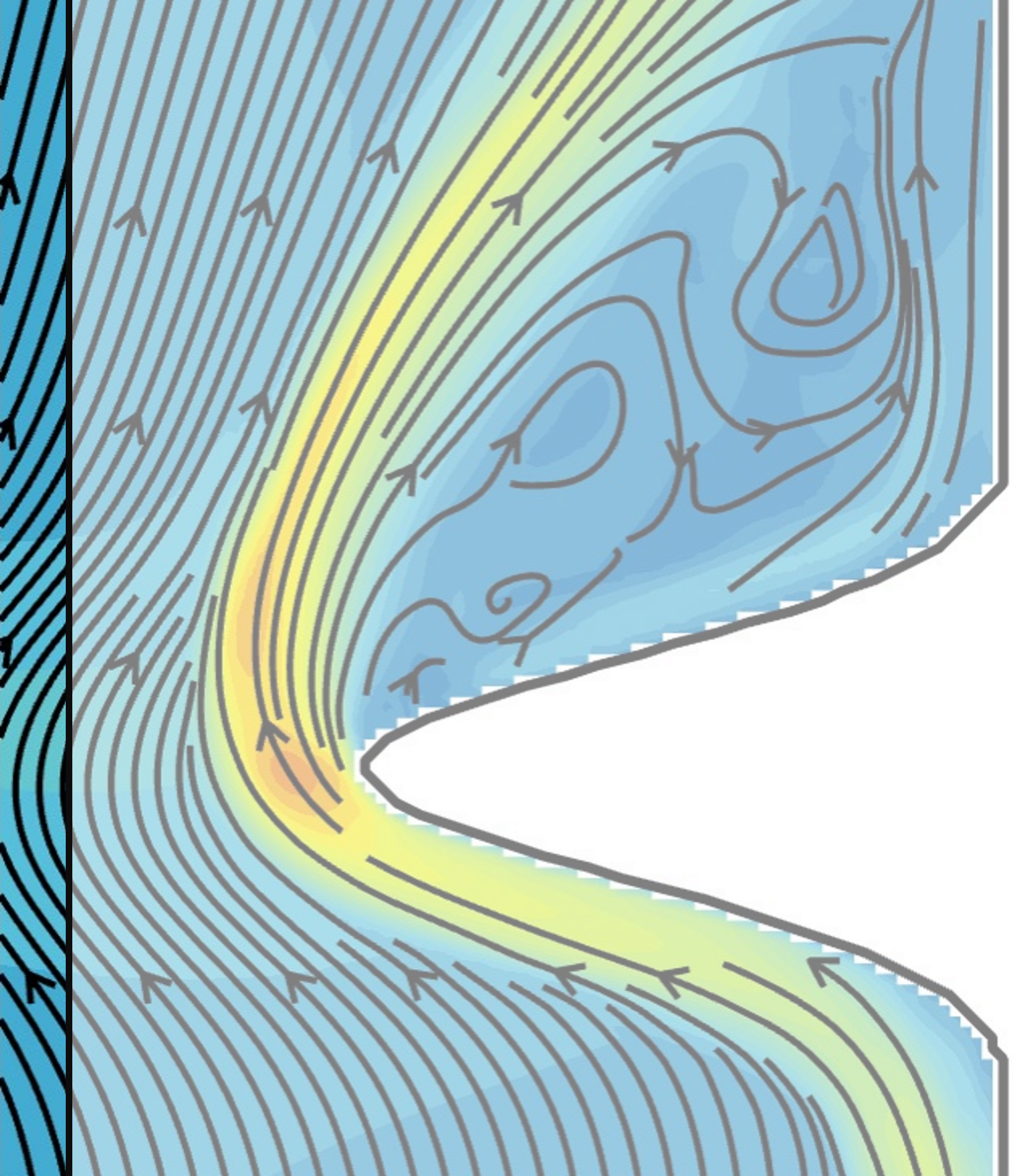

CIRCULATION AND RETENTION OF RIVER PLUMES AROUND CAPES

The Role of Capes on River Plume Mixing, Retention, and Transport in the Coastal Ocean: Idealized Modeling

L. Fernando Pareja-Roman, Ph.D.
with Bob Chant, Piero Mazzini and Kelly Cole
Rutgers, VIMS, & University of Maine

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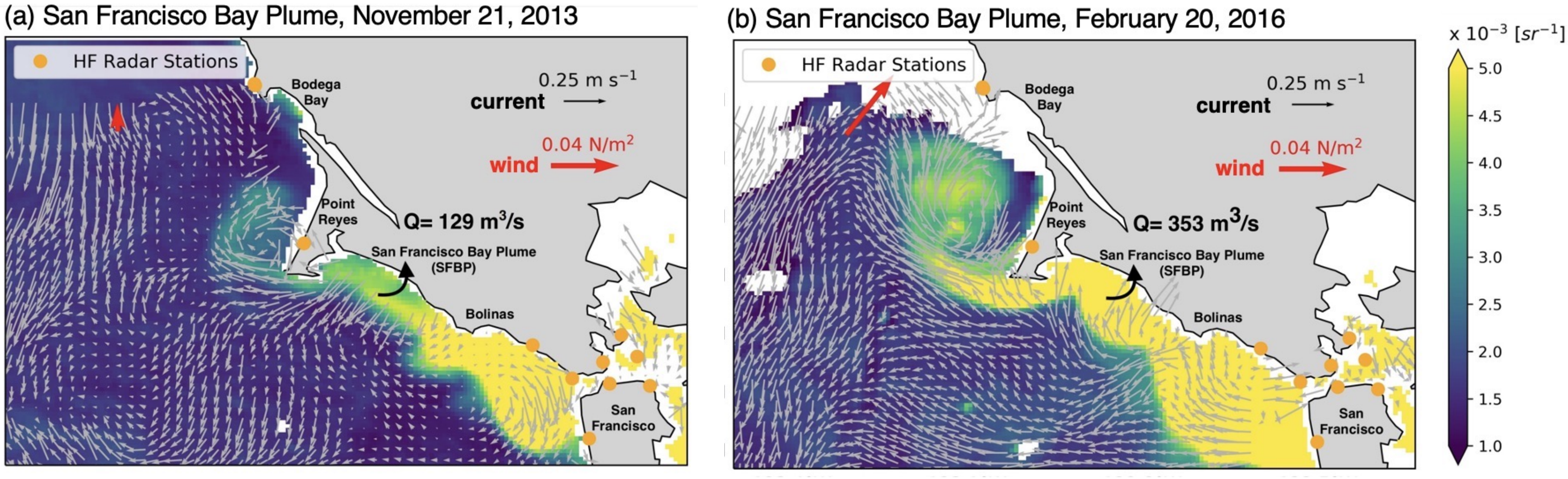
New Orleans, USA, February 2024

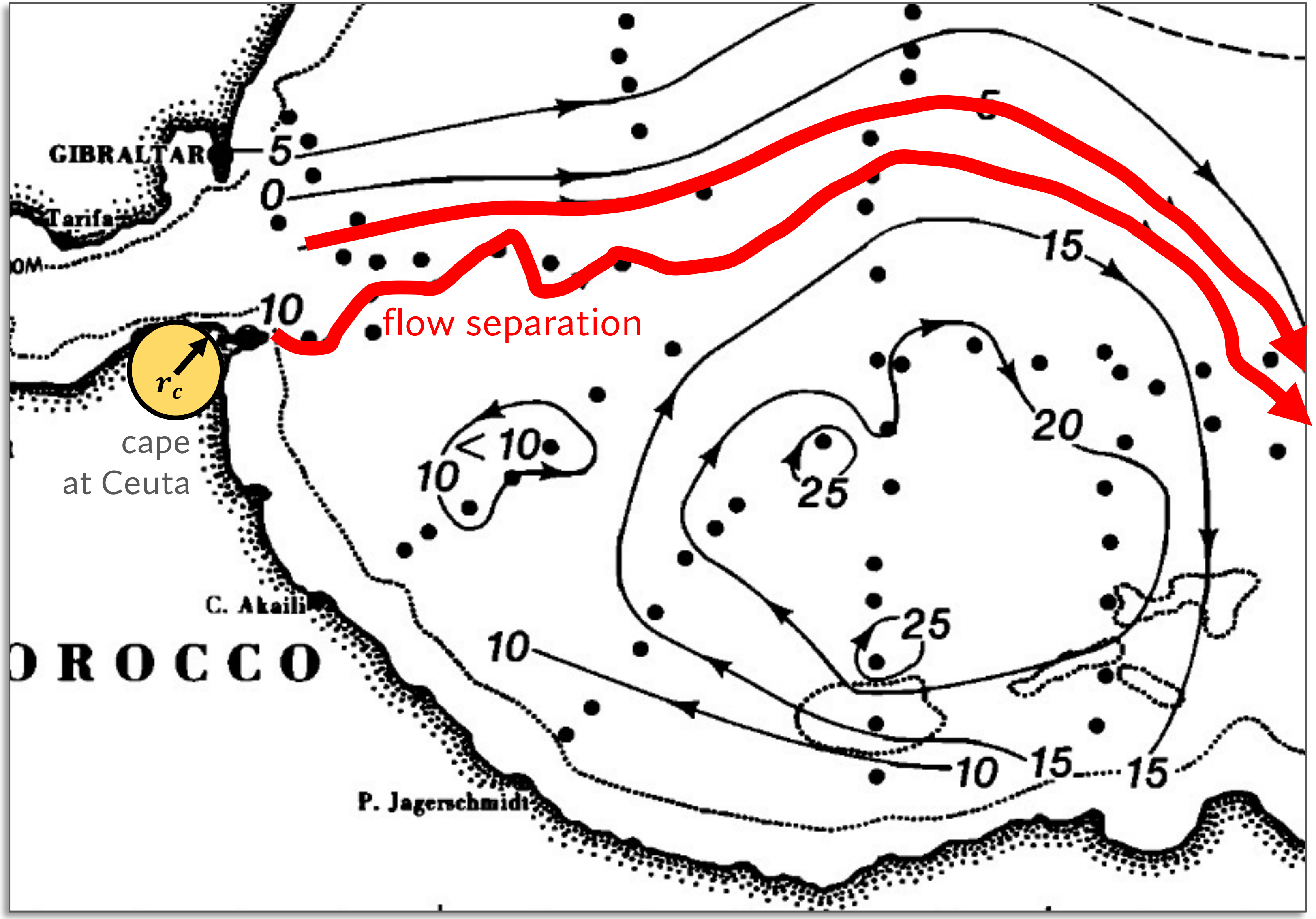
River plumes often interact with capes, headlands, and other features.

How do these features affect flow separation, mixing, and retention?



Remote sensing data shows flow separation and recirculation of the San Francisco Bay river plume at Point Reyes in the Coastal Pacific Ocean.

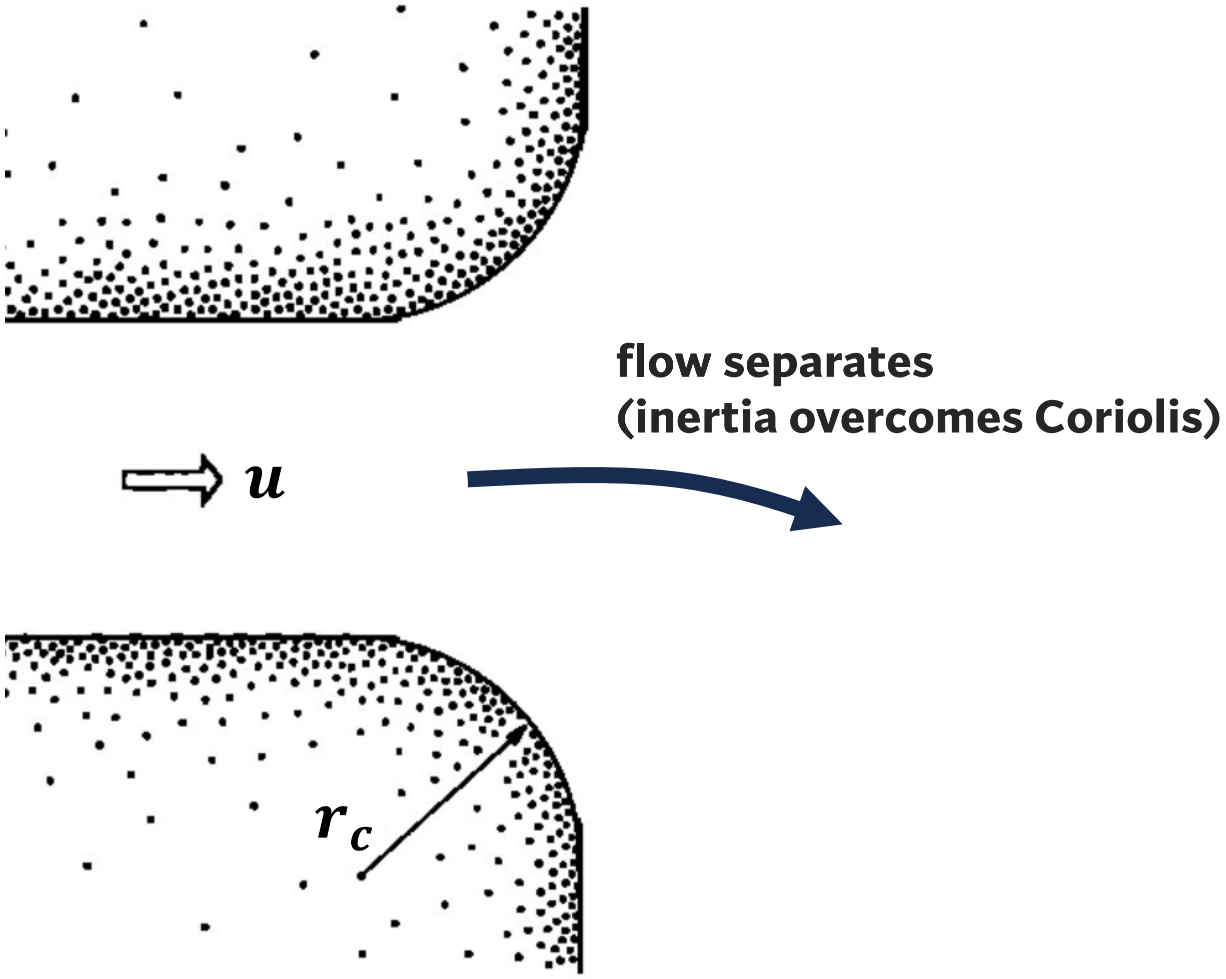
A view of the Alborean Sea in the Mediterranean (Bormans and Garrett, 1989): Flow Separation at Ceuta



Bormans, M., and Garrett, C. (1989). A simple criterion for gyre formation by the surface outflow from a strait, with application to the Alborean Sea. J. Geophys. Res., 96, 12 637–12 644.

Bormans and Garrett saw that the inflow at the Gibraltar Strait **separates at a cape in Ceuta**, creating a gyre in the Alborean Sea

A view of the Alborean Sea in the Mediterranean (Bormans and Garrett, 1989): Flow Separation at Ceuta



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A view of the Alborean Sea in the Mediterranean (Bormans and Garrett, 1989):
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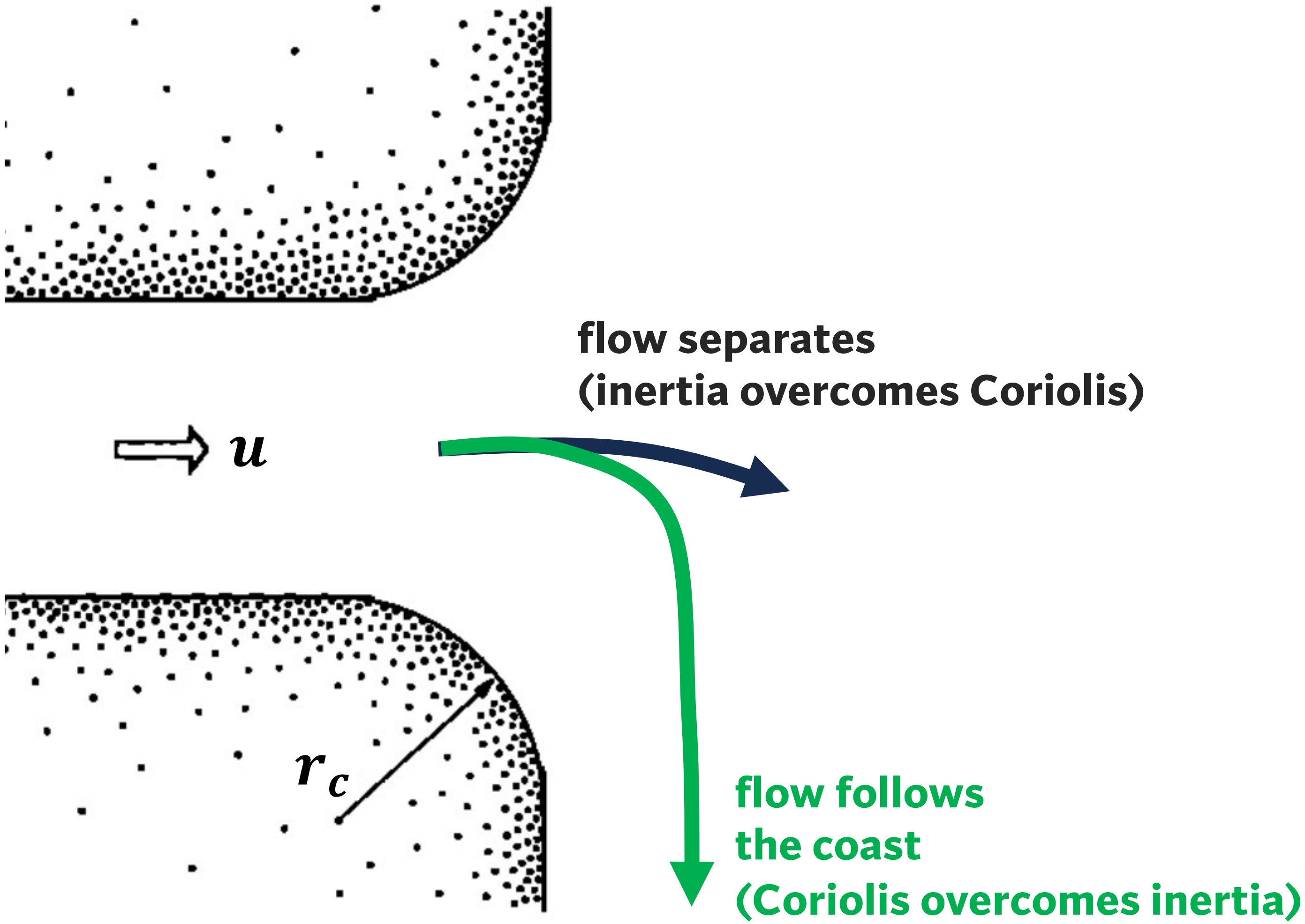

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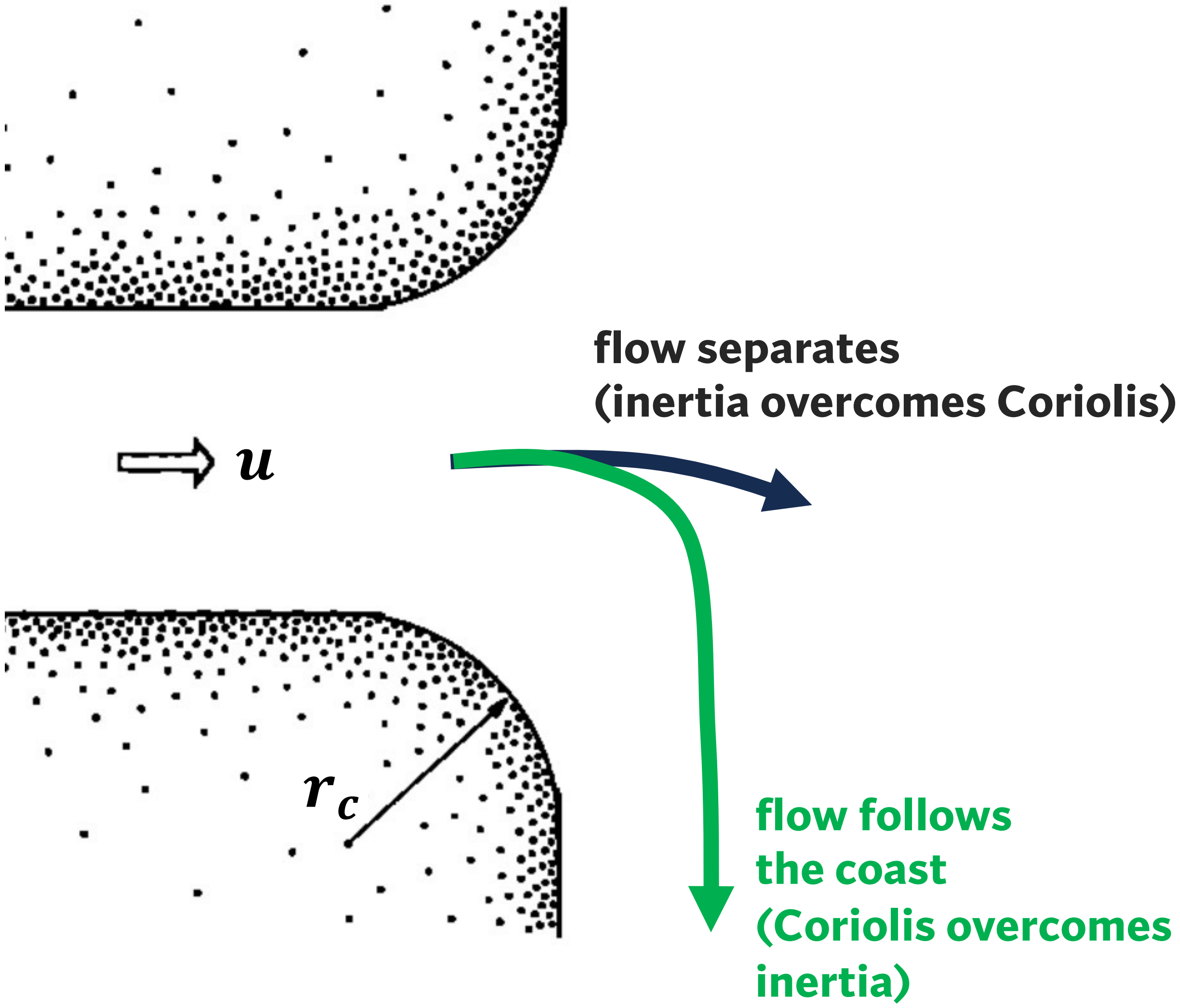
A view of the Alborean Sea in the Mediterranean (Bormans and Garrett, 1989): Idealized flow separation



Separation criteria compares the inertial radius to the radius of curvature of the cape (or corner), assembling a **Rossby number**.

$$Ro = \frac{u/f}{r_c}$$

For separation, **Ro > 1**
For coastal attachment, **Ro < 1**

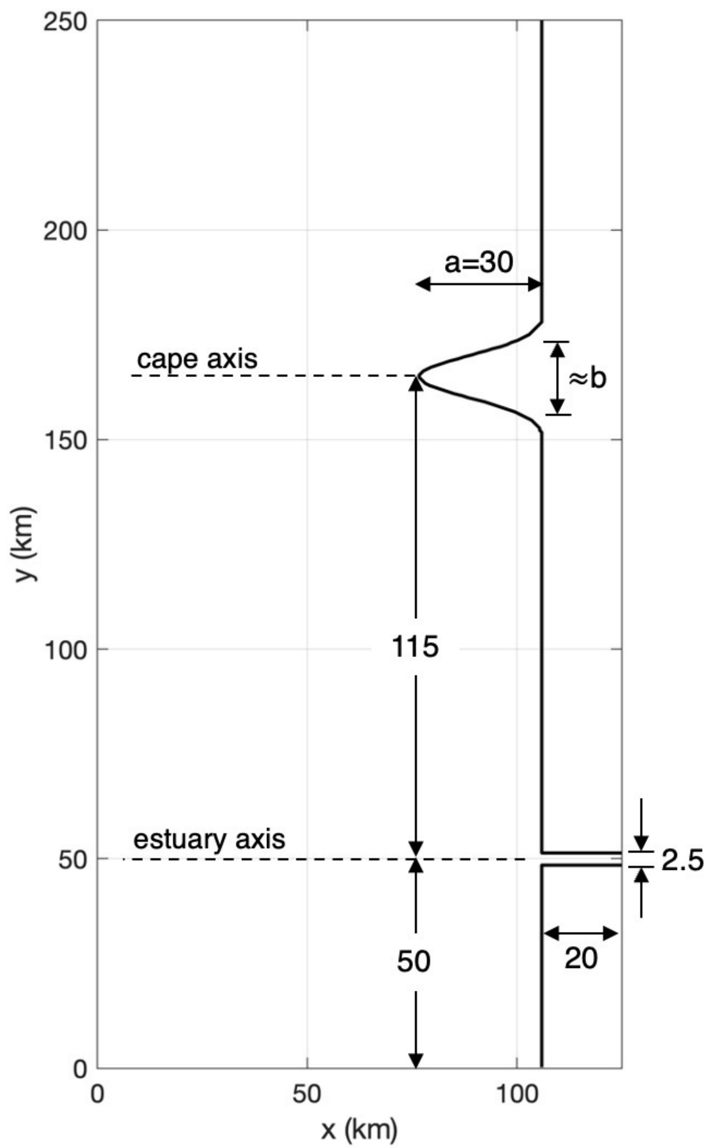
Can we apply this criterion to river plumes?

What about freshwater transport and retention?

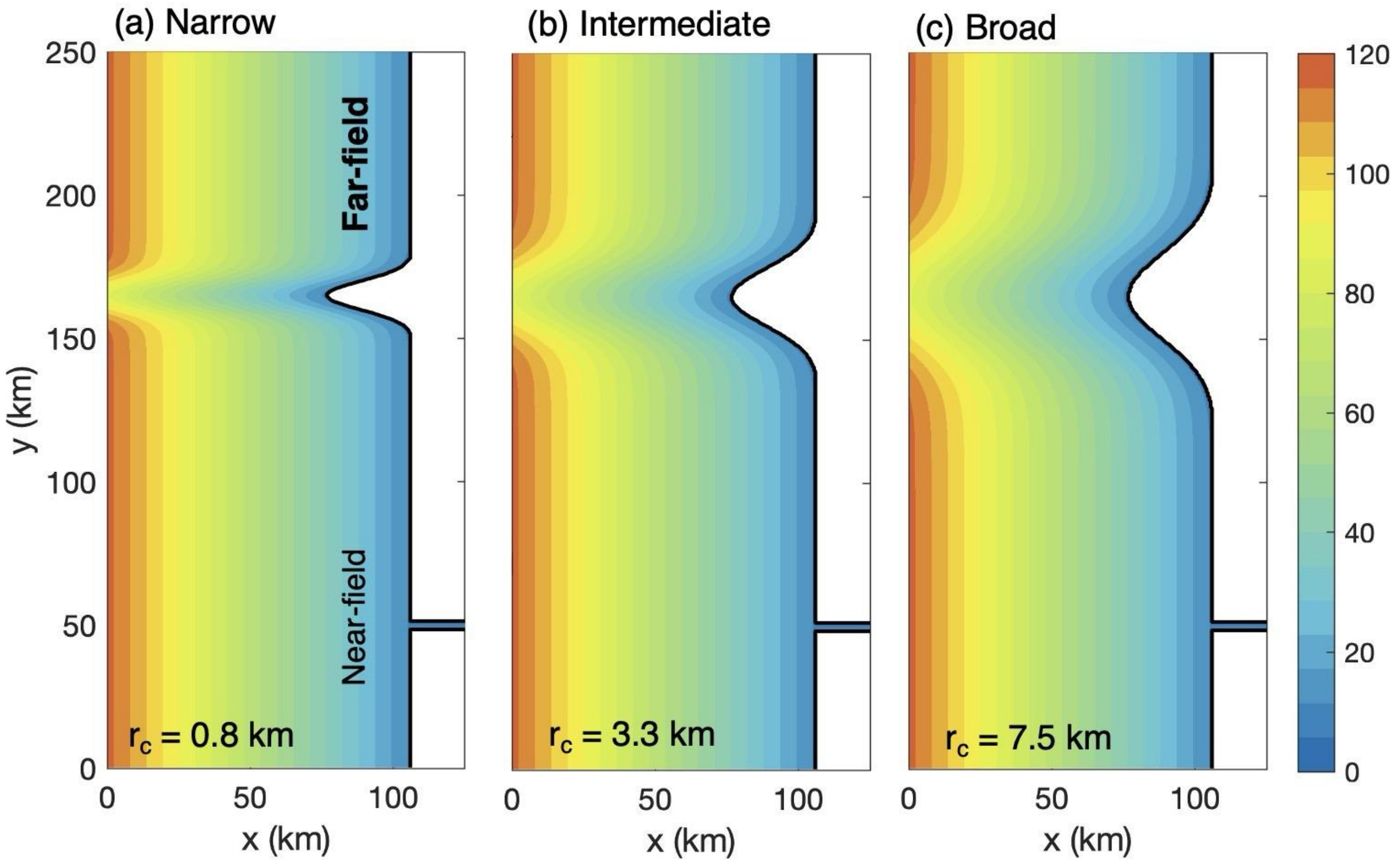
Bormans, M., and Garrett, C. (1989). A simple criterion for gyre formation by the surface outflow from a strait, with application to the Alborean Sea. J. Geophys. Res., 96, 12 637–12 644.

Model Setup (Idealized ROMS)

Dimensions



Three cape geometry scenarios:



Cape shape and radius

$$x_{cape} = a \exp\left[-\frac{1}{2}\left(\frac{y}{b}\right)^2\right]$$

$$r_c = \frac{b^2}{a}$$

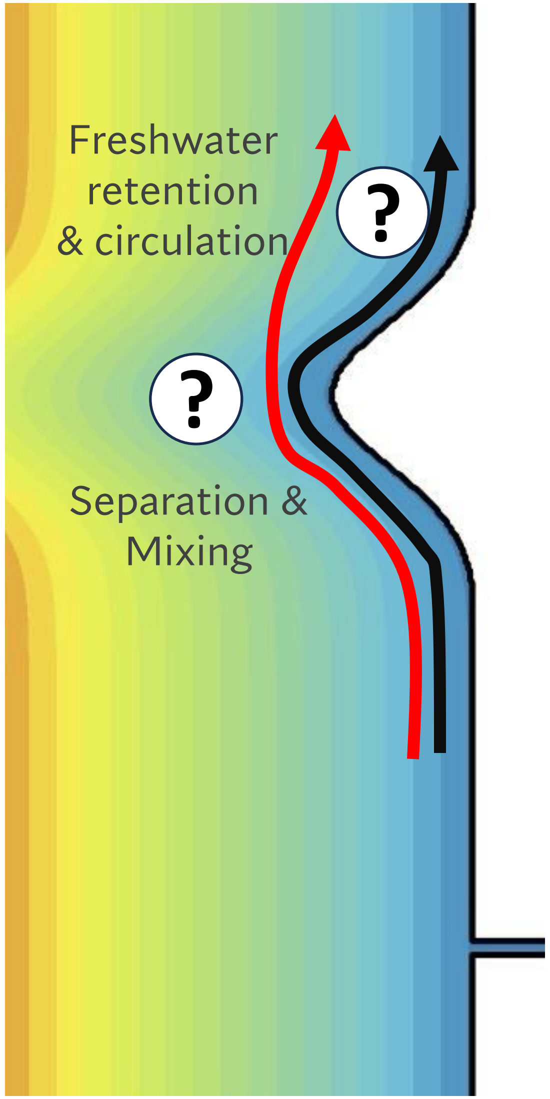
Forcing scenarios

No wind: 0 N/m^2
Downwelling: 0.05 N/m^2

River

Q_r =1500 m^3/s

What to investigate? Focus on the far field of the plume



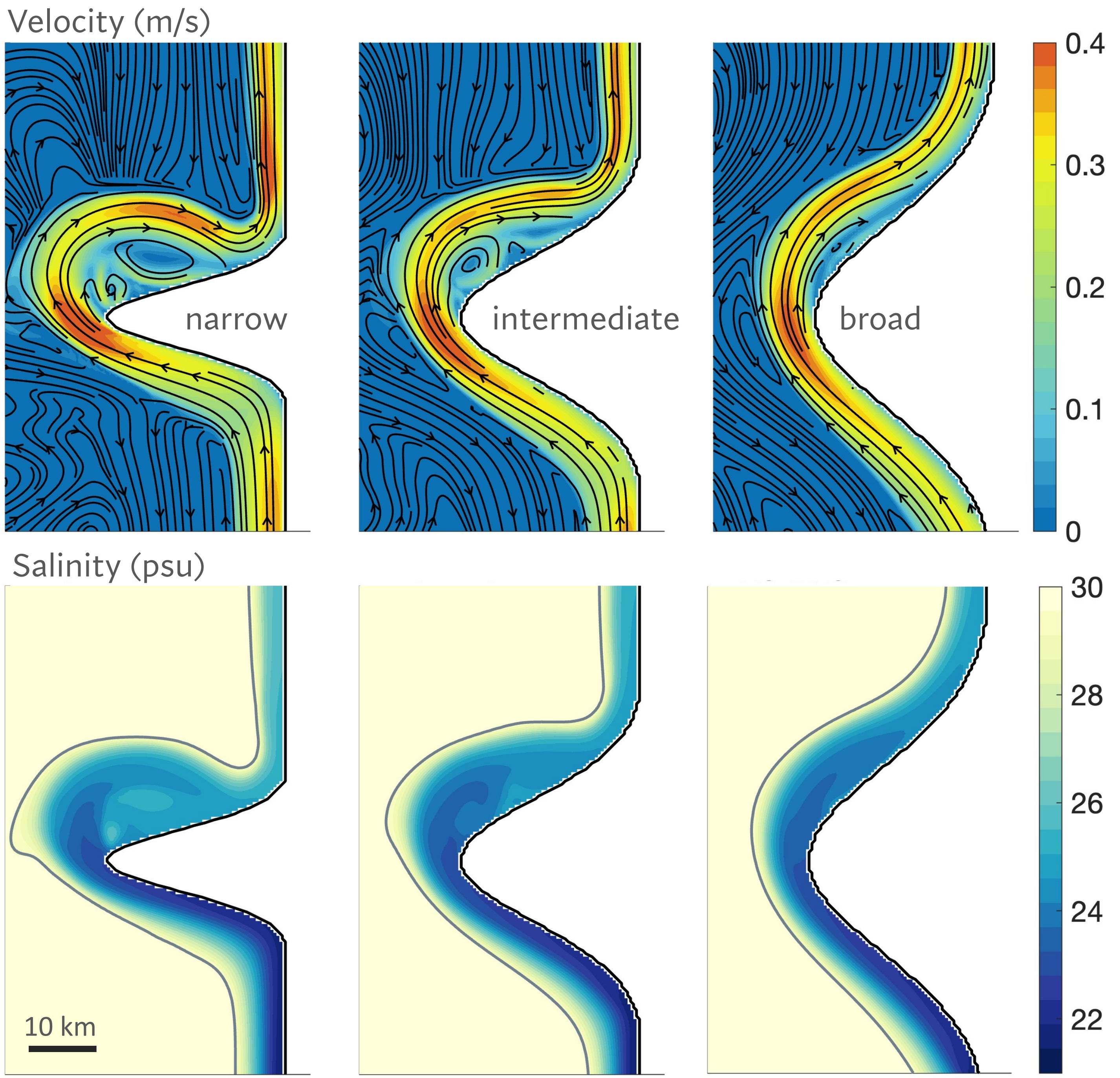
Extensive parameter space!

- Keep river discharge constant to focus on wind and cape geometry
- No tides or ambient currents to focus on river plume
- 3-week model run for plume to leave the domain. Analyze last 48 hours.
- Explore:
  - Velocity
  - Salinity
  - Freshwater transport
  - Mixing (destruction of salinity variance based on salinity variance budget)

Surface Velocity and Salinity

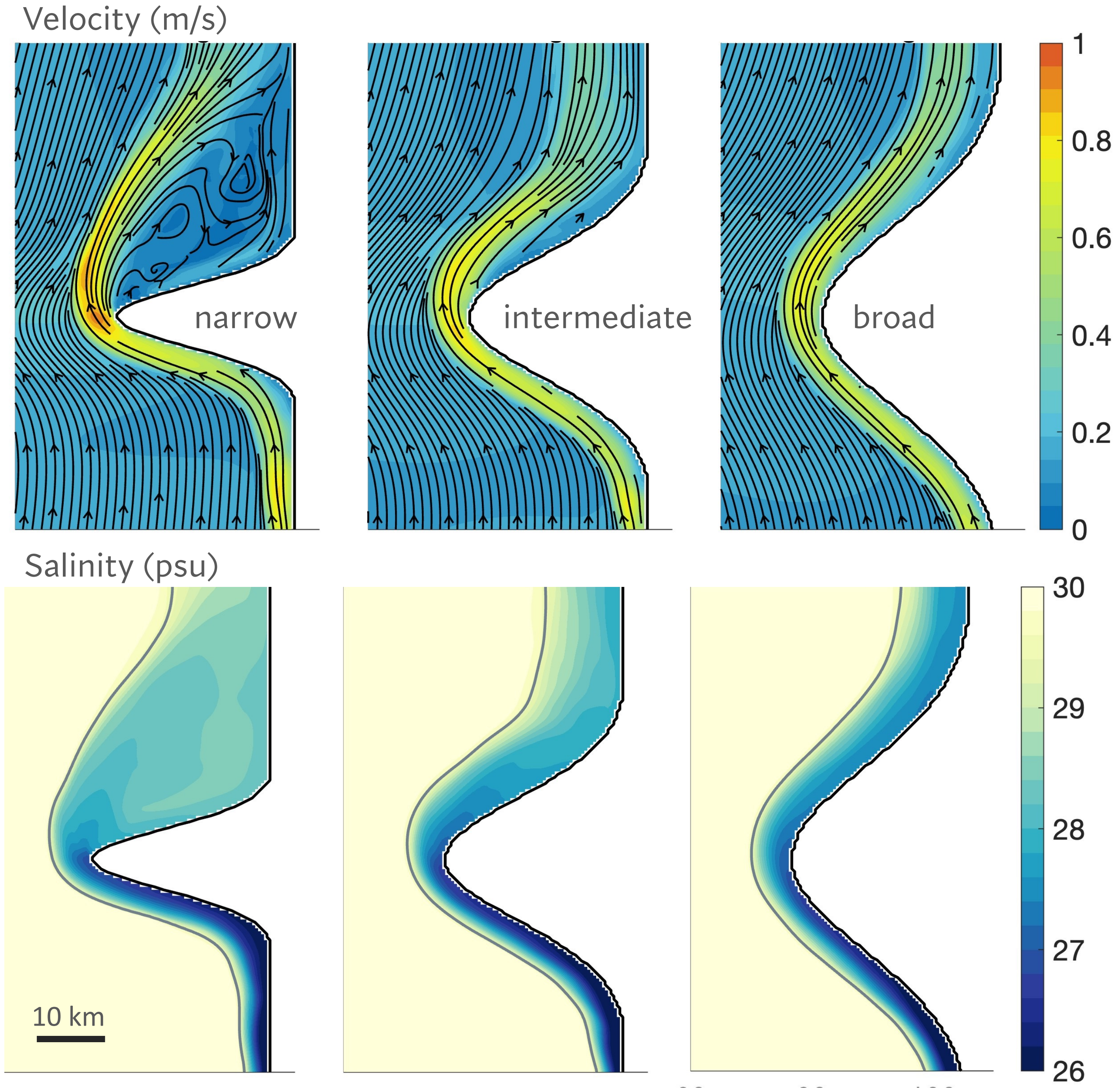
Experiment: **No Wind**

Cape Scenario	Rossby number
Narrow	5.0
Intermediate	1.2
Broad	0.5



Experiment: **Downwelling Wind**

Cape Scenario	Rossby number
Narrow	11.5
Intermediate	2.4
Broad	1.0

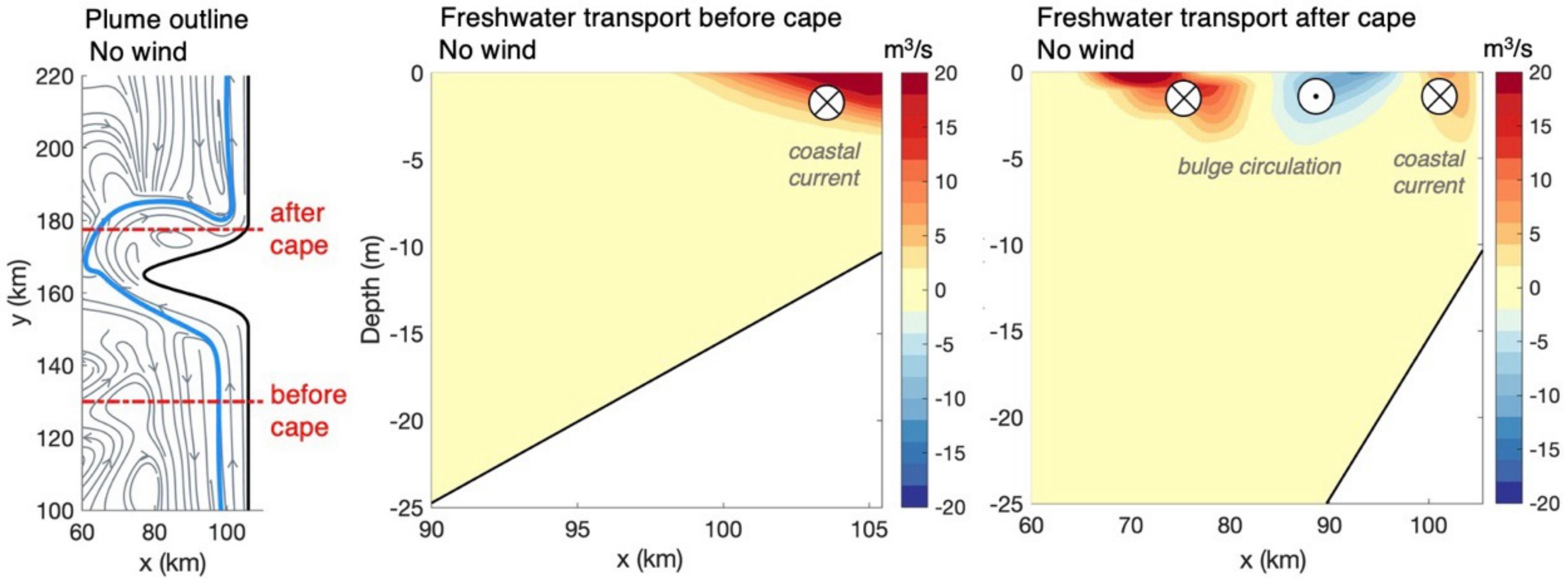


Role of Capes and Wind on Lateral Plume Structure

(narrow cape only)

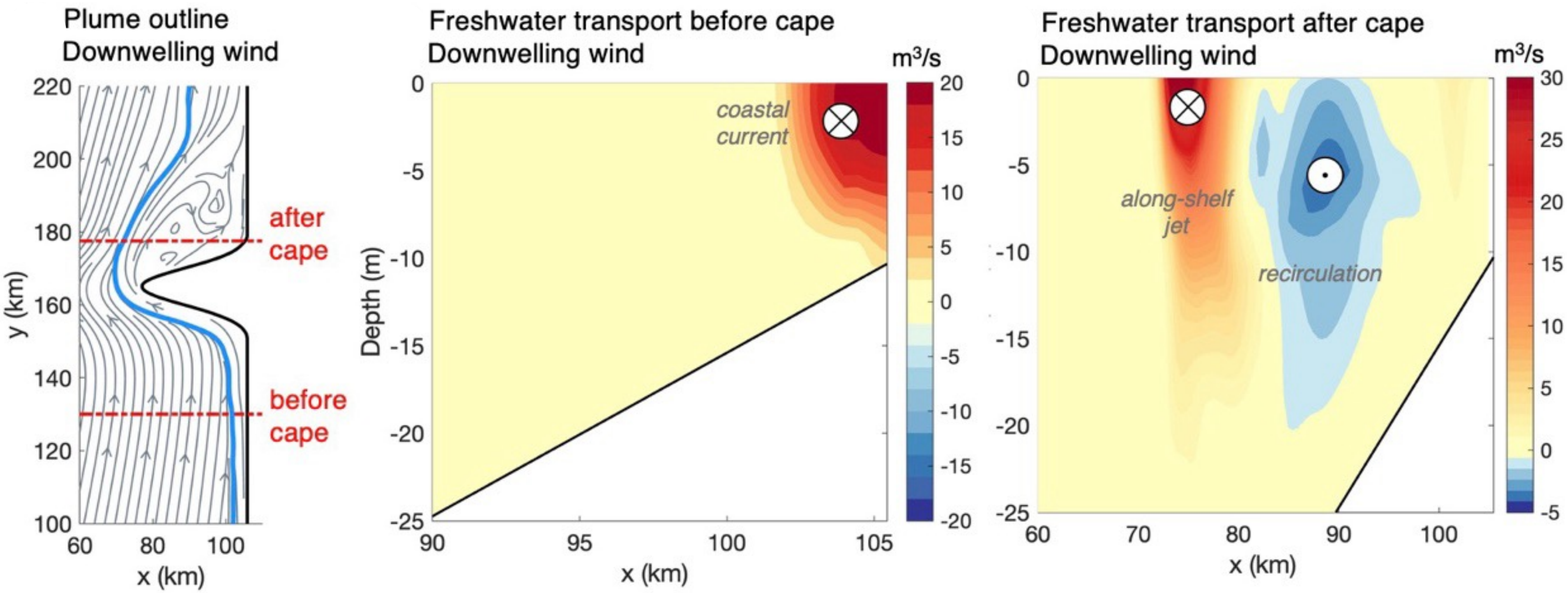
Lateral Structure

Narrow cape, no wind



Lateral Structure

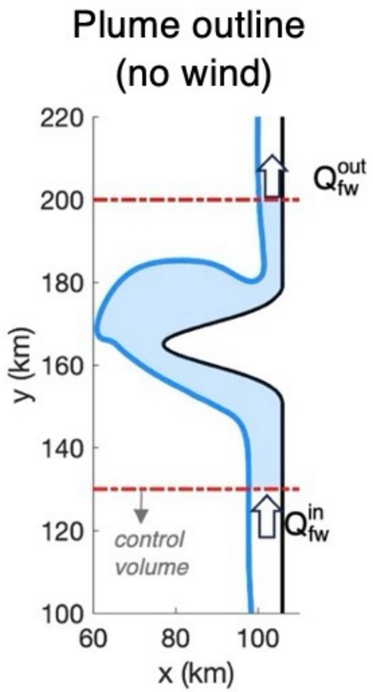
Narrow cape, downwelling wind



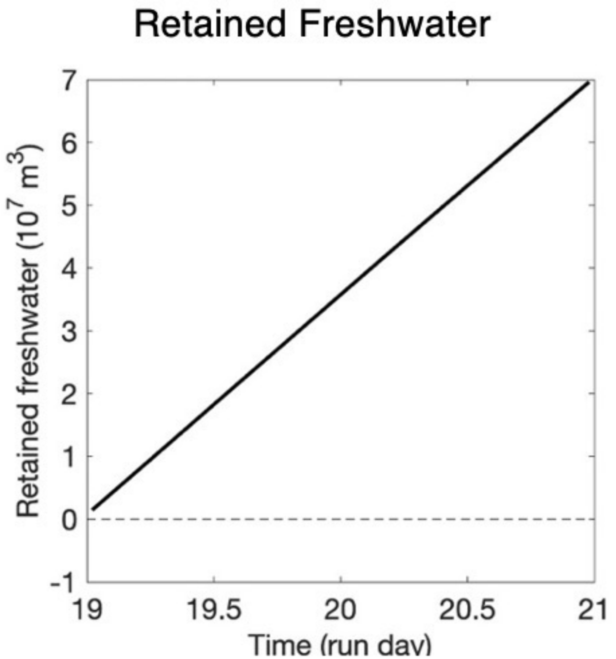
What about Freshwater Retention?

(narrow & broad capes only)

Freshwater retention:
Narrow Cape

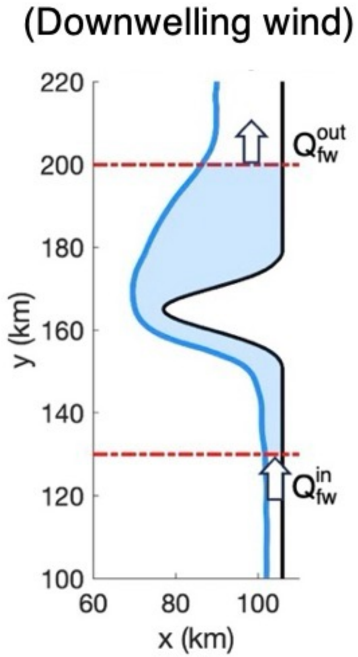


More freshwater accumulation under no wind

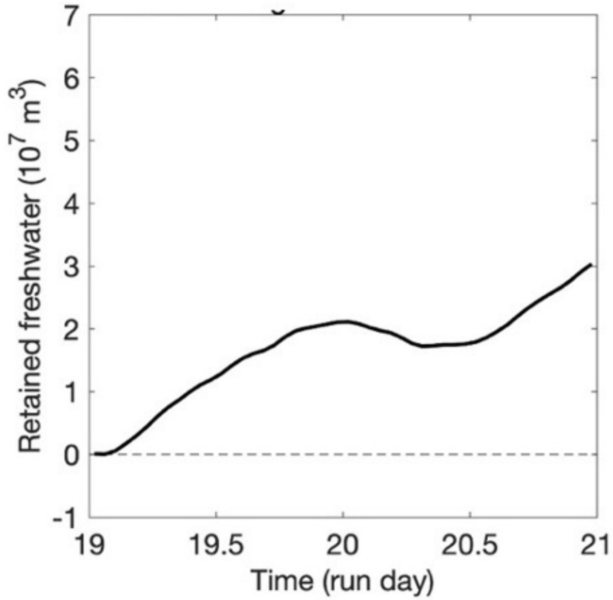


Freshwater retention:
Narrow Cape

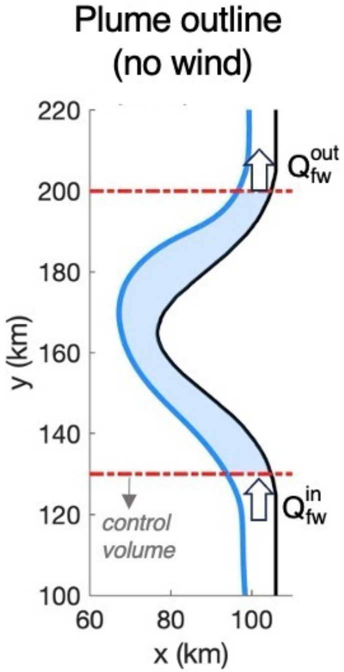
More freshwater accumulation under no wind



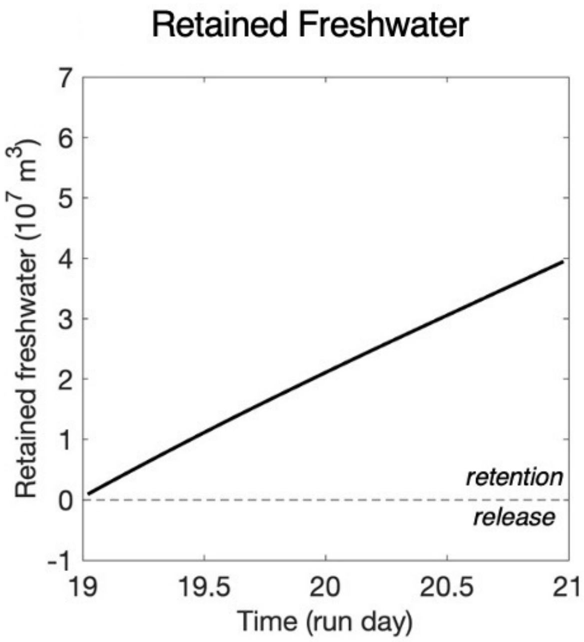
Less freshwater accumulation under downwelling wind



Freshwater retention:
Broad Cape



More freshwater accumulation under no wind, but less than in narrow cape



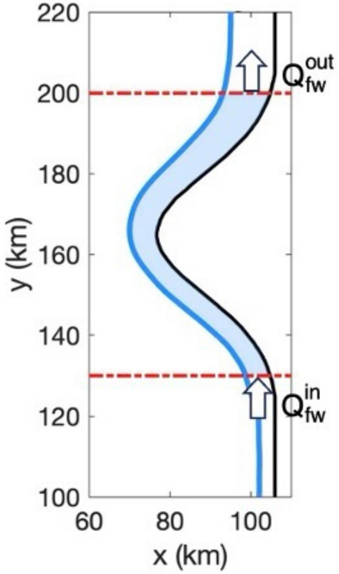
Freshwater retention:
Broad Cape

Plume outline
(no wind)

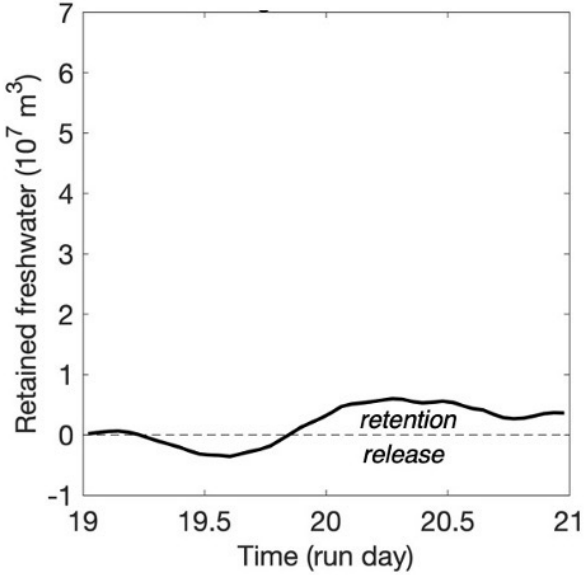
More freshwater accumulation under no wind, but less than in narrow cape

Retained Freshwater

(Downwelling wind)



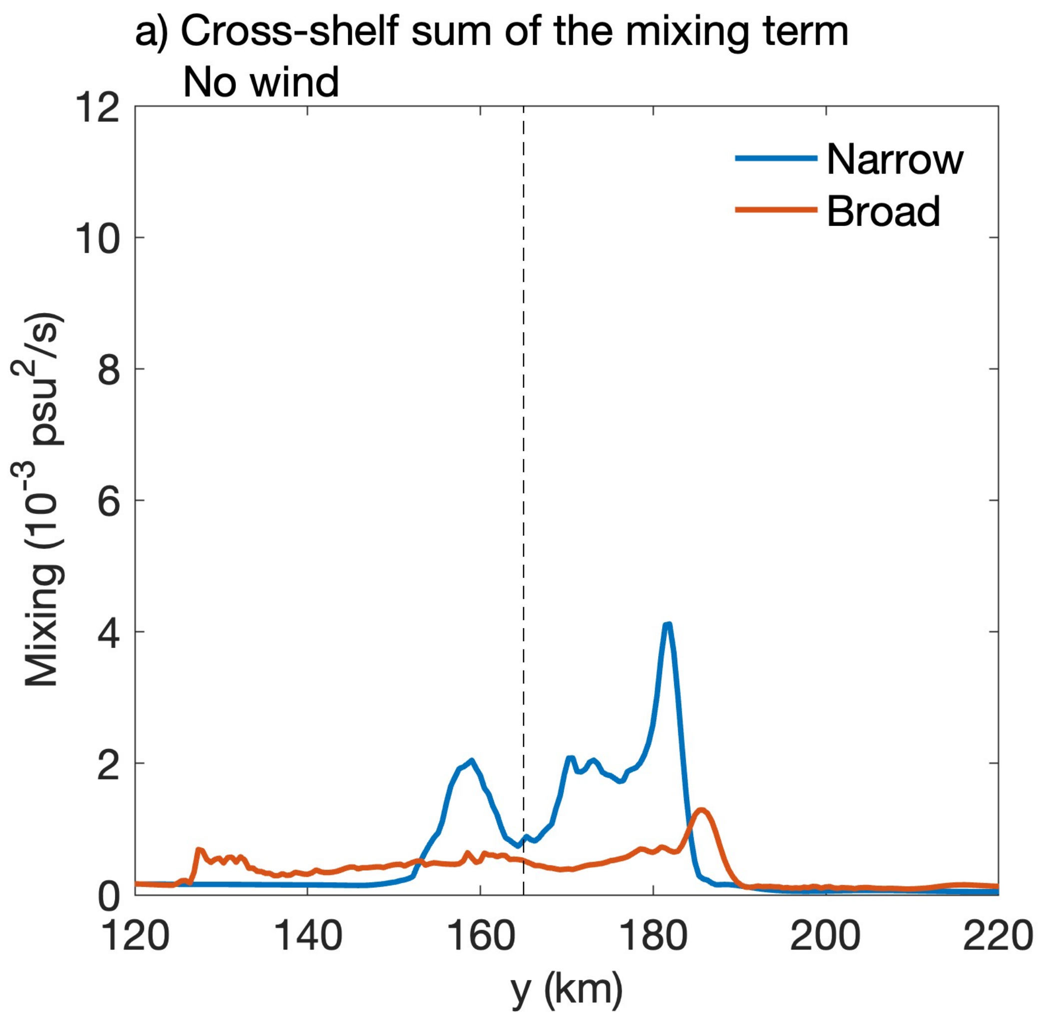
Alternating freshwater retention and release



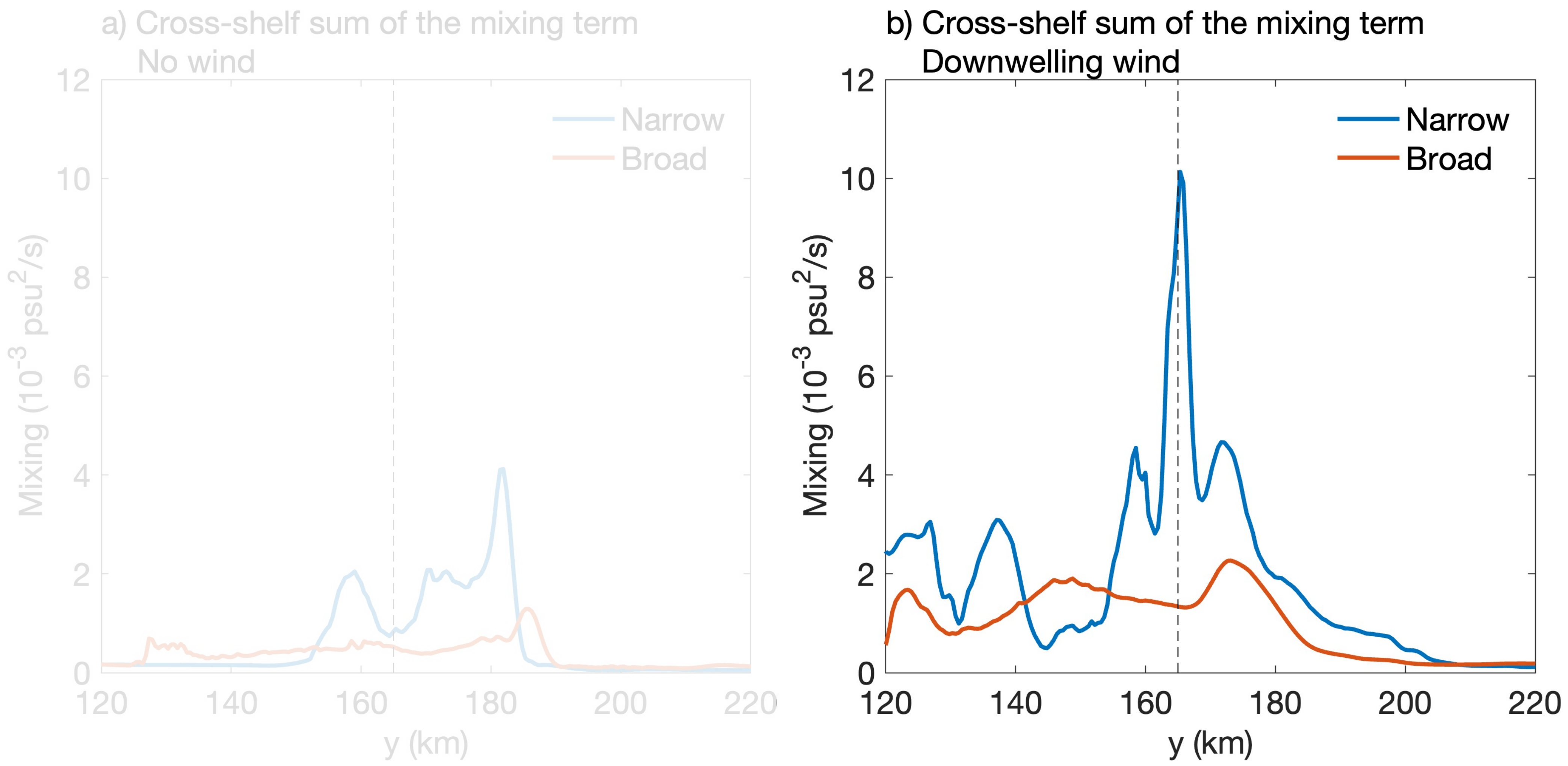
Mixing

(narrow & broad capes only)

Sum of the Mixing term in a salinity variance budget (Mixing = destruction of the salinity variance)



Sum of the Mixing term in a salinity variance budget (Mixing = destruction of the salinity variance)

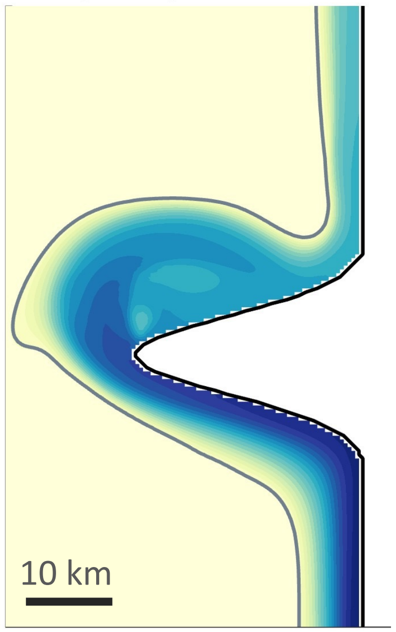


Recap

Freshwater retention

Most

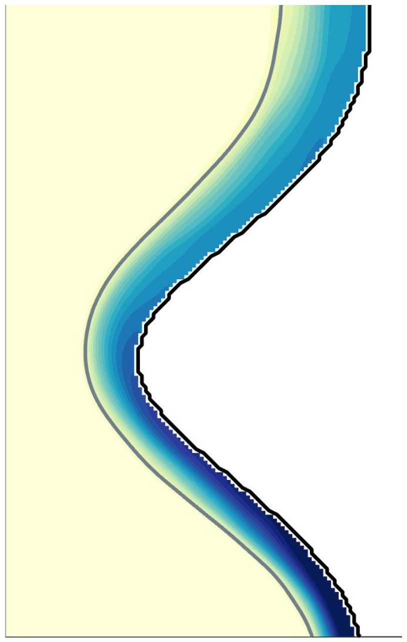
Narrow cape,
no wind



2-day retention:
7×10^7 m^3

Least

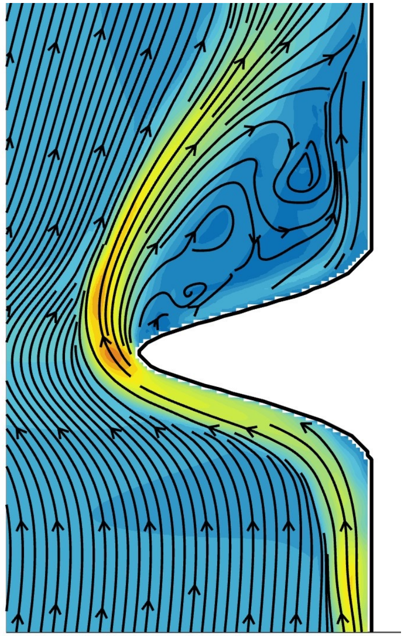
Broad cape,
downwelling wind



2-day retention:
0.3×10^7 m^3

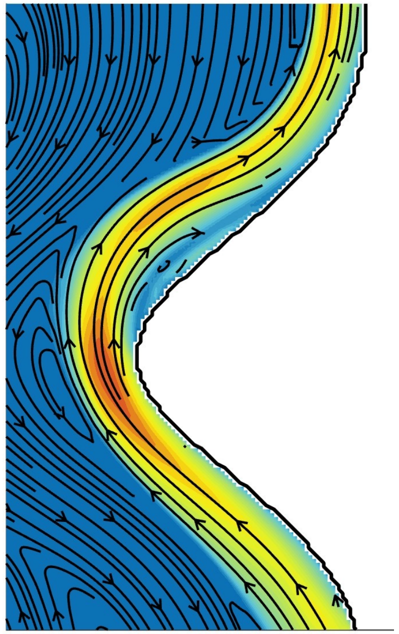
Flow Separation

Strongest
Narrow cape,
downwelling wind



Ro = 11.5

Weakest
Broad cape,
no wind



Ro = 0.5

Broader Implications: Transport Processes in the Coastal Ocean

- River plumes, eddies, and currents influence **nutrient transport**, shaping regional biogeochemistry in coastal waters.
- Freshwater retention and circulation, influenced by capes, **could play a key role in facilitating harmful algal bloom growth**, impacting water quality indicators.
- These dynamics would be strongly tied to **synoptic/mesoscale wind variability** and changes in river discharge.

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For future work:

- Studies emphasizing water age and residence time
- Broader parameter space (Burger number, variable river discharge, wind variability)
- Coupled Physical-Biogeochemical modeling