Local sea surface temperatures add to extreme precipitation in northeast Australia during La Niña

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[1] This study examines the role played by high sea surface temperatures around northern Australia, in producing the extreme precipitation which occurred during the strong La Niña in December 2010. These extreme rains produced floods that impacted almost 1,300,000 km$^2$, caused billions of dollars in damage, led to the evacuation of thousands of people and resulted in 35 deaths. Through the use of regional climate model simulations the contribution of the observed high sea surface temperatures to the rainfall is quantified. Results indicate that the large-scale atmospheric circulation changes associated with the La Niña event, while associated with above average rainfall in northeast Australia, were insufficient to produce the extreme rainfall and subsequent flooding observed. The presence of high sea surface temperatures around northern Australia added ~25% of the rainfall total. Citation: Evans, J. P., and I. Boyer-Souchet (2012), Local sea surface temperatures add to extreme precipitation in northeast Australia during La Niña, Geophys. Res. Lett., 39, L10803, doi:10.1029/2012GL052014.

1. Introduction

[2] December 2010 was an exceptional month for rainfall and flooding in northeast Australia, particularly in the state of Queensland [National Climate Centre, 2011] (Figure 1). Averaged over Queensland the December rainfall was an all-time high at 154% above normal. A number of weather systems brought rainfall to the state during December, with most of the extreme rainfall occurring between December 23 and 28. During this time a moist easterly flow covered most of Queensland. Circulation associated with tropical cyclone Tasha, which made landfall south of Cairns, brought further moisture into the region on December 24 and 25. During this period large parts of eastern Queensland received more than 100 mm of rain. Several stations set all-time daily rainfall total records with some receiving around 300 mm in a single day.

[3] Extensive rains through spring and early December meant that most of Queensland was experiencing wet conditions, with many rivers at high levels, before December 23. The extreme rainfall in the following days produced flooding across a vast region with many rivers in eastern Queensland flooding simultaneously. This unprecedented widespread flooding, damage and loss of life, led the Queensland government to establish the “Queensland floods commission of inquiry”. This commission is looking into many aspects of the flooding and its impacts, including, mitigation, planning, emergency response and early warning systems. The initial findings have been released in an interim report [Queensland Government, 2011].

2. Observations

[4] Rainfall over much of Queensland is enhanced when La Niña conditions are present in the tropical Pacific ocean [McBride and Nicholls, 1983; Murphy and Ribbe, 2004; Suppiah, 2004; Risbey et al., 2009]. The spatial distribution of observed rainfall during December 2010 is shown in Figure 1. The precipitation observations are taken from the gridded station dataset developed at the Australian Bureau of Meteorology [Jones et al., 2009]. The last 31 years of mean Queensland rainfall and the Southern Oscillation Index can also be seen in Figure 1. The strong La Niña occurring during December 2010 has led some to conclude that it is likely responsible for the extreme precipitation which occurred [Nicholls, 2011], though a possible role for high SSTs could not be ruled out. Previous work has shown that the amount of rainfall associated with the SOI is now greater than it was in the past [Nicholls et al., 1996], however variability in the tropical Pacific accounts for only a portion of the summer rainfall variability in Queensland [Murphy and Ribbe, 2004].

[5] Simultaneously with this strong La Niña, the sea surface temperatures (SSTs) around northern Australia were anomalously high, reaching record temperatures in some places. Figure 2a shows the difference between the SSTs observed in December 2010 and the mean December SSTs of all the La Niña Decembers in the previous 30 years (1981, 1984, 1988, 1996, 1998, 2000) as determined using a multiple indices approach [Meyers et al., 2007]. The SST observations were obtained from the daily high-resolution SST dataset of Reynolds et al. [2007]. December 2010 had higher SSTs around northern Australia than was seen in previous La Niña events, with some areas being more than 2°C warmer. It can also be seen that this La Niña was stronger than average with SSTs in the western tropical Pacific being up to a degree cooler. The time series of December SSTs averaged over three regions around northern Australia can be seen in Figure 2b. A general warming trend can be seen in each of the regions. The trends are +0.22°C/decade, +0.26°C/decade, and +0.21°C/decade for the north-west, north, and north-east regions respectively. These trends are significant at a 0.05 level according to a two-tailed t-test (n = 30) with P values of 0.015 in the north-west...
and 0.002 in the north, while the P value in the north-east is 0.063.

3. Model Experiment

To quantify the role of these anomalously high SSTs a series of Regional Climate Model (RCM) experiments were performed. The Weather Research and Forecasting (WRF) model version 3.2.1 [Skamarock et al., 2008] in a regional climate configuration was used in this study. The physical parameterizations used include: the WSM5 microphysics scheme; The RRTM longwave and Dudhia shortwave radiation schemes; the Mellor-Yamada-Janjic planetary boundary layer scheme; the Betts-Miller-Janjic cumulus scheme; and the Noah land surface scheme. The model used 50 km horizontal resolution over the domain shown in Figure 2a and 30 vertical levels. Spectral nudging of the winds and geopotential height was used above 500 hPa.

First, a series of 40 simulations using the observed SSTs and lateral boundary conditions, and internal spectral nudging data, from the NCEP/NCAR reanalysis was performed, providing the control ensemble (referred to as the CTL ensemble). Second, a series of 40 simulations using the same lateral boundary conditions but with the average SSTs from La Niña events of the previous 30 years (referred to as the La Niña mean or LNM ensemble) were produced. This second series of simulations generates the regional climate given the same large scale circulation produced by the observed extreme La Niña, but with local SSTs representative of previous La Niña events.

Every simulation covered the period from November 2010 through January 2011. The ensembles were created by initializing each RCM simulation 6 hours apart. The first was initialized at 0 UTC on the 1st of November, and each subsequent simulation was initialized 6 hours after the one before it. While the simulations cover November 2010 through January 2011 the analysis presented here focuses on the extreme precipitation which occurred during 20–30 December 2010, coincident with anomalously high SSTs.

4. Results and Discussion

The CTL ensemble mean precipitation from December 20 to December 30 is shown in Figure 3. Using the observed SSTs, the RCM is able to capture the high precipitation in the east and north of the state, with extreme precipitation south of Cairns and in the Mackay area. Figure 3 also shows the probability that the CTL precipitation did not come from the LNM precipitation distribution, with most of the high precipitation region over 99% using the non-parametric Mann-Whitney U test. This indicates that these extreme

Figure 1. Map of December 2010 rain and time series of the December Southern Oscillation Index (SOI) and total December rainfall.

Figure 2. (a) The difference between observed Sea Surface Temperatures (SSTs) and the mean SST for La Niña Decembers since 1980. (b) The time series of SST averaged over the three regions indicated in Figure 2a for December.
precipitation amounts could not be reproduced using the large-scale La Niña conditions alone, but that the observed high SSTs around northern Australia were necessary for their production. The CTL ensemble produces ~25% more precipitation on average than the LNM ensemble over Queensland.

The high SSTs off NE Australia directly contributed to the low level water vapor flux coming from that direction, and hence to the total amount precipitated. While the proximity of these high SSTs allows them to impact the observed extreme precipitation, the high SSTs off NW Australia also appear to play an important role. On December 14 a low pressure center forms off the NW Australian coast. In the high SST (CTL) experiments this system transports large amounts of low level water vapor toward the east over Indonesia and Papua New Guinea. From December 23 to 26 the winds over NE Australia become northerly and bring this moisture south where they add to the precipitating systems. In the LNM experiments this flux is much weaker and does not contribute substantially to the precipitation.

If the observed warming trend in the SSTs continues, this result suggests that future La Niña events are more likely to produce extreme precipitation and flooding than is present in the historical record. If the SST increases can be attributed to global warming, then the probability of La Niña events producing extreme precipitation responses similar to December 2010 will increase in the future. It should be noted however, that as this is the strongest La Niña event during the satellite record, it may be that the record high local SSTs, particularly around north-west Australia, are merely a bi-product of such an extreme La Niña event and may have occurred before the satellite record begins.

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References


