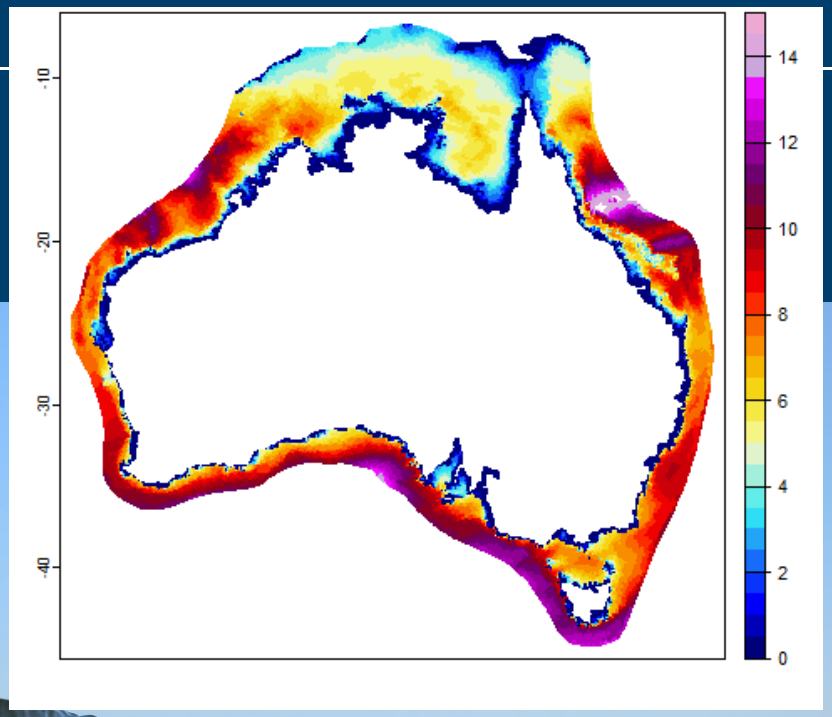
Australian Government

Australian Climate Service

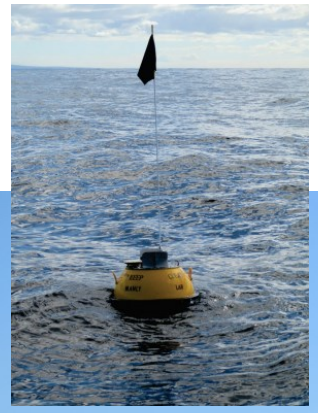
From Buoys to CCHaPS: Tracking the 40 Year trend of Extreme Waves on Australia's East

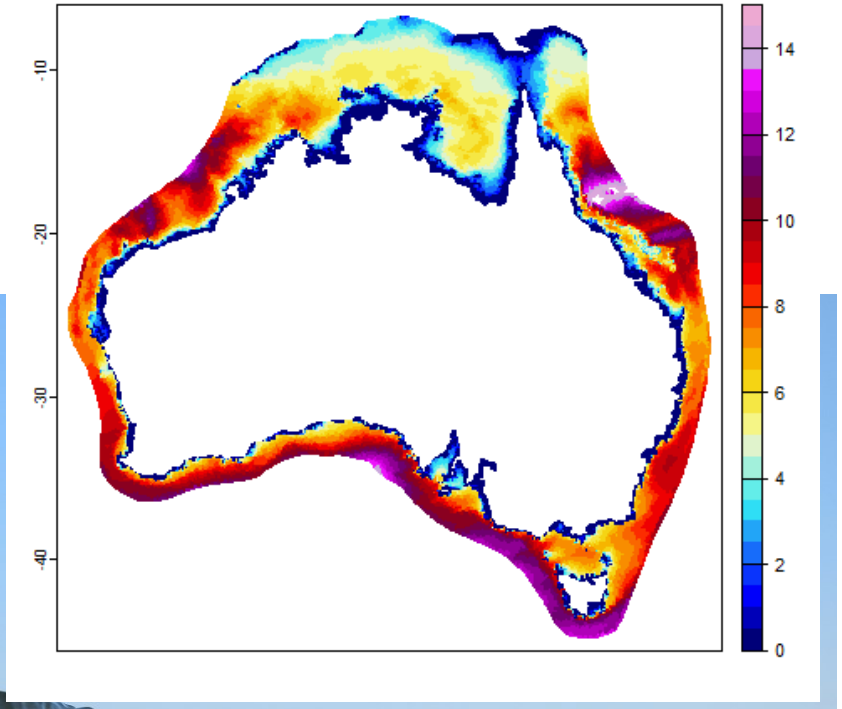
Julian O'Grady, Vanessa Hernaman, Ron Hoeke, Claire Trenham, Bryan Hally, Emilio Echevarria



Overview

- Longterm wave monitoring in QLD and NSW and previous EVA analysis
- ACS WHACS and CCHaPS wave models
- Mixed climate EVDs results
- Non-stationary trends results





Queensland Wave Climate

Wave Monitoring Annual Summary

November 2014 to October 2015

Coastal Impacts Unit, DSITI

Table 2 Wave monitoring history, some early (starting 1968) short–term records from the Gold Coast regions not listed.

Site	Start date	End date	Restart	Directional start date	Total years	Directional years
Tweed Heads	13/01/1995	-	-	13/01/1995	20.8	20.8
Gold Coast	21/03/1987	-	-	17/07/2007	28.6	8.3
Brisbane	31/10/1976	-	-	20/01/1997	39.0	18.8
Caloundra	01/05/2013	-	-	01/05/2013	2.5	2.5
North Moreton Bay	08/03/2010	-	-	08/03/2010	5.7	5.7
Mooloolaba	20/04/2000	-	-	11/05/2005	15.5	10.5
Gladstone	23/09/2009	-	-	23/09/2009	6.1	6.1
Emu Park	24/07/1996	-	-	24/07/1996	19.3	19.3
Hay Point	24/04/1977	25/05/1987	3/04/1993	31/10/2009	32.7	6.0
Mackay	19/09/1975	-	-	13/03/2002	40.1	13.6
Abbot Point	17/01/2012	-	-	17/01/2012	3.8	3.8
Townsville	20/11/1975	-	-	29/10/2008	40.1	7.0
Cairns	04/05/1975	-	-	-	40.5	0.0
Albatross Bay (Weipa)	22/12/1978	-	-	25/11/2008	36.9	6.9

Coastal Data System - Waves (T

data.qld.gov.au/dataset/coastal-data-system-waves-townsville

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PEN DATA

Dataset Groups Activity Stream Comments

Coastal Data System - Waves (Townsville)

Data usability rating : ✓✓✓✓✓

Contains file schema and open format machine-readable open data.

Measured and derived wave parameters from data collected by a wave monitoring buoy anchored at Townsville. For more information please refer to www.qld.gov.au/waves.
Field names;
Hs - Significant wave height, an average of the highest third of the waves in a record (26.6 minute recording period).
Hmax - The maximum wave height in the record.
Tz - The zero upcrossing wave period.
Tp - The peak energy wave period.
Peak Direction - Direction (related to true north) from which the peak period waves are coming from.
SST - Sea surface temperature as measured by a sensor embedded in the hull of the buoy.

Data and Resources

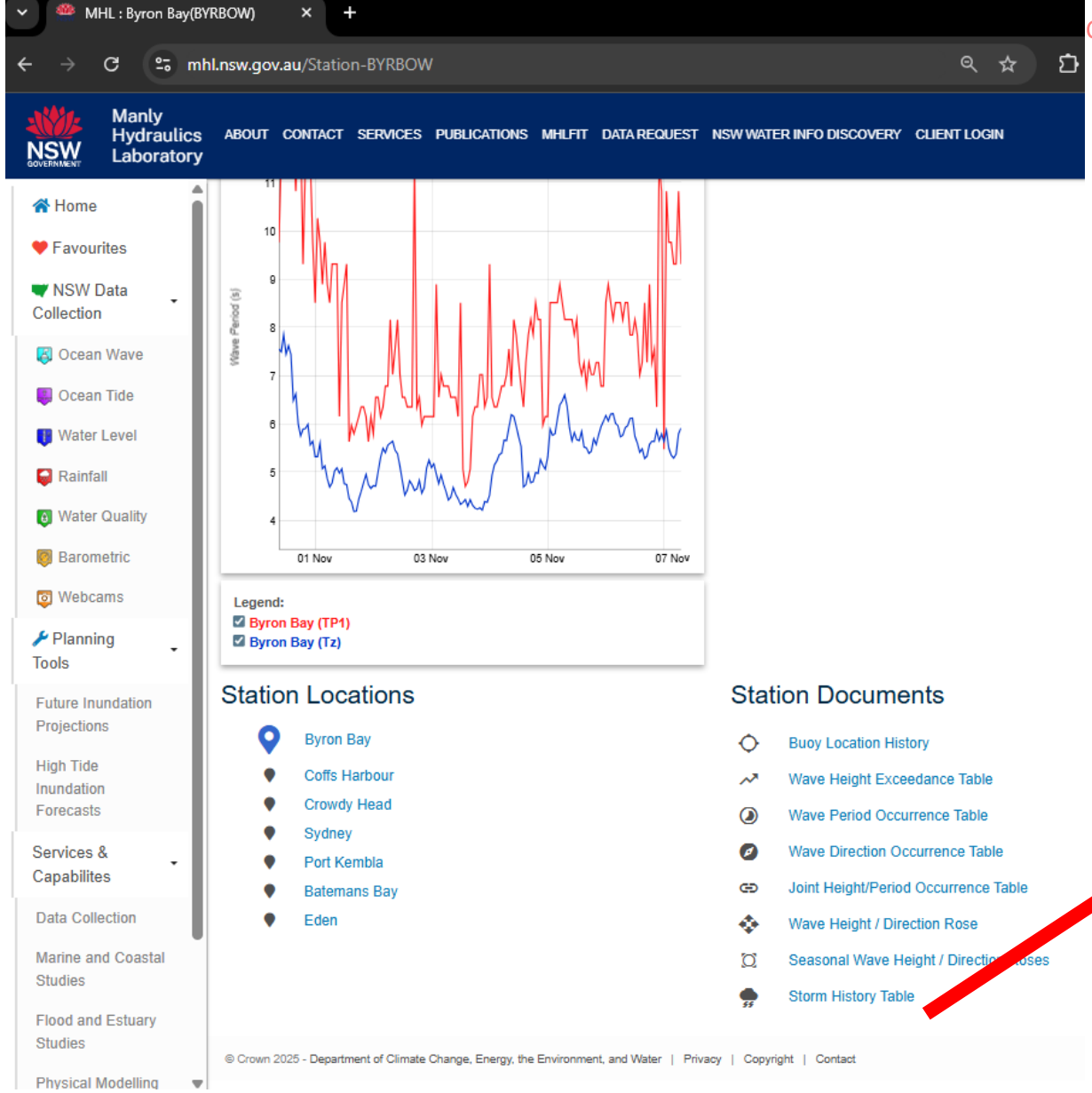
CSV API **Wave data - 2025**
2024 wave data from the Townsville wave monitoring site.

CSV API **Wave data - 2024**
2024 wave data from the Townsville wave monitoring site.

CSV API **Wave data - 2023**
2023 wave data from the Townsville wave monitoring site.

CSV API **Wave data - 2022**
2022 wave data from the Townsville wave monitoring site.

Hourly observations for around 1995



Manly Hydraulics Laboratory

NSW Wave Climate

Byron Bay Waverider Buoy Storm History

Site Commissioned: 14-Oct-76

Date Capture: 76.7%

Storm Date		Storm Duration (Hours) of Hsig (m) greater than:											Peak Hsig	Mean Hsig	Peak Hmax	Mean Tsig	Mean TP1	Peak Power	Mean Power	Deepwater Wave Direction	
Start	Finish	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	(m)	(m)	(m)	(s)	(s)	(kW/m)	(kW/m)	(° TN)	(Compass)
19-Jan-77	19-Jan-77	6	3	0	0	0	0	0	0	0	0	0	3.9	3.9	6.5	8.7	10.8	#	#	90	E
21-Feb-77	22-Feb-77	9	3	0	0	0	0	0	0	0	0	0	3.9	3.5	6.5	8.2	10.1	#	#	67	ENE
2-Mar-77	2-Mar-77	3	0	0	0	0	0	0	0	0	0	0	3.1	3.1	5.2	8.7	10.8	#	#	90	E
16-Mar-77	17-Mar-77	9	3	0	0	0	0	0	0	0	0	0	3.7	3.6	6.2	7.1	8.8	#	#	135	SE
10-Apr-77	11-Apr-77	15	3	0	0	0	0	0	0	0	0	0	3.5	3.2	5.9	8.7	10.8	#	#	135	SE
1-May-77	4-May-77	9	0	0	0	0	0	0	0	0	0	0	3.4	3.2	5.7	9.8	12.2	#	#	112	ESE
17-May-77	20-May-77	57	33	12	9	6	3	0	0	0	0	0	5.6	3.9	9.5	9.0	11.2	#	#	112	ESE
20-Jun-77	20-Jun-77	9	3	0	0	0	0	0	0	0	0	0	3.5	3.4	5.9	8.2	10.1	#	#	180	S
5-Sep-77	5-Sep-77	9	6	3	0	0	0	0	0	0	0	0	4.0	3.6	6.8	8.2	10.1	#	#	180	S
28-Dec-77	29-Dec-77	15	9	3	0	0	0	0	0	0	0	0	4.0	3.8	6.8	9.4	11.7	#	#	135	SE
8-Jan-78	8-Jan-78	9	0	0	0	0	0	0	0	0	0	0	3.3	3.3	5.5	9.8	12.2	#	#	90	E
17-Mar-78	20-Mar-78	27	3	0	0	0	0	0	0	0	0	0	3.9	3.4	6.7	9.2	11.3	#	#	112	ESE
14-Apr-78	17-Apr-78	51	15	3	0	0	0	0	0	0	0	0	4.1	3.5	7.0	9.3	11.6	#	#	135	SE
14-Aug-78	14-Aug-78	15	3	0	0	0	0	0	0	0	0	0	3.5	3.4	5.2	10.3	11.0	76.5	67.9	180	S
30-Sep-78	30-Sep-78	6	3	0	0	0	0	0	0	0	0	0	3.5	3.5	6.2	8.2	9.9	53.7	53.7	135	SE
30-Dec-78	30-Dec-78	9	0	0	0	0	0	0	0	0	0	0	3.2	3.2	5.1	8.0	9.2	41.8	40.9	90	E
28-Jan-79	28-Jan-79	3	0	0	0	0	0	0	0	0	0	0	3.3	3.3	4.8	8.2	9.9	45.8	45.8	90	E
5-Feb-79	5-Feb-79	3	0	0	0	0	0	0	0	0	0	0	3.4	3.4	5.1	13.4	14.3	83.5	83.5	90	E
8-Feb-79	8-Feb-79	3	0	0	0	0	0	0	0	0	0	0	3.4	3.4	6.0	8.5	9.9	52.5	52.5	90	E
25-Mar-79	25-Mar-79	9	3	0	0	0	0	0	0	0	0	0	3.9	3.6	6.7	9.6	11.7	76.6	67.9	135	SE
11-Apr-79	11-Apr-79	6	0	0	0	0	0	0	0	0	0	0	3.1	3.1	4.8	9.1	8.6	44.8	44.8	135	SE
20-Apr-79	20-Apr-79	6	6	3	0	0	0	0	0	0	0	0	4.4	4.4	9.2	6.5	11.7	58.9	58.9	180	S
30-Apr-79	30-Apr-79	9	0	0	0	0	0	0	0	0	0	0	3.2	3.2	5.5	9.0	9.9	53.8	51.0	112	ESE
22-May-79	22-May-79	3	0	0	0	0	0	0	0	0	0	0	3.1	3.1	6.1	9.6	11.7	51.4	51.4	135	SE
1-Jun-79	2-Jun-79	27	9	0	0	0	0	0	0	0	0	0	3.9	3.4	6.2	9.6	11.3	77.3	62.1	135	SE
1-Sep-79	2-Sep-79	9	3	0	0	0	0	0	0	0	0	0	3.5	3.4	5.9	9.3	11.5	#	#	180	S

NSW Nearshore Wave Tool Update

Offshore Wave Height Extreme Value Analysis

24 October 2024 | 12359.201.R2.Rev0

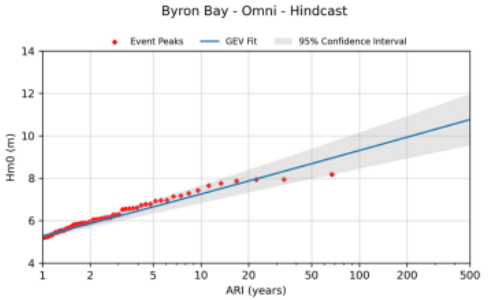
Baird. Innovation Engineered.

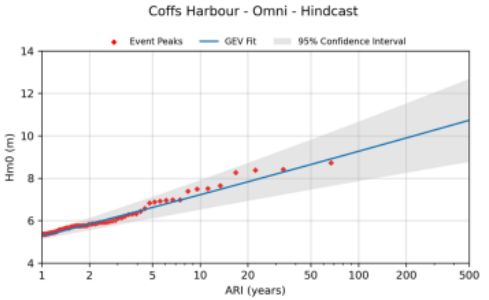
The wave buoy program captured data at 12 or 6-hour intervals until 1984 when the first location was upgraded to capture data at 1-hour intervals. All locations were collecting data at 1-hour intervals by 1985 (and Sydney from this location's first deployment in 1987). For consistency, this analysis only utilises the available 1-hour interval records from each location. The available data periods are summarised in Table 2.3. The effective record length is presented which accounts for all available data excluding outages and data flagged as bad by MHL quality control processes.

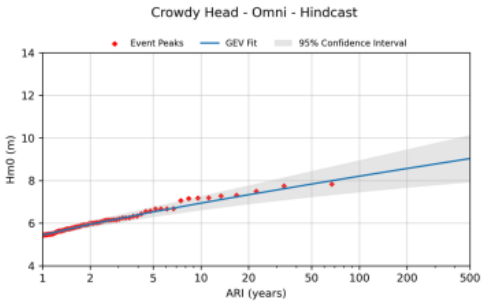
Table 2.3: Wave Buoy Data Availability and Effective Record Length.

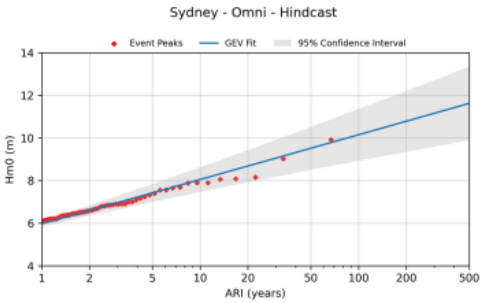
Location	Start Date		End Date	Effective Record Length (years)	
	Hourly	Directional		Hourly	Directional
Byron Bay	28/06/1984	26/10/1999	31/12/2023	32.7	20.4
Coffs Harbour	27/06/1984	14/02/2012	31/12/2023	34.4	10.4
Crowdy Head	10/10/1985	19/08/2011	31/12/2023	33.6	11.1
Sydney	17/07/1987	3/03/1992	31/12/2023	33.7	29.3
Port Kembla	14/06/1984	20/06/2012	31/12/2023	34.2	9.3
Batemans Bay	27/05/1986	23/02/2001	31/12/2023	33.9	20.3
Eden	27/03/1985	16/12/2011	31/12/2023	34.3	10.4

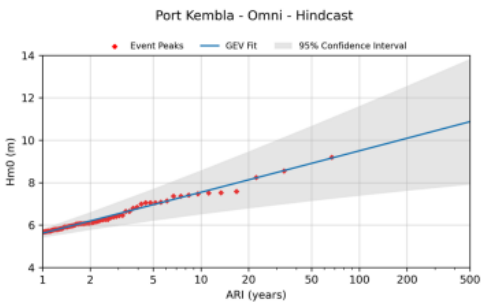
Waverider buoy

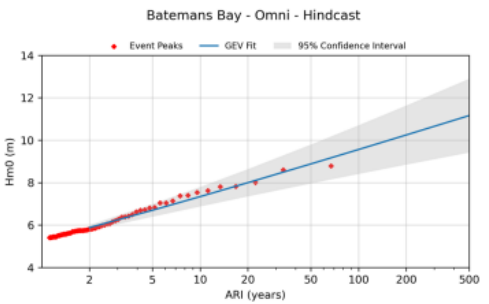


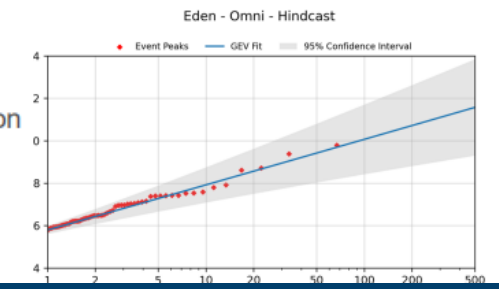












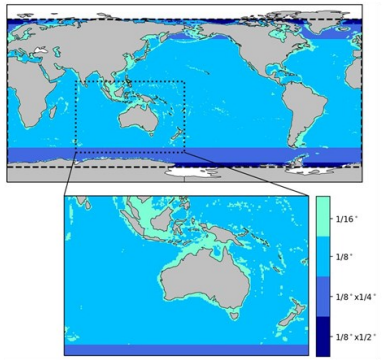
- Shand et al (2011) considered a range of extreme value distributions to apply to the NSW data and evaluated in detail the FT-1 (Gumbel, Type-I) and Weibull (Type-III) distributions based on recommendations in You (2007). Shand *et al* (2011) ultimately adopted Weibull distribution based on improved goodness of fit statistics compared to the FT-1 distribution. Glatz et al (2017) generally adopted methods consistent with Shand *et al* (2011) and also ultimately adopted the Weibull distribution.

POT MLE
inhouse EVDs

WHACS: Wave Hindcast for Australian Climate Service

Providing a global reanalysis of ocean waves to support planning and risk assessment

- Next generation global wave hindcast
- WAVEWATCH III version 6.07
- Spherical Multiple-Cell (SMC) grid, aligning with AUSWAVE
- Higher resolution near coasts and on shelf regions (5 to 7 km)
- Driven by ERA-5 winds and ice
- Hourly data; 1979 to near-present
- Bulk wave parameters available globally and spectral output points across Indo-Pacific country regions
- Will replace the CAWCR Wave Hindcast



WWIII Name	Description	Variable Name	units
HS	Significant Height of Wind and Swell Wave	hs	m
WND	Eastward Wind	uwnd	m/s
	Northward Wind	vwnd	m/s
T01	Mean Period (T01)	t01	s
T02	Mean Period (T02)	t02	s
T0M1	Mean Period (T0m1)	t0m1	s
FP	Peak Wave Frequency	fp	Hz
DIR	Mean Wave Direction	dir	degree
DP	Peak Direction	dp	
SPR	Directional Spread	spr	degree
PQP	Peakedness Partition [0-3]	pqp[0-3]	
PHS	Wave Significant Height Partition [0-3]	phs[0-3]	m
PTP	Peak Period Partition [0-3]	ptp[0-3]	s
PDIR	Wave Direction Partition [0-3]	pdir[0-3]	degree
PDP	Peak Direction Partition [0-3]	pdp[0-3]	degree
PPE	Peak Enhancement Factor [0-3]	ppe[0-3]	
PSPR	Directional Spread Partition [0-3]	pspr[0-3]	degree
CGE	Wave Energy Flux	cge	kW/m

Gridded bulk output parameters

Available data formats:
1. full SMC grid data
2. regridded at 1/8 deg globally
3. regridded at 1/16 deg in the Australian region

Spectral outputs will be available at a later date.

Further information:
Smith et al. (2025) WHACS: Global Wave Hindcast for the Australian Climate Service with focus on Extremes, *in review*.

Data access: https://data.csiro.au/collection/csiro:64350
DOI: https://doi.org/10.25919/shdk-7p29

This research has been funded by the Australian Climate Service. The Australian Climate Service is a partnership made of the Bureau of Meteorology, CSIRO, the Australian Bureau of Statistics and Geoscience Australia.

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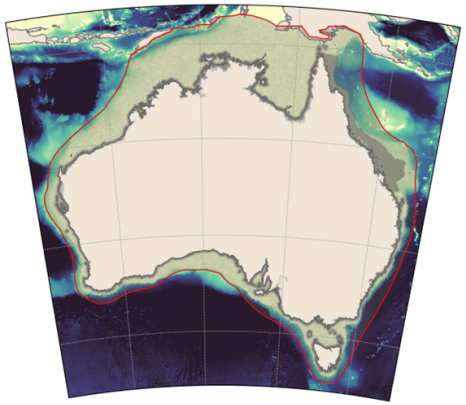
Coupled Coastal Hazards Prediction System (CCHaPS): National Hindcast

- Coupled wave-hydrodynamics model (SCHISM-WWMIII v5.9) simulating water levels, tides, currents and waves
- Unstructured computational mesh resolution: ~250 m @coastline (100 m in major river mouths) to ~5 km @open ocean boundary
- BARRA-R2 atmospheric forcing, WHACS wave and TPXO9.2 Tides, ORAS5 water levels boundary conditions
- Hourly data; 1981 to near-present*



variable name	description	units
zos	Sea surface height above geoid	metre
u0	Depth averaged velocity (east)	metres per second
v0	Depth averaged velocity (north)	metres per second
hs	Significant wave height	metre
dm	Mean wave direction	degree
dp	Peak wave direction (deg)	degree
dp_rad	Peak wave direction (rad)	radians
t01	Mean wave period based on first moment	second
t02	Mean wave period (zero crossing)	second
tp	Peak wave period	second
dspr	Mean directional spreading	degree
pspr	Peak directional spreading	degree
uorb	Orbital velocity	metres per second
wetdry_node	Model node wet/dry status	boolean

Output parameters

Related datasets planned for future release:
1. CCHaPS Hindcast-based annual exceedance probabilities (AEPs)
2. CCHaPS climate projections

Further information:
Hernaman et al. (2025) CCHaPS: An Australian Coupled hydrodynamic-wave Coastal Hazards Prediction System, *in prep*.

Data access: https://data.csiro.au/collection/csiro:65669
DOI: https://doi.org/10.25919/6tbn-px91

This research has been funded by the Australian Climate Service. The Australian Climate Service is a partnership made of the Bureau of Meteorology, CSIRO, the Australian Bureau of Statistics and Geoscience Australia.

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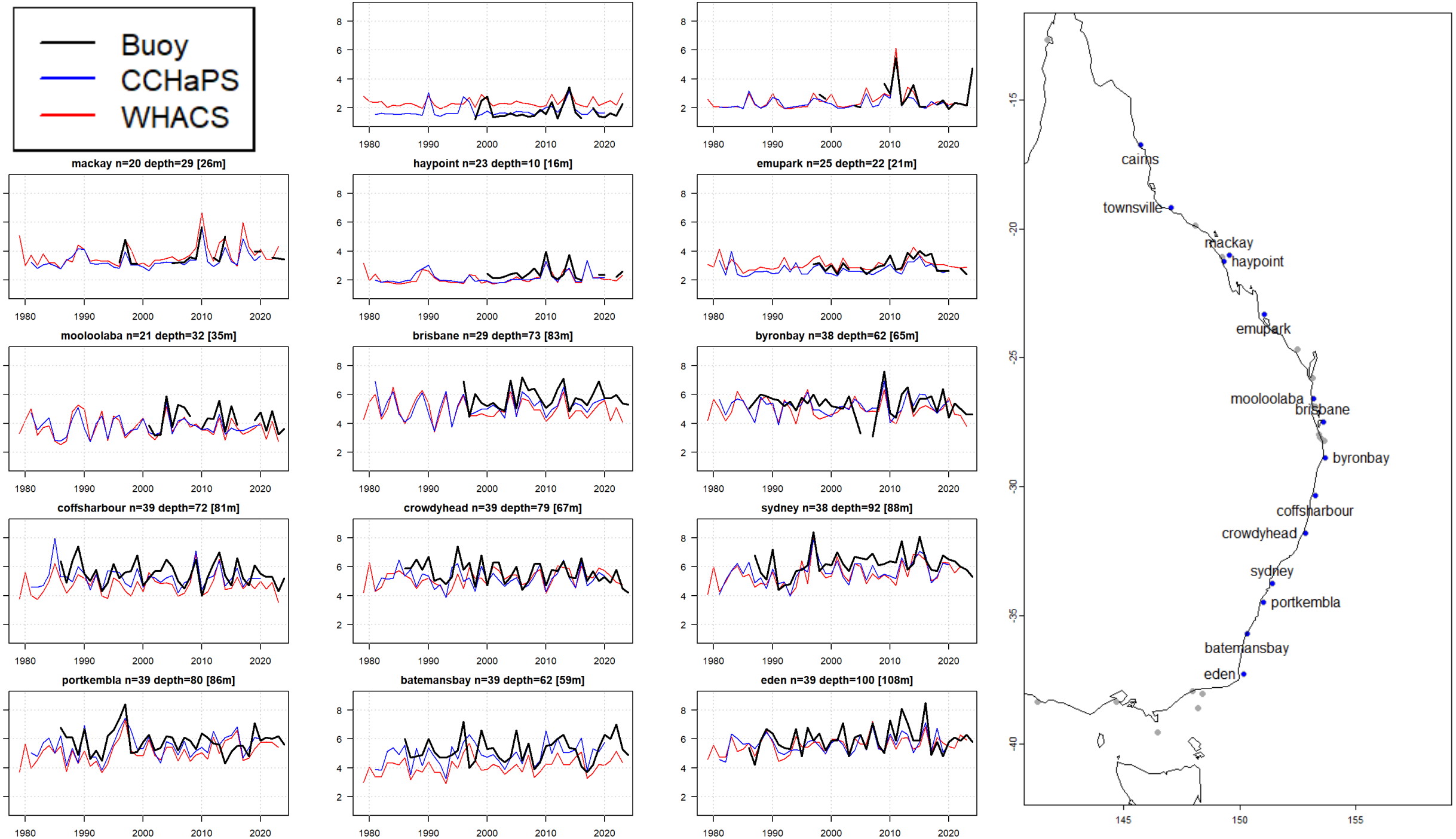
Buoy
CCHaPS
WHACS
cairns n=26 depth=15 [19m]
townsville n=22 depth=18 [21m]
mackay n=20 depth=29 [26m]
haypoint n=23 depth=10 [16m]
emupark n=25 depth=22 [21m]
mooloolaba n=21 depth=32 [35m]
brisbane n=29 depth=73 [83m]
byronbay n=38 depth=62 [65m]
coffsharbour n=39 depth=72 [81m]
crowdyhead n=39 depth=79 [67m]
sydney n=38 depth=92 [88m]
portkembla n=39 depth=80 [86m]
batemansbay n=39 depth=62 [59m]
eden n=39 depth=100 [108m]
1980
1990
2000
2010
2020
2
4
6
8
cairns
townsville
mackay
haypoint
emupark
mooloolaba
brisbane
byronbay
coffsharbour
crowdyhead
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portkembla
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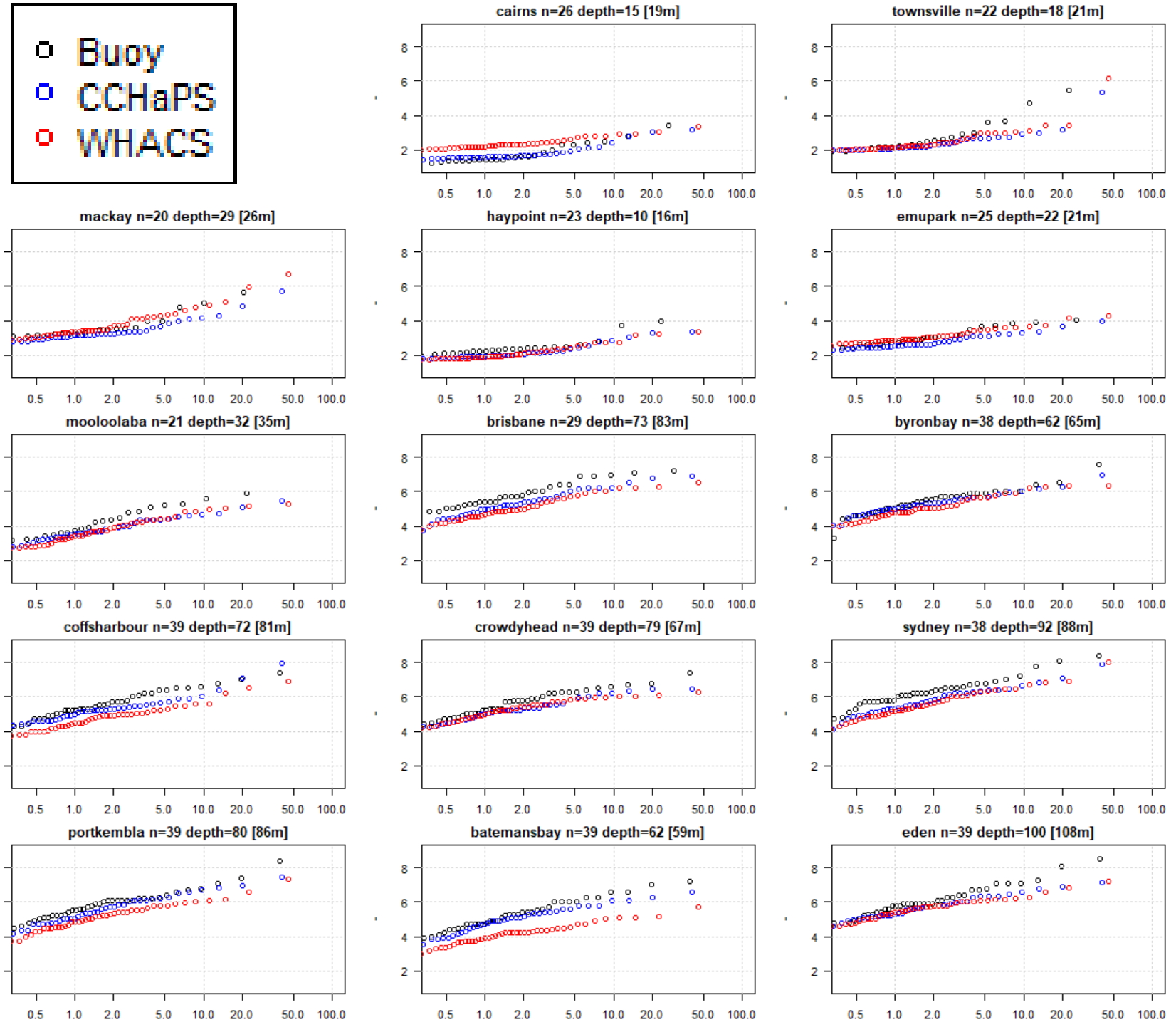
-15
-20
-25
-30
-35
-40
145
150
155



Empirical ARIs

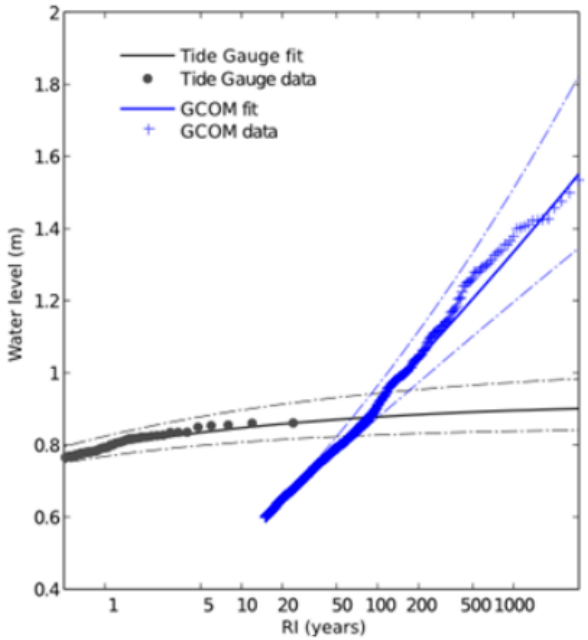
ARI ~ (n-i+1)/i

n = number of years
i = order index (high to low)

What is the 100-year Hs?

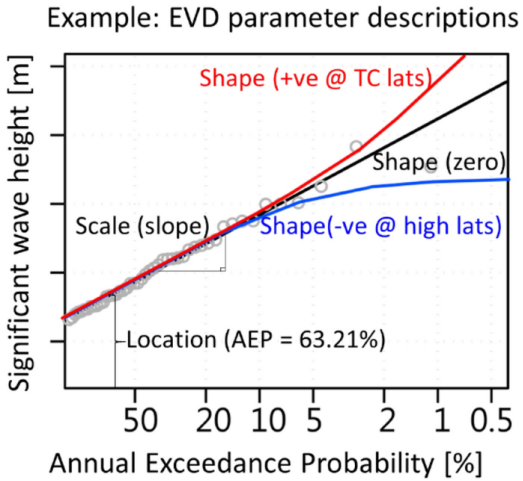
Mixed climate (two Gumbel) TC and non-TC EVD water levels.

Q? Why are tide gauge and synthetic TC distributions different?



Apia Samoa (Hoeke et al 2014)
Australia (Haigh et al 2014)

Which EVD?



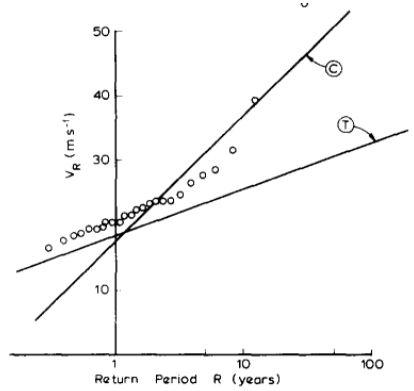
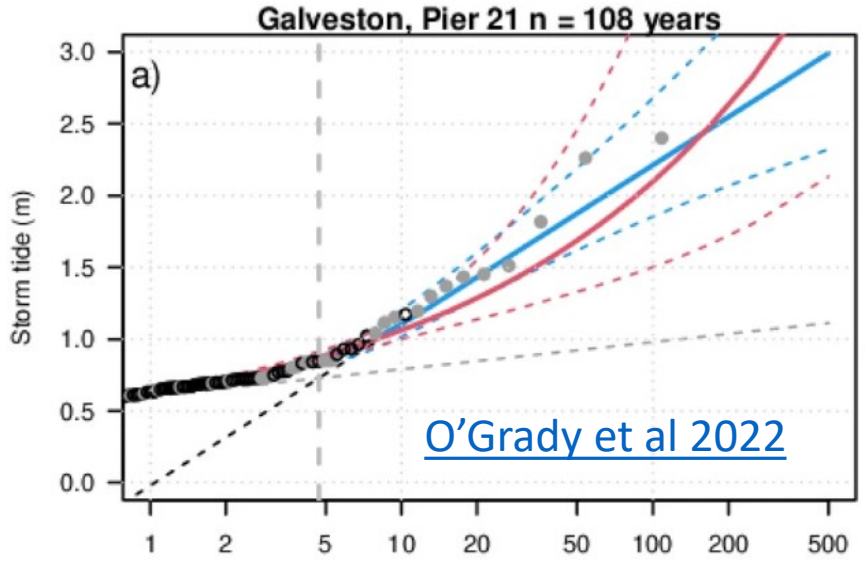


Fig. 6. Extreme gust speeds for Townsville.

Mixed climate EVD
Gomes & Vickery 1977

Can we observe it in long tide gauge obs?



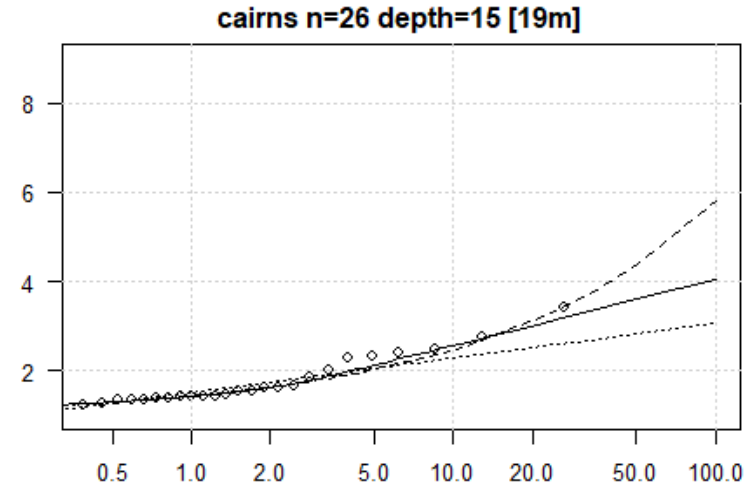
GoF: Which EVD is better?

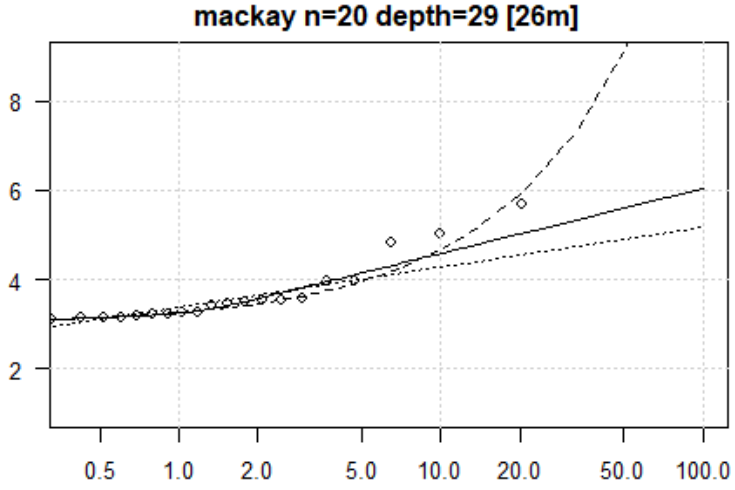
Number of model parameters

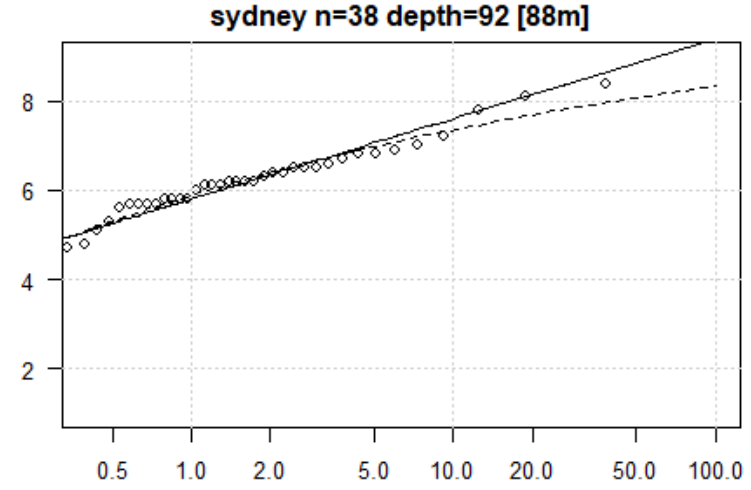
$$AIC = 2k - 2\ln(\mathcal{L})$$

$\mathcal{L} = \mathcal{L}(\hat{\theta})$ = maximum value of the likelihood function of the model

Gumbel
GEV
Mixed Gumbel







Number of model parameters

$$AIC = 2k - 2\ln(\mathcal{L})$$

$\mathcal{L} = \mathcal{L}(\hat{\theta})$ = maximum value of the likelihood function of the model

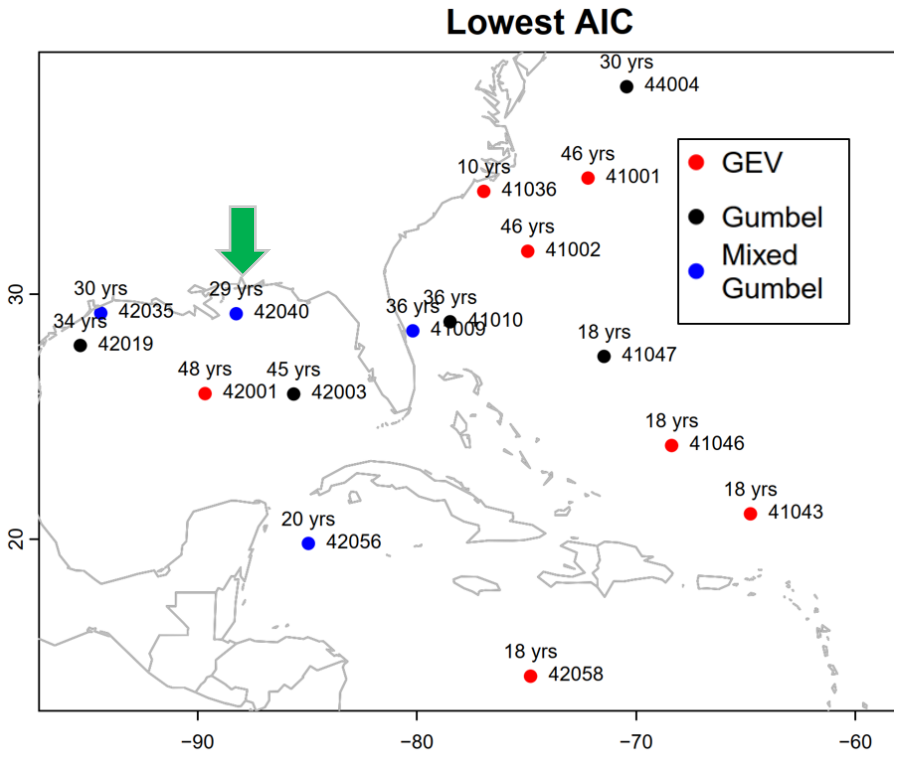
location	Buoy	CCHaPS	WHACS
cairns	+ Mixed Gumbel	+ Mixed Gumbel	+ Gumbel
townsville	+ GEV	+ GEV	+ GEV
mackay	+ GEV	+ GEV	+ GEV
haypoint	+ GEV	+ Mixed Gumbel	+ Mixed Gumbel
emupark	+ Mixed Gumbel	+ GEV	+ Gumbel
mooloolaba	- Gumbel	- Gumbel	- Gumbel
brisbane	- Gumbel	- Gumbel	- Gumbel
byronbay	- Gumbel	- Gumbel	- Gumbel
coffsharbour	- Gumbel	+ Gumbel	- Gumbel
crowdyhead	- Gumbel	- Gumbel	- Gumbel
sydney	- Gumbel	- Gumbel	- Gumbel
portkembla	- Gumbel	- Gumbel	- Gumbel
batemansbay	- Gumbel	- Gumbel	- Gumbel
eden	- Gumbel	- Gumbel	- Gumbel

Can we observe mixed climates in wave buoy records?

Number of model parameters

$$AIC = 2k - 2\ln(\mathcal{L})$$

$\mathcal{L} = \mathcal{L}(\hat{\theta})$ = maximum value of the likelihood function of the model



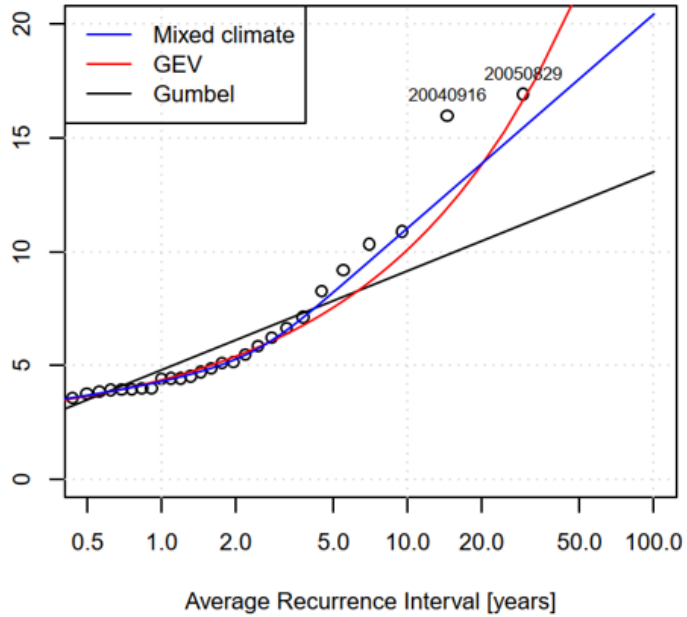
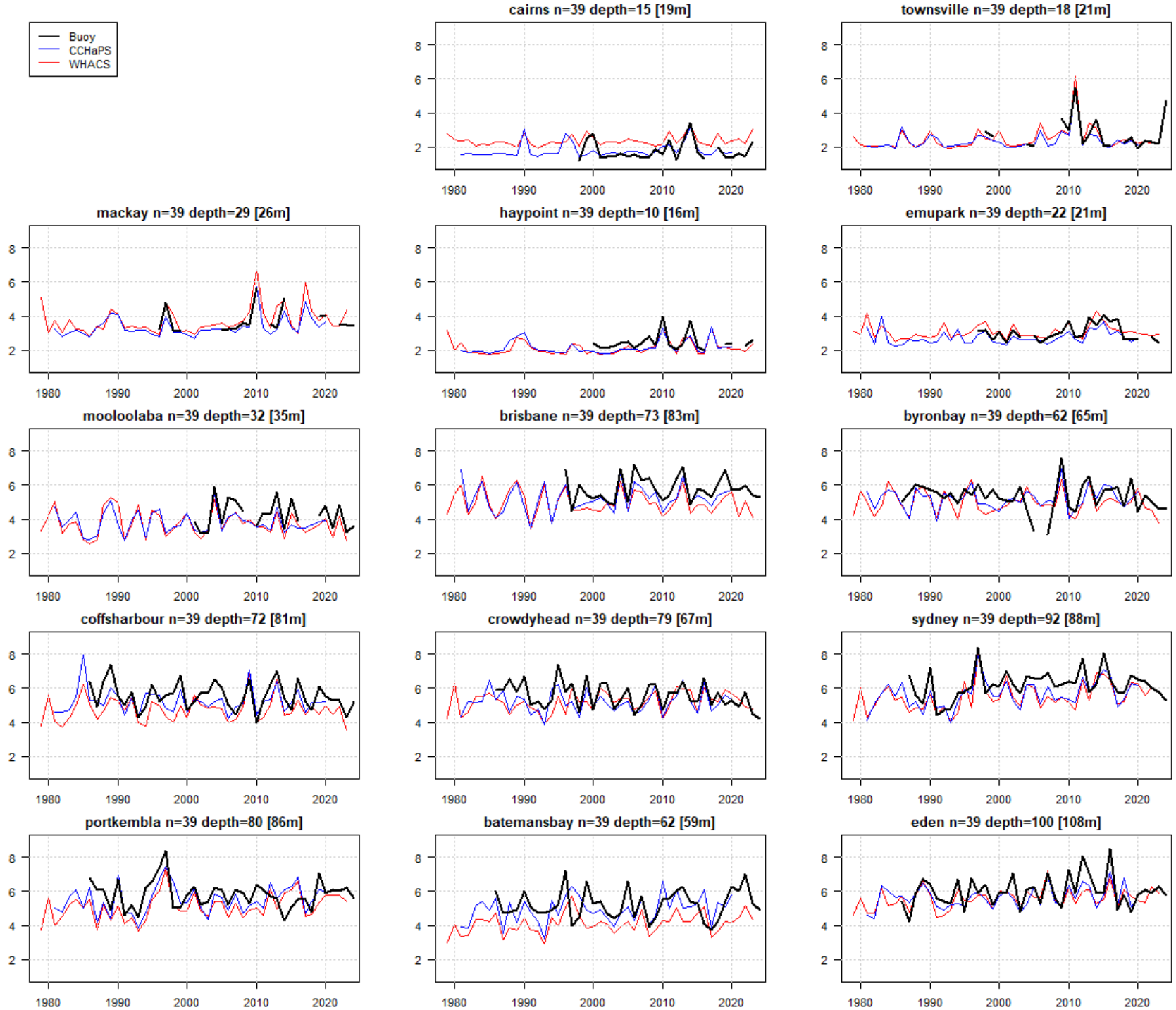


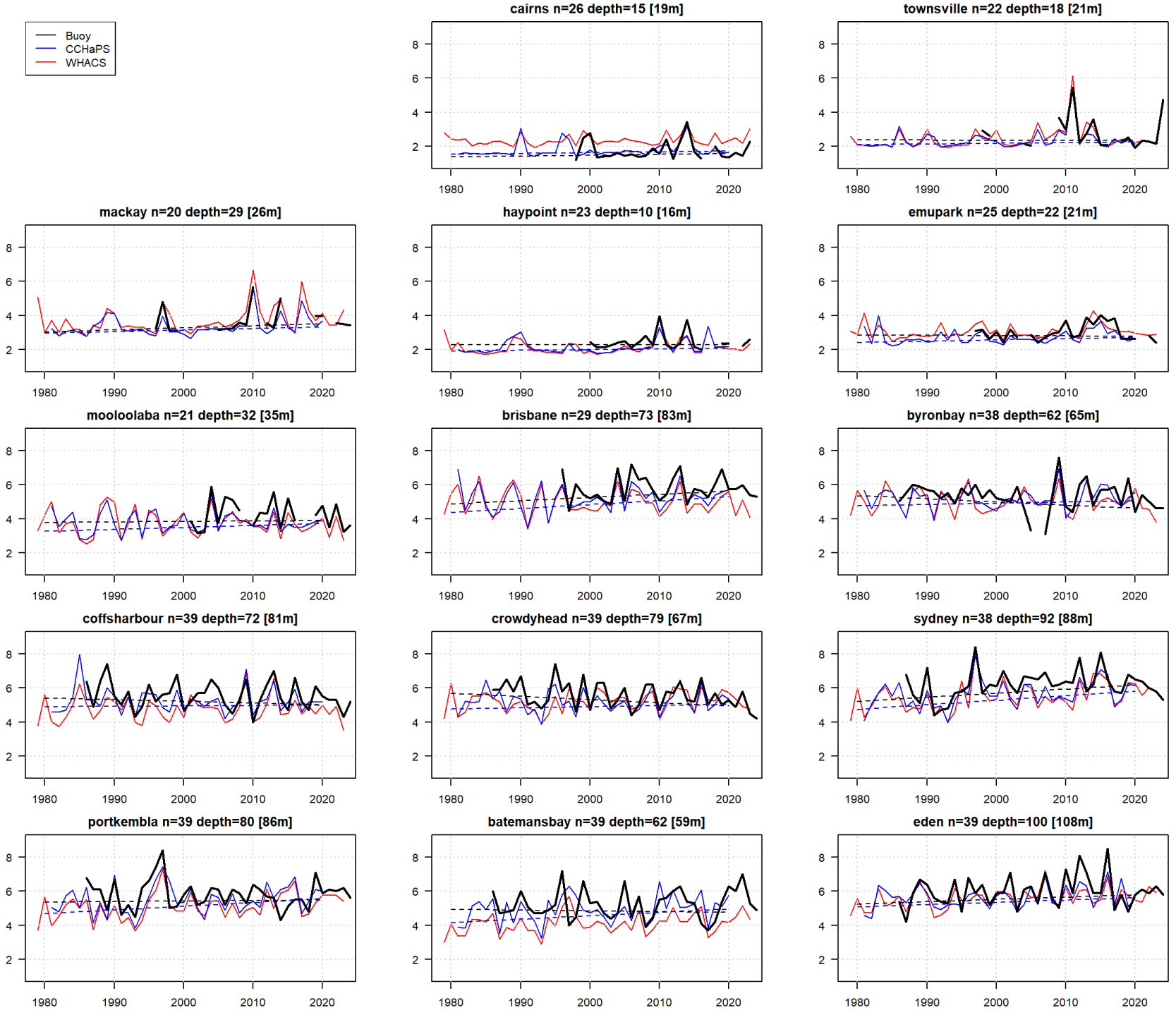
Figure 2 - Return-level plot for NDBC 42040. The top two empirical annual maxima are labelled 20040916 and 20050829, corresponding to Hurricane Ivan and Hurricane Katrina, respectively.

ICCE TX abstract
https://github.com/JulianOG/Wave_riding_mixed_climate_evds



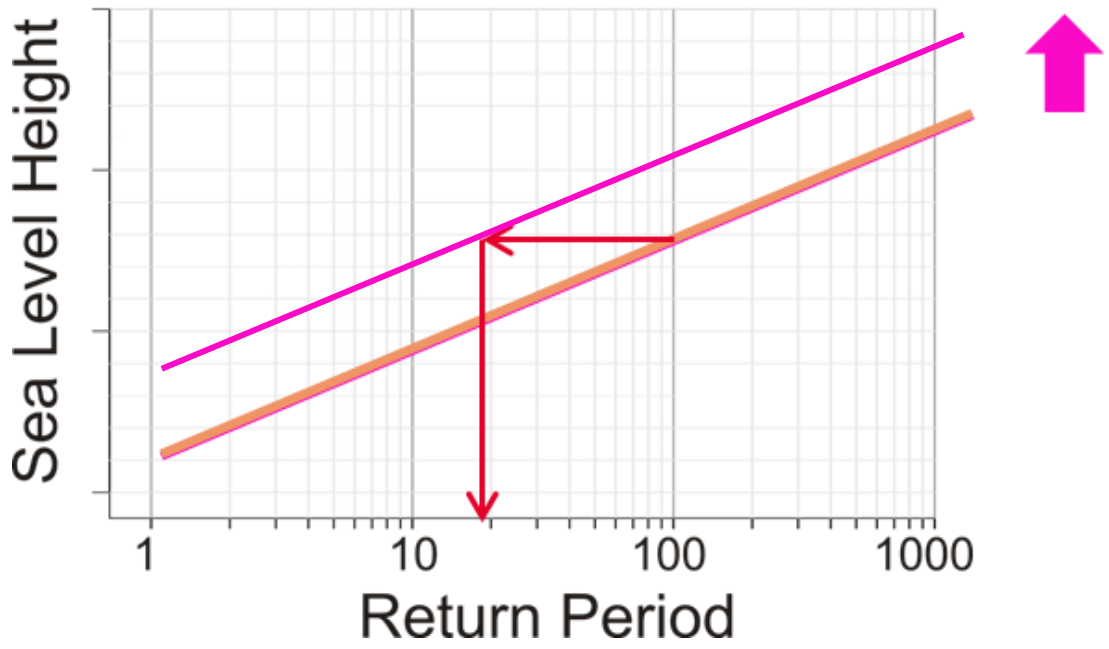
Trends are determined by fitting non-stationary Gumbel EVD

$$\text{loc} + \frac{\Delta \text{loc}}{\Delta t} t + \text{scale} * \frac{((-\log(\text{AEP}))^{(-\text{shape})} - 1)}{\text{shape}}$$



20-year change in Hs [m]

location	Buoy	CCHaPS	WHACS
cairns	0.1	0.1 *	0.06
townsville	-0.02	0.08	0.12 *
mackay	0.24	0.18 *	0.24 *
haypoint	-0.02	0.08	0.08
emupark	-0.04	0.14 *	0.1
mooloolaba	0.06	0.22 *	0.04
brisbane	0.38 *	0.46 *	0.06
byronbay	-0.38	0.16	-0.04
coffsharbour	-0.2	0.04	0.04
crowdyhead	-0.38 *	0.14	0.24 *
sydney	0.48 *	0.54 *	0.54 *
portkembla	0.06	0.44 *	0.54 *
batemansbay	-0.1	0.4 *	0.3 *
eden	0.28	0.26 *	0.36 *



AEP Multiplication factor over 20 years

location	Buoy	CCHaPS	WHACS
cairns	1.37	1.62 *	1.32
townsville	0.96	1.36	1.42 *
mackay	1.93	1.75 *	1.65 *
haypoint	0.95	1.47	1.42
emupark	0.9	1.8 *	1.39
mooloolaba	1.09	1.57 *	1.07
brisbane	1.92 *	1.95 *	1.09
byronbay	0.65	1.3	0.94
coffsharbour	0.75	1.09	1.07
crowdyhead	0.55 *	1.26	1.57 *
sydney	1.99 *	2.22 *	2.48 *
portkembla	1.09	1.86 *	2.48 *
batemansbay	0.88	1.75 *	1.76 *
eden	1.44	1.68 *	2.17 *

Loopevd

Features:

- builds on {evd} extremes and {terra} spatial R packages
- loops across grids {terra} or point/stations {parallel}
- Annual max for practical estimate
- Maximum likelihood estimation
- mixed climate EVDs (evd::gumbelx)
- non-stationary location covariates.
- AIC, CI and uncertainty

https://github.com/AusClimateService/loopevd

https://ausclimateservice.github.io/buoys2cchaps/buoys2cchaps.html

AGCD tmax Vignette