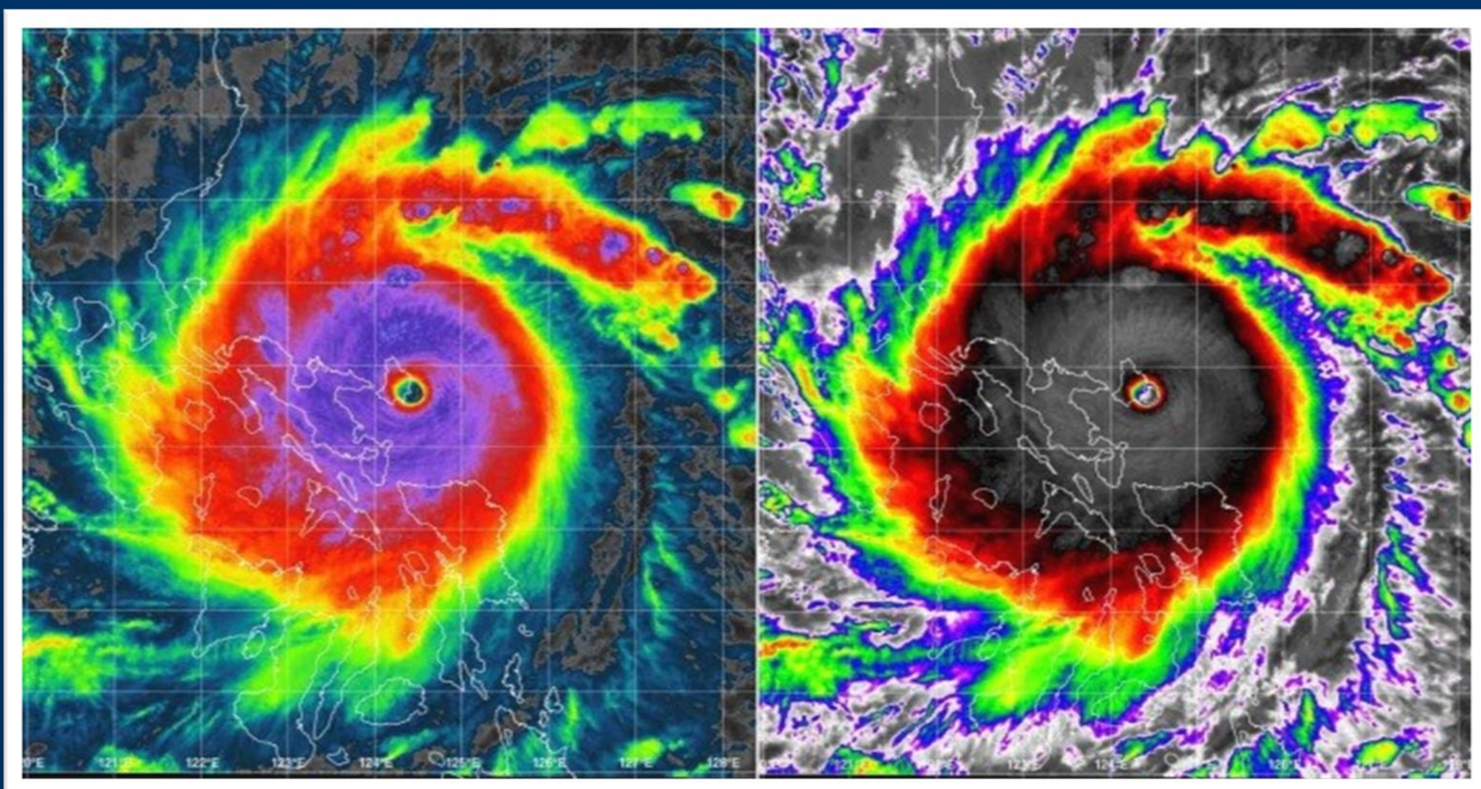
Joint Typhoon Warning Center

Annual Tropical Cyclone Report

2020



ANGELA S. FRANCIS

Commander, United States Navy

Commanding Officer

BRIAN R. STRAHL

Director, Joint Typhoon Warning Center

Cover: The cover shows Super Typhoon 22W (Goni), making landfall in the Philippines on 1 November 2020, potentially the strongest land-falling tropical cyclone on record with sustained winds of 170kts. Image courtesy of NRL

Executive Summary

This Annual Tropical Cyclone Report (ATCR) was prepared by the staff of the Joint Typhoon Warning Center (JTWC), a jointly manned United States Navy / Air Force organization.

The Joint Typhoon Warning Center was officially established on 1 May 1959 when the Joint Chiefs of Staff directed the Commander-in-Chief, US Pacific Command (USCINCPAC), to provide a single tropical cyclone warning center for the western North Pacific region. USCINCPAC delegated the tropical cyclone forecast and warning mission to Commander, Pacific Fleet (PACFLT), and subsequently tasked Commander, Pacific Air Force (PACAF) to provide tropical cyclone (TC) reconnaissance support. Since 1959, JTWC's area of responsibility (AOR) for its TC forecast and warning mission has expanded to include the area from the east coast of Africa to the International Dateline in the northern hemisphere, and from the east coast of Africa to the west coast of the Americas in the southern hemisphere. JTWC also monitors TC activity in the eastern and central Pacific Ocean, coordinating with the National Hurricane Center and Central Pacific Hurricane Center to promulgate warnings and provide tailored support to DOD customers. Altogether, this AOR encompasses over 63-million square miles of tropical oceans, and includes portions of five geographic combatant commands. Accurate and timely TC warning and decision support products from JTWC protect life and property of U.S. assets, and enable DOD commanders to sustain operations across an area within which over 80% of global tropical cyclone activity occurs annually.

This edition of the ATCR documents the 2020 TC season, and describes operationally or meteorologically significant cyclones that occurred within the JTWC AOR. Details highlight significant challenges and/or shortfalls in the TC warning system and serve as a focal point for future research and development efforts. Also included are TC reconnaissance statistics and a summary of TC research and development efforts, operational tactics, techniques and procedure (TTP) development, and outreach that members of the JTWC conducted or contributed to throughout the year.

Across all forecast basins for the 2020 storm season (1 January 2020 through 31 December 2020 for the Northern Hemisphere and 1 July 2019 through 30 June 2020 for the Southern Hemisphere), JTWC produced 757 warnings[1] for 58 TCs, or 789 warnings for 61 TCs during the 2020 *calendar* year (not shown). Additionally, JTWC repackaged 316 warnings for cyclones in the eastern and central Pacific basins. Figure P-1 (below) shows the timeline of JTWC-warned tropical cyclone activity across the JTWC AOR for calendar year 2020. In Nov, 2017, JTWC began issuing warnings at 6-hour intervals for all southern hemisphere TCs. Beginning with the 2020 southern hemisphere TC season, JTWC once again modified its policy in order to balance workload. Figure P-2 depicts the areas of 6 and 12 hour forecast frequency for the southern hemisphere.

In the western North Pacific (WESTPAC), the year began with ENSO neutral conditions and transitioned to a weak La Niña event beginning in August, based on the Oceanic Niño Index for the Niño 3.4 region. JTWC's total of 26 numbered tropical cyclones was below the long-term mean of 30, while the accumulated cyclone energy (ACE) of 155.7 units was well below the 20-year mean value of 274.2.

WESTPAC mean absolute errors (MAE) for track forecast improved, breaking or tying records across all lead times. The five-day 155.7 nm MAE, in particular, was only 6 nm above the 2009 US INDOPACOM forecast goal. On the other hand, four and five-day intensity forecast skill compared to

[1] NOTE: JTWC issued all southern hemisphere warnings at 6-hour intervals between Nov 2017 and Jun 2019, increasing the southern hemisphere and total warnings counts during this timeframe.

climatology and persistence fell sharply. However, skill at 1-2 day lead times improved to new highs, in part due to recent improvements in rapid intensity change detection and prediction.

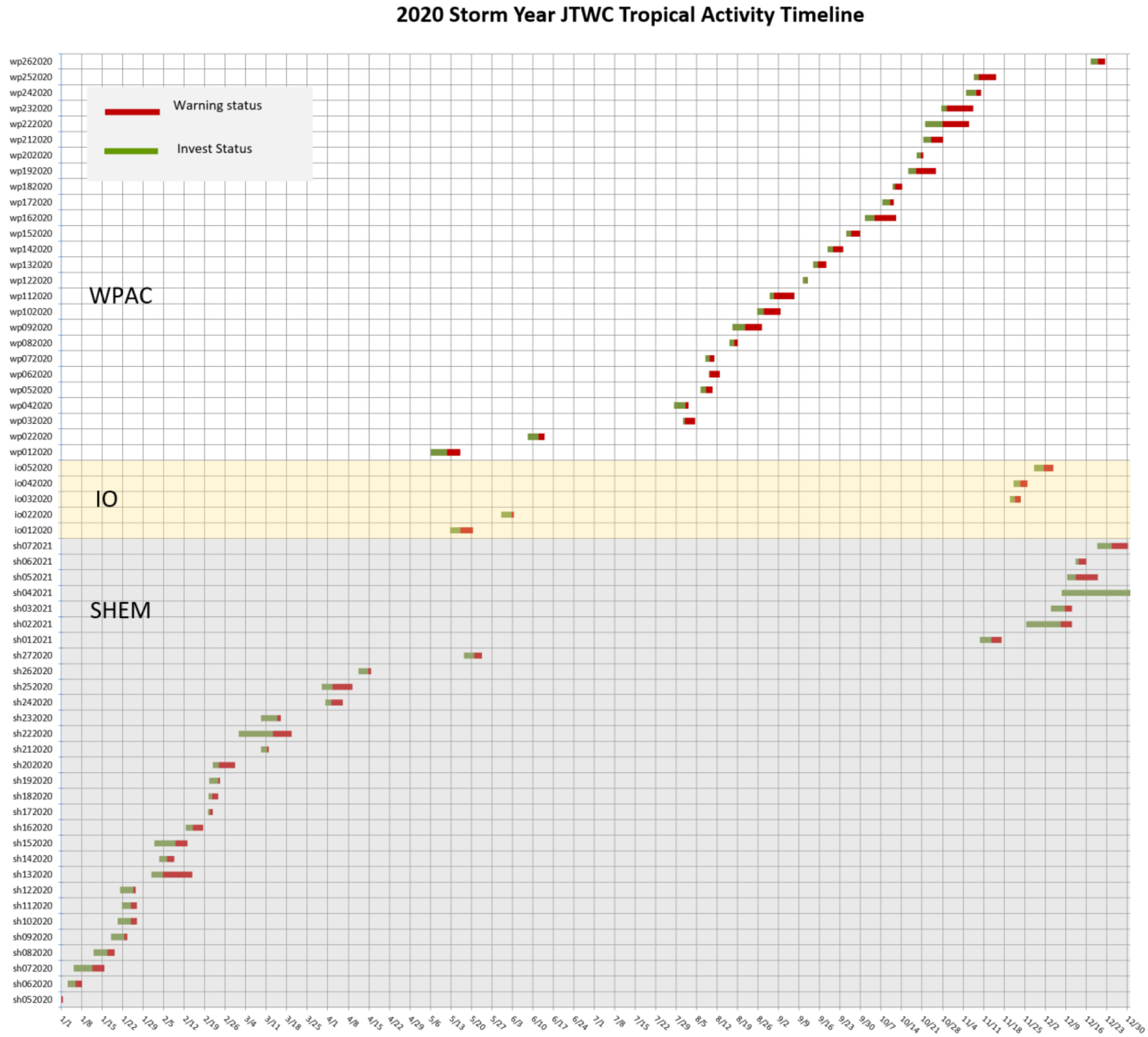


Figure P-1: Timeline of JTWC-warned tropical cyclone activity across the JTWC AOR during the 2020 calendar year.

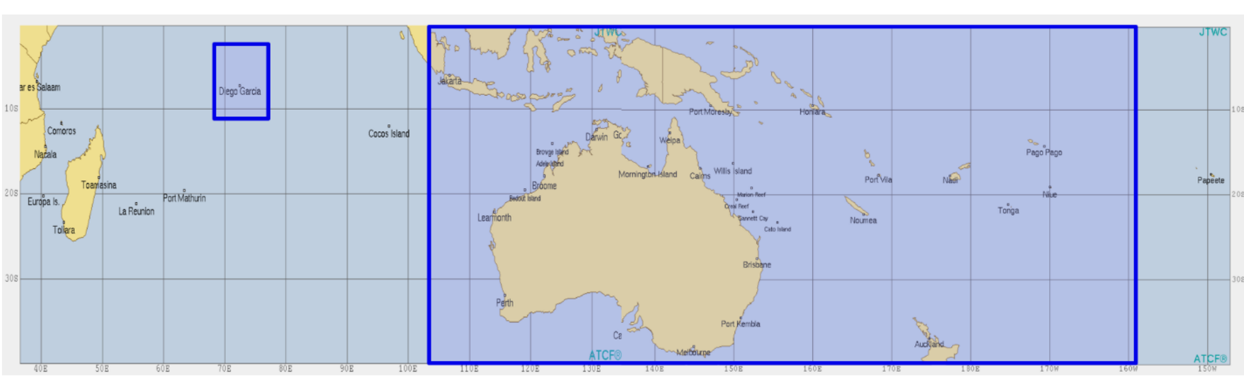


Figure P-2: Southern hemisphere regions of 6-hourly forecast intervals (blue shading) versus 12-hourly (unshaded).

Meteorological satellite data remain critical to the TC reconnaissance mission of the JTWC. In late 2020, the Electro-optical Infrared Weather System Geostationary (EWS-G), formerly GOES-13, was declared operational in its new mission to provide persistent coverage over the western Indian Ocean. At almost the same time, the Navy's WindSat satellite was deactivated, ending a nearly 20 year science mission that provided high-resolution microwave imagery and passive radiometer wind estimates. Satellite analysts administratively assigned to the 17th Operational Weather Squadron, exploited available electro-optic (EO), infrared (IR) and satellite data to produce 3,211 position and intensity estimates (fixes) using the USAF Mark IVB and Navy FMQ systems. Analysts also produced 3,596 TC center position, structure, and intensity fixes based on all available geo-located microwave and scatterometer imagery data, provided by the Fleet Numerical Meteorology and Oceanography Center (FNMOC) and Naval Research Laboratory, Monterey (NRL-MRY) via the Automated Tropical Cyclone Forecast (ATCF) system. JTWC continued evaluating data from new and emerging sources, such as L-band radiometer data from NASA's Soil Moisture Active Passive (SMAP), and monitored the progress of various "CubeSat" and "microsat" research projects.

JTWC collaborated with various TC forecast support and research organizations, such as the FNMOC, NRL-MRY, the Naval Postgraduate School, the Office of Naval Research (ONR), the 557th Weather Wing, and NOAA Line Offices, in order to develop and advance TC reconnaissance tools, numerical models, and forecast aids.

At the heart of all these efforts is the dedicated team of men and women, military and civilian at JTWC. Maintaining a watch against one of the most powerful forces of Mother Nature is a challenging endeavor in a normal year. 2020 was far from normal. In February, 2020, Mr. Brian Strahl was selected as the new JTWC Director. Two weeks later, the global COVID-19 pandemic challenged nearly every aspect of conducting "business as usual." Despite this paradigm shift and the challenges presented by COVID, 24x7 on-site operations continued uninterrupted. As the DoD rolled out new virtual tools, and telework increasingly became the new normal, the outstanding professionals working behind the scenes throughout the Administrative, Information Services, Technical Services, Training, and Requirements Departments continued their tireless efforts to ensure that JTWC had the necessary support and resources to fulfill its mission.

JTWC extends special thanks to FNMOC for its operational data and modeling support, NRL-MRY and ONR for their dedicated TC research, NOAA National Environmental Satellite Data and Information Service for satellite reconnaissance and TC fixing support, NRL-MRY for outstanding support and continued development of the ATCF system, and lastly… to the numerous individuals and partners throughout government, industry and academia who continuously pursue new and innovative ways to improve the state of the science of tropical cyclone forecasting.

JTWC personnel between Jan 1 & Dec 31, 2020

Leadership
CDR Corey Cherrett, Commanding Officer (2018 - 2020)
CDR Angela Francis, Commanding Officer (2020 - present)
Mr. Brian Strahl, Director (2020 - present)
CDR Elias George, Executive Officer (2019 - present)
AGCS William Cady, Senior Enlisted Advisor (2017 - 2020)
AGCS Michael Conklin, Senior Enlisted Advisor (2020 - present)

Support Services Department
LT Helena Cheslack, Support Services Department Head (2019 - present)
Mrs. Leilanie Bonini, Support Services Department Head (2019 - present)
Mr. Lyntillus Boyd, Administrative Assistant (2018 - 2020)
LS1 Kristofer Gaffud, Logistics Specialist (2017 - 2020)
LS1 Anthony Wheelehan, Logistics Specialist (2020 - present)

Satellite Reconnaissance Department
Capt Amanda Nelson, Satellite Operations Flight Commander (2019 - present)*
MSgt Richard Kienzle, Satellite Operations NCOIC (2019 - 2020)
MSgt Aaron Goodman, Satellite Operations NCOIC (2020 - present)
TSgt Sonny Richardson, Satellite Analyst (2019 - 2020)
TSgt Jessica Elias, Satellite Analyst (2018 - present)
Mrs. Brittany Bermea, Satellite Analyst (2016 - present)
TSgt Jeremy Heins, Satellite Analyst (2020 - present)
TSgt Jonathan Young, Satellite Analyst (2020 - present)
SrA Isaiah Martin, Satellite Analyst (2018 - present)
SrA Philip Stigsson, Satellite Analyst (2018 - 2020)
SSgt Jonathan Rhoades, Satellite Analyst (2019 - present)

Operations Department
LT Caitlin Fine, Operations Department Head (2017 - 2020)
LT Andrew Sweeney, Typhoon Duty Officer (2017 - 2020)
LT Lee Suring, Operations Department Head (2018 - present)
LT William Dearing, Typhoon Duty Officer (2020 - present)
LT Jillian Homola, Typhoon Duty Officer (2019 - present)
LT Joseph Pinto, Command Duty Officer (2019 - present)
LT Anthony Prochilo, Command Duty Officer (2019 - present)
LTJG Sean Egan, PhD, Typhoon Duty Officer (2019 -present)
LTJG William Venden, Command Duty Officer (2018 -2020)
LTJG Timothy Ragan, Command Duty Officer (2018 -present)
CWO2 Justin Coryell, Typhoon Duty Officer (2020 - present)
AGC Justin Knaebel, Command Duty Officer (2017 - 2020)
AG1 Michael Clute, Forecast Duty Officer (2019 - present)
AG1 Eric Waring, Forecast Duty Officer (2017 - present)
AG1 Rodney Rumph, Forecast Duty Officer (2016 - 2020)
AG2 Dylan Howard, Forecast Duty Officer (2019 - present)
AG2 Alexa May, Forecast Duty Officer (2019 - present)
AG2 Terrell Grantwaters, Forecast Duty Officer (2019 - present)
AGAN Javonni Christopher, Geophysical Technician (2019 - present)
AGAR Ethan Carrodus, Geophysical Technician (2018 - 2020)
AGAR Asia Davis, Geophysical Technician (2019 - present)
AG2 Jayde Bejer, Geophysical Technician (2019 - 2020)
AG3 Kain Enright, Geophysical Technician (2018 - 2020)
AG3 Koreaun Elliot, Geophysical Technician (2019 - 2020)
AG3 Samuel Wyss, Geophysical Technician (2017 - present)
Mr. Richard Ballucanag, Typhoon Duty Officer (2006 - present)
Mr. Stephen Barlow, Typhoon Duty Officer (2006 - present)
Dr. Brian Belson, Typhoon Duty Officer (2018 - 2020)
Mr. Brian Howell, Typhoon Duty Officer (2020 - present)

Plans and Requirements Department
Mr. Brian Strahl, Plans and Requirements Department Head (2011 - 2020)*

Information Services Department
Mr. Joshua Nelson, Information Services Department Head (2014 - 2020)
Mr. Angelo Alvarez, System Administrator (2003 - present)
Mr. Brandon Brevard, System Administrator (2016 - 2020)
Mr. Andrew Rhoades, Information Assurance Officer (2007 - present)
IT1 Kenneth Surline, Information Technology (2015 - 2020)
IT2 Nathaniel Natanauan, Information Technology (2018 - present)
IT2 Brenden Miranda, Information Technology (2018 - present)

Training Department
Mr. Owen Shieh, Training Department Head (2016 - present)*

Technical Services Department
Mr. Matthew Kucas, Technical Services Department Head (2009 - present)*
Mr. James Darlow, Technical Services Technician (2009 - present)***

Note: "present"- expresses Tour of Duty extends past 31DEC20

* Typhoon Duty Officer (augmentation) ** Command Duty Officer (augmentation) *** Satellite Analyst (augmentation)

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Section 1 Informational Tables

Table 1-1 is a summary of TC activity in the western North Pacific Ocean during the 2020 season. JTWC issued warnings on 26 tropical cyclones. Table 1-2 shows the monthly distribution of TC activity summarized for 1959 - 2020 and Table 1-3 shows the monthly average occurrence of TCs separated into: (1) typhoons and (2) tropical storms and typhoons. Table 1-4 summarizes Tropical Cyclone Formation Alerts (TCFAs) issued. Figure 1-1 depicts the 2020 western North Pacific Ocean TC tracks. The annual number of TCs of tropical storm (TS) strength or higher appears in Figure 1-2, while the number of TCs of super typhoon (STY) intensity appears in Figure 1-3. Figure 1-4 illustrates a monthly average number of cyclones based on intensity categories.

Table 1-1
WESTERN NORTH PACIFIC SIGNIFICANT TROPICAL CYCLONES
(01 JAN 2020 - 31 DEC 2020)

TC	NAME*	PERIOD**		WARNINGS ISSUED	EST MAX SFC WINDS KTS
01W	VONGFONG	11 May / 1800Z	16 May / 0600Z	19	100
02W	NURI	12 Jun / 0000Z	14 Jun / 0000Z	9	35
03W	HAGUPIT	01 Aug / 0000Z	04 Aug / 1200Z	15	75
04W	SINLAKU	01 Aug / 0600Z	02 Aug / 0600Z	5	45
05W	JANGMI	08 Aug / 0600Z	10 Aug / 1200Z	10	40
06W	SIX	09 Aug / 1200Z	13 Aug / 0000Z	15	45
07W	MEKKHALA	09 Aug / 1200Z	11 Aug / 0000Z	7	70
08W	HIGOS	17 Aug / 1800Z	19 Aug / 0000Z	6	60
09W	BAVI	21 Aug / 1200Z	27 Aug / 0600Z	24	100
10W	MAYSAK	28 Aug / 0000Z	02 Sep / 1800Z	24	120
11W	HAISHEN	31 Aug / 1200Z	07 Sep / 1200Z	29	135
12W	TWELVE	11 Sep / 1800Z	12 Sep / 0000Z	2	25
13W	NOUL	15 Sep / 1200Z	18 Sep / 0600Z	12	50
14W	DOLPHIN	20 Sep / 1200Z	24 Sep / 0000Z	15	55
15W	KUJIRA	26 Sep / 1800Z	29 Sep / 1800Z	13	65
16W	CHAN-HOM	04 Oct / 1800Z	12 Oct / 0600Z	31	80
17W	LINFA	10 Oct / 0000Z	11 Oct / 0600Z	6	40
18W	NANGKA	11 Oct / 1800Z	14 Oct / 0600Z	11	50
19W	SAUDEL	19 Oct / 0000Z	25 Oct / 1800Z	28	75
20W	TWENTY	20 Oct / 1200Z	21 Oct / 1200Z	5	30
21W	MOLAVE	24 Oct / 0000Z	28 Oct / 0600Z	18	105
22W	GONI	28 Oct / 0000Z	06 Nov / 0000Z	37	170
23W	ATSANI	29 Oct / 1200Z	07 Nov / 1200Z	37	50
24W	ETAU	08 Nov / 1200Z	10 Nov / 0600Z	8	45
25W	VAMCO	09 Nov / 0600Z	15 Nov / 0600Z	25	115
26W	KROVANH	20 Dec / 0000Z	22 Dec / 1200Z	11	30

* As designated by the responsible RSMC

**** Dates based on issuance of JTWC warnings on system (or DTG of ≥ 25kts criteria if no warning)**

*** Warnings issued by JTWC

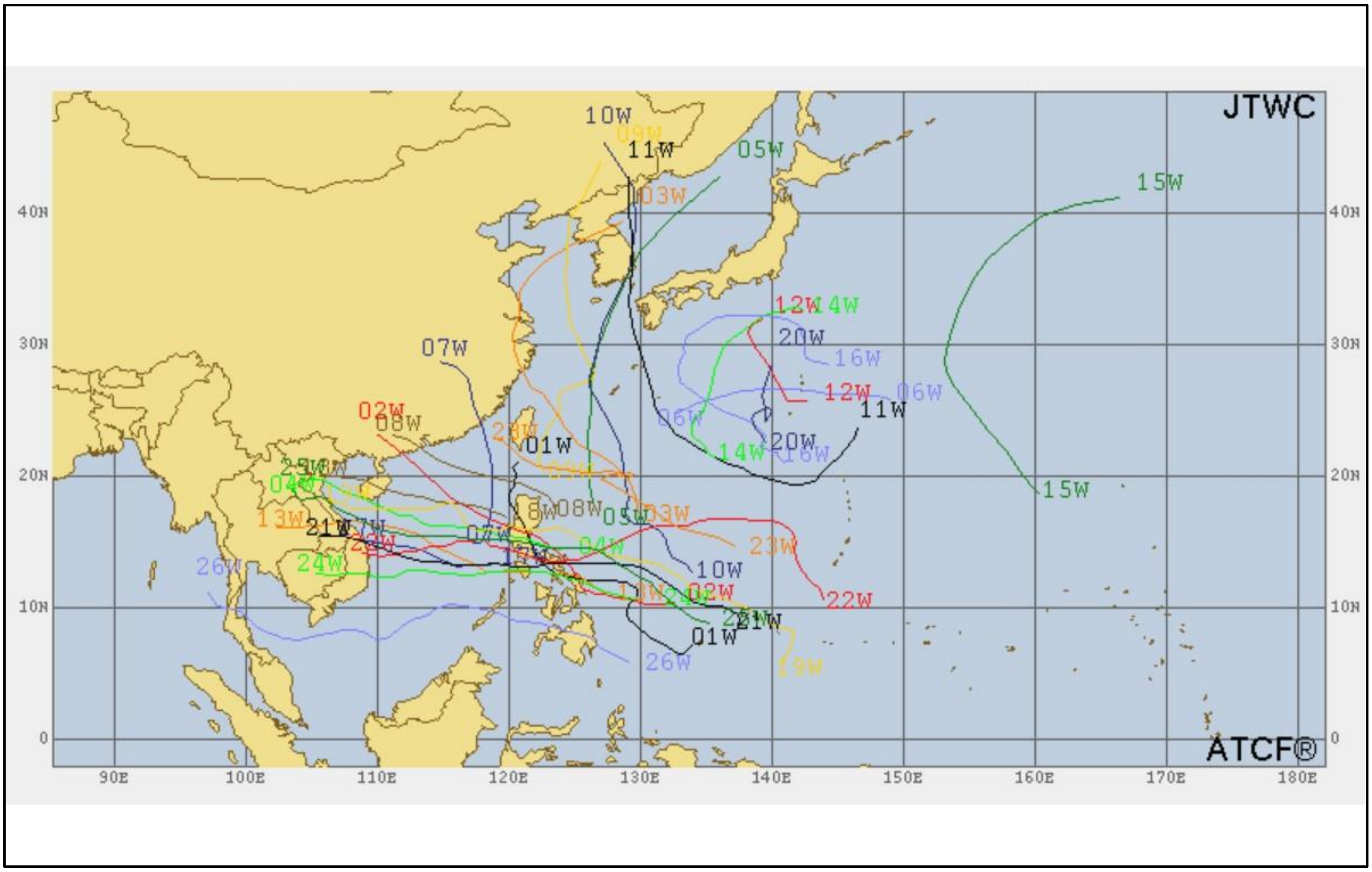

Figure 1-1. Western North Pacific Tropical Cyclones.

Table 1-2
DISTRIBUTION OF WESTERN NORTH PACIFIC TROPICAL CYCLONES FOR 1959 - 2020

YEAR	JAN				FEB				MAR				APR				MAY				JUN			
1959	0	0	0	0	1	0	1	0	1	0	1	1	1	1	0	0	0	0	0	0	1	0	0	1
1960	1	0	0	1	0	0	0	0	1	0	0	1	1	1	0	0	1	0	1	0	3	2	1	0
1961	1	0	1	0	1	0	1	0	1	1	0	0	1	0	1	0	4	2	1	1	6	1	1	4
1962	0	0	0	0	1	0	1	0	0	0	0	0	1	1	0	0	3	2	0	1	0	0	0	0
1963	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0	4	3	1	0
1964	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	1	2	2	0	0
1965	2	1	1	0	2	0	2	0	1	0	1	0	1	1	0	0	2	1	0	1	4	3	1	0
1966	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2	2	0	0	1	1	0	0
1967	1	0	1	0	0	0	0	0	2	1	1	0	1	1	0	0	1	0	1	0	1	1	0	0
1968	0	0	0	0	1	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	4	2	0	2
1969	1	1	0	0	0	0	0	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0
1970	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	0
1971	1	0	1	0	0	0	0	0	1	0	1	0	2	2	0	0	5	2	3	0	2	2	0	0
1972	1	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	4	2	2	0
1973	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1974	1	0	1	0	0	0	0	0	1	0	1	0	1	0	1	0	1	1	0	0	4	1	2	1
1975	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
1976	1	1	0	0	1	0	1	0	0	0	0	0	2	1	1	0	2	2	0	0	2	2	0	0
1977	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	1	1	0	1	0
1978	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	3	0	3	0
1979	1	1	0	0	0	0	0	0	1	1	0	0	1	1	0	0	2	0	1	1	0	0	0	0
1980	0	0	0	0	0	0	0	0	1	0	0	1	1	0	1	0	4	2	2	0	1	0	1	0
1981	0	0	0	0	0	0	0	0	1	1	0	0	1	0	1	0	1	0	1	0	2	2	0	0
1982	0	0	0	0	0	0	0	0	3	2	1	0	0	0	0	0	1	1	0	0	3	1	2	0
1983	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
1984	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0
1985	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	3	2	0	1
1986	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	2	1	1	0	2	1	1	0
1987	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	2	1	1	0
1988	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	3	1	1	1
1989	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	2	2	0	0	2	1	1	0
1990	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2	1	1	0	4	2	1	1
1991	0	0	0	0	0	0	0	0	2	1	1	0	1	0	1	0	1	1	0	0	1	1	0	100
1992	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	1	0
1993	0	0	0	0	0	0	0	0	2	0	1	1	2	0	0	2	1	0	1	0	2	1	0	1
1994	1	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	2	1	0	1	2	0	2	0
1995	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2	0	2	0
1996	1	0	0	1	1	0	0	1	0	0	0	0	2	0	1	1	2	1	1	0	0	0	0	0
1997	1	0	1	0	0	0	0	0	0	0	0	0	2	1	1	0	3	1	2	0	3	3	0	0
1998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	1	0	1	0	1	0	1	0	0	0	0	0	3	2	1	0	0	0	0	0	1	1	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	1	2	0	0	0	0
2001	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	1	1	0	1	0	2	2	0	0
2002	1	0	1	0	1	1	0	0	1	0	0	1	1	0	0	1	2	1	0	1	3	3	0	0
2003	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	3	1	1	1	2	1	1	0
2004	0	0	0	0	1	0	1	0	1	0	1	0	1	1	0	0	3	2	1	0	5	5	0	0
2005	1	1	0	0	0	0	0	0	1	1	0	0	1	1	0	0	0	0	0	0	1	1	0	0
2006	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	1	0	0	1	0	1	0
2007	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0
2008	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	4	3	1	0	1	1	0	0
2009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	2	1	1	0
2010	1	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	2	1	1	0	3	0	2	1
2012	0	0	0	0	1	0	0	1	1	0	1	0	0	0	0	0	1	1	0	0	4	2	2	0
2013	1	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4	1	3	0
2014	2	0	1	1	1	1	0	0	1	1	0	0	2	1	1	0	0	0	0	0	1	0	1	0
2015	1	1	0	0	1	1	0	0	2	1	1	0	1	0	1	0	2	2	0	0	1	0	1	0
2016	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
2017	1	0	0	1	0	0	0	0	0	0	0	0	2	0	1	1	0	0	0	0	1	0	1	0
2018	1	0	1	0	1	0	1	0	1	1	0	0	0	0	0	0	1	0	1	0	5	1	4	0
2019	1	0	0	1	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0
2020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	1	0

YEAR	JUL				AUG				SEP				OCT				NOV				DEC				TOTALS			
																									Total	≥64kt	34-63kt	≤33 kt
1959	3	1	1	1	8	5	1	2	9	4	2	3	3	2	1	0	2	2	0	0	2	2	0	0	31	17	7	7
1960	3	2	1	0	9	8	1	0	5	0	4	1	4	4	0	0	1	1	0	0	1	1	0	0	30	19	8	3
1961	5	3	2	0	7	3	1	3	6	5	1	0	7	3	2	2	2	1	0	1	1	1	0	0	42	20	11	11
1962	8	5	1	2	8	7	0	1	7	3	1	3	5	3	1	1	4	3	0	1	2	0	2	0	39	24	6	9
1963	5	3	1	1	4	3	0	1	4	2	2	0	6	5	1	0	0	0	0	0	3	2	1	0	28	19	6	3
1964	8	6	1	1	8	3	5	0	8	5	2	1	7	3	3	1	6	4	2	0	2	1	0	1	44	26	13	5
1965	6	4	1	1	7	3	2	2	9	5	3	1	3	2	0	1	2	1	1	0	1	0	1	0	40	21	13	6
1966	4	3	1	0	9	5	3	1	10	5	3	2	4	1	1	2	5	1	2	2	2	1	0	1	38	20	10	8
1967	8	3	3	2	10	3	4	3	8	5	3	0	4	2	1	1	4	4	0	0	1	0	1	0	41	20	15	6
1968	3	1	2	0	8	3	4	1	4	4	0	0	6	5	1	0	4	4	0	0	0	0	0	0	31	20	7	4
1969	3	2	1	0	3	2	1	0	6	2	0	4	5	4	1	0	2	1	1	0	1	0	1	0	23	13	6	4
1970	3	0	2	1	7	4	2	1	4	2	2	0	6	3	2	1	4	1	3	0	0	0	0	0	27	12	12	3
1971	8	6	2	0	5	3	1	1	7	5	1	1	4	3	1	0	2	1	1	0	0	0	0	0	37	24	11	2
1972	5	4	1	0	5	3	2	0	6	4	1	1	5	4	1	0	2	2	0	0	3	2	1	0	32	22	8	2
1973	7	4	3	0	6	2	3	1	3	2	0	1	4	4	0	0	3	0	3	0	0	0	0	0	23	12	9	2
1974	5	2	3	0	7	2	3	2	5	3	2	0	4	4	0	0	4	2	2	0	2	0	2	0	35	15	17	3
1975	1	0	1	0	6	4	1	1	5	4	1	0	6	3	2	1	3	2	1	0	2	0	2	0	25	14	8	3
1976	4	2	2	0	4	1	3	0	5	4	1	0	0	0	0	0	2	1	1	0	2	0	2	0	25	14	11	10
1977	4	3	0	1	2	0	2	0	5	2	3	0	4	3	1	0	2	2	0	0	1	1	0	0	21	11	8	2
1978	4	3	1	0	8	3	4	1	4	3	1	0	7	4	1	2	4	1	2	1	0	0	0	0	32	15	13	4
1979	5	2	2	1	4	2	0	2	6	3	3	0	3	2	1	0	2	1	1	0	3	1	1	1	28	14	9	5
1980	5	3	1	1	3	2	0	1	7	5	1	1	4	2	2	0	1	1	0	0	1	0	1	0	28	15	9	4
1981	5	2	3	0	8	2	5	1	4	4	0	0	2	1	1	0	3	2	1	0	2	2	0	0	29	16	12	1
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1987	4	4	0	0	4	3	1	0	7	5	1	1	2	2	0	0	3	1	2	0	1	1	0	0	25	18	6	1
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1996	7	6	1	0	10	4	3	3	7	6	1	0	5	2	1	2	6	1	3	2	3	1	1	1	44	21	12	11
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2003	2	2	0	0	5	4	1	0	3	3	0	0	6	2	1	3	3	3	0	0	1	0	1	0	27	17	6	4
2004	2	1	1	0	9	6	2	1	3	1	1	1	3	3	0	0	2	2	0	0	2	0	2	0	32	21	9	2
2005	4	1	3	0	6	6	0	0	5	4	1	0	3	2	0	1	2	1	1	0	1	0	1	0	25	18	6	1
2006	3	2	1	0	8	3	4	1	5	3	0	2	4	2	1	1	2	2	0	0	2	1	0	1	27	14	8	5
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2013	3	1	2	0	5	2	2	1	8	4	3	1	7	6	0	1	3	1	1	1	1	0	0	1	33	15	12	6
2014	4	3	1	0	2	1	1	0	5	2	2	1	1	1	0	0	3	2	1	0	2	1	0	1	24	13	8	3
2015	5	4	1	0	4	2	1	1	4	2	2	0	5	4	1	0	1	1	0	0	2	1	0	1	29	19	8	2
2016	5	3	1	1	9	4	5	0	6	4	1	1	4	3	1	0	4	2	1	1	1	1	0	0	30	17	9	4
2017	8	3	5	0	6	3	3	0	4	2	0	2	5	3	0	2	4	1	2	1	2	1	1	0	33	13	13	7
2018	7	3	4	0	10	6	3	1	5	3	1	1	1	0	1	0	3	1	0	2	2	0	0	2	37	15	16	6
2019	4	0	4	0	5	3	2	0	6	4	2	0	4	4	0	0	6	6	0	0	1	0	1	0	30	19	10	1
2020	0	0	0	0	9	5	4	0	4	1	2	1	8	4	3	1	2	1	1	0	1	0	0	1	26	12	11	3

TABLE 1-3 WESTERN NORTH PACIFIC TROPICAL CYCLONES													
TYPHOONS (1945 - 1958)													
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN	0.4	0.1	0.3	0.4	0.7	1.1	2	2.9	3.2	2.4	2	0.9	16.4
CASES	5	1	4	5	10	15	28	41	45	34	28	12	228
TYPHOONS (1959 - 2020)													
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN	0.2	0.1	0.2	0.4	0.7	1.0	2.5	3.5	3.2	2.9	1.6	0.6	16.8
CASES	12	6	13	24	44	60	153	214	198	181	97	40	1042
TROPICAL STORMS AND TYPHOONS (1945 - 1958)													
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN	0.4	0.2	0.5	0.5	0.8	1.6	2.9	4	4.2	3.3	2.7	1.2	22.3
CASES	6	2	7	8	11	22	44	60	64	49	41	18	332
TROPICAL STORMS AND TYPHOONS (1959 - 2020)													
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN	0.5	0.3	0.5	0.6	1.1	1.7	3.9	5.6	4.8	4.0	2.5	1.2	26.7
CASES	29	16	28	38	68	108	244	348	300	246	155	73	1653

TABLE 1-4 TROPICAL CYCLONE FORMATION ALERTS FOR THE WESTERN NORTH PACIFIC OCEAN 1976 - 2020					
YEAR	INITIAL TCFAS	TROPICAL CYCLONES WITH TCFAS	TOTAL TROPICAL CYCLONES	PROBABILITY OF TCFA WITHOUT WARNING*	PROBABILITY OF TCFA BEFORE WARNING
1976	34	25	25	26%	100%
1977	26	20	21	23%	95%
1978	32	27	32	16%	84%
1979	27	23	28	15%	82%
1980	37	28	28	24%	100%
1981	29	28	29	3%	97%
1982	36	26	28	28%	93%
1983	31	25	25	19%	100%
1984	37	30	30	19%	100%
1985	39	26	27	33%	96%
1986	38	27	27	29%	100%
1987	31	24	25	23%	96%
1988	33	26	27	21%	96%
1989	51	32	35	37%	91%
1990	33	30	31	9%	97%
1991	37	29	31	22%	94%
1992	36	32	32	11%	100%
1993	50	35	38	30%	92%
1994	50	40	40	20%	100%
1995	54	33	35	39%	94%
1996	41	39	43	5%	91%
1997	36	30	33	17%	91%
1998	38	18	27	53%	67%
1999	39	29	33	26%	88%
2000	40	31	34	23%	91%
2001	34	28	33	18%	85%
2002	39	31	33	21%	94%
2003	31	27	27	13%	100%
2004	35	32	32	9%	100%
2005	26	25	25	4%	100%
2006	23	22	26	4%	85%
2007	27	26	27	4%	96%
2008	23	23	28	0%	82%
2009	26	22	28	15%	79%
2010	24	18	19	25%	95%
2011	32	26	27	19%	96%
2012	31	26	27	16%	96%
2013	36	31	33	14%	94%
2014	32	23	23	28%	100%
2015	33	29	29	12%	100%
2016	34	29	30	15%	97%
2017	38	30	33	21%	91%
2018	39	35	36	10%	97%
2019	35	30	30	14%	100%
2020	29	24	26	17%	92%
MEAN	35	28	30	20%	94%
CASES	1562	1250	1336		
* Percentage of initial TCFAs not followed by warnings.					

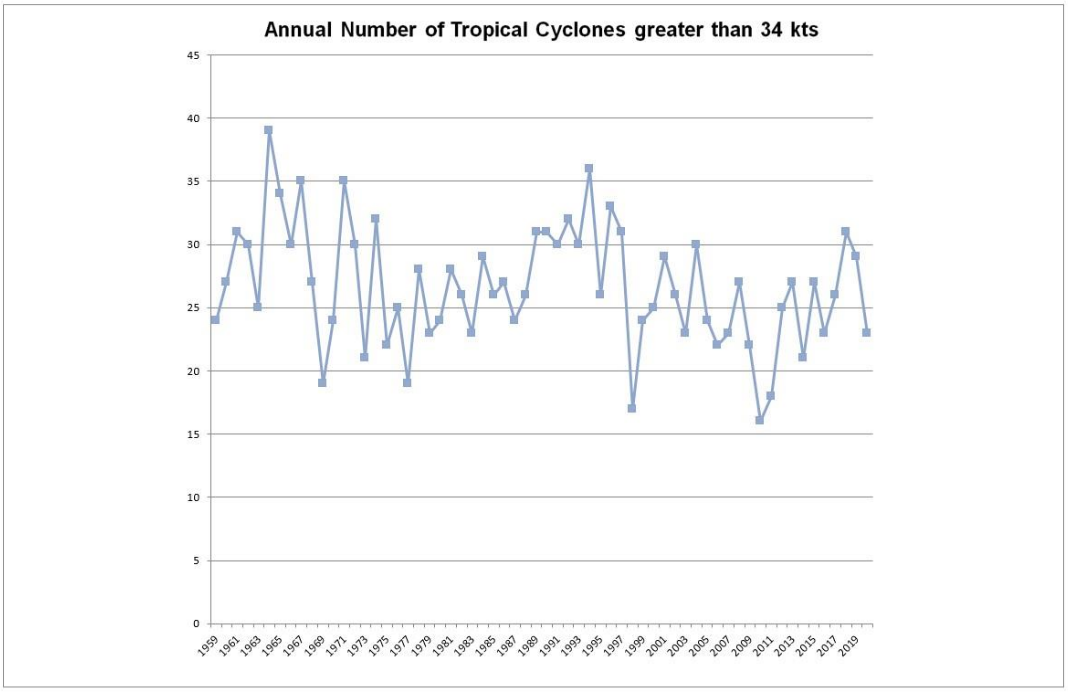


Figure 1-2. Annual number of western North Pacific TCs greater than 34 knots intensity.

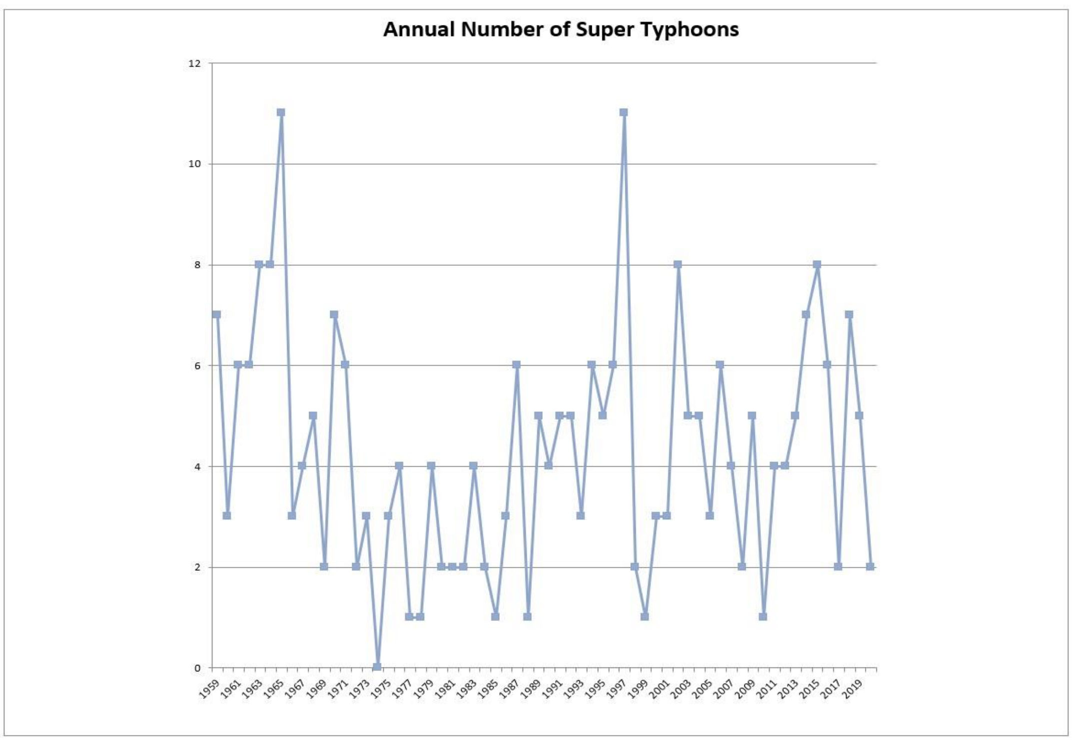
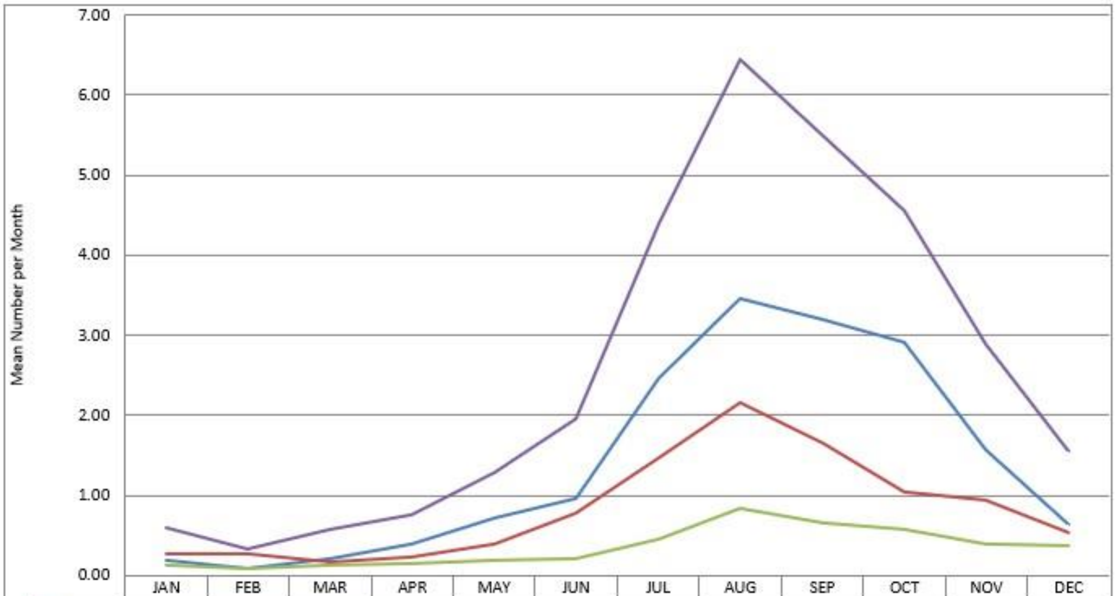


Figure 1-3. Annual number of western North Pacific TCs greater than 129 knots intensity.



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
TY AVG	0.19	0.10	0.21	0.39	0.71	0.97	2.47	3.45	3.19	2.92	1.56	0.65
TS AVG	0.27	0.27	0.16	0.23	0.39	0.77	1.47	2.16	1.65	1.05	0.94	0.53
TD AVG	0.13	0.08	0.13	0.15	0.19	0.21	0.45	0.84	0.66	0.58	0.39	0.37
All AVG	0.60	0.34	0.58	0.76	1.29	1.95	4.39	6.45	5.50	4.55	2.89	1.55

Figure 1-4. Average number of western North Pacific TCs (all intensities) by month, 1959-2020.

Section 2 Cyclone Summaries

This section presents a synopsis of each cyclone that occurred during 2020 in the western North Pacific Ocean. Each cyclone is presented, with the number and basin identifier used by JTWC, along with the name assigned by the Regional Specialized Meteorological Center (RSMC).

Dates listed are JTWC's first designation of various stages of pre-warning development: LOW, MEDIUM, and HIGH (concurrent with TCFA). These classifications are defined as follows:

- "Low" formation potential describes an area that is being monitored for development, but is unlikely to develop within the next 24 hours.
- "Medium" formation potential describes an area that is being monitored for development and has an elevated potential to develop, but development will likely occur beyond 24 hours.
- "High" formation potential describes an area that is being monitored for development and is either expected to develop within 24 hours or development has already begun, but warning criteria have not yet been met. All areas designated as "High" are accompanied by a TCFA.

Initial and final JTWC warning dates are also presented with the number of warnings issued. JTWC initiates tropical cyclone warnings when one or more of the following four criteria are met:

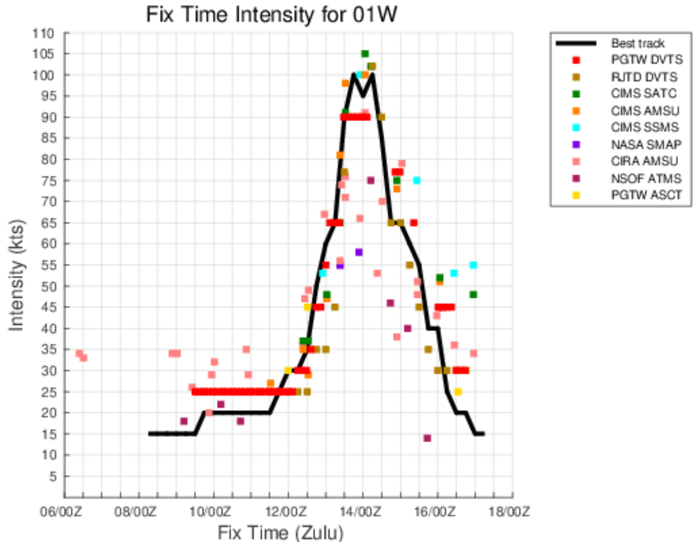
- Estimated maximum sustained wind speeds within a closed tropical circulation meet or exceed a designated threshold of 25 knots in the North Pacific Ocean or 35 knots in the South Pacific and Indian Oceans.
- Maximum sustained wind speeds within a closed tropical circulation are expected to increase to 35 knots or greater within 48 hours.
- A tropical cyclone may endanger life and/or property within 72 hours.
- USINDOPACOM directs JTWC to begin tropical cyclone warnings.

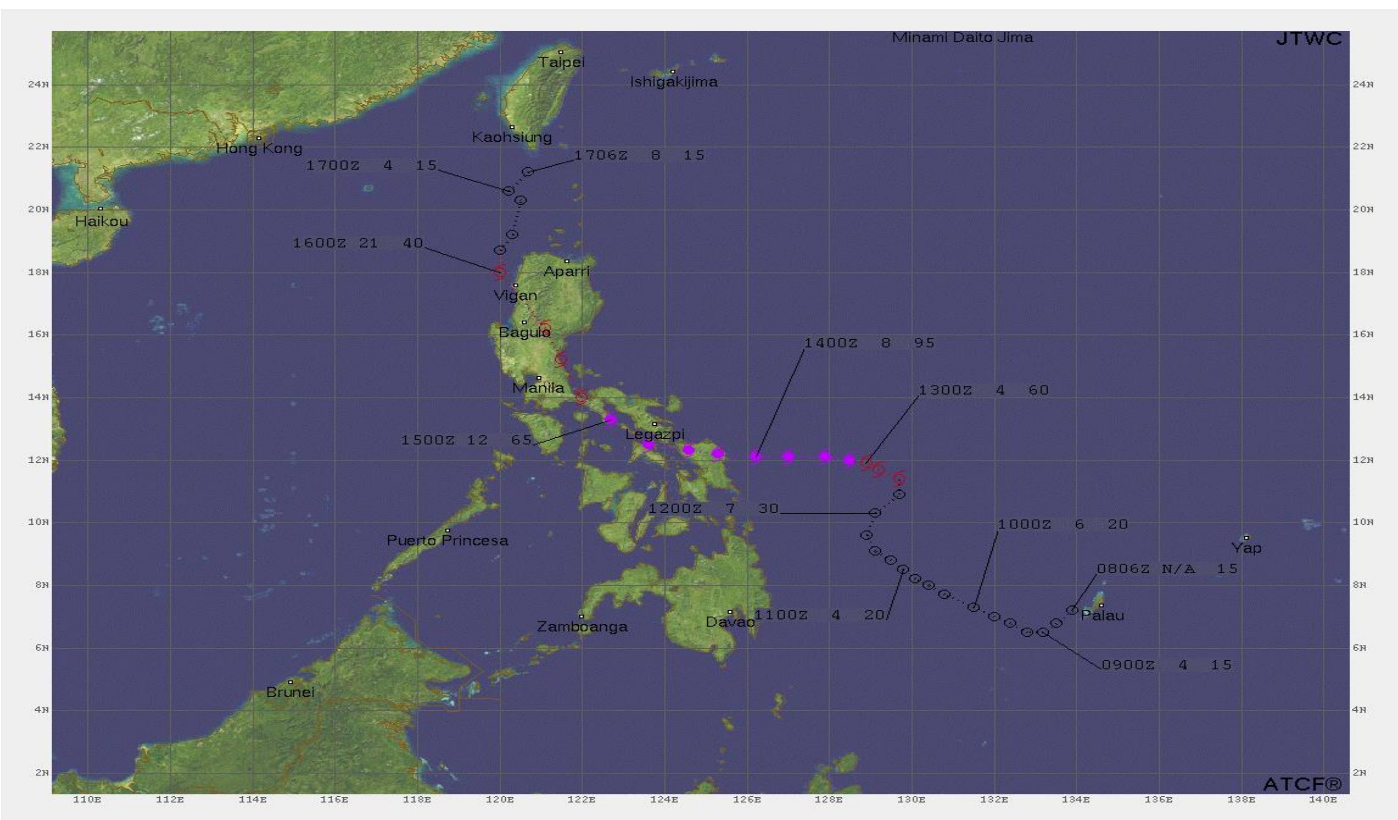
The JTWC post-event, reanalysis best track is provided for each cyclone. Data included on the best track are position and intensity noted with color-coded cyclone symbols and track line. Best track position labels include the date, time, track speed in knots, and maximum wind speed in knots, as well as the approximate locations where the cyclone made landfall over major landmasses. A second graph depicts best track intensity versus time, where fix plots are color coded by fixing agency.

In addition, when this document is viewed as a pdf, each map has been hyperlinked to a corresponding keyhole markup language (kmz) file that will allow the reader to access and view the best-track data interactively using Geographic Information System (GIS) software. Simply hold the control button and click the map image to download and open the file. Users may retrieve kmz files for the entire season from:
https://www.metoc.navy.mil/jtwc/products/best-tracks/2020/2020s-bwp/WP_besttracks_2020-2020.kmz

01W TYPHOON VONGFONG

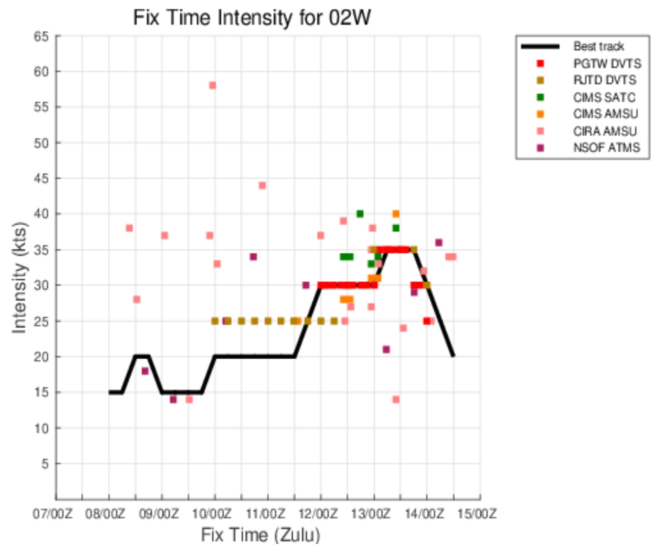
ISSUED LOW:	05 May / 1900Z
ISSUED MED:	09 May / 0030Z
FIRST TCFA:	10 May / 0300Z
FIRST WARNING:	11 May / 1800Z
LAST WARNING:	16 May / 0600Z
MAX INTENSITY:	100
WARNINGS:	19

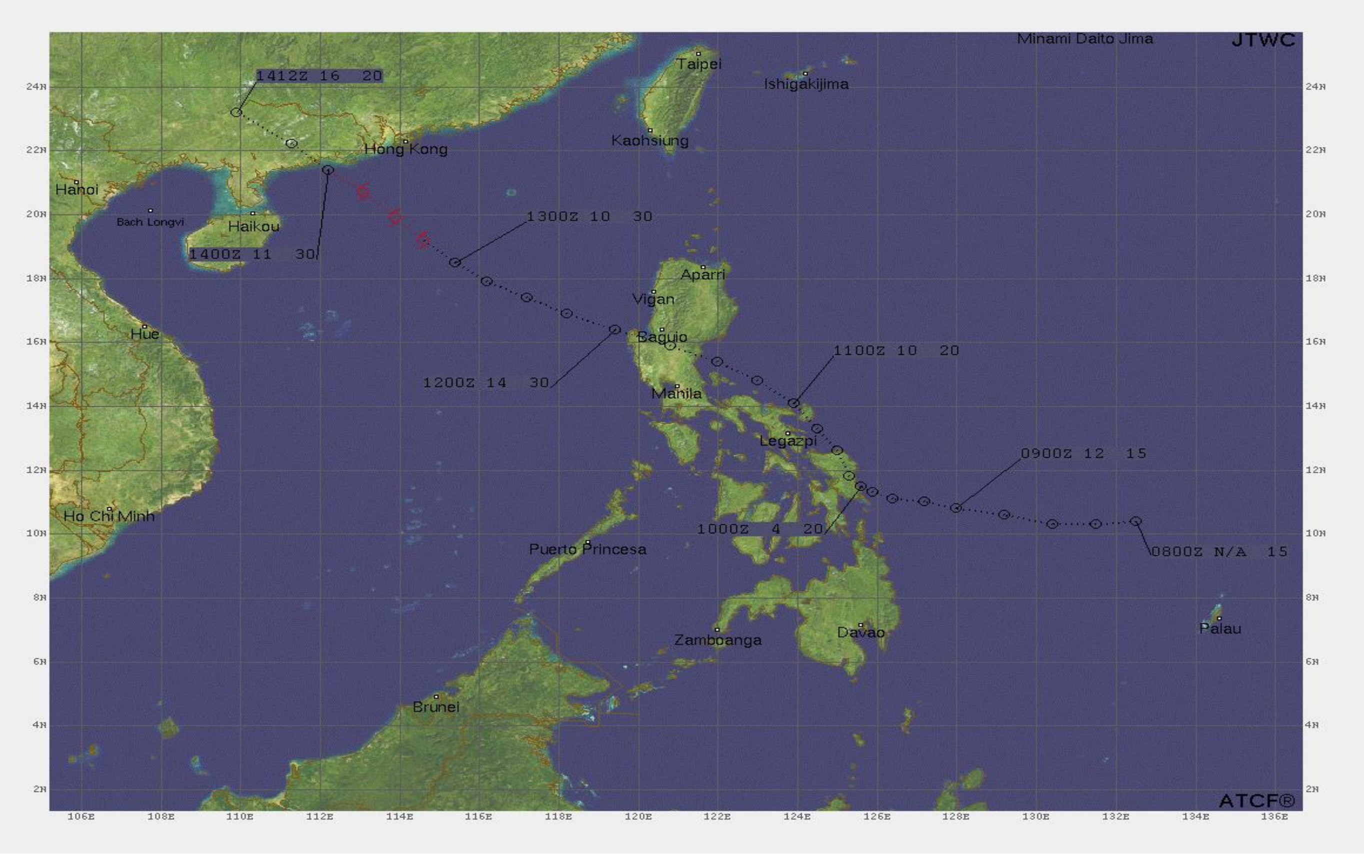




02W TROPICAL STORM NURI

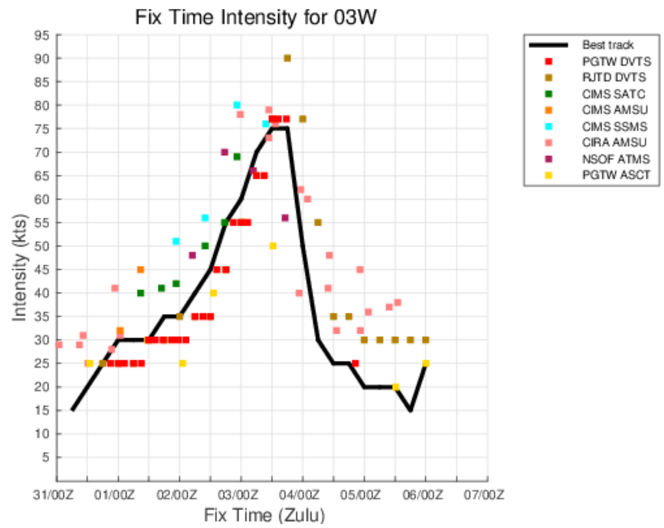
ISSUED LOW:	08 Jun / 1330Z
ISSUED MED:	09 Jun / 1830Z
FIRST TCFA:	11 Jun / 1500Z
FIRST WARNING:	12 Jun / 0000Z
LAST WARNING:	14 Jun / 0000Z
MAX INTENSITY:	35
WARNINGS:	9

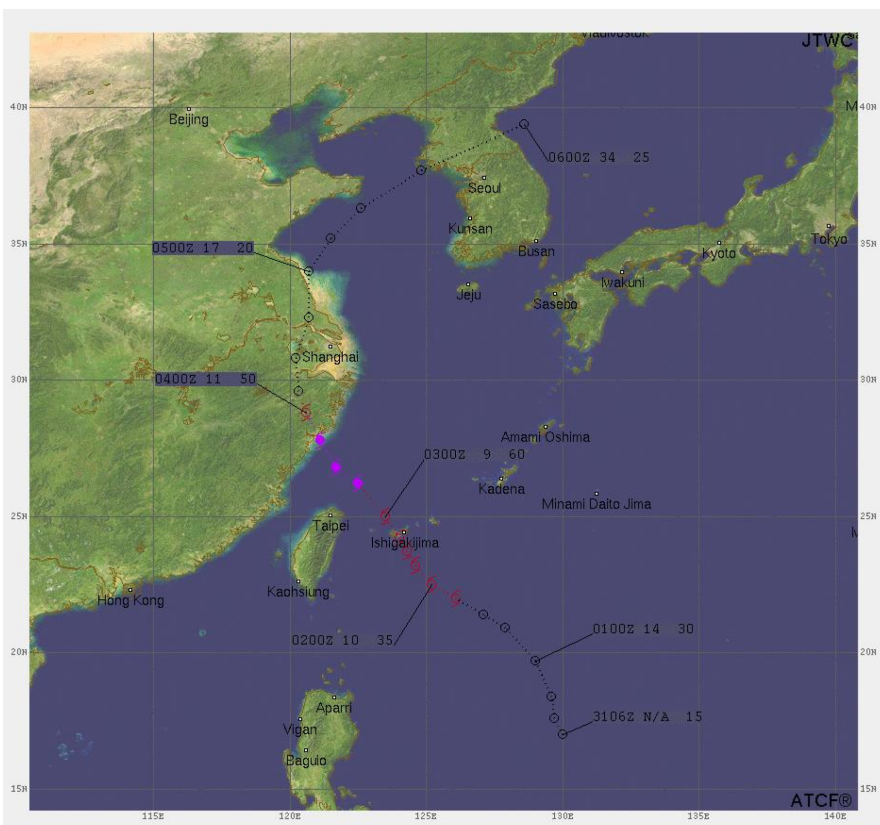




03W TYPHOON HAGUPIT

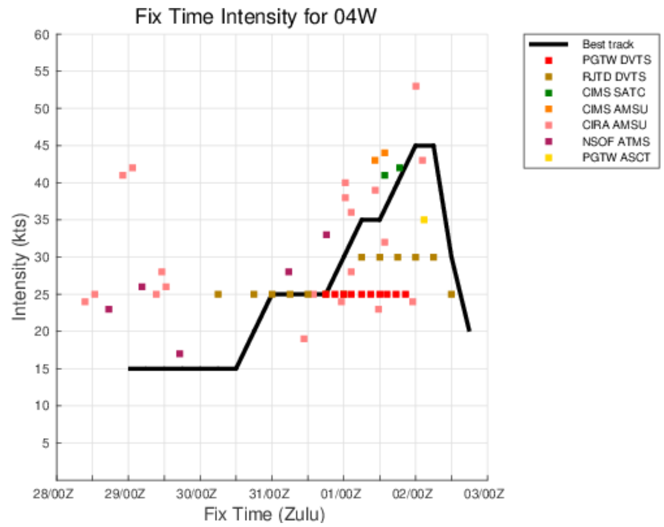
ISSUED LOW:	31 Jul / 0300Z
ISSUED MED:	31 Jul / 0600Z
FIRST TCFA:	31 Jul / 2130Z
FIRST WARNING:	01 Aug / 0000Z
LAST WARNING:	04 Aug / 1200Z
MAX INTENSITY:	75
WARNINGS:	15

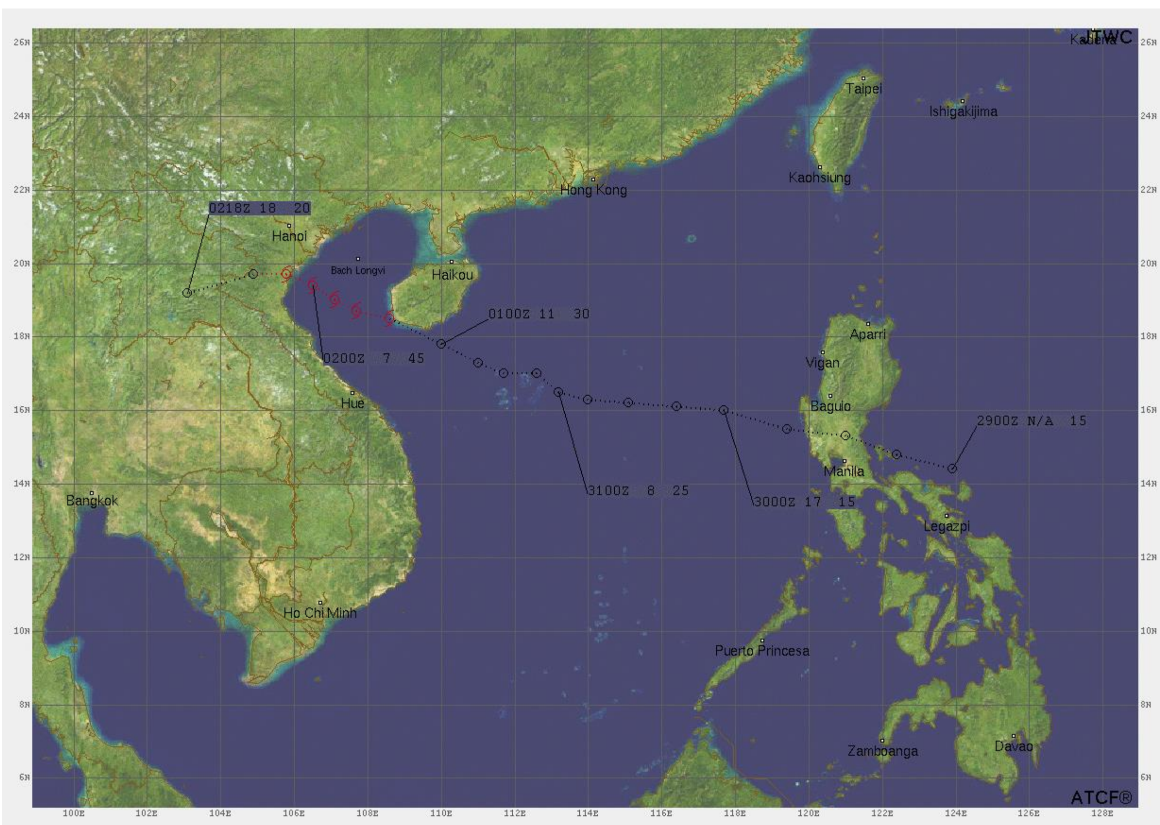




04W TROPICAL STORM SINLAKU

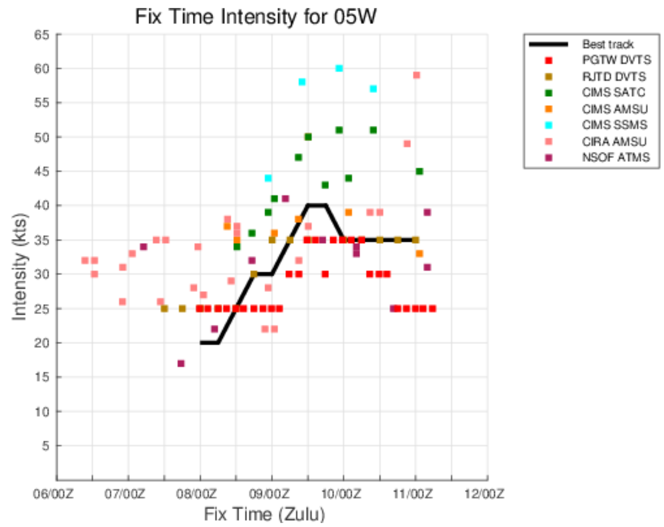
ISSUED LOW:	29 Jul / 0600Z
ISSUED MED:	30 Jul / 1730Z
FIRST TCFA:	31 Jul / 1830Z
FIRST WARNING:	01 Aug / 0600Z
LAST WARNING:	02 Aug / 0600Z
MAX INTENSITY:	45
WARNINGS:	5

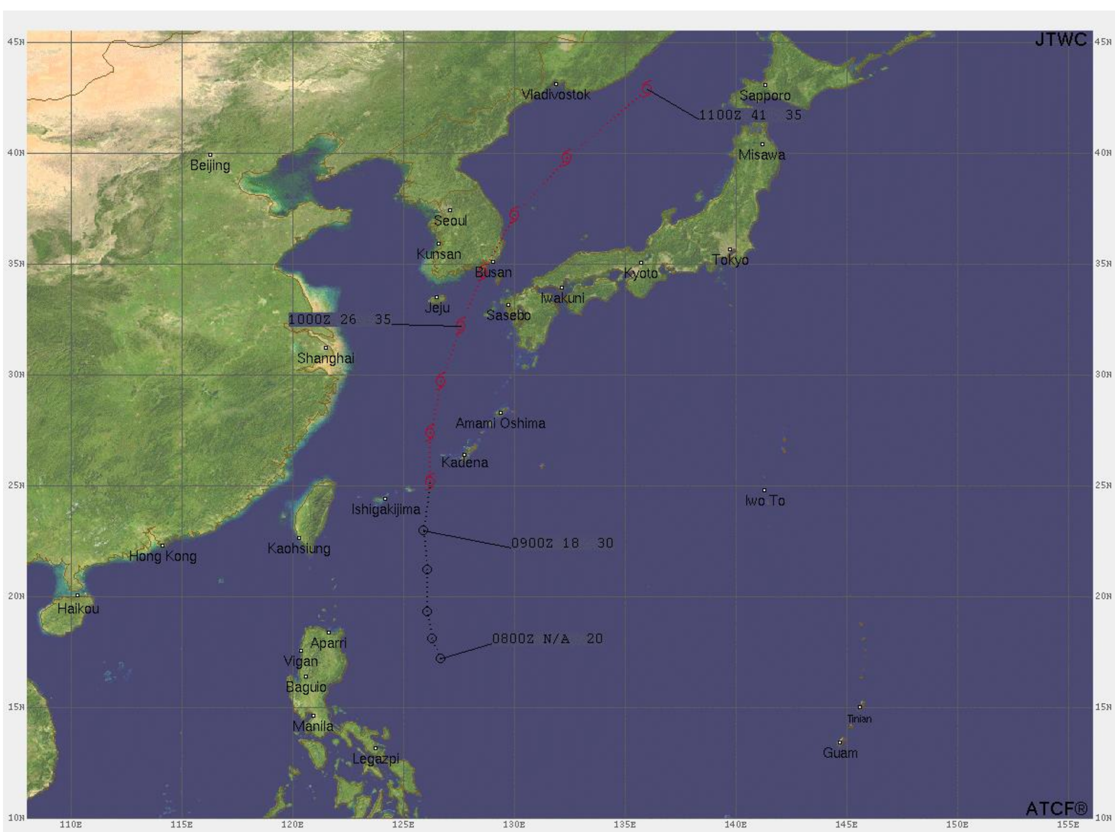




05W TROPICAL STORM JANGMI

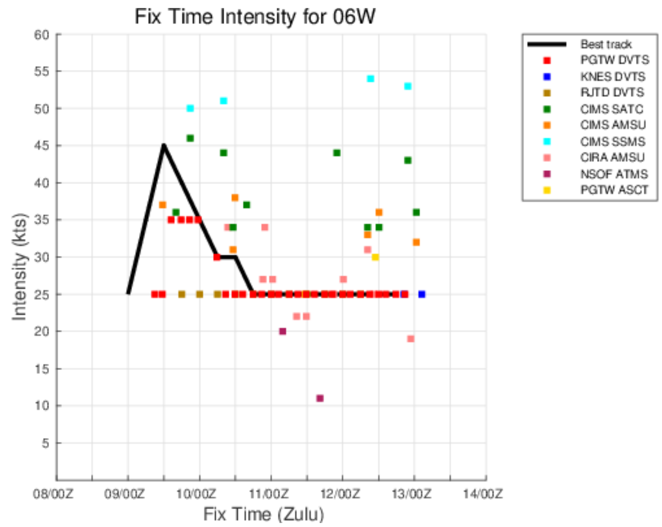
ISSUED LOW:	07 Aug / 0600Z
ISSUED MED:	07 Aug / 1230Z
FIRST TCFA:	07 Aug / 2130Z
FIRST WARNING:	08 Aug / 0600Z
LAST WARNING:	10 Aug / 1200Z
MAX INTENSITY:	40
WARNINGS:	10

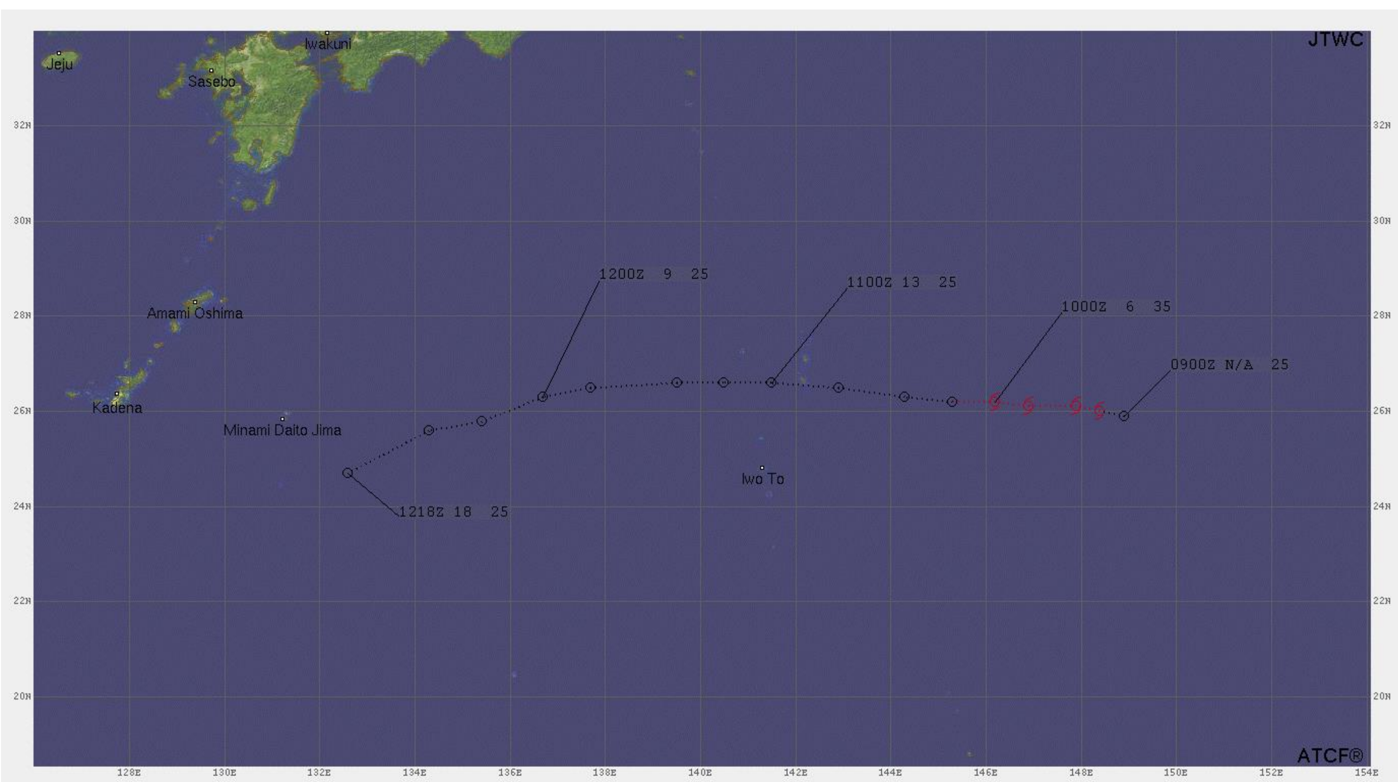




06W TROPICAL STORM SIX

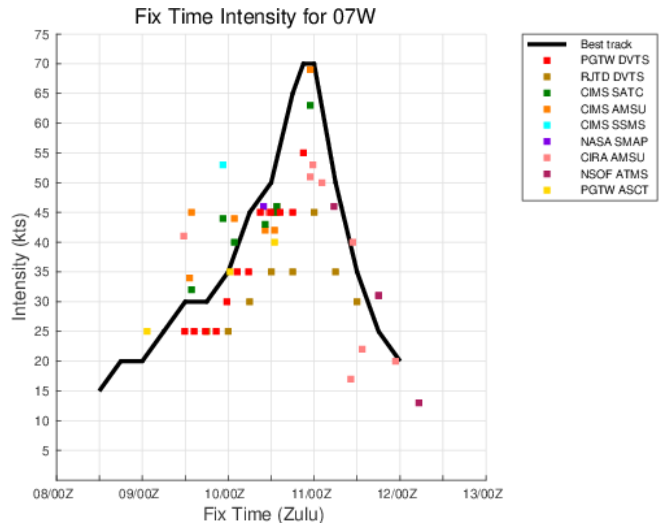
ISSUED LOW: N/A
ISSUED MED: N/A
FIRST TCFA: 09 Aug / 0830Z
FIRST WARNING: 09 Aug / 1200Z
LAST WARNING: 13 Aug / 0000Z
MAX INTENSITY: 45
WARNINGS: 15

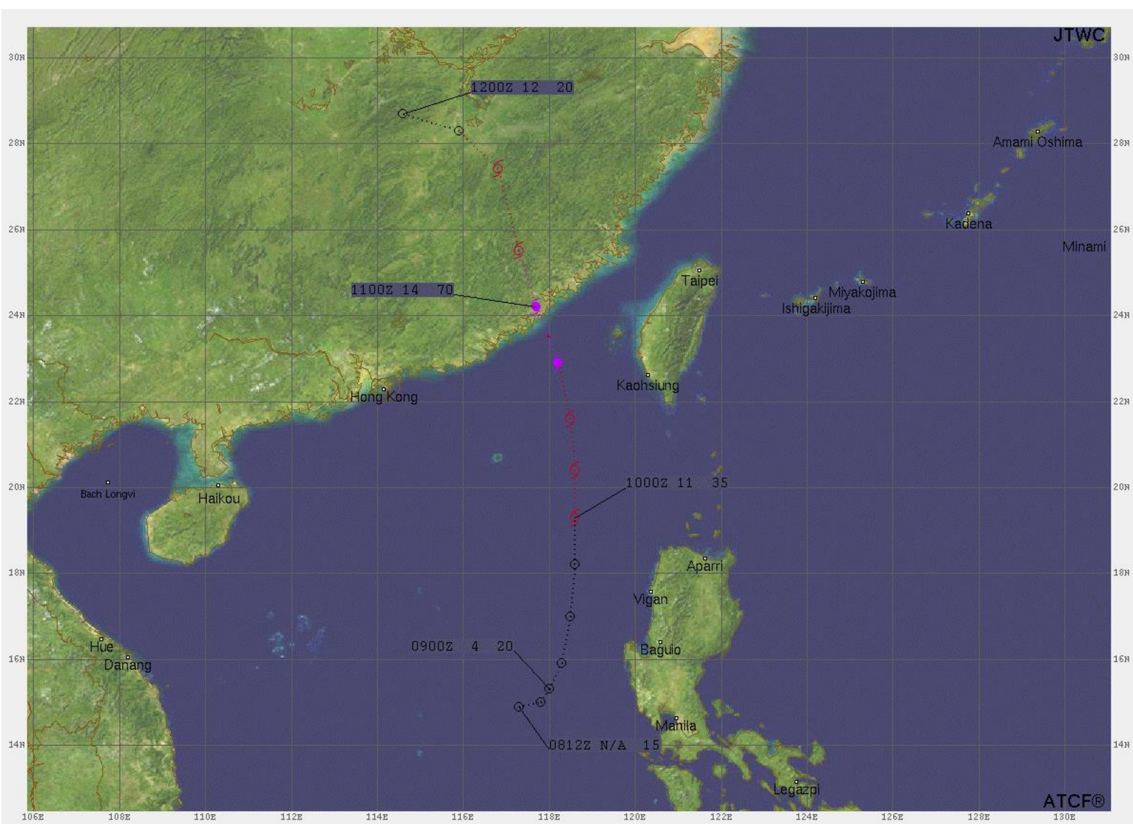




07W TYPHOON MEKKHALA

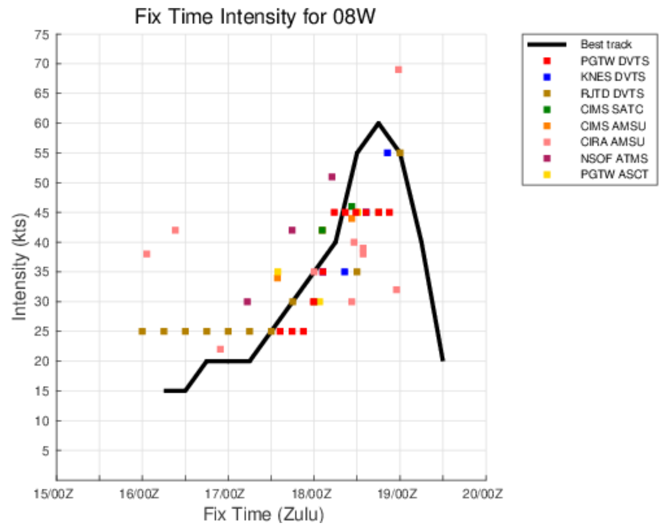
ISSUED LOW:	08 Aug / 0600Z
ISSUED MED:	09 Aug / 0600Z
FIRST TCFA:	09 Aug / 0900Z
FIRST WARNING:	09 Aug / 1200Z
LAST WARNING:	11 Aug / 0000Z
MAX INTENSITY:	70
WARNINGS:	7

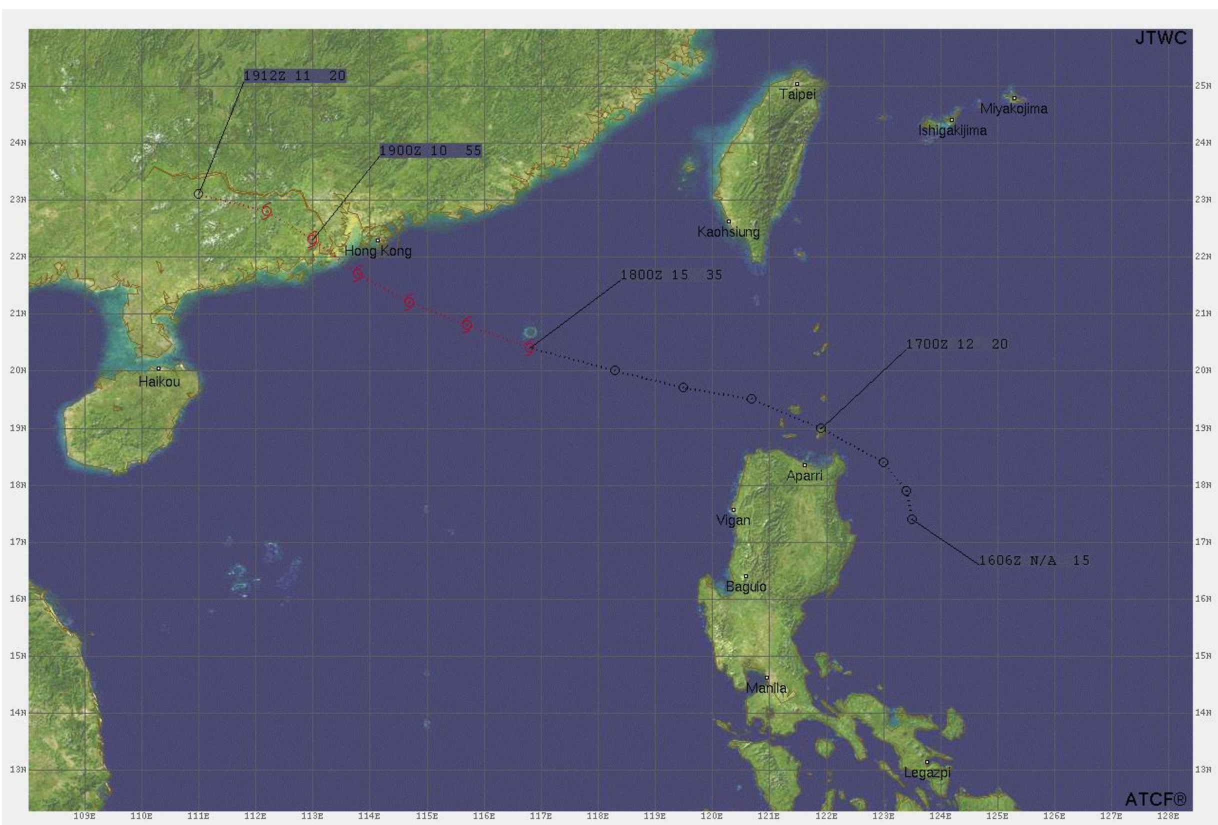




08W TROPICAL STORM HIGOS

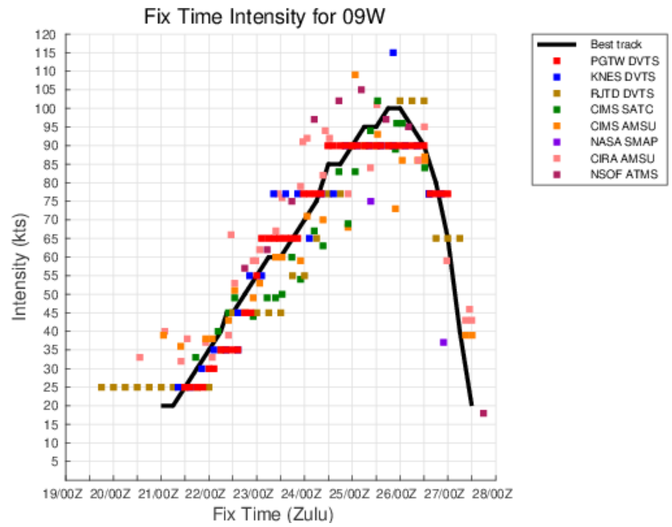
ISSUED LOW:	N/A
ISSUED MED:	16 Aug / 0600Z
FIRST TCFA :	17 Aug / 0330Z
FIRST WARNING:	17 Aug / 1800Z
LAST WARNING:	19 Aug / 0000Z
MAX INTENSITY:	60
WARNINGS:	6

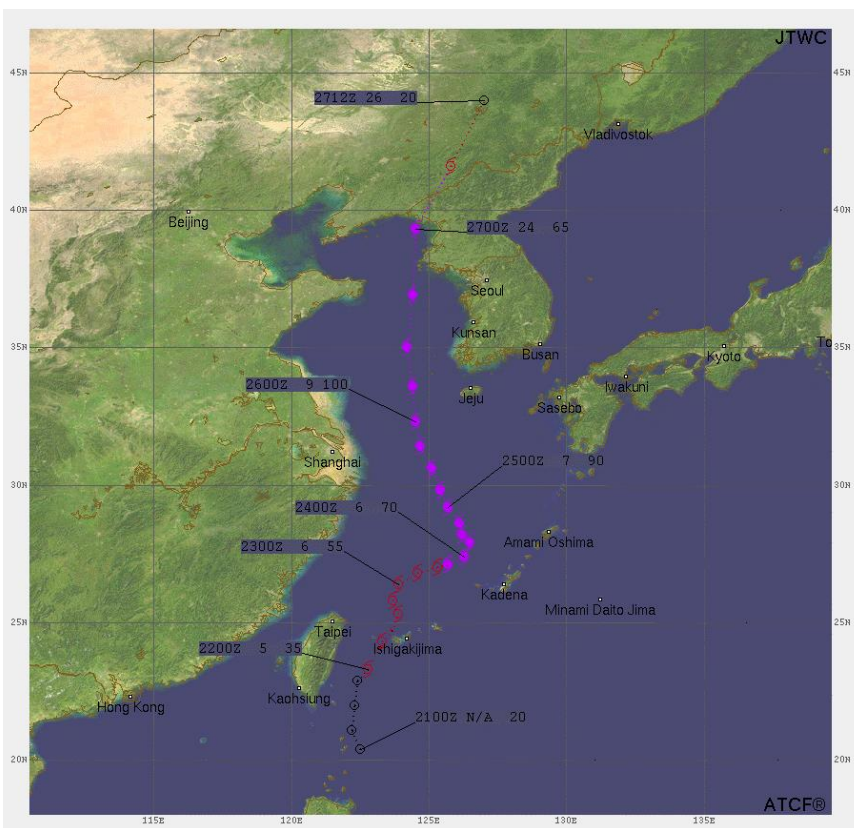




09W TYPHOON BAVI

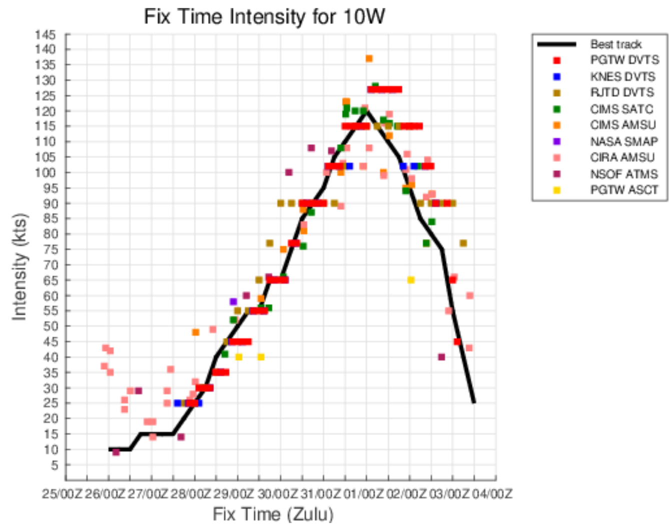
ISSUED LOW:	19 Aug / 1000Z
ISSUED MED:	20 Aug / 0600Z
FIRST TCFA:	20 Aug / 2200Z
FIRST WARNING:	21 Aug / 1200Z
LAST WARNING:	27 Aug / 0600Z
MAX INTENSITY:	100
WARNINGS:	24

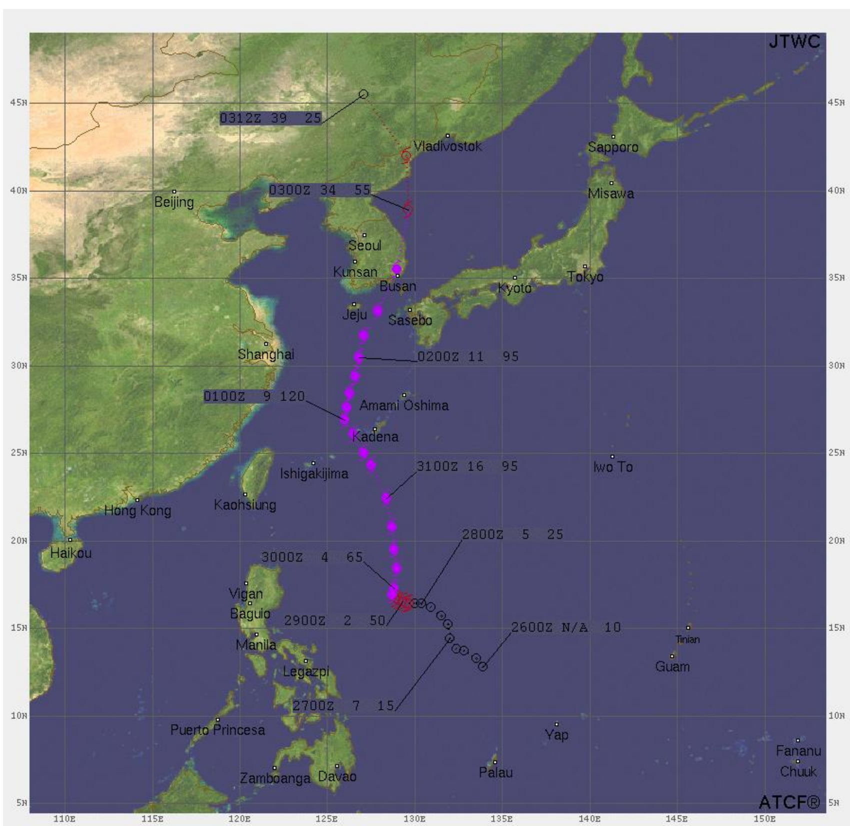




10W TYPHOON MAYSAK

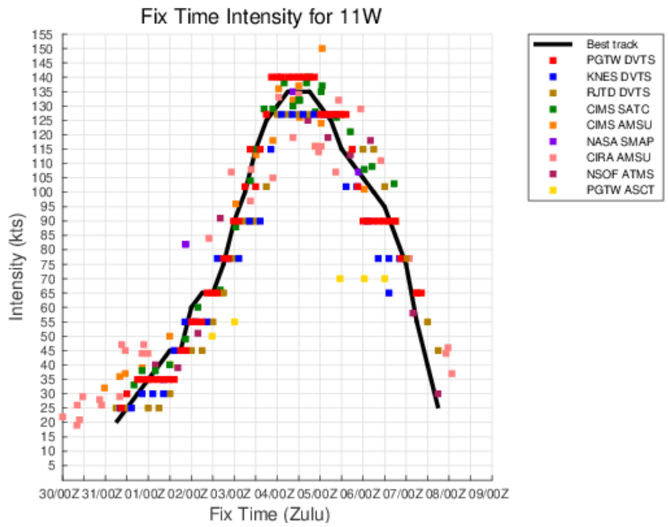
ISSUED LOW:	26 Aug / 0200Z
ISSUED MED:	26 Aug / 2100Z
FIRST TCFA:	27 Aug / 0900Z
FIRST WARNING:	28 Aug / 0000Z
LAST WARNING:	02 Sep / 1800Z
MAX INTENSITY:	120
WARNINGS:	24

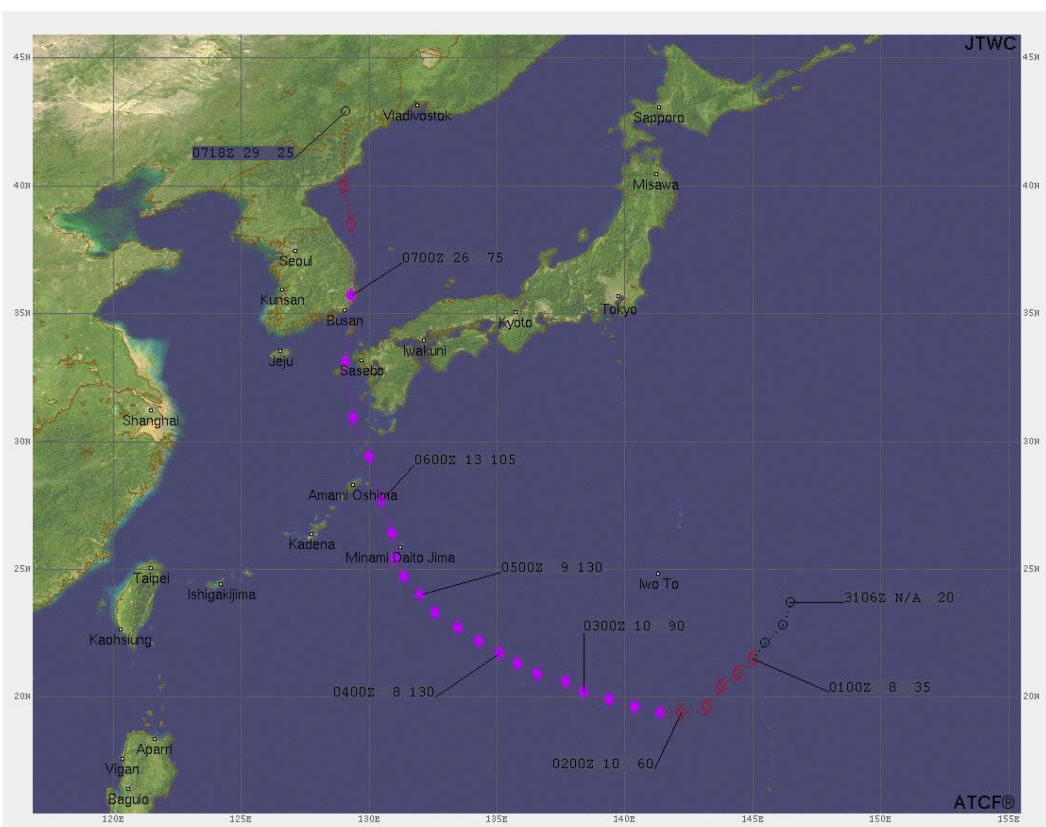




11W SUPER TYPHOON HAISHEN

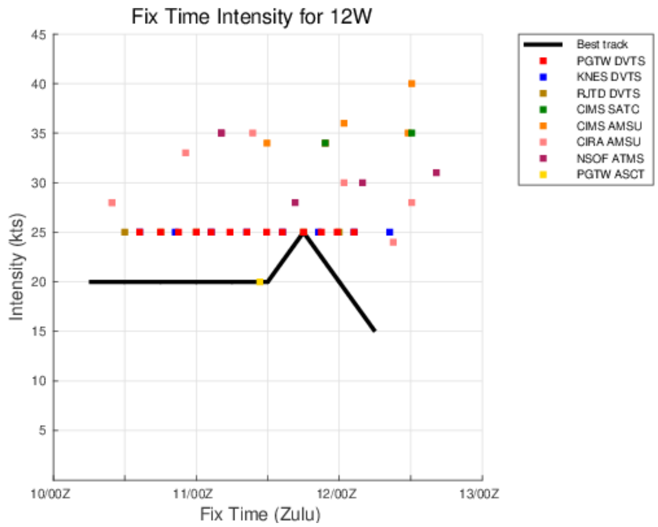
ISSUED LOW: 30 Aug / 0600Z
ISSUED MED: 31 Aug / 0200Z
FIRST TCFA: 31 Aug / 1030Z
FIRST WARNING: 31 Aug / 1200Z
LAST WARNING: 07 Sep / 1200Z
MAX INTENSITY: 135
WARNINGS: 29

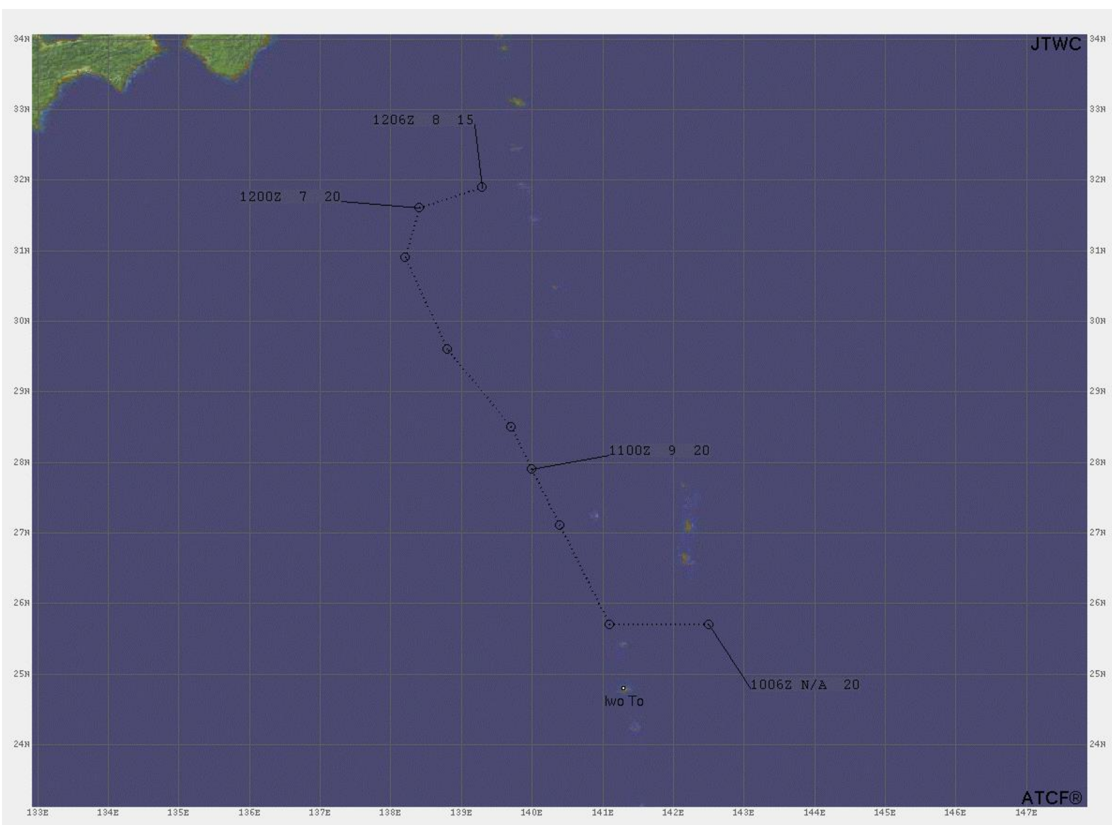




12W TROPICAL DEPRESSION TWELVE

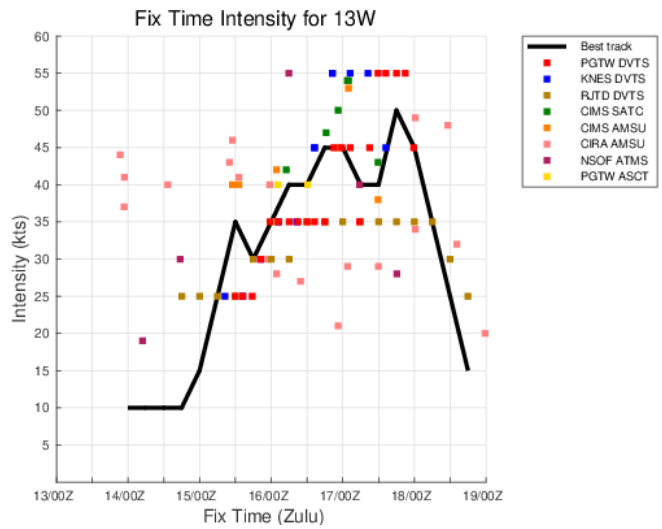
ISSUED LOW:	10 Sep / 0600Z
ISSUED MED:	10 Sep / 1330Z
FIRST TCFA:	10 Sep / 1500Z
FIRST WARNING:	11 Sep / 1800Z
LAST WARNING:	12 Sep / 0000Z
MAX INTENSITY:	25
WARNINGS:	2

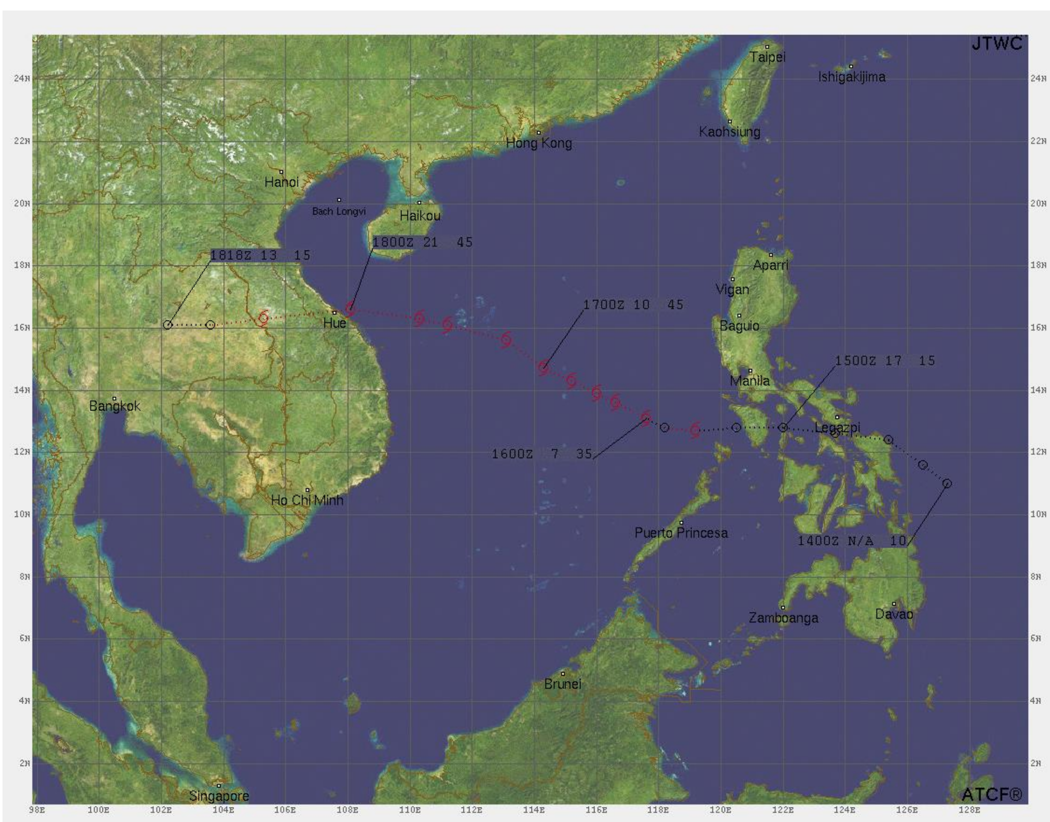




13W TROPICAL STORM NOUL

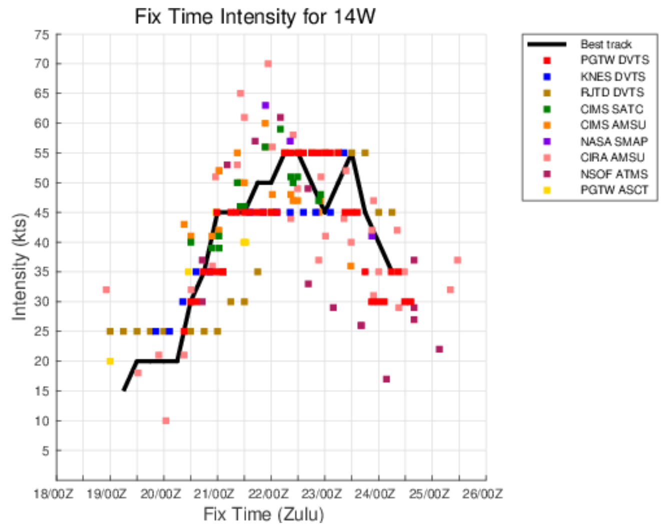
ISSUED LOW:	14 Sep / 0600Z
ISSUED MED:	14 Sep / 1300Z
FIRST TCFA:	15 Sep / 0200Z
FIRST WARNING:	15 Sep / 1200Z
LAST WARNING:	18 Sep / 0600Z
MAX INTENSITY:	50
WARNINGS:	12

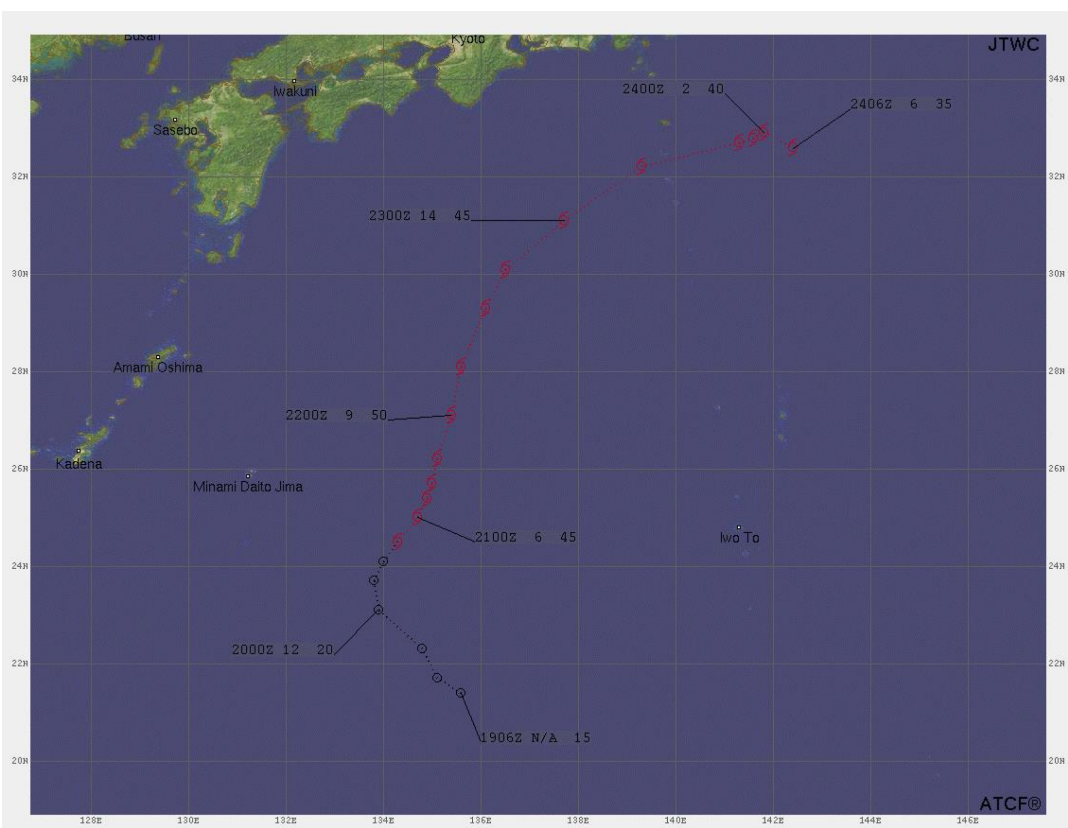




14W TROPICAL STORM DOLPHIN

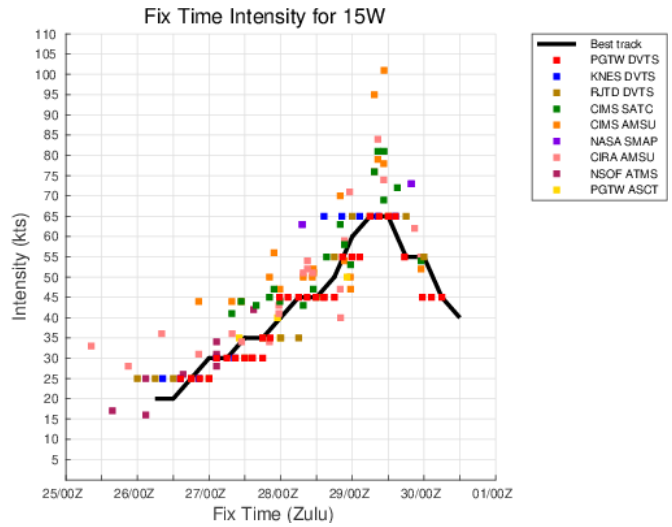
ISSUED LOW:	19 Sep / 1500Z
ISSUED MED:	20 Sep / 0600Z
FIRST TCFA:	N/A
FIRST WARNING:	20 Sep / 1200Z
LAST WARNING:	24 Sep / 0000Z
MAX INTENSITY:	55
WARNINGS:	15

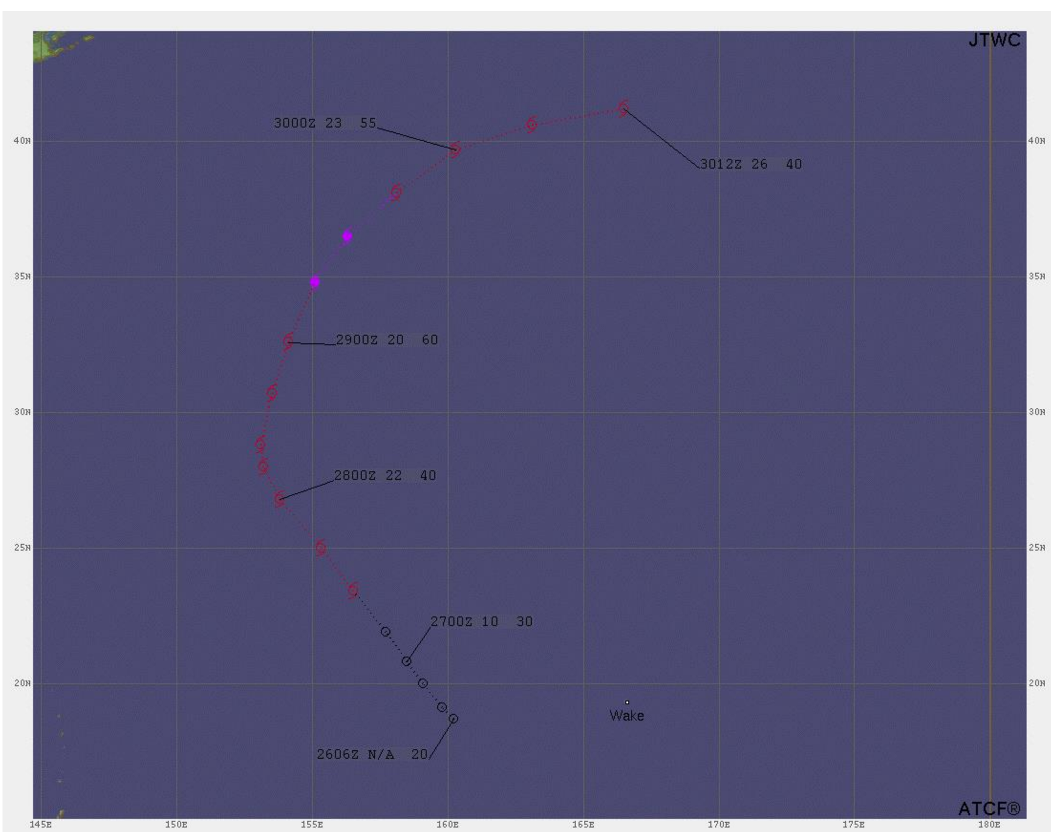




15W TYPHOON KUJIRA

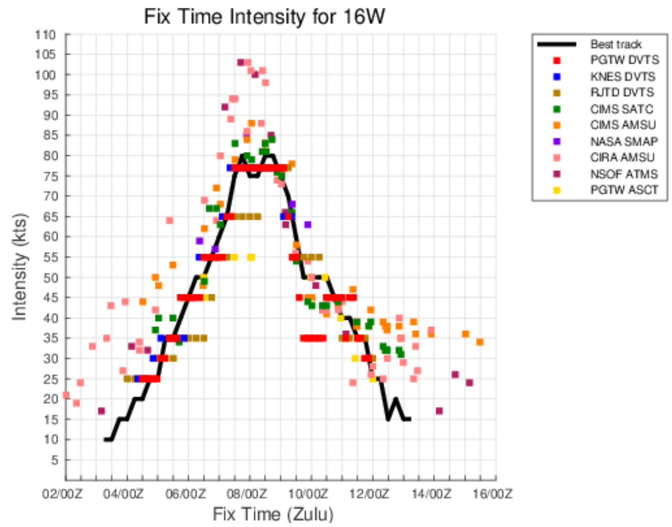
ISSUED LOW:	26 Sep / 0200Z
ISSUED MED:	26 Sep / 0600Z
FIRST TCFA:	26 Sep / 0900Z
FIRST WARNING:	26 Sep / 1800Z
LAST WARNING:	29 Sep / 1800Z
MAX INTENSITY:	65
WARNINGS:	13

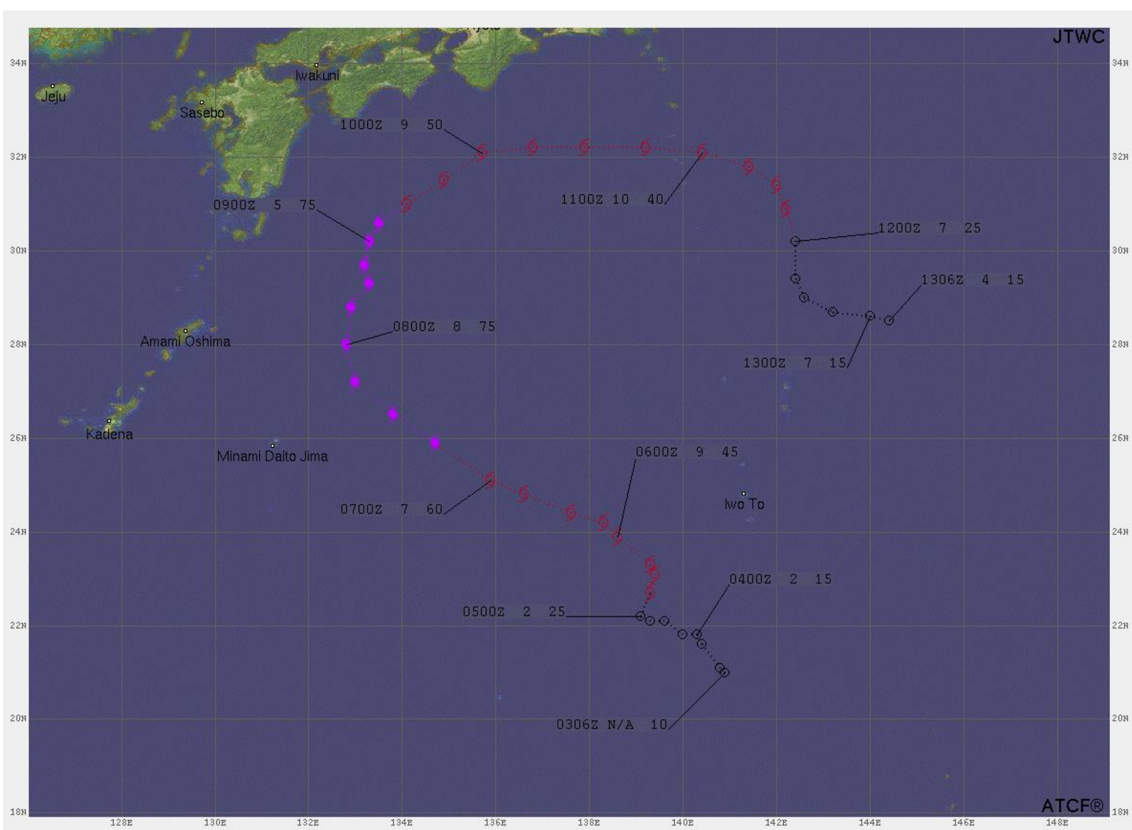




16W TYPHOON CHAN-HOM

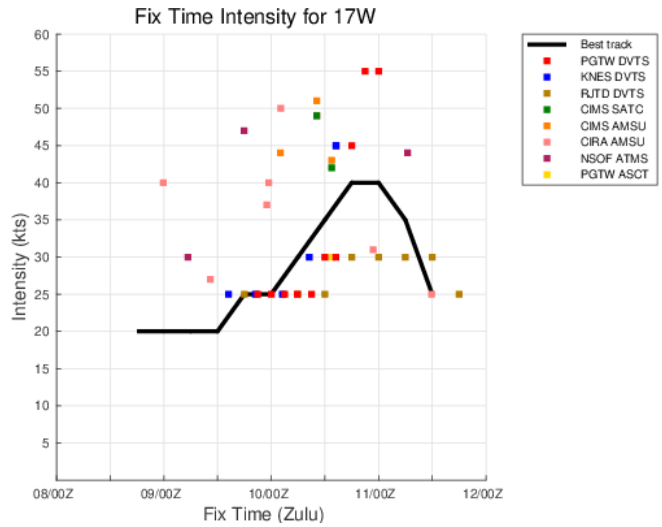
ISSUED LOW:	03 Oct / 0900Z
ISSUED MED:	04 Oct / 0200Z
FIRST TCFA:	04 Oct / 0900Z
FIRST WARNING:	04 Oct / 1800Z
LAST WARNING:	12 Oct / 0600Z
MAX INTENSITY:	80
WARNINGS:	31

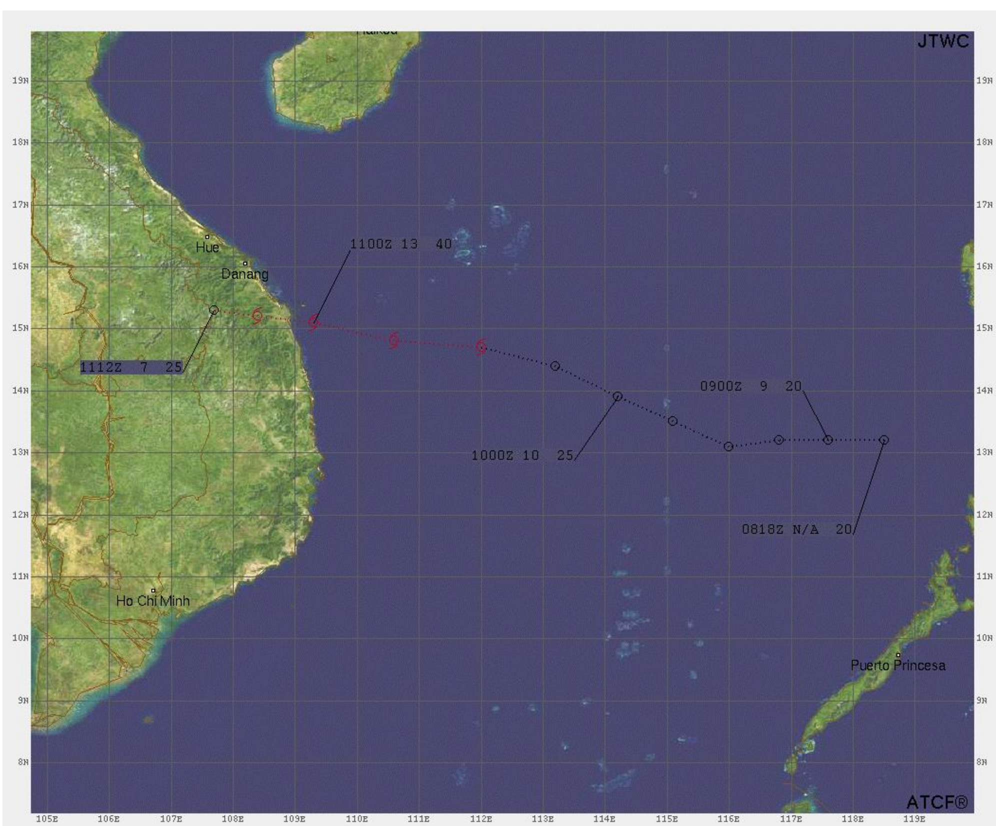




17W TROPICAL STORM LINFA

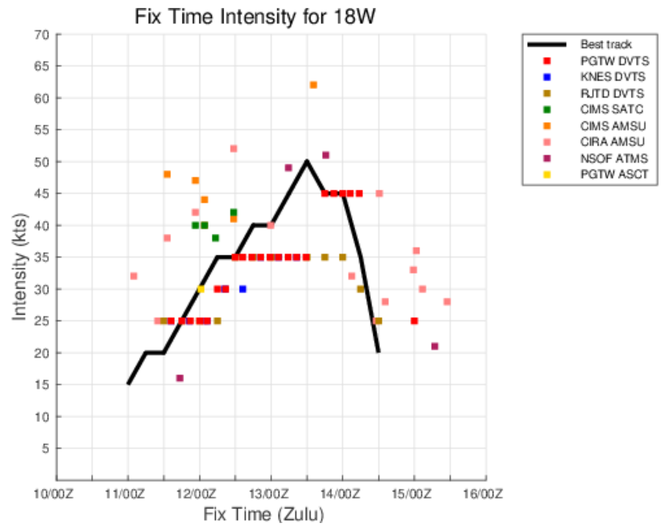
ISSUED LOW:	08 Oct / 1930Z
ISSUED MED:	09 Oct / 0600Z
FIRST TCFA:	09 Oct / 1100Z
FIRST WARNING:	10 Oct / 0000Z
LAST WARNING:	11 Oct / 0600Z
MAX INTENSITY:	40
WARNINGS:	6

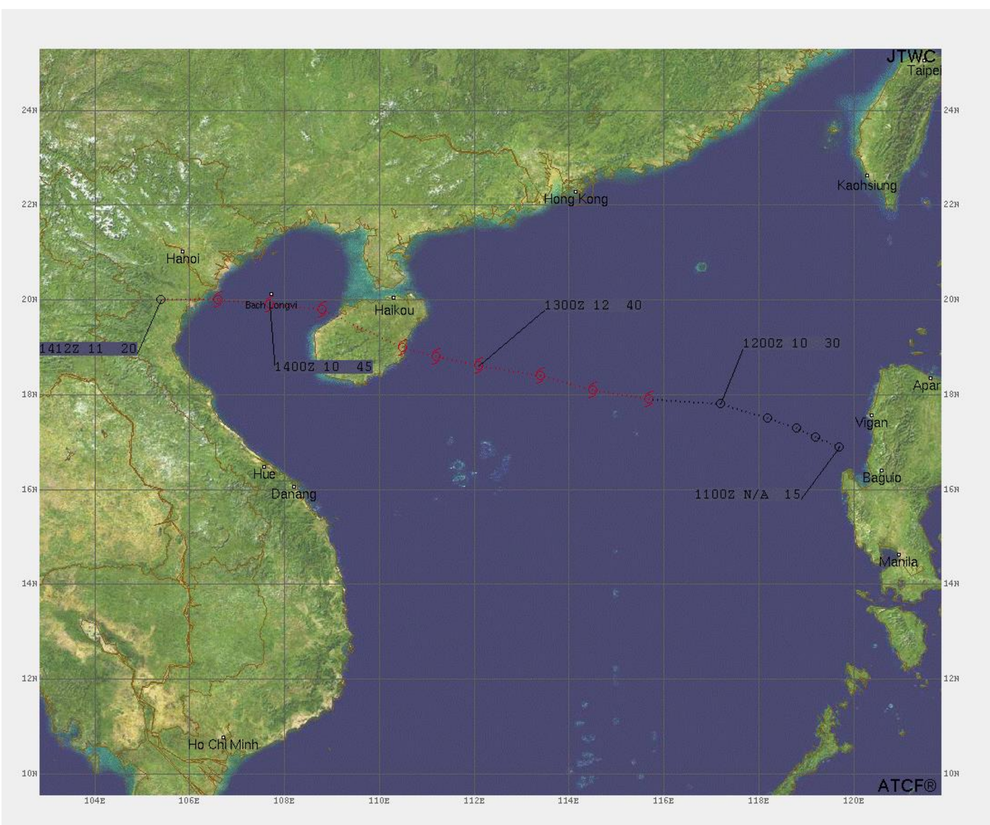




18W TROPICAL STORM NANGKA

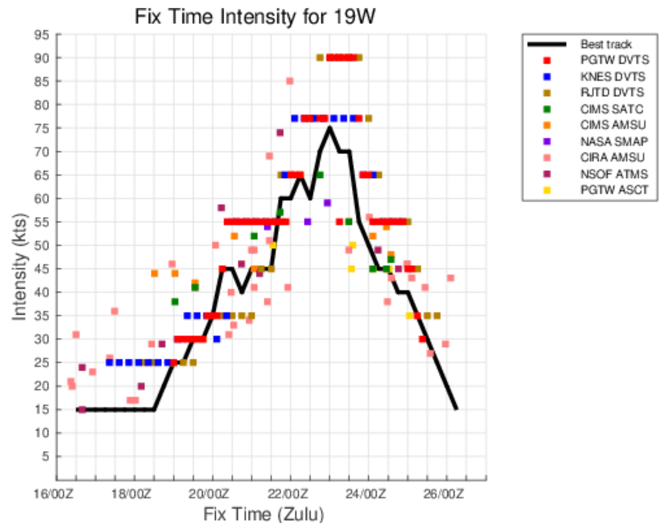
ISSUED LOW:	N/A
ISSUED MED:	11 Oct / 0600Z
FIRST TCFA:	11 Oct / 0930Z
FIRST WARNING:	11 Oct / 1800Z
LAST WARNING:	14 Oct / 0600Z
MAX INTENSITY:	50
WARNINGS:	11

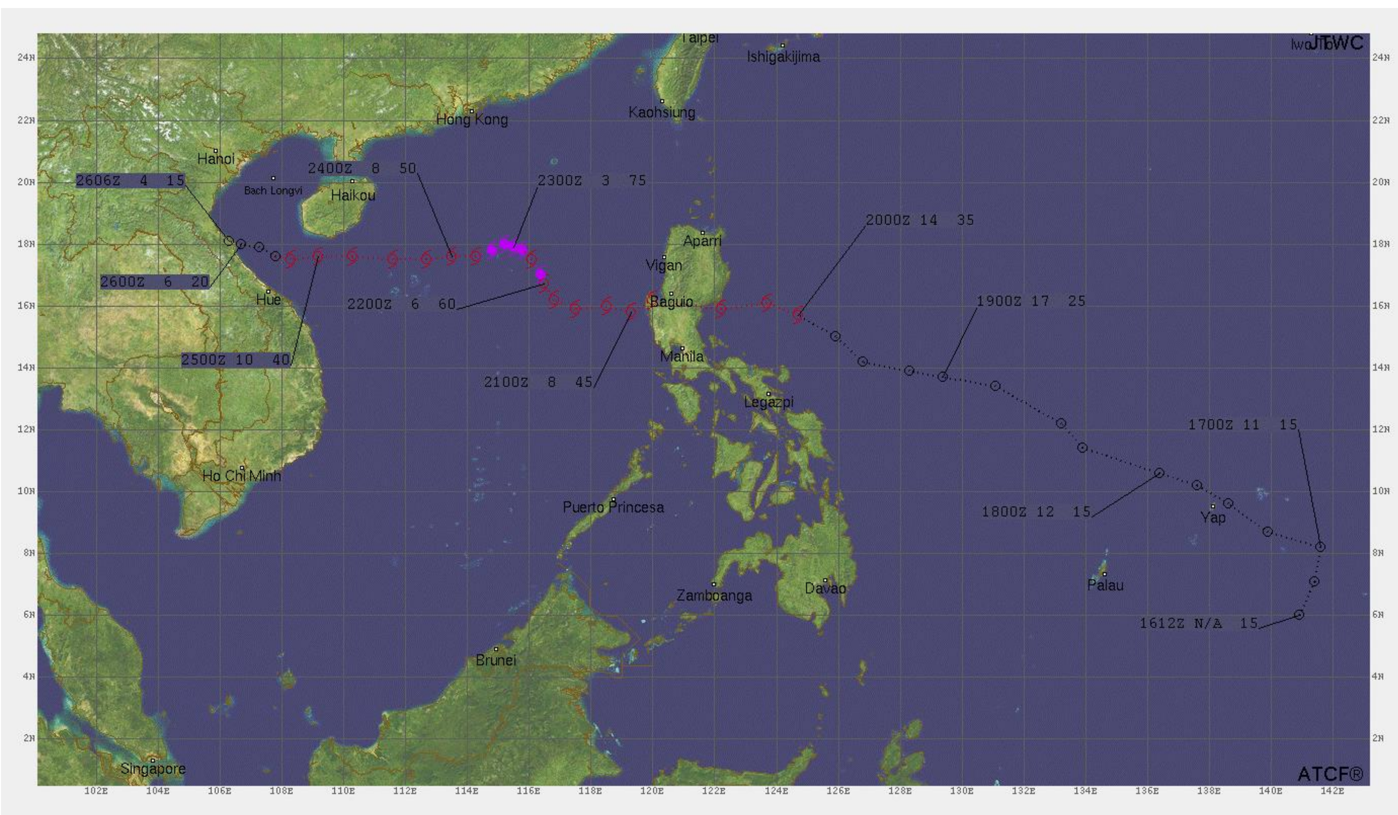




19W TYPHOON SAUDEL

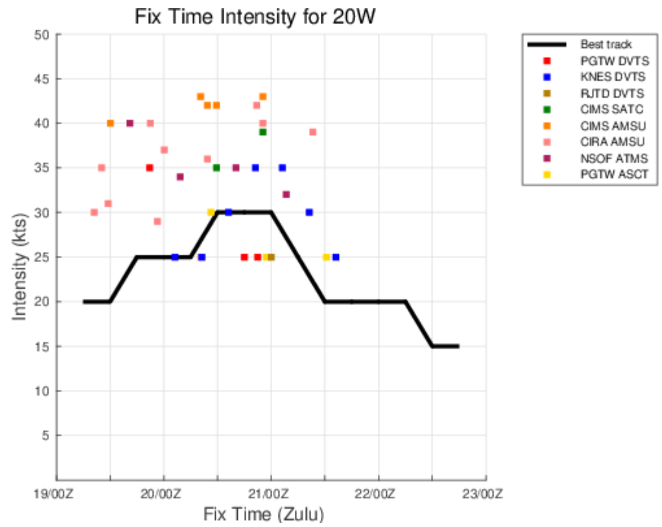
ISSUED LOW:	16 Oct / 1500Z
ISSUED MED:	18 Oct / 0200Z
FIRST TCFA:	N/A
FIRST WARNING:	19 Oct / 0000Z
LAST WARNING:	25 Oct / 1800Z
MAX INTENSITY:	75
WARNINGS:	28

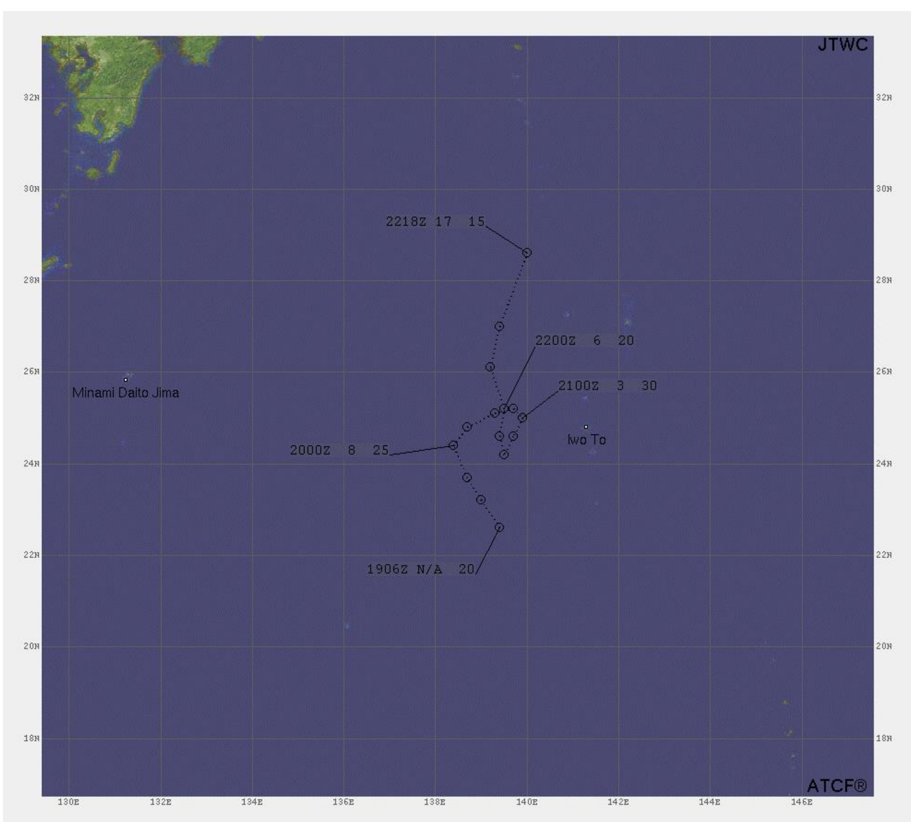




20W TROPICAL DEPRESSION TWENTY

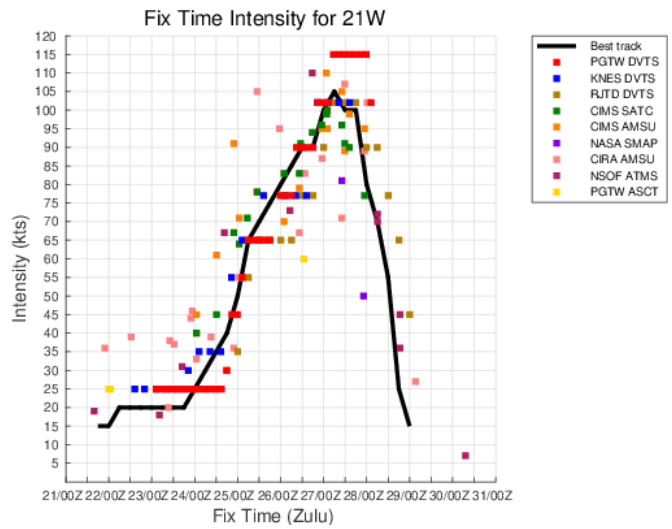
ISSUED LOW:	N/A
ISSUED MED:	19 Oct / 2100Z
FIRST TCFA:	20 Oct / 0200Z
FIRST WARNING:	20 Oct / 1200Z
LAST WARNING:	21 Oct / 1200Z
MAX INTENSITY:	30
WARNINGS:	5

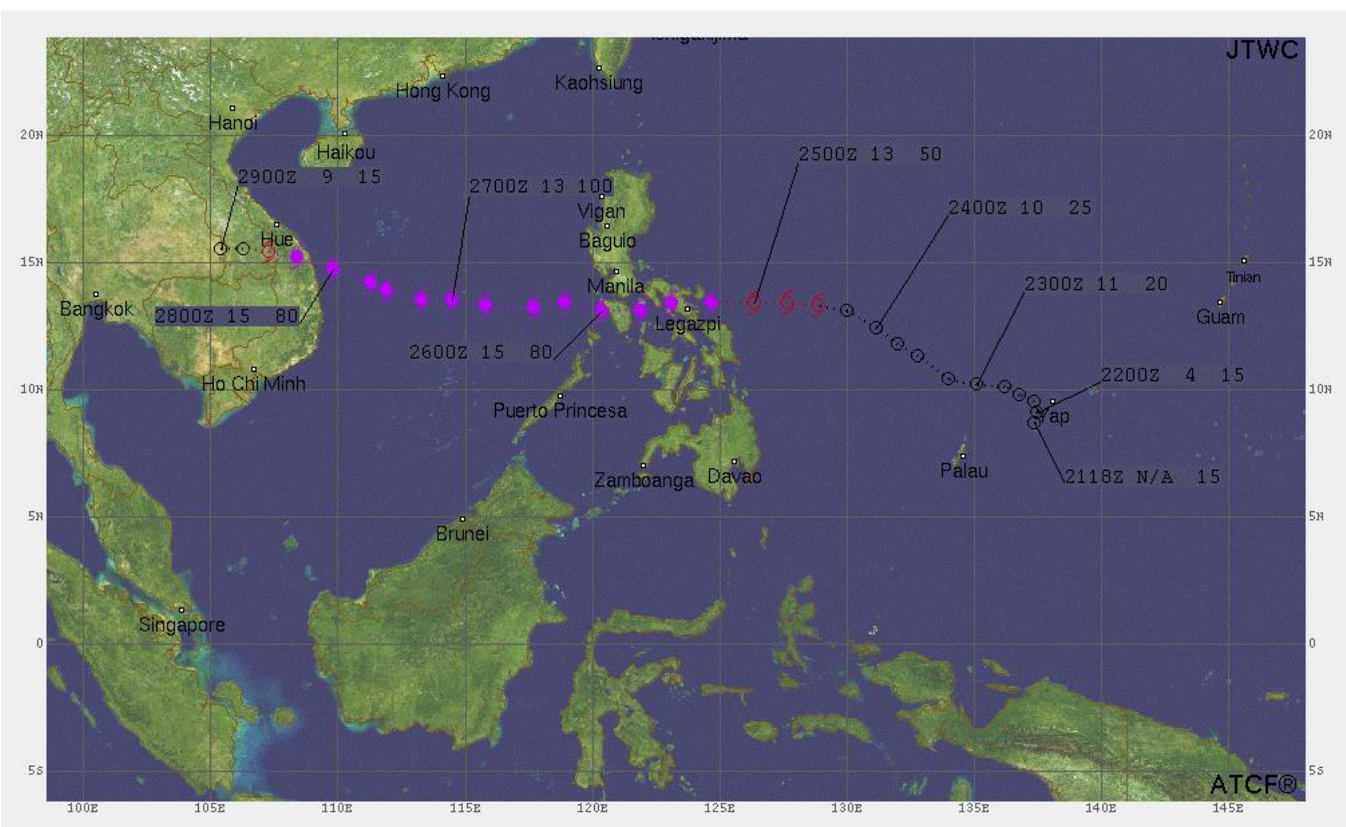




21W TYPHOON MOLAVE

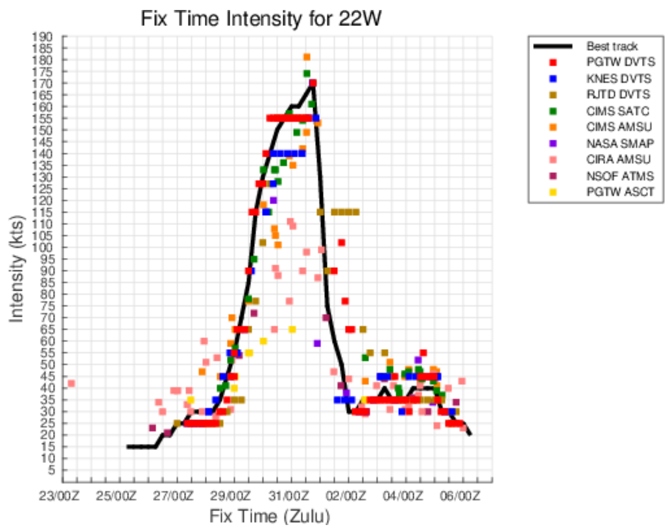
ISSUED LOW:	22 Oct / 1530Z
ISSUED MED:	23 Oct / 0600Z
FIRST TCFA:	23 Oct / 1400Z
FIRST WARNING:	24 Oct / 0000Z
LAST WARNING:	28 Oct / 0600Z
MAX INTENSITY:	105
WARNINGS:	18

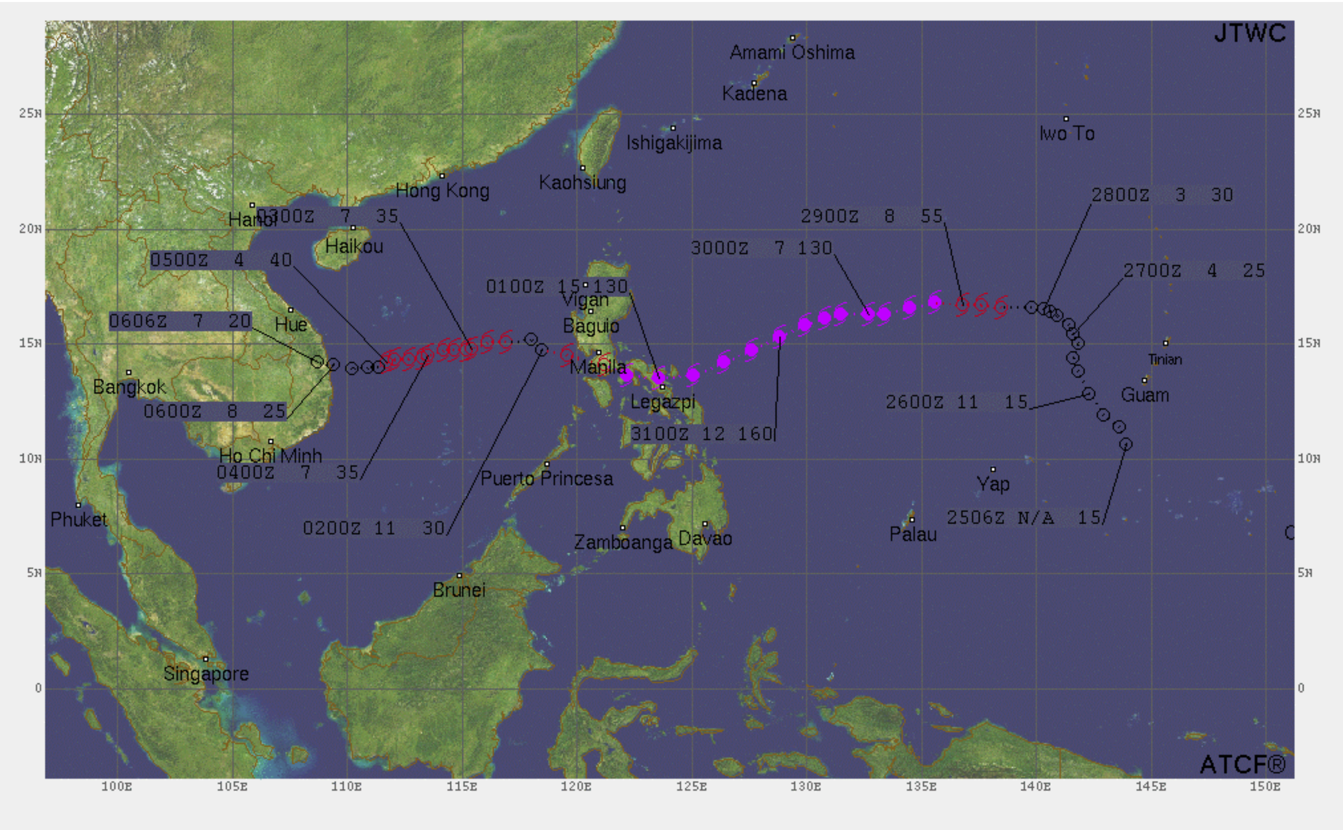




22W SUPER TYPHOON GONI

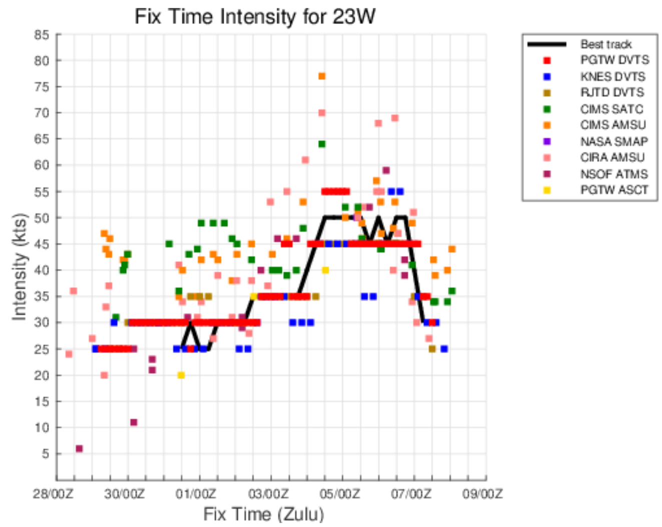
ISSUED LOW:	23 Oct / 0600Z
ISSUED MED:	27 Oct / 0200Z
FIRST TCFA:	27 Oct / 1100Z
FIRST WARNING:	28 Oct / 0000Z
LAST WARNING:	06 Nov / 0000Z
MAX INTENSITY:	170
WARNINGS:	37

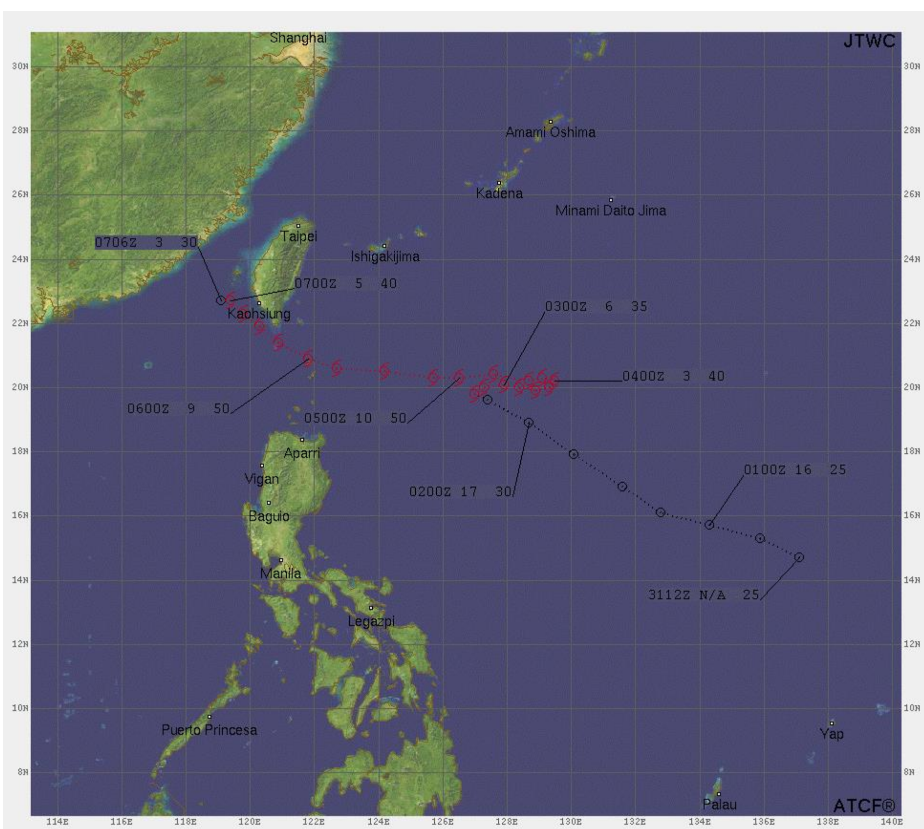




23W TROPICAL STORM ATSANI

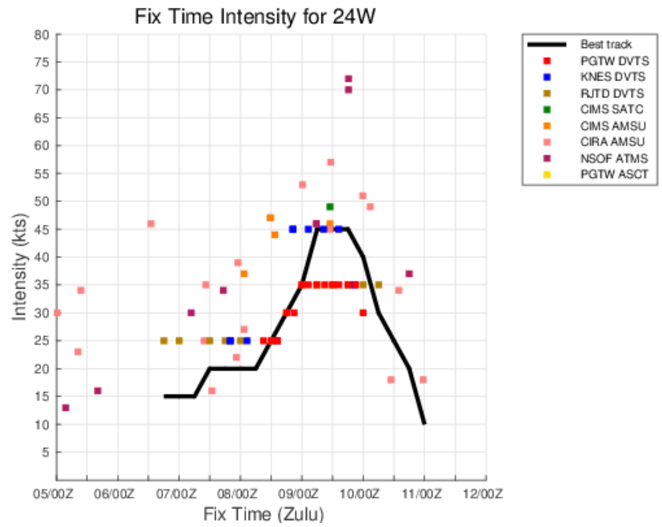
ISSUED LOW:	28 Oct / 0930Z
ISSUED MED:	28 Oct / 1830Z
FIRST TCFA:	29 Oct / 0730Z
FIRST WARNING:	29 Oct / 1200Z
LAST WARNING:	07 Nov / 1200Z
MAX INTENSITY:	50
WARNINGS:	37

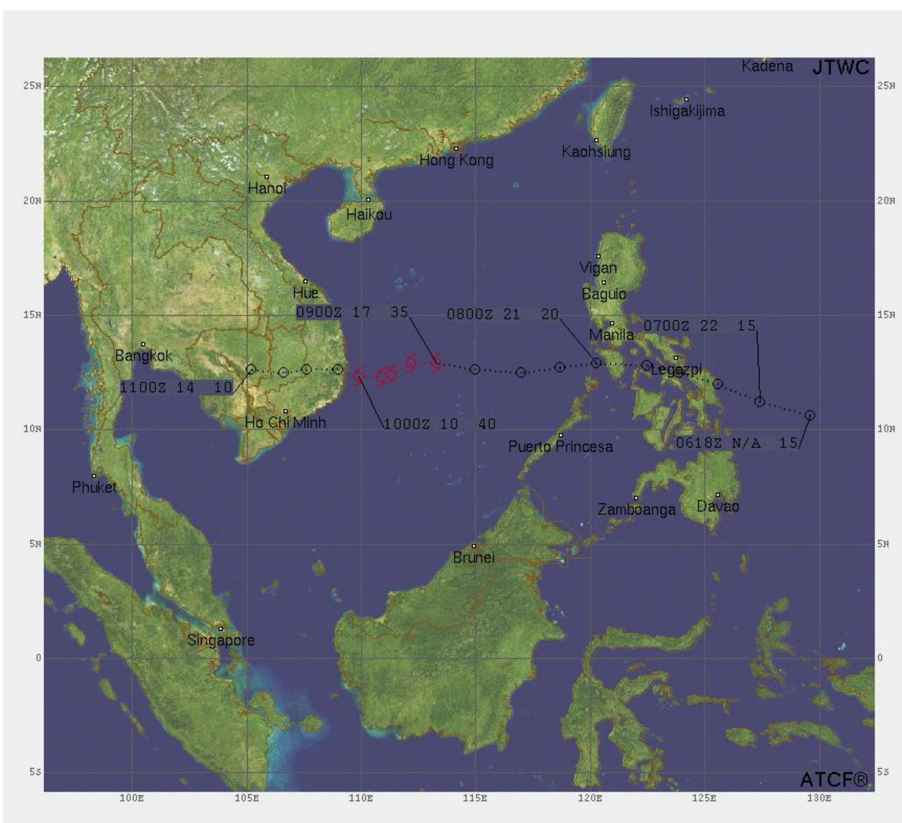




24W TROPICAL STORM ETAU

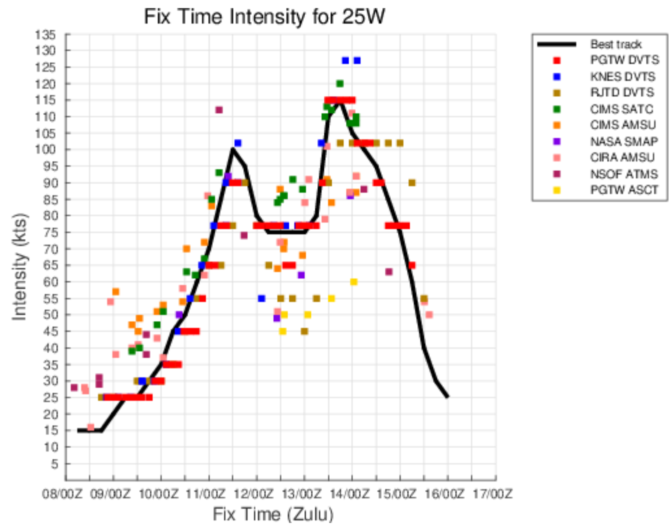
ISSUED LOW:	06 Nov / 0600Z
ISSUED MED:	07 Nov / 0230Z
FIRST TCFA:	07 Nov / 1500Z
FIRST WARNING:	08 Nov / 1200Z
LAST WARNING:	10 Nov / 0600Z
MAX INTENSITY:	45
WARNINGS:	8

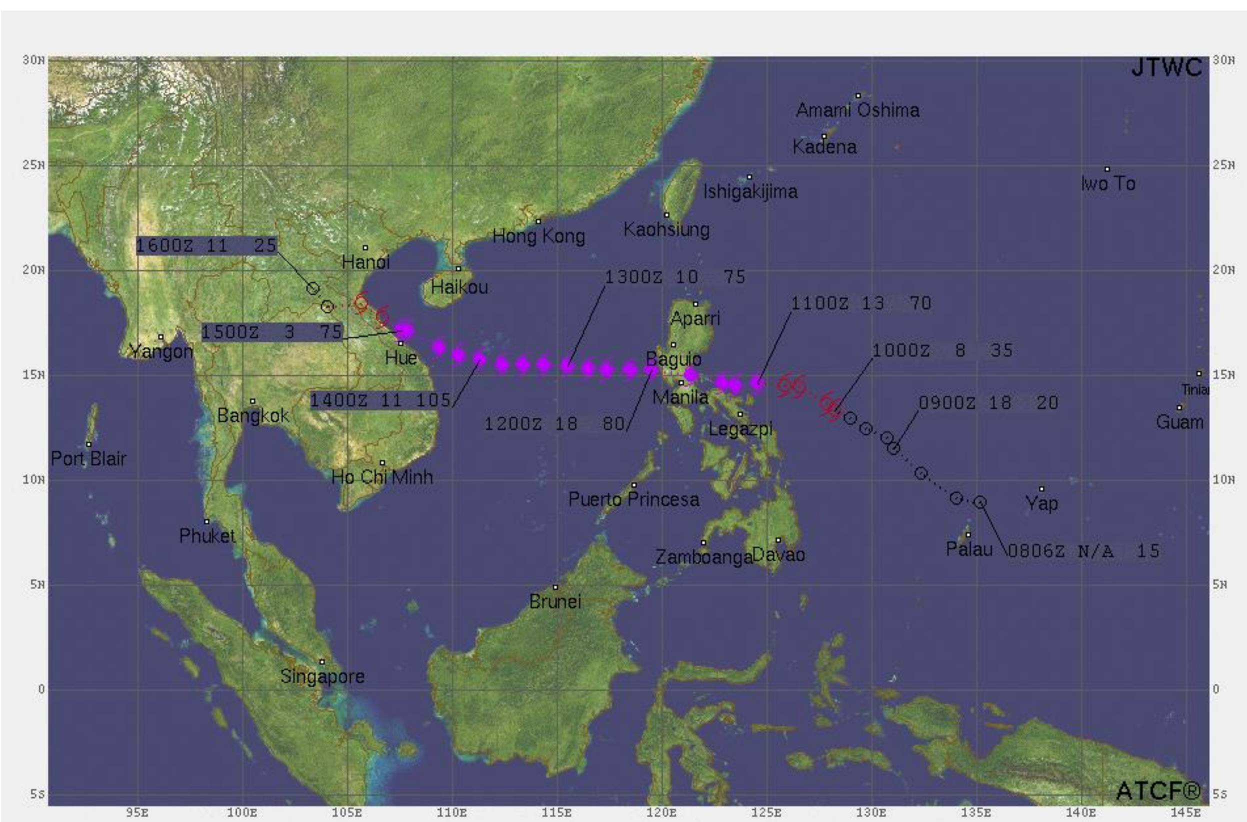




25W TYPHOON VAMCO

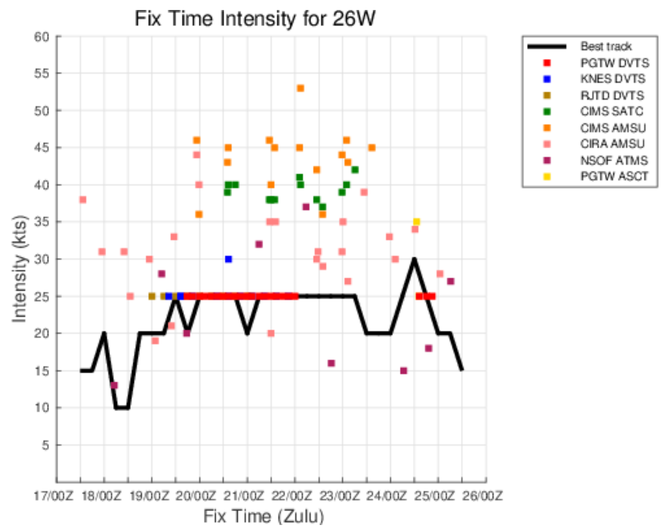
ISSUED LOW:	08 Nov / 0300Z
ISSUED MED:	08 Nov / 0730Z
FIRST TCFA:	08 Nov / 1400Z
FIRST WARNING:	09 Nov / 0600Z
LAST WARNING:	15 Nov / 0600Z
MAX INTENSITY:	115
WARNINGS:	25

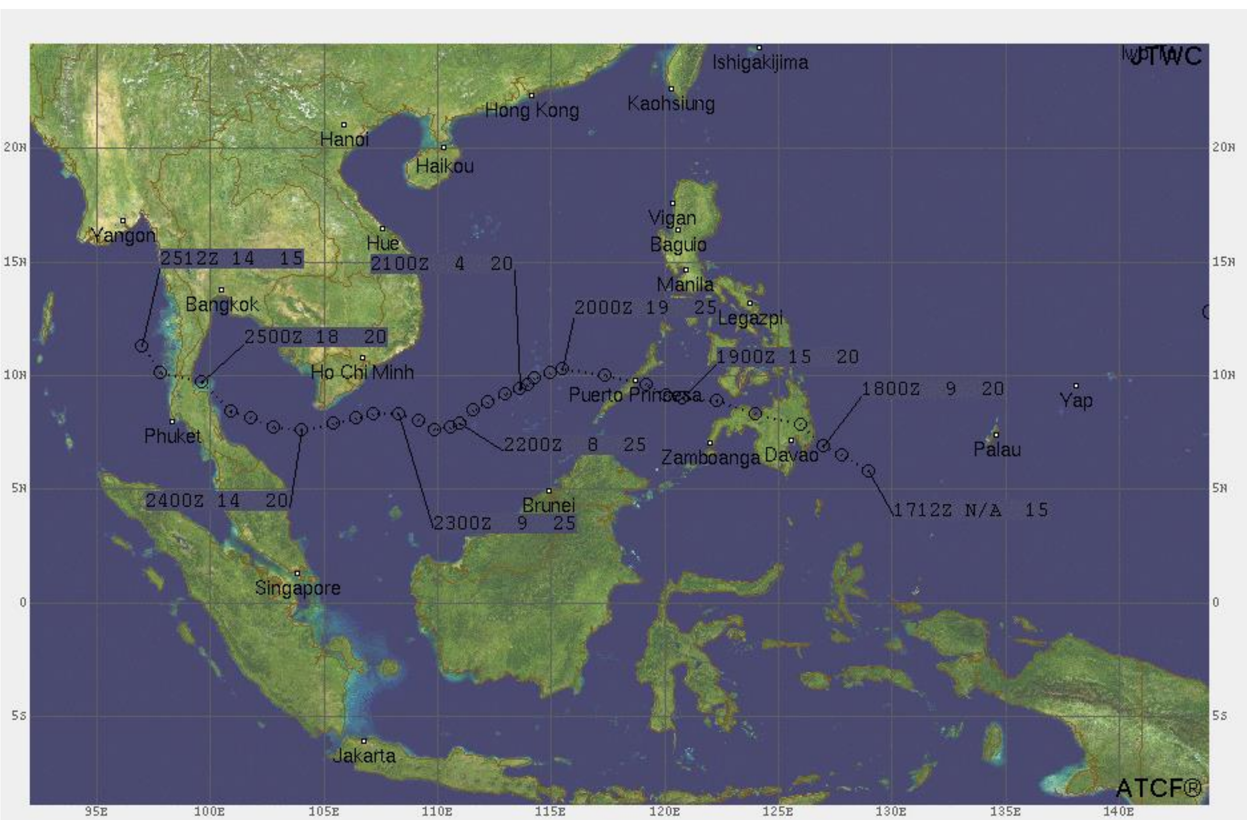




26W TROPICAL DEPRESSION KROVANH

ISSUED LOW:	N/A
ISSUED MED:	17 Dec / 1930Z
FIRST TCFA:	18 Dec / 2030Z
FIRST WARNING:	20 Dec / 0000Z
LAST WARNING:	22 Dec / 1200Z
MAX INTENSITY:	30
WARNINGS:	11





Chapter 2 North Indian Ocean Tropical Cyclones

Section 1 Informational Tables

Table 2-1 is a summary of TC activity in the North Indian Ocean during the 2020 season. Five cyclones occurred in 2020, with four systems reaching intensity greater than 64 knots. Table 2-2 shows the monthly distribution of Tropical Cyclone activity for 1975 - 2020.

Table 2-1

NORTH INDIAN OCEAN SIGNIFICANT TROPICAL CYCLONES

(01 JAN 2020- 31 DEC 2020)

TC	NAME*	PERIOD**		WARNINGS ISSUED	EST MAX SFC WINDS KTS
01B	AMPHAN	16 May / 0600Z	20 May / 1200Z	18	145
02A	NISARGA	02 Jun / 1800Z	03 Jun / 1200Z	4	85
03A	GATI	21 Nov / 1800Z	23 Nov / 1800Z	9	100
04B	NIVAR	23 Nov / 1200Z	26 Nov / 0000Z	11	70
05B	BUREVI	01 Dec / 1200Z	04 Dec / 1800Z	14	45

* As designated by the responsible RSMC

** Dates are based on Issuance of JTWC warnings on system.

*** Dates based on period of winds >34kts.

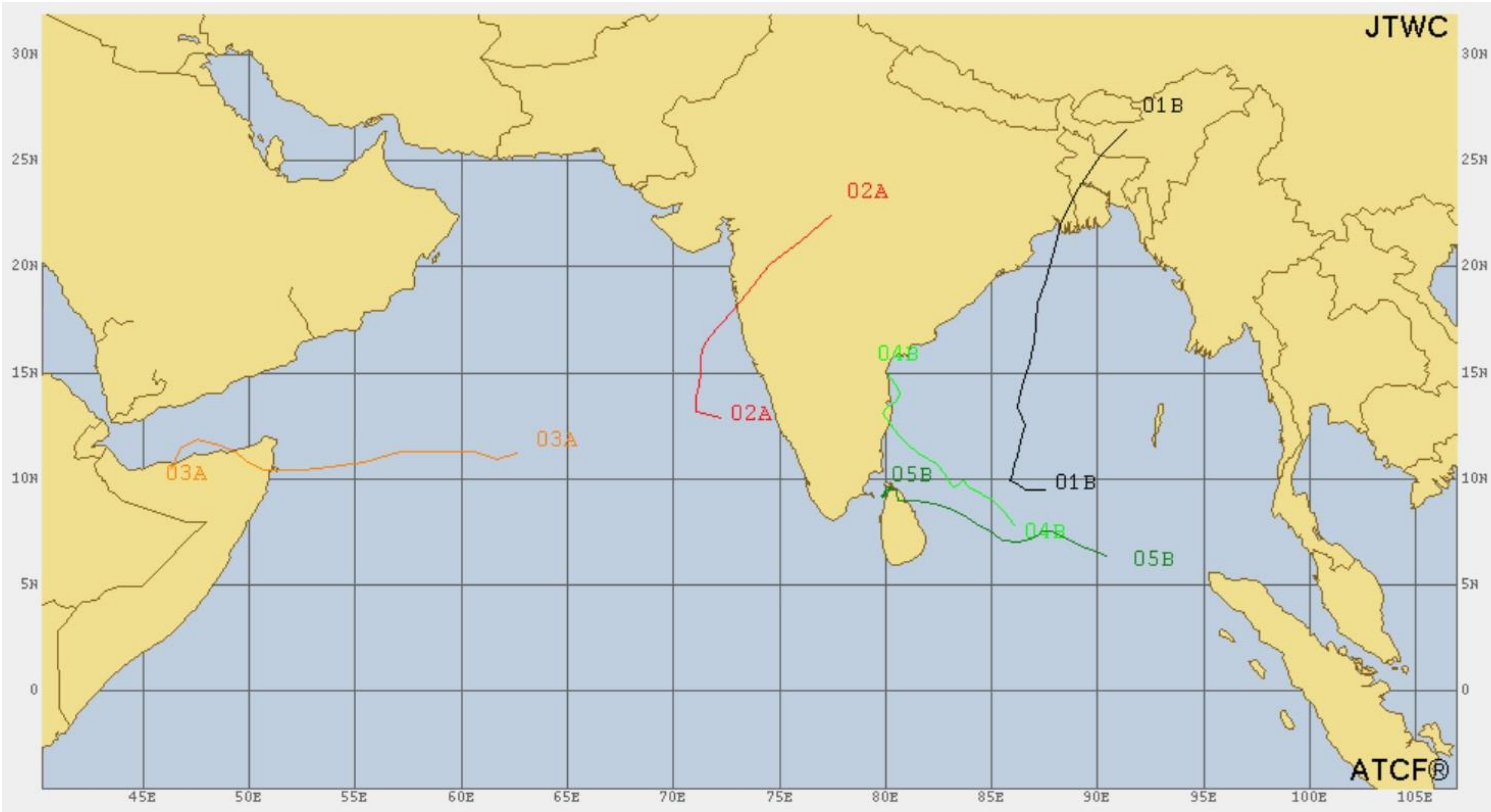


Figure 2-1. North Indian Ocean Tropical Cyclones.

Table 2 - 2
DISTRIBUTION OF NORTH INDIAN OCEAN TROPICAL CYCLONES FOR 1975 - 2020

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS	≥64kt	34-63kt	≤33kt
	1	0	0	0	2	0	0	0	0	1	2	0	6			
1975	010	000	000	000	200	000	000	000	000	100	020	000		3	3	0
	0	0	0	1	0	1	0	0	1	1	0	1	5			
1976	000	000	000	010	000	010	000	000	010	010	000	010		0	5	0
	0	0	0	0	1	1	0	0	0	1	0	2	5			
1977	000	000	000	000	010	010	000	000	000	010	000	110		1	4	0
	0	0	0	0	1	0	0	0	0	1	2	0	4			
1978	000	000	000	000	010	000	000	000	000	010	200	000		2	2	0
	0	0	0	0	1	1	0	0	2	1	2	0	7			
1979	000	000	000	000	100	010	000	000	011	010	011	000		1	4	2
	0	0	0	0	0	0	0	0	0	0	1	1	2			
1980	000	000	000	000	000	000	000	000	000	000	010	010		0	2	0
	0	0	0	0	0	0	0	0	1	0	1	1	3			
1981	000	000	000	000	000	000	000	000	010	000	100	100		2	1	0
	0	0	0	0	1	1	0	0	0	2	1	0	5			
1982	000	000	000	000	100	010	000	000	000	020	100	000		2	3	0
	0	0	0	0	0	0	0	1	0	1	1	0	3			
1983	000	000	000	000	000	000	000	010	000	010	010	000		0	3	0
	0	0	0	0	1	0	0	0	0	1	2	0	4			
1984	000	000	000	000	010	000	000	000	000	010	200	000		2	2	0
	0	0	0	0	2	0	0	0	0	2	1	1	6			
1985	000	000	000	000	020	000	000	000	000	020	010	010		0	6	0
	1	0	0	0	0	0	0	0	0	0	2	0	3			
1986	010	000	000	000	000	000	000	000	000	000	020	000		0	3	0
	0	1	0	0	0	2	0	0	0	2	1	2	8			
1987	000	010	000	000	000	020	000	000	000	020	010	020		0	8	0
	0	0	0	0	0	1	0	0	0	1	2	1	5			
1988	000	000	000	000	000	010	000	000	000	010	110	010		1	4	0
	0	0	0	0	1	1	0	0	0	0	1	0	3			
1989	000	000	000	000	010	010	000	000	000	000	100	000		1	2	0
	0	0	0	1	1	0	0	0	0	0	1	1	4			
1990	000	000	000	001	100	000	000	000	000	000	001	010		1	1	2
	1	0	0	1	0	1	0	0	0	0	1	0	4			
1991	010	000	000	100	000	010	000	000	000	000	100	000		2	2	0
	0	0	0	0	1	2	1	0	1	3	3	2	13			
1992	000	000	000	000	100	020	010	000	001	021	210	020		3	8	2
	0	0	0	0	0	0	0	0	0	0	2	0	2			
1993	000	000	000	000	000	000	000	000	000	000	200	000		2	0	0
	0	0	1	1	0	1	0	0	0	1	1	0	5			
1994	000	000	010	100	000	010	000	000	000	010	010	000		1	4	0
	0	0	0	0	0	0	0	0	1	1	2	0	4			
1995	000	000	000	000	000	000	000	000	010	010	200	000		2	2	0
	0	0	0	0	1	3	0	0	0	2	2	0	8			
1996	000	000	000	000	010	120	000	000	000	110	200	000		4	4	0
	0	0	0	0	1	0	0	0	1	1	1	0	4			
1997	000	000	000	000	100	000	000	000	100	010	010	000		2	2	0
	0	0	0	0	2	1	0	0	1	1	2	1	8			
1998	000	000	000	000	110	100	000	000	010	010	200	100		5	3	0
	0	1	0	0	1	1	0	0	0	2	0	0	5			
1999	000	010	000	000	100	010	000	000	000	200	000	000		3	2	0
	0	0	0	0	0	0	0	0	0	2	1	1	4			
2000	000	000	000	000	000	000	000	000	000	020	100	010		1	3	0
	0	0	0	0	1	0	0	0	1	1	1	0	4			
2001	000	000	000	000	100	000	000	000	010	010	001	000		1	2	1
	0	0	0	0	2	0	0	0	0	0	2	1	5			
2002	000	000	000	000	020	000	000	000	000	000	020	010		0	5	0
	0	0	0	0	1	0	0	0	0	0	1	1	3			
2003	000	000	000	000	100	000	000	000	000	000	100	010		2	1	0
	0	0	0	0	2	0	0	0	0	2	1	0	5			
2004	000	000	000	000	020	000	000	000	000	020	100	000		1	4	0
	2	0	0	0	0	0	0	0	0	2	1	2	7			
2005	011	000	000	000	000	000	000	000	000	020	010	020		0	6	1
	1	0	0	1	0	0	1	0	2	0	1	0	6			
2006	010	000	000	100	000	000	010	000	020	000	010	000		1	5	0
	0	0	0	0	1	3	0	0	0	1	1	0	6			
2007	000	000	000	000	100	120	000	000	000	010	100	000		3	3	0
	0	0	0	1	0	0	0	0	1	2	2	1	7			
2008	000	000	000	100	000	000	000	000	010	011	020	010		1	5	1
	0	0	0	1	1	0	0	0	1	0	1	1	5			
2009	000	000	000	010	100	000	000	000	010	000	010	010		1	4	0
	0	0	0	0	2	1	0	0	0	1	1	0	5			
2010	000	000	000	000	110	100	000	000	000	100	010	000		3	2	0
	0	0	0	0	0	1	0	0	0	1	3	1	6			
2011	000	000	000	000	000	010	000	000	000	010	030	100		1	5	0
	0	0	0	0	0	0	0	0	0	2	1	1	4			
2012	000	000	000	000	000	000	000	000	000	020	010	010		0	4	0
	0	0	0	0	1	0	0	0	0	1	3	1	6			
2013	000	000	000	000	010	000	000	000	000	100	210	100		4	2	0
	1	0	0	0	0	0	1	0	0	2	1	0	5			
2014	010	000	000	000	000	000	010	000	000	200	010	000		2	3	0
	0	0	0	0	0	1	1	0	0	2	1	0	5			
2015	000	000	000	000	000	010	010	000	000	110	100	000		2	3	0
	0	0	0	0	1	1	0	0	0	1	1	1	5			
2016	000	000	000	000	010	010	000	000	000	010	010	100		1	4	0
	0	0	0	1	1	0	0	0	0	0	1	1	4			
2017	000	000	000	010	100	000	000	000	000	000	100	010		2	2	0
	0	0	0	0	3	0	0	0	1	2	1	1	8			
2018	000	000	000	000	210	000	000	000	010	200	100	010		5	3	0
	0	0	0	1	0	1	0	0	1	1	1	2	7			
2019	000	000	000	100	000	100	000	000	010	100	100	020		4	3	0
	0	0	0	0	1	1	0	0	0	0	2	1	5			
2020	000	000	000	000	100	100	000	000	000	000	200	010		4	1	0
(1975-2020)																
MEAN	0.2	0.0	0.0	0.2	0.7	0.6	0.1	0.0	0.3	1.1	1.3	0.6	5.2			
CASES	7	2	1	9	34	26	4	1	15	48	62	29	233			

Section 2 Cyclone Summaries

This section presents a synopsis of each cyclone that occurred during 2020 in the North Indian Ocean. Each cyclone is presented, with the number and basin identifier used by JTWC, along with the name assigned by the RSMC.

Dates listed are JTWC's first designation of various stages of pre-warning development: LOW, MEDIUM, and HIGH (concurrent with TCFA). These classifications are defined as follows:

- "Low" formation potential describes an area that is being monitored for development, but is unlikely to develop within the next 24 hours.
- "Medium" formation potential describes an area that is being monitored for development and has an elevated potential to develop, but development will likely occur beyond 24 hours.
- "High" formation potential describes an area that is being monitored for development and is either expected to develop within 24 hours or development has already begun, but warning criteria have not yet been met. All areas designated as "High" are accompanied by a TCFA.

Initial and final JTWC warning dates are also presented with the number of warnings issued. JTWC initiates tropical cyclone warnings when one or more of the following four criteria are met:

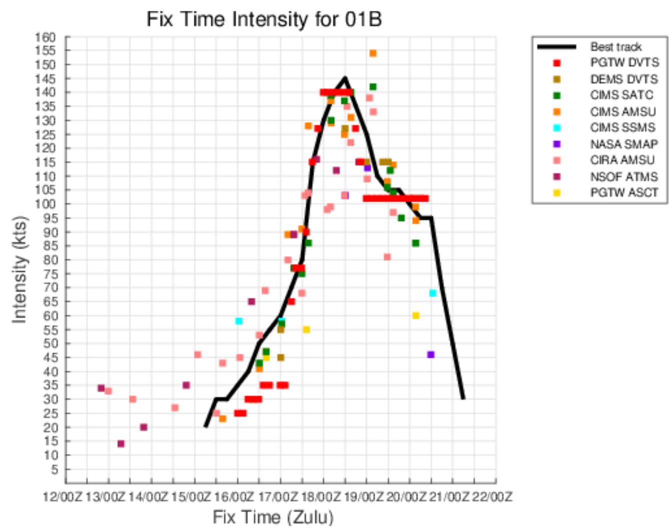
- Estimated maximum sustained wind speeds within a closed tropical circulation meet or exceed a designated threshold of 25 knots in the North Pacific Ocean or 35 knots in the South Pacific and Indian Oceans.
- Maximum sustained wind speeds within a closed tropical circulation are expected to increase to 35 knots or greater within 48 hours.
- A tropical cyclone may endanger life and/or property within 72 hours.
- USINDOPACOM directs JTWC to begin tropical cyclone warnings.

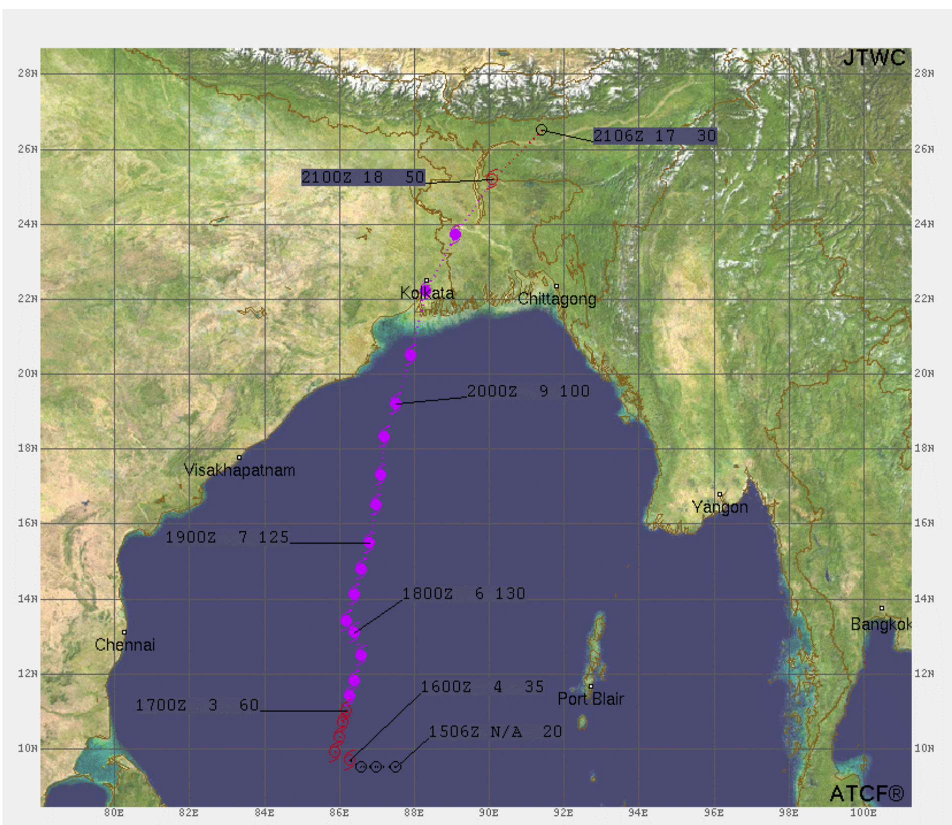
The JTWC post-event, reanalysis best track is provided for each cyclone. Data included on the best track are position and intensity noted with color-coded cyclone symbols and track line. Best track position labels include the date, time, track speed in knots, and maximum wind speed in knots, as well as the approximate locations where the cyclone made landfall over major landmasses. A second graph depicts best track intensity versus time, where fix plots are color coded by fixing agency.

In addition, when this document is viewed as a pdf, each map has been hyperlinked to a corresponding kmz file that will allow the reader to access and view the best-track data interactively using GIS software. Simply hold the control button and click the map image to download and open the file. Users may retrieve kmz files for the entire season from:
https://www.metoc.navy.mil/jtwc/products/best-tracks/2020/2020s-bio/IO_besttracks_2020-2020.kmz

01B TROPICAL CYCLONE AMPHAN

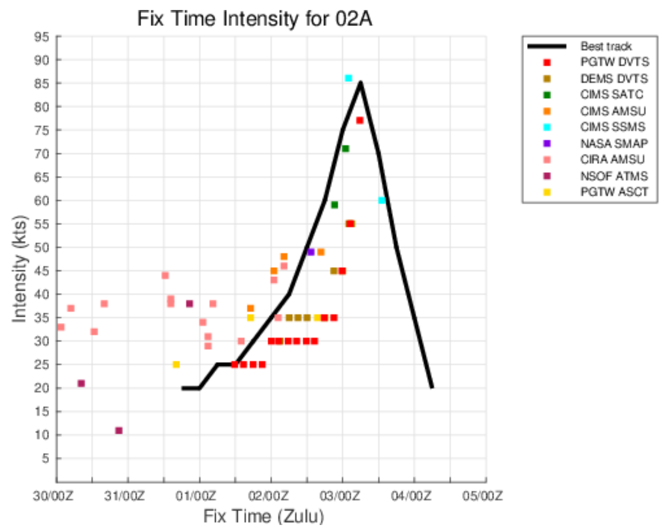
ISSUED LOW:	13 May / 1800Z
ISSUED MED:	14 May / 1800Z
FIRST TCFA:	15 May / 1000Z
FIRST WARNING:	16 May / 0600Z
LAST WARNING:	20 May / 1200Z
MAX INTENSITY:	145
WARNINGS:	18

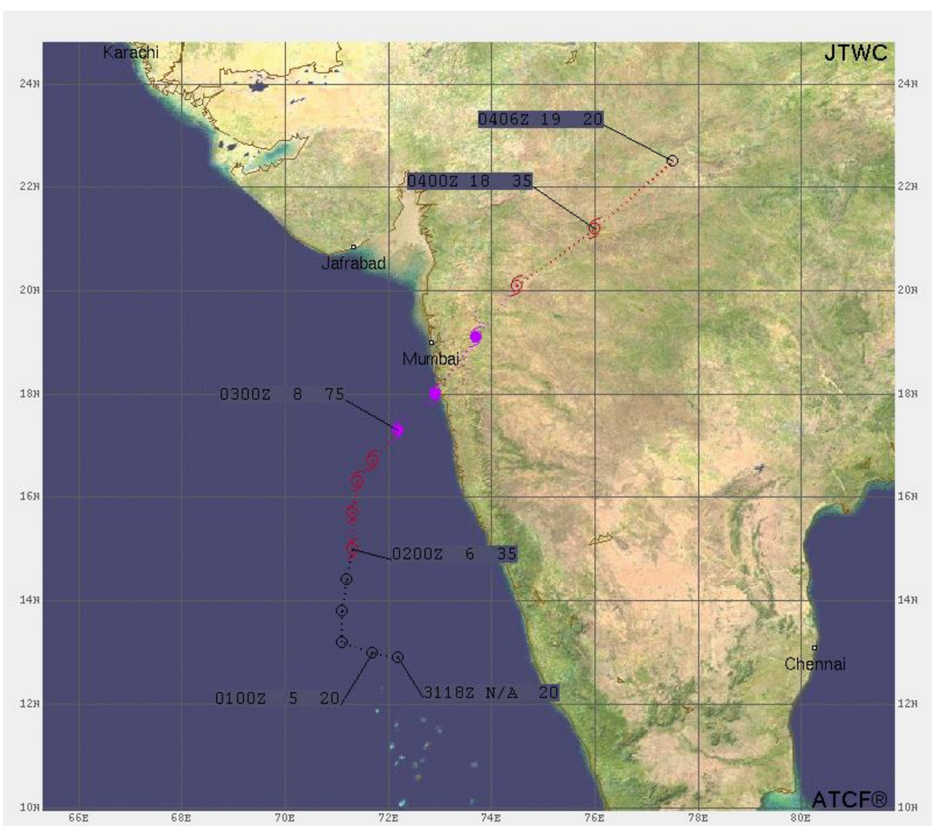




02A TROPICAL CYCLONE NISARGA

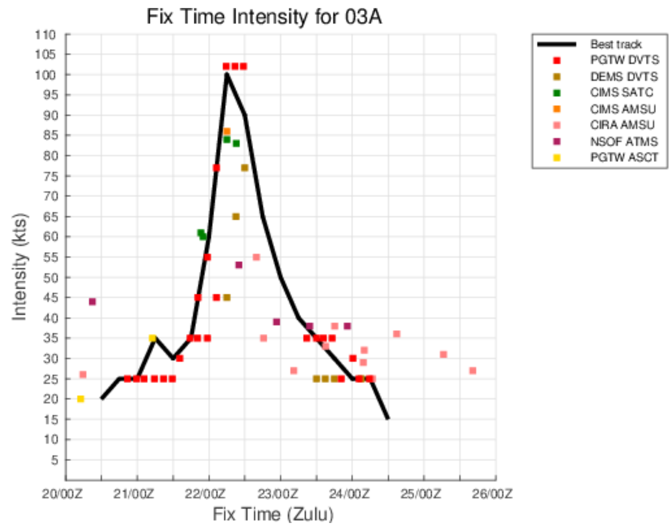
ISSUED LOW:	30 May / 1800Z
ISSUED MED:	31 May / 0900Z
FIRST TCFA:	01 Jun / 1400Z
FIRST WARNING:	02 Jun / 1800Z
LAST WARNING:	03 Jun / 1200Z
MAX INTENSITY:	85
WARNINGS:	4

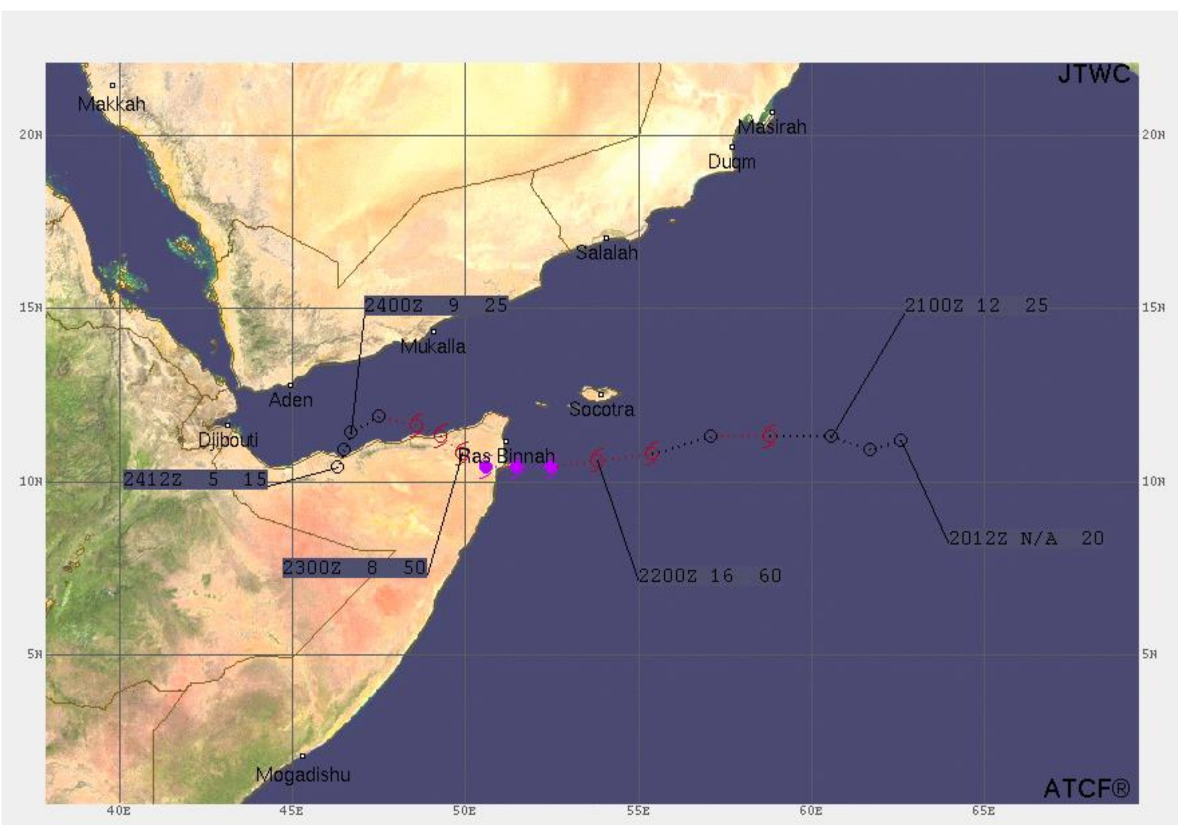




03A TROPICAL CYCLONE GATI

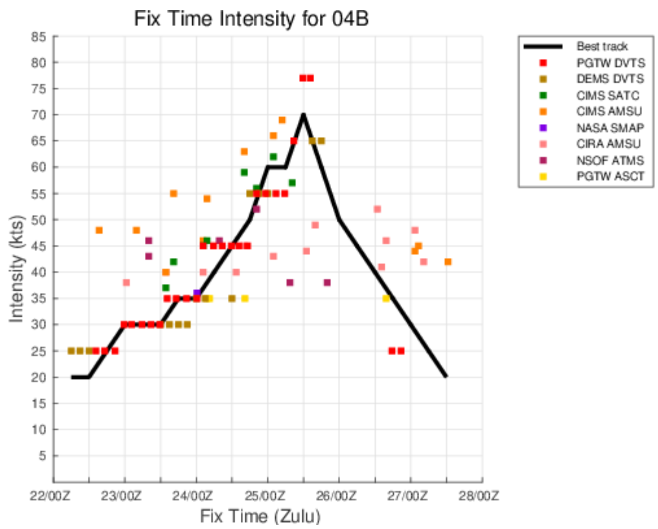
ISSUED LOW:	20 Nov / 1800Z
ISSUED MED:	21 Nov / 0200Z
FIRST TCFA:	21 Nov / 0800Z
FIRST WARNING:	21 Nov / 1800Z
LAST WARNING:	23 Nov / 1800Z
MAX INTENSITY:	100
WARNINGS:	9

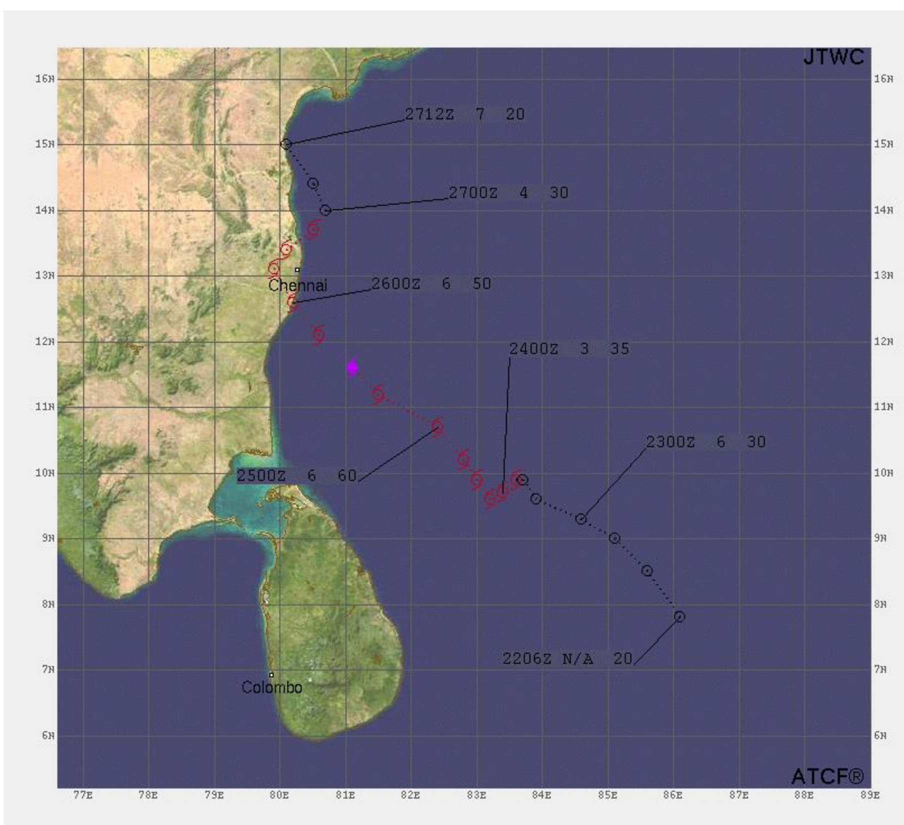




04B TROPICAL CYCLONE NIVAR

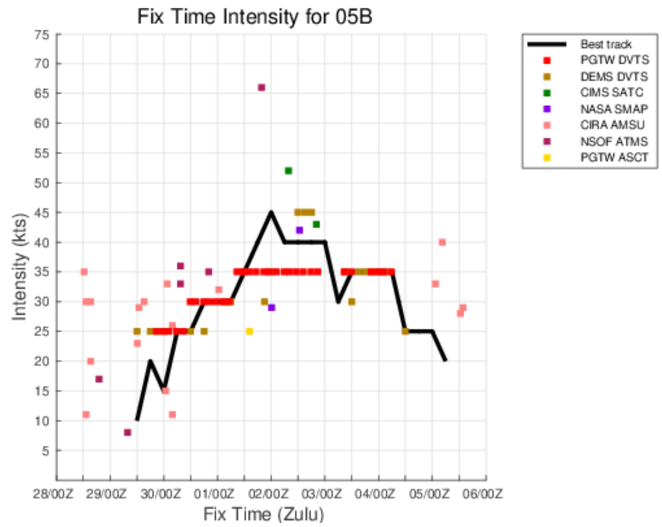
ISSUED LOW:	21 Nov / 1800Z
ISSUED MED:	22 Nov / 0630Z
FIRST TCFA:	22 Nov / 1530Z
FIRST WARNING:	23 Nov / 1200Z
LAST WARNING:	26 Nov / 0000Z
MAX INTENSITY:	70
WARNINGS:	11

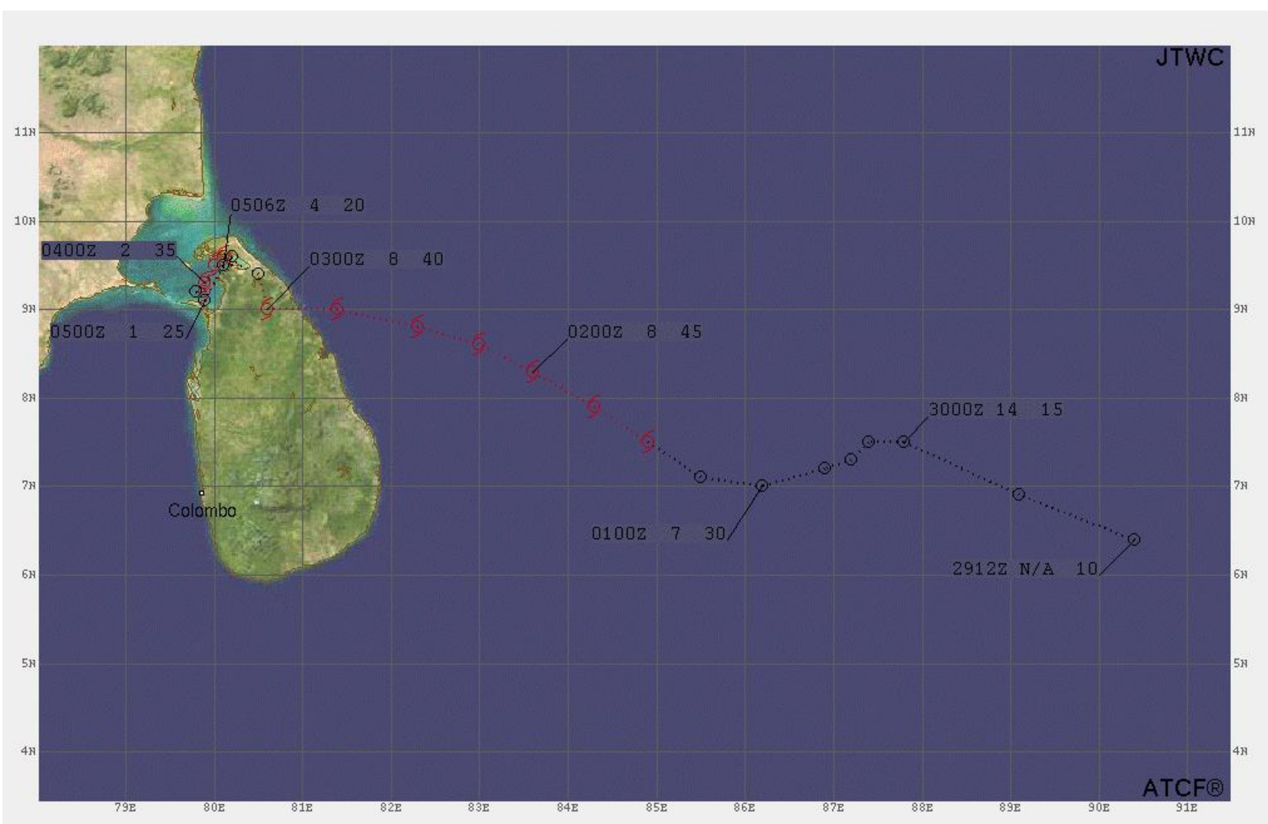




05B TROPICAL CYCLONE BUREVI

ISSUED LOW:	28 Nov / 1230Z
ISSUED MED:	29 Nov / 1800Z
FIRST TCFA:	30 Nov / 0930Z
FIRST WARNING:	01 Dec / 1200Z
LAST WARNING:	04 Dec / 1800Z
MAX INTENSITY:	45
WARNINGS:	14





Chapter 3 South Pacific and South Indian Ocean Tropical Cyclones

This chapter contains information on South Pacific and South Indian Ocean TC activity that occurred during the 2020 season (1 July 2019 – 30 June 2020) and the monthly distribution of TC activity summarized for 1958 - 2020.

Section 1   Informational Tables

Table 3-1 is a summary of TC activity in the Southern Hemisphere during the 2020 season.

Table 3-1 SOUTHERN HEMISPHERE TROPICAL CYCLONES (01 JULY 2019- 30 JUNE 2020)					
TC	NAME*	PERIOD**		WARNINGS ISSUED	EST MAX SFC WINDS KTS
01P	RITA	24 Nov / 0000Z	26 Nov / 1800Z	12	70
02S	BELNA	04 Dec / 1800Z	11 Dec / 0600Z	14	105
03S	AMBALI	04 Dec / 1800Z	08 Dec / 0000Z	9	140
04P	SARAI	26 Dec / 0600Z	31 Dec / 0600Z	21	75
05S	CALVINIA	29 Dec / 1200Z	01 Jan / 1200Z	7	75
06S	BLAKE	05 Jan / 1800Z	08 Jan / 0000Z	10	55
07S	CLAUDIA	11 Jan / 1200Z	15 Jan / 1800Z	18	85
08P	TINO	16 Jan / 1800Z	19 Jan / 0600Z	11	85
09S	NINE	22 Jan / 1200Z	23 Jan / 1200Z	3	45
10S	DIANE	24 Jan / 1800Z	26 Jan / 1800Z	5	55
11S	ESAMI	24 Jan / 1800Z	26 Jan / 1800Z	5	45
12P	TWELVE	25 Jan / 1200Z	26 Jan / 1200Z	5	35
13S	FRANCISCO	04 Feb / 1800Z	06 Feb / 0600Z	4	45
13S	FRANCISCO (rewarn)	13 Feb / 1800Z	14 Feb / 1800Z	3	40
14S	DAMIEN	06 Feb / 0000Z	08 Feb / 1200Z	11	95
15P	UESI	09 Feb / 0000Z	13 Feb / 0000Z	17	80
16S	GABEKILE	15 Feb / 0000Z	18 Feb / 1200Z	8	90
17P	VICKY	20 Feb / 1800Z	21 Feb / 1800Z	5	45
18P	WASI	21 Feb / 1200Z	23 Feb / 1200Z	9	60
19P	ESTHER	23 Feb / 1200Z	24 Feb / 0600Z	4	50
20S	FERDINAND	23 Feb / 1800Z	29 Feb / 0600Z	23	100
21S	TWENTYONE	11 Mar / 0600Z	11 Mar / 1800Z	3	45
22S	HEROLD	13 Mar / 0600Z	19 Mar / 1800Z	14	100
23P	GRETEL	14 Mar / 1800Z	16 Mar / 0000Z	6	65
24S	IRONDRO	02 Apr / 0600Z	06 Apr / 0600Z	9	105
25P	HAROLD	02 Apr / 1800Z	09 Apr / 1200Z	28	150
26S	JERUTO	14 Apr / 1800Z	15 Apr / 1800Z	3	40
27S	MANGGA	21 May / 0000Z	23 May / 1800Z	12	40
* As designated by the responsible RSMC					
** Dates are based on the issuance of JTWC warnings on the system.					

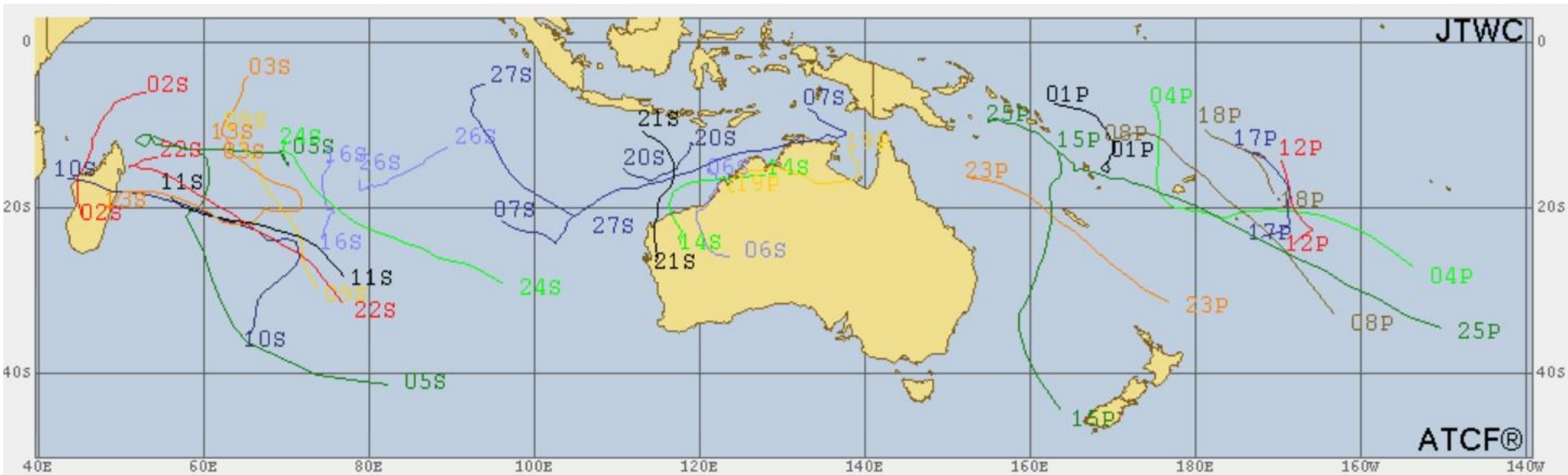


Figure 3-1. Southern Hemisphere Tropical Cyclones.

Table 3-2 DISTRIBUTION OF SOUTH PACIFIC AND SOUTH INDIAN OCEAN TROPICAL CYCLONES FOR 1958 - 2020													
YEAR	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**TOTALS**
1958 - 1977 AVERAGE*													
-	-	-	-	0.4	1.5	3.6	6.1	5.8	4.7	2.1	0.5	-	24.7
1981 - 2020													
	JUL	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	
1981	0	0	0	1	3	2	6	5	3	3	1	0	24
1982	1	0	0	1	1	3	9	4	2	3	1	0	25
1983	1	0	0	1	1	3	5	6	3	5	0	0	25
1984	1	0	0	1	2	5	5	10	4	2	0	0	30
1985	0	0	0	0	1	7	9	9	6	3	0	0	35
1986	0	0	1	0	1	1	9	9	6	4	2	0	33
1987	0	1	0	0	1	3	6	8	3	4	1	1	28
1988	0	0	0	0	2	3	5	5	3	1	2	0	21
1989	0	0	0	0	2	1	5	8	6	4	2	0	28
1990	2	0	1	1	2	2	4	4	10	2	1	0	29
1991	0	0	1	1	1	3	2	5	5	2	1	1	22
1992	0	0	1	1	2	5	4	11	3	2	1	0	30
1993	0	0	1	1	0	5	7	7	2	2	2	0	27
1994	0	0	0	0	2	4	8	4	9	3	0	0	30
1995	0	0	0	0	2	2	5	4	5	4	0	0	22
1996	0	0	0	0	1	3	7	6	6	4	1	0	28
1997	1	1	1	2	2	6	9	8	3	1	3	1	38
1998	1	0	0	3	2	3	7	9	6	6	0	0	37
1999	1	0	1	1	1	6	6	8	7	2	0	0	33
2000	0	0	0	0	0	3	6	5	7	6	0	0	27
2001	0	1	0	0	1	1	4	6	2	5	0	1	21
2002	0	0	0	2	4	1	4	5	4	2	3	0	25
2003	0	0	1	0	2	5	5	7	5	2	1	1	29
2004	0	0	0	1	1	3	6	3	7	1	1	0	23
2005	0	0	1	1	2	2	7	7	4	2	0	0	26
2006	0	0	0	1	2	1	6	5	5	3	0	0	23
2007	0	0	0	0	1	2	2	5	6	6	1	1	24
2008	1	0	0	0	3	4	7	5	6	3	0	0	29
2009	0	0	0	1	2	2	7	4	8	3	0	0	27
2010	0	0	0	0	2	4	5	6	5	2	0	0	24
2011	0	0	0	1	1	2	6	7	2	2	0	0	21
2012	0	0	0	0	0	4	5	6	2	1	1	2	21
2013	0	0	0	1	1	4	7	5	2	3	1	0	24
2014	0	0	0	1	1	4	5	4	6	3	0	0	24
2015	0	0	0	0	2	2	5	5	6	4	0	1	25
2016	0	1	0	1	2	2	3	5	3	3	0	0	20
2017	1	0	0	0	0	1	1	5	5	4	2	0	19
2018	0	0	0	0	1	1	6	2	8	3	0	0	21
2019	0	0	2	0	2	4	3	5	6	3	2	0	27
2020	0	0	0	0	1	4	7	9	3	3	1	0	28
(1981 - 2020)													
MEAN	0.3	0.1	0.3	0.6	1.5	3.1	5.6	6.0	4.9	3.0	0.8	0.2	26.3
CASES	10	4	11	24	60	123	225	241	194	121	31	9	1053
* (GRAY, 1978)													

Section 2 Cyclone Summaries

This section presents a synopsis of each cyclone that occurred during 2020 in the South Pacific and South Indian Oceans. Each cyclone is presented, with the number and basin identifier used by JTWC, along with the name assigned by the RSMC.

Dates listed are JTWC's first designation of various stages of pre-warning development: LOW, MEDIUM, and HIGH (concurrent with TCFA). These classifications are defined as follows:

- "Low" formation potential describes an area that is being monitored for development, but is unlikely to develop within the next 24 hours.
- "Medium" formation potential describes an area that is being monitored for development and has an elevated potential to develop, but development will likely occur beyond 24 hours.
- "High" formation potential describes an area that is being monitored for development and is either expected to develop within 24 hours or development has already begun, but warning criteria have not yet been met. All areas designated as "High" are accompanied by a TCFA.

Initial and final JTWC warning dates are also presented with the number of warnings issued. JTWC initiates tropical cyclone warnings when one or more of the following four criteria are met:

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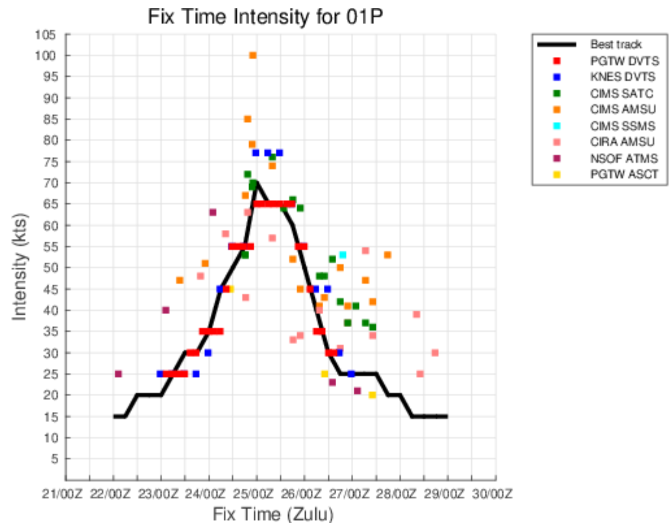
- A tropical cyclone may endanger life and/or property within 72 hours.
- USINDOPACOM directs JTWC to begin tropical cyclone warnings.

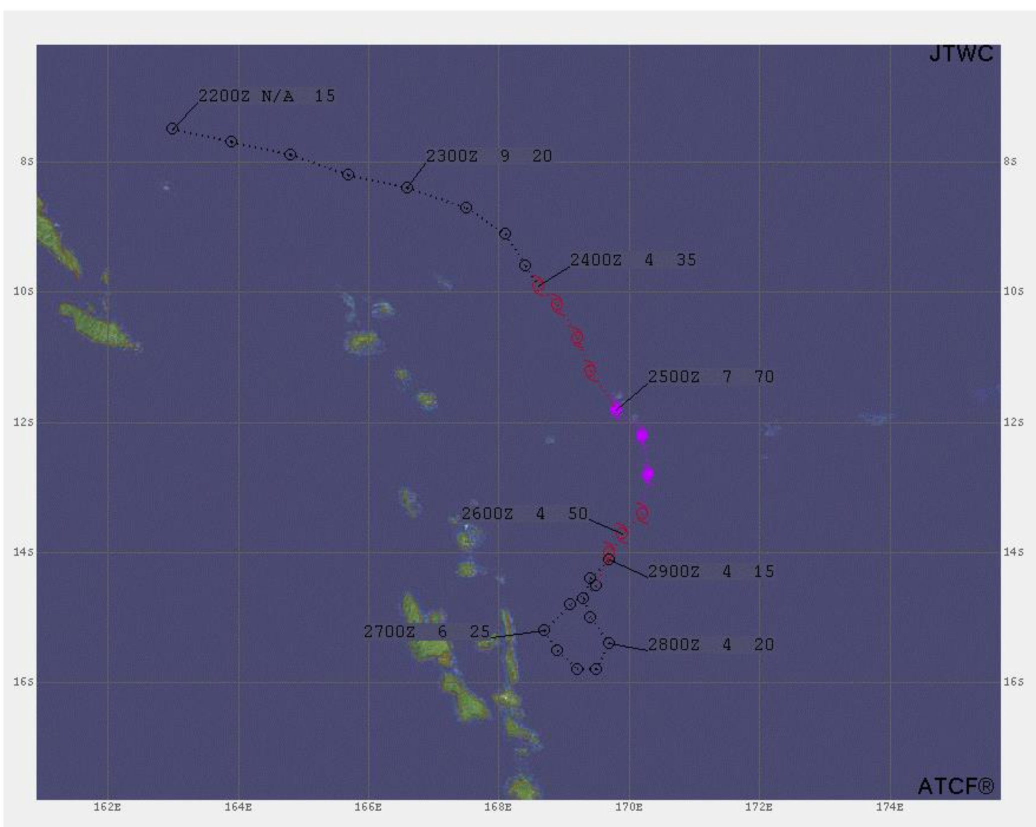
The JTWC post-event, reanalysis best track is provided for each cyclone. Data included on the best track are position and intensity noted with color-coded cyclone symbols and track line. Best track position labels include the date, time, track speed in knots, and maximum wind speed in knots, as well as the approximate locations where the cyclone made landfall over major landmasses. A second graph depicts best track intensity versus time, where fix plots are color coded by fixing agency.

In addition, when this document is viewed as a pdf, each map has been hyperlinked to a corresponding kmz file that will allow the reader to access and view the best-track data interactively using GIS software. Simply hold the control button and click the map image to download and open the file. Users may retrieve kmz files for the entire season from:
https://www.metoc.navy.mil/jtwc/products/best-tracks/2020/2020s-bsh/SH_besttracks_2020-2020.kmz

01P TROPICAL CYCLONE RITA

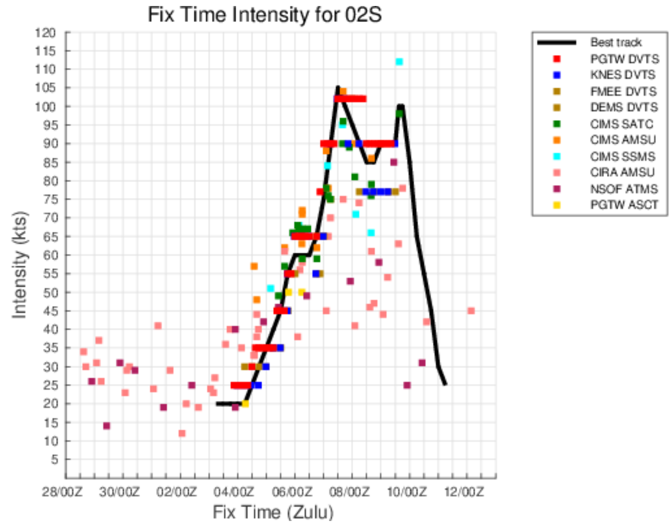
ISSUED LOW:	22 Nov / 0600Z
ISSUED MED:	22 Nov / 2200Z
FIRST TCFA:	23 Nov / 0330Z
FIRST WARNING:	24 Nov / 0000Z
LAST WARNING:	26 Nov / 1800Z
MAX INTENSITY:	70
WARNINGS:	12

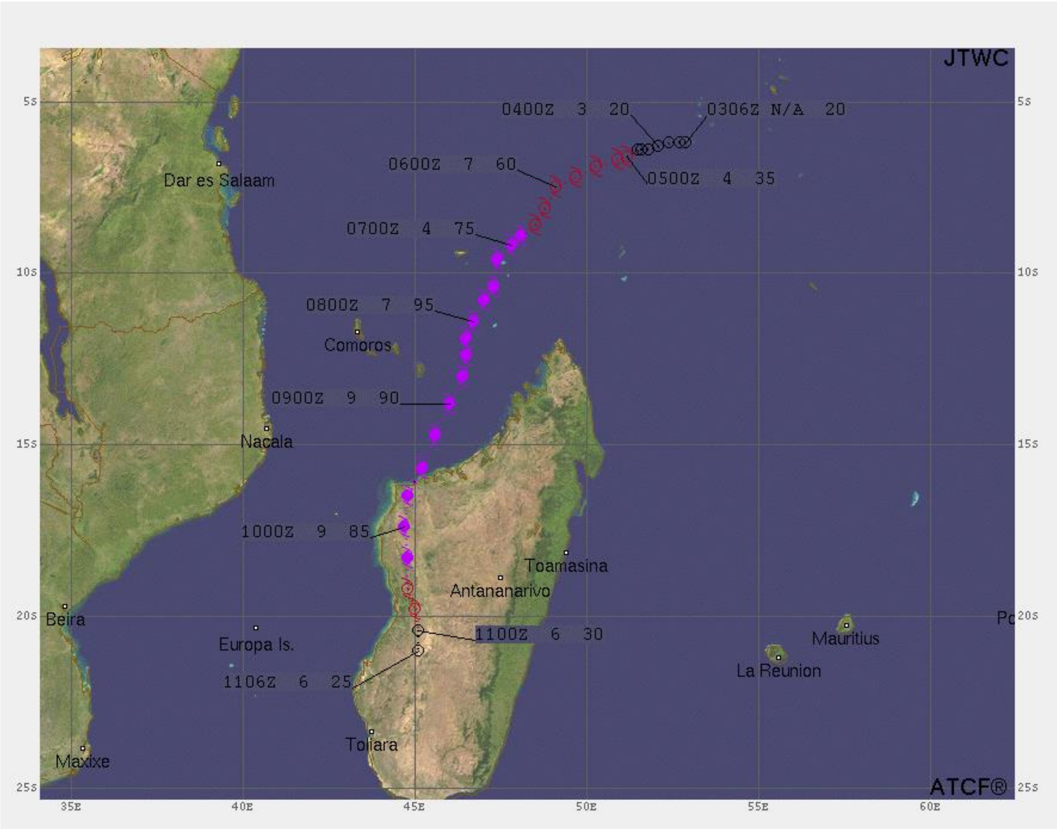




02S TROPICAL CYCLONE BELNA

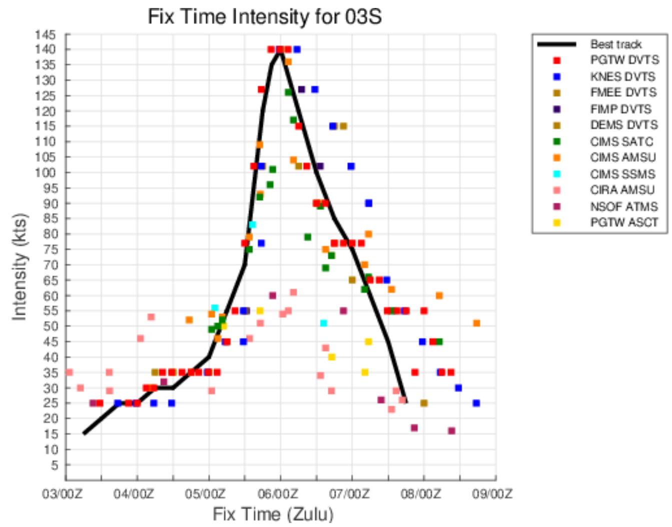
ISSUED LOW:	28 Nov / 0330Z
ISSUED MED:	01 Dec / 2230Z
FIRST TCFA:	04 Dec / 0330Z
FIRST WARNING:	04 Dec / 1800Z
LAST WARNING:	11 Dec / 0600Z
MAX INTENSITY:	105
WARNINGS:	14

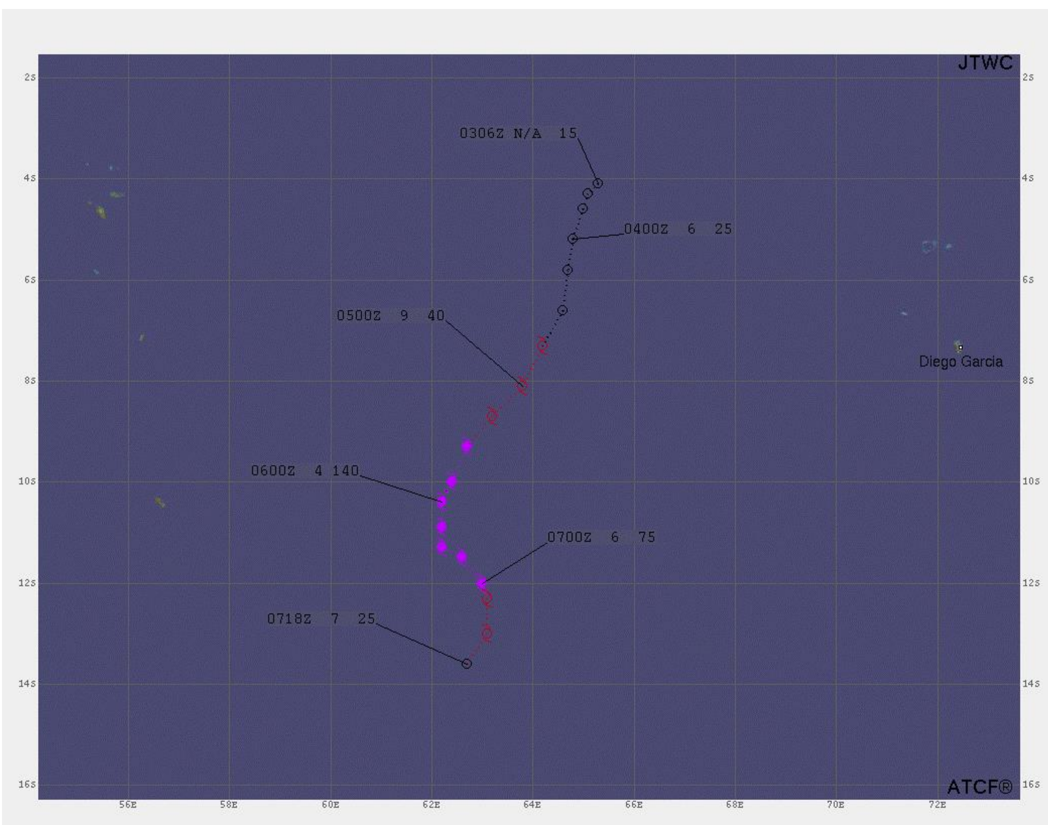




03S TROPICAL CYCLONE AMBALI

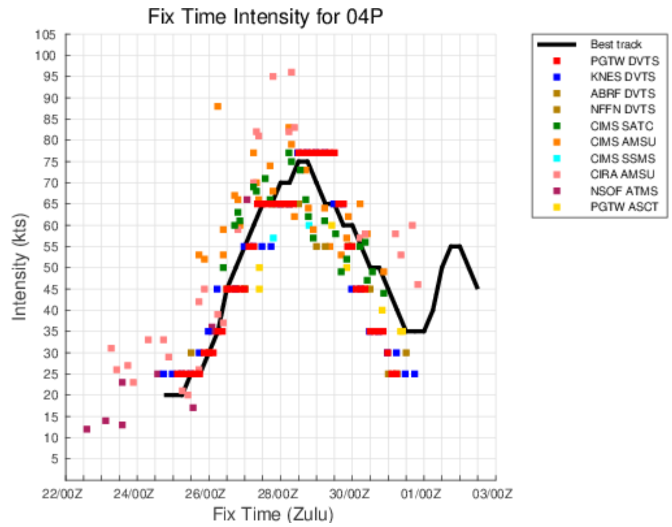
ISSUED LOW:	03 Dec / 1800Z
ISSUED MED:	04 Dec / 0400Z
FIRST TCFA:	04 Dec / 0630Z
FIRST WARNING:	04 Dec / 1800Z
LAST WARNING:	08 Dec / 0000Z
MAX INTENSITY:	140
WARNINGS:	9

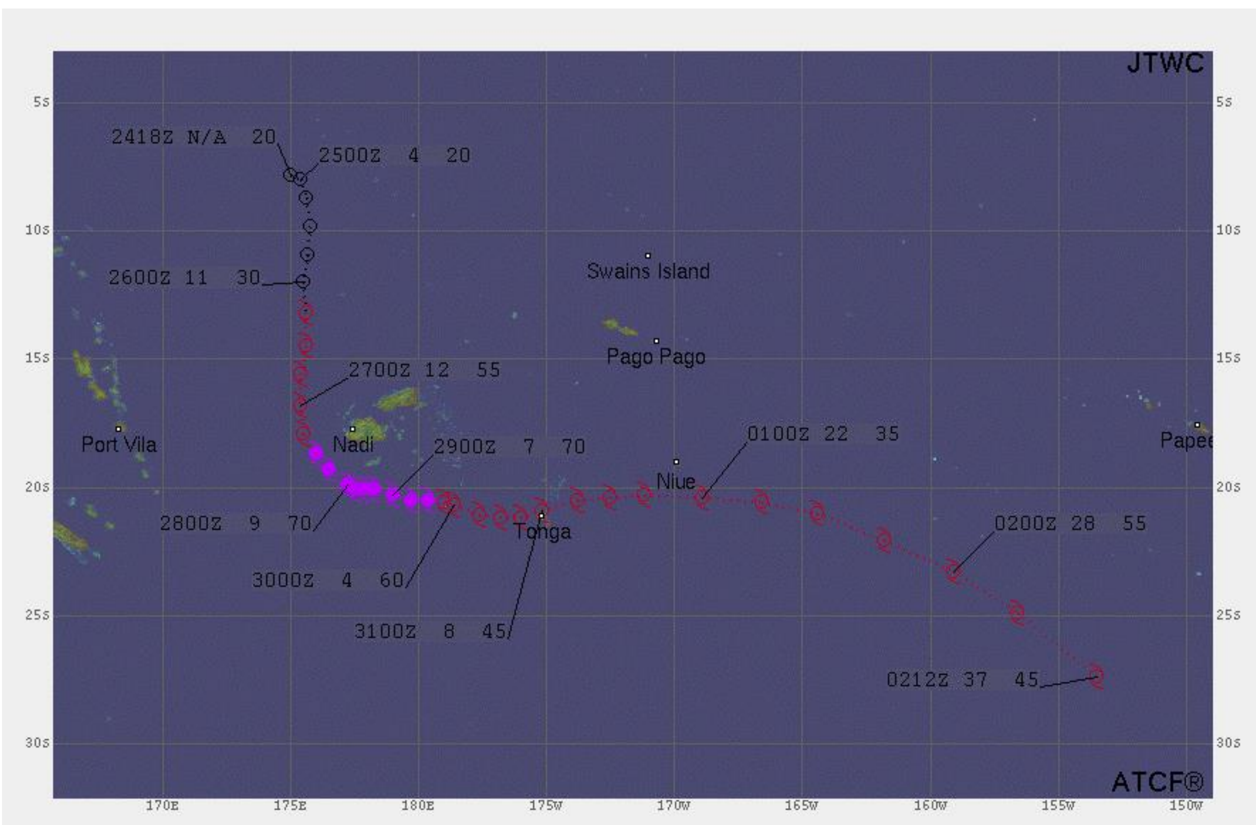




04P TROPICAL CYCLONE SARAI

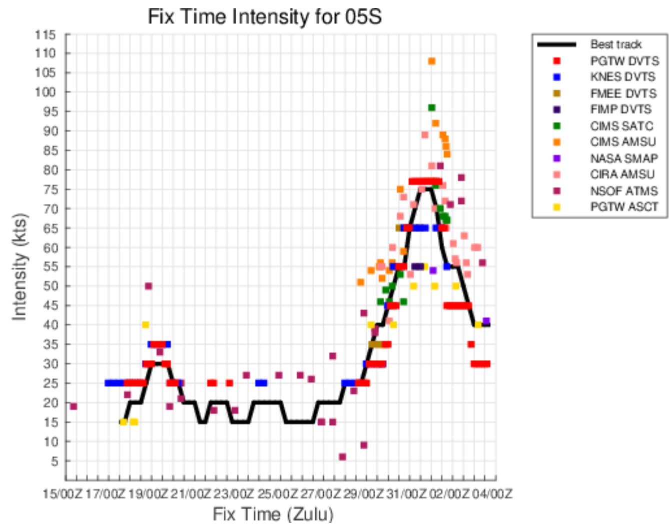
ISSUED LOW:	23 Dec / 1930Z
ISSUED MED:	24 Dec / 0600Z
FIRST TCFA:	26 Dec / 0300Z
FIRST WARNING:	26 Dec / 0600Z
LAST WARNING:	31 Dec / 0600Z
MAX INTENSITY:	75
WARNINGS:	21

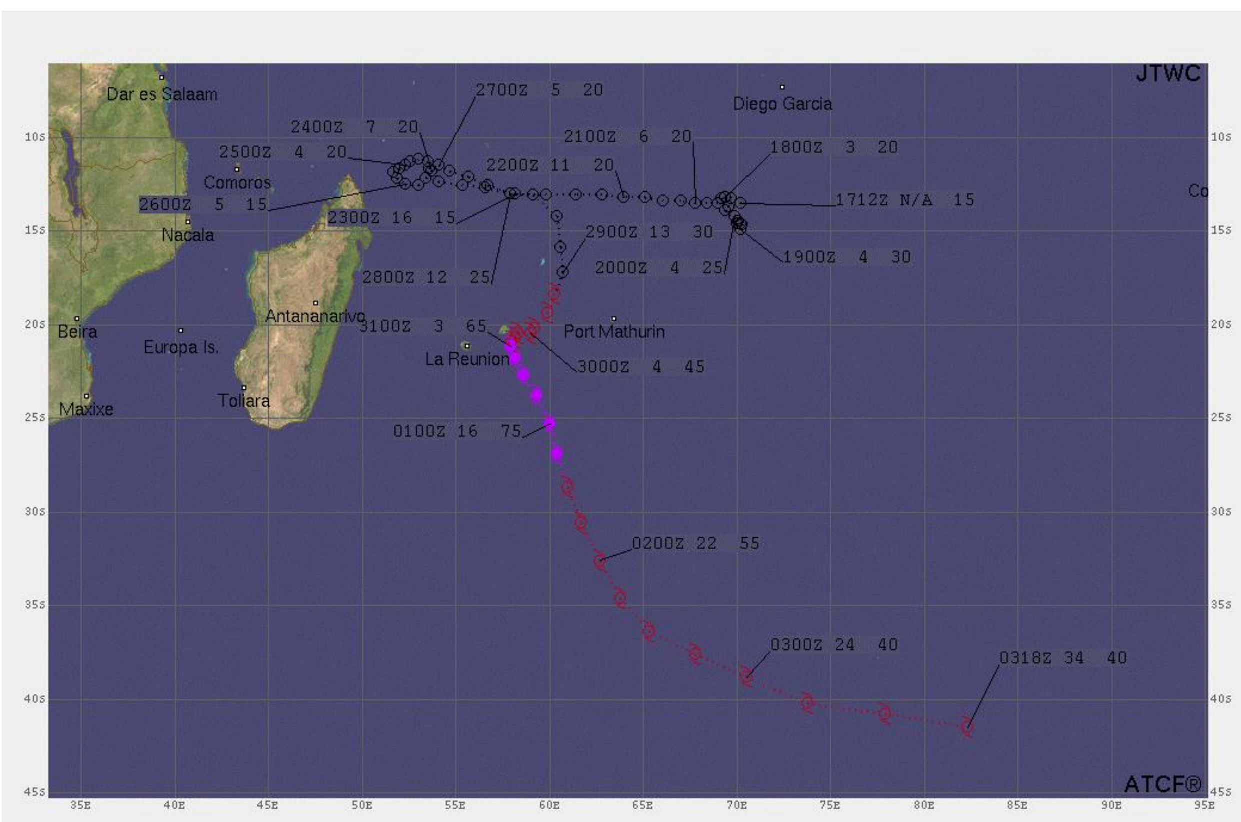




05S TROPICAL CYCLONE CALVINIA

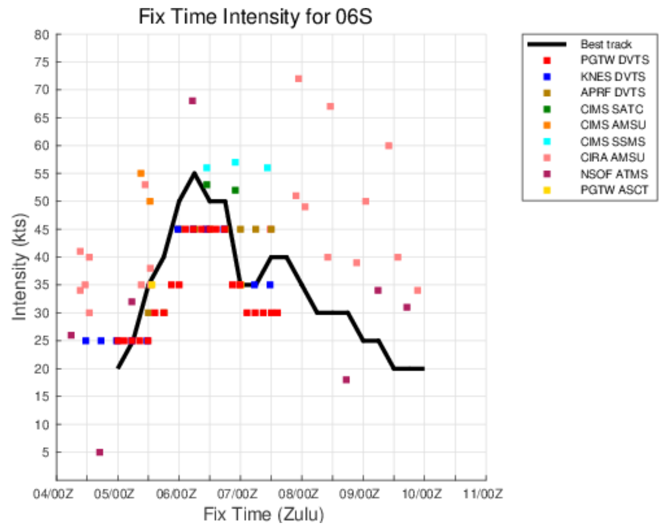
ISSUED LOW:	16 Dec / 1100Z
ISSUED MED:	27 Dec / 0130Z
FIRST TCFA:	27 Dec / 1500Z
FIRST WARNING:	29 Dec / 1200Z
LAST WARNING:	01 Jan / 1200Z
MAX INTENSITY:	75
WARNINGS:	7

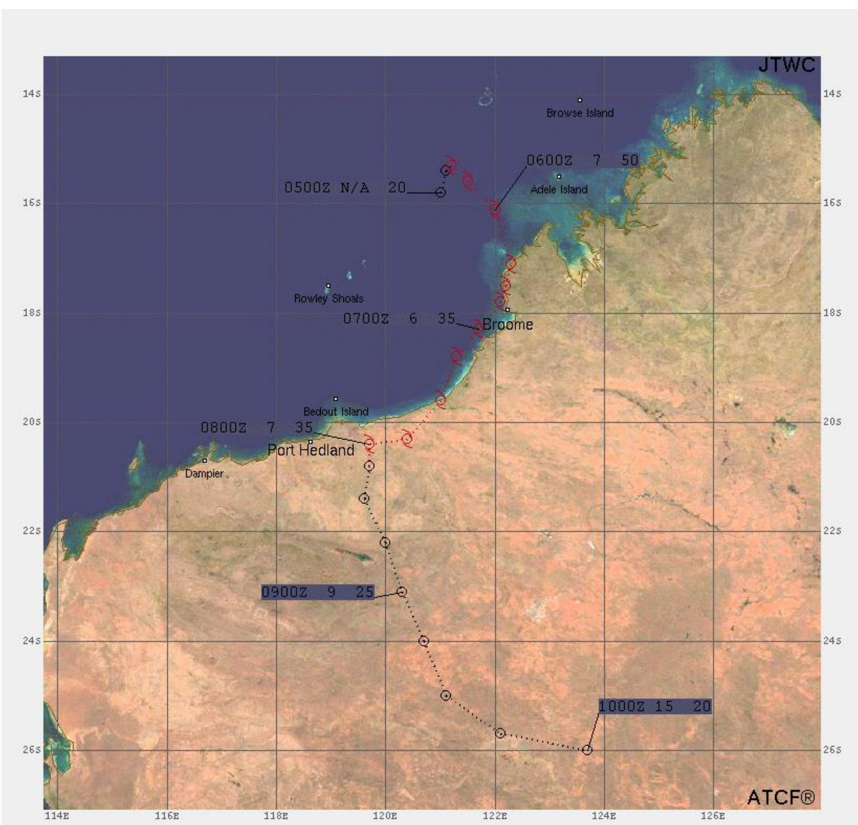




06S TROPICAL CYCLONE BLAKE

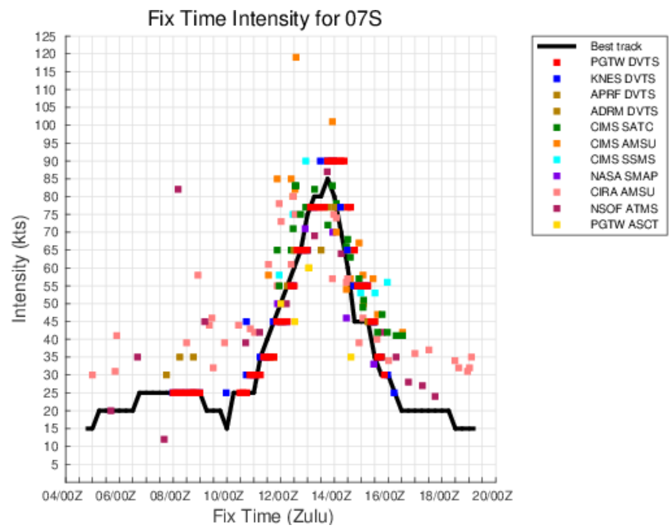
ISSUED LOW:	03 Jan / 1800Z
ISSUED MED:	04 Jan / 0300Z
FIRST TCFA:	05 Jan / 0330Z
FIRST WARNING:	05 Jan / 1800Z
LAST WARNING:	08 Jan / 0000Z
MAX INTENSITY:	55
WARNINGS:	10

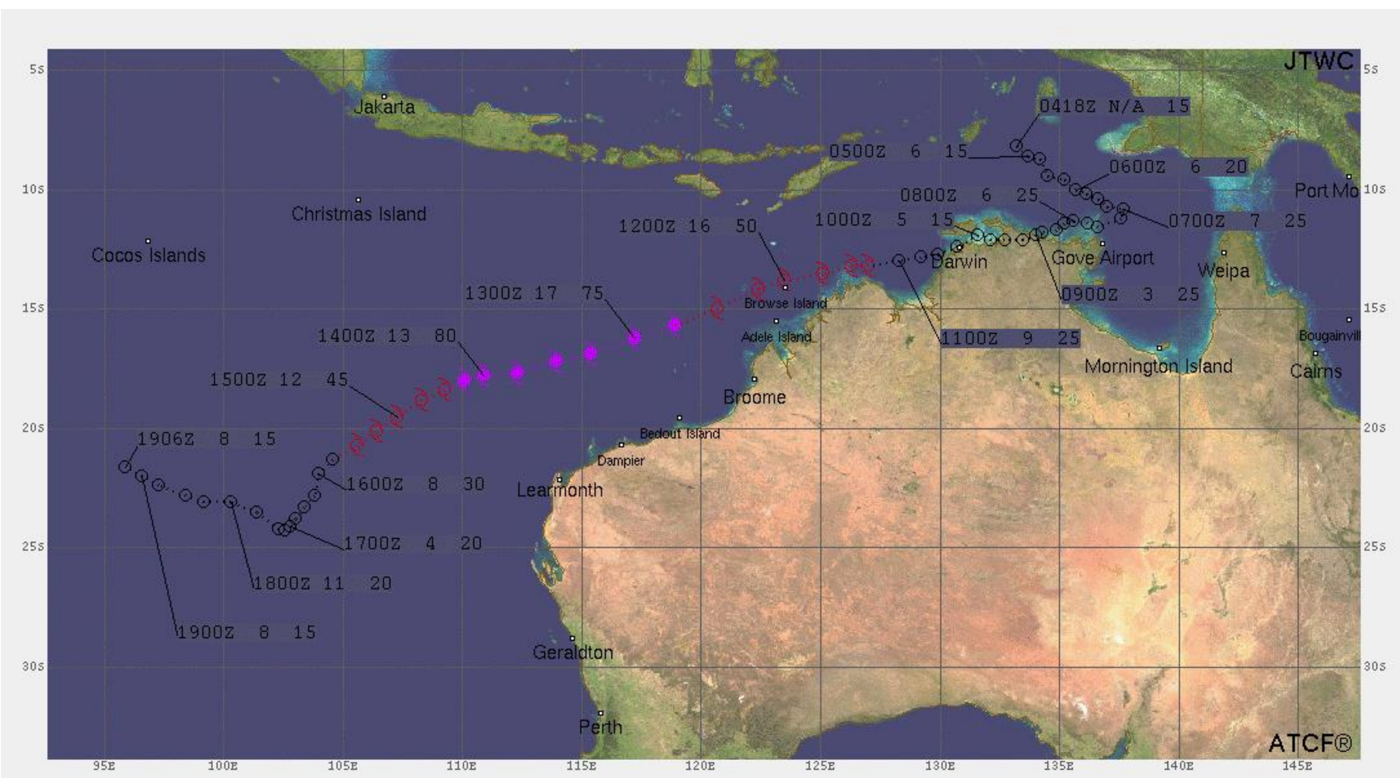




07S TROPICAL CYCLONE CLAUDIA

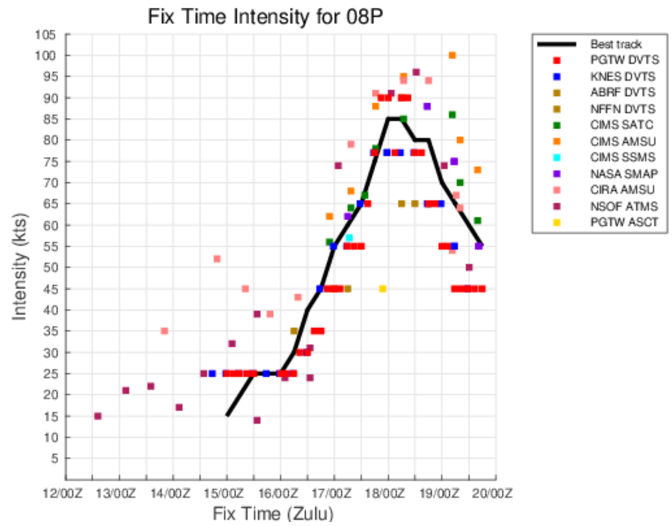
ISSUED LOW:	05 Jan / 0900Z
ISSUED MED:	09 Jan / 0600Z
FIRST TCFA:	10 Jan / 0300Z
FIRST WARNING:	11 Jan / 1200Z
LAST WARNING:	15 Jan / 1800Z
MAX INTENSITY:	85
WARNINGS:	18

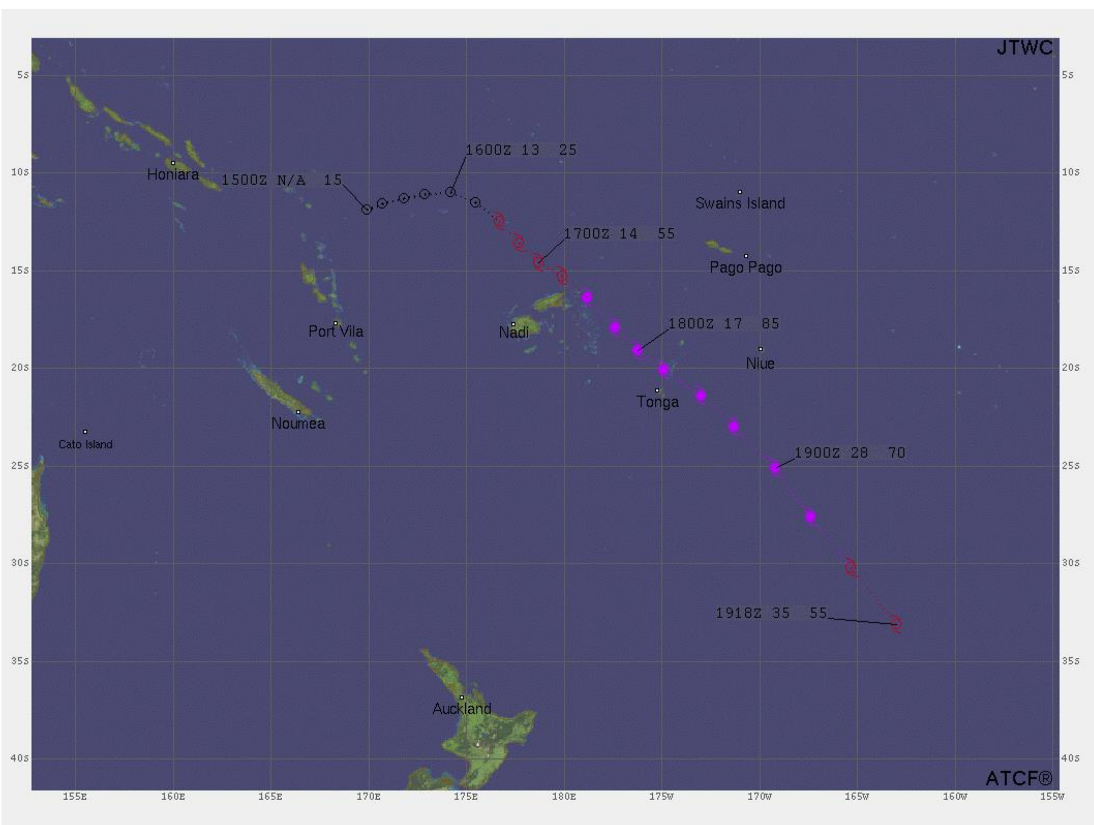




08P TROPICAL CYCLONE TINO

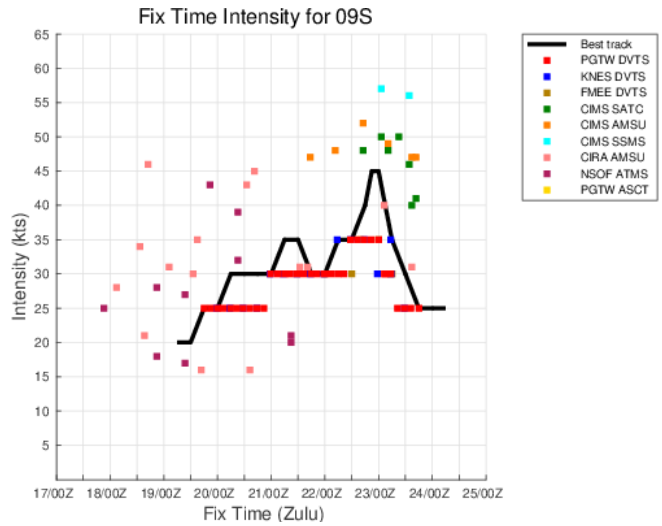
ISSUED LOW:	12 Jan / 2100Z
ISSUED MED:	14 Jan / 0600Z
FIRST TCFA:	15 Jan / 2100Z
FIRST WARNING:	16 Jan / 1800Z
LAST WARNING:	19 Jan / 0600Z
MAX INTENSITY:	85
WARNINGS:	11

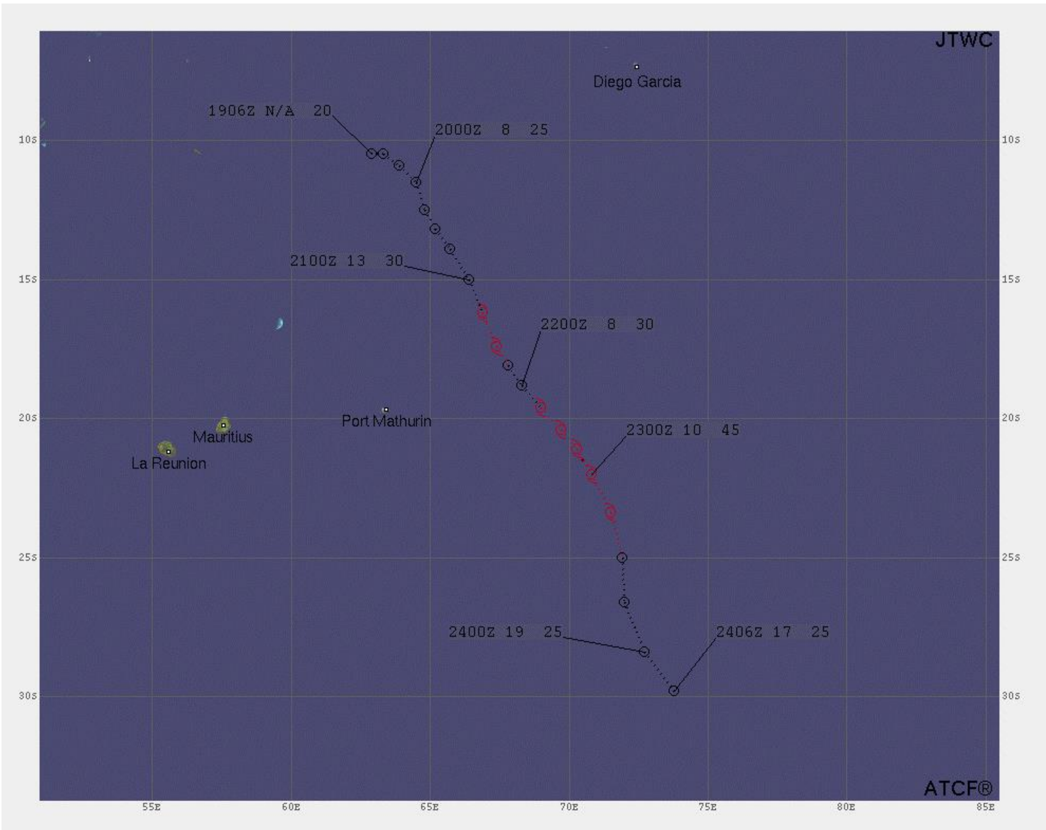




09S TROPICAL CYCLONE NINE

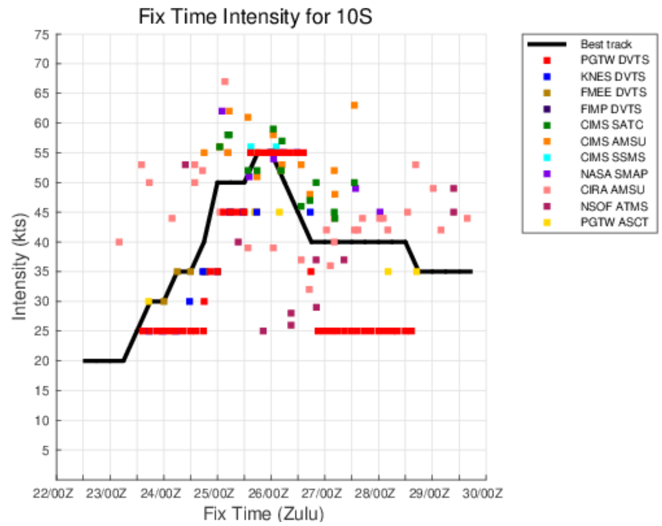
ISSUED LOW:	18 Jan / 1800Z
ISSUED MED:	19 Jan / 1330Z
FIRST TCFA:	20 Jan / 0900Z
FIRST WARNING:	22 Jan / 1200Z
LAST WARNING:	23 Jan / 1200Z
MAX INTENSITY:	45
WARNINGS:	3

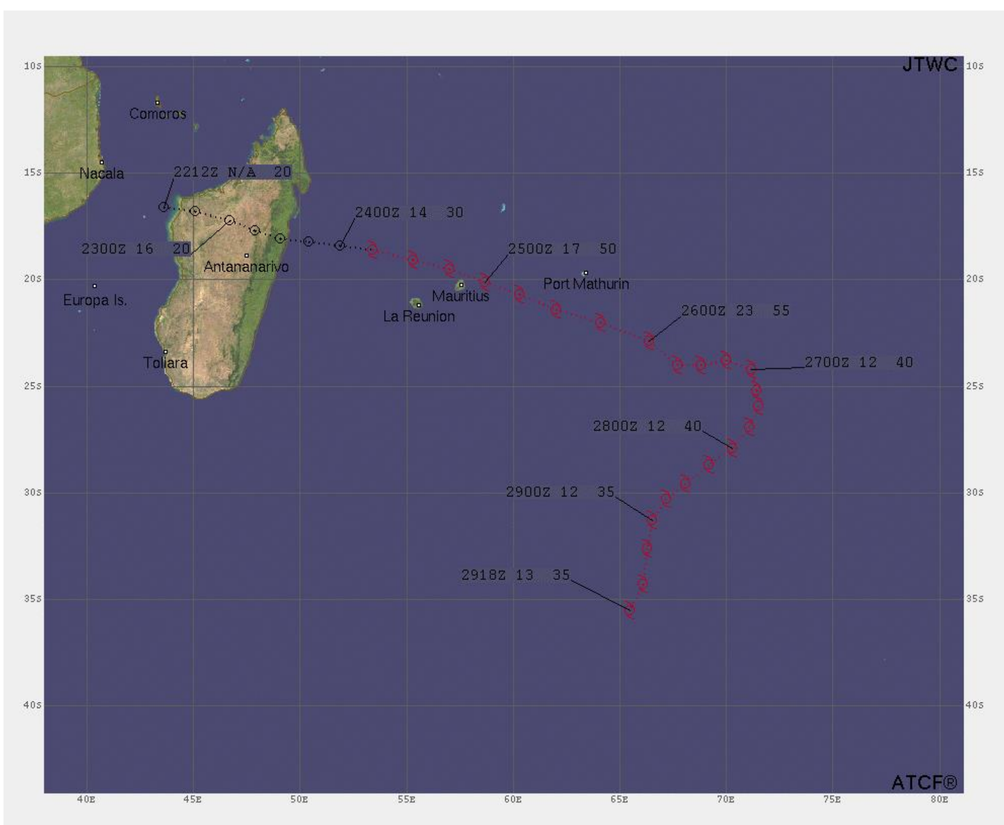




10S TROPICAL CYCLONE DIANE

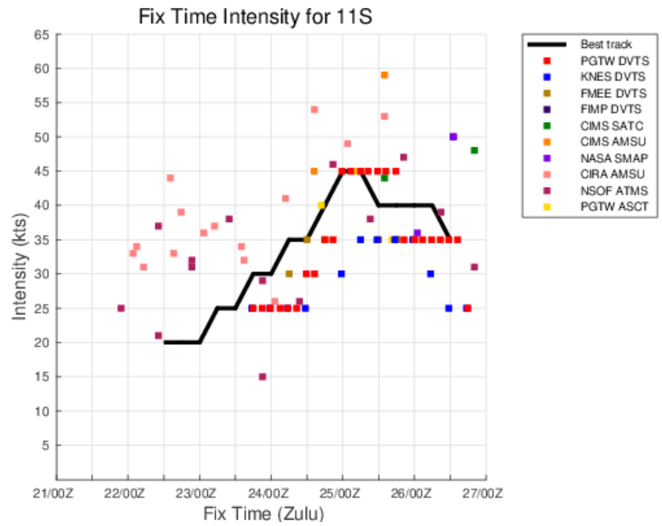
ISSUED LOW:	21 Jan / 1800Z
ISSUED MED:	N/A
FIRST TCFA:	23 Jan / 2100Z
FIRST WARNING:	24 Jan / 1800Z
LAST WARNING:	26 Jan / 1800Z
MAX INTENSITY:	55
WARNINGS:	5

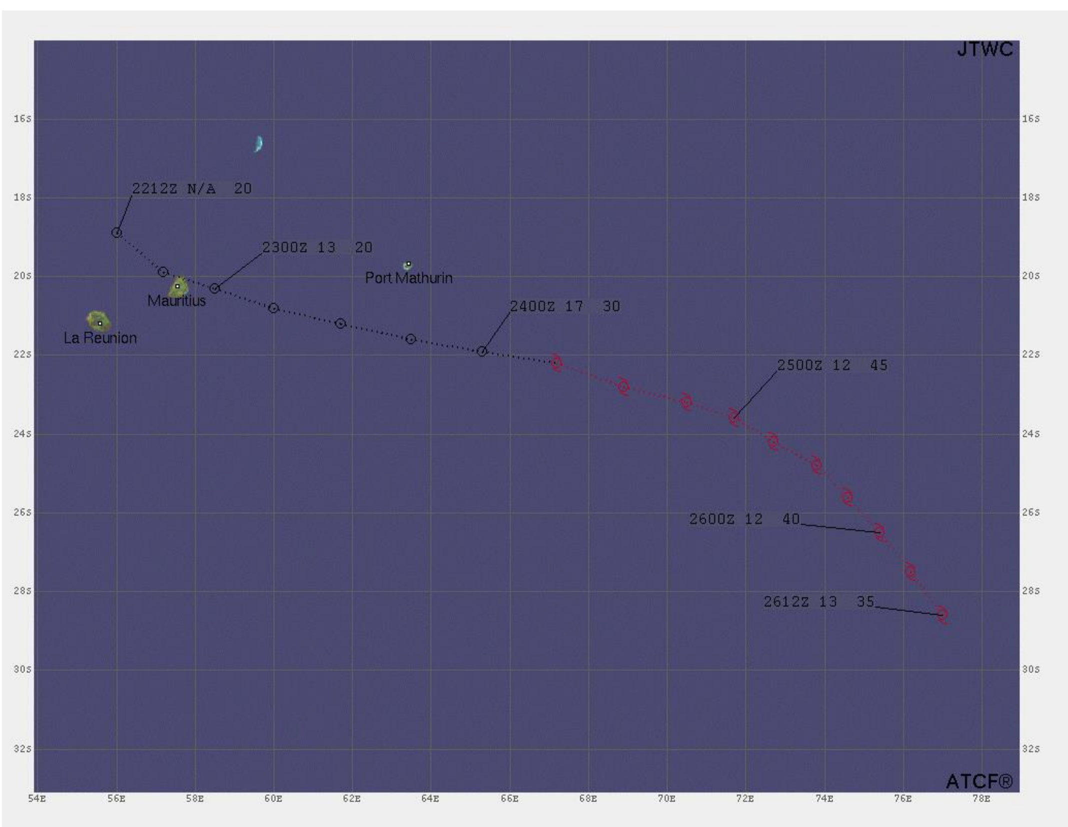




11S TROPICAL CYCLONE ESAMI

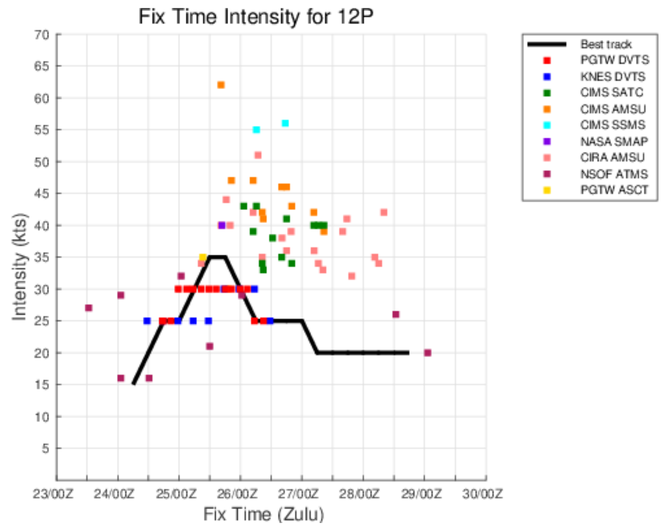
ISSUED LOW:	22 Jan / 0930Z
ISSUED MED:	23 Jan / 1800Z
FIRST TCFA:	N/A
FIRST WARNING:	24 Jan / 1800Z
LAST WARNING:	26 Jan / 1800Z
MAX INTENSITY:	45
WARNINGS:	5

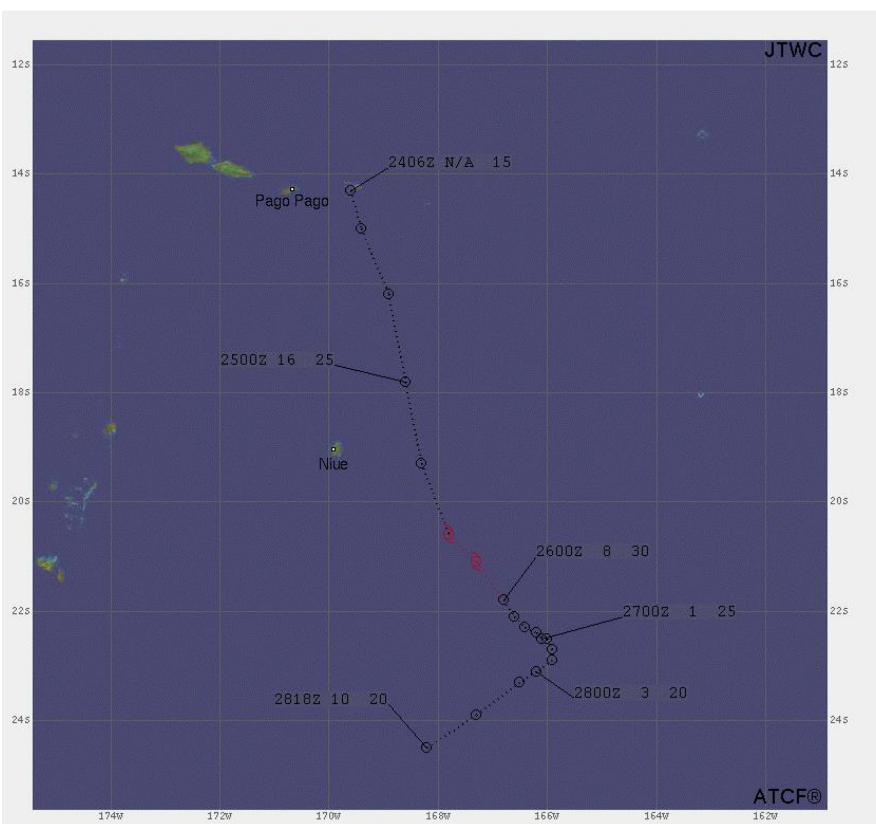




12P TROPICAL CYCLONE TWELVE

ISSUED LOW:	23 Jan / 2000Z
ISSUED MED:	24 Jan / 1800Z
FIRST TCFA:	24 Jan / 2200Z
FIRST WARNING:	25 Jan / 1200Z
LAST WARNING:	26 Jan / 1200Z
MAX INTENSITY:	35
WARNINGS:	5





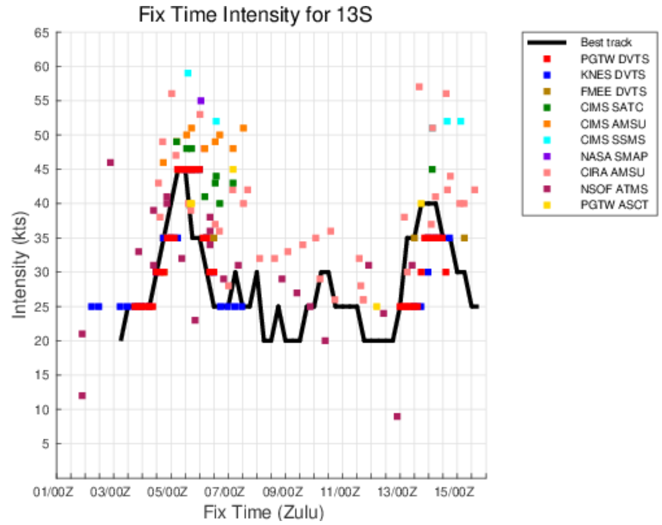
13S TROPICAL CYCLONE FRANCISCO

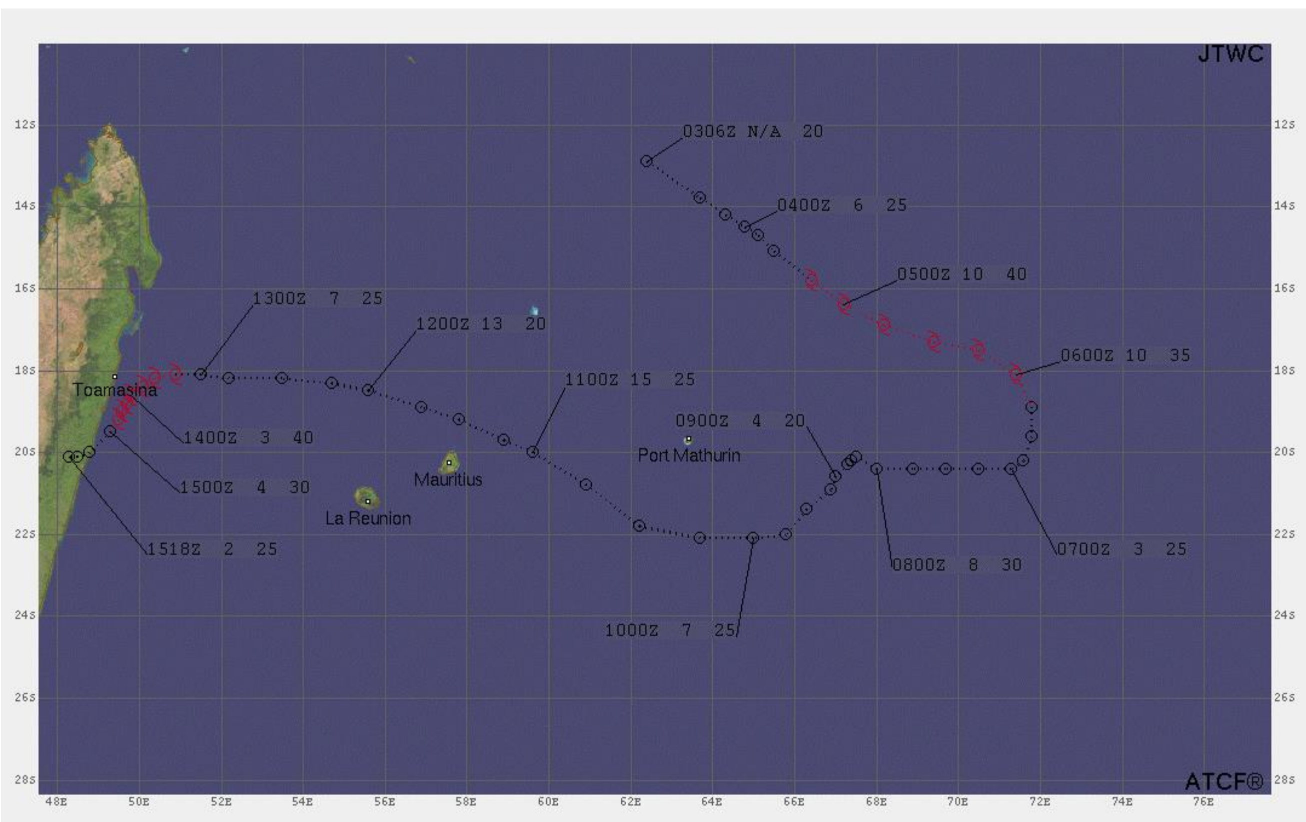
Initial warnings

ISSUED LOW:	01 Feb / 1800Z
ISSUED MED:	03 Feb / 1800Z
FIRST TCFA:	04 Feb / 1500Z
FIRST WARNING:	04 Feb / 1800Z
LAST WARNING:	06 Feb / 0600Z
MAX INTENSITY:	45
WARNINGS:	4

Rewarn

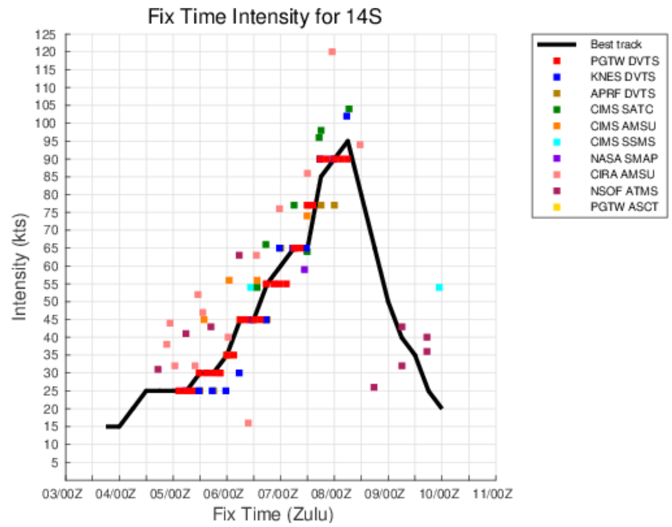
ISSUED LOW:	13 Feb / 1230Z
ISSUED MED:	N/A
FIRST TCFA:	N/A
FIRST WARNING:	13 Feb / 1800Z
LAST WARNING:	14 Feb / 1800Z
MAX INTENSITY:	N/A
WARNINGS:	3

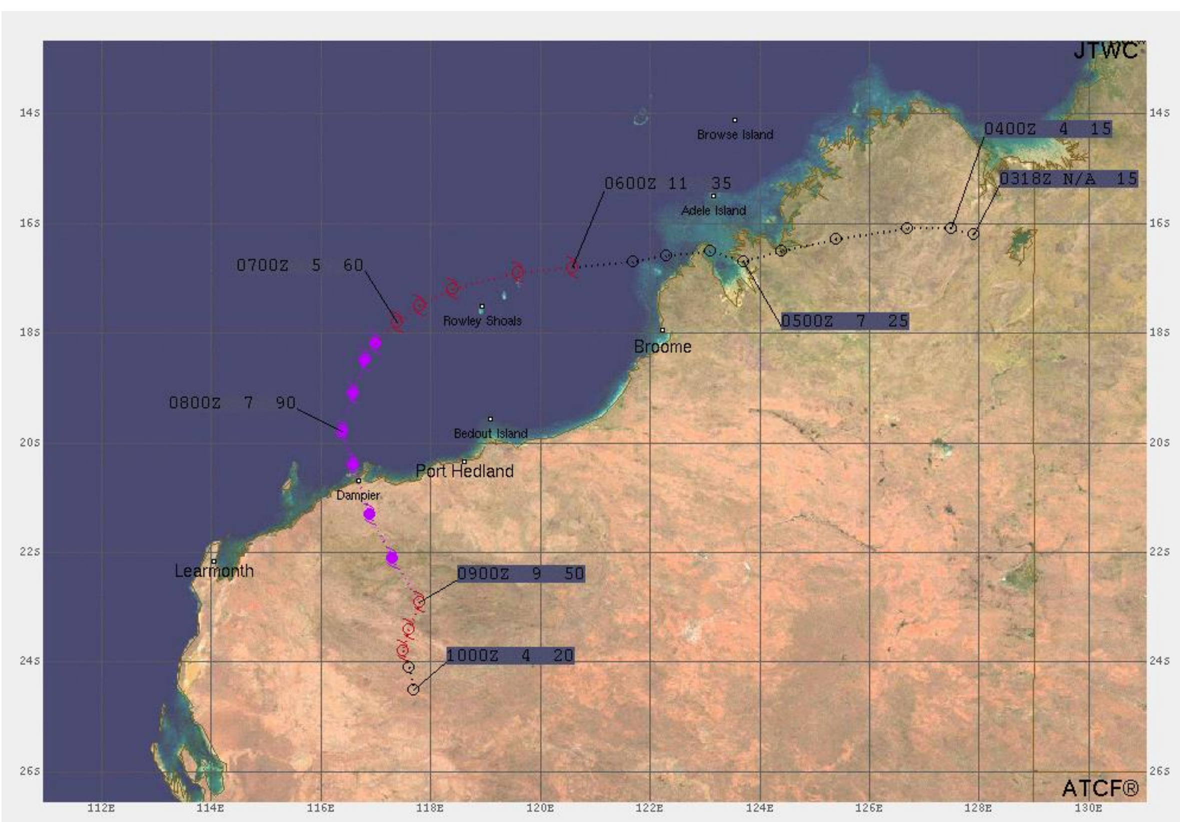




14S TROPICAL CYCLONE DAMIEN

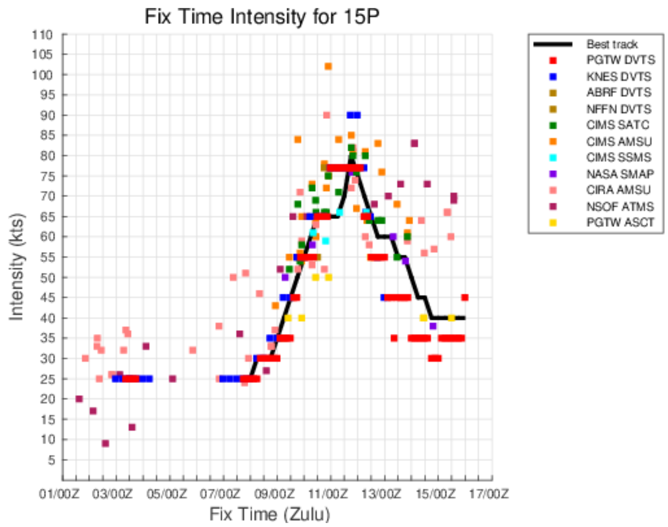
ISSUED LOW:	N/A
ISSUED MED:	04 Feb / 1530Z
FIRST TCFA:	05 Feb / 0330Z
FIRST WARNING:	06 Feb / 0000Z
LAST WARNING:	08 Feb / 1200Z
MAX INTENSITY:	95
WARNINGS:	11

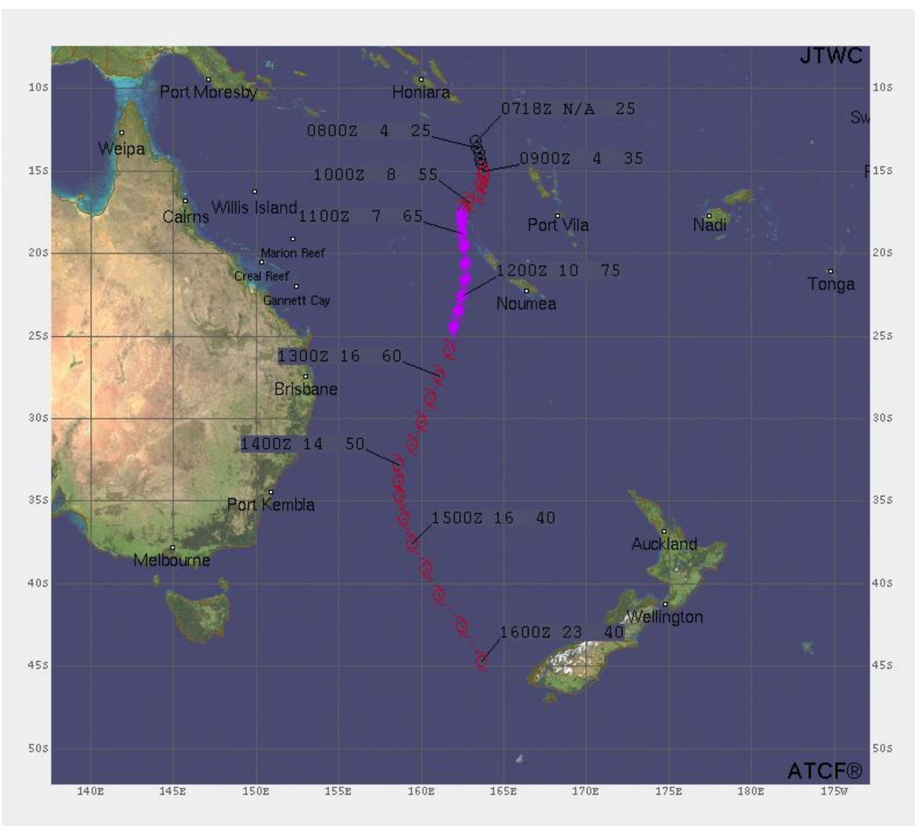




15P TROPICAL CYCLONE UESI

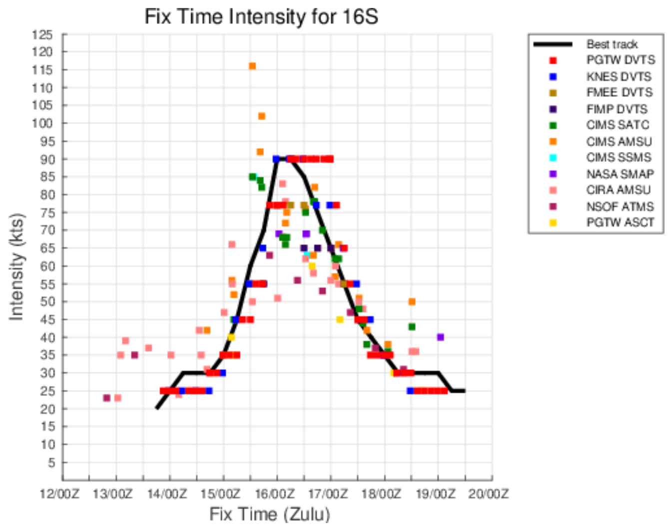
ISSUED LOW:	06 Feb / 0600z
ISSUED MED:	07 Feb / 0600Z
FIRST TCFA:	08 Feb / 0300Z
FIRST WARNING:	09 Feb / 0000Z
LAST WARNING:	13 Feb / 0000Z
MAX INTENSITY:	80
WARNINGS:	17

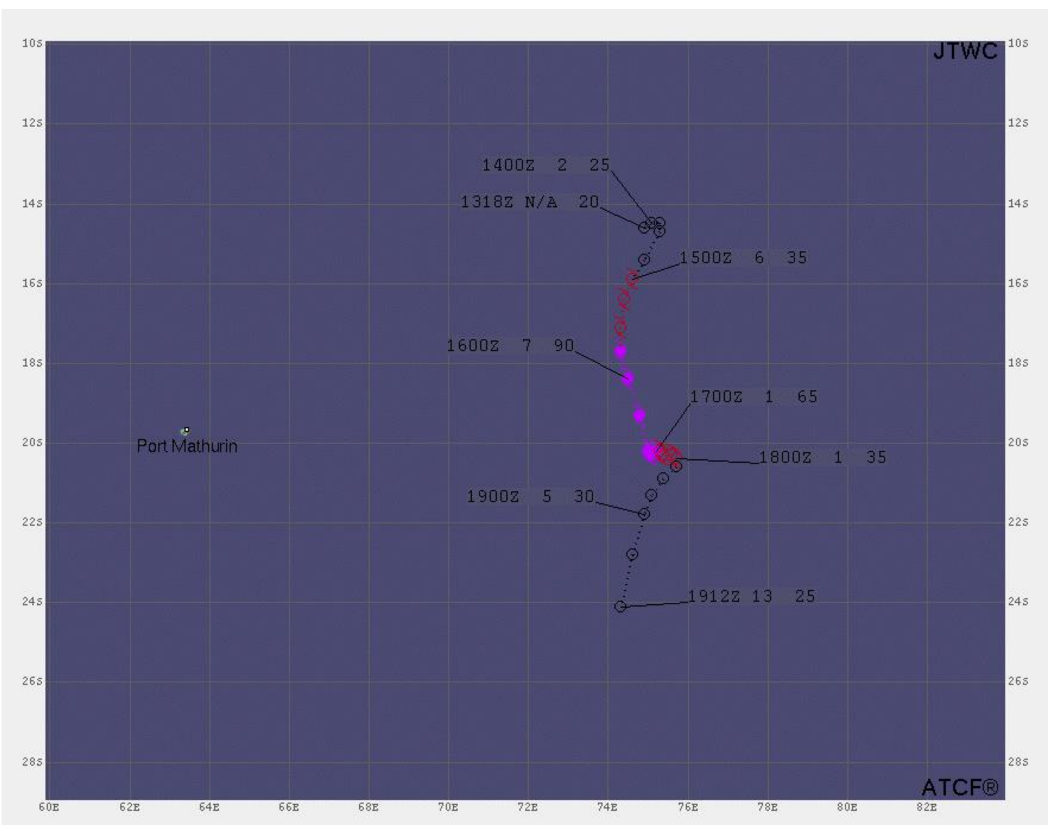




16S TROPICAL CYCLONE GABEKILE

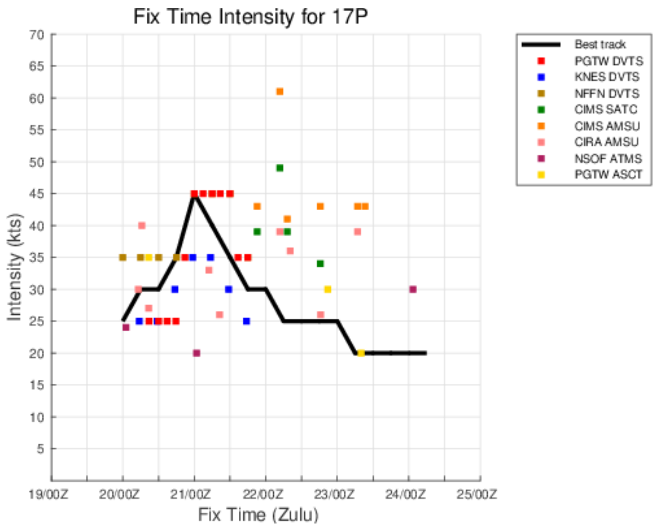
ISSUED LOW:	12 Feb / 1800Z
ISSUED MED:	13 Feb / 1230Z
FIRST TCFA:	14 Feb / 0900Z
FIRST WARNING:	15 Feb / 0000Z
LAST WARNING:	18 Feb / 1200Z
MAX INTENSITY:	90
WARNINGS:	8

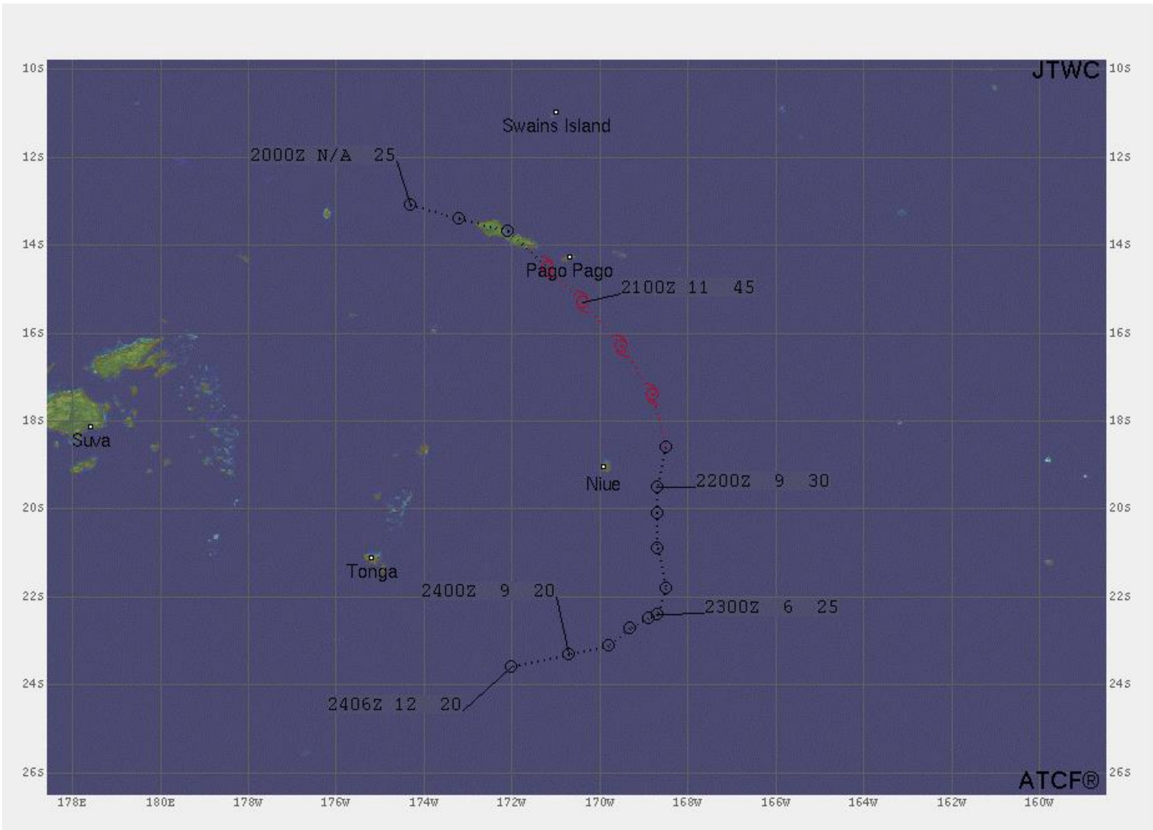




17P TROPICAL CYCLONE VICKY

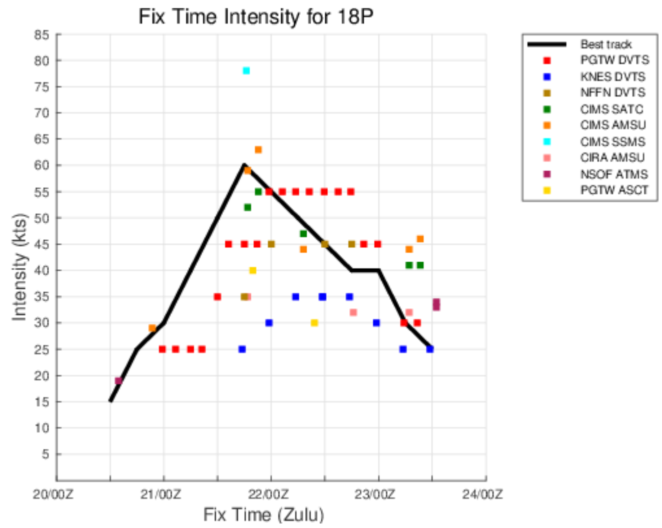
ISSUED LOW:	N/A
ISSUED MED:	N/A
FIRST TCFA:	20 Feb / 0400Z
FIRST WARNING:	20 Feb / 1800Z
LAST WARNING:	21 Feb / 1800Z
MAX INTENSITY:	45
WARNINGS:	5

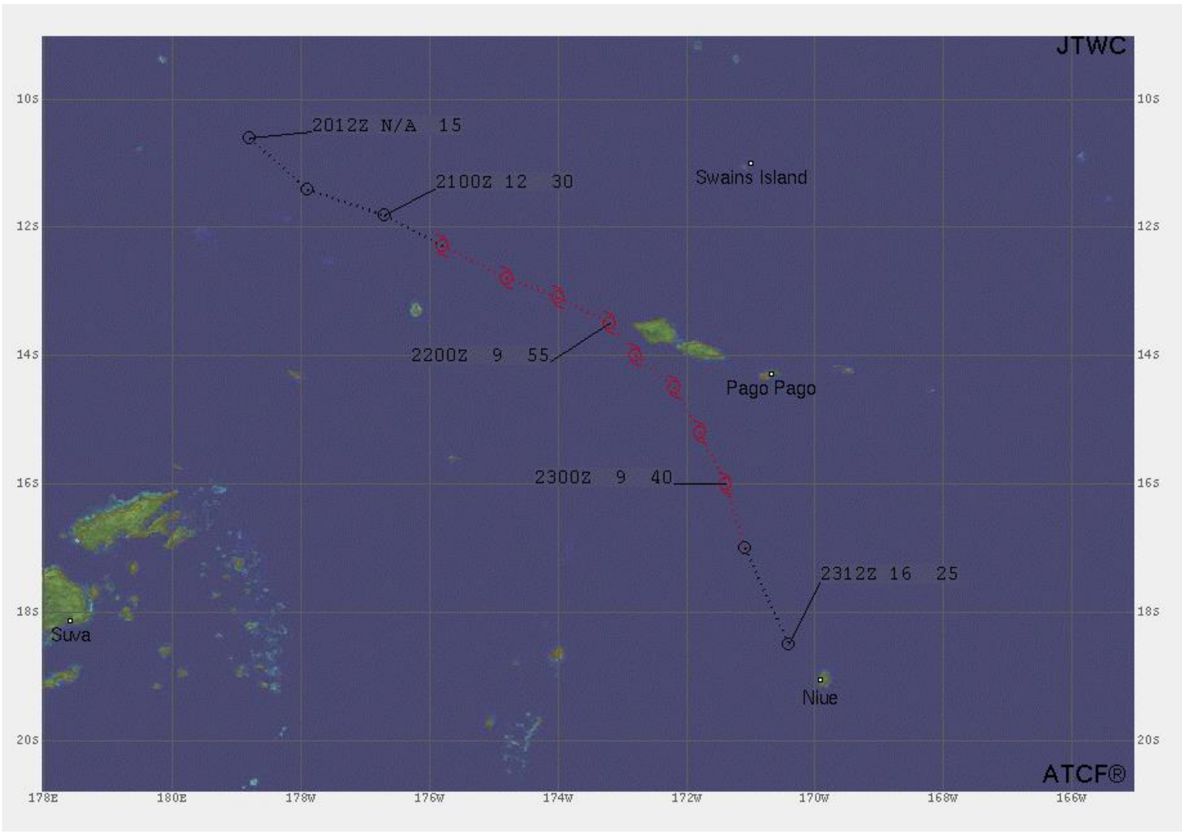




18P TROPICAL CYCLONE WASI

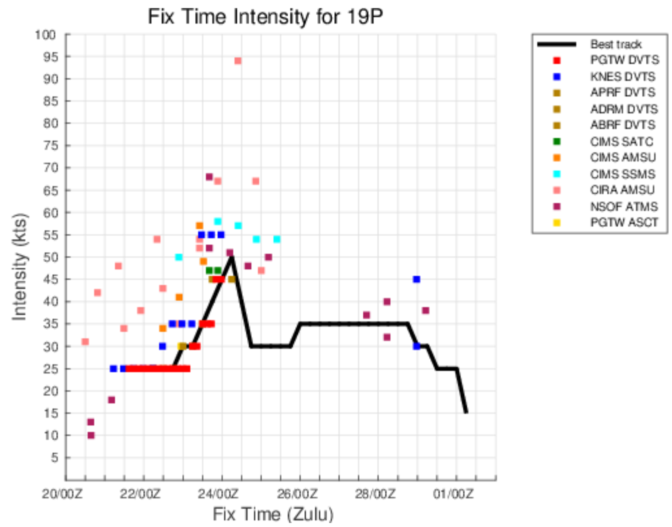
ISSUED LOW:	N/A
ISSUED MED:	20 Feb / 2100Z
FIRST TCFA:	21 Feb / 0230Z
FIRST WARNING:	21 Feb / 1200Z
LAST WARNING:	23 Feb / 1200Z
MAX INTENSITY:	60
WARNINGS:	9

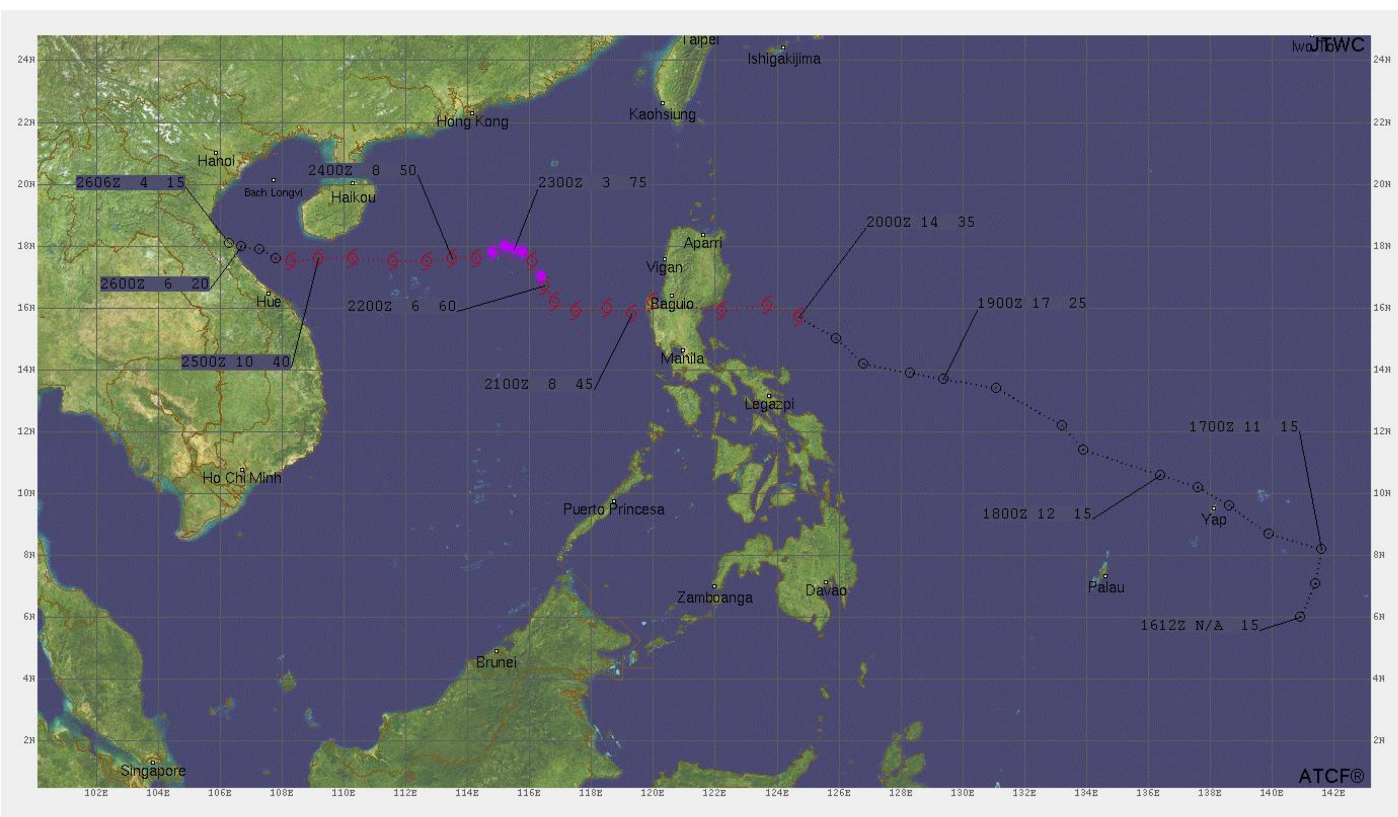




19P TROPICAL CYCLONE ESTHER

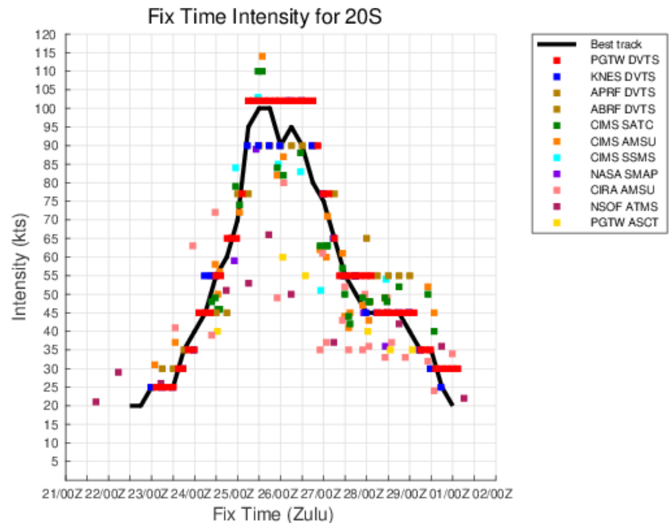
ISSUED LOW:	20 Feb / 2100Z
ISSUED MED:	21 Feb / 0600Z
FIRST TCFA:	22 Feb / 0330Z
FIRST WARNING:	23 Feb / 1200Z
LAST WARNING:	24 Feb / 0600Z
MAX INTENSITY:	50
WARNINGS:	4

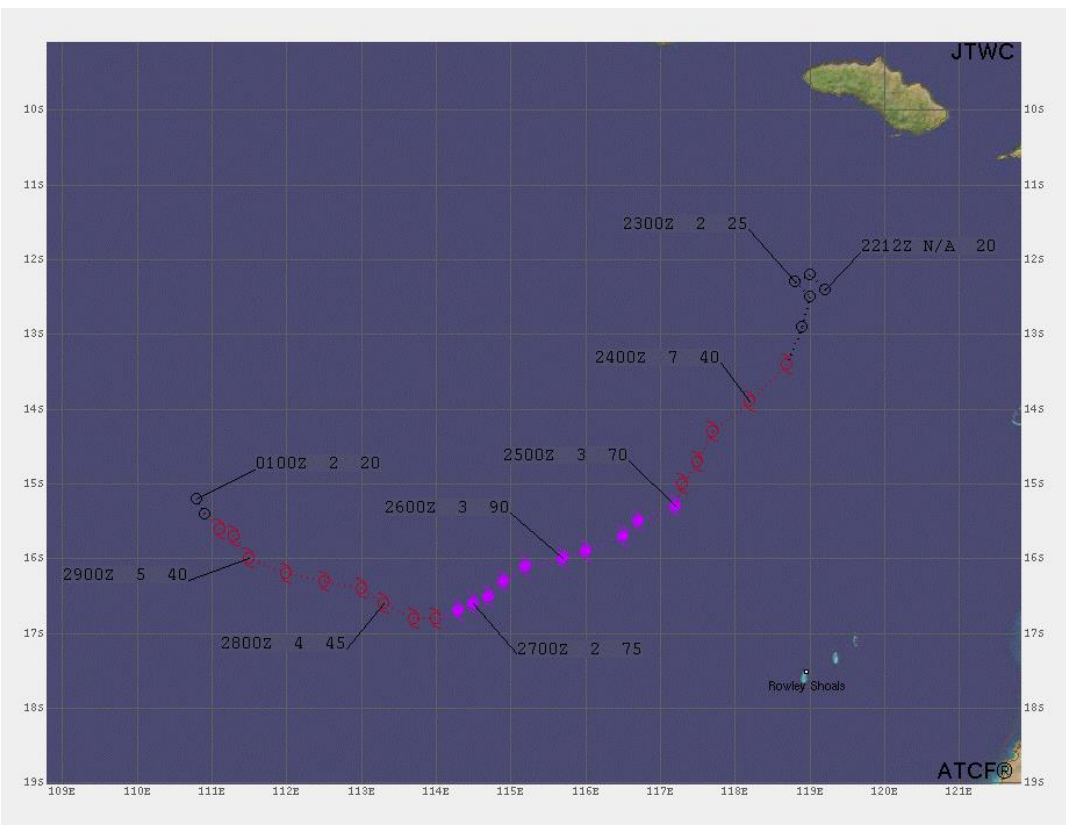




20S TROPICAL CYCLONE FERDINAND

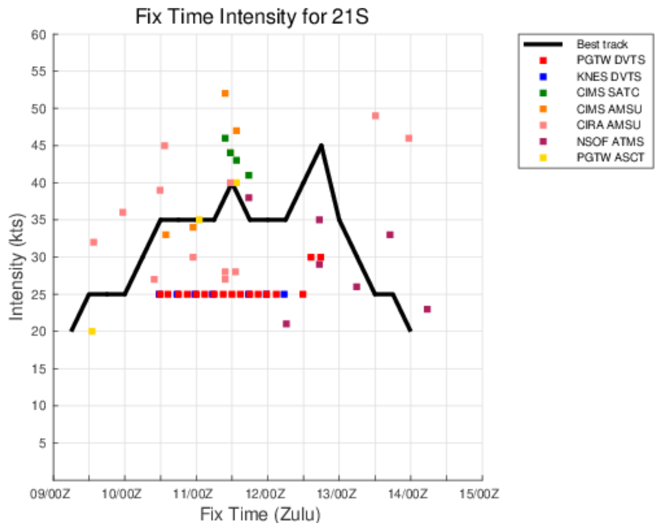
ISSUED LOW:	22 Feb / 2200Z
ISSUED MED:	23 Feb / 0530Z
FIRST TCFA:	23 Feb / 1000Z
FIRST WARNING:	23 Feb / 1800Z
LAST WARNING:	29 Feb / 0600Z
MAX INTENSITY:	100
WARNINGS:	23

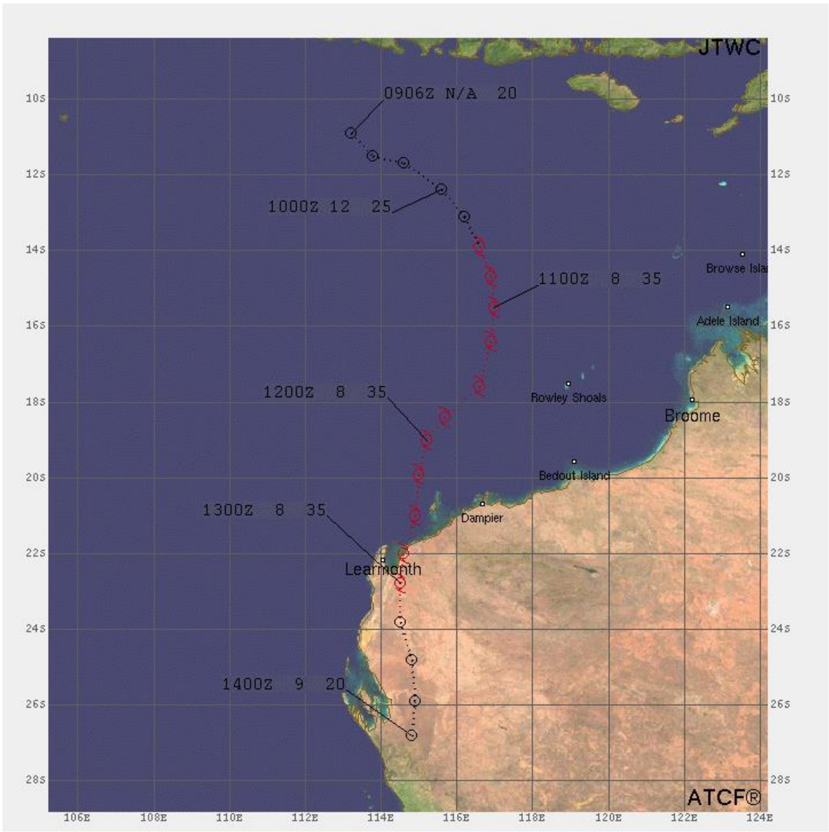




21S TROPICAL CYCLONE TWENTYONE

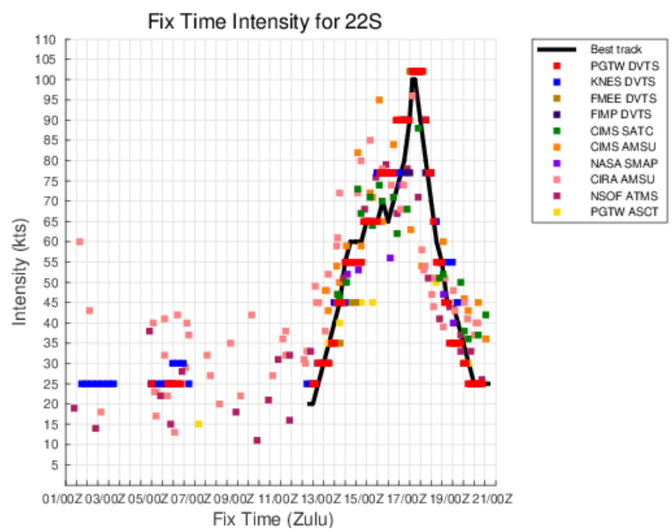
ISSUED LOW:	09 Mar / 1000Z
ISSUED MED:	09 Mar / 1800Z
FIRST TCFA:	10 Mar / 1600Z
FIRST WARNING:	11 Mar / 0600Z
LAST WARNING:	11 Mar / 1800Z
MAX INTENSITY:	45
WARNINGS:	3

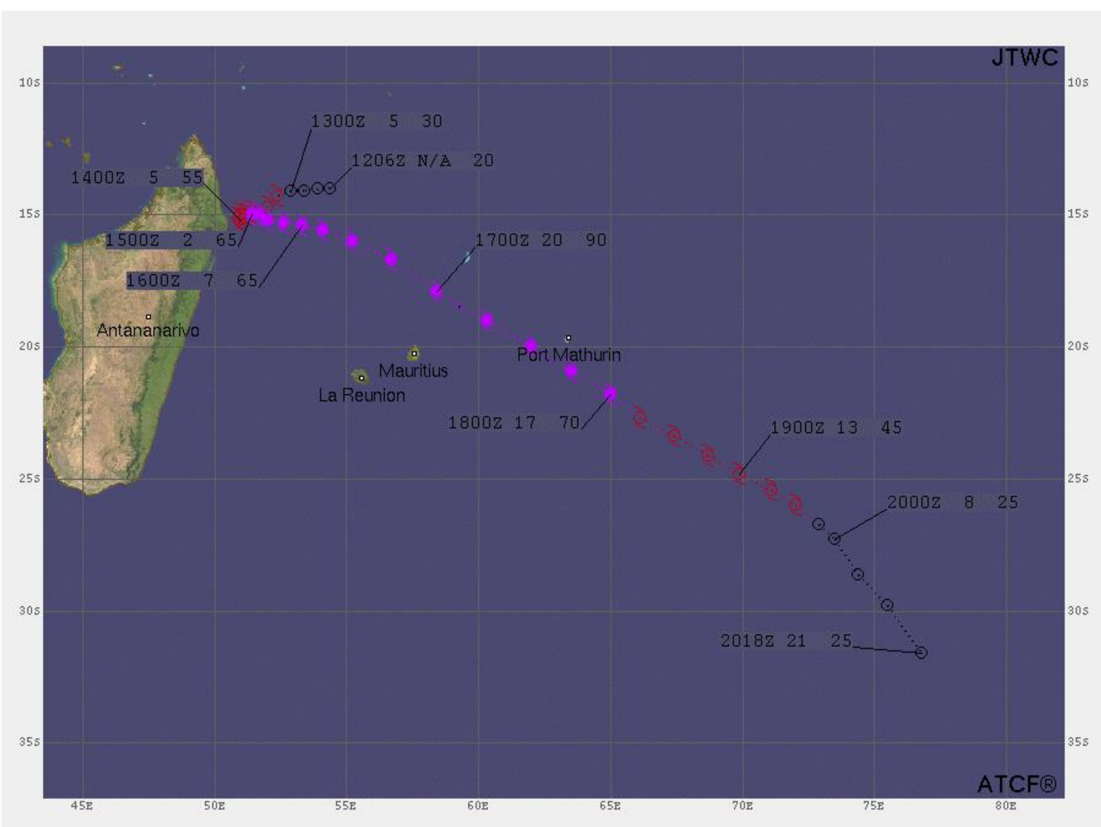




22S TROPICAL CYCLONE HAROLD

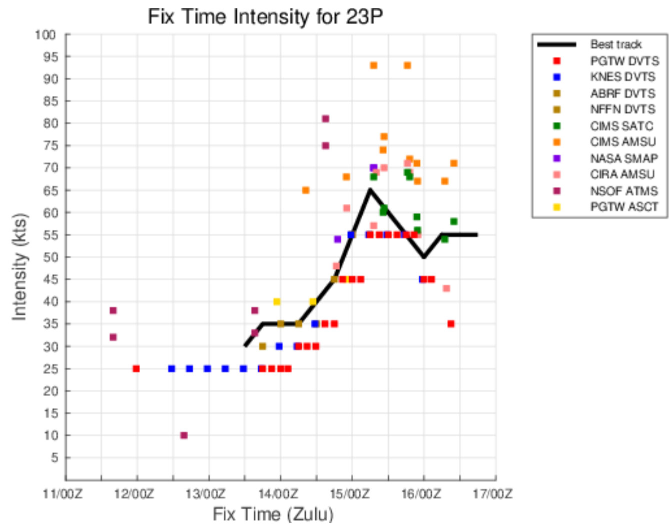
ISSUED LOW:	N/A
ISSUED MED:	12 Mar / 1200Z
FIRST TCFA:	13 Mar / 0330Z
FIRST WARNING:	13 Mar / 0600Z
LAST WARNING:	19 Mar / 1800Z
MAX INTENSITY:	100
WARNINGS:	14

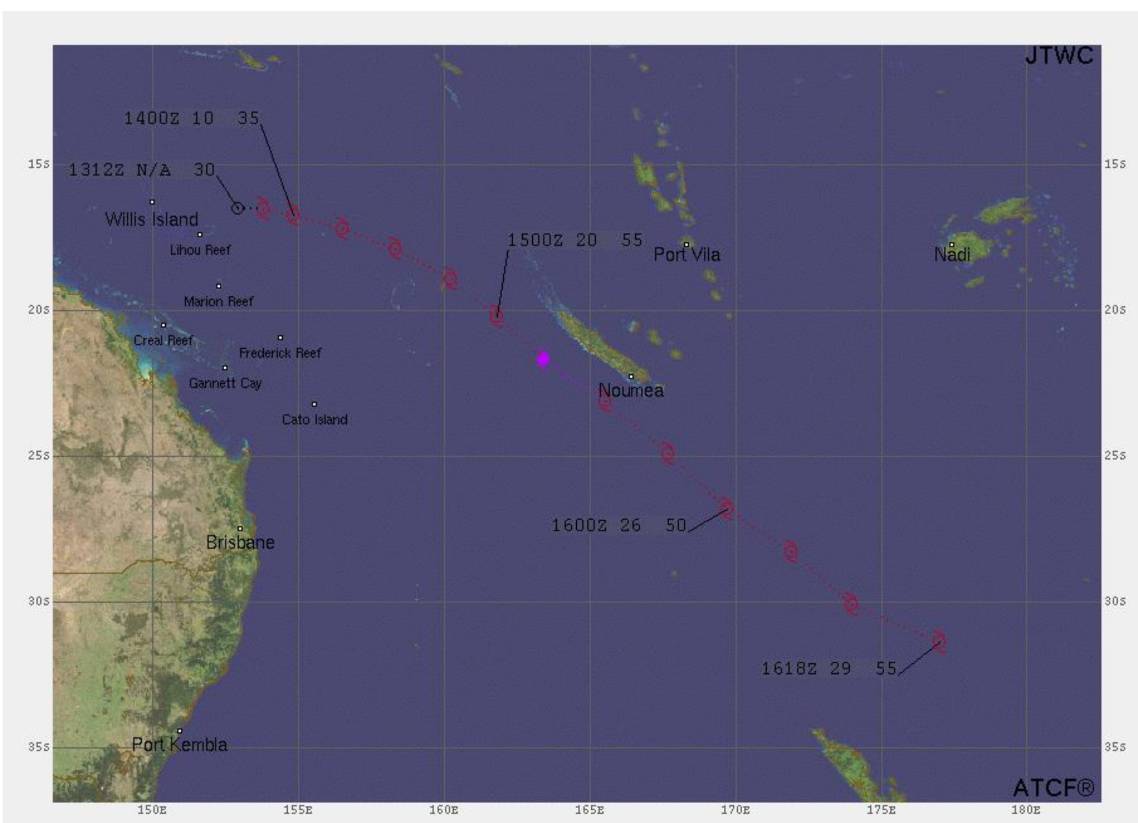




23P TROPICAL CYCLONE GRETEL

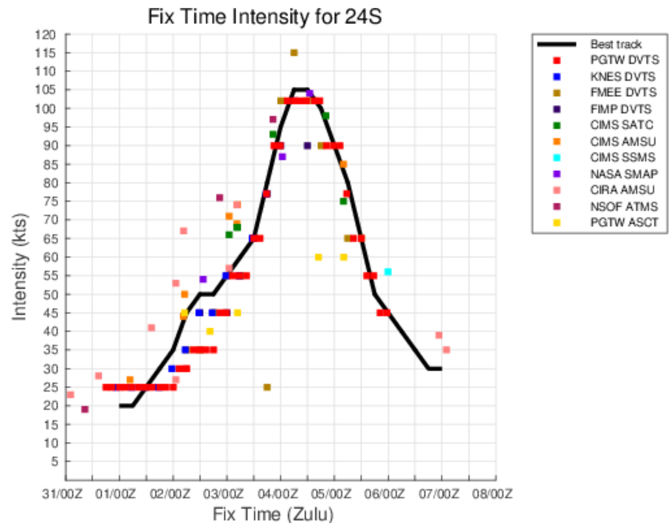
ISSUED LOW:	09 Mar / 1530Z
ISSUED MED:	11 Mar / 0600Z
FIRST TCFA:	11 Mar / 1500Z
FIRST WARNING:	14 Mar / 1800Z
LAST WARNING:	16 Mar / 0000Z
MAX INTENSITY:	65
WARNINGS:	6

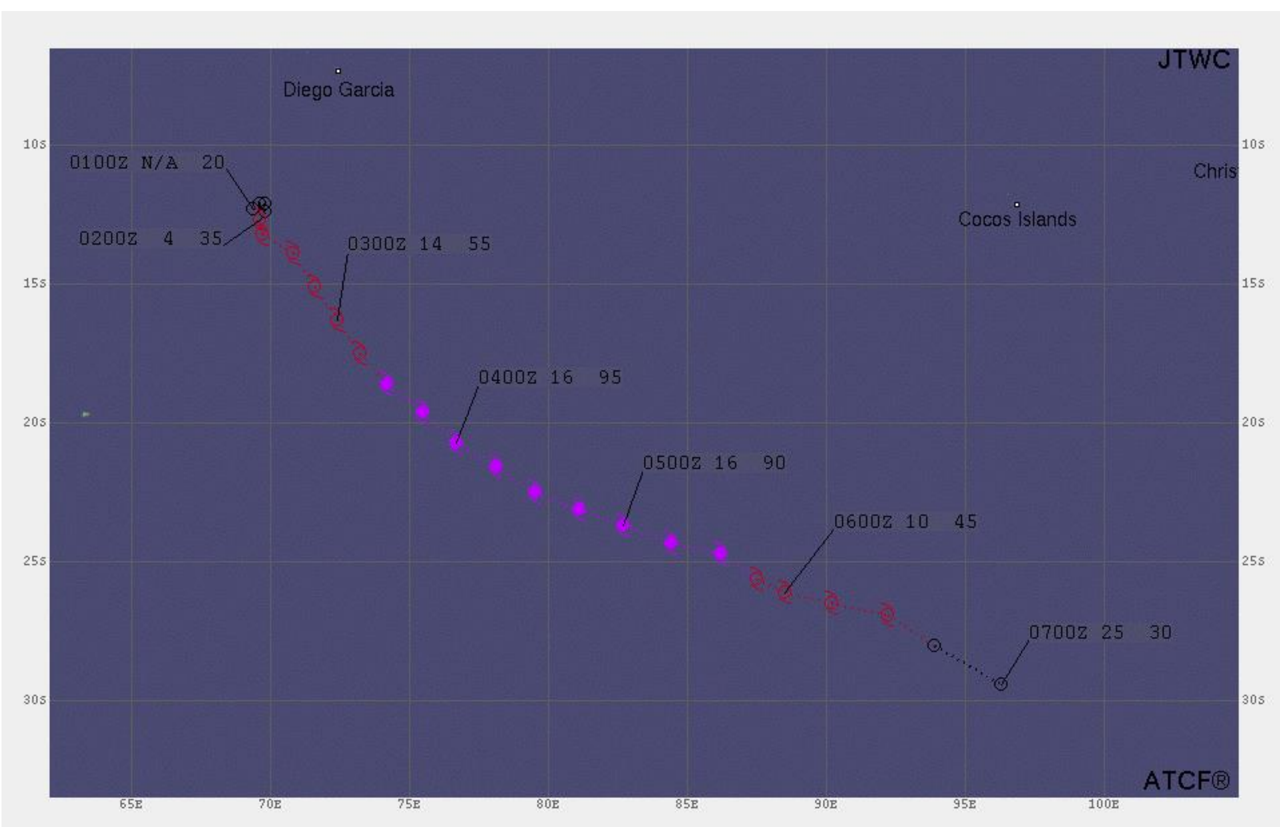




24S TROPICAL CYCLONE IRONDRO

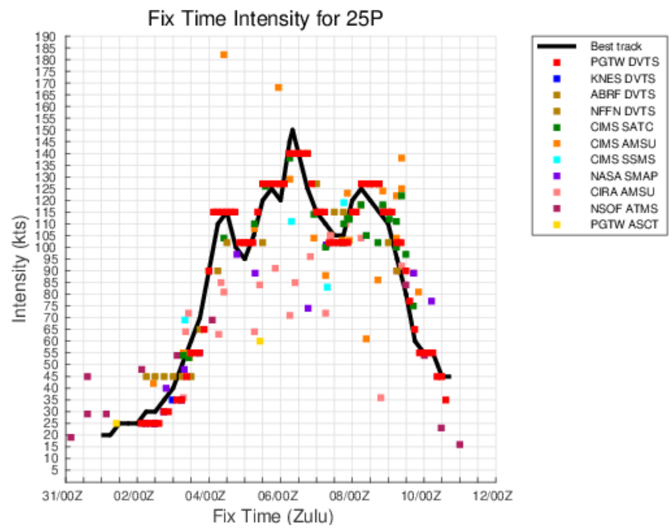
ISSUED LOW:	31 Mar / 0030Z
ISSUED MED:	31 Mar / 1200Z
FIRST TCFA:	01 Apr / 0300Z
FIRST WARNING:	02 Apr / 0600Z
LAST WARNING:	06 Apr / 0600Z
MAX INTENSITY:	105
WARNINGS:	9

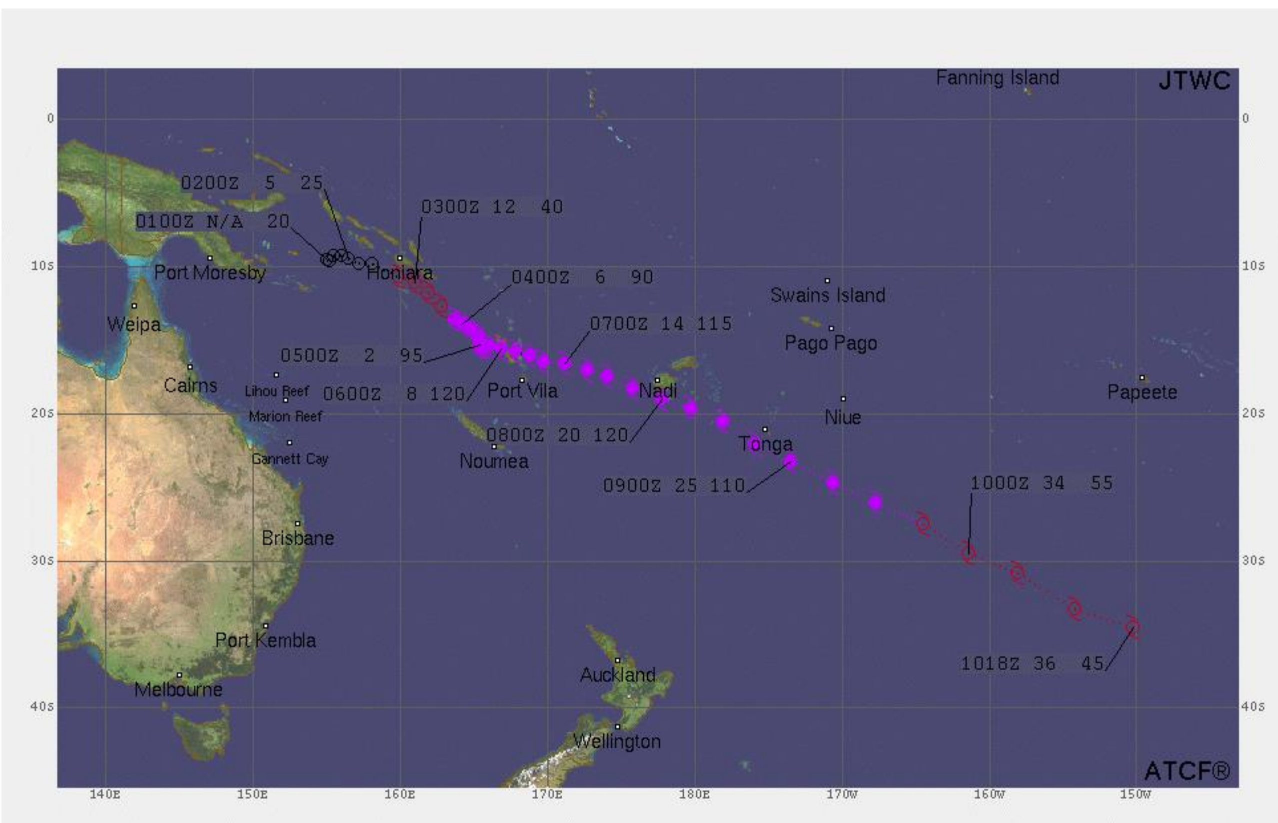




25P TROPICAL CYCLONE HAROLD

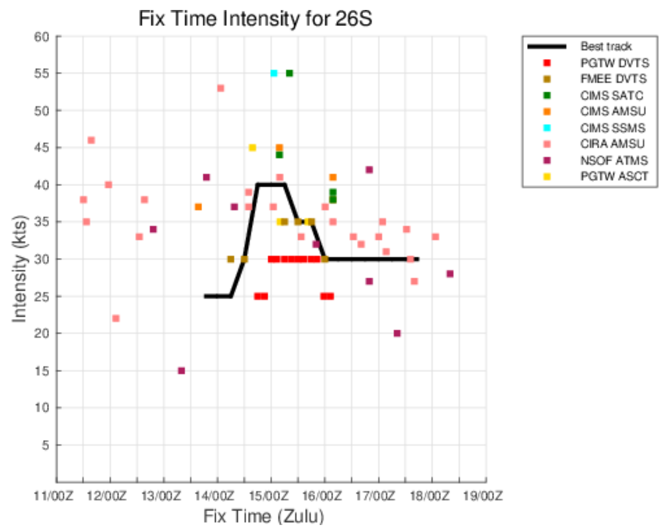
ISSUED LOW:	31 Mar / 0000Z
ISSUED MED:	01 Apr / 0100Z
FIRST TCFA:	02 Apr / 0600Z
FIRST WARNING:	02 Apr / 1800Z
LAST WARNING:	09 Apr / 1200Z
MAX INTENSITY:	150
WARNINGS:	28

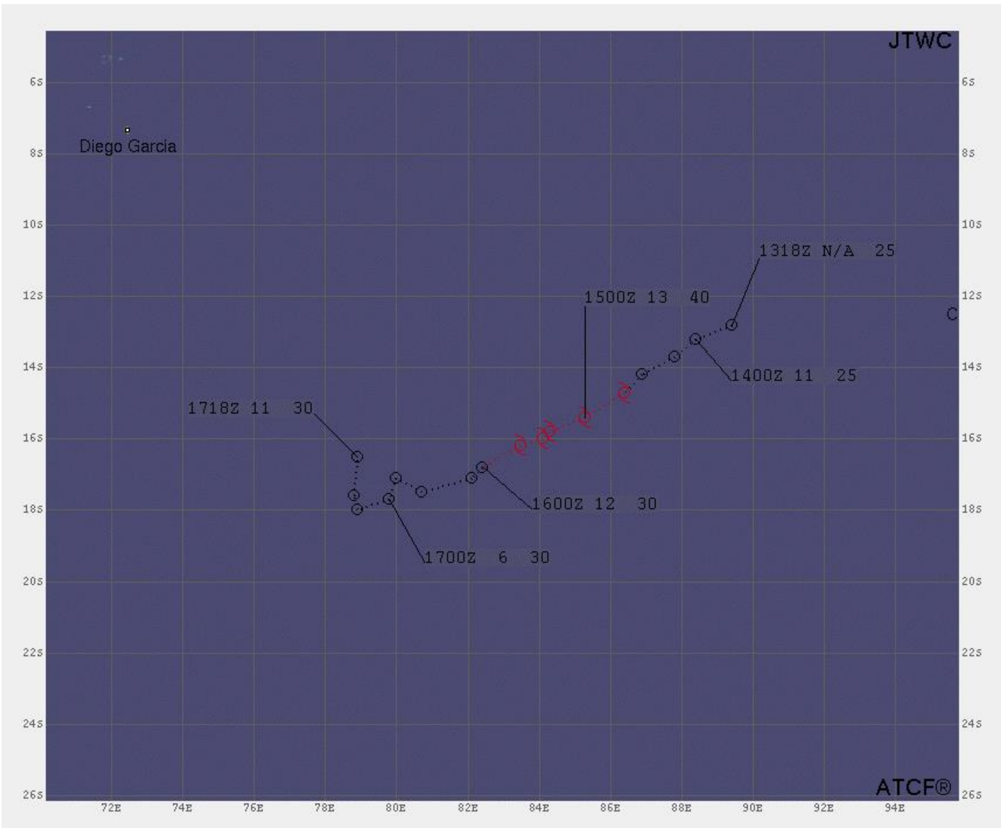




26S TROPICAL CYCLONE JERUTO

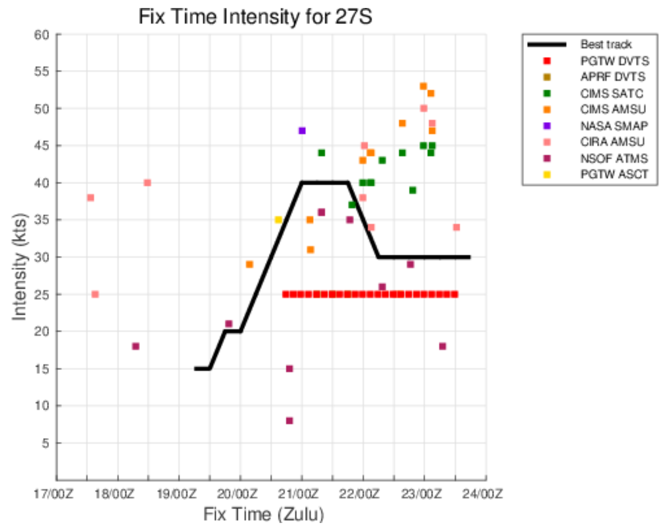
ISSUED LOW:	12 Apr / 1100Z
ISSUED MED:	14 Apr / 0130Z
FIRST TCFA:	14 Apr / 1500Z
FIRST WARNING:	14 Apr / 1800Z
LAST WARNING:	15 Apr / 1800Z
MAX INTENSITY:	40
WARNINGS:	3

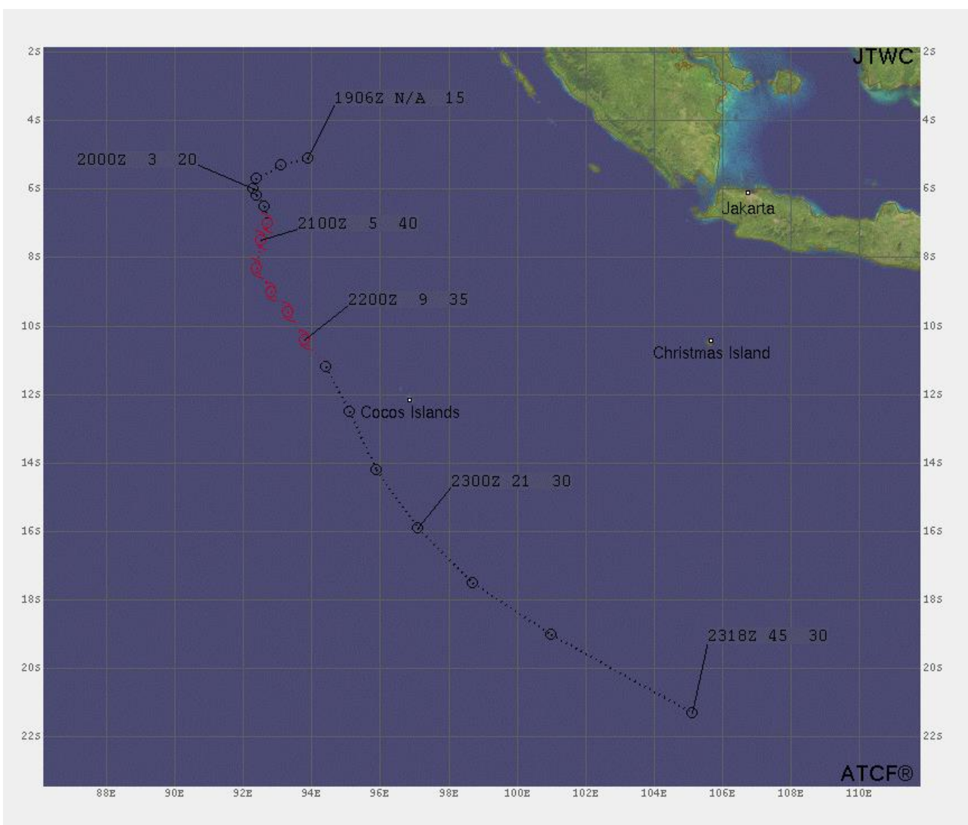




27S TROPICAL CYCLONE MANGGA

ISSUED LOW:	17 May / 1800Z
ISSUED MED:	19 May / 1800Z
FIRST TCFA:	20 May / 0300Z
FIRST WARNING:	21 May / 0000Z
LAST WARNING:	23 May / 1800Z
MAX INTENSITY:	40
WARNINGS:	12





Chapter 4 Tropical Cyclone Fix Data

Section 1 Background

Meteorological satellite data continued to be the mainstay for the TC reconnaissance mission at JTWC. JTWC satellite analysts produced 6,807 position and intensity estimates. A total of 3,596 of those 6,807 fixes were made using microwave imagery, amounting to almost 53 percent of the total number of fixes. A total of 923 of those 6,807 fixes were scatterometry fixes amounting to almost 14 percent of the total number of fixes.

The USAF primary weather satellite direct readout system, Mark IVB, and the USN FMQ-17 continued to be invaluable tools in the TC reconnaissance mission. The USN FMQ-26 was installed during the later portion of 2020 and will be put into operational use during the 2021 Tropical Cyclone Season.

Section 2 Fix Summary by Basin

Section 2 tables depict fixes produced by JTWC satellite analysts, stratified by basin and storm number. Following the final numbered storm for each section is a value representing the number of fixes for invests considered as Did Not Develop (DND) areas. DNDs are areas that were fixed on but did not reach warning criteria. The total DND fixes for all basins was 545, which accounted for 8 percent of all JTWC fixes in 2020.

TABLE 4-1

WESTERN NORTH PACIFIC OCEAN FIX SUMMARY FOR 2020

Tropical Cyclone	Name	Visible/Infrared	Microwave/Scatterometry	Total
01W	VONGFONG	94	60	154
02W	NURI	43	29	72
03W	HAGUPIT	41	51	92
04W	SINLAKU	20	18	38
05W	JANGMI	30	68	98
06W	SIX	28	52	80
07W	MEKKHALA	20	43	63
08W	HIGOS	25	27	52
09W	BAVI	53	71	124
10W	MAYSAK	65	159	224
11W	HAISHEN	62	134	196
12W	TWELVE	15	26	41
13W	NOUL	31	28	59
14W	DOLPHIN	47	67	114
16W	CHAN-HOM	77	95	172
17W	LINFA	20	24	44
18W	NANGKA	29	37	66
19W	SAUDEL	68	99	167
20W	TWENTY	23	18	41
21W	MOLAVE	53	67	120
22W	GONI	86	108	194
23W	ATSANI	75	111	186
24W	ETAU	23	17	40
25W	VAMCO	58	86	144
26W	KROVANH	42	27	69
DND	-	102	30	132
Totals	-	**1230**	**1552**	**2782**
Percentage of Total	-	**44.21%**	**55.79%**	

TABLE 4-2

NORTH INDIAN OCEAN (BAY OF BENGAL/ARABIAN SEA) FIX SUMMARY FOR 2020

Tropical Cyclone	Name	Visible/Infrared	Microwave/Scatterometry	Total
01B	AMPHAN	49	86	135
02A	NISARGA	31	35	66
03A	GATI	37	26	63
04B	NIVAR	43	52	95
05B	BUREVI	45	24	69
DND	-	108	30	138
Totals	-	**313**	**253**	**566**
Percentage of Total	-	**55.30%**	**44.70%**	

TABLE 4-3 SOUTH PACIFIC & SOUTH INDIAN OCEAN FIX SUMMARY FOR 2020				
Tropical Cyclone	**Name**	**Visible/Infrared**	**Microwave/Scatterometry**	**Total**
01P	RITA	46	45	91
02S	BELNA	64	78	142
03S	AMBALI	42	63	105
04P	SARAI	55	62	117
05S	CALVINIA	95	67	162
06S	BLAKE	42	32	74
07S	CLAUDIA	99	82	181
08P	TINO	36	43	79
09S	NINE	36	33	69
10S	DIANE	59	74	133
11S	ESAMI	27	44	71
12P	TWELVE	32	25	57
13S	FRANCISCO	89	121	210
14S	DAMIEN	43	38	81
15P	UESI	85	115	200
16S	GABEKILE	45	63	108
17P	VICKY	29	22	51
18P	WASI	21	29	50
19P	ESTHER	75	55	130
20S	FERDINAND	60	97	157
21S	TWENTYONE	37	42	79
22S	HEROLD	95	122	217
23P	GRETEL	39	32	71
24S	IRONDRO	54	72	126
25P	HAROLD	78	118	196
26S	JERUTO	16	35	51
27S	MANGGA	29	19	48
DND	-	150	78	228
Totals	**-**	**1578**	**1706**	**3284**
Percentage of Total	**-**	**48.05%**	**51.95%**	

TABLE 4-4 CENTRAL PACIFIC OCEAN FIX SUMMARY FOR 2020				
Tropical Cyclone	**Name**	**Visible/Infrared**	**Microwave/Scatterometry**	**Total**
DND	-	30	17	47
Totals	**-**	**30**	**17**	**47**
Percentage of Total	**-**	**63.83%**	**36.17%**	

TABLE 4-5 EASTERN PACIFIC OCEAN FIX SUMMARY FOR 2020				
Tropical Cyclone	**Name**	**Visible/Infrared**	**Microwave/Scatterometry**	**Total**
03E	BORIS	10	8	18
08E	DOUGLAS	50	60	110
DND	-	0	0	0
Totals	**-**	**60**	**68**	**128**
Percentage of Total	**-**	**46.88%**	**53.13%**	

Chapter 5 Technical Development Summary

Section 1 Operational Priorities

The top operational priority of the Joint Typhoon Warning Center remains sustained development and support of the Automated Tropical Cyclone Forecast System (ATCF; Sampson and Schrader 2000). ATCF is the DoD's primary software for analyzing and forecasting TCs, and the principal platform through which emerging research transitions into JTWC operations. JTWC cannot generate TC formation alerts or warnings without the capabilities provided by ATCF. The system tracks all invest areas (developing disturbances) and TC activity, automatically processes objective forecasting aids, produces TC formation alerts, warning text and graphical products and provides core capabilities for analyzing TCs and their environment. Additionally, ATCF offers JTWC Contingency of Operations Plan (COOP) backup capabilities to Fleet Weather Center (FWC)-Norfolk and analytic support to FWC-San Diego for tasks such as setting Tropical Cyclone Conditions of Readiness (TCCOR), forecasting on-station wind speed, designating Optimum Track Ship Routing (OTSR) “MODSTORM” locations, and preparing diverts and advisories.

JTWC has also prioritized operationalizing the National Weather Service (NWS) Advanced Weather Interactive Processing System (AWIPS-II) to facilitate visualization and fusion of meteorological data. The 2021 ATCR will provide an overview of the system's operational implementation. While AWIPS-II capabilities are promising, replicating the functionality, cost-effectiveness, and long-term research to operations (R2O) efficiency of ATCF remains a significant challenge. JTWC continues to participate in discussions with the National Weather Service, which is working to develop an ATCF-like capability within the AWIPS-II framework.

Section 2 Research and Development Priorities

The top five JTWC requirements for research and development (R&D), reviewed and updated in February 2020, are presented in Table 5-1. Data exploitation moved up to the second highest priority, reflecting JTWC's requirement to integrate rapidly-evolving satellite datasets and data processing and display capabilities into operations. TC structure specification, TC track forecast improvement, and TC genesis forecasts round out the priority list. The following section of this report highlights recent efforts by JTWC to address each of these R&D priorities.

Priority	Need
1 TC Intensity Change	***Basin-specific*** **(WESTPAC, SHEM, NIO, SIO, and SWPAC) probabilistic and deterministic** ***forecast guidance for TC intensity change*****,** ***particularly*** **the onset, duration, and magnitude of** ***rapid intensity change*** **events (including ERC, over-water weakening, etc.) at 2-3 day lead times.**
2 Data Exploitation	**Techniques, products, or sources that** ***improve*** **the utility and** ***exploitation of microwave satellite, ocean surface wind vectors, and radar data*** **for fixing (center, intensity, radii) TCs, or for diagnosing RI, ETT, ERC,** ***etc*****. (*****e.g.*****, develop a "Dvorak-like" technique using microwave imagery). Leverage machine learning methods to maximize automation, and ensure rapid integration into visualization system.**
3 TC Structure Specification	***Basin-specific*** **(WESTPAC, SHEM, NIO, SIO, and SWPAC) probabilistic and deterministic guidance for the** ***specification*** **(analysis and forecast)** ***of key TC structure variables*****,** ***including*** **the production of 34-, 50- and 64- knot wind radii and a** ***dynamic*** **(situational) confidence-based** ***swath*** **of potential 34-kt wind impacts**
4 TC Track Improvement	**Model and DA enhancements or guidance to** ***improve TC track forecast skill and*** **the** ***conveyance of probabilistic track uncertainty*****. Includes development of guidance-on-guidance to identify and reduce forecast error outliers resulting from large speed (e.g., accelerating recurvers) and directional (e.g., loops) errors, or from specific forecast problems such as upper-level trough interaction, near/over-land, elevated terrain, and extratropical transition.**
5 TC Genesis Timing and Forecast	**Guidance to** ***improve*** **the** ***forecasting of TC genesis timing*** **and the subsequent track, intensity and structure of pre-genesis tropical disturbances out to two week lead-times, that exhibits a high probability of detection and a low false alarm rate. Techniques to diagnose and predict the formation of TCs via transition of non-classical disturbances (e.g. monsoon depressions, sub-tropical, hybrids, etc).**

Table 5-1. JTWC R&D priorities.

Section 3 Technical Development Efforts

JTWC pursued multiple development efforts to support the operational forecasting mission during calendar year 2020. Workflow disruptions precipitated by the COVID-19 pandemic introduced both challenges and opportunities for the command as a whole, and for the development team in particular. Thanks to proactive support from the chain-of-command, developers maintained access to key information systems, including virtual network desktops and teleworking tools like CVR Teams. These new capabilities enabled the development team to address JTWC R&D priorities by evaluating and transitioning various tools and techniques into operations without interruption. A few highlights of these efforts follow.

1. Tropical cyclone intensity change

a. Intensity consensus (ICNW)

NRL-MRY and JTWC annually review performance and reliability of various U.S. and international agency models to optimize accuracy of the multi-model intensity forecasting consensus, ICNW. Component members of ICNW, as of June 2022, are listed in Table 5-2.

Model	ICNW Tracker	Model Type
SHIPS (NAVGEM input)	DSHN	Statistical-dynamical
SHIPS (GFS input)	DSHA	Statistical-dynamical
COAMPS-TC	CTCI / COTI	Dynamical (mesoscale)
GFS	AHNI	Dynamical (global)
HWRF	HHFI	Dynamical (mesoscale)
RI Prediction Aid	RIPA	Statistical-dynamical

Table 5-2. Primary objective aids comprising the operational JTWC tropical cyclone intensity (ICNW) consensus (current members as of June 2022).

b. COAMPS-TC ensemble

Fleet Numerical Meteorology and Oceanography Center (FNMOC) transitioned the COAMPS-TC ensemble into operations for forecasting TCs in JTWC's primary basins. JTWC collaborated closely with FNMOC to evaluate the model's TC track and intensity forecast performance, incorporate TC vortex tracker data into ATCF, and implement specialized graphic-generating software developed by the Naval Research Laboratory's COAMPS-TC team. COAMPS-TC ensemble forecast data had an immediate, positive impact on JTWC operations, particularly for intensity prediction. The COAMPS-TC ensemble provided the only probabilistic numerical model guidance for the rate of intensity change, including rapid intensification. Unlike existing statistical-dynamical rapid intensification prediction techniques, which only quantify the potential for rapid intensification starting from the analysis time, COAMPS-TC forecasts quantify the potential for rapid intensification to commence (and end) at any point within the model's five-day integration period (Figure 5-1). The COAMPS-TC ensemble and Rapid Intensification Prediction Aid (RIPA) together contributed to improve 24-48 hour forecast intensity skill.

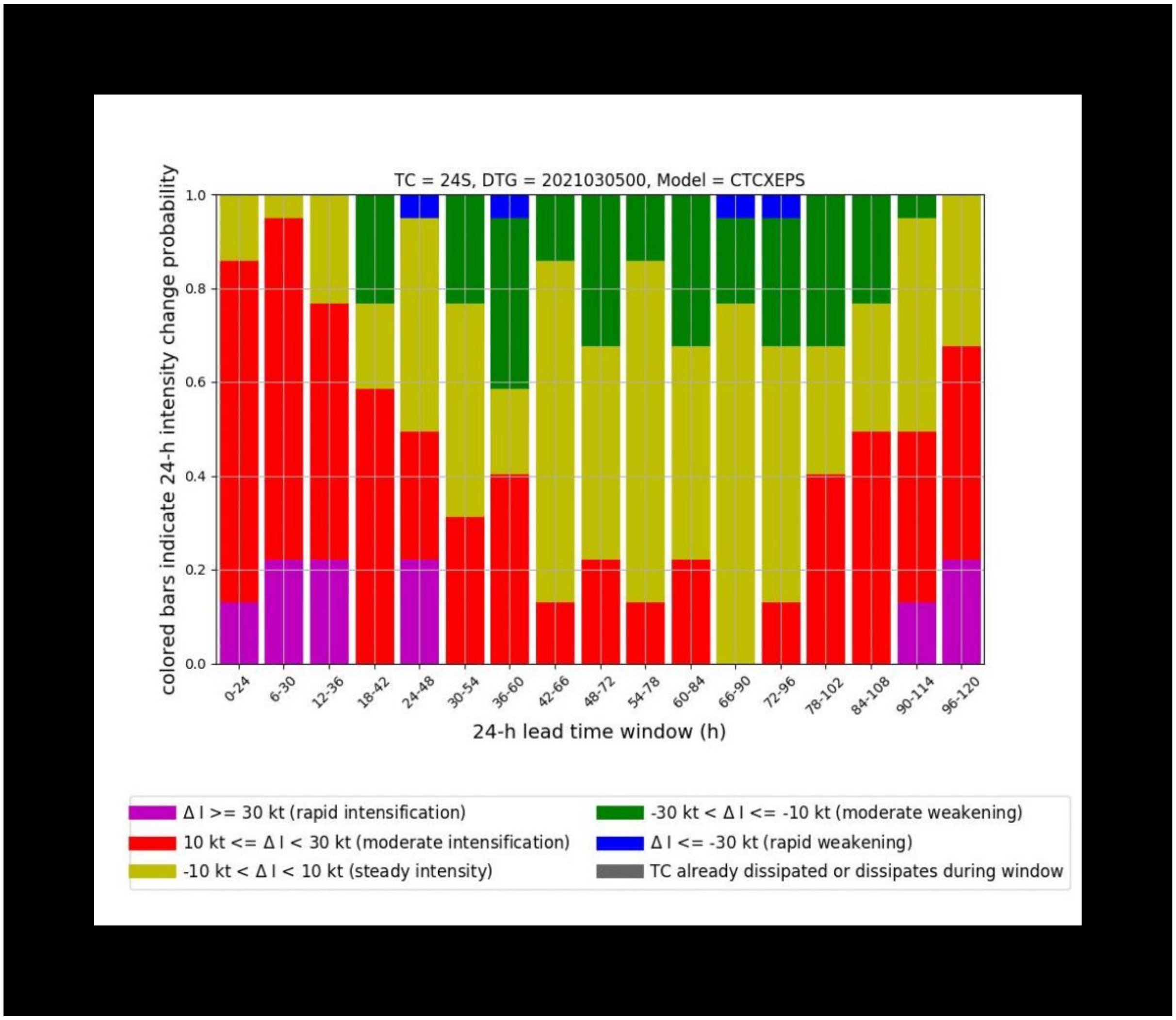


Figure 5-1. Example graphical plot of intensity change probabilities (TC 24S, 2021) derived from COAMPS-TC ensemble vortex tracker output (graphics code developed by NRL). The plot indicates elevated probabilities of rapid intensification occurring during the one-to-two-day and four-to-five-day lead times. RI verified during both of those forecast periods.

2. TC structure specification

a. Wind radii consensus (RVCN)

NRL-MRY and JTWC annually review performance and reliability of various U.S. and international agency models to optimize accuracy of the multi-model 34-, 50- and 64-knot wind radii forecasting consensus, RVCN. Component members of RVCN, as of June 2022, are listed in Table 5-3.

Model	RVCN Tracker	Model Type
GFS	AHNI	Dynamical (global)
HWRF	HHFI	Dynamical (mesoscale)
ECMWF	EHXI	Dynamical (global)
COAMPS-TC	CHCI	Dynamical (mesoscale)
SHIPS (GFS input)	DSHA	Statistical-dynamical
UKMET Office Global Model	UHMI	Dynamical (global)
DRCL	DRCL	Climatology and Persistence

Table 5-3. Primary objective aids comprising the operational JTWC tropical cyclone wind radii (RVCN) consensus (as of June 2022).

b. Model-based wind radii aids

In 2020, JTWC began processing several new, model-based TC wind-radii forecasting aids. ECMWF incorporated 34-, 50- and 64-knot wind radii into the existing suite of TC vortex trackers derived from both the medium-range, high-resolution deterministic model and the ensemble prediction system. Other new sources for 34-, 50- and 64-knot wind radii forecasts included FNMOC's operational COAMPS-TC ensemble (see section 3.1.b), the Australian Community Climate and Earth-System Simulator global deterministic (ACCESS-G) and ensemble (ACCESS-GE) models and the 557^{th} Weather Wing's Global Air-Land Weather Exploitation Model (GALWEM) global ensemble. Data from all of these sources are under consideration for possible incorporation into the wind radii forecast consensus, RVCN.

c. TC wind radii post analysis QA/QC

JTWC best track post-analysis has historically been limited to position and intensity. However, beginning in 2015, NRL-Monterey and JTWC initiated an effort to re-analyze the radius of 34-knot winds (R34) in order to facilitate development and maintenance of new techniques for analyzing and forecasting TC wind structure and to streamline the operational workflow. In past years, wind radii post-analysis was limited to R34 and western North Pacific TCs, with R50 and R64 values derived via linear regression from the R34 values. JTWC is continuing wind radii best tracking for 2020, but now covering all TCs in the western North Pacific, Indian Ocean and Southern Hemisphere basins as well as all wind radii thresholds (R34, R50 and R64). JTWC plans to release these data once post-analysis is complete.

3. Data exploitation/applications of environmental satellite data

a. Geolocated Information Processing System (GeoIPS)

NRL-MRY began processing a wide variety of TC satellite visualizations using GeoIPS software in 2020. The Technical Services and SATOPS teams assisted NRL in evaluating TC Web and ATCF products during the transition of legacy satellite imagery processing to GeoIPS. The flexibility of GeoIPS is enabling rapid transition of new satellite data sources into the operational environment. Additional details of this ongoing work will be captured in the 2021 ATCR.

4. TC track improvement: Improved and extended tropical cyclone forecast track guidance

a. TC track consensus (CONW)

NRL-MRY and JTWC annually review performance and reliability of various U.S. and international agency models to optimize accuracy of the multi-model track forecasting consensus, CONW. Component members of CONW, as of June 2022, are listed in Table 5-4.

Model	CONW Tracker	Model Type
NAVGEM	NVGI	Dynamical (global)
GALWEM	AFUI	Dynamical (global)
GFS	AVNI	Dynamical (global)
UKMET Office Global Model	EGRI	Dynamical (global)
JMA Global Spectral Model	JGSI	Dynamical (global)
ECMWF Global Model	ECMI	Dynamical (global)
GEFS	AEMI	Dynamical (ensemble)
ECMWF EPS	EEMI	Dynamical (ensemble)
UKMET Office MOGREPS-G	UEMI	Dynamical (ensemble)

Table 5-4. Primary objective aids comprising the operational JTWC tropical cyclone track (CONW) consensus (as of June 2022).

b. New TC vortex trackers

In 2020, the 16th Weather Squadron (16 WS) began providing TC vortex tracker data derived from the GALWEM global ensemble to JTWC. Additionally, the Australia Bureau of Meteorology shared ACCESS global, ACCESS TC and ACCESS ensemble model TC vortex trackers. The JTWC Technical Services Team developed scripts to process these tracker data into ATCF and plot ensemble members for forecaster visualization.

5. TC genesis timing and forecasts

a. JTWC / 14th Weather Squadron Collaboration

In August 2020, the JTWC Technical Services and 14th Weather Squadron (14 WS) Climate Monitoring, Analysis and Prediction teams commenced weekly collaboration calls via Microsoft Teams to coordinate 14 WS Week 3 TC formation outlooks for JTWC forecast basins. Although JTWC has no near-term plans to extend its two-week TC formation outlook to the Week 3 period, the collaboration has infused valuable tools and perspectives from 14 WS climatology experts into the existing JTWC extended range forecasting process.

b. JTWC / 16th WS Collaboration

In 2020, the 16th Weather Squadron's (16 WS) numerical modeling team developed and published a suite of tropical cyclone prediction guidance for DOD forecasters. The JTWC and 16 WS maintained a productive dialogue regarding product design and utility throughout the year. Among the new 16 WS guidance was a multi-model ensemble, large-scale probability of wind speed exceedance forecast product, which JTWC directly integrated into the two-week TC outlook forecasting toolkit.

c. S2S product evaluation

The JTWC Technical Services Team evaluated ECMWF, NCEP and UK Met Office seasonal-to-subseasonal (S2S) model forecast data provided by NRL as part of a real time pilot project. JTWC applied the data to craft input for Climate Prediction Center Global Tropics Hazards and Benefits and 14 WS Week 3 TC outlook discussions. The Technical Services Team also participated in the Navy ESPC model's operational testing review panel and successfully incorporated that model's forecasts into the 14 WS Week 3 outlook collaboration process.

Section 4 Other Scientific Collaborations

a. Joint Polar Satellite System Proving Ground Risk Reduction projects (JPSS PGRR)

JTWC Technical Services Team personnel agreed to serve as operational collaborators for two funded JPSS PGRR projects designed to develop advance applications of JPSS satellite data for TC analysis and forecasting. These collaborations began near the end of the calendar year; additional details will be provided in future ATCRs.

b. Hurricane Forecast Improvement Program (HFIP)

JTWC has benefited significantly from work performed under the auspices of the HFIP, particularly with respect to the improvements in data assimilation, numerical TC track and intensity forecasting, rapid intensification prediction, ensemble modeling, and tropical cyclogenesis forecasting. JTWC maintains ongoing collaborative efforts with HFIP modeling teams from NRL-MRY and NCEP.

Section 5 Scientific and Technical Exchanges

Participating in national and international-level meetings and conducting technical exchanges with members of the scientific community are essential to the success of JTWC's strategic development efforts. A summary of JTWC's 2020 conference attendance and technical exchange meetings follows:

- 100th AMS Annual Meeting
- 2nd TROPICS Applications Workshop (Feb 2020)
- 74th Interdepartmental Hurricane Conference (Mar 2020)
- NOAA/NESDIS Geostationary and Extended Orbits Weather Stakeholder Virtual Workshop (Jul 2020)
- Unified Forecast System (UFS) Users Workshop
- Hurricane Forecast Improvement Program (HFIP) Annual Meeting (Nov 2020)

References

Sampson, C.R. and A.J. Schrader, 2000: The Automated Tropical Cyclone Forecasting System (version 3.2). *Bull. Amer. Meteor. Soc.*, **81**, 1231–1240.

Chapter 6 Forecast Verification Summary

Verification of warning position and intensities at 24-, 48-, 72-, 96- and 120-hour forecast periods are made against the final best track. The (scalar) total track, along-track and cross-track forecast errors were calculated for each verifying JTWC forecast (illustrated in Figure 6-1), included in this chapter. This section summarizes verification data for the 2020 season and contrasts it with annual verification statistics from previous years.

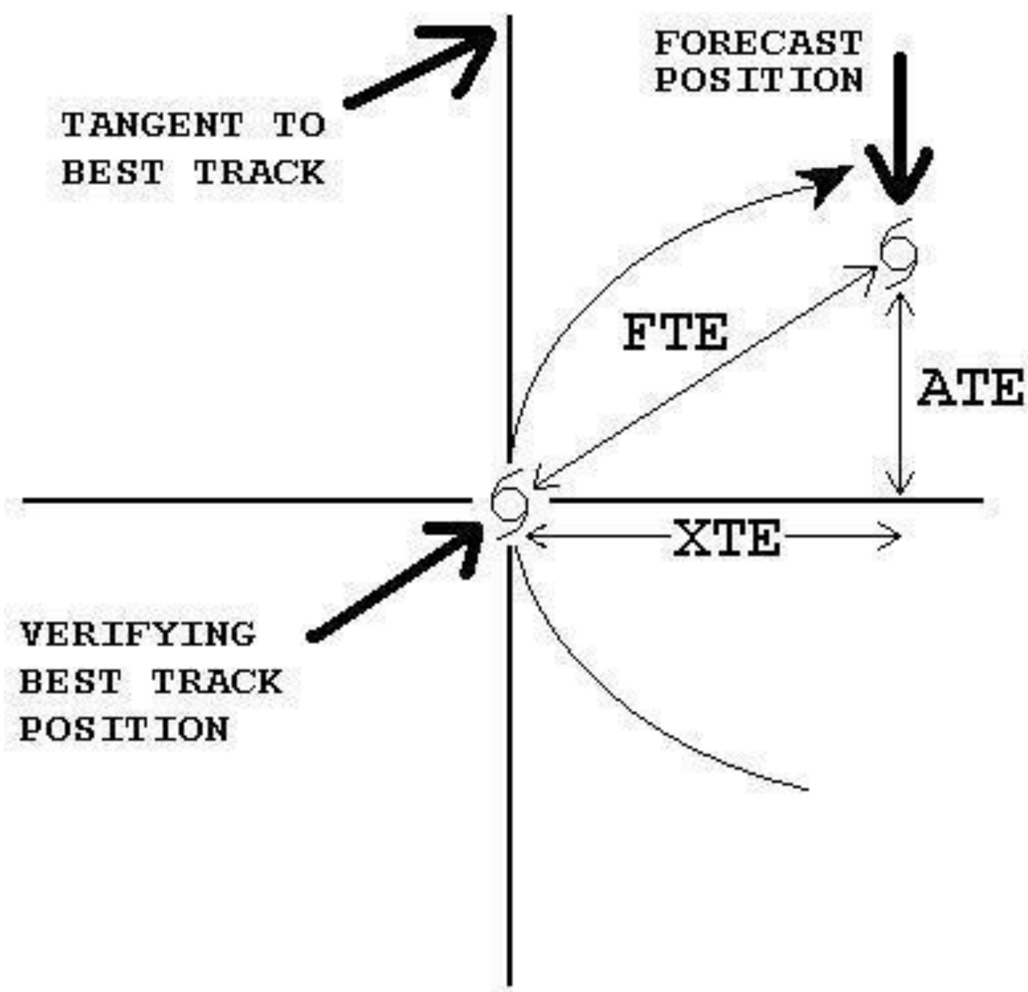


Figure 6-1. Definition of cross track error (XTE), along track error (ATE), and forecast track error (FTE). In this example, the forecast position is ahead of and to the right of the verifying best track position. Therefore, the XTE is positive (to the right of track) and the ATE is positive (ahead of the best track). Adapted from Tsui and Miller (1988).

TABLE 6-1
MEAN FORECAST ERRORS (NM) FOR WESTERN NORTH PACIFIC
TROPICAL CYCLONES FROM 1959 - 2020

	24-Hour					48-Hour					72-Hour					96-Hour					120-Hour				
Year (Note)	Cases	TY Mean Error	TC Mean Error (3)	Cross Track Mean Error (2)	Along Track Mean Error (2)	Cases	TY Mean Error	TC Mean Error (3)	Cross Track Mean Error (2)	Along Track Mean Error (2)	Cases	TY Mean Error	TC Mean Error (3)	Cross Track Mean Error (2)	Along Track Mean Error (2)	Cases (1)	TY Mean Error	TC Mean Error (3)	Cross Track Mean Error (2)	Along Track Mean Error (2)	Cases (1)	TY Mean Error	TC Mean Error (3)	Cross Track Mean Error (2)	Along Track Mean Error (2)
1959		117					267																		
1960		177					354																		
1961		136					274																		
1962		144					287					476													
1963		127					246					374													
1964		133					284					429													
1965		151					303					418													
1966		136					280					432													
1967		125					276					414													
1968		105					229					337													
1969		111					237					349													
1970		98	104				181	190				272	279												
1971		99	111	64			203	212	118			308	317	177											
1972		116	117	72			245	245	146			382	381	210											
1973		102	108	74			193	197	134			245	253	162											
1974		114	120	78			218	226	157			256	348	245											
1975		129	138	84			279	288	181			442	450	290											
1976		117	117	71			232	230	132			336	338	202											
1977		140	148	83			266	283	157			290	407	228											
1978		120	127	71	87		241	271	151	194		459	410	218	296										
1979		113	124	76	81		219	226	138	146		319	316	182	214										
1980		116	126	76	86		221	243	147	165		362	389	230	266										
1981		117	124	77	80		215	221	131	146		342	334	219	206										
1982		114	113	70	74		229	238	142	162		337	342	211	223										
1983		110	117	73	76		247	260	164	169		384	407	263	259										
1984		110	117	64	84		228	232	131	163		361	363	216	238										
1985		112	117	68	80		228	231	138	153		355	367	227	230										
1986		117	126	70	85		261	261	151	183		403	394	227	276										
1987		101	107	64	71		211	204	127	134		318	303	186	198										
1988	353	107	114	58	85	255	222	216	103	170	183	327	315	159	244										
1989	585	107	120	69	83	458	214	231	127	162	343	325	350	177	265										
1990	551	98	103	60	72	453	191	203	110	148	334	299	310	168	225										
1991	673	93	96	53	69	570	187	185	97	137	467	298	287	146	229										
1992	890	97	107	59	77	739	194	205	116	143	610	295	305	172	210										
1993	744	102	112	63	79	596	205	212	117	151	469	320	321	173	226										
1994	920	96	105	56	76	762	172	186	105	131	623	244	258	152	176										
1995	521	105	123	67	89	409	200	215	117	159	315	311	325	167	240										
1996	868	85	105	56	76	707	157	178	89	134	604	252	272	137	203										
1997	905	86	93	55	76	783	159	164	87	134	665	251	245	120	202										
1998	354	127	124	58	98	257	263	239	127	178	189	392	370	201	274										
1999	433	88	106	59	74	300	150	176	102	119	191	225	234	139	155										
2000	605	75	81	45	57	467	136	142	80	98	363	205	209	118	144										
2001	627	66	73	42	49	512	114	122	75	78	395	169	180	110	120	191		289	169	200	139		420	237	299
2002	657	50	66	37	47	535	94	116	67	79	421	144	166	88	120	260		232	107	183	201		292	131	230
2003	602	59	73	41	52	495	119	128	68	94	397	186	186	89	147	238		241	107	197	173		304	126	249
2004	766	52	70	41	48	646	94	122	69	84	537	180	173	95	121	328		206	111	147	242		274	147	195
2005	507	41	61	38	38	407	81	102	59	72	316	138	156	76	120	168		213	106	164	111		263	122	200
2006	512	47	62	39	40	405	85	104	61	73	327	133	151	77	112	206		216	115	155	141		309	167	222
2007	343	45	61	24	42	260	72	100	58	69	189	89	148	83	102	105		189	107	127	63		215	117	155
2008	354	45	66	38	46	261	104	120	75	78	192	201	198	110	140	138		300	163	219	87		447	246	313
2009	498	46	66	35	47	395	102	123	65	90	303	179	183	102	130	227		258	145	183	174		298	158	213
2010	253	57	59	33	42	192	101	101	63	65	140	157	160	95	102	92	154	223	134	147	54	154	279	174	179
2011	455	56	61	36	43	365	85	93	54	66	290	117	129	74	91	177	159	177	103	121	164	233	252	150	163
2012	535	48	50	30	34	439	87	89	52	61	340	121	127	67	93	248	160	163	82	123	178	218	224	105	176
2013	448	39	46	29	31	332	65	74	47	49	232	96	102	61	71	152	156	156	92	105	87	248	240	142	161
2014	406	49	49	29	34	362	81	82	48	56	258	119	123	71	85	200	164	167	102	111	146	218	227	147	146
2015	669	32	43	26	29	561	52	68	42	44	469	80	98	57	68	382	122	138	81	94	303	171	187	107	132
2016	385	38	46	29	30	295	60	85	50	57	219	97	133	74	94	147	133	181	105	123	93	117	233	124	160
2017	406	48	50	30	34	285	92	90	57	60	195	147	142	89	94	139	200	194	112	140	97	228	230	143	147
2018	628	41	43	26	29	500	70	68	42	45	394	101	103	59	71	294	144	153	91	102	213	207	223	132	151
2019	520	45	45	27	30	409	80	79	44	54	313	125	121	64	88	218	163	155	84	113	148	201	191	111	135
2020	323	37	41	24	28	231	52	58	34	41	161	85	90	54	60	111	126	126	75	85	71	153	157	88	111
Avg (1978-2020)	554	78	86	49	60	444	150	160	91	111	347	234	239	135	168	201	153	199	110	142	144	195	263	144	187
5yr Avg	452	42	45	27	30	344	71	76	45	51	256	111	118	68	81	182	153	162	93	113	124	181	207	120	141

(1) JTWC extended warning period from 72hrs to 120hrs in 2001. 96-hour and 120-hour data is not available prior to 2001.
(2) Cross-track and along-track errors were adopted by the JTWC in 1986. Right angle errors (used prior to 1986) were recomputed as cross-track errors after-the fact to extend the data base.
(3) Mean forecast errors for all warned systems in Northwest Pacific.

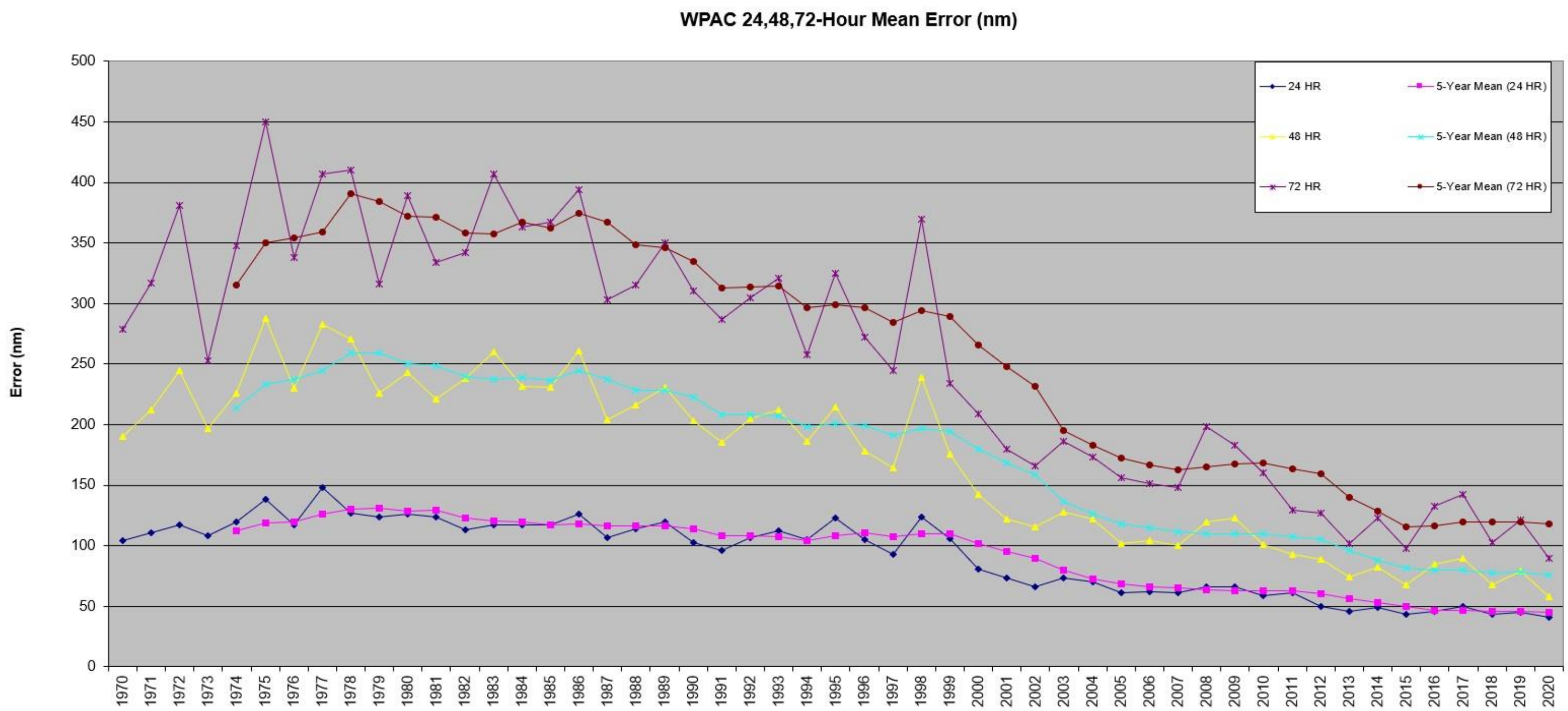


Figure 6-2. JTWC track forecast errors and five year running mean errors for the western North Pacific at 24, 48 and 72 hours.

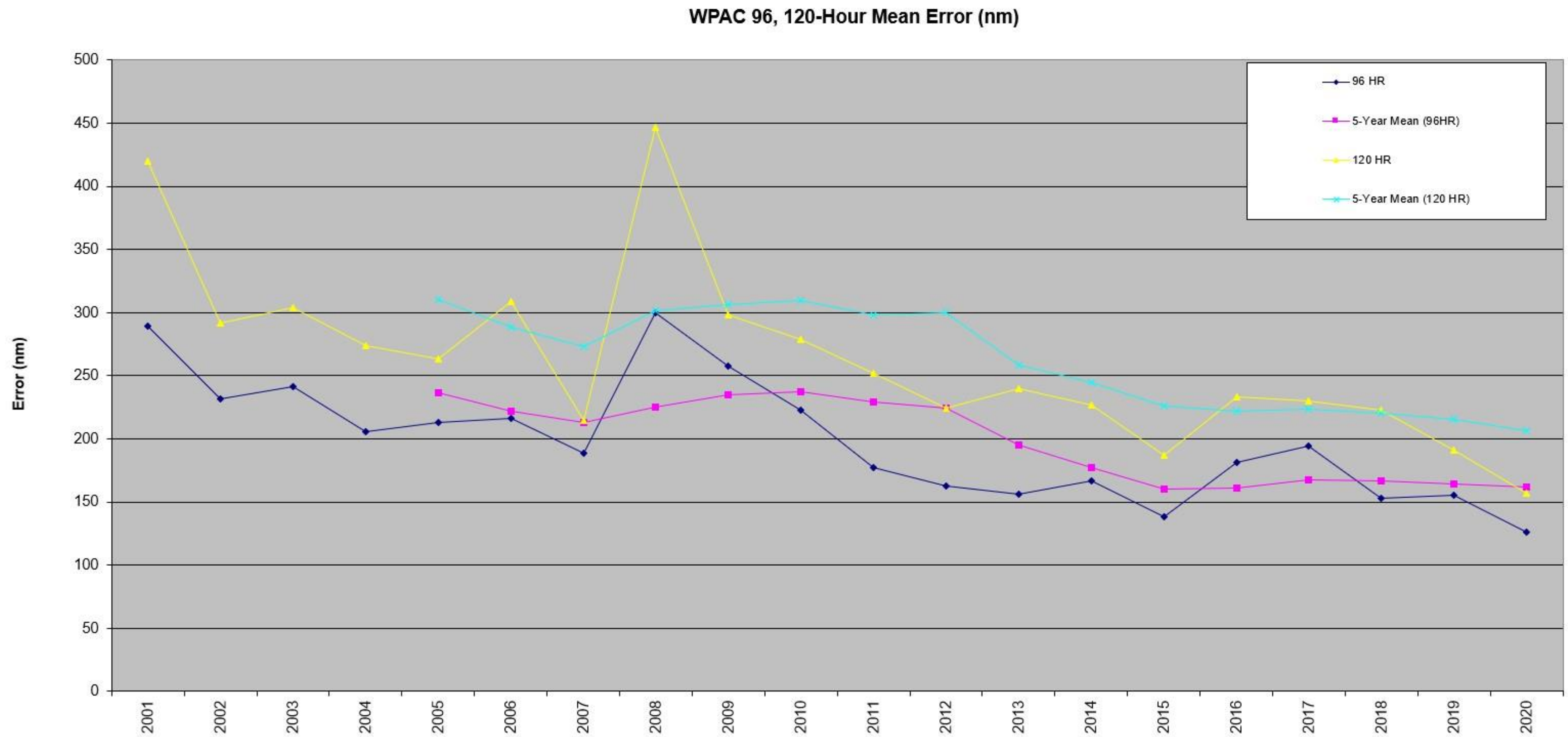


Figure 6-3. JTWC track forecast errors and five year running mean errors for the western North Pacific at 96 and 120 hours.

Table 6-2
MEAN FORECAST TRACK ERRORS (NM) FOR NORTH INDIAN OCEAN

TROPICAL CYCLONES FROM 1985-2020

	24-HOUR				48-HOUR				72-HOUR				96-HOUR				120-HOUR			
YEAR (Notes)	Cases	Mean Error	Cross Track Mean Error	Along Track Mean Error	Cases	Mean Error	Cross Track Mean Error	Along Track Mean Error	Cases	Mean Error	Cross Track Mean Error	Along Track Mean Error	Cases	Mean Error	Cross Track Mean Error	Along Track Mean Error	Cases	Mean Error	Cross Track Mean Error	Along Track Mean Error
1985	30	122	102	53	8	242	119	194	0											
1986	16	134	118	53	7	168	131	80	5	269	189	180								
1987	54	144	97	100	25	205	125	140	21	305	219	188								
1988	30	120	89	63	18	219	112	176	12	409	227	303								
1989	33	88	62	50	17	146	94	86	12	216	164	11								
1990	36	101	85	43	24	146	117	67	17	185	130	104								
1991	43	129	107	54	27	235	200	89	14	450	356	178								
1992	149	128	73	86	100	244	141	166	62	398	276	218								
1993	28	125	87	79	20	198	171	74	12	231	176	116								
1994	44	97	80	44	28	153	124	63	13	213	177	92								
1995	47	138	119	58	32	262	247	77	20	342	304	109								
1996	123	134	94	80	85	238	181	127	58	311	172	237								
1997	42	119	87	49	29	201	168	92	17	228	195	110								
1998	55	106	84	51	34	198	135	106	17	262	188	144								
1999	41	79	59	38	22	184	130	116	10	374	309	177								
2000	24	61	47	26	16	85	69	37	1	401	399	38								
2001	41	61	40	37	31	115	71	71	22	166	44	154								
2002	30	84	41	63	18	137	92	83	10	185	92	133								
2003	37	108	66	69	31	196	115	132	7	354	210	252								
2004	46	81	53	52	36	140	95	85	9	173	144	86								
2005	67	62	41	40	49	116	71	73	18	118	35	109								
2006	19	64	37	44	13	92	58	60	0		-	-								
2007	38	61	38	36	23	94	56	65	10	140	92	93								
2008	59	70	46	44	38	99	71	55	24	127	94	127								
2009	25	93	42	74	10	206	79	169	1	387	102	373								
2010	63	52	31	33	42	90	67	44	22	170	116	84	11	332	175	259	6	587	154	545
2011	46	56	38	34	35	96	59	63	23	118	59	87	12	108	44	95	4	156	65	118
2012	19	67	38	42	7	51	34	31	3	30	22	15	0				0			
2013	99	49	27	37	75	80	37	66	52	102	61	69	32	138	68	109	17	207	104	167
2014	59	40	27	26	40	55	36	36	25	76	52	45	16	136	101	84	8	182	139	112
2015	62	38	22	27	44	75	49	49	31	115	74	76	19	156	104	108	7	209	126	159
2016	47	53	29	37	31	82	50	48	18	104	81	41	9	144	138	38	5	177	199	53
2017	34	45	21	31	20	55	23	46	12	67	21	62	7	63	54	27	3	144	104	96
2018	95	39	27	23	72	60	32	40	49	78	48	50	31	102	57	71	21	125	75	81
2019	137	40	25	25	111	50	28	36	92	62	36	43	71	101	51	78	52	149	71	118
2020	48	55	37	29	31	83	58	42	16	99	72	55	5	100	41	87	1	111	44	102
Avg (1985-2019)	52	85	59	48	35	142	96	83	20	214	145	122	19	138	83	96	11	205	108	155
5Yr Avg	72	46	28	29	53	66	38	42	37	82	52	50	25	102	68	60	16	141	99	90

(1) JTWC extended warning period from 72hrs to 120hrs in 2010. 96-hour and 120-hour data is not available prior to 2010.

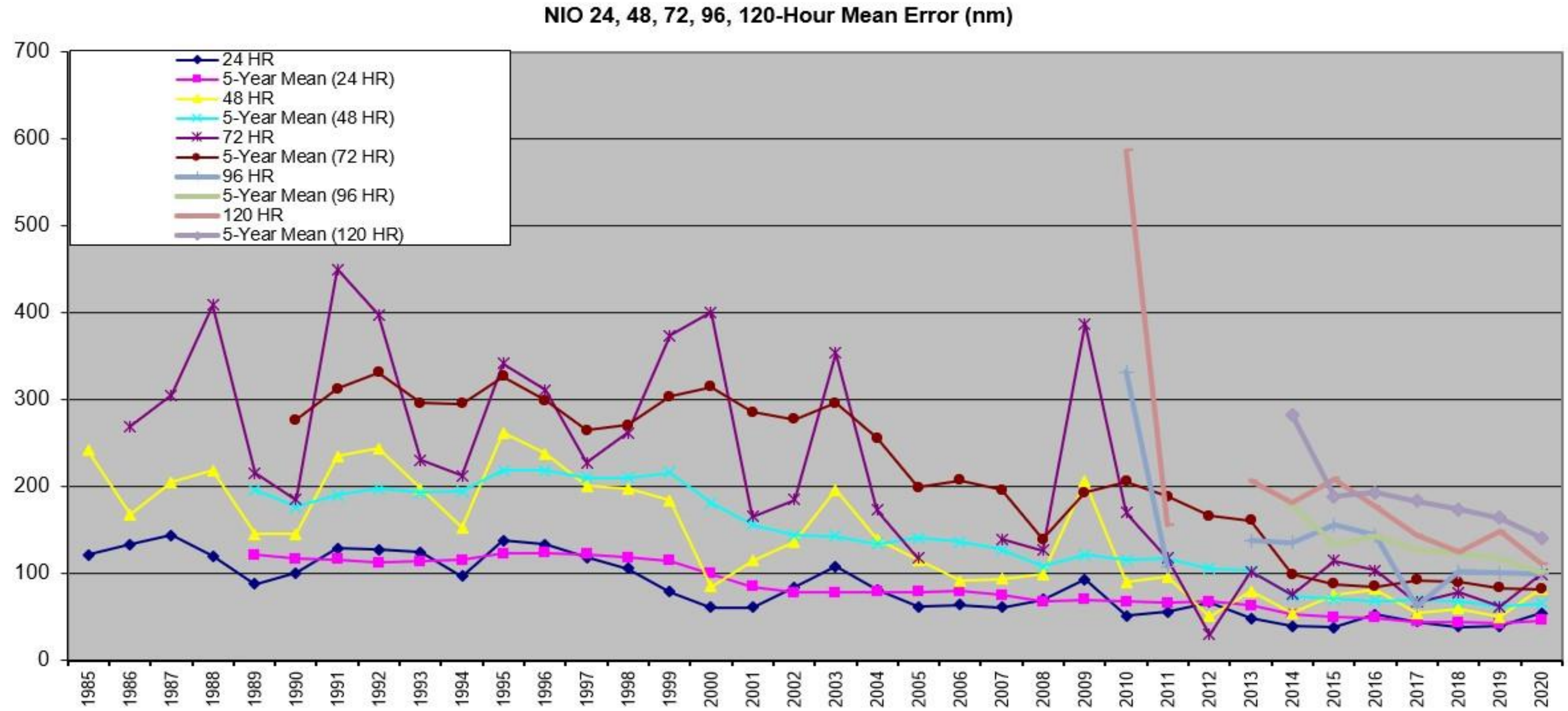


Figure 6-4. JTWC track forecast errors and five year running mean errors for the north Indian Ocean at 24, 48, 72, 96 and 120 hours. (Note: No 96-hr or 120-hr forecasts for NIO TCs verified in 2012).

TABLE 6-3

MEAN FORECAST ERRORS (NM) FOR SOUTHERN HEMISPHERE TROPICAL CYCLONES 1985 - 2020

	24-Hour				48-Hour				72-Hour				96-Hour				120-Hour			
Year (Notes)	Cases	Mean Error	Cross Track Mean Error	Along Track Mean Error	Cases	Mean Error	Cross Track Mean Error	Along Track Mean Error	Cases	Mean Error	Cross Track Mean Error	Along Track Mean Error	Cases	Mean Error	Cross Track Mean Error	Along Track Mean Error	Cases	Mean Error	Cross Track Mean Error	Along Track Mean Error
1985	257	134	79	92	193	236	132	169												
1986	227	129	77	86	171	262	164	169												
1987	138	145	90	94	101	280	138	153												
1988	99	146	83	98	48	290	144	246												
1989	242	124	73	84	186	240	136	166												
1990	228	143	74	105	177	263	152	178												
1991	231	115	69	75	185	220	129	152												
1992	230	124	64	91	208	240	129	177												
1993	225	102	57	74	176	199	114	142												
1994	345	115	68	77	282	224	134	147												
1995	222	108	55	82	175	198	108	144	53	291	190	169								
1996	298	125	67	90	237	240	129	174	46	277	133	221								
1997	499	109	72	82	442	210	135	163	150	288	175	248								
1998	305	111	52	85	245	219	108	169	81	349	171	261								
1999	322	113	64	80	245	226	132	159	59	286	164	198								
2000	313	72	45	47	245	135	86	84	58	180	139	94								
2001	147	84	44	61	113	148	86	105	11	248	197	133								
2002	200	82	43	60	146	133	75	93	5	102	41	91								
2003	279	74	37	57	221	127	68	90	37	123	54	99								
2004	277	77	45	52	233	142	89	92	47	210	102	162								
2005	214	70	44	44	170	116	77	72	41	199	117	136								
2006	191	65	37	46	140	116	69	79	32	201	101	151								
2007	186	74.9	41	52	131	147	80	105	3	173	146	73								
2008	269	61	38	40	211	106	64	72	27	97	53	65								
2009	166	74	42	51	118	128	74	89	14	114	89	54								
2010	206	66	40	45	161	109	67	57	125	149	76	109	89	207	117	145	64	276	159	191
2011	164	53	32	34	127	81	50	54	88	109	62	76	54	173	114	107	31	274	205	151
2012	187	58	33	41	145	99	53	72	117	149	71	116	91	202	96	162	64	272	149	192
2013	216	49	28	34	175	80	45	54	140	114	63	78	103	138	72	101	69	166	76	131
2014	180	53	28	39	132	90	47	65	95	133	64	102	69	162	83	122	50	198	98	147
2015	185	51	29	35	137	87	48	60	88	123	75	76	55	188	121	108	37	287	201	147
2016	197	53	24	41	155	92	41	73	121	148	63	120	91	217	107	163	66	297	169	205
2017	127	52	33	33	99	86	54	53	69	116	69	72	40	154	83	94	23	232	107	147
2018	349	41	24	27	275	61	41	37	204	77	50	49	140	88	57	54	91	102	78	48
2019	534	40	25	26	445	63	38	41	360	85	50	57	272	108	58	77	202	139	67	107
2020	226	41	23	28	150	67	38	48	92	99	46	78	50	124	55	100	24	146	52	125
Avg (1985-2020)	241	87	49	61	189	160	91	111	83	171	99	119	96	160	88	112	66	217	124	145
5Yr Avg	287	45	26	31	225	74	42	50	169	105	56	75	119	138	72	98	81	183	95	126

(1) JTWC extended warning period from 72hrs to 120hrs in 2010. 96-hour and 120-hour data is not available prior to 2010.

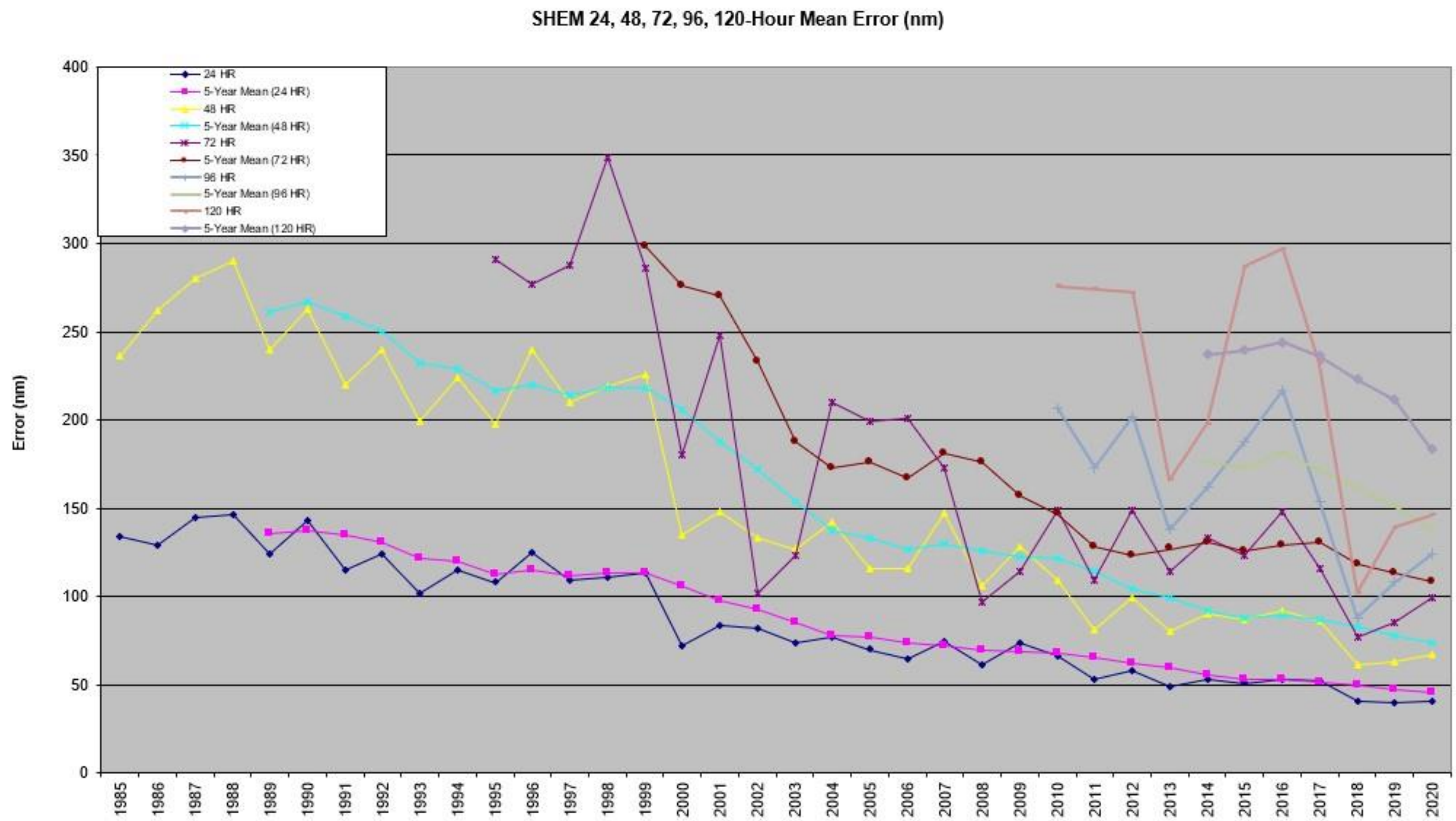


Figure 6-5. JTWC forecast errors for the Southern Hemisphere at 24, 48, 72, 96, and 120 hours.

TABLE 6-4							
MEAN FORECAST INTENSITY ERRORS FOR WESTERN NORTH PACIFIC TROPICAL CYCLONES 2000-2020							
Year	**12 HR**	**24 HR**	**36 HR**	**48 HR**	**72 HR**	**96 HR**	**120 HR**
2000	7.1	11.9	15.4	19.3	24.1	24.0	29.5
2001	6.8	11.1	14.7	16.9	20.6	29.2	28.1
2002	6.3	10.1	13.4	16.2	21.2	31.3	35.4
2003	7.0	10.7	13.8	15.9	19.2	21.5	18.6
2004	6.9	11.1	14.5	17.3	20.4	22.7	25.7
2005	7.2	11.7	14.8	17.7	23.1	24.7	25.0
2006	8.3	13.3	16.0	17.8	20.0	21.8	23.5
2007	7.2	11.4	15.1	18.1	23.0	22.8	23.9
2008	7.9	12.4	16.4	18.7	21.1	22.1	27.5
2009	7.8	11.9	15.8	19.4	24.5	25.8	26.6
2010	6.2	9.2	10.7	11.8	15.7	20.6	22.0
2011	7.3	12.1	15.4	18.1	23.2	23.3	25.6
2012	7.1	10.9	14.0	15.5	17.4	20.1	21.3
2013	6.7	10.3	12.5	14.8	15.8	14.3	12.9
2014	7.3	11.0	14.8	17.7	19.8	21.6	25.7
2015	8.1	11.8	14.1	16.3	18.9	20.1	20.4
2016	8.7	11.7	14.1	16.2	19.4	21.3	26.4
2017	7.0	10.1	12.2	14.2	15.7	17.2	17.9
2018	6.9	9.6	11.3	13.0	15.2	16.5	18.6
2019	7.8	10.3	12.8	15.3	19.2	19.3	18.2
2020	6.8	10.0	12.3	14.5	16.9	18.5	17.8
AVG	7.3	11.1	14.0	16.4	19.7	21.8	23.4
5Yr Avg	7.7	10.7	12.9	15.0	17.7	18.9	20.3

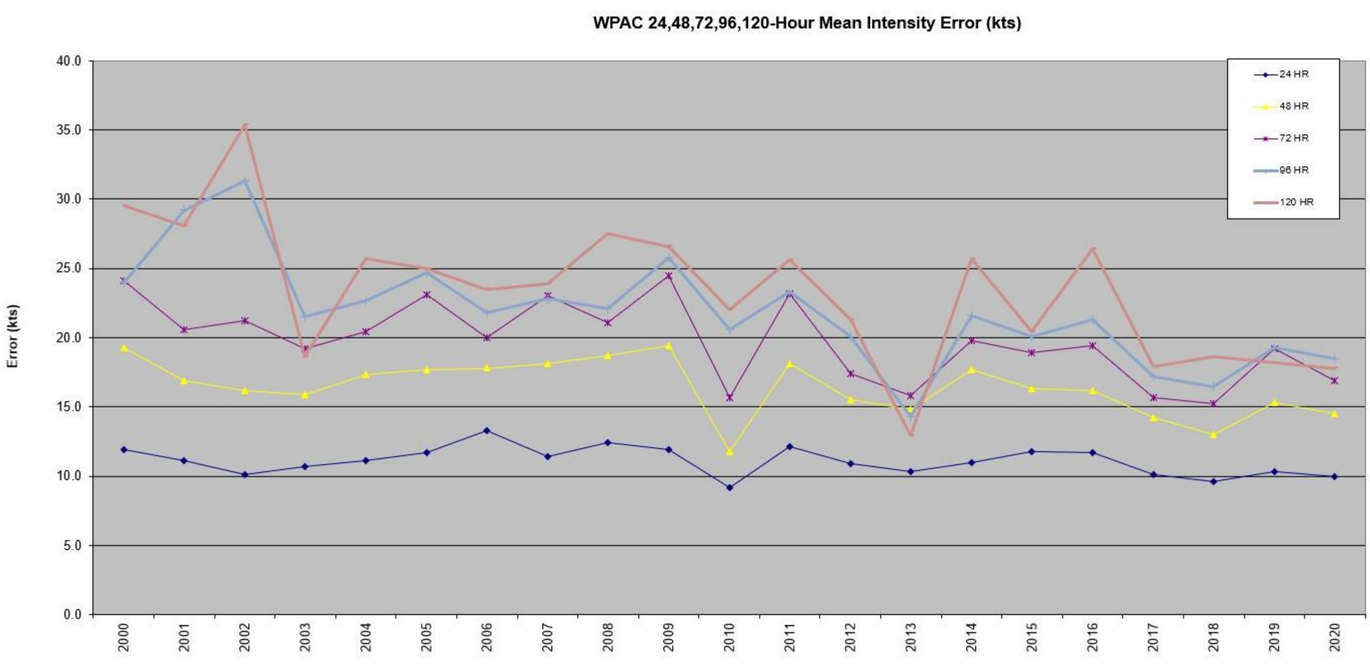


Figure 6-6. JTWC intensity forecast errors for the western North Pacific at 24, 48, 72, 96 and 120 hours.

TABLE 6-5							
MEAN FORECAST INTENSITY ERRORS FOR NORTHERN INDIAN OCEAN TROPICAL CYCLONES 2000-2020							
Year	12 HR	24 HR	36 HR	48 HR	72 HR	96 HR	120 HR
2000	5.2	9.6	11.8	12.1			
2001	8.6	11.8	18.7	22.1	27.6		
2002	5.0	7.2	8.8	7.5	8.3		
2003	6.9	11.9	17.8	22.7	18.1		
2004	6.2	7.9	9.6	13.1	37.1		
2005	3.7	4.7	5.7	7.6			
2006	7.4	11.8	17.3	28.5			
2007	11.1	19.9	28.0	29.8	25.5		
2008	6.9	10.7	14.9	16.7	12.7		
2009	6.2	6.6	10.6	13.5	35.0		
2010	11.3	17.1	17.6	19.2	20.5	28.6	4.2
2011	6.5	8.6	11.2	13.4	16.9	23.9	10.0
2012	4.6	7.9	11.9	9.3	5.0		
2013	7.3	11.2	17.0	20.2	23.0	27.3	19.4
2014	9.5	13.4	15.8	18.4	22.6	19.1	11.3
2015	10.6	14.9	16.2	16.3	16.3	14.7	11.4
2016	7.1	9.3	12.7	12.6	12.2	12.8	6.0
2017	5.9	6.4	7.9	8.5	10.8	14.3	23.3
2018	7.5	11.3	13.6	14.8	17.2	18.9	23.9
2019	8.9	12.0	14.3	15.2	18.9	21.8	25.0
2020	11.9	12.9	14.5	11.4	9.4	19.0	4.9
AVG	7.5	10.8	14.1	15.9	18.7	20.0	13.9
5Yr Avg	8.0	10.8	12.9	13.5	15.1	16.5	17.9

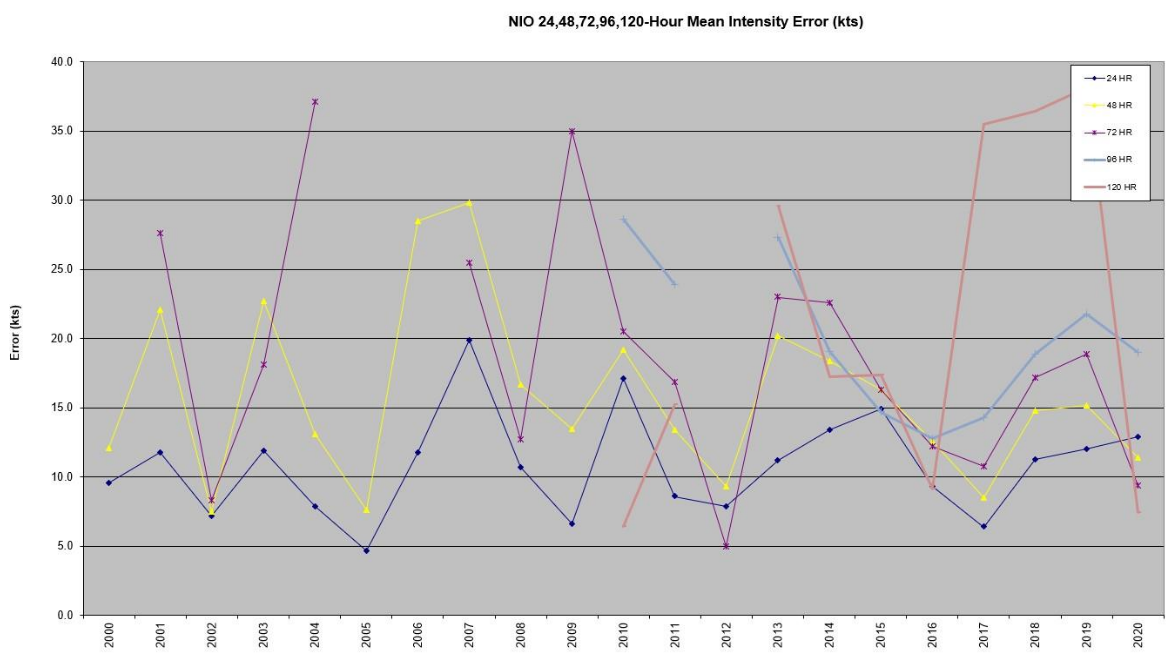


Figure 6-7. JTWC intensity forecast errors for the North Indian Ocean at 24, 48, 72, 96, and 120 hours. (Note: No 96 hr or 120 hr forecasts for NIO TCs verified in 2012).

TABLE 6-6							
MEAN FORECAST INTENSITY ERRORS FOR SOUTHERN HEMISPHERE TROPICAL CYCLONES 2000-2020							
Year	**12 HR**	**24 HR**	**36 HR**	**48 HR**	**72 HR**	**96 HR**	**120 HR**
2000	6.6	12.3	17.4	22.5	17.5		
2001	6.9	10.9	16.2	21.0	34.5		
2002	7.0	13.3	19.2	23.2	22.0		
2003	7.2	12.8	17.8	21.8	20.1		
2004	7.3	11.9	15.8	19.3	31.9		
2005	9.4	15.5	21.4	25.0	32.9		
2006	8.9	13.9	16.9	19.5	18.9		
2007	9.0	13.6	18.4	21.7	11.7		
2008	7.1	11.7	15.5	18.9	24.1		
2009	7.4	11.0	13.7	14.7	17.7		
2010	8.9	14.2	18.2	20.7	19.9	21.9	26.4
2011	6.3	9.3	12.2	14.4	16.3	17.1	17.3
2012	7.9	11.3	13.6	15.0	17.1	18.8	19.5
2013	6.7	11.4	15.4	17.8	20.8	19.9	22.1
2014	8.3	13.5	18.1	21.1	22.1	25.8	26.3
2015	10.1	16.3	20.5	20.7	21.0	24.1	23.8
2016	9.5	14.3	16.9	19.3	23.1	22.4	20.7
2017	7.4	10.5	11.5	12.1	12.7	15.0	16.0
2018	7.9	10.5	12.8	14.4	15.5	14.9	15.9
2019	7.6	10.6	12.5	13.4	13.5	13.3	12.7
2020	8.3	10.9	11.1	11.9	13.4	17.2	21.3
AVG	7.9	12.4	16.0	18.5	20.3	19.1	20.2
5Yr Avg	8.5	12.4	14.8	16.0	17.2	17.9	17.8

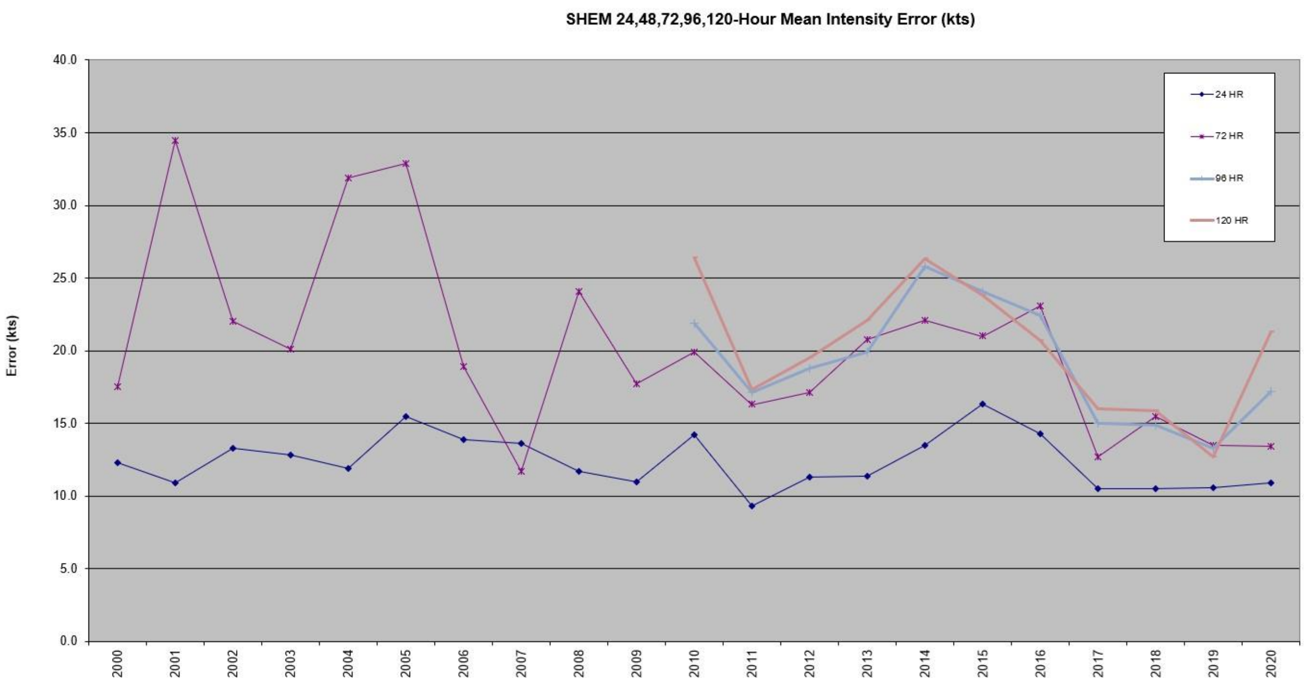


Figure 6-8. JTWC intensity forecast errors for the Southern Hemisphere at 24, 48, 72, 96 and 120 hours

Chapter 7 Detailed Cyclone Reviews

Section 1   Super Typhoon 22W (Goni)

Super Typhoon (STY) Goni (22W, 2020) was the most intense tropical cyclone to develop in the western North Pacific (WPAC) basin since STY Haiyan in 2013. The JTWC began tracking the initial disturbance (Invest 99W) south of Guam on 21 October 2020. GFS, ECMWF, UKMET, JGSM and NAVGEM global numerical model forecasts from 00Z on 21 October depicted gradual intensification of the circulation, with an initially poleward track followed by a generally westward track towards the Philippines. These model track solutions converged toward the path of the tropical cyclone that had developed immediately prior, TY Molave (21W, 2020). 21W had formed in a similar location, and steadily intensified to a peak of 70 kts as it tracked generally westward along a continuous subtropical steering ridge prior to making landfall along the Philippine coast. In contrast, STY Goni (22W) underwent multiple episodes of rapid intensification prior to its eventual landfall in the Philippines as mid-latitude systems passing to the north weakened the subtropical steering ridge and aided formation of supportive poleward outflow channels.

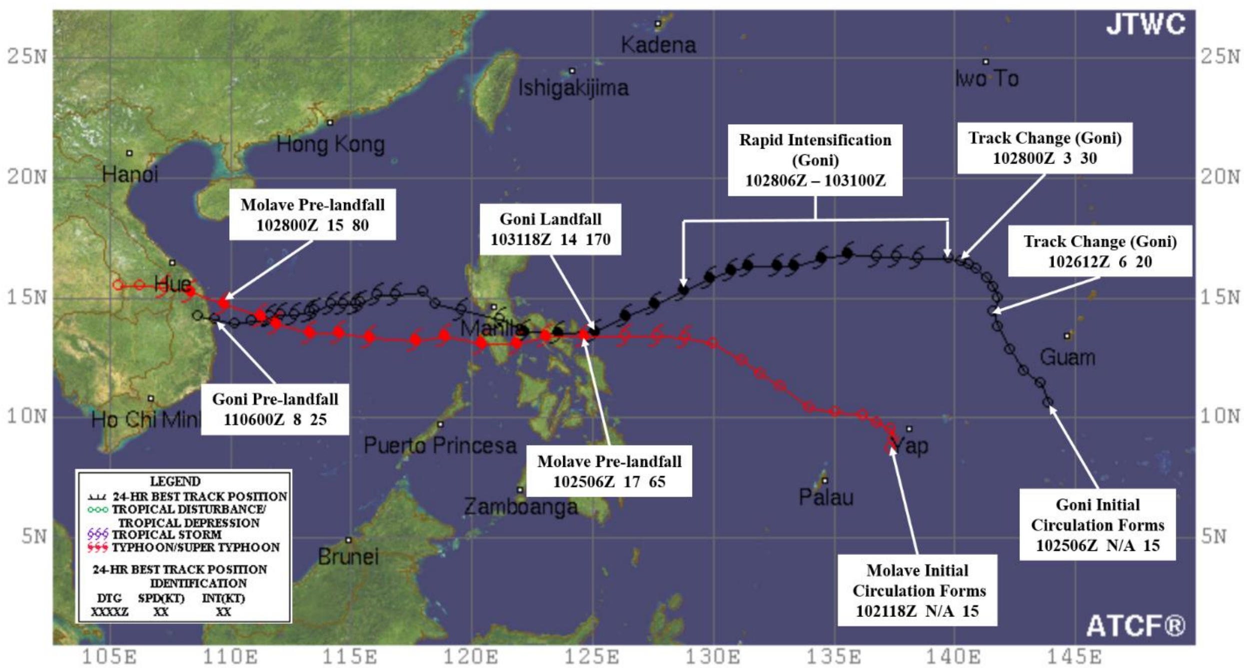


Figure 7-1: Tracks of STY Goni (black) and TY Molave (red) with significant events labeled.

Favorable environmental conditions including warm sea surface temperatures (SST) (>26° Celsius), high ocean heat content (OHC) (> 100 kJ cm^{-2}), and low (5-10 kts) vertical wind shear (VWS) supported 22W's incipient circulation. However, convergent flow aloft limited intensification early in the system's lifecycle (Figure 7-2).

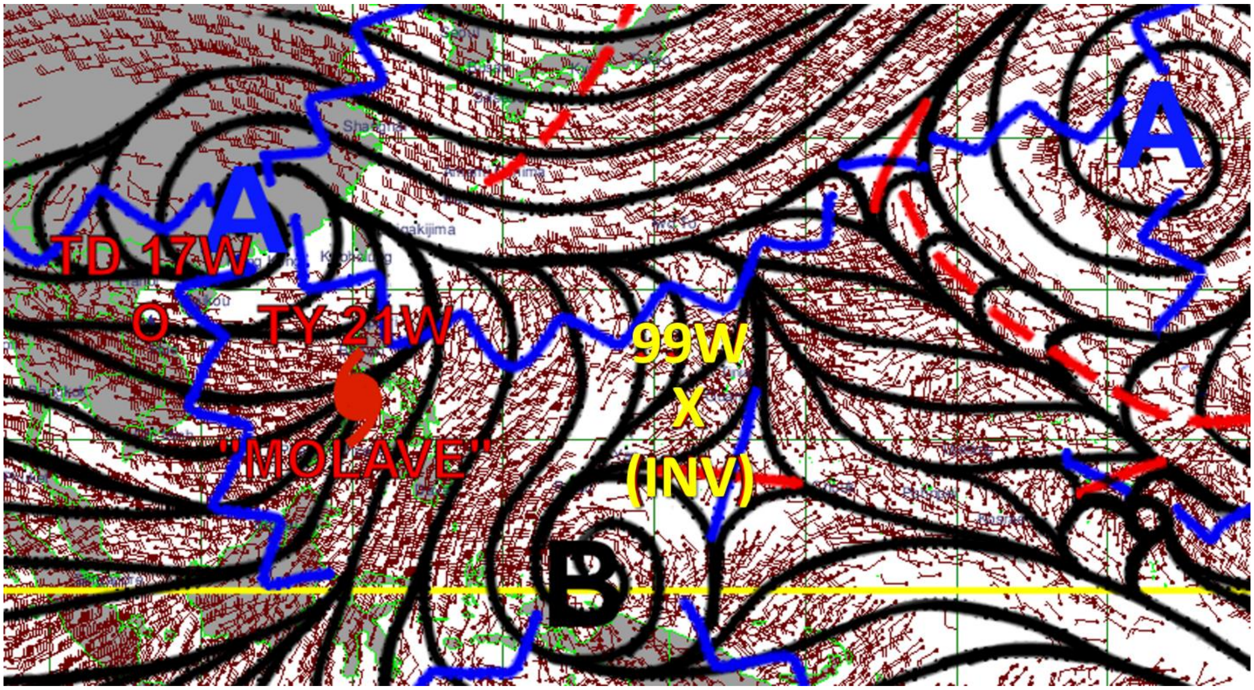


Figure 7-2: JTWC western North Pacific upper-level (100-400 mb) streamline analysis valid at 00Z on 26 October. The approximate center position of the pre-formation disturbance that later developed into 22W (Invest 99W) is marked with a gold "X." Convergent flow aloft limited intensification early in the system's lifecycle.

By 12Z on 26 October, a shortwave trough eroded the subtropical ridge to the north of 22W (Figure 7-3), forming a col region between two anticyclone centers. Prior to interacting with the shortwave trough, the subtropical ridge (STR) extended uninterrupted across the western Pacific basin. TY Molave (21W) had steadily intensified and tracked generally westward under the influence of this continuous deep-layer easterly flow. However, for STY Goni (22W), formation of the col region and subsequent ridge/trough interactions yielded a more dynamic storm track and intensity trend.

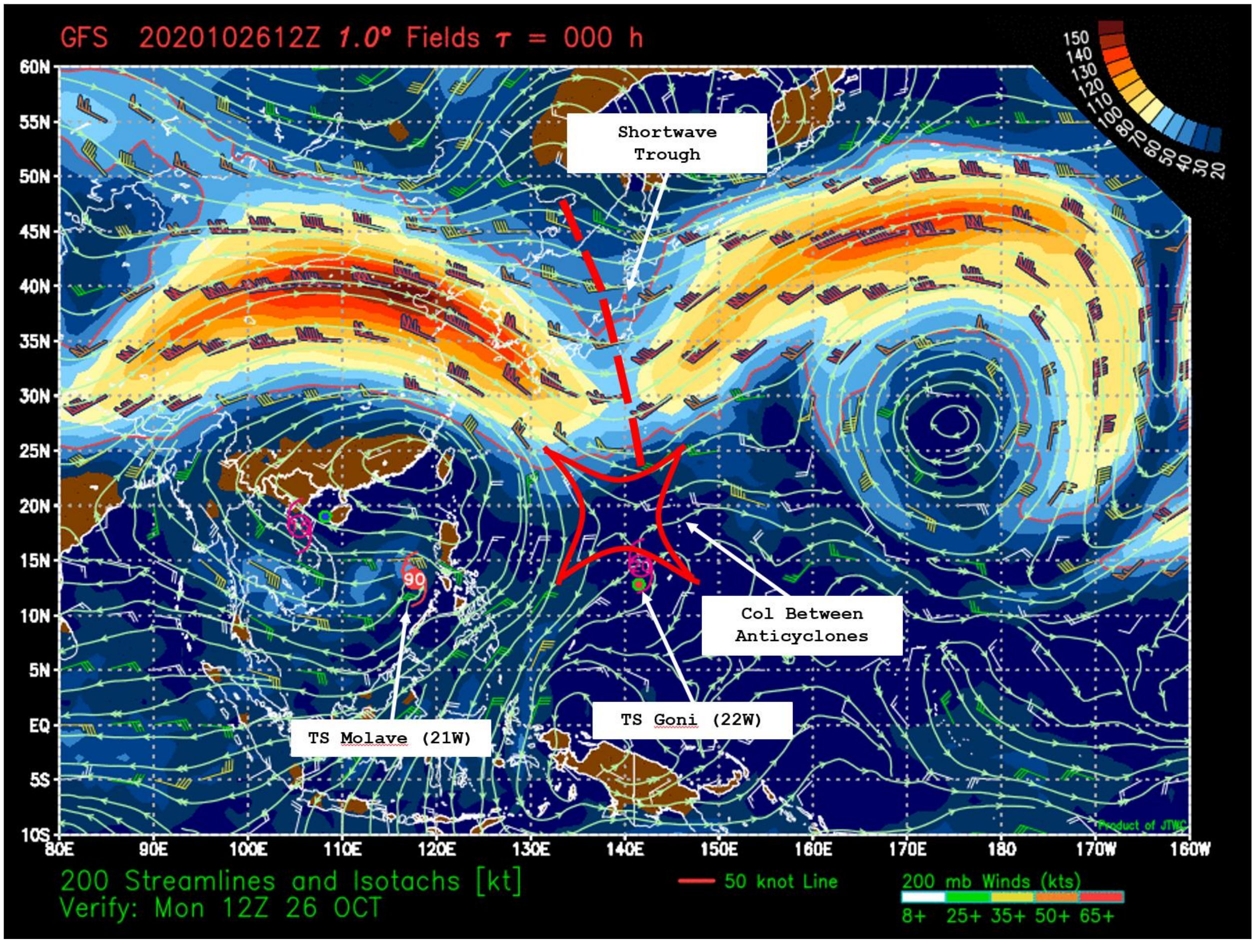


Figure 7-3: Operational GFS 200mb upper level wind analysis, with shortwave trough and induced col annotated. Formation of this col was a primary factor for track and intensity differences between TY Molave (21W, 2020) and STY Goni (22W, 2020), which formed in a similar area just a few days apart.

Ongoing reorientation of the subtropical ridge allowed 22W to establish moderate poleward and robust equatorward outflow (Figure 7-4). The improving outflow pattern, coupled with warm SST and low VWS, supported steady intensification to Tropical Storm strength (35 kts) by 12Z on 28 October.

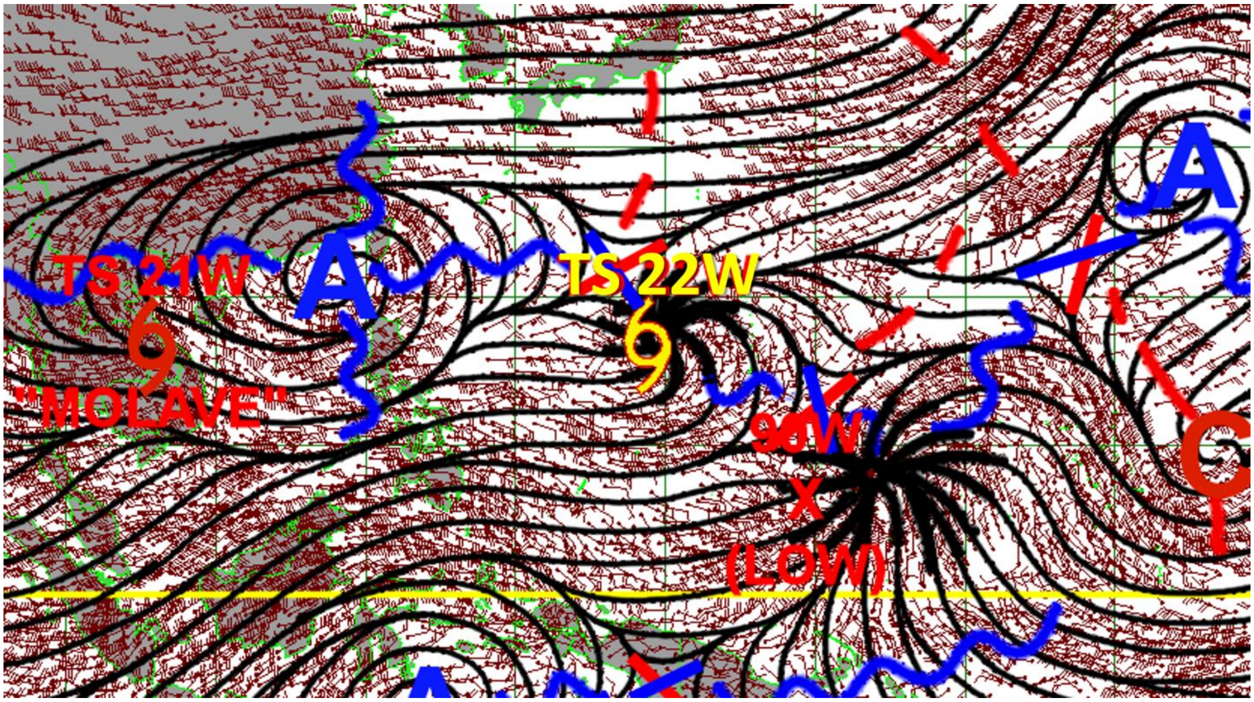


Figure 7-4: JTWC western North Pacific upper-level (100-400 mb) streamline analysis valid at 12Z on 28 October. The approximate center position of 22W is marked with a gold tropical storm (TS) symbol. Note the markedly improved outflow pattern compared to the pre-formation pattern depicted in Figure 7-2.

Numerical models diverged during a period of rapid intensification for 22W that began on 28 October, with two dominant solutions. The GFS, ECMWF and NAVGEM models depicted aggressive intensification along a generally westward track. However, UKMET and JGSM model guidance depicted west-southwestward tracks with only minimal intensification. The divergence in these model solutions reflected uncertainty in the timing and strength of an eastward-propagating, mid-latitude shortwave trough and the overall dynamic setup of the STR and associated anticyclone center over China. The GFS, ECMWF and NAVGEM fields all depicted a deeper trough and greater erosion of the subtropical ridge, with enhanced poleward outflow along the eastern periphery of the resulting col area aiding storm intensification.
In the end, the subtropical ridge and outflow pattern repositioned in response to the shortwave trough, consistent with the GFS/ECMWF/NAVGEM forecasts. Retreat of the subtropical ridge resulted in robust poleward outflow for STY Goni (22W) and supported the consequent episode of rapid intensification (Figure 7-5). The pattern differed substantially from the continuous subtropical ridge and westerly flow that had influenced TY Molave (21W) just a few days prior. In that case, the lack of ridge/trough interactions limited intensification to a slower and steadier rate (Figure 7-6).

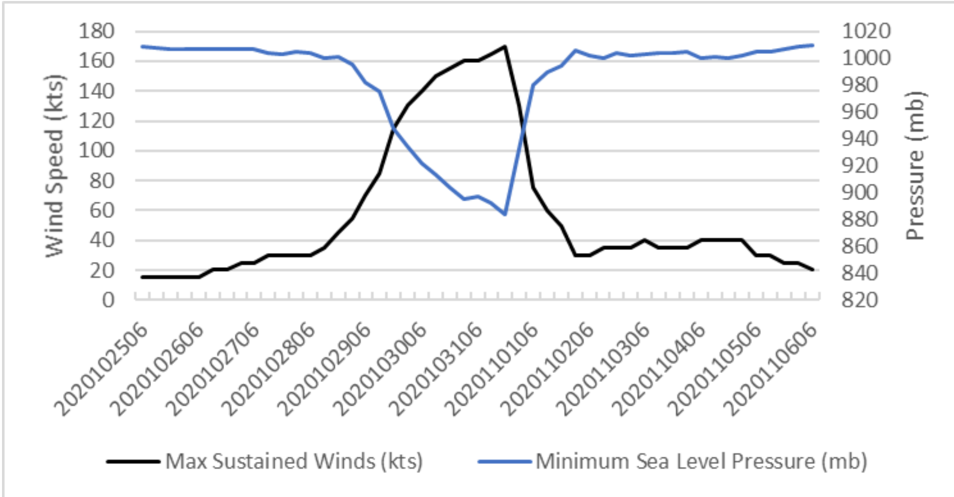


Figure 7-5: JTWC best track maximum sustained winds and pressure for STY Goni (22W). Note periods of rapid intensification and rapid weakening between 28 October and 2 November. Rapid weakening resulted from terrain interaction with the Philippines.

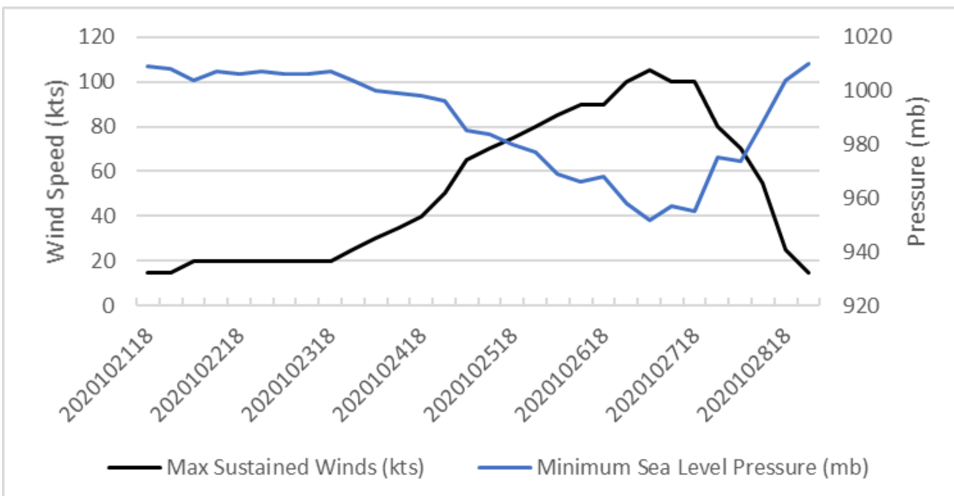


Figure 7-6: JTWC best track max sustained winds and pressure for TY Molave (21W).

By 06Z on 29 October, 22W had rapidly intensified to typhoon strength (70 kts at 06Z), establishing robust poleward and equatorward outflow aloft (Figure 7-6). This enhanced outflow, coupled with very warm (28+ Celsius) SST and low (5-10 kts) VWS, enabled rapid intensification to continue. The remarkably favorable upper level outflow pattern is clearly evident in Figure 7-7.

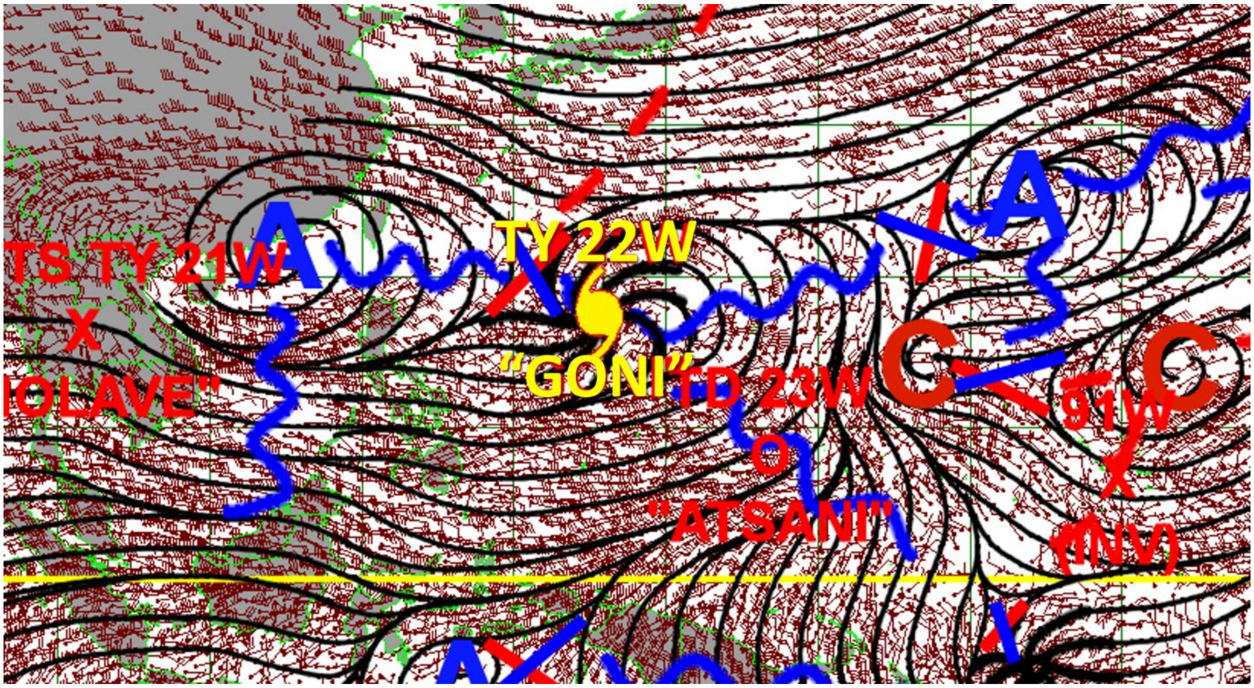


Figure 7-7: JTWC western North Pacific upper-level (100-400 mb) streamline analysis valid at 12Z on 29 October. The approximate center position of 22W is marked with a gold typhoon (TY) symbol. The outflow was ideal for rapid intensification, with mesoscale, anticyclonic flow over the cyclone center and a poleward outflow channel enhanced by midlatitude westerly flow.

By 18Z on 29 October, the system had developed a clear eye feature (Figure 7-8C). As mid-latitude troughing progressed eastward, ridging rebuilt to the north of 22W and the system began to accelerate westward towards the Philippines.

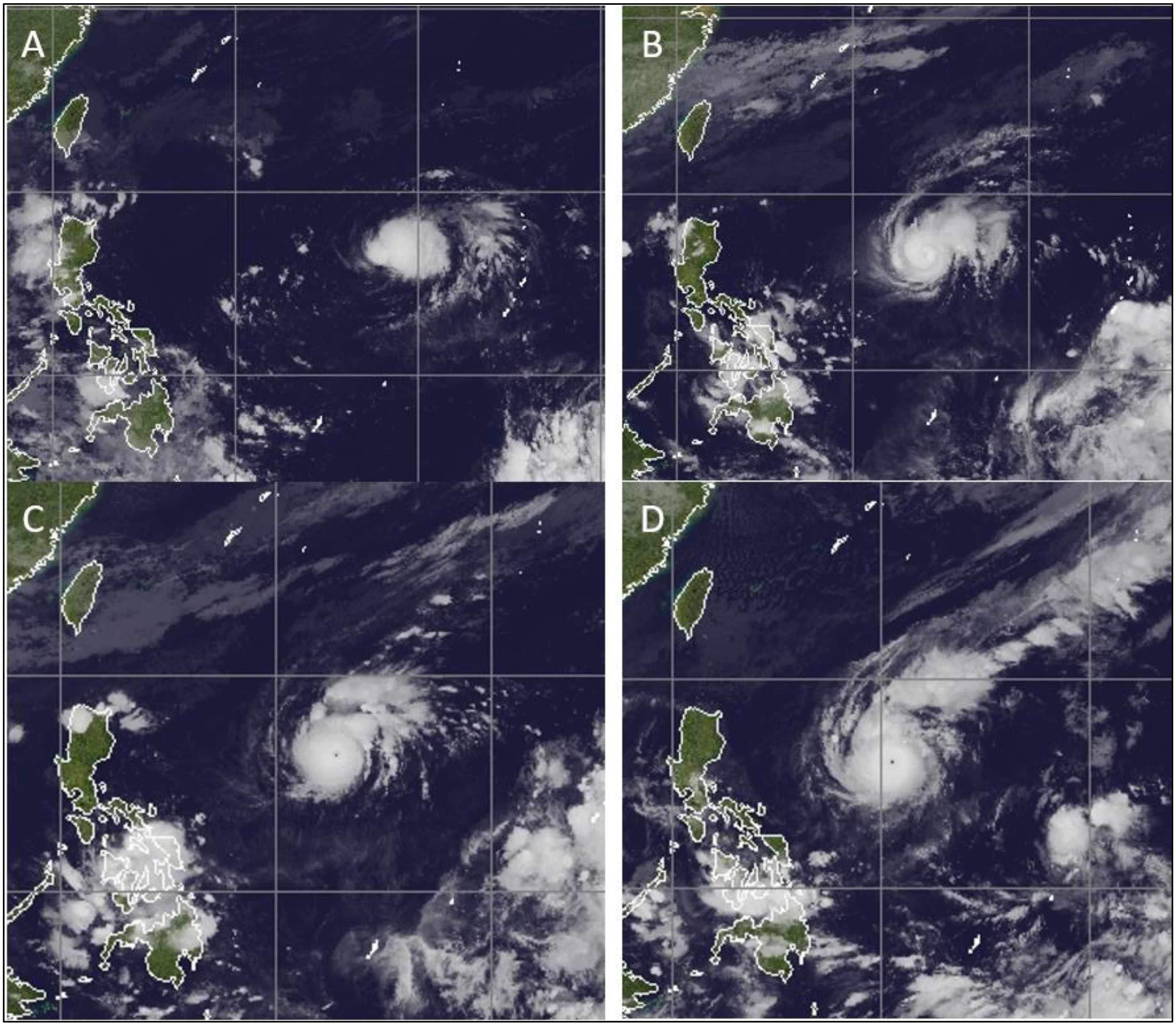


Figure 7-8: Himawari-8 infrared images of 22W at 1330Z on 28 October (A, upper left), at which time 22W was upgraded to a tropical storm; 1330Z on 29 October (B, upper right); 2230Z on 29 October (C, lower left) at which point the system revealed an eye structure; and 1330Z on 30 October (D, lower right). Upper-level support (outflow) is evident in all four images, improves with each frame.

Highly favorable environmental conditions supported rapid intensification until 00Z on October 31. However, microwave satellite imagery indicates that an eyewall replacement cycle began shortly after 12Z on 30 October. The onset of ERC, which is typical of storms of this magnitude, is evident in 2036Z SSMIS microwave imagery from 30 October (Figure 7-8). The entire ERC process lasted nearly 20 hours, with the newly formed eyewall clearly evident in microwave imagery by 0755Z on 31 October (Figure 7-9). Interestingly, the ERC had only a modest negative impact on the intensification trend.

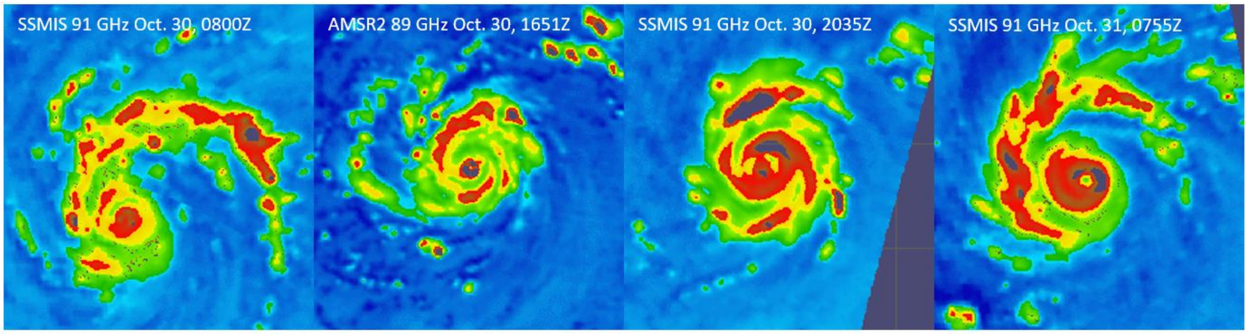


Figure 7-9: Microwave (89-91 GHz) imagery from SSMIS and AMSR2 depicting stages of an eyewall replacement cycle for 22W that took place between 30 and 31 October.

Upon conclusion of the ERC, 22W intensified a bit more under the influence of robust poleward outflow. The system reaching an estimated peak intensity of 170 kts prior to making landfall along the coast of the Catanduanes just after 18Z on 31 October. Synthetic aperture radar from Sentinel-1B captured positioning of the eyewall just south of Catanduanes Island (Figure 7-10). While the best track intensity just prior to landfall was 170 kts at 18Z (based on subjective Dvorak estimates of T=8.0 from PGTW, KNES and RJTD and an automated satellite consensus (SATCON) estimate of 174 kts from 1256Z), the next 6 hours witnessed a period of rapid weakening to 130 kts (Figure 7-5). Observations from Legazpi Station (13.2N 123.7E) indicated 144 kts winds at 23Z on 31 October, and a reading from Daet station (14.1N 1232.0E) revealed wind speeds exceeding instrument capabilities at 22Z.

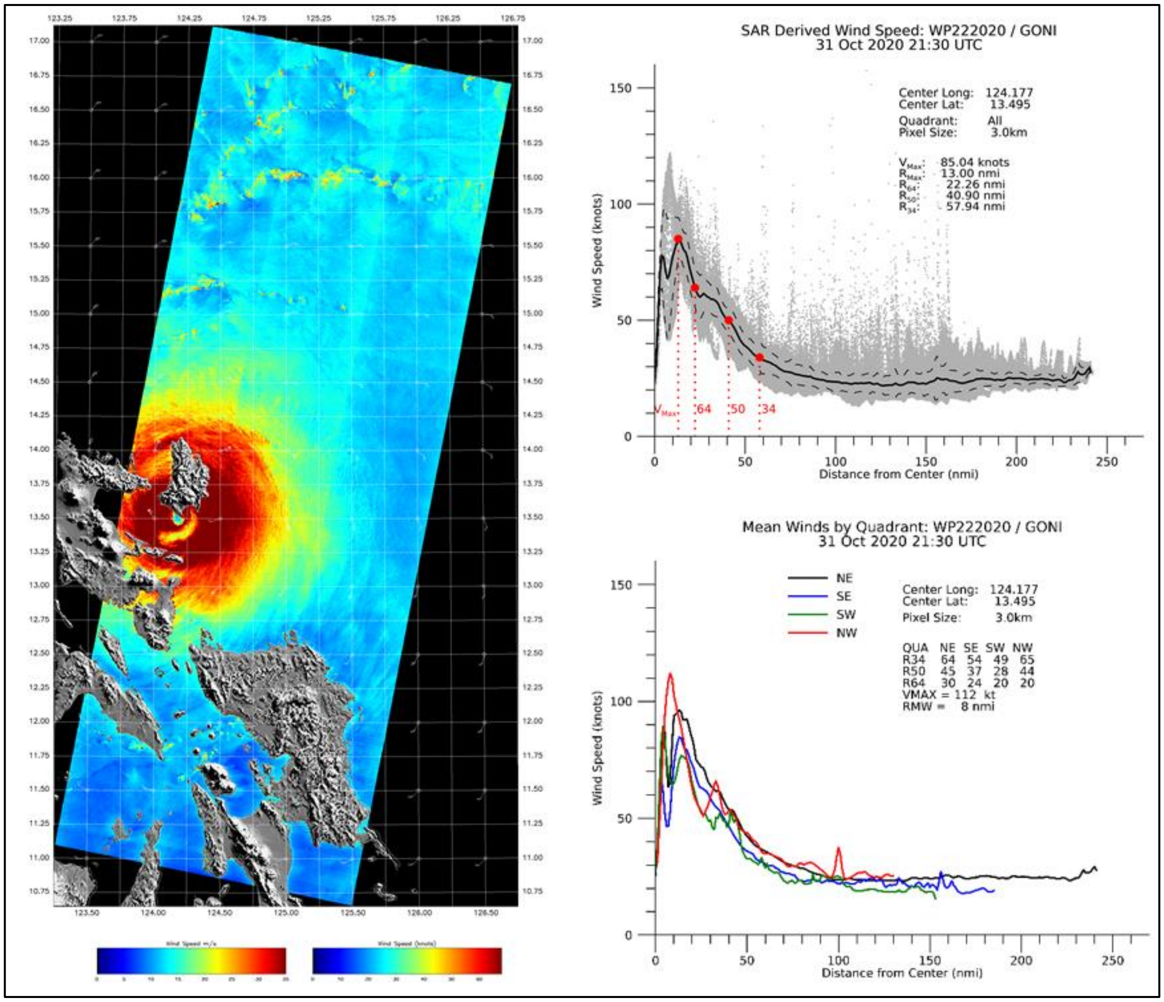


Figure 7-10: Synthetic aperture radar retrieval for TY Goni (A, left) at 2130Z on 31 October by NOAA NESDIS STAR, shortly after the storm made landfall along the southeastern coast of Catanduanes Island, Philippines. An average peak intensity of 85 kts (B, upper right) is noted with a localized peak intensity of 112 kts in the NW quadrant (C, lower right). The decrease in intensity from the peak of 170 kts just a few hours prior is indicative of rapid weakening due to interaction with the underlying terrain.

After reemerging over the South China Sea between 12Z and 18Z on 01 November, 22W struggled to re-intensify. In contrast, 21W had reached its estimated peak intensity of 105 kts within the South China Sea and made landfall along the coast of central Vietnam as a typhoon just a few days prior. When TY Molave traversed the South China Sea, erosion of the STR to the north allowed a deep layer anticyclone to develop over China. This anticyclone provided a robust equatorward outflow mechanism, supporting intensification. In contrast, when STY Goni (22W) entered the South China Sea, a continuous STR had rebuilt to the north. This continuous ridging limited outflow and prevented intensification as Goni tracked towards Vietnam. Additionally, strong low-level winds driven by both TY 21W and deep-layer ridging to the north that developed in the wake of 21W reduced sea surface temperatures and available ocean heat content across the central South China Sea prior to 22W's passage. 22W made its final landfall as a weak tropical depression in Vietnam, a muted end to an otherwise significant and consequential system.

Section 2 Tropical Cyclones 17P and 18P

Introduction

2020 South Pacific Subtropical and Tropical Cyclone Outbreak – In February 2020, a series of subtropical/hybrid and tropical cyclones developed along an elongated area of surface troughing associated with the South Pacific convergence zone, in the vicinity of the Samoan Islands. This event highlighted the challenges of handling complex compact hybrid systems, as well as deficiencies in the Dvorak intensity estimation method. It also underscored once again the vital need for high resolution microwave satellite imagery to assess core structures not readily apparent in geostationary imagery. The JTWC closely monitored the unusual synoptic pattern for potential TC development, and provided real-time support to U.S. National Weather Service (NWS) Weather Service Office (WSO) Pago Pago, in American Samoa. Close coordination and communication, consistent with updated operational support procedures outlined in the 2020 National Hurricane Operations Plan (NHOP), enabled WSO Pago Pago and emergency responders to prepare the local population for this complex and hazardous weather scenario.

Synoptic Environment

On 15 February, a strong surface high formed east of New Zealand (centered near 45°S 178°W). Simultaneously, a region of broad ridging formed to the northeast of American Samoa. This configuration induced a narrow band of low-level troughing, which persisted in the cyclonic flow between the ridges for more than a week. This low-level troughing extended eastward from northeastern Australia, to the north of Fiji and then east of the International Dateline before reorienting to the southeast, providing ideal conditions for convective activity and cyclones to develop (Figure 7-11) near American Samoa.

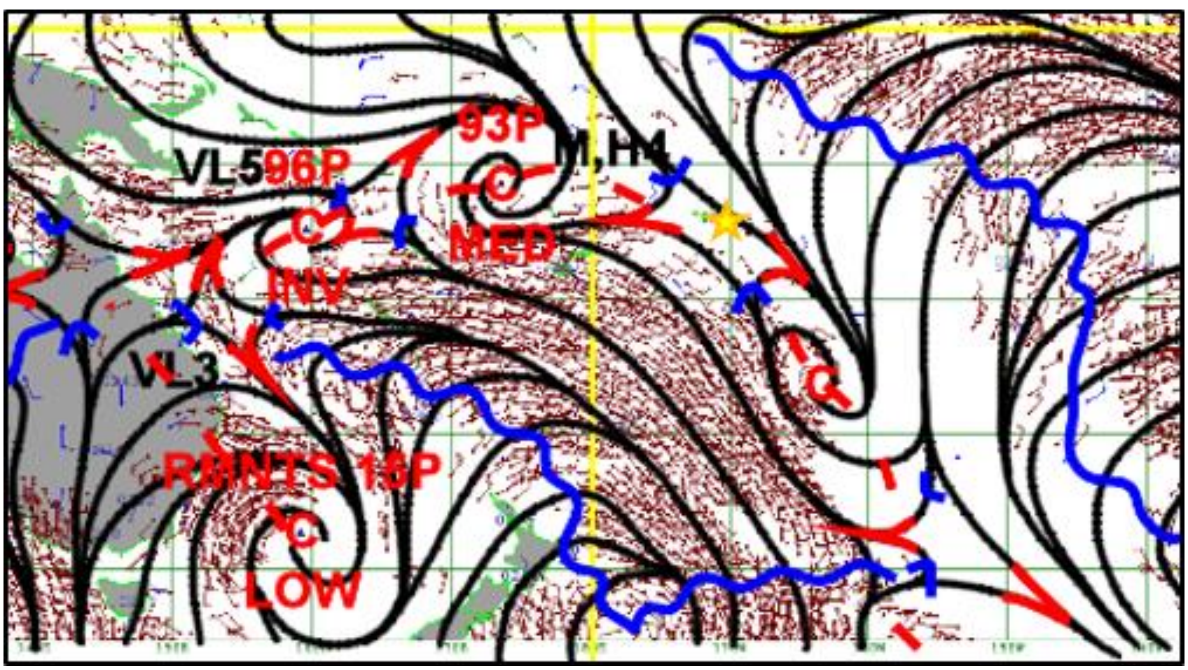


Figure 7-11. Surface level streamline analysis for 15 February 2020, 0000Z. The star symbol marks the approximate location of American Samoa.

During the two-week period that low-level troughing persisted, animated satellite total precipitable water loops revealed deep moisture signatures with small pockets of cyclonic turning spinning up along the trough, indicating a high likelihood of discrete cyclone formation. JTWC classified and monitored four associated cyclonic disturbances as invest areas: 93P, 96P, 97P, and 98P. Initially, conditions along the low-level trough were highly conducive to formation of subtropical/hybrid systems due to the baroclinic influence of a deep upper-level 200mb trough positioned to the south of American Samoa (Figure 7-12a). This upper-level trough induced strong westerly flow aloft, which inhibited the vertical development characteristic of bona-fide tropical circulations, but provided a strong outflow mechanism for convective activity and surface low intensification. The presence of a 500mb trough and associated low pressure region south of American Samoa (Figure 7-12b) and very warm (29-31° Celsius) sea surface temperatures (Figure 7-13) in the region further contributed to the overall favorable environment for convection and subtropical/hybrid cyclone formation. GFS model analysis fields (Figures 7-12a and 7-12f) indicated 40-50kt, 200 mb winds over the area around American Samoa, as well as a low-level trough forming just equatorward of a 500-1000mb thickness gradient. As disturbances developed and propagated eastward along the low-level trough, and around the periphery of subtropical ridging to the north and east, they quickly transited into the baroclinic zone.

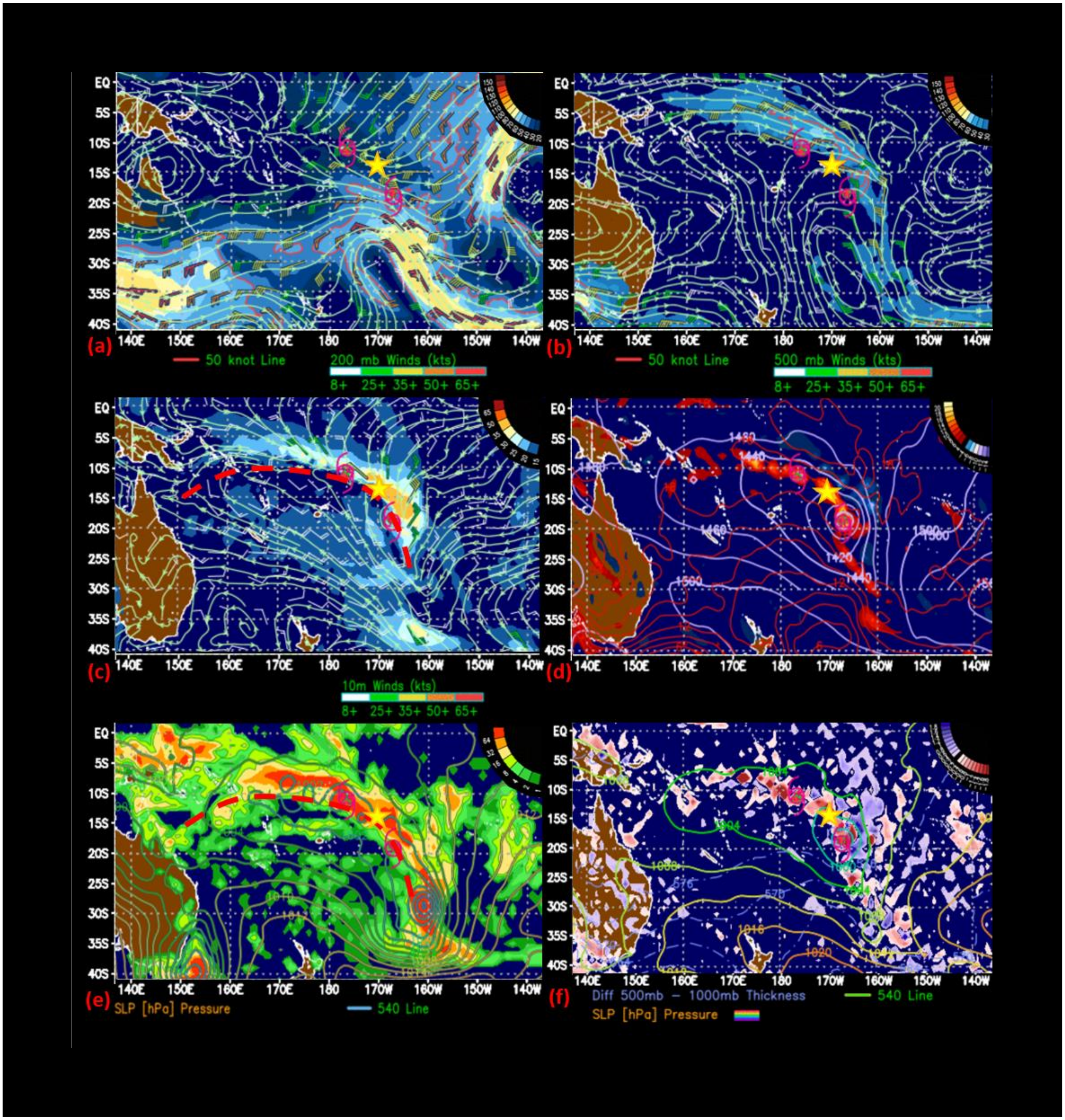


Figure 7-12. 17 February, 1800Z GFS model analyses: a) 200mb streamlines and isotachs (kts), b) 500mb streamlines and wind barbs (kts), c) 10 meter surface winds (kts), d) 850mb heights and relative vorticity values, e) 6-hourly precipitation rates (mm/day) and SLP, and f) 1000-500mb thickness (dm) and SLP. Star symbols mark the approximate location of American Samoa.

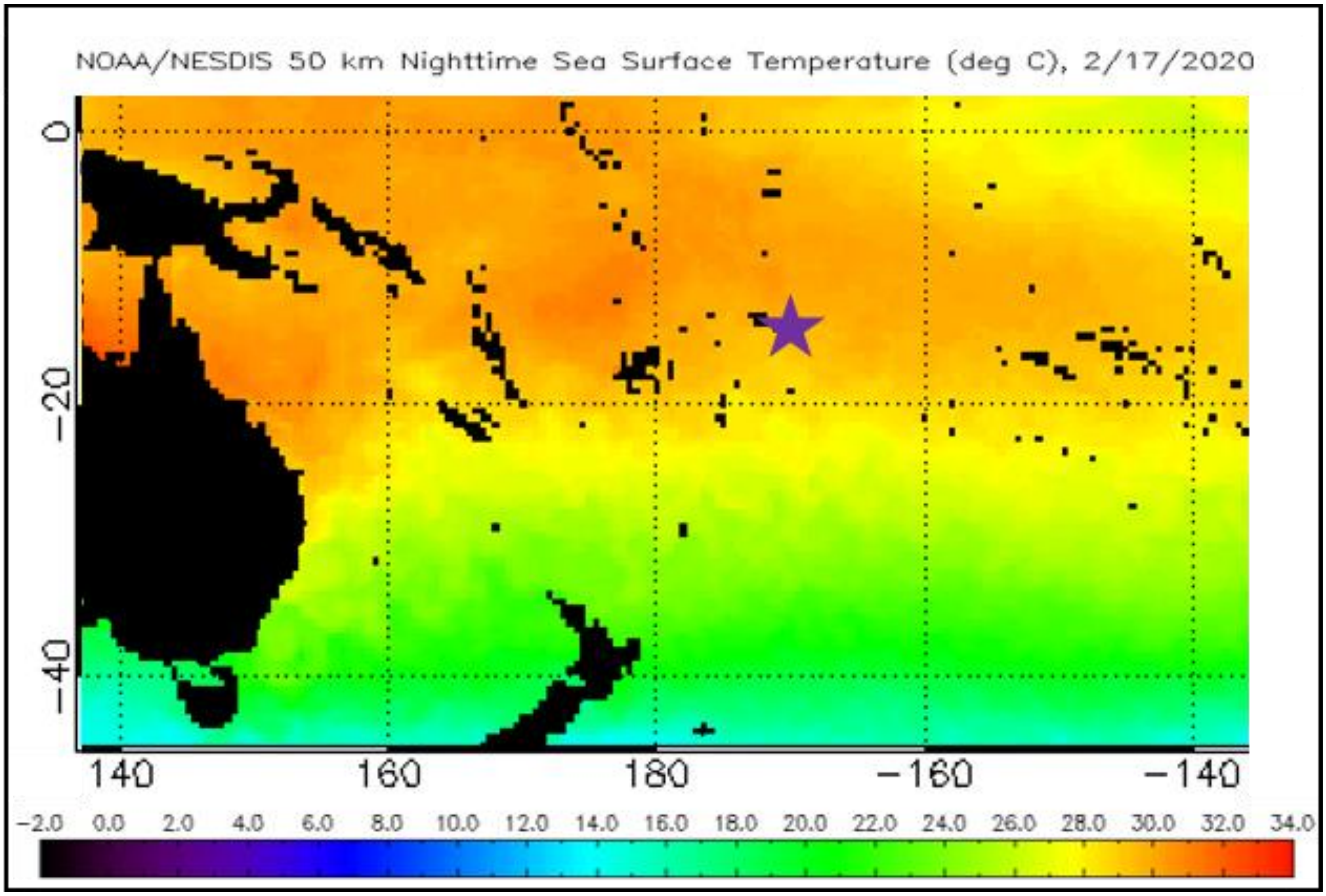


Figure 7-13. 17 February sea surface temperatures. The star symbol marks the approximate location of American Samoa (Image source: NOAA/NESDIS).

Hybrid/Subtropical Lows

JTWC observed a significant increase in cyclone development potential around 13 February, when a disturbance that forecasters had been tracking for about a week (Invest 93P) merged into the extensive South Pacific low-level trough. JTWC simultaneously established coordination with WSO Pago Pago through the NWS Chat platform to discuss Invest 93P and the broader synoptic pattern. This coordination continued as the region became increasingly active with small, spurious circulations rapidly developing within the trough. Beginning on 14 February, JTWC hosted telephone conferences twice daily with NOAA Regional Operations Center staff to provide support and additional forecast details for the complex, hybrid circulations as they developed. These critical updates were incorporated into local forecasts to increase the public's awareness of the approaching dangerous weather conditions, including high winds, increased precipitation, and potential flash flooding. On 15 February, JTWC upgraded Invest 93P's TC development potential to medium, and assessed the system as subtropical with an asymmetric, elongated wind field characterized by stronger (40-50kt) winds within the northeast quadrant and weaker (15-25kt) winds to the southwest. Invest 93P dissipated as it quickly moved southward and commenced extratropical transition upon interacting with the 200mb jet flow.

JTWC designated the next suspect circulation to develop within the active low-level trough as Invest 96P, and set the 24-hour TC development potential to medium on 17 February. Model solutions depicted Invest 96P tracking to the north of Pago Pago with associated surface wind speeds of 30-35kts and an indistinct circulation center. In satellite data, Invest 96P presented a symmetric wind field and vorticity signatures along with a relatively small radius of maximum wind as it developed. However, JTWC assessed the disturbance as subtropical based on its asymmetric moisture and convective signatures, weak - but apparent - horizontal temperature gradient, and associated cold temperature anomaly in the mid- to upper-troposphere.

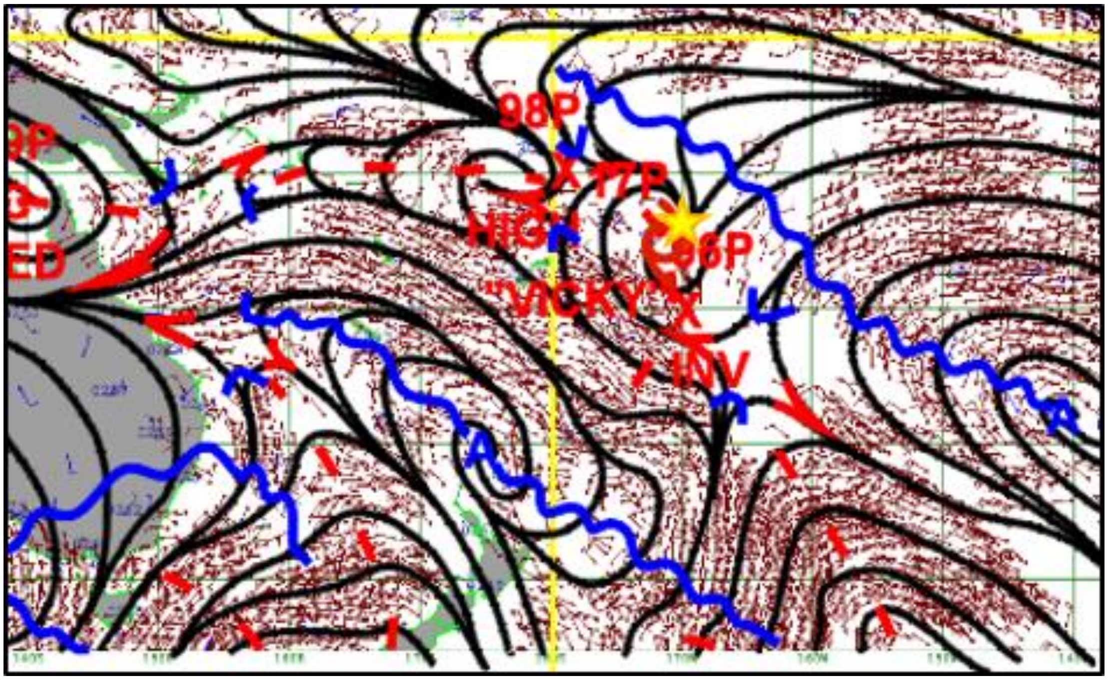


Figure 7-14. Surface streamline analysis for 21 February, 0000Z. The star symbol marks the approximate location of American Samoa.

Following passage of the two hybrid systems (Invests 93P and 96P), the environment slowly shifted to support tropical cyclone development as upper-level winds weakened (25-35kts at 500mb) and the deep 200mb trough that had been positioned over the development area propagated further to the east (see JTWC surface analysis, Figure 7-14, and GFS surface fields, Figure 7-15). These environmental changes allowed new disturbances to consolidate within the low-level trough as warm-core, tropical cyclones.

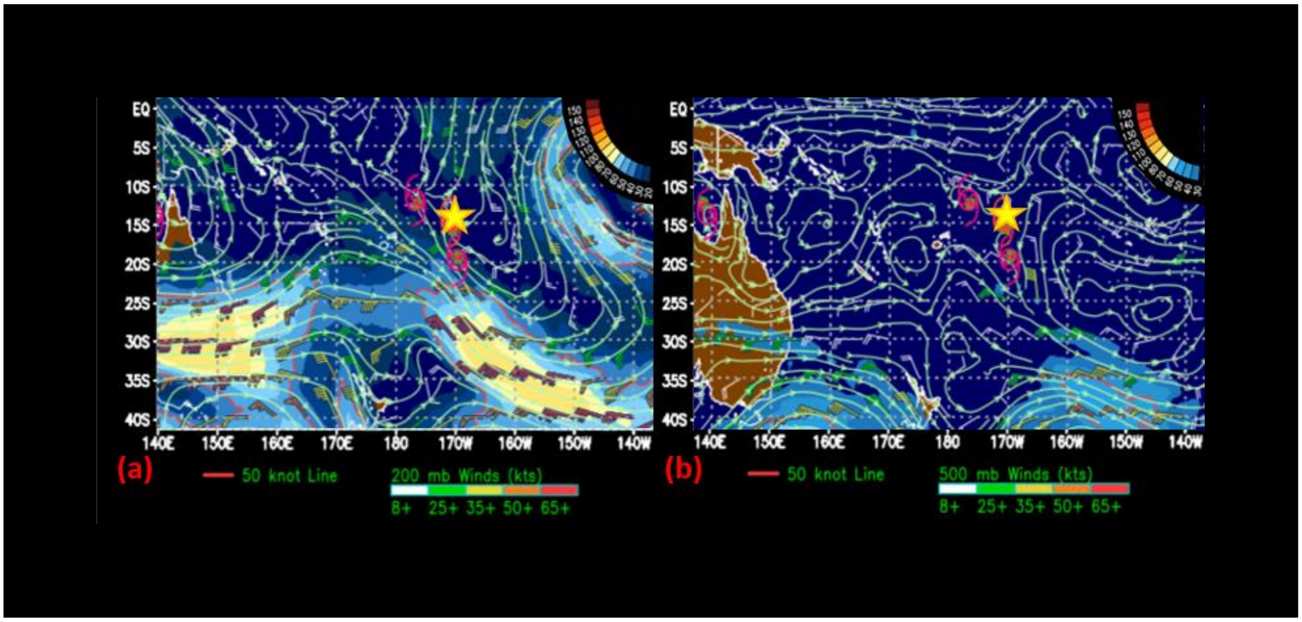


Figure 7-15. 21 February, 0000Z GFS model analyses: a) 200mb streamlines and b) 500mb streamlines. Star symbols mark the approximate location of American Samoa.

Tropical Cyclones

In the wake of the initial subtropical systems, two additional invest areas (97P and 98P) rapidly developed within the persistent low-level trough and intensified into named tropical cyclones. On 19 February, JTWC opened Invest 97P based on satellite imagery depicting a consolidating low-level circulation center with 25kt winds displaced to the northeast. Within five hours, the forecaster issued a TCFA as the disturbance rapidly consolidated in a very favorable environment. When Invest 97P passed just to the west of American Samoa around 1900Z on 20 February, local reports from WSO Pago Pago indicated an observed 20-minute period of 37-40kt sustained winds with gusts around 65kts. JTWC issued the first warning on this system (designated TC 17P) by 2300Z on 20 February. TC 17P (Vicky) reached an estimated peak intensity of 45kts at 0000Z on 21 February (Figure 7-16) as it tracked southeastward along the axis of the low-level trough. The tropical cyclone was short-lived, with JTWC issuing the final warning issued at 0000Z on 22 February as increasingly unfavorable vertical wind shear and an overall hostile environment weakened the system to dissipation.

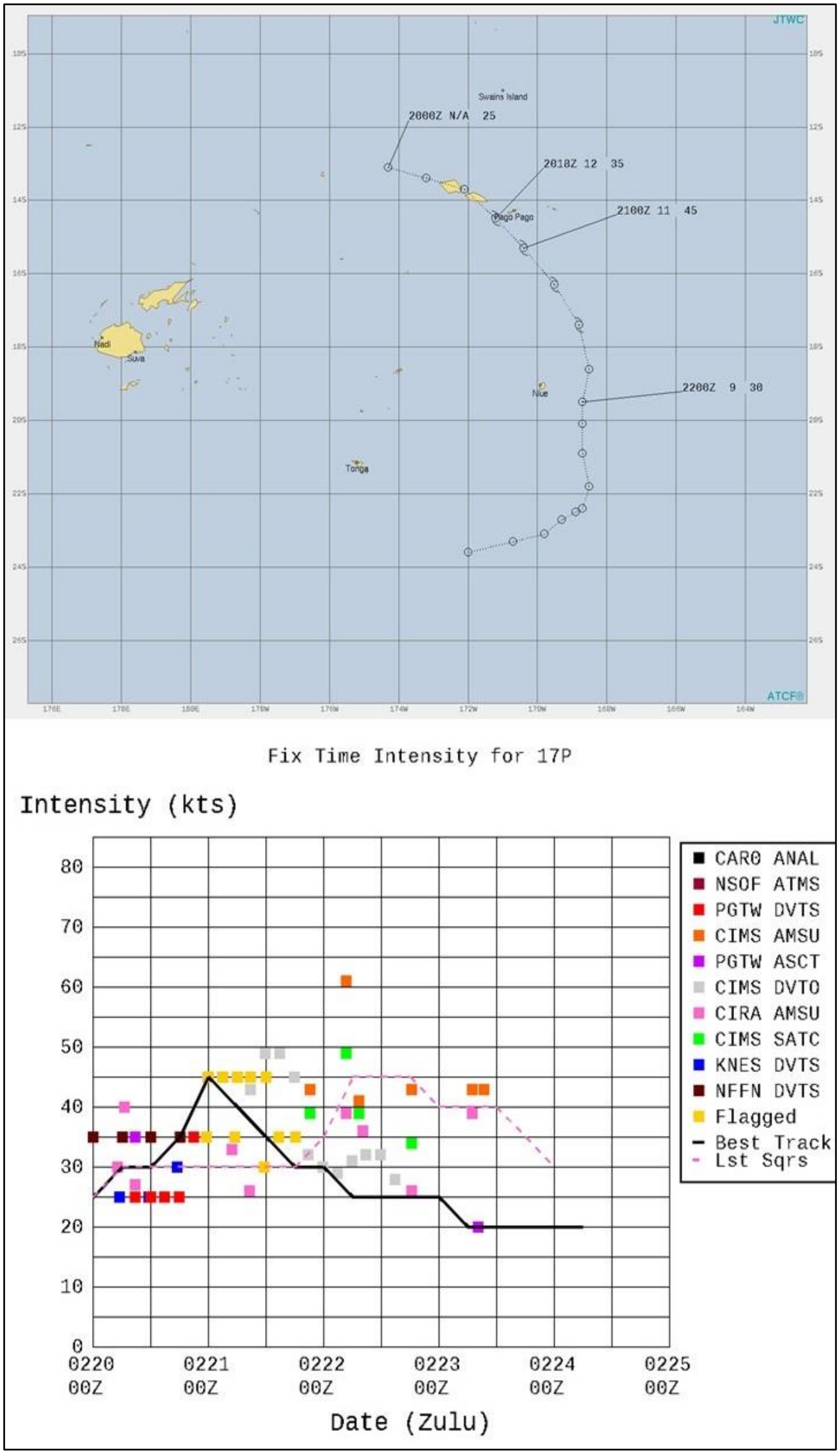


Figure 7-16. TC 17P (Vicky) best track data and Fix Time Intensity plot.

On 20 February, JTWC began tracking Invest 98P as a small area of circulating convection within the persistent trough. Although the system initially appeared ragged in satellite imagery, the TDO quickly upgraded the area's TC development potential to medium based on the expected consolidation and intensification within a very favorable environment as the disturbance tracked toward American Samoa. JTWC issued a TCFA early on 21 February based on scatterometer data, which indicated associated 25-30kt surface winds (not shown). JTWC issued the first warning on this system – designated as TC 18P (Wasi) – at 1200Z on 21 February, anticipating that the system would intensify to at least 35kts as it approached American Samoa. Unfortunately, due to microwave data latency and inherent difficulty associated with analyzing small, compact systems like 18P, JTWC underestimated the system's intensity at the time of the first warning. Throughout the first 12 hours of issuing warnings, JTWC experienced multi-hour delays in receiving microwave satellite imagery. Late-arriving imagery eventually revealed a major discrepancy between a very organized microwave structure and disorganized flaring convection apparent in most of the corresponding infrared and visible imagery available in real-time. Specifically, by 0000Z on 22 February, delayed microwave imagery indicated the presence of a ragged microwave eye from as early as 211247Z (Figure 7-17). As the forecasters analyzed these images, they also identified the very brief presentation of a "dimple," potentially associated with nascent eye formation, in coincident infrared satellite imagery. This information suggested that TC 18P had been significantly stronger than initially analyzed at the first warning time. In fact, the data showed that TC 18P was in the midst of a weakening trend by 0000Z on 22 February, and that the peak intensity had actually occurred around 6-12 hours earlier.

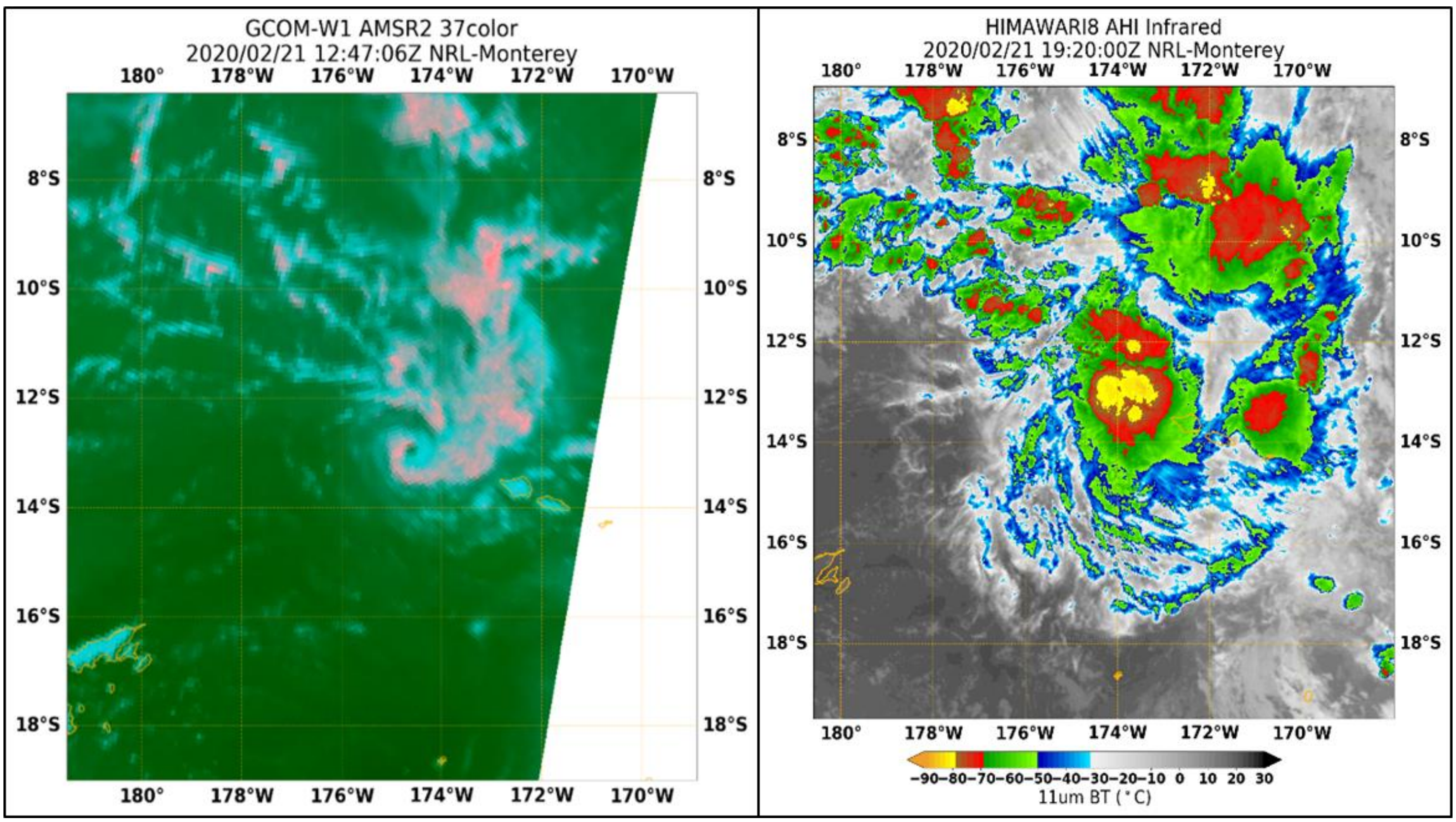


Figure 7-17. 211247Z February AMSR2 37 GHz color composite image and 211920Z February infrared satellite imagery.

The forecaster adjusted TC 18P's previous intensities upward within JTWC's local storm data archive after discovering the discrepancies evident in microwave imagery. The 21 February, 1800Z intensity was adjusted to 60kts – the system's peak. The forecaster also added remarks to the third warning indicating that the system had been stronger than analyzed and forecasted in the previous warnings. Due to its small, compact nature (Figure 7-18), the Dvorak intensity estimates for this system were consistently too low, resulting in large discrepancies between the post-analysis, final best track intensity, and the Dvorak estimates (Figure 7-19). TC 18P continued to move south-southeastward for the duration of the forecast, gradually weakening until dissipation around 1200Z on 23 February.

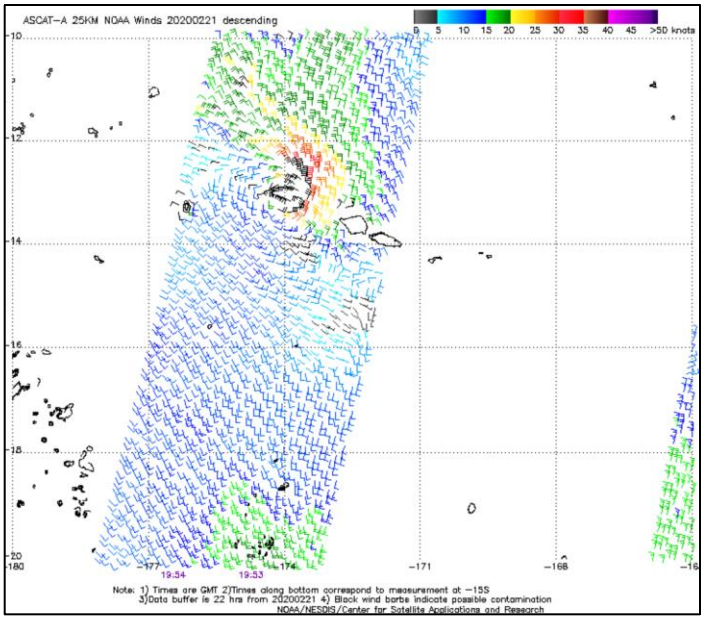


Figure 7-18. 211954Z Metop-A ASCAT 25-km pass showing the compact surface wind field for TC 18P (Wasi).

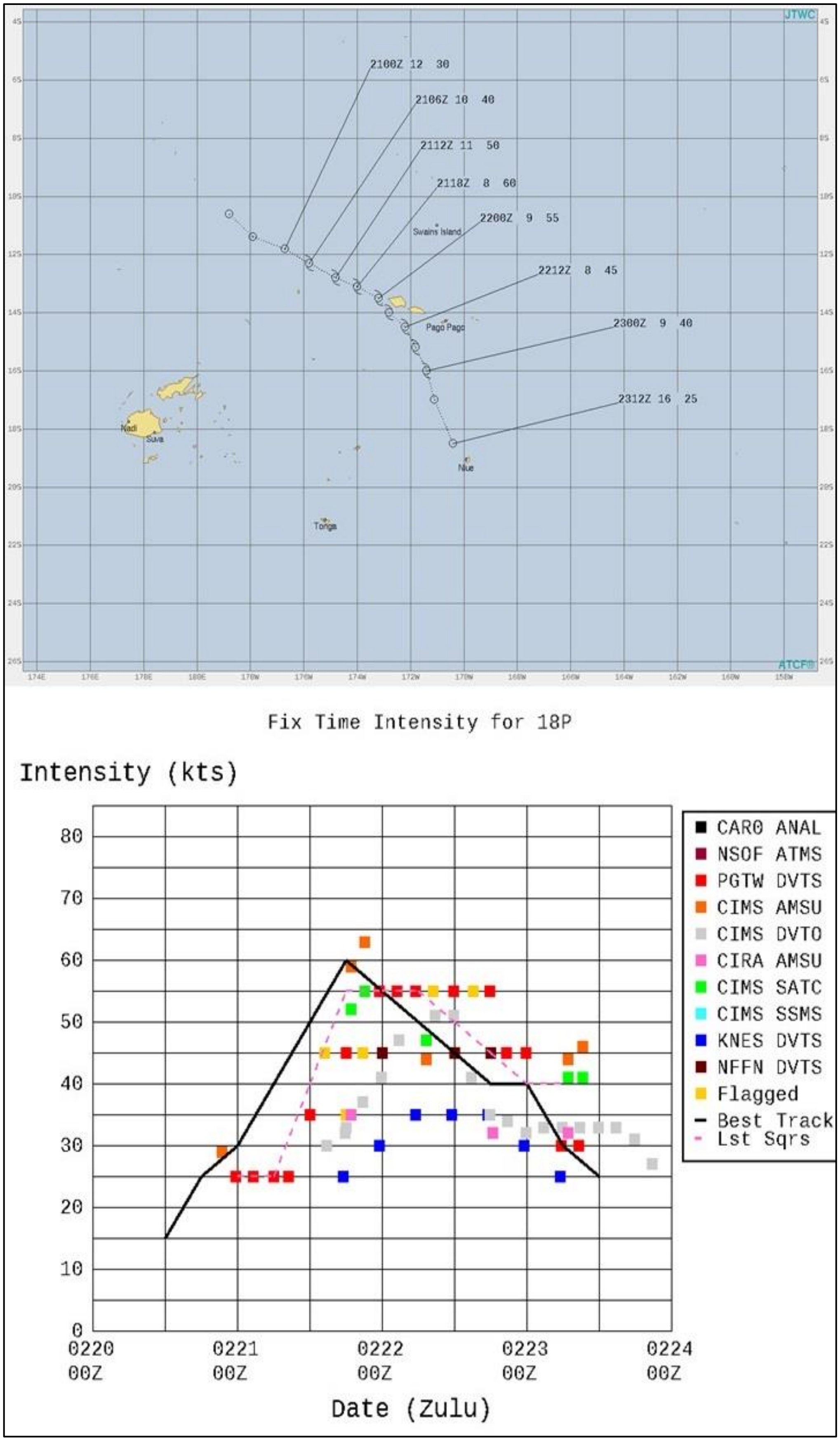


Figure 7-19. TC 18P (Wasi) best track data and Fix Time Intensity plot.

Operational Impacts

Although the systems that formed along the persistent South Pacific low-level trough in February narrowly missed a direct track over the Samoan Islands, the hybrid lows created hazardous conditions to include dangerous surf, high winds and flash flooding. Activity along the trough brought 18.37 inches of rainfall to Pago Pago, exceeding the monthly average of around 13 inches and comprising a large portion of the new monthly record of 32.73 inches set that month (Malala, 2020). For the very wet year as a whole, WSO Pago Pago surpassed the previous annual rainfall record of 165.48 inches (1981) to set a new annual record of 191.39 inches in 2020 (Malala, 2020).

JTWC maintained open communication with WSO Pago Pago throughout this highly active period, to include teleconferences and aforementioned collaboration through the NWS Chat platform. This collaboration reflected an emerging operational relationship between JTWC and WSO Pago Pago that was codified in the 2020 NHOP. Specifically, the NHOP states that “JTWC will consult with WSO Pago Pago regarding all tropical cyclones having the potential to impact American Samoa within the forecast period.” JTWC is required to inform WSO Pago Pago prior to issuing the initial and final advisories for a system, and to notify the office if there is a significant change to the forecast intensity or forecast track. WSO Pago Pago is tasked with issuing public advisories, watches, and warnings within the South Pacific Ocean, specifically the Territory of American Samoa, using JTWC’s products as guidance.

Finally, JTWC provided real-time operational support via the DoD Commercial Virtual Remote environment’s Microsoft Teams application to WSO Pago Pago. The collaborative software enabled JTWC and the regional office to effectively communicate forecast philosophies, share imagery, and conduct collaborative after-action analysis of each event.

Summary and Conclusion

The persistent, stationary, hybrid, and evolving nature of the February 2020 low-level trough near American Samoa introduced significant support challenges for both JTWC and WSO Pago Pago. The trough spawned numerous, compact systems characterized by both subtropical and tropical characteristics. Of the four disturbances that formed within the trough over a two-week period, two areas developed into named tropical cyclones that tracked through WSO Pago Pago’s area of interest. JTWC effectively supported WSO Pago Pago through teleconferences and direct forecaster-to-forecaster communication while the trough persisted, facilitating early notification to the populace and resource protection throughout the region. Close coordination during this event laid the groundwork for a newly-codified real-time support paradigm and set the stage for an effective working relationship between JTWC and WSO Pago Pago in the years ahead.

References

Malala, H. (2020). American Samoa Climate 2020 [PDF slides].
U.S. Department of Commerce / National Oceanic and Atmospheric Administration Office of the Federal Coordinator for Meteorological Services and Supporting Research, 2020: National Hurricane Operations Plan. FCM-P12-2020, 178 pp.

Section 3 Tropical Cyclone 25P (Harold)

Overview

Tropical cyclone (TC) 25P (Harold) formed near the Solomon Islands on 02 April and tracked steadily southeastward throughout its lifecycle (Figure 7-19). Slowing forward motion and environmentally favorable conditions allowed TC 25P to rapidly intensify into a super typhoon equivalent tropical cyclone, which made landfall over the islands of Vanuatu at peak intensity with devastating effects. The system was identified as the second strongest TC to impact Vanuatu behind TC Pam in 2015. The system also brought heavy rainfall and strong winds to Fiji as it passed to the south of Viti Levu. JTWC track forecasts (Figure 7-20) and multi-model consensuses (Figure 7-21) were highly consistent and position errors were below mean annual errors at all lead times except tau 120, which had larger errors due to faster-than-expected along-track speeds (Table 7-1).

Previous Annual Tropical Cyclone Report storm reviews have showcased numerous cases of RI and ERC; however, TC 25P provided a unique opportunity to examine the reliability and biases of operational intensity prediction guidance as the cyclone underwent multiple phases of RI, ERC, and weakening during its lifecycle. Primary intensity prediction aids did not reliably forecast observed intensity changes for TC 25P, particularly RI events, although the UW-CIMSS M-PERC technique did successfully predict the onset of ERC. This paper discusses the intensity forecast challenges associated with TC 25P and examines the potential applicability of another data source – real-time lightning data – as a complementary predictor for RI and weakening cycles in an operational setting, particularly when primary guidance is inaccurate or unavailable.

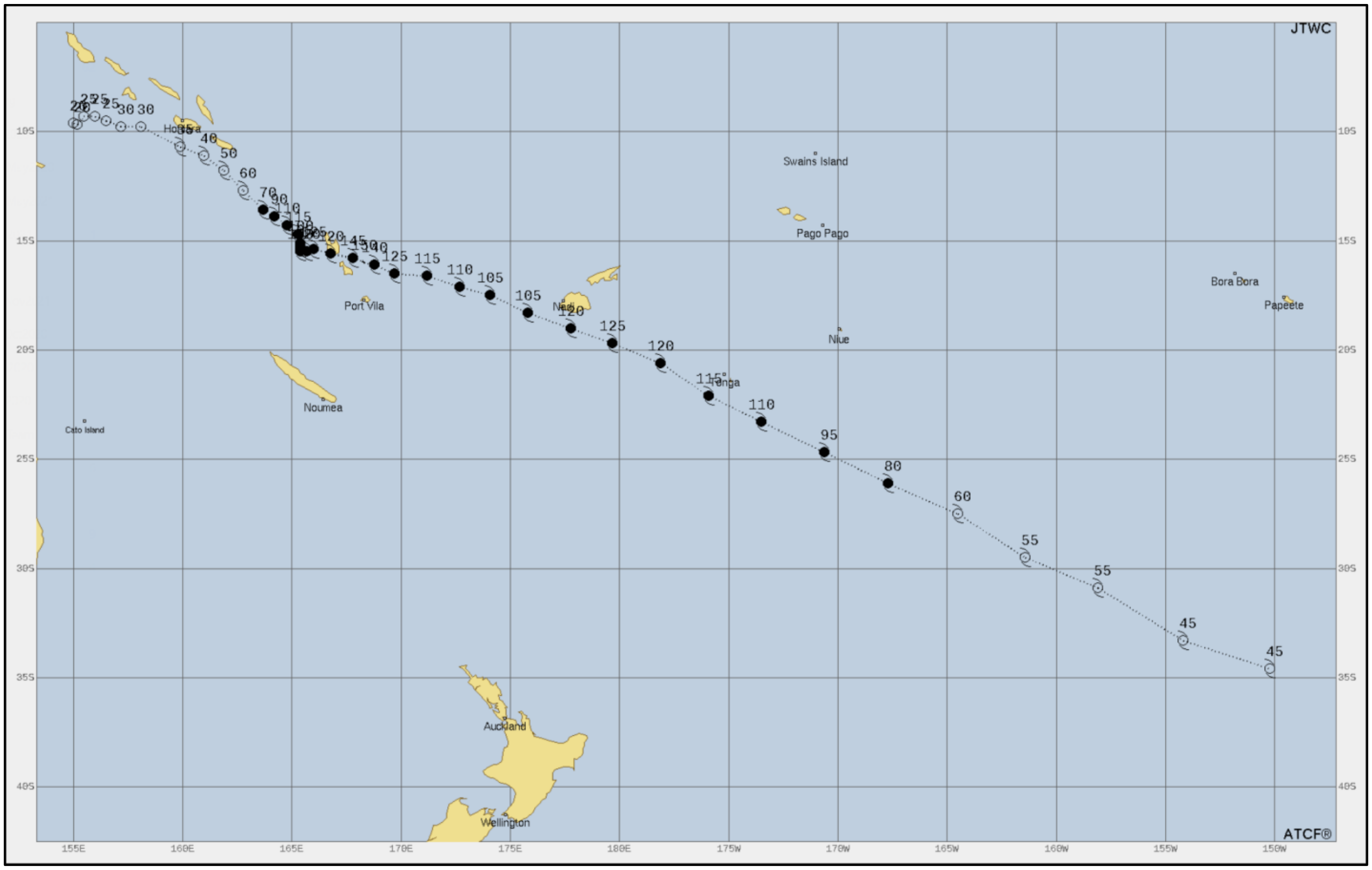


Figure 7-19: Official JTWC best track for TC 25P (2020) labeled with maximum sustained wind (V_{max}) values.

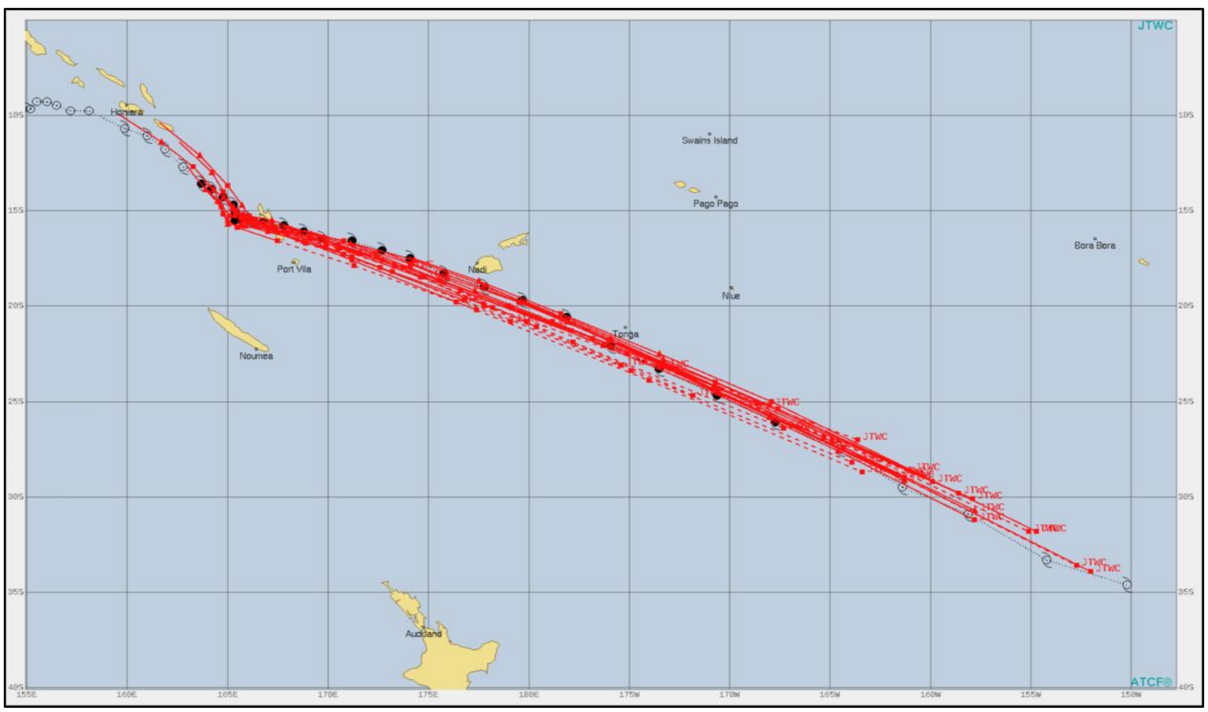


Figure 7-20: Official JTWC forecasts overlaid onto the official JTWC best track for TC 25P (2020).

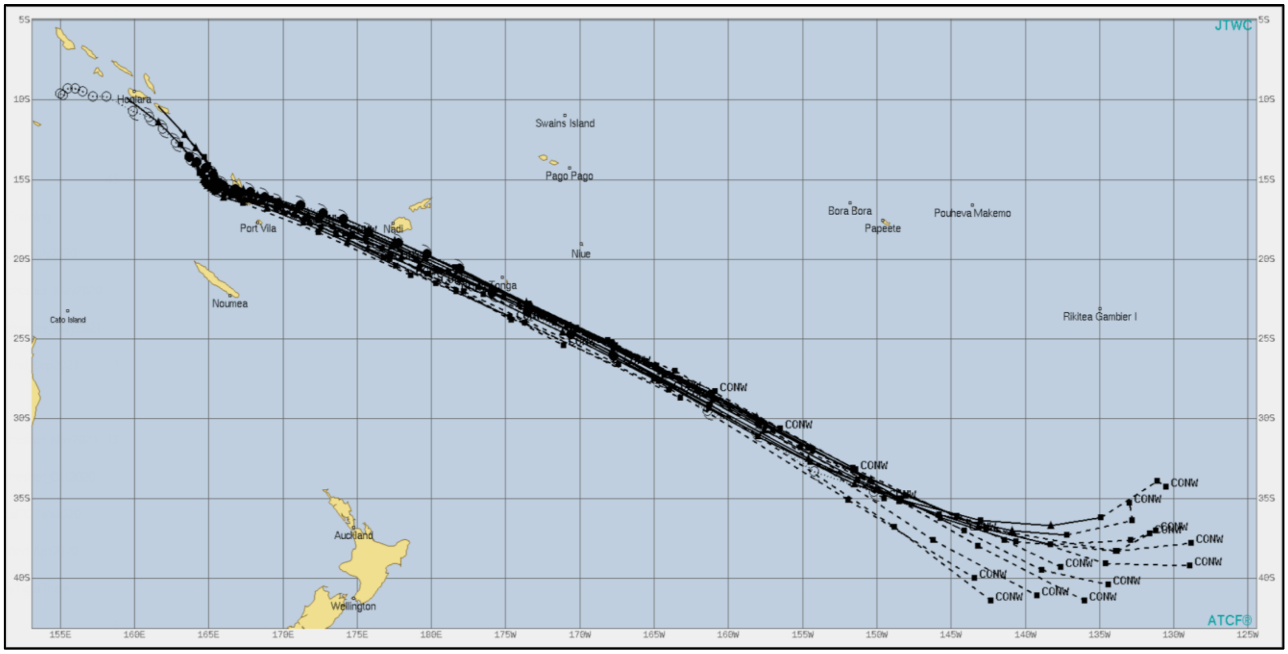


Figure 7-21: Multi-model consensuses (CONW) overlaid onto the official JTWC best track for TC 25P (2020).

	24	48	72	96	120
JTWC	27.4	51.6	111.2	151.9	285.1
CONW	29.1	49.3	93.0	130.0	209.2
MEAN	45.9	76.2	111.7	154.9	213.6
#CASES	24	20	16	12	8

Table 7-1: Official JTWC and CONW homogeneous forecast track errors (nm) for TC 25P (2020) with the 5 year (2016-2020) mean forecast track error.

Contrary to the generally straight-forward steering environment and highly-consistent track forecasts for TC 25P intensity considerations were more complex. TC 25P initially underwent rapid consolidation followed by sustained rapid intensification (RI ≥ 30 knots in 24 hours) from 02/12Z to 04/12Z (RI-1, 30 to 115 knots). After a brief period of weakening (04/12Z to 05/00Z), TC 25P rapidly intensified again twice within a 36-hour period from 05/00Z to 05/18Z (RI-2, 95 to 125 knots) and 06/00Z to 06/08Z (RI-3, 120 knots to the peak 150-knot intensity) (Figure -22).

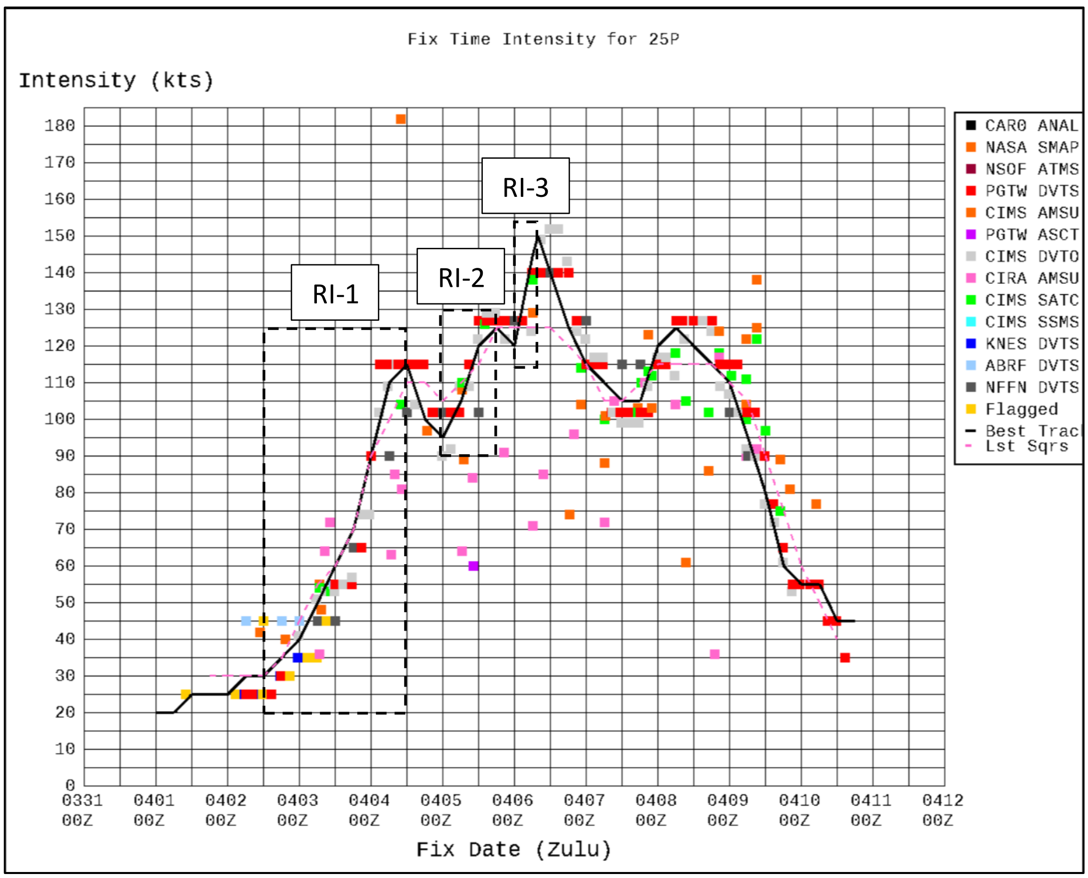


Figure 7-22: Fix time intensity plot for TC 25P (2020).

Due to the multiple phases of RI and ERCs, intensity forecasting for TC 25P presented significant challenges to the JTWC forecasters. Typically reliable intensity guidance exhibited significant negative biases during the rapid intensification phases (Tables 7-2 and 7-3). Both the HWRF and the Rapid Intensification Prediction Aid (RIPA) failed to capture the sustained

RI that occurred from 02/12Z to 04/12Z (Figure 7-22), as well as subsequent RI events that pushed the peak intensity to 150 knots (Figure 7-23). RIPA intensity guidance (Knaff et al. 2020), which is triggered when RI probabilities exceed 40%, was limited to the 03/00Z - 04/00Z time period (the middle of RI-1) but did not trigger either prior to or during RI-2 and RI-3.

	24	48	72	96	120
JTWC	-8.6	-16.6	-25.7	-29.1	-33.6
ICNW	-16.4	-23.2	-27.3	-33.2	-39.6
HHFI	-10.0	-9.8	-12.1	-25.9	-46.4
COTI	-17.0	-26.4	-33.6	-25.6	-13.7
CTCI	-14.5	-24.8	-26.9	-33.5	-36.9
#CASES	22	19	15	11	7

Table 7-2: Official homogeneous mean intensity forecast biases (knots) for TC 25P (2020) for the JTWC official forecasts, the intensity forecast consensus (ICNW), Hurricane Weather Research and Forecasting Model (HHFI), COTI (COAMPS-TC, NAVGEM initial conditions), CTCI (COAMPS-TC, GFS initial conditions).

	12	24
RIPA	-19.6	-20.0
#CASES	5	5

Table 7-3: RIPA (Rapid Intensification Prediction Aid) mean intensity forecast biases (knots) for TC 25P (2020) (RIPA forecasts are limited to Taus 12 and 24)

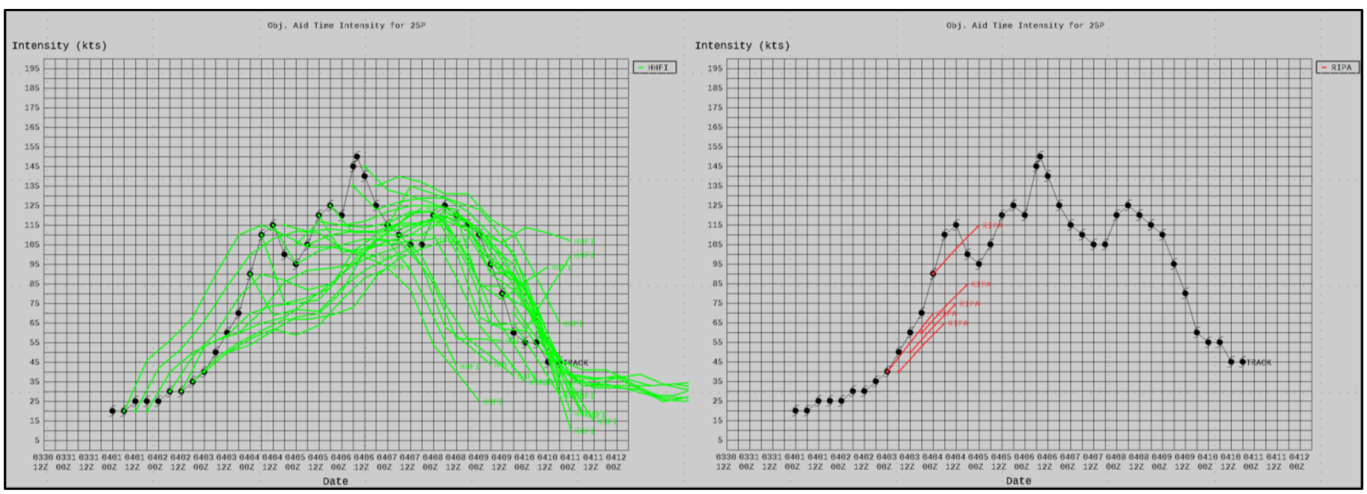


Figure 7-23: Hurricane Weather Research and Forecasting (HHFI) forecasts (left) and the statistical-dynamical Rapid Intensification Prediction Aid (RIPA) forecasts for TC 25P (2020).

TC 25P weakened slightly from 125 to 120 knots between 05/18Z and 06/00Z as it skirted the southern coast of Vanuatu's largest island, Espiritu Santo, which has elevated terrain as high as 6164 feet (Figure 7-24). A series of hourly enhanced infrared satellite images (Figure 7-25) from 05/2100Z to 06/1200Z indicate that a small, well-defined eye persisted as the system passed over Espiritu Santo, briefly back over water, and to the southeast of Pentecost Island, Vanuatu. Although the core convection weakened slightly over Espiritu Santo, TC 25P rapidly intensified from 120 knots to 150 knots after the system reemerged over water, and intensity peaked as the system approached Pentecost Island.

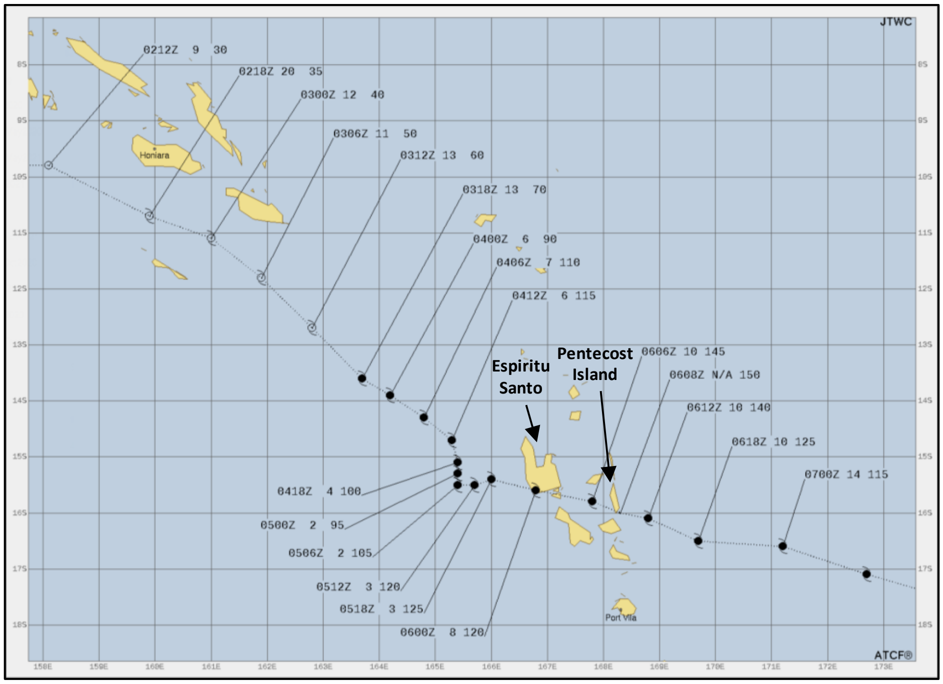


Figure 7-24: Segment of official JTWC best track (02/12Z to 07/00Z) for TC 25P (2020) labeled with DTG, track speed and maximum sustained wind (V_{max}) values.

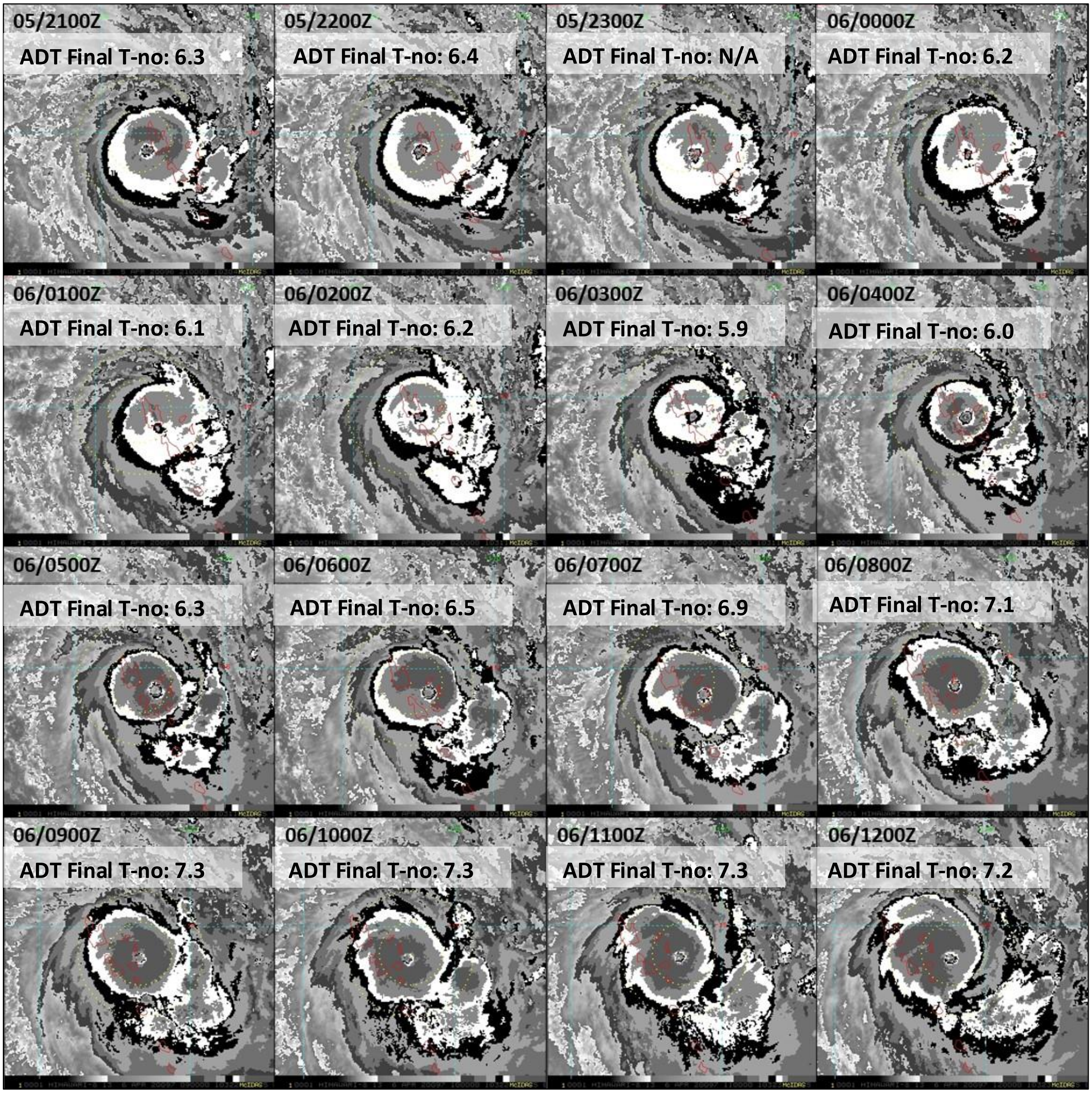


Figure 7-25: Time sequence of Himawari-8 enhanced infrared images with the BD-curve enhancement from 05/2100Z to 06/1200Z depicting TC 25P's passage over Vanuatu (Images courtesy of CIRA RAMMB).

A fortuitous 06/0713Z Sentinel-1A SAR pass (Figure 7-26, left) provided a high-resolution glimpse into the TC 25P's small (RMW=7nm), intense core as the cyclone made landfall on Pentecost Island. The NESDIS STAR wind speed estimate, based on 3-km resolution subsampled SAR data, revealed maximum sustained winds of 149 knots over the northeastern quadrant, with significantly lower winds ranging from 110 to 125 knots over the remaining quadrants (Figure 7-26, right). During the post-storm best track review, this SAR data provided primary support for adjusting the best track intensity at 06/0600Z from 135 to 145 knots and adding a 06/0800Z intermediate best track position at the peak intensity of 150 knots. These reassessments were also supported by CIMSS ADT final-T numbers (Figure 7-25) ranging from 7.3 to 7.4 (149-152 knots) from 06/0840-1140Z and CIMSS ADT raw T-numbers peaking at 7.4 (152 knots) from 06/0710 to 0940Z. The reassessed maximum intensity remained within the range of uncertainty associated with subjective Dvorak estimates, which peaked and plateaued at 140 knots.

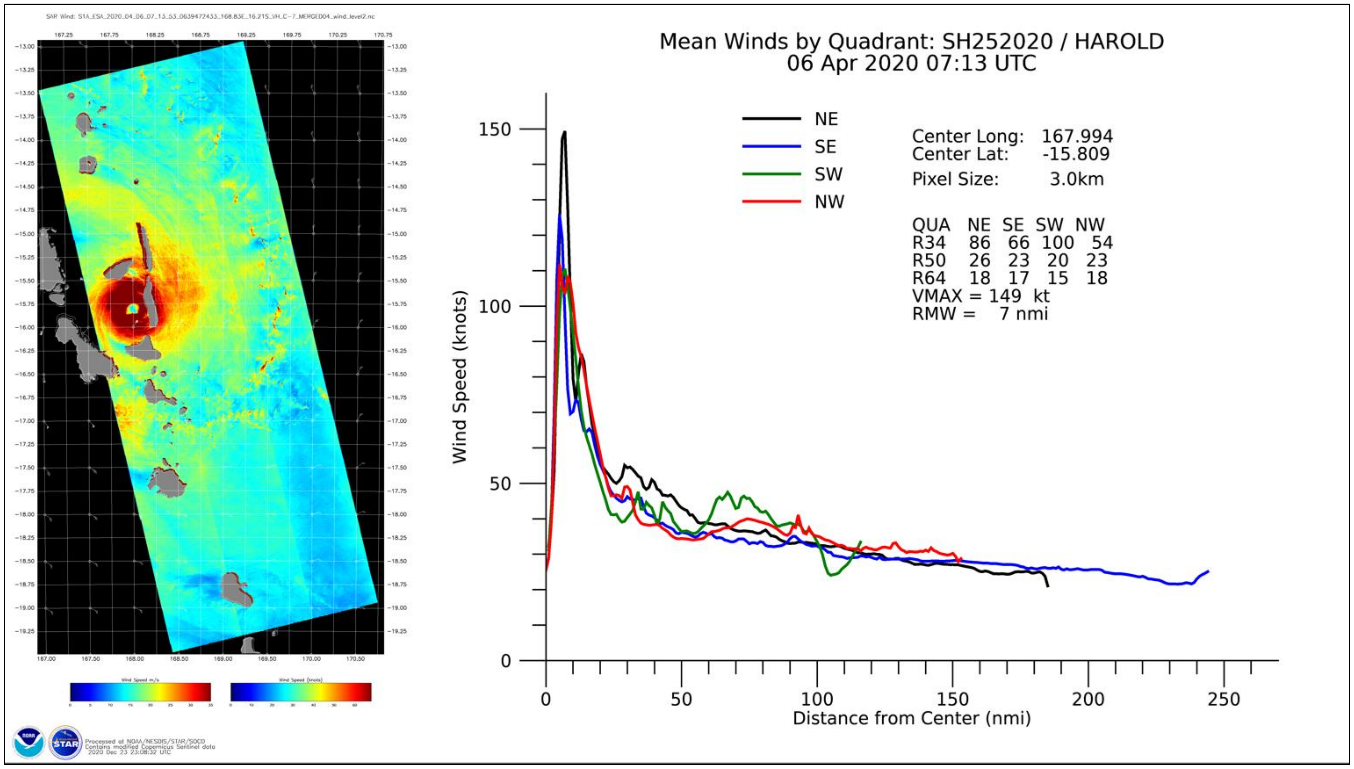


Figure 7-26: 06 April, 0713Z Sentinel-1A SAR image (left) showing a compact, intense wind structure for TC 25P (2020) and the corresponding Mean Winds by Quadrant plot (right) (Image courtesy of the NOAA/NESDIS Center for Satellite Applications and Research).

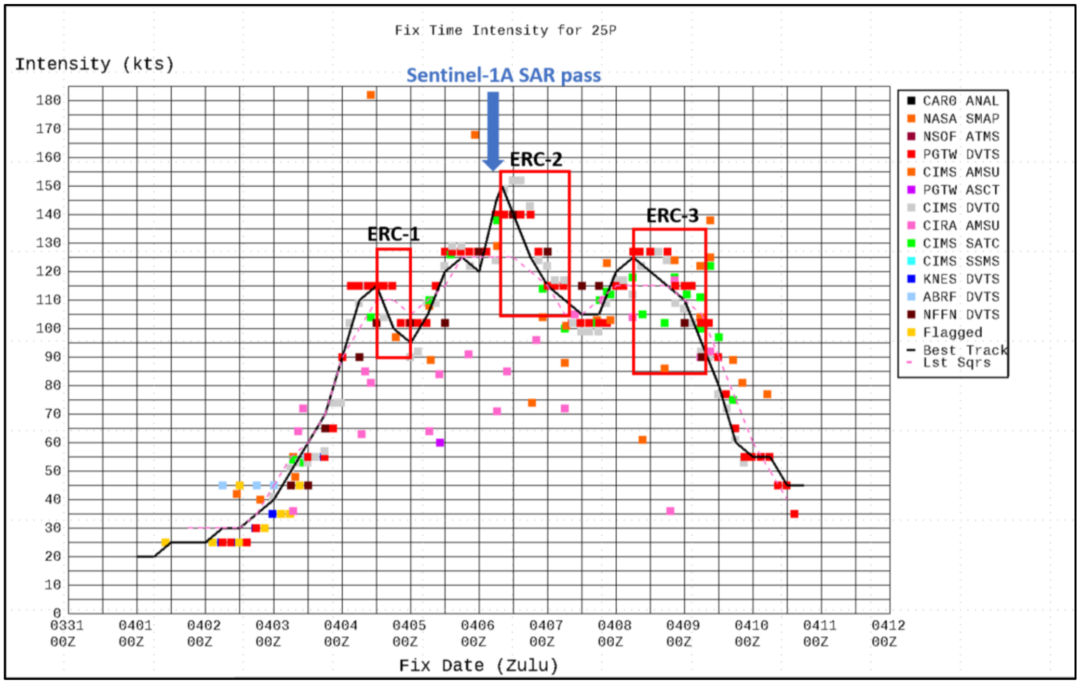


Figure 7-27: Fix Time Intensity Plot for TC 25P. Possible eyewall replacement cycles (ERC) based on the UW-CIMSS M-PERC product are indicated by the red boxes. A blue arrow denotes a corresponding 06/0713Z Sentinel-1A SAR pass supporting the 150 knot peak intensity estimate, which occurred just prior to the system's center making landfall on Pentecost Island, Vanuatu.

A pronounced weakening trend commenced after 06/0900Z (Figure 7-27), especially over the eastern semicircle, likely associated with the onset of an ERC. This ERC is clearly evident in a sequence of microwave images (Figure 7-28) that initially show an outer spiral band wrapping around the very small inner, pinhole eyewall followed by development of a secondary eyewall by 07/0101Z (GPM GMI 89H image) and erosion of the original inner eyewall. Further weakening occurred until the system reconsolidated and a new, defined microwave eye feature formed by 07/1819Z, just prior to the system impacting Fiji. ERC was predicted accurately by the UW-CIMSS M-PERC product, which showed ERC onset occurring at about 06/0300Z when the 'Full Model' values first exceeded the 50% threshold. The 'Full Model' values continued to rise sharply to near 100% by 06/1200Z, with an ERC clearly evident in the converging branches of the outer and inner eyewall ring scores (Figure 7-29).

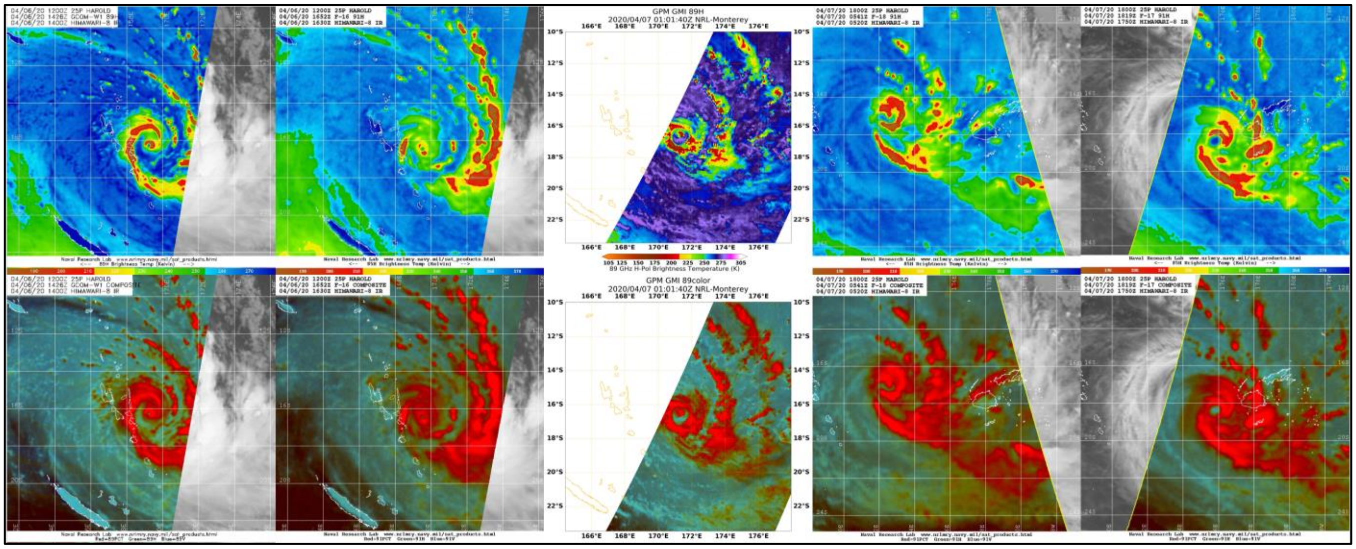


Figure 7-28: Time sequence of microwave images from 06/1426Z to 07/1819Z depicting TC 25P's ERC (Courtesy of NRL).

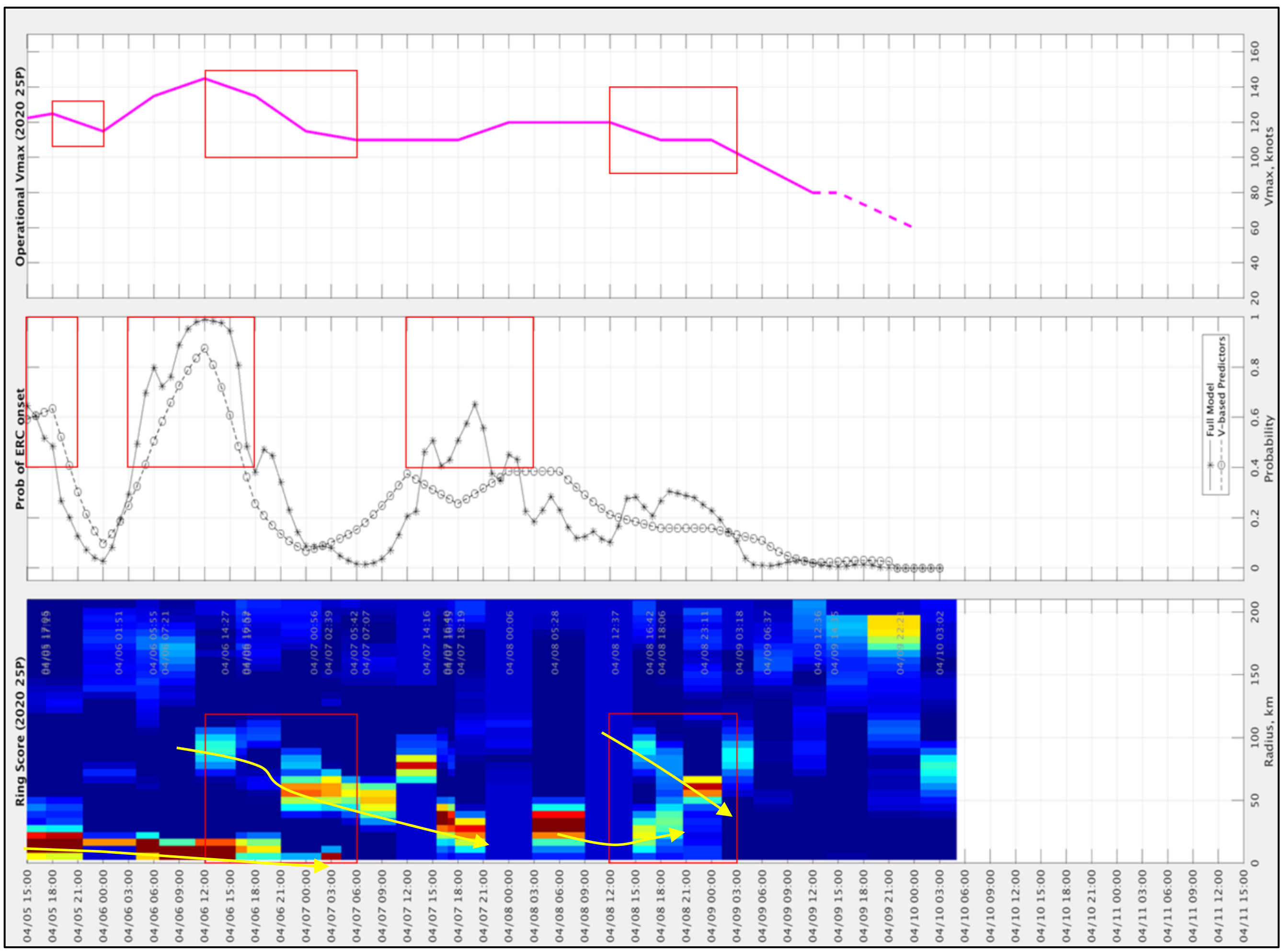


Figure 7-29: TC 25P M-PERC (Microwave Probability of ERC) image showing the operational V_{max} (top panel, unofficial data prior to post-storm review and revisions), probability of ERC onset (middle panel), and ring score (bottom panel) (Image courtesy of UW-CIMSS).

Real-time lightning data

The relationship between bursts of lightning activity (both in-cloud and cloud-ground) in or near the core of a tropical cyclone (TC) has been studied extensively over the past two decades (Molinari et al. 1999; Squires and Businger 2008; DeMaria et al. 2012; Lin and Chou 2020; Stevenson et al. 2018; Vagasky 2017). Recent improvements in the availability of near real-time lightning location services present an opportunity to utilize lightning data as a complementary tool for nowcasting or forecasting TC intensification, particularly when primary intensity prediction guidance is inaccurate or unavailable. Published research regarding the relationship between lightning activity and TC intensity change, while extensive, is not entirely conclusive and even contradictory. However, available evidence generally supports the hypothesis that inner-core lightning bursts (ICLBs) often occur prior to the onset of intensification. JTWC is just beginning to investigate the potential applicability of real-time lightning data as an operational forecasting tool, primarily using data from the World Wide Lightning Location Network (WWLLN) and Vaisala's Global Lightning Dataset (GLD360). Global Lightning Location Services (LLS) such as WWLLN and GLD360 generally measure the same physical processes, the very low frequency (3 – 30 kHz) waves emanated by lightning discharges, called "sferics." These sferic signals can travel very long ranges and, using time-difference-of-arrival and direction finding, can be geolocated to various degrees of precision (Vagasky 2017; Hutchins et al. 2012). Due to multiple issues including station outages, ionospheric conditions and the minimum detectable energy level of the station, these various networks do not, and cannot, provide 100% detection efficiency. The WWLLN was established in 2004, originally with 18 detection stations scattered across the globe. Since establishment, the network has been expanded to include nearly 70 sensors located on every continent on earth. The increase in stations has increased the overall probability of detection of individual ICLBs. But, as the issues noted above are highly variable, the detection efficiency (DE) is thus also highly variable (Hutchins et al. 2012). Because real-time availability of WWLLN data is limited, it is mostly useful as data source for post-storm analysis and research.

Similar to WWLLN, GLD360 leverages the VLF signal emitted by lightning strokes and is subject to the same issues that impact DE. The GLD360, however, utilizes a larger number of sensors, and applies proprietary waveform recognition and propagation corrections to the time of arrival data to reduce location errors. The GLD360 system has also been updated recently to include more robust processing algorithms (Said and Murphy 2016). GLD360 data is available to JTWC in near real-time, making this source of data potentially useful for nowcasting.

As previously mentioned, available research examining the relationship between ICLBs and intensification is at times contradictory, with some studies suggesting ICLBs are associated with intensification (Molinari et al. 1999, Squires and Businger 2008) or weakening (DeMaria et al. 2012). However, more recent studies have noted distinct correlations between ICLBs and intensification (Lin and Chou 2020), particularly when these events occur within the RMW (Stevenson et al. 2018). Additionally, a study by Vagasky (2017) introduced the concept of the Enveloped Eyewall Lightning (EEL), in which a burst of lightning activity completely envelops or surrounds a tropical cyclone eye and persists for at least six hours preceding subsequent intensification above 130 knots.

As described in Solorzano et al. (2018), real-time lightning data collected by the WWLLN at the University of Washington, is utilized to provide continuous tropical cyclone monitoring via a website known as WWLLN-TC (wwlln.net). This website provides near-real time access to TC centered lightning data, and post-storm summary data to include lightning histogram and density plots and lightning/microwave imagery overlay graphics. For the purposes of this report, all lightning data were obtained from the post-storm analysis section of the WWLLN-TC website.

As discussed earlier, TC 25P underwent multiple periods of RI. We obtained TC-centered lightning data from the WWLLN monitoring website for the entirety of the system's lifecycle and found a weak correlation between several ICLBs and the RI periods. Figure 7-30 depicts minimum sea level pressure (mb), maximum wind speed (knots) and lightning flash density (flashes per hour) as measured by the WWLLN for the area within 100 km of the assessed best track position for TC 25P (hereafter the "inner core"). As depicted in Figure 7-30, four distinct ICLBs occurred shortly prior to or during periods of intensification or rapid intensification. ICLB 1 (red ellipse) featured a very large number of flashes during the late-stages of the first RI event, about 6-12 hours prior to the first peak intensity of 115 knots. A secondary peak flash count occurred after the onset of an ERC. ICLB 2 (green ellipse) featured a secondary, lower flash count ICLB in the early hours of 05 April, following completion of the ERC and the beginning of another period of RI. ICLB 3 (gold ellipse) was a low flash density event that occurred approximately six hours prior to the system reaching peak intensity (as observed by SAR). ICLB 4 (blue ellipse) feature a relative large number of flashes during a period of weakening (corresponding to another ERC) that preceded a brief intensification late in the storm's lifecycle. Figure 7-31 below shows the geographical location and timing of ICLBs 1 through 3 along the track and intensity history for TC 25P. Figure 7-32 shows an overlay of lightning data (black circles) on corresponding 91GHz microwave imagery (+/- 15 minutes).

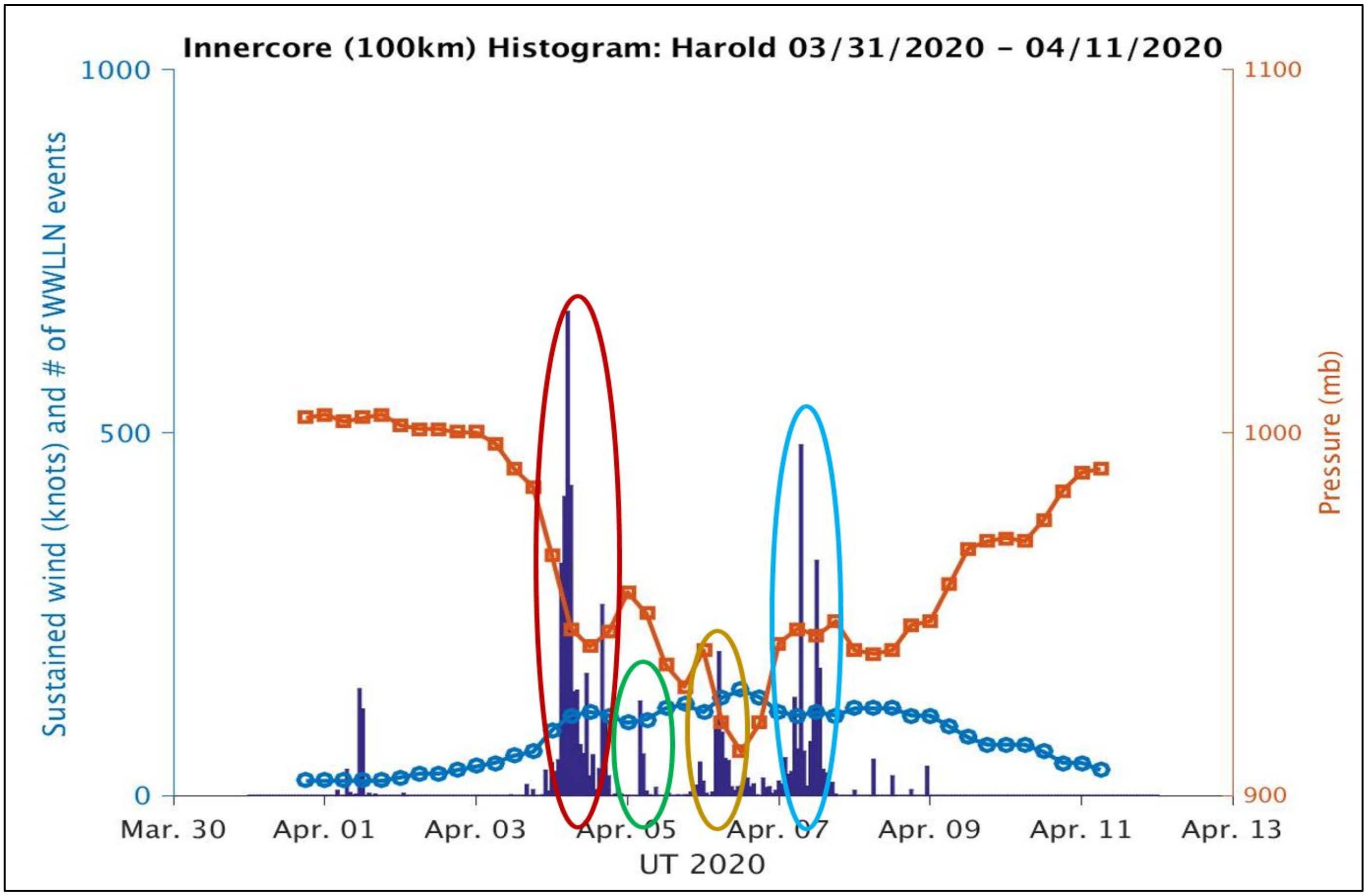


Figure 7-30: Inner core (100km) histogram: TC 25P (Harold) 31 March – 11 April 2020. Plot of sustained wind speed (knots), minimum sea level pressure (mb), and a histogram of the number of lightning strokes per hour, with four ICLBs highlighted by red, green, gold and blue ellipses (Data source: wwlln.net).

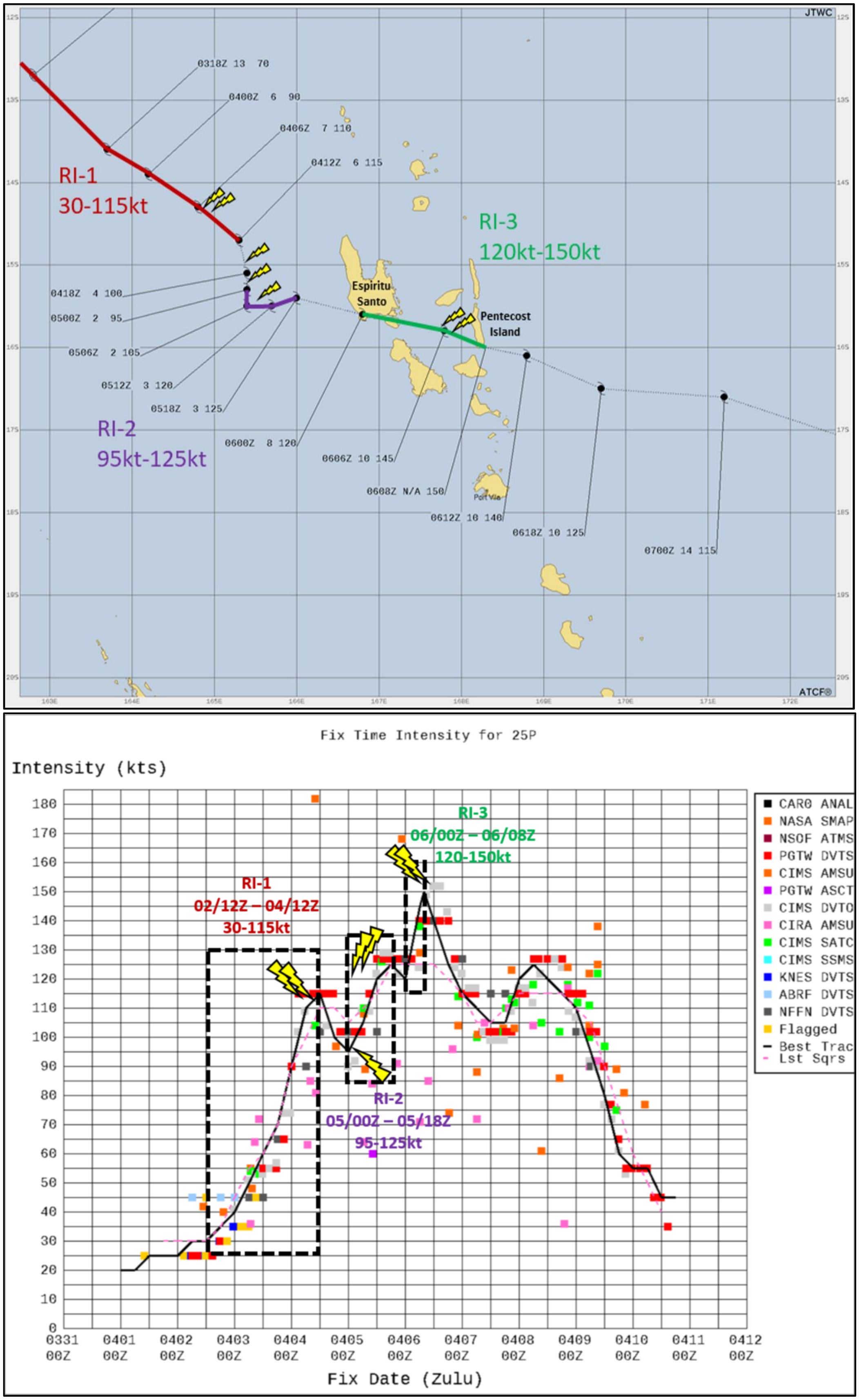
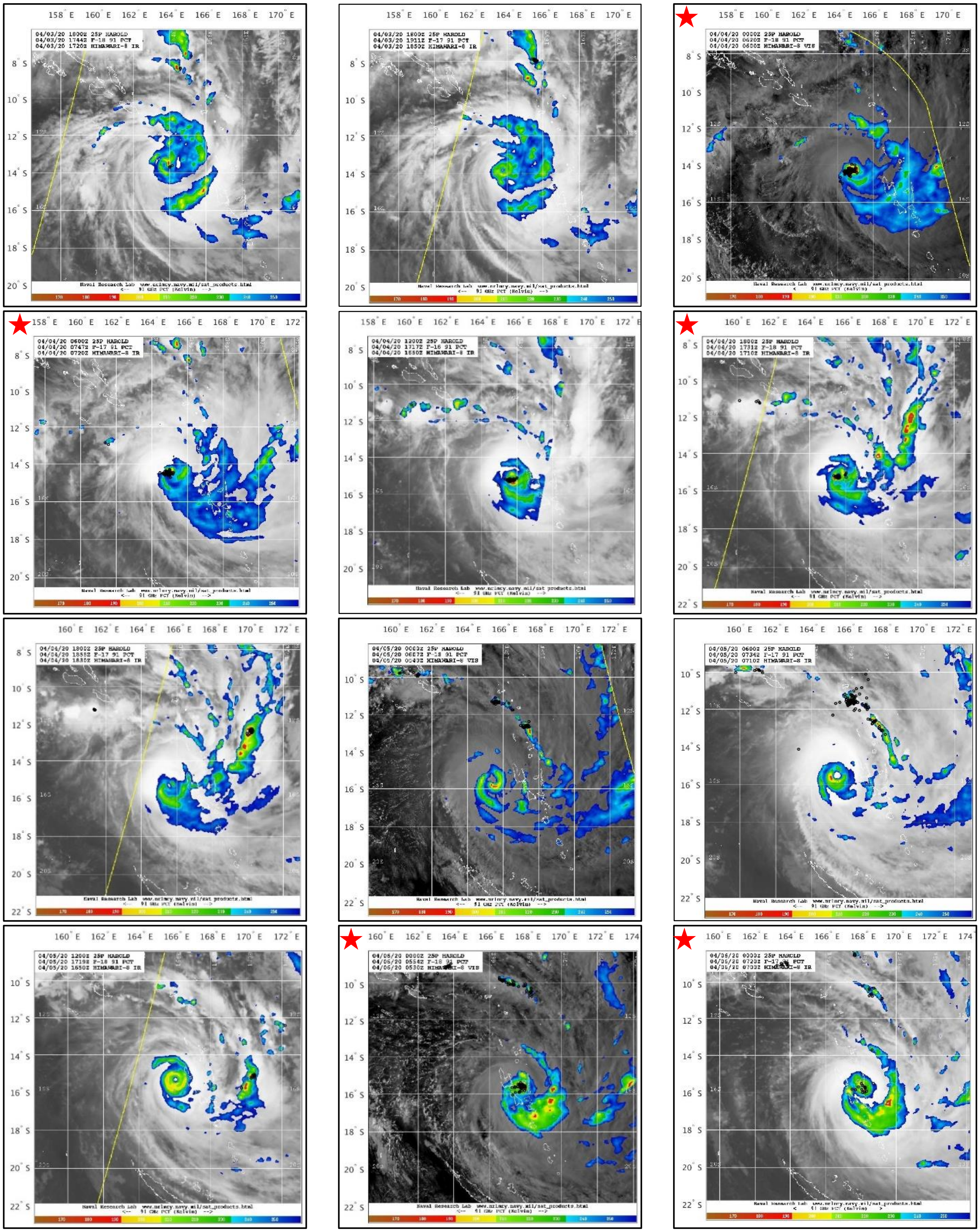


Figure 7-31: Location of three ICLBs (marked with lightning bolt symbols) along both the track and intensity history for TC 25P.



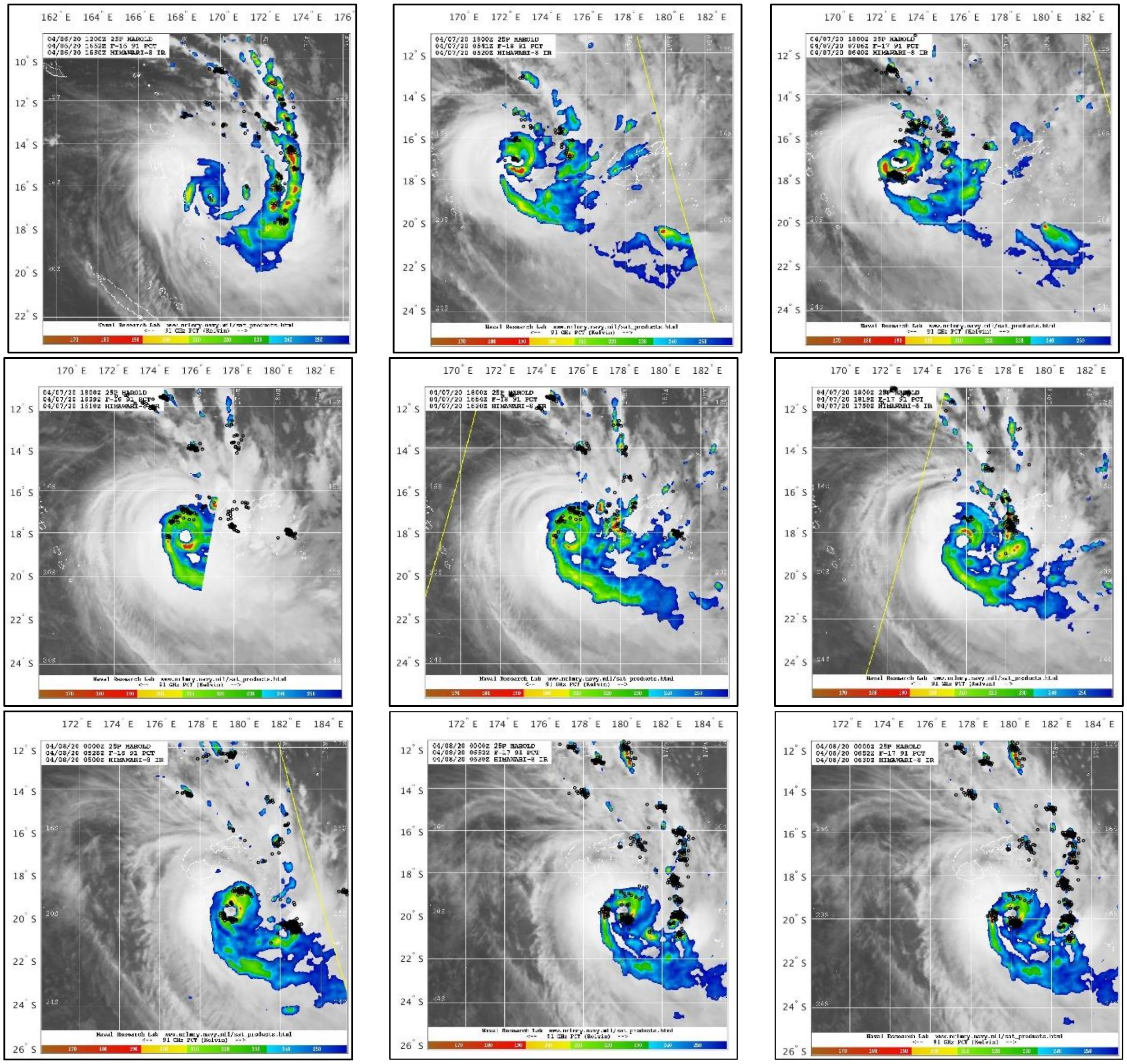


Figure 7-32: SSMIS imagery lightning stroke overlays (black circles) +/- 15 minutes of satellite image time (Data source: wwlln.net). Image panels marked with a red star denote those associated with the ICLBs noted in Figures 7-30 and 7-31.

Figure 7-33 depicts lightning strokes within the outer bands of TC 25P, extending outwards from 100 km to 1,000 km from the assessed center. Events in the outer bands generally follow the diurnal tropical convection cycle, which has limited impact on intensity change. Some research suggests that outer band (outside of the RMW) lightning bursts (OBLBs) unassociated with the diurnal cycle signal the onset of weakening (Stevenson et al. 2018), and the data shown in Figure 7-33 appear to support that finding. Four distinct OBLBs appear to be superimposed on the lower flash density diurnal OBLB signal. OBLB 1 (red ellipse) occurred after the peak intensity and commencement of an ERC and at the beginning of a rapid weakening trend. OBLB 2 (green ellipse) followed shortly thereafter, just before the system reached an intensity minimum prior to the onset of another period of intensification. OBLB 3 (gold ellipse), the most pronounced OBLB observed during TC 25P, occurred during a period of steady weakening. OBLB 4 (blue ellipse) occurred at the beginning of the final dissipation phase.

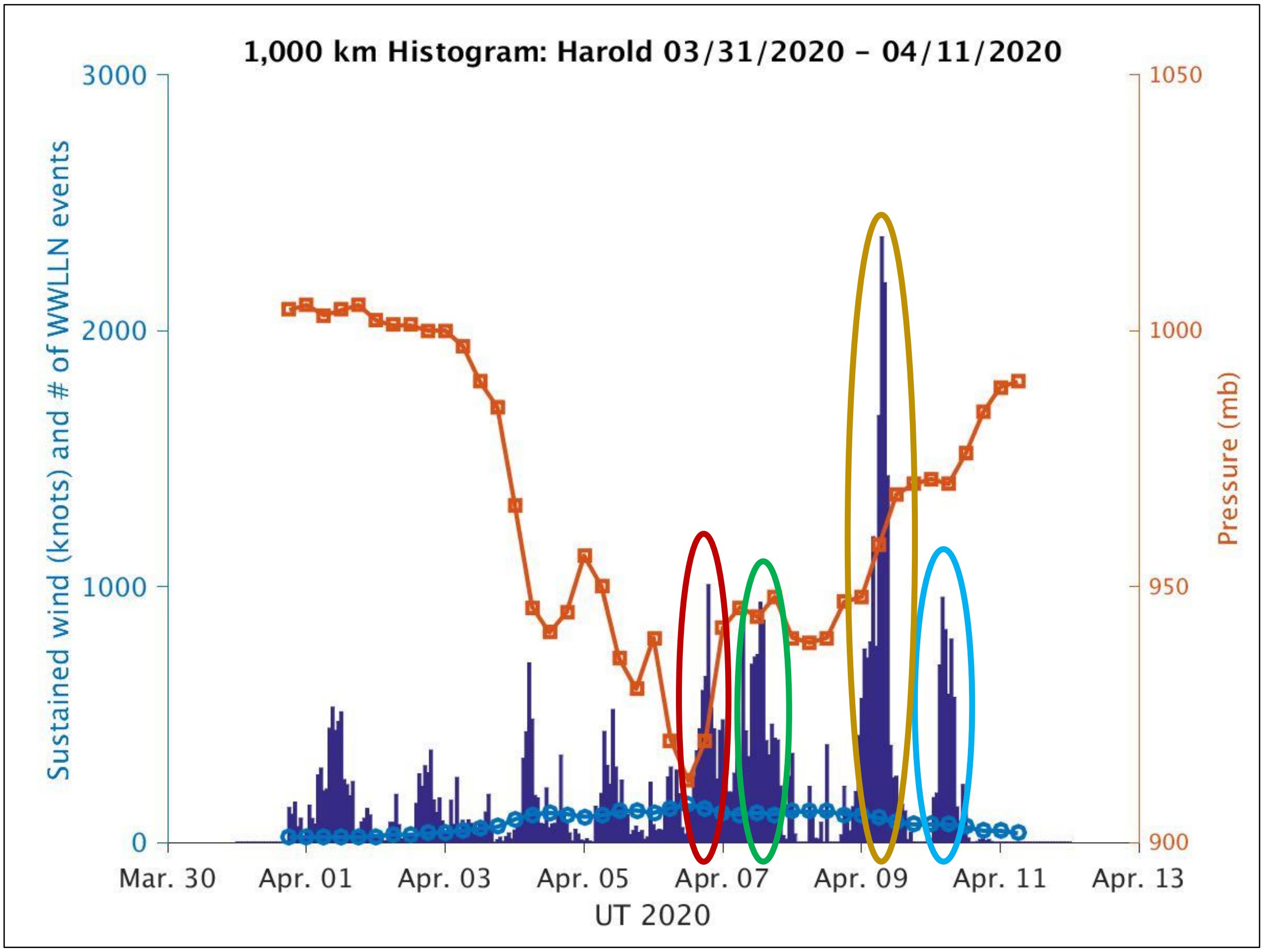


Figure 7-33: Outer bands (100 km to 1,000km) histogram: TC 25P (Harold) 31 March – 11 April. Plot of sustained wind speed (knots), minimum sea level pressure (mb), and a histogram of the number of lightning strokes per hour for lightning between 100 km to 1000 km of the storm center (Data source: wwlln.net).

Discussion

TC 25P (Harold) rapidly intensified as it tracked eastward from the Solomon Islands early in its lifecycle. Despite an ERC and brief weakening trend that occurred west of Vanuatu, TC 25P re-intensified to a 125-knot system before it passed near the southern edge of Espiritu Santo. The system continued to consolidate as it subsequently approached and crossed Pentecost Island, and it intensified to a peak of 150 knots (Figure 7-24) shortly thereafter. TC 25P was one of the most intense TCs on record to impact Vanuatu, causing extensive damage on both Espiritu Santo and Pentecost Islands.

While the UW-CIMSS' M-PERC product provided useful real-time guidance on ERC events and potential short-term weakening trends, intensity guidance on RI events was inaccurate and inconsistent. The intensity consensus (IVCN) and high-resolution TC models including COAMPS-TC and HWRF significantly under-predicted RI events, resulting in large negative mean intensity biases. Early HWRF model forecasts predicted widely varying peak intensities and peak intensity timing. The RI Prediction Aid (RIPS) only triggered during the first RI event. And large gaps of in the availability of microwave satellite imagery (MI) of 7-to-13 hours (Figure 7-28) hindered timely assessment of some key structural changes.

Since TC 25P (2020), JTWC has incorporated probabilistic intensity forecast data from the operational COAMPS-TC ensemble (Komaromi et al. 2021) and new statistical-dynamical methods into the forecast process. Complementing the expanded intensity forecasting toolkit, near real-time, high resolution lightning data could aid in short-term forecasting of tropical cyclone weakening / intensification trends, particularly when primary forecast aids or microwave imagery are unavailable or inaccurate. While the lightning data for TC 25P appear to support research findings that ICLBs are indicative of intensification while OBLBs are indicative of weakening, additional research and investigation is required before the data can be applied with confidence in the JTWC operational setting.

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