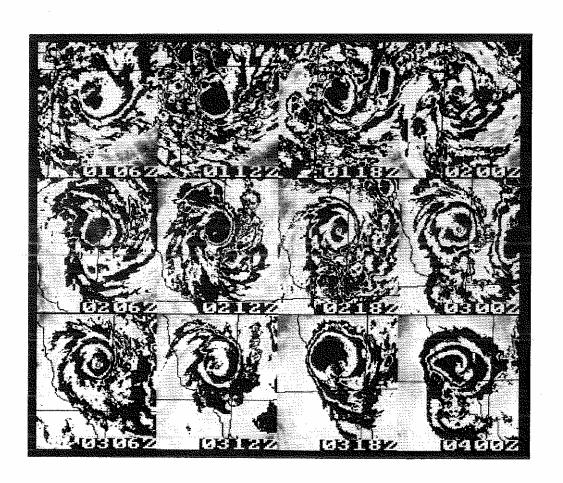


# REPORT ON SEVERE TROPICAL CYCLONE AIVU

**APRIL** 1989



June 1990

Published by the Bureau of Meteorology 1990 Commonwealth of Australia 1990

## **FOREWORD**

The Bureau of Meteorology is responsible for "the issue of warnings of gales, storms and other weather conditions likely to endanger life and property', a responsibility it assumed from the States shortly after Federation, and reaffirmed by the Meteorology Act (1955-1973).

The operation of the Tropical Cyclone Warning Service has long been a top Priority function with the Bureau. Following all major cyclone impacts, the Bureau examines meteorological aspects of the event, and critically appraises the performance of the warning system.

This report documents the features of severe tropical cyclone *Aivu*, which Made landfall over the Burdekin River delta near the township of Home Hill on 4 April 1989. The event occurred approximately two years after a Federal Government decision to provide additional staff and funds to upgrade severe weather warning services within the Bureau.

Although the upgrades were only partially implemented at the time, Significant progress had been made. Tropical cyclone *Aivu* enabled a preliminary Assessment to be made of the impact of upgrading the warning system, as well as Highlighting aspects requiring further attention.

It was gratifying to find that public perception of the performance of the Tropical Cyclone Warning System was generally much more favourable during *Aivu* than with recent Queensland cyclones *Winifred* (1986) and *Charlie* (1988)

This report was compiled by the staff of the Queensland Severe Weather Section with contributions from other areas of the Bureau's Regional Office.

P. F. Noar Assistant Director Services 6 June 1990

## **CONTENTS**

		Page
Foreward		iii
Executive summary		1
Impact of Aviu		2
Physical characteristics Introduction Movement and track Pressure and wind profiles Satellite surveillance Radar imagery Storm surge Rainfall Flooding Comparison with other notable cyclones	5 17 18	5 5 5 10 10 14 18
Operation of the cyclone warning system Introduction Warning Performance System performance		23 23 23 27
Public and media reaction and post-cyclone activities	28	
Lessons learnt and future needs	31	
Conclusion		33
References		34
Appendix		
1. Selected tropical cyclone advices.		35
Tables		
<ol> <li>Estimated agricultural losses.</li> <li>Terrain influence on wind gust factors.</li> <li>Terrain influence on maximum wind gusts.</li> <li>Warning verification statistics for recent tropical cyclones.</li> <li>Error statistics for various forecast guidance products.</li> </ol>		

# Figures

- 1. Location map.
- 2. Detailed track of cyclone Aivu.
- 3. (a) Barograph trace Ayr.
  - (b) Barograph trace Gumlu.
- 4. Computed radial profile of *Aiuv's* tangential winds.
- 5. (a) Visible wavelength photograph from GMS at 4 pm on 3 April.
  - (b) Visible wavelength photograph from GMS at 10 am on 4 April.
- 6. Infrared wavelength photographs from GMS (6-hourly intervals).
- 7. Radar track of *Aivu* (hourly positions).
- 8. (a) Townsville radar photograph at 10.10 am on 4 April.

- 8 (b) "Merged" radar photograph at 10.10 am on 4 April.
- 9 Bowen storm tide profile on 4 April.
- 10 Rainfall isohyetal map for the 72-hour period to 9 am on 7 April.
- 11 Pioneer River flood hydrographs and mean catchment rainfalls for the period 3 to 5 April.
- 12. Warning verification statistics.

# Damage photographs

- A. Demolished Home Hill residence. (Source: Ayr Advocate)
- B. Catholic Church in Brandon off its stumps. (Source: Ayr Advocate)
- C. Malpass Hotel in Home Hill minus its roof. (Source: Townsville Bulletin)
- D. Remains of foreshore huts on Wunjunga Beach. (Source: Mr R. Brennan, Home Hill)

#### **EXECUTIVE SUMMARY**

Under the Meteorology Act (1955), the Bureau of Meteorology is responsible for "the issue of warnings of gales, storms and other weather conditions likely to Endanger life and property".

Shortly after a major cyclone impacts on Australia, the Bureau of Meteorology conducts an examination of the meteorological aspects of the event and critically reviews the performance of the Tropical Cyclone Warning System.

Public reaction to the warning service during *Aivu* was gauged by actively seeking feedback from citizens and industry groups affected. Senior Bureau officers travelled to the affected areas to attend meetings, distribute survey forms, consult with various individuals and authorities, and conduct media interviews.

Severe tropical cyclone *Aivu*, which crossed the north Queensland coast near Home Hill in the Burdekin River delta on 4 April 1989, was the second cyclone in as many years to affect communities between Townsville and Bowen. On 1 March 1988, tropical cyclone *Charlie*, a relatively weaker system, made final landfall 50 kilometres south of Home Hill.

*Aivu* had significantly greater impact with direct quantifiable damages estimated at \$90M. The only known fatality was an elderly man who drowned in the accompanying storm surge in Upstart Bay, which is situated to the immediate south of the Burdekin River delta.

The Tropical Cyclone Warning Centre in Brisbane issued the first warning for the coastal sector between Townsville and Bowen at 2 pm Sunday 2 April. This effectively gave communities two days to prepare for cyclone *Aivu*. At regular intervals during the 24-hour period prior to landfall, public advices were issued highlighting the major threat posed by the very destructive core of *Aivu*. Communities were also urged to take precautions and, in the final hours, to seek shelter.

It is notable that a leading supermarket in Ayr increased its daily takings from \$19 000 to \$60 000 on Monday 3 April which strongly suggests that the Bureau's messages, promulgated repeatedly via the media, were being correctly interpreted by the public.

Precipitation associated with *Aivu* was directly responsible for record and near record rainfall totals for the month of April at many localities on Queensland's central coast and in the central interior. Major flooding occurred in most creeks and rivers between Townsville and Mackay. Heavy rains subsequently extended over the interior with floodwaters in several inland rivers and streams.

Public criticism of the Bureau's performance was restricted to a handful of individuals whose claims were generally difficult to substantiate. In fact a number of public figures praised the standard of warning service provided during *Aivu*.

Minor technical problems were experienced with Townsville weather watch radar equipment and the Bureau's internal computing system which controls forecast and warning preparation and dissemination. These shortcomings had little or no adverse effect on the warning service.

This report describes the meteorological aspects of *Aivu* together with a critical assessment of the Tropical Cyclone Warning System.

#### IMPACT OF AIVU

Severe tropical cyclone *Aivu* crossed the north Queensland coast near Home Hill late in the morning on Tuesday 4 April 1989. During that afternoon, *Aivu* moved over the Burdekin River delta passing close to the townships of Clare and Ravenswood while weakening into a rain depression. Destructive winds reached the coast around mid-morning though gales had been experienced several hours earlier. Figure 1 identifies the location of landmarks in the landfall zone.

Wind damage extended from Giru in the north to Bowen in the south and about 100 km inland to the ranges south of Charters Towers. The worst affected communities are Ayr, Home Hill, Inkerman and surrounding areas. Of most significance was the destruction of numerous beachfront properties in Upstart Bay, just south of the Home Hill, caused by a 2.5 to 3-metre storm surge.

Only one death was reported. An elderly man was drowned at Molongle Landing in Upstart Bay when the storm surge inundated the foreshore. More than 20 people were treated at hospitals after being struck by flying debris, but these injuries were relatively minor.

While a few buildings were damaged beyond repair by the cyclonic winds, structural damage was generally light. Most damage was of a superficial nature, such as twisted signs, detached awnings and partially unroofed buildings.

Crop and vegetation damage was moderate. Some sugar cane, fruit and field crops were destroyed with no possibility of eventual recovery. Defoliation of trees was in most part confined to exposed hillsides.

In keeping with such events, the total cost of damage caused by *Aivu* is difficult to estimate as there are many losses which can not readily be measured. The quantifiable losses are estimated to total around \$90M. These losses include property damage of nearly \$40M, agricultural losses in the vicinity of \$40M and utilities restoration of close to \$10M.

Insurance payout on property damage including buildings, contents, motor vehicles and boats amounted to \$25M to \$26M. An estimated \$12M to \$15M of similar damage was either uninsured or underinsured.

The crop losses may be compared with an estimate of around \$15M caused by tropical cyclone *Charlie* which affected much the same area some 13 months earlier. The initial worth of sugar cane loss was \$26M but this was adjusted downwards when it was realised that the ensuing rains in the area had increased the yield per hectare of the surviving crop, thus offsetting a portion of the loss. Anticipated agricultural losses are set out in Table 1.

Table 1. Estimated agricultural losses in Aivu

Damage to sugar crop	\$17M
Loss of sugar mill production	\$5M
Damage to market garden crops	\$8-10M
Damage to mango trees	\$2.5M
Damage to other fruit crops	\$4.5M
Damage to field crops	\$2M

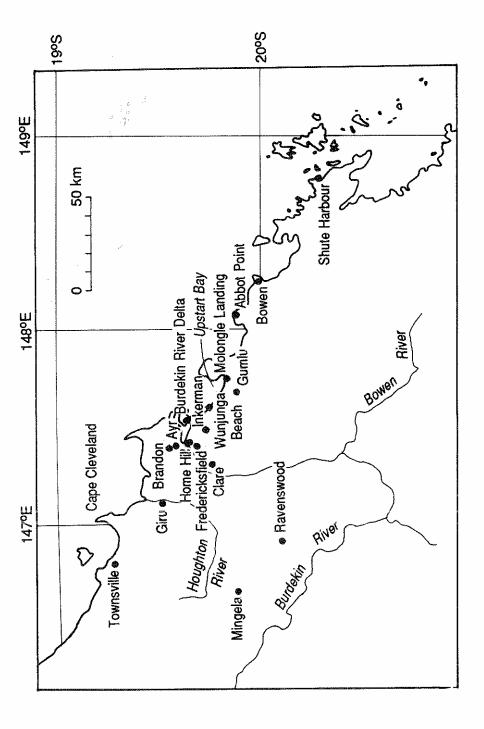


Fig. 1 Location map.

In addition, an estimated \$10M was expended by local authorities on the restoration of public utilities, including rubbish removal by local councils, restoration of power, telephones and water, and road repair.

The Bureau wishes to acknowledge the following organisations for their assistance in providing the preliminary figures presented:

- The Insurance Council of Australia
- Commonwealth Department of Primary Industries and Energy
- Burdekin Shire Council
- Bowen Shire Council
- Main Roads Department
- Water Resources Commission
- North Queensland Electricity Board
- Telecom Australia

# PHYSICAL CHARACTERISTICS

#### Introduction

An assessment of the physical characteristics of cyclone *Aivu* is based on a careful post-analysis of both operationally available data, and information, including detailed barographs, received after the event. For instance, interpretation of radar satellite photographs is simplified somewhat by reference to both preceding and succeeding photographs, which is not possible operationally.

## Movement and track

On Friday 31 March, a 1000 hPa tropical low developed in the Louisiade Archipelago, just off the southeast tip of Paua New Guinea. During the next 24 hours or so, the system intensified while travelling slowly towards the south-southwest. *Aivu* was named by the Tropical Cyclone Warning Centre (TCWC) in Port Moresby at 11 am Saturday 1 April when surrounding winds were estimated to have reached gale force.

At 11 pm that same evening, *Aivu* moved south of latitude 12oS into the area of responsibility of the Brisbane TCWC. The Brisbane TCWC then issued its first storm warning to shipping and aviation.

Throughout Sunday and Monday, *Aivu* tracked in a general southwesterly direction across the Coral Sea towards the Queensland coast at speeds averaging 15 to 20 kilometres per hour. When the pressure fell below 970 hPa early Monday morning, the system was classified as severe. The lowest central pressure during the lifetime of *Aivu* was estimated to be 935 hPa at 4pm Monday.

Early on Tuesday morning *Aivu* began to accelerate towards the coast. Travelling at 30 km/h, *Aivu* made a landfall between Home Hill and Inkerman at 10.30 am Tuesday 4 April with an estimated central pressure of 957 hPa and wind gusts in the vicinity of 200 km/h.

Subsequently, *Aivu* moved inland past Charters Towers and degenerated into a rain depression over western Queensland. The detailed track of *Aivu* is shown in Fig. 2 with the bounds of the very destructive core and the extent of destructive winds given prominence.

## Pressure and wind profiles

The lowest recorded pressure was 959 hPa at Fredricksfield, 10 km south-southwest of Home Hill, while in the cyclone's eye. This reading occurred at 10.45 am on Tuesday 4 April. The highest recorded mean wind was 118 km/h at Holmes Reef (about 240 km east-mortheast of Cairns) at 3.30 pm on Monday 3 April when *Aivu's* centre was 40 km from the reef.

The pressure – radial wind profile of *Aivu* close to the time of coastal crossing was reconstructed using mainly the available barograph data from Ayr and Gumlu. No reliable anemometer readings were available from that area. Therefore the derived profile could not be verified against measured wind data.

The closest approach of the cyclone eye to Gumlu was about 10 km when *Aivu* was straddling the coastline. The lowest corrected mean sea level pressure recorded at Gumlu was 982 hPa at that time (10.30am). The eye passed directly over Ayr shortly after landfall with a corrected minimum mean sea level pressure

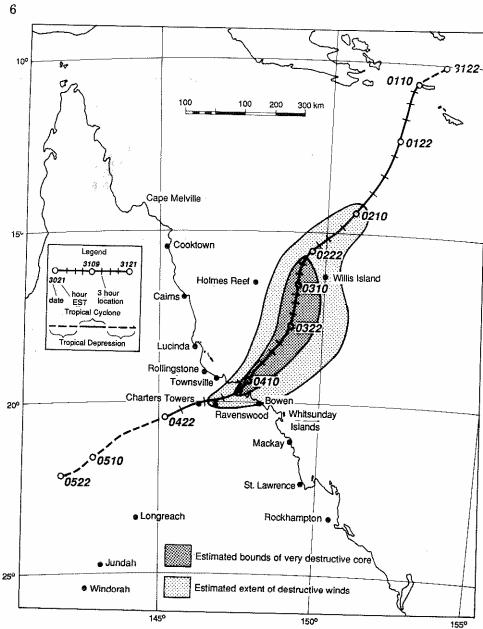


Fig. 2 Detailed track of cyclone Aivu.

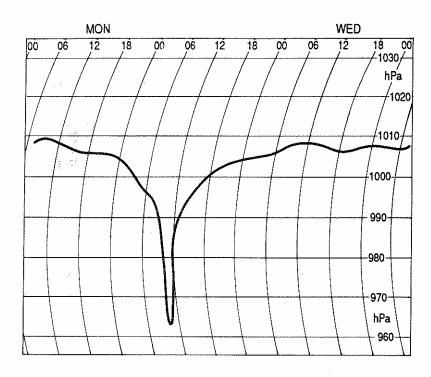


Fig. 3(a) Barograph trace - Ayr.

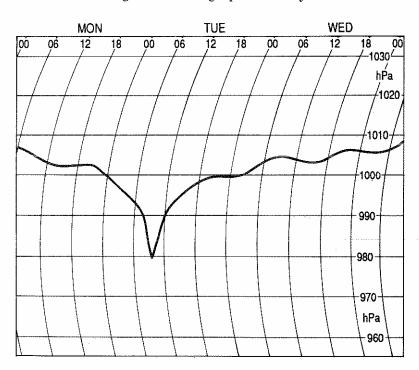


Fig. 3(b) Barograph trace - Gumulu.

of 963 hPa at 11 am. Ayr and Gumlu barograph traces are shown in Figs 3(a) and 3(b) respectively.

Pressure and wind recordings at half-hourly intervals were also available from the Australian Institute of Marine Science (AIMS) automatic weather station (AWS) on Cape Bowling Green. In the post-analysis environment, it was found that the pressure readings appeared to be marginally too low and the wind readings could not easily be converted to 10-minute averages. Hence these data were not used in the profile reconstruction exercise.

An idealised distribution of *Aivu's* tangential wind field just before landfall is provided in Figure 4. This distribution is derived by computing the wind field expected from a symmetrical vortex with *Aivu's* central and environmental pressures. The speed of movement of the cyclone (in this case 30 km/h) is added to the computed winds field to give an estimate of the winds to the southeast of the cyclone centre where the winds speeds are increased by the movement of the system to provide an estimate of the "strongside" winds. Similarly the speed of movement is subtracted from the winds to northeast of the centre to provide an estimate of the "weakside" winds.

The display is an idealised representation of the pressure – radial wind field over the open ocean just prior to *Aivu's* landfall. Both the 10-minute mean wind structure and the gust envelope are displayed. In addition, the extent of hurricane, storm and gale force wind speeds of 120, 90 and 63 km/h respectively.

Radar measurements of the eye radius ranged from 11 km at 10 am, 15 km at 10.30 am (landfall) and 17 km at 11 am. Over a short timeframe of several hours an increasing eye radius is indicative of a weakening system. In contrast, the radius of maximum winds remained more or less constant at 22 km throughout the landfall phase. The estimate of radius of maximum winds was based largely on interpretation of radar photographs and estimated surface wind reports.

Relevant wind gust factors were determined by using the technique described in a workshop paper by George R. Walker (1988), in which he provided a succinct formula for estimating gust factors for various terrain types. Those relationships relevant to the *Aivu* case are presented in Table 2.

Table 2. Terrain in	fluence on win	d gust factors.
---------------------	----------------	-----------------

Terrian Type	Terrain catergory	Gust factor
Calm water/offshore	1	1.3
Rough water/islands	2	1.35
Coastal areas/towns	3	1.4

An adjustment factor of 0.8 (BoM 1978; Powell 1982) is applied to the offshore wind speed to obtain 10-minute estimates for terrain category 3, and 0.9 for terrain category 2. The computed extreme 10-minute mean wind speeds and maximum gusts at time of landfall for all three terrain categories are listed in Table 3. The conclusion to be drawn from these figures is that only areas on the exposed coast and islands to the immediate south of the landfall point would have experienced wind gusts in excess of 200 km/h. Damage reports are not inconsistent with the computed wind profile.

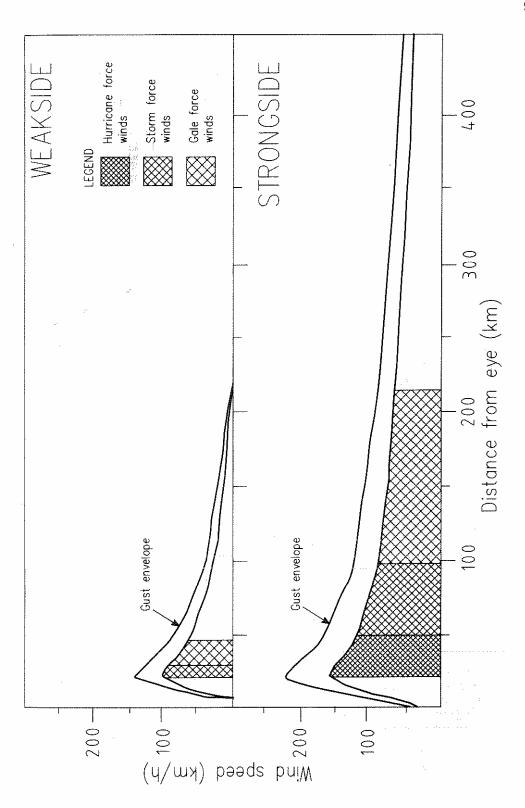


Fig. 4 Computed radial profile of Aivu's tangential winds

Table 3. Terrain influence on maximum wind gusts.

Terrain Type	10-minute wind speed (km/h)	Maximum wind gust (km/h)
Calm water/offshore Rough water/islands	170 155	220 205
Coastal areas/towns	135	190

## Satellite surveillance

Throughout the event, hourly visible and infrared satellite photographs were available from the Japanese Geostationary Meteorological Satellite (GMS). Figure 5(a) and 5(b) show images received near the time of maximum intensity, and at landfall.

A well-defined eye was visible between 2 am Monday and 2 am Tuesday, and between 7 am Tuesday and 10 am Tuesday. During the early hours of Tuesday morning, the cyclone centre was largely obscured by high cloud. In actual fact, it is very likely that *Aivu* had a distinct eye from around midnight Sunday until crossing the coast late on Tuesday morning.

On the "Dvorak" scale (Dvorak 1985), which meteorologists commonly use to classify the intensity of cyclones by interpreting satellite imagery, *Aivu* peaked at T6.5 during the daylight hours on Monday (with an eye diameter around 30 km) and was a T5 when crossing the coast. These values convert to estimated central pressures of approximately 935 and 955 hPa respectively. Figure 6 is a panel of "Dvorak" enhancements of *Aivu* at 6-hourly intervals from 4pm 1 April (0106 Z) to 10 am 4 April (0400 Z).

# Radar imagery

The main radar feature of a tropical cyclone is the eye, an essentially echo-free area surrounded by eyewall clouds organised in a circular or slightly elliptical formation. Further from the cyclone's centre are clouds arranged in spiral bands extending out from the eyewall, typically  $100 \ \text{km} - 300 \ \text{km}$  from the centre.

When the central features of a cyclone are visible on radar, this provides the best available means of determining its location. The hourly radar track of *Aivu's* centre is shown in Fig. 7.

Townsville weather watch radar first detected the spiral bands of *Aivu* around midnight on Monday. By 2 am Tuesday 4 April, the system was sufficiently well defined on radar to confidently track its progress. At that time, *Aivu* was some 220 km northeast of the radar station.

At no time did *Aivu* come within range of the Cairns weather watch radar. Mackay radar was used in conjunction with Townsville during the coastal crossing phase and for several hours before and after. Images were transmitted every 10 minutes from both radars and conveniently displayed with high resolution clarity on a VDU in the Brisbane TCWC.

Although not accessible in real-time during the Aivu event, images from adjacent radars can now be merged to form a composite picture. The significant increase in information content can be readily appreciated by comparing Fig. 8(a) – which is the Townsville radar image alone – with Fig. 8(b) – which is merged

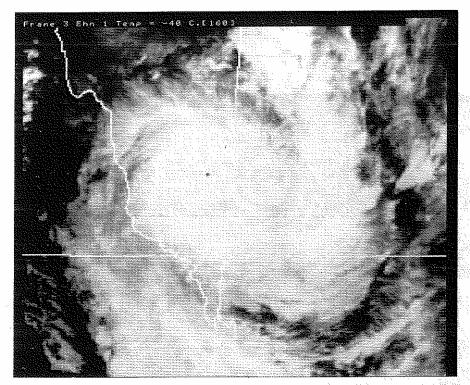


Fig. 5(a) Visible wavelength photograph from GMS at 4 pm on 3 April.

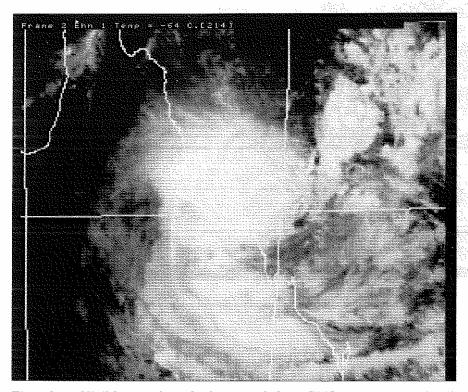


Fig. 5(b) Visible wavelength photograph from GMS at 10 am on 4 April.

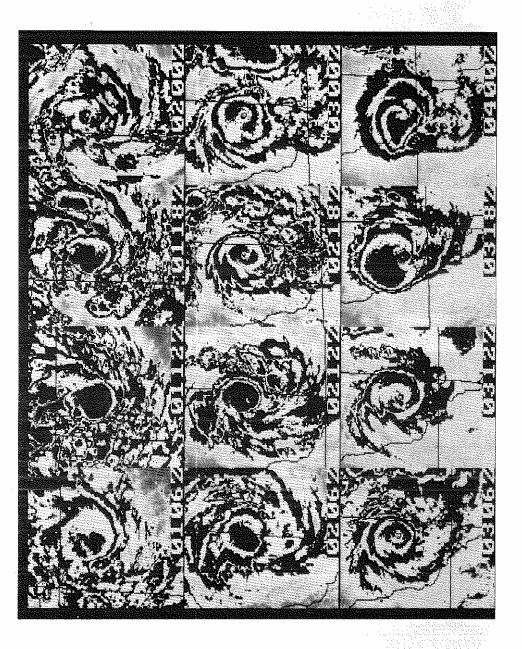


Fig. 6

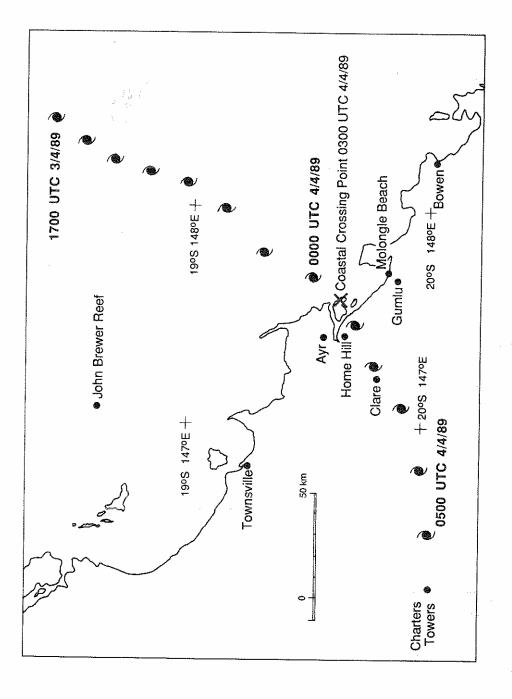


Fig. 7 Radar track of Aivu (hourly positions).

Display from Cairns, Townsville and Mackay radars. *Aivu* was very close to landfall at that time.

#### Storm surge

When a tropical cyclone crosses or closely approaches a coastline there is a concomitant rise in sea level above that expected from astronomical tides alone. This rise in water level is called a storm surge. The abnormal rise in level is caused principally by wind stress on the water surface and (to a lesser degree) by the reduction in atmospheric pressure. A storm tide is defined as the summation of the storm surge and the astronomical tide.

The Bureau of Meteorology has responsibility for the preparation and dissemination of confidential quantitative storm tide warnings indicating potential storm heights to the State Counter Disaster Organisation (SCDO). Warnings are issued only if the predicted storm tide height exceeds the Highest Astronomical Tide (HAT) at the locations under threat. When relevant, qualitative descriptions of storm tide threat are included in public Tropical Cyclone Advices.

Throughout Monday and Tuesday storm tide gauges (operated by the Queensland Department of Harbours and Marine) at Bowen, Abbot Point, Cape Ferguson and Lucinda were interrogated at regular intervals to monitor tide levels. At all locations, levels were above predicted astronomical tides for most of the period.

The closest storm tide recording gauge to the point of landfall was located at Bowen (100 km to the southeast) where a maximum surge of about 1.2metres occurred near 11 am. Figure 9 shows a graphical representation of the Bowen storm tide profile.

A preliminary storm tide warning was issued at 2.30 pm Monday 3 April to the SCDO advising of an expected landfall between Innisfail and Mackay on Tuesday afternoon or evening. The first quantitative storm tide warning was issued at 1.20 am Tuesday advising of the possibility of a storm tide 3 metres above Australian Height Datum (AHD) with the peak storm tide expected near Bowen. Anticipated time of landfall was given as 7 pm.

The 5.15 am warning extended the area of the peak storm tide to the coast between Ayr and Bowen and advanced the expected time of landfall to 4 pm. The 8.15 am warning brought the time of landfall further ahead to 2 pm. A final storm tide warning was issued at 11.15 am after *Aivu's* centre had crossed the coast.

Hourly public advices between 4 am and 10 am Tuesday made specific reference to the storm tide threat. The 4 am advice was directed at communities between Ayr and Shute Harbour but the remainder targetted the Ayr to Bowen coastal zone. Thje actual text of the message read: 'Coastal residents between Ayr and Bowen are warned of the dangerous storm tide which will occur if the cyclone should slow down and cross the coast after 5 pm with this evening's high tide. Low-lying land could be inundated by waves and strong currents.'

The Queensland Department of Harbours and Marine is preparing a detailed report on the storm surge associated with *Aivu*. A final peak surge height is not yet available though preliminary estimates range from 2.5 to 3 metres.

The 'Jelesnianski Nomogram' technique (Jelesnianski 1967; Trajer 1973) is used operationally for storm surge height estimation in the Brisbane TCWD. At a location 22 km along the coast to the south of the coastal crossing point, a peak

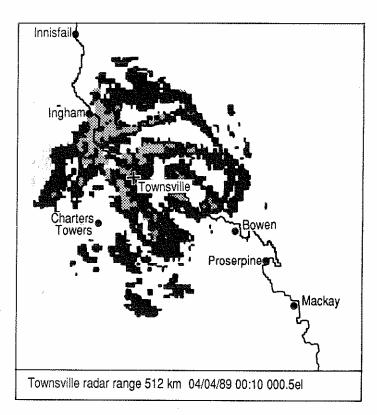


Fig. 8(a) Townsville radar photograph at 10.10 am on 4 April.

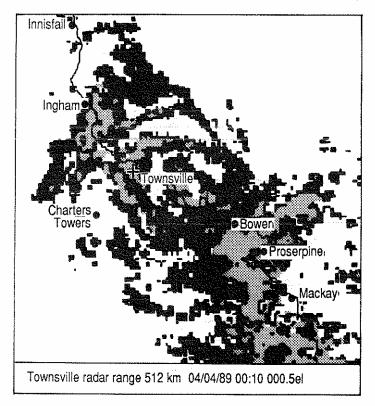


Fig. 8(b) 'Merged' radar photograph at 10.10 am on 4 April.

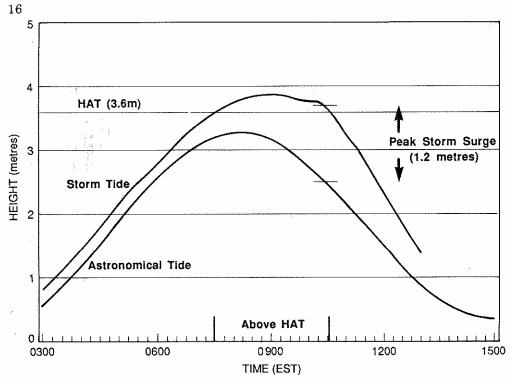


Fig.9 Bowen strorm tide profile on 4 April.

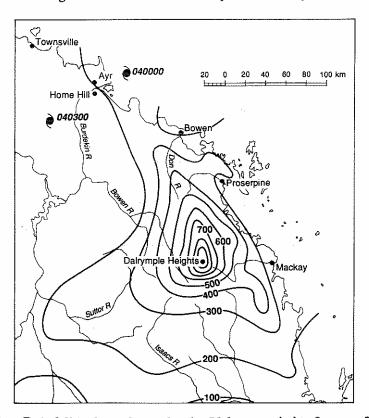


Fig.10 Rainfall isohyetal map for the 72-hour period to 9 am on 7 April.

Surge height of 2.6 metres was derived. This agrees with the preliminary estimate.

To summarise, the confidential storm tide warnings referred to the possibility of a 3 metre surge between Ayr and Bowen on the evening high tide if *Aivu* should slow down. In fact *Aivu* accelerated when nearing the coast, and produced a 2.5 to 3 metre surge in Upstart Bay on the outflowing morning high tide. The operational storm surge model successfully predicted the height of the storm surge.

#### Rainfall

Precipitation associated with *Aivu* produced record and near record rainfall totals for the month of April over large parts of Queensland's central coast and central interior.

An isohyetal map for the 72-hour period to 9 am on 6 April is drawn at Fig. 10 with the daily position of *Aivu* and the subsequent rain depression superimposed. Rainfalls in excess of 200 mm were recorded along the coastal belt between Ayr and St Lawrence. Exceptionally high falls were reported in the ranges to the west of Mackay with several stations receiving in excess of 500 mm for the period. The maximum total was 1082 mm at Dalrymple Heights.

Daily rainfalls were also high with reports of greater than 100 mm in 24 hours being common. Again the highest registration was received at Dalrymple Heights with 581 mm.

In general the areas of heaviest precipitation were located well to the south of the cyclone centre where topographic features enhanced precipitation associated with the outer spiral rainbands.

As *Aivu* moved inland and weakened into a rain depression the heaviest falls contracted into the central west and then across the southern interior of the State. Some significant falls were registered including 200 mm at Longreach – the highest daily rainfall total on record for that township.

The coastal centre of Ayr, 11 metres above sea level and directly in *Aivu's* path, reported the highest recorded one-hour rainfall (for this event) of 71 mm. This fall has an average recurrence interval (ARI) of four years and is consistent with rainfall produced by relatively fast-moving cyclones and their associated convergence zones.

Dalrymple Heights, 680 metres above sea level and 200 km south of *Aivu's* path, reported 434 mm between 6 am and 6 pm on 4 April. This fall has an ARI in excess of 100 years. In comparison, Dalrymple Height's 72-hour total of 1082 mm has an ARI of just greater than 100 years.

As *Aivu* crossed the coast, moist convergent (gale-force) winds were already being experienced over the Pioneer River catchment and these persisted for 48 hours or more. The strongest low-level convergence, as exhibited by the Townsville and Mackay upper wind observations, occurred between 9 am and 9 pm on 4 April. However, the extreme convergence zone and highest three-hour rainfall intensities were evident over the lower Burdekin River near the time of landfall and then moved steadily southward over the Don, Proserpine and Pioneer catchments.

Regular three-hour observations from Longreach indicate that 90 per cent of that centre's rainfall of 185 mm (in the 24 hours to 9 am on 6 April) was recorded between noon and midnight and that 86 per cent of Windorah's total of 57 mm fell between 3 pm and 3 am. Private communication with unofficial rainfall observers in the area confirms that the bulk of the rain fell from about mid-afternoon to shortly after midnight. To place this notable rainfall event into perspective, 24-hour rainfalls of 215 mm for the Longreach-Jundah area have an ARI of near 100 years.

# **Flooding**

Severe local flooding developed in creeks between Townsville and Mackay during Tuesday 4 April. The main flood areas were in the Pioneer River and its tributary Cattle Creek west from Mackay. Major flooding occurred overnight on 4/5 April and produced a flood peak of 7.8 metres at Mackay at about 3 am on Wednesday 5 April.

The major flood peak at Mirani (on the Pioneer River) of 12.20 metres is the third highest in recent times after the February 1958 flood (16.46 metres) and the January 1970 flood (14.02 metres). The corresponding flood at Mackay was 7.80 metres; 0.70 metres lower than the official Bureau forecast. This error was probably due to courseness of the model between Mirani and Mackay which had not taken into account variations in local runoff and attenuation of the peak flood flow due to the spiky nature of the Mirani flood hydrograph.

Pioneer River flood hydrographs and mean catchment rainfalls for the period 3 to 5 April are shown in Fig. 11.

Major flooding in the Proserpine River and moderate flooding in the Don River occurred during Tuesday 4 April. Moderate flooding took place in the Burdekin River below the dam from heavy tributary inflow from the Bowen and Bogie Rivers. This caused a moderate flood peak of 10 metres at Inkerman Bridge.

*Aivu* rainfalls for the 72 hours ended 9am on 6 April also extended south into the headwaters of the Fitzroy River basin and into the Connors and Isaacs Rivers and Funnel Creek catchments. This lead to major flooding in Connors River and Funeral Creek with a subsequent moderate flood peak of 6.0 metres at Rockhampton on 15 April.

Heavy inland rain associated with the low which was formerly *Aivu* fell during the 5 and 6 April in the Thomson and Barcoo River catchments. Severe local flooding occurred initially to the southwest of Longreach. These floodwaters soon made their way into the Thomson River and caused major flooding between Longreach and Jundah within one to two days of the heavy rainfall event. The exceptional rainfall also caused moderate to major flooding in the Bulloo and Paroo Rivers.

More than 60 flood warnings were issued for the period which commenced on 4 April. The flooding in the Thomson, Barcoo and Cooper Creek and the Bulloo and Paroo rivers merged later in the month, coupled with renewed flooding caused by further rainfall in western areas.

# Comparison with other notable cyclones

The Bureau of Meteorology will introduce the concept of cyclone severity categories into cyclone warning messages from the commencement of the 1989/90 cyclone season. The scale ranges from '1' for a system which just reaches cyclone strength to '5' for the most severe tropical cyclones.

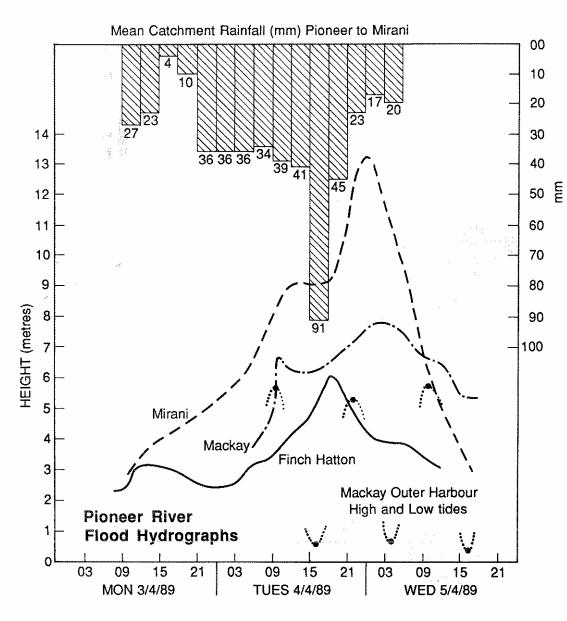


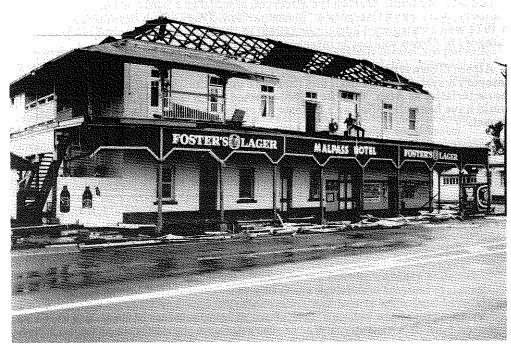
Fig. 11 Pioneer River flood hydrographs and mean catchment rainfalls for the period 3 to 5 April.



Demolished Home Hill residence.



Catholic Church in Brandon off its stumps.



 $Malpass\ Hotel\ in\ Home\ Hill\ minus\ its\ roof.$ 



Remains of foreshore huts on Wunjunga Beach.

At time of landfall, *Aivu* would have been classified as a Category 3 cyclone on this severity scale. During the afternoon of Monday 3 April, when at maximum intensity, *Aivu* was a category 4. In comparison, *Tracy* which devastated Darwin in 1974 was a category 4 and *Orson* (1989) in the West Australian region was a Category 5. *Orson* was not so intense when making landfall.

Althea (Townsville 1971) and Winifred (Innisfail 1986) were both Category 3 systems at landfall and therefore quite similar with respect to damage characteristics as Aivu. Charlie (1988) affected much the same area as Aivu but would have been classified as a Category 2 cyclone and accordingly had far less impact.

#### OPERATION OF THE CYCLONE WARNING SYSTEM

#### Introduction

The overall objective of the tropical cyclone warning system is directed towards the mitigation of cyclone impacts on life and property through the provision of timely, accurate and comprehensible warnings which, at the same time, meet community needs.

The Bureau program is designed to alert the public and counter-disaster organisations as soon a cyclone threat exists, and to provide continuous meteorological advice and warnings until the danger has passed. Appropriate public and institutional response to those warnings is an integral component of the entire process.

The warning system in Queensland is based at the TCWC which is activated when required in the Queensland Regional Office Brisbane. The TCWC is staffed by experienced senior meteorologists and technical staff, with assistance given by officers from the recently established regional severe weather section. Important support roles are provided by Bureau staff in field offices throughout the state.

Modern technology has impacted greatly on the Bureau's ability to detect, track and predict the future behaviour and characteristics of tropical cyclones. Coloured photographs from sophisticated radars and hourly high quality satellite imagery are received and displayed in the TCWC. Regular wind pressure data from offshore automatic weather stations (AWS) together with land-based, ship and aircraft observations are routinely gathered, processed and analysed.

Once a Tropical Cyclone Advice is prepared in the TCWC, it must be disseminated as rapidly and efficiently as possible. Both the preparation and distribution of advices are achieved through the Automated Regional Operating System (AROS). This modern computer system is capable of sending a large number of messages to different telex addresses throughout Queensland in a matter of several minutes.

When gale force winds associated with a tropical cyclone or developing cyclone are expected to affect the coast within 48 hours, a cyclone WATCH is declared for those communities under threat. Advices are normally issued every six hours with amendments when necessary.

On the other hand, if gale force winds are likely within 24 hours, a cyclone WARNING is issued with public advices at least every three hours. However, when a cyclone is close to the coast and being tracked by radar, full-length advices are updated hourly.

Tropical cyclone movement is often of an oscillatory nature. While *Aivu* maintained a generally southwestward track, it fluctuated at times between SSW and WSW. Furthermore, the cyclone accelerated from 15 km/h to 30 km/h in the six hours preceding landfall.

# **Warning Performance**

The first public Tropical Cyclone Advice containing a WATCH message was issued by the Brisbane TCWC at 11.15 am Sunday 2 April for coastal and island communities between Cape Melville and Bowen. These communities were alerted to the possibility of gale force winds developing in their area in one to two days time.

Shortly afterwards at 2 pm, the public advice was upgraded to include a WARNING message from Cooktown to the Whitsunday Islands (which included the Ayr-Home Hill region). Gales were then predicted to develop within 24 hours. The advice issued at 8 am Monday – more than 24 hours before landfall – classified *Aivu* as a severe tropical cyclone and made specific reference to the very destructive core.

Also in the advices was a public service message aimed at minimising the cyclone's impact. Residents in the threatened zone wre urged to take precautions. Warnings from 8 am Monday onwards emphasised that the cyclone posed a major threat to coastal and island communities.

Tropical Cyclone Advices containing WARNING messages were issued at three-hourly intervals until hourly full-length advices commenced at 4 am Tuesday 4 April when *Aivu* came within range of Townsville radar.

From 9 am Tuesday, communities between Townsville and Mackay were advised to complete preparations quickly and take shelter. The warnings focussed on the 100 km radius of destructive or very destructive winds and residents between Ayr and Shute Harbour (in the Whitsundays) were specifically warned of a storm surge.

Coastal crossing details were first given at 4 am Tuesday 4 April, namely, 'later this afternoon between Cape Cleveland and Shute Harbour'. Subsequent Advices included the following predictions:

• 5 am	Advice	'this afternoon between Rollingstone and Bowen'
• 6 am	Advice	'this afternoon between Townsville and Bowen'
• 7am	Advice	'No specific reference to a coastal crossing'
• 8 am	Advice	'No specific reference to a coastal crossing'
• 9 am	Advice	'next few hours between Ayr and the Whitsundays'
• 10 am	Advice	'next few hours between Ayr and Bowen'
• 11 am	Advice	'now crossing the coast near Home Hill'

In summary, 33 Tropical Cyclone Advices were issued for *Aivu* between 11.15 am Sunday 2 April and 10 pm Tuesday 4 April. The final six were abbreviated and did not include a watch or warning area. At one time or another, warning zones stretched from Cooktown to Mackay and watch zones from Cape Melville to Gladstone.

In brief, the Tropical Cyclone Warning System performed creditably with progressively more precise and accurate warnings being issued as *Aivu* approached the coast and the threat increased.

The real-time plot of the track of a tropical cyclone made in a TCWC under operational conditions is subject to errors from various sources. In general, cyclone tracking becomes more accurate as a system becomes more intense and/or moves within range of coastal radar surveillance.

Occasionally there are significant differences between the operational track as presented to the public in Tropical Cyclone Advices and the reconstructed track prepared in the post-analysis phase with the benefit of hindsight and supplementary observational data, unavailable to the TCWC forecasters in real-time.

With respect to the centre of *Aivu*, the average difference between the real-time location and the corresponding post-analysed position was 31 km. This statistic compares more than favourably with the average cyclone position error in

Australia's northeastern region which has been steadily declining over the past decade to now average 40 km.

Another quantitative measure of performance is the average forecast error of the cyclone's central position 12 and 24 hours ahead. Only the 12-hour forecast is given in public advices. The average difference between the operational forecasts for *Aivu* and the corresponding post-analysed track positions was 139 km and 192 km at 12 and 24 hours respectively.

Refer to Fig. 12 which indicates a long-term downwards trend of the 12-hour position error in Australia's northeastern region. The average error is currently about 130 km which is only marginally less than that achieved for *Aivu* Table 4 compares these various statistics for cyclones *Winifred, Charlie and Aivu*. Note that smaller errors occur when a cyclone is close to the coast and being tracked by radar.

Table 4. Warning verification statistics for recent tropical cyclones.

	Initial position Errors (km)		12 h forecast errors (km)		24 h forecast errors (km)	
	Inside radar range	Outside radar range	All	Inside radar range	All	All
Winifred	05	49	42	44	129	350
Charlie	13	48	40	113	126	241
Aivu	24	32	31	67	139	192

Since November 1988, the Meteorological Office in the United Kingdom has distributed analyses and prognoses of tropical cyclones in the Australian region. Guidance products are also received from the National Meteorological Centre in Melbourne in the form of computer derived 'Topend' and 'Cyclone' predictions. Various error statistics relating to *Aivu* are given in Table 5. The 24-hour 'Cyclogue' forecasts were slightly more accurate than the operational forecasts for the same timeframe. As the sample size was quite small, no firm conclusion can be reached.

**Table 5. Error statistics for various forecast guidance products.** 

United Kingdom Global Model		Topend (Aust)	Cyclogue (Aust)	
Initial position	231 km	N/A km	N/A km	
24 h forecasts	312 km	200 km	130 km	
48 h forecasts	435 km	410 km	450 km	
72 h forecasts	600 km	N/A km	N/A km	

The Severe Weather Section of the Brisbane Regional Office has recently developed a technique for predicting the movement of tropical cyclones as they approach the east coast of Queensland. Basically it involves the manner in which cyclones interact with migratory weather systems that sweep across the continent from the west, and produce characteristic vertical wind profiles at coastal observing stations. During the *Aivu* event, the technique predicted 24 hours in

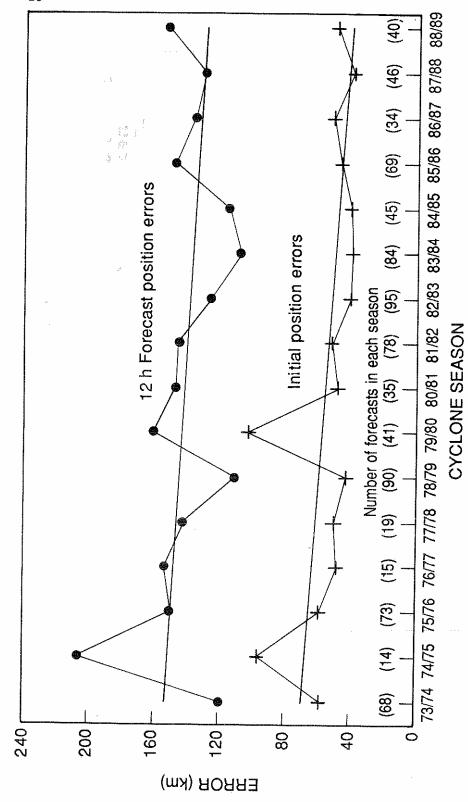


Fig. 12 Warning verification statistics.

Advance that the cyclone would make the landfall between Townsville and Mackay and not, for example, recurve away from the coast.

The media plays a vital ole in relaying the message contained in Tropical Cyclone Advices across to all communities in threatened areas. In addition to the regular issue of official warnings, the Bureau's Regional Director in Brisbane and his senior staff conducted numerous radio and television interviews- especially on Monday and Tuesday – in which they emphasised that the very destructive winds around *Aivu* extended out to 100 km from the cyclone centre and that appropriate precautions should be taken.

# **System performance**

Dissemination of all advices was satisfactorily achieved despite the fact that the operational computer system (AROS) was operating close to maximum capacity. To exacerbate the situation, Flood Warnings were also being disseminated. Importantly, no meteorological data was lost and hourly advices were processed efficiently.

On normal days, AROS transmits approximately 2000 messages. On 4 April the system sent in excess of 5000 messages. For the first time ever, the circular file which logs the telex calls over-wrote itself. Consequently, the size of the journal file in Queensland has been increased to accommodate 7000 messages.

The ensuing rain situation over southern Queensland resulted in more rainfall reports being received than on any previous occasion. The Database and Statistics Package in AROS could not extract the large number of rainfall reports until the size of temporary storage file was enlarged.

The effect of a significant increase in both product dissemination and processing of incoming data impacted severely upon the response of the Tandem computer driving AROS. In addition to complaints of poor terminal response from TCWC meteorologists, the processes controlling recognition and storage of incoming data experienced some delays- at one point by 50 minutes. This resulted in late plotting of the upper level winds scheduled around 11 am on 4 April. Remedial action consisting of central processor unit (CPU) balancing was taken to clear the processing backlog.

Dissemination of public advices was maintained at high priority and queues did not build up on any of the outgoing telex lines. While one particular advice took up to 24 minutes to clear the last call, the vast majority were transmitted within 15 minutes of issue from the AROS terminals. The later ones were generally attributable to telex recalls.

Overall the performance of the AROS system was adequate, with no computer software faults or mechanical breakdowns. Even when fully loaded, no data were last and no timeouts occurred. Nevertheless, the system appeared to be working very close to full capacity with delays of incoming data and (at times) poor terminal response. The solution to these problems is a full CPU upgrade which is scheduled for 1990.

Some technical problems were encountered with Townsville radar though these had little of no adverse effect on the ability of the TCWC to satisfactorily monitor the progresss of AIVU. Automatic transmission of radar pictures (Rapics) to the TCWC was interrupted for two short periods, the first around midnight on Monday and the second about daybreak on Tuesday. Except during the actual power failures, radar pictures were available at all times from the Townsville Meteorological Office where polaroid photographs wre taken and sent by facsimile to the Brisbane TCWC.

## PUBLIC AND MEDIA REACTION AND POST-CYCLONE ACTIVITIES

Criticism of the Bureau's warning service appeared in a front page headline article in the Brusbane 'sun' on Wednesday 5 April. North Queenslanders were quoted as saying that the warnings intimated the cyclone would affect Bowen, some 100 km to the southeast, and that they were not adequately warned of the impending danger. In response to that criticism, it should be noted that the 8am advice on Tuesday referred explicitly to the likelihood of 'very destructive winds' between Ayr and the Whitsunday Islands later in the morning.

In a press release on 5 April, the Hon Stewart West (Federal Minister for Department of Administrative Services) refuted the claims made on the front page of the Brisbane Sun earlier in the day. He emphasised the point that the story published did not agree with the facts. To quote from that press release: 'The Bureau produced very accurate advance warning of the cyclone and issued detailed warning information on an hour-by-hour basis as it approached the coast'.

Later in the press release, the Hon Stewart West spoke of the increased effectiveness of warning services brought about by the Federal Government's action to upgrade the Bureau's basic equipment and provide additional specialist staff for the TCWCs. In conclusion, he noted that 'it was pleasing to see that measures taken by the Government and dedication of the Bureau's staff in Queensland resulted in such effective warnings for this destructive cyclone'.

The Regional Director of the Brisbane Bureau also replied to the story in the Sun with a letter to the Editor, the substance of which was printed in the final edition that same day.

Just a few days after the event, two officers from the Bureau's Regional Office in Brisbane visited coastal areas from Townsville to Bowen and inland to Charters Towers. On one excursion, they were accompanied by the acting officer-in-charge of the Townsville, Ayr, Home Hill, Bowen, Charters Towers, Mingela, Ravenswood, Clare, Molongle Landing and Wunjunga Beach.

The purpose of these visits was to:

- Conduct a public opinion survey focussing on the perceived effectiveness of the warning service;
- Liase with counter disaster organisations;
- Contact local media outlets to provide interviews and conduct talk-back radio sessions;
- Check as many barometers and barographs as possible in the general area;
- Obtain additional information on the effects of the cyclone, especially with respect to the landfall point, storm tide effects and extent of damage.

## **Public opinion survey**

This was conducted in several ways. Firstly questionnaire forms were distributed at two major shopping centres, one in Ayr and the other in Bowen. The forms were generally completed on the spot and collected. Forms were also given to almost everyone who made enquiries, for later completion and return by mail. Lastly bundles of questionnaires were left at Home Hill Post Office, Gumlu Post Office, Clare Post Office, Charters Towers, Mingela, Ravenswood, Wunjunga Beach and Molongle Landing – for later distribution and return by mail.

Analysis of the questionnaire returns indicates a marked shift in public

opinion for the better. Communities were generally more satisfied with the warning service than during past cyclone events, eg *Charlie* in 1988. In the past, the Bureau has received praise from a minority; this is now a significant majority. Furthermore, some people are defending the Bureau in public against those who still choose to complain.

The main negative public reaction was attributed to the use of a condtional 'if' statement in tome advices. The phrase 'if the cyclone crosses the coast after 5 pm' in advices 16 through 21 was construed in one of two ways:

- In the case of people who were already aware that they were vulnerable to storm surges, the phrase was virtually ignored and the message was interpreted as a warning of a storm surge.
- In the case of people who are not geographically under serious threat from storm surges, the time '5 pm' was interpreted as the forecast coastal crossing time with the morning landfall coming as somewhat of a surprise.

## Liason with counter disaster organisations

A senior Bureau officer attended a formal meeting of the Burdekin Local Authority Counter Disaster Committee in Ayr. The committee made specific comment on the superior accuracy of Tropical Cyclone Advices for *Aivu*. The same Bureau officer also held discussions in Bowen with representatives of the Bowen Shire Council, Police and State Emergency Services (SES).

A week later two senior Bureau officers – including the Queensland Regional Director – attended the final debriefing meeting in Ayr, convened by the Townsville Disaster District Coordinator (DDC), at which all aspects of warning services, community response and recovery were discussed. Points to emerge from this meeting were:

- Criticism by the DCC of the standard of media reporting during and after the event;
- Heightened awareness of SES to storm tide problems;
- Praise of Bureau performance by Mr R. Braithwaite MHR for Dawson at a previous meeting of counter disaster groups on 5 April was firmly endorsed by all present. (Note that this assessment is in stark contrast to the Brisbane Sun headline of 5 April claiming public outrage at Bureau performance.)
- SES foreshadowed a meeting to review coordinated procedures for storm tide warning and evacuation following the experience of *Aivu*.

#### **Media contacts**

The problems associated with networking arrangements were discussed with local media. The desirability of not taking scheduled network programs during cyclone events was generally agreed upon. Interviews were given on radio stations ABC, 4TO and 4GC and also on the commercial television channel (TNQ7) in Townsville.

TNQ7 has employed academic staff from Townsville's James Cook University to interpret advices both during *Charlie* in 1988 and again during *Aivu*. The feasibility of using Bureau staff for future 'live' presentations was favourably viewed by local media management.

## **Barometers and barographs**

These were checked at several locations and the majority were found to be accurate to with in 2 hPa.

## **Additional information**

Bureau officers took numerous photographs of damage sites and also arranged for copies of photographs taken by the local print media and by private citizens to be forwarded to the Brisbane Regional Office. These were later archived as part of the complete cyclone record.

Complimentary messages relating to Bureau performance during *Aivu* were received from the following north Queensland identities:

- Senator The Hon Margaret Reynolds;
- Mr R.A.Braithwaite Federal Member for Dawson (MHR);
- (the late) Professor K.P.Stark from James Cook University;
- Mr J.D.Holden General Manager of the Dalrymple Bay Coal Terminal near Mackay.

#### LESSONS LEARNT AND FUTURE NEEDS

The Tropical Cyclone Warning Service is very complex and continuously evolving. Every major cyclone tests the system and highlights the criticality of various components. The Bureau's review of *Aivu* has brought into focus the following aspects of the service.

## Storm tide warnings

There is a need to review procedures for the provision of confidential storm tide warnings to the SCDO, with the objective of providing more lead time for emergency evacuation procedures. Storm tide messages to the public and SCDO must be geared to a 'worst probable' scenario, assuming landfall at high tide.

Although the above procedures will lead to more frequent and extensive emergency evacuations, they will provide added safeguards against a last minute change in warning strategy and a disastrous failure to evacuate in time. Agreement has been reached with SCDO to review procedures in line with the above findings.

The Bureau's research centre in Melbourne has recently developed a sophisticated computer model which simulates a cyclone storm surge. The model will undergo thorough testing during a number of cyclone events before it is implemented operationally. Storm surge predictions with higher resolution in time and space should result.

# **Tropical Cyclone Advices**

More effort needs to placed on maintaining a consistent and predictable message format. Computer software designed to facilitate text preparation is being evaluated.

Commencing with the 1989/90 cyclone season, an estimate of cyclone severity will be included in all public advices. Communities will then be able to be better assess the degree of cyclone threat and take appropriate action. As noted previously, categories of cyclone severity range from '1' for a system just reaching cyclone strength to '5' for the most severe cyclone. However, there is no direct correspondence between storm tide and cyclone severity category as other factors besides cyclone intensity are involved.

## **Radar and Satellite systems**

The coastal weather watch radar network again proved invaluable in monitoring the progress of *Aivu* in the critical hours prior to landfall. Over the next few years, radars will be installed in the southern Gulf of Carpentaria and on Willis Island (in the Coral Sea), thereby further improving the Bureau's capability to track tropical cyclones.

During the 1988/89 cyclone season, the capacity to receive hourly high resolution satellite imagery in the TCWC was realised. The computer system which enables direct access to such imagery is the Australian Region McIDAS (ARM). This advanced system is undergoing continual development and will ultimately function as the primary workstation for meteorologists in the TCWC.

#### **Automatic weather stations**

The Bureau's existing AWS network provides the only reliable direct measurements of tropical cyclones threatening the coast. This network needs to

be strengthened with robust, compatible equipment. The technology to ingest regular observations from these observation platforms direct into Bureau computers is already available. Current plans are to install AWS at Hardy Reef (near Mackay), Cape Bowling Green (near Townsville) and Bougainville Reef (western Coral Sea) within the next 12 months.

## **Observations**

As was stated earlier, there were no instrumented wind measurements in the Ayr-Home Hill region. Accordingly, the Bureau is actively pursuing the provison and installation of a synchrotac anemometer and data logging device at the Aur observing station as part of a planned upgrade of the coastal anemometer network.

In the light of experience during *Aivu*, emergency cyclone observers reruited by the Bureau will be encouraged to spontaneously commence reporting when a cyclone threat is imminent in case the Bureau is unable to make the initial contact due to communication problems. Arrangements have recently been made to obtain emergency observations from SES volunteers. As only one report was received by the TCWC during *Aivu*, the new initiative requires some promotion.

## **State Government action**

Queensland State Cabinet has commissioned an independent assessment of response effectiveness during *Aivu*. An operating budget of \$45 000 has been allocated for research into the effects of *Aivu*, focusing on the physical and psychological impacts. More appropriate ways of coping with natural disasters are expected to emerge. The research team will be directed by Professor George Kearney, Pro-Vice Chancellor and Professor of Behavioural Sciences at James Cook University in Townsville.

## **Public awareness**

Although *Aivu* was classified as a severe cyclone, the potential for a more intense and damaging system, perhaps affecting a major centre, must be recognized. In collaboration with the SCDO, the Bureau plans to do its part in seeing that communities are fully aware of the associated risks. To assist with the public awareness drive, and informative brochure on the Tropical Cyclone Warning System has recently been released and is freely available.

# **CONCLUSION**

Aivu was the second severe tropical cyclone to directly affect the north Queensland coast this decade. In February 1986, Winifred had serious impact on the Innisfail region with a total damage bill estimated to be in excess of \$130M. Although a preliminary damage figure of \$90M has been quoted for Aivu, the final cost to the community may not be too far short of that inflicted by Winifred.

Given the complexity of the behaviour of tropical cyclones and the inherent difficulty in forecasting the precise time and location of landfall, the warning system performed very effectively. At least 24 hours warning was given of destructive winds between Ayr and the Whitsunday Islands and numerous media interviews given by senior Bureau staff emphasised the serious nature of the threat.

Technical problems encountered with Townsville radar and the AROS computer system were relatively minor and are being internally redressed. Importantly, they had no adverse effect on the warning service provided by the Brisbane TCWC.

Isolated pockets of public criticism directed at the performance of the Bureau were found in most instances to have little substance. In retrospect, the communication of storm tide information near the time of landfall was somewhat confusing due to the acceleration of the cyclone and an attempt to relate possible coastal crossing times to the astronomical tide range.

Nevertheless, the storm tide message contained in the broadcast Tropical Cyclone Advice from 4 am Tuesday was received loud and clear by the public in beachfront areas. Storm tide warning strategies have been revised in consultationj with SES as a result of the experience.

Visits of senior Bureau personnel to the affected region shortly after the event were considered to be extremely worthwhile by all parties, including the general public, heads of industry, media representatives and SCDO personnel. Through constructive feedback from these sources, the Bureau is able to make sound decisions on upgrades to the Tropical Cyclone Warning Sevice.

At the commencement of the 1989/90 cyclone season the Bureau introduced a five-level severity scale for tropical cyclones. The primary goal of this initiative is to enable communities to better assess the degree of threat posed by any cyclone. Within the next few years, weather watch radar coverage will be extended to encompass the southern Gulf of Carpentaria and waters surrounding Willis Island in the Coral Sea. More coastal and offshore automatic weather stations are also planned.

Over the next five years or so, the Queensland Tropical Cyclone Warning System should benefit greatly from several factors- the Bureau's equipment upgrade, the research efforts of specialist staff, and a more visible and relevant public education program.

# **REFERENCES**

- Bureau of Meteorology. 1978. Australian Tropical Cyclone Forecasting Manual. Bur. Met., Australia.
- Dvorak, V.F. 1984. Tropical cyclone intensity analysis using satellite data. NOAA Technical Report NESDIS 11, 47 pp.
- Jelesnianski, C.P. 1967. Numerical computations of storm surges with bottom stress. MWR Volume 95, 740-56.
- Powell, M.D. 1982. The Transition of the Hurricane Frederic Boundary-Layer Wind Field from the Open Gulf of Mexico to Landfall. MWR Volume 110, 1912-32.
- Trajer, F.L. 1973. A manual storm surge forecasting scheme. First Australian Conference on Coastal Engineering, I.E.Aust., Crows Nest, NSW, 215-19.
- Walker, G.R. 1988. Wind Characteristics. Cyclone Engineering in Coastal Regions Seminar, James Cook University of North Queensland, Townsville.

# SELECTED TROPICAL CYCLONE ADVICES

Tropical Cyclone Advice No.	1 issued 11.15am Sunday 2 April 1989.	
2 issued	2pm	Sunday 2 April 1989.
8 issued	8am	Monday 3 April 1989.
13 issued	11pm	Monday 3 April 1989.
15 issued	4am	Tuesday 4 April 1989.
17 issued	6am	Tuesday 4 April 1989.
20 issued	9am	Tuesday 4 April 1989.
21 issued	10am	Tuesday 4 April 1989.
22 issued	11am	Tuesday 4 April 1989.
23 issued	Noon	Tuesday 4 April 1989.

**PRIORITY** 

TROPICAL CYCLONE ADVICE NUMBER 1 ISSUED BY THE BUREAU OF METEOROLOGY BRISBANE AT 11.15 AM EST SUNDAY 2/4/1989.

A TROPICAL CYCLONE WATCH IS NOW CURRENT FOR COASTAL AND ISLAND COMMUNITIES BETWEEN CAPE MELVILLE AND BOWEN. AT 10 AM TROPICAL CYCLONE AIVU WAS LOCATED NEAR LATITUDE 14.2 SOUTH LONGITUDE 150.8 EAST, WHICH IS 680 KILOMETRES EAST OF CAPE

MELVILLE AND MOVING SOUTHWEST AT ABOUT 18 KILOMETRES PER HOUR. IT IS EXPECTED TO MOVE CLOSER TO THE COAST AND MAY EFFECT COASTAL AREAS LATE MONDAY.

RESIDENTS BETWEEN CAPE MELVILLE AND BOWEN SHOULD CONSIDER ACTION

THEY

WILL NEED TO TAKE IF THE CYCLONE THREAT INCREASES AND LISTEN TO THE NEXT ADVICE AT ABOUT 5 PM EST TODAY.

PRIORITY FLASH TROPICAL CYCLONE ADVICE NUMBER 2 ISSUED BY THE BUREAU OF METEOROLOGY BRISBANE AT 2 PM EST SUNDAY 2/4/19

A TROPICAL CYCLONE WARNING IS NOW CURRENT FOR COASTAL AND ISLAND COMMUNITIES BETWEEN COOKTOWN AND THE WHITSIINDAY ISLANDS. A TROPICAL CYCLONE WATCH EXTENDS SOUTH TO ST LAWRENCE.

TROPICAL CYCLONE AIVU HAS ACCELERATED AND IS EXPECTED TO CONTINUE MOVING CLOSER TO THE COAST. GALES AND HEAVY RAINS MAY DEVELOP ON THE COAST BETWEEN COOKTOWN AND THE WHITSUNDAY ISLANDS EARLY ON MONDAY.

DETAILS OF TROPICAL CYCLONE AIVU AT 2 PM 2/4/1989 LOCATION OF CENTRE: WITHIN 60 KILOMETRES OF

LATITUDE 15.1 DEGREES SOUTH

LONGITUDE 150.0 DEGREES EAST

CENTRAL PRESSURE : 985 HECTOPASCALS

CURRENT MOVEMENT: SOUTHWEST AT 25 KILOMETRES PER HOUR MAXIMUM WIND GUSTS: 125 KILOMETRES PER HOUR NEAR THE CENTRE

THE NEXT ADVICE WILL BE ISSUED AT 5 PM SUNDAY

PRIORITYTROPICAL CYCLONE ADVICE NUMBER 8 ISSUED BY THE BUREAU OF METEOROLOGY BRISBANE AT 8 AM MONDAY 3/4/1989

A TROPICAL CYCLONE WARNING IS NOW CURRENT FOR COASTAL AND ISLAND COMMUNITIES BETWEEN CAIRNS AND THE WHITSUNDAY ISLANDS.

A TROPICAL CYCLONE WATCH EXTENDS SOUTH TO YEPPOON.

SEVERE TROPICAL CYCLONE AIVU NOW HAS A VERY DESTRUCTIVE OORE WITH WIND CUSTS TO 230 KILOMETRES PER HOUR NEAR ITS CENTRE. AIVU IS POSING A MAJOR THREAT AND IS EXPECTED TO MOVE SLOWLY CLOSER TO THE COAST AND PRODUCE GALES ALONG THE COAST BETWEEN CAIRNS AND THE WHITSUNDAY ISLANDS LATER TODAY. THESE GALES SHOULD INCREASE DURING THE NIGHT. RAIN SHOULD ALSO INCREASE ALONG THE COAST DURING THE DAY.

DETAILS OF SEVERE TROPICAL CYCLONE AIVU AT 8 AM 3/4/1989

LOCATION OF CENTRE : WITHIN 40 KILOMETRES OF

LATITUDE 16.4 DEGREES SOUTH LONGITUDE 149.1 DEGREES EAST

ABOUT 390 KILOMETRES EAST OF PORT

**DOUGLAS AND** 

ABOUT 400 KILOMETRES NORTHEAST OF

**TOWNSVILLE** 

CENTRAL PRESSURE : 950 HECTOPASCALS

CURRENT MOVEMENT : SOUTHWEST AT 10 KILOMETRES PER HOUR DESTRUCTIVE WINDS : OUT TO 120 KILOMETRES PER HOUR NEAR

THE CENTRE

RESIDENTS BETWEEN CAIRNS AND THE WHITSUNDAY ISLANDS ARE ADVISED TO TAKE PRECAUTIONS AND LISTEN TO FURTHER ADVICES.

THE NEXT ADVICE WILL BE ISSUED AT 11 AM.

PRIORITY TROPICAL CYCLONE ADVICE NUMBER 13 ISSUED THE BUREAU OF METEOROLOGY BRISBANE AT 11 PM MONDAY 3/4/1989.

A TROPICAL CYCLONE WARNING IS NOW CURRENT FOR COASTAL AND ISLAND COMMUNITIES BETWEEN CARDWELL AND MACKAY.
A TROPICAL CYCLONE WATCH EXTENDS SOUTH TO YEPPOON.
THE CYCLONE WARNING IS CANCELLED FROM CAIRNS TO CARDWELL.

SEVERE TROPICAL CYCLONE AIVU HAS A VERY DESTRUCTIVE CORE WITH WIND GUSTS TO 230 KILOMETRES PER HOUR NEAR ITS CENTRE. AIVU IS POSING A MAJOR THREAT AND IS EXPECTED TO CONTINUE TO MOVE SLOWLY TOWARDS THE COAST. GALES SHOULD DEVELOP BETWEEN CARDWELL AND MACKAY EARLY ON TUESDAY WITH DESTRUCTIVE WINDS FROM AYR TO THE WHITSUNDAY ISLANDS LATER IN THE MORNING.

DETAILS OF SEVERE TROPICAL CYCLONE AIVU AT 11 PM 3/4/1989

LOCATION OF THE CENTRE :WITHIN 40 KILOMETRES OF

: LATITUDE 17.8 DEGREES SOUTH : LONGITUDE 148.9 DEGREES EAST : ABOUT 300 KILOMETRES EAST OF

: TULLY AND

: ABOUT 250 KILOMETRES NORTH

NORTHEAST OF BOWEN

CENTRAL PRESSURE : 940 HECTOPASCALS

CURRENT MOVEMENT : SOUTH AT 12 KILOMETRES PER HOUR DESTRUCTIVE WINDS : OUT TO 100 KILOMETRES FROM THE

CENTRE

MAXIMUM WIND GUSTS : 230 KILOMETRES PER HOUR NEAR THE

CENTRE

RESIDENTS BETWEEN CARDWELL AND MACKAY ARE ADVISED TO TAKE PRECAUTIONS AND LISTEN TO FURTHER ADVICES.

THE NEXT ADVICE WILL BE ISSUED AT 2 AM.

TOP PRIORITY TROPICAL CYCLONE ADVICE NUMBER 15 ISSUED BY THE BUREAU OF METEOROLOGY BRISBANE AT 4 AM TUESDAY 4/4/1989.

A TROPICAL CYCLONE WARNING IS NOW CURRENT FOR COASTAL AND ISLAND COMMUNITIES BETWEEN INGHAM AND MACKAY.
A TROPICAL CYCLONE WATCH EXTENDS SOUTH TO YEPPOON.

THE VERY DESTRUCTIVE CORE OF SEVERE TROPICAL CYCLONE AIVU WITH EXTREME GUSTS UP TO 230 KM/H SHOULD CROSS THE COAST BETWEEN CAPE CLEVELAND AND SHUTE HARBOUR LATER THIS AFTERNOON.

SEVERE TROPICAL CYCLONE AIVU IS NOW BEING TRACKED BY RADAR AND HAS A VERY DESTRUCTIVE CORE WITH WIND GUSTS TO 230 KILOMETRES PER HOUR NEAR ITS CENTRE. AIVU IS POSING A MAJOR THREAT AND IS EXPECTED TO CONTINUE TO MOVE TOWARDS THE COAST. GALES DEVELOPING BETWEEN CARDWELL AND MACKAY WITH DESTRUCTIVE WINDS FROM AYR TO THE WHITSUNDAY ISLANDS DURING THIS MORNING INCREASING TO VERY DESTRUCTIVE WINDS THIS AFTERNOON.

COASTAL RESIDENTS BETWEEN AYR AND SHUTE HARBOUR ARE SPECIFICALLY WARNED OF THE DANGEROUS STORM TIDE EXPECTED WHEN THE CYCLONE CENTRE CROSSES THE COAST. TIDES ARE LIKELY TO RISE RAPIDLY TO VERY MUCH ABOVE- HIGH WATER MARK. LOW LYING COASTAL LAND WILL BE INUNDATED WITH WAVES AND STRONG CURRENTS.

FLOOD RAINS ARE LIKELY BETWEEN AYR AND MACKAY.

DETAILS OF SEVERE TROPICAL CYCLONE AIVU AT 4 AM 4/4/1989

LOCATION OF CENTRE : WITHIN 20 KILOMETRES OF

LATITUDE 18.4 DEGREES SOUTH LONGITUDE 148.4 DEGREES EAST

ABOUT 200 KILOMETRES EAST NORTHEAST OF

TOWNSVILLE AND

ABOUT 160 KILOMETRES NORTH OF BOWEN

CENTRAL PRESSURE : 940 HECTOPASCALS

CURRENT MOVEMENT : SOUTH SOUTHWEST AT 12 KILOMETRES PER

**HOUR** 

DESTRUCTIVE WINDS ; OUT TO 100 KILOMTRES FROM THE CENTRE

MAXIMUM WIND GUSTS: 230 KILOMETRES PER HOUR NEAR THE

CENTRE

RESIDENTS BETWEEN CARDWELL AND MACKAY ARE ADVISED TO TAKE PRECAUTIONS AND LISTEN TO FURTHER ADVICES.

THE NEXT ADVICE WILL BE ISSUED AT 5 AM.

TOP PRIORITY TROPICAL CYCLONE ADVICE NUMBER 17 ISSUED BY THE BUREAU OF METEOROLOGY BRISBANE AT 6 AM TUESDAY 4/4/1989.

A TROPICAL CYCLONE WARNING IS NOW CURRENT FOR COASTAL AND ISLAND COMMUNITIES BETWEEN INGHAM AND MACKAY.
A TROPICAL CYCLONE WATCH EXTENDS SOUTH TO YEPPOON.

THE VERY DESTRUCTIVE CORE OF SEVERE TROPICAL CYCLONE AIVU WITH EXTREME GUSTS UP TO 210 KM/H HOULD CROSS THE COAST BETWEEN TOWNSVILLE AND BOWEN THIS AFTEROON.

SEVERE TROPICAL CYCLONE AIVU IS NOW BEING TRACKED BY RADAR AND IS MOVING SOUTHWEST AT 15 KM/H TOWARDS THE COAST.

AIVU HAS A VERY DESTRUCTIVE CORE WITH WIND GUSTS TO 210 KILOMETRES PER HOUR NEAR ITS CENTRE AND IS POSING A MAJOR THREAT TO COASTAL AREAS BETWEEN ROLLINGSTONE AND BOWEN. DESTRUCTIVE WINDS ARE EXPECTED TO DEVELOP THIS MORNING ALONG THE COAST AND INCREASE TO VERY DESTRUCTIVE THIS AFTERNOON.

COASTAL RESIDENTS BETWEEN AYR AND BOWEN ARE SPECIFICALLY WARNED OF THE DANGEROUS STORM TIDE EXPECTED IF THE CYCLONE CROSSES THE COAST AFTER 5 PM THIS AFTERNOON. LOW LYING LAND COULD BE INUNDATED BY WAVES AND STRONG CURRENTS.

FLOOD RAINS ARE LIKELY BETWEEN AYR AND MACKAY.
DETAILS OF SEVERE TROPICAL CYCLONE AIVU AT 6 AM 4/4/1989

LOCATION OF CENTRE : WITHIN 20 KILOMETRES OF

LATITUDE 18.7 DEGREES SOUTH LONGITUDE 148.1 DEGREES EAST

ABOUT 155 KILOMETRES NORTHEAST OF

**TOWNSVILLE AND** 

ABOUT 137 KILOMETRES NORTH OF BOWEN

CENTRAL PRESSURE : 945 HECTOPASCALS

CURRENT MOVEMENT : SOUTHWEST AT 15 KILOMETRES FROM THE

**CENTRE** 

DESTRUCTIVE WINDS : OUT TO 100 KILOMETRES FROM THE CENTRE

MAXIMUM WIND GUSTS: 210 KILOMETRES PER HOUR NEAR THE

**CENTRE** 

RESIDENTS BETWEEN INGHAM AND MACKAY ARE ADVISED TO TAKE PRECAUTIONS AND LISTEN TO FURTHER ADVICES.

TOP PRIORITY TROPCIAL CYCLONE ADVICE NUMBER 20 ISSUED BY THE BUREAU OF METEOROLOGY BRISBANE AT 9 AM TUESDAY 4/4/1989.

A TROPICAL CYCLONE WARNING IS NOW CURRENT FOR COASTAL AND ISLAND COMMUNITIES BETWEEN INGHAM AND ST LAWRENCE. A TROPICAL CYCLONE WATCH EXTENDS SOUTH TO YEPPOON.

THE VERY DESTRUCTIVE CORE OF SEVERE TROPICAL CYCLONE AIVU WITH EXTREME GUSTS UP TO 200 KM/H SHOULD CROSS THE COAST BETWEEN AYR AND THE WHITSUNDAY ISLANDS WITHIN THE NEXT FEW HOURS. DESTRUCTIVE WINDS ARE EXPECTED BETWEEN TOWNSVILLE AND MACKAY.

SEVERE TROPICAL CYCLONE AIVU IS BEING TRACKED BY RADAR AND IS MOVING SOUTH-SOUTHWEST AT 20 KM/H TOWARDS THE COAST.

REPEATING AIVU IS POSING A MAJOR THREAT TO COASTAL AREAS BETWEEN TOWNSVILLE AND MACKAY.

COASTAL RESIDENTS BETWEEN AYR AND BOWEN ARE WARNED OF THE DANGEROUS STORM TIDE WHICH WILL OCCUR ONLY IF THE CYCLONE SHOULD SLOW DOWN AND CROSS THE COAST AFTER 5 PM WITH THIS EVENING'S HIGH TIDE. LOW LYING LAND COULD BE INUNDATED BY WAVES AND STRONG CURRENTS.

FLOOD RAINS ARE LIKELY BETWEEN AYR AND MACKAY.

DETAILS OF SEVERE TROPICAL CYCLONE AIVU AT 9 AM 4/4/1989

LOCATION OF CENTRE : WITHIN 20 KILOMETRES OF

LATITUDE 19.2 DEGREES SOUTH LONGITUDE 147.9 DEGREES EAST ABOUT 120 KILOMETRES EAST OF

TOWNSVILLE AND

ABOUT 90 KILOMETRES NORTH-NORTHWEST

OF BOWEN

CENTRAL PRESSURE : 950 HECTOPASCALS

CURRENT MOVEMENT : SOUTH-SOUTHWEST AT 20 KILOMETRES PER

**HOUR** 

DESTRUCTIVE WINDS ; OUT TO 100 KILOMETRES FROM THE CENTRE

MAXIMUM WIND GUSTS: 200 KILOMETRES PER HOUR NEAR THE

**CENTRE** 

RESIDENTS BETWEEN TOWNSVILLE AND MACKAY ARE ADVISED TO COMPLETE PREPARATIONS QUICKLY AND BE PREPARED TO SHELTER IN A SAFE PLACE.

TOP PRIORITY TROPICAL CYCLONE ADVICE NUMBER 21 ISSUED BY THE BUREAU OF METEOROLOGY BRISBANE AT 10 AM TUESDAY 4/4/1989.

A TROPICAL CYCLONE WARNING IS NOW CURRENT FOR COASTAL AND ISLAND COMMUNITIES BETWEEN INGHAM AND ST LAWRENCE. A TROPICAL CYCLONE WATCH EXTENDS SOUTH TO YEPPOON.

THE VERY DESTRUCTIVE CORE OF SEVERE TROPICAL CYCLONE AIVU WITH EXTREME GUSTS UP TO 200 KM/H SHOULD CROSS THE BETWEEN AYR AND BOWEN DURING THE NEXT FEW HOURS. DESTRUCTIVE WINDS AR EXPECTED BETWEEN TOWNSVILLE AND MACKAY.

SEVERE TROPICAL CYCLONE AIVU IS BEING TRACKED BY RADAR AND IS MOVING SOUTH-SOUTHWEST AT 25 KM/H TOWARDS THE COAST.

REPEATING AIVU IS POSING A MAJOR THREAT TO COASTAL AREAS BETWEEN TOWNSVILLE AND MACKAY.

COASTAL RESIDENTS BETWEEN AYR AND BOWEN AR WARNED OF THE DANGEROUS STORM TIDE WHICH WILL OCCUR ONLY IF THE CYCLONE SHOULD SLOW DOWN AND CROSS THE COAST AFTER 5 PM WITH THIS EVENING'S HIGH TIDE. LOW LYING LAND COULD BE INUNDATED BY WAVES AND STRONG CURRENTS.

FLOOD RAINS ARE LIKELY BETWEEN AYR AND MACKAY.

DETAILS OF SEVERE TROPICAL CYCLONE AIVU AT 10 AM 4/4/1989

LOCATION OF CENTRE : WITHIN 20 KILOMETRES OF

LATITUDE 19.5 DEGREES SOUTH LONGITUDE 147.8 DEGREES EAST

ABOUT 105 KILOMETRES EAST-SOUTHEAST

OF TOWNSVILLE

ABOUT 70 KILOMETRES NORTHWEST OF

**BOWEN** 

CENTRAL PRESSURE : 950 HECTOPASCALS

CURRENT MOVEMENT : SOUTH-SOUTHWEST AT 25 KILOMETRES PER

**HOUR** 

DESTRUCTIVE WINDS : OUT TO 100 KILOMETRES FROM THE CENTRE

MAXIMUM WIND GUSTS; 200 KILOMETRES PER HOUR NEAR THE

**CENTRE** 

RESIDENTS BETWEEN TOWNSVILLE AND MACKAY ARE ADVISED TO REMAIN IN SHELTER FOR THE DURATION OF THE DANGEROUS CONDITIONS WHICH SHOULD CONTINUE FOR SEVERAL HOURS.

TOP PRIORITY TROPICAL CYCLONE ADVICE NUMBER 22 ISSUED BY THE BUREAU OF METEOROLOGY BRISBANE AT 11 AM TUESDAY 4/4/1989

A TROPICAL CYCLONE WARNING IS NOW CURRENT FOR THE COAST AND ADJACENT INLAND BETWEEN TOWNSVILLE AND MACKAY.

THE VERY DESTRUCTIVE CORE OF SEVERE TROPICAL CYCLONE AIVU WITH EXTREME GUSTS UP TO 200 KM/H IS CROSSING THE COAST NEAR HOME HILL.

DESTRUCTIVE WINDS ARE EXPECTED BETWEEN TOWNSVILLE AND THE WHITSUNDAYS FOR ANOTHER FEW HOURS.

SEVERE TROPICAL CYCLONE AIVU IS BEING TRACKED BY RADAR AND IS MOVING SOUTH-SOUTHWEST AT 25 KM/H.

FLOOD RAINS ARE LIKELY BETWEEN AYR AND MACKAY.

DETAILS OF SEVERE TROPICAL CYCLONE AIVU AT 11 AM 4/4/1989

LOCATION OF CENTRE : WITHIN 20 KILOMETRES OF

LATITUDE 19.7 DEGREES SOUTH LONGITUDE 147.6 DEGREES EAST

TO THE IMMEDIATE EAST OF HOME HILL

CENTRAL PRESSURE : 950 HECTOPASCALS BUT SLOWLY RISING
CURRENT MOVEMENT : SOUTH-SOUTHWEST AT 25 KILOMETRES PER

**HOUR** 

DESTRUCTIVE WINDS : OUT TO 100 KILOMETRES FROM THE CENTRE

MAXIMUM WIND GUSTS: 200 KILOMETRES PER HOUR NEAR THE

**CENTRE** 

RESIDENTS BETWEEN TOWNSVILLE AND THE WHITSUNDAYS ARE ADVISED TO REMAIN IN SHELTER FOR THE DURATION OF THE DANGEROUS CONDITIONS WHICH SHOULD CONTINUE FOR SEVERAL HOURS.

TOP PRIORITY TROPICAL CYCLONE ADVICE NUMBER 23 ISSUED BY THE BUREAU OF METEOROLOGY BRISBANE AT NOON TUESDAY 4/4/1989.

A TROPICAL CYCLONE WARNING IS CURRENT FOR THE COAST AND ADJACENT INLAND BETWEEN TOWNSVILLE AND MACKAY.

TROPICAL CYLONE AIVU WITH GUSTS TO 150 KM/H IS NEAR HOME HILL AND BEGINNING TO LOSE INTENSITY. AIVU IS TRAVELLING IN A SOUTHWESTERLY DIRECTION AND SHOULD CONTINUE TO MOVE FURTHER INLAND. DESTRUCTIVE WINDS ARE EXPECTED BETWEEN TOWNSVILLE AND THE WHITSUNDAYS FOR ANOTHER 2 HOURS OR SO BUT GALES MAY CONTINUE FOR SEVERAL HOURS YET.

TROPICAL CYCLONE AIVU IS BEING TRACKED BY RADAR AND IS MOVING SOUTHWEST AT 20 KM/H.

FLOOD WARNINGS ARE CURRENT FOR THE PIONEER RIVER AND COASTAL STREAMS BETWEEN MACKAY AND TOWNSVILLE.

DETAILS OF TROPICAL CYCLONE AIVU AT NOON 4/4/1989

LOCATION OF CENTRE : WITHIN 20 KILOMETRES OF

LATITUDE 19.8 DEGREES SOUTH LONGITUDE 147.3 DEGREES EAST

TO THE IMMEDIATE SOUTHWEST OF HOME

HILL

CENTRAL PRESSURE : 975 HECTOPASCALS BUT SLOWING RISING
CURRENT MOVEMENT : SOUTHWEST AT 20 KILOMETRES PER HOUR
DESTRUCTIVE WINDS : OUT TO 100 KILOMETRES FROM THE CENTRE

MAXIMUM WIND GUSTS: 150 KILOMETRES PER HOUR NEAR THE

**CENTRE**