NEFA BACKGROUND PAPER
North East NSW expected climate changes
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Australia's land and oceans have warmed by an average of almost one degree celsius in the past century, with most of the warming occurring since 1950. Climate change is underway in north-east NSW's native forests. We have already initiated significant environmental changes, though our future actions will determine the magnitude of those changes.

In line with world and Australian trends, NSW's climate is changing, as noted by Hennessy et. al. (2004)

> *From 1950 to 2003, the NSW annual mean maximum temperature rose 0.15°C/decade and the NSW annual mean minimum temperature rose 0.19°C/decade. There has been an increase in hot days (35°C or more) of 0.10 days per year, an increase in hot nights (20°C or more) of 0.26 nights per year, a decrease in cold days (15°C or less) of 0.22 days per year and a decrease in cold nights (5°C or less) of 0.29 nights per year.*

As climate change gathers momentum it will have a myriad of consequences for north-east NSW:

- Temperature increases are likely to exceed 2 degrees sometime later this century. Rises leading to more extreme heatwaves, increasing evaporation, more intense droughts, and increases in extreme fire weather and wildfires.
- Rainfall is likely to become more erratic, with downpours increasing in intensity and longer dry periods. Floods will increase in frequency and size. Hail storms will become more frequent.
- Sea-level rises are likely to exceed 50cm sometime this century, though could rise more than a metre.
- Cyclones and East Coast Lows may become less frequent, though their magnitude is likely to increase. Storm surges will increase in size and attack coastal defences, backed by extreme winds and rainfalls.

The East Australian Current has a major influence on north-east NSW's weather. It is warming and extending south. It warming waters are energising our weather system. As sea temperatures rise along the coast this will add to sea level rises and fuel a greater intensification of storm systems.

Even if we ceased CO_2 emissions today we have already put in train significant future impacts. Sea-levels are going to continue rising for centuries. The longer we go on polluting, particularly at our current accelerating rate, the more extreme those impacts will be. Currently, in regards to both emissions and impacts, we are trending along the worst case trajectory. As we proceed down this path it is becoming increasingly apparent that many of the impacts are a lot worse than we imagined a few years ago.

Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions, and we have not started yet.

Temperatures

Australia's climate is warming at an accelerating rate (CSIRO & BoM 2012, 2014):

- Global mean temperature has risen by 0.85°C from 1880 to 2012
- Australian annual-average daily mean temperatures have increased by 0.9 °C since 1910.
- Australian annual-average daily maximum temperatures have increased by 0.8°C since 1910, with most of the warming trend occurring since 1970.
- Australian annual-average overnight minimum temperatures have warmed by more than 1.1 °C since 1910, with more than 0.8 °C of that warming occurring since 1960.
- Australian average temperatures are projected to rise by 0.6 to 1.5 °C by 2030 when compared with the climate of 1980 to 1999
- Australian average temperatures are projected to rise by 1.0 to 5.0 °C by 2070 when compared with the climate of recent decades.

The Office of Environment and Heritage (OEH 2014) consider:

> *The North Coast Region is projected to continue to warm in the near future (2020–2039) and far future (2060–2079), compared to recent years (1990–2009). The warming is projected to be on average about 0.7°C in the near future, increasing to about 2°C in the far future. The number of high temperature days is projected to increase, while a reduction is anticipated in instances of potential frost risk.*

According to OEH (2014) maximum temperatures are projected to increase by *2060–2079* by 1.5 – 2.4°C and minimum temperatures by 1.6 – 2.5°C . The number of cold nights will decrease.

On average, the North Coast experiences fewer than 10 hot days per year (when maximum temperature is greater than 35°C) The number of hot days will increase, with another nine hot days by 2070. Inland around Casino and the Richmond Valley is expected to have a relatively greater increase with up to 20 more hot days per year by 2070

Rainfall

It remains uncertain how climate change will effect rainfall in north-east NSW, though some Australian changes are apparent (CSIRO & BoM 2012, 2014):

- spring and summer monsoonal rainfall across Australia's north appears to be increasing,
- late autumn and winter rainfall across the southern Australia is decreasing
- Climate models suggest long-term drying over southern areas during winter and over southern and eastern areas during spring.
- an increase in the number of dry days is expected,
- an increase in intense rainfall events is expected in many areas

Hennessy *et. al*. (2004) expect rainfall in north-east NSW to marginally decline into the next century in summer and, most significantly, spring. He expects the combination of declining rainfalls and rapid rises in evaporation (due to rising temperatures) will cause a general drying of the landscape (Hennessy *et. al*. 2004a). OEH (2014) consider that rainfall is projected to decrease in winter and increase in autumn and spring.

The expected increase in the intensity, duration, and frequency of extreme rainfall events will have significant impacts on erosion and flooding. In north-east NSW the most extreme rainfall occurrences are generally considered to be in the inland mountainous regions, where rainfall events greater than 500 mm a day have been recorded (Abbs 2004)

CSIRO (2007) note that by 2070 the Northern Rivers is likely to experience an increase in extreme one day rainfall events of 5-10%. Though these changes may not be as apparent in the immediate future, as Abbs (2004) modelled likely changes in extreme rainfall events from 2000 until 2040 in north-east NSW and south-east Queensland, finding *that the extreme rainfall events increase in intensity over the mountainous terrain but tend to decrease elsewhere.* Abbs (2004) notes "*The 2040-climate curve shows that extreme rainfall events are predicted to become both more intense and more frequent. The most extreme rainfall events are up to 30% more intense".*

McLuckie *et. al.* (2006) note *"Preliminary results from this work generally show a trend for maintaining existing rainfall intensities to 2030 with increased rainfall intensities across the NSW coast by 2070 across the full range of ARIs assessed. ... Therefore, the impacts of climate change on rarer events, of more interest in flood risk management, appears to be greater than in more frequent events and could be well in excess of 10% by 2030 and 20% by 2070. Therefore increasing rainfall intensities in higher ARI events is a real possibility for NSW even with a reduction in average annual precipitation."*

Hennessy *et. al*. (2004b) used four climate models to project changes for the years 2030 and 2070, which indicate that for north-east NSW: extreme one-day rainfall events are likely to decline in Autumn and Winter and increase in Spring and Summer by 2070, and *"Most* *models project an increase in the intensity of extreme rainfall in spring and summer on the north-east coast";*

Haines and Thom (2007) note:

> With respect to rainfall, a decrease in average rainfall is predicted by HENNESSY *et al.* (2004b), particularly during winter and spring and is likely to result in an increase of droughts by about 70% by the year 2030 and by more than 200% by the year 2070 (HENNESSY *et al.*, 2004a). An increase in actual rainfall storm intensity is also predicted (WALSH, 2004a; HENNESSY *et al.*, 2004a). Further, in response to increased global air temperatures, evaporation is likely to increase by between 1% and 8% by the year 2030 and by between 2% and 24% by 2070 (relative to 1990 levels) (HENNESSY *et al.,* 2004b).

Abbs (2004) found that *"the most extreme current-climate rainfall events will become more frequent, with the 1-in-40 year event of today corresponding with a 1-in-15 year event in 2040".*

In relation to flood frequencies, McLuckie et. al. (2006) state that *"current design events would happen more frequently as rainfall intensities increase. For instance, the current 100 year event could occur every 50 years as a result of an increase in rainfall intensity of just over 10%. The same event could occur every 20 years with a 30% increase in rainfall intensity. This may result in more regular damaging flood events with resultant increase in the frequency the community is exposed to the associated hazards and damages. Economic and social impacts could be potentially devastating".*

Marine

It is evident that climate change is having a significant impact on our seas, they are rising as they warm, expand and are fed by melting terrestrial ice masses, the atmospheric carbon they are absorbing is acidifying their waters, species are moving south, giant kelp forests are disappearing to the south and corals are bleaching to the north.

The trends are clear, as recognised CSIRO & BoM (2012, 2014):

- global mean sea level has risen by 225 mm from 1880 to 2012;
- sea-surface temperatures in the Australian region have warmed by 0.9°C since 1900;
- sea-surface temperatures around Australia have increased faster than the global average; and,
- ocean acidity levels have increased since the 1800s due to increased CO2 absorption from the atmosphere.

Around Australia sea-levels have been rising at an accelerating rate in recent times, with rates of 1.7$\pm$0.3 mm per annum for the 20th century, 3.1$\pm$0.4 per annum from 1993-2004 and 5.3 mm per annum from early 1990s to Jan 2006 (White and Church 2006).

There are various estimates of possible sea-level rises relative to 1990. Globally the IPCC (2013) identify the likely range of sea rises under various scenarios to be 18-38 cm by 2046-2065, and 26-82 cm by 2081-2100. For the worse scenario they note *"the rise by the year 2100 is 0.52 to 0.98 m, with a rate during 2081 to 2100 of 8 to 16 mm yr^{-1}".*

Horton et.al..(2013) summarised that *"the IPCC AR5 projected a likely (i.e. 66% likelihood range) global-average sea-level rise of 28-61 cm for a scenario of drastic emissions reductions (RCP 2.6) and 52-98 cm in case of unmitigated growth of emissions (RCP 8.5) by*

AD 2100 (relative to AD 1986-2005)". Horton et.al..(2013) sought to review this by surveying 90 leading sea-level experts, finding:

> *Most experts estimate a larger sea-level rise by AD 2100 than the IPCC AR5 projects. The body of expert opinion is more in line with the recent NOAA sea-level scenarios. We expect on average about 0.5 m of sea-level rise for the low and 1.0 m for the upper temperature scenario. Thirteen experts estimated a 17% probability of exceeding 2.0 m of sea-level rise by AD 2100 under the upper temperature scenario.*

The waters off the coast of NSW are projected to warm at above average rates due to a strengthening of the East Australian Current, with temperature increases of 0.6-0.9ºC by 2030, with this possibly doubling by 2050 (CSIRO 2007c). Due to this increasing heat there is expected to be an above average sea-level rise this century (about 0.2 m above the global average) off the east coast of Australia (CSIRO 2007c, Church et.al. 2008)

As the seas rise they are attacking the coastline. On natural sandy coasts the active beach system comprises dunes, the beach, and out to sea as far as the waves affect the seafloor. As the seas rise the active beach system seeks to maintain its equilibrium profile as it moves inland. An array of factors influence beach recession associated with rising sea-levels, including changes in the frequency and intensity of severe storms, background rates of recession (or accretion), sediment supply and changing wave environments. SMEC (2009) identify that *"Shoreline retreat can be 50 – 200 times the vertical sea level rise, depending on coastal geomorphology".* This means that for a metre sea-level rise, sandy coasts want to move inland by 50--200m.

Human infrastructure is increasingly coming into conflict with coastal recession. Coastal squeeze is occurring as beaches, mangroves and saltmarsh are being eroded by the sea but are prevented from retreating inland as we defend our roads and buildings.

Climate Variability

Future climate change is usually considered in terms of averages, though it is its effects on extremes that affect us the most. In north east NSW the principal climatic variations on interannual scales (2-7 years) are related to El Nino and La Nina events. Overlying these are multi-decadal (16-32 years) variations due to the Inter-decadal Pacific Oscillation (ie Chan 2008, Bryan *et. al.* 2008, WMO 2006, Church et.al. 2008).

El Nino events are associated with below average rainfall, droughts, higher daytime temperatures, heatwaves, suppressed sea levels, reduced sea surface temperatures, less frequent cyclones, and cyclones forming further to east. La Nina events are associated with above average rainfall, floods, lower daytime temperatures, rise in sea levels, increased sea surface temperatures, more frequent cyclones, cyclones forming further to west, and more intense East Coast Lows.

It appears that climate change is causing an intensification in the El Nino cycle (McGregor et. al. 2013, Power et. al. 2013)) which means extreme weather is becoming more extreme.

Extreme Events

The frequency and intensity of extreme events is increasing and will continue to do so into the future. Drought conditions are intensifying due to the more erratic rainfall, higher temperatures and higher evaporation. These too are increasing the frequency and intensity of wildfires. Floods are increasing due to increasing atmospheric moisture and intensifying rainfall events. Extreme storms may decline in frequency, though are increasing in intensity, along with their associated flooding, winds and storm tides. Hail storms are also increasing.

McLuckie et. al. (2006) note that an increase in extreme events would *"have significant implications for flooding due to an increase in occurrence of flood producing weather systems with associated increase in frequency of flood events for coastal areas of NSW. This work also predicts an increase in the confluence of extreme wind and rainfall events, with associated potential impacts on the level of wave activity (and ocean levels) during flood events with expected changes in ocean storm surge and run-up levels."*

Storms

The most extreme storms to affect north-east NSW are East Coast Lows and Tropical Cyclones. Storm hazards are related to strong winds, intense rainfall, flooding, large waves, storm surges, and coastal erosion.

Tropical cyclones are intense tropical low pressure weather systems. Tropical cyclone activity is influenced by a variety of physical factors, such as sea surface temperatures, wind shear, moisture availability, and atmospheric stability (Santer *et. al.* 2006). Sea surface temperature is the prime contributor (Queensland Government 2001, CSIRO 2007c). CSIRO note:

> *In the Australian region, variations in the number of tropical cyclones from year-to-year are strongly correlated with local sea surface temperature before and near the start of the cyclone season, with the strongest correlations being with October sea surface temperatures.*

The impacts of climate change on the intensity and frequency of tropical cyclones (including typhoons and hurricanes) is widely debated. In summary the numbers of cyclones around Australia are expected to decrease, though may increase off north-east Australia. Cyclones are expected to get bigger and move further south (ie CSIRO & BoM 2012).

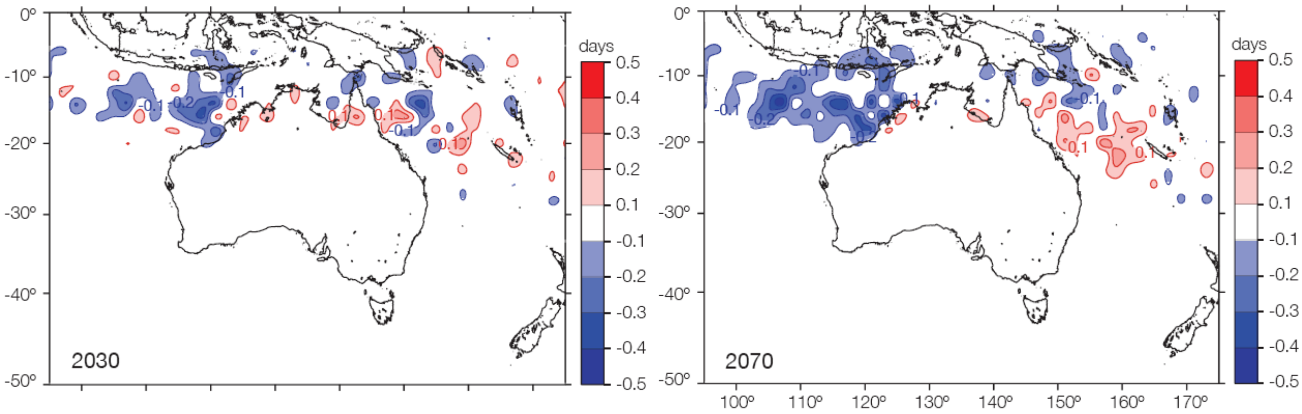


Figure: Simulated change in annual average tropical cyclone occurrence in the Australian region for 40-year time slices centred on 2030 and 2070. Blue regions indicate a decrease in tropical cyclone occurrence and red regions indicate an increase in occurrence. Results are from the CCAM Mark3 simulations forced with the SRES A2 scenario presented in Abbs *et al*.(2006), cited by CSIRO 2007c).

As cyclone tracks are projected to extend polewards (Church *et. al.* 2008, Leslie et. al. 2007, Solomon *et. al* 2007, CSIRO 2002, Walsh and Katzfey 2000, Hennessy *et. al.* 1998,) irrespective of changes in the overall numbers of cyclones, they are likely to impact on north-east NSW more frequently, as noted by Hennessy *et. al.* (1998):

> *Tropical cyclones may occur further south with the result that more systems may affect northern coastal NSW and more may redevelop into severe extratropical lows further south.*

For Australia, global warming is expected to result in increases of up to 20% in average and maximum cyclone intensities by 2050 (McInnes et. al. 2000, Pittock 2003).

For Queensland the Department of Natural Resources and Mines (2004) note:

> *tropical cyclones are expected to become more intense ...by 2050. The amount of rain produced by tropical cyclones is also expected to increase by up to 30 per cent over the same period, with implications for flood levels*

From their modelling of tropical cyclones Yoshimura *et. al.* (2006) found:

> *Mean precipitation near TC centers is heavier in the greenhouse-warming experiments than in the present-day-climate experiments, as compared for TCs with the same maximum wind speed. Since heavy rainfall near TCs sometimes causes severe floods, heavier precipitation could have important societal effects in a warmer climate.*

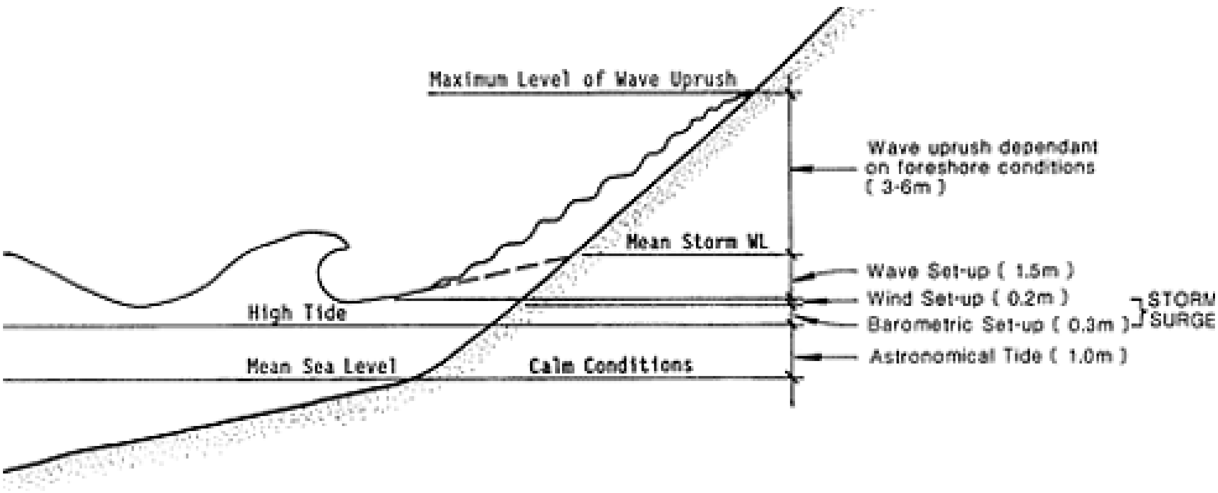
East Coast Lows are intense low-pressure systems which can develop rapidly off the eastern coast of Australia, most frequently during autumn and winter and often in clusters. East Coast Lows have been identified as responsible for 16% of all heavy rain events, and 7% of major Australian disasters (Wiles *et. al.* 2009). East coast low pressure systems are expected to become less frequent with climate change, though their intensity is expected to increase (Hennessy *et. al.* 1998, CSIRO 2002).

The likely southward extension of the East Australian Current will bring warmer water further southward along the east coast and enable a greater intensification of storm systems, Church et. al, (2008) report:

> *In a climate model simulation in which this pattern of EAC intensification occurs, it was found that east coast low pressure systems with central pressures of 990 hPa or deeper were 60% more frequent in 2070 (McInnes et al. 2007b).*

Storm Tides

The impacts of extreme storms on coastal communities is accentuated by storm tides. A storm tide is the total elevation of the sea above or below mean sea level due to the combination of astronomical tides, storm surges and wave setup. Storm tides elevate sea-levels and thus allow waves to directly attack sand dunes and infrastructure, while backing up water in estuaries and increasing flood heights.



Elevation of water levels during a storm (from NSW Coastal manual 1990)

During a storm the combination of reduced barometric pressure and winds result in storm surges. The magnitude of the surge is related to the combination of the reduced pressure, surface winds, the speed of the storm and regional bathymetry. Surges can last for periods of several hours, generally manifesting as gradual increases in water levels which can accelerate rapidly near the peak of the surge. Under the present climate NSW (1990) identifies that storm surge can elevate ocean water levels along the NSW coastline by 0.3 to 0.6m. Though, based on the likelihood of more intense cyclones around Byron Bay, DPW (1978) assume storm surges of up to 1.2 metres.

Also during storms the breaking of the swell and waves driven ashore by storms results in an increase in water level within the surf zone known as "wave setup", which adds to the storm surge impact. The degree of setup depends upon the type, size and period of the waves at breaking and the slope of the beach (NSW 1990). The NSW Coastal Manual recognises that under the present climate *"On the New South Wales coast wave setup during severe storms can be in the order of 1.5m and often makes the largest contribution to the elevated water level"*.

Wave runup refers to the vertical distance the uprush of water from a breaking wave reaches above the elevated water levels. The magnitude of runup is directly related to the significant wave height, though is influenced by a variety of other factors, particularly the wave period, beach slope and roughness of the runup surface. The NSW Coast Manual (1990) identifies that "*A wave runup of more than 6m can occur".*

The impact of storm surges is proportional to the height of the tide. Dewar and McLuckie (2008) identify typical peak ocean levels along the NSW coast as -0.4m for a low tide, +0.6 m for a high tide and +1.1m for the highest tide in a year. Together the tide, storm surge and wave setup constitute the storm tide.

As sea-levels rise and storms intensify so too will the magnitude and impacts of storm tides. Hardy *et.al* (2004) modelled an increase in cyclone intensities and frequencies of 10%, a poleward shift in tracks of 1.3° (about 130 km) and a mean sea level rise of 300mm and found that for the Sunshine coast this scenario resulted in a storm tide increase of about 0.5 m at all return periods, while for Hervey Bay the increase varied from around 0.5 to 0.6 m for a 10 year return period to 0.8 to 0.9 m for a 3000 year return period.

Church et. al (2006) found that for Australia extreme sea-levels "*that occur on annual to decadal timescales increased their frequency of occurrence by a factor of about three during the 20th century"*. Based on this, Hunter (2008) estimates that for a mean sea level rise of 0.5 metres the mean multiplying factor for Australia would be 286, "indicating that events which now happen every few years would happen every few days", *"or the present '100 year event' happening every few months"*.

Hail Storms

There is also expected to be a significant increase in the intensity and frequency of hail storms affecting north-east NSW due to climate change. CSIRO (2007c) note:

> *Projections of changes in hail risk for the end of the century (based on the A2 scenario) indicate a dramatic increase along the southeastern coastline*

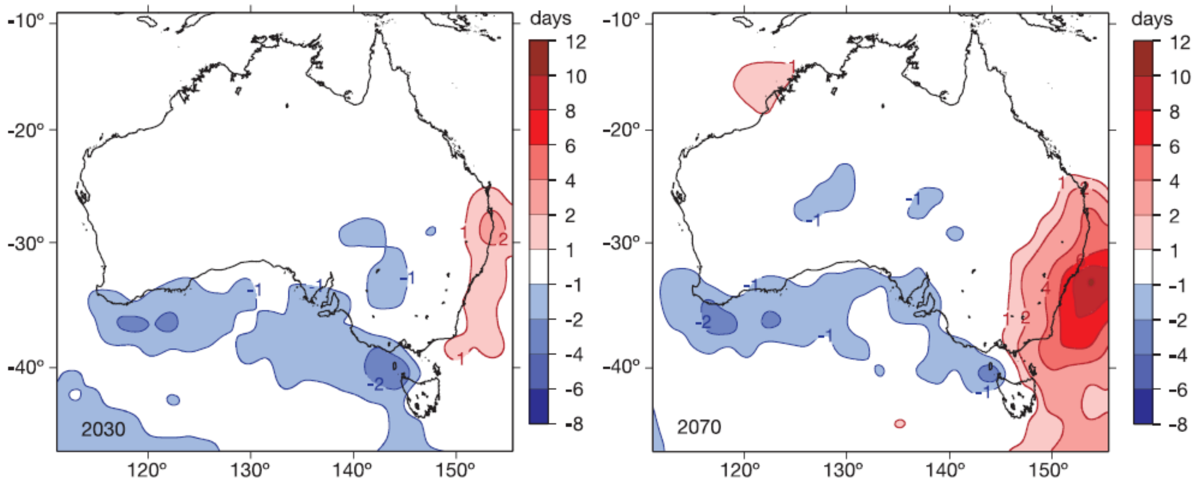


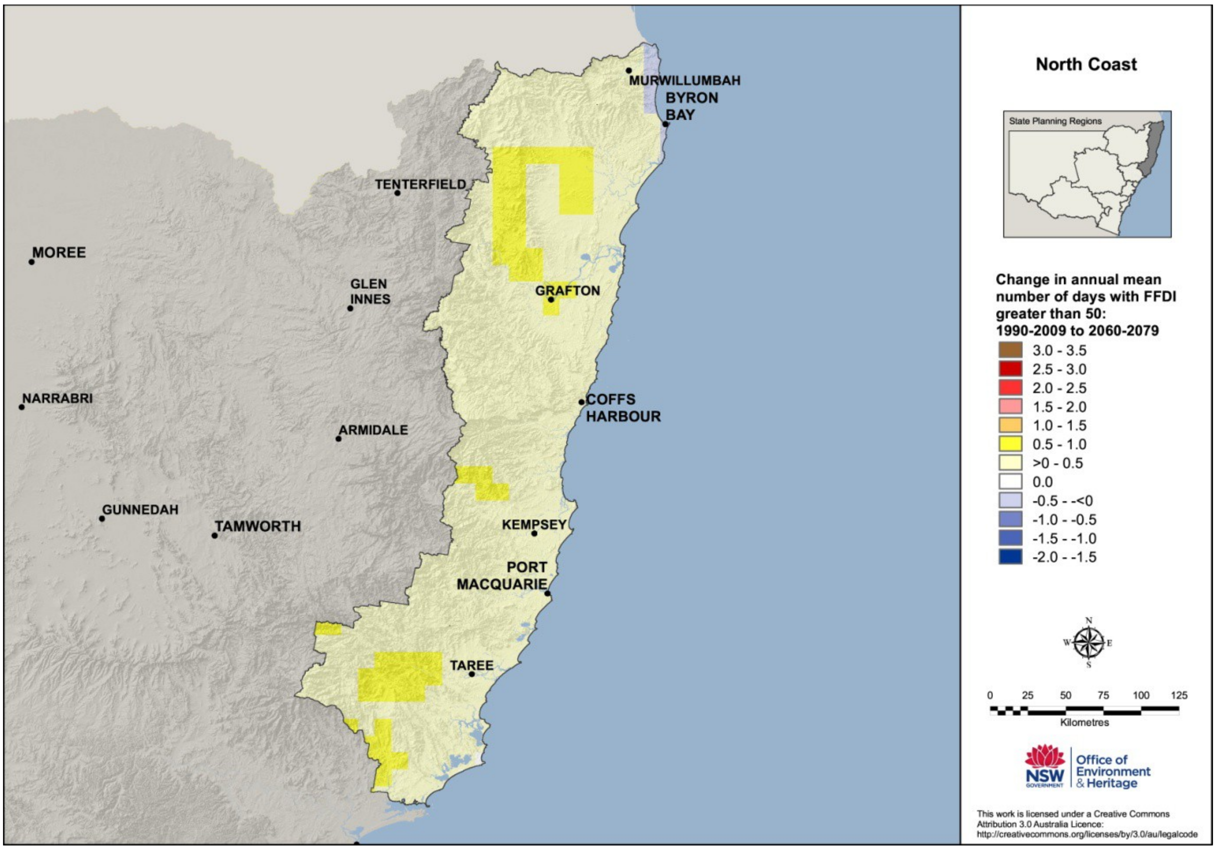
Figure: Projected changes in hail risk (hail-days per year) for 2030 and 2070 from the CSIRO Mark 3.5 model for the SRES A2 scenario. Blue regions indicate a decrease in hail risk and red regions indicate an increase in hail risk. The large-hail risk for this region is projected to almost double, increasing by between 4 to 6 days per year. (From CSIRO 2007c)

Fire Storms

The projected hotter, drier, windier conditions associated with climate change are increasing the frequency and intensity of bushfires in Australia. The fire storms being experienced in southern Australia are the worst manifestations of this.

The Forest Fire Danger Index (FFDI) is used in NSW to quantify fire weather. The FFDI combines observations of temperature, humidity and wind speed with an estimate of the fuel state. The highest average FFDI occurs in spring and the lowest in autumn. Fire weather is classified as 'severe' when the FFDI is above 50. Severe fire weather conditions are estimated to occur on average two days per year at Casino, but are rare at Lismore and Coffs Harbour (OEH 2014). Severe fire weather days are projected to increase in summer and spring

Using the Forest Fire Danger Index as an indicator of fire risk, Hennessy et al. (2005) predicted an increase in very high and extreme risk days by 12% to 15% in Coffs Harbour and by 13% to 18% in Williamtown by 2050. This equates to an increase from the current average of 4.4 days a year to up to a possible 7.6 days a year for Coffs Harbour, and an increase from the current 16.4 days a year in Williamtown to up to 23.6 days.



Changes in annual mean number of days with FFDI greater than 50 by 2070 (OEH 2014)

Carbon Storage

Sequestering and Storing Carbon in Forests

REFERENCES

Abbs, D. (2004) A high-resolution Modelling Study of the Effect of Climate Change on the Intensity of Extreme Rainfall Events. CSIRO Atmospheric Research.

Bryan,K.R., Paul S. Kench, P.S. and Hart, D.E. (2008) Multi-decadal coastal change in New Zealand: Evidence, mechanisms and implications. *New Zealand Geographer,* (2008), 64, 117–128

Chan, J.C.L., (2008) Decadal variations of intense typhoon occurrence in the western North Pacific. Proc. R. Soc. A (2008) 464, 249–272.

Church, J.A., White N.J., Hunter, J.R., McInnes, K.L, Cowell. P.J and O'Farrell, S.P (2008) Sea-level Rise and the Vulnerability of Coastal Environments. Chapter 12 in Transitions: Transitioning to Resilient Cities, CSIRO Publishing, Melbourne, Australia. pp 191- 209.

Church, J.A., J.M. Gregory, N.J. White, S.M. Platten, and J.X. Mitrovica. 2011. Understanding and projecting sea level change. *Oceanography* 24(2):130–143, http://dx.doi.org/10.5670/oceanog.2011.33.

CSIRO (2002) Climate Change and Australia's Coastal Communities. Information sheet.

CSIRO (2007c) Climate Change in Australia – Technical Report 2007. http://climatechangeinaustralia.gov.au/documents/resources/TR_Web_Ch5iv.pdf (Accessed May 2009)

CSIRO & BoM (2012) State of the Climate 2012.

CSIRO & BoM (2014) State of the Climate 2014.

Dewar, R. And McLuckie, D. (2008) Floodplain Management in NSW – Adapting for Sea Level Rise. IPWEA National Conference- Responding to Sea Level Rise, Novotel Pacific Bay Resort, Coffs Harbour NSW 3-5th August 2008.

Department of Natural Resources and Mines (2004) Climate Change, the Challenge for Natural Resource Management. Department of Natural Resources and Mines, Queensland.

Department of Public Works (1979) Summary of Byron Bay – Hastings Point Erosion Study. DPW.

Hardy, T., Mason, L., Astorquia, A. and Harper B. (2004) Tropical Cyclone- induced Water Levels and Waves: Hervey Bay and Sunshine Coast. Queensland Climate Change and Community Vulnerability to Tropical Cyclones: Ocean Hazards Assessment Stage 2. Queensland Environmental Protection Agency

Hennessy K., Page C., McInnes K., Jones R., Bathols J., Collins D. and Jones D. (2004) Climate Change in New South Wales. CSIRO Consultancy report for the New South Wales Greenhouse Office.

Haig, J, Nott, J & Reichart, G.(2014) Australian tropical cyclone activity lower than at any time over the past 550–1,500 years. Nature V505

OEH, Office of Environment and Heritage (2014) North Coast Climate change snapshot, Adapt NSW.

Haines, P.E. and Thom, B.G., 2007. Climate change impacts on entrance processes of intermittently open/closed coastal lagoons in New South Wales, Australia. Journal of Coastal Research, SI 50 (Proceedings of the 9th International Coastal Symposium), 242 – 246. Gold Coast, Australia, ISSN 0749.0208.

Hennessy, K.J., Whetton P.H., Katzfey, J.J., McGregor, J.L., Jones R.N., Page, C.M, and. Nguyen, K.C. (1998) Fine Resolution Climate Change Scenarios for New South Wales, Annual Report 1997-98. Research undertaken for the New South Wales Environment Protection Authority.

Hennessy, K., Page, C., McInnes, K., Jones, R., Bathlos, J., Collins, D., and Jones, D. (2004a) Climate Change in New South Wales, Part 1: Past climate variability and projected changes in average climate. CSIRO Consultancy Report for NSW Greenhouse Office.

Hennessy, K., McInnes, K., Abbs, D., Jones, R., Bathlos, J., Suppian, R., Ricketts, J., Rafter, T., Collins, D., and Jones, D. (2004b) Climate Change in New South Wales, Part 2: Projected changes in climate extremes. CSIRO Consultancy Report for NSW Greenhouse Office.

Hennessy K., Lucas C., Nicholls N., Bathols J., Suppiah R., and Ricketts J. (2005) Climate change impacts on fire-weather in south-east Australia. Commonwealth Scientific and Industrial Research Organisation

Hunter, J. (2008) Sea-level Rise and the Vulnerability of Coastlines. 2nd Regional Forum on Climate Change and Coastal Communities, Lismore, 3-4 July 2008.

IPCC (2013) Climate Change 2013, The Physical Science Basis. Summary for Policymakers. Working Group 1 Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Leslie, L. M., Karoly, D. J., Leplastrier M., and Buckley, B. W. (2007)Meteorology and Atmospheric Physics, Volume 97, Numbers 1-4 / August, 2007

McGregor S., Timmermann A., England M. H., Elison Timm O., and Wittenberg A. T. (2013) Inferred changes in El Niño–Southern Oscillation variance over the past six centuries. Clim. Past, 9, 2269–2284,

McGregor S. Timmermann3A., England M. H., Elison Timm O., and Wittenberg A. T. (2013) Inferred changes in El Niño–Southern Oscillation variance over the past six centuries. Clim. Past, 9, 2269–2284,

McInnes, K.L., Walsh, K.J.E. and Pittock, A.B. (2000) Impact of sea-level rise and storm surges on coastal resorts. A report for CSIRO Tourism Research, CSIRO, Canberra, 24 pp.

McLuckie, D., Lord D., and Gibbs J. (2006) Climate Change – the Future is Uncertain. 46th NSW Floodplain Management Authorities Conference, Lismore February 28 to March 2, 2006.

NSW Coastal manual (1990) NSW Coastline Management Manual, *New South Wales Government. September 1990,* ISBN 0730575063. http://www.environment.gov.au/archive/coasts/publications/nswmanual/index.html

Horton B.P., Rahmstorf S., Engelhart S.E. and Kemp A.C.(2013) Expert assessment of sea-level rise by AD 2100 and AD 2300. Quaternary Science Reviews 84 (2014) 1-6.

OEH (2014), North Coast Climate change snapshot. Office of Environment and Heritage.

Pittock, B. (Ed) (2003) Climate Change: An Australian Guide to the Science and Potential Impacts. Australian Greenhouse Office.

Power, S., Delage F., Chung, C., Kociuba G. and Keay, K, (2013) Robust twenty-first-century projections of El Niño and related precipitation variability. Nature 502, 541–545

Queensland Government (2001) Queensland Climate Change and Community Vulnerability to Tropical Cyclones, Ocean Hazards Assessment - Stage 1. Department of Natural Resources and Mines.

Santer, B.D., Wigley, T.M.L., Gleckler, P.J., Bonfils, C., Wehner, M.F., Achuta Rao, K., Barnett, T. P., Boyle, J. S., Bru¨ggemann, W., Fiorino, M., Gillett, N., Hansen, J. E., Jones, P. D., Klein, S. A., Meehl, G. A., Raper, S. C. B., Reynolds, R. W., Taylor, K. E. and Washington, W. M. (2006) Forced and unforced ocean temperature changes in Atlantic and Pacific tropical cyclogenesis regions. *Proceedings of the National Academy of Sciences of the United States of America, 103*(38), 13905-13910

SMEC (2009) Climate Change Adaptation Actions for Local Government . Australian Greenhouse Office, Department of the Environment and Water Resources in 2007.

Solomon, S., D. Qin, M. Manning, R.B. Alley, T. Berntsen, N.L. Bindoff, Z. Chen, A. Chidthaisong, J.M. Gregory, G.C. Hegerl, M. Heimann, B. Hewitson, B.J. Hoskins, F. Joos, J.

Jouzel, V. Kattsov, U. Lohmann, T. Matsuno, M. Molina, N. Nicholls, J. Overpeck, G. Raga, V. Ramaswamy, J. Ren, M. Rusticucci, R. Somerville, T.F. Stocker, P. Whetton, R.A. Wood and D. Wratt, 2007: Technical Summary. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Walsh KJE and Katzfey JJ (2000) The impact of climate change on the poleward movement of tropical cyclone-like vortices in a regional climate model. Journal of Climate, 2000

White, N.J. and Church, J.A. (2006) A 20th century increase in the rate of sea-level rise- a challenge for Coastal Managers. Coast to Coast 2006, Victorian Coastal Council, 22 - 25 May.

WMO, World Meteorological Organisation (2006) Statement on Tropical Cyclones and Climate Change. WMO International Workshop on Tropical Cyclones, IWTC-6, San Jose, Costa Rica, November 2006.

Wiles, P., Pepler, A., and Speer, M. (2009) Inter-annual Variability in Australian East Coast Lows and its relation with Key Climatic Indices. http://www.bom.gov.au/events/9icshmo/manuscripts/PT_EFG31_Wiles.pdf

Yoshimura, J., Sugi, M., & Noda, A. (2006). Influence of greenhouse warming on tropical cyclone frequency. *Journal of the Meteorological Society of Japan, 84*(2), 405-428.