Guide to the Science of Climate Change in the 21st Century

Chapter 11
El Niño-Southern Oscillation

David H. Manz
PhD., P. Eng., AOE, FCAE
2020

Eco-print, “Tropical Heat” Nora Manz 2020

Table of Contents

List of Figures

List of Tables

11.0 El Niño-Southern Oscillation (El Niño and La Niña)

11.1 Introduction

The El Niño/La Niña -Southern Oscillation commonly known as ENSO refers to the periodic fluctuation of the ocean sea surface temperature (El Niño) and the air pressure of the overlying atmosphere across the equatorial Pacific Ocean (Southern Oscillation). It is considered the most significant of the large-scale anomalies that influence the variability of the atmospheric and ocean circulation known as a teleconnection. (There are several others listed at the end of this chapter.) Teleconnections are important because they demonstrate the interaction, importance and complexity of the ocean-atmosphere circulations. While occurring in a relatively narrow band of the Pacific Ocean (approximately 15 degrees north and south of the equator between Peru and Australia), ENSO has a significant effect on global weather beyond this region.

11.2 ENSO normal conditions

Under normal conditions, also known as neutral conditions, the easterly flowing trade winds move air from central and eastern Pacific Ocean to Asia. As the air moves westward equatorial heating combined with a large increase in moisture content results in a region of low pressure in the western Pacific conducive to the development of extensive convection systems that carry the warm moist air upwards to produce significant rainfall. The high-altitude colder air flows eastward completing the atmospheric circulation. As well, the easterly trade winds cause the sea level to increase on the western side of the Pacific (wind setup) resulting in a warm water flow from the west to the east side of the Pacific. This causes an upwelling of the cold nutrient rich water of the Humboldt Current or Peru Current that flows from the Arctic Ocean, southern Chile to northern Peru (See Figure 8.4.). This circulation of air and water, known as the Walker circulation, is shown in Figure 11.1 and in Figure 11.2.

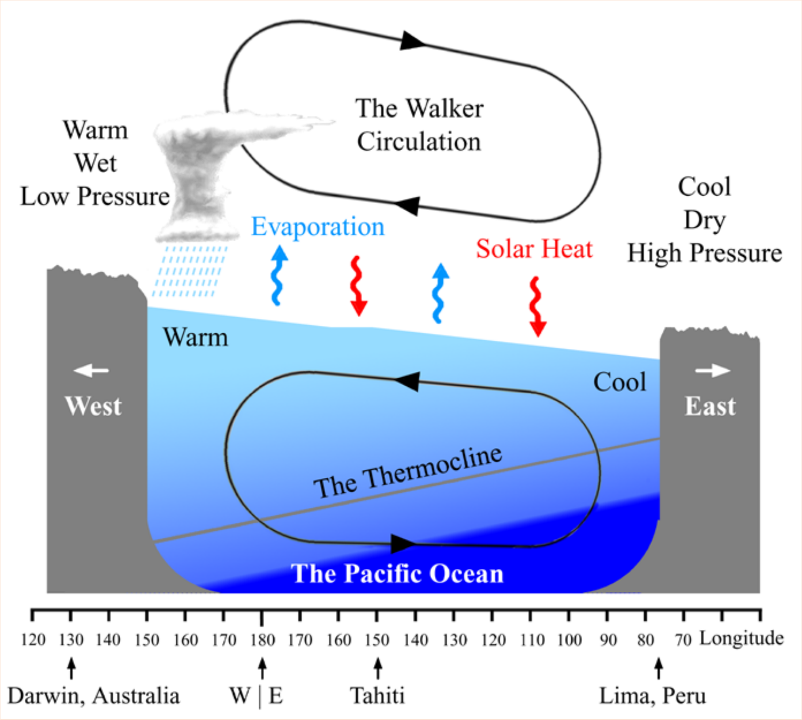


Figure 11.1 The Walker circulation.

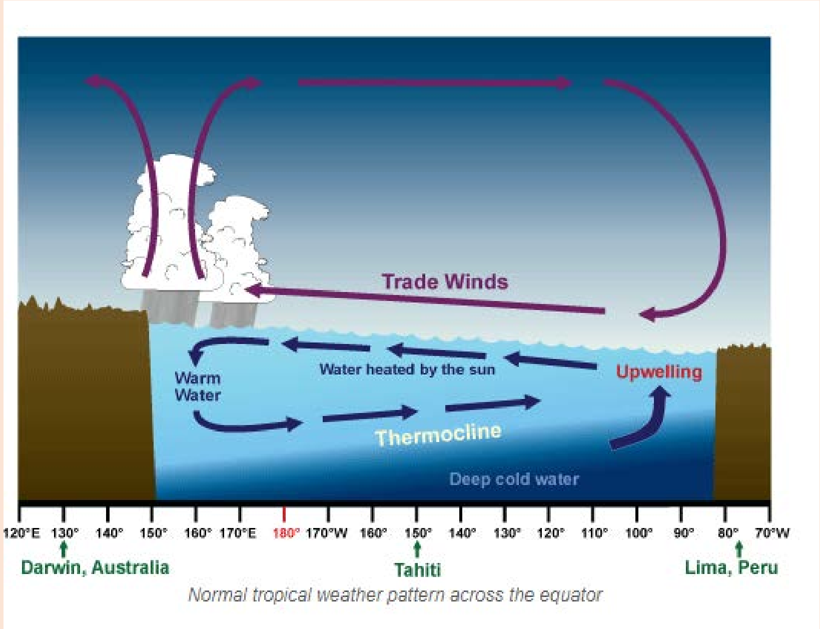


Figure 11.2 Normal or neutral equatorial atmospheric and ocean water circulation.
https://www.weather.gov/jetstream/enso_patterns

11.3 El Niño

Every three to seven years the Walker circulation changes to produce an El Niño. During an El Niño event, the surface waters in the central and eastern Pacific Ocean become significantly warmer than normal. That change is intimately tied to atmospheric pressure and to the winds blowing over the Pacific. El Niño is accompanied by higher surface pressure in the tropical western Pacific. Easterly trade winds (which blow from the Americas toward Asia) falter and can even turn around into westerlies. This allows warm water from the western Pacific to move toward the Americas covering the cold water and reducing the upwelling of cooler, nutrient-rich waters from the deep—shutting down or reversing ocean currents along the equator and along the west coast of South and Central America. This type of water movement is called a seiche wave. It is illustrated in Figure 11.3.

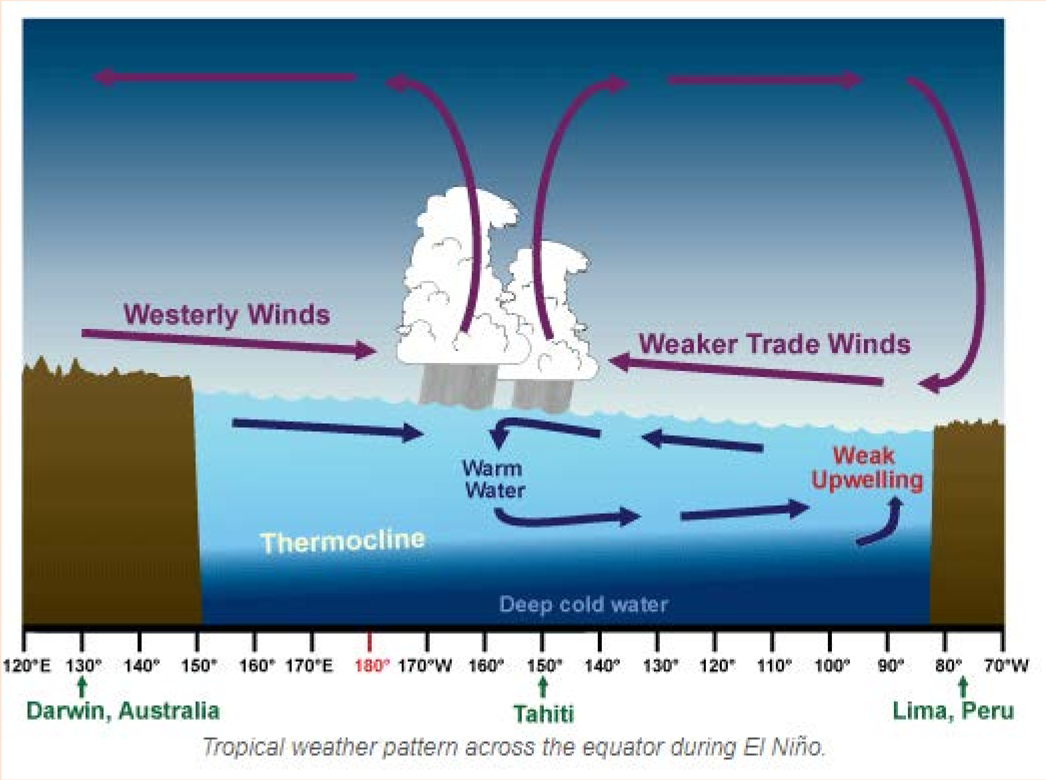


Figure 11.3 Equatorial atmospheric and ocean water circulation during El Niño. https://www.weather.gov/jetstream/enso_patterns

11.4 La Niña

Frequently, El Niño is followed by a reversal of atmospheric circulation known as a La Niña event.   During a La Niña event, the surface waters in the central and western Pacific Ocean become warmer than normal accompanied by significantly lower surface pressure. The effect is the development of strong easterly trade winds and strong upwelling as shown in Figure 11.4. The normal, El Niño and La Niña events are summarized in Figure 11.5.

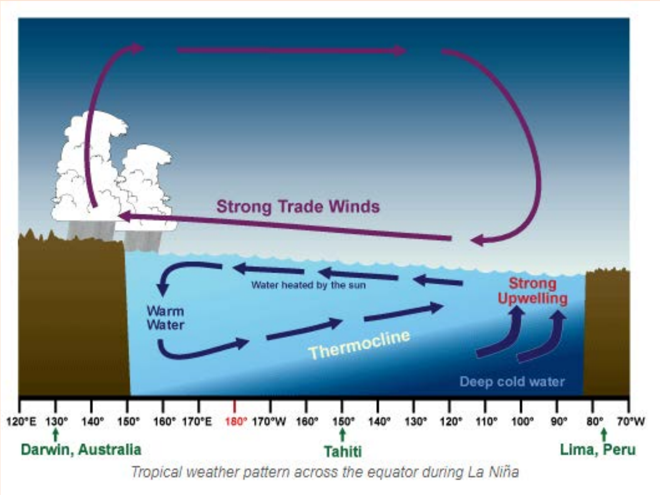


Figure 11.4 Equatorial atmospheric and ocean water circulation during La Niña.
https://www.weather.gov/jetstream/enso_patterns

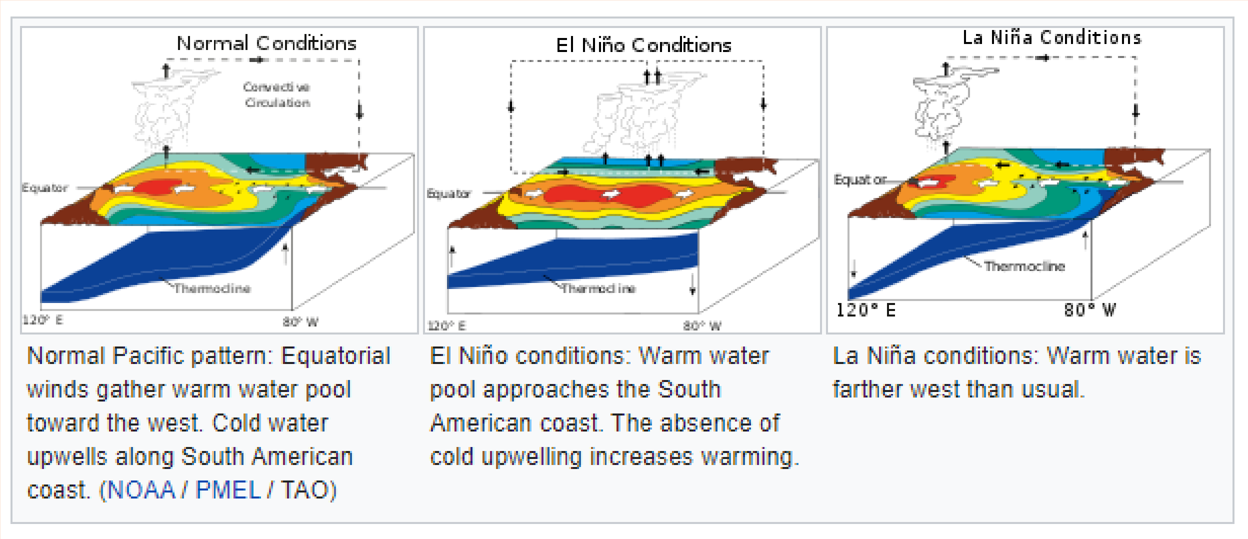


Figure 11.5 Summary of conditions associated with normal, El Niño and La Niña events.

11.5 Global impact of ENSO

The effect of ENSO extends far beyond the equatorial region of the Pacific as shown in Figure 11.6. The strong convective activity impacts the circulation of the Hadley cells, Ferrel cells and ultimately the polar cells and the jet streams that they define (See Figure 7.4). This is illustrated in Figure 11.7.

The regional effects of the El Niño and La Niña events are summarized in Figures 11.8 (a), (b), (c) and (d). These figures do not reflect the profound human impact these events cause and why prediction of these events to enable timely preparation is so important.

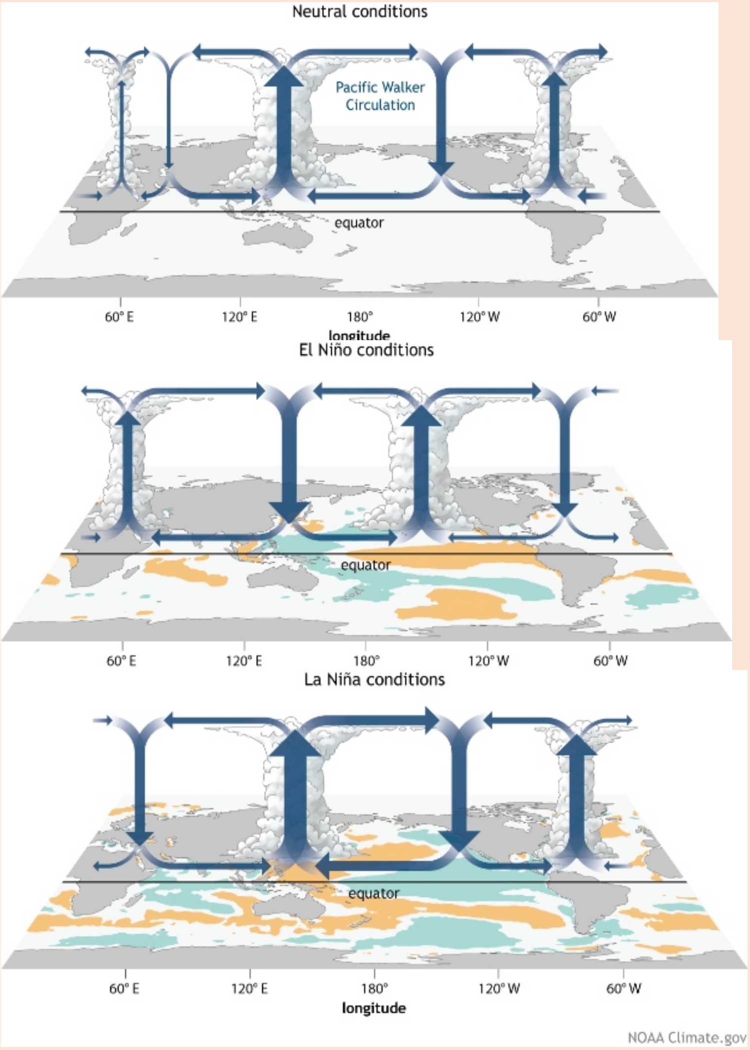


Figure 11.6 ENSO conditions and their east-west impact on global climate. Source: NOAA Climate.gov drawing by Fiona Martin.

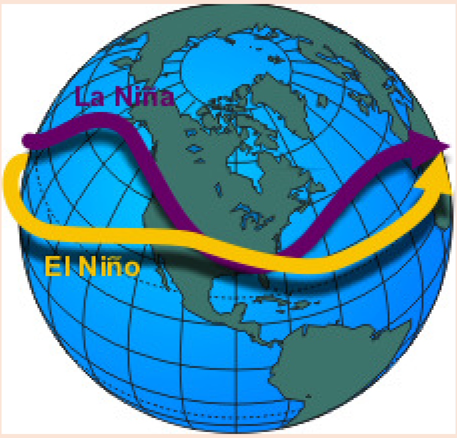


Figure 11.7 Typical average position of the jet stream during El Niño and La Niña
https://www.noaa.gov/jetstream/enso_impacts

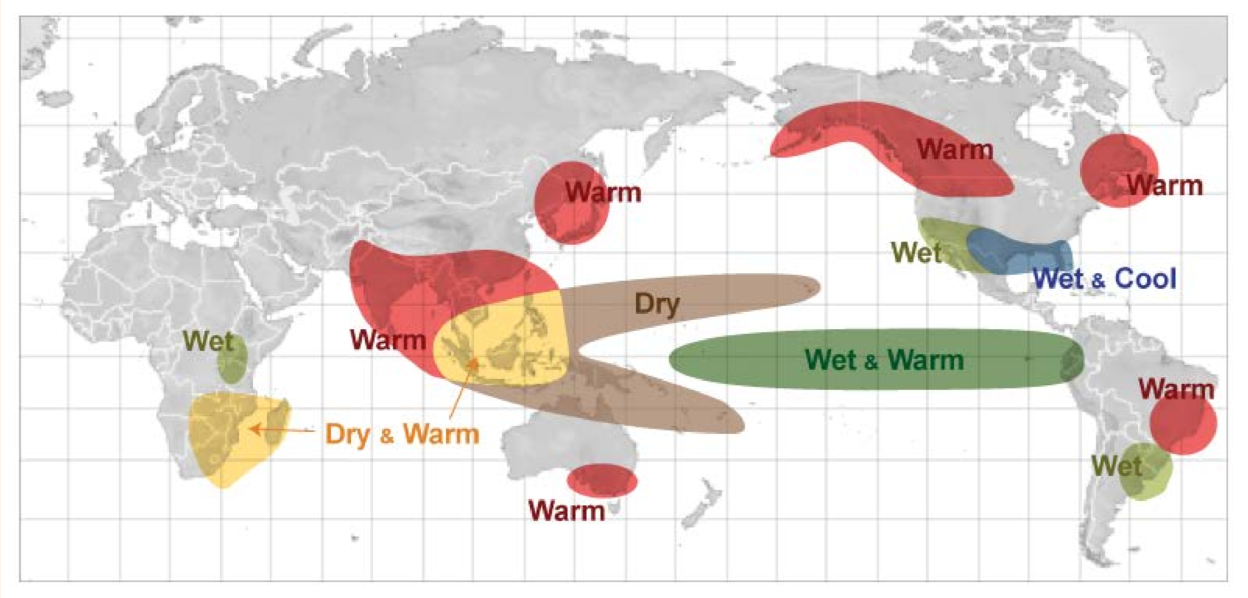


Figure 11.8 (a) El Niño effects during December through February.
https://www.weather.gov/jetstream/enso_impacts

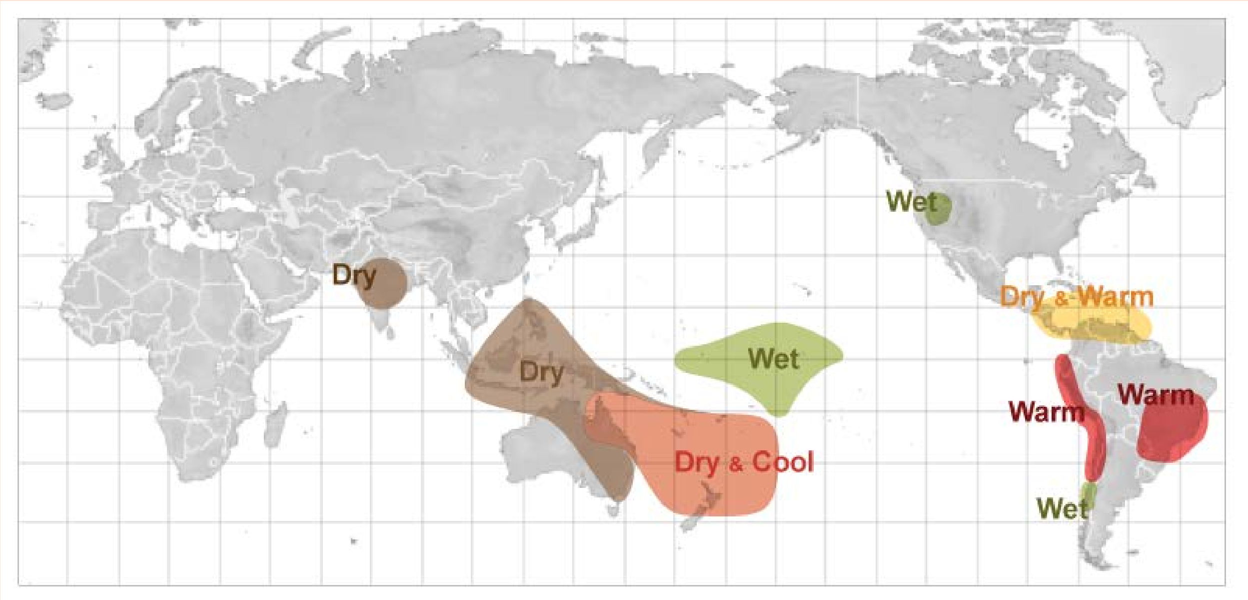


Figure 11.8 (b) El Niño effects during June through August.

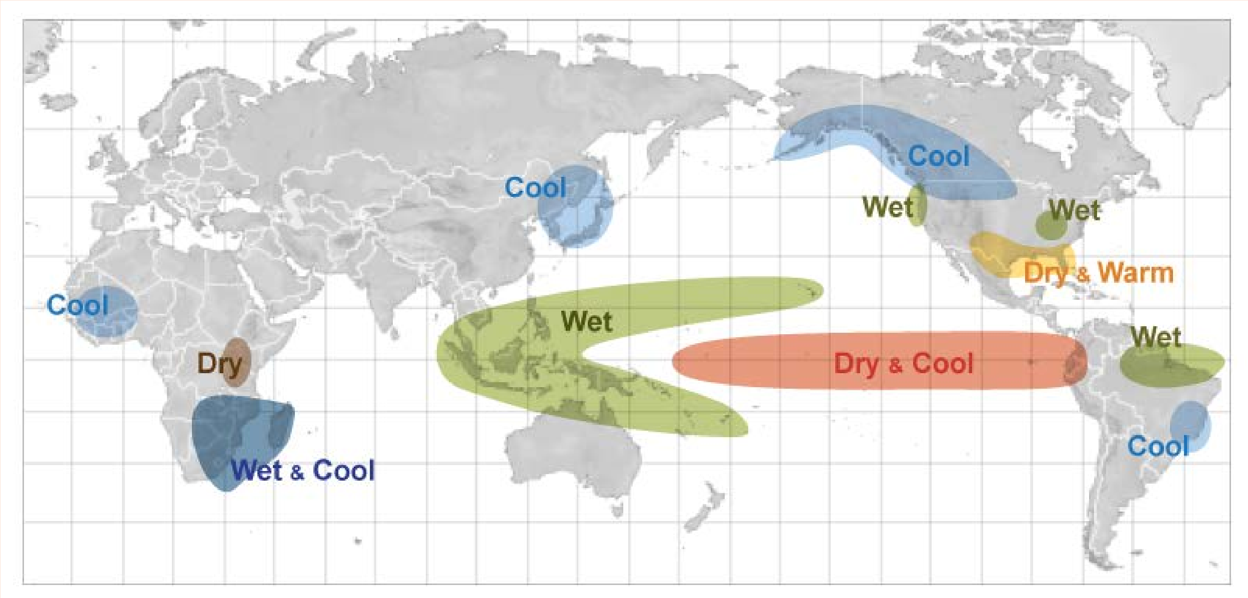


Figure 11.8 (c) La Niña effects during December through February.

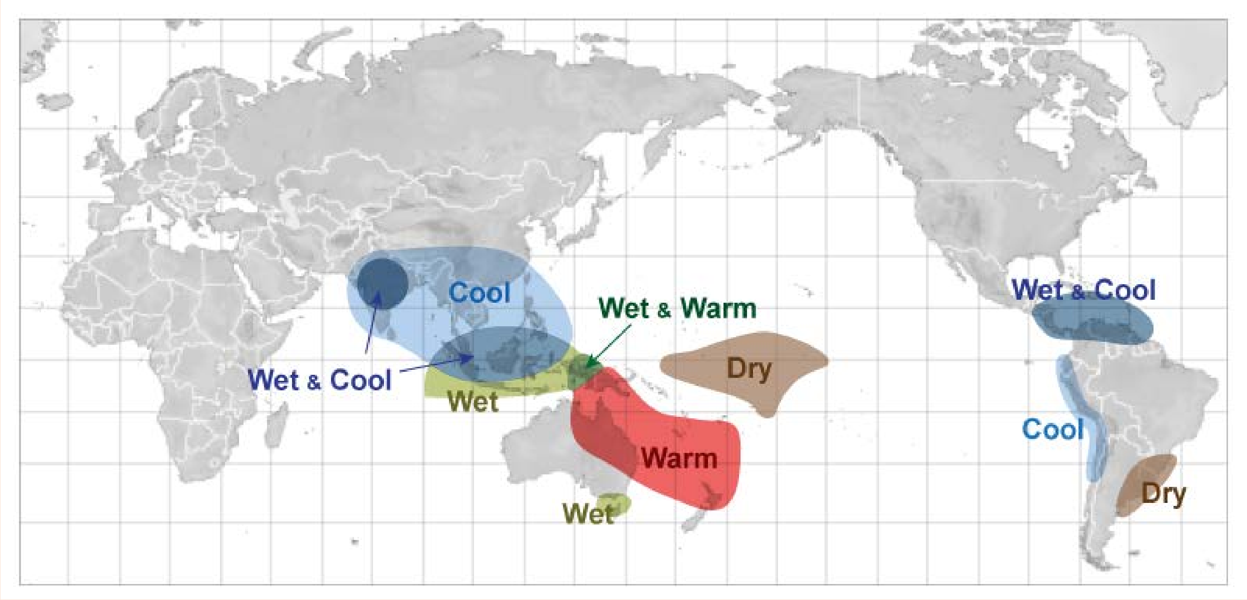


Figure 11.8 (d) La Niña effects during June through August.

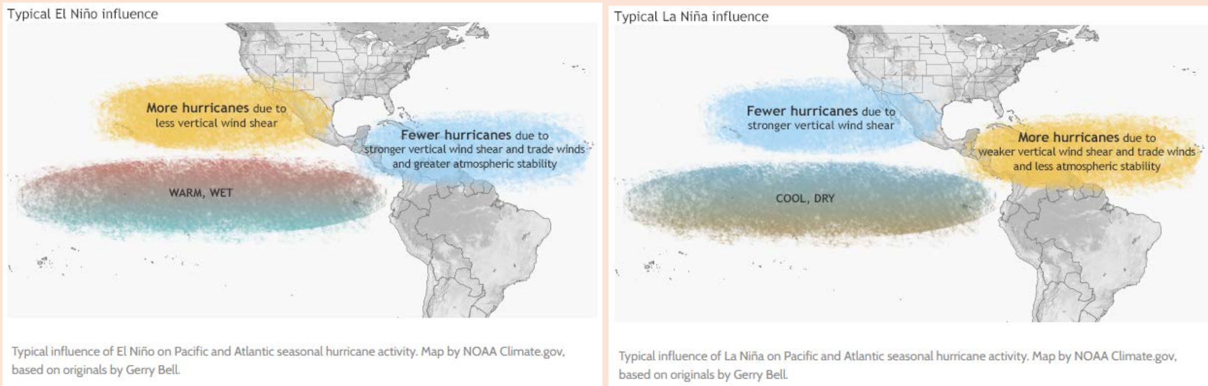
The reader is referred to the book, El Nino, cited at the end of this chapter which describes how broad and significant the human affects of ENSO are. Also see https://oceanservice.noaa.gov/facts/ninonina.html .

The effect of ENSO on tropical cyclones is shown in Table 11.1. The impacts of ENSO on the hurricane season in the Atlantic and eastern Pacific are shown in Figure 11.9.

From Australia Bureau of Meteorology

Region		El Niño Years		Non-El Niño Years	
		Number of Storms	Intensity	Number of Storms	Intensity
North Atlantic		Large Decrease	Small Decrease	Small Increase	Small Increase
Eastern North Pacific		Slight Increase	Increase	Slight Decrease	Decrease
Western North Pacific	Eastern half	Increase	No Change	Decrease	No Change
	Western half	Decrease	No Change	Increase	No Change
Indian Ocean (North / South)		No Change	No Change	No Change	No Change
Australian Region	Western	Slight Decrease	No Change	Slight Increase	No Change
	Central and East	Decrease	Slight Decrease	Increase	Slight Increase
South / Central Pacific (>160°E)		Increase	Increase	Decrease	Slight Decrease

Table 11.1 Effect of ENSO on tropical cyclones.



Typical influence of El Niño on Pacific and Atlantic seasonal hurricane activity. Map by NOAA Climate.gov, based on originals by Gerry Bell.

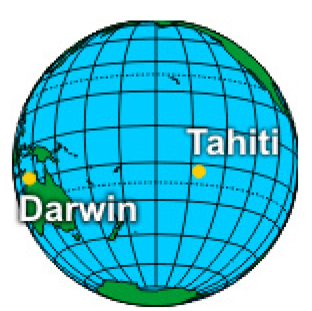
Typical influence of La Niña on Pacific and Atlantic seasonal hurricane activity. Map by NOAA Climate.gov, based on originals by Gerry Bell.

Figure 11.9 The impacts of ENSO on the hurricane season in the Atlantic and eastern Pacific from https://www.climate.gov/news-features/blogs/enso/impacts-el-ni%C3%B1o-and-la-ni%C3%B1a-hurricane-season.

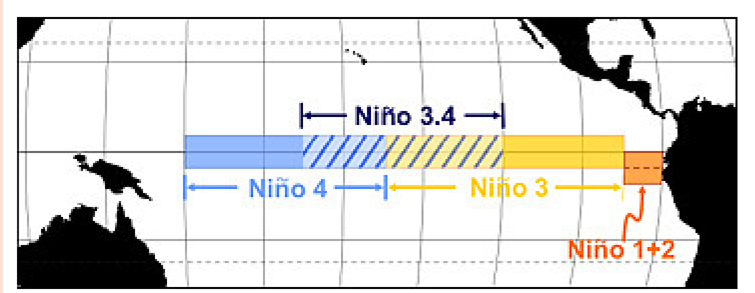
11.6 Prediction of ENSO events

The ability to predict changes in ENSO condition is very important because of its effect on regional climate and ocean characteristics. This is performed by monitoring the sea surface temperature (SST) in the Niño 3.4 zone and the Southern Oscillation Index (SOI) which is based on atmospheric pressure differences between Tahiti and Darwin, Australia (See Figure 11.10.). The SOI is a mathematical way of smoothing the daily fluctuations in air pressure between Tahiti and Darwin and standardizing the information. The use of this information to predict and confirm El Niño and La Niña events is illustrated in Figure 11.11.

The National Oceanic Atmospheric Administration uses the Oceanic Niño Index (ONI). The ONI is based on SST departures from average in the Niño 3.4 region, and is a principal measure for monitoring, assessing, and predicting ENSO. Defined as the three-month running-mean SST departures in the Niño 3.4 region. The use of the ONI is shown in Figure 11.12. If the ONI is equal to +0.5 or greater an El Niño is occurring or forecast. If the ONI is equal to or less than -0.5 La Niña is occurring or forecast.



The locations of Tahiti and Darwin, Australia.



Location of El Niño monitoring zones

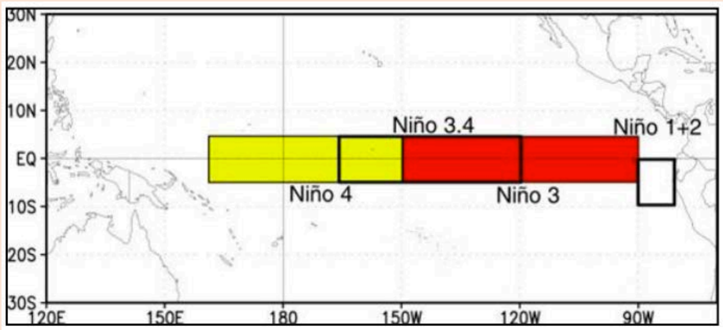


Figure 11.10 Niño regions and locations where atmospheric pressure is monitored to calculate the SOI. https://www.weather.gov/jetstream/enso

The two graphs (right) show this correlation. The top graph shows the change in water temperature from normal for Niño 3.4. The bottom graph shows the southern oscillation index for the same period.

When the pressure in Tahiti is *lower* than Darwin, Australia the temperature in Niño 3.4 is *higher* than normal and El Niño is occurring; the warm episode of ENSO.

Conversely, when the pressure in Tahiti is *higher* than Darwin, Australia the temperature in Niño 3.4 is *lower* than normal and La Niña is occurring; the cool episode of ENSO.

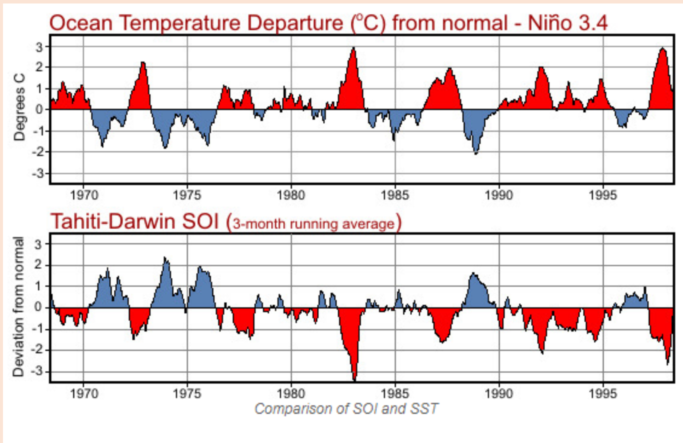


Figure 11.11 Prediction and confirmation of El Niño and La Niña events based on SST in Niño 3.4 and the SOI. https://www.weather.gov/jetstream/enso

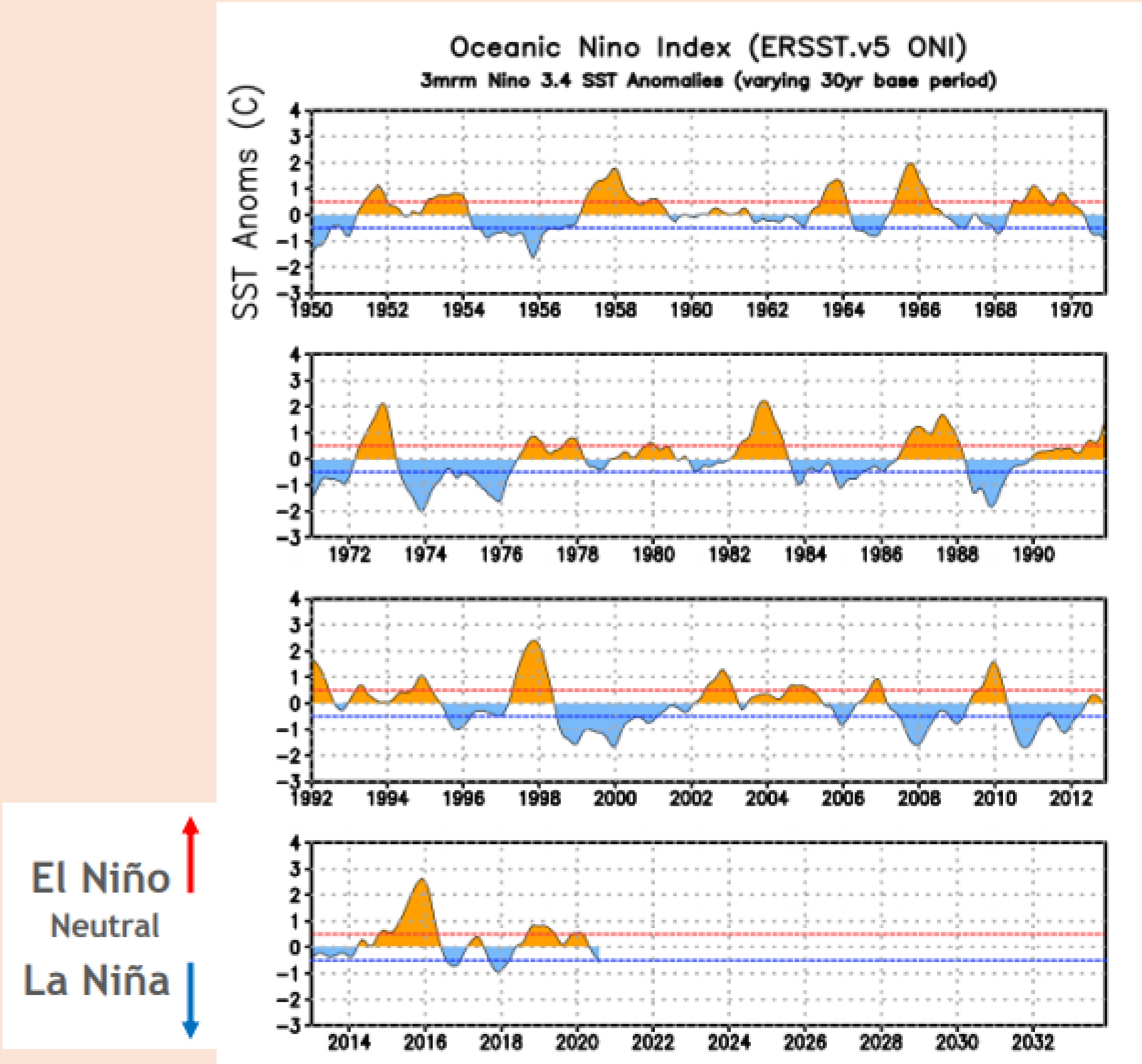


Figure 11.12 The use of the Oceanic Nino Index for predicting El Niño and La Niña events from https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina/enso_evolution-status-fcsts-web.pdf.

There are several other oscillations in Earth's ocean and atmosphere system that occur in a variety of geographic and time scales. These include:

- Antarctic Oscillation (AAO),
- Arctic Oscillation (AO),
- Atlantic Multidecadal Oscillation (AMO),
- Indian Ocean Dipole (IOD),
- Madden-Julian Oscillation (MJO),
- North Atlantic Oscillation (NAO),

- North Pacific Gyre Oscillation (NPGO),
- North Pacific Oscillation NPO),
- Pacific Decadal Oscillation (PDO), and the
- Pacific-North American (PNA) Pattern.

All of the oscillations are subjects of intensive research to explain their causes, effects, occurrence and what their interrelationships might be.

A very important question: Is climate change affecting the oscillations?

A recent study of the Gulf Stream and the larger Atlantic Ocean circulation known as the Atlantic Meridional Ocean Current or AMOC suggests that there is evidence (approximately 1500 years of proxy data) that the circulation is weakening https://www.pik-potsdam.de/en/news/latest-news/gulf-stream-system-at-its-weakest-in-over-a-millennium . A very good description of the AMOC, with animation, was recently published by the New York Times, https://www.nytimes.com/interactive/2021/03/02/climate/atlantic-ocean-climate-change.html?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20210303&utm_medium=email&utm_source=Revue%20Daily . The complexity of the circulation and how little is actually known about it is emphasized. It is suggested that the melting of the Greenland Ice Sheet is a likely cause for the weakening, if it is in fact weakening. A weakening AMOC would change the climate of northern Europe, cause warming of southern regions of the Atlantic with the result of drier conditions in the Sahel region of Africa and more frequent severe hurricanes. Because the AMOC is a large part of the 'ocean conveyor' the effects of its weakening would be global.

A study reported in the journal Nature Geoscience, (https://www.nature.com/articles/s41561-021-00730-3?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20210416&utm_medium=email&utm_source=Revue%20Daily) and in the Journal of Climate (https://journals.ametsoc.org/view/journals/clim/27/24/jcli-d-14-00254.1.xml) describe how ENSO induced teleconnections over the North Pacific and North America may be intensified in response to greenhouse warming. A paper published in the journal, Nature Climate Change, in August 26, 2021 titled Future high-resolution El Nino/ Southern Oscillation dynamics describes present advances in modelling the ENSO phenomena https://www.nature.com/articles/s41558-021-01132-4?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20210827&utm_medium=email&utm_source=Revue%20Daily .

A publication by the World Meteorological Organization (WMO), El Nino/ Southern Oscillation, https://library.wmo.int/doc_num.php?explnum_id=7888, is a useful overview.

11.7 Information support

Key web sites:

1. El Niño. https://earthobservatory.nasa.gov/features/ElNino

2. What happens in the atmosphere during El Niño. https://psl.noaa.gov/enso/enso.description.html

3. El Niño/Southern Oscillation (ENSO) technical discussion. https://www.ncdc.noaa.gov/teleconnections/enso/enso-tech.php#:~:text=Although%20the%20exact%20initiating%20causes,across%20the%20equatorial%20Pacific%20weaken.

4. El Niño and other oscillations. https://www.whoi.edu/know-your-ocean/ocean-topics/ocean-circulation/el-nio-other-oscillations/

5. El Niño – Southern Oscillation. https://en.wikipedia.org/wiki/El_Ni%C3%B1o%E2%80%93Southern_Oscillation

6. Humboldt Current. https://en.wikipedia.org/wiki/Humboldt_Current#:~:text=The%20Humboldt%20Current%2C%20also%20called,310%E2%80%93620%20mi)%20o

7. Teleconnections. https://www.ncdc.noaa.gov/teleconnections/

8. Walker circulation. https://en.wikipedia.org/wiki/Walker_circulation

9. The Walker cell and ENSO. https://www.eoas.ubc.ca/courses/atsc113/sailing/met_concepts/09-met-winds/9c-walker-cell-enso/

10. Impacts of ENSO. https://www.pmel.noaa.gov/elnino/impacts-of-el-nino

11. ENSO advisory. https://www.climate.gov/enso

12. ENSO forecast. https://www.weather.gov/jetstream/enso

13. Weather impacts of ENSO. https://www.noaa.gov/jetstream/enso_impacts

14. What are El Nino and La Nina? NOAA. https://oceanservice.noaa.gov/facts/ninonina.html

15. Effects of ENSO in the Pacific. https://www.weather.gov/jetstream/enso_patterns

16. El Nino Theme Page, Pacific Marine Environmental Laboratory, NOAA. https://www.pmel.noaa.gov/elnino/

17. Impacts of El Nino and La Nina on the hurricane season. https://www.climate.gov/news-features/blogs/enso/impacts-el-ni%C3%B1o-and-la-ni%C3%B1a-hurricane-season

18. Peru current. https://www.britannica.com/place/Peru-Current

19. ENSO: Recent evolution, current status and predictions. https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina/enso_evolution-status-fcsts-web.pdf

20. Atlantic Meridional Ocean Circulation, AMOC. https://www.pik-potsdam.de/en/news/latest-news/gulf-stream-system-at-its-weakest-in-over-a-millennium

21. Atlantic Meridional Ocean Circulation, AMOC. https://www.nytimes.com/interactive/2021/03/02/climate/atlantic-ocean-climate-change.html?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20210303&utm_medium=email&utm_source=Revue%20Daily

22. El Nino intensification induced by anomalies under greenhouse warming, Nature Geoscience. https://www.nature.com/articles/s41561-021-00730-3?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20210416&utm_medium=email&utm_source=Revue%20Daily

23. Global warming induced changes in El Nino teleconnections over the North Pacific and North America, Journal of Climate. https://journals.ametsoc.org/view/journals/clim/27/24/jcli-d-14-00254.1.xml

24. El Nino/ Southern Oscillation, World Meteorological Organization. https://library.wmo.int/doc_num.php?explnum_id=7888

25. Future high-resolution El Nino/ Southern Oscillation, Wengel, C., Lee, S. S., Stuecker, M. F., Timmermann, A.,, Chu, J. E., and Schloesser, F., https://www.nature.com/articles/s41558-021-01132-4?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20210827&utm_medium=email&utm_source=Revue%20Daily

Books:

1. Nash, J. Madeleine, 2002. El Niño, Unlocking the Secrets of the Master Weather-Maker, Warner Books, New York, USA, 348 pp.

2. Sarachik, Edward S. and Cane, Mark A., 2010. The El Niño-Southern Oscillation Phenomenon, Cambridge University Press, Cambridge, United Kingdom, 377 pp.

Videos:

1. https://www.youtube.com/watch?v=dzat16LMtQk
2. https://www.youtube.com/watch?v=WPA-KpldDVc
3. https://www.youtube.com/watch?v=J6hOVatamYs