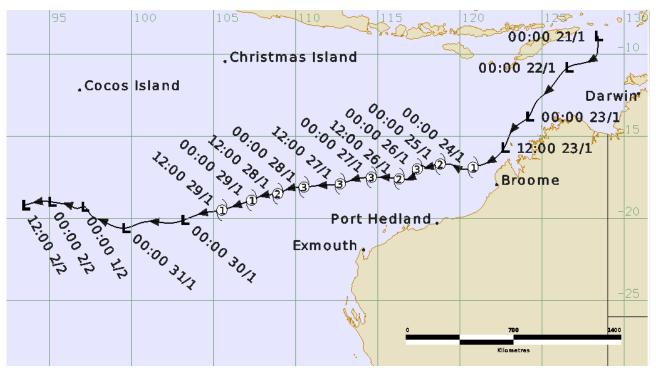


Severe Tropical Cyclone Riley

21 January - 2 February 2019

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Revision history

Date	Version	Author	Description
28/04/2023	1.0	Joe Courtney	Final draft ready

Review status

Date	Version	Reviewer	Description
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Cover image: Track of Severe Tropical Cyclone Riley. Times in UTC.

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1. Summary

Severe Tropical Cyclone Riley moved over waters off north-west Australia and did not directly impact the Australian coastline.

A weak tropical low was identified on 21 January in the Timor Sea moving to the south-west. The low gradually strengthened off the Kimberley coast, reaching tropical cyclone intensity on 24 January when it was located about 180 kilometres north-west of Broome.

Riley then moved on a general west south-west track roughly parallel to the Pilbara coast. Riley battled against ongoing easterly vertical wind shear but benefited from increased monsoonal inflow. This allowed it to strengthen into a category 2 tropical cyclone on 25 January then briefly category 3 intensity on 26 January before weakening. Riley re-intensified to category 3 intensity on 27 January and peaked that day when it was north of Exmouth.

Riley weakened from 28 January as it became disconnected from the moist monsoon flow and also moved over cooler waters. It weakened into a category 1 tropical cyclone on 29 January well to the north-west of Exmouth and then below tropical cyclone intensity on 30 January.

Although Severe Tropical Cyclone Riley did not directly impact the Australian coast, operations of the oil and gas industry off the north-west Australian coast were affected as the cyclone passed by. Tropical Cyclone Advices were issued for the north-west Kimberley coast between Kuri Bay and Beagle Bay and then for the Pilbara coast between Whim Creek and Exmouth for potential gales should the cyclone have tracked closer to the coast than expected.

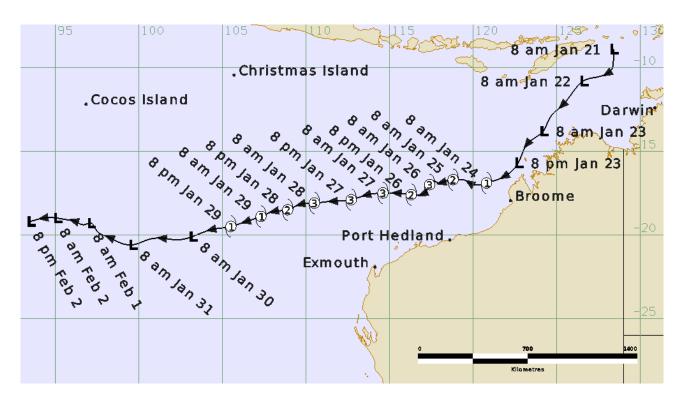


Figure 1a. Best track of Severe Tropical Cyclone Riley (times in AWST, UTC +8).

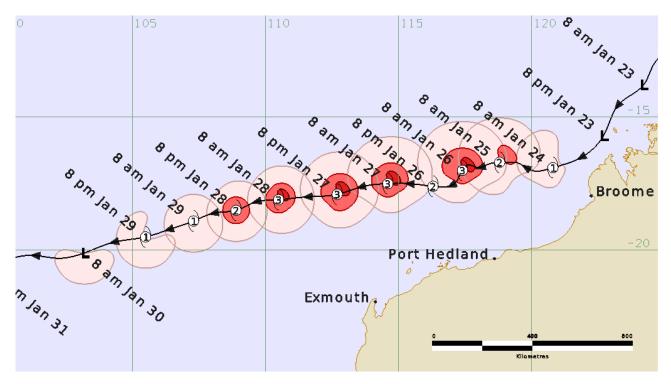


Figure 1b. Detailed best track of Severe Tropical Cyclone Riley showing wind radii (gale - pink, storm - red and hurricane force – dark red) (times in AWST, UTC +8).

Table 1. Best track summary for Severe Tropical Cyclone Riley, 21 January - 2 February 2019. UTC=AWST-8h.* Not at tropical cyclone intensity as gales less than halfway around centre.

Year	Month	Day	Hour	Pos.	Pos.	Pos.	Max Wind	Max	Cent.	Rad. of gales	Rad. of storm	RMW
			UTC	Lat.	Long.	Acc.	10min	gust	Press.	(NE/SE/	(NE/SE/	nm
				S	E	nm	kn	kn	hPa	SW/NW)	SW/NW)	
2019	1	21	0000	8.9	128.4	50	10	30	1006	0/0/0/0	0/0/0/0	-
2019	1	21	0600	9.6	128.4	60	10	30	1004	0/0/0/0	0/0/0/0	-
2019	1	21	1200	10.1	128.3	60	10	35	1004	0/0/0/0	0/0/0/0	-
2019	1	21	1800	10.5	127.7	60	15	35	1004	0/0/0/0	0/0/0/0	-
2019	1	22	0000	10.8	126.6	60	15	45	1004	0/0/0/0	0/0/0/0	-
2019	1	22	0600	11.3	126.1	60	15	45	1000	0/0/0/0	0/0/0/0	-
2019	1	22	1200	12.3	125.3	50	15	45	1000	0/0/0/0	0/0/0/0	-
2019	1	22	1800	13.0	124.6	40	20	45	998	0/0/0/0	0/0/0/0	-
2019	1	23	0000	13.8	124.2	30	20	45	998	0/0/0/0	0/0/0/0	-
2019	1	23	0600	14.5	123.3	30	20	45	998	0/0/0/0	0/0/0/0	-
2019	1	23	1200	15.7	122.7	25	25	45	996	0/0/0/0	0/0/0/0	-
2019	1	23	1800	16.6	121.7	20	30	45	995	0/0/0/0	0/0/0/0	-
2019	1	24	0000	16.9	120.8	15	40	55	992	20/30/50/90	0/0/0/0	20
2019	1	24	0600	17.0	120.0	20	45	65	990	50/40/50/90	0/0/0/0	20
2019	1	24	1200	16.7	119.4	20	45	65	990	70/50/60/90	0/0/0/0	20
2019	1	24	1800	16.7	119.1	20	50	70	985	90/50/70/90	30/0/0/0	20
2019	1	25	0000	16.7	118.8	15	50	70	982	100/50/80/100	40/0/0/0	20
2019	1	25	0600	16.8	118.3	20	50	70	982	100/60/80/100	40/0/0/0	25
2019	1	25	1200	16.9	118.0	20	50	70	982	100/70/70/110	40/0/0/0	25
2019	1	25	1800	16.8	117.6	20	55	70	979	110/70/80/110	40/0/0/30	25
2019	1	26	0000	17.0	117.4	20	65	90	973	110/60/80/110	50/30/30/50	25
2019	1	26	0600	17.5	117.1	20	60	75	978	110/50/80/110	50/40/0/50	25
2019	1	26	1200	17.6	116.3	20	55	70	980	110/50/60/110	50/0/0/40	25
2019	1	26	1800	17.5	115.4	15	60	75	979	110/60/60/100	50/0/0/40	25
2019	1	27	0000	17.5	114.6	20	65	90	975	110/70/60/100	50/30/30/40	20
2019	1	27	0600	17.6	113.7	20	70	100	971	100/70/60/90	50/30/30/40	20
2019	1	27	1200	17.9	112.7	20	65	90	974	100/80/70/90	50/40/30/40	20
2019	1	27	1800	18.0	111.5	20	70	100	972	90/80/70/80	50/40/30/30	20
2019	1	28	0000	18.1	110.5	20	70	100	970	80/80/70/70	40/30/30/30	20
2019	1	28	0600	18.2	109.6	20	65	90	973	70/70/70/60	40/30/30/30	20
2019	1	28	1200	18.5	108.9	25	60	85	978	70/70/70/60	30/30/30/30	20
2019	1	28	1800	18.6	108.1	25	50	70	984	60/70/70/60	30/30/30/30	25
2019	1	29	0000	18.9	107.3	20	45	65	988	60/70/70/60	0/0/0/0	25
2019	1	29	0600	19.3	106.3	20	45	65	990	60/70/70/60	0/0/0/0	25
2019	1	29	1200	19.5	105.5	20	40	55	993	0/70/70/60	0/0/0/0	30
2019	1	29	1800	19.7	104.3	25	35	50	995	0/70/70/60	0/0/0/0	30
2019	1	30	0000	20.1	103.2	20	35*	50	995	0/70/70/0	0/0/0/0	-
2019	1	30	0600	20.3	102.2	20	35*	50	995	0/70/70/0	0/0/0/0	-
2019	1	30	1200	20.2	101.4	20	30	50	998	0/0/0/0	0/0/0/0	-
2019	1	30	1800	20.3	100.5	20	30	50	1000	0/0/0/0	0/0/0/0	-
2019	1	31	0000	20.6	99.6	20	30	45	1002	0/0/0/0	0/0/0/0	-
2019	1	31	0600	20.4	98.7	15	25	45	1002	0/0/0/0	0/0/0/0	-
2019	1	31	1200	20.1	98.1	20	25	45	1002	0/0/0/0	0/0/0/0	-
2019	1	31	1800	19.8	97.5	20	25	45	1002	0/0/0/0	0/0/0/0	-
2019	2	1	0000	19.3	97.1	15	25	45	1002	0/0/0/0	0/0/0/0	-
2019	2	1	0600	19.4	96.7	15	25	45	1002	0/0/0/0	0/0/0/0	-
2019	2	1	1200	19.2	96.2	20	20	45	1002	0/0/0/0	0/0/0/0	-
2019	2	1	1800	19.1	95.7	20	20	45	1002	0/0/0/0	0/0/0/0	-

2. Meteorological description

2.1 Intensity analysis

A comparison of the intensity estimates is shown in Figure 2.

A weak tropical low was identified on 21 January in the Timor Sea. The low remained weak during 22 and into 23 January as it tracked to the south-west roughly parallel to the coast. The environment was generally conducive for intensification having low vertical wind shear, high moisture and sea surface temperatures of 29-30°C.

Deep convection became more organised overnight on 23 into 24 January and by 00 UTC 24 January tropical cyclone intensity was estimated based upon the Dvorak CI estimate having reached 3.0. Well defined curved bands were evident on microwave imagery (2158 UTC SSMIS) and on visible imagery for example at 00UTC 24 January shown in Figure 3. An OSCAT scatterometry pass at 0054UTC suggested gales were most extensive north-west of the centre.

Riley passed to the north of Rowley Shoals (about 350 kilometres to the west of Broome) which reported gale force winds for periods late on the 24 January and during 25 January.

Increasing easterly wind shear contributed to a shift in the deep convection primarily to the west of the centre during 24 January. However, an increase in the monsoonal inflow to the circulation enhanced the development late on 24 January. Riley strengthened into a category 2 tropical cyclone overnight from 24 to 25 January confirmed by 50 kn winds observed in the north-east quadrant on the ASCAT-B pass at 0103 UTC 25 January (shown in Figure 4), and ASCAT-A at 0135 UTC 25 January. The subsequent ASCAT-B at 1333 UTC 25 January indicated a similar picture with ongoing easterly shear.

Despite the ongoing easterly wind shear, deep convection subsequently extended into the north-east quadrant which was observed in microwave imagery. This strong convection has deflected the upper-level easterly flow effectively reducing the shear impacting the circulation. A SMAP pass at 2155 UTC 25 January shown in Figure 5 showed winds exceeding 65 kn in the north-east quadrant so hence Riley is estimated to have reached category 3 intensity at 0000 UTC 26 January.

However, the convective pattern appears to have been a brief diurnal peak as convection weakened during 26 January, and the intensity was reduced to 55 kn at 0600 26 January.

The environmental wind shear eased overnight on 26-27 January and once more deep convection extended into eastern quadrants. The SSMI microwave image in Figure 6 shows the development of an eye that was not evident on IR imagery. An eye emerged on visible imagery on 27 January as shown on the image at 06 UTC in Figure 7 and the intensity estimate increased to 70 kn.

A SMAP pass at 1040 UTC 27 January (not shown) indicated peak winds to 65 kn in the north-east quadrant. The satellite pattern continued to vary. Some weakening was evident before an eye redeveloped on IR imagery for a period from 13 to 15 UTC 27 January. The eye remained evident on microwave imagery as shown on the SSMIS 91 GHz image at 2025 UTC 27 January shown in Figure 8.

During 28 January the ragged eye on Visible and IR imagery weakened and deep convection contracted to the north-east quadrant under the influence of increasing wind shear and drier surrounding environment. Later in the day Riley moved over an area of sea surface temperatures of less than 26°C which also contributed to the weakening.

Riley weakened into a category 1 tropical cyclone over open waters in the Indian Ocean on 29 January and then below cyclone intensity on 30 January. Gales continued in southern quadrants until later that day.

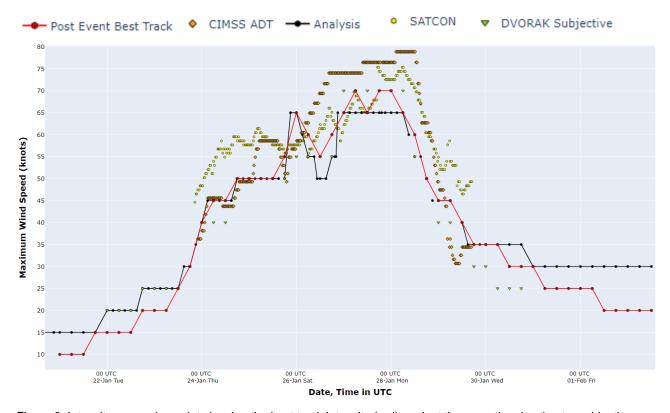


Figure 2. Intensity comparison plot showing the best track intensity (red) against the operational estimate, subjective Dvorak and objective estimates (SATCON and CIMSS ADT).

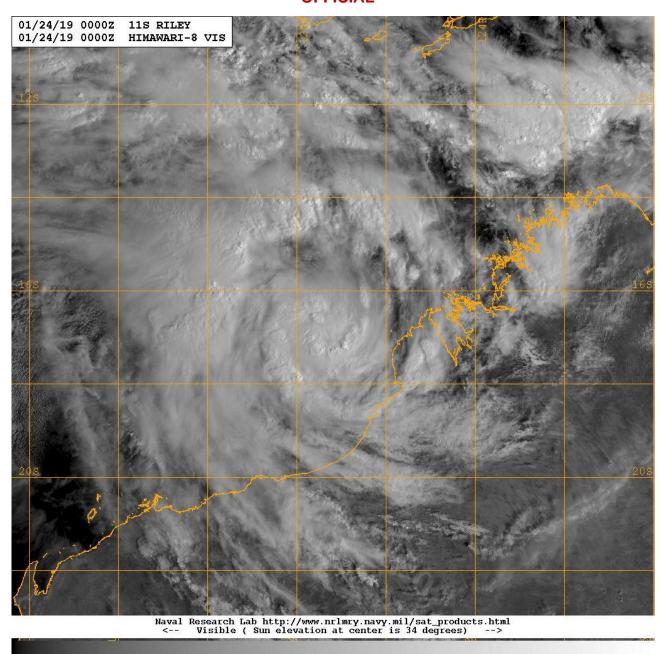


Figure 3. Visible image at 0000 UTC 24 January 2023 showing well defined curvature in deep convection indicative that tropical cyclone intensity had been attained. Image courtesy NRL: https://www.nrlmry.navy.mil/TC.html

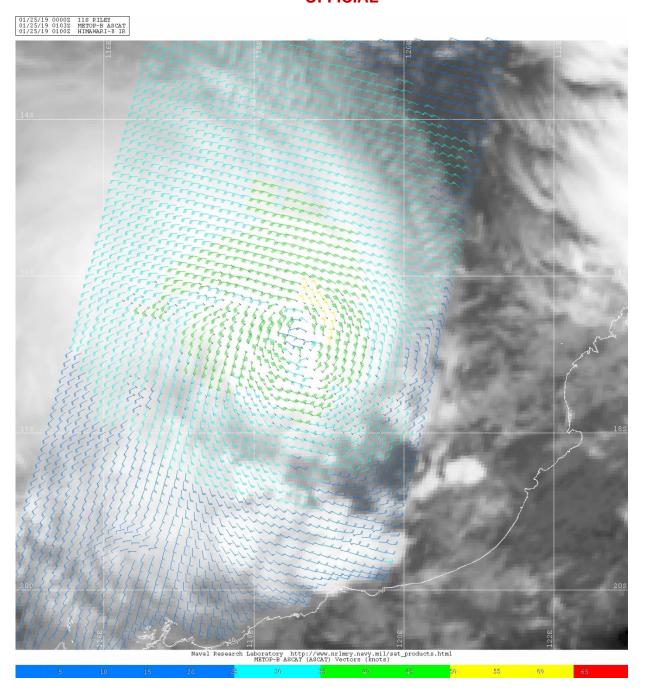


Figure 4. Advanced Scatterometer (ASCAT-B) wind distribution at 0103 UTC 25 January showing 50 kn winds (in yellow) in the north-east quadrant. Image courtesy NRL: https://www.nrlmry.navy.mil/TC.html

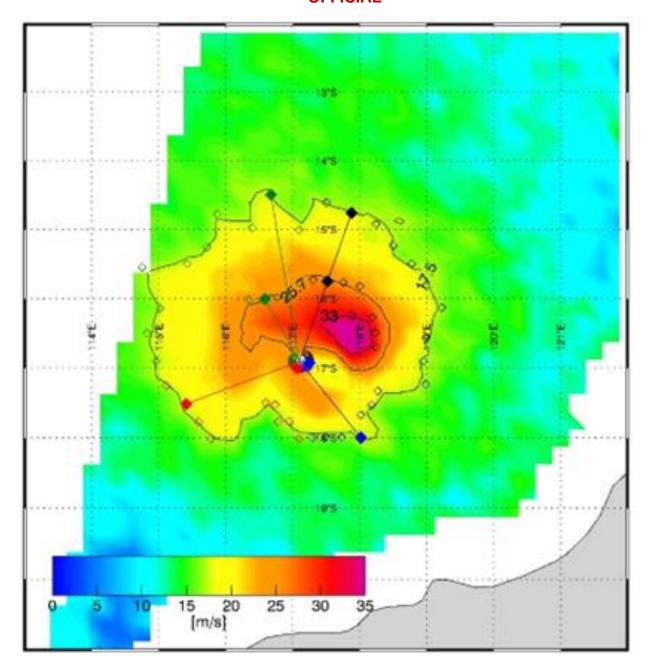


Figure 5. SMAP at 2155 UTC 25 January showing winds exceeding 65 kn north-east of the centre indicating that Riley had reached severe tropical cyclone intensity. Image courtesy REMSS: https://www.remss.com

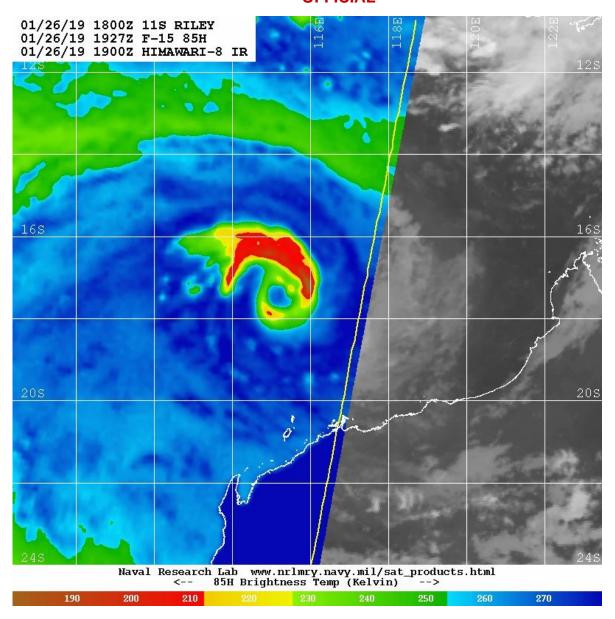


Figure 6. Special Sensor Microwave Imager (SSMI) microwave image at 1927 UTC 26 January, showing the development of an eye indicating intensification was occurring. Image courtesy NRL: https://www.nrlmry.navy.mil/TC.html

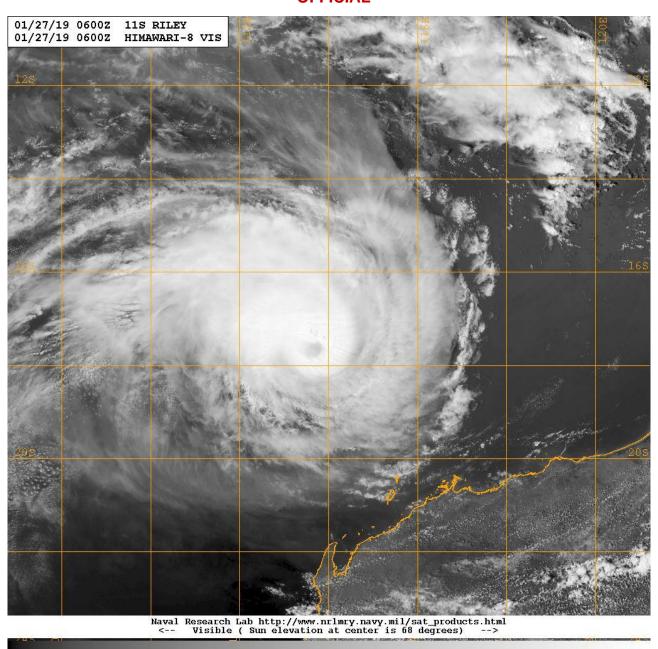


Figure 7. Visible image at 0600 UTC 27 January 2023 showing a distinct eye as Riley reached peak intensity. Image courtesy NRL: https://www.nrlmry.navy.mil/TC.html

OFFICIAL 01/27/19 1800Z 11S RILEY 01/27/19 2025Z F-16 91H 01/27/19 2000Z HIMAWARI-8 IR Naval Research Lab www.nrlmry.navy.mil/sat_products.html <-- 85H Brightness Temp (Kelvin) -->

Figure 8. Special Sensor Microwave Imager/Sounder (SSMIS) 91GHz microwave image at 2025 UTC 27 January, showing a well-defined eye. Image courtesy NRL: https://www.nrlmry.navy.mil/TC.html

190

200

210

250

2.1 Structure

Gales were initially most evident in western quadrants aligned with the strongest convection. A strengthening monsoon and enhanced convection north of the centre meant that the strongest winds occurred in the north-east quadrant during 25-27 January as shown in the ASCAT and SMAP wind distributions in Figures 4 and 5. The gale radius extended to 110 nm (204 km) in northern quadrants for much of this period. During the period that Riley was at category 3 intensity (26-28 January), it is estimated that hurricane-force winds were constrained to the northeast quadrant.

The circulation became more symmetric later on 27 January having a gale radius of 70-90 nm (130-167 km) as the monsoon inflow weakened and the circulation increased its westerly motion to about 10 km (18 km/h). As the circulation weakened gales eased in northern quadrants late on 29 January. Gales persisted in southern quadrants on 30 January assisted by synoptic east southeasterly winds associated with the ridge to the south.

The radius to maximum winds (RMW) generally ranged from 20-25 nm (37-46 km).

2.2 Motion

The mid-level ridge south of the track was the dominant steering mechanism throughout Riley's life cycle. During formation stages the ridge was located over south-eastern Australia steering the circulation to the south-west from the Timor Sea to parallel the Kimberley coast. From 24 January when Riley was named, the steering ridge strengthened to the south taking Riley on a west southwest track.

3. Impact

Although Severe Tropical Cyclone Riley did not directly impact the Australian coast, operations of the oil and gas industry off the north-west Australian coast were affected as the cyclone passed by.

4. Observations

4.1 Winds

Rowley Shoals registered a peak ten-minute mean wind of 42 kn (78 km/h) at 0021 UTC 25 January and a peak gust of 51 kn (94 km/h) at 0005 UTC 25 January. The site reported gale-force winds for periods starting from 0940 UTC 24 January to 1236 UTC 25 January.

5. Forecast performance

Tropical Cyclone products were initiated from 07 UTC 22 January until 01 UTC 30 January.

Tropical Cyclone Advices were issued initially for the north-west Kimberley coast from Kuri Bay to Beagle Bay starting from 1500 AWS 22 January, and then progressively along the coast until finally being cancelled for the Pilbara coast between Whim Creek to Exmouth at noon 25 January. The advices were for potential gales should the cyclone have tracked closer to the coast than expected, however Riley remained sufficiently offshore for gales not to reach the coast.

The accuracy figures for Severe Tropical Cyclone Riley are below and also shown in Figures 9 a and 9 b. These show that the forecast position was similar or slightly better than the five-year average at all time steps. The intensity forecasts were better than the five-year average beyond 48 hours but slightly worse before then. The forecasts issued during the developing stages correctly identified the intensification through to 27 January and then weakening from 28 January but variations in timing accounted for the errors. This is reflected in Figure 10 that shows intensity forecasts issued between 22-25 January plotted against the best track intensity. The initial intensification was well forecast to the actual peak of 70 kn. However, forecasts generally indicated weakening would start on 27 January when in fact Riley remained strong and commenced weakening on 28 January.

Table 2. Verification statistics for Severe Tropical Cyclone Riley.

	0	6	12	18	24	36	48	72	96	120
Position Absolute error (km)	18	37	51	64	73	89	101	122	130	144
Intensity Absolute error (kn)	3.1	4.6	6.4	6.9	7.7	9.4	9.8	10.2	8.7	7.5
Sample Size	32	32	32	32	32	32	32	32	30	26

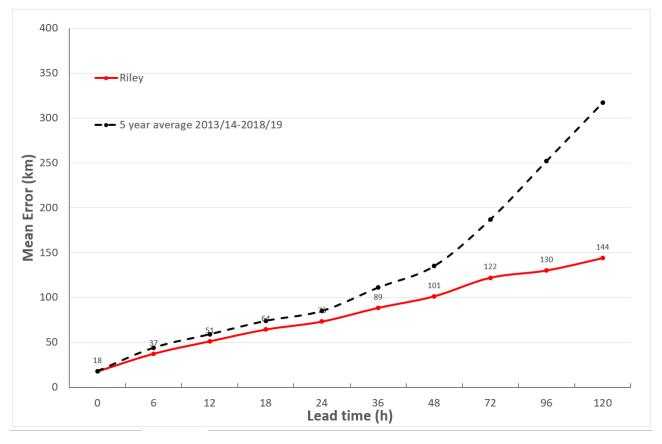


Figure 9 a. Position accuracy figures for Severe Tropical Cyclone Riley.

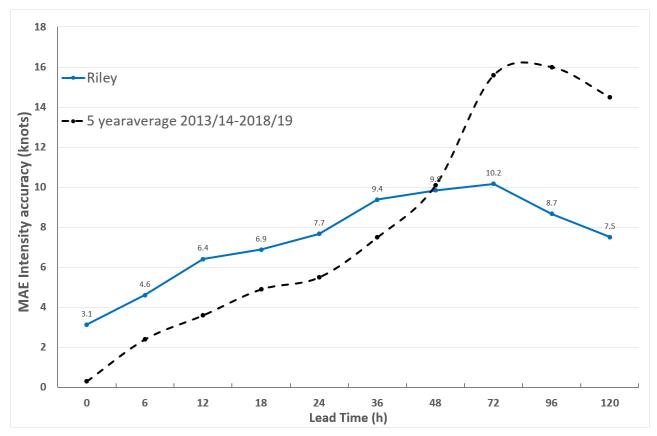


Figure 9 b. Intensity accuracy figures for Severe Tropical Cyclone Riley.

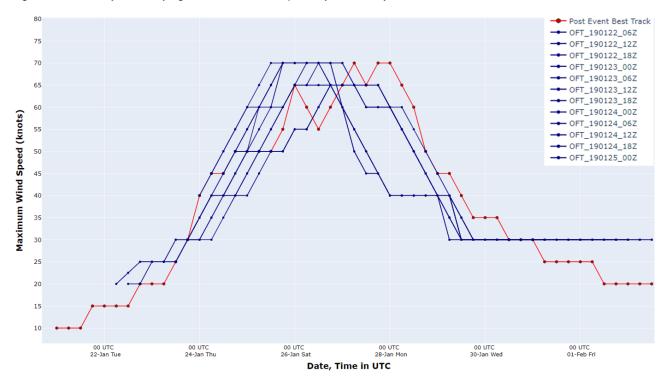


Figure 10. Intensity forecasts (blue) 06 UTC 22 January to 00 UTC 25 January against the best track intensity (red).

1. Appendix: List of abbreviations

Abbreviation	Term
ADT	Advanced Dvorak Technique
ACST	Australian Central Standard Time
AEST	Australian Eastern Standard Time
AMSR2	Advanced Microwave Scanning Radiometer
ASCAT	Advanced Scatterometer
ATMS	Advanced Technology Microwave Sounder
AWS	automatic weather station
AWST	Australian Western Standard Time
°C	Celsius
CI	Current intensity
CIMSS	Cooperative Institute for Meteorological Satellite Studies (USA)
CIRA	Cooperative Institute for Research in the Atmosphere (USA)
EIR	Enhanced InfraRed
ERC	eyewall replacement cycle
FNMOC	Fleet Numerical Meteorology and Oceanography Centre (USA)
FT	Final T-number
GCOM	Global Change Observation Mission
GHz	Gigahertz
GMI	Global Precipitation Measurement Microwave Imager
h	hour
hPa	hectopascal
HSCAT	Hai Yang 2 Scatterometer (HY-2B, HY-2C)
km	kilometres
km/h	kilometres per hour
kn	knot
LLCC	LLCC
MET	Model Expected T-number

METOP	Meteorological Operational Satellite
MJO	Madden-Julian Oscillation
mm	millimetres
MSLP	mean sea level pressure
nm	nautical mile
NOAA	National Oceanic and Atmospheric Administration
NRL	Navy Research Lab (USA)
PAT	Pattern T-number
RH	relative humidity
RMW	radius of maximum winds
RSMC	Regional Specialised Meteorological Centre
SAR	Synthetic Aperture Radar
SATCON	satellite Consensus
SMAP	Soil Moisture Active Passive
SMOS	Soil Moisture and Ocean Salinity
SSMIS	Special Sensor Microwave Imager/Sounder
TC	Tropical Cyclone
TCWC	Tropical Cyclone Warning Centre
UTC	Universal Time Co-ordinated