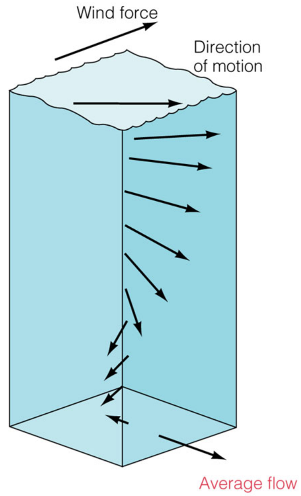
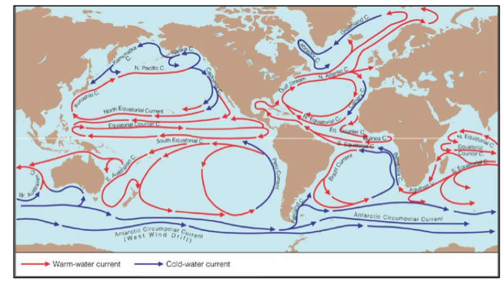
Ekman ≠ Geostrophic

- Ekman transport is a short-term phenomenon
  - Coriolis & friction
  - Upper water layer responds to change in wind speed and/or direction
    - Takes a few hours to a few days
    - Transient, not equilibrium



Ekman ≠ Geostrophic

- Geostrophic current is a long-term pattern
  - Integrates conditions over months to years
  - Equilibrium between Coriolis & pressure
    - Slow to change with wind fluctuations
    - Local variations occur with storms, etc.

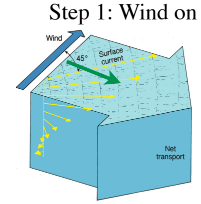


Ekman ➔ Geostrophic

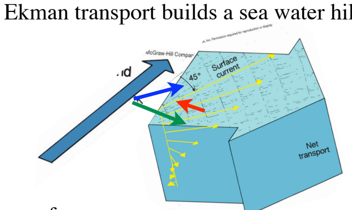
- Consider an ocean with no motion
  - Turn on the wind
  - Within hours-days, the Ekman Spiral develops
- Ekman is the agent of its own demise
  - Ekman transport pushes water 90˚ to the wind
  - Builds a hill of sea water to one side
    - Right north, left south
  - The hill slope creates pressure (gradient) force
    - Counteracts Coriolis & Ekman
    - Current turns to parallel the wind
  - Geostrophic flow

Ekman ➔ Geostrophic

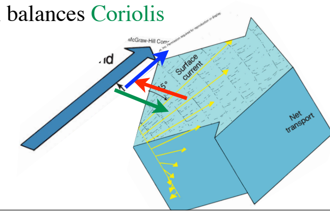
Step 1: Wind on a calm ocean produces Coriolis effect & Ekman transport

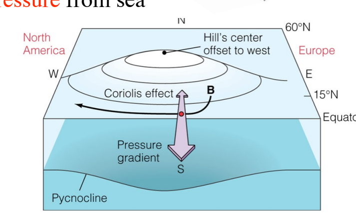


Step 2: Current turns as Ekman transport builds a sea water hill & pressure



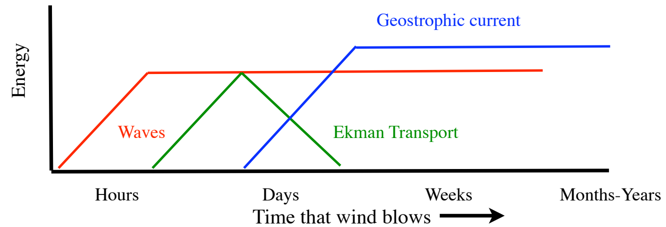
Step 3: Geostrophic current parallels wind as pressure from sea water hill balances Coriolis





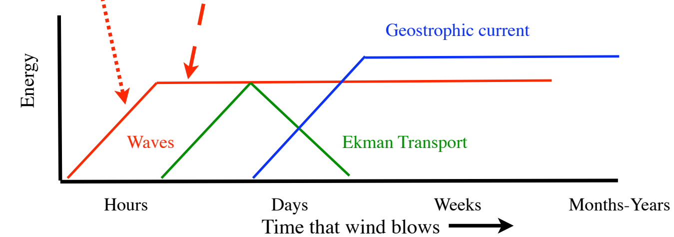
Waves vs. Currents

- 3 main differences:
  - Waves are periodic, currents are continuous
  - Waves move energy, but no ***net*** movement of water (until they break)
    - Currents move water and energy
  - Waves arise more quickly, currents more slowly



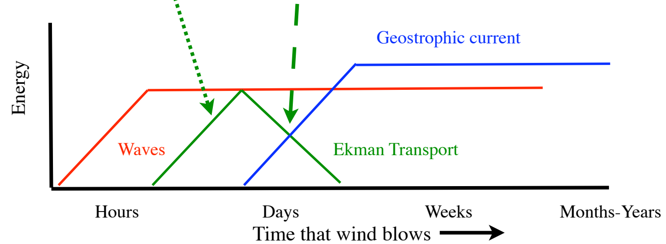
Time Scale of Waves

- Waves arise within a few hours
  - ”Full developed seas” within 2-3 days
    - Depending on speed & fetch
    - Continue as long as wind blows
  - Additional energy goes into net water movement (currents)



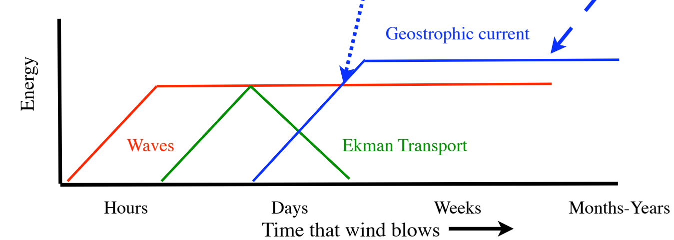
Time Scale of Currents

- Ekman Transport
  - Arises in 1–2 days
    - Depending on speed & fetch
  - Persists for days-weeks
    - But changes to geostrophic as sea level adjusts



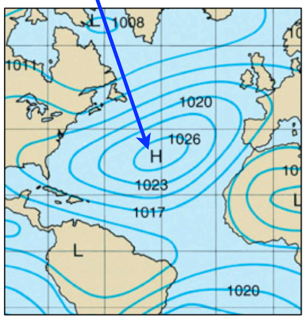
Time Scale of Currents

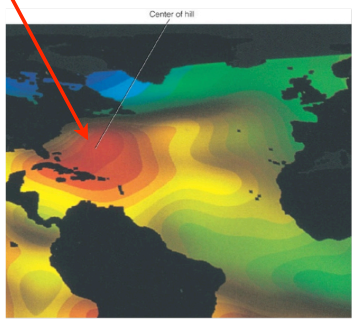
- Geostrophic current arises in 1–2 weeks
  - Sea slope rises in response to steady wind
    - Resulting pressure balances Coriolis
    - Current turns to become more parallel to wind
  - Stores tremendous energy over seasons-years
    - Momentum carries it after wind dies or reverses



Time Scale of Sea Level

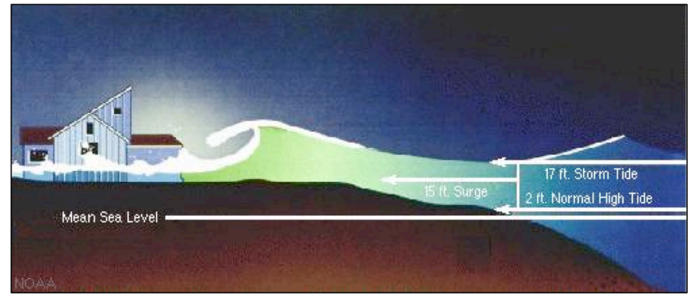
- Note a match between atmospheric pressure & sea level?
  - High atmospheric pressure
  - High sea level (& pressure acting on current)





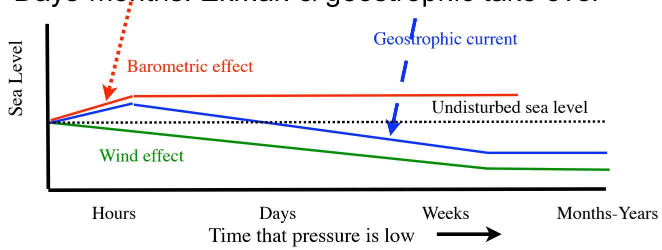
Time Scale of Sea Level

- But what about storm surge?
  - ***Low*** atmospheric pressure = high sea level
  - High pressure = low sea level
  - Wind also pushes water to raise sea level



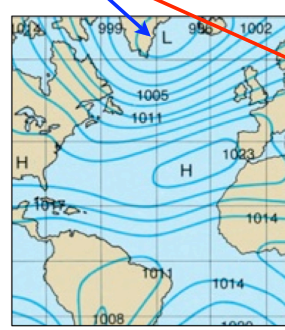
Time Scale of Sea Level

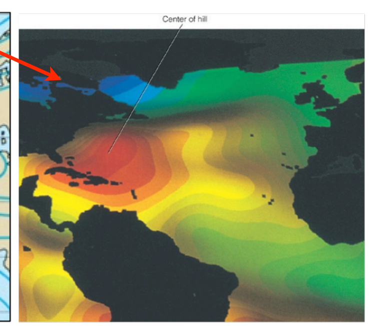
- The difference: time scale
  - Imagine a hurricane (low pressure) arrives
    - Hours-days: barometric effect dominates
    - Sea level rises
  - Imagine the hurricane stayed in one place
    - Days-months: Ekman & geostrophic take over



Time Scale of Sea Level

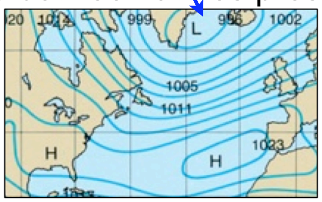
- So long-term sea level matches long-term average atmospheric pressure
  - Low atmospheric pressure
  - Low sea level

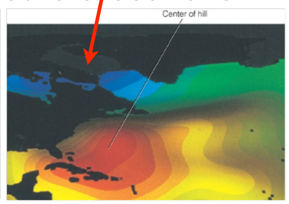




Two Key Distinctions

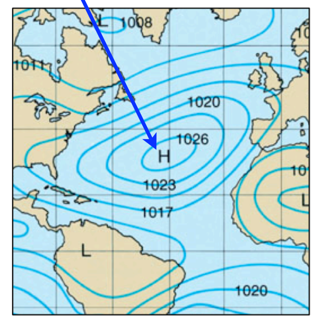
- #1 High atmospheric pressure = high sea surface pressure
  - But low atmospheric pressure also = high sea surface pressure
  - High sea surface pressure results from steep sea surface slope
  - Match is between atmos pressure & sea level

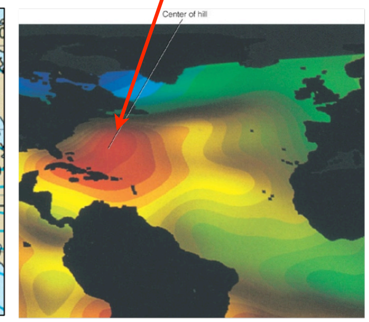




Two Key Distinctions

- #2 Note high atmospheric pressure is centered over the ocean basin
  - But high sea level is toward the west side of the basin



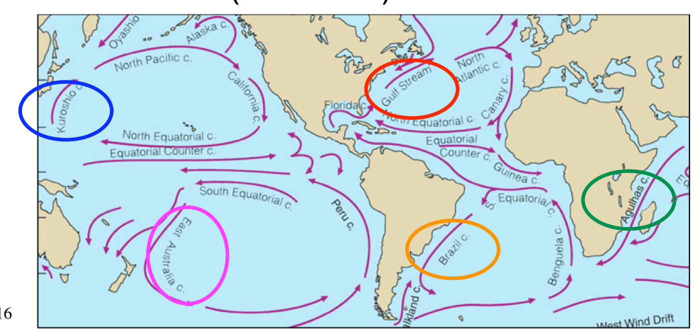


The Asymmetrical Oceans

- Currents differ on the east & west sides of ocean basins
  - Western Boundary Currents
    - Fast, narrow, deep, & well-defined
    - Weak upwelling
    - Warm
  - Eastern Boundary Currents
    - Slow, broad, shallow, less distinct
    - Strong upwelling
    - Cold

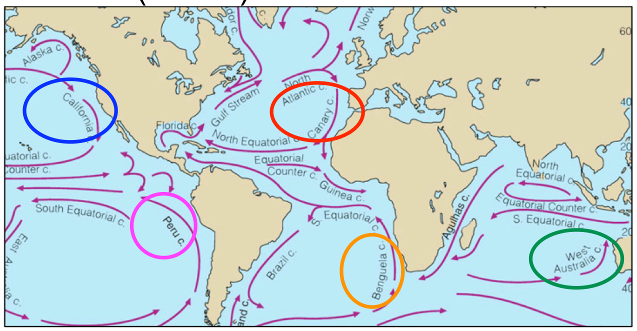
Western Boundary Currents

- On the west sides of ocean basins
  - Gulf Stream (N. Atlantic), Kuroshio (N. Pacific)
  - Agulhas (Indian), Brazil (S. Atlantic), E. Australia (S. Pacific)



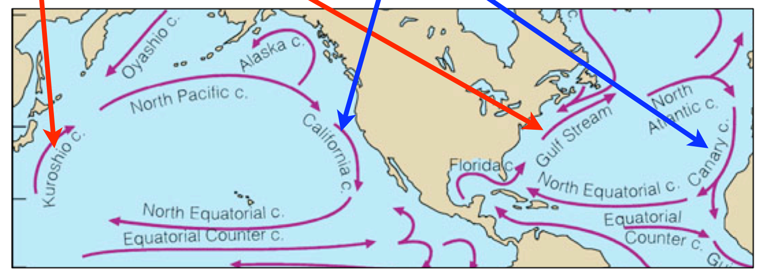
Eastern Boundary Currents

- On the east sides of ocean basins
  - Canary (N. Atlantic), California (N. Pacific)
  - Peru (S. Pacific), Benguela (S. Atlantic), W. Australia (Indian)



“Western Intensification”

- Western Boundary Currents
  - Warm, fast, narrow, deep, clearly defined
- Eastern Boundary Currents
  - Cool, slow, wide, shallow, less defined



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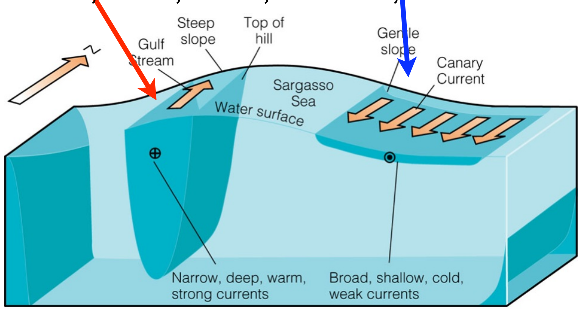
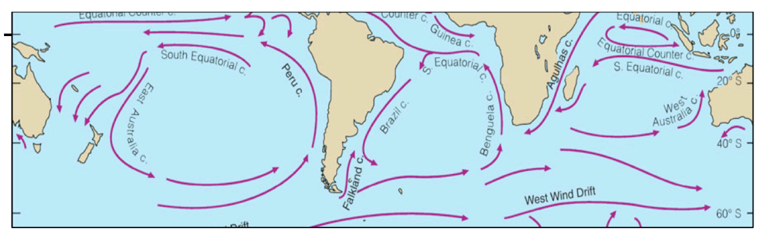


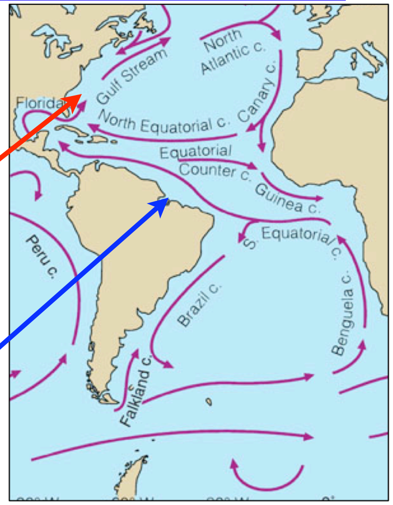
Western Intensification

- Ultimate causes are:
  - Blocking effect of continents
  - Earth’s rotation
- Generally weaker in S. hemisphere
  - Shape & size of basins & continents
  - Orientation of coastline



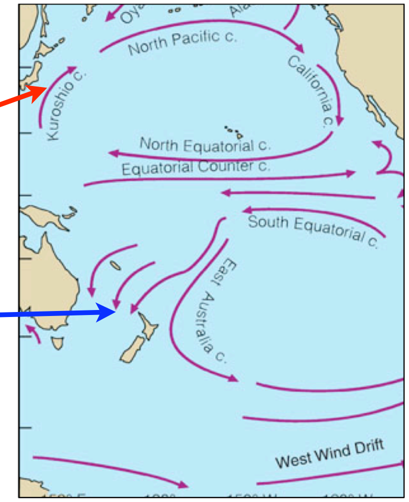
Blocking effect of continents

- Gulf Stream is stronger than Brazil Current
  - Shape of N. America
    - Funnel-shaped
    - Forces sharper turn of Equatorial Current
  - Shape of S. America
    - Diverts S. Equatorial Current into N. Atlantic



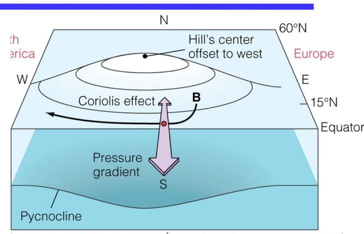
Blocking effect of continents

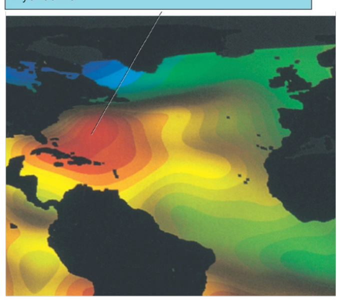
- Kuroshio is stronger than E. Australia Current
  - Asia solid
    - Strongly blocks N. Equatorial Current
  - Australia & New Zealand islands
    - Only weakly block S. Equatorial Current



Effect of Earth's Rotation

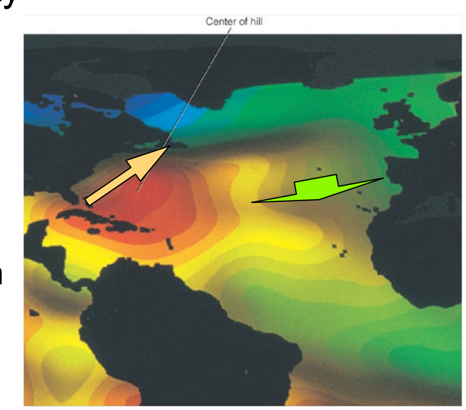
- Too technical to examine details of Coriolis
  - More descriptive explanation
  - Picture the "hill" of sea surface
    - Ideally in the center of the ocean basin
    - But actually skewed toward the western side





Simplest Description

- Volume continuity
  - Same volume of water must be traveling all the way around the gyre.
  - On west it must squeeze through a narrow width, so travels faster.
  - East wider & slower



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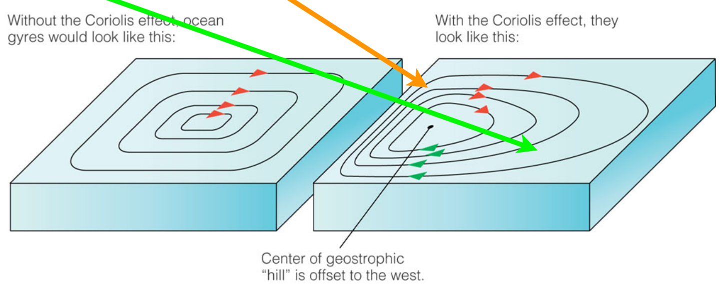
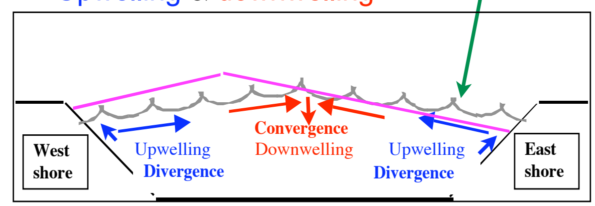


Sea Surface Profile: Ideal

- Cross-sectional schematic view
  - From the Equator looking north in N. Hemisphere
    - Idealized sea surface: gray scallops
    - Water diverges from coasts
    - Water converges in ocean center
    - Upwelling & downwelling



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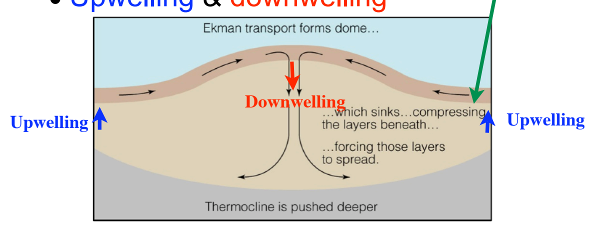
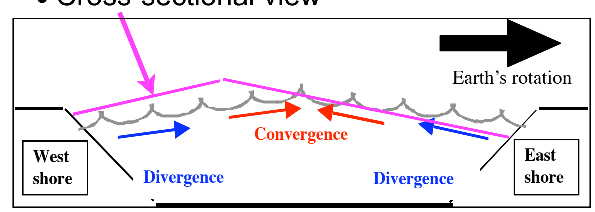


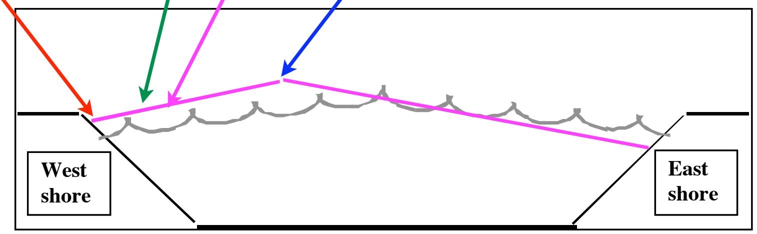
Sea Surface Profile: Actual

- Earth rotates (accelerates) eastward
  - Water "lags" on trailing edge
  - Water accumulates on the western side of ocean basins
    - (Backward sloshing of water in a dishpan when you take a quick step forward)
    - Cross-sectional view



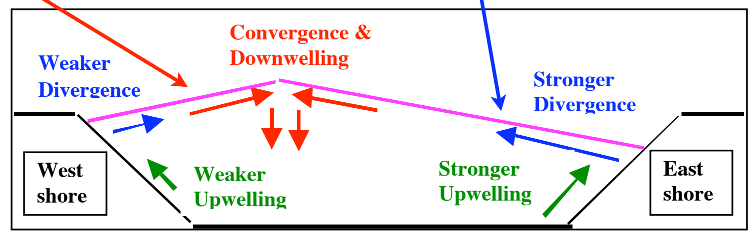
Sea Surface Profile: Actual

- Asymmetry in sea level & sea surface slope
  - Sea level is higher on west & lower on east
  - Summit of sea level “hill” shifts westward
  - Slope is steeper on west & less steep on east
  - Current is narrower on west & wider on east



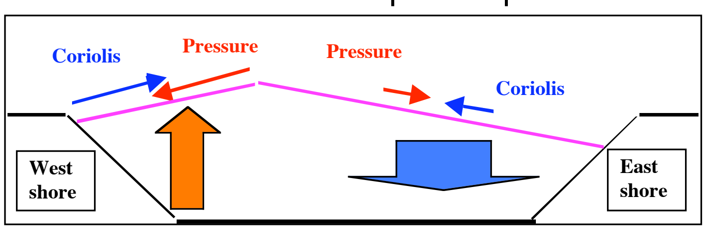
Sea Surface Profile: Actual

- Asymmetry in convergence & divergence, upwelling & downwelling
  - Steeper slope, greater pressure inhibit divergence & upwelling on west side
  - Gentler slope, weaker pressure enhance divergence & upwelling on east side



Western Intensification

- Fast, narrow geostrophic current on west
  - Steeper slope, greater pressure, faster speed
  - Coriolis increases with speed = pressure
- Slower, wider geostrophic current on east
  - Gentler slope, weaker pressure, slower speed
  - Coriolis decreases with speed = pressure

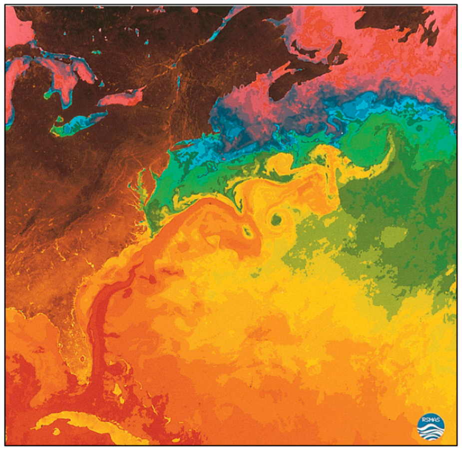


Technical Explanation

- Western flank of "hill" is steeper
  - Gravity/pressure gradient force is greater
  - Water tends to accelerate downhill faster
  - Greater speed increases Coriolis effect
  - Turning tendency is stronger
  - Stronger Coriolis balances stronger gravity/ pressure force.
  - Geostrophic current

Western Boundary Currents

- Sharp temperature, speed, & color changes at western edges give impression of "river”
  - Gulf Stream
  - (Photo shows sea surface temperature)



Oceanography 101, Richard Strickland Lecture 14 © 2006 University of Washington

Western Boundary Currents

- Strong western boundaries are unstable & tend to “wobble.”
  - This creates “eddies.”
    - Warm-core rings
    - Cold-core rings