MET 200 Lecture 11 Local Winds

- Scales of Motion
- Eddies
- Sea Breeze
- Mountain-Valley Circulations
- Chinook - Snow Eater
- Drainage Wind - Katabatic Wind

Last Lecture: Forces

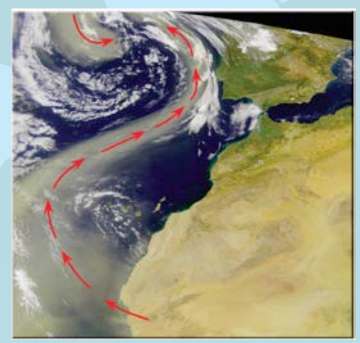
Review of Forces

1. Pressure Gradient Force* – changes in pressure over a distance causes air to move.
2. Gravity* – only acts in the vertical direction
3. Coriolis Force – due to Earth's rotation underneath the moving air.
4. Centrifugal Force – whenever there is curved flow (curved isobars)
5. Friction – only important near the Earth's surface

* Only the pressure gradient force and gravity can cause winds in air that is initially at rest.

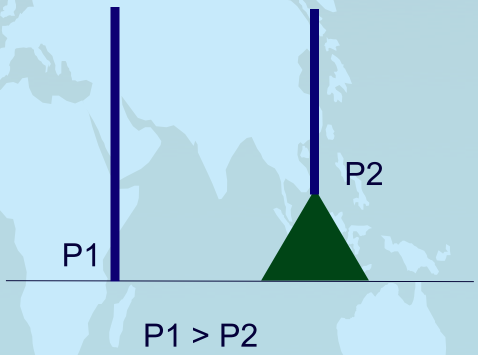
Balance of Forces

- Cyclostrophic Balance – Pressure Gradient Force = Centrifugal Force
- Geostrophic Balance – Pressure Gradient Force = Coriolis Force
- Gradient Wind Balance – Pressure Gradient Force = Centrifugal + Coriolis Forces
- Hydrostatic Balance – Pressure Gradient Force = Gravity



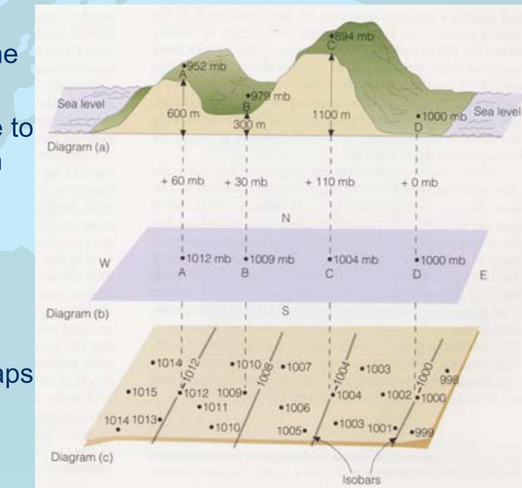
Surface Pressure vs Sea Level Pressure

- A change in pressure over some distance (pressure gradient) causes air to move.
- Elevation changes cause pressure differences, but not necessarily motion. Why?

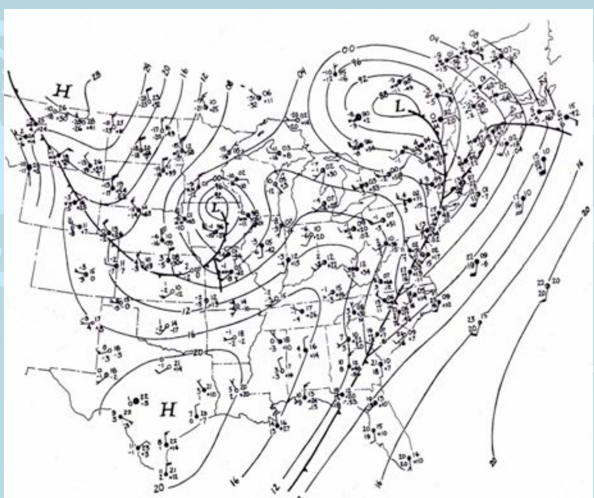


Surface Pressure vs Sea Level Pressure

- Pressure is force per unit area.
- Air pressure is determined by the weight of air above.
- So pressure drops as you move to higher elevation. That is how an altimeter works on an airplane.
- Stations in mountains will show large pressure gradients as a result of elevation changes.
- Therefore, pressures must be altitude adjusted on weather maps to convey forces and winds correctly.

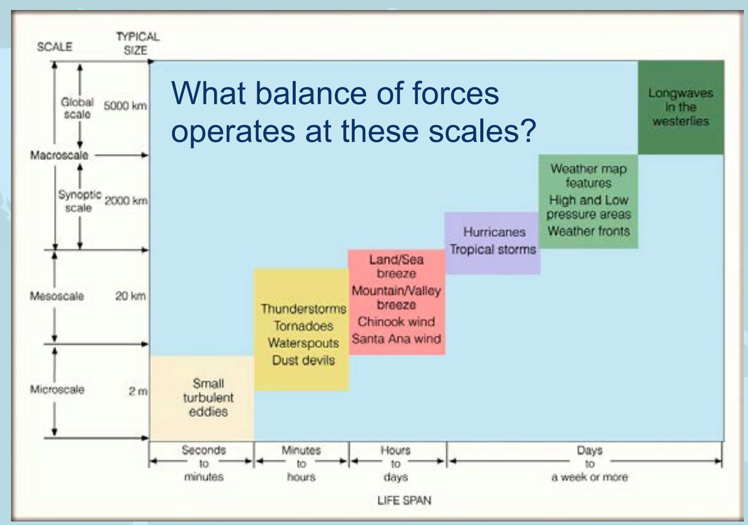


Surface Pressure Maps



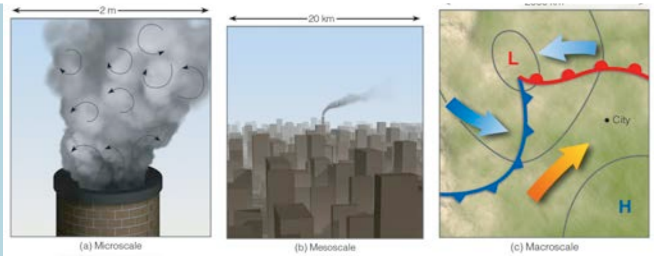
Altitude-adjusted surface station pressures are used to construct "sea-level" pressure contours that convey forces correctly.

Scales of Motion



Phenomena with large length scales occur over long time scales and vice versa.

Scales of Motion

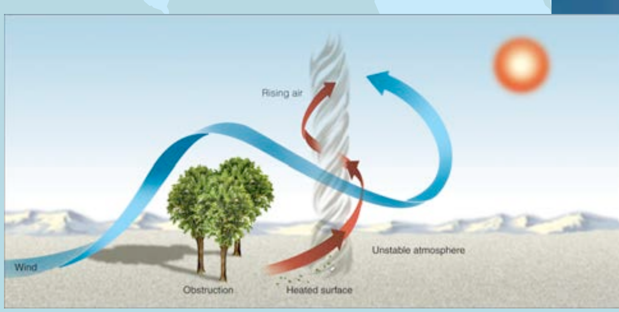


- Microscale: meters
  - Turbulent eddies
    - Formed by friction near the surface or by wind shear near jetstreams or convection
    - Lifetimes of minutes
- Mesoscale: km’s to 100’s of km’s
  - Local winds and circulations
    - Land/sea breezes, mountain/valley winds, thunderstorms, tornadoes
    - Lifetimes of minutes to hours
- Synoptic scale: 100’s to 1000’s of km’s
  - Circulations around high and low pressure systems
    - Lifetimes of days to weeks
- Global scale: systems ranging over entire globe
  - Hadley circulation, waves in the jetstream, ENSO
    - Lifetimes of months to seasons and longer

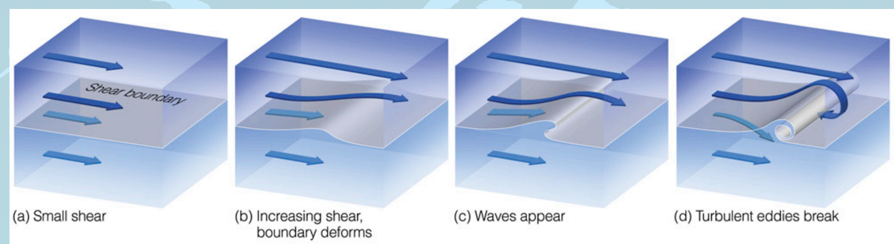
Microscale: Eddies

Dust Devils

- Surface heating produces convection
- Wind blowing past object twists rising air
- Air rushes into rising column lifting dirt and debris

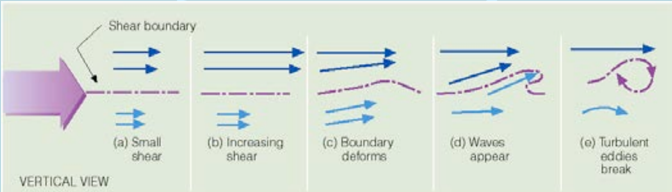


Wind Shear-Induced Eddies



Large gradients in wind speed over short distances cause strong wind shear
- Clear air turbulence can result, producing dangerous conditions for aircraft

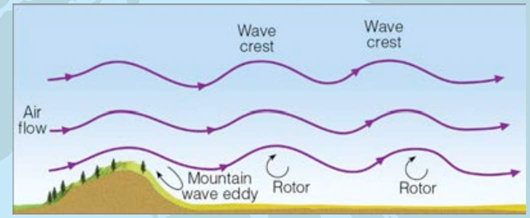
Wind Shear-Induced Eddies



Mountain Waves

Waves and eddies are produced by flow past a mountain range in a stable atmosphere

- Can form lenticular and rotor clouds
- Rotor clouds indicate dangerous conditions for aviation, including strong up and down drafts and turbulence.



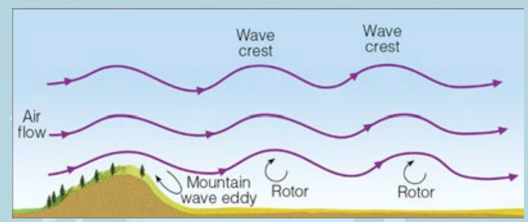
Mountain Waves

Rotor clouds indicate dangerous conditions for aviation, including strong up and down drafts and turbulence.

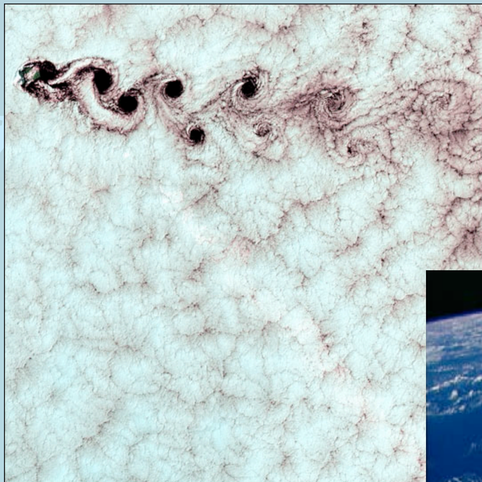

Rotor cloud


Wave cloud

Mountain Waves




Mt. Wave Cloud
or Lenticular Cloud



Friction Induced Eddies

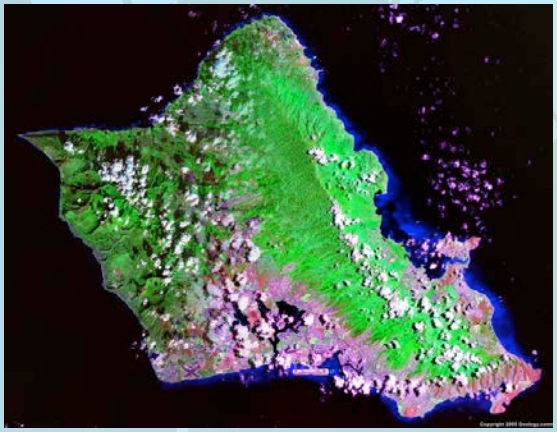
Sea Breeze and Land Breeze Circulations

Sea Breeze and Land Breeze Circulations

Sea and Land Breezes

- Mesoscale coastal winds
- Thermal circulations driven by differential heating/cooling of adjacent land and water surfaces
- Most prevalent when/where solar heating is strong

Oahu Sea-Breezes Cause Clouds



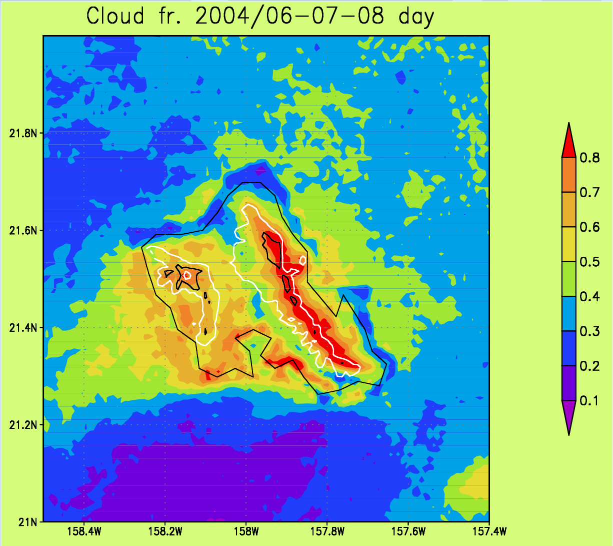
Sea breeze front from pearl harbor to Waikiki.

Offshore sinking air over the North Shore and windward waters.

Oahu Sea-Breezes Cause Clouds

Sea breezes on Oahu are strongest on light trade wind days.

Oahu Sea Breezes Cause Clouds

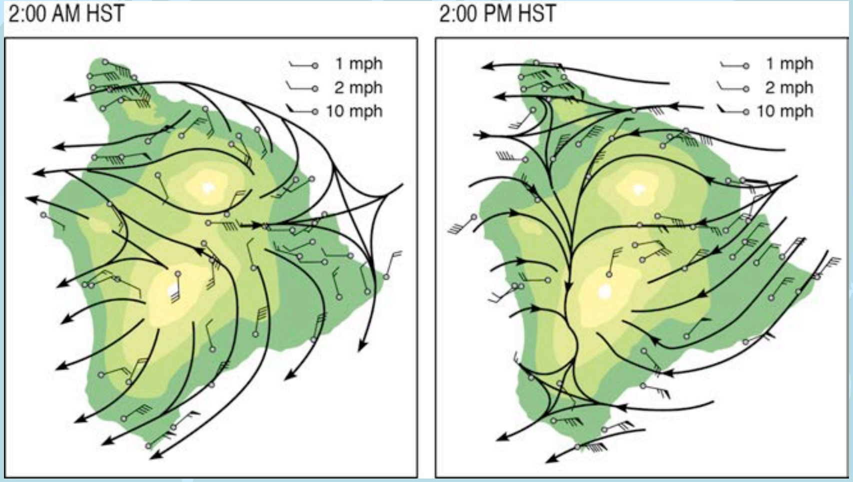


Daytime Cloud Fraction for Oahu

Sea breeze front from pearl harbor to Waikiki.

Offshore sinking air over the North Shore and windward waters.

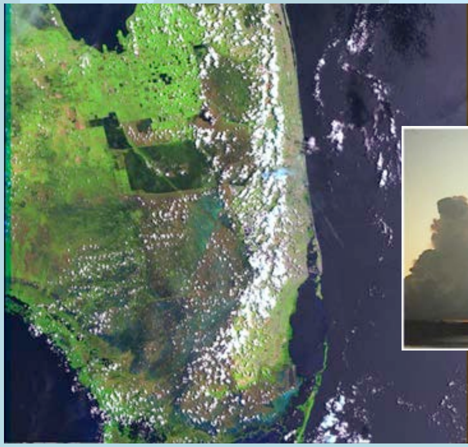
Island of Hawaii July Diurnal Winds



Island of Hawaii with contours for elevation plotted every 3000 ft and average winds (mph) during a six-week period during July and August, 1990.

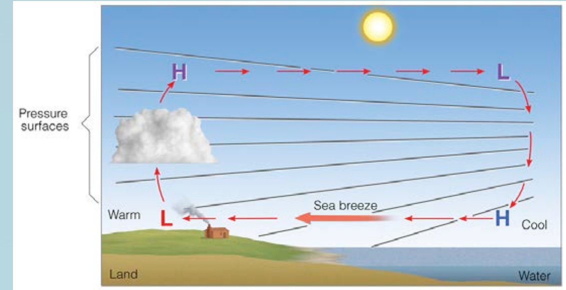
Sea Breeze Circulation

Converging Gulf of Mexico and Atlantic sea breezes produce uplift and thunderstorm development in Florida.



Cumulonimbus due to converging sea breezes on Florida Key

Sea Breeze Development



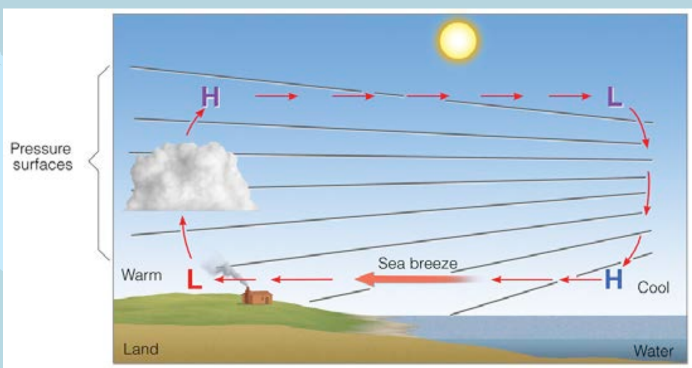
(a) Sea breeze

We can think of sea breeze formation in terms of pressure gradients

1. Land is heated creating "bulging" pressure surfaces
2. Heated column produces "**H**" aloft over land
3. Air aloft flows outward from land to ocean
4. Upper flow creates surface "**H**" over water
5. Surface flow responds with flow toward land at low levels

- Large scale ascent over land destabilizes column - enhances cloud development -thunderstorms
- descent over ocean stabilizes oceanic column

Sea and Land Breezes

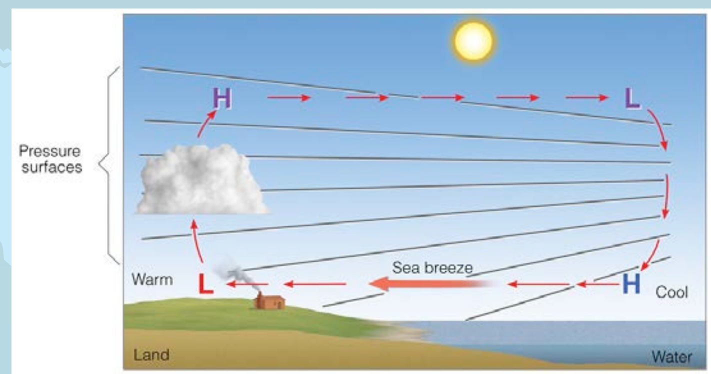


(a) Sea breeze

Sea breezes

- Cool coastal communities
- Bring more humid air
  - Haze
  - Fog
- Often produce summer thunderstorms inland from the coast

Sea and Land Breezes



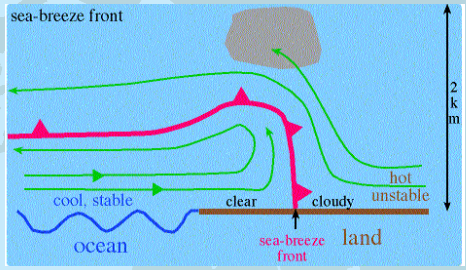
(a) Sea breeze

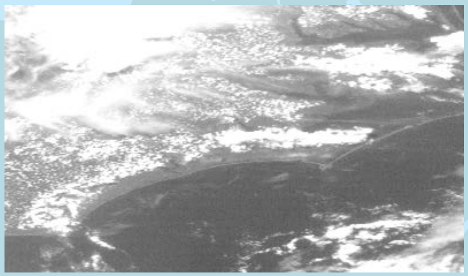
Sea breeze development summary

- Solar heating raises land temperature more than water
- Air in contact with land warms and rises
- Cooler (denser) sea air moves in to replace rising air over land
- Air sinks over the water in response to surface air movement, producing return circulation (land-to-sea breeze) aloft

Sea Breeze

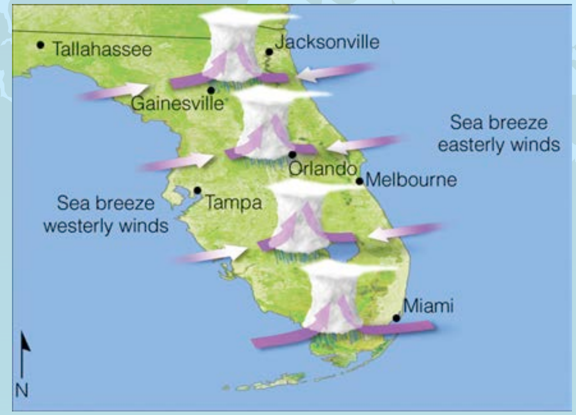
The leading edge of the cooler sea breeze air is like a shallow cold front, which forces warmer inland air to rise, triggering showers and thunderstorms.





Sea Breeze

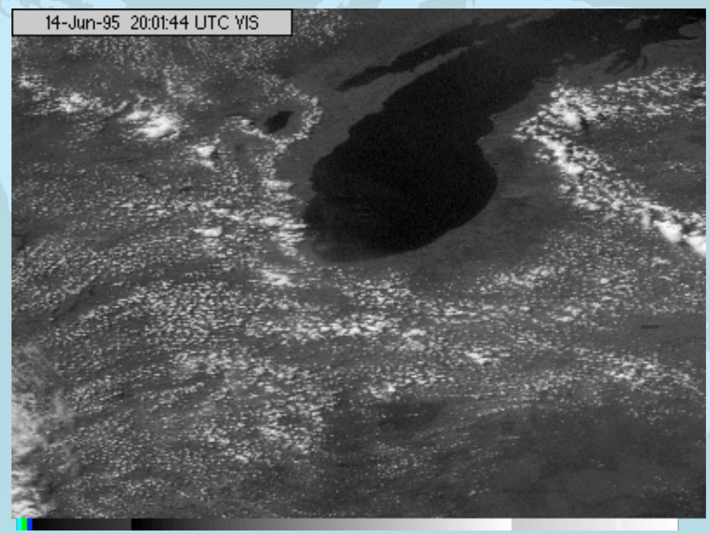
- Converging Gulf of Mexico and Atlantic sea breezes produce uplift and thunderstorm development in Florida
- Disruption of sea breezes reduces rainfall and can lead to a bad fire season



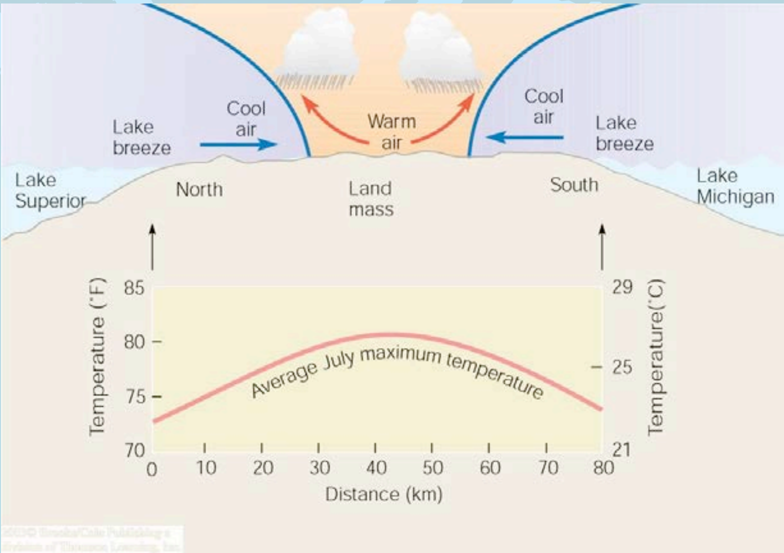
Sea Breeze Circulation

Converging Gulf of Mexico and Atlantic sea breezes produce uplift and thunderstorm development in Florida.

Lake Breeze

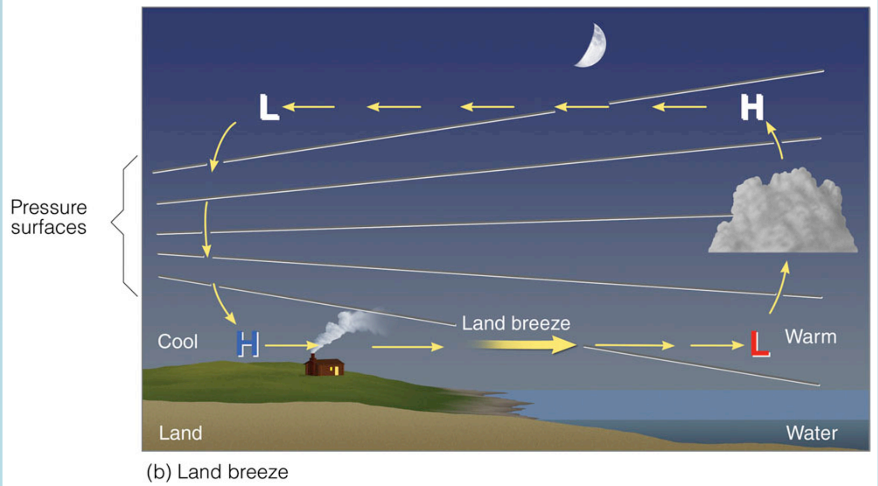


Lake Breeze



Land Breeze

Land breezes form at night due to stronger radiative cooling of the land surface leading to sinking and offshore flow of this cooler air mass with return flow aloft

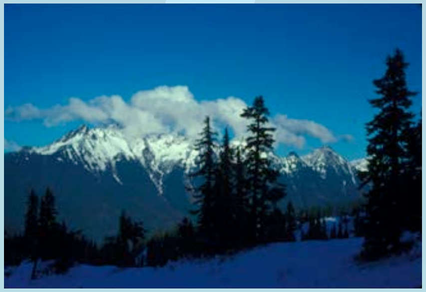


(b) Land breeze

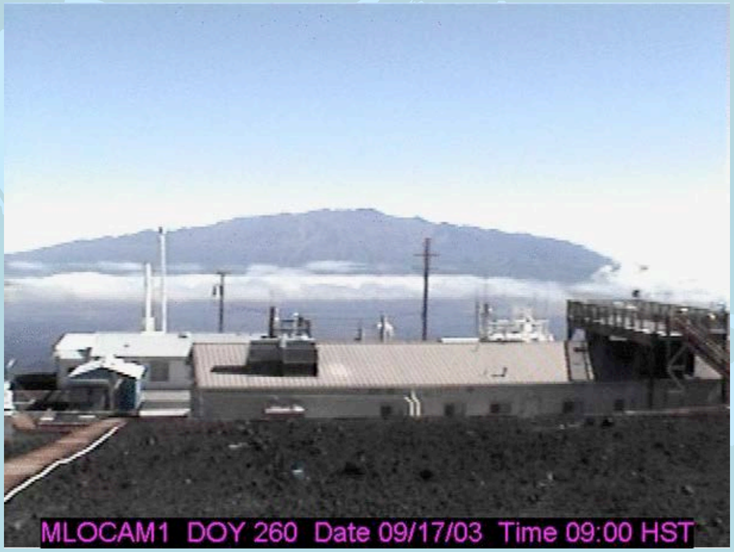
Land Breeze

Land breezes form at night due to stronger radiative cooling of the land surface leading to sinking and offshore flow of this cooler air mass with return flow aloft. Thunderstorms may form at night over the offshore waters.

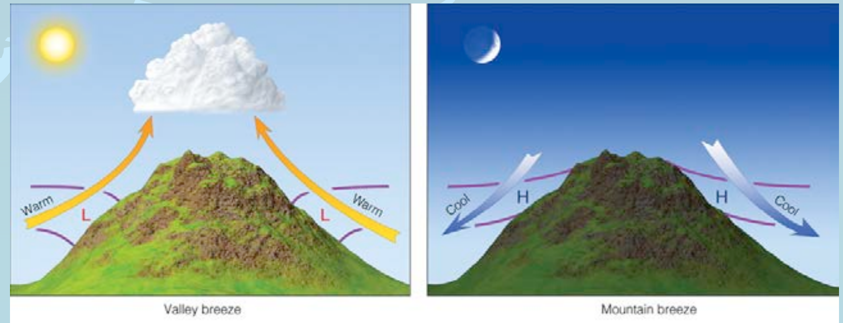
Mountain/Valley Winds



Mountain/Valley Winds



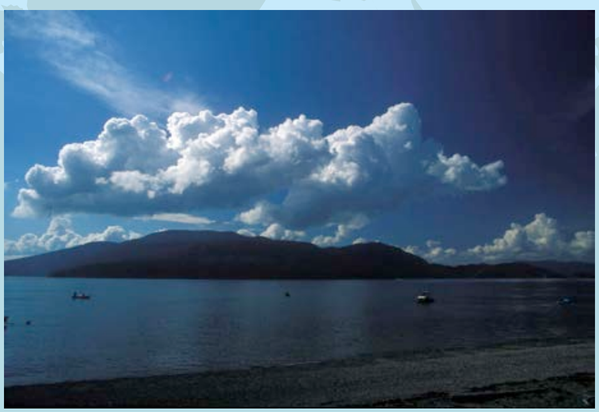
Mountain/Valley Winds



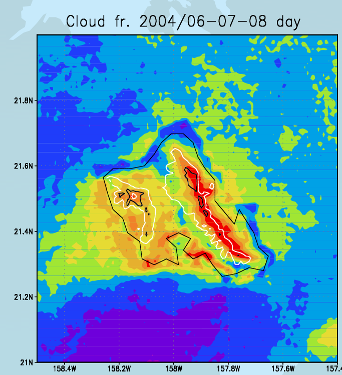
- Sunlight heats mountain slopes during the day and they cool by radiation at night
- Air in contact with surface is heated/cooled in response
- A difference in air density is produced between air next to the mountainside and air at the same altitude away from the mountain
- Density difference produces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

Consequences of Mountain/Valley winds

- Upslope flow during the day leads to formation of clouds and precipitation along mountain ranges
  - When is the best time for hiking and climbing?
- Upslope flow along the Front Range transports pollutants from the urban corridor into the high country



Combined Sea Breeze and Mountain - Valley Circulations



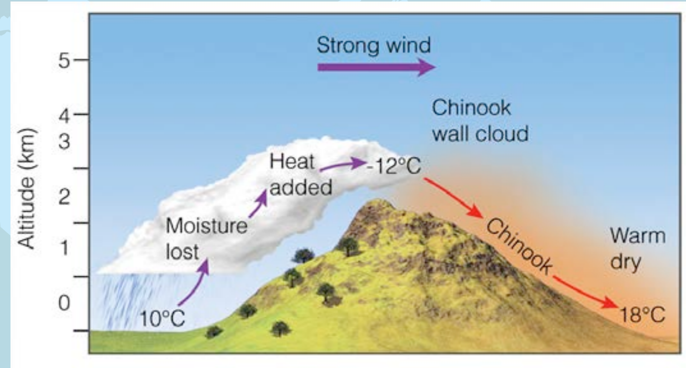
In Hawaii, the sea-breeze and mountain-valley circulations are combined to produce an island scale circulation that can be quite vigorous, especially when trade winds are light.

Chinook Winds

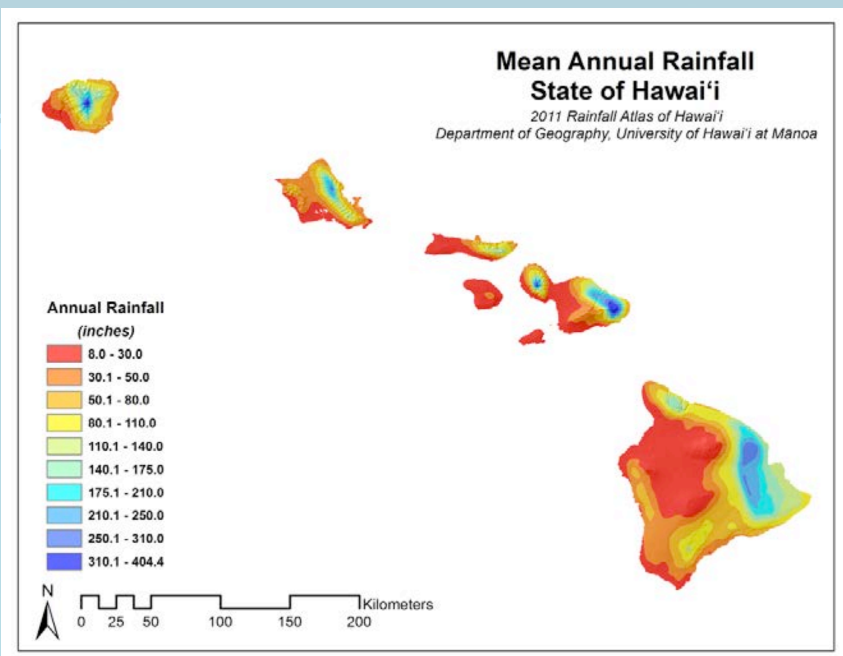
Chinook means snow easter. Why?

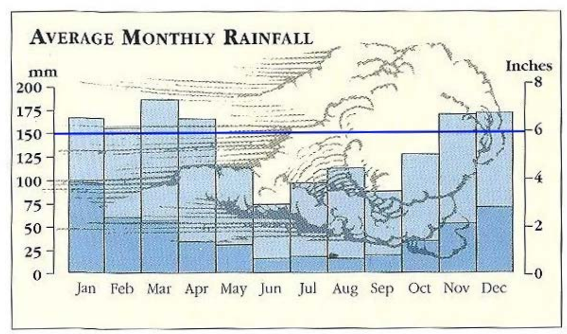
- The relative humidity during a Chinook is very low, often less than 10%.
- The temperatures are often quite warm, often in the 50's or 60's in the middle of winter.
- Coupled with the strong wind, snow rapidly sublimates and disappears.

Chinook Downslope Winds



- 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

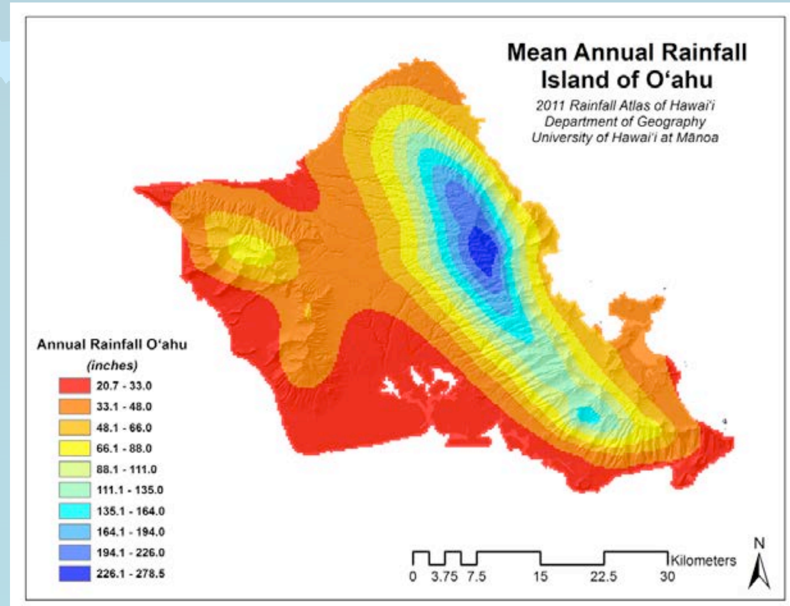




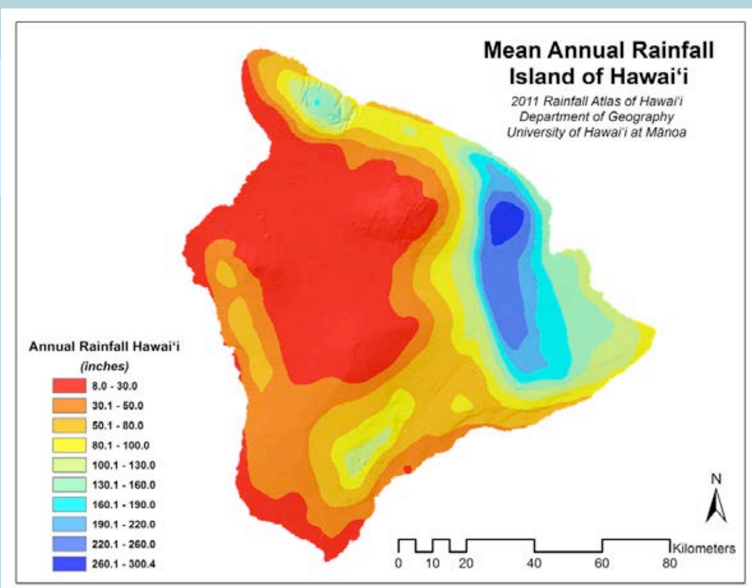
Rainfall Chart
This two-tiered chart gives average figures for all of Hawai'i. The dark blue indicates rainfall on the sheltered, leeward coasts, while the light blue indicates the higher rainfall on the exposed windward coasts. The winter months, from November through to April, receive the most rainfall, while the summer months, May to October, receive the least.

NASA Image of Hawaii

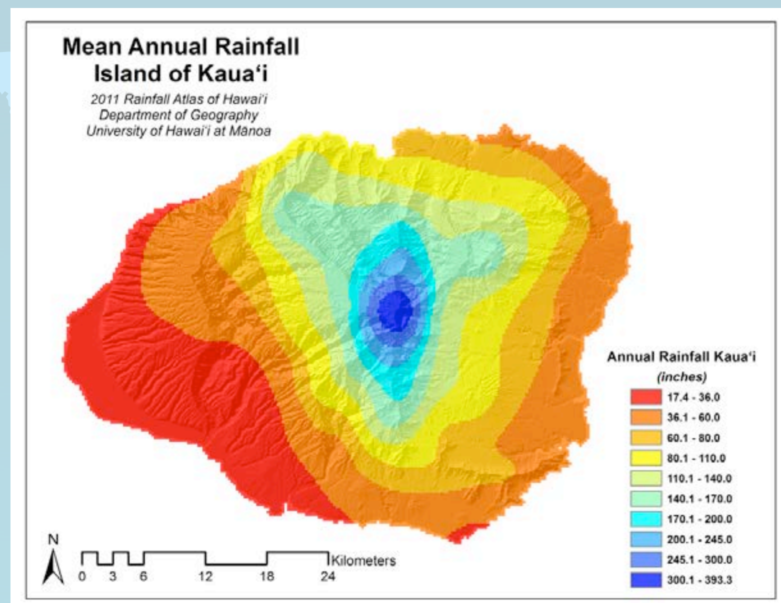
Annual Rainfall for Oahu



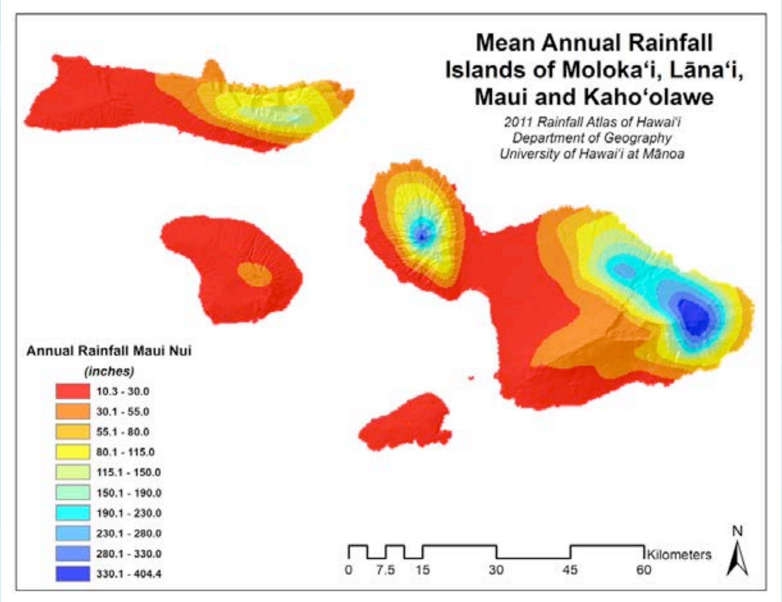
Annual Rainfall for Island of Hawaii



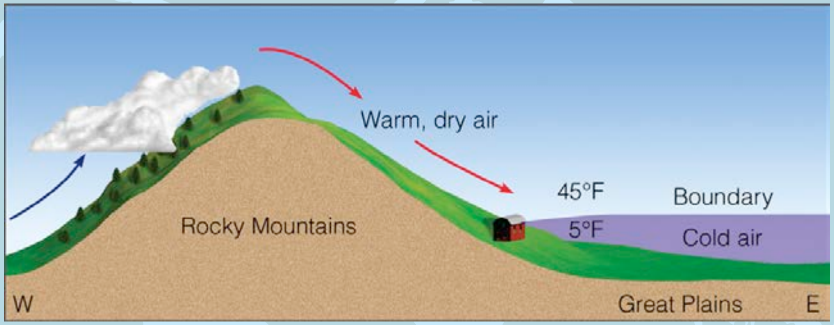
Annual Rainfall for Island of Kauai



Annual Rainfall for Maui & Molokai

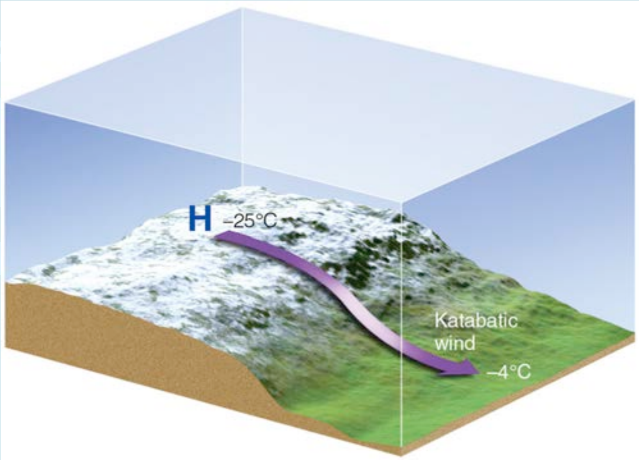


Chinook Down-slope Winds



- High pressure over the mountains
- Low pressure over the plains
- Very stable atmosphere on the upwind slope
  - Often a temperature inversion
- Strong winds aloft - above 15,000 ft
  - Jet Stream present

Drainage Winds (katabatic winds)



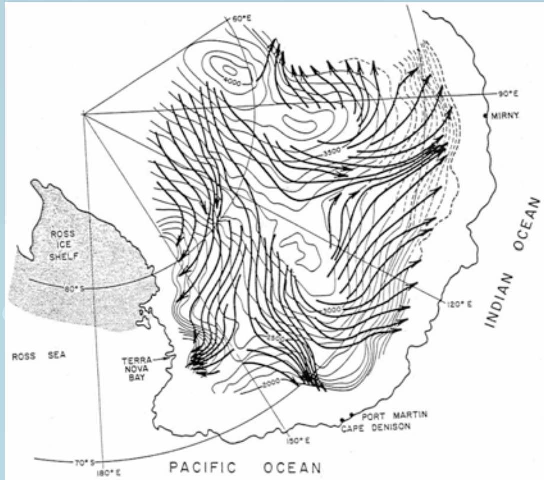
Local to mountainous regions.
Occur under calm, clear conditions.
Cold, dense air flows down valleys onto the land below.
Drainage winds can be extremely cold and strong.

Drainage Winds (katabatic winds)

Known by different local names

- Yugoslavia - Bora
- France - Mistral
- Alaska - Taku

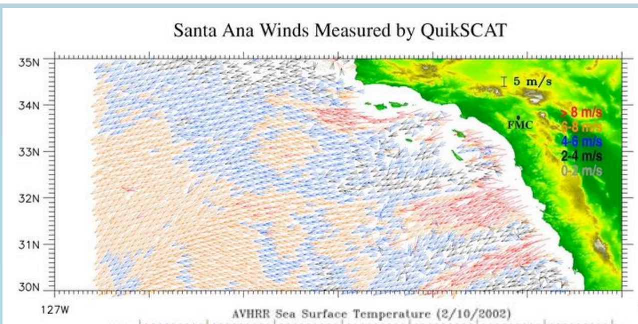
Katabatic winds over Antarctica

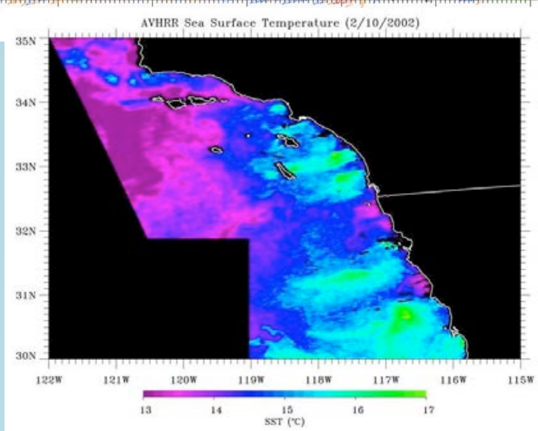


Time-average winter surface wind flow pattern in East Antarctica. Cape Denison is the windiest place on Earth.

Santa Ana Winds
A kind of gap wind

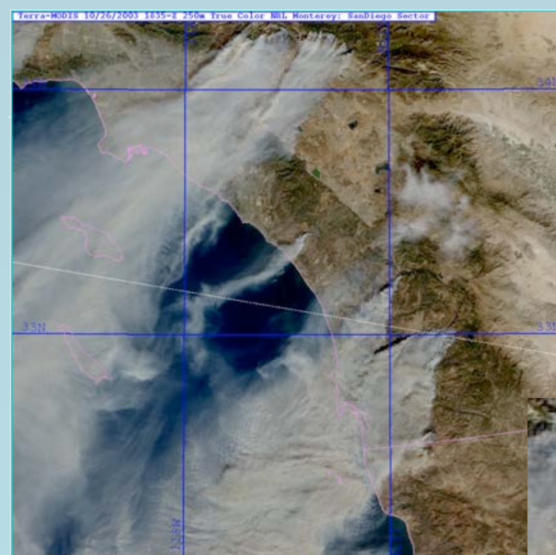
Surface weather map in February





Santa Ana Winds
A kind of gap wind

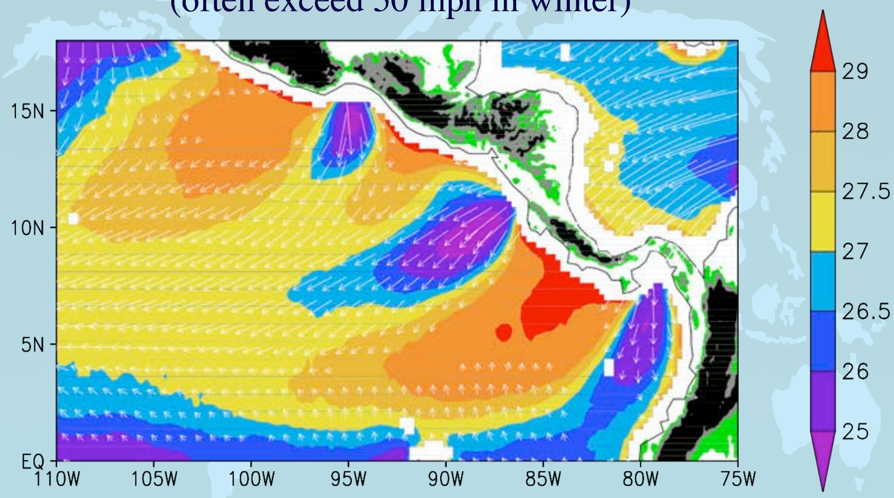
California Wild Fires



- October 2003

Central American Gap Winds

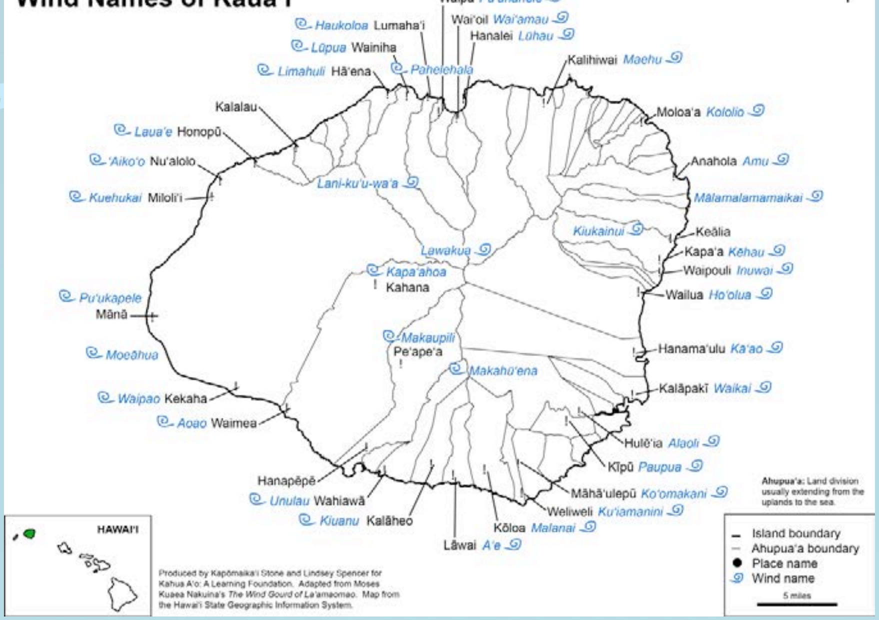
(often exceed 50 mph in winter)



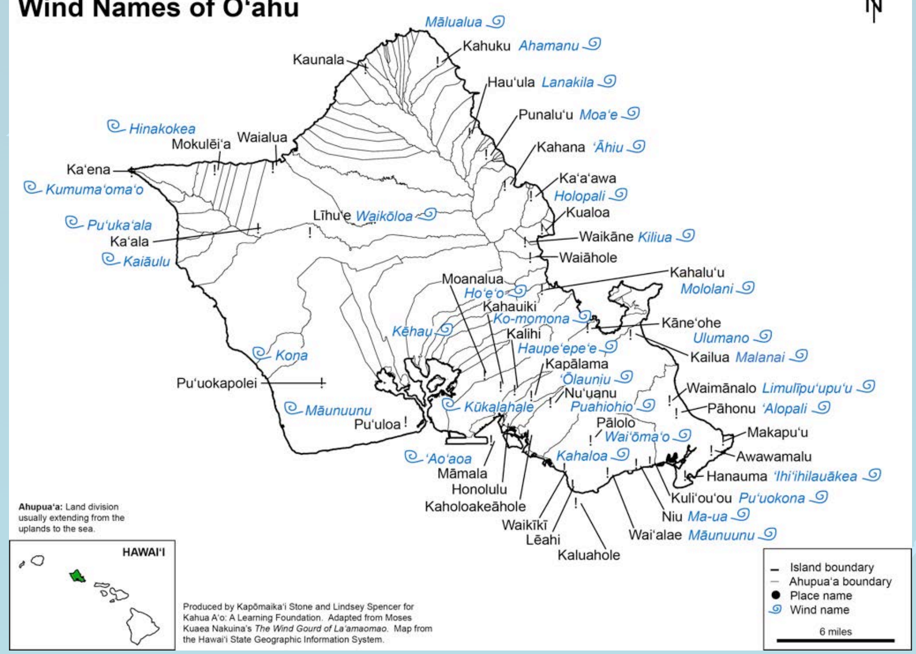
Wind & sea surface temperature (^oC)

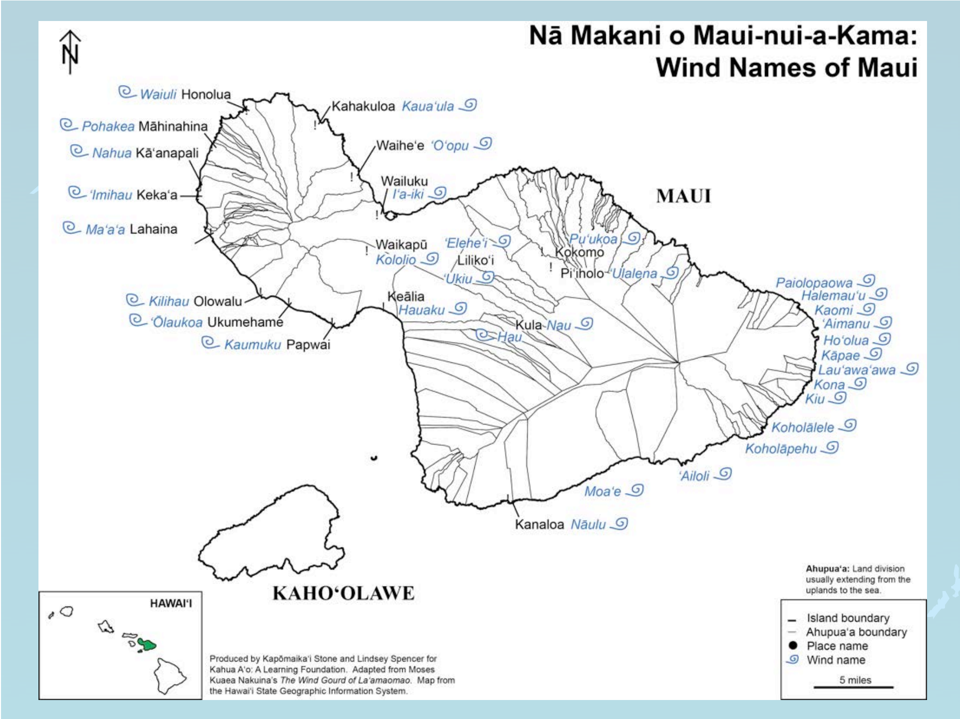
Questions?

Nā Makani o Kaua'i-a-Mano: Wind Names of Kaua'i



Nā Makani o O'ahu-nui-a-Lua: Wind Names of O'ahu




Nā Makani o Maui-nui-a-Kama:
Wind Names of Maui
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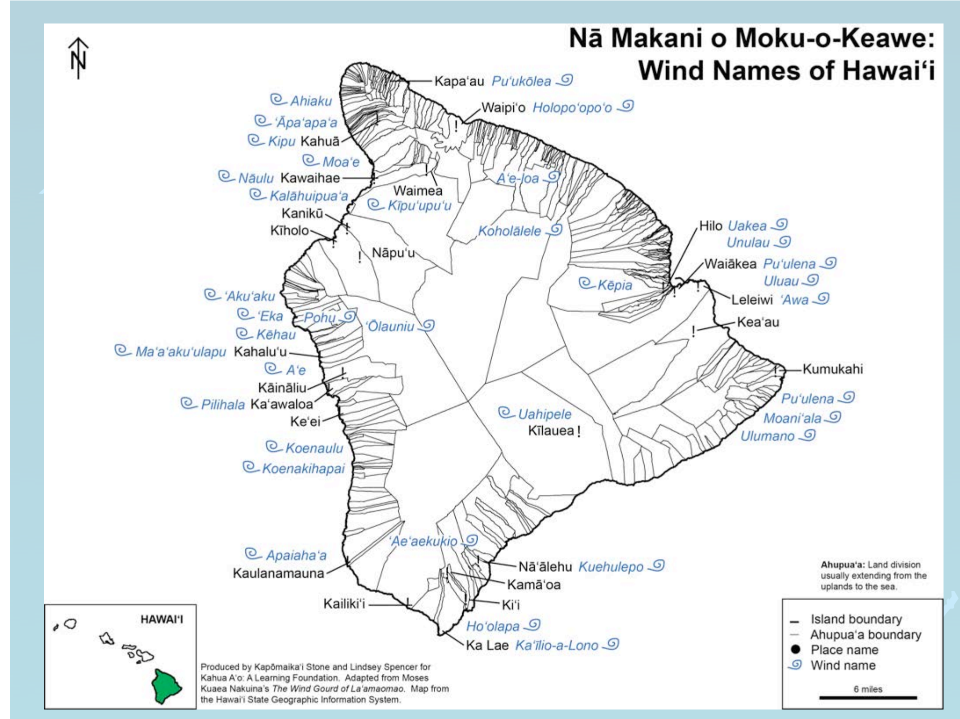
Waiuli Honolua
Pohakea Māhinahina
Nahua Kā'anapali
'Imihau Keka'a
Ma'a'a Lahaina
Kahakuloa Kaua'ula
Waihe'e 'O'opu
Wailuku
I'a-iki
MAUI
Waikapū
Kololio
'Elehe'i
Liliko'i
'Ukiu
Pu'ukoa
Kokomo
Pi'iholo
Ualena
Kilihau Olowalu
'Ōlaukoa Ukumehame
Kaumuku Papwai
Keālia
Hauaku
Kula
Nau
Hau
Paiolopaowa
Halemau'u
Kaomi
'Aimanu
Ho'olua
Kāpae
Lau'awa'awa
Kona
Kiu
Koholālele
Koholāpehu
'Ailoli
Moa'e
Kanaloa Nāulu
KAHO'OLAWE
HAWAI'I
Ahupua'a: Land division usually extending from the uplands to the sea.
Island boundary
Ahupua'a boundary
Place name
Wind name
5 miles
Produced by Kapōmaika'i Stone and Lindsey Spencer for Kahua A'o: A Learning Foundation. Adapted from Moses Kuaea Nakuina's The Wind Gourd of La'amaomao. Map from the Hawai'i State Geographic Information System.


Nā Makani o Moku-o-Keawe:
Wind Names of Hawai'i
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Kapa'au Pu'ukōlea
Waipi'o Holopo'opo'o
Ahiaku
'Āpa'apa'a
Kipu Kahuā
Moa'e
Nāulu Kawaihae
Waimea
A'e-loa
Kalāhuipua'a
Kīpu'upu'u
Kanikū
Kīholo
Nāpu'u
Koholālele
Hilo Uakea
Unulau
Waiākea Pu'ulena
Uluau
Leleiwi 'Awa
Kēpia
'Aku'aku
'Eka
Pohu
'Ōlauniu
Kēhau
Kea'au
Ma'a'aku'ulapu Kahalu'u
A'e
Kāināliu
Pilihala Ka'awaloa
Ke'ei
Kumukahi
Pu'ulena
Moani'ala
Ulumano
Uahipele
Kīlauea
Koenaulu
Koenakihapai
'Ae'aekukio
Apaiaha'a
Kaulanamauna
Nā'ālehu Kuehulepo
Kamā'oa
Kailiki'i
Ki'i
Ho'olapa
Ka Lae Ka'īlio-a-Lono
HAWAI'I
Ahupua'a: Land division usually extending from the uplands to the sea.
Island boundary
Ahupua'a boundary
Place name
Wind name
6 miles
Produced by Kapōmaika'i Stone and Lindsey Spencer for Kahua A'o: A Learning Foundation. Adapted from Moses Kuaea Nakuina's The Wind Gourd of La'amaomao. Map from the Hawai'i State Geographic Information System.