# Oceanography: Air-Sea Interaction

I. EARTH-SUN RELATIONSHIPS

A. General

1. The earth's dependence on the sun for solar energy is essential for all life, drives biosphere, atmosphere, and hydrosphere.
2. Movements of the Earth: Rotation vs. Revolution

   a. Rotation- the earth rotates on its axis from west to east (counter clockwise direction viewed from top), complete revolution of 360 $^{o}$ every 24 hrs.

      (1) Since the earth spins from west to east, the moon and sun and stars appear to relatively move (rising and setting) in the opposite sense: east to west.

      (2) Speed of rotation of the earth is greatest at the equator and decreases to 0 at the poles, function of revolving different diameters about a pole.

   b. Effects of the Rotation of the earth

      (1) Constancy of the earth's rotation results in coriolis effect in which the flow of air and water on the earth's surface is deflected by the centrifugal forces

      (2) rotation brings varying portions of the earth into increasing and decreasing gravitational fields relative to the moon and sun, thus driving diurnal tidal fluctuations

      (3) rotation results in diurnal variation of lightness and darkness, as the earth turns relative to the position of the sun

   c. Revolution Around the Sun: earth revolves around the sun in a similar west to east rotation, once every 365.25 days (known as the tropical year)

      (1) The path of the earth's orbit around the sun is not a circle but an ellipse with varying radius of orbit.
      (2) Perihelion- position on January 3, the earth = 91,445,00 miles from the sun
      (3) aphelion - position on July 4, the earth = 94,555,000 miles (farthest from the sun in our summer).

Perihelion and aphelion are oriented at 180$^{o}$ to one another: do not so significant effects on seasonal temperature variation.

B. Season Temperature/Weather/Insolation Changes

1. Plane of the ecliptic- the plane the passes through the sun and earth, enscribing the orbital path of the earth around the sun.

2. The axis of the earth and the plane of the equator is tilted approximately 23.5$^o$ with respect to the plane of the ecliptic (i.e. polar axis is not perpendicular to the plane of the ecliptic).

   a. The axis of the earth is always parallel to itself, pointing at all seasons of the year towards polaris the north star..

   b. The rotation, revolution, and tilt of the earths axis is such that the amount of insolation or energy the hits the earth is at different angles throught the year of revolution.

THE MORE DIRECT THE STRIKE OF THE SUN'S RAYS, THE EFFECTIVE IS THE HEATING OF THE EARTH'S SURFACE

THE MORE OBLIQUE THE STRIKE OF THE SUN'S RAYS, THE MORE DIFFUSED THE ENERGY IS OVER A LARGER LAND SURFACE.

3. Latitudinal changes in insolation with seasons

   a. SUMMER SOLISTICE: NORTHERN HEMISPHERE

      (1) Tropic of Cancer- 23.5$^o$ north latitude, marks the northernmost location reached by the vertical/direct rays of the sun in annual revolution pattern (occurs on the summer solistice in the northern hemisphere, June 21)

      (2) At solistice, all points lying north of the Arctic Circle (66.5$^o$ N.) are placed within the circle of illumination for 24 hours continuously

      (3) At northern solistice, all points south of the anarctic circle (66.5$^o$ S) are placed in continual darkness, outside the circle of illumination

   b. WINTER SOLISTICE: NORTHERN HEMISPHERE

      (1) Tropic of Capricorn- 23.5$^o$ S. latitude, marks the southernmost location reached by the vertical/direct rays of the sun in annual revolution pattern (occurs on Dec. 21, more or less).

      (2) At winter solistice, all points lying south of the Antarctic Circle lay continually within the circle of illumination, whereas, points north of Arctic circle lay within continual darkness.

   c. EQUINOXES: (spring March 20, and fall: sept. 22)

      (1) The perpendicular rays of the sun strike the equator
      (2) The circle of illumination just touches both poles
      (3) The periods of daylight and darkness are each 12 hours long all over the earth
      (4) equinoxes represent midpoints in the shifting of direct rays of the sun between the Tropic of Cancer and the Tropic of Capricorn

## II. CONTROLS OF AIR TEMPERATURE

A. Land and Water

1. Land has lower heat capacity than water
    a. land heats more rapidly and to higher temps. than water, and cools more rapidly and to lower temps. than water

2. Reasons for differential heating of land compared to water
    a. water has high specific heat (i.e. it takes more energy to raise temp. of water than similar volume of land)
    b. Land surfaces are opaque, thus heat only absorbed at surface. Water is transparent and allows heat to penetrate throughout body
    c. Water transfers heat by convection, thus distributing the heat through a larger mass
    d. Evaporation (a cooling or heat loss process) from water bodies is greater than that for land

3. Example Coastal Areas
    a. ocean bodies can have a buffering effect on local climates, due to high heat capacity and lag in heat transfer, warming air above ocean and influencing air temps inland.

B. Altitude

1. > altitude, < atmospheric content, < heat capacity, < T

C. Geographic Position (Latitudinal Position with Respect to Sun)

1. Latitudinal influences on amount of incoming solar radiation
    a. Tropics vs. arctic

## III. HUMIDITY, CONDENSATION, AND PRECIPITATION

A. Terminology

1. Humidity- amount of water vapor in air
2. Vapor Pressure- total atmospheric pressure that can be attributed to water vapor content
3. Vapor Saturation- maximum amount of water vapor the air can hold,
    a. rate of evaporation = rate of condenstation
    b. "Vapor Capacity"- measure of amount water vapor air can hold
    c. Temperature dependent
        (1) >T, air can hold more moisture (>expansion of volume, > motion of molecules)
        (2) <T, air can hold less moisture (< expansion of volume)

| Temp. C | Vapor Capacity (gm/kg) |
|---|---|
| -40 | 0.1 |
| -20 | 0.75 |
| 0 | 3.5 |
| 10 | 7 |
| 20 | 14 |
| 30 | 26.5 |
| 40 | 47 |

(3) Thus by taking an unsaturated system to lower temperature, system can become saturated

4. Specific Humidity- amount of water vapor contained in unit of air (expressed as wt. of vapor/mass of air = gm/kg)
    a. not affeted by changes in pressure or temperature

5. Relative Humidity- ratio of airs water vapor content to its water vapor capacity at a given temperature

for given temp.

$$R.H. = \frac{\text{water vapor}}{\text{vapor capacity}} \times 100\%$$

E.g. referring to table above, given a temp of 20 C, vapor capacity of air is 14 gm/kg. Assume a specific humidity of 7 gm/kg, relative humidity = 7/14 x 100% = 50%

a. Temperature influence on relative humidity

Relative humidity changes with temperature according to vapor capacity of air. In example above at 20 C, vapor capacity is 14 gm/kg, assuming a specific humidity of 7 gm/kg, relative humidity = 7/14 x 100% = 50%.

By decreasing the temperature to 10 C, vapor capacity of air is now 7 gm/kg, assuming the same specific humidity of 7 gm/kg, the relative humidity = 7/7 x 100% = 100% humidity.

Vapor capacity must be exceeded to oversaturation for condensation/precipitation to occur

(1) In sum: a decrease in air temperature will result in an increase in relative humidity, and an increase in air temperature will result in decrease in relative humidity

(2) <T, > R.H.; >T, < R.H.

(3) In terms of absolute air moisture...
    (a) cold air contains less specific humidity than warm air, although cold air relative humidity and warm air relative humidities may be identical (e.g. 85%), the vapor capacities are different, and the warm air will have much more moisture than cold air at same relative humidity

6. Dew Point Temperature

    a. Temperature at which air would have to be cooled in order to reach saturation
    (1) at temperatures colder than dew point, air vapor capacity is exceeded and condensation would occur

IV. FORCEFUL LIFTING (A Mechanism for Lifting and Cooling Air)

A. Air may be forced upward regardless of stability of air mass or adiabatic processes
B. Methods of Forceful lifting of air

1. Convergence- flowing of air masses together, occupies less space, air column forced to rise vertically
   a. air forced to rise upward
   b. enhances instability
   c. E.g. Florida: on warm summer days
      (1) Atlantic air flow westward over land
      (2) Gulf air flow eastward over land
         (a) convergence + vertical uplift + intense solar heating = high rate of thunderstorm occurrence (greatest occurrence in U.S.)

2. Orographic Lifting- sloping terrain/mountain slopes act as barriers to air flow, forces air to ascend
   a. Rain fall on windward side, rising moist air masses, <Temp during ascent, >saturation point.... rain
      (1) e.g. Mt. Waialeale Hawaii: 38 Ft rain/yr
   b. Lee sides: dry air descends... orographic deserts
      (1) Rain shadow deserts
      (2) e.g. Columbia Basin of Wash, Mojave of Calif.

3. Frontal Wedging- cool air acts as a barrier over which warm, less dense air rises
   a. Responsible for rainfall patterns over much of continental U.S.
      (1) Cold Fronts moving in from w-nw, forcing warm continental air above
         (a) Arctic/Canandian cold fronts moving into US

      (2) Warm Fronts moving in from w-nw, riding over cold

V. FACTORS AFFECTING WIND

A. General
1. Wind = horizontal movement of air (advective motion)
2. Wind and Pressure
   a. basic gas law: air of higher pressure moves towards air of lower pressure
   b. wind = drive toward equilbrium of air pressure
3. Pressure Differences on Earth's Surface
   a. Caused by unequal heating of atmosphere by sun
   b. Variable solar insolation due to tilt of earth, orbital path, latitudinal changes

B. Factors Influencing Air Motion

1. General : if earth did not rotate and there were no friction of air motion, wind would be simply controlled by air motion from high pressure to low pressure

2. Influencing factors
   - a. Pressure Gradient Force- degree of pressure changes per unit distance
   - b. Coriolis Effect- motion on rotating objects/centrifugal force
   - c. air friction- resistance to flow

C. Pressure Gradient Force

1. Pressure variation = wind
   - a. > press. diff, > wind speed

2. Mapping air pressure
   - a. pressure contour maps
   - b. isobars = lines on constant air pressure

3. Pressure Gradient = $\frac{\text{change in pressure}}{\text{unit distance}}$
   - a. gradient to hill
     - (1) steeper the hill (pressure gradient)
       - (a) > press. gradient, > wind acceleration
       - (b) > close spacing of isobars
     - (2) gentler the hill slope (pressure gradient)
       - (a) < press. gradient, < wind acceleration
       - (b) widely spaced isobars

4. Coriolis Effect
   - a. Coriolis = apparent shift due to rotation and velocity variation by latitude
     - (1) Earth rotating in counterclockwise direction as viewed from north pole
     - (2) Net result:
       - (a) Northern Hemisphere: air deflected to right in the direction of travel
       - (b) Southern Hemisphere: air deflected to left in direction of travel
   - b. View from north pole
     - (1) counter clockwise rotation
     - (2) air deflection to right, due to coriolis
   - c. View from south pole
     - (1) clockwise rotation
     - (2) air deflection to left, due to coriolis
   - d. Coriolis relationships
     - (1) deflection always directed at right angles to direction of airflow
     - (2) deflection affects only wind direction, not wind speed
     - (3) deflection affected by wind speed
       - (a) > speed, > deflection

5. Friction
    a. friction of air motion with earth's surface/topography
    b. acts to slow wind velocity
        (1) tends to deflect wind via "refraction"
        (2) friction effects prominent to 2000 Ft altitude
    c. rough mountainous landscape: > friction
    d. smooth ocean surface: < friction

6. Air motion and Isobars

    a. in frictionless, non-rotating environment, air motion perpendicular to isobars
    b. Coriolis + friction effects ------
        (1) Upper level (high altitude) airflow parallel to isobars
            (a) Jet stream: "rivers of air" flowing at 75-150 mph at upper altitudes (reduced friction > speed)
        (2) near-surface air flow winds cross isobars at an acute angle

VI. CYCLONES AND ANTICYCLONES
A. General
1. Cyclones: low pressure center
2. Anticyclones: high pressure center
B. Cyclonic and Anticyclonic Winds
1. Cyclones
    a. Northern Hemisphere
        (1) low pressure center (influenced by coriolis and friction)
        (2) winds blow inward and counterclockwise around the low
    b. Southern Hemisphere
        (1) winds blow inward and clockwise
2. anticyclones
    a. Northern Hemisphere
        (1) high pressure center
        (2) winds blow outward and clockwise around the high
    b. Southern Hemisphere
        (1) winds blow outward and counterclockwise

C. Weather Generalizations about Highs and Lows
1. Rising air: associated with clouds/precipitations
2. subsiding air: adiabatic heating and clearing conditions
3. Cyclone: low pressure system
    a. inward flow of air
    b. winds converge to center
        (1) air pile up
        (2) pushes air upward
        (3) > pressure due to rising column of coverged air (a paradox, low pressure results in > pressure)
        (4) rising air cools adiabatically---- clouds/condensation---precipitation associated with low pressure system

4. Anticyclone: high pressure system
    a. outward flow of air
    b. winds diverge from center
        (1) air descends and thins
        (2) pushes air downward
        (3) descending air is compressed and warmed
        (4) air moisture vaporizes and clears
5. Short range weather predictions
    a. barometric tendency
        (1) rising barometeter: high pressure system approaching, clearing weather
        (2) falling barometer: low pressure system approaching, clouds and rain
    b. Cyclones---- rain
    c. Anticyclones---- clear

VII. GENERAL CIRCULATION OF ATMOSPHERE

A. Causes of Air Motion

1. Unequal heating of earth's surface
    a. Tropical Regions/Low Latitudes = receive > solar radiation, less reflection
    b. Polar Areas = receive < solar radiation, > reflectance/albedo

2. General Circulation (ideal on a non-rotating earth)
    a. Heat Imbalance: high at equator, low at poles
        (1) warm air rises from equator and circulates symmetrically to north and south pole
        (2) cold air sinking at the poles, circulated back to equator for reheating/circulation

    b. Complications to the ideal model
        (1) friction/turbulence
        (2) coriolis: effects of air motion due to centrifugal force on a rotating planet
        (3) secondary ocean current influences

** Result: breaks air flow into smaller cells of circulation, mid-latitude circulation shows complex airflow patterns

3. Idealized Global Circulation of Air on a Rotating Planet
    a. Standard terminology for wind direction
        (1) Easterly wind: blowing from east to west
        (2) Westerly wind: blowing from west to east
        (3) Southwesterly: blowing from southwest to NE,... etc.
    b. Equatorial Low
        (1) Low pressure Zone at Equator
        (2) Warming/Rising Air
        (3) Convergence of Northeasterly Trade Winds and Southeasterly Trade Winds
        (4) Abundant Precipitation/Tropical Climates

c. Subtropical High
  (1) Zone of subsiding, adiabitically warming air at 30 N and S latitudes
  (2) Warm/arid areas
    (a) World deserts in this belt
      i) Australian Desert
      ii) Arabian Peninsula
      iii) Sahara Desert
      iv) Gobi Desert

  (3) Divergent air at subtropical high, adiabatic warming, air diverging pushed to the south and north at 30 degree high
    (a) Trade Winds: reliable steady winds
      i) N. Hemisphere: northeasterlies pushed back to soutwest towards equator
        a) Deflected to right (SW) due to coriolis

      ii) S. Hemisphere: southeasterlies pushed back to the northwest towards equator
        a) Deflected to left (NW due to coriolis

    (b) Mid-latitude Westerlies: North and south of 30 degrees N. and S. latitude
      i) remainder of diverging, subsiding air (in Hadley cell) forced north and south respectively
      ii) Northern Hemisphere: air pushed to north, deflected to the right in an eastward direction--- forming westerlies

d. Subpolar Low
  (1) Northern portion of mid-latitude cell with air rising, < pressure to form subpolar low
  (2) Polar Easterlies
  (3) Polar Front
    (a) contact between cold polar air and warm mid-latitude air
    (b) Forms stormy northern belt

e. Polar High
  (1) At poles: high pressure
  (2) cold subsiding dry air forced equatorward

f. Summary
  (1) Four Pressure Zones
    (a) Subtropical and Polar highs
      i) dry subsiding air pushed equatorward
    (b) Equatorial and Subpolar Lows
      i) converging and upward moving airflow
      ii) sites of precipitation/instability

VIII. LOCAL WINDS

A. Seas and Land Breezes

1. Variation in coastal winds daily due to water having higher heat capacity than land
   a. i.e. land warms and cools faster than ocean on daily basis
   b. Differential heating
2. Daytime: Sea breezes (towards land)
   a. cool sea air directed inland
   b. land and air above heats faster than ocean
   c. land air---warm, rises, circulates out to sea
   d. sea air relatively cool, descends and pushed towards land
3. Nightime: Land breezes (towards sea)
   a. land and overlying air cools/loses heat faster than ocean
   b. land air cools, subsides and forced in oceanward direction
   c. ocean air warms and rises circulating landward

IX. AIR MASSES

A. General

1. Air Mass - immense body of air, characterized by homogeneity of temperature and moisture at any given altitude
   a. 1000 miles or more in breadth
   b. Passes through area over the course of days
      (1) e.g. Summer: heat wave, high temps, high humidities
         (a) ends with series of thunderstorms and few days of cooler weather
      (2) e.g. Winter: frigid clear, subzero cold spell
         (a) ends with thick stratus clouds, rising temps. and snowfall.
2. Front: boundary between two adjoining air masses having contrasting characteristics
   a. passage of a front marks a change in weather

B. Source Regions

1. Source Region: area of earth's surface over which air masses assume their distinguishing characteristics
2. Types of Air Masses
   a. Classified According to Latitude and Temperature
      (1) Polar (P) air masses
         (a) originate in high latitudes
         (b) cold air mass temps.
      (2) Tropical (T) air masses
         (a) originate in low latitudes
         (b) warm air mass temps
   b. Classified According to Geographic Source and moisture
      (1) Continental (C) designates land source
         (a) On the dry side

(2) Maritime (M) designates ocean/water source
(a) On the wet side

c. Four Basic Types of Air Masses
(1) Continental Polar
(a) On dry and cold side
(2) Continental Tropical
(a) On dry and warm side
(3) Maritime Polar
(a) On wet and cold side
(4) Maritime Tropical
(a) On wet and warm side

X. FRONTS
A. General
1. Fronts- boundaries that separate air masses of different densities
a. one warmer and often higher in moisture
b. avg. 15-200 km wide, narrow compared to breadth of air mass
2. Vertical Configuration
a. Warm air: less dense
(1) warm air over cold air (more dense)
(2) warm air/cold air interface often sloping/wedge shaped at low angle
b. Fronts often collisional in nature
c. Always warm air forced aloft, with colder bottom air acting as a wedge

B. Warm Fronts
1. warm air moves over wedge of cold air
a. map symbol: line with semi-circles extending into cold air
2. Average slope of warm front: 1:200 (V:H)
3. Ascending Warm Air
a. cooling by adiabatic expansion
b. often clouds and precipitation
(1) several hours of gentle precipitation over large region
(a) gentle slope of front does not encourage convective activity
c. Increase in temperature

C. Cold Fronts
1. cold air moves into region of warm air
a. map symbol: line with triangular barbs extending into warm air
2. Average slope of cold front: 1:100 (V:H)
a. steeper than that of warm front
b. cold fronts in general advance more rapidly than warm fronts

3. Actively forces warm air aloft
a. cold fronts produce more violent weather
(1) sudden downpours
(2) wind gusts
(3) >intensity, < duration compared to warm front

4. Behind Front
    a. cold air mass, subsiding air
    b. Often clear and cold behind the front

D. Occluded Fronts
    1. Cold front over takes a warm front
    2. Wedging of warm air aloft between two cold air masses
    3. Complex weather patterns/ heavy or light rain possible

XI. MIDDLE LATITUDE WAVE CYCLONES (LOW PRESSURE SYSTEMS)

A. General
    1. At Middle Latitudes (Like U.S.)
        a. Cold and Warm Front Activity Commonly Associated with Low Pressure Systems
            (1) Cyclone = low pressure system, counterclockwise rotation
                (a) Common Harbringer of Rainfall to Central and Eastern U.S.
            (2) "Wave" Cyclone- refers to a low pressure system comprised of cold and warm air, with the front commonly bending into a swirling low pressure system

B. Role of Upper Level Jetstream in Maintaining Low Pressure System
    1. Cyclone: low pressure system with converging air drawn inward
        a. with inward flow, if there were no mechanism for air escape, the low pressure area would eventually "fill up" with converging air and cease to exist

            (1) However, we know that low pressure systems can exist for low periods of time, migrating across U.S.

    2. Upper level air flow
        a. With converging air into low pressure system, air is piped to higher altitudes aloft, where it escapes the low pressure zone into the upper jetstream
            (1) "piping" of air through the low to the jet stream allows low pressures to be maintained in the cell over longer periods of time
                (a) otherwise the cell would "fill up" and the pressure would rise

        b. Air flow aloft also helps direct and mobilize cyclonic systems through shear flow

    3. Moral of the story: air flow aloft, is important in maintaining and influencing lower level weather patterns

XII. HURRICANES

A. Hurricanes- whirling tropical cyclones with wind speeds up to 185 mph
    1. highly destructive because of high winds in coastal areas
    2. may form 50 "storm surge" waves

B. Character
  1. Form in tropical waters between 5 and 20 Latitude
    a. Atlantic = "Hurricanes"
      (1) U.S. avg. = 5/yr
    b. Pacific = "typhoons"
      (1) N. Pacific highest no. of occurrence =20/yr
    c. Indian = "Cyclones"
  2. Characteristics
    a. wind speed = > 74 mi/hr
    b. rotary counterclockwise circulation
    c. Dimensions
      (1) D=375 mi
      (2) Height = up to 40,000 Ft altitude
    d. Low pressure centers
      (1) outside press. - inside press. = 60 millibars
      (2) steep pressure gradient
      (3) inward, converging, spiraling winds
    e. Upper level air flow
      (1) divergent and outward, maintaining the low pressure center of the storm
  3. Morphology
    a. Eye of Hurricane
      (1) low pressure center of cyclone
        (a) avg. 12 mile in Diameter
        (b) zone of calm and scattered clould cover
        (c) warm zone
    b. swirling rotation of storm function of coriolis effect

  4. Process
    a. Hurricane = heat energy built up and liberated by release of water vapor
    b. hurricanes form over oceans in late summer, with abundant warm moist air plentiful
      (1) water temps to 80 F, warm moist overlying air
      (2) can not form in cool water temps, hence limited latitudinally
    c. Storm Progression
      (1) Tropical depression- cyclone with wind speed < 38 mi/hr
      (2) Tropical Storm- cyclone with wind speed 38-74 mi/hr
      (3) Hurricane - cyclone with wind speed > 74 mi/hr
      (4) Land docked hurricane
        (a) loses moisture source
        (b) frictional effect of land slows winds
        (c) pressure gradient dissipated
C. Identification
  1. weather satellit imagery
  2. storm tracking and prediction
  3. emergency management and contingency in coastal areas
D. Destructive Force
  1. high winds/wind shear
  2. Storm surge in coastal areas