Wind: Small-scale and Local Systems

Scales of Atmospheric Motion

- Atmospheric motions/phenomena occur on many diverse spatial and temporal scales.
- Weather forecasters tend to focus on **Mesoscale and synoptic scales**
- Microscale motions affect our lives daily
  - Most microscale phenomena form in the boundary layer
  - Can't forecast microscale motions - spatial scale is too small for current models - motions are chaotic, unpredictable

![Diagram showing different scales of atmospheric motion](image)
Fraction and Turbulence in the Boundary layer

1. Internal friction related to *molecular viscosity*
   - *viscosity* is the slowing of a fluid due to molecular movement
   - this type of friction is dominant in a shallow layer near the ground

• Air molecules at ground level are not moving as they are in contact with the stationary ground
• Hence the wind speed decreases as you get closer to the ground

• Large changes of wind speed exist near the ground in the lowest millimeter or so.
Fraction and Turbulence in the Boundary layer

2. Eddy viscosity refers to the internal friction generated as laminar (smooth, steady) flow becomes irregular and turbulent as it passes over irregularities on the surface (trees, buildings, mountains, etc)
   - Eddy motions created by obstructions are commonly referred to as mechanical turbulence
   - mechanical turbulence produces a frictional affect (drag) on the air flow that is much larger than caused by molecular viscosity
Turbulence in the boundary layer - thermal turbulence

- In addition to the *mechanically generated turbulence*, *thermal turbulence* is also generated in the boundary layer.
- Thermal turbulence is essentially rising thermals of air in the boundary layer generated by surface heating.
- Thermal turbulence is maximum during max surface heating - mid afternoon.
- The diurnal variation of the boundary layer and turbulence generation within the boundary layer.

Thermal and Mechanical Turbulence interact with each other

Surface winds are usually stronger in the afternoon!

When the air is stable and the terrain fairly smooth (a), vertical mixing is at a minimum, and the effect of surface friction only extends upward a relatively short distance above the surface. When the air is unstable and the terrain rough (b), vertical mixing is at a maximum, and the effect of surface friction extends upward through a much greater depth of atmosphere. Within the region of frictional influence, vertical mixing increases the wind speed near the ground and decreases it aloft. (Wind at the surface is measured at 10 m above the surface.)
• The depth of mixing and, hence, fractional influence in the boundary layer depend primarily upon three factors:
  – Surface heating– producing a steep lapse rate and strong thermal turbulence
  – Strong wind speeds -- producing strong mechanical turbulent motions
  – Rough or hilly landscape -- producing strong mechanical turbulence

Eddies – Big and Small

Satellite image of eddies forming on the leeward (downwind) side of the Cape Verde Islands during April, 2004. As the air moves past the islands, it breaks into a variety of swirls as indicated by the cloud pattern. (The islands are situated in the Atlantic Ocean, off Africa’s western coast.)
flow over a mountain

• Generating:
  – wave clouds
  – rotor circulations on the leeward side of the mountain - bad for airplanes and gliders!!
  – rotors can have strong vertical motions
  – waves and rotors sometimes generate *clear-air turbulence (CAT)*

The Force of Wind

Strong winds flowing past an obstruction, such as these hills, can produce a reverse flow of air that strikes an object from the side opposite the general wind direction.
With the prevailing wind blowing from off the ocean, the steep cliffs along the coast of Southern California promote rising air and good hang-gliding conditions.

Dangerous conditions !!

Microscale Wind blowing over the earth surface
- Wind and exposed soil
• Wind and Snow surface

Snow rollers—natural cylindrical rolls of snow—grow larger as the wind blows them down a hillside.

• Wind and Vegetation

A properly designed shelterbelt can reduce the air flow downwind for a distance of 25 times the height of the belt. The minimum wind flow behind the belt is typically measured downwind at a distance of about 4 times the belt’s height.
• **Wind and Wave**
  - Wind waves—energy transferred to the water
    - The wind speed
    - The length of time that the wind blows over water
    - The fetch, or distance, of deep water over which the wind blows
  - Microscale winds help wave grow taller!

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**Measuring wind**

- **Wind speed and direction**
- **Wind measuring instruments include:**
  - wind vane (direction)
  - wind sock (direction)
  - anemometer (speed)
  - aerovane (direction and speed)
  - pilot balloons (both)
  - remote sensing instruments:
    - radars
    - profilers
    - lidars
Wind direction

- Wind direction is given as the direction from which it is blowing – a north wind blows from the north toward the south.
- Onshore wind and offshore wind
- Upslope wind and downslope wind.

Wind direction can be expressed in degrees about a circle or as compass points.

The Influence of Prevailing Wind

- Weather
- Building an individual home
- Biological and geological activities
- Landscape

The prevailing wind can be represented by a wind rose.

The volcano’s Shape
Wind Power

Local Wind Systems

- Thermal Circulation
  - Sea and land breezes
  - The monsoon
  - Mountain and Valley breezes
- Katabatic wind
- Chinook (Foehn) winds
- Santa Ana Winds
- Desert winds
Thermal circulation

- Many mesoscale phenomena are the result of a thermal circulation.
- Thermal circulation - a circulation generated by pressure gradients produced by differential heating.
- Thermal circulations tend to be shallow - do not extend up through the depth of the troposphere.
- Weakening with height.
- Being maintained, for the most part, by local heating and cooling.

Thermal (cold core) highs and thermal (warm-core) lows

[Diagram showing thermal low and thermal high with altitude in km and temperature colors.]
Land-sea breezes

- Due to uneven heating/cooling rate of land and water
  - Daytime: land warming fast
  - Nighttime: land cooling fast

The sea-breeze front

- The sea-breeze front is the boundary between the cool, stable sea-breeze flow and the hot, unstable winds over land
- sea-breeze frontal passage is noted by:
  - change of wind speed and direction
  - temperature decrease
  - moisture increase
  - change in air quality
- Max temperature at a station is often realized just before frontal passage
- Clouds often form along the front
- The clouds along the front and the coastal clearing is often seen in satellite imagery
Typically, during the summer over Florida, converging sea breezes in the afternoon produce uplift that enhances thunderstorm development and rainfall.

The convergence of two lake breezes and their influence on the maximum temperature during July in upper Michigan.
Local winds and Water

- Local winds will change speed and direction as they cross a large body of water
  - Fraction differences over water and land
  - Coriolis force chance with wind speed
- Changes in wind speed along the shore of a large lake → cloud formation

Seasonally Changing Winds— The Monsoon

- A monsoon wind system is one that changes direction seasonally, blowing from one direction in summer and from the opposite direction in winter.
- Well developed in eastern and southern Asia
- Factors impact the monsoon wind system
  - Latent heat release
  - Weak, westward moving low-pressure areas (monsoon depressions)
  - El Nino

Winter Monsoon: wind from land to ocean; dry

Summer Monsoon: wind from ocean to land; wet
Monsoon and Precipitation

- Heavy precipitation during summer monsoon
- Annual rain fall in Wyoming ~ 12 in.

Average annual precipitation for Cherrapunji, India. Note the abundant rainfall during the summer monsoon (April through October) with the lack of rainfall during the winter monsoon (November through March).

Monsoon in the southwestern US
Mountain and Valley Breezes

- During day, sunlight warms the valley walls, which in turn warm the air in contact with them.
  - Upslope wind
- During night, the valley walls cool radiatively, which in turn cool the air in contact with them.
  - Downslope wind

As mountain slopes warm during the day, air rises and often condenses into cumuliform clouds, such as these.
Katabatic Winds

- Downslope wind that are much stronger than mountain breezes
- Normally at 10 knots or less, but could up to 100 knots.

Cold on the plateau → High pressure + Low pressure along the plateau = Downhill wind

Chinook (Foehn) Winds

- chinooks are descending, warm, dry winds on the lee side of a mountain range
- Produced as strong westerly flow rides up and over the mountains
  - Due to compressional heating
  - Chinooks are common east of the Rockies
  - also observed in the Alps - called the foehn

Cities near the warm air–cold air boundary can experience sharp temperature changes if cold air should rock up and down like water in a bowl.
A chinook wall cloud forming over the Colorado Rockies (viewed from the plains).

Santa Ana Winds

- A warm, dry wind that blows from the east or northeast into Southern California is the Santa Ana wind
- Need a strong high over the southwestern U.S.
- Winds descend from the higher desert terrain down into the L.A. Basin - parcels become warmer and drier due to compressional heating
- Wind speeds are enhanced as the flow channels through the mountain passes
Strong northeasterly Santa Ana winds on October 28, 2003, blew the smoke from massive wild fires across southern California out over the Pacific Ocean. The fires damaged more than 740,000 acres, destroyed over 2800 homes, and took 20 lives.

Desert Winds (Haboobs)

- A haboob is a sand and/or dust storm
- Generated as a thunderstorm produces a downdraft of cold air
  - the downdraft air descends, strikes the surface and spreads out generating strong surface winds
  - the strong surface winds are able to loft sand and dust into the air
  - the leading edge of the cold, sandy, dusty air is called the thunderstorm gust front
The formation of a **dust devil**. On a hot, dry day, the atmosphere next to the ground becomes unstable. As the heated air rises, wind blowing past an obstruction twists the rising air, forming a rotating column, or **dust devil**. Air from the sides rushes into the rising column, lifting sand, dust, leaves, or any other loose material from the surface.

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**TABLE 9.2**

<table>
<thead>
<tr>
<th>NAME</th>
<th>DESCRIPTION</th>
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</thead>
<tbody>
<tr>
<td><strong>Cold Winds</strong></td>
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<tr>
<td>Buran</td>
<td>A strong, cold wind that blows over Russia and central Asia</td>
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<tr>
<td>Purga</td>
<td>A buran accompanied by strong winds and blowing snow</td>
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<tr>
<td>Pampero</td>
<td>A cold wind blowing from the south over Argentina, Uruguay, and into the Amazon Basin</td>
</tr>
<tr>
<td>Bura</td>
<td>A cold northeasterly wind in Alaska usually accompanied by snow; similar to the buran and purga of Russia</td>
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<tr>
<td>Bise</td>
<td>Generally a cold north or northeast wind that blows over southern France; often brings damaging spring frosts</td>
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<tr>
<td>Popocayo</td>
<td>A cold northeasterly wind along the Pacific coast of Nicaragua and Guatemala; occurs when a cold air mass overrides the mountains of Central America</td>
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<tr>
<td>Tehuantepec</td>
<td>A strong wind from the north or northwest funneled through the gap between the Mexican and Guatemalan mountains and out into the Gulf of Tehuantepec</td>
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<tr>
<td><strong>Mild Winds</strong></td>
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<tr>
<td>Levanter</td>
<td>A mild, humid, and often rainy east or northeast wind that blows across southern Spain</td>
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<tr>
<td>Harmattan</td>
<td>A dry, dusty but mild wind from the northeast or east that originates over the cool Sahara in winter and blows over the west coast of Africa; brings relief from the hot, humid weather along the coastal region</td>
</tr>
<tr>
<td><strong>Hot Winds</strong></td>
<td></td>
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<tr>
<td>Simoom</td>
<td>A strong, dry, and dusty desert wind that blows over the African and Arabian deserts; name means &quot;poison wind&quot; because it is often accompanied by temperatures in excess of 52°C (125°F), which may cause heat stroke</td>
</tr>
</tbody>
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