

Severe Tropical Cyclone Veronica

18 - 28 March 2019

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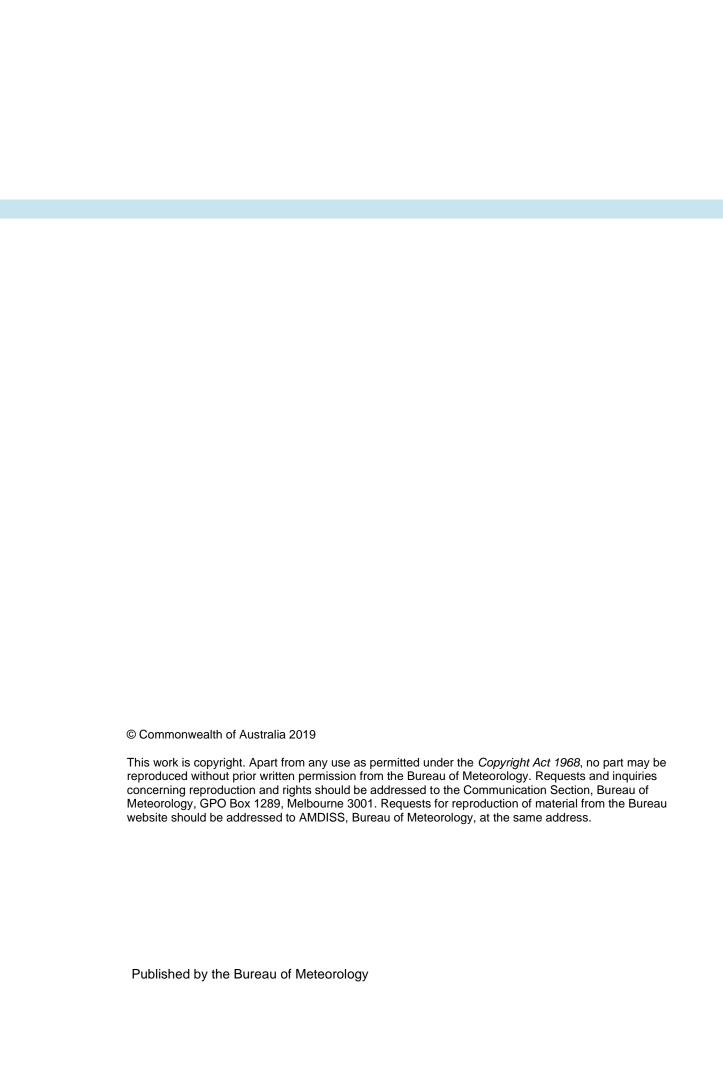


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Summary

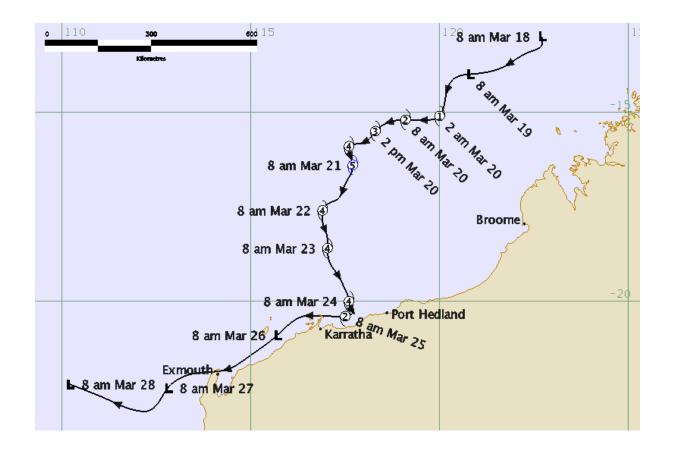
Severe Tropical Cyclone Veronica reached category five intensity north of Western Australia. Although it did not actually cross the Pilbara coast it caused significant disruption to the mining and offshore oil and gas industry and damage to infrastructure. The total losses are estimated at about \$2 billion making Veronica one of Western Australia's costliest weather events.

A low formed in the waters to the north of Western Australia, about 550 kilometres (km) north of Broome early on 18 March. The low moved southwest and intensified in favourable conditions, attaining tropical cyclone intensity at 1800 Universal Time Coordinated (UTC) 19 March, 0200 Australian Western Standard Time (AWST) 20 March (AWST = UTC + 8 hours). *Veronica* intensified very quickly and reached a peak intensity of 115 knots (kn) (213 kilometres per hour (km/h)) at 0000 UTC 21 March. From 1200 UTC 21 March *Veronica* weakened slightly as conditions became less favourable. From 22 to 24 March the tropical cyclone moved slowly in a southerly direction towards the Pilbara coast and maintained a category 4 intensity. *Veronica* stopped about 80 km north of the Pilbara coast and remained near stationary for around 24 hours (h) while gradually weakening. The weakened tropical cyclone was then steered in a westerly direction parallel to the Pilbara coast and decreased to below tropical cyclone strength by 0000 UTC 26 March. The remains of the low continued to move west, across the North West Cape and into the Indian Ocean where it eventually dissipated.

Despite Severe Tropical Cyclone *Veronica* not crossing the Pilbara coast it caused significant disruption and damage to Pilbara industry and communities. Port Hedland, Karratha and other smaller communities were subjected to a prolonged period of gale and storm force winds and heavy rainfall. Exposed coastal sites experienced periods of near hurricane force winds and very destructive gusts. The coastline to the east of *Veronica*'s centre experienced tides well above the normal high tide mark due to a significant storm surge. Shipping data suggests that Veronica caused more than 15 megatonnes in lost exports or about \$2 billion in lost revenue. About 2000 cattle were estimated to have died.

Significant flooding occurred due to heavy rainfall and many homes were evacuated after being cut off by floodwaters in the Port Hedland area. Many streams and waterways in the De Grey catchment reached minor flood level. The Coongan River at Marble Bar Road peaked at approximately 5.215 metres (m) and the Shaw River at Marble Bar Rd peaked at approx. 4.746 m.

FIGURE 1. Best track of Severe Tropical Cyclone *Veronica* 18 - 28 March 2019 (times in AWST, UTC+8).



Meteorological Description

2.1 Intensity analysis

A weak low formed in a very active monsoon trough to the north of Western Australia during 17 March and a Dvorak Data T number (DT) 1.0 was assigned at 0000 UTC 18 March. An Advanced Scatterometer (ASCAT) partial pass early on 18 March showed a weak circulation and a WindSat Polarimetric Radiometer (WINDSAT) pass later that day showed an elongated circulation. During 18 and 19 March satellite imagery showed improved curvature and an evening OSCAT pass showed several 35 kn wind barbs in the eastern quadrants. A DT 3.0 was reached at around 1800 UTC 19 March, refer Figure 2, an Advanced Microwave Scanning Radiometer 2 (AMSR2) pass.

Veronica continued to intensify rapidly in favourable conditions and though an eye pattern showed signs of developing during the afternoon of 20 March, it wasn't until around 1500 UTC that a warm eye appeared in a cold surround. Raw DT numbers climbed to 7.0 at 2100 UTC and 0000 UTC 21 March and a three-hour average peak of 6.7 was reached. Dvorak constraints meant that the Final T (FT) and the Current Intensity (CI) were held at 6.0 which gives a 10-minute mean wind speed of 100-105 kn (185 – 195 km/h). Figure 3 shows a Special Sensor Microwave Imager/Sounder (SSMI/S) pass at 2130 UTC 20 March when Veronica was approaching peak intensity. Objective intensity estimates climbed rapidly through this period with Satellite Consensus (SATCON) reaching a peak intensity of 100 kn (185 km/h) and Advanced Dvorak Technique (ADT) 115kn (213 km/h) between 0000 and 0300 UTC 21 March. Best track peak intensity was set at 115 kn (213 km/h) at 0000 and 0600 UTC 22 March. A Soil Moisture Active Passive (SMAP) pass at 1028 UTC 21 March gave a 10-minute wind speed estimate of 110 kn (204 km/h). Refer to Figure 4 for a comparison of objective and subjective intensity estimates.

While Veronica was near peak intensity a SSMI pass at 0725 UTC 21 March showed a small, symmetric cyclone with a pin-hole eye, refer Figure 6. From this point the intensity of Veronica weakened slightly. The Cooperative Institute for Meteorological Satellite Studies (CIMMS) wind shear figures show a sudden increase in the vertical wind shear over Veronica from 0600 UTC 21 March, refer to Figure 5 for a comparison of vertical wind shear and intensity. The ARCHER Eye Wall Replacement Cycle (ERC) probability plot showed that it was likely Veronica also underwent an eye wall replacement during 21 March. In response to these changes the eye pattern disappeared from Enhanced Infrared Imagery (EIR) at 0900 UTC 21 March, returning around 1900 UTC but with lower DTs of between 5.0 and 6.0. The intensity of Veronica dropped from 115 kn (213 km/h) at 0600 UTC 21 March to 95 kn (176 km/h) by 0000 UTC 22 March. This held steady throughout 22 March before decreasing again to 90 kn (167 km/h) by 0000 UTC 23 March. The ARCHER ERC plot showed a high probability that Veronica underwent another eye wall replacement from 1200 UTC 22 March. An SSMI/S pass at 2106 UTC 22 March showed though Veronica still had an intact eye wall structure, the structure of the cyclone had altered and the diameter of

the eye had increased significantly from 10 nautical miles (nm) (18 km) at 1200 UTC 22 March to around 50 nm (93 km) by 0000 UTC 23 March, refer Figure 7.

Through the period 21-24 March *Veronica* was very slow moving. Sea surface temperature (SST) plots show an upwelling of cooler water induced by the motion of *Veronica* over the ocean occurred on the 22 and 23 March. These combined factors of increased vertical wind shear, slow movement over cooler SSTs and an ERC would have contributed to the decrease in intensity of *Veronica* during the period 21 to 23 March, as it moved towards the Pilbara coast. By 0000 UTC 23 March the intensity of *Veronica* had fallen to 90 kn (167 km/h). Objective intensity estimates were clustered around this figure and a subsequent Synthetic Aperture Radar (SAR) pass of 90 kn (167 km/h) agreed with this estimate.

Veronica re-intensified slightly as it approached the Pilbara coast and the best track intensity increased to 95 kn (175 km/h) between 1800 UTC 23 March and 0600 UTC 24 March. SATCON and ADT intensity estimates showed an increase in intensity starting at 1800 UTC 23 March and reaching a peak around 0000 UTC 24 March. Microwave and radar imagery throughout this period showed a cyclone with a large eye diameter but deep, cold convection still mostly encircling the centre.

Despite a weakening satellite signature, a 1338 UTC 24 March SAR pass, refer Figure 8, taken slightly after the second peak in intensity showed an area of about 90 to 100 kn (167 to 185 km/h) to the west of the centre of the tropical cyclone. This is consistent with a documented and modelled feature of tropical cyclones where frictional effects due to the proximity of land produces a strong wind maximum in the offshore wind quadrant(s) rather than the traditional right forward quadrant. For this reason, the 1200 UTC 24 March best track intensity was held at 90 kn (165 km/h).

From this second peak in intensity at 0000 UTC 24 March *Veronica* weakened steadily as it turned in a westerly direction and travelled parallel to the Pilbara coast. Satellite and radar imagery showed the deep convection associated with *Veronica* decreased quickly and eventually became detached from the low-level centre under increased vertical wind shear. *Veronica* weakened below tropical cyclone strength by 0000 UTC 26 March. The remaining low continued to track westwards, over the North West Cape and into the Indian Ocean where it eventually dissipated.

2.2 Structure

Veronica was a reasonably symmetric tropical cyclone with gale radius initially around 50-90 nm (93-167 km), this increased to a maximum of around 130 nm (240 km) in eastern quadrants during 22 March. As the tropical cyclone moved closer to the Pilbara coast the gale radii decreased to around 80-100 nm (148-185 km) and then down to 25-40 nm (46-74 km).

Radius to maximum wind (RMW) ranged from 20 nm (37 km) initially before decreasing to 10 nm (18 km) during *Veronica*'s very intense stage. The RMW increased again during 22 and 23 March as Veronica underwent an eye wall replacement cycle. At the end of this cycle the RMW had increased significantly to 30 nm (55 km).

Eye diameter was 5 nm (9 km) when the eye first emerged on 21 March, as *Veronica* weakened slightly this increased to 20 nm (46 km) on 22 March. During the later stages the eye diameter increased again to 50 nm (93 km) on 23 March.

2.3 Motion

Veronica was initially steered to the southwest by the mid-level ridge located to the east of the tropical cyclone. The mid-level ridge was eroded during the 22 March by a mid-level trough over the south of Western Australia and Veronica was steered in a more southerly direction towards the Pilbara coast. The trough steered the tropical cyclone in a south-southeast direction on 23 March. On 24 March the trough relaxed and Veronica's motion slowed to an almost stop off the Pilbara coast as the steering influences became balanced between the relaxing trough to the southwest and the ridge to the east.

As *Veronica* weakened the lower levels of the atmosphere became the dominant steering influence. During 25 March *Veronica* began to move westwards due to the 700 hectoPascal (hPa) ridge located to the southeast of the cyclone. *Veronica* continued to move westwards under this steering regime until it dissipated in the Indian Ocean on 28 March.

3 Impact

Despite not crossing the Pilbara coast *Veronica* had a significant impact on both offshore and onshore industry and communities located along the Pilbara coast.

Both offshore and onshore industry suffered a prolonged period of shutdown during *Veronica* as the tropical cyclone was slow moving for periods of its life. Wind and flooding damage were experienced at plant and port sites along the coast. Overall *Veronica* caused an estimated \$2 billion worth of revenue losses to affected industry. Also affected were graziers who estimated about 2000 head of livestock were lost due to the cyclone.

Communities along the Pilbara coast between Port Hedland and Karratha experienced a prolonged period of gale and storm force winds. Port Hedland Automatic Weather Station (AWS) experienced periods of gale force winds for around 19 and a half hours. Roebourne AWS experienced at least gale force strength winds for a total of 36 hours and storm force winds for 13 hours. Karratha AWS recorded at least gale force winds for a total of 22 hours.

Port Hedland community was in Red Alert (a time when people are not allowed to leave their shelters) for a period of 39 hours and Karratha 33 hours. This included the surrounding communities between these two Pilbara towns. This is an unusually extended period for a Red Alert to be in place.

Several communities, including Port Hedland, were affected by significant rainfall and flooding which caused evacuations and significant disruption to traffic.

Observations

4.1 Wind

Port Hedland AWS recorded periods of gale force winds between 1649 UTC 23 March and 1908 UTC 24 March. The maximum 10-minute mean wind recorded was 45 kn (83 km/h) at 0457 UTC 24 March and the maximum 3-second wind gust recorded was 64 kn (118 km/h) at 0152 24 March.

Legendre Island (AWS) data set was incomplete as the AWS went offline at 2242 UTC 23 March. Gale force winds were recorded between 2313 – 2324 UTC 22 March, 2341 UTC 22 March - 0002 UTC 23 March, 0025 - 0201 and 0212 – 0326 UTC 23 March, 0346 UTC – 2242 UTC 23 March. Storm force winds were recorded between 1258 - 1311, 1319 – 1330, 1341 – 1359 and 1407 – 2242 23 March. The maximum 10-minute mean wind recorded was 62 kn (115 km/h) between 2107 – 2112 UTC 23 March. The maximum 3-second wind gust recorded was 85 kn (157 km/h) at 2103 UTC 23 March.

Karratha AWS recorded periods of gale force winds between 0713 UTC 23 March and 1339 UTC 25 March. Storm force winds were recorded between 2239 - 2256 and 2338 – 2342 UTC 23 March and 0101 – 0108 and 0319 – 0338 UTC 24 March. The maximum 10-minute mean wind recorded was 49.3 km (91 km/h) at 0327 UTC 24 March. A maximum 3-second wind gust recorded of 67 kn (124 km/h) was recorded at 0059 and 0303 UTC 24 March.

Roebourne AWS recorded periods of gale force winds between 1342 UC 23 March and 1254 UTC 25 March. Storm force winds were recorded between 2129 UTC 23 March and 0403 UTC 24 March, 0425 UTC, 0432 – 0706 UTC and 0713 – 1122 UTC 24 March. The maximum 10-minute mean wind recorded was 60.1 kn (111 km/h) at 0541 UTC 24 March and the maximum 3-second wind gust recorded was 83 kn (154 km/h) at 0352 UTC 24 March.

4.2 Pressure

<u>Port Hedland AWS</u> recorded a minimum mean sea level (MSL) pressure of 992.6 Hectopascals (hPa) at 2028 and 2031 UTC 23 March.

<u>Legendre Island (AWS)</u> recorded a minimum MSL pressure of 978.4 hPa at 2221 UTC 23 March.

<u>Karratha AWS</u> recorded a minimum MSL pressure of 989.9 hPa at 2335 and 2336 UTC 23 March.

Roebourne AWS recorded a minimum MSL pressure of 984.8 hPa between 0531 - 0535 UTC 24 March.

4.3 Rainfall

The highest rainfall totals recorded in the 72 hr to 9am AWST 26 March were 468 millimetres (mm) at Upper North Pole, 391 mm at Carlindie, 380 mm at Malina and 355.6 mm at Port Hedland. Refer Figure 9 for a plot of the rainfall for the week ending 27 March.

4.4 Storm Surge

The highest storm surge recorded was 1.5 m at Port Hedland during the early hours of 24 March. This occurred around the time of low tide, refer to Figure 10 for a plot of the total tide and residual heights recorded at Port Hedland.

Forecast Performance

The accuracy figures for Severe Tropical Cyclone *Veronica* show that the forecast performed better than the five-year average at all time steps except the 120 h.

The accuracy statistics obtained by comparing the forecast positions against the best track positions for *Veronica* are

	00	06	12	18	24	36	48	72	96	120
Absolute error (km)	17	36	52	59	70	97	106	149	210	323
RMS Error (km)	25	48	65	70	80	113	121	171	235	347
Sample Size	23	23	23	23	24	24	24	21	16	12

Figure 11 is a plot of the accuracy figures for *Veronica* compared to the five-year mean.

TABLE 1. Best track summary for Severe Tropical Cyclone Veronica

Refer to the Australian Tropical Cyclone database for complete listing of parameters. WST is UTC + 8 hours.

Year	Month	Day	Hour UTC	Pos. Lat S	Pos. Long. E	Pos. Acc. nm	Max Wind 10 min kn	Max gust kn	Cent. Press. hPa	Rad. of gales (NE/SE/ SW/NW)	Rad. of storm (NE/SE/ SW/NW)	RMW n mi
2019	03	18	00	13.0	122.7	60	20	45	1006			
2019	03	18	06	13.2	122.7	60	20	45	1005			
2019	03	18	12	13.4	122.4	60	25	45	1003			
2019	03	18	18	13.8	121.7	60	25	45	1002			
2019	03	19	00	14.0	120.8	60	30	45	1001			
2019	03	19	06	14.1	120.4	30	30	45	1000			
2019	03	19	12	14.2	120.3	45	35	50	997	25/80/0/0		20
2019	03	19	18	15.1	120.0	45	45	65	991	80/90/80/ 50		20
2019	03	20	00	15.2	119.1	20	50	70	990	80/90/80/ 50	30	20
2019	03	20	06	15.5	118.3	20	65	90	979	70/90/90/ 60	40	20
2019	03	20	12	15.8	118.0	20	75	105	968	60/90/90/ 60	40/40/30/ 30	15
2019	03	20	18	15.9	117.6	10	90	125	954	80/90/80/ 60	40/35/30/ 30	10
2019	03	21	00	16.4	117.7	10	115	160	928	80/90/70/ 60	40/30/20/ 20	10
2019	03	21	06	16.9	117.5	10	115	160	928	80/100/6	30	10

Year	Month	Day	Hour UTC	Pos. Lat S	Pos. Long. E	Pos. Acc. nm	Max Wind 10 min kn	Max gust kn	Cent. Press. hPa	Rad. of gales (NE/SE/ SW/NW)	Rad. of storm (NE/SE/ SW/NW)	RMW n mi
										0/60		
2019	03	21	12	17.3	117.3	10	105	145	938	90/120/5 0/60	30	10
2019	03	21	18	17.4	117.0	10	100	140	943	110/120/ 80/80	40	15
2019	03	22	00	17.6	116.9	10	95	135	945	130/130/ 90/100	50	15
2019	03	22	06	17.7	116.9	10	95	135	945	120/120/ 90/100		15
2019	03	22	12	17.9	116.9	10	95	135	945	100/100/ 90/90		15
2019	03	22	18	18.2	117.0	15	95	135	945	110/110/ 90/90		20
2019	03	23	00	18.6	117.0	15	90	125	951	130/120/ 90/90		25
2019	03	23	06	19.0	117.1	15	90	125	951	120/110/ 90/90		30
2019	03	23	12	19.3	117.3	15	90	125	950	110/95/8 5/90		25
2019	03	23	18	19.7	117.5	20	95	135	944	110/80/9 0/90		25
2019	03	24	00	20.0	117.6	10	95	135	941	100/80/8 0/80		25
2019	03	24	06	20.1	117.6	15	95	135	942	110/70/8 0/80	60/40/55/ 60	25

Year	Month	Day	Hour UTC	Pos. Lat S	Pos. Long. E	Pos. Acc. nm	Max Wind 10 min kn	Max gust kn	Cent. Press. hPa	Rad. of gales (NE/SE/ SW/NW)	Rad. of storm (NE/SE/ SW/NW)	RMW n mi
2019	03	24	12	20.3	117.7	20	90	135	947	80/60/65/ 60	50/40/55/ 50	15
2019	03	24	18	20.3	117.7	20	80	110	954	70/60/45/ 45	30/35/30/ 30	15
2019	03	25	00	20.4	117.5	15	60	85	975	60/60/30/ 35	0/20/20/0	15
2019	03	25	06	20.4	117.1	15	45	65	985	40/30/25/ 35		15
2019	03	25	12	20.4	116.9	15	40	55	988	30/25/25/ 35		15
2019	03	25	18	20.4	116.4	15	35	50	993	20/20/20/ 0		15
2019	03	26	00	20.9	115.7	10	30	45	1000			
2019	03	26	06	21.5	114.9	10	30	45	1000			
2019	03	26	12	21.8	114.4	15	30	45	1000			
2019	03	26	18	21.9	113.6	15	30	45	1000			
2019	03	27	00	22.3	112.8	10	30	45	1002			
2019	03	27	06	22.9	112.3	15	30	45	1002			
2019	03	27	12	22.9	112.0	20	30	45	1002			
2019	03	27	18	22.6	111.2	20	30	45	1002			
2019	03	28	00	22.2	110.2	20	30	45	1003			

FIGURE 2. AMSR2 pass at 1743 UTC 19 March as *Veronica* showed improved curvature and reached tropical cyclone strength.



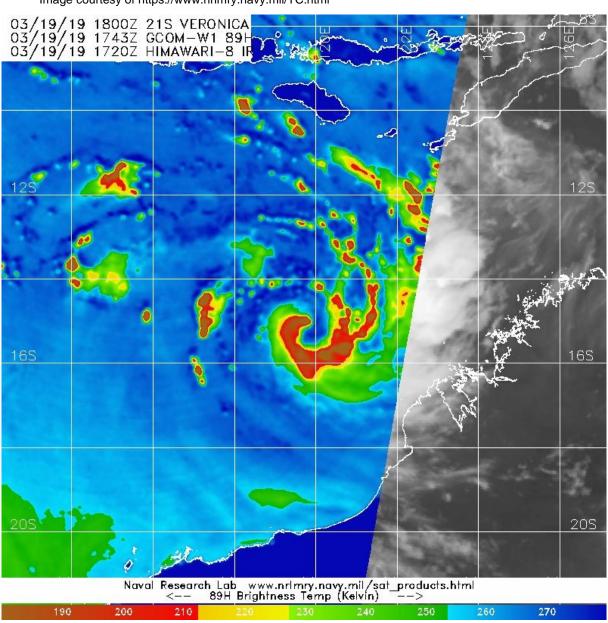


FIGURE 3. SSMI/S image at 2130 UTC 20 March as *Veronica* approached peak intensity.

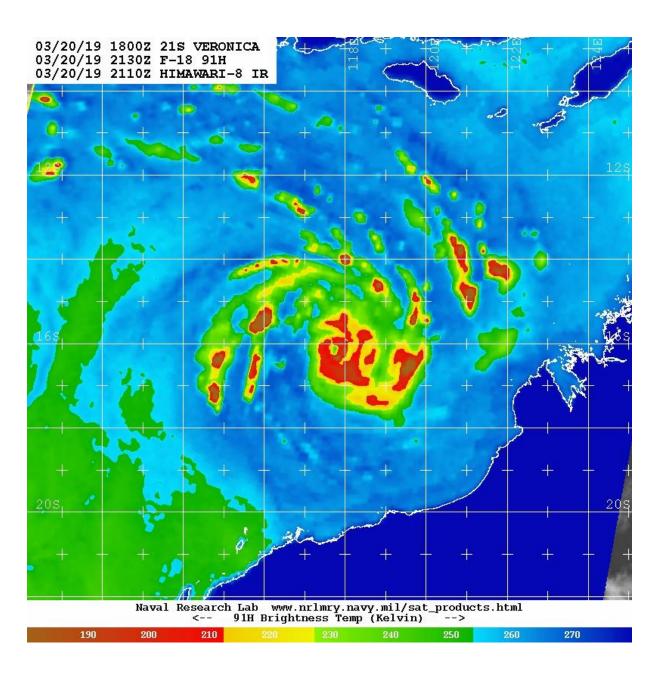


FIGURE 4. Plot of objective and subjective intensity estimates for *Veronica*.

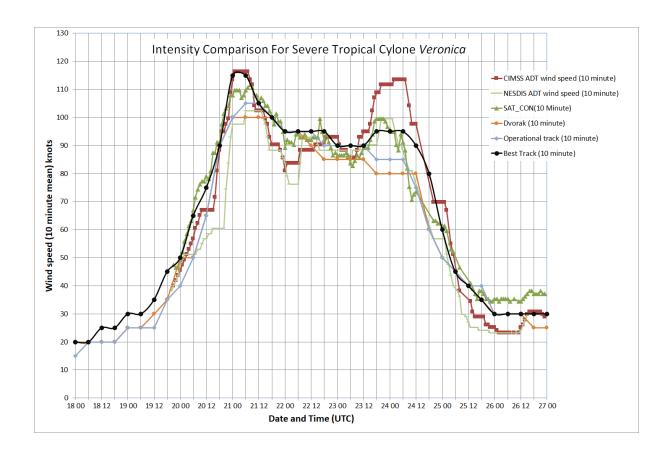


FIGURE 5. Comparison of vertical wind shear and intensity for Veronica.

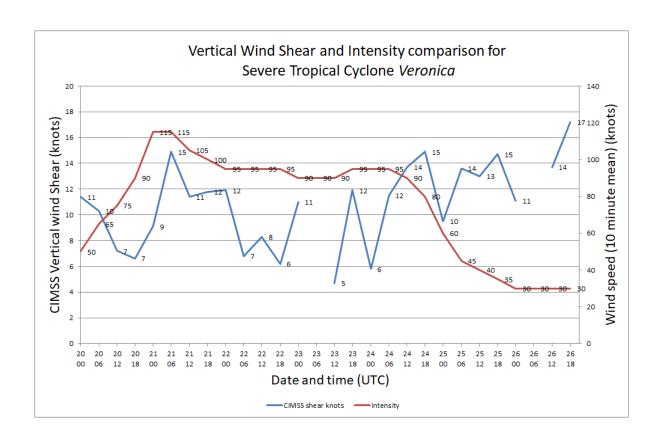


FIGURE 6. SSMI/S image at 0725 21 March prior to weakening.



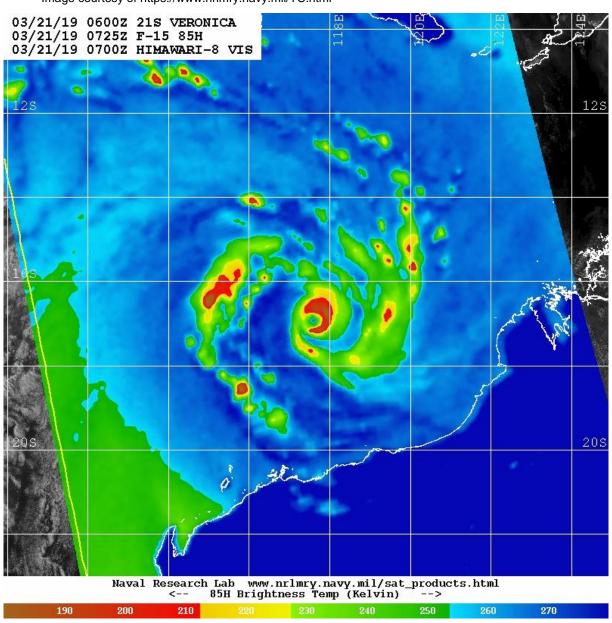


FIGURE 7. SSMI/S image at 2106 22 March showing an enlarged eye diameter.

Image courtesy of https://www.nrlmry.navy.mil/TC.html

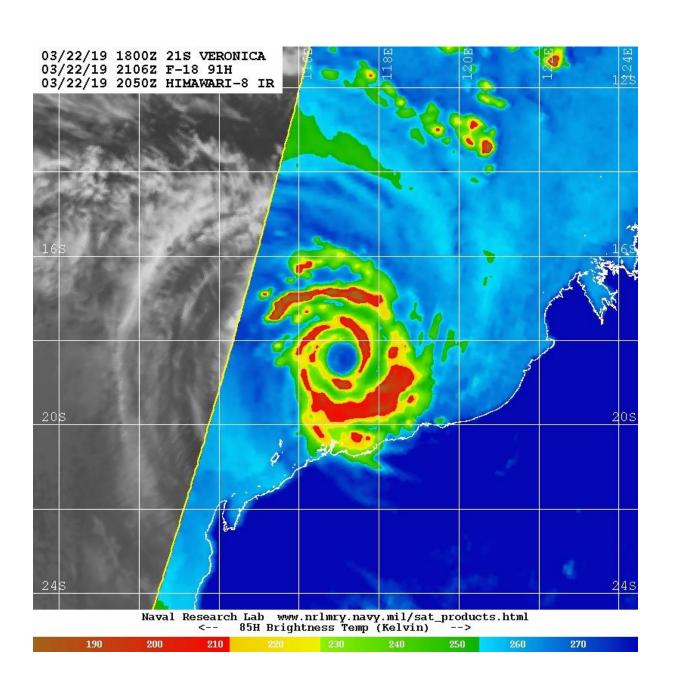


FIGURE 8. 1338 UTC 24 March SAR pass showing an area of intense winds while *Veronica* was located just offshore from the Pilbara coast.

Image courtesy of IFREMER

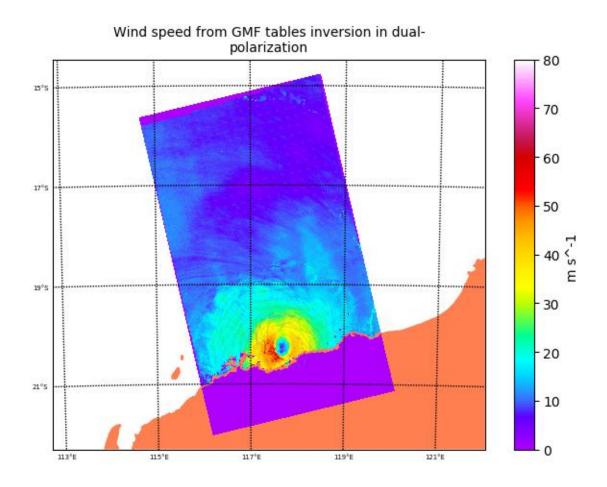


FIGURE 9. Plot of rainfall totals for the week ending 27 March.

Western Australian Rainfall Totals (mm) Week Ending 27th March 2019
Australian Bureau of Meteorology

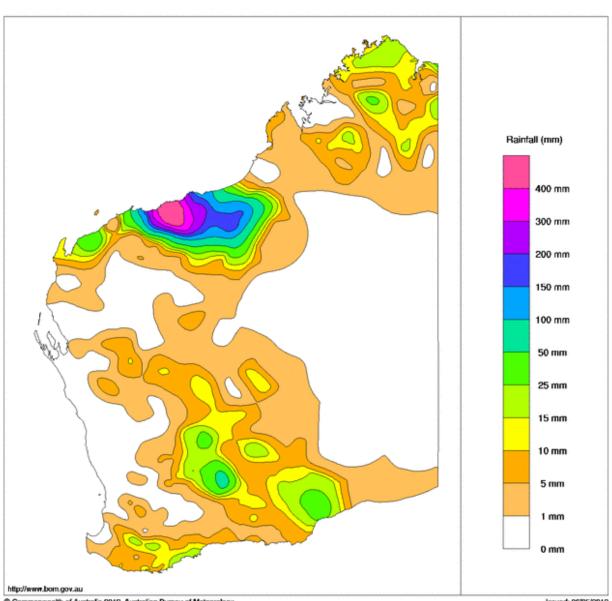


FIGURE 10. Plot of the total tide and residual heights from Port Hedland.

Figure courtesy of the Department of Transport https://www.transport.wa.gov.au/imarine/coastal-data-and-charts.asp

Updated Mon 25th Mar 2019 21:30hrs

Recorded Tide:

2.41

Metres to LAT Port Headland

Residual: 12cm Predicted: 2.29m

Next:	Time:	Height:
High	01:56	6.59
Low	07:51	1.36

Predicted Tides (Metres)

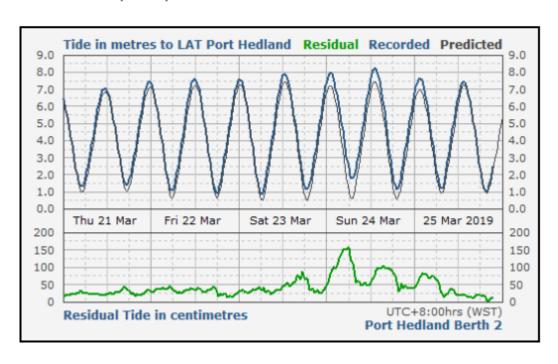


FIGURE 11. Accuracy figures for Severe Tropical Cyclone Veronica

