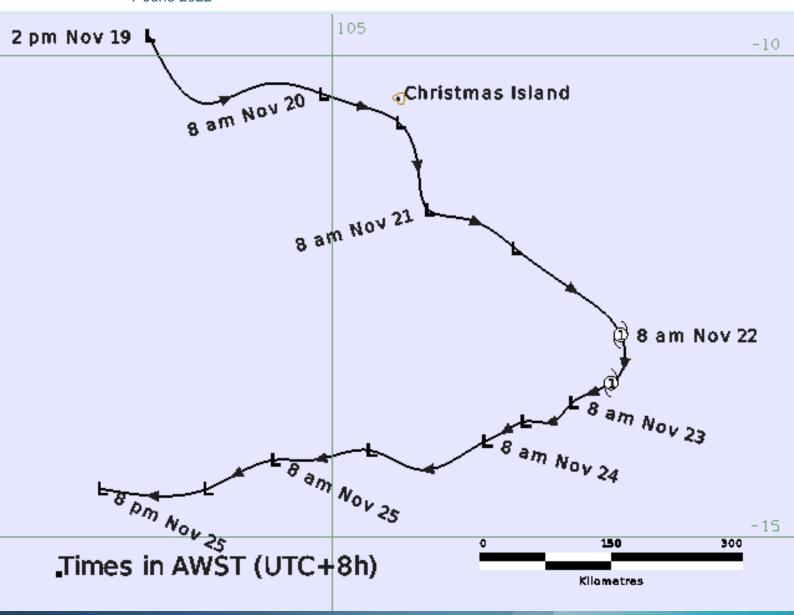


Tropical Cyclone Paddy

17 November 2021 – 25 November 2021

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Table of Contents

1	Sumr	mary	1
	FIGU	RE 1 a: Best track of Tropical Cyclone <i>Paddy</i> 19 November 2021 – 25 Nove 2021 (times in AWST, UTC+8)	
	FIGU	RE 1 b: Best track of Tropical Cyclone <i>Paddy</i> in Indian Ocean 21 Novembe – 25 November 2021 (times in AWST, UTC+8)	r 2021
	FIGU	RE 2: MSLP Analysis; 12 UTC 17- 22 November 2021	
	FIGU	RE 3: Bureau of Meteorology MJO monitoring 1 October 2021 to 31 Decem 2022	
	FIGU	RE 4: ASCAT-B 0153UTC 22 November 2021 – peak wind barb 40kn	
2	Mete	orological Description	7
	2.1	Intensity analysis	7
	FIGU	RE 5: Sea Surface Temperature analysis courtesy of National Oceanic and Atmospheric Administration (NOAA) 20 and 22 November 2021	
	FIGU	9 IRE 6: Cooperative Institute for Meteorological Satellite Studies (CIMSS) Will Shear analyses 0000UTC 22 November 2021	
		9	
	FIGU	RE 7: Advanced Scaterometry (ASCAT); Left ASCAT-C at 1358UTC 21 November, Right: ASCAT-B at 1446UTC 21 November	10
	FIGU	RE 8: Left: HIMAWARI-8 Visible Satellite Imagery 0000UTC 22 November,	Right:
		SSMIS 89GHZ Microwave Imagery 2119UTC 21 November	
		RE 9: ASCAT-C 0245UTC 22 November – peak wind barb 35kn	
	FIGU	RE 10: ASCAT-B 1405UTC 23 November – peak wind barb 45kn, gales resto southern quadrants.	
	FIGU	RE 11: Radiometer imagery; Left: SMOS 2316UTC 22 November, Right:	12
		AMSR2rss 0627UTC 23 November	13
		RE 12: Intensity estimates, from multiple sources.	
		RE 13: ASCAT-C 0204UTC 24 November – peak wind barb 25kn	
	2.2	Structure	
	FIGU	RE 14: SMAP 2251UTC 21 November – gales in all quadrants, though note moderate centre position uncertainty	; 17
	2.3	Motion	
3		ct	
4	•	ervations	
4			
	4.1 4.2	WindLowest Mean Seal Level (MSL) Pressure	
	4.2	Rainfall	
		RE 15: Daily Weather and Rainfall Observations for Christmass Island Nove	
		2021	
	44	High waves and storm tide	20

	TABLE 1. Best track summary for Tropical Cyclone <i>Paddy</i> 19 November 2021	to 25
	November 2021	21
5	Forecast Performance	22
	FIGURE 16 a: Position accuracy figures for Tropical Cyclone <i>Paddy</i>	23
	FIGURE 16 b: Intensity accuracy figures for Tropical Cyclone <i>Paddy</i>	23

1 Summary

Tropical Cyclone *Paddy* was the first tropical cyclone of the 2021/22 tropical cyclone season. *Paddy* maintained tropical cyclone intensity in the Indian Ocean for 18 hours before weakening (Figure 1).

The system originated as a tropical low, west of Christmas Island, overnight on 17 November and remained slow moving for the next few days, without developing significantly (Figure 2). The low subsequently intensified, reaching tropical cyclone intensity on the morning of 22 November. A moderately strong pulse of the Madden-Julian Oscillation (MJO), located over the Maritime Continent was a significant contributing factor to the favourable environmental conditions leading to the formation of *Paddy* (Figure 3). *Paddy* peaked as a category 1 system, confirmed by scatterometry observations including ASCAT imagery indicating intensity of 40kn (Figure 4).

Paddy then moved in a southerly then southwesterly direction, quickly weakening below tropical cyclone intensity early on the morning of 23 November. Gales persisted on the southern side of the system during 23 November and overnight as the system weakened further and moved to the west under the influence of the sub-tropical ridge to the south. The remnant low continued to move to the west and weaken during the following days.

The most significant impact attributed to *Paddy* was its contribution to a period of heavy rain at Christmas Island.

FIGURE 1 a: Best track of Tropical Cyclone *Paddy* 19 November 2021 – 25 November 2021 (times in AWST, UTC+8).

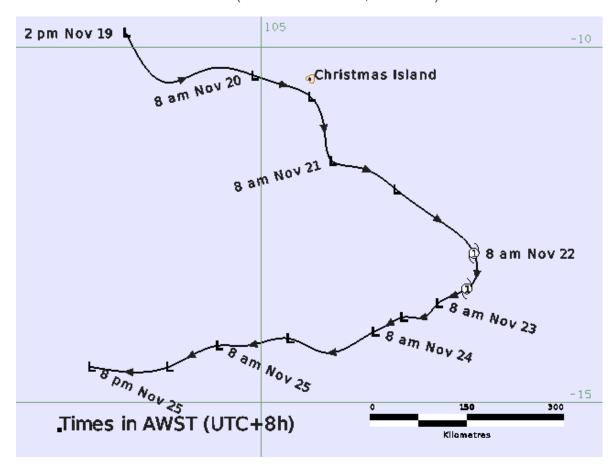


FIGURE 1 b: Best track of Tropical Cyclone *Paddy* in Indian Ocean 21 November 2021 – 25 November 2021 (times in AWST, UTC+8).

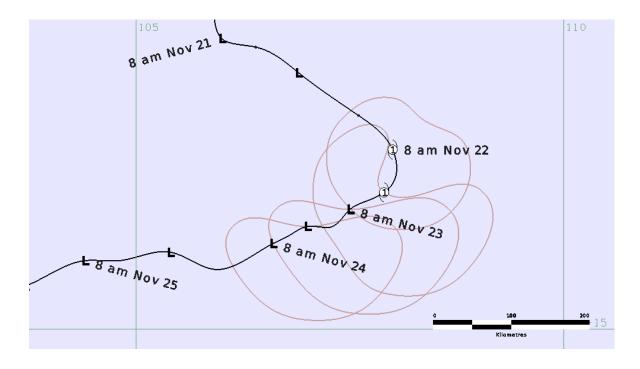


FIGURE 2: MSLP Analysis; 12 UTC 17- 22 November 2021.

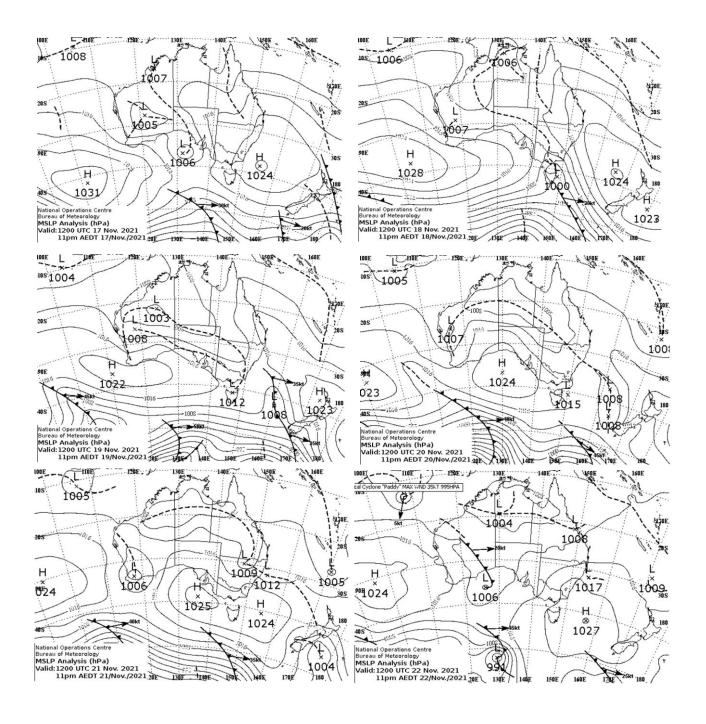


FIGURE 3: Bureau of Meteorology MJO monitoring 1 October 2021 to 31 December 2022.

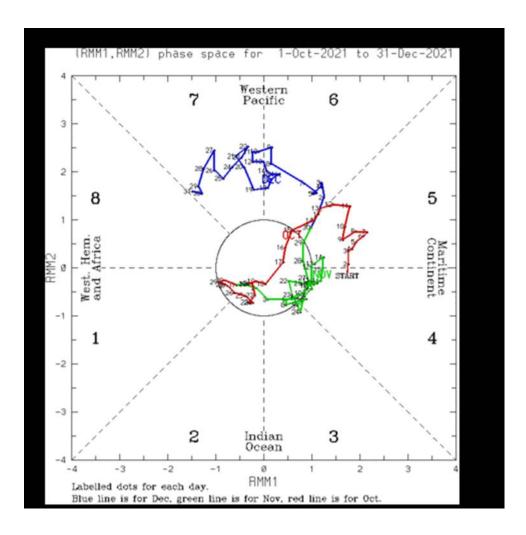
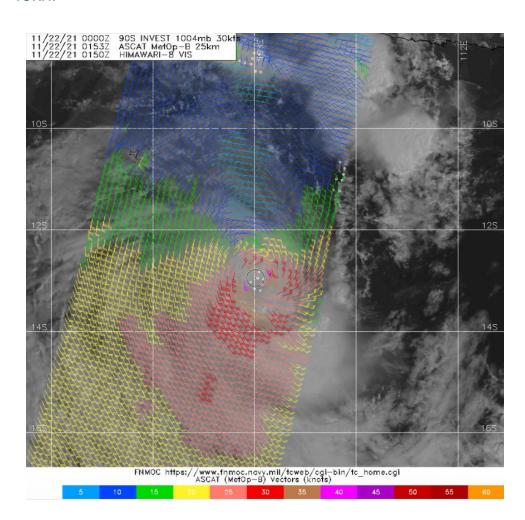


FIGURE 4: ASCAT-B 0153UTC 22 November 2021 – peak wind barb 40kn.



2 Meteorological Description

2.1 Intensity analysis

A low formed along a trough in the Indian Ocean, to the west of Christmas Island overnight on 17 November. Deep convection increased sufficiently near the centre to indicate an initial Dvorak intensity T1.0 by the evening of 20 November.

Under the influence of a ridge to the east and an upper trough to the south, the system was steered to the southeast, with the upper trough providing good poleward outflow though increasing shear as the system moved further south. Other environmental conditions, such as warm ocean temperatures and low shear (Figure 5 & 6), assisted development during 20 to 22 November.

Overnight of 20 November and into the morning of 21 November, convection near the centre of the system increased and consolidated, resulting in a steady increase in Dvorak analysis to T2.5 by the evening of 21 November. Advanced Scatterometer (ASCAT) on the evening of 21 November highlighted a centre that was still somewhat elongated though near gales were present on the southern side. ASCAT-C at 1358UTC showed peak winds of 35kn to the south, while ASCAT-B at 1446UTC showed a peak of 30kn (Figure 7).

Tropical Cyclone intensity is estimated to have first been reached at 00UTC 22 November, based on improved satellite imagery and supported by earlier microwave imagery at 2119UTC (Figure 8) highlighting the curved banding around the centre. Advanced scatterometry (ASCAT) followed at 0153UTC (Figure 4) with intensity set at 40kn based on this imagery.

Several inputs contributed to the analysis of peak intensity of this short-lived system. Dvorak analyses at 0000, 0600, 1200 UTC on 22 November 2021 indicated a Current Intensity (CI) of 3.0, corresponding to winds of 35-45 kn. Scatterometry indicated a peak of 40kn at 0153UTC 22 November (Figure 4), later ASCAT-C imagery at 0245UTC while only capturing western quadrants indicated a peak wind of 35kn (Figure 9). The subjective Dvorak trend changed to Stationary (S) at 1200 UTC and W- from 1500 UTC on 22 November. At the same time, satellite imagery indicated a weakening signature with an increase in north westerly environmental shear. This evidence assisted in analysing a short-lived system with a peak intensity of 40kn while a tropical cyclone. *Paddy* reacted quickly to the increasing north westerly shear, and to dry air entrainment, weakening below tropical cyclone intensity very early on 23 November.

As the high to the south strengthened, the synoptic pressure gradient between this feature and Ex-Tropical Cyclone *Paddy* increased, increasing winds to the south of the system centre. Advanced scatterometer (ASCAT) confirmed intensity of 45kn during the afternoon and evening of 23 November (Figure 10). This imagery along with earlier Soil Moisture and Ocean Salinity (SMOS) and Advanced Microwave Scanning Radiometer (AMSR2) radiometer imagery (Figure 11) indicated gales persisting though not wrapping more than halfway around the centre and hence the system was no longer at tropical cyclone intensity. Given this, where imagery indicated sector gales, maximum winds were maintained higher than Dvorak estimates and even increased to 45kn at 0600 and 1200 UTC on 23 November.

This increase in maximum winds after *Paddy* reduced below tropical cyclone intensity is consistent with objective intensity estimates (Figure 12). These increased maximum wind estimates after subjective Dvorak weakened, noting that objective estimates only started during 22 November.

Weakening of sector gales occurred rapidly during 24 November with advanced scatterometry (ASCAT) indicating 25kn at 0204UTC (Figure 13).

FIGURE 5: Sea Surface Temperature analysis courtesy of National Oceanic and Atmospheric Administration (NOAA) 20 and 22 November 2021.

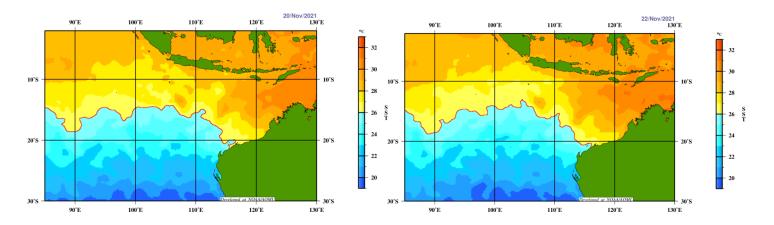


FIGURE 6: Cooperative Institute for Meteorological Satellite Studies (CIMSS) Wind Shear analyses 0000UTC 22 November 2021.

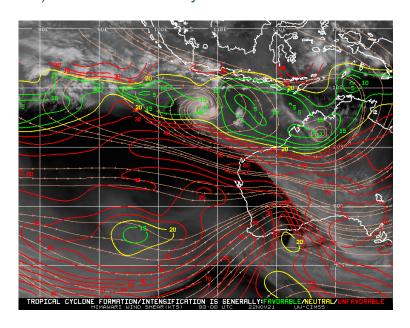
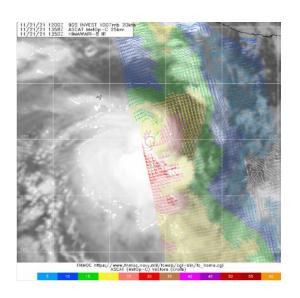


FIGURE 7: Advanced Scaterometry (ASCAT); Left ASCAT-C at 1358UTC 21 November, Right: ASCAT-B at 1446UTC 21 November.



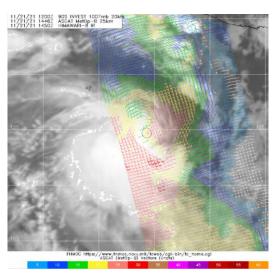
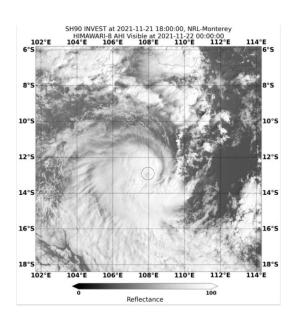


FIGURE 8: Left: HIMAWARI-8 Visible Satellite Imagery 0000UTC 22 November, Right: SSMIS 89GHZ Microwave Imagery 2119UTC 21 November.



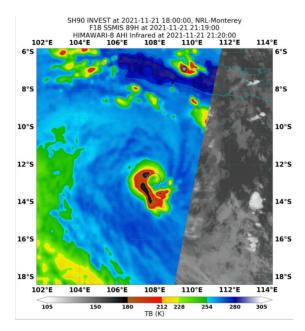


FIGURE 9: ASCAT-C 0245UTC 22 November – peak wind barb 35kn.

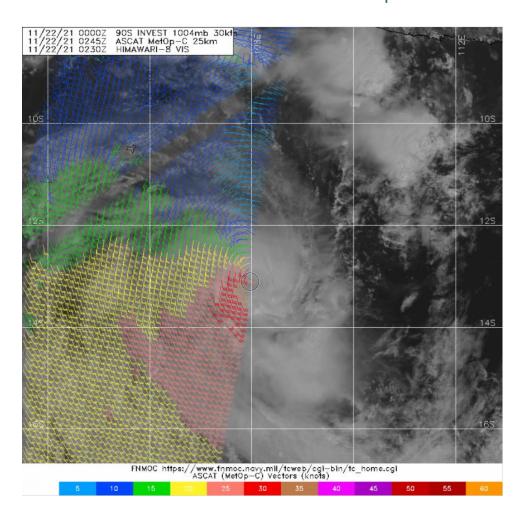


FIGURE 10: ASCAT-B 1405UTC 23 November – peak wind barb 45kn, gales restricted to southern quadrants.

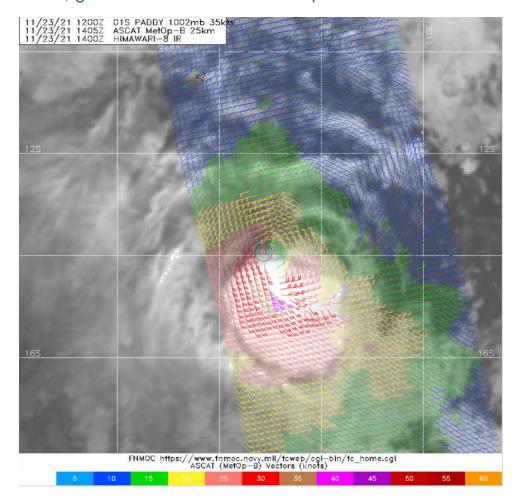


FIGURE 11: Radiometer imagery; Left: SMOS 2316UTC 22 November, Right: AMSR2rss 0627UTC 23 November.

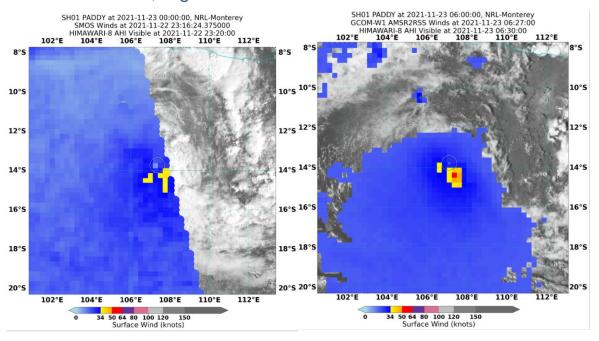


FIGURE 12: Intensity estimates, from multiple sources.

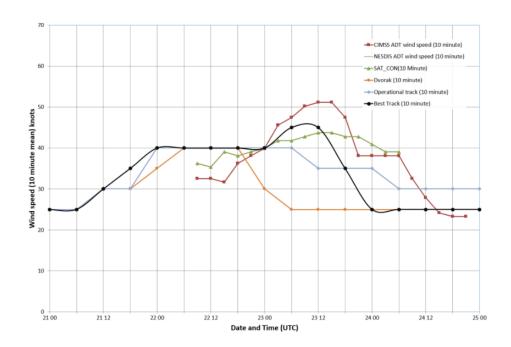
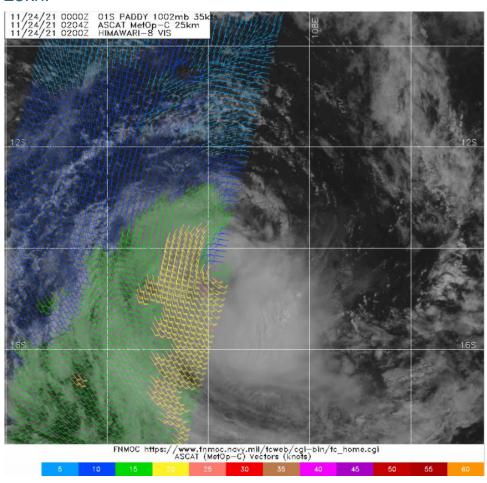


FIGURE 13: ASCAT-C 0204UTC 24 November – peak wind barb 25kn.



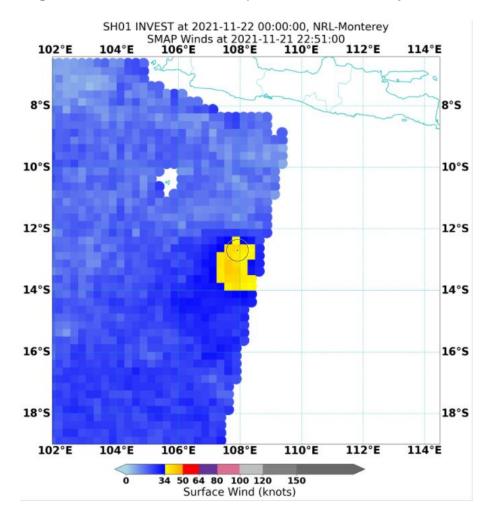
2.2 Structure

Generally, there was good coverage from scatterometry and radiometry to analyse the structure of the wind field. Quadrant gales were indicated by the Soil Moisture Active Passive (SMAP) sensor at 2251 UTC 21 November (Figure 13) and showed a larger gale radius to the south. With some indications of gales in the southwest quadrant in earlier ASCAT imagery (Figure 7), quadrant gales were analysed from 1800 UTC 21 November.

Again, the strongest winds with the largest radii were located to the south of the centre with subsequent ASCAT at 0153 UTC (Figure 4). This imagery significantly contributed to gale radii analysis and assessment of the radius of maximum winds.

As the influence of the sub-tropical ridge to the south increased, dry air and shear saw gales reduce in northern quadrants. By 0000 UTC on 23 November, gales were assessed as less than halfway around as indicated by radiometry (Figure 11). Sector gales persisted during 23 November before easing below gale force by 0000 UTC on 24 November.

FIGURE 14: SMAP 2251UTC 21 November – gales in all quadrants, though note moderate centre position uncertainty.



2.3 Motion

In the early stages of the system's life, the circulation moved slowly southeast, passing to the southwest of Christmas Island, steered by a high to the northeast and an upper trough to the southeast. After reaching tropical cyclone intensity, *Paddy* began moving with a more southerly motion as the upper trough moved further east and the sub-tropical ridge to the south strengthened. By 1200 UTC 22 November, with the ridge strengthening further, it dominated steering and the system began moving to the south southwest as it weakened.

3 Impact

Tropical Cyclone *Paddy* was an oceanic system with no direct impact to Christmas Island or the Western Australian mainland. It did however contribute to a period of heavy rainfall at Christmas Island as it passed by as a tropical low before reaching tropical cyclone intensity. 251.2mm of rainfall was recorded in the 5-day period to 9am on 22 November (Figure 15).

4 Observations

4.1 Wind

The highest measured winds were via advanced scatterometry (ASCAT) and indicated 40kn while a tropical cyclone and 45kn on the southern side after the system no longer had gales wrapping more than halfway around (Figure 4 and 10).

4.2 Lowest Mean Seal Level (MSL) Pressure

As an oceanic system well away from any observing stations, the lowest MSLP was not captured by instruments. Pressure values were estimated from the Knaff and Zehr pressure wind equation using the technique in (Courtney and Knaff, 2009).

4.3 Rainfall

Christmas Island: Heavy rain fell associated with the early stages of the low from 17-21 November. Figure 15 shows the daily rainfall total during November, highlighting a peak of 100.2mm on 17 November with further rain in the following days until 21 November.

FIGURE 15: Daily Weather and Rainfall Observations for Christmas Island November 2021.

Christmas Island November 2021 Daily Weather Observations

		Temps	D-:	Fuer	C	Max wind gust 9 am							3	pm 3						
)ate	Day	Min Max	Rain	Evap	Sun	Dir	Spd	Time	Temp	RH	Cld	Dir	Spd	MSLP	Temp	RH	Cld	Dir	Spd	MSL
		°C °C	mm	mm	hours		km/h	local	°C	%	8 th		km/h	hPa	°C	%	8 th		km/h	hi
- 1	Мо	21.5 26.5	0			SE	33	10:40	23.9	81	8	SE	- 11	1013.9	25.5	75	8	SE	17	1010
2	Tu	22.1 26.6	3.2			SE	35	12:33	24.7	80	8	SSE	15	1013.5	24.1	81	8	SE	17	1010
3	We	22.8 27.6	1.0			SE	31	23:50	26.4	78	8	SE	17	1012.6	25.8	85	8	SE	17	1009
4	Th	23.7 25.1	6.0			SE	39	03:57	23.7	95	8	SE	19	1012.4	23.9	95	8	SE	17	1009
5	Fr	22.8 26.7	47.0			SE	41	02:33	23.9	99	8	SE	20	1011.0	25.1	93	7	SE	15	1008
6	Sa	23.1 25.4	55.8			ESE	44	05:59	24.8	99	8	ESE	20	1008.9	23.6	98	7	SE	13	1006
7	Su	23.0 26.9	49.2			SE	41	01:00	24.8	99	7	Е	15	1008.2	24.9	97	8	NNE	11	1006
8	Мо	23.5 27.4	7.4			NNW	35	11:55	26.3	92	8	ENE	9	1008.5	25.5	92	8	W	6	1006
9	Tu	22.6 26.6	51.6			N	41	07:52	22.9	98	8	NW	15	1009.9	26.1	88	7	WNW	17	1007
10	We	22.9 26.8	38.2			N	31	05:45	24.9	98	8	N	13	1010.9	26.0	93	8	N	9	1007
11	Th	22.2 27.6							26.6	87	8	NW	11	1010.2	25.2	93	8	SW	6	1007
12	Fr	22.3 27.5				WNW	17	05:55	26.6	86	8	SSE	7	1011.8	26.6	87	6	SSE	9	1008
13	Sa	22.8 27.6	37.0			SE	26	14:36	26.6	85	5	SE	9	1011.7	23.7	94	8	SSE	9	1008
14	Su	23.2 27.7	0.6			SE	22	13:10	25.9	81	3	Е	15	1012.1	26.2	77		Е	13	1007
15	Мо	24.0 26.9	0			SE	26	08:36	25.1	90	8	SE	17	1010.4	24.7	89	8	SE	13	1007
16	Tu	23.1 27.2	0.4			ESE	28	19:37	26.4	87	8	ESE	9	1009.8	25.3	90	7	SE	7	1007
17	We	22.8 26.7	100.2			ESE	26	00:13	23.6	99	7	(Calm	1010.5	24.2	97	8	SSW	4	1007
18	Th	23.1 25.4	52.4			NNE	35	12:14	24.1	99	7	NE	13	1009.1	23.6	98	8	NNE	17	1005
19	Fr	22.3 26.6	24.0			NNE	43	09:29	23.9	99	8	NE	15	1008.1	25.7	93	8	NNE	17	1005
20	Sa	23.0 24.5	43.6			NW	31	22:50	24.0	99	7	ESE	- 11	1007.2	23.8	98	7	NE	15	1004
21	Su	23.0 26.6	31.0			SSW	52	12:35	23.9	98	8	wsw	13	1006.8	25.3	88	6	S	22	1003
22	Мо	23.5 26.5	3.2			SSW	37	00:53	25.7	91	8	SW	13	1009.1	24.4	96	7	SW	11	1006
23	Tu	23.3 28.1	4.0			SW	24	00:27	25.3	92	4	SW	- 11	1009.8	27.3	80	8	W	9	1007
24	We	22.6 29.3	0.2			SW	26	08:03	26.4	80	2	SW	11	1009.8	26.6	77	8	W	11	1007
25	Th	22.2 29.3	0			NNW	26	10:59	27.1	80	4	NE	7	1009.8	27.8	78	5	NE	9	1007
26	Fr	23.0 27.9	0.2			ESE	24	13:46	25.7	92	8	SE	7	1010.9	23.8	97	8	SE	9	1008
27	Sa	21.7 29.0	7.6			wsw	24	11:26	27.1	79	4	SSE	6	1011.1	28.0	73	8	NNE	6	1008
28	Su	22.3 28.5							27.2	78	1	SE	9	1011.2	26.7	82	5	SE	13	1008
29	Мо	20.5 28.6	0			ESE	22	11:31	26.5	73	- 1	SSE	7	1010.2	27.0	77	8	SE	7	1007
30	Tu	22.5 28.3	0			Е	28	13:03	26.3	77	7	Е	19	1010.8	26.8	74	8	Е	17	1007
Statis	stics	for Nove	mber 2	2021																
N	lean	22.7 27.2							25.3	89	6		12	1010.3	25.4	87	7		12	1007
		20.5 24.5	0						22.9	73	1			1006.8	23.6	73	5	SSW		1003
		24.0 29.3	100.2			SSW	52		27.2	99	8	#		1013.9	28.0	98	8	S		1010
	Total		563.8																	

4.4 High waves and storm tide

There were no significant waves or storm tide observed with Tropical Cyclone Paddy.

TABLE 1. Best track summary for Tropical Cyclone *Paddy* 19 November 2021 to 25 November 2021.

Refer to the Australian Tropical Cyclone database for complete listing of parameters and track from 19 November to 25 November. Note: UTC is AWST - 8 hours.

*not at tropical cyclone intensity. **sub-tropical from 00 UTC 2 January.

Year	Month	Day	Hour	Pos. Lat.	Pos. Long.	Pos.	Max Wind	Max	Cen.	Rad. of gales	Rad. of storm	RMW
			UTC	S	E	Acc.	10min	gust	Press.	(NE/SE/	(NE/SE/	n mi
				J	_	nm	kn	kn	hPa	SW/NW)	SW/NW)	
2021	11	19	0600	-9.8	103.1	20	20	45	1006	0/0/0/0	0/0/0/0	_
2021	11	19	1200	-10.5	103.7	30	20	45	1006	0/0/0/0	0/0/0/0	-
2021	11	19	1800	-10.3	104.3	40	20	45	1005	0/0/0/0	0/0/0/0	-
2021	11	20	0000	-10.4	104.9	25	20	45	1005	0/0/0/0	0/0/0/0	-
2021	11	20	0600	-10.5	105.2	25	20	45	1005	0/0/0/0	0/0/0/0	-
2021	11	20	1200	-10.7	105.7	30	20	45	1005	0/0/0/0	0/0/0/0	-
2021	11	20	1800	-11.2	105.9	15	25	45	1003	0/0/0/0	0/0/0/0	-
2021	11	21	0000	-11.6	106	15	25	45	1003	0/0/0/0	0/0/0/0	-
2021	11	21	0600	-11.7	106.4	20	25	45	1003	0/0/0/0	0/0/0/0	-
2021	11	21	1200	-12	106.9	25	30	45	1002	0/0/0/0	0/0/0/0	-
2021	11	21	1800	-12.5	107.6	30	35*	50	999	0/0/50/0	0/0/0/0	-
2021	11	22	0000	-12.9	108	30	40	55	997	30/60/50/40	0/0/0/0	20
2021	11	22	0600	-13.3	108	30	40	55	997	30/70/50/40	0/0/0/0	25
2021	11	22	1200	-13.4	107.9	15	40	55	995	0/80/50/50	0/0/0/0	30
2021	11	22	1800	-13.5	107.7	15	40	55	994	0/80/70/50	0/0/0/0	30
2021	11	23	0000	-13.6	107.5	30	40*	55	996	0/80/60/0	0/0/0/0	-
2021	11	23	0600	-13.8	107.3	20	45*	65	993	0/70/50/0	0/0/0/0	-
2021	11	23	1200	-13.8	107	25	45*	65	992	0/70/60/0	0/0/0/0	-
2021	11	23	1800	-13.9	106.8	25	35*	50	998	0/60/60/0	0/0/0/0	-
2021	11	24	0000	-14	106.6	20	25	45	1004	0/0/0/0	0/0/0/0	-

5 Forecast Performance

Official tropical cyclone forecasts were issued from 22-24 November. Ocean wind warnings for a tropical cyclone were issued in the Indian Ocean for this period. No tropical cyclone advices were issued for *Paddy;* however heavy rainfall during the development of the initial tropical low was included on the forecast for Christmas Island.

The accuracy figures for Tropical Cyclone *Paddy* below and in Figure 16 show that the forecast position was slightly above the five-year average for the 0-48 hour forecast range.

The intensity forecasts had similar errors compared to the five-year average for the first 12 hours, though performed better than the average beyond this. These were based on official forecast tracks issued from 0600 UTC 22 November to 1800 UTC 23 November.

There are a limited number of forecasts for this short-lived system, with a sample size of less than 10 beyond lead time +36 hrs. Drawing conclusions about the forecast performance when the sample size is small has limited value.

Lead Time (hr)	00	06	12	18	24	36	48	72
Position Absolute error (km)	31	70	87	91	119	126	167	169
Intensity Absolute error (kn)	0.5	3.8	3.7	2.5	3.6	3.1	5.0	5.0
Sample Size	15	14	13	11	11	8	8	6

FIGURE 16 a: Position accuracy figures for Tropical Cyclone Paddy.

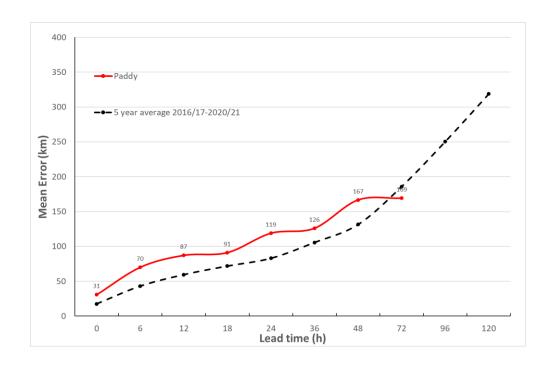


FIGURE 16 b: Intensity accuracy figures for Tropical Cyclone Paddy.

