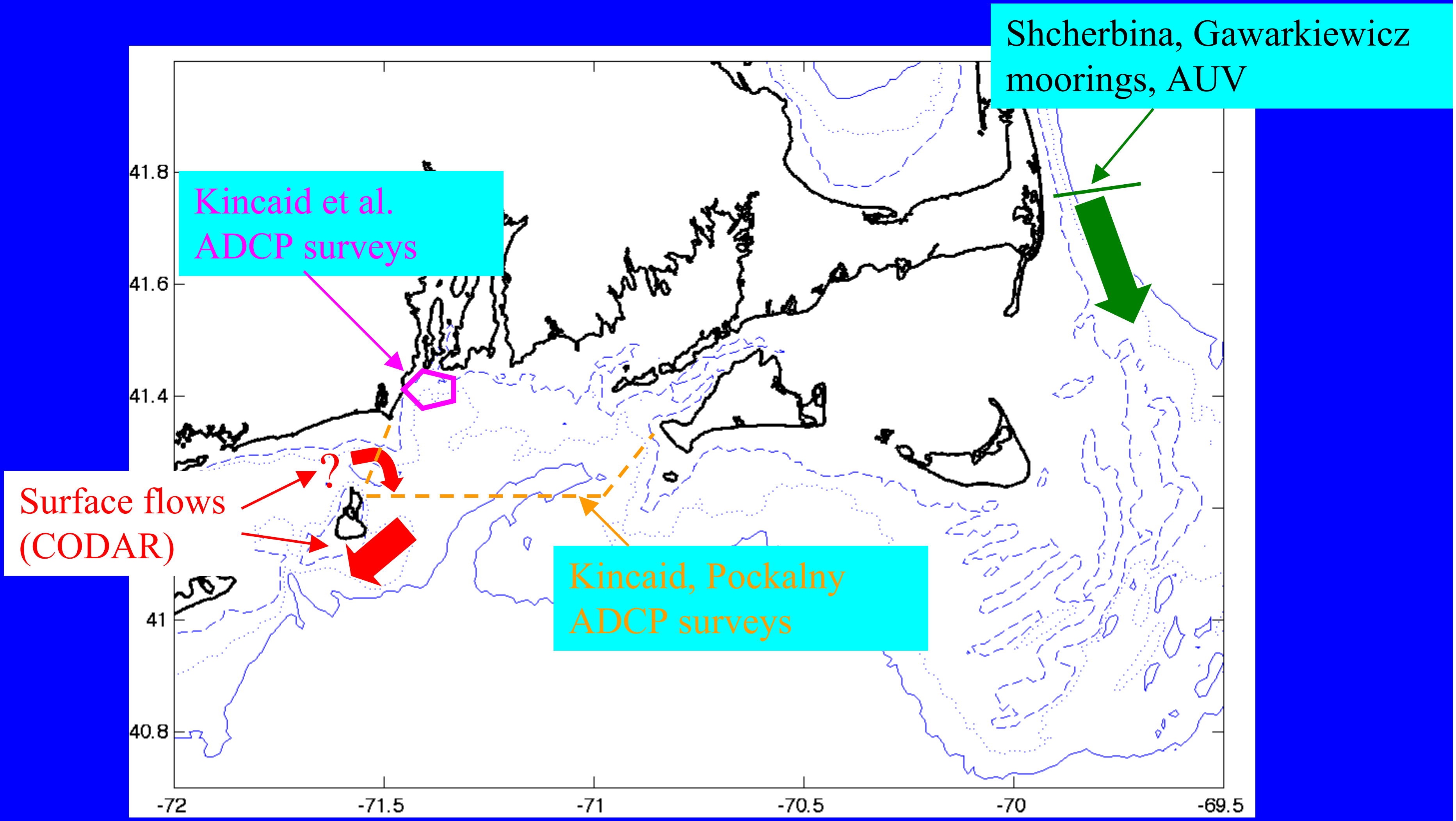
Tidal Stress



Lagrangian perspective: 2 exchange pathways

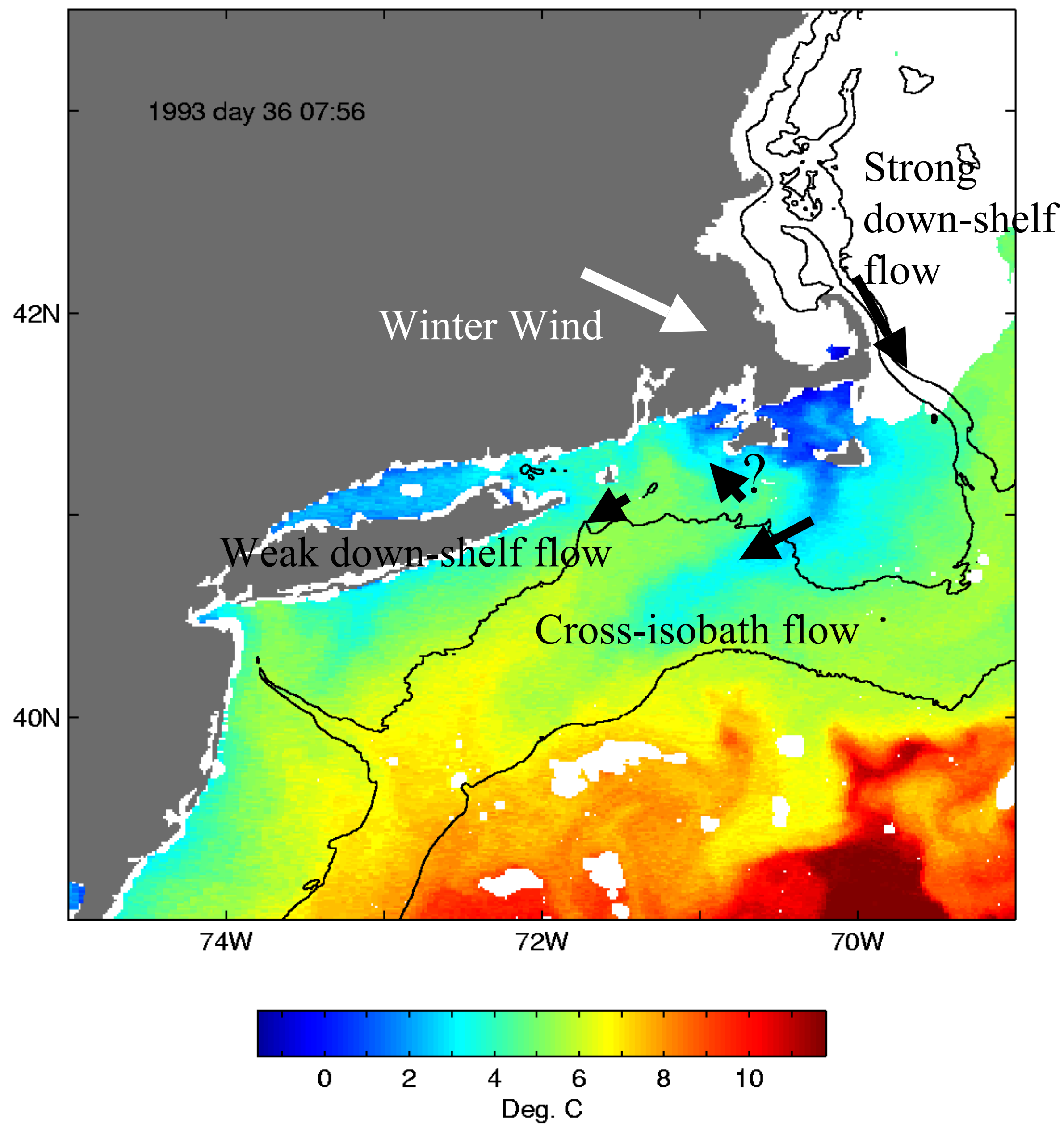


Observations Relevant to Understanding of Rhode Island Sound Circulation



SST Observations Show Cross-Isobath Flow in Winter at Nantucket Shoals

Related to convergence of along-shelf flow?

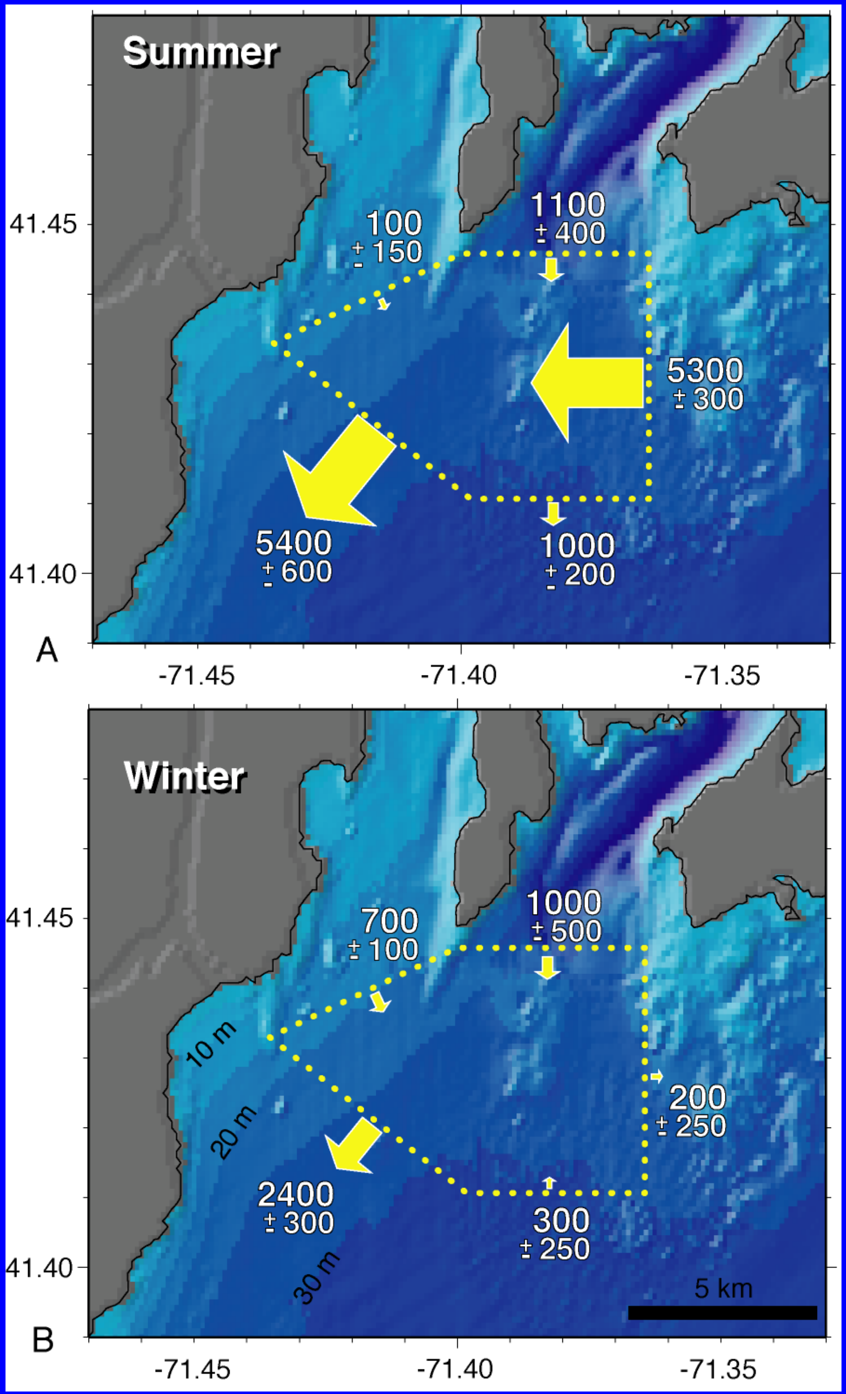


Coastal flow south of Narragansett Bay exhibits seasonal cycle

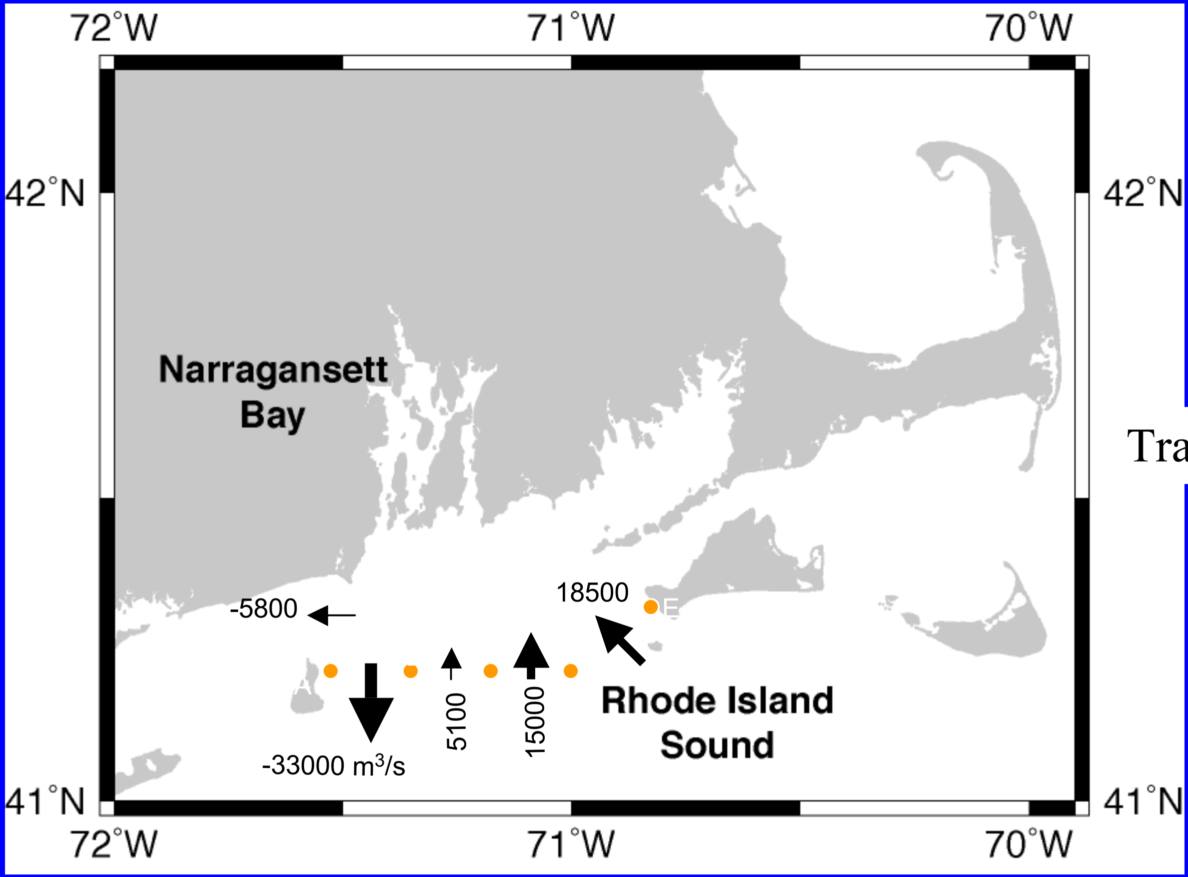
Same seasonal cycle as south of BI:

•Strong in summer, weaker in winter.

From: Kincaid, Pockalny, Huzzey, JGR 2003



Residual transport to Rhode Island Sound (EN410-Summer)

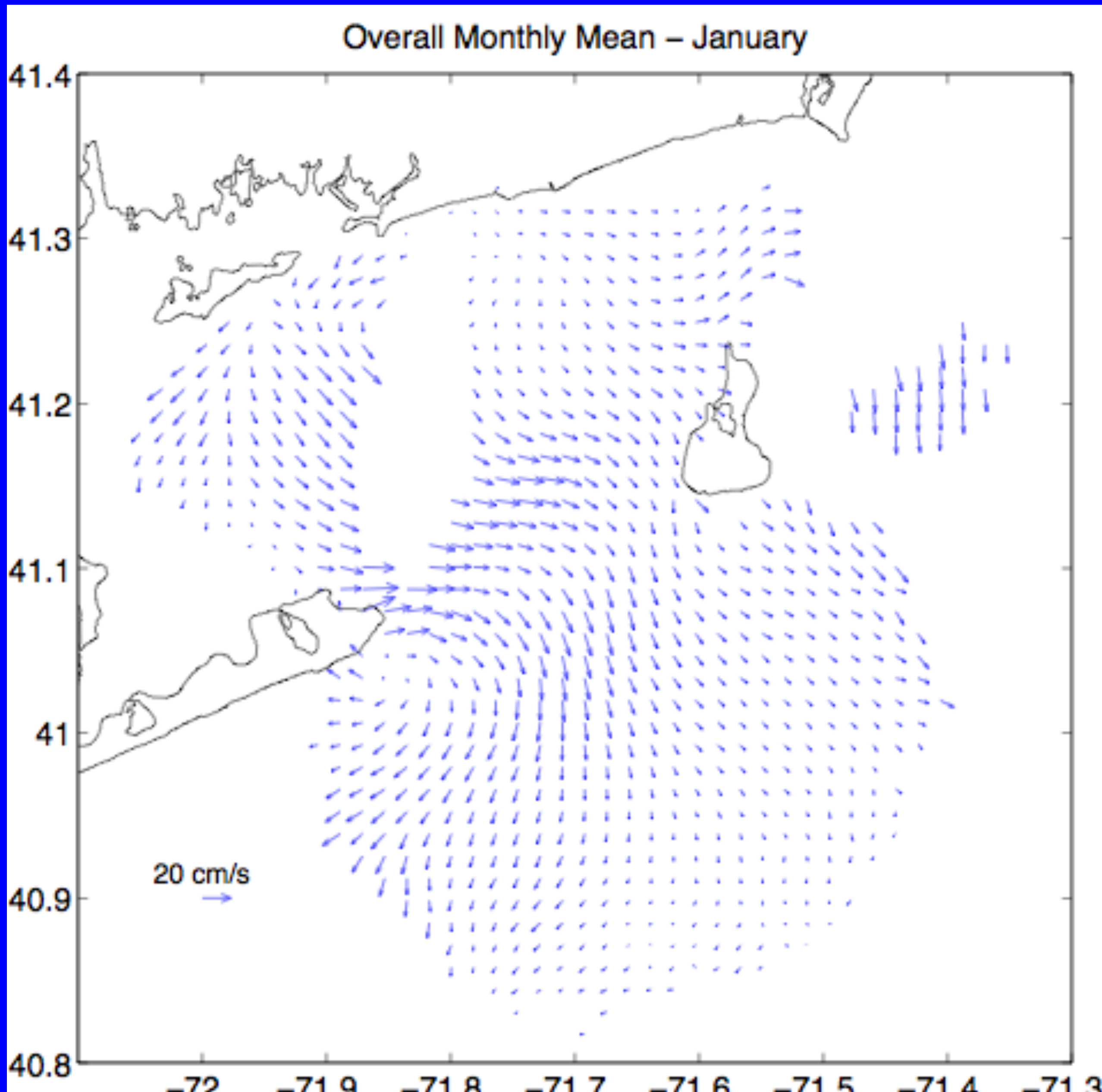


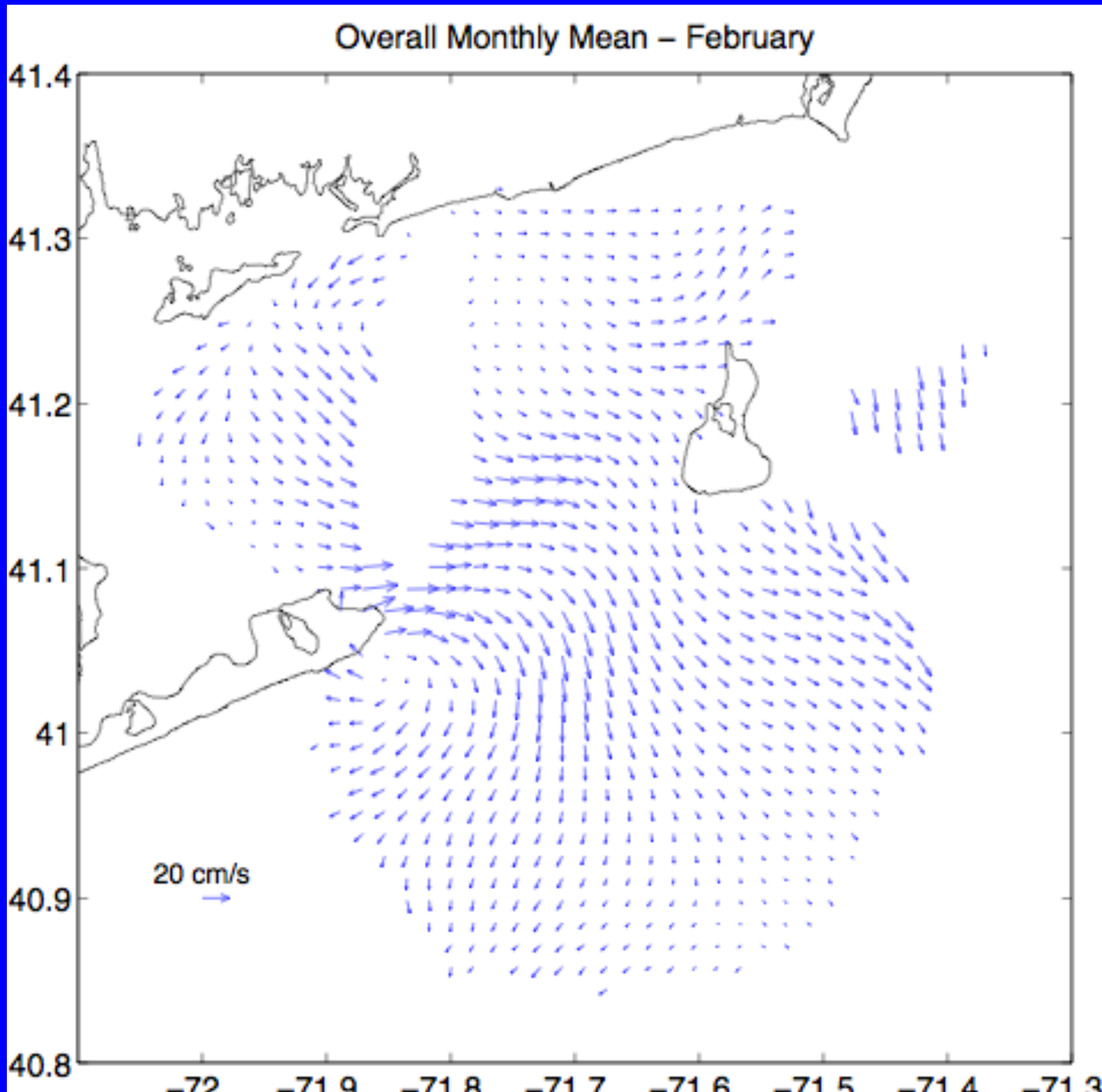
Transports in m^3/s

Figure from C. Kincaid and R. Pockalny

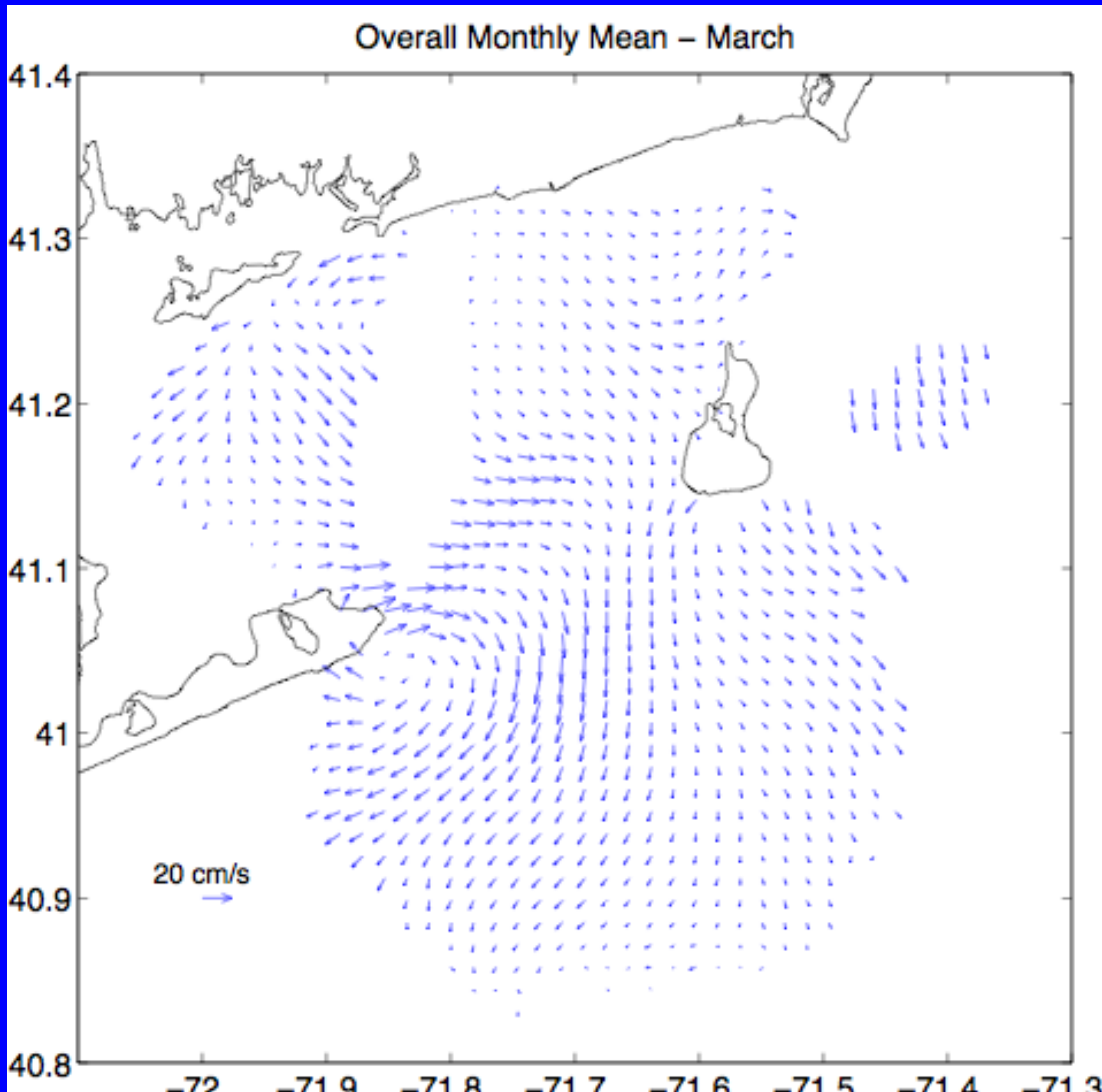
Conclusions

1. Long Island Sound surface outflow exits via Block Island Sound and joins southwestward coastal current.
   - Major outflow from BIS across southern boundary.
   - Minor outflow into RIS.
2. Coastal current varies strongly on seasonal time scales due to seasonal fluctuations in buoyancy and wind forcing.
3. Some evidence that coastal current is quasi-continuous from east of Cape Cod to south of Long Island.
4. Stronger surface current variability (scales of days) in winter.
   - Results in greater cross-shelf (and upshelf) exchange of LIS outflow?

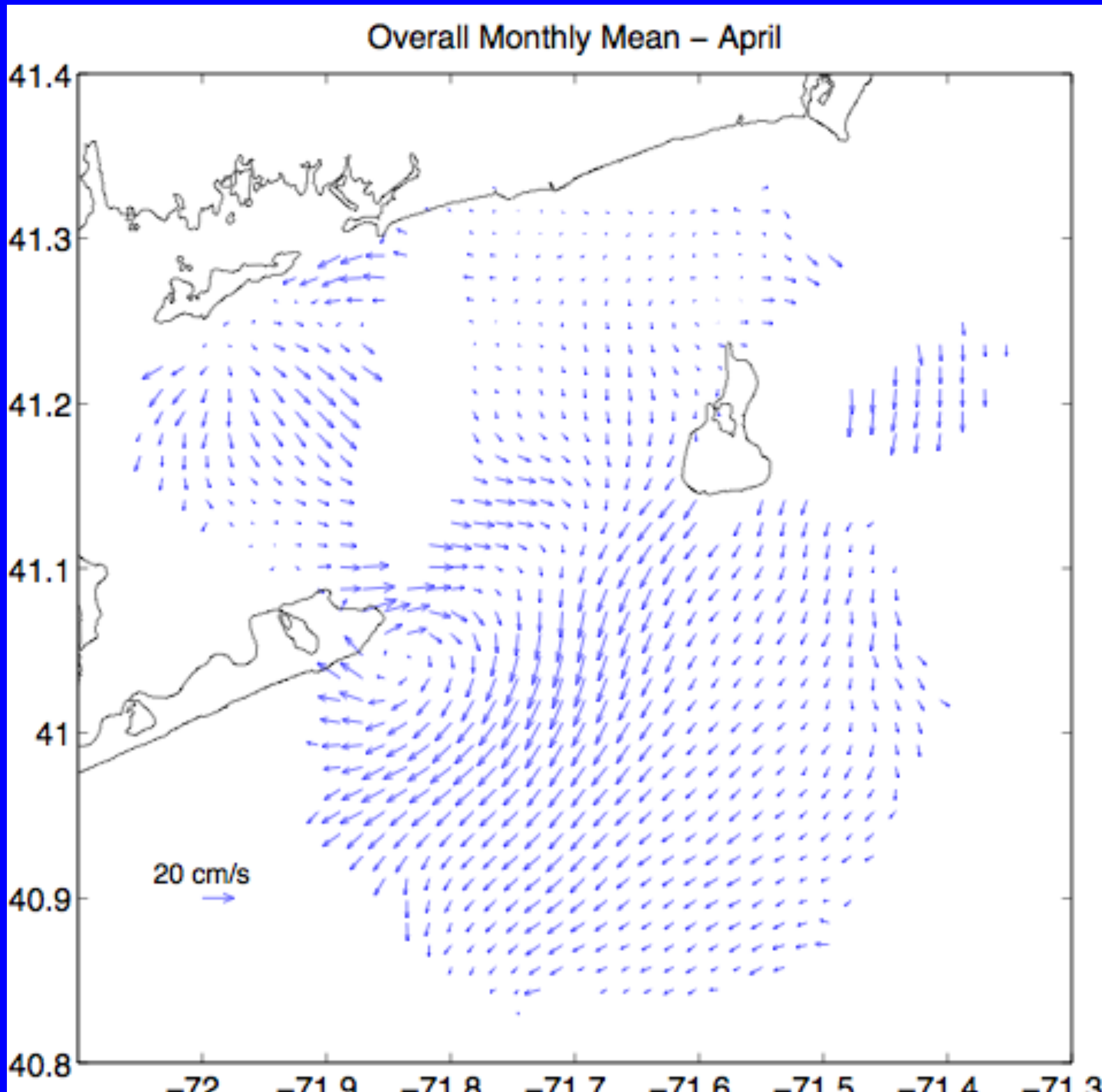

Overall Monthly Mean – January
41.4
41.3
41.2
41.1
41
40.9
40.8
–72
–71.9
–71.8
–71.7
–71.6
–71.5
–71.4
–71.3
20 cm/s



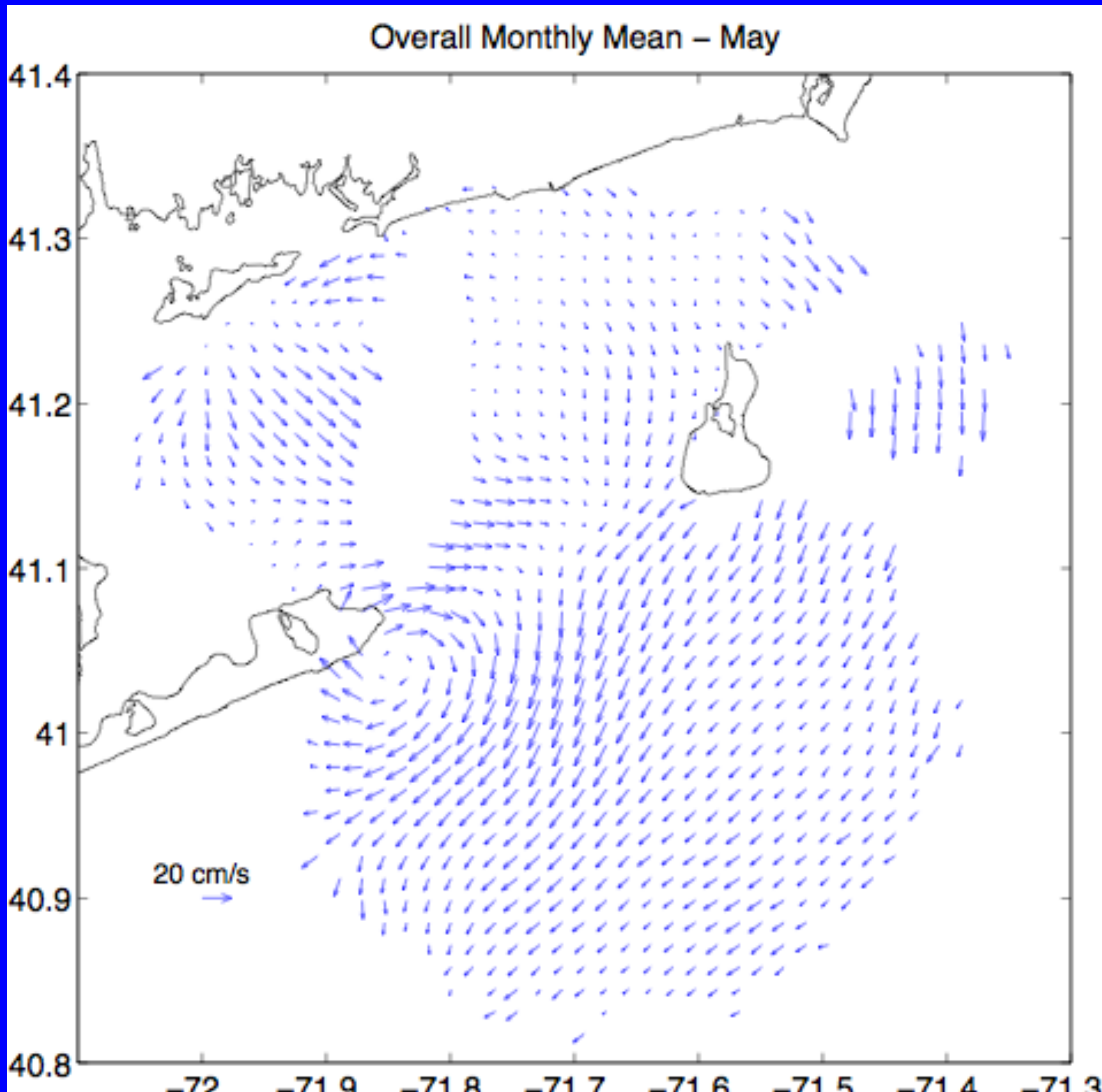
Overall Monthly Mean – February
41.4
41.3
41.2
41.1
41
40.9
40.8
20 cm/s
–72
–71.9
–71.8
–71.7
–71.6
–71.5
–71.4
–71.3

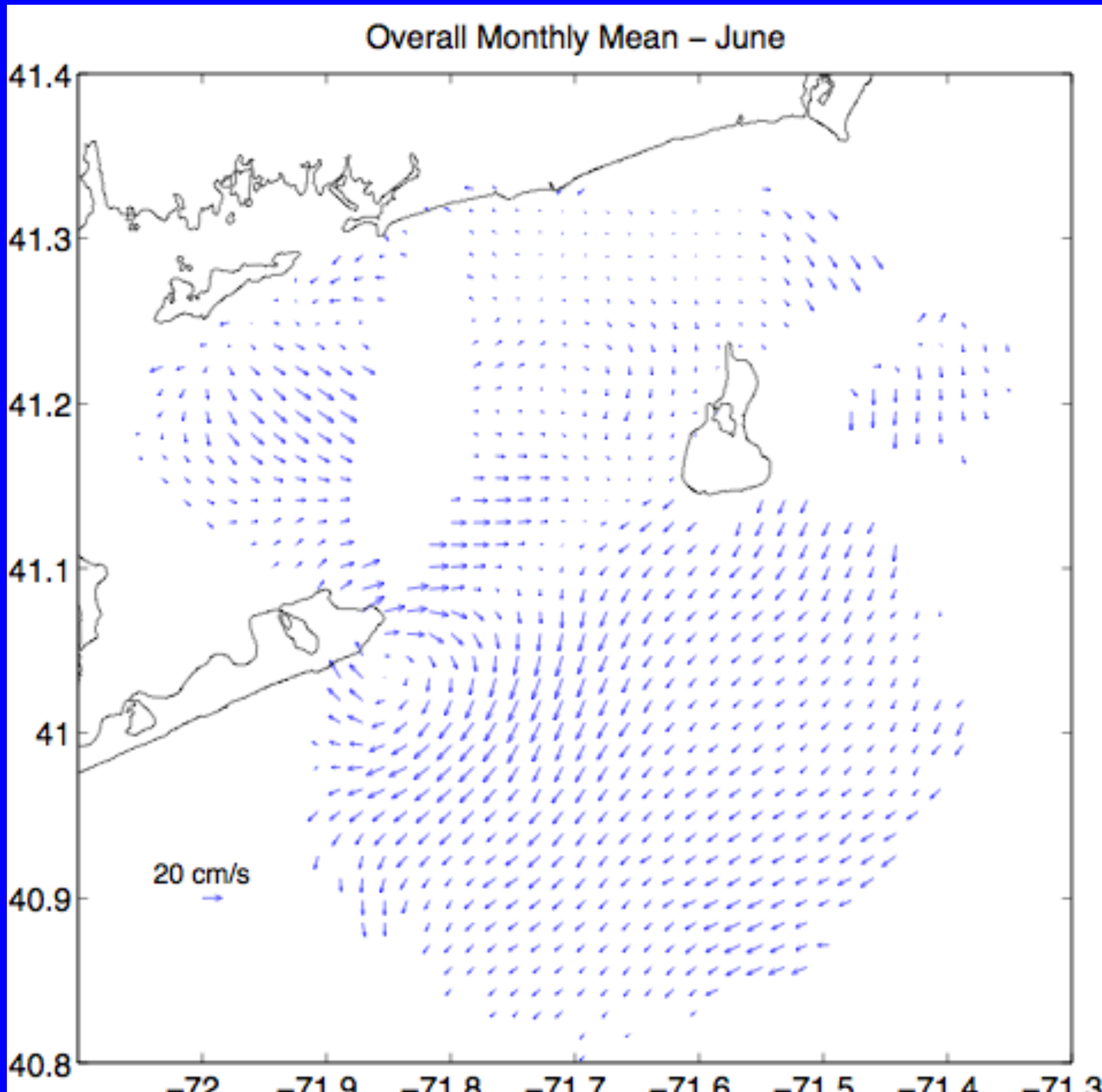


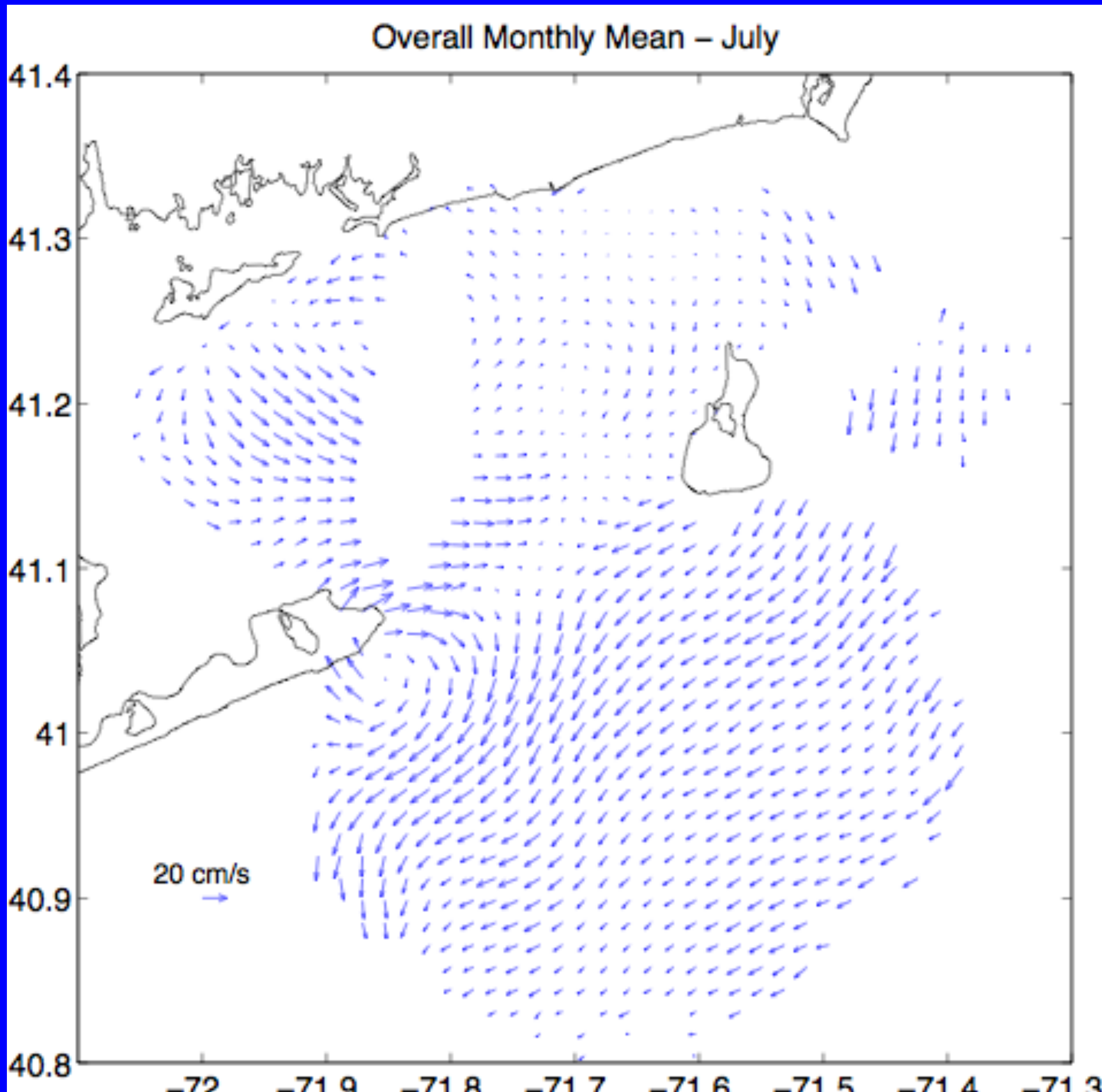
Overall Monthly Mean – March
41.4
41.3
41.2
41.1
41
40.9
40.8
20 cm/s
–72
–71.9
–71.8
–71.7
–71.6
–71.5
–71.4
–71.3



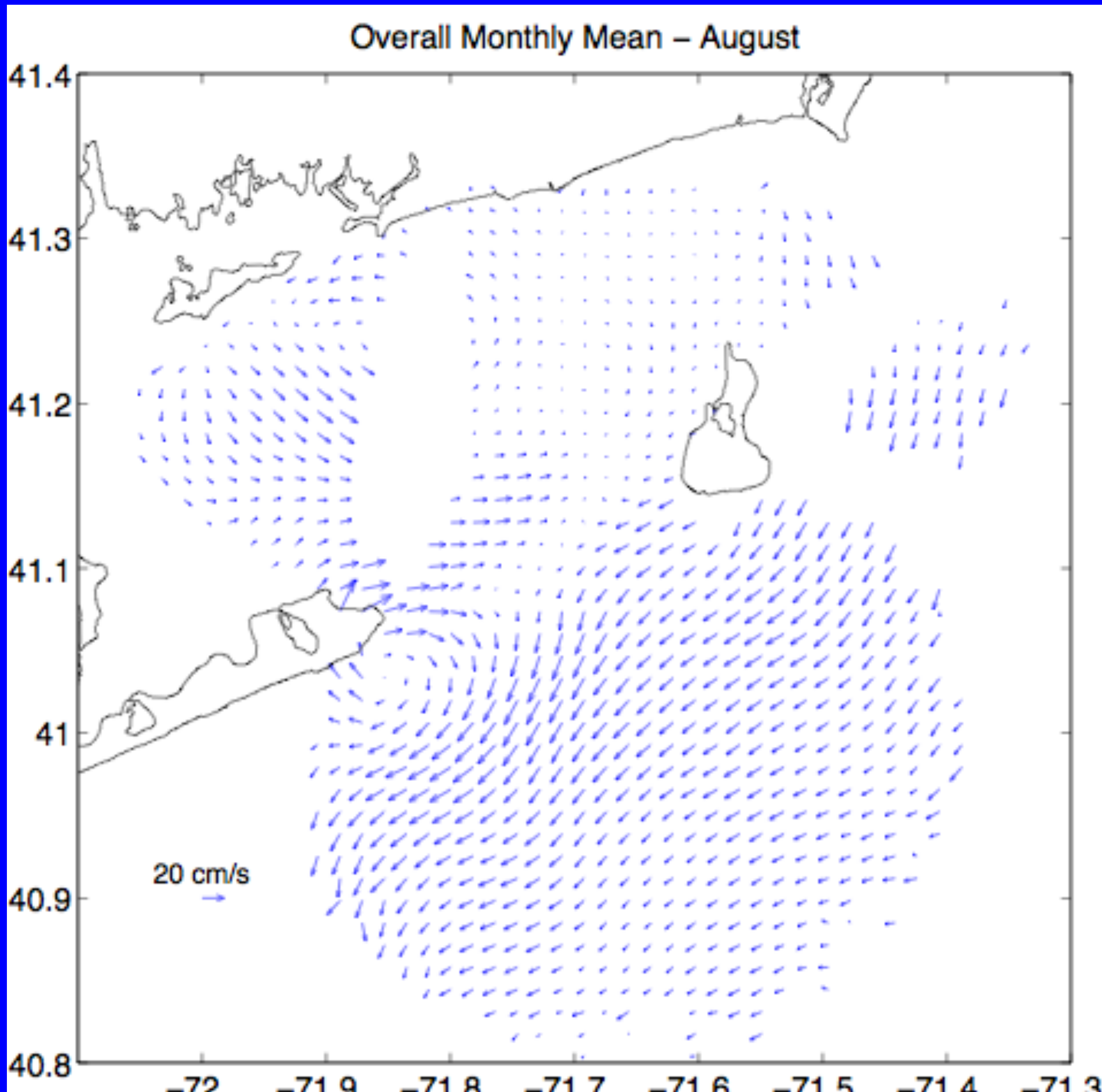
Overall Monthly Mean – April
41.4
41.3
41.2
41.1
41
40.9
40.8
20 cm/s
–72
–71.9
–71.8
–71.7
–71.6
–71.5
–71.4
–71.3


Overall Monthly Mean – May
41.4
41.3
41.2
41.1
41
40.9
40.8
−72
−71.9
−71.8
−71.7
−71.6
−71.5
−71.4
−71.3
20 cm/s

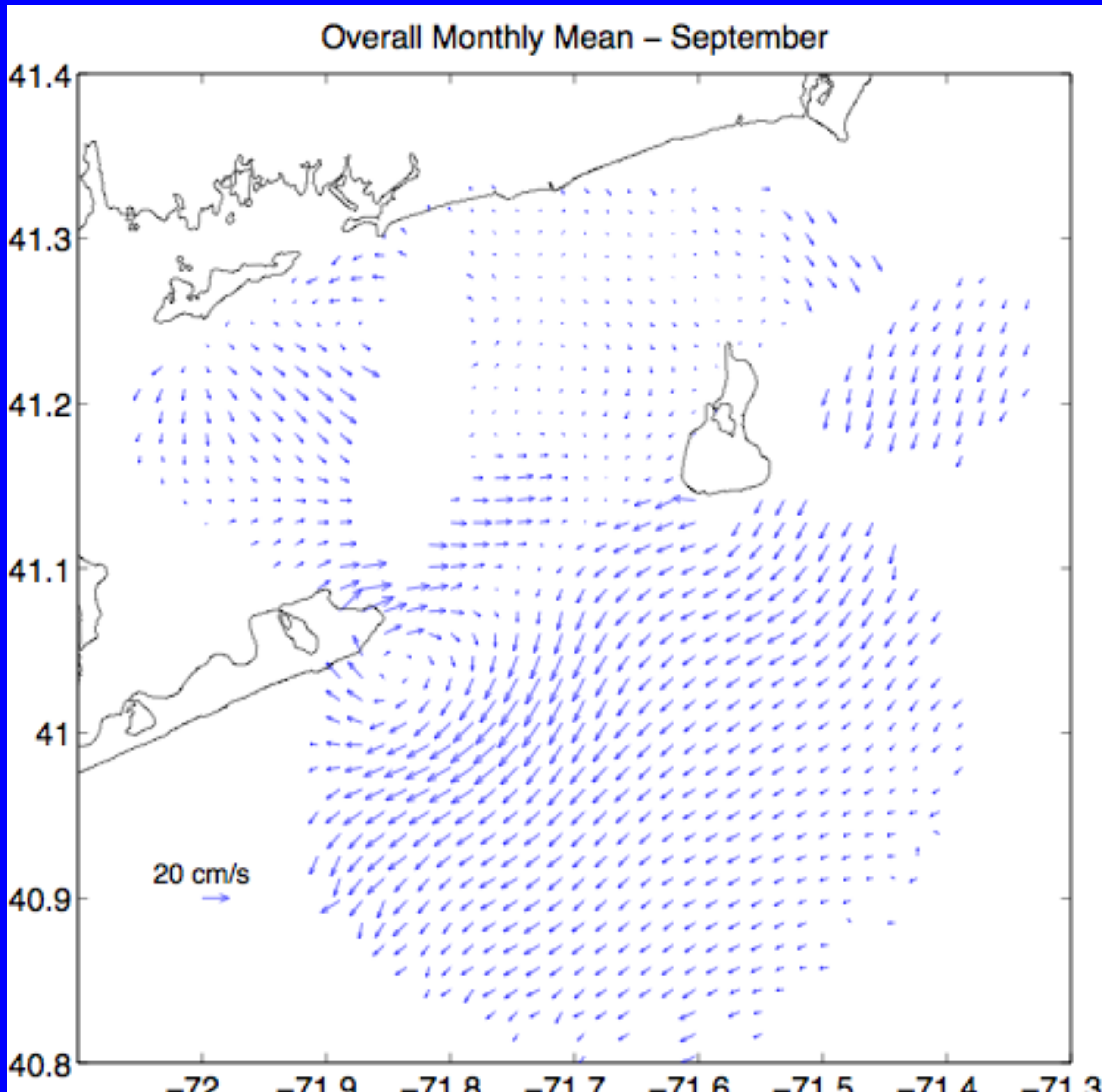

Overall Monthly Mean – June
41.4
41.3
41.2
41.1
41
40.9
40.8
–72
–71.9
–71.8
–71.7
–71.6
–71.5
–71.4
–71.3
20 cm/s



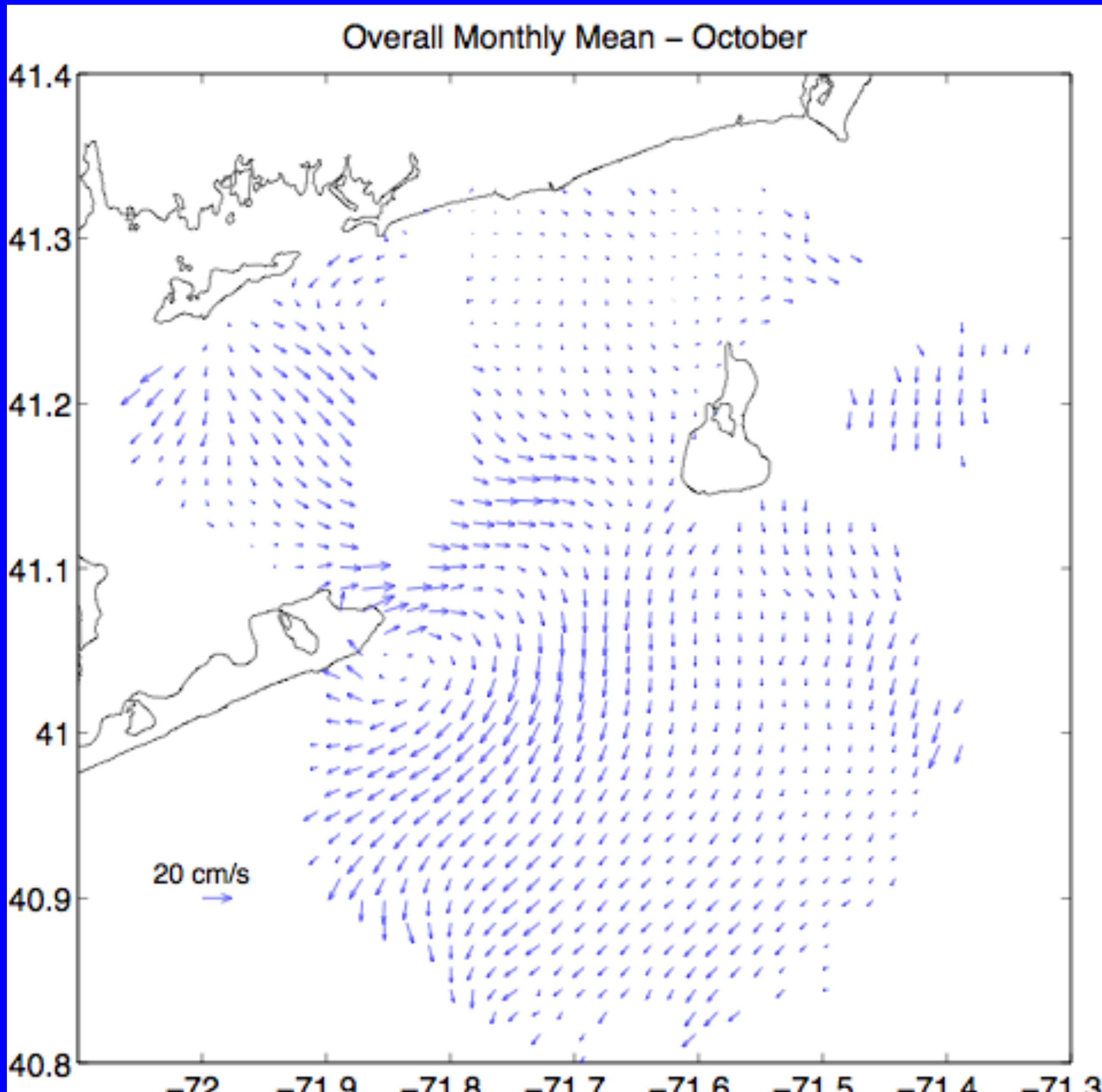
Overall Monthly Mean – July
41.4
41.3
41.2
41.1
41
40.9
40.8
20 cm/s
−72
−71.9
−71.8
−71.7
−71.6
−71.5
−71.4
−71.3

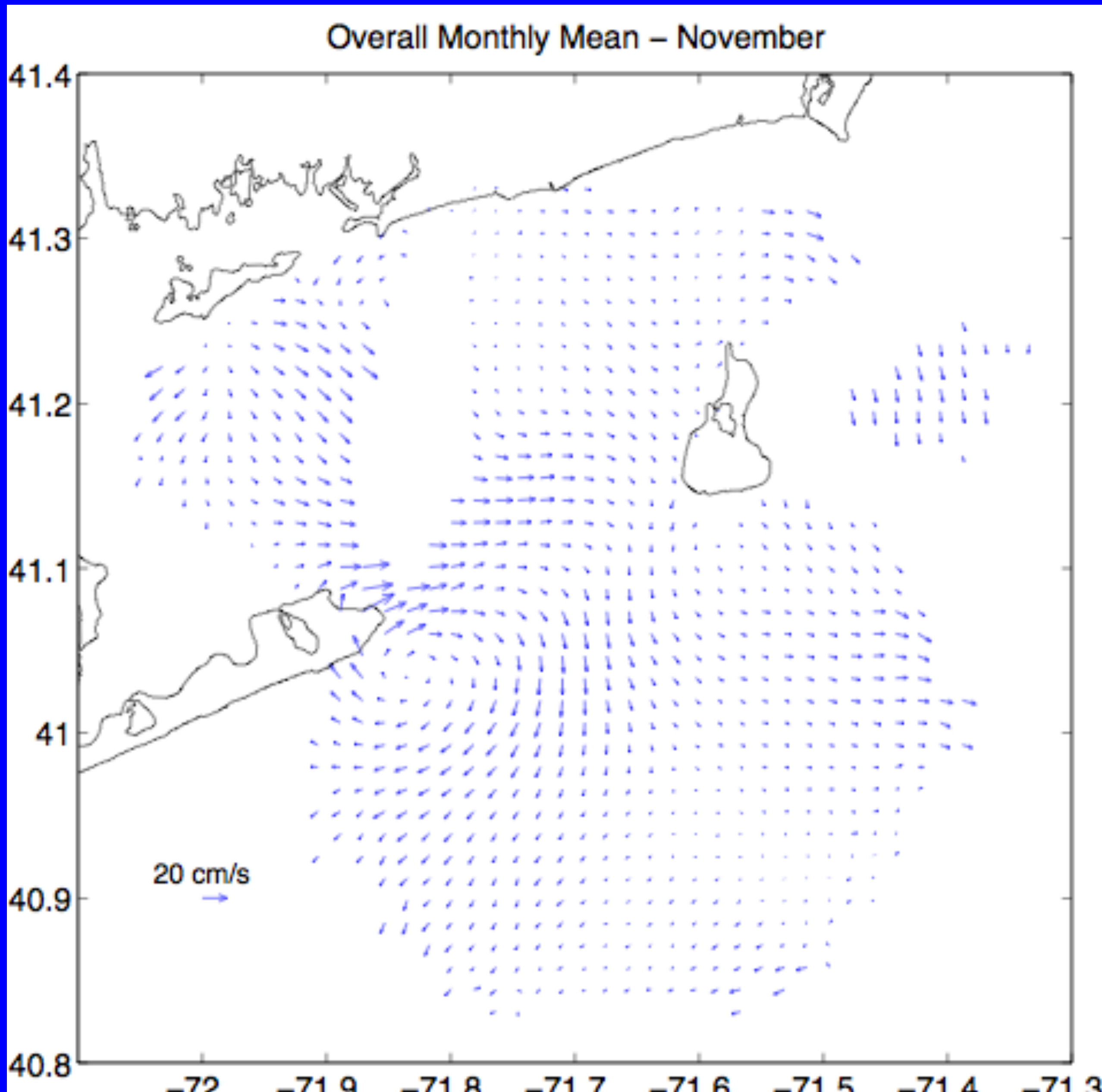


Overall Monthly Mean – August
41.4
41.3
41.2
41.1
41
40.9
40.8
20 cm/s
−72
−71.9
−71.8
−71.7
−71.6
−71.5
−71.4
−71.3

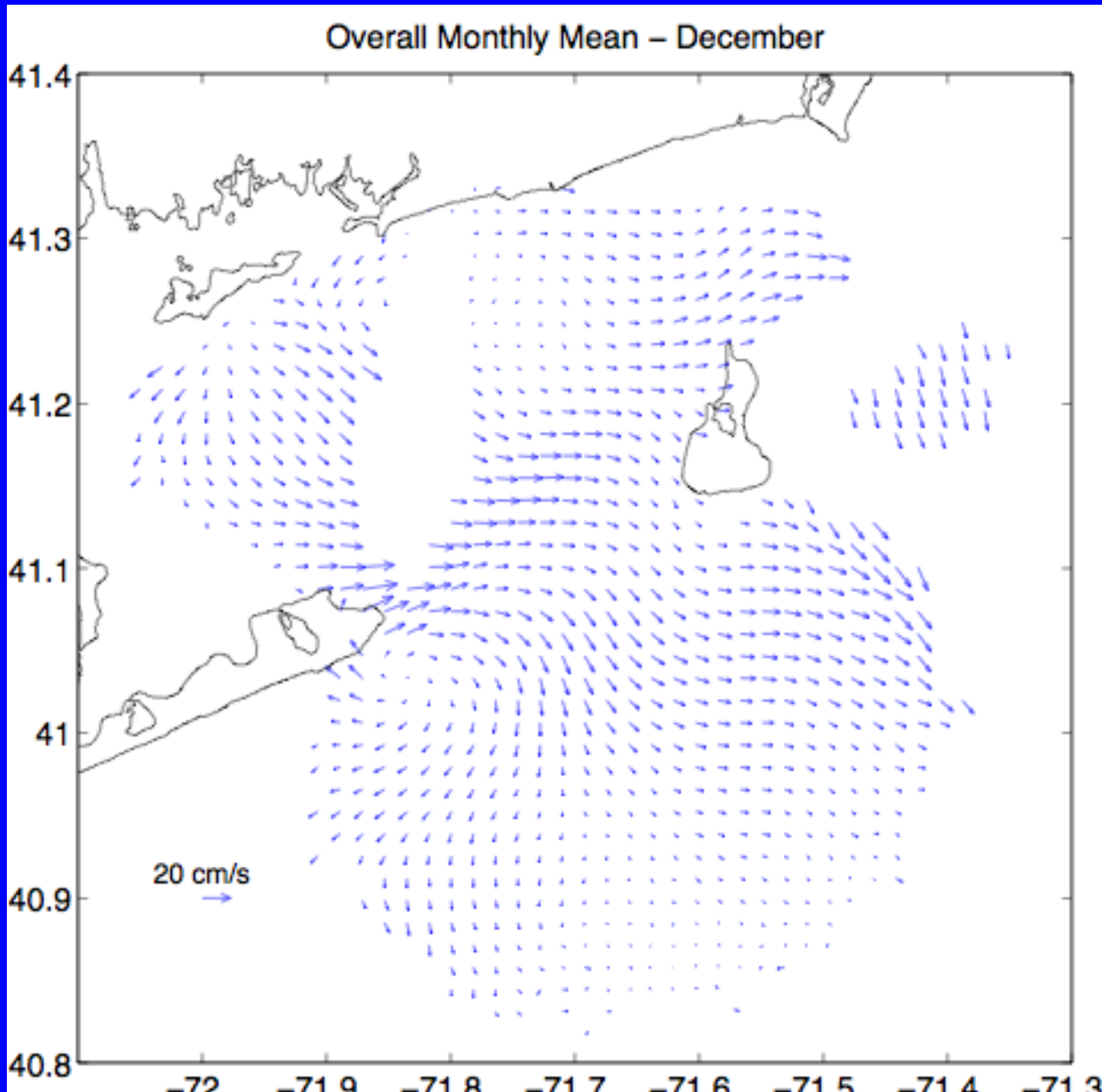


Overall Monthly Mean – September
41.4
41.3
41.2
41.1
41
40.9
40.8
20 cm/s
−72
−71.9
−71.8
−71.7
−71.6
−71.5
−71.4
−71.3


Overall Monthly Mean – October
41.4
41.3
41.2
41.1
41
40.9
40.8
20 cm/s
–72
–71.9
–71.8
–71.7
–71.6
–71.5
–71.4
–71.3



Overall Monthly Mean – November
41.4
41.3
41.2
41.1
41
40.9
40.8
–72
–71.9
–71.8
–71.7
–71.6
–71.5
–71.4
–71.3
20 cm/s



Overall Monthly Mean – December
41.4
41.3
41.2
41.1
41
40.9
40.8
−72
−71.9
−71.8
−71.7
−71.6
−71.5
−71.4
−71.3
20 cm/s

Internal Waves?

Block Island

From: Porter et al.

JGR 2001

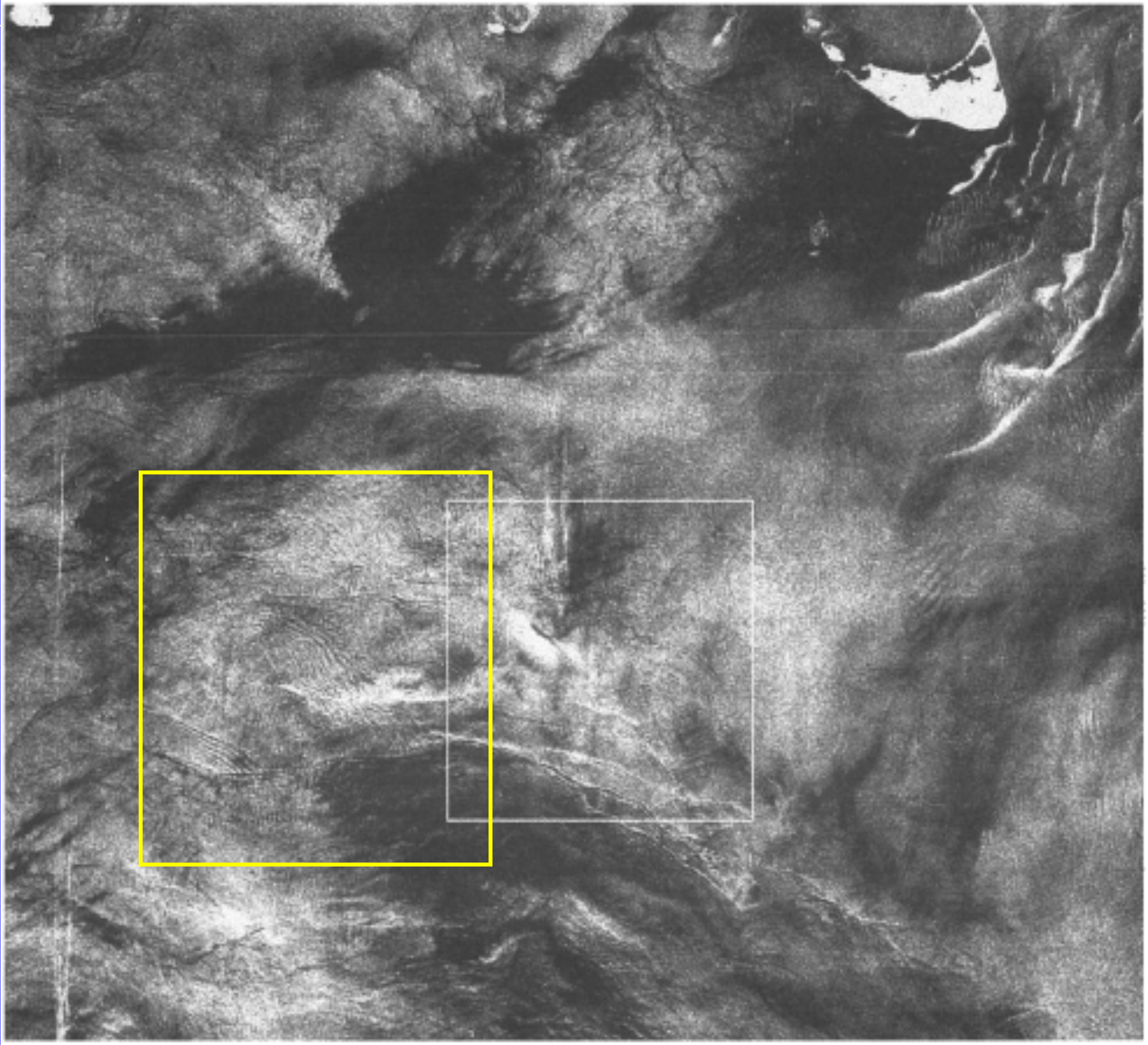


Figure 4. Radarsat SAR image from 2236 UTC, May 31, 1997, showing Nantucket in the upper right corner. The white box enscribes the CMO area. There are a large number of internal waves west of the CMO area.

Internal Waves?