The Influence Winds Have On Sea Surface Temperature And Sea Surface Height Anomaly In The Tropical Pacific


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ABSTRACT

Westerly wind bursts in the Eastern tropical Pacific associated with the MJO, occurred during the El Niño event of 1997/1998 and dwarfed the usual process of the reflecting rossby wave off the western boundary. Wind relates to SST by affecting the level of evaporation at the surface and also relates to large changes in SSHa by initiating downwelling equatorial kelvin waves. The direction of the wind causes the change in correlation with wind speed and SST across the Pacific as the west is negatively correlated due to the presence of occasional westerlies. The event had global teleconnections and it was found that wind speed in the tropical Atlantic decreased during an El Niño event after a period of about 3-5 months of the maximum El Niño signal. This is thought to be linked to the Pacific-North American pattern.
INTRODUCTION

Leading Questions

2. How is Sea Surface Temperature (SST) and Sea Surface Height Anomaly (SSHa) linked to the wind?
4. How unusual was the 1997/1998 event in a larger context, especially the winds.

Background Information

ENSO

El Niño is the term given to a global weather phenomenon which occurs across the tropical Pacific basin approximately every 4-5 years and usually last for 1-2 years (Burgers & Stephenson, 1998). Unusually warm water is present off the Pacific coast of South America which results in high levels of precipitation. On the other side of the Pacific basin a drought occurs due to the change in the walker circulation (Wyrtki, 1975; Kiladis and Dias, 1989; Glantz et al, 1991) (Figure 1.1).

Figure 1.1. A schematic showing the atmospheric walker circulation in La Niña conditions. Precipitation occurs when the air is rising - where the clouds are situated (Madl, 2000).
The counterpart of this climatic phenomenon is known as La Niña, where anomalous cold waters are found off the South American coast. These are both the extremes of a natural climatic oscillation known as El Niño Southern Oscillation (ENSO). The Southern Oscillation is the varying difference in atmospheric pressure between Darwin, Australia and Tahiti, Hawaii (Figure. 1.2.) first observed by Walker (1924). It is usually given as an index from the normalised pressure gradient. This is a negative feedback process as the data ‘see-saws’ and prevents one phase dominating.

![Southern Oscillation Indices](image)

**Figure. 1.2.** Southern oscillation index (SOI). Note the strong negative pressures in 1982 and 1998 in relation to El Niño events. University Corporation for Atmospheric Research (2009).

The El Niño phenomenon is caused by a combination of physical processes, which have a knock on effect leading to temperature increase across the equatorial pacific. Predominantly, the process will then breakdown in reverse and the system tends to go into the La Niña phase. The actual causes of an El Niño are still argued but there are numerous theories to explain the variability (Bjerknes, 1966; Madden and Julian, 1971; Battisti, 1988). However, the weak

A key role in initiating an El Niño event from normal conditions is a drop in the easterly trade winds (Chaves et al., 1998). The wind initially drives warm water to the west, maintaining a position known as the West Equatorial Warm Pool (WEWP) - defined as having a temperature of over 29°C (McPhaden, 1999). When the wind speed drops beyond a certain level the warm pool flows across the equatorial Pacific (Kessler et al., 1995). As the warm waters flows across the Pacific it causes a change in the walker circulation (Figure 1.1). The tropical Indian circulation expands and the easterlies associated with it moves into the Pacific ocean. This positive feedback ensures that the warm water moves to the eastern pacific once the motion has started (Figure 1.3. a)). Along with the pool of warm water comes a high level of water vapour, cloud cover and precipitation due to large levels of evaporation.

Figure 1.3. A figure showing the atmospheric circulation and tilt of the thermocline during a) El Niño and b) La Nina. Tropical Atmosphere Ocean project (2000).
The Sea level height variability is a manifestation of the integrated water column temperature and therefore the amount of potential energy. This is most obvious when observed as an anomaly from the climatological height at that position. The SSHa can give qualitative data on the thermocline depth. If the anomaly is high then the water has more energy than usual and the thermocline is lower indicating warmer water present above the thermocline. The El Niño event is associated with the gradient of sea level height decreasing along the equator as the water spreads out by ageostrophic flow (Figure. 1.3.). The most obvious variable change is the SST. The increasing SSHa in the eastern equatorial Pacific is accompanied by increasing water temperature showing these variables are linked. The SST has been studied in great detail throughout the tropical Pacific and El Niño events (Enfield, 1986).

The atmospheric and oceanographic cycles that cause El Niño occur on different time scales. Due to the change in frequency of these cycles no two El Niño events are the same. A cycle which has been closely linked to El Niño is the Madden-Julian Oscillation (MJO) (Madden and Julian, 1971; Jones et al, 1998). The oscillation occurs due to dynamic mechanisms in the atmosphere, and has a period of approximately 30-60 days and moves eastward at 3-6 m/s (Kessler and McPhaden, 1995). It originates over the Indian Ocean and is a coupled atmospheric and oceanic feedback process, which affects the SST and surface heat fluxes. MJO also influences long gravity waves which in turn affect the El Niño system. Wind forcing along the equator can initiate kelvin waves. These travel at speeds of approximately 2.4 m/s (Kessel et al, 1995) along the equator as they are non-dispersive and influenced by the coriolis force back towards the equator in each hemisphere and take about 2-3 months to cross the Pacific basin (Dijkstra and Burgers, 2002). The waves can deepen or shoal the thermocline – which is where they are most easily observed. Rossby waves can be formed as the Kelvin wave reflects off the eastern side of the basin and reflected back towards the west. Likewise, a rossby wave can reflect off the western basin side and produce kelvin waves.

(Dijkstra and Burgers, 2002). These waves play a key part in the formation and duration of El Niño events.

El Niño events mainly end due to the wind anomalies during the event generating equatorial planetary waves that travel westward to the west Pacific coast, reflect and return east along the equator, re-establishing cool water in the eastern Pacific. As the SST returns to normal, the atmosphere feels the reviving SST contrast and the trade winds begin to return, amplifying the ocean redevelopment. Here the coupling is crucial.

**Project outline**

The Grid All the Date you can GET (GADGET) data base has been created by the National Oceanography Centre Southampton (NOCS) which provides satellite data of SST, SSHa, wind, cloud cover, precipitation, water vapour and chlorophyll. Chlorophyll and SSHa are available globally, whereas, the other variables only in the latitude bands of 40°N – 40°S. The SSHa data begins in 1993 but unfortunately, the other variables start from approximately December 1997 and therefore do not show the full development of the 1997/1998 El Niño. It is still possible to observe data at the end of the El Niño and how the results changed into La Niña. The aims of this project were stated as:

- To look at the evolution of the winds of the 1997-1998 El Niño. This will be achieved by animating the monthly wind data and along with its anomalous plot see how it changes over time using computer programmes written in Matlab.

- To create Hof-muller plots to demonstrate any advection of the data in space and time and the plots. This will show if two or more variables are linked.
To observe the cross correlation of data for an averaged area and show exactly how the variables are linked. This will be achieved by plotting the correlation on a map and considering if there is a possible lag in the system.

To show how outstanding the 1997/1998 El Niño was in comparison to all the other data throughout the whole time series. Averaged areas during the time series will show how the data changes over time.

To understand the teleconnections in which El Niño causes in the tropical Atlantic by observing a change in wind speed.

**METHODS**

**Satellite Data**

The wind data obtained comes from the joint US-Japanese programme: TMI – TRMM (Tropical Rainfall Measuring Mission) Tropical Microwave Imager satellite. The satellite was launched on the 28/11/1997 to a height of 350km high above the ground. It has an inclination of 35° latitude and therefore can cover ± 40° N/S around the globe (Robinson, 2004) making it specialised for observing tropical process. The orbit is not sun-synchronous and it takes approximately three days to cover the entire area with a swath width of 780km and resolution of 0.5° x 0.5°. It provides data from December 1997 to present.

The actual measurements of wind speeds come from the sensor recording the level of sea surface roughness by a scatterometer (Martin, 2004). The signal sent out is both horizontally and vertically polarized to build up a 2D array of sea surface roughness levels as the satellite looks at the same FOV (Field of View) as it goes along its track. The same algorithm as the
SSM/I (Special Sensor Microwave Imager) created by Wents et al (1997) is applied to the sea surface roughness. As sampling does not take place at the same time everyday this has to be taken into account and the algorithm uses this as a triangular weighting method. In-situ measurements are also needed for calibration with information from surface buoys and radiosonde weather sites. The errors of the measurements are no more than ±0.9m/s. Surface glint from the sun results in null values and these are left in that state so no interpolation around the null pixel is done.

The satellite sensor emits two frequency bands; 37 Ghz to measure the wind speed ‘highs (hi)’ and 11Ghz to measure the wind speed ‘lows’ at 10m height from the ground. However, there is little difference between both variables (Figure. 2.1) therefore the wind speed ‘hi’s’ will be referred to solely as wind speed throughout this study.

![Figure. 2.1. The different results in the 2 frequency bands a) the wind speed low at 11Ghz b) the wind speed high at 37 Ghz.](image)

SST data is also provided by the TMI. The scale measured is 4.05°C - 34.049°C which is sufficient from tropical seas. It has an additional frequency band at 10.7 Ghz, which is sensitive to ocean temperature variations above 15°C (Robinson, 2004). The satellite’s height measures SST below the clouds (Donlon et al, 2001) leading to clear cloud free images. The
sensor measures to a resolution of ¼ latitude and longitude and produces monthly averages. SST is measured from the algorithm of an adaption of the AMSR (Advanced Microwave Scanning Radiometer) algorithm (Wentz and Meissner, 2000).

SSHa data is available weekly from 1993 to the present date from the DUACS (Data Unification and Altimetry Combination System). SSHa is measured using an altimeter. Satellite radar altimeters send out a nadir directed pulse which reflects off the sea surface as a backscatter coefficient. The speed of the return signal is related to how far away the target is in relation to other points along the track. Once a years worth of data is achieved anomalies can be calculated from these.

**GADGET**

The data has been provided through the NOCS (National Oceanography Centre, Southampton) GADGET (Grid All the Data you can GET) database. The UNIX system was used to gain online secure access to the server and provided an interface to make it easier to upload the data into Matlab. This is where all the images have been produced and data processing took place. Along with the data were the readme files for the variables and a few starter m-files to help load the data into Matlab.

**RESULTS**

**Wind Speed**

The monthly wind data in the tropical Pacific (120°W – 290°W, 30°N – 30°S) is variable from one moth to the next. Therefore, the seasonal averages from winter 1998 to winter 2001 have been calculated and created into an animation (see animation `seasonal_wind.avi`). The initial

Trends show a strengthening of the wind in either hemisphere with respective winter. The wind speed is always fairly low at the equator, especially in the east. Wind speed is greater in the centre of the large anti-cyclonic gyres. In the first image of winter 1998 the wind speed is approximately 4m/s in the mid South Pacific when the El Niño was at its most intense. In summer 1998 the winds dramatically increased up to 10m/s in parts of the southern Pacific. Next in autumn 1998 the winds became fairly intense in the northern hemisphere. During 1999 the wind was slightly more intense at 6m/s or greater across most of the Pacific except around Papua New Guinea. During 2000 the winds were at their strongest, especially throughout the summer as most the southern hemisphere is up to 10m/s. Lastly, for the duration of spring in 2001 the winds relaxed across the equator and in the summer the winds are not as strong.

The monthly anomalous plots against the climatological plot can be found in the animation wind_anomaly.avi. April 1998 shows a huge increase in wind speed north of the Galapagos Islands with wind speeds greater than 5m/s than the usual. In May 1998 there was an increase in wind speed in the western Pacific which spread across the 200°W. By June 1998 the winds across the Pacific relaxed and the values were similar to the climatology. July 1998 presented an anomalous cold wind in the western Pacific, around Papua New Guinea, yet still showed strong anomalous wind speed in the southern Pacific. Next in September 1998, the winds at the equator were fairly low at 3m/s less than normal. This is amplified in November as speeds drop even more. Winds were up to 4m/s slower in January 1999 in the eastern Pacific compared to the climatology. In the summer of 1999 the winds speeds were greater, especially in the northern tropical Pacific. During November 1999 wind speeds were anomalously low in the western Pacific at about 2-3 m/s. In early 2000 most months present a higher than average wind speed in the mid Pacific (1-2 m/s greater). In summer 2000 the anomalous wind speed is quite sporadic and does not present any obvious trends. In winter
2000 it is clear to see there is a drop in wind speed in the mid-Pacific, while December 2000 shows an increase to the west. An increase in wind speed of 2-4 m/s occurs in February 2001. Next in April 2001 the wind speed is far greater than the climatology, particularly in the eastern and southern tropical Pacific. In May 2001 wind speeds are greater in the equatorial region and mostly throughout summer. Finally, in autumn through to Winter 2001 the wind speed drops back to its climatological value.

**Hof-Muller plots**

A hof-muller plot shows how trends evolve over spatial and temporal scales by averaged data along either longitude or latitude changing along the opposite band. The hof-muller plot of wind in the NINO3 Region (See Appendix 1.1) clearly shows a drop in wind speed during 1997/1998 (Figure. 3.1.a) which lasts for approximately one year. The plots also show the general wind pattern as it is lower at the equator than at 5° north and south. However, there is contrasting results of El Niño events wind speed as the El Niño of 1997/1998 event showed a drop in the wind speed, whereas, the 2003 El Niño showed a large increase in wind speed. (Figure. 3.1.b).

![Hof-muller plots](image-url)

**Figure. 3.1.** Hof-muller plots of a) wind speed b) wind speed anomaly (m/s) averaged in the NINO3 region. 1998-2008.
The SST hof-muller plot (Figure 3.2 a)) shows an increase in temperature of a constant 29°C in early 1998 enduring until summer 1998 which spreads across the equator. After this occurs at the equator and slightly into the southern hemisphere the temperature dropped to about 22°C within just a few months. The cold water did not persist through the boreal winter but reappeared the following summer. SST results then fluctuated back to a normal phase.
Figure 3.2. b) shows exactly how strong the 1998 SST was by a clear anomaly of 3°C for approximately 4 months. The anomalous cold water of La Niña is also present in early 1999 and early 2000.

The SSHa hof-muller plot for the NINO3 region from 1993-2008 shows a clear large increase in surface height during 1997 and into 1998 (Figure 3.3.). The height difference is up to 0.5m higher than usual for approximately a month but is at least 0.15m higher for about 3 months. Following this there is a large decrease in sea surface height in mid 1998 (~ -0.15m) and this lasted until early 2000. The second highest increase in SSHa is during 2003 (Figure 3.3.).

The hof-muller plots of the different variables show some comparable results. Unfortunately, the wind and SST data does not start before December 1997 therefore not allowing any correlation to be found for early El Niño. The wind anomalous plot (Figure 3.1. b)) shows a great wind speed increase of more than 1m/s over the course of a month at the start of 2003, which is initially at the equator but slightly shifts south over time. This is associated with an increase in the SSHa. Likewise, a decrease in the SSHa during 1999 and 2000 (Figure 3.3.) is accompanied by a great drop in the usual wind speed (Figure 3.1. b)). Wind speed and SST anomalies show a relationship where an increase in wind speed leads to a decrease in SST, yet this is not always true (Figure 3.1. and 3.2.). Analysis must be careful as the data is averaged over the entire width of the Pacific.

**Variable Correlation**

Cross correlation between the wind and SST shows some areas with strong negative correlation in the Western mid Pacific and some areas of strong negative correlation in the Eastern mid Pacific (Figure 3.4. a)). Figure 3.4 shows the how the wind data of one
month correlates with the SST in 3 months. The positive and negative correlated areas are persistent for up to a year but the size of the strongly correlated areas are reduced with an increased lag.

Figure 3.4. a) Cross correlation between the wind and SST in the tropical Pacific (120°W – 290°W, 30°N – 30°S) b) Cross correlation of wind and SST 3 months later.

I looked further into the correlated areas to see the variability between the wind and SST over the entire time series (Figure 3.5.). Both plots shows that an increase in wind speed causes a decrease in SST and vice versa. The negatively correlated area has peaks of wind speed and SST occurring at the same time, whereas, the positively correlated area has a slight lag in the opposite peaks of both variables. From 1998-2003 the SST lags the wind by approximately 1-2 months.
Figure 3.5. a) The negatively correlated area between wind and SST (2.5°N-2.5°S 180-190°W) b) The positively correlated area between wind and SST (2.5°N-2.5°S 230-250°W)

**Averaged Areas**

Weighted averages of areas are useful to see the general long term trend. The wind in the NINO3 region strikingly shows the El Niño event of 1997/1998 by a large decrease in wind speed and a wind speed increase to only 5.5m/s in late 1998. The NINO1+2 region to the east (Appendix 1.1) has a more consistent wind fluctuation pattern. This area usually has consistent winds (seasonal_wind.avi) and slightly picks up any El Niño/La Niña extreme signals.

**Figure 3.6.** Monthly mean average values of wind speed December 1997 – December 2008 in a) NINO3 region and b) NINO 1+2 regions. The black line is the line of best fit to an order of 5.

**Figure 3.7.** Monthly mean average values of SST December 1997 – December 2008 in a) NINO3 region and b) NINO 1+2 regions. The black line is the line of best fit to an order of 5.
The SST area averaged results in the NINO3 (Figure 3.6. a)) and the NINO1+2 regions have similar results. There is a very high SST increase in early 1998 to 29°C for a few months. Then in summer the SST rapidly decreased to 23.5°C and 21°C in the NINO3 and NINO1+2 regions, respectively, within a period of 3 to 4 months. The results then fluctuate with seasonal and annual variability. The winter of 2003 in the NINO3 region showed the second warmest SST of approximately 25.4°C.

The SSHa data shows an outstanding increase of 0.3m in both regions observed during late 1997 (Figure. 3.6.a) and b)). The height then rapidly decreased to ~ 0.15m in early 1999 and to ~ 0.1m in early 2000 in the NINO1+2 region to the lowest in the time series.
Wind speed teleconnections

An area in the tropical Atlantic defined by Klein et al (1999) as 5-22.5°N, 300-342.5°W was chosen as the specified area of study due its previous attention of atmospheric teleconnections. The same latitude was then chosen in the tropical Pacific for the NINO3 longitudes to observe any links within the same atmospheric cell across the globe.

Figure. 3.8. The mean monthly wind speed (m/s) for the tropical Pacific region 5-22.5°N, 210-270°W (solid black line) and for the tropical Atlantic region 5-22.5°N, 300-342.5°W (dashed blue line). The tropical Atlantic data has been lagged by 3 months and then re-plotted over the Pacific data.

Figure. 3.8. Shows the wind speed in the tropical Pacific is strongly linked to the wind speed in the tropical Atlantic with a lag of approximately 3-5 months. The North Atlantic seems to amplify the signal in the North Pacific on El Niño and La Niña events i.e. 1999, 2000, 2003.
DISCUSSION

Evolution and development of the 1997/1998 El Niño winds

McPhaden (1999) looked at how such a strong El Niño came to terms. In late 1996 surface winds caused by MJO (initially propagating east from the Indian Ocean (Wang and Xie, 1998)) increased more than usual over warm waters of the west Pacific. Low wind speeds occurred in the southern Pacific during early 1997 when El Niño was at its most intense (Chavez et al., 1998; Yoshimitsu and Youichi, 2006). By summer the winds picked up in the South and around the area known as the WEWP. The increase in wind speed is likely to have come about due to atmospheric processes caused by solar forcing. In the southern hemisphere winter wind speed is usually higher due to the instability of the atmosphere. The strength of the wind speed is higher the west and lower in the east which correlates to the SST (Figure. 3.7. b)). The rapid change of SST in summer 1998 (Figure. 3.2. a)) is likely to have had a feedback onto the wind. Wang et al (1999) described the relationship between the feedback mechanisms of wind speed-evaporation-SST. Winds are affected by the latent heat at the ocean surface which affects its stress input into the ocean. The increase in SST increases the cumulus convection and moisture content difference. This induces surface wind convergence which decreases the heat flux and decreases the wind speed. The opposite is also true. By winter 1999 the wind speed is high across most of the Pacific as the La Niña state starts to dominate. The high easterly wind speed anomalies in the east pushed the water towards the west and upwelling occurred due to the surface water being replaced by deeper water (Vialard et al, 2001). This is turn causing a decrease in the SST (Figure. 3.2. b)).
During the La Niña of 1999/2000 the winds remained quite high until summer 2000 (wind_anomaly.avi). The winds then decreased again most likely due to the atmospheric forcing or possibly the feedback from the warmer SST starting to emerge. Another negative feedback process which succumbs to ending events is the presence of kelvin and rossby waves. Westerly wind bursts relating to the MJO would have likely to initiated a downwelling equatorial kelvin wave (McPhaden and Yu, 1999; Vialard et al, 2001). The westerly wind bursts force a semi-annual jet known as the Wyrtki jet in the equatorial western Indian Ocean (Wyrtki, 1973), which is setup within a week of onset (Sprintall et al, 2000) This wave travels from the surface to approximately 150m depth and carries with it a large amount of warm water (Meyers et al, 1998; Edwards, 2003). This is present at the surface as a large increase in SSHa (Figure. 3.3). Once the kelvin wave reaches the eastern boundary it erupts its warm water content into the surface (Figure. 3.2. a)). Therefore, warm water usually appears in the eastern Pacific before the mid Pacific (Battisti, 1988). Once the warm water is lost the thermocline begins to shoal. Some of the energy is reflected off the eastern boundary as a rossby wave. A rossby wave is influenced by the changing coriolis with latitude and usually causes thermocline variability in 2 dimensions (Polito and Sato, 2003; Capotodi et al, 2003). It takes a maximum of one year for a rossby wave to cross the Pacific at the equator, which roughly corresponds to half the time of an El Niño event (McGregor et al, 2008). However, this is hard to quantify (Picaut, 1997). The occurrence of rossby waves explains the slight noise in SST anomaly in the NINO3 region (Figure. 3.2.b)) causing meridional advection.
How SST and SSHa is linked to the wind

The wind also has observable effects on the SSHa. Figure. 3.3, reports a large increase in SSHa in late 1997 and early 1998 in the NINO3 region when the wind is low. The drop in wind speed allows for the warm surface water to travel across the Pacific into the NINO3 region. As the warm water starts to move westerlies are often present to help advect the water. The warm water has more potential energy and associated with a lower thermocline (Kim and Jeon, 2008) therefore causing a high SSHa. This wind also affects the upper ocean circulation which then effects the position of the thermocline.

Figure. 3.4, shows how the wind is linked to SST. In the eastern tropical Pacific SST and wind speed are strongly positively coupled that an increase in wind speed relates to a decrease in SST. This area is most likely affected by easterly winds. The winds act to increase upwelling and decrease SST. In the west the opposite occurs, as SST is higher and wind speed is lower at the same time compared to the east probably due to the occasional influence from easterly winds. Smith (1988) has calculated coefficients for wind stress, heat flux and wind profiles from SST and wind speed data and quantifiably how wind speed relates to SST.

Teleconnections

The most common teleconnections occur through the atmospheric ‘bridge’ (Alexander et al, 2002). The global atmospheric cells interaction with each other at either converging or diverging points. Teleconnections occur commonly but are not much different from the normal signal, hence not picked up. When extreme events occur such as the 1997/1998 El Niño the effects extend much further than just the tropical Pacific. The atmosphere usually
takes about 2 weeks to respond to the SST anomaly and can take up to 3-6 months to carry the signal to the Ferrel cell in the North Pacific from the Hadly cell in the equatorial region.

Wind speed in the tropical North Atlantic is linked to the wind speed in the tropical Pacific. During El Niño there is a weakening of the trade winds in the tropical North Atlantic which reduces surface evaporation and increases SST (Klein et al., 1999). The ENSO signal in the North Atlantic is prominently the anomalous southwesterlies over the Caribbean Sea near 20°N. At latitudes south of 20°N the southwesterlies oppose the mean trade wind easterlies, leading to a reduction in wind speed (Enfield and Mayer, 1997). This can be seen in the very start of the time series in (Figure. 8) One hypothesis for the reduction in trade winds during El Niño is the anomalous low pressure centre that is located over the southeast United States and is associated with another climatic phenomenon known as the Pacific-North American Pattern (Wallace and Gutzler, 1981).

**The 1997/1998 El Niño and subsequent La Niña in a larger context**

The 1997/1998 El Niño is claimed to be the climatic event of the century and has lead to a great increase in the study of El Niño events (Leetma, 1999; Changnon, 2000). The averaged wind speed in the NINO3 region and also the NINO1+2 region show the strength of the 1997/1998 El Niño. The winter of 1999 had the lowest wind speed in the NINO3 region the data set by about 0.5m/s. The upwelling area of NINO1+2 region shows a huge drop in the wind speed down to 3.5m/s (not including the average seasonal cycle is at about 5.5m/s) also in winter 1999 as the El Niño event rapidly shifted into La Niña.

During the 1997/1998 El Niño and into the 1999/2000 La Niña SST results went from the highest on record to a very low level (Figure. 3.5. a)). This is highly unusual as after an El
Niño event it is usually a few years until the next El Niño or La Niña event. The NINO1+2 region is similar to the NINO3 region at the start of the time series as it shows a great increase in SST but the SST then returns to normal and does not show the 1999/2000 La Niña. This is likely due to planetary waves returning the signal in this region back to normal much quicker.

The SSHa is the best variable to show the scale and duration of the 1997/1998 El Niño compared to the last 16 years. The NINO3 region is more variable than the NINO1+2 region probably due to the greater wind stress as opposed to the greater SST flux. The NINO3 region shows the SSHa going from ~0.325m in late 1997 down to -0.1m in early 1999. The NINO1+2 region’s large SSHa of the 1997/1998 El Niño lasted for almost 2 years. There is a greater lag here is because it takes a long time for planetary waves to cross the Pacific basin and therefore have a slight influence against the eastern boundary in this position.

CONCLUSION

It is clear the 1997/1998 El Niño has been the strongest El Niño event to have been recorded. The El Niño rapidly shifted into a strong La Niña which the made phenomenon more unusual. The wind speed is variable due to the nonlinear interactions between the annual and interannual cycles in the tropics (Wang, 1999). However, patterns are clear, such as westerly wind bursts in the Western Pacific at the beginning of the El Niño event. The spatial variability of the wind can be seen across the Pacific yet the temporal variation can only be observed on the interannual scale, however there may be longer time scale events. High wind speed anomalies, usually as a result of arising warm SST anomalies can initiate planetary waves. The planetary waves travel across the Pacific basin and influence the depth of the
thermocline which affects SSHa and SST. Wind speed directly has a complex link with SST in the tropical Pacific based on its location. It is generally found a decrease in wind speed leads to an increase in SST. Data on wind direction as well, would underline the importance of westerly wind bursts to initiation of El Niño in comparison with initiation be a reflected rossby wave.

Weekly resolution of the wind would show the smaller spatial scale variability of the wind and the rapid transition into the 1999/2000 La Niña would be clearer. This study has demonstrated the influence wind speed can have on the global climate during strong El Niño events. It was found that wind speed in the tropical North Atlantic decreased during El Niño events. It would be interesting to see if the wind climate in the southern hemisphere also had the same trend during the 1997/1998 El Niño.
REFERENCES


APPENDIX

El Niño regions:

The regions used for further investigation have are given in Figure. 4.1, which have all previously been studied in great depth.

![Niño Regions](image)

Figure. 4.1 A map of the NINO regions which are most commonly analysed. Gold Gate Weather Services. (2000).

The regions in which I am interested in are:

- NINO3 region: 5°S, 5°N – 210°W, 270°W
- NINO1+2 region: 10°S, 0 – 270°W, 280°W