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THE SOCIAL IMPACTS OF THE EL-NIÑO/SOUTHERN OSCILLATION CYCLE

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Introduction

The El-Nino/Southern Oscillation, or ENSO, cycle affects human communities around the world, particularly in the Pacific Basin. The ENSO cycle influences already existing climate patterns, affecting meteorological patterns across the Pacific and around the world. The first section of this paper, *Mechanics of the ENSO Cycle*, explains how the ENSO cycle affects the climate patterns of the Pacific Ocean. Within the section are five subsections. The first, *Pacific Climate Patterns*, explains the meteorological and oceanic mechanisms of the Pacific Ocean. The second subsection, *Anatomy of the ENSO Cycle*, describes the air-sea interactions that characterize the ENSO cycle. The third subsection, *Variability of the ENSO Cycle*, describes how the ENSO cycle has changed in the past and may change in the future. The fourth subsection, *Interdependence of Climate Factors*, investigates the causality of the ENSO cycle and its relation to global climate change. The final subsection, *Meteorological Effects of the ENSO cycle on the Pacific Basin*, summarizes the effects of the ENSO cycle on rainfall and temperature patterns across the Pacific Basin.

The meteorological effects of the ENSO cycle in turn impact human communities in both direct and indirect ways. The second section of this paper, *Social Impacts of the ENSO cycle*, describes how ENSO's meteorological effects impact the people of the Pacific Basin. Drought, flooding, economic collapse and epidemics are some of the social impacts of the ENSO cycle to particularly vulnerable communities. The second section of this paper is broken up into five subsections. The first four subsections, *Impact of ENSO on Public Health*, *Impact of ENSO on Public Safety*, *Impact of ENSO on Pacific Ecosystems*, and *Impact of ENSO on Pacific Economies*, describe the health-related, disaster-related, ecological, and economic impacts of the ENSO cycle in the Pacific, respectively. The final subsection, *Factors Affecting the Severity*

of ENSO's Human Impact, investigates the causes of ENSO's varying effects on society, specifically what factors contribute toward the most severe impacts. The climatic disruptions induced by the ENSO cycle have immense social impact across the Pacific Basin. Consequently, understanding the ENSO cycle and its effects is vital to being able to respond to ENSO's impact on humanity.

Mechanics of the ENSO Cycle

The climate of the Pacific is a highly complex system that must be understood as a prerequisite to understanding the ENSO cycle. The ENSO cycle is characterized by specific mechanisms and processes that dominate the behavior of the Pacific climate system. These mechanisms cause the atmospheric and oceanic processes of the Pacific to oscillate between ENSO's two extremes, El Niño and La Niña. The ENSO cycle is extremely complex and difficult to predict because of the interconnected nature of the processes and mechanisms of ENSO and the Pacific Climate system. Because of this complexity it is important to first understand the climatic mechanisms of the Pacific before analyzing the ENSO cycle itself.

Pacific Climatic Patterns

An understanding of the ENSO cycle depends on a working knowledge of the physical mechanisms of Pacific climate.. The mechanisms that dominate air and water flow in the Pacific are complex and interdependent, and are critical to understanding Pacific climate. Wind and temperature patterns and oceanic circulation, including upwelling, greatly each affect the Pacific climate in different and interconnected ways. The mechanisms that affect Pacific climate are so interdependent it is almost impossible to determine causality. This makes the climate system very difficult to model, and it must be understood that the following explanations assume that the mechanisms are much simpler than they truly are. The details of the behavior and interactions of the mechanisms of the Pacific Climate system are explained in the following sections.

The Coriolis Effect and Global Air Patterns

The climate patterns of the Pacific basin are largely driven by a specific set of wind patterns. Because equatorial regions receive more solar energy than the Polar Regions, regional differences in solar heating create a meridional (latitudinal) pressure gradient with high pressure at the poles and low pressure at the equator. As the Earth's axis is tilted relative to its orbit, the amount of sunlight reaching the higher latitudes changes with the seasons. However the amount of sunlight reaching the equatorial region is consistently strong, so over a year the equator receives more sunlight than the poles. Because more of the sun's rays reach the earth at the equator than at the poles, the earth's atmosphere is warmer there. The warmer air at the equator is less dense than at the poles, so there are more air molecules above someone standing at the North Pole than at the equator. The weight of the air molecules above us is what causes atmospheric pressure, so there is greater air pressure at the poles than at the equator (Tomczak & Godfrey 2003). A fluid such as air will flow from the area of highest pressure to the area of lowest pressure. If the earth were not rotating and there were no continents, this would create two large convection "cells", or loops, with air sweeping from the poles to the equator, getting heated by the sun, rising due to its lower density, and journeying back to the poles to descend and start the process all over again (Tomczak & Godfrey 2003). This phenomenon, however, does not happen. The rotation of the earth and the presence of continents break the super cells into smaller convection cells.

The earth's rotation influences the behavior of all moving objects when viewed with respect to the earth. This influence is known as the Coriolis Effect, and is an artifact of measuring motion from a rotating coordinate system. Every object on the surface of the earth has the same speed of rotation about the Earth's axis, but their straight-line speeds through space may be different. As linear speed through space of an object revolving about an axis is

proportional to the rotational speed times the radius to the axis of revolution, objects closer to the earth's axis are moving slower than objects farther away. Therefore the linear speed through space is greatest at the equator and negligible at the poles. The result of this is that objects that travel along the earth's surface in a northern or southern direction experience the Coriolis Effect because the linear speed of the surface of the earth is changing below them.

An example of this would be if two people played catch across the northern hemisphere. For example, If Person A was on the North Pole, and Person B was standing on the Equator, and they were to attempt to play catch, Person B would throw a baseball due north. The baseball will have a northward velocity from Person B's throw and an eastward velocity caused by the movement of the earth rotating about its axis. As the baseball approaches Person A on the North Pole, it maintains the eastward velocity that it had at its starting point over the equator. However, as an object moves toward one of the poles, its distance from the earth's axis decreases. So as the baseball flies northward the linear speed of the earth's surface beneath it is getting slower and slower. The earth is still spinning the same speed but because the distance to the earth's axis is decreasing, the linear speed of any point on the earth is less than at the equator. So the farther the baseball goes north the greater the difference between the baseball's velocity and the ground's velocity, causing the baseball to "deflect" to the right, or eastward in this case.

At the north pole, Person A, who is completely stationary and spinning about the earth's axis, and will never see the baseball as it will land far eastward of its intended target. If Person A then took another baseball and tried to throw it to Person B, the same phenomenon would happen. Person A's baseball would have a southern velocity but no velocity at all in the east-west direction. By the time it reaches the equator where Person B is hurtling around the earth's

axis at considerable speed, Person B will be east of ball, inducing a “deflection” of the ball’s path to the right, just as when Person B threw the ball to Person A.

This phenomenon also exists in the southern hemisphere, although because the deflection is measured with respect to the object and not to the earth, it has been observed that objects are deflected to the right in the northern hemisphere and to the left in the southern hemisphere, as shown below in Figure 1.

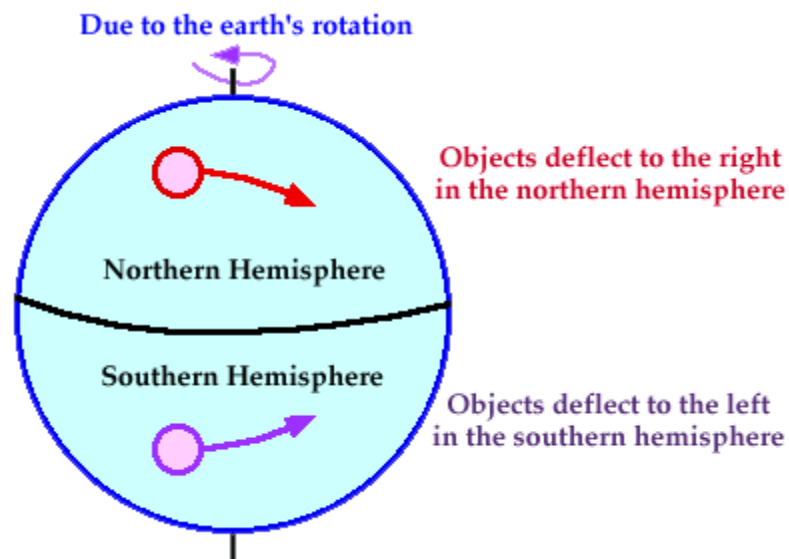


Figure 1: The Coriolis Effect in the Northern and Southern Hemispheres
Source: Hall 2010

The Coriolis Effect is primarily responsible for the breaking up of the two theoretical super convection cells into the smaller Hadley cells. The Coriolis Effect causes air to move eastward relative to the surface of the earth to such an extent that the air mass’s meridional movement is eclipsed by its zonal (longitudinal) movement (Tomczak & Godfrey 2003). This in turn creates atmospheric disturbances in the form of the low pressure systems at about 65° N and S Latitude. These systems reverse the atmospheric pressure gradient, breaking up the two

fictional hemispheric convection cells into six major cells, called Hadley Cells. The six Hadley cells can be observed in Figure 2. Additionally, from the wind patterns in Figure 1 it can be observed that all of the wind patterns in the northern hemisphere have been deflected to the right from straight north or south and all wind patterns in the southern hemisphere have likewise been deflected to the left of straight north or south.

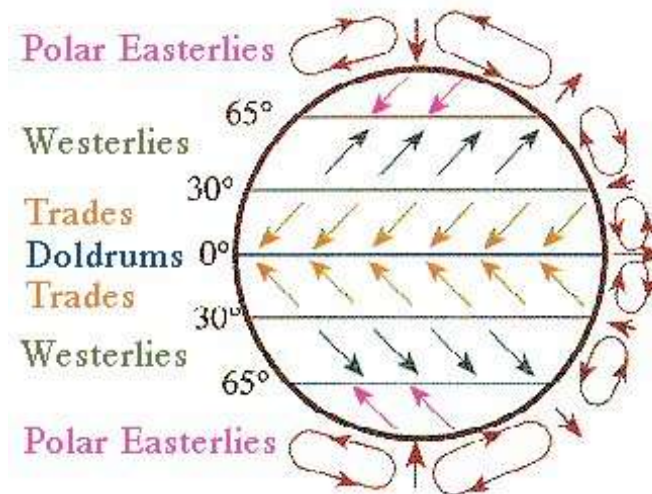


Figure 2: Convection Cells and Major Wind Patterns
Source: Tomczak & Godfrey 2003

Air and Water Movement in the Central Pacific

Hadley cells in the Central Pacific induce the NE and SE trade winds, which are important features of the Equatorial Pacific climate. The Hadley cells between 0° and 30° induce winds blowing toward the equator, which are deflected by the Coriolis Effect to blow from the NE and SE. It is worth note that the NE trades blow toward the Southwest, NE referring to the direction the wind is *coming from*, not going. The trade winds are the dominant atmospheric feature of the Central Pacific, driving the Northern and Southern Equatorial currents steadily westward as well as atmospheric weather systems. The Central Pacific's Zonal (latitudinal) air circulation is fueled by the Sun. The Sun heats up the surface layers of the Ocean. The warm

water is pushed westward by the trade winds. Because of the high heat capacity of water, the warm water accumulated in the Western Pacific greatly affects the air directly above it (D'Aleo 2002). Energy flows from the water to the air, which becomes less dense and rises, creating clouds and rain. Having lost most of its moisture to cloud formation, the air is then pushed eastward by a zonal pressure gradient in the upper atmosphere. The eastward-flowing air then cools and descends to complete the zonal convection cell (Glantz 1996). This zonal convective loop is called Walker Circulation, shown in Figure 3.

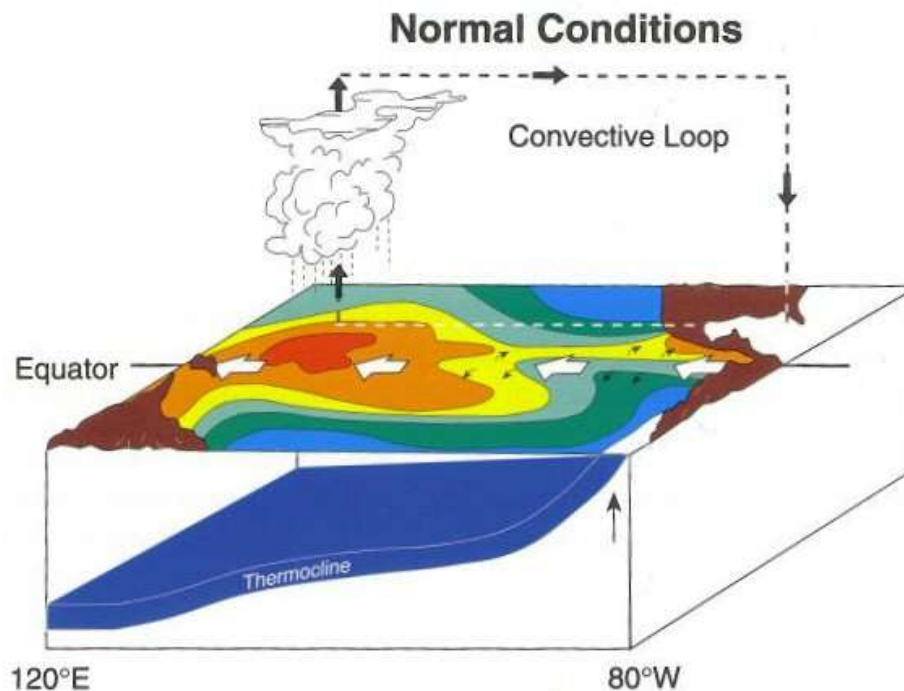


Figure 3: Walker Circulation
Source: Allan et al 1996

The convergence of the NE and SE trades near the equator creates an area of meteorological instability without consistent wind patterns. Known as the Intertropical Convergence Zone or ITCZ, this phenomenon is a major characteristic of the Pacific climate system. In general, convergence zones are characterized by low winds, warm water, and high rainfall. They are formed when wind patterns converge and push air upward, which loses its

moisture in the form of rain (Tomczak & Godfrey 2003). In the case of the ITCZ, the convergence of the trade winds causes the air to rise, which is then driven away from the equator as part of the Hadley cell system. The ITCZ is not fixed at the equator but is driven northward and southward by climatic fluctuations and local weather. In the Pacific the ITCZ is usually a few degrees north of the Equator (Tomczak & Godfrey 2003). The ITCZ spans the globe but is best observed in the world's largest ocean, the Pacific, as shown in Figure 4 (Allan et al 1996).

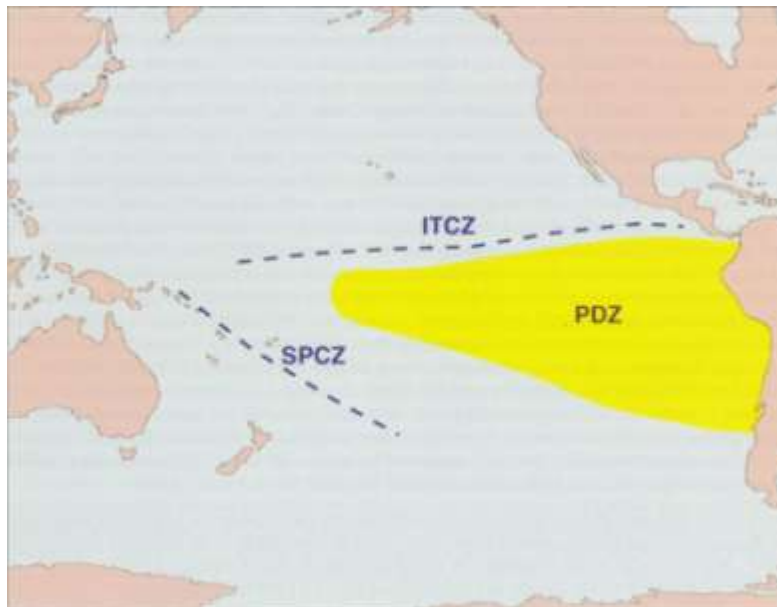


Figure 4: The Intertropical Convergence Zone, South Pacific Convergence Zone, and Pacific Dry Zone shown in their annual mean positions in the Pacific Basin

Source: Allan et al 1996

The ITCZ is not the only major convergence zone in the Pacific, the South Pacific Convergence Zone, or SPCZ, spans from about 30°S, 120° West to near the coast of New Guinea where it merges with the ITCZ (Vincent 1994). The SPCZ is formed by warm air rising from the warm water in the southwestern Pacific. The specific drivers of the phenomenon are not fully known, but it has been observed that annually there is the most rain over the areas of the Pacific

that are the warmest (Tomczak & Godfrey 2003). This increased rainfall is indicative of warm air rising and losing its moisture in the form of rain. When the sea surface temperature is higher, more energy is transferred to the air, which causes more air to rise, which increases the rainfall as more air sheds its moisture as rain.

The Pacific Dry Zone, or PDZ, covers most of the Eastern Pacific and characterizes much of the climate in that region. Most of the Pacific Ocean west of the SPCZ and south of the ITCZ is within the Pacific Dry Zone, as shown in Figure 4. The Pacific dry zone is characterized by steady winds, few clouds, and little rain. Though the specific set of factors leading to the formation of the PDZ are not fully understood, Hastenrath (1999) theorized that its conditions are connected to the Walker circulation present in the equatorial region.

Ocean Circulation

The major currents of the Pacific Ocean play a significant role in Pacific climate. The Pacific's system of currents transports water and heat around the Pacific Ocean, greatly influencing the climate patterns observed. As the El Niño/Southern Oscillation is most strongly tied to the processes in the Central Pacific, the focus of this section will be on the major currents of the Central Pacific (Philander 1996). As shown in Figure 5, the major currents of the Central Pacific Ocean are the North Equatorial Countercurrent (NECC), North Equatorial Current (NEC), and South Equatorial Current (SEC). The Equatorial Undercurrent (EUC), not shown in Figure 5, also plays an important role in water mass and heat transfer in the Central Pacific.

The Northern Equatorial Countercurrent, or NECC, plays a key role in the dynamics of the Central Pacific climate system and equatorial water mass transport. It is fed by the coastal eddies north of New Guinea and flows eastward to the waters off of South America. Over most

of this distance the current is positioned at about 5° N, the same approximate latitude of the ITCZ in the Pacific. NECC is the only major surface current in the Central Pacific that flows contrary to the direction of the trade winds, a phenomenon made possible by the weak winds of the ITCZ under which the NECC usually flows (Tomczak & Godfrey 2003).

The North Equatorial Current, or NEC, plays a key role in the dynamics of the Central Pacific climate system and equatorial water mass transport. Unlike the pressure gradient driven NECC, the NEC is primarily wind driven. The NEC is pushed west by the NE trade winds and is very sensitive to the seasonal and interannual fluctuations in those winds (Tomczak & Godfrey 2003). The NEC typically flows just north of 10° N latitude, flowing from the western coast of Central America to the southern tip of the Philippines (Philander, 1990).

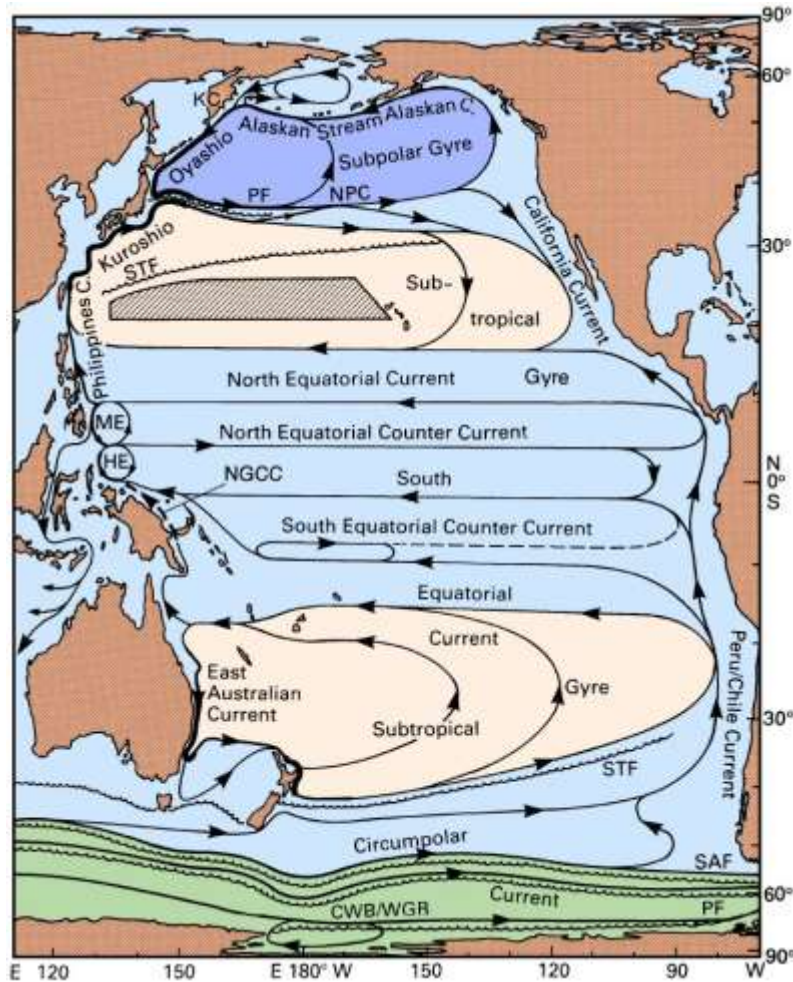


Figure 5: The Major Currents of the Pacific

Source: Tomczak & Godfrey 2003

The South Equatorial Current, or SEC, also plays a key role in the dynamics of the Central Pacific climate system and equatorial water mass transport. Like the NEC, the SEC is also driven primarily by wind. The SEC is pushed west by the SE trade winds and is very sensitive to the seasonal and interannual fluctuations in those winds (Tomczak & Godfrey 2003). The SEC typically flows just south of 3° N latitude, flowing from the western coast of Central America to the southern tip of the Philippines (Philander, 1990).

The last major water movement in the Central Pacific Ocean is the Equatorial Undercurrent, or EUC. The EUC is not a surface current, but an eastward-flowing, subsurface current of water at the equator. This 14,000 kilometer-long flow is about 200 meters thick and has a width of up to 400 kilometers. The EUC is driven by the pressure gradient created by water accumulated in the Western Pacific due to the trade winds, the SEC, and the NEC. The trade winds and associated currents raise the sea level of the Western Pacific with respect to the Eastern Pacific, creating a zonal pressure gradient. In response to this gradient the water in the Western Pacific flows “downhill” to the east. This phenomenon is shown in Figure 6 (Tomczak & Godfrey 2003).

Understanding the currents of the Pacific Ocean is critical to an understanding of the ENSO cycle. The ENSO cycle has a considerable effect upon the flow of water and heat around the Pacific, and can greatly disrupt the typical current system of the Pacific. The full effect of the ENSO cycle on water movement in the Pacific is discussed in *ENSO's Effect on Heat and Water Transport* under the *Mechanics of the ENSO Cycle* section of this paper.

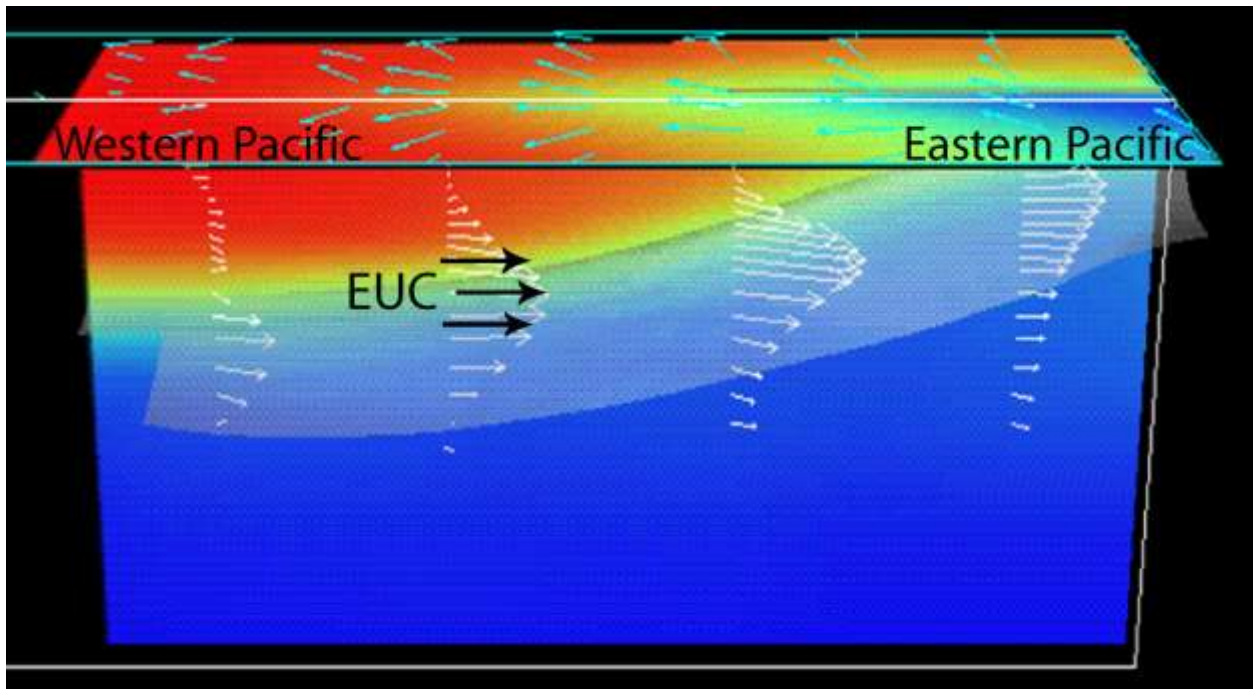


Figure 6: The Equatorial Undercurrent (EUC)

Source: American Samoa & the Pacific Remote Islands 2010

Upwelling of Subsurface Water Masses

The upwelling of deeper water masses in the Central and Eastern Pacific play a key role in the ocean's climate and the ENSO cycle. Oceanic and atmospheric processes induce the upwelling of cold, deep subsurface water masses toward the surface. The upwelling of cold water to the surface greatly affects meteorological, biological, and oceanic processes. The rising deep water carries nutrients to the surface and induces mixing throughout the water column, a process of great benefit to the ecological productivity, including fishery yields, of the region. The upwelling water also greatly affects the temperature and pressure gradients that drive the meteorological and oceanic processes of the Pacific Climate system.

To understand the basic principles of upwelling in the Pacific Ocean the hydrography of the ocean must first be understood. The waters of the Pacific Ocean are divided into distinct bodies, known as water masses, with specific properties. The salinity, temperature and dissolved oxygen content of a water mass is linked to the conditions of the water mass's formation (Anderson et al 2010). Generally, water masses maintain the temperature, salinity, and dissolved oxygen content that they had at their formation. The temperature and salinity each affect the density of the water. Colder temperatures and higher salinities make water denser, while warmer temperatures and lower salinities make water less dense. Additionally, differences in density between water masses caused by salinity and temperature differences inhibit mixing, preserving the existence of discrete separate water masses.

If a body of water is not disturbed by wind or turbulence, Water that is cold and salty will sink and water that is warm and less salty will float. Because the ocean's primary source of heat is the sun, water is heated at the surface. The water effected by the sun's rays heat up and become less dense, creating layers of increasingly warm water as depth decreases. This is called stratification, and it is most evident in areas with low winds and high temperatures.

The major water masses of the Central Pacific Ocean are the North Pacific Equatorial Water, or NPEW, the South Pacific Equatorial Water, or SPEW, Antarctic Bottom Water, or AABW, Antarctic Intermediate Water, or AAIW, Pacific Deep Water, or PDW, and subtropical Central Water (Tomczak & Godfrey 2003). The deeper water masses are shown in a meridional cross-section of the Pacific Ocean in Figure 7.

Differences in density inhibit the mixing of water masses at their boundary. The boundary is most defined between surface water masses and deeper water masses, where it is called the thermocline. The thermocline is the contact point between warm surface water and

cold, salty deepwater. It is at the thermocline that the salinity and temperature changes the greatest with depth. The depth of the thermocline is a good indicator of how much warm water is present on the surface. A deeper thermocline generally corresponds with warmer surface temperatures and a greater volume of warm water near the surface (Anderson et al 2010).

Each of these water masses has specific properties determined by the conditions of their formation. When upwelling brings a deeper water mass toward the surface the water mass brings with it its intrinsic properties, affecting the air-sea interactions at the surface.

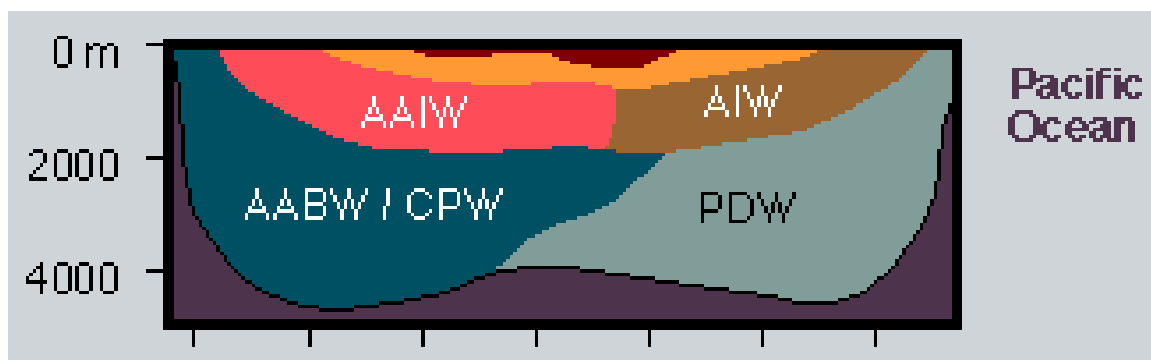


Figure 7: Deep Water Masses of the Pacific Ocean

Source: An Introduction to Physical Oceanography 2002

The upwelling of subsurface water masses is an important oceanographic process that directly affects the Pacific climate system and the communities dependent on it. This phenomenon has numerous manifestations, the most important being two zones of upwelling in the Central Equatorial Pacific and on the Peruvian Coast. Peruvian and Equatorial upwelling, while both having significant importance to the Pacific climate, are driven by markedly different mechanisms.

Peruvian upwelling is an example of a phenomenon known as “coastal” upwelling, and is caused by atmospheric and oceanic pressure gradients. Under normal (mean) conditions in the Pacific Ocean, the trade winds push a substantial amount of warm surface water westward, reducing the depth of the surface water mass in the East. The westward-bound water is replaced by cool, deep water upwelling toward the surface (Pinet 1992).

Peruvian upwelling serves as an excellent example of how the ocean and atmospheric systems are interconnected. Zonal atmospheric convection (i.e., Walker Circulation) induces the trade winds, which in turn move warm surface water westward, which is replaced by cold subsurface water. The accumulation of warm water in the West Pacific in turn heats up the air in that region, contributing to the atmospheric convection (Segar 1998).

In contrast, equatorial upwelling is caused by trade-wind induced Ekman transport causing warm surface water to be displaced by cold subsurface water. The Coriolis Effect causes water movement to deflect to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The effect of this deflection throughout the water column, called Ekman transport, is manifested as a net flow perpendicular to the direction of the wind-induced surface flow, as shown in Figure 8.

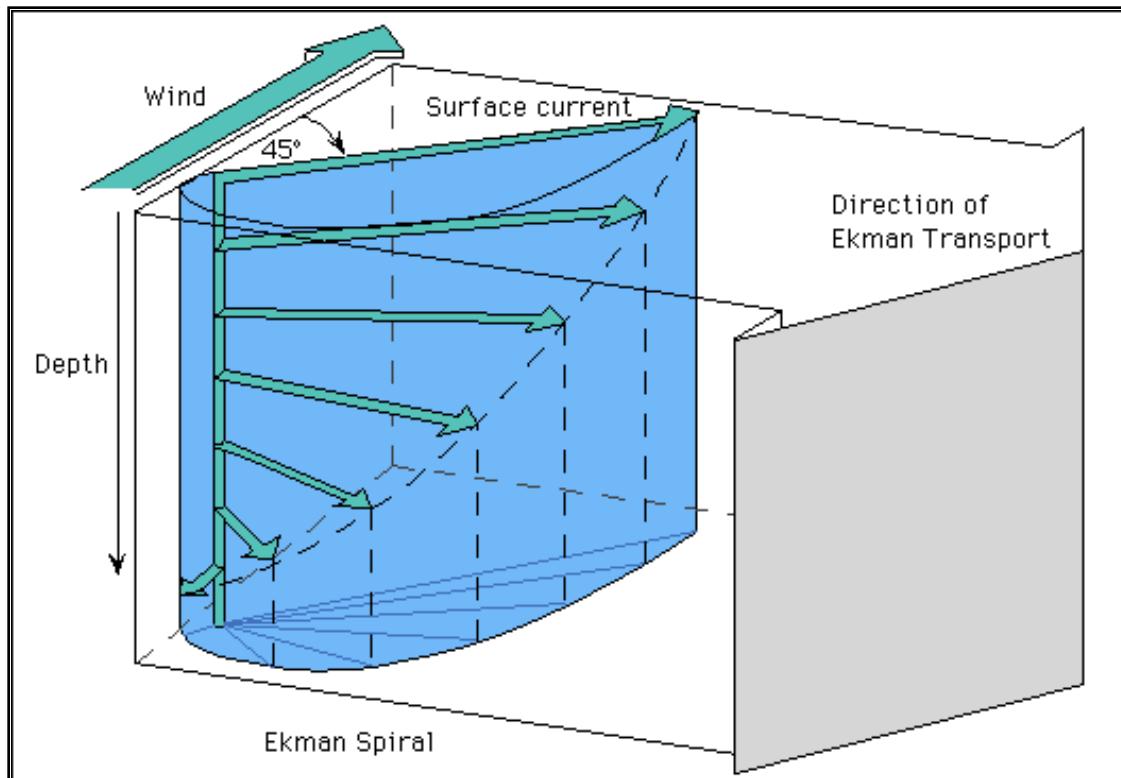


Figure 8: Ekman Transport

Source: Adapted From Thurman 1996

As the trade winds induce Ekman transport to the north and south of the equator, surface water is diverted northward and southward. The surface water is then replaced by colder subsurface water upwelling to take its place. This process is shown in Figure 9. In the Pacific, this creates a band of surface water near the equator that is notably cooler and richer in nutrients than the water just to the north and south of it (Pinet 1992).

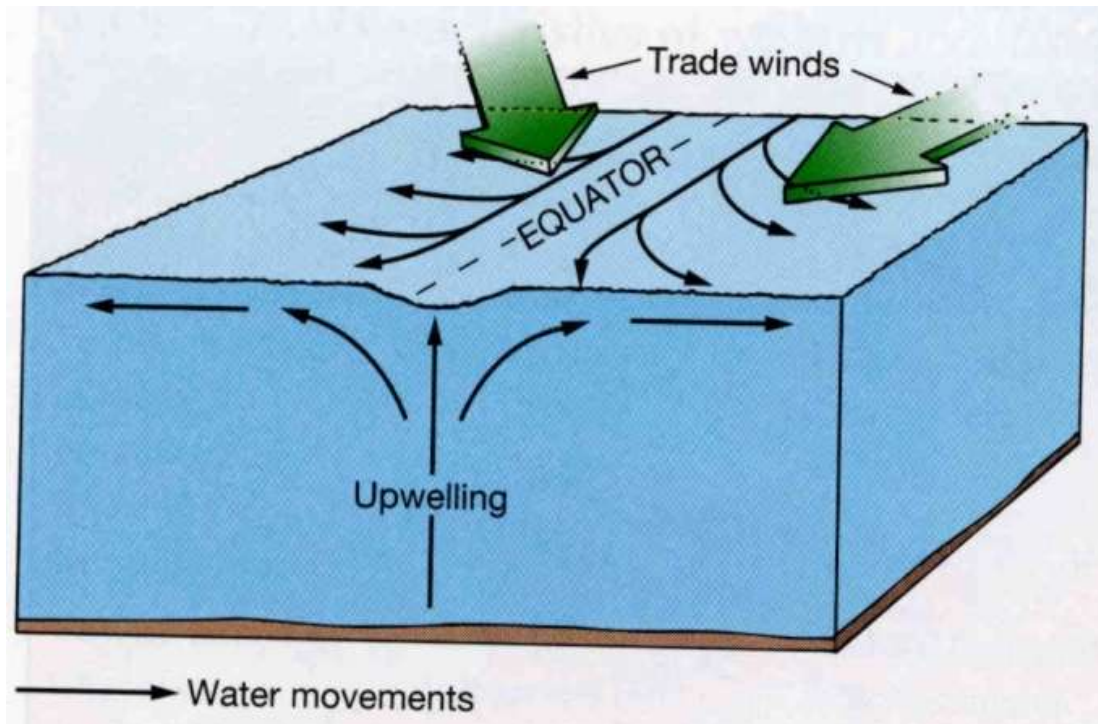


Figure 9: Equatorial Upwelling

Source: Thurman and Trujillo 1999

The upwelling mechanism is important to the Pacific climate system in both of its manifestations. Despite being driven by different processes, both mechanisms have the same effect of bringing cool, nutrient-rich water to the surface. Equatorial and Peruvian upwelling are both key factors in the climatic and ecological systems of the Pacific Ocean, greatly affecting these systems in their regions and the Pacific as a whole.

Anatomy of the ENSO Cycle.

While the El Niño/Southern Oscillation cycle affects climate worldwide, it is controlled by a specific series of air-sea interactions in the central Pacific Ocean. The interaction of atmospheric and oceanic circulation, heat and mass transport, and weather systems of the Pacific

create an oscillating phenomenon that dominates the Pacific climate system. In their regional oceanography textbook, Tomczak & Godfrey (2003) describe the ENSO cycle as “an instability of the coupled ocean-atmosphere system in the tropics”.

Phases of the ENSO cycle

The ENSO cycle can be described as a dynamic oscillating phenomenon consisting of two discrete phases, El Niño and La Niña. These phases are the extremes of a continuous oscillating system. El Niño is one extreme of the system, and La Niña is the other extreme.

During the El Niño extreme of the ENSO cycle, the trade winds weaken, or even reverse direction. The water that was previously pushed westward by the trade winds is then allowed to flow back east, driven by the same oceanic pressure gradients as the Equatorial Undercurrent and North Equatorial Countercurrent (Segar 1998). This warm surface water spreads over the water in the eastern Pacific that is otherwise upwelled by the trade winds. As the trade winds are weakened, they no longer have the power to induce upwelling, leading to a stratification of the water column. The result of this is a period where the Central Pacific Ocean is characterized by weak (or reversed) trade winds, warm SST's, and stratification of the water column in the Central and Eastern Pacific (Philander 1996), which prevents mixing of cold and nutrient-rich deep water with surface waters. This process is shown in Figure 10.

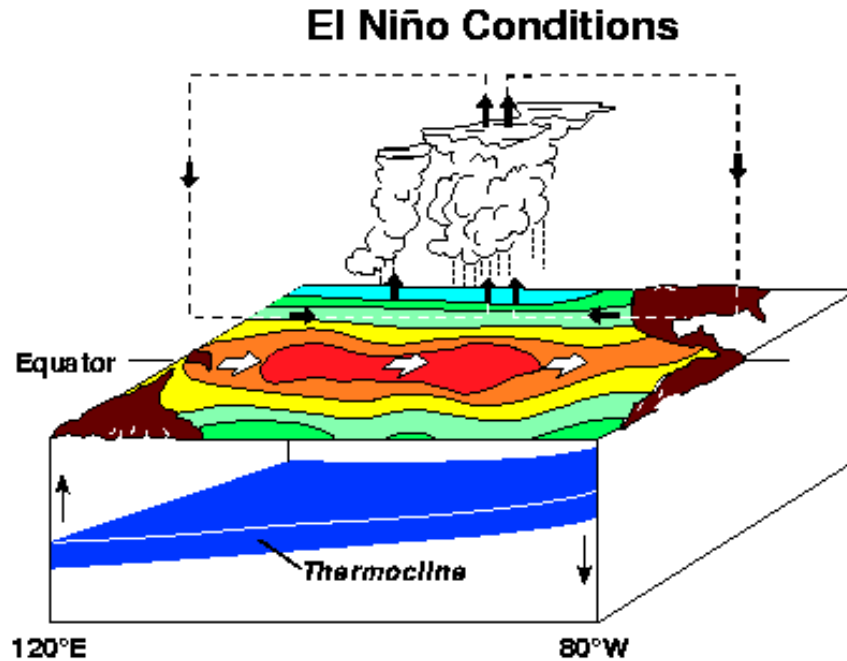


Figure 10: El Niño Conditions

Source: NOAA 2011

During the La Niña phase of the ENSO cycle, the trade winds are strengthened, increasing westward water flow and pulling even more warm surface water from the Eastern Pacific, increasing upwelling in that region. Additionally, the strengthened trade winds increase Ekman transport and therefore Equatorial upwelling in the Central Pacific. This increase in upwelling in turn lowers SST's in the Central and Eastern Pacific (Segar 1998). In summary, La Niña is characterized by strong trade winds, cool SST's and strong upwelling in the Central and Eastern Pacific (Philander 1996), resulting in substantial movement of nutrients from deep to surface waters. This process is shown in Figure 11.

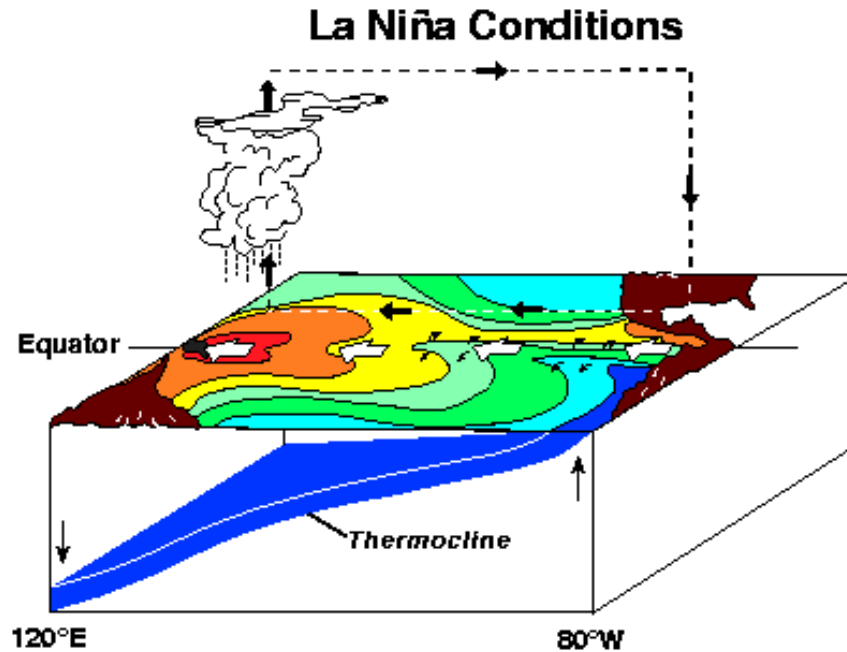


Figure 11: La Niña Conditions

Source: NOAA 2011

ENSO's Effect upon Atmospheric Patterns

The extremes of the ENSO cycle have significant effects on Pacific Climate. The extremes of the ENSO cycle have a significant effect on the intensity of the trade winds. An El Niño Event weakens and can even reverse the trade winds, while a La Niña event strengthens the trade winds. The ENSO cycle's effect on the trade winds is due in most part to its effect upon zonal atmospheric convection. In an El Niño event, the warm water in the Central and Eastern Pacific causes air to heat up and rise in that region, increasing rainfall and shifting the center of the Walker circulation system eastward, as shown in Figure 10 (Glantz 1996). This increased convection strengthens the trade winds.

In a La Niña event, the warm water in the Western Pacific causes air to heat up and rise in that region, increasing rainfall and augmenting the Walker circulation already present over the

Pacific, as seen in Figure 11. This change in zonal circulation weakens the trade winds. The intermediate condition, shown in Figure 3, is physically similar to a La Niña event, but its effects are of a much lower magnitude.

One of the manifestations of the movement of warm surface water and the corresponding updraft of air with associated rains is the movement of the ITCZ and SPCZ. During normal conditions and the La Niña extreme the ITCZ and SPCZ converge in the West Pacific near Indonesia, as shown in Point A of Figure 12. During the El Niño extreme, the SST-updraft-rain system moves eastward such that the convergence of the ITCZ and SPCZ is near Point B in Figure 12 (Tomczak & Godfrey 2003).

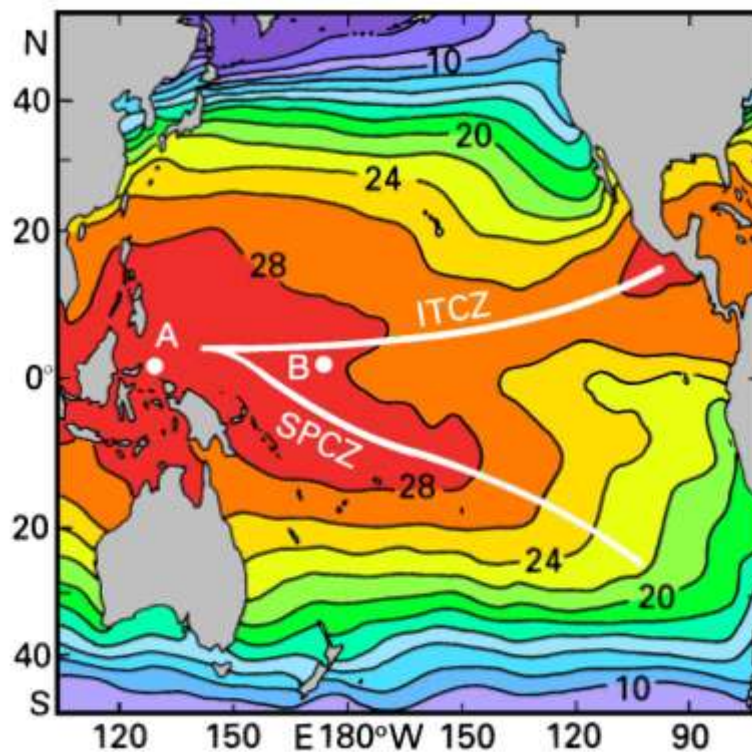


Figure 12: Movement of the ITCZ and SPCZ due to ENSO

Source: (Tomczak & Godfrey 2003).

ENSO's Effect on Heat and Water Transport

The ENSO cycle is characterized by a specific mechanism of water mass transport. The oscillation of Pacific climate patterns affected by the ENSO cycle sets into motion a series of oceanic mechanisms of water transport unique to ENSO and the conditions of the Equatorial Pacific. The manifestation of these effects is present in the zonal transport of Pacific surface water, specifically in the Kelvin wave oceanic mechanism.

The zonal movement of warm surface water in the Central Pacific is one of the key mechanisms of the ENSO cycle. As previously mentioned, El Niño is tied to weak or reversed trade winds, and La Niña is tied to strong trade winds. During mean and La Niña conditions, the westward flow of surface water propelled by the trade winds causes a thickening of the surface water layer in the western Pacific. The thicker surface layer pushes the thermocline, or boundary layer between warm surface water and cold subsurface water, to a greater depth. The result is a westward-sloping thermocline, as can be seen in Figure 11 (Pinet 1992). Conversely, during El Niño weak or reversed trades allow the warm surface water to flow back eastward. The eastward flow of warm surface water during El Niño is greatly augmented by the reduction of thermocline slope during that phase, as can be seen in Figure 10 (Tomczak & Godfrey 2003), (Pinet 1992). These effects on the slope and depth of the thermocline are attributed to the propagation of Kelvin waves eastward across the Pacific during the El Niño extreme. These are eastward-flowing equatorial waves that traverse the entire Pacific Ocean in a number of months with little dissipation. As a Kelvin wave moves eastward, it decreases the thermocline depth in the West Pacific and increases the thermocline depth in the Eastern Pacific, reducing the thermocline's westward slope (Pinet 1992).

ENSO's Effect on Upwelling

One of the most important effects of the ENSO cycle is its effect on Equatorial and Peruvian upwelling. ENSO's effect on the trade winds and water transport greatly affects the upwelling in the Pacific. To review, the El Niño extreme is characterized by negligible Equatorial and Peruvian upwelling, while the La Niña extreme is characterized by pronounced Equatorial and Peruvian upwelling. During mean conditions there is moderate Equatorial and Peruvian upwelling.

The phase of ENSO has a pronounced effect upon upwelling in the Pacific. During the La Niña extreme of the ENSO cycle, both Equatorial and Peruvian upwelling in the Pacific Ocean is highly pronounced. The strengthened trade winds of the La Niña phase increase the Equatorial upwelling via Ekman transport and also push greater amounts of surface water westward, causing Peruvian upwelling (Segar 1998). During the El Niño extreme of the ENSO cycle, both Equatorial and Peruvian upwelling in the Pacific Ocean is suppressed. The weakened trade winds associated with El Niño do not induce a significant amount of Equatorial upwelling, and if the trade winds reverse they in fact induce downwelling (Tomczak & Godfrey 2003). Additionally, Peruvian upwelling is suppressed by the reduction or reversal of westward surface water flow during El Niño. In summary, El Niño's effect on the trade winds suppresses both Equatorial and Peruvian upwelling.

Variability of the ENSO Cycle

The ENSO cycle follows a cyclical pattern but is prone to significant year-to-year variability. The ENSO cycle has been oscillating regularly for at least hundreds of years, but

variability due to the effect of random weather patterns and climatic trends make it extremely difficult to predict.

The ENSO cycle is a natural oscillation of the Pacific air-sea interaction. The ENSO cycle has been oscillating for at least as long as humanity has been able to observe it. Its effects have been observed off the coast of Peru for hundreds of years but it was not studied scientifically until the late nineteenth century. Figure 13 shows the standardized departure from average of a multivariate ENSO index with respect to time. , Essentially, this is how far the ENSO index is from the mean state. Positive values (in red) represent El Niño conditions and negative values (in blue) represent La Niña conditions.

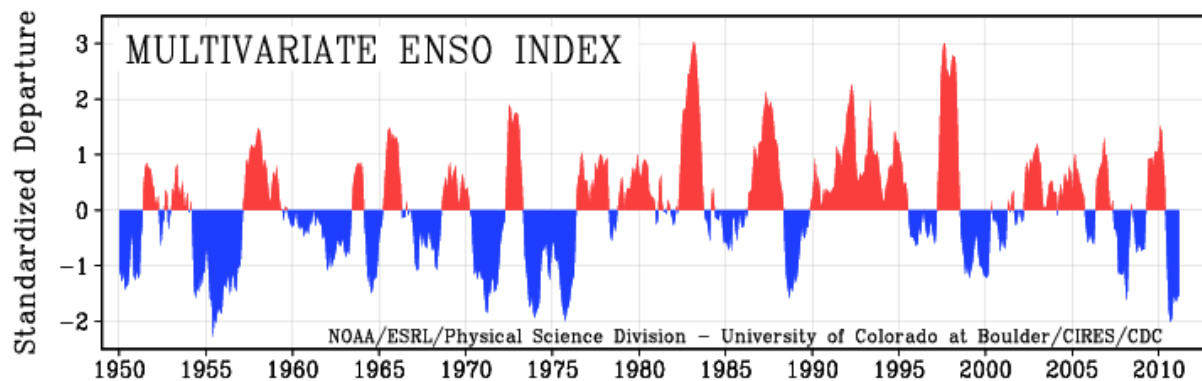


Figure 13: ENSO Index with Respect to Time

Source: NOAA 2011

The period of the ENSO cycle varies both interannually and interdecadally. The local period of the ENSO cycle's oscillation varies from 2 to 7 years, while the oscillation also varies on an inter-decadal timescale of 10-30 years (Fielder 2002). For instance, the ENSO cycle oscillates between La Niña and La Niña on a short (2 to 7 year) timescale, but the intensity and length of the ENSO cycle changes on a longer timescale The resulting oscillation is a high

amplitude high frequency wave superimposed on a low amplitude low frequency wave, as shown in Figure 13. However, the effects of random weather and climatic shifts make it extremely difficult to make any future predictions based on this model (Philander 1990). As can be seen in Figure 13, the oscillations between El Niño and La Niña are far from regular, with the intensity and period of each event varying greatly.

Interdependence of Climatic Factors

The climatic factors that influence the ENSO cycle are complex and interdependent. Upwelling, SST, atmospheric convection, and water transport are all interconnected and interdependent. The resulting system is extremely complex and exceptionally difficult to model or determine causality for (Fedorov et al 2003). The global impact of the ENSO cycle hinges on its effect on the complex meteorological processes across the greater Pacific region and its long range teleconnections around the world. Teleconnections, according to Glantz (1996), are “linkages between climate anomalies at some distance from each other.” The climatic effects of the ENSO cycle can be observed around the globe, as shown in Figures 14 and 15. ENSO affects the global climate system through its effects on atmospheric and oceanic convection patterns. The disruption of atmospheric circulation and water transport in the Pacific sets into motion processes that affect weather patterns around the globe (Philander 1990). The meteorological and human impacts of these teleconnections are addressed in the second and third sections of this paper.

Causality

While the scientific community has been able to describe the mechanics of the ENSO cycle for some time, no single trigger or cause has been isolated, highlighting the complexity of

the climatic system. Most studies of the phenomenon focus on describing its effects but have been unable to determine what triggers the process (Climate Research Committee, National Research Council 1983). Due to the interconnection of the processes involved in and factors affecting the ENSO cycle it is extremely difficult to identify the root causes or triggers of the ENSO cycle.

Studies of different subsets of the Pacific climate system have revealed how interrelated the different factors are. Oceanographers studying the oceanic process of the ENSO have concluded that the trade winds are the driving force of the system, while meteorologists have concluded that the wind patterns of the Pacific are driven by differences in sea surface temperature determined by oceanic processes. What is evident from this is that oceanic and atmospheric systems in the Pacific are inexorably tied (Pinet 1992).

Climate Change and ENSO

Climate change may prove to be a significant factor on the mean state and magnitude of the ENSO cycle. A significant increase in the average temperature of the Pacific, as would be caused by acute global warming, would redefine the mean state of the ENSO cycle. In a warmer world, the mean state of the ENSO cycle would be closer to the El Niño extreme we see today than today's mean state. In addition to this effect, the magnitude of the ENSO cycle would increase, making both La Niña and El Niño conditions more extreme (Timmermann et al 1998).

It is unlikely, however, that any change in ENSO's dynamics due to climate change will be observed any time soon. A 2005 study of 19 climate models for the Intergovernmental Panel on Climate Change predicted no significant changes in the mean state or magnitude of the ENSO cycle over the next century (Oldenborgh et al 2005). While climate change may someday greatly

affect the mechanics of the ENSO cycle, it will most likely be a long time until it reaches a magnitude that will have a measurable effect.

Meteorological Effects of the ENSO cycle on the Pacific Basin

The ENSO cycle affects weather patterns across the world, particularly in the Pacific basin. The ENSO cycle changes rainfall and temperature patterns around the Pacific Basin, often causing droughts in some areas while causing floods in others. Figures 14 and 15 show the effect of both El Niño and La Niña on rain and temperature patterns around the globe. This section describes these effects on the areas of South America, North America, Japan and Coastal China, Indonesia, Australia, and the Central Pacific.

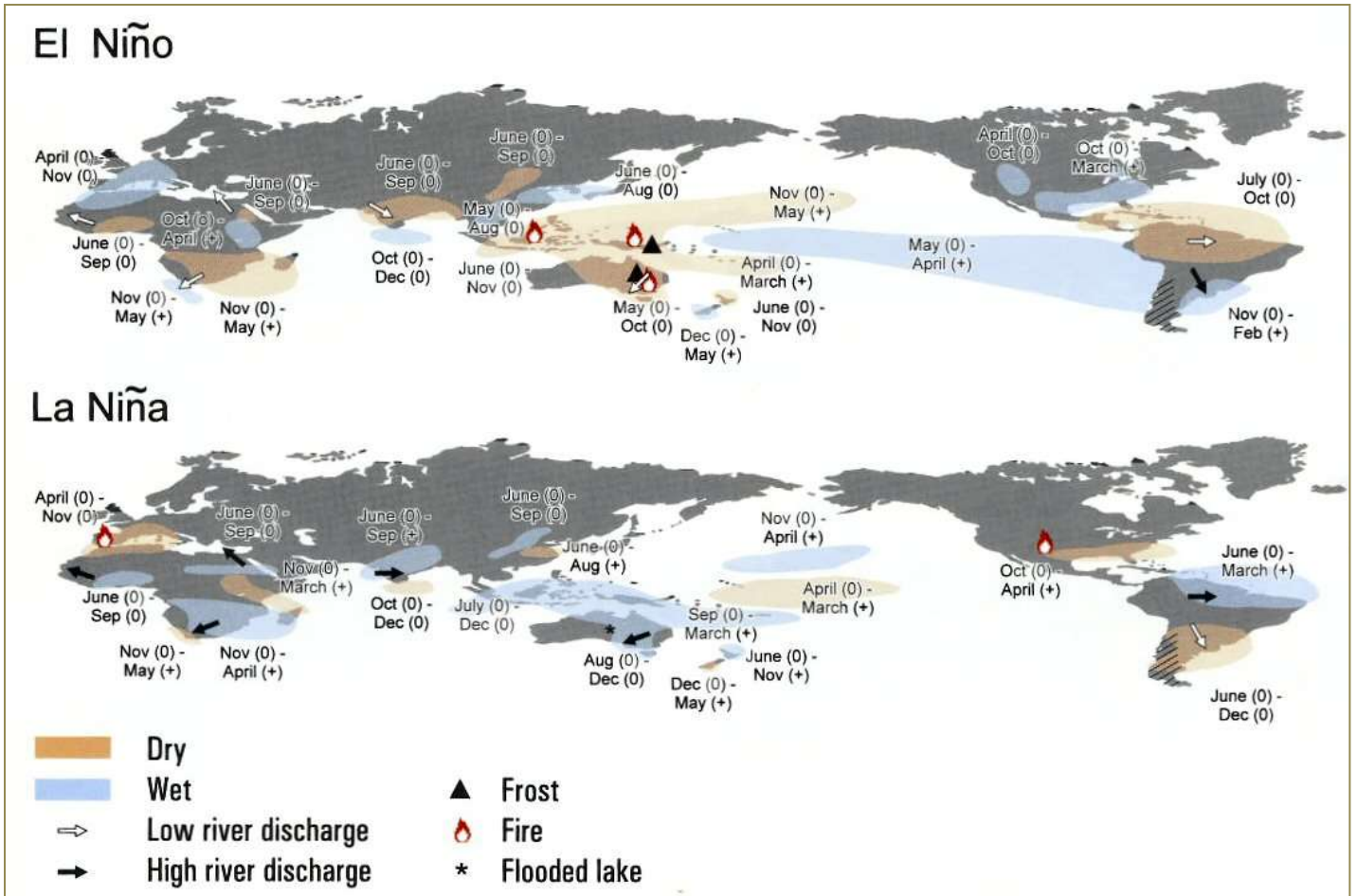


Figure 14: ENSO Rainfall Teleconnections

Source: Allan et al 1996 citing Halpert and Ropelewski 1992

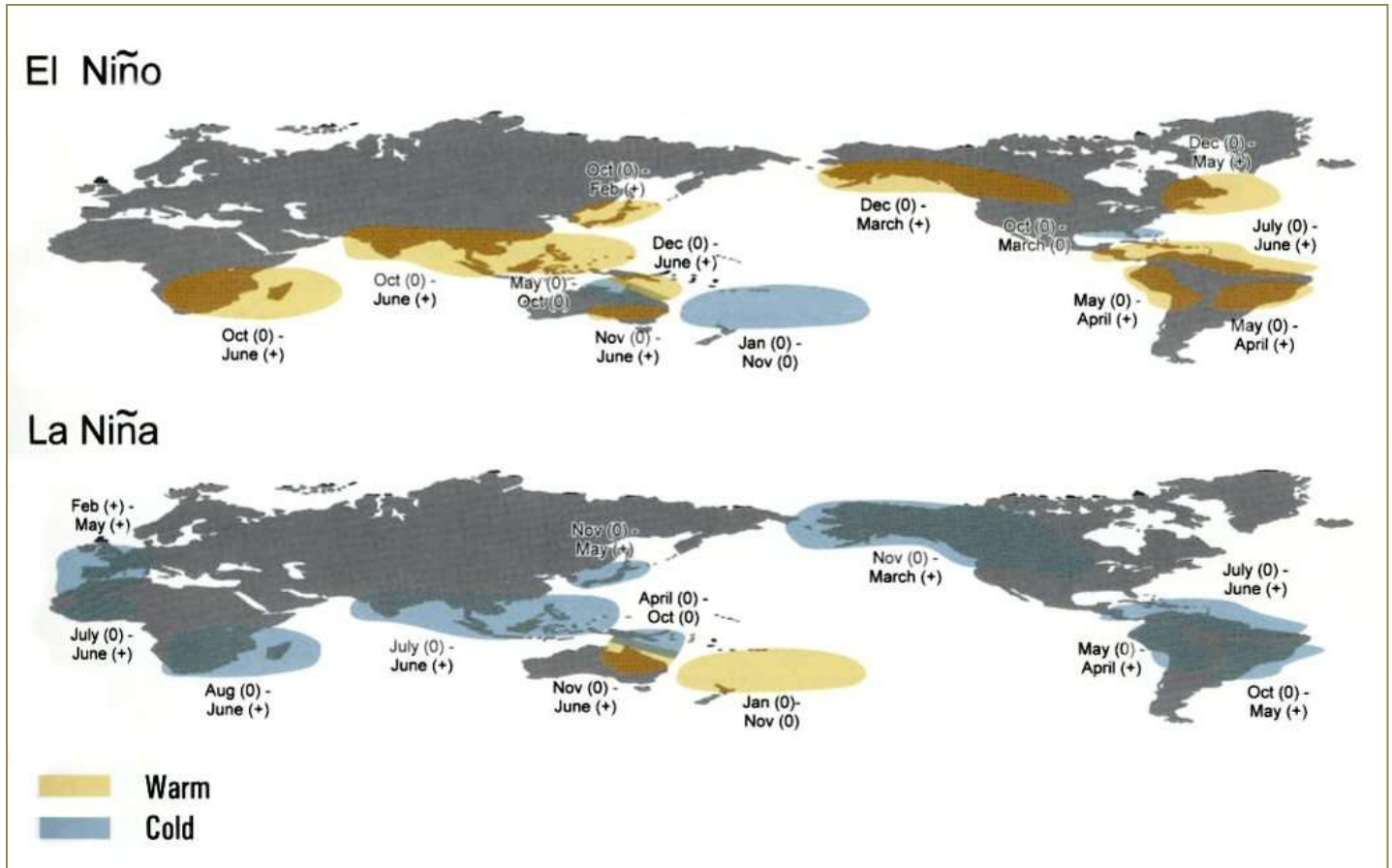


Figure 15: ENSO Temperature Teleconnections

Source: Allan et al 1996 citing Halpert and Ropelewski 1992

In South America, the ENSO cycle has a significant impact on climate. Both the El Niño and La Niña phases of the ENSO cycle affect the precipitation and temperature patterns of the region. During the El Niño phase of the ENSO cycle, the northern portion of the continent experiences diminished rainfall, while its southeastern coast experiences increased rainfall, as shown in Figure 14. The dry area in the north extends from about 10 °N to 10 °S, while the wet area on the southeastern coast extends from about 25 °S to 45 °S (Philander 1990). In addition to affecting rainfall, El Niño increases temperature averages in the northern area of the continent.

Along the continent's northern, northwestern, and northeastern coast, air temperature increases during El Niño events, as shown in Figure 15 (Allan et al 1996).

During the La Niña phase of the ENSO cycle, the effects of the cycle on rainfall and temperature are effectively reversed. In the northern section of the continent there is increased rainfall while on the southeastern coast there is diminished rainfall, as shown in Figure 14 (Allan et al 1996). The temperature of the northern, northeastern, and northwestern coast is likewise cooler than average during the La Niña phase of the cycle, as can be seen in Figure 15 (Glantz 2002).

The ENSO cycle also has a measureable effect on the climate of North America. Both the El Niño and La Niña phases of the ENSO cycle affect the precipitation and temperature patterns of the region. During the El Niño phase of the ENSO cycle there is increased rainfall near the Gulf of Mexico along the southern coast of the United States, as well as in the western United States near 110 °W, as shown in Figure 14 (Philander 1990). In addition to rainfall increases, El Niño induces temperature changes in North America. El Niño events increase temperatures in southern Alaska, western Canada and eastern Quebec, while decreasing temperatures along the southern coast of the continental United States, as shown in Figure 15 (Allan et al 1996).

The La Niña phase of the cycle manifests itself in different ways in North America. The only conclusive rainfall teleconnection of La Niña in North America is a decrease in rainfall in northern Mexico and the southern United States. In similar fashion, the only conclusive temperature teleconnection to La Niña is the cooling of Alaska and western Canada (Glantz 2002). These teleconnections can be readily observed in Figures 14 and 15.

In coastal Asia, the ENSO cycle has a significant impact, particularly in Japan and Coastal China. Both the El Niño and La Niña phases of the ENSO cycle affect the precipitation, temperature, and typhoon patterns of the region. During the El Niño phase of the ENSO cycle increased rainfall is experienced in southern Japan, the Korean peninsula, and southeastern China. Additionally, the air temperature in Japan and on the Asian coast of the Sea of Japan is warmer during El Niño events (Allan et al 1996). Both of these effects can be seen in Figures 14 and 15.

The effects of the La Niña phase of the ENSO cycle on rainfall in coastal Asia are limited to an area of decreased rainfall in eastern China near the East China Sea, as shown in Figure 14 (Allan et al 1996). Its effect on temperature is a cooling along the southernmost tip of the Chinese coast as well as around the Sea of Japan and Japanese Islands, as can be seen in Figure 15 (Glantz 2002).

In addition to affecting temperature and rainfall patterns in coastal Asia, the ENSO cycle has been observed to affect the intensity of typhoons that hit the region. During El Niño the frequency of extremely severe typhoons, or super-typhoons, is greater than during La Niña (Fei and Shibin 2010).

In Indonesia and Australia, both the El Niño and La Niña phases of the ENSO cycle affect the precipitation and temperature patterns of the region. The El Niño phase of the ENSO cycle is manifested in Indonesia and Australia by a significant decrease in rainfall and increased risk of wildfires throughout Indonesia and in Eastern Australia, as can be seen in Figure 14 This is accompanied by generally warmer conditions throughout Indonesia and Southeast Asia, as

well as cooler conditions in Northern Australia and warmer conditions and southern Australia, as shown in Figure 15 (Allan et al 1996).

The La Niña phase of the ENSO cycle is manifested in Indonesia and Australia by an increase in rainfall over Indonesia and Central Australia, as shown in Figure 14 In addition to this, La Niña causes a decrease in temperature in Indonesia and Southeast Asia and an increase in temperature in Northeast Australia, as can be seen in Figure 15 (Glantz 2002).

In the central Pacific Ocean, the ENSO cycle is the dominant climatic factor. Both the El Niño and La Niña phases of the ENSO cycle affect the precipitation and temperature patterns of the region. The ENSO cycle is inexorably tied to events in the central Pacific and greatly affects the climatic conditions there. El Niño is tied to warmer sea surface temperatures in the Central Equatorial Pacific while La Niña is tied to cooler sea surface temperatures in the region (Philander 1996).

During the El Niño phase of the ENSO cycle, the Central Pacific is marked by increased rainfall at Equatorial latitudes and decreased rainfall to the north and south of the region, between approximately 10° and 25° North and South, as can be observed in Figure 14 (Philander 1990). In addition to the warm conditions in the Equatorial Central Pacific tied to El Niño, the Central Pacific is marked by a decrease in temperature in the Southern Central Pacific, shown in Figure 15 (Allan et al 1996).

During the La Niña phase of the ENSO cycle, there is less rainfall in the Central Equatorial Pacific and increased rainfall in Central Northern and Southern Pacific, shown in Figure 14 In contrast to the cool temperatures it brings to the Equatorial Pacific, the La Niña

phase of the ENSO cycle is manifested by warmer conditions in the Central Southern Pacific, shown in Figure 15 (Allan et al 1996).

In sum, the ENSO cycle has a significant effect on the climate of the entire Pacific Basin, which in turn has a major impact on the people that live there. The meteorological effects mentioned in the above section have a large-scale impact on the economic development, public health, and public safety of communities across the Pacific Basin and the world. The following section describes the extent and severity of these impacts.

Social Impacts of the ENSO cycle

The ENSO cycle has a tremendous impact on the climate of the Pacific Basin and the human communities it encompasses. The oscillation of the ENSO cycle greatly affects the climate of the different regions of the Pacific Basin, as explained in the previous section of this paper. The changes in climate brought by the ENSO cycle can have dramatic effects on the public health, public safety, environment and economies of Pacific communities.

Impact of ENSO on Public Health

The climatic changes wrought by the ENSO cycle have been tied to many epidemic diseases around the world, particularly in tropical areas. Changes in temperature and rainfall affect the susceptibility of communities to epidemics, although how these teleconnections effect people varies for different diseases and locations. Figure 16 is a graphical representation of how ENSO-induced droughts and floods interact with other factors to contribute to the severity of an epidemic. These interactions are discussed throughout the rest of this section. ENSO has been tied to a range of epidemics, from cholera and other diarrhoeal diseases to malaria, dengue fever, hantavirus infection, and other host-transported diseases (Kovats 2000).

ENSO and disease. ENSO events cause physical effects such as droughts and floods (blue circle). Where these overlap and interact with suitable ecological and socioeconomic conditions (within dotted lines) they may cause disease outbreaks (dark shaded area).

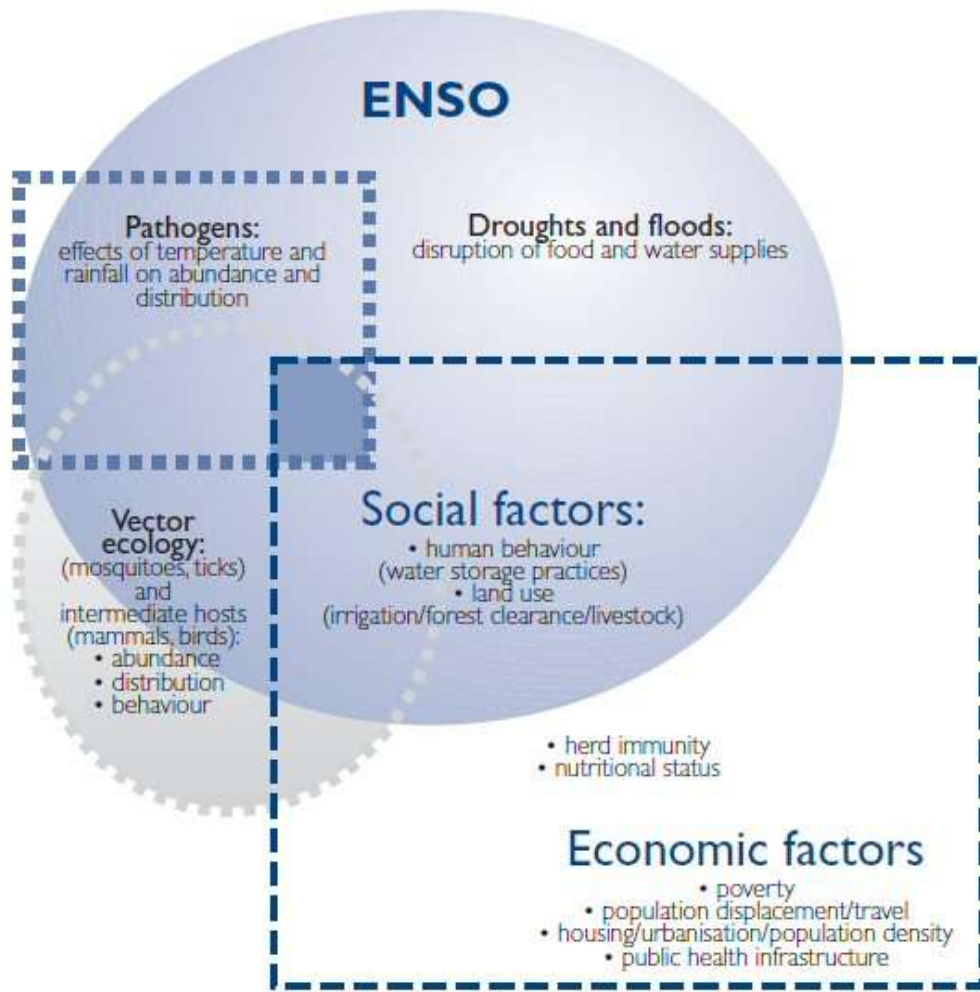


Figure 16: ENSO and Factors Contributing to Epidemics

Source: Hales et al 2003.

Cholera is one of the most virulent and widespread diarrhoeal diseases in the world, infecting 3-5 million people per year and causing between 100 and 120 thousand fatalities. The disease is caused by the bacterium *Vibrio cholerae*, and exposure is usually from drinking contaminated water. The disease causes acute diarrhea, leading to extreme dehydration. The

bacterium leaves the human body through the digestive tract, making sanitation a major factor in preventing disease transmission. Poor sanitation practices leading to contaminated drinking water can quickly cause the disease to escalate into an epidemic (Cholera 2011).

Disruptions in rainfall patterns or an increase in temperature has been observed to contribute to cholera epidemics worldwide. Either an increase or decrease in rainfall can influence the spread of the disease, which thrives in standing water. Flooding from increased rainfall can lead to standing water, but it can also turn standing water into a flowing torrent. Conversely a decrease in rainfall can make standing water dry up or turn a flowing river into a standing pool. So while some of ENSO's rainfall disruptions contribute to the spread of cholera, some inhibit its spread (Kovats 2000).

ENSO's temperature disruptions, however, have been more closely tied to the spread of cholera (Kovats 2000). It has been found that the increase of water temperatures improves conditions for the bacterium's reproduction. A case study of this phenomenon is in Bangladesh. Cholera epidemics there have been found to correspond to temperature increases in the Bay of Bengal. Not only has this been found but the interannual variability of the epidemics has been positively correlated to the ENSO cycle (Pascual et al 2000). It can therefore be concluded that the ENSO cycle has an undeniable, if not necessarily direct, connection to cholera epidemics.



Figure 17: Flooding in Thailand. Flooding can increase the risk of water contamination and water-borne diseases such as cholera.

Source: Typhoon Ketsana batters Southeast Asia 2011

ENSO's effect on epidemics is not limited to diarrhoeal diseases. The mosquito-borne diseases of malaria and dengue fever have also been linked to the ENSO cycle. Malaria affects about 300 million people each year and is caused by the *Plasmodium* parasite carried by infected mosquitoes. Dengue fever, a virus transmitted via mosquito, infects about 50 million people per year. While only a small percentage of infected cases are fatal, the diseases still have an immense impact on human communities due to the large number cases and the stresses they put on health infrastructure. Children in developing countries are especially vulnerable to both of the diseases (Malaria 2011; Dengue and dengue haemorrhagic fever 2011).

The severity of a malaria or dengue fever epidemic is dependent on the population of the mosquitoes that transmit the diseases. Mosquitoes breed in warm, stagnant water, so climate that creates such conditions increases the risk of malaria and dengue fever (Gagnon et al 2001). As

previously discussed, an increase in rainfall may or may not create more stagnant water, and in some conditions a decrease in rainfall may convert running water into stagnant water. Therefore a change in rainfall may or may not increase the risk of malaria or dengue fever. In general warmer temperatures have been associated with increases in both malaria and dengue fever, as they contribute to creating ideal mosquito breeding conditions (Kovats 2000).

In addition to its effect on the mosquitoes, the climatic disruptions brought on by the ENSO cycle affects the virulence of the diseases carried by them. When ENSO creates conditions that expose communities to malaria that do not have any immunity to the disease, a severe epidemic can ensue. An example of this is in the dry areas of northern Peru. When El Niño induces heavy rainfall there, the population is exposed to malaria, for which they have no immunity (Gagnon et al 2002). Such climatic disruptions also affect dengue fever, but are more connected to water storage practices than with people's immunity to the disease. For instance, during a drought more people store water in their home, giving mosquitoes a place to breed if the containers are open to the air (Gagnon et al 2001).

The transmission of epidemic diseases is not limited to mosquitoes. Various ticks and rodents have been carriers of epidemic diseases worldwide. Many of these diseases are not limited to tropical areas, unlike most of the mosquito-borne diseases. An example of a rodent-borne disease that affects temperate areas is hantaviruses (Kovats 2000).

Hantaviruses are responsible for the disease hantavirus cardiopulmonary syndrome, which has affected the southwestern United States for over 20 years. The virus is carried in the deer mouse, which is not affected by the virus but can transmit it to humans. Exposure to humans generally occurs from breathing in the mouse's excrement in aerosol form. During El Niño,

increased rainfall in the western United States contributes toward an increase in deer mouse populations, increasing the likelihood of human-mouse proximity and disease transmission (Hjelle and Glass 2000.)

Impact of ENSO on Public Safety

The ENSO cycle can induce extreme weather events and natural disasters in the areas it affects. While both El Niño and La Niña cause flooding in some areas and droughts in others, El Niño has been correlated to more natural disasters worldwide (Dilley and Heyman 1995). The climatic fluctuations tied to the ENSO cycle have been related to severe drought and flooding as well as tropical cyclone frequency and severity.

The ENSO cycle's climatic disruptions affect tropical cyclone (hurricane) patterns worldwide. Any change in tropical cyclone patterns has serious impacts on human populations, especially if tropical cyclones impact communities that are normally not impacted and are therefore unprepared.

The ENSO cycle's effect on tropical cyclones varies throughout the world, but in general, warmer sea surface temperatures increase the frequency and intensity of tropical cyclones (Fei and Shibin 2010; Evans and Allan 1992.). How ENSO-induced climatic changes interact with local conditions to affect tropical cyclone activity is highly variable and different for different areas of the world. For instance, during El Niño the frequency of tropical cyclones in the Caribbean and Queensland, Australia is reduced while at the same time the intensity of tropical cyclones over China is increased (Kovats 2000; Fei and Shibin 2010). Super-Typhoon Winnie, which occurred during the especially severe 1997-98 El Niño, is shown in Figure 18.



Figure 18: Super-Typhoon Winnie, as seen from orbit

Source: Super Typhoon Winnie 1997

In addition to influencing tropical cyclone patterns the ENSO cycle can cause severe drought and flooding in many areas worldwide. During the extremes of the ENSO cycle's oscillation its teleconnections are most pronounced. During a particularly strong El Niño or La Niña areas enhanced rainfall teleconnections increase the likelihood of drought in the case of a reduced rainfall teleconnections and flooding in the case of an increased rainfall teleconnections (Lyon 2004.). While the ENSO cycle's teleconnections affect both drought and flooding disasters, it has been found that ENSO is much better correlated with drought events than with flooding events (Dilley and Heyman 1995).

Drought has both direct and indirect impacts on communities worldwide. The direct impact of reduced rainfall is less availability to drinking water. When combined with temperature increases this considerably increases the population's risk of severe dehydration.

The indirect impacts of drought are famine and wildfires brought about by dryer conditions (Hales et al 2003).

Severe drought often leads to agricultural failure and causes a famine, or food shortage. A famine's social impacts are death from starvation, increased risk of disease due to malnutrition, and socio-politico disruption or population displacement (Hales et al 2003). ENSO-induced agricultural disruption and famine is one of the most severe impacts of ENSO on communities worldwide, affecting billions of people worldwide (Dilley and Heyman 1995.).

The dry conditions associated with ENSO-induced drought greatly increase the risk of wildfires in many areas around the world, particularly in Indonesia and Malaysia (Kita K, Fujiwara M, Kawakami S. 2000). Wildfires in Indonesia, shown in Figure 19, have been correlated with ENSO as far back as 1982 (Kovats 2000). The impact of wildfires on human communities is threefold. The wildfires endanger people directly, the smoke becomes a public health hazard, and the fires destroy property and crops, which can lead to economic collapse or famine (Hales et al 2003; Khandekar et al 2000). Because of the varied and severe impacts of ENSO-triggered wildfires, and the great number of people exposed to such dangers, the risk they pose to human communities is considerable (Kovats 2000).



Figure 19: Wildfires in Indonesia

Source: A Dangerous Intersection 2004

In addition to drought, the rainfall teleconnections brought about by the ENSO can cause flooding in different areas around the world. The impacts of flooding are both direct and indirect. Risks to human populations include drowning, economic and social damage due to loss of property, homes, or crops, and drinking water contamination (Hales et al 2003). Additionally, flooding increases the risk of communities to water-borne diseases that are more prevalent during flooding conditions (D'Aleo 2002). These combined risks make flooding a serious threat to vulnerable communities.

Impact of ENSO on Pacific Ecosystems

The ENSO cycle's climatic teleconnections has dramatic impacts on ecosystems across the Pacific Basin. Changes in these ecosystems affect people both directly and indirectly. The communities spanning the Pacific Basin all live in and depend on their ecosystems. Ecological changes can have a great impact on both a community's health and on agricultural and fishery

yield. In these ways the ENSO cycle's effect on Pacific ecosystems affects the communities of the Pacific Basin.

ENSO-triggered ecological changes can affect the health of a community because many diseases are transmitted to humans via animal carriers. As mentioned previously, rodent and mosquitoes carry endemic diseases that have a tremendous impact on public health around the globe (Kovats 2000). An ENSO event that affects an ecosystem that includes disease-carrying animals will in turn affect the public health of nearby human communities.

Ecological changes due to the ENSO cycle can also have a great impact on agricultural and fishing yield, which are ecosystem services that people depend on directly for resources or food. As crops and fish are part of complex and interconnected ecosystems, any changes in those ecosystems affect them and in turn the people who depend on them (Holmgren et al 2001).

Studies of ENSO's effect on ecosystems tend to focus on marine and desert ecosystems, where its effects are most dramatic (Holmgren et al 2001). For instance, a study of the effects of the ENSO cycle on Amazon rain forests found only small effects on plant productivity, which decreased by 3.1% during El Niño and increased 3.8% during La Niña. Such a small change will not have measurable effects on the ecosystem and its interactions with human communities there (Foley et al 2000). Because the effects of ENSO on marine and arid ecosystems are most pronounced, they are appropriate case studies for how ENSO interacts with ecosystems around the Pacific Basin.

The ENSO cycle can have a dramatic impact on the state of arid ecosystems. ENSO teleconnections cause many areas that are otherwise arid to experience heavy precipitation. This can transform a desert ecosystem in a very short time span. For example, in the arid islands of

the Gulf of California, plant cover nearly doubles during El Niño years. This increase in plant life generally translates to an increase in herbivore populations, which is followed by an increase in carnivore populations (Holmgren et al 2001).

The ENSO cycle's impact on marine ecosystems is also quite pronounced. The climatic shifts and temperature changes associated with ENSO greatly affect primary productivity (plant life) which in turn impacts the rest of the food chain from the ground up. The chief example of this is in the Central Equatorial Pacific.

During El Niño, when the trade winds slacken or reverse, the ocean in the Central Equatorial Pacific region is stratified, with the surface water masses not mixing with the cooler, nutrient-rich water masses below. This severely limits primary productivity near the water's surface. During La Niña, the trade winds drive upwelling in the Central Equatorial Pacific of cold, nutrient-rich, deep water, which mixes with the warm water at the surface, creating an ideal environment for maximizing primary productivity. Oceanic plant life (phytoplankton) is the energy source for the entire marine food chain. It should therefore not be surprising that changes in primary productivity impact the population levels and migrational patterns of fish through several levels of the food chain (Lehodey 2001).

Impact of ENSO on Pacific Economies

The impact of the ENSO cycle on Pacific economies is both immense and varied. While the ENSO cycle's threat to public safety has considerable economic consequences, so too does its effect on agricultural and fishing yield. The ENSO cycle's meteorological effects can affect

Pacific economies directly or can change ecosystem dynamics, which in turn affects agriculture and fishing.

The ENSO cycle's impact on agriculture is due to rainfall teleconnections. While flooding damage can reduce agricultural yield, in general greater rainfall is correlated with greater agricultural yield (El Niño-History and Crisis 2000). The economic impact of this is that farms will be more productive and during teleconnections of increased rainfall and less productive during teleconnections of decreased rainfall (Selvaraju 2003). The exception to this rule would be during flooding conditions where crops are destroyed, which could lead to famine or economic collapse (Hales et al 2003).

The ENSO cycle also has a significant influence on fishery yields in the Pacific. Changes in upwelling, sea surface temperature and primary productivity (plant abundance) due to the ENSO cycle affects both coastal and pelagic (open ocean) fisheries.

The ENSO cycle's effect on upwelling off the coast of Peru has a direct effect on fishery yield. An increase in upwelling brought upon by La Niña increases the anchovy population and fishery catch, while El Niño induced stratification can choke the population and drastically reduce the anchovy catch (D'Aleo 2002). For example, in 1972, an especially severe El Niño completely inhibited upwelling off the Peruvian coast, cutting the anchovy population off from the nutrient-rich upwelled water and decimating it (Caviedes 1975). As a result, the fishery completely collapsed and did not recover until after several La Niña events (D'Aleo 2002.).



Figure 20: Peruvian Fishing Ship; the Peruvian Anchovy fishery is greatly affected by the ENSO cycle.

Source: Courcoux 2011

The ENSO cycle's effect on pelagic fisheries is considerably less pronounced. As described previously, equatorial upwelling due to La Niña supports the augmentation of Pacific fish populations, while El Niño induced stratification generally reduces fish populations. This pattern holds generally true in the Central and Eastern Pacific, where the conditions are less dynamic than the western Pacific, where primary productivity is more variable (Lehodey 2001). In the Western Pacific, consistent warm temperatures and sufficient food make it an ideal region for skipjack tuna. It is believed that the productivity in the region, normally low due to stratification, is enhanced by the convergence of currents at the edge of the Pacific Basin (Lehodey et al 1997). The net result of these interactions is a decrease in East Pacific fishery yield and increase in West Pacific fishery yield during El Niño and the opposite effect during La Niña. This impact is significantly economically because 70% of the world tuna catch is from the Pacific Ocean (Lehodey et al 1997).

Factors Affecting Severity of ENSO's Human Impact

The severity of ENSO's impact on human communities of the Pacific Basin depends on a number of key factors. The most influential of these are the severity of the ENSO event and the vulnerability of the society being affected. As ENSO's oscillation varies in magnitude, the intensity of its teleconnections also varies, and therefore so does its impact on society (Changnon 2000). The vulnerability of a society also plays a major role in ENSO's impact, as not all societies have the same ability to deal with climatic changes (Hales et al 2003).

The variability of the ENSO cycle causes some ENSO events to be more severe than others. The increase in teleconnection intensity from more severe ENSO events in turn increases the impact upon society. An example of this is the 1997-1998 El Niño, which had especially pronounced teleconnections worldwide, even having a significant impact on weather patterns across the United States (Changnon 2000).

The other key factor to the social impact of the ENSO cycle is the vulnerability of the societies affected to extreme weather events and climatic changes. Factors in a society's vulnerability include natural vulnerability, resource dependency, economic resources, and disaster response capability (Adger 1999)

A society's natural vulnerability and resource dependency is generally connected with the society's location and economic structure. An agrarian society in an exposed location would be more vulnerable to economic and social disruption than an industrialized society in a protected location in the event of an extreme weather event, such as an ENSO-induced super-typhoon. Because of this, many developing countries with coastal cities are extremely vulnerable to severe weather events (Hales et al 2003).

A society's economic resources and disaster response capability also play a major role in its vulnerability to severe climate events. Societies with greater economic resources are generally better equipped to deal with climatic extremes and to recover from natural disasters (Adger 1999). In contrast developing countries often suffer the most from climatic changes, as they do not have the health and disaster response infrastructure that more industrialized nations possess (Hales et al 2003).

One solution to reduce the social impact of the ENSO cycle would be to institute an early warning system, which would allow communities worldwide to prepare for ENSO's effects in advance. Such procedures exist in the United States and other developed countries, but many countries across the Pacific and worldwide do not have access to accurate weather and climate forecasts. During the El Niño of 1997-1998, ENSO's teleconnections were predicted six months in advance, allowing individuals and institutions to prepare in advance for its effects (Changnon 2000). Progress has already been made toward such a system, with the National Oceanic and Atmospheric Administration Office of Global Programs (NOAA/OGP) leading the way. NOAA/OGP has set up a series of forums around the world to better inform government institutions worldwide on climate forecasts and preparation methods to minimize the social impact of the ENSO cycle worldwide (Buizer et al 2000.)

Conclusion

The ENSO cycle has immense social impacts across the Pacific Basin and will continue to shape climate patterns there for the foreseeable future. While increasing development in Pacific Basin countries may reduce vulnerability to extreme weather events, ENSO's social impacts will still affect them for a long time to come. It is therefore imperative that further research be conducted into the causes and future outlook of the ENSO cycle to aid prediction and response efforts. In addition to this, efforts must be made to reduce the vulnerability of communities worldwide to extreme weather events, particularly in the developing world. The importance of this is augmented by the prospects of global climate change and future population growth, which will put an increasing number of people at risk to natural disasters and climatic changes in the future.

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