In the News: SNOW!!!

• 8 inches (official) reported as of 8 am Bozeman

• Snotel:
  – Brackett cr. 9”
  – Sacajawea 3”
  – Lone Mt. 1”
  – Lick cr. 1”

http://cateye.msu.montana.edu/
Atmospheric Circulation

a) Global atmospheric circulation
b) Semipermanent Pressure Cells
c) Upper Troposphere Patterns
d) Oceans
e) Major Wind Systems
f) Air-Sea Interactions

Sea surface temperature index during mild 2006 El Niño.
f) Air-Sea Interactions

ENSO is *variable* in space, time, and intensity, thus so are teleconnections!
f) Air-Sea Interactions

ENSO-related teleconnections:

![Map of Air-Sea Interactions](image)

Textbook Figure 8-33

Copyright © 2007 Pearson Prentice Hall, Inc.
f) Air-Sea Interactions

El Niño Southern Oscillation Index (ENSO):

- ENSO = Tahiti\textsubscript{SLP} − Darwin\textsubscript{SLP}
  - H − L = +
  - L − H = −
f) Air-Sea Interactions

- ENSO = Tahiti_{SLP} – Darwin_{SLP}
  L – H = -

* Negative
ENSO = El Niño*

![Map showing Air-Sea Interactions](image)
f) Air-Sea Interactions

- ENSO = \( \text{Tahiti}_{\text{SLP}} - \text{Darwin}_{\text{SLP}} \)

\[ H - L = + \]

* Positive

ENSO = La Niña*

\[ \text{La Niña} \]

NCEP/NCAR Reanalysis
f) Air-Sea Interactions

El Niño Southern Oscillation Index (ENSO): 
[http://www.cgd.ucar.edu/cas/catalog/climind/soiAnnual.html](http://www.cgd.ucar.edu/cas/catalog/climind/soiAnnual.html)

![Graph of El Niño Southern Oscillation Index](image)

La Niña

El Niño
f) Air-Sea Interactions

El Niño Southern Oscillation Index (ENSO):

http://www.ncdc.noaa.gov/paleo/recons.html#ocean

[Graph showing the El Niño Southern Oscillation index from 1400 to 2000 AD, with peaks indicating El Niño and troughs indicating La Niña events.]
f) Air-Sea Interactions

**ENSO Impacts: Fire in the southwest**


In The US Southwest:  La Nina → dry springs  
El Nino → wet springs
f) Air-Sea Interactions

Pacific Decadal Oscillation (PDO)

- Shift in SST between N/NW Pacific and E tropical Pacific
- + values $\rightarrow$ warm eastern tropical Pacific (warm phase)
- - values $\rightarrow$ cool eastern tropical Pacific (cool phase)

http://jisao.washington.edu/pdo/
f) Air-Sea Interactions

Pacific Decadal Oscillation (PDO)

- **Warm phase** – warm water, eastern tropical Pacific
- **Cool phase** – cool water, eastern tropical Pacific

http://jisao.washington.edu/pdo/
f) Air-Sea Interactions

Arctic Oscillation (AO) and North Atlantic Oscillation (NAO):

- Pressure oscillation between Icelandic Low and Bermuda-Azores High pressure centers
- Warm phase (+): low surface pressure over Arctic, high surface pressure at lower latitudes (ca 45°)
- Cool phase (-): high pressure over Arctic, low pressure at lower latitudes
f) Air-Sea Interactions

Phase relationships: phase of one oscillation affects the impacts of other oscillations

Subalpine Forest Fires in Rocky Mountain National Park:

- Expected fire occurrence (1700-1978)
- Observed fire occurrence (n = 17)

Phase Combination

a. Formation and types of air masses

b. Fronts

http://www.srh.weather.gov/srh/jetstream/synoptic/airmass.htm

http://www.opc.ncep.noaa.gov/UA.shtml
a) Formation of air masses

Air masses:

- Large volumes of air (subcontinental) with ≈ uniform characteristics (temp., humidity)

Source regions:

- Area of uniform topography and surface conditions
- Only occur in mid to high latitudes

Identified by moisture content and temperature

- Continental (c) or Maritime (Marine) (m)
- Arctic (A), Polar (P), Tropical (T)
a) Types of air masses
## a) Types of air masses

<table>
<thead>
<tr>
<th>TYPE</th>
<th>SOURCE REGIONS</th>
<th>PROPERTIES AT SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continental Arctic (cA)</td>
<td>Highest latitudes of Asia, North America, Greenland, and Antarctica</td>
<td>Extremely cold and very dry. Extremely stable. Minimal cloud cover.</td>
</tr>
<tr>
<td>Continental Polar (cP)</td>
<td>High-latitude continental interiors</td>
<td>Cold and dry. Very stable. Minimal cloud cover.</td>
</tr>
<tr>
<td>Maritime Polar (mP)</td>
<td>High-latitude oceans</td>
<td>Cold, damp, and cloudy. Somewhat unstable.</td>
</tr>
<tr>
<td>Continental Tropical (cT)</td>
<td>Low-latitude deserts</td>
<td>Hot and dry. Very unstable.</td>
</tr>
<tr>
<td>Maritime Tropical (mT)</td>
<td>Subtropical oceans</td>
<td>Warm and humid.</td>
</tr>
</tbody>
</table>

Textbook Table 9-1
a) Types of air masses

Continental polar (cP) and Continental Arctic:
a) Types of air masses

Continental polar (cP) vs. Continental arctic (cA):

- cA shallow relative to cP
- cA rarely reaches CAN – US border

Textbook Figure 9-2
a) Types of air masses

Maritime polar (mP):
- Originate in high-latitude oceans
- Cool and moist
  - Commonly affect PNW in winter
  - Affect East Coast via *northeasters* (aka: *nor’ easters*)
a) Types of air masses

Maritime polar (mP): nor’ easters
a) Types of air masses

**Continental tropical (cT):**
- Originate over desert regions (e.g. southwestern US)
- Hot and dry
- Inherently unstable (but still dry)

**Maritime tropical (mT):**
- Originate over tropical oceans (e.g. Gulf of Mexico)
- Warm and moist
- Inherently unstable
a) Types of air masses
b) Fronts

Four fronts:

- Cold
- Warm
- Stationary
- Occluded
b) Fronts

**Cold Fronts:**
- Cold air displaces warm air
- Steep uplift causes cumulonimbus clouds and heavy precipitation
b) Fronts

Cold Fronts:

- surface slope 1:100
- Moves in different direction from warm air ahead of front
b) Fronts

**Warm Fronts:**

- Warm air displaces cold air
- Warmer air flow upward along boundary (overrunning)
- Shallow lifting produces stratus clouds and light precipitation
b) Fronts

**Warm Fronts:**

- **Surface Front:**
- **Cool Air:**
- **Warm Air (stable):**
- **Nimbostratus:**
- **Altostratus:**
- **Cirrostratus:**
- **Cirrus:**

Textbook Figure 9-8
b) Fronts

Stationary Fronts:

- Nonmoving boundary between cold and warm front
- Frontal boundary slopes towards cold air
b) Fronts

Occluded Fronts:

- Formed with a cold front overtakes a warm front
- Creates complex weather
- Precipitation associated with warm air being forced aloft

Textbook Figure 9-10
b) Fronts

Occluded Fronts:

- **Cold-type occlusion:** air behind front colder than air it is overtaking; mostly occurs east of the Rockies
- **Warm-type occlusion:** air behind front warmer than air it is overtaking; mostly occurs on west coast (e.g. mP overtakes cP)
b) Fronts

Occluded Fronts:

Textbook Figure 9-10
b) Fronts

**Occluded Fronts:**

Other sources:
Intersection of cold and warm fronts moves along warm front

Textbook Figure 9-11
b) Fronts

Fronts: defined subjectively based on

- Temperature changes
- Dew point changes
- Bands of clouds
- Wind direction changes (NW in cold sector, SW in warm sector)
- Pressure changes

Textbook Figure 9-7
Which air mass has a source region at “A”?

1. continental Tropical
2. maritime Tropical
3. continental Polar
4. none of these
09.01 Which air mass has a source region at “A”?

1. continental Tropical
2. maritime Tropical
3. continental Polar
4. none of these
Which of the following describes continental Tropical air masses?

<table>
<thead>
<tr>
<th></th>
<th>Properties at Source</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Extremely cold and very dry. Extremely stable. Minimal cloud cover.</td>
<td>1. A</td>
</tr>
<tr>
<td>B</td>
<td>Cold and dry. Very stable. Minimal cloud cover.</td>
<td>2. B</td>
</tr>
<tr>
<td>C</td>
<td>Cold, damp, and cloudy. Somewhat unstable.</td>
<td>3. C</td>
</tr>
<tr>
<td>D</td>
<td>Hot and dry. Very unstable.</td>
<td>4. D</td>
</tr>
</tbody>
</table>
Which of the following describes continental Tropical air masses?

<table>
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<tbody>
<tr>
<td>A</td>
<td>Extremely cold and very dry. Extremely stable. Minimal cloud cover.</td>
</tr>
<tr>
<td>B</td>
<td>Cold and dry. Very stable. Minimal cloud cover.</td>
</tr>
<tr>
<td>C</td>
<td>Cold, damp, and cloudy. Somewhat unstable.</td>
</tr>
<tr>
<td>D</td>
<td>Hot and dry. Very unstable.</td>
</tr>
</tbody>
</table>

1. A
2. B
3. C
4. D
This figure shows a(n) _______.

1. upper air disturbance
2. middle latitude cyclone
3. anticyclone
4. occluded front
This figure shows a(n) _______.

1. upper air disturbance
2. middle latitude cyclone
3. anticyclone
4. occluded front
Which frontal symbol is used for a stationary front?

1. A
2. B
3. C
4. D
09.04 Which frontal symbol is used for a stationary front?

1. A
2. B
3. C
4. D
Which frontal symbol is used for a warm front?

1. A
2. B
3. C
4. D
Which frontal symbol is used for a warm front?

1. A
2. B
3. C
4. D
This diagram shows __________.

1. a cold front
2. an arctic front
3. a middle latitude cyclone
4. overrunning
This diagram shows _______.

1. a cold front
2. an arctic front
3. a middle latitude cyclone
4. overrunning
Over the next few days this warm front will probably _______.

1. stay the same  
2. become less steep  
3. become more steep  
4. become a cold front
Over the next few days this warm front will probably _______.

1. stay the same
2. become less steep
3. become more steep
4. become a cold front
An occluded front will first form at _______.

1. C
2. D
3. E
4. F
An occluded front will first form at _______.

1. C
2. D
3. E
4. F
This cross section shows a(n) _______ front at the surface.

1. cold
2. warm
3. stationary
4. occluded
This cross section shows a(n) _______ front at the surface.

1. cold
2. warm
3. stationary
4. occluded
This map shows a(n) _______.

1. set up for tornadoes
2. northeaster
3. huge continental Tropical air mass
4. anticyclone
This map shows a(n) ________.

1. set up for tornadoes
2. northeaster
3. huge continental Tropical air mass
4. anticyclone
At “A,” _______ is the name of the air mass.

1. continental Polar
2. Great Lakes
3. maritime Polar
4. maritime Tropical
At "A," _______ is the name of the air mass.

1. continental Polar
2. Great Lakes
3. maritime Polar
4. maritime Tropical
Maritime Tropical air has a source region at ___.

1. A
2. B
3. C
4. D
Maritime Tropical air has a source region at ___.

1. A
2. B
3. C
4. D
Midlatitude Cyclones

a. Why do we care about midlatitude cyclones?

b. Polar front theory

c. Life cycle of a midlatitude cyclone

http://upload.wikimedia.org/wikipedia/commons/2/2c/Feb242007_blizzard.gif
a. Why midlatitude cyclones?

**Midlatitude cyclones:**

Low pressure center characterized by the presence of frontal boundaries; travel great distances and affect large areas

http://upload.wikimedia.org/wikipedia/commons/3/35/Extratropical_formation_areas.jpg
a. Why midlatitude cyclones?

Midlatitude cyclones:

Textbook Figure 10-1.
a. Why midlatitude cyclones?

Midlatitude cyclones:

Look at latest:

http://www.hpc.ncep.noaa.gov/basicwx/day0-7loop.html

http://upload.wikimedia.org/wikipedia/commons/3/35/Extratropical_formation_areas.jpg
b. Polar Front theory

Polar Front Theory:

- Vilhem Bjerknes, Bergen Norway, early 20th century
- Described formation, growth, and dissipation of midlatitude cyclones


http://upload.wikimedia.org/wikipedia/en/0/01/Vilhelmbjerknes.jpg
b. Polar Front theory
c. Life cycle of a midlatitude cyclone

Cyclogenesis

- Begins along the polar front
- Low pressure forms
- Fronts develop
c. Life cycle of a midlatitude cyclone

Cyclogenesis
Life cycle of a midlatitude cyclone

Cyclogenesis:
c. Life cycle of a midlatitude cyclone

Cyclogenesis

- Begins along the polar front
- Low pressure forms
- Fronts develop

![Diagram of cyclogenesis showing polar front, jet stream, and pressure system.](Textbook figure 8.9)