Unusual mechanisms for driving coastal upwelling and near-shore currents: Examples from the Caribbean Sea and biological consequences

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“Classic wind-driven Upwelling”

Other Mechanisms:

• Eddies
• Diverging currents
• Storms (e.g., Hurricanes)
• Topographic features
Important impacts in the Caribbean Sea:

1. Caribbean Eddies (and their interaction with the coastal ocean)
Propagation of **meso-scale eddies** dominate the dynamics of the Caribbean Sea and the Gulf of Mexico and may impact the coastal dynamics as well.
Important impacts in the Caribbean Sea:

2. Hurricanes (and their interaction with the coastal ocean)
Upwelling (blue) caused by a moving Hurricane

The MBRS includes protected regions and marine reserves which are sensitive to environmental changes.
Major spawning aggregation sites are found in the region (Heyman et al. 2001, 2008). How are they related to topography and variation of the flow along the reef?
Craig (1966): Geography of Fishing in British Honduras

Only limited number of observations exist in this region

WOCE drifters (2000)
Note that the drifter moved **north** along the reef, while the mean flow there is to the **south**.
Observations of currents along the reef show poor correlation with local wind, so what drive the flow?

(B. Armstrong, MS Thesis, SC, 2005)
Basin-scale models can provide boundary conditions for regional high resolution models:
Princeton Ocean Model (POM) for the Western Caribbean Sea (WCS)
Simple data assimilation to introduce eddies in the model
Based on surface-subsurface correlation method (Mellor & Ezer, 1991; Ezer & Mellor, 1994, 1997)

\[ T(x,y,z,t) = T_{avr}(x,y,z) + F(x,y,z) \Delta SSH(x,y,t) \]

Use 3D diagnostic calculations to infer the dynamically adjusted flow field and sea level associated with given temperature field, T.
Jan 29-1999: Cyclonic eddy near MABRS

Apr 19-1999: Anti-Cyc. eddy near MABRS

OBS

SSH Anomaly

MOD

SSH Anomaly

OBS

SSH Anomaly

MOD

SSH Anomaly
Sea surface height and surface velocity after adjustment from initial conditions

Jan-1999                       Apr-1999
Focus on the MABRS:

(c) SSH and Vel. – Jan 29, 1999

(d) SSH and Vel. – Apr 19, 1999
Can the existence of eddies explain the discrepancy in the flow direction?

Kraig (1966): Geography of Fishing in British Honduras

WOCE drifters (2000)
Altimeter SSH anomaly when the drifter was released (Apr. 2000) shows a positive (anti-cyclonic) anomaly in the GOH.

Under similar conditions (Apr. 1999) the model predicts NORTHWARD flow near Turneffee Reef.
What are the consequences of eddies for biological activities along the reef?

Simulations of eggs drifting from reefs known for spawning aggregations.
However, different models may give different results—indicating the importance of getting the dynamics correctly before biological consequences are inferred.

Note the drift toward opposite directions from the same reef.
How does the interaction of currents and small-scale topography affect the dispersion of eggs near the reef?

Heyman et al., (2008)
The south-east Caribbean Sea is one of the most productive regions due to the strong upwelling caused by the Trade Winds.
There are two periods of upwelling: main upwelling (March) and secondary upwelling (July) However, during the summer the coastal trade winds are weak, so what causes the secondary upwelling?
Wind from S-E Caribbean stations
The upwelling lifts the isotherms more than 100m and has considerable interannual variations, as seen from the Cariaco time-series data.
Some years have significantly stronger upwelling than others, but the upwelling occurs at the same spots.
Possible mechanism for the secondary upwelling:
the winds in the north peak later
than
the winds in the south coast
causing N-S wind gradients and
wind-stress curl upwelling

Upwelling due to wind-stress Curl

\[ W_E = \left( \frac{\rho_w}{f} \right) \text{curl}(\tau) \]
The spatial pattern of the wind-stress curl is similar to the upwelling zone.

Increase offshore wind
Decrease coastal wind
The role of Caribbean eddies:
Every summer there is an intense eddy activity offshore the Cariaco Basin (originated from the Brazil retroflection zone)

Could the eddies influence the wind-stress curl?
Potential climatic changes (?):
Can impact upwelling and biological consequences

Temporal changes?

Spatial changes?
Some points to think about:

• Forcing mechanisms for coastal upwelling may be complex and involve offshore processes that are not always well understood or predicted

• High-resolution (~1 km) models are needed to account for small-scale flow-topography interactions

• Physical-biological modeling is challenging as we need to get both, the physical & biological right
Thank You