TROPICAL CYCLONE SEASONAL SUMMARY 2022/23 SEASON

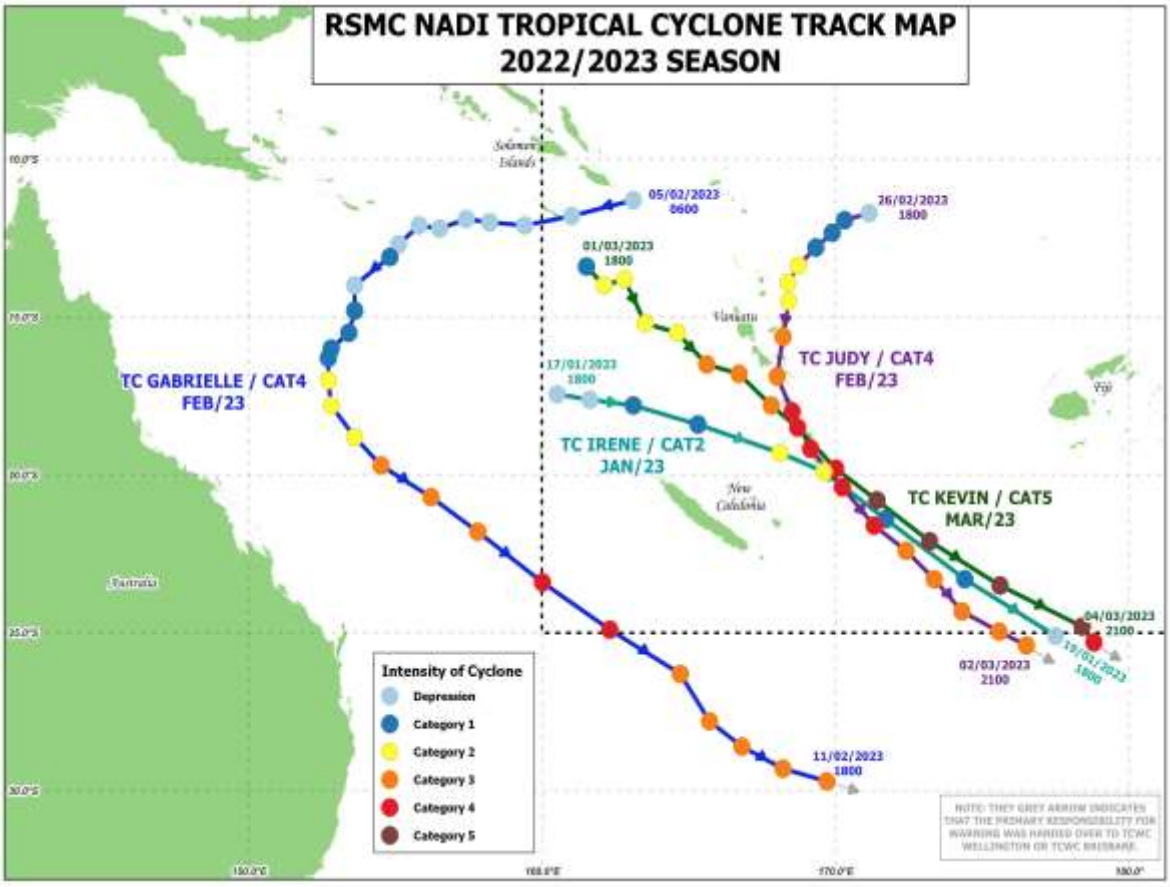


Table of Contents

Introduction

The RSMC Nadi–Tropical Cyclone Center is a Regional Specialized Meteorological Centre (RSMC) that carries out specialized activities in analysis, tracking and forecasting of all Southwest Pacific tropical cyclones (TCs) within the framework of the World Weather Watch (WWW) Program of the World Meteorological Organization (WMO).

RSMC Nadi conducts the following operations on a routine basis:
(1) Preparation of information on the formation, movement and development of TCs and associated meteorological phenomena
(2) Preparation of information on synoptic-scale atmospheric situations that affect the behavior of TCs
(3) Provision of the above information to National Meteorological Services (NMHSs) and in particular to WMO Tropical Cyclone Committee Members, in appropriate formats for operational processing.

This report summarizes the activities of RSMC Nadi and reviews the 5 Tropical Cyclones that developed and affected the Southwest Pacific, RSMC Nadi's area of responsibility (AOR) during the 2022/23 tropical cyclone season including one cyclone that crossed the southwestern edge of the Nadi AoR (approximately 6 hours) from TCWC Melbourne's AOR and into TCWC Wellington AoR and one that was named by RSMC Nadi but was short lived and was concluded to be a deep tropical depression and not a tropical cyclone after the post event analysis.
A total of 12 disturbances were monitored and handled by RSMC Nadi of which 7 developed into depressions and 3 developed further into tropical cyclones that affected the AoR.

The next section outlines routine operations performed at RSMC Nadi and its operational products while Section 3 describes atmospheric and oceanic conditions in the tropics and notes the highlights of TC activity in the 2022/23 cyclone season. Section 4 presents verification statistics relating to operational forecasts and other guidance models and storm surge prediction. Best track data for 2022/23 Tropical Cyclones are shown in table and chart form in the appendices.

Section 1.0 <u>Operations at RSMC Nadi during the 2022/23 Tropical Cyclone Season</u>

RSMC Nadi's area of Responsibility (AoR) covers the Southwest Pacific (0° –25S, 160°E–120°W) [Figure 1.1]. RSMC Nadi carries out analysis and forecasting in relation to tropical cyclones (TCs) in the area and also provides the relevant National Meteorological and Hydrological Services (NMHSs) with RSMC products via the Global Telecommunication System (GTS), the Aeronautical Fixed Telecommunication Network (AFTN) and email. The products are also available on the Fiji Meteorological Service (FMS) website, the internet and other media including social media for public consumption during the tropical disturbance and cyclone development period and existence in the Nadi AoR.

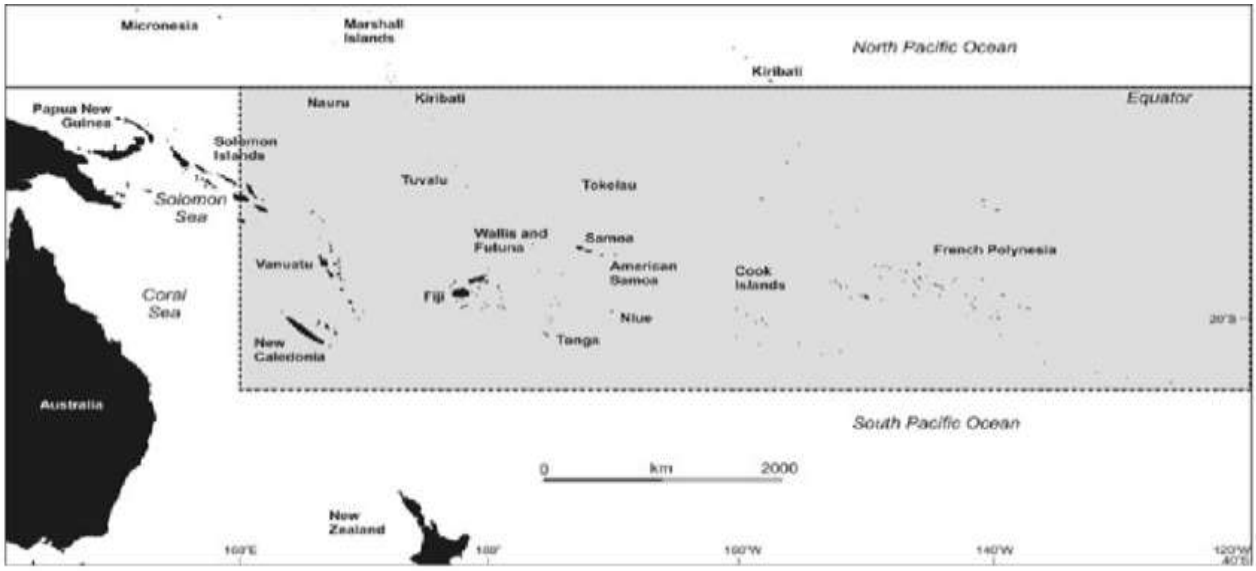


Figure 1.1:RSMC Nadi Area of Responsibility(AoR)in Grey shade

Image:https://www.researchgate.net/figure/Area-of-responsibility-of-the-RSMC-Nadi-in-Fiji-grey-box-and-the-spread-of-island_fig1_225353473#:~:text=The%20RSMC%2DNadi%20area%20of,1)

1.1 <u>Analysis</u>

TC analysis is performed at least four times a day for 00, 06, 12 and 18UTC fix for RSMC Nadi TC Products. It begins with the determination of the TC's center position and the Dvorak analysis to determine the estimated intensity of the TC. However, it is done well for 03, 09, 15 and 21UTC merely for position and to monitor the Dvorak Intensity trends as well as for Special Weather Bulletin update. The Dvorak analysis for these times are analyzed but are not distributed, but the corresponding Special Weather Bulletins (SWB) are sent for distribution. Cloud and Himawari Cast images of TCs from the Himawari-8 are the principal source for the determination of TC center position and intensity through Dvorak analysis for the 2022/23 cyclone season. Information on the TC's direction and speed of movement is extracted primarily from 6, 12 or 24 hourly displacement vectors of the center position. The maximum sustained wind speed in the vicinity of the TC's center is determined mainly from the CI number, which is derived from satellite imagery using the Dvorak method. The central pressure of the TC is then determined from the maximum sustained wind speed with the assumption of a certain pressure profile around the TC, that is the radius of the outermost closed isobar and 1000hpa isobar which is automatically derived in TC Module which is the Bureau of Meteorology tropical cyclone program used operationally in RSMC Nadi. The radii of circles representing winds with speeds exceeding 35, 50 and 65 knots are determined mainly from surface observation, ASCAT observation and Atmospheric Motion Vector (AMV) based Sea surface Wind (ASWind) data derived from satellite images in the vicinity of the TC, CIRA TC Page or TC model used operationally. The size of the central dense overcast area of the TC as observed in satellite imagery is also referenced to determine the radius of 35-45 knot wind speed radii.

1.2 Forecasts

RSMC Nadi issues TC track (position) and intensity forecasts of up to 72 hours ahead. As a primary basis for TC track forecasts, RSMC Nadi mainly uses the consensus track for TC track forecasts. This approach involves taking the mean of predicted TC positions after eliminating outliers with bias towards ECMWF and JTWC prediction. The intensity forecast is determined from considering multiple deterministic models and other forecast centers prediction but most importantly the environment the system is expected to encounter in the next 72hrs. Further, TC intensity central pressure forecast are determined mainly derived automatically from TC Module once the maximum sustained wind speeds are filled in.

1.3 Provision of RSMC Products

RSMC Nadi prepares and distributes part of or all the RSMC bulletins listed below via the GTS or the AFTN when:
-a tropical cyclone exists in RSMC Nadi area of responsibility
-a depression has a high chance to reach or exceed cyclone intensity in the area within 24 to 48 hours.
- system expected to remain as a TC, south of 25S into the NZ Met Service AOR (eg. TC Kevin).

RSMC products are continually issued while any tropical cyclone (or severe tropical cyclone) is in the RSMC Nadi area of responsibility and few products are issued daily during the tropical cyclone season (November to April).

2.0 Summary of 2022/23 Tropical Cyclone Season

In the 2022/23 Tropical Cyclone season, a total of 4 named Tropical Cyclones affected RSMC Nadi's Tropical Cyclone's area of responsibility (AOR) and its vicinity.

- 3 of the Tropical Cyclone developed through disturbances that intensified to depression stages before reaching tropical cyclone status named by RSMC Nadi with 2 reaching severe tropical cyclone stages (>category 3) stages with maximum sustained winds of more than 64 knots near the center. i.e. Severe Tropical Cyclone (STC) Judy and Severe Tropical Cyclone Kevin. The other 1 was Tropical Cyclone Gabrielle which was monitored by TCWC Melbourne and TCWC Wellington.
- Tropical cyclones Gabrielle developed in the Australian region (west of 160E longitude) and named by TCWC Melbourne, moved into RSMC Nadi's region for a very short period before exiting into TCWC Wellington AoR.

All in all, 4 tropical cyclones affected RSMC Nadi's AOR and its vicinity from the predicted (4-6) named tropical cyclones expected in RSMC Nadi's area of responsibility (AoR) between November 2022 to April 2023.

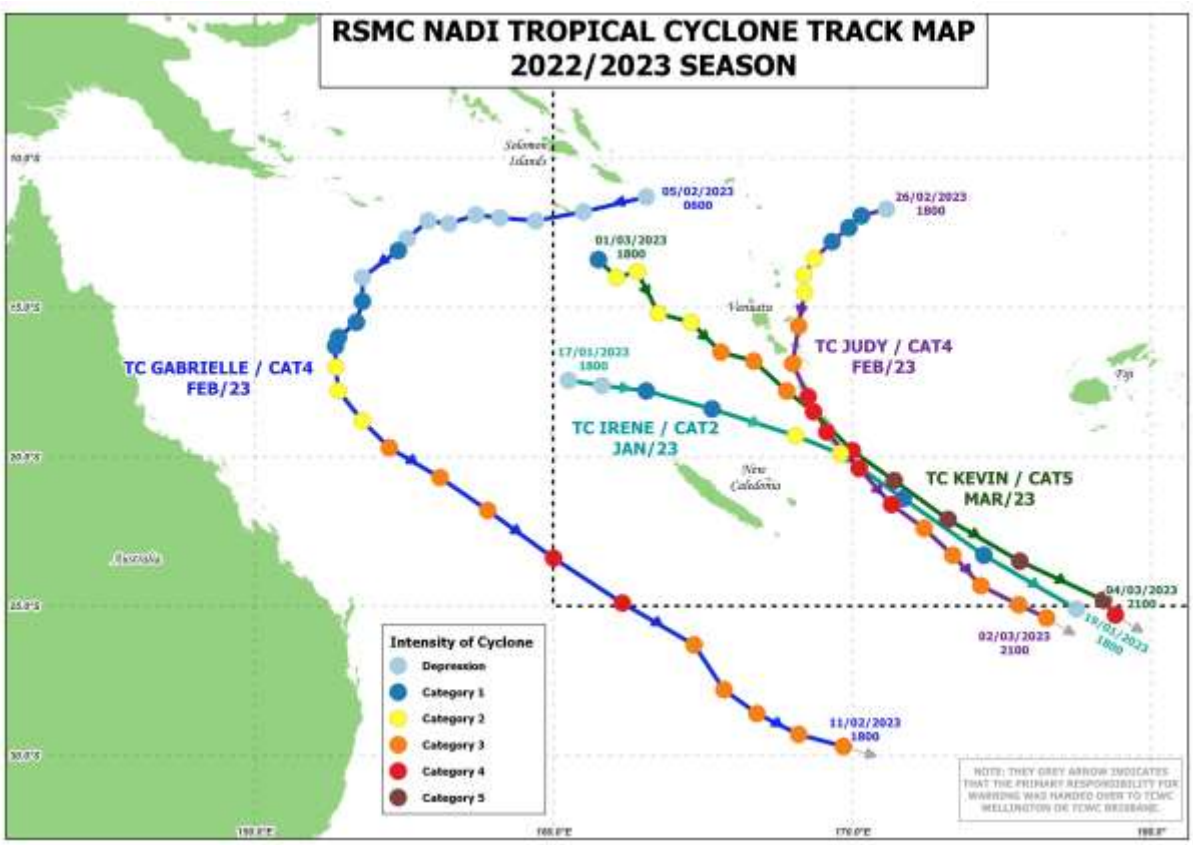


Figure 2.1 above shows the different tracks for the TC 2022/23 season.

Table 2.1 below shows a list of tropical systems reaching TC intensity or higher in the 2022/23 TC season. It also highlights the TC intensity of individual cyclone.

Tropical Cyclone/ Category	Dates	Duration	Minimum Central Pressure				Maximum Winds (knots)	Named by
			(UTC)	Lat(S)	Lon(E)	hPa		
TC Irene (2)	17/01/23 – 19/01/23	3 days	18/1800	19.3	168.1	985	55	RSMC Nadi
TC Gabrielle (4)	10/02/23	Less than 12hrs	TCWC Melbourne					
STC Judy (4)	26/02/23 – 02/03/23	4 days	01/0600	19.2	169.1	940	100	RSMC Nadi
STC Kevin (5)	01/03/23 – 04/03/23	3 days	04/0600	22.1	173.2	913	125	RSMC Nadi

Colour Key:

	Named by RSMC Nadi in AOR and reached Category 2 status
	Named by RSMC Nadi in AOR and reached more than Category 3 status
	Monitored and Named by TCWC Brisbane and reached Category 3 status

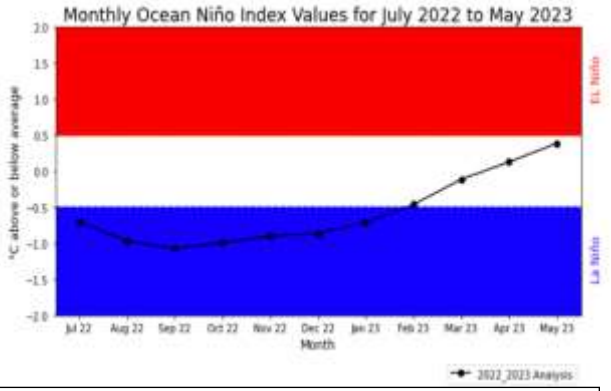
A total of 12 tropical disturbances (TD) developed and monitored by RSMC Nadi during the 2022/23 tropical cyclone season. Table 2.2 below shows a brief summary of all TDs.

Tropical Disturbance Number	Date (UTC Days)	Max. Wind Intensity Reached (knots)	TC Name	Remarks
01F	11th to 12th December 2022	25	-	-Remained a disturbance -Developed over open waters southwest of Tonga and dissipating while drifting south.
02F	22nd to 31st December 2022	25	-	-Remained a disturbance -Developed in open waters between Vanuatu and New Caledonia tracking towards open waters southeast of New Caledonia and weakening.
03F	5th to 6th January 2023	25	-	-Remained a disturbance -Developed in open waters between Vanuatu and New Caledonia and dissipating.
04F	7th to 8th January 2023.	30	- Remained as a depression upon re-analysis, however was named Hale operationally.	- Remained a deep depression over open waters to the southwest of New Caledonia. - More detailed information could be found in the seasonal summary and TC report
05F	Named by RSMC Nadi's AOR from 16th to 19th January 2023.	55	Irene (18/01/23) – 18UTC	More detailed information could be found in TC Irene seasonal summary and TC report
06F	21st to 23rd January 2023.	30	-	-Developed into a disturbance to the west of New Caledonia and -Developed into a depression while drifting southeast away from New Caledonia.
07F	10th February 2023	85	Gabrielle (Named by BOM)	Monitored by TCWC Melbourne and Wellington
08F	Named and monitored by RSMC Nadi's from 24th February to 2nd March 2023	95	Judy (27/02/23) – 00UTC	More detailed information could be found in TC Judy seasonal summary and TC report
09F	Named and monitored by RSMC Nadi's from 1st to 4th March 2023	125	Kevin (01/03/23) – 21UTC	More detailed information could be found in TC Kevin seasonal summary and TC report
10F	10th to 11th March 2023	30	-	-Depression -Developed in open waters between Niue and Southern Cooks before dissipating.
11F	10th to 15th March 2023	30	-	-Depression -Developed in open waters between Niue and Northern parts of Tonga.
12F	11th to 15th March 2023	25	-	-Remained a disturbance -Developed in open waters northeast

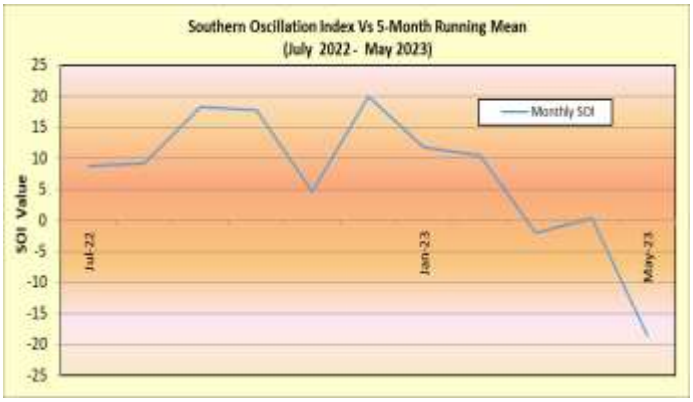
				of Vanuatu and gradually drifting southeast over land areas towards open waters northwest of New Caledonia
13F	16th to 18th April 2023	25	-	-Remained a disturbance -Developed in open waters northwest of New Caledonia and gradually drifting southeast between the southern parts of Vanuatu and New Caledonia while gradually dissipating over open waters.

2.1 Atmospheric and Oceanographic Conditions in the Tropics

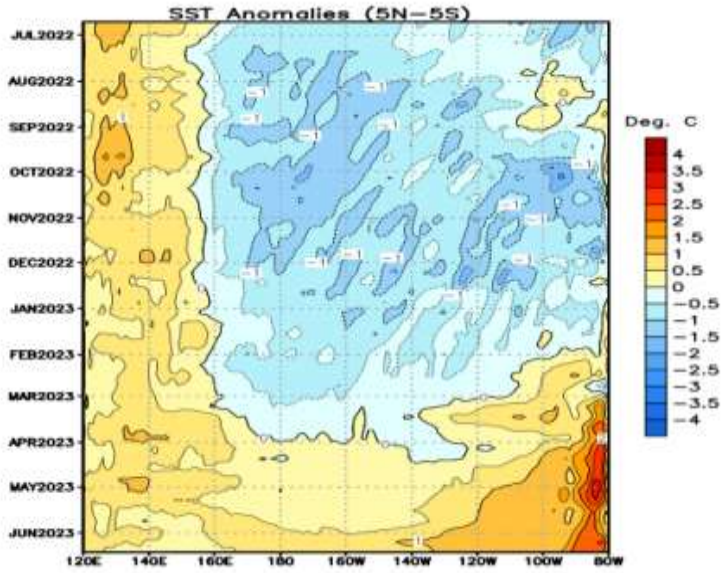
ENSO-neutral conditions prevailed during July 2022 and lasted until October, when La Niña was declared. The La Niña event reached its peak around December and early January, before it started to dissipate again. By March 2023, ENSO- neutral conditions returned and continued to persist until the end of the cyclone season.



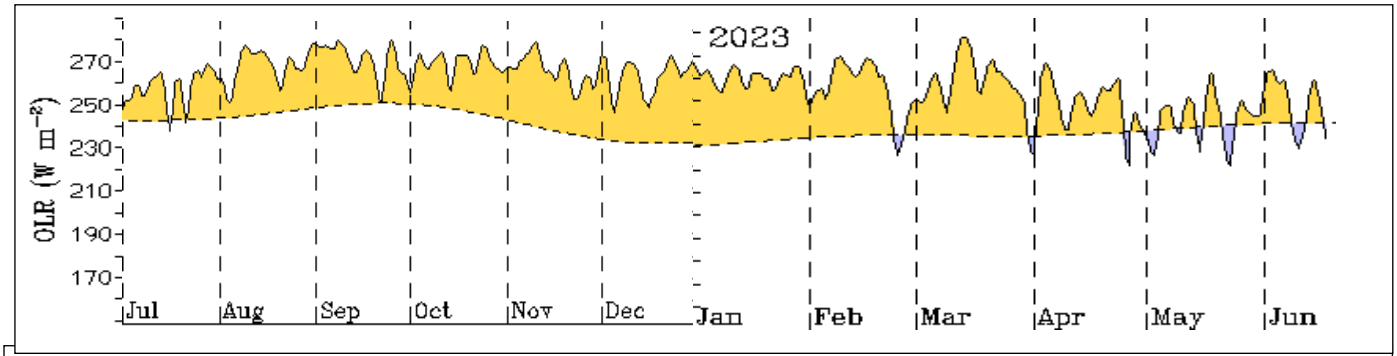
Monthly NINO3.4 anomalies indicate that the Pacific Ocean was in a La Nina, until Feb 2023.



Season started off with La Nina conditions in place, which later dissipated in March 2023.

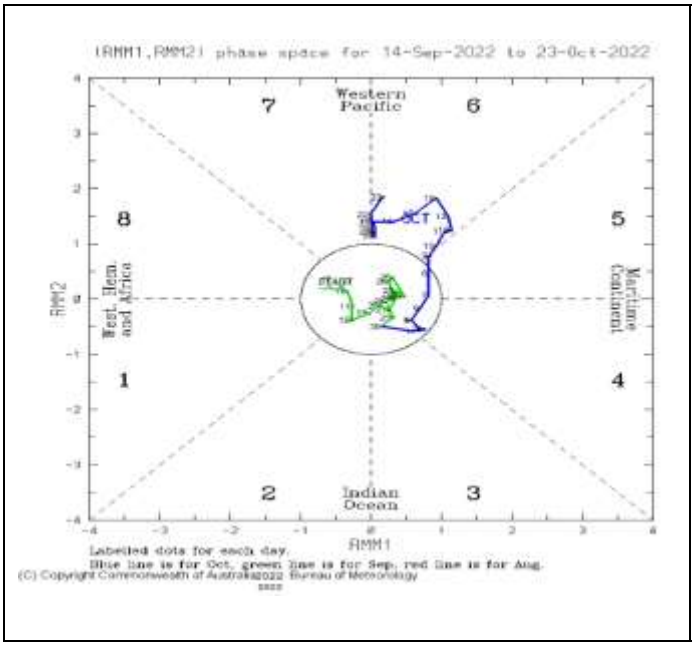


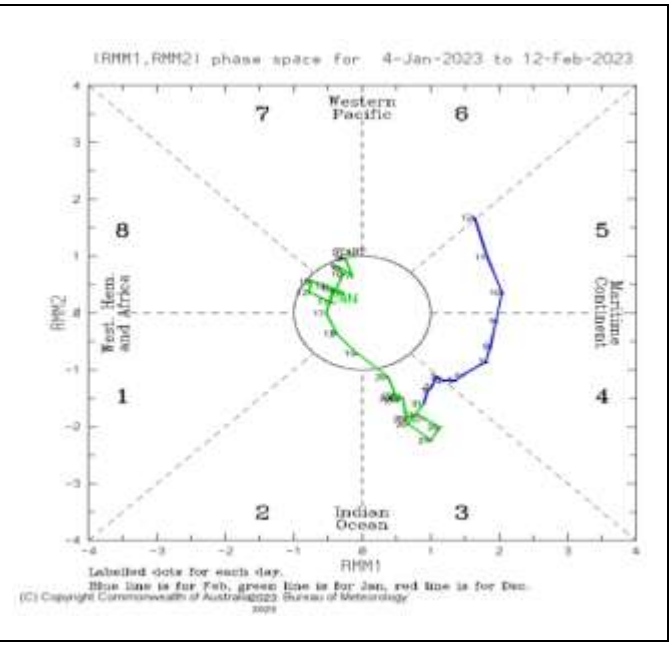
Below average SST persisted during most of 2022. However, the beginning of 2023 saw the transition of below normal to above normal. Positive anomalies in the eastern Pacific have now also gradually expanded westward.

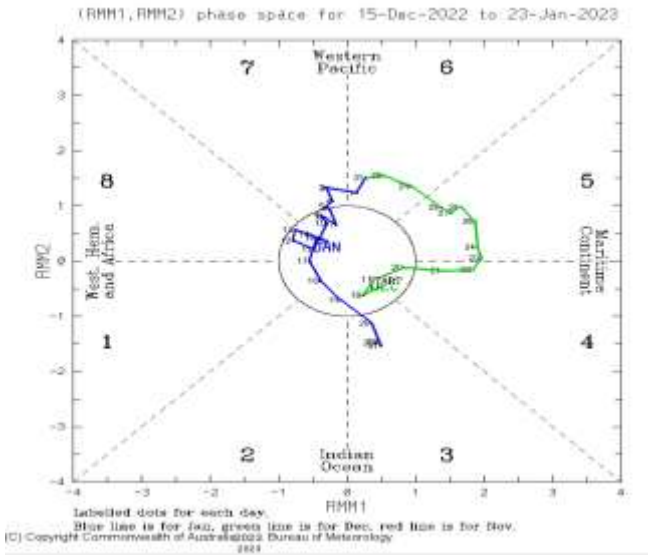


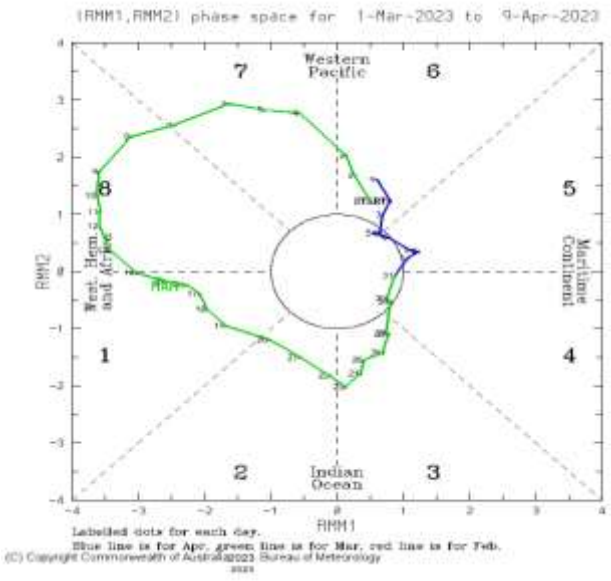
Generally, below average cloudiness was experienced throughout the 2nd half of 2022 and likewise for the first half of 2023.

Active MJO Phases in the Western Pacific:






(RMM1,RMM2) phase space for 15-Dec-2022 to 23-Jan-2023
Western Pacific
7
6
8
5
1
4
2
3
Indian Ocean
West. Hem. and Africa
Maritime Continent
RMM1
RMM2
Labelled dots for each day.
Blue line is for Jan, green line is for Dec, red line is for Nov.
(C) Copyright Commonwealth of Australia2023 Bureau of Meteorology


(RMM1,RMM2) phase space for 1-Mar-2023 to 9-Apr-2023
Western Pacific
7
6
8
5
1
4
2
3
Indian Ocean
West. Hem. and Africa
Maritime Continent
RMM1
RMM2
Labelled dots for each day.
Blue line is for Apr, green line is for Mar, red line is for Feb.
(C) Copyright Commonwealth of Australia2023 Bureau of Meteorology

2.2 Tropical Cyclones in 2022/23 Season

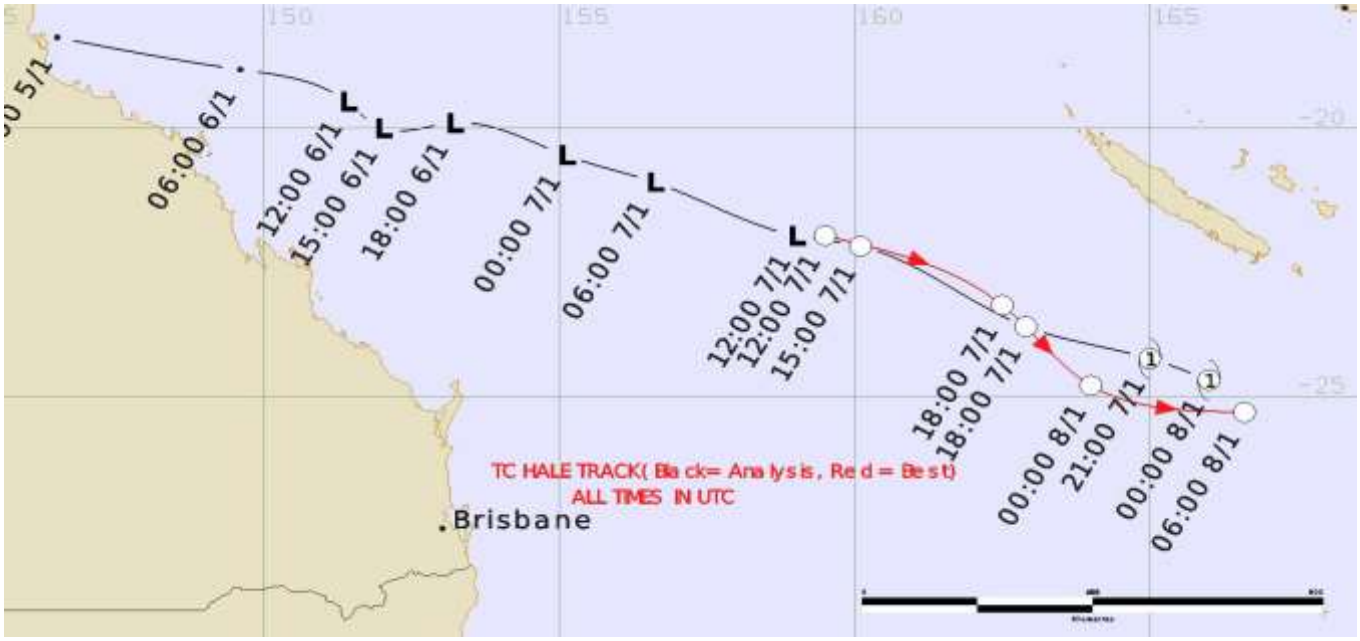
There were 4 TCs that developed in RSMC Nadi's AOR in the 2022/23 TC Season and 1 moved into the area from the Australian region.

2022/23-1: Tropical Cyclone Hale

TD04F entered RSMC, Nadi Area of Responsibility (AOR) at around 1500UTC on the 7th of January as a deep Tropical Depression (TD) with a central pressure of 996HPa. TD04F was named TC Hale at around 2100UTC on the 7th.

TD04F was the first named tropical cyclone in the 2022/2023 TC season. However, reanalysis shows that TD04F remained a deep TD, had gales but not close to the centre and did not meet the RSMC Nadi TC criteria.

No major damages from winds were reported in RSMC, Nadi AOR. However, in preparation for Ex-TC Hale, Met Service issued heavy rain and wind warnings for many parts of New Zealand. A state of emergency was later declared in the northeastern part of New Zealand as it approached the country. Hale caused widespread flooding and slips in northern and eastern parts of the country on January 10 and 11, particularly in the Coromandel and Gisborne areas. Washed away forestry slash clogged many rivers in the Gisborne region, exacerbating the flooding and accumulating around bridges downstream. Several metres of foreshore was eroded away by the storm surge in Whitianga, threatening waterfront buildings such as the Mercury Bay Boating Club.



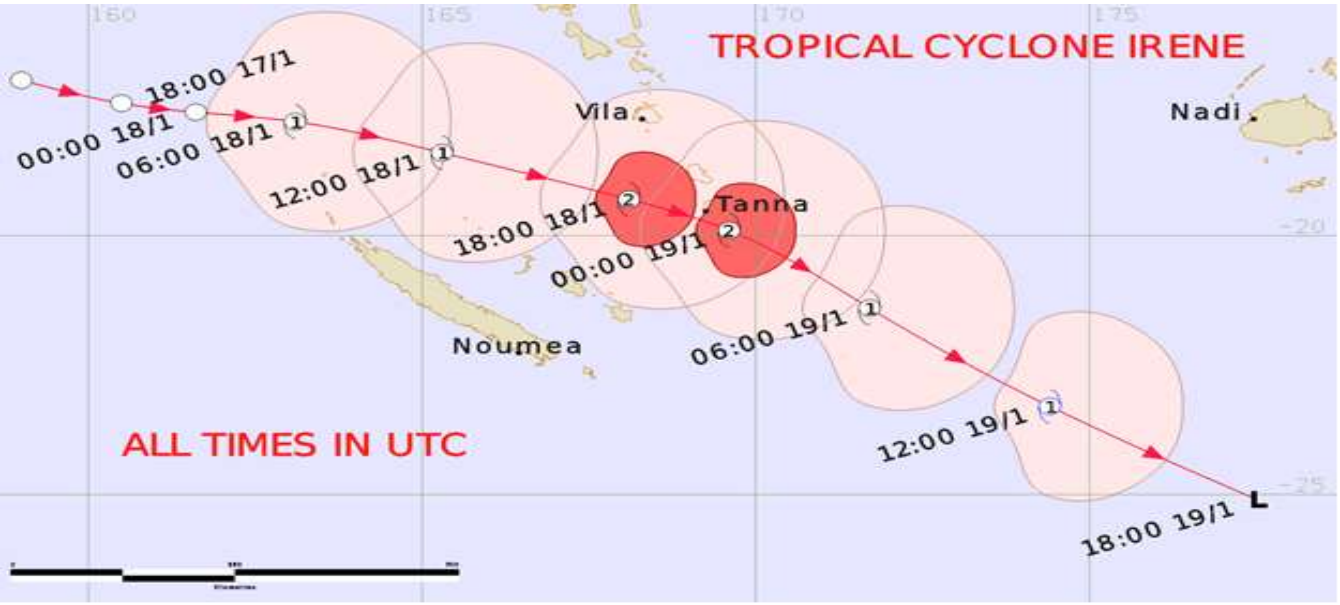
2022/23-2: Tropical Cyclone Irene

A tropical low developed over northern Vanuatu waters on 13th January 2023. This low pressure system intensified into Tropical Disturbance 05F (TD05F) 24 hours later in open waters between Solomon Islands and Vanuatu whilst slowly moving west. The system moved west of 160° East longitude, that is, the system moved out of Regional Specialized Meteorological Center (RSMC) Nadi's area of responsibility (AOR) on Sunday night, the 15th of January and continued to move west into the Coral Sea.

The system made a turn and moved southeast on the 17th of January whilst in the Coral Sea and re-entered RSMC Nadi's area of responsibility in the early morning at 1800UTC of Monday, 17th January as it continued to track east-southeast as Tropical Depression, TD05F. TD05F intensified into a category 1 Tropical Cyclone 12 hours later and named Tropical Cyclone(TC) Irene. This was northeast of Grand Terre, New Caledonia as Irene continued to move east-southeast towards Vanuatu.

Due to continuing favorable environmental conditions for tropical cyclones, TC Irene further intensified into a Category 2 system, 9 hours after its formation. This was northwest of Grand Terre, New Caledonia as the system continued to move east-southeast towards southern Vanuatu. The system remained a category 2 system till midday on 19th January as it passed between Tanna and Aneityum islands, in southern Vanuatu.

Irene weakened to a category 1 system as it moved south of 20° South latitude due to strong northwesterly wind shear. Irene continued to move southeast and remained a category 1 system before moving south of 25° latitude exiting RSMC Nadi's AOR.
TC Irene was the second tropical cyclone in RSMC Nadi's area of responsibility for the 2022/23 season.



2022/23-3: <u>Tropical Cyclone Gabrielle</u>

A low formed in the Coral Sea south of the Solomon Islands on 5 February. The low moved west southwest and developed into a tropical cyclone on 8 February as it passed to the east of Willis Island in the Australian region. *Gabrielle* then turned to the south and then to the southeast. On 10 February *Gabrielle* accelerated to the southeast intensifying into a Category 3 tropical cyclone before transitioning into a sub-tropical cyclone. Gabriele tracked across the edge of RSMC Nadi AoR where it reached a peak 10-minute mean wind intensity of 150 km/h on 10 February.

Gabrielle spent approximately 6 hrs in the Nadi AoR and the warning times were both at the border of the AoR. After careful consideration and analysis, followed through proper coordination and collaboration between RSMC

Nadi and the TCWCs; RSMC Nadi eventually requested that TCWC Melbourne to directly hand over the warning responsibility to Wellington AoR which turned out to be very efficient and effective for RSMC Nadi. RSMC Nadi sincerely acknowledges and thanked the neighboring TCWCs for their cooperation in handling the TC warning responsibilities.

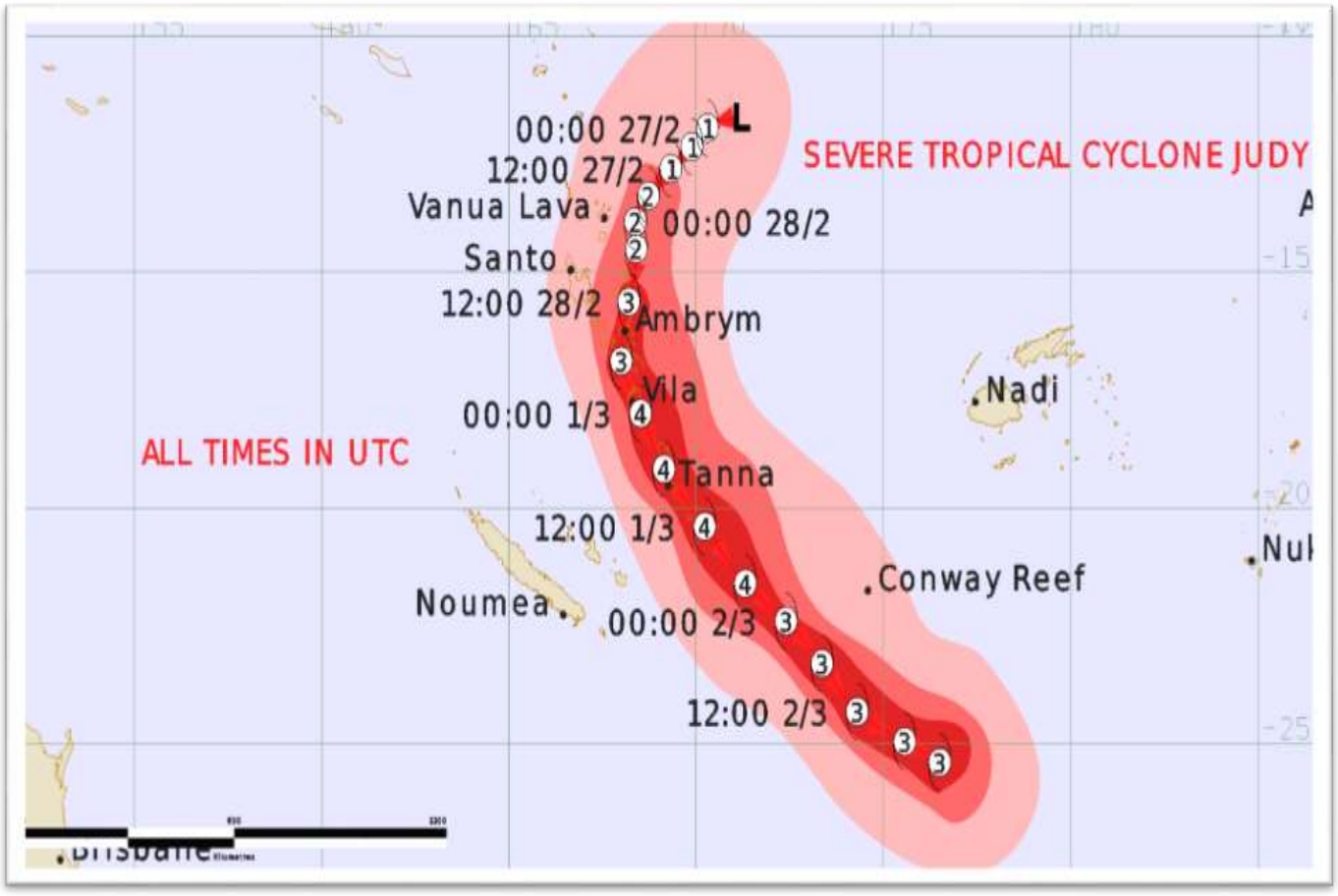
2022/23-4: <u>Severe Tropical Cyclone Judy</u>

Judy was the fourth tropical cyclone to form in the South Pacific and named by the Nadi Regional Specialised Meteorological Centre (RSMC) for the 2022/23 season. Judy reached category 4 cyclone intensity with sustained winds estimated to be 95 knots and gusts to 135 knots while in RSMC Nadi's Area of Responsibility.

The system was monitored by Nadi, RSMC from its early development stage as a tropical disturbance to the southeast of Halalo in Wallis & Futuna on February 23rd then was named while situated southeast of Fatutaka in the Solomons at 0000UTC on February 27th. Judy generally made a south-southwestwards and intensifying towards Vanuatu where it crossed over Pentecost Island as a severe category 3 tropical cyclone at 1200UTC on February 28th. The system later intensified into a category 4 cyclone at about 15nm(25km) northeast of Efate Island and 25nm(45km) north-northeast of Port Vila.

On its re-curving south-southeast track over Vanuatu, Judy caused extensive damages over land and coastal communities ranging from very destructive winds, torrential rainfall and flooding affecting population in high risk areas exposed to impacts generated from hazards linked to this meteorological event. Damages were inflicted on human lives, properties and infrastructures, livestock and agriculture, disruption in communication networks, power shut down, communities being cut off due to flooding and land slide.

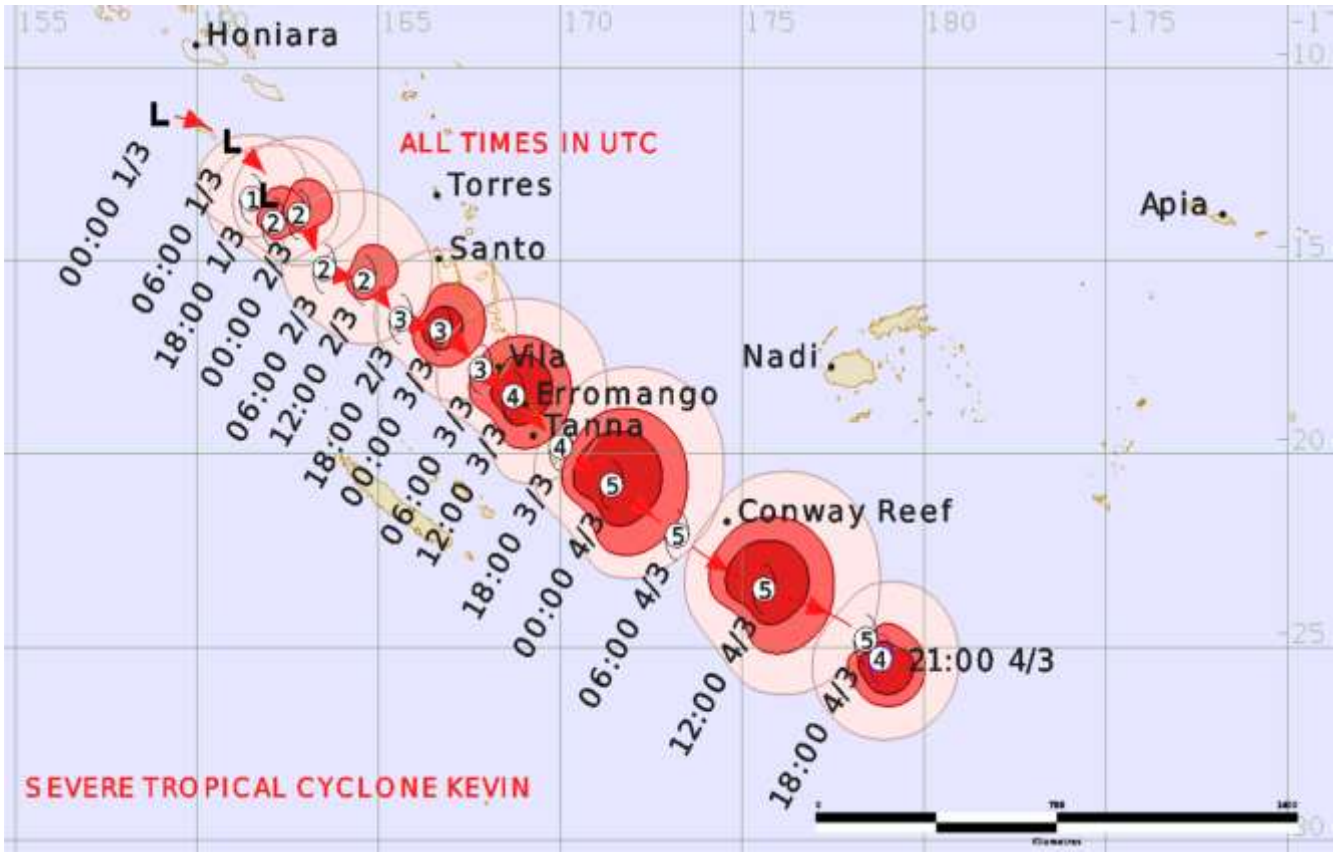
The system eventually moved over open waters while gradually weakening towards 25S where Wellington, TCWC continued with monitoring at 1500UTC on March 2nd.



2022/23-5: <u>Severe Tropical Cyclone Kevin</u>

Kevin was the fifth tropical cyclone to form in the South Pacific and named by the Nadi Regional Specialised Meteorological Centre (RSMC) for the 2022/23 season. Kevin reached category 5 cyclone intensity with sustained winds estimated to be 125 knots and gusts to 175 knots while in RSMC Nadi's Area of Responsibility

Tropical cyclone Kevin, developed from an active trough just northwest of Vanuatu as a tropical low pressure system at 2100UTC 28 February. Kevin was monitored by the Nadi RSMC for about ninety-six hours or four days until it exited the Nadi RSMC AOR at 2100UTC 04 March. Through its life span, Kevin made a general south-eastwards track as it approached the Vanuatu group of islands where it made land fall over Erromango. The system later dissipated away over open waters to the south of Fiji into TCWC Wellington area of responsibility. According to the Vanuatu National *Early Recovery Plan*, there were prolonged impacts on communities already inflicted by TC Judy. So the Early Recovery cost (VUV) on the Society Pillar for both TC Judy and Kevin was estimated at (VUV) 2,101,482,283.


Honiara
Torres
Santo
Vila
Erromango
Tanna
Nadi
Apia
Conway Reef
ALL TIMES IN UTC
SEVERE TROPICAL CYCLONE KEVIN
00:00 1/3
06:00 1/3
18:00 1/3
00:00 2/3
06:00 2/3
12:00 2/3
18:00 2/3
00:00 3/3
06:00 3/3
12:00 3/3
18:00 3/3
00:00 4/3
06:00 4/3
12:00 4/3
18:00 4/3
21:00 4/3

2.3 Tropical Cyclone Products

2.3.1 Provision of RSMC Products

RSMC Nadi provides operational products for Tropical cyclone forecasting to NMHSs via GTS, AFTN and other networks including the FMS website. Monthly and annual totals of all issued TC products for the 2022/23 TC season are listed in Table 2.3.1. below.

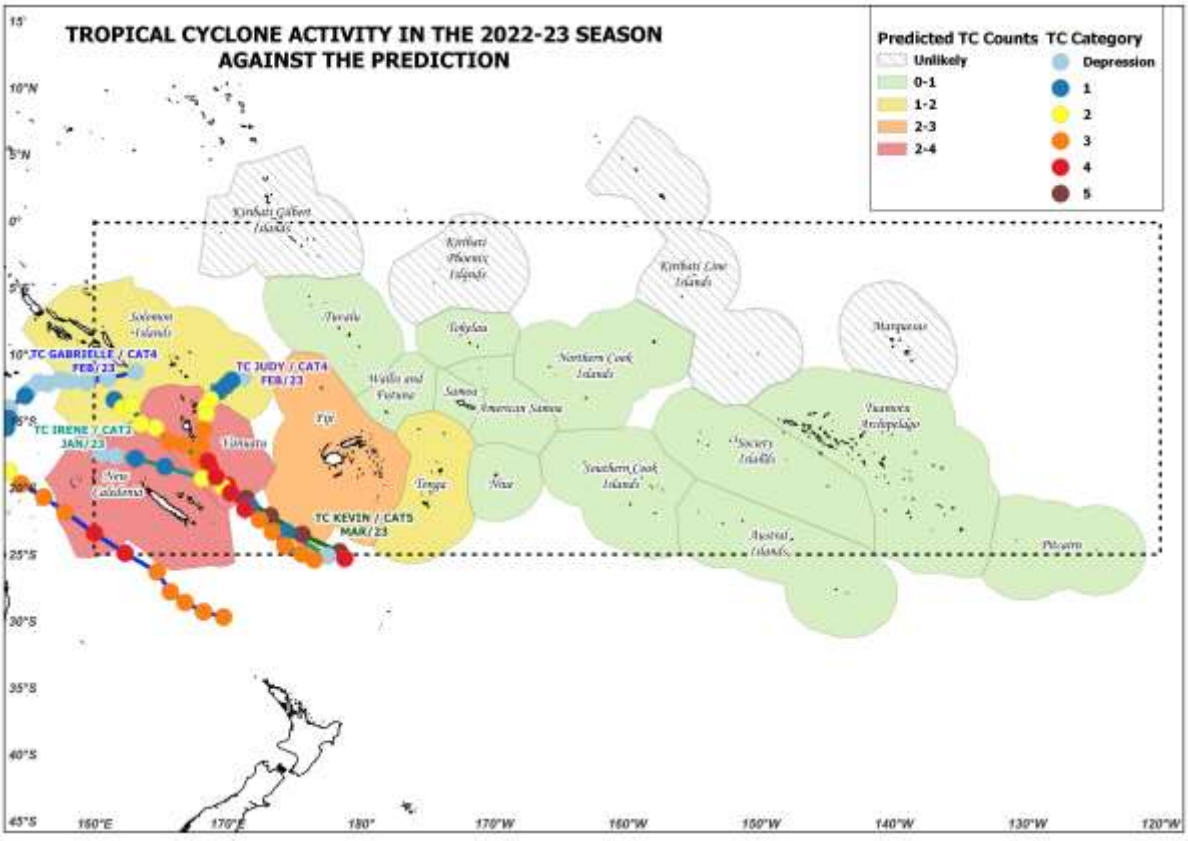
Product	Product ID/Header	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
5 Day TC Outlook	FKPS20	30	31	31	28	31	30	-	**181**
5 Day TC Outlook (Graphical)	-	30	31	31	28	31	30	-	**181**
International Marine Warnings	WOPS,WTPS, WHPS	-	-	19	13	24	-	-	**56**
Tropical Disturbance Summary	WWPS21	60	62	62	56	62	60	-	**362**
Tropical Disturbance Advisory (TDA)	WTPS11, WTPS12, WTPS13, WTPS14	-	-	19	11	20	-	-	**50**
CREX	KSX01, KSX02, KSXS03	-	-	12	10	20	-	-	**42**
Tropical Cyclone Advisory (TCA)	FKPS01, FKPS02, FKPS03	-	-	8	16	20	-	-	**44**
TC Sigmets	WCFJ01, WCFJ02, WCFJ03, WCFJ04	-	-	10	9	14	-	-	**33**
Special Weather Bulletins(SWB)	WWFJ40,	-	-	-	-	-	-	-	**-**
TC Uncertainty Forecast Track Map	-	-	-	12	10	20	-	-	**42**
TC Threat Map	-	-	-	12	10	20	-	-	**42**
Storm Surge Forecast	-	-	-	-	-	6	-	-	**6**
TOTAL		**120**	**124**	**216**	**191**	**268**	**120**	-	**1039**

Section 3.0 Verification of Tropical Cyclone Forecast for the 2022/23 Tropical Cyclone Season

3.1 TC Seasonal Outlook for 2022/23 Season

The Climate Division at the Fiji Meteorological Service does tropical seasonal outlook for Fiji and the region before the TC Season every year. This is highlighted here as it is used by NMHS's in the region as well. The TC outlook is based on the statistical technique predicting the outlook for an upcoming tropical cyclone season whereby analogue seasons are identified, i.e. seasons in the past with similar ENSO state. The analogue seasons are identified based on the state of tropical Pacific in the months preceding the tropical cyclone season, in particular, between May and September. The analogue seasons are further narrowed based on ENSO outlooks from the global climate models. This outlook uses the three-month running mean of the NINO3.4 index and the Southern Oscillation Index for analogue identification, the most widely used indices for defining the ENSO. For the 2022/23 TC Season, 7 analogue years were identified from the past TC seasons includes 1971-72, 1974-75, 1984-85, 2000-01, 2008-09, 2011-12 and 2017-18 driven by the La Nina event.

Figure 3.1: TC Outlook for RSMC AoR for the 2022/23 cyclone season with actual named Tropical cyclones with their intensity for the season.



From the Outlook above:

1) The predicted 2-4 TCs in the red zone, all 4 TCs tracked through the region, TC Irene developed in the region.

2) The predicted 2-3 TCs over Fiji, TC Irene, STC Judy, STC Kevin eventuated.

3) The predicted 1-2 over Solomon Islands and Tonga, STC Judy and STC Kevin developed and evolved over the Solomon Islands region.

Table 3.1 below shows the accuracy of the TC Outlook comparing the Tropical Cyclone Activity for the 2022/23 Season and the Predictions (Outlook).

Outlook	**Actual**	**Remarks**
Five to seven (5-7) named TCs expected in AOR between November 2022 to April 2023	4 TCs affected the AOR between November 2022 to April 2023 i.e. Irene, Gabrielle, Judy, Kevin	- Gabrielle was fully monitored by BOM though it cross through the south-western edge of the Nadi AOR
1-4 severe TCs expected for AOR	3 STC	Gabrielle, Judy and Kevin
1-2 TCs east of Dateline & 1-3 west of Dateline in AOR	All TCs developed to the west of dateline and nil to the east of the dateline	All TCs were west of the Dateline
Fiji: 2-3 TC and 1-2 to be STC	3 TC and 2 became STC	TC Irene, STC Judy, STC Kevin
New Caledonia: 2-4 TC and 1-2 to be STC	2 TC and 1 became STC	TC Irene, STC Gabrielle
Vanuatu: 2-4 TC with 1-2 to be STC	3 TC and 2 became STC	TC Irene, STC Judy, STC Kevin
Solomon Islands: 1-2 TC with 0-1 to ne STC	2 TC	TC Judy and TC Kevin
Tonga: 1-2 TC with 0-1 to be STC	Nil	Nil
The rest of the Pacific Islands: 0-1 TC with 0-1 to be STC	Nil	Nil

3.2 Verification of Operational Forecasts

Operational forecasts for the named TCs that formed in RSMC Nadi's AOR for the 2022/23 TC Season were verified using the post event analysis from data such as scatterometry data and microwave imagery to obtain the most accurate center position. The Dvorak re-analysis of satellite cloud imagery was also used to obtain the best maximum sustained winds. These verified elements were analyzed for 12hr, 24hr, 36hr, 48hr and 72hr. All official forecast track and model guidance forecast were verified against the post-event best track data for each TC using the TC Module Verification tool. Verification statistics for position and intensity for named TCs are in the Appendix.

3.2.1 Centre position

RSMC Nadi Forecast Position error(km)

The Position forecast verification statistics based on Official forecast track (OFT) verified against post event best track. Mean is the mean distance error in kilometers from the forecast to the actual position of TCs.

Table 3.2.1: 2022/23 TC Forecast Position mean distance error (km)

Tropical Cyclone	12-hr forecasts		24-hr forecasts		36-hr forecasts		48-hr forecasts		72-hr forecasts	
	Mean (km)	S.D. (km)	Mean (km)	S.D. (km)	Mean (km)	S.D. (km)	Mean (km)	S.D. (km)	Mean (km)	S.D. (km)
1. Irene	61	44	93	22	155	60	200	76	0	0
2. STC Judy	74	69	102	64	137	64	166	64	207	131
3. STC Kevin	54	29	87	46	137	81	193	103	187	264

Note 1: Mean – is the average distance error from the actual estimated position, S.D. – is the standard deviation.
2: The data is only for TC/STC that affected RSMC AoR.

3.2.2 Maximum Intensity(knots)

RSMC Nadi Intensity Forecast error(knots)

The TC Intensity forecast remains to be a challenge comparing the Dvorak Technique, observations and NWP consensus model data incorporated in TC Module.

Table 3.2.2: 2021/22 TC Intensity Forecast error (knots)

Tropical Cyclone	12-hr forecasts		24-hr forecasts		36-hr forecasts		48-hr forecasts		72-hr forecasts	
	Mean (kts)	S.D. (kts)	Mean (kts)	S.D. (kts)	Mean (kts)	S.D. (kts)	Mean (kts)	S.D. (kts)	Mean (kts)	S.D. (kts)
1. Irene	6	7	8	12	10	15	12	15	0	0
2. STC Judy	8	10	12	12	16	12	21	12	36	15
3. STC Kevin	9	8	19	10	27	13	28	16	28	39

Note 1: Mean – is the average distance error from the actual estimated position, S.D – is the standard deviation.
2: The data is only for TC/STC that affected RSMC AoR.

3.2.3 Storm Surge Model

The Southwest Pacific islands are surrounded by ocean and are very vulnerable to coastal inundation especially from severe tropical cyclones as experienced in the last 5 years. RSMC Nadi was fortunate to have a storm surge model developed by Japan Meteorological Agency (JMA) through the JICA and CIFDP project. It has been very fortunate that the storm
surge model has been running operationally in RSMC Nadi for at least the last 4 tropical cyclone seasons. It has proven its worth in previous cyclone estimating wave heights especially for tropical cyclone of category 3 and above especially due to the lack of model capability in the region.

For the 2022/23 TC season, the storm surge model was run for STC Judy and STC Kevin with significant impacts over the closest land mass, infrastructures and vulnerable communities. As both STC headed over Vanuatu with reports and feedback from the National Early Recovery Plan and correspondence from Vanuatu meteorological service.

3.3.3 Impacts

The estimated impact level according to the operational impact table was severe with the following possible impacts in alignment to the damages inflicted on the ground (Appendix 4.6).

Meanwhile, according to damage reports (Appendix 4.6) on Judy and Kevin, there were extensive damages encountered due to destructive to very destructive winds, torrential rainfall, flooding, storm surges, damaging heavy swells, high waves and phenomenal over land and coastal communities especially over Villa, Erromango and the other southern group of islands.
As a result, huge humanitarian impact according to the National *Early Recovery Plan* inflicted by STC Judy and Kevin.

4.0 APPENDIX

4.1 Appendix 1 **Operational Best Track Data for 2022/23 TC Season**

Name *(HALE)*	YYYY	MM	DD	HHHH	LAT	LON	PRES	W(KT)	CAT
DEPRESSION	2023	01	07	1200	-22.0	159.5	996	30	0
DEPRESSION	2023	01	07	1800	-23.3	162.5	996	30	0
DEPRESSION	2023	01	08	0000	-24.8	164.0	996	30	0
DEPRESSION	2023	01	08	0600	-25.3	166.6	996	30	0

Name	YYYY	MM	DD	HHHH	LAT	LON	PRES	W(KT)	CAT
DEPRESSION	2023	01	17	1200	-17.0	159.0	998	25	0
DEPRESSION	2023	01	17	1800	-17.4	160.5	998	25	0
DEPRESSION	2023	01	18	0000	-17.6	161.6	997	30	0
IRENE	2023	01	18	0600	-17.8	163.1	995	35	1
IRENE	2023	01	18	1200	-18.4	165.3	987	45	1
IRENE	2023	01	18	1800	-19.3	168.1	980	55	2
IRENE	2023	01	19	0000	-19.9	169.6	985	50	2
IRENE	2023	01	19	0600	-21.4	171.7	987	45	1
IRENE	2023	01	19	1200	-23.3	174.4	993	35	1
DEPRESSION	2023	01	19	1800	-25.1	177.5	997	30	0

Name	YYYY	MM	DD	HHHH	LAT	LON	PRES	W(KT)	CAT
GABRIELLE	2023	02	08	0000	-15.4	153.4	996	35	1
GABRIELLE	2023	02	08	0600	-16	152.8	988	45	1
GABRIELLE	2023	02	08	1200	-16.8	152.8	986	51	2
GABRIELLE	2023	02	08	1800	-17	152.8	985	51	2
GABRIELLE	2023	02	09	0000	-18.1	153	987	51	2
GABRIELLE	2023	02	09	0600	-18.9	153.9	975	64	3
GABRIELLE	2023	02	09	1200	-19.6	154.8	975	70	3
GABRIELLE	2023	02	09	1800	-20.7	156.1	971	74	3
GABRIELLE	2023	02	10	0000	-22.2	157.7	968	80	3
GABRIELLE	2023	02	10	0600	-23.3	159.6	958	89	4
GABRIELLE	2023	02	10	1200	-24.8	162.4	968	74	3

Name	YYYY	MM	DD	HHHH	LAT	LON	PRES	W(KT)	CAT
DEPRESSION	2023	02	26	1800	-11.7	171.1	998	30	0
JUDY	2023	02	27	0000	-11.9	170.3	994	40	1
JUDY	2023	02	27	0600	-12.3	169.9	990	45	1
JUDY	2023	02	27	1200	-12.8	169.3	990	45	1
JUDY	2023	02	27	1800	-13.4	168.7	986	50	2
JUDY	2023	02	28	0000	-13.9	168.4	975	55	2
JUDY	2023	02	28	0600	-14.5	168.4	975	60	2
JUDY	2023	02	28	1200	-15.6	168.2	970	65	3
JUDY	2023	02	28	1800	-16.9	168.0	956	85	3
JUDY	2023	03	01	0000	-18.0	168.5	945	95	4
JUDY	2023	03	01	0600	-19.2	169.1	940	100	4

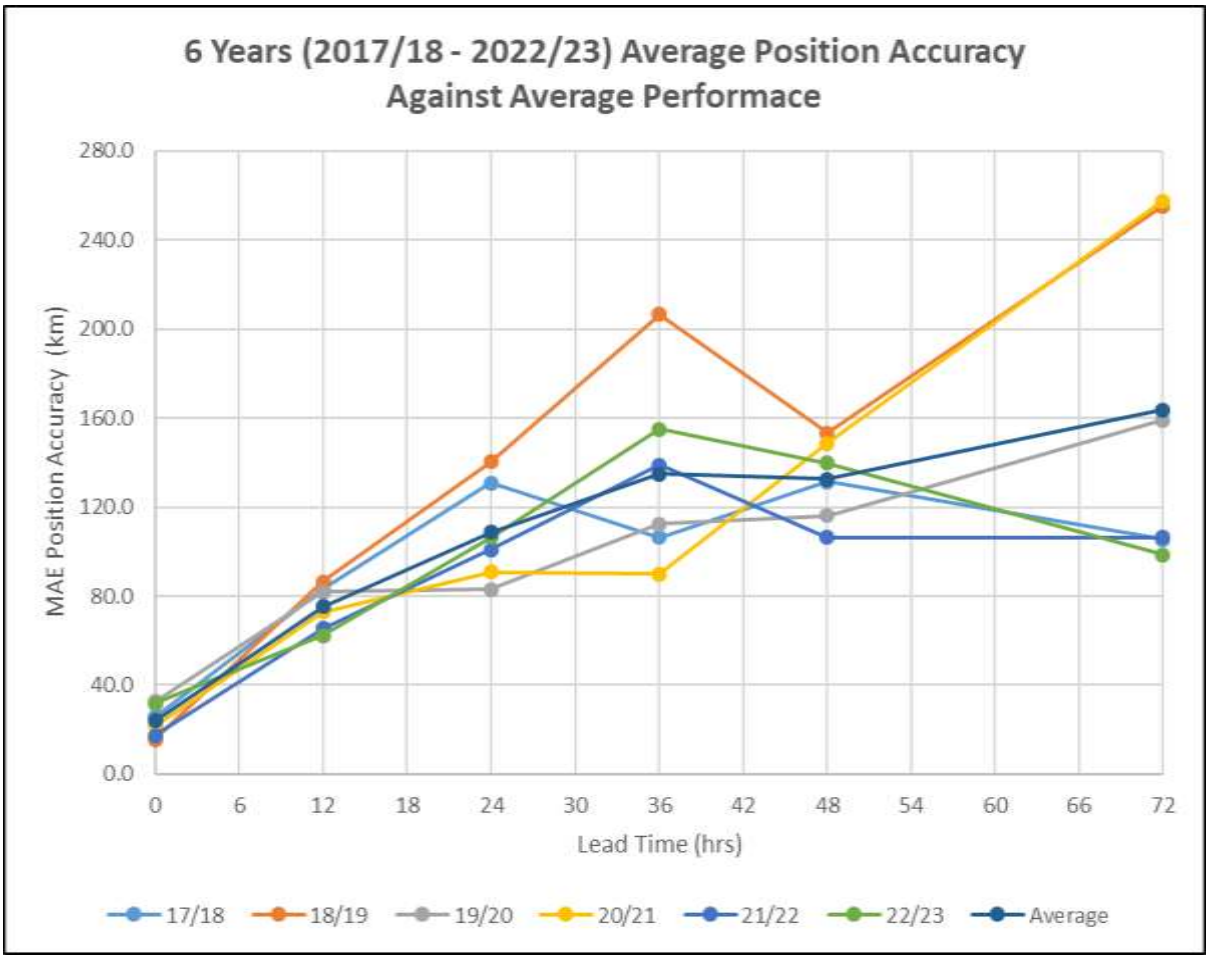
JUDY	2023	03	01	1200	-20.4	170.2	940	100	4
JUDY	2023	03	01	1800	-21.6	171.3	948	95	4
JUDY	2023	03	02	0000	-22.4	172.4	957	85	3
JUDY	2023	03	02	0600	-23.3	173.4	957	80	3
JUDY	2023	03	02	1200	-24.3	174.3	967	80	3

Name	YYYY	MM	DD	HHHH	LAT	LON	PRES	W(KT)	CAT
DEPRESSION	2023	03	01	0000	-11.2	158.9	1001	25	0
DEPRESSION	2023	03	01	0600	-11.9	160.9	998	25	0
DEPRESSION	2023	03	01	1200	-13.3	161.9	996	30	0
KEVIN	2023	03	01	1800	-13.4	161.5	987	40	1
KEVIN	2023	03	02	0000	-13.8	162.8	985	50	2
KEVIN	2023	03	02	0600	-15.2	163.5	985	50	2
KEVIN	2023	03	02	1200	-15.5	164.6	985	60	2
KEVIN	2023	03	02	1800	-16.5	165.6	985	70	3
KEVIN	2023	03	03	0000	-16.8	166.7	961	80	3
KEVIN	2023	03	03	0600	-17.8	167.8	957	85	3
KEVIN	2023	03	03	1200	-18.5	168.7	943	95	4
KEVIN	2023	03	03	1800	-19.8	170.0	939	100	4
KEVIN	2023	03	04	0000	-20.8	171.4	929	110	5
KEVIN	2023	03	04	0600	-22.1	173.2	913	125	5
KEVIN	2023	03	04	1200	-23.5	175.6	914	125	5
KEVIN	2023	03	04	1800	-24.8	178.4	926	115	5
KEVIN	2023	03	04	2100	-25.3	178.8	942	100	4

Appendix 4.2 :

a) 6 Years (2017/18 – 2022/23) Performance of RSMC Nadi

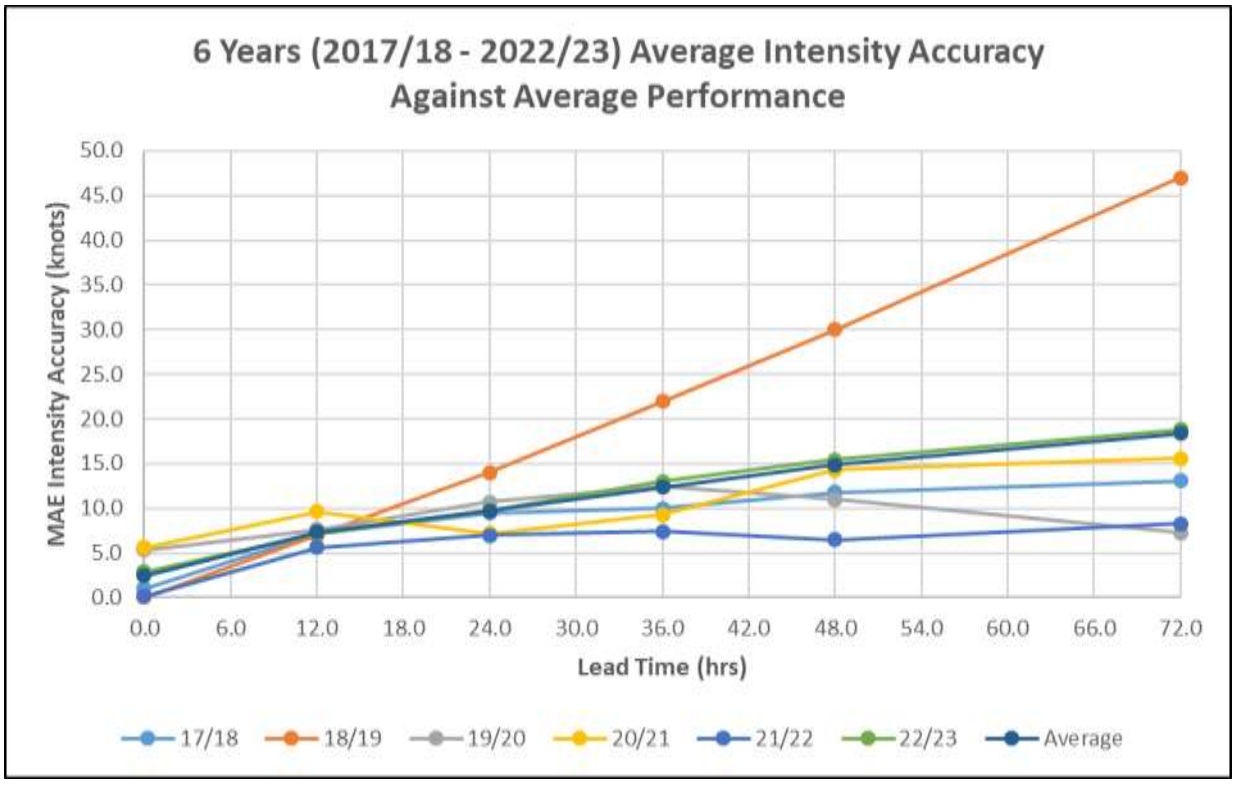
i) RSMC Nadi Position Performance



The figure above shows the comparison of the past six (6) years TC seasons mean error position accuracy forecast from 2017/18 to 2022/23 against the six-year average.

The result above highlights that the position accuracy for the season 2022/23 was higher than the average from the start then from 24hrs to the 48hrs while it was better or showed good performance for the other time step.

ii) RSMC Nadi Intensity Performance



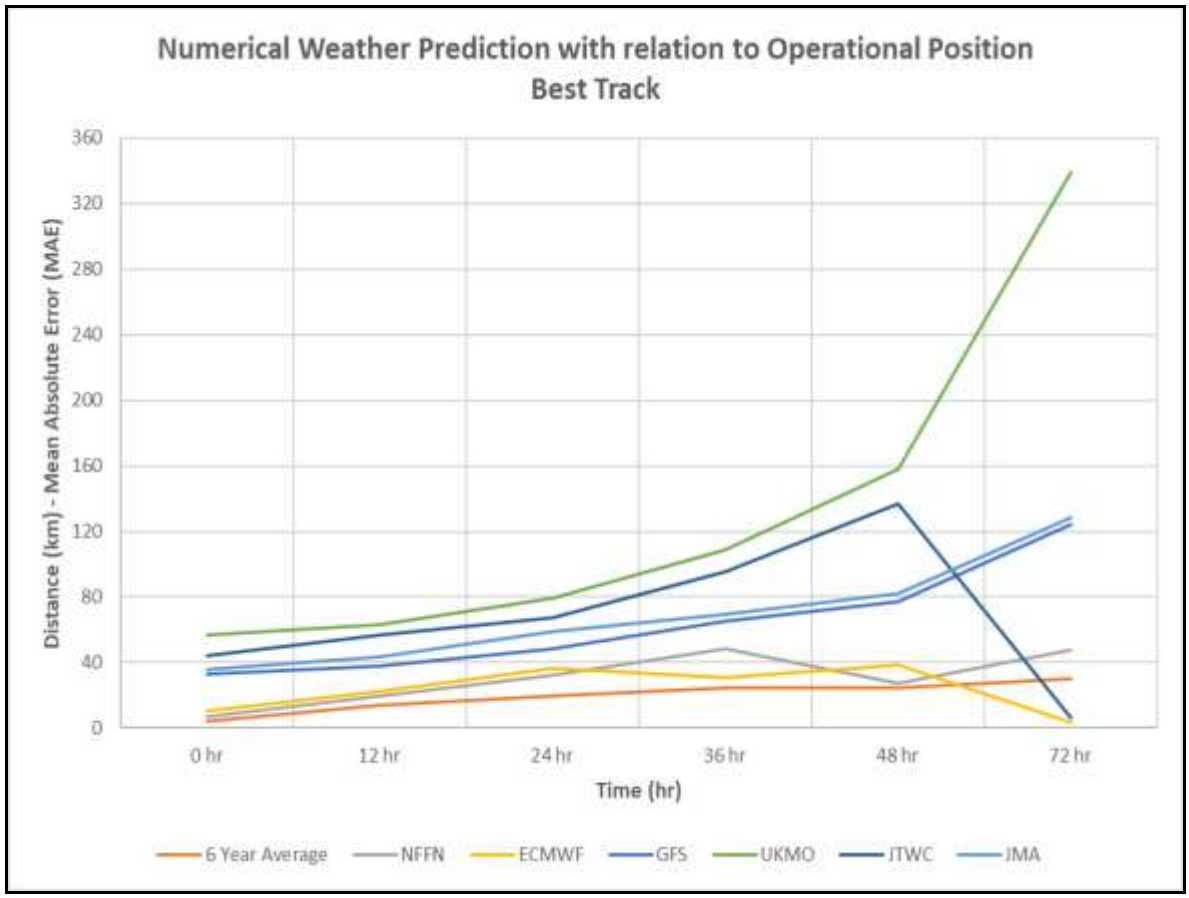
The figure above shows the comparison of the past six (6) years TC seasons mean error intensity accuracy forecast from 2017/18 to 2022/23 against the six-year average.

The result above highlights that the intensity accuracy for the season 2022/23 was better for the whole period.

b) Numerical Weather Prediction (Model) Performance

a) Position

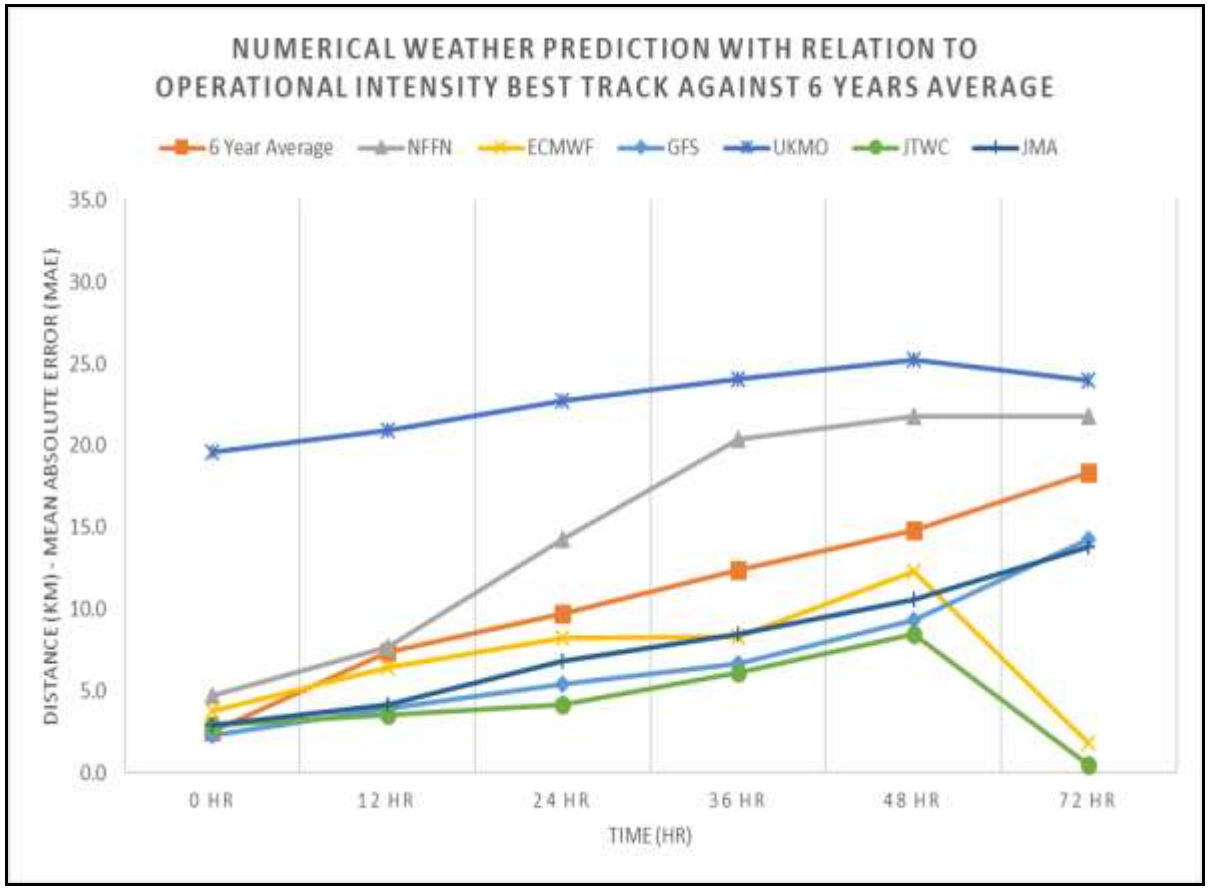
Numerical Weather Prediction(NWP) performance with relation to operational position best track against 6-year average.



The forecasts of center position for the season issued by the Nadi RSMC highlights close agreement with ECMWF followed by GFS till 36 hours while the others showed extreme variation. Beyond 48hours most models showed great mean distance errors in the position forecast or unreliable sample size.

b) Intensity

Numerical Weather Prediction(NWP) performance with relation to operational intensity best track against 6-year average.



The forecasts intensity for the season issued by the Nadi RSMC highlights an increasing trend relationship between most of the model with UKMO highlighting considerable variation.
The intensity Mean absolute error for most of the model except UKMO fairly showed minimal variation below 10 knots for the first 12 hours. Meanwhile, beyond 12hours all models showed great mean distance errors in the intensity forecast.

Appendix 4.3: <u>Position and Intensity Verification for 2021/2022 TC Season</u>

3.1 TC Irene

Table 3.1a) below shows the Position forecast verification statistics for Cyclone Irene based on warnings issued by RSMC Nadi (NFFN) and other Global models downloaded through the JTWC Collaboration Site via TC Module. Mean is the mean distance error in kilometers from the forecast to the actual position of TC Irene.

Center	**Distance \ Lead Times (hrs)**	**00**	**12**	**24**	**36**	**48**	**72**
NFFN	Mean (km)	9	61	93	155	200	0
	Std Dev(km)	14	44	22	60	76	0
ECMWF	Mean (km)	101	71	214	0	0	0
	Std Dev(km)	0	0	0	0	0	0
GFS-AVNI2	Mean (km)	16	43	28	62	0	0
	Std Dev(km)	0	0	0	0	0	0
JTWC	Mean (km)	11	50	80	134	0	0
	Std Dev(km)	0	7	10	3	0	0
UKMO-EGR2	Mean (km)	14	56	96	148	222	0
	Std Dev(km)	9	31	48	56	0	0
JMA-JG2	Mean (km)	14	41	69	102	133	278
	Std Dev(km)	9	35	28	41	106	0

Table 3.1b) below shows the Intensity forecast verification statistics for Cyclone Irene based on Dvorak analysis, microwave imagery analysis and ASCAT by RSMC Nadi (NFFN) and some other sources. Mean is the mean speed error in knots from the forecast to the estimated intensity of TC Irene.

Center	**Intensity \ Lead Times (hrs)**	**00**	**12**	**24**	**36**	**48**	**72**
NFFN	Mean (knots)	1	6	8	10	12	0
	Std Dev(knots)	3	7	12	15	15	0
ECMWF	Mean (knots)	5	8	21	0	0	0
	Std Dev(knots)	0	0	0	0	0	0
GFS-AVNI2	Mean (knots)	5	10	5	10	15	20
	Std Dev(knots)	0	0	0	0	0	0
JTWC	Mean (knots)	5	5	10	17	0	0
	Std Dev(knots)	0	7	10	3	0	0
UKMO-EGR2	Mean (knots)	41	40	43	42	35	0
	Std Dev(knots)	10	9	7	10	0	0
JMA-JG2	Mean (knots)	5	4	12	11	13	14

	Std Dev(knots)	5.7	6.3	14.8	10.7	16.9	0

3.2 TC Judy

Table 3.2a) below shows the Position forecast verification statistics for Cyclone Judy based on warnings issued by RSMC Nadi (NFFN) and other Global models downloaded through the JTWC Collaboration Site via TC Module. Mean is the mean distance error in kilometers from the forecast to the actual position of TC Judy.

Center	**Distance \ Lead times (hrs)**	**0hr**	**12hr**	**24hr**	**36hr**	**48hr**	**72hr**
NFFN	Mean(km)	43	74	102	137	166	207
	Std Dev(km)	25	69	64	64	64	131
GFS-AVNI	Mean(km)	45	62	76	96	102	167
	Std Dev(km)	40	66	50	65	101	118
ECMWF	Mean(km)	62	102	129	126	121	87
	Std Dev(km)	44	54	61	40	54	25
JTWC	Mean(km)	41	61	84	118	137	145
	Std Dev(km)	26	60	45	53	69	81
UKMO	Mean(km)	43	67	125	204	300	418
	Std Dev(km)	44	30	46	52	91	302
JMA	Mean(km)	46	95	128	143	166	171
	Std Dev(km)	47	70	72	75	57	103

Table 3.2b) below shows the Intensity forecast verification statistics for Cyclone Judy based on Dvorak analysis, microwave imagery analysis and ASCAT by RSMC Nadi (NFFN) and some other sources. Mean is the mean speed error in knots from the forecast to the estimated intensity of TC Judy.

Center	**Intensity / Lead times (hrs)**	**0hr**	**12hr**	**24hr**	**36hr**	**48hr**	**72hr**
NFFN	Mean(knots)	3	8	12	16	21	36
	Std Dev(knots)	3	10	12	12	12	15
GFS-AVNI	Mean(knots)	4	11	17	18	20	28
	Std Dev(knots)	5	13	20	19	14	10
ECMWF	Mean(knots)	15	15	21	28	36	42
	Std Dev(knots)	16	14	12	28	36	42
JTWC	Mean(knots)	3	7	9	9	12	12
	Std Dev(knots)	5	9	13	9	8	3
UKMO	Mean(knots)	7	7	6	5	4	2

	Std Dev(knots)	24	21	17	14	9	4
JMA	Mean(knots)	3	10	22	29	36	47
	Std Dev(knots)	5	9	17	25	23	15

3.3 TC Kevin

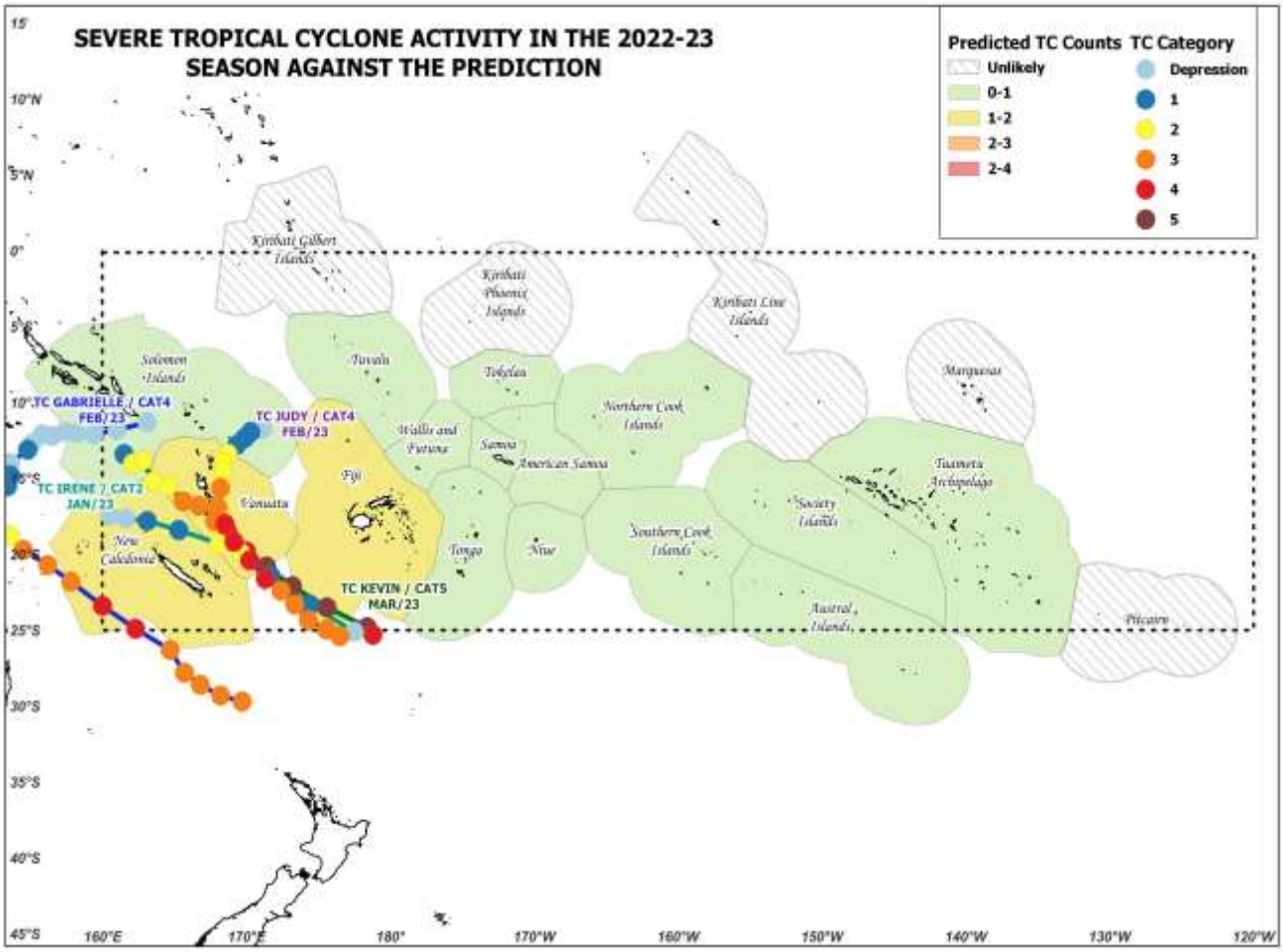
Table 3.3a) below shows the Position forecast verification statistics for Cyclone Kevin based on warnings issued by RSMC Nadi (NFFN) and other Global models downloaded through the JTWC Collaboration Site via TC Module. Mean is the mean distance error in kilometers from the forecast to the actual position of TC Kevin.

Model	**Distance /Lead times (hrs)**	**0 hr**	**12 hr**	**24 hr**	**36 hr**	**48 hr**	**72 hr**
NFFN	Mean(km)	9	54	87	137	193	187
	Std Dev(km)	12	29	46	81	103	264
ECMWF	Mean(km)	19	55	89	121	161	0
	Std Dev(km)	17	25	59	49	93	0
GFS	Mean(km)	139	148	197	246	308	564
	Std Dev(km)	369	363	396	458	534	694
UKMO	Mean(km)	253	257	346	475	693	1546
	Std Dev(km)	545	538	582	665	798	0
JTWC	Mean(km)	196	234	273	406	631	0
	Std Dev(km)	473	491	484	589	786	0
JMA	Mean(km)	149	167	230	273	358	581
	Std Dev(km)	384	370	409	456	527	669

Table 3.3b) below shows the Intensity forecast verification statistics for Cyclone Kevin based on Dvorak analysis, microwave imagery analysis and ASCAT by RSMC Nadi (NFFN) and some other sources. Mean is the mean speed error in knots from the forecast to the estimated intensity of TC Kevin.

Model	**Intensity/Lead times(hrs)**	**0 hr**	**12 hr**	**24 hr**	**36 hr**	**48 hr**	**72 hr**
NFFN	Mean (knots)	6	9	19	27	28	28
	Std Dev(knots)	7	8	10	13	16	39
ECMWF	Mean (knots)	14	25	30	34	55	0
	Std Dev(knots)	17	25	12	8	7	0
GFS	Mean (knots)	9	12	19	26	37	59
	Std Dev(knots)	17	17	15	12	13	20
UKMO	Mean (knots)	78	91	99	106	113	115
	Std Dev(knots)	32	28	22	18	13	0
JTWC	Mean (knots)	9	11	14	24	38	0
	Std Dev(knots)	22	18	11	8	8	0
JMA	Mean (knots)	9	15	26	33	41	54
	Std Dev(knots)	18	20	18	19	21	41

Appendix 4.4: Severe Tropical Cyclone Activity in the season 2022-23 against Prediction



Appendix 4.5 Storm Surge Model Output

RSMC Nadi Storm Surge Model (developed by JMA)

The storm surge model was run every 6 hours with result usually available at 0230UTC, 0830UTC, 1430UTC and 2030UTC or earlier.

Vanuatu Run, during STC Kevin

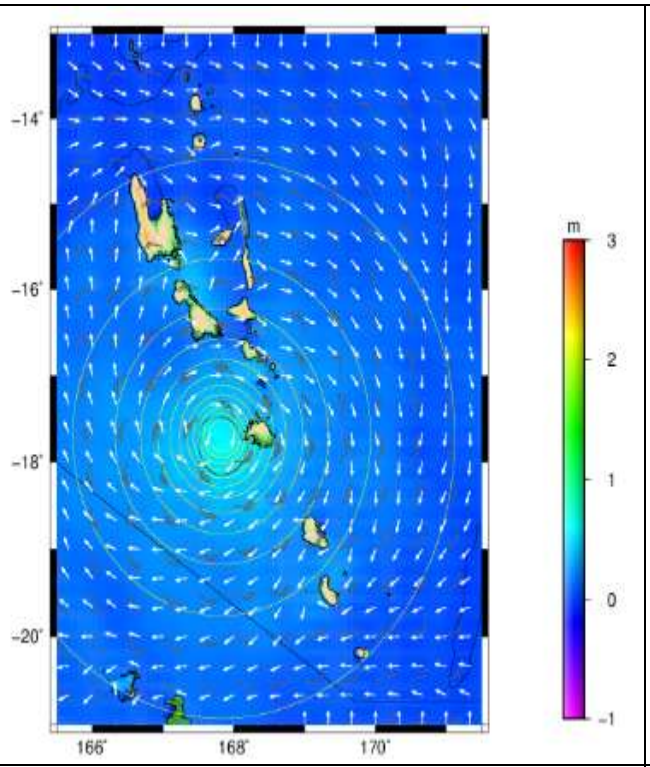


Figure 19.i: Model run at 03/0600UTC estimating surge below 1m with total water level, that is including (high tide) tide about 1.3 m near the centre. The storm surge model forecasted very little surge at this time over about Villa with 8 hours lead time.

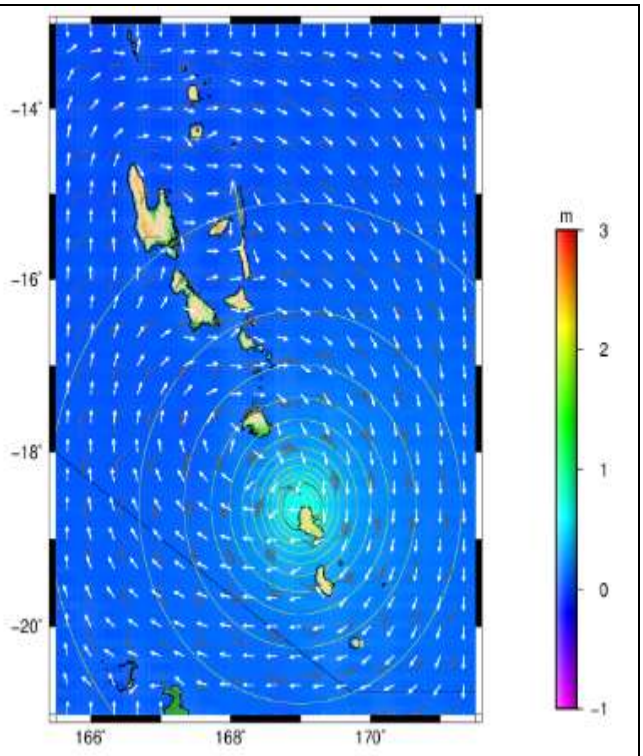


Figure 19.ii: Forecast Model run at 03/1200UTC.
Forecast at 03/1200UTC, TC Kevin approaching Erremango from the northwest with surge estimated close to 1m. The storm surge model forecasted very little surge at this time over about Erromango with 8 hours lead time. Note: wind driven waves are normally very high and this could be a contribution in surges over some coastal communities.

Appendix 4.6: Impacts

i) Damages During TC Judy

As TC Judy slowly moves away from Vanuatu, the island is left with damage to crops, vegetation, buildings, structure and power lines. afternoon.


VANUATU DAILY POST


VANUATU DAILY POST

Waterfront

ii) Damages during TC Kevin

a) Severe to widespread damage to structures, houses destroyed, roofs blown off and overturned.

b) Disruption to power service and communication due to downed power lines affecting transport routes.

c) Disruption to aviation services, waves/beach with material and debris being thrown onto coastal routes, sea fronts, and coastal communities. All marine operators at risk with damages to craft.

d) Widespread of fallen trees and flying debris. Livestock at risk with most plants/ crops damaged, trees broken and blocking/affecting transport routes

e) Vanuatu Cricket Association (VCA) Office - (FB)