Identifying East Coast Lows with climate hazards on the eastern seaboard

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East Coast Lows are an important weather system that can produce severe wind, wave and rainfall events along the eastern seaboard of Australia. While a number of databases of these systems have been produced, this information has historically not been readily accessible to potential users outside the research sector. This paper details the development of a new product, Maps and Tables of Climate Hazards on the Eastern Seaboard (MATCHES), that bridges this gap. It combines a new database of East Coast Lows with weather impacts across the eastern seaboard. Through use of user-defined impacts thresholds and an intuitive front-end interface, this new tool provides an easy way to link East Coast Lows with their weather impacts.

1. Introduction

The importance of East Coast Lows (ECLs) as both a cause of severe weather and flooding and a contributor to water security along the eastern seaboard is increasingly well known (e.g. Hopkins and Holland 1997, Pepler and Rakich 2010, Pepler et al. 2014a). The eastern seaboard, defined as the region between the Great Dividing Range and the Tasman Sea (Figure 1), is home to approximately 40% of Australia's population, with a correspondingly large proportion of major infrastructure susceptible to high impact ECL events. Notably, an ECL in June 2007 caused more than AU$1.5 billion in damage (ICA 2015), including the beaching of the bulk carrier Pasha Bulker, with subsequent ECLs causing Sydney's water storage to increase from 33.7% to 54.4% during June 2007. Due to their large contribution to both interannual rainfall variability and extreme events, a good understanding of the past impacts of ECLs is critical to effective planning by emergency management groups, catchment managers, and other agencies, particularly as there is considerable uncertainty regarding future rainfall changes in this region (Dowdy 2015).

Over the past decade, at least three other databases of ECLs have been developed (Speer et al. 2009, Dowdy et al. 2011, 2014, Browning and Goodwin 2013), both to assess the interannual variability of ECLs as well as to improve climate change projections. However, while some of these tie ECLs to their associated impacts, there is limited capacity for users to access information about individual historical events, beyond brief descriptions of events with significant coastal impacts in Callaghan and Helman (2008). Notably, while the Callaghan and Helman database includes substantial information on coastal erosion, river flooding and ship losses associated with coastal storms, it has limited information on the location, intensity or behaviour of the low pressure system, although much of this data is now available in the supplementary material to Callaghan and Power (2014). There is also a substantial problem with the definition of an ECL between the databases, with studies using different identification criteria, intensity thresholds, and regions of interest.

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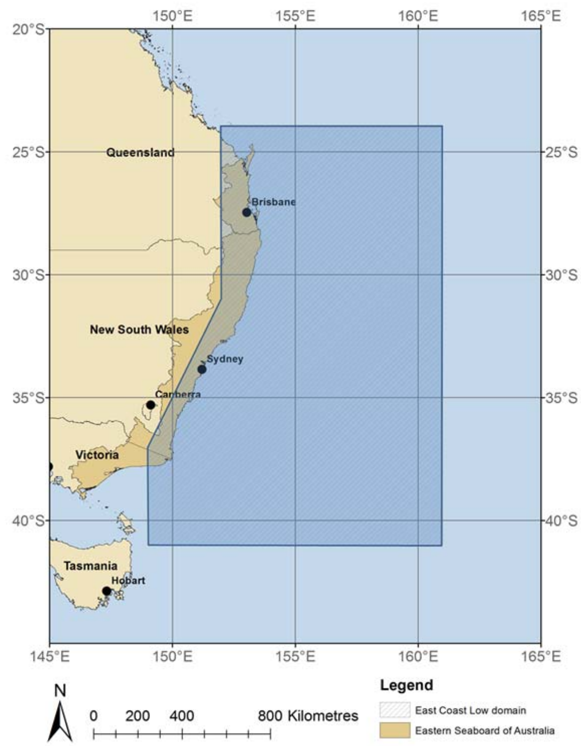

Figure 1 The eastern seaboard of Australia stretching from Hervey Bay, Queensland in the north, to Wilsons Promontory, Victoria in the south. Major cities are marked, with the ECL identification domain shown in dark blue.

In recent years, both the Bureau of Meteorology (http://www.bom.gov.au/cgi-bin/silo/cyclones.cgi) and the National Ocean and Atmospheric Administration (http://csc.noaa.gov/hurricanes) have made available historical tropical cyclone track information, both as an interactive tool and as downloadable data, allowing users to identify the dates, path and intensity of any historical cyclone. Additionally, over recent years groups have made global datasets of gridded and station-based climate extremes available through graphical interfaces and data downloads, such as at http://www.climdex.org. However, to the authors' knowledge there is no current website that combines both of these features. The MATCHES tool is potentially a world-first in attempting to provide both the location and development of an individual weather system as well as any associated extreme weather, to better tie historical events with their impacts.

In this paper, we will present the MATCHES database as it stands, and detail the processes behind its creation. We first discuss the development of the ECL database, including the importance of choosing the criteria that indicate the occurrence of an ECL. We next describe the databases of associated weather impacts, including the selection of minimum thresholds for severe events. This is followed by a discussion of the design process and a review of the stakeholder response, before we conclude with a discussion of both the successes of the tool and important lessons learned for future developments.

2. The East Coast Low database

The selection of an ECL database was a critical part of the development of MATCHES. The manually-developed databases of Callaghan and Helman (2008), Speer et al. (2009) and Callaghan and Power (2014) incorporate human pattern recognition skills as well as knowledge of associated impacts, and thus contain the majority of severe or intense events. However, such databases are time-consuming to produce and require further manual work to update over time. Their subjective nature also allows for inconsistencies in the classification of events, particularly those that are weak or at the borders of the domain. Furthermore, their low temporal resolution (daily) prevents the display of detailed cyclone tracks and low development as is available in the tropical cyclone tools.

For these reasons, over recent decades there has been a move towards the use of objective tracking algorithms to identify mid-latitude cyclones from gridded pressure reanalysis fields (e.g. Murray and Simmonds 1991, Neu et al. 2013). The use of these methods retains some subjectivity in the choice of cyclone identification criteria. They also have known issues with the detection of very small lows (e.g. Uotila et al. 2009) and in separating rapidly moving or complex systems into multiple event tracks (e.g. Mesquita et al. 2009). However, they offer significant advantages in terms of objectivity, analysis frequency and the amount of information available about a given ECL, with more advanced methods (e.g. Simmonds et al. 1999) providing information such as the radius and movement of the low as well as its location and intensity.

While a number of such methods exist, for the purposes of this study we used the Bureau of Meteorology tracking scheme (Jones and Simmonds 1993), which is a version of the Murray and Simmonds (1991) scheme. This is one of the more widely used tracking schemes in the literature, however it does lack some of the later refinements in Simmonds et al. (1999). A comparison of this scheme with other tracking methods, including the Simmonds et al. (1999) version, found little difference in the locations of lows, or in the detection of ECLs associated with significant impacts (Pepler et al. 2014b).

The criteria for classifying a low as an ECL and its verification against the Speer et al. (2009) database are described in Pepler and Coutts-Smith (2013). Briefly, the low pressure system must:

1. persist for at least two consecutive time steps (6 hours);
2. have closed circulation in at least one instance; and
3. pass through the region indicated in Figure 1, corresponding to that used by Speer et al. (2009).

The resultant database was found to identify 92% of ECL days considered ‘significant’ by Speer et al. (2009), with all ‘missed’ events representing borderline ECLs, reflecting the subjectivity of the Speer et al. (2009) database. Using the ‘default’ intensity threshold for the chosen tracking scheme, there were an average of 55 ECLs per year during the period 1970–2006, substantially higher in the Speer et al. (2009) database (22). This was the result of a number of factors, including splitting of ECLs into multiple events and the improved detection of weak, short-lived or fast-moving events. Pepler and Coutts-Smith (2013) consequently recommended that an intensity threshold be applied when searching the database to narrow the number of events to users’ needs, based on the strength of the Laplacian of the pressure around the low centre. However, for the purposes of MATCHES, the full dataset is maintained, allowing users to identify any ‘potential’ ECLs for further investigation rather than further restricting the dataset; this is particularly important as very small mesoscale lows may appear weak in low-resolution fields while still causing substantial rainfall or localised winds (Holland et al. 1987).

To obtain a 50+ year climatology of ECLs, surface pressure was obtained from the NCEP1 reanalysis (Kalnay et al. 1996), which has 6-hourly 2.5° pressure data available from 1948 to present. There are known issues with extremes in precipitation and temperature extremes in NCEP1 when compared to other reanalyses (e.g. Donat et al. 2014). However, it is one of the few reanalyses for which a long period of analysis is available, with known issues with detection of cyclones in the 20th Century Reanalysis ensemble mean (e.g. Wang et al. 2013, Pepler et al. 2016). The NCEP1 reanalysis is of a coarser resolution than more modern reanalyses, which may result in a failure to detect smaller-scale systems, or underestimation of their intensity and the structure of the inner core. However, this reanalysis is adequate to detect the majority of large or impactful ECLs (Pepler and Coutts-Smith 2013), with recent work by Di Luca et al. (2015) showing little change in ECL frequency or characteristics between NCEP1 and other reanalyses when upscaled to the same resolution.

We also tested this briefly by comparing ECLs identified using the NCEP1 reanalysis to results from two satellite period reanalyses at the same resolution during the overlap period 1979–2009 (Table 1). The overall frequency and interannual variability is very similar between the databases, with interannual correlations of close to 0.8 and 70–80% of ECL days in common between the reanalyses, as measured by the Critical Success Index:

$$CSI = \frac{Hits}{Hits + Misses + False\ Alarms} \tag{1}$$

More than 80% of ECLs in the MATCHES database between 1979–2008 also have a corresponding ECL within 500 km of the identified low centre at least once during the event in both the NCEP2 and ERAI datasets, indicating strong agreement on the location and timing of ECLs.

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	NCEP1	*NCEP2*	*ERAI (3°)*
Reference	Kalnay et al. (1996)	Kanamitsu et al. (2002)	Dee et al. (2011)
Available from	1948	1979	1979
ECL events per year	53.2	58.1	54.7
Standard deviation of ECL events (annual)	9.4	9.6	9.6
Interannual correlation		0.84	0.76
Critical Success Index (ECL days)		0.78	0.68
Proportion of ECLs matched within 500 km		91%	83%

Table 1 ECLs identified in the NCEP1 reanalysis compared to two comparable reanalyses during 1979–2008. Note that ERAI has been regridded to 3° to provide comparable results.

ECLs in the MATCHES database were also compared between the pre-satellite (1950–1978) and post-satellite (1979–2008) periods. There were 15% fewer ECLs identified during the post-satellite period, with an increase in the average duration from 34 to 46 hours. This potentially reflects better identification of low pressure centres with increasing data. However, there is no appreciable change in either the number of days with an ECL present in the ECL region, or the average central pressure of ECLs. Consequently, while pre-1979 reanalyses should always be used with caution, the NCEP1 reanalysis is not expected to induce large discrepancies in the ECL database. This is consistent with results found for midlatitude cyclones using the 20th Century Reanalysis (Wang et al. 2013, Pepler et al. 2016), with a clear step-change in southern hemisphere cyclones around 1950 but only a small decline in the 1950–2012 period.

The current version of the MATCHES tool incorporates the ECL database for the period 1950–2008, based on sea level pressure data available at the time of database development. The 6-hourly location and central pressure of each ECL is available for viewing or download. The utility of the MATCHES system enables further developments in the future, including additional ECL datasets, breakdown into ECL sub-types (e.g. Browning and Goodwin 2013), additional ECL information such as speed or radius of the low pressure system, or the potential for user-defined ECL intensity thresholds similar to those available for rainfall, wind and waves (see section three below).

3. Impacts databases

For the purposes of this paper, the term ‘impacts’ refers to hazardous weather phenomena associated with ECLs such as heavy rain, strong winds and high seas, which are readily obtainable from observation datasets (Table 2), rather than ‘impacts’ on health or infrastructure. Further information on East Coast Lows with erosion or shipping impacts is available in Callaghan and Helman (2008), and ECLs associated with severe flooding in Callaghan and Power (2014). Due to limits of availability of both wind and wave data prior to the mid-1970s, this data is restricted to the period from 1970. The use of minimum thresholds for each impact was applied in the database to strike a balance between the need for a limited dataset (to increase responsiveness of the tool) and user-defined threshold requirements.

Data	*Length of record*	*Search parameters*	*Minimum threshold*	*Maintained by*
Rainfall	1970 to 2011	Daily (mm) Hourly (mm) 6-min (mm)	25 mm 10 mm 5 mm	Bureau of Meteorology
Wind	1970 to 2011	Gust (kts) Sustained (kts)	37 kts 28 kts	Bureau of Meteorology
Waves	Mid-1970s to 2011	Peak wave height (m) Wave power (MW/m)	2.5 m 25 MW/m	Manly Hydraulics Laboratory Queensland Department of Environment and Resource Management Sydney Ports Corporation
Water level	Mid-1980s to 2011	Peak water level (m) Peak water level anomaly (m)	0.5 m 0.1 m	Manly Hydraulics Laboratory Sydney Ports Corporation

Table 2 Impacts data included in the interface. Length of record refers to the maximum length, with actual record length station-dependent.

There are a large range of rainfall thresholds used throughout previous studies, ranging from local extreme rainfall such as the 99th percentile (e.g. Alexander et al. 2007) or 20 year recurrence interval (e.g. Zwiers et al. 1998) to static daily totals such as 10 mm (Expert Team on Climate Change Detection and Indices), 25 mm (Plummer et al. 1999), or 50 mm (Karl and Knight 1998). To allow the maximum flexibility, while restricting data to a reasonable subset, we chose to use a static minimum rainfall threshold consistent with the lowest 1 in 5 year average recurrence interval across the eastern seaboard, with the users able to specify higher rainfall thresholds as needed. For daily rainfall, the threshold corresponds to 25 mm and is consistent with the definition of ECLs with significant rainfall by Speer et al. (2009).

While users often have a good understanding of the impacts of different rainfall thresholds on their systems, knowledge of the impacts associated with different wind speeds and wave heights is limited. For this reason, rather than being a flexible threshold above a minimum, the user is presented with a dropdown menu of wind and wave thresholds with known impact levels.

For wind speeds, the threshold options are taken from the Beaufort scale, with corresponding maximum three-second wind gusts calculated using the Durst (1960) curve. The minimum category was chosen as ‘Near Gale’, 28 knots (52 km/h), which is similar to the Bureau of Meteorology’s definition of ‘strong winds’ for coastal and marine severe weather warnings. This corresponds to a maximum three-second wind gust of 37 knots, slightly below the minimum gusts associated with building damage of 50–70 knots (Holmes 2001, Coleman 2002, Khanduri and Morrow 2003).

Wave data used in MATCHES is sourced from Manly Hydraulics Laboratory (MHL), Queensland Department of Environment and Resource Management (DERM) and Sydney Ports Corporation (SPC) and includes daily maximum significant wave height and wave power. The time span covered by the wave records is station dependent with coverage from the mid-1970s to present; Botany Bay has the earliest observations, beginning in April 1971. The minimum threshold for wave heights was determined using the Classification of Storms by Intensity, as outlined in Table 3 (Blain et al. 1985), and are similar to those used by Dowdy et al. (2014).

Water level data used in MATCHES was sourced from a recent study of New South Wales Ocean Water Levels (MHL 2011) and includes peak water level and peak water level anomaly data for 22 stations along the NSW coast, most recording from the mid-1980s. Fort Denison is the main exception, with records dating back to 1915. Unlike the other datasets, these are not continuous and are based on an analysis of the top 20 events experienced at each of the recording stations along the eastern seaboard, with the minimum water level threshold restricted to the lowest level available in that study. When real-time datasets for water level and water level anomaly are readily available they could be incorporated into MATCHES.

Category	*Significant wave height (m)*	*Severity*
X	> 6.0	Extreme
A	5.0–6.0	Severe
B	3.5–5.0	Moderate
C	2.5–3.5	Low

Table 3 Storm wave intensity classification scheme of Blain et al. (1985) used to define thresholds in MATCHES.

4. Website design

4.1 Design principles

Data visualisation is a powerful tool that allows the graphical presentation of multi-dimensional data in a way that allows users to understand relationships present in data. Based on common user-centred design guidelines, the MATCHES interface should be:

1. intuitive to use;
2. engaging; and
3. aesthetically pleasing.

An intuitive interface can be defined as one where the users can access the information they require with minimum difficulty, or where the gap between a user’s pre-existing knowledge and that needed to use the MATCHES tool is small. To minimise the gap and make MATCHES intuitive to use we opted for frequently used toolsets with which users were likely to be familiar. A web-based user interface was built using the OpenLayers JavaScript mapping library. An online help feature was also incorporated into the interface that would lead the user through the steps needed to find the information they were after.

An engaging interface can be considered one that minimises frustration and, where possible, ‘delights’ the user. This can be a significant problem when downloading large quantities of data over the internet, with the MATCHES application accessing a database of more than 4 million observations. To optimise the response time for each event query, it was vital to devise an efficient method of accessing and displaying the requested data. This also led to imposing limits on how much information can be displayed at any one time, with a maximum of one year being applied to the possible date ranges as well as minimum thresholds for each weather impact.

To provide the best possible aesthetics, an emphasis was placed on getting a consistent look and feel across the interface and to ensure that the ratios of the various panels worked well for both large and small screens. A great deal of time and consideration was given to colour selection, changing the size of icons (and their borders) and the choice of symbols to represent the different features.

4.2 Construction of the MATCHES interface

The tool was built using open source toolsets—OpenLayers and ExtJS for the user interface and PostgreSQL for the database—with the majority of the backend source code written in Python. The background map is provided by the Burau via a Web Map Service (WMS) with the ECL and impacts data overlaid as Vector layers. The eastern seaboard region boundary was provided by the Bureau’s New South Wales Climate Services Centre and is rendered as a WMS layer. The interface was built using an extensible architecture, enabling the addition of new layers in future development.

On accessing MATCHES, the user is presented with the event view—a map of the eastern seaboard and dropdown boxes that allow the user to select wind, rain or ocean state thresholds (see Figure 2). Two alternate views exist, which can be accessed by selecting a tab and allows the user to view the layer controls or the legend. After selecting a date range, the user can refresh the view and this will update the map with points of central pressure and tracks for the ECL that occurred during that date range.

By clicking on the central pressure of the ECL the user is given information on the central pressure and is able to view the corresponding daily gridded rainfall (Figure 2, upper panel). By entering a threshold for an impact (e.g. 50 mm of rainfall) and refreshing the view, all the stations where that impact threshold have been exceeded are highlighted. In this way the user can easily see the concurrent rainfall, wind and wave observations that were recorded over the duration over a particular ECL event. It should be noted however that the tool cannot determine if all rainfall, wind and wave observations above the specified thresholds were associated directly with the ECL event. The visualisations of the tool act as a prompt for further investigation of these relationships.

The user is also able to click on the station icon and a chart of the rainfall for that period is displayed with the option to download the data as a comma-separated value (CSV) file (Figure 2, lower panel).

5. Stakeholder engagement

To ensure the MATCHES interface was developed in line with end-user requirements, regular meetings were held with stakeholders, such as the New South Wales State Emergency Management Committee – Climate Change Working Group (SEMC-CCWG), as well as part of the broader consultative process of the Eastern Seaboard Climate Change Initiative. These meetings were used to obtain input and feedback as to what hazard-related information was needed, where it could be sourced and how functional the MATCHES interface was. End-users were also asked for an insight as to how they envisaged using the application within their operations and how it might improve their current work practices.

To assess the extent to which the final tool achieved the goals of clarity and ease of use, a brief survey was sent to those users who registered for the MATCHES tool. Only six of the fifty registered users responded to the survey, all from a research background, limiting our ability to draw conclusions on the usefulness of the page. While five of the six users found the webpage intuitive, only 50% were able to find the information they were seeking. From the comments received, this is because users were hoping to download the complete datasets including both the ECL and impacts data, for further analysis relating to their field of study.

The largest flaw identified by users was the use of a static database of ECLs, precluding users from investigating events that may be recent or topical, as well as insufficient guidance as to the length of data available. There were also requests for better and more detailed explanatory material. The respondents noted that the most popular feature of the site was being able to link the ECLs with their associated weather impacts, with one commenting that it is a great resource.

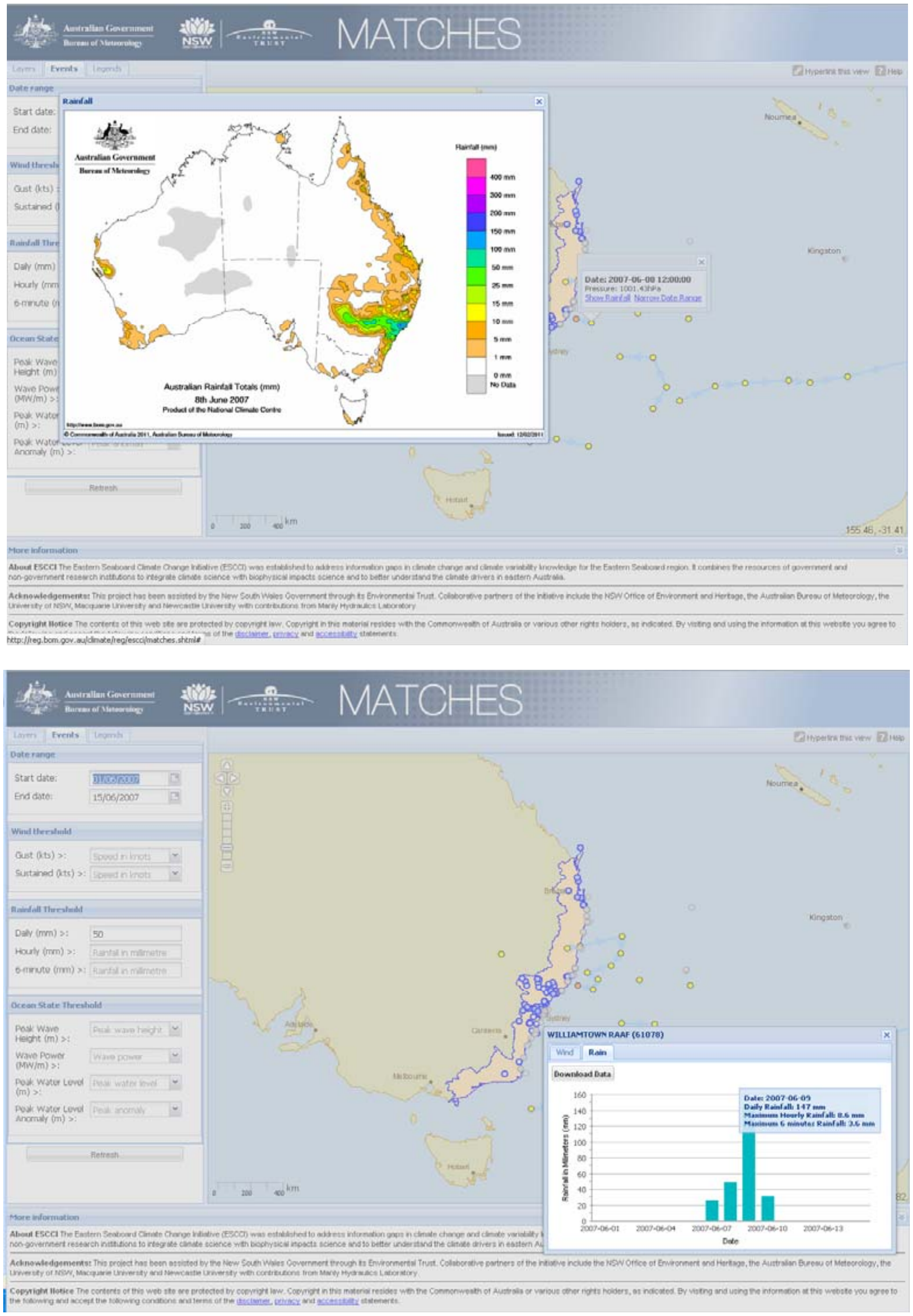

Figure 2 Image of the MATCHES interface showing ECL tracks for the period 1–15 June 2007 with the corresponding daily gridded rainfall (top) and a chart of daily rainfall totals (bottom).

6. Conclusions

The MATCHES tool is one of the first to combine both detailed information on a synoptic system (the Australian East Coast Low) with its associated rain, wind and wave impacts. This was defined as an interactive tool, allowing a variety of stakeholders from both research organisations and the government sector to identify and understand historical ECL events of interest. The tool has supported a number of agencies as well as research in the area of ECLs.

Stakeholder reception was generally positive, however several flaws were identified. Notably, restrictions on timing and funding, and a lack of support for ongoing maintenance, have prevented ongoing updates of the MATCHES tool, which hinders the ability of users to see the impacts of ECLs that are recent and topical. This draws attention to the necessity of such projects to be guaranteed ongoing support, or including a management interface as part of the design to allow updates by non-expert staff.

There are a number of additional areas for further development of the MATCHES tool, including the incorporation of real-time data and mean sea level pressure charts, or using a non-flash solution to allow the website to be accessed on mobile devices. The flexible nature of the tool also offers significant scope for incorporating multiple databases of ECLs or other synoptic systems of interest, such as cold fronts or thunderstorms, as well as additional datasets such as temperatures or user-defined impacts. This would offer significant improvement of stakeholders' ability to understand and identify extreme climate events beyond East Coast Lows.

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