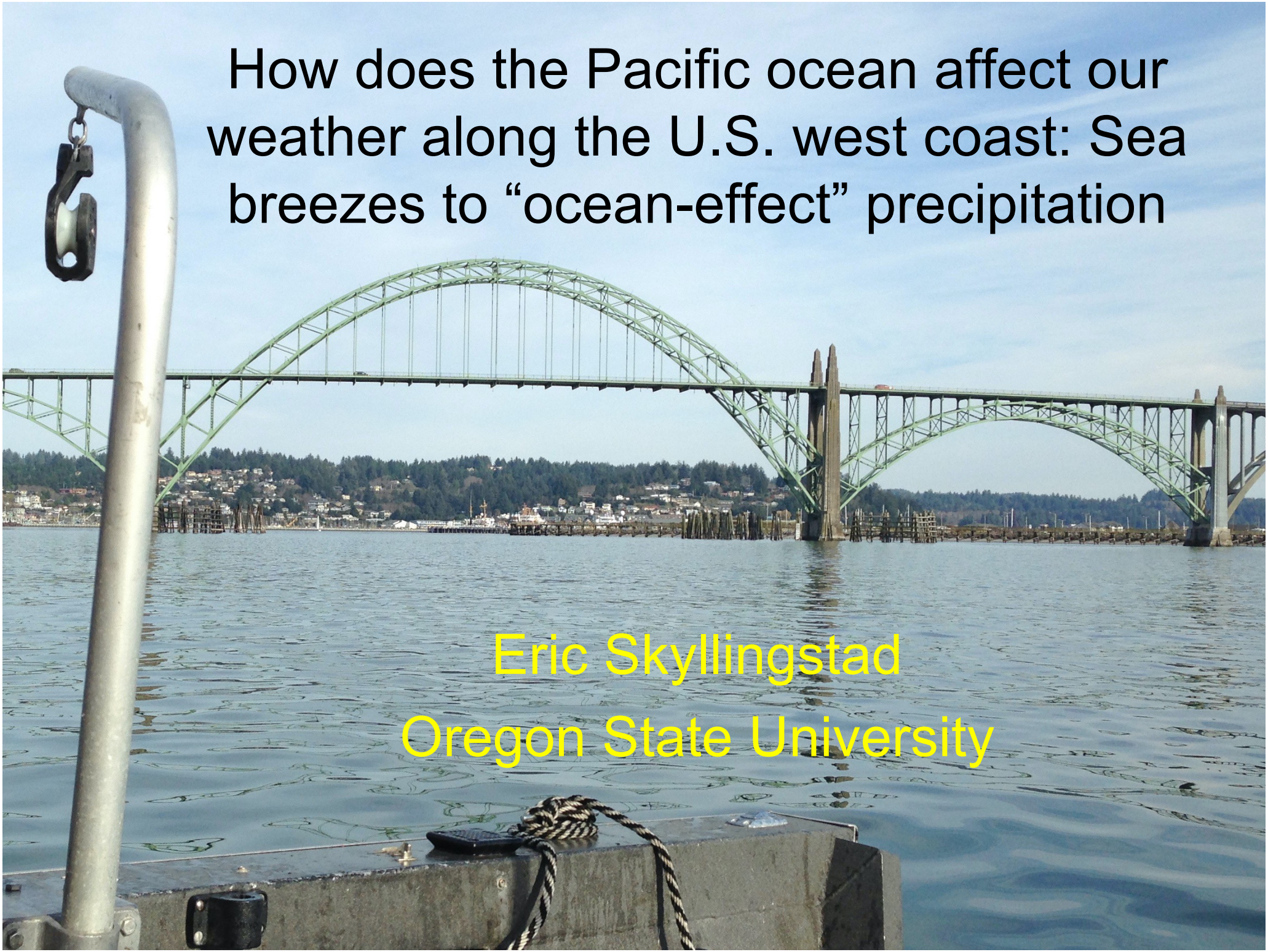

How does the Pacific ocean affect our weather along the U.S. west coast: Sea breezes to “ocean-effect” precipitation
Eric Skyllingstad
Oregon State University

Outline

- What drives the wind?
- Small-scale circulations
  - Channeled flows
  - Sea/Land breeze
- Winter weather
- Summer weather
- Upwelling
- Tropical connections: La Nina, La Nada

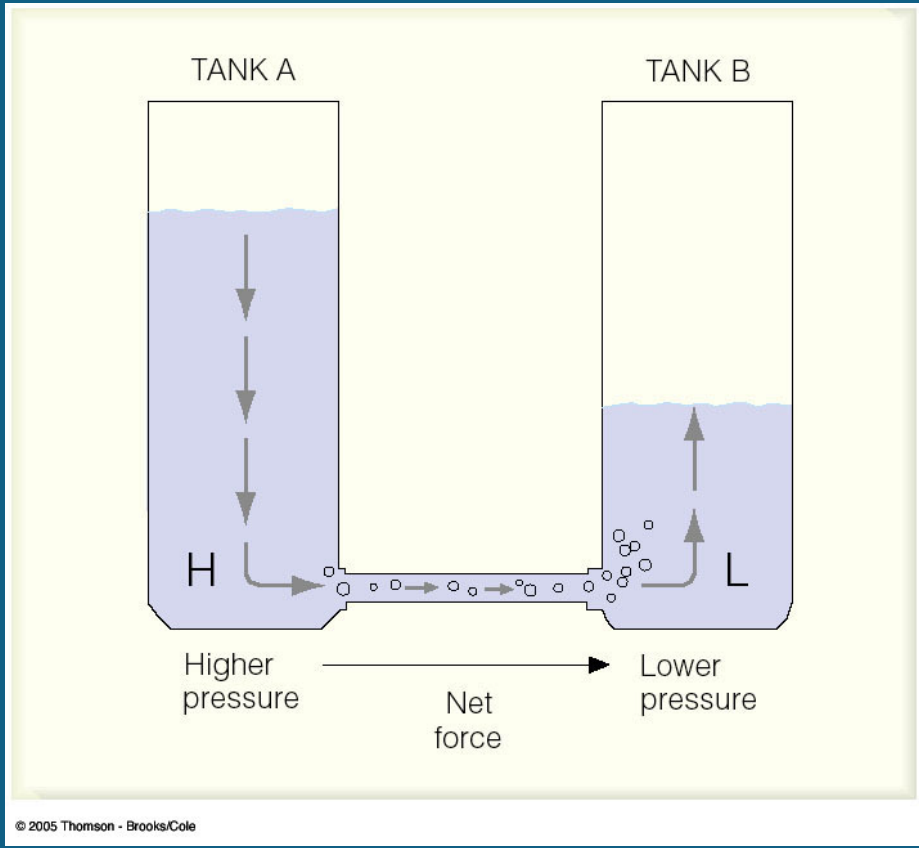
Outline: What Forces the Wind to Blow along the Coast

First we will review some fluid dynamics

1) Pressure force
2) Coriolis force:
   - What is it?
   - What does it do?
3) Surface friction
4) Centrifugal force ("felt" in a rotating coordinate system)

Pressure Force

- Consider two tanks containing water.
- Tank A is filled with more water than tank B.
- The pressure at the bottom, a measure of the weight of the water above, is higher in Tank A than Tank B.
- A **pressure force** wants to push water from tank A into tank B (high pressure to low).



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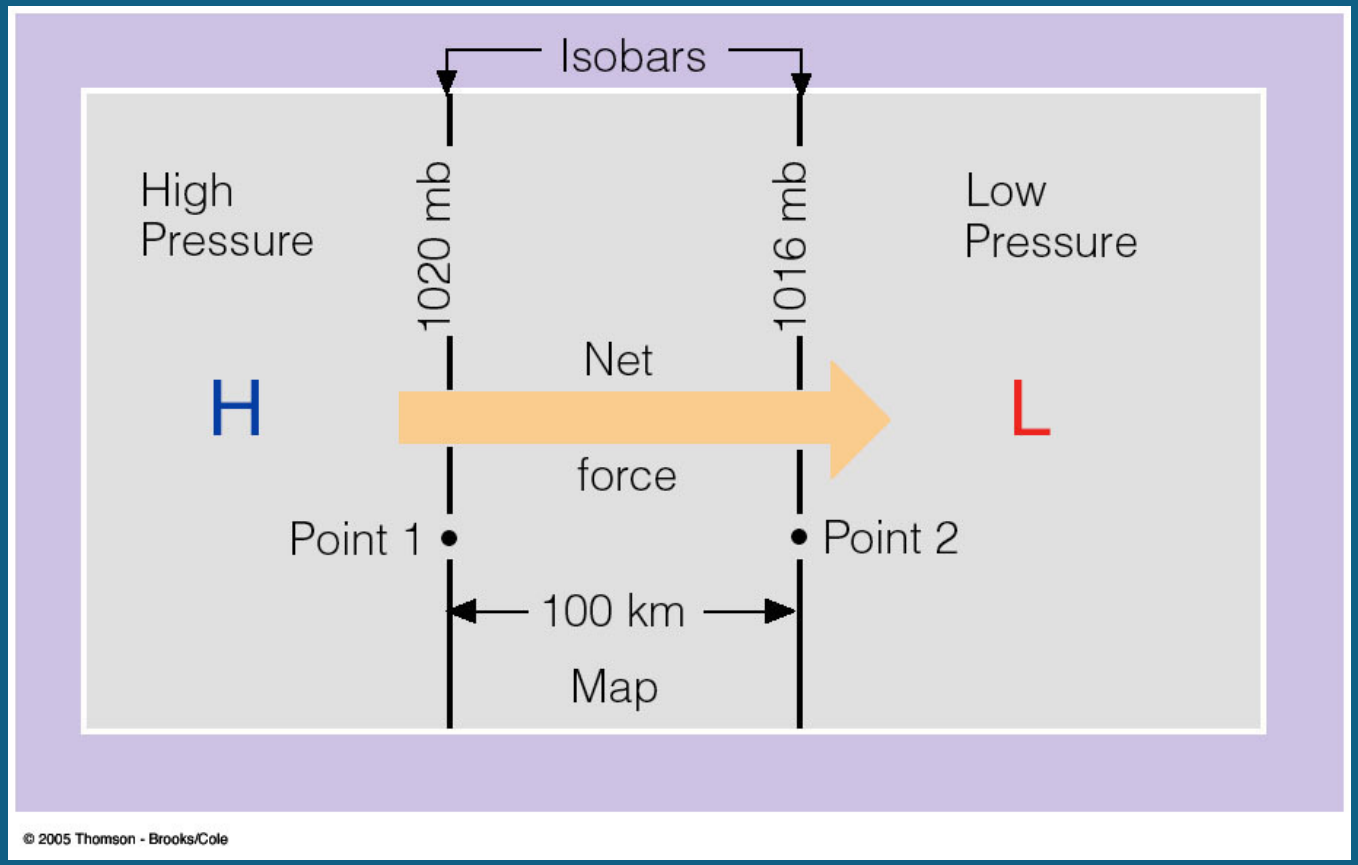
Pressure Force.

Directed from High to Low Pressure



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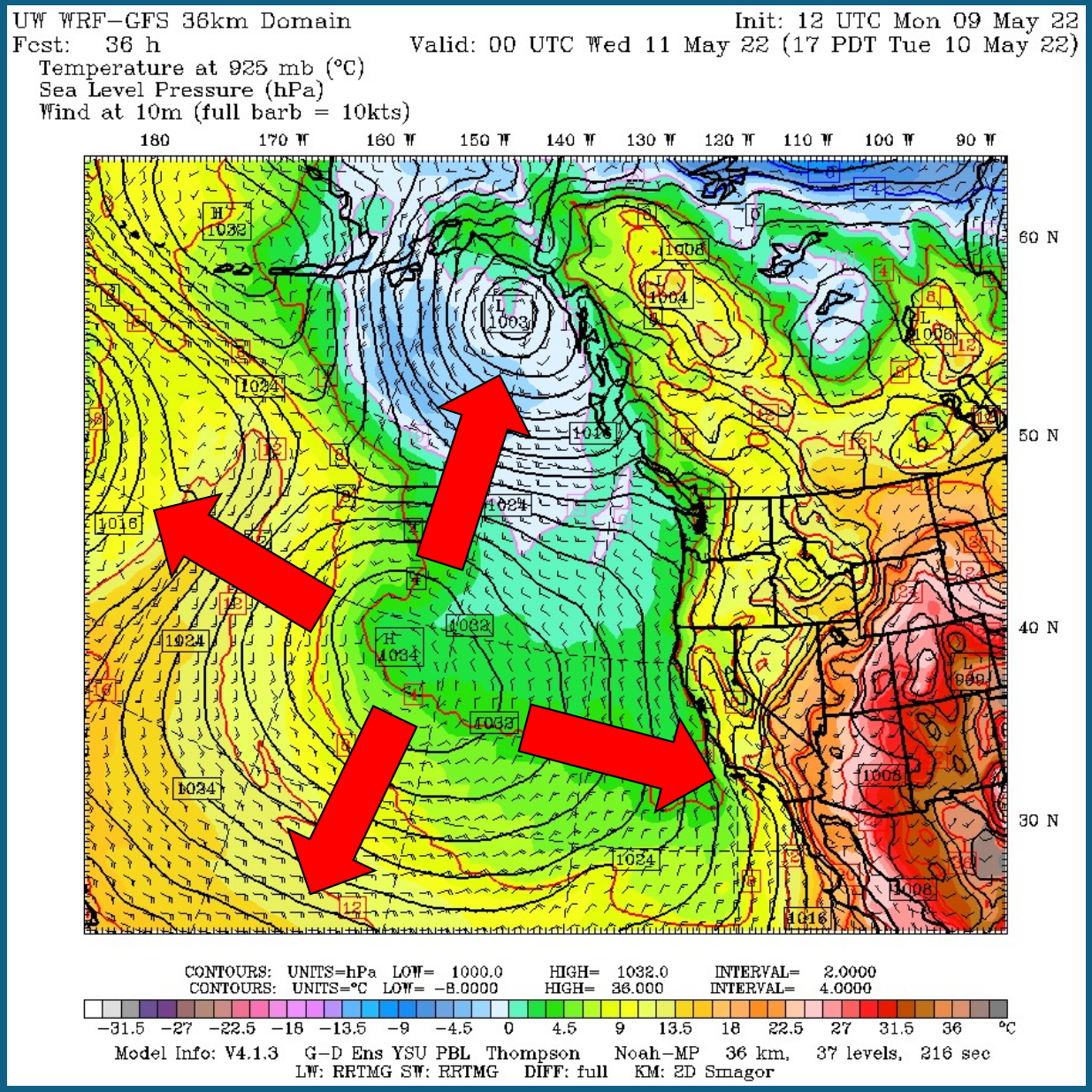
Pressure Gradient Force

Red arrows show the of the pressure gradient force.

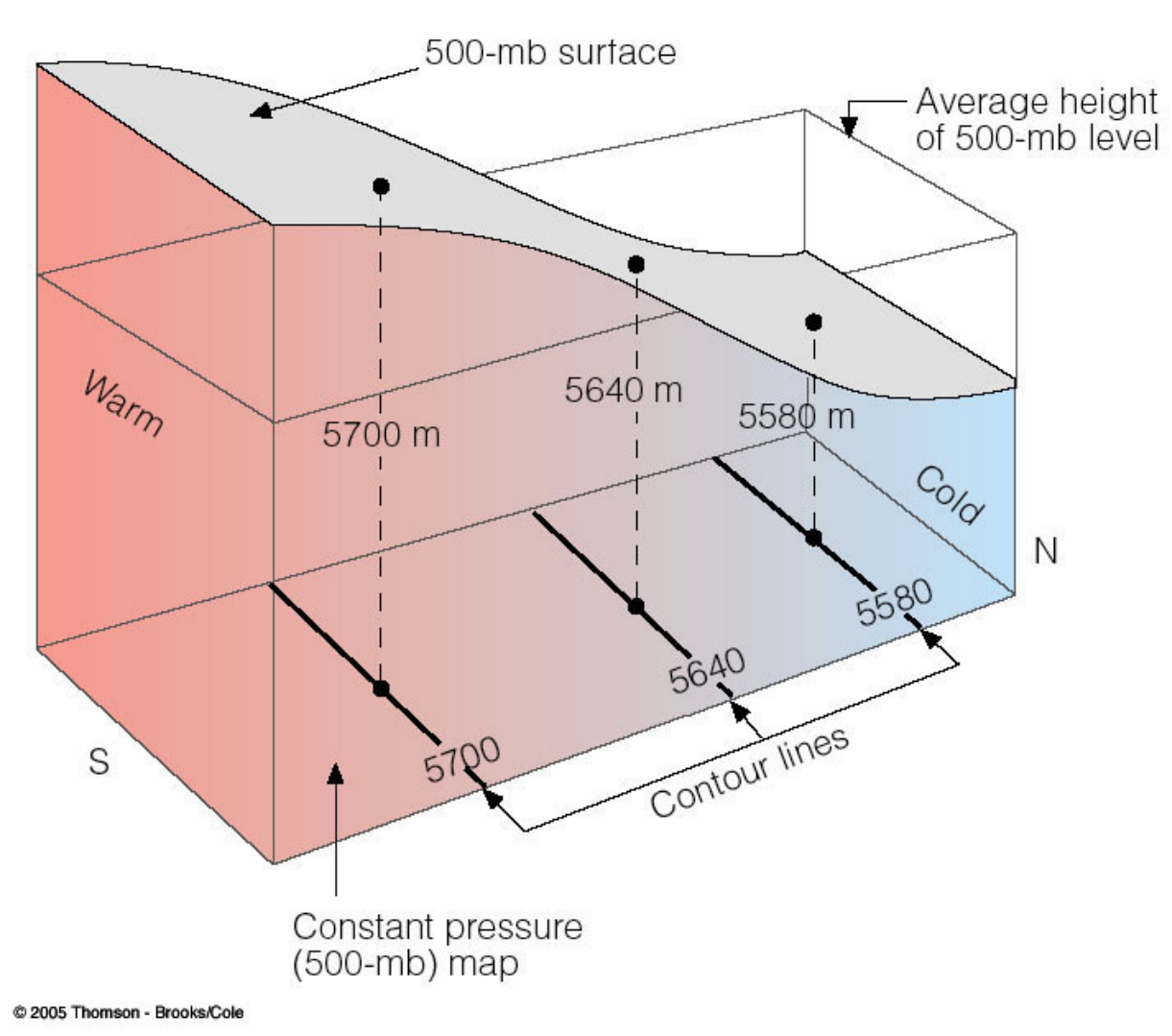
Note, pressure lines packed closer together corresponds to a stronger force.

Force is toward lower pressure, but on the larger scales, wind doesn't generally blow that direction.



Weather isn't just at the surface

- The plot on the right shows a typical pressure surface and how it might change with height across a temperature gradient
- Notice that regions of low height are the same as regions of low pressure, if you do a horizontal slice across the map.



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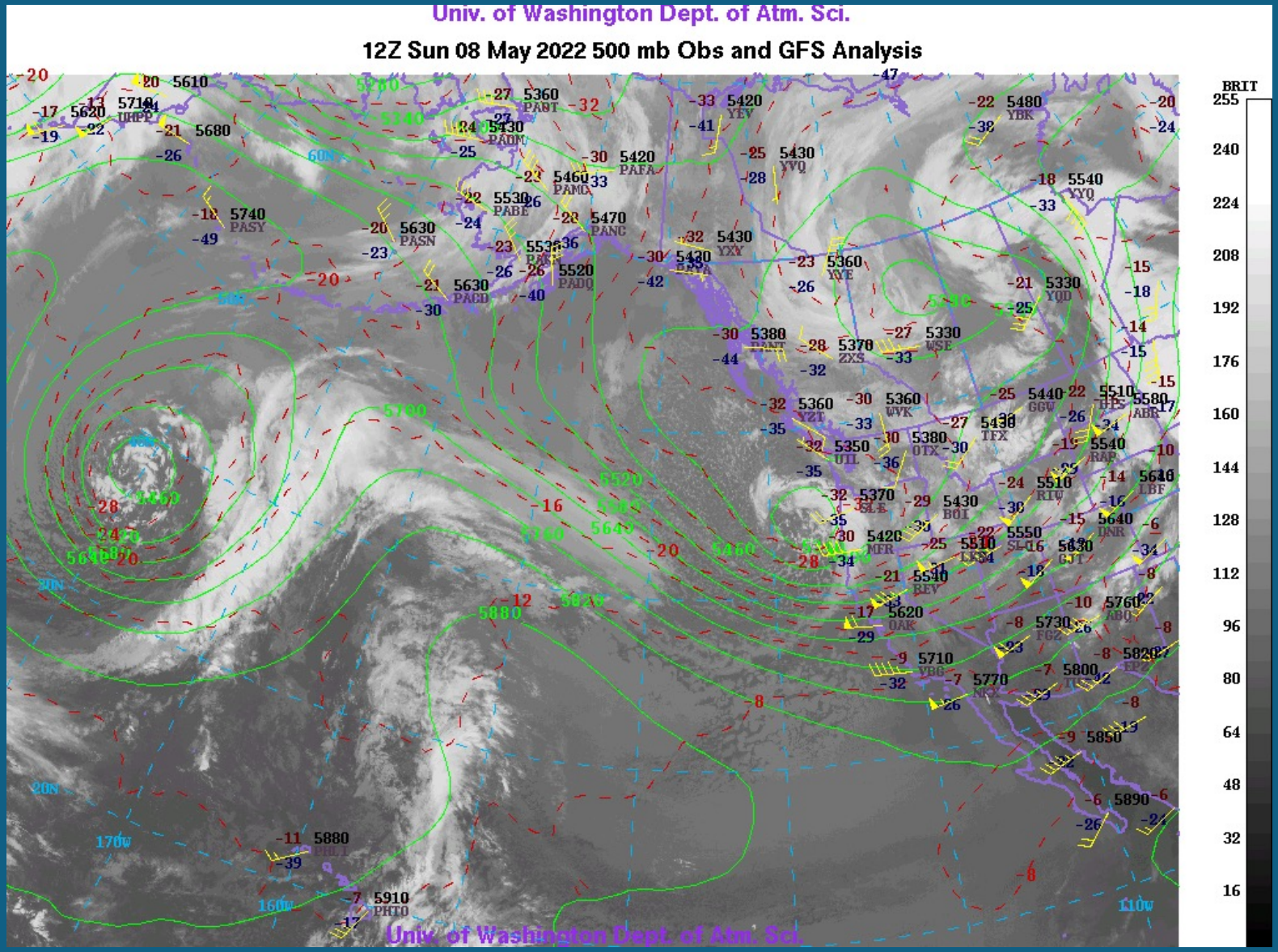
500 hPa, Temperatures and IR Satellite



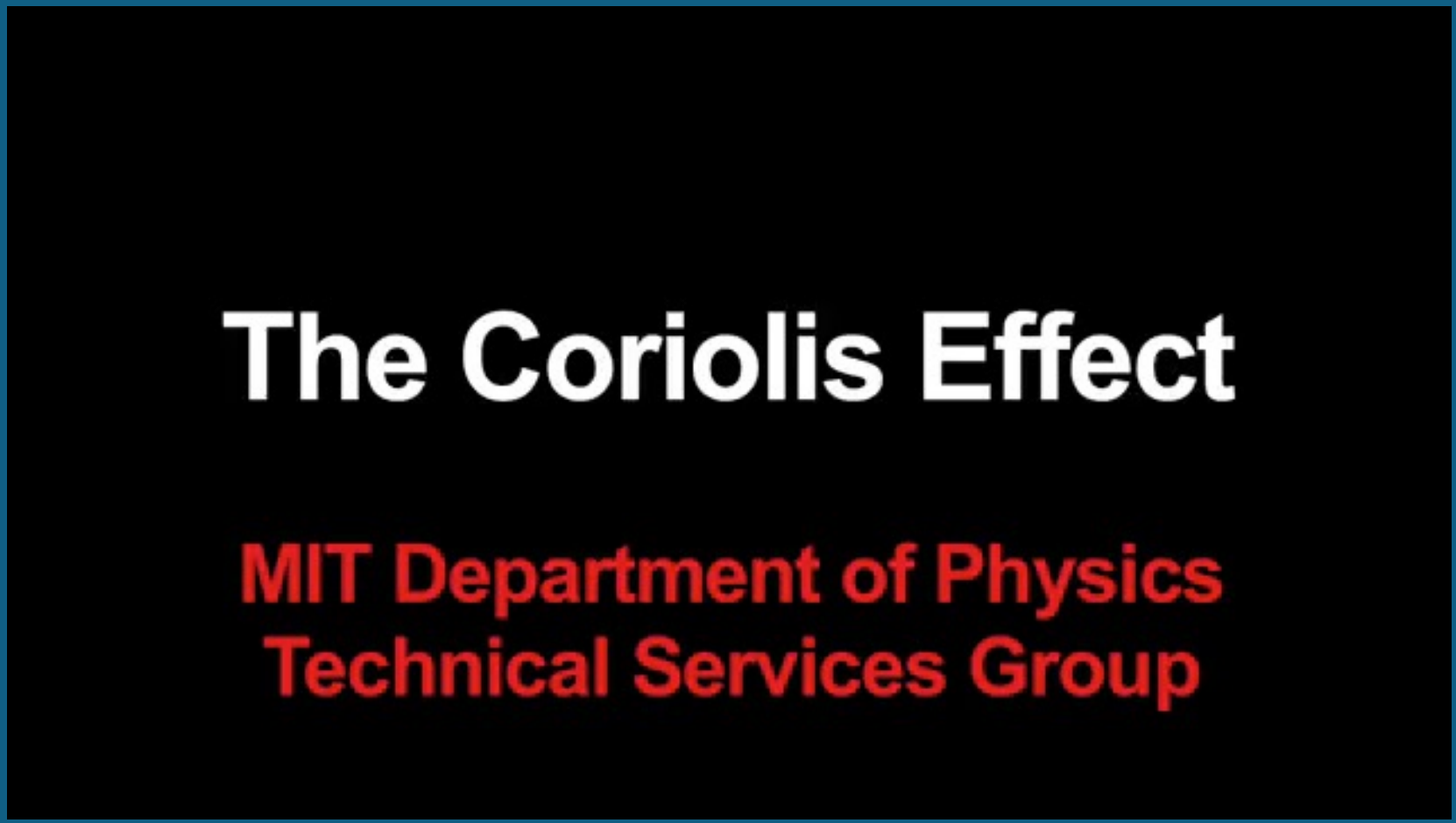
Half way through the atmosphere – Surface is at about 1000 hPa

The Coriolis Force

- Northern Hemisphere: a force directed to the right of your direction of motion (does not affect speed).
- Southern Hemisphere: a force to the left of your direction of motion.
- The Coriolis force increases with wind speed.
- The Coriolis force increases toward the Poles, and is zero at the Equator.

Why Does the Coriolis Force Exist?

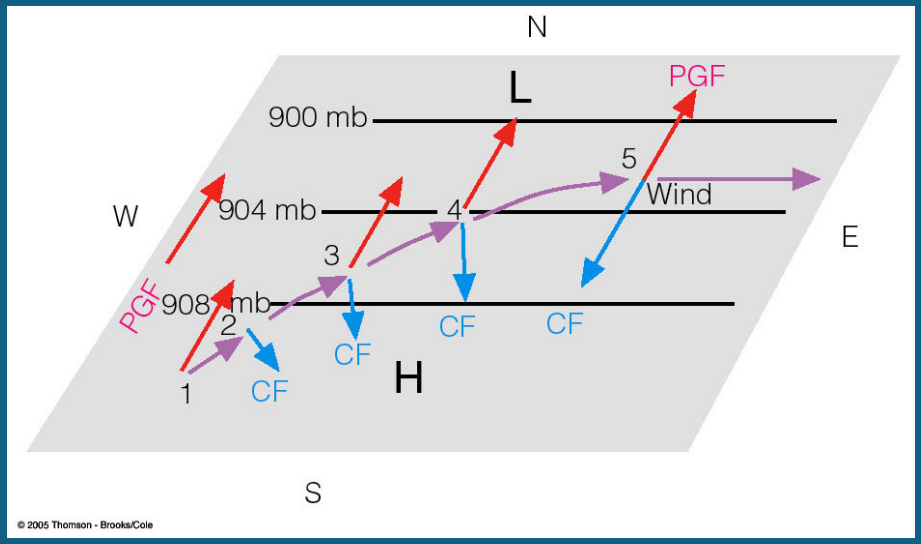
An example is provided by a ball being sent across a rotating turntable, and the turntable rotating underneath it. This is a good demonstration that motions look different to an observer in a rotating vs. nonrotating reference .



Pressure Force = Coriolis Force
Geostrophic Flow

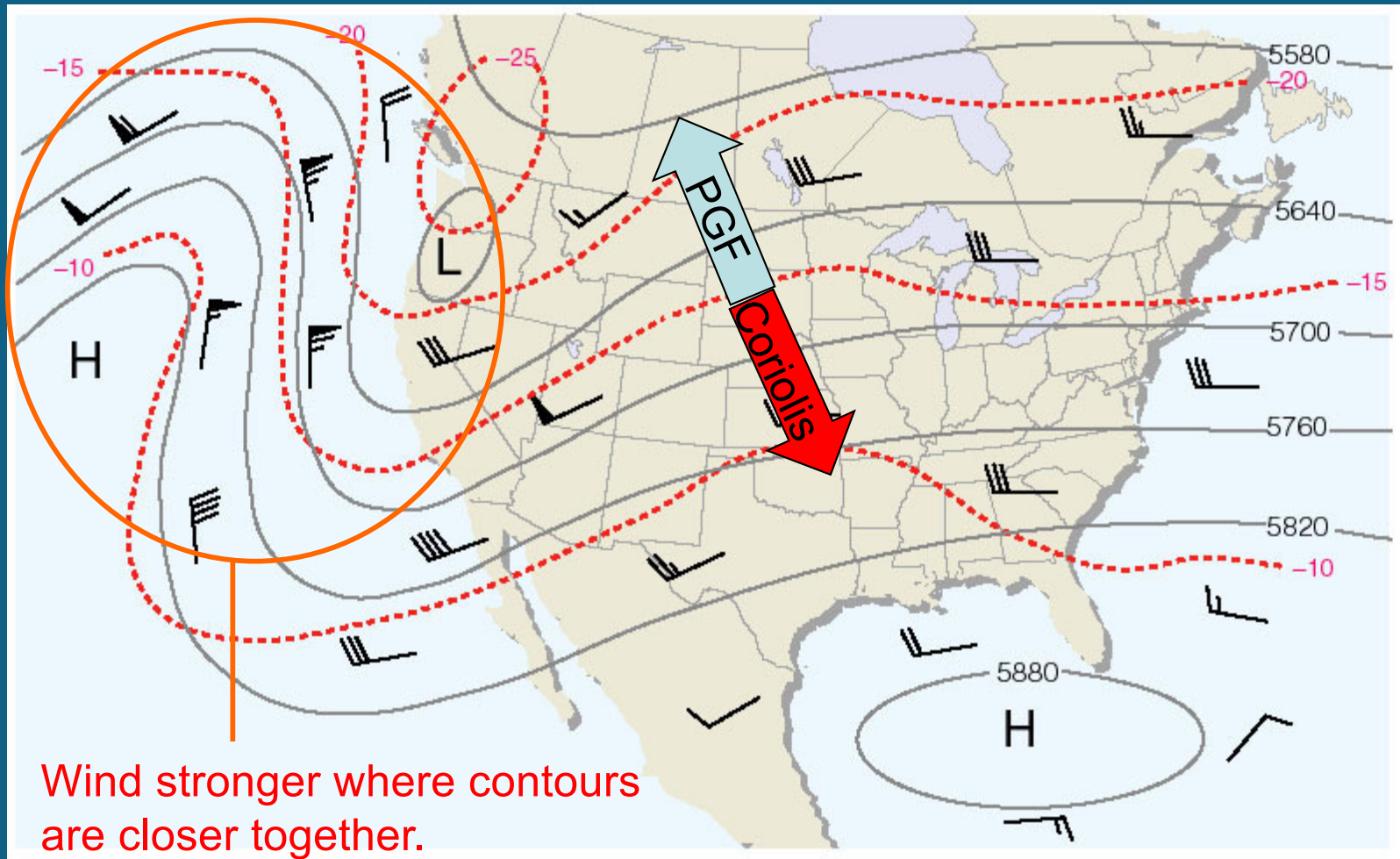
- The exact balance between these two forces, with the wind moving parallel to isobars, is called **geostrophic balance**.
- In the Northern Hemisphere, low pressure is to the left of motion, and the Coriolis force is to the right. Just the opposite in the Southern Hemisphere

Northern Hemisphere



Geostrophic Flow Far Above the Surface

500 mb Map showing winds parallel to lines of constant height (analogous to isobars)



	Miles (statute) per hour	Knots
	Calm	Calm
	1–2	1–2
	3–8	3–7
	9–14	8–12
	15–20	13–17
	21–25	18–22
	26–31	23–27
	32–37	28–32
	38–43	33–37
	44–49	38–42
	50–54	43–47
	55–60	48–52
	61–66	53–57
	67–71	58–62
	72–77	63–67
	78–83	68–72
	84–89	73–77
	119–123	103–107

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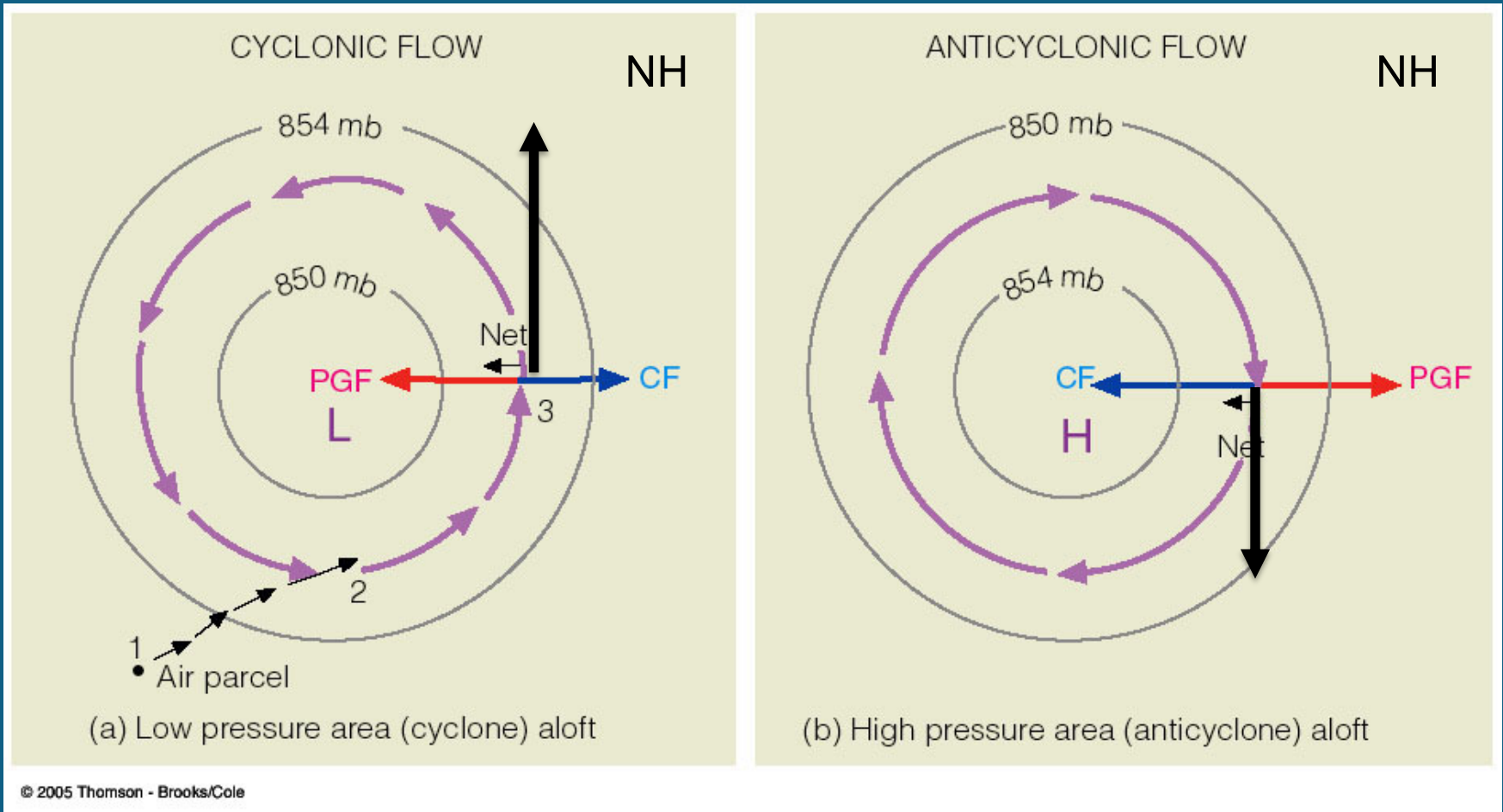
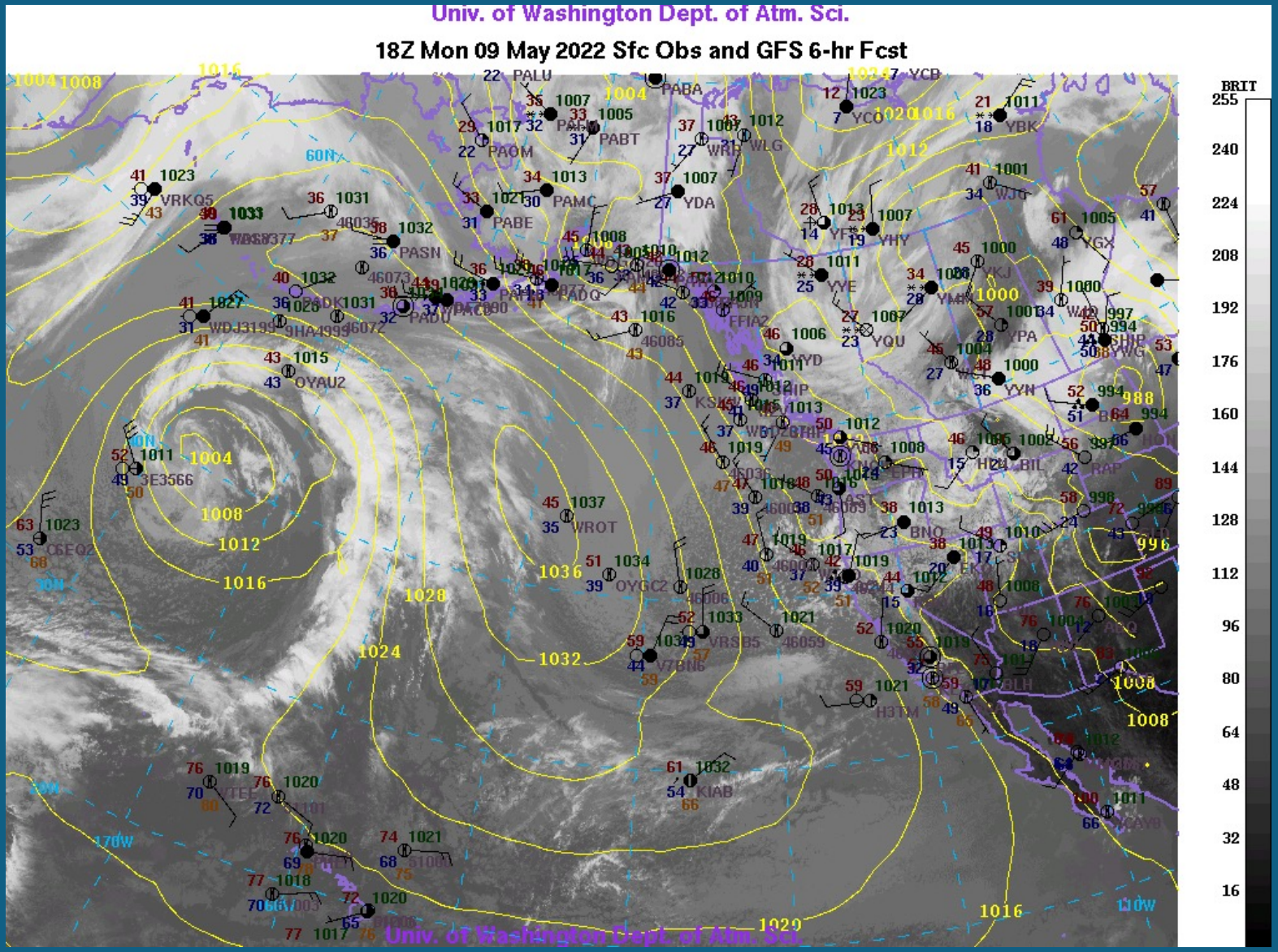
But there is another force for rotating flow….

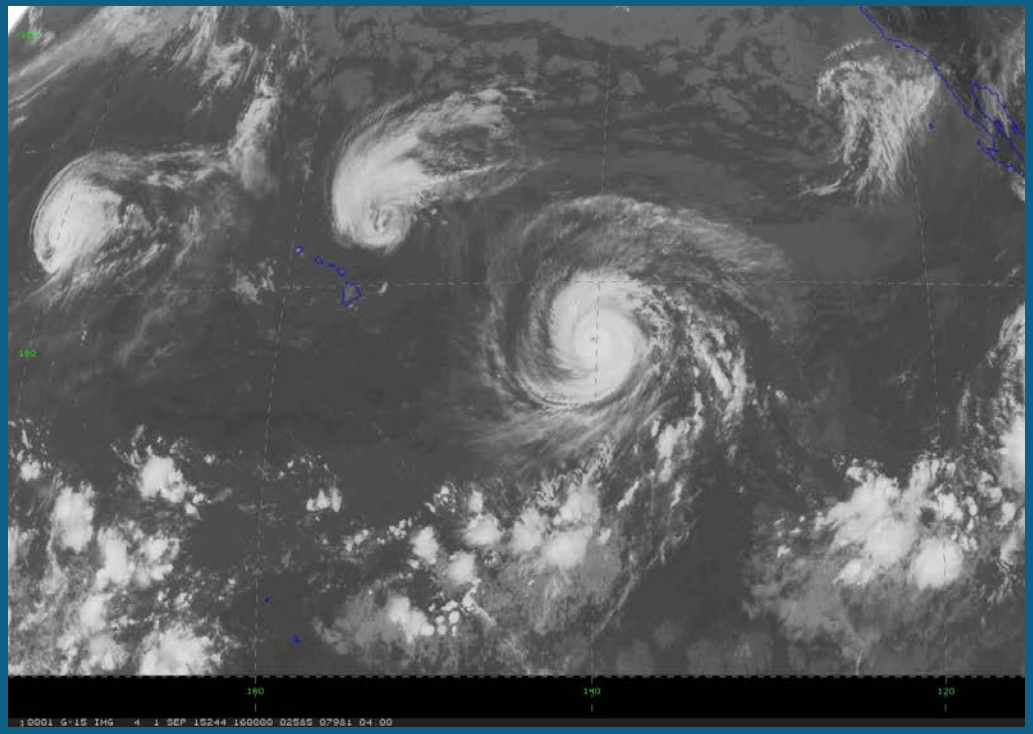


Air wants to travel in a straight line – Centrifugal Force

Wind parallel to the pressure contours
Centrifugal force is small…



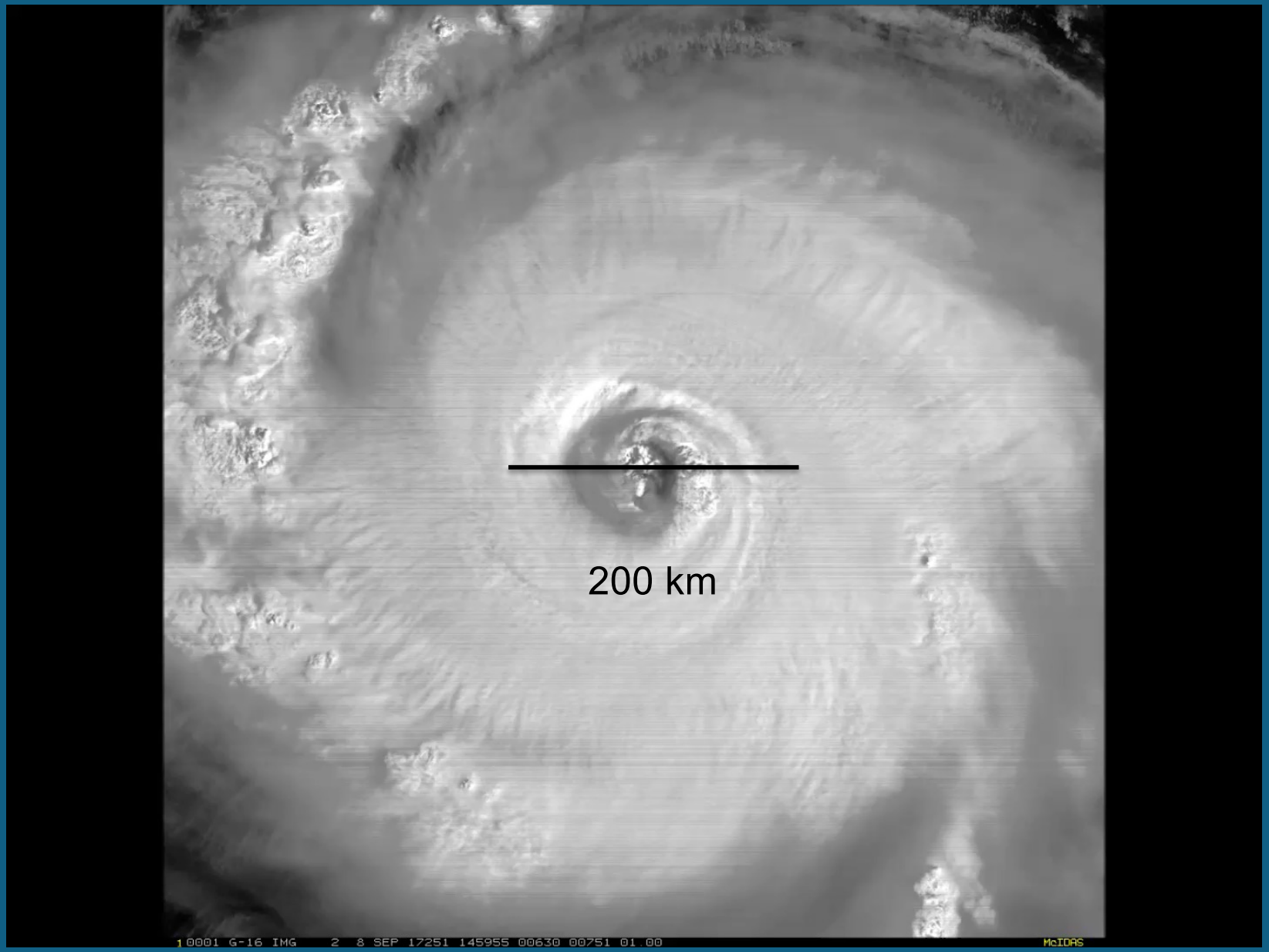
What if Centrifugal = Pressure Force?
Cyclostrophic Flow



Hurricane

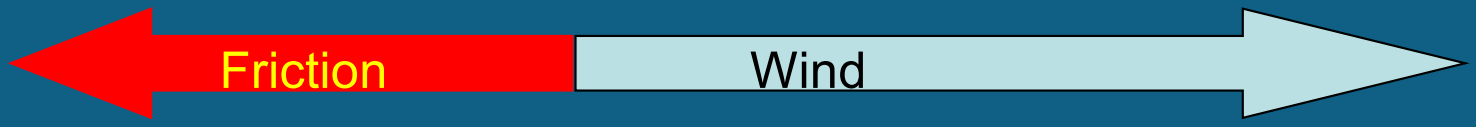
Tornado

Hurricane Irma



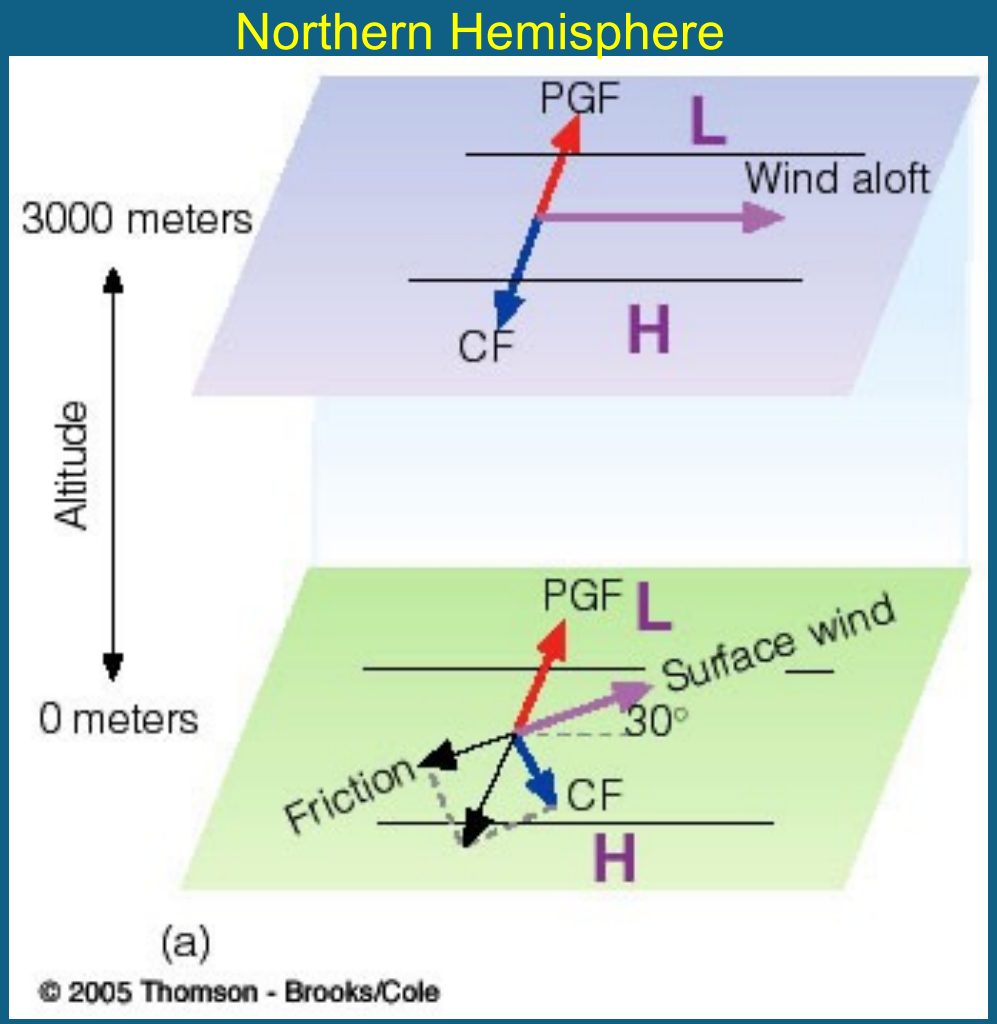
Surface Friction

- Near the surface, frictional drag exists that directly opposes the wind.
- Frictional drag is greater over land than over the ocean.
- This tends to change the force balance and the flow near the surface much more complex.



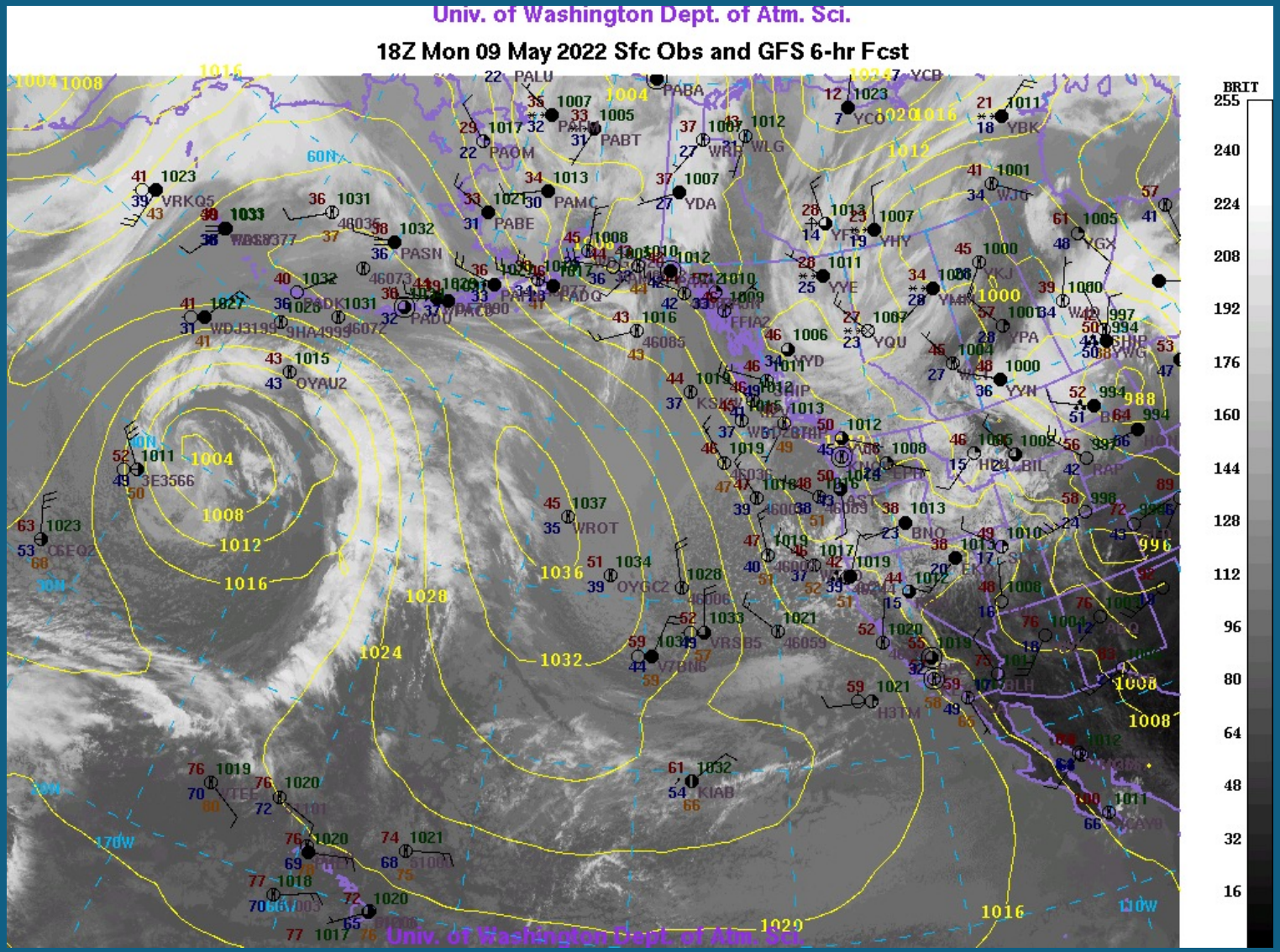
Force Balance at Surface Versus the Balance Aloft

- Surface friction reduces the wind speed, reducing the Coriolis force
- The pressure force is significantly greater than the Coriolis force, making wind blow across the pressure field



Cross Isobar Flow

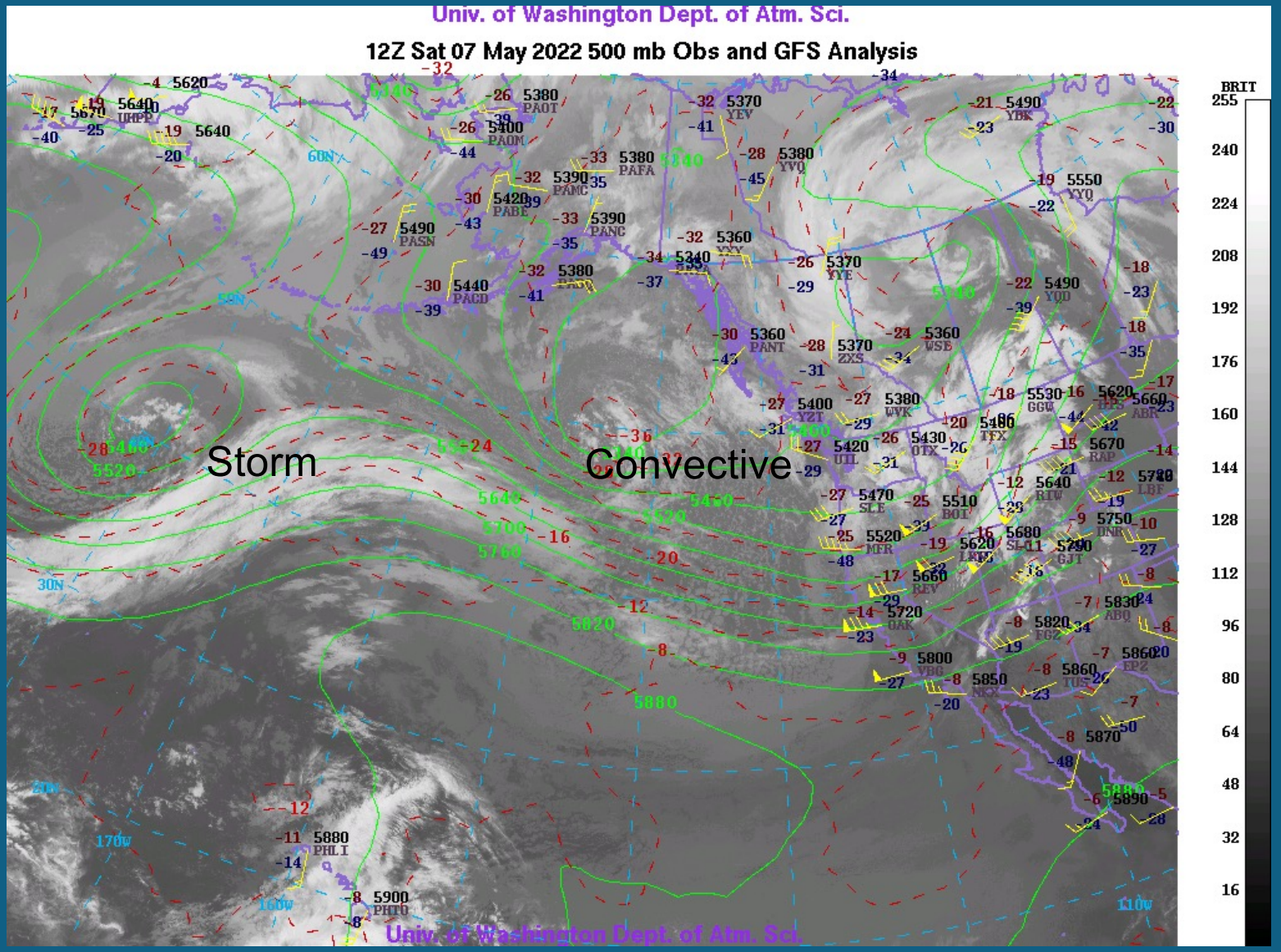
Winds directed toward lower pressure because of friction



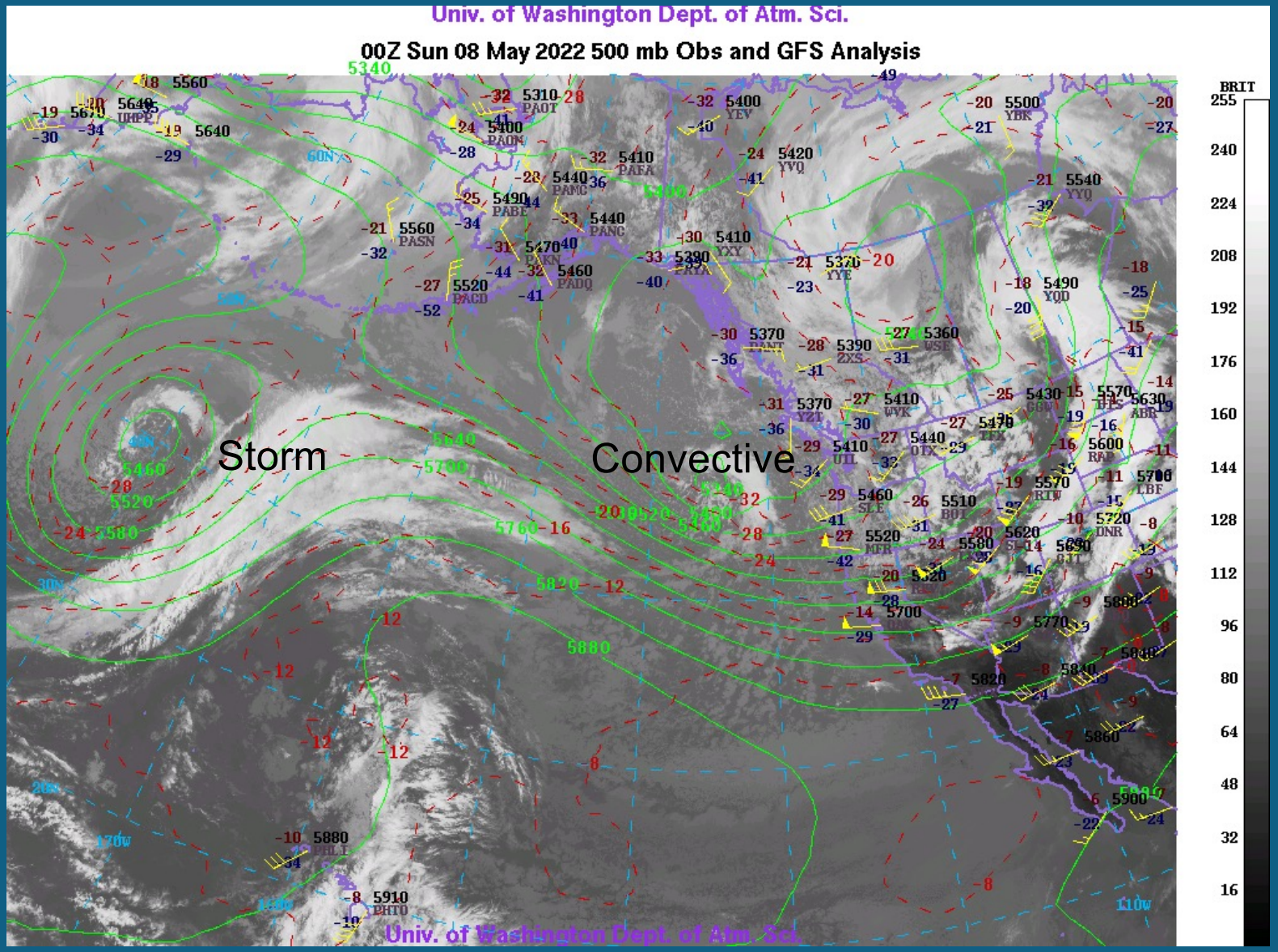
Coastal Winter Weather

- Two main sources of precipitation: Storm systems and convective showers
- Air-sea interaction fuels convective showers much like lake-effect snow
- Without warm ocean, showers would not exist

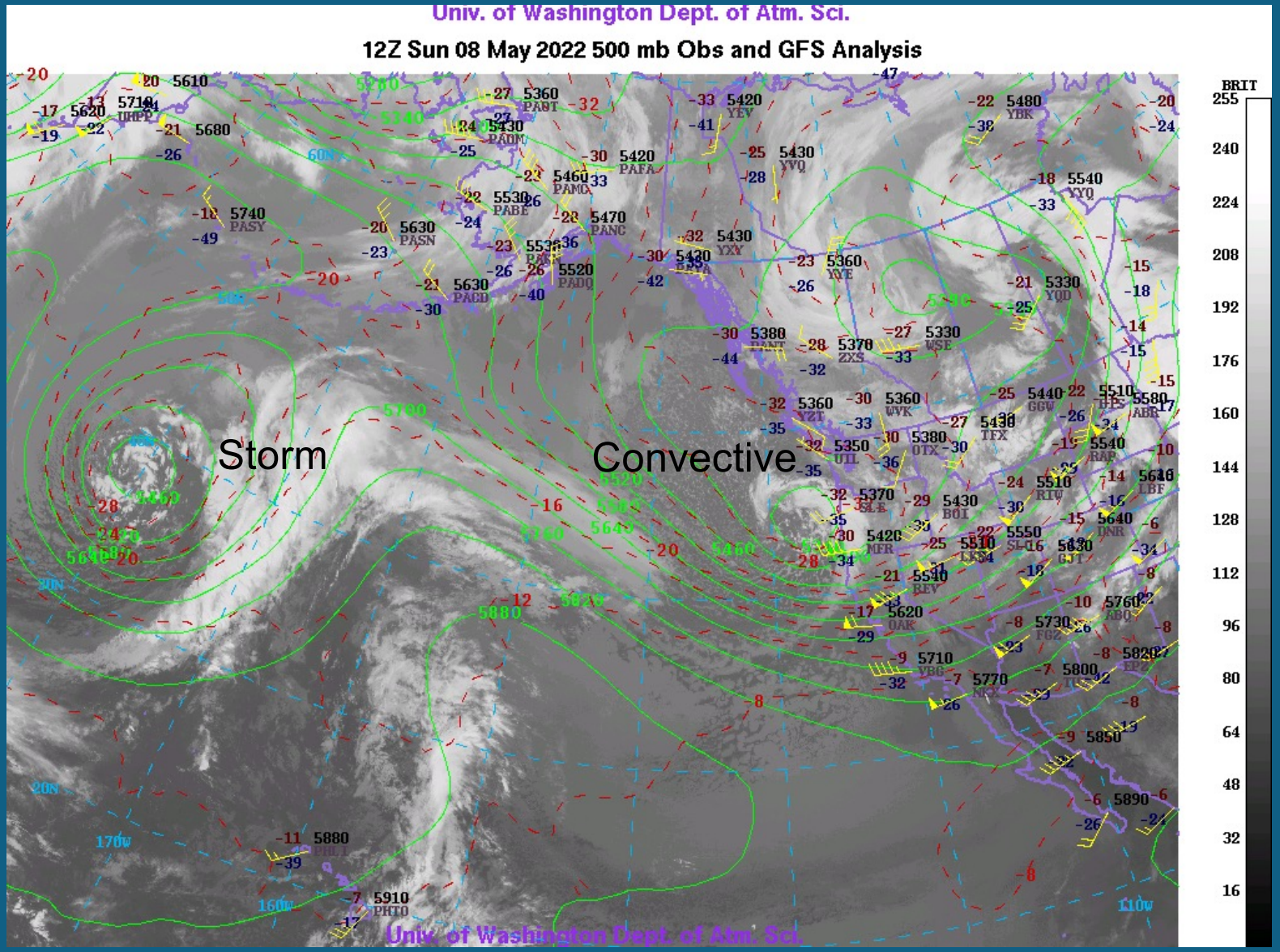
Cold air over ”Warm” water



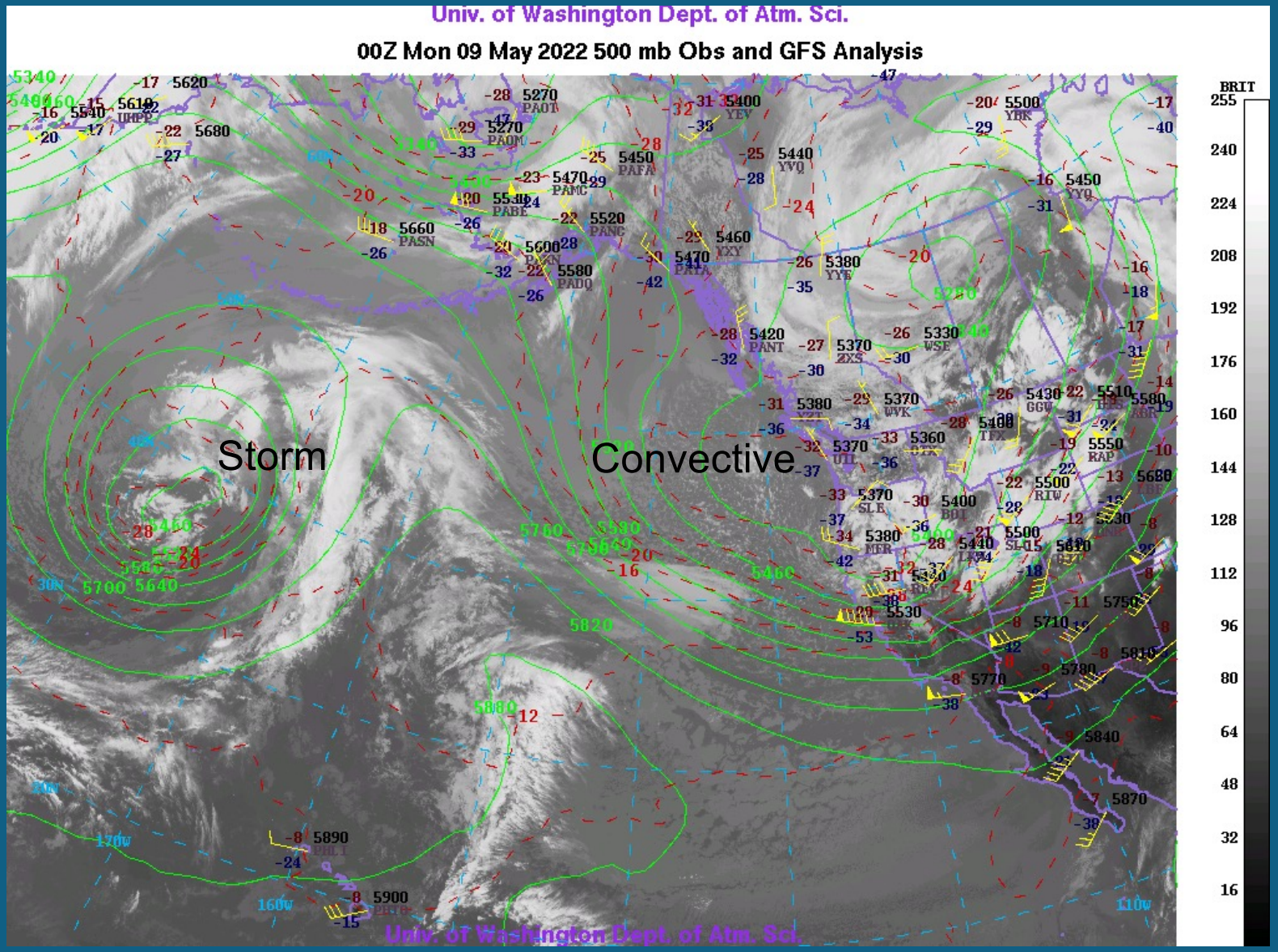
Cold air over ”Warm” water



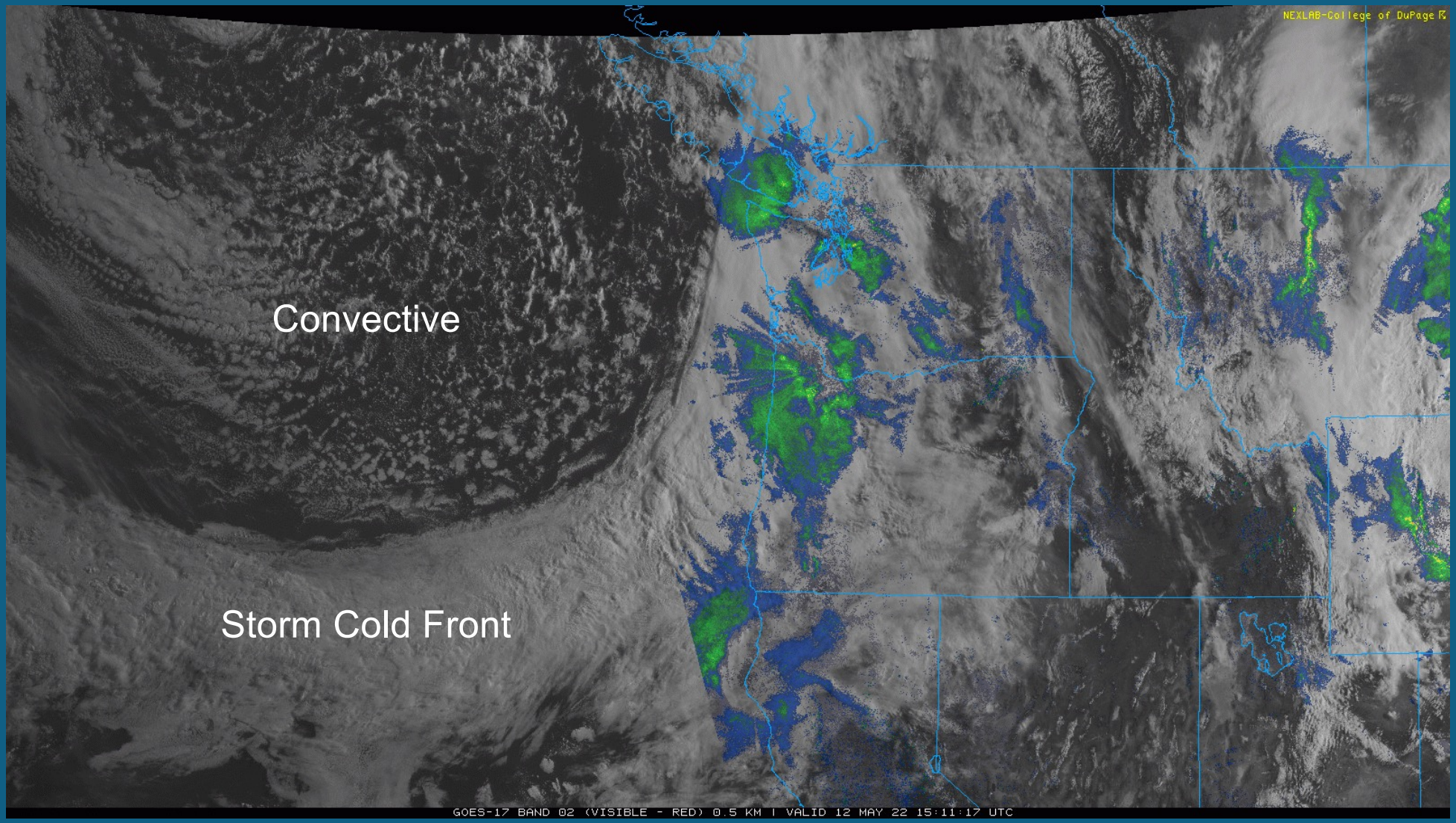
Cold air over ”Warm” water



Cold air over ”Warm” water

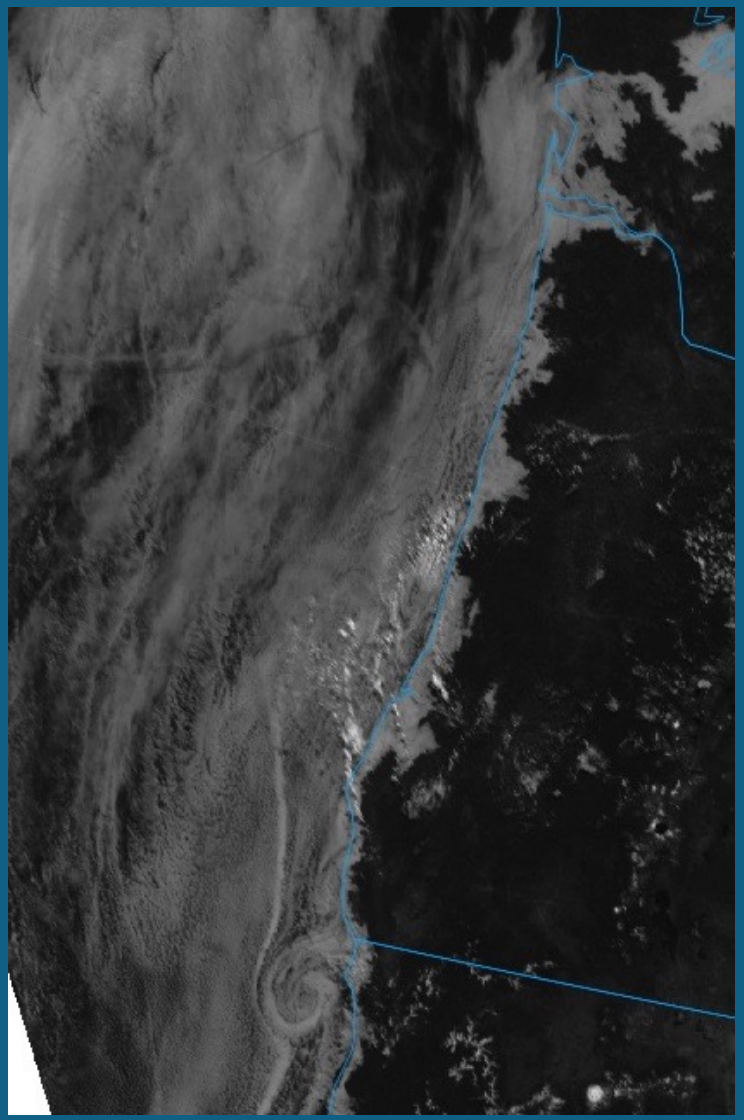


Today's PNW Weather



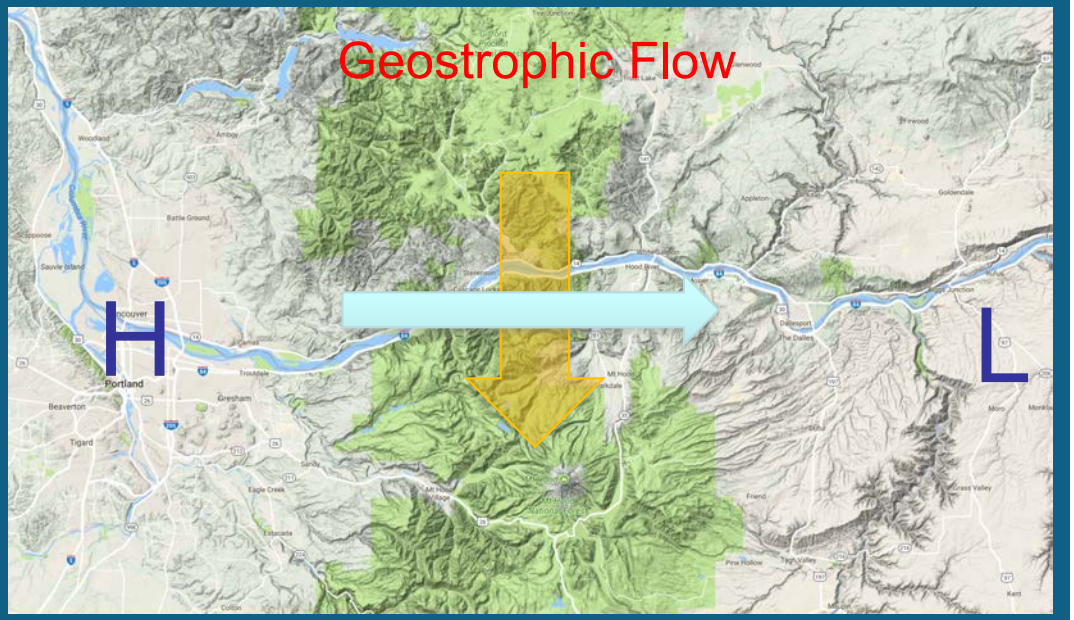
Local Wind Systems

- Coastal circulations are often controlled by local pressure gradient driven motions at a small-enough scale where the Coriolis force can be neglected
- Terrain and friction act to control flow



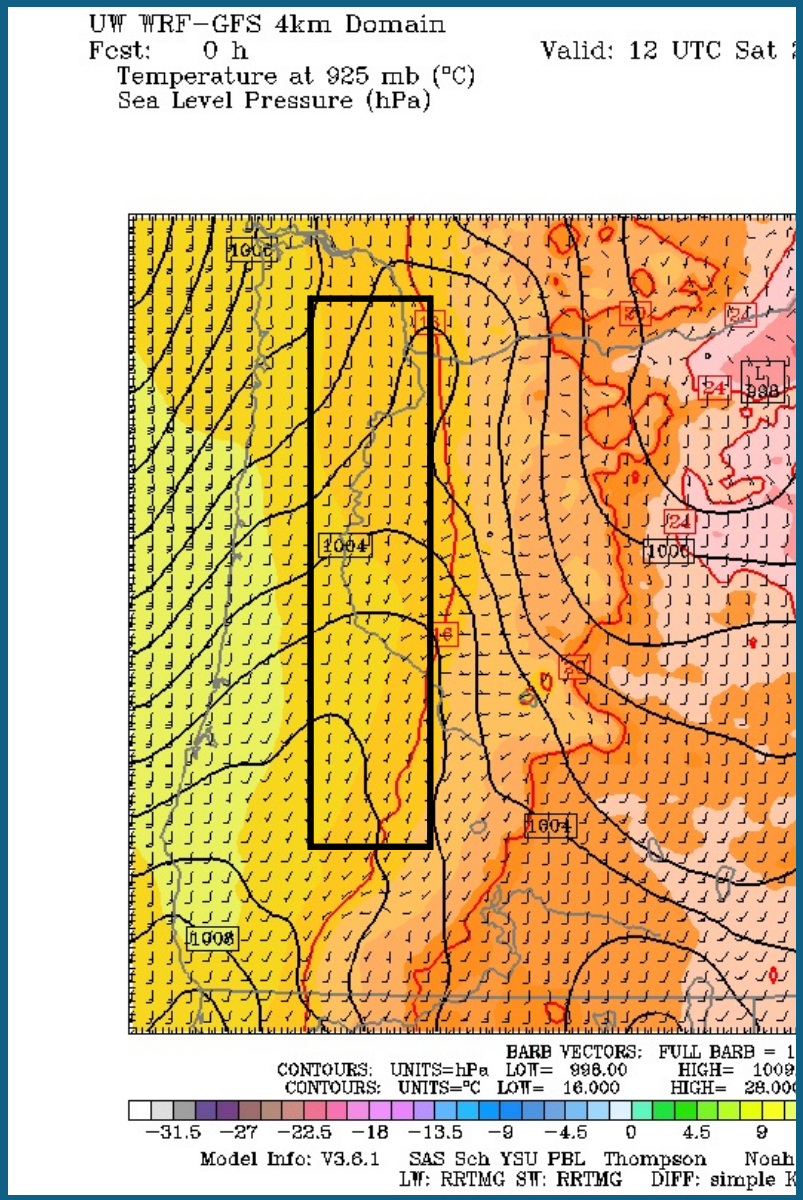
Only on ***Small Scales*** Does the Wind Blow in the Direction of Pressure Gradient Force

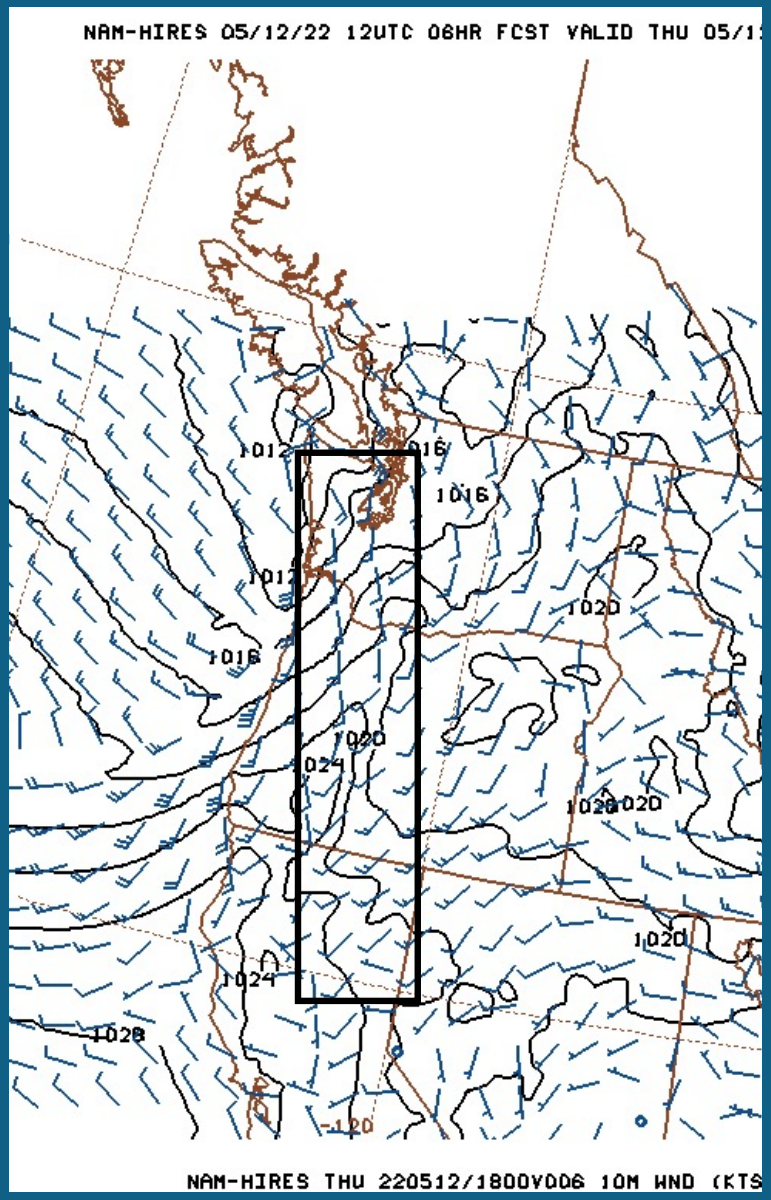
- The Columbia Gorge is one example where the pressure gradient force determines the wind direction (primarily east-west). The funneling effect of canyon walls helps to keep winds aligned east-west as well.
- Portland and The Dalles are about 90 miles apart.
- Another example is local circulations associated with sea breezes/land breezes, etc.



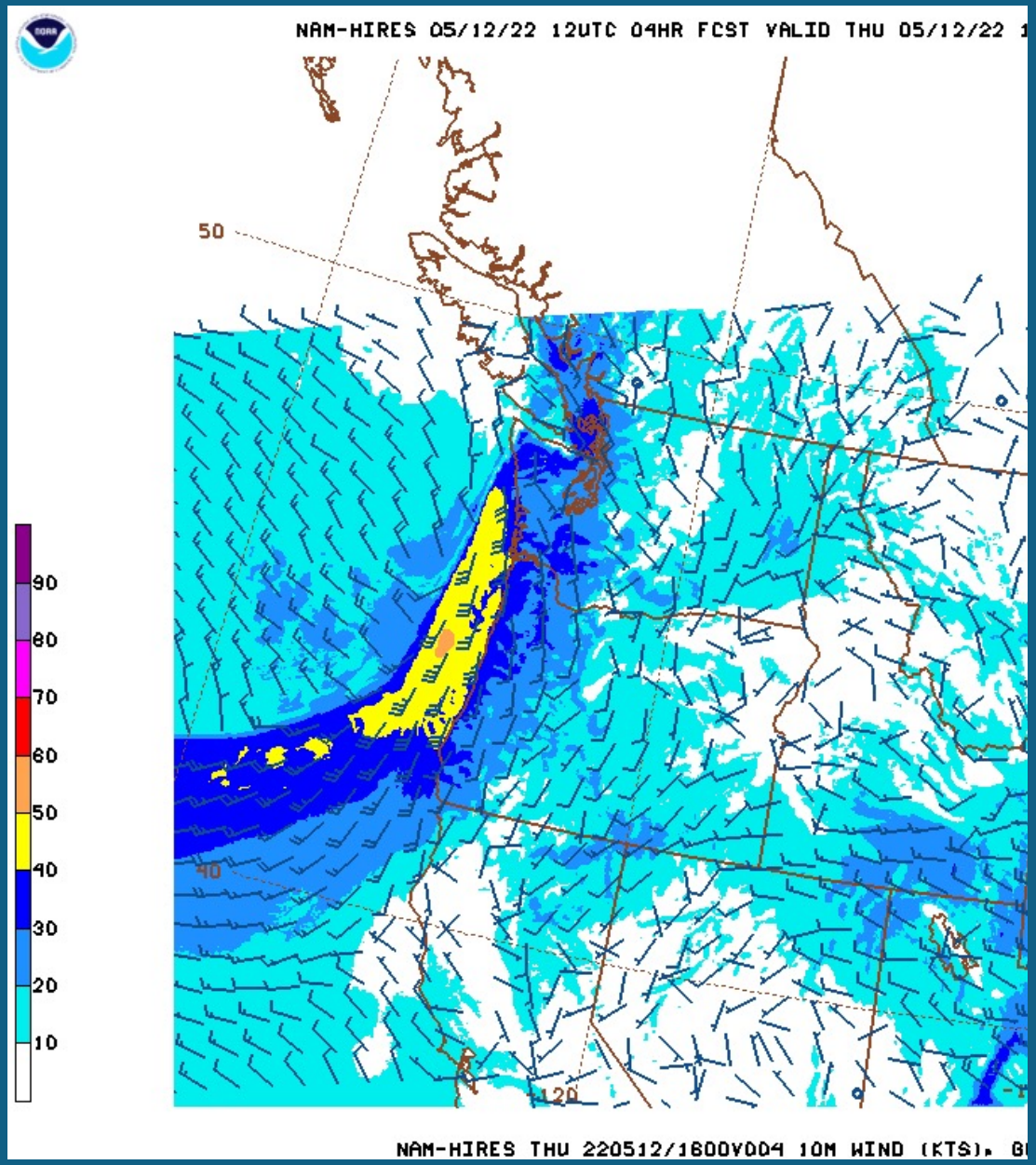
Willamette Valley

Surface winds, Pressure, and Temperature (shaded)





Coastal Jet



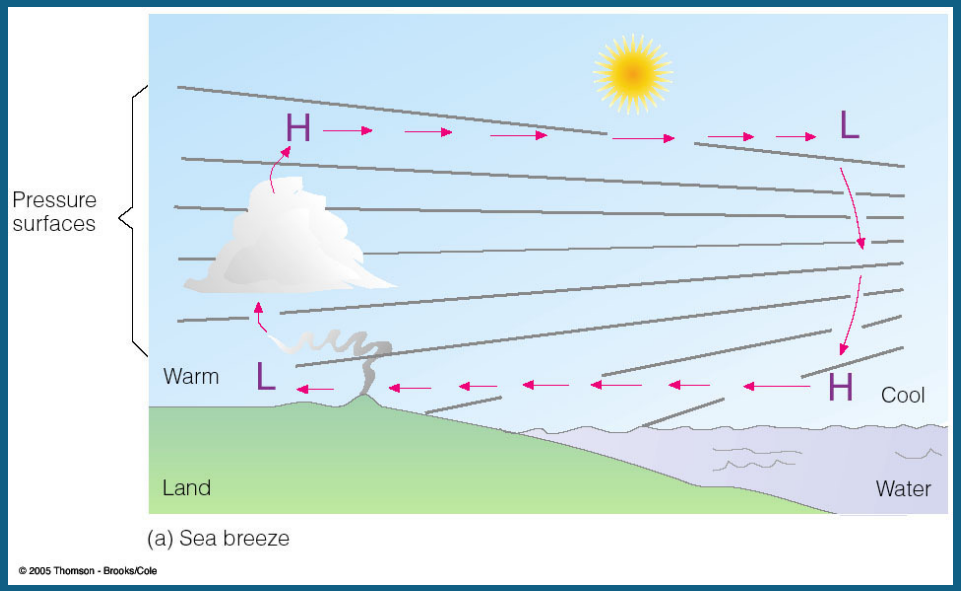
Winds are blocked by coastal terrain causing air to move cross isobars and accelerate.

West Coast Summer Weather

- Storm track is far north
- Weather dominated by Land – Sea temperature difference
- High pressure over cool water
- Low pressure over warm land

Sea Breeze

- Near the ocean, the land warms up relative to the ocean in the afternoon, creating a pressure gradient near the surface (particularly with clear weather). The ocean has a high heat capacity and is relatively resistant to temperature changes
- This pressure gradient drives an onshore flow in late afternoon
- Strong summer heating in the Willamette valley can cause a sea breeze to even influence far inland areas



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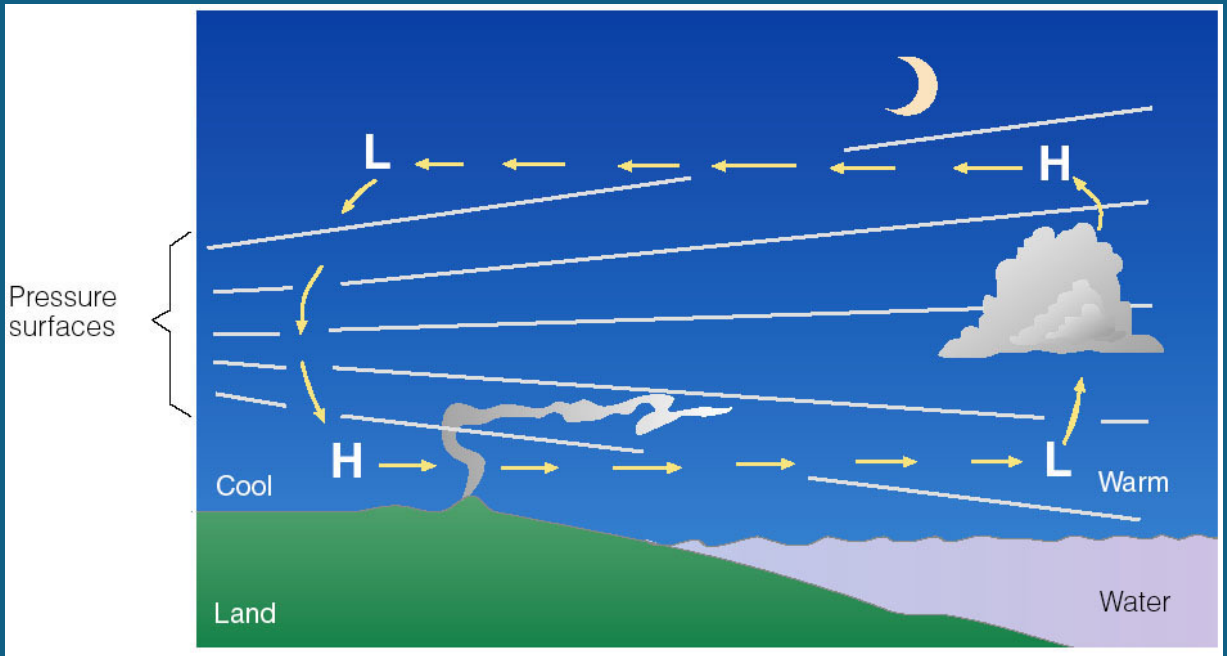
Land Breeze

- Near the ocean, the land cools relative to the ocean during the night, creating a pressure gradient near the surface (particularly under clear skies and strong radiative cooling).
- This pressure gradient drives an offshore flow during night



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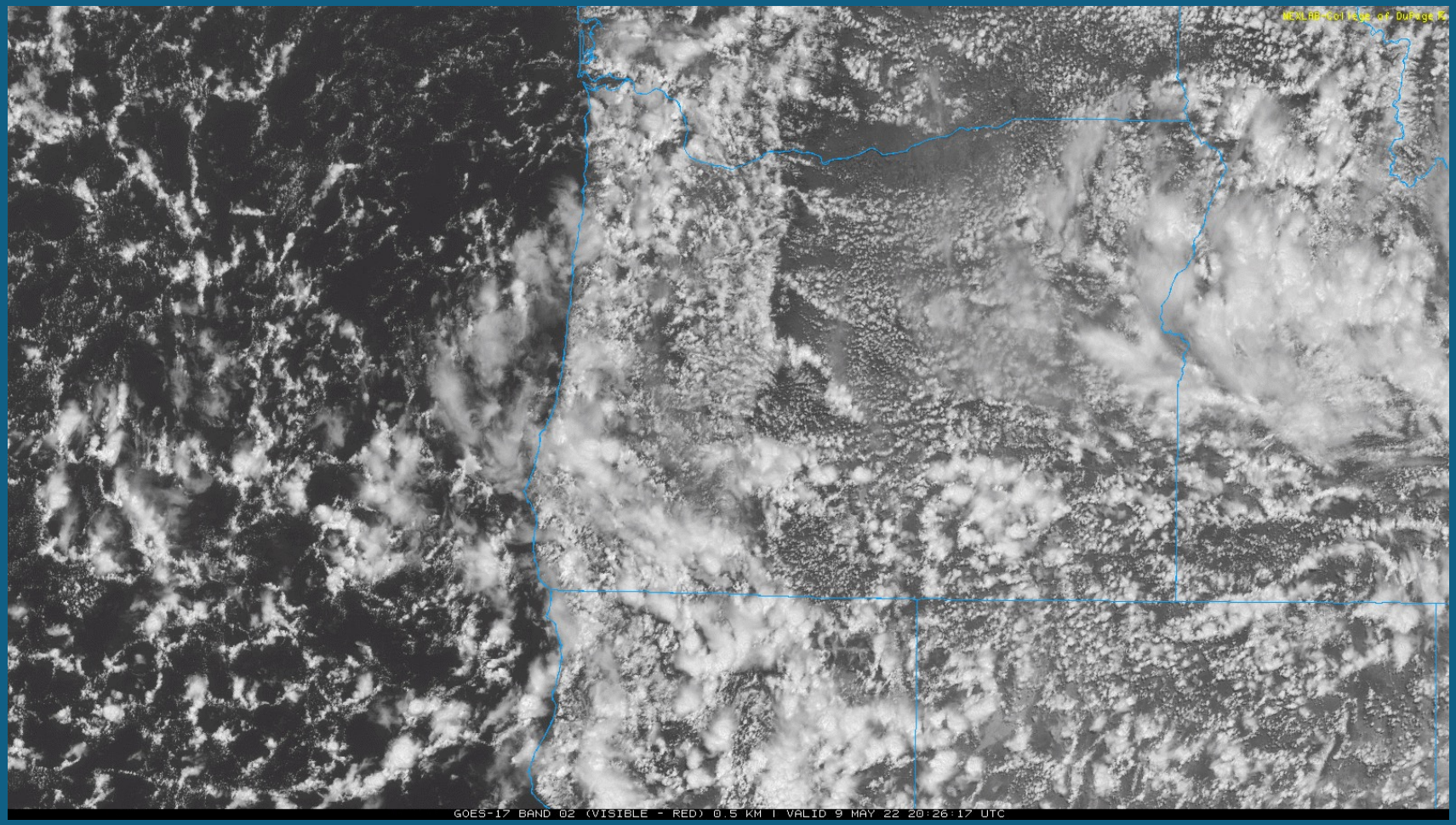
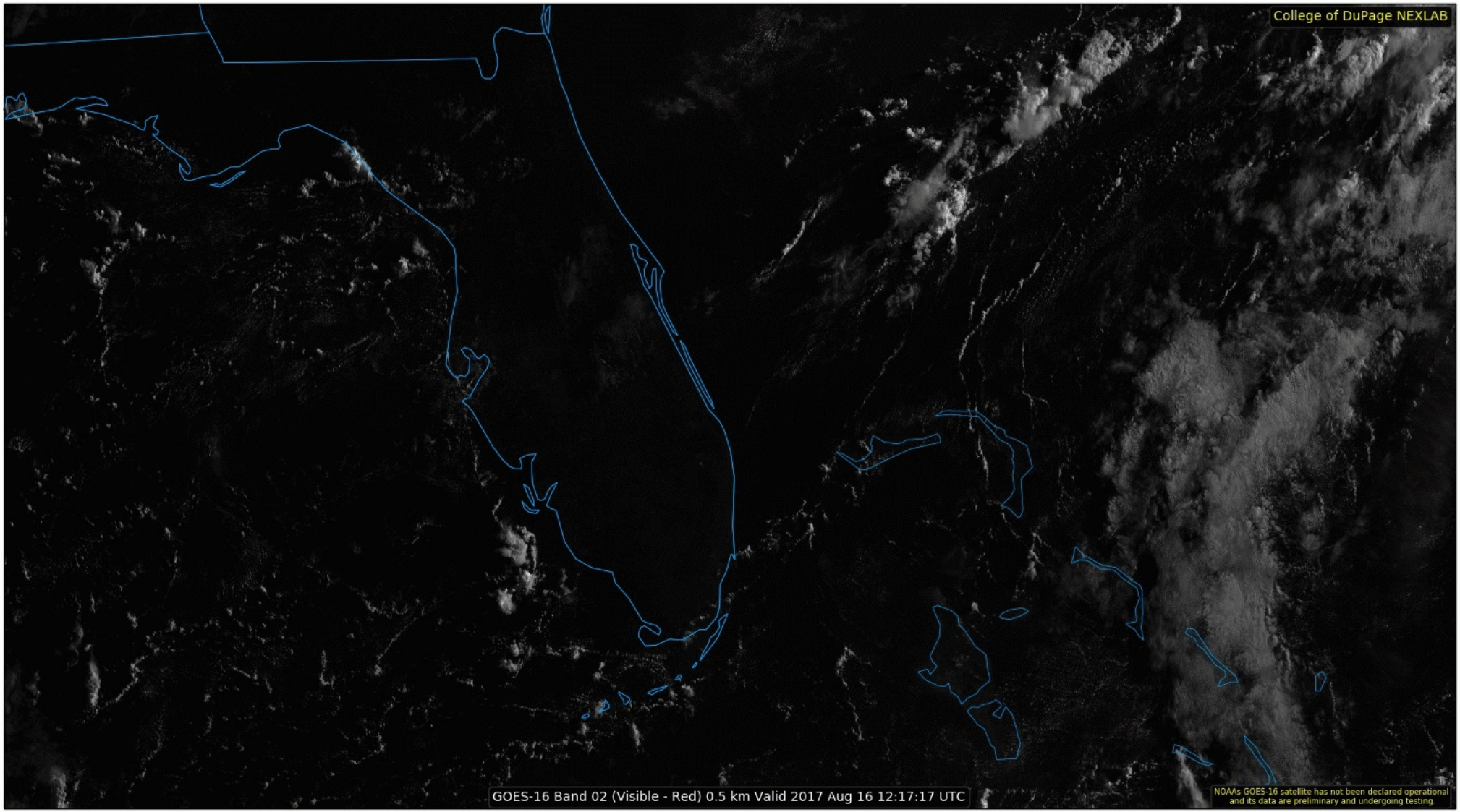
Land Sea Effects

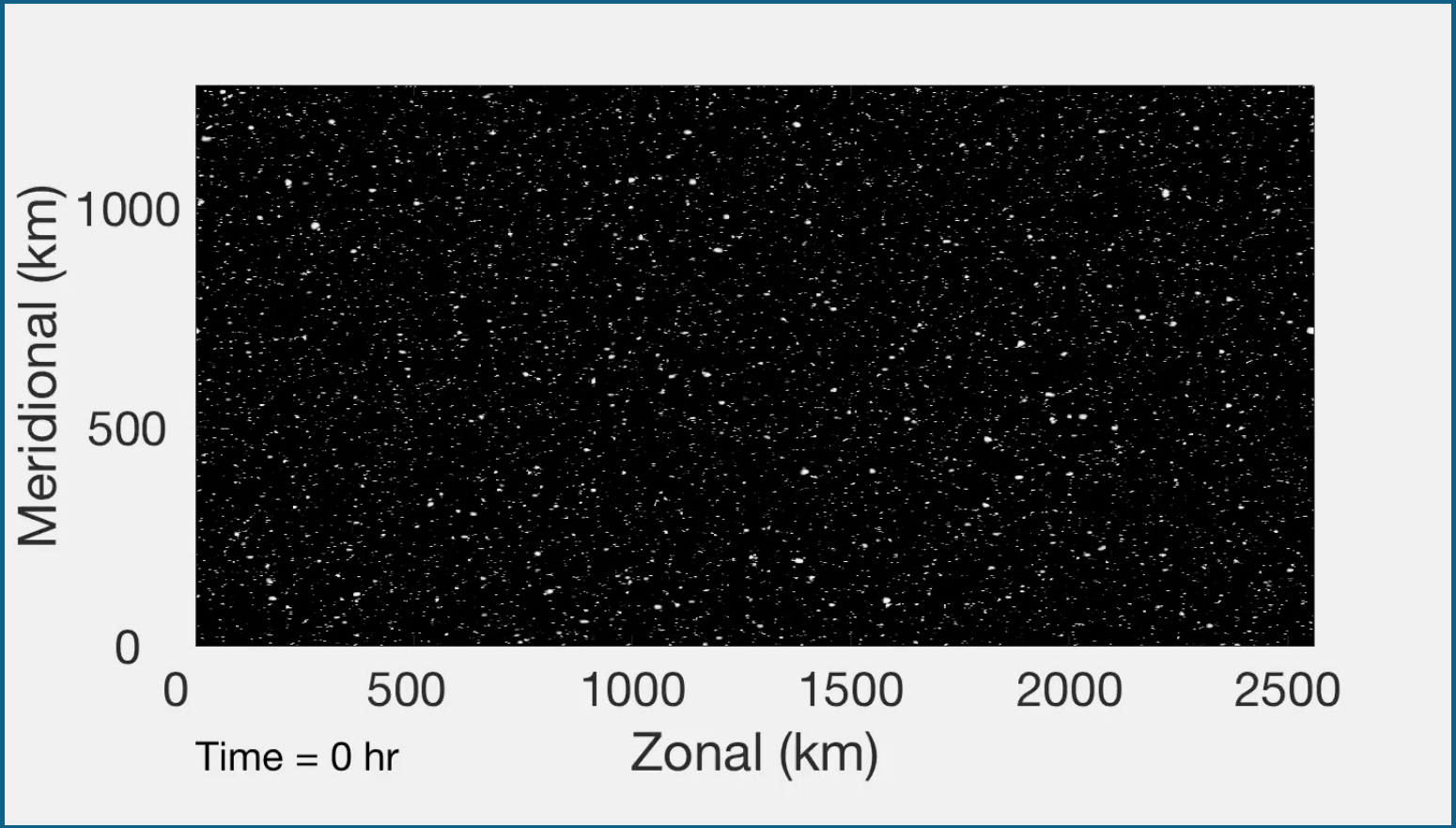


Warm land surface causes widespread convective clouds
Cellular convection over water

Florida Sea Breeze

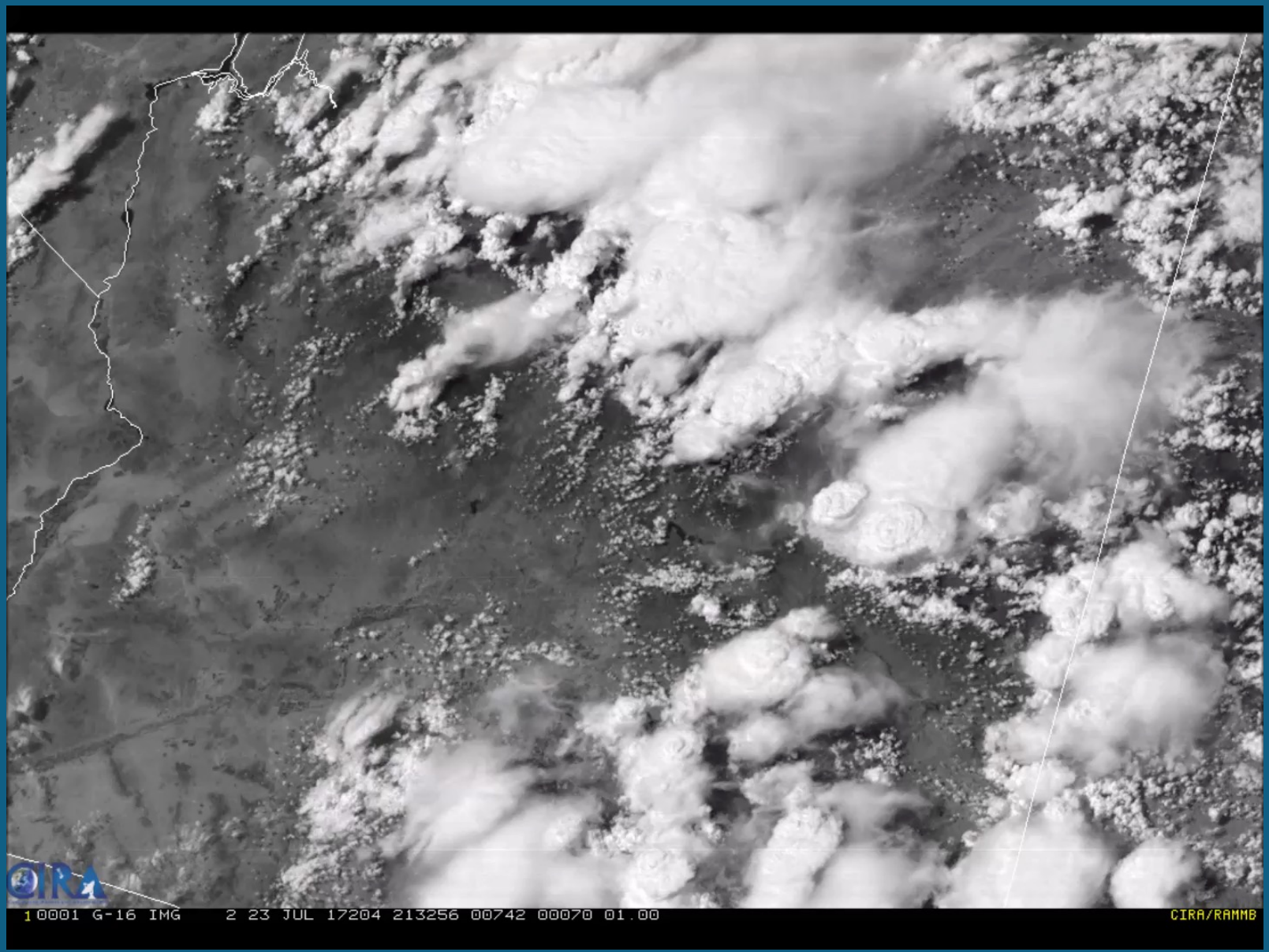


Convective Outflows

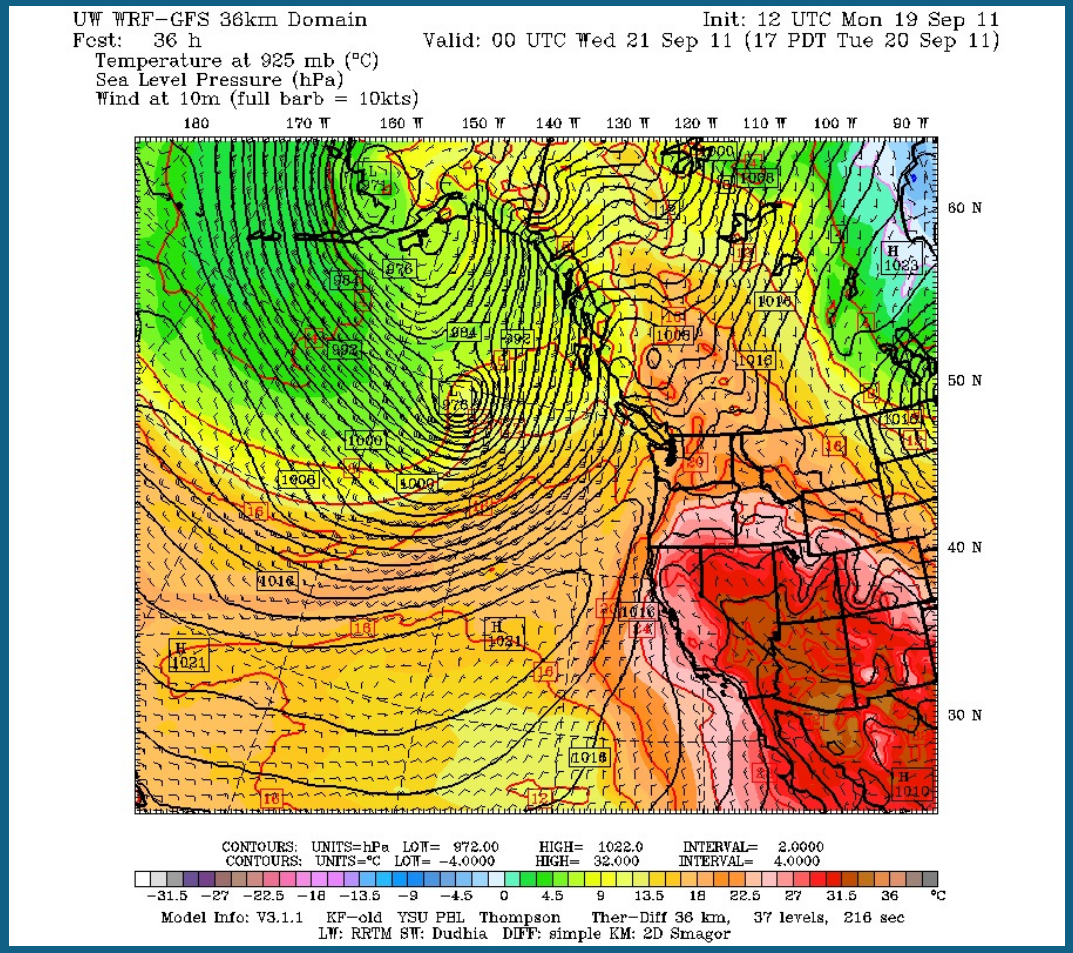


Rain cools air causing cold pools to form on surface under cells

Arizona Outflows



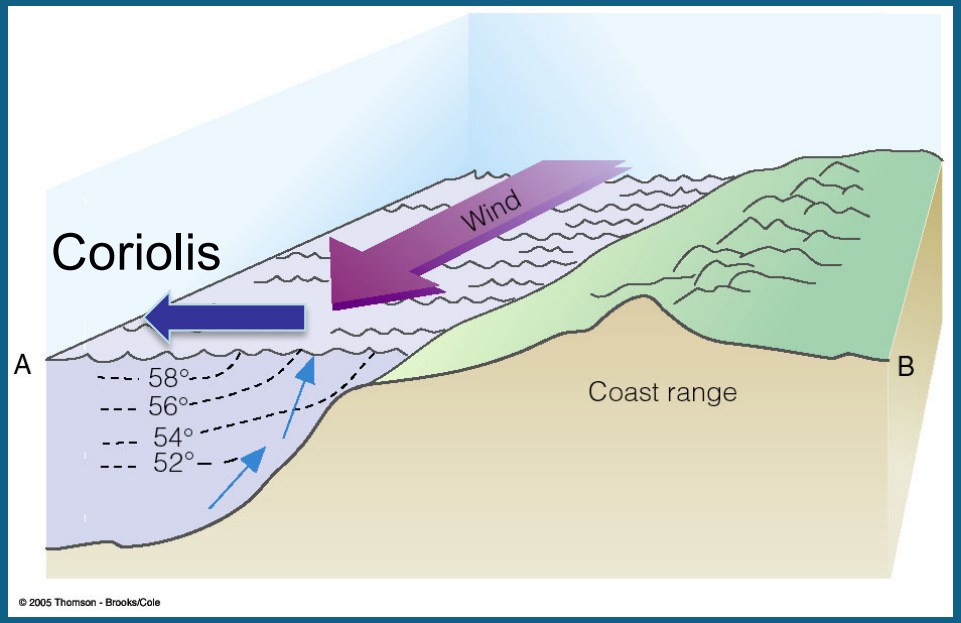
Thermal Trough – Coastal Upwelling



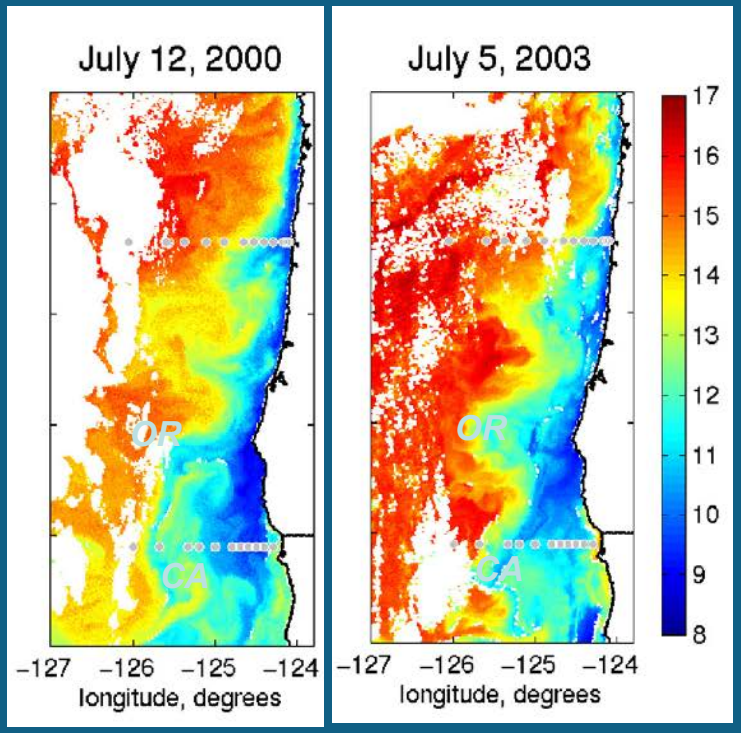
- Heating over interior generates strong gradient along southern coast
- Couples with the shallow marine boundary layer to force strong coastal winds
- Coriolis is affecting the flow at these scales

Coastal upwelling and satellite observations of the Northeastern Pacific

Classical 2-D upwelling picture



SST (°C), GLOBEC 1-km
(*Huyer et al., 2005*)

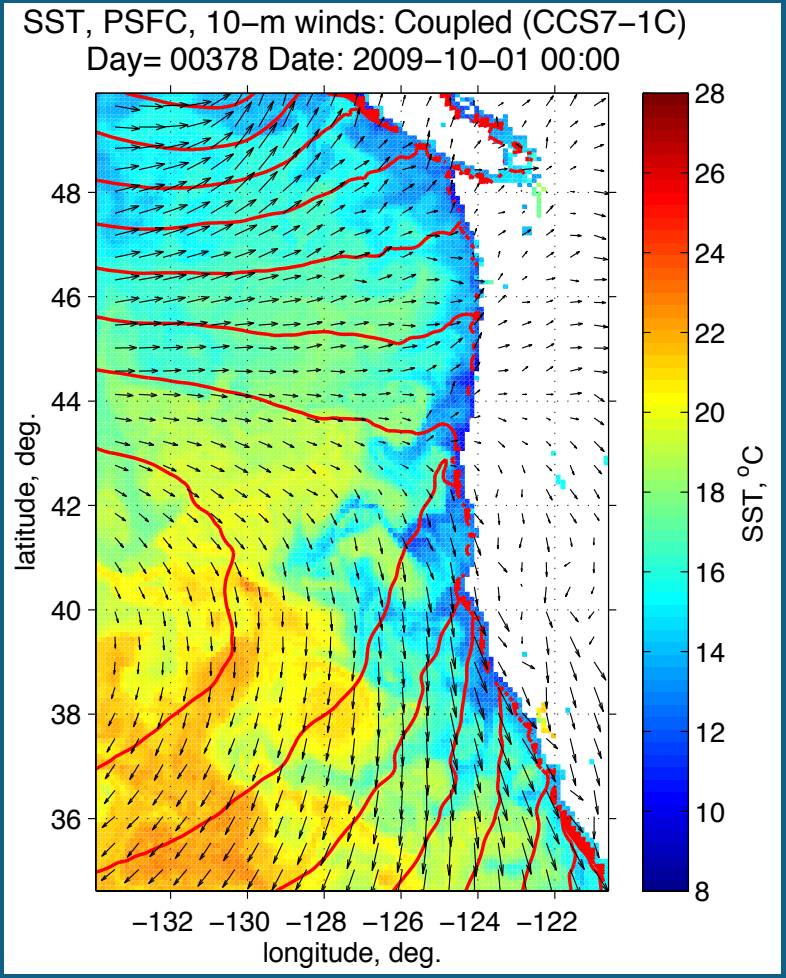


- Coastal upwelling occurs along the Pacific coast during persistent northerly winds, observed in summertime
- Coastal upwelling jet often separates off the capes and form seaward propagating mesoscale eddies

Coastal Upwelling

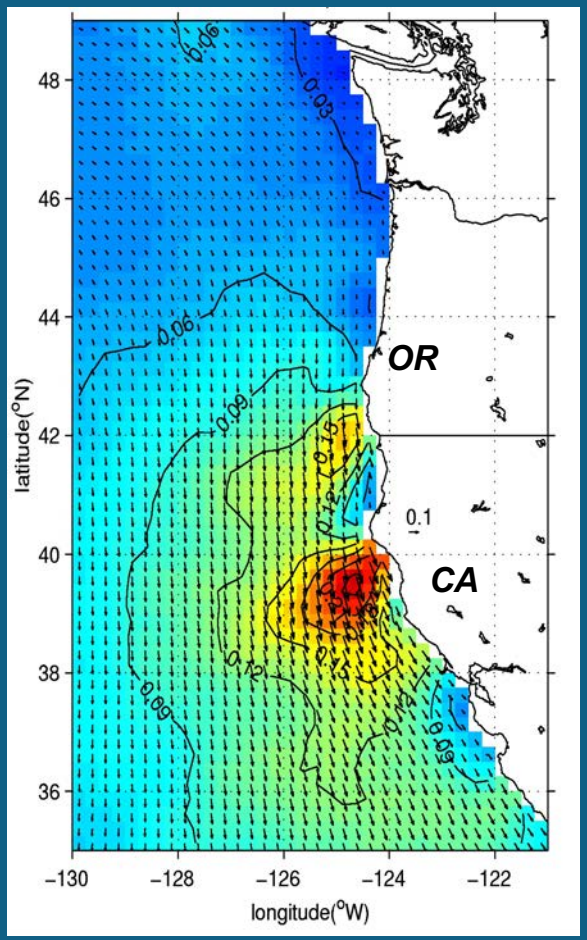
- The Coastal upwelling during summer is often associated with fog. Warmer air is advected over cold water.
- This upwelled water is rich in nutrients, and aids West Coast fisheries.

Snapshot of Summertime Ocean Temps



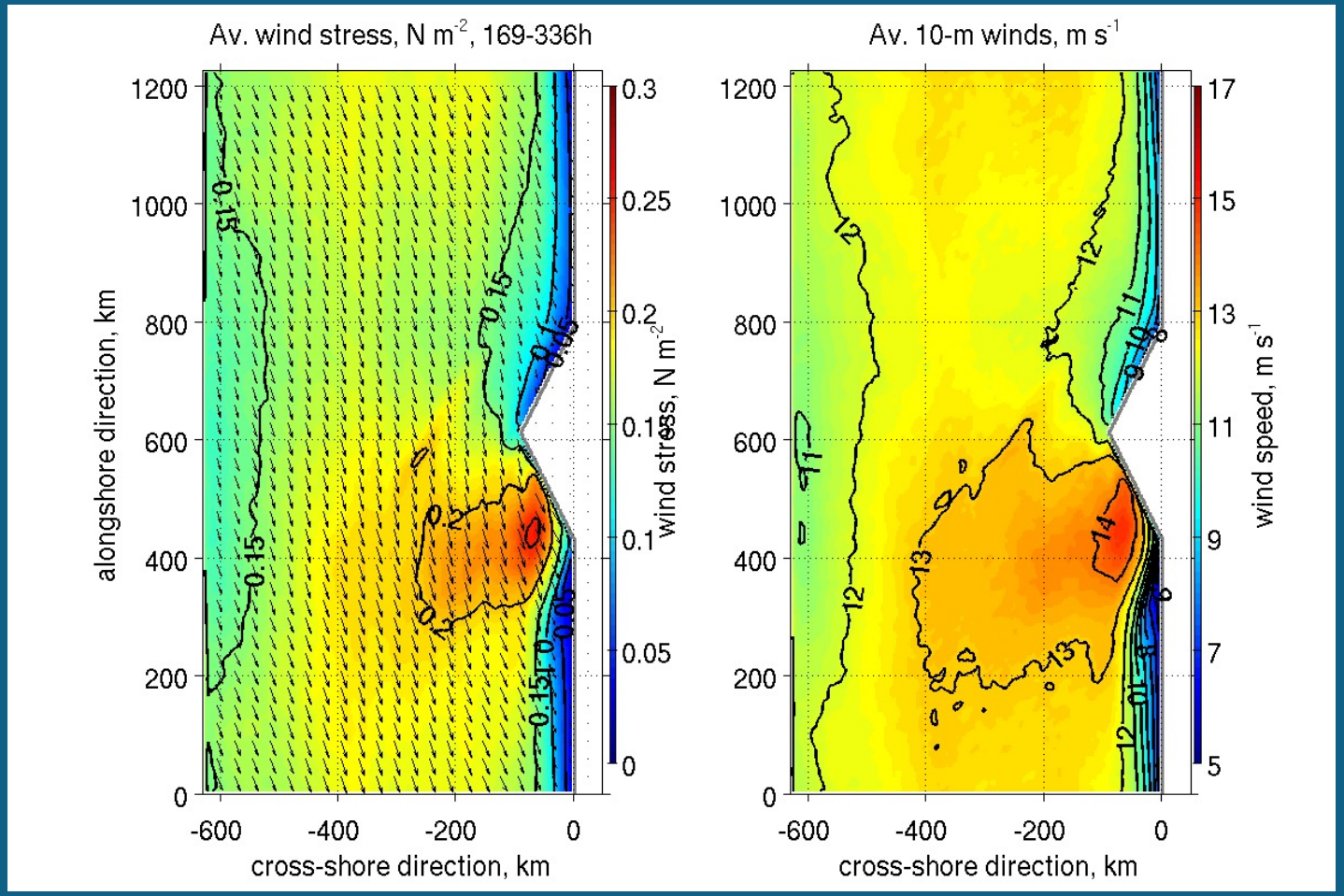
Satellite Wind Observations

QuikSCAT mean wind stress (N m^{-2})
for two summer periods, 2000, 2001
(*Perlin et al., 2004*)



- Orographic wind intensification occurs off major capes, modifies wind forcing of the coastal ocean
- Winds can vary dramatically over short distances
- Important hazard for commercial and recreational fishing

Average Wind Stress and 10-m Wind Speed

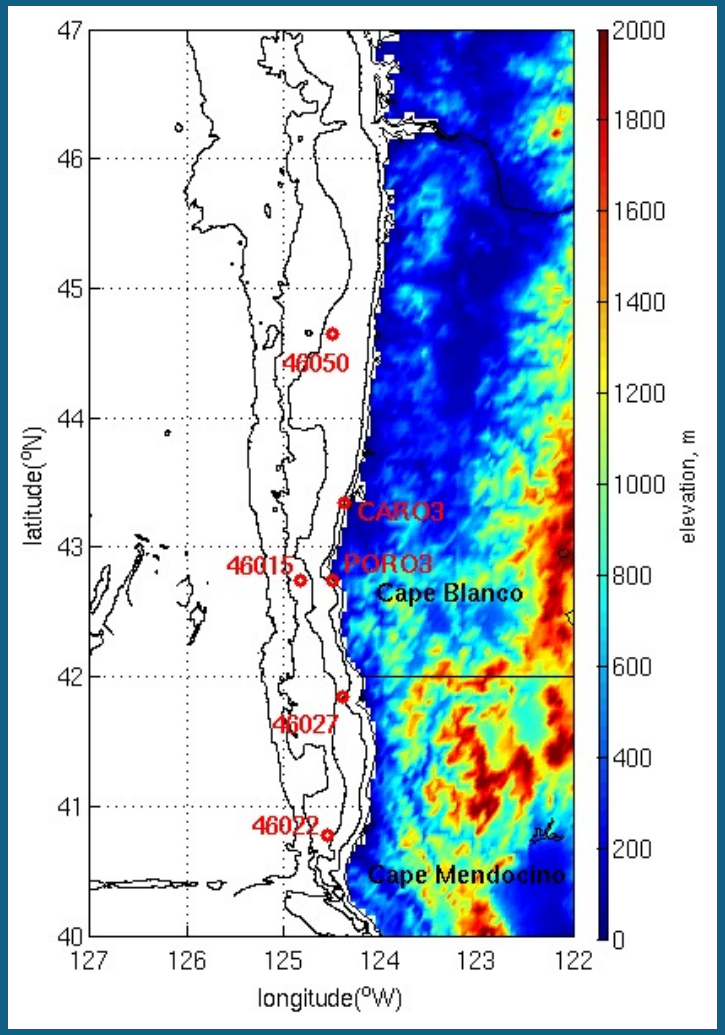


Weak winds over upwelling

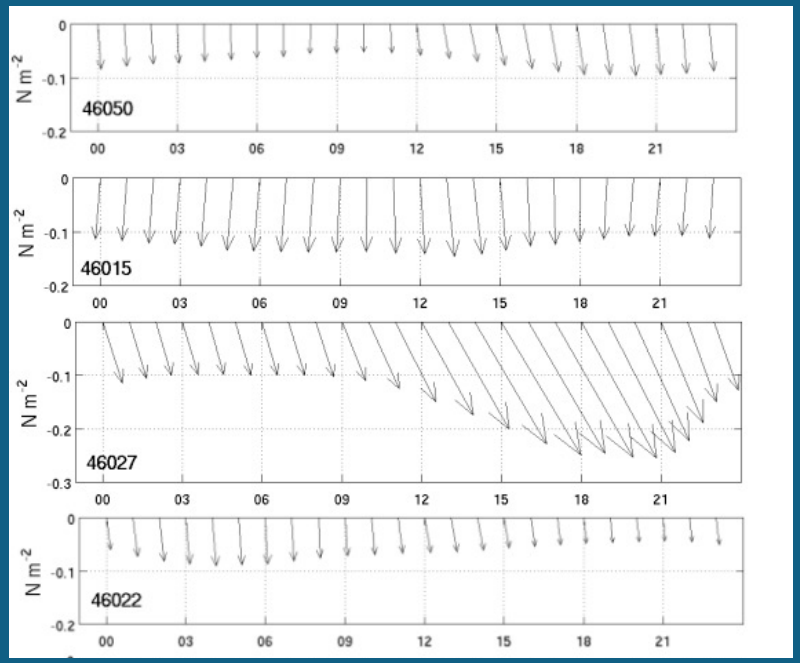
Strong winds downwind from cape

14 day simulation - average over last 7 days

Daily cycle from buoys and coastal stations



2001 (2002) – 2007, June-Sept.
full day records, southerly w.stress



20NM west of Newport

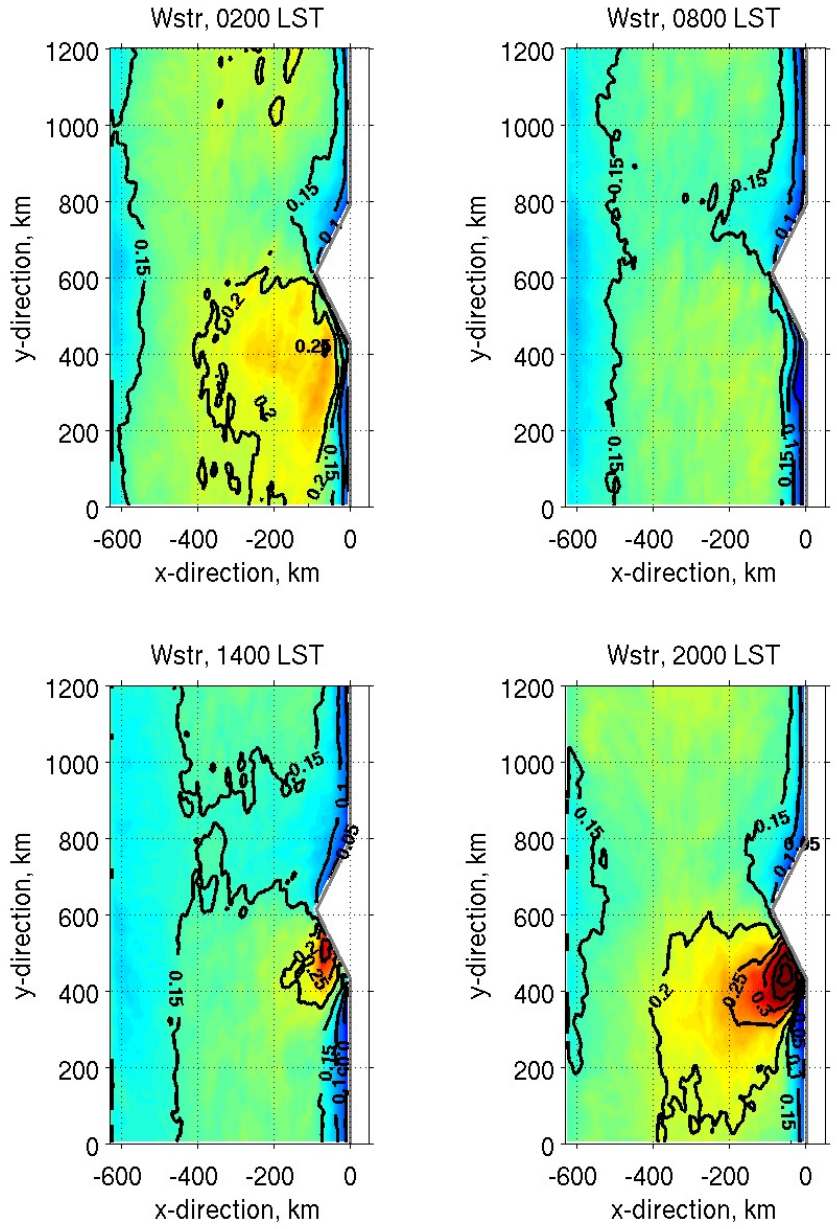
15NM west of Port Orford

8NM WNW of Crescent City

17NM WSW of Eureka, CA

This is caused by land heating up each afternoon and cooling at night –
Sea breeze – Land breeze

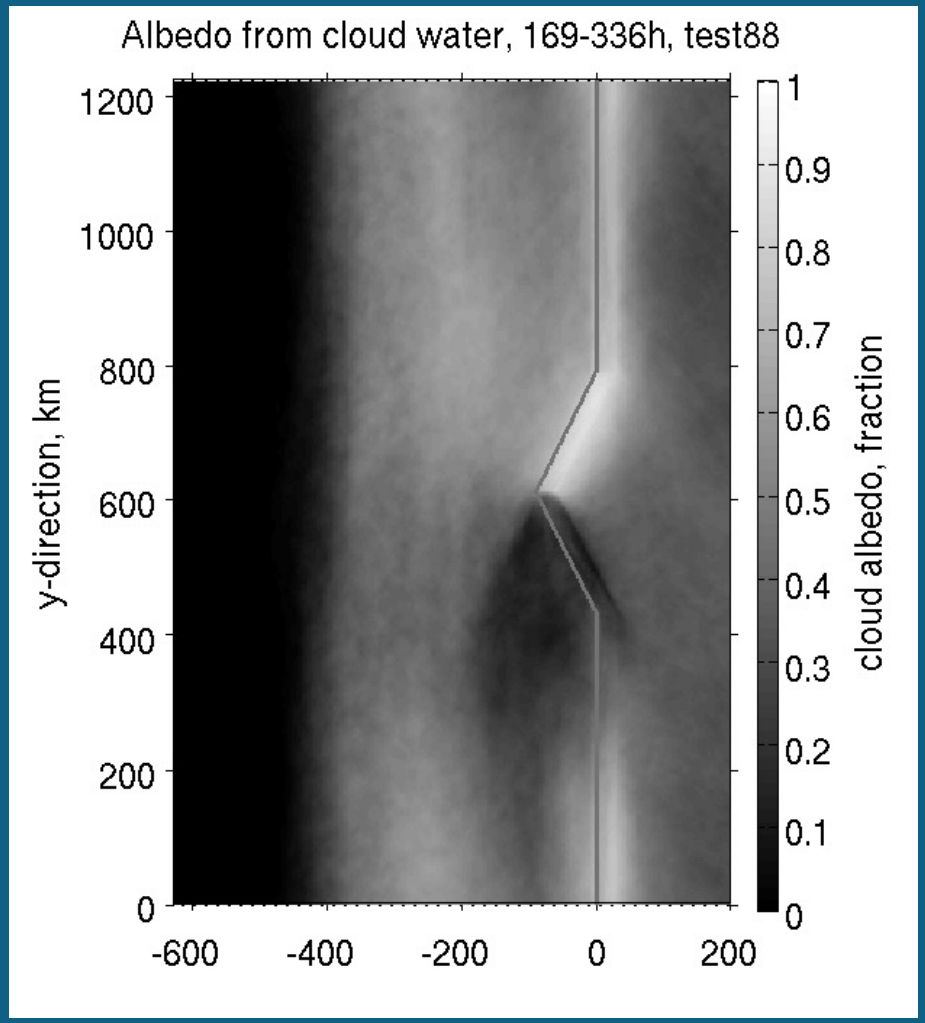
Modeled Daily Cycle



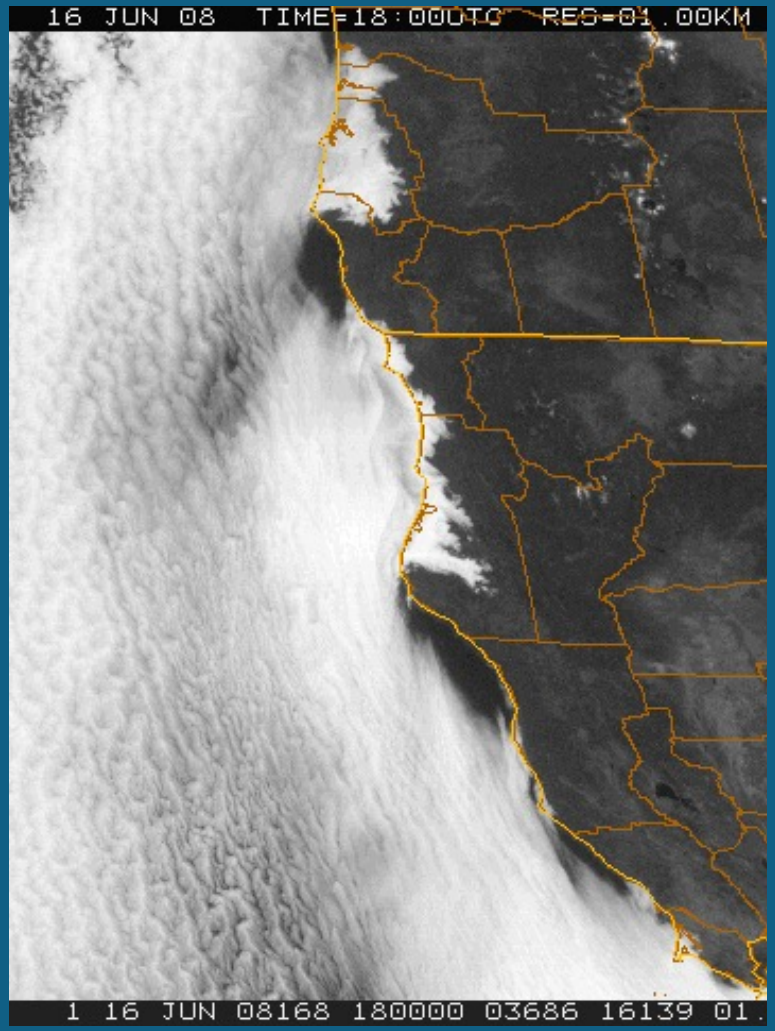
Maximum Wind Stress in Afternoon

Clouds and Fog

Average Simulated Cloud Albedo



Observed Cloud Brightness



Similar enhanced cloudiness upstream and clear slot downstream from points

Coastal Surge

Marine boundary layer is cool and dense

As thermal trough moves offshore, marine Layer sneaks northward

Abrupt wind shift and fog formation

Cape Lookout Stratus

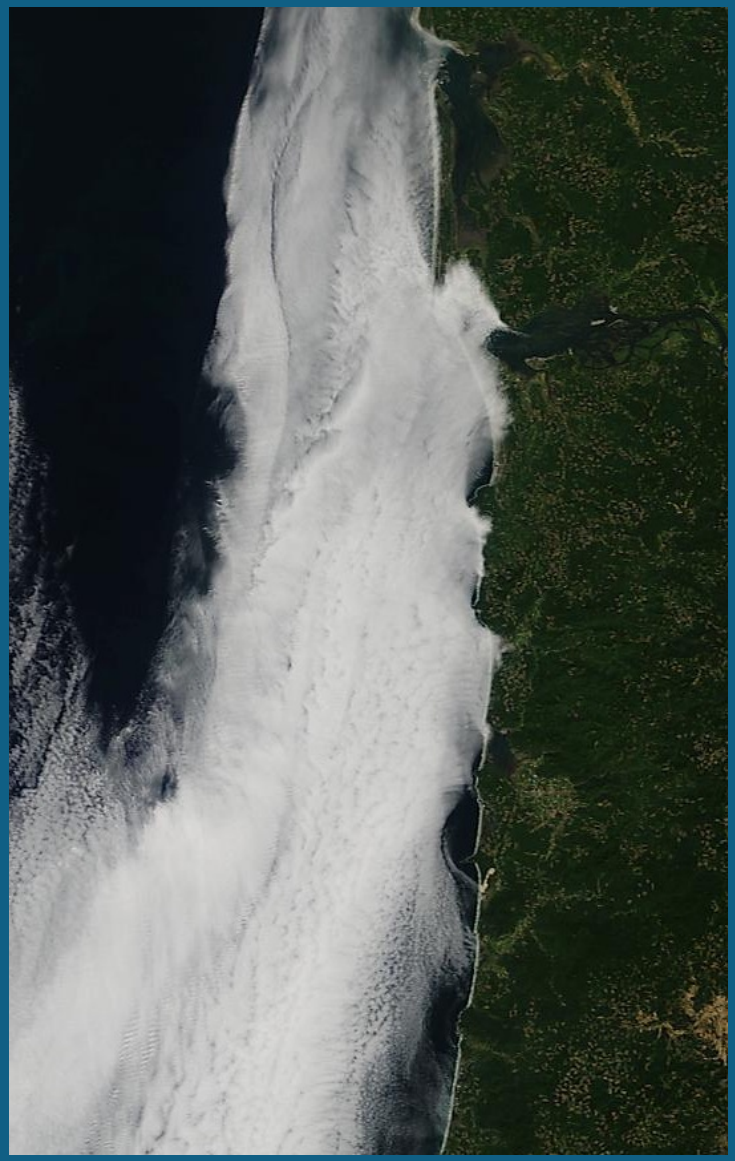
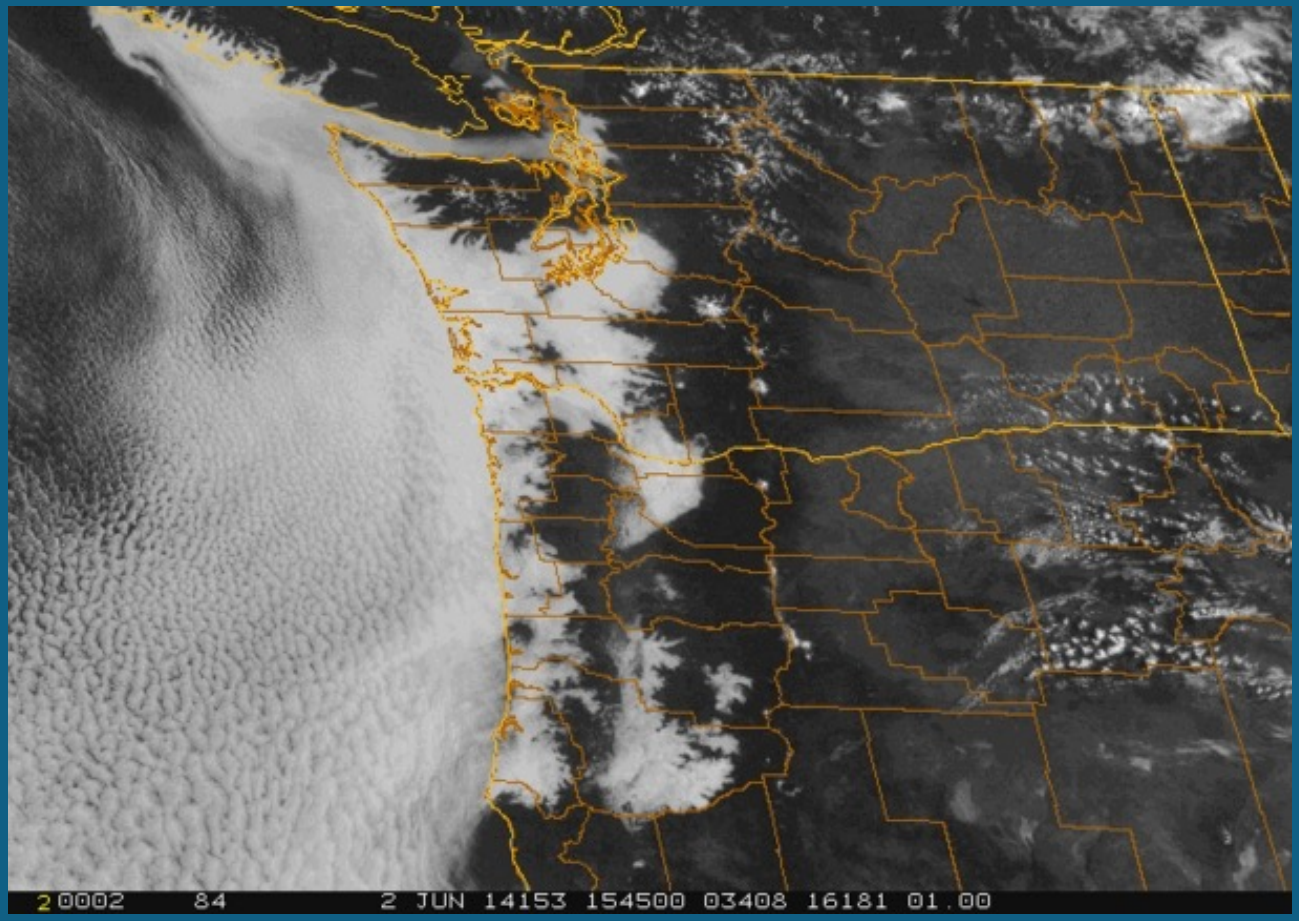


Photo from Roger Samelson on his way to Hawaii on August 20th 2016

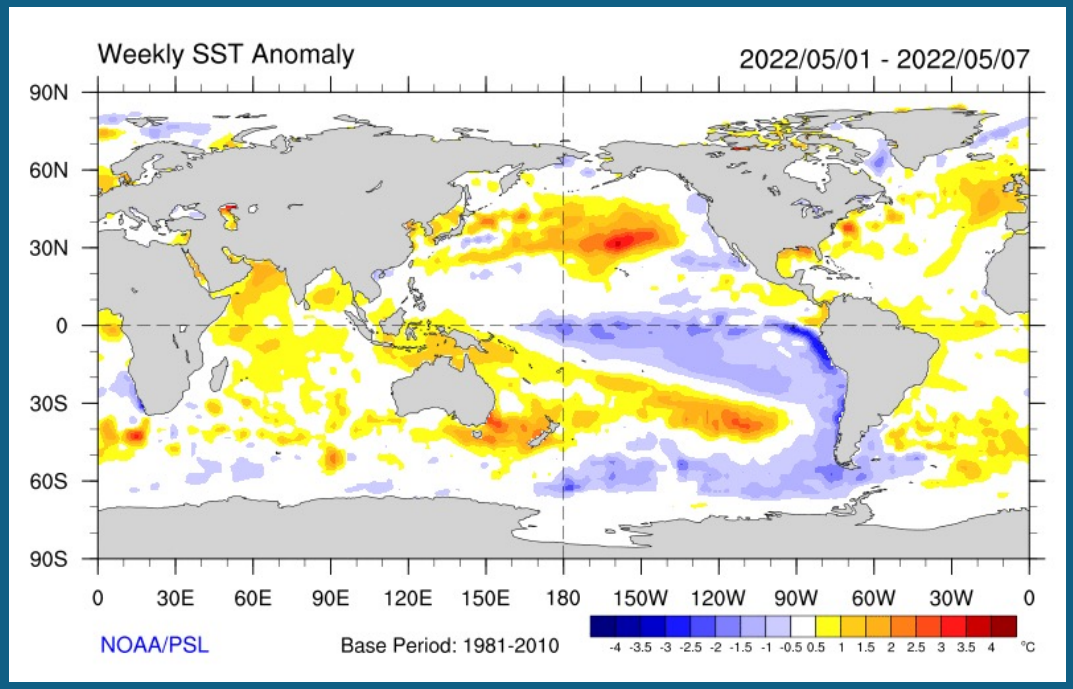
MODIS image on right a little later in the day

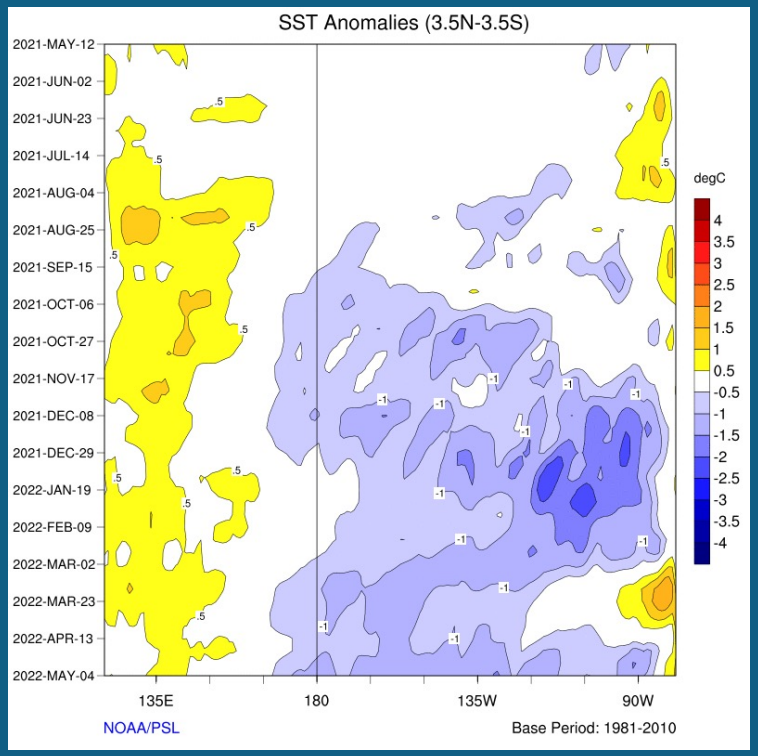
Marine Push



If the marine layer depth exceeds the coast range height, air will spill into the valley
Afternoon sea breeze is often the trigger

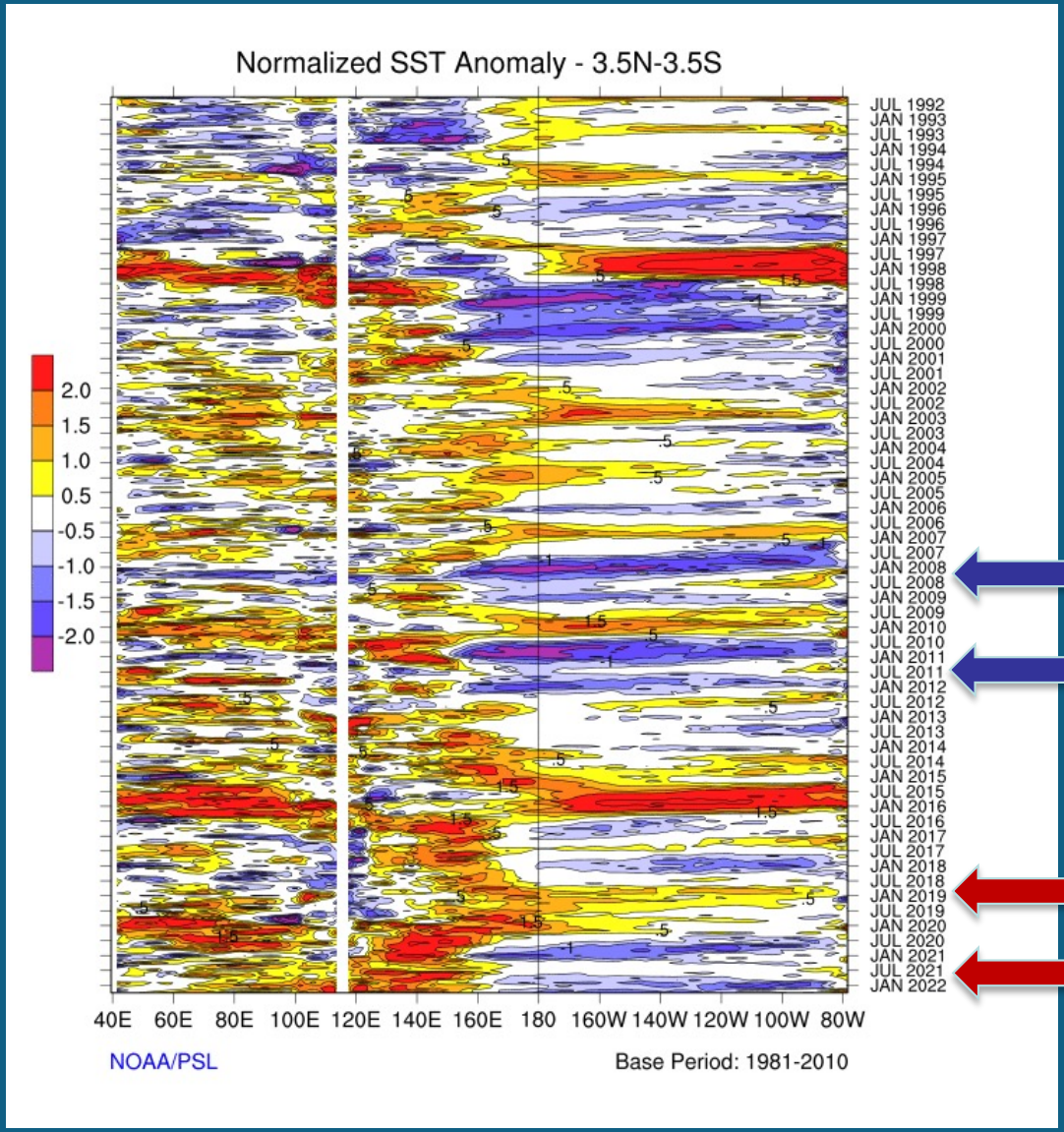
Large Scale Effects
El Nino – La Nina





Strong La Nina for this time of year

Past Events

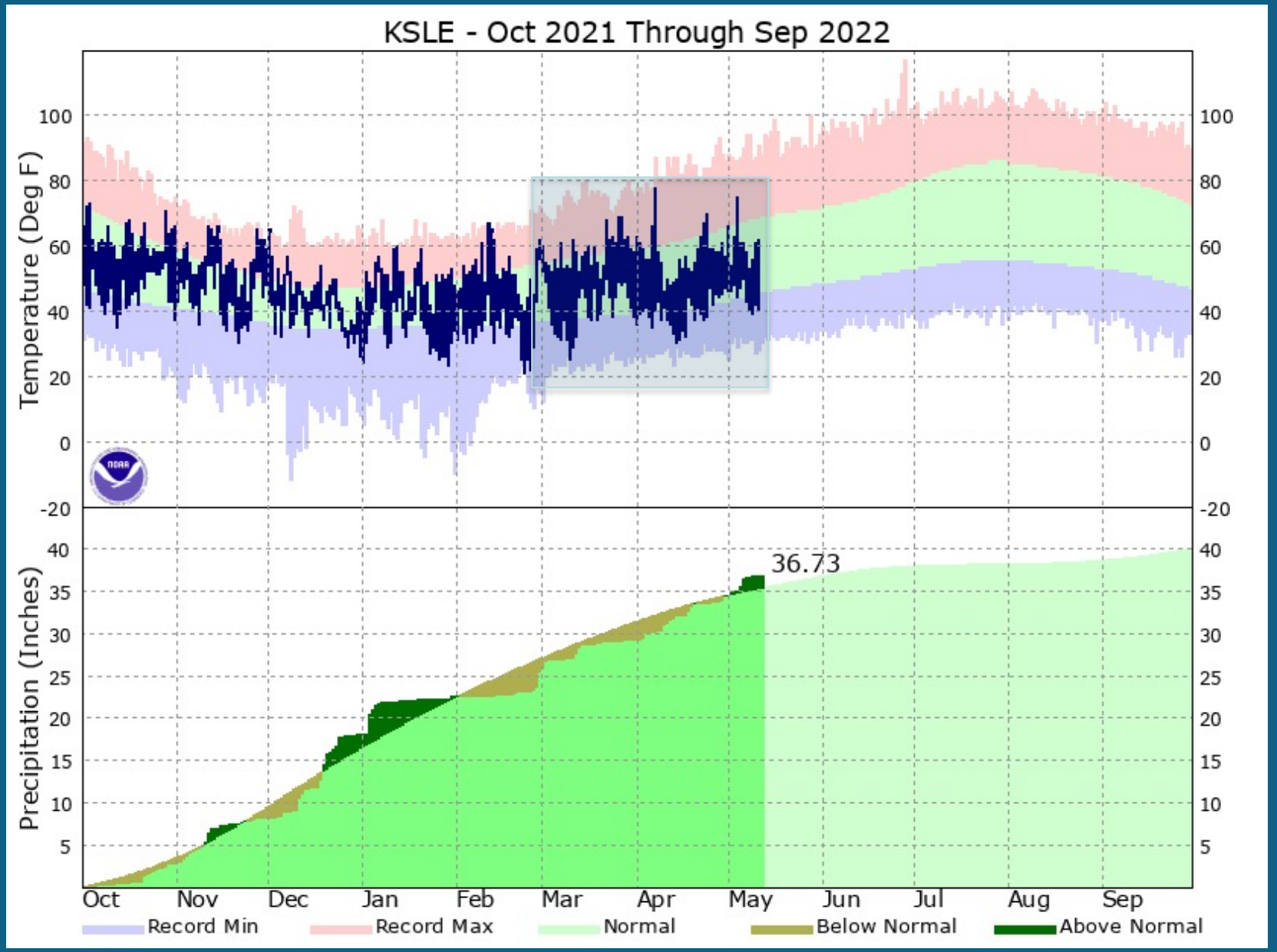


La Nina Springs

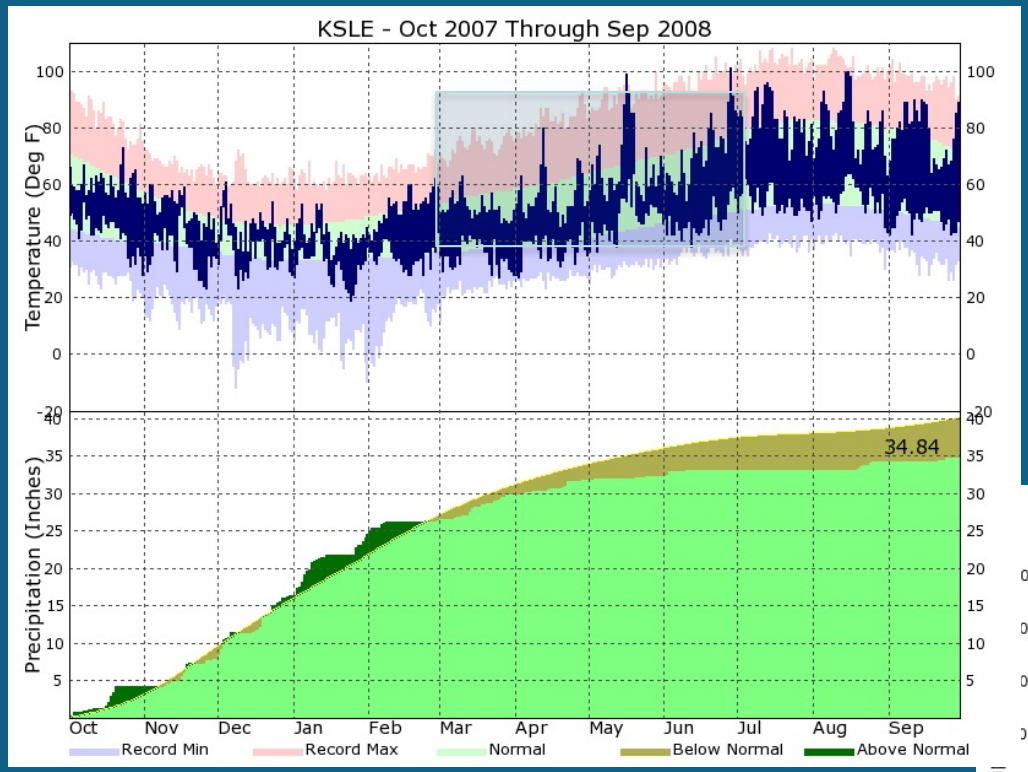
La Nada Springs

From NOAA CDC Map Room

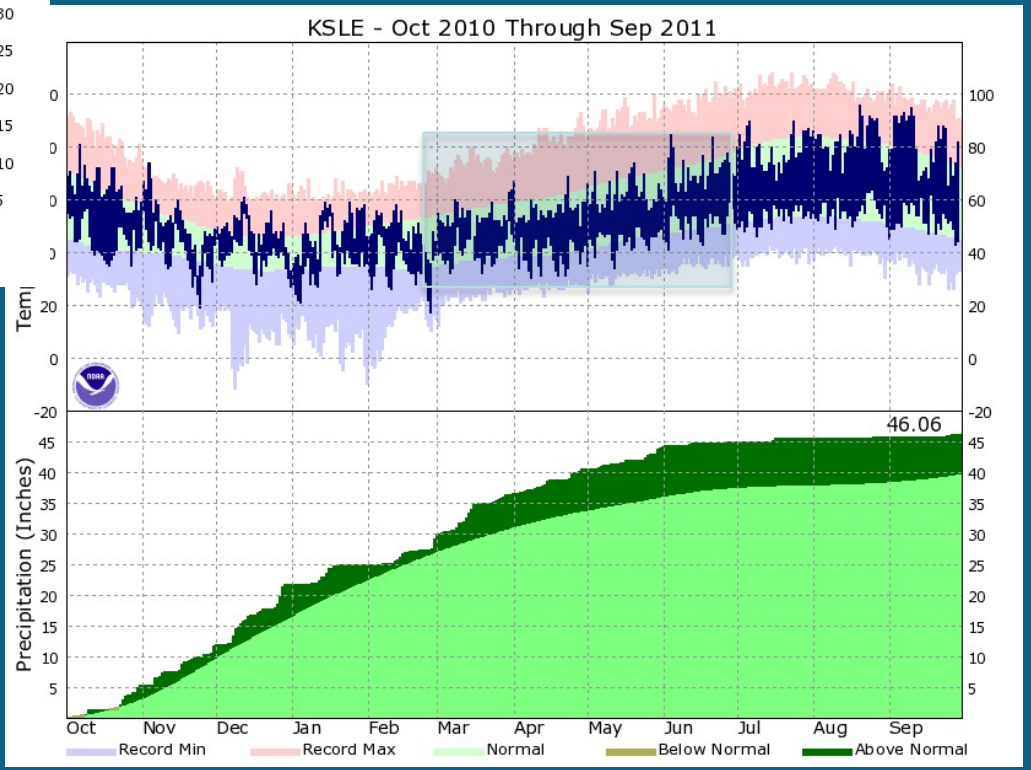
Salem 2022 Temperature Precipitation



Salem 2008 and 2011

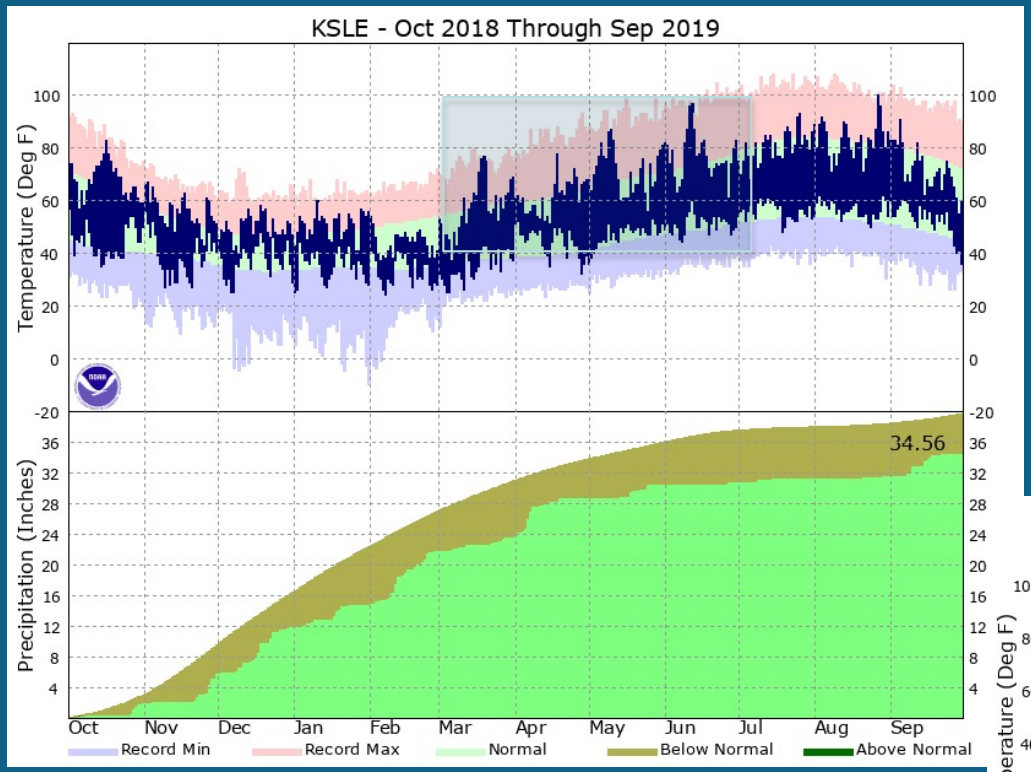


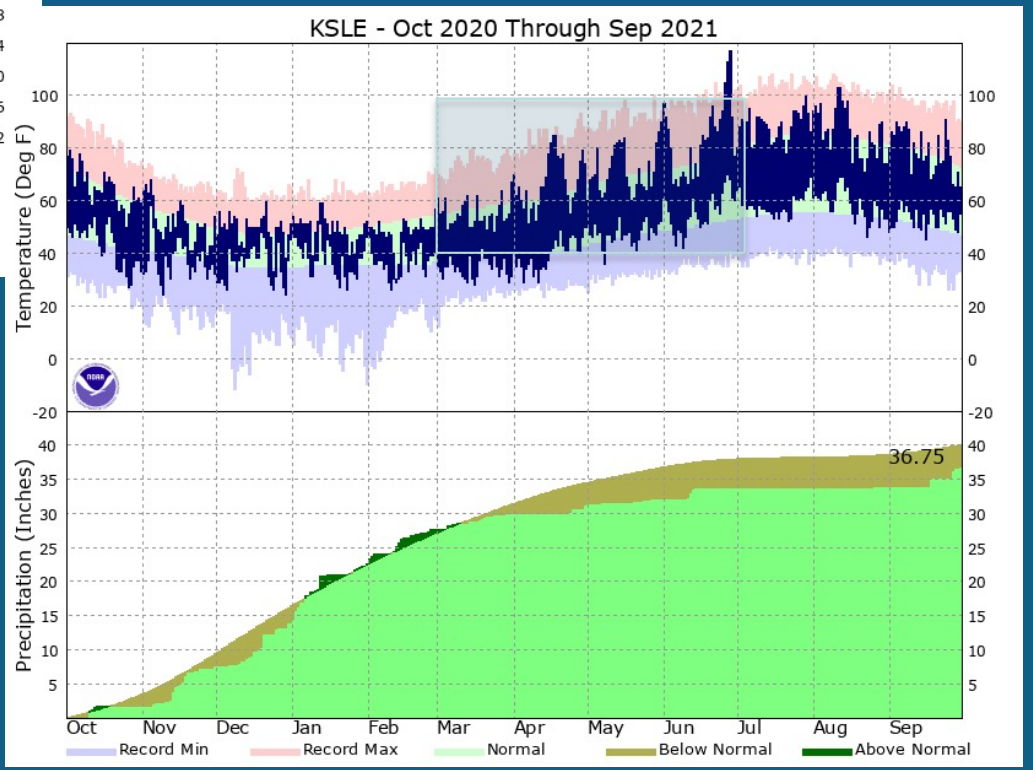
Need to be careful:
Sample size is really small!



La Nina Spring

Salem 2018 and 2020





La Nada Springs

Questions?

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