

# Chapter 12 Study Guide and Case Studies: Ocean Currents, Winds and Weather

## Key Concepts

- The global ocean heat conveyor is driven by thermo-haline circulation.
- Circulation loops in the oceans are called gyres. Western boundary currents (along east coasts) are narrow, deep and fast-moving. Eastern boundary currents (along west coasts) are wide, shallow and slow-moving.
- In the Northern Hemisphere south-moving currents along west coasts cause coastal upwelling, while north-moving currents cause downwelling. The situation is reversed in the Southern Hemisphere, where north-moving currents along west coasts cause coastal upwelling.
- In an adiabatic process, air moves without exchanging energy with its surroundings. Adiabatically rising air cools and expands, while adiabatically sinking air heats and contracts. Condensation and evaporation end adiabatic processes. Rising air leaves behind a low surface pressure while sinking air causes a high surface pressure. Air tends to move from high to low pressure.
- The Coriolis effect deflects moving air to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. In the Northern Hemisphere air therefore moves counterclockwise around a low-pressure system and clockwise around a high-pressure system. In the Southern Hemisphere, air moves clockwise around a low-pressure system and counterclockwise around a high-pressure system. Air flow around a low-pressure system is cyclonic, while air flow around a high-pressure system is anti-cyclonic.
- The direction of air movement in the Northern Hemisphere can be determined using the right-hand rule.
- Air circulation in the atmosphere occurs in three principal convection cells between the equator and the pole. Three windy belts (zones of trade winds, westerlies, polar easterlies) are separated by calm belts of convergent or divergent surface air.
- The calm belt of convergent surface air near the equator is the intertropical convergence zone. Its seasonal shift away from the equator brings rainy monsoons to many regions in the world.
- Jet streams are very fast winds that are found near the top of the troposphere where two atmospheric convection cells meet. Jet streams meander, where the southward extent changes throughout the year. They can control the path of big storm systems.
- The three principal types of clouds are cumulus, stratus and cirrus clouds. The term “nimbus” and the prefix “nimbo” determine whether the cloud can produce

- precipitation. The temperature profile in the atmosphere determines in what form the precipitation falls, e.g. rain, sleet, snow or hail.
- El Niño and La Niña are climate phenomena that last from several months to more than a year and return every few years. El Niños are accompanied by above-normal sea surface temperatures in the equatorial Eastern Pacific Ocean. The low-pressure system usually located in Indonesia shifts into the central Pacific Ocean, bringing drought conditions to Indonesia. A lack of coastal upwelling off the west coast of South America leads to the collapse of local fisheries.
  - The Pineapple Express is a warm soggy winter storm bringing intense, flood-causing rainfall to the west coast of North America, particularly the Pacific Northwest. The Pineapple Express forms when the Polar Jet Stream meanders unusually far south.
  - Marine layers form when warm, moisture-rich marine air moves over cold ocean currents. The water vapor then condenses to form fog or low clouds. This condition often occurs in June along Southern California's coasts, making it the least sunny time of the year.

## Key Terms

- global ocean heat conveyor
- thermo-haline circulation
- gyres
- western and eastern boundary currents
- coastal up- and downwellings
- adiabatic heating and cooling
- pressure gradient
- high- and low-pressure systems
- on-shore and off-shore airflow
- cyclonic and anti-cyclonic air flow
- right-hand rule
- isobars
- Hadley cells
- Ferrel cell,
- trade winds
- doldrums
- horse latitudes
- intertropical convergence zone
- monsoons
- jet streams
- Pineapple Express
- convective lifting
- frontal lifting
- convergent lifting
- orographic lifting
- cumulus clouds
- stratus clouds
- cirrus clouds
- rain
- drizzle
- sleet
- snow
- graupel
- hail
- El Niño
- La Niña
- ENSO
- Pacific Decadal Oscillation
- Walker Circulation
- marine layer and June Gloom

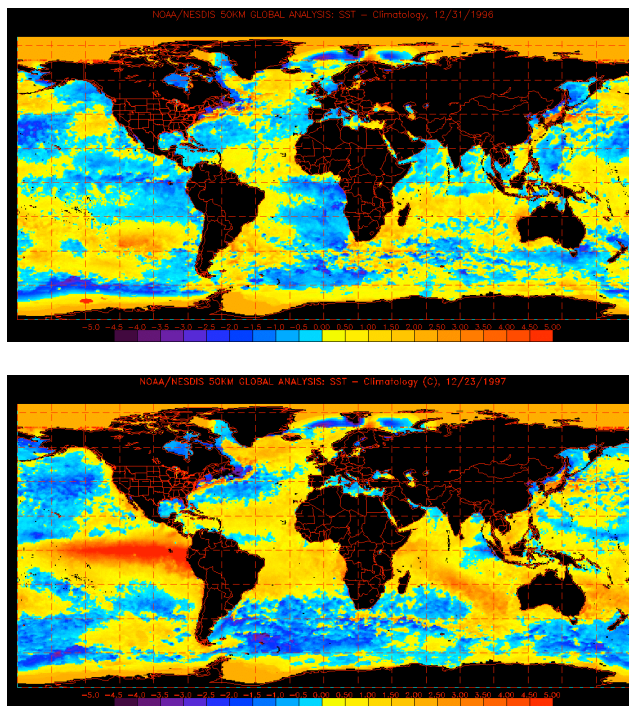
## Questions for Review

1. Explain the concept of thermo-haline ocean circulation.
2. Along the U.S. west coast, in which directions do the winds have to blow to cause coastal upwelling?
3. What happens to air during adiabatic heating?
4. Which process typically ends adiabatic cooling?
5. What is cyclonic air flow?
6. How does the right-hand rule help to determine air flow around a high-pressure system in the Northern Hemisphere?
7. How could we use a similar rule for the Southern Hemisphere?
8. Name and describe the three principal air circulation cells.
9. What are the three wind belts in the Northern Hemisphere?
10. Where would we find the horse latitudes and what is particular about them?
11. What is the wind direction of the trade winds?
12. Describe how the ITCZ is related to the South Asia Monsoon?
13. Give two examples of other monsoons in the world.
14. Where is the Polar Jet Stream located?
15. What are the typical wind speeds of the jet streams?
16. How does the Polar Jet Stream change throughout the year?
17. Why is it important for San Diego to watch the path of the Polar Jet Stream during winter?
18. Which of the following clouds is likely to produce rain: cirrostratus, nimbostratus, cirrus,
19. cumulus, cumulonimbus?
20. Up to which maximum altitude do most clouds form?

21. What is the maximum altitude at which H<sub>2</sub>O exists as water?
22. Describe the conditions for snow and hail to form.
23. What is an El Niño and how often does it occur?
24. How does an El Niño influence weather?
25. Why does an El Niño lead to the collapse of fisheries off the coast of South America?
26. What is a Pineapple Express and how does it form?
27. What causes the June Gloom in San Diego, CA?

## Case Studies

### Case Study 1: Shifts in Water and Air Flow during El Niño and La Niña



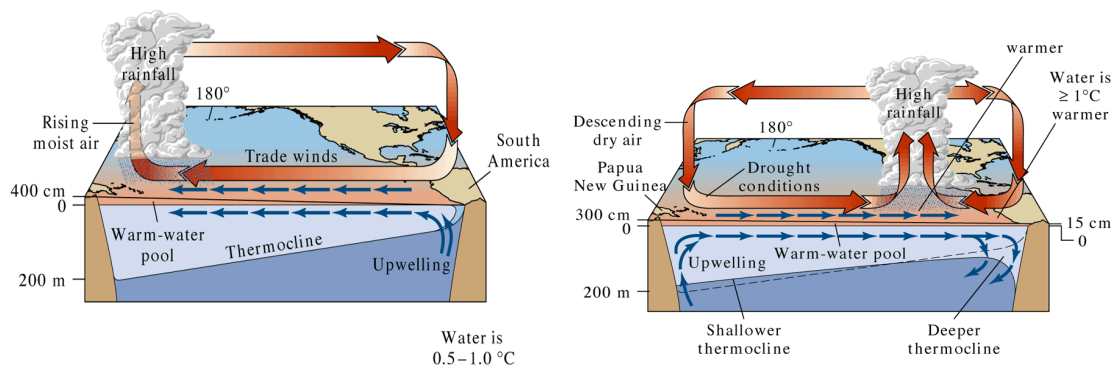
**Figure C12.1** Global sea surface temperature (SST) anomalies during normal times (December 1996, top) and during an El Niño (December 1997, bottom). Anomalies are visualized by subtracting the long-term mean SST, at each location for that time of year. During an El Niño, sea surface temperatures in the eastern Pacific Ocean can be elevated by as much as 5°C (9°F). Though to a lesser extent, SSTs are also elevated in the Southern Pacific Ocean off the coast of East Australia and even in the India Ocean.

El Niño is Spanish for boy and refers to the "Christ Child". The term was first used hundreds of years ago by **Peruvian fishermen** who observed that, every few years or so, fish were less abundant around Christmas time. The phenomenon is tied to unusually warm surface waters off the coast of western South America that can persist for months, sometimes into June. Sometimes, the situation is so dire that entire fisheries collapse.

Nowadays, scientists use satellite imagery to predict and monitor El Niños. The main observation hereby is that during an El Niño, equatorial surface waters in the East Pacific ocean are up to 5°C warmer than normal (Fig. C12.1). Similarly, every few years or so, the opposite occurs when surface waters are colder than normal during a **La Niña** (the

girl). During an El Niño, other parts of the Pacific Ocean are also affected as drought conditions persist throughout to the Western Pacific (Indonesia, Papua New Guinea). In the Southern Pacific Ocean, weather patterns in Australia are affected in a similar way as in Indonesia. For this reason, El Niños are more comprehensively called **El Niño-Southern Oscillations** (ENSOs).

The study of El Niños is a hot research area because evidence is mounting that these short-term climate variations have a negative global impact through wide-spread devastating droughts and epic floods. El Niños occur every 3 to 7 years but not on a regular basis. El Niños and La Niñas also do not have to occur in sequence. They typically last from 9 to 18 months and vary in strength as they interact with other recurring processes in the Pacific Ocean, such as the **Pacific Decadal Oscillation** that occurs every 20 to 30 years.



**Figure C12.2** Shifts in global air flow under normal conditions (left) and during an El Niño (right). Under normal conditions, trade winds push warm surface water westward. A low-pressure cell forms over the western Pacific Ocean. During an El Niño, trade winds weaken and the low-pressure cell moves eastward. Warm surface water now piles up in the eastern Pacific Ocean, thereby hampering or even inhibiting coastal upwelling off the west coast of South America. (source: ME)

Scientists still try to determine the exact causes and consequences of El Niños but they agree on the basic sequence of events. Under normal conditions easterly trade winds push warm equatorial surface waters westward (by means of generating ocean waves) (Fig. C12.2). There, warm surface air rises to form a low-pressure system in the equatorial western Pacific Ocean. High pressure forms over South America and the sinking air completes the circulation in the atmosphere, also called **Walker Circulation**. During an El Niño, trade winds that usually blow from the northeast (southeast in the Southern Hemisphere) weaken or may even turn eastward. In the equatorial Pacific, the Equatorial Counter Current (see Fig. 12.2) now dominates and can transport warm surface water eastward that piles up all the way to the west coast of South America. The low-pressure system moves into the eastern Pacific Ocean, causing drought conditions in the equatorial western Pacific Ocean.

So, why are there less fish off the coast of Peru during an El Niño? Under normal conditions, the Peru Current (**Humboldt Current**), a cold eastern boundary current,

causes coastal upwellings. Colder, nutrient-rich deeper water reaches the sea surface and provide the basis of the marine food web. That fact that the Walker Circulation moves warm equatorial waters westward enhances upwelling in the Eastern Pacific Ocean (Fig. C12.2 left). Under El Niño conditions, the faltering Walker Circulation effectively puts a lid on eastern Pacific waters and hampers or even inhibits coastal upwelling. The food web is interrupted and fisheries diminish. These days, not only local fishermen are affected but everyone else who depends on the catch. With 10.7 million tonnes (in 2004) the **Peruvian anchoveta fishery** is now the largest in the world<sup>(7)</sup>. Most of this is not eaten locally but used as feed fish, processed into fishmeal for fish farms elsewhere in the world (46%), prominently the Salmon farms in the Northern Hemisphere, and to feed pigs (24%) and poultry (22%). A strong El Niño, such as the 1997 El Niño therefore has a serious economic impact on the international market.

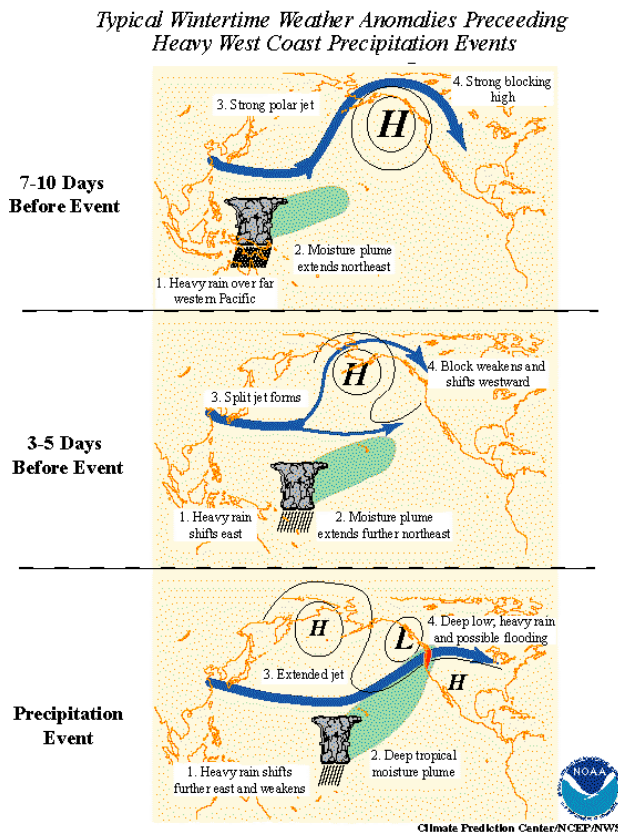
A fascinating story involves **indigenous farmers in the Andes** as they cope with droughts during the regular potato-growing season (October – May) in El Niño years<sup>(8)</sup>. A shallow-rooted crop, potatoes are most vulnerable to drought at planting when low soil moisture inhibits root formation, and again a few weeks later when the sprouts have depleted the residual moisture in the seed tubers. But a moderate delay in planting dates may save the potato harvest. In late June, indigenous farmers, and their ancestors hundreds of years ago, therefore observed and counted the number of stars in the star cluster Pleiades (or Seven Sisters) in the constellation of Taurus. Poor visibility of the stars is a harbinger of a drought and the farmers delay the planting, while good visibility promises the much-needed rain. The poor visibility is caused by an increase of invisible cirrus clouds near the top of the troposphere. There is more moisture in the atmosphere leading into warm El Niños as opposed to normal years but the formation of rain-producing clouds is inhibited or delayed.

## Case Study 2: The Pineapple Express - A Warm, Soggy Winter Storm

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**Pineapple Express** is a non-technical term for a strong and persistent flow of atmospheric moisture from the waters around Hawaii to the North American west coast. The moisture is pushed by the subtropical jet stream or a branch of the polar jet stream. A pineapple express event causes warm soggy storms in late fall and winter along the U.S. West Coast. Hawaii is the land of pineapples, which is how the Pineapple Express received its name. This moisture can be drawn into storm systems that form in the North Pacific and migrate south along the west coast or develop just off-shore (Figs. C12.3 and C12.4). The unusually heavy rain from the Pineapple Express causes extensive flooding and can trigger deadly landslides. A more recent and more general term to describe the phenomenon is ‘atmospheric river’, first used by Scripps Institution of Oceanography meteorologist Marty Ralph. Atmospheric rivers can occur elsewhere, e.g. over the Atlantic ocean.





**Figure C12.3** The arrangement of the jet stream(s) leading into a Pineapple Express. (source: NOAA)



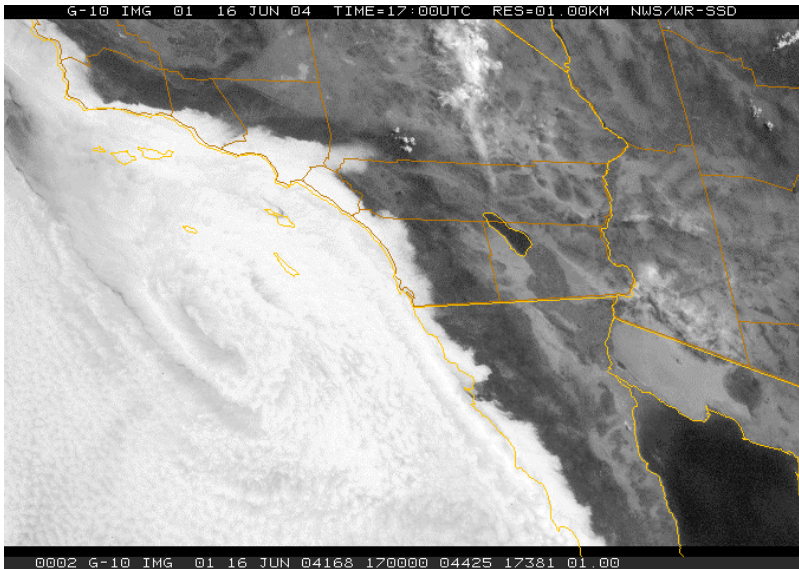
**Figure C12.4** A 10 January 2005 landslide destroyed 13 homes in La Conchita, CA. The landslide was triggered by heavy rain from a Pineapple Express (source: Santa Barbara Search and Rescue)

**Remarkable Pineapple Express Events:**

- Winter 2017: several historically strong storms brought flooding and mudslides to California, closure to major free and highways, and destroyed homes. The Sierra Nevada reached a state record of snow at over 20 m after a particularly strong



- storm. The severe weather brought significant flooding to Los Angeles and most of southern California, and killed 3 people.
- December 2014: a powerful winter storm hit northern California with snow, wind and flood watches, and a blizzard warning for the northern Sierra Nevada. The storm caused power outages for over 50,000 people. On 12 December, a rare tornado touched down in Los Angeles.
  - 15-22 December 2010: a storm in southern California brought as much as 61 cm of rain to the San Gabriel Mountains and over 4 m of snow to the Sierra Nevada. Coasts and hillsides were affected by mudslides and major flooding from San Diego to San Bernardino.
  - First week of November 2006: a storm in the Pacific Northwest (Oregon/Washington) brought record rainfall, flooding rivers, washing out roads and killing 4. The flooding forced closure of Mt. Rainier National Park for the first time since 1980, when it was closed after the eruption of Mt. St. Helens.
  - 7-11 January 2005: a storm battered Southern California. It was the biggest to hit the area since the 1997/1998 El Niño winter. The storm caused mudslides and flooding in the normally dry Morongo Valley. It also triggered a catastrophic landslide in La Conchita in Southern California, killing 10 people (Fig. 12.21).
  - El Niño winter of 1997/1998: Wide-spread flooding and landslides occurred in Southern California and Tijuana, Mexico in the first week of February. Record runoffs were observed from Mt. Shasta in Northern California to Fresno in the south. Levees overtopped or were stressed to the maximum by flows higher than their design capacity. The heavy El Niño rains arrived just two months after the U.S. Army Corps of Engineers completed levee reconstruction efforts.
  - 26 December 1996 – 3 January 1997: hundreds of landslides in Northern California and catastrophic flooding throughout Northern and Central California. Over 100,000 people had to flee their homes and mudslides closed roads. Property damages amounted to more than \$1.5 billion (including crop losses) and 8 people lost their lives. Yosemite National Park sustained over \$170 Mio in damages due to flooding and was forced to close for more than 2 months. (Ahrens, 2003)
  - Late January – mid-February 1996: the Willamette Valley, OR Flood was part of a larger series of floods in the Pacific Northwest that were caused by storms in January and February. With 8 fatalities, the Willamette Valley Flood was Oregon's deadliest and costliest flood in the 1990ies. Flooding in the Pacific Northwest caused \$ 500 million in damages and 300,000 residents were displaced.



**Figure C12.5** Satellite image of Southern California's June Gloom marine layer on 16 June 2004. The marine layer is enhanced by the Catalina eddy, a vortex of counter-clockwise rotating upper-level air flow. Its center can be seen near the western edge of the Southern California Bight. (source: Wikipedia)

## Case Study 3: San Diego's Marine Layer and June Gloom

May Grey and June Gloom describes a situation along the Southern California coast where a persisting **marine layer** causes overcast and even foggy conditions along the coast (Fig. C12.5). June gloom makes the month of June the least sunny time in San Diego (it is sunny less than 60% of the time, instead of the usual 70% or more), frustrating residents and tourists alike, who expect sunny summer conditions. Inland, the fog usually burns off before noon but along the beaches it can persist throughout much of the day. This gloomy condition occurs along the beaches when land is significantly hotter than the oceans, with slight on-shore flow conditions (i.e. this does not happen during a Santa Ana even though land is hot!). It occurs quite often in June but can occur earlier and later in the summer, particularly when the Pacific Ocean stays cooler than normal<sup>(10)</sup>.

Above the ocean surface, warm moist marine air flowing from the open ocean toward the coast is cooled by the cold California Current. Water vapor condenses to fog, if the dew point is reached. This type of sea fog is also called **advection fog** because warm moist air is moved over a cooling surface (by wind). Onshore flow during nighttime pushes this fog on land. Rapid daytime heating on land burns off the fog by noon but, quite often, the marine layer lingers off-shore throughout the day and returns on land in the late afternoon. Sometimes, however, the marine layer can persist throughout the day when air that is heated above land pushes out to sea, above the cold air over the ocean. The warm air then puts a lid on the cold marine air. In this case, the cold air and fog cannot ascend

and so cannot “burn off”. This thermodynamically stable condition is called a **temperature inversion**. Recall that warm air below cold air wants to rise, which leads to convection. Air in a temperature inversion is typically still and smog can develop in areas with high pollution. The marine layer is more likely to occur during La Niña years when sea surface temperatures are lower than normal though local conditions complicate precise predictions. There is also still debate among experts on how ocean currents in the Southern California Bight in particular are affected by El Niño and La Niña.

The marine layer is not particular to Southern California. In fact, the marine fog in San Francisco is more famous than the Southern California June Gloom (Fig. C12.6). The marine layer forms along all cold eastern boundary currents, such as the California Current but also the Peru Current (or Humboldt Current) along the west coast of South America, the Canary Current off Northwestern Africa, and the Benguela Current off Namibia).

In southern California, the marine layer is enhanced by the short-lived Catalina eddy, a counter-clockwise rotating vortex (Fig. C12.5). It is generated when upper-level northwesterly air flow along the California coast is deflected inland but then blocked by the mountains surrounding the Los Angeles Basin. The counter-clockwise movement of air enhances the on-shore flow of the coastal fog. The Catalina eddy can form any time during the year but is most common from April through September, peaking in June.



**Figure C12.6** Fog over San Francisco Bay. This sea fog, a specific type of fog, is also called advection fog because moist warm air is moved over a cold ocean current by advection (wind) and is thereby cooled to the dew point. (source: Wikipedia)