Joint Typhoon Warning Center

Annual Tropical Cyclone Report

2018

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Commanding Officer

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Cover: August 16, 2018, "… a rather busy day at JTWC". Six tropical circulations of interest shown west to east: TS 20W (Bebinca) in the South China Sea; remnants of TS 18W (Yagi) inland over China; TS 21W (Rumbia) south-southwest of Korea; Typhoon 22W (Soulik) northwest of Guam as a tropical storm; TY 23W (Cimaron) precursory disturbance north of Pohnpei; and remnants of STY 10E (Hector) near the Dateline; Image credit: NASA (https://worldview.earthdata.nasa.gov)

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 2018 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 2018 storm season (Northern Hemisphere 1 January 2018 through 31 December 2018 + Southern Hemisphere 1 July 2017 through 30 June 2018), JTWC produced 1,350 warnings for 66 tropical cyclones (1,476 warnings for 72 TCs for the 2018 calendar year[1]), eclipsing the 1,193 warnings that JTWC produced during the strong El Niño event of 2015. The 2018 figure is partially attributable to the large number of TCs in the AOR, and the above-average mean duration of these systems (mean best track length was 1,968 miles). Additionally, 2018 was the first year in which JTWC regularly produced six-hourly forecasts in the southern hemisphere. Without a defined break between JTWC's multi-hemisphere forecasting responsibilities, the high warning frequency limited the time available for Typhoon Duty Officers and JTWC staff to produce the 2018 post-analyzed best tracks and this report. Figure P-1 (below) shows the timeline of tropical activity across the JTWC AOR for calendar year 2018.

In the western North Pacific, the primary TC genesis region was largely consistent with an ENSO-neutral environment. The Oceanic Niño Index (ONI) for the Niño 3.4 region began the year with a weak cold anomaly before turning neutral for the summer months, and then ending the year with weak warm anomalies. There were 36 total warned TCs in the basin, which is one standard deviation above the current 25-year climatological mean of 30. Additionally, one TC that formed in the eastern Pacific (Hector) crossed into the Central Pacific, and then briefly into the western Pacific before dissipating.

[1] The southern hemisphere TC runs from July 1 to June 30. JTWC warned on 27 total southern hemisphere TCs during the 2018 calendar year.

Note that JTWC began warning on 36W, “Pabuk”, when it consolidated into a tropical depression on the last day of the year. Therefore, WP36 is included in the 2018 JTWC records, as seen in Figure P-1. However, the official RSMC began issuing warnings on Pabuk once it reached tropical storm intensity on the following day (January 1, 2019). A commensurate discrepancy between the agency records may be expected. Broken down by category, the above average number of tropical cyclones is largely attributable to an increased number of tropical storms. The number of typhoons (16) is consistent with the long-term mean, although the number of typhoons which reached super-typhoon status was slightly higher than average (seven versus five, respectively). Accumulated Cyclone Energy (ACE) for the basin registered at the third highest value since 2000, thanks in part to 26W (Mangkhut) and 31W (Yutu), which maintained super typhoon status for extended periods. Both of these systems tracked through the Northern Mariana Islands, with Tinian experiencing a direct hit from Yutu as the cyclone passed over the island with sustained core winds of 150 knots. Super typhoon Maria (detailed in a storm review included in this report) made landfall on Guam as a tropical storm. Five tropical cyclones crossed mainland Japan, and two crossed South Korea. Although frequently under the threat of tropical cyclones, Okinawa experienced only one land-falling tropical storm.

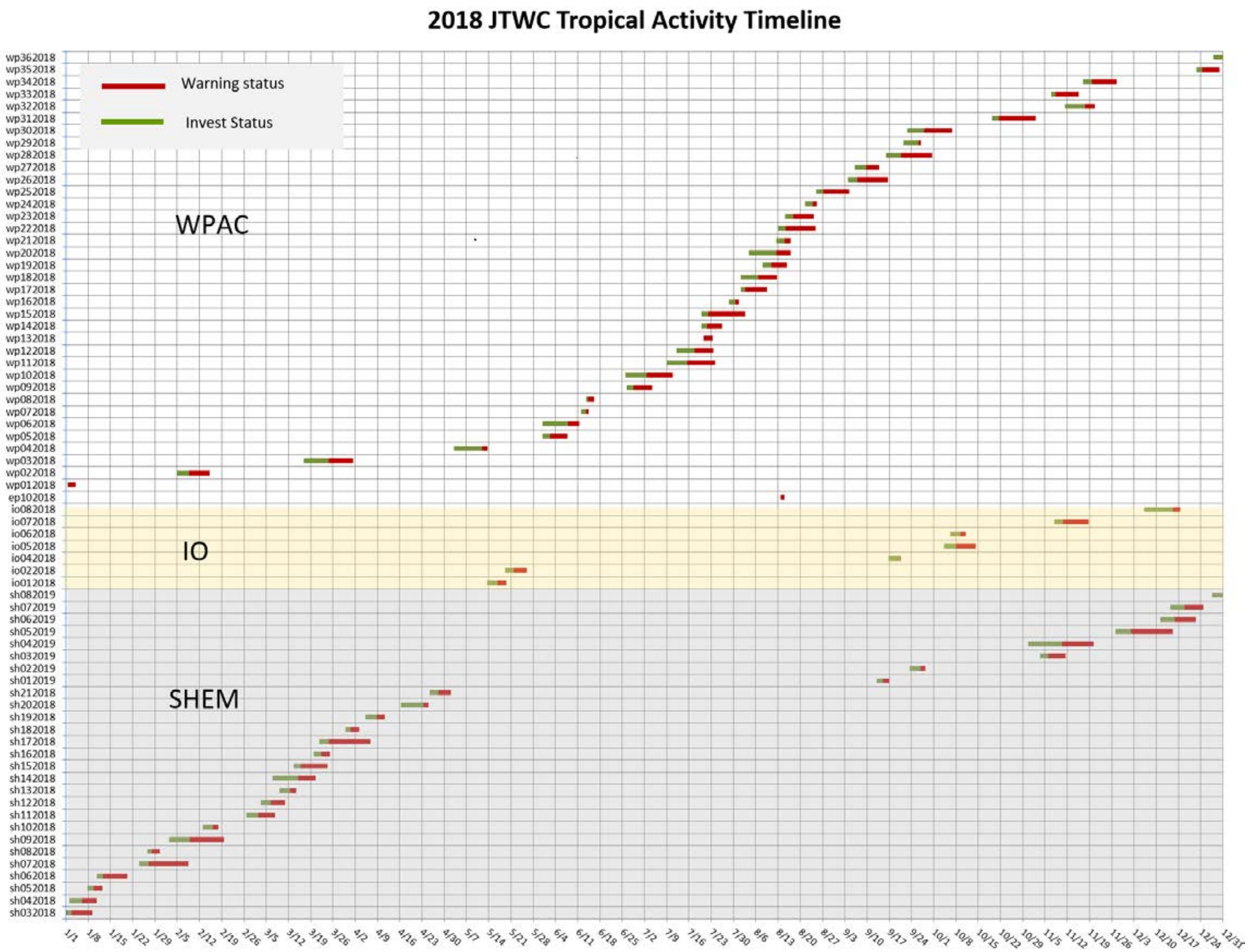

Figure P-1: Timeline of tropical cyclone activity across the JTWC AOR during the 2018 calendar year

Activity in the north Indian Ocean was elevated, with eight total tropical cyclones distributed between the Arabian Sea and Bay of Bengal compared to the long-term mean of five. Five of these eight cyclones peaked at intensities equivalent to typhoon status. Southern Hemisphere activity was once again below the 25-year mean of 26, with 21 total tropical cyclones developing during the season[1]. Activity in the Gulf of Carpentaria was unusually light with only one cyclone, while four cyclones made landfall along the northwestern coast of Australia. There was no tropical cyclone activity observed in the Mozambique Channel.

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 10,859 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 Post Graduate 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.

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 2018

Leadership

CDR Corey Cherrett, Commanding *Officer (2018 - present)*
CDR Jillene Bushnell, *Commanding Officer (2016 - 2018)*
Mr. Robert Falvey, *Director (2006 - present)*
LCDR Katherine Coyle, *Executive Officer (2017 - present)*
AGC William Cady, *Senior Enlisted Advisor (2017 - present)*

Support Services Department

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

Satellite Reconnaissance Department

Capt Sean Zoufaly, *Satellite Operations Flight Commander* (2017 - 2018)*
TSgt Matthew Drew, *Satellite Operations NCOIC (2015 - 2018)****
MSgt Sonny Richardson, *Satellite Operations NCOIC (2017 - present)****
TSgt Jessica Elias, *Satellite Analyst (2018 - present)*
SrA Francisco Martinez, *Satellite Analyst (2016 - 2018)*
Mrs. Brittany Bermea, *Satellite Analyst (2016 - present)*
SSgt Cheyenne Lembke, *Satellite Analyst (2014 - 2018)*
SSgt Lyndsay Veerkamp, *Satellite Analyst (2017 - present)*
SrA Tyler Milam, *Satellite Analyst (2018 -present)*
SrA Thomas Lowe, *Satellite Analyst (2017 - 2018)*
SrA Myles Davis, *Satellite Analyst (2017 - present)*
A1C Isaiah Martin, *Satellite Analyst (2018 - present)*

Operations Department

LCDR Brian Howell, *Operations Department Head (2015 - 2018)**
LT David Price, *Operations Department Head (2018 - present)**
AGC Justin Coryell, *Operations Department LCPO (2017 - 2018)***
LT Caitlin Fine, *Command Duty Officer (2018 - present)*
LT Stephanie Geant, *Command Duty Officer (2016 - 2018)*
LT Edward Jacobs, *Command Duty Officer (2015 - 2018)*
LTJG Raul Ramirez, *Command Duty Officer (2017 - present)*
LT Lee Suring, *Command Duty Officer (2018 - present)*
LTJG Ricardo Uribe, *Command Duty Officer (2017 -present)*
AG1 Michael Schmidt, *Command Duty Officer (2015 -2018)*
AG2 Dakota Bennett, *Geophysical Technician (2015 -2018)*
AG2 Frandys Ferreras, *Geophysical Technician (2016 - 2018)*
AG2 Cole Bedgood, *Geophysical Technician (2016 - present)*
AGAN Austin Beauchamp, *Geophysical Technician (2017- 2018)*
AGAR Ethan Carrodus, *Geophysical Technician (2018 - present)*
AG3 Kain Enright, *Geophysical Technician (2018 - present)*
AG3 Samuel Wyss, *Geophysical Technician (2018 - 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)*
LT Christopher Machado, *Typhoon Duty Officer (2015 - 2018)***
LT Andrew Sweeney, *Typhoon Duty Officer (2017 - present)*

Plans and Requirements Department

Mr. Brian Strahl, *Plans and Requirements Department Head (2011 - present)**
AG2 Christopher Hoole, *Geophysical Technician (2015 - 2018)*

Information Services Department

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

Training Department

Mr. Owen Shieh, *Training Department Head (2016 - present)**
AG2 Carol Fisher, *Geophysical Technician (2015 - 2018)*

Technical Services Department

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

** 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 2018 season. JTWC issued warnings on 36 tropical cyclones. Table 1-2 shows the monthly distribution of TC activity summarized for 1959 - 2018 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 2018 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 2018 - 31 DEC 2018)

TC	NAME*	PERIOD**		WARNINGS ISSUED	EST MAX SFC WINDS KTS
01W	BOLAVEN	01 Jan / 1800Z	04 Jan / 0000Z	10	35
02W	SANBA	08 Feb / 1800Z	15 Feb / 0600Z	27	40
03W	JELAWAT	24 Mar / 1800Z	01 Apr / 0600Z	31	130
04W	FOUR	12 May / 0000Z	13 May / 1800Z	8	35
05W	EWINIAR	02 Jun / 0600Z	07 Jun / 1800Z	23	40
06W	MALIKSI	08 Jun / 0000Z	11 Jun / 1200Z	15	60
07W	SEVEN	13 Jun / 1800Z	14 Jun / 1200Z	4	35
08W	GAEMI	14 Jun / 0600Z	16 Jun / 0600Z	9	45
09W	PRAPIROON	28 Jun / 1200Z	04 Jul / 1200Z	25	80
10W	MARIA	02 Jul / 1800Z	11 Jul / 0000Z	34	145
11W	SON-TINH	15 Jul / 1200Z	24 Jul / 0600Z	26	50
12W	AMPIL	17 Jul / 1800Z	23 Jul / 1800Z	25	55
13W	THIRTEEN	20 Jul / 1800Z	23 Jul / 1200Z	12	35
14W	WUKONG	21 Jul / 1800Z	26 Jul / 1200Z	20	65
15W	JONGDARI	22 Jul / 0000Z	02 Aug / 1800Z	48	90
16W	SIXTEEN	30 Jul / 1200Z	31 Jul / 1800Z	6	35
17W	SHANSHAN	02 Aug / 1800Z	09 Aug / 1200Z	28	85
18W	YAGI	06 Aug / 1800Z	12 Aug / 1800Z	25	45
19W	LEEPI	11 Aug / 0000Z	15 Aug / 1800Z	20	65
20W	BEBINCA	12 Aug / 1200Z	17 Aug / 0000Z	19	60
10E	HECTOR	13 Aug / 1800Z	15 Aug / 0000Z	6	135
21W	RUMBIA	15 Aug / 0000Z	17 Aug / 0000Z	9	50
22W	SOULIK	15 Aug / 1200Z	24 Aug / 1800Z	38	105
23W	CIMARON	17 Aug / 1800Z	24 Aug / 0600Z	27	115
24W	TWENTYFOUR	23 Aug / 1800Z	25 Aug / 0600Z	7	30
25W	JEBI	27 Aug / 0600Z	04 Sep / 1200Z	34	155
26W	MANGKHUT	07 Sep / 0000Z	16 Sep / 1200Z	39	155
27W	BARIJAT	09 Sep / 1800Z	13 Sep / 1800Z	17	45
28W	TRAMI	20 Sep / 1800Z	30 Sep / 1200Z	40	140
29W	TWENTYNINE	26 Sep / 0600Z	27 Sep / 0000Z	4	30
30W	KONG-REY	28 Sep / 0000Z	06 Oct / 1800Z	36	150
31W	YUTU	21 Oct / 1200Z	02 Nov / 0000Z	47	55
32W	TORAJI	17 Nov / 1200Z	20 Nov / 1800Z	7	18
33W	USAGI	18 Nov / 0600Z	25 Nov / 1200Z	30	79
34W	MAN-YI	19 Nov / 1800Z	27 Nov / 1200Z	32	33
35W	THIRTY-FIVE	24 Dec / 1200Z	30 Dec / 0000Z	23	21
36W	PABUK	31 Dec / 0600Z	05 Jan / 1800Z	23	32

* 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

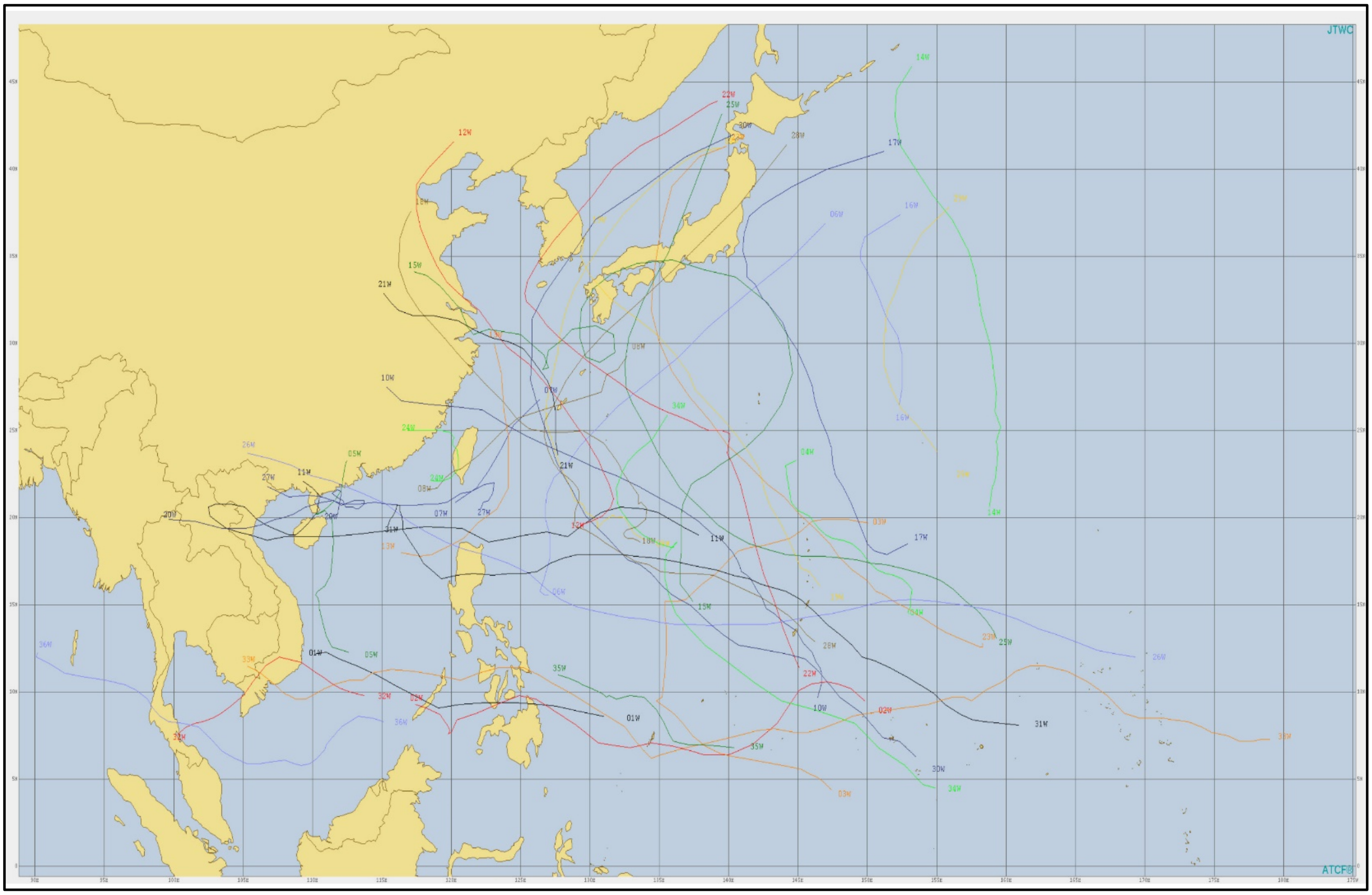

Figure 1-1. Western North Pacific Tropical Cyclones.

Table 1-2
DISTRIBUTION OF WESTERN NORTH PACIFIC TROPICAL CYCLONES
FOR 1959 - 2018

YEAR	JAN			FEB			MAR			APR			MAY			JUN			JUL			AUG			SEP			OCT			NOV			DEC			TOTALS (Total)		
																																					≥64kt	34-63kt	≤33 kt
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	
	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	2	0	0	6	1	1	3	5	0	5	2	1	3	3	1	4	2	0	1	0	1	26	13	5
1965		2			2			1			1			2			4			6			7			9			3			2			1			40	
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1966		0			0			0			1			2			1			4			9			10			4			5			2			38	
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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	
	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	2	0	2	1	2	0	3	4	1	4	0	0	5	1	0	4	0	0	0	0	0	20	7	4
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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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
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1978		1			0			0			1			0			3			4			8			4			7			4			0			32	
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1979		1			0			1			1			2			0			5			4			6			3			2			3			28	
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1983		0			0			0			0			0			1			3			6			3			5			5			2			25	
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1986		0			1			0			1			2			2			2			5			2			5			4			3			27	
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1987		1			0			0			1			0			2			4			4			7			2			3			1			25	
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1988		1			0			0			0			1			3			2			5			8			4			2			1			27	
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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	
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1991		0			0			2			1			1			1			4			8			6			3			6			0			32	
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1992		1			1			0			0			0			3			4			8			5			6			5			0			33	
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2000		0			0			0			0			4			0			8			9			6			3			3			1			34	
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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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2011		0			0			0			2			2			3			4			4			7			1			1			3			27	
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2016		0			0			0			0			1			0			5			9			6			4			4			1			30	
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2017		1			0			0			2			0			1			8			6			4			5			4			2			33	
	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	3	5	0	3	3	0	2	0	2	3	0	2	1	2	1	1	1	0	13	13	7
2018		1			1			1			0			1			5			7			10			5			1			3			2			37	
	0	1	0	0	1	0	1	0	0	0	0	0	0	1	0	1	4	0	3	4	0	6	3	1	3	1	1	0	1	0	1	0	2	0	0	2	15	16	6

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 - 2018)													
	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	2.6	3.4	3.2	2.9	1.5	0.7	16.9
CASES	12	5	13	24	43	60	153	206	193	173	90	39	1011
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 - 2018)													
	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	15	27	38	67	106	240	334	291	235	147	72	1601

TABLE 1-4 TROPICAL CYCLONE FORMATION ALERTS FOR THE WESTERN NORTH PACIFIC OCEAN 1976 - 2018					
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%
MEAN	34	27	29	20%	93%
CASES	1498	1196	1280		
* Percentage of initial TCFAs not followed by warnings.					

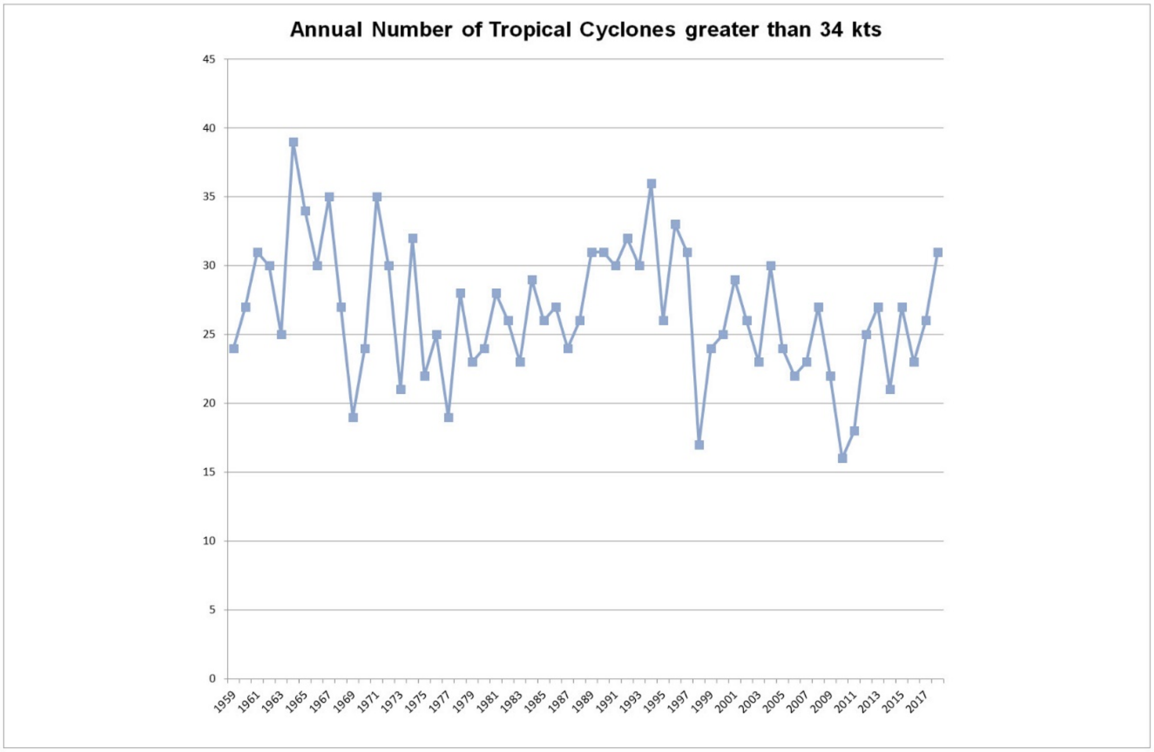


Figure 1-2. Annual number of western North Pacific TCs greater than 34 knots intensity.

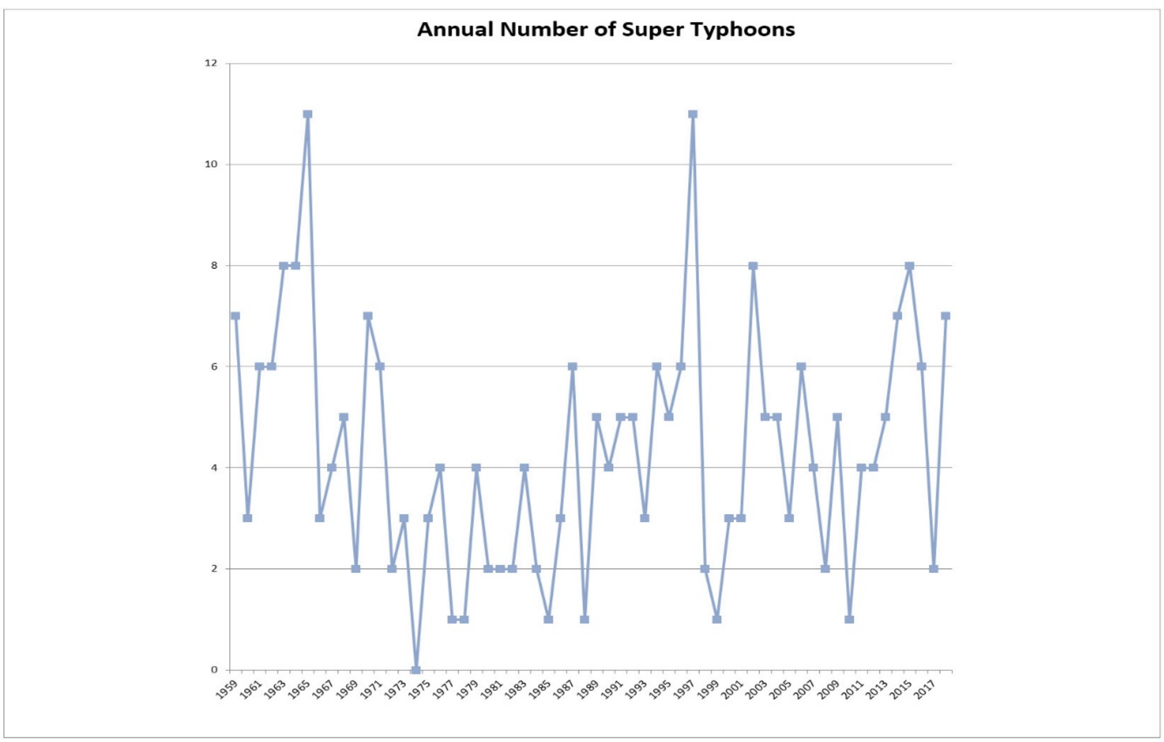
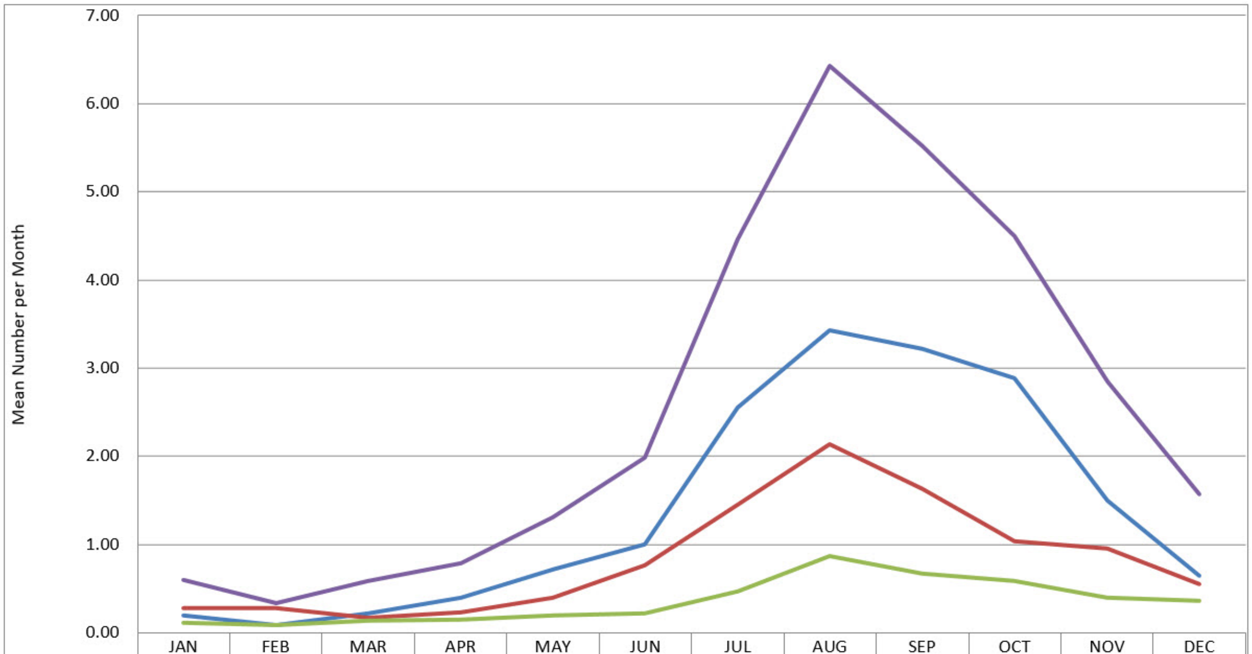


Figure 1-3. Annual number of western North Pacific TCs greater than 129 knots intensity.



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
TY AVG	0.20	0.08	0.22	0.40	0.72	1.00	2.55	3.43	3.22	2.88	1.50	0.65
TS AVG	0.28	0.28	0.17	0.23	0.40	0.77	1.45	2.13	1.63	1.03	0.95	0.55
TD AVG	0.12	0.08	0.13	0.15	0.20	0.22	0.47	0.87	0.67	0.58	0.40	0.37
All AVG	0.60	0.33	0.58	0.78	1.32	1.98	4.47	6.43	5.52	4.50	2.85	1.57

Figure 1-4. Average number of western North Pacific TCs (all intensities) by month 1959-2018.

Section 2 Cyclone Summaries

This section presents a synopsis of each tropical cyclone that occurred during storm year 2018 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 Regional Specialized Meteorological Center (RSMC) Tokyo, Japan.

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

- "Low" formation potential describes an area that is being monitored for warning-level TC 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 TC warnings when one or more of the following four criteria are met:

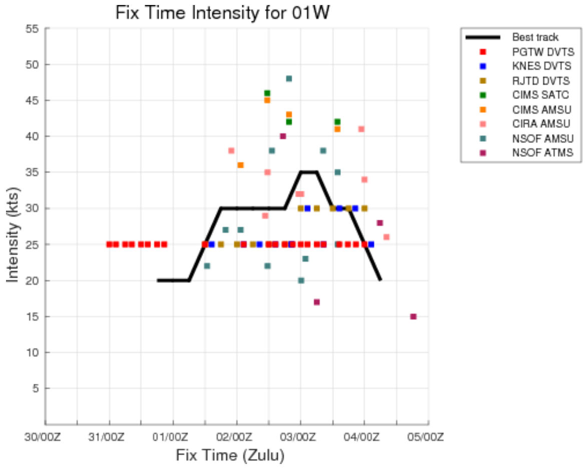
- Estimated maximum sustained wind speeds within a closed tropical circulation meet or exceed a designated threshold of 25 knots in the North Pacific Ocean or 35 knots in the South Pacific and Indian Oceans.
- Maximum sustained wind speeds within a closed tropical circulation are expected to increase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

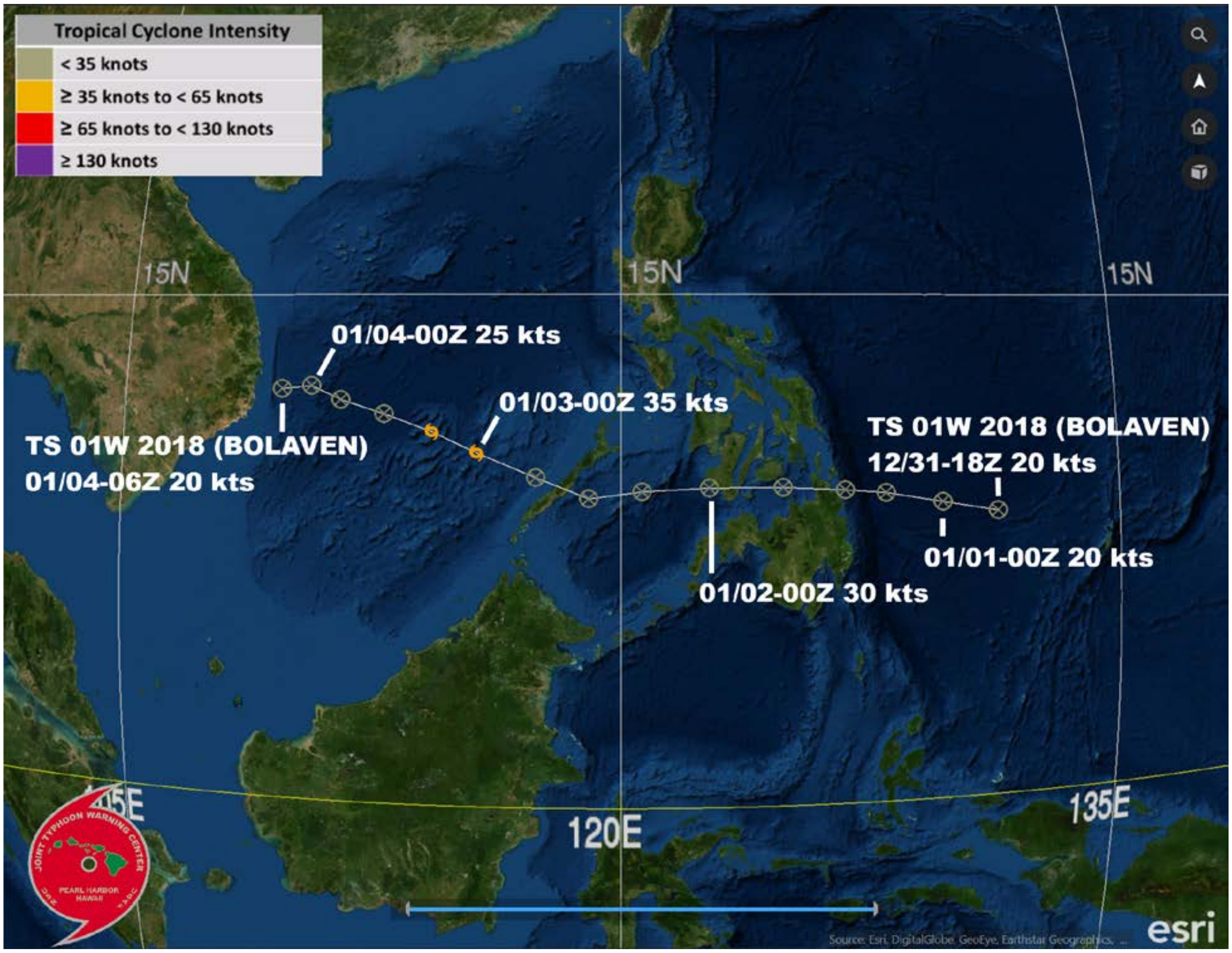
The JTWC post-event, reanalysis best track is provided for each cyclone. Data included on the best track are position and intensity noted with color-coded cyclone symbols and track line. Best track position labels include the date, time, track speed in knots, maximum wind speed in knots, as well as the 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/2018/2018s-bwp/WP_besttracks_2018-2018.kmz

01W TROPICAL STORM BOLAVEN

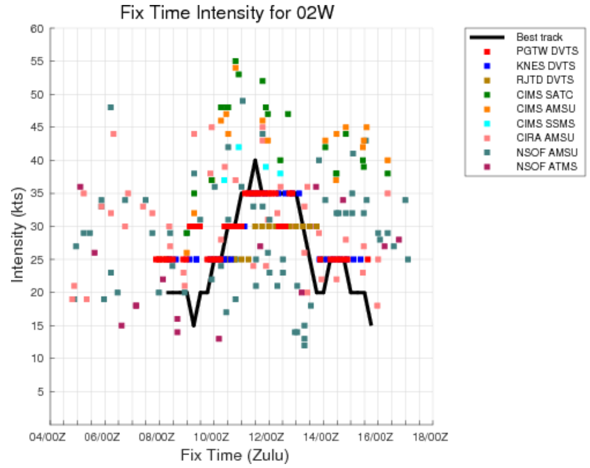
ISSUED LOW:	30 Dec / 1930Z
ISSUED MED:	31 Dec / 0130Z
FIRST TCFA:	01 Jan / 1330Z
FIRST WARNING:	01 Jan / 1800Z
LAST WARNING:	04 Jan / 0000Z
MAX INTENSITY:	35
WARNINGS:	10

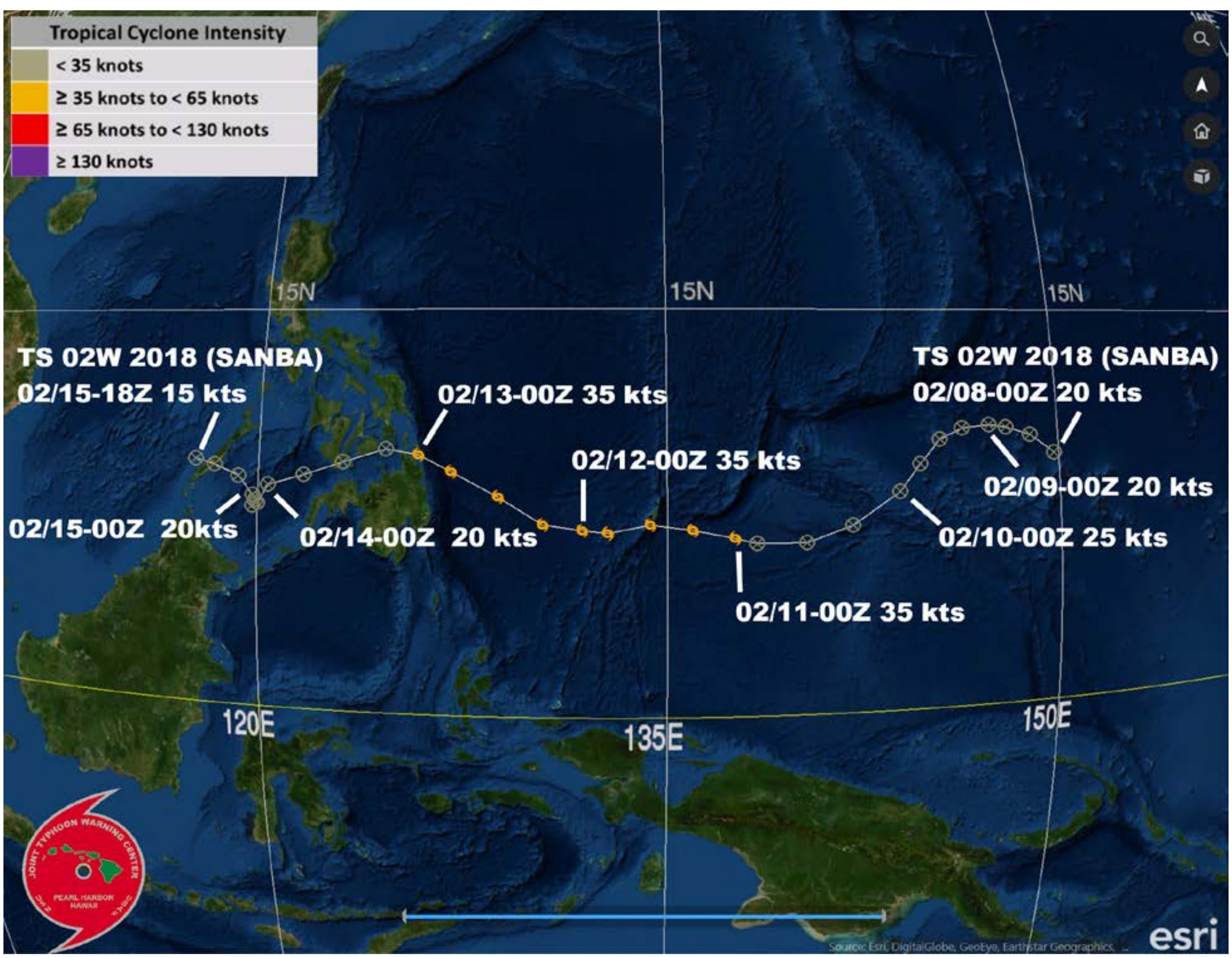




02W TROPICAL STORM SANBA

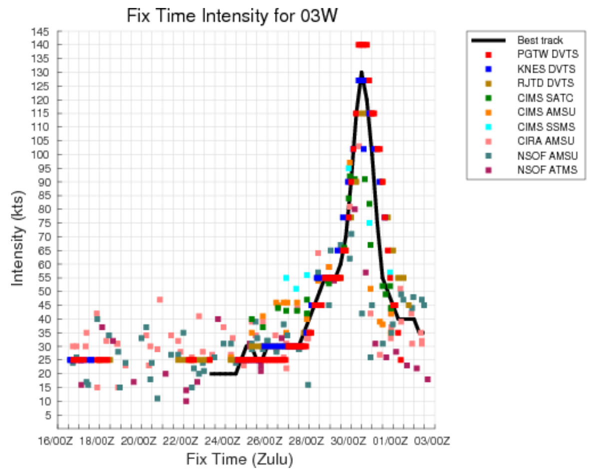
ISSUED LOW:	06 Feb / 0600Z
ISSUED MED:	07 Feb / 0000Z
FIRST TCFA:	07 Feb / 2230Z
FIRST WARNING:	08 Feb / 1800Z
LAST WARNING:	15 Feb / 0600Z
MAX INTENSITY:	40
WARNINGS:	27

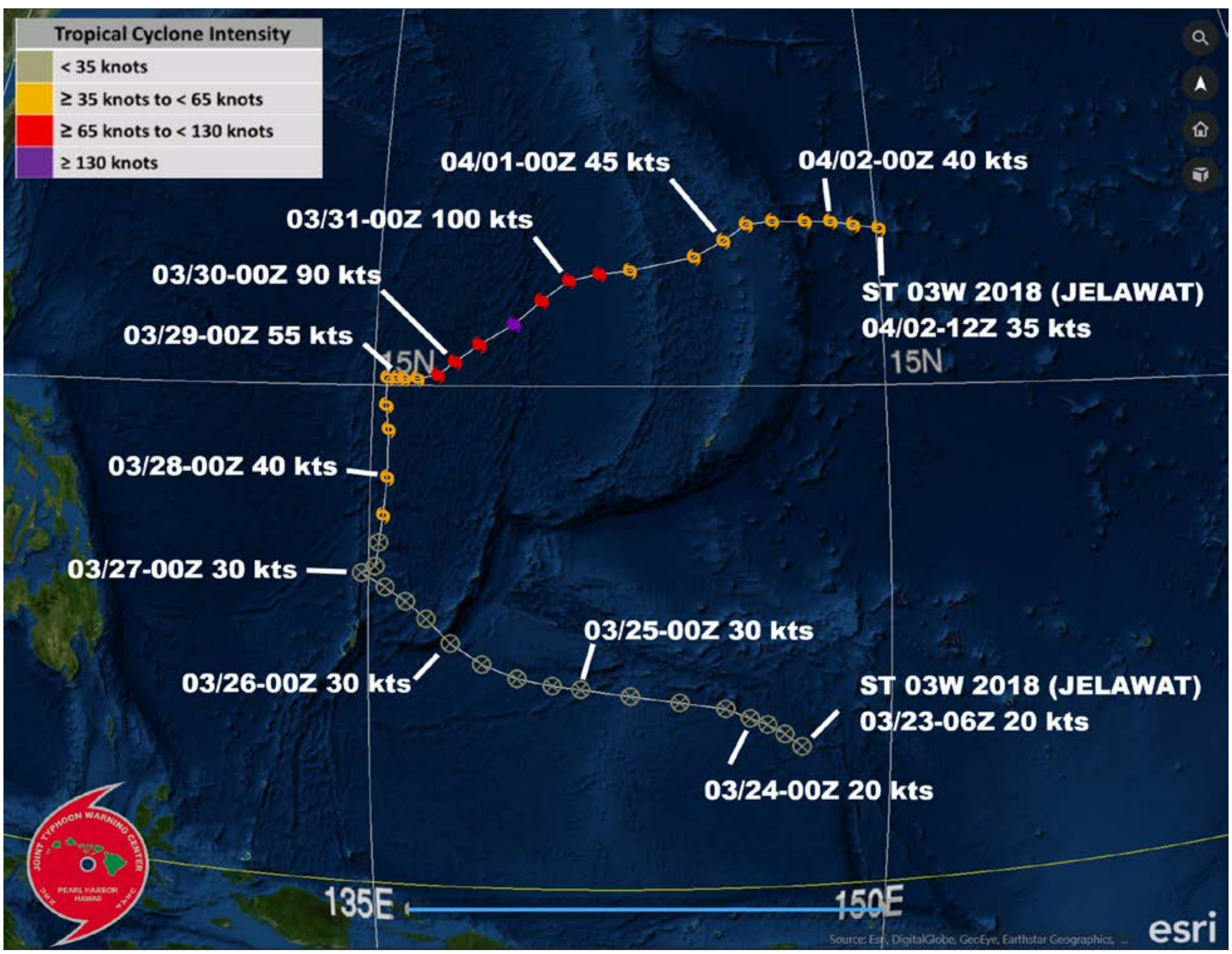




03W SUPER TYPHOON JELAWAT

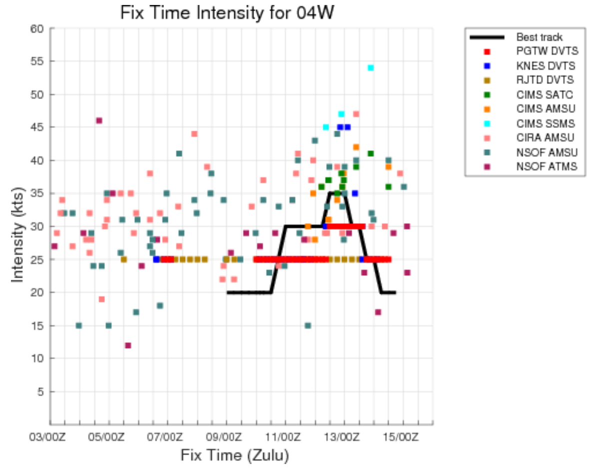
ISSUED LOW:	N/A
ISSUED MED:	16 Mar / 2000Z
FIRST TCFA:	23 Mar / 0530Z
FIRST WARNING:	24 Mar / 1800Z
LAST WARNING:	01 Apr / 0600Z
MAX INTENSITY:	130
WARNINGS:	31

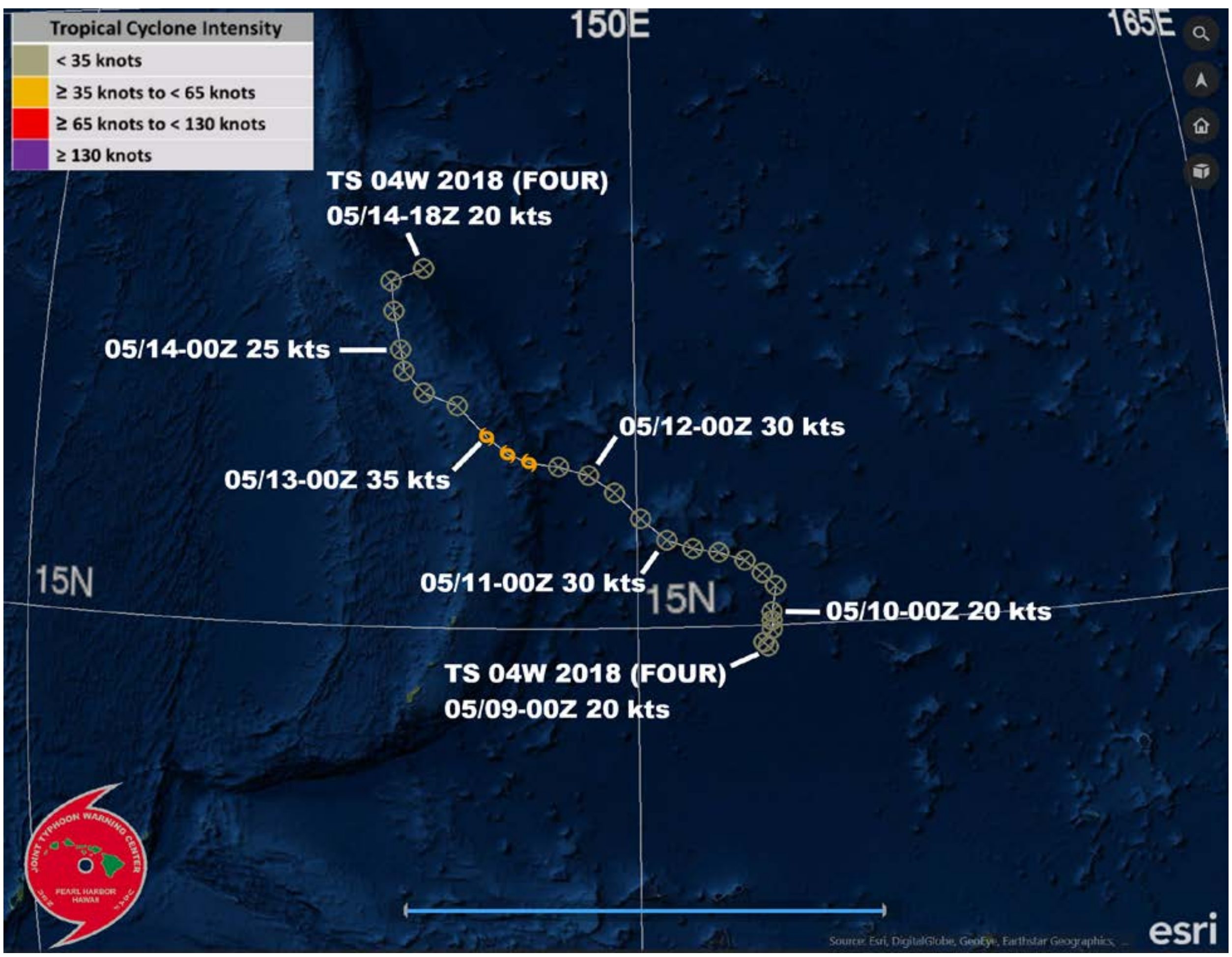




04W TROPICAL STORM FOUR

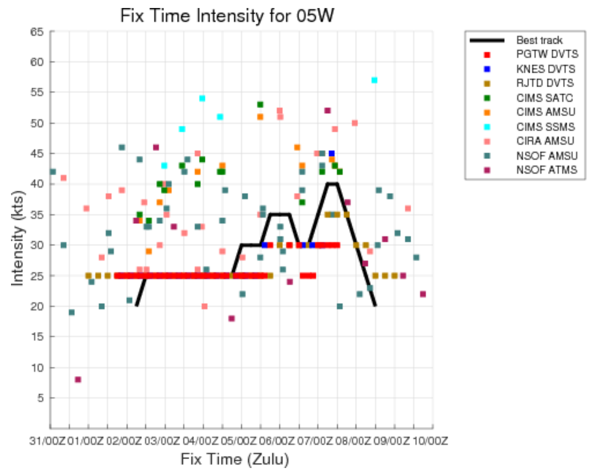
ISSUED LOW:	03 May / 1400Z
ISSUED MED:	N/A
FIRST TCFA:	10 May / 2230Z
FIRST WARNING:	12 May / 0000Z
LAST WARNING:	13 May / 1800Z
MAX INTENSITY:	35
WARNINGS:	8

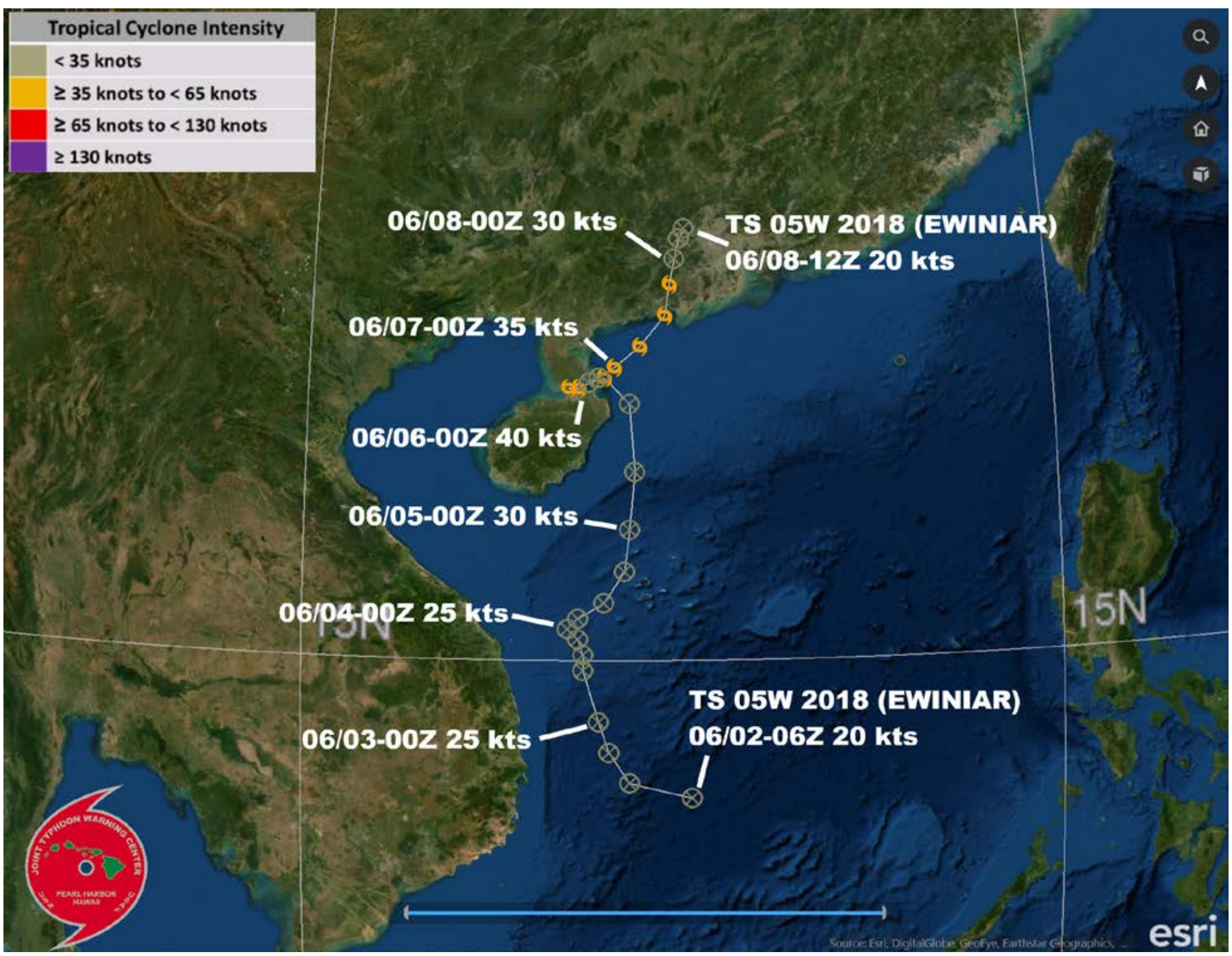




05W TROPICAL STORM EWINIAR

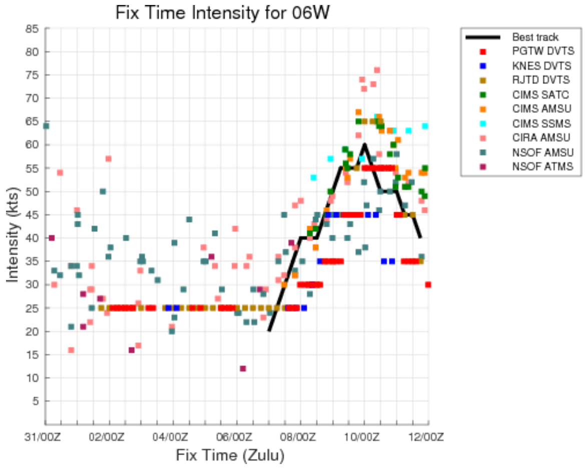
ISSUED LOW:	31 May / 0600Z
ISSUED MED:	31 May / 2000Z
FIRST TCFA:	01 Jun / 0230Z
FIRST WARNING:	02 Jun / 0600Z
LAST WARNING:	07 Jun / 1800Z
MAX INTENSITY:	40
WARNINGS:	23

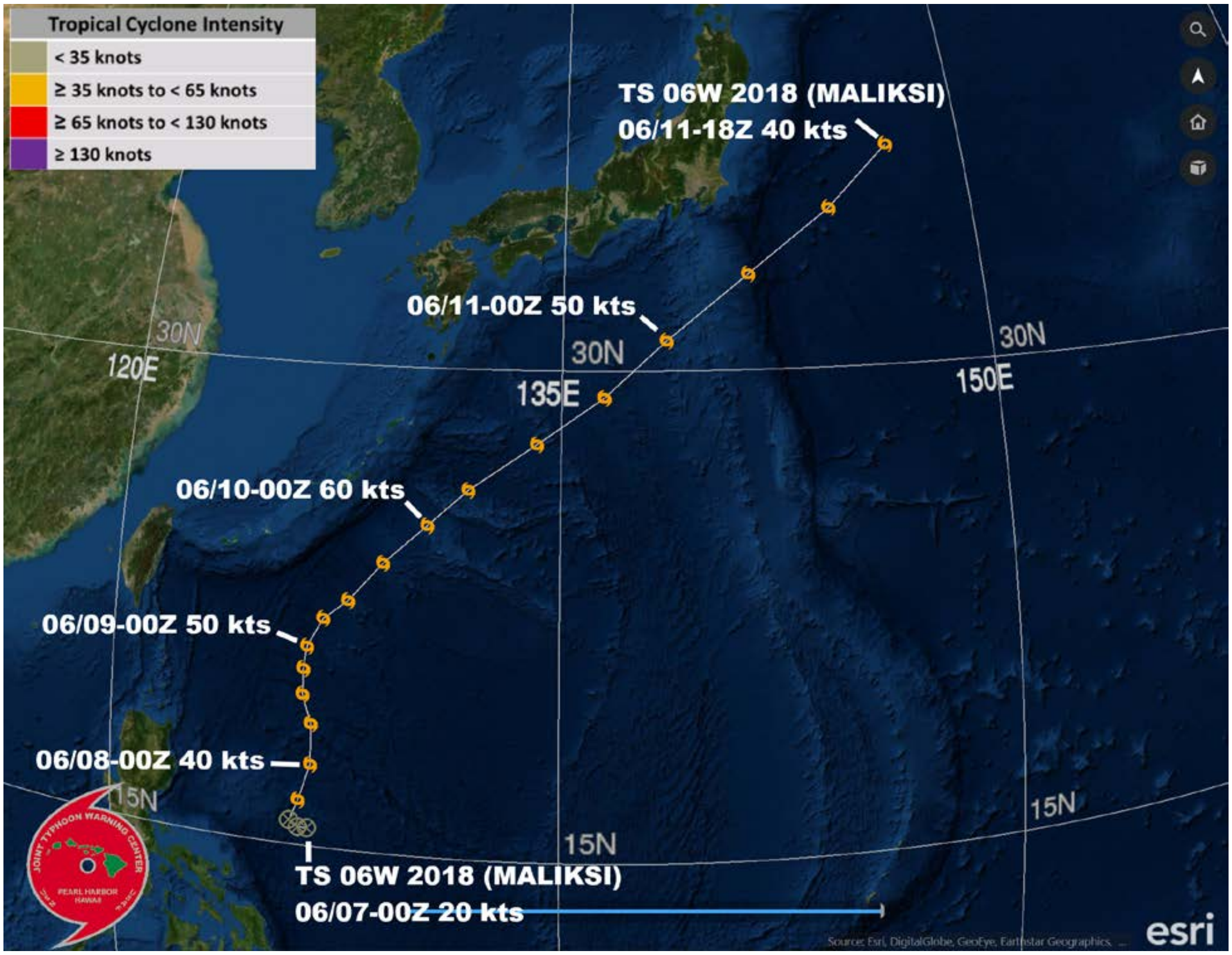




06W TROPICAL STORM MALIKSI

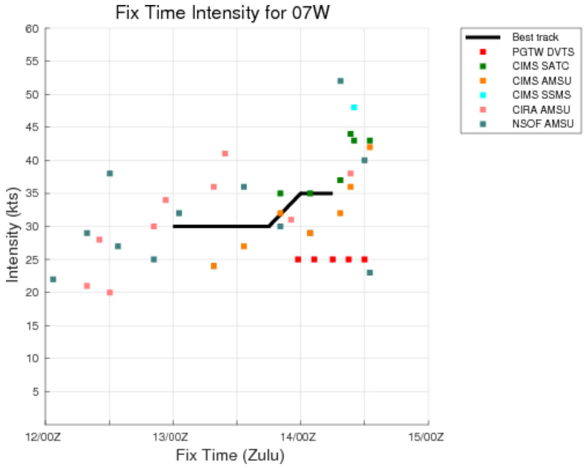
ISSUED LOW:	31 May / 0600Z
ISSUED MED:	02 Jun / 0030Z
FIRST TCFA:	05 Jun / 1400Z
FIRST WARNING:	08 Jun / 0000Z
LAST WARNING:	11 Jun / 1200Z
MAX INTENSITY:	60
WARNINGS:	15

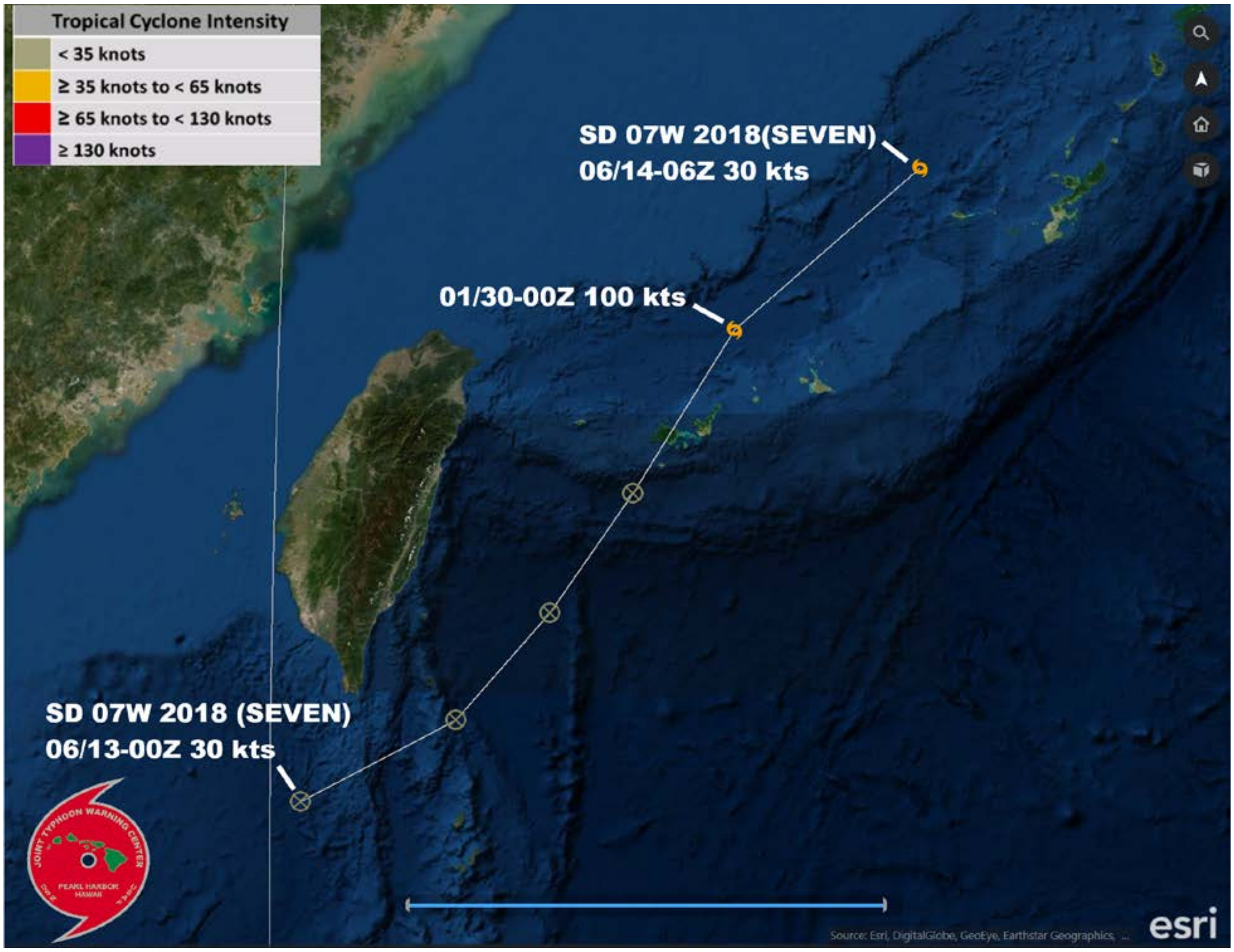




07W TROPICAL STORM SEVEN

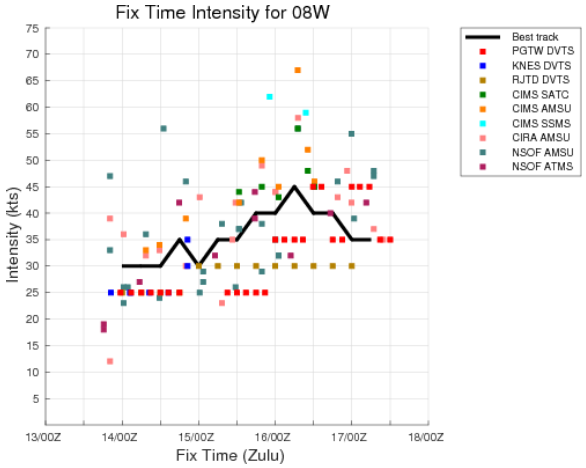
ISSUED LOW:	12 Jun / 0600Z
ISSUED MED:	12 Jun / 1430Z
FIRST TCFA:	13 Jun / 0200Z
FIRST WARNING:	13 Jun / 1800Z
LAST WARNING:	14 Jun / 1200Z
MAX INTENSITY:	35
WARNINGS:	4

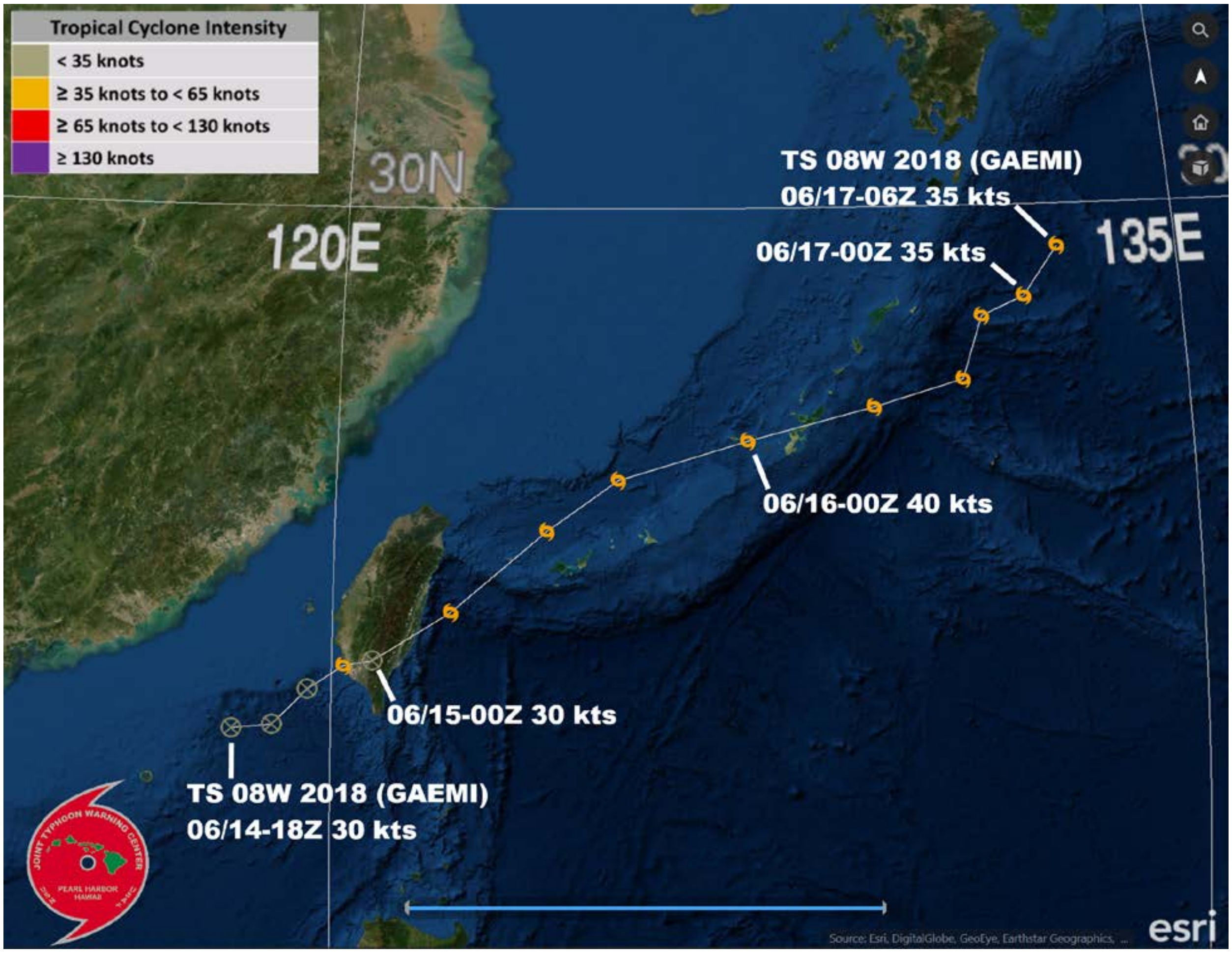




08W TROPICAL STORM GAEMI

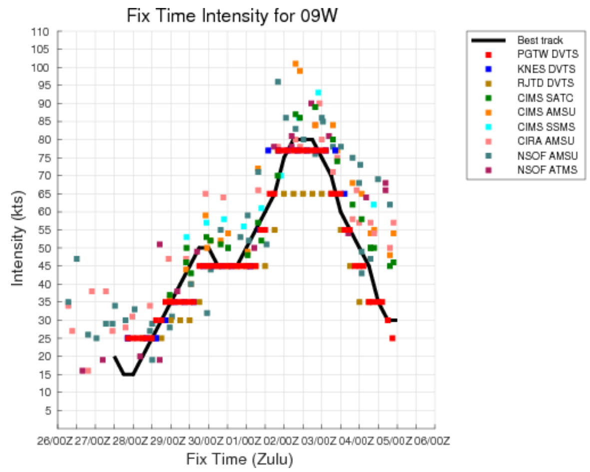
ISSUED LOW:	13 Jun / 2300Z
ISSUED MED:	N/A
FIRST TCFA:	14 Jun / 0430Z
FIRST WARNING:	14 Jun / 0600Z
LAST WARNING:	16 Jun / 0600Z
MAX INTENSITY:	45
WARNINGS:	9

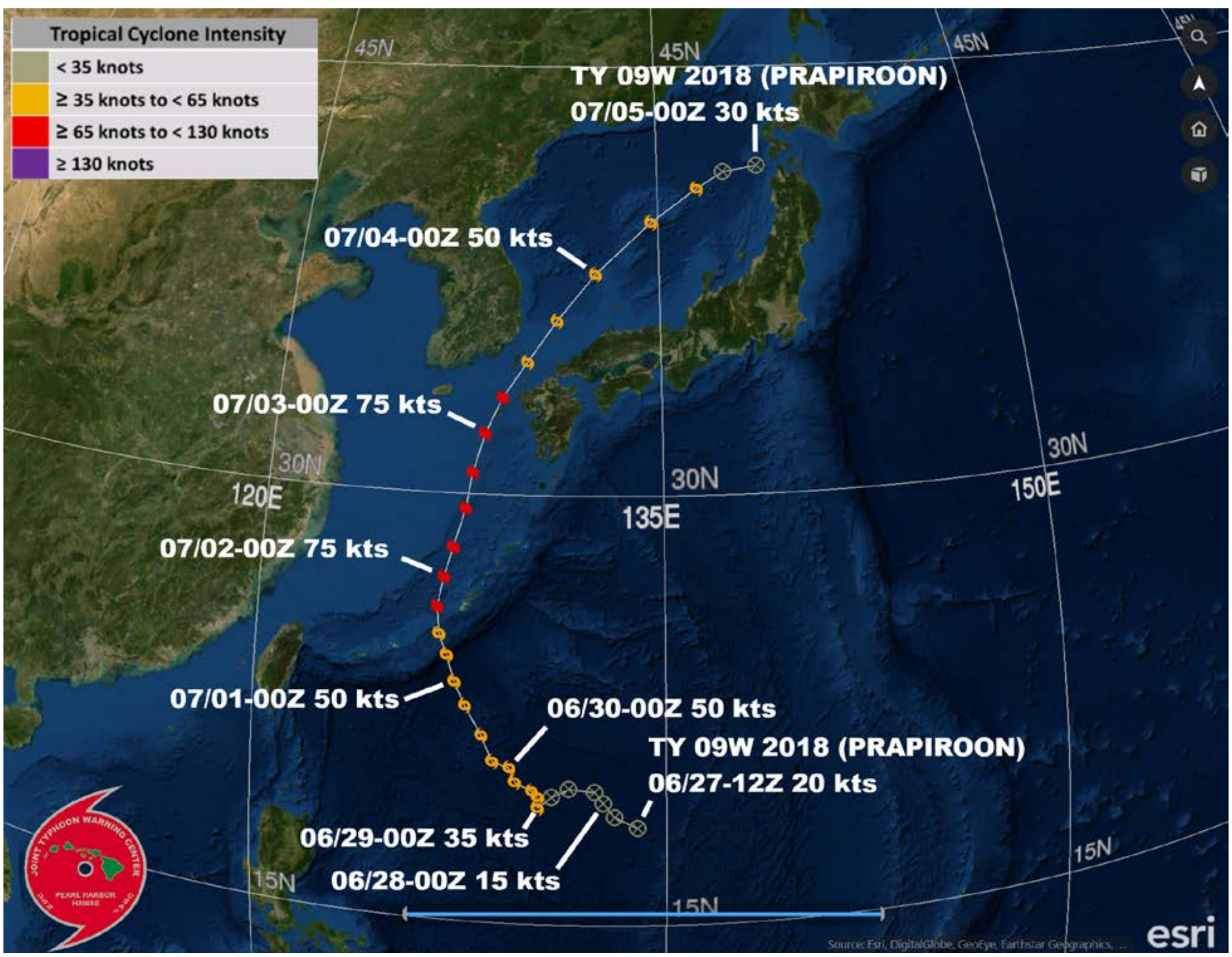




09W TYPHOON PRAPIROON

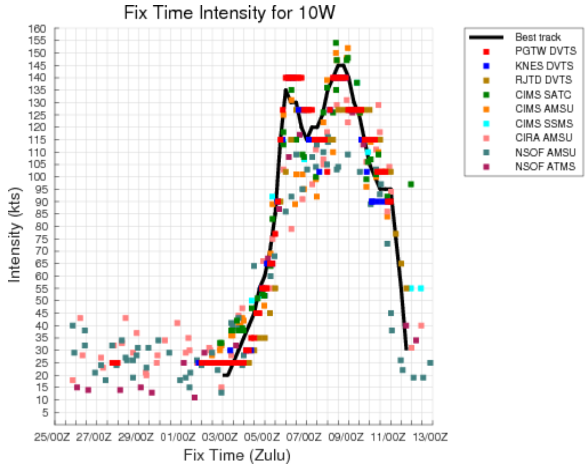
ISSUED LOW:	27 Jun / 2000Z
ISSUED MED:	28 Jun / 0030Z
FIRST TCFA:	28 Jun / 0830Z
FIRST WARNING:	28 Jun / 1200Z
LAST WARNING:	04 Jul / 1200Z
MAX INTENSITY:	80
WARNINGS:	25

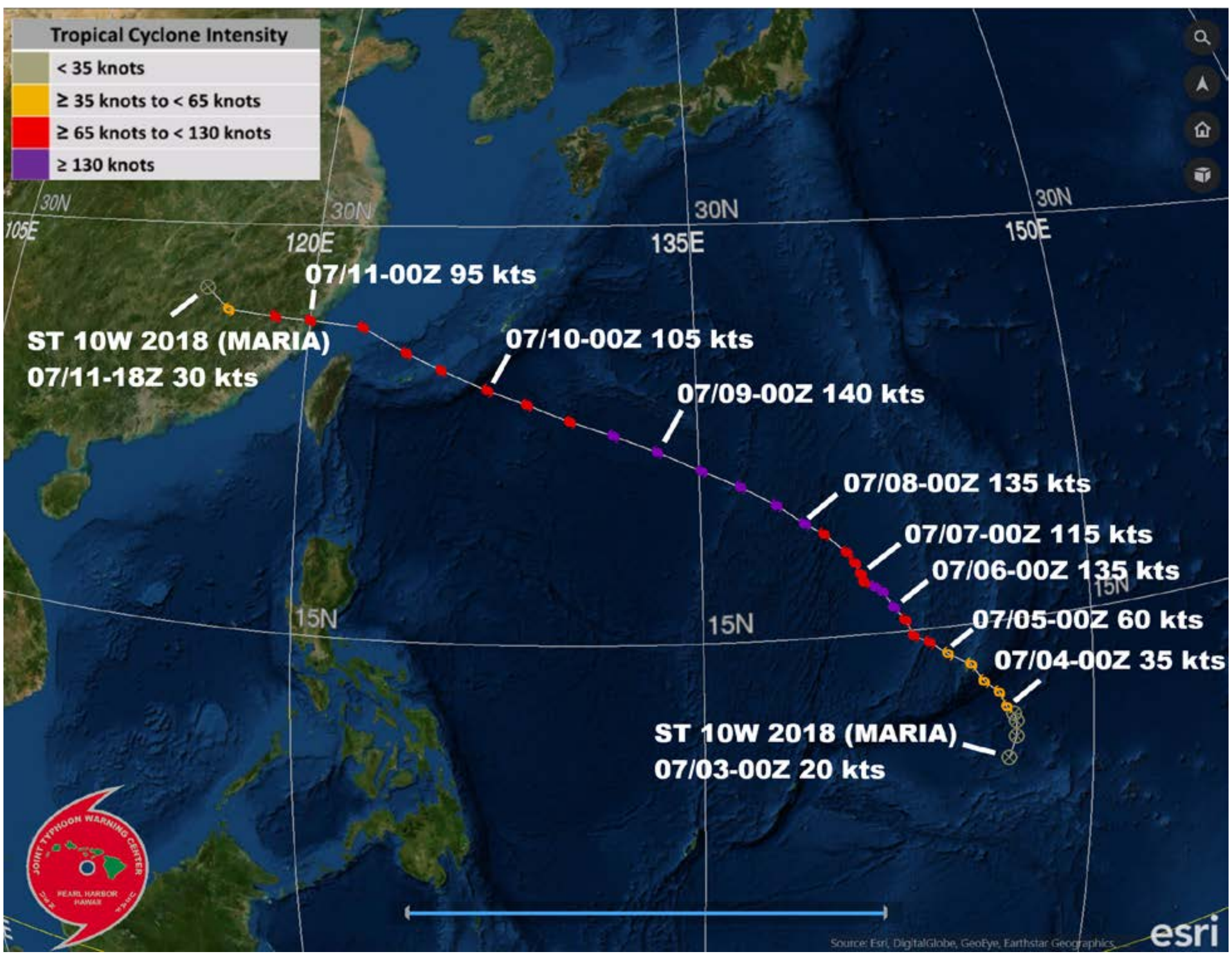




10W SUPER TYPHOON MARIA

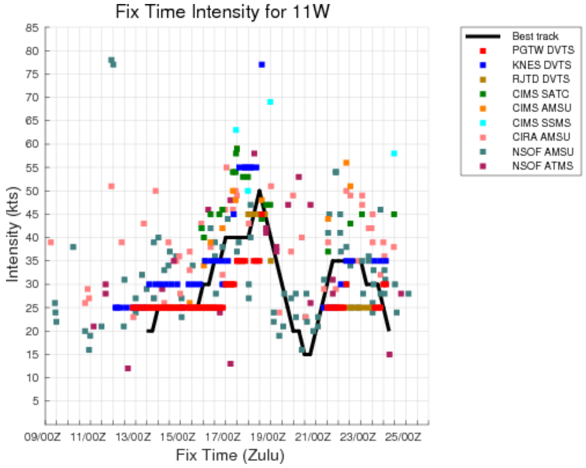
ISSUED LOW:	27 Jun / 2000Z
ISSUED MED:	01 Jul / 2300Z
FIRST TCFA:	02 Jul / 0300Z
FIRST WARNING:	02 Jul / 1800Z
LAST WARNING:	11 Jul / 0000Z
MAX INTENSITY:	145
WARNINGS:	34

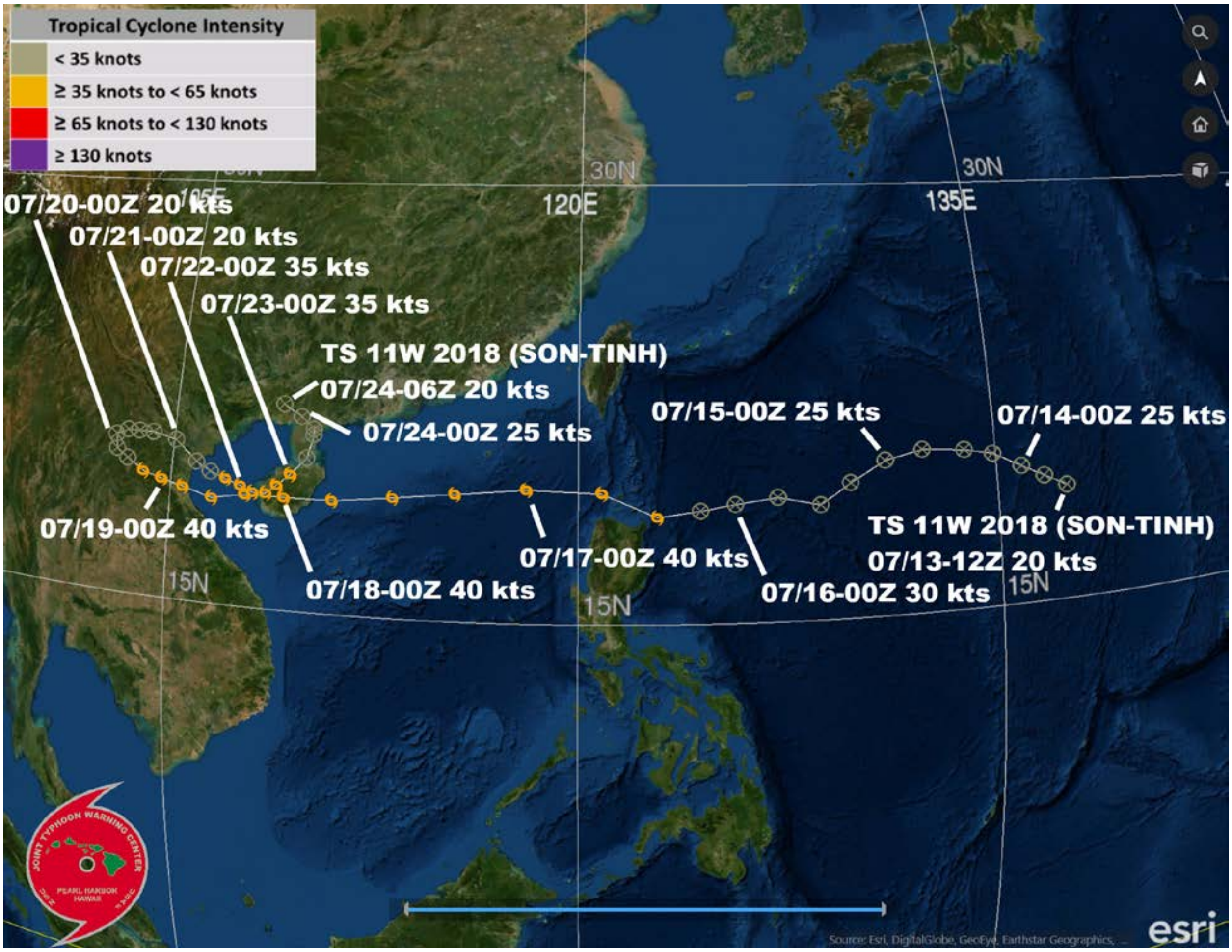




11W TROPICAL STORM SON-TINH

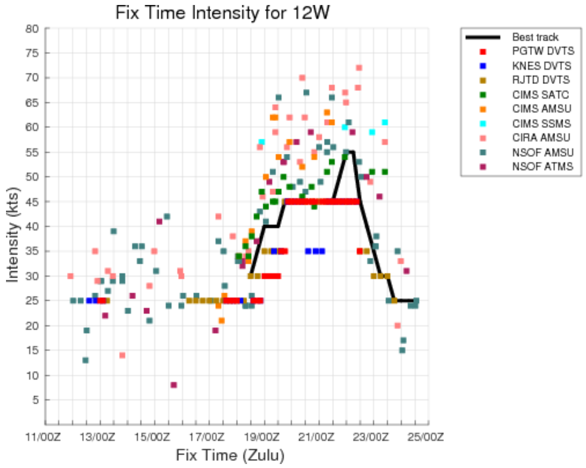
ISSUED LOW:	11 Jul / 0300Z
ISSUED MED:	12 Jul / 0600Z
FIRST TCFA:	14 Jul / 0200Z
FIRST WARNING:	15 Jul / 1200Z
LAST WARNING:	18 Jul / 1800Z
MAX INTENSITY:	50
WARNINGS:	14

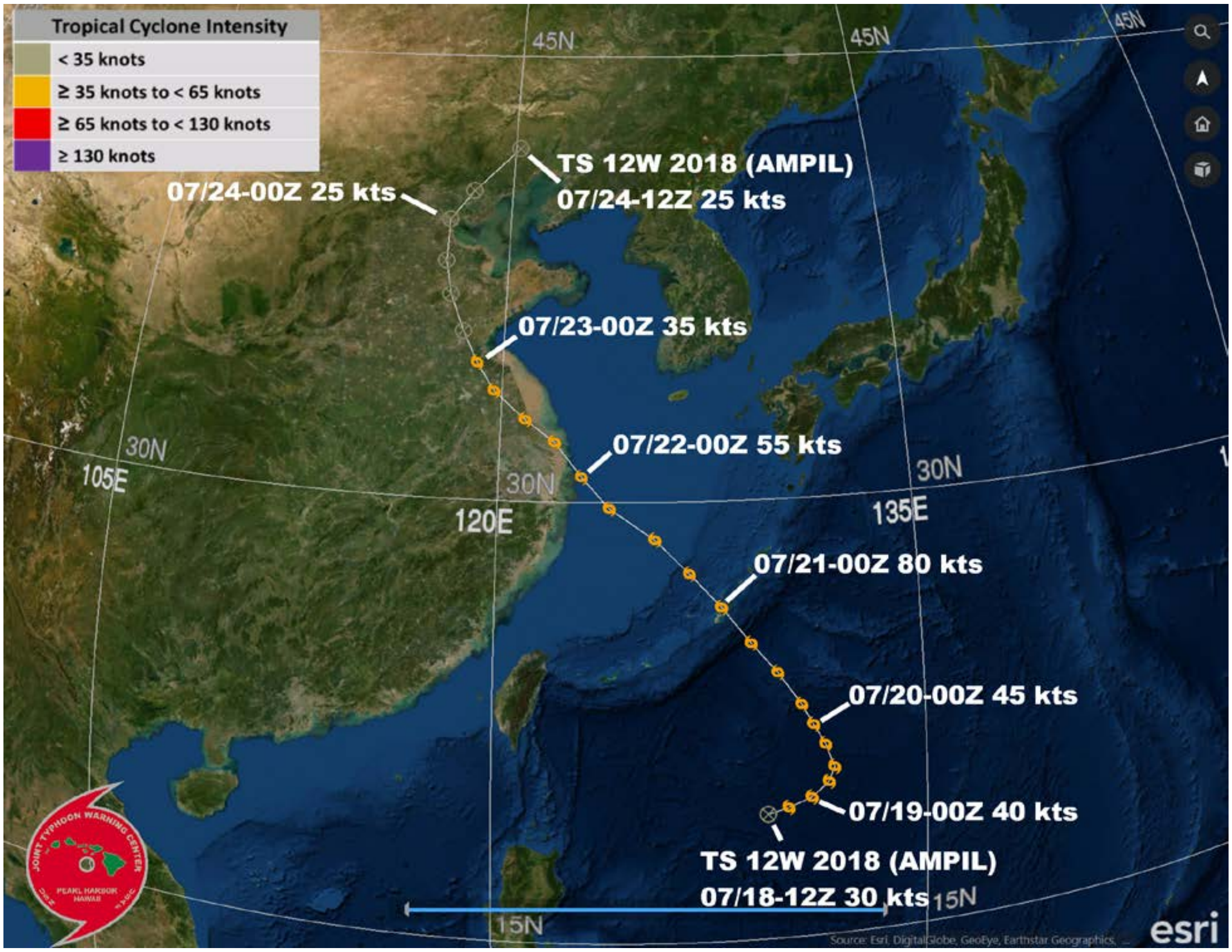




12W TROPICAL STORM AMPIL

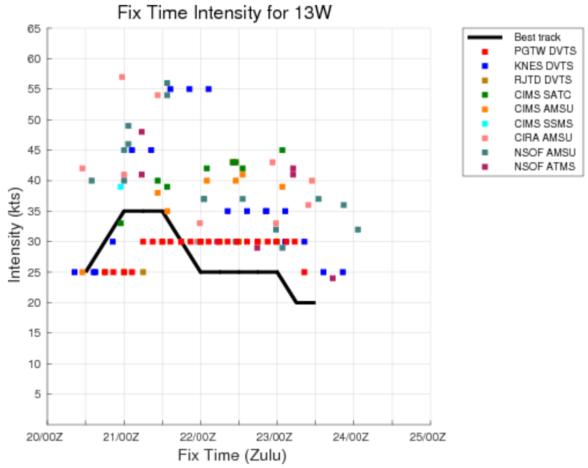
ISSUED LOW:	N/A
ISSUED MED:	15 Jul / 1730Z
FIRST TCFA:	17 Jul / 1000Z
FIRST WARNING:	17 Jul / 1800Z
LAST WARNING:	23 Jul / 1800Z
MAX INTENSITY:	55
WARNINGS:	25

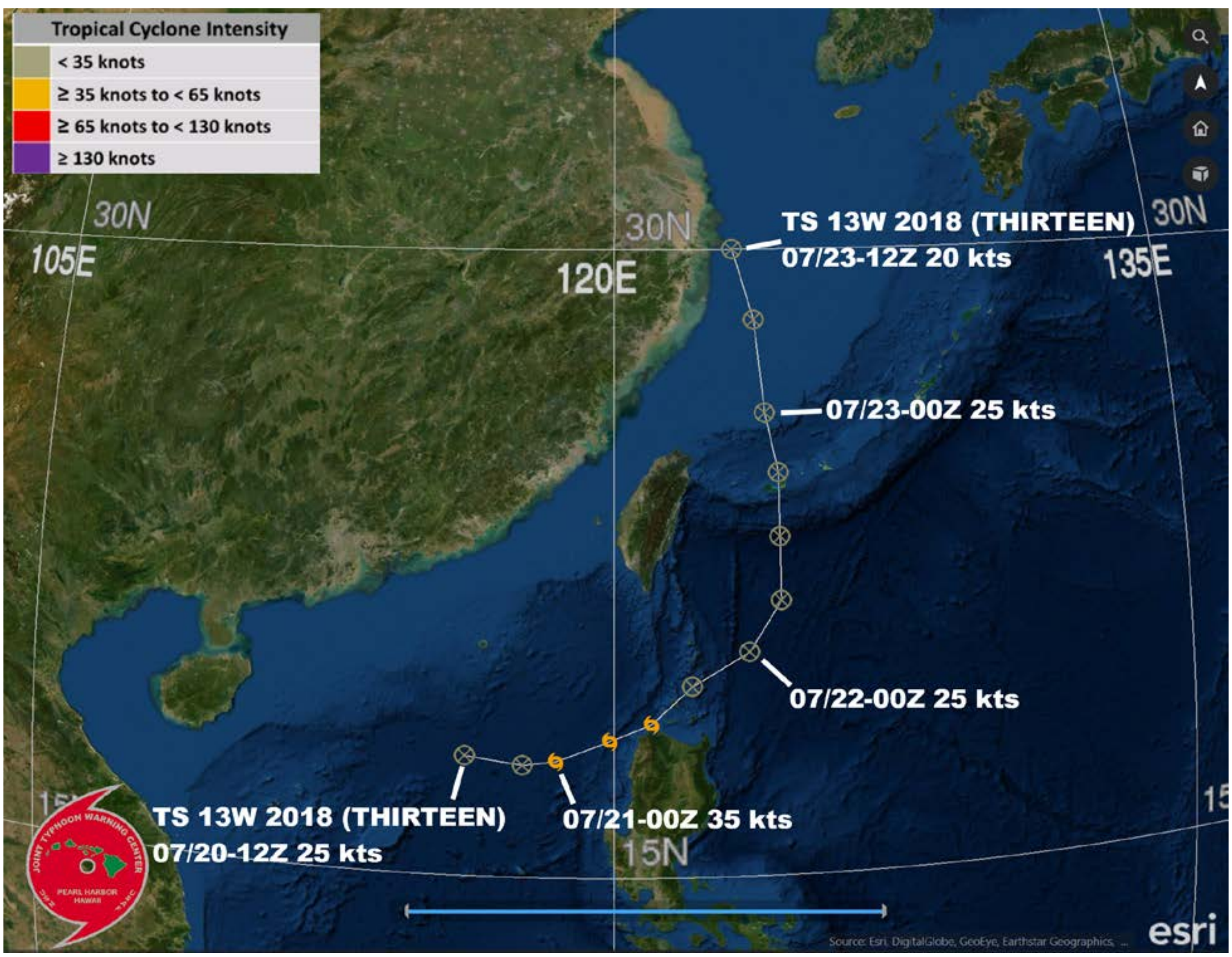




13W TROPICAL STORM THIRTEEN

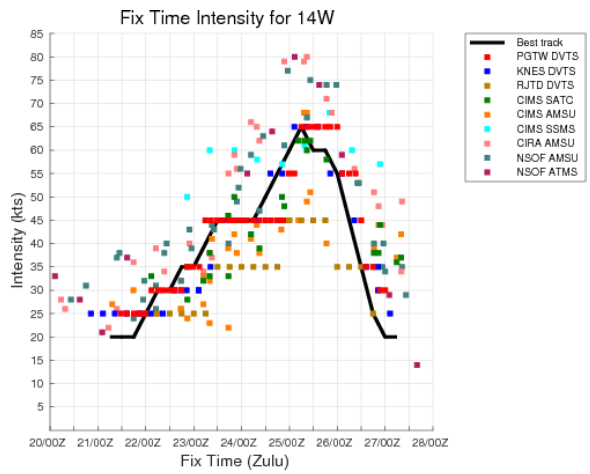
ISSUED LOW:	20 Jul / 0600Z
ISSUED MED:	N/A
FIRST TCFA:	20 Jul / 1630Z
FIRST WARNING:	20 Jul / 1800Z
LAST WARNING:	23 Jul / 1200Z
MAX INTENSITY:	35
WARNINGS:	12

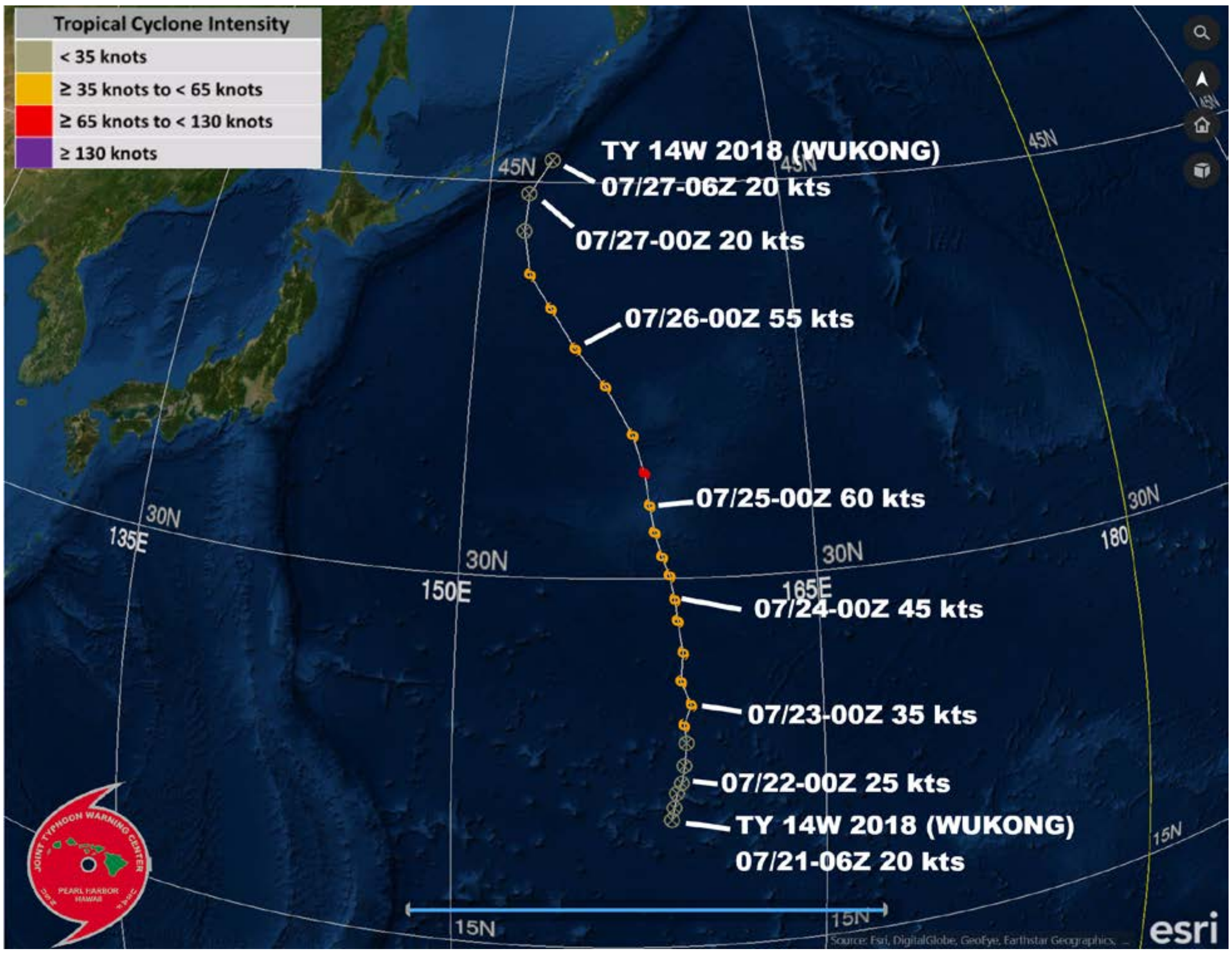




14W TYPHOON WUKONG

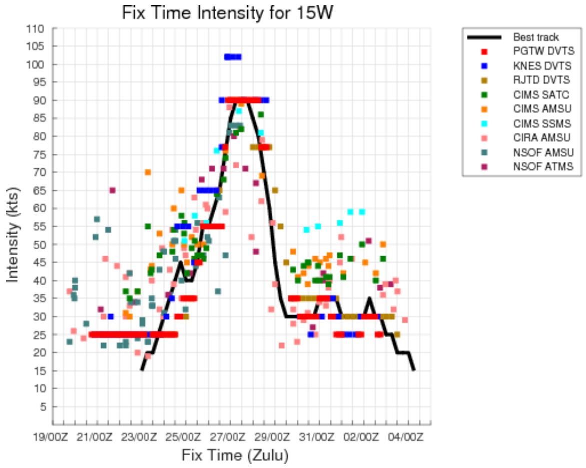
ISSUED LOW:	N/A
ISSUED MED:	21 Jul / 0600Z
FIRST TCFA:	21 Jul / 1700Z
FIRST WARNING:	21 Jul / 1800Z
LAST WARNING:	26 Jul / 1200Z
MAX INTENSITY:	65
WARNINGS:	20

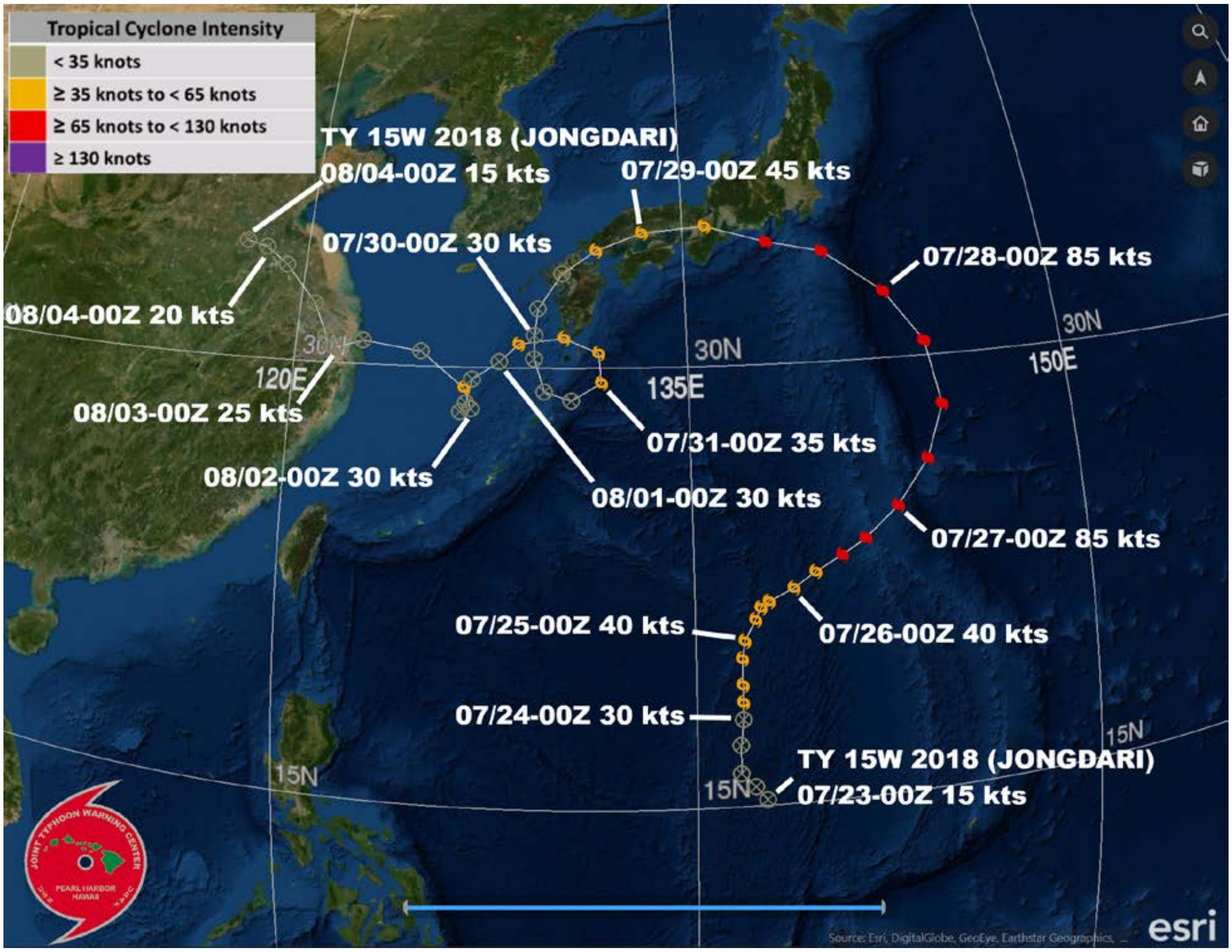




15W TYPHOON JONGDARI

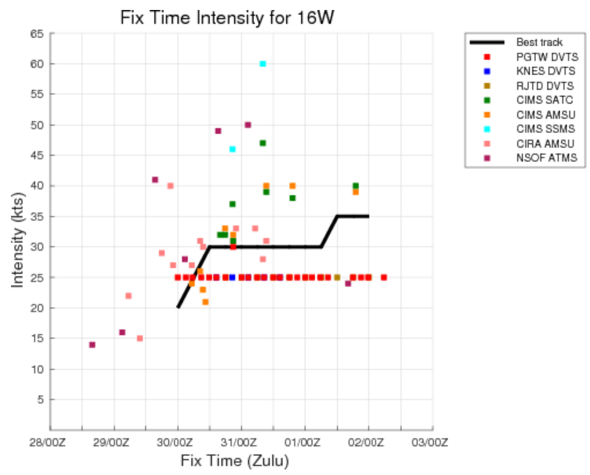
ISSUED LOW:	20 Jul / 2200Z
ISSUED MED:	21 Jul / 0600Z
FIRST TCFA:	21 Jul / 1300Z
FIRST WARNING:	22 Jul / 0000Z
LAST WARNING:	02 Aug / 1800Z
MAX INTENSITY:	90
WARNINGS:	48

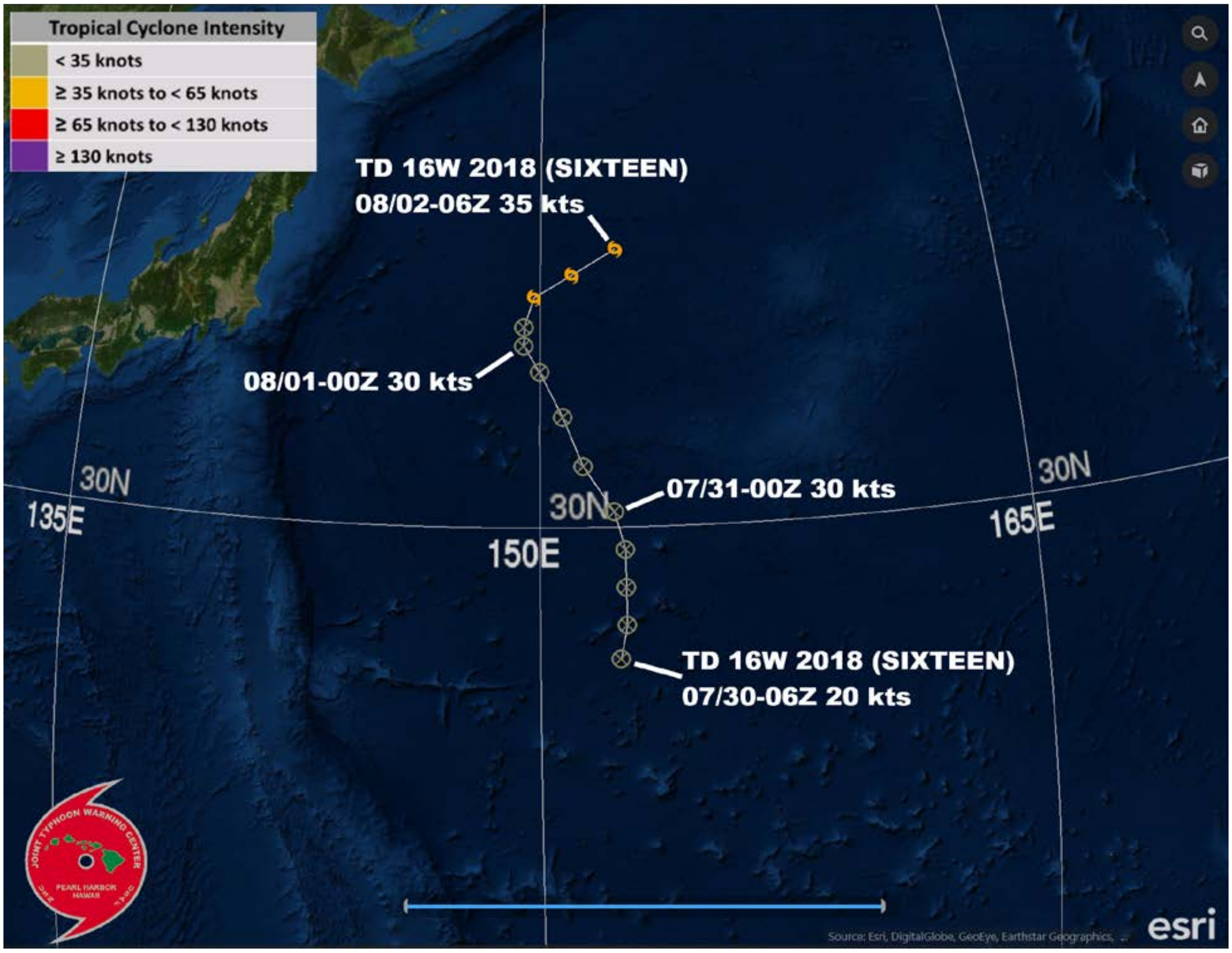




16W TROPICAL STORM SIXTEEN

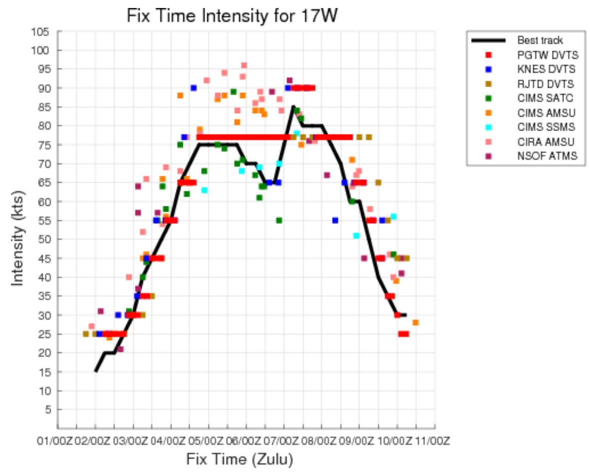
ISSUED LOW:	29 Jul / 0600Z
ISSUED MED:	29 Jul / 1900Z
FIRST TCFA:	29 Jul / 2100Z
FIRST WARNING:	30 Jul / 1200Z
LAST WARNING:	31 Jul / 1800Z
MAX INTENSITY:	35
WARNINGS:	6

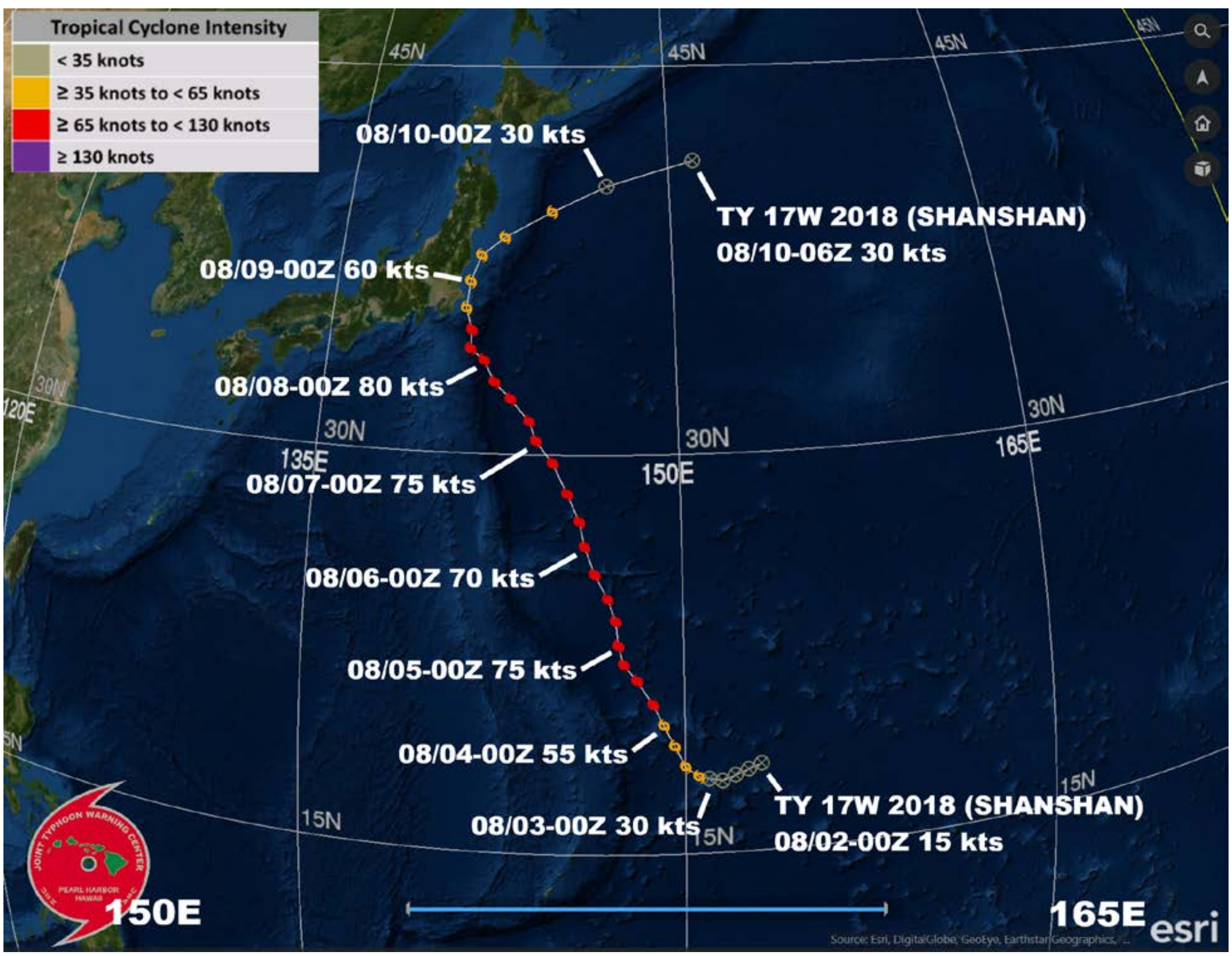




17W TYPHOON SHANSHAN

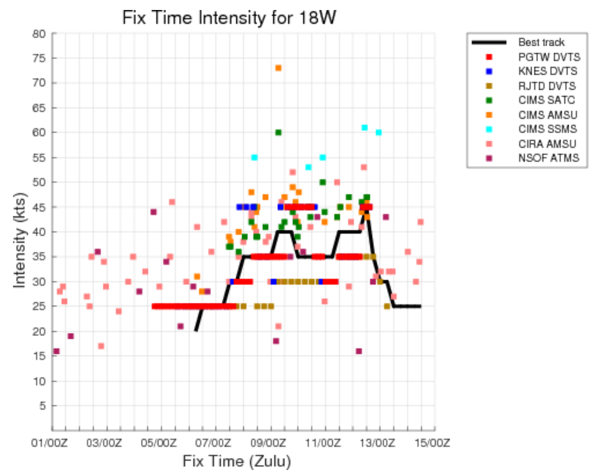
ISSUED LOW:	01 Aug / 0600Z
ISSUED MED:	02 Aug / 0100Z
FIRST TCFA:	02 Aug / 0700Z
FIRST WARNING:	02 Aug / 1800Z
LAST WARNING:	09 Aug / 1200Z
MAX INTENSITY:	85
WARNINGS:	28

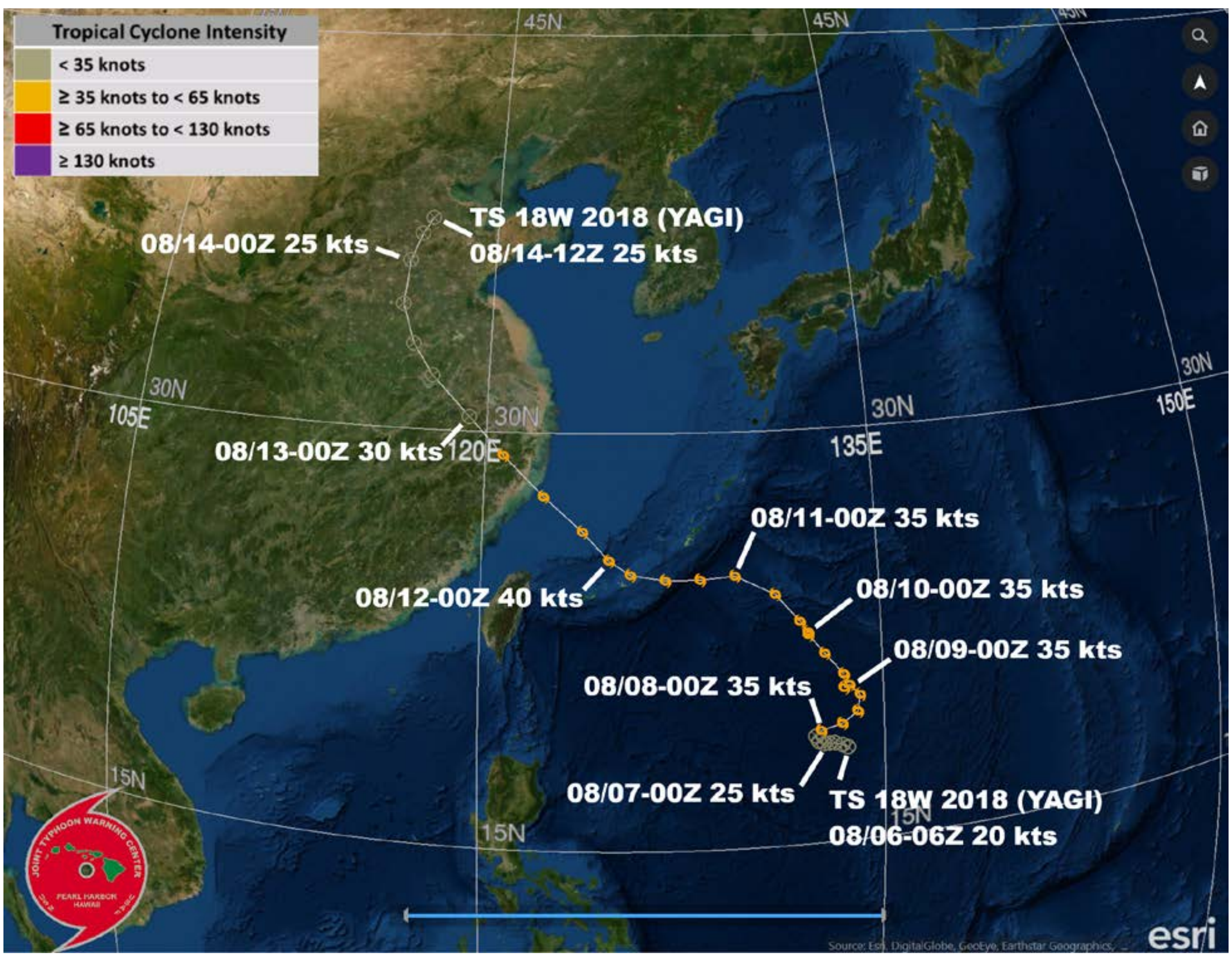




18W TROPICAL STORM YAGI

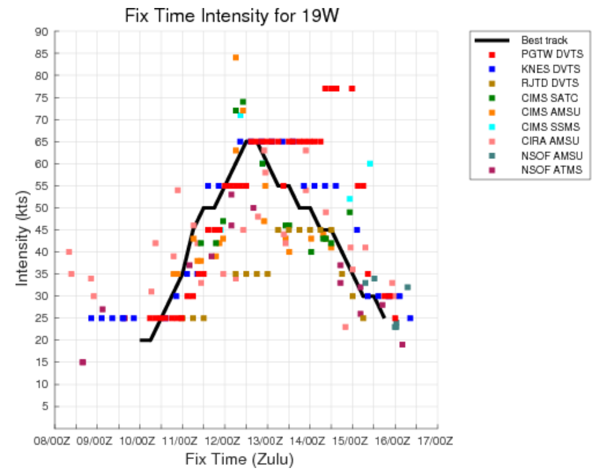
ISSUED LOW:	01 Aug / 0600Z
ISSUED MED:	05 Aug / 0600Z
FIRST TCFA:	05 Aug / 2030Z
FIRST WARNING:	06 Aug / 1800Z
LAST WARNING:	12 Aug / 1800Z
MAX INTENSITY:	45
WARNINGS:	25

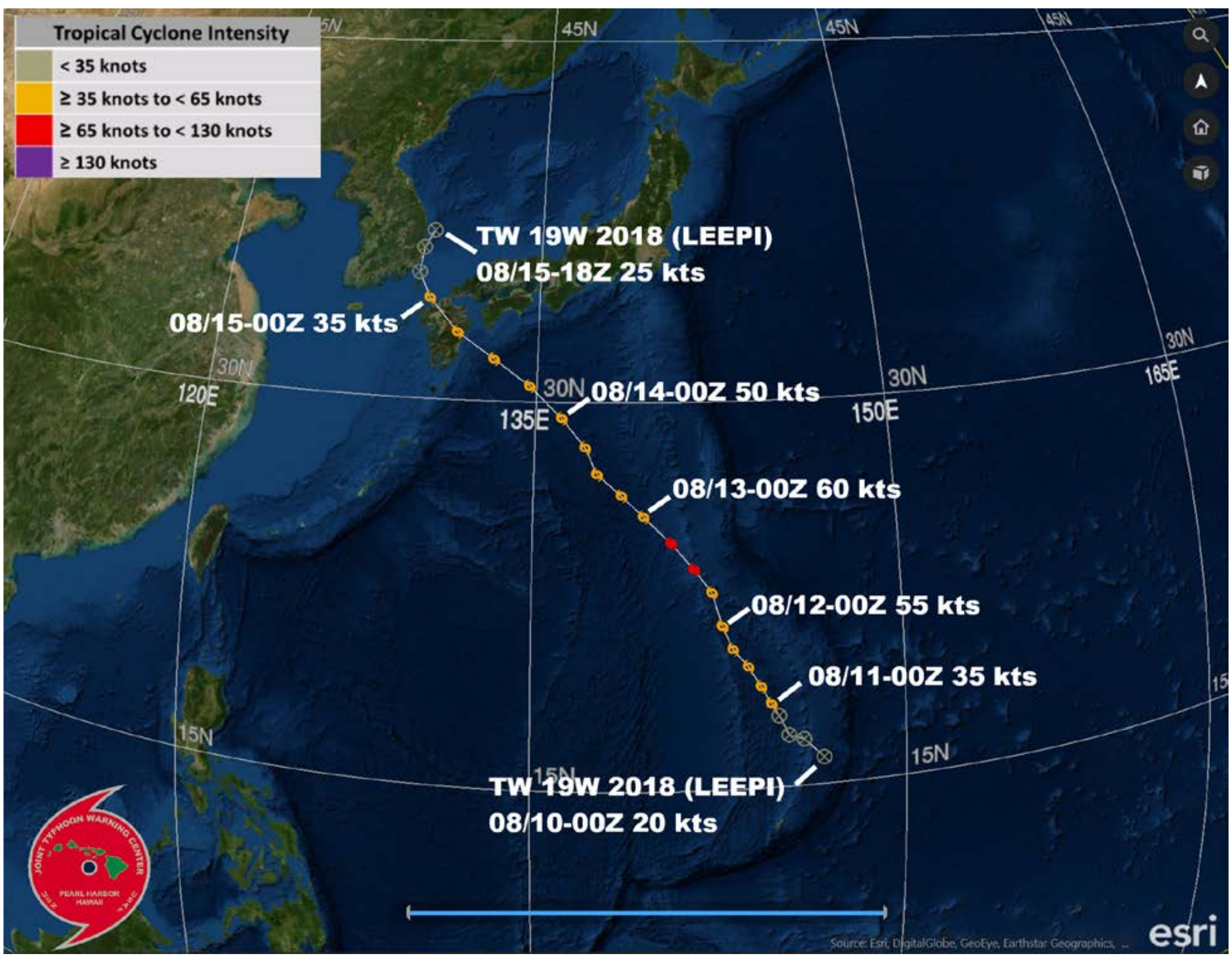




19W TYPHOON LEEPI

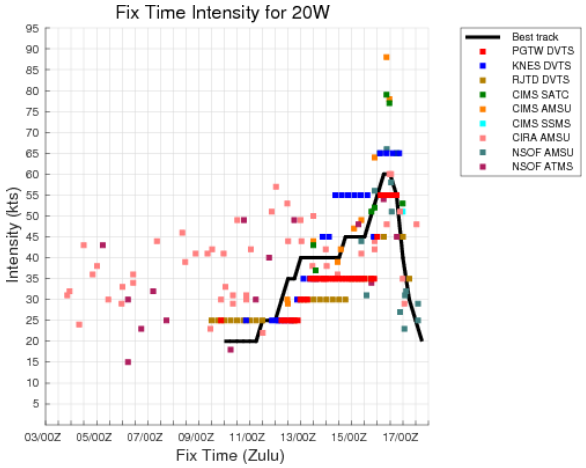
ISSUED LOW:	09 Aug / 2200Z
ISSUED MED:	10 Aug / 0600Z
FIRST TCFA:	N/A
FIRST WARNING:	11 Aug / 0000Z
LAST WARNING:	15 Aug / 1800Z
MAX INTENSITY:	65
WARNINGS:	20

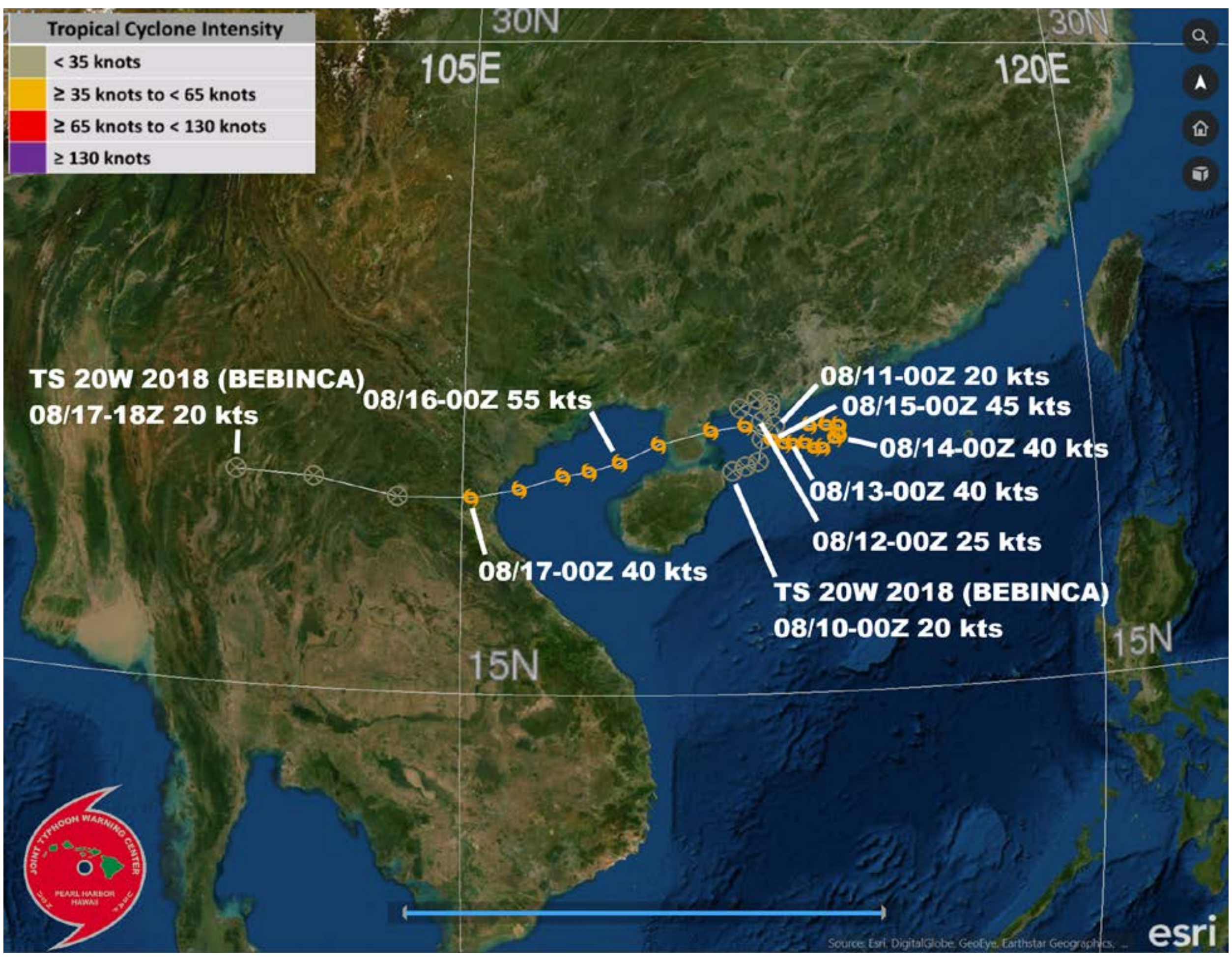




20W TROPICAL STORM BEBINCA

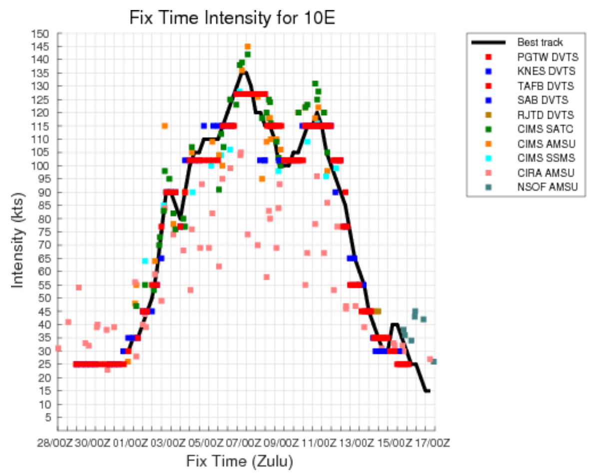
ISSUED LOW:	03 Aug / 2330Z
ISSUED MED:	08 Aug / 1100Z
FIRST TCFA:	12 Aug / 0530Z
FIRST WARNING:	12 Aug / 1200Z
LAST WARNING:	17 Aug / 0000Z
MAX INTENSITY:	60
WARNINGS:	19

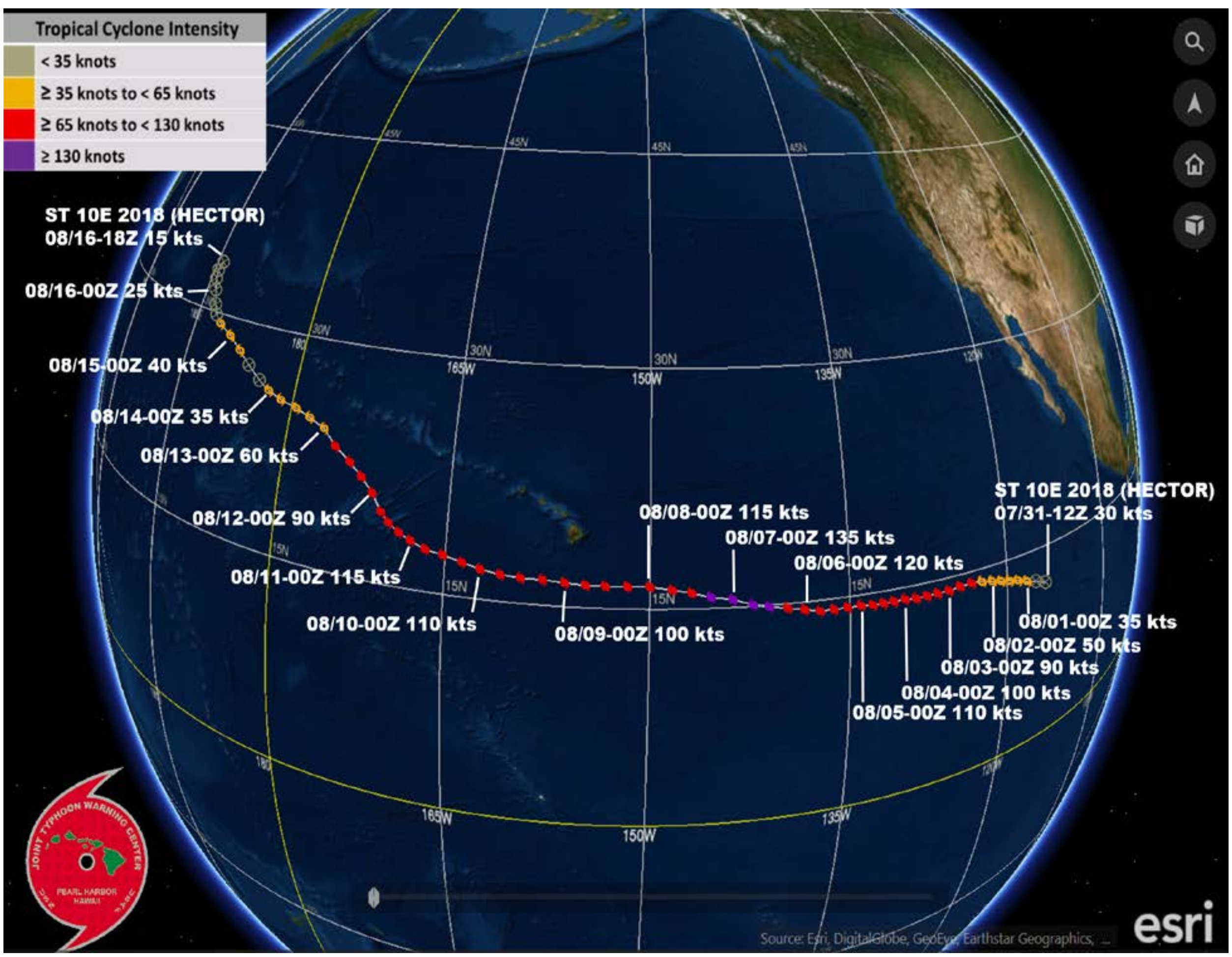




10E SUPER TYPHOON HECTOR

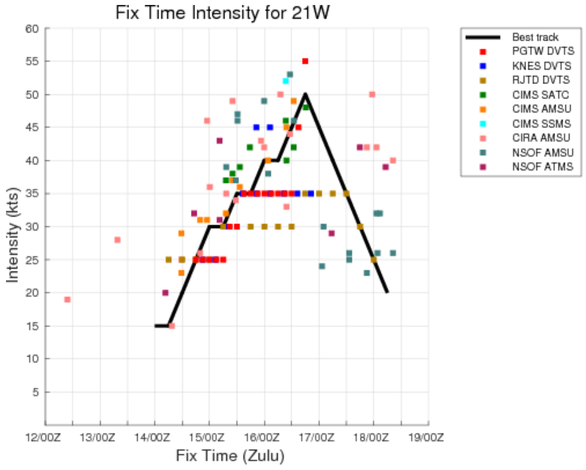
ISSUED LOW:	N/A
ISSUED MED:	N/A
FIRST TCFA:	31 Jul / 0530Z
FIRST WARNING:	13 Aug / 1800Z
LAST WARNING:	15 Aug / 0000Z
MAX INTENSITY:	135 (East of 180°)
WARNINGS:	6

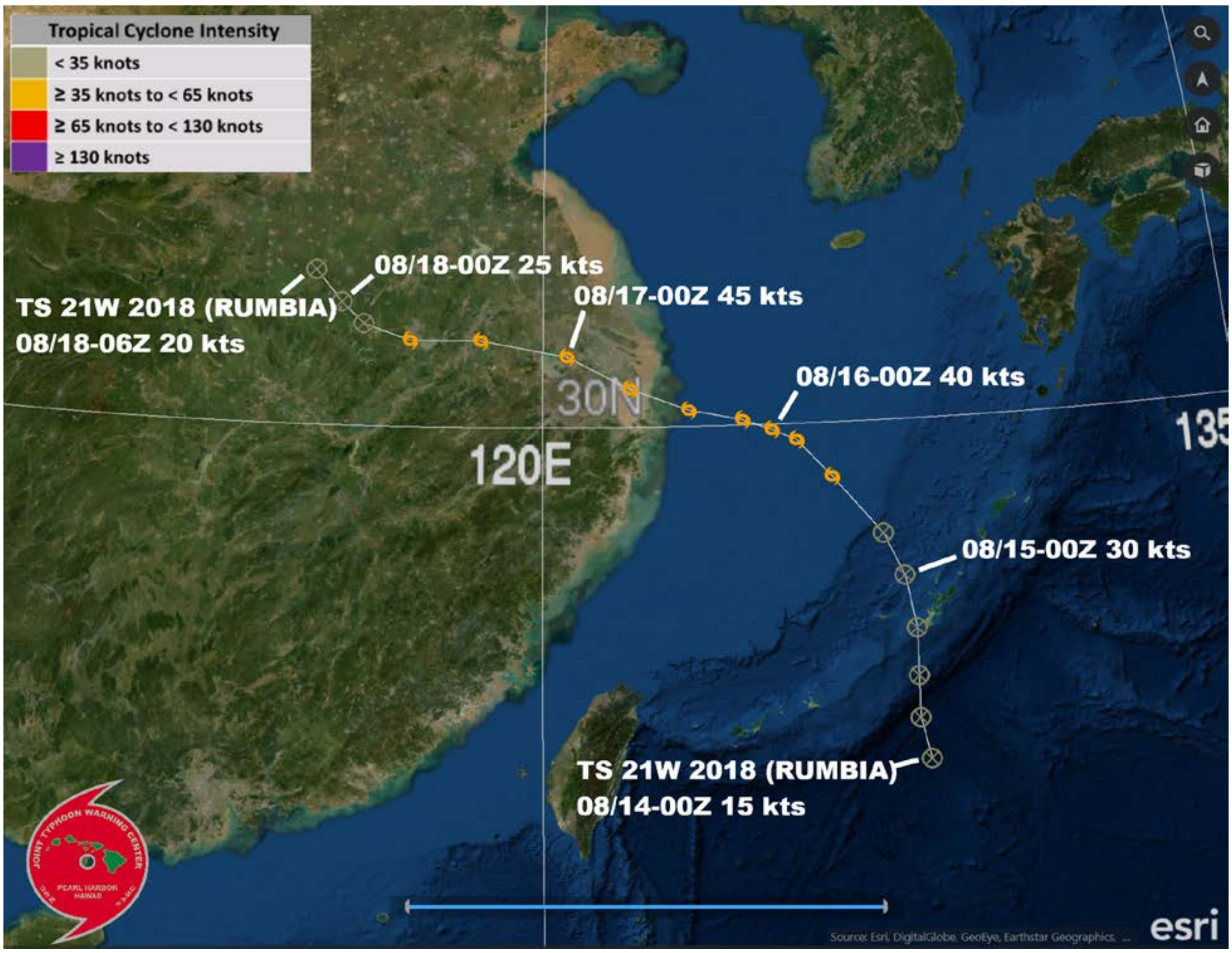




21W TROPICAL STORM RUMBIA

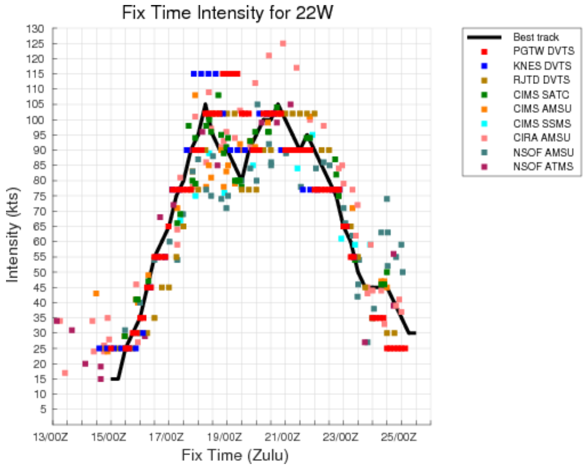
ISSUED LOW:	13 Aug / 0600Z
ISSUED MED:	14 Aug / 1500Z
FIRST TCFA:	14 Aug / 2200Z
FIRST WARNING:	15 Aug / 0000Z
LAST WARNING:	17 Aug / 0000Z
MAX INTENSITY:	50
WARNINGS:	9

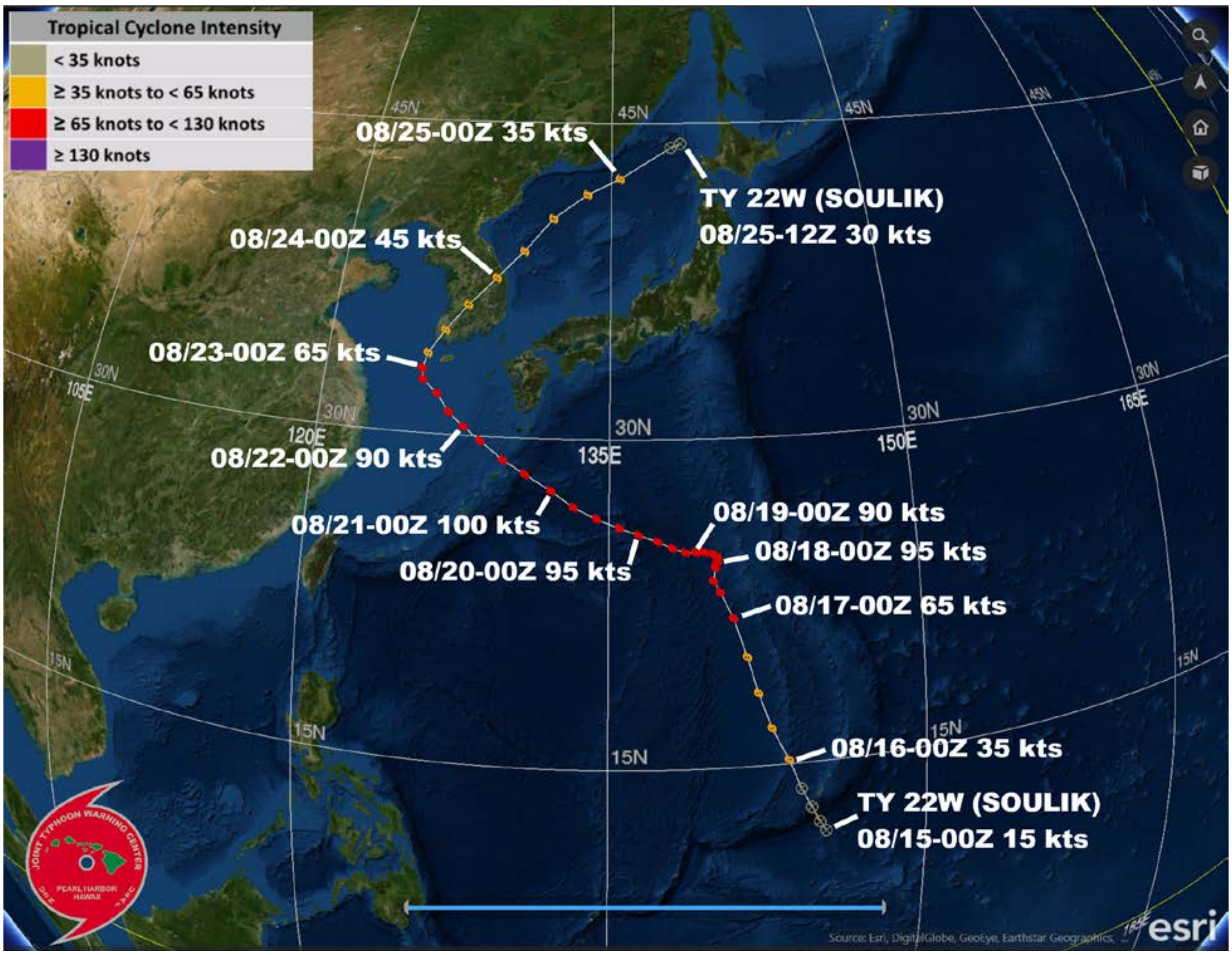




22W TYPHOON SOULIK

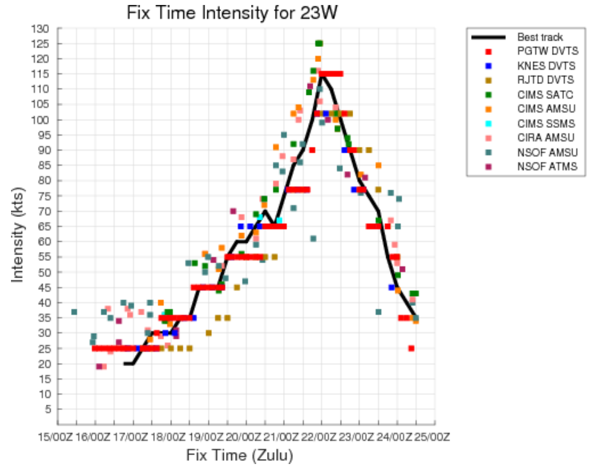
ISSUED LOW:	14 Aug / 0600Z
ISSUED MED:	14 Aug / 1500Z
FIRST TCFA:	14 Aug / 2230Z
FIRST WARNING:	15 Aug / 1200Z
LAST WARNING:	24 Aug / 1800Z
MAX INTENSITY:	105
WARNINGS:	38

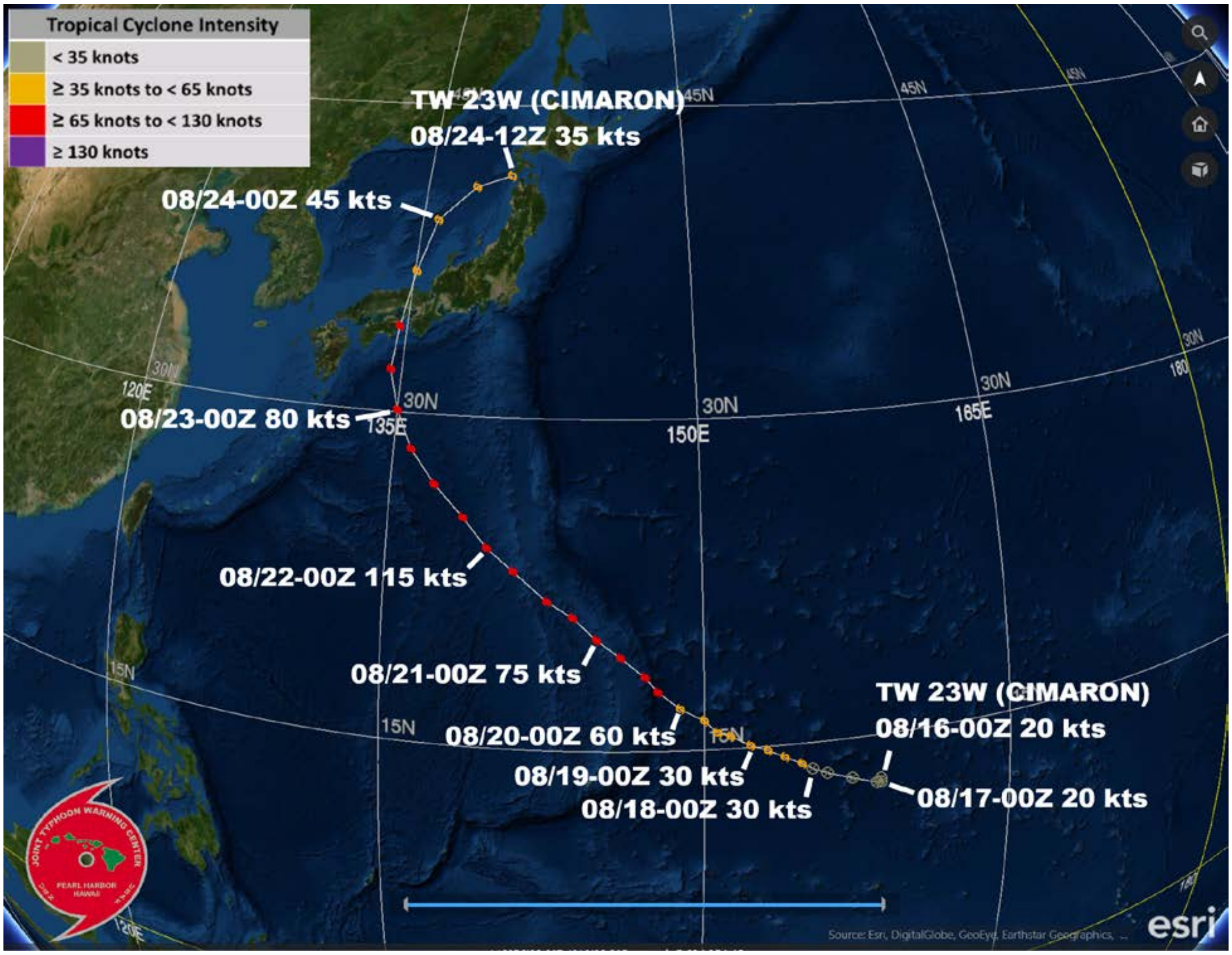




23W TYPHOON CIMARON

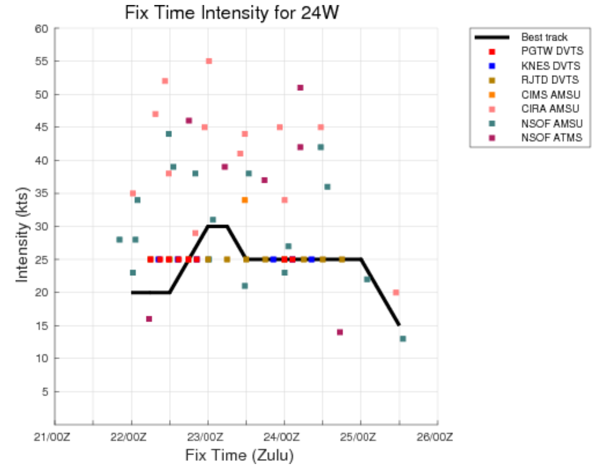
ISSUED LOW:	15 Aug / 1600Z
ISSUED MED:	15 Aug / 1900Z
FIRST TCFA:	17 Aug / 0530Z
FIRST WARNING:	17 Aug / 1800Z
LAST WARNING:	24 Aug / 0600Z
MAX INTENSITY:	115
WARNINGS:	27

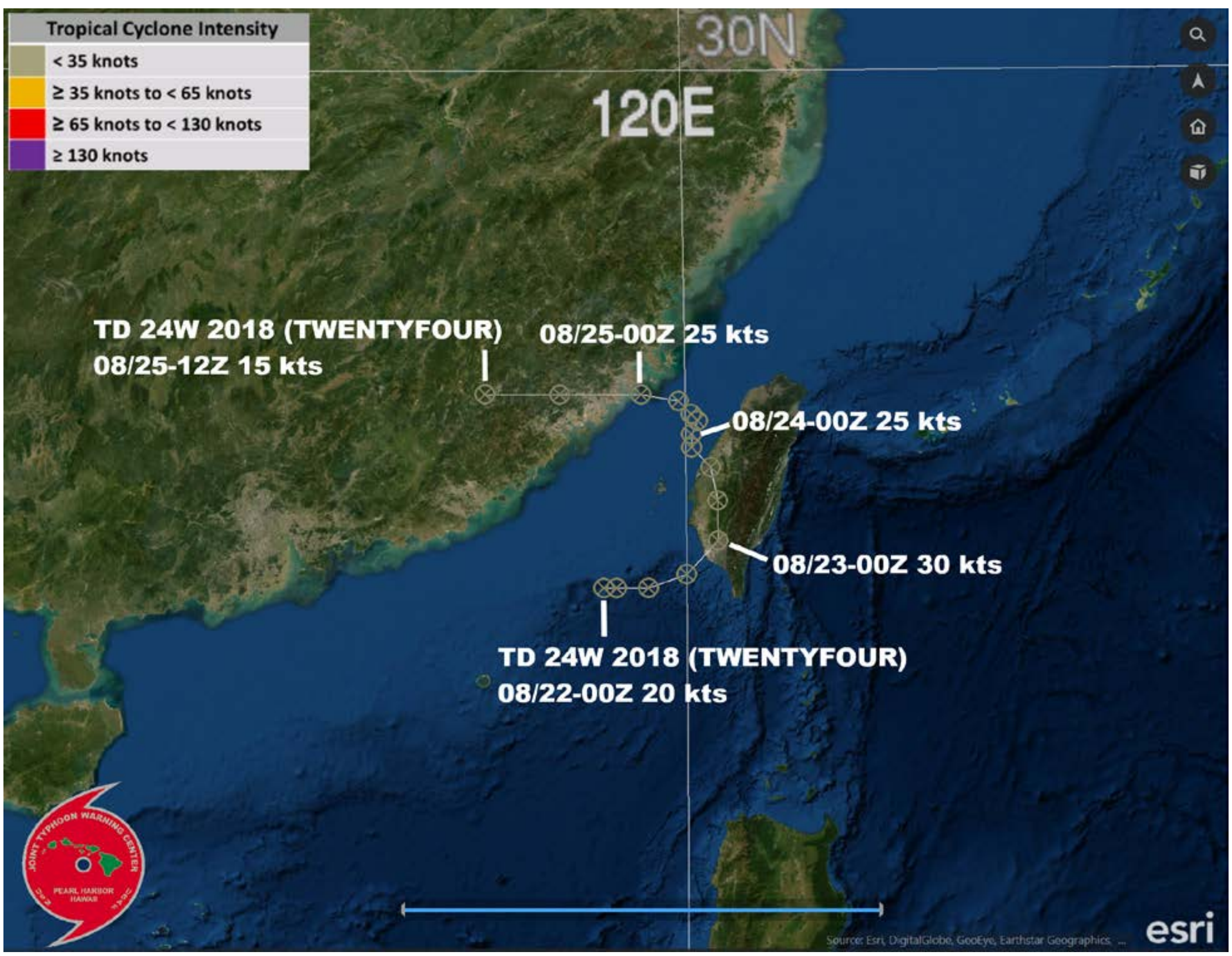




24W TROPICAL DEPRESSION TWENTYFOUR

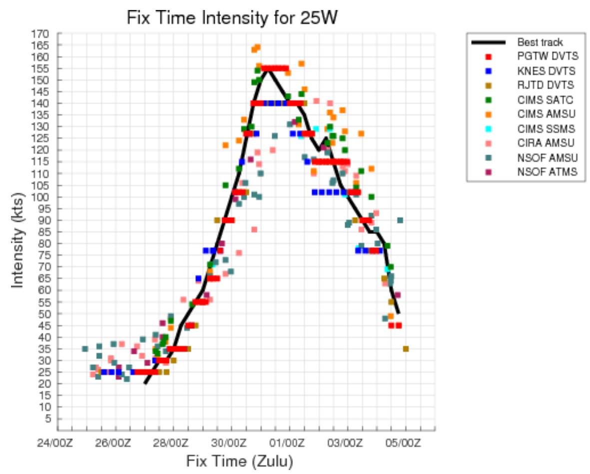
ISSUED LOW:	21 Aug / 2030Z
ISSUED MED:	22 Aug / 0600Z
FIRST TCFA:	22 Aug / 0900Z
FIRST WARNING:	23 Aug / 1800Z
LAST WARNING:	25 Aug / 0600Z
MAX INTENSITY:	30
WARNINGS:	7

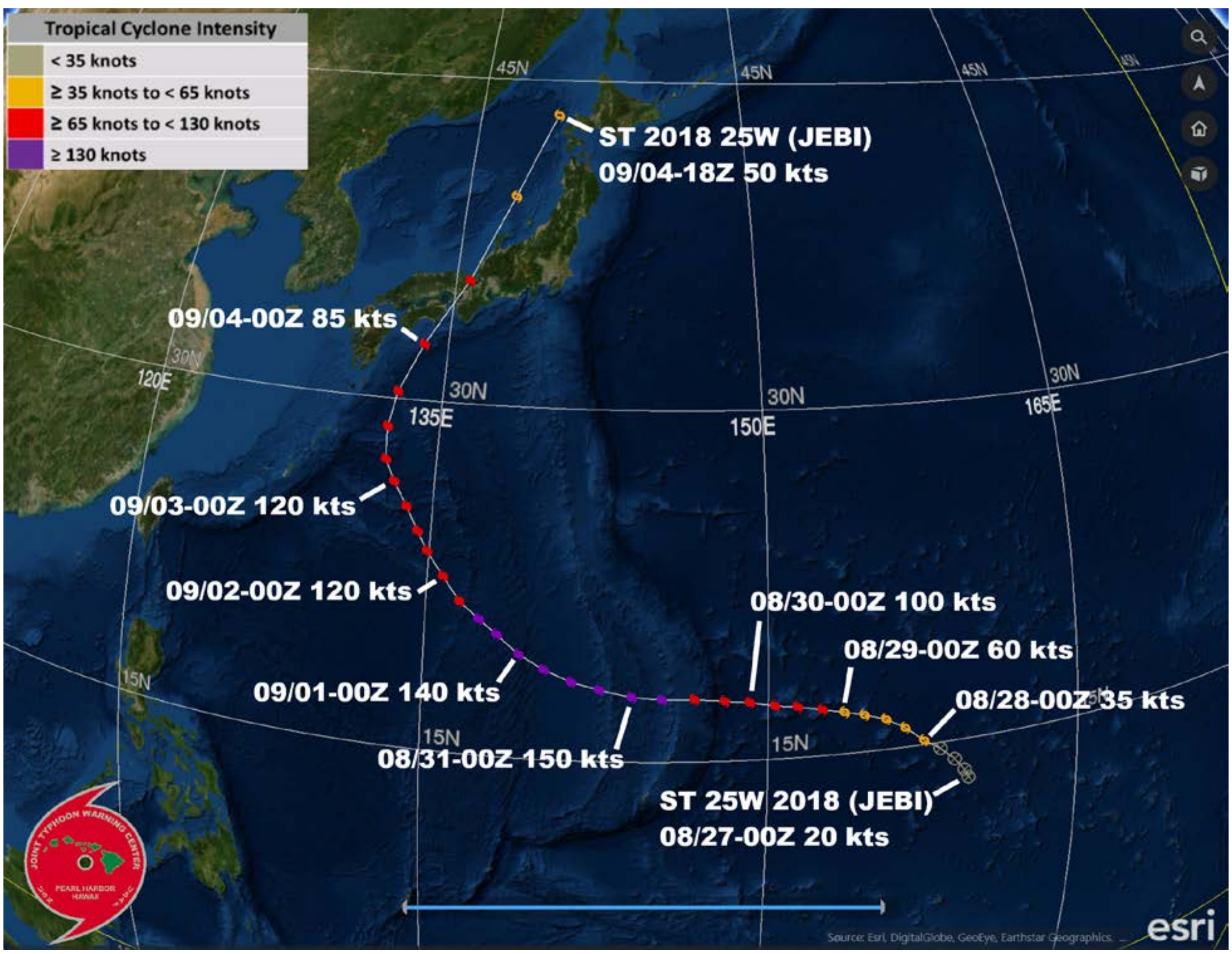




25W SUPER TYPHOON JEBI

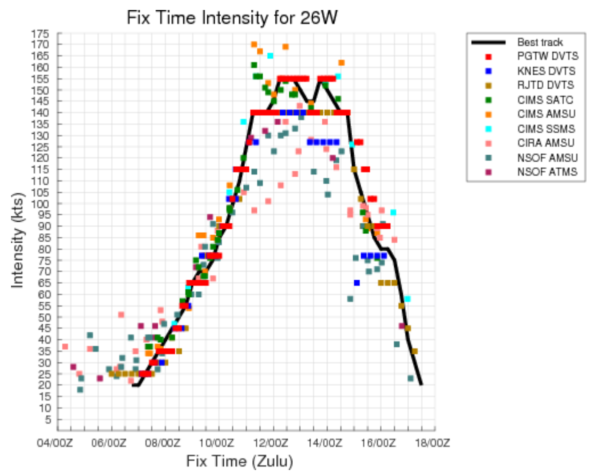
ISSUED LOW:	26 Aug / 0600Z
ISSUED MED:	26 Aug / 2030Z
FIRST TCFA:	27 Aug / 0200Z
FIRST WARNING:	27 Aug / 0600Z
LAST WARNING:	04 Sep / 1200Z
MAX INTENSITY:	155
WARNINGS:	34

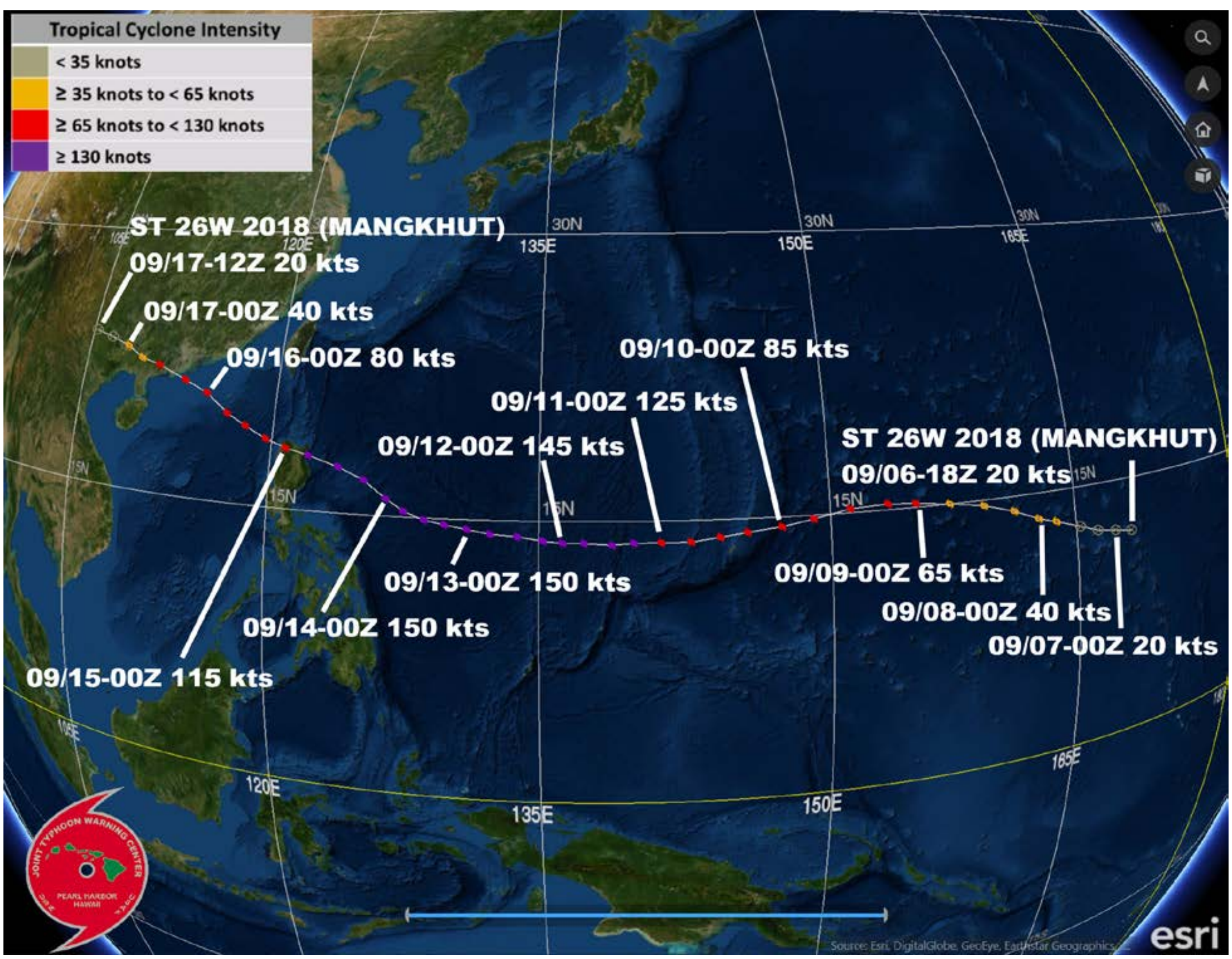




26W SUPER TYPHOON MANGKHUT

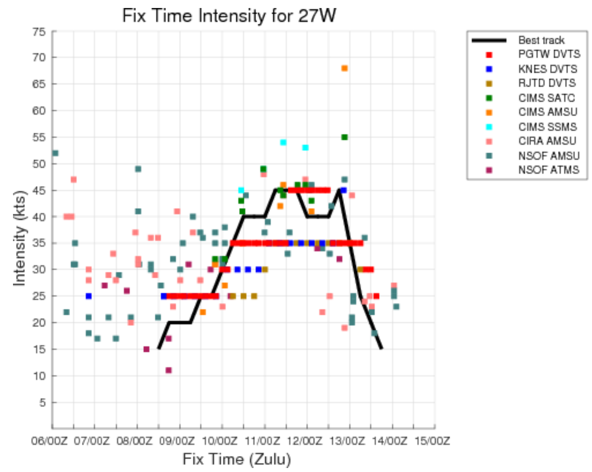
ISSUED LOW:	05 Sep / 2030Z
ISSUED MED:	06 Sep / 1330Z
FIRST TCFA:	06 Sep / 2130Z
FIRST WARNING:	07 Sep / 0000Z
LAST WARNING:	16 Sep / 1200Z
MAX INTENSITY:	155
WARNINGS:	39

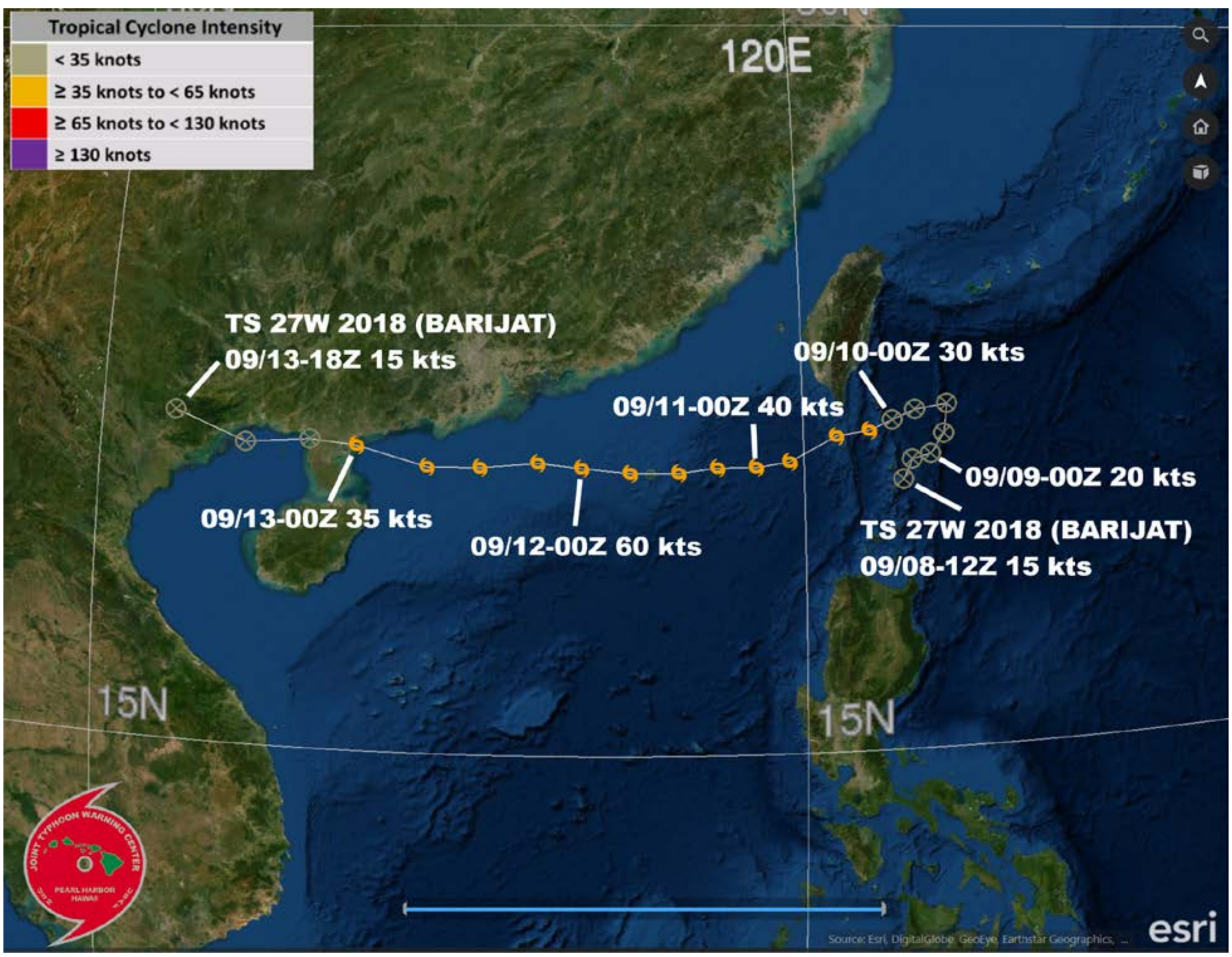




27W TROPICAL STORM BARIJAT

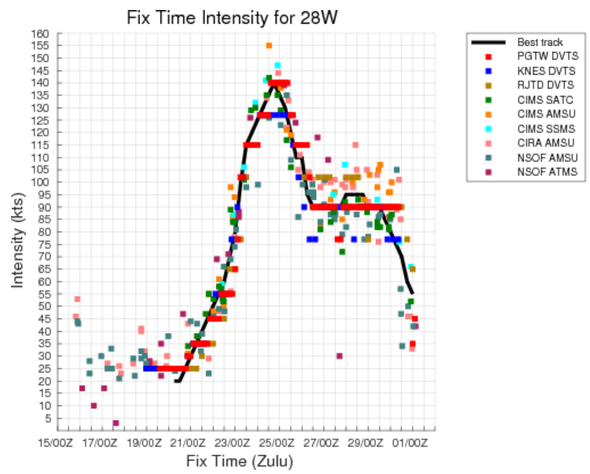
ISSUED LOW:	06 Sep / 0600Z
ISSUED MED:	07 Sep / 2000Z
FIRST TCFA:	08 Sep / 1930Z
FIRST WARNING:	09 Sep / 1800Z
LAST WARNING:	13 Sep / 1800Z
MAX INTENSITY:	45
WARNINGS:	17

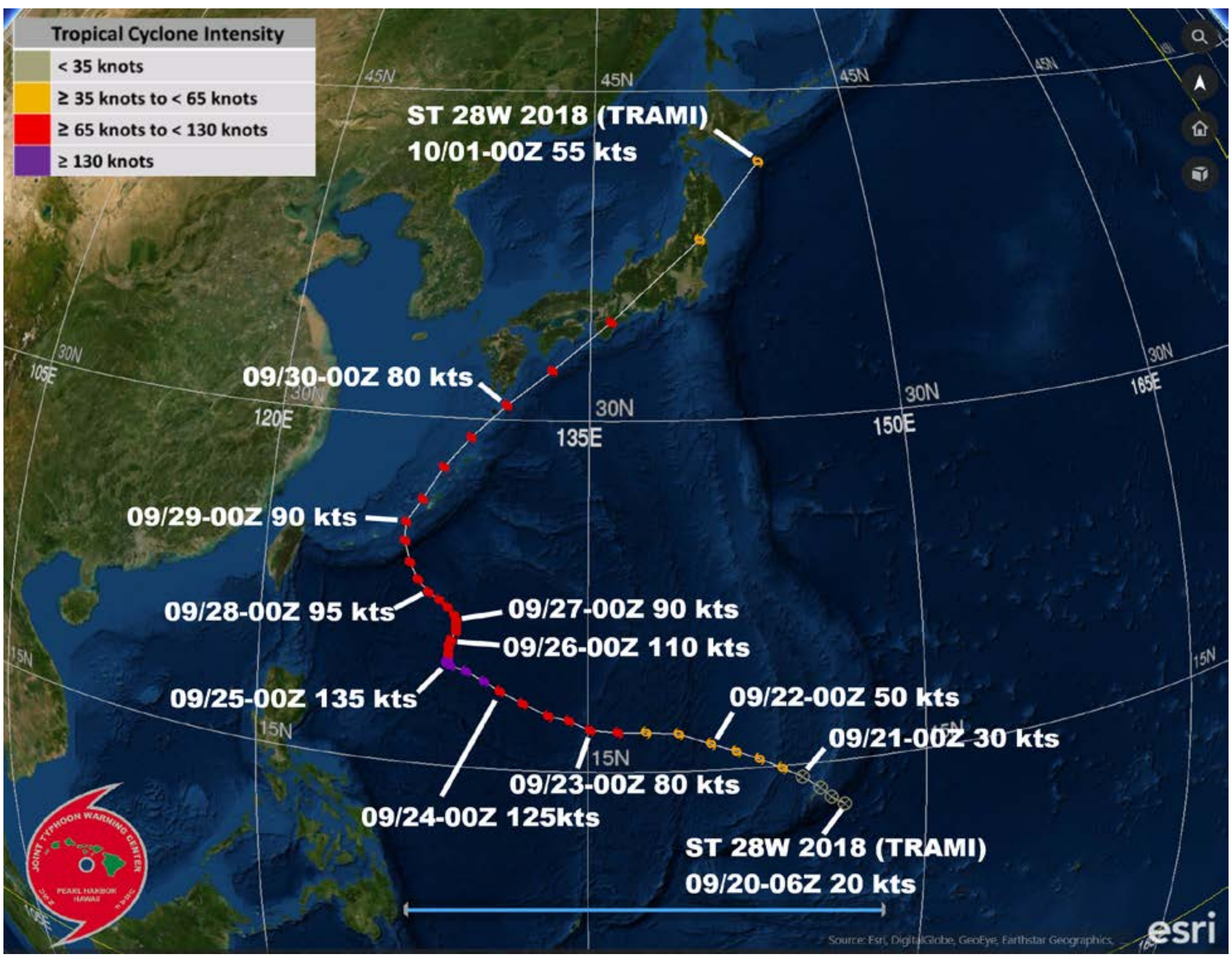




28W SUPER TYPHOON TRAMI

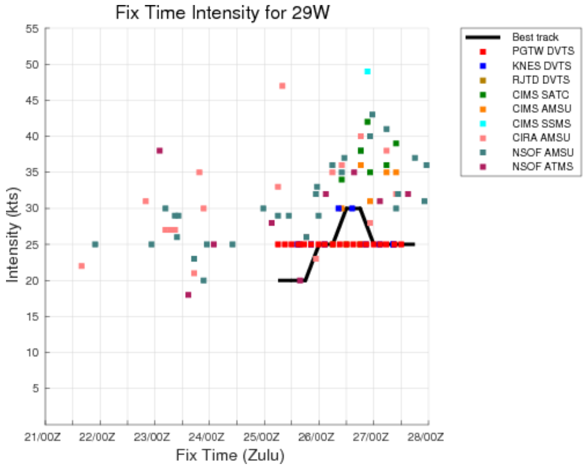
ISSUED LOW:	17 Sep / 2030Z
ISSUED MED:	18 Sep / 0600Z
FIRST TCFA:	20 Sep / 0900Z
FIRST WARNING:	20 Sep / 1800Z
LAST WARNING:	30 Sep / 1200Z
MAX INTENSITY:	140
WARNINGS:	40

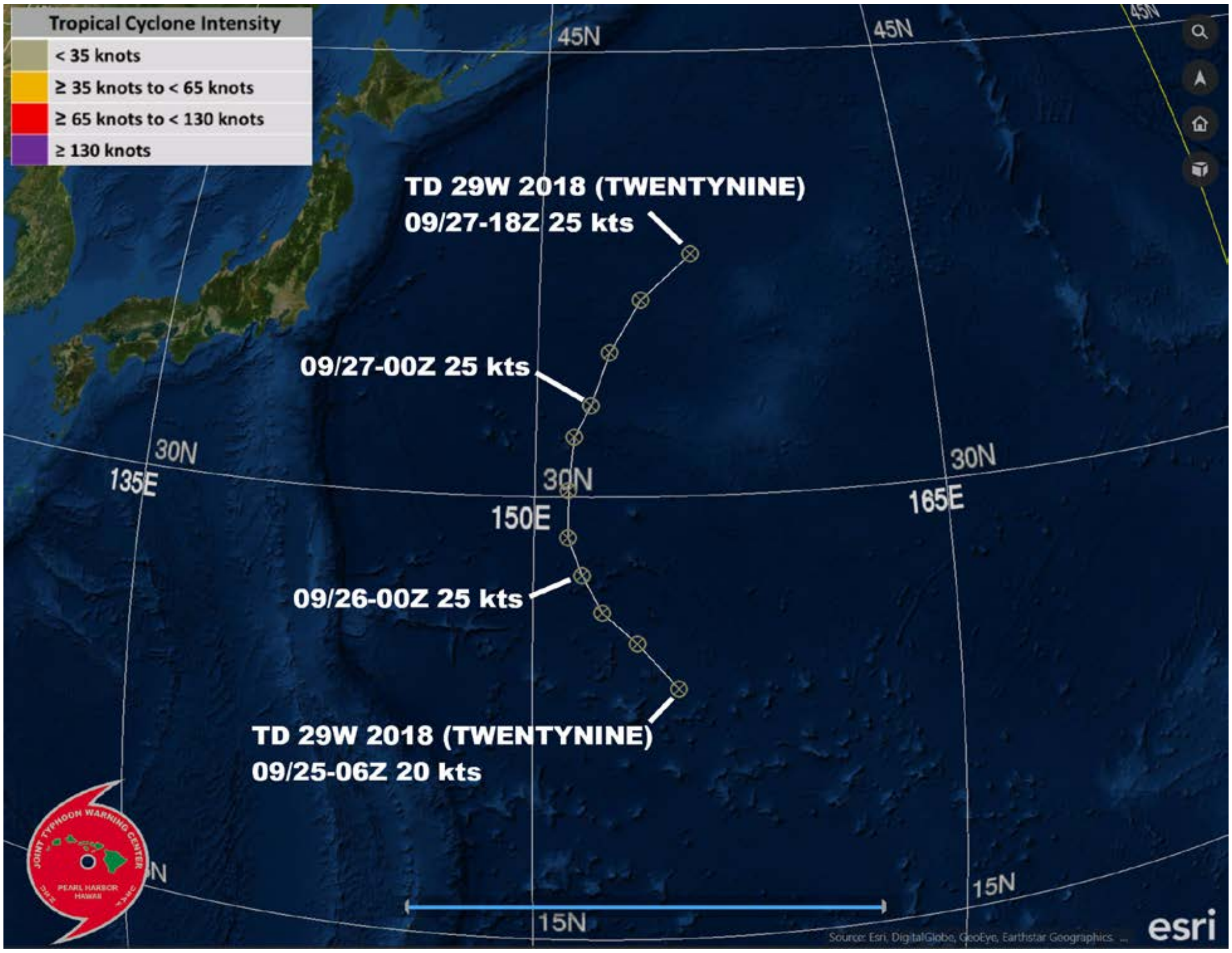




29W TROPICAL DEPRESSION TWENTYNINE

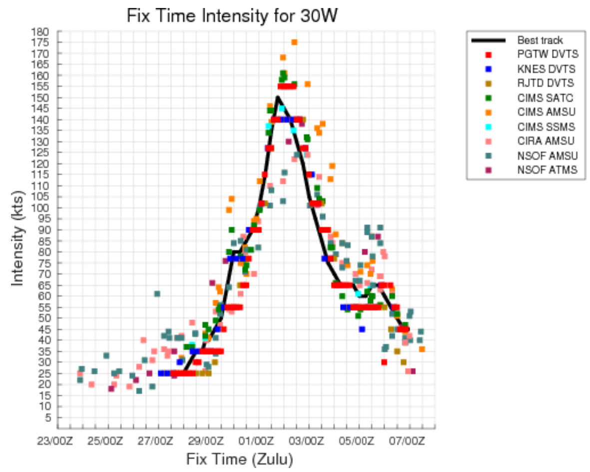
ISSUED LOW:	24 Sep / 0230Z
ISSUED MED:	25 Sep / 0600Z
FIRST TCFA:	25 Sep / 1430Z
FIRST WARNING:	26 Sep / 0600Z
LAST WARNING:	27 Sep / 0000Z
MAX INTENSITY:	30
WARNINGS:	4

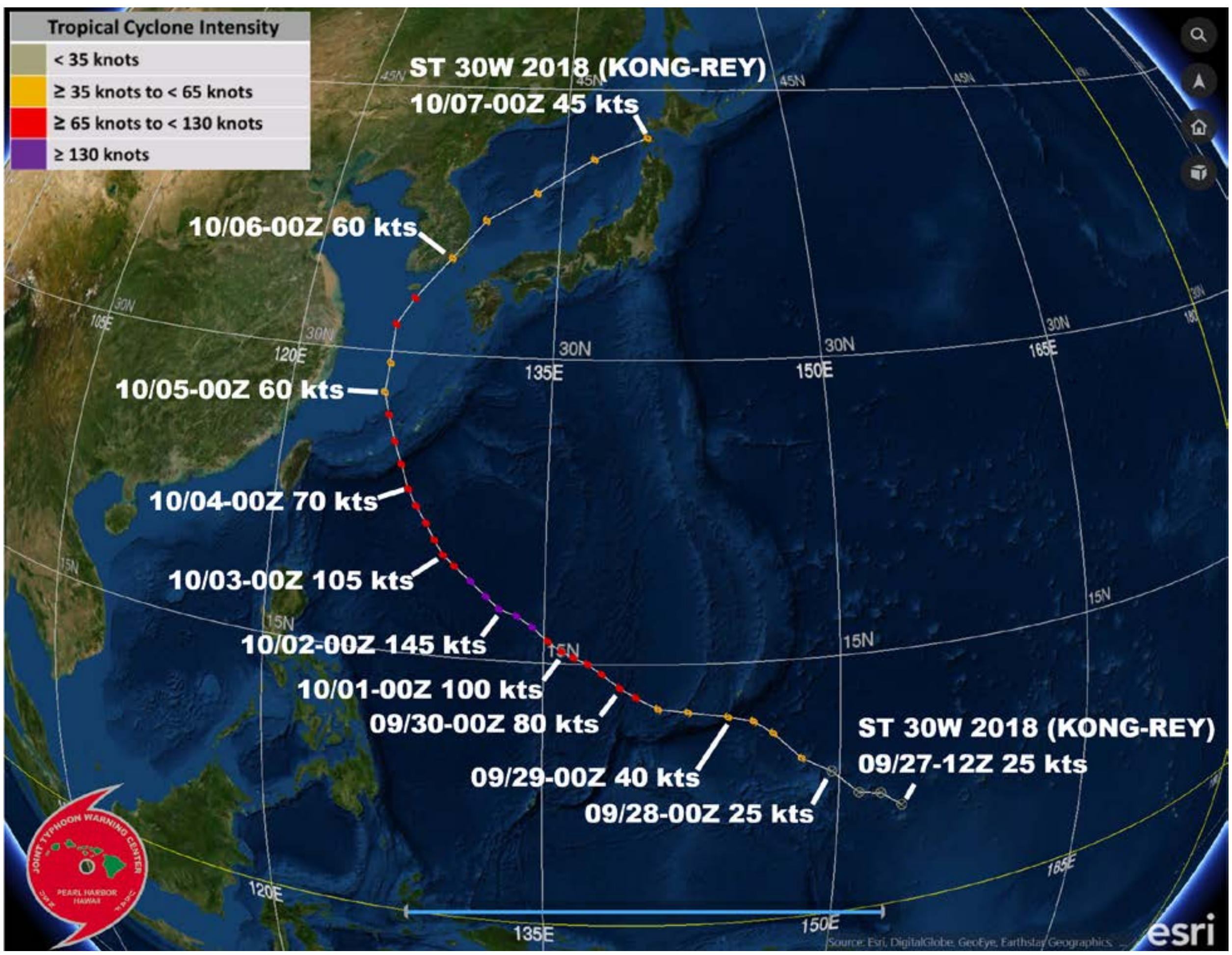




30W SUPER TYPHOON KONG-REY

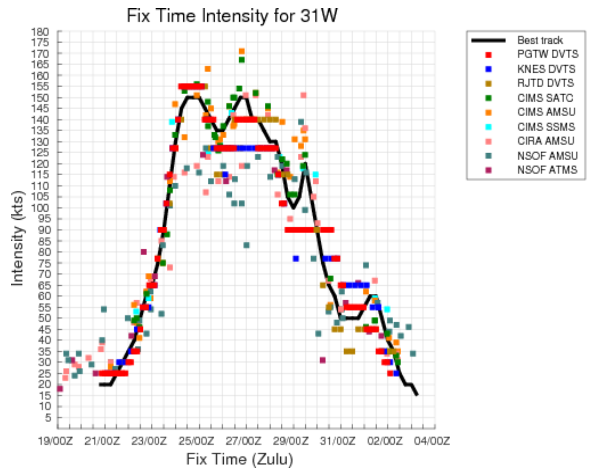
ISSUED LOW:	25 Sep / 0600Z
ISSUED MED:	26 Sep / 0600Z
FIRST TCFA:	27 Sep / 0830Z
FIRST WARNING:	28 Sep / 0000Z
LAST WARNING:	06 Oct / 1800Z
MAX INTENSITY:	150
WARNINGS:	36

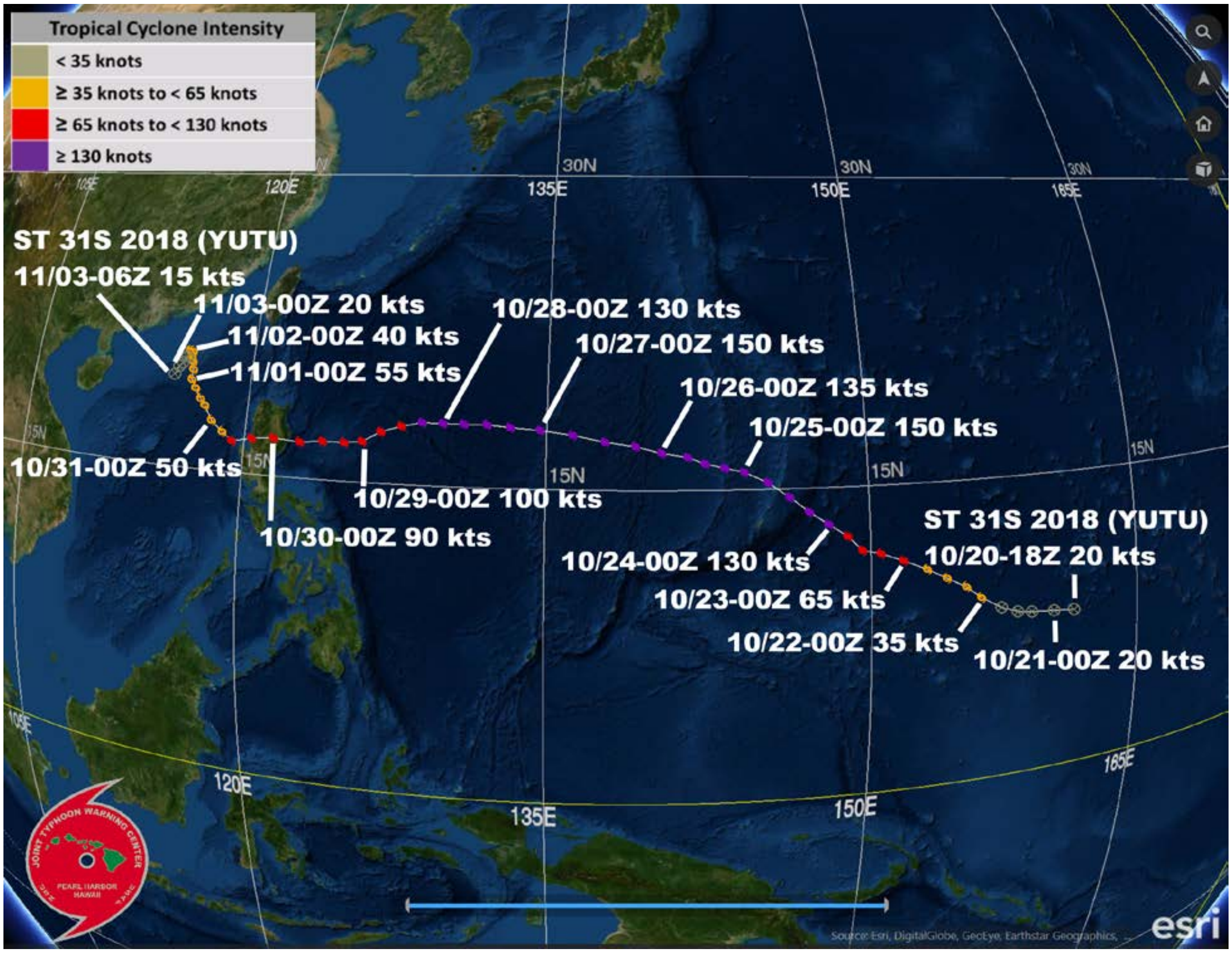




31W SUPER TYPHOON YUTU

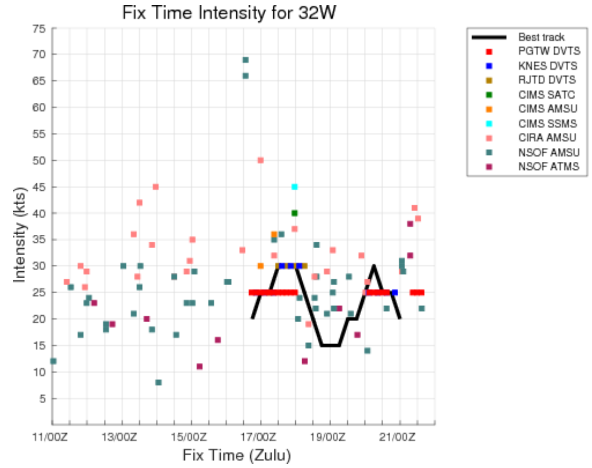
ISSUED LOW:	19 Oct / 2100Z
ISSUED MED:	20 Oct / 0600Z
FIRST TCFA:	20 Oct / 2130Z
FIRST WARNING:	21 Oct / 1200Z
LAST WARNING:	02 Nov / 0000Z
MAX INTENSITY:	150
WARNINGS:	47

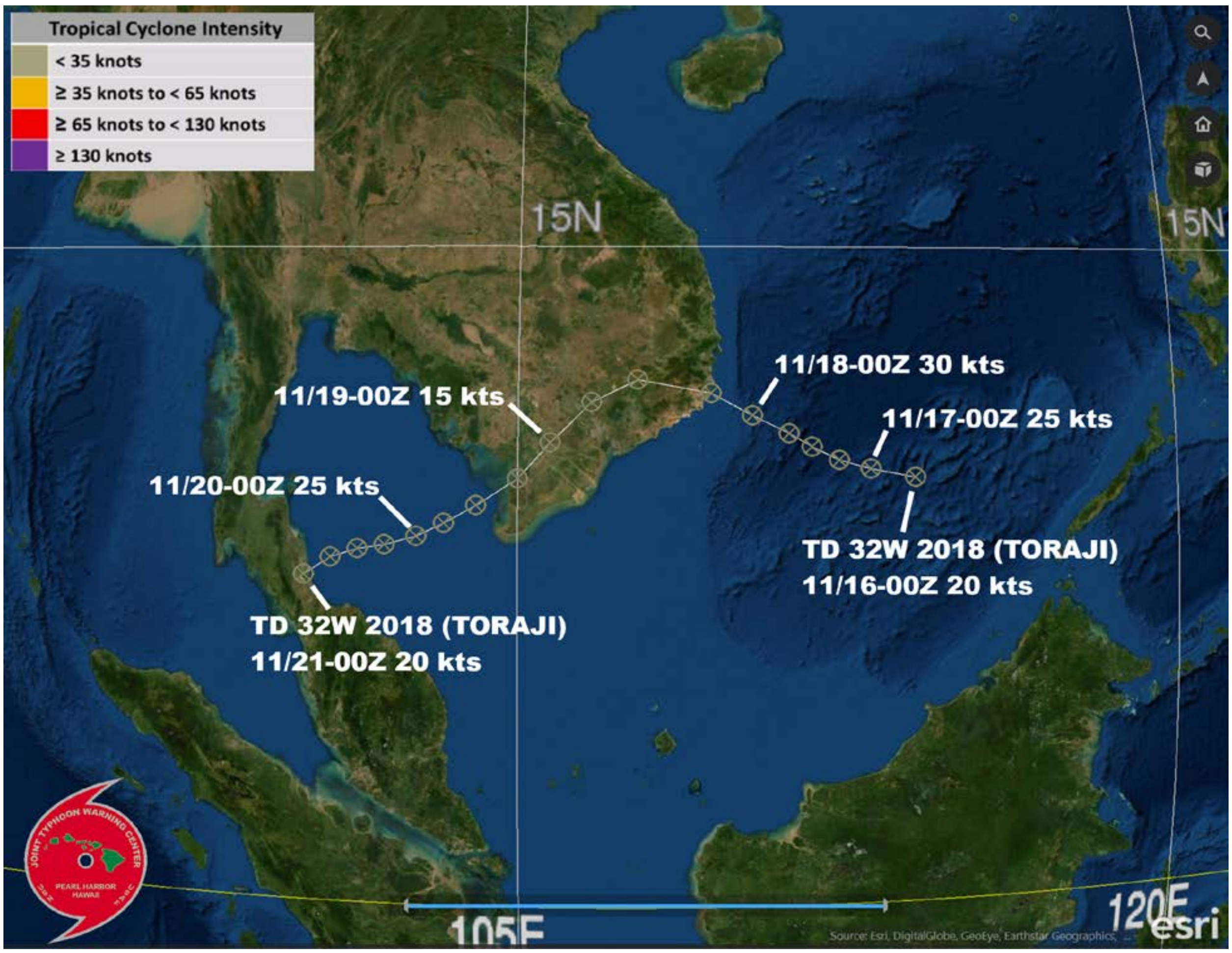




32W TROPICAL DEPRESSION TORAJI

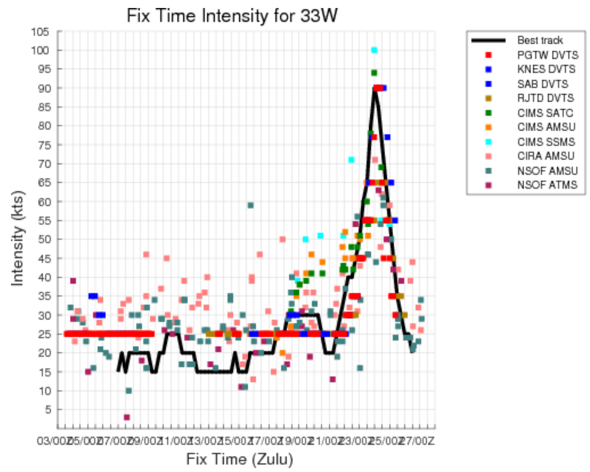
ISSUED LOW: 15 Nov / 1930Z
ISSUED MED: N/A
FIRST TCFA: 16 Nov / 2230Z
FIRST WARNING: 17 Nov / 1200Z
LAST WARNING: 18 Nov / 0600Z
MAX INTENSITY: 30
WARNINGS: 4

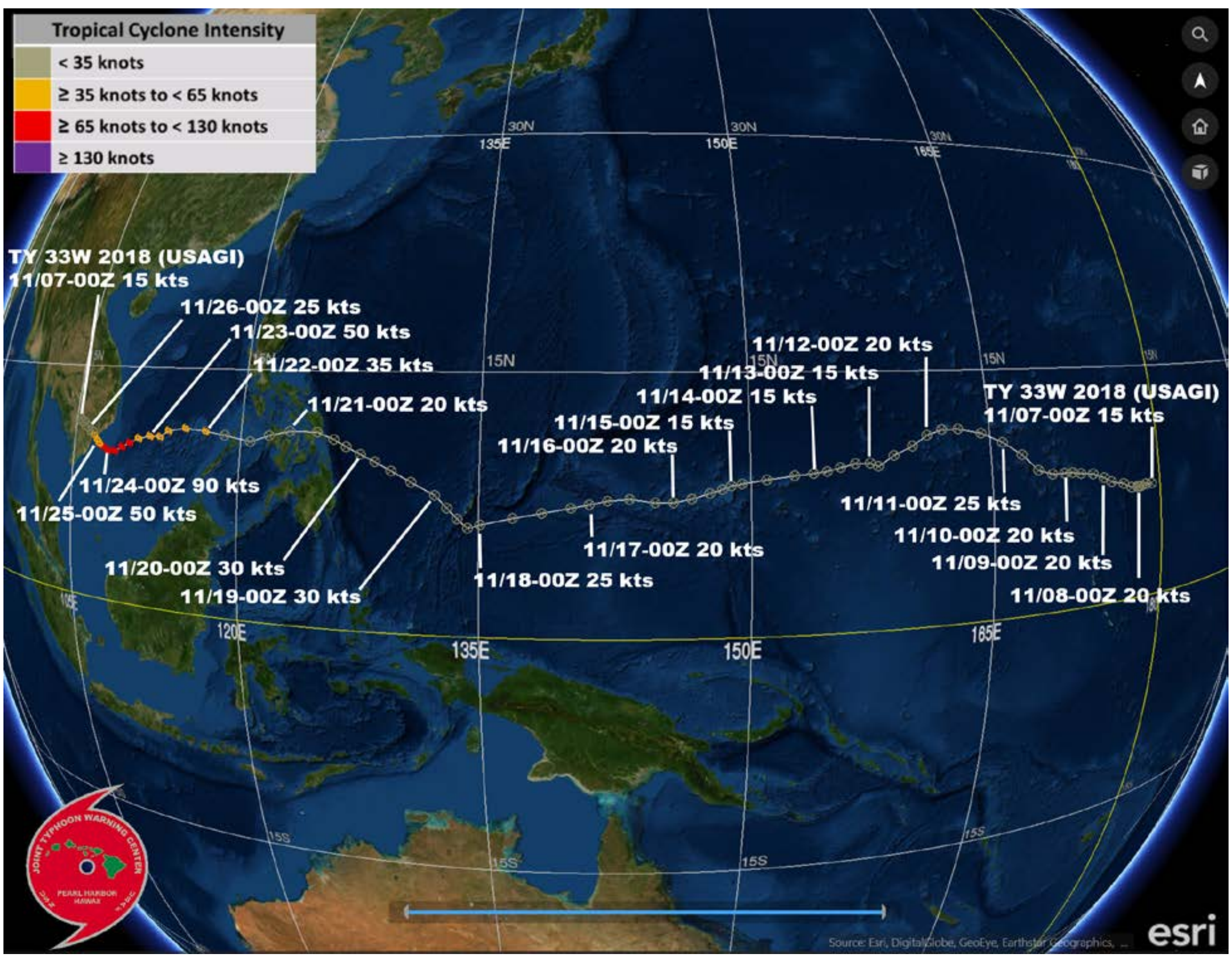




33W TYPHOON USAGI

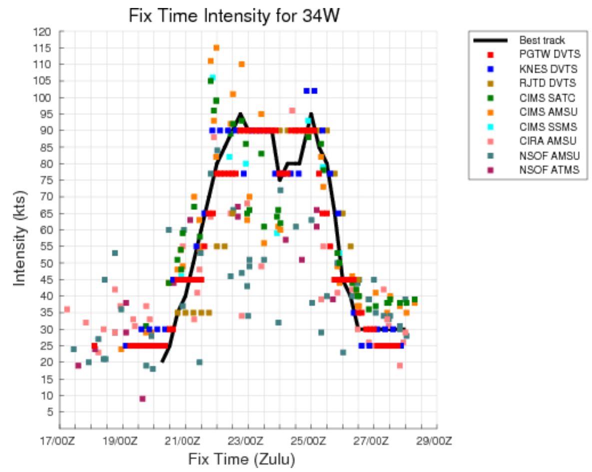
ISSUED LOW:	11 Nov / 0600Z
ISSUED MED:	14 Nov / 2000Z
FIRST TCFA:	17 Nov / 1430Z
FIRST WARNING:	18 Nov / 0600Z
LAST WARNING:	25 Nov / 1200Z
MAX INTENSITY:	90
WARNINGS:	30

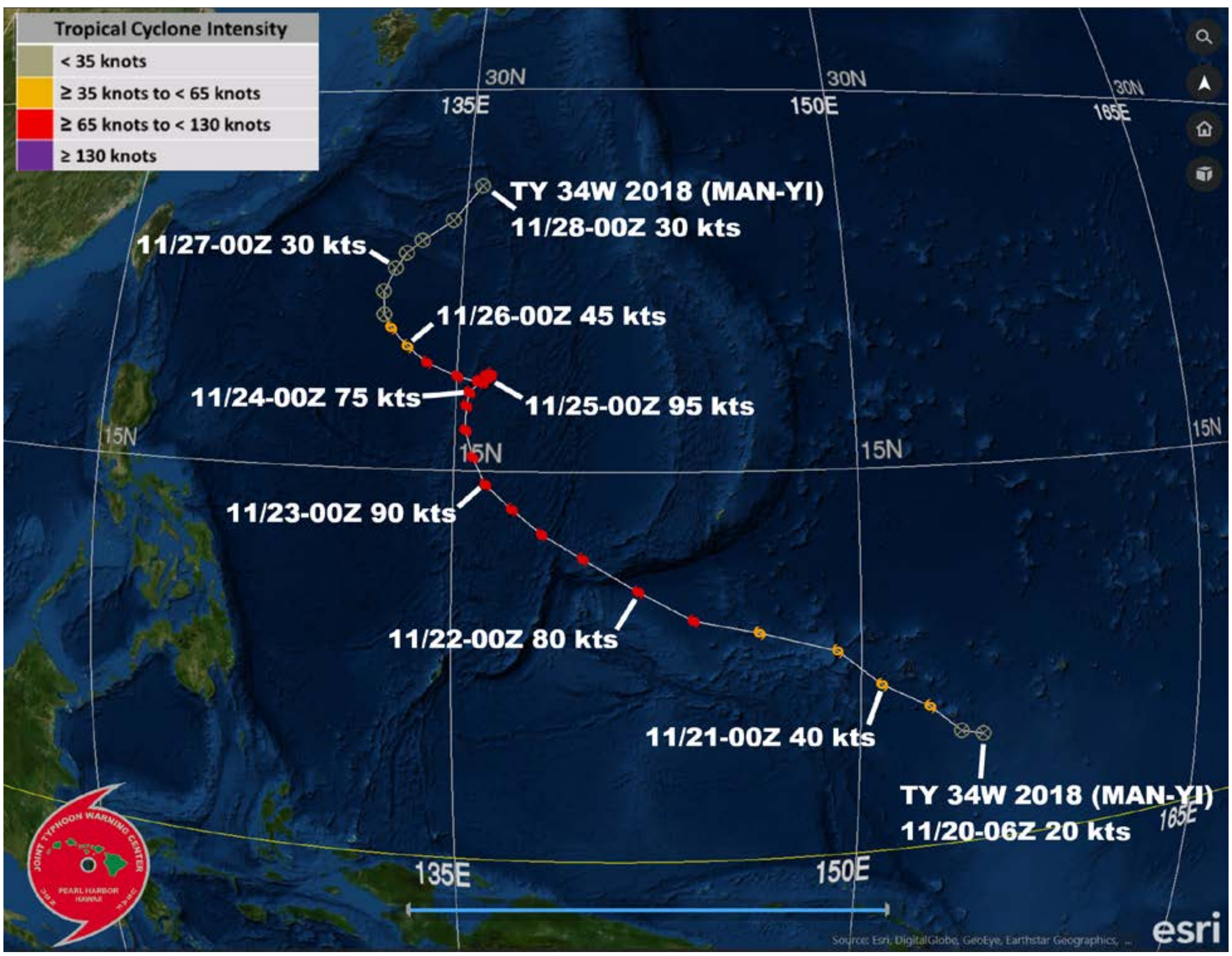




34W TYPHOON MAN-YI

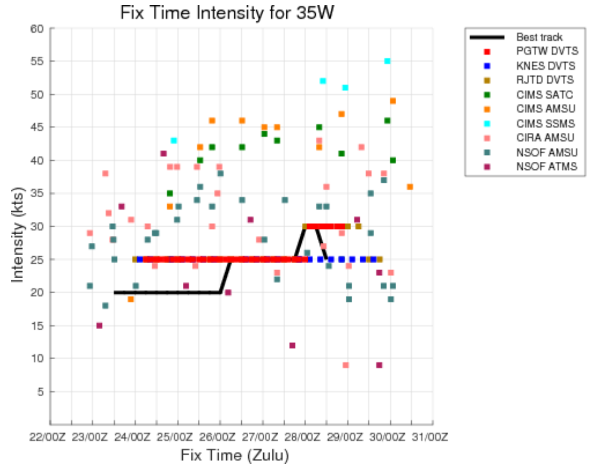
ISSUED LOW:	17 Nov / 0600Z
ISSUED MED:	19 Nov / 0600Z
FIRST TCFA:	19 Nov / 1130Z
FIRST WARNING:	19 Nov / 1800Z
LAST WARNING:	27 Nov / 1200Z
MAX INTENSITY:	95
WARNINGS:	32

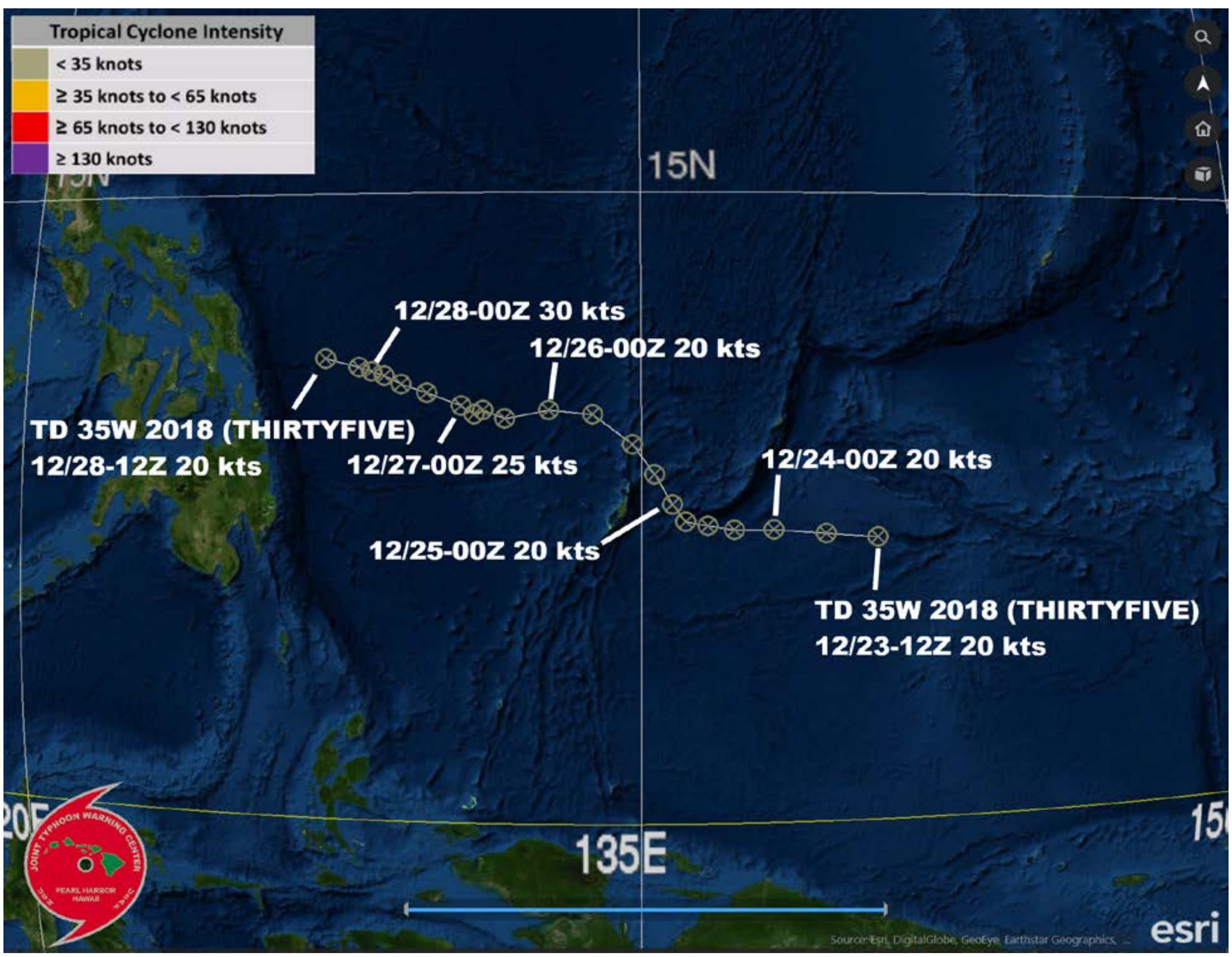




35W TROPICAL DEPRESSION THIRTY-FIVE

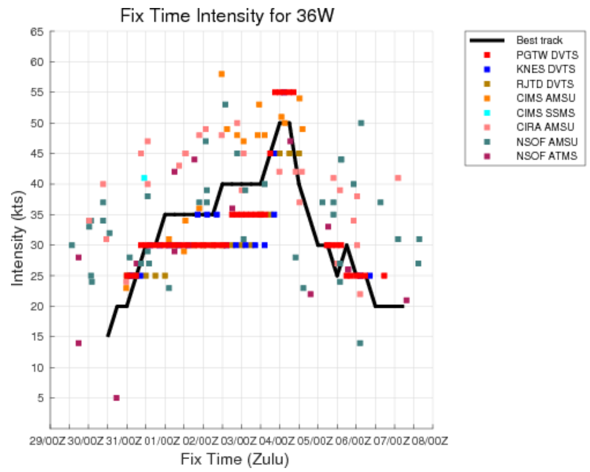
ISSUED LOW:	23 Dec / 1630Z
ISSUED MED:	23 Dec / 1930Z
FIRST TCFA:	24 Dec / 0900Z
FIRST WARNING:	24 Dec / 1200Z
LAST WARNING:	30 Dec / 0000Z
MAX INTENSITY:	30
WARNINGS:	23

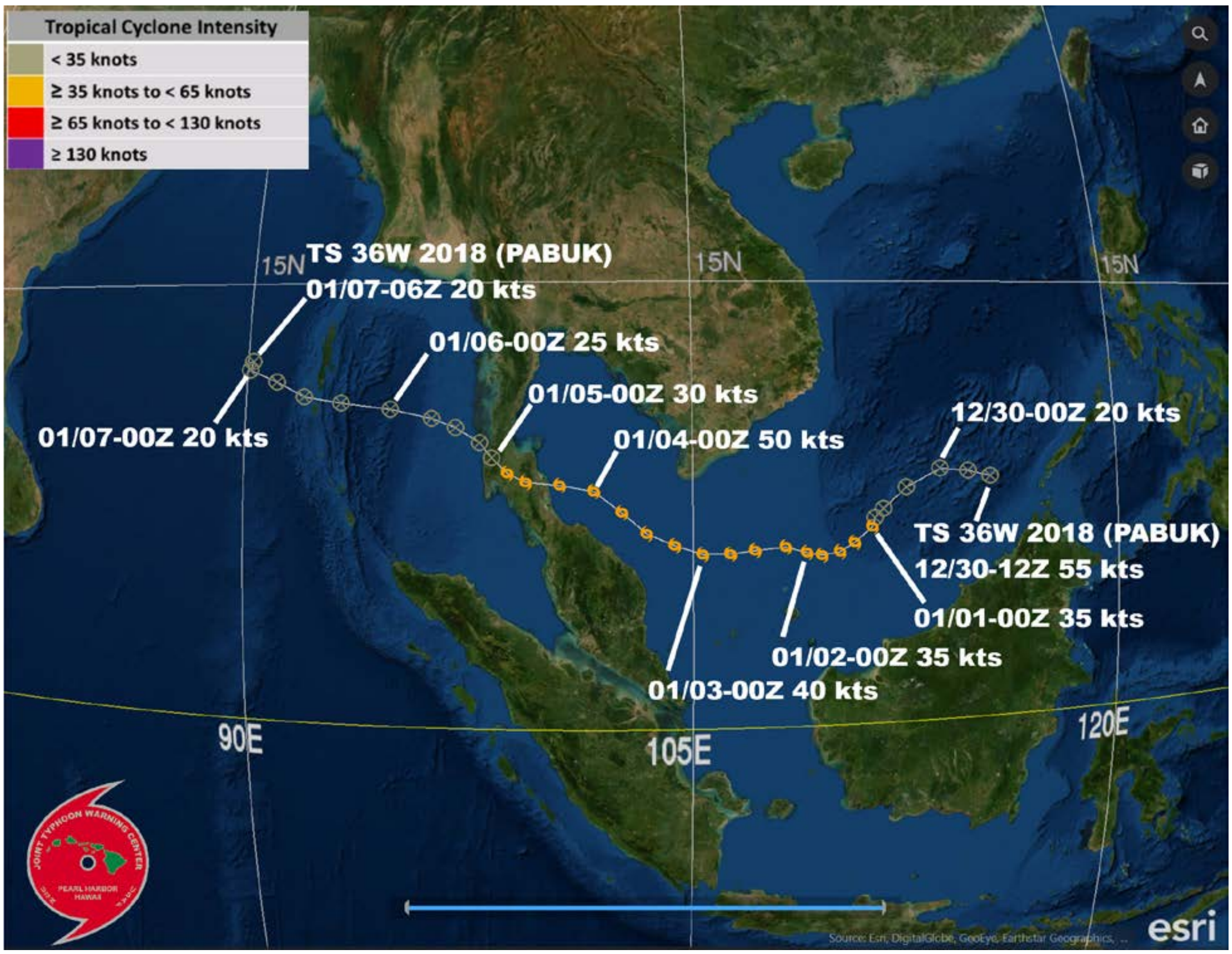




36W TROPICAL STORM PABUK

ISSUED LOW:	30 Dec / 0330Z
ISSUED MED:	30 Dec / 0600Z
FIRST TCFA:	30 Dec / 2030Z
FIRST WARNING:	31 Dec / 0600Z
LAST WARNING:	05 Jan / 1800Z
MAX INTENSITY:	50
WARNINGS:	23





Super Typhoon 10W (Maria)

Rapidly consolidating tropical cyclone (TC) 10W (Maria), approached Guam on the morning of July 5, 2018 (local time). Weather forecasters closely monitoring the system at both the 17th Operational Weather Squadron and the 36th Operational Support Squadron (36 OSS) Weather Flight at Andersen AFB identified a hook echo embedded within the developing tropical cyclone's convection in Guam radar imagery. Consequently, 36 OSS forecasters issued a tornado watch for Andersen AFB at 04/1650Z, followed by a tornado warning 26 minutes later, at 04/1716Z (Ludwig, 2019). Intense convective cells, which developed along the northern flank of TC 10W (Maria), tracked across northern Guam and Andersen AFB, producing a sudden spike of severe winds gusting as high as 83 knots (04/1742Z), as well as a sharp, 12-mb decrease in sea level pressure (SLP) between about 04/1722Z and 04/1751Z (figure 1-5). Due to a major radar communication outage during the event, no radar data were available after 04/1728Z to confirm the presence of a tornado during this period of severe weather. However, available evidence suggests that the localized event was likely associated with an intense mesoscale convective vortex and embedded vortical hot towers, rather than tornadic activity.

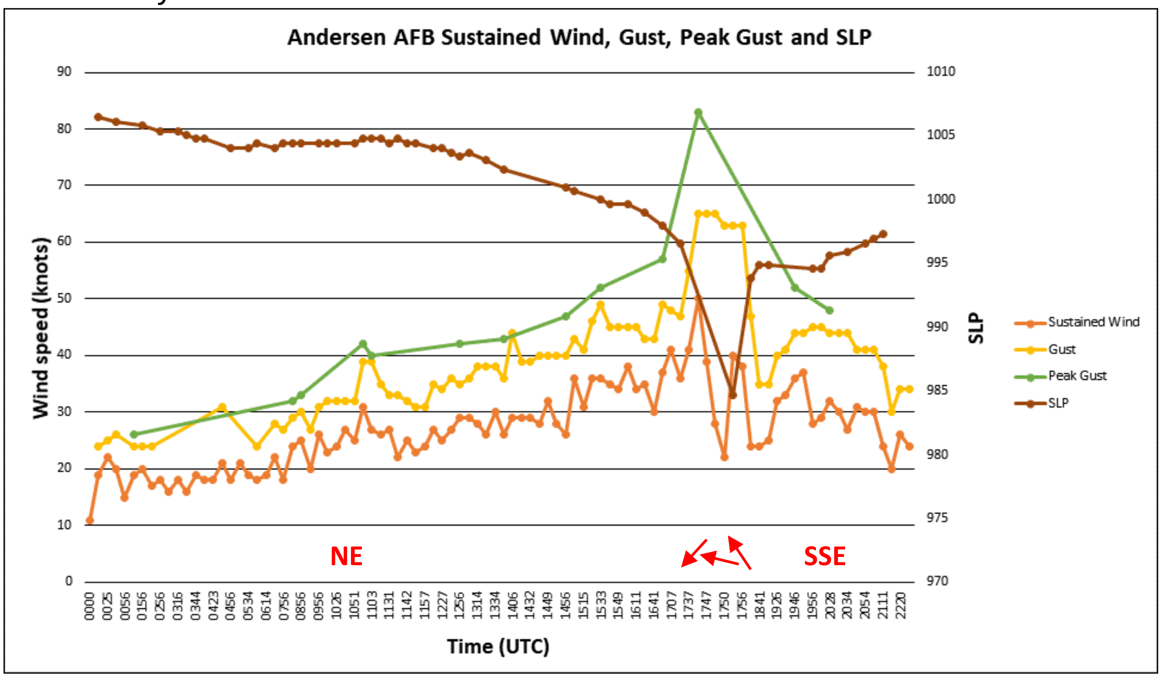


Figure 1-5: Andersen AFB surface wind and pressure observations (period 04/0000Z to 04/2220Z) showing the rapid increase in winds and precipitous drop in sea level pressure associated with the passage of an intense mesoscale convective vortex. During the 04/1722-1751Z period, the wind directions shifted abruptly from 050 → 100 → 150 degrees (as denoted by the RED TEXT AND ARROWS), which suggests that TC 10W's primary center passed just to the south. The Andersen AFB runway is located about 9 miles northeast of the Guam IAP runway at an elevation of 612 feet AMSL.

Andersen AFB reported maximum wind gusts (63-83 knots), minimum SLP (984.7mb) and winds quickly veering from northeasterly to easterly to southeasterly during a short interval of 10 minutes (from 04/1746 to 04/1756Z). These observations imply that TC 10W's center passed to the south of Andersen AFB. Sustained winds were predominantly 22-40 knots gusting to 63-65 knots, with the exception of an isolated 50G65 (peak gust of 83 knots) observation at 1742Z.

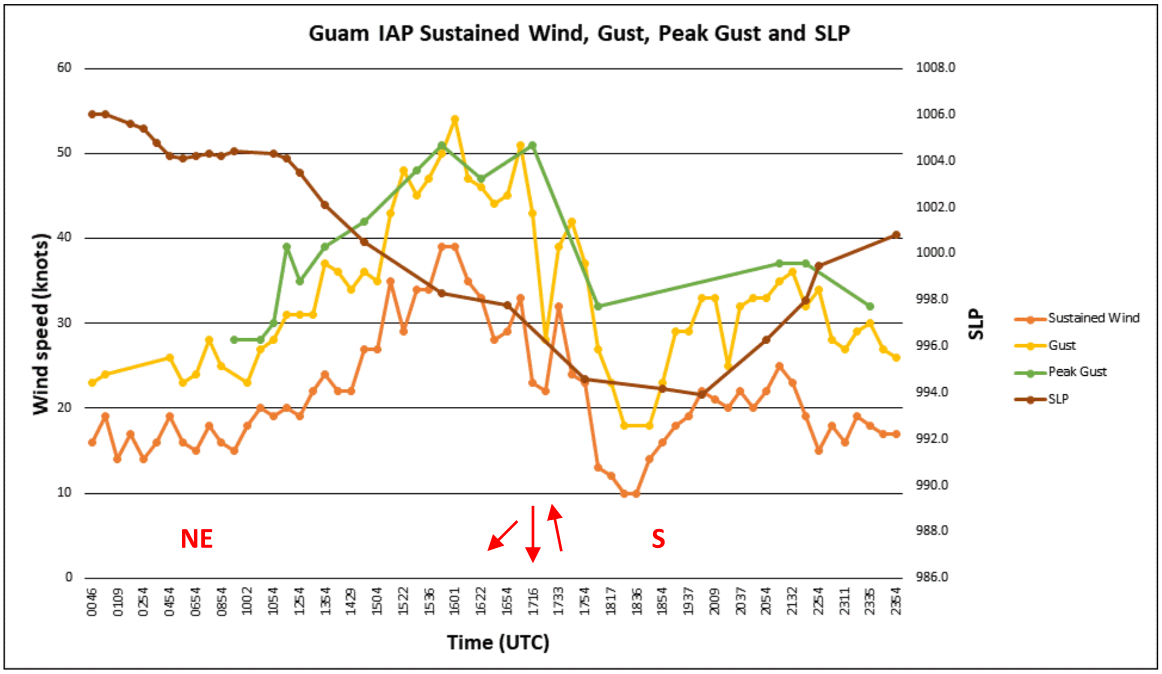


Figure 1-6: Guam International Airport (IAP) surface wind and pressure observations (period 04/0046Z to 04/2354Z) showing a steady increase in winds and a more gradual decrease in sea level pressure than was observed at Andersen AFB. Peak winds occurred from 1154Z to 1716Z, prior to the mesoscale convective vortex passage over northern Guam. The minimum sea level pressure of 993.9mb occurred at 1954Z. During the 04/1741-1817Z period, the wind direction shifted abruptly from 040 → 000 → 170 degrees (as denoted by the RED TEXT AND ARROWS). The Guam IAP runway is located about 9 miles southwest of the Andersen AFB runway at an elevation of 305 feet AMSL.

Maximum sustained winds observed at Guam International Airport (IAP) (figure1-6) were significantly lower than winds observed at Andersen AFB, with 30-35 knots sustained northeasterly to east-northeasterly winds occurring from 04/1513 to 04/1733Z. Peak gusts ranged from 50-54 knots. However, the minimum SLP of 993.9mb was recorded much later, at 04/1954Z, as 10W's primary center coalesced to the west of Guam. Neither the Guam IAP nor the Andersen AFB wind / sea level pressure profiles reflect patterns typically associated with the passage of an eyewall or tornadic event.

Upper air observations were limited due to the strong wind event, so only the 04/12Z and 05/00Z soundings are available. The 04/12Z Guam IAP sounding (figure 1-7) indicates deep easterly flow over Guam with east-northeasterly winds in the lower levels, which supports location of the primary circulation center to the southeast of Guam at that time. The 05/00Z sounding (not shown) indicated strong southerly flow in the lower levels, consistent with a rapidly developing low-level circulation center to the west of Guam.

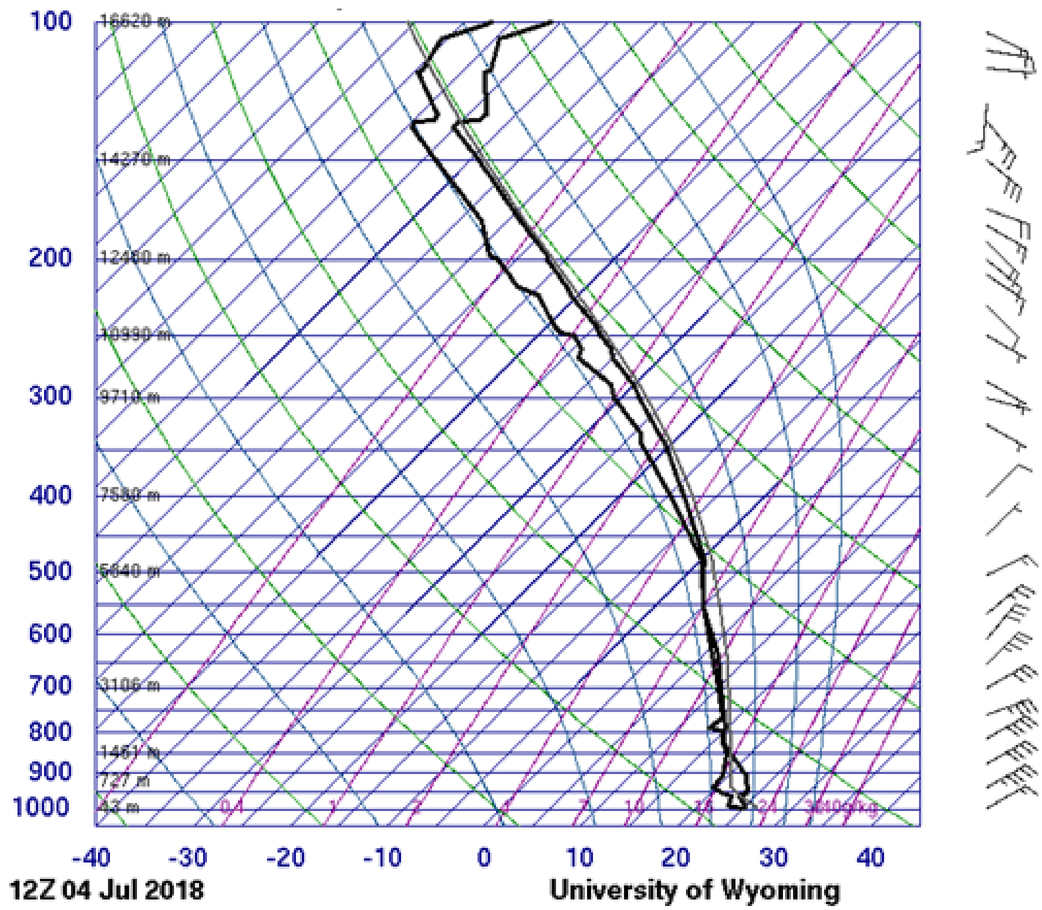


Figure 1-7: Guam International Airport sounding 04 July 2018 / 12Z indicating east-northeasterly winds through the boundary layer, consistent with a low-level circulation center located to the southeast of Guam IAP at 04/12Z. Image credit: University of Wyoming.

Based on reanalysis of all available data (figure 1-8), it appears that TC 10W underwent rapid intensification (RI) early in its lifecycle, starting at 03/18Z (25 knots) and continuing through 04/18Z (55 knots) - a 30 knot increase in intensity over a 24-hour period. A more significant ERI (extreme rapid intensification) event occurred from 04/18Z (55 knots) to 05/18Z (115 knots) - a 60 knot increase in 24 hours.

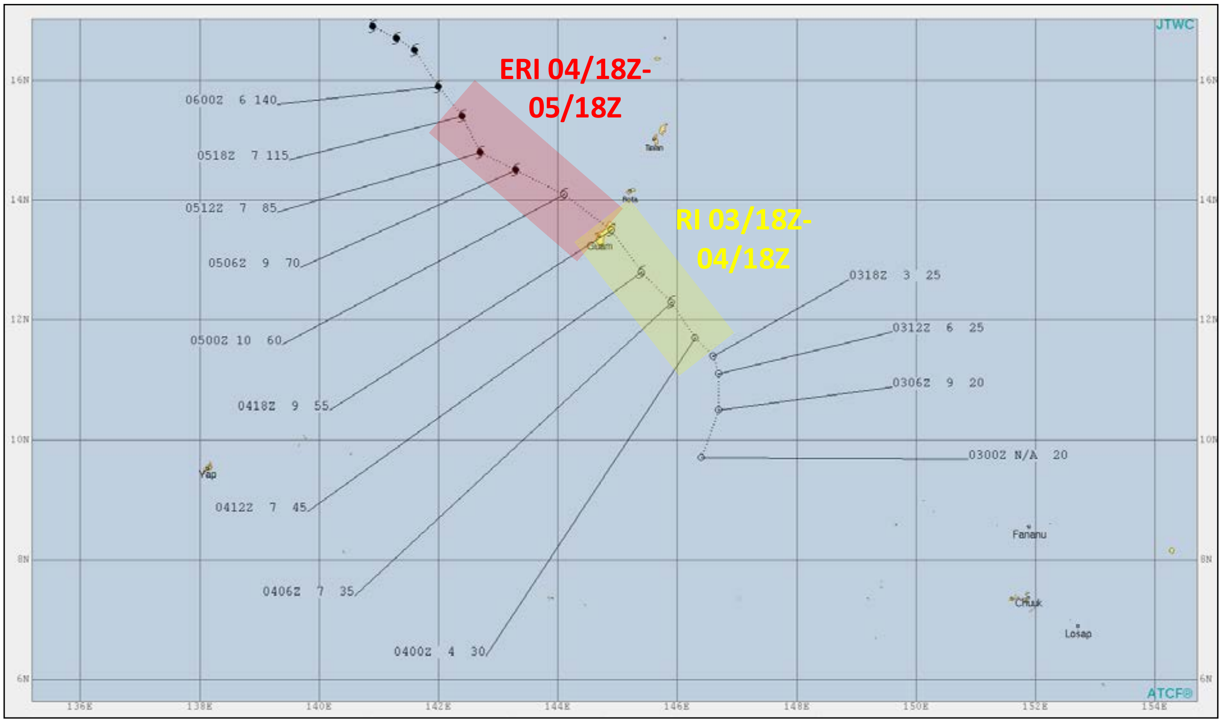


Figure 1-8: Final JTWC best track for STY 10W (Maria), indicating that the center likely consolidated rapidly as it passed over and to the west of Guam on 04 July from 15Z through 21Z.

As TC 10W strengthened to the southeast of Guam, microwave imagery (figures 1-9 through 1-11) indicated a broad, defined center with narrow but intense convective banding over the eastern and northern quadrants. As evidenced in the 04/0532-04/1140Z microwave images (figures 1-12 through 1-14), the system strengthened as fragmented deep convective banding wrapped tightly into a more defined center. The 04/1552-04/1809Z images (figures 1-15 through 1-16) indicate that the system developed an improved banding and convective structure and rapidly consolidated as it approached and tracked over Guam.

As TC 10W tracked just west of Guam, microwave images (figure 1-17 through 1-19) clearly showed improved spiral banding wrapping into a well-defined center, with multiple feeder bands evident over the southern semicircle. By 05/0350-05/0835Z (figures 1-20 through 1-21), the cyclone had intensified to 70+ knots, and a well-defined microwave eye feature emerged.

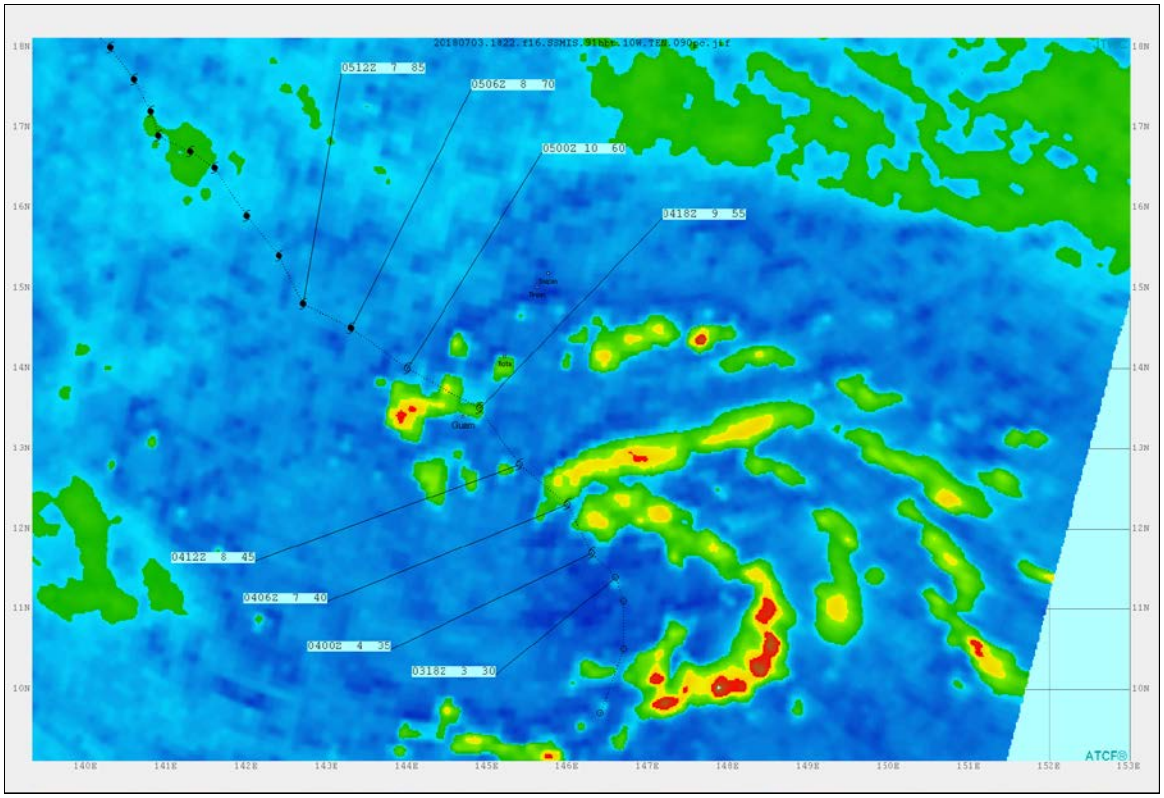


Figure 1-9: July 3 1822Z SSMIS 91 GHz image.

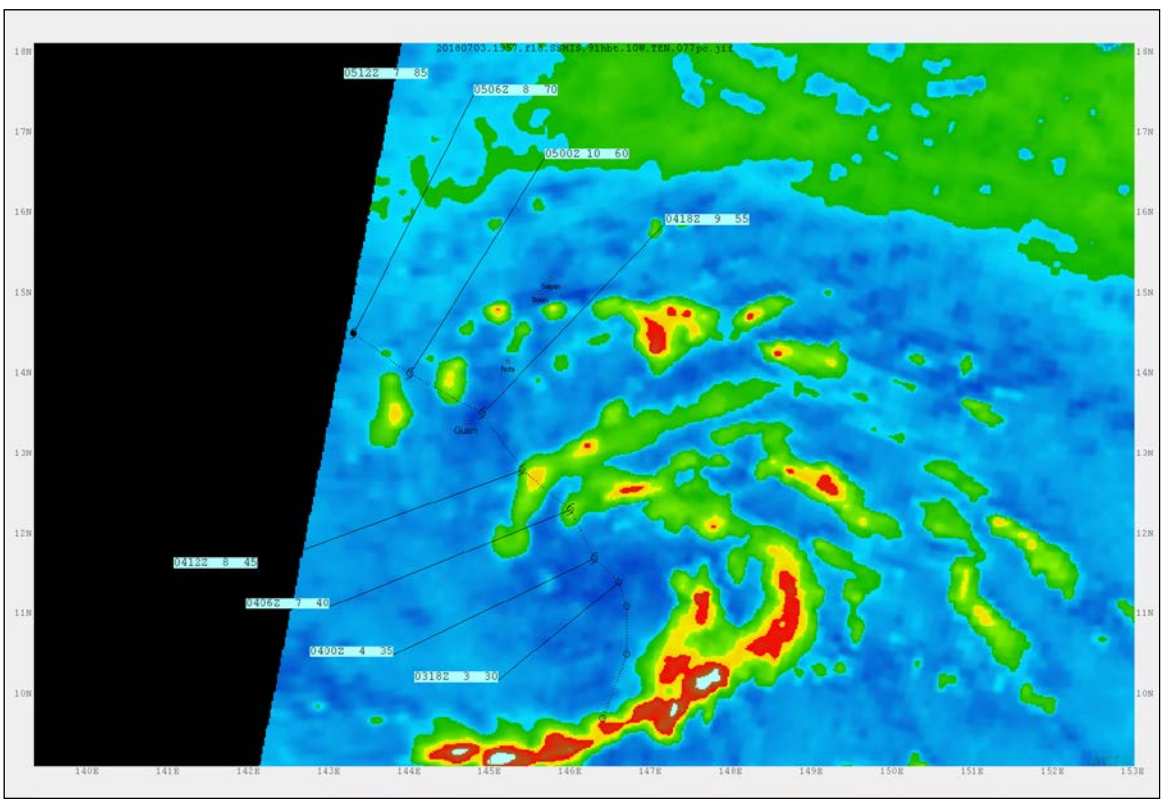


Figure 1-10: July 3 1957Z SSMIS 91 GHz image.

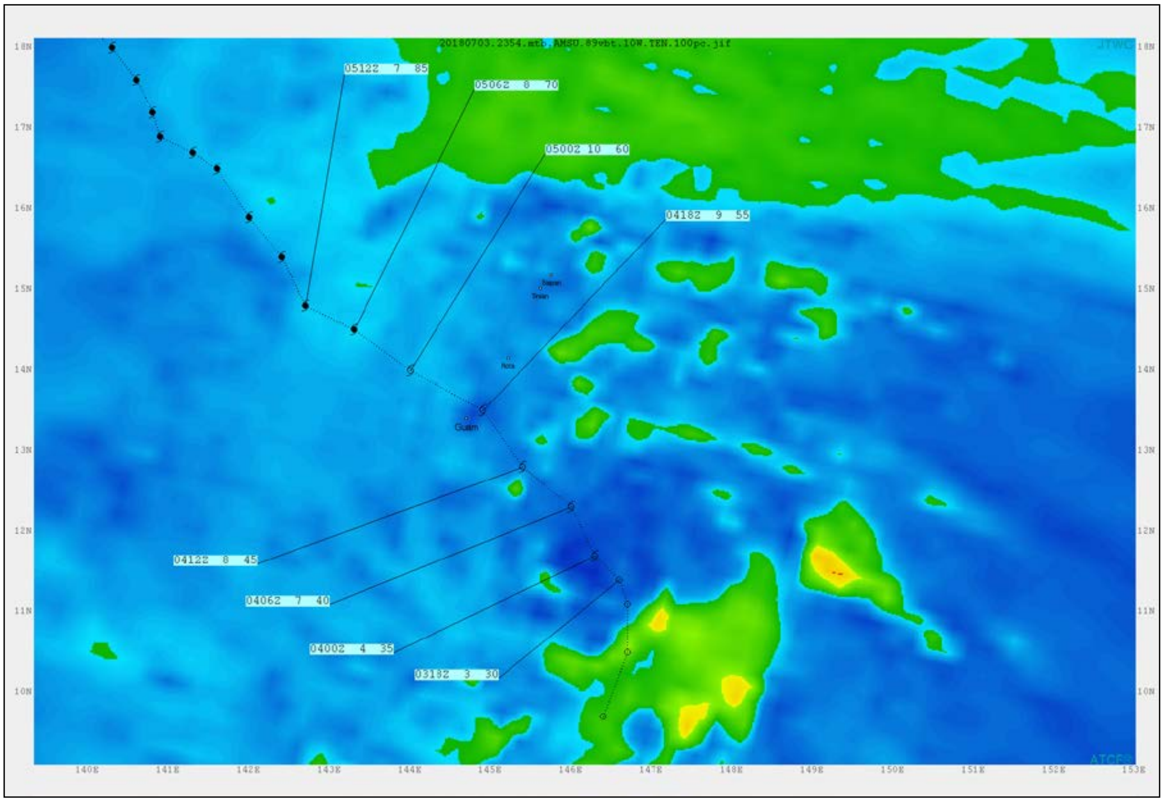


Figure 1-11: July 3 2354Z AMSU 89 GHz image.

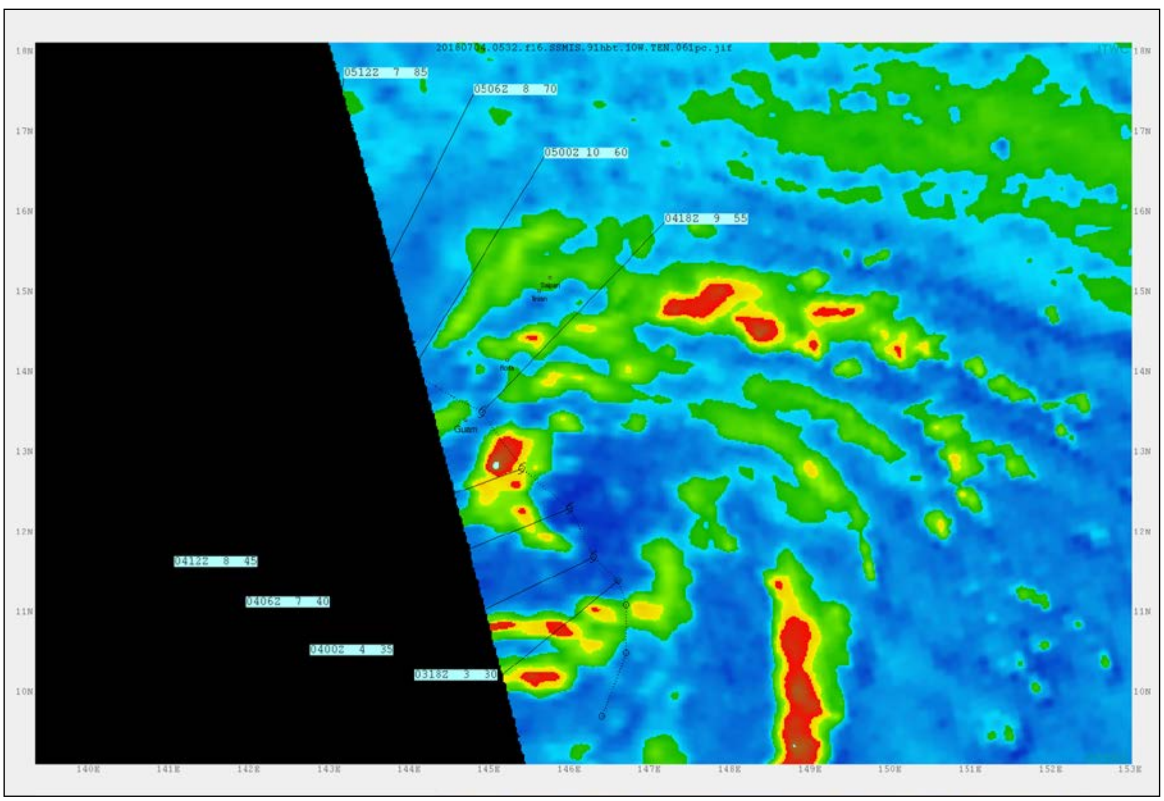


Figure 1-12: July 4 0532Z SSMIS 91 GHz image.

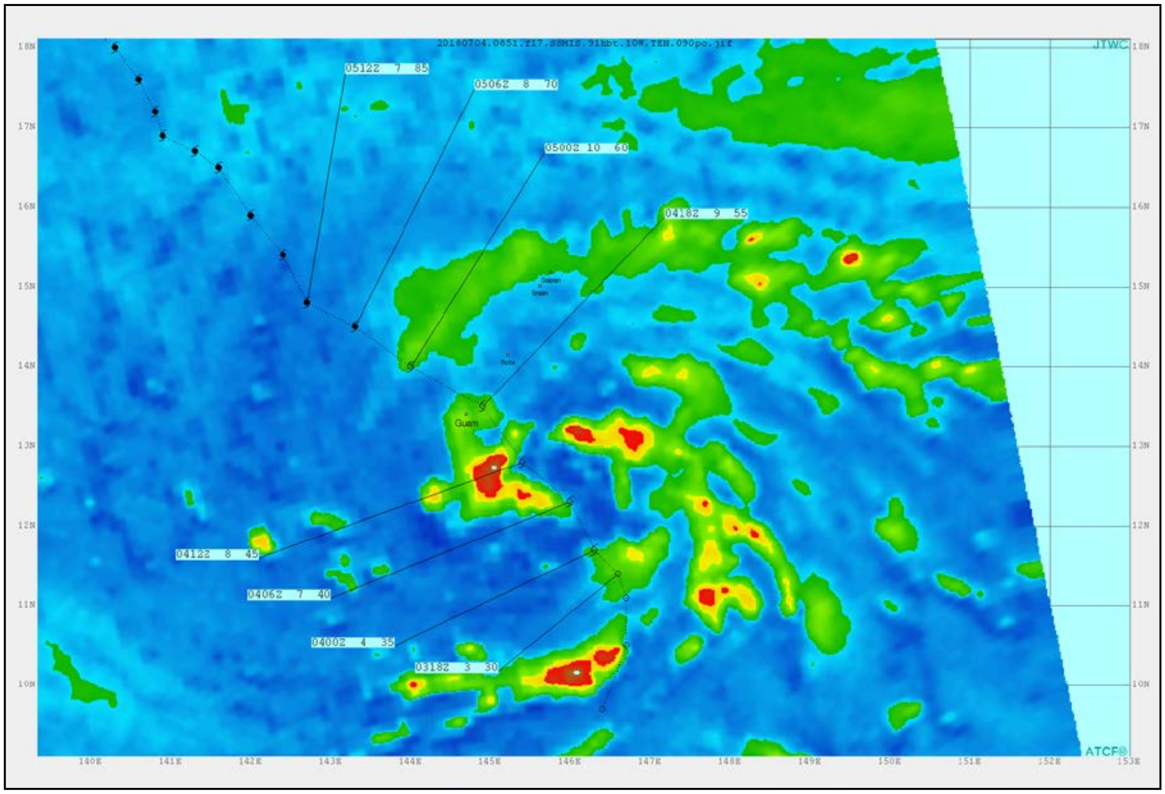


Figure 1-13: July 4 0851Z SSMIS 91 GHz image.

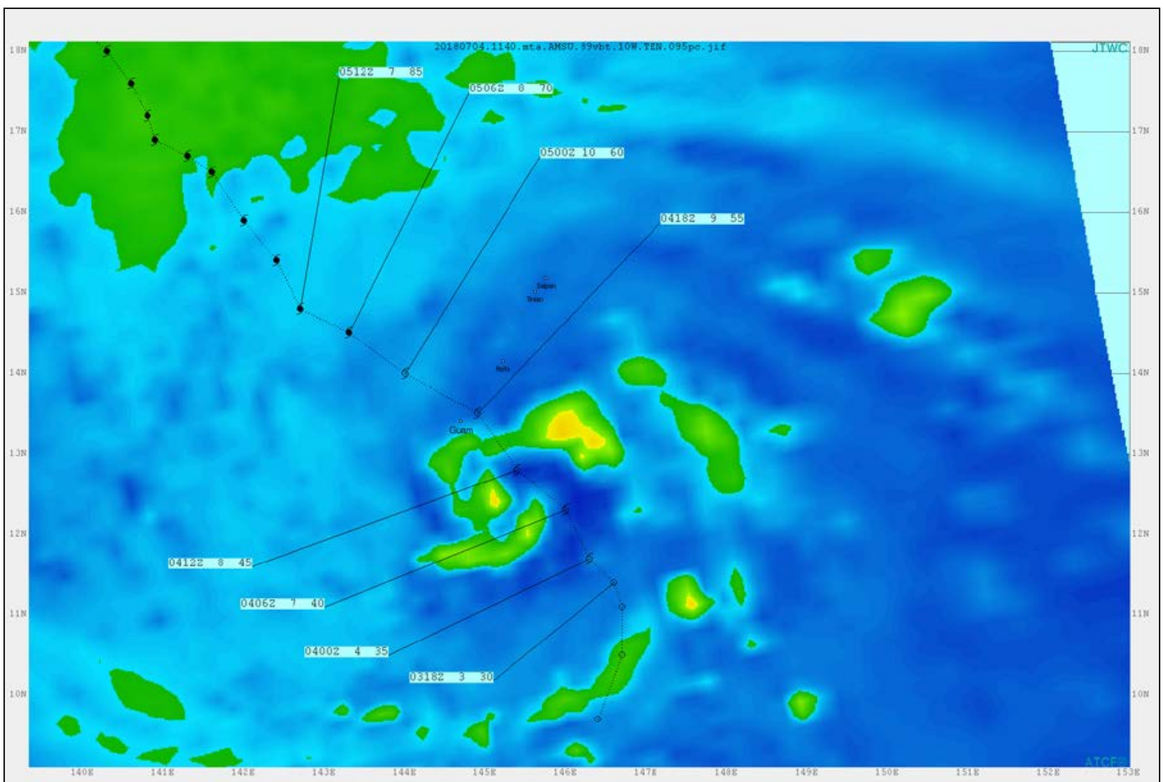


Figure 1-14: July 4 1140Z AMSU 89 GHz image.

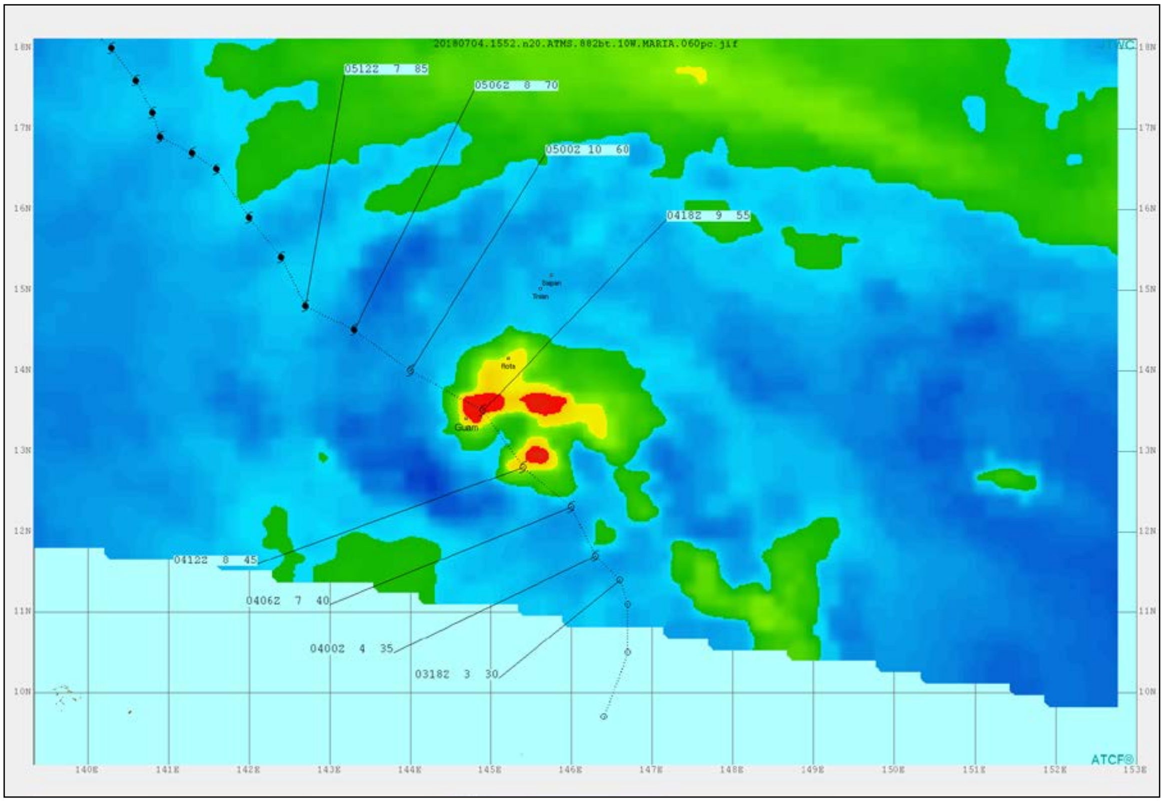


Figure 1-15: July 4 1552Z ATMS 88.2 GHz image.

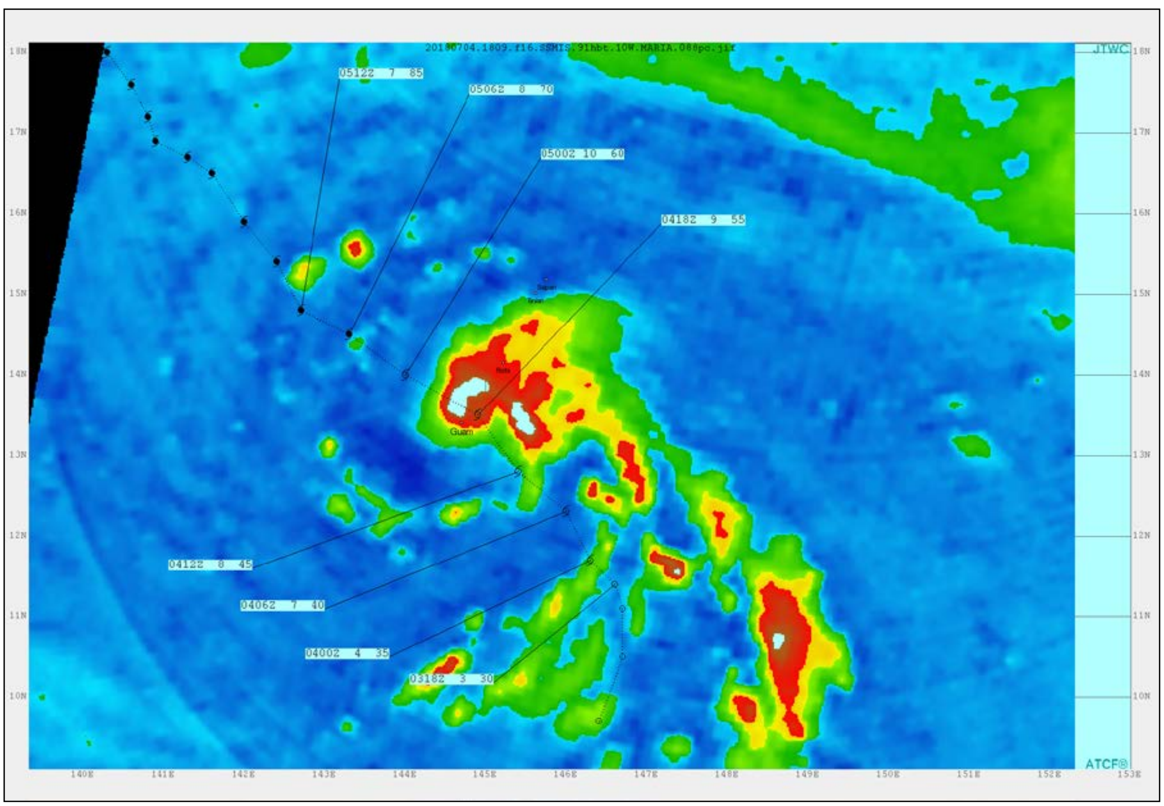


Figure 1-16: July 4 1809Z SSMIS 91 GHz image.

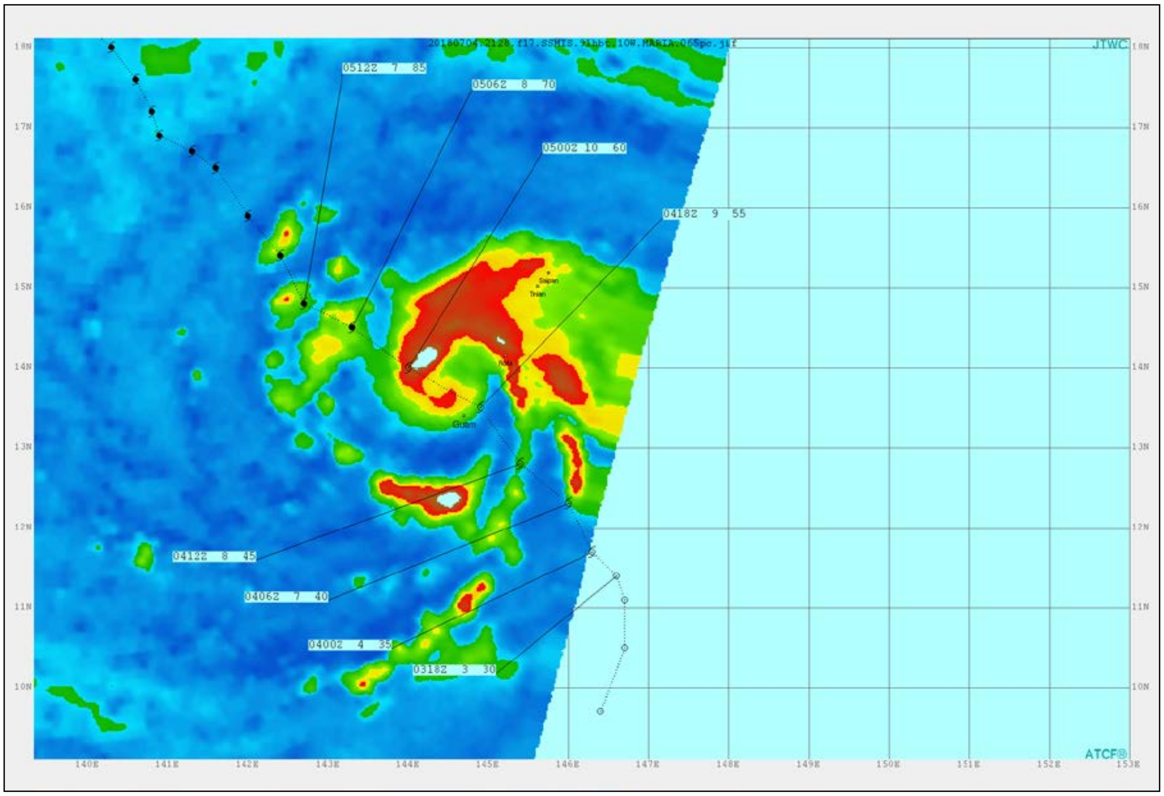


Figure 1-17: July 4 2128Z SSMIS 91 GHz image.

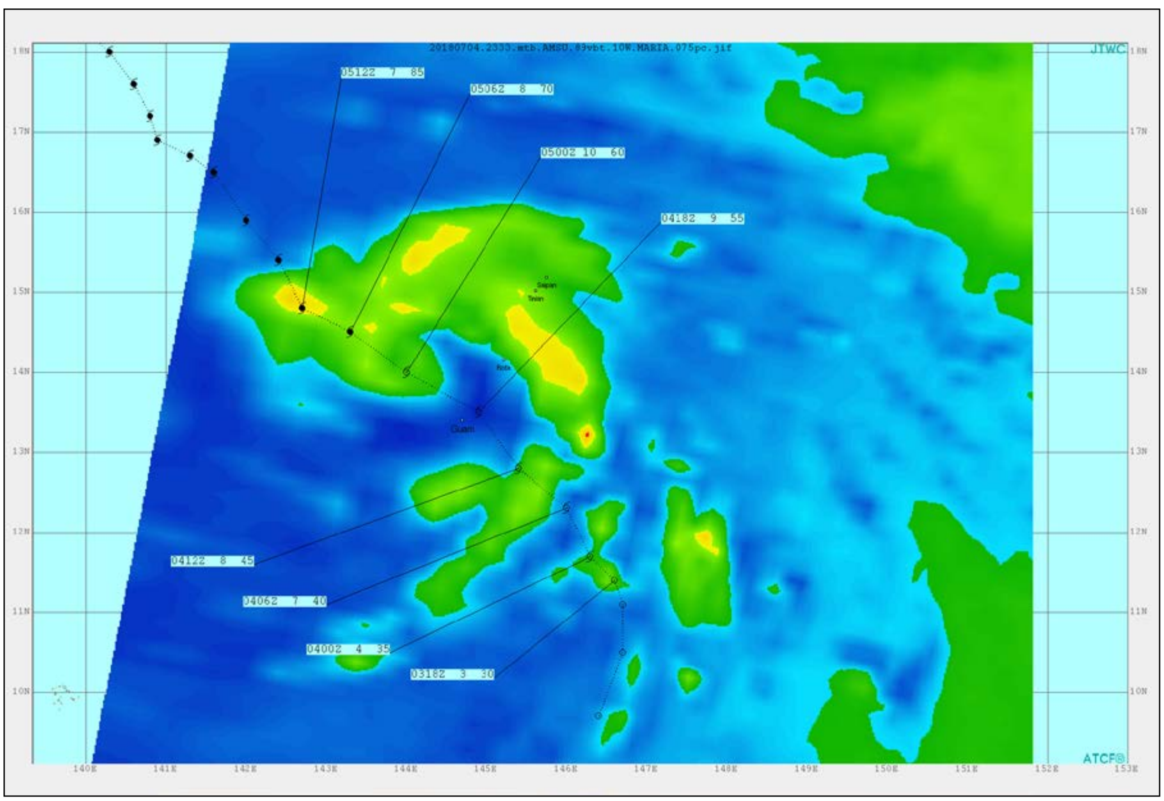


Figure 1-18: July 4 2333Z MHS 89 GHz image.

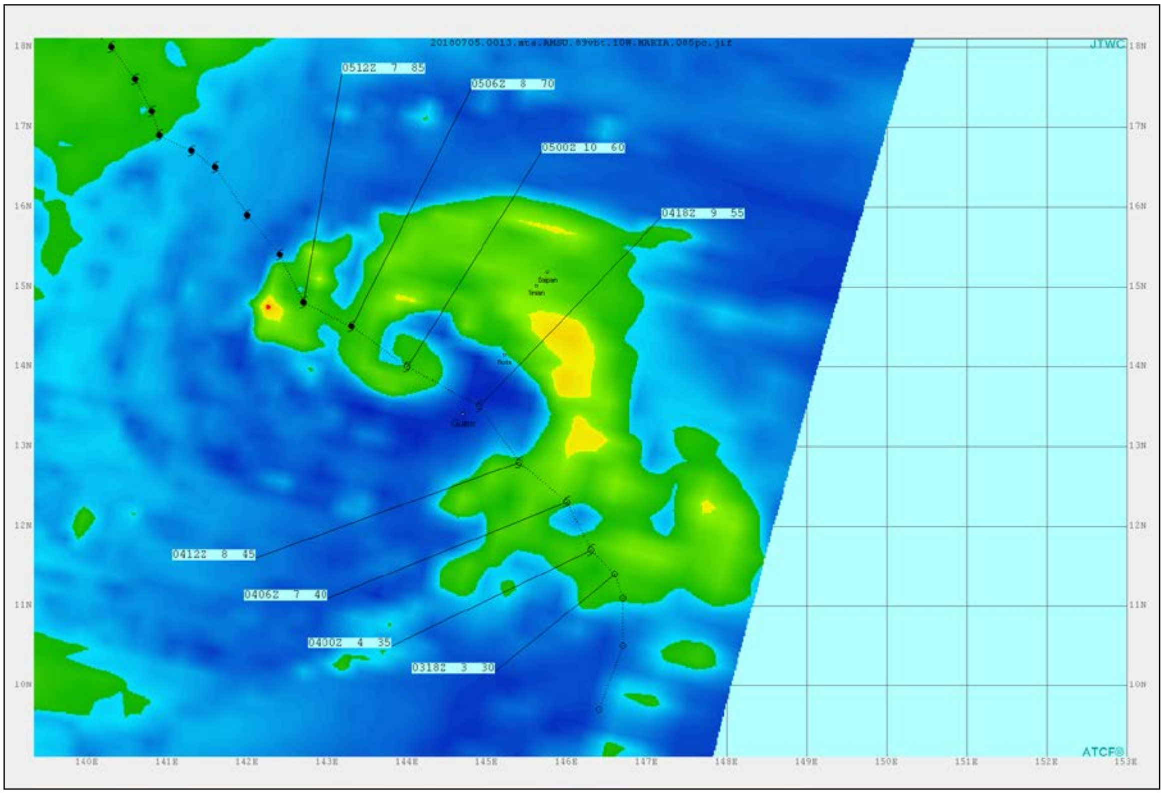


Figure 1-19: July 5 0019Z MHS 89 GHz image.

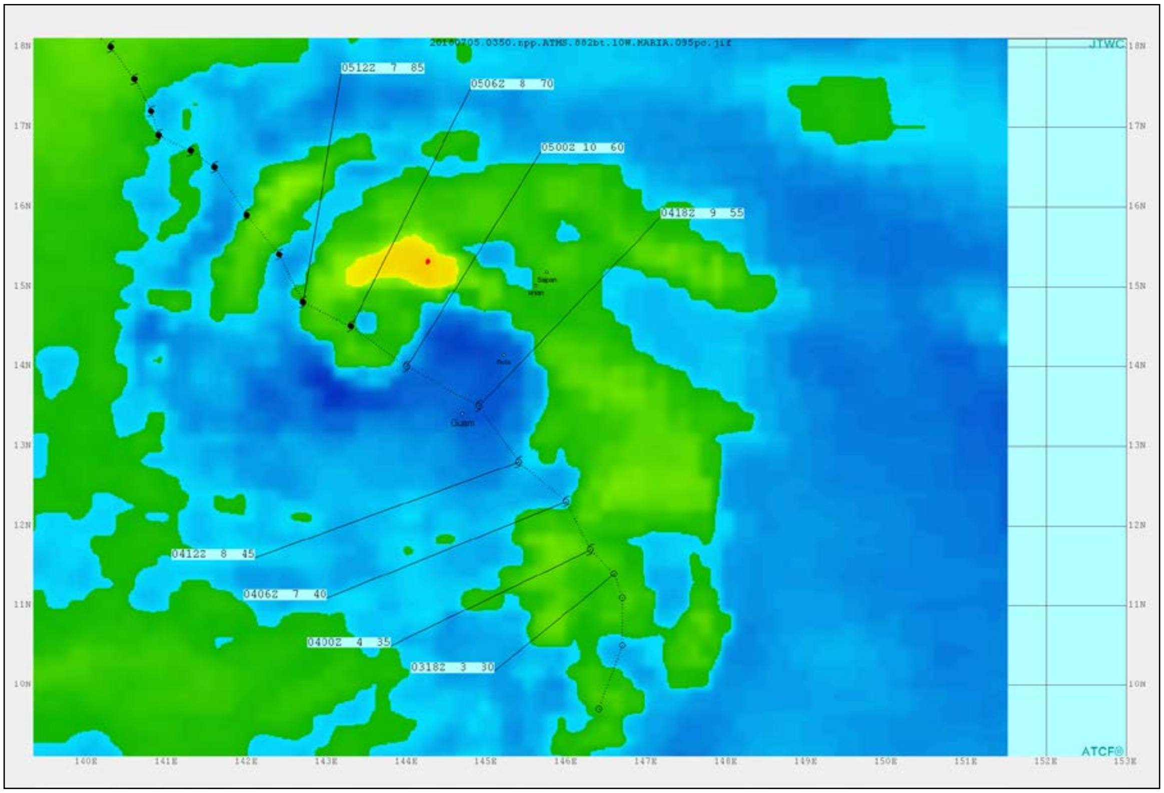


Figure 1-20: July 5 0350Z ATMS 88.2 GHz image.

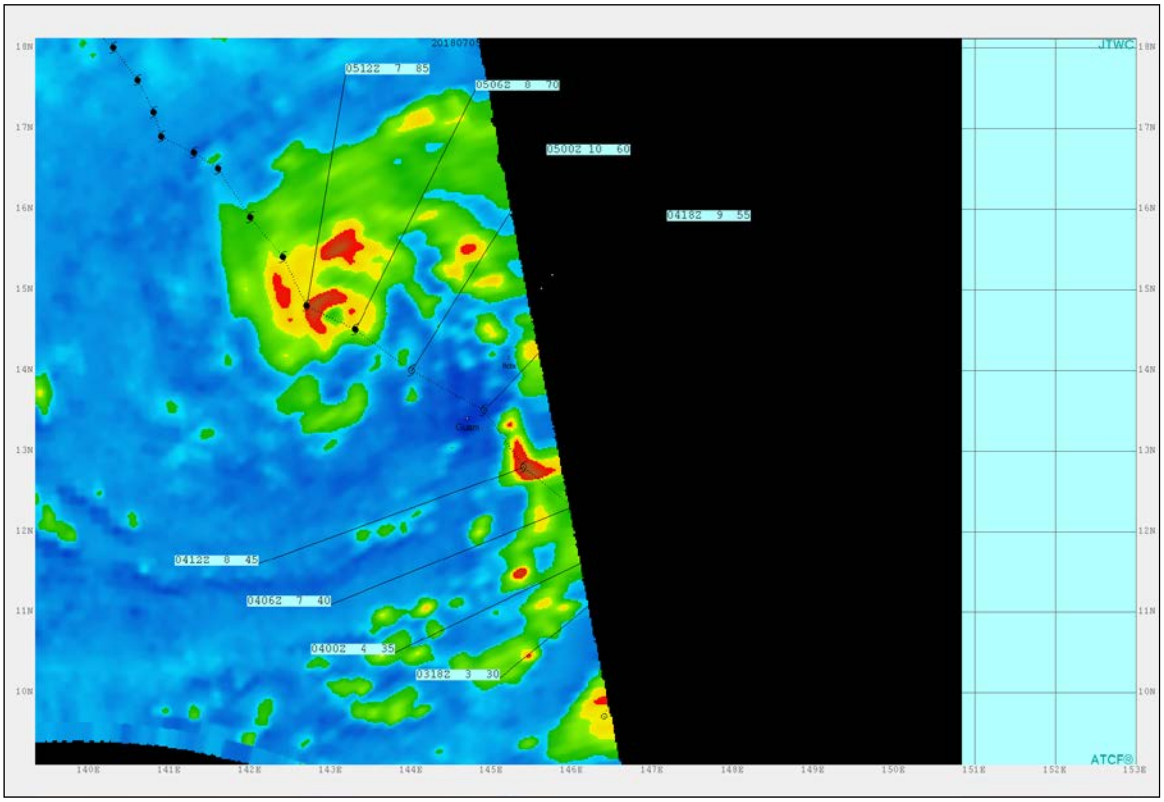


Figure 1-21: July 5 0835Z SSMIS 91 GHz image.

In response to the unexpected severe weather that occurred on Andersen AFB and resultant damage to aircraft on the runway, JTWC conducted a preliminary post-storm review of TC 10W within a few weeks of the event's conclusion. Based on an analysis of available satellite imagery, radar data and observations, JTWC initially concluded that the localized severe weather event at Andersen AFB was indeed an effect of TC 10W, but not the direct result of tropical cyclone center passage. Available data suggested that the cyclone's center had passed to the south of the Guam. A more detailed post-storm analysis incorporating additional surface and boundary-layer wind data, sea level pressure data and radar imagery identified clear evidence to confirm that the center passed to the south of Andersen AFB. However, since the low-level circulation center consolidated quickly and available imagery for the period of storm passage is limited, there is insufficient data to place the center south of the island of Guam with any confidence.

Both JTWC and Weather Forecast Office Guam leadership have hypothesized that Andersen AFB experienced passage of a mesoscale convective vortex (MCV) and an embedded, localized phenomenon known as a "vortical hot tower" (VHT), which has been associated with the rapid genesis of a TC (Montgomery et al. 2006; Montgomery and Smith 2014). Andersen AFB radar indicated that the MCV and embedded VHT were traveling at approximately 50 knots toward the base. This motion, combined with sustained tropical storm-force background winds of 30 to 35 knots, could have produced the observed, severe surface wind gusts exceeding 80 knots. JTWC's forecasts for lower sustained wind speeds verified across much of Guam, except for the northern portion of the island over which the VHT feature traversed. It is worth noting that a similar, albeit less severe, event occurred in Guam during Super Typhoon Ed in 1993 (Stewart and

Lyons 1996).

An extensive post-storm survey on Guam revealed, “the wind damage was in a straight line, which is not indicative of a TC eye passage (which would show easterly wind damage first followed by westerly wind damage, based on the rotation of the winds)” (Guard and Lander 2018). Following a similar line of reasoning, Ludwig (2019) acknowledged the strong rotation evident in radar imagery, which triggered the tornado warning, but asserted that the “three-hour duration and lack of westerly wind damage eliminates the tornado as a viable candidate.” Spratt et al. (1997) indicates that “outer rainband tornadoes have a typical duration of 1-2 hours and a core diameter of 1 nm,” which was not observed in this case.

Formulating a comprehensive characterization of this complex event is complicated by: (1) the lack of high-resolution microwave imagery during a critical period when the system was undergoing RI and approaching Guam and (2) an untimely radar outage at 04/1728Z as the system consolidated over and to the west of Guam. Despite these data gaps, there is sufficient radar evidence to suggest that a mesoscale convective vortex / vortical hot tower mechanism was the primary driver of the severe weather event observed on Andersen AFB. A brief discussion of these mechanisms follows.

Mesoscale Convective Vortex (MCV):

A mesoscale convective system (MCS) is a conglomeration of individual thunderstorms organized within a single, mesoscale feature. The lifespan of a typical MCS is several hours or more. An MCV is a cyclonically rotating vortex, approximately 10-100km (5.4-54nm) in diameter, which develops within an MCS. MCVs that form over tropical ocean areas can act as focal points for tropical cyclone formation as they generate localized potential vorticity anomalies (Sippel et al. 2006).

Sippel et al. (2006) highlighted a case of MCV-driven tropical cyclone formation. Much like TC 10W, Tropical Storm Allison, which formed in the Gulf of Mexico in June 2001, displayed a common, asymmetric distribution of precipitation on the eastern and northern sides of a broad, low-level circulation. Additionally, radar and satellite data indicated that multiple, small-scale circulation centers, with associated deep convection, developed within the broader circulation surrounding the cyclone. The presence of these circulations rendered the primary circulation center of the broader circulation difficult to track.

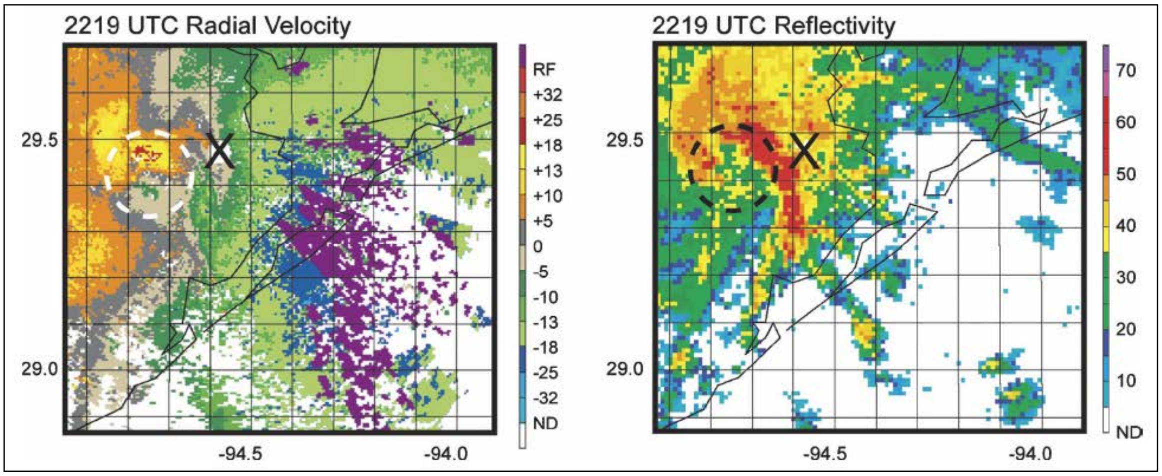


Figure 1-22: Radial velocity (m/s) and coincident reflectivity (dBz) images showing a mesoconvective vortex (denoted with dashed white and black circles) associated with Tropical Storm Allison tracking inland (Sippel et al. 2006). Used with permission.

Stewart and Lyons (1996) observed that the merging of small-scale vortices, evident in Guam radar data, appeared to support development of Super Typhoon Ed (1993). According to that study, a period of rapid intensification commenced after Ed's eyewall 'ingested' a series of thunderstorms with mesocyclones." Molinari et al. (2006) posited that, in addition to supporting development through merger, an individual MCV can sometimes transition into the primary tropical cyclone center.

Vortical Hot Tower (VHT)

Montgomery and Smith (2014) described VHTs as "cyclonically-rotating updrafts" with "lifetimes on the order of an hour" that "dominate the intensification period at early times." According to Hendricks et al. (2004), VHTs play a key role in TC genesis through a two-stage process:

"(i) preconditioning of the local environment via diabatic production of multiple small-scale lower-tropospheric cyclonic potential vorticity anomalies, and

(ii) multiple mergers and axisymmetrization of these low-level potential vorticity anomalies"

In addition to supporting TC genesis, VHTs likely play a key role in TC rapid intensification though localized, but intense, effects on the broader flow pattern within a tropical cyclone's primary convective region (Fang and Zhang 2011; Montgomery and Smith 2014).

Satellite measurements have provided much of the direct, observational evidence of mesoscale phenomena, such as VHTs, that occur within TCs over the open ocean. The Tropical Rainfall Measuring Mission (TRMM), which collected data over a 17-year period from its launch in November 1997 to April 2015, leveraged a precipitation radar (PR) and microwave imager (TMI) to gather data on TC structure and formation. TRMM advanced scientific understanding of TC dynamics, and provided observational evidence regarding the role of vortical hot towers in in TC formation and rapid intensification. The Global Precipitation Measurement (GPM) Mission, launched in February 2014 has carried forward TRMM's legacy with its 13-channel microwave imager and a dual-frequency precipitation radar (NASA 2011). Figures 1-23 through 1-26 provide several examples of VHT signatures observed by these two satellite sensors.

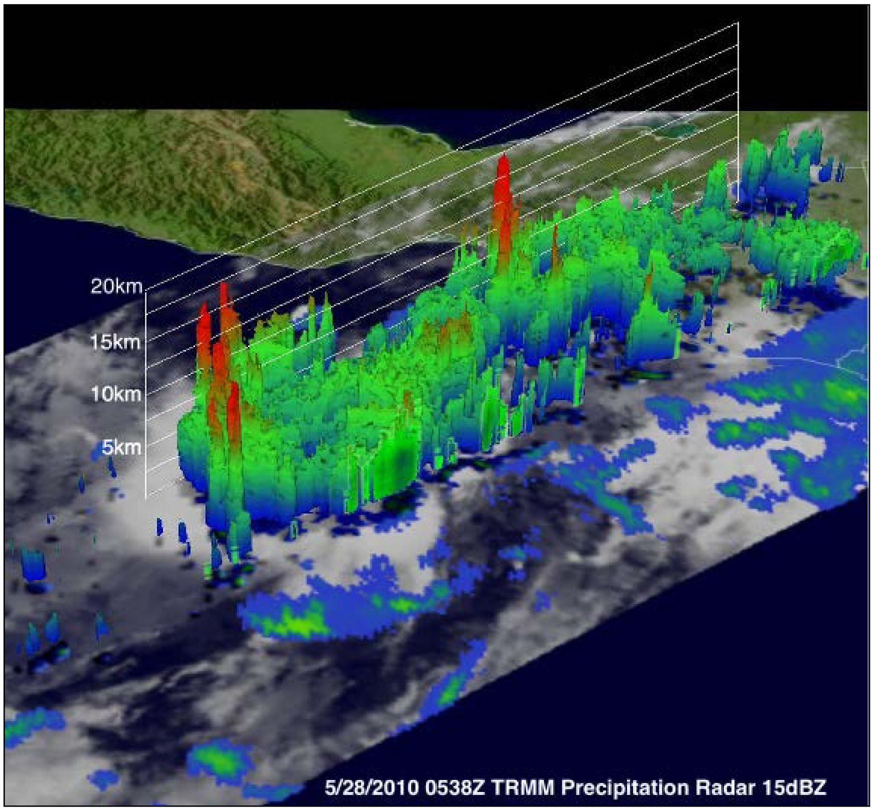


Figure 1-23: Image of vortical hot towers from Tropical Storm Agatha (2010 Eastern Pacific) using the TRMM PR. Image credit: NASA Goddard Space Flight Center.

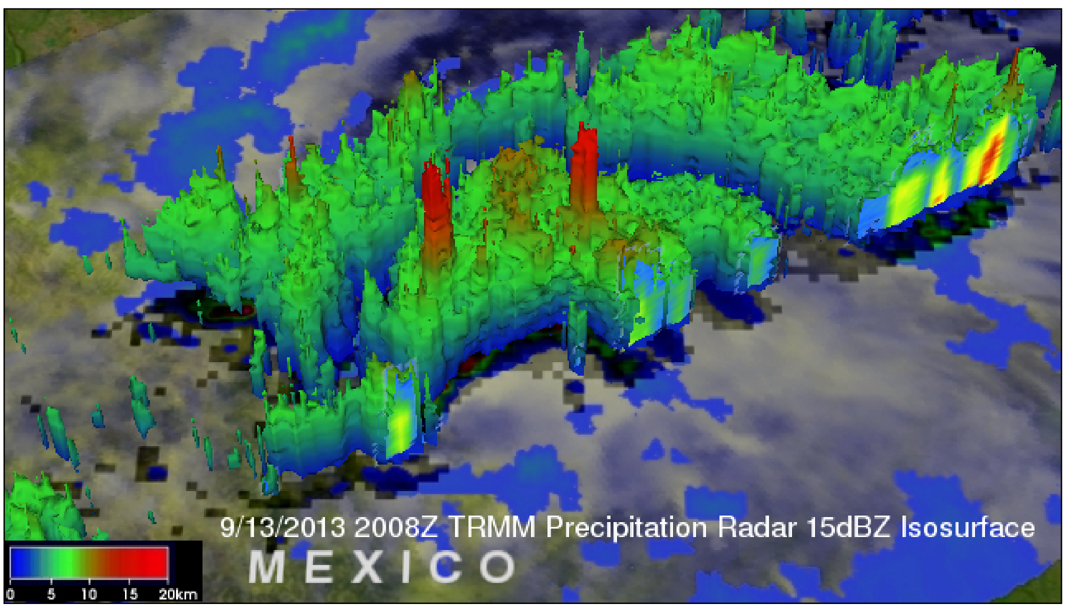


Figure 1-24: TRMM PR image of vortical hot towers observed in Tropical Storm Ingrid (September 13, 2013). Image credit: NASA Goddard Space Flight Center.

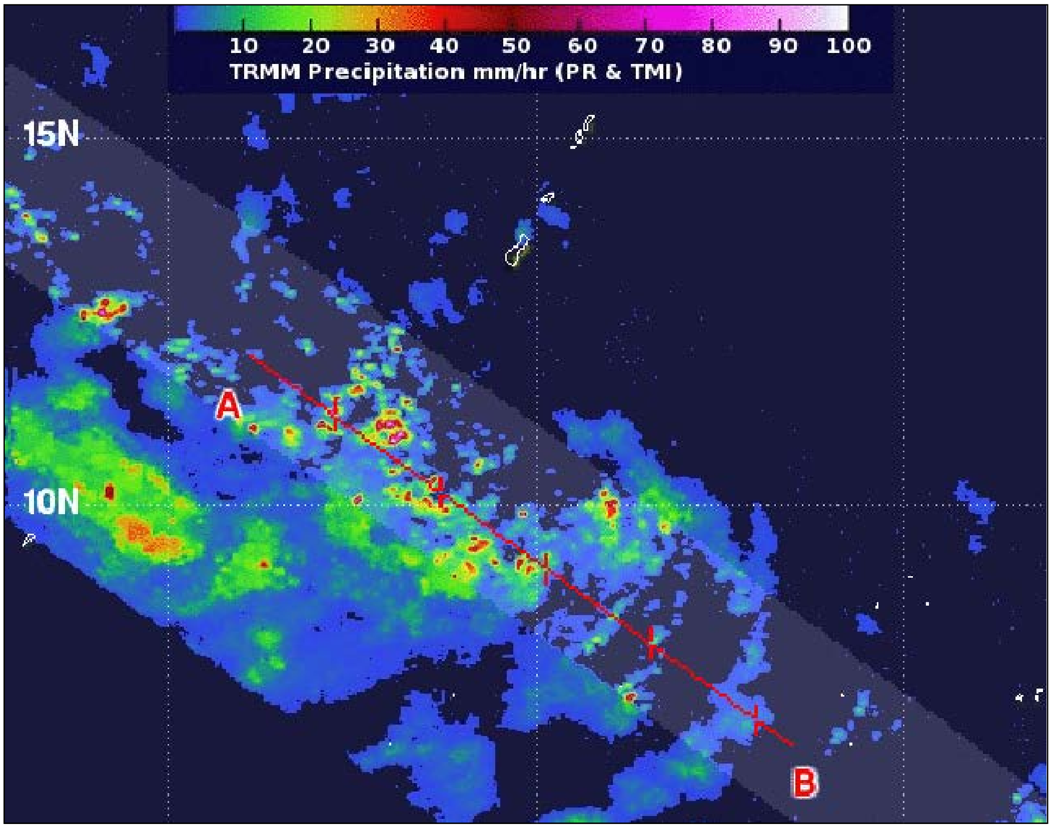


Figure 1-25: TRMM PR image of Tropical Depression 08W (July 3, 2014 (0851Z)) showing VHTs within convective band wrapping into a broad center south of Guam. Image credit: NASA Goddard Space Flight Center.

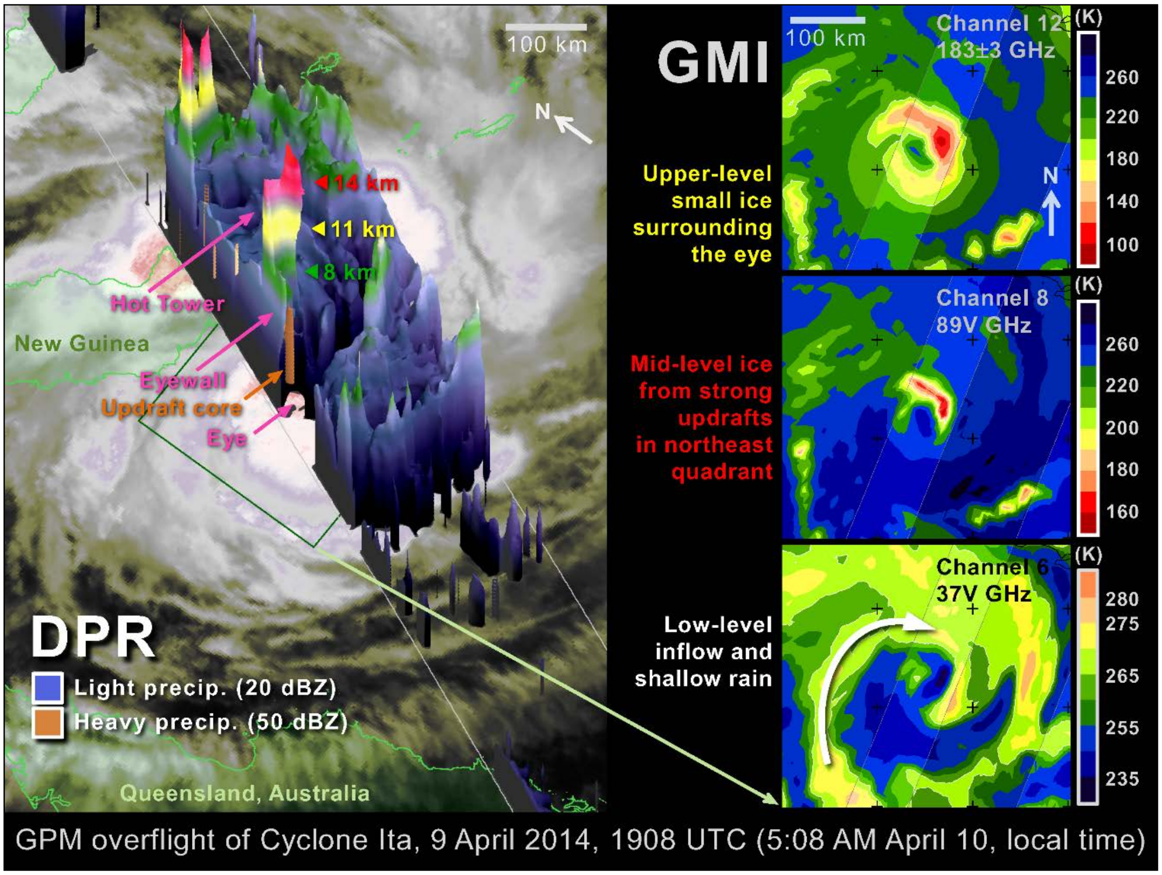


Figure 1-26: GPM overflight of TC Ita (9 April 2014) near Australia as it rapidly intensified from a category 1 to category 4 system. Note presence of vortical hot towers in the spiral banding (George Mason, 2019). Used with permission.

Radar Discussion:

At 04/1536Z, radar depicted three distinct mesoscale convective vortices (MCV) embedded within the developing low-level circulation of STY 10W (figures 1-27 and 1-28). White, red and orange circles highlight these MCVs in each of the following radar images, generated with Gibson Ridge radar display software.

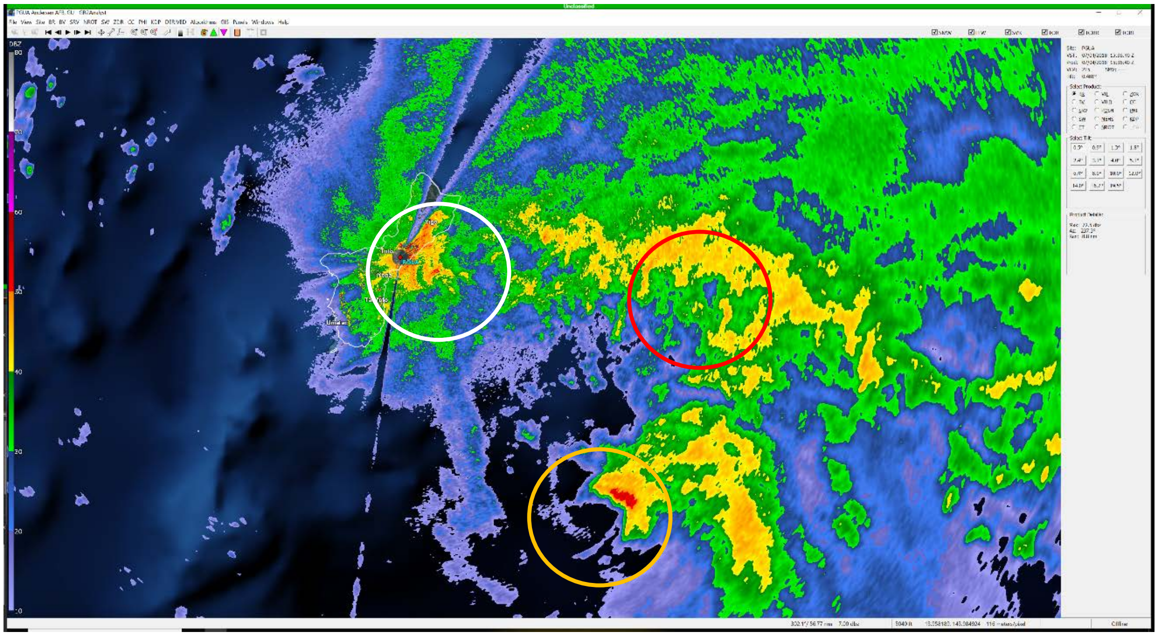


Figure 1-27: July 4 1536Z Base reflectivity product.

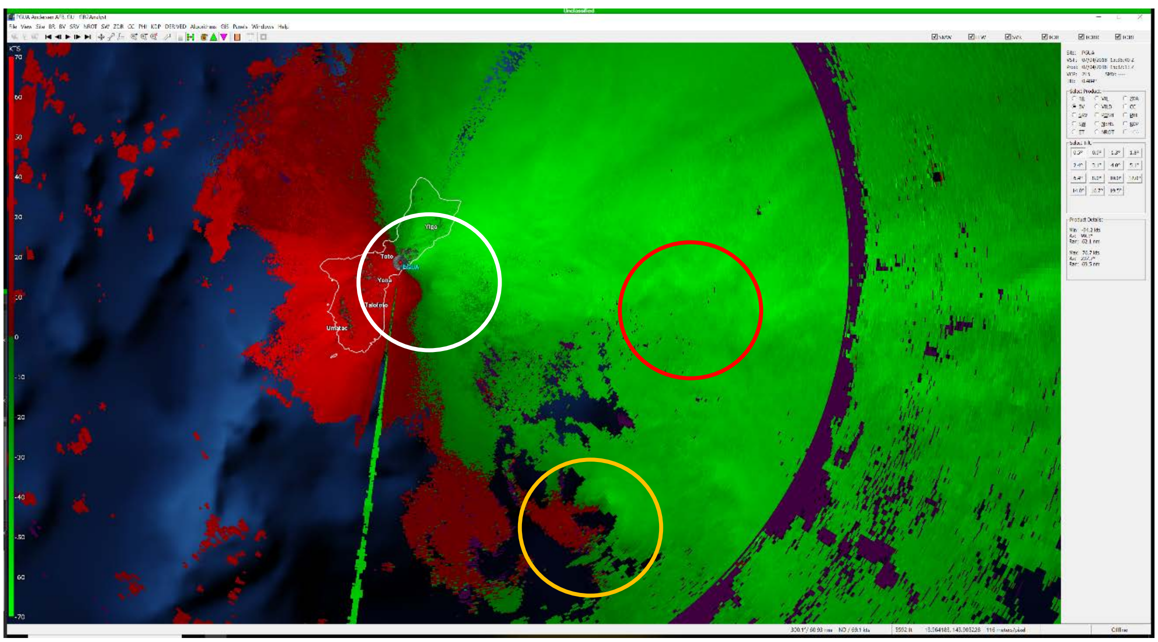


Figure 1-28: July 4 1536Z Base velocity product.

By 04/1613Z, MCV #1 (white circle) had begun to dissipate over Guam (figures 1-29 and 1-30). No notable effect on surface winds or SLP associated with this vortex is evident in observations from Andersen AFB (figure 1-5). MCV #2 (red circle) was better defined, but very small and embedded within an MCS to the north of MCV #3 (orange circle). MCV #3 was larger, about 15-20nm in diameter, and clearly the dominant MCV. Additionally, figure 1-30 indicates a strong rotational component of MCV #3 in the base velocity image.

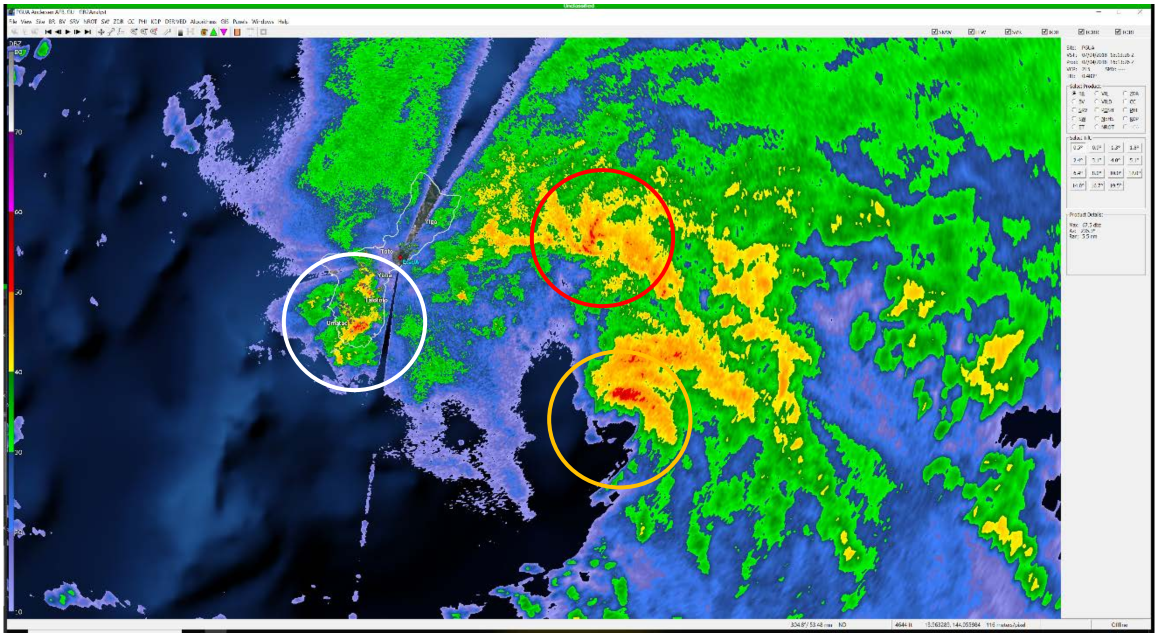


Figure 1-29: July 4 1613Z Base reflectivity product.

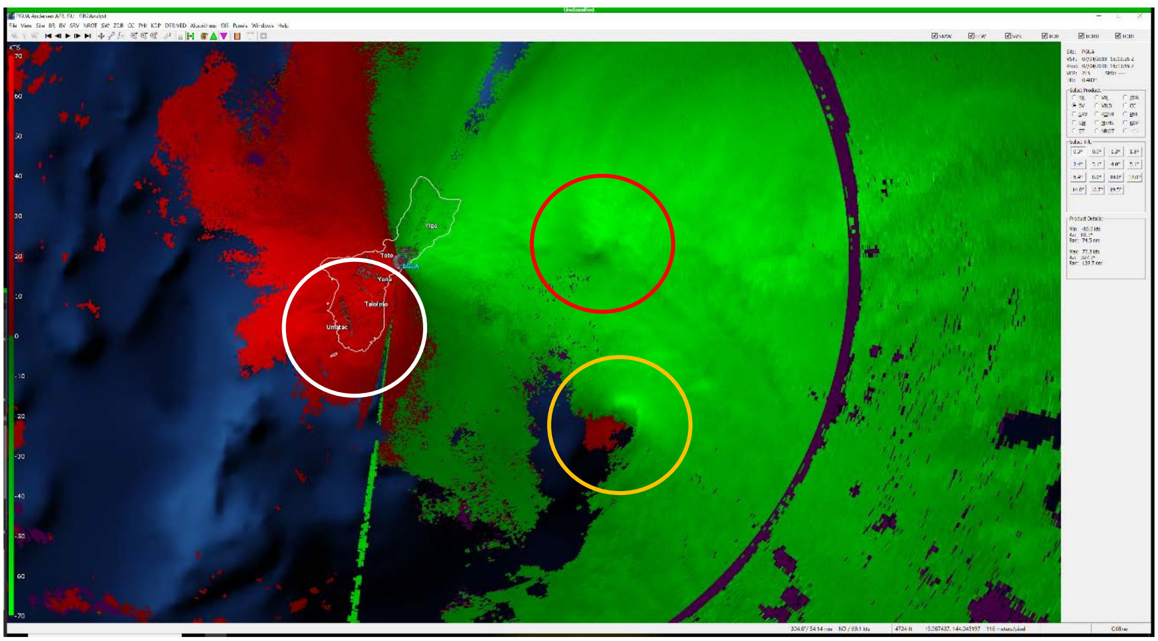


Figure 1-30: July 4 1613Z Base velocity product.

By 04/1631Z, both MCV #2 and MCV #3 had developed a more defined structure with strong convection (figures 1-31 and 1-32). MCV #3 remained the dominant MCV with a 15-20nm diameter and strong rotational component.

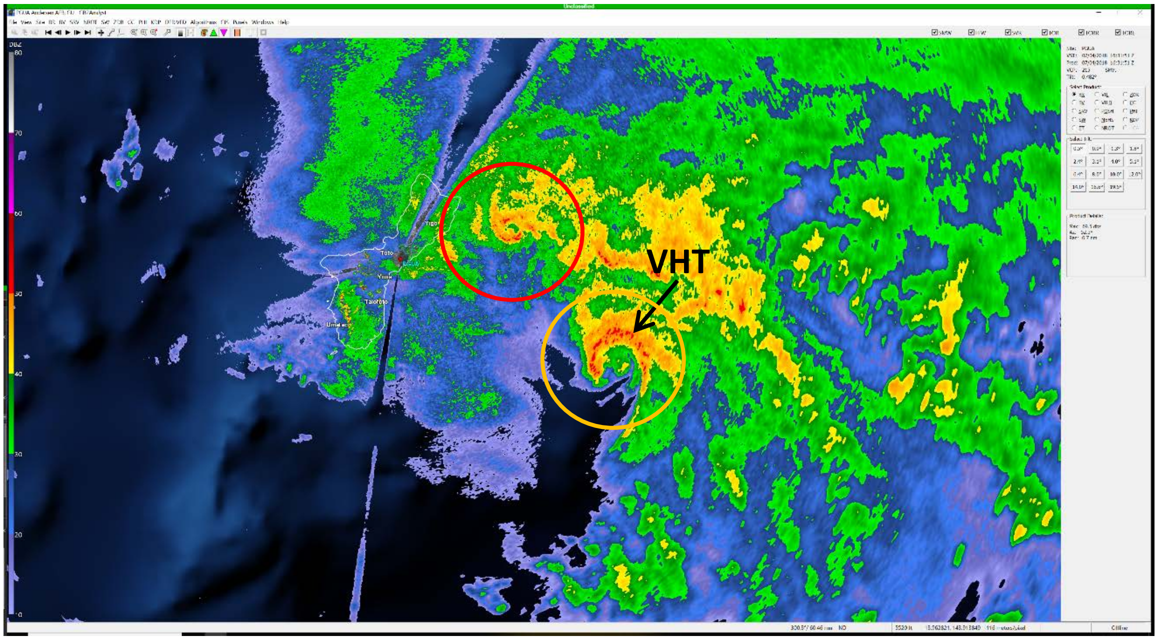


Figure 1-31: July 4 1631Z Base reflectivity product. Approximate position of VHT (see radar cross-sections in figures 1-33 and 1-34) marked with black arrow.

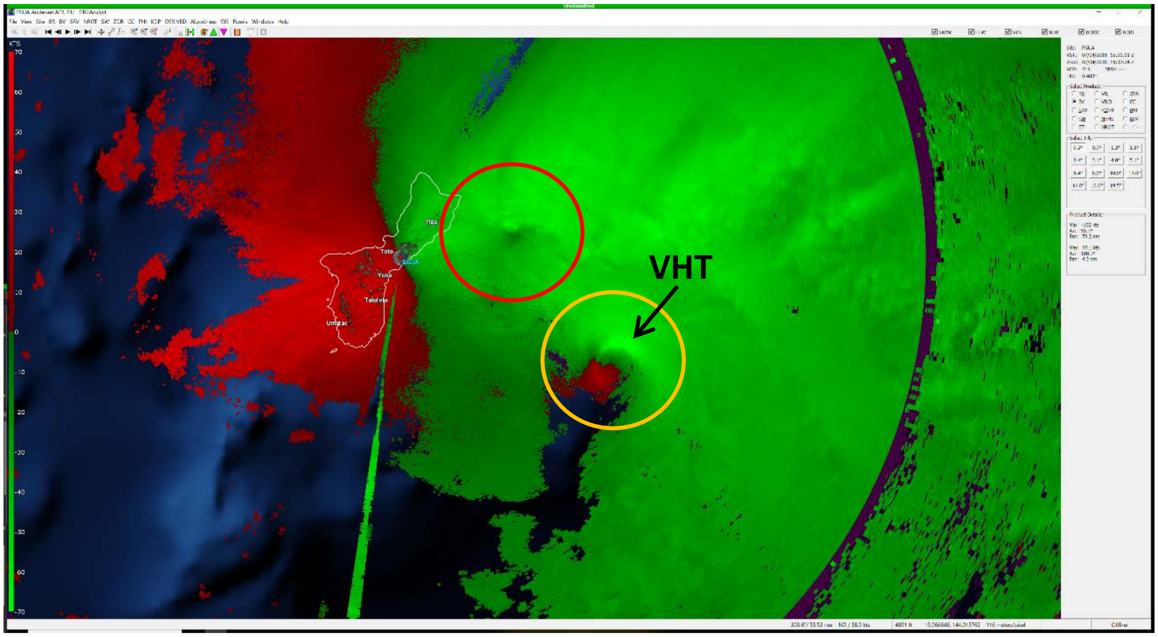


Figure 1-32: July 4 1631Z Base velocity product. Approximate position of VHT (see radar cross-sections in figures 1-33 and 1-34) marked with black arrow.

Figures 1-33 and 1-34 represent radar cross-sections corresponding to the images in figures 1-31 and 1-32, including a distinct VHT located within the northern banding of MCV #3 extending up to 55k feet.

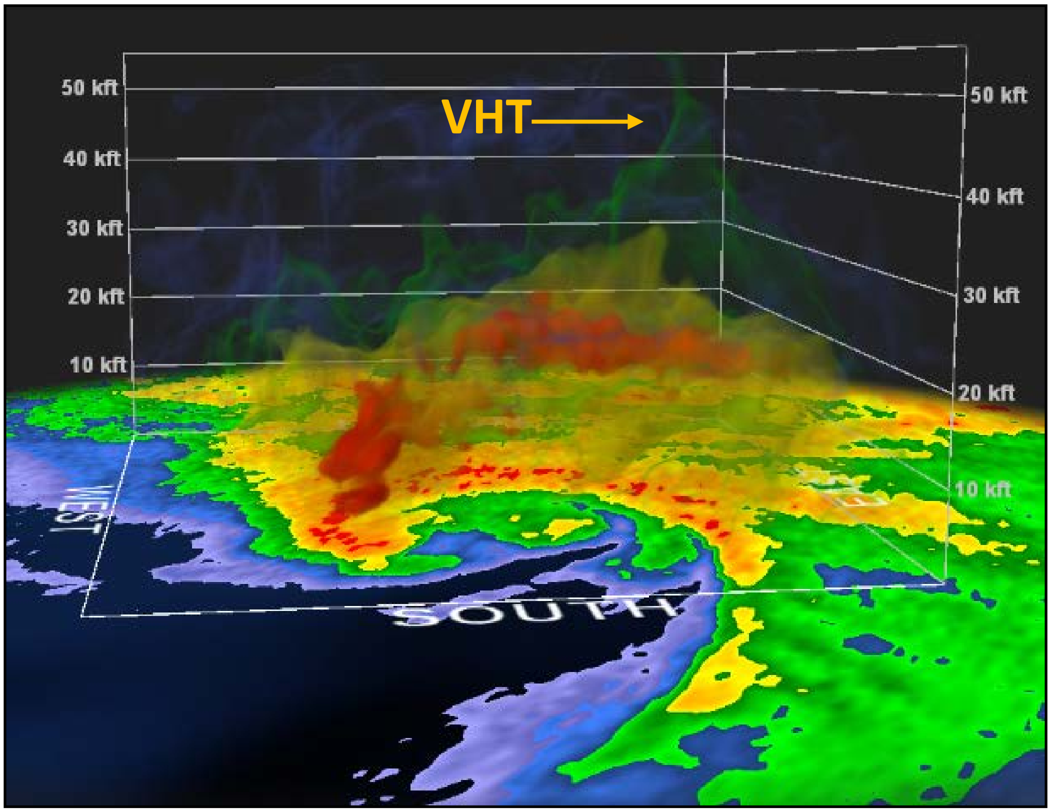


Figure 1-33: July 4 1631Z reflectivity cross-section.

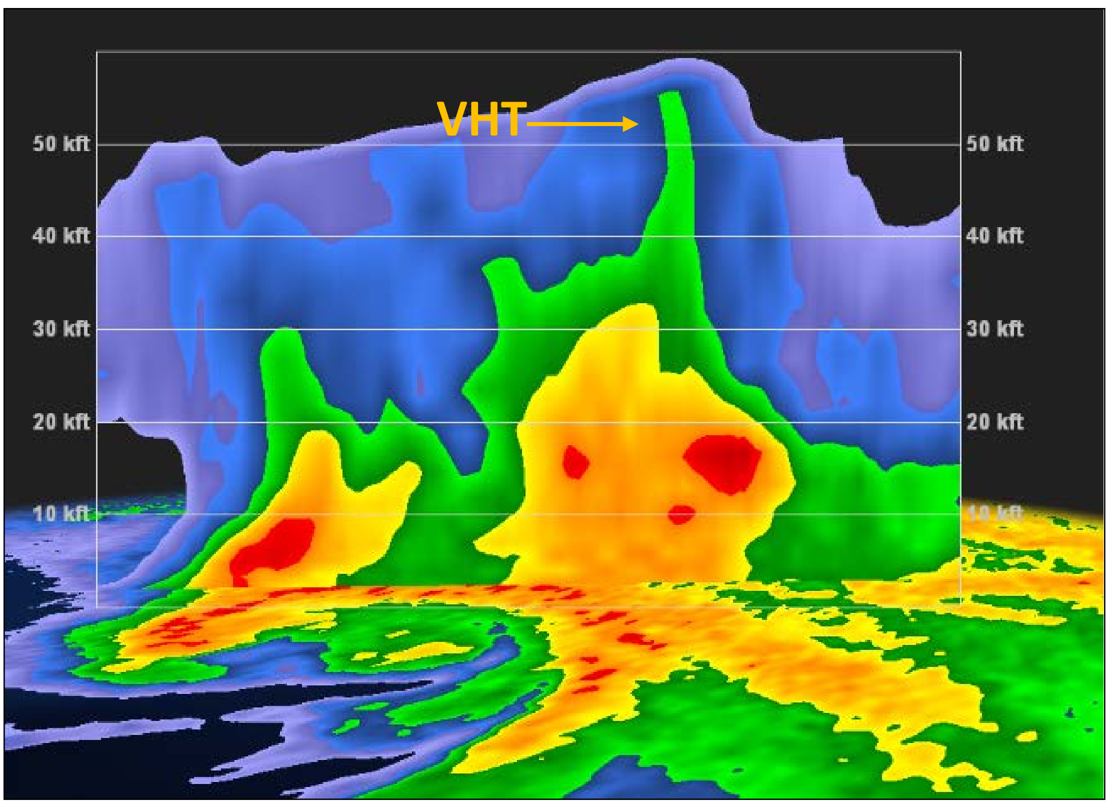


Figure 1-34: July 4 1631Z reflectivity cross-section.

At approximately 04/1637Z, MCV #2 tracked over northern Guam (figures 1-5 and 1-6) with no significant indication of impact evident in the surface winds and SLP plots (figures 1-35 and 1-36). MCV #3 continued to rotate cyclonically toward Guam while strengthening and maintaining a strong rotational field (figures 1-35 through 1-38).

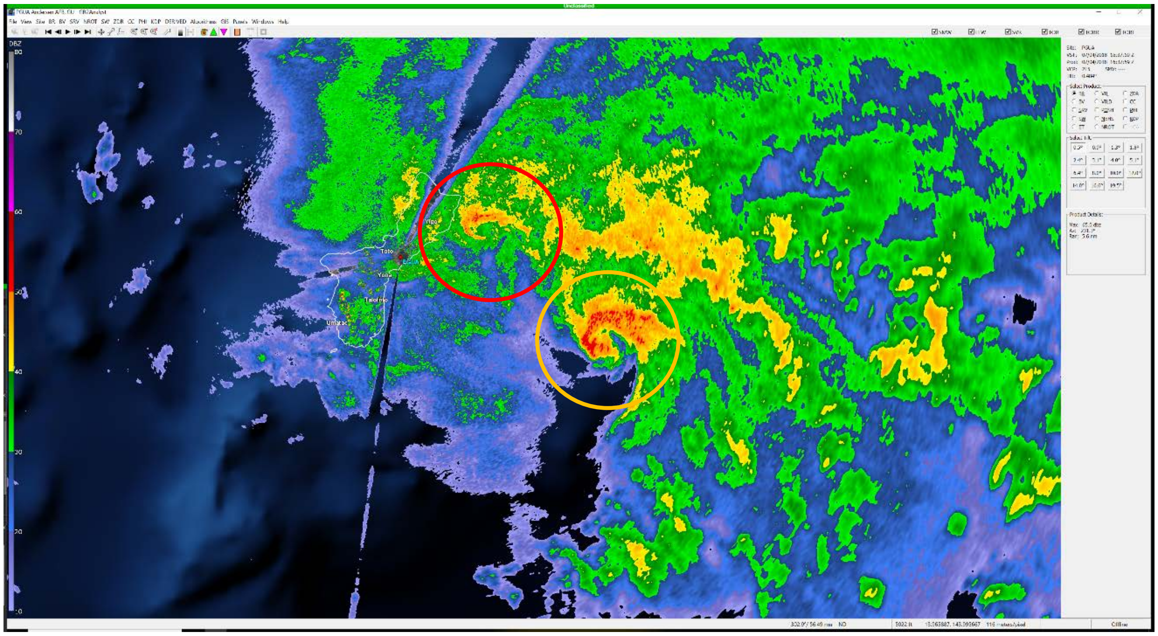


Figure 1-35: July 4 1637Z Base reflectivity product.

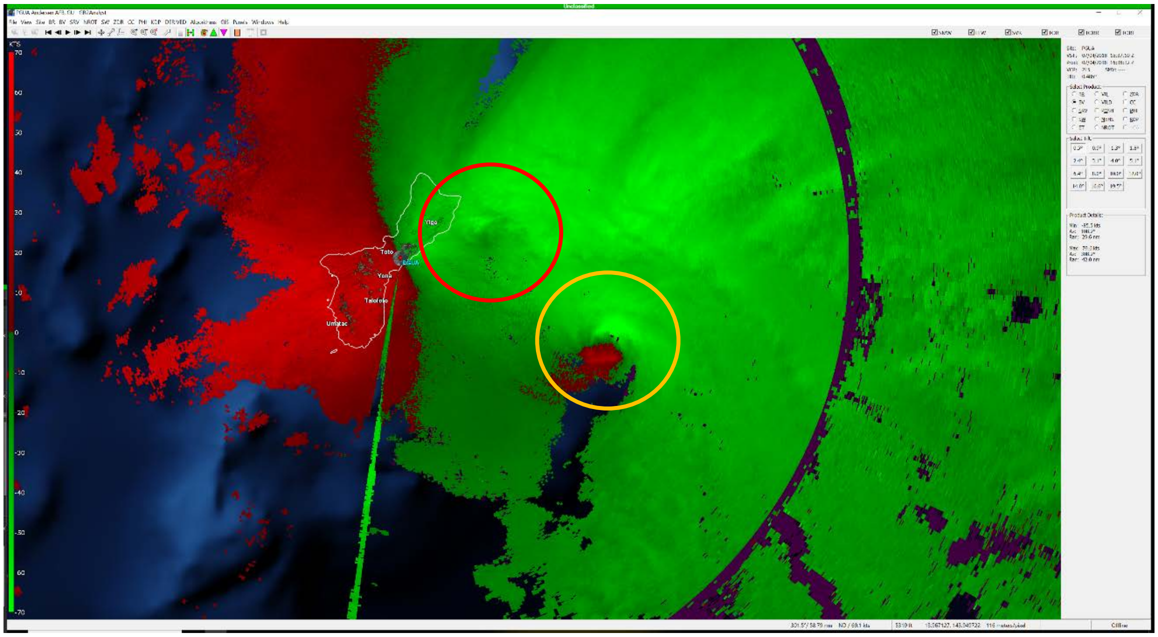


Figure 1-36: July 4 1637Z Base velocity product.

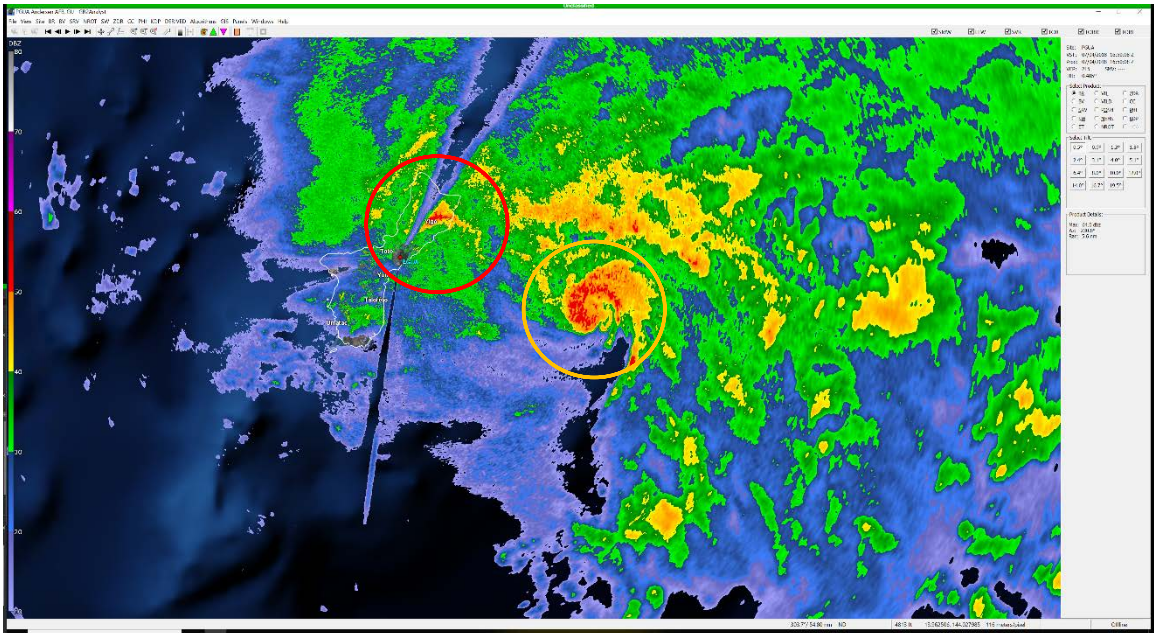


Figure 1-37: July 4 1650Z Base reflectivity product.

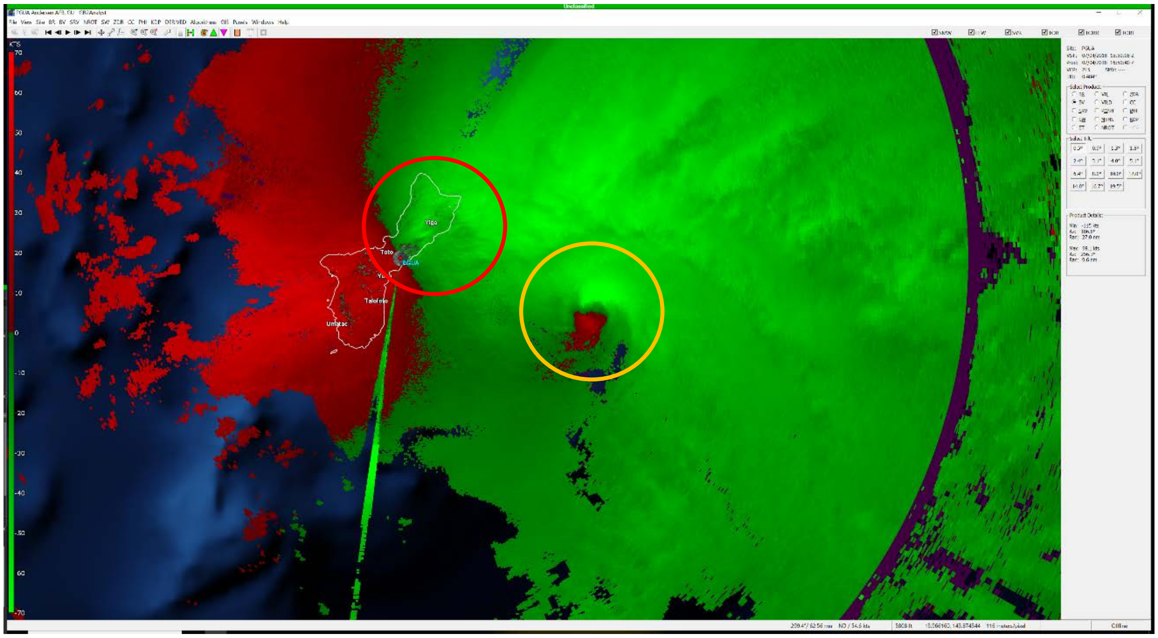


Figure 1-38: July 4 1650Z Base velocity product.

At 04/1722Z, the last image available prior to the radar outage indicated a 20-25nm diameter MCV just to the east of northern Guam Passage of this MCV coincided with the sharp spike in surface winds and rapid pressure drop observed at Andersen AFB (figure 1-5). Figure 1-39 shows convective banding wrapping into MCV #3, suggesting it was rapidly transitioning into the feature that would eventually anchor the system’s primary circulation center.

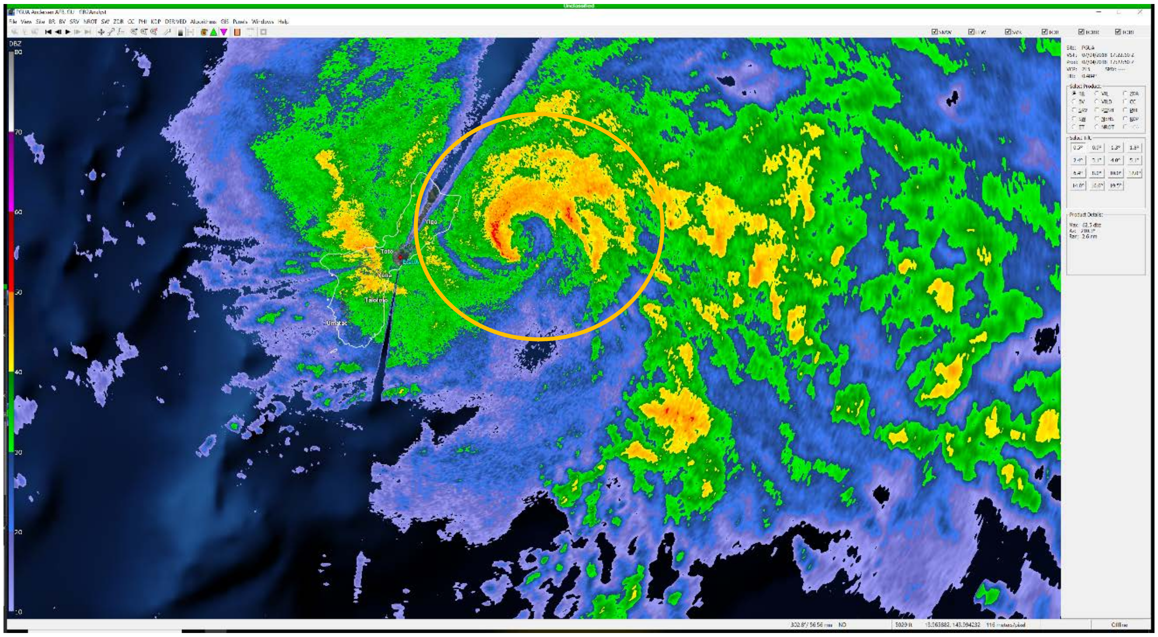


Figure 1-39: July 4 1722Z Base reflectivity product.

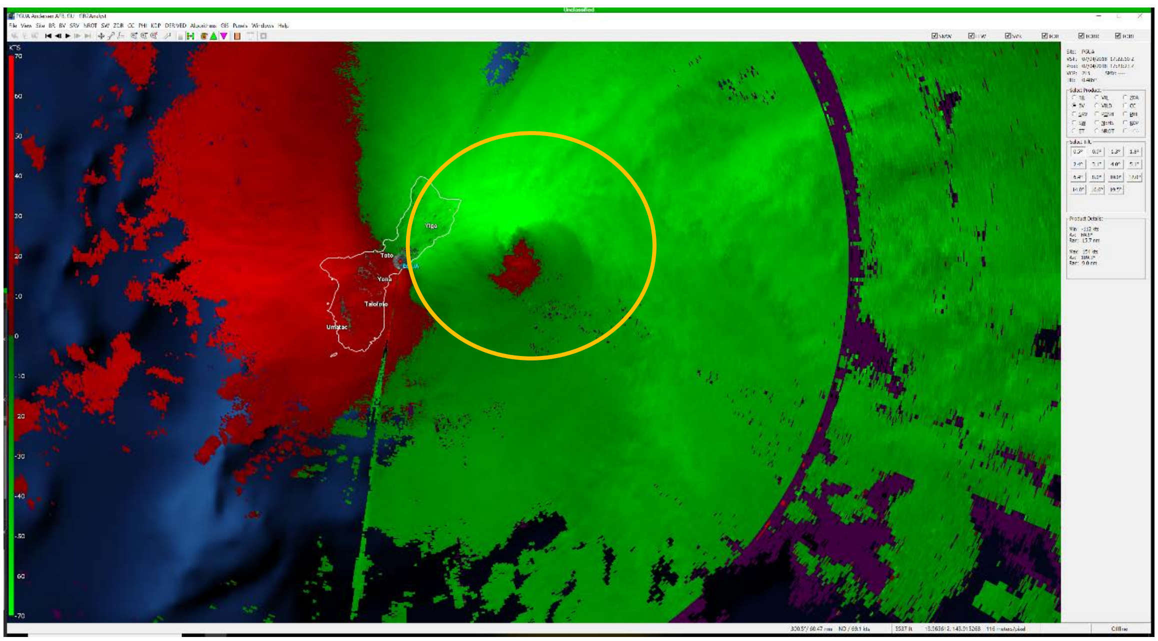


Figure 1-40: July 4 1722Z Base velocity product.

Discussion:

STY 10W (Maria) presented a rare forecasting challenge. Previous research and case studies demonstrated that mesoscale convective vortexes and vortical hot towers are common mechanisms for tropical cyclone formation and rapid intensification. Empirical evidence suggests that these phenomena contributed to the localized severe weather observed at Andersen AFB as TC 10W crossed Guam.

It is widely known that localized, severe weather, such as tornadoes, hail, heavy rainfall, microbursts and damaging winds, can occur within a tropical cyclone's spiral banding. Spratt et al. (1997) highlights this often-underestimated risk, explaining: "it is at these greater distances from the TC center, where the severe weather awareness may not be high, that tornadoes could be the primary threat." Constructing a more complete picture of the localized phenomena spurred by tropical cyclones requires increasing our understanding of mesoscale convective vortexes and vortical hot towers. Specifically, forecasters should be aware of the "rotating-convection paradigm" for TC intensification, and the fact that mesoscale vortices and vortical hot towers can influence local weather regardless of TC intensity. For example, a weak tropical storm, particularly an intensifying one, can significantly influence local weather when these features are present.

JTWC forecasts "storm-scale" features of tropical cyclones, including position, intensity and wind radii. These forecasts do not have the inherent spatial or temporal fidelity necessary to highlight temporary, localized phenomena. They also do not account for channelization and terrain effects, which may have enhanced the winds observed at Andersen AFB in association with TC 10W. Additionally, Andersen AFB's runway lies on the northeast side of Guam at an elevation of 612 feet AMSL. JTWC forecast 10-meter surface winds, the standard measurement height of wind sensors. Although JTWC's TC forecasts do not explicitly incorporate local weather impacts, trends in JTWC forecasts can highlight the potential for localized phenomena to occur. For example, based on the discussion presented in this paper, a JTWC forecast that indicates the potential for rapid intensification may imply an elevated probability of localized impacts associated with MCVs, VHTs or tornadic activity.

TC track and intensity fluctuations between depicted forecast times are often non-linear, particularly during periods of rapid intensity or abrupt trajectory changes. Thus, there is inherent uncertainty in both TC position and intensity relative to fixed locations that fall between forecast points, such as Guam in the case of TC 10W. JTWC warning #8 for TC 10W called for intensification from 35 knots at the analysis time, 04/12Z (prior to Guam passage), to 45 knots at 05/00Z (following Guam passage) and to 80 knots by 06/00Z. Thus, the forecast intensity trend indicated that rapid intensification would begin near Guam around 04/18Z and continue for at least the next 24 hours (from approximately 40 at 04/18Z to 70 knots at 05/18Z, based on linear interpolation of forecast intensities). Unfortunately, because it fell between forecast points, the anticipated start time of rapid intensification was not readily apparent on first glance of warning #8. Forecasters must inspect intensify forecast trends closely in order to identify these potential "off-hour" discontinuities.

Forecast uncertainties highlighted in both prognostic reasoning messages and customer conference calls provide decision-makers additional, actionable information to determine worst-case local impacts. Prognostic reasoning messages issued for TC 10W from 02/18Z onward conveyed a consistent and clear message regarding the "possibility of RI” in the near-term forecast. Additionally, the 04/12Z prognostic reasoning message stated that “high uncertainty remains regarding the track” and that “mesoscale models indicate rapid intensification (RI) is likely in the next 24 hours.” A portion of the track forecasting challenge stemmed from uncertainty in the cyclone’s center position. There were only 13 usable microwave passes in the 48 hours prior to Maria's impact to Guam and about half of them were low resolution AMSU passes from NOAA and METOP (European) satellites. Additionally, there were only three usable scatterometry passes during that same period. As a result, the initial position was referred to as "low confidence" in the JTWC prognostic reasoning bulletins. The availability of additional, high-resolution microwave imagery (including SMAP, SAR and ASCAT) would have enabled accurate assessments of center location, intensity and RI onset prior to landfall.

Although JTWC’s storm-scale forecasts and forecast discussions for STY 10W were sufficient to support appropriate decision-making at the local level, more work is required to ensure that all potential, localized impacts of tropical cyclones, VHTs and MCVs, are thoroughly considered. Risk-based, operations-focused research on VHTs and MCVs, including methods to predict and / or identify these phenomena, is advisable. Leaders should support development of additional, active (radar or microwave) overhead weathers sensors that can penetrate upper-level clouds to “see” the atmosphere’s lowest levels. Finally, leaders should provide all forecasters advanced training on the potential localized impacts of tropical cyclones, particularly worst-case scenarios, and how to effectively convey the worst-case risks to operators.

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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 2018 season. Eight cyclones occurred in 2018, with five systems reaching intensity greater than 64 knots. Table 2-2 shows the monthly distribution of Tropical Cyclone activity for 1975 - 2018.

Table 2-1

NORTH INDIAN OCEAN SIGNIFICANT TROPICAL CYCLONES

(01 JAN 2018- 31 DEC 2018)

TC	NAME*	PERIOD**		WARNINGS ISSUED	EST MAX SFC WINDS KTS
01A	SAGAR	16 May / 1800Z	19 May / 1200Z	12	65
02A	MEKUNU	22 May / 0000Z	26 May / 0000Z	17	100
03B	THREE	29 May / 0000Z***	29 May / 1800Z***	0	45
04B	FOUR	20 Sep / 1200Z	20 Sep / 1800Z	2	35
05A	LUBAN	08 Oct / 0000Z	14 Oct / 0600Z	26	85
06B	TITLI	09 Oct / 0600Z	11 Oct / 0000Z	8	105
07B	GAJA	10 Nov / 1800Z	18 Nov / 1800Z	33	80
08B	PHETHAI	15 Dec / 0600Z	17 Dec / 1200Z	10	55

* As designated by the responsible RSMC

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

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

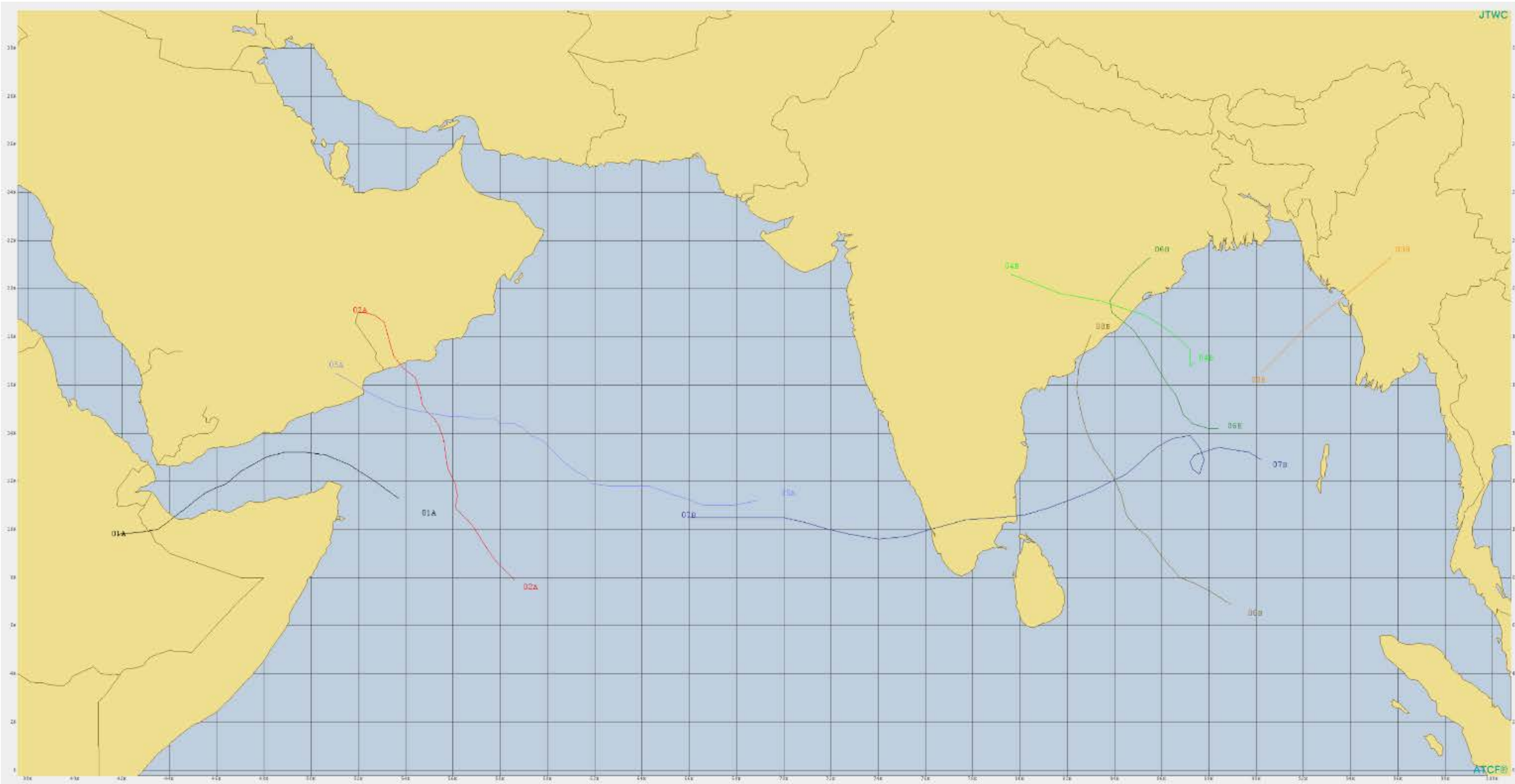


Figure 2-1. North Indian Ocean Tropical Cyclones.

Table 2 - 2
DISTRIBUTION OF NORTH INDIAN OCEAN TROPICAL CYCLONES
FOR 1975 - 2018

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS ≥64kt	TOTALS 34-63kt	TOTALS ≤33 kt
	1	0	0	0	2	0	0	0	0	1	2	0		6	
1975	0 1 0	0 0 0	0 0 0	0 0 0	2 0 0	0 0 0	0 0 0	0 0 0	0 0 0	1 0 0	0 2 0	0 0 0	3	3	0
	0	0	0	1	0	1	0	0	1	1	0	1		5	
1976	0 0 0	0 0 0	0 0 0	0 1 0	0 0 0	0 1 0	0 0 0	0 0 0	0 1 0	0 1 0	0 0 0	0 1 0	0	5	0
	0	0	0	0	1	1	0	0	0	1	0	2		5	
1977	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	0 1 0	0 0 0	0 0 0	0 0 0	0 1 0	0 0 0	1 1 0	1	4	0
	0	0	0	0	1	0	0	0	0	1	2	0		4	
1978	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	2 0 0	0 0 0	2	2	0
	0	0	0	0	1	1	0	0	2	1	2	0		7	
1979	0 0 0	0 0 0	0 0 0	0 0 0	1 0 0	0 1 0	0 0 0	0 0 0	0 1 1	0 1 0	0 1 1	0 0 0	1	4	2
	0	0	0	0	0	0	0	0	0	0	1	1		2	
1980	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	0 1 0	0	2	0
	0	0	0	0	0	0	0	0	1	0	1	1		3	
1981	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	0 0 0	1 0 0	1 0 0	2	1	0
	0	0	0	0	1	1	0	0	0	2	1	0		5	
1982	0 0 0	0 0 0	0 0 0	0 0 0	1 0 0	0 1 0	0 0 0	0 0 0	0 0 0	0 2 0	1 0 0	0 0 0	2	3	0
	0	0	0	0	0	0	0	1	0	1	1	0		3	
1983	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	0 0 0	0 1 0	0 1 0	0 0 0	0	3	0
	0	0	0	0	1	0	0	0	0	1	2	0		4	
1984	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	2 0 0	0 0 0	2	2	0
	0	0	0	0	2	0	0	0	0	2	1	1		6	
1985	0 0 0	0 0 0	0 0 0	0 0 0	0 2 0	0 0 0	0 0 0	0 0 0	0 0 0	0 2 0	0 1 0	0 1 0	0	6	0
	1	0	0	0	0	0	0	0	0	0	2	0		3	
1986	0 1 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 2 0	0 0 0	0	3	0
	0	1	0	0	0	2	0	0	0	2	1	2		8	
1987	0 0 0	0 1 0	0 0 0	0 0 0	0 0 0	0 2 0	0 0 0	0 0 0	0 0 0	0 2 0	0 1 0	0 2 0	0	8	0
	0	0	0	0	0	1	0	0	0	1	2	1		5	
1988	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	0 0 0	0 0 0	0 0 0	0 1 0	1 1 0	0 1 0	1	4	0
	0	0	0	0	1	1	0	0	0	0	1	0		3	
1989	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	0 1 0	0 0 0	0 0 0	0 0 0	0 0 0	1 0 0	0 0 0	1	2	0
	0	0	0	1	1	0	0	0	0	0	1	1		4	
1990	0 0 0	0 0 0	0 0 0	0 0 1	1 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 1	0 1 0	1	1	2
	1	0	0	1	0	1	0	0	0	0	1	0		4	
1991	0 1 0	0 0 0	0 0 0	1 0 0	0 0 0	0 1 0	0 0 0	0 0 0	0 0 0	0 0 0	1 0 0	0 0 0	2	2	0
	0	0	0	0	1	2	1	0	1	3	3	2		13	
1992	0 0 0	0 0 0	0 0 0	0 0 0	1 0 0	0 2 0	0 1 0	0 0 0	0 0 1	0 2 1	2 1 0	0 2 0	3	8	2
	0	0	0	0	0	0	0	0	0	0	2	0		2	
1993	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	2 0 0	0 0 0	2	0	0
	0	0	1	1	0	1	0	0	0	1	1	0		5	
1994	0 0 0	0 0 0	0 1 0	1 0 0	0 0 0	0 1 0	0 0 0	0 0 0	0 0 0	0 1 0	0 1 0	0 0 0	1	4	0
	0	0	0	0	0	0	0	0	1	1	2	0		4	
1995	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	0 1 0	2 0 0	0 0 0	2	2	0
	0	0	0	0	1	3	0	0	0	2	2	0		8	
1996	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	1 2 0	0 0 0	0 0 0	0 0 0	1 1 0	2 0 0	0 0 0	4	4	0
	0	0	0	0	1	0	0	0	1	1	1	0		4	
1997	0 0 0	0 0 0	0 0 0	0 0 0	1 0 0	0 0 0	0 0 0	0 0 0	1 0 0	0 1 0	0 1 0	0 0 0	2	2	0
	0	0	0	0	2	1	0	0	1	1	2	1		8	
1998	0 0 0	0 0 0	0 0 0	0 0 0	1 1 0	1 0 0	0 0 0	0 0 0	0 1 0	0 1 0	2 0 0	1 0 0	5	3	0
	0	1	0	0	1	1	0	0	0	2	0	0		5	
1999	0 0 0	0 1 0	0 0 0	0 0 0	1 0 0	0 1 0	0 0 0	0 0 0	0 0 0	2 0 0	0 0 0	0 0 0	3	2	0
	0	0	0	0	0	0	0	0	0	2	1	1		4	
2000	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 2 0	1 0 0	0 1 0	1	3	0
	0	0	0	0	1	0	0	0	1	1	1	0		4	
2001	0 0 0	0 0 0	0 0 0	0 0 0	1 0 0	0 0 0	0 0 0	0 0 0	0 1 0	0 1 0	0 0 1	0 0 0	1	2	1
	0	0	0	0	2	0	0	0	0	0	2	1		5	
2002	0 0 0	0 0 0	0 0 0	0 0 0	0 2 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 2 0	0 1 0	0	5	0
	0	0	0	0	1	0	0	0	0	0	1	1		3	
2003	0 0 0	0 0 0	0 0 0	0 0 0	1 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	1 0 0	0 1 0	2	1	0
	0	0	0	0	2	0	0	0	0	2	1	0		5	
2004	0 0 0	0 0 0	0 0 0	0 0 0	0 2 0	0 0 0	0 0 0	0 0 0	0 0 0	0 2 0	1 0 0	0 0 0	1	4	0
	2	0	0	0	0	0	0	0	0	2	1	2		7	
2005	0 1 1	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 2 0	0 1 0	0 2 0	0	6	1
	1	0	0	1	0	0	1	0	2	0	1	0		6	
2006	0 1 0	0 0 0	0 0 0	1 0 0	0 0 0	0 0 0	0 1 0	0 0 0	0 2 0	0 0 0	0 1 0	0 0 0	1	5	0
	0	0	0	0	1	3	0	0	0	1	1	0		6	
2007	0 0 0	0 0 0	0 0 0	0 0 0	1 0 0	1 2 0	0 0 0	0 0 0	0 0 0	0 1 0	1 0 0	0 0 0	3	3	0
	0	0	0	1	0	0	0	0	1	2	2	1		7	
2008	0 0 0	0 0 0	0 0 0	1 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	0 1 1	0 2 0	0 1 0	1	5	1
	0	0	0	1	1	0	0	0	1	0	1	1		5	
2009	0 0 0	0 0 0	0 0 0	0 1 0	1 0 0	0 0 0	0 0 0	0 0 0	0 1 0	0 0 0	0 1 0	0 1 0	1	4	0
	0	0	0	0	2	1	0	0	0	1	1	0		5	
2010	0 0 0	0 0 0	0 0 0	0 0 0	1 1 0	1 0 0	0 0 0	0 0 0	0 0 0	1 0 0	0 1 0	0 0 0	3	2	0
	0	0	0	0	0	1	0	0	0	1	3	1		6	
2011	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	0 0 0	0 0 0	0 0 0	0 1 0	0 3 0	1 0 0	1	5	0
	0	0	0	0	0	0	0	0	0	2	1	1		4	
2012	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 2 0	0 1 0	0 1 0	0	4	0
	0	0	0	0	1	0	0	0	0	1	3	1		6	
2013	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	0 0 0	0 0 0	0 0 0	0 0 0	1 0 0	2 1 0	1 0 0	4	2	0
	1	0	0	0	0	0	1	0	0	2	1	0		5	
2014	0 1 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	0 0 0	0 0 0	2 0 0	0 1 0	0 0 0	2	3	0
	0	0	0	0	0	1	1	0	0	2	1	0		5	
2015	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	0 1 0	0 0 0	0 0 0	1 1 0	1 0 0	0 0 0	2	3	0
	0	0	0	0	1	1	0	0	0	1	1	1		5	
2016	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	0 1 0	0 0 0	0 0 0	0 0 0	0 1 0	0 1 0	1 0 0	1	4	0
	0	0	0	1	1	0	0	0	0	0	1	1		4	
2017	0 0 0	0 0 0	0 0 0	0 1 0	1 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	1 0 0	0 1 0	2	2	0
	0	0	0	0	3	0	0	0	1	2	1	1		8	
2018	0 0 0	0 0 0	0 0 0	0 0 0	2 1 0	0 0 0	0 0 0	0 0 0	0 1 0	2 0 0	1 0 0	0 1 0	5	3	0
(1975-2018)															
MEAN	0.2	0.0	0.0	0.2	0.8	0.5	0.1	0.0	0.3	1.1	1.3	0.6		5.1	
CASES	7	2	1	8	33	24	4	1	14	47	59	26		226	

Section 2 Cyclone Summaries

This section presents a synopsis of each tropical cyclone that occurred during storm year 2018 in the North Indian Ocean. Each cyclone is presented, with the number and basin identifier used by JTWC, along with the name assigned by Regional Specialized Meteorological Center (RSMC) New Delhi, India.

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

- "Low" formation potential describes an area that is being monitored for warning-level TC 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 TC warnings when one or more of the following four criteria are met:

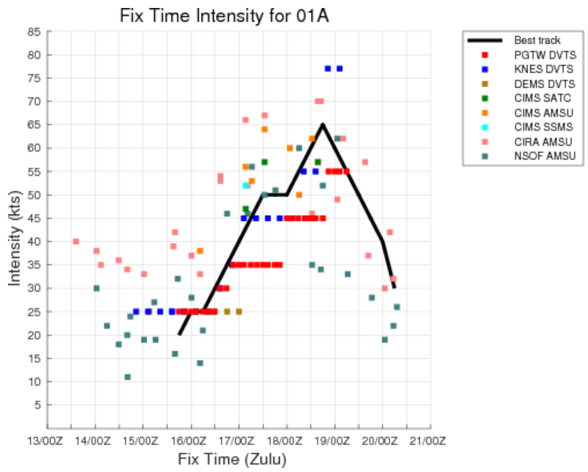
- Estimated maximum sustained wind speeds within a closed tropical circulation meet or exceed a designated threshold of 25 knots in the North Pacific Ocean or 35 knots in the South Pacific and Indian Oceans.
- Maximum sustained wind speeds within a closed tropical circulation are expected to increase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

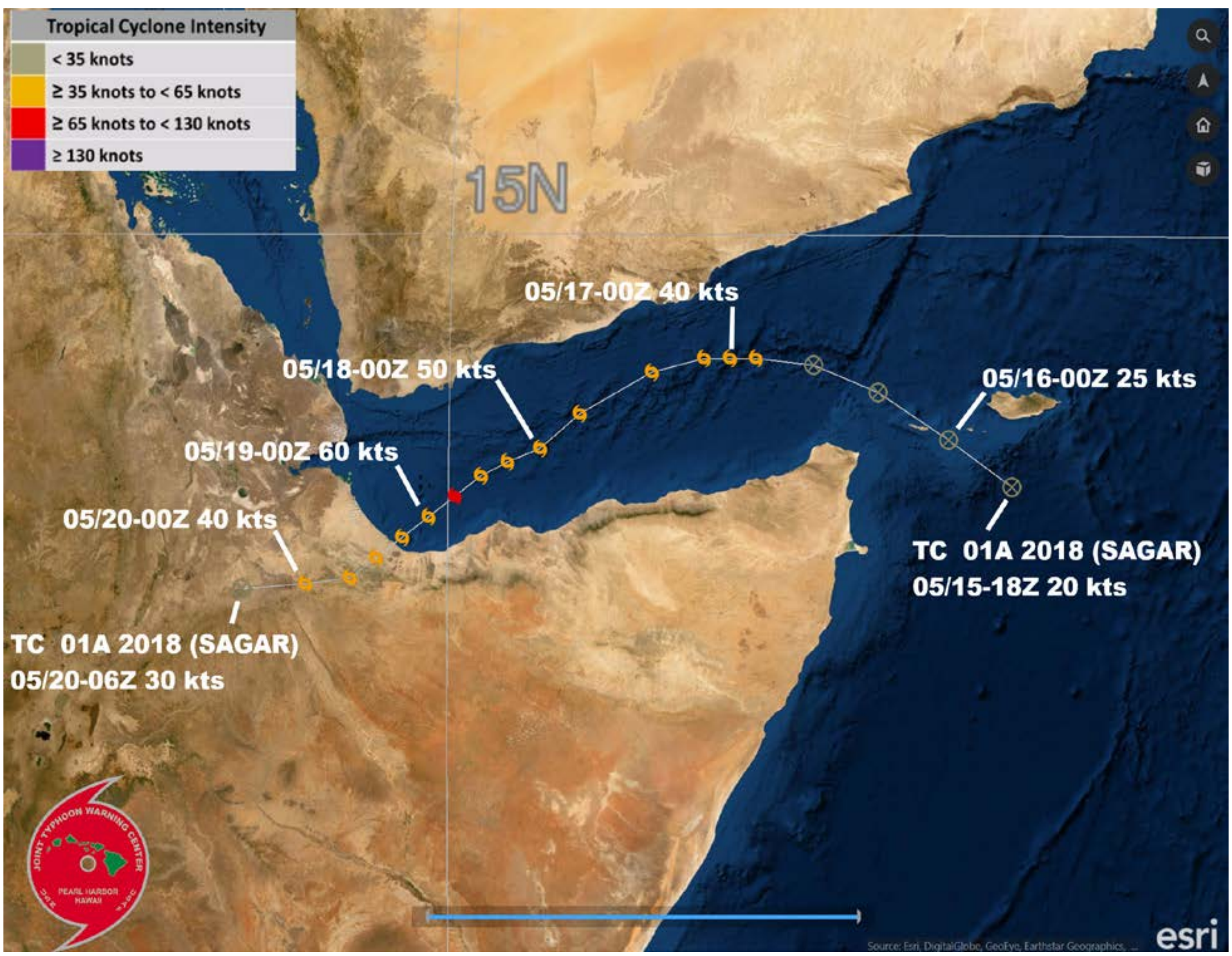
The JTWC post-event, reanalysis best track is provided for each cyclone. Data included on the best track are position and intensity noted with color-coded cyclone symbols and track line. Best track position labels include the date, time, track speed in knots, maximum wind speed in knots, as well as the 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/2018/2018s-bio/IO_besttracks_2018-2018.kmz

01A TROPICAL CYCLONE SAGAR

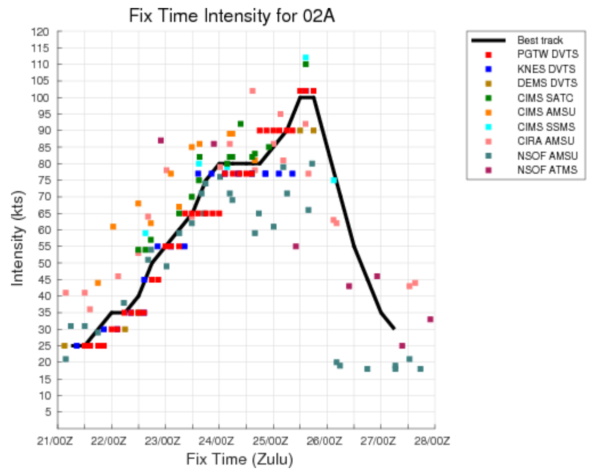
ISSUED LOW:	14 May / 1800Z
ISSUED MED:	15 May / 1130Z
FIRST TCFA:	16 May / 0300Z
FIRST WARNING:	16 May / 1800Z
LAST WARNING:	19 May / 1200Z
MAX INTENSITY:	65
WARNINGS:	12

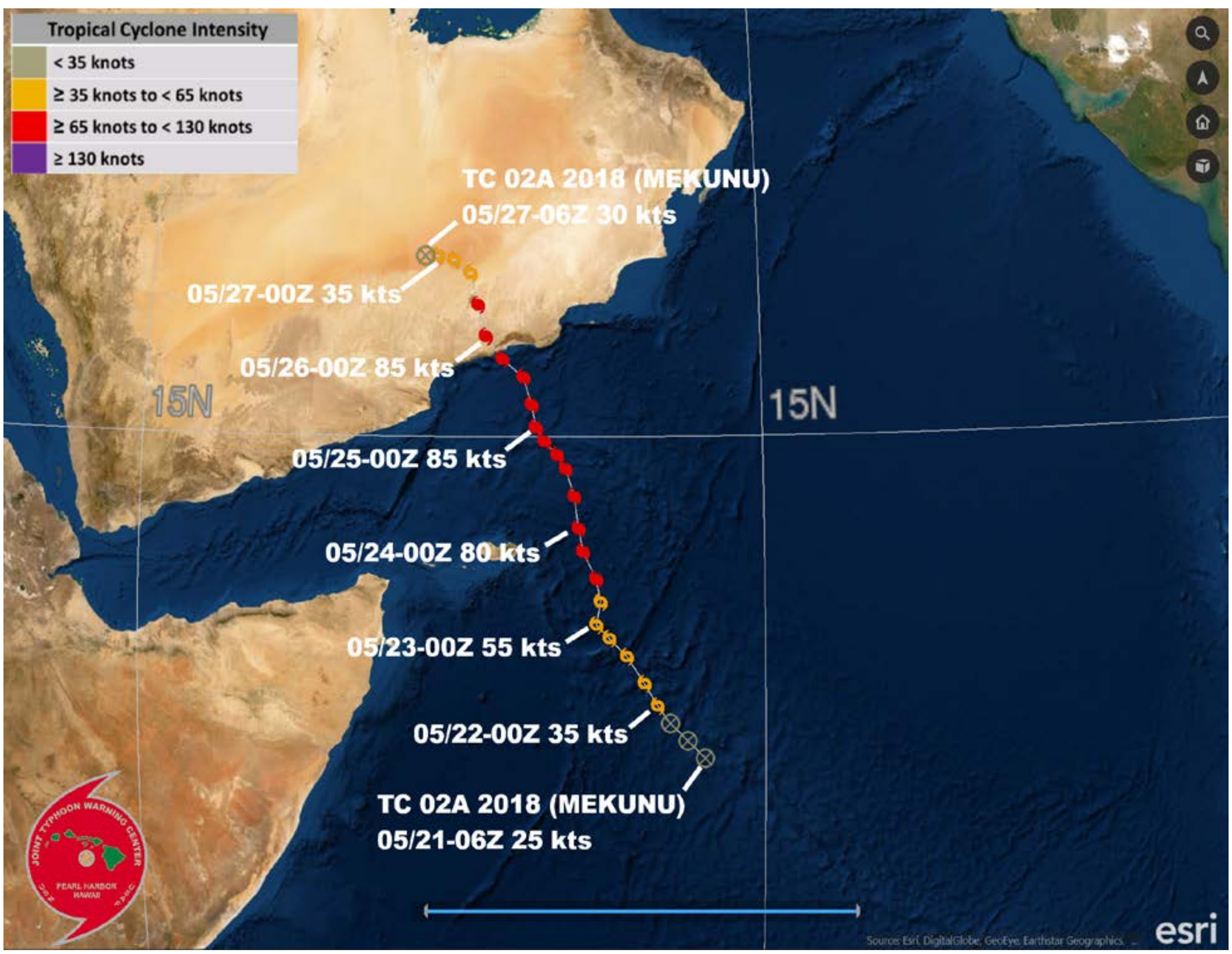




02A TROPICAL CYCLONE MEKUNU

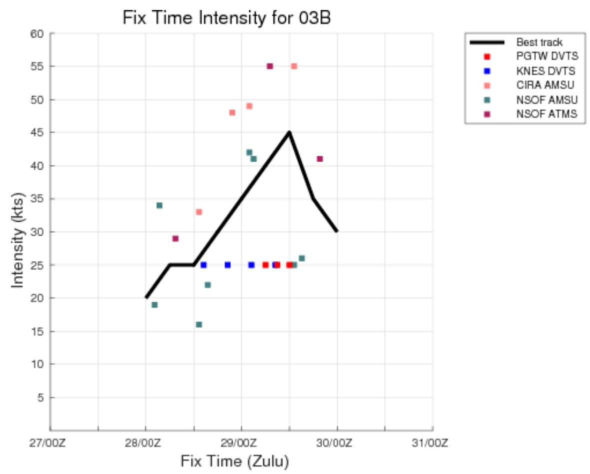
ISSUED LOW:	18 May / 1800Z
ISSUED MED:	21 May / 0400Z
FIRST TCFA:	21 May / 1400Z
FIRST WARNING:	22 May / 0000Z
LAST WARNING:	26 May / 0000Z
MAX INTENSITY:	100
WARNINGS:	17

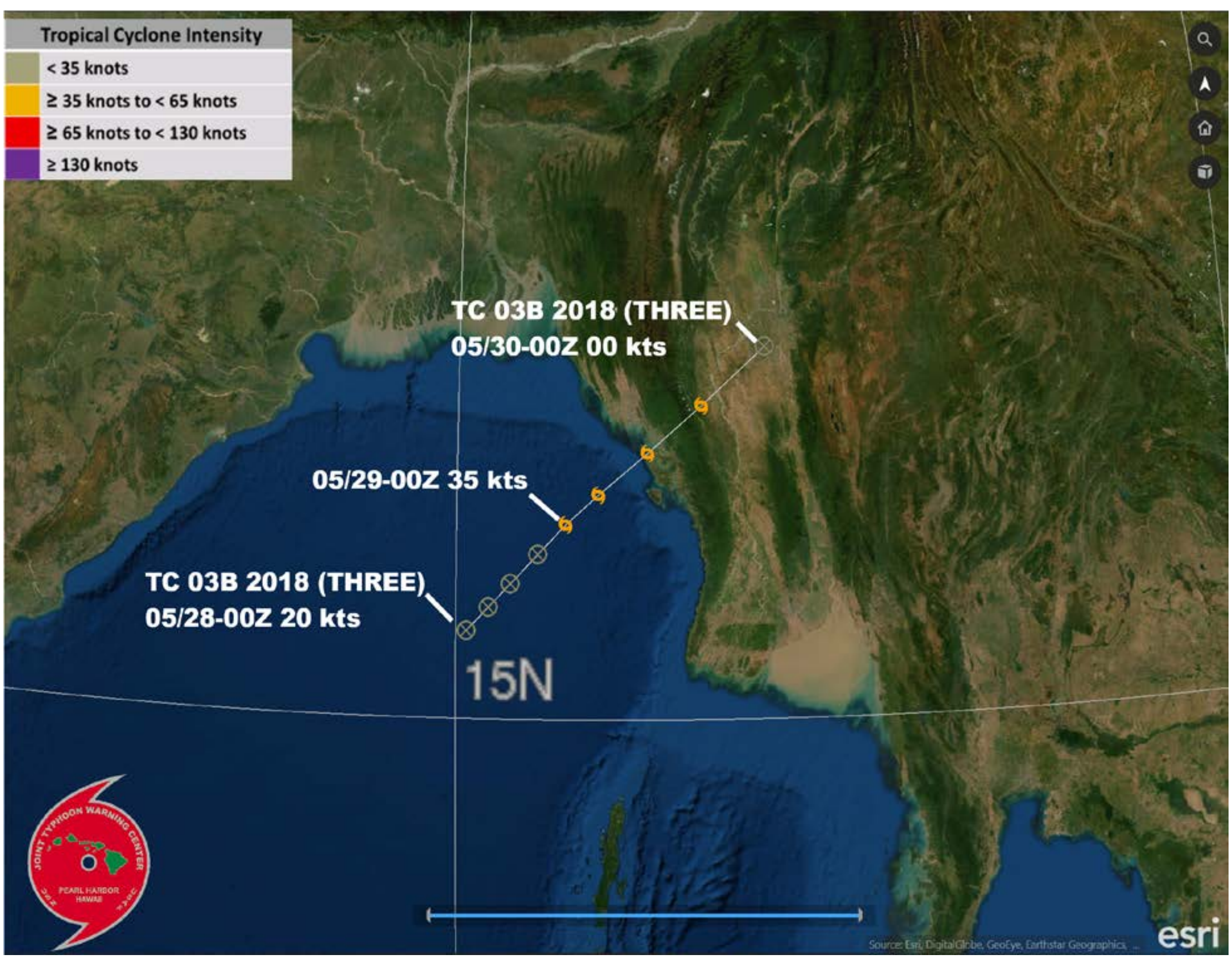




03B TROPICAL CYCLONE THREE

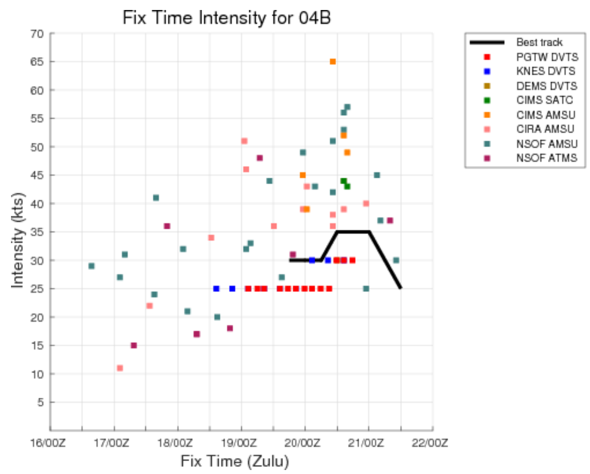
ISSUED LOW:	28 May / 0200Z
ISSUED MED:	28 May / 1330Z
FIRST TCFA:	29 May / 0630Z
FIRST WARNING:	N/A
LAST WARNING:	N/A
MAX INTENSITY:	45
WARNINGS:	0

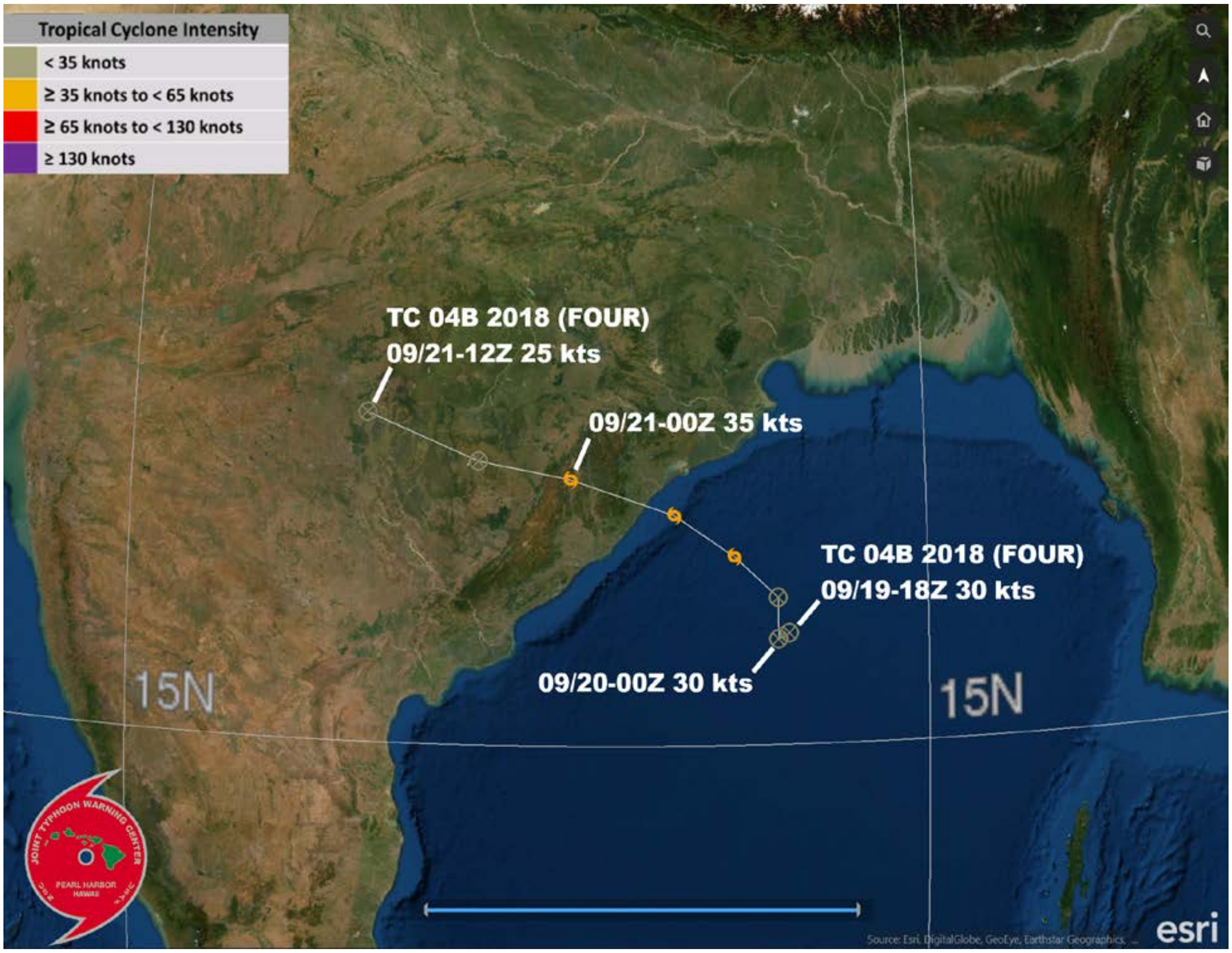




04B TROPICAL CYCLONE FOUR

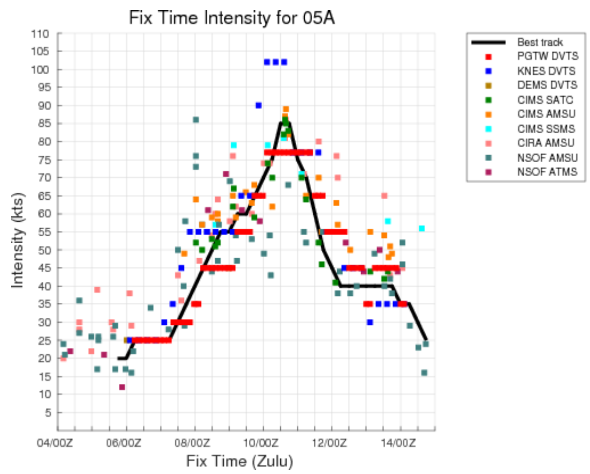
ISSUED LOW:	17 Sep / 1800Z
ISSUED MED:	18 Sep / 1800Z
FIRST TCFA:	19 Sep / 1400Z
FIRST WARNING:	20 Sep / 1200Z
LAST WARNING:	20 Sep / 1800Z
MAX INTENSITY:	35
WARNINGS:	2

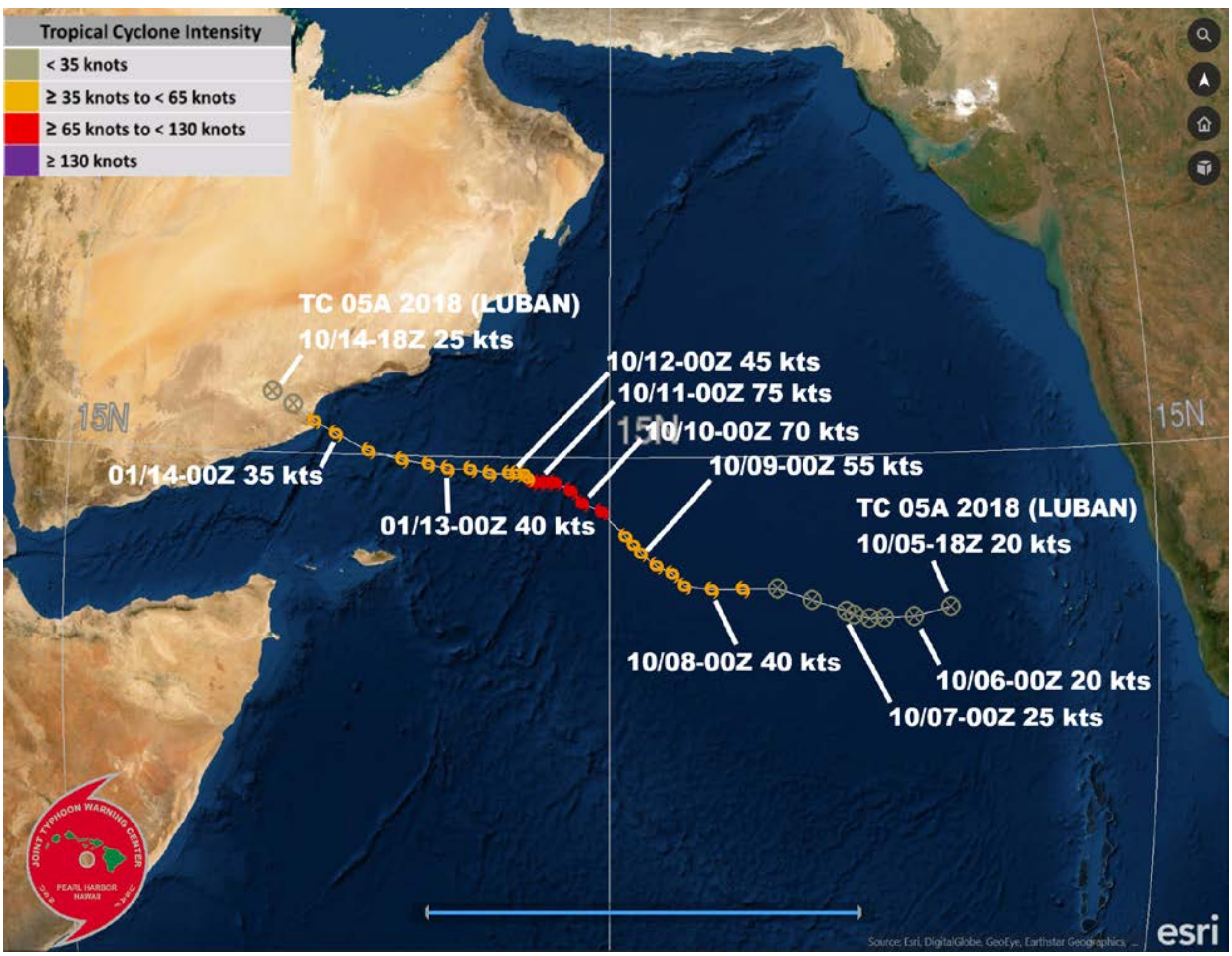




05A TROPICAL CYCLONE LUBAN

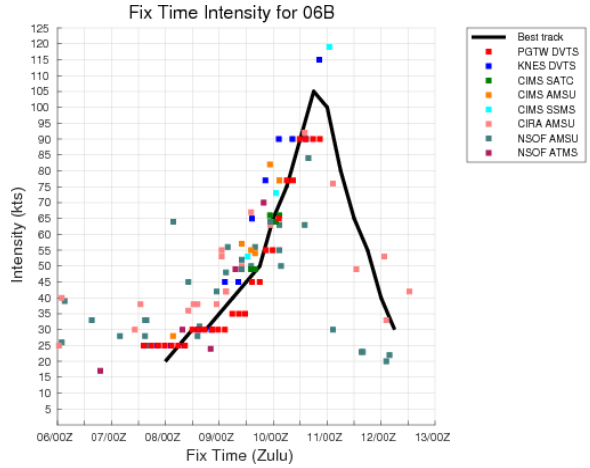
ISSUED LOW:	04 Oct / 1800Z
ISSUED MED:	05 Oct / 1800Z
FIRST TCFA:	06 Oct / 0830Z
FIRST WARNING:	08 Oct / 0000Z
LAST WARNING:	14 Oct / 0600Z
MAX INTENSITY:	85
WARNINGS:	26

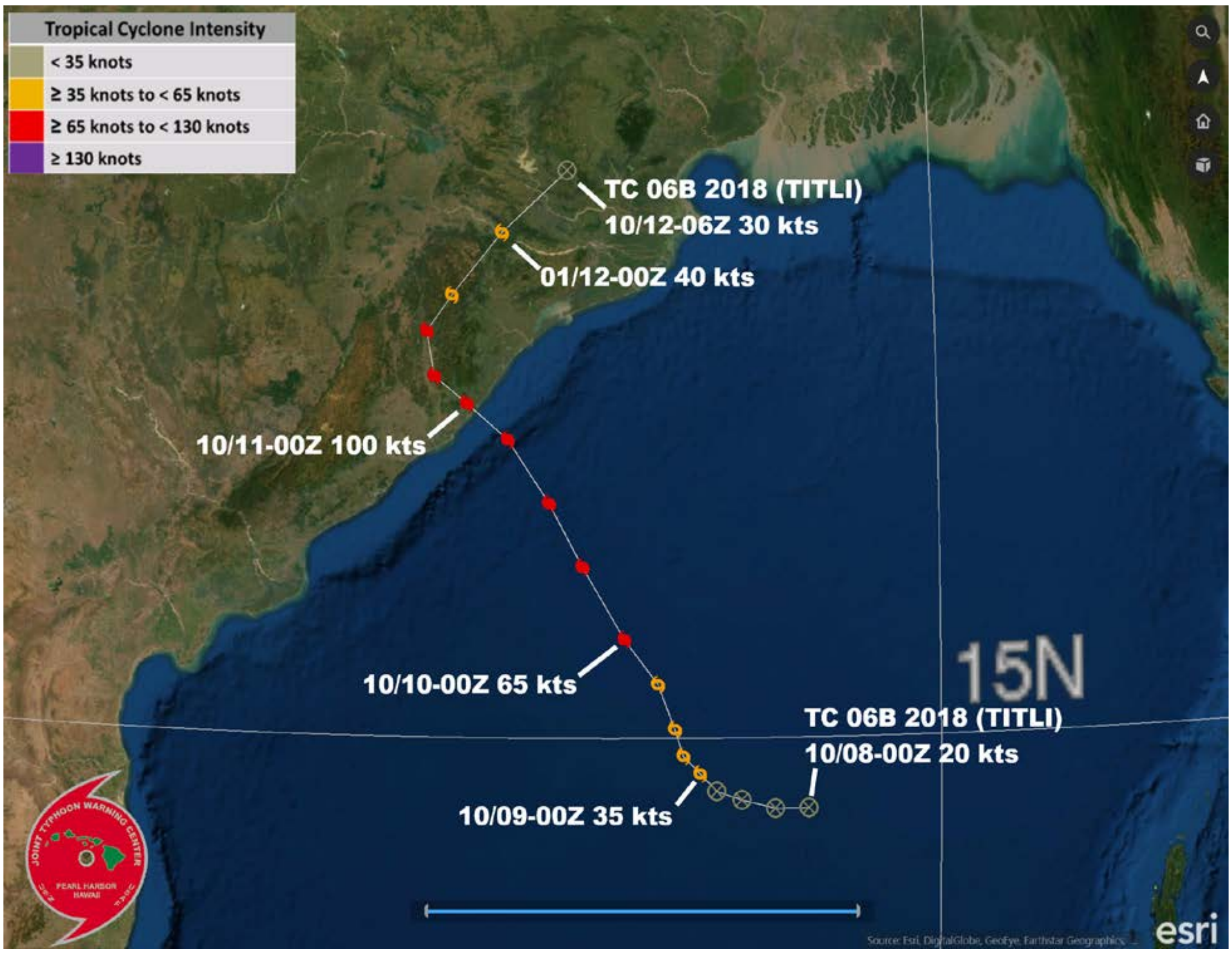




06B TROPICAL CYCLONE TITLI

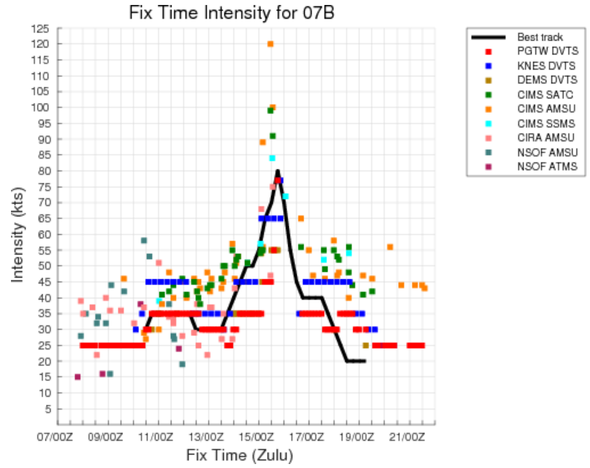
ISSUED LOW:	07 Oct / 0900Z
ISSUED MED:	08 Oct / 0630Z
FIRST TCFA:	08 Oct / 1430Z
FIRST WARNING:	09 Oct / 0600Z
LAST WARNING:	11 Oct / 0000Z
MAX INTENSITY:	105
WARNINGS:	8

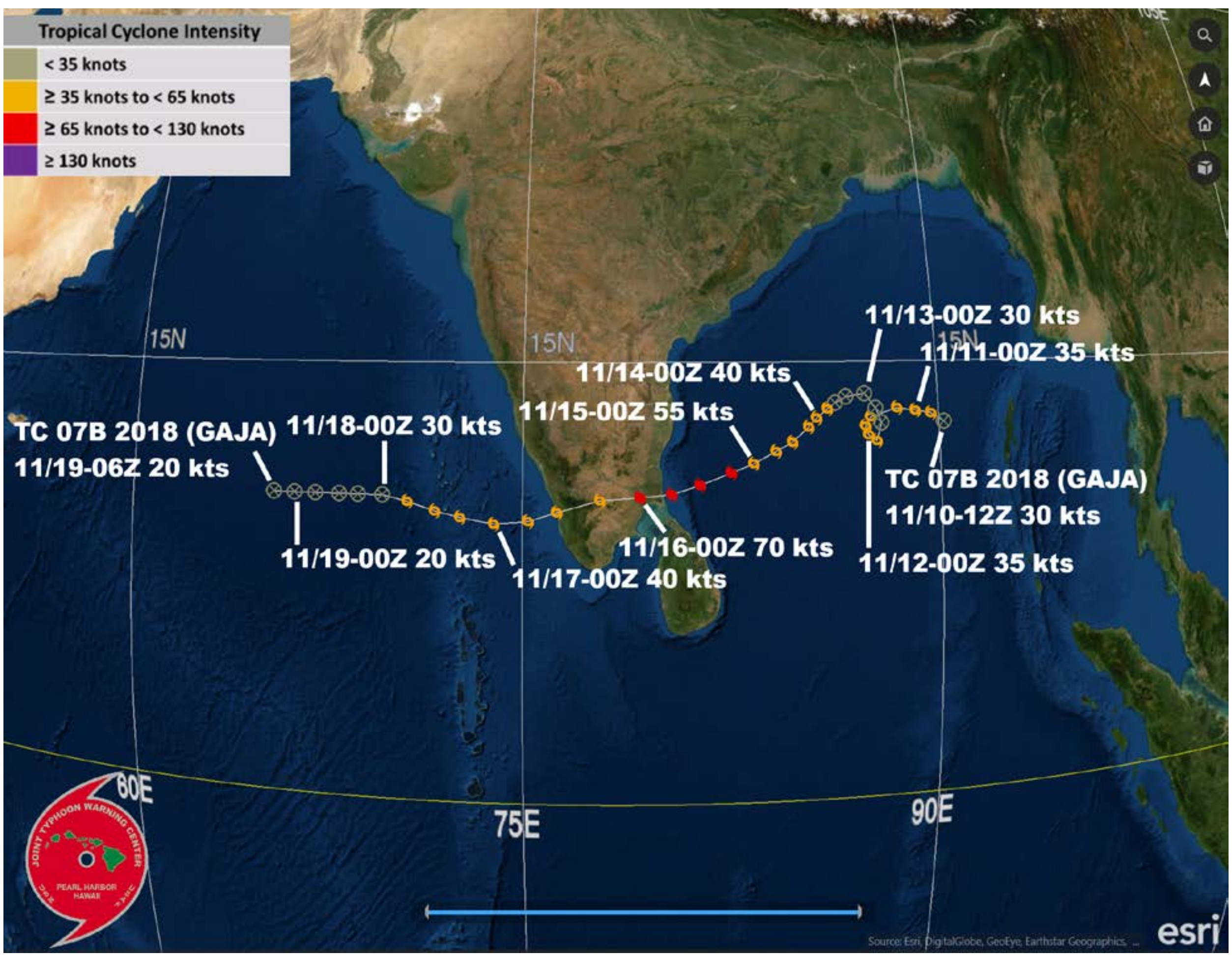




07B TROPICAL CYCLONE GAJA

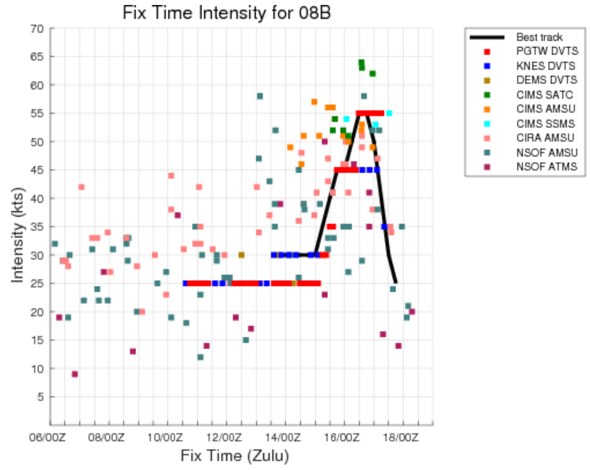
ISSUED LOW:	07 Nov / 1800Z
ISSUED MED:	08 Nov / 0230Z
FIRST TCFA:	10 Nov / 0300Z
FIRST WARNING:	10 Nov / 1800Z
LAST WARNING:	18 Nov / 1800Z
MAX INTENSITY:	80
WARNINGS:	33

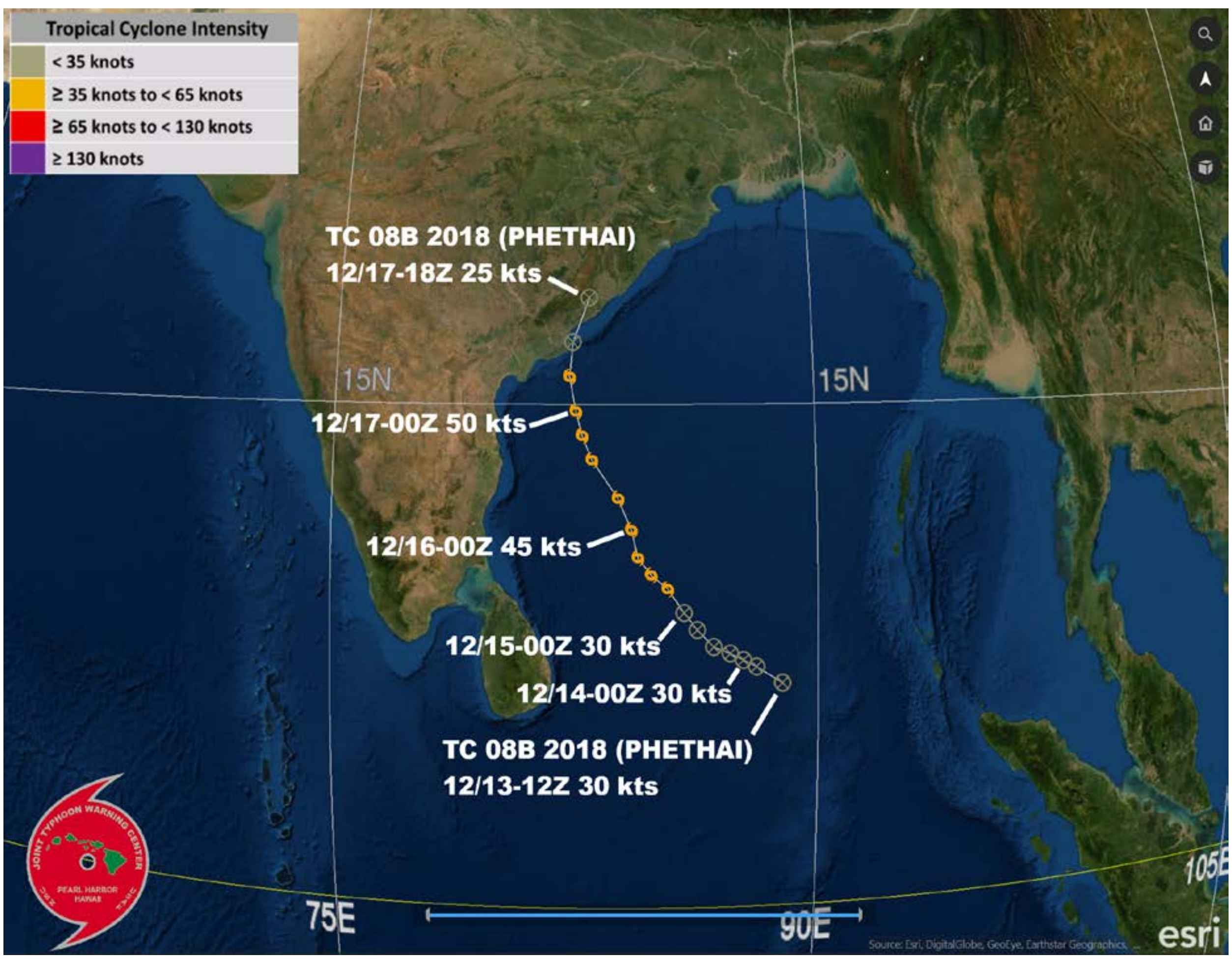




08B TROPICAL CYCLONE PHETHAI

ISSUED LOW:	07 Dec / 0800Z
ISSUED MED:	11 Dec / 1800Z
FIRST TCFA:	13 Dec / 0300Z
FIRST WARNING:	15 Dec / 0600Z
LAST WARNING:	17 Dec / 1200Z
MAX INTENSITY:	55
WARNINGS:	10





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 2018 season (1 July 2017 – 30 June 2018) and the monthly distribution of TC activity summarized for 1975 - 2018.

Section 1 Informational Tables

Table 3-1 is a summary of TC activity in the Southern Hemisphere during the 2018 season.

Table 3-1

SOUTHERN HEMISPHERE TROPICAL CYCLONES

(01 JULY 2017- 30 JUNE 2018)

TC	NAME*	PERIOD**		WARNINGS ISSUED	EST MAX SFC WINDS KTS
01S	DAHLIA	30 Nov / 0000Z	03 Dec / 1800Z	16	55
02S	HILDA	27 Dec / 1800Z	28 Dec / 0000Z	2	50
03S	AVA	02 Jan / 1800Z	09 Jan / 0600Z	27	95
04S	IRVING	06 Jan / 0000Z	10 Jan / 1800Z	20	95
05S	JOYCE	09 Jan / 1800Z	12 Jan / 1200Z	12	50
06S	BERGUITTA	12 Jan / 1800Z	20 Jan / 0600Z	31	105
07S	CEBILE	27 Jan / 0000Z	08 Feb / 1200Z	51	115
08P	FEHI	28 Jan / 0000Z	30 Jan / 1200Z	11	55
09P	GITA	09 Feb / 0000Z	19 Feb / 1800Z	44	125
10S	KELVIN	16 Feb / 0600Z	18 Feb / 0000Z	8	75
11S	DUMAZILE	02 Mar / 1200Z	07 Mar / 1800Z	22	110
12P	HOLA	06 Mar / 1200Z	11 Mar / 0000Z	19	105
13P	LINDA	12 Mar / 1200Z	14 Mar / 1200Z	9	55
14S	ELIAKIM	15 Mar / 0000Z	20 Mar / 1200Z	23	65
15S	MARCUS	15 Mar / 1800Z	24 Mar / 0600Z	35	150
16P	NORA	22 Mar / 0600Z	25 Mar / 0000Z	12	100
17P	IRIS	24 Mar / 1800Z	06 Apr / 1800Z	31	55
18P	JOSIE	31 Mar / 1200Z	03 Apr / 0600Z	12	50
19P	KENI	08 Apr / 1800Z	11 Apr / 0600Z	11	90
20S	FAKIR	23 Apr / 1200Z	25 Apr / 0000Z	7	75
21S	FLAMBOYAN	28 Apr / 0600Z	02 May / 0000Z	16	70

* As designated by the responsible RSMC

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

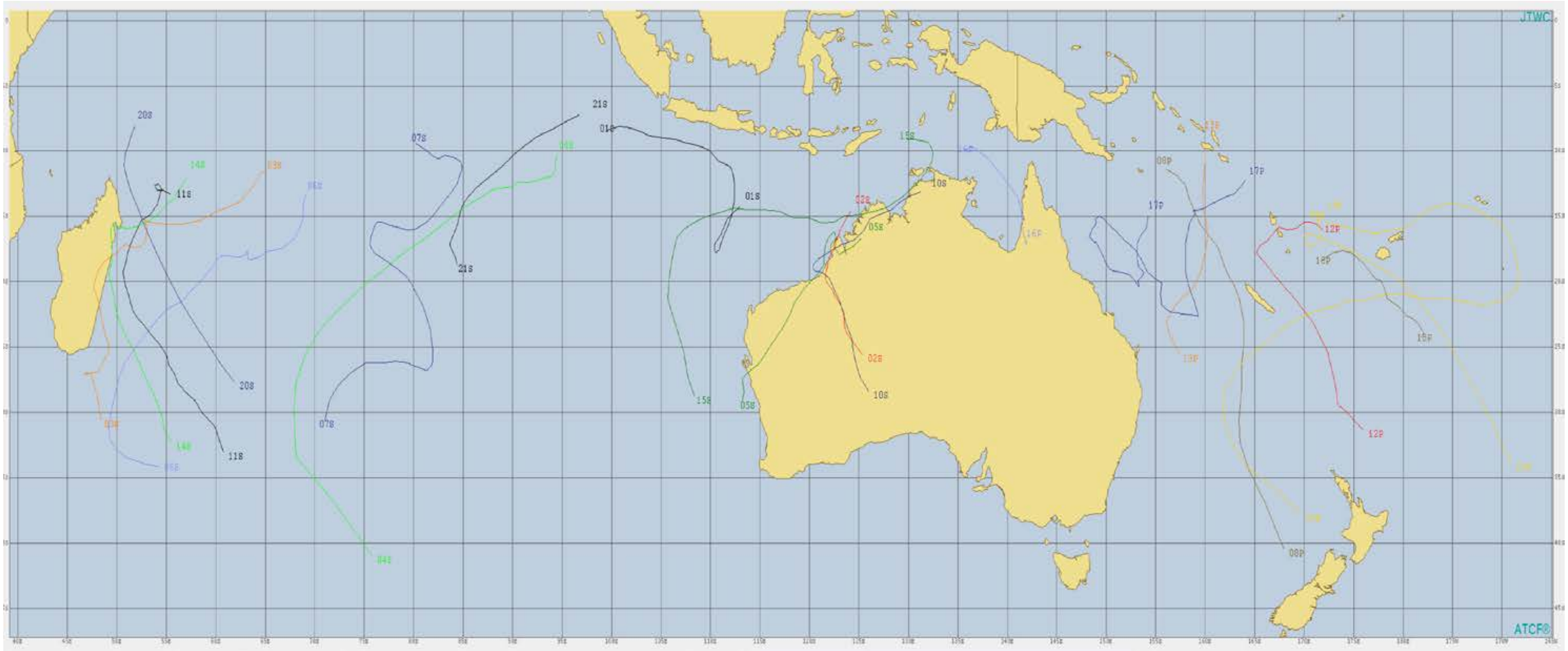


Figure 3-1. Southern Hemisphere Tropical Cyclones.

Table 3-2												
DISTRIBUTION OF SOUTH PACIFIC AND SOUTH INDIAN OCEAN TROPICAL CYCLONES												
FOR 1958 - 2018												
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 - 2017													
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
(1981 - 2018)													
MEAN	0.3	0.1	0.2	0.6	1.5	3.0	5.7	6.0	4.9	3.0	0.7	0.2	26.3
CASES	10	4	9	24	57	115	215	227	185	115	28	9	998
* (GRAY, 1978)													

Table 3-2 Monthly distribution of Tropical Cyclone activity summarized for 1975 - 2018.

Section 2 Cyclone Summaries

This section presents a synopsis of each tropical cyclone that occurred during storm year 2018 in the South Indian and Pacific Oceans. Each cyclone is presented, with the number and basin identifier used by JTWC, along with the name assigned by Regional Specialized Meteorological Centers (RSMC) in La Réunion, Australia or Fiji.

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

- "Low" formation potential describes an area that is being monitored for warning-level TC 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 TC warnings when one or more of the following four criteria are met:

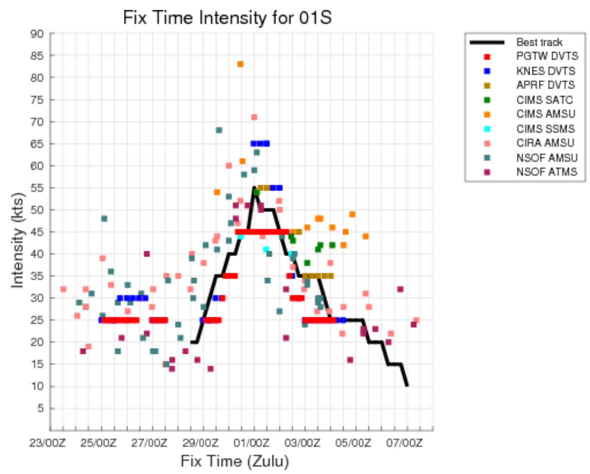
- Estimated maximum sustained wind speeds within a closed tropical circulation meet or exceed a designated threshold of 25 knots in the North Pacific Ocean or 35 knots in the South Pacific and Indian Oceans.
- Maximum sustained wind speeds within a closed tropical circulation are expected to increase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

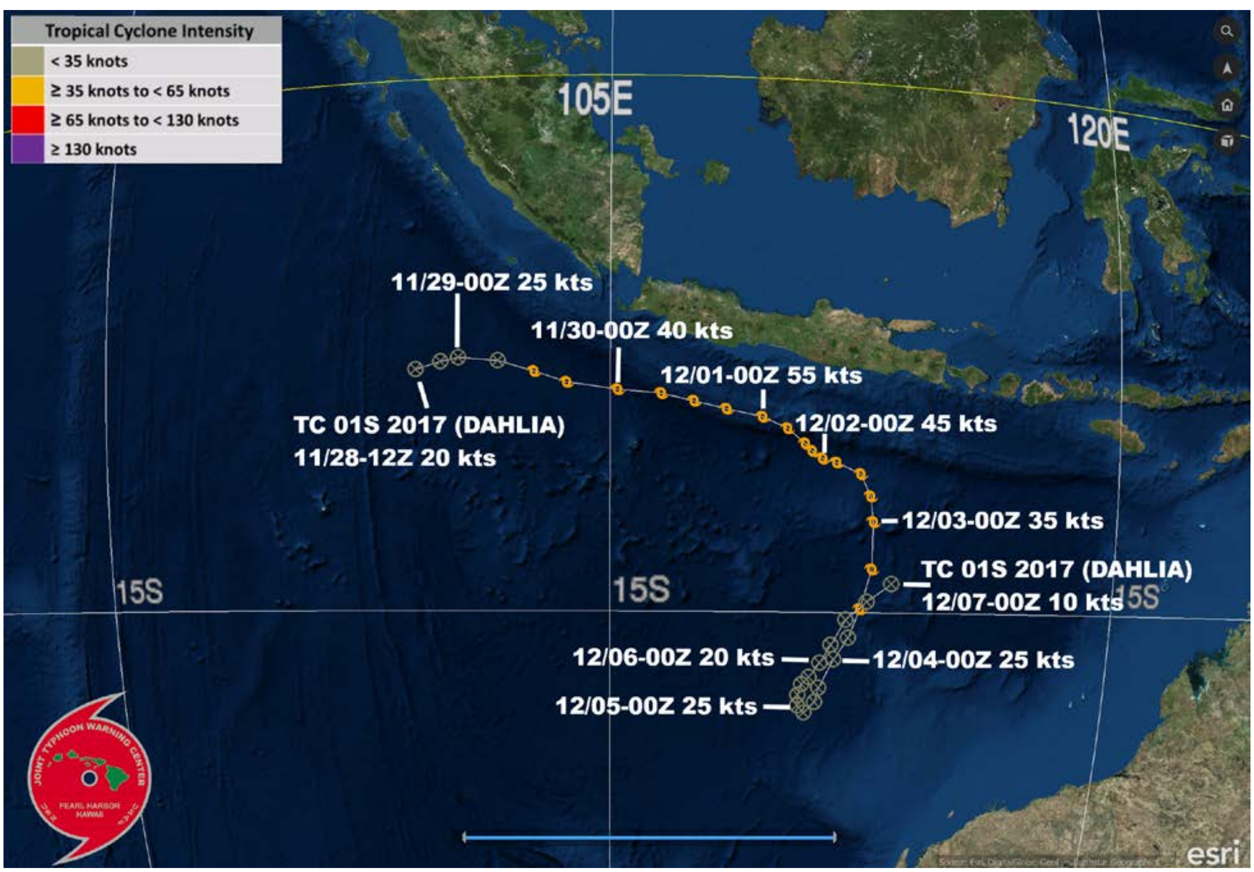
The JTWC post-event, reanalysis best track is provided for each cyclone. Data included on the best track are position and intensity noted with color-coded cyclone symbols and track line. Best track position labels include the date, time, track speed in knots, maximum wind speed in knots, as well as the 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/2018/2018s-bsh/SH_besttracks_2018-2018.kmz

01S TROPICAL CYCLONE DAHLIA

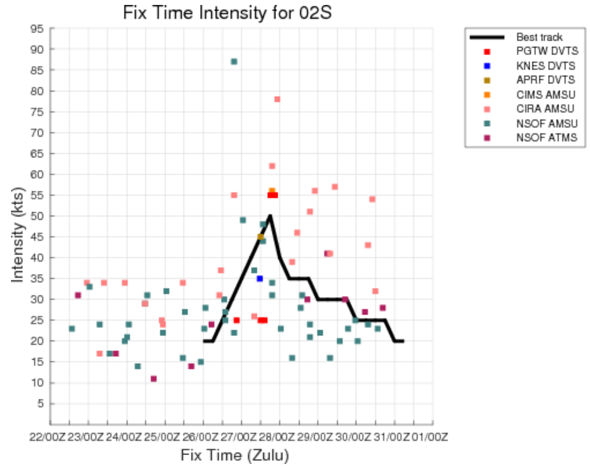
ISSUED LOW:	24 Nov / 1800Z
ISSUED MED:	25 Nov / 1300Z
FIRST TCFA:	29 Nov / 0430Z
FIRST WARNING:	30 Nov / 0000Z
LAST WARNING:	03 Dec / 1800Z
MAX INTENSITY:	55
WARNINGS:	16

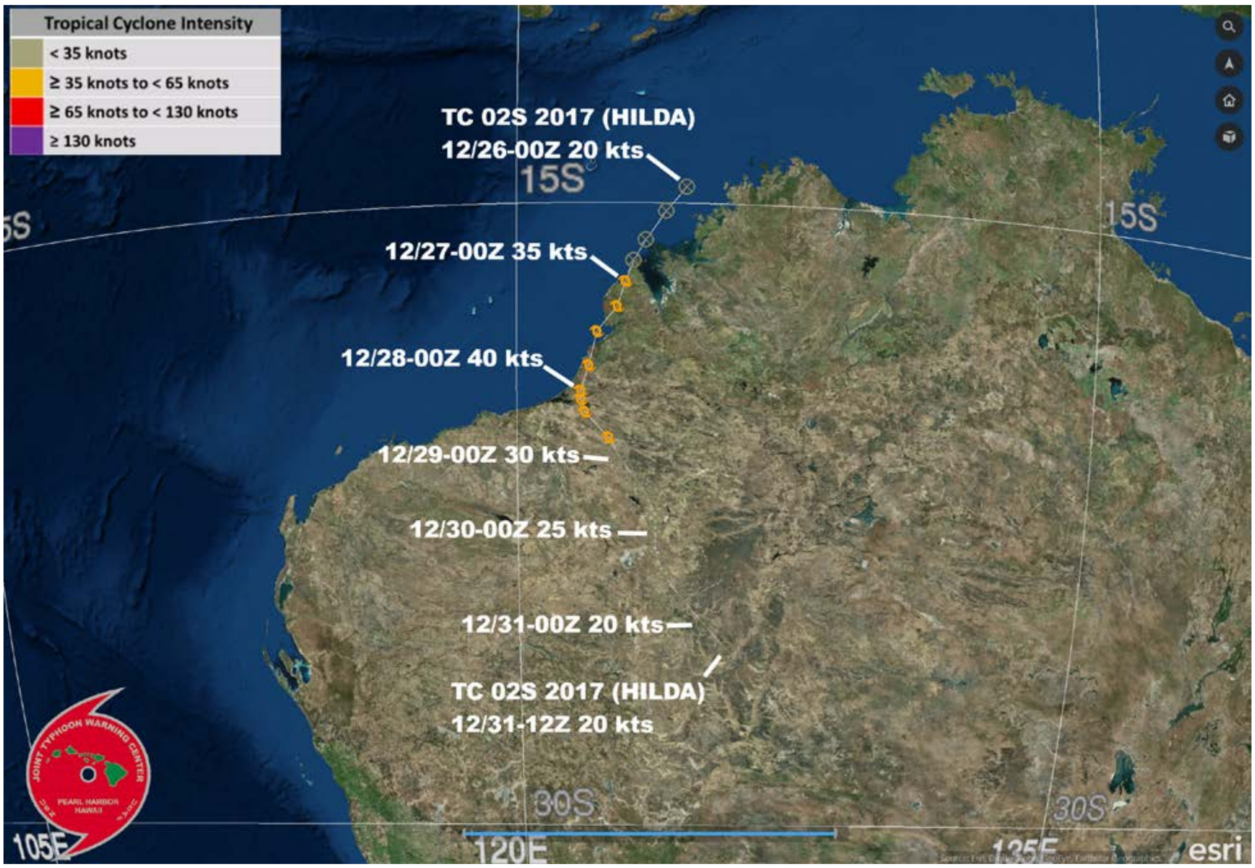




02S TROPICAL CYCLONE HILDA

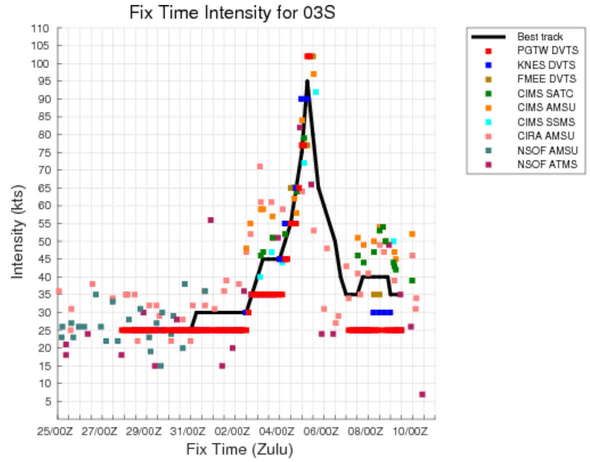
ISSUED LOW:	25 Dec / 1800Z
ISSUED MED:	26 Dec / 0200Z
FIRST TCFA:	26 Dec / 2300Z
FIRST WARNING:	27 Dec / 1800Z
LAST WARNING:	28 Dec / 0000Z
MAX INTENSITY:	50
WARNINGS:	2

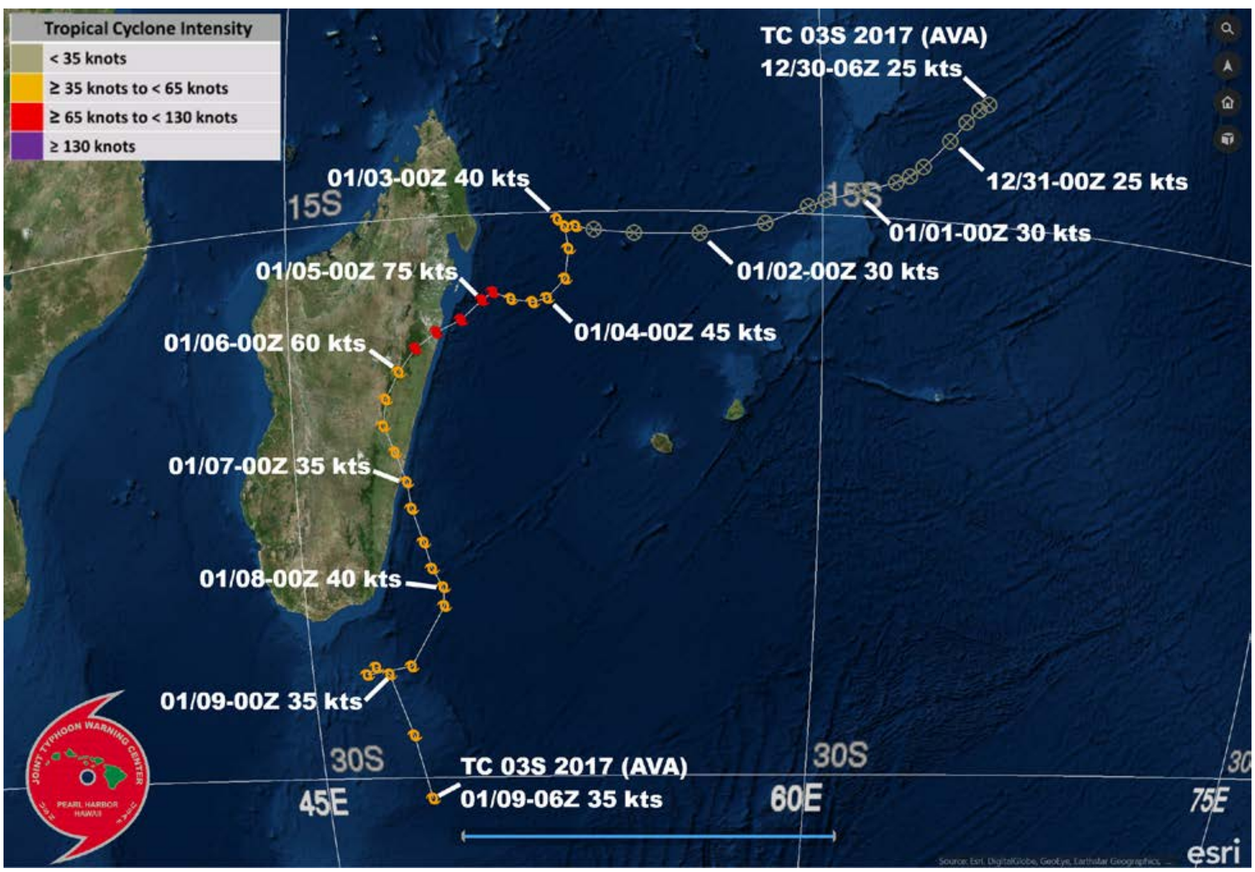




03S TROPICAL CYCLONE AVA

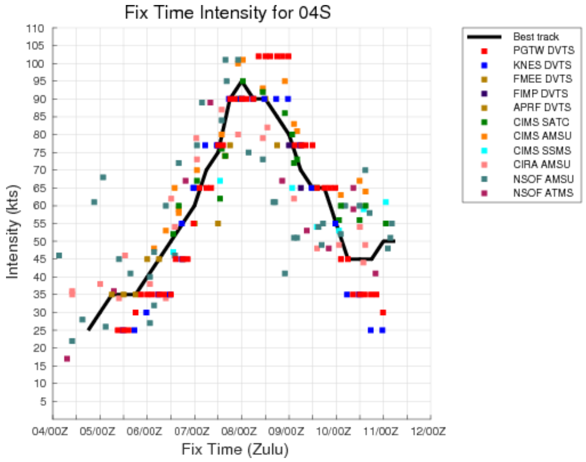
ISSUED LOW:	27 Dec / 2330Z
ISSUED MED:	30 Dec / 1800Z
FIRST TCFA:	02 Jan / 0930Z
FIRST WARNING:	02 Jan / 1800Z
LAST WARNING:	09 Jan / 0600Z
MAX INTENSITY:	95
WARNINGS:	27

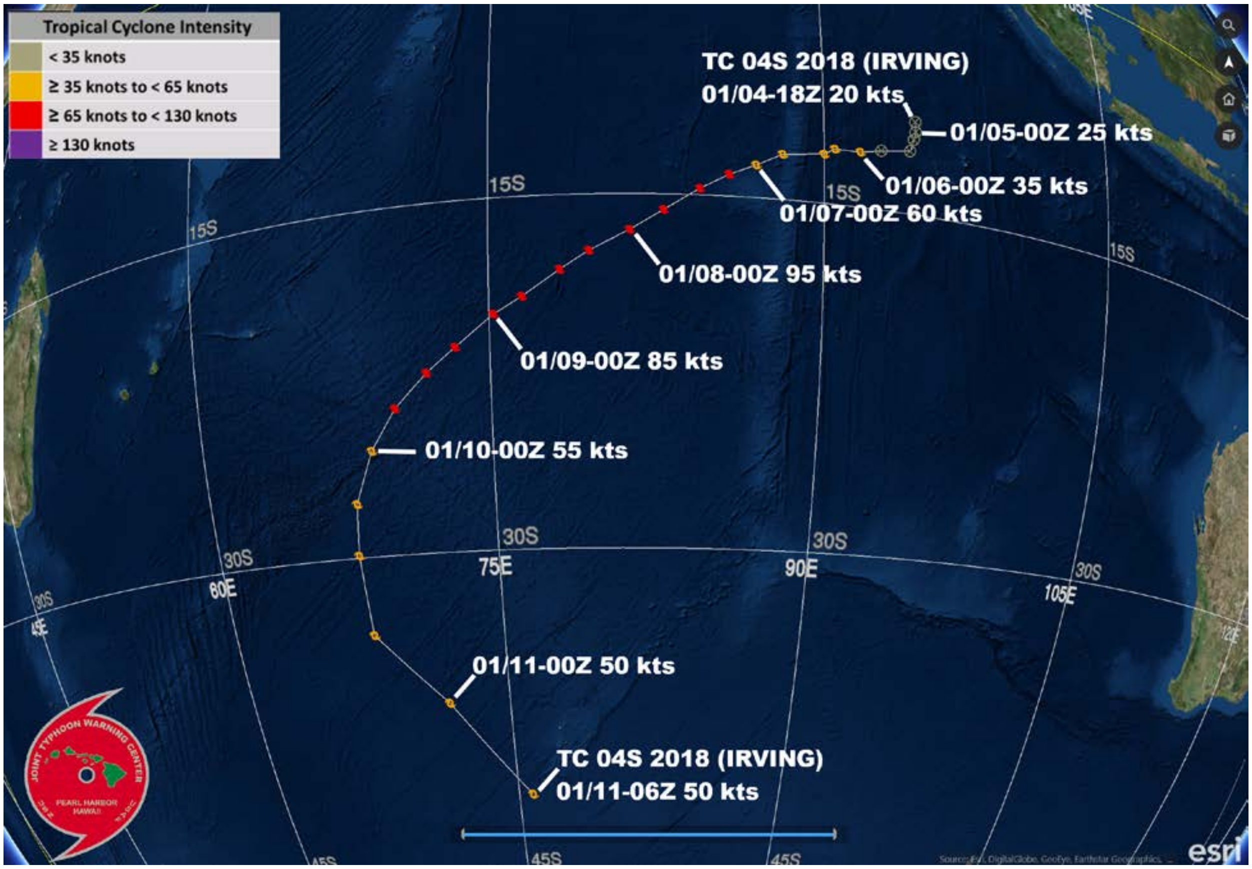




04S TROPICAL CYCLONE IRVING

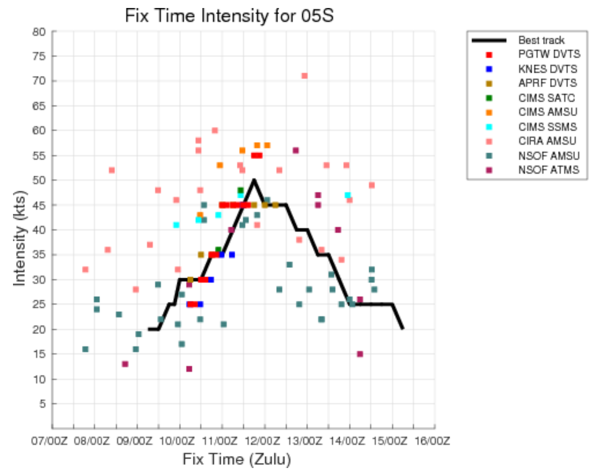
ISSUED LOW:	04 Jan / 0630Z
ISSUED MED:	05 Jan / 0730Z
FIRST TCFA:	05 Jan / 1400Z
FIRST WARNING:	06 Jan / 0000Z
LAST WARNING:	10 Jan / 1800Z
MAX INTENSITY:	95
WARNINGS:	20

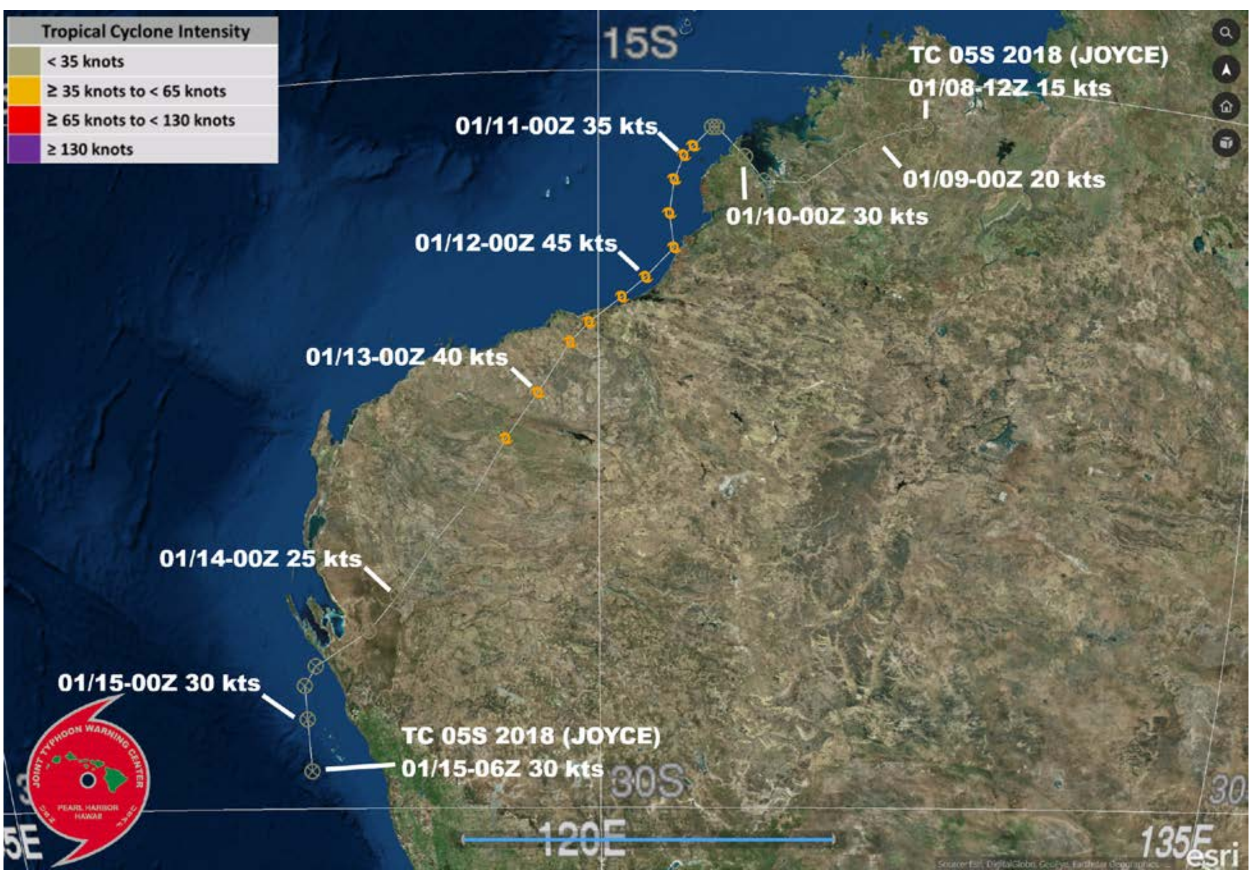




05S TROPICAL CYCLONE JOYCE

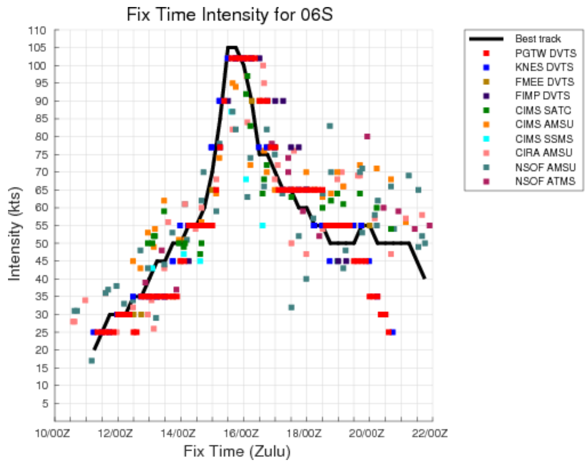
ISSUED LOW:	08 Jan / 0930Z
ISSUED MED:	08 Jan / 1800Z
FIRST TCFA:	09 Jan / 0230Z
FIRST WARNING:	09 Jan / 1800Z
LAST WARNING:	12 Jan / 1200Z
MAX INTENSITY:	50
WARNINGS:	12

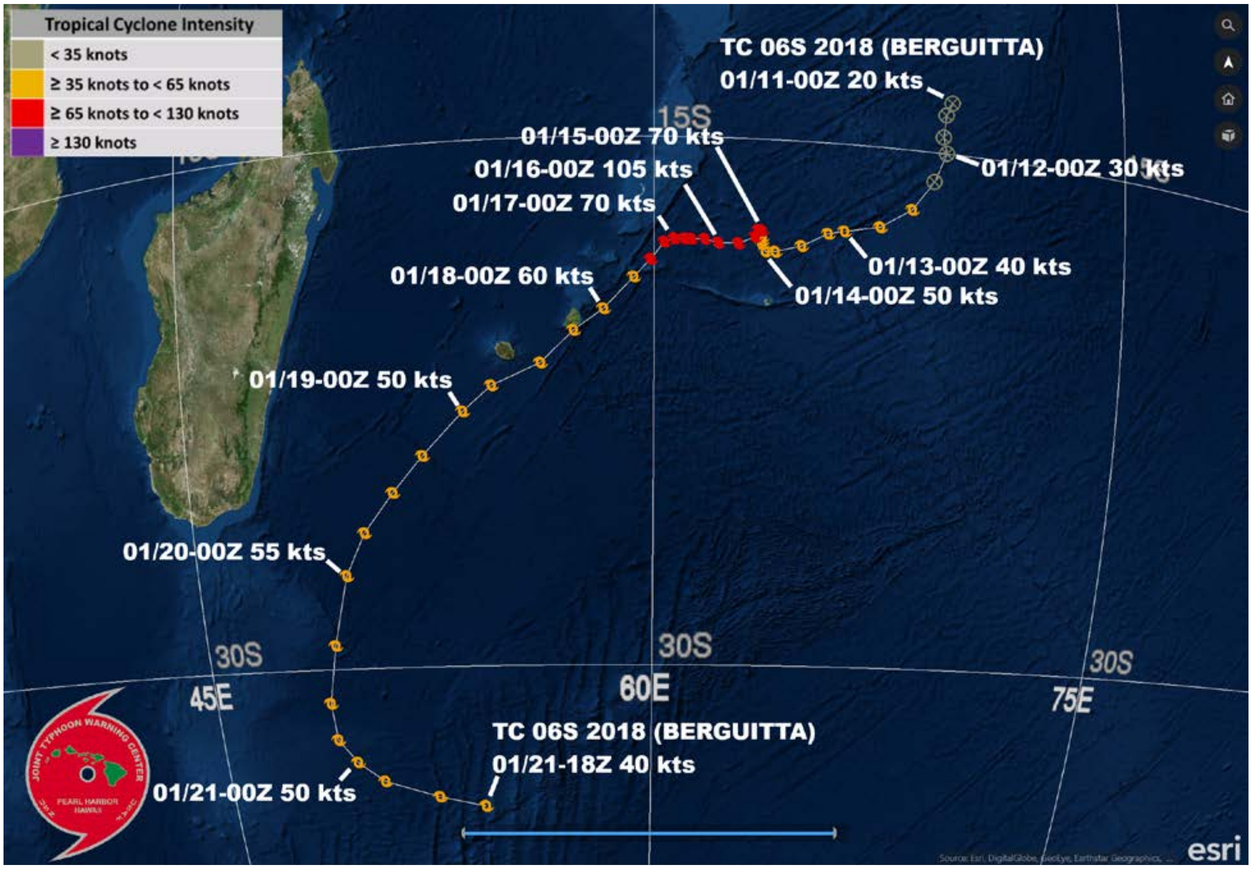




06S TROPICAL CYCLONE BERGUITTA

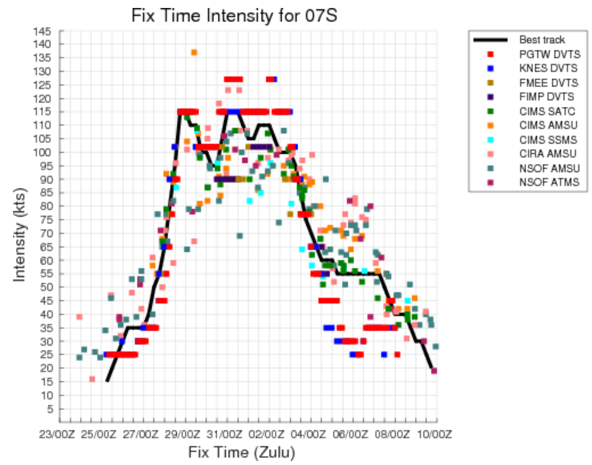
ISSUED LOW:	11 Jan / 0100Z
ISSUED MED:	11 Jan / 1330Z
FIRST TCFA:	12 Jan / 0130Z
FIRST WARNING:	12 Jan / 1800Z
LAST WARNING:	20 Jan / 0600Z
MAX INTENSITY:	105
WARNINGS:	31

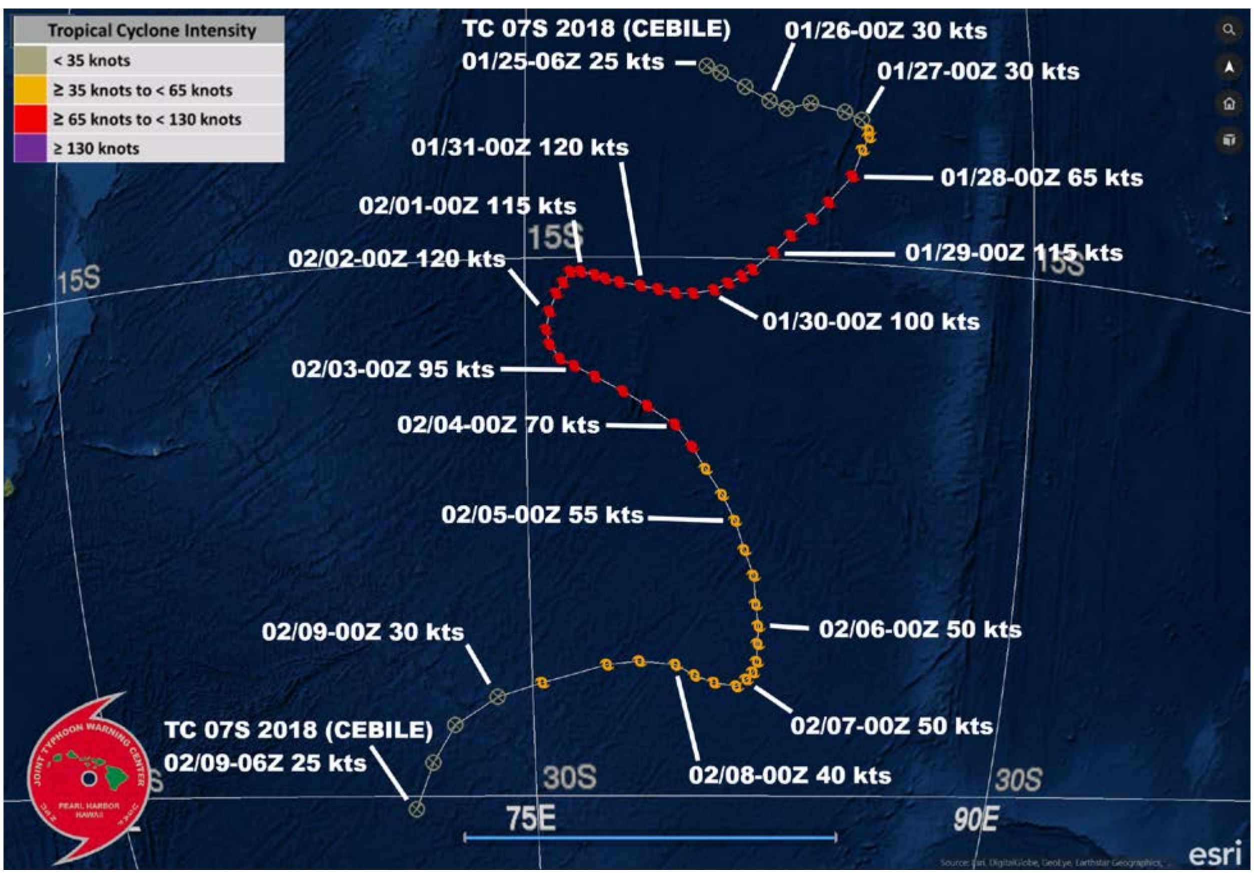




07S TROPICAL CYCLONE CEBILE

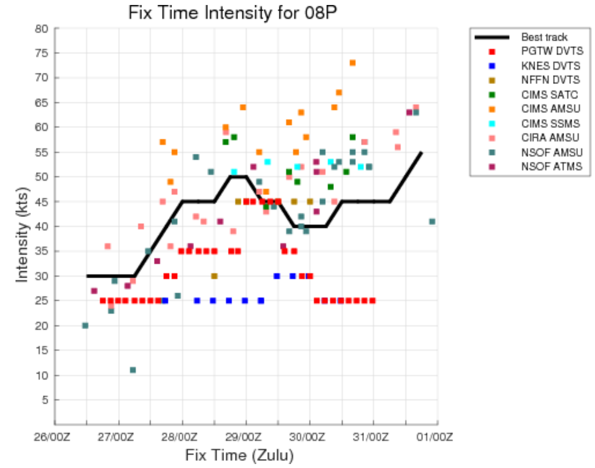
ISSUED LOW:	N/A
ISSUED MED:	25 Jan / 0700Z
FIRST TCFA:	26 Jan / 0130Z
FIRST WARNING:	27 Jan / 0000Z
LAST WARNING:	08 Feb / 1200Z
MAX INTENSITY:	115
WARNINGS:	51

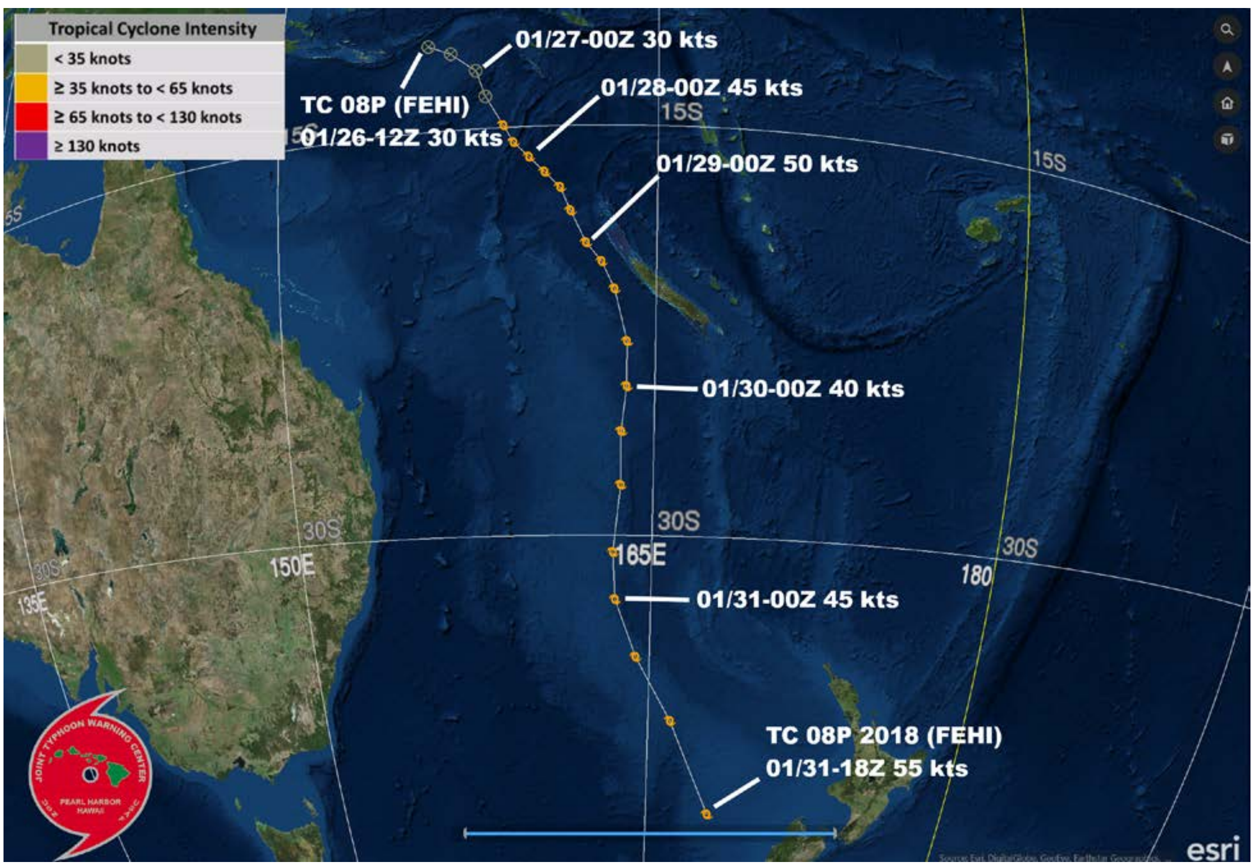




08P TROPICAL CYCLONE FEHI

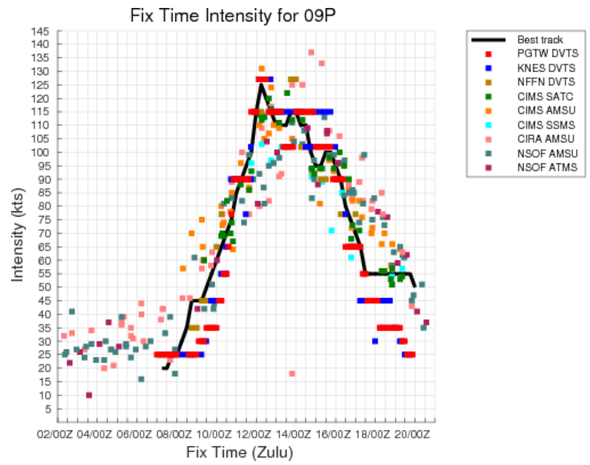
ISSUED LOW:	N/A
ISSUED MED:	26 Jan / 1400Z
FIRST TCFA:	26 Jan / 2100Z
FIRST WARNING:	28 Jan / 0000Z
LAST WARNING:	30 Jan / 1200Z
MAX INTENSITY:	50*
WARNINGS:	11

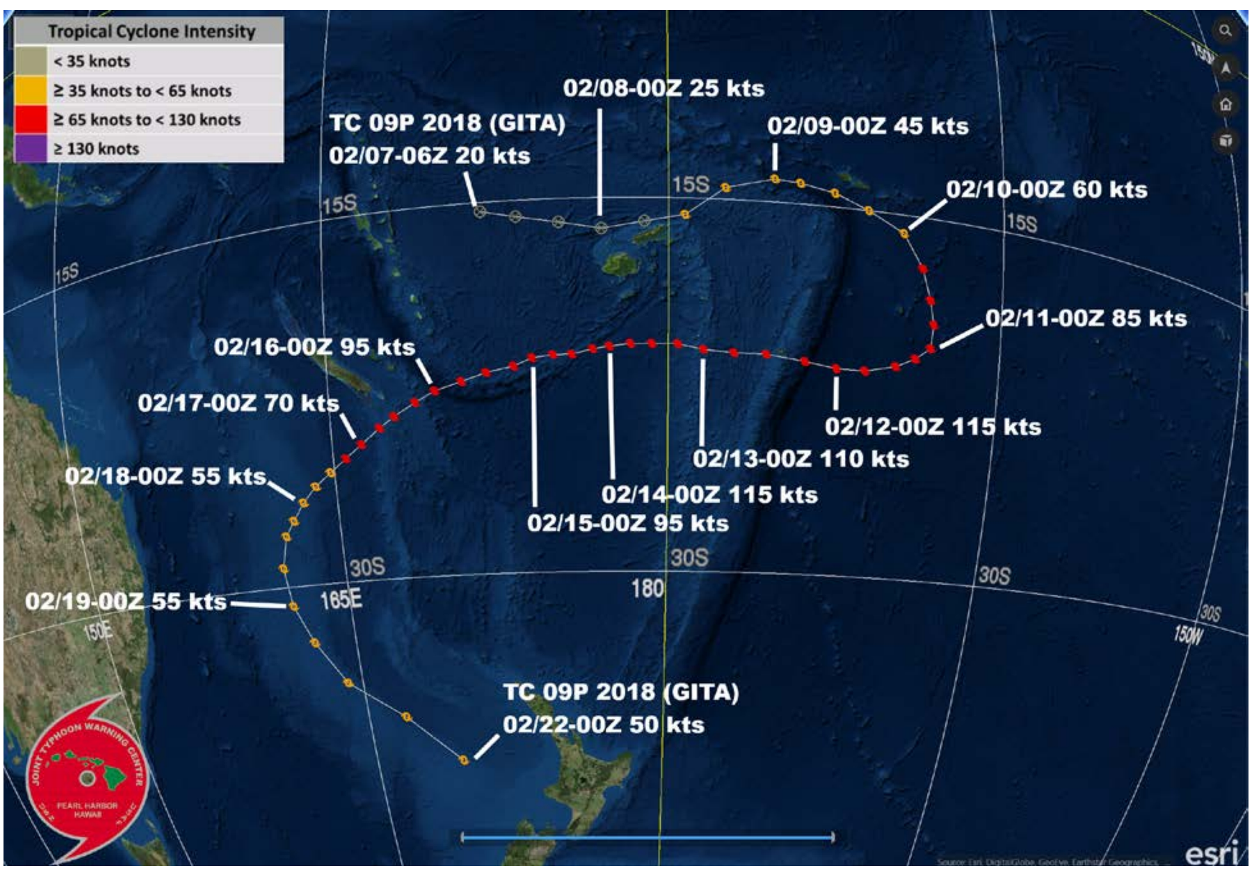




09P TROPICAL CYCLONE GITA

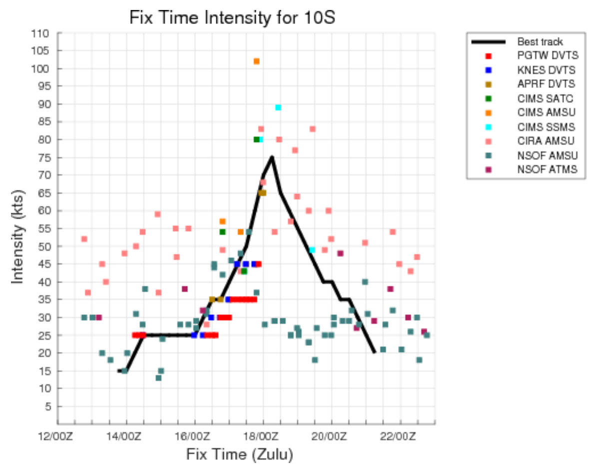
ISSUED LOW:	07 Feb / 0130Z
ISSUED MED:	07 Feb / 2300Z
FIRST TCFA:	N/A
FIRST WARNING:	09 Feb / 0000Z
LAST WARNING:	19 Feb / 1800Z
MAX INTENSITY:	125
WARNINGS:	44

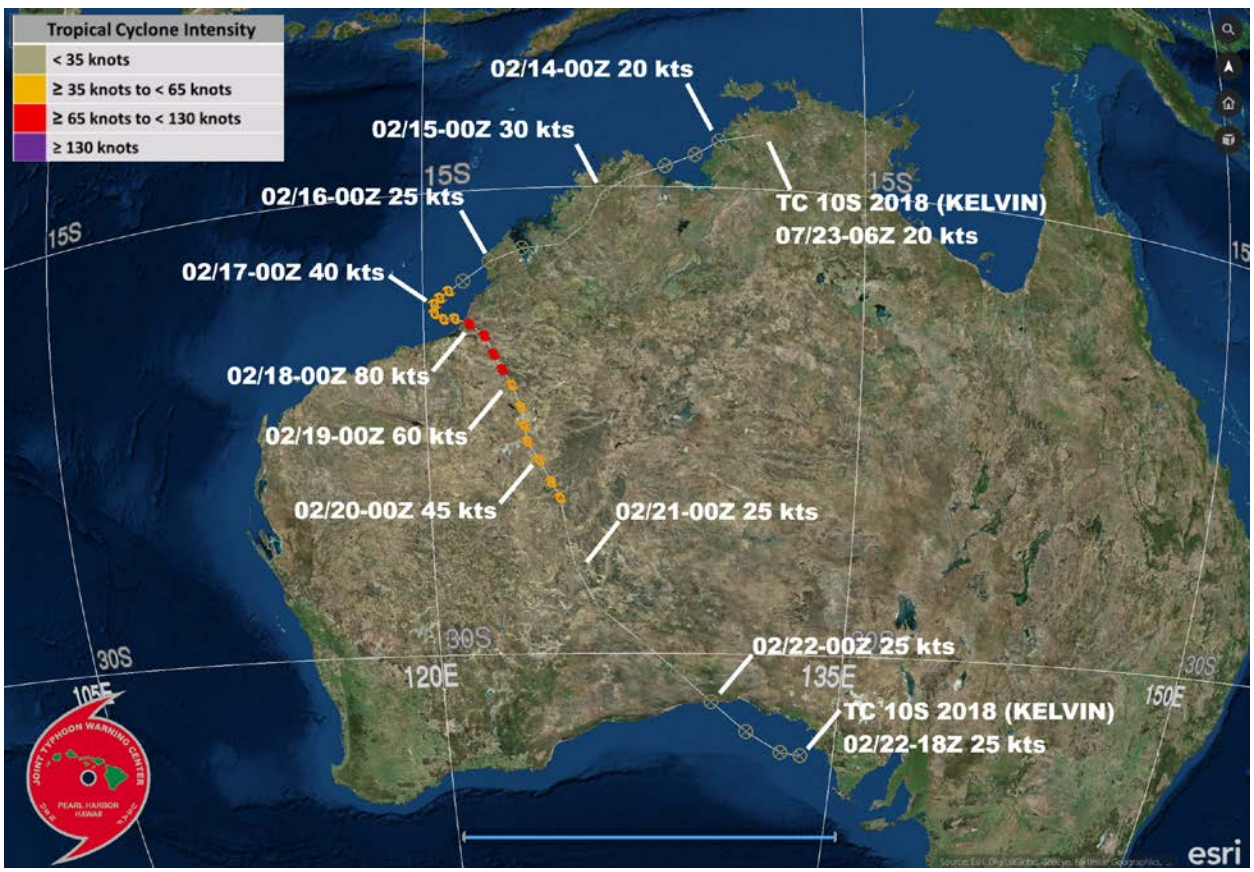




10S TROPICAL CYCLONE KELVIN

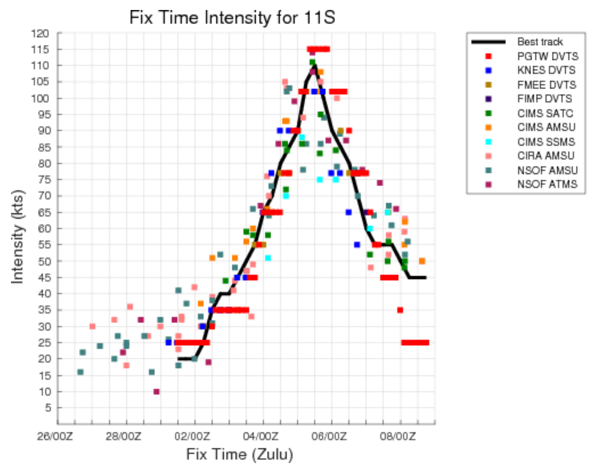
ISSUED LOW:	13 Feb / 1230Z
ISSUED MED:	13 Feb / 1800Z
FIRST TCFA:	15 Feb / 1400Z
FIRST WARNING:	16 Feb / 0600Z
LAST WARNING:	18 Feb / 0000Z
MAX INTENSITY:	75
WARNINGS:	8

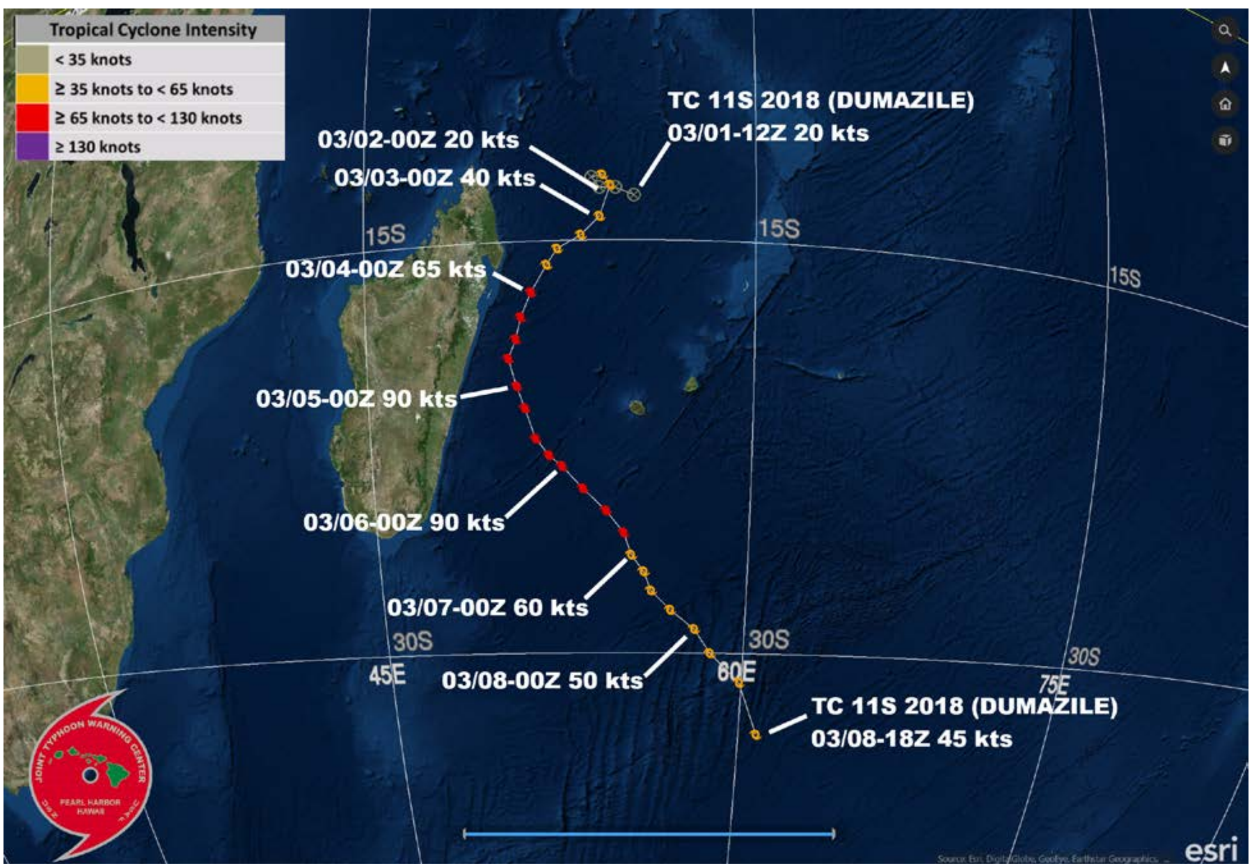




11S TROPICAL CYCLONE DUMAZILE

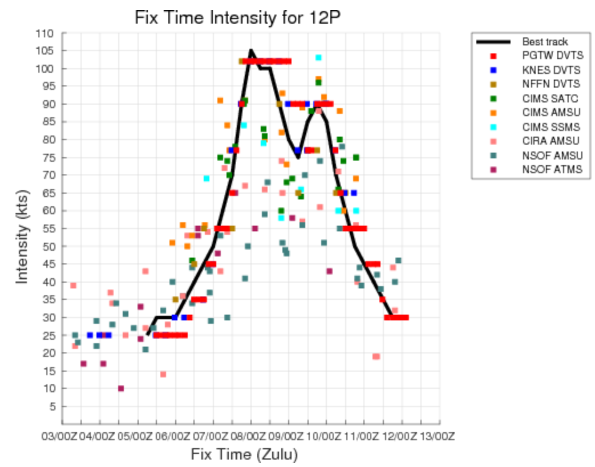
ISSUED LOW:	26 Feb / 1800Z
ISSUED MED:	27 Feb / 1230Z
FIRST TCFA:	01 Mar / 1430Z
FIRST WARNING:	02 Mar / 1200Z
LAST WARNING:	07 Mar / 1800Z
MAX INTENSITY:	110
WARNINGS:	22

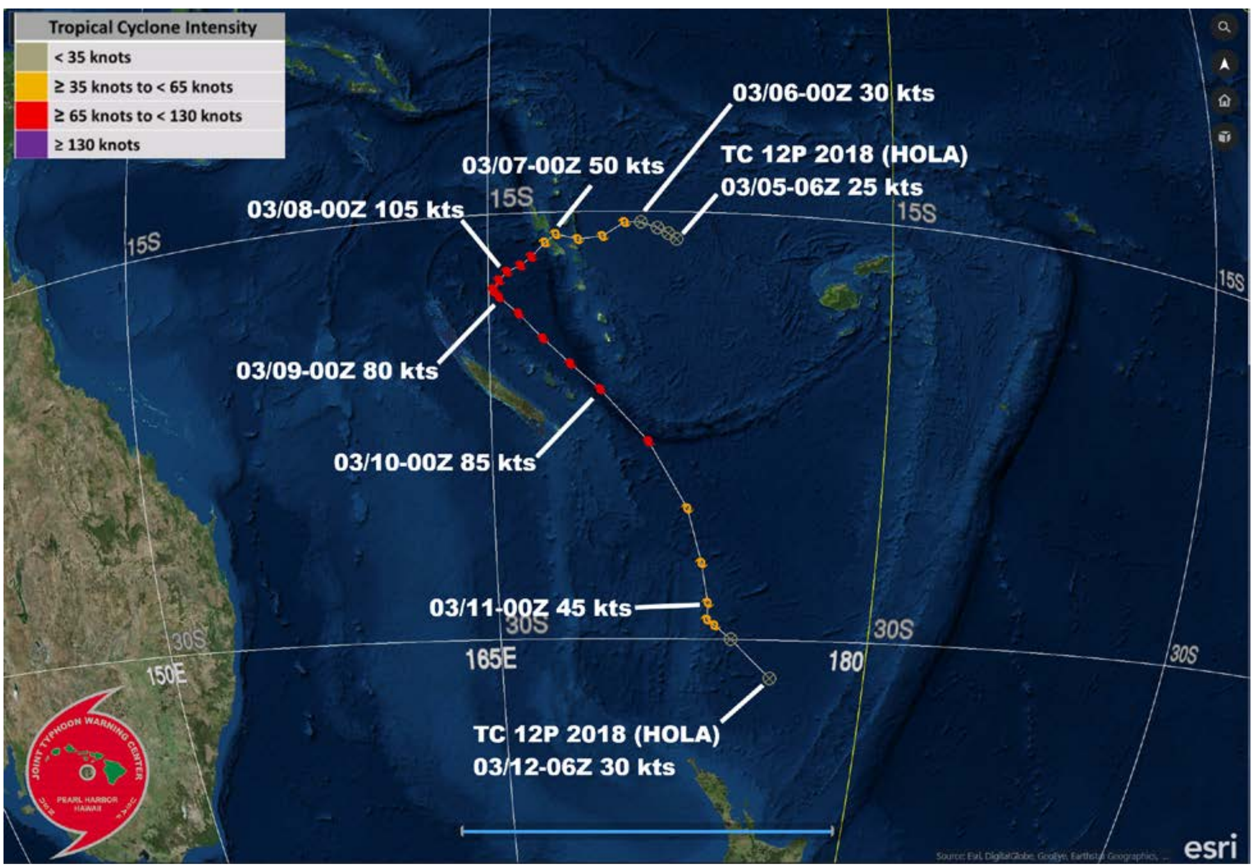




12P TROPICAL CYCLONE HOLA

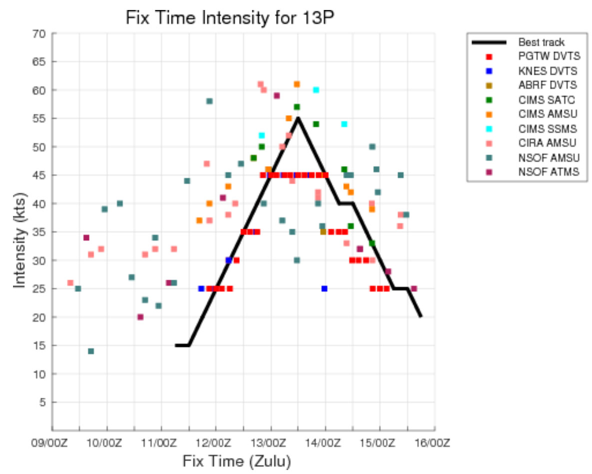
ISSUED LOW:	03 Mar / 1000Z
ISSUED MED:	04 Mar / 1730Z
FIRST TCFA:	05 Mar / 1400Z
FIRST WARNING:	06 Mar / 1200Z
LAST WARNING:	11 Mar / 0000Z
MAX INTENSITY:	105
WARNINGS:	19

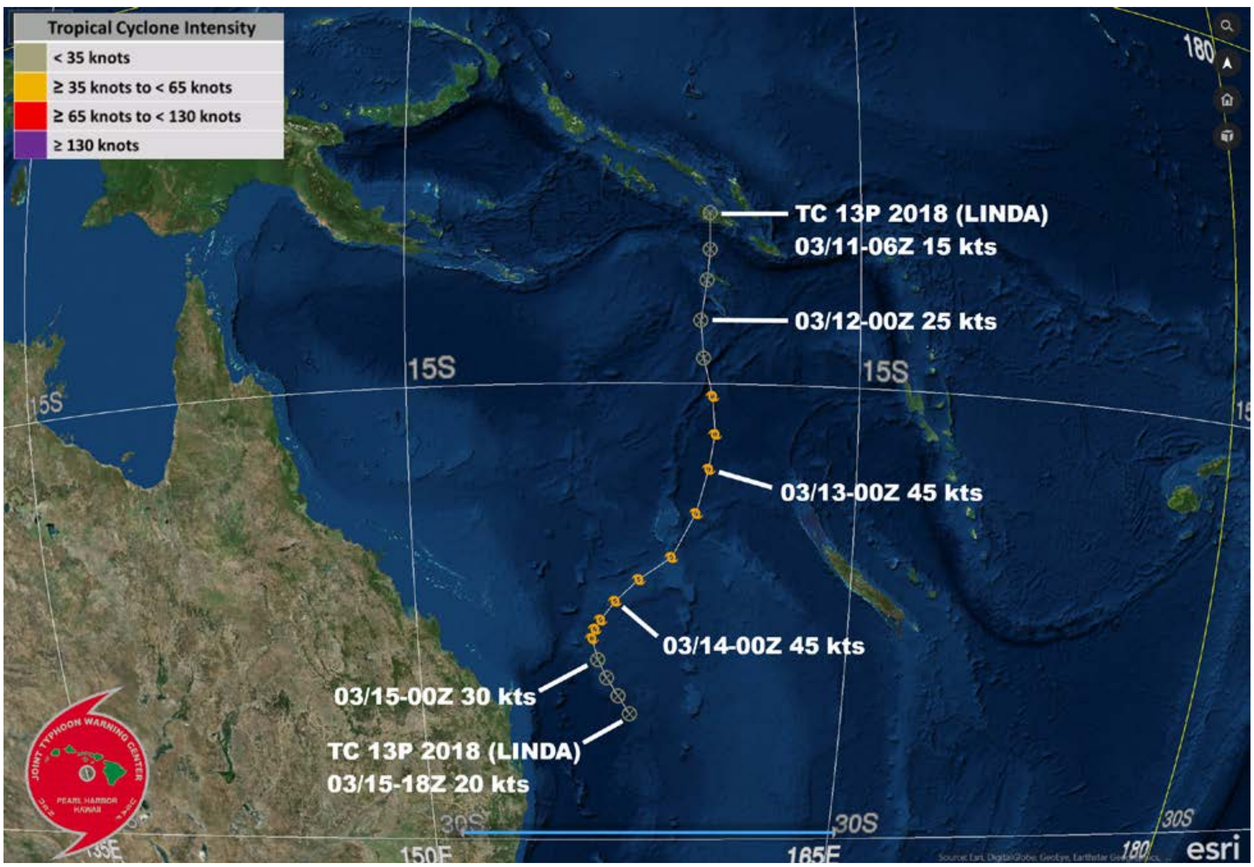




13P TROPICAL CYCLONE LINDA

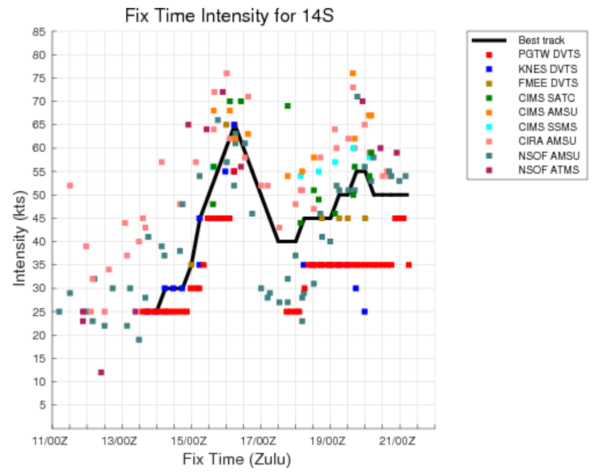
ISSUED LOW:	N/A
ISSUED MED:	11 Mar / 2200Z
FIRST TCFA:	12 Mar / 0300Z
FIRST WARNING:	12 Mar / 1200Z
LAST WARNING:	14 Mar / 1200Z
MAX INTENSITY:	55
WARNINGS:	9

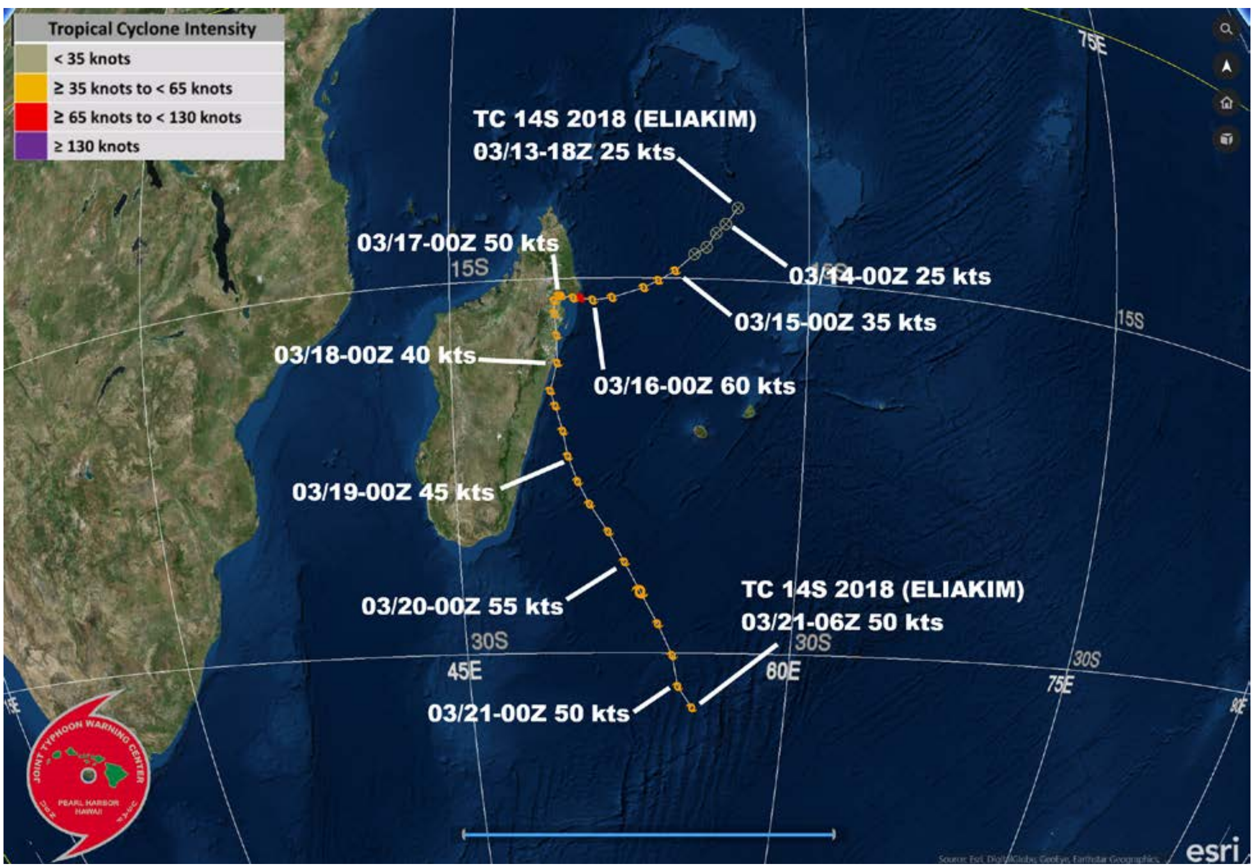




14S TROPICAL CYCLONE ELIAKIM

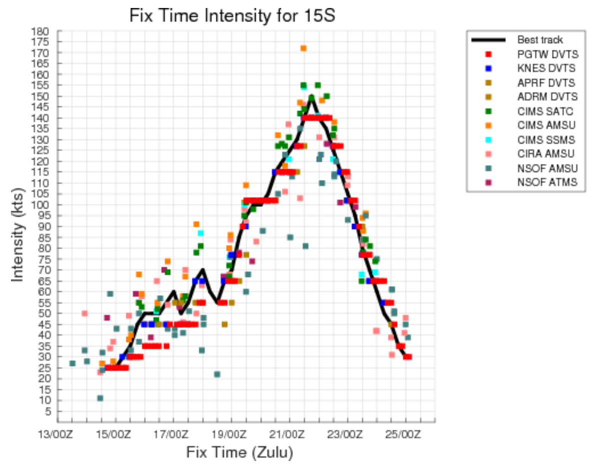
ISSUED LOW:	09 Mar / 1030Z
ISSUED MED:	12 Mar / 1800Z
FIRST TCFA:	14 Mar / 0300Z
FIRST WARNING:	15 Mar / 0000Z
LAST WARNING:	20 Mar / 1200Z
MAX INTENSITY:	65
WARNINGS:	23

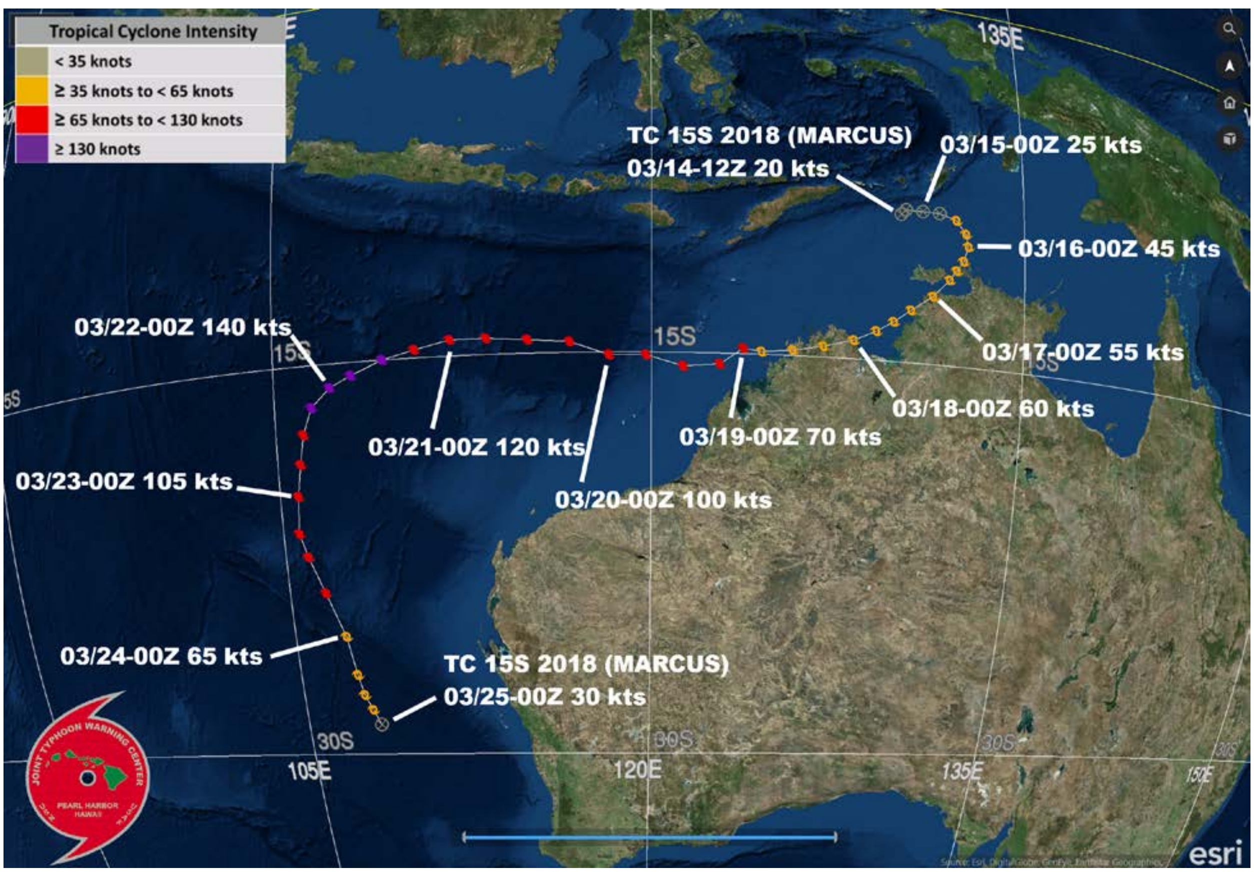




15S TROPICAL CYCLONE MARCUS

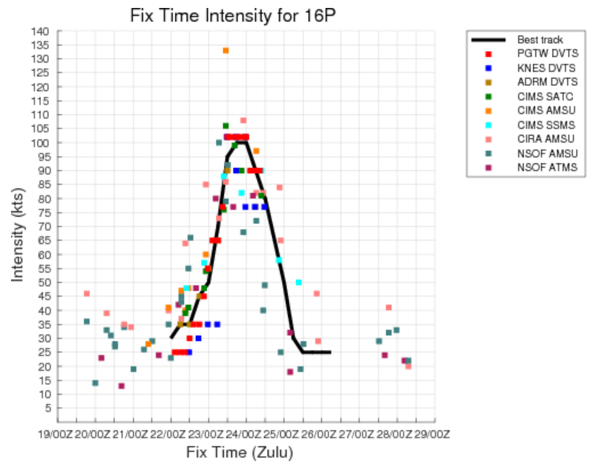
ISSUED LOW:	N/A
ISSUED MED:	13 Mar / 2200Z
FIRST TCFA:	15 Mar / 0500Z
FIRST WARNING:	15 Mar / 1800Z
LAST WARNING:	24 Mar / 0600Z
MAX INTENSITY:	150
WARNINGS:	35

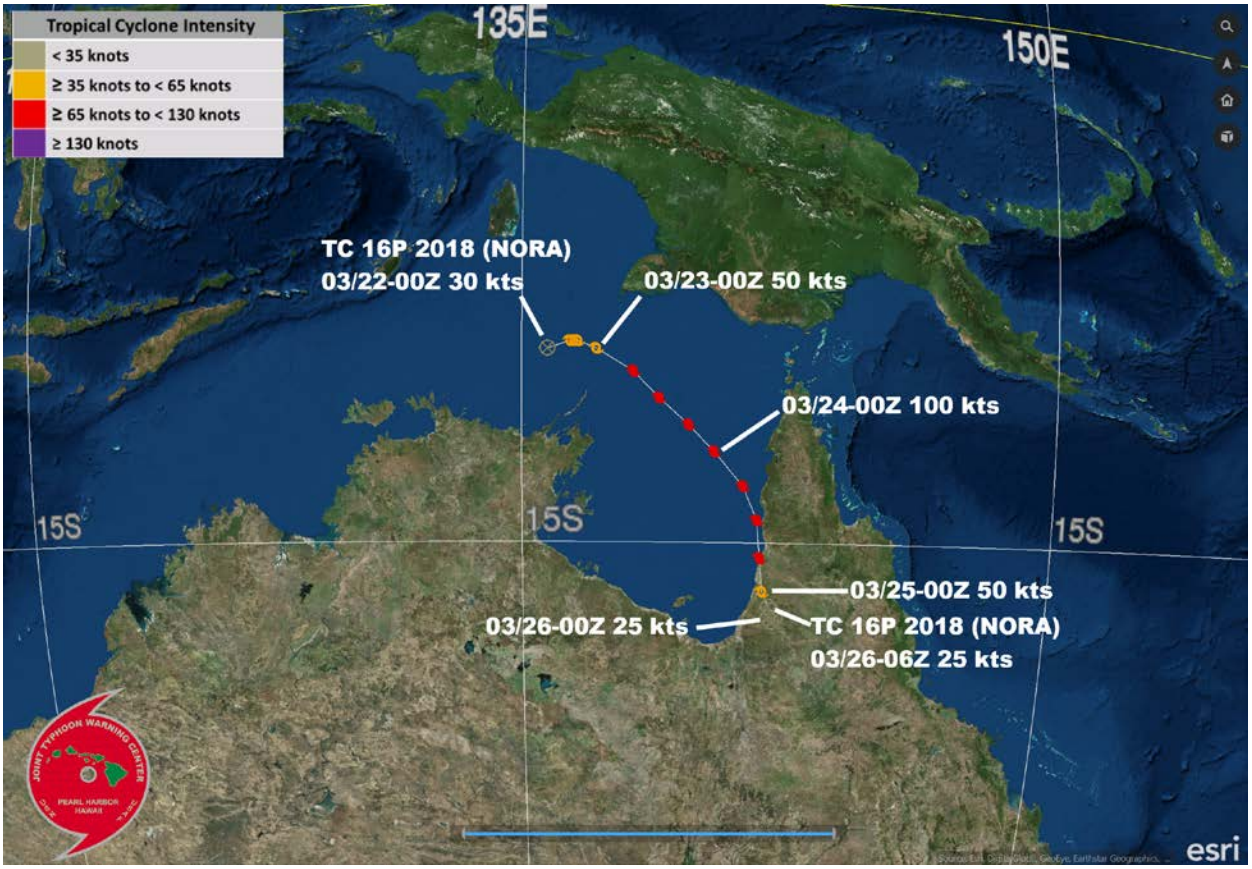




16P TROPICAL CYCLONE NORA

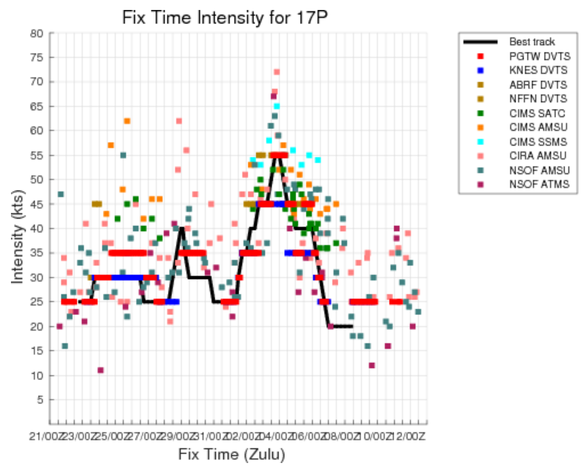
ISSUED LOW:	20 Mar / 0600Z
ISSUED MED:	N/A
FIRST TCFA:	21 Mar / 1830Z
FIRST WARNING:	22 Mar / 0600Z
LAST WARNING:	25 Mar / 0000Z
MAX INTENSITY:	100
WARNINGS:	12

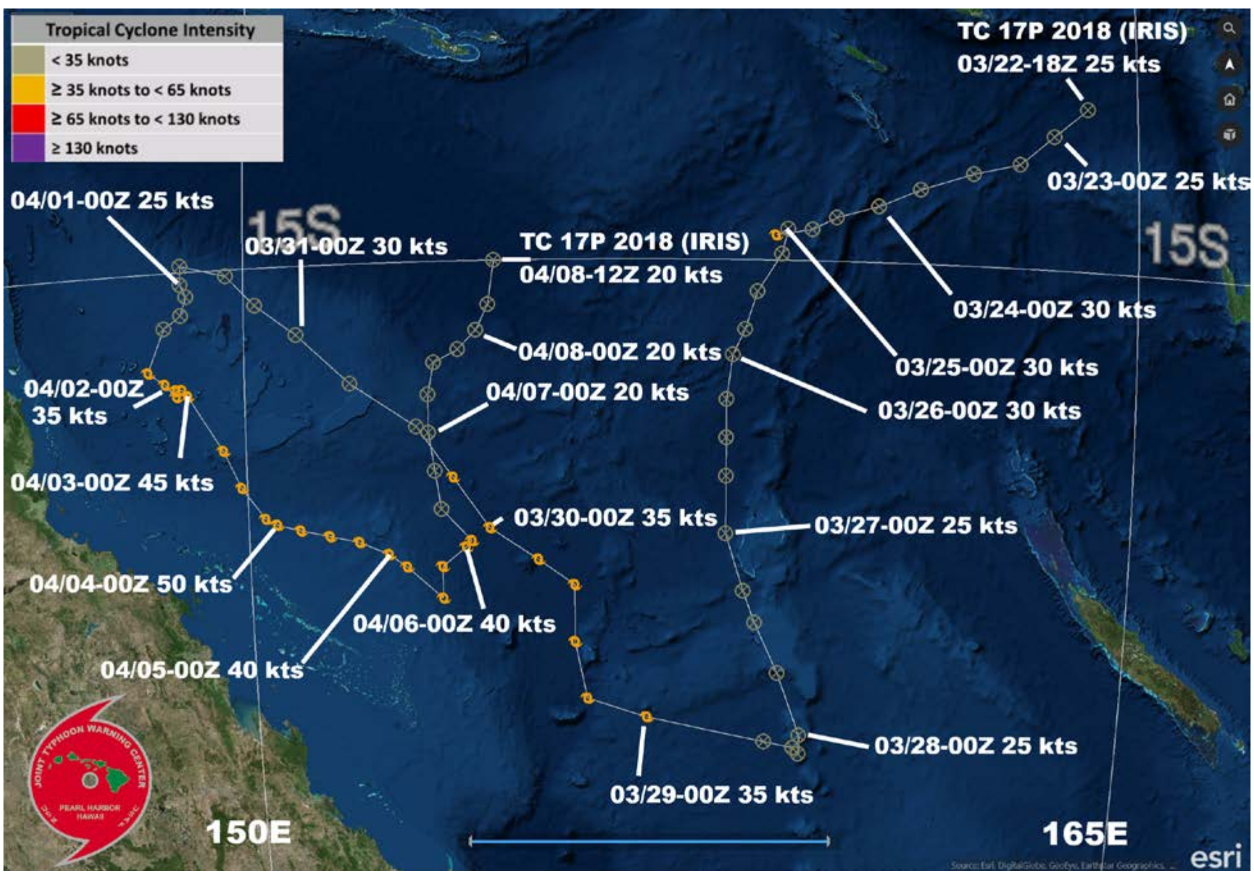




17P TROPICAL CYCLONE IRIS

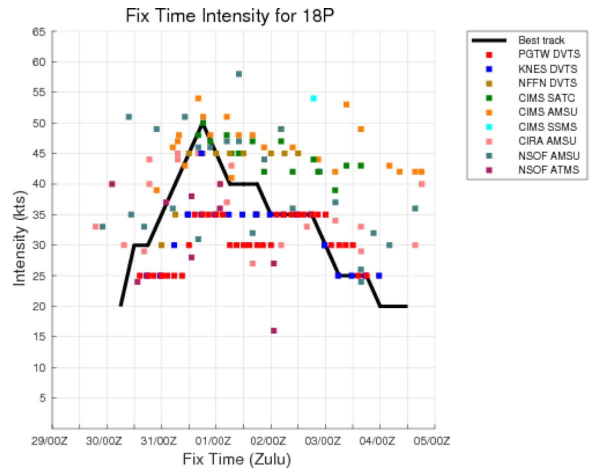
ISSUED LOW:	N/A
ISSUED MED:	21 Mar / 1900Z
FIRST TCFA:	23 Mar / 0230Z
FIRST WARNING:	24 Mar / 1800Z
LAST WARNING:	06 Apr / 1800Z
MAX INTENSITY:	55
WARNINGS:	11

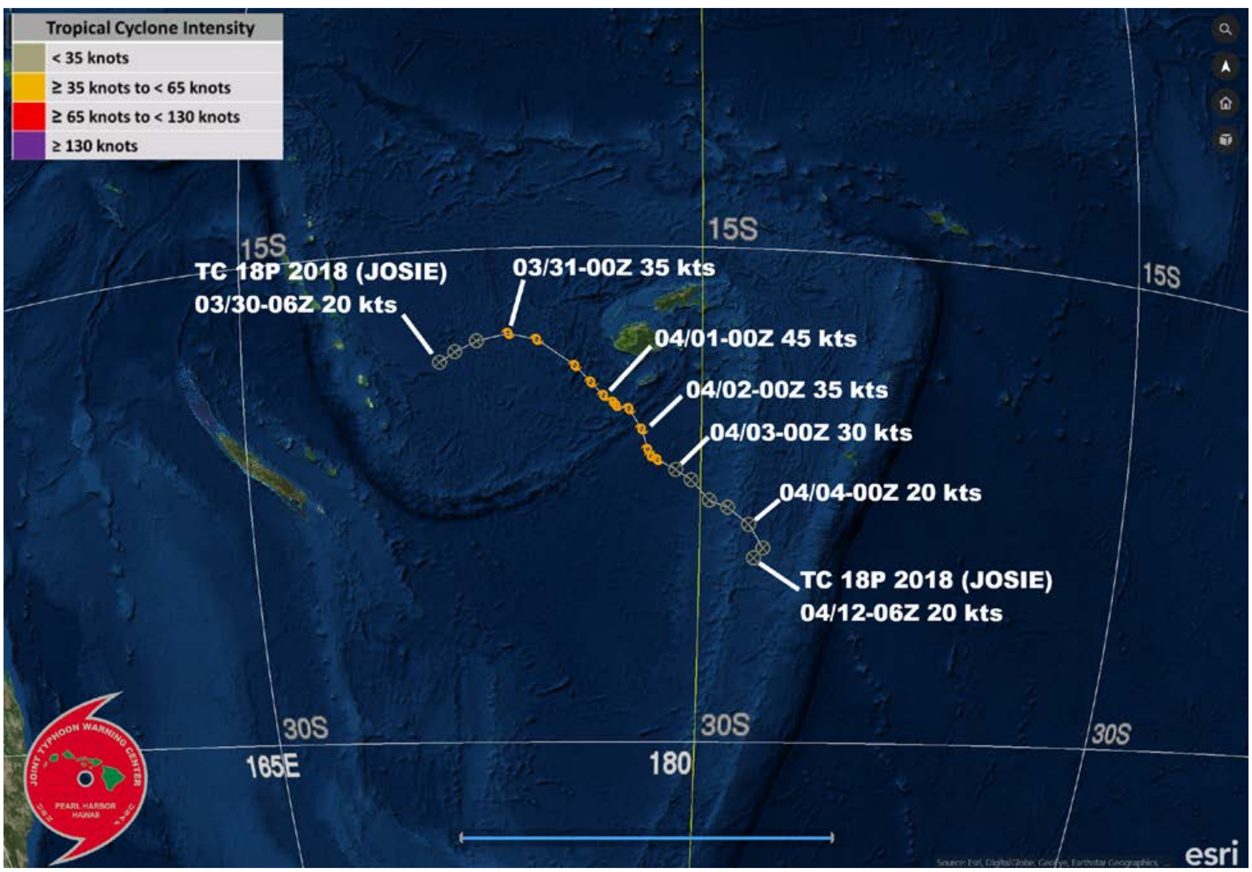




18P TROPICAL CYCLONE JOSIE

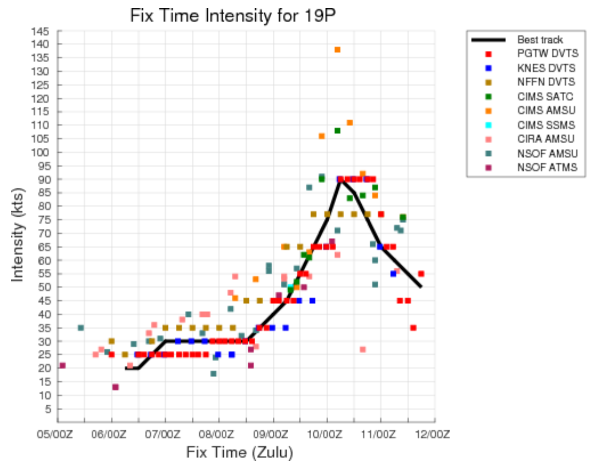
ISSUED LOW:	30 Mar / 0600Z
ISSUED MED:	30 Mar / 2130Z
FIRST TCFA:	31 Mar / 0230Z
FIRST WARNING:	31 Mar / 1200Z
LAST WARNING:	03 Apr / 0600Z
MAX INTENSITY:	50
WARNINGS:	12

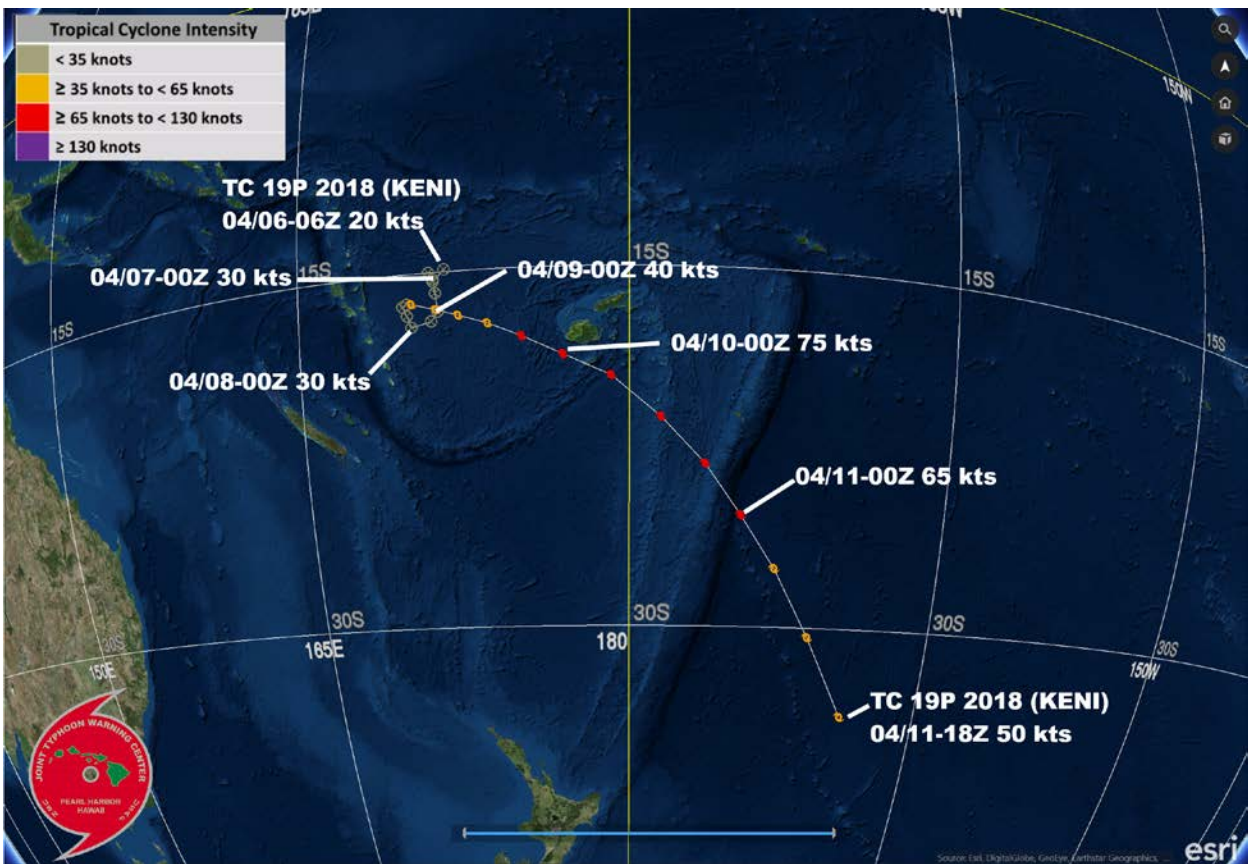




19P TROPICAL CYCLONE KENI

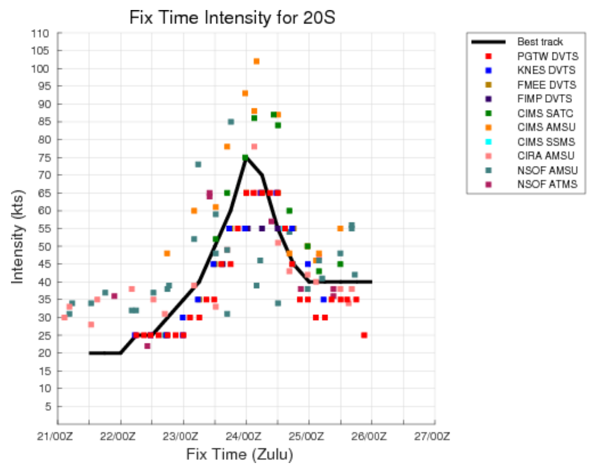
ISSUED LOW:	05 Apr / 0130Z
ISSUED MED:	05 Apr / 1930Z
FIRST TCFA:	08 Apr / 0200Z
FIRST WARNING:	08 Apr / 1800Z
LAST WARNING:	11 Apr / 0600Z
MAX INTENSITY:	90
WARNINGS:	11

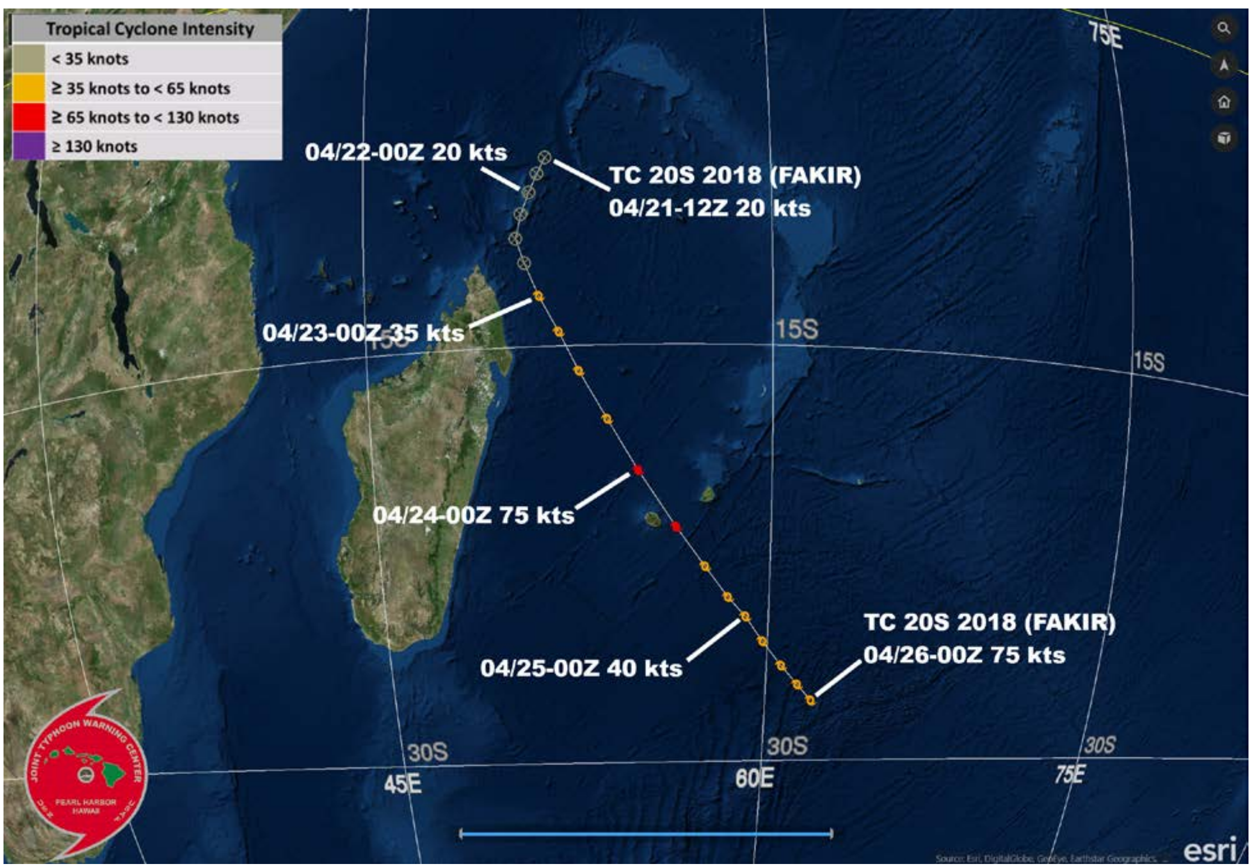




20S TROPICAL CYCLONE FAKIR

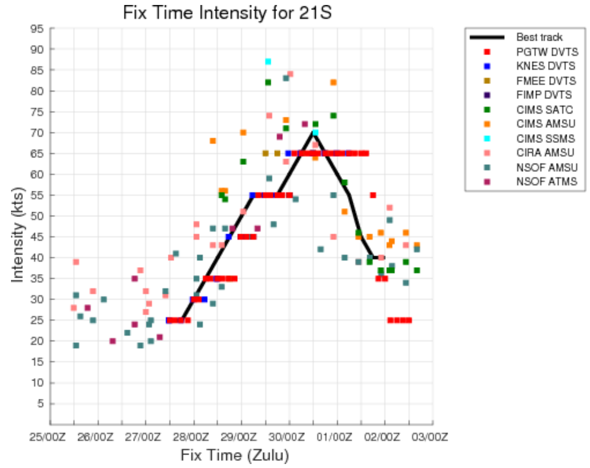
ISSUED LOW:	20 Apr / 1400Z
ISSUED MED:	20 Apr / 1800Z
FIRST TCFA:	22 Apr / 0800Z
FIRST WARNING:	23 Apr / 1200Z
LAST WARNING:	25 Apr / 0000Z
MAX INTENSITY:	75
WARNINGS:	7

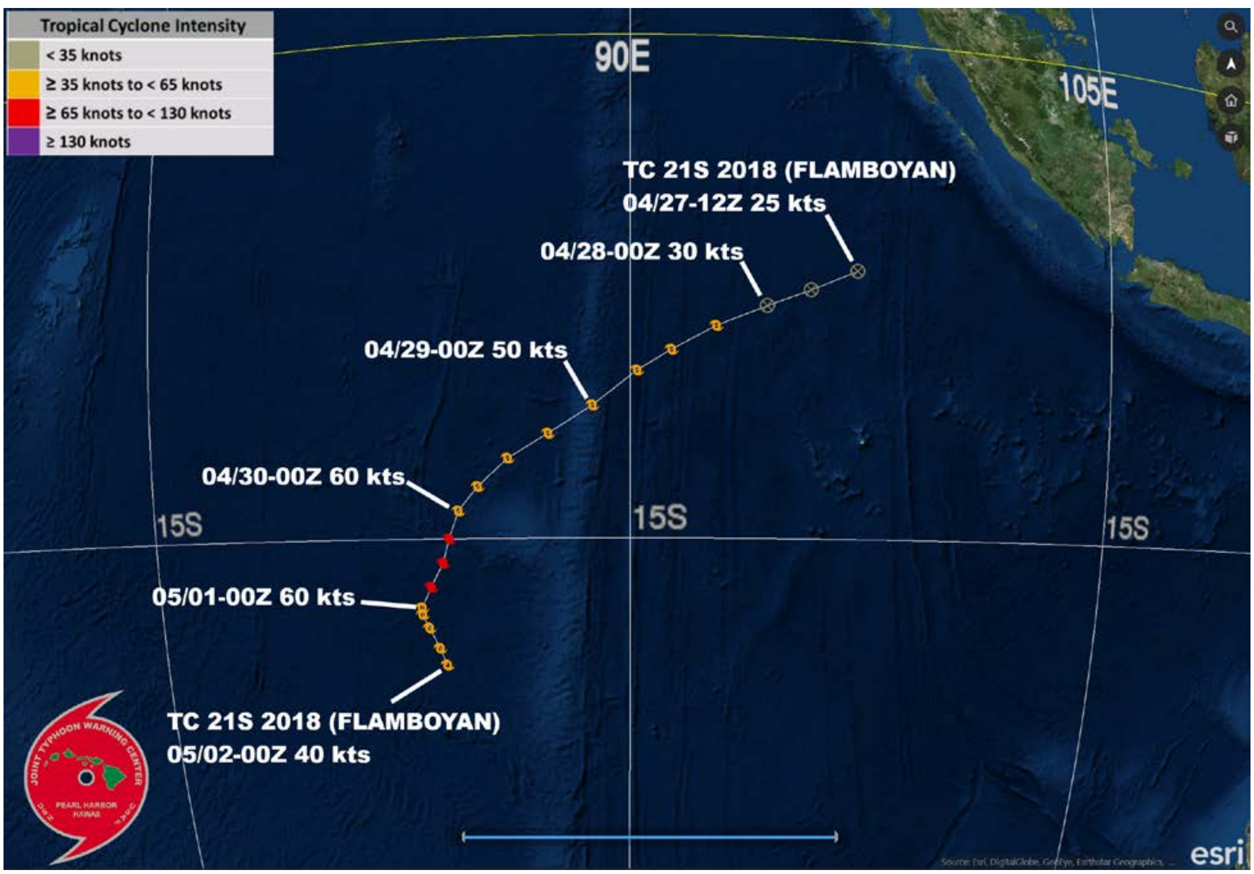




21S TROPICAL CYCLONE FLAMBOYAN

ISSUED LOW:	27 Apr / 1300Z
ISSUED MED:	27 Apr / 1800Z
FIRST TCFA:	28 Apr / 0130Z
FIRST WARNING:	28 Apr / 0600Z
LAST WARNING:	02 May / 0000Z
MAX INTENSITY:	70
WARNINGS:	16





Chapter 4 Tropical Cyclone Fix Data

Section 1 Background

Meteorological satellite data continued to be the primary tool for the TC reconnaissance mission at JTWC. JTWC satellite analysts produced 10,859 position and intensity estimates. A total of 4,409 of those 10,859 fixes were made using microwave imagery, amounting to approximately 41 percent of the total number of fixes. 1,362 of those 10,859 fixes were scatterometry fixes, amounting to just over 12.5 percent of the total number of fixes.

The USAF primary weather satellite direct readout system, Mark IVB, and the USN FMQ-17 continued to be invaluable tools in the TC reconnaissance mission. Section 2 tables depict fixes produced by JTWC satellite analysts, stratified by basin and storm number. Following the final numbered storm for each section, is a value representing the number of fixes for invests considered as Did Not Develop (DND) areas. DNDs are areas that were fixed on, but did not reach warning criteria. The total DND fixes for all basins was 1,280, which accounted for approximately 12% of all fixes in 2018.

Section 2 Fix Summary by Basin

TABLE 4-1 WESTERN NORTH PACIFIC OCEAN FIX SUMMARY FOR 2018				
Tropical Cyclone	**Name**	**Visible/Infrared**	**Microwave/Scatterometry**	**Total**
10E	HECTOR	**29**	**17**	**46**
01W	BOLAVEN	35	41	76
02W	SANBA	78	85	163
03W	JELAWAT	122	152	274
04W	FOUR	72	96	168
05W	EWINIAR	67	61	128
06W	MALIKSI	71	107	178
07W	SEVEN	7	8	15
08W	GAEMI	29	31	60
09W	PRAPIROON	60	62	122
10W	MARIA	108	141	249
11W	SON-TINH	99	75	174
12W	AMPIL	67	63	130
13W	THIRTEEN	30	29	59
14W	WUKONG	56	68	124
15W	JONGDARI	116	111	227
16W	SIXTEEN	27	31	58
17W	SHANSHAN	68	86	154
18W	YAGI	92	64	156
19W	LEEPI	55	57	112
20W	BEBINCA	73	41	114
21W	RUMBIA	29	7	36
22W	SOULIK	88	129	217
23W	CIMARON	73	91	164
24W	TWENTYFOUR	28	9	37
25W	JEBI	72	121	193
26W	MANGKHUT	81	132	213
27W	BARIJAT	57	36	93
28W	TRAMI	91	142	233
29W	TWENTYNINE	21	19	40
30W	KONG-REY	78	131	209
31W	YUTU	114	178	292
32W	TORAJI	29	15	44
33W	USAGI	139	73	212
34W	MAN-YI	74	94	**168**
35W	THIRTYFIVE	53	47	**100**
36W	PABUK	11	8	**19**
DND		368	122	490
Totals		**2767**	**2780**	**5547**
Percentage of Total		**49.88%**	**50.12%**	**100**

TABLE 4-2 NORTH INDIAN OCEAN (BAY OF BENGAL/ARABIAN SEA) FIX SUMMARY FOR 2018				
Tropical Cyclone	**Name**	**Visible/Infrared**	**Microwave/Scatterometry**	**Total**
01A	SAGAR	36	58	94
02A	MEKUNU	48	57	105
3	INVEST	7	22	29
04B	FOUR	18	13	31
05A	LUBAN	70	84	154
06B	TITLI	44	39	83
07B	GAJA	113	121	234
08B	PHETHAI	53	33	86
DND		73	36	109
Totals		**462**	**463**	**925**
Percentage of Total		**49.95%**	**50.05%**	**100**

TABLE 4-3 SOUTH PACIFIC & SOUTH INDIAN OCEAN FIX SUMMARY FOR 2018				
Tropical Cyclone	**Name**	**Visible/Infrared**	**Microwave/Scatterometry**	**Total**
01S	DAHLIA	86	132	218
02S	HILDA	45	37	82
03S	AVA	102	127	229
04S	IRVING	46	81	127
05S	JOYCE	49	61	110
06S	BERGUITTA	76	144	220
07S	CEBILE	122	265	387
08P	FEHI	35	55	90
09P	GITA	102	203	305
10S	KELVIN	72	56	128
11S	DUMAZILE	60	127	187
12P	HOLA	58	87	145
13P	LINDA	31	62	93
14S	ELIAKIM	67	117	184
15S	MARCUS	88	154	242
16P	NORA	44	47	91
17P	IRIS	164	227	391
18P	JOSIE	43	85	128
19P	KENI	49	94	143
20S	FAKIR	33	58	91
21S	FLAMBOYAN	41	74	115
DND		446	235	681
Totals		**1859**	**2528**	**4387**
Percentage of Total		**42.38%**	**57.62%**	**100**

Chapter 5 Technical Development Summary

Section 1 Operational Priorities

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

Recent upgrades to ATCF include improvements to the Rapid Intensification Prediction Aid (RIPA), described in Knaff et al. (2018, 2019). Further refinements to the display and interrogation of remotely sensed data such as L-band radiometer data from SMAP and SMOS satellites are also ongoing (Figure 5-1). ATCF's objective wind radii estimation and visualization tools provide forecasters automated inputs from these sensors to assist initial storm size estimation, and to improve JTWC's overall storm structure analyses. Despite their relatively coarse resolution, these sensors have also shown skill at estimating TC winds in excess of 64 knots (Strahl et al., 2019). Planned improvements for 2019 include developing a new data archive and retrieval system to improve post-analysis, ingest and display of Synthetic Aperture Radar (SAR) data (Mouche et al., 2019) from Sentinel spacecraft flying under the auspices of ESA's Copernicus Program (Figure 5-2), and expansion of operational TC wind probabilities throughout JTWC's entire area of responsibility.

JTWC has also prioritized operationalizing the National Weather Service (NWS) Advanced Weather Interactive Processing System (AWIPS-II) to facilitate visualization and fusion of meteorological data. JTWC installed AWIPS-II in Spring 2018, but initial operating capability is currently not anticipated until early 2020 due to the network accreditation timeline.

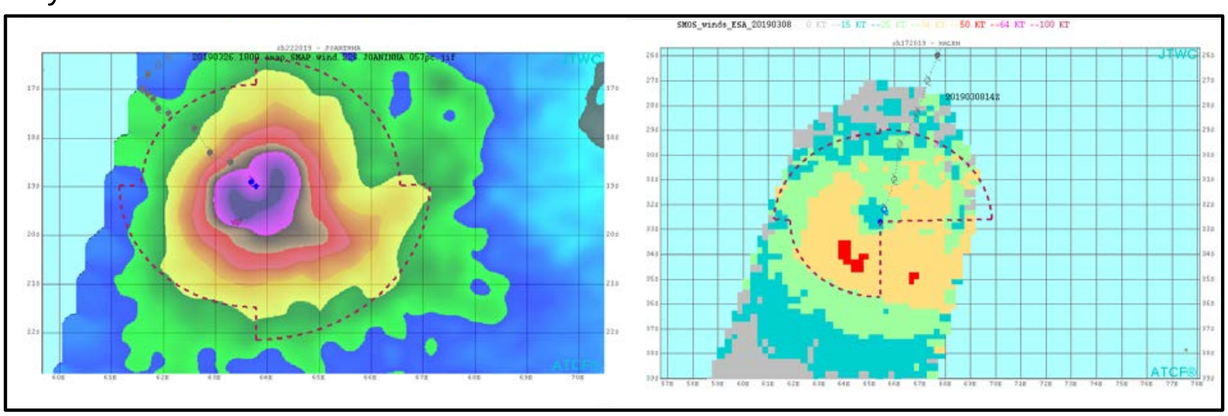


Figure 5-1. SMAP (Left) and SMOS (Right) data depicted in ATCF with objective 34-knot wind radii

In the meantime, the JTWC Technical Services Team is configuring the system, developing standard operating procedures, and drafting user training. While AWIPS-II capabilities are promising, replicating the functionality, cost-effectiveness, and long-term research to operations (R2O) efficiency of ATCF remains a significant challenge. JTWC is participating in discussions with the National Weather Service, which is working to develop an ATCF-like capability within the AWIPS-II framework.

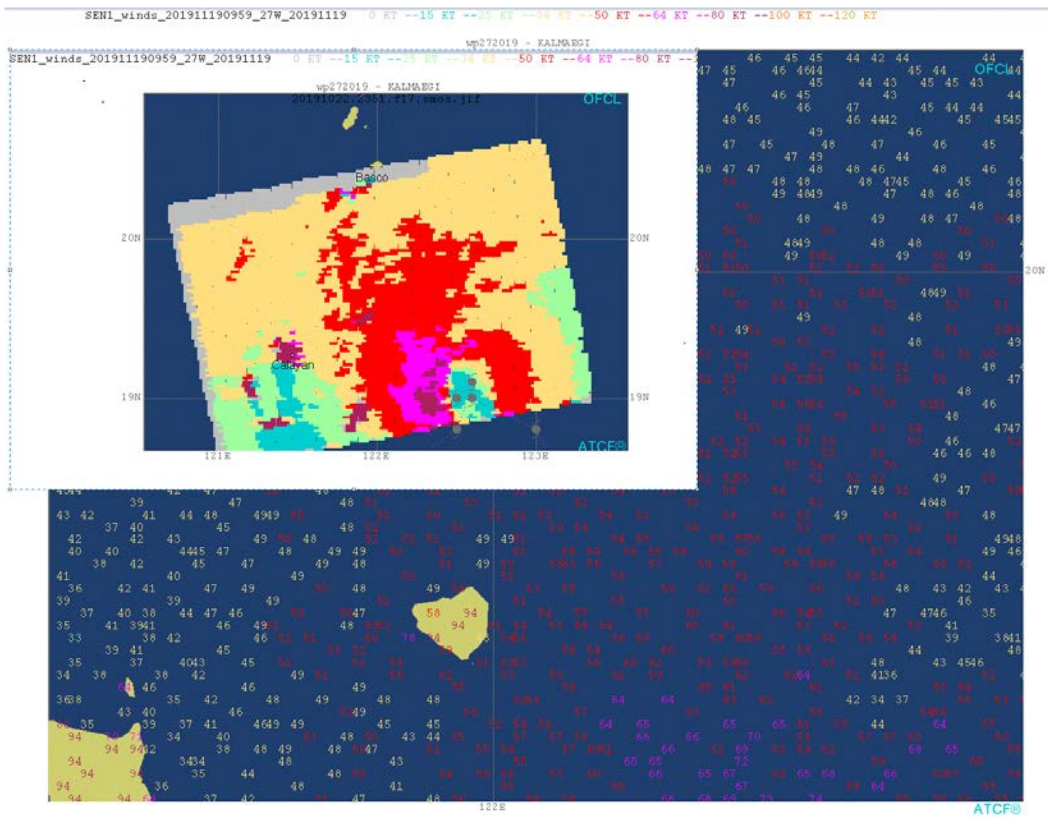


Figure 5-2. Sentinel-1 Synthetic Aperture Radar visualization in ATCF

Section 2 Research and Development Priorities

The top five JTWC needs for research and development (R&D), provided as inputs to the FY18 annual report of the Office of the Federal Coordinator for Meteorological Services and Supporting Research at the Interdepartmental Hurricane Conference and to the Office of Naval Research call for topics, are presented in Table 5-1. Developing guidance to improve TC intensity forecast accuracy, particularly the onset, duration, and magnitude of rapid intensity change, remains the highest R&D priority. TC structure specification improvement is the number two priority, as the radius of 34-knot winds (R34) impacts specification of the 34-knot danger swath, wind speed probabilities, TCCOR and wave forecasting. Data exploitation, TC track forecast improvement and TC genesis forecasts round out the priority list. The following section of this report highlights recent efforts by JTWC to address each of these R&D priorities.

Priority	Need
1 TC Intensity Change	*Basin-specific* (WESTPAC, SHEM, NIO, SIO, and SWPAC) probabilistic and deterministic *forecast guidance for TC intensity change*, *particularly* the onset, duration, and magnitude of *rapid intensity change* events (including ERC, over-water weakening, etc.) at 2-3 day lead times.
2 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
3 Data Exploitation	Techniques or products 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).
4 TC Track Improvement	Model 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 at both the short-range (0-48 hours) and the medium-range (48-120 hours), 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. 2018 JTWC R&D priorities

Section 3 Technical Development Efforts

JTWC personnel have collaborated on numerous efforts to evaluate promising R&D efforts and to transfer mature projects into operations in accordance with R&D priorities listed above.

1. Tropical cyclone intensity change

a. Intensity consensus (ICNW)

NRL-MRY and JTWC annually review performance and reliability of various U.S. and international agency models to optimize accuracy of the multi-model intensity forecasting consensus, ICNW. Component members of ICNW, as of July 2019, are listed in table 5-2.

Model	ICNW Tracker	Model Type
SHIPS (NAVGEM input)	DSHN	Statistical-dynamical
SHIPS (GFS input)	DSHA	Statistical-dynamical
COAMPS-TC	CTCI / COTI	Dynamical (mesoscale)
CHIPS	CHII	Dynamical (mesoscale)
HWRF	HWFI	Dynamical (mesoscale)
SHIPS-RI (GFS input)	RI40	Statistical-dynamical
SHIPS-RI (GFS input)	RI55	Statistical-dynamical
SHIPS-RI (GFS input)	RI70	Statistical-dynamical

Table 5-2. Primary objective aids comprising the operational JTWC tropical cyclone intensity (ICNW) consensus (current members as of August 2019).

b. Deterministic rapid intensity forecast guidance

2018 was the first full year in which CIRA's Rapid Intensification Predication Aid was available operationally in all of JTWC's forecast basins. RIPA uses probabilistic forecasts based on two methods - linear discriminant analysis and logistic regression - to forecast the likelihood of rapid intensification within a 24-hour forecast period (25, 30, 35 and 40 knots), 36-hour forecast period (45 and 55 knots) and 48-hour forecast period (70 knots) (Knaff et al. 2018, 2019). The linear discriminant analysis probability forecasts, which execute like “on-off switches,” are combined with the smoother, and more conservative, logistic regression forecasts using a simple, equal weighting. If the consensus probability exceeds 50% for any intensification threshold within the 24-hour, 36-hour and/or 48-hour forecast periods, a separate deterministic forecast is triggered for each forecast lead. These short-term, deterministic rapid intensification forecasts are then integrated into the intensity consensus whenever they are available. Independent results based on 2016 western North Pacific retrospective model runs indicate intensity consensus forecasts biases and errors were significantly and slightly reduced, respectively, when these deterministic RI forecasts were incorporated. Initial operational results support earlier testing, indicating that deterministic forecasts are triggered approximately 20%-25% of the time in the RI-conducive western North Pacific. Recent refinements to RIPA include improving handling of RI forecasts for storms approaching landfall and for invest areas that have not yet reached tropical storm intensity, as well as relaxing the persistence predictor to account for temporary periods of arrested TC development. Additionally, the intensity Goerss Predicted Consensus Error (GPCE) was re-derived to account for the new RI guidance, providing a more realistic spread in potential RI cases. JTWC has forecasted RI events more frequently and with lower MAE as predictions for the onset of rapid intensification by mesoscale models, such as the COAMPS-TC and HWRF, and by statistical-dynamical guidance such as the RIPA and SHIPS-RI, have continued to improve in recent years (Knaff et al., 2019).

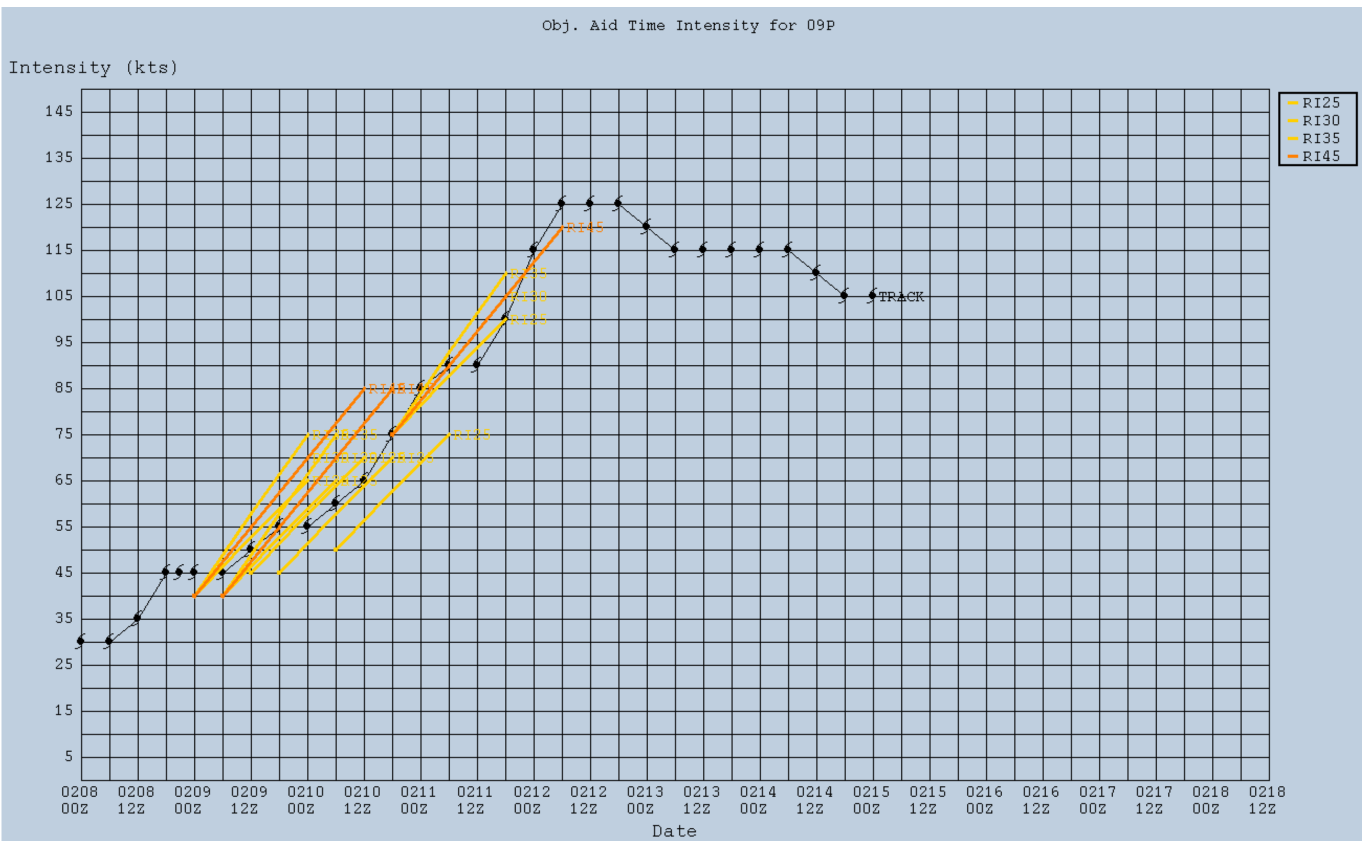


Figure 5-3. Example RI guidance displayed in ATCF for TC 09P (2018). The solid black line and TC symbols represent the verifying best track data.

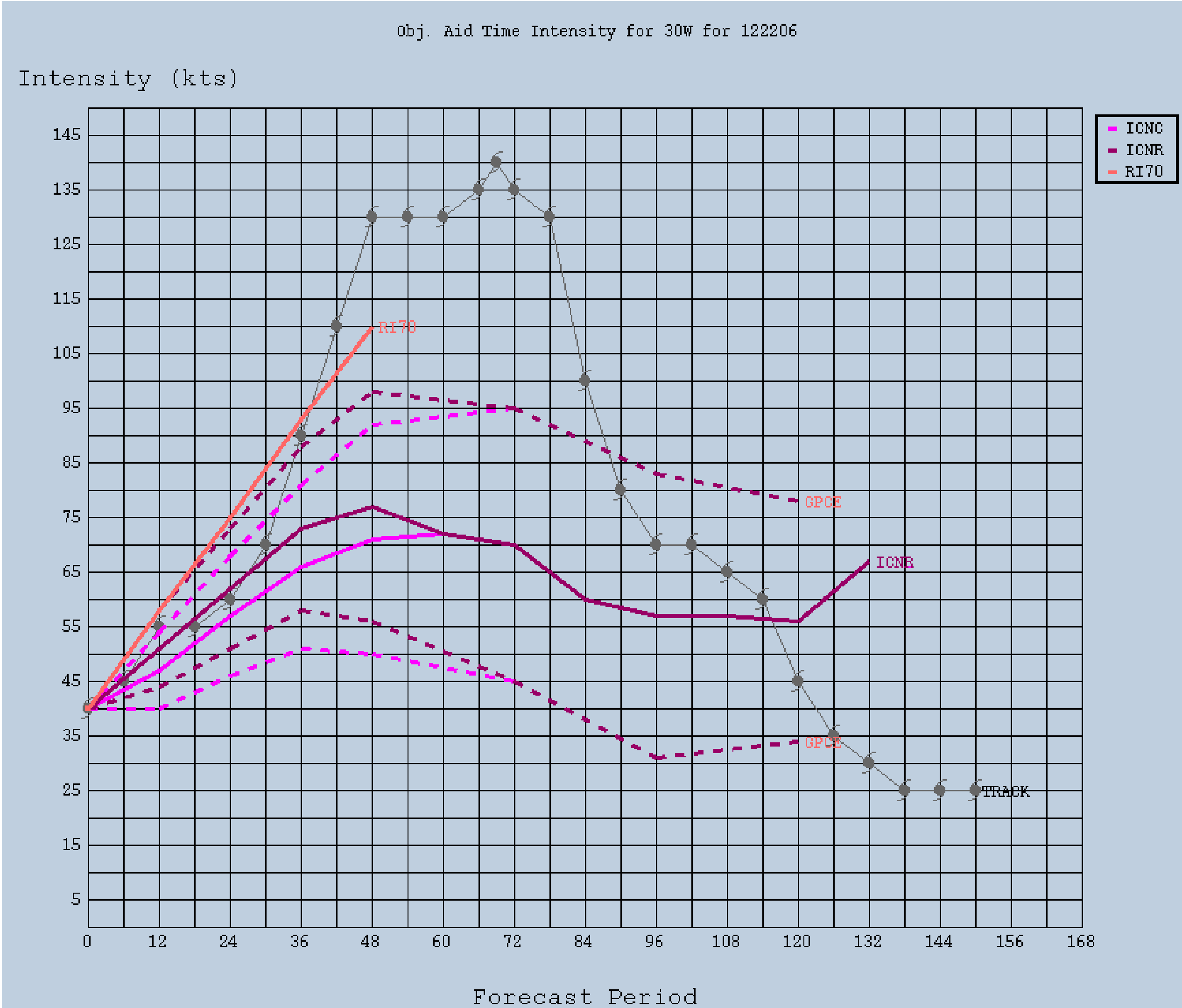


Figure 5-4. Example consensus intensity aids and GPCE spread without RIPA included (ICNC) and with RIPA (ICNR). The solid black line and TC symbols represent the verifying best track data.

c. Eyewall replacement cycle forecast guidance

Eyewall replacement cycles (ERC) contribute considerably to TC intensity forecast errors because their timing, duration and scale are difficult to forecast. To address these difficulties, the Cooperative Institute for Meteorological Satellite Studies (CIMSS) recently developed and fielded the Microwave Prediction of ERC (M-PERC) model at the National Hurricane Center as a Joint Hurricane Testbed (JHT) project (Wimmers et al., 2018). M-PERC objectively analyzes trends in microwave satellite imagery of tropical cyclones (TCs) to calculate the probability of an emerging ERC. Forecasters can synthesize these probabilities with additional guidance to anticipate the decrease in maximum sustained winds (sometimes as much as 20 knots) and increase in radius of damaging winds that may result from an imminent ERC. In coordination with JTWC, the Office of Naval Research (ONR) is funding an effort to extend ARCHER (Wimmers et al., 2016) automated fixes and M-PERC model calculations into JTWC forecast basins and make the guidance available in ATCF for further evaluation.

2. TC structure specification

a. Wind radii consensus (RVCN)

NRL-MRY and JTWC annually review performance and reliability of various U.S. and international agency models to optimize accuracy of the multi-model 34-, 50- and 64-knot wind radii forecasting consensus, RVCN. RVCN members, as of July 2019, are listed in table 5-3.

Model	RVCN Tracker	Model Type
GFS	AHNI	Dynamical (global)
HWRF	HHFI	Dynamical (mesoscale)
ECMWF	EMXI	Dynamical (global)
COAMPS-TC	CHCI	Dynamical (mesoscale)
SHIPS (GFS input)	DSHA	Statistical-dynamical

Table 5-3. Primary objective aids comprising the operational JTWC tropical cyclone wind radii (RVCN) consensus (as of August 2019).

b. JTWC TC diagnostics products

In collaboration with JTWC, Dr. Michael Fiorino (NOAA ESRL) developed a suite of real-time tropical cyclone diagnostics products that highlight TC structure and the near-storm environment as represented in analysis and forecast output from various global forecast models. These products, available through an interactive website, include graphical, storm-centered plots of storm structure characteristics such as surface winds, sea-level pressure, moisture and upper-level flow patterns. Additional derived parameters, such as radius of maximum winds and outermost closed isobar, minimum sea level pressure, and pressure of the outermost closed isobar are included with these graphics. Forecasters regularly consider the diagnostics graphics and derived data during the best tracking, bogussing and model analysis phases of each forecasting cycle.

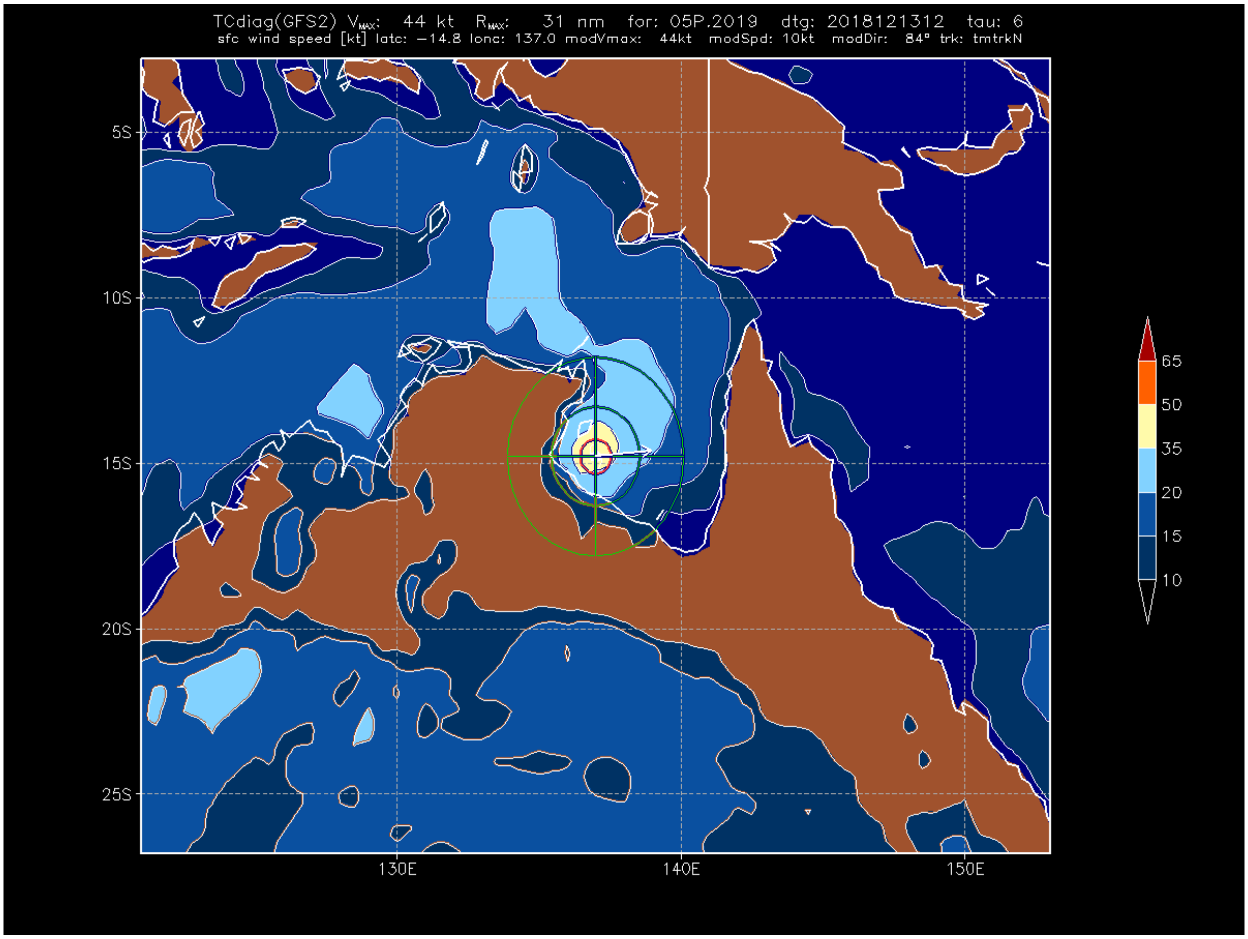


Figure 5-5. Example JTWC TC diagnostics surface wind graphic derived from the GFS model's 12 December 2018 1200Z, 6-hour forecast for TC 05P (2019)

c. TC wind radii post analysis QA/QC

In 2018, JTWC continued efforts to provide best track data with post-analyzed 34-knot wind radii (R34) information for the western North Pacific basin. JTWC best track post-analysis has historically been limited to position and intensity. However, beginning in 2015, NRL-Monterey and JTWC initiated an effort to re-analyze R34 in order to facilitate development and maintenance of new techniques for analyzing and forecasting TC wind structure and to streamline the operational workflow. Archived 2016 and 2017 best track data contain quality-controlled R34 data. Due to a lack of observational data, R50 and R64 values are derived via linear regression from the R34 values. JTWC is continuing wind radii best tracking in 2018, and plans to release these data once post-analysis is complete. A major upgrade to JTWC's ability to archive and recall data such as scatterometry and L-band radiometer wind estimates within ATCF is planned for 2019.

d. Space-based wind radii estimates

Wind radii estimates from SMAP and SMOS (described in section 3 of this summary) have been incorporated into JTWC objective best-track wind radii (OBTK) guidance. Data from the NASA CYGNSS mission and Sentinel-1 SAR are under evaluation for potential incorporation into the OBTK as well.

e. SHIPS wind radii

JTWC continued to process wind radii estimates (R34/50/64) based on SHIPS statistical-dynamical data (Knaff et al., 2017) in the ATCF system throughout 2018. These estimates are included into the RVCN forecast wind radii consensus (aid name is DSHA). SHIPS computes wind radii estimates using track, intensity and diagnostic information from the GFS model, as well as IR imagery. The routine availability of SHIPS radii reduces forecast-to-forecast variability in RVCN, particularly for R50/R64, as the overall SHIPS wind radii bias is less than NWP aids.

f. Objective ASCAT fix generation

ATCF produces objective R34 estimates from scatterometry and L-band radiometer data. These estimates help forecasters to assess TC structure, and they increase the accuracy of objective best track wind radii estimates (see the next section), particularly for cases in which limited consensus members are available (e.g., early in the TC lifecycle). Sampson et al. (2018) estimated objective best track consensus R34 RMSE to be 17 nautical miles (nm) when scatterometry data are available, equivalent to 15% of mean R34. RMSE is greater than 17 nm without these data.

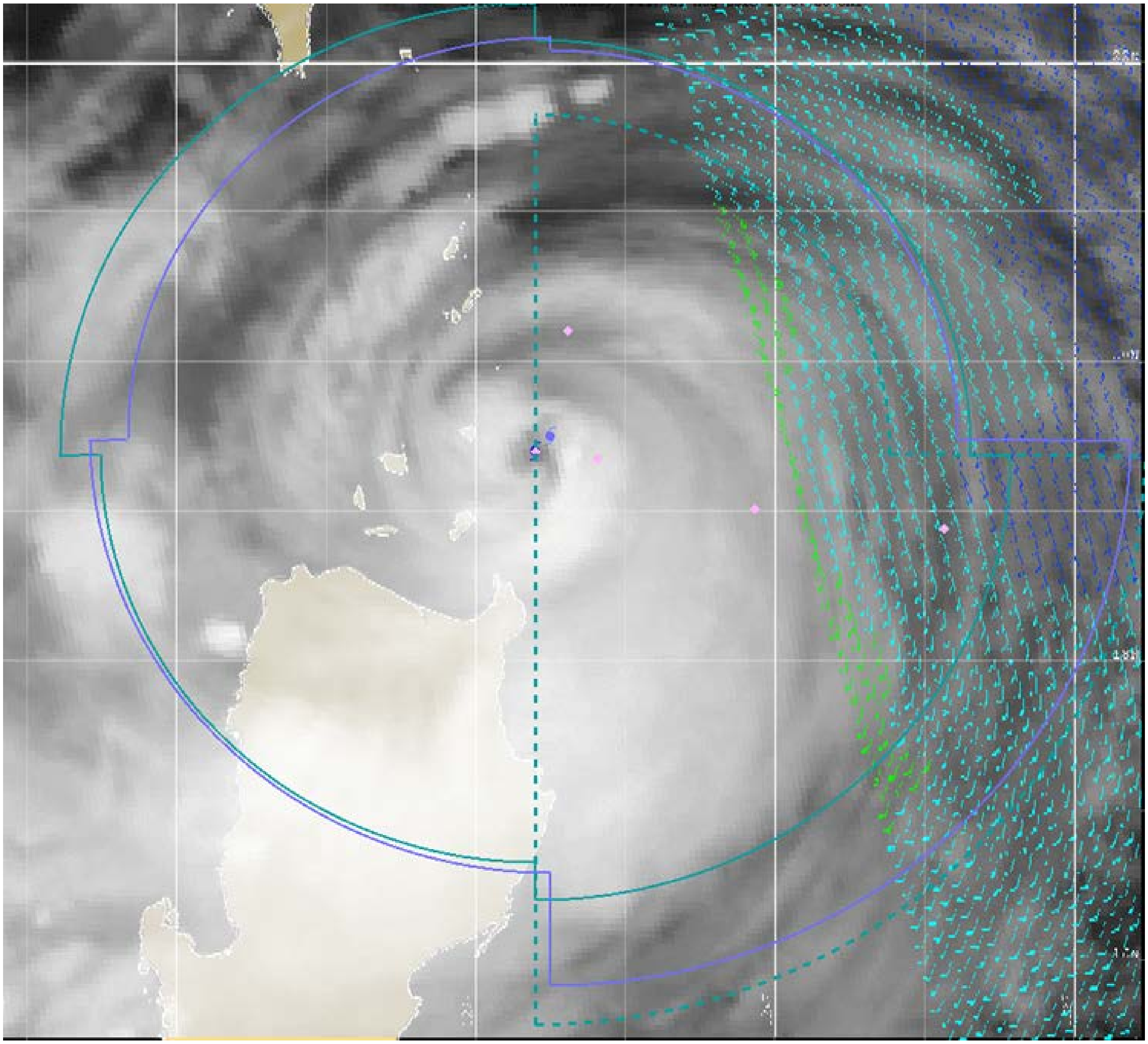


Figure 5-6. Example objective scatterometry estimate (dashed line) versus OBTK (solid blue line) and working best track estimate (solid green line) for Typhoon 16W (2015) (Goni)

g. Objective best track wind radii (OBTK)

Analyzed TC structure parameters (e.g. R34, R50, and R64) affect multiple aspects of TC forecasts and derived guidance. Analysis wind radii are critical inputs to numerical weather predictions models that ingest JTWC "TC bogus" data. They also anchor forecast wind radii values, which are used to generate the swath of potential 34-knot winds depicted on JTWC warning graphics, and drive TCCOR setting guidance, wind probabilities and wave model forecasts. Due to infrequent and/or incomplete scatterometer overpasses and the lack of in-situ observational data throughout the JTWC AOR, high uncertainty is associated with TC structure analysis in many cases. These challenges have resulted in a documented historical small bias for large TCs and frequent step function-like growth in the non-quality controlled, operational best track wind radii data. A non-weighted average of R34 estimates (OBTK; Sampson et al. 2017), developed using AMSU estimates (Demuth et al. 2004), multi-platform TC surface wind analyses (CIRW; Knaff et al. 2011), Dvorak wind radii estimates (DVRK; Knaff et al. 2016), automated NRL ASCAT estimates, and 6-hour NWP forecasts (Sampson et al. 2017), was operational in ATCF throughout 2018. Verification for 2014-2016 (Figure 5-7) indicates the OBTK has lower mean errors than any of the individual members of the consensus, greatly reducing the previously observed small bias, and resulting in smooth R34 growth curves. The implementation of OBTK in ATCF provides TDOs pre-filled first-guess R34 estimates, streamlining the production process.

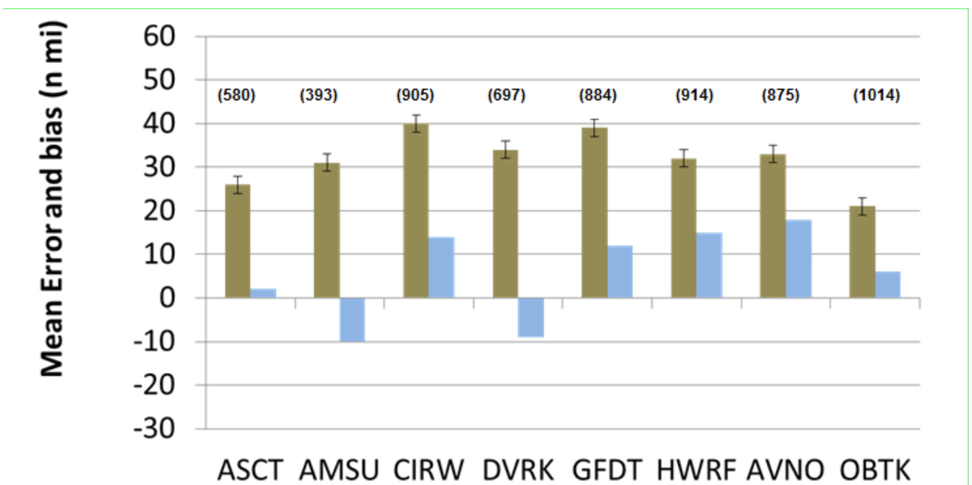


Figure 5-7. 34-knot wind radii estimate mean errors (brown) and biases (blue) relative to JTWC 2014-2016 best tracks coincident with ASCAT. Standard error is indicated by the black error bars that overlap the means.

h. Dynamically sized swath of potential gale force winds

The swath of potential-34 knot winds that accompanies JTWC TC forecasts, also known as the 34-knot wind danger area, is a function of TC forecast wind radii and JTWC's 5-year average forecast track errors. A dynamically-sized swath that adjusts the swath radius by the ratio of GPCE climatology to the situation-based GPCE value was tested in 2015 (Strahl et al. 2016). This study indicated that applying the traditional GPCE method yielded JTWC swath sizes that were scaled appropriately to account for probabilistic forecast outcomes in high certainty scenarios. However, in cases of very high uncertainty, the swath size could become unrealistically large. Additionally, the technique undesirably increased across-track swath radius even for cases in which consensus spread was predominately a result of along-track speed differences. Two new methods to calculate the dynamically sized swath will be tested on storm data from 2018-2019, and will be evaluated for potential implementation into future operations. The first method utilizes the earlier GPCE-based swath work and incorporates an adjustment to swath growth to account appropriately for along-track speed uncertainty. The second method tests the applicability of the 5% R34 wind probability contour (DeMaria et al., 2013) as the outer boundary of the swath. If accepted and implemented into operations, the later method would provide customers a truly probabilistic, situation-based swath dependent on GPCE information used in the existing wind probability code. That method would also benefit from incremental improvements to the wind probability code, such as an update implemented at JTWC in July, 2018, which incorporated the effect of decay over land (Figure 5-8).

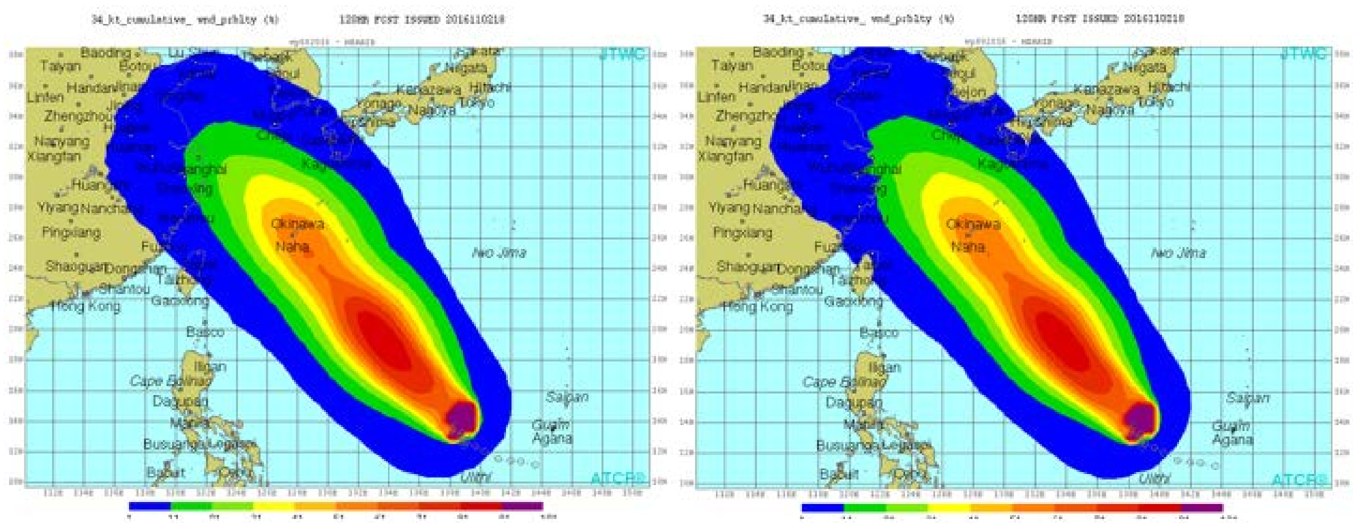


Figure 5-8. Example wind probability graphic without (left) and with (right) over-land decay

3. Data exploitation/applications of environmental satellite data

a. NASA Soil Moisture Active Passive (SMAP) and ESA Soil Moisture Ocean Salinity (SMOS) radiometer wind data

JTWC forecasters analyzed 10-min maximum-sustained wind data from the SMAP L-band radiometer (Meissner et al. 2017) throughout 2018, and began to evaluate similar data from the SMOS radiometer (Reul et al., 2012). Forecasters can view SMAP and SMOS winds in ATCF alongside other available TC wind data and best track information. The SMAP study authors note that while the horizontal resolution is somewhat less than other active and passive microwave satellite sensors and subject to slightly higher RMSE, SMAP winds have been shown to accurately quantify open-ocean wind speeds up to 70 m/s (136 knots), with less rainfall-induced signal attenuation than measurements from other sensors. SMAP provides a unique capability for JTWC forecasters who traditionally rely heavily on the Dvorak technique (Dvorak 1984) for intensity estimation due to the lack of aerial reconnaissance. JTWC may incorporate experimental data from additional low-earth orbiting satellites (e.g., CYGNSS and SAR) into ATCF to examine their potential applicability to TC analysis.

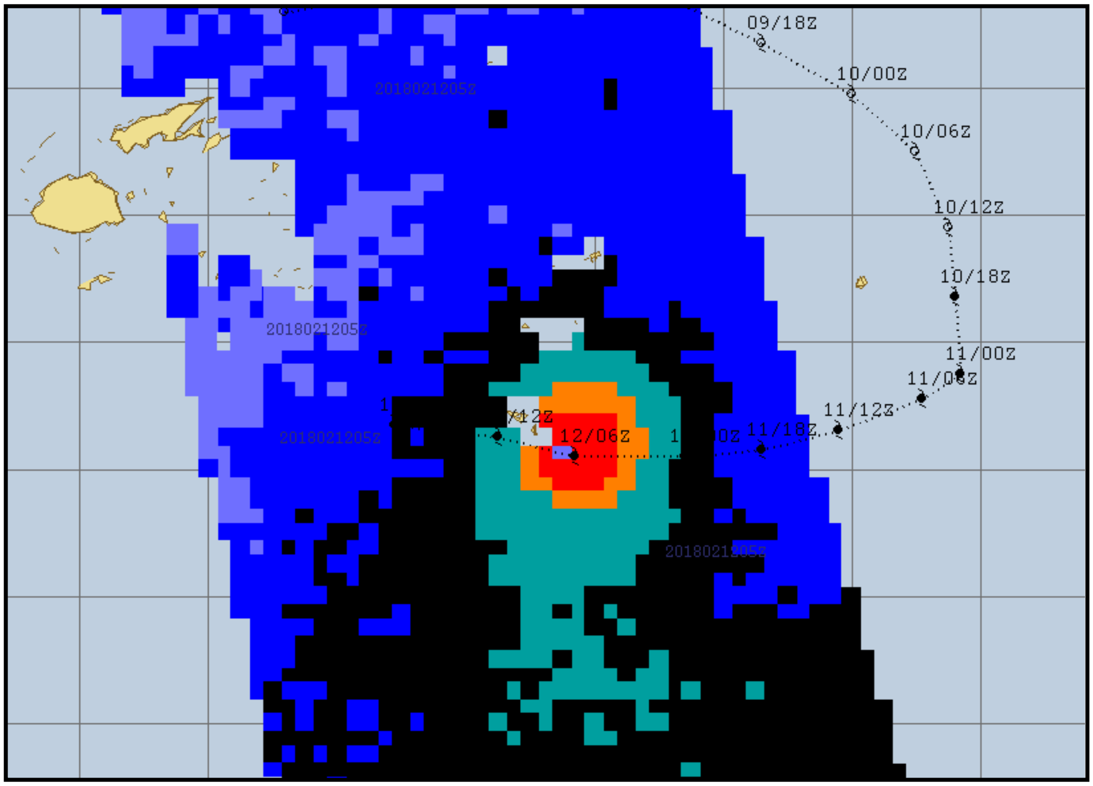


Figure 5-9. Example SMAP winds as displayed in ATCF for Tropical Cyclone Gita. Red pixels indicate winds in excess of 64 knots. A few periwinkle pixels within the R64 indicate winds in excess of 100 knots.

b. Estimating TC intensity from microwave satellite imagery

In consultation with JTWC's Technical Services Team, Air Force Institute of Technology (AFIT) student Capt Amanda Nelson applied machine learning techniques to 91 GHz Special Sensor Microwave Imagery/Sensor microwave satellite images of tropical cyclones to identify spatial patterns associated with various TC intensity thresholds (Nelson 2019). Capt Nelson's master's thesis research expanded upon earlier studies on microwave imagery / TC intensity relationships conducted at AFIT (Perkins 2018; JTWC 2017). These studies provide a basis for developing operational methods to estimate TC intensity from microwave satellite imagery through both subjective and objective visual pattern matching.

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

a. TC track consensus (CONW)

NRL-MRY and JTWC annually review performance and reliability of various U.S. and international agency models to optimize accuracy of the multi-model track forecasting consensus, CONW. JTWC updated CONW in early 2019 to include only global deterministic and ensemble model forecasts. CONW members as of August 2019 are listed in table 5-4.

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

Table 5-4. Primary objective aids comprising the operational JTWC tropical cyclone track (CONW) consensus (as of August 2019).

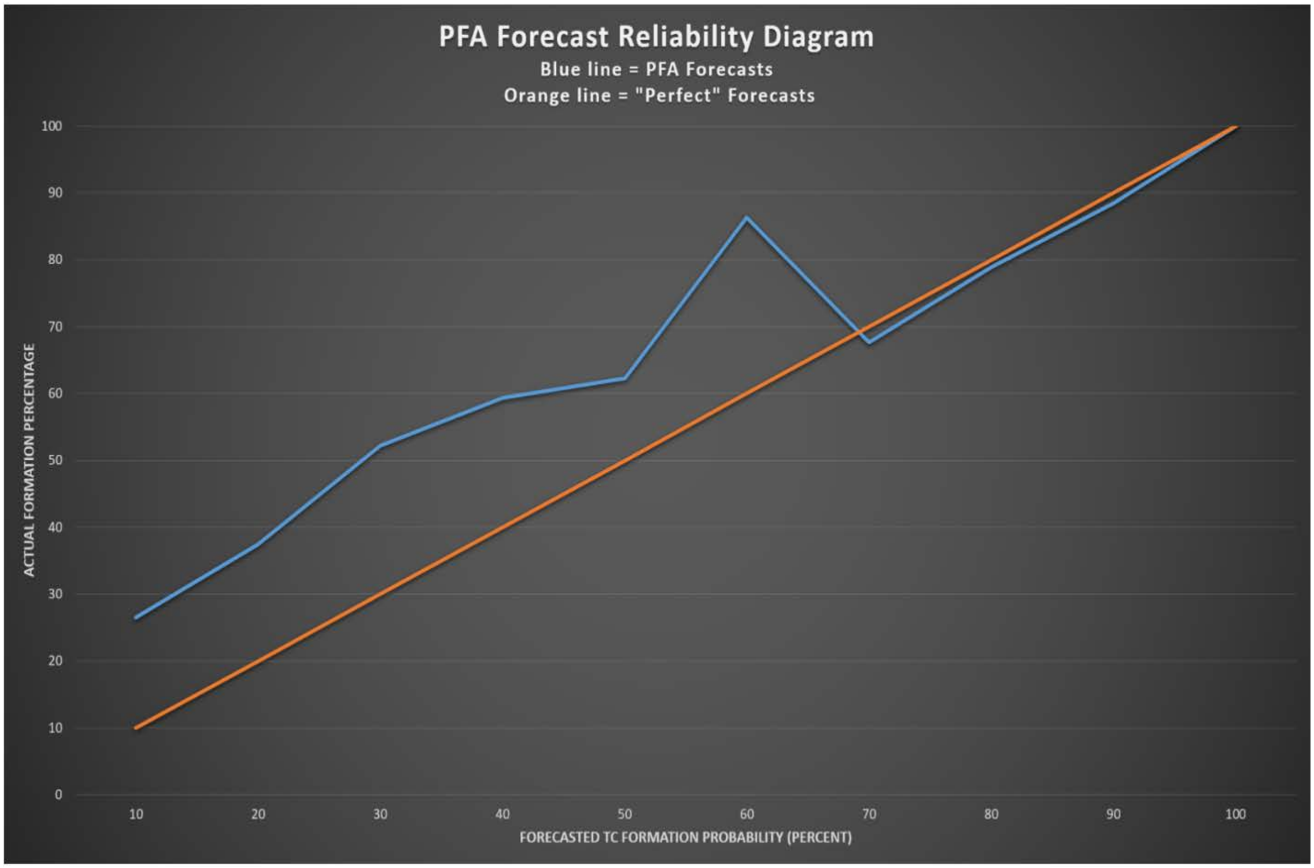
In addition to the CONW forecast models, JTWC evaluates TC track forecasts from HWRF, COAMPS-TC, ACCESS-TC, TWRF, CMC, ARPEGE, MEPS and the UK Met Office global ensemble (MOGREPS).

5. TC genesis timing and forecasts

a. Two-week TC formation outlooks

JTWC has generated and distributed Two-Week TC Formation Outlooks to its customers at least twice per day since 01 July 2018. These outlooks highlight geographic areas in the western North Pacific Ocean, Indian Ocean and South Pacific Ocean basins within which tropical cyclogenesis is favored by predicted environmental conditions and indicated by numerical models during the 14-day forecast period. Highlighted locations are referred to as a “Potential Formation Areas (PFAs).” Forecasters identify PFA candidate areas through careful inspection of deterministic and ensemble numerical forecast model output, status of the Madden-Julian Oscillation and climatology. They designate TC formation geographic areas, timelines and probabilities at their subjective discretion.

JTWC’s Technical Services Team conducted a statistical evaluation of forecasts issued between 01 July 2018, when JTWC began distributing the Two-Week TC Outlook as an operational product, and 10 April 2019. Results indicated that two-week outlooks significantly extend TC formation notification lead times beyond the two- to three-day mean lead time associated with traditional investigation (invest) areas. Additionally, development probabilities associated with individual PFA forecasts generally followed the “perfect forecast” trend – higher formation probabilities were assigned to developers and lower probabilities to non-developers. However, a small but systematic low bias was evident in forecasts for low to medium formation probabilities (up to 60%) (see Figure 5-10).



#Cases

10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
475	288	249	182	106	44	68	71	26	1

Figure 5-10. Reliability diagram for development probabilities associated with PFA forecasts issued between 01 July 2018 and 10 April 2019, along with the number of cases (forecasts) corresponding to each probability threshold (10% to 100%, 10% intervals).

Section 4 Other Scientific Collaborations

1. Joint Hurricane Testbed

JTWC is collaborating with principal investigators to test and evaluate two 2017-2019 JHT funded projects.

a. Improvements to operational statistical tropical cyclone intensity forecast models using wind structure and eye predictors, G. Chirokova (CSU/CIRA), John Kaplan (AOML/HRD)

This project addresses TC Intensity Change (Priority #1), via the following efforts:

- Completing a number of upgrades to SHIPS/LGEM intensity models, the multi-lead time probabilistic Rapid Intensification Index (MLTRII), and the global Rapid Intensification Index (GRII).

- Adding a tropical cyclone wind structure based predictor or combination of predictors.
- Adding a predictor or a group of predictors based on the probability of the eye existence and the code to calculate that probability.

b. Ensemble-Based Pre-Genesis Watches and Warnings for Atlantic and North Pacific Tropical Cyclones, Russ Elsberry (UC-CS)

This project addresses TC Genesis Timing and Forecast (Priority #5), via the following efforts:

- Providing GEFS and ECMWF ensemble-based guidance products for the genesis timing and locations (with uncertainty measures) along ensemble storm forecast tracks that will be useful for issuing pre-genesis watches and warnings in the North Atlantic and throughout the North Pacific basin.
- Providing seven-day intensity and intensity spread guidance products that are fully compatible with the GEFS and ECMWF ensemble-based genesis in timing and locations along the ensemble storm forecast track.

The project lead and participants began providing real-time, long-range intensity forecasts for pre-formation disturbances through the western North Pacific basin beginning in August 2019. A comprehensive analysis of these forecast data and their potential utility at JTWC is pending.

2. Hurricane Forecast Improvement Project (HFIP)

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

Section 5 Scientific and Technical Exchanges

Participating in national and international-level meetings and conducting technical exchanges with members of the scientific community are essential to the success of JTWC's strategic development efforts. A summary of JTWC's 2018 conference attendance and technical exchange meetings follows.

- 98th AMS Annual Meeting (Jan 2018)
- PACOM Joint Tropical Cyclone Forecasting Program Assembly (Feb 2018)
- 50th Annual ESCAP / WMO Typhoon Committee Meeting (Feb/Mar 2018)
- 72nd Interdepartmental Hurricane Conference (Mar 2018)
- 33rd AMS Conference on Hurricanes and Tropical Meteorology (Apr 2018)
- JTWC TC diagnostics development with Dr. Michael Fiorino – NOAA ESRL (Sep/Oct 2018)
- Hurricane Forecast Improvement Program (HFIP) Annual Meeting (Nov 2018)
- 9th International Workshop on Tropical Cyclones (IWTC) (Dec 2018)

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Chapter 6 Summary of Forecast Verification

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) track forecast, along and cross track errors were calculated for each verifying JTWC forecast (illustrated in Figure 6-1), included in this chapter. This section summarizes verification data for the 2018 season and contrasts it with annual verification statistics from previous years.

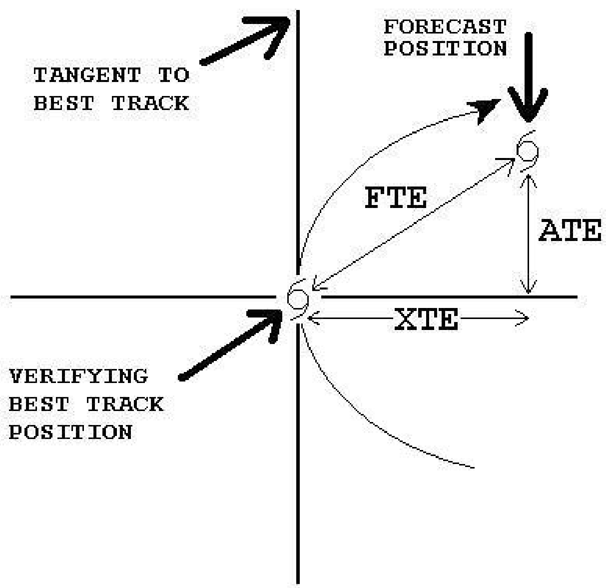

Figure 6-1. Definition of cross track error (XTE), along track error (ATE), and forecast track error (FTE). In this example, the forecast position is ahead of and to the right of the verifying best track position. Therefore, the XTE is positive (to the right of track) and the ATE is positive (ahead of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

Section 1 Annual Forecast Verification

TABLE 6-1
MEAN FORECAST ERRORS (NM) FOR WESTERN NORTH PACIFIC TROPICAL CYCLONES FROM 1959 - 2018

	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
Avg (1978-2018)	563	79	89	50	62	452	154	164	94	115	354	240	246	139	173	205	155	205	113	147	148	199	273	149	194
5yr Avg	490	41	46	28	31	389	70	78	48	52	295	107	117	69	81	219	153	165	97	113	157	198	223	133	150

(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.

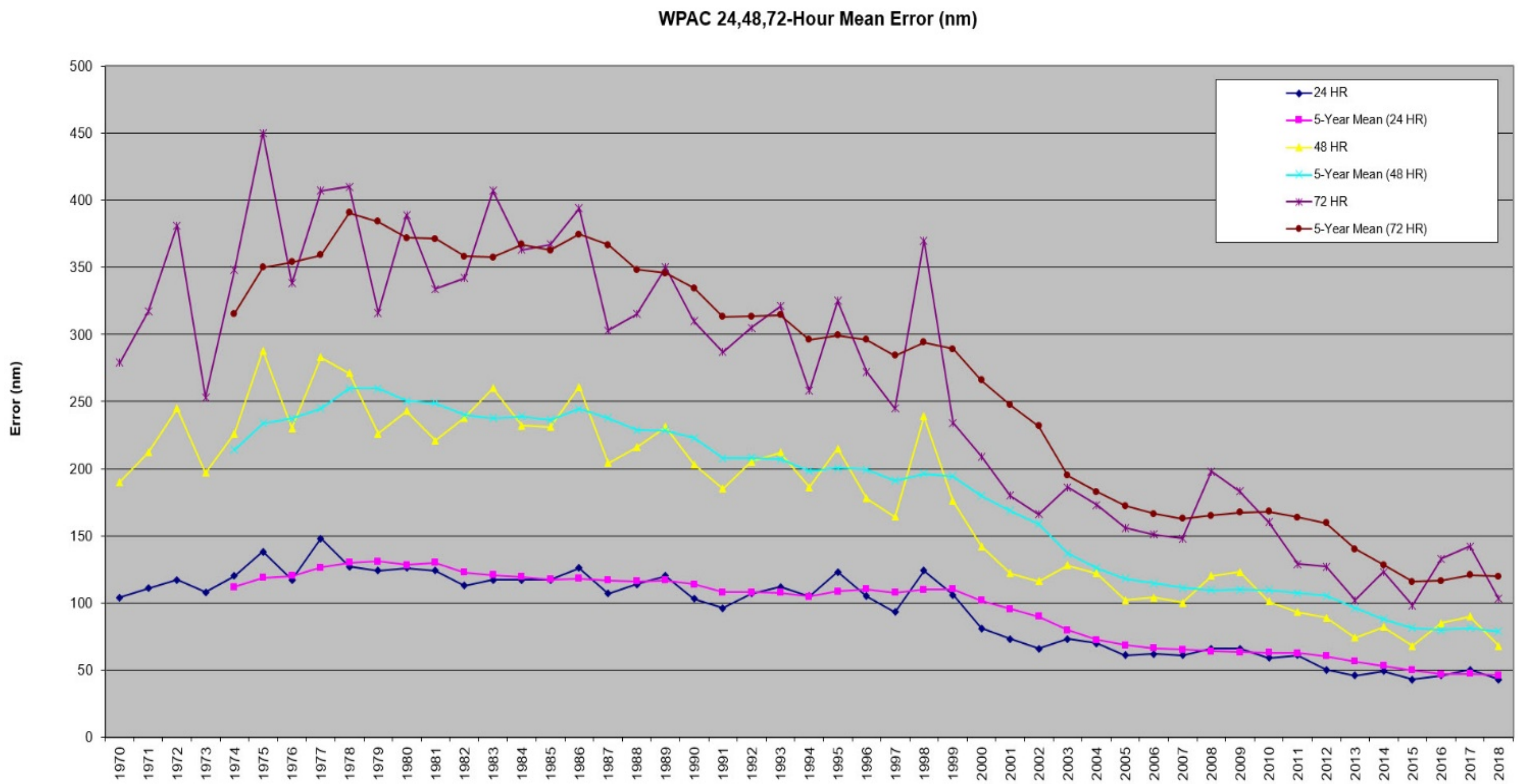

Figure 6-2. JTWC forecast errors and five year running mean errors for the western North Pacific at 24, 48 and 72 hours.

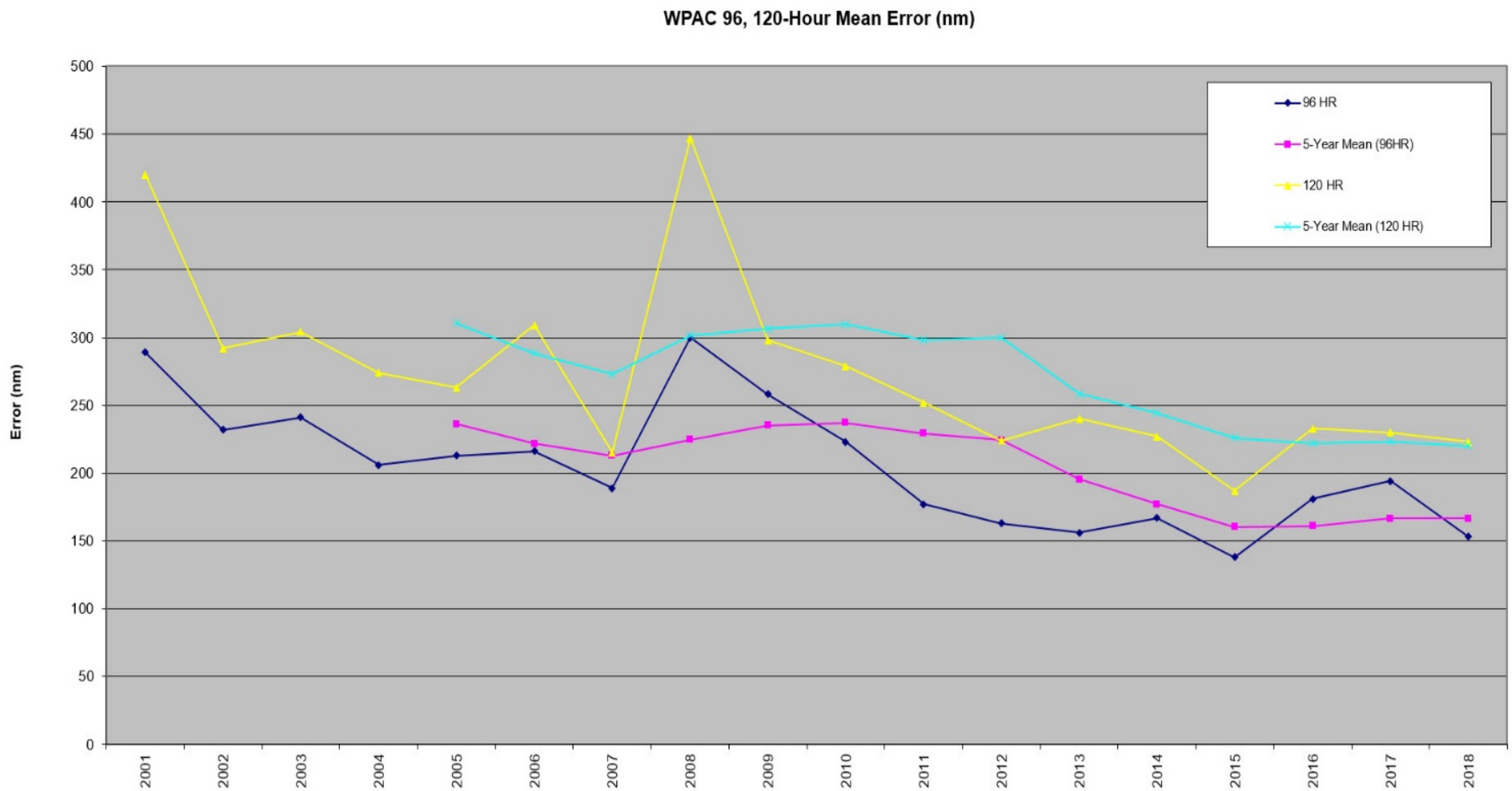

Figure 6-3. JTWC forecast errors and five year running mean errors for the western North Pacific at 96 and 120 hours.

Table 6-2
MEAN FORECAST TRACK ERRORS (NM) FOR NORTH INDIAN OCEAN
TROPICAL CYCLONES FROM 1985-2018

	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
Avg (1985-2018)	49	87	60	49	33	146	99	85	18	222	151	127	15	147	93	99	8	223	121	166
5Yr Avg	59	43	25	29	41	65	38	44	27	88	55	55	16	120	91	66	9	167	129	100

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

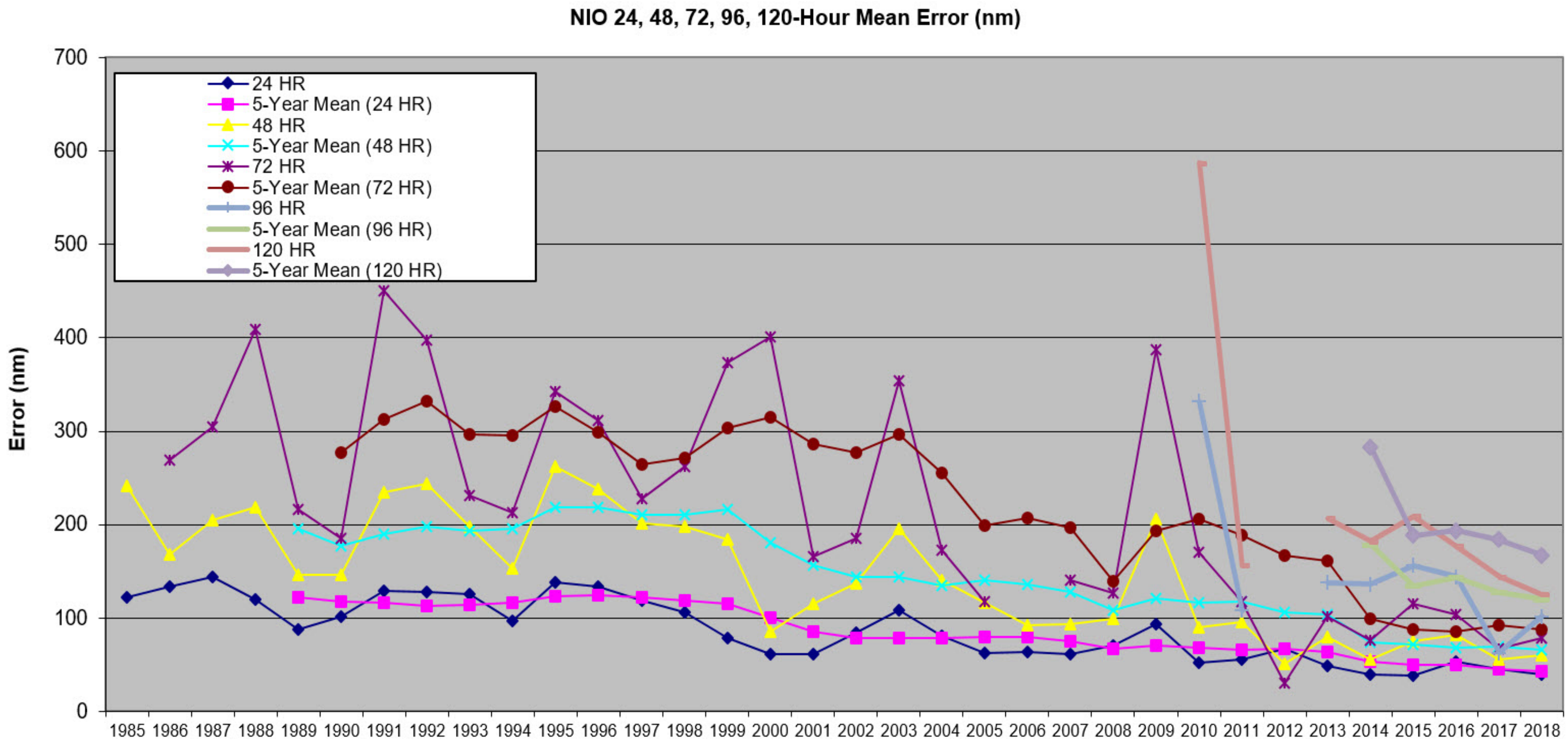

Figure 6-4. JTWC forecast errors and five year running mean errors for the north Indian Ocean at 24, 48, 72, 96 and 120 hours. (Note: No 96 HR, 120 HR data for 2012)

TABLE 6-3
MEAN FORECAST ERRORS (NM) FOR SOUTHERN HEMISPHERE TROPICAL CYCLONES 1985 - 2018

	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
Avg (1985-2018)	233	90	51	63	183	166	94	115	71	177	103	123	81	170	94	117	55	234	138	151
5Yr Avg	208	50	28	35	160	83	46	58	115	119	64	84	79	162	90	108	53	223	131	139

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

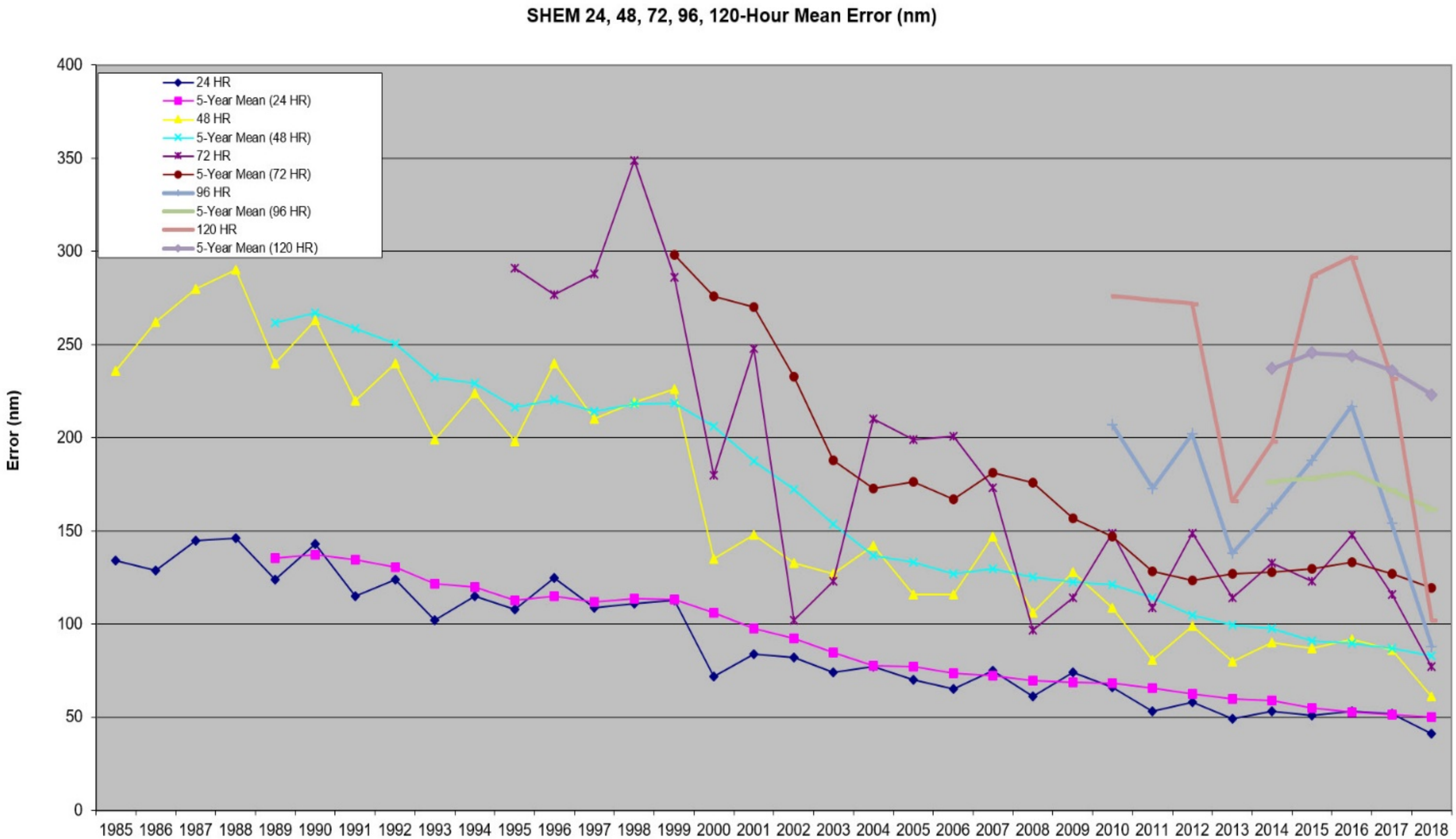

Figure 6-5. JTWC forecast errors for the Southern Hemisphere at 24, 48, 72, 96, and 120 hours.

TABLE 6-4							
MEAN FORECAST INTENSITY ERRORS FOR WESTERN NORTH PACIFIC TROPICAL CYCLONES 2000-2018							
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
AVG	7.3	11.2	14.2	16.6	19.9	22.2	23.9
5Yr Avg	7.6	10.8	13.3	15.5	17.8	19.3	21.8

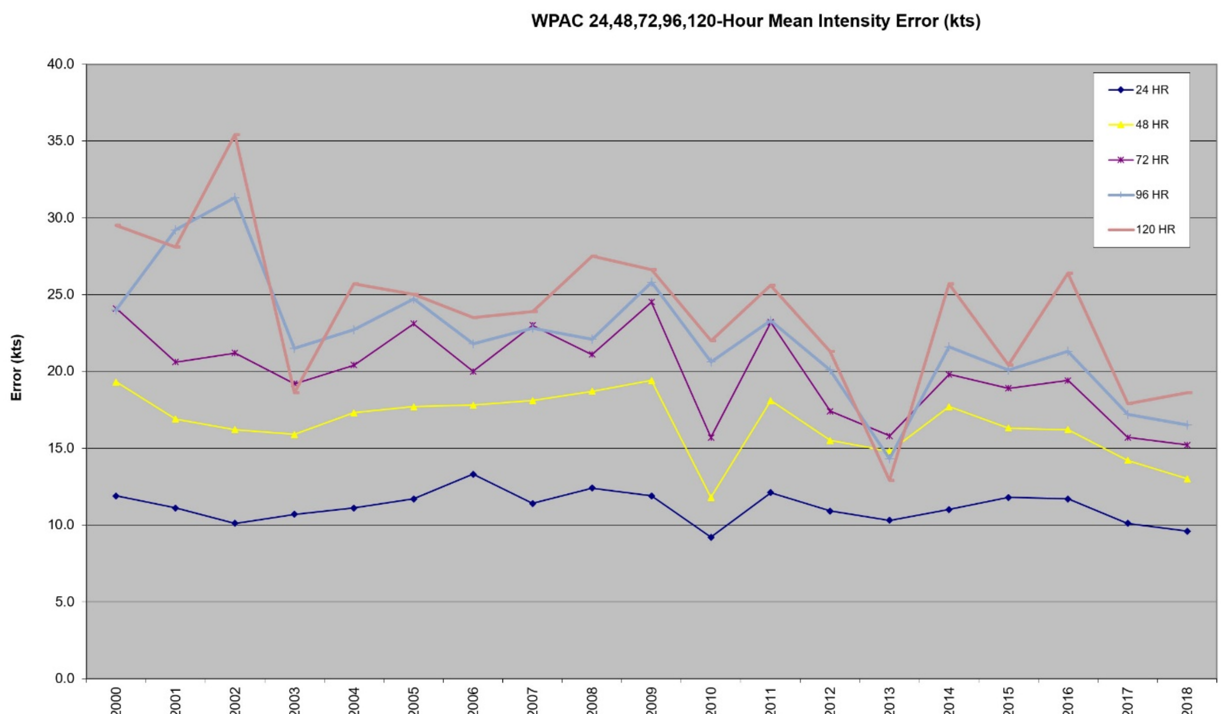

Figure 6-6. JTWC intensity forecast errors for the western North Pacific at 24, 48, 72, 96 and 120 hours.

TABLE 6-5							
MEAN FORECAST INTENSITY ERRORS FOR NORTHERN INDIAN OCEAN TROPICAL CYCLONES 2000-2018							
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
AVG	7.2	10.6	14.1	16.1	19.3	20.0	13.7
5Yr Avg	8.1	11.1	13.2	14.1	15.8	16.0	15.2

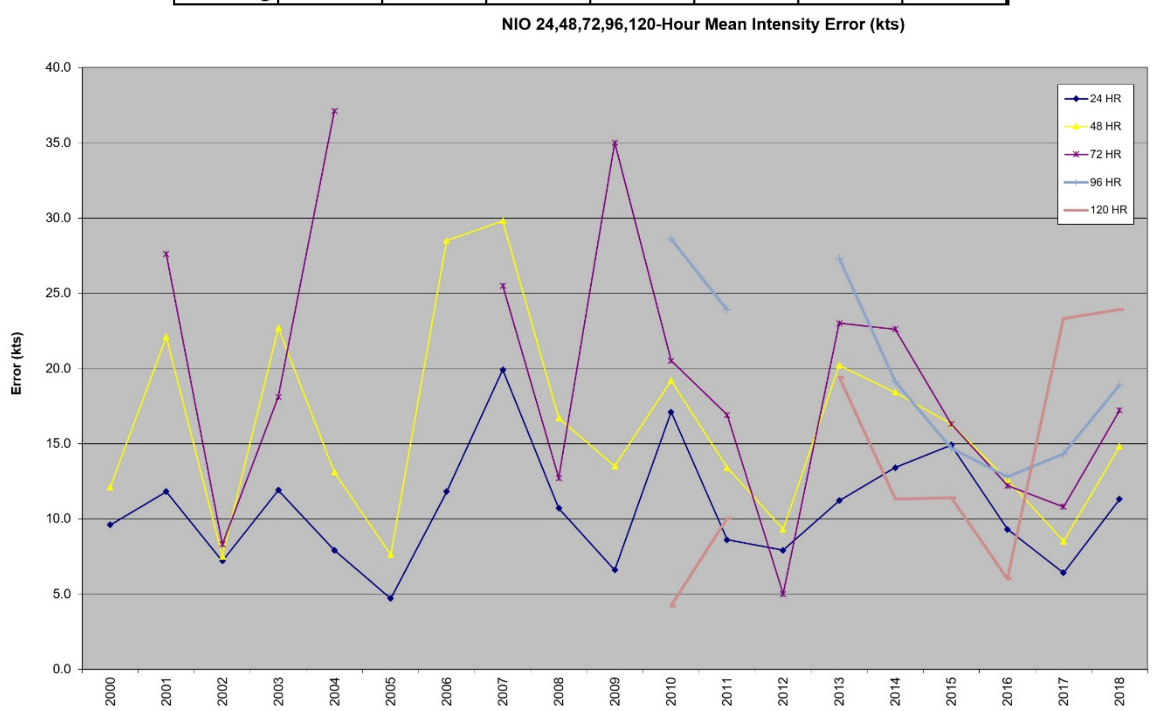

Figure 6-7. JTWC intensity forecast errors for the North Indian Ocean at 24, 48, 72, 96, and 120 hours. (Note: No 96 hr or 120 hr forecasts for NIO TCs verified in 2012)

TABLE 6-6							
MEAN FORECAST INTENSITY ERRORS FOR SOUTHERN HEMISPHERE TROPICAL CYCLONES 2000-2018							
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
AVG	7.9	12.5	16.4	19.1	21.0	20.0	20.9
5Yr Avg	8.6	13.0	15.9	17.5	18.9	20.4	20.5

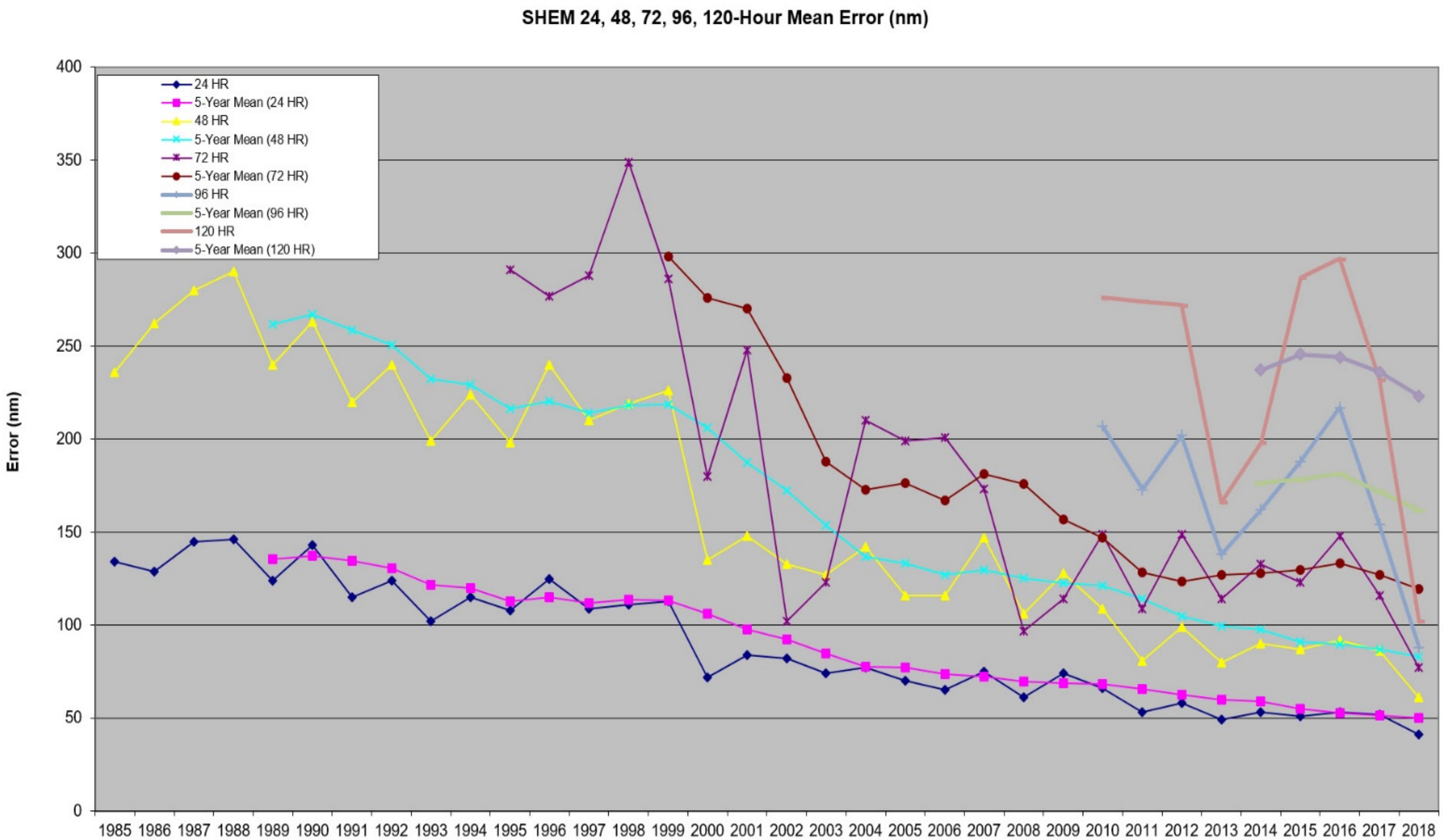

Figure 6-8. JTWC intensity forecast errors for the Southern Hemisphere at 24, 48, 72, 96 and 120 hours.