1 **CHAPTER 7**
Ocean Circulation
2 ***Words...***
3 **Ocean currents**
- Moving seawater
- Surface ocean currents
  - Transfer heat from warmer to cooler areas
  - Similar to pattern of major wind belts
  - Affect coastal climates
- Deep ocean currents
  - Provide oxygen to deep sea
- Affect marine life
-

4 **Types of ocean currents**
- Surface currents
  - Wind-driven
  - Primarily horizontal motion
- Deep currents
  - Driven by differences in density caused by differences in temperature and salinity
  - Vertical and horizontal motions

5 **Measuring surface currents**
- Direct methods
  - Floating device tracked through time
  - Fixed current meter
- Indirect methods
  - Pressure gradients
  - Radar altimeters
  - Doppler flow meter

6
7 **Measuring surface currents**
8 **Measuring surface currents (accidentally)**
9 **Curt Ebbesmeyer**
10 **Measuring surface currents**
11 **Measuring deep currents**
- Floating devices tracked through time
- Chemical tracers
  - Tritium
  - Chlorofluorocarbons
- Characteristic temperature and salinity

12 **Measuring Deep Currents**
- Argo
  - Global array of free-drifting profiling floats
  - Floating device tracked through time
-

13 **Measuring Deep Currents**
- Argo

14 **Surface Currents**
- Occur above pycnocline
  - Affect only 10% of ocean water on Earth
- Friction between wind and ocean surface
  - 2% of wind energy transferred to ocean surface
  - Surface currents slower speed than corresponding winds

- Generally follow Earth's wind belt pattern

15 **Surface currents**
- Frictional drag between wind and ocean
- Wind plus other factors such as
  - Distribution of continents
  - Gravity
  - Friction
  - Coriolis effect
- Gyres or large circular loops of moving water

16 **Ocean gyres**

17 **Other surface currents**
- Equatorial Countercurrents
- Subpolar gyres

18 **Ocean Circulation**

19 **surface currents**

From Curt Ebbesmeyer:

20 **Five Subtropical Gyres**
- North Atlantic – Columbus Gyre
- South Atlantic – Navigator Gyre
- North Pacific – Turtle Gyre
- South Pacific – Heyerdahl Gyre
- Indian Ocean – Majid Gyre

21 **Subtropical Gyres and Currents**

22 **Gyres and Boundary Currents**

23 **Subtropical Gyre Currents**
- Equatorial Currents
  - North or south
  - Travel westward along equator
- Western Boundary Currents
  - Warm waters from equatorial regions
  - Western edge of ocean basins
-

24 **Subtropical Gyre Currents**
- Northern or Southern Boundary Currents
  - Easterly water flow across ocean basin
  - Northern boundary currents in Northern Hemisphere
  - Southern boundary currents in Southern Hemisphere
- Eastern Boundary Currents
  - Cool waters
  - Eastern edge of ocean basins
-

25 **Other Surface Currents**
- Equatorial Countercurrents
  - Eastward flow between North and South Equatorial Currents
  - Due to minimal Coriolis effect at equator
- Subpolar Gyres
  - Rotate opposite subtropical gyres
  - Smaller and fewer than subtropical gyres

26 **Ekman Spiral and Ekman Transport**
- Observation that Arctic Ocean ice moved at a 20- to 40-degree angle to the right of the wind
- Southern Hemisphere movement to the left of the wind

27 **Ekman Spiral**
- V. Walfrid Ekman
  - Developed circulation model in 1905
- Ekman spiral
  - Explains balance between friction and Coriolis effect
  - Describes direction and flow of surface waters at different depths

28 **Ekman spiral**
- Surface currents move at angle to wind
- Ekman spiral describes speed and direction of seawater flow at different depths
- Each successive layer moves increasingly to right (N hemisphere)

29 **Ekman transport**
- Average movement of seawater under influence of wind
- 90^{o} to right of wind in Northern hemisphere
- 90^{o} to left of wind in Southern hemisphere

30 **Ekman Spiral**

31 **Geostrophic flow**
- Ekman transport piles up water within subtropical gyres
- Surface water flows downhill (gravity) and
- Also to the right (Coriolis effect)
- Balance of downhill and to the right causes geostrophic flow around the "hill"

32 **Western Intensification**
- Top of hill of water displaced toward west due to Earth's rotation.
- Western boundary currents intensified in both hemispheres.
  - Faster
  - Narrower
  - Deeper
  - Warmer
- Coriolis effect contributes to western intensification.

33 **Eastern Boundary Currents**
- Eastern side of ocean basins
- Tend to have the opposite properties of Western Boundary Currents
  - Cold
  - Slow
  - Shallow
  - Wide

34 **Eastern and Western Boundary Currents**

35 **Ocean currents and climate**
- Warm ocean currents warm air at coast
  - Warm, humid air
  - Humid climate on adjoining landmass
- Cool ocean currents cool air at coast
  - Cool, dry air
  - Dry climate on adjoining landmass

36 **Ocean currents and climate**

37 **Ocean currents and climate**

38 **Upwelling and Downwelling**
- Upwelling – Vertical movement of cold, nutrient-rich water to surface
  - High biological productivity – an abundance of algae at the base of the food web
- Downwelling – Vertical movement of surface water downward in water column

39 **Diverging surface seawater**

40 **Converging surface seawater**

41 **Coastal upwelling and downwelling**
- Ekman transport moves surface seawater onshore (downwelling) or
- Offshore (upwelling)

42 **Coastal upwelling and downwelling**
- Ekman transport moves surface seawater onshore (downwelling) or
- Offshore (upwelling)

43 **Other Causes of Upwelling**
- Offshore winds
- Seafloor obstruction
- Coastal geometry change
- Lack of pycnocline
  - High latitude oceans

44 **Antarctic Circulation**
- Antarctic Circumpolar Current
  - Also called West Wind Drift and Penguin Gyre
  - Only current to completely encircle Earth
  - Moves more water than any other current
  -

45 **Antarctic Circulation**
- Antarctic Convergence
  - Cold, dense Antarctic waters converge with warmer, less dense sub-Antarctic waters.
  - Northernmost boundary of Antarctic Ocean
- East Wind Drift
  - Polar Easterlies
  - Creates surface divergence with opposite flowing Antarctic Circumpolar Current
- Antarctic Divergence
  - Abundant marine life

46 **Atlantic Ocean Circulation**
- North Atlantic Subtropical Gyre
-
  - North Equatorial Current
  - Gulf Stream
  - North Atlantic Current
  - Canary Current
  - South Equatorial Current
  - Atlantic Equatorial Counter Current

47

48 **Atlantic Ocean circulation**

49 **Gulf Stream**
- Best studied of all ocean currents
- Meanders and loops
- Merges with Sargasso Sea
  - Circulates around center of North Atlantic Gyre
  - Unique biology – *Sargassum*

50 **Gulf Stream**
- Meanders or loops may cause loss of water volume and generate:
  - Warm-core rings – warmer Sargasso Sea water trapped in loop surrounded by cool water
  - Cold-core rings – cold water trapped in loop surrounded by warmer water
- Unique biological populations

51

52

53 **Other North Atlantic currents**

- Labrador Current
- Irminger Current
- Norwegian Current
- North Atlantic Current
-

54 **Climate effects of North Atlantic currents**

- Gulf Stream warms East coast of U.S. and Northern Europe
- North Atlantic and Norwegian Currents warm northwestern Europe
- Labrador Current cools eastern Canada
- Canary Current cools North Africa coast

55 **Indian Ocean Circulation**

- Monsoons – seasonal reversal of winds over northern Indian Ocean
- Heat Capacity Differential
- Northeast monsoon – winter
- Southwest monsoon – summer

56 **Indian Ocean Circulation**

57 **Indian Ocean Monsoon**

- Affects seasonal land weather
- Affects seasonal Indian Ocean current circulation
- Affects phytoplankton productivity

58 **Indian Ocean Circulation**

- Indian Ocean Subtropical Gyre
  - Agulhas Current
  - Australian Current
  - Leeuwin Current

59 **Pacific Ocean Circulation**

- North Pacific Subtropical Gyre
  - Kuroshio Current
  - North Pacific Current
  - California Current
  - North Equatorial Current
  - Alaskan Current

60 **Pacific Ocean Circulation**

- South Pacific Subtropical Gyre
  - East Australian Current
  - Antarctic Circumpolar Current
  - Peru Current
  - South Equatorial Current
  - Equatorial Counter Current

61

62 **Atmospheric and oceanic disturbances in Pacific Ocean**

- Normal conditions
  - Air pressure across equatorial Pacific is higher in eastern Pacific
  - Strong southeast trade winds
  - Pacific warm pool on western side
  - Thermocline deeper on western side
  - Upwelling off the coast of Peru

63 **Normal conditions**

64 **Atmospheric and oceanic disturbances in Pacific Ocean**

- El Niño-Southern Oscillation (ENSO)

- Warm (El Niño) and cold phases (La Niña)
- High pressure in eastern Pacific weakens
- Weaker trade winds
- Warm pool migrates eastward
- Thermocline deeper in eastern Pacific
- Downwelling
- Lower biological productivity
  - Corals particularly sensitive to warmer seawater

65 **El Niño-Southern Oscillation (ENSO): Warm phase (El Niño)**

66 **ENSO Conditions in the Pacific Ocean**

67 **El Niño-Southern Oscillation (ENSO): cool phase (La Niña)**

- Increased pressure difference across equatorial Pacific
- Stronger trade winds
- Stronger upwelling in eastern Pacific
- Shallower thermocline
- Cooler than normal seawater
- Higher biological productivity

68 **El Niño-Southern Oscillation (ENSO) Cool phase (La Niña)**

69 **La Niña Conditions**

70 **El Niño and La Niña**

71 **ENSO events**

72 **ENSO Has Global Impacts**

73 **Notable ENSO Events**

- 1982–1983
- 1997–1998
- Flooding, drought, erosion, fires, tropical storms, harmful effects on marine life
- Unpredictable

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- 1997–1998
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- Unpredictable

75 **Occurrence of ENSO Events**

- El Niño warm phase about every 2–10 years
- Highly irregular
- Phases usually last 12–18 months
- 10,000-year sediment record of events
- ENSO may be part of Pacific Decadal Oscillation (PDO)
  - Long-term natural climate cycle
  - Lasts 20–30 years

76 **Predicting El Niño Events**

- Tropical Ocean–Global Atmosphere (TOGA) program
  - 1985
  - Monitors equatorial South Pacific
  - System of buoys
- Tropical Atmosphere and Ocean (TOA) project

  - Continues monitoring
- ENSO still not fully understood

77 **Deep-Ocean Currents**
- Thermohaline Circulation – deep ocean circulation driven by temperature and density differences in water
- Below the pycnocline
- 90% of all ocean water
- Slow velocity

78 **Thermohaline circulation**
- Movement caused by differences in density (temperature and salinity)
  - Cooler seawater denser
  - Saltier seawater denser

79 **Thermohaline Circulation**
- Originates in high latitude surface ocean
- Cooled, now dense surface water sinks and changes little.
- Deep-water masses identified on temperature–salinity (T–S) diagram
  - Identifies deep water masses based on temperature, salinity, and resulting density

80 **T–S Diagram**

81 **Thermohaline circulation**
- Selected deep-water masses
  - Antarctic Bottom Water
  - North Atlantic Deep Water
  - Antarctic Intermediate Water
  - Oceanic Common Water
- Cold surface seawater sinks at polar regions and moves toward equator

82 **Thermohaline circulation**

83

84 **Conveyor-belt circulation**
- Combination deep ocean currents and surface currents

85 **Deep ocean currents**
- Cold, oxygen-rich surface water to deep ocean
- Dissolved O_2 important for life and mineral processes
- Changes in thermohaline circulation can cause global climate change
  - Example, warmer surface waters less dense, not sink, less oxygen deep ocean

86 **Power from Currents**
- Currents carry more energy than winds.
- Florida–Gulf Stream Current System
- Underwater turbines
  - Expensive
  - Difficult to maintain
  - Hazard to boating

87 **End of CHAPTER 7**
Ocean Circulation