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Review

The Eastern Australian Floods of February 2022 and Its Relationship with Climate Change

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Abstract

During February 2022 major riverine flooding occurred in an area which has the fastest population growth in Australia. This extended from the Mary River in Southeast Queensland (SEQ) to the Clarence River in Northeast NSW (NENSW). Two centres within this area were devastated by floods unprecedented in living memory. One was the Brisbane Metropolitan area where all-time record daily rainfall in the suburbs flooded creeks. This creek flooding was much worse than that caused by the Brisbane River itself where Wivenhoe Dam played a role in preventing more disastrous flooding. The other was in the Northern New South Wales city of Lismore where rainfall in the Wilsons River catchment exceeded all known rainfall rates there. The structure of the weather system generating the rainfall responsible for these two floods is studied along with the climatology of such events. One event which occurred during 1954 stands out and is examined in detail. A climate shift in 1976 resulted in two decades of relatively benign weather in the region and tourism flourished there due to mild summers and warm winters. The area experienced a huge growth in population with fading memories of past disastrous weather events and huge residential development occurred in flood plain areas. During the twenty-first century these extreme events have returned although so far not as frequent as earlier decades but still result in some residents experiencing multiple

flooding events. The 1954 event occurred during an extended period of devastating flood events not experienced in recent decades. With the huge increase in population in this area since the 1970s such a series of events like those in the 1950s would stretch the resources of disaster managers given the problems, they faced in 2022.

Keywords
Extreme rain; major floods; climate change; population increase

1. Introduction

Special Climate Statement 76 by the Bureau of Meteorology describes the full effects of the Southeast Queensland (SEQ) and Northeast New South Wales (NENSW) February 2022 floods. Updated data from the Insurance Council of Australia [1] shows these series of floods were Australia's costliest flood since 1967 with a cost of 4.3 billion Australian dollars. This assessment was prior to the July 2022 floods. The worst of these floods were in the Brisbane Creeks and in the Wilsons River catchments with the latter passing through the city of Lismore. These are the events described in this paper. There were fifteen fatalities associated with these floods (10 in SEQ and five in Lismore). The region is known for its devastating weather events besides the 2022 floods. Since 1967 five of the top eight Australian events in terms of insurance disaster costs occurred in this region [2]:

- Rated third 1966/1967 Cyclone Dinah QLD/NSW $4.685 billion 2017 Australian dollars.
- Rated fifth 1973/1974 SEQ/NE NSW floods $3.160 billion 2017 Australian dollars.
- Rated seventh 1984/1985 Brisbane Hailstorm $2.274 billion 2017 Australian dollars.
- Rated eighth 2010/2011 Brisbane & Lockyer Valley Flooding $2.260 billion 1967 Australian dollars.
- Seasonal event 1967 Gold Coast Beach Erosion $9.000 billion 2017 Australian dollars.

The event causing these devastating 2022 floods in Brisbane and Lismore in February 2022 was an East Coast Low (ECL). The term ECL is used in Australia to refer to a low-pressure system with or without a tight closed cyclonic circulation at sea level that forms and/or intensifies in a maritime environment within the vicinity of the east coast of Australia, although it should also be noted that a range of secondary criteria are used in different studies. They can cause significant wind, flood, and ocean damage and are often responsible for loss of life. For a review of ECLs see Dowdy et al [3]. Early ECL studies include Holland et al 1987 [4], Hopkins and Holland 1997 [5] and Callaghan [6]. The Queensland (Qld) Office of the BOM have examined the vertical structure of many ECL events [7-12]. Based on these extensive analyses, we know that the most common pattern is where strong mean sea level (msl) low pressure systems result from a tropopause undulation (TU) approaching the developing low-pressure area in a region where 850 hPa winds turn in an anticyclonic fashion up to 500 hPa. As this wind structure resembles Quasi Geostrophic warm air advection (WAA) it is referred to as WAA in this paper. Earlier Hirschberg and Fritsch [13-15] identified these phenomena causing cyclogenesis although since then little published work has occurred to consolidate their way of thinking. This event is compared with an event which occurred in SEQ and NENSW during February 1954 which had a death toll of thirty-six people. The Gold Coast in 1954 had a population

of around 30,000 which by 2022 had grown to around 720,000 which makes planners there terrified of another 1954 type cyclone making landfall there again. Why this is so is explained below. These events were much more prevalent in the late nineteenth century and from 1949 to 1976. Following this there was a period of relative calm encouraging huge development of Tourism and building on the flood plains of coastal rivers over SEQ and NENSW. A resurgence of the severe flooding events began again during the 21st century when a series of La Nina episodes began to occur.

As a background to the February 2022 floods mean Reanalysis chart for 22-28 February 2022 (Figure 1) are drawn. Humid air (dewpoints 21-23°C) was advected down from the tropics and this can be seen from the tongue of large amounts of precipitable water coming down towards coastal stations in the right frame of Figure 1. The msl pattern (Figure 1 left frame) shows strong onshore flow into SEQ and NENSW with a strong ridge to the south across the southern Tasman Sea. The ridge was maintained over the period by a succession of high cells moving in from the west.

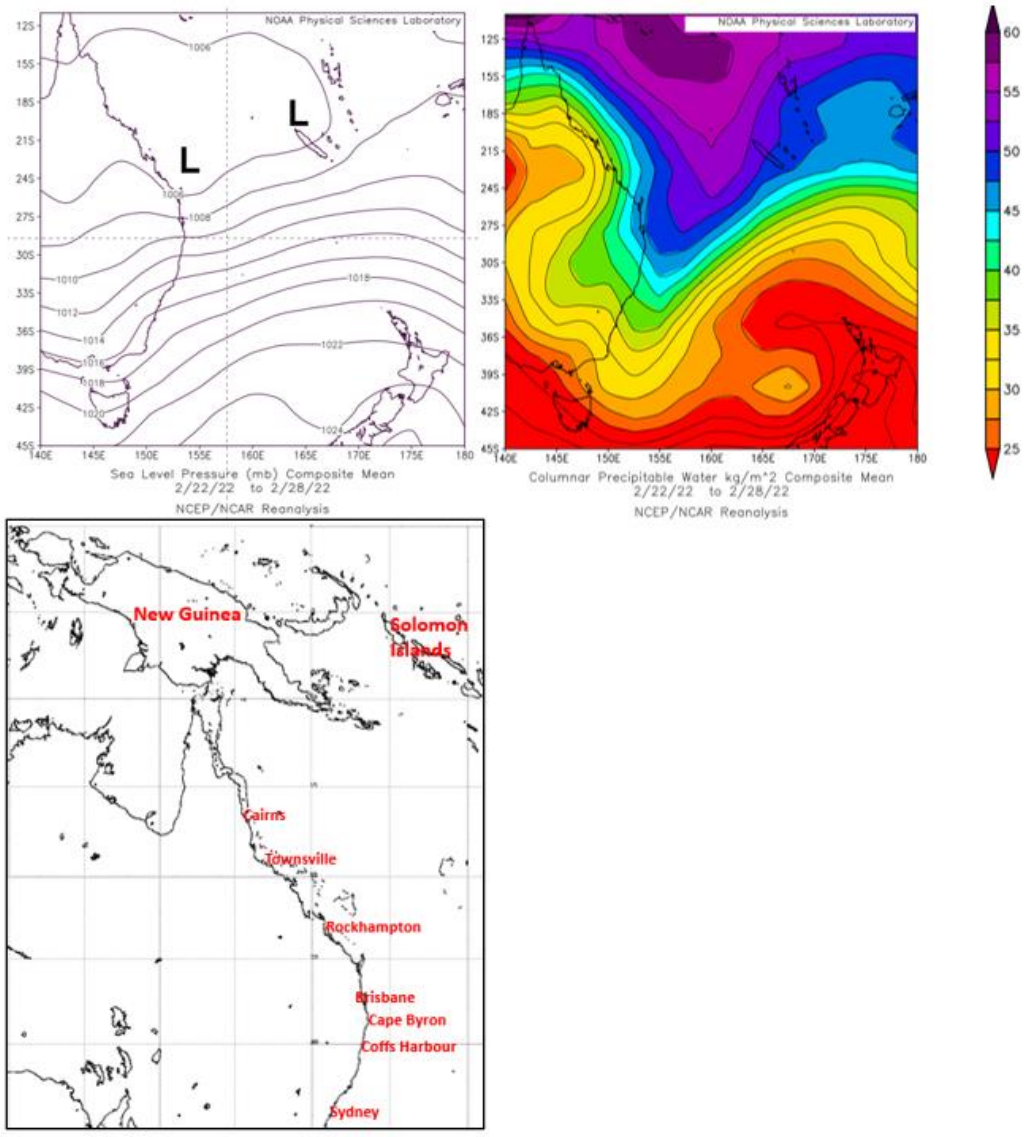

Figure 1 US NCEP/NCAR reanalysis of average Mean Sea level (hPa) analysis over the period 22 February 2022 to 28 February 2022 (left) and average Precipitable Water over the period 22 February 2022 to 28 February 2022 (right). Location map (Lower Frame).

Although the floods affected a large area of Southeast Queensland and Northeast NSW this study focusses on record floods in the Brisbane suburbs and in Lismore in northern NSW and the aim of this study is to show that if history is to be repeated than more extreme events can occur in this area in the future.

2. Data Sources

In this report we have used data from the Australian Bureau of Meteorology and data from the National Centres for Environmental Prediction/National Centre for Atmospheric Research (NCEP/NCAR) Reanalysis Project**.**

3. Evolution of the February 2022 Wind Structure in the Brisbane Suburbs and Northeast New South Wales Floods

Over 22 February 22 and 23 February 2022 a tropical low was located at mean sea level (msl) just to the northeast of the North Queensland coastal City Townsville (Latitude 19.25 South and had moved east of Townsville by 24 February. This occurred as a TU in western Queensland at 12:00 UTC 22 February moved towards SEQ. Over 24 and 25 February the low became a trough which crossing the coast near Gladstone and extending into NE NSW. During 26 February a large high developed in the southern Tasman Sea and by 27 February a low developed along the SE Qld coast with a strong pressure gradient between the high and the low increasing onshore winds about SEQ and NENSW.

Heavy rain and thunderstorms developed over Eastern Australia as the TU moved towards Southeast Queensland. By 25 February a TU, identified by the region of 200 hPa warm temperatures (Figure 2 top left). It can be seen northwest of Brisbane with 200 hPa WAA directed towards Brisbane. Strong northeasterly winds over Brisbane at 850 hPa are located south of a cyclonic circulation to the north near K'Gari (Fraser Island). The slope of the circulation to the southwest brings 700 hPa WAA onto the coast between Brisbane and K'Gari. This 700 hPa WAA extended southwards onto the coast and by 1200UTC 25 February (Figure 3) and 00:00 UTC 26 February (Figure 4) covered large areas of Southeast Queensland and Northeast NSW. Heavy rain began in Brisbane suburbs around 05:00 UTC 25 February 2022. From Figures 5 to 8 the WAA gradually became more coastal in the Brisbane area and further south and by 00:00 UTC 28 February 2022 had contracted down into Northern NSW.

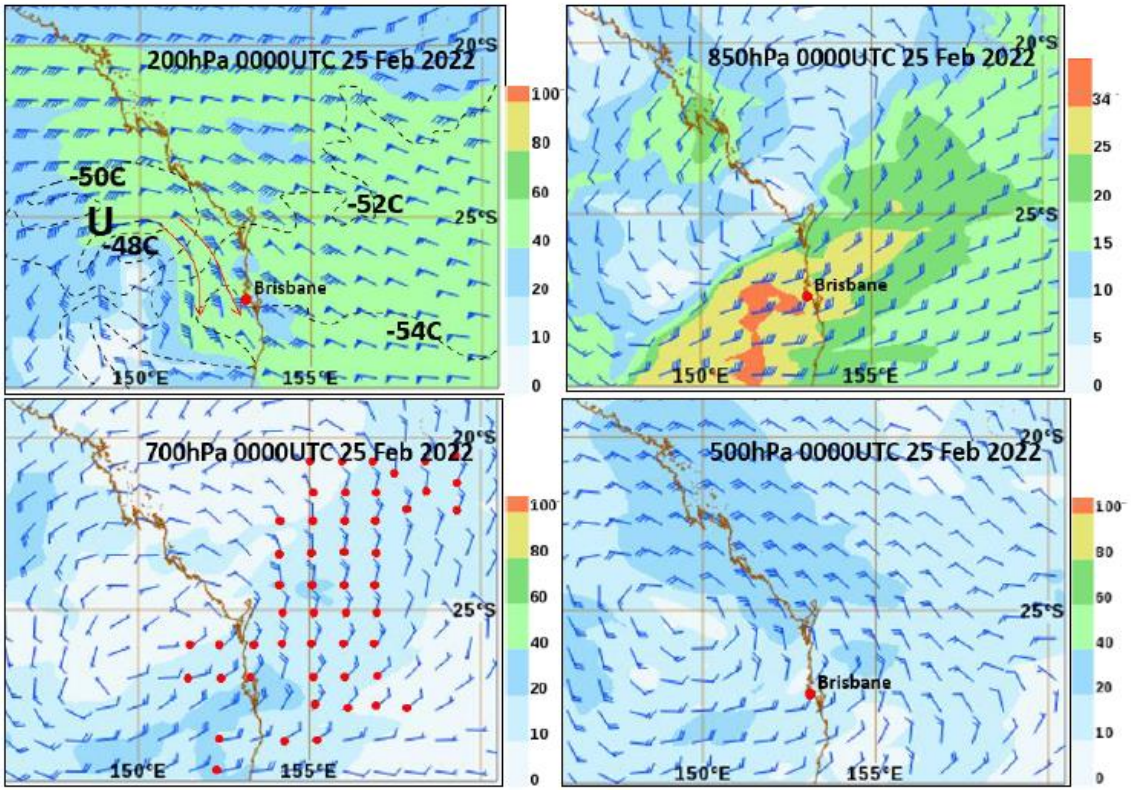

Figure 2 Same as in Figure 2 except for 00:00 UTC 25 February 2022 and 200 hPa in top left frame 850 hPa in the top right frame, 700 hPa in the lower left frame and 500 hPa in the lower right frame.

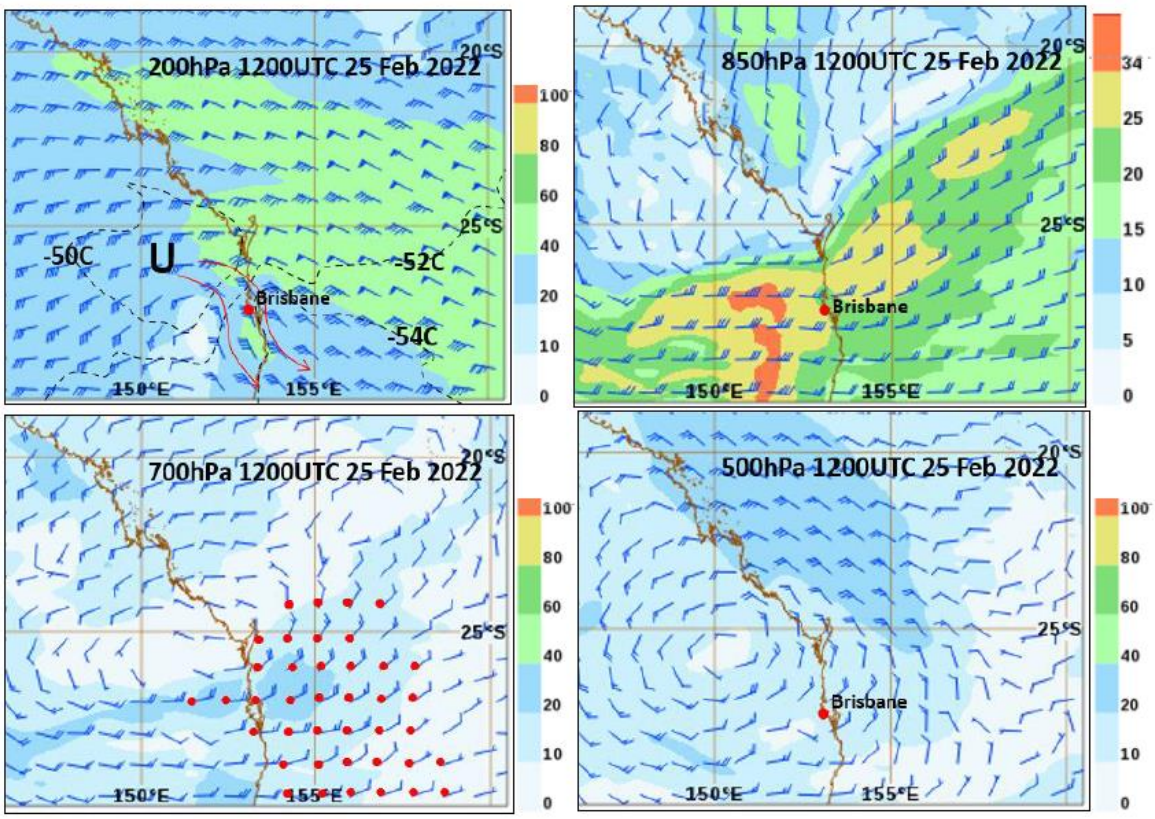

Figure 3 Same as in Figure 2 except for 12:00 UTC 25 February 2022.

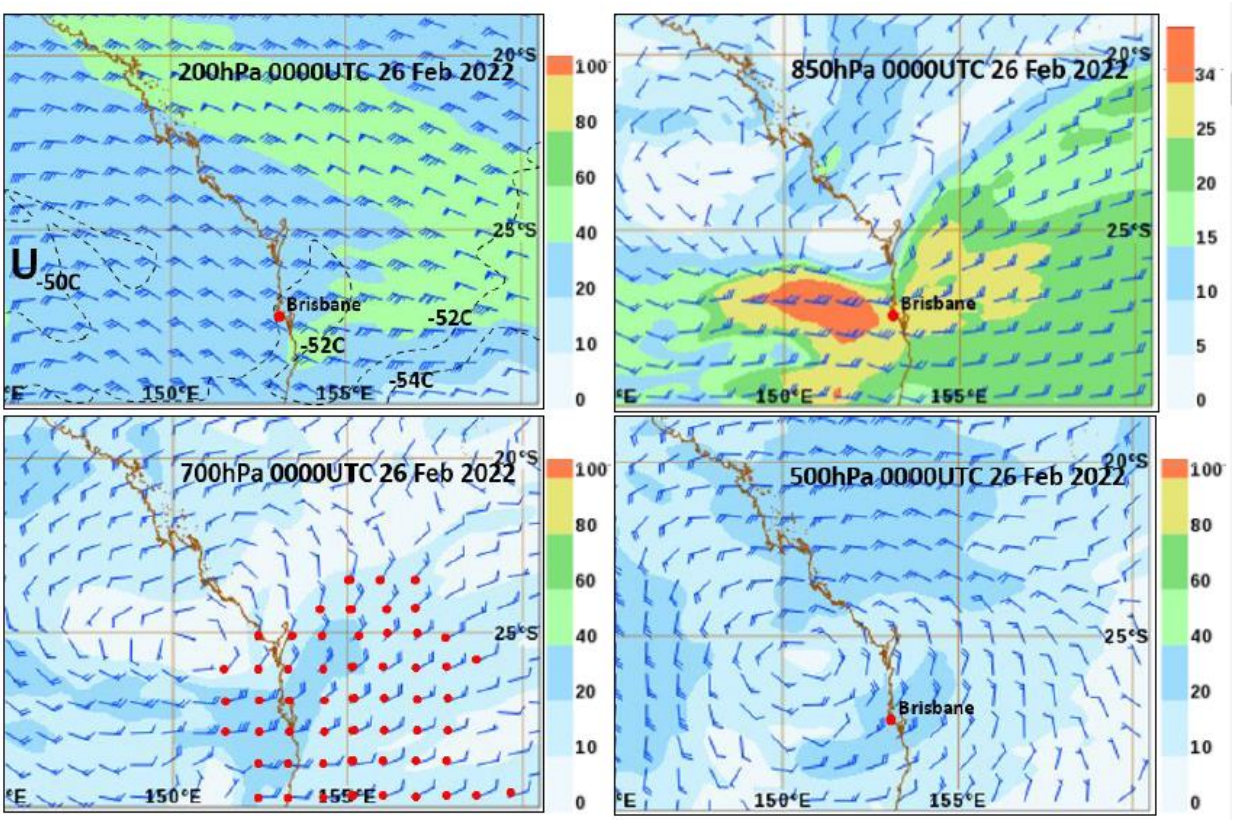

Figure 4 Same as in Figure 2 except for 00:00 UTC 26 February 2022.

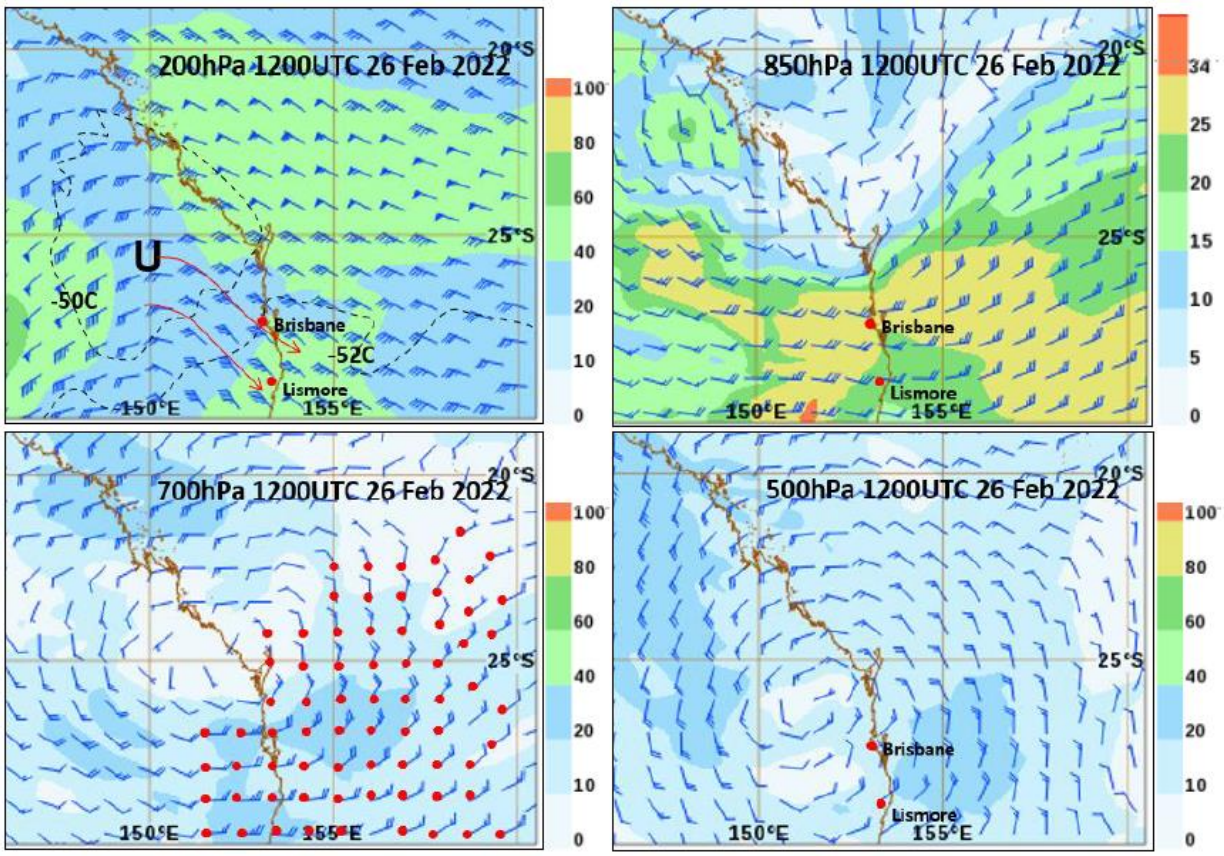

Figure 5 Same as in Figure 2 except for 12:00 UTC 26 February 2022.

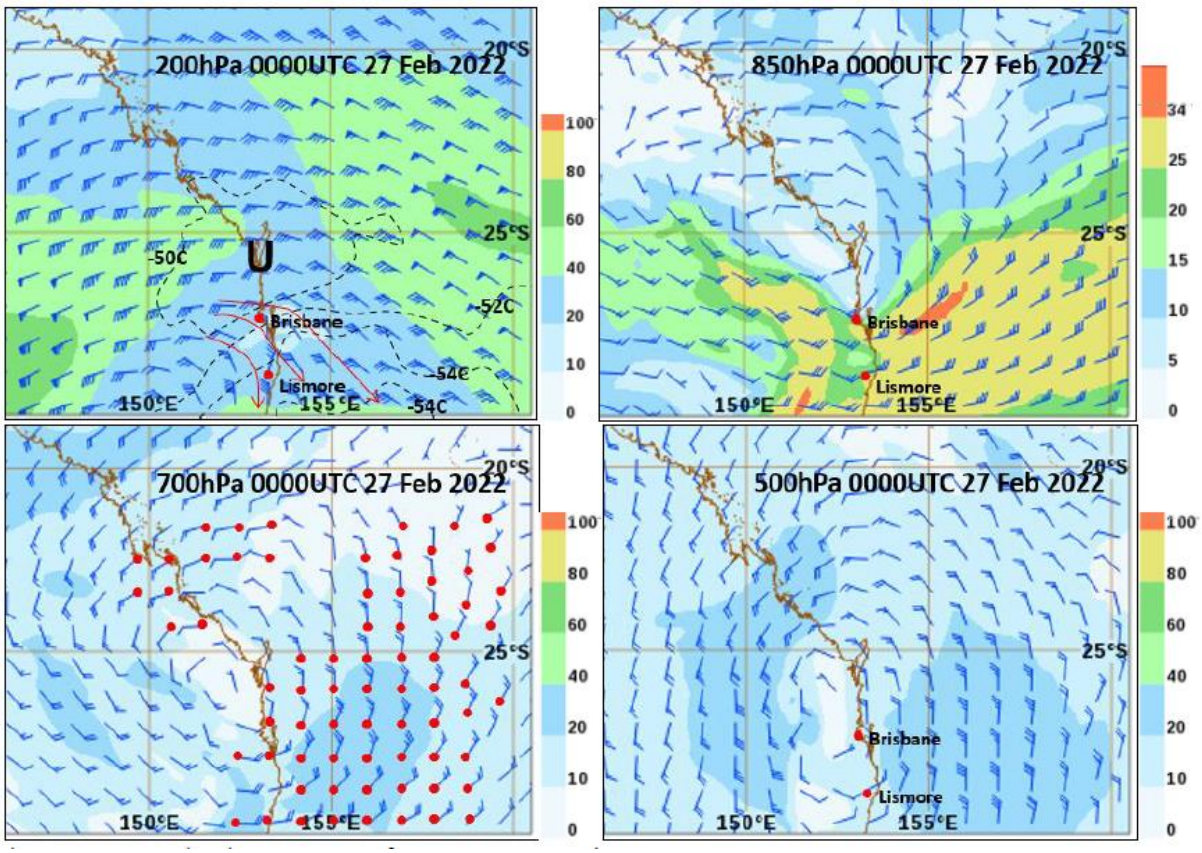

Figure 6 Same as in Figure 2 except for 00:00 UTC 27 February 2022.

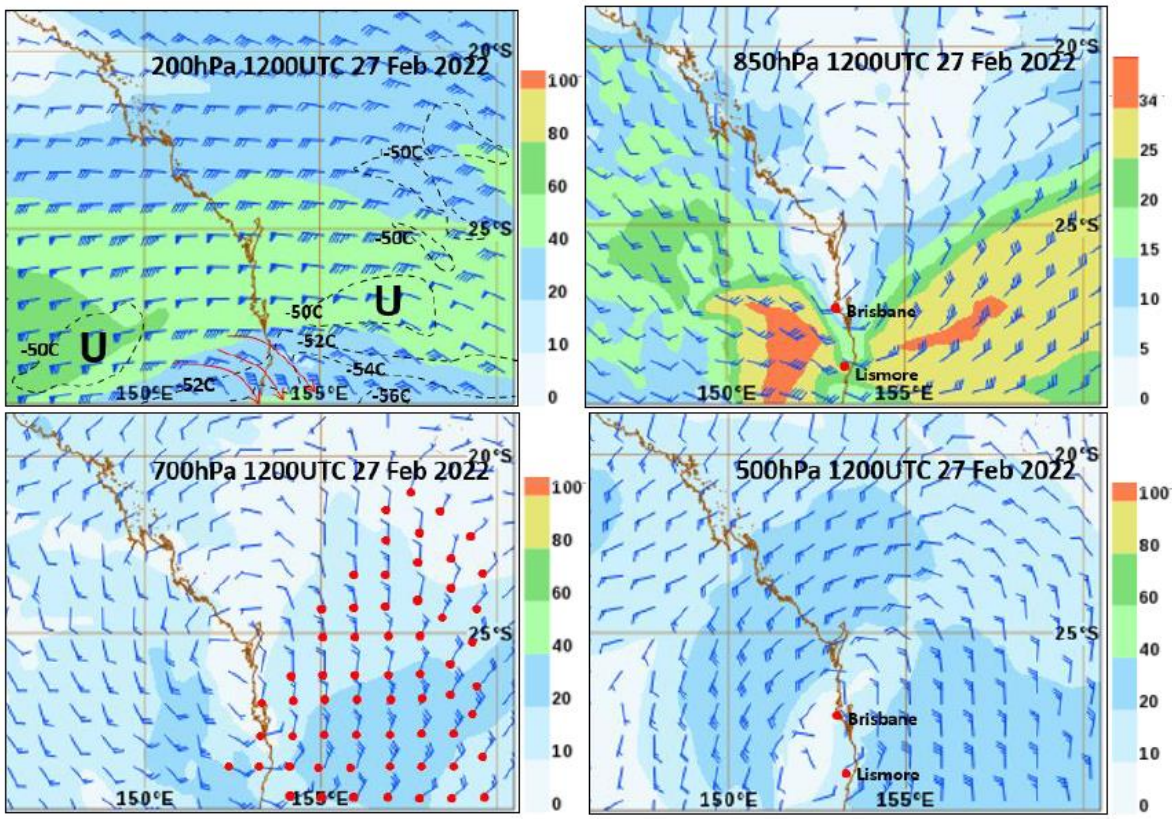

Figure 7 Same as in Figure 2 except for 12:00 UTC 27 February 2022.

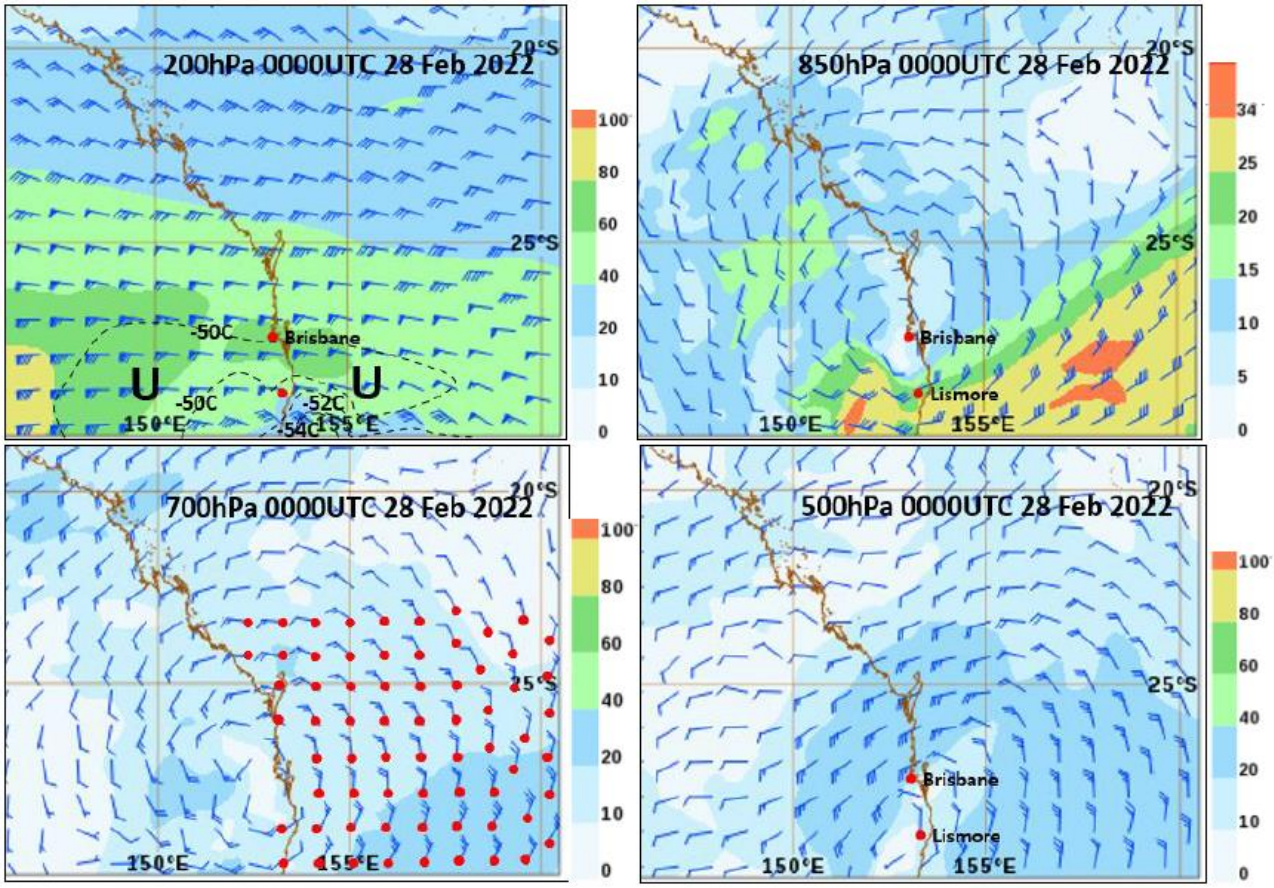

Figure 8 Same as in Figure 2 except for 00:00 UTC 28 February 2022.

4. The Role of Brisbane Creeks on Brisbane Flooding

On 19 May 2022 Brisbane City Council Lord Mayor Adrian Schrinner, whose area covers the Brisbane Creeks, reported that about 200 council buildings, 100 sports fields and 285 kilometres of roads were affected by the February 2022 flood, and that the council said the damage bill for these would be up to $330 million, three times more than the cost of the 2011 flood. He also warned that the damage bill for the city's ferries, roads, lights, parks, and bikeways could be triple the $440 million cost of the 2011 floods. Breakfast Creek Mouth had a peak flood on the high tide of 4.7 m (Major level 3.3 m) at 10:00 UTC 27 February 2022 12 hours before the peak in the river in Brisbane City. The severe flooding in Kedron Brook (near northern suburbs of Brisbane) caused the permanent closure of a large shopping complex (Toombul Shopping Town). In Brisbane suburbs heavy rain mostly occurred from the afternoon of 25 February to the evening of 27 February. Brisbane City Council reported that 177 suburbs and 20,000 homes were affected by flooding.

Table 1 shows the very heavy rainfall in Brisbane suburbs in the 72 hours to 23:00 UTC 27 February 2022 and the heavy daily rainfall noting the ones which broke all-time records.

Table 1 Brisbane City and suburban rainfall.

24 hour period	Station	Rainfall (mm)	24-hour Record details	72 hour rainfall (mm) to 23:00 UTC 27 February 2022
24 h to 23:00 UTC 26 Feb 2022	Brisbane (Kangaroo Pt)	228.4	All-time record since 1999	687.9
24 h to 23:00 UTC 27 Feb 2022	Alderley	344.8	All-time record since 1899	886.0
24 h to 23:00 UTC 26 Feb 2022	Mt Coo-tha Gardens	294.0	All-time record since 2005	716.4
24 h to 23:00 UTC 26 Feb 2022	Brisbane Airport	234.2	All-time record since 1992	623.0
24 h to 23:00 UTC 26 Feb 2022	Clontarf	340.0	All-time record since 2005	950.0
24 h to 23:00 UTC 26 Feb 2022	Deception Bay	294.0	All-time record since 2006	793.0
24 h to 23:00 UTC 27 Feb 2022	Redcliffe	305.6	All-time record since 2003	844.0
24 h to 23:00 UTC 25 Feb 2022	Karalee	206.4	All-time record since 2001	608.0
24 h to 23:00 UTC 25 Feb 2022	Highvale	295.8	All-time record since 1954	707.0
24 h to 23:00 UTC 25 Feb 2022	Morayfield	268.0	All-time record since 2006	705.0
24 h to 23:00 UTC 25 Feb 2022	Bellbird Park	196.0	All-time record since 2007	491.0
24 h to 23:00 UTC 25 Feb 2022	Greenbank	221.0	All-time record since 1988	571.0
24 h to 23:00 UTC 27 Feb 2022	Carole Park	229.0	All-time record since 1989	626.0
24 h to 23:00 UTC 27 Feb 2022	Jingle Downs	151.0	All-time record since 2007	388.0
24 h to 23:00 UTC 25 Feb 2022	Mt Gravatt	224.0	All-time record since 2007	612.0
24 h to 23:00 UTC 25 Feb 2022	Archerfield	197.8	Record of 343.7 on 6 Feb 1931	546.0
24 h to 23:00 UTC 25 Feb 2022	Oxley	200.4	Record of 179.1 on 12 Feb 1972	564.0
24 h to 23:00 UTC 27 Feb 2022	Regents Park	188.2	All-time record since 2005	525.0
24 h to 23:00 UTC 25 Feb 2022	Capalaba	280.0	All-time record since 1971	704.0

24 h to 23:00 UTC 27 Feb 2022	Manly	224.0	Record of 304.8 on 6 Feb 1931	442.0
24 h to 23:00 UTC 25 Feb 2022	Calamvale	246.0	All-time record since 1989	658.0
24 h to 23:00 UTC 25 Feb 2022	Shailer Park	237.8	All-time record since 1980	613.0
24 h to 23:00 UTC 25 Feb 2022	Mt Cotton West	272.0	Record of 509.0 on 6 Feb 1931	657.0

Figure 9 shows the location of intense hourly rainfall on 27 February and the cluster of events around Kedron Brook which led to the demise of Toombul Shopping Town.

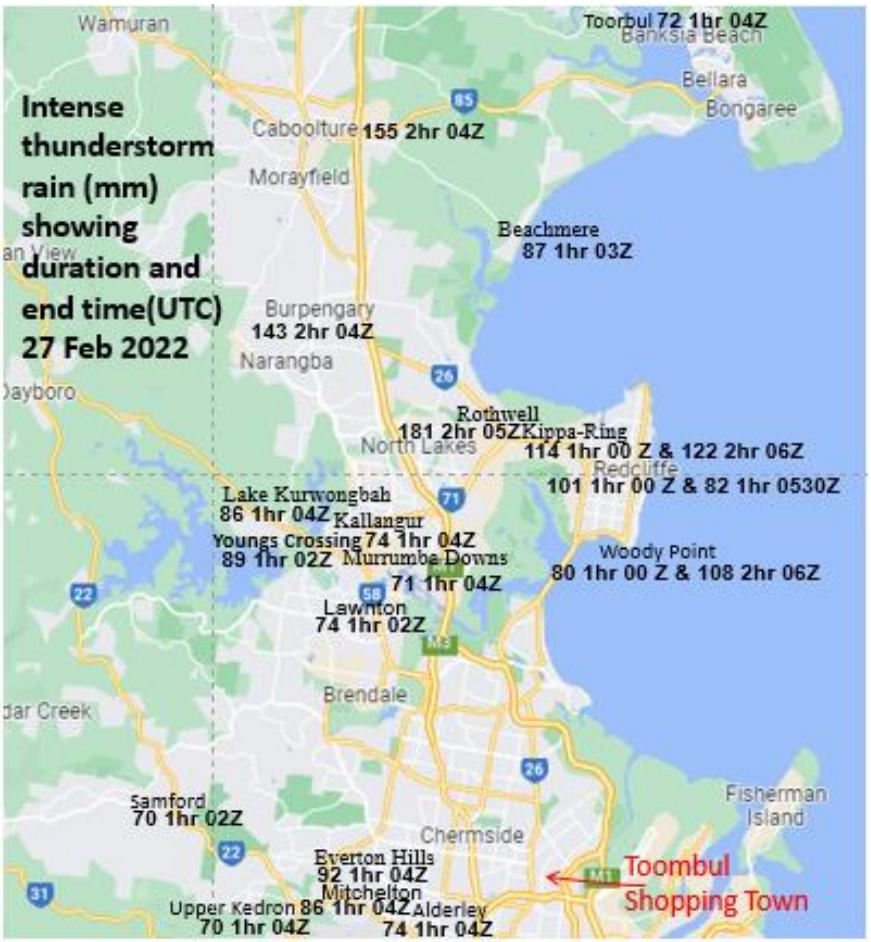

Figure 9 Short term intense rainfall Brisbane northern suburbs 23:00 UTC 26 February 2022 to 06:00 UTC 27 February 2022 with location of Toombul Shopping Town a major shopping centre virtually destroyed by flash floods of Kedron Brook with cluster of intense rain events around Kedron Brook in southern sector of the Figure.

From Figure 9 it can be seen that areas north of the Brisbane City Council region were also affected and this comes under the duristintion of the Moreton Bay Council although part of the Brisbane Statistial area. In the Moreton Bay Counci area the SES attended 942 properties for flooding, structural damage and trees blown down. Throughout the Moreton Bay numerous major roads were closed including the Bruce and D'Aguilar Highways.

A major feature of Kedron Brook was a bike and walk pathway from the western suburbs to Moreton Bay which was destroyed by flooding leaving last sections on upturned concrete slabs. The next creek south (Enoggera/Breakfast Creek) also had significant flooding and damage. The msl sequence in Figure 10 shows the high dewpoints and the coastal trough associated with the intense rainfall while Figures 5 to 8 show the associated 700 hPa WAA over this period.

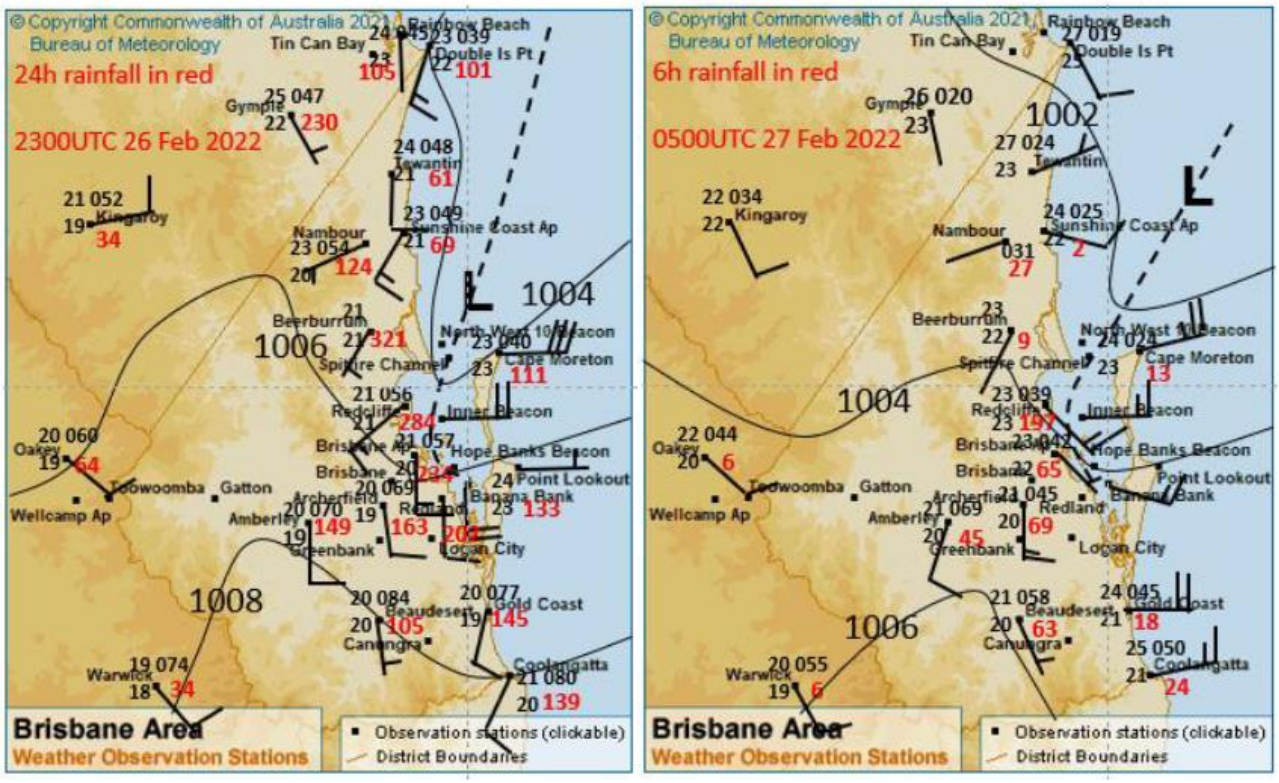

Figure 10 msl analyses showing isobars (hPa), mean wind plots, temperature, and dewpoints (degrees Celsius) observations and the last three digits of pressure observations to one decimal point for 23:00 UTC 26 February 2022 with 24 hr rainfall in red (left frame) and at 05:00 UTC 27 February 2022 with 6 hr rainfall in red (right frame).

This strong 700 hPa WAA associated with the intense hourly rainfall was verified by strong winds turning anticyclonic with height (WAA) and high humidity over the same period by the Brisbane Airport radiosonde data as indicated below:

Brisbane Airport balloon released at 17:00 UTC 25 February 2022
Wind 850 hPa 120/18 m/s wind 700 hPa 095/21.5 m/s wind 500 hPa 070/17.5 m/s

Brisbane Airport balloon released at 23:00 UTC 25 February 2022
850 hPa Temp 15.20°C Dewpoint 15.20°C wind 095/15.96 m/s.
700 hPa Temp 6.60°C Dewpoint 5.10°C wind 085/14.93 m/s
500 hPa Temp -5.90°C Dewpoint -6.20°C wind 030/14.93 m/s

Brisbane Airport balloon released at 17:00 UTC 26 February 2022
wind 850 hPa 125/14 m/s wind 700 hPa 065/12.5 m/s wind 500 hPa 045/10.5 m/s

Brisbane Airport balloon released at 23:00 UTC 26 February 2022
850 hPa Temp 14.8°C Dewpoint 14.8°C wind 075/20.08 m/s.
700 hPa Temp 6.6°C Dewpoint 6.6°C wind 055/15.96 m/s.
500 hPa Temp -5.9°C Dewpoint -5.90°C wind 005/13.90 m/s.

5. Lismore Floods

By 21:00 UTC 26 January 2022 (Figure 11) the low developed and moved into the region of the Nightcap and Jerusalem National Park where the headwaters of the Wilsons River are located. This shows how such extreme rainfall was focused on such a small area with the low providing a likely convergence zone between northeasterly winds and southeasterly winds.

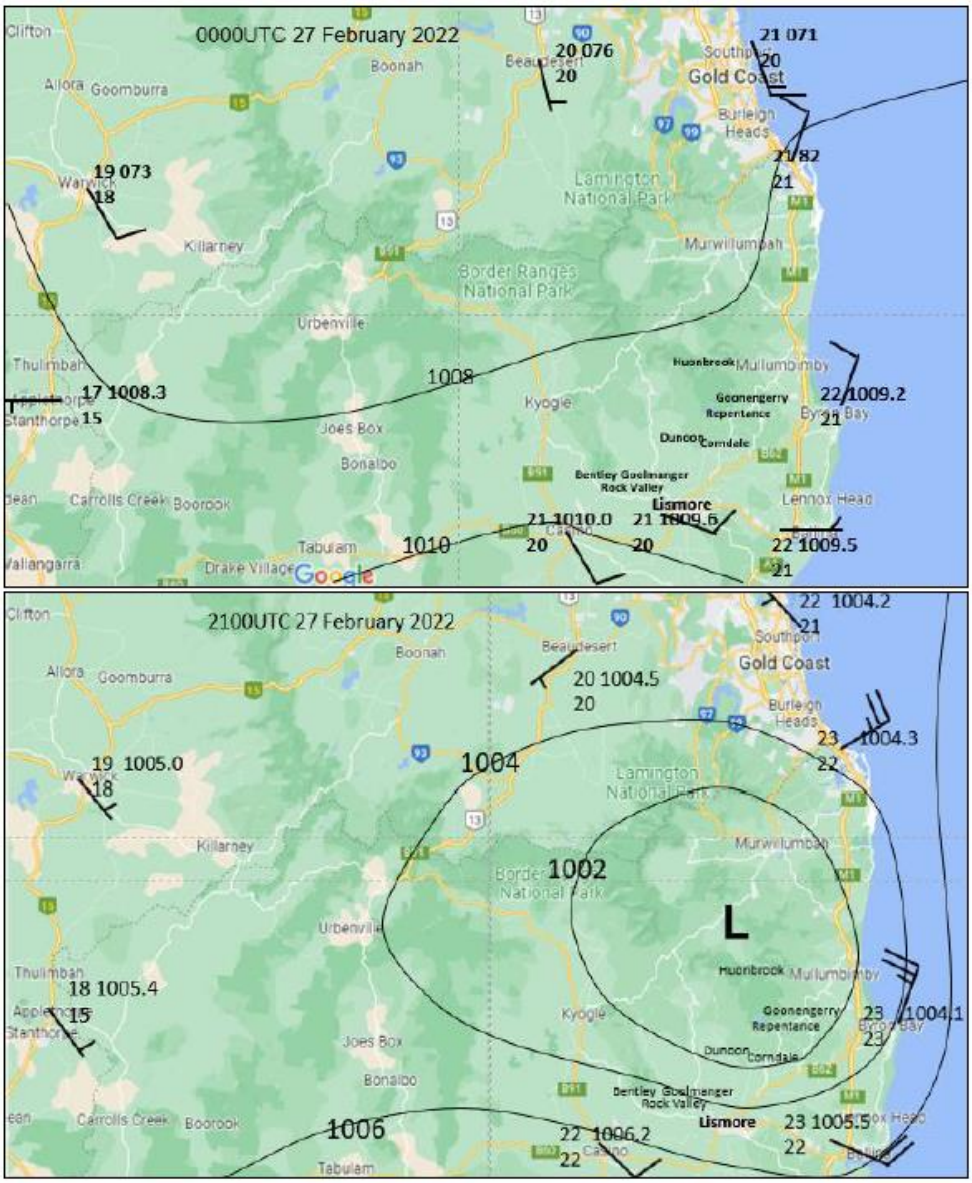

Figure 11 msl analyses showing isobars (hPa), mean wind plots, temperature, and dewpoints (degrees Celsius) observations and the last three digits of pressure observations to one decimal point for 00:00 UTC 27 February 2022 (top frame) and at 21:00 UTC 27 February 2022 (bottom frame).

WAA at 700 hPa was also evident around Lismore leading up to and over this period (Figures 4 to 8) thus there was a trigger and ascent available for the generation of intense convection particularly with the dewpoints around Lismore in the 22°C to 23°C range.

Most of the rainfall reports in the Wilsons River broke all time daily rainfall records. The City of Lismore lies in the southern catchment of this river, and it suffered its worst flood on record going back to 1887.

General rainfall totals over the Lismore catchment of 200 to 300 mm but reaching 455 mm at Doon Doon were recorded over the 96 hours to 23:00 UTC 26 February 2022 (Figure 12 top frame). This would have saturated the ground throughout the catchment. The falls in the 24 hour to 23:00 UTC 27 February 2022 were unprecedented (Figure 12 bottom frame) with all-time records broken.

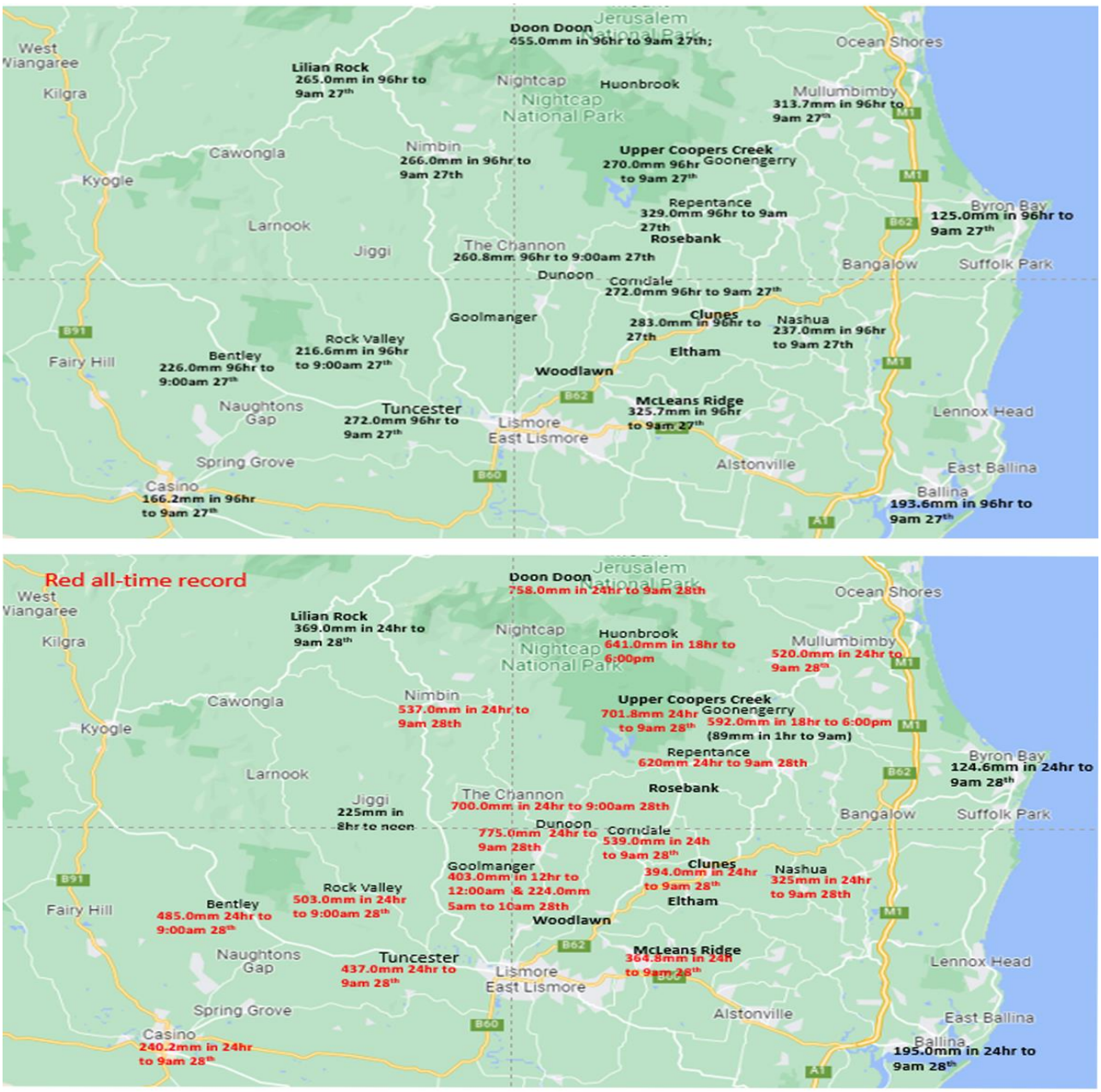

Figure 12 Rainfall (mm) in and near the Wilsons River Catchment in the 72 hours to 23:00 UTC 26 February 2022 (9 am 27th local time) (top frame) and in the 24 hours to 23:00 UTC 27 February (bottom frame) with all-time records in red.

The peak flood height at Lismore reached the record height of 14.39 metres at 01:59 UTC 28 February 2022 and in the hours leading up to this there were intense hourly rainfall registrations throughout the Wilsons River and its tributeries (Table 2). Notable among these at Lismore were extreme totals of 101.0 mm in the hour to 22:00 UTC and 102.0 mm in the hour to 23:00 UTC just a few hours before the flood peak. This would have been enough on its own to cause severe flashflooding in Lismore let alone on top of a major flood which at 21:00 UTC 27 February was measured as 13.58 metres.

Table 2 Wilsons River Alert hourly rainfall 27 February 2022 from Bureau of Meteorology external web page.

Station	18:00 UTC	19:00 UTC	20:00 UTC	21:00 UTC	22:00 UTC	23:00 UTC
Bentley	46	9.5	27	20	40	54
Corndale	13	14	13	39	61	18
Tuncester	17	31	16	10	26	30
Nimbin	13	32	21	34	35	16
Jiggi	22	22	24	26	55	27
Goolmangar	37	53	9.4	14	41	70
Rock Valley	34	37	15	18	44	49
Cawongla	5,6	14	7.2	28	34	16
Goonengerry	63	12	12	56	88	17
Nashua	0.9	9.5	10	31	29	11
Repentance	38	11	12	40	79	30
Doon Doon	38	28	46	57	37	23
Lilian Rock	4.4	14	16	27	18	25
Dunoon	71	28	11	30	84	56
Huonbrook	54	19	19	62	57	15
Lismore	11	20	9.6	9.4	101	102

6. Climatology of Sub Tropical East Coast Floods

The Lismore floods are the worst since floods were first recorded in 1887 so should be examined in the context of climate change. We have established that there is an increasing trend in the frequency of major flooding in coastal areas between Brisbane and the NSW/Victorian Border [16]. Power and Callaghan 2015 [17] also showed that the average number of floods in La Niña years are much higher than in their El Niño-year counterparts. In agreement with this is the linear trend increase in NSW heavy rainfall from 1900 to 2021 (Figure 13 upper left frame). The 5 year running mean trend (Figure 13 upper right frame) shows this is brought about from the prolonged occurrences of La Nina episodes from 1949 to June 1976, 1998-1999, 2020-2021 and 2021-2022. The lower frames in Figure 13 show that the Australian trends are similar.

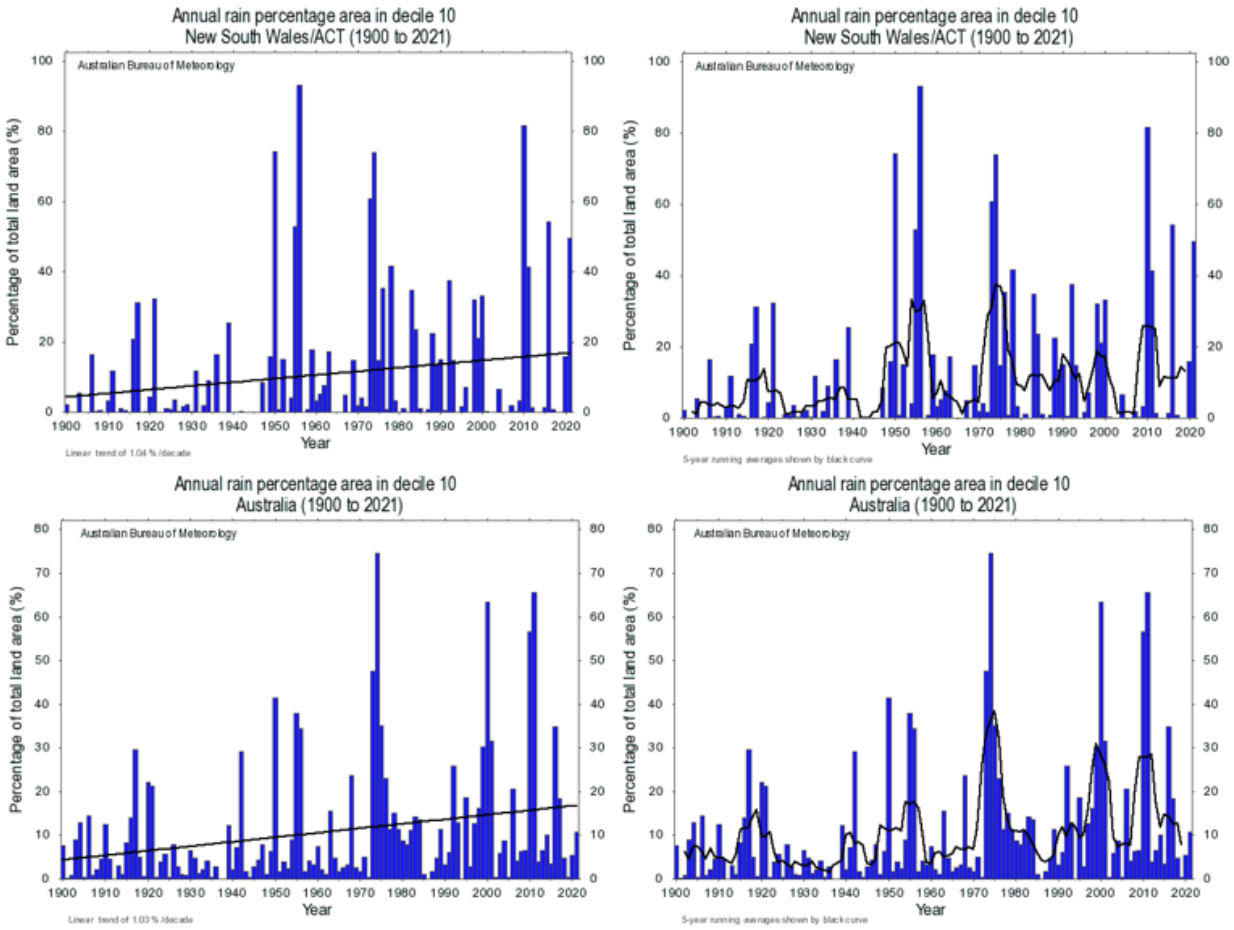

Figure 13 Trends in heavy rain left linear trend and right 5 year running mean in the top frames for New South Wales and in the lower frames for Australia.

Figure 14 is a graph of the cumulative monthly Southern Oscillation Index (SOI). It highlights the number of flood event during La Nina episodes or at least where the Southern Oscillation Index (SOI) is continually positive (rising curve) in red. This shows that most east coast floods occurred where the graph was rising (SOI positive). There was an unprecedented number of El Niño events following June 1976 and this is often referred to as a Climate Shift [18]. El Niño's occurred in 1982-83, 1987-88, 1991/92, 1993-94, 1994-95, 1997-98, 2002-03, 2006-07, 2009-10 and 2015-16. Speer [19] showed a large drop in rainfall in New South Wales in the twenty years following the Climate Shift. In Callaghan [9] changes around the Globe following the Climate shift are recorded. The number of flood events which occurred during extensive periods of positive SOIs (red numbers) was 174, during negative SOIs (black numbers) 66 and neutral (green numbers) 6.

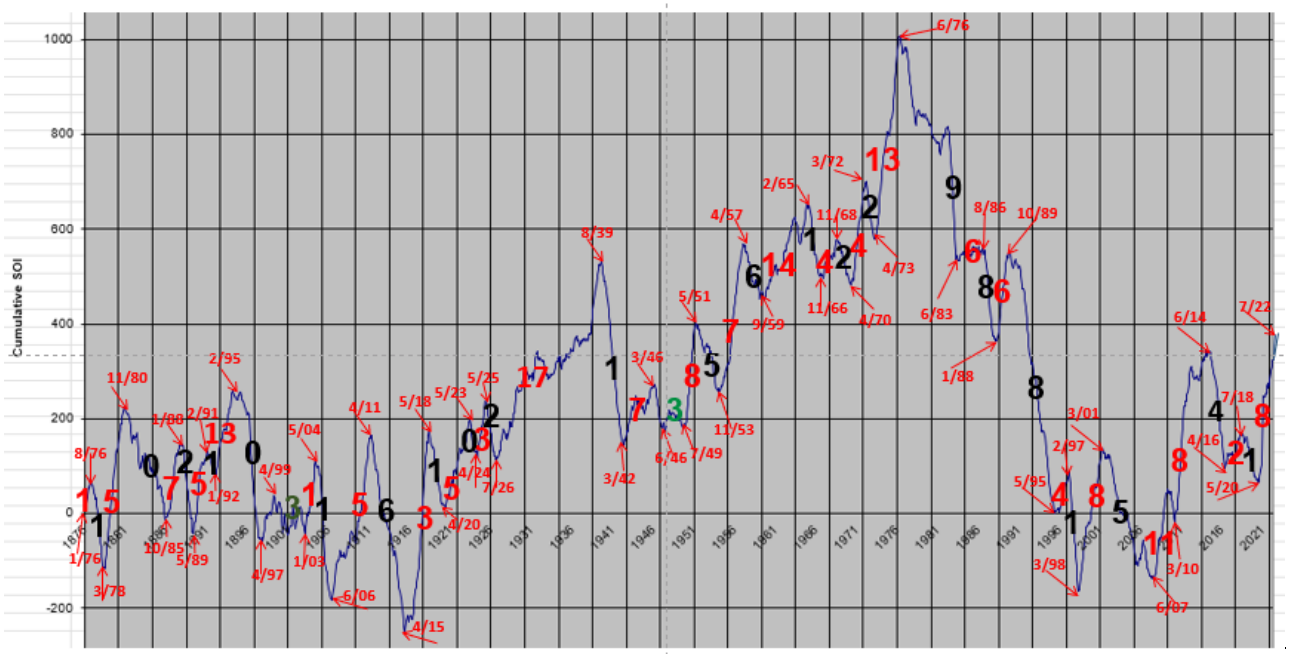

Figure 14 Cumulative monthly SOI 1876 to 2022 with numbers of east coast major floods when the graph is rising (red) falling (black) and neutral (green).

7. 2022 Storms

Obviously, we need the climate models to be able to forecast prolonged periods where the SOI is positive to confidently state that east coast flooding events will continue to increase.

7.1 Recent record Storms

Above we examined two of the worst 2022 floods at Brisbane and Lismore which were embedded in a period of recent severe storms and effects shown below:

- 21 Apr 2015 NSW SES received 21,506 requests for assistance over a two-week period, one of the largest number of requests ever received in such a short space of time.
- 1-2 May 2015 Six people perished in major floods in SEQ.
- 24 Aug 2015 Major flood Jervis Bay to 26 August.
- 5 Jan 2016 Major flood Hunter River.
- 4-5 June 2016 Major Flood Georges River and major Beach erosion Sydney.
- TC Debbie 30-31st March 2017. Major flooding occurred in the Logan and Albert Rivers in far southeast Queensland. The Tweed River had a record flood with eight fatalities and 20,000 people were evacuated from the Lismore and Murwillumbah areas.
- 8 Feb 2020 11 Feb the SES attended 12,000 jobs across the state from Wednesday 5 February night — 8,220 of those were in Sydney and the Blue Mountains — including 254 flood rescues. Major floods Georges, Nepean, Hawkesbury, Colo and Orara.
- March 2021-For the full coastal region of NSW the week ending 24 March was the wettest on record, with a regional average of 255.1 mm, surpassing the previous record of 240.4 mm set in the week from 7 to 13 February 2020. Flooding reached record heights on the Camden Haven and Manning Rivers.
- February 2022 Record flooding in SEQ and NE NSW.

- March 2022 Major flooding Nepean Hawksbury Rivers
- 30 March 2022 Major flood Lismore from band of thunderstorms.
- 13 14 May 2022 Major Floods Beaudesert, Lockyer Creek, Warrill Creek, Bremer River.
- July 2022 Major flooding Sydney to Newcastle

7.2 Historical Active Periods

(From Table 3) The most active period of flood events was in the late nineteenth century from January 1892 to February 1895 when there were 4.21 events per year while the whole period from October 1885 to February 1895 averaged 2.92 events per year. The events are detailed in Callaghan [17] and contain all-time record flood and rain events.

Table 3 Frequency of major flooding in the coastal rivers from the Brisbane River Catchment down through NSW at various periods since 1876.

Period	No of events	Period Length (years)	Events per year
January 1876 to April 1915	50	39.33	1.27
October 1885 to February 1895	27	9.25	2.92
January 1892 to February 1895	13	3.09	4.21
April 1915 to July 1949	42	34.25	1.23
July 1949 to February 1956	21	6.67	3.15
July 1949 to June 1976	66	26.91	2.45
April 1973 to June 1976	13	3.16	4.11
June 1976 to March 1998	39	21.75	1.79
March 1998 to March 2022	46	24.0	1.92
April 2015 to July 2022	15	7.25	2.07

Another very active period was from April 1973 to June 1976 with 4.11 events per year. Some notable events occurred during this period including the Signa Storm of May 1974 Callaghan [20] and the Brisbane floods of January 1974.

7.3 Devastating Events in the 1950s

However, seeing that the February 2022 event was so extraordinary we compare in with a similarly remarkable event in February 1954 which was embedded in an active period of frequent flood events from July 1949 to February 1956. These storms occurred at the rate of 2.45 events per year and 13 of the worst are listed below.

- 19 July 1949 7 fatalities. 1600 homes in the Maitland district were under water or uninhabitable. Georges River reached 7.6 metres at Liverpool Weir (second largest since 1898. Bulli Pass boulders weighing up to thirty tons swept down from the cliff tops. Singleton experienced its worst flood since 1913.
- 25 26 August 1949 Kempsey, Macksville 6 fatalities. On August 27, 1949. The flood reached drowned more than 15,000 head of livestock. Fifty-three homes and businesses were washed away, three hundred homes were so severely damaged they were uninhabitable, and a total of 2,000 people were left homeless.

- 16-19 January 1950 Intensifying monsoon low Gulf to Sydney with 10 Fatalities. Bar down to 988 hPa in Sydney with girl drowned after swept off the Esplanade at Cronulla and four lost in flashflood at Grafton. Seven yachts were completely wrecked in Sydney Harbour.
- 6-8 Feb 1950 Bega & Hunter River at Maitland. Tathra 354.8 mm 8th All-time record daily rainfall record. Major floods Bega River.
- 15-16 June 1950 11 Fatalities from floods Navy ship *Fair Wind* lost with crew of 17. Cronulla surf club collapsed into sea and there was extensive damage to other foreshore installations along the NSW coast. At Grafton 3000 people were made homeless with six houses washed away. At Maitland 3200 were made homeless. Aerial surveys from Newcastle to Queensland revealed hundreds of blocks swept clear of homes.
- Sydney Newcastle Wollongong floods 10-12 September 1950 1 fatality. Severe flash flood in Sydney 6 metre wall of water swept down the Georges River at Campbelltown. Illawarra all time daily record rainfall at Foxground Road 432.8 mm 11th and three bridges washed away.
- 17-19 January 1951, 1000 people evacuated at Maitland, three fatalities in floods and six lives lost on the Collier *Kiama* near the Entrance.
- 14-16 June 1952. Four fatalities and 24 h rainfall Illawarra to 408.9 mm at Viaduct Creek in the Illawarra (all-time record) and Severe floods Illawarra Northern suburbs for 3 days.
- 24–28 July 1952 Camden had its worst flood in history with flood waters in the town up to 30 feet (9.1 metres). The Nepean River at Richmond reached a record height 45 feet 6 inches (13.72 metres)
- 12-15 August 1952 Major floods at Bellingen, Mudgee, Singleton, Walcha, and Kempsey.
- 23-25 March 1953 Two fatalities. Major flood Macksville.
- 10- 11 February 1954 24 h rainfall 11 February 1954 Northern Rivers-Bangalow 246.6 mm 3 people drowned in flash flood near Lismore.
- The NSW floods of 1955 [21] twenty-five fatalities.
- 21-23 January 1956 Unprecedented floods over Darling Downs were experienced in the Condamine and Macintyre rivers. Heavy rain e.g., Inglewood 275 mm in 16 hours, Leyburn 150 mm in 4 hours.
- 9-11 February 1956 major floods Georges, Hawkesbury & Shoalhaven Rivers 7 fatalities.
- 17-19 February 1956 Murwillumbah, Lismore & Grafton 2 fatalities.

8. The February 1954 Tropical Cyclone

One of the worst events to strike the SEQ NENSW region was what was known as the Great Cyclone of 1954. The coastal region was a series of small towns in 1954, with around 30,000 on the Gold Coast and 13,000 on the Sunshine Coast. Today the Tweed has 98,000 people, the Gold Coast 720,000 and Sunshine Coast 395,000 being the fastest growing region in Australia.

The cyclone initially affected SEQ where a man was killed at Newmarket Brisbane when his car collided with a train in driving rain. A man was electrocuted at Nanango by a fallen livewire and a man was killed by a fallen tree when on the Esk to Toogoolawah highway.

The cyclone caused 36 fatalities in total though critics have suggested today these may be reduced with improved warnings today. However, with the huge increase in population along with the difficulty in warning for floods in the fast response streams along the Gold Coast and Northern NSW Rivers suggest that a similar event total would have a much higher death toll. Evidence in

forecasting the rapid response of rivers in the NSW Northern Rivers district came from The Tweed Shire Council when they commented how the record Tweed flood at Murwillumbah in March 2017 causing 8 fatalities was forecast to be only a moderate flood (see [22]). Increased casualties would also be expected from the 1954 cyclone as large storm surges associated with this event would strike much larger population centres today.

The cyclone then moved south near the coast. People in NSW knew it was coming as heavy rain caused a landslide sending tons of saturated earth crashing down from Kirra Hill (near the Qld NSW border) on to the Pacific Highway at 09:30 UTC 19 February 1954. It made landfall at the border in the Twin Towns of Coolangatta-Tweed Heads at 10:30 UTC 20 February 1954 with the bar having dropped to dropped to 28.6 inches or 968.5 hPa. It then passed over Condong Sugar Mill inland from Coolangatta and near Murwillumbah. There were two barometers at the sugar mill, one an aneroid registered 28.8 inches (975 hPa) while the other read 973 hPa. The eye took two hours to pass over the mill. The eye passed over around 13:00 UTC 20 February. The track through NSW is shown in Figure 15 with the sea surface temperatures (SSTs) in Figure 16. Note that SSTs in 1954 were warmer than those in February 2022.

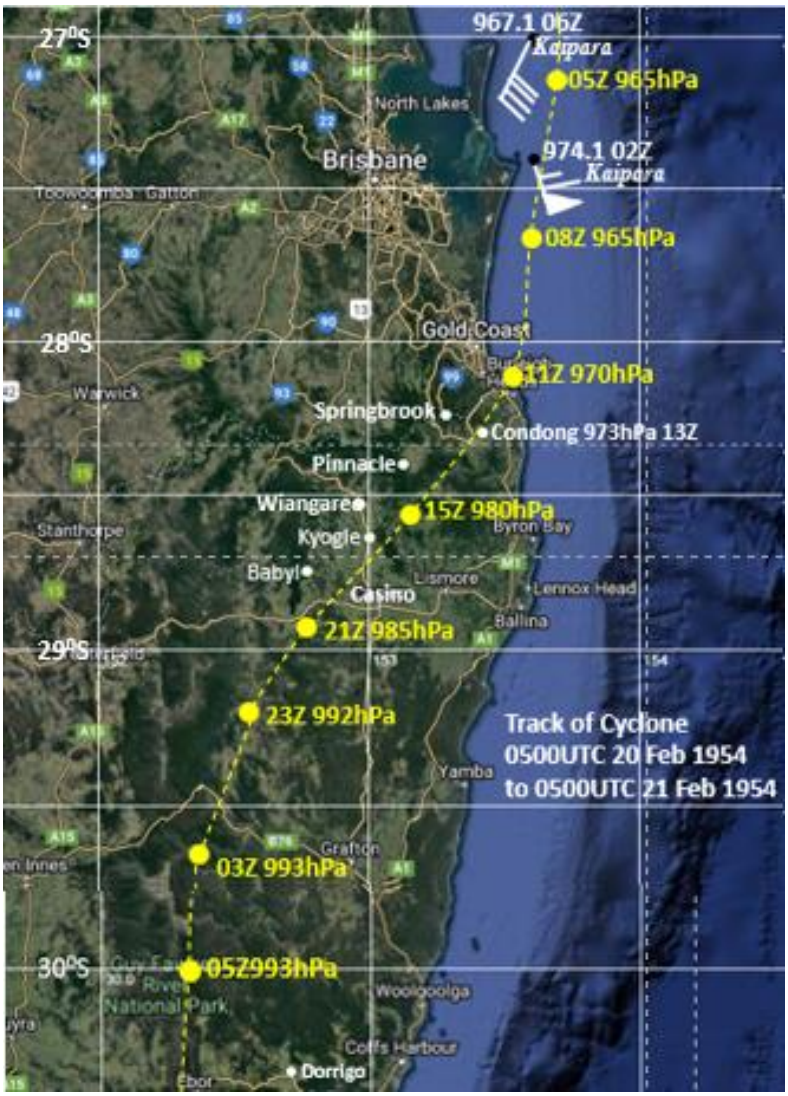

Figure 15 Track of 1954 Cyclone through Southern Queensland and New South Wales.

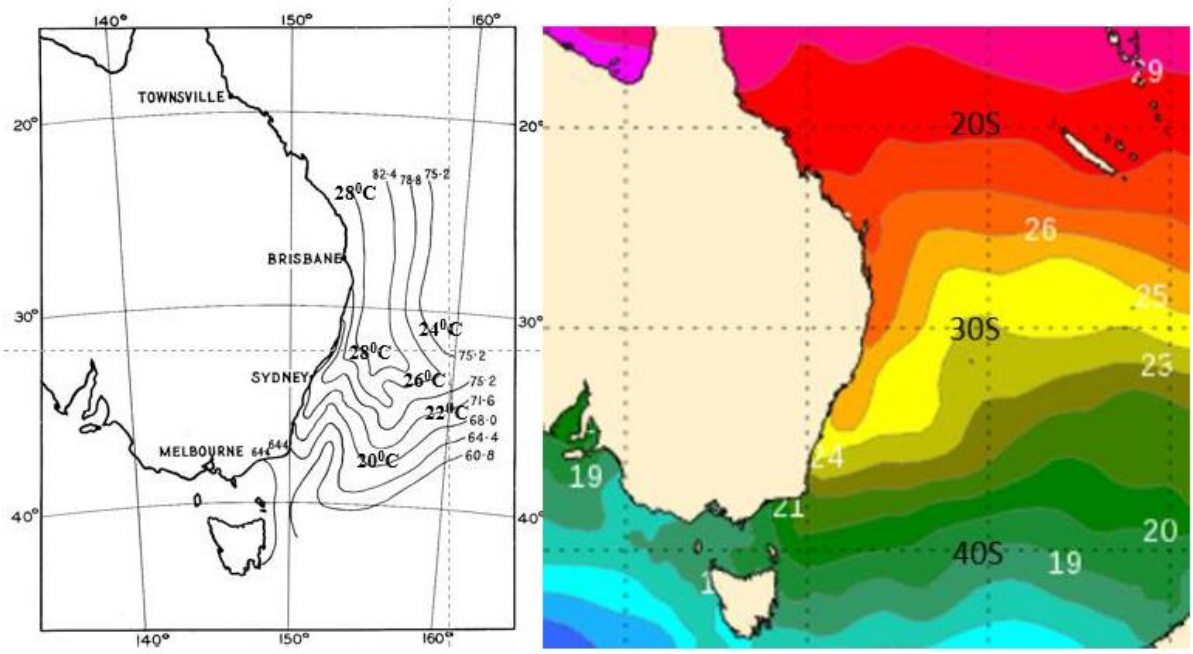

Figure 16 Sea Surfaces Temperature for the month of February 1954 after Moss 1958 [23] (left) and February 2022 (right).

At Dorrigo (see location in Figure 17) extreme rainfall caused severe damage to roads, gouging trenches more than a metre deep and washing bridges away. An NSW 24 hour rainfall record of 809.2 mm was broken there which still stands today, and the heaviest rain fell from 10:00 UTC to 13:00 UTC 20 February falling at the rate of 75 mm per hour. This was around the time the cyclone made landfall which illustrates the enormous size of the storm. The size can also be seen in Figure 4 of Callaghan and Power [12] which shows a WAA onshore ascent pattern develop south from the centre of the cyclone down to Newcastle from 00:00 UTC 20 July 1954 to 00:00 UTC 21 July 1954. This event produced severe wind damage from the Sunshine Coast in Qld to Kempsey in NSW. Kempsey experienced a night of terror when the town was struck by cyclone winds and had 150.0 mm of rain in six hours. Also illustrating the huge size of the destructive winds accompany this cyclone, from around 12:00 UTC 20 February (close to landfall time on the Tweed) houses were unroofed at Kempsey (not on the coast), fences flattened, trees uprooted, and communications were cut. Scarcely a house escaped damage. Tiled roofs at the nearby coastal town of Southwest Rocks were swept away.

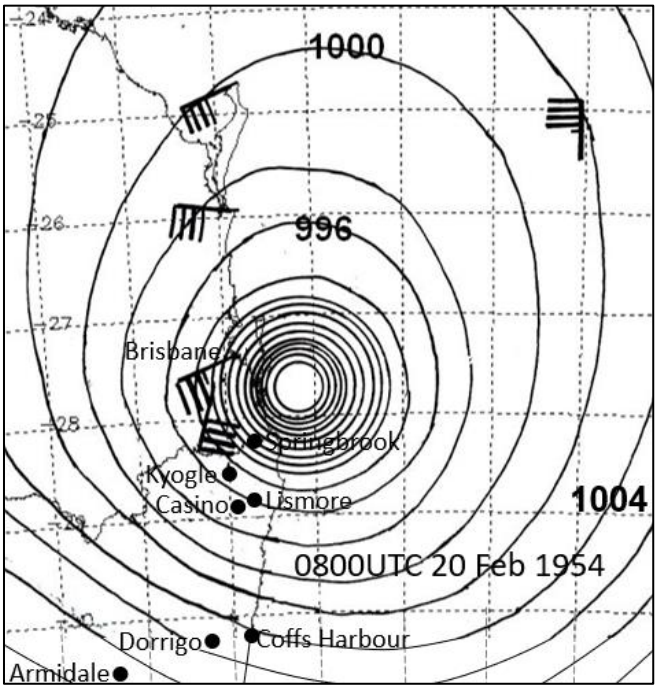

Figure 17 The 1954 cyclone during the heaviest rainfall between Springbrook and Coffs Harbour and the start of the heaviest rain at Dorrigo.

In Armidale Six persons were drowned at near Armidale, after a car was washed into a flooded creek on Saturday around 12:00 UTC 20 February. A man and a baby drowned at Grafton, two drovers drowned at Maitland and a boy was drowned in a canal at White Bay in Sydney on Tuesday 23 February.

However, the deadliest area of the cyclone was along the main arm of the Richmond River and rainfall and flooding effects were:

Twenty-four-hour rainfall registrations of 900.4 mm broke all-time records at Springbrook Forestry (Elevation 806 m) see Table 4, falling in the 24 hr to 22:45 UTC 20 February 1954 and 250 mm fell between 07:00 UTC to 11:30 UTC which was the most intense period. The total rainfall from the pluviograph agreed with the rain gauge total as reported by Brunt [24].

Table 4 Springbrook (Elevation 806 m) Pluviograph rainfall intensities February 1954.

Duration	Rainfall amount (mm)
30minutes	35.6
60minutes	69.85
2hours	134.0
3hours	182.1
4hours	227.8
5hours	275.8
6hours	319.3
7hours	354.6
9hours	458.7
10hours	513.8

12hours	606.6
14hours	689.4
20hours	819.4
24hours	900.4
28hours	971.5
32hours	1020.1
36hours	1044.4

The station lies on the Tweed Caldera which is one of the best-preserved erosion calderas in the world and its steep escarpments produces some of the heaviest rainfall in Australia. Along the western escarpment of the Caldera (see Figure 18) there are no recording rainfall stations and several creeks follow a steep descent of around 800 metres into the Richmond River.

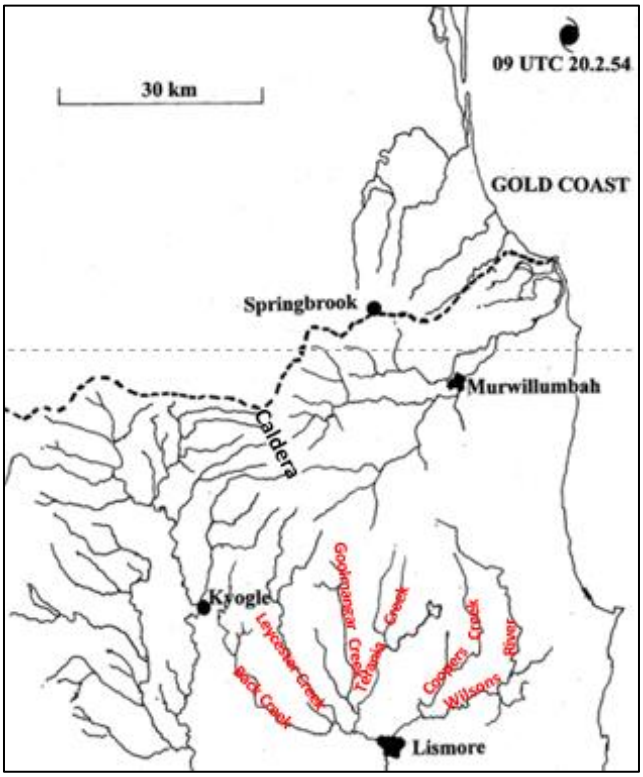

Figure 18 Location Tweed, Lismore, and Kyogle catchments together with location of the western edge of the Tweed Caldera, Springbrook, and position of the cyclone around the time Kyogle was devastated.

At Kyogle at 06:45 UTC 20 February the river reached 16.37 metres and by 08:30 UTC 20 February 18.28 metres and by 09:00 UTC 18.898 metres. That is 2.53 metres in 2 h 15 min or 1.2 metres per hour.

All-Time daily record rainfall was also recorded from other stations on the Border Ranges: Darlington 197.1 mm to 23:00 UTC 19 February 1954 and 377.7 mm to 23:00 UTC 20 February 1954, Tallebudgera 154.7 mm to 23:00 UTC 19 February 1954 and 417.3 mm to 23:00 UTC 20 February 1954 and Widgee 179.6 mm to 23:00 UTC 19 February 1954 and 436.4 mm to 23:00 UTC 20 February 1954.

Because of the extreme rainfall late 19 February (UTC +10 hours) to late 20 February in the Border Ranges the Nerang, Tweed, Richmond, and Wilsons Rivers came up very fast and when rescue aircraft surveyed the area on the morning of 21 February the sun was shining, and hundreds of motor vehicles could be seen on the hills where people had fled the floods and others were marooned on rooftops miles from safety. It looked like a vast sea between Kyogle and the coast. On the night of 20 February 300 people were rescued from their homes at Lismore. Throughout the Richmond Tweed area cars and trucks could be seen half flooded or overturned on roads which bore testimony to how fast the waters rose. Scores of abandoned vehicles could be seen in the foothills bogged or stopped by terrain. On the lower reached of the Tweed where the record flood occurred a surfboat and two army ducks were rescuing people from roof tops.

The power of the rising water was more evident in the main arm of the Richmond River. The three towns on the main arm of Wiangaree, Kyogle and Casino suffered severely because of this flood. At all towns the river rose rapidly to a peak which surpassed previous known flood levels by many feet. Because of the fast rate of rise to considerable heights above the riverbanks, large differences in head were developed between the river and the surrounding terrain. The flow of floodwaters from the river to low lying areas was therefore fast and destructive and constituted the main cause of the loss of life NSW Water Conservation and Irrigation Commission [25]. At Wiangaree the river reached a peak though no lives were lost but damage to buildings and property was considerable. At 09:00 UTC 20 February, the flood reached a level 18.898 m at Kyogle; many homes were swept away, and ten persons lost their lives. At Casino the river broke its high banks which is rare and inundated low-lying sections of the town. The peak gauge height of 53'-1" (16.18 m) occurred at 06:00 UTC on the 21st. Seven houses were destroyed, and two lives were lost. Another two lives were lost 7 km east of the town when a boat was upturned in large waves generated by gales in the inland sea. Serious riverbank erosion occurred along the whole length of the Richmond River. As a result of this erosion, one span of the road bridge at Casino collapsed. Further east the Wilsons Rover at Lismore rose rapidly to a record level of 44'-0" (13.411 m) at 18:00 UTC 20 February and six lives were lost. A seven-year-old boy was swept away in the flood. In another incident a family was rescued by boat from a farmhouse near Lismore. The boat then traversed back across 1.7 km of water and when they were half was across, it was swamped by metre high waves generated by the gales and a woman with two children were drowned. Another man and a boy were drowned near Lismore. The Tweed River had record floods of 6.04 m AHD at Murwillumbah with one life lost. At Tweed Heads it varied from a record 2.51 m AHD near the river mouth to 2.05 m AHD in the town centre.

The heavy rain was associated with high dewpoints as Cape Byron reported dewpoints of 22-24 degrees Celsius range from 05:00 UTC 19 February to 11:00 UTC 20 February 1954.

Following a storm surge at Surfers Paradise a record flood peak was measured there as the Springbrook rain came down the Nerang River. All-time record floods were experienced on the Main arm of the Richmond River at Wiangaree, Kyogle, and Casino. Record floods were also recorded at Dorrigo where all-time 24 hour rainfall were also recorded including an NSW state record at Dorrigo as follows:

Dorrigo Myrtle St (Elevation 740 m) 189.5 mm to 9 am 20th 809.2 mm to 9 am 21st

Dorrigo Post Office (Elevation 731 m) 169.4 mm to 9 am 20th 744.7 mm to 9 am 21st

Tallowwood Point 144.3 mm to 9 am 20th 504.7 mm to 9 am 21st

Meldrum 89.7 mm to 9 am 20th 479.0 mm to 9 am 21st

Megan 76.2 mm to 9 am 20th 431.8 mm to 9 am 21st

Kalang Rd 71.1 m to 9 am 20th 446.3 mm to 9 am 21st

Glenreagh Forestry 53.8 m to 9 am 20th 440.9 m to 9 am 21st

Glenreagh PO 397.8 mm to 9 am 21st

Coramba 105.9 mm to 9 am 20th 421.1 mm to 9 am 21st (Feb only)

Upper Orara (Aurania) 158.2 mm to 9 am 20th 420.6 mm to 9 am 21st (Feb only)

Record rainfall also fell in the Manning and Hastings Rivers with Elands Post Office 273.1 mm to 9 am 21st and Bellangry State Forest 246.6 mm to 9 am 21st (Feb record only).

Major floods occurred at Dorrigo, Lismore, Casino, Grafton, Murwillumbah, Coffs Harbour Bellinger River, Hastings River, Macksville, and Kempsey.

The 1954 cyclone also produced severe storm surge damage as follows:

- **Sunshine Coast** The sea submerged areas of land around Noosa (population 6,300 in 1954 and 56,796 in 2021).
- **Moreton Bay**-Mountainous seas had hurled more than thirty vessels (including ten each worth £5000) on to the banks at Beachmere (population 1954 194 and now in 2022 4.600). When the water receded, some were left balanced precariously on treetops, others lay in tangled telephone and powerlines, and the rest were scattered in broken heaps alone the grassy banks. The foreshores of Deception Bay and Bramble Bay between Sandgate and Toorbul Point, about twelve miles east of Brisbane, were littered with wreckage of prawning vessels and private launches.
- At Surfers Paradise the Nerang River was more than a mile wide and hundreds of houses and some business houses were surrounded by 1.52 m to 1.83 m of water with the river extending into Ferny Av in places. Storm surge caused some fifty families to be evacuated from the Broadwater on the Gold Coast and a dramatic rescue of people from Macintosh Island. Macintosh Island in those days was farming land and the residents there were huddled in chest deep water on the highest point of the Island before being rescued by a surfboat and police boats during the calm conditions in the eye of the cyclone. After being rescued a wall of flood water swept over the Island.
- At Kirra Beach waves ran up to the area in front of the Surf Pavilion and crossed the parking area and the Pacific Highway carrying immense quantities of debris. The veranda in front of the Pavilion was engulfed by seawater to chest height. A four-ton covered truck parked near the retaining wall had a large wave break right over it is shifting the vehicle 4.57 m to 6.10 m.
- A monstrous wave struck the Currumbin Surf club and rushed length ways around Rock (Between Elephant Rock and Beach Road) and the resultant surge carried away the boat and gear shed together with one downstairs wall of the Surf Club. The upstairs part of the club was left suspended with only the back wall fully intact.
- The Tweed River was across the Pacific Highway at Tweed Heads near the Presbyterian Church and at the corner with Recreation Street which had water to 1 metre over it and 1.4 metres of water covered the southern approaches to Boyd Bay Bridge and over the road to Cobaki.
- At Tweed Heads the camping area near the Bowls Club was under seawater forcing its way through 100 yards wide current and over a 2.5 metre high sand bank.
- Large waves at Mermaid Beach caused severe erosion and spilled over onto Hedges Avenue (elevation around 7 metres.)

- Byron Bay-The sea came right into the town The outer section of the jetty was swept away at Byron Bay taking with it all twenty-two vessels comprising the fishing fleet.
- Sydney - The cyclone struck on 21 February with floods cutting the North Richmond Bridge and the wind capsizing dozens of boats in the Harbour and a dingy smashed to pieces on Kirribilli. Ferries were stopped and the airport was closed to traffic from 05:45 UTC 21 February.

Comparing the US Reanalysis charts of a column of Precipitable Water for 12:00 UTC 20 February 1954 with 18:00 UTC 27 February 1954 shows the effect of the 1954 cyclone bringing much higher moisture in the precipitation zone than the 2022 East Coast low (Figure 19).

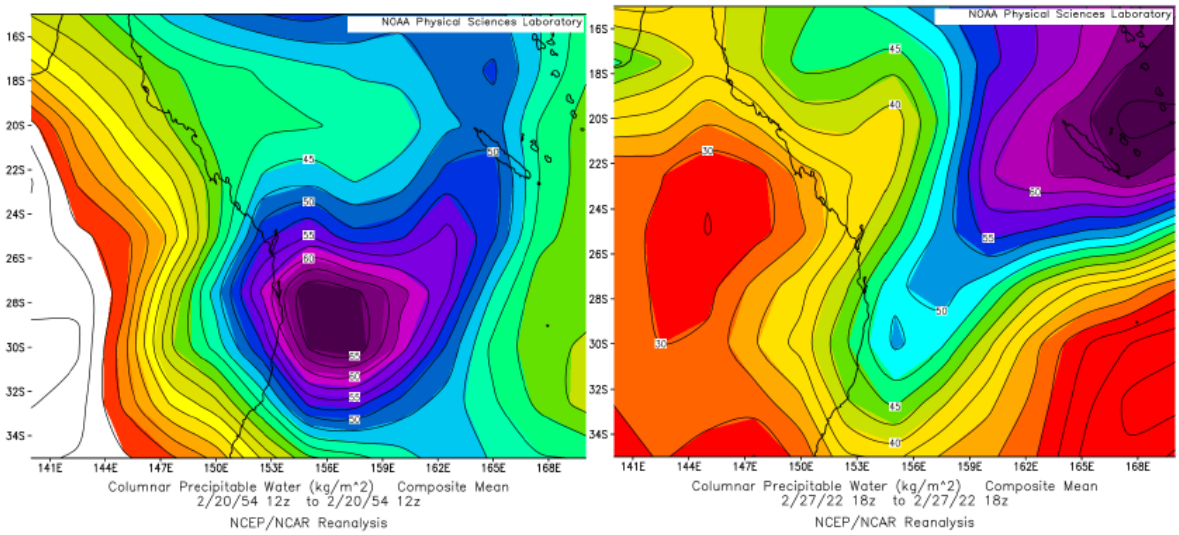

Figure 19 US Reanalysis charts of a column of Precipitable Water for 12:00 UTC 20 February 1954 compared with 18:00 UTC 27 February 1954.

9. The Future and Management of Severe Weather Impacts

Global warming currently being observed is generally expected to continue until preventative measures are carried out. For examples increased use of renewable energy. Warming obviously makes heatwaves during drought periods worse, encouraging catastrophic wildfires. In coastal areas like this study area, sea level rises expected with this warming makes flooding near the coast worse both from riverine flooding and coastal storm surges. Adding to this is the rapid population increase expected in this area adds to the impact. Urbanizing coastal areas increases the runoff from heavy rain which markedly increased flood levels.

During June 24-25, 1852 flooding from an ECL caused the deaths an estimated 80 lives were lost in Gundagai on the Murrumbidgee River in southwest New South Wales. Settlers had lived on the riverbanks and this added to the loss of life. Following this the settlers moved further away from the river. Unfortunately, little was learned from this as even today housing developments in the study area are proceeding along the flood plains. Some obvious action can be taken to manage these problems as follows:

- Purchase by local or state government authorities of properties extremely vulnerable to riverine or coastal flooding. This buy back action should be continued over time for less

vulnerable properties, which will inevitably become more vulnerable, as funds become available.

- The development on flood plains should cease immediately.

Considering El Nino episodes which induce drought and from the combined effects of population growth and global warming water will become an extremely sought-after resource. Several major dam proposals such as the Burdekin Dam in North Queensland. Controlled burning actions preventing wildfires has become a controversial topic. Studies should be carried out to clearly show its beneficial properties to satisfy all parties.

10. Conclusion

The February 2022 floods saw record rainfall and floods in Brisbane suburbs and Lismore which may have not been exceeded over the past two hundred years in those areas. Examination of other regions in the coastal rivers between the Brisbane River catchment and the NSW Victorian border identify three periods where this kind of rainfall and flooding may have occurred. This was in the periods from January 1892 to February 1895, where there were 4.21 major flood events per year; July 1949 to February 1956 with 3.15 events per year and April 1973 to June 1976 with 4.11 events per year.

In the current period from April 2015 to July 2022 there have been a lot less with 2.07 flood events per year although five occurred in 2022. Several of the events in the earlier periods were more catastrophic than the 2022 events particularly when considering inflation and population growth. Common to most of these events was their occurrence during positive phases of the SOI so that to determine if these types of events will increase in the future, climate models must be able to forecast the frequency and length of positive phases of the SOI.

Alternatively, there is some evidence of a strong El Nino during 1820-1860 [26]. Such a long period on El Nino occurring today would have diabolical circumstances for Australia with drought, water shortages, fires, and crop failures. Proof of this El Nino comes from the Vessel *Coolangatta* driven ashore at North Kirra Beach (just to the north of Tweed River) on the 19 August 1846 in easterly to northeasterly gales. The crew walked northwards along the beach unimpeded and came to Amity Point (northern tip of North Stradbroke Island). That is Stradbroke Island was connected to the mainland. After 1860 storm periods resumed and the Stradbroke Island region suffered severe erosion from storms particularly in the 1880s and 1890s culminating in the Island fracturing into two Islands [20]. This could be worse for Australia than under extended La Nina's in a warming world with heat waves wildfires, droughts, crop failures and water shortages. It is imperative for us that our Climate research attempts to understand what causes the frequency and lengths of SOI episodes of sustained positive or negative signs.

Author Contributions

The author did all the research work of this study.

Competing Interests

The author has declared that no competing interests exist.

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