Australian Government
Bureau of Meteorology

# Tropical Cyclone *Caleb*

## 21 – 30 March 2017

August 2018

Published by the Bureau of Meteorology

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# 1 Summary

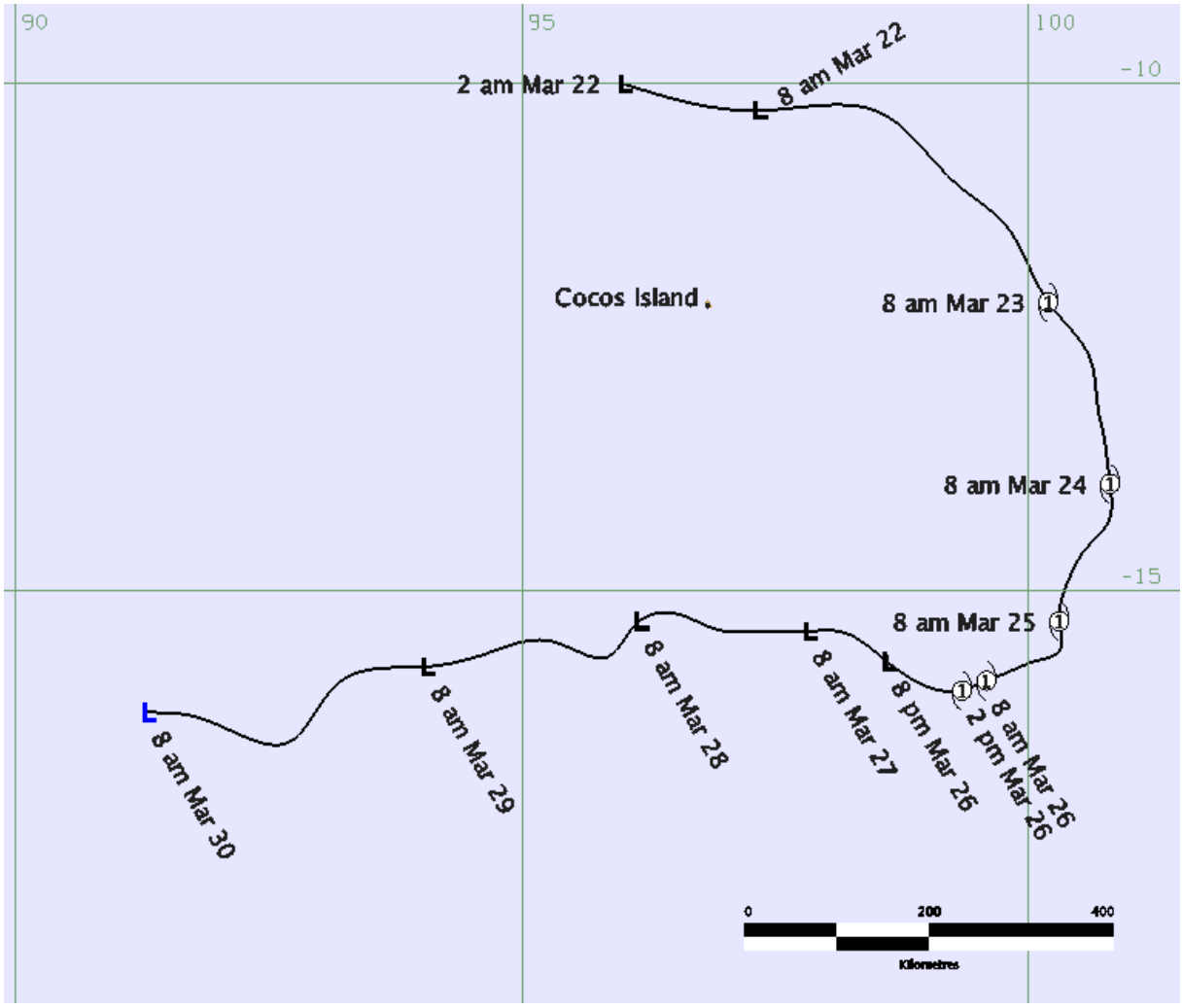
A low formed in an active monsoon trough at 1800 Universal Time Co-ordinated (UTC) 21 March (0200 Australian Western Standard Time (AWST) = UTC+8 hours (h)) approximately 250 kilometres (km) north northwest of the Cocos (Keeling) Islands. The low moved east southeast and developed into a tropical cyclone at 0000 UTC 23 March. *Caleb*'s formation occurred in what is traditionally considered an unfavourable environment of very strong vertical wind shear.

*Caleb* developed slowly during the next 48 hours as it drifted in a generally southerly direction, away from Cocos (Keeling) and Christmas Islands. It is estimated that *Caleb* reached a peak 10-minute mean wind intensity of 45 knots (kn) (83 kilometres per hour (km/h)) between 1200 and 1800 UTC 24 March.

Once *Caleb* moved south of 15 $^{o}$S, it tracked in a westerly direction, and by late on 26 March had weakened below tropical cyclone intensity due to a combination of entrainment of dry air and cooler sea surface temperatures.

The strong monsoon flow that assisted the formation of *Caleb* produced a period of heavy rainfall and gusty winds during 21 and 22 March at the Cocos (Keeling) Islands. The tropical cyclone itself did not cause any wind or rainfall impacts on the Islands or mainland Western Australia.

FIGURE 1. Best track of *Caleb* 22 – 30 March 2017 (times in AWST, UTC+8).



# 2 Meteorological Description

## 2.1 Intensity analysis

A low formed in an active monsoon trough around 1800 UTC 21 March and moved to the east and then the southeast. During 22 March Cooperative Institute for Meteorological Satellite Studies (CIMSS) vertical wind shear analyses indicated the low was in an environment of 30-40 kn (55 – 75 km/h) east northeast vertical wind shear. Normally tropical cyclone formation in this environment would be considered unlikely. Advanced Scatterometer (ASCAT) data showed 20-30 kn (37 – 55 km/h) south-easterly winds to the south of the system with similar strength north-westerly winds to the north of the developing tropical cyclone. There may have been two factors contributing to the formation of Caleb that were strong enough to overcome negative effects of the strong vertical wind shear during the early stages of its lifetime. The first may have come from the strong low-level monsoonal flow that Caleb developed in. The second could have come from the passage of a high amplitude mid-level trough to the south of the developing low between 20 – 22 March.

An 0214 UTC 23 March ASCAT pass, refer Figure 2, showed a circulation with 30-40 kn (55 – 75 km/h) winds wrapping three quarters around the tropical cyclone. Visible (VIS) satellite imagery at this time, refer Figure 3, showed an exposed low-level system centre (LLSC) with a significant convective band on the western side of the centre, consistent with strong easterly vertical wind shear. The 0000 UTC 23 March CIMSS shear analysis showed the magnitude of the shear was around 40 kn. However subsequent analyses showed the vertical wind shear decreased markedly during the 23 March and by 0000 UTC 24 March the magnitude was 20 kn.

During 24 March convection remained confined to the western quadrants. A 1426 24 March ASCAT pass, refer Figure 4, showed *Caleb* had intensified slightly with a smaller radius to maximum wind (RMW) and a slight increase in the number of 40 – 45 kn (75 – 83 km/h) wind barbs in the western half. It is estimated that *Caleb* reached a peak 10-minute mean wind intensity of 45 kn (83 km/h) between 1200 and 1800 UTC 24 March, refer Figure 5. By 1800 UTC 24 March the vertical wind shear had decreased to 15 kn.

*Caleb* maintained an intensity of 40 kn during 25 March as vertical wind shear continued to fall markedly, reaching a low of 3 kn by 0600 UTC 26 March. As *Caleb* moved further south the tropical cyclone weakened as it moved over cooler seas surface temperatures (SSTs) and was affected by the entrainment of dry air. A 1239 UTC 26 March microwave image, refer Figure 6, showed a marked decrease in deep, cold convection around *Caleb*. It is likely that gales were present only in the southern quadrants and that *Caleb* had weakened to below tropical cyclone strength at this time. A 1524UTC ASCAT pass, refer Figure 7, captured *Caleb* and confirmed 30-35 kn (55 – 65 km/h) winds in the southern quadrants. The pass also showed the gale radius had enlarged significantly in the south as *Caleb* weakened. A low persisted for many days

after this but subsequent ASCAT passes showed there were no gale force winds associated with it.

Figure 8 shows a plot of both subjective and objective intensity analyses during *Caleb*'s lifetime. Objective guidance such as ADT and SATCON are usually less reliable when analysing sheared tropical cyclones so less weight was given to these methods. The intensity of *Caleb* was mainly determined using ASCAT data.

Figure 9 shows a plot of the vertical wind shear compared to the intensity of tropical cyclone *Caleb*. It shows that *Caleb* developed despite being initially located in an environment of high vertical wind shear. As *Caleb* reached peak intensity the vertical wind shear had decreased to around 15 kn and it continued to decrease further over subsequent days.

## 2.2 Structure

*Caleb* was an averaged sized system for the Australian region, this is unusual for a tropical cyclone that formed under a strong vertical wind regime, these systems are usually smaller and very asymmetric.

The radius to gales was 60 nautical miles (nm) (111 km) in the southwest and northeast quadrants increasing to 90 nm (167 km) in the north-western quadrant. As *Caleb* intensified the gale radii became more symmetric at around 60 nm (111 km) in most quadrants. As *Caleb* weakened the south-eastern quadrant expanded to 150 nm (278 km) at its largest.

The radius to maximum wind (RMW) ranged from 50 nm (93 km) in initial stages to 20 nm (37 km) at its most intense.

## 2.3 Motion

Between 21- 24 March *Caleb* was steered to the east and then east southeast by a mid-level trough to the south of the tropical cyclone. By 0000 UTC 24 March the trough had moved far enough to the east of *Caleb* that it no longer governed the tropical cyclone's motion. *Caleb* moved very slowly south over the following 24 hours before beginning to move to the west under the influence of the mid-level ridge located to the south of the tropical cyclone. The tropical cyclone continued to move to the west until it finally dissipated.

# 3 Impact

*Caleb* had no impact on mainland or island territories of Western Australia.

# 4 Observations

There were no observations recorded during *Caleb*'s lifetime.

# 5 Forecast Performance

The accuracy figures for *Caleb* were very similar to the 2010 – 2015 five-year average.

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

| | **00** | **06** | **12** | **18** | **24** | **36** | **48** | **72** | **96** | **120** | **144** | **168** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Absolute error (km)** | 48 | 58 | 66 | 73 | 84 | 101 | 125 | 174 | 239 | 375 | 495 | 718 |
| **RMS Error (km)** | 58 | 64 | 74 | 81 | 90 | 109 | 135 | 195 | 265 | 397 | 525 | 721 |
| **Sample Size** | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 16 | 12 | 7 | 5 |

Figure 10 is a plot of the accuracy figures for *Caleb* compared to the five-year mean.

## TABLE 1. Best track summary for Tropical Cyclone *Caleb*

Refer to the Australian Tropical Cyclone database for complete listing of parameters. AWST 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 | 03 | 21 | 18 | 10.0 | 96.0 | 25 | 15 | 45 | 1007 | | | |
| 2017 | 03 | 22 | 00 | 10.3 | 97.3 | 20 | 20 | 45 | 1007 | | | |
| 2017 | 03 | 22 | 06 | 10.3 | 98.5 | 20 | 25 | 45 | 1006 | | | |
| 2017 | 03 | 22 | 12 | 11.0 | 99.3 | 20 | 30 | 45 | 1004 | | | |
| 2017 | 03 | 22 | 18 | 11.4 | 99.7 | 20 | 30 | 45 | 1003 | | | |
| 2017 | 03 | 23 | 00 | 12.1 | 100.2 | 15 | 35 | 50 | 1001 | 60/0/60/90 | | 50 |
| 2017 | 03 | 23 | 06 | 12.7 | 100.6 | 10 | 35 | 50 | 1000 | 60/0/60/60 | | 50 |
| 2017 | 03 | 23 | 12 | 13.3 | 100.7 | 20 | 35 | 50 | 1000 | 60/60/60/60 | | 40 |
| 2017 | 03 | 23 | 18 | 13.3 | 100.7 | 10 | 40 | 55 | 998 | 60/60/60/70 | | 40 |
| 2017 | 03 | 24 | 00 | 13.9 | 100.8 | 15 | 40 | 55 | 997 | 60/60/60/70 | | 40 |
| 2017 | 03 | 24 | 06 | 14.3 | 100.8 | 10 | 40 | 55 | 997 | 60/60/70/70 | | 30 |
| 2017 | 03 | 24 | 12 | 14.6 | 100.5 | 15 | 45 | 65 | 994 | 60/60/90/70 | | 20 |
| 2017 | 03 | 24 | 18 | 14.9 | 100.4 | 10 | 45 | 65 | 994 | 60/60/90/70 | | 20 |

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 | 03 | 25 | 00 | 15.3 | 100.3 | 15 | 40 | 55 | 996 | 60/60/90/ 70 | | 20 |
| 2017 | 03 | 25 | 06 | 15.6 | 100.3 | 15 | 40 | 55 | 996 | 60/60/90/ 70 | | 20 |
| 2017 | 03 | 25 | 12 | 15.7 | 100.1 | 15 | 40 | 55 | 996 | 40/40/60/ 60 | | 20 |
| 2017 | 03 | 25 | 18 | 15.8 | 99.8 | 15 | 40 | 55 | 996 | 40/40/60/ 60 | | 25 |
| 2017 | 03 | 26 | 00 | 15.9 | 9.6 | 15 | 40 | 55 | 998 | 40/40/60/ 60 | | 30 |
| 2017 | 03 | 26 | 06 | 16.0 | 9.3 | 15 | 40 | 55 | 998 | 0/60/60/6 0 | | 40 |
| 2017 | 03 | 26 | 12 | 15.7 | 98.6 | 10 | 35 | 50 | 1000 | 0/120/60/ 0 | | 40 |
| 2017 | 03 | 26 | 18 | 15.4 | 98.1 | 10 | 35 | 50 | 1002 | 0/150/60/ 0 | | 40 |
| 2017 | 03 | 27 | 00 | 15.4 | 97.8 | 10 | 30 | 45 | 1004 | | | |
| 2017 | 03 | 27 | 06 | 15.4 | 97.2 | 10 | 30 | 45 | 1005 | | | |
| 2017 | 03 | 27 | 12 | 15.4 | 97.0 | 10 | 30 | 45 | 1005 | | | |
| 2017 | 03 | 27 | 18 | 15.2 | 96.5 | 10 | 30 | 45 | 1005 | | | |
| 2017 | 03 | 28 | 00 | 15.3 | 96.2 | 15 | 30 | 45 | 1005 | | | |
| 2017 | 03 | 28 | 06 | 15.6 | 95.8 | 15 | 30 | 45 | 1005 | | | |
| 2017 | 03 | 28 | 12 | 15.5 | 95.3 | 15 | 30 | 45 | 1005 | | | |

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 | 03 | 28 | 18 | 15.6 | 94.7 | 15 | 30 | 45 | 1005 | | | |
| 2017 | 03 | 29 | 00 | 15.7 | 94.0 | 15 | 30 | 45 | 1005 | | | |
| 2017 | 03 | 29 | 06 | 15.9 | 93.2 | 10 | 25 | 45 | 1008 | | | |
| 2017 | 03 | 29 | 12 | 16.5 | 92.7 | 10 | 25 | 45 | 1008 | | | |
| 2017 | 03 | 29 | 18 | 16.2 | 91.8 | 15 | 25 | 45 | 1008 | | | |
| 2017 | 03 | 30 | 00 | 16.2 | 91.3 | 15 | 25 | 45 | 1009 | | | |

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## FI15GURE 2. ASCAT pass at 0214 UTC 23 March 2017 during the early stages of *Caleb's* development.

Image courtesy of https://manati.star.nesdis.noaa.gov/datasets/ASCATData.php

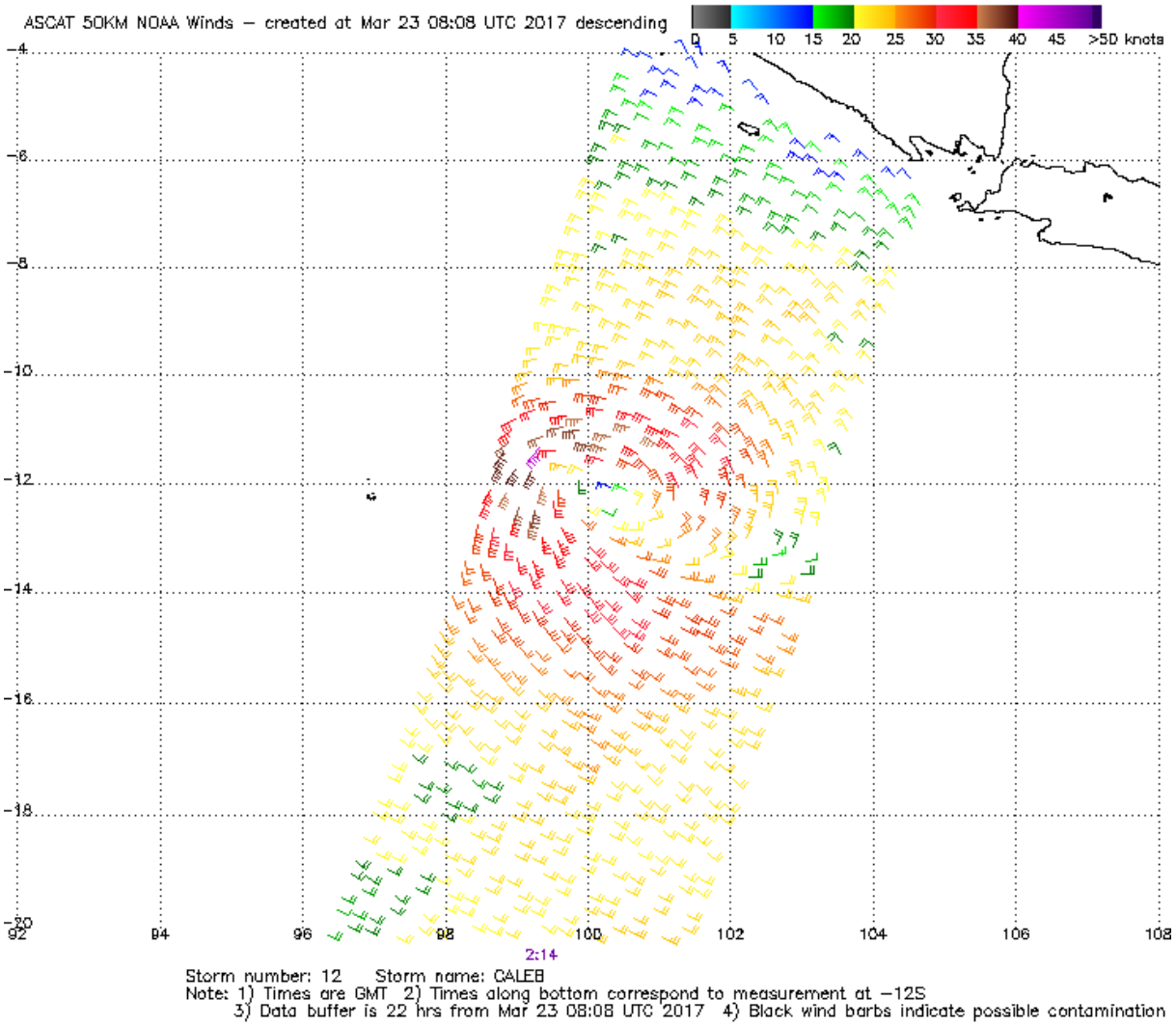
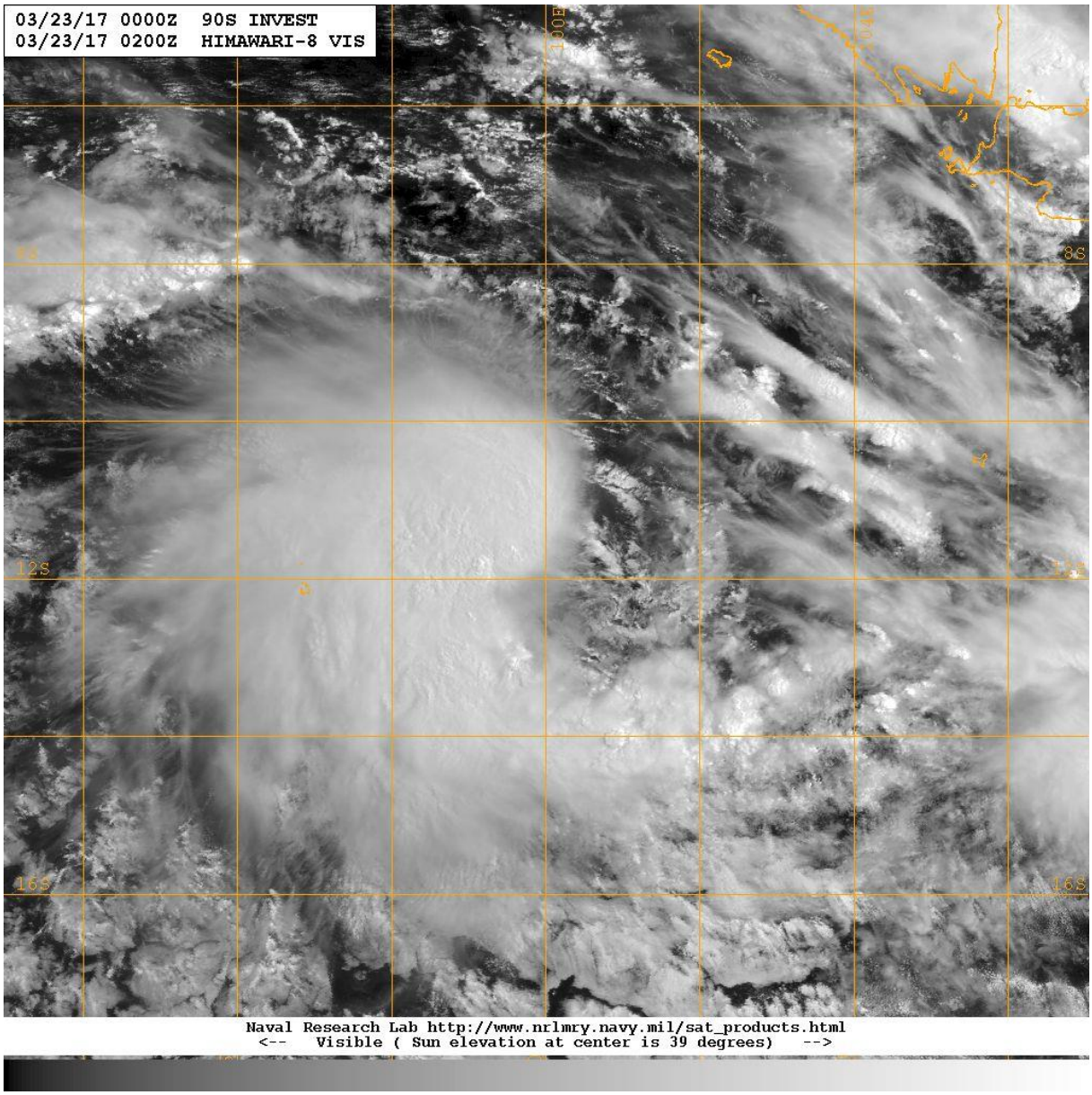


FIGURE 3. Himawari-8 VIS image at 0200 UTC 23 March 2017 during the early stages of *Caleb's* development.

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



## FIGURE 4. A 1426 UTC 24 March ASCAT pass.

Image courtesy of https://manati.star.nesdis.noaa.gov/datasets/ASCATData.php

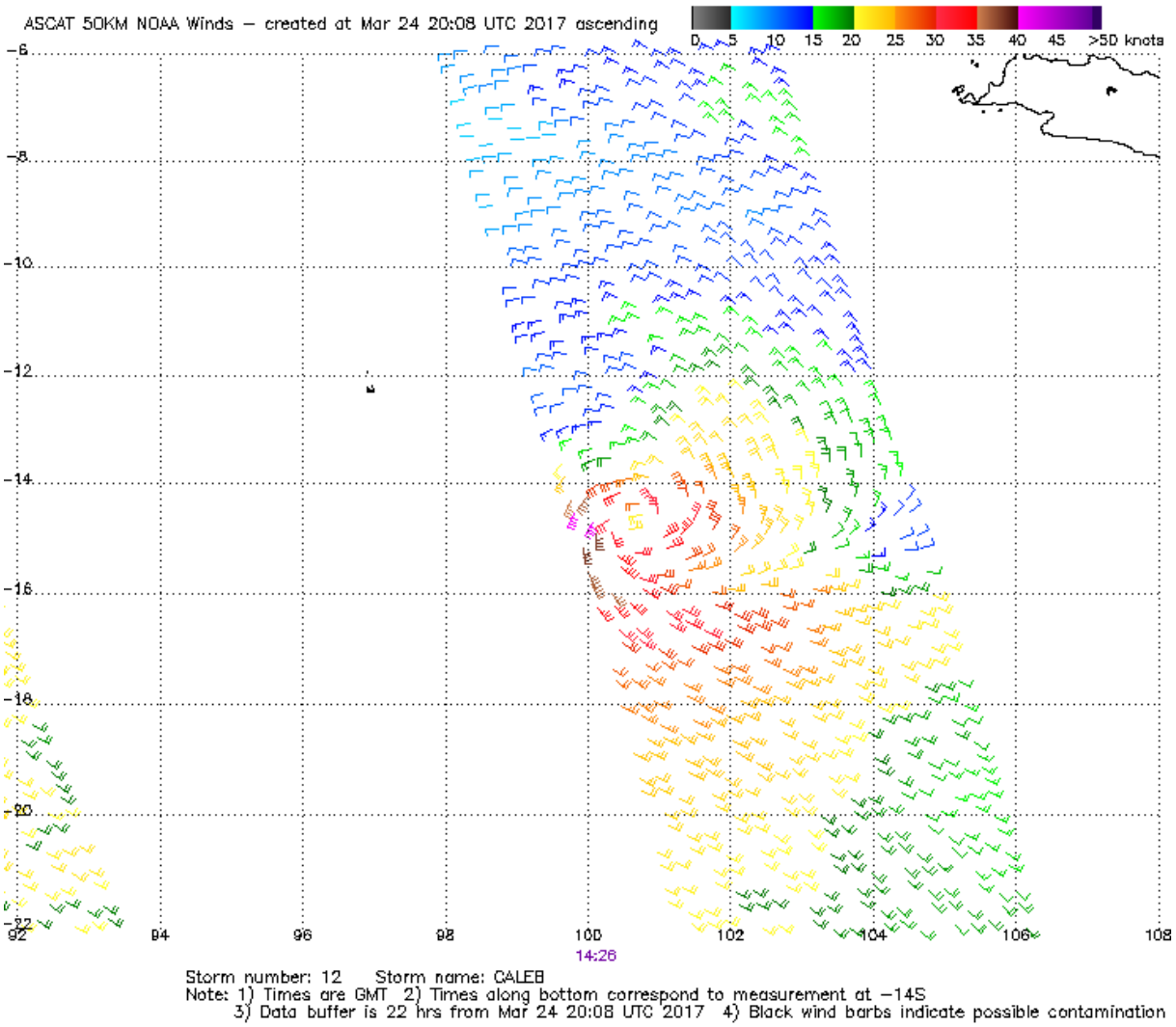


FIGURE 5. 89 GHz colour image of *Caleb* at 1833 UTC 24 March Advanced Microwave Scanning Radiometer 2, around the time of maximum intensity.

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

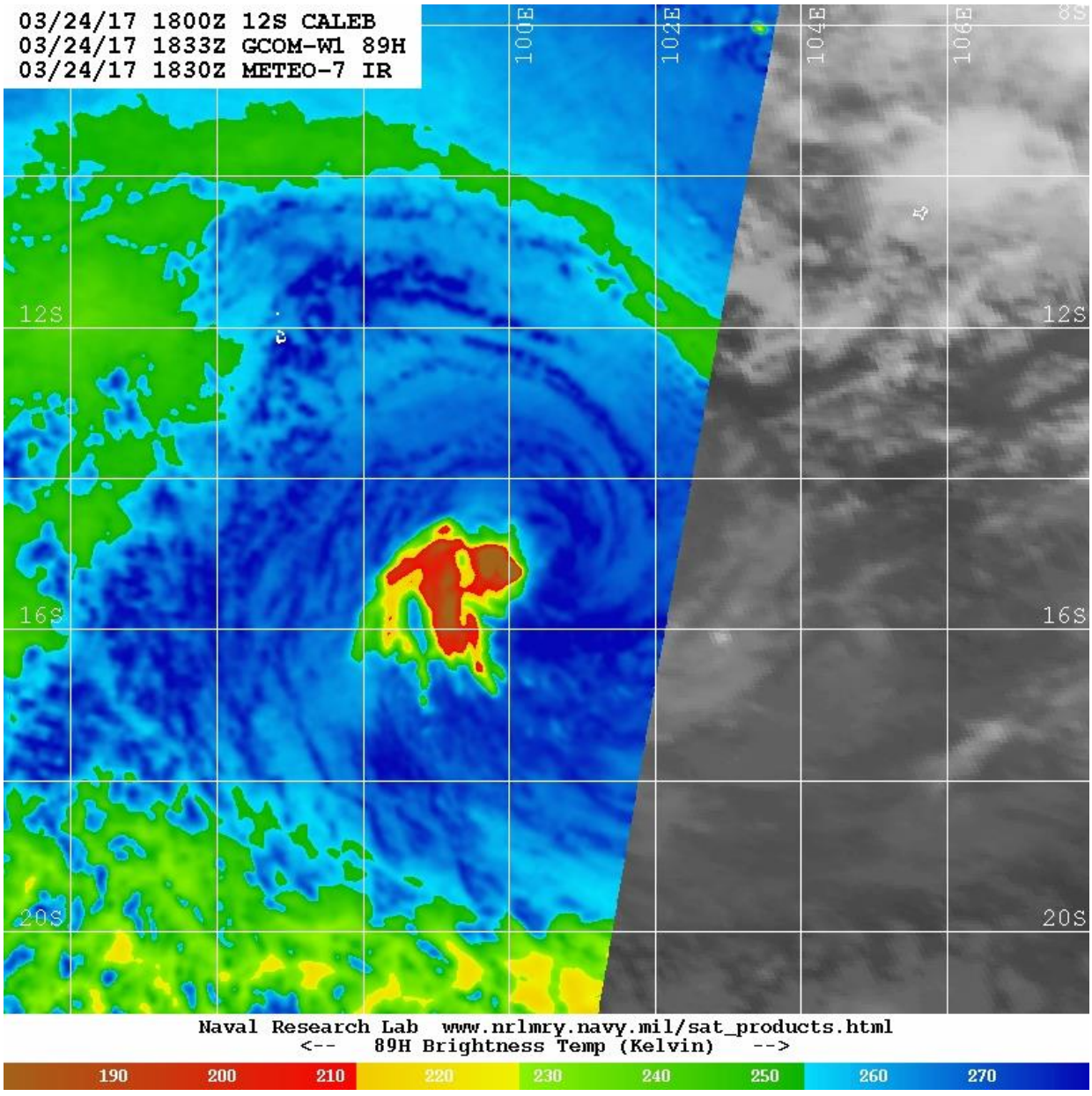


FIGURE 6. A Special Sensor Microwave Imager/Sounder (SSMIS) 91 gHz pass at 1239 UTC 26 March as *Caleb* weakened below tropical cyclone strength.

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

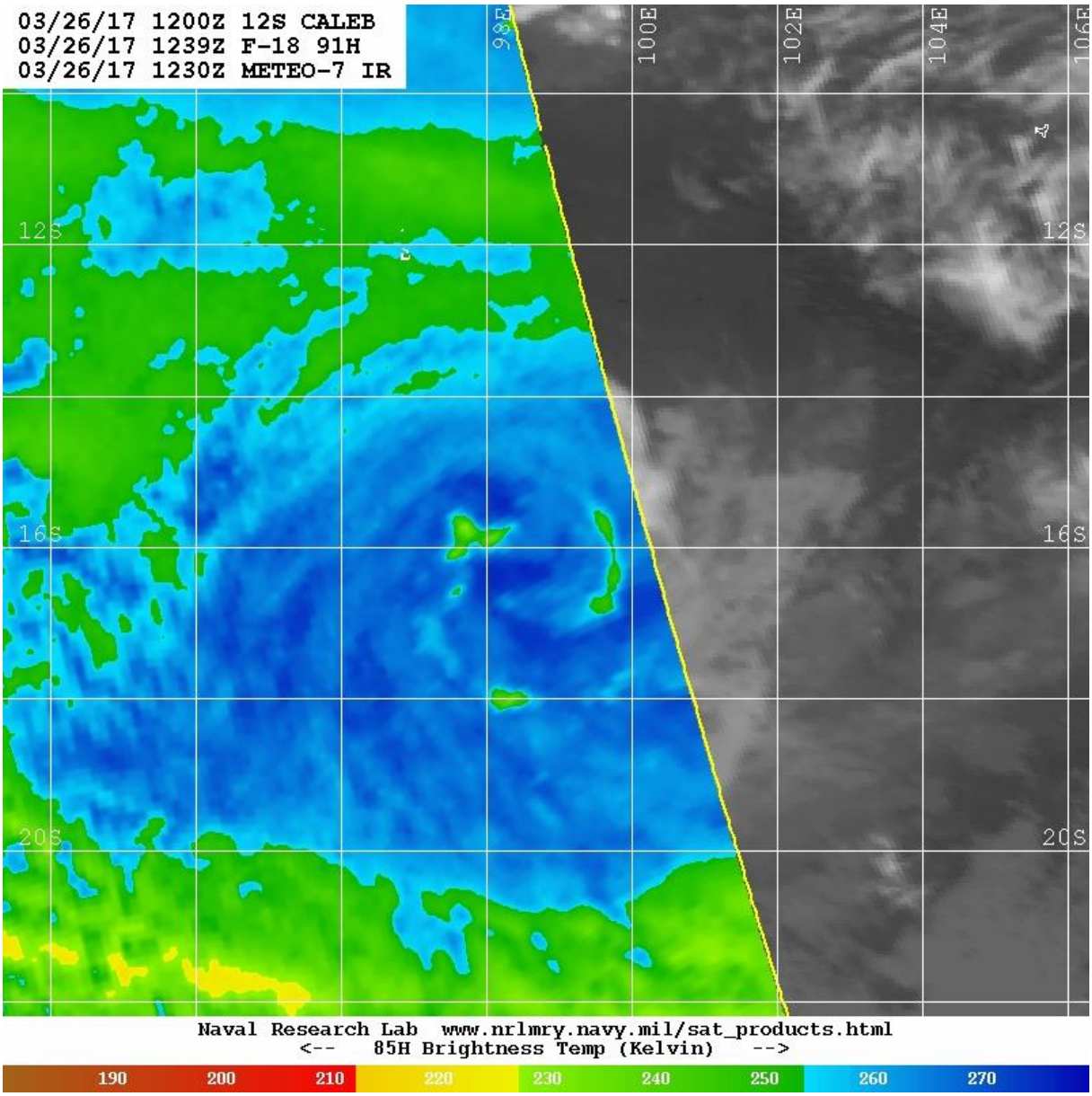


FIGURE 7. A 1524 UTC 26 March ASCAT pass which showed that gales had contracted to be present in southern quadrants only and that *Caleb* had weakened to below tropical cyclone strength.

Image courtesy of https://manati.star.nesdis.noaa.gov/datasets/ASCATData.php

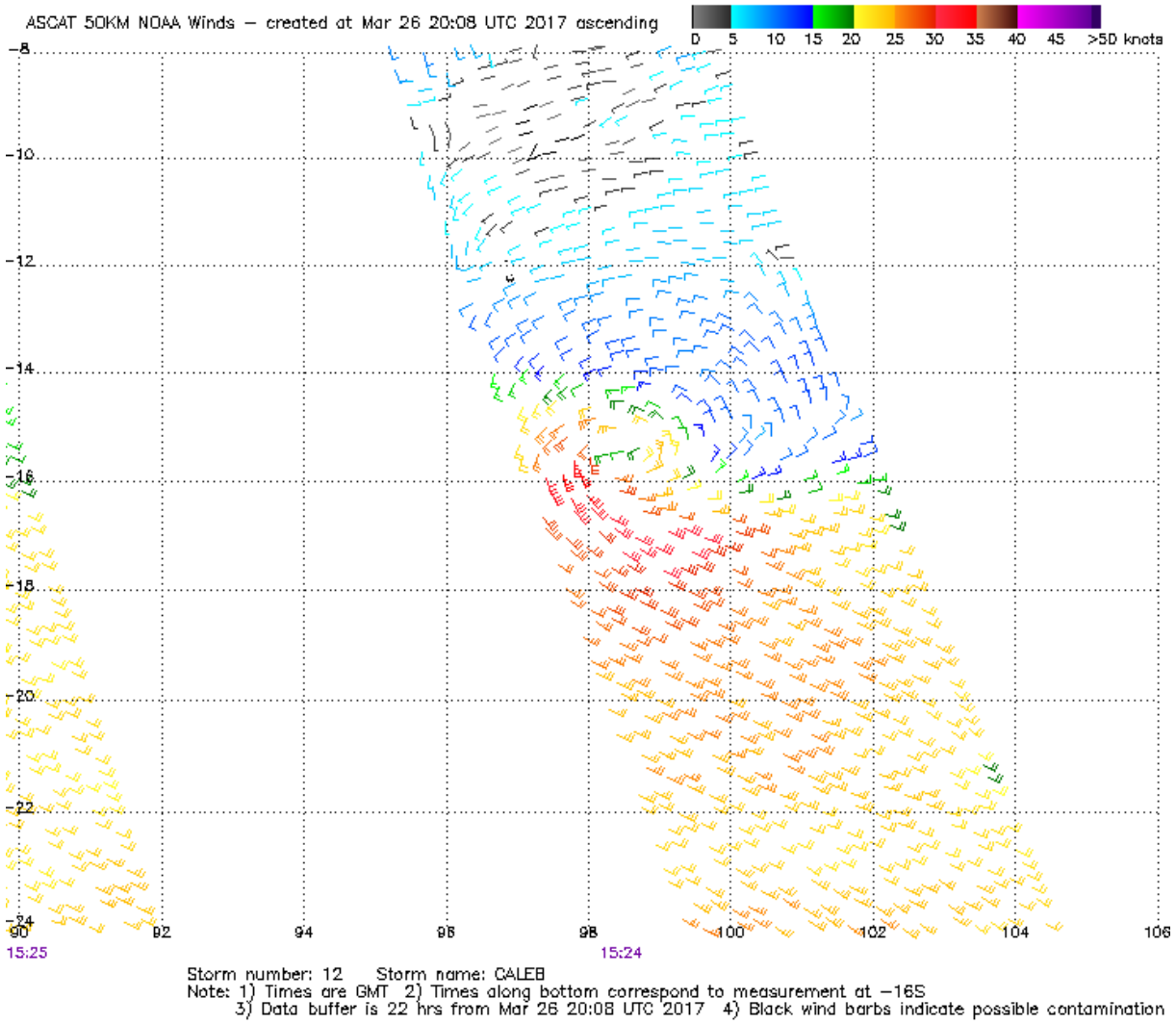


FIGURE 8. Intensity analysis of Tropical Cyclone *Caleb*

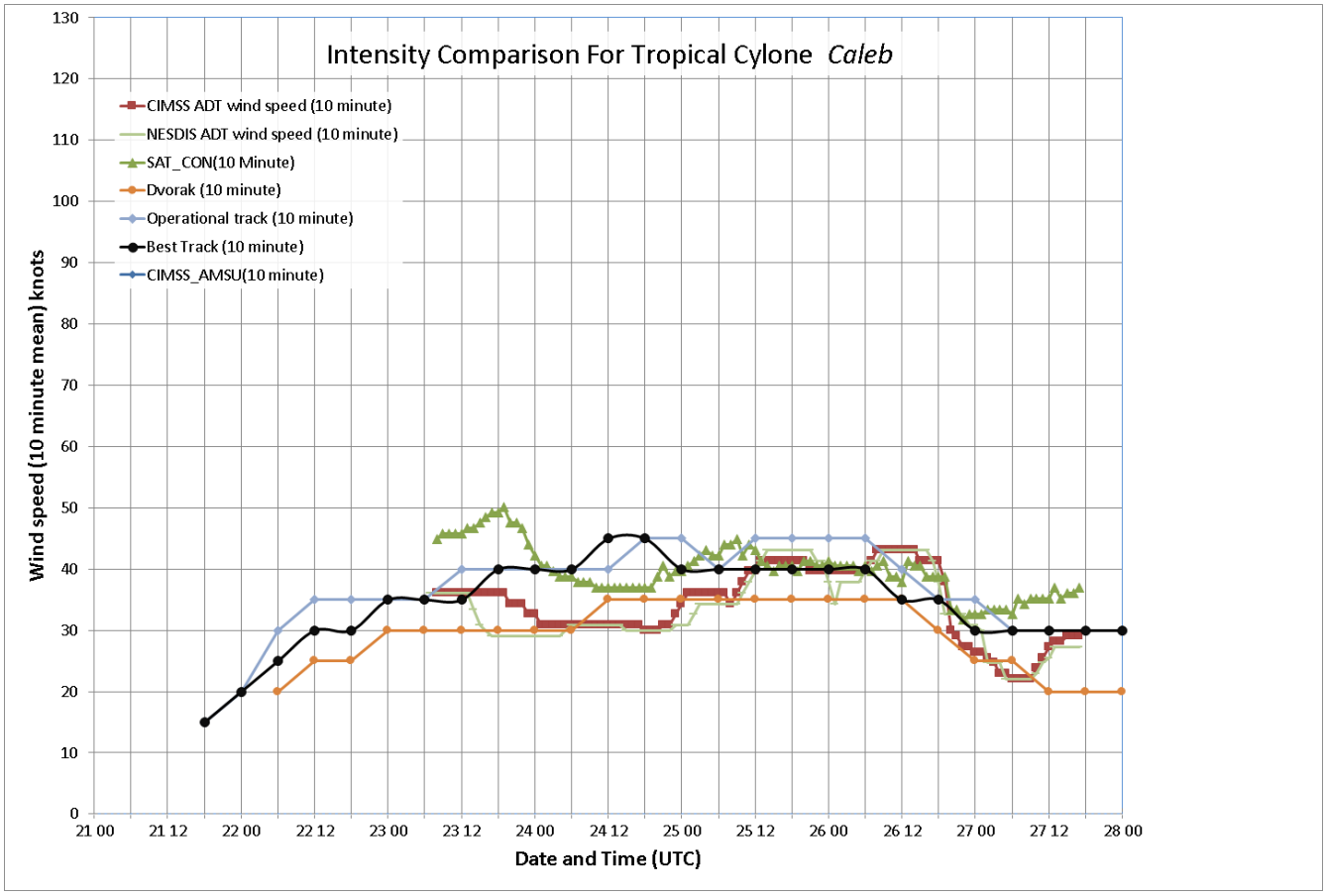


FIGURE 9. A plot of environmental vertical wind shear compared to the intensity of *Caleb*.

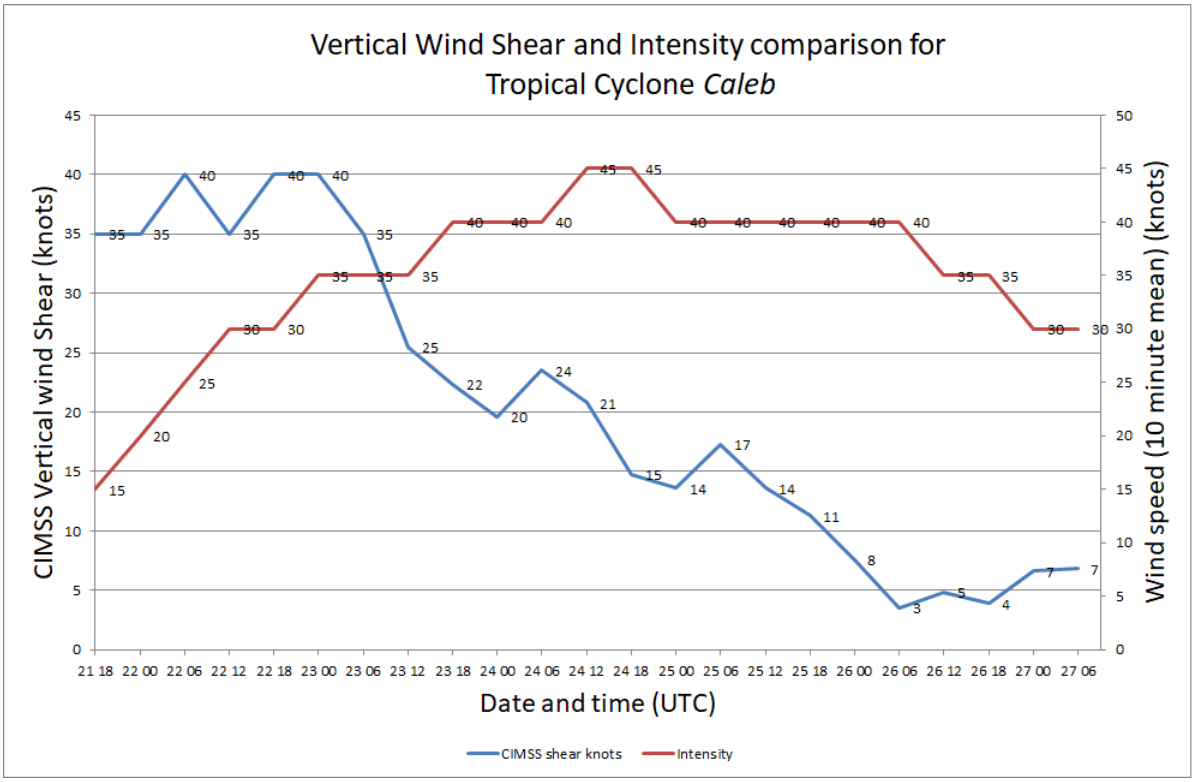


FIGURE 10. Accuracy figures for Tropical Cyclone *Caleb*