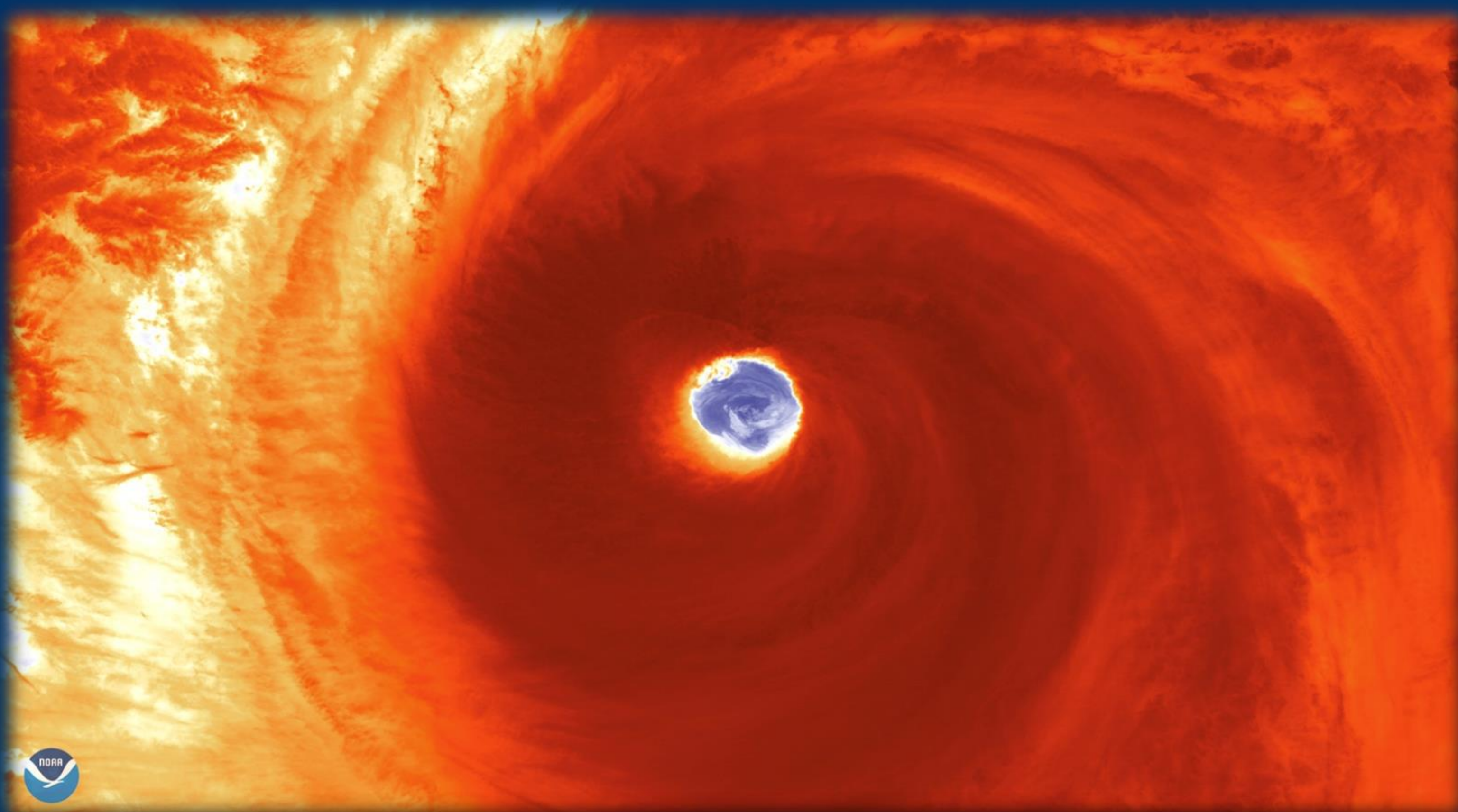
Joint Typhoon Warning Center

Annual Tropical Cyclone Report

2019



R. COREY CHERRETT, Ph.D.

Commander, United States Navy
Commanding Officer

ROBERT J. FALVEY

Director, Joint Typhoon Warning Center

Cover: The cover shows Super Typhoon Hagibis, located approximately 600 miles south of Yokosuka, Japan, as observed from NOAA-20 on October 10th, 2019 (0340z). Hagibis packed maximum sustained winds of 130 knots at image time, having peaked at 160 knots about 72 hours prior.

Image courtesy of NOAA NESDIS (https://www.nesdis.noaa.gov/sites/default/files/20191010-TYPHagibis.jpg)

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 approximately 80-million square miles of ocean, 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 2019 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 2019 storm season (1 January 2019 through 31 December 2019 for the Northern Hemisphere and 1 July 2018 through 30 June 2019 for the Southern Hemisphere), JTWC produced 1,372 warnings for 64 TCs (1,289 warnings for 62 TCs for the 2019 calendar year). Additionally, JTWC repackaged 362 warnings for cyclones in the eastern and central Pacific basins. Figure P-1 (below) shows the timeline of tropical activity across the JTWC AOR for calendar year 2019.

After the elevated tropical cyclone activity of 2018 with a likely record number of JTWC warnings produced, 2019 saw a return of activity to near climatological mean values in all basins except in the north Indian Ocean, which was above normal. The Oceanic Niño Index for the Niño 3.4 region indicated slight warm anomalies at the beginning of the year; however, by summer the basin returned to ENSO neutral conditions. The general distribution of TC formation locations reflects these neutral conditions (Figure 1-1). 2019 WESTAC Accumulated Cyclone Energy (ACE) was below the 19-year mean value. Despite the near-normal number of TCs, there were multiple periods with concurrent activity of 3 or more systems, resulting in 73 forecast cycles requiring augmented watch support. Overall, track forecast skill declined slightly at all lead times compared to 2018, whereas intensity forecast skill for 1-2 day lead time improved significantly. Track forecast mean error remained above 2009 US INDOPACOM goal.

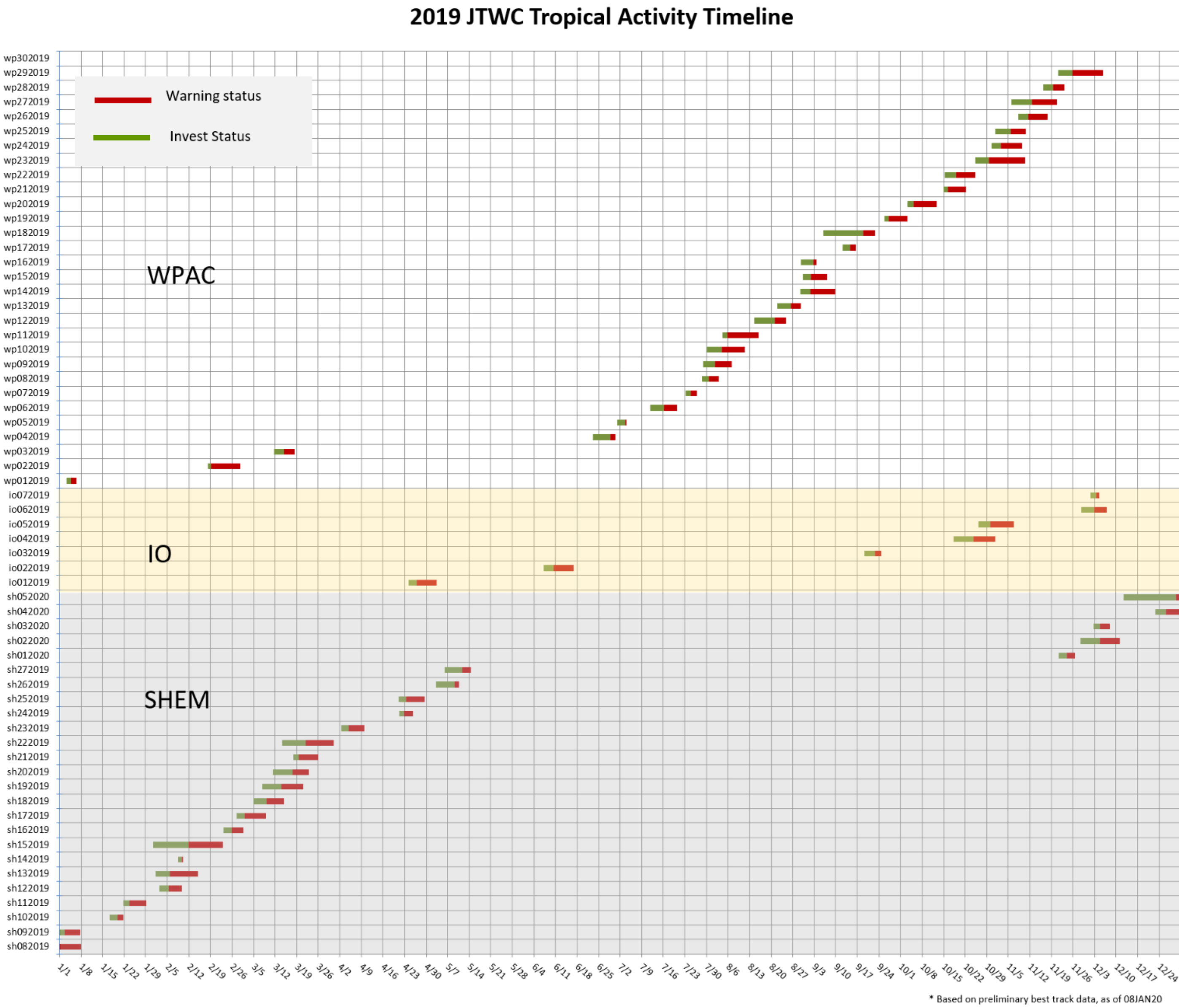


Figure P-1: Timeline of tropical cyclone activity across the JTWC AOR during the 2019 calendar year

Meteorological satellite data remain critical to the TC reconnaissance mission of the JTWC. Satellite analysts administratively assigned to the 17th Operational Weather Squadron, exploited a wide variety of electro-optic (EO), infrared (IR) and microwave satellite data to produce 8,733 position and intensity estimates (fixes). Satellite Analysts primarily used the USAF Mark IVB information system to view and fix on geostationary satellite imagery. However, application of the USN FMQ-17 satellite direct readout system increased following a mid-2018 upgrade that enabled direct read-out of Japan Meteorological Agency (JMA) Himawari geostationary satellite data. JTWC Satellite Analysts and Typhoon Duty Officers also prepared numerous TC center position fixes and structure and wind field analyses using geo-located microwave and scatterometer imagery overlays 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 routinely evaluated satellite 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 “Cube Sat” and “Micro Sat” research projects.

JTWC sustained collaboration 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. U.S. Navy collaboration with NOAA, contracted with Raytheon, for the Advanced Weather Interactive Processing System continued to move forward, with network authority to operate anticipated in late 2019 or early 2020.

At the heart of all these efforts are the dedicated team of men and women, military and civilian at JTWC. Maintaining a 24/7 watch against one of the most powerful forces of Mother Nature is a relentless endeavor. Behind the operational scenes are the outstanding professionals throughout the Administrative, Information Services, Technical Support Services, Training, and Strategy and Requirements Departments who worked tirelessly 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 throughout government, industry and academia who continuously pursue new and innovative ways to apply remote sensing technologies.

JTWC Personnel 2019

Leadership

CDR Corey Cherrett, Commanding *Officer (2018 - present)*
Mr. Robert Falvey, *Director (2006 - 2019)*
LCDR Katherine Coyle, *Executive Officer (2017 - 2019)*
LCDR Elias George, *Executive Officer (2019 - present)*
AGC William Cady, *Senior Enlisted Advisor (2017 - present)*

Support Services Department

Mr. Roberto Macias, *Support Services Department Head (2016 -2019)*
Mrs. Leilania Bonini, *Support Services Department Head (2019 -present)*
Mr. Lyntillus Boyd, *Administrative Assistant (2018- 2019)*
LS1 Kristofer Gaffud, Logisitics Specialist (2017-present)

Satellite Reconnaissance Department

Capt Amanda Nelson, *Satellite Operations Flight Commander* (2019 - *present)**
MSgt Richard Kienzle, *Satellite Operations NCOIC (2019 - present)****
TSgt Sonny Richardson, *Satellite Analyst (2019 - present)*
TSgt Jessica Elias, *Satellite Analyst (2018 - present)*
Mrs. Brittany Bermea, *Satellite Analyst (2016 - present)*
SSgt Lyndsay Veerkamp, *Satellite Analyst (2017 - present)*
SrA Myles Davis, *Satellite Analyst (2017 – 2019)*
SrA Thomas Lowe , *Satellite Analyst (*2016-2019)
SrA Tyler Milam, *Satellite Analyst (2018 -2019)*
SrA Isaiah Martin, *Satellite Analyst (2018 - present)*
SrA Philip Stigsson, *Satellite Analyst (2018-present)*
SSgt Jonathan Rhoades, *Satellite Analyst* (2019 – present)

Operations Department

LCDR Brian Howell, *Typhoon Duty Officer* (2016-2019)
LT David Price, *Operations Department Head* (2016 - 2019)
LT Andrew Sweeney*, Typhoon Duty Officer* (2017 - present)
LT Lee Suring, *Typhoon Duty Officer* (2018 - present)
LT Helena Cheslack, *Command Duty Officer* (2019 - present)
LT Caitlin Fine, *Typhoon Duty Officer* (2017 - present)
LT Stephanie Geant*, Command Duty Officer* (2016 - 2019)
LT Jillian Homola, *Typhoon Duty Officer* (2019 - present)
LT Edward Jacobs, *Command Duty Officer* (2016 - 2019)
LT Joseph Pinto*, Command Duty Officer* (2019 – present)
LT Anthony Prochilo, *Command Duty Officer* (2019 - present)
LT Raul Ramirez, *Command Duty Officer* (2016 - 2019)
LTJG Sean Egan, PhD, *Command Duty Officer* (2019 -present)
LTJG Ricardo Uribe, *Command Duty Officer* (2017 -2019)
ENS William Venden, *Command Duty Officer* (2018 -present)
ENS Timothy Ragan, *Command Duty Officer* (2018 -present)
AGC Justin Knaebel, *Command Duty Officer* (2017-present)
AG1 Michael Clute*, Forecast Duty Officer* (2019 -present)
AG1 Eric Waring, *Forecast Duty Officer* (2017 -present)
AG1 Rodney Rumph*, Forecast Duty Officer* (2016 -2019)
AG2 Dylan Howard, *Forecast Duty Officer* (2019 -present)
AG2 Cole Bedgood, *Geophysical Technician* (2016 - 2019)
AG2 Joshua Beven, *Geophysical Technician* (2016 - 2019)
AG2 Nicholas Crumpler, *Forecast Duty Officer* (2017 - 2019)
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 - present)
AGAR Asia Davis, *Geophysical Technician* (2019 - present)
AG3 Jayde Bejer, *Geophysical Technician* (2019 - present)
AG3 Kain Enright, *Geophysical Technician* (2018 - present)
AG3 Koreaun Elliot, *Geophysical Technician* (2019 - present)
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 - present)

Plans and Requirements Department

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

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Information Services Department

Mr. Joshua Nelson, *Information Services Department Head (2014 - present)*
Mr. Angelo Alvarez, *System Administrator (2003- present)*
Mr. Brandon Brevard, *System Administrator (2016 - present)*
Mr. Andrew Rhoades, *Information Assurance Officer (2007 - present)*
IT1 Kenneth Surline*, Information Technology (2017-present)*
IT2 Khristian Ebreo, *Information Technology (2019 - present)*
IT2 Nathaniel Natanauan, *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 31DEC19

** 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 2019 season. JTWC issued warnings on 30 tropical cyclones. Table 1-2 shows the monthly distribution of TC activity summarized for 1959 - 2019 and Table 1-3 shows the monthly average occurrence of TC's separated into: (1) typhoons and (2) tropical storms and typhoons. Table 1-4 summarizes Tropical Cyclone Formation Alerts issued. Figures 1-1 depicts the 2019 western North Pacific Ocean TC tracks. The annual number of TC's of tropical storm (TS) strength or higher appears in Figure 1-2, while the number of TC's 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 2019 - 31 DEC 2019)

TC	NAME*	PERIOD**		WARNINGS ISSUED	EST MAX SFC WINDS KTS
01W	ONE	04 Jan / 1800Z	06 Jan / 1200Z	8	30
02W	WUTIP	19 Feb / 0600Z	28 Feb / 1800Z	39	145
03W	THREE	15 Mar / 0000Z	18 Mar / 0600Z	14	35
04W	FOUR	28 Jun / 1800Z	30 Jun / 1200Z	8	35
05W	MUN	03 Jul / 1800Z	04 Jul / 0000Z	2	35
06W	DANAS	16 Jul / 0600Z	20 Jul / 1200Z	18	45
07W	NARI	25 Jul / 0000Z	27 Jul / 0000Z	9	35
08W	WIPHA	30 Jul / 1800Z	03 Aug / 0000Z	14	55
09W	FRANCISCO	01 Aug / 1800Z	07 Aug / 0600Z	23	80
10W	LEKIMA	04 Aug / 0000Z	11 Aug / 1200Z	31	135
11W	KROSA	05 Aug / 1800Z	16 Aug / 0000Z	42	100
12W	BAILU	21 Aug / 0600Z	24 Aug / 1800Z	15	60
13W	PODUL	26 Aug / 1200Z	29 Aug / 1800Z	14	40
14W	FAXAI	01 Sep / 1800Z	09 Sep / 1800Z	33	115
15W	LINGLING	02 Sep / 0000Z	07 Sep / 0600Z	22	120
16W	KAJIKI	02 Sep / 1800Z	03 Sep / 1800Z	5	35
17W	PEIPAH	14 Sep / 1800Z	16 Sep / 1200Z	8	35
18W	TAPAH	19 Sep / 0000Z	22 Sep / 1800Z	16	65
19W	MITAG	27 Sep / 0600Z	03 Oct / 0600Z	25	90
20W	HAGIBIS	05 Oct / 0600Z	12 Oct / 1800Z	31	160
21W	NEOGURI	16 Oct / 1200Z	22 Oct / 0600Z	24	95
22W	BUALOI	19 Oct / 0000Z	25 Oct / 0600Z	26	140
23W	MATMO	29 Oct / 1800Z	30 Oct / 1800Z	5	55
23W	MATMO (rewarn)	06 Nov / 1800Z	10 Nov / 1200Z	16	105
24W	HALONG	02 Nov / 1200Z	09 Nov / 1200Z	29	165
25W	NAKRI	05 Nov / 1800Z	10 Nov / 1800Z	21	65
26W	FENGSHEN	11 Nov / 1200Z	17 Nov / 1800Z	26	115
27W	KALMAEGI	12 Nov / 1800Z	20 Nov / 1800Z	33	90
28W	FUNG-WONG	19 Nov / 1200Z	23 Nov / 0600Z	15	65
29W	KAMMURI	25 Nov / 1800Z	05 Dec / 1800Z	41	120
30W	PHANFONE	21 Dec / 1800Z	28 Dec / 1800Z	29	105

* 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

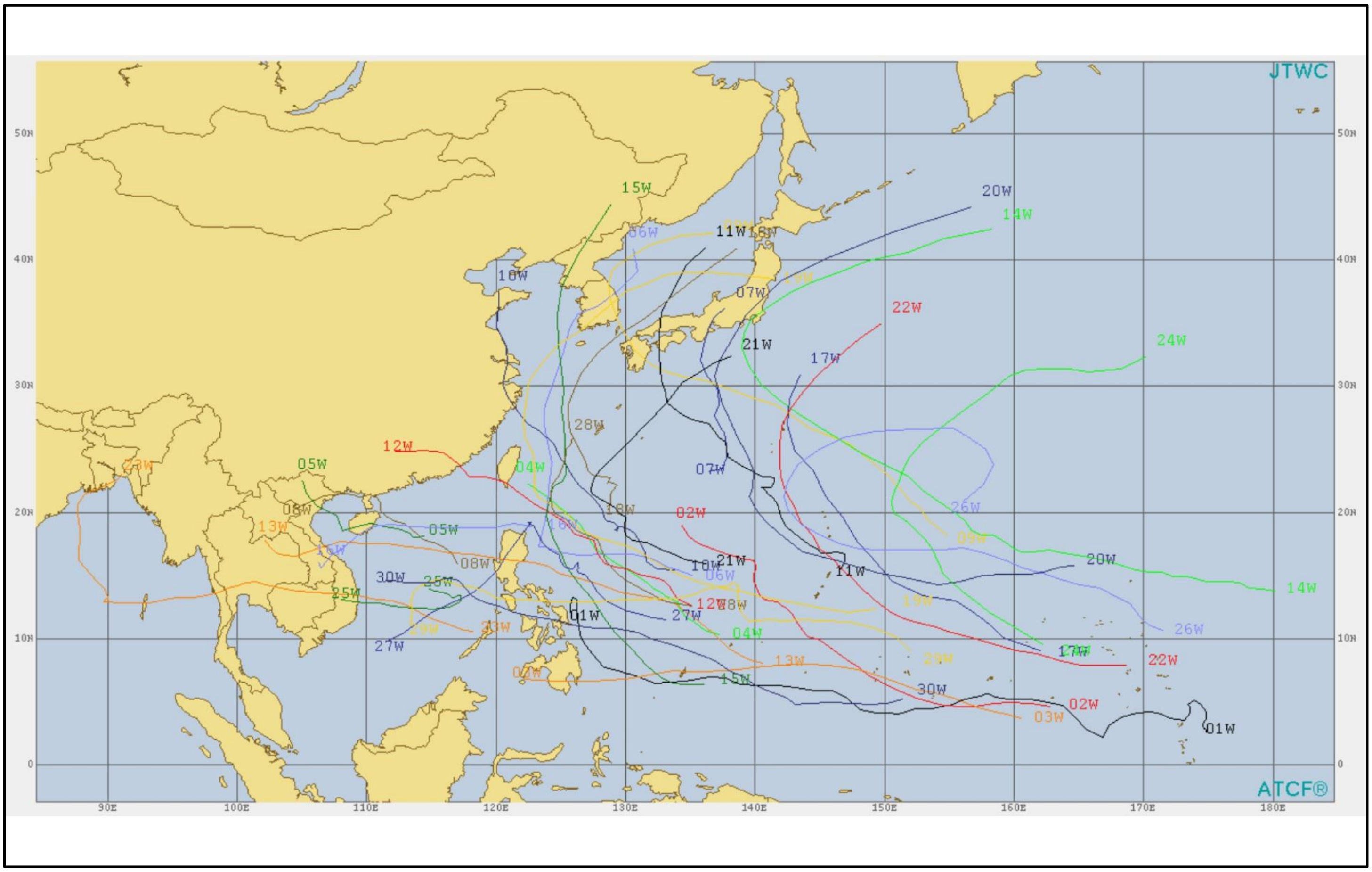

Figure 1-1. Western North Pacific Tropical Cyclones.

Table 1-2
DISTRIBUTION OF WESTERN NORTH PACIFIC TROPICAL CYCLONES FOR 1959 - 2019

YEAR	JAN			FEB			MAR			APR			MAY			JUN			JUL			AUG			SEP			OCT			NOV			DEC			Total		
																																					≥64kt	34-63kt	≤33kt
																																						TOTALS	
1959		0			1			1			1			0			1			3			8			9			3			2			2			31	
	0	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	1	1	1	1	5	1	2	4	2	3	2	1	0	2	0	0	2	0	0	17	7	7
1960		1			0			1			1			1			3			3			9			5			4			1			1			30	
	0	0	1	0	0	0	0	0	1	1	0	0	0	1	0	2	1	0	2	1	0	8	1	0	0	4	1	4	0	0	1	0	0	1	0	0	19	8	3
1961		1			1			1			1			4			6			5			7			6			7			2			1			42	
	0	1	0	0	1	0	1	0	0	0	1	0	2	1	1	1	1	4	3	2	0	3	1	3	5	1	0	3	2	2	1	0	1	1	0	0	20	11	11
1962		0			1			0			1			3			0			8			8			7			5			4			2			39	
	0	0	0	0	1	0	0	0	0	1	0	0	2	0	1	0	0	0	5	1	2	7	0	1	3	1	3	3	1	1	3	0	1	0	2	0	24	6	9
1963		0			0			1			1			0			4			5			4			4			6			0			3			28	
	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	3	1	0	3	1	1	3	0	1	2	2	0	5	1	0	0	0	0	2	1	0	19	6	3
1964		0			0			0			0			3			2			8			8			8			7			6			2			44	
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1966		0			0			0			1			2			1			4			9			10			4			5			2			38	
	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	1	0	0	3	1	0	5	3	1	5	3	2	1	1	2	1	2	2	1	0	1	20	10	8
1967		1			0			2			1			1			1			8			10			8			4			4			1			41	
	0	1	0	0	0	0	1	1	0	1	0	0	0	1	0	1	0	0	3	3	2	3	4	3	5	3	0	2	1	1	4	0	0	0	1	0	20	15	6
1968		0			1			0			1			0			4			3			8			4			6			4			0			31	
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1969		1			0			1			1			0			0			3			3			6			5			2			1			23	
	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	2	1	0	2	1	0	2	0	4	4	1	0	1	1	0	0	1	0	13	6	4
1970		0			1			0			0			0			2			3			7			4			6			4			0			27	
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1971		1			0			1			2			5			2			8			5			7			4			2			0			37	
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1972		1			0			1			0			0			4			5			5			6			5			2			3			32	
	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	2	0	4	1	0	3	2	0	4	1	1	4	1	0	2	0	0	2	1	0	22	8	2
1973		0			0			0			0			0			0			7			6			3			4			3			0			23	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	3	0	2	3	1	2	0	1	4	0	0	0	3	0	0	0	0	12	9	2
1974		1			0			1			1			1			4			5			7			5			4			4			2			35	
	0	1	0	0	0	0	0	1	0	0	1	0	1	0	0	1	2	1	2	3	0	2	3	2	3	2	0	4	0	0	2	2	0	0	2	0	15	17	3
1975		1			0			0			1			0			0			1			6			5			6			3			2			25	
	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	4	1	1	4	1	0	3	2	1	2	1	0	0	2	0	14	8	3
1976		1			1			0			2			2			2			4			4			5			0			2			2			25	
	1	0	0	0	1	0	0	0	0	1	1	0	2	0	0	2	0	0	2	2	0	1	3	0	4	1	0	0	0	0	1	1	0	0	2	0	14	11	10
1977		0			0			1			0			1			1			4			2			5			4			2			1			21	
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1978		1			0			0			1			0			3			4			8			4			7			4			0			32	
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1980		0			0			1			1			4			1			5			3			7			4			1			1			28	
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1981		0			0			1			1			1			2			5			8			4			2			3			2			29	
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1982		0			0			3			0			1			3			4			5			6			4			1			1			28	
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1986		0			1			0			1			2			2			2			5			2			5			4			3			27	
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	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	4	0	0	3	1	0	5	1	1	2	0	0	1	2	0	1	0	0	18	6	1
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1989		1			0			0			1			2			2			6			8			4			6			3			2			35	
	0	1	0	0	0	0	0	0	0	1	0	0	2	0	0	1	1	0	2	3	1	3	3	2	2	2	0	6	0	0	3	0	0	1	0	1	21	10	4
1990		1			0			0			1			2			4			4			5			5			5			4			1			32	
	1	0	0	0	0	0	0	0	0	0	1	0	1	1	0	2	1	1	2	2	0	5	0	0	4	1	0	2	3	0	3	1	0	1	0	0	21	10	1
1991		0			0			2			1			1			1			4			8			6			3			6			0			32	
	0	0	0	0	0	0	1	1	0	0	1	0	1	0	0	1	0	100	4	0	0	3	3	2	4	2	0	3	0	0	3	3	0	0	0	0	20	10	2
1992		1			1			0			0			0			3			4			8			5			6			5			0			33	
	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	1	0	2	2	0	4	4	0	4	1	0	5	1	0	3	1	1	0	0	0	21	11	11
1993		0			0			2			2			1			2			5			8			5			6			4			3			38	
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1994		1			0			1			0			2			2			9			9			8			7				0		2			41	
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1996		1			1			0			2			2			0			7			10			7			5			6			3			44	
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1998		0			0			0			0			0			0			3			3			8			6			3			4			27	
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1999		1			1			0			3			0			1			5			9			6			2			3			3			34	
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2000		0			0			0			0			4			0			8			9			6			3			3			1			34	
	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0	2	3	3	4	3	2	4	1	1	2	1	0	1	1	1	1	0	0	15	10	9
2001		0			1			0			1			1			2			6			7			5			3			3			4			33	
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2002		1			1			1			1			2			3			6			8			3			5			1			1			33	
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2006		0			0			1			0			1			1			3			8			5			4			2			2			27	
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2007		0			0			1			0			1			0			3			6			5			5			6			0			27	
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2008		1			0			0			1			4			1			2			5			6			3			3			1			27	
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2009		0			0			0			0			2			2			3			5			7			4			4			1			28	
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2010		1			0			1			0			0			0			2			5			4			4			1			1			19	
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2011		0			0			0			2			2			3			4			4			7			1			1			3			27	
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2012		0			1			1			0			1			4			4			5			3			5			2			1			27	
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2017		1			0			0			2			0			1			8			6			4			5			4			2			33	
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2018		1			1			1			0			1			5			7			10			5			1			3			2			37	
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2019		1			1			1			0			0			1			4			5			6			4			6			1			30	
	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	4	0	3	2	0	4	2	0	4	0	0	6	0	0	1	0	0	19	10	1

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 - 2019)													
	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	3.4	3.2	2.9	1.6	0.7	16.9
CASES	12	6	13	24	43	60	153	209	197	177	96	40	1030
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 - 2019)													
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN	0.5	0.3	0.5	0.6	1.1	1.8	4.0	5.6	4.9	3.9	2.5	1.2	26.7
CASES	29	16	28	38	67	107	244	339	297	239	153	73	1630

TABLE 1-4 TROPICAL CYCLONE FORMATION ALERTS FOR THE WESTERN NORTH PACIFIC OCEAN 1976 - 2019					
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%
MEAN	35	28	30	20%	94%
CASES	1533	1226	1310		
* Percentage of initial TCFAs not followed by warnings.					

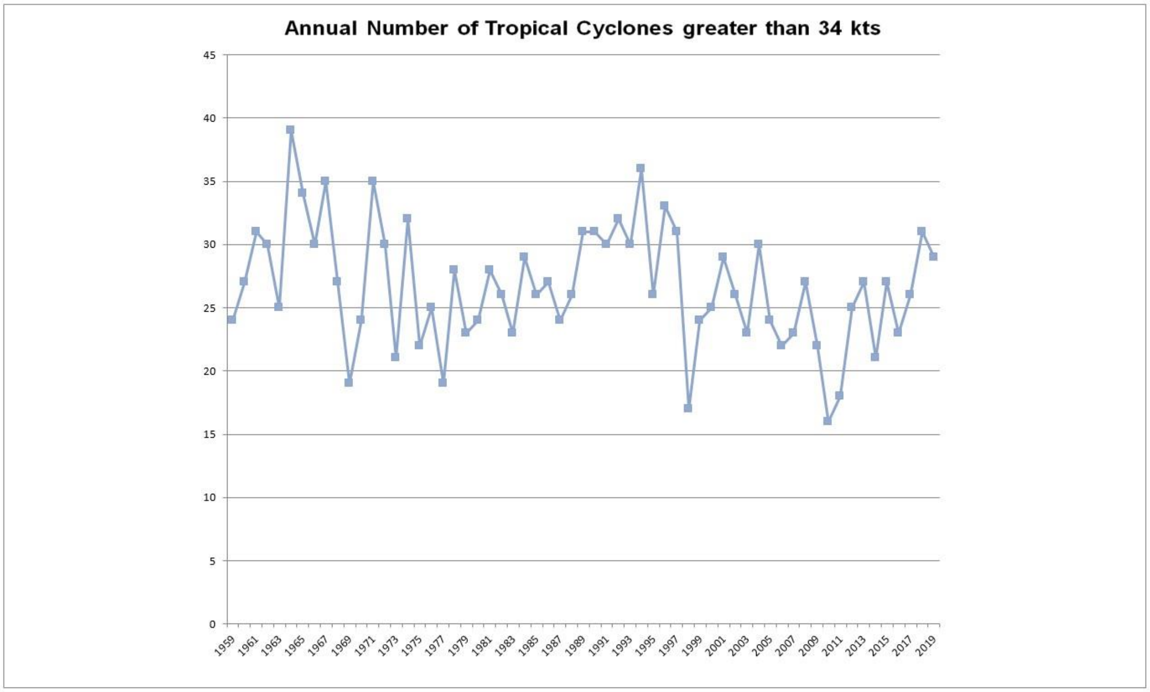


Figure 1-2. Annual number of western North Pacific TCs greater than 34 knots intensity.

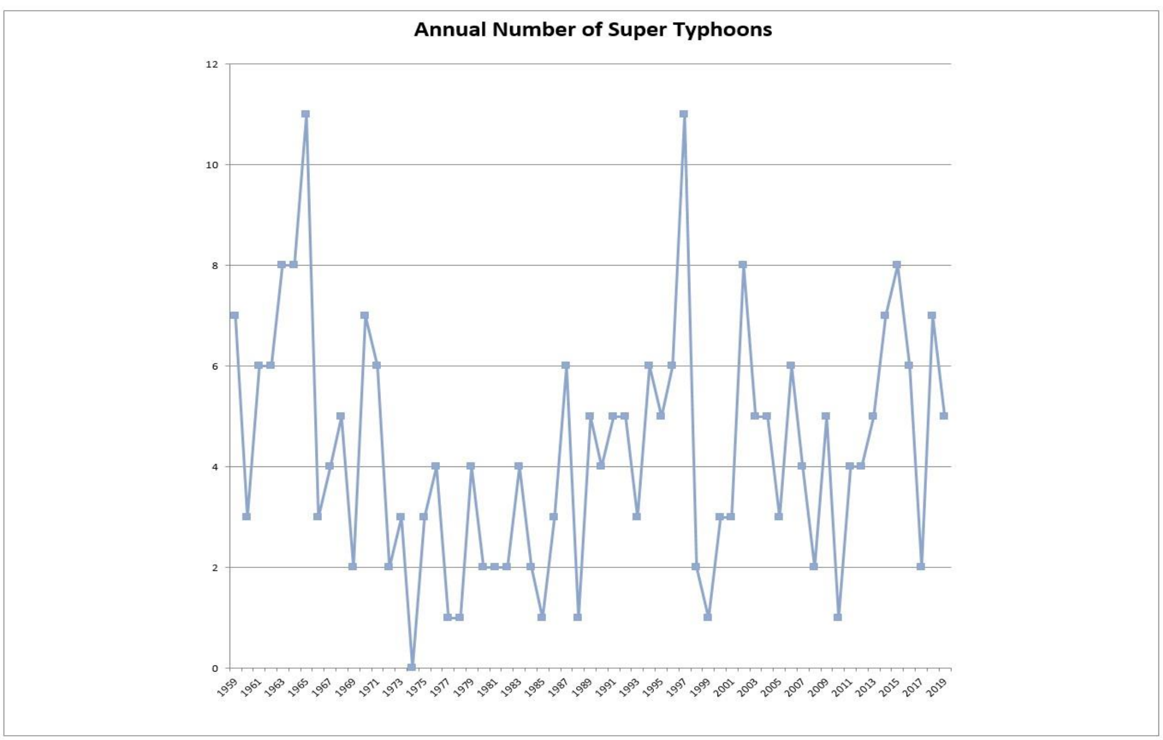
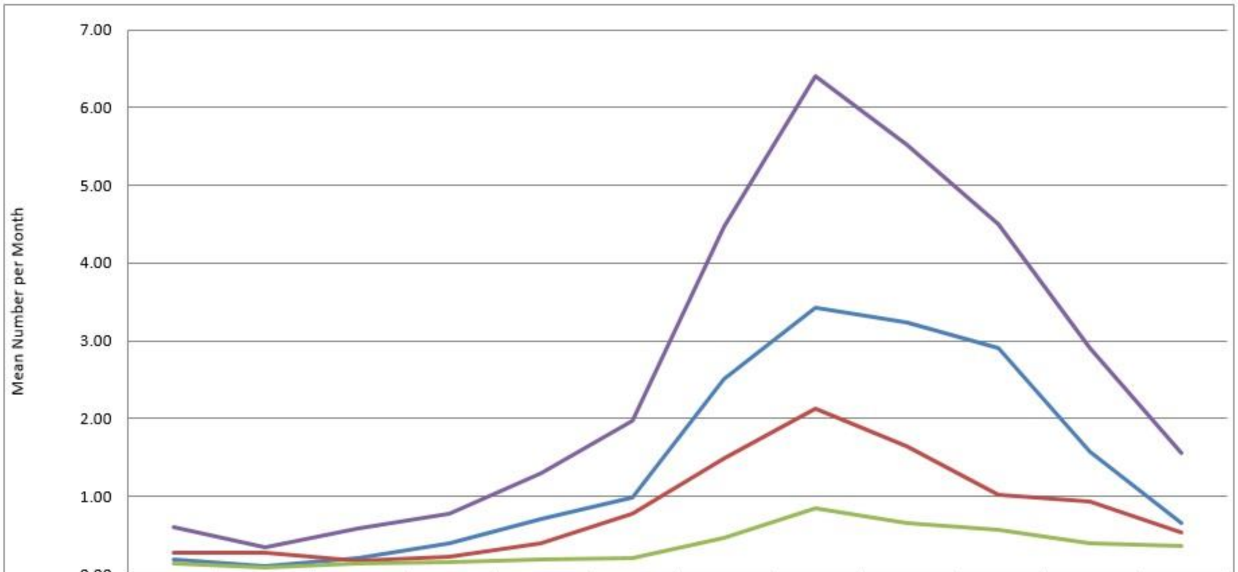


Figure 1-3. Annual number of western North Pacific TCs greater than 129 knots intensity.



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
TY AVG	0.20	0.10	0.21	0.39	0.70	0.98	2.51	3.43	3.23	2.90	1.57	0.66
TS AVG	0.28	0.28	0.16	0.23	0.39	0.77	1.49	2.13	1.64	1.02	0.93	0.54
TD AVG	0.13	0.08	0.13	0.15	0.20	0.21	0.46	0.85	0.66	0.57	0.39	0.36
All AVG	0.61	0.34	0.59	0.77	1.30	1.97	4.46	6.41	5.52	4.49	2.90	1.56

Figure 1-4. Average number of western North Pacific TCs (all intensities) by month 1959-2019.

Section 2 Cyclone Summaries

This section presents a synopsis of each cyclone that occurred during 2019 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 TC formation alert (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 by JTWC. Landfall over major landmasses with approximate locations is presented as well. JTWC initiates tropical cyclone warnings when one or more of the following four criteria are met:

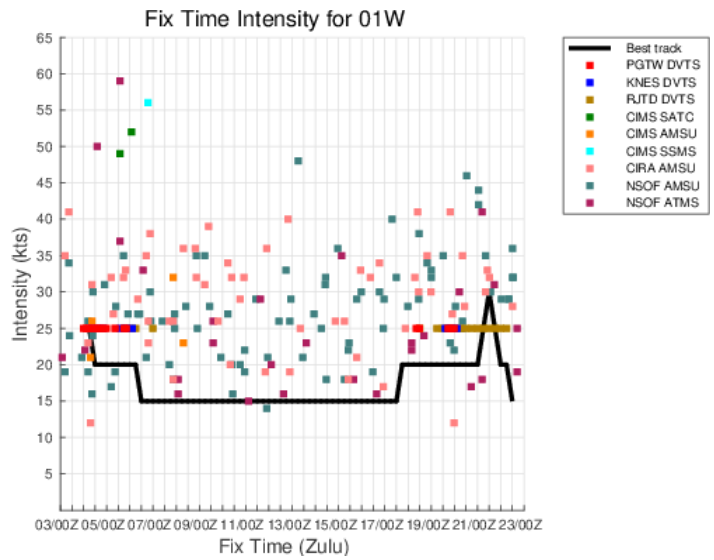
- Estimated maximum sustained wind speeds within a closed tropical circulation meet or exceed a designated threshold of 25 knots in the North Pacific Ocean or 35 knots in the South Pacific and Indian Oceans.
- Maximum sustained wind speeds within a closed tropical circulation are expected to increase 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.

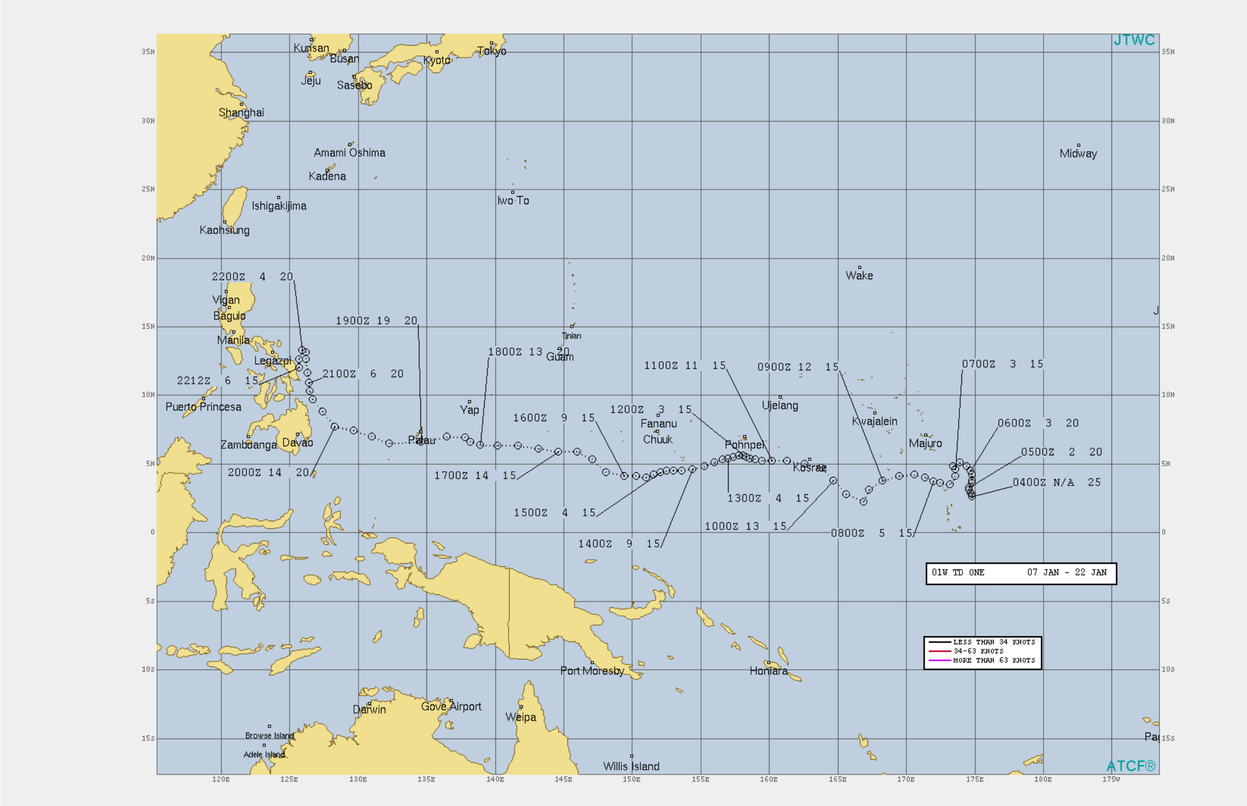
The JTWC post-event, reanalysis best track is provided for each cyclone. Data included on the best track are position and intensity noted with color-coded cyclone symbols and track line. Best track position labels include the date, time, track speed in knots, and maximum wind speed in knots, as well 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/2019/2019s-bwp/WP_besttracks_2019-2019.kmz

01W TROPICAL DEPRESSION ONE

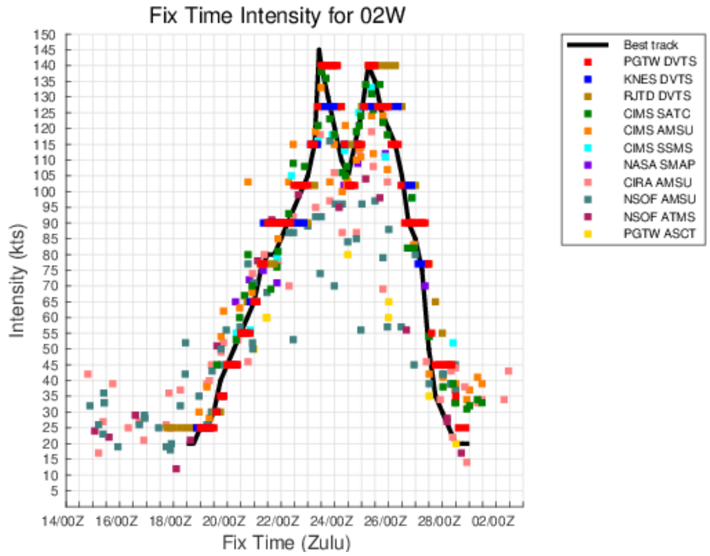
ISSUED LOW:	03 Jan / 0400Z
ISSUED MED:	03 Jan / 0600Z
FIRST TCFA:	04 Jan / 0530Z
FIRST WARNING:	04 Jan / 1800Z
LAST WARNING:	06 Jan / 1200Z
MAX INTENSITY:	30
WARNINGS:	8

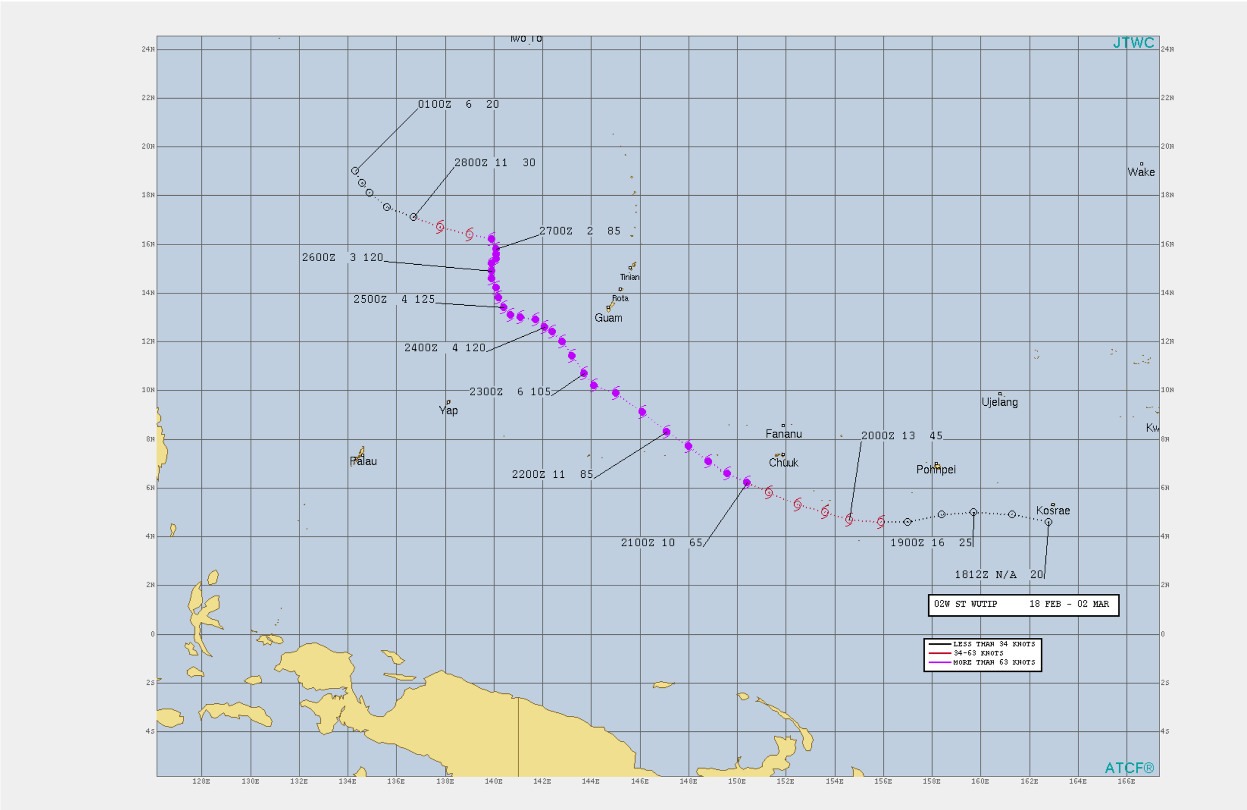




02W SUPER TYPHOON WUTIP

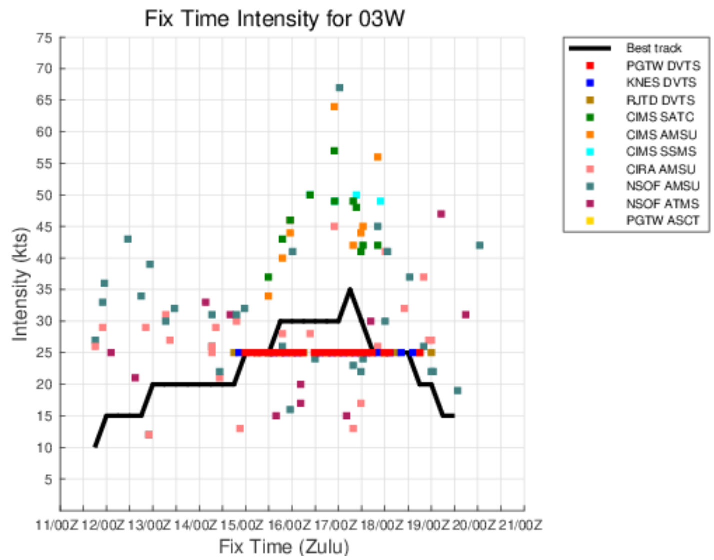
ISSUED LOW:	16 Feb / 0600Z
ISSUED MED:	17 Feb / 1300Z
FIRST TCFA:	18 Feb / 0300Z
FIRST WARNING:	19 Feb / 0600Z
LAST WARNING:	28 Feb / 1800Z
MAX INTENSITY:	145
WARNINGS:	39

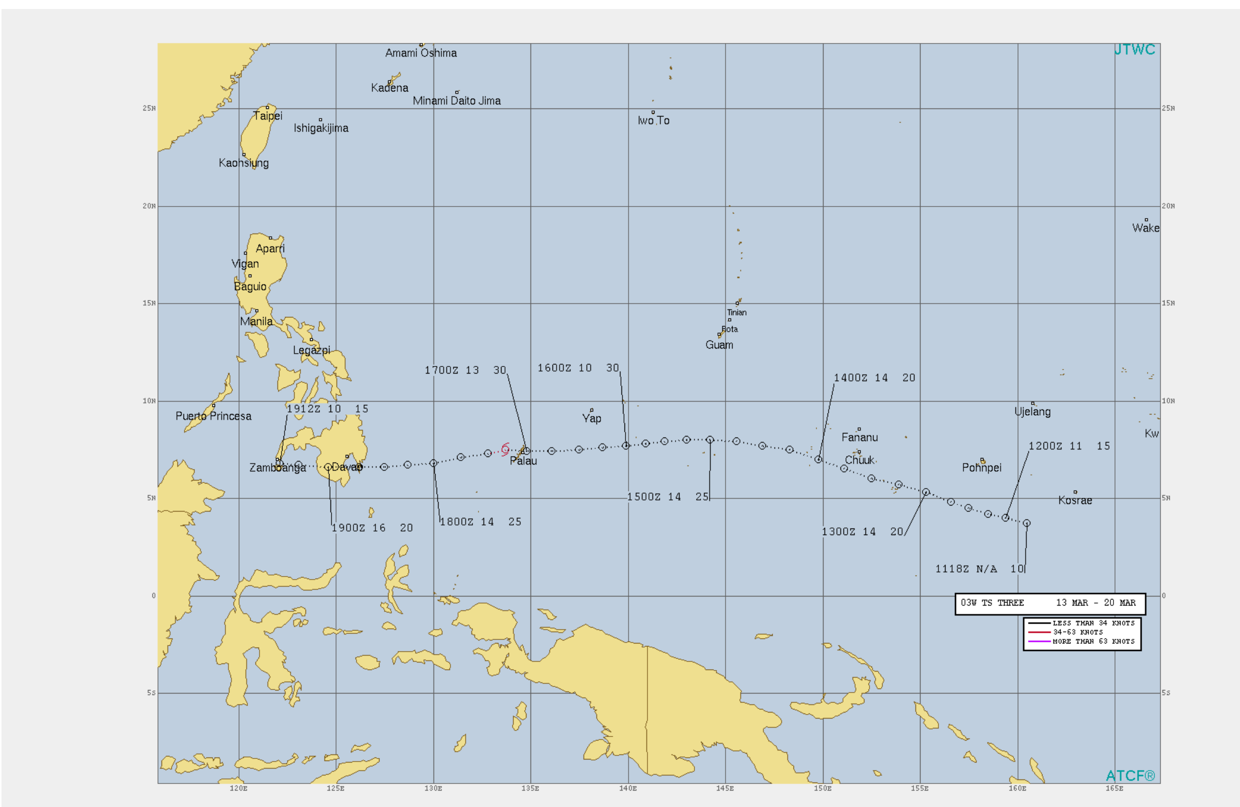




03W TROPICAL STORM THREE

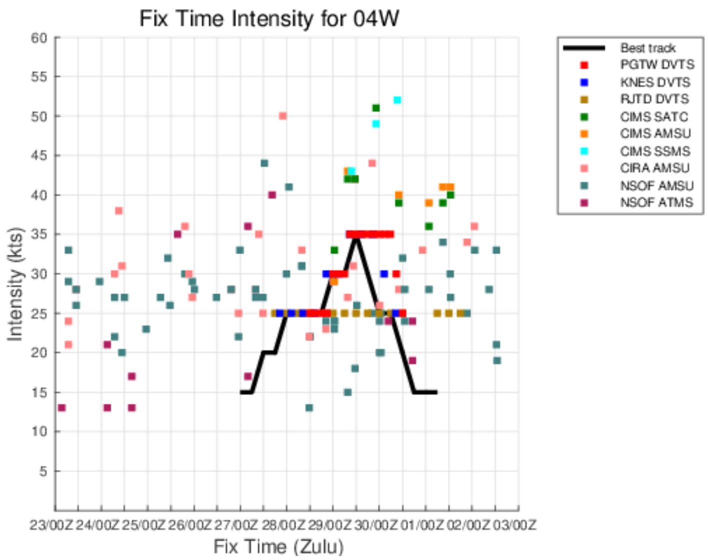
ISSUED LOW: N/A
ISSUED MED: 13 Mar / 0600Z
FIRST TCFA: 14 Mar / 1000Z
FIRST WARNING: 15 Mar / 0000Z
LAST WARNING: 18 Mar / 0600Z
MAX INTENSITY: 35
WARNINGS: 14

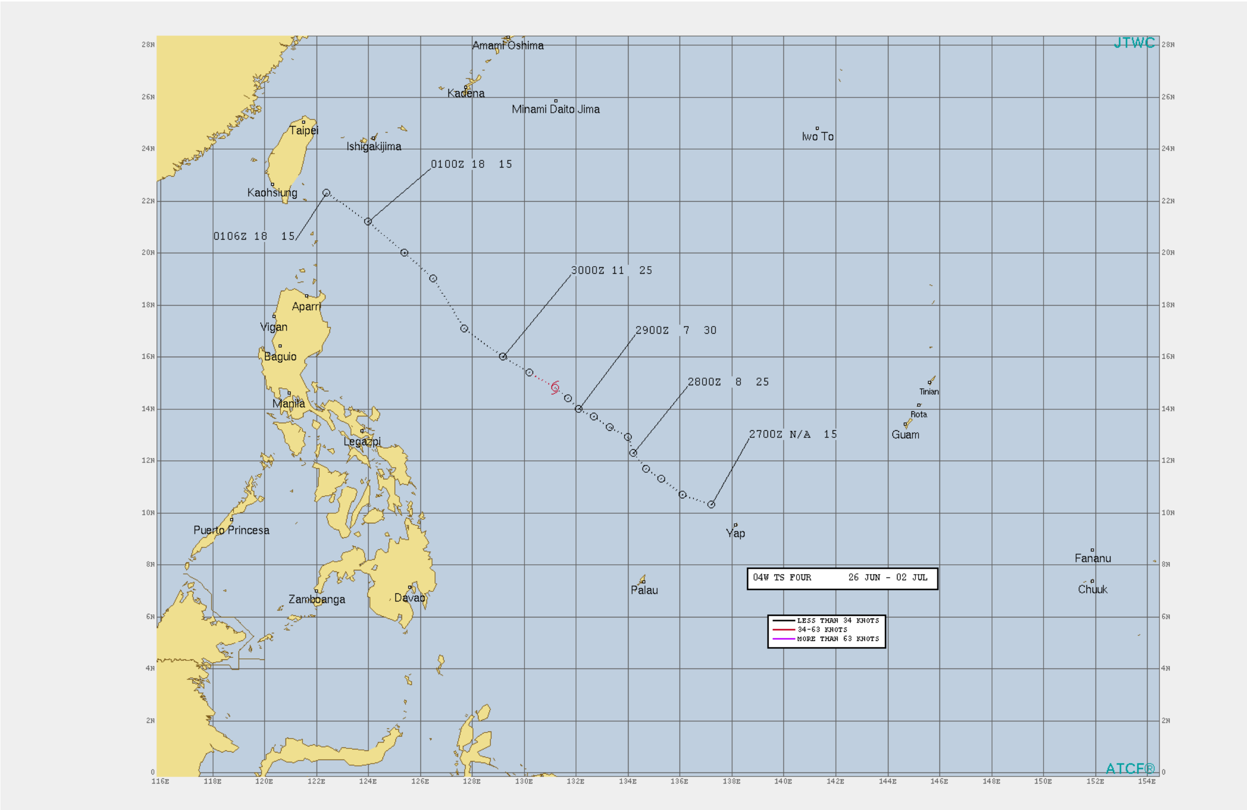




04W TROPICAL STORM FOUR

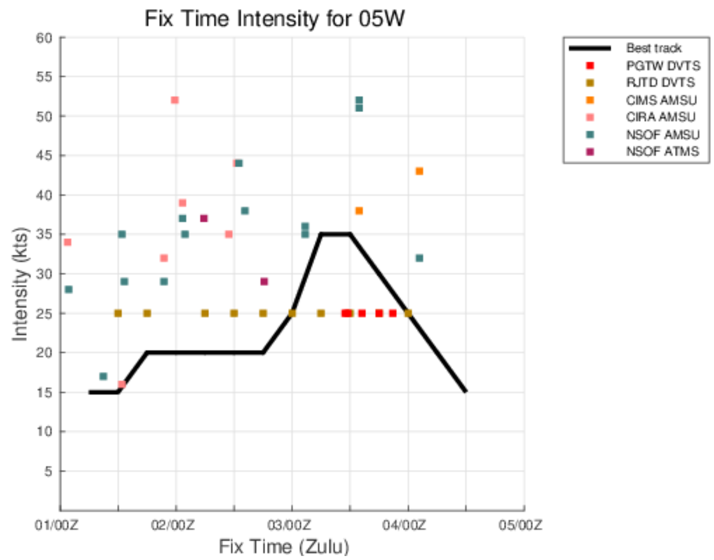
ISSUED LOW:	27 Jun / 0600Z
ISSUED MED:	28 Jun / 0100Z
FIRST TCFA:	28 Jun / 0430Z
FIRST WARNING:	28 Jun / 1800Z
LAST WARNING:	30 Jun / 1200Z
MAX INTENSITY:	35
WARNINGS:	8

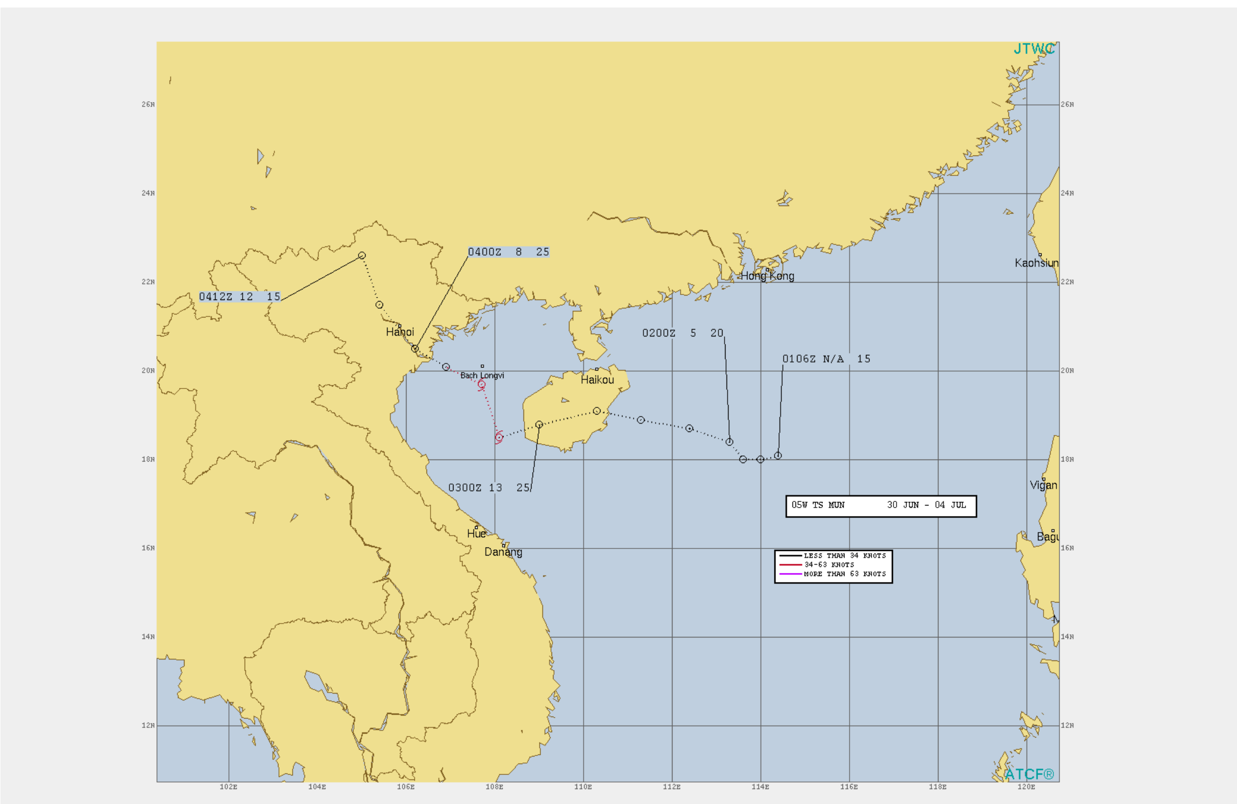




05W TROPICAL STORM MUN

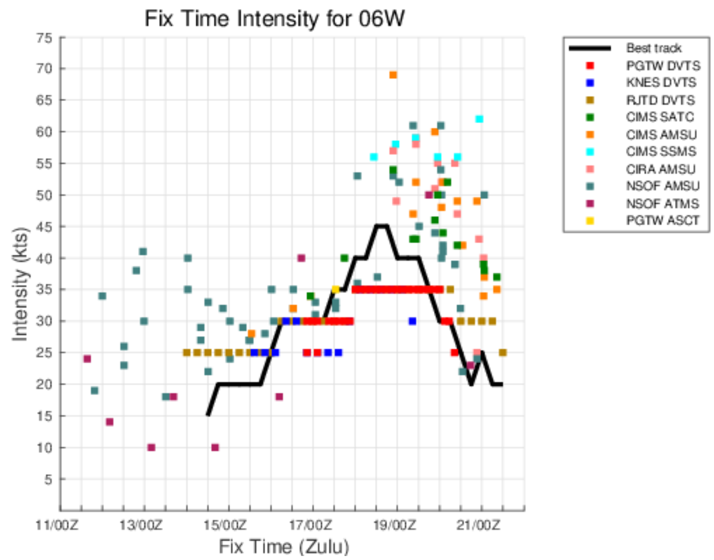
ISSUED LOW:	01 Jul / 0600Z
ISSUED MED:	01 Jul / 1430Z
FIRST TCFA:	01 Jul / 2100Z
FIRST WARNING:	03 Jul / 1800Z
LAST WARNING:	04 Jul / 0000Z
MAX INTENSITY:	35
WARNINGS:	2

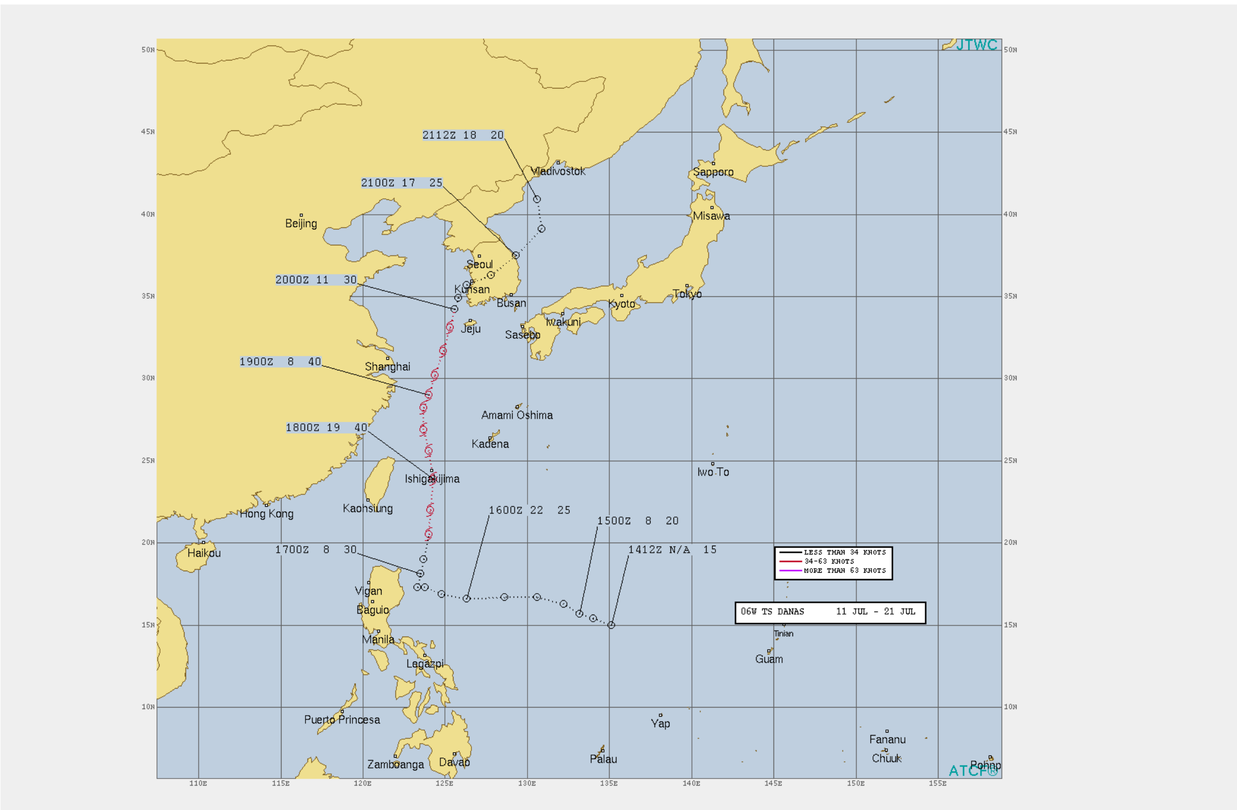




06W TROPICAL STORM DANAS

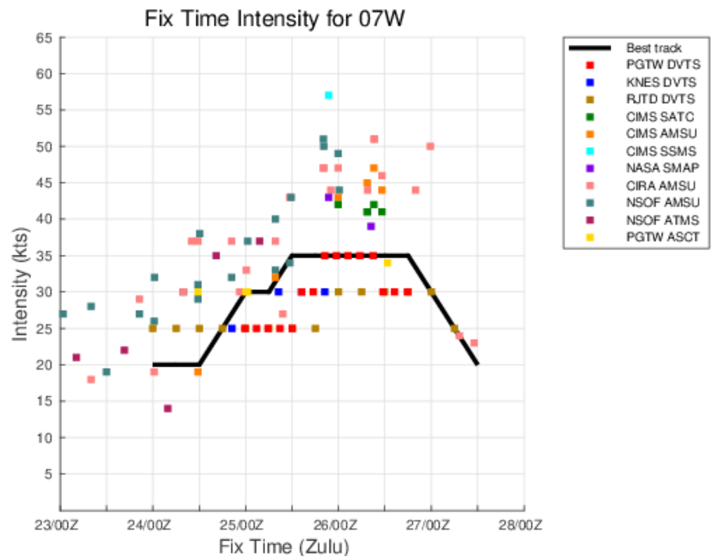
ISSUED LOW:	14 Jul / 1400Z
ISSUED MED:	15 Jul / 0600Z
FIRST TCFA:	15 Jul / 2230Z
FIRST WARNING:	16 Jul / 0600Z
LAST WARNING:	20 Jul / 1200Z
MAX INTENSITY:	45
WARNINGS:	18

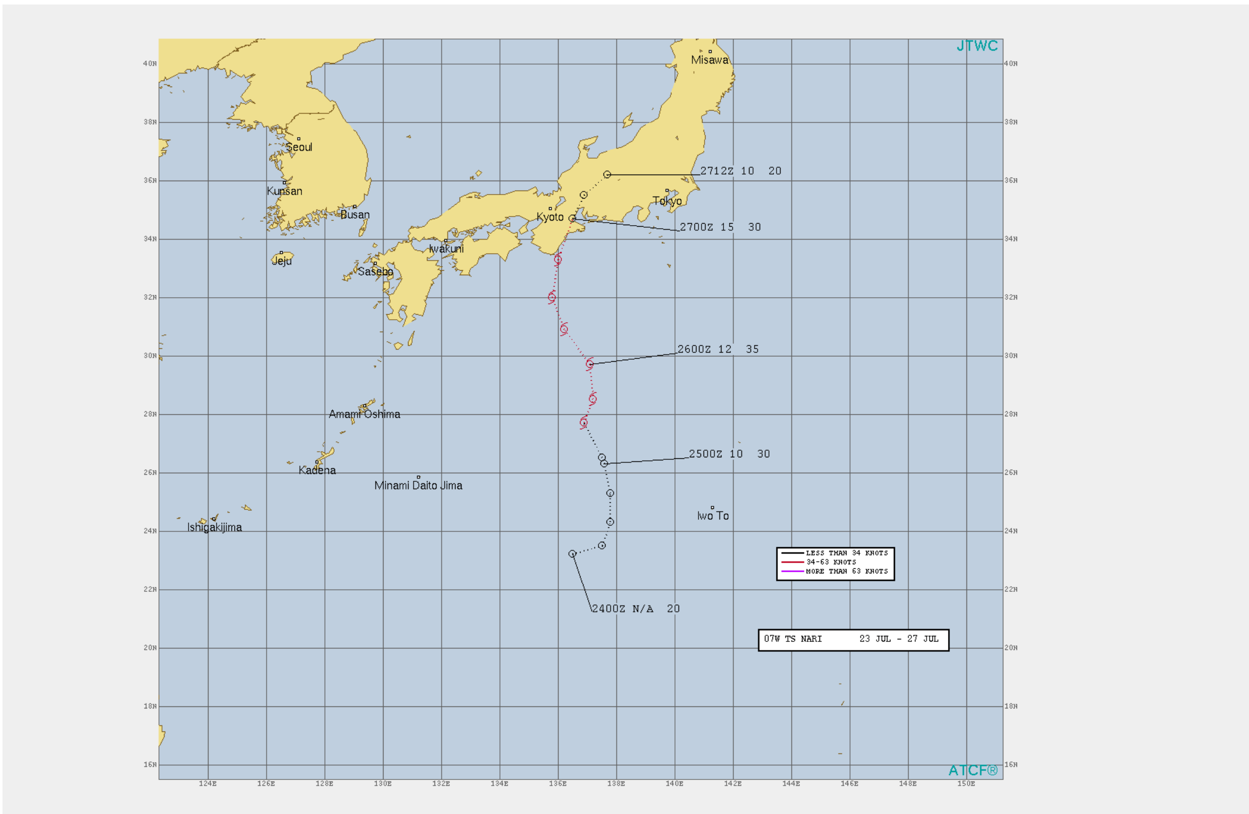




07W TROPICAL STORM NARI

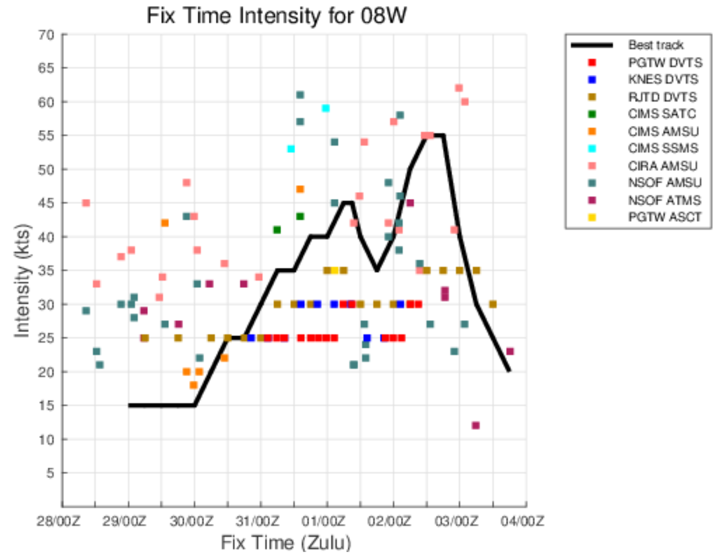
ISSUED LOW:	23 Jul / 0600Z
ISSUED MED:	24 Jul / 0200Z
FIRST TCFA:	24 Jul / 0800Z
FIRST WARNING:	25 Jul / 0000Z
LAST WARNING:	27 Jul / 0000Z
MAX INTENSITY:	35
WARNINGS:	9

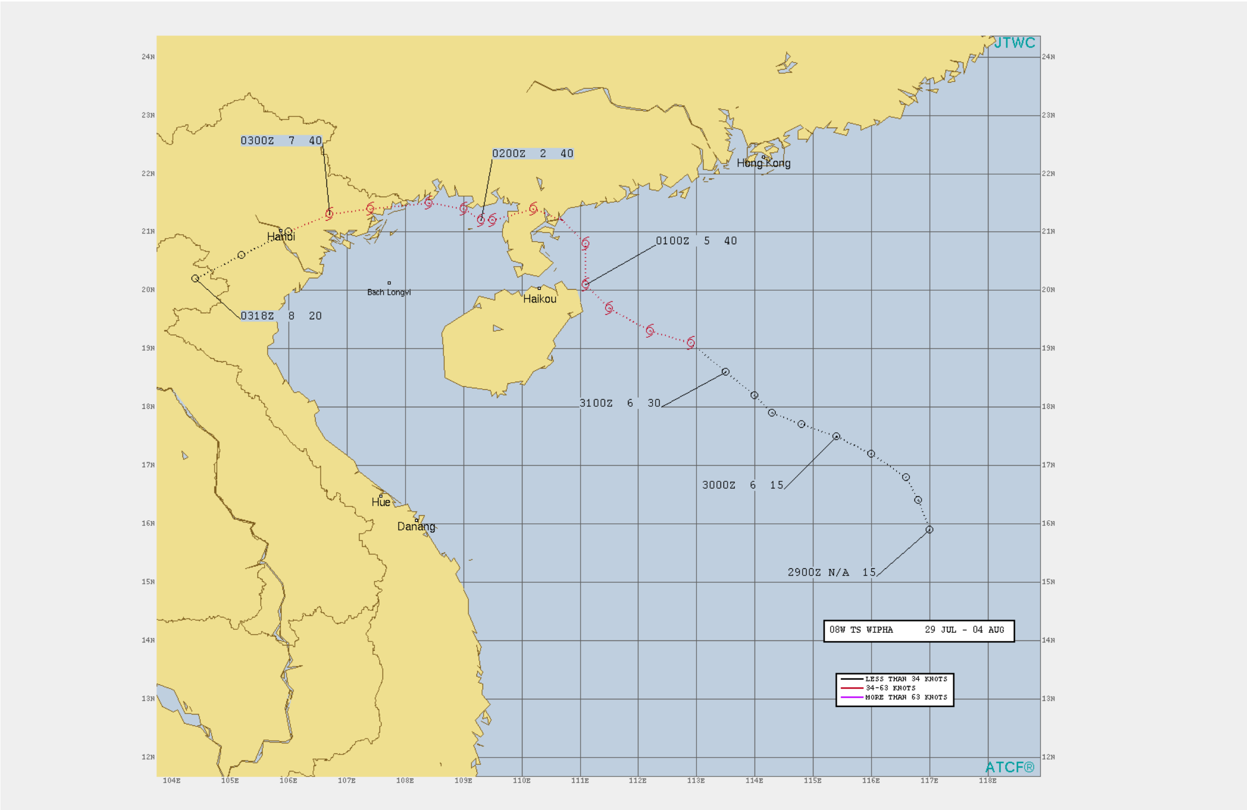




08W TROPICAL STORM WIPHA

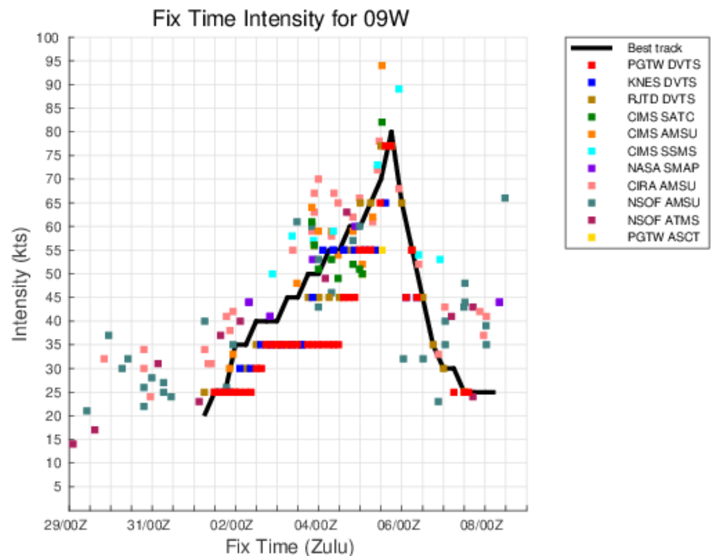
ISSUED LOW:	N/A
ISSUED MED:	29 Jul / 0600Z
FIRST TCFA:	29 Jul / 2100Z
FIRST WARNING:	30 Jul / 1800Z
LAST WARNING:	03 Aug / 0000Z
MAX INTENSITY:	55
WARNINGS:	14

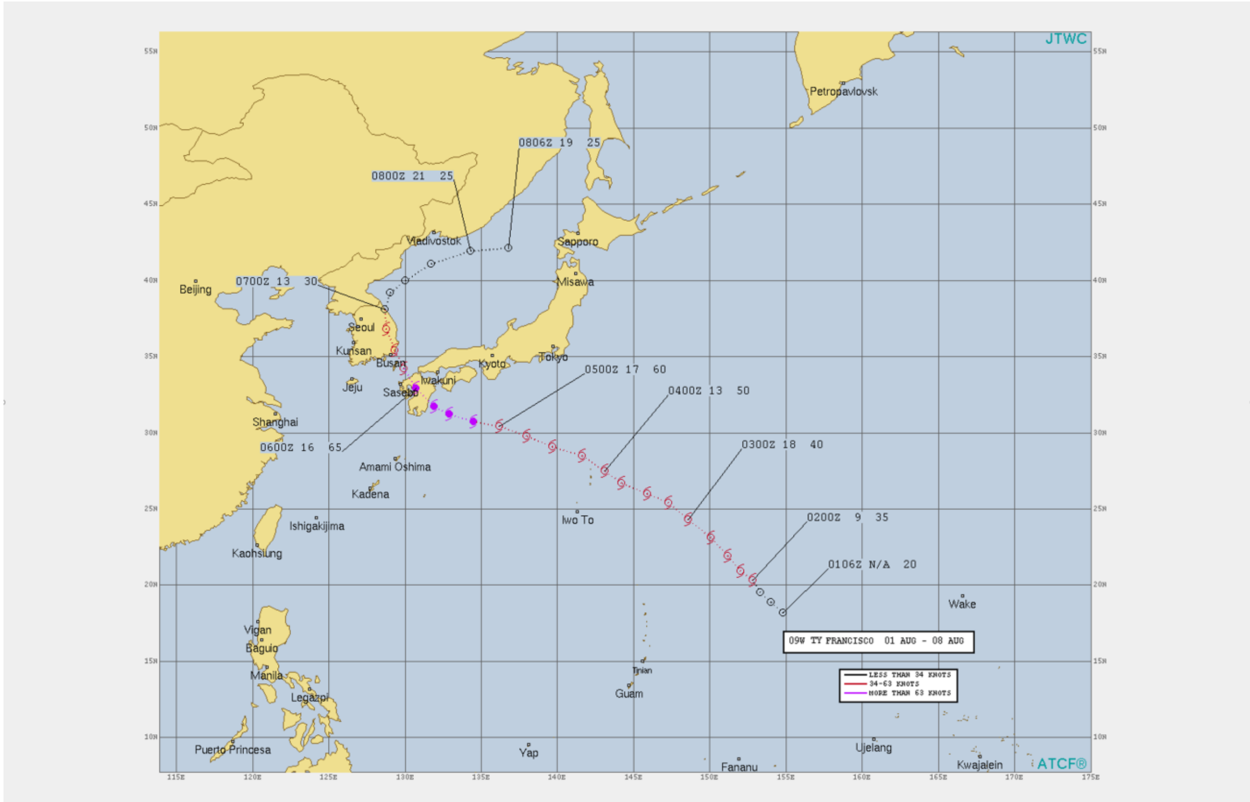




09W TYPHOON FRANCISCO

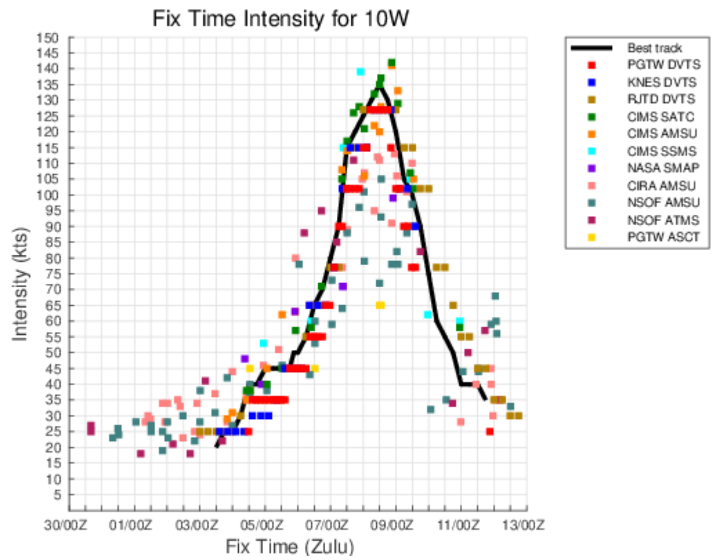
ISSUED LOW:	29 Jul / 2130Z
ISSUED MED:	01 Aug / 0600Z
FIRST TCFA:	01 Aug / 1330Z
FIRST WARNING:	01 Aug / 1800Z
LAST WARNING:	07 Aug / 0600Z
MAX INTENSITY:	80
WARNINGS:	23

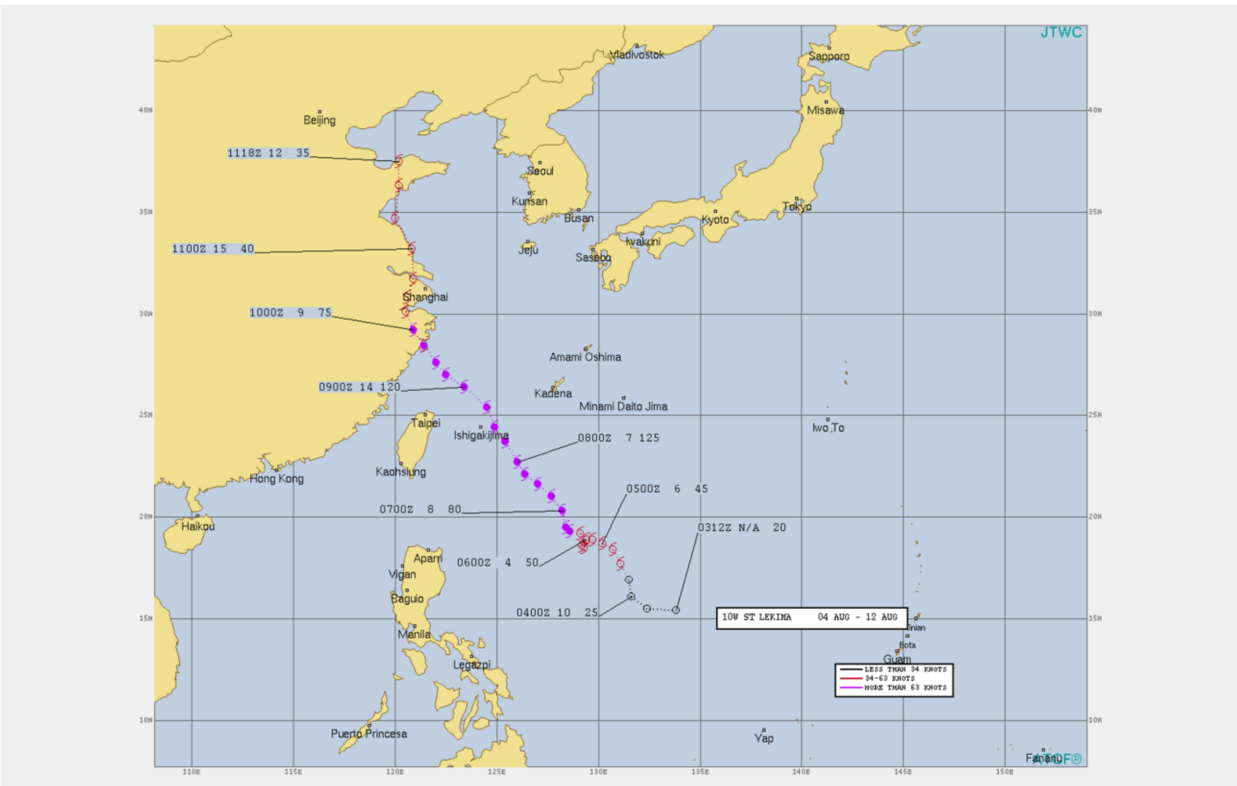




10W SUPER TYPHOON LEKIMA

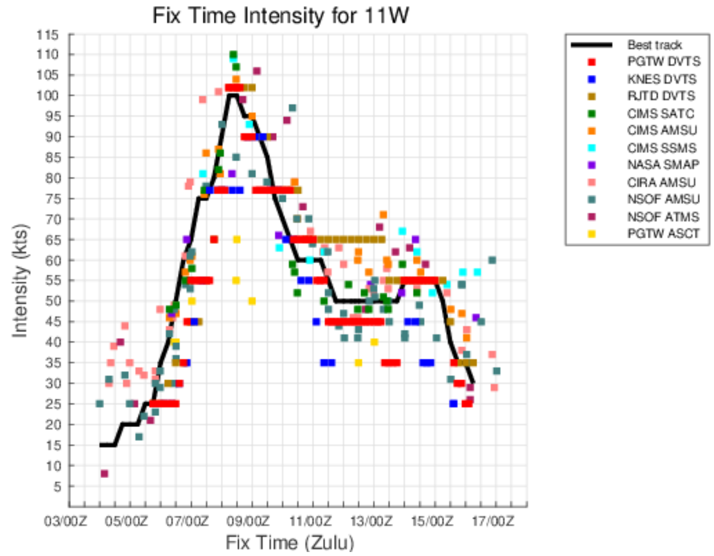
ISSUED LOW:	01 Aug / 0200Z
ISSUED MED:	02 Aug / 0000Z
FIRST TCFA:	03 Aug / 1200Z
FIRST WARNING:	04 Aug / 0000Z
LAST WARNING:	11 Aug / 1200Z
MAX INTENSITY:	135
WARNINGS:	31

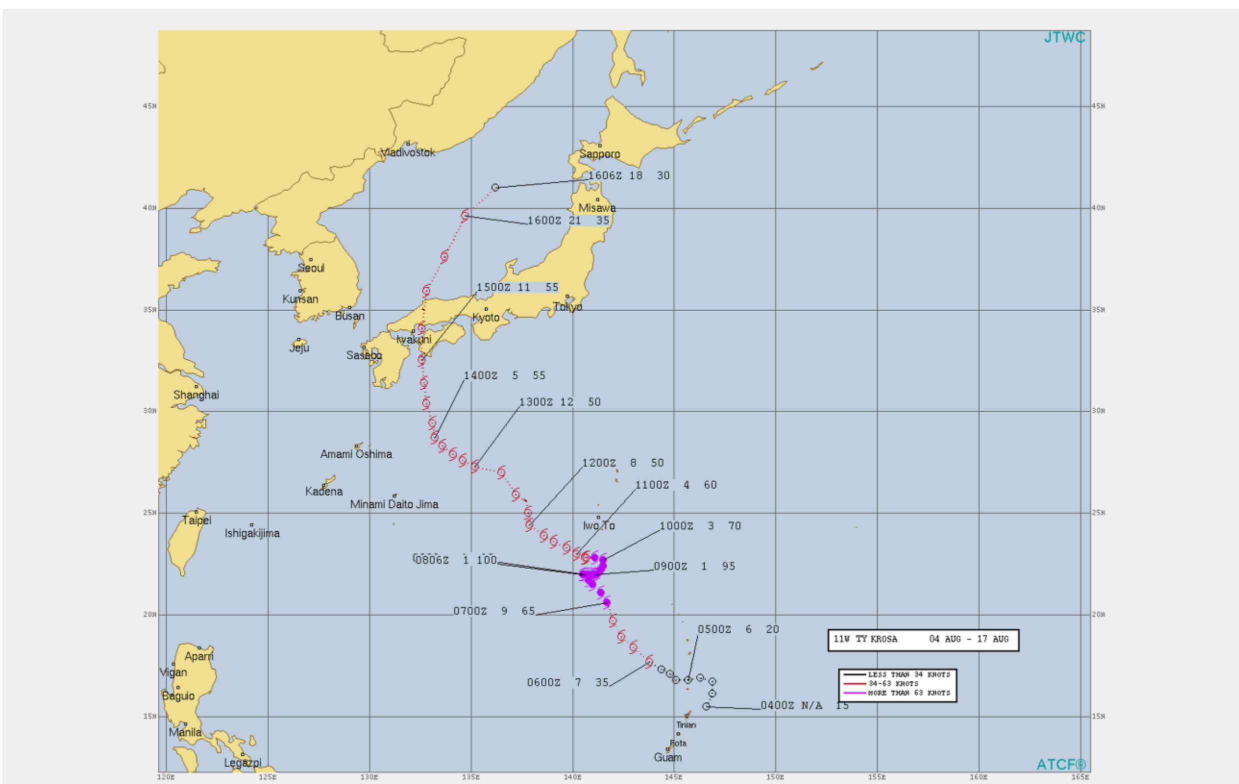




11W TYPHOON KROSA

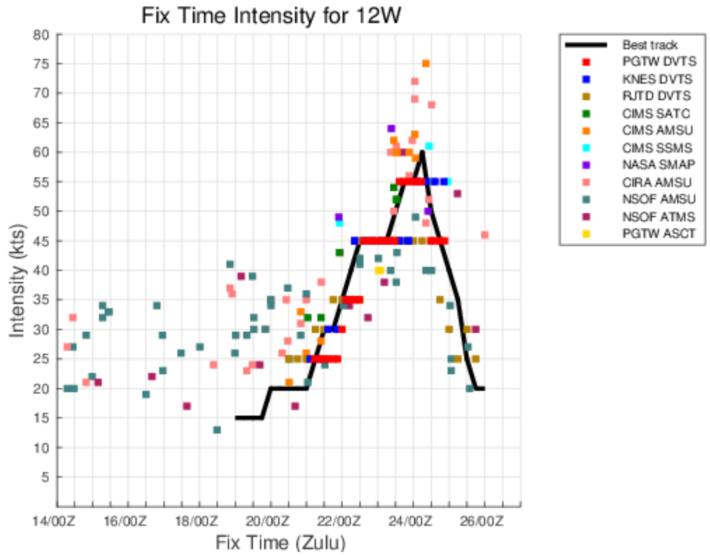
ISSUED LOW:	04 Aug / 1700Z
ISSUED MED:	05 Aug / 0600Z
FIRST TCFA:	05 Aug / 1330Z
FIRST WARNING:	05 Aug / 1800Z
LAST WARNING:	16 Aug / 0000Z
MAX INTENSITY:	100
WARNINGS:	42

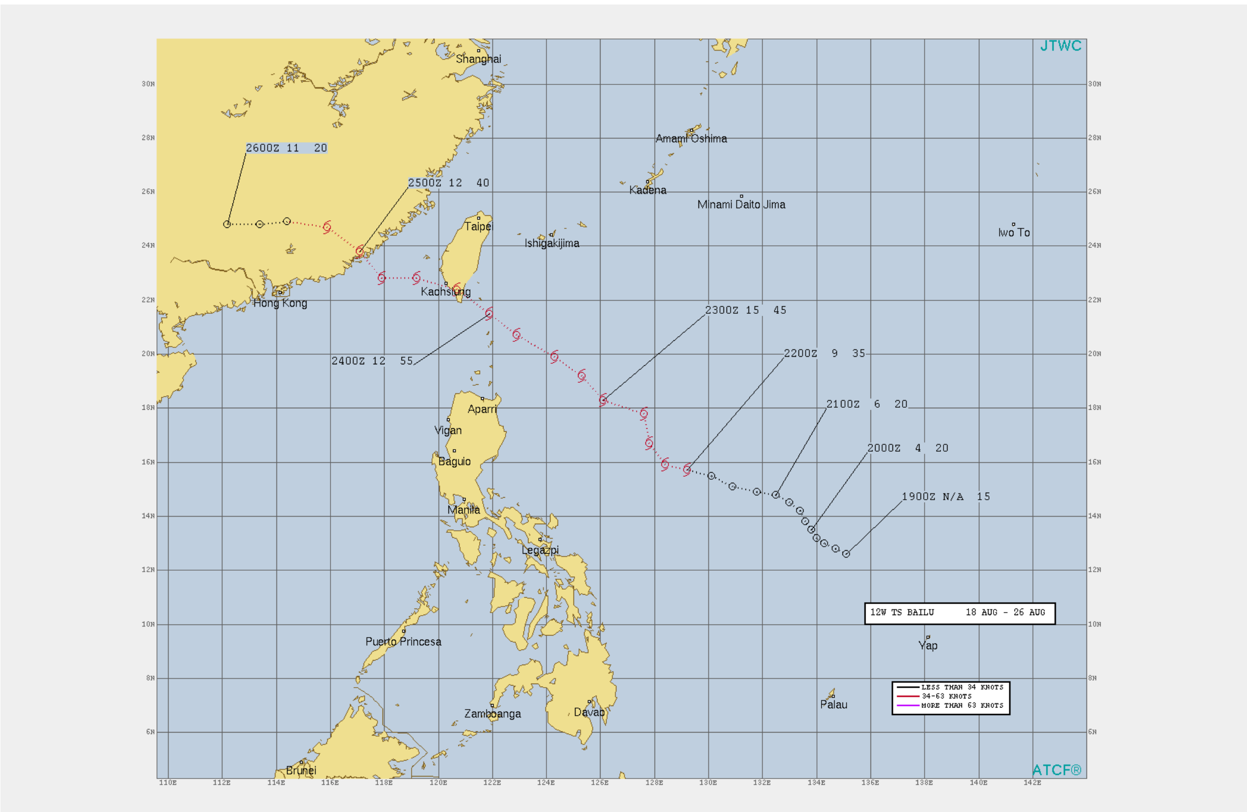




12W TROPICAL STORM BAILU

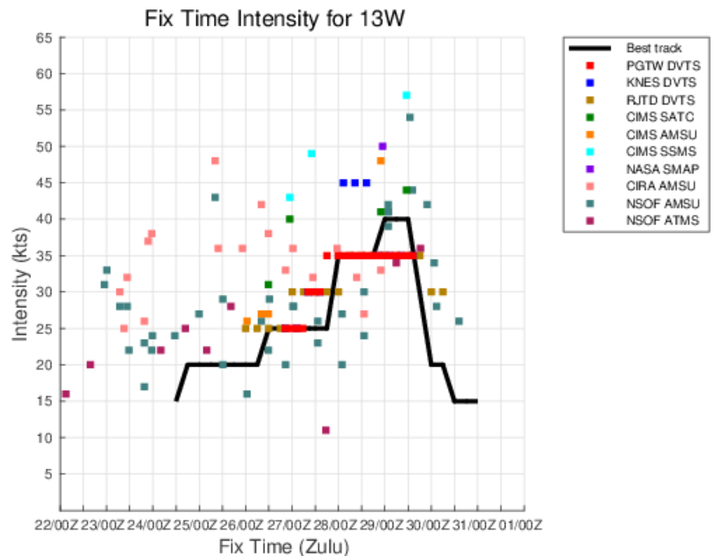
ISSUED LOW:	19 Aug / 0600Z
ISSUED MED:	20 Aug / 0130Z
FIRST TCFA:	20 Aug / 0930Z
FIRST WARNING:	21 Aug / 0600Z
LAST WARNING:	24 Aug / 1800Z
MAX INTENSITY:	60
WARNINGS:	15

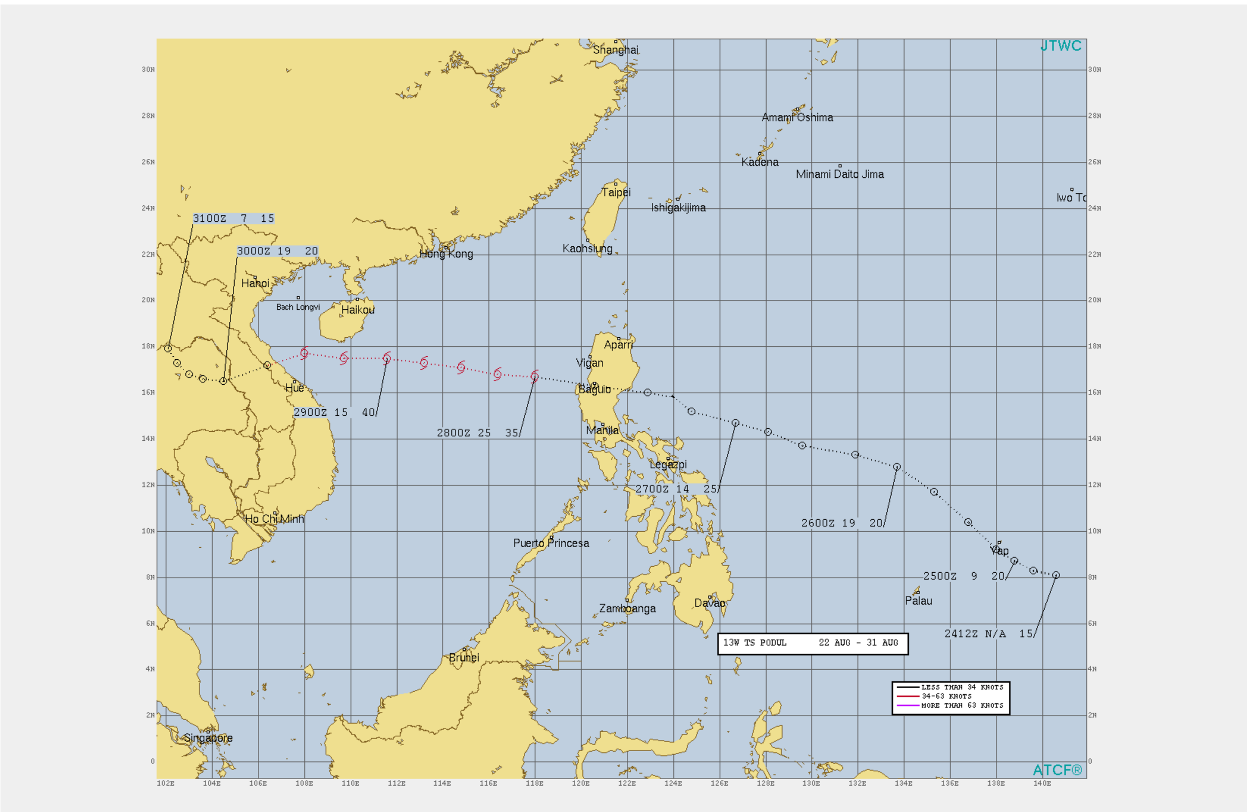




13W TROPICAL STORM PODUL

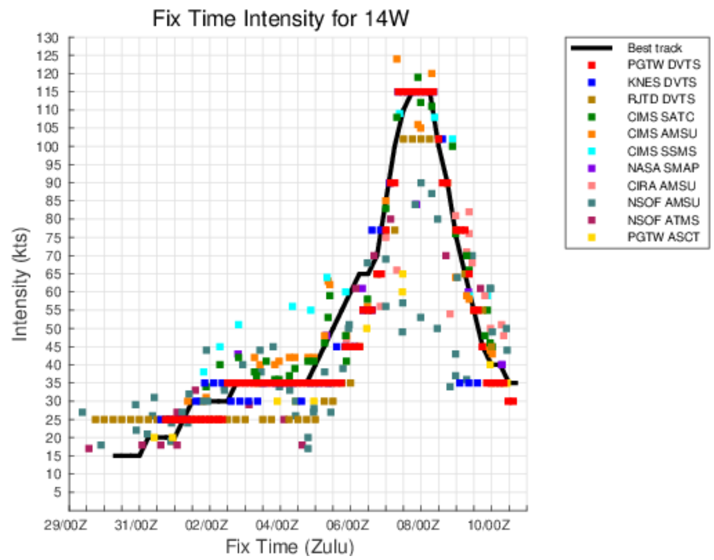
ISSUED LOW:	N/A
ISSUED MED:	24 Aug / 0200Z
FIRST TCFA:	25 Aug / 0600Z
FIRST WARNING:	26 Aug / 1200Z
LAST WARNING:	29 Aug / 1800Z
MAX INTENSITY:	40
WARNINGS:	14

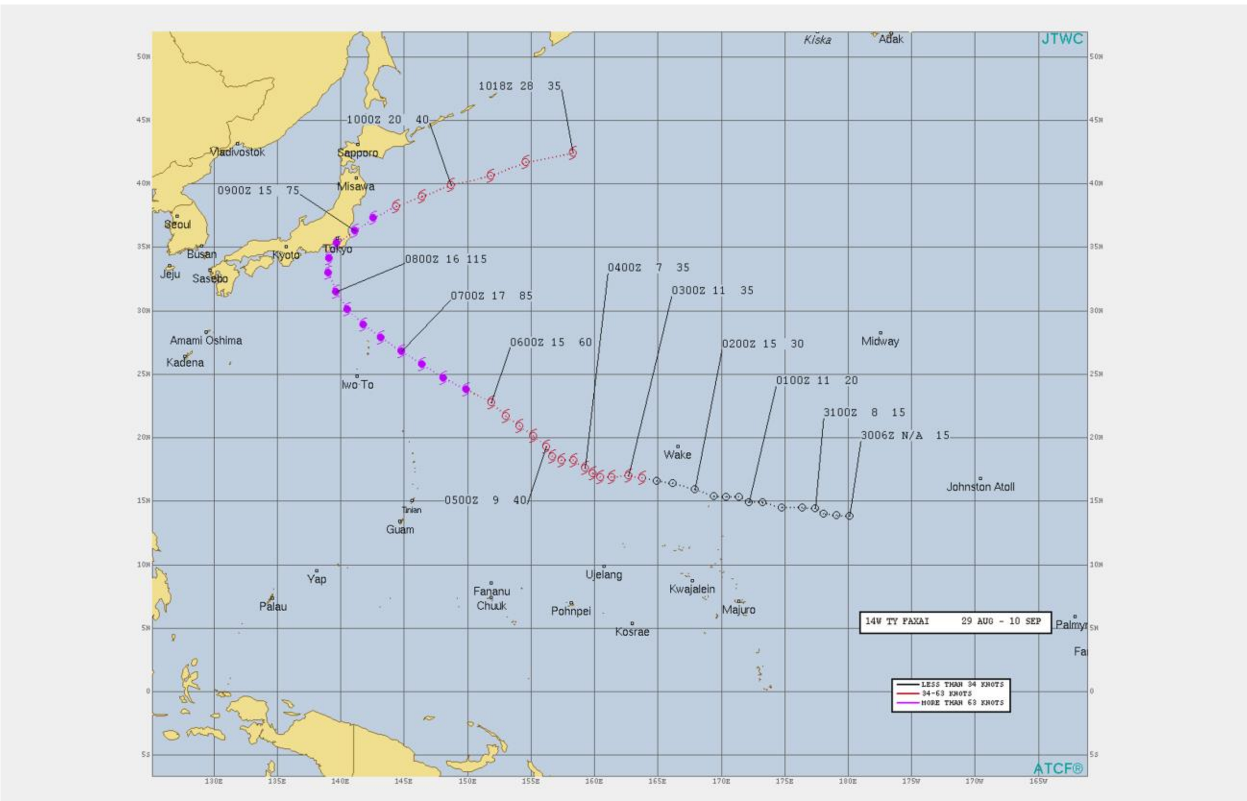




14W TYPHOON FAXAI

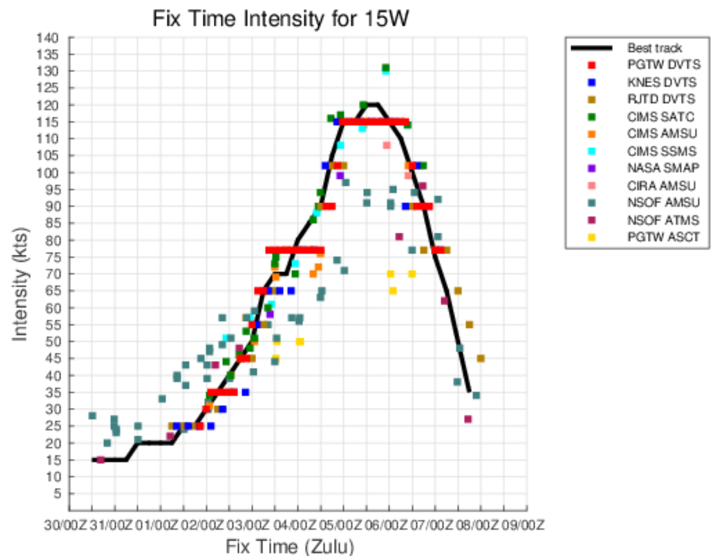
ISSUED LOW:	30 Aug / 1200Z
ISSUED MED:	31 Aug / 2000Z
FIRST TCFA:	01 Sep / 0900Z
FIRST WARNING:	01 Sep / 1800Z
LAST WARNING:	09 Sep / 1800Z
MAX INTENSITY:	115
WARNINGS:	33

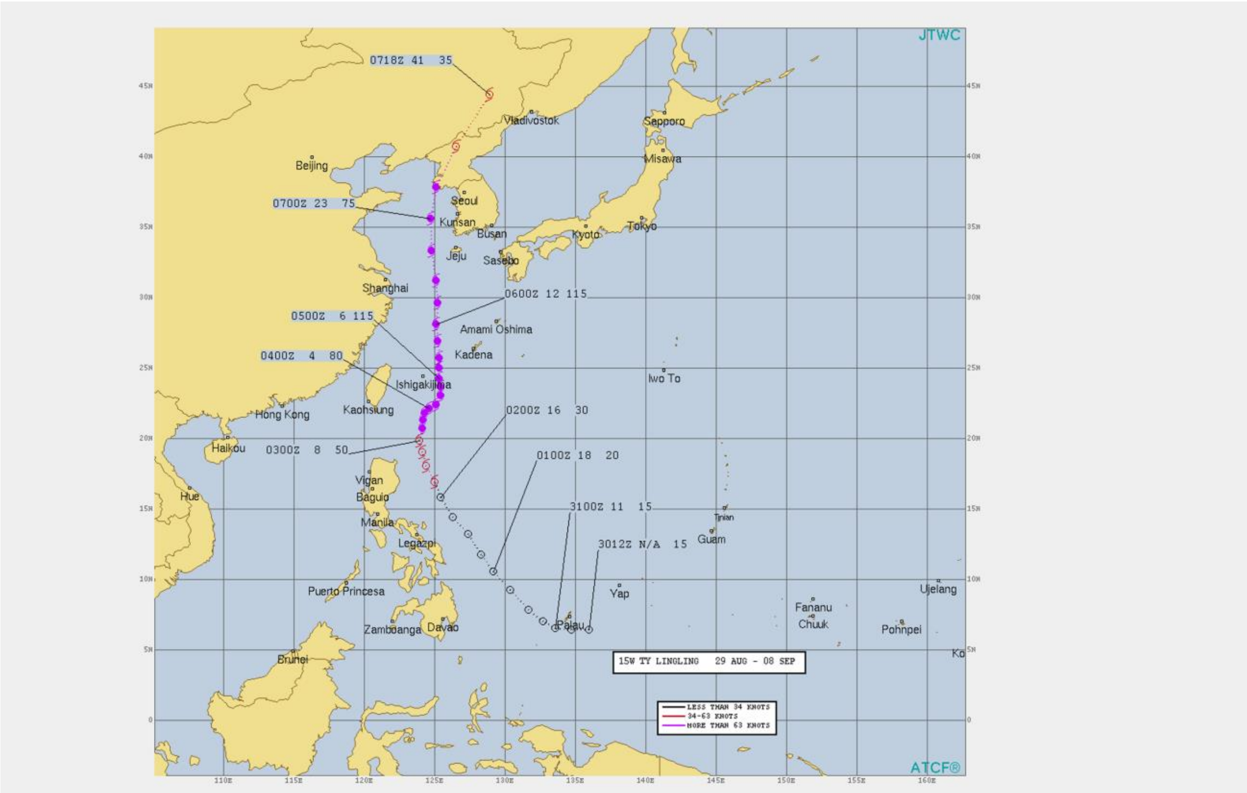




15W TYPHOON LINGLING

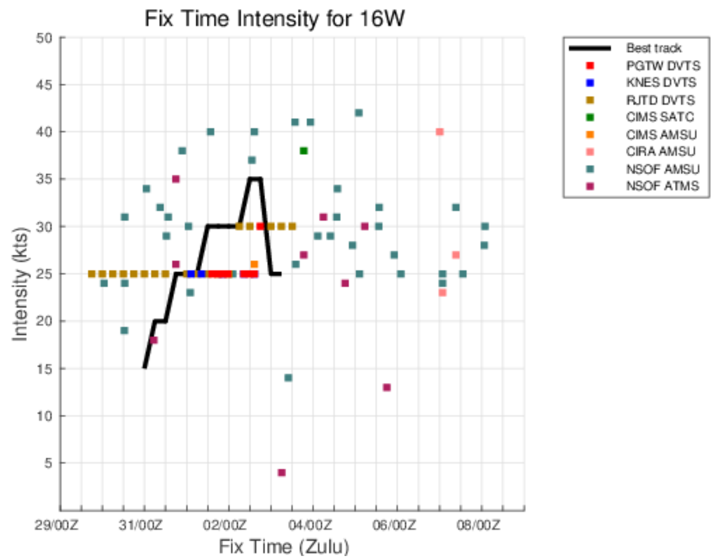
ISSUED LOW:	31 Aug / 0600Z
ISSUED MED:	31 Aug / 1000Z
FIRST TCFA:	31 Aug / 1930Z
FIRST WARNING:	02 Sep / 0000Z
LAST WARNING:	07 Sep / 0600Z
MAX INTENSITY:	120
WARNINGS:	22

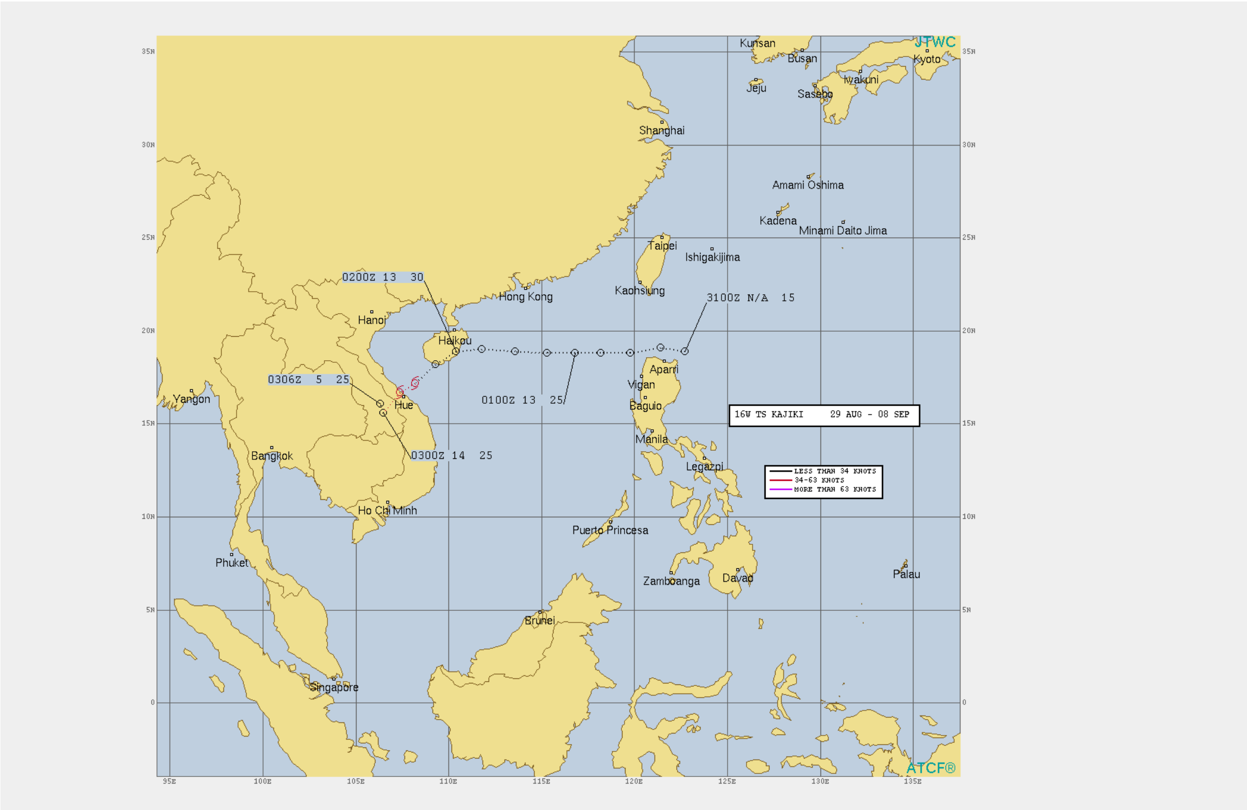




16W TROPICAL STORM KAJIKI

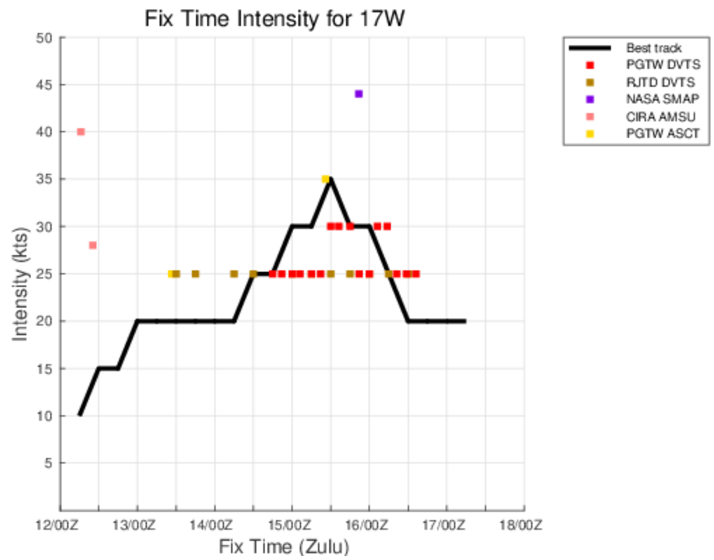
ISSUED LOW:	30 Aug / 1200Z
ISSUED MED:	31 Aug / 0600Z
FIRST TCFA:	01 Sep / 1900Z
FIRST WARNING:	02 Sep / 1800Z
LAST WARNING:	03 Sep / 1800Z
MAX INTENSITY:	35
WARNINGS:	5

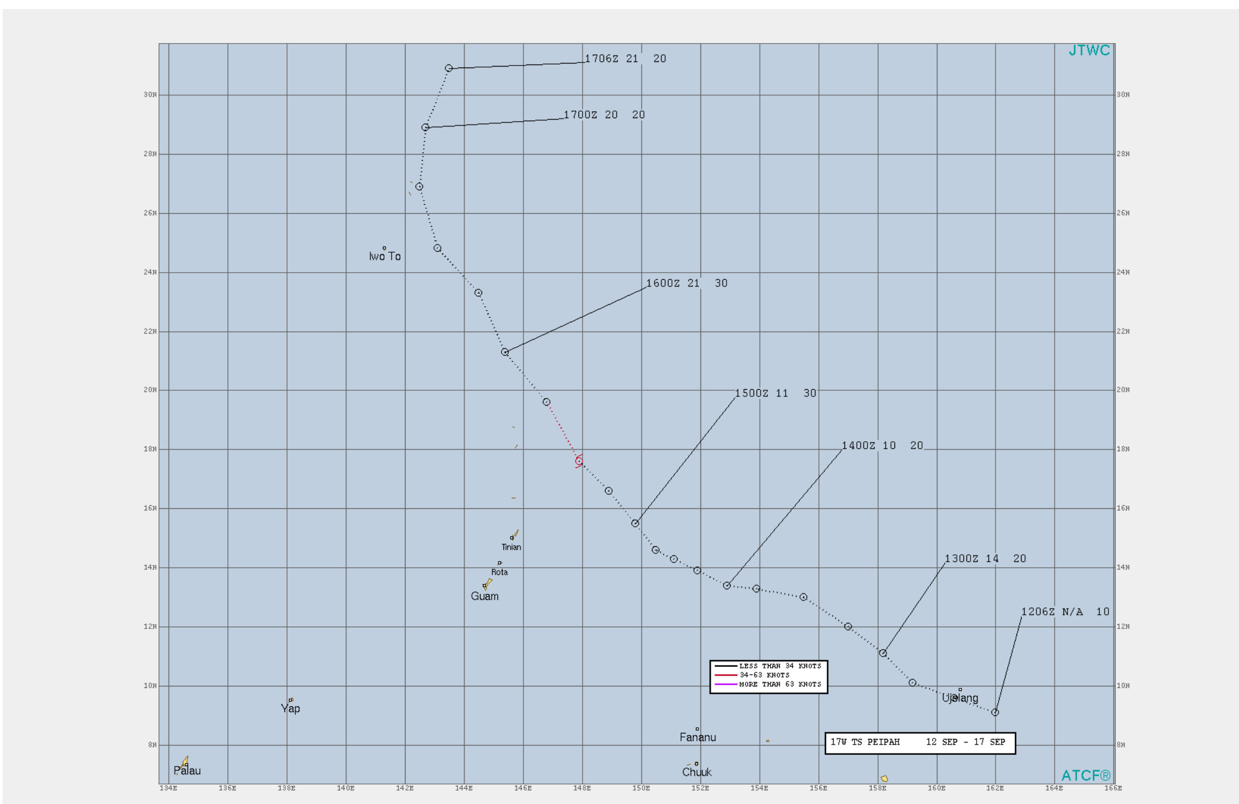




17W TROPICAL STORM PEIPAH

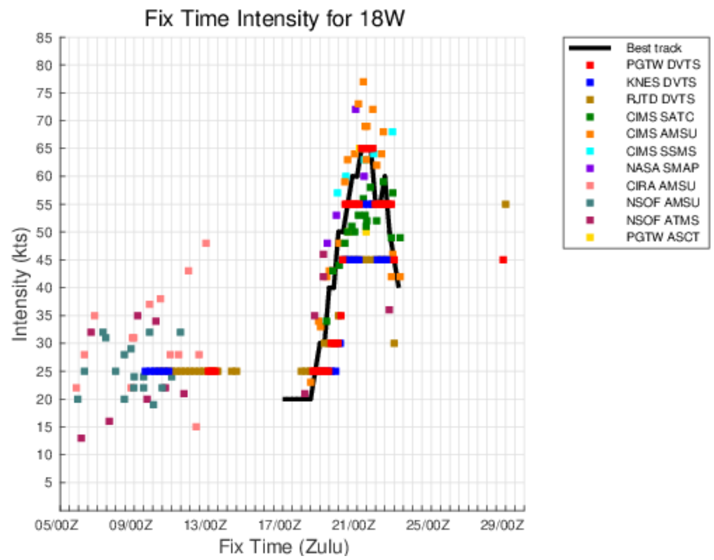
ISSUED LOW:	13 Sep / 0600Z
ISSUED MED:	13 Sep / 1000Z
FIRST TCFA:	14 Sep / 1700Z
FIRST WARNING:	14 Sep / 1800Z
LAST WARNING:	16 Sep / 1200Z
MAX INTENSITY:	35
WARNINGS:	8

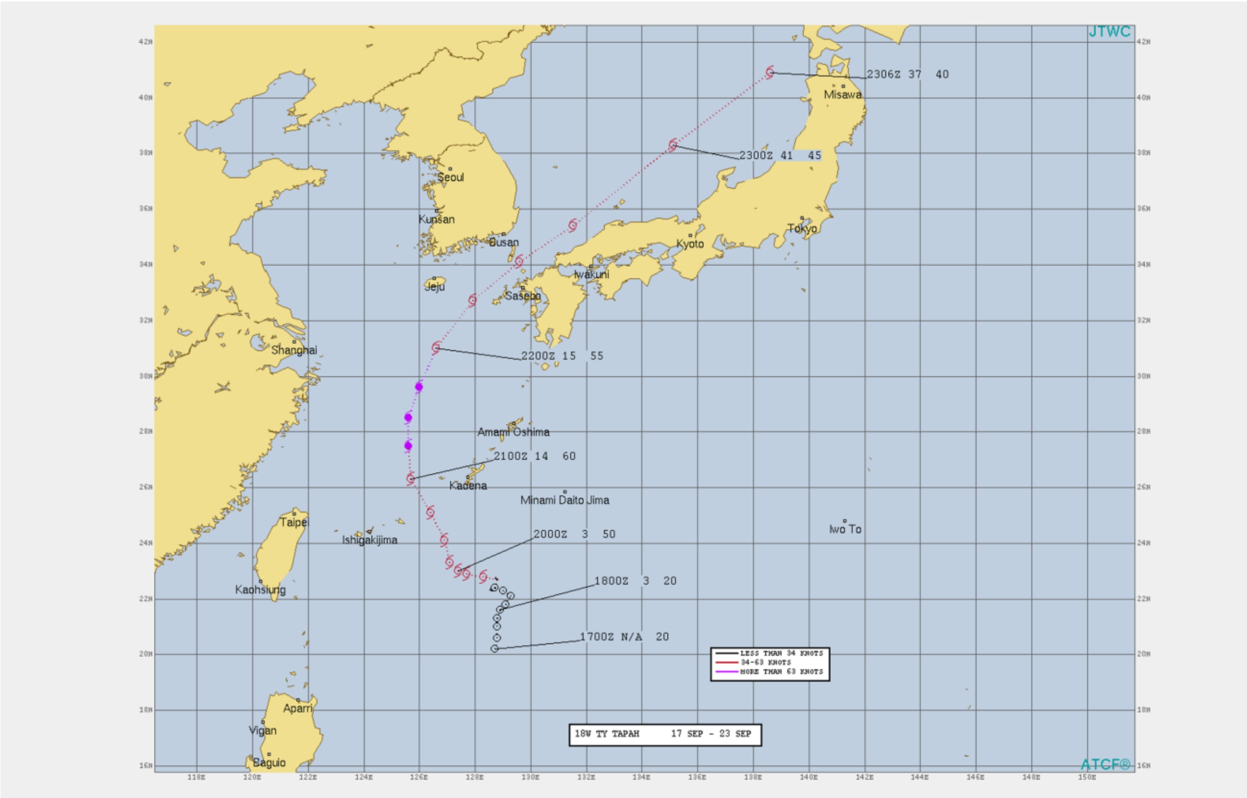




18W TYPHOON TAPAH

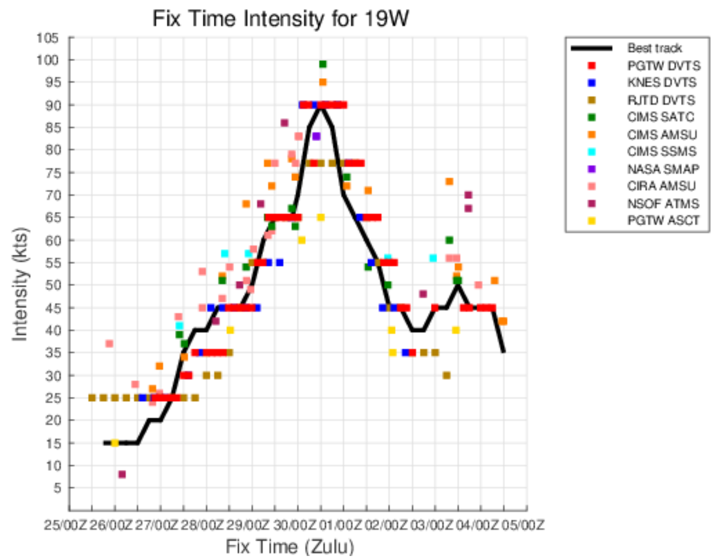
ISSUED LOW:	15 Sep / 0530Z
ISSUED MED:	17 Sep / 0600Z
FIRST TCFA:	18 Sep / 0900Z
FIRST WARNING:	19 Sep / 0000Z
LAST WARNING:	22 Sep / 1800Z
MAX INTENSITY:	65
WARNINGS:	16

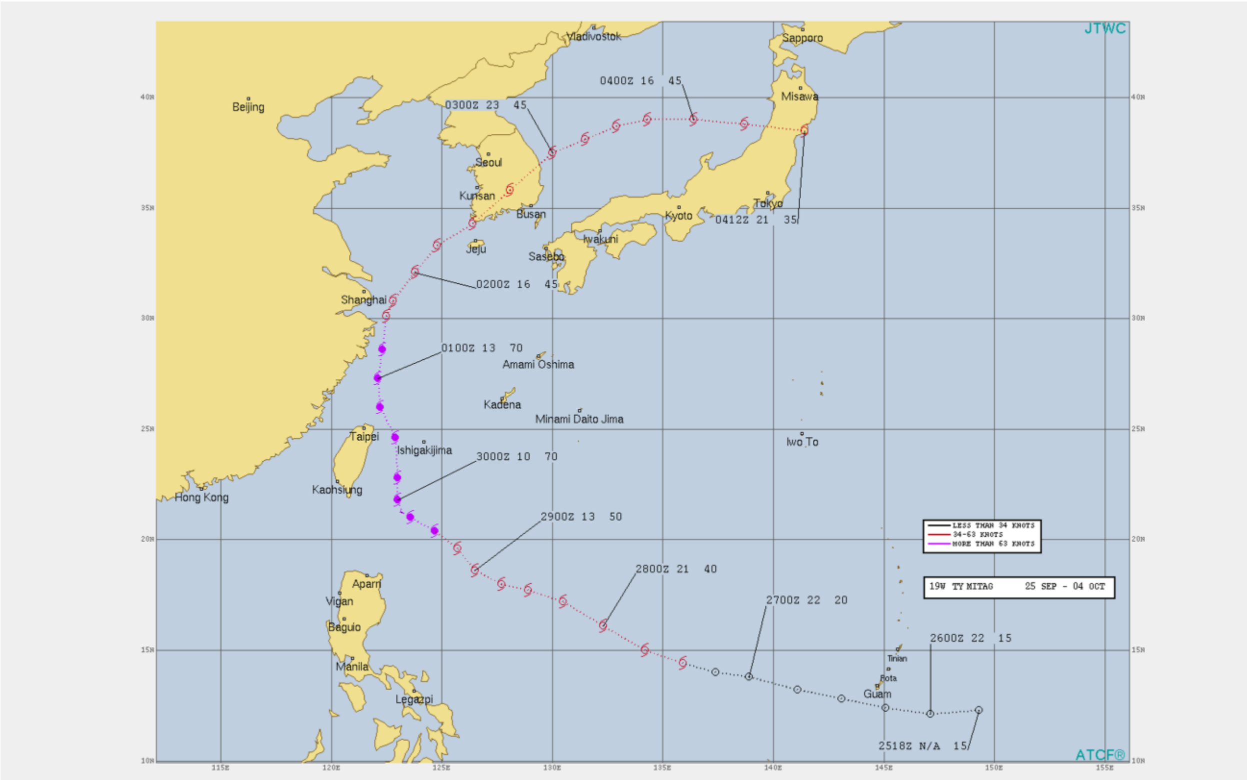




19W TYPHOON MITAG

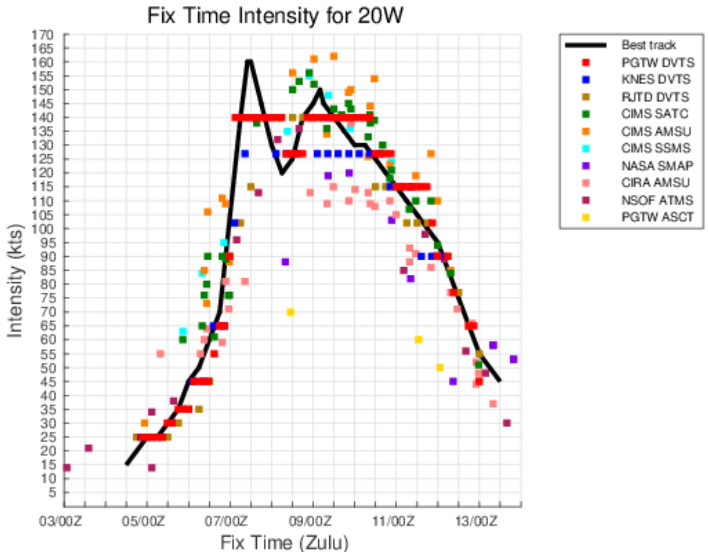
ISSUED LOW:	25 Sep / 0600Z
ISSUED MED:	25 Sep / 2200Z
FIRST TCFA:	26 Sep / 1430Z
FIRST WARNING:	27 Sep / 0600Z
LAST WARNING:	03 Oct / 0600Z
MAX INTENSITY:	90
WARNINGS:	25

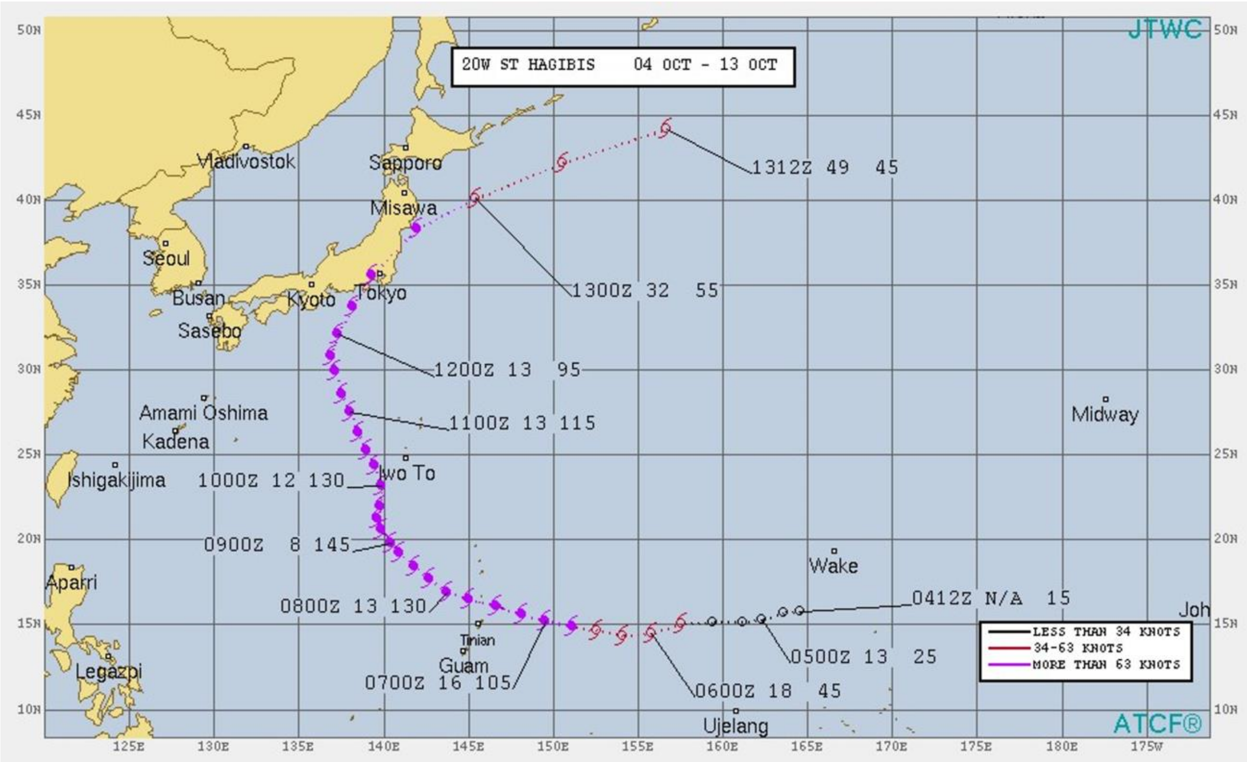




20W SUPER TYPHOON HAGIBIS

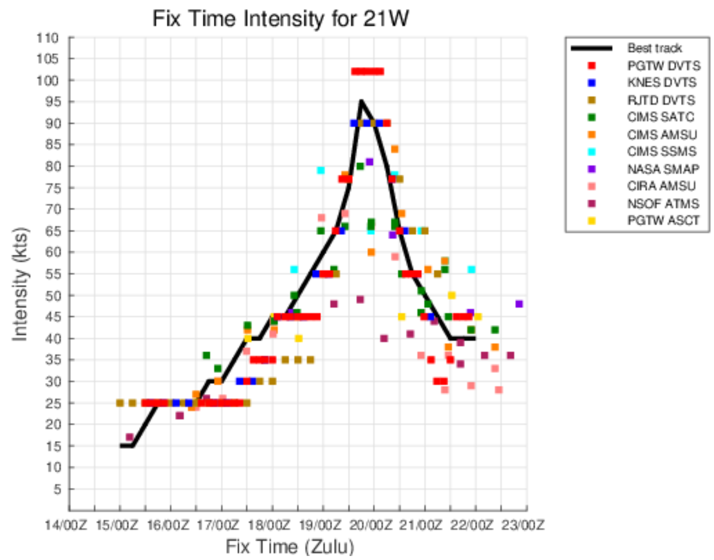
ISSUED LOW:	04 Oct / 0600Z
ISSUED MED:	N/A
FIRST TCFA:	05 Oct / 0230Z
FIRST WARNING:	05 Oct / 0600Z
LAST WARNING:	12 Oct / 1800Z
MAX INTENSITY:	160
WARNINGS:	31

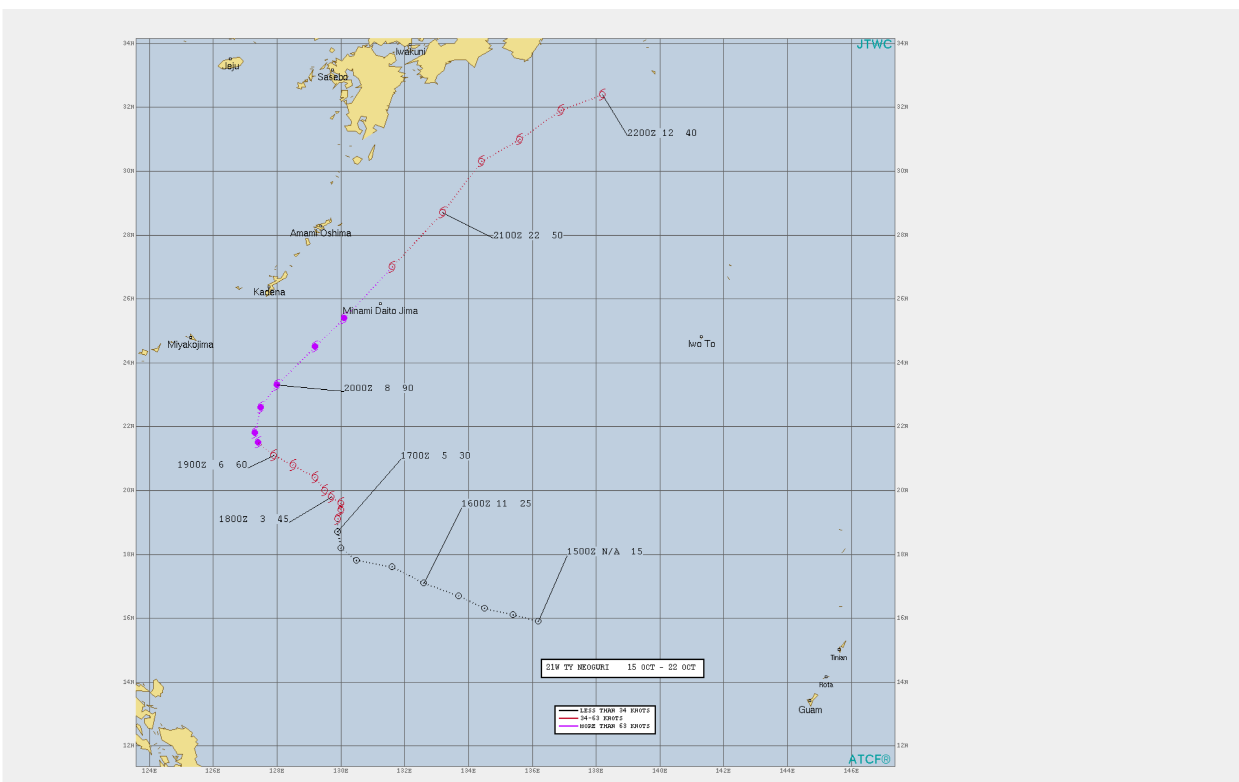




21W TYPHOON NEOGURI

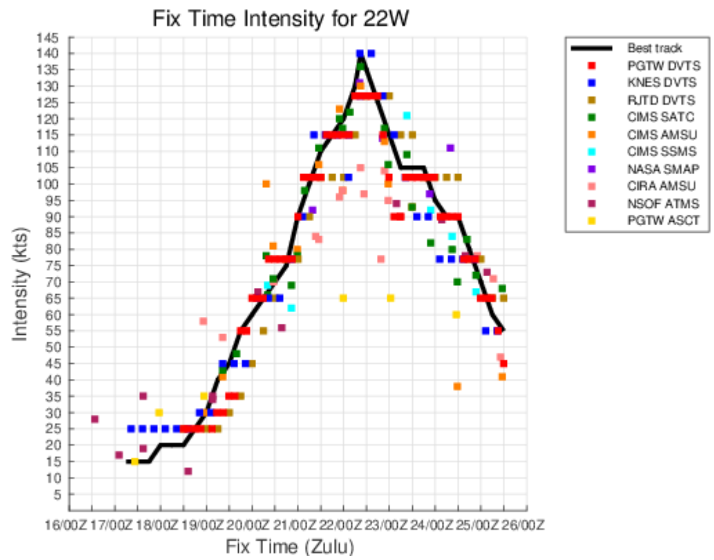
ISSUED LOW:	N/A
ISSUED MED:	15 Oct / 0600Z
FIRST TCFA:	15 Oct / 2100Z
FIRST WARNING:	16 Oct / 1200Z
LAST WARNING:	22 Oct / 0600Z
MAX INTENSITY:	95
WARNINGS:	24

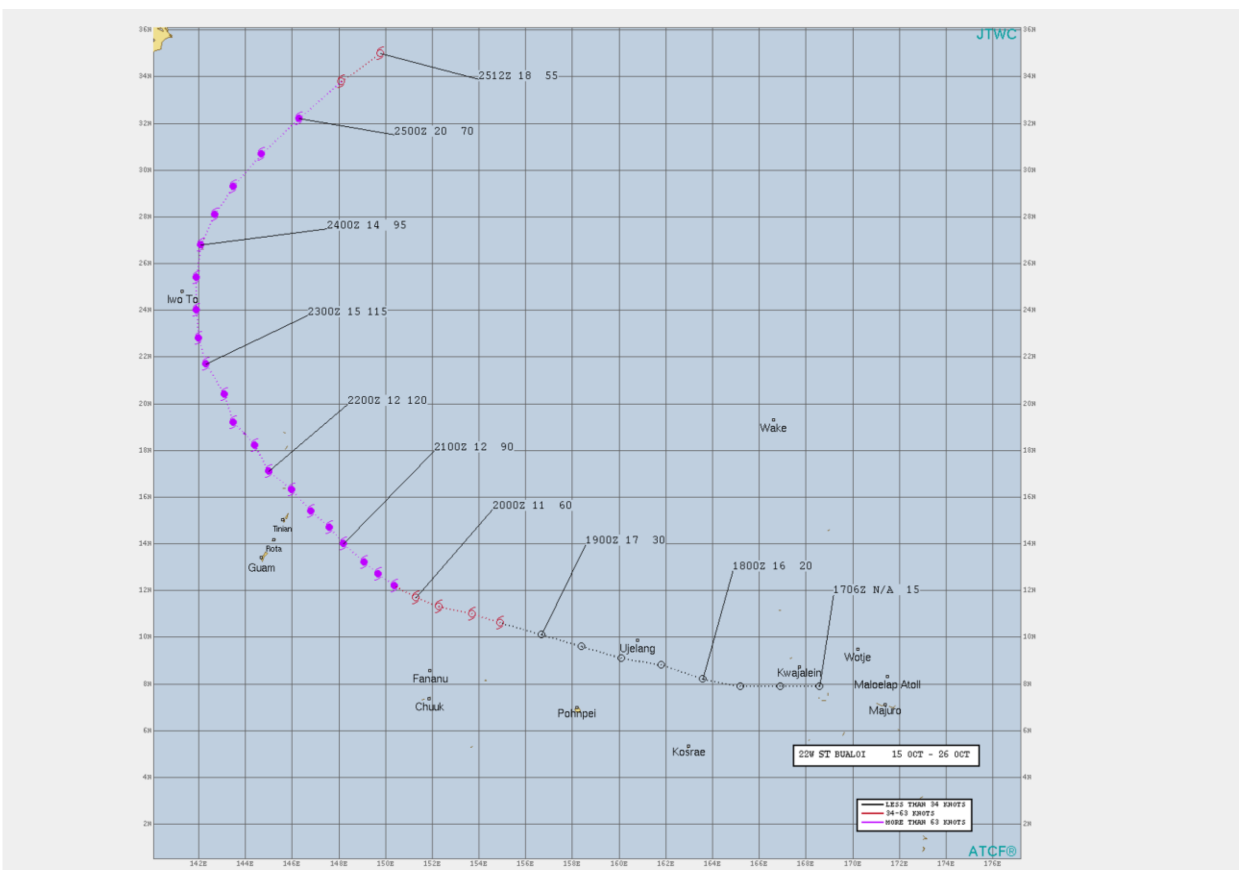




22W SUPER TYPHOON BUALOI

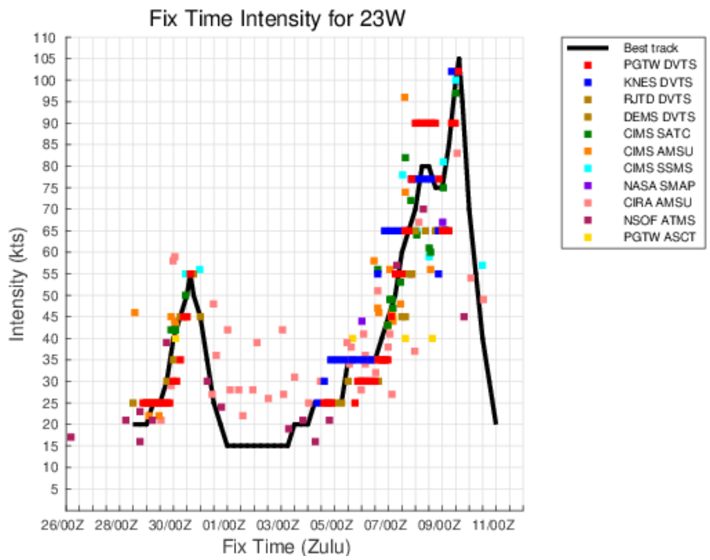
ISSUED LOW:	17 Oct / 0600Z
ISSUED MED:	18 Oct / 0600Z
FIRST TCFA:	18 Oct / 1530Z
FIRST WARNING:	19 Oct / 0000Z
LAST WARNING:	25 Oct / 0600Z
MAX INTENSITY:	140
WARNINGS:	26

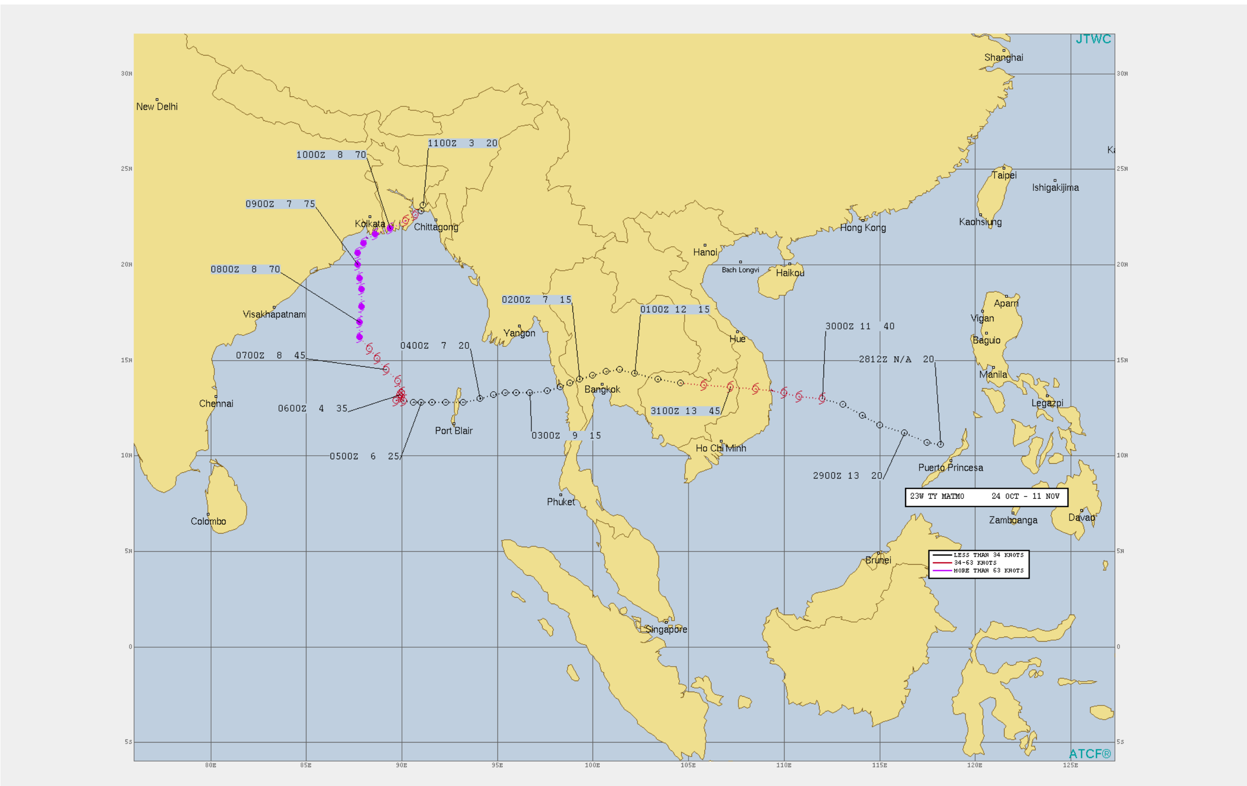




23W TYPHOON MATMO

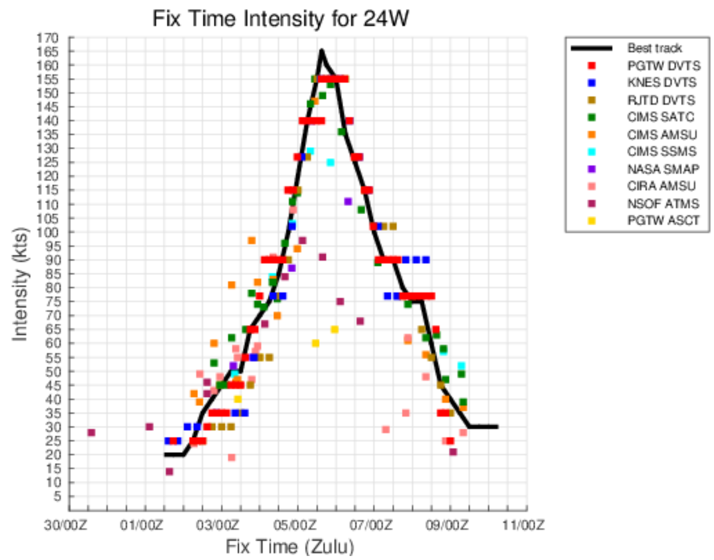
ISSUED LOW:	27 Oct / 0600Z
ISSUED MED:	28 Oct / 0600Z
FIRST TCFA:	28 Oct / 2130Z
FIRST WARNING:	29 Oct / 1800Z
LAST WARNING:	10 Nov / 1200Z
MAX INTENSITY:	105
WARNINGS:	21

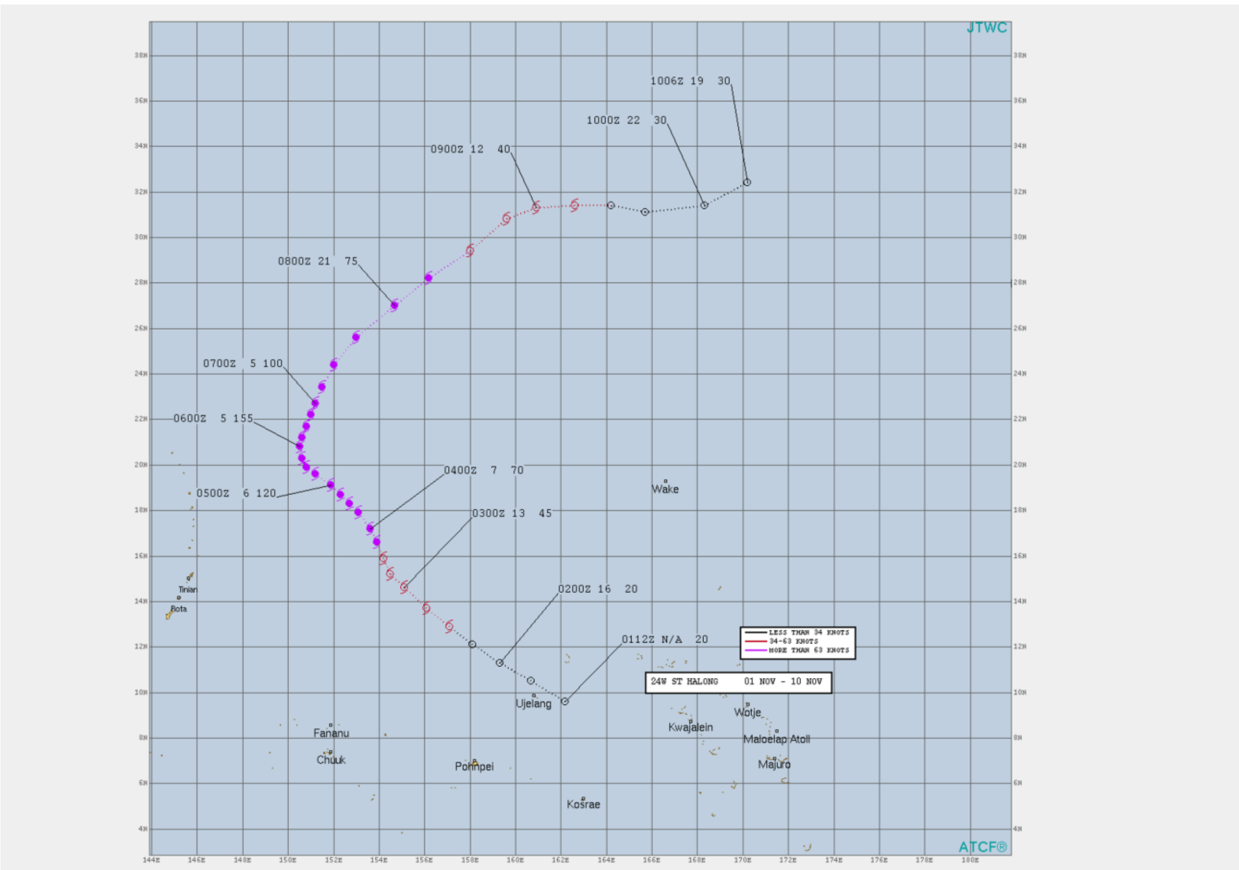




24W SUPER TYPHOON HALONG

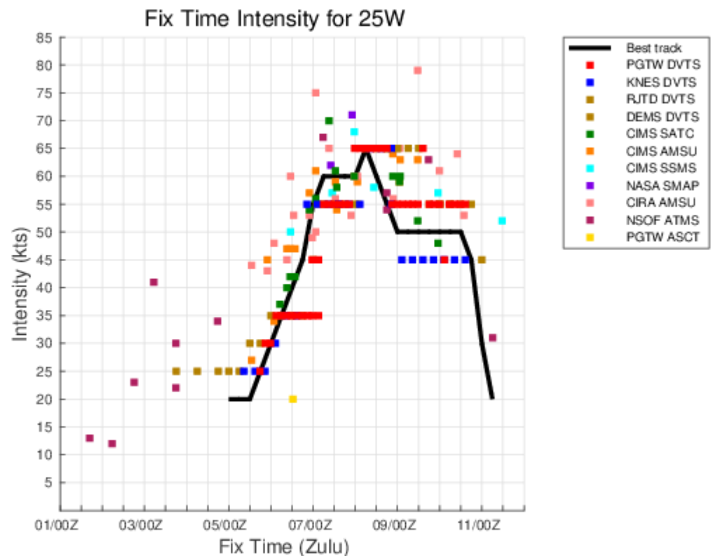
ISSUED LOW:	31 Oct / 0600Z
ISSUED MED:	01 Nov / 0600Z
FIRST TCFA:	02 Nov / 0900Z
FIRST WARNING:	02 Nov / 1200Z
LAST WARNING:	09 Nov / 1200Z
MAX INTENSITY:	165
WARNINGS:	29

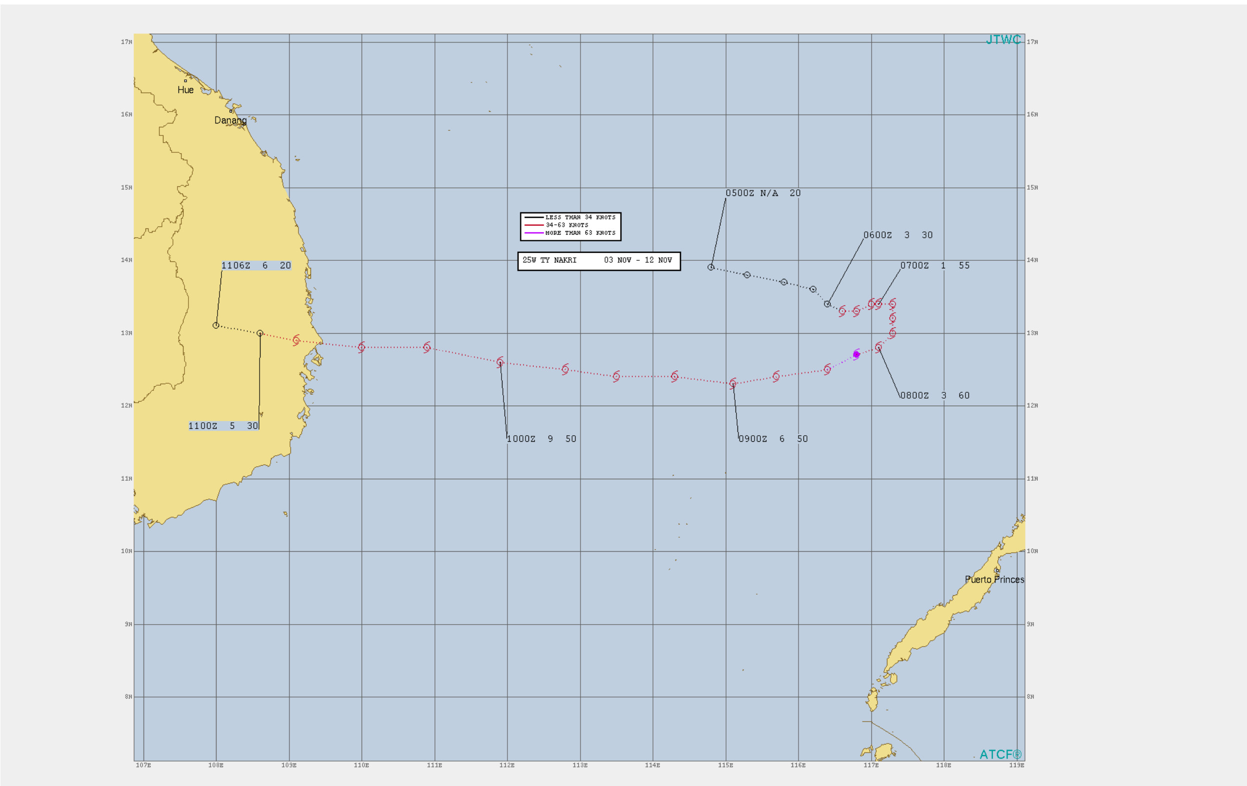




25W TYPHOON NAKRI

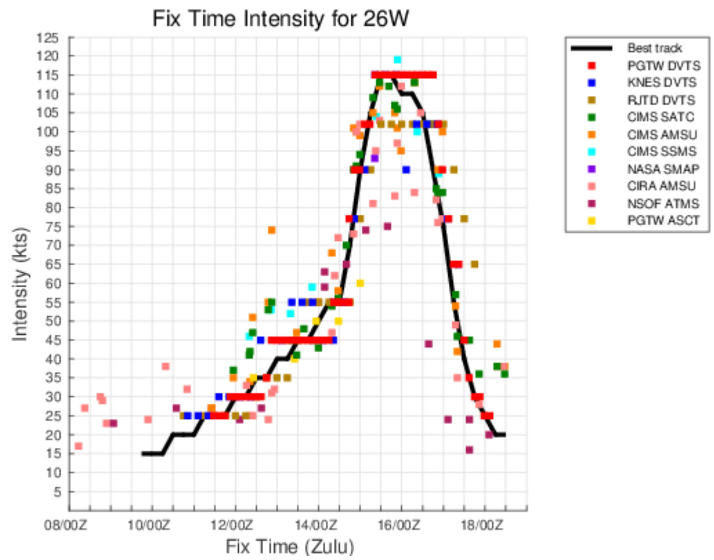
ISSUED LOW:	03 Nov / 0400Z
ISSUED MED:	03 Nov / 1530Z
FIRST TCFA:	04 Nov / 0330Z
FIRST WARNING:	05 Nov / 1800Z
LAST WARNING:	10 Nov / 1800Z
MAX INTENSITY:	65
WARNINGS:	21

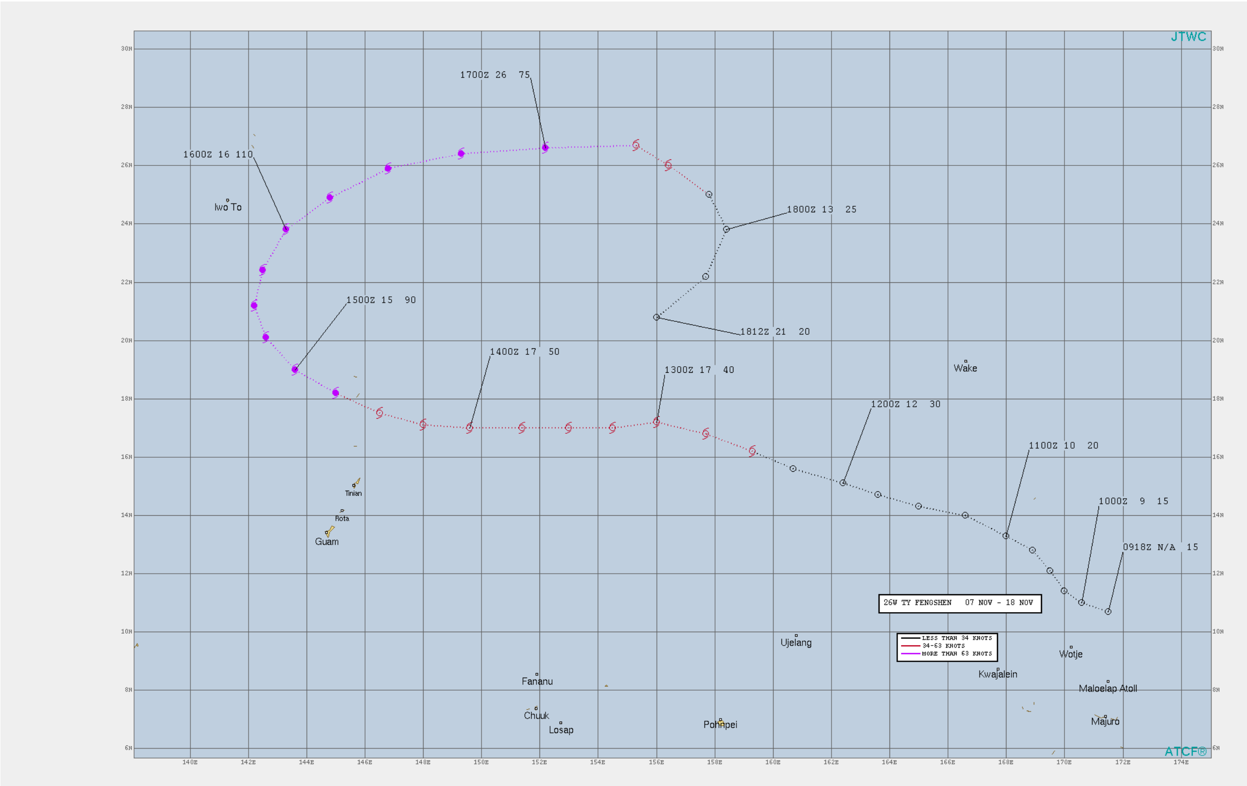




26W TYPHOON FENGSHEN

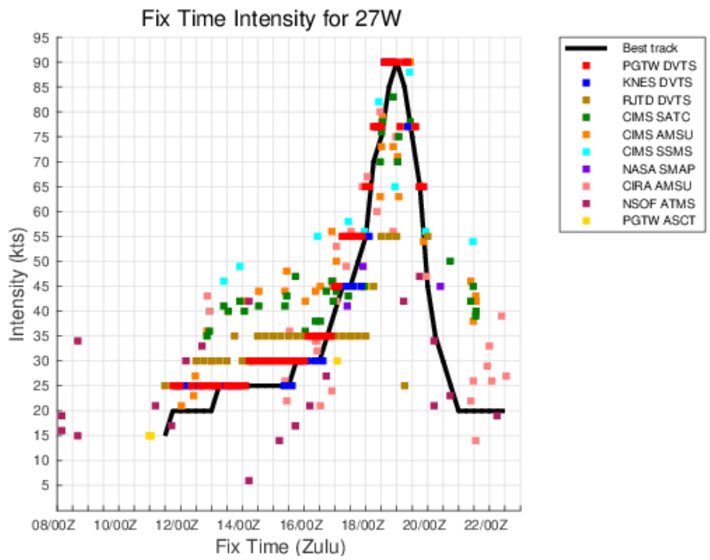
ISSUED LOW:	10 Nov / 0200Z
ISSUED MED:	10 Nov / 2130Z
FIRST TCFA:	11 Nov / 0300Z
FIRST WARNING:	11 Nov / 1200Z
LAST WARNING:	17 Nov / 1800Z
MAX INTENSITY:	115
WARNINGS:	26

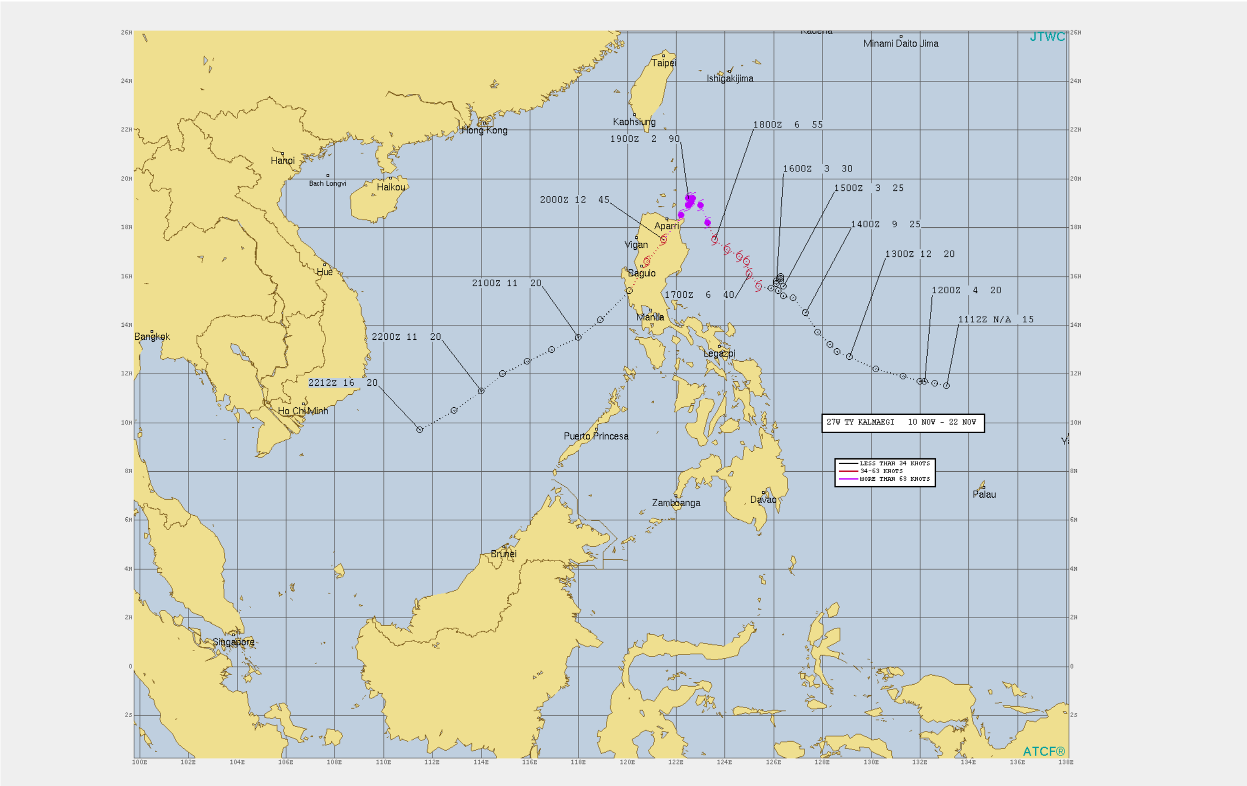




27W TYPHOON KALMAEGI

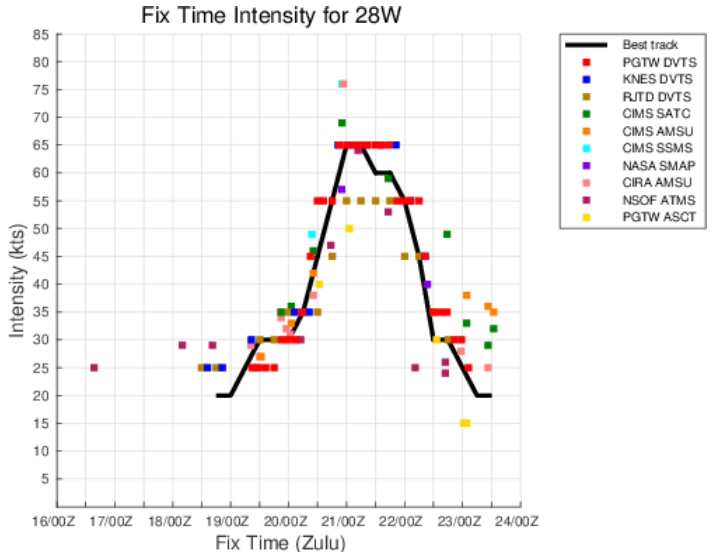
ISSUED LOW:	10 Nov / 2130Z
ISSUED MED:	N/A
FIRST TCFA:	11 Nov / 2130Z
FIRST WARNING:	12 Nov / 1800Z
LAST WARNING:	20 Nov / 1800Z
MAX INTENSITY:	90
WARNINGS:	33

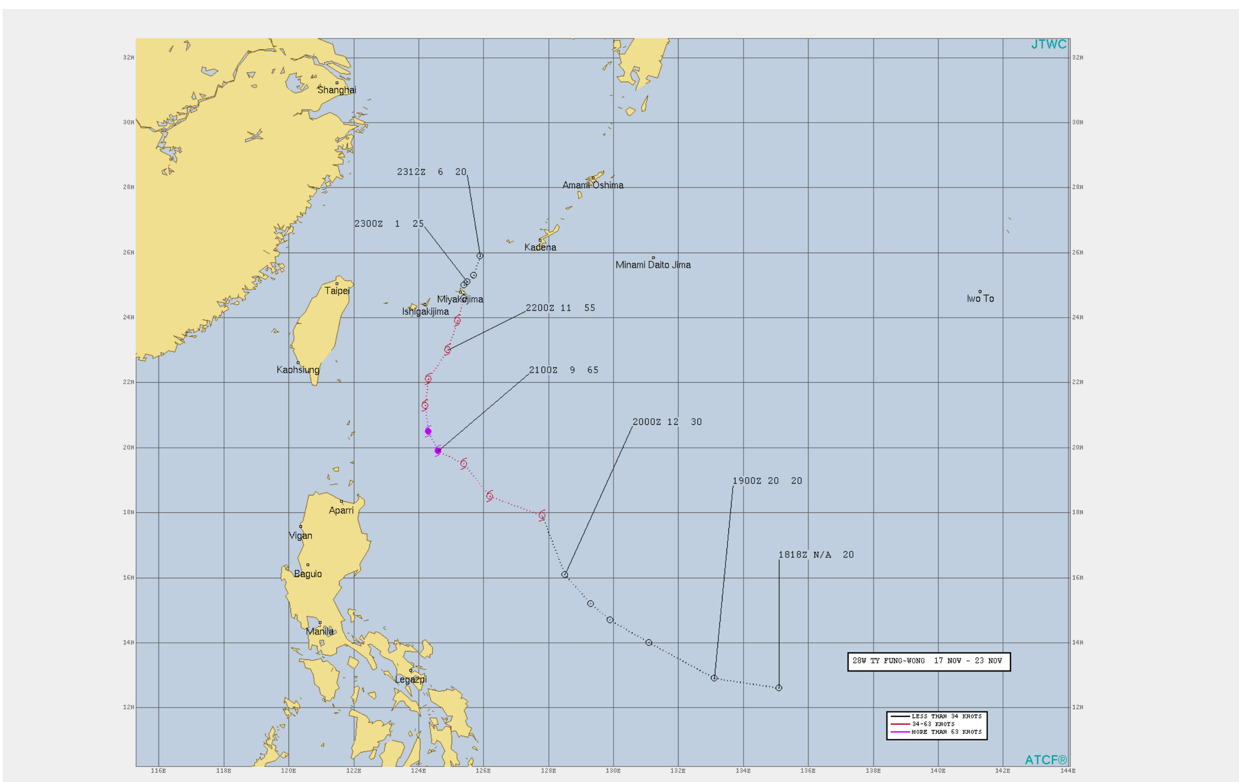




28W TYPHOON FUNG-WONG

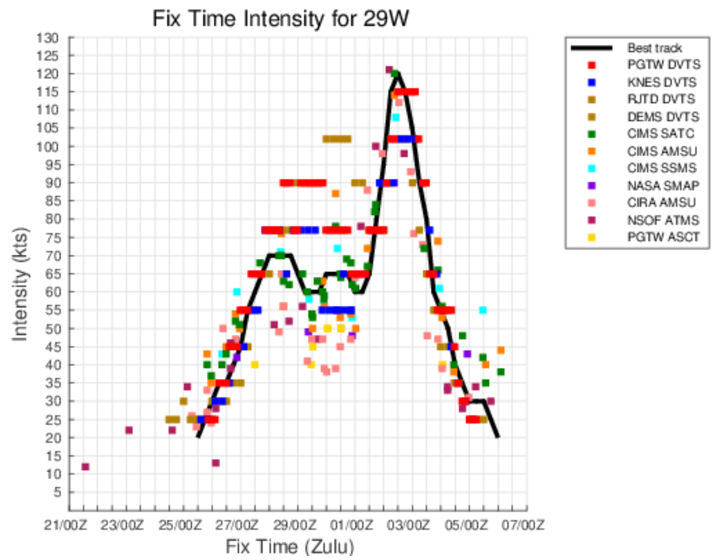
ISSUED LOW:	17 Nov / 1430Z
ISSUED MED:	18 Nov / 0600Z
FIRST TCFA:	18 Nov / 2200Z
FIRST WARNING:	19 Nov / 1200Z
LAST WARNING:	23 Nov / 0600Z
MAX INTENSITY:	65
WARNINGS:	15

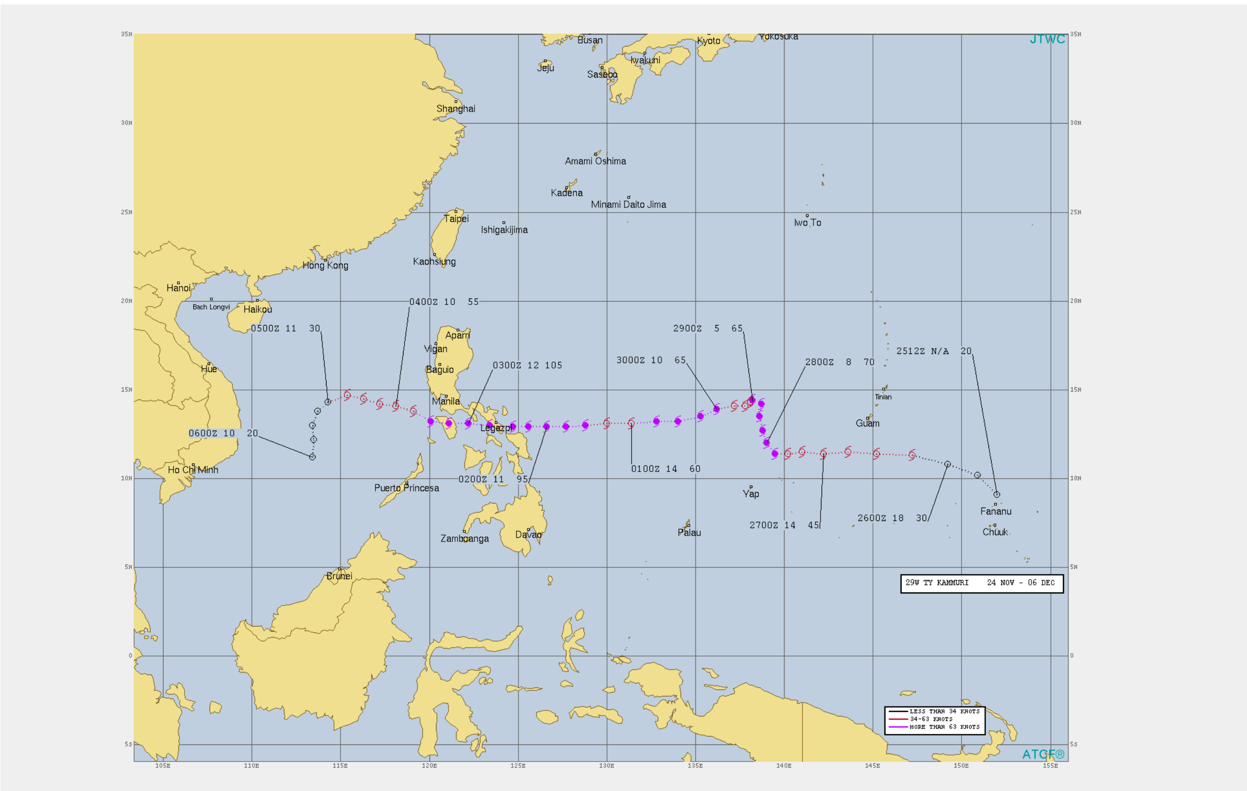




29W TYPHOON KAMMURI

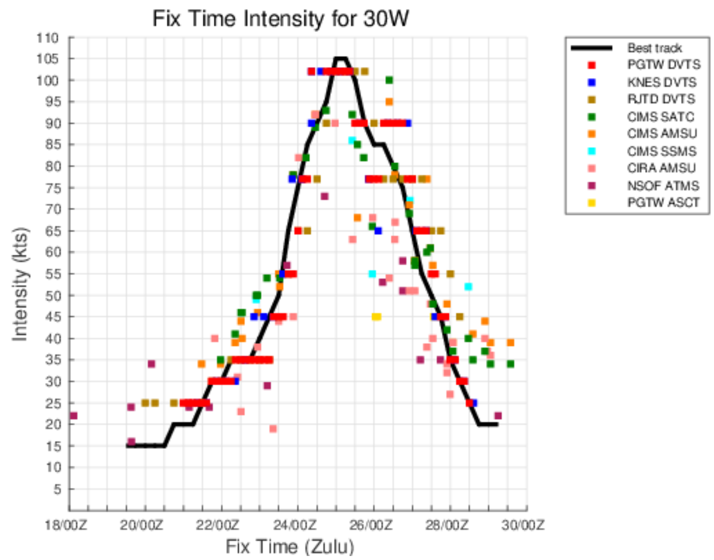
ISSUED LOW:	22 Nov / 2200Z
ISSUED MED:	24 Nov / 0330Z
FIRST TCFA:	25 Nov / 0900Z
FIRST WARNING:	25 Nov / 1800Z
LAST WARNING:	05 Dec / 1800Z
MAX INTENSITY:	120
WARNINGS:	41

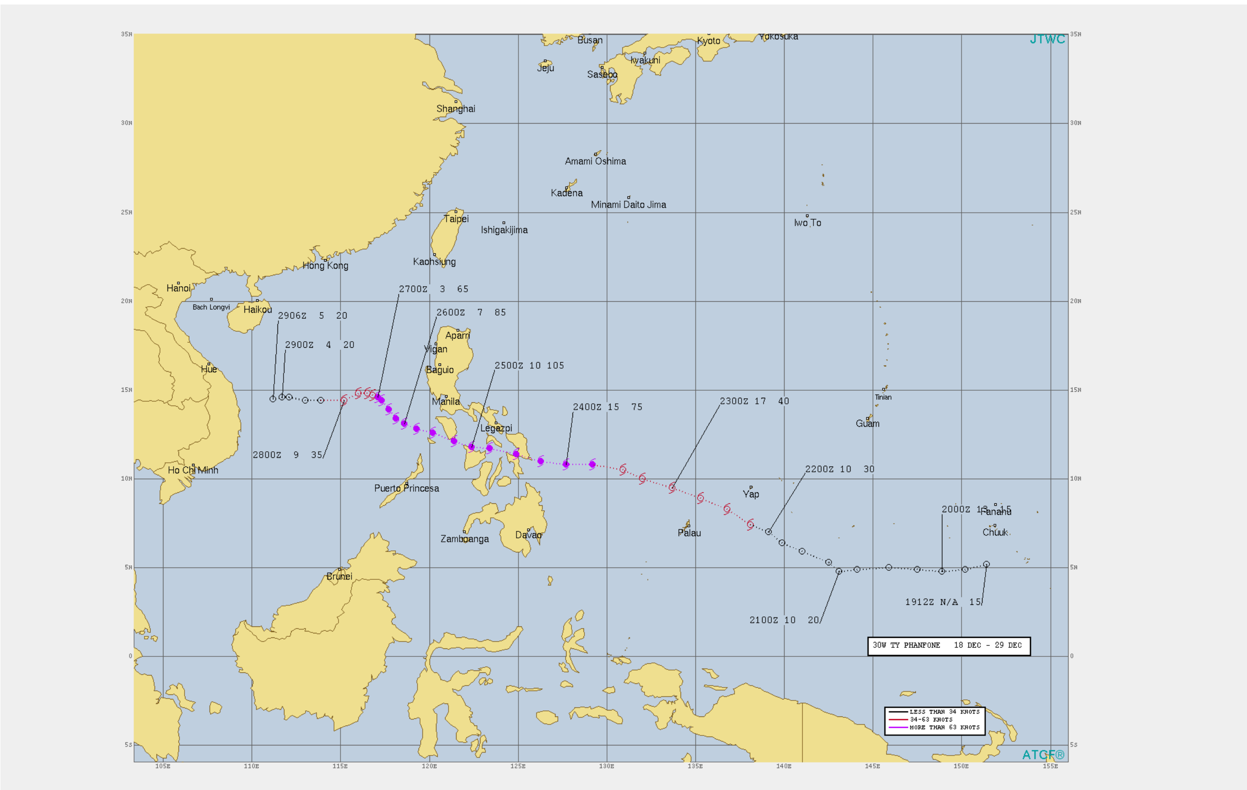




30W TYPHOON PHANFONE

ISSUED LOW:	18 Dec / 1900Z
ISSUED MED:	20 Dec / 0600Z
FIRST TCFA:	21 Dec / 0300Z
FIRST WARNING:	21 Dec / 1800Z
LAST WARNING:	28 Dec / 1800Z
MAX INTENSITY:	105
WARNINGS:	29





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 2019 season. Seven cyclones occurred in 2019, with five systems reaching intensity greater than 64 knots. Table 2-2 shows the monthly distribution of Tropical Cyclone activity for 1975 - 2019.

Table 2-1

NORTH INDIAN OCEAN SIGNIFICANT TROPICAL CYCLONES

(01 JAN 2019- 31 DEC 2019)

TC	NAME*	PERIOD**		WARNINGS ISSUED	EST MAX SFC WINDS KTS
01B	FANI	27 Apr / 0000Z	03 May / 1200Z	27	150
02A	VAYU	10 Jun / 1200Z	17 Jun / 0000Z	27	100
03A	HIKAA	22 Sep / 1800Z	24 Sep / 1800Z	9	90
04A	KYARR	24 Oct / 1800Z	31 Oct / 1800Z	29	135
05A	MAHA	30 Oct / 0600Z	06 Nov / 1800Z	31	105
06A	PAWAN	03 Dec / 0000Z	07 Dec / 0000Z	17	45
07A	SEVEN	03 Dec / 1200Z	04 Dec / 1200Z	5	55

* As designated by the responsible RSMC

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

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

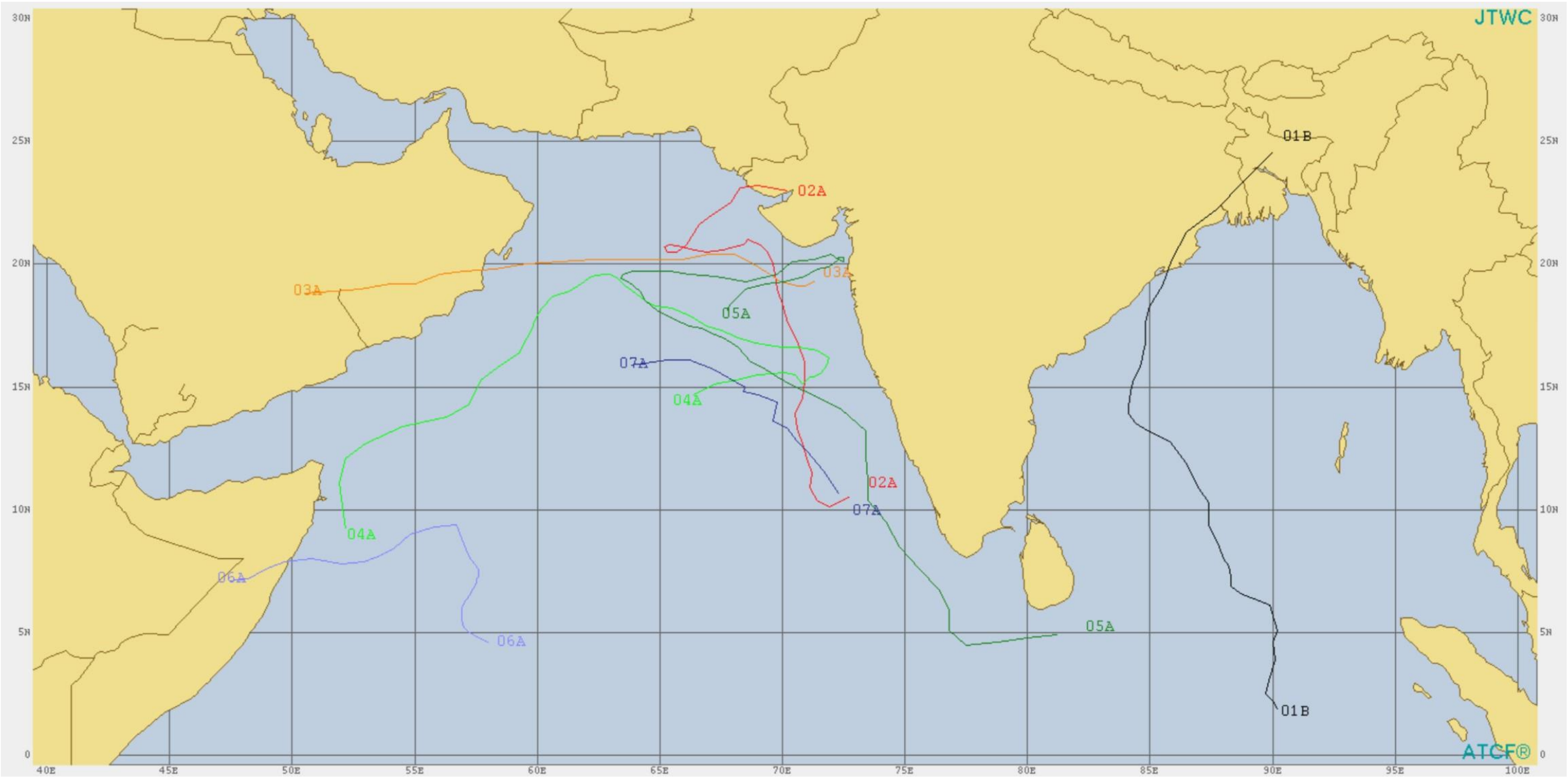


Figure 2-1. North Indian Ocean Tropical Cyclones.

Table 2 - 2
DISTRIBUTION OF NORTH INDIAN OCEAN TROPICAL CYCLONES FOR 1975 - 2019

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS (Total ≥64kt)	(Total 34-63kt)	(Total ≤33 kt)
	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
							(1975-2019)								
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	33	25	4	1	15	48	60	28	233		

Section 2   Cyclone Summaries

This section presents a synopsis of each cyclone that occurred during 2019 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 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 TC formation alert (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 started, 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 by JTWC. Landfall over major landmasses with approximate locations is presented as well. JTWC initiates tropical cyclone warnings when one or more of the following four criteria are met:

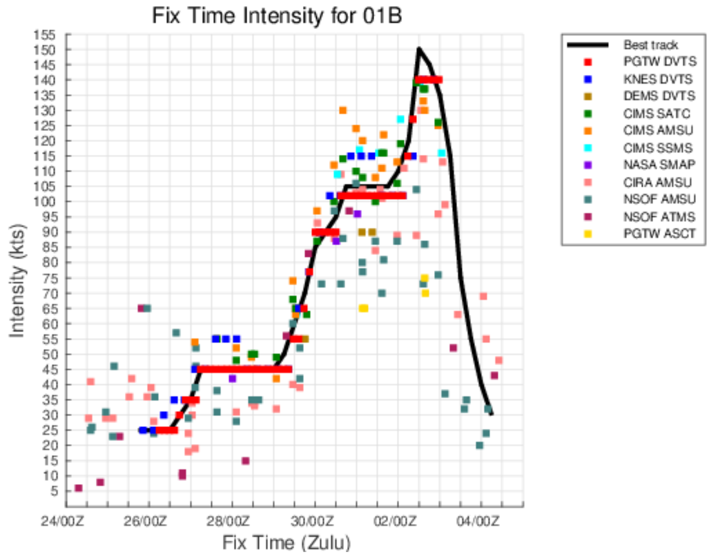
- Estimated maximum sustained wind speeds within a closed tropical circulation meet or exceed a designated threshold of 25 knots in the North Pacific Ocean or 35 knots in the South Pacific and Indian Oceans.
- Maximum sustained wind speeds within a closed tropical circulation are expected to increase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

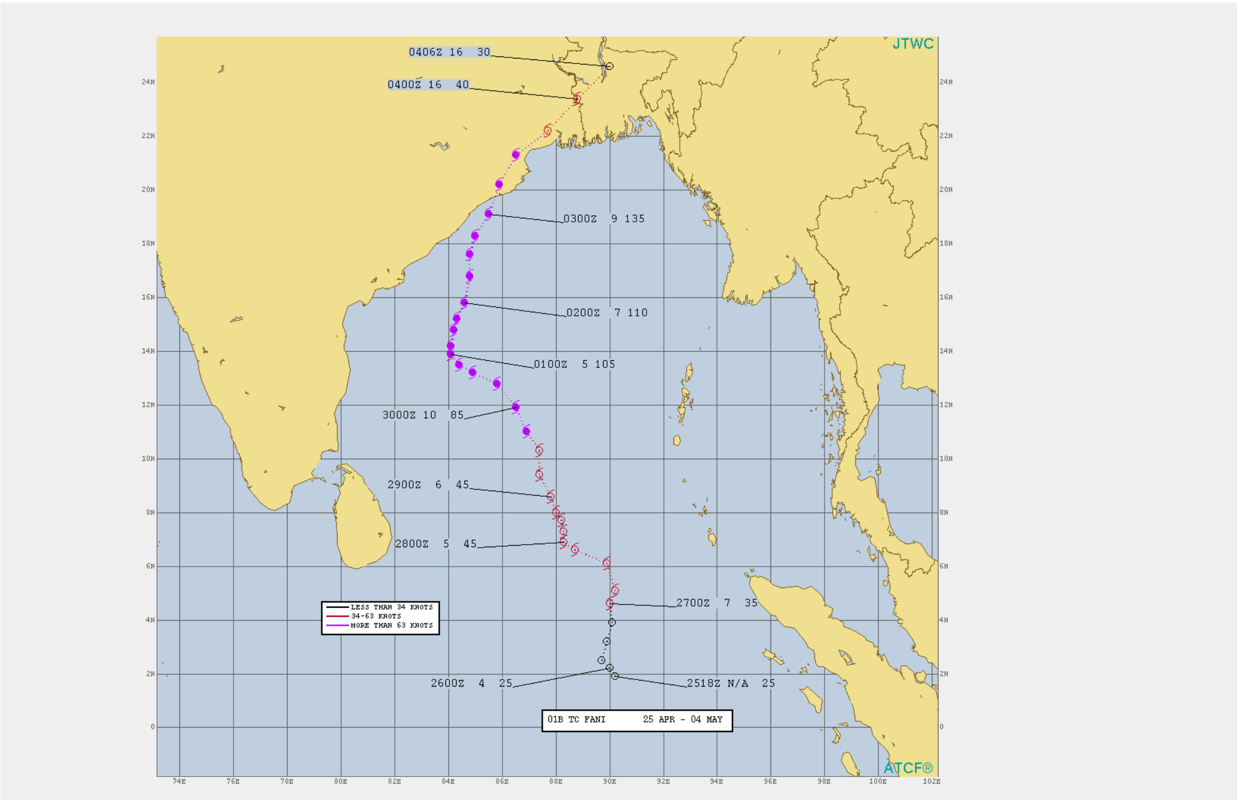
The JTWC post-event, reanalysis best track is provided for each cyclone. Data included on the best track are position and intensity noted with color-coded cyclone symbols and track line. Best track position labels include the date, time, track speed in knots, maximum wind speed in knots, as well as the 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/2019/2019s-bio/IO_besttracks_2019-2019.kmz

01B TROPICAL CYCLONE FANI

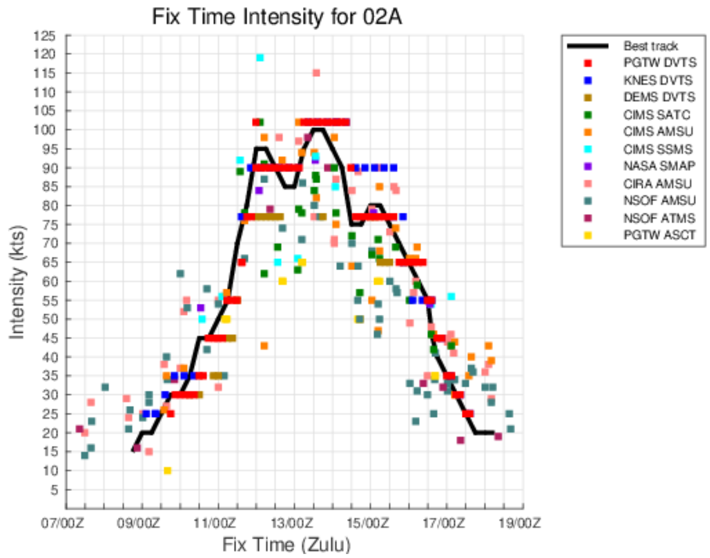
ISSUED LOW:	N/A
ISSUED MED:	25 Apr / 1000Z
FIRST TCFA:	26 Apr / 0900Z
FIRST WARNING:	27 Apr / 0000Z
LAST WARNING:	03 May / 1200Z
MAX INTENSITY:	150
WARNINGS:	27

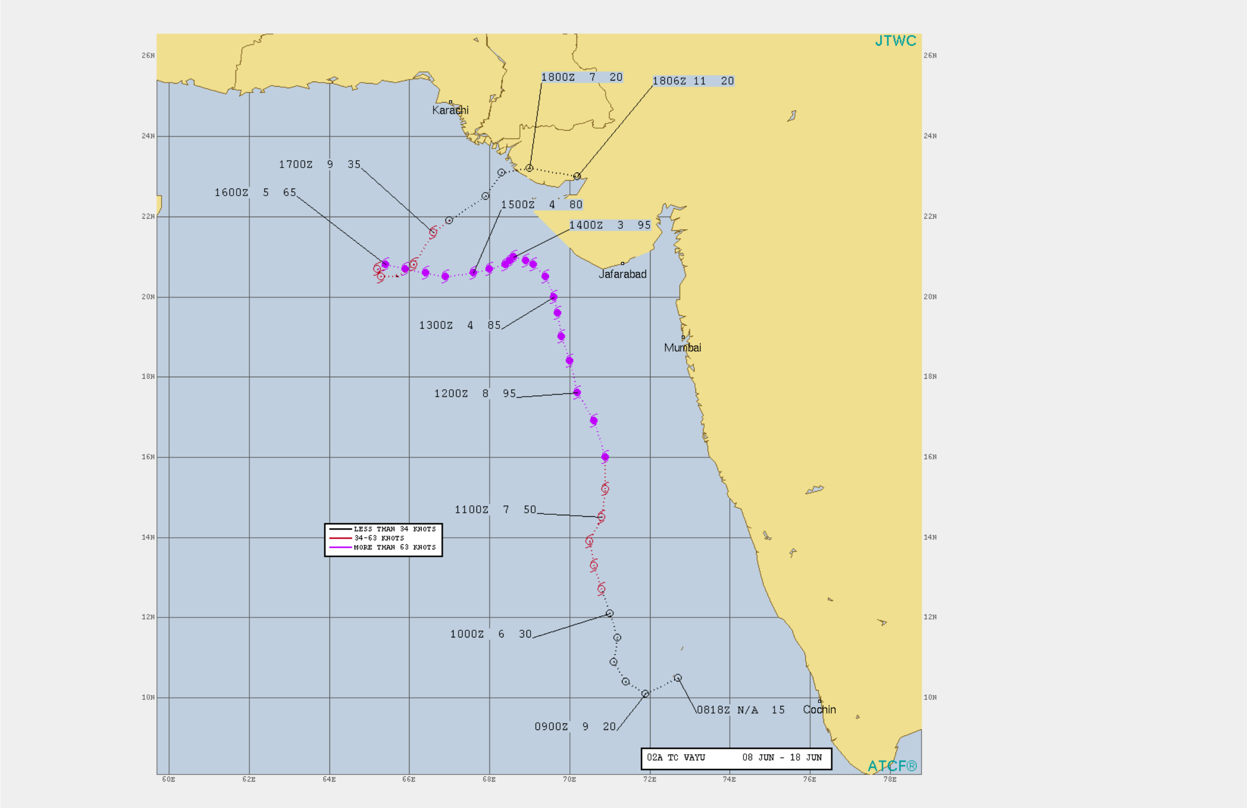




02A TROPICAL CYCLONE VAYU

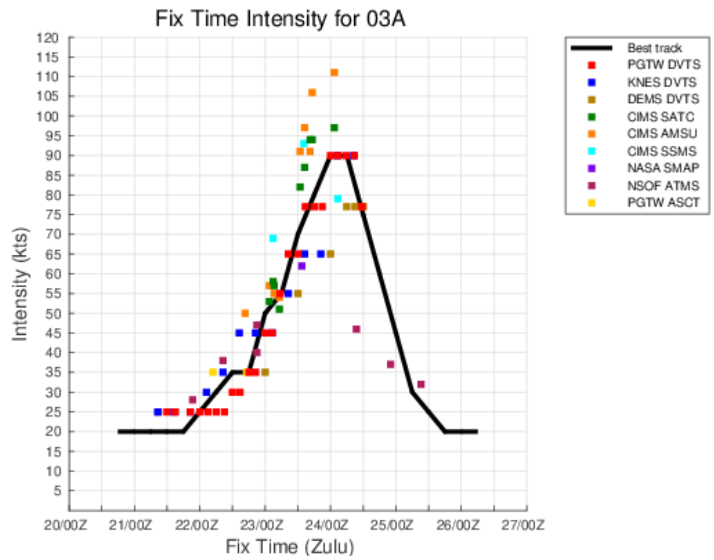
ISSUED LOW:	8 Jun / 1800Z
ISSUED MED:	9 Jun / 1800Z
FIRST TCFA:	9 Jun / 2230Z
FIRST WARNING:	10 Jun / 1200Z
LAST WARNING:	17 Jun / 0000Z
MAX INTENSITY:	100
WARNINGS:	27

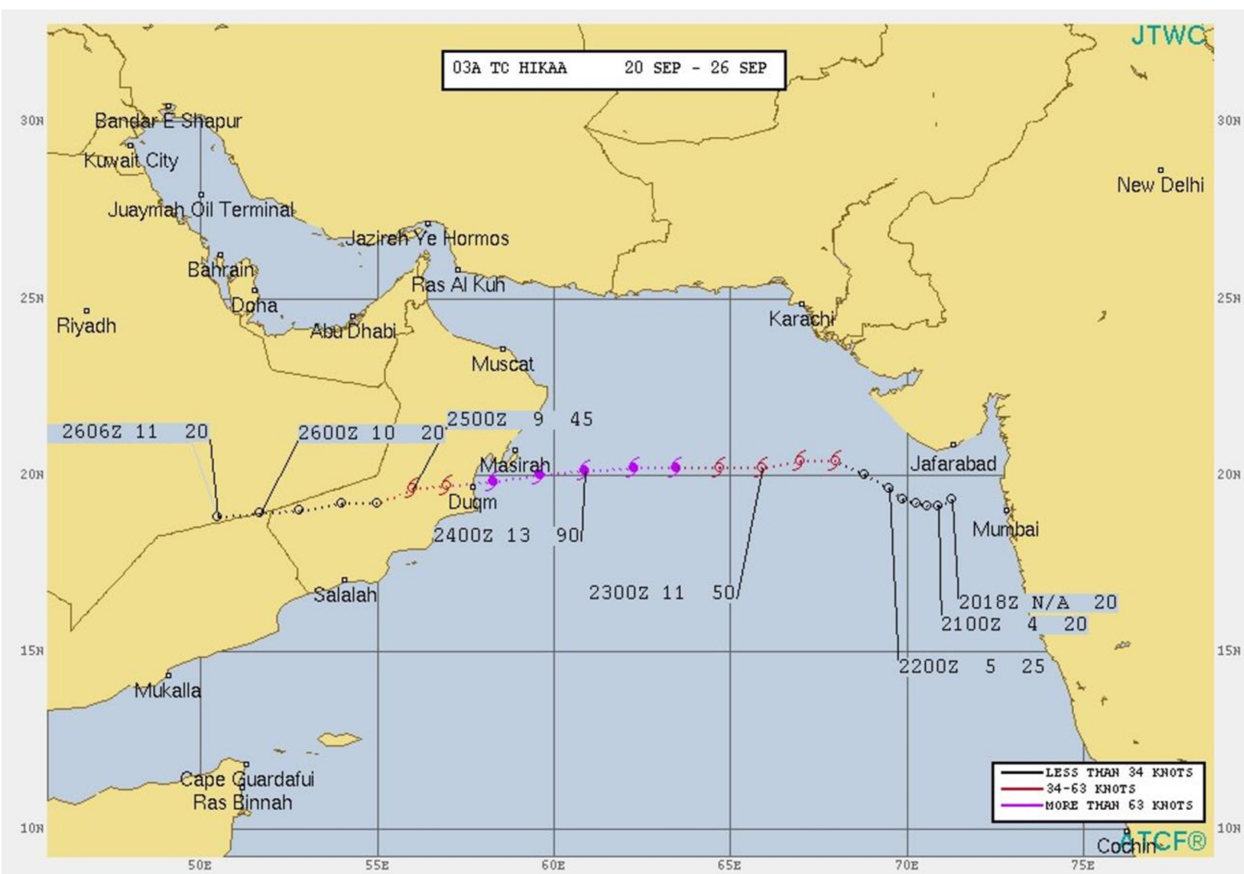




03A TROPICAL CYCLONE HIKAA

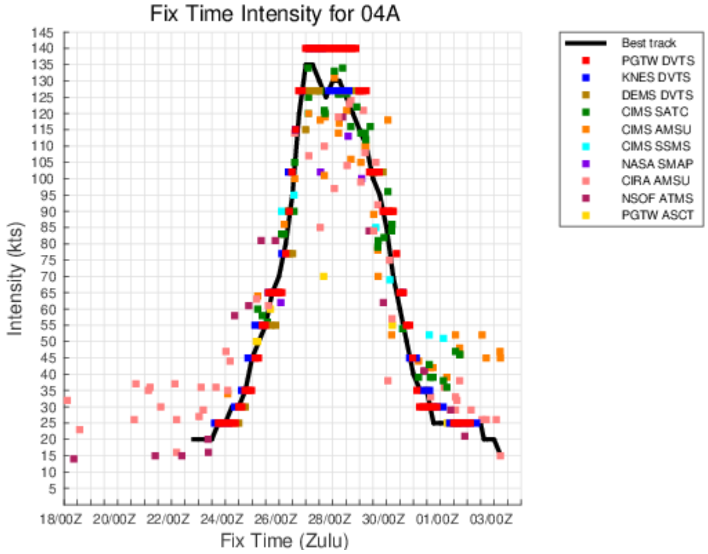
ISSUED LOW:	19 Sep / 1800Z
ISSUED MED:	21 Sep / 2300Z
FIRST TCFA:	22 Sep / 1330Z
FIRST WARNING:	22 Sep / 1800Z
LAST WARNING:	24 Sep / 1800Z
MAX INTENSITY:	90
WARNINGS:	9

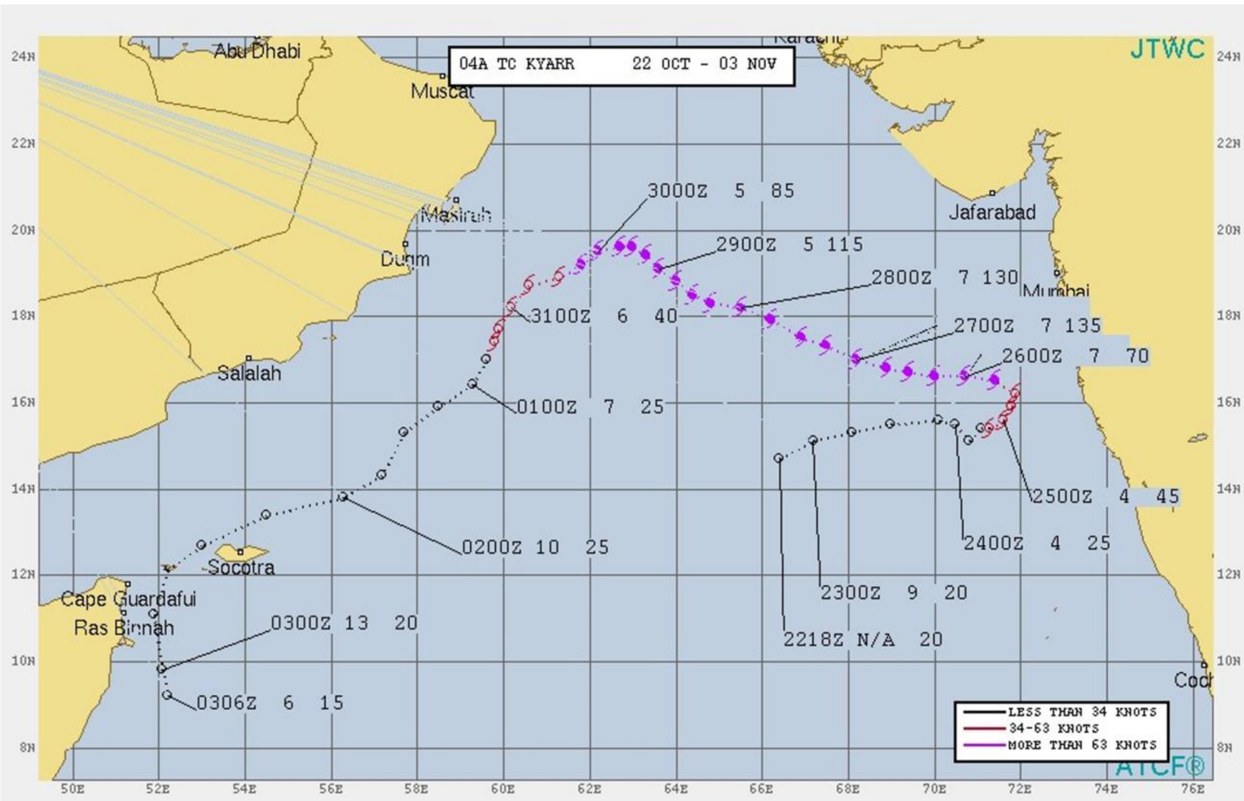




04A TROPICAL CYCLONE KYARR

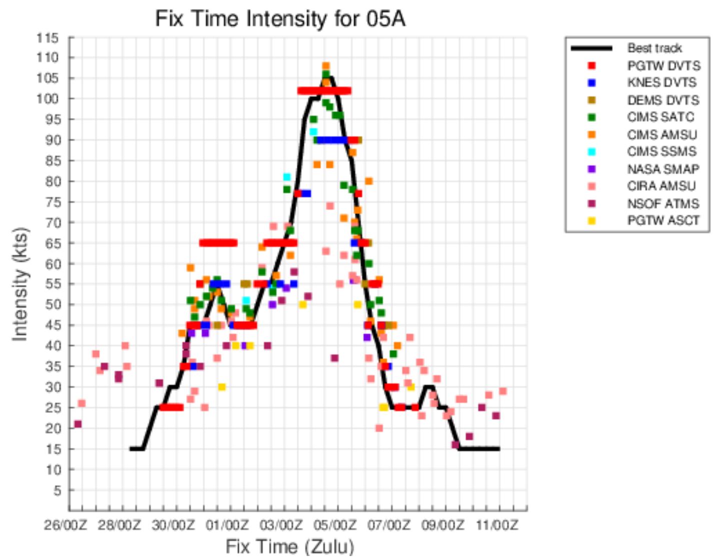
ISSUED LOW:	18 Oct / 1800Z
ISSUED MED:	22 Oct / 1800Z
FIRST TCFA:	24 Oct / 0300Z
FIRST WARNING:	24 Oct / 1800Z
LAST WARNING:	31 Oct / 1800Z
MAX INTENSITY:	135
WARNINGS:	29

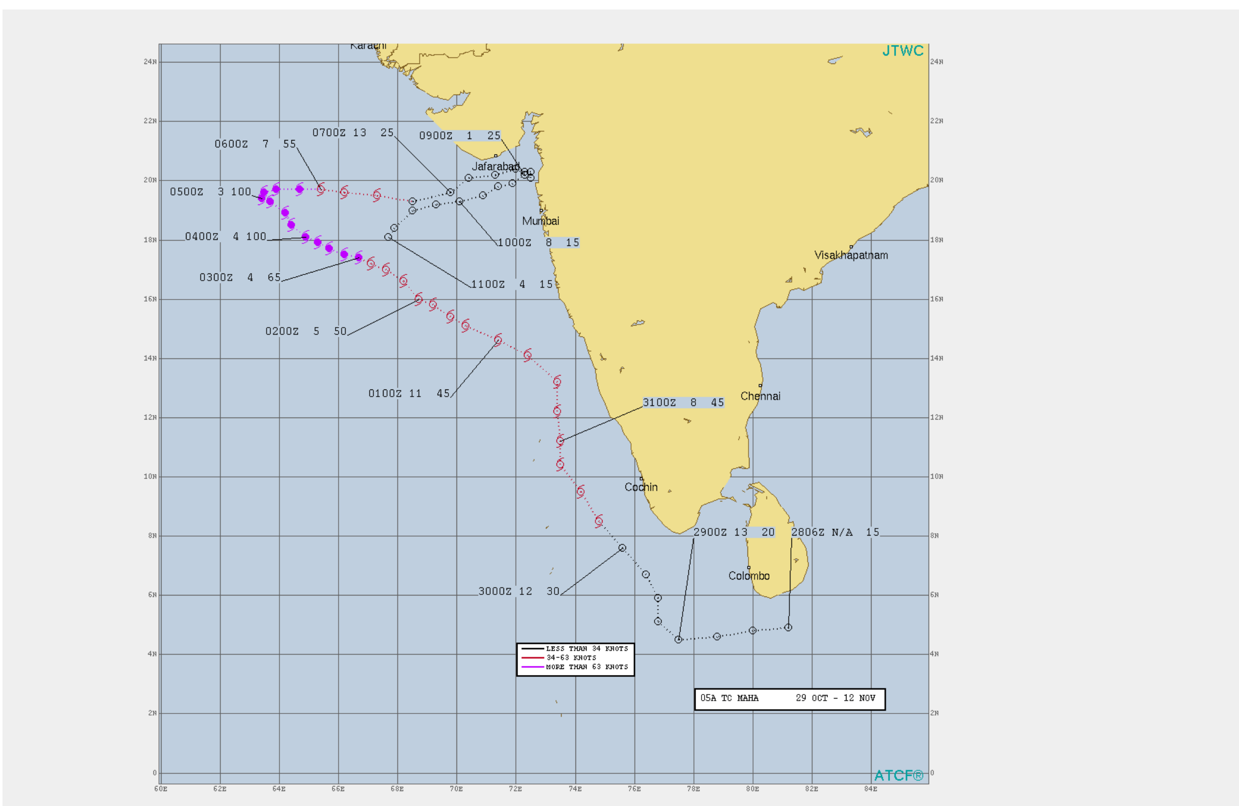




05A TROPICAL CYCLONE MAHA

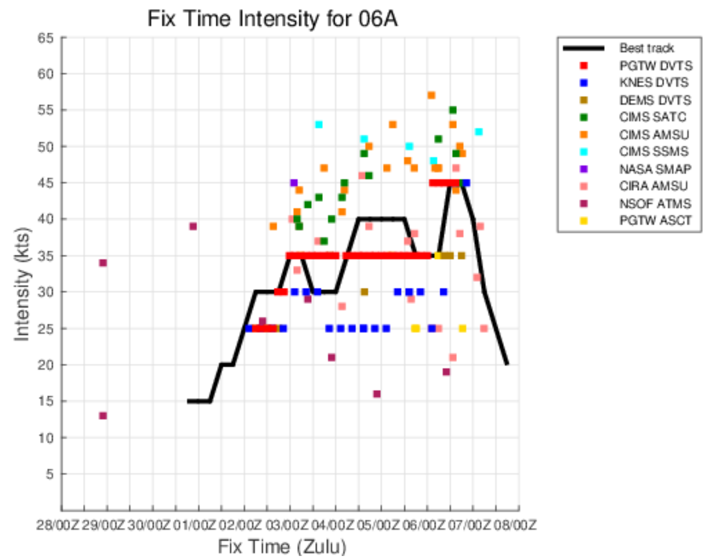
ISSUED LOW:	27 Oct / 1800Z
ISSUED MED:	29 Oct / 0230Z
FIRST TCFA:	N/A
FIRST WARNING:	30 Oct / 0600Z
LAST WARNING:	06 Nov / 1800Z
MAX INTENSITY:	105
WARNINGS:	31

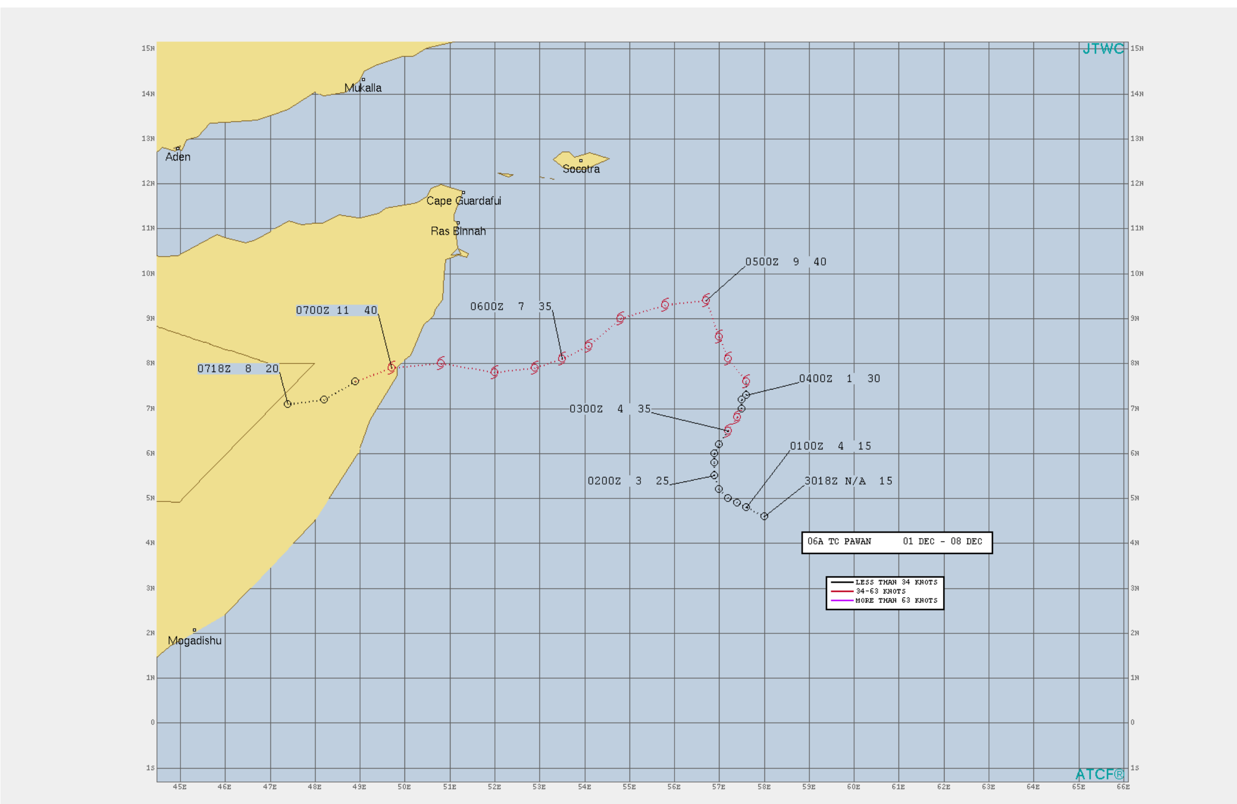




06A TROPICAL CYCLONE PAWAN

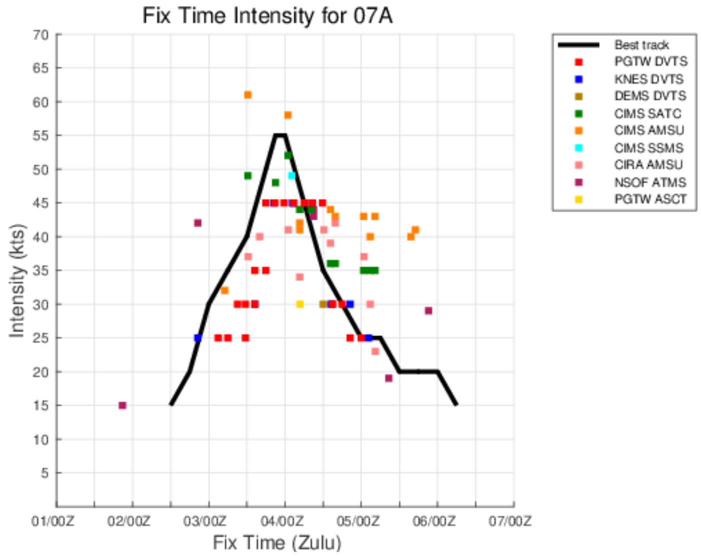
ISSUED LOW:	28 Nov / 1800Z
ISSUED MED:	01 Dec / 2230Z
FIRST TCFA:	02 Dec / 0900Z
FIRST WARNING:	03 Dec / 0000Z
LAST WARNING:	07 Dec / 0000Z
MAX INTENSITY:	45
WARNINGS:	17

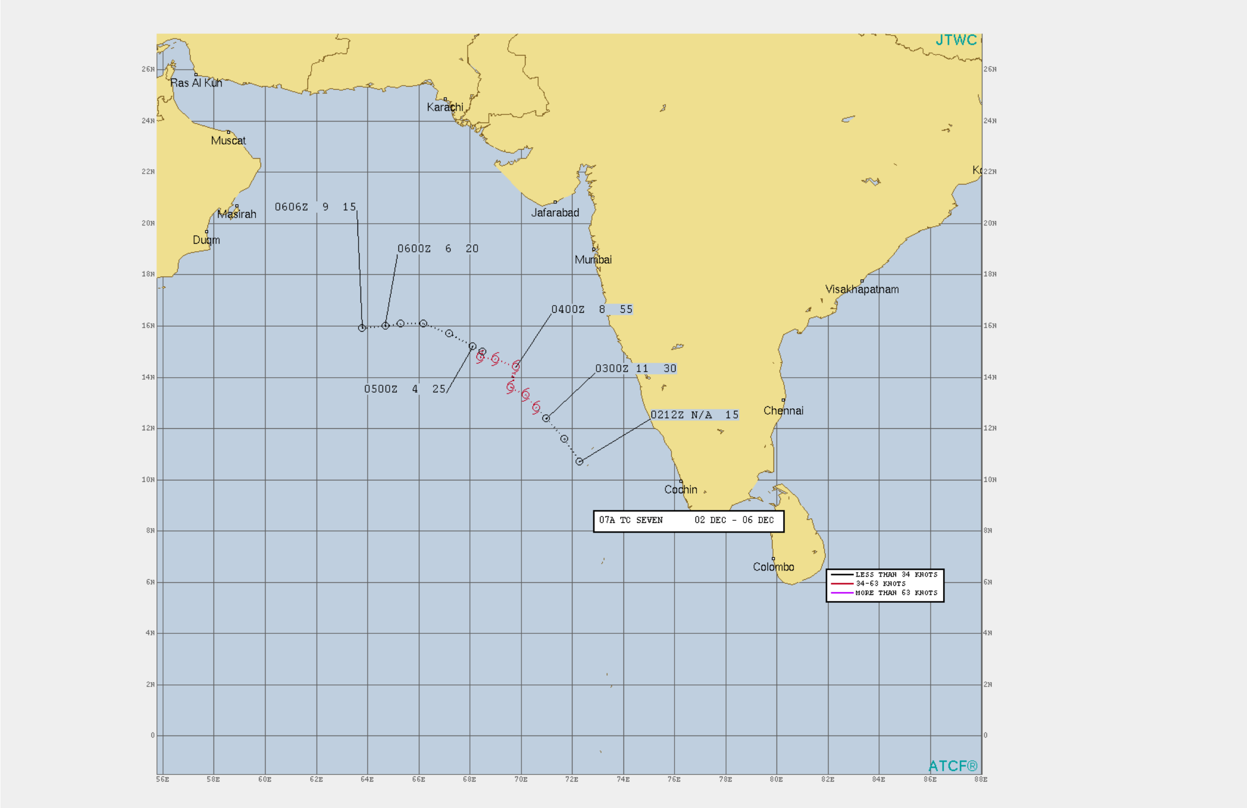




07A TROPICAL CYCLONE SEVEN

ISSUED LOW:	01 Dec / 2230Z
ISSUED MED:	N/A
FIRST TCFA:	03 Dec / 1100Z
FIRST WARNING:	03 Dec / 1200Z
LAST WARNING:	04 Dec / 1200Z
MAX INTENSITY:	55
WARNINGS:	5





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 2019 season (1 July 2018 – 30 June 2019) and the monthly distribution of TC activity summarized for 1975 - 2019.

Section 1 Informational Tables

Table 3-1 is a summary of TC activity in the Southern Hemisphere during the 2019 season.

Table 3-1

SOUTHERN HEMISPHERE TROPICAL CYCLONES

(01 JULY 2018- 30 JUNE 2019)

TC	NAME*	PERIOD**		WARNINGS ISSUED	EST MAX SFC WINDS KTS
01S	ONE	15 Sep / 0000Z	17 Sep / 0000Z	9	45
02P	LIUA	26 Sep / 1800Z	28 Sep / 0600Z	7	45
03S	ALCIDE	06 Nov / 0000Z	11 Nov / 1200Z	23	115
04S	BOUCHRA	10 Nov / 0600Z	13 Nov / 0600Z	13	60
05P	OWEN	02 Dec / 0000Z	04 Dec / 1200Z	11	55
05P(rewarn)	OWEN	11 Dec / 1200Z	15 Dec / 0600Z	16	85
06S	KENANGA	15 Dec / 1800Z	22 Dec / 1200Z	28	115
07S	CILIDA	19 Dec / 0000Z	24 Dec / 1800Z	24	135
08P	PENNY	31 Dec / 0000Z	08 Jan / 0000Z	33	55
09P	MONA	02 Jan / 1800Z	07 Jan / 1800Z	21	50
10S	DESMOND	20 Jan / 0000Z	21 Jan / 1800Z	8	45
11S	RILEY	23 Jan / 1800Z	29 Jan / 0600Z	23	75
12S	FUNANI	05 Feb / 1200Z	09 Feb / 1800Z	18	120
13S	GELENA	06 Feb / 0000Z	15 Feb / 0000Z	37	120
14P	NEIL	09 Feb / 1800Z	10 Feb / 0600Z	3	40
15P	OMA	12 Feb / 0000Z	23 Feb / 0000Z	45	75
16P	POLA	26 Feb / 0000Z	01 Mar / 1800Z	16	100
17S	HALEH	02 Mar / 0600Z	09 Mar / 0000Z	28	115
18S	IDAI	09 Mar / 0600Z	15 Mar / 0000Z	24	115
19S	SAVANNAH	14 Mar / 0000Z	21 Mar / 0600Z	30	105
20P	TREVOR	17 Mar / 1800Z	23 Mar / 0000Z	22	110
21S	VERONICA	19 Mar / 1800Z	26 Mar / 0000Z	26	130
22S	JOANINHA	22 Mar / 0000Z	31 Mar / 0000Z	37	120
23S	WALLACE	05 Apr / 0000Z	10 Apr / 0000Z	21	60
24S	KENNETH	23 Apr / 0000Z	25 Apr / 1800Z	12	125
25S	LORNA	23 Apr / 1200Z	29 Apr / 1200Z	25	90
26S	LILI	09 May / 0600Z	10 May / 1800Z	7	55
27P	ANN	11 May / 1800Z	14 May / 1200Z	12	60

* As designated by the responsible RSMC

** Dates are based on the issuance of JTWC warnings on the system.

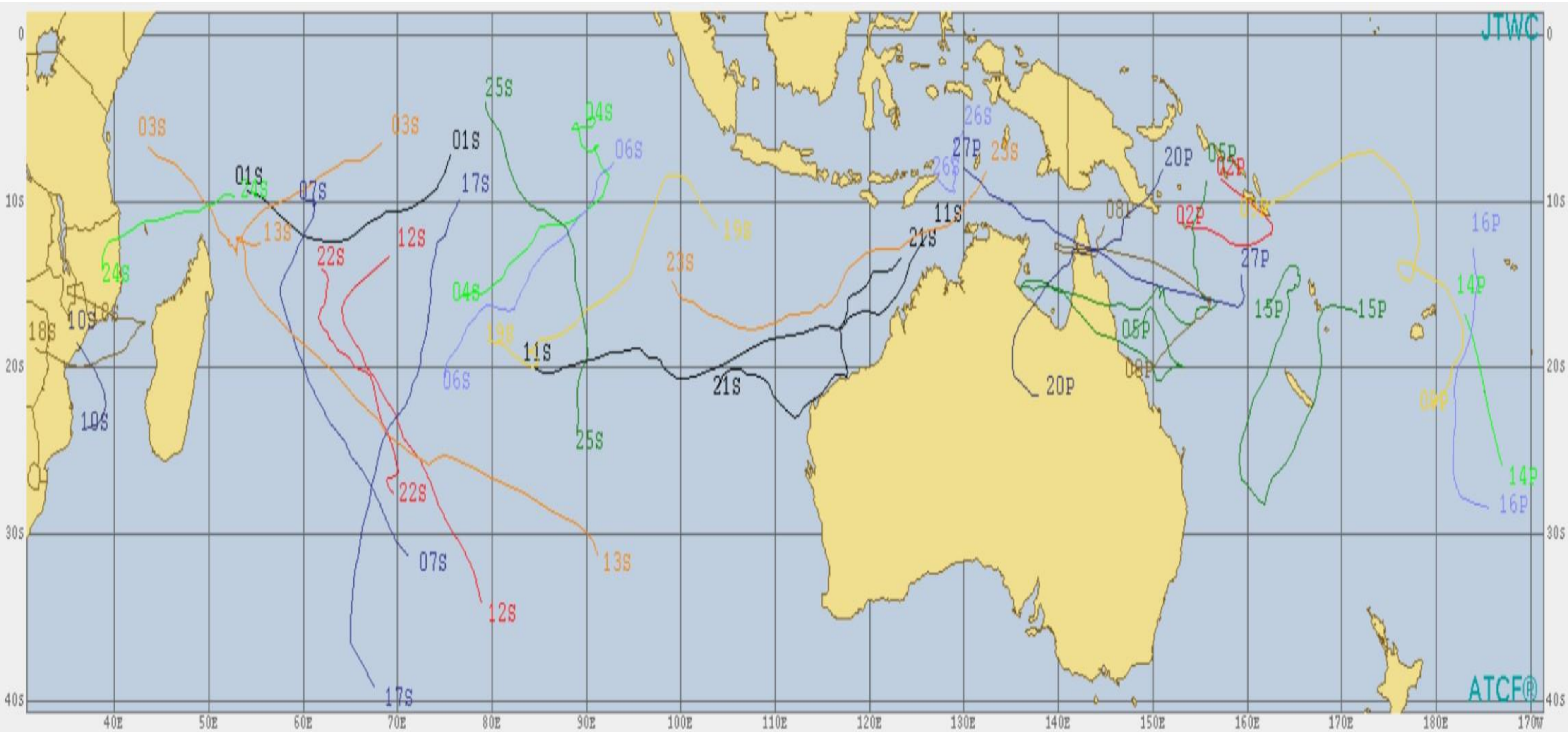


Figure 3-1. Southern Hemisphere Tropical Cyclones.

Table 3-2													
DISTRIBUTION OF SOUTH PACIFIC AND SOUTH INDIAN OCEAN TROPICAL CYCLONES													
FOR 1958 - 2019													
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 - 2019													
	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
(1981 - 2019)													
MEAN	0.3	0.1	0.3	0.6	1.5	3.1	5.6	5.9	4.9	3.0	0.8	0.2	26.3
CASES	10	4	11	24	59	119	218	232	191	118	30	9	1025
* (GRAY, 1978)													

Table 3-2 Monthly distribution of Tropical Cyclone activity summarized for 1975 - 2019.

Section 2 Cyclone Summaries

This section presents a synopsis of each cyclone that occurred during 2019 in the South Indian Ocean and South 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 TC formation alert (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 started, 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 by JTWC. Landfall over major landmasses with approximate locations is presented as well. 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.

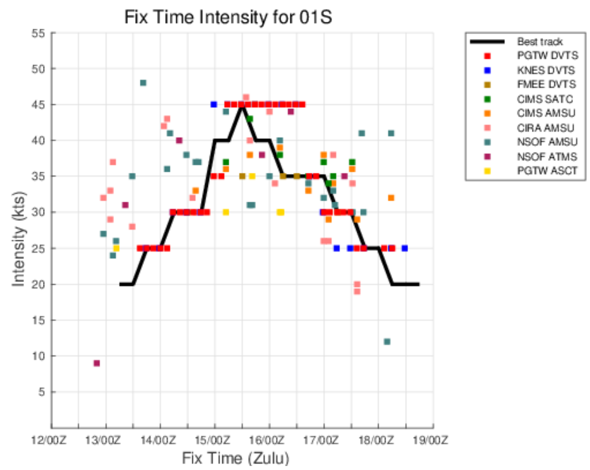
USPACOM directs JTWC to begin tropical cyclone warnings.

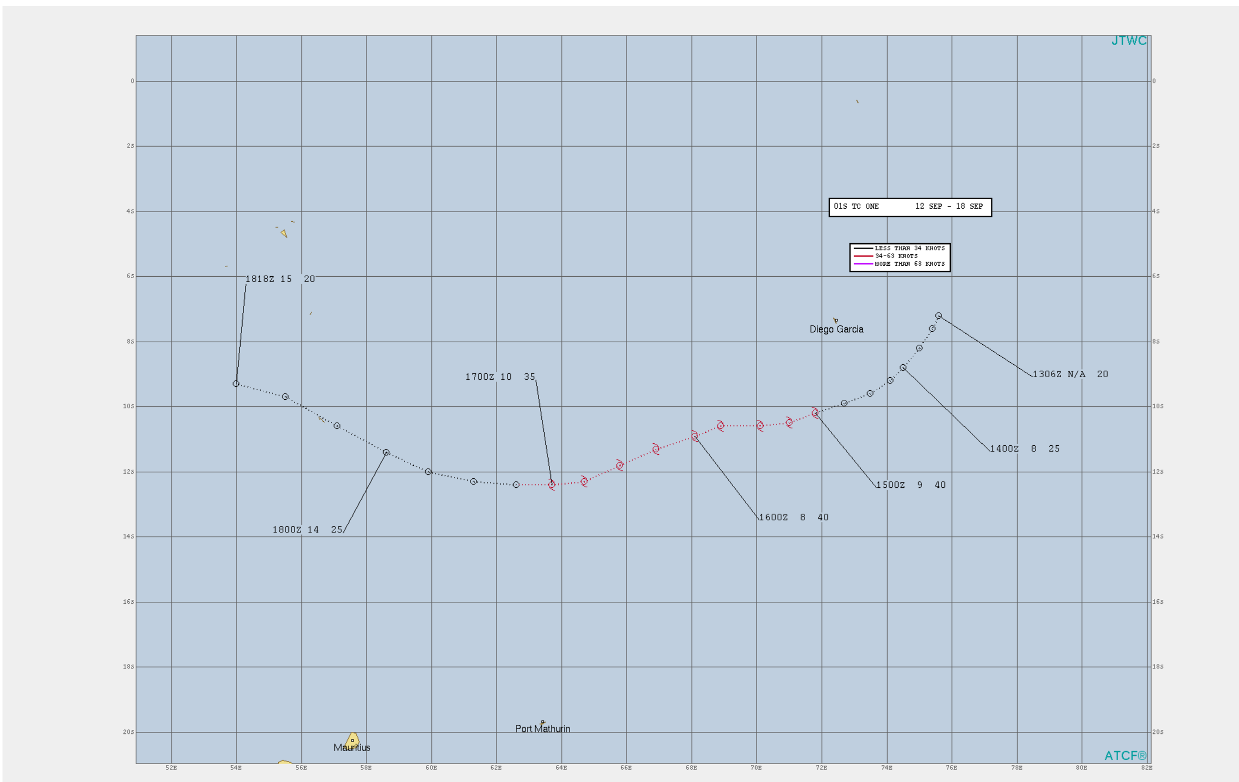
The JTWC post-event, reanalysis best track is provided for each cyclone. Data included on the best track are position and intensity noted with color-coded cyclone symbols and track line. Best track position labels include the date, time, track speed in knots, maximum wind speed in knots, as well as the 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/2019/2019s-bsh/SH_besttracks_2019-2019.kmz

01S TROPICAL CYCLONE ONE

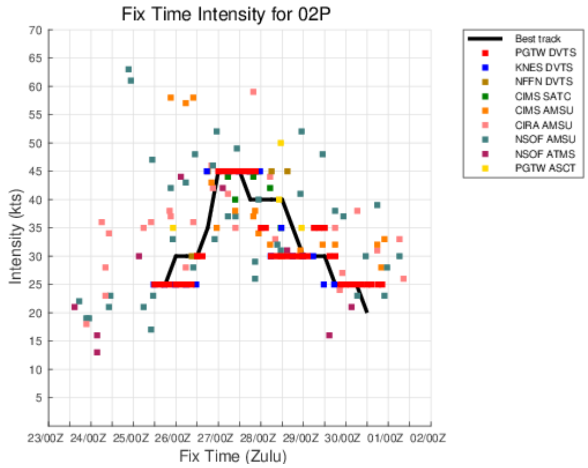
ISSUED LOW:	13 Sep / 1800Z
ISSUED MED:	14 Sep / 0100Z
FIRST TCFA:	14 Sep / 0900Z
FIRST WARNING:	15 Sep / 0000Z
LAST WARNING:	17 Sep / 0000Z
MAX INTENSITY:	45
WARNINGS:	9

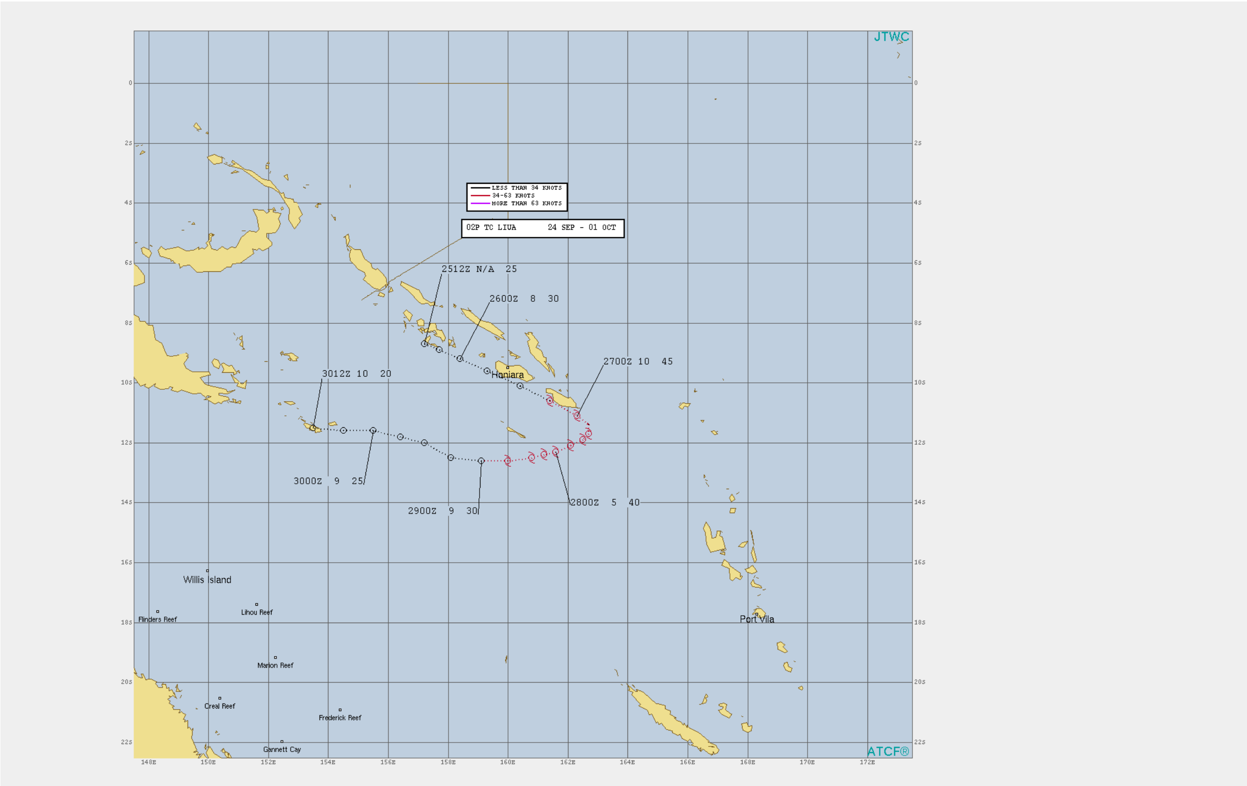




02P TROPICAL CYCLONE LIUA

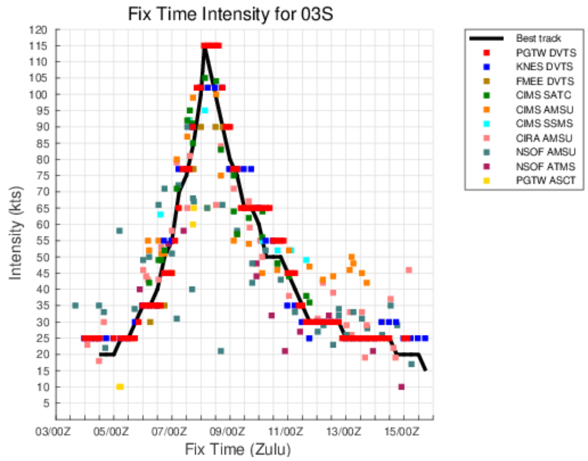
ISSUED LOW:	24 Sep / 0230Z
ISSUED MED:	24 Sep / 0600Z
FIRST TCFA:	26 Sep / 0130Z
FIRST WARNING:	26 Sep / 1800Z
LAST WARNING:	28 Sep / 0600Z
MAX INTENSITY:	45
WARNINGS:	7

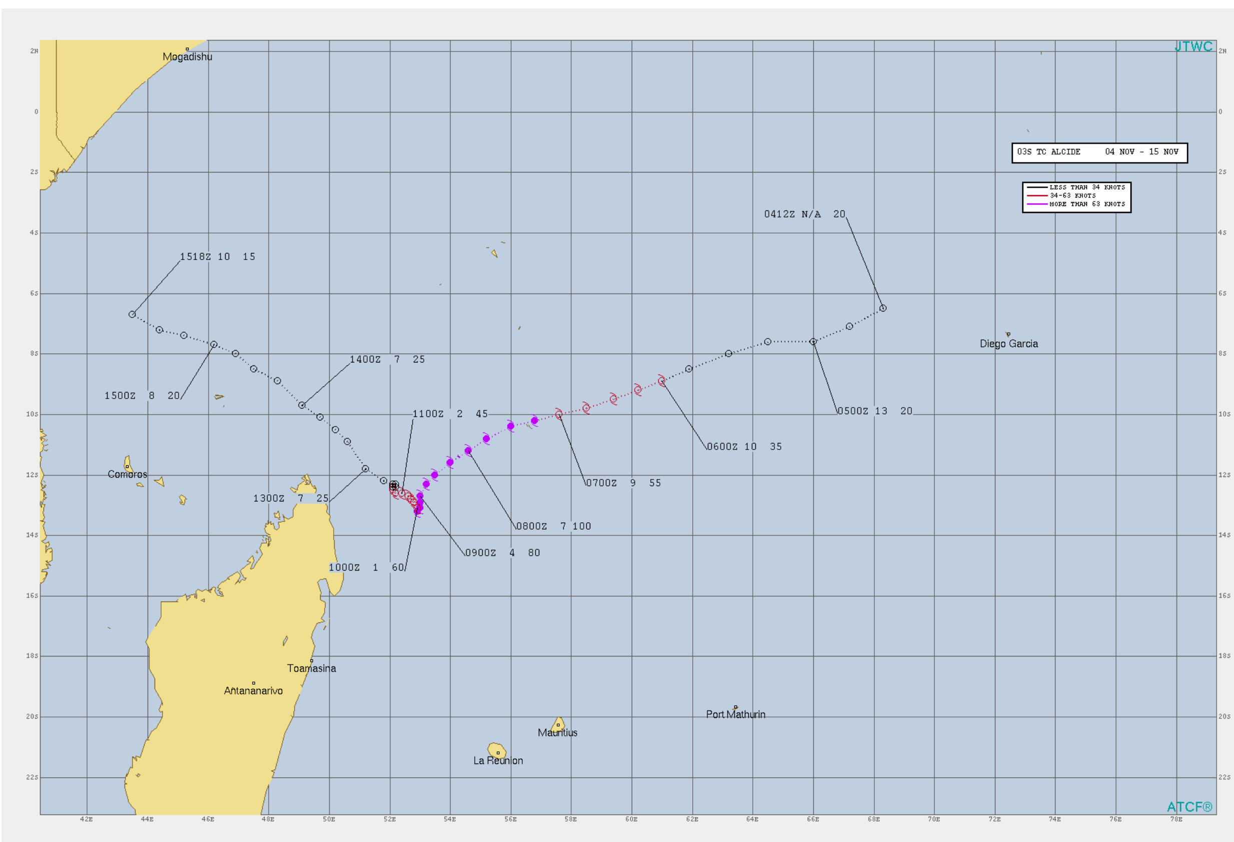




03S TROPICAL CYCLONE ALCIDE

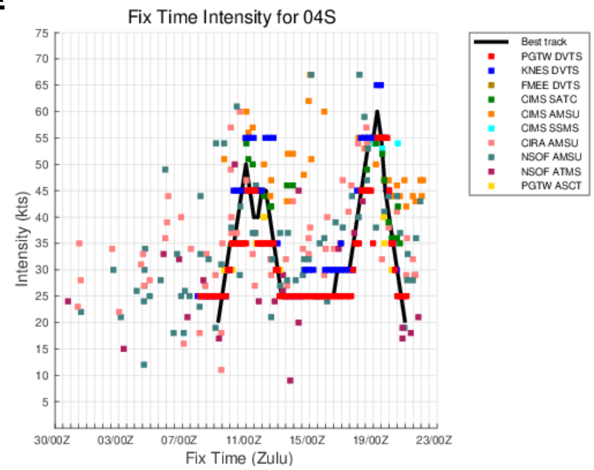
ISSUED LOW:	N/A
ISSUED MED:	04 Nov / 0130Z
FIRST TCFA:	05 Nov / 0800Z
FIRST WARNING:	06 Nov / 0000Z
LAST WARNING:	11 Nov / 1200Z
MAX INTENSITY:	115
WARNINGS:	23

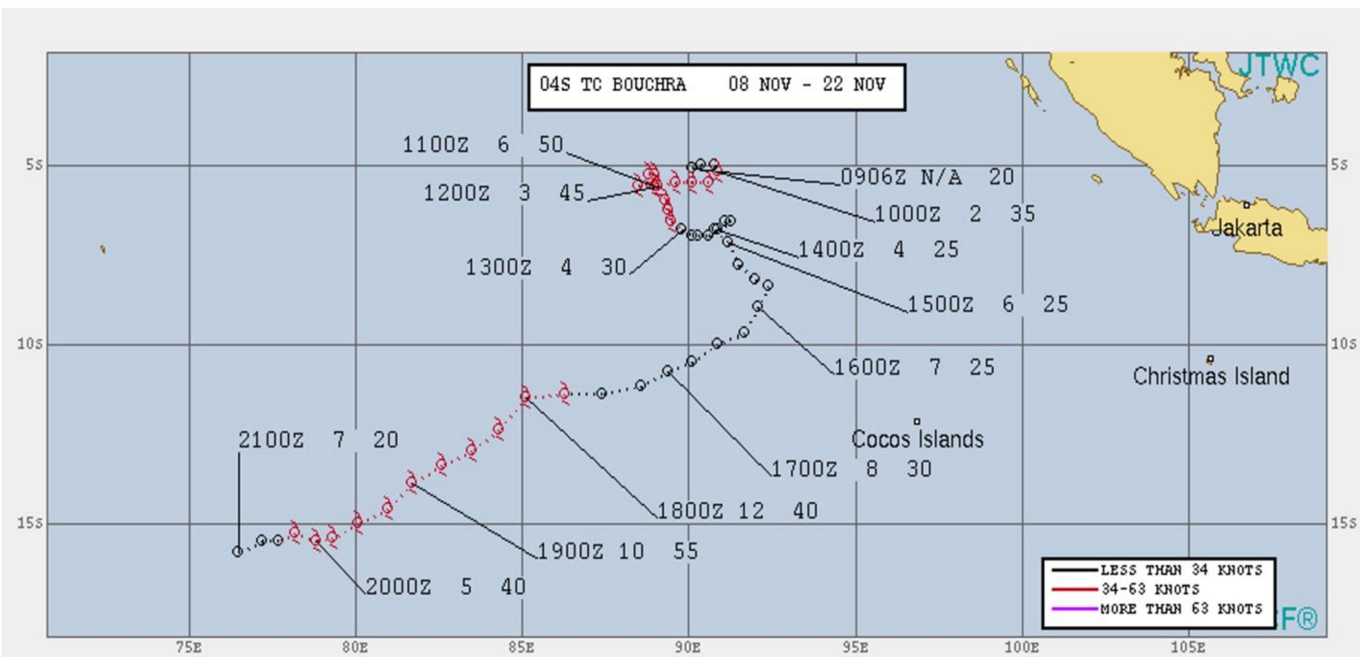




04S TROPICAL CYCLONE BOUCHRA

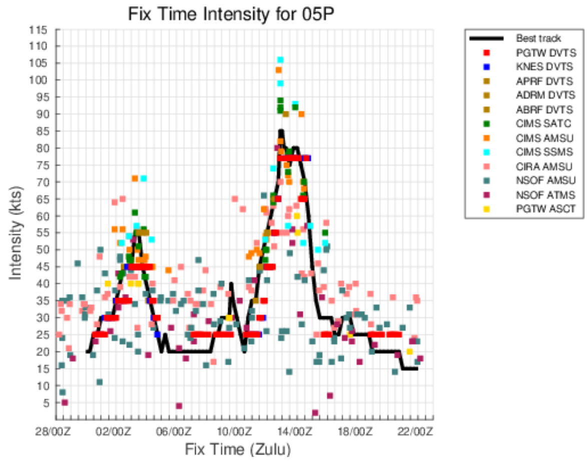
ISSUED LOW:	07 Nov / 1800Z
ISSUED MED:	N/A
FIRST TCFA:	10 Nov / 0230Z
FIRST WARNING:	10 Nov / 0600Z
LAST WARNING:	13 Nov / 0600Z
MAX INTENSITY:	60
WARNINGS:	13

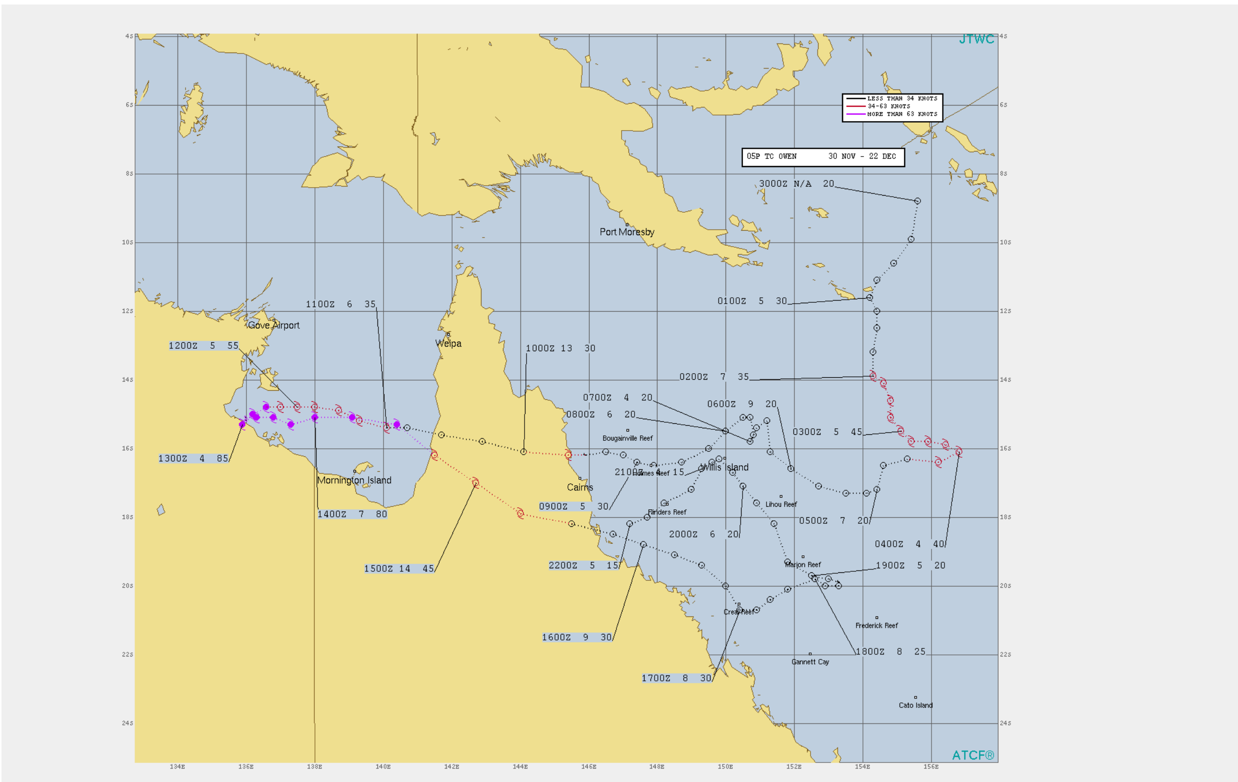




05P TROPICAL CYCLONE OWEN

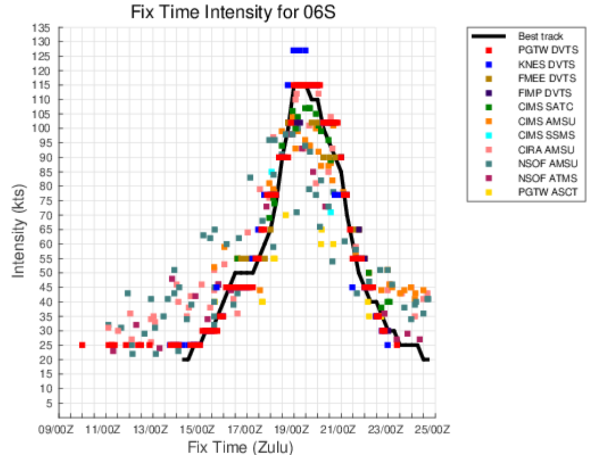
ISSUED LOW:	28 Nov / 2030Z
ISSUED MED:	29 Nov / 0600Z
FIRST TCFA:	30 Nov / 1530Z
FIRST WARNING:	02 Dec / 0000Z
LAST WARNING:	15 Dec / 0600Z
MAX INTENSITY:	85
WARNINGS:	27

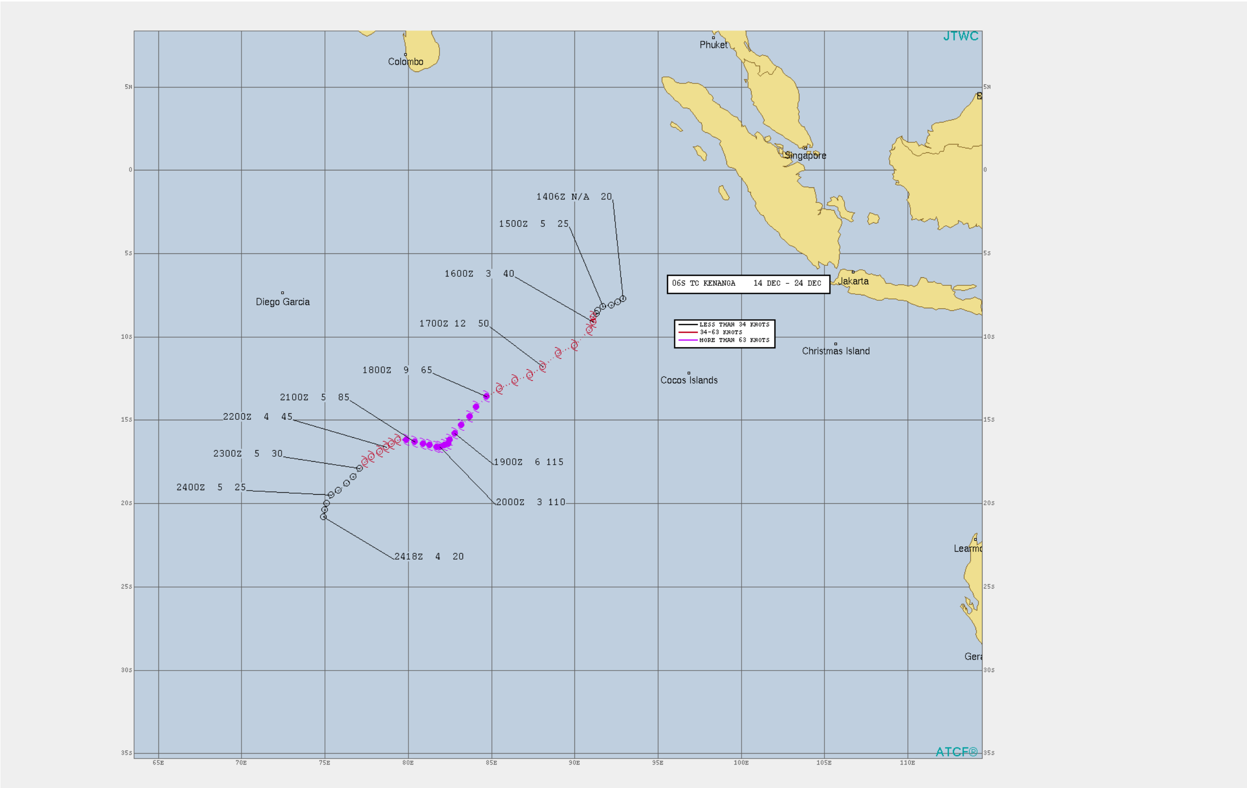




06S TROPICAL CYCLONE KENANGA

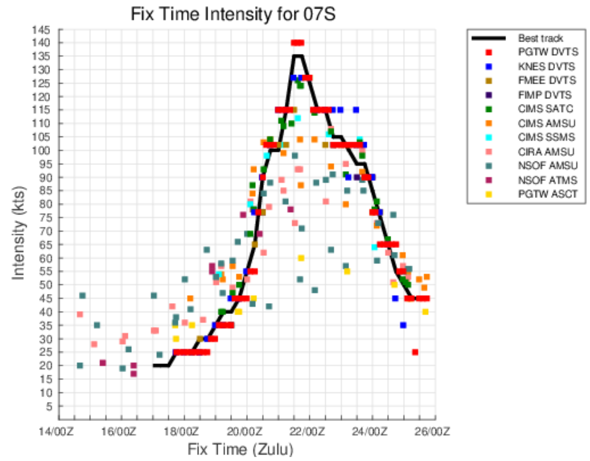
ISSUED LOW:	12 Dec / 1800Z
ISSUED MED:	13 Dec / 1000Z
FIRST TCFA:	13 Dec / 2100Z
FIRST WARNING:	15 Dec / 1800Z
LAST WARNING:	22 Dec / 1200Z
MAX INTENSITY:	115
WARNINGS:	28

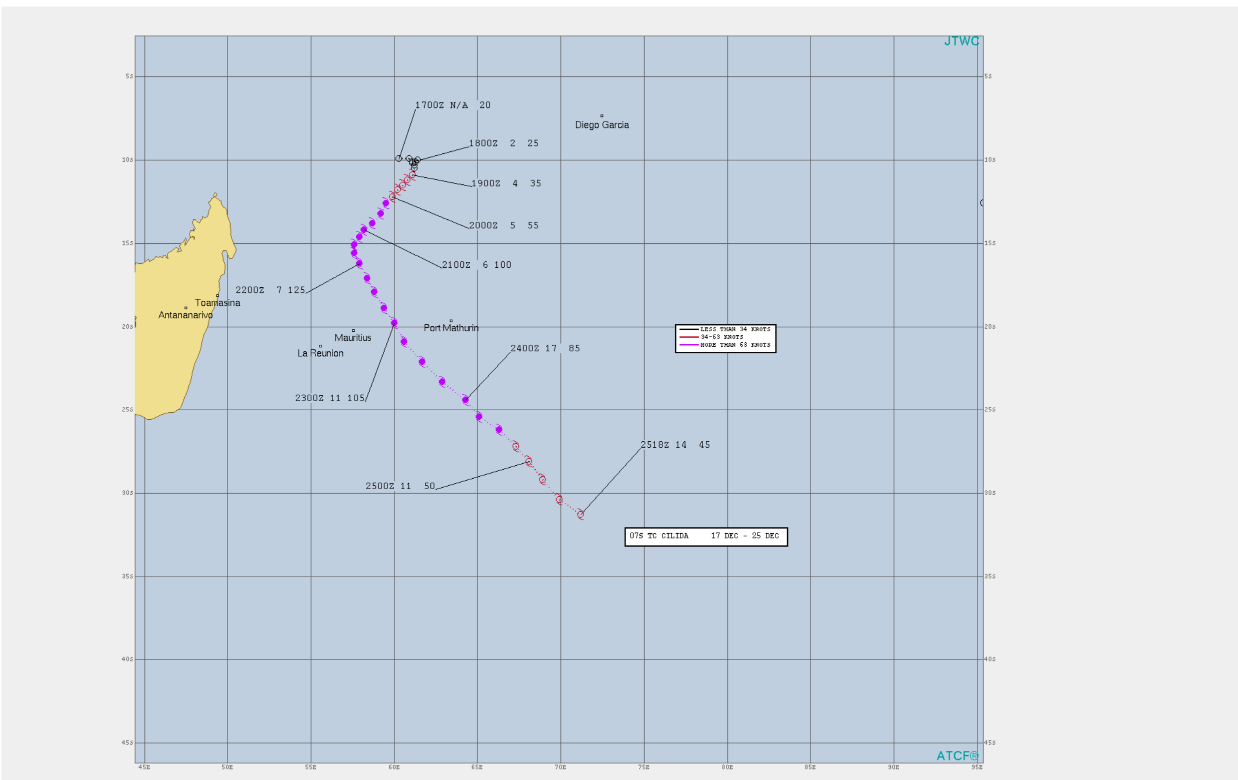




07S TROPICAL CYCLONE CILIDA

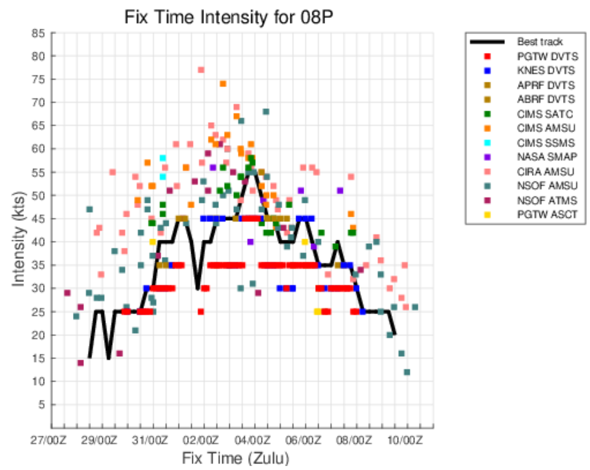
ISSUED LOW:	15 Dec / 0500Z
ISSUED MED:	18 Dec / 0200Z
FIRST TCFA:	18 Dec / 2100Z
FIRST WARNING:	19 Dec / 0000Z
LAST WARNING:	24 Dec / 1800Z
MAX INTENSITY:	135
WARNINGS:	24

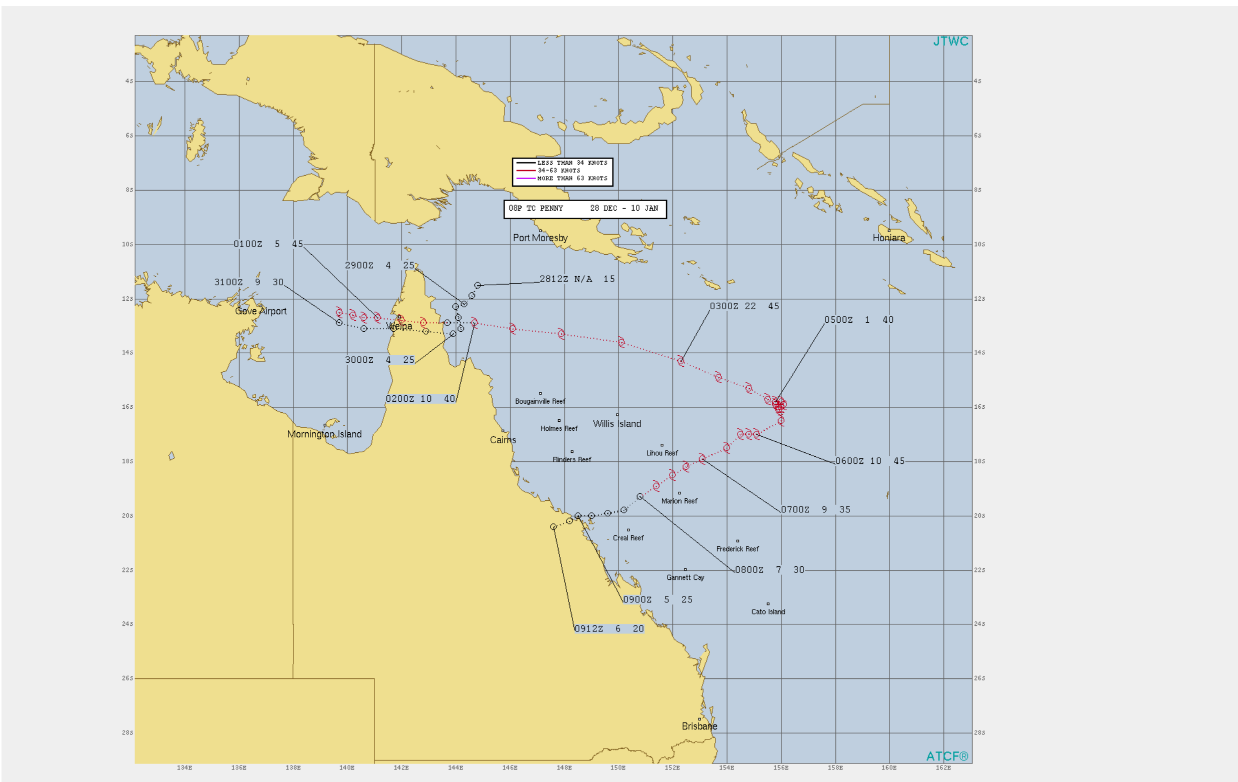




08P TROPICAL CYCLONE PENNY

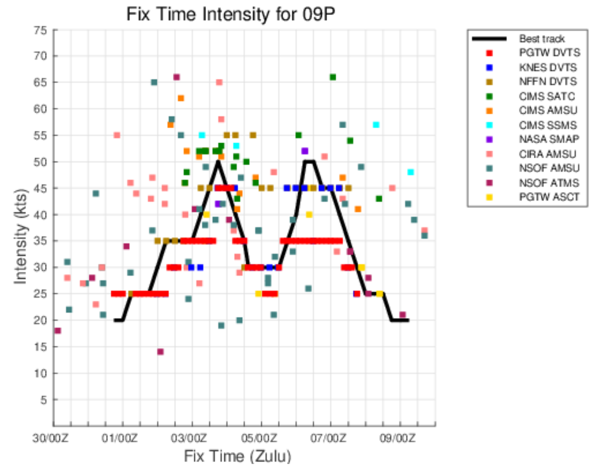
ISSUED LOW:	28 Dec / 0600Z
ISSUED MED:	28 Dec / 2130Z
FIRST TCFA:	30 Dec / 0030Z
FIRST WARNING:	31 Dec / 0000Z
LAST WARNING:	08 Jan / 0000Z
MAX INTENSITY:	55
WARNINGS:	33

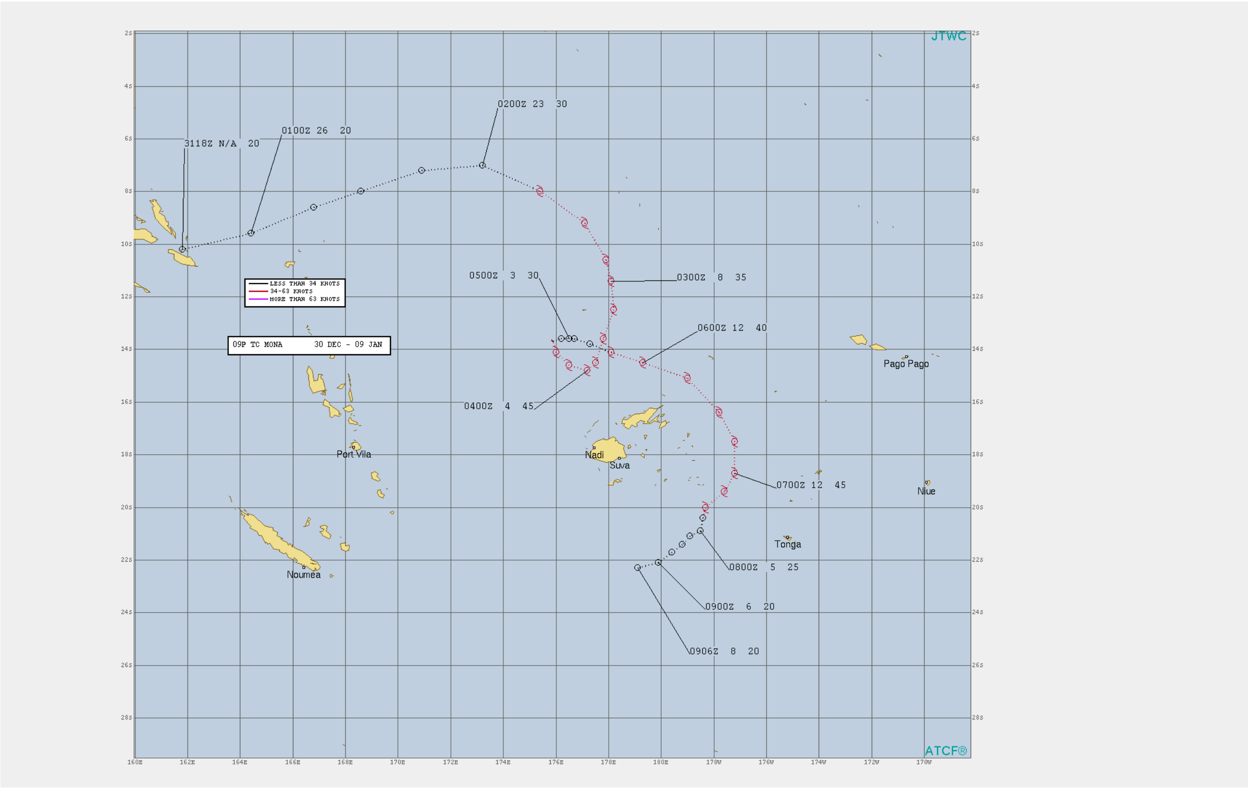




09P TROPICAL CYCLONE MONA

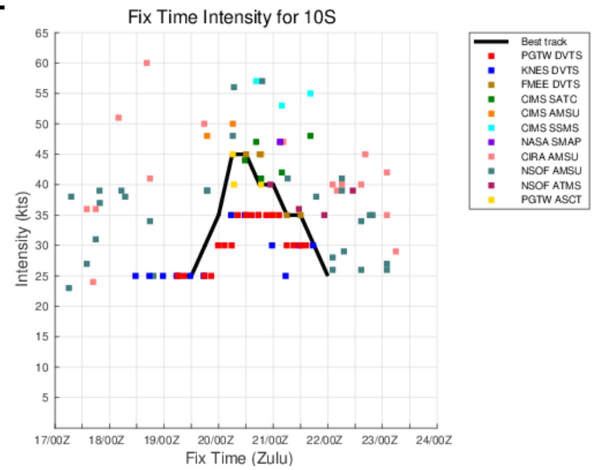
ISSUED LOW:	N/A
ISSUED MED:	30 Dec / 1430Z
FIRST TCFA:	31 Dec / 2300Z
FIRST WARNING:	02 Jan / 1800Z
LAST WARNING:	07 Jan / 1800Z
MAX INTENSITY:	50
WARNINGS:	21

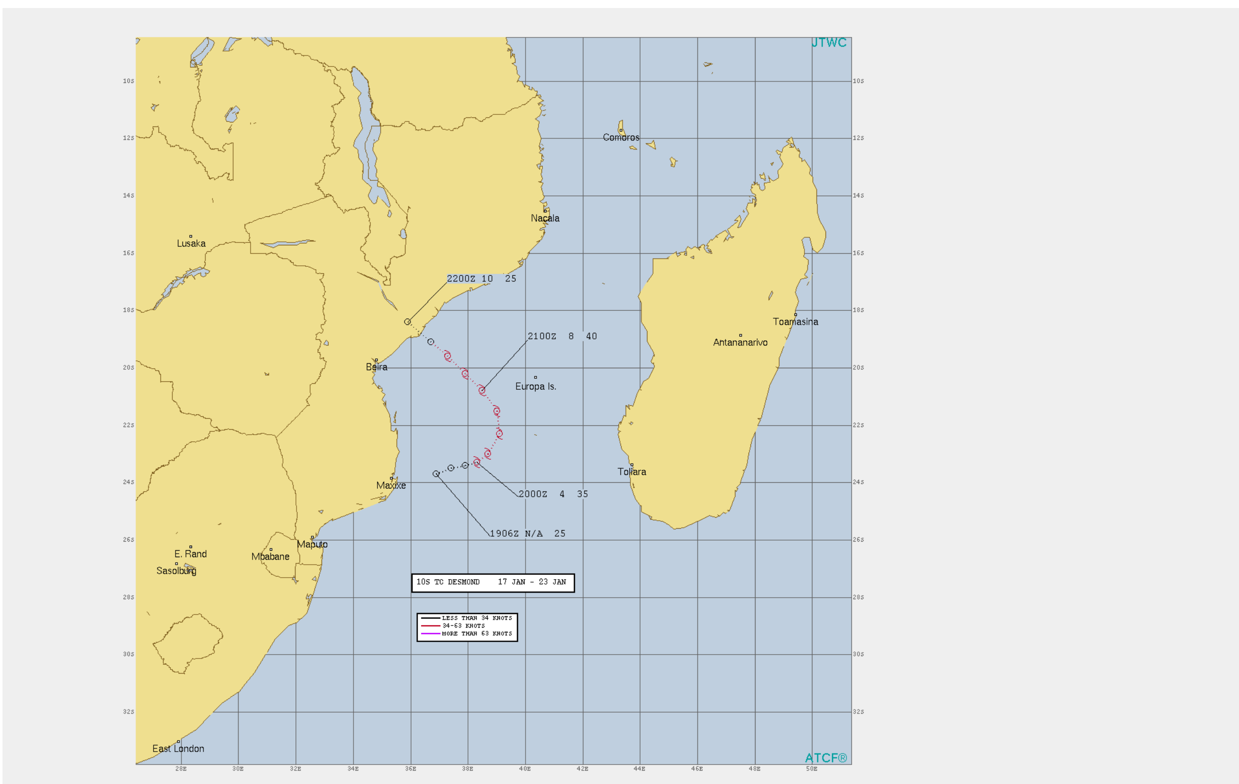




10S TROPICAL CYCLONE DESMOND

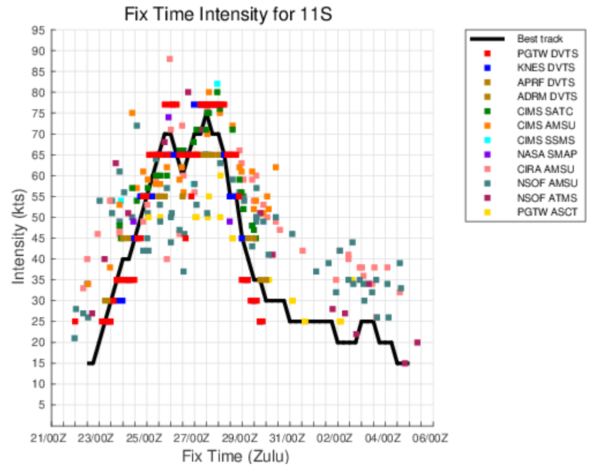
ISSUED LOW:	17 Jan / 1800Z
ISSUED MED:	18 Jan / 1800Z
FIRST TCFA:	19 Jan / 0400Z
FIRST WARNING:	20 Jan / 0000Z
LAST WARNING:	21 Jan / 1800Z
MAX INTENSITY:	45
WARNINGS:	8

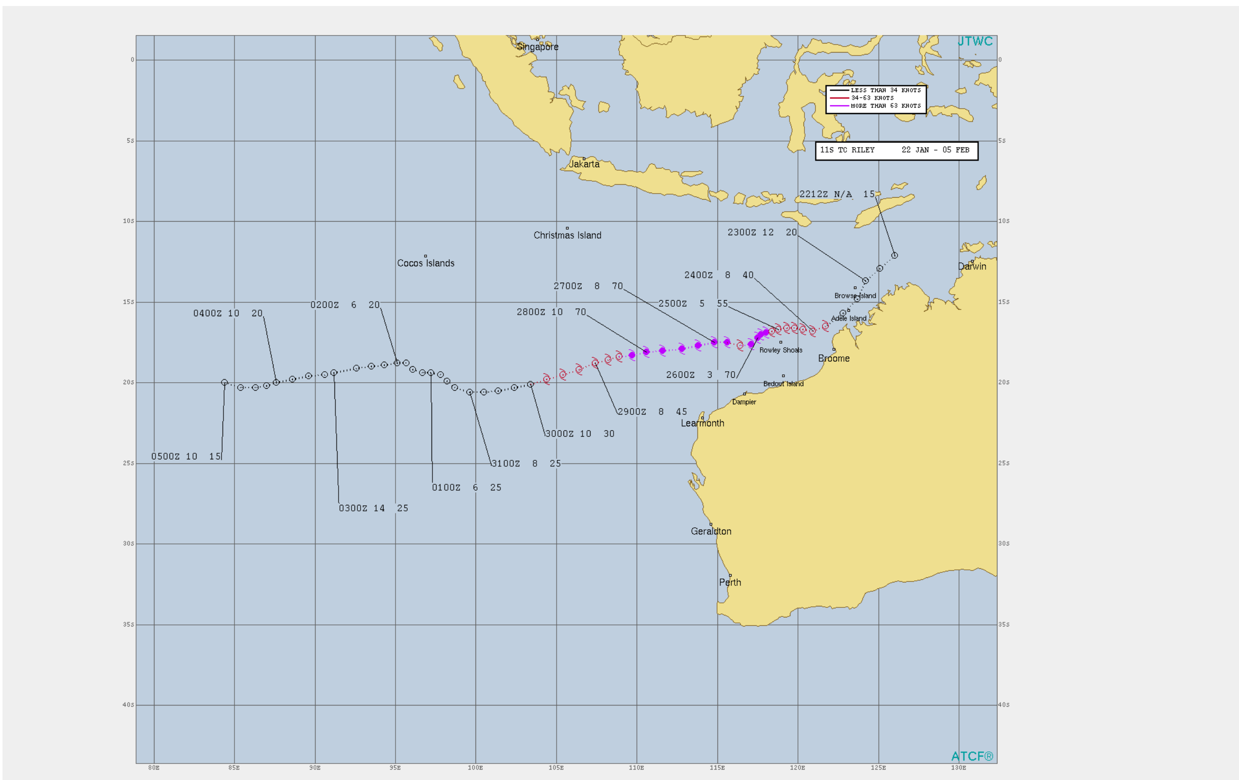




11S TROPICAL CYCLONE RILEY

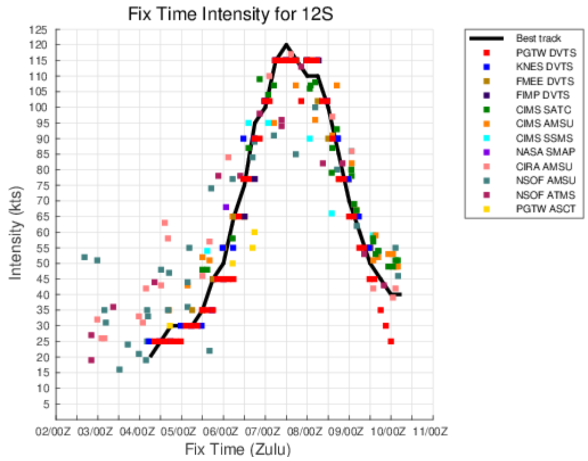
ISSUED LOW:	22 Jan / 0630Z
ISSUED MED:	22 Jan / 1800Z
FIRST TCFA:	23 Jan / 0730Z
FIRST WARNING:	23 Jan / 1800Z
LAST WARNING:	29 Jan / 0600Z
MAX INTENSITY:	75
WARNINGS:	23

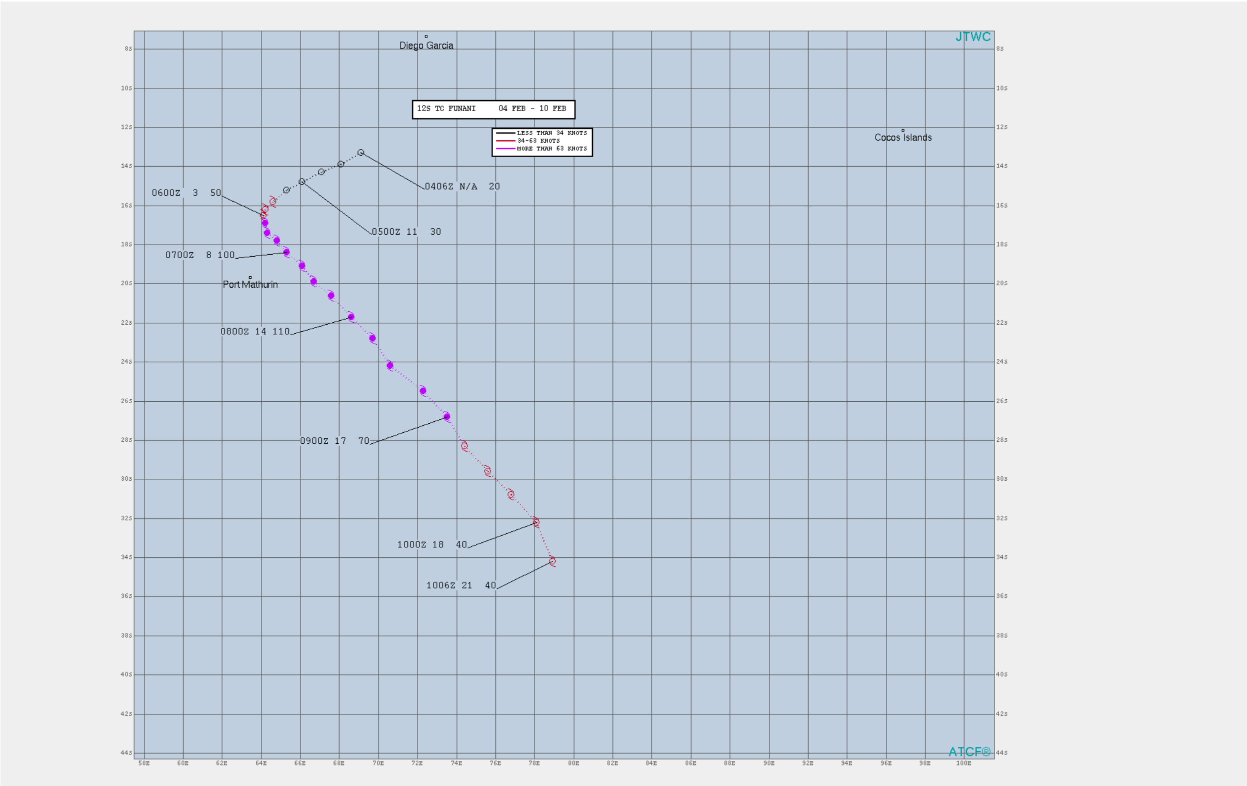




12S TROPICAL CYCLONE FUNANI

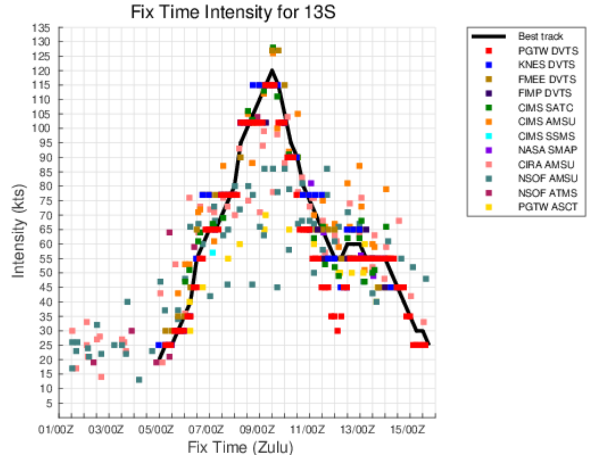
ISSUED LOW:	03 Feb / 0900Z
ISSUED MED:	04 Feb / 1200Z
FIRST TCFA:	04 Feb / 2100Z
FIRST WARNING:	05 Feb / 1200Z
LAST WARNING:	09 Feb / 1800Z
MAX INTENSITY:	120
WARNINGS:	18

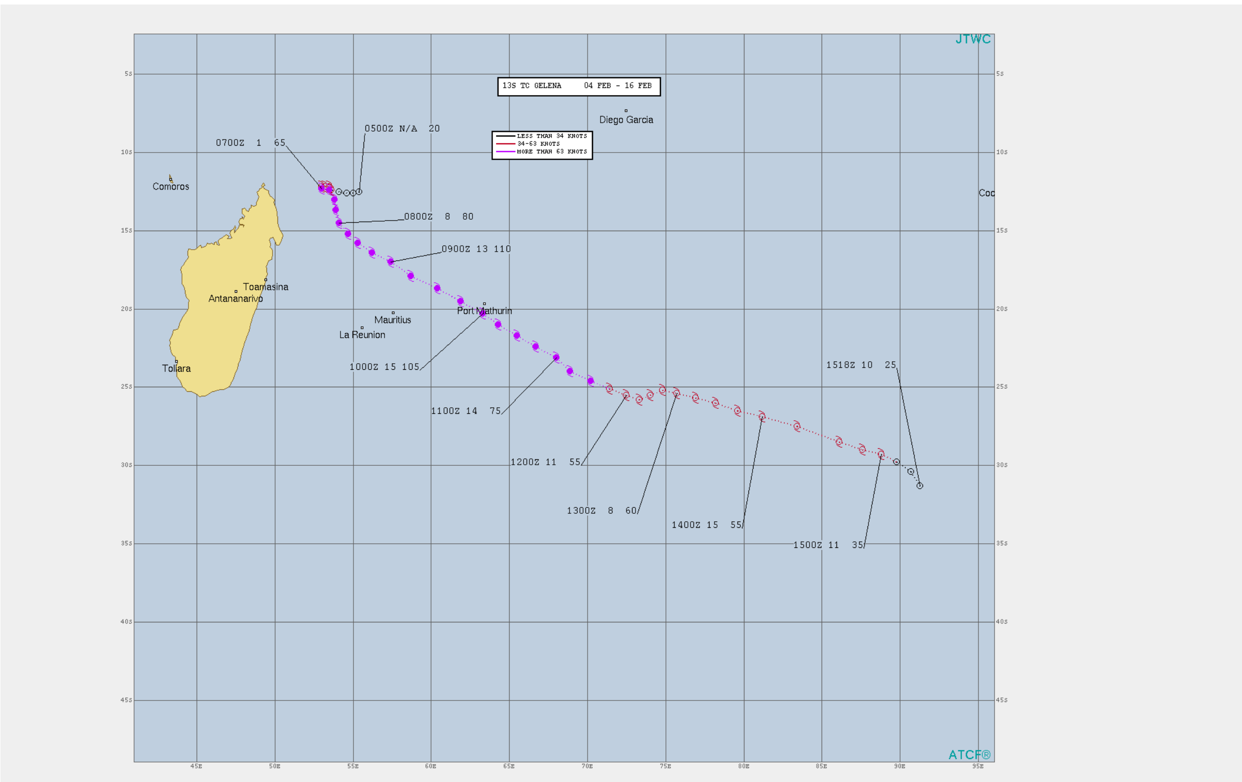




13S TROPICAL CYCLONE GELENA

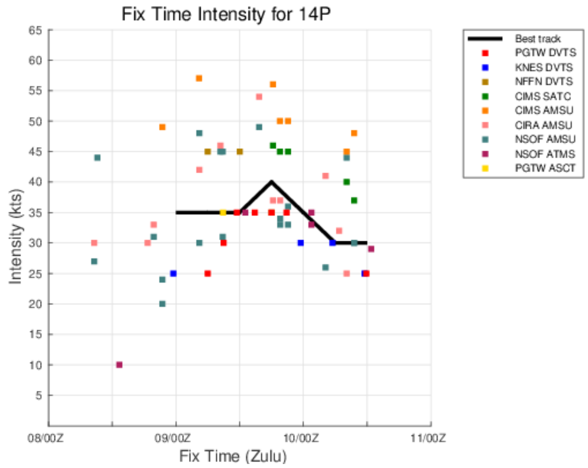
ISSUED LOW: 04 Feb / 1200Z
ISSUED MED: 05 Feb / 0630Z
FIRST TCFA: 05 Feb / 1400Z
FIRST WARNING: 06 Feb / 0000Z
LAST WARNING: 15 Feb / 0000Z
MAX INTENSITY: 120
WARNINGS: 37

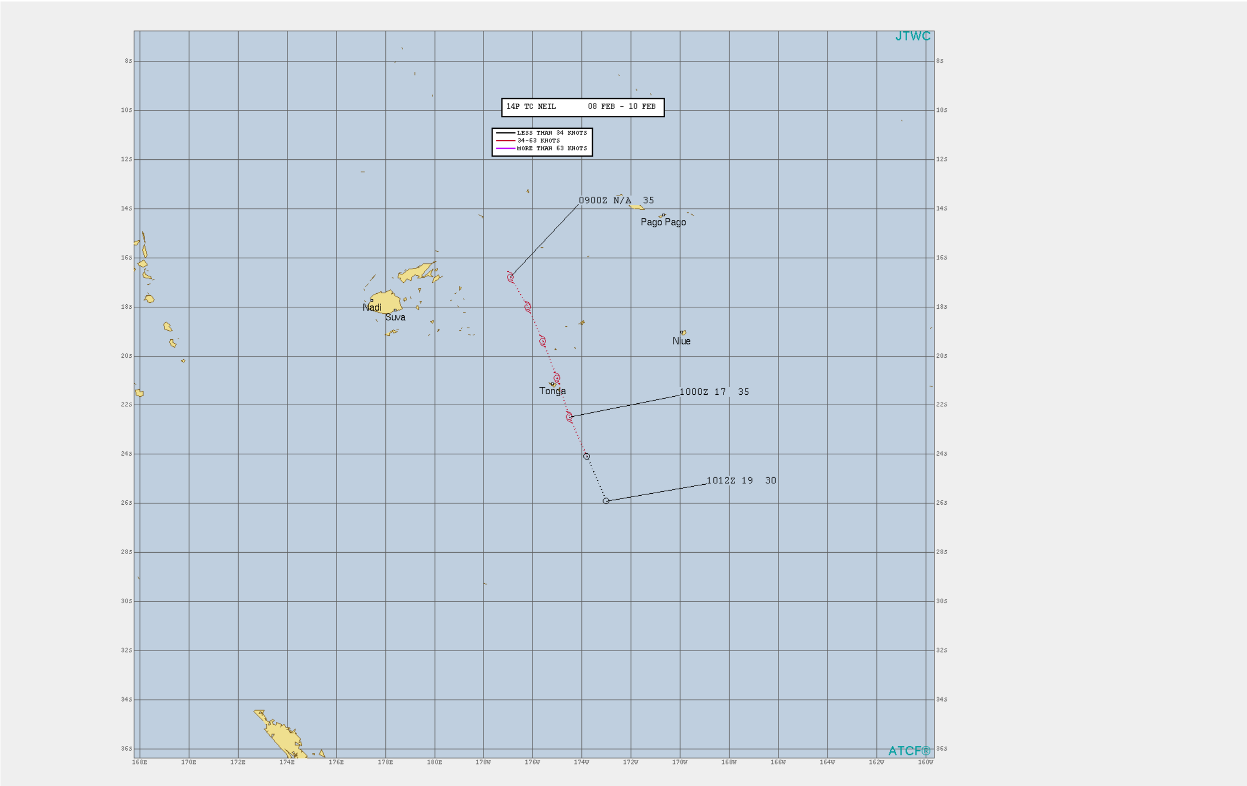




14P TROPICAL CYCLONE NEIL

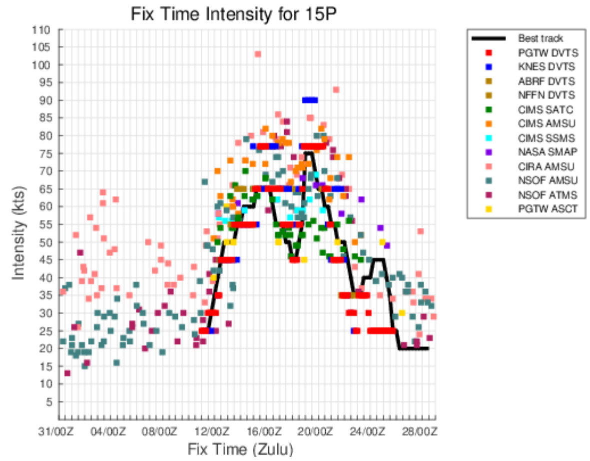
ISSUED LOW:	N/A
ISSUED MED:	08 Feb / 2330Z
FIRST TCFA:	09 Feb / 1230Z
FIRST WARNING:	09 Feb / 1800Z
LAST WARNING:	10 Feb / 0600Z
MAX INTENSITY:	40
WARNINGS:	3

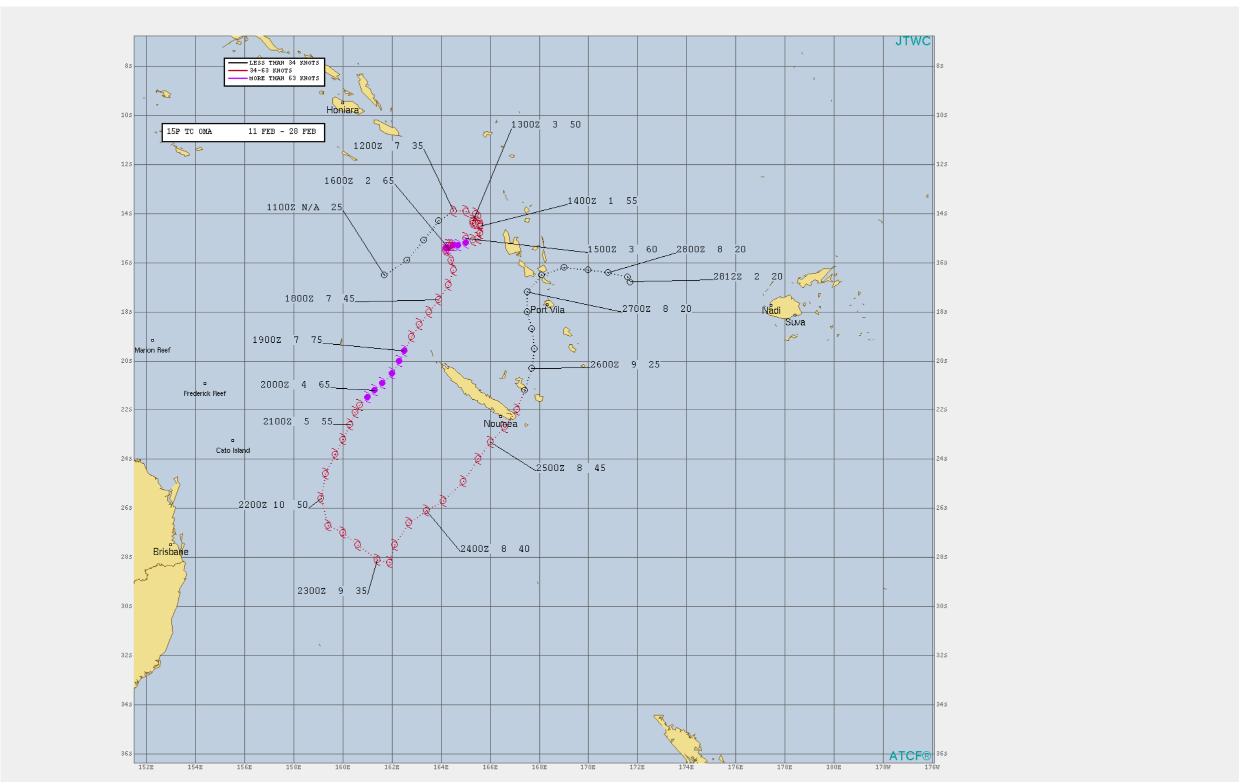




15P TROPICAL CYCLONE OMA

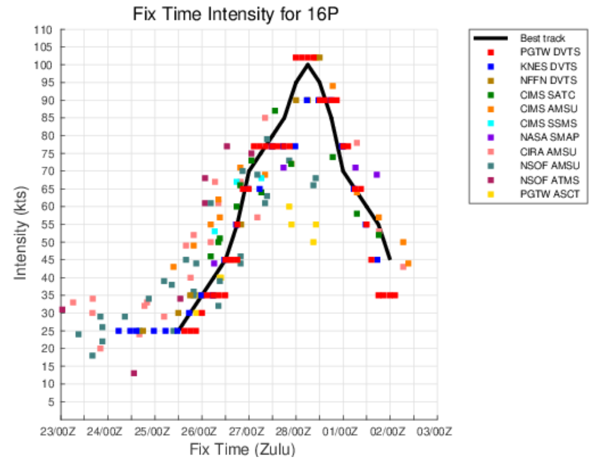
ISSUED LOW:	08 Feb / 0200Z
ISSUED MED:	11 Feb / 0600Z
FIRST TCFA:	11 Feb / 2100Z
FIRST WARNING:	12 Feb / 0000Z
LAST WARNING:	23 Feb / 0000Z
MAX INTENSITY:	75
WARNINGS:	45

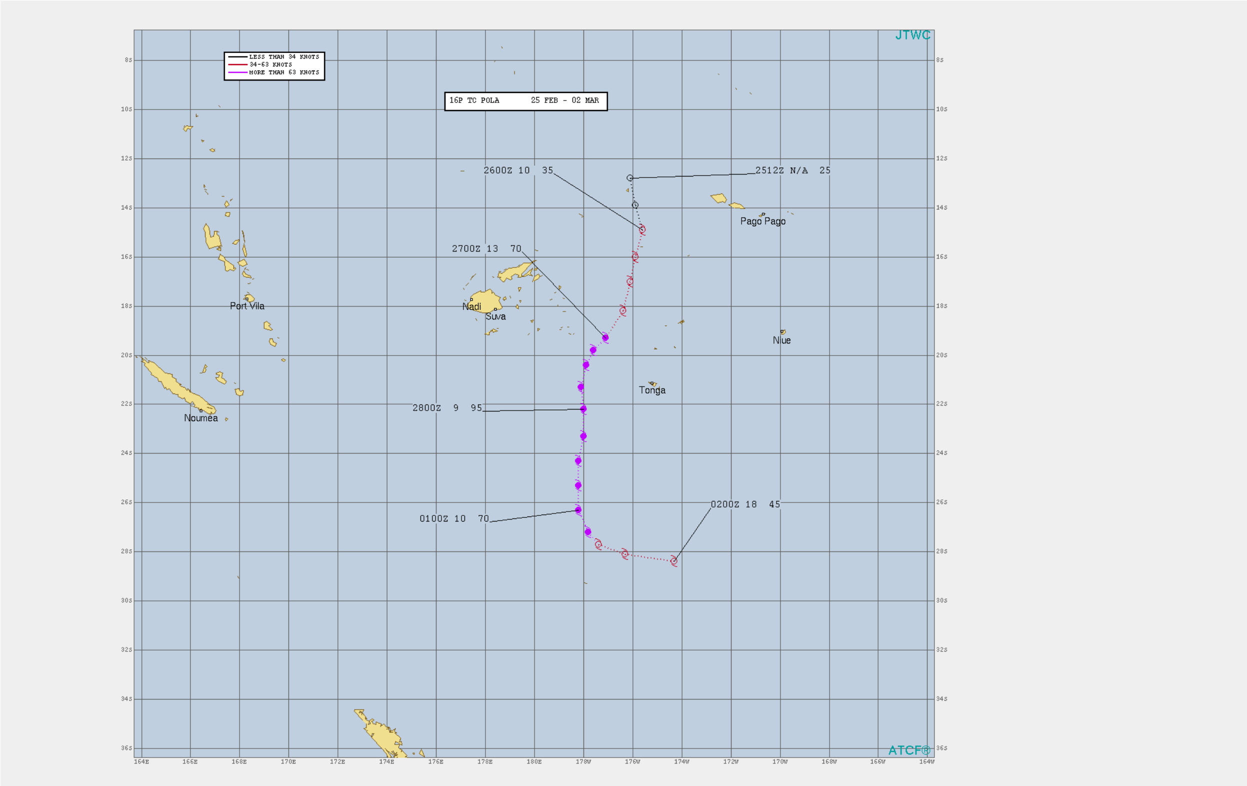




16P TROPICAL CYCLONE POLA

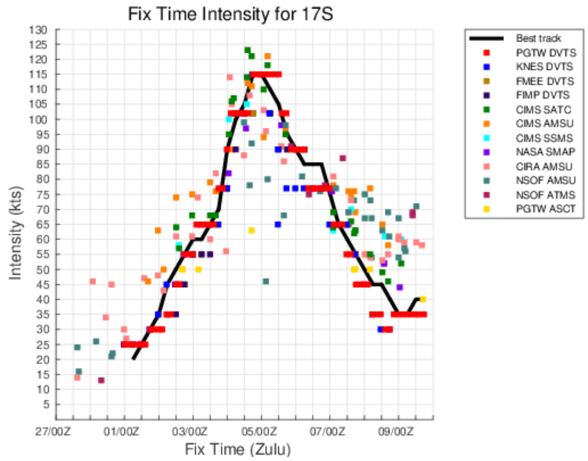
ISSUED LOW:	23 Feb / 1430Z
ISSUED MED:	24 Feb / 0130Z
FIRST TCFA:	25 Feb / 1300Z
FIRST WARNING:	26 Feb / 0000Z
LAST WARNING:	01 Mar / 1800Z
MAX INTENSITY:	100
WARNINGS:	16

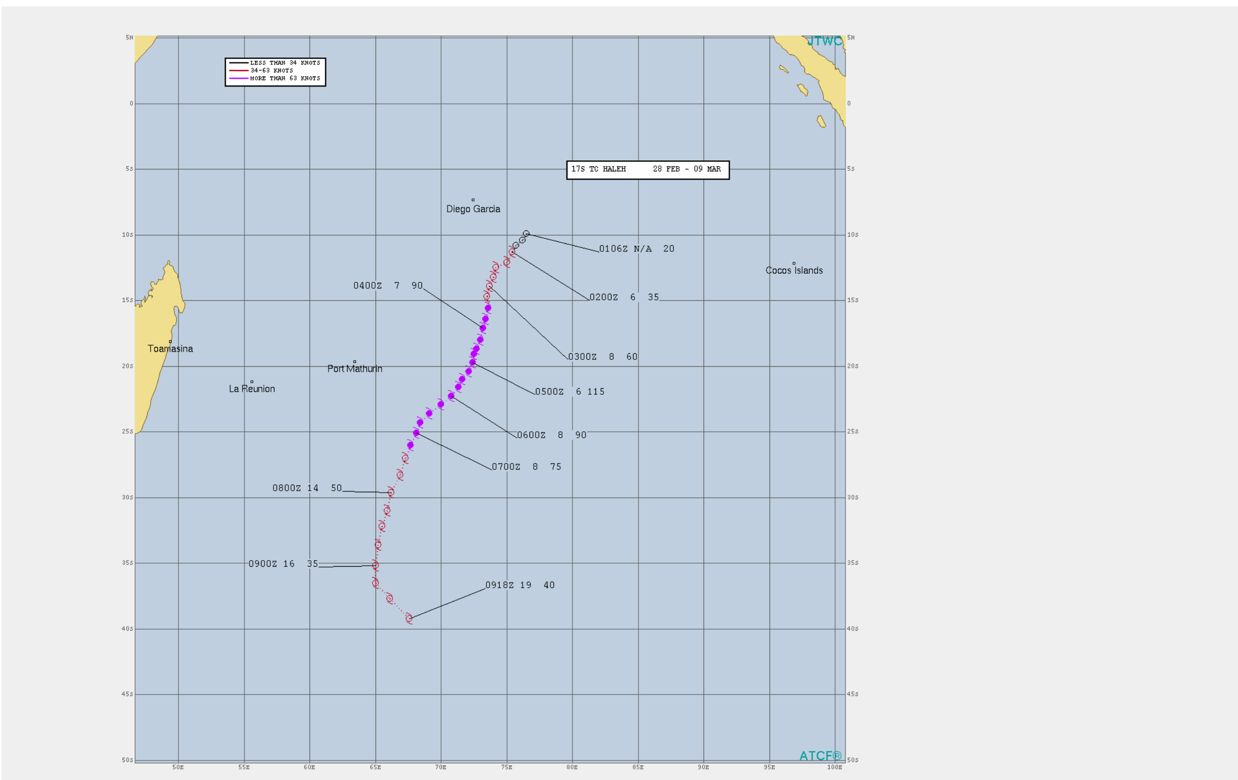




17S TROPICAL CYCLONE HALEH

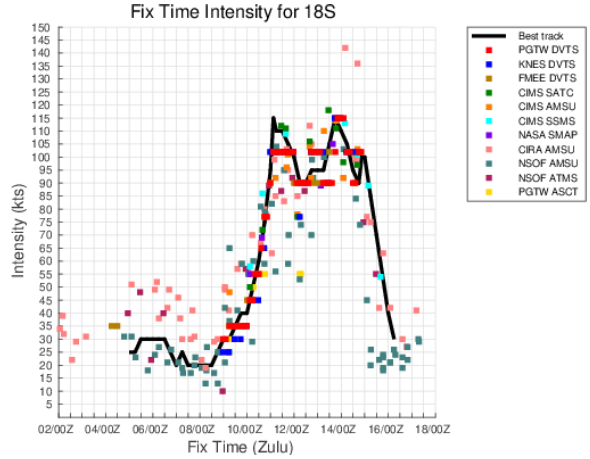
ISSUED LOW:	27 Feb / 1800Z
ISSUED MED:	28 Feb / 1800Z
FIRST TCFA:	01 Mar / 0900Z
FIRST WARNING:	02 Mar / 0600Z
LAST WARNING:	09 Mar / 0000Z
MAX INTENSITY:	115
WARNINGS:	28

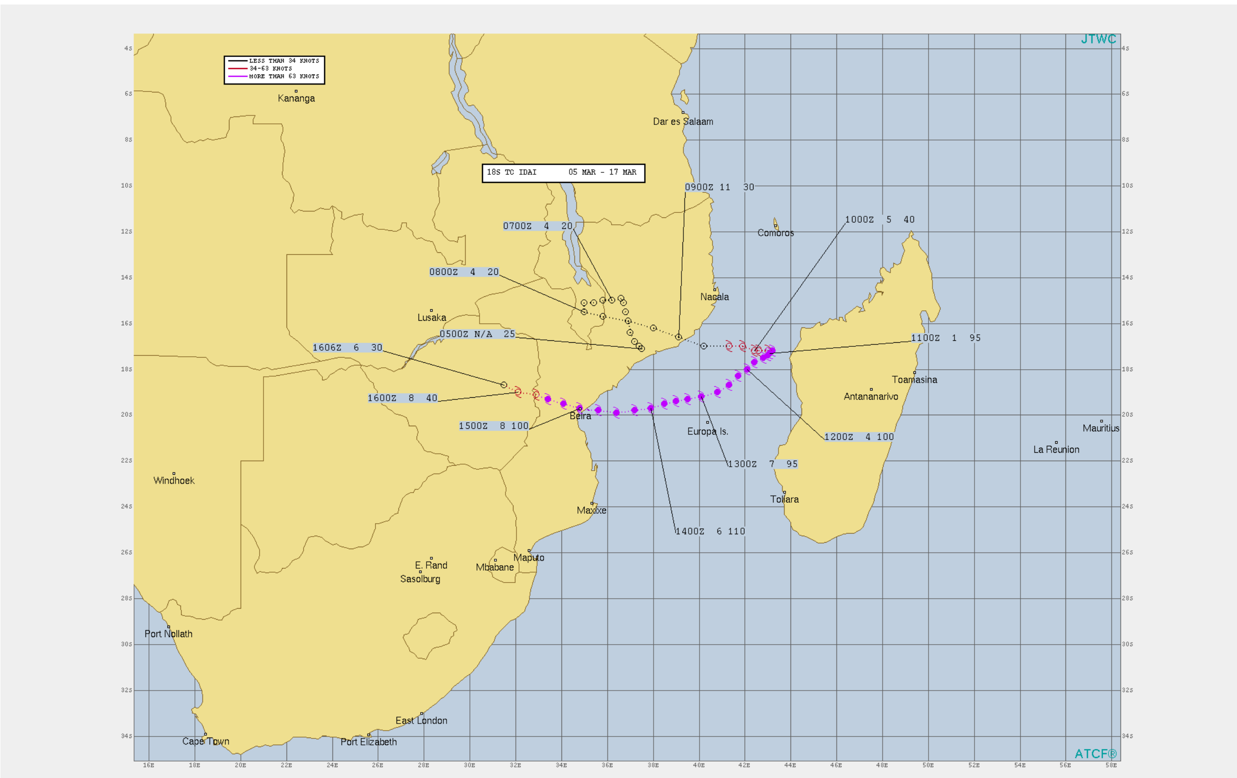




18S TROPICAL CYCLONE IDAI

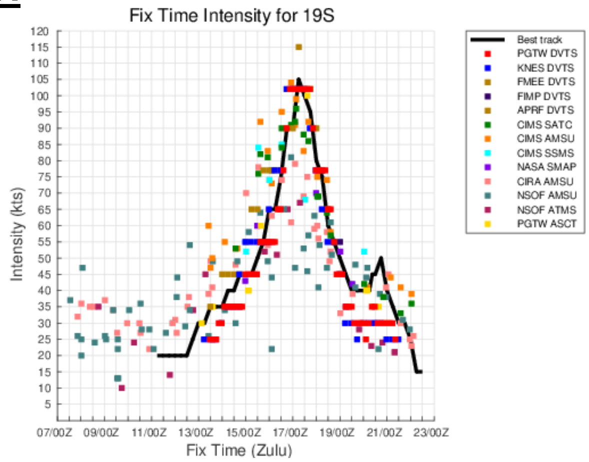
ISSUED LOW:	04 Mar / 1800Z
ISSUED MED:	06 Mar / 0130Z
FIRST TCFA:	08 Mar / 2200Z
FIRST WARNING:	09 Mar / 0600Z
LAST WARNING:	15 Mar / 0000Z
MAX INTENSITY:	115
WARNINGS:	24

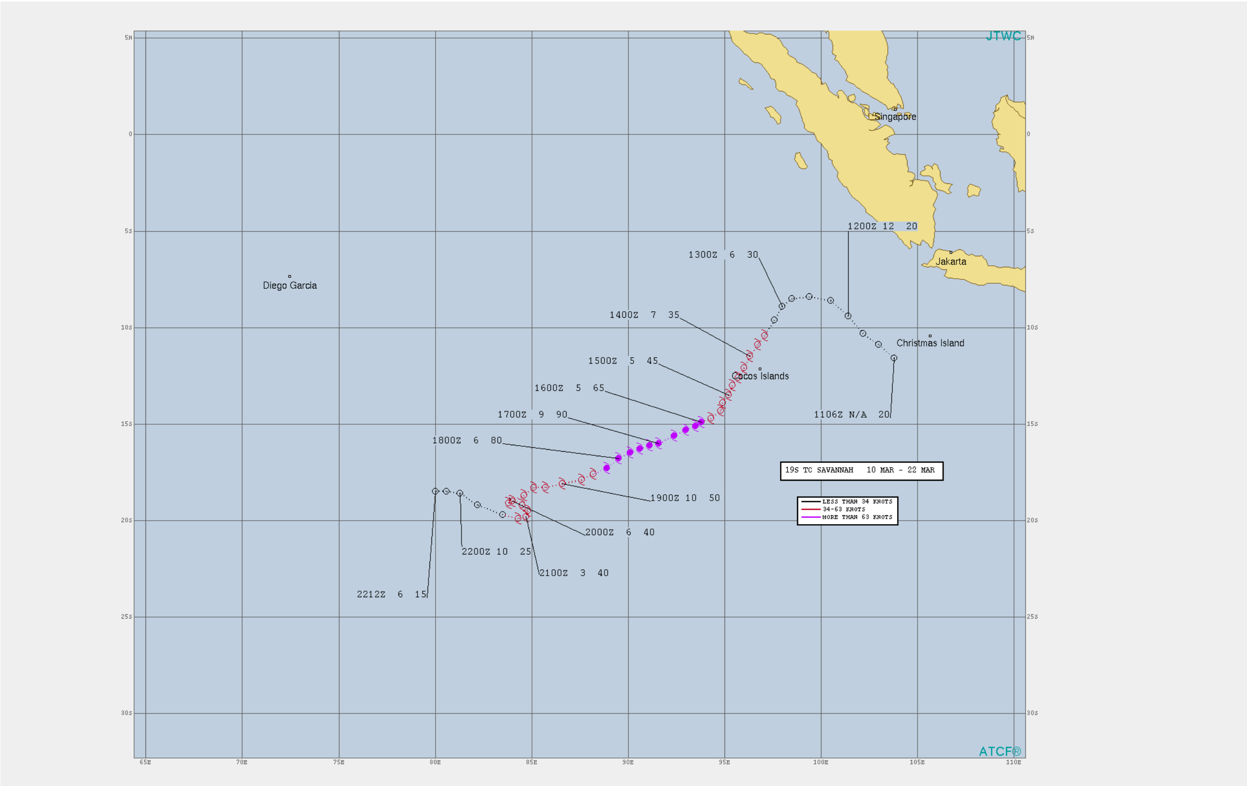




19S TROPICAL CYCLONE SAVANNAH

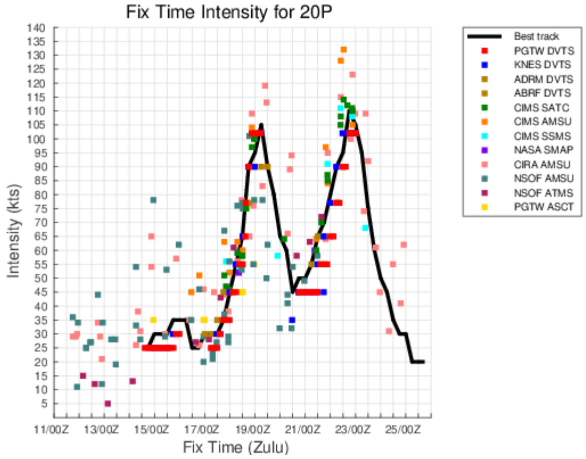
ISSUED LOW:	08 Mar / 0500Z
ISSUED MED:	N/A
FIRST TCFA:	13 Mar / 1730Z
FIRST WARNING:	14 Mar / 0000Z
LAST WARNING:	21 Mar / 0600Z
MAX INTENSITY:	105
WARNINGS:	30

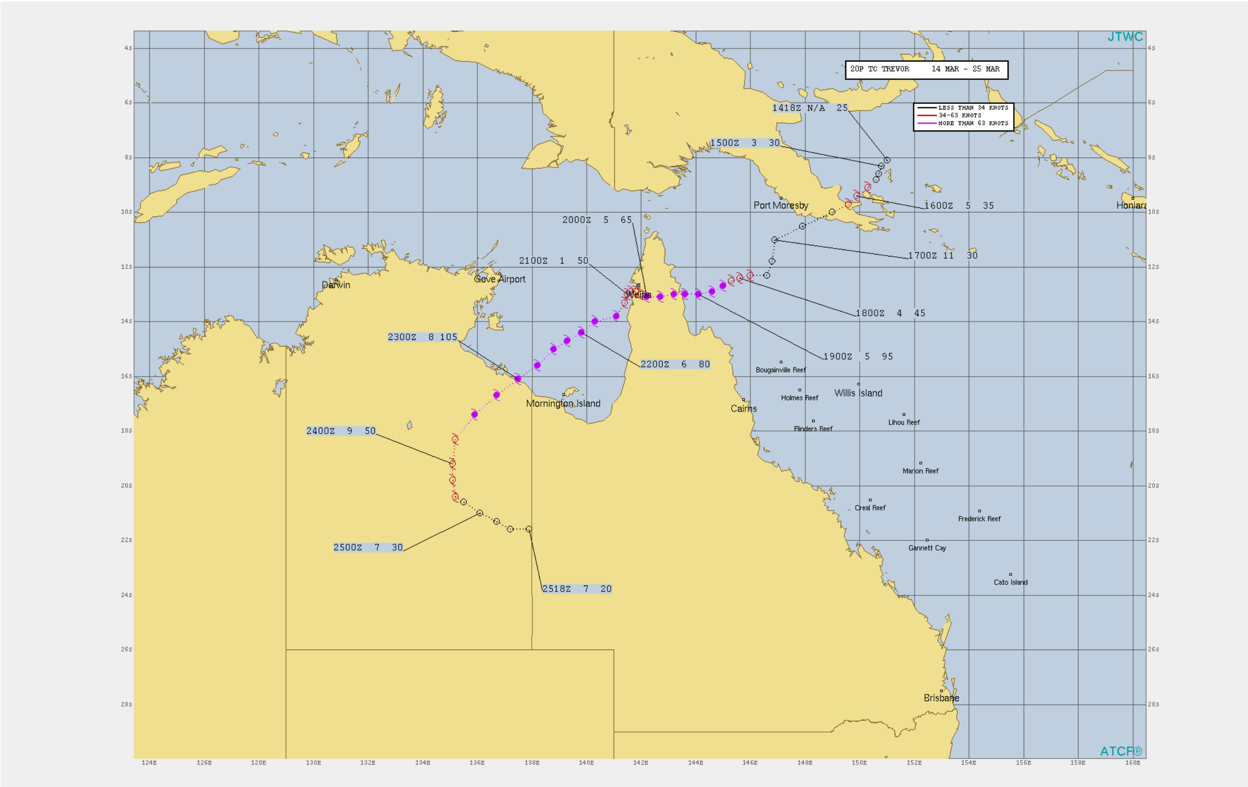




20P TROPICAL CYCLONE TREVOR

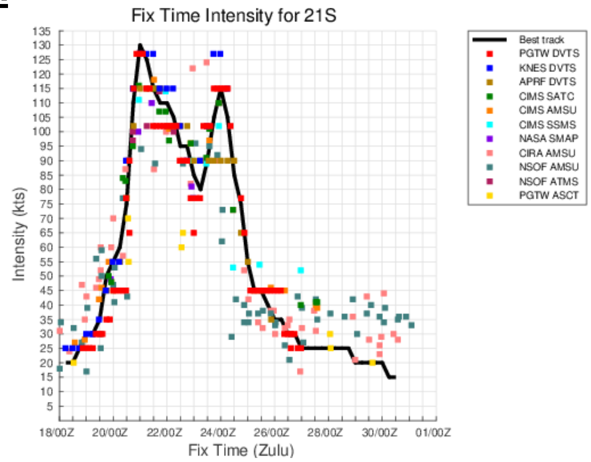
ISSUED LOW:	14 Mar / 0200Z
ISSUED MED:	14 Mar / 1700Z
FIRST TCFA:	15 Mar / 0130Z
FIRST WARNING:	17 Mar / 1800Z
LAST WARNING:	23 Mar / 0000Z
MAX INTENSITY:	110
WARNINGS:	22

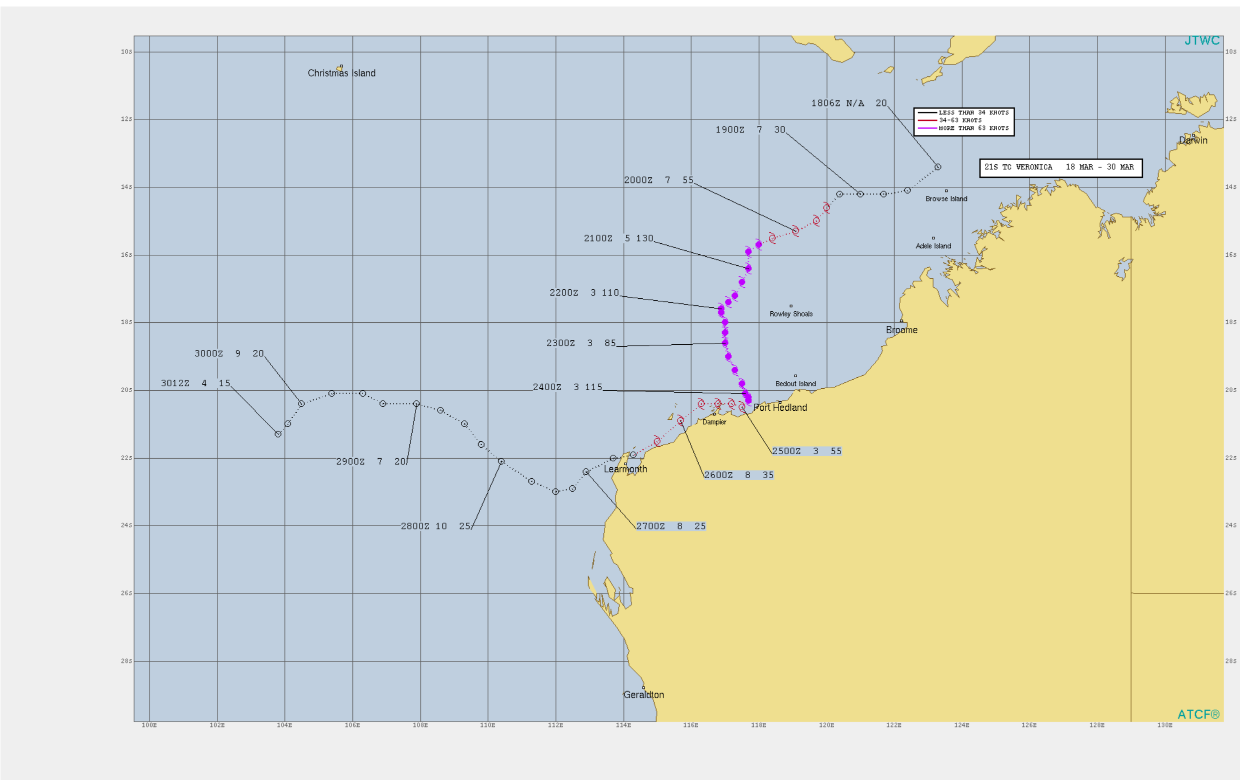




21S TROPICAL CYCLONE VERONICA

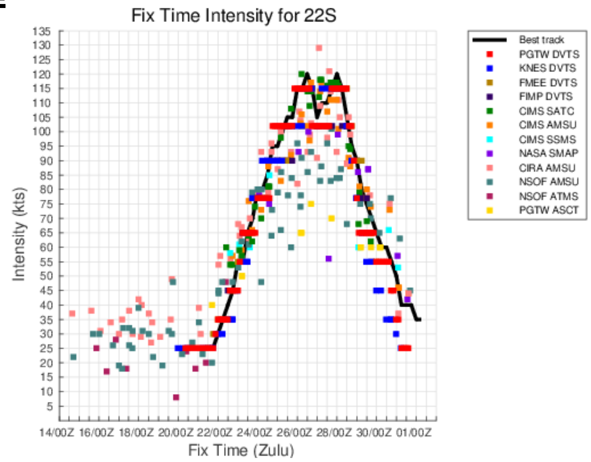
ISSUED LOW:	N/A
ISSUED MED:	18 Mar / 1300Z
FIRST TCFA:	19 Mar / 0300Z
FIRST WARNING:	19 Mar / 1800Z
LAST WARNING:	26 Mar / 0000Z
MAX INTENSITY:	130
WARNINGS:	26

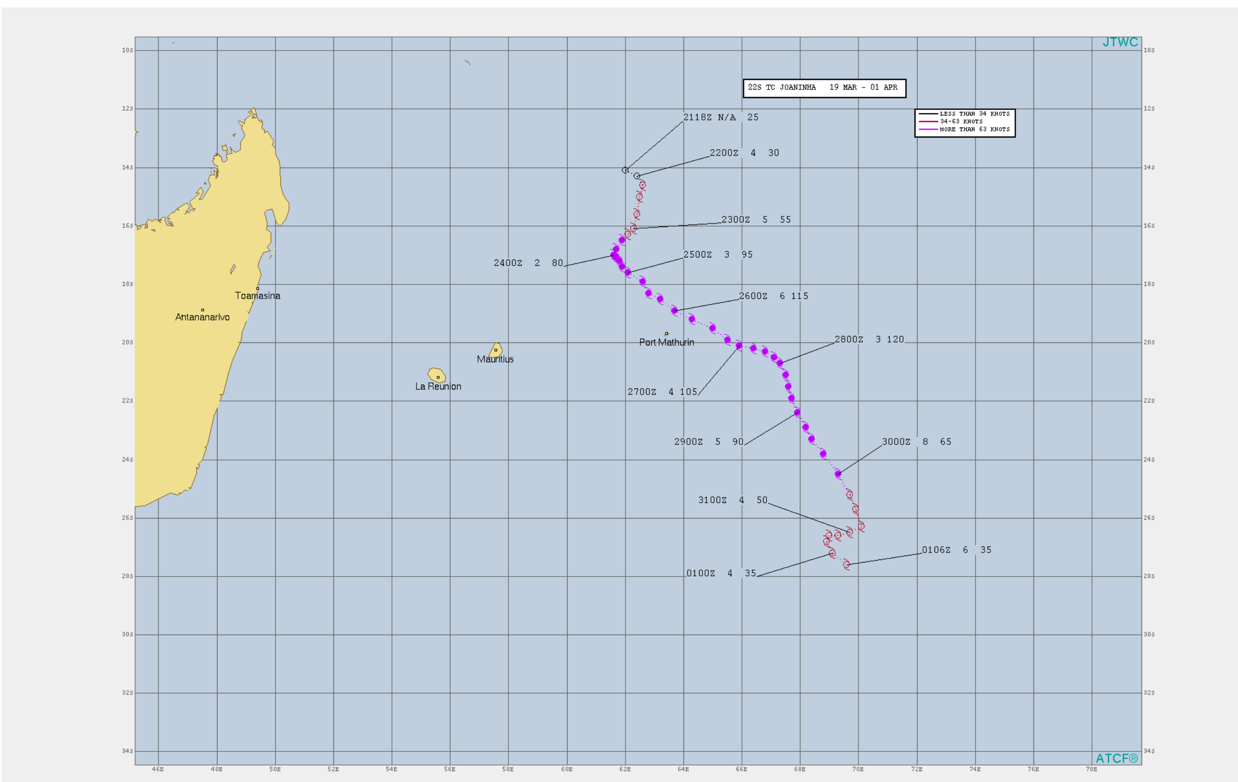




22S TROPICAL CYCLONE JOANINHA

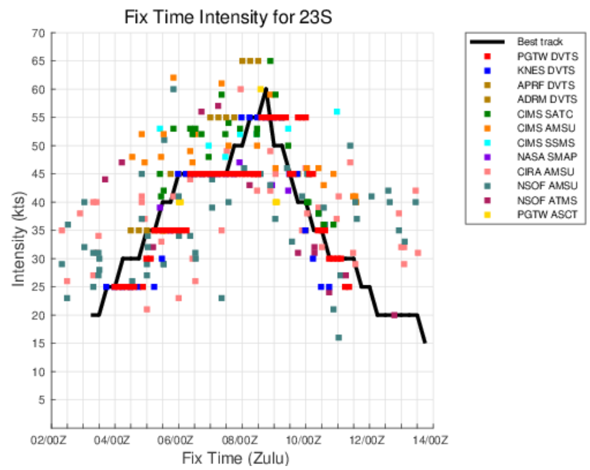
ISSUED LOW:	19 Mar / 0300Z
ISSUED MED:	19 Mar / 2230Z
FIRST TCFA:	20 Mar / 2130Z
FIRST WARNING:	22 Mar / 0000Z
LAST WARNING:	31 Mar / 0000Z
MAX INTENSITY:	120
WARNINGS:	37

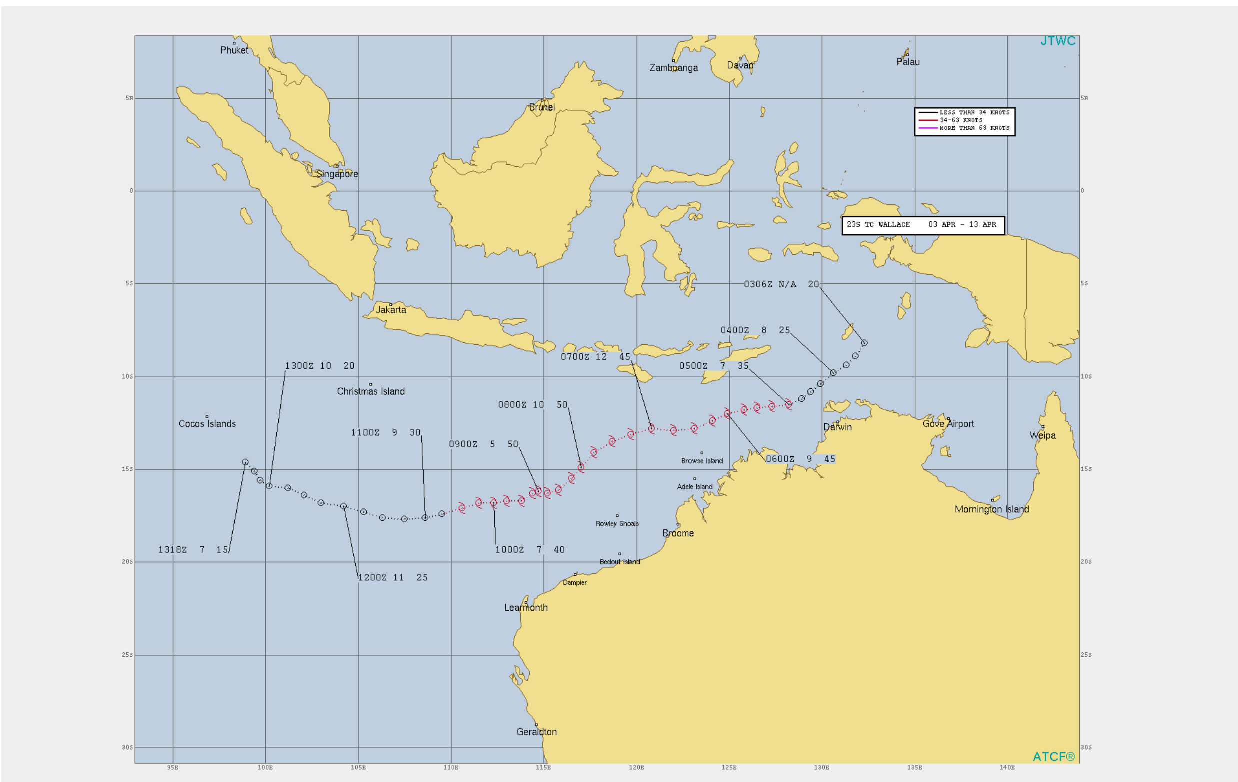




23S TROPICAL CYCLONE WALLACE

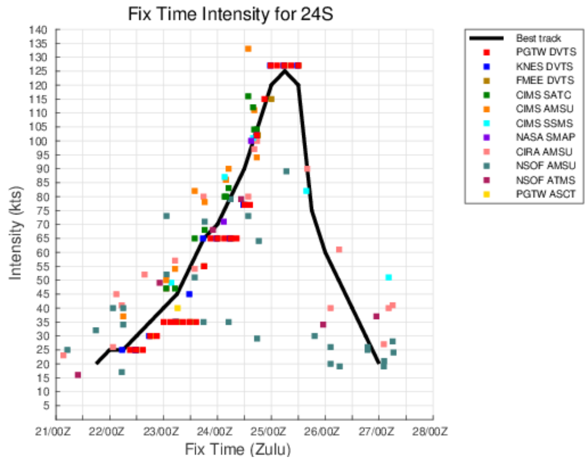
ISSUED LOW:	02 Apr / 0000Z
ISSUED MED:	03 Apr / 0400Z
FIRST TCFA:	04 Apr / 0130Z
FIRST WARNING:	05 Apr / 0000Z
LAST WARNING:	10 Apr / 0000Z
MAX INTENSITY:	60
WARNINGS:	21

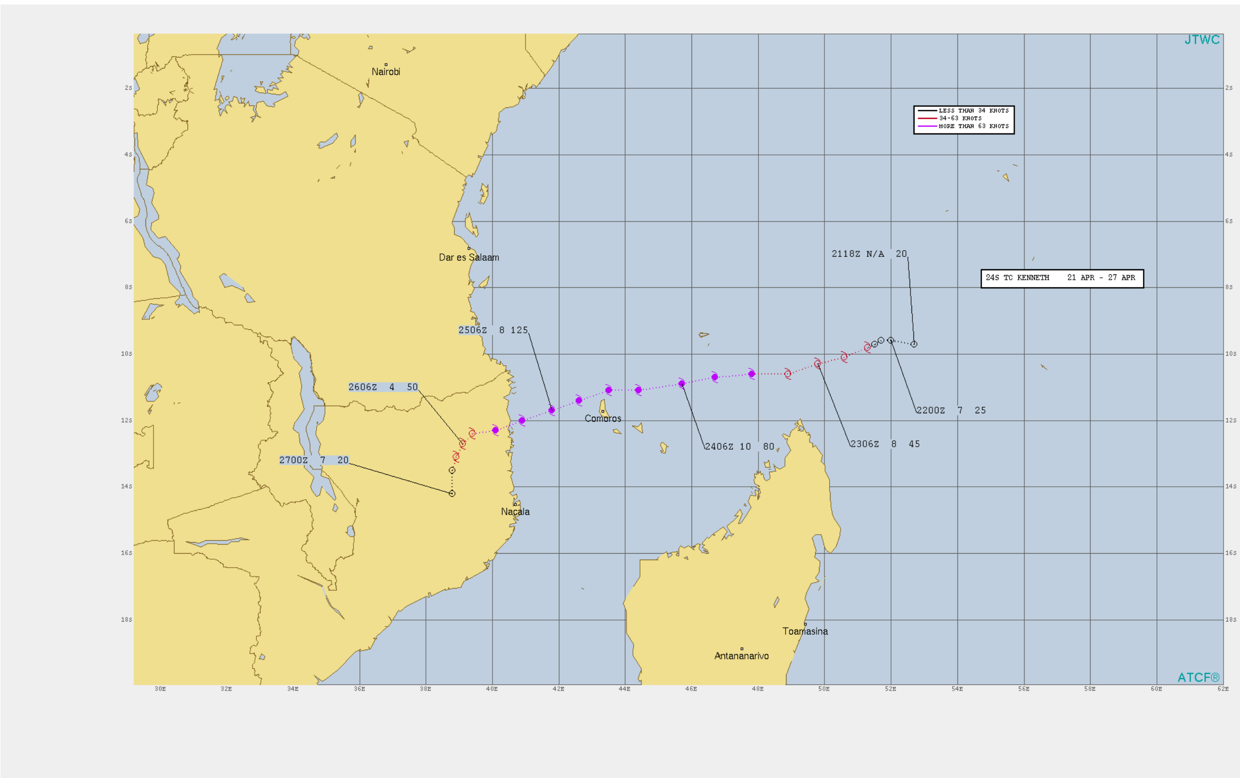




24S TROPICAL CYCLONE KENNETH

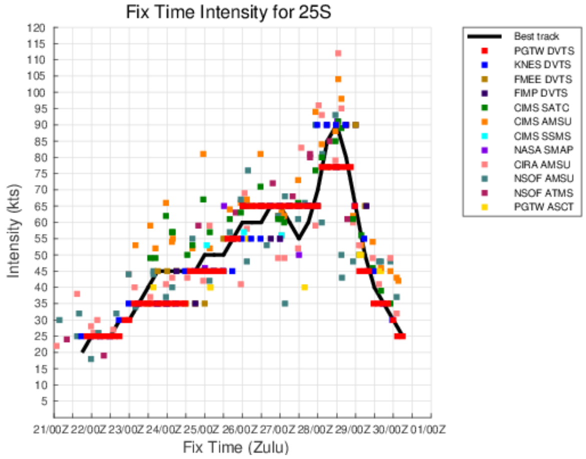
ISSUED LOW:	21 Apr / 1400Z
ISSUED MED:	21 Apr / 1800Z
FIRST TCFA:	22 Apr / 1430Z
FIRST WARNING:	23 Apr / 0000Z
LAST WARNING:	25 Apr / 1800Z
MAX INTENSITY:	125
WARNINGS:	12

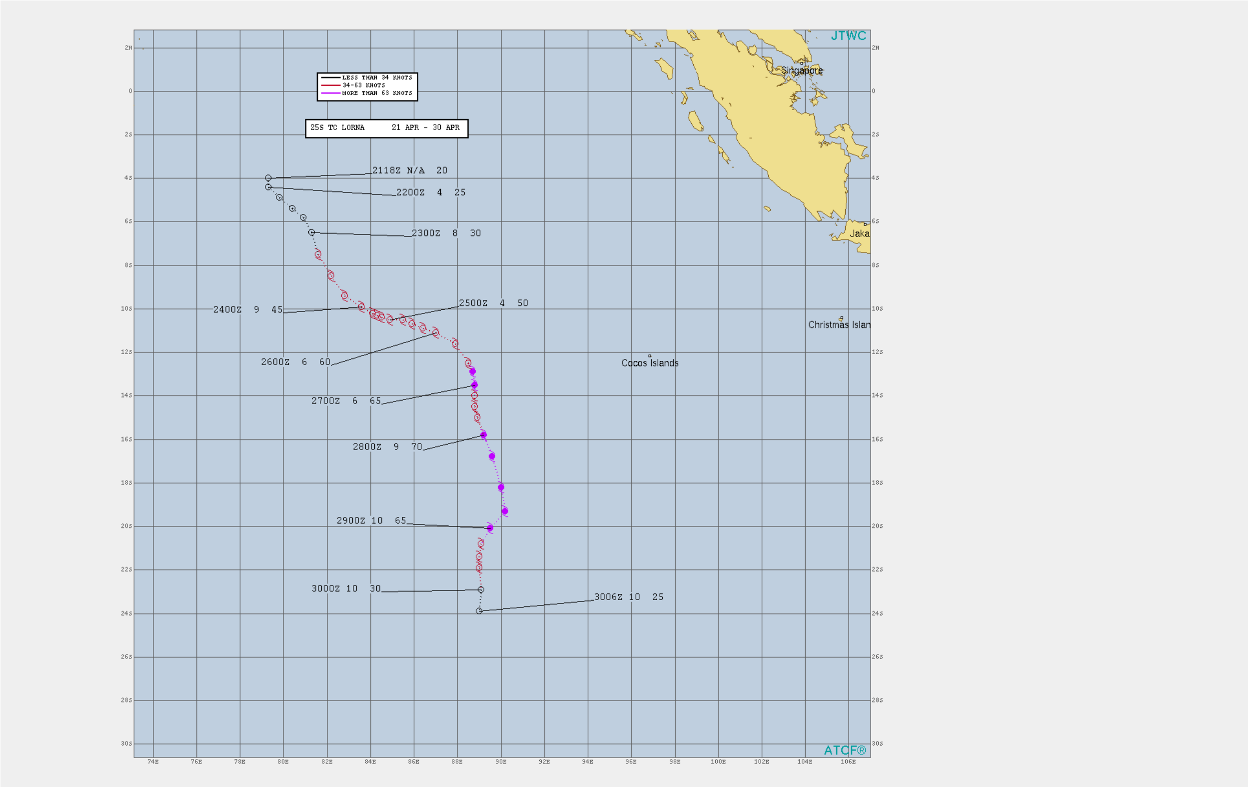




25S TROPICAL CYCLONE LORNA

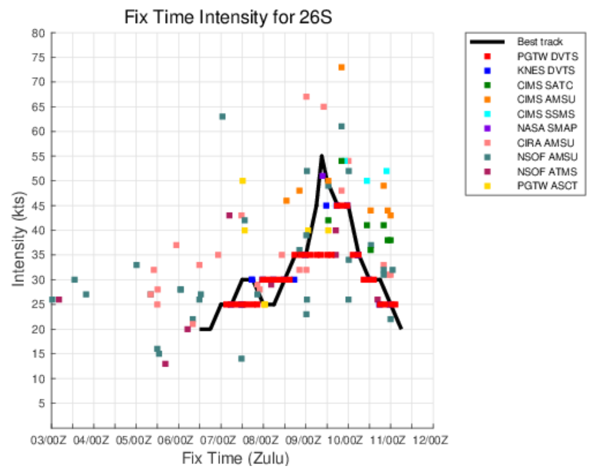
ISSUED LOW:	21 Apr / 1400Z
ISSUED MED:	21 Apr / 1800Z
FIRST TCFA:	22 Apr / 2300Z
FIRST WARNING:	23 Apr / 1200Z
LAST WARNING:	29 Apr / 1200Z
MAX INTENSITY:	90
WARNINGS:	25

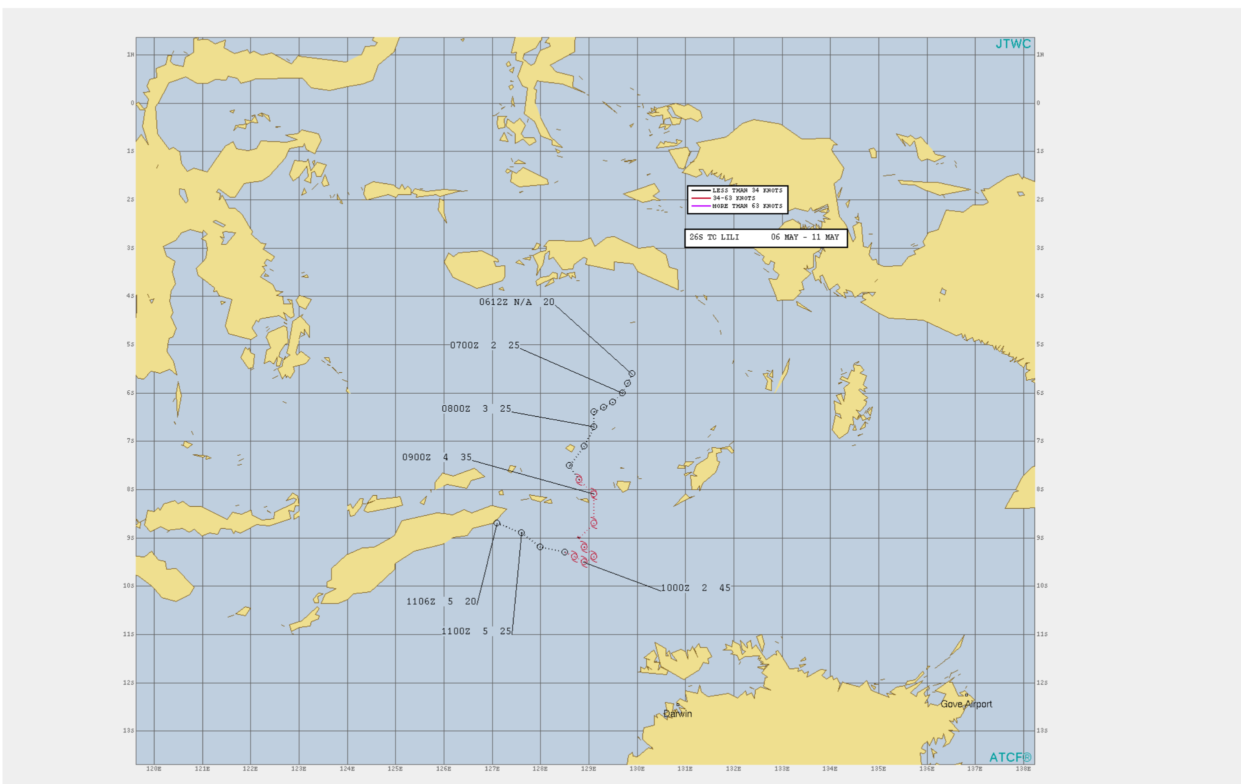




26S TROPICAL CYCLONE LILI

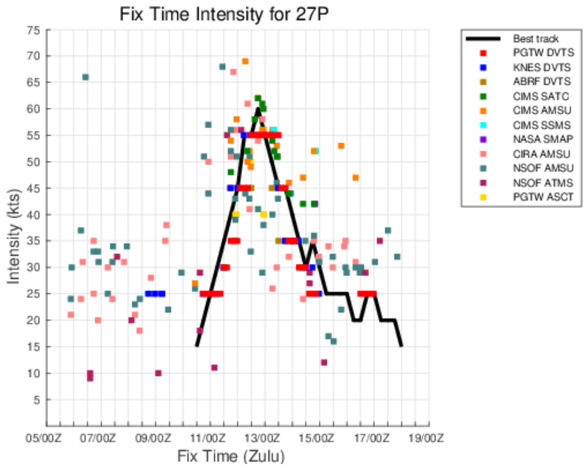
ISSUED LOW:	07 May / 0230Z
ISSUED MED:	N/A
FIRST TCFA:	07 May / 1730Z
FIRST WARNING:	09 May / 0600Z
LAST WARNING:	10 May / 1800Z
MAX INTENSITY:	55
WARNINGS:	7

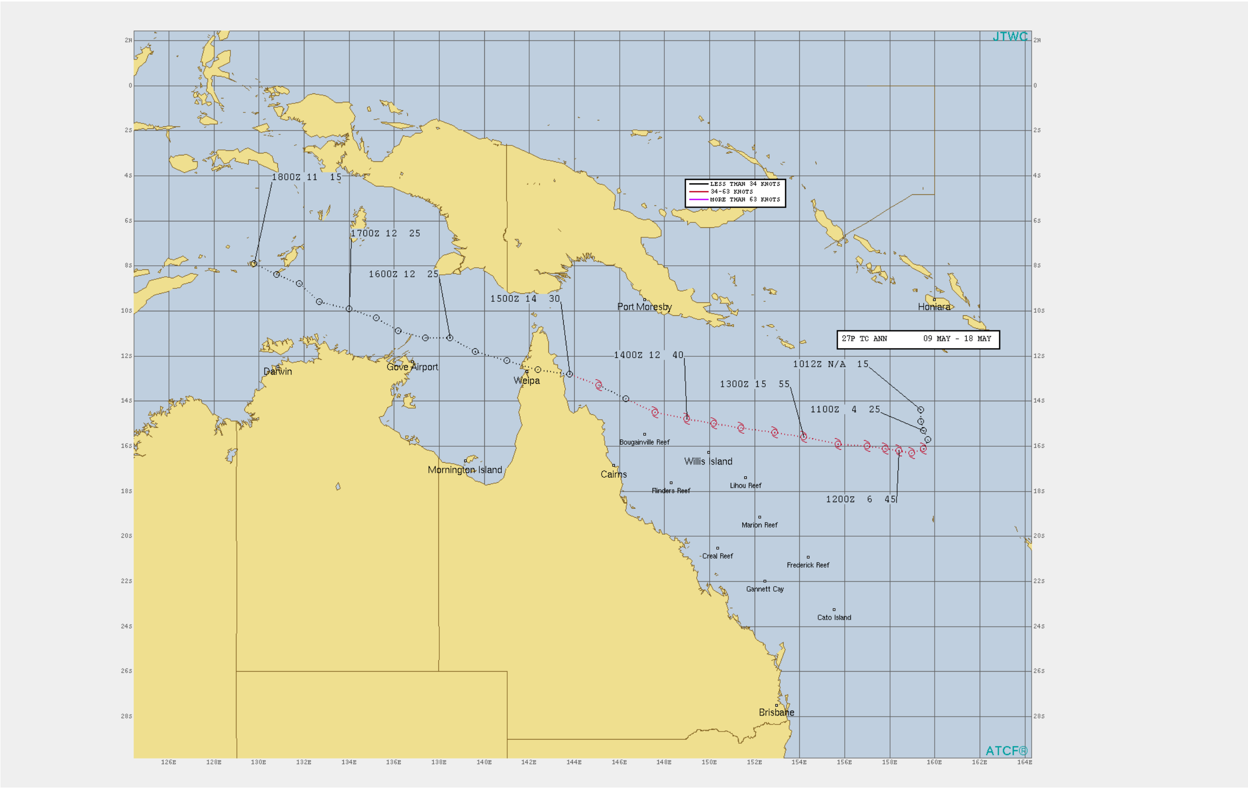




27P TROPICAL CYCLONE ANN

ISSUED LOW:	09 May / 0600Z
ISSUED MED:	11 May / 0100Z
FIRST TCFA:	11 May / 1530Z
FIRST WARNING:	11 May / 1800Z
LAST WARNING:	14 May / 1200Z
MAX INTENSITY:	60
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. Satellite analysts at JTWC produced 9,858 position and intensity estimates. A total of 3,867 of those 9,858 fixes were made using microwave imagery, amounting to 39.23 percent of the total number of fixes. A total of 1,244 of those 9,858 fixes were scatterometry fixes amounting to 12.62 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 to the TC reconnaissance mission. 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. These are areas that were fixed on but did not reach warning criteria. The total DND fixes for all basins was 646, which accounted for approximately 6.55 percent of all fixes in 2019.

Section 2 Fix Summary by Basin

TABLE 4-1 WESTERN NORTH PACIFIC OCEAN FIX SUMMARY FOR 2019				
Tropical Cyclone	**Name**	**Visible/Infrared**	**Microwave/Scatterometry**	**Total**
01W	ONE	65	14	79
02W	WUTIP	96	145	241
03W	THREE	35	101	136
04W	FOUR	30	41	71
05W	MUN	17	3	20
06W	DANAS	45	82	127
07W	NARI	32	43	75
08W	WIPHA	37	60	97
09W	FRANCISCO	53	97	150
10W	LEKIMA	63	123	186
11W	KROSA	83	69	152
12W	BAILU	44	69	113
13W	PODUL	31	65	96
14W	FAXAI	92	80	172
15W	LINGLING	46	141	187
16W	KAJIKI	36	41	77
17W	PEIPAH	25	64	89
18W	TAPAH	57	103	160
19W	MITAG	59	147	206
20W	HAGIBIS	66	149	215
21W	NEOGURI	51	103	154
22W	BUALOI	61	144	205
23W	MATMO	75	42	117
24W	HALONG	63	61	124
25W	NAKRI	53	25	78
26W	FENGSHEN	63	66	129
27W	KALMAEGI	85	38	123
28W	FUNG-WONG	37	27	64
29W	KAMMURI	84	57	141
30W	PHANFONE	68	64	132
DND	-	99	27	126
Totals		**1751**	**2291**	**4042**
Percentage of Totals		**43.32%**	**56.68%**	**100%**

TABLE 4-2

SOUTH PACIFIC & SOUTH INDIAN OCEAN FIX SUMMARY FOR 2019

Tropical Cyclone	Name	Visible/Infrared	Microwave/Scatterometry	Total
01S	ONE	43	72	115
02P	LIUA	51	54	105
03S	ALCIDE	90	125	215
04S	BOUCHRA	111	107	218
05P	OWEN	175	127	302
06S	KENANGA	91	121	212
07S	CILIDA	66	112	178
08P	PENNY	91	79	170
09P	MONA	72	57	129
10S	DESMOND	32	29	61
11S	RILEY	109	148	257
12S	FUNANI	46	61	107
13S	GELENA	86	144	230
14P	NEIL	11	20	31
15P	OMA	163	130	293
16P	POLA	40	44	84
17S	HALEH	72	99	171
18S	IDAI	99	76	175
19S	SAVANNAH	90	88	178
20P	TREVOR	83	55	138
21S	VERONICA	102	91	193
22S	JOANINHA	95	120	215
23S	WALLACE	79	71	150
24S	KENNETH	43	30	73
25S	LORNA	70	41	111
26S	LILI	42	14	56
27P	ANN	58	54	112
DND	-	313	147	460
Totals		**2423**	**2316**	**4739**
Percentage of Totals		**51.13%**	**48.87%**	**100%**

TABLE 4-3

NORTH INDIAN OCEAN (BAY OF BENGAL/ARABIAN SEA)
FIX SUMMARY FOR 2019

Tropical Cyclone	Name	Visible/Infrared	Microwave/Scatterometry	Total
01B	FANI	67	59	126
02A	VAYU	74	101	175
03A	HIKAA	37	30	67
04A	KYARR	77	102	179
05A	MAHA	100	57	157
06A	PAWAN	44	21	65
07A	SEVEN	27	19	46
DND	-	34	26	60
Totals		**460**	**415**	**875**
Percentage of Totals		**52.57%**	**47.43%**	**100%**

Chapter 5 Technical Development Summary

The 2020 Annual Tropical Cyclone Report (ATCR) will include a detailed overview of JTWC technical development efforts and priorities spanning calendar years 2019 and 2020. This year's abbreviated summary presents JTWC's research and development priorities, forecasting consensus aid information, 2019 technical development highlights and a list of scientific and technical exchanges that took place in 2019.

Section 1 Research and Development Priorities

The top five JTWC needs for research and development (R&D), reviewed and updated in February 2020, are presented in Table 5-1. Data exploitation overtook TC structure specification as the second highest priority, reflecting JTWC's requirement to integrate rapidly evolving satellite datasets and data processing and display capabilities into operations.

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 2 JTWC Forecasting Consensus Aids

Naval Research Laboratory (NRL) Monterrey and JTWC annually review performance and reliability of various U.S. and international agency models to optimize accuracy of the multi-model track (CONW), intensity (ICNW) and 34-, 50- and 64-knot wind radii (RVCN) forecasting consensuses. Component members of each consensus are summarized in this section.

a. **TC track consensus (CONW)**

JTWC incorporated UKMet Office MOGREPS-G ensemble mean track forecasts into CONW in September 2019. Component members of CONW, as of May 2021, are listed in Table 5-3.

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 5-2. Primary objective aids comprising the operational JTWC tropical cyclone track (CONW) consensus (as of May 2021).

b. Intensity consensus (ICNW)

JTWC implemented several changes to ICNW component members in August 2019. Specifically, intensity forecasts from GFS global model (adjusted) and the Rapid Intensification Prediction Aid were incorporated, and intensity forecasts from the Coupled Hurricane Intensity Prediction System and SHIPS Rapid Intensification model were removed. Component members of ICNW, as of May 2021, are listed in Table 5-3.

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 5-3. Primary objective aids comprising the operational JTWC tropical cyclone intensity (ICNW) consensus (current members as of May 2021).

c. Wind radii consensus (RVCN)

The RVCN consensus suite increased from five to seven members with the addition of UKMET Office global model (Aug 2019) and DRCL wind radii climatology and persistence model (Jan 2020) wind radii forecasts. Component members of RVCN, as of May 2021, are listed in Table 5-4.

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 5-4. Primary objective aids comprising the operational JTWC tropical cyclone wind radii (RVCN) consensus (as of May 2021).

Section 3 Technical Development Highlights

JTWC pursued numerous technical development efforts throughout 2019 to address the center's R&D priorities and support the operational forecasting mission, including:

- Collaborating with NRL and the Cooperative Institute for Research in the Atmosphere (CIRA) to evaluate and implement new L-band radiometer-based visualizations, fixes and associated guidance products for operational use within ATCF

- Incorporating Two-Week TC Formation Outlooks into the JTWC Collaboration website, expanding their availability to a broader audience of national and international partners and researchers

- Regularly providing two-week TC formation forecast assessments to the Climate Prediction Center (CPC) for incorporation into weekly Global Tropics Hazards/Benefits Outlooks (GTH)

- Collaborating with the 16th Weather Squadron to plan innovative, ensemble model-based TC decision-impact products

- Preparing the Advanced Weather Interactive Processing System 2 (AWIPS2) for integration into JTWC operations by completing training, advancing collaboration with various National Atmospheric and Ocean Administration (NOAA) partners and supporting National Hurricane Center (NHC) efforts to develop AWIPS TC forecasting capabilities

- Evaluating CubeSat platform proxy products and providing input for an Air Force Small Business Innovation Research Program (SBIR) CubeSat proposal

- Supporting an Air Force Institute of Technology Master's Degree student's thesis research project, which applied machine-learning techniques to identify spatial patterns in passive microwave satellite imagery associated with various TC intensity thresholds

- Evaluating a weighted analog intensity forecast technique for pre-formation disturbances (Joint Hurricane Testbed (JHT) funded project)

Section 4 Scientific and Technical Exchanges

Attending and presenting at 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. JTWC participated in the following technical conferences and exchanges in 2019:

- 99th AMS Annual Meeting (Jan 2019)
- 73rd Interdepartmental Hurricane Conference (Mar 2019)
- INDOPACOM METOC Summit / Tropical Cyclone Conference (Apr 2019)
- NWS Pago Pago operational support technical exchange (Aug 2019)
- 8th NCEP Ensemble Users Workshop (Aug 2019)
- Climate Prediction Center Stakeholder Meeting (Sep 2019)
- NRL long-range prediction and TC intensification technical exchange (Sep 2019)
- NHC AWIPS II TC module technical exchange (Sep 2019)
- Hurricane Forecast Improvement Program (HFIP) Annual Meeting (Nov 2019)
- ESCAP/WMO Typhoon Committee 14th Integrated Workshop (Nov 2019)
- NCEP Production Suite Review (Nov 2019)

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 2019 season and contrasts it with annual verification statistics from previous years.

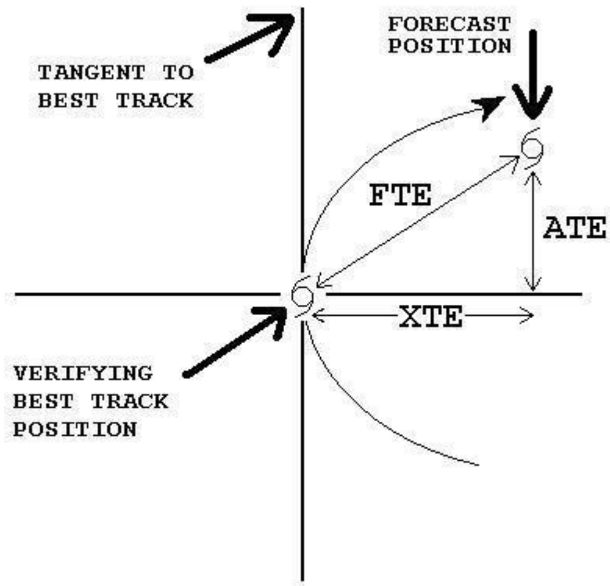


Figure 6-1. Definition of cross track error (XTE), along track error (ATE), and forecast track error (FTE). In this example, the forecast position is ahead of and to the right of the verifying best track position. Therefore, the XTE is positive (to the right of track) and the ATE is positive (ahead of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

TABLE 6-1
MEAN FORECAST ERRORS (NM) FOR WESTERN NORTH PACIFIC TROPICAL CYCLONES FROM 1959 - 2019

	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
Avg (1978-2019)	562	79	88	50	61	450	152	162	93	113	353	237	243	137	171	206	156	203	111	145	148	200	269	147	191
5yr Avg	522	41	45	28	30	410	71	78	47	52	318	110	119	69	83	236	152	164	95	114	171	185	213	123	145

(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.

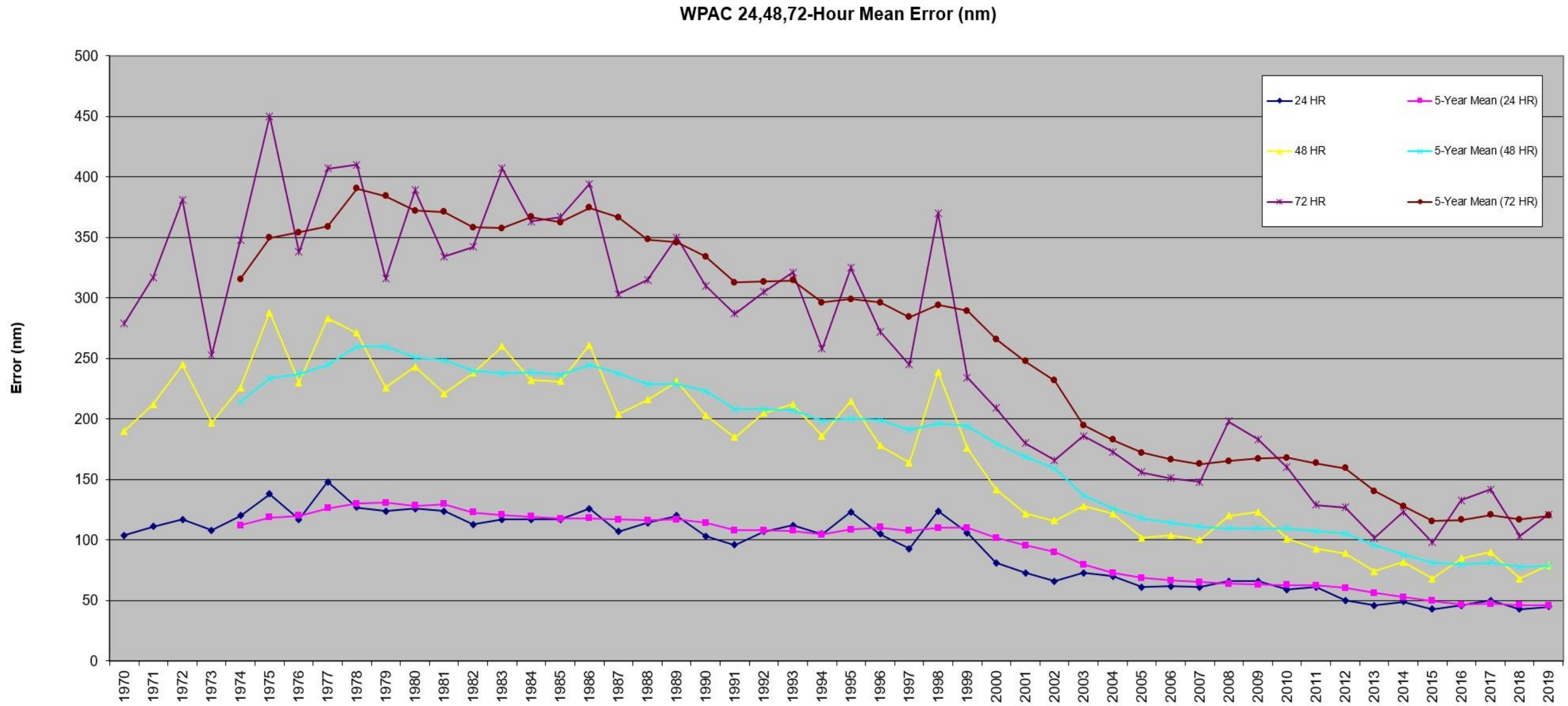


Figure 6-2. JTWC track forecast errors and five year running mean errors for the western North Pacific at 24, 48 and 72 hours.

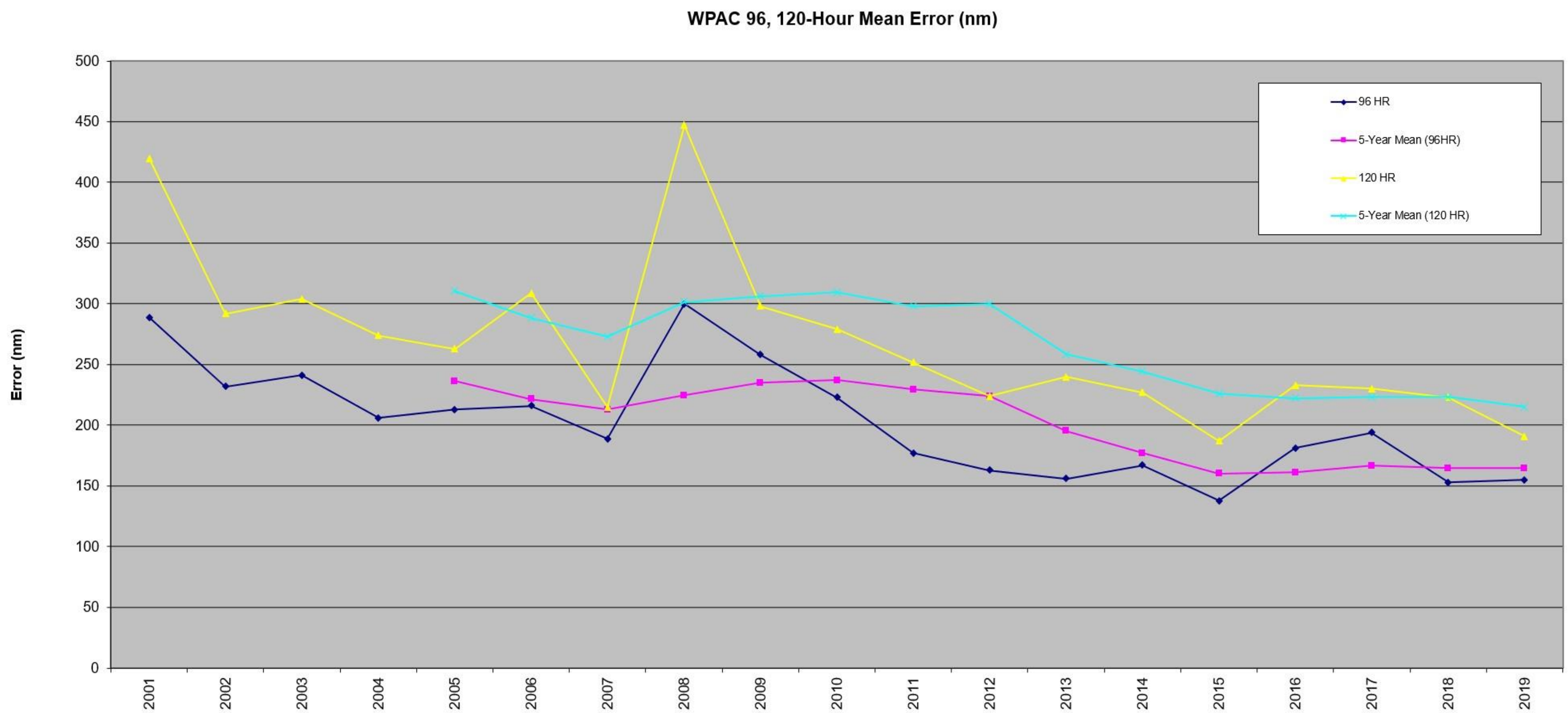


Figure 6-3. JTWC track forecast errors and five year running mean errors for the western North Pacific at 96 and 120 hours.

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

TROPICAL CYCLONES FROM 1985-2019

	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
Avg (1985-2019)	52	85	59	49	35	143	97	84	21	217	147	124	21	142	88	97	12	215	115	161
5Yr Avg	75	43	25	29	56	64	36	44	40	85	52	54	27	113	81	64	18	161	115	101

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

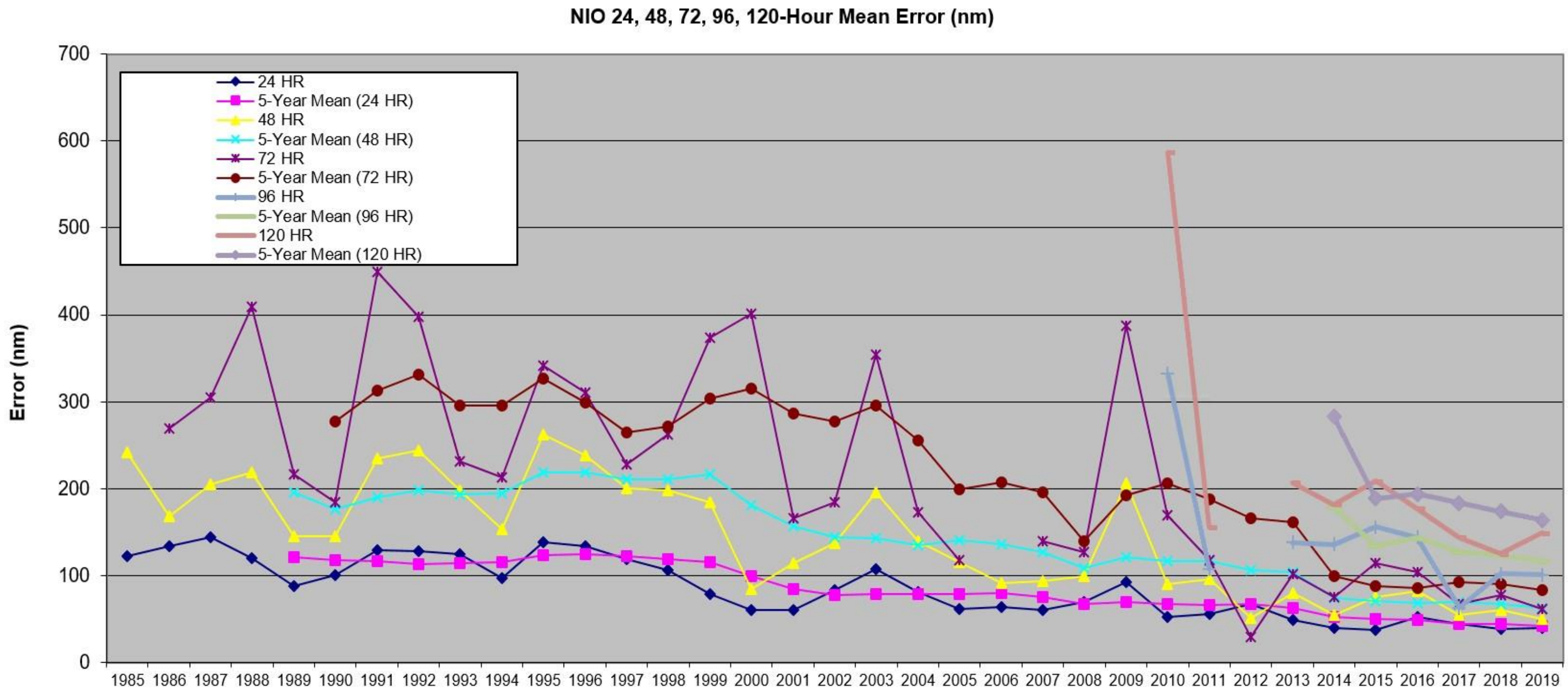


Figure 6-4. JTWC track forecast errors and five year running mean errors for the north Indian Ocean at 24, 48, 72, 96 and 120 hours. (Note: No 96 hr or 120 hr forecasts for NIO TCs in 2012).

TABLE 6-3 MEAN FORECAST ERRORS (NM) FOR SOUTHERN HEMISPHERE TROPICAL CYCLONES 1985 - 2019																				
	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
Avg (1985-2019)	242	88	50	62	190	163	92	113	83	174	101	120	100	164	91	113	70	224	131	147
5Yr Avg	278	47	27	32	222	78	44	53	168	110	61	75	120	151	85	99	84	211	124	131

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

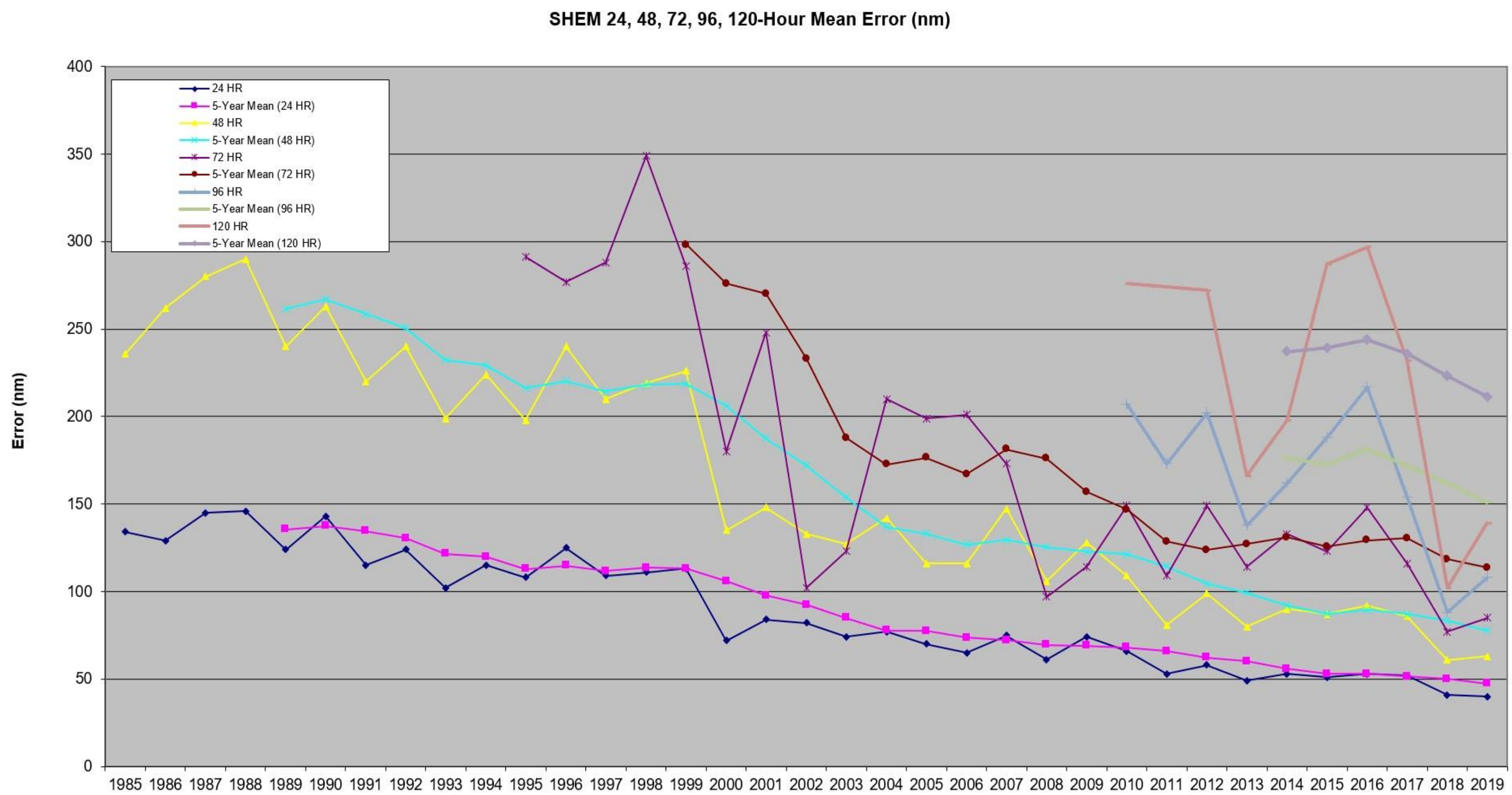


Figure 6-5. JTWC forecast errors for the Southern Hemisphere at 24, 48, 72, 96, and 120 hours.

TABLE 6-4							
MEAN FORECAST INTENSITY ERRORS FOR WESTERN NORTH PACIFIC TROPICAL CYCLONES 2000-2019							
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
AVG	7.3	11.1	14.1	16.5	19.9	22.0	23.6
5Yr Avg	7.7	10.7	12.9	15.0	17.7	18.9	20.3

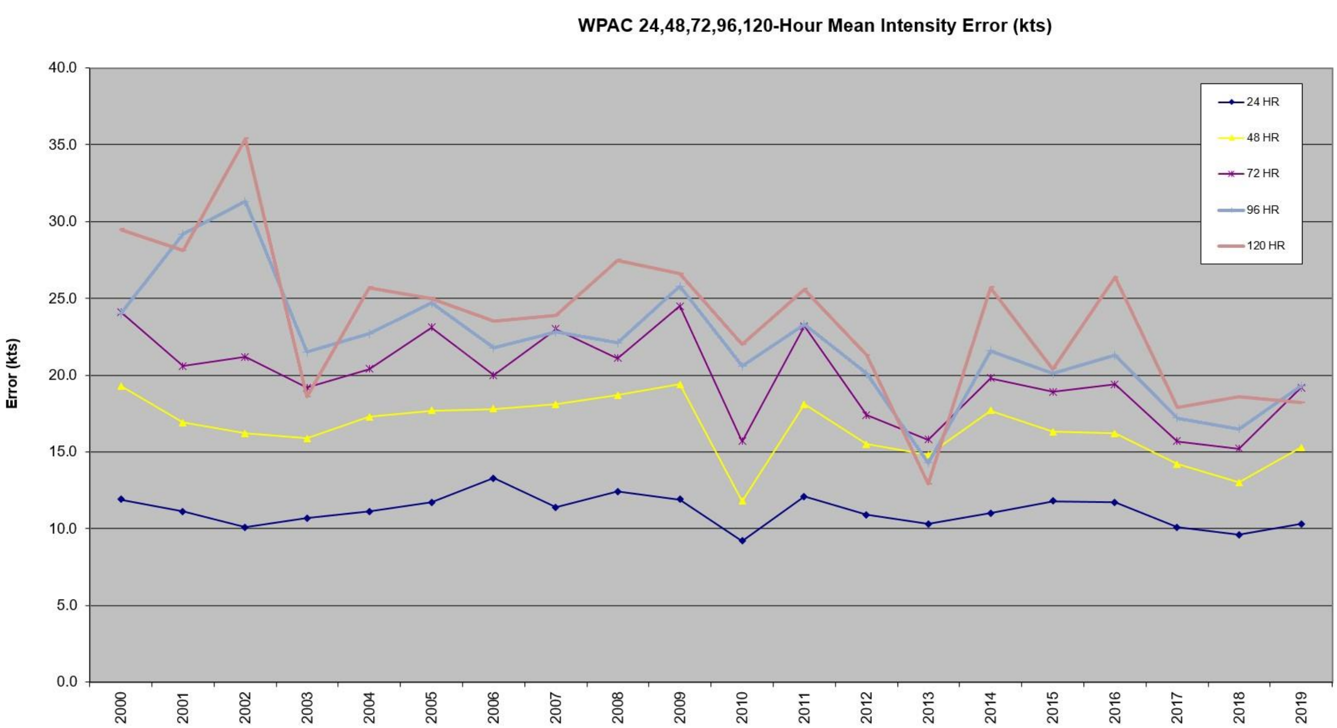


Figure 6-6. JTWC intensity forecast errors for the western North Pacific at 24, 48, 72, 96 and 120 hours.

TABLE 6-5							
MEAN FORECAST INTENSITY ERRORS FOR NORTHERN INDIAN OCEAN TROPICAL CYCLONES 2000-2019							
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
AVG	7.3	10.7	14.1	16.1	19.3	20.2	14.9
5Yr Avg	8.0	10.8	12.9	13.5	15.1	16.5	17.9

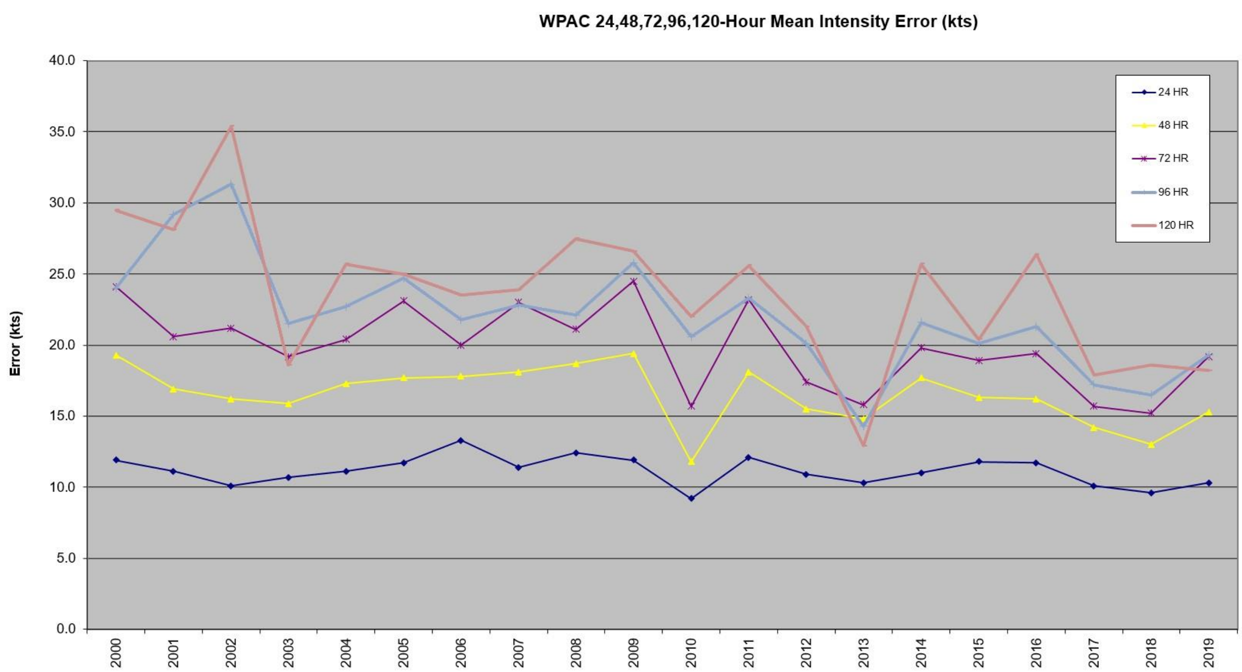


Figure 6-7. JTWC intensity forecast errors for the North Indian Ocean at 24, 48, 72, 96, and 120 hours. (Note: No 96 hr or 120 hr forecasts for NIO TCs verified in 2012).

TABLE 6-6							
MEAN FORECAST INTENSITY ERRORS FOR SOUTHERN HEMISPHERE TROPICAL CYCLONES 2000-2019							
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
AVG	7.9	12.4	16.2	18.8	20.7	19.3	20.1
5Yr Avg	8.5	12.4	14.8	16.0	17.2	17.9	17.8

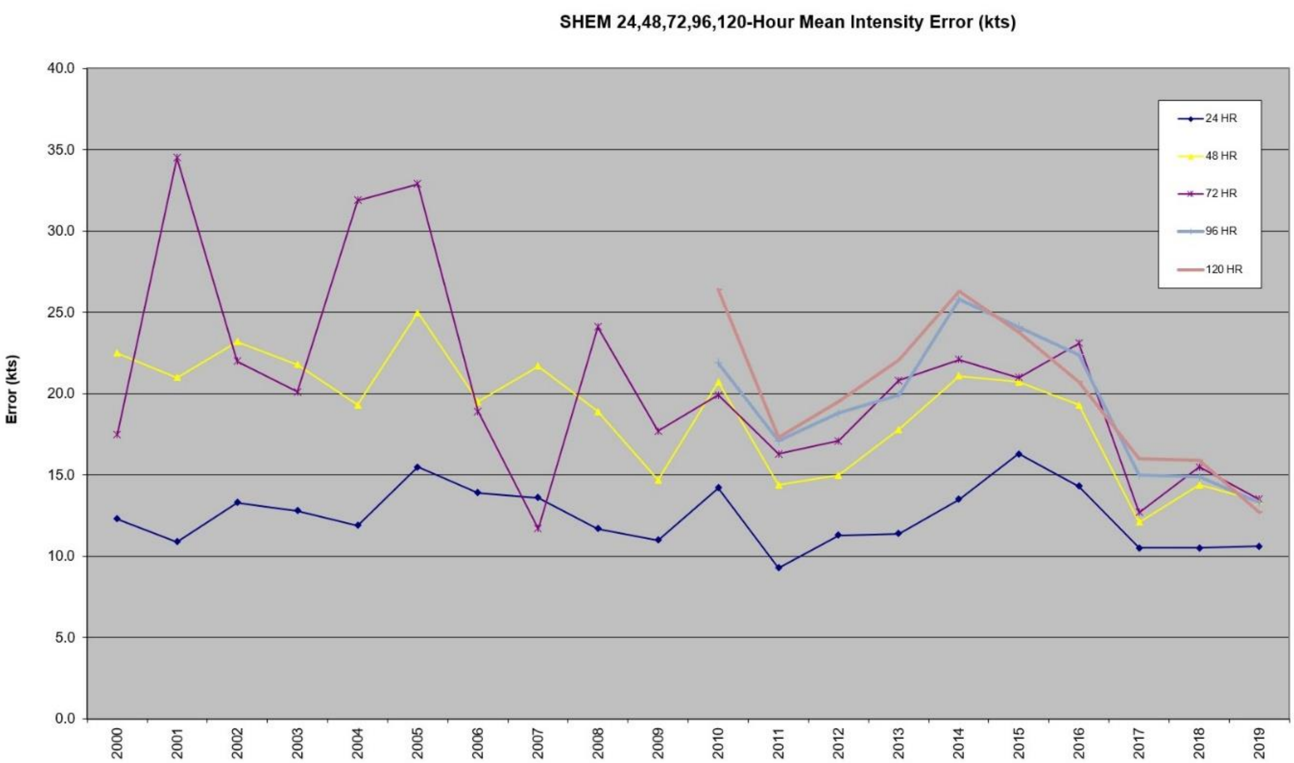


Figure 6-8. JTWC intensity forecast errors for the Southern Hemisphere at 24, 48, 72, 96 and 120 hours

Chapter 7 Detailed Cyclone Reviews

Section 1 Subtropical Storm 94W

Subtropical Storm 94W presented significant forecasting and operational challenges to JTWC due to its hybrid/subtropical characteristics and prolonged track near major U.S. Department of Defense assets in Okinawa and southern mainland Japan. Its timing coincided with the G20 summit held in Osaka, Japan from 28 to 29 June 2019, prompting additional attention and interest in the system. JTWC assessed and classified invest area 94W as a subtropical storm as it brushed the southern coast of Honshu. In contrast, the Japan Meteorological Agency (JMA) assessed the system as a tropical cyclone (TC) and issued warnings on the system. JTWC applied lessons learned from this unusual case to improve procedures for describing subtropical systems in operational Significant Tropical Weather Advisories. These improvements included adding a standardized, subtropical system summary section to the text bulletins and annotating subtropical systems on the accompanying large-scale satellite image. These text and graphical product updates are detailed in this report.

Figure 7-1: JMA best track map for subtropical storm 94W (designated by JMA as Tropical Storm Sepat). Image source: Wikipedia summary of 2019 Pacific typhoon season.

Determining cyclone phase

JTWC does not routinely issue tropical cyclone warnings for subtropical/hybrid systems, even if associated maximum sustained wind speeds meet or exceed established TC warning criteria. However, JTWC closely monitors subtropical and hybrid systems for potential transition into a tropical cyclone, and will issue tropical cyclone warnings on subtropical systems if they pose a significant threat to DoD assets or if issuing warnings will facilitate efforts to protect life and property. In those instances, JTWC forecasters describe the subtropical characteristics of the systems in warning remarks and prognostic reasoning discussions. In some cases, designated World Meteorological Organization

Regional Specialized Meteorological Centers (RSMC) may issue tropical cyclone warnings for systems in their respective areas-of-responsibility that JTWC assesses to be subtropical and, therefore, does not coincidentally describe in TC warnings. This was the case for subtropical storm 94W.

JTWC has developed and implemented a robust methodology to assess cyclone phase (i.e., tropical, subtropical and extratropical) and diagnose transitions between phases. Classifying subtropical cyclones is challenging because those systems display characteristics of both tropical and extra-tropical cyclones. Common characteristics of subtropical cyclones include (OFCM 2019):

- Occurrence in regions of weak to moderate horizontal temperature gradient
- Sea surface temperature typically 24-26°C
- Relatively broad zone of maximum winds that is removed from the center, and often a more asymmetric wind field and distribution of convection than a tropical cyclone
- Radius of maximum winds larger than that observed in tropical cyclones, typically > 100 nautical miles from center
- Maximum sustained winds < 64 knots
- Preferential development within certain subtropical geographic areas

Determining cyclone phase – tropical, subtropical or extratropical - can be challenging due to conflicting signals in analysis data. In order to improve the quality and consistency of real-time cyclone phase analyses, JTWC developed an interactive Cyclone Phase Classification Worksheet through a deliberative study of operational practices and datasets, relevant research, and numerous case studies (Kucas et al 2014). This worksheet guides forecaster assessments of various parameters (**Figure 7-2**) to formulate objective cyclone phase recommendations. The Phase Classification Worksheet is particularly useful for analyzing ambiguous structural characteristics that cyclones within the subtropics often present. Duty forecasters regularly apply the worksheet as a primary tool for determining whether or not to classify a cyclone as subtropical.

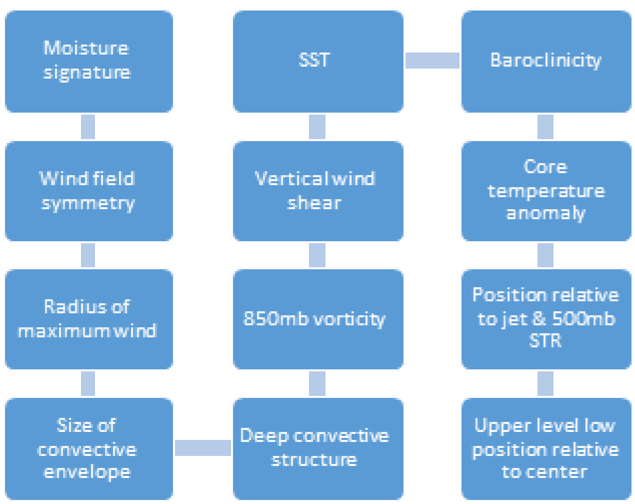


Figure 7-2: Primary parameters of a Cyclone Phase Classification Worksheet analyzed to assess cyclone phase.

While JTWC forecasters apply the Cyclone Phase Worksheet to guide cyclone phase analyses, they routinely assess other datasets to forecast cyclone phase transitions. Cyclone phase space products hosted by Florida State University (Hart 2003) and cyclone storm state predictions included in Statistical-dynamical Hurricane Intensity Prediction System (SHIPS) guidance (CIRA 2021) are two primary tools for predicting phase transition potential. Forecasters also evaluate a wide variety of satellite imagery, observational data and numerical model output fields to determine whether and when a subtropical cyclone may transition into a tropical cyclone, or undergo other types of phase transitions.

Subtropical storm 94W discussion

On 16 June 2019, JTWC began monitoring invest area 94W near Palau. As the disturbance tracked westward and convection flared over the course of the following week, JTWC initially upgraded the area's development potential in the ABPW bulletin to "low" and then to "medium." However, forecasters subsequently downgraded development potential to "low" as the system failed to consolidate (**Figure 7-3**) within an unfavorable upper-level environment characterized by moderate vertical wind shear.

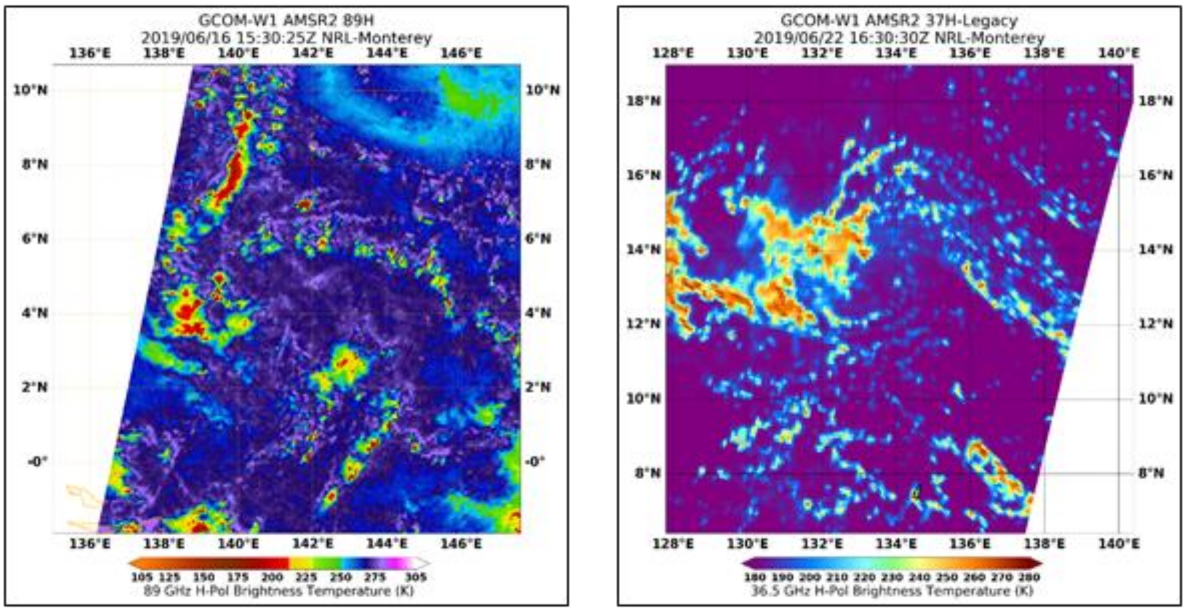


Figure 7-3: AMSR2 microwave sensor satellite imagery (89 GHz and 37 GHz) of invest area 94W from 16 June 2019 (left) and 22 June 2019 (right). The invest area's structure changed little during this period as unfavorable upper-level conditions inhibited development (Image sources: NRL).

On 24 June, as invest 94W passed east of Luzon, JTWC once again upgraded the disturbance's development potential to "medium" based on its consolidating convective signature (**Figure 7-4**) and global model forecasts that favored modest development.

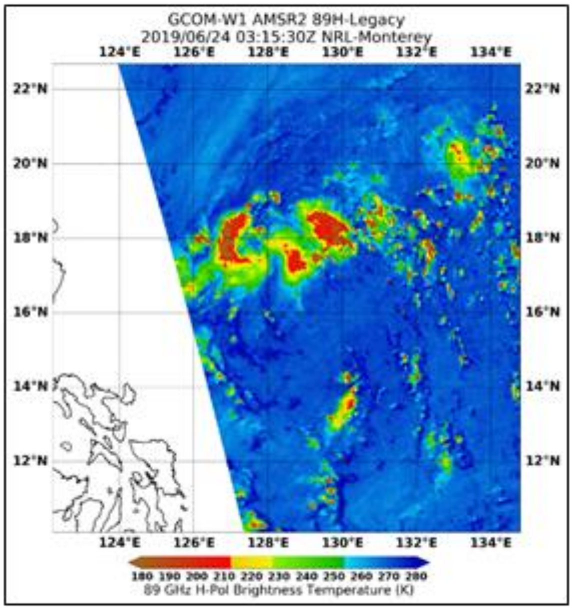


Figure 7-4: AMSR2 microwave sensor satellite image (89 GHz) from 24 June 2019. Consolidating convection supported an upgrade in the forecaster-assessed development potential classification to medium (Image source: NRL).

On 25 June, JTWC upgraded 94W's development potential to high and issued a Tropical Cyclone Formation Alert (TCFA). The TCFA remarks noted a complex environment and the disturbance's hybrid/subtropical characteristics.

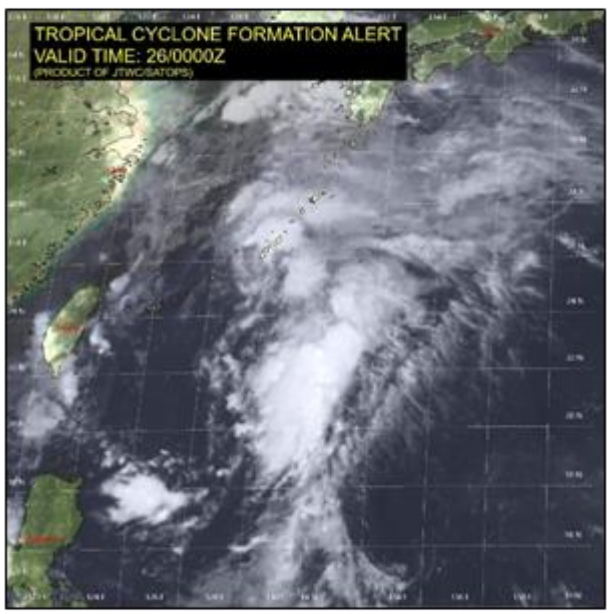


Figure 7-5: Satellite imagery associated with 94W's second TCFA message.

The system failed to consolidate into a tropical cyclone as it increasingly adopted subtropical characteristics, including an asymmetric wind field, large radius of max winds (> 100 nm), shortwave trough interaction and moderate to high vertical wind shear (15-25 knots). **Figures 7-6 through 7-8** highlight some of the key characteristics that supported the forecasters' cyclone phase assessments. Despite the lack of consolidation and subtropical characteristics, JTWC re-issued the TCFA for invest 94W on 26 June due to operational concerns.

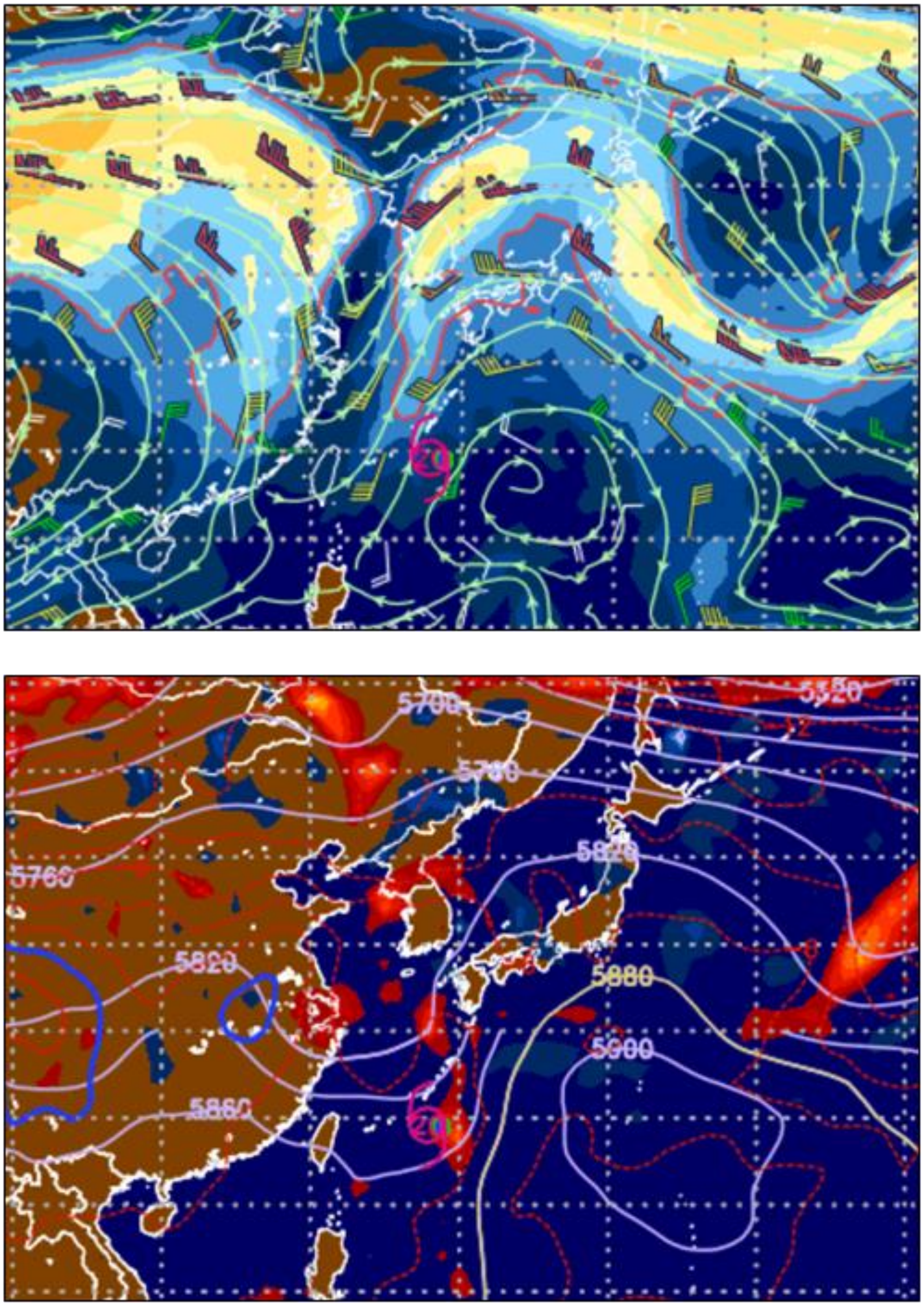


Figure 7-6: GFS 200mb streamlines and isotachs (kts) (top image) and GFS 500mb heights/relative vorticity/temperature (C) (bottom image) analysis fields from 26 June 2019 at 1200Z, depicting Subtropical Storm 94W's position along the eastern edge of a deep subtropical shortwave trough situated over the East China Sea.

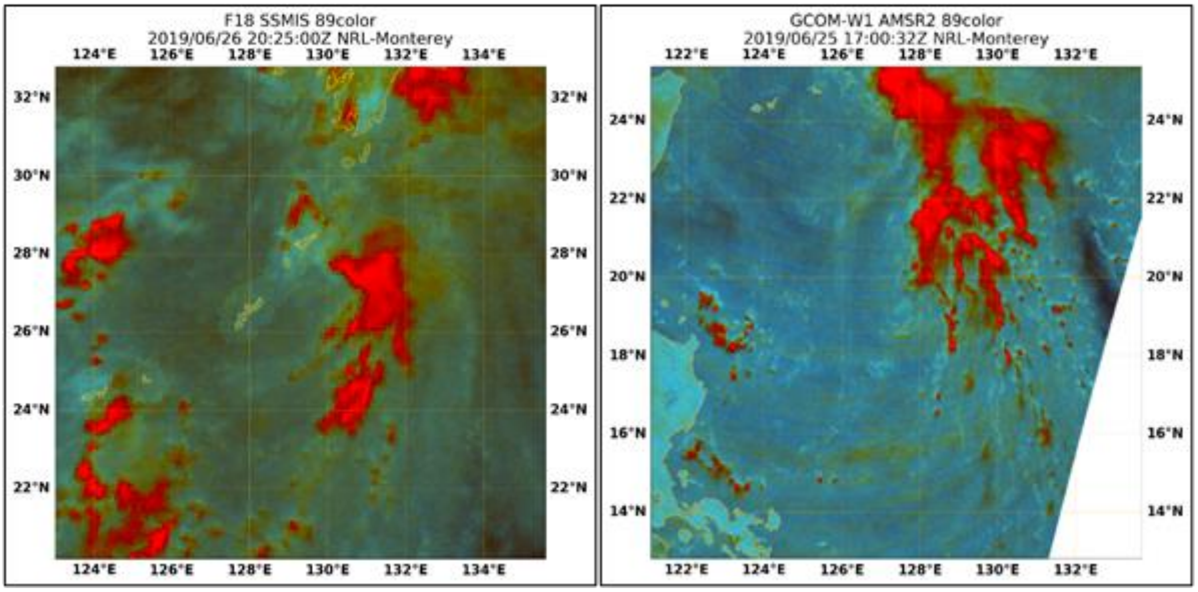


Figure 7-7: GCOM-W1 AMSR 89 GHz and F18 SSMIS 89 GHz images showing asymmetric deep convective bands displaced over the eastern semicircle with a broad exposed low-level circulation center (Image sources: NRL).

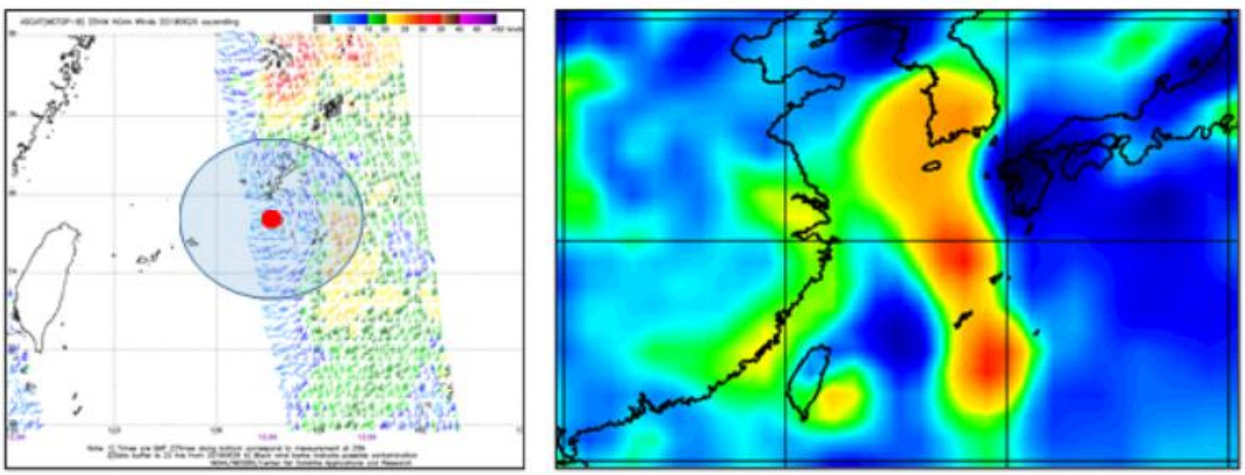


Figure 7-8: 26 June 2019, 1259Z ASCAT-B image (left) depicting an asymmetric wind field with an elongated circulation and enhanced southerly flow at 25-30 knots (Image source: NESDIS). Coincident 26 June 2019, 1200Z 850mb relative vorticity image (right) showing a linear band of cyclonic vorticity encompassing invest 94W (Image source: CIMSS). The best track at 26 June 2019, 1200Z was positioned at 24.6N 127.9E (denoted by red dot in ASCAT image).

On 27 June, JMA briefly classified invest 94W as a tropical storm (TS Sepat) with a peak intensity of 75km/h, or approximately 40 kts, before redesignating the system as an extratropical low shortly thereafter. JTWC also canceled the TCFA for 94W on 27 June as the system embedded in a 500 mb trough and became clearly extratropical. JTWC closed invest 94W two days later, when the low-level circulation was no longer trackable.

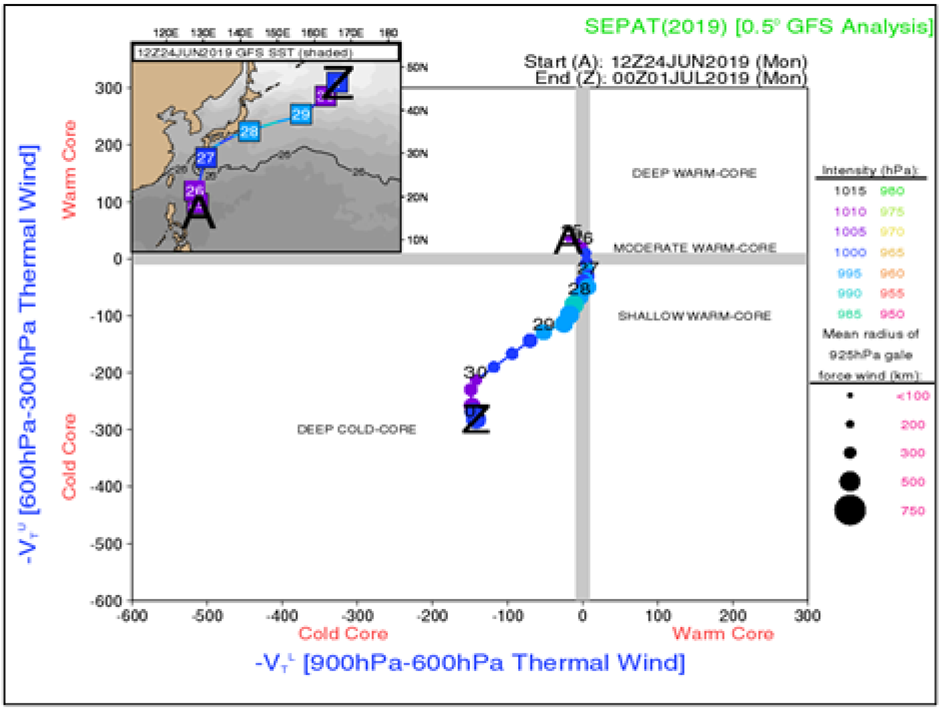


Figure 7-9: Florida State University GFS phase space evolution from 24 June 2019, 1200Z through 01 July 2019, 0000Z showing a hybrid circulation straddling the shallow warm-core and deep cold-core categories starting around 26 June 2019, 0000Z, before fully transitioning to cold core cyclone after 28 June 2019, 0000Z.

Subtropical system: New operational procedures

In October 2019, JTWC modified the format of Significant Tropical Weather Advisories (ABPW and ABIO analysis bulletins) and accompanying satellite images to specifically annotate subtropical systems and provide additional clarity to the organization's customers, particularly for situations in which the WMO RSMC issues warnings for subtropical systems and JTWC does not. With this update, JTWC added a subtropical system subsection (subsection c) to the bulletins. Subsection c details the characteristics of current subtropical systems observed within the JTWC AOR, and describes their potential to transition into TCs. TC development potential characterizations for subtropical systems are as follows:

- Low: If subtropical system is unlikely to transition into a significant TC (i.e., a TC that meets or exceeds established warning criteria) within 24 hours - regardless of the subtropical system's current maximum sustained wind speed - the potential for development of a significant TC shall be classified as "low" in subsection (c) on the appropriate Significant Tropical Weather Advisory Bulletin.
- Medium: If a subtropical system is likely to transition to a TC, but after 24 hours have passed, TC development potential shall be classified as "medium."
- High: If a subtropical system is expected to transition into a significant TC within 24 hours, TC development potential shall be classified as "high" and JTWC will issue a TCFA.

Within subsection (c) of the ABIO and ABPW bulletins, forecasters accurately describe the wind fields and maximum sustained wind speeds associated with subtropical systems, which can exceed tropical cyclone warning thresholds of 25 knots in the western North Pacific and 35 knots in the North Indian Ocean and Southern Hemisphere basins. Subtropical cyclones with maximum sustained wind speeds that meet or exceed typical warning thresholds must be discussed on the ABPW/ABIO regardless of their potential to transition into a tropical cyclone. Subtropical system summaries also refer to Fleet Weather Center San Diego and other agency warning products that depict gale force winds and elevated seas that may associated with subtropical systems. Additionally, JTWC annotates all subtropical systems discussed in subsections (c) of the ABPW and ABIO bulletins with a cyan circle on accompanying satellite images.

The following ABPW/ABIO bulletin examples, corresponding to the 0330Z analysis time on 26 June, illustrate changes in format that accompanied the incorporation of a subtropical system summary. The OLD ABPW/ABIO Format bulletin example is a real-time bulletin describing subtropical system 94W, and the NEW ABPW/ABIO Format bulletin example shows how the same information would be presented in the new format. Text added to the new format bulletin is highlighted. As previously discussed, JTWC had extended the TCFA for invest 94W cited in these bulletins based on operational concerns rather than the meteorological assessment, which clearly favored subtropical development. Had JTWC issued TC warnings in this case, those warnings would have clearly annotated the system's subtropical structure.

OLD ABPW/ABIO Format

```
ABPW10 PGTW 260330
MSGID/GENADMIN/JOINT TYPHOON WRNCEN PEARL HARBOR HI//
SUBJ/SIGNIFICANT TROPICAL WEATHER ADVISORY FOR THE WESTERN AND
/SOUTH PACIFIC OCEANS REISSUED/260330Z-260600ZJUN2019//
RMKS/
1. WESTERN NORTH PACIFIC AREA (180 TO MALAY PENINSULA):
   A. TROPICAL CYCLONE SUMMARY: NONE.
   B. TROPICAL DISTURBANCE SUMMARY:
      (1) THE AREA OF CONVECTION (INVEST 94W) PREVIOUSLY LOCATED
NEAR 18.2N 126.5E, IS NOW LOCATED NEAR 20.7N 128.2E, APPROXIMATELY
```

```
384 NM SOUTH OF KADENA AB, OKINAWA. ANIMATED MULTISPECTRAL SATELLITE
IMAGERY AND A 252117Z SSMIS 91GHZ MICROWAVE IMAGE DEPICT A BROAD,
DISORGANIZED LOW LEVEL CIRCULATION (LLC) WITH DEEP CONVECTION TO THE
NORTHEAST. A 251320Z METOP-B ASCAT PASS SHOWED WEAK, DISORGANIZED
WINDS IN THE VICINITY OF THE BEST TRACK POSITION. UPPER-LEVEL
ANALYSIS INDICATES A MARGINAL ENVIRONMENT WITH MODERATE (20 TO 25
KNOT) VERTICAL WIND SHEAR, STRONG POLEWARD OUTFLOW DUE TO THE JET
LOCATED TO THE NORTH, AND WARM (28 TO 30 CELSIUS) SEA SURFACE
TEMPERATURES (SSTS). HOWEVER, THE SYSTEM ALREADY LOOKS SUBTROPICAL
WITH A COMMA CLOUD STRUCTURE, CONVECTION DISPLACED TO THE NORTH AND
EAST, ELONGATING LOW LEVEL CIRCULATION CENTER, AND A WEAK TO NEUTRAL
WARM CORE TEMPERATURE ANOMALY. GLOBAL MODELS ARE IN GOOD AGREEMENT
THAT 94W WILL TRACK NORTHWARD NEAR OKINAWA WITHIN THE NEXT 2 DAYS.
THE SYSTEM WILL INTERACT WITH A SHARP, DEEP SHORTWAVE TROUGH OVER
THE EAST CHINA SEA IN THE NEXT SEVERAL DAYS, AND WILL ALSO BE MOVING
INTO A REGION OF COOLER SSTS AND UNDER THE WESTERLY MIDLATITUDE JET,
FACILITATING EXTRATROPICAL TRANSITION. SO, WHILE 94W MAY DEVELOP A
STRONG WIND FIELD, WITH WINDS PARTICULARLY ENHANCED TO THE EAST DUE
TO GRADIENT FLOW, IT WILL NOT BE A TROPICAL SYSTEM. MAXIMUM
SUSTAINED SURFACE WINDS ARE ESTIMATED AT 18 TO 23 KNOTS. MINIMUM SEA
LEVEL PRESSURE IS ESTIMATED TO BE NEAR 1004 MB. THE POTENTIAL FOR
THE DEVELOPMENT OF A SIGNIFICANT TROPICAL CYCLONE WITHIN THE NEXT 24
HOURS REMAINS HIGH. SEE REF A (WTPN21 PGTW 260200) FOR FURTHER
DETAILS.
      (2) NO OTHER SUSPECT AREAS.
2. SOUTH PACIFIC AREA (WEST COAST OF SOUTH AMERICA TO 135 EAST):
   A. TROPICAL CYCLONE SUMMARY: NONE.
   B. TROPICAL DISTURBANCE SUMMARY: NONE.
3. JUSTIFICATION FOR REISSUE: REISSUED TCFA IN PARA 1.B.(1).//
NNNN
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NEW ABPW/ABIO Format

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ABPW10 PGTW 260330
MSGID/GENADMIN/JOINT TYPHOON WRNCEN PEARL HARBOR HI//
SUBJ/SIGNIFICANT TROPICAL WEATHER ADVISORY FOR THE WESTERN AND
/SOUTH PACIFIC OCEANS REISSUED/260330Z-260600ZJUN2019//
RMKS/
1. WESTERN NORTH PACIFIC AREA (180 TO MALAY PENINSULA):
   A. TROPICAL CYCLONE SUMMARY: NONE.
   B. TROPICAL DISTURBANCE SUMMARY: NONE.
   C. SUBTROPICAL SYSTEM SUMMARY:
 (1) THE AREA OF CONVECTION (INVEST 94W) PREVIOUSLY LOCATED
NEAR 18.2N 126.5E, IS NOW LOCATED NEAR 20.7N 128.2E, APPROXIMATELY
384 NM SOUTH OF KADENA AB, OKINAWA. THE SYSTEM IS CURRENTLY CLASSIFIED
AS A SUBTROPICAL DISTURBANCE, GENERALLY CHARACTERIZED AS HAVING BOTH TROPICAL AND MID-LATITUDE
CYCLONE FEATURES. ANIMATED MULTISPECTRAL SATELLITE IMAGERY AND A 252117Z SSMIS 91GHZ MICROWAVE
IMAGE DEPICT A BROAD, DISORGANIZED LOW LEVEL CIRCULATION (LLC) WITH DEEP CONVECTION TO THE
NORTHEAST. A 251320Z METOP-B ASCAT PASS SHOWED WEAK, DISORGANIZED WINDS IN THE VICINITY OF THE
BEST TRACK POSITION. UPPER-LEVEL ANALYSIS INDICATES A MARGINAL ENVIRONMENT WITH MODERATE (20
TO 25 KNOT) VERTICAL WIND SHEAR, STRONG POLEWARD OUTFLOW DUE TO THE JET
 LOCATED TO THE NORTH, AND WARM (28 TO 30 CELSIUS) SEA SURFACE TEMPERATURES (SSTS). THE
SYSTEM IS EXHIBITING A COMMA CLOUD STRUCTURE, WITH CONVECTION DISPLACED TO THE NORTH AND EAST,
ELONGATING THE LOW LEVEL CIRCULATION CENTER, AND A WEAK TO NEUTRAL WARM CORE TEMPERATURE
ANOMALY. GLOBAL MODELS ARE IN GOOD AGREEMENT THAT 94W WILL TRACK NORTHWARD NEAR OKINAWA WITHIN
THE NEXT 2 DAYS. THE SYSTEM WILL INTERACT WITH A SHARP, DEEP SHORTWAVE TROUGH OVER THE EAST
CHINA SEA IN THE NEXT SEVERAL DAYS, AND WILL ALSO BE MOVING INTO A REGION OF COOLER SSTS AND
UNDER THE WESTERLY MIDLATITUDE JET, FACILITATING EXTRATROPICAL TRANSITION. SO, WHILE 94W MAY
DEVELOP A STRONG WIND FIELD, WITH WINDS PARTICULARLY ENHANCED TO THE EAST DUE TO GRADIENT
FLOW, IT WILL NOT BE A TROPICAL SYSTEM. MAXIMUM SUSTAINED SURFACE WINDS ARE ESTIMATED AT 18 TO
```

```
23 KNOTS. MINIMUM SEA LEVEL PRESSURE IS ESTIMATED TO BE NEAR 1004 MB. FOR HAZARDS AND
WARNINGS, REFERENCE THE FLEET WEATHER CENTER SAN DIEGO HIGH WINDS AND SEAS PRODUCT OR REFER TO
LOCAL WMO DESIGNATED FORECAST AUTHORITY. THE POTENTIAL FOR THE DEVELOPMENT OF A SIGNIFICANT
TROPICAL CYCLONE WITHIN THE NEXT 24 HOURS REMAINS HIGH. SEE REF A (WTPN21 PGTW 260200) FOR
FURTHER DETAILS.
       (2) NO OTHER SUBTROPICAL SYSTEMS.
 2. SOUTH PACIFIC AREA (WEST COAST OF SOUTH AMERICA TO 135 EAST):
    A. TROPICAL CYCLONE SUMMARY: NONE.
    B. TROPICAL DISTURBANCE SUMMARY: NONE.
    C. SUBTROPICAL SYSTEM SUMMARY: NONE.//
 NNNN
```

JTWC marks invests described in the ABPW/ABIO bulletins' subtropical system summary sections with cyan circles on the accompanying satellite images. As with tropical invests, the color of the subtropical system's invest number text (yellow, orange, or red) corresponds to the forecaster-designated tropical cyclone development potential ("low," "medium" or "high"). **Figure 7-10** shows the annotations that JTWC includes on ABPW/ABIO satellite images to mark both subtropical and tropical invest areas described in the bulletins.

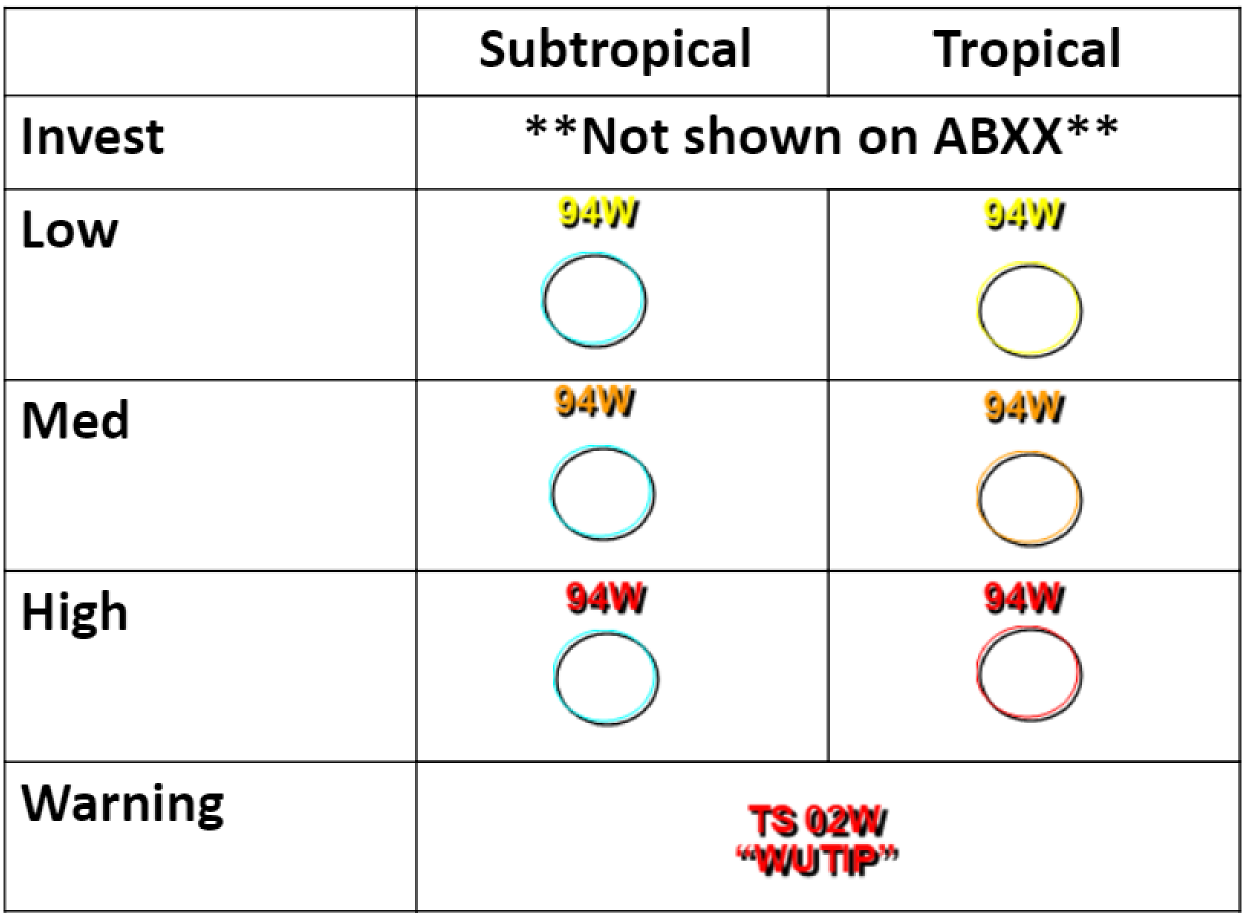

Figure 7-10: An invest can transition through low, medium and high and/or subtropical low, subtropical medium and subtropical high development classification levels before potentially developing or transitioning into a tropical cyclone. Cyan rings on ABPW/ABIO satellite images indicate that an invest is a subtropical system, but the associated invest label text color indicates the development classification level – "low," "medium" or "high" – as it does for tropical invests.

For illustration, **Figure 7-11** shows how subtropical invest 94W was annotated in the 26 June 2019, 0330Z ABPW/ABIO satellite image, and **Figure 7-12** shows how invest 94W would have been annotated in the new format.

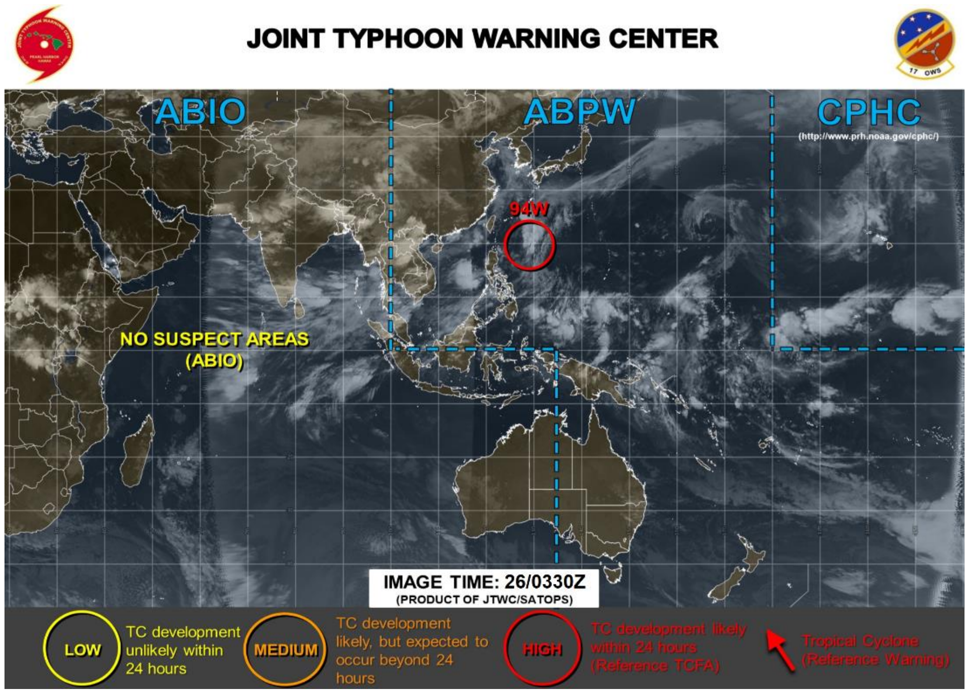

Figure 7-11: ABPW/ABIO satellite image showing subtropical system 94W in the old format, prior to incorporation of the subtropical system summary into the corresponding bulletins.

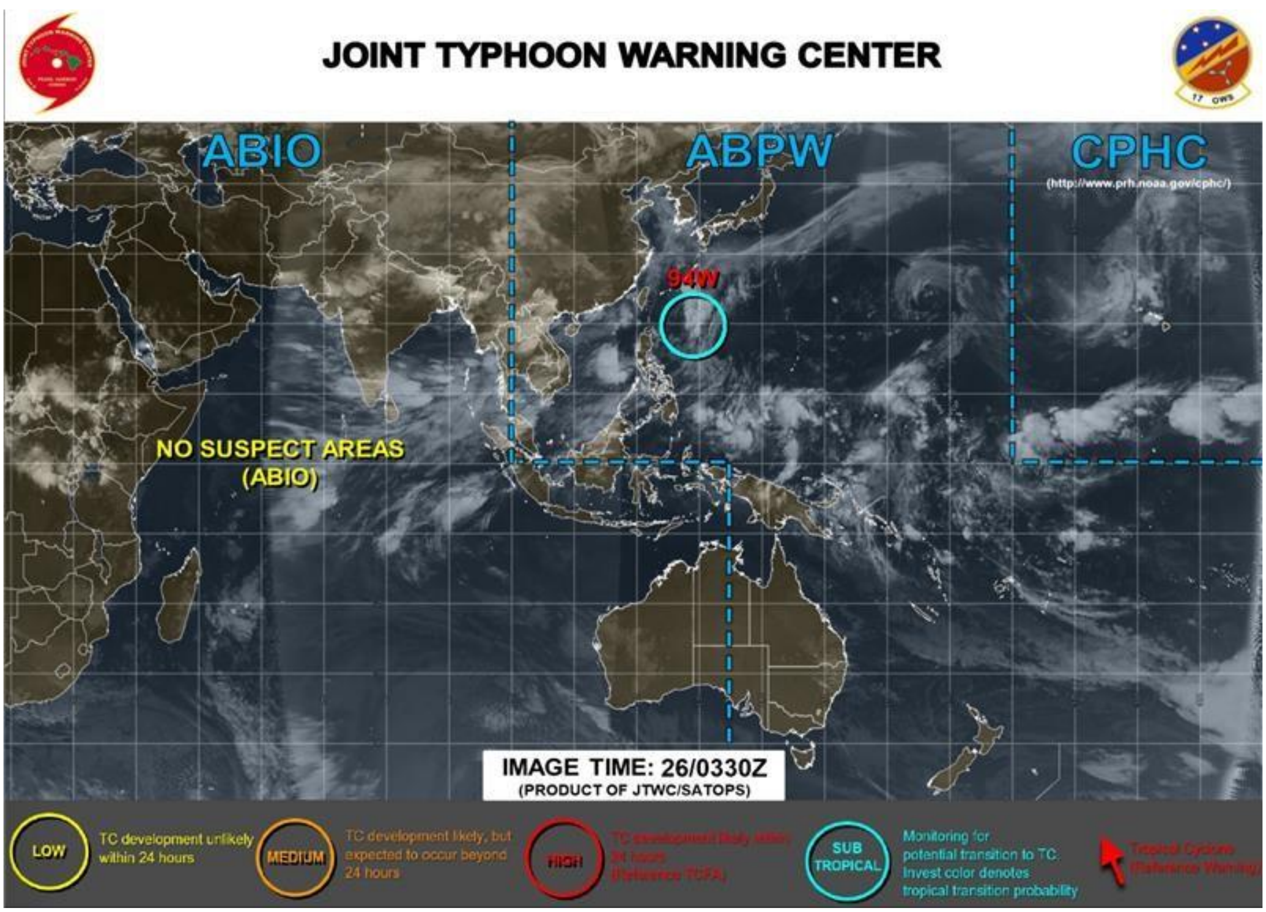

Figure 7-12: ABPW/ABIO satellite image showing subtropical system 94W in the new format, as it would have appeared following incorporation of the subtropical system summary into the corresponding bulletins.

References

CIRA, 2021: Tropical cyclone shear / instability phase space study. Accessed 12 January 2021, http://rammb.cira.colostate.edu/research/tropical_cyclones/tc_phase_space/

Hart R.E., 2003: A cyclone phase space derived from thermal wind and thermal asymmetry. *Mon. Wea. Rev.*, **131**, 585-616.

Kucas, M.E., S.J. Barlow and R.C. Ballucanag, 2014: Subtropical cyclones: Operational practices and analysis methods applied at the Joint Typhoon Warning Center. *31st Conf on Hurricanes and Tropical Meteorology*, San Diego, CA. Amer. Meteor. Soc., 17A.1, https://ams.confex.com/ams/31Hurr/webprogram/Paper245159.html

OFCM, 2019: National hurricane operations plan. Office of the Federal Coordinator for Meteorological Services and Supporting Research Publication FCM-P12-2019, 176 pp. [Available online at https://www.icams-portal.gov/publications/nhop/fcm-p12-2019.pdf].

Section 2 Comparative Review of Landfalling Typhoons 14W (Faxai) & 20W (Hagibis)

Introduction

The rapid changes in convective structure and surface wind fields that typically occur as a landfalling tropical cyclone (TC) interacts with terrain complicate the task of analyzing TC intensity (i.e., maximum sustained wind) and wind fields. Moreover, significant and abrupt changes in TC structure, short-term motion and track speed associated with landfall often contribute uncertainty to TC center position analyses. Similarly, changes in storm structure and motion that occur as a TC interacts with the midlatitude flow during extratropical transition can increase uncertainty in both TC intensity and position analyses. When both landfall and midlatitude flow interactions are at play, forecasting the timing and location of the TC center's closest point of approach (CPA), intensity and local impacts are complex endeavors that require careful scrutiny of storm structure and environmental characteristics on a case-by-case basis. To illustrate these points, this case study examines Typhoon 14W (Faxai) and Super Typhoon 20W (Hagibis), which formed about a month apart in September and October 2019, and exhibited similar recurving tracks over the Kanto Plain. Despite their track similarities, the two systems differed substantially in their size, convective structure and environmental influences.

Typhoon 14W (Faxai) overview

Typhoon (TY) 14W (Faxai) began its life cycle (**Figure 7-13**) as a weak tropical disturbance approximately 800 nautical miles southeast of Wake Island. The disturbance slowly intensified while tracking west-northwestward under the steering influence of a low-layer reflection of the subtropical ridge (STR) to the north. JTWC issued the first warning on Tropical Depression 14W on 01 September 2019 at 1800Z, and the system gradually intensified into a tropical storm by the time it passed just to the southwest of Wake Island 24 hours later. 14W meandered westward to west-northwestward under the steering influence of the STR over the next two days while maintaining its 35-knot intensity. After 1800Z on 04 September, TY 14W turned sharply northwestward and began intensifying at a near-climatological rate of approximately 20 knots per 24 hours.

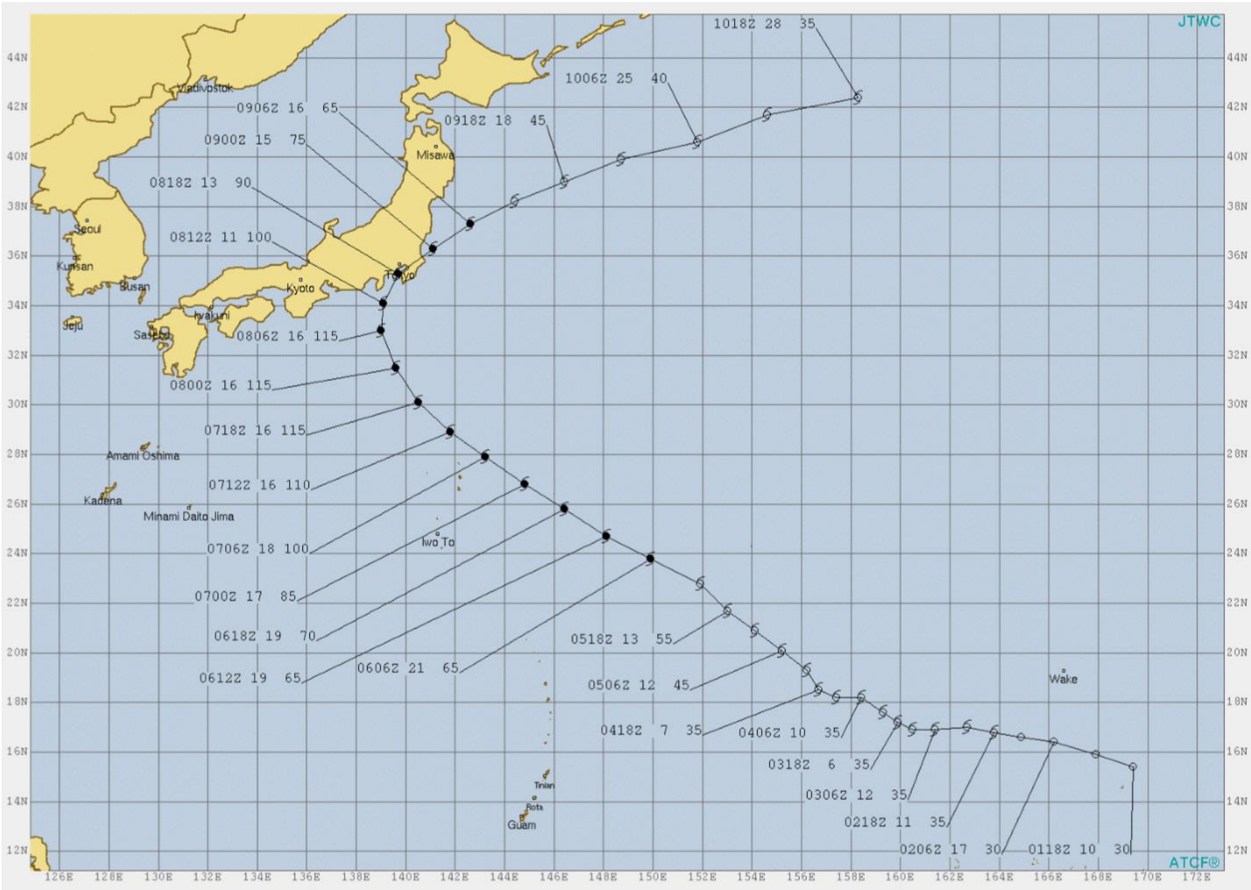

Figure 7-13: TY 14W (Faxai) official best track segment from first warning on 01 September 2019 at 1800Z, southeast of Wake Island, to the final best track position at 10 September 1800Z over the North Pacific Ocean.

14W began to rapidly intensify at 0600Z on 06 September, approximately 480 nm east of Iwo-To. Supported by robust upper-level outflow (**Figure 7-2**) and low to moderate vertical wind shear, TY 14W intensified from 65 knots at 06 September 1200Z to its peak intensity of 115 knots at 07 September 1800Z, an increase of 50 knots over a 30-hour period (**Figure 7-3**).

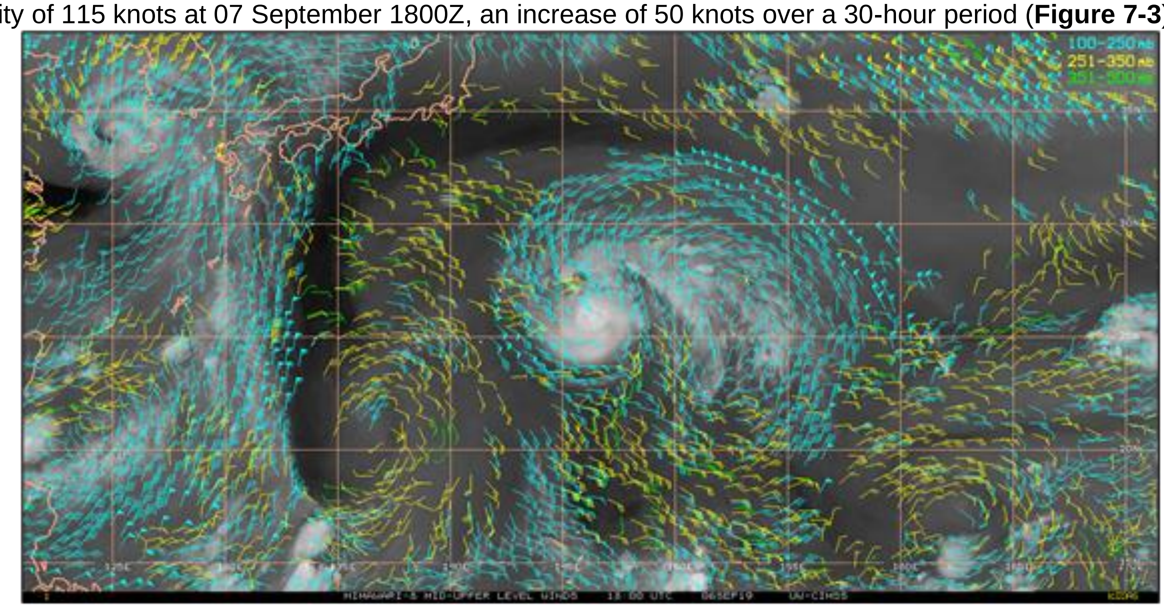

Figure 7-14: Himawari-8 infrared image (06 September 2019 at 1800Z) with derived, upper-level atmospheric motion vector winds. Strong upper-level winds near TY 14W indicate that outflow was robust as the system rapidly intensified. Image source: University of Wisconsin-CIMSS Tropical Cyclones archive.

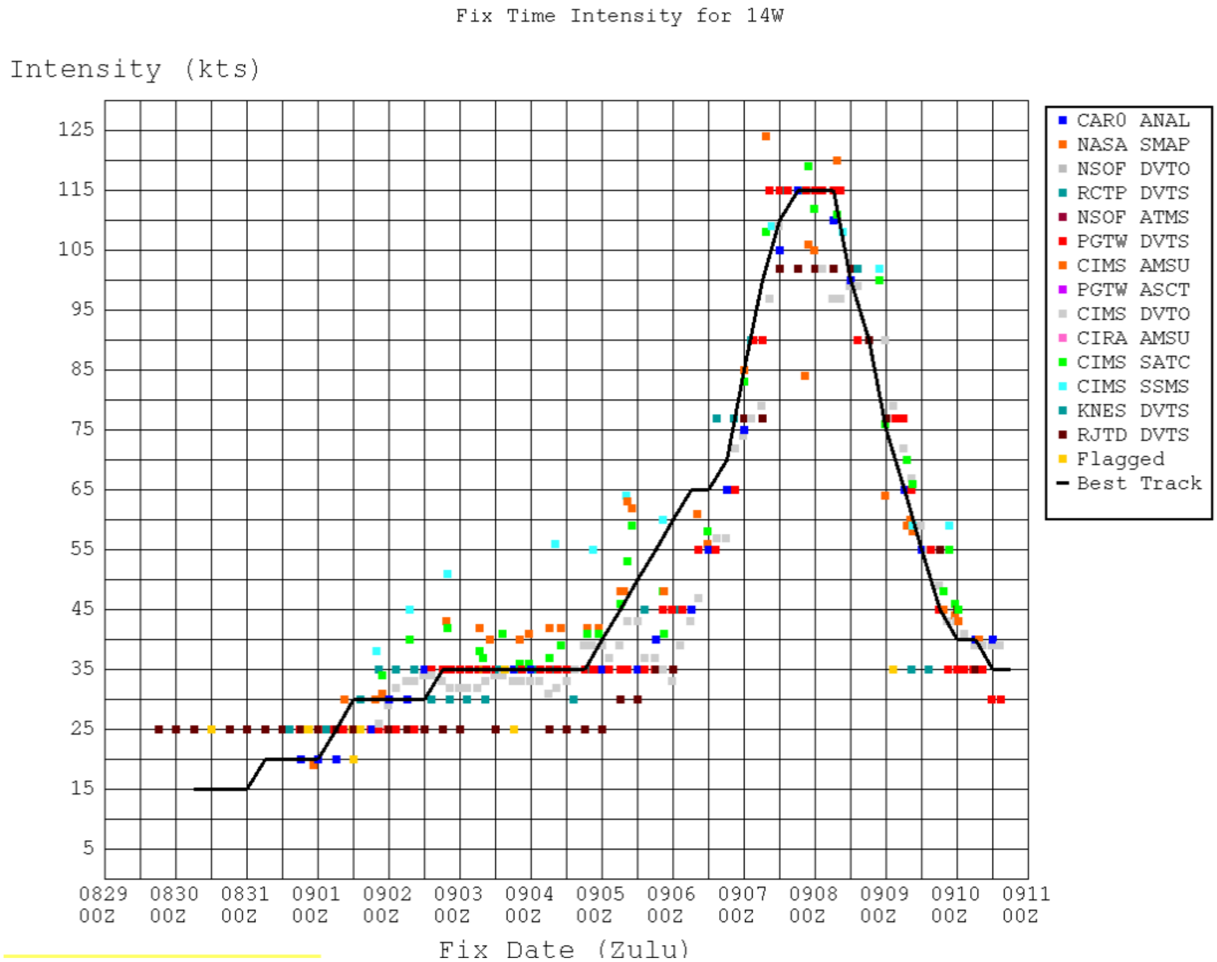

Figure 7-15: Fix Time Intensity plot for TY 14W (Faxai) showing slow initial intensification through 04 September 1800Z, rapid intensification from 06 September 1200Z to 07 September 1800Z, and rapid weakening after 08 September 0600Z, during extratropical transition.

TY 14W's steering and upper-level environment

TY 14W tracked along the southwestern periphery of a broad subtropical ridge, which extended into the Sea of Japan. A deep, short-wave trough at 200mb was situated over Eastern China with strong southwesterly flow present over the Korean Peninsula into Northeast Asia (**Figure 7-16**). In general, environmental conditions remained favorable for development and sustainment with low vertical wind shear and radial outflow, allowing the system to maintain peak intensity for about 12 hours as it neared the STR axis.

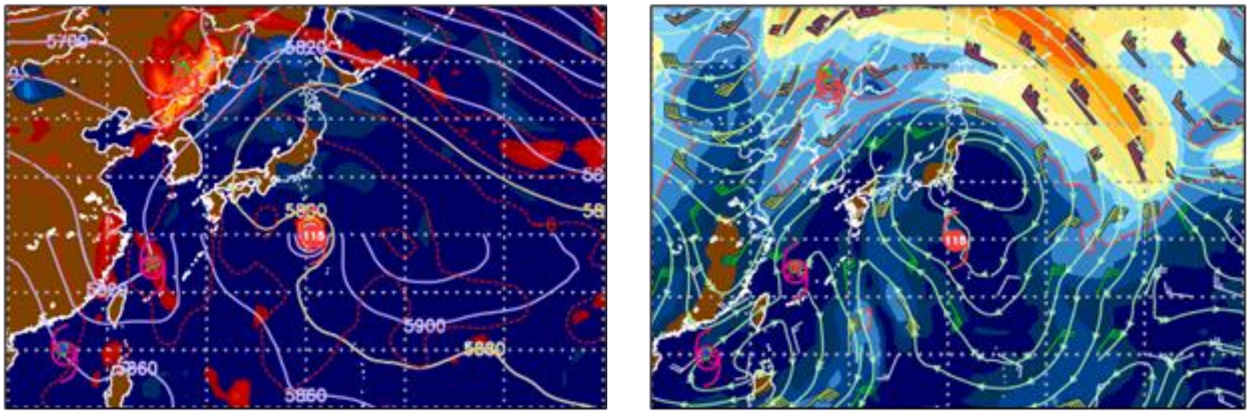

Figure 7-16: GFS 500mb Height / Relative Vorticity (left) and 200mb Streamline and Isotach (right) analyses for 07 September 2019 at 1800Z.

Around 08 September 0600Z, TY 14W tracked poleward along the western periphery of the broad subtropical ridge with favorable upper-level conditions persisting (**Figure 7-17**). Around this time, a 08 September 0431Z GPM 89H GHz microwave image (**Figure 7-31**), showed a compact, well-organized typhoon with tightly-curved banding wrapping into a small microwave eye feature.

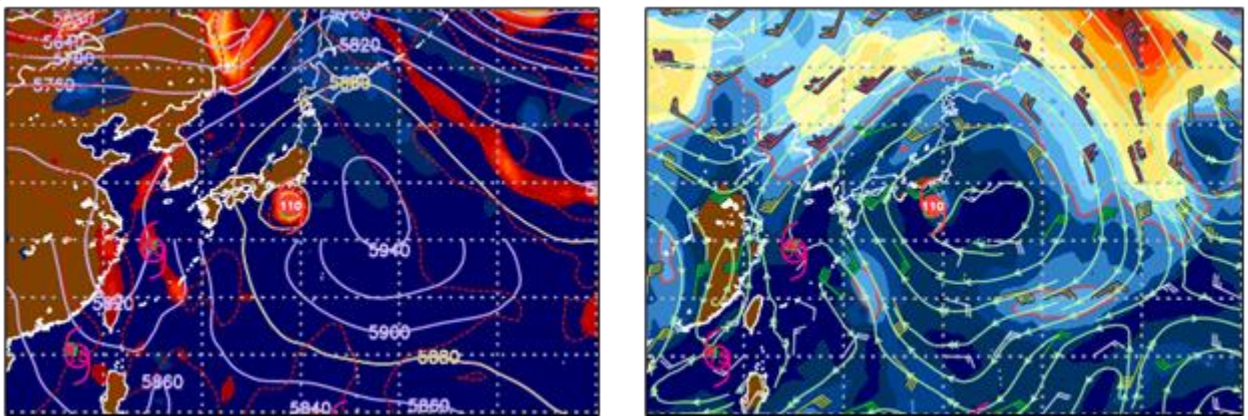

Figure 7-17: GFS 500mb Height / Relative Vorticity (left) and 200mb Streamline and Isotach (right) analyses for 08 September 2019 at 0600Z.

The subtropical steering ridge maintained its overall positioning to the east and northeast of the system through landfall. However, westerlies pushing into the Sea of Japan eroded the northwestern periphery of the subtropical ridge, establishing a steering flow pattern that would drive a tight turn to the east-northeast after 08 September 1200Z. By the time TY 14W tracked directly over U.S. Fleet Activities Yokosuka at 08 September 1800Z, environmental conditions had degraded gradually with upper-level flow data indicating low to moderate (15-20 knots) vertical wind shear offset by enhanced poleward outflow into the midlatitude westerlies (**Figure 7-18**).

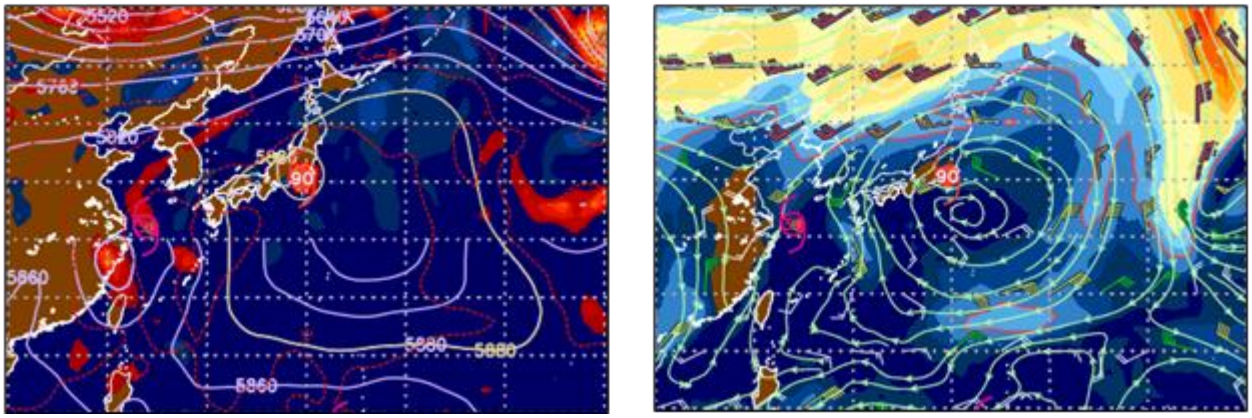

Figure 7-18: GFS 500mb Height / Relative Vorticity (left) and 200mb Streamline and Isotach (right) analyses for 08 September 2019 at 1800Z.

Despite weakening, Faxai was still a very intense 90-knot typhoon when it made landfall over the Kanto Plain on 08 September at 1800Z. The cyclone briefly moved through the Tokyo region before accelerating northeastward and reentering the Pacific Ocean six hours later. TY 14W decayed quickly as it passed over colder waters on the poleward side of the STR. By 10 September at 0000Z, TY 14W began extratropical transition as it merged into the baroclinic zone. By 1800Z, the system had fully transformed into a strong gale-force cold core low with an expanding wind field approximately 800 nm east of Misawa Air Base, Japan.

Super Typhoon 20W (Hagibis) overview

Super Typhoon (STY) 20W (Hagibis) formed as a tropical disturbance south-southwest of Wake Island on 04 October 2019 (**Figure 7-19**). On 05 October at 0600Z, JTWC issued the first warning on the system, which quickly intensified into a 35-knot tropical storm by 05 October at 1800Z, under optimal upper-level conditions (**Figure 7-20**). Hagibis then began a remarkable period of sustained rapid intensification as it tracked westward toward the Northern Mariana Islands. Over the next 42 hours, Hagibis intensified 125 knots to a peak of 160 knots (**Figure 7-21**), with 100 knots of that intensification occurring in the span of just 22 hours – a near record-breaking rate. Although this review focuses primarily on the characteristics of TY 14W and STY 20W during or just prior to their respective landfalls over mainland Japan, further discussion of STY 20W's rapid intensification is warranted.

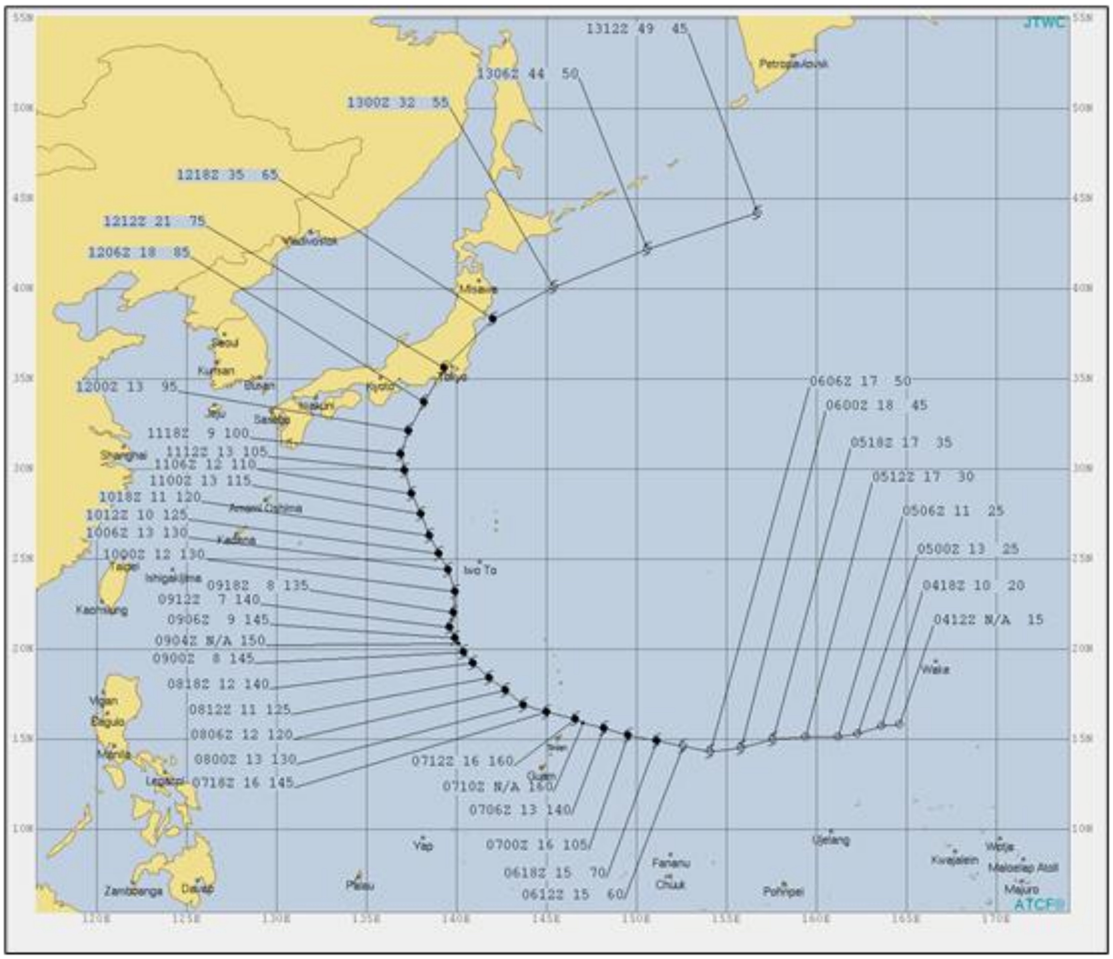

Figure 7-19: STY 20W (Hagibis) official best track from first warning on 04 October at 1200Z to the final best track position on 13 October at 1200Z over the North Pacific Ocean.

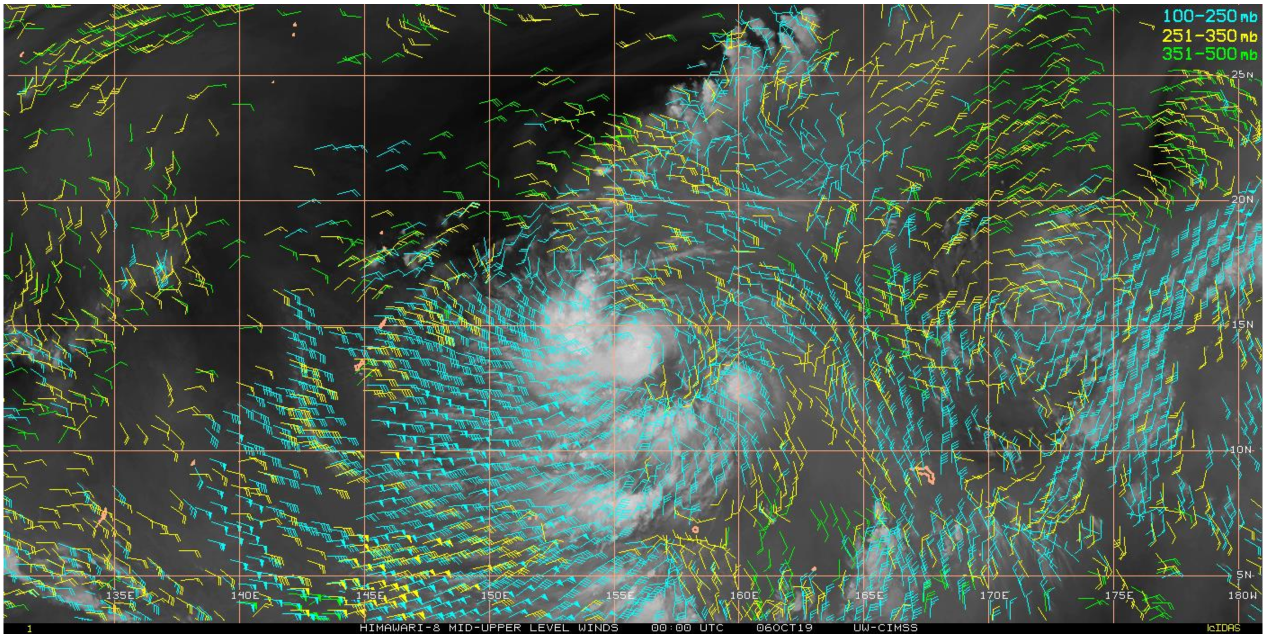

Figure 7-20: Himawari-8 infrared image at 06 October 2019 at 0000Z with derived, upper-level atmospheric motion vector winds. Robust and expansive radial, upper-level outflow drove the rapid intensification phase. Image source: University of Wisconsin-CIMSS Tropical Cyclones archive.

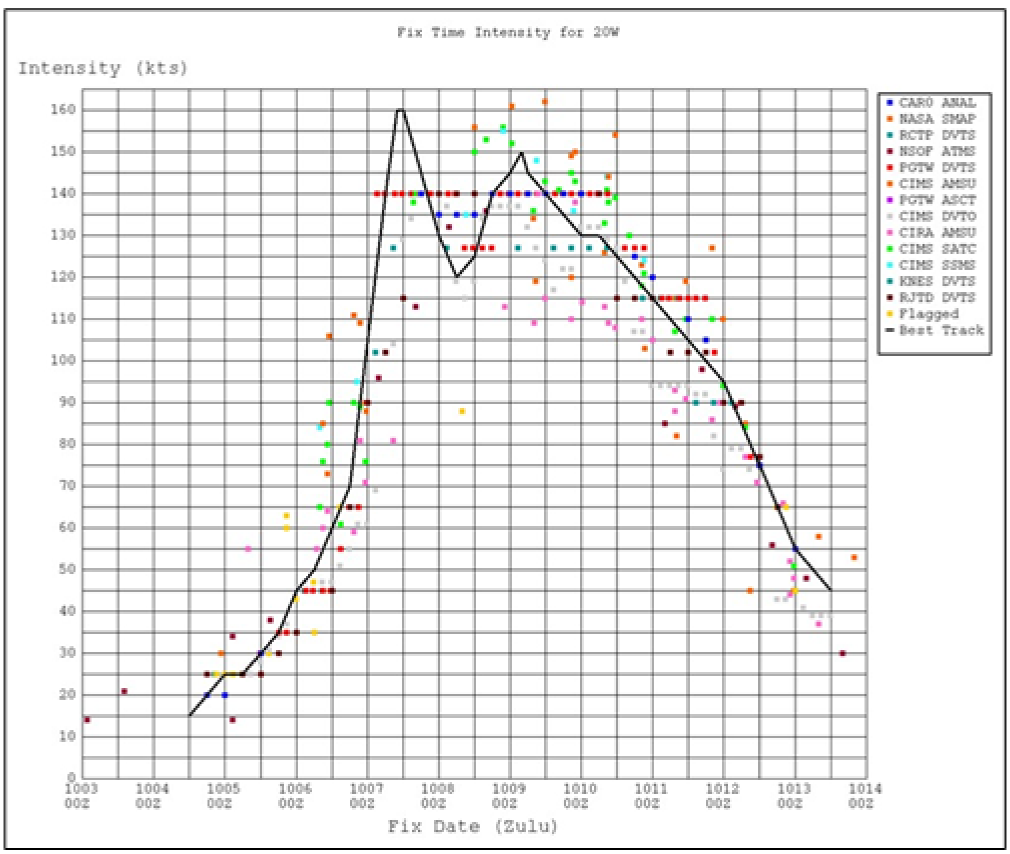

Figure 7-21: Fix time intensity plot for STY 20W (Hagibis) showing rapid intensification through 07 October at 1000Z with a peak intensity of 160 knots, a secondary peak intensity of 150 knots on 09 October at 0400Z, followed by steady weakening during extratropical transition.

STY Hagibis was difficult to analyze in real-time during its explosive deepening, marked by the rapidly evolving presentation in satellite imagery (**Figure 7-22**). Best track intensities for STY Hagibis are derived from various agency subjective Dvorak fixes and from automated intensity estimates, which are calculated from infrared data from geostationary satellites and microwave temperature sounding data from low Earth orbiting satellites. Precise intensities are not verifiable due to a lack of aerial reconnaissance in the western North Pacific. On 06 October at 1200Z, the intensity was initially estimated at 50 knots, but later revised upward to 60 knots during reanalysis. At the time, infrared imagery indicated a center-obscuring Central Dense Overcast feature, but time-delayed microwave imagery revealed tightly-wrapped banding indicative of a well-organized system.

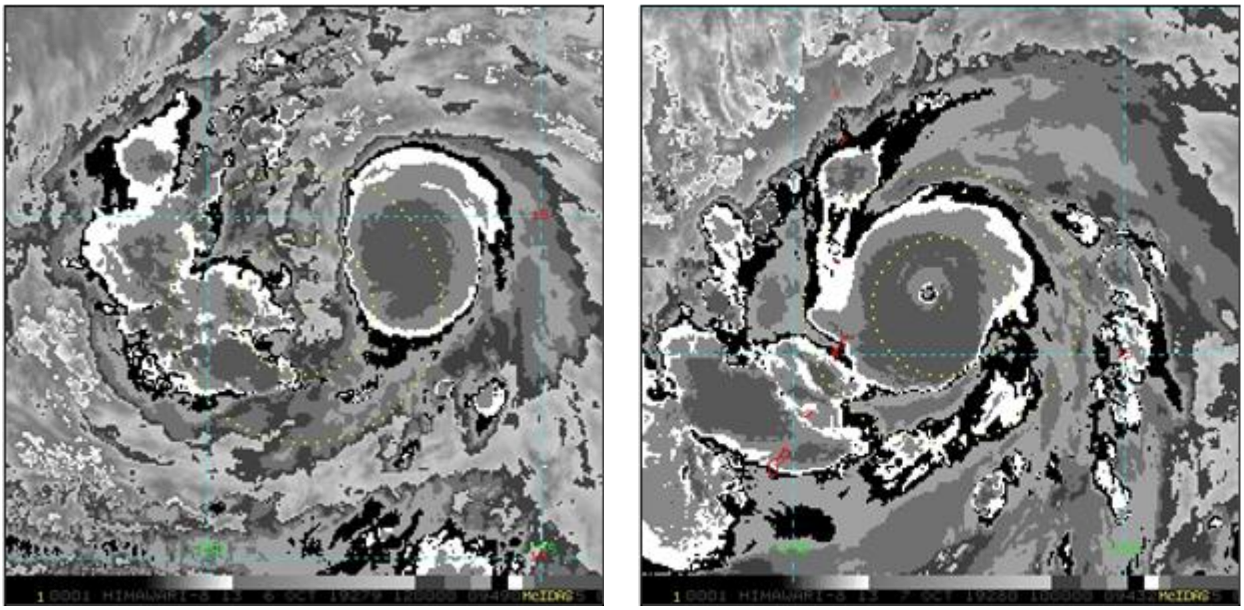

Figure 7-22: Enhanced infrared satellite images from the beginning of the 100-knot RI phase on 06 October 2019 at 1200Z (left) to the peak intensity of 160 knots on 07 October at 1000Z (right). Image source: CIRA RAMMB.

The environment was favorable throughout the period of rapid intensification, with very warm ocean water, low vertical wind shear, and robust equatorward and westward outflow. Agency subjective Dvorak estimates were initially limited by "constraints" inherent in the Dvorak technique, which are representative of climatological rates of convective changes in developing and weakening TCs. The Satellite Consensus (SATCON) method from the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin at Madison initially led the intensification rate (Velden and Herndon 2020). SATCON combines the Advanced Dvorak Technique (ADT- automated analysis of IR imagery) along with several automated analyses of roughly contemporaneous microwave temperature sounding data.

Hagibis began to develop a pinhole eye by 0000Z on 07 October, when JTWC analyzed the intensity at 105 kts. Hagibis reached an estimated peak intensity of 160 knots at 1000Z on 07 October. The peak intensity estimate is based on an after-the-fact, off-cycle subjective Dvorak intensity estimate on visible satellite imagery of T7.5 (155 kts), as well as ADT "raw T-numbers" of T7.8 at 1010Z and 1040Z on 07 October. The temperature difference between the warm eye and coldest cloud top was 93.25 degrees Celsius, which - along with a banding feature - would support a higher estimate using the Dvorak eye technique. Hagibis' extremely warm, pinhole eye and large cross-eye temperature gradient at the peak intensity time indicated a very steep eyewall slope, which is typically associated with more intense systems (Sanabia et al. 2014).

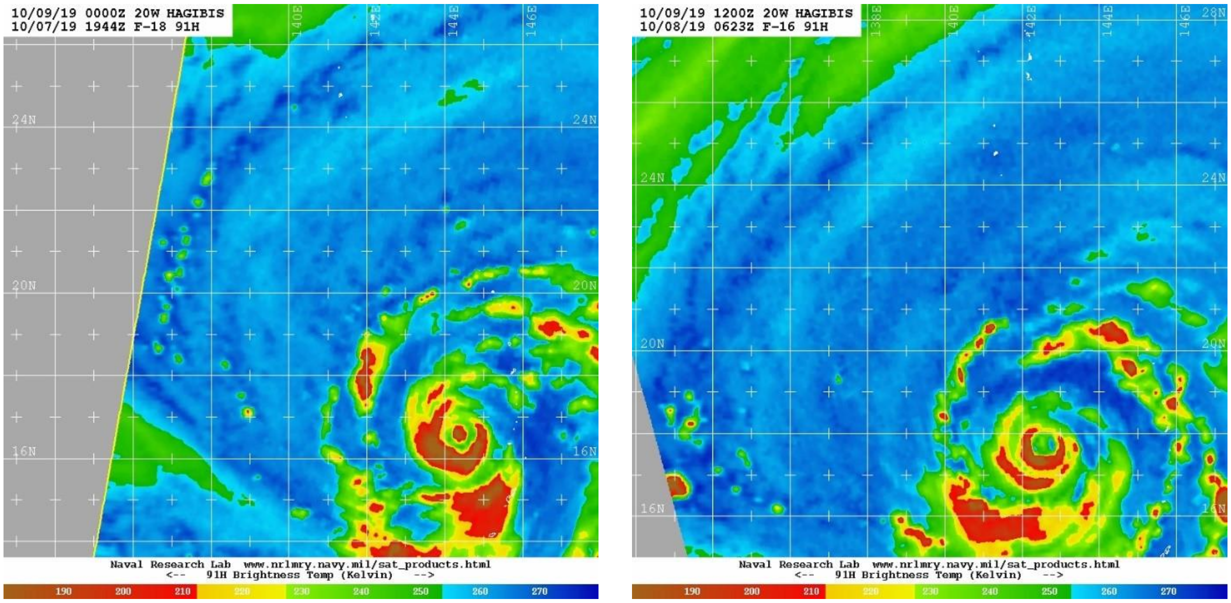

Figure 7-23: Eyewall replacement cycle evident in a 07 October 1944Z SSMIS 91 GHz image (left) and a 08 October 0623Z SSMIS 91 GHz image (right). Image source: Naval Research Laboratory.

Rapid intensification ended when Hagibis began an eyewall replacement cycle, which is evident in a 07 October 1944Z SSMIS 91GHZ microwave image and a 08 October 0623Z SSMIS 91 GHz image (**Figure 7-23**). By 0325Z on 08 October, an AMSR-2 89GHZ microwave image (not shown) indicated that the newly-formed outer eyewall had become the primary eyewall. The new primary eye was cooler within and generally more ragged, resulting in lower multi-agency, subjective and automated intensity estimates. Hagibis' estimated intensity was accordingly lowered to 120 kts at 0600Z on 08 October. As the new eyewall began to contract and the eye warmed again, Hagibis briefly intensified once more to a peak of 150 kts at 04Z on 09 October, before beginning a slow weakening trend as it moved north and the environment became less favorable.

STY 20W's steering and upper-level environment

Following the eyewall replacement cycle described above, STY 20W turned and tracked poleward along the western periphery of a broad, north-south oriented subtropical ridge situated over the western North Pacific Ocean and approached the island of Honshu by 11 October (**Figure 7-24**). Although, the midlatitude westerlies were situated well to the north of the system prior to landfall due to the unusually strong STR, a broad subtropical trough persisted south of Japan. At 200mb, the subtropical trough, with associated strong southerly flow gradually enveloped 20W and eroded much of the deep convection, as depicted in a 11 October 0936Z GPM 89H GHz image (**Figure 7-31**). However, a robust poleward outflow channel offset deleterious convergence aloft and allowed the system to maintain an estimated intensity of 100 knots on 11 October at 1800Z, with extensive spiral banding evident over the northern semicircle.

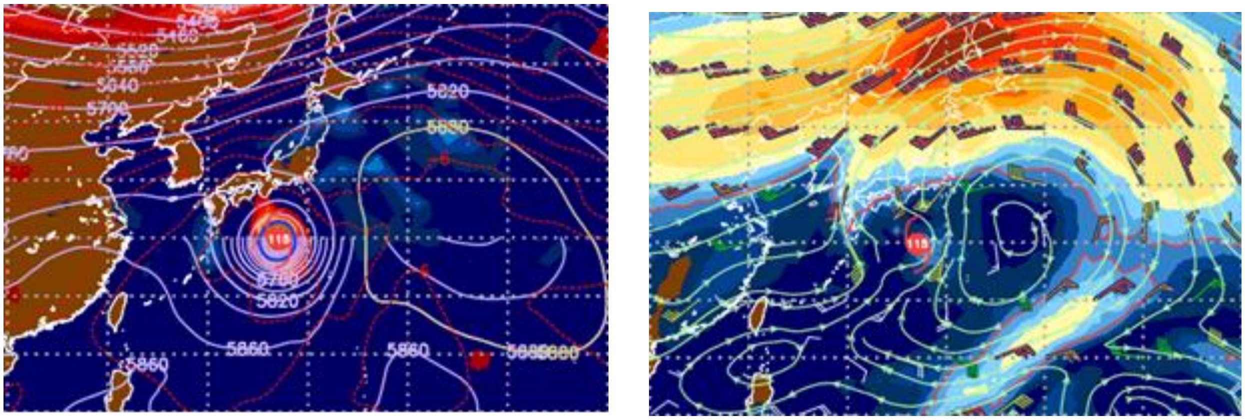

Figure 7-24: GFS 500mb Height / Relative Vorticity (left) and 200mb Streamline and Isotach (right) analyses for 11 October at 1200Z.

By 12 October at 0000Z (**Figure 7-25**), 20W came under the influence of increasing vertical wind shear (20-30 knots) and convergence aloft associated with the subtropical trough deepening south of Japan. At 200mb, the system remained embedded within the trough, under strong southerly flow that drove a steady weakening trend.

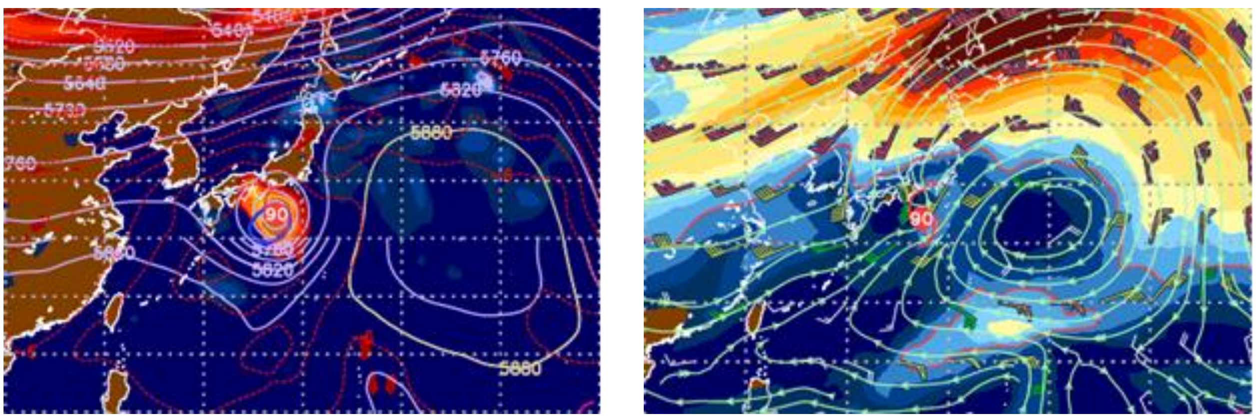

Figure 7-25: GFS 500mb Height / Relative Vorticity (left) and 200mb Streamline and Isotach (right) analyses for 12 October at 0000Z.

Strong vertical wind shear (25-30 knots) induced by enhanced 500 mb flow within the subtropical trough and robust poleward outflow into the jet positioned to the north influenced 20W as it tracked over the Kanto Plain region (**Figure 7-26**). Track speeds increased to 18 to 21 knots as 20W subsequently recurved into the midlatitude westerlies.

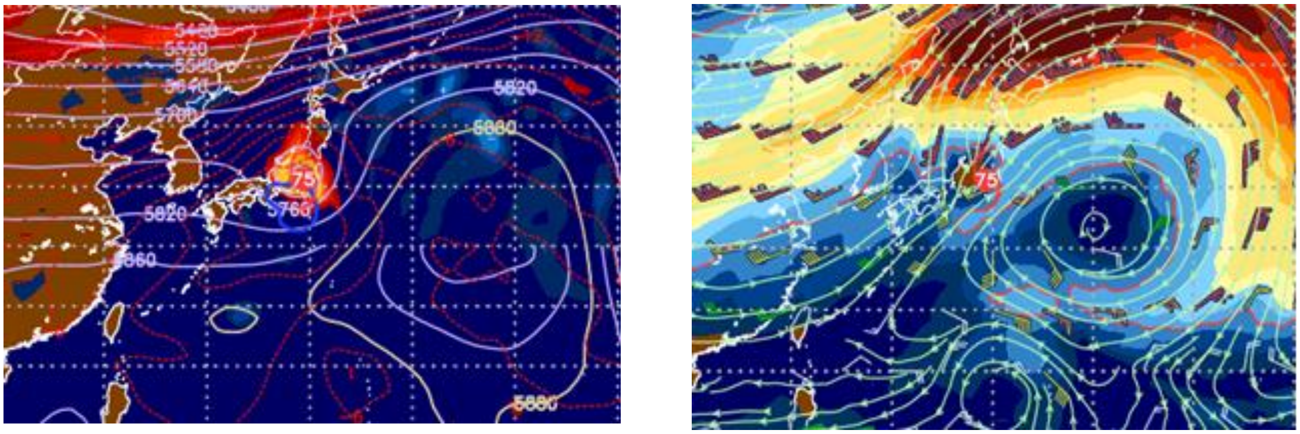

Figure 7-26: GFS 500mb Height / Relative Vorticity (left) and 200mb Streamline and Isotach (right) analyses for 12 October at 1200Z.

Average forecast track error statistics for 14W and 20W

JTWC forecasts for TY 14W consistently indicated a brief landfall near Tokyo as the system recurved to the northeast (**Figure 7-27**). Average JTWC forecast track error (FTE; **Table 7-1**) was less than 120 nm for all extended range (72 to 120 hours) forecast periods. By comparison, average FTE for the 96- and 120-hour forecast error for STY 20W was notably higher (**Table 7-1**), primarily due to a more complex synoptic steering environment and five early 'outlier' JTWC forecasts, which significantly degraded the FTE statistics. Although 20W took a previously unpredicted and short-lived northward jog south of Iwo-To, the bulk of the JTWC forecasts consistently indicated passage over the Kanto Plain Region.

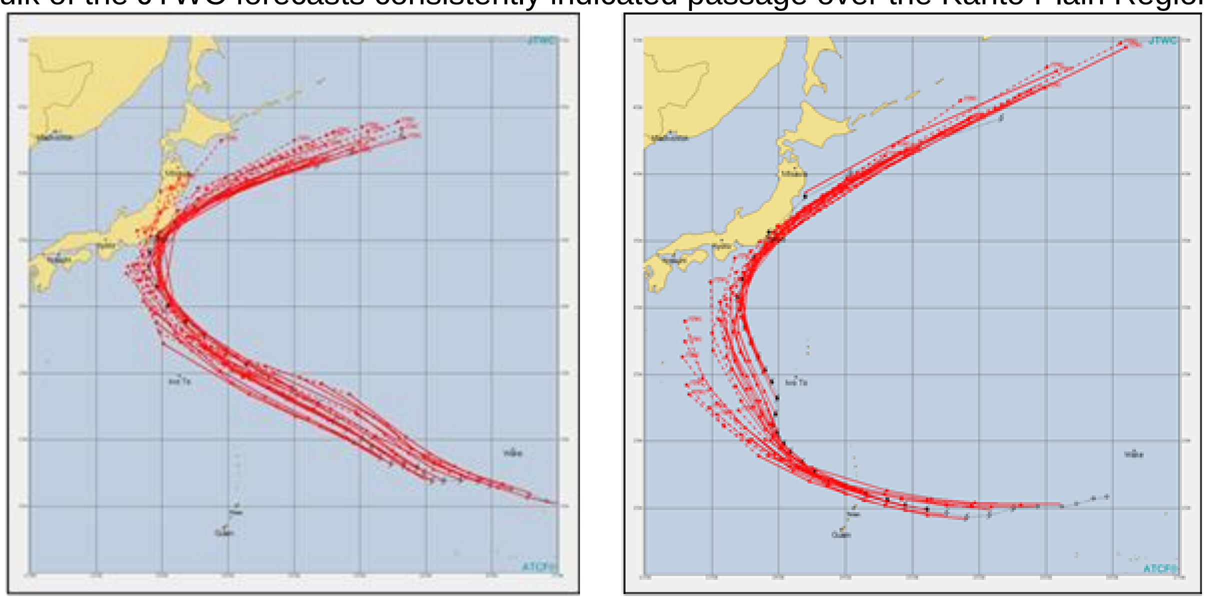

Figure 7-27: JTWC forecasts (red) for 14W (left) and 20W (right) with the verifying JTWC final best tracks (black).

	Tau 24	Tau 36	Tau 48	Tau 72	Tau 96	Tau 120
JTWC (14W)	51.4	76.7	94.8	118.2	110.2	111.8
#CASES	29	27	25	21	17	13
JTWC (20W)	31.2	40.1	55.0	98.3	171.4	272.3
#CASES	27	25	23	19	15	11

Table 7-1: Mean JTWC forecast track error (FTE) statistics for TY 14W and STY 20W.

Overall, CPA forecasts for TY 14W verified well (**Figure 7-28**) with forecasts out to five days falling within +/- 4 hours of the observed CPA time of 08 September 1800Z. The CPA distance forecasts from 05 September at 0600Z, 3.5 days out, were excellent at 30 nm or less.

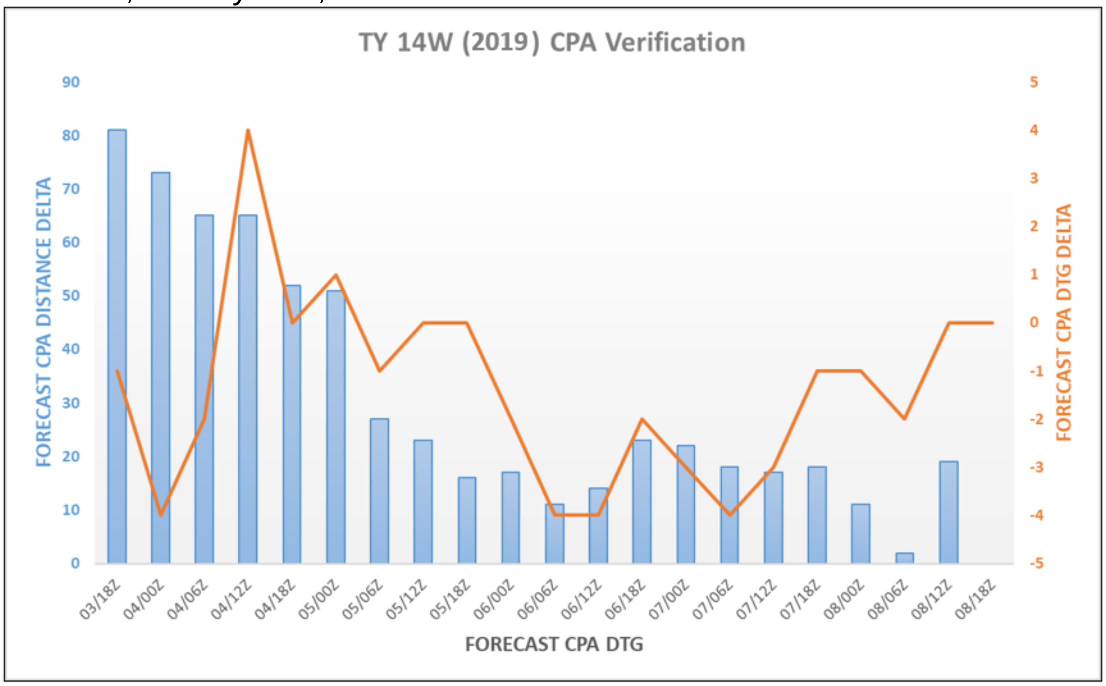

Figure 7-28: TY 14W 'Forecast CPA Distance Delta' (difference between actual CPA distance and forecast CPA distance in nautical miles) and 'Forecast CPA DTG Delta' (difference between observed CPA date/time and forecast date/time in hours) for all JTWC forecasts from 03 September 1800Z through 08 September 1800Z.

CPA forecasts for STY 20W also verified well (**Figure 7-29**), with forecasts out to four and a half days falling within +/- 6 hours of the observed CPA time of 12 September 1200Z. The CPA distance forecasts from 08 September at 0000Z, 4.5 days out, were excellent at 30 nm or less.

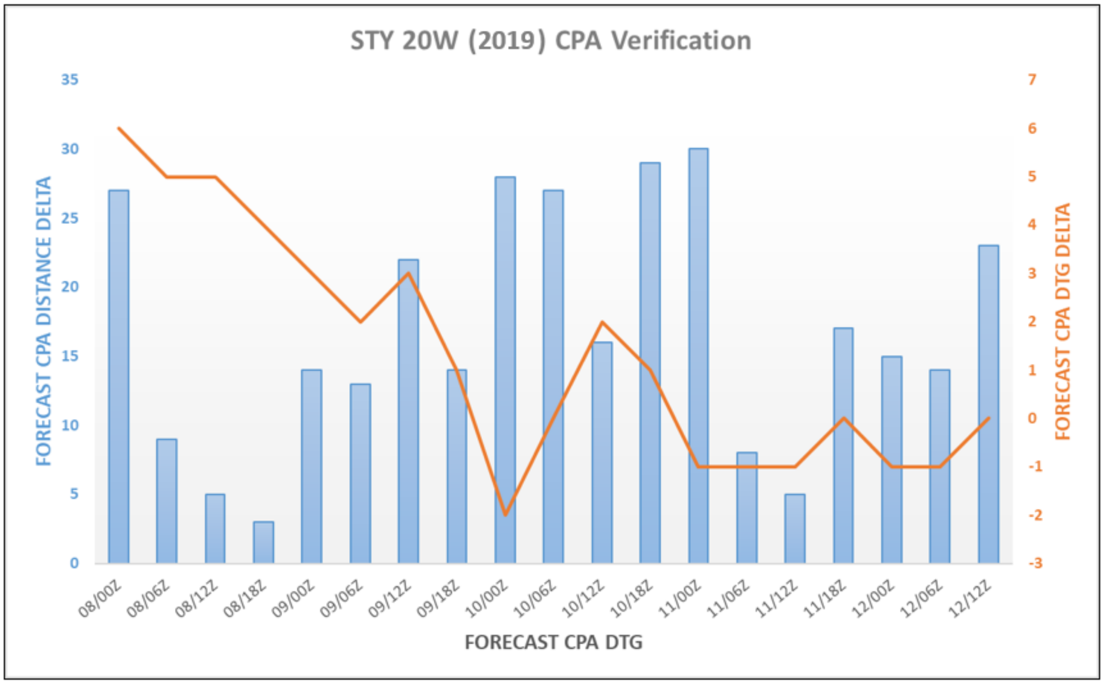

Figure 7-29: STY 20W 'Forecast CPA Distance Delta' (difference between actual CPA distance and forecast CPA distance in nautical miles) and 'Forecast CPA DTG Delta' (difference between actual CPA date/time and forecast date/time in hours) for all JTWC forecasts from 08 October 0000Z through 12 October 1200Z.

Key Structural Differences Between 14W and 20W

Both 14W and 20W produced typhoon-strength winds as they recurved over the Kanto Plain, but there were major differences in their wind fields (**Figure 7-30**) and convective structures (**Figure 7-31**). TY 14W was a small system with 50-knot (storm force) wind radii ranging from 55-80 nautical miles (nm) and 64-knot wind radii ranging from 30-40 nm (08 September from 0600Z to 1200Z) while STY 20W (12 October at 0000Z) maintained expansive, asymmetric storm force (70-85nm from center) and typhoon force (115-175 nm from center) winds. 14W's track speeds were generally fast. The system tracked at around 15 knots before briefly slowing during recurvature, and then reaccelerated back to speeds around 15 knots as it recurved northeastward. STY 20W tracked poleward at speeds of 12-13 knots offshore, prior to recurvature. However, the system accelerated quickly to 18-21 knots as it approached Yokosuka and then to 35 knots as it reemerged over the Northern Pacific Ocean.

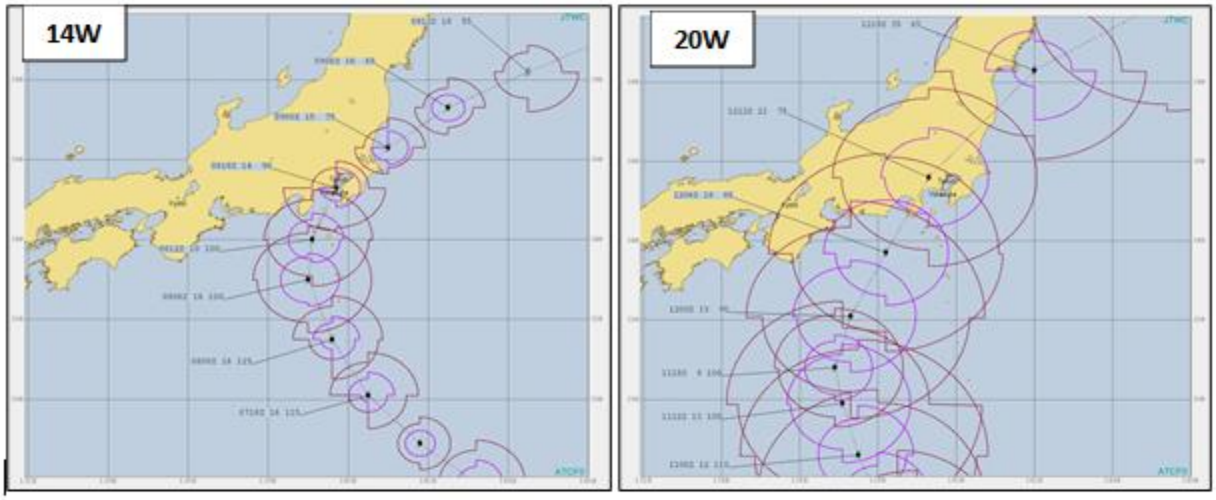

Figure 7-30: Preliminary (working) 50- and 64-knot wind radii analyses for TY 14W (left) and STY 20W (right) reflecting major differences in the wind field structures and, implicitly, system sizes.

Figure 7-31 shows a sequence of microwave images for both 14W and 20W as the systems tracked toward and recurved over the Kanto Plain. A 07 September 1846Z GPM 89H GHz image of 14W depicts a compact system with spiral banding over the southern semicircle. As 14W tracked poleward, it maintained its well-organized core convection as evidenced by the small microwave eye over Yokosuka. The system then weakened as it recurved northeastward over the Northern Pacific Ocean. STY 20W contained a much larger region of deep convection, with the bulk displaced over the northern semicircle due to persistent southerly vertical wind shear. Although the system maintained a weak microwave eye, as evident in the 11 October 0936Z GPM 89H GHz image, the spiral banding over the southern semicircle and the inner core were eroding due to steadily increasing vertical wind shear. As the center passed over Yokosuka, extensive deep convection persisted, with tightly-curved shallow banding and an exposed center evident in the 11 October 2032Z SSMIS 91H GHz and 12 October 0753Z SSMIS 91H GHz images.

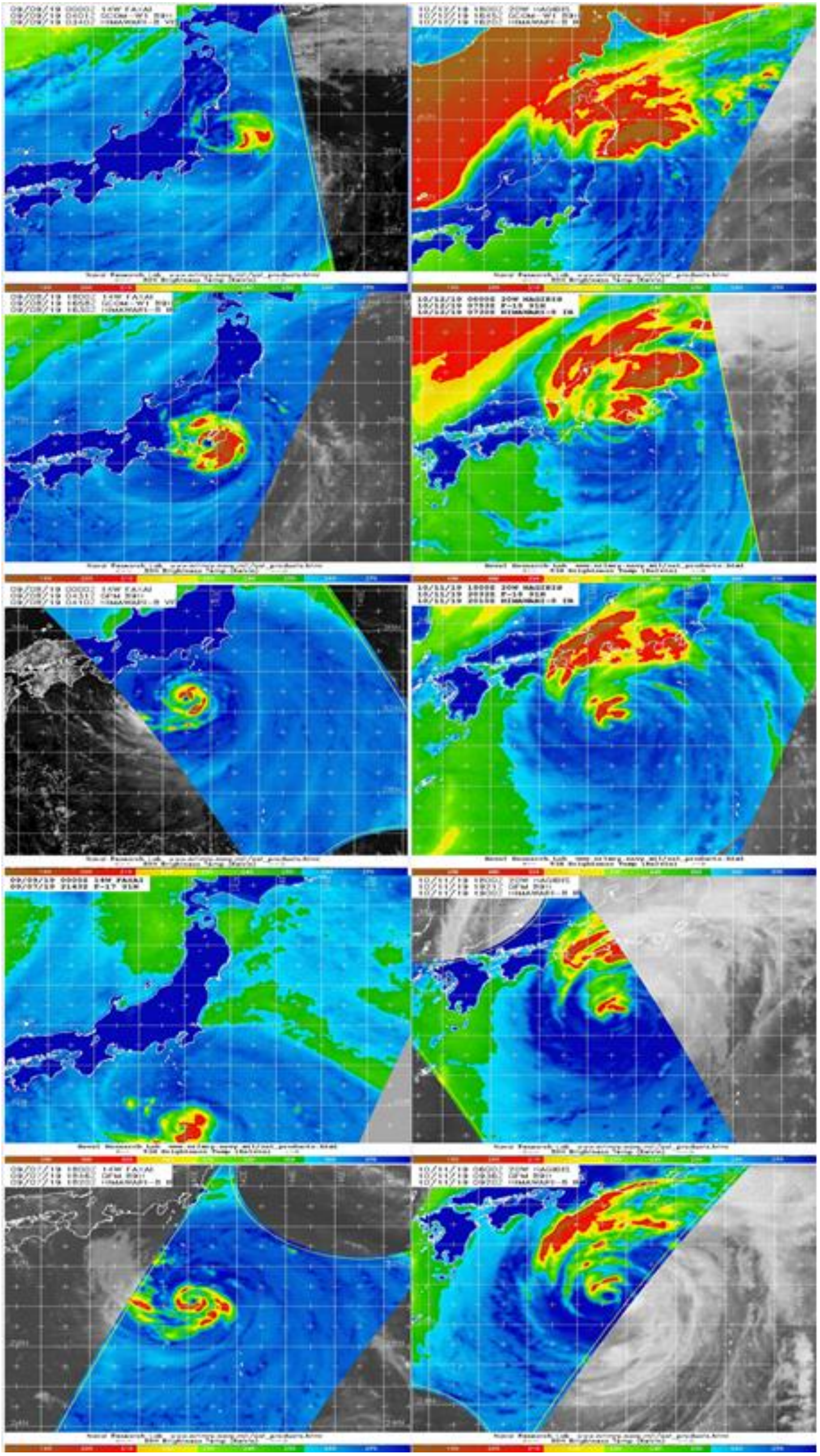

Figure 7-31: Microwave image sequence highlighting the structural differences between TY 14W (left panels) and STY 20W (right panels) as they approached and recurved over central Japan. Image source: Naval Research Laboratory.

Contrasting two landfalling typhoons impacting U.S. Fleet Activities Yokosuka

As a tropical cyclone approaches a landmass (including small islands), it begins to "feel the effects of a landmass' diminished moisture and heat capacity long before the center of the storm makes landfall" (Bloemer 2009). This complex interaction produces a significant change in both structure and intensity, which can lead to "sudden track changes, including sharp turning, unexpected acceleration, and meandering often observed prior to landfall of a TC" (Duan et al. 2019). Depending on the orography and surface roughness, sustained winds decrease and gustiness increases due to the increased friction and turbulence, which brings higher winds down to the surface. The horizontal profile of the surface winds will also vary widely as a function of surface roughness, obstacles and the distribution of convection. Additionally, after a TC's center makes landfall and tracks inland, rapid weakening occurs as the system loses access to the surface energy fluxes from the warm, moist ocean surface. The wind traces for 14W (**Figure 7-33**) and 20W (**Figure 7-35**) confirm that gusty wind patterns, driven by multiple complex factors, were observed at Yokosuka around the time of center passage for both systems. The peak reported wind gust associated with 20W was 76 knots, compared to the peak gust of 86 knots associated with 14W. These peak values were close in magnitude despite the more cohesive eyewall/structure of 14W as it passed directly over Yokosuka, and a decoupling convective structure of 20W as its center passed to the west and northwest of the station.

Some of the large-scale environmental features associated with 14W and 20W were similar, including the presence of a strong and expansive subtropical ridge to the east of each system. However, the synoptic environment associated with 14W was more conducive to maintaining a cohesive tropical cyclone core convective structure over Yokosuka, as 20W was impacted by subtropical westerlies and a shortwave trough overhead. When Typhoon (TY) 14W (Faxai) recurved over the Miura Peninsula on 08 Sep 2019, the compact, well-organized tropical cyclone maintained tightly-curved spiral banding wrapping into a well-defined eye, which passed directly over Yokosuka. Due to its small size, the center of TY 14W slipped between the mountainous Izu Peninsula to the west and the Bōsō Peninsula to the east, where it avoided significant weakening. The system produced instantaneous peak wind gusts of 113 knots at Kozushima, 92 knots at Oshima and 81 knots at Miura (**Figure 7-32**).

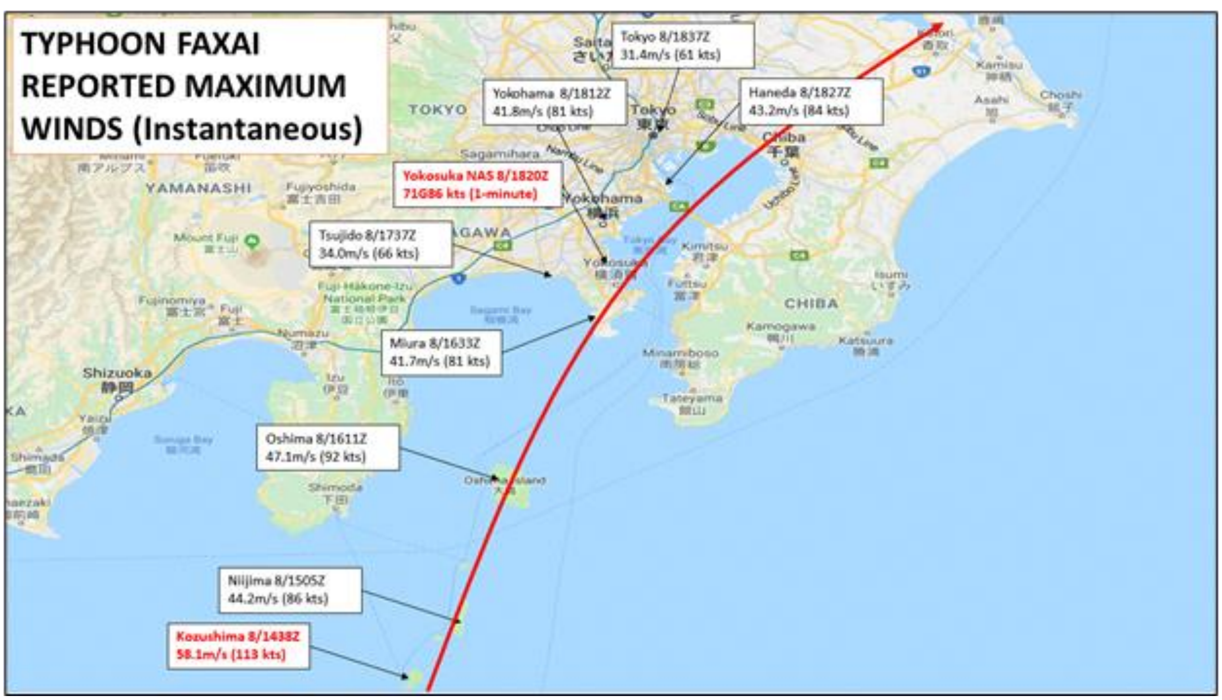

Figure 7-32: Maximum instantaneous wind gusts reported along Typhoon 14W's recurving path (solid red arrow) with maximum sustained winds (1-minute average) and peak gust reported at Yokosuka.

A 08 September 1658Z AMSR2 89 GHz microwave image (**Figure 7-33**) indicates intense spiral banding and a well-defined eyewall just prior to TY 14W's passage over Yokosuka. The wind / sea level pressure profile shows the classic sharp spike in winds, both prior to, and following the weak winds in the eye, accompanied by a precipitous drop in sea level pressure. Yokosuka reported maximum sustained winds of 71 knots gusting to 86 knots (1-minute average).

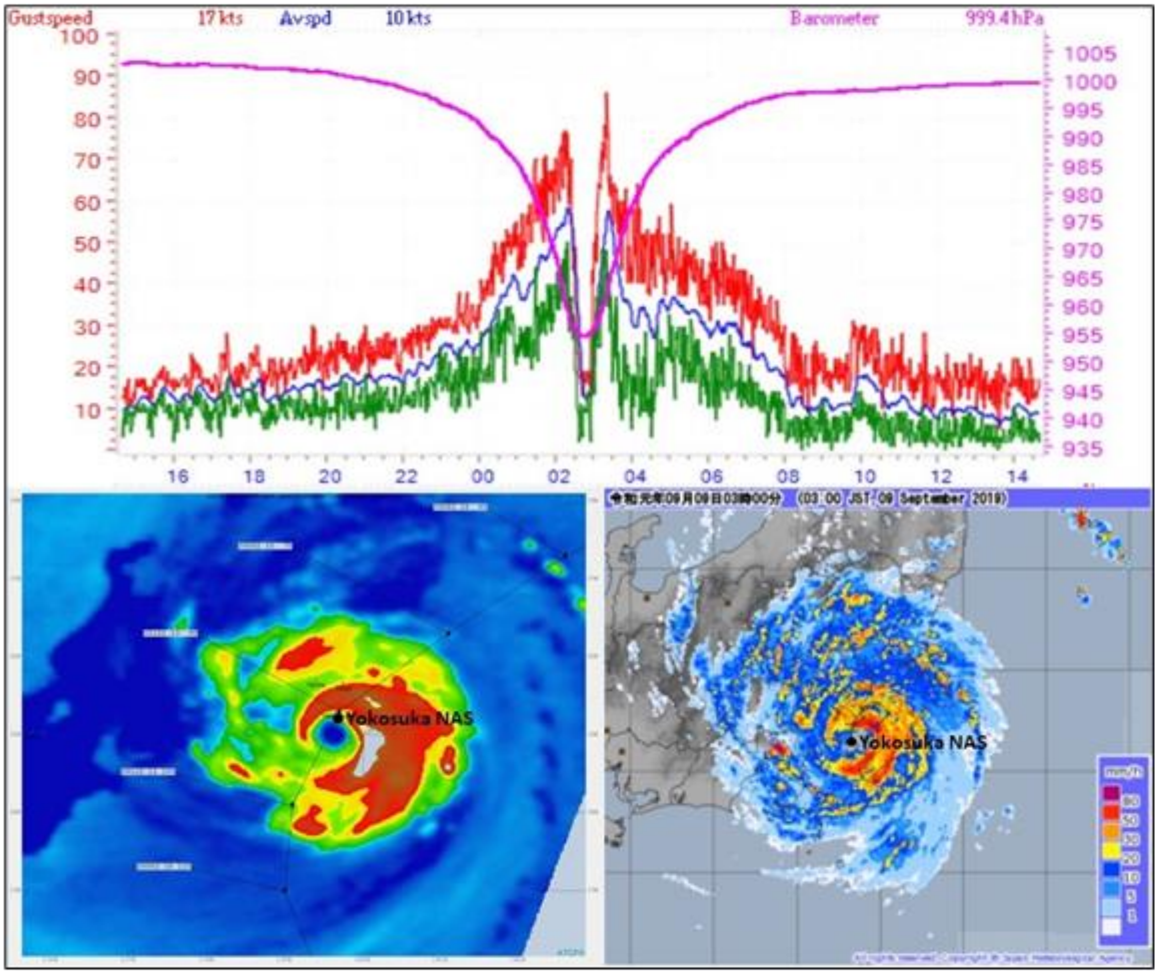

Figure 7-33: 08 September 2019 1658Z AMSR2 89 GHz image (bottom left), 1200Z radar image (bottom right) of 14W positioned just south-southwest of Yokosuka with wind trace (**RED** = instantaneous wind maximum gust speed (knots); **BLUE** = average 1-minute wind speed (knots); **GREEN** = instantaneous wind minimum gust speed (knots)) during the eyewall passage (top image source: NOAC Yokosuka; bottom image source: JMA).

Super Typhoon (STY) 20W (Hagibis) followed a similar trajectory to Typhoon 14W, but recurved over the Izu Peninsula with the center passing about 25 nm west of Yokosuka on 12 October at 1200Z. In sharp contrast to 14W, STY 20W was a large system that interacted significantly with land during its passage. Additionally, the system was undergoing extra-tropical transition and accelerating to forward track speeds of 18 to 21 knots. Many observation sites reported typhoon-strength peak instantaneous wind gusts with Kozushima, Yokohama and Edogawa each reporting instantaneous peak wind gusts of 85-87 knots (**Figure 7-34**).

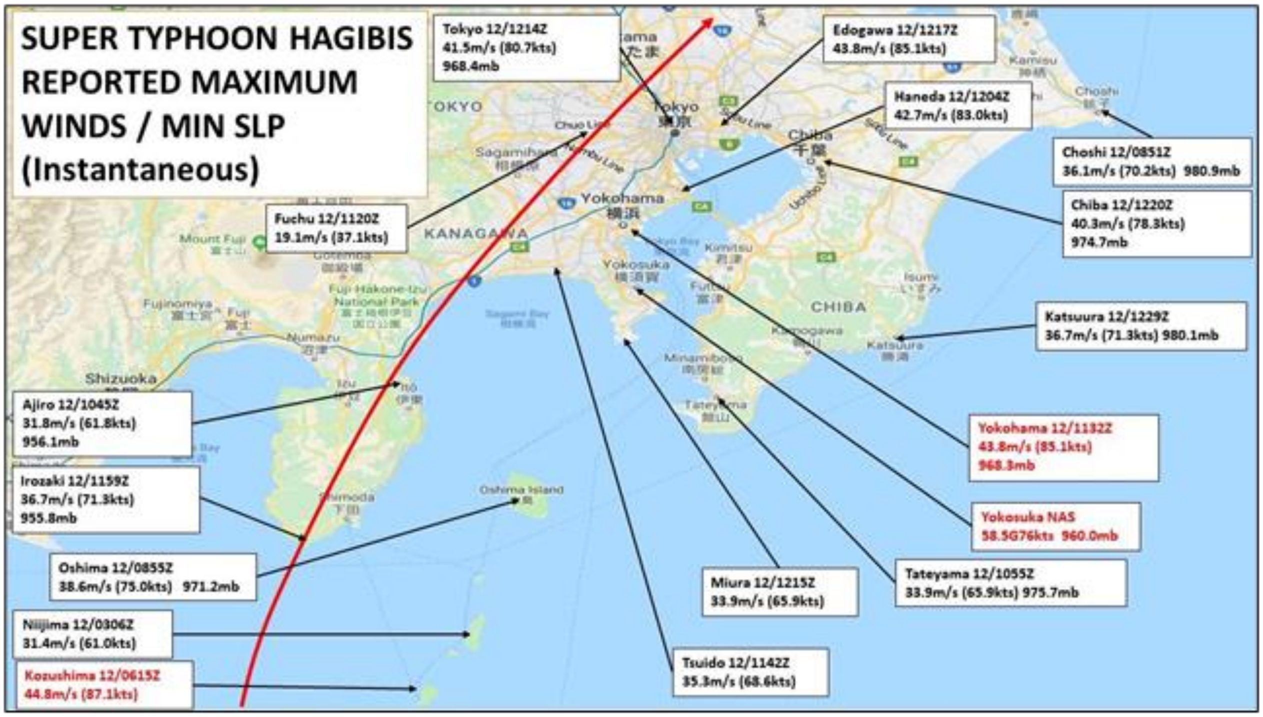

Figure 7-34: Maximum instantaneous winds and minimum SLP values reported along Super Typhoon 20W's recurving path (solid red arrow) with maximum sustained winds (1-minute average) and peak gust reported at Yokosuka.

A 12 October 0753Z SSMIS 91 GHz microwave image (**Figure 7-35**) shows a partially-exposed center with expansive deep convection sheared poleward over central Honshu. The wind / sea level pressure profile indicates a more gradual build-up in surface winds as STY 20W approached Yokosuka with maximum sustained 1-minute average winds of 58.5 knots gusting to 76 knots. Sea level pressure decreased steadily to a minimum of 960 mb as the center passed by, then increased quickly as the center accelerated away to the northeast.

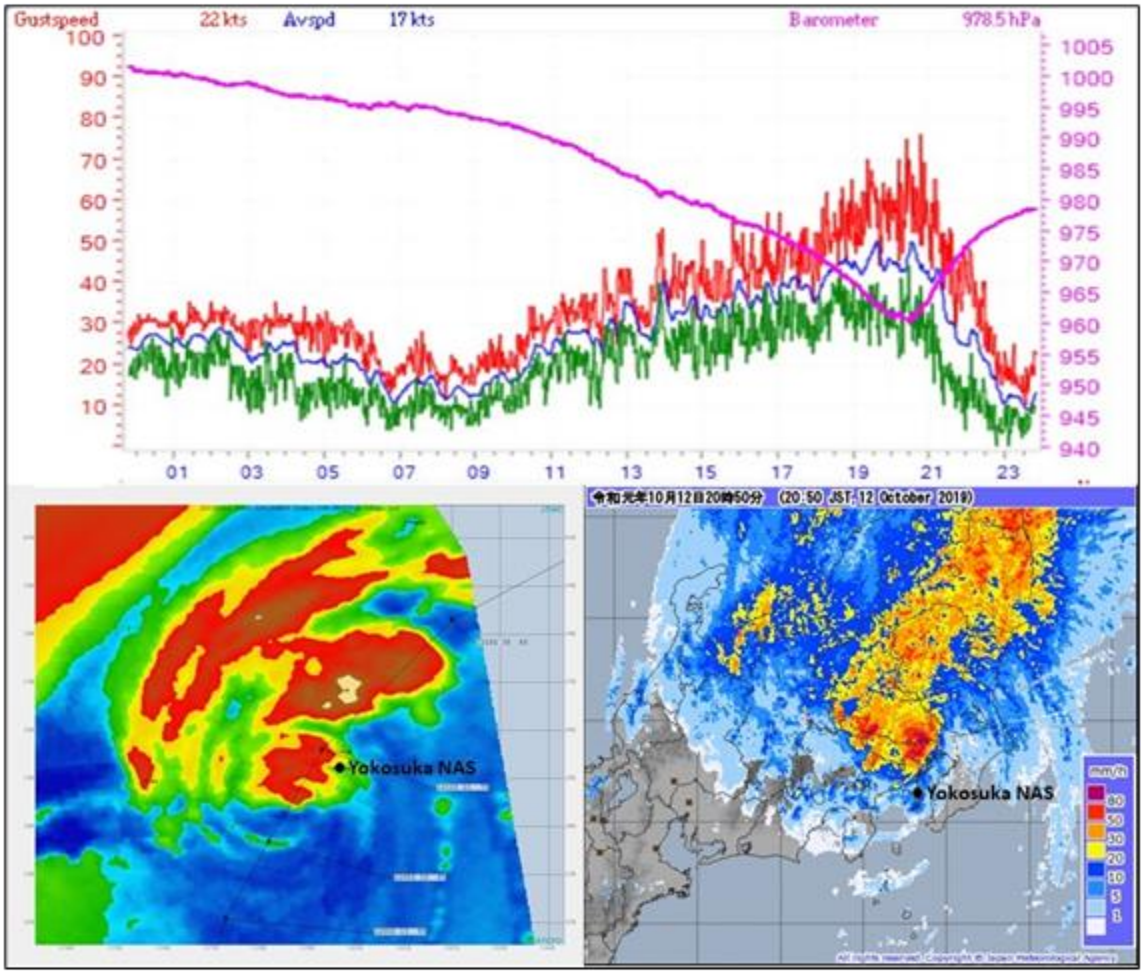

Figure 7-35: 12 October 2019 0753Z SSMIS 91 GHz image (bottom left), 1150Z radar image (bottom right) of 20W near Yokosuka with wind / sea level pressure (top) trace (**RED** = instantaneous wind maximum gust speed (knots); **BLUE** = average 1-minute wind speed (knots); **GREEN** = instantaneous wind minimum gust speed (knots)) during center passage (top image source: NOAC Yokosuka; bottom image source: JMA).

Conclusion

Researchers have documented the complexities associated with landfalling TCs, noting that structure and intensity changes that occur during landfall are not fully understood and require specialized forecasting techniques (e.g., Marks et al. 1998; Elsberry et al. 2013; Leroux et al. 2018; Duan et al. 2019). In 1998, Marks et al. succinctly highlighted three major factors that must be accurately analyzed and represented in numerical models to effectively forecast the evolution of landfalling TCs: 1) the structure of the upper-ocean circulations that control the oceanic mixed layer heat content, 2) the storm's inner core dynamics, and 3) the structure of the synoptic-scale upper tropospheric environment. Although progress has been made toward understanding, analyzing and modeling each of these factors, efforts to improve landfalling TC forecasts continue. For example, China recently initiated the Landfalling Tropical Cyclone Research Project (LTCRP) to focus on improved understanding of landfalling TCs that impact that nation's extensive coastal regions. Specifically, the LTCRP aims to focus on the physical processes that are closely related to structure and intensity changes during landfall, including strong winds and heavy rain in the TC inner core as well as severe weather features within the outer circulation such as squall lines, tornados, and supercells (Duan et al. 2019).

The challenges associated with analyzing tropical cyclones over water and the dependence of forecast accuracy on analysis data are recognized within the DoD METOC community. Unfortunately, TC center position, intensity and wind field analyses are typically less precise and more uncertain for landfalling cyclones since all three parameters are intrinsically linked to a system's structure, which can change rapidly and significantly near and over land. Key local forecast considerations with respect to the structure of landfalling TCs include size (particularly 34-, 50- and 64-knot wind radii and the radius of maximum wind), convective structure (e.g., compactness, convective distribution, and banding structure) and environmental interactions (e.g., vertical wind shear and extra-tropical transition). As a result of these structural factors, 14W and 20W produced markedly different wind speed and sea level pressure trends at Yokosuka. 14W induced the classic eye passage signature with double peak intensity and coincident sharp pressure drop. 20W induced a steady build-up of winds and a steadily decreasing SLP trend prior to center passage, followed by a steady decrease in wind speed (no double peak) and increase in sea level pressure.

Despite increased uncertainty over land, there is a greater need for accurate analyses and forecasts to support fixed DoD installations and assets, which are responsible for forecasting local conditions and base preparedness decisions. TY 14W and STY 20W highlighted some of the challenges associated with analyzing and forecasting intensity for landfalling tropical cyclones. Both systems shared similar synoptic steering environments (with subtle differences), similar intensity profiles prior to landfall and similar tracks re-curving over the Kanto Plain region. Yet these systems differed in meaningful ways, producing unique local weather impacts.

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Section 3 TY 21W (Neoguri)

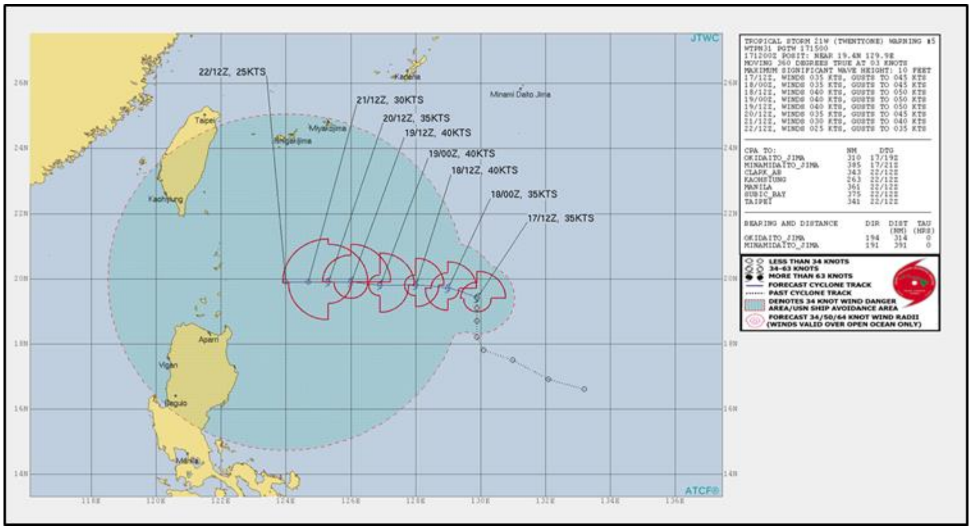
Typhoon (TY) 21W began its lifecycle as a disturbance embedded within the western North Pacific (WESTPAC) monsoon trough over the Philippine Sea. The system quickly consolidated to reach the JTWC warning threshold intensity of 25 knots (kts) at 1200Z on 16 October 2019, less than 36 hours after first mention on the JTWC Significant Tropical Weather Advisory Bulletin (ABPW). Early forecasts predicted that the system would remain weak as it tracked westward along the southern periphery of a subtropical ridge (STR), and dissipate over or near northern Luzon, Philippines due to interaction with a low- to mid-level northeasterly surge. However, over the next six days, Neoguri underwent rapid intensification (RI), reaching a peak intensity of 95 knots, and its track unexpectedly recurved northeastward, eventually passing within 160 nm of Yokota AB. The unanticipated recurvature resulted in 96-hour forecast errors of up to 889 nm (no 120-hour forecasts verified), by far the largest 2019 track forecast errors in the WESTPAC basin. Track forecast errors for TY 21W accounted for a 5-10% increase in mean track error for the entire 2019 WESTPAC tropical cyclone season, despite representing only about 3% of the total number of forecasts (see Table 7-2). In addition to the large track forecast errors, 72-hour forecast intensity errors for four warnings exceeded 50 kts due to the unanticipated RI.

COMPARISON OF TRACK ERRORS BY FORECAST TAU							
	0	12	24	36	48	72	96
TY 21W	13.1 (23)	56.2 (21)	103.6 (19)	150.6 (17)	207.1 (15)	422.3 (11)	807.6 (4)
WESTPAC 2019	12.1 (613)	30.6 (568)	44.4 (512)	60 (456)	76.6 (399)	118.1 (303)	151 (209)
WESTPAC 2019 (w/o 21W)	12 (590)	29.7 (547)	42.1 (493)	56.5 (439)	71.5 (384)	106.7 (292)	138.2 (205)

Table 7-2: Forecast track errors for TY 21W, the 2019 WESTPAC season, and the 2019 WESTPAC season excluding TY 21W (sample sizes in parentheses). Although forecasts for TY 21W represented about 3% of the total number of forecasts issued during the 2019 WESTPAC season, they accounted for 5% (tau 24) to 10% (tau 72) of the seasonal track forecast errors.

Model guidance available at the first warning time for 21W, including the GFS and NAVGEM deterministic trackers and the GEFS ensemble members and mean, predicted a westward track with a 72-hour spread of only 40 nm. Earlier model track forecasts, including the Air Force GALWEM deterministic model, UKMET Office MOGREPS-G ensemble mean and ECMWF ensemble mean, had also indicated a high likelihood of a westward track. Consistency in the model guidance provided the forecaster high confidence in the initial, westward-oriented track forecast. JTWC continued to forecast a westward-oriented track for the first five warnings. However, the forecasts shifted to a recurvature scenario with warning number 6, as reanalyzed poleward storm motion and shifting numerical model forecast guidance increasingly favored that scenario (**Figure 7-36**).

Data latency and temporal refresh rate of microwave satellite sensing are critical quantities for real-time analysis, particularly during early stages of tropical cyclone development, when the low-level circulation is difficult to locate. Early in the 21W's lifecycle (warnings 1-5), real-time best track analyses indicated a westward component to storm motion. However, retrospective analyses revealed that the storm had actually turned sharply northward during that period. Notably, forecasters shifted all five of the associated initial (best track positions) eastward after the warnings were issued, based on features evident in late-arriving microwave and scatterometer imagery (see **Figure 7-37)**. Had these images arrived earlier, the real-time best track analysis would likely have been more accurate, which may have prompted an earlier adjustment to the forecast philosophy. This case illustrates the negative impact of declining TC sensor revisit rates as many operational low Earth orbiting satellites reach end of life, with replacements potentially years away.



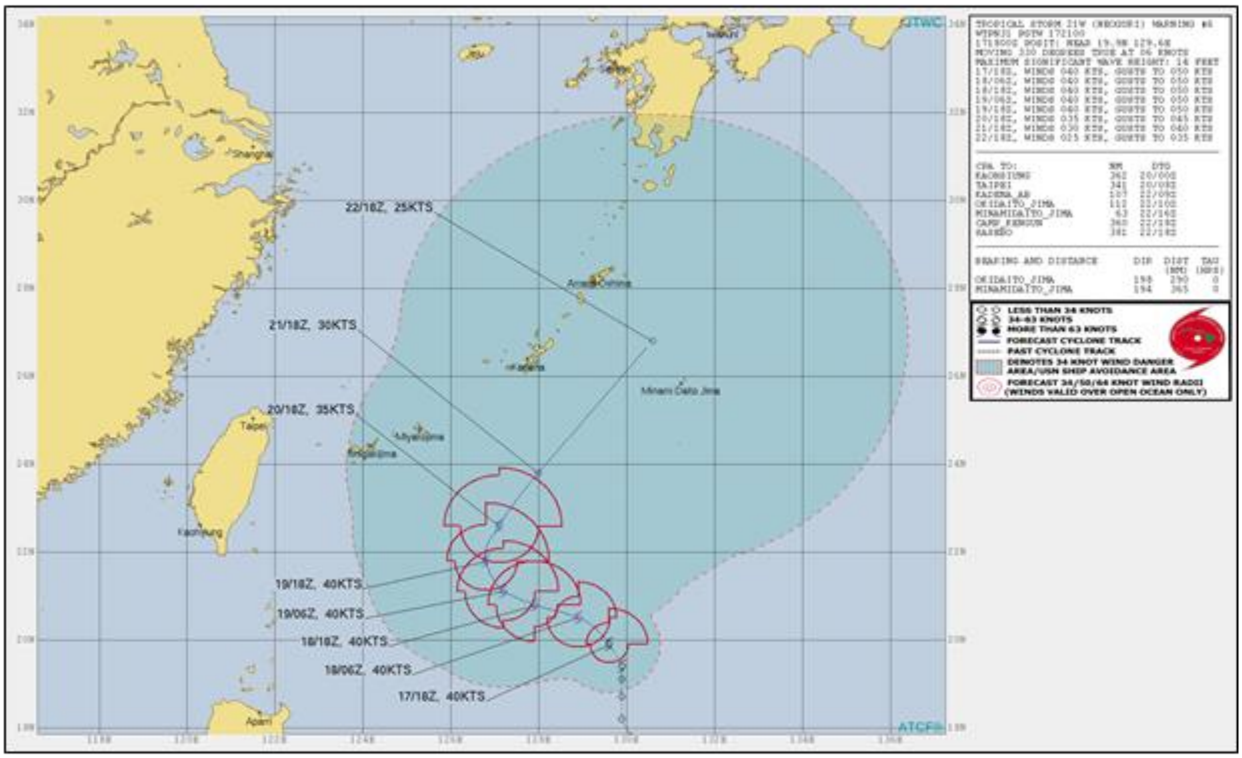


Figure 7-36: Warning graphics for warning numbers 5 (top image: 17 October 17 at 1200Z) and 6 (bottom image: 17 October at 1800Z). Warning number 5 is the last warning in which JTWC forecasted 21W to track westward. Warning number 6 is the first warning depicting recurvature. Both warnings indicated a peak forecast intensity of 40 kts.

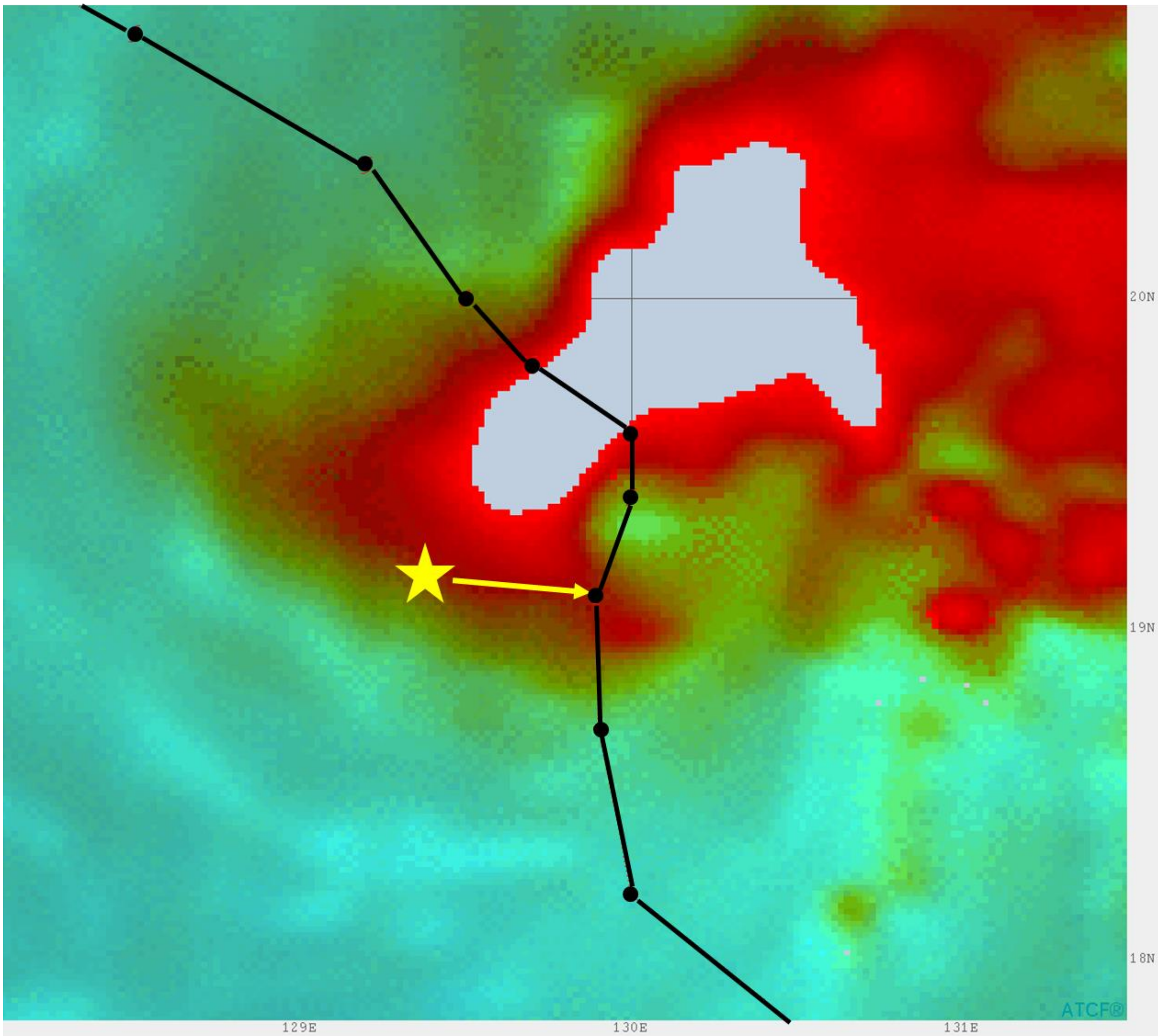
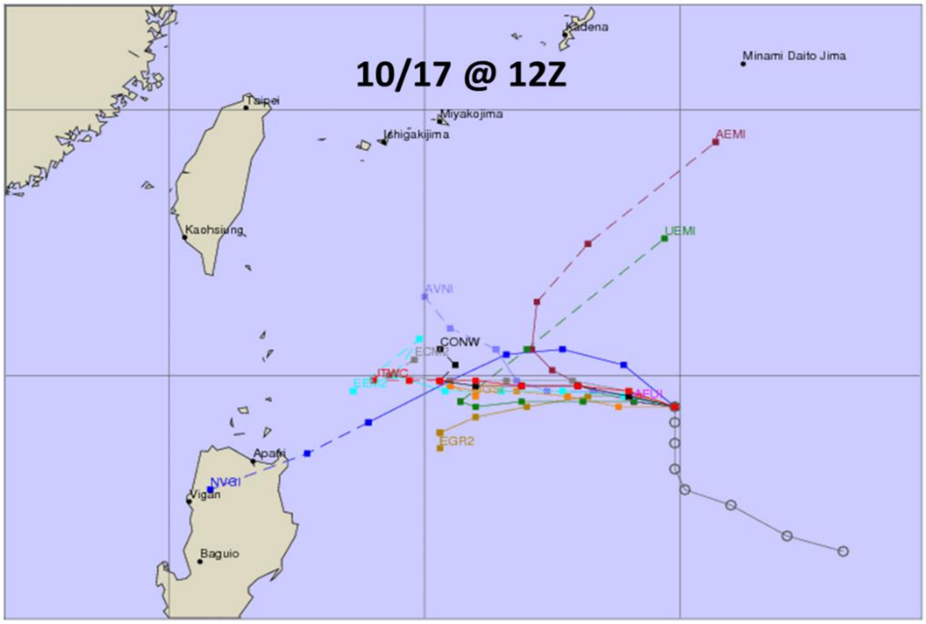


Figure 7-37: Example post-warning adjustment to 21W best track position for 17 October 2019 at 06Z. The black line represents the final TC best track and circles mark 6-hourly positions. The yellow star indicates the working (original) best track position designated by the forecaster when the 17 October 06Z warning was issued. The yellow arrow points to the reanalyzed, final best track position. A 17 October, 0731Z GPM GMI 89 GHz PCT microwave image (shown) supports the adjusted position. The 27 nm eastward shift in the best track revealed that 21W had been tracking nearly due northward, contrary to northwestward motion analyzed in real-time.

Evolution of the official forecasts

Aside from adjusting initial best track positions as noted, forecasters made only minor changes to the official forecast early in the storm's lifecycle. By warning number 4 (17 October at 0600Z), forecast duration had increased to 96 hours and confidence in the track forecast had decreased because two ensemble-based members of CONW (the GFS ensemble mean and the UK MOGREPS-G ensemble mean) depicted a recurvature scenario (**Figure 7-38**). The remaining members continued to depict a westward track. However, as the situation evolved, GEFS ensemble members increasingly favored a poleward turn and potential recurvature. **Figure 7-39** shows the GEFS ensemble forecast tracks for 0000Z and 1200Z on 17 October 2019. The GEFS ensemble mean (brown track) depicted a poleward turn at both forecast times. However, the depicted turn was sharper and farther to the east in the 1200Z forecast, as the number of members depicting a poleward turn increased from 5 (of 20) at 0000Z to 13 (of 20) at 1200Z. While the GFS ensemble members and mean track shifted steadily eastward between 17 October 0000Z and 17 October 1200Z, the majority of CONW members still favored a westward track until 17 October 1800Z. Because the increasing probability of a poleward turn and recurvature evident in the GEFS ensemble members alone did not support a major change in the forecast philosophy, the official forecast track followed the westward scenario until the 17 October 1800Z forecast. However, forecast discussions for warning number 4 (17 October 0600Z) and 5 (17 October 1200Z) did mention the possibility of the poleward recurvature based on orientation of both the GEFS and UK MOGREPS-G ensemble means. This case demonstrates that detailed analyses and discussions of ensemble member forecasts and trends in prognostic reasoning messages may provide useful information regarding evolving track forecast probabilities.

Post-storm analysis suggests that the unanticipated northward movement of 21W early in its lifecycle allowed an approaching mid-latitude trough over Asia to propagate eastward and weaken the STR, resulting in the observed recurvature. As Figure 7-40 illustrates, the evolution of this trough was apparently well-forecasted by the numerical models. Unexpected poleward motion early in the storm's lifecycle may have enabled 21W to avoid the initially-predicted negative interaction with a low- to mid-level northeasterly surge to the west. Additional study is required to determine the exact mechanisms responsible for differences between forecasted and observed steering patterns.



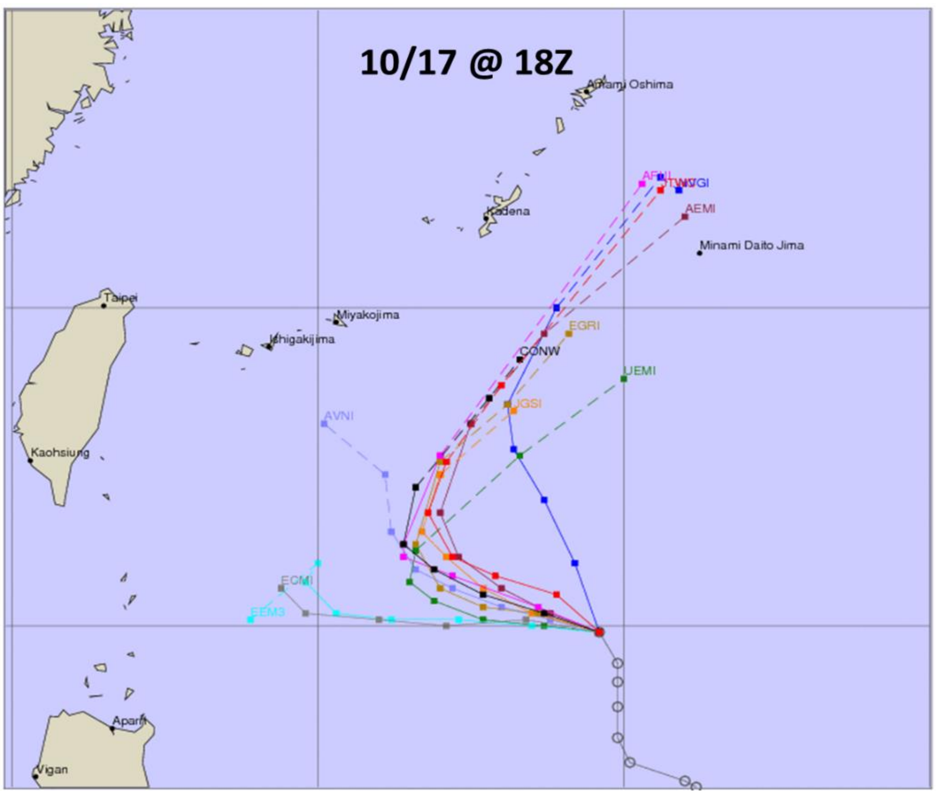


Figure 7-38: TY 21W objective aids for 17 October 2019 at 1200Z (top image: warning 5) and 1800Z (bottom image: warning 6). At 1200Z, two members of CONW (GFS ensemble mean – AEMI and UK MOGREPS-G ensemble mean – UEMN) indicated recurvature. At 1800Z, nearly all models except ECMWF depicted some degree of recurvature.

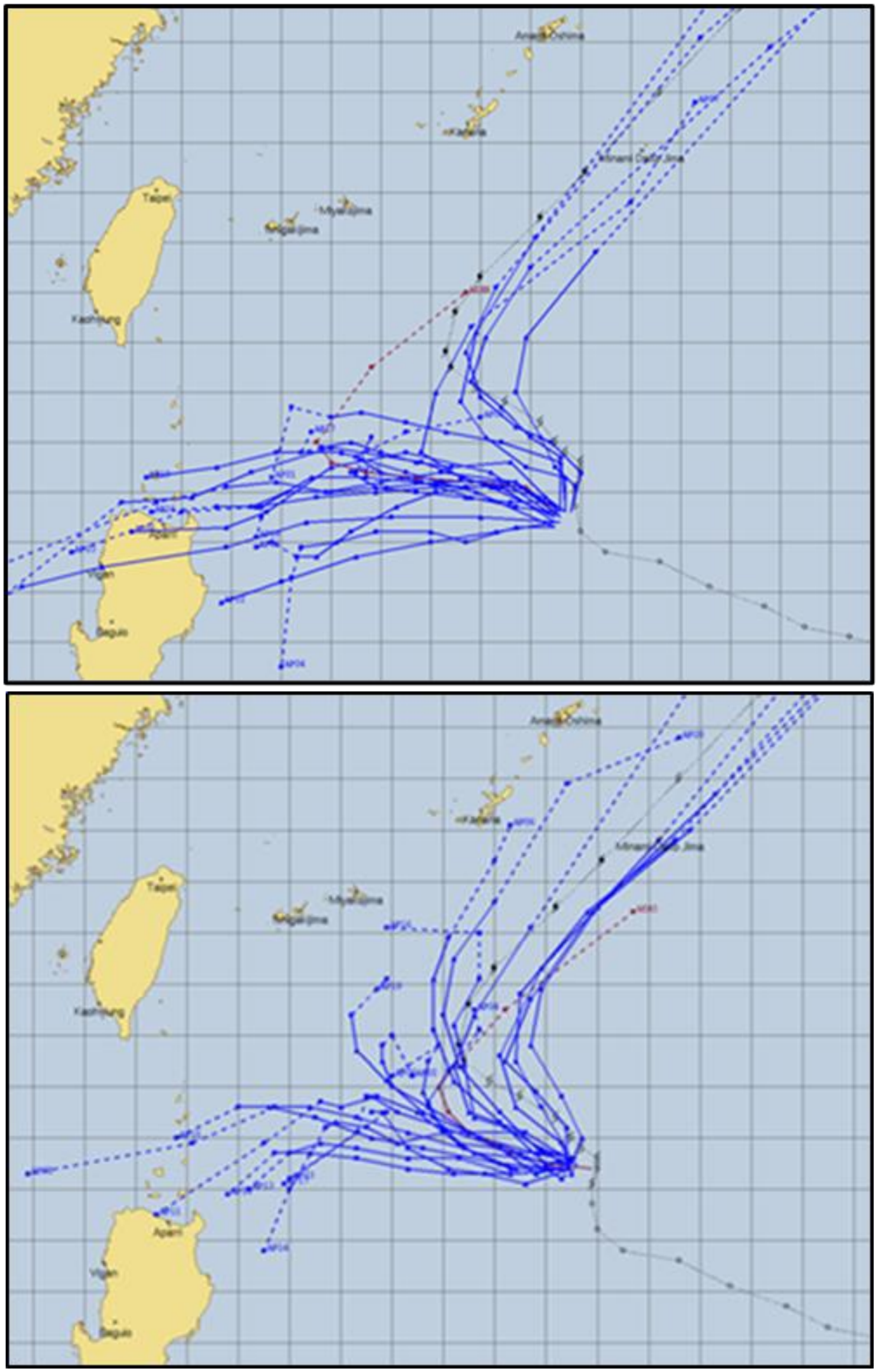


Figure 7-39: Raw (noninterpolated) GFS ensemble members for 17 October 2019 at 0000Z (top) and 1200Z (bottom). The GFS ensemble mean is brown, individual members are blue. At 0000Z, 5 of 20 members depicted recurvature. By 1200Z, 13 of 20 members depicted recurvature.

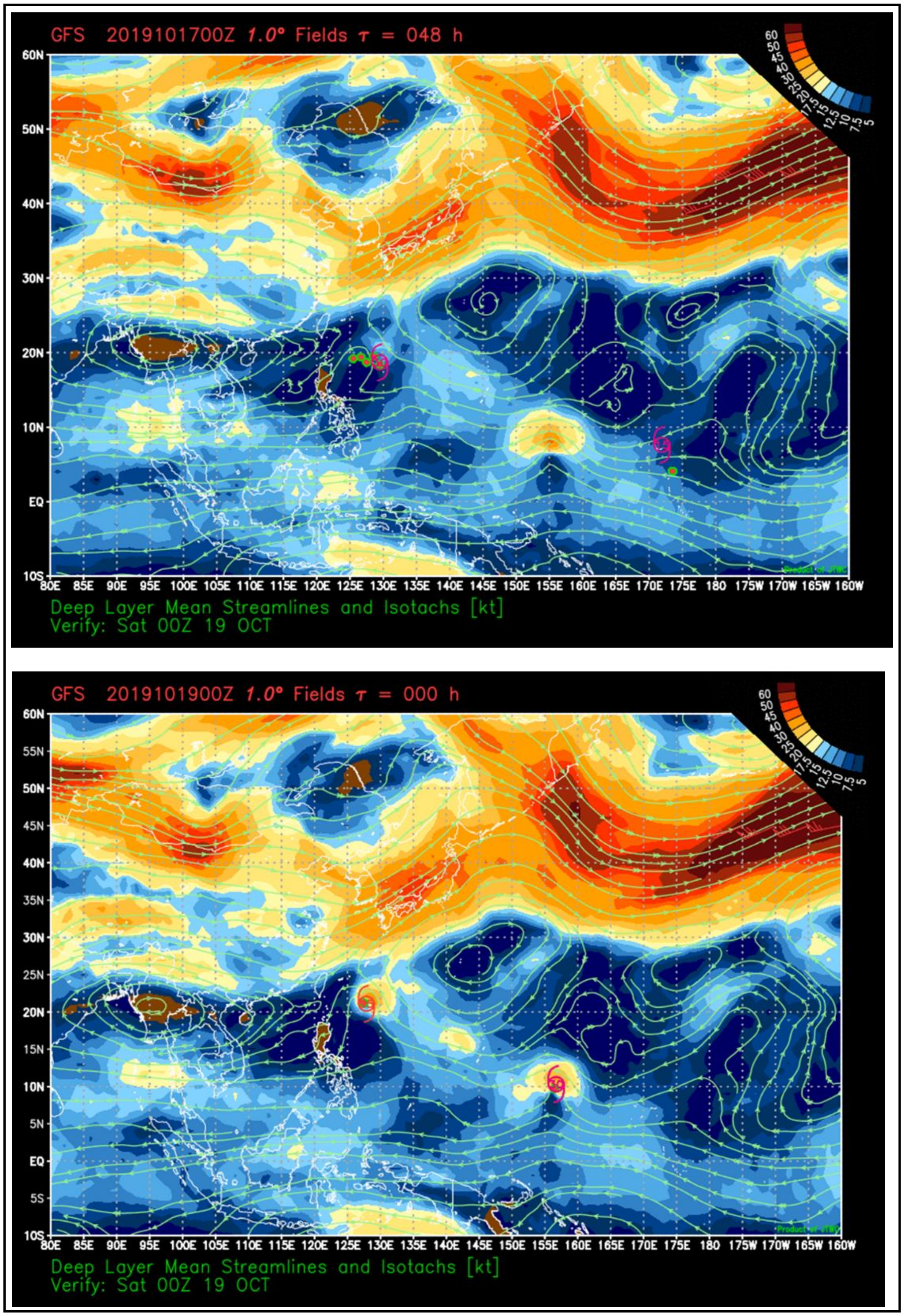
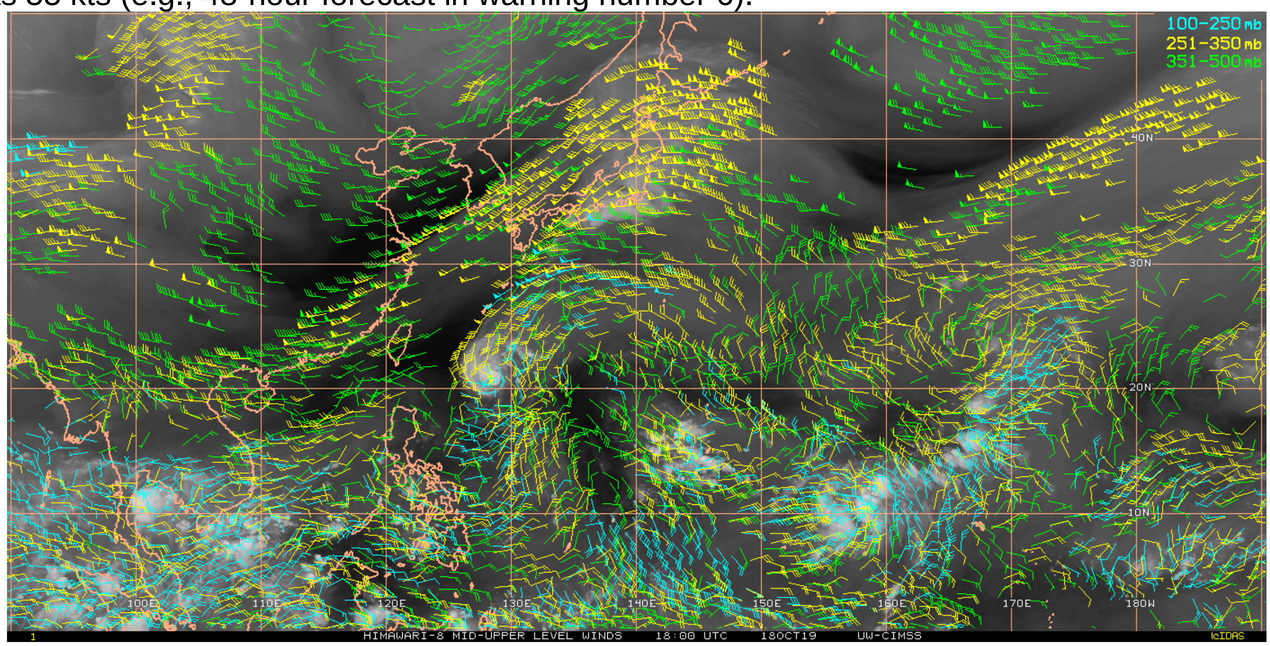


Figure 7-40: GFS Deep layer Mean Streamlines and Isotachs, 48-hour forecast from the 17 October 2019 0000Z model run (top) and the 19 October 0000Z verifying analysis time (bottom). Both graphics indicate a weakness in the sub-tropical ridge near 22N 125E and a mid-latitude trough extending equatorward along the east coast of China. The 19 October 0000Z analysis indicates a stronger storm circulation located farther to the north and east than depicted in the 17 October 0000Z forecast. In contrast, the orientation of the steering ridge and approaching mid-latitude trough appear quite similar in both depictions.

Beginning with warning number 6 (17 October at 1800Z), official JTWC track forecasts accurately depicted TY 21W's poleward turn and recurvature. Although track forecasts had shifted to the correct orientation, errors were still large since forecasted motion around the STR axis was slower than observed. Between 17 October at 1800Z and 19 October at 1200Z, uncertainty was very high, with end-to-end spread among the CONW members exceeding 1500 nm in six of the eight forecasts issued. During this time period, JTWC forecast positions were placed near the consensus with low confidence. For warnings 7-9 (18 October 0000Z-1200Z), 72-hour forecast errors exceeded 500 nm as TY 21W rounded the STR axis more quickly than anticipated. The more rapid transit around the STR axis allowed the system to accelerate as it interacted with the mid-latitude westerlies sooner, and explains the large along-track errors evident in the first several forecasts issued after JTWC shifted to the recurvature scenario.

Forecasting intensity through the recurvature portion of 21W's storm track was also challenging. As TY 21W rounded the STR axis, model intensity guidance and JTWC forecasts failed to predict a 24-hour RI period (18 October 1800Z – 19 October 1800Z), following which the intensity peaked at 95 kts. Tropical cyclones that round the axis of a STR weakened by a mid-latitude trough often experience a period of RI as poleward outflow increases while vertical wind shear (VWS) remains low to moderate. In the case of TY 21W, the forecast discussions described an environment with robust poleward outflow and moderate VWS (**Figure 7-41**). Although the robust outflow channel was evident in satellite imagery and the CIMSS upper-level derived wind product, VWS was difficult to assess due to a strong shear gradient to the north of the system. It is possible that both available model guidance (**Figure 7-43**) and forecasters failed to predict RI due to a combination of underestimating the supportive influence of outflow (both equatorward and poleward) and overestimating the magnitude or depth of the VWS. Further study would be required to confirm these assumptions. After TY 21W rounded the STR axis, strong VWS caused rapid weakening (**Figure 7-42**). The unpredicted RI period resulted in intensity errors as high as 55 kts (e.g., 48-hour forecast in warning number 6).



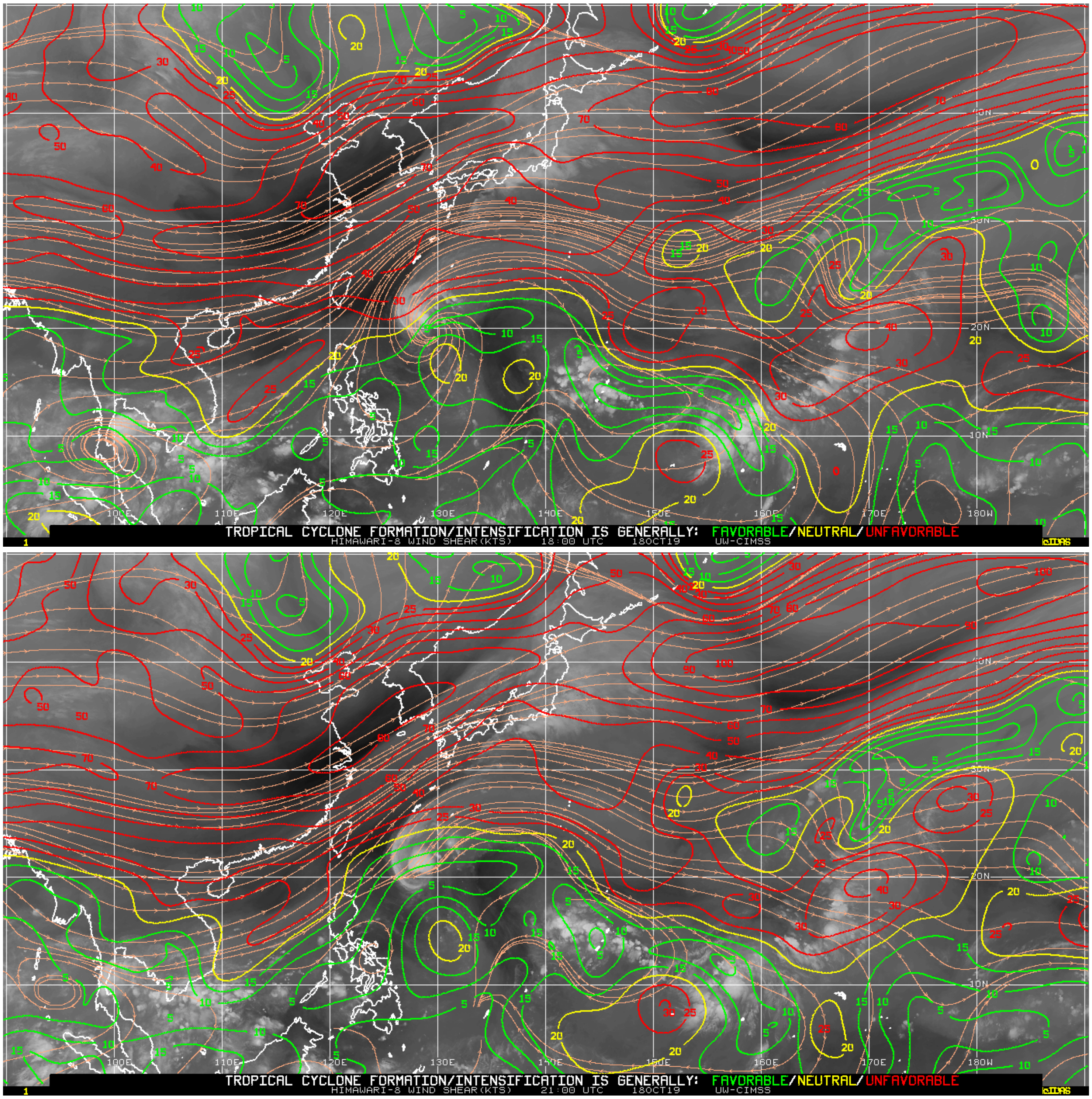


Figure 7-41: University of Wisconsin-Madison, Cooperative Institute for Meteorological Satellite Studies (UW-CIMSS) upper-level atmospheric motion vector wind graphic for 18 October 2019 at 1800Z (top) and VWS graphics for 18 October 2019 at 1800Z (middle) and 2100Z (bottom). These images indicate robust poleward outflow, limited equatorward outflow, and low VWS conditions in proximity to 21W near the onset of RI. Image source: CIMSS online Tropical Cyclones archive.

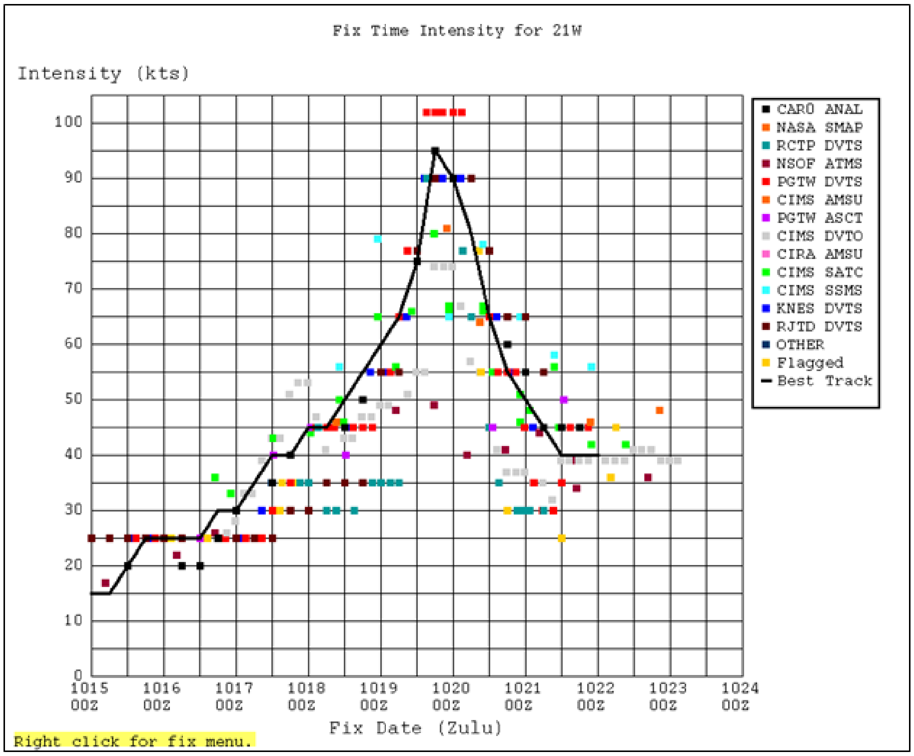


Figure 7-42: Fix Time Intensity chart for TY 21W. Intensity increased by 45 kts in 24 hours (18 October 2019 1800Z to 19 October 1800Z) before decreasing by 40 kts over the subsequent 24-hour period.

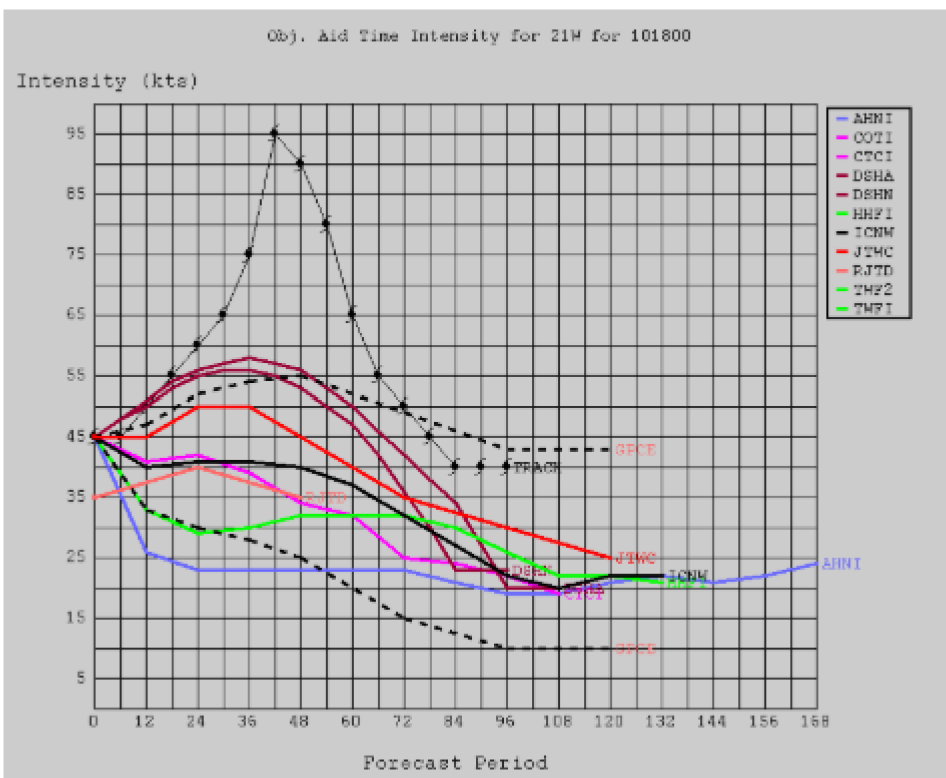


Figure 7-43: JTWC intensity aids for warning number 7 (18 October 2019 at 0000Z). Graph is representative of intensity guidance for TY 21W after models shifted to the recurvature scenario. The 48-hour intensity error was 45 kts for warning number 7.

Conclusion

TY 21W presented forecasting challenges from the early through middle portion of its lifecycle, resulting in large track and intensity forecast errors. These errors may have cascaded from the unpredicted (by both forecasters and models) northward storm movement observed during the first 24 hours following the storm's formation. During this period of northward movement, microwave and scatterometry data that arrived after warning generation prompted forecasters to adjust best track positions. The observed poleward movement, which had been largely underpredicted by the numerical models, may have eroded the STR as a mid-latitude trough simultaneously approached from the northwest. Resultant steering flow within that break pushed TY 21W poleward, and enabled an unpredicted, 24-hour RI period as TY 21W responded to low VWS and robust poleward outflow.

Deterministic members of CONW adjusted to the evolving steering pattern later than the ensemble means, which began indicating recurvature by the time JTWC issued warning number 3. Interestingly, the trend of the individual GEFS ensemble members indicated a two-and-half-fold increase in the likelihood of recurvature, from 25% to 65% (based on number of members), between 0000Z and 1200Z on 17 October. This trend demonstrated the potential value of adopting increasingly probabilistic approaches to forecasting tropical cyclones and conveying forecast information to customers. The JTWC prognostic reasoning message issued with warning number 4 (17 October at 0600Z) flagged the potential for recurvature indicated by several members of the model consensus. However, following current operational practices, the bulletin did specify probabilities or trends in probabilistic data. Providing more information about evolving probabilistic guidance, in this case, could have alerted ships and customers north of the original forecast track to a steadily increasing risk of the storm turning towards them. JTWC is investigating new tools and techniques, communication methods and forecast product improvements to better convey actionable, probabilistic information to the organization's customers.