Demise of tropical cyclones:
- Increased vertical shear near Japan
- Decreased sea surface temperature

A week ago with max wind of 130 Kts
Symmetrical with a clear eye

Max wind: 60 Kts
Outgoing Longwave Radiation at the top of atmosphere

- Radiative Equilibrium, only in the global mean sense.
- Radiation Imbalance. At a given latitude, incoming solar radiation is generally NOT in balance with longwave radiation emitted back into space.

Winds in the atmosphere and currents in the oceans redistribute the excess energy, moving the energy from the lower latitudes to the poles to compensate for the radiation imbalance.
A schematic of the Earth’s weather machine bringing warm moist air northward and cold dry air southward (sensible and latent heat).

Europe’s heating system: warmer Gulf Stream (red) transports heat north while cold deep water flows south underneath (blue).
Seasonal Cycle

Why is summer warmer? Hypothesis: closer to the sun?

**Hypothesis testing 1**: Farther from sun in July!

**Hypothesis testing 2**: When Northern Hemisphere is summer, Southern Hemisphere is winter.
The tilted axis causes seasonal change on Earth

Length of day
Angle of incoming sunlight: path length through atmosphere; intensity per unit surface area
6

March 20, Sept 22
Equinox
Dec 21
NH winter

Geometry

**Table 2.3** Length of Time from Sunrise to Sunset for Various Latitudes on Different Dates

<table>
<thead>
<tr>
<th>Latitude</th>
<th>March 20</th>
<th>June 21</th>
<th>Sept. 22</th>
<th>Dec. 21</th>
<th>At (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>12 hr</td>
<td>12.0 hr</td>
<td>12 hr</td>
<td>12.0 hr</td>
<td>0.0</td>
</tr>
<tr>
<td>10°</td>
<td>12 hr</td>
<td>12.6 hr</td>
<td>12 hr</td>
<td>11.4 hr</td>
<td>1.2</td>
</tr>
<tr>
<td>20°</td>
<td>12 hr</td>
<td>13.2 hr</td>
<td>12 hr</td>
<td>10.8 hr</td>
<td>2.4</td>
</tr>
<tr>
<td>30°</td>
<td>12 hr</td>
<td>13.9 hr</td>
<td>12 hr</td>
<td>10.1 hr</td>
<td>3.8</td>
</tr>
<tr>
<td>40°</td>
<td>12 hr</td>
<td>14.9 hr</td>
<td>12 hr</td>
<td>9.1 hr</td>
<td>5.8</td>
</tr>
<tr>
<td>50°</td>
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<td>16.3 hr</td>
<td>12 hr</td>
<td>7.7 hr</td>
<td>8.6</td>
</tr>
<tr>
<td>60°</td>
<td>12 hr</td>
<td>18.4 hr</td>
<td>12 hr</td>
<td>5.6 hr</td>
<td>12.8</td>
</tr>
<tr>
<td>70°</td>
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<td>2 months</td>
<td>12 hr</td>
<td>0 hr</td>
<td></td>
</tr>
<tr>
<td>80°</td>
<td>12 hr</td>
<td>4 months</td>
<td>12 hr</td>
<td>0 hr</td>
<td></td>
</tr>
<tr>
<td>90°</td>
<td>12 hr</td>
<td>6 months</td>
<td>12 hr</td>
<td>0 hr</td>
<td></td>
</tr>
</tbody>
</table>

Source: Sun in summer Alaska
Angle of incoming sunlight $\rightarrow$ intensity per unit surface area

Same flash light

Larger lighted area

Smaller radiation per unit area: $S/\text{area}$

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Food for Thought

• Seasons are driven by variations in solar radiation.

• These variations (length of day/angle of sun) are a function of latitude.

• So...why are seasons so different at these two cities, even though they are at the same latitude?
Additional concepts of heat

- **Specific heat**: Heat required to increase one unit mass of a substance by 1°C (specific heat of water ~ 4 that of air)

- **Heat capacity**: Heat required to increase an object (of a given mass; = specific heat times mass) by 1°C (heat capacity of one liter water ~ 1600 that of one liter air)

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Over ocean, winter convection allows seasonal change to penetrate ~100 m while over land, seasonal change is confined in the top few meters of a heat capacity equivalent to 1-2 m water.
Ocean’s role in climate

Atmospheric mass = 10 m deep water
Atmospheric heat capacity = 4 m water
Ocean depth = 4,000 m
Ocean involved in seasonal cycle ~ 100 m

In addition to its large heat content, Ocean currents transport and redistribute the heat from one region to another.

Land vs. Water

The temperature of the ocean changes slowly because:
- Specific heat of water is larger than that of ground
- Radiation received by water can penetrate several meters.
- Evaporation
- Easy mixing (advection and convection)
In the NH open ocean, maximum and minimum temperatures are observed in September and March, respectively.

Ocean heat capacity → 2-3 months delay in Tmax.

<table>
<thead>
<tr>
<th></th>
<th>SAN FRANCISCO</th>
<th>RICHMOND</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td>°F</td>
<td>°C</td>
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<tr>
<td>Mean annual</td>
<td>14</td>
<td>57</td>
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<tr>
<td>temperature</td>
<td></td>
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</tr>
<tr>
<td>Annual temperature</td>
<td>6</td>
<td>11</td>
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<tr>
<td>range</td>
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<td></td>
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<tr>
<td>Record high</td>
<td>39</td>
<td>163</td>
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<tr>
<td>Record low</td>
<td>−3</td>
<td>27</td>
</tr>
</tbody>
</table>

Temperature at sea level

Winter: Cold over continent & warm over ocean; West coast warmer than east coast because of warm advection by the westerly winds

Summer: Hot over continent & cool over ocean.

Larger north-south gradients in winter; Larger amplitudes in mid/high latitudes.

← Solar radiation
Temperature at sea level

Controls of Temperature
- Latitude (insolation)
- Elevation
- Land, vegetation & water distribution
- Ocean currents (warmer North Atlantic than North Pacific Ocean)

Food for Thought
Since polar latitudes receive the longest period of sunlight during summer, why aren’t temperatures highest there?

Why aren’t temperatures highest at the summer solstice?