Review for the second quarter

Mechanisms for cloud formation

- 6 km
  Convection

- 150 km
  Topography

- 500 km
  Convergence of air

- 1500 km
  Lifting along weather fronts
Rising air expands and cools; Sinking air compresses and warms.

**Dry adiabatic lapse rate** (10 °C/km): the rate of temperature decrease with height with no heat gain or loss.

**Moist adiabatic rate** (~6 °C/km): the rate of temperature decrease with height for a saturated air parcel (the latent heat of condensation makes it less than the dry adiabatic rate).

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**The Warm Cloud Process**

**STEPS**

1. **Cooling** – usually a result of lifting results in saturation of the air.

2. **Condensation** – water vapor condenses onto condensation nuclei after reaching super-saturation. A slow process without relative motion among droplets.

3. **Coalescence** – takes over as the falling drop starts to collide and merge with smaller droplets in its path.
The Cold Cloud Process

STEPS

1. **Cooling** – leading to saturation and condensation – same as warm cloud case.

2. **Freezing** – As cloud continues to rise, the air temperature cools below freezing to activate ice nuclei within super-cooled cloud droplets resulting in freezing.

3. **Ice crystal growth**
   - **Deposition** – saturation vapor pressure around ice crystals is less than around water droplets → crystals grow rapidly at expense of cloud droplets.
   - **Accretion** (capture of water drops) – as they fall through cloud, ice crystals grow by collecting super-cooled droplets that freeze on contact.
   - **Aggregation** – Falling ice crystals collide and stick to other ice crystals → snow flakes

Mountain/Valley Winds (without large-scale winds)

- Sunlight heats mountain slopes during the day and they cool by radiation at night
- Air in contact with surface is heated/cooled in response
- A difference in air density is produced between air next to the mountainside and air at the same altitude away from the mountain
- Density difference produces upslope (day) or downslope (night) flow
- Daily upslope/downslope wind cycle is strongest in clear summer weather when prevailing winds are light
Chinook (Foehn) Winds with prevailing wind

- Main source of heating is compression during downslope flow
  - Key is loss of moisture on upwind slope so downslope heating occurs at higher dry adiabatic rate
- Latent heat release from condensation during upwind ascent also contributes
  - If condensed water is removed as precipitation on upwind slope

The key to solving the mystery that winds blow around, instead of towards, the low pressure center.

Pressure gradient force:
Pressure diff/distance

Coriolis Force

\[ = 2 \times \text{Earth Rotation Rate} \times \sin (\text{latitude}) \times \text{velocity} \]

Important for large-scale/long-lasting wind systems away from the equator
Important points

- Why is there wind? Horizontal variations in temperature (pressure gradient force).
- In NH, wind blows counter-clockwise around a low pressure, and clockwise around a high. (Facing the direction wind blows, high pressure to the right and low to the left.) Empirical
- Why does it blow the way it is? Balance between the pressure gradient and Coriolis forces. Physical/dynamical
- Coriolis force: An apparent force due to Earth’s rotation, directing to the right of the wind vector and proportional to the wind speed in magnitude.
- Wind speed: tighter the spacing of isobars, the faster.
- In SH, all the rules remain the same but with the direction reversed.

Three-cell model

considers earth rotation effects and explains the easterly trades in the subtropics and prevailing westerlies in the mid-latitudes.
Surface Pressure & Wind over the North Pacific
Based on historical ship reports

North-south asymmetry of tropical climate

- In January, intense solar radiation in the SH tries to pull the rain bands (ITCZ) south of the equator, as is observed over continents.
- Mystery: rain bands (ITCZ) remain north of the equator in the eastern Pacific and Atlantic Oceans.

➢ Why is the ITCZ displaced in the Northern Hemisphere?

For a historical account and latest research, see
http://iprc.soest.hawaii.edu/~xie/
Monsoon is not confined to India but spans from west Africa, through the Bay of Bengal, all the way to the western North Pacific.

The summer monsoon of Asia is dominated by the southwestery winds in the lower atmosphere.

The Tibetan Plateau: an elevated heat source in summer and a wind block in winter.

Tectonic mountain building since 50 million years ago when the Indian Plate collided with the Eurasian Plate.

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Ekman flow

- Important in the top 10 m
- Surface flow in response to wind
- To the right of the wind
- Observable from iceberg drift

Ekman (1905) explained Nansen’s observation that icebergs moved to the right of the wind direction in the Arctic.
Summer upwelling off California

Northerly winds along the coast
→ Offshore surface Ekman flow
→ Deep cold water rises to compensate
→ Fog formation on Californian coast
→ High nutrients and good fisheries
(Coastal water is not much warmer, but still warmer, in summer than winter.)

Vertical Structure of the Ocean

• Warm water floating on cold deep water that sinks in higher latitudes. 27-28°C at surface but 10°C at 400 m
• Thermocline is a thin layer with a rapid upward increases in temperature.
**El Nino of the Century**

**Dec 1997**

**Dec 1998**

**El Nino**: abnormal warming in the central/eastern equatorial Pacific Ocean (including the Peruvian coast).

**Southern Oscillation**: seesaw in sea level pressure between the western (Darwin, Australia) and central (Tahiti) Pacific.

**ENSO**

- Warming in the east
  - Eastward shift of deep convection & reduced air pressure in the east
  - Reduced easterly trades
  - Warmer water flushes back toward the east

El Nino is a coupled ocean-atmosphere phenomenon.

(sea surface temperature changes)
Number of seasons with anomalous rainfall in Hawaii among 20 El Ninos analyzed (Chu 1995, *J. Climate*).

Enhanced subsidence due to strong convection in the central/eastern equatorial Pacific.

Three largest El Ninos since 1970: observed NINO3.4 SST anomalies (thick red) & model predictions started 24, 21, 18 and 15 months before the peak of each El Nino. Chen et al. (2004, *Nature*).