Tropical Climate Systems

ENSO and the Monsoons
ENSO

The El Niño-Southern Oscillation is a coupled ocean-atmosphere system in the tropical Pacific

‘Coupled’ means that the ocean influences conditions in the atmosphere; and the atmosphere influences conditions in the ocean

Oscillation indicates the system moves around a stable state (no beginning or end)
**ENSO States**

La Niña is the cooling of sea surface temperatures (SSTs) below normal in the eastern and central Pacific.

Normal (or neutral) are long-term average SST conditions for the equatorial Pacific.

El Niño is the warming of SSTs in the eastern and central equatorial Pacific.
ENSO States

Conditions are very warm in the equatorial Pacific. The warm SSTs support moist warm surface air temperatures and lots of convection.

The organization of this convection depends on both on SSTs (>28°C) and the geographic distribution of those SSTs.
Precipitation over the Equatorial Pacific

Warm SST anomalies support increased precipitation over the Pacific
Southern Oscillation

The Southern Oscillation is the atmospheric component of ENSO and refers specifically to the difference in surface pressure between Tahiti and Darwin, Australia.

The negative phase of the Southern Oscillation occurs during El Niño episodes when abnormally high air pressure covers Indonesia and the western tropical Pacific and abnormally low air pressure covers the eastern tropical Pacific.
Coupled System

Time series of El Niño and the Southern Oscillation reveal that the two systems are tightly correlated.
Atmospheric General Circulation

Lots of Features:

Highs in the subtropics
Lows in polar regions

Westerlies in mid-latitudes
Easterlies near the equator

Clouds near the equator

Hadley cell circulation

Fig. 1.15 Schematic depiction of sea-level pressure isobars and surface winds on an idealized aqua planet with the sun directly overhead on the equator. The rows of H’s denote the subtropical high-pressure belts, and the rows of L’s denote the subpolar low-pressure belt. Hadley cells and tropospheric jet streams (J) are also indicated.
Normal (Neutral) Conditions

- SSTs are warmer in the west Pacific, and colder in the east.
- The cold feature in the east Pacific is generally called the cold tongue, a narrow band of upwelled water on/near the equator.
Normal (Neutral) Conditions

- The Trade Winds (easterlies) push surface waters from east to west
- This action piles the warm waters in the western Pacific and upwells colder subsurface water in the east
- Sea Surface Height is elevated in the west so there is both a pressure gradient and a temperature gradient
- The higher SSTs in the western Pacific (warm pool) support more convection (which produces lower atmospheric surface pressures)
Normal (Neutral) Conditions

The trade winds and SST gradient support convection in the west and feed the Walker circulation, which reinforces the winds and inhibits convection in the central and eastern Pacific
The Major Balance during Normal Periods

- Westward force provided by easterly wind is balanced by the eastward force provided by water piled into west Pacific.

Westward wind stress on ocean = Eastward pressure gradient force in upper ocean
A relaxation of the trade winds (or a burst of westerly winds) disrupts the force balance. The warm surface waters in the west slosh to the east. Upwelling in the east slackens and central and eastern Pacific SSTs warm.
Global pattern of SST anomalies during El Niño Years
Global pattern of Surface Pressure anomalies during El Niño Years
The Warm Phase of ENSO (El Niño)

- The resulting warm event (called an El Niño event) is associated with warm water across the equatorial Pacific, and a shift in convection to the east Pacific.
- The thermocline across the Pacific is flat, and equatorial winds are generally from the west (supporting the shift in convection).
- Air is sinking over the west Pacific, and rising over the east.
- A warm event typically occurs once every 3-7 years.

The Cold Phase of ENSO (La Niña)

An intensification of the trade winds leads to more upwelling in the east, a greater west-east sea surface height and SST differential, and a more intense Walker circulation.
ENSO Events Affect the Global Circulation

- When convection is moved to the east and central Pacific, this has profound effects on global atmospheric pressure and wind patterns.
- The plot on the right shows a “train” of anomalous pressure centers that extend toward North America from the region of unusually strong El Niño convection/precipitation in the central/east Pacific.

Horel and Wallace (1981)
Some Impacts El Niño Events

ENSO events are associated with changes in temperatures and precipitation around the world.
Some Impacts La Niña Events

ENSO events are associated with changes in temperatures and precipitation around the world.
What is Going on Now?
What is Going on Now?

We are in a weak La Niña
Atmospheric Circulations Occur at a Variety of Scales

Table 7.1 The Scales of Atmospheric Motion with the Phenomena’s Average Size and Life Span*

- Earth’s rotation important
- Longwaves in the westerlies
- Weather map features: High and Low pressure areas, Weather fronts
- Hurricanes, Tropical storms
- land/sea breeze
- Mountain/valley breeze
- Chinook wind
- Santa Ana wind
- Thunderstorms, Tornadoes, Waterspouts, Dust devils
- Small turbulent eddies

*Because the actual size of certain features may vary, some of the features fall into more than one category.

Local Wind Systems (Mesoscale)

- Consider a case where pressure is initially uniform from north to south.
- The pressure at every height is the same everywhere, and surface pressure is uniform.
- Now, warm up the atmosphere to the south (assume this is on the order of tens of kilometers from the barn), and cool it to the north.
- The atmosphere will expand to the south, and pressure surfaces will move upwards with height.
- The atmosphere shrinks to the north, and pressure surfaces move down with height.
Local Wind Systems

- This causes a pressure gradient force from south to north, and ends up moving mass north.
- Because mass has been removed from the atmospheric column to the south, surface pressure falls there.
- Because mass is added to the atmosphere to the north, surface pressure rises there.
Local Wind Systems

- A circulation near the surface is driven by the pressure gradient force, with air moving from north to south.
- Because the scale is small, the Earth’s rotation is not important, and wind blows in the direction of the pressure gradient force.
- Such local circulations are very prominent in Oregon.
Example: 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.
Example: Land Breeze

- Near the ocean, the land cools more than 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
Example: Diurnal Wind Variations near the Coast

A few days of clear skies and a strong diurnal cycle in temperature over land near North Bend on the Coast. The ocean temperature changed very little.
Diurnal Variation in Winds Near the Coast

The wind dramatically switches from slightly onshore in the late afternoon, to offshore during the night. Note: the Oregon coastal system has complicating factors that prevent the wind from blowing directly onshore or offshore (east-west).
Florida Sea Breeze

Surface heating and lifting of air along a sea breeze produce the frequent summer thunderstorms in south Florida.
Monsoons can be thought of as larger scale land/sea breezes

- **Monsoon**: A regional circulation system characterized by seasonal changes in wind speed or direction
  - South Asian monsoon
  - Southwestern United States
- At the root of such systems is a differential heating of land vs. ocean at different times of the year that creates a pressure gradient, much like in the local systems (e.g. sea breeze)
- However, the Earth’s rotation (and therefore the Coriolis force) become increasingly important in such systems due to the larger scale
Monsoon System of South Asia

- Just as for local circulations that are forced on diurnal timescales by a temperature gradient between ocean and land areas, seasons force differences in the temperature of land versus ocean in monsoon regions.
- South Asian land areas become very hot by May and June, creating lower pressure over land than ocean. The pressure differences drive circulations.
- The land of South Asia is cooler than the ocean during winter, forcing a pressure difference between land and ocean that is opposite of that during summer.
Monsoon System of South Asia

Monsoon circulation

summer
hot warm air rises

winter
cold cold air sinks
Seasonal Reversal of Indian Ocean Winds and Pressure

Note that the flow forced by the land-ocean temperature and pressure differences does begin to adjust to the Earth’s rotation on these scales. (Along the equator the Coriolis force vanishes and winds generally blow directly from high to low pressure).
The Tibetan Plateau is particularly critical for the development of the South Asian monsoons.

- Upper tropospheric air temperatures above elevated land surfaces are significantly warmer than corresponding air temperatures above surfaces at lower elevations (Molnar and Emanuel, 1999).

- The Tibetan Plateau region (with elevations above 3000m) supports a summertime high pressure ridge and the warmest summertime upper tropospheric temperatures on the planet (Li and Yanai 1996).

- Intensifies the land-sea contrast
Indian precipitation is generally highest during the summertime months of July through September, and suppressed during winter.
The Seasonal Cycle of Indian Precipitation
Monsoon System of The Southwestern United States

Precipitation Peaks in Most Places in the Desert SW during July and August (not true on the West Coast). The shift in the flow is associated with an increase in atmospheric moisture and precipitation during summer.
Monsoon System of The Southwestern United States

During Summertime

Mid-Summer Circulation and Pressure

Fig. 1. Important physiographic features, states, and place names mentioned in the text: Empalme (E), Mazatlán (M), Phoenix (P), and Yuma (Y).

Adams and Comrie (1997)
Monsoons circulations are seasonal averages.

There is much day-to-day variability.

‘Failure’ of the Indian monsoon is not complete drought. It can refer to a late onset of rains, a long break in the rains during the monsoon time of year, or a low seasonal amount of rain (~75% of normal).
Like the sea breeze, the strength of the summer high pressure ridge above the Tibetan Plateau and the upper tropospheric temperature gradient between the Plateau and Indian Ocean are tied to the strength of the monsoon circulation and rains.

![Diagram showing the relationship between Tibetan Plateau snow depth and monsoon circulation strength.](image_url)