1 Physical Environment: Atmosphere and Oceans - Circulation

EVPP 110 Lecture

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2 Global Environments

✓ **Biome**
- – type of plant and animal community that covers large geographic areas

✓ Global Environments
- – distribution of biomes
  - • result of
    - – physical geography
    - – solar radiation
    - – global circulation patterns
      - » oceanic
      - » atmospheric

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4 Global Environments

✓ Global Environments
- – interdependent relationship between ocean and atmosphere
  - • same physical processes determine operation of both systems
    - – changes in ocean lead to long-term shifts in general circulation of atmosphere

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Solar radiation

✓ Global Environments
- – atmosphere and ocean together act like a **global heat engine**
  - • redistributing heat that reaches earth from sun

6 Solar Radiation

✓ **Solar radiation**
- – warms earth's surface
- – drives circulation of oceans and atmosphere

7 Solar Radiation

✓ **Solar radiation**
- – emitted by sun
  - • in form of radiant energy
  - • at same average rate in all directions
- – received on earth's surface
  - • in varying amounts, depending on
    - – distance
    - – duration of daylight
    - – angle at which sun's rays impinge on surface

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10 Solar Radiation

- **Solar radiation**
  - variations in amount earth's surface
    - lead to uneven heating of atmosphere and oceans
      - temperatures at equator higher than temperatures at poles
      - drives interrelated patterns of circulation of oceans and atmosphere

11 Global Circulation Patterns - Atmospheric

- **Global winds**
  - winds that blow steadily from specific directions over long distances
  - produced by movement of air between equator and poles
    - produces **convection currents**
      - warm air rises at equator, air pressure is lower
      - cold air sinks at poles, air pressure is higher

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13 Fig. 17.2

14 Global Circulation Patterns - Atmospheric

- **Global winds**
  - would blow in straight line from poles toward equator if earth did not rotate
  - rotation of earth prevents winds from blowing in straight line
    - as winds move, earth rotates from west to east under them
      - making it seem as if winds have curved
        - » is known as **Coriolis effect**

15 Global Circulation Patterns - Atmospheric

- **Global winds**
  - **Coriolis effect**
    - Norhtern Hemisphere
      - deflects winds to right of direction of travel
    - Southern Hemisphere
      - deflects winds to left of direction of travel

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17 Global Circulation Patterns - Atmospheric

- **Global wind belts**
  - patterns of calm areas and wind belts
    - calm areas
      - air moving vertically (rising or falling)
        - » doldrums
        - » horse latitudes
    - wind belts

– air moving horizontally
  » trade winds
  » prevailing westerlies
  » polar easterlies

18 Fig. 17.2

19 Global Circulation Patterns - Atmospheric

✓ **Global wind belts**
– calm areas
• **doldrums**
– areas of steadily rising warm air near equator
– area of low pressure
– very little horizontal movement of air
  » little to no wind

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21 Global Circulation Patterns - Atmospheric

✓ **Global wind belts**
– calm areas
• **horse latitudes**
– areas of steadily sinking air
  » warm air that rises at equator divides and flows N and S
  » at ~30° N and S latitude, air stops moving toward poles, sinks
– area of high pressure
– very little horizontal movement of air
  » little to no wind

22 Global Circulation Patterns - Atmospheric

✓ **Global wind belts**
– calm areas
• **horse latitudes**
– origin of name
  »

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24 Global Circulation Patterns - Atmospheric

✓ **Global wind belts**
– wind belts
• **trade winds**
– surface pressure differential between 30 ° N & S latitude and equator
  » low pressure at equator
  » high pressure at horse latitudes
– causes winds to blow from region of horse latitudes towards equator

25 Global Circulation Patterns - Atmospheric

✓ **Global wind belts**
- wind belts
  - **trade winds**
    - Northern Hemisphere (between ~30°N and equator)
      - » blow from northeast
      - » deflected right by Coriolis effect
    - origin of name

26 # Global Circulation Patterns - Atmospheric

✓ **Global wind belts**
- wind belts
  - **trade winds**
    - Southern Hemisphere (between ~30°S and equator)
      - » blow generally from southeast
      - » deflected left by Coriolis effect

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28 # Global Circulation Patterns - Atmospheric

✓ **Global wind belts**
- wind belts
  - **prevailing westerlies**
    - surface pressure differential between 30 ° N & S lat and 60 ° N & S lat
      - » low pressure at 60 ° N & S lat
      - » high pressure at 30 ° N & S lat
    - causes winds to blow from region of
      - » 30 ° N to 60 ° N
      - » 30 ° S to 60 ° S

29 # Global Circulation Patterns - Atmospheric

✓ **Global wind belts**
- wind belts
  - **prevailing westerlies**
    - so named because they blow from west to east
    - Northern Hemisphere
      - » blow generally from southwest
      - » deflected right by Coriolis effect
    - Southern Hemisphere
      - » blow generally from northwest
      - » deflected left by Coriolis effect

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31 # Global Circulation Patterns - Atmospheric

✓ **Global wind belts**
- wind belts
  - **polar easterlies**

– cold air near poles sinks
  » flows back toward lower latitudes

32 Global Circulation Patterns - Atmospheric

✓ **Global wind belts**
- wind belts
  - **polar easterlies**
    - Northern Hemisphere
      - » air flows from high pressure at north pole (90°N) to low pressure at 60 °N
      - » deflected to right by Coriolis effect

33 Global Circulation Patterns - Atmospheric

✓ **Global wind belts**
- wind belts
  - **polar easterlies**
    - Southern Hemisphere
      - » air flows from high pressure at north pole (90°S) to low pressure at 60 °S
      - » deflected to left by Coriolis effect

34 Global Circulation Patterns - Atmospheric

✓ **Global wind belts**
- wind belts
  - **polar easterlies**
    - meet the prevailing westerlies at ~ 60°N and S latitude
      - » a region called the polar front
      - » mixing of warm and cold air along polar front effect weather in US

35 Fig. 17.2

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37 Global Circulation Patterns - Oceanic

✓ The Oceans
- circulation
  - El Nino
- tides

38 Global Circulation Patterns - Oceanic

✓ Historical perspective
- early knowledge of ocean currents
  - Pliny (~AD 50)
  - Arabs (around 9th century)
  - Benjamin Franklin (in 18th century)

39 Global Circulation Patterns - Oceanic

- ✓ Historical perspective
  - – Matthew Fontaine Maury
    - first to use large amounts of ocean data in a systematic study of surface currents
    - from 1841 - 1853 he compiled data accumulated in thousands of old log books

40 Global Circulation Patterns - Oceanic

- ✓ Historical perspective
  - – Matthew Fontaine Maury
    - other involvements

41 Global Circulation Patterns - Oceanic

- ✓ Circulation patterns of oceans
  - – two types of circulation exist in oceans
    - **surface circulation**
      - – horizontal movement of water
      - – driven by force of winds at water surface
    - **thermohaline circulation**
      - – vertical movement of water
      - – driven by density differences resulting from variations in water
        - » temperature
        - » salinity

42 Global Circulation Patterns - Oceanic

- ✓ Circulation patterns of oceans
  - – affected by four main factors
    - **wind** acting on ocean surface
    - **containment** of oceans within boundaries set by land masses
    - **earth's rotation**
    - **water density**

43 Global Circulation Patterns - Oceanic

- ✓ mechanics of ocean circulation patterns
  - – **effect of wind**
    - wind exerts a push on water
      - – friction forces stronger in water than in air
        - » speed of water is only a fraction of that of wind
      - – response time of ocean currents to changes in atmospheric circulation is many months

44 Global Circulation Patterns - Oceanic

✓ mechanics of ocean circulation patterns
- **effect of wind**
  - if earth was covered entirely with water
    - winds would form well-defined belts
    - ocean currents would move in distinct belts under influence of prevailing winds

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46 ## Global Circulation Patterns - Oceanic

✓ mechanics of ocean circulation patterns
- **effect of continents**
  - presence of landmasses, modifies idealized oceanic circulation patterns
  - since ocean current cannot leave its basin
    - generalized circulation patterns in ocean basins tend to consist of closed loops called **gyres**

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48 ## Global Circulation Patterns - Oceanic

✓ mechanics of ocean circulation patterns
- **effect of earth's rotation**
  - due to rotation of earth
    - objects moving in straight line along its surface are deflected
      - » as if a sidewise force were acting on it
    - called the **Coriolis effect**
      - » always acts sidewise on objects moving horizontally on earth

49 ## Global Circulation Patterns - Oceanic

✓ mechanics of ocean circulation patterns
- **effect of earth's rotation**
  - because earth spins to east, Coriolis effect causes a deflection
    - to right of direction of motion in Northern Hemisphere
    - to left of direction of motion in Southern Hemisphere

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51 ## Global Circulation Patterns - Oceanic

✓ mechanics of ocean circulation patterns
- **effect water density**
  - density increases with
    - increases in salinity
    - increases in pressure
    - decreases in temperature
  - thermohaline circulation

52 ## Global Circulation Patterns - Oceanic

✓ mechanics of ocean circulation patterns

- **effect water density**
  - **thermohaline circulation**
    - primarily a convection flow
      - » cold, dense waters from polar latitudes sink and move towards tropics
      - » replaced by warmer surface waters that originated in tropics

53 Global Circulation Patterns - Oceanic

✓ Ocean surface circulation

- dominated by two huge surface gyres
  - which move around subtropical zones of high pressure between 30° N & 30° S latitudes
    - Northern Hemisphere gyre
    - Southern Hemisphere gyre

54 Global Circulation Patterns - Oceanic

✓ Ocean surface circulation

- Northern Hemisphere gyre
  - circulates in clockwise direction
    - prevailing winds blow W to E due to earth's eastward rotation are deflected to the right
- Southern Hemisphere gyre
  - circulates in counterclockwise direction
    - prevailing winds blow west to east due to earth's eastward rotation are deflected to the left

55 Global Circulation Patterns - Oceanic

✓ Principle oceanic surface currents

- tend to
  - form loops of circulation marked by
    - strong currents on perimeters
    - relatively little movement internally
  - move
    - warm water poleward
    - cold water toward tropics
    - helps equalize distribution of heat

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57 Global Circulation Patterns - Oceanic

✓ Principle oceanic surface currents

- western boundary currents
- eastern boundary currents
- equatorial currents
- polar circulation

58 ## Global Circulation Patterns - Oceanic

✓Principle oceanic surface currents
- **western boundary currents**
  - general northward current of warm equatorial water
  - flow at west edge of ocean basins
  - tend to be narrow, swift, deep flows with well-defined boundaries

59 ## Global Circulation Patterns - Oceanic

✓Principle oceanic surface currents
- **western boundary currents**
  - strong in Northern Hemisphere
    - Gulf Stream in Atlantic Ocean
    - Kuroshio (or Japanese) Current in Pacific Ocean
  - weaker inSouthern Hemisphere
    - Brazil Current in Atlantic Ocean
    - West Australia Current in Pacific Ocean

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61 ## Global Circulation Patterns - Oceanic

✓Principle oceanic surface currents
- **western boundary currents, examples**
  - **Gulf Stream**
    - warm northward current in north Atlantic Ocean
    - runs from Cape Hatteras to near Grand Banks of Newfoundland
    - reaches Europe near southern British Isles
      - » result, western Europe warmer and more temperate than eastern North American at similar latitudes

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63 ## Global Circulation Patterns - Oceanic

✓Principle oceanic surface currents
- **western boundary currents, examples**
- **Kuroshio Current**
    - warm northward current in northern Pacific Ocean
    - runs along Japan northeast towards Alaska
      - » result, Alaska has a more temperate climate than would be expected based on latitude

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65 Global Circulation Patterns - Oceanic

✓ Principle oceanic surface currents
- **eastern boundary currents**
  - eastern sides of oceans
  - broad, weak, shallow flows with poorly-defined boundaries
  - force of wind and Coriolis effect combine at western continental seacoast
    - cause warm surface water to move away from coast and out to sea
    - deep cold water moves upward to replace water that blows seaward
      - » produces **upwelling**

66 Global Circulation Patterns - Oceanic

✓ Principle oceanic surface currents
- **eastern boundary currents, examples**
  - Northern Hemisphere
    - Canary Current in Atlantic Ocean
    - California Current in Pacific Ocean
  - Southern Hemisphere
    - Benguela Current in Atlantic Ocean
    - Peru (Humboldt) Current in Pacific Ocean

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68 Global Circulation Patterns - Oceanic

✓ Principle oceanic surface currents
- **eastern boundary currents**
  - **significance of upwelling**
    - brings deep, cool, nutrient-rich water to surface
      - » water rich in nutrients because of numerous creatures that die in surface waters and sink
    - Peru (Humboldt) Current is an example

69 Global Circulation Patterns - Oceanic

- ✓Principle oceanic surface currents
  - – **eastern boundary currents**
    - **significance of upwelling**
      - – Peru (Humboldt) Current
        - » flows northward along western coast of South America
        - » large amount of upwelling associated with this current

70 Global Circulation Patterns - Oceanic

- ✓Principle oceanic surface currents
  - – **eastern boundary currents**
    - **significance of upwelling**
      - – Peru (Humboldt) Current
        - » upwelling provides nutrients for enough phytoplankton to support largest anchovy population in world
        - » anchovy fishery is one of largest industries in Peruvian economy

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72 Global Circulation Patterns - Oceanic

- ✓Principle oceanic currents
  - – **equatorial currents**
    - confined mostly to surface
    - warm, well-mixed surface layer
    - sharp thermocline
      - – separates warm surface water from cold water below
      - – except at equator where mixing across thermocline occurs

73 Global Circulation Patterns - Oceanic

- ✓Principle oceanic currents
  - – **equatorial currents**
    - North Equatorial Current
    - Equatorial Countercurrent
    - South Equatorial Current

74 Global Circulation Patterns - Oceanic

- ✓Principle oceanic currents
  - – **polar circulation**
    - circulation differs at N vs S polar regions

- north polar region
  - Arctic Ocean covered by pack ice
  - sluggish counterclockwise drift
  - deep cold water from Arctic Ocean is kept from mixing freely with that in Atlantic and Pacific Oceans

75 Global Circulation Patterns - Oceanic

✓Principle oceanic currents

- **polar circulation**
  - south polar region
    - water flows freely between Atlantic and Pacific Oceans
    - Antarctic Circumpolar Current
      - » largest current in world
      - » circles Antarctica
      - » extends all way to bottom
      - » flows eastward

76 Global Circulation Patterns - Oceanic

✓**El Nino**

- name originally coined in late 1800s by Peruvian fishermen
- seasonal shift in current pattern off coast of Ecuador and Peru
  - occurred around Chrsitmas time
    - El Nino (Spanish for "Christ child)
  - would replace cold, nutrient rich water with less productive, warm southward flowing water
    - slightly reducing fish population
    - giving fishermen some time off

77 Global Circulation Patterns - Oceanic

✓El Nino

- now refers to catastrophic version of original annual event
- part of phenomenon known as **El Nino-Southern Oscillation (ENSO)**
  - continual but irregular cycle of shifts in ocean and atmospheric conditions that affect globe

78 Global Circulation Patterns - Oceanic

✓**El Nino-Southern Oscillation (ENSO)**

- normally, Pacific Ocean is fanned by constantly blowing east-to-west trade winds
  - push away the warm surface water along western coasts of Peru, Chile, Ecuador
    - allows cold, nutrient-rich water from depths to well up (upwelling)

79 Global Circulation Patterns - Oceanic

✓**El Nino-Southern Oscillation (ENSO)**

- warm water that was pushed away from coast "piles" up in western portion of Pacific Ocean

- results in waters of western Pacific Ocean being
  - several degrees warmer
  - about one meter higher
    - » than waters in eastern portion of Pacific

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Global Circulation Patterns - Oceanic

✓El Nino-Southern Oscillation (ENSO)

- if east-to-west trade winds slacken briefly
  - warm water begins to slosh back across Pacific Ocean from west to east
  - the warmer the eastern ocean gets, the warmer and lighter the air above it becomes

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Global Circulation Patterns - Oceanic

✓**El Nino-Southern Oscillation (ENSO)**

- thus, the more similar to air on western side
  - reducing difference in pressure across ocean
    - since a pressure difference is what makes wind blow, a lack thereof causes easterly trade winds to weaken
    - continued reduction in winds allows warm water to continue its eastward advance

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Global Circulation Patterns - Oceanic

✓**El Nino-Southern Oscillation (ENSO)**

- end result is to shift weather systems of western Pacific Ocean about 6000km eastward
  - tropical rainstorms usually drench Indonesia and Philippines
    - when warm water moves east, so do clouds, leaving previously rainy Indonesia and Philippines in drought

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Global Circulation Patterns - Oceanic

✓**El Nino-Southern Oscillation (ENSO)**

- ecological effects during an El Nino
  - in waters of Peru and northern Chile
    - commercial fish stocks virtually disappear
    - plankton decrease in abundance

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92 ## Global Circulation Patterns - Oceanic

- **El Nino-Southern Oscillation (ENSO)**
  - ecological effects during an El Nino
    - weather effects are propagated across world's weather systems
      - violent winter storms, flooding, on coast of California
      - colder and wetter winters occur in Florida and along Gulf Coast
      - American Midwest and Mid-east experience heavier than usual rains

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94 ## Global Circulation Patterns - Oceanic

- **El Nino-Southern Oscillation (ENSO)**
  - effects of El Nino are clear, trigger is not
    - models suggest that type of climate change that triggers El Nino is chaotic
      - wind and ocean currents return again and again to same condition but never in a regular pattern
        - small nudges can send them off in many different directions

95 ## Global Circulation Patterns - Oceanic

- El Nino-Southern Oscillation (ENSO)
  - noteworthy El Ninos
    - 1982 - 1983: 2100 deaths, $13 billion in damages
      - Austraila
      - drought in sub-Saharan Africa
      - southern Ecuador and northern Peru

96 ## Global Circulation Patterns - Oceanic

- El Nino-Southern Oscillation (ENSO)
  - noteworthy El Ninos
    - 1997 - 1998:
      - California
      - Florida
      - Panama Canal
      - Indonesia

97 ## Global Circulation Patterns - Oceanic

✓ **Tides**

- another type of movement of ocean waters
- normally raise and lower the water level of a coast
- are significant
  - geomorphically
  - biologically

98 ## Global Circulation Patterns - Oceanic

✓ **Tides**

- geomorphic
  - changes in water level expose different parts of coast to erosive action of waves
- biologic
  - organisms living in areas subject to changes in water level must have adaptations to deal with alternating periods of submersion and exposure

99 ## Global Circulation Patterns - Oceanic

✓Tides

- definition
  - periodic rise and fall of Earth's oceans

100 ## Global Circulation Patterns - Oceanic

✓Tides

- caused by
  - gravitational effects of sun & moon on oceans
    - produce "bulges" of water
    - magnitude of "bulges" is determined by varying and complex interactions resulting from relative positions of earth, moon and sun

101 ## Global Circulation Patterns - Oceanic

✓ **Tides**

- role of sun and moon
  - sun's gravitational pull on earth is less than 1/2 that of moon
    - its significance on tides
      - » secondary to influence of moon
      - » strongest when sun aligns with moon and during equinoxes

102 ## Global Circulation Patterns - Oceanic

✓ **Tides**

- role of sun and moon
  - moon's gravitational pull on earth is ~ 2X that of sun
    - it is primarily responsible for tides
    - since moon's distance from earth varies, so does its attractive forces

103 Global Circulation Patterns - Oceanic

✓ Tides
- characteristics
  - frequency
  - time of day
  - height

104 Global Circulation Patterns - Oceanic

✓ Tides
- characteristics
  - frequency
    - some areas
      - » 2 high tides each day
      - » only 1
    - average interval between successive high tides is app. 12.5 hours

105 Global Circulation Patterns - Oceanic

✓ Tides
- characteristics
  - time of day
    - changes each day
  - height
    - typically 1 - 2 meters above average sea level
    - varies with relative positions of earth, moon & sun
    - influenced by local coastal topography