

Western Boundary Currents



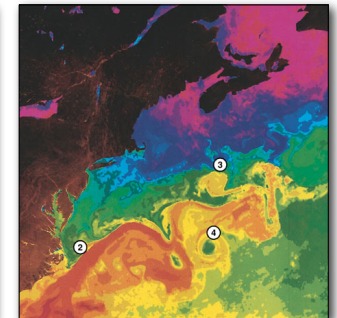
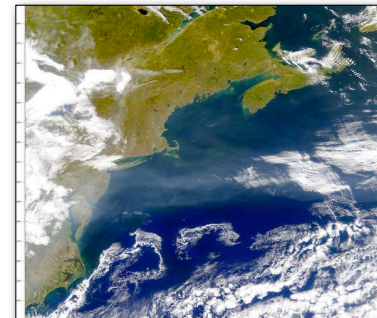
- Outstanding characteristics
 - Heat & water transport
 - Sharp boundaries
- Case Study: the Gulf Stream
 - Effects on shipping
 - Climate effects on Europe
 - Global climate effects
 - Climate effects on N. America
 - Online reading:
 - Philadelphia Inquirer
 - http://www.philly.com/mld/inquirer/news/special_packages/gulfstream/

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Gulf Stream & Shipping



- Warm Gulf Stream water is clear blue
 - Cooler northern water is cloudier & greener
 - Visible true color vs. infrared false color



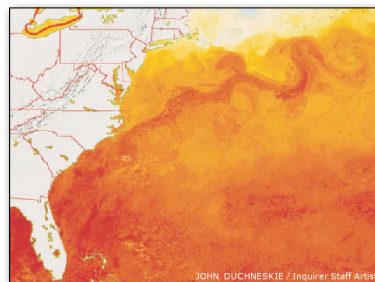
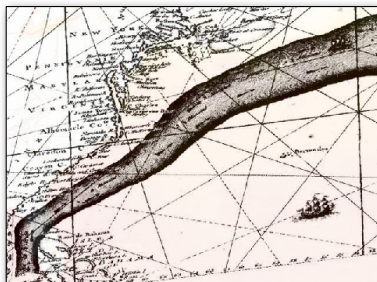
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http://visibleearth.nasa.gov/view_rec.php?id=1453

Gulf Stream & Shipping



- Ben Franklin first mapped current 1769
 - Based on changes in surface temperature & color
 - As postmaster he noted delays in European mail
 - Saved sailors time wasted fighting the current



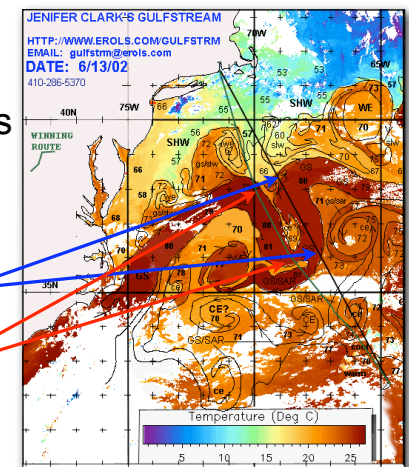
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www.realcities.com/multimedia/philly/inquirer/KRT_packages/archive/slideshow/gulfgraphics/index.html

Gulf Stream & Shipping



- Today satellite photos of Stream are used
- Valued in sailing races
 - Example: Newport - Bermuda race 2002
 - Most direct route
 - Against the current
 - Winning route
 - Followed current



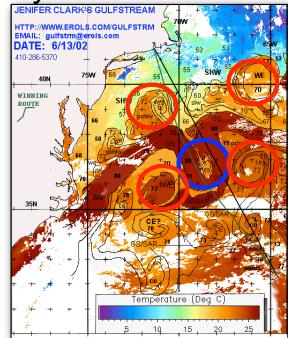
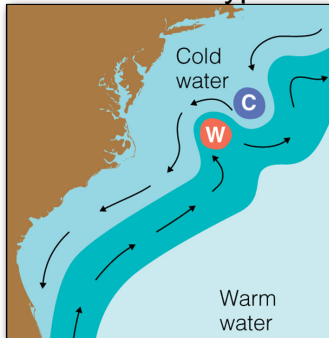
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<http://users.erols.com/gulfstm/>
www.philly.com/mld/inquirer/news/special_packages/gulfstream/13415385.htm

Gulf Stream & Shipping



- A **cold-core ring** was forming
 - **Warm-core rings** already present
 - Affects number & type of fish you can catch

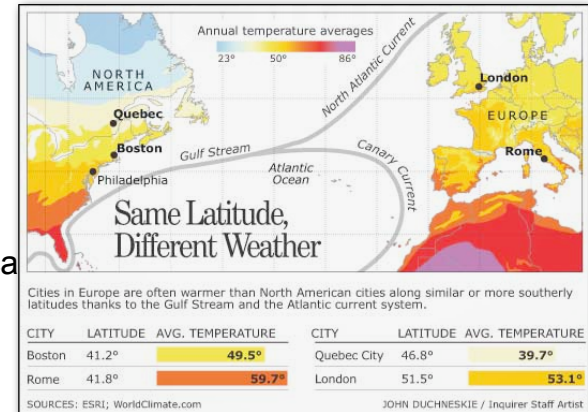


5 Garrison Fig. 9.12 p. 208

Gulf Stream & Climate



- Heat transport
 - Europe much warmer than N. America at same latitude
 - Ice-free ports
 - Farming

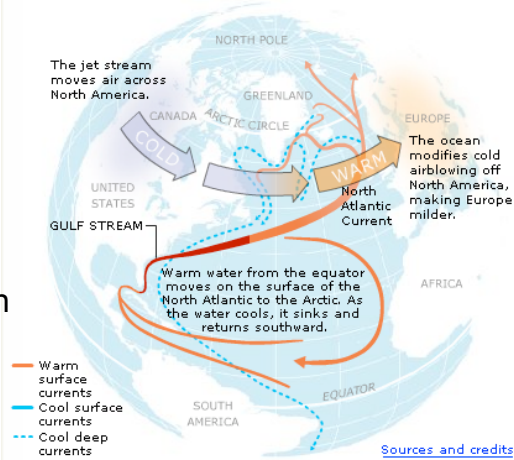


6 www.realcities.com/multimedia/philly/inquirer/KRT_packages/archive/slideshow/gulfgraphics/index.html

Gulf Stream & Climate



- Heat transport
 - Prevailing westerlies blowing over the warm N. Atlantic
 - Europe much warmer than N. America at same latitude

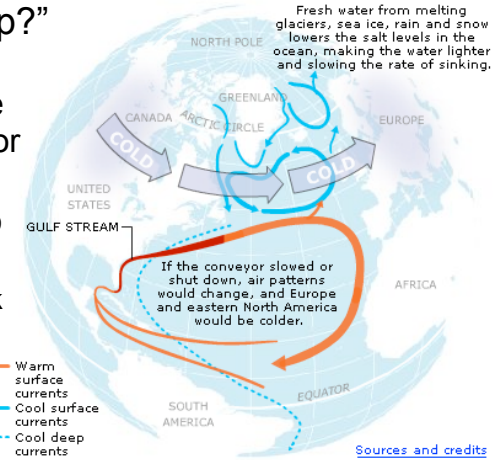


7 www.realcities.com/multimedia/philly/inquirer/KRT_packages/archive/slideshow/gulfgraphics/index.html

Gulf Stream & Climate



- Climate "flip-flop?"
 - Concern that warmer climate could weaken or divert current
 - Europe back to Ice Age
 - Happened 11k years ago
 - Ocean 102



8 www.realcities.com/multimedia/philly/inquirer/KRT_packages/archive/slideshow/gulfgraphics/index.html

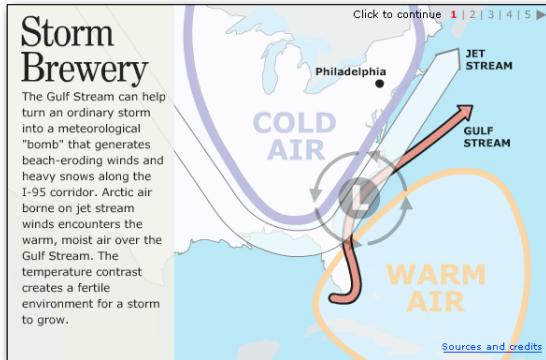
Gulf Stream & Weather



- Temperature contrast
 - Also heavy moisture content of air from tropics

Similar to the way hurricanes form

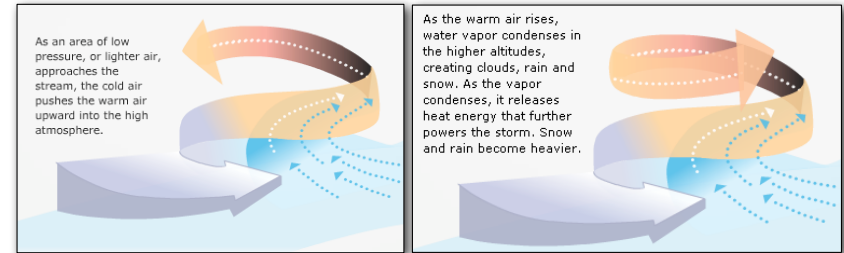
- Rising air
- Condensation
- “Latent heat”



Gulf Stream & Weather



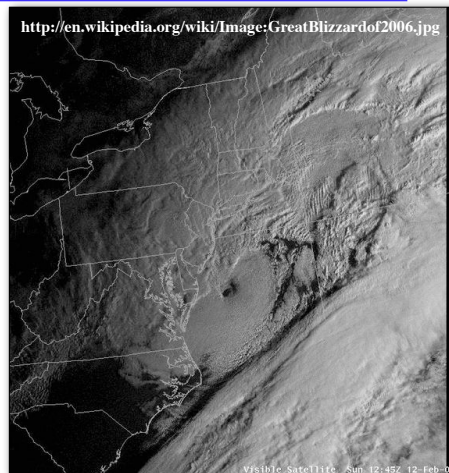
- Hurricanes powered by ocean heat & moisture
 - Gulf storms get lift from heavy, cold air
 - Shove warm, moist air aloft
 - Condensation takes over to power storms



The Perfect Storm



- Famous “nor-easters”
 - Low pressure systems spawned by clash of Gulf Stream & cold continental air
 - Counterclockwise flow gives winds from NE along coast



<http://en.wikipedia.org/wiki/Image:GreatBlizzardof2006.jpg>

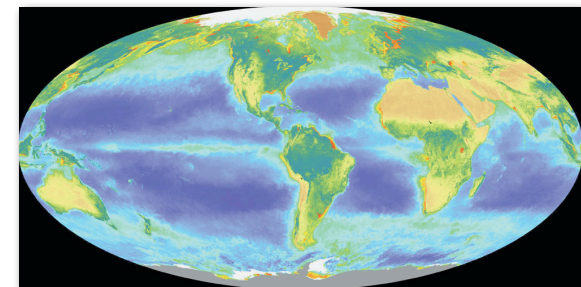
VFSINJC_Satellite_Aug_12_45Z_12_Feb_06

• Animation

Eastern Boundary Currents



- Upwelling affects physics, chemistry, & biology
 - Supplies nutrients to the surface for production
 - Upwelling areas are generally the most biologically productive areas in the oceans.
 - Green color indicates chlorophyll



Coastal Upwelling

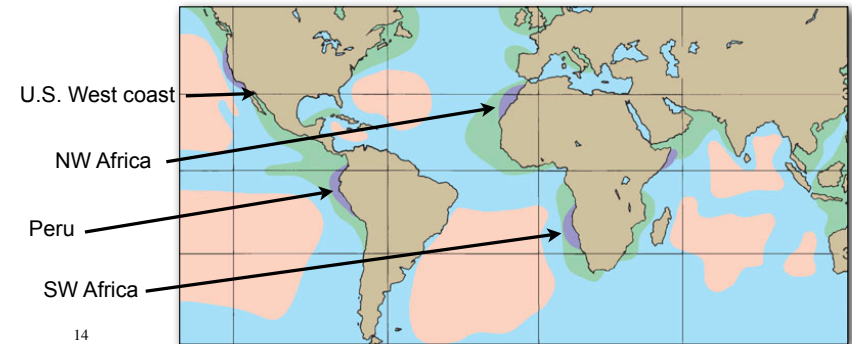


- Coastal upwelling is more transient than the large-scale gyre circulation.
 - Driven by wind & Ekman transport
 - Starts and stop within a few hours or days in response to changing winds.
 - Appears and disappears with the changing seasons in temperate zones, e.g. Pacific Northwest coast
 - Fluctuations are superimposed on the large-scale mean gyre circulation

Coastal Upwelling



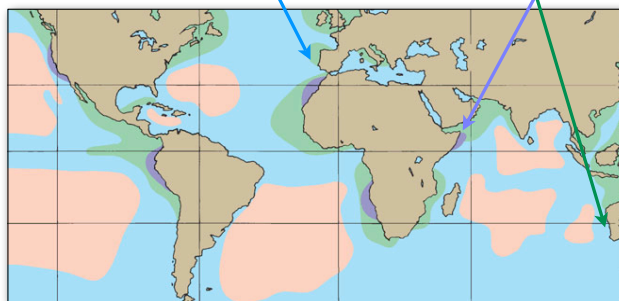
- Strong upwelling along the coasts on the eastern sides of the ocean basins
 - Especially on a long, straight coastline



Coastal Upwelling



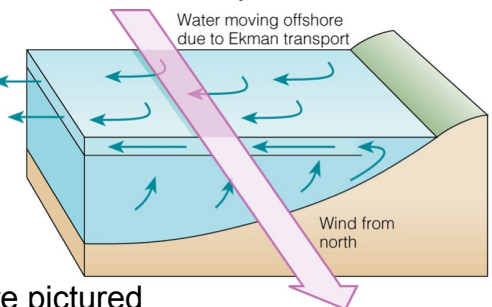
- Weaker off Europe & W. Australia due to lack of long, straight coastline.
- Monsoons generate upwelling on Somali coast in late summer



General Upwelling Principle



- We already looked at equatorial upwelling
- Wind blowing parallel to a coastline
 - Driven by wind & Ekman transport
 - Water driven away from shore
 - Replaced by upward movement of deep water
 - N. Hemisphere pictured

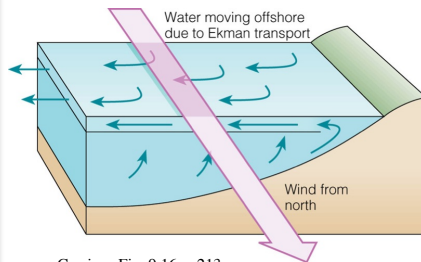
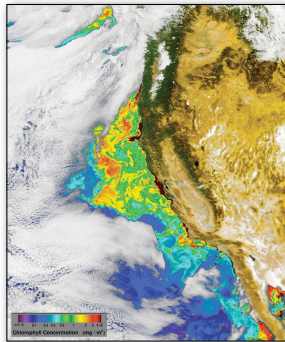


Garrison Fig. 9.16 p. 213

General Upwelling Principle



- Properties of upwelled deep water
 - Cold, nutrient-rich, oxygen-poor
 - Chlorophyll (green-yellow-red) pictured off California

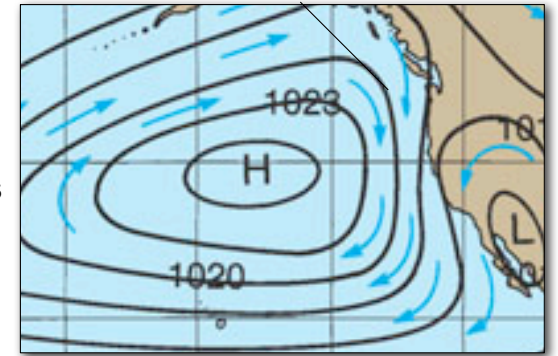


Garrison Fig. 9.16 p. 213

Northwest Coast



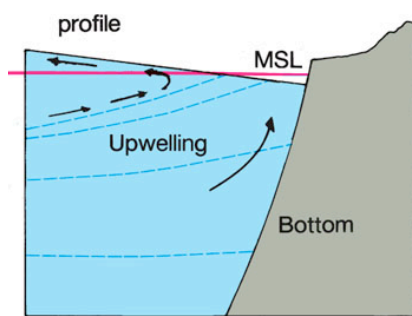
- High pressure off West Coast in summer
 - Wind from north & coastal upwelling
 - Happens any time of year when winds are from north for 1-3 days
 - Stops if south wind blows in summer



Northwest Coast



- Wind (W) from the north/northwest
 - Gives offshore Ekman transport (T)
 - Upwelling, lower sea level at coast

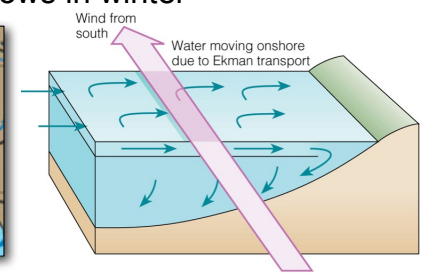
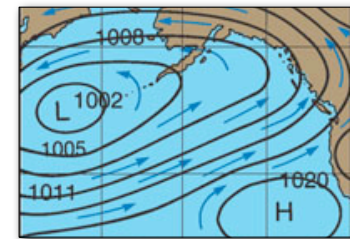


(a) Summer

Northwest Coast



- Low pressure off WA/OR in winter
 - Wind from S/SW & coastal downwelling
 - Happens any time of year when winds are from south for 1-3 days
 - Stops if north wind blows in winter

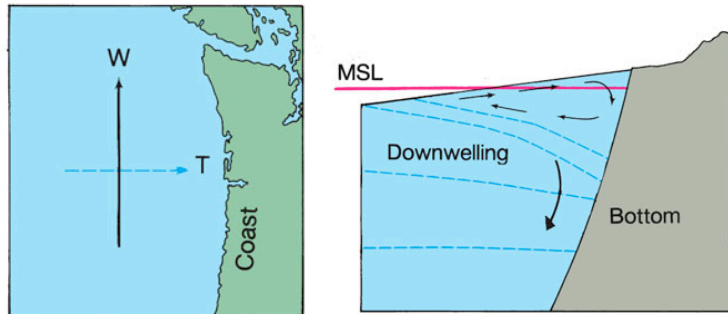


Garrison Fig. 9.17 p. 214

Northwest coast



- Wind (W) from the south/southwest
 - Gives onshore Ekman transport (T)
 - Downwelling, higher sea level at coast

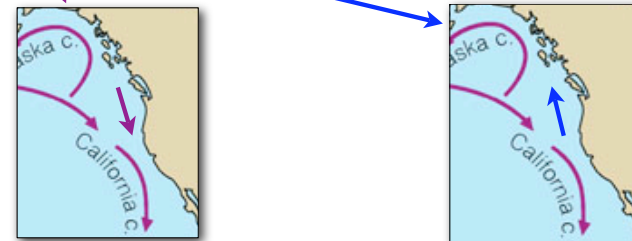


21 (b) Winter

Northwest Coast



- Seasonal upwelling & downwelling cycle
 - Superimposed on long-term average geostrophic current
 - Summer: California C. stronger, moves onshore
 - Winter: California C. weaker, moves offshore
 - Wind-driven downwelling counter-current forms

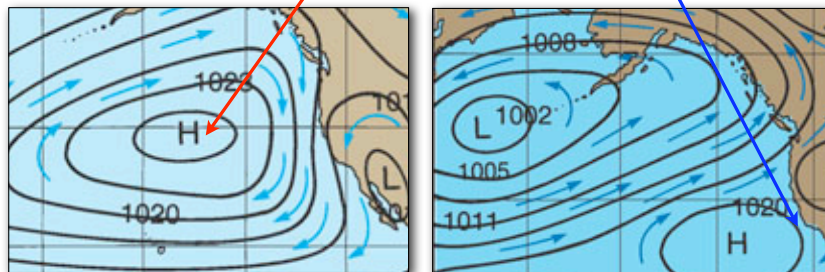


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Northwest coast



- Upwelling occurs all year off California
 - Average high pressure persists all year
 - Accounts for cold ocean temp & SF fog.
 - Pressure, wind & upwelling weaker in winter

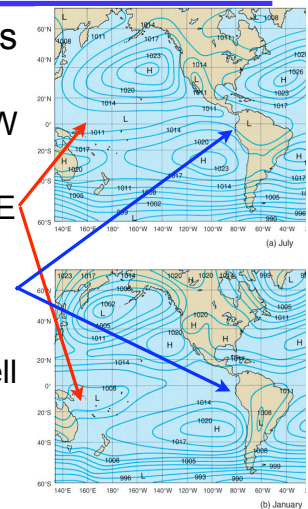


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More Ocean Asymmetry



- Pacific so large, it makes its own climate
 - Low atmospheric pressure W
 - Indonesia & Australia
 - High atmospheric pressure E
 - S. American coast
 - Greater difference in SH summer (Dec.-Jan.)
 - An East-West convection cell on the Equator
 - "Walker circulation"

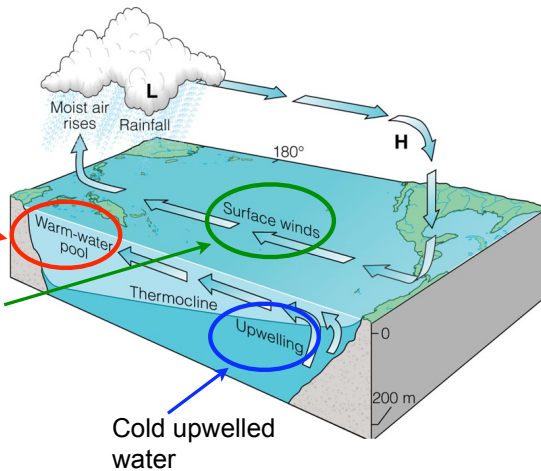


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More Ocean Asymmetry



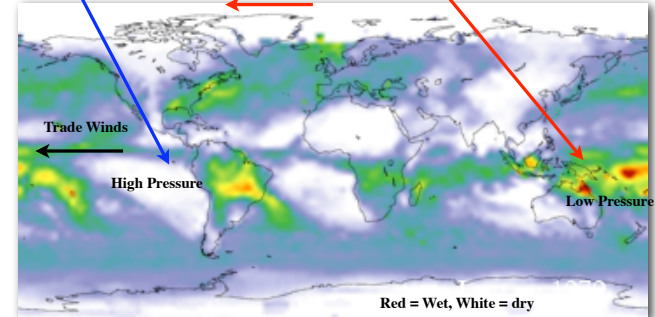
- Convection cell on the Equator
 - Driven by difference in ocean temperature
 - Trade winds push water westward
 - Weak coriolis



More Ocean Asymmetry



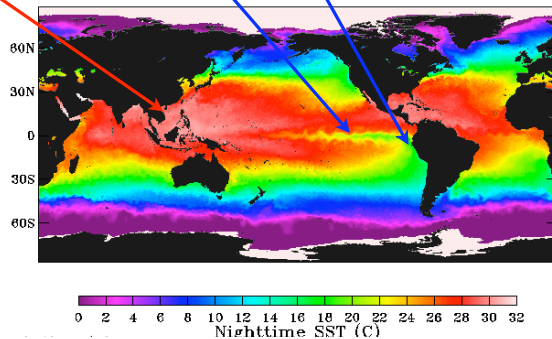
- Convection cell on the Equator
 - Dry desert climate in eastern equatorial Pacific
 - Wet rain forest climate in Indonesia & N. Australia



More Ocean Asymmetry



- Cold upwelled water in eastern equatorial Pacific & along Equator
- Surface "warm water pool" in Indonesia & N. Australia
 - Water warms as it flows to west
 - Long distance
 - Weak Ekman

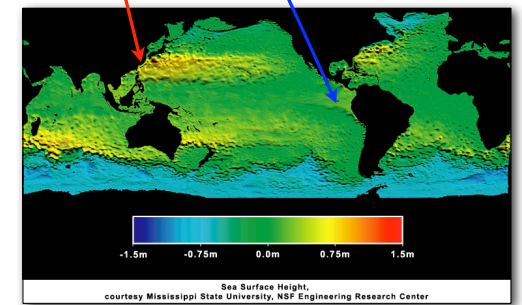


<http://podaac-www.jpl.nasa.gov/sst/images/mcsst.gif>

More Ocean Asymmetry



- Low sea level in E. Pacific & along Equator
 - Coastal divergence from upwelling
- High sea level in W. Pacific
 - Trade winds & Earth's rotation push water to west
 - Western intensification

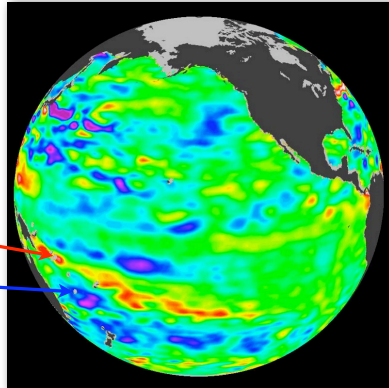


<http://oceanworld.tamu.edu/students/elينو/index.html>

Sea-Surface Elevation



- Continuously monitored by satellite “Jason”
 - Anomalies from long-term average displayed
- An example of near-average conditions
 - May 2006
 - Green = average sea surface height
 - Red = high anomaly
 - Blue = low anomaly



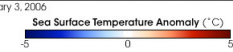
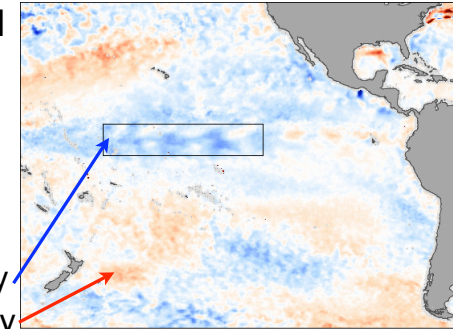
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http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17291

Sea-Surface Temperature



- Continuously monitored by satellite “AMSR-E”
 - Anomalies from long-term average displayed
- An example of cool equatorial Pacific conditions
 - Jan.-Feb. 2006
 - White = average sea surface temp
 - Blue = low anomaly
 - Red = high anomaly



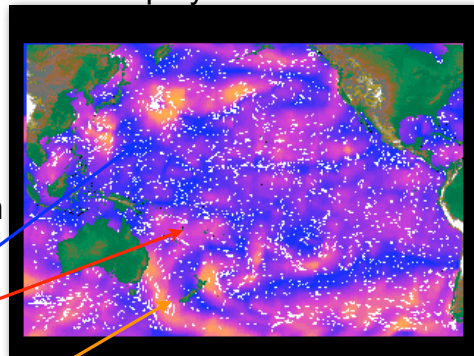
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http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17180

Pacific Trade Winds



- Continuously monitored by satellite “ADEOS”
 - Wind speed & direction displayed
- An example of average Pacific conditions
 - Sept. 1996
 - White = direction
 - Blue = low wind
 - Red = moderate wind
 - Orange = high wind



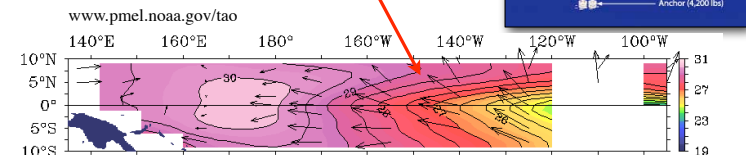
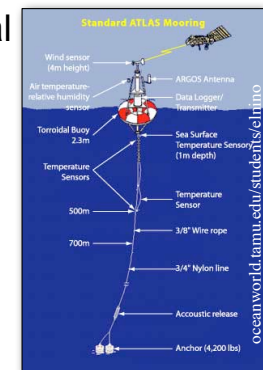
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http://earthobservatory.nasa.gov/Library/QuikSCAT/QuikSCAT_3.html

Ocean Buoy Array



- Buoys moored along equatorial Pacific
 - Wind speed & direction
 - Air temperature
 - Ocean temperature
 - Upper 500 meters
 - Each arrow = 1 buoy



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