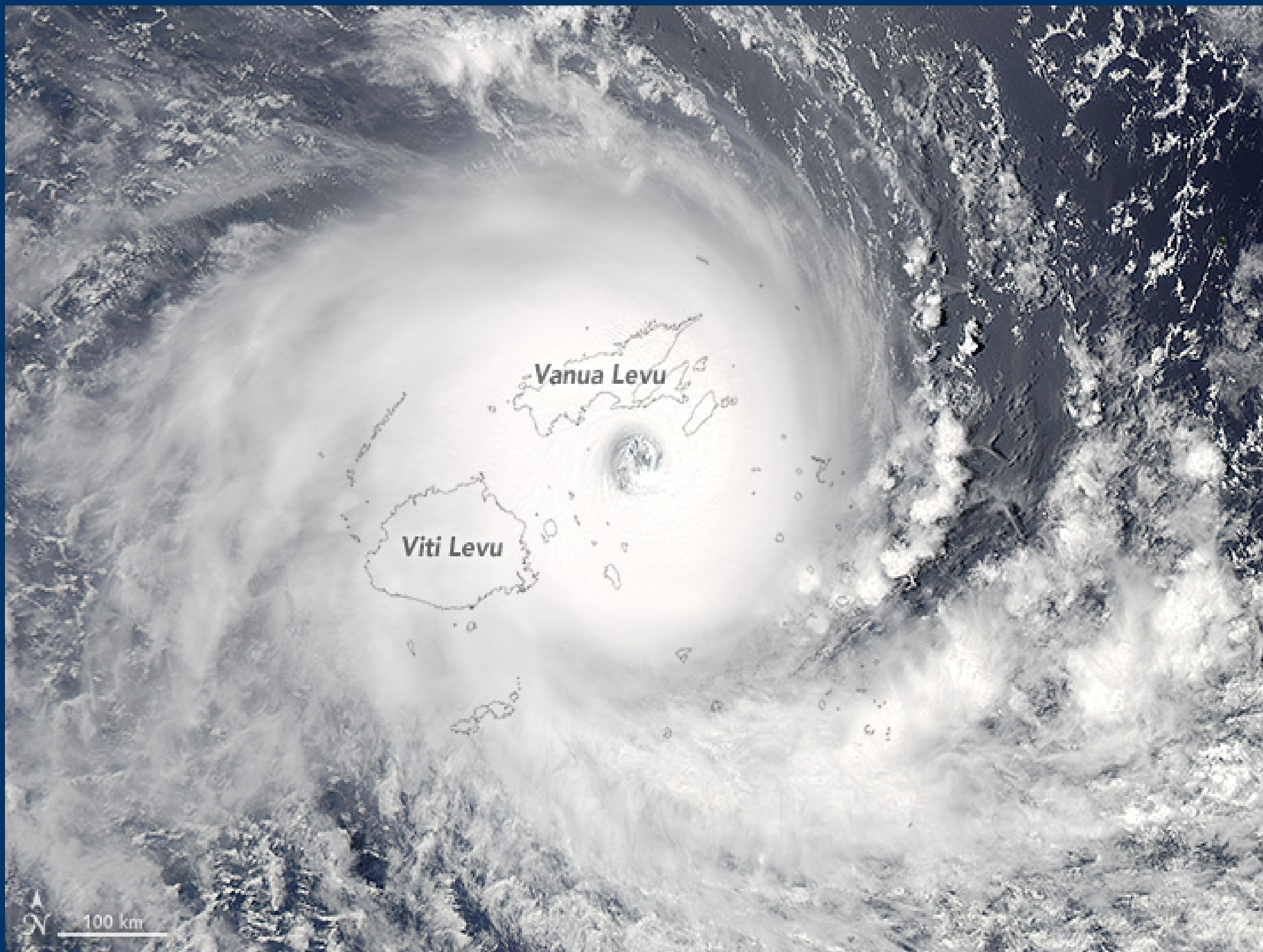
Annual Tropical Cyclone Report 2016



JILLENE M. BUSHNELL
Commander, United States Navy
Commanding Officer

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Director, Joint Typhoon Warning Center

Cover: Aqua MODIS imagery depicts Super Typhoon Winston as it moves over Fiji on February 20th 2016. Best track data shows maximum sustained winds of 155kts shortly after this image was taken. Image courtesy of NASA Earth Observatory

Executive Summary

The Annual Tropical Cyclone Report (ATCR) is prepared by the staff of the Joint Typhoon Warning Center (JTWC), a jointly manned United States Air Force (USAF)/Navy (USN) organization under the operational command of the Commanding Officer, Joint Typhoon Warning Center under the Commander, Naval Meteorology and Oceanography Command (CNMOC).

The JTWC was established on 1 May 1959 when the Joint Chiefs of Staff directed Commander-in-Chief, US Pacific Command (USCINCPAC) to provide a single tropical cyclone warning center for the Northwestern Pacific region. USCINCPAC delegated the tropical cyclone forecast and warning mission to Commander, Pacific Fleet (PACFLT). A subsequent USCINCPAC directive further tasked Commander, Pacific Air Force (PACAF) to provide for tropical cyclone (TC) reconnaissance mission for the JTWC. A recent USAF Weather re-organization reassigned all USAF operational weather personnel to the Air Combat Command (ACC); JTWC's USAF Satellite Analysts, administratively assigned to the 17th Operational Weather Squadron (OWS), are under ACC. USN personnel remain assigned operationally through CNMOC to Commander, U.S. Fleet Forces (USFF) and administratively to Commander, Navy Information Forces (NAVIFOR). Currently, JTWC operations are guided by USPACOM Instruction 0539.1, 2017 CNMOC/CTG 80.7 OPORD, and PACAF Instruction 15-101.

This edition of the ATCR documents the 2016 TC season and details operationally or meteorologically significant cyclones noted within the JTWC Area of Responsibility. Details are provided to describe either significant challenges and/or shortfalls in the TC warning system and to serve as a focal point for future research and development efforts. Also included are tropical cyclone reconnaissance statistics and a summary of tropical cyclone research or tactics, techniques and procedure (TTP) development that members of JTWC conducted.

The 2015 strong El Nino gave way to neutral conditions for 2016 which resulted in the formation region shift back westward in the Northwestern Pacific. While the total number of 30 storms was near normal, the season started very late with the first named storm not occurring until 3 July 2016. Impacted areas included Okinawa by two cyclones, Guam by one cyclone, South Korea by one cyclone, and mainland Japan by five cyclones.

The Southern Hemisphere activity was well below the long term average of 28, with only 20 cyclones. There was a notable minimum of cyclones that impacted Australia; one made landfall on the Northwestern coast and the other in the Gulf of Carpentaria. There was also a notable increase in activity in the South Pacific, with 10 cyclones that occurred east of 155 E. The North Indian Ocean experienced normal activity of five cyclones, with four in the Bay of Bengal and one in the Arabian Sea.

Microwave, Electro-optic, Infrared and scatterometry satellite data remained critical to the TC reconnaissance mission at JTWC. USAF Satellite Analysts exploited a wide variety of conventional and microwave satellite data to produce 8,274 position and intensity estimates (fixes), primarily using the USAF Mark IVB and the USN FMQ-17 satellite receiving and direct readout systems. Geo-located microwave satellite imagery overlays available via the Automated Tropical Cyclone Forecast (ATCF) system from Fleet Numerical Meteorology and Oceanography Center (FNMOC) and the Naval Research Laboratory, Monterey (NRLMRY) were also used by JTWC to make TC fixes. This year, EUMETSAT announced METEOSAT-7, positioned at longitude 57 East, would run out of fuel and would no longer provide imagery over the Indian Ocean starting in April 2017. It was decided that METEOSAT-8 would be moved to cover part of the area until the World Meteorological Organization could assign geostationary satellite coverage to another member. The selected position, longitude 41.5 East, left the eastern portion of the Indian Ocean and the Bay of Bengal on the edge of the satellite field of view, making position and intensity estimation much less accurate in these areas.

JTWC continued to collaborate with TC forecast support and research organizations such as the FNMOC, NRLMRY, Naval Post Graduate School, the Office of Naval Research, the 557 Weather Wing, and NOAA Line Offices for continued development of TC reconnaissance tools, numerical models and forecast aids. Additionally, the USN contracted with Raytheon to purchase the Advanced Weather Interactive Processing System at JTWC, FWC Norfolk and FWC SD.

The Technical Services Department remained the voice of JTWC to the research and development community. They continued to evaluate numerical modes, including the Global Air Land Weather Exploitation Model (GALWEM), and moved forward on their "pre-genesis" work, hoping to provide longer leadtime on TC genesis as well as providing the timing of genesis and general movement. The command also reconstituted the Requirements and Planning Department to ensure continuity of resources from both the Navy and Air Force.

Behind all these efforts are the dedicated team of men and women, military and civilian at JTWC. Special thanks to the entire JTWC Information Services Department for their continued outstanding IT support and the administrative and Training Departments who worked tirelessly to ensure JTWC had the necessary resources and professional development enabling mission accomplishment during extremely volatile financial times.

A Special thanks also to: FNMOC for their operational data and modeling support; the NRLMRY and ONR for its dedicated TC research; the National Oceanic and Atmospheric Administration National Environmental Satellite, Data, and Information Service for satellite reconnaissance support; Dr. John Knaff, Mr. Richard Bankert, Dr. Mark DeMaria, and Mr. Chris Velden for their continuing efforts to exploit remote sensing technologies in new and innovative ways; Mr. Charles R. "Buck" Sampson and Mr. Mike Frost for their outstanding support and continued development of the ATCF system.

Finally, we wish a fond farewell to Mrs. Kerri Kanbara and Ms. Kehau Koa. Thank you both for your outstanding support to the JTWC mission. We hope you enjoy a long and happy life in retirement.

JTWC Personnel 2016

<u>Administration Department</u>
CDR Thomas Keefer, *Executive Officer*
AGCS Thomas Brickler, *Senior Enlisted Advisor*
Ms. Kerri Kanbara, *Administrative Officer*
Mr. Roberto Macias, *Administrative Officer*
Mrs. Sharee Evans *Administrative Assistant*

<u>Budget/Logistics Department</u>
Ms. Kehau Koa, *Budget Analyst*
LSC Arcyria Lockley, *Logistics and Supply*

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Mr. Angelo Alvarez, *System Administrator*
Mr. Andrew Rhoades, *Information Assurance Officer*
Mr. Albert Leyendecker, *System Administrator*
Mr. Brandon Brevard, *System Administrator*
IT1 Jeffery Gross, *Information Technology*
IT2 Isaac Wilson, *Information Technology*
IT3 Sha'nae Wilson, *Information Technology*

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LT Thai Phung, *Operations Officer*
Mr. Brian Strahl, *Senior Scientist*
LT Chris Chitwood, *Command Duty Officer*
LT Denie Kiger, *Command Duty Officer*
LT Amy Price, *Command Duty Officer*
LT Vincent Chamberlain, *Typhoon Duty Officer*
LT Christopher Machado, *Typhoon Duty Officer*
Mr. Stephen Barlow, *Typhoon Duty Officer*
Mr. Richard Ballucanag, *Typhoon Duty Officer*
Mr. Aaron Lana, *Typhoon Duty Officer*
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ENS Sarah Beemiller, *Command Duty Officer*
AGC Christopher McKinstry, *Command Duty Officer*
AG1 Nadine McBee, *Command Duty Officer*
AG1 Cecil Jordan, *Command Duty Officer*
AG1 Michael Schmidt, *Command Duty Officer*
AG2 Jack Tracey, *Geophysical Technician*
AG2 Jake Wilson, *Geophysical Technician*
AG2 Janie Sherrock, *Geophysical Technician*
AG2 Carol Fisher, *Geophysical Technician*
AG3 Christopher Hoole, *Geophysical Technician*
AGAN Dakota Bennett, *Geophysical Technician*
AGAA Frandys Ferreras, *Geophysical Technician*
AGAA Jeremiah Meeker, *Geophysical Technician*
AGAR Cole Bedgood, *Geophysical Technician*

<u>Technical Services</u>
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Mr. James Darlow, *Technical Services*

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MSgt Ricky Frye, *NCOIC Satellite Operations*
TSgt Matthew Drew, *Analyst/NCOIC Satellite Operations*
SSgt Donald Chappotin*, Satellite Analyst*
Mrs. Brittany Bermea, *Satellite Analyst*
SSgt Kyle Hart, *Satellite Analyst*
SrA Francisco Martinez, *Satellite Analyst*
SrA Cheyenne Lembke, *Satellite Analyst*
Mr. Dana Uehara, *Satellite Analyst*

Table of Contents

Chapter 1 Western North Pacific Ocean Tropical Cyclones

Section 1 Informational Tables

Table 1-1 is a summary of TC activity in the western North Pacific Ocean during the 2016 season. JTWC issued warnings on 29 of 30 tropical cyclones. Table 1-2 shows the monthly distribution of TC activity summarized for 1959 - 2016 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. The annual number of TC's of tropical storm strength or higher appears in Figure 1-1, while the number of TC's of super typhoon intensity appears in Figure 1-2. Figure 1-3 illustrates a monthly average number of cyclones based on intensity categories. Figures 1-4 and 1-5 depict the 2016 western North Pacific Ocean TC tracks and intensities.

Table 1-1

WESTERN NORTH PACIFIC SIGNIFICANT TROPICAL CYCLONES FOR 2016 (01 JAN 2016 - 31 DEC 2016)

TC	NAME*	PERIOD**		WARNINGS ISSUED	EST MAX SFC WINDS KTS
01W	ONE	26 May / 1200Z	27 May / 0600Z	N/A	30
02W	NEPARTAK	03 Jul / 0000Z	09 Jul / 0600Z	26	155
03W	THREE	17 Jul / 0600Z	17 Jul / 1200Z	2	25
04W	LUPIT	23 Jul / 1200Z	24 Jul / 0600Z	4	45
05W	MIRINAE	25 Jul / 1200Z	27 Jul / 1200Z	9	65*
06W	NIDA	29 Jul / 1200Z	02 Aug / 0000Z	15	80
07W	OMAIS	04 Aug / 1200Z	08 Aug / 1800Z	18	65
08W	CONSON	08 Aug / 0600Z	14 Aug / 1200Z	26	55
09W	CHANTHU	13 Aug / 0600Z	17 Aug / 0000Z	16	60
10W	MINDULLE	17 Aug / 1800Z	22 Aug / 1800Z	21	65
11W	DIANMU	18 Aug / 0000Z	19 Aug / 0600Z	6	45
12W	LIONROCK	18 Aug / 0000Z	30 Aug / 1200Z	52	120
13W	KOMPASU	19 Aug / 1800Z	21 Aug / 0000Z	6	35
14W	FOURTEEN	23 Aug / 0600Z	24 Aug / 1200Z	6	40
15W	NAMTHEUN	31 Aug / 1200Z	5 Sep / 0000Z	19	100
16W	MERANTI	08 Sep / 1800Z	14 Sep / 1800Z	25	170
17W	SEVENTEEN	11 Sep / 0000Z	11 Sep / 1800Z	4	35
18W	MALAKAS	11 Sep / 1800Z	20 Sep / 1800Z	37	115
19W	RAI	12 Sep / 0000Z	12 Sep / 1800Z	4	30
20W	MEGI	23 Sep / 0000Z	27 Sep / 1800Z	20	120
21W	CHABA	28 Sep / 0000Z	05 Oct / 0600Z	30	150
22W	AERE	05 Oct / 1200Z	10 Oct / 0000Z	19	55
23W	SONGDA	08 Oct / 0600Z	12 Oct / 0600Z	17	130
24W	SARIKA	12 Oct / 1200Z	19 Oct / 0600Z	28	115
25W	HAIMA	14 Oct / 1800Z	21 Oct / 0600Z	27	145
26W	MEARI	02 Nov / 1800Z	07 Nov / 0600Z	19	90
27W	MA-ON	09 Nov / 1800Z	12 Nov / 0600Z	11	35
28W	TWENTYEIGHT	11 Nov / 0000Z	12 Nov / 0600Z	6	25
29W	TOKAGE	24 Nov / 1200Z	28 Nov / 0600Z	16	80
30W	NOCK-TEN	21 Dec / 0600Z	28 Dec / 0000Z	28	140

* 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

Note: JTWC issued a TCFA but did not issue warnings on 01W. However, it was determined during post analysis that it met warning criteria and, therefore, was added after the fact.

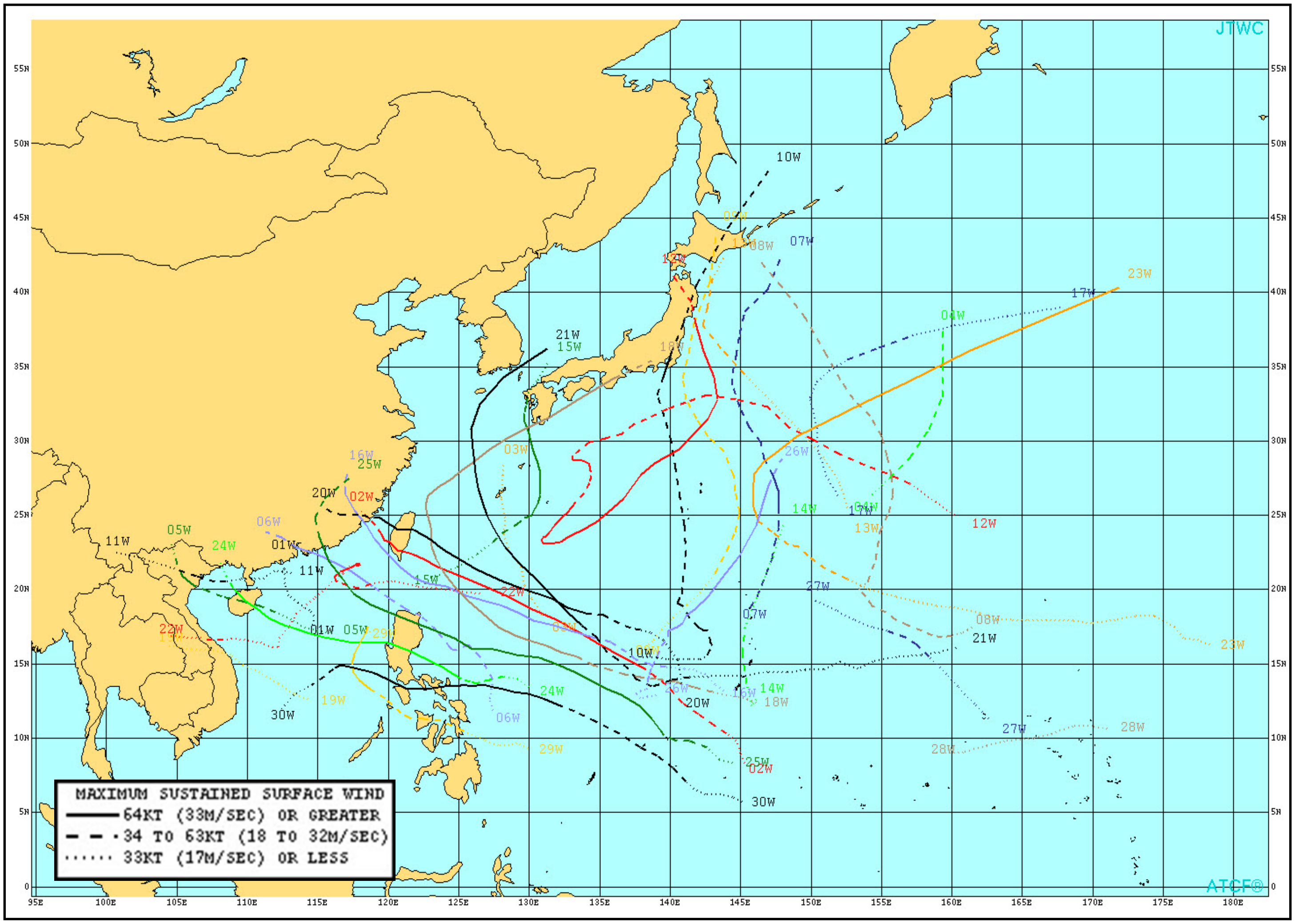

Figure 1-1. 2016 Western North Pacific Tropical Cyclones.

Table 1-2
DISTRIBUTION OF WESTERN NORTH PACIFIC TROPICAL CYCLONES
FOR 1959 - 2016

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

YEAR	MAY				JUN				JUL				AUG			
1959	0	0	0	0	1	0	0	1	3	1	1	1	8	5	1	2
1960	1	0	1	0	3	2	1	0	3	2	1	0	9	8	1	0
1961	4	2	1	1	6	1	1	4	5	3	2	0	7	3	1	3
1962	3	2	0	1	0	0	0	0	8	5	1	2	8	7	0	1
1963	0	0	0	0	4	3	1	0	5	3	1	1	4	3	0	1
1964	3	2	0	1	2	2	0	0	8	6	1	1	8	3	5	0
1965	2	1	0	1	4	3	1	0	6	4	1	1	7	3	2	2
1966	2	2	0	0	1	1	0	0	4	3	1	0	9	5	3	1
1967	1	0	1	0	1	1	0	0	8	3	3	2	10	3	4	3
1968	0	0	0	0	4	2	0	2	3	1	2	0	8	3	4	1
1969	0	0	0	0	0	0	0	0	3	2	1	0	3	2	1	0
1970	0	0	0	0	2	1	1	0	3	0	2	1	7	4	2	1
1971	5	2	3	0	2	2	0	0	8	6	2	0	5	3	1	1
1972	0	0	0	0	4	2	2	0	5	4	1	0	5	3	2	0
1973	0	0	0	0	0	0	0	0	7	4	3	0	6	2	3	1
1974	1	1	0	0	4	1	2	1	5	2	3	0	7	2	3	2
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1976	2	2	0	0	2	2	0	0	4	2	2	0	4	1	3	0
1977	1	0	0	1	1	0	1	0	4	3	0	1	2	0	2	0
1978	0	0	0	0	3	0	3	0	4	3	1	0	8	3	4	1
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1980	4	2	2	0	1	0	1	0	5	3	1	1	3	2	0	1
1981	1	0	1	0	2	2	0	0	5	2	3	0	8	2	5	1
1982	1	1	0	0	3	1	2	0	4	2	2	0	5	5	0	0
1983	0	0	0	0	1	0	1	0	3	3	0	0	6	2	3	1
1984	0	0	0	0	2	0	2	0	5	4	1	0	7	2	3	2
1985	1	1	0	0	3	2	0	1	1	1	0	0	7	5	2	0
1986	2	1	1	0	2	1	1	0	2	2	0	0	5	4	1	0
1987	0	0	0	0	2	1	1	0	4	4	0	0	4	3	1	0
1988	1	1	0	0	3	1	1	1	2	1	1	0	5	2	3	0
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1992	0	0	0	0	3	2	1	0	4	2	2	0	8	4	4	0
1993	1	0	1	0	2	1	0	1	5	3	2	0	8	6	1	1
1994	2	1	0	1	2	0	2	0	9	3	4	2	9	6	3	0
1995	1	0	1	0	2	0	2	0	3	2	1	0	7	4	2	1
1996	2	1	1	0	0	0	0	0	7	6	1	0	10	4	3	3
1997	3	1	2	0	3	3	0	0	4	3	1	0	8	6	1	1
1998	0	0	0	0	0	0	0	0	3	0	1	2	3	2	1	0
1999	0	0	0	0	1	1	0	0	5	1	1	3	9	4	2	3
2000	4	1	1	2	0	0	0	0	8	2	3	3	9	4	3	2
2001	1	0	1	0	2	2	0	0	6	4	1	1	7	3	3	1
2002	2	1	0	1	3	3	0	0	6	3	2	1	8	4	3	1
2003	3	1	1	1	2	1	1	0	2	2	0	0	5	4	1	0
2004	3	2	1	0	5	5	0	0	2	1	1	0	9	6	2	1
2005	0	0	0	0	1	1	0	0	4	1	3	0	6	6	0	0
2006	1	1	0	0	1	0	1	0	3	2	1	0	8	3	4	1
2007	1	1	0	0	0	0	0	0	3	2	1	0	6	3	2	1
2008	4	3	1	0	1	1	0	0	2	2	0	0	5	1	4	0
2009	2	2	0	0	2	1	1	0	3	1	1	1	5	3	2	0
2010	0	0	0	0	0	0	0	0	2	2	0	0	5	2	3	0
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2012	1	1	0	0	4	2	2	0	4	3	1	0	5	4	1	0
2013	0	0	0	0	4	1	3	0	3	1	2	0	5	2	2	1
2014	0	0	0	0	1	0	1	0	4	3	1	0	2	1	1	0
2015	2	2	0	0	1	0	1	0	5	4	1	0	4	2	1	1
2016	1	0	0	1	0	0	0	0	5	3	1	1	9	4	5	0

YEAR	SEP				OCT				NOV				DEC				TOTALS	Total ≥64kt	Total 34-63kt	Total ≤33kt
1959	9	4	2	3	3	2	1	0	2	2	0	0	2	2	0	0	31	17	7	7
1960	5	0	4	1	4	4	0	0	1	1	0	0	1	1	0	0	30	19	8	3
1961	6	5	1	0	7	3	2	2	2	1	0	1	1	1	0	0	42	20	11	11
1962	7	3	1	3	5	3	1	1	4	3	0	1	2	0	2	0	39	24	6	9
1963	4	2	2	0	6	5	1	0	0	0	0	0	3	2	1	0	28	19	6	3
1964	8	5	2	1	7	3	3	1	6	4	2	0	2	1	0	1	44	26	13	5
1965	9	5	3	1	3	2	0	1	2	1	1	0	1	0	1	0	40	21	13	6
1966	10	5	3	2	4	1	1	2	5	1	2	2	2	1	0	1	38	20	10	8
1967	8	5	3	0	4	2	1	1	4	4	0	0	1	0	1	0	41	20	15	6
1968	4	4	0	0	6	5	1	0	4	4	0	0	0	0	0	0	31	20	7	4
1969	6	2	0	4	5	4	1	0	2	1	1	0	1	0	1	0	23	13	6	4
1970	4	2	2	0	6	3	2	1	4	1	3	0	0	0	0	0	27	12	12	3
1971	7	5	1	1	4	3	1	0	2	1	1	0	0	0	0	0	37	24	11	2
1972	6	4	1	1	5	4	1	0	2	2	0	0	3	2	1	0	32	22	8	2
1973	3	2	0	1	4	4	0	0	3	0	3	0	0	0	0	0	23	12	9	2
1974	5	3	2	0	4	4	0	0	4	2	2	0	2	0	2	0	35	15	17	3
1975	5	4	1	0	6	3	2	1	3	2	1	0	2	0	2	0	25	14	8	3
1976	5	4	1	0	0	0	0	0	2	1	1	0	2	0	2	0	25	14	11	10
1977	5	2	3	0	4	3	1	0	2	2	0	0	1	1	0	0	21	11	8	2
1978	4	3	1	0	7	4	1	2	4	1	2	1	0	0	0	0	32	15	13	4
1979	6	3	3	0	3	2	1	0	2	1	1	0	3	1	1	1	28	14	9	5
1980	7	5	1	1	4	2	2	0	1	1	0	0	1	0	1	0	28	15	9	4
1981	4	4	0	0	2	1	1	0	3	2	1	0	2	2	0	0	29	16	12	1
1982	6	3	2	1	4	3	0	1	1	1	0	0	1	1	0	0	28	19	7	2
1983	3	1	1	1	5	3	2	0	5	3	2	0	2	0	2	0	25	12	11	2
1984	4	1	3	0	8	5	4	1	3	3	0	0	1	1	0	0	30	16	13	3
1985	5	3	2	0	5	4	1	0	1	0	1	0	2	1	1	0	27	17	9	1
1986	2	2	0	0	5	3	2	0	4	2	2	0	3	2	1	0	27	19	8	0
1987	7	5	1	1	2	2	0	0	3	1	2	0	1	1	0	0	25	18	6	1
1988	8	2	6	0	4	4	0	0	2	2	0	0	1	0	1	0	27	14	12	1
1989	4	2	2	0	6	6	0	0	3	3	0	0	2	1	0	1	35	21	10	4
1990	5	4	1	0	5	2	3	0	4	3	1	0	1	1	0	0	32	21	10	1
1991	6	4	2	0	3	3	0	0	6	3	3	0	0	0	0	0	32	20	10	2
1992	5	4	1	0	6	5	1	0	5	3	1	1	0	0	0	0	33	21	11	11
1993	5	4	1	0	6	3	2	1	4	1	1	2	3	3	0	0	38	21	9	8
1994	8	4	4	0	7	5	1	1	0	0	0	0	2	1	1	0	41	21	15	5
1995	7	4	1	2	8	5	1	2	2	0	2	0	3	0	1	2	34	15	11	8
1996	7	6	1	0	5	2	1	2	6	1	3	2	3	1	1	1	44	21	12	11
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2003	3	3	0	0	6	2	1	3	3	3	0	0	1	0	1	0	27	17	6	4
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2006	5	3	0	2	4	2	1	1	2	2	0	0	2	1	0	1	27	14	8	5
2007	5	2	2	1	5	3	2	0	6	3	1	2	0	0	0	0	27	15	8	4
2008	6	3	3	0	3	0	3	0	3	0	3	0	1	1	0	0	27	12	15	0
2009	7	4	1	2	4	3	1	0	4	1	1	2	1	0	0	1	28	15	7	6
2010	4	3	1	0	4	2	2	0	1	0	0	1	1	0	0	1	19	9	6	4
2011	7	2	5	0	1	0	0	1	1	0	0	1	3	0	1	2	27	7	11	9
2012	3	2	1	0	5	2	3	0	2	1	0	1	1	0	1	0	27	15	10	2
2013	8	4	3	1	7	6	0	1	3	1	1	1	1	0	0	1	33	15	12	6
2014	5	2	2	1	1	1	0	0	3	2	1	0	2	1	0	1	23	12	8	3
2015	4	2	2	0	5	4	1	0	1	1	0	0	2	1	0	1	29	19	8	2
2016	6	4	1	1	4	3	1	0	4	2	1	1	1	1	0	0	30	17	9	4

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 - 2016)													
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN	0.2	0.1	0.2	0.4	0.7	1.0	2.5	3.4	3.2	2.9	1.5	0.7	16.9
CASES	12	5	12	24	43	59	147	197	188	171	87	38	983
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 - 2016)													
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN	0.5	0.2	0.4	0.6	1.1	1.7	3.9	5.5	4.9	4.0	2.4	1.2	26.6
CASES	28	14	26	37	66	100	225	319	285	232	142	70	1544

TABLE 1-4 TROPICAL CYCLONE FORMATION ALERTS FOR THE WESTERN NORTH PACIFIC OCEAN 1976 - 2016					
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%
MEAN	35	28	30	20%	93%
CASES	1421	1131	1211		
* Percentage of initial TCFAs not followed by warnings.					

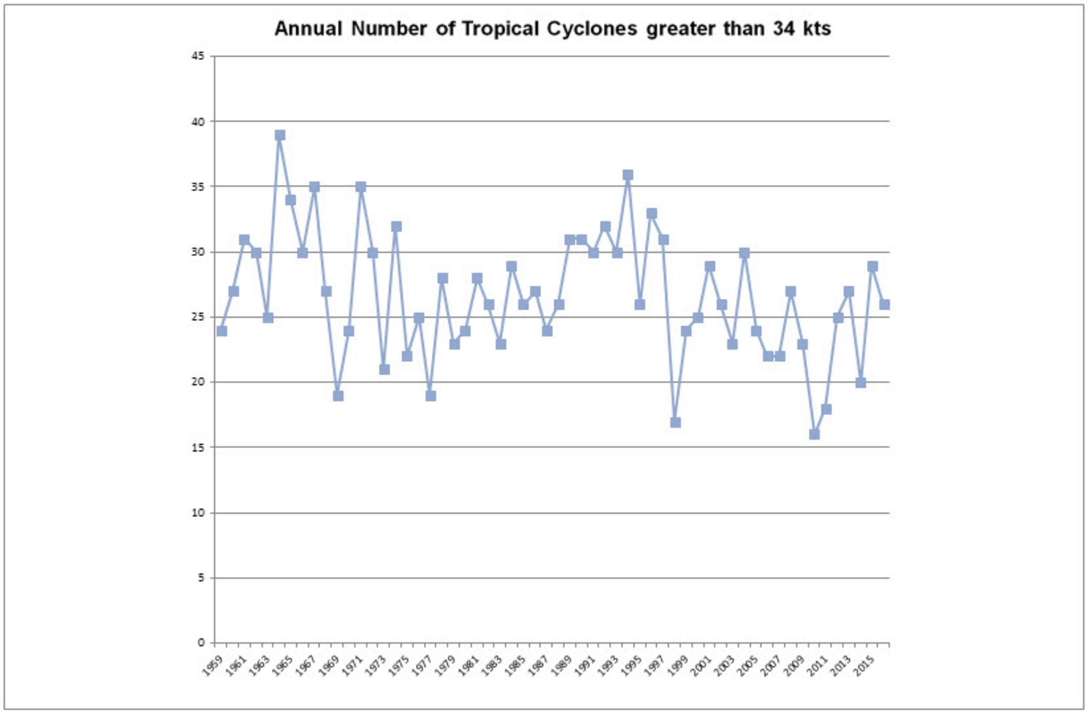


Figure 1-2. Annual number of western North Pacific TCs greater than 34 knots intensity.

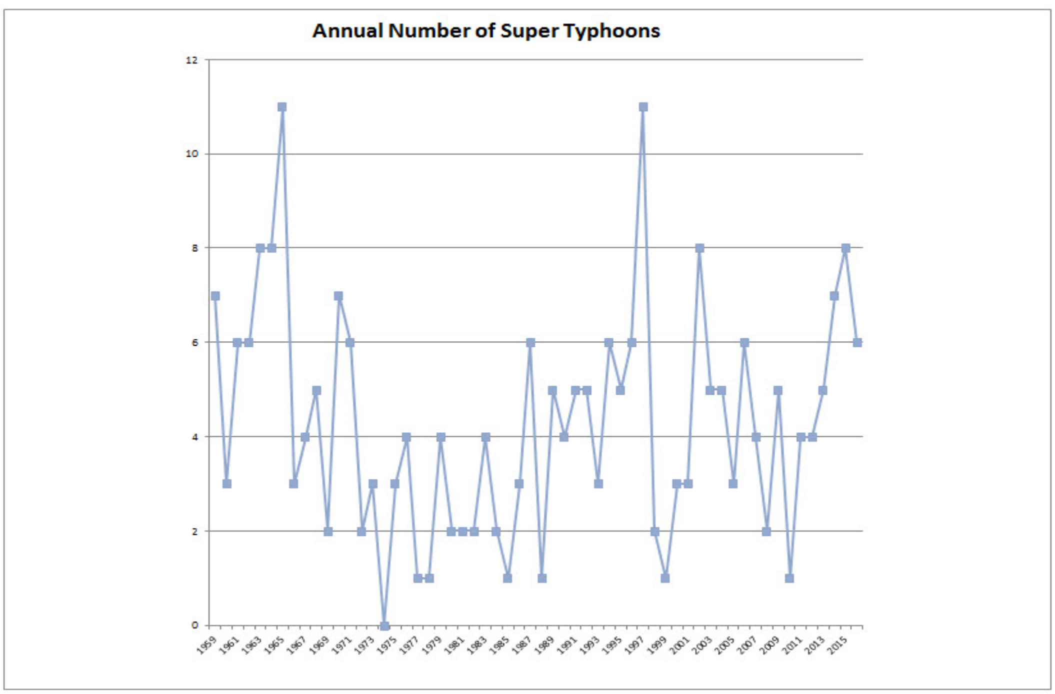
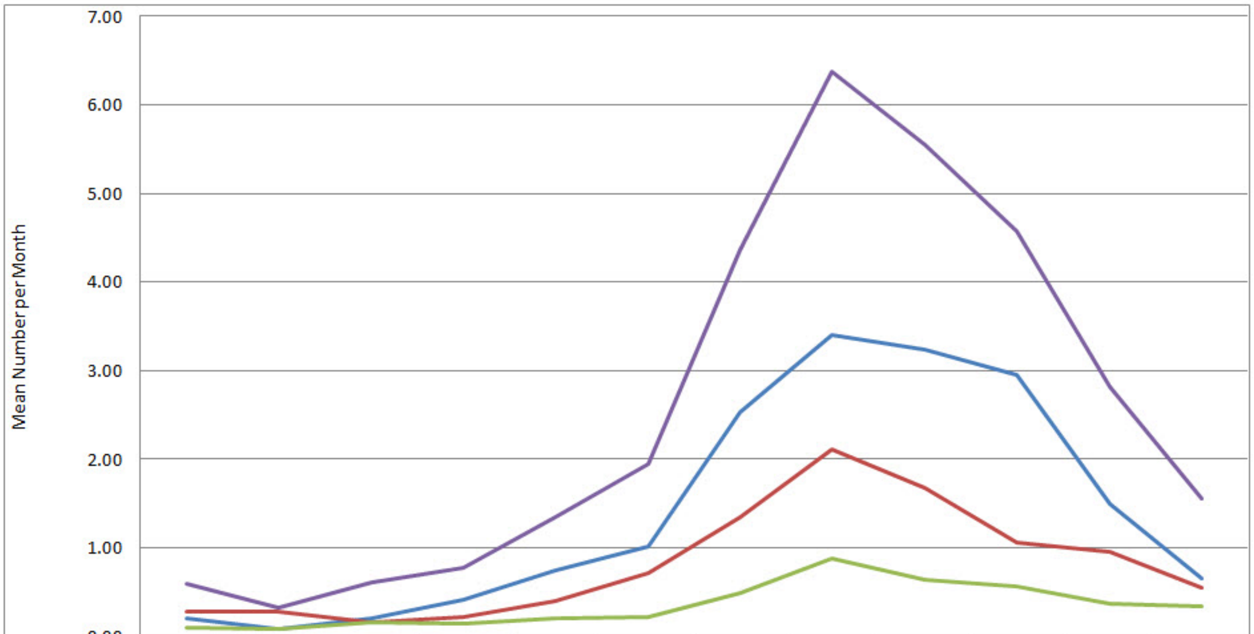


Figure 1-3. Annual number of western North Pacific TCs greater than 129 knots intensity.



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
TY AVG	0.21	0.09	0.21	0.41	0.74	1.02	2.53	3.40	3.24	2.95	1.50	0.66
TS AVG	0.28	0.28	0.16	0.22	0.40	0.71	1.34	2.10	1.67	1.05	0.95	0.55
TD AVG	0.10	0.09	0.16	0.14	0.21	0.22	0.48	0.88	0.64	0.57	0.36	0.34
All AVG	0.59	0.33	0.60	0.78	1.34	1.95	4.36	6.38	5.55	4.57	2.81	1.55

Figure 1-4. Average number of western North Pacific TCs (all intensities) by month 1959-2016.

Section 2 Cyclone Summaries

This section presents a synopsis of each cyclone that occurred during 2016 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.

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

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

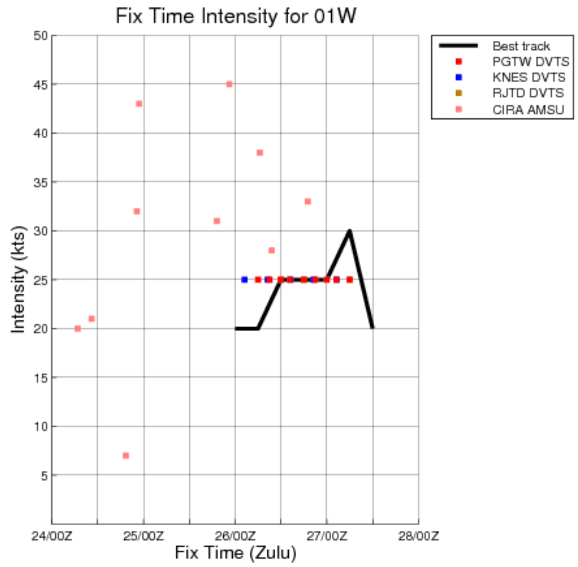
Initial and final JTWC warning dates are also presented with the number of warnings issued by JTWC. Landfall over major landmasses with approximate locations is presented as well.

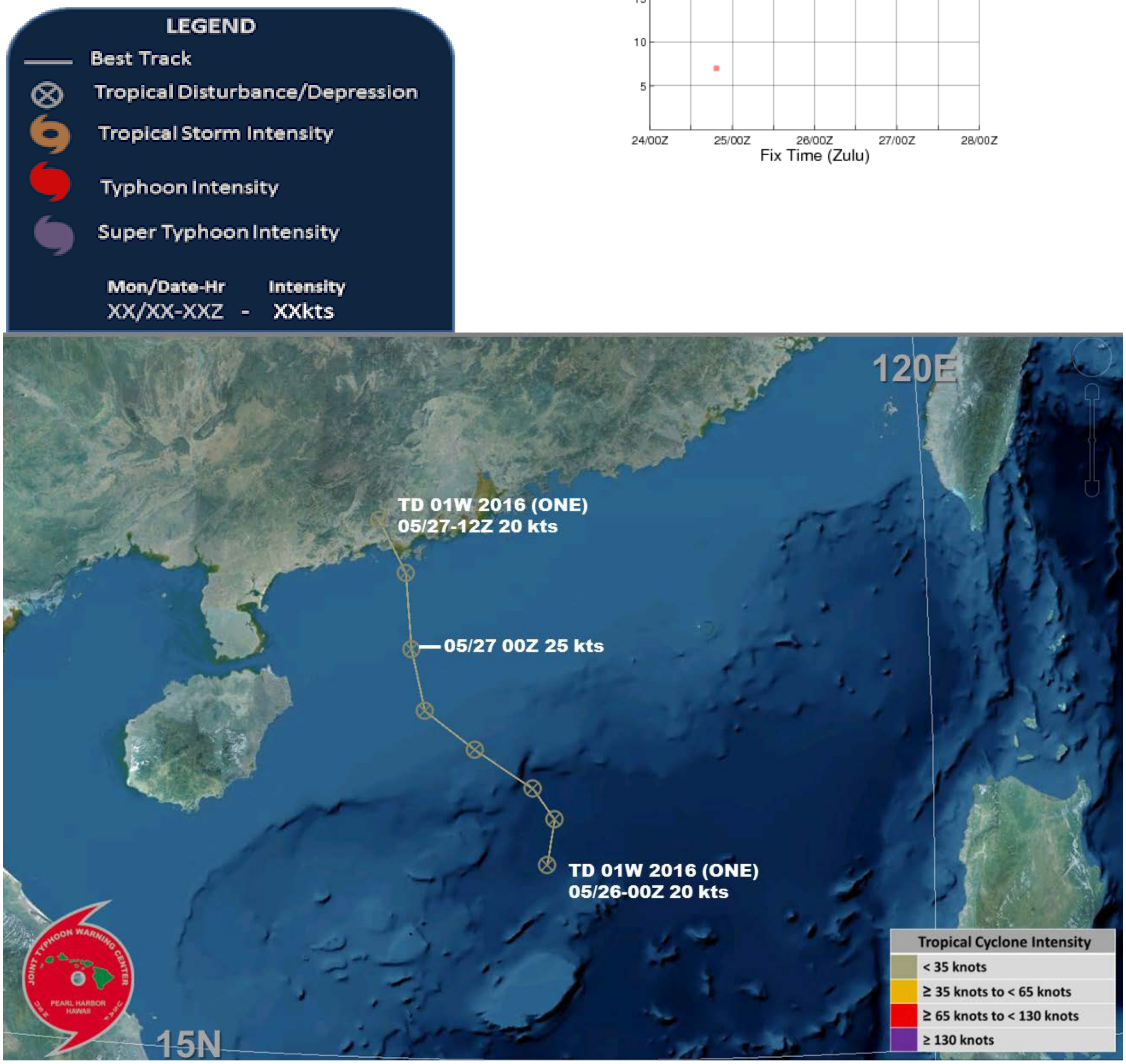
The JTWC post-event reanalysis best track is also provided for each cyclone. Data included on the best track are position and intensity noted with cyclone symbols and color coded track. Best track position labels include the date-time, track speed in knots, and maximum wind speed in knots. A graph of best track intensity and fix intensity versus time is presented. The fix plots on this graph are color coded by fixing agency.

In addition, when this document is viewed as a pdf, each map has been hyperlinked to the appropriate keyhole markup language (kmz) file that will allow the reader to access and view the best-track data interactively on their computer using Google Earth software. Simply hold the control button and click the map image. The link will open, allowing the reader to download and open the file.
Users may retrieve kmz files for the entire season from:
https://metoc.ndbc.noaa.gov/ProductFeeds-portlet/img/jtwc/best_tracks/2016/2016s-bwp/WP_besttracks_2016-2016.kmz

01W TROPICAL DEPRESSION ONE

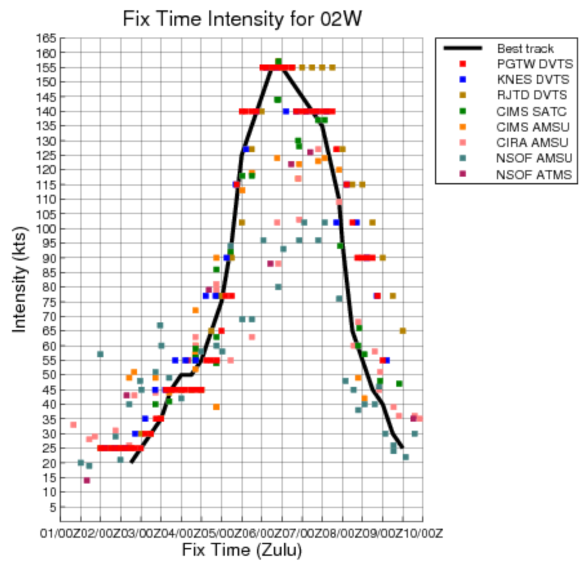
ISSUED LOW: None
ISSUED MED: None
FIRST TCFA: 26 May / 0500Z
FIRST WARNING: None
LAST WARNING: None
MAX INTENSITY: 30
WARNINGS: None

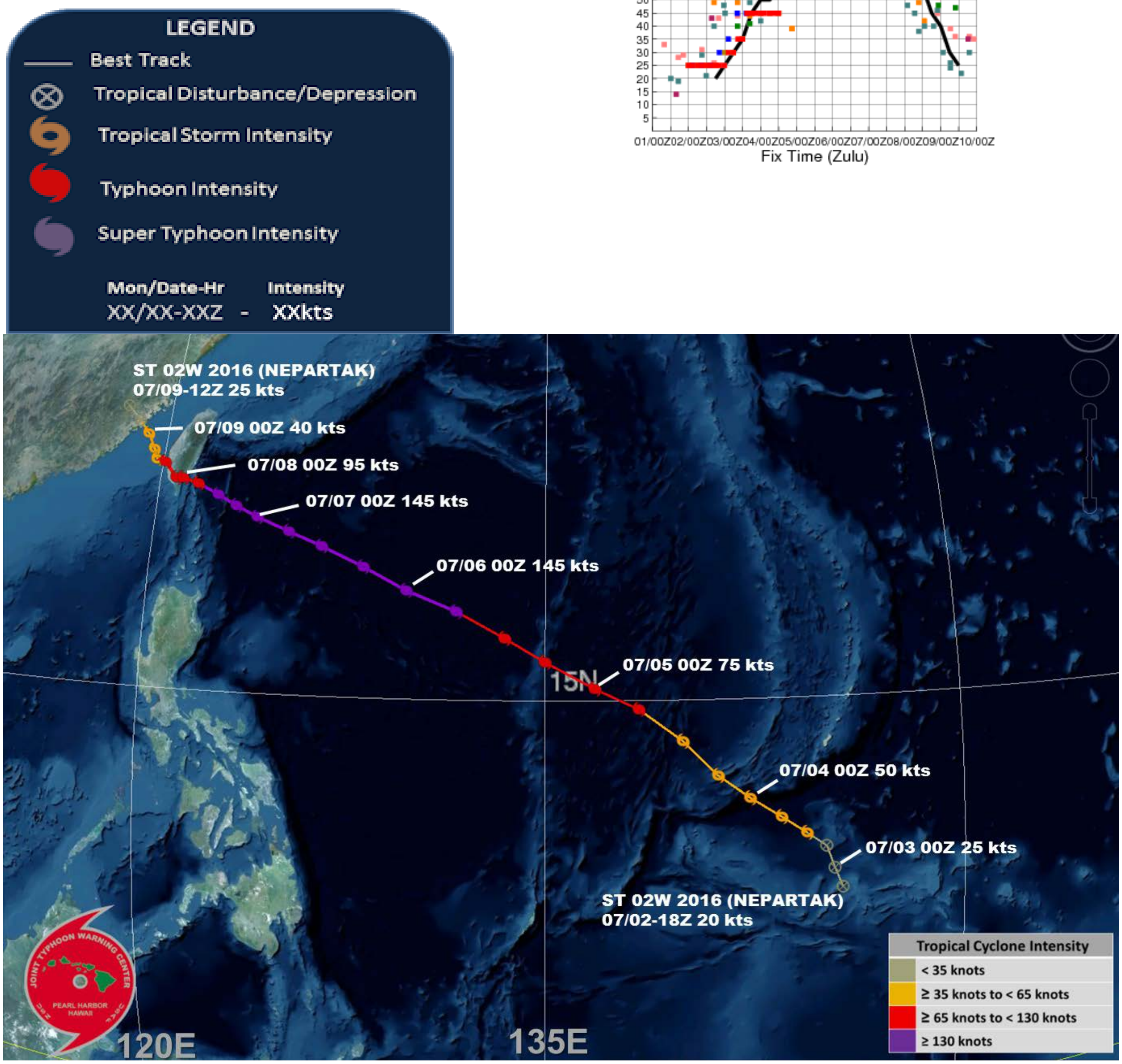




02W SUPER TYPHOON NEPARTAK

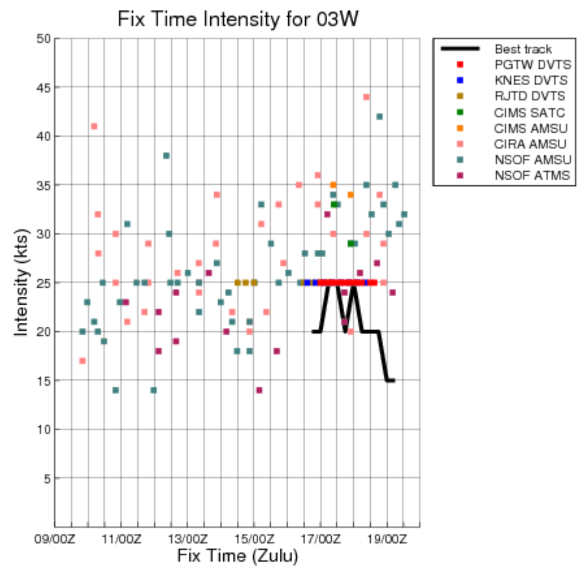
ISSUED LOW:	None
ISSUED MED:	01 Jul / 1700Z
FIRST TCFA:	02 Jul / 0630Z
FIRST WARNING:	03 Jul / 0000Z
LAST WARNING:	09 Jul / 0600Z
MAX INTENSITY:	155
WARNINGS:	26

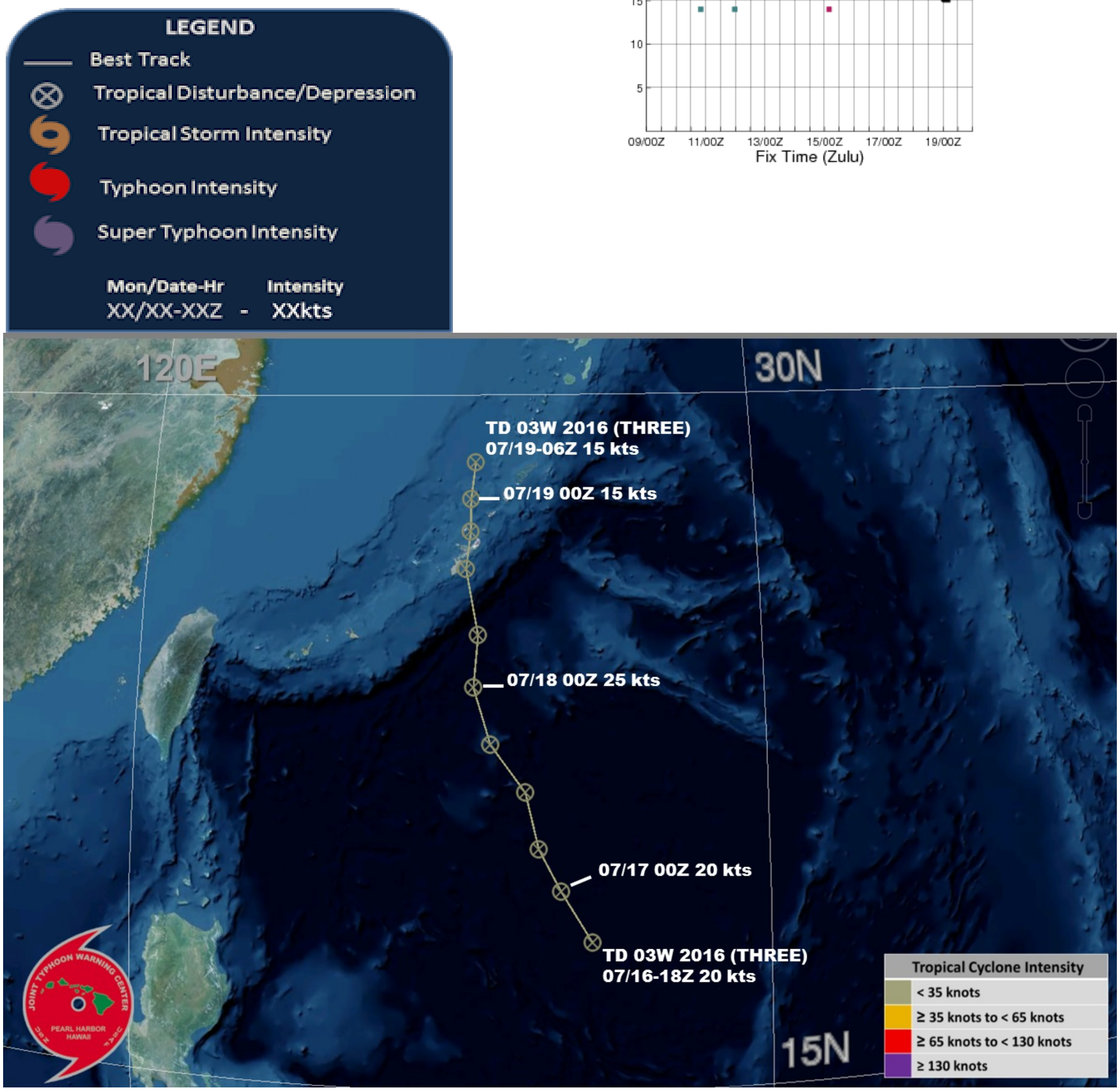




03W TROPICAL DEPRESSION THREE

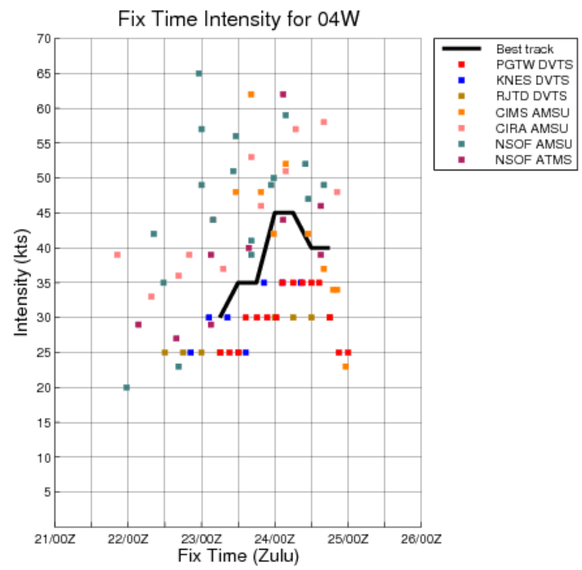
ISSUED LOW:	None
ISSUED MED:	16 Jul / 1400Z
FIRST TCFA:	17 Jul / 0400Z
FIRST WARNING:	17 Jul / 0600Z
LAST WARNING:	17 Jul / 1200Z
MAX INTENSITY:	25
WARNINGS:	2

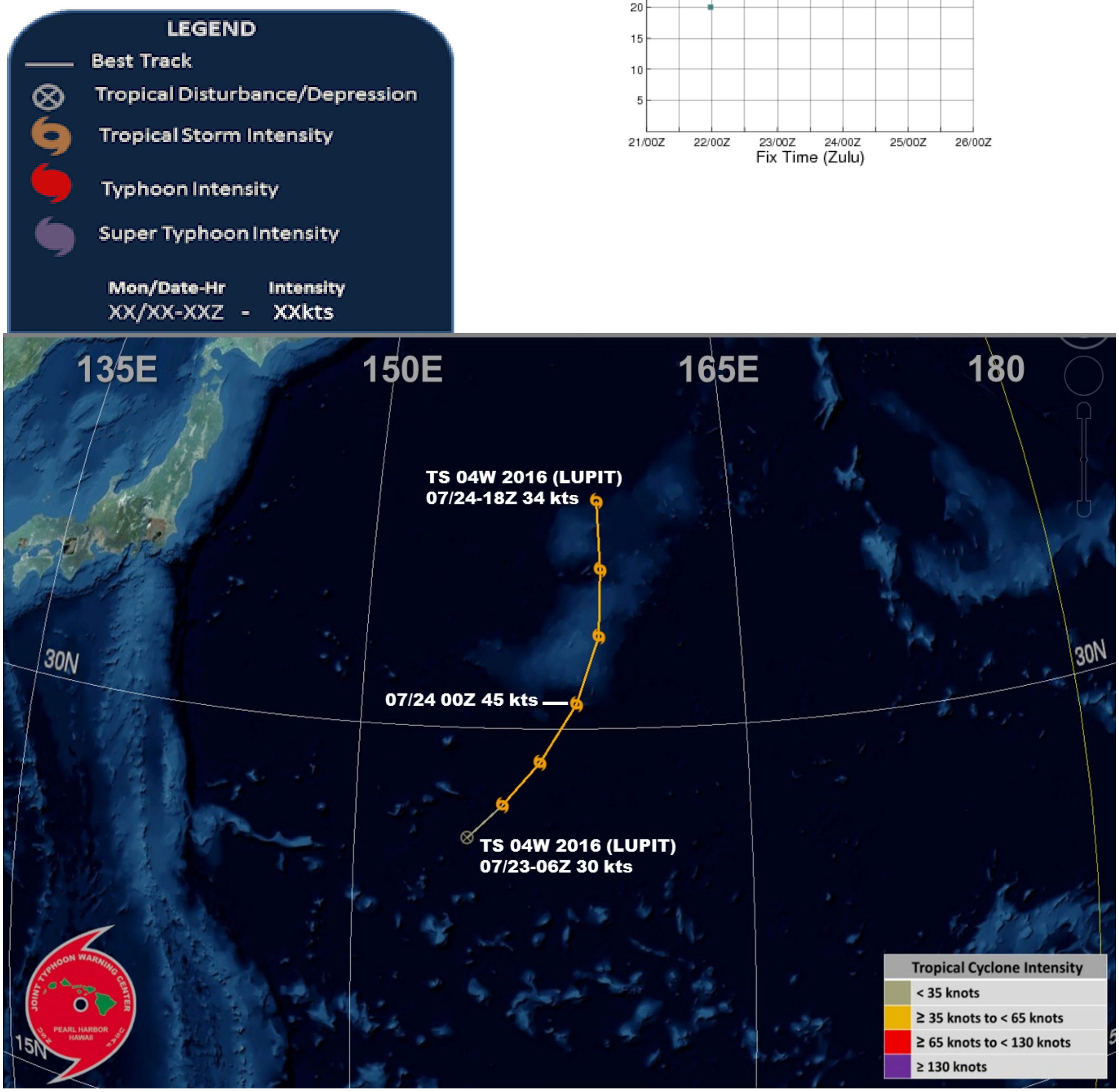




<u>04W TROPICAL STORM LUPIT</u>

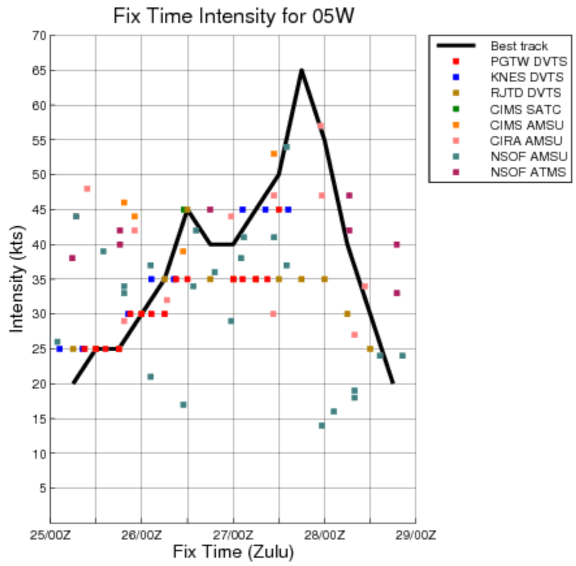
ISSUED LOW:	22 Jul / 0600Z
ISSUED MED:	23 Jul / 0600Z
FIRST TCFA:	None
FIRST WARNING:	23 Jul / 1200Z
LAST WARNING:	24 Jul / 0600Z
MAX INTENSITY:	45
WARNINGS:	4

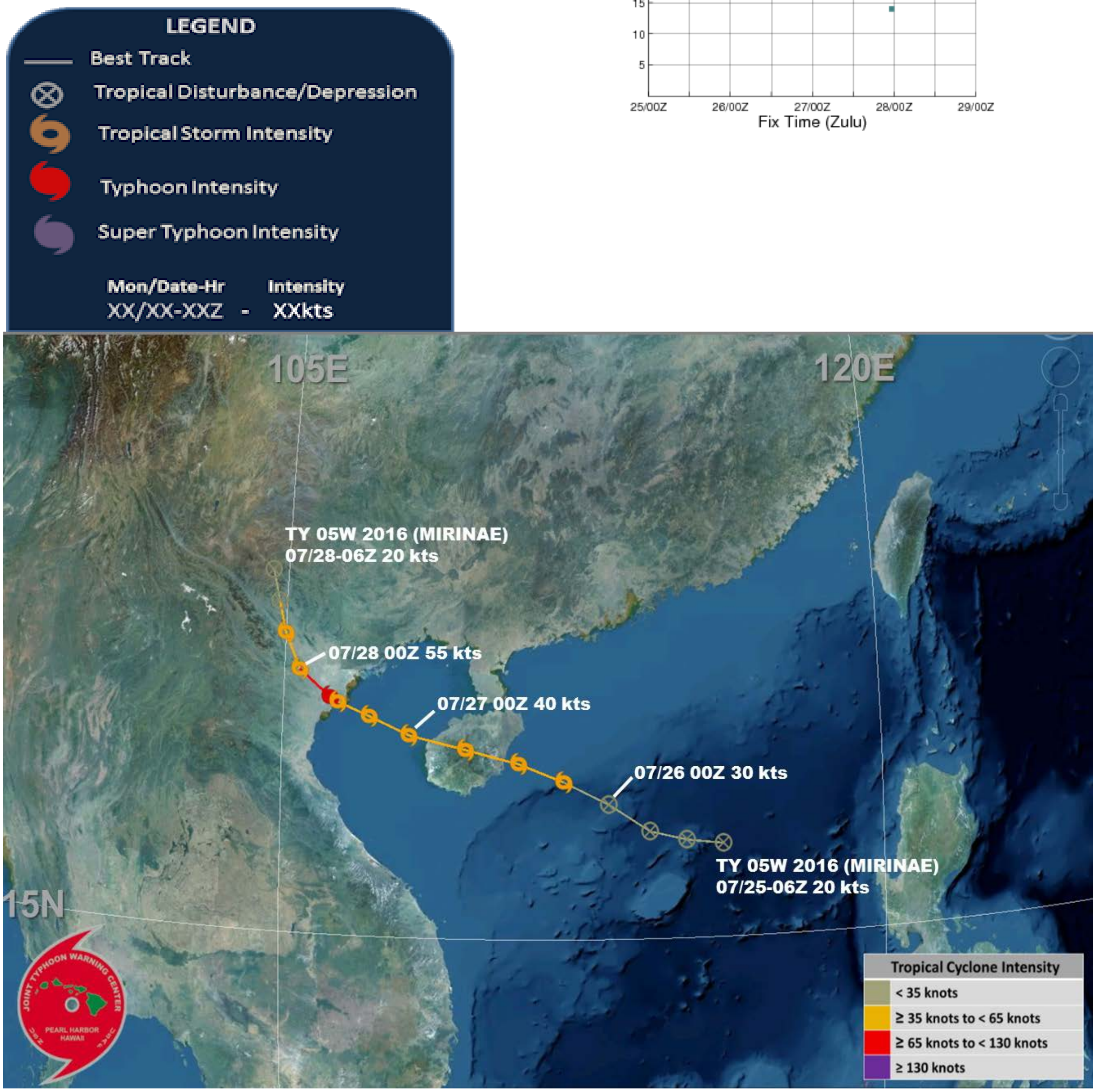




05W TYPHOON MIRINAE

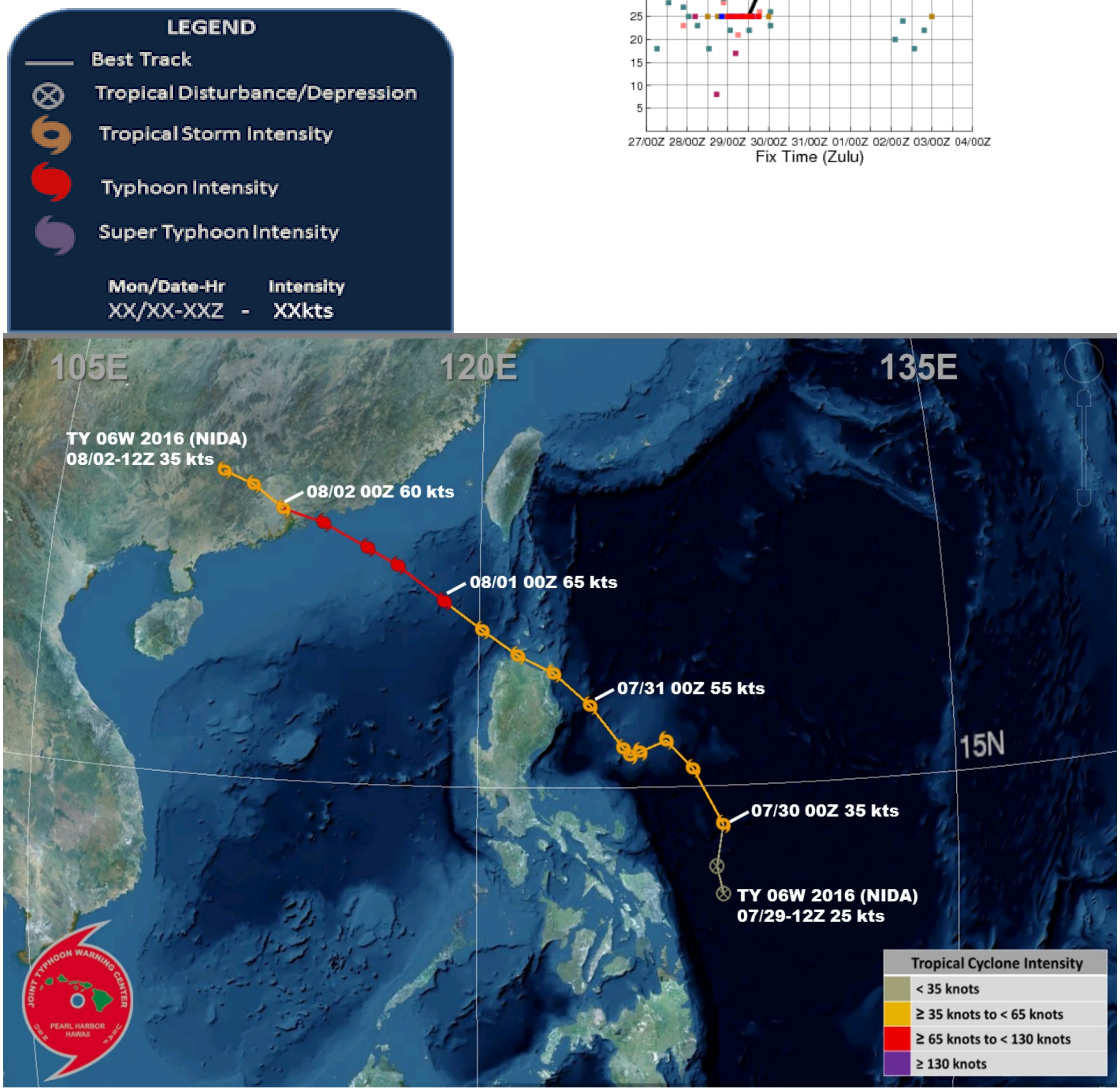
ISSUED LOW:	None
ISSUED MED:	25 Jul / 0200Z
FIRST TCFA:	25 Jul / 0900Z
FIRST WARNING:	25 Jul / 1200Z
LAST WARNING:	27 Jul / 1200Z
MAX INTENSITY:	65
WARNINGS:	9





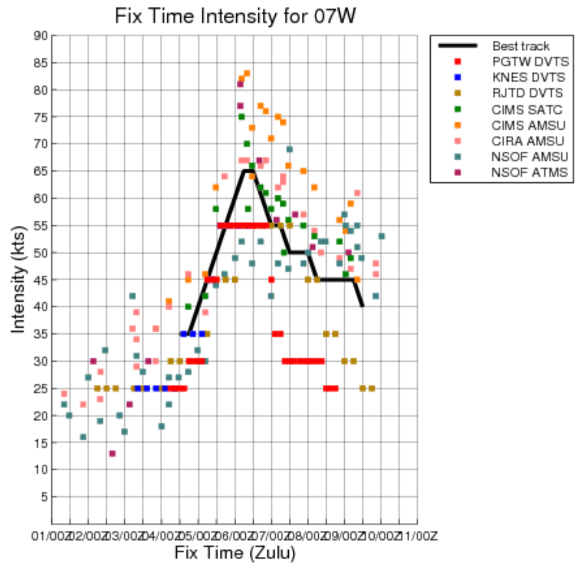
06W TYPHOON NIDA

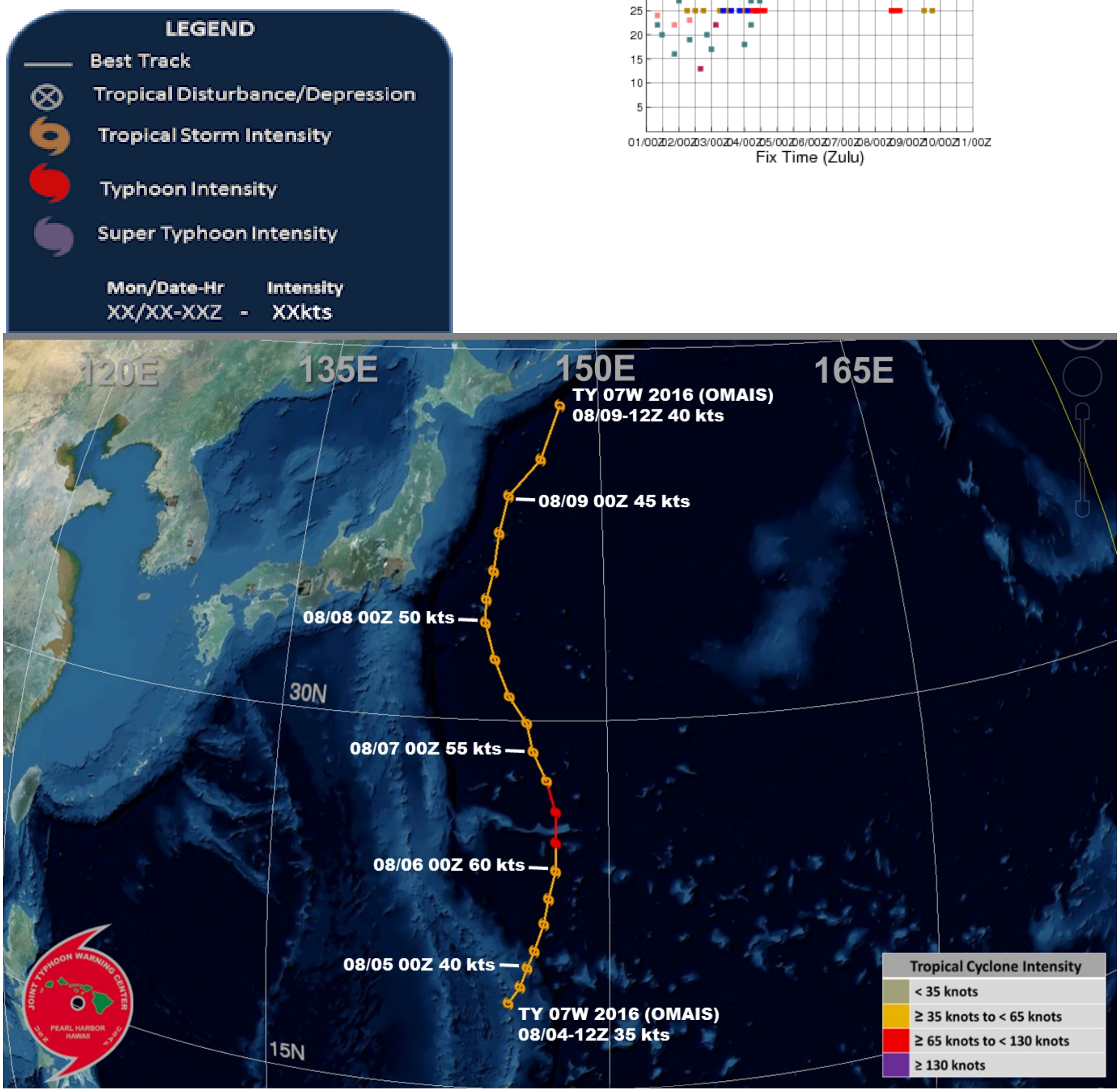
ISSUED LOW:	28 Jul / 1230Z
ISSUED MED:	28 Jul / 2030Z
FIRST TCFA:	29 Jul / 0130Z
FIRST WARNING:	29 Jul / 1200Z
LAST WARNING:	02 Aug / 0000Z
MAX INTENSITY:	80
WARNINGS:	15



07W TYPHOON OMAIS

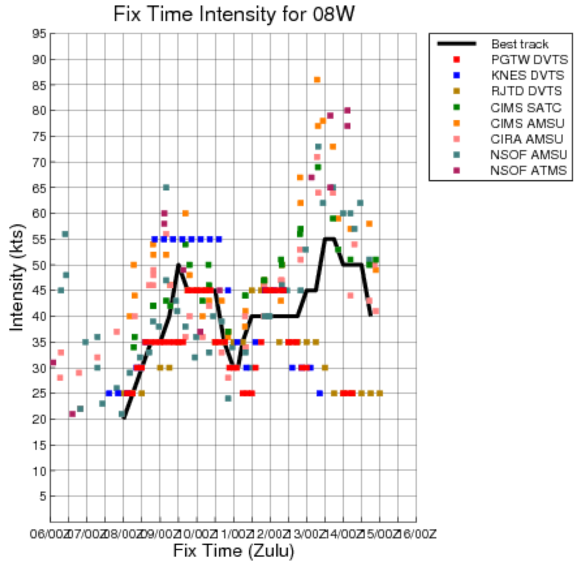
ISSUED LOW:	02 Aug / 0600Z
ISSUED MED:	03 Aug / 0600Z
FIRST TCFA:	04 Aug / 0430Z
FIRST WARNING:	04 Aug / 1200Z
LAST WARNING:	08 Aug / 1800Z
MAX INTENSITY:	65
WARNINGS:	18

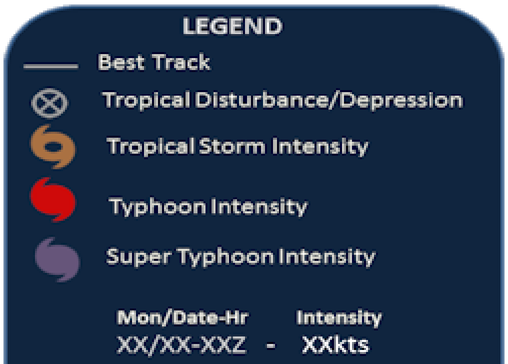


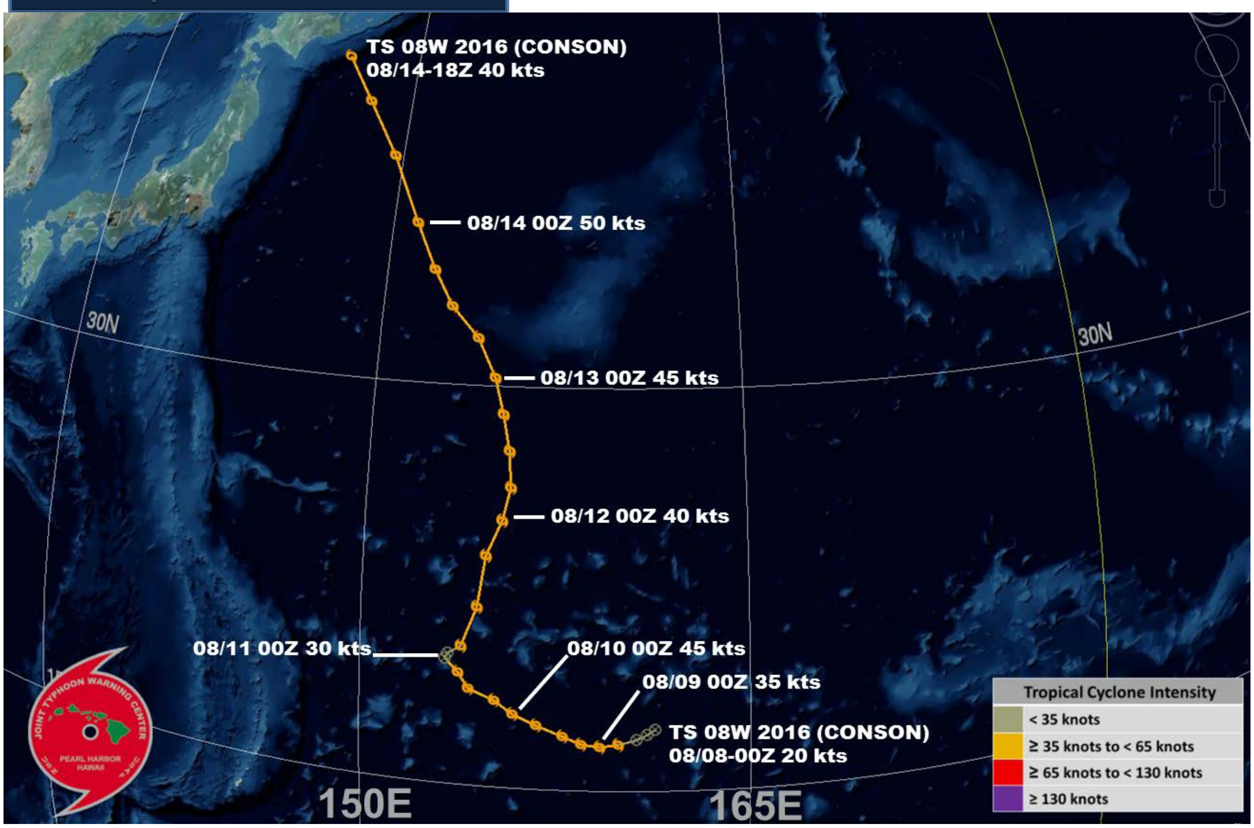


<u>**08W TROPICAL STORM CONSON**</u>

ISSUED LOW:	06 Aug / 0600Z
ISSUED MED:	07 Aug / 0600Z
FIRST TCFA:	08 Aug / 0330Z
FIRST WARNING:	08 Aug / 0600Z
LAST WARNING:	14 Aug / 1200Z
MAX INTENSITY:	55
WARNINGS:	26

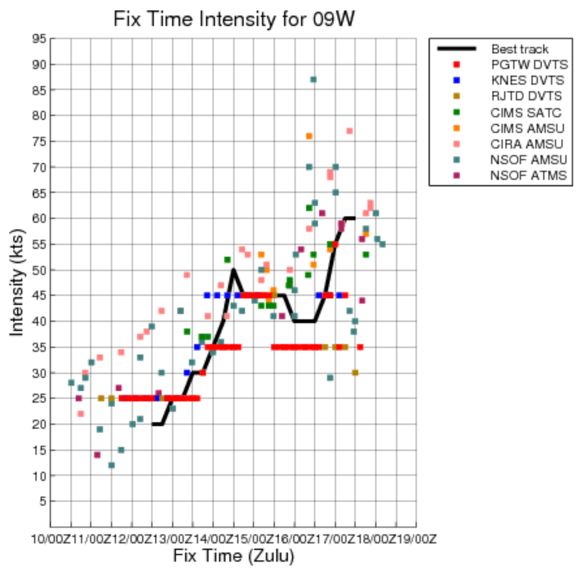


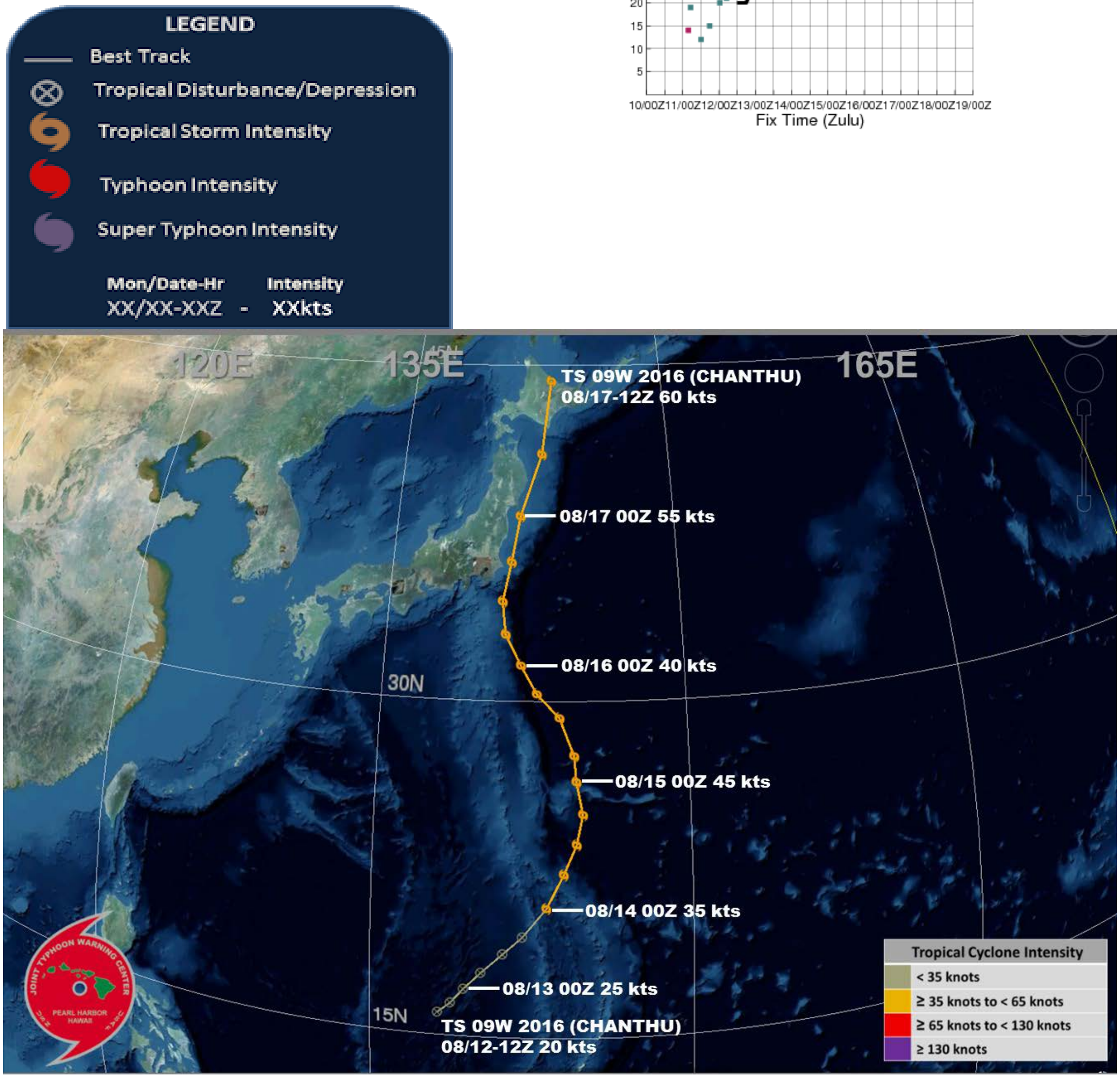




09W TROPICAL STORM CHANTHU

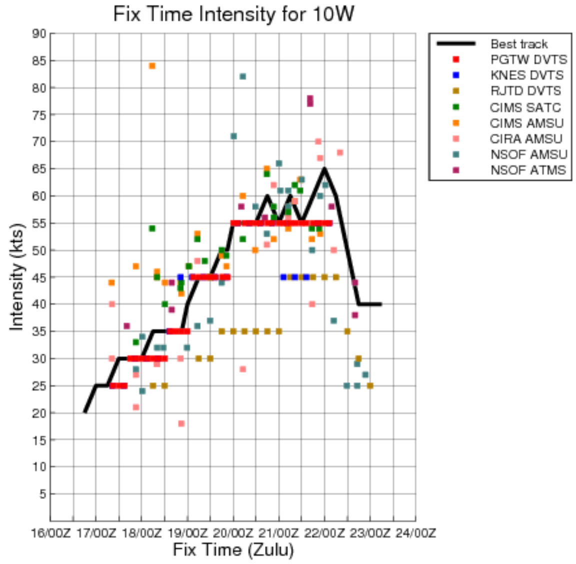
ISSUED LOW:	11 Aug / 0600Z
ISSUED MED:	11 Aug / 1900Z
FIRST TCFA:	11 Aug / 2130Z
FIRST WARNING:	13 Aug / 0600Z
LAST WARNING:	17 Aug / 0000Z
MAX INTENSITY:	60
WARNINGS:	16

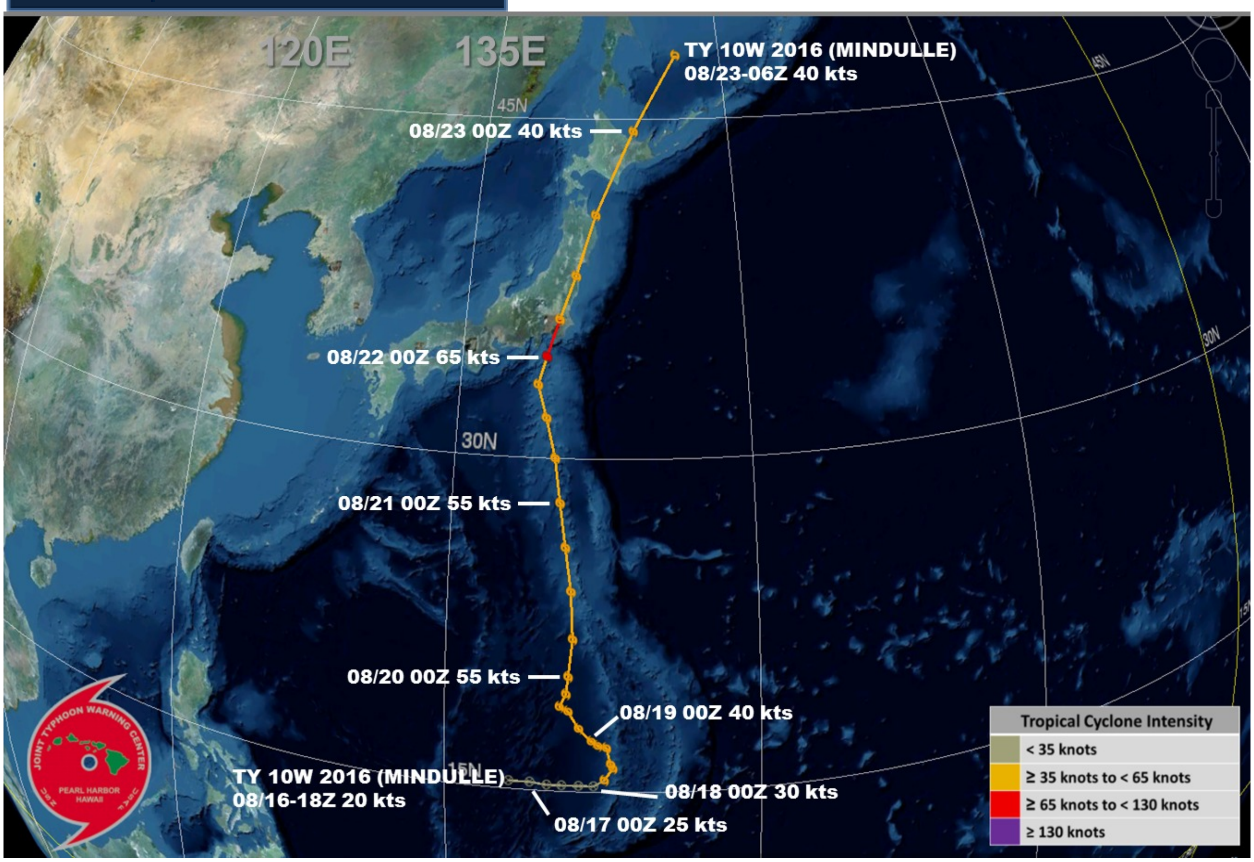




10W TYPHOON MINDULLE

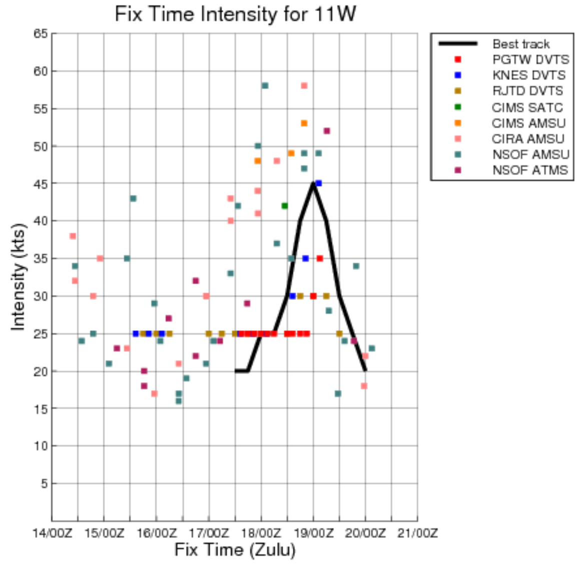
ISSUED LOW:	17 Aug / 1330Z
ISSUED MED:	None
FIRST TCFA:	17 Aug / 1600Z
FIRST WARNING:	17 Aug / 1800Z
LAST WARNING:	22 Aug / 1800Z
MAX INTENSITY:	65
WARNINGS:	21

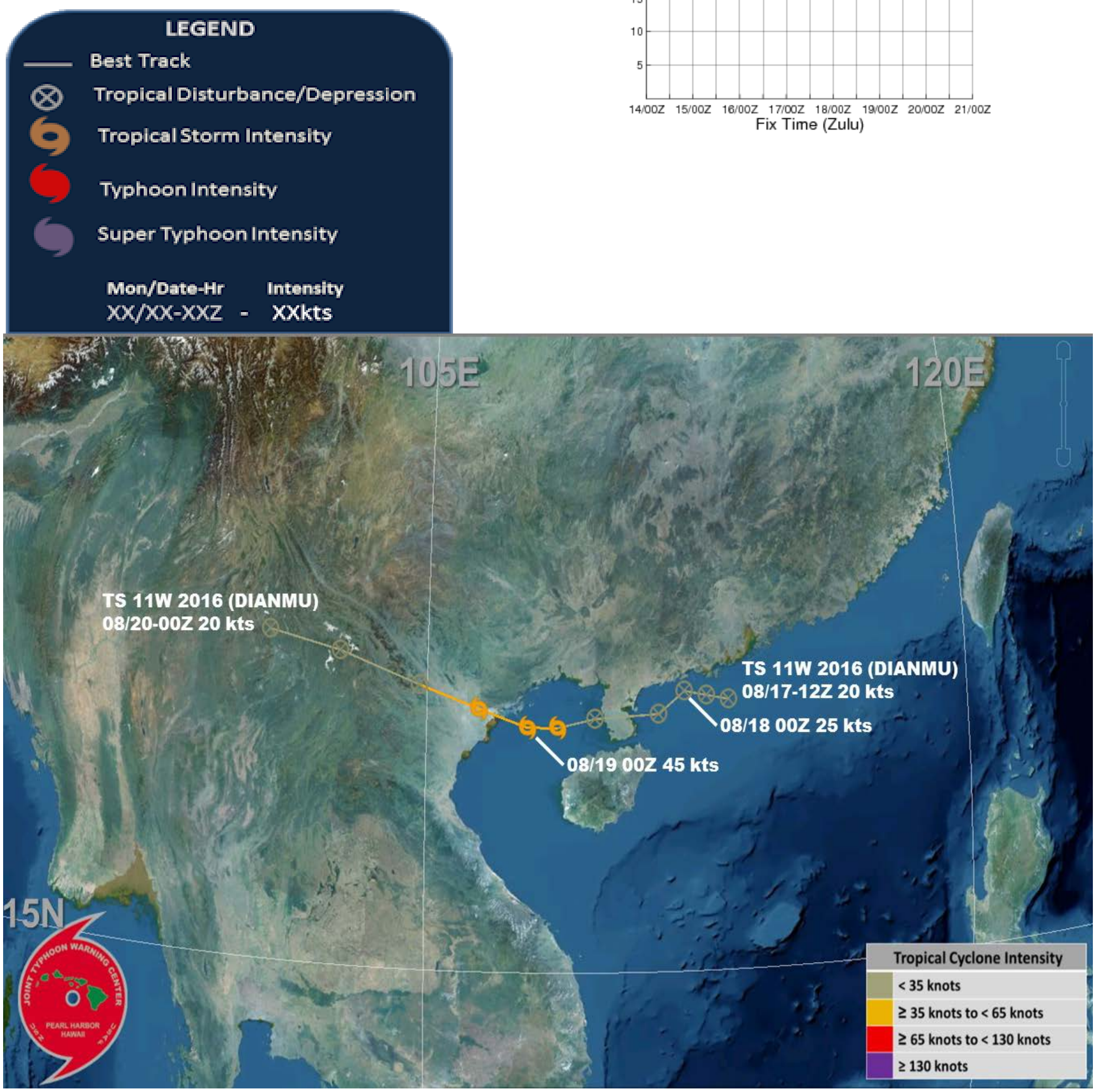




11W TROPICAL STORM DIANMU

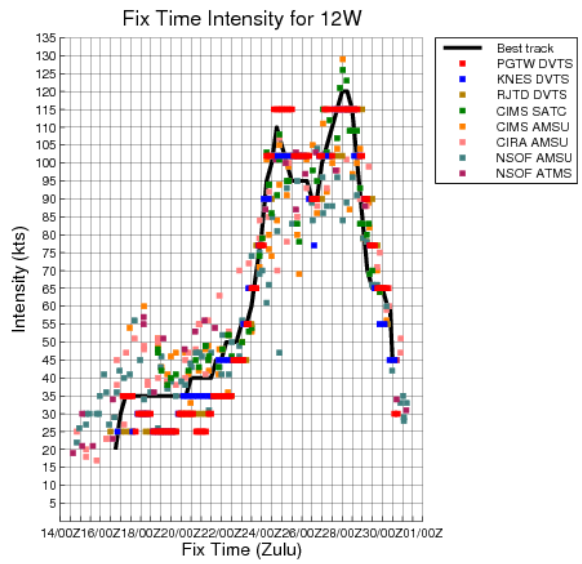
ISSUED LOW:	14 Aug / 1130Z
ISSUED MED:	15 Aug / 0100Z
FIRST TCFA:	17 Aug / 1730Z
FIRST WARNING:	18 Aug / 0000Z
LAST WARNING:	19 Aug / 0600Z
MAX INTENSITY:	45
WARNINGS:	6

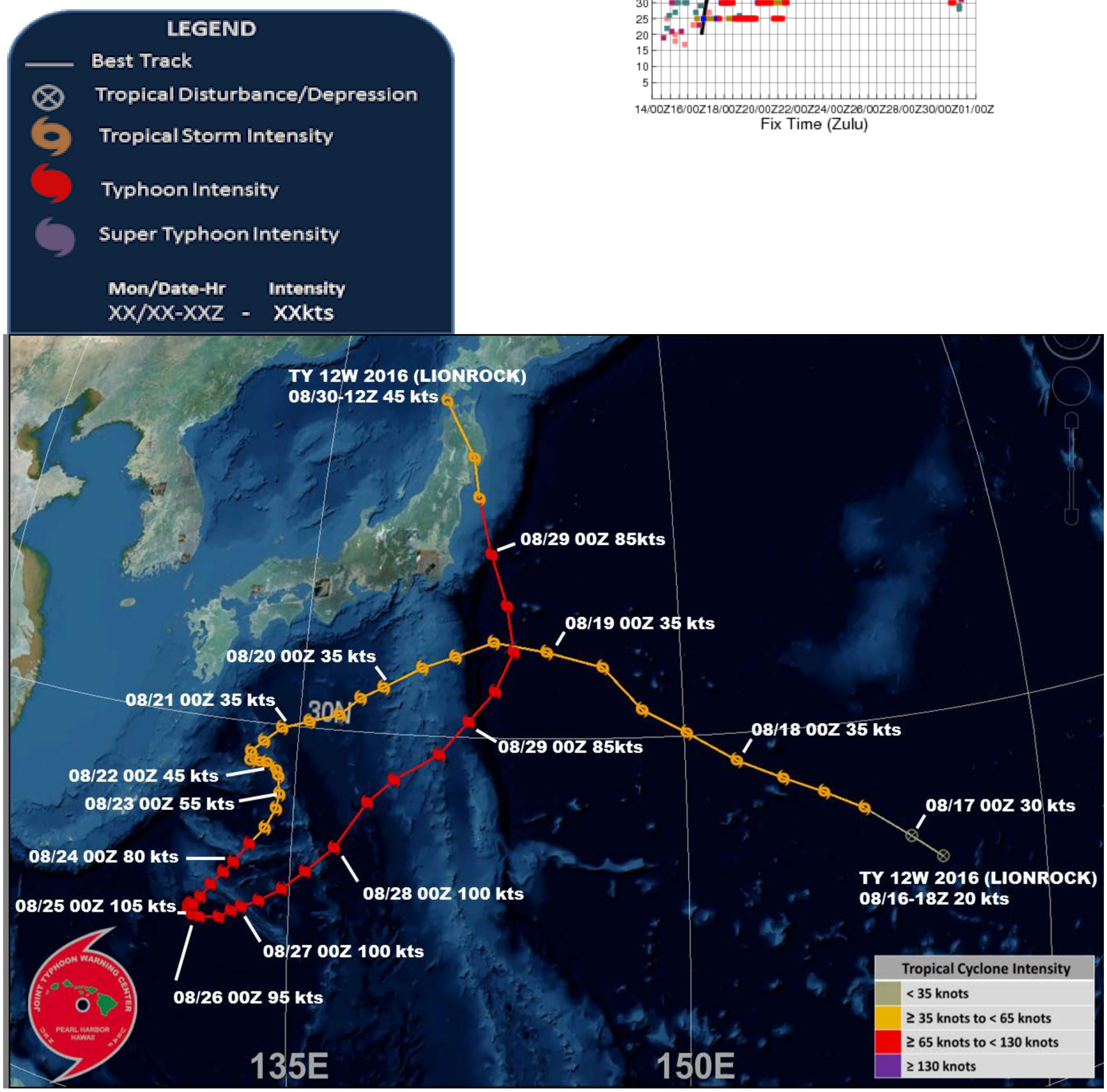




12W TYPHOON LIONROCK

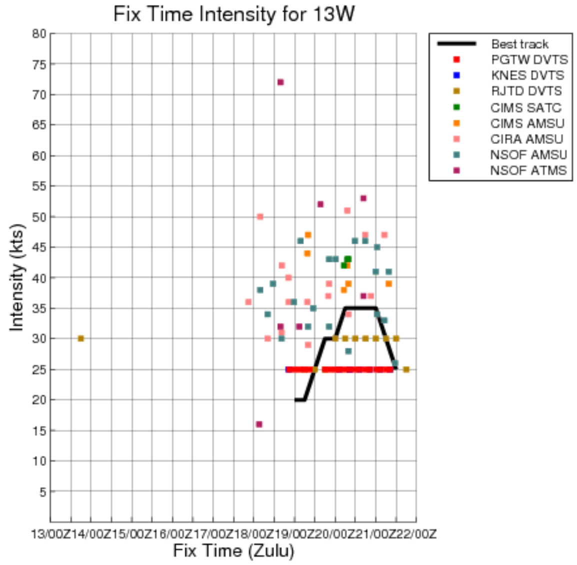
ISSUED LOW:	15 Aug / 0100Z
ISSUED MED:	17 Aug / 2130Z
FIRST TCFA:	17 Aug / 2300Z
FIRST WARNING:	18 Aug / 0000Z
LAST WARNING:	30 Aug / 1200Z
MAX INTENSITY:	120
WARNINGS:	52

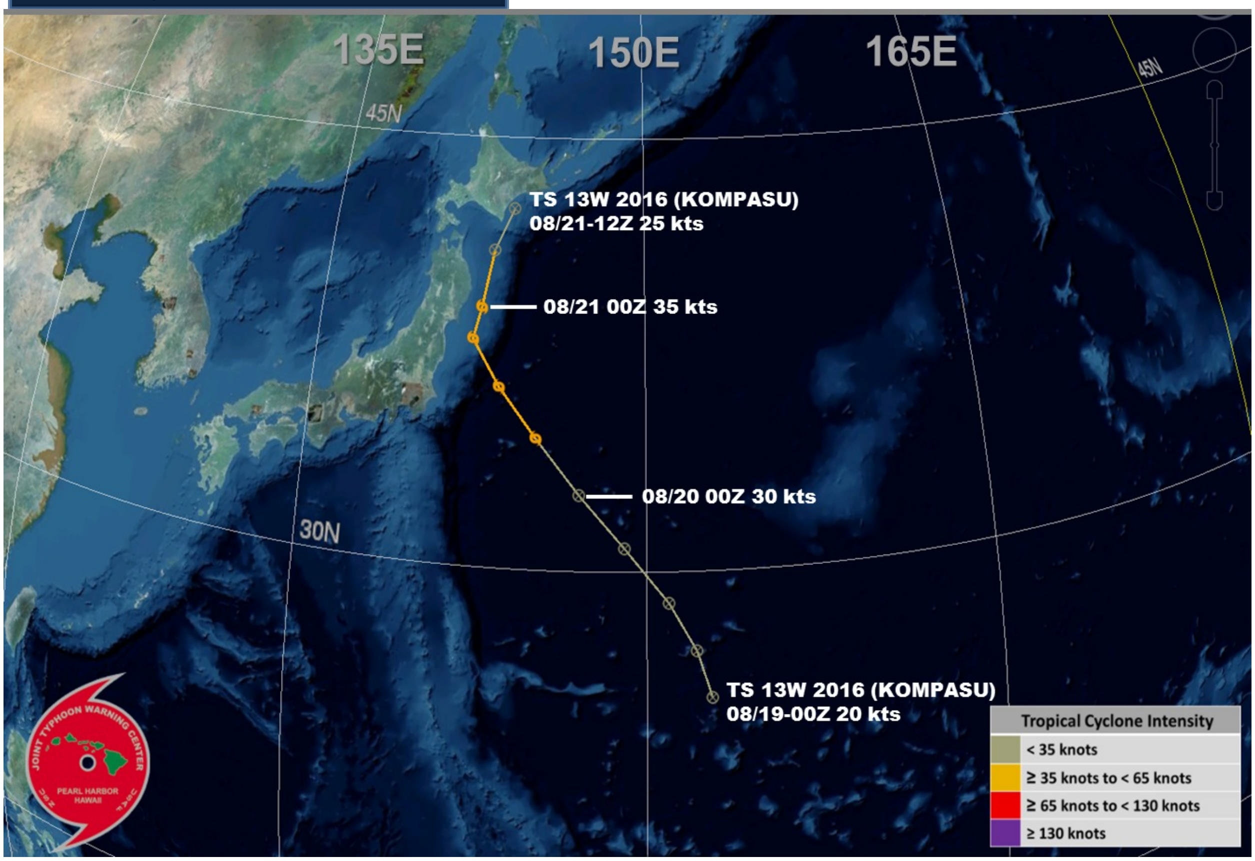




13W TROPICAL STORM KOMPASU

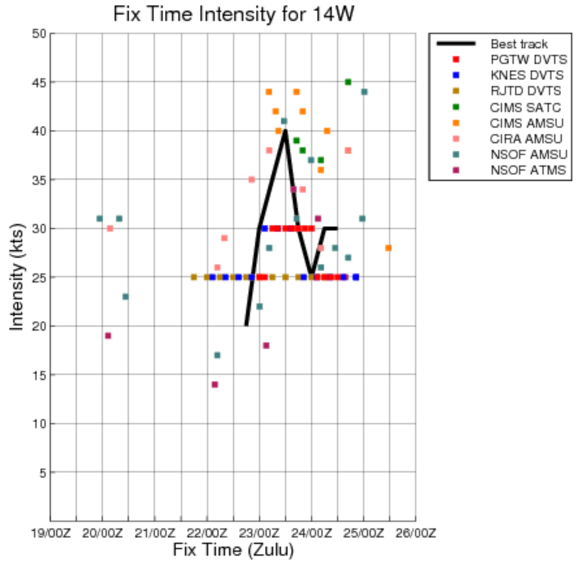
ISSUED LOW:	17 Aug / 2130Z
ISSUED MED:	18 Aug / 0600Z
FIRST TCFA:	18 Aug / 2300Z
FIRST WARNING:	19 Aug / 1800Z
LAST WARNING:	21 Aug / 0000Z
MAX INTENSITY:	35
WARNINGS:	6

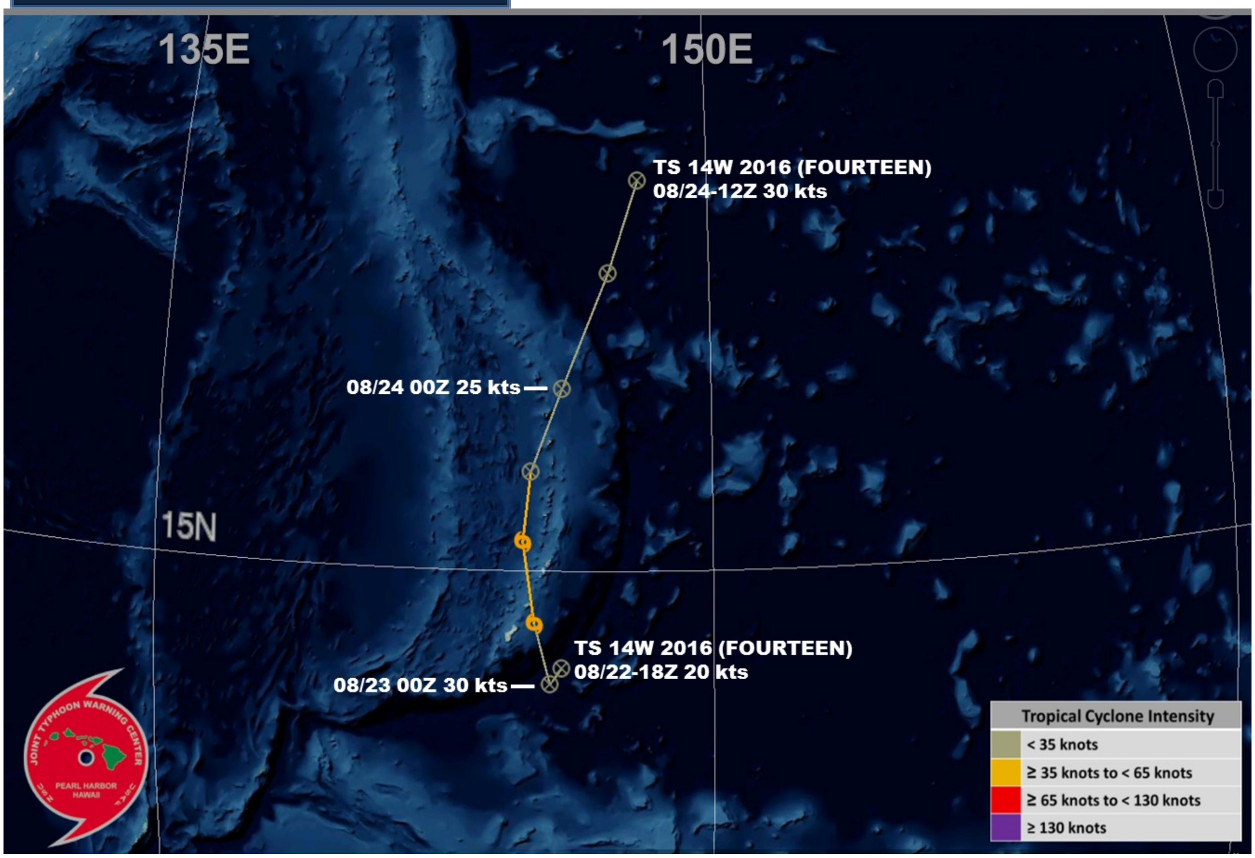




14W TROPICAL STORM FOURTEEN

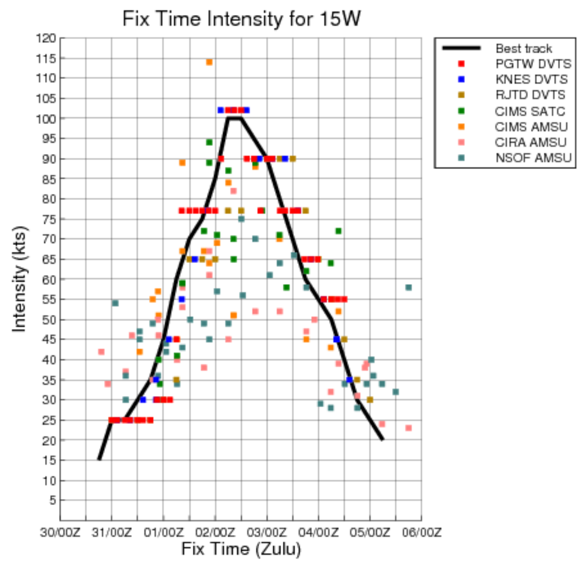
ISSUED LOW:	22 Aug / 0600Z
ISSUED MED:	None
FIRST TCFA:	23 Aug / 0130Z
FIRST WARNING:	23 Aug / 0600Z
LAST WARNING:	24 Aug / 1200Z
MAX INTENSITY:	40
WARNINGS:	6

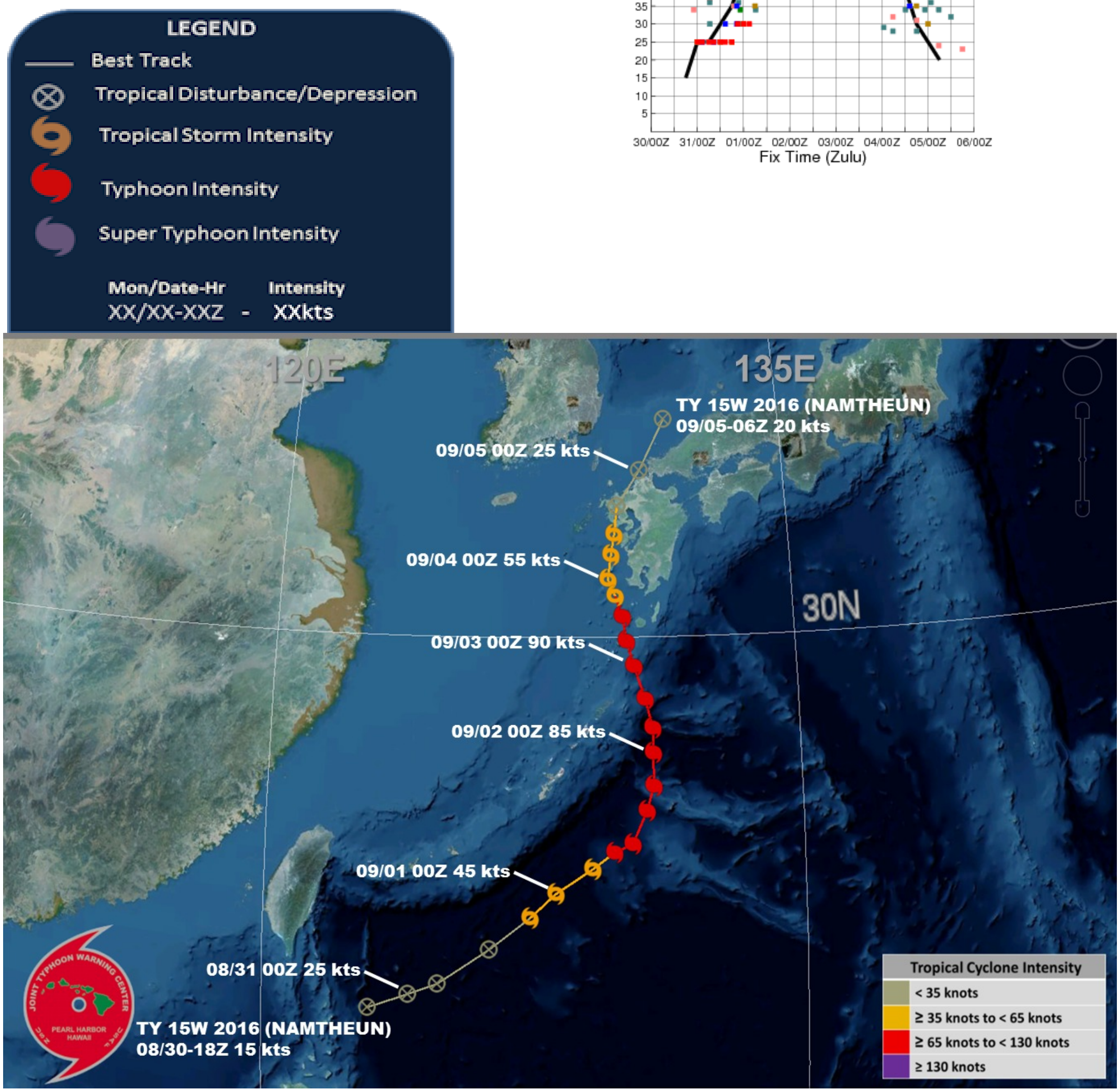




15W TYPHOON NAMTHEUN

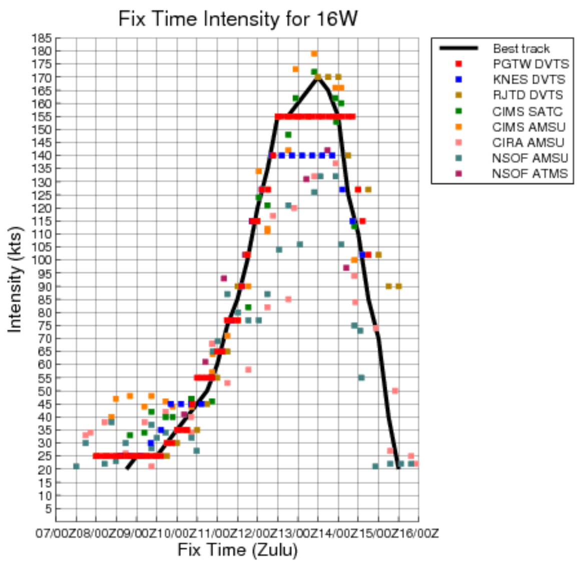
ISSUED LOW:	None
ISSUED MED:	31 Aug / 0600Z
FIRST TCFA:	31 Aug / 0930Z
FIRST WARNING:	31 Aug / 1200Z
LAST WARNING:	05 Sep / 0000Z
MAX INTENSITY:	100
WARNINGS:	19

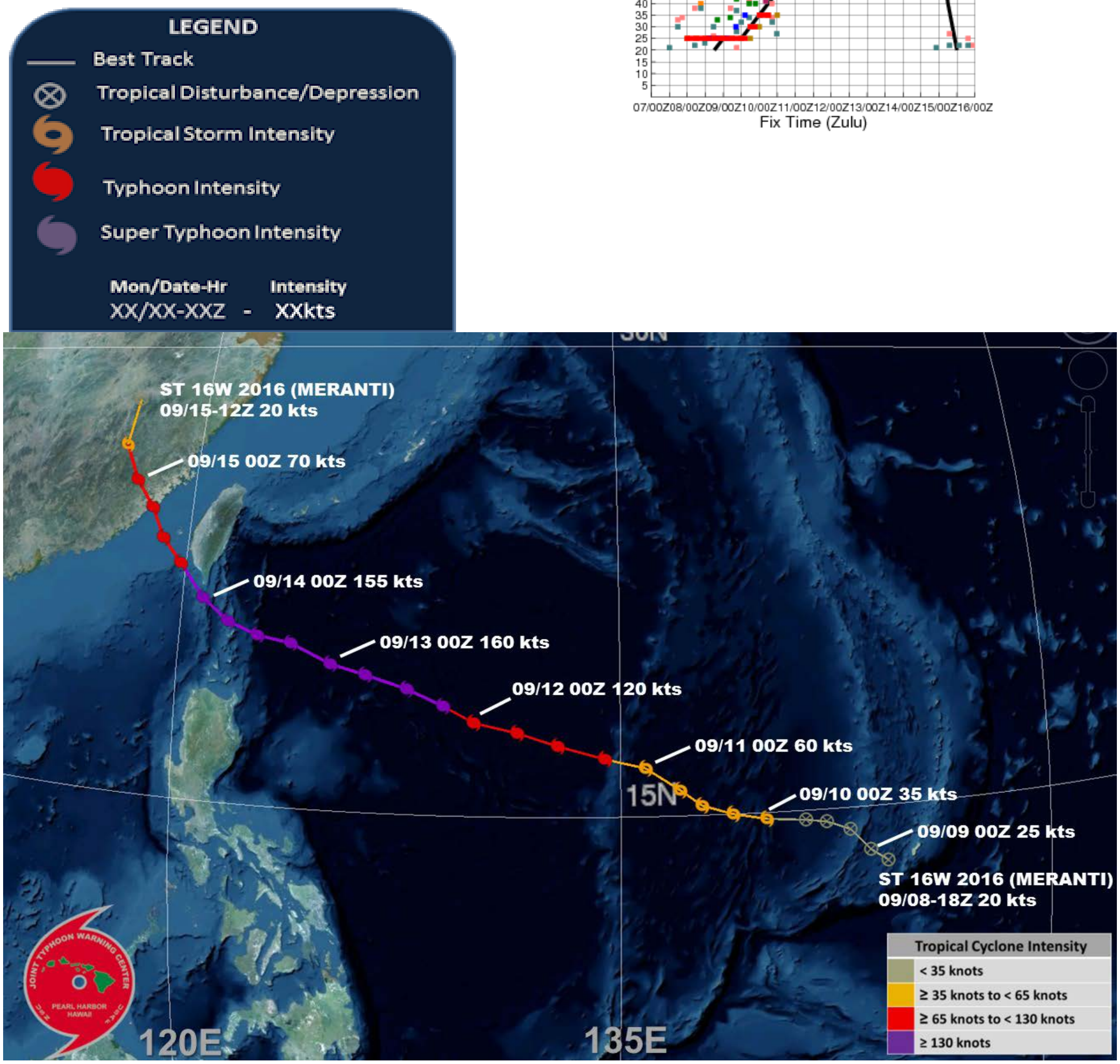




16W SUPER TYPHOON MERANTI

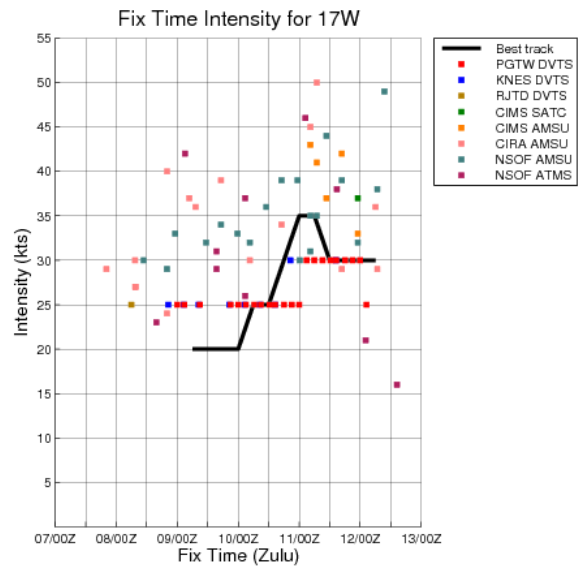
ISSUED LOW:	08 Sep / 0200Z
ISSUED MED:	None
FIRST TCFA:	08 Sep / 0530Z
FIRST WARNING:	08 Sep / 1800Z
LAST WARNING:	14 Sep / 1800Z
MAX INTENSITY:	170
WARNINGS:	25

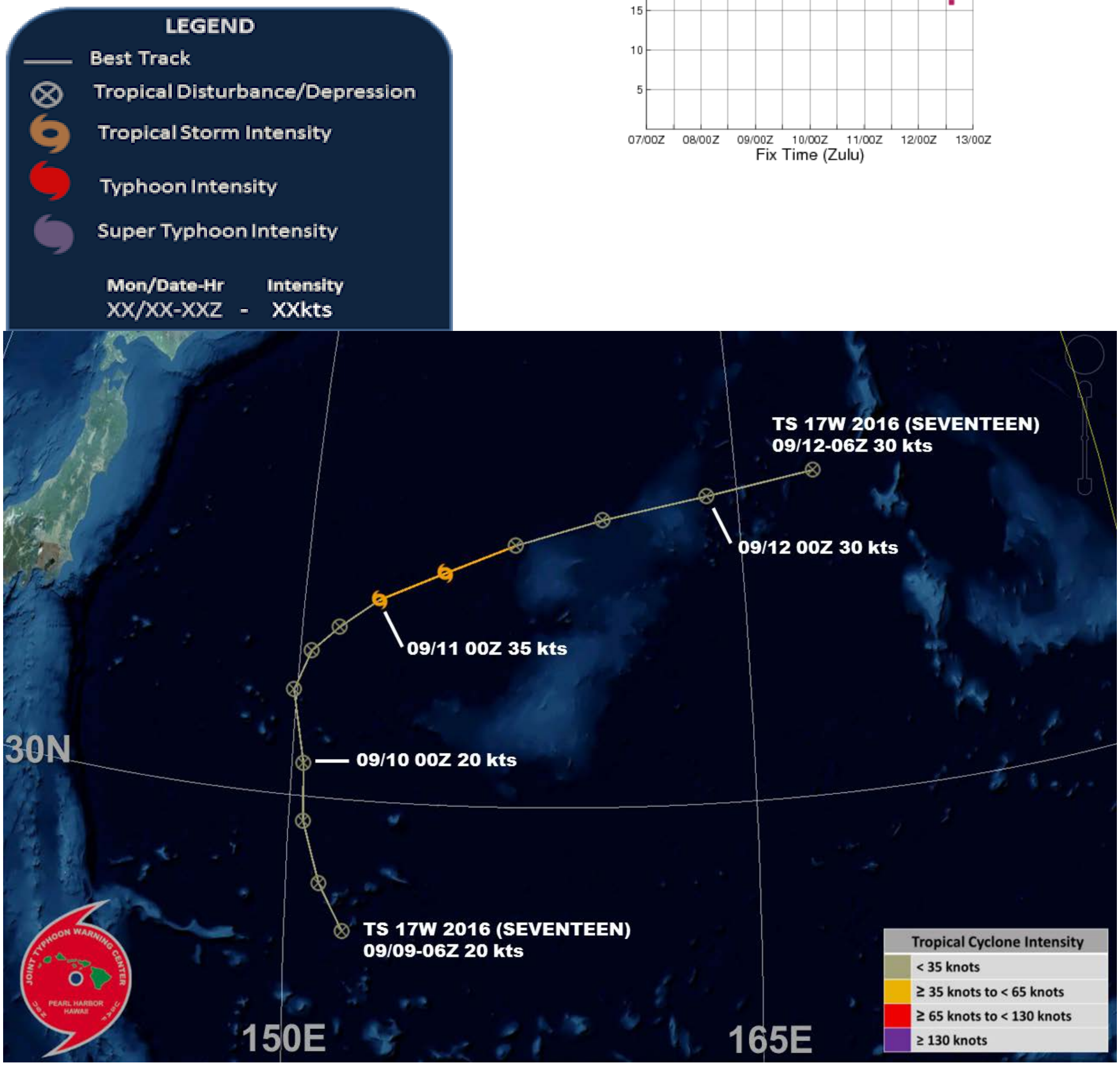




17W TROPICAL STORM SEVENTEEN

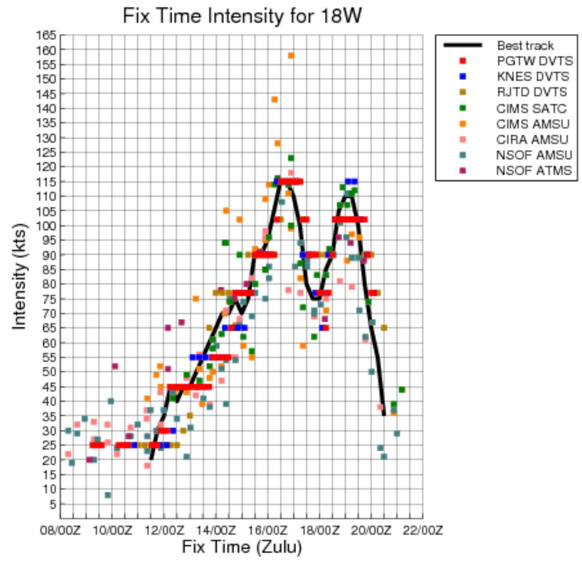
ISSUED LOW:	09 Sep / 0300Z
ISSUED MED:	None
FIRST TCFA:	10 Sep / 2230Z
FIRST WARNING:	11 Sep / 0000Z
LAST WARNING:	11 Sep / 1800Z
MAX INTENSITY:	35
WARNINGS:	4

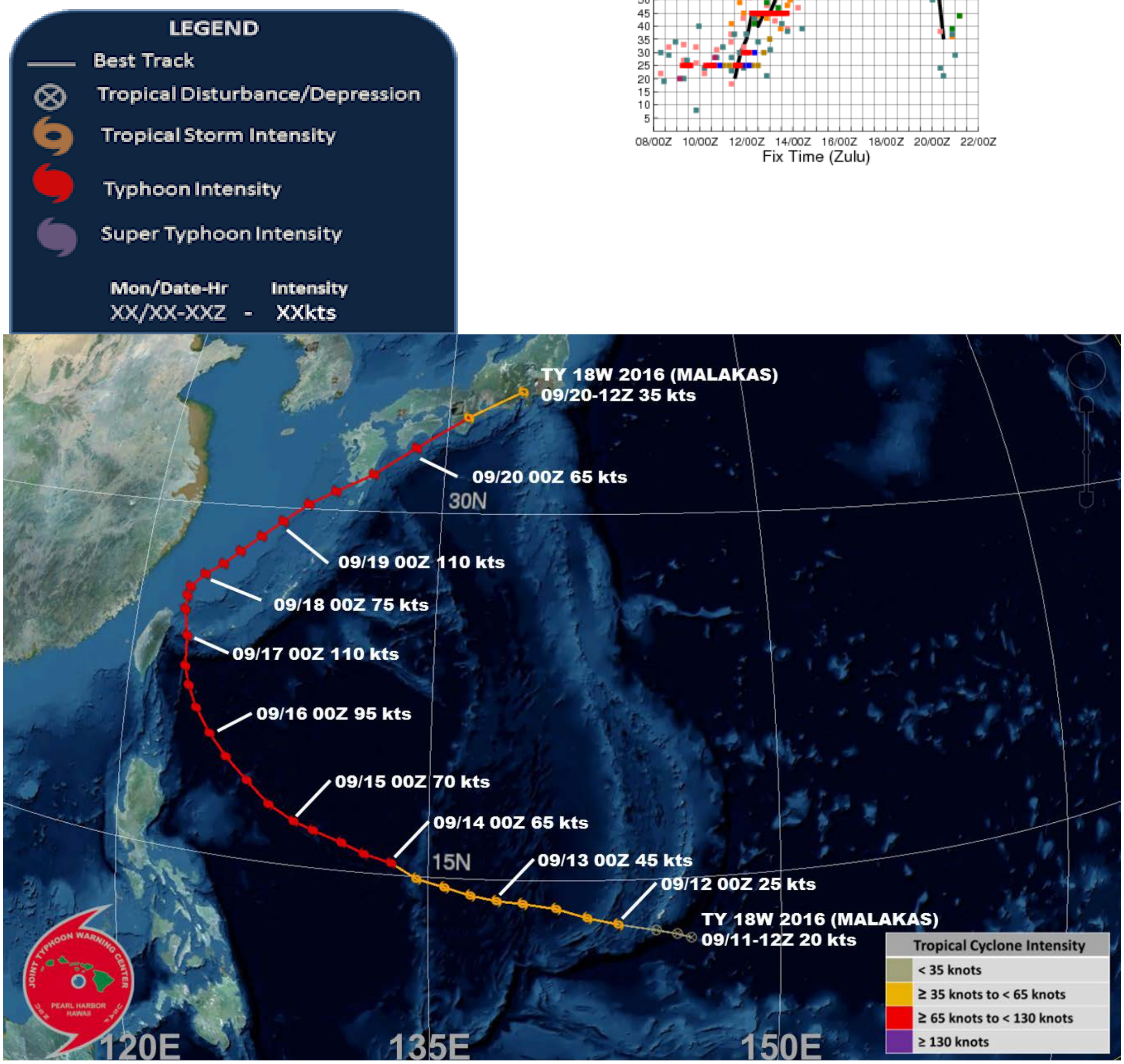




18W TYPHOON MALAKAS

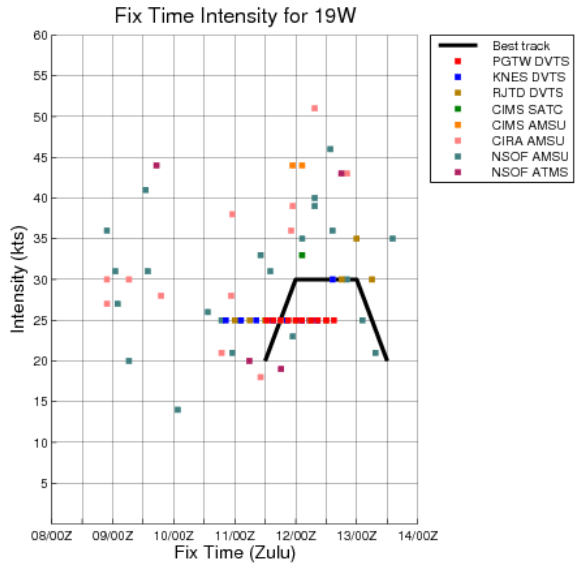
ISSUED LOW:	08 Sep / 2230Z
ISSUED MED:	09 Sep / 0600Z
FIRST TCFA:	11 Sep / 1400Z
FIRST WARNING:	11 Sep / 1800Z
LAST WARNING:	20 Sep / 1800Z
MAX INTENSITY:	115
WARNINGS:	37

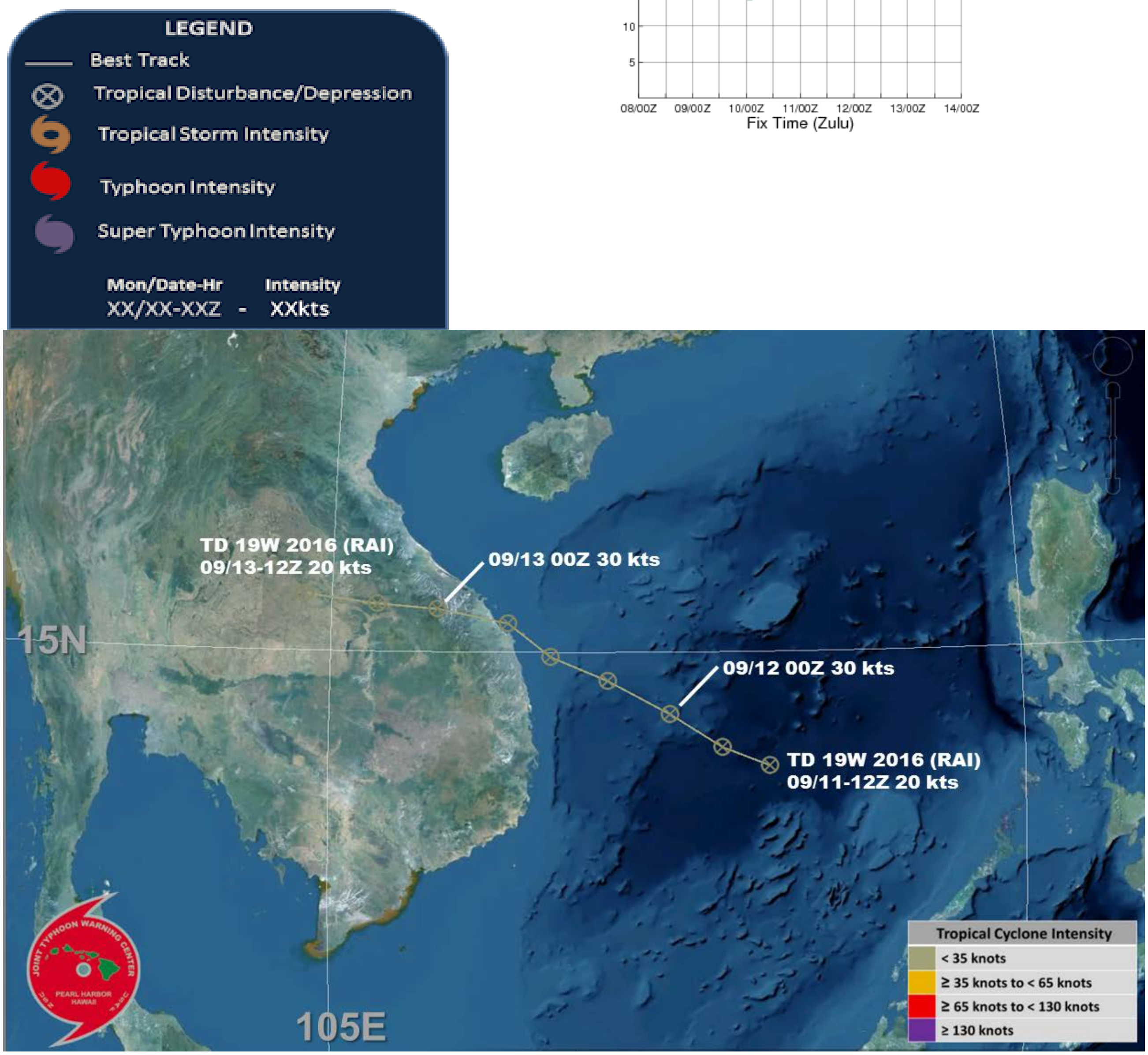




19W TROPICAL DEPRESSION RAI

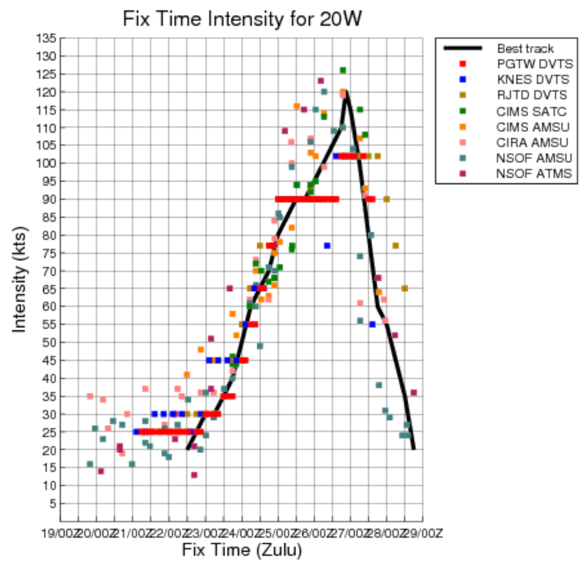
ISSUED LOW:	11 Sep / 0000Z
ISSUED MED:	None
FIRST TCFA:	11 Sep / 1630Z
FIRST WARNING:	12 Sep / 0000Z
LAST WARNING:	12 Sep / 1800Z
MAX INTENSITY:	30
WARNINGS:	4

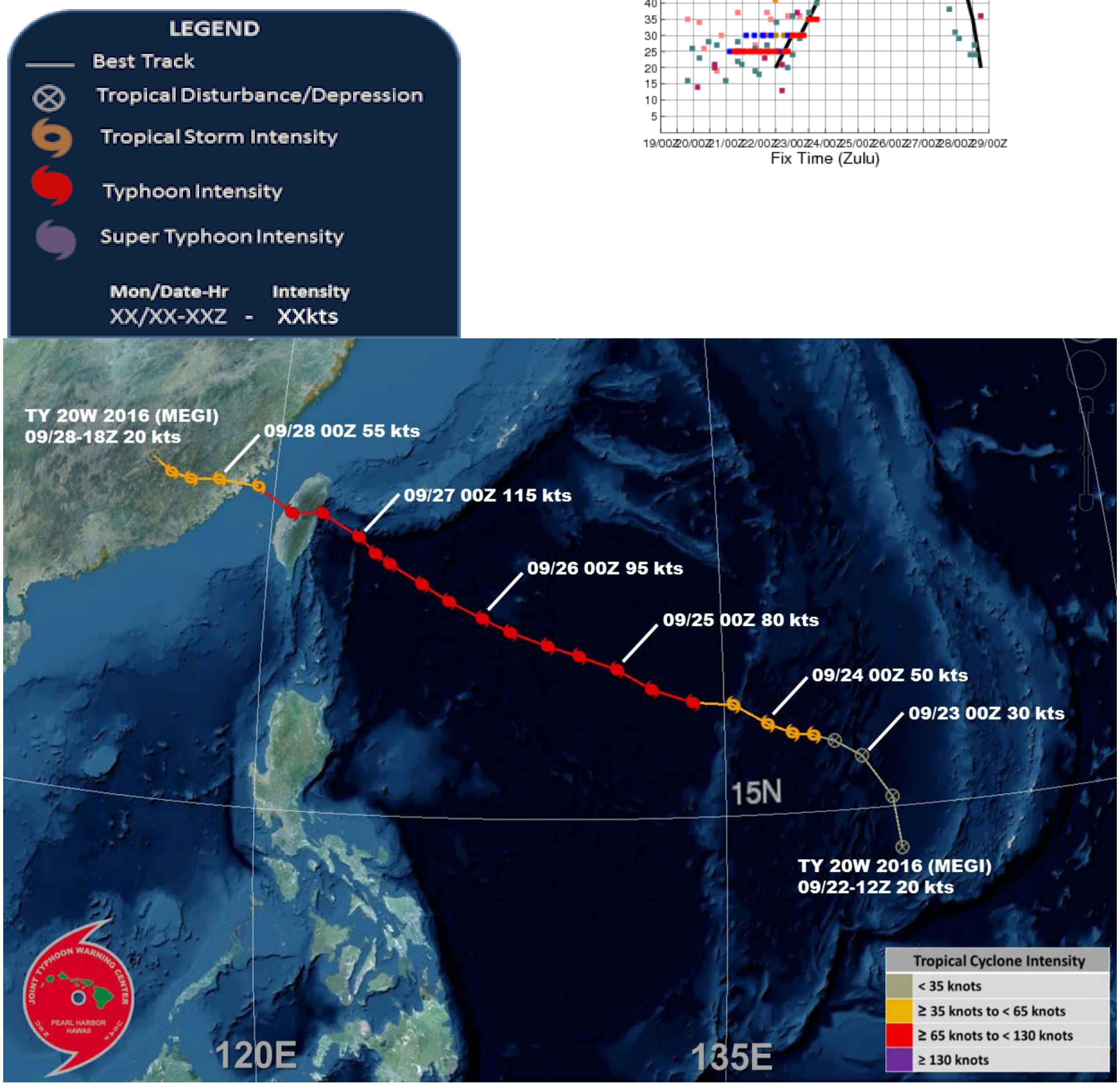




20W TYPHOON MEGI

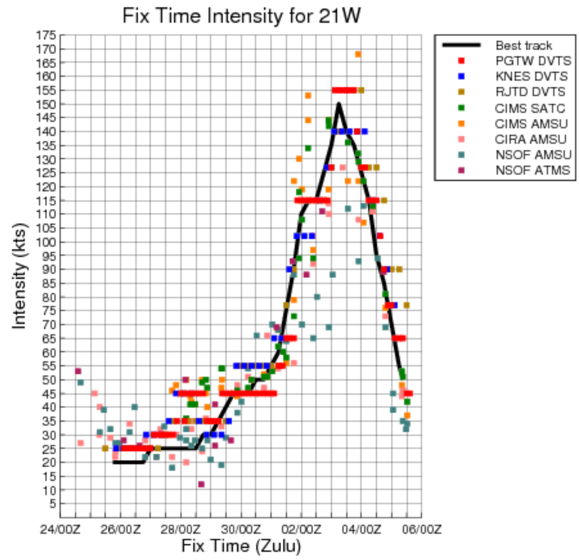
ISSUED LOW:	20 Sep / 0600Z
ISSUED MED:	20 Sep / 2200Z
FIRST TCFA:	21 Sep / 0600Z
FIRST WARNING:	23 Sep / 0000Z
LAST WARNING:	27 Sep / 1800Z
MAX INTENSITY:	120
WARNINGS:	20

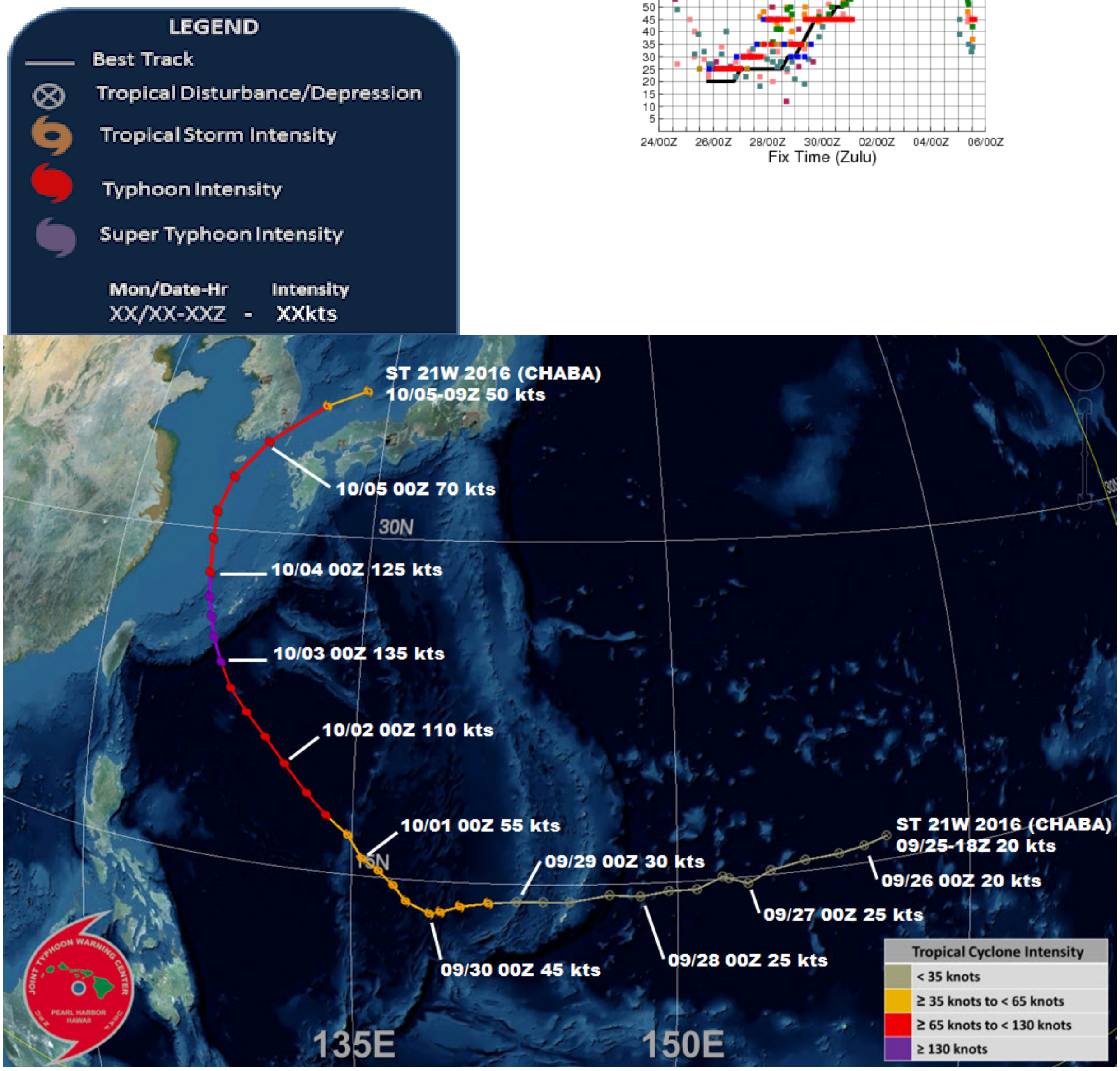




21W SUPER TYPHOON CHABA

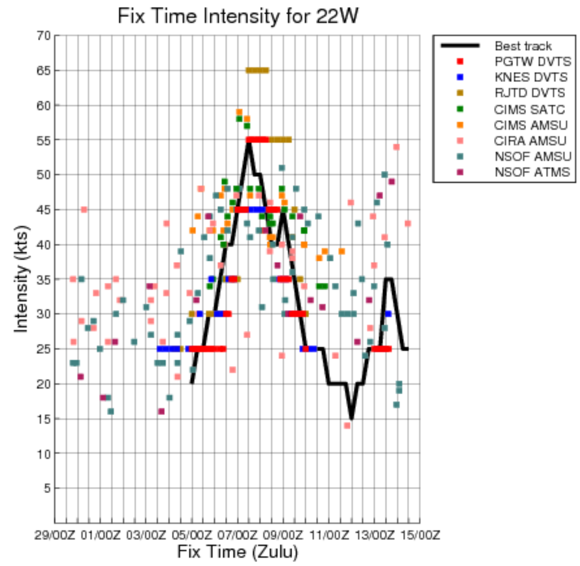
ISSUED LOW:	26 Sep / 0600Z
ISSUED MED:	27 Sep / 0600Z
FIRST TCFA:	27 Sep / 2000Z
FIRST WARNING:	28 Sep / 0000Z
LAST WARNING:	05 Oct / 0600Z
MAX INTENSITY:	150
WARNINGS:	30

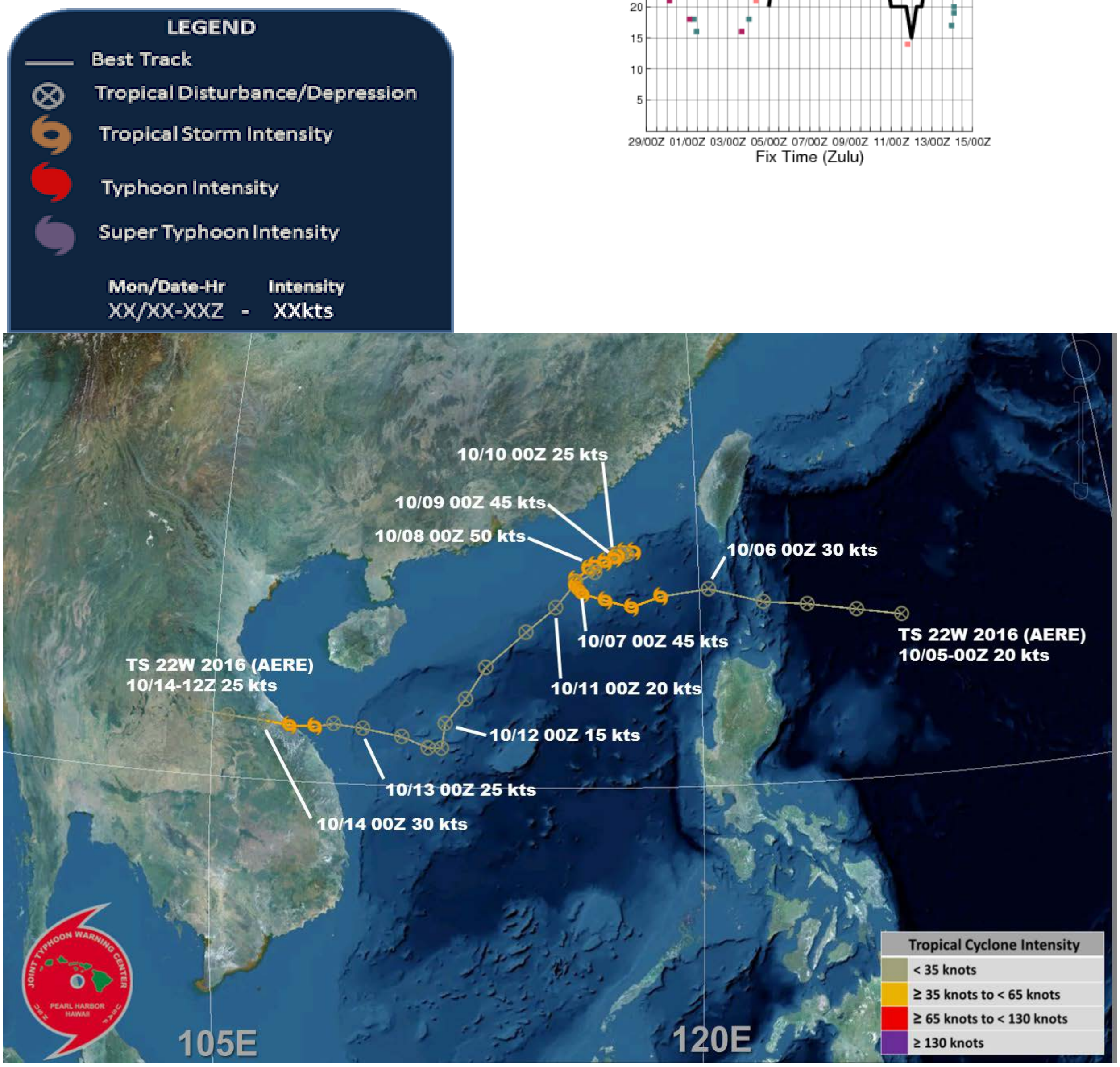




22W TROPICAL STORM AERE

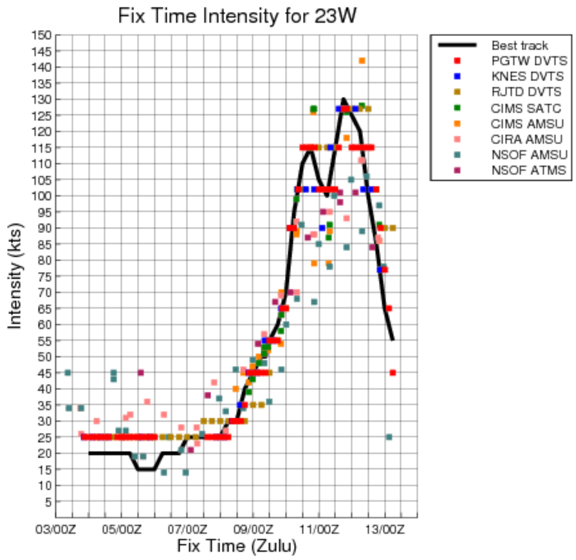
ISSUED LOW:	02 Oct / 0600Z
ISSUED MED:	03 Oct / 1500Z
FIRST TCFA:	05 Oct / 0130Z
FIRST WARNING:	05 Oct / 1200Z
LAST WARNING:	10 Oct / 0000Z
MAX INTENSITY:	55
WARNINGS:	19

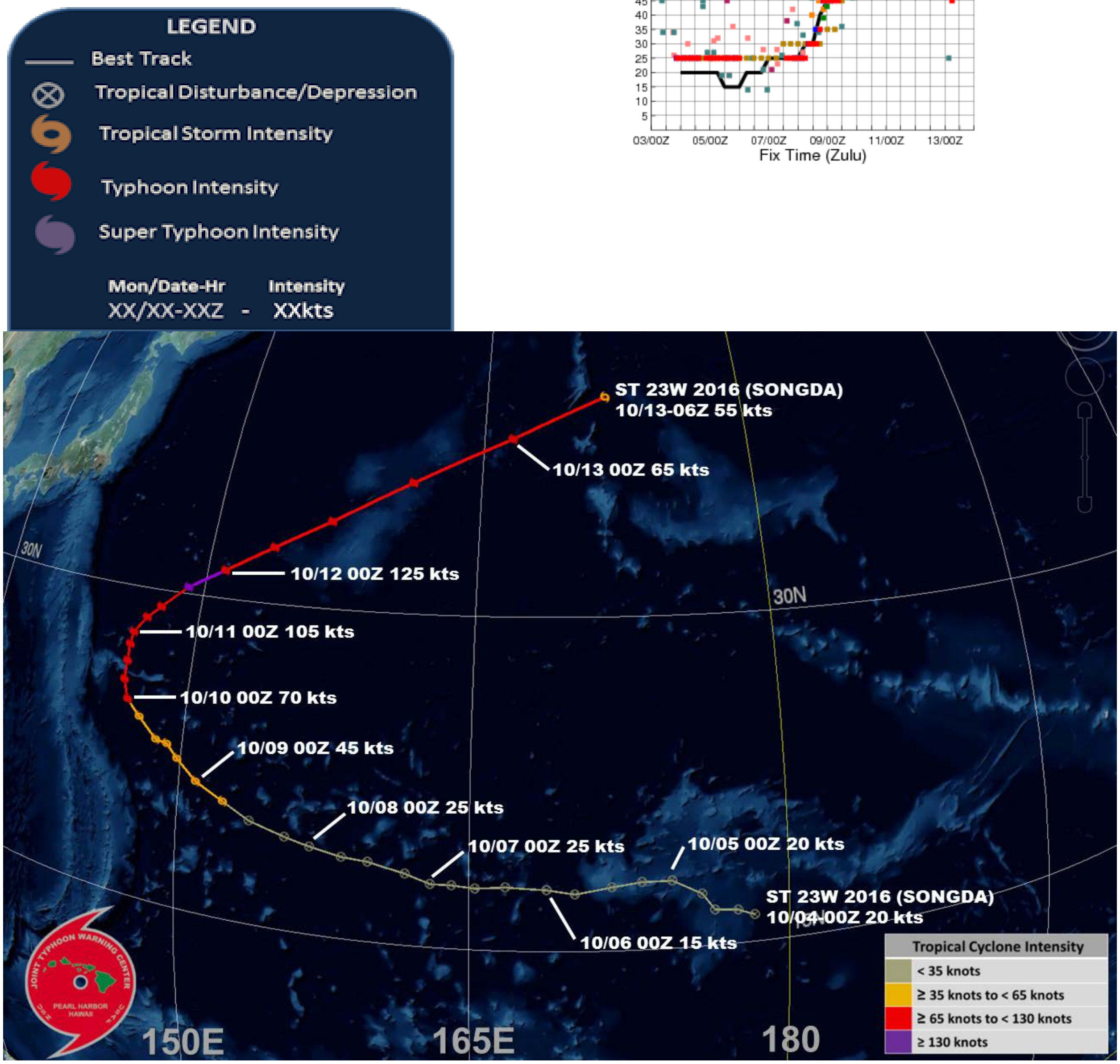




23W SUPER TYPHOON SONGDA

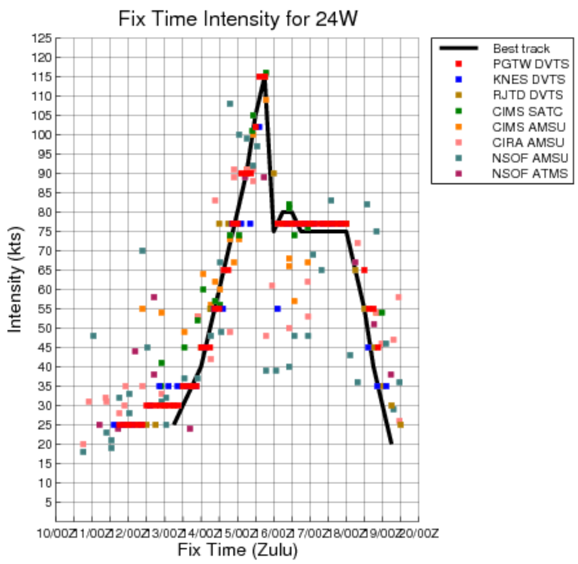
ISSUED LOW:	04 Oct / 0230Z
ISSUED MED:	05 Oct / 0200Z
FIRST TCFA:	07 Oct / 2200Z
FIRST WARNING:	08 Oct / 0600Z
LAST WARNING:	12 Oct / 0600Z
MAX INTENSITY:	130
WARNINGS:	17

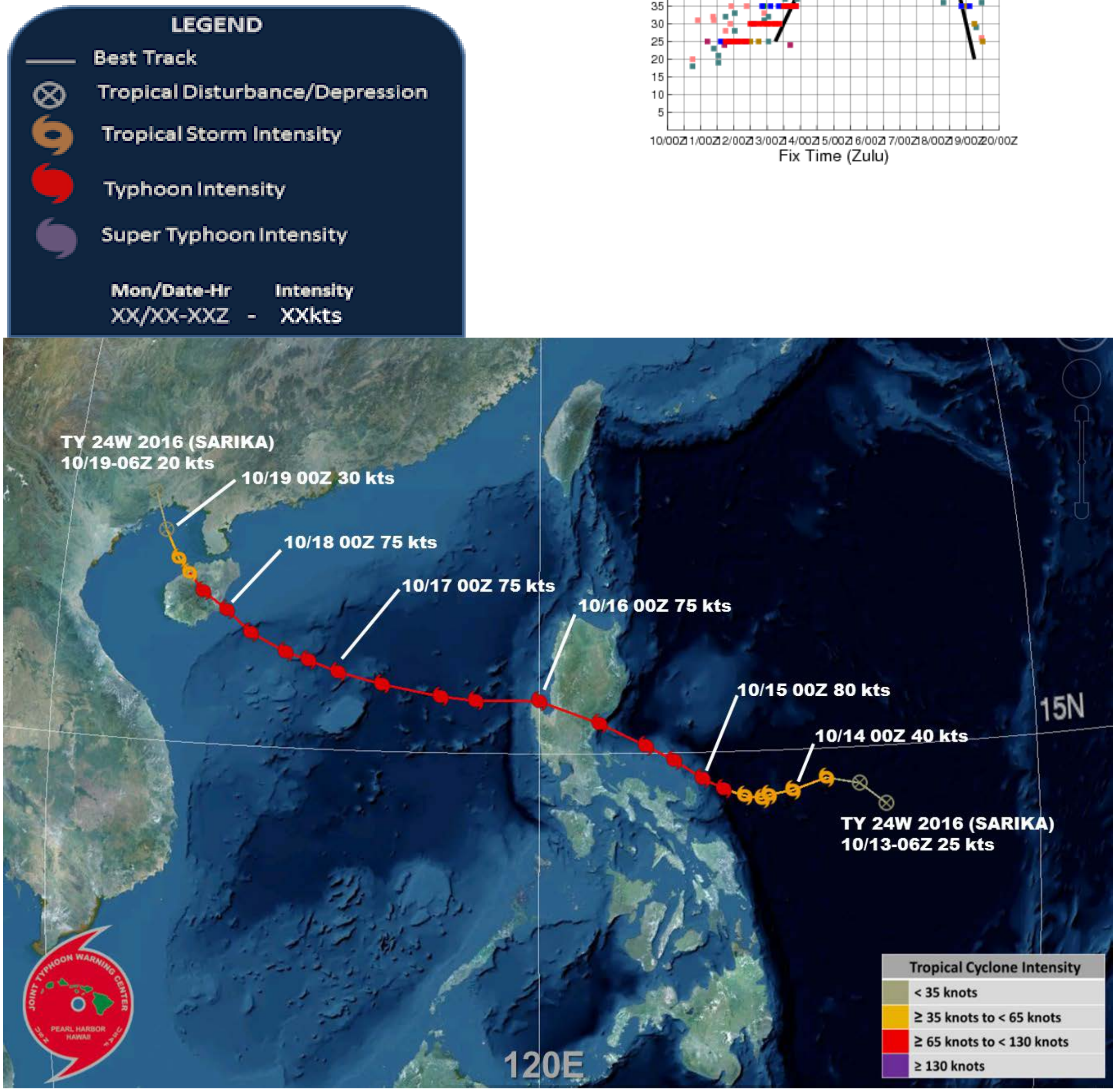




24W TYPHOON SARIKA

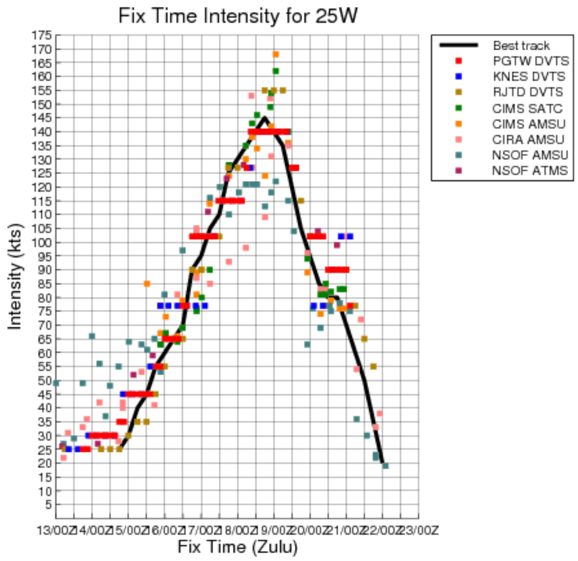
ISSUED LOW:	11 Oct / 0600Z
ISSUED MED:	None
FIRST TCFA:	11 Oct / 2200Z
FIRST WARNING:	12 Oct / 1200Z
LAST WARNING:	19 Oct / 0600Z
MAX INTENSITY:	115
WARNINGS:	28

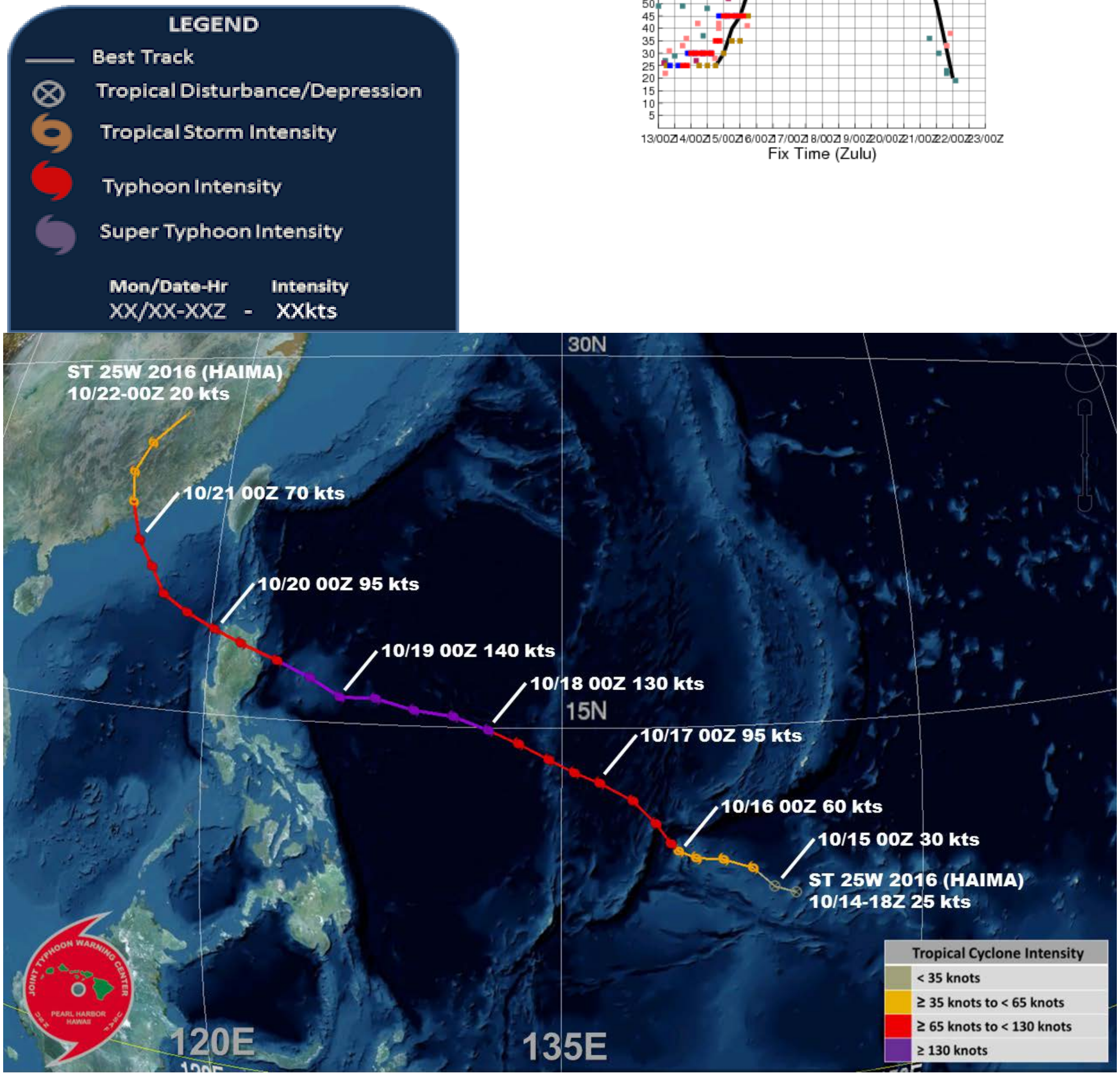




25W SUPER TYPHOON HAIMA

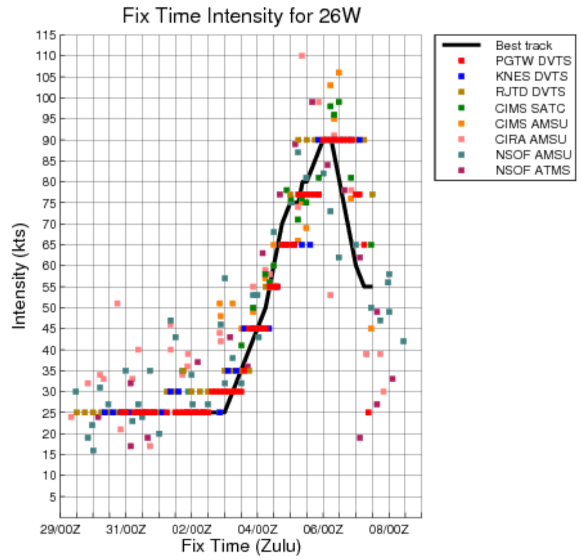
ISSUED LOW:	13 Oct / 0600Z
ISSUED MED:	None
FIRST TCFA:	13 Oct / 2030Z
FIRST WARNING:	14 Oct / 1800Z
LAST WARNING:	21 Oct / 0600Z
MAX INTENSITY:	145
WARNINGS:	27

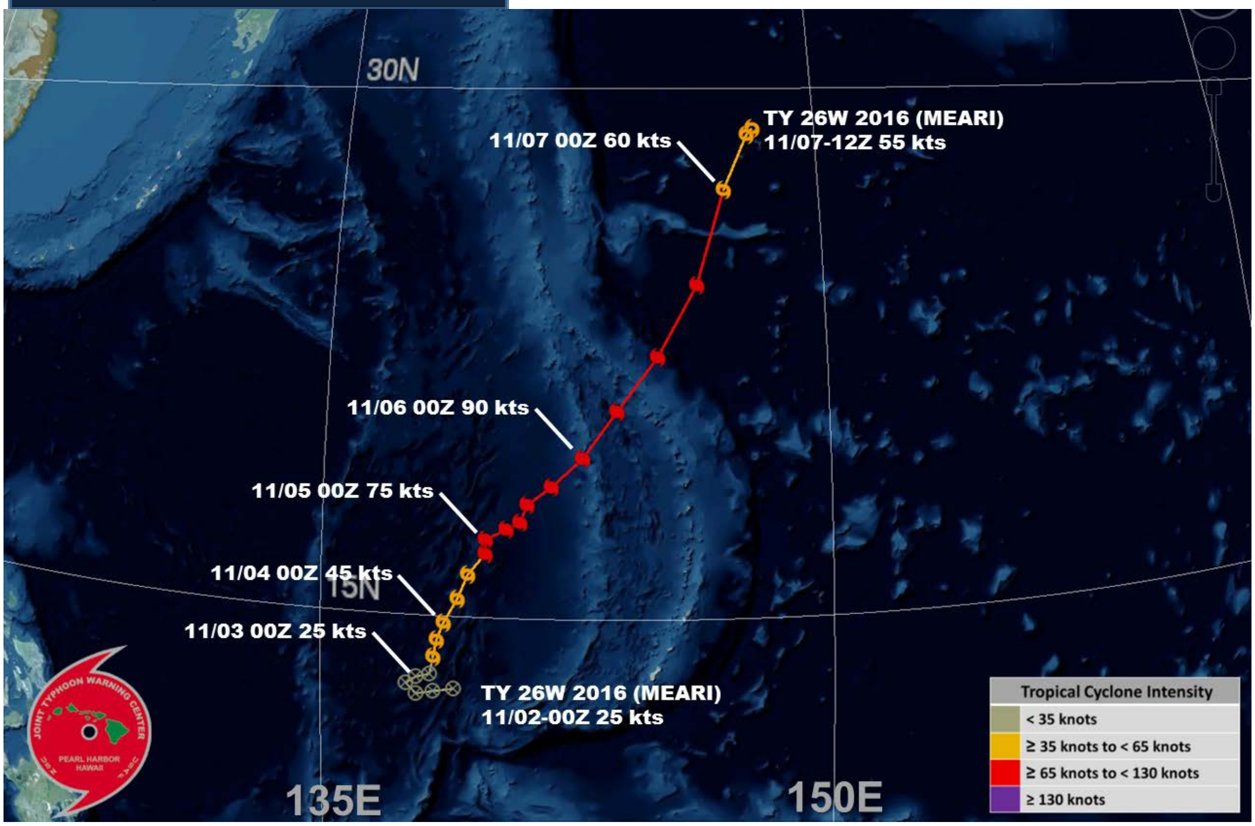




26W TYPHOON MEARI

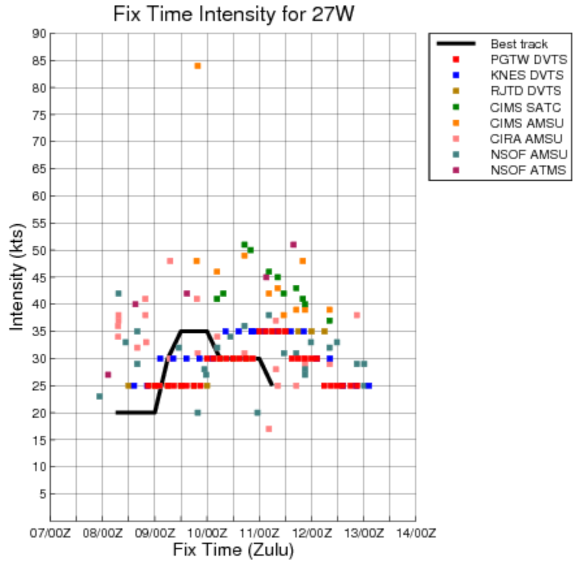
ISSUED LOW:	None
ISSUED MED:	01 Nov / 0600Z
FIRST TCFA:	02 Nov / 0430Z
FIRST WARNING:	02 Nov / 1800Z
LAST WARNING:	07 Nov / 0600Z
MAX INTENSITY:	90
WARNINGS:	19

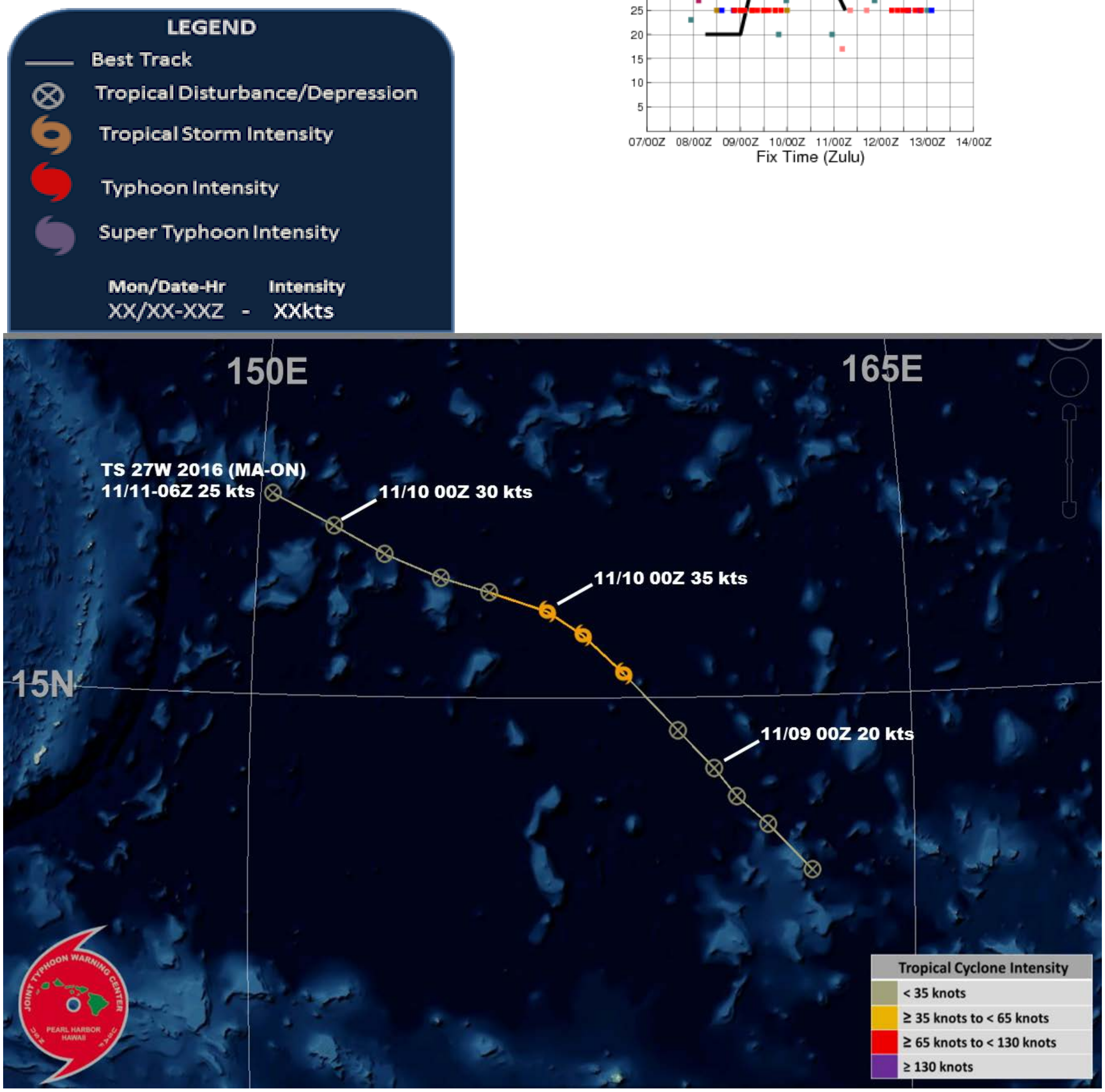




27W TROPICAL STORM MA-ON

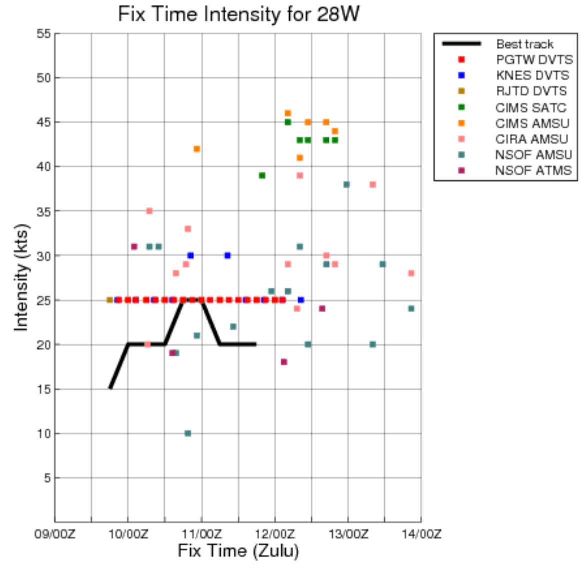
ISSUED LOW:	None
ISSUED MED:	None
FIRST TCFA:	09 Nov / 0300Z
FIRST WARNING:	09 Nov / 1800Z
LAST WARNING:	12 Nov / 0600Z
MAX INTENSITY:	35
WARNINGS:	11

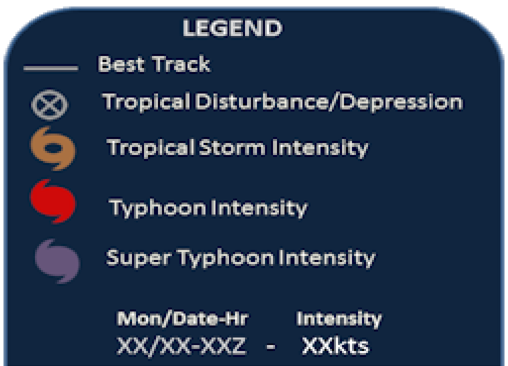


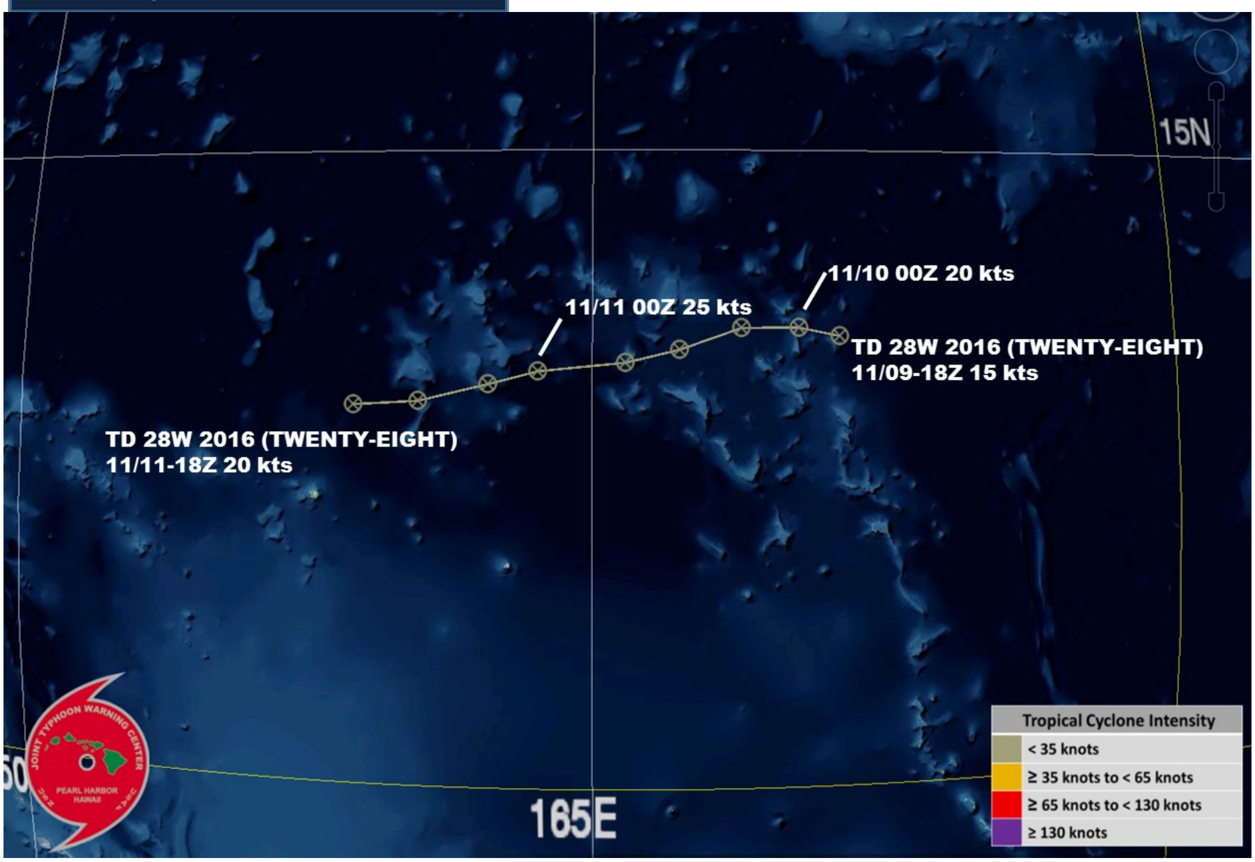


28W TROPICAL DEPRESSION TWENTYEIGHT

ISSUED LOW:	09 Nov / 2330Z
ISSUED MED:	None
FIRST TCFA:	10 Nov / 0530Z
FIRST WARNING:	11 Nov / 0000Z
LAST WARNING:	12 Nov / 0600Z
MAX INTENSITY:	25
WARNINGS:	6

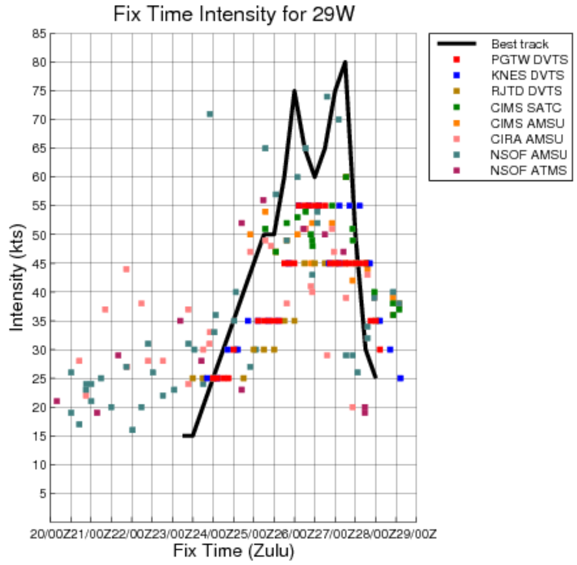


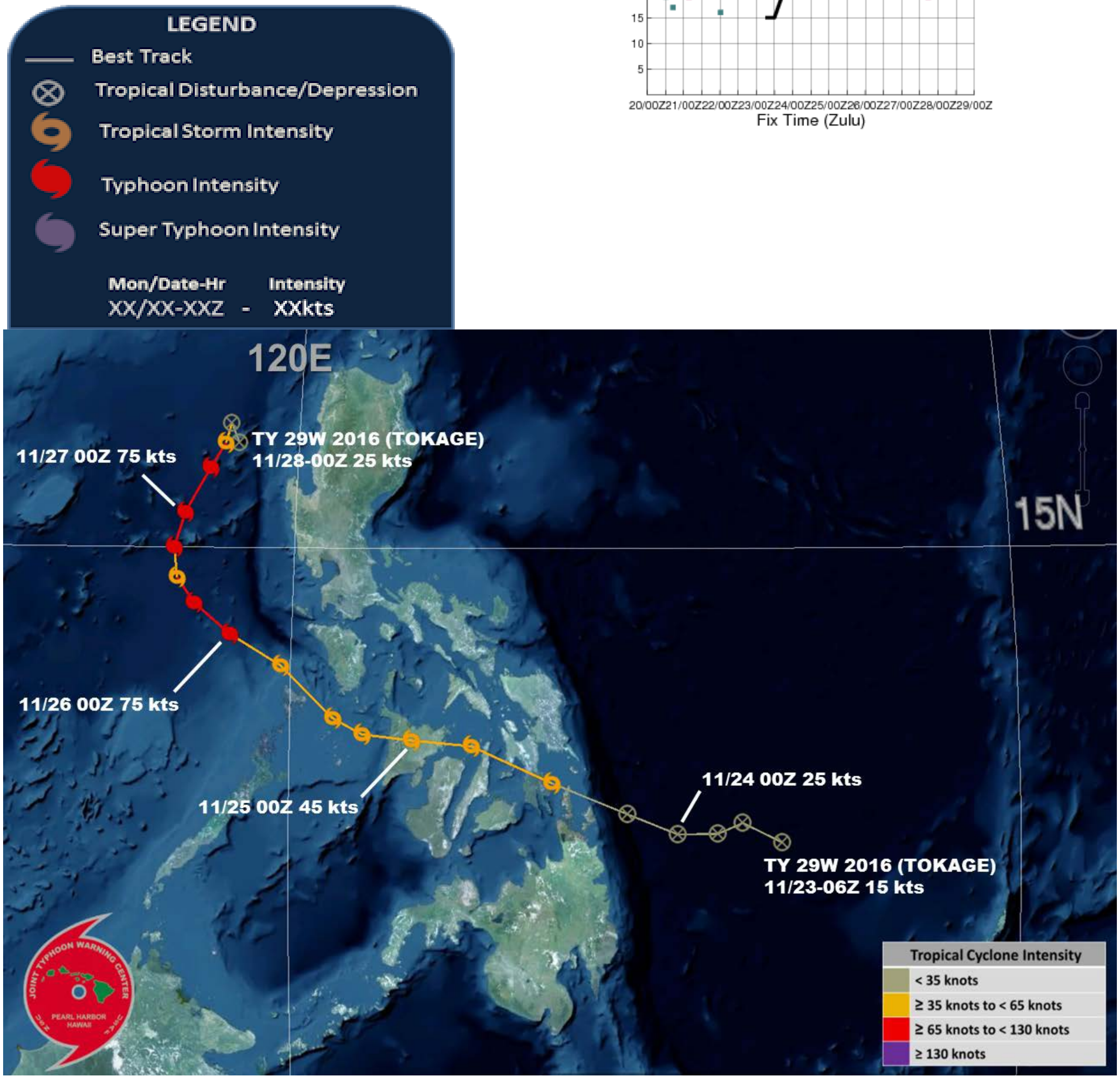




29W TYPHOON TOKAGE

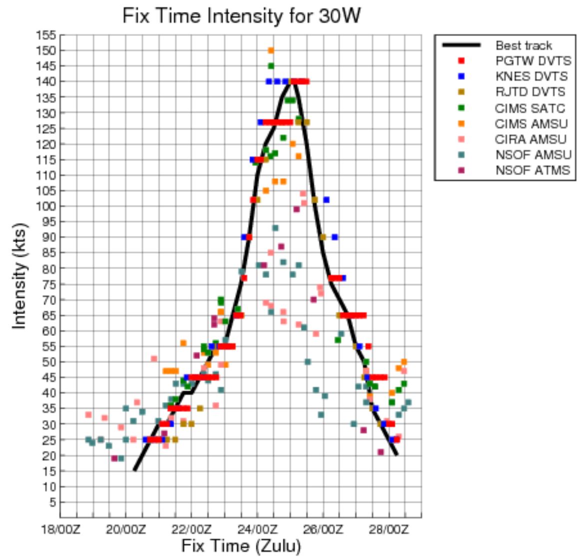
ISSUED LOW:	21 Nov / 1430Z
ISSUED MED:	23 Nov / 2300Z
FIRST TCFA:	24 Nov / 0330Z
FIRST WARNING:	24 Nov / 1200Z
LAST WARNING:	28 Nov / 0600Z
MAX INTENSITY:	80
WARNINGS:	16

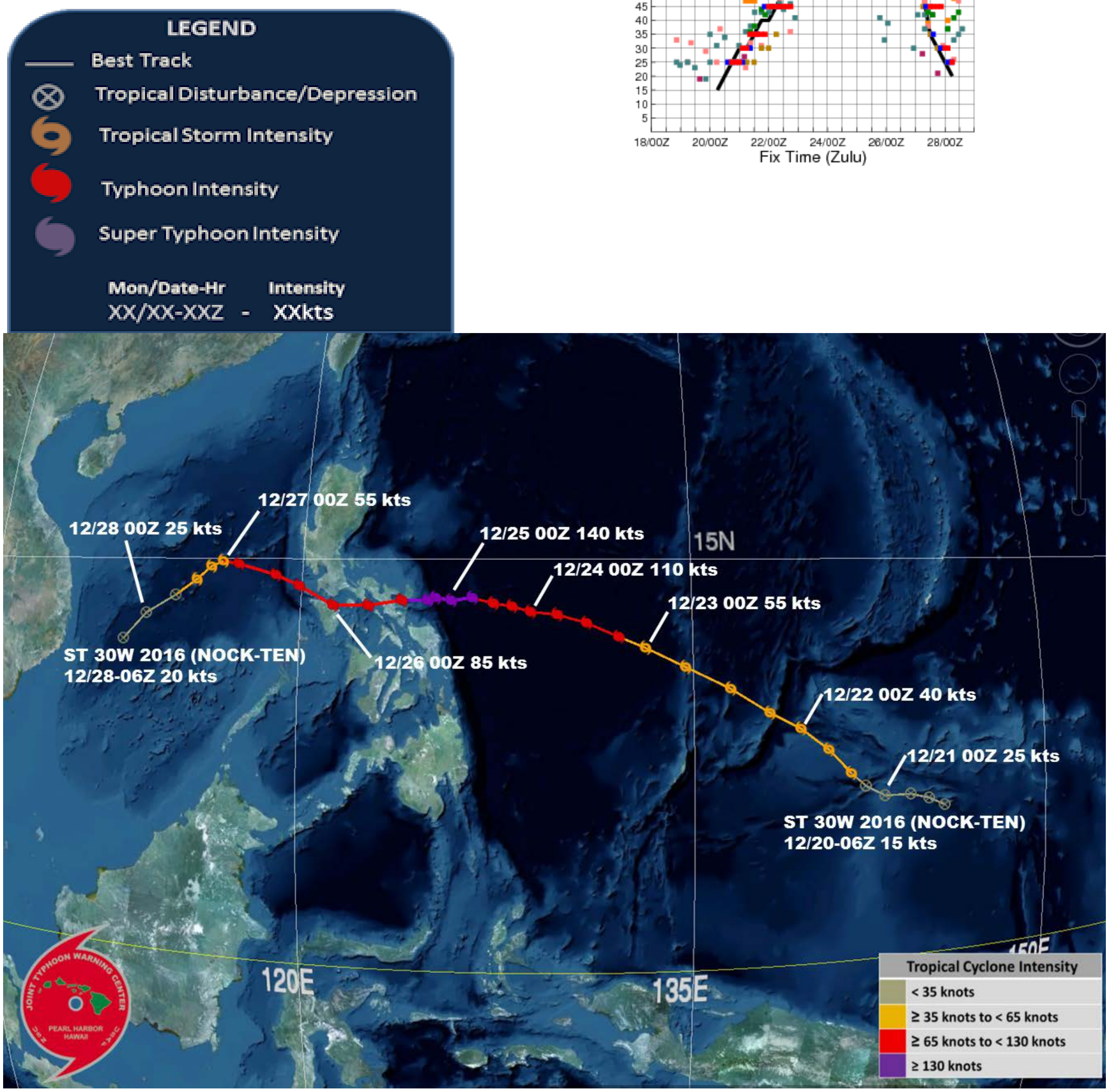




30W SUPER TYPHOON NOCK-TEN

ISSUED LOW:	20 Dec / 0600Z
ISSUED MED:	21 Dec / 0130Z
FIRST TCFA:	21 Dec / 0300Z
FIRST WARNING:	21 Dec / 0600Z
LAST WARNING:	28 Dec / 0000Z
MAX INTENSITY:	140
WARNINGS:	28





Chapter 2 North Indian Ocean Tropical Cyclones

This chapter contains information on north Indian Ocean TC activity during 2016 and the monthly distribution of TC activity summarized for 1975 - 2016. North Indian Ocean tropical cyclone best tracks appear following Table 2-2.

Section 1 Informational Tables

Table 2-1 is a summary of TC activity in the north Indian Ocean during the 2016 season. Five cyclones occurred in 2016, with one system reaching intensity greater than 64 knots. Table 2-2 shows the monthly distribution of Tropical Cyclone activity for 1975 - 2016.

Table 2-1

NORTH INDIAN OCEAN SIGNIFICANT TROPICAL CYCLONES

(01 JAN 2016- 31 DEC 2016)

TC	NAME*	PERIOD**		WARNINGS ISSUED	EST MAX SFC WINDS KTS
01B	ROANU	18 May / 0600Z	21 May / 1200Z	14	60
02A	TWO	27 Jun / 0000Z	28 Jun / 1800Z	8	40
03B	KYANT	25 Oct / 0000Z	26 Oct / 1800Z	8	40
04B	NADA	29 Nov / 1800Z	01 Dec / 1200Z	8	45
05B	VARDAH	07 Dec / 1200Z	12 Dec / 0600Z	20	85

* As designated by the responsible RSMC

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

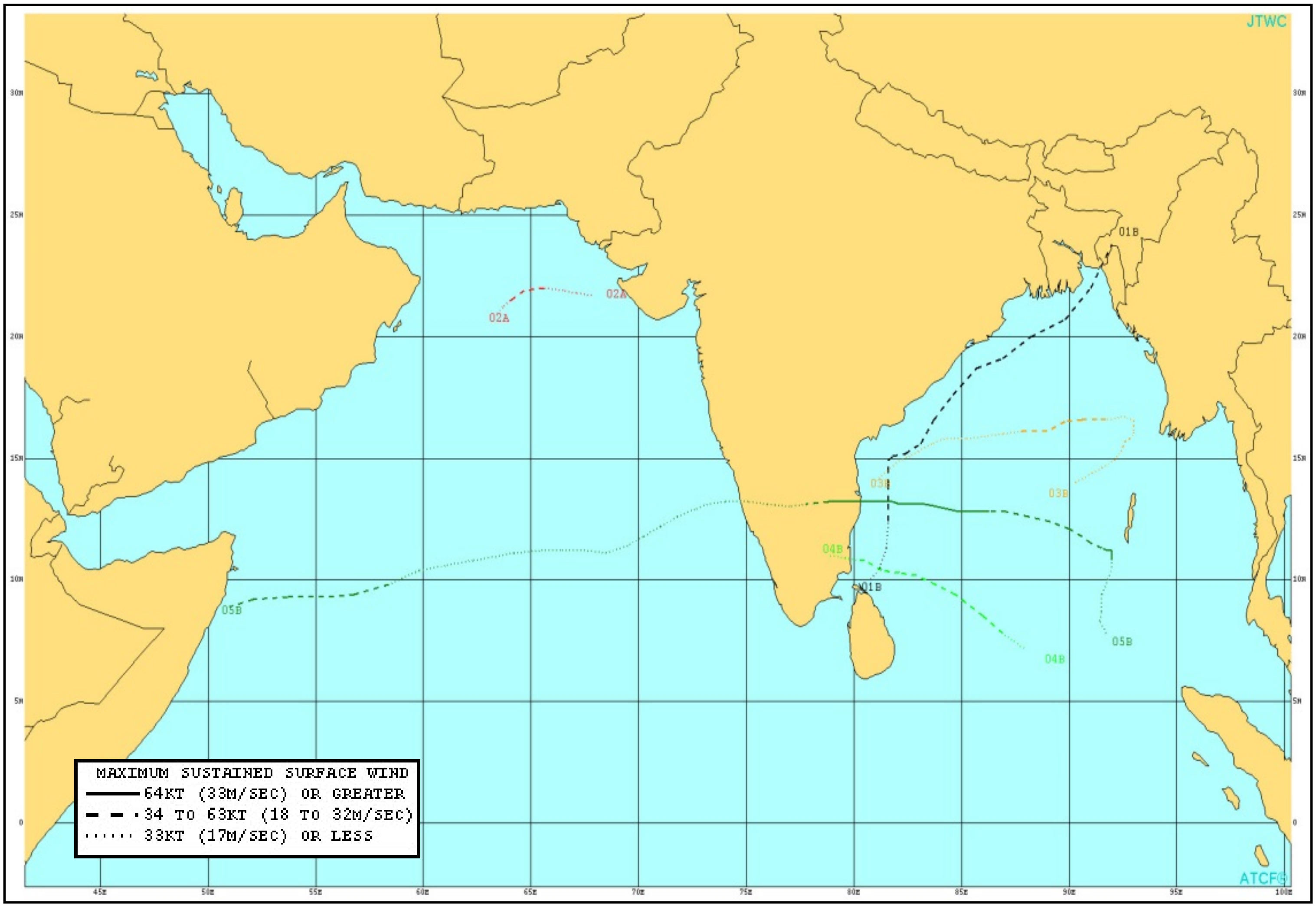


Figure 2-1. North Indian Ocean Tropical Cyclones.

Table 2 - 2
DISTRIBUTION OF NORTH INDIAN OCEAN TROPICAL CYCLONES FOR 1975 - 2016

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total ≥64kt	Total 34-63kt	Total ≤33 kt
													TOTALS		
	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
(1975-2016)															
MEAN	0.2	0.0	0.0	0.2	0.7	0.6	0.1	0.0	0.3	1.1	1.4	0.6	5.1		
CASES	7	2	1	7	29	24	4	1	13	45	57	24	214		

Section 2 Cyclone Summaries

Each cyclone is presented, with the number and basin identifier assigned by JTWC, along with the RSMC assigned cyclone name. Dates are also listed when JTWC first designated Low and Medium stages of development:

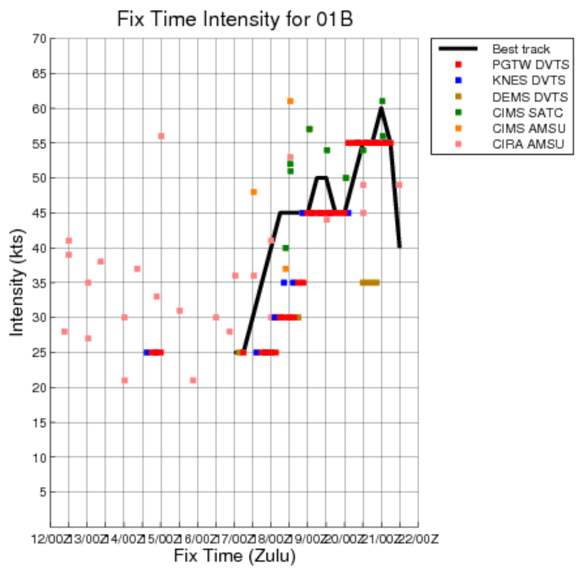
The first Tropical Cyclone Formation Alert (TCFA) and the initial and final warning dates are also presented with the number of warnings issued by JTWC. Landfall over major landmasses with approximate locations are presented as well.

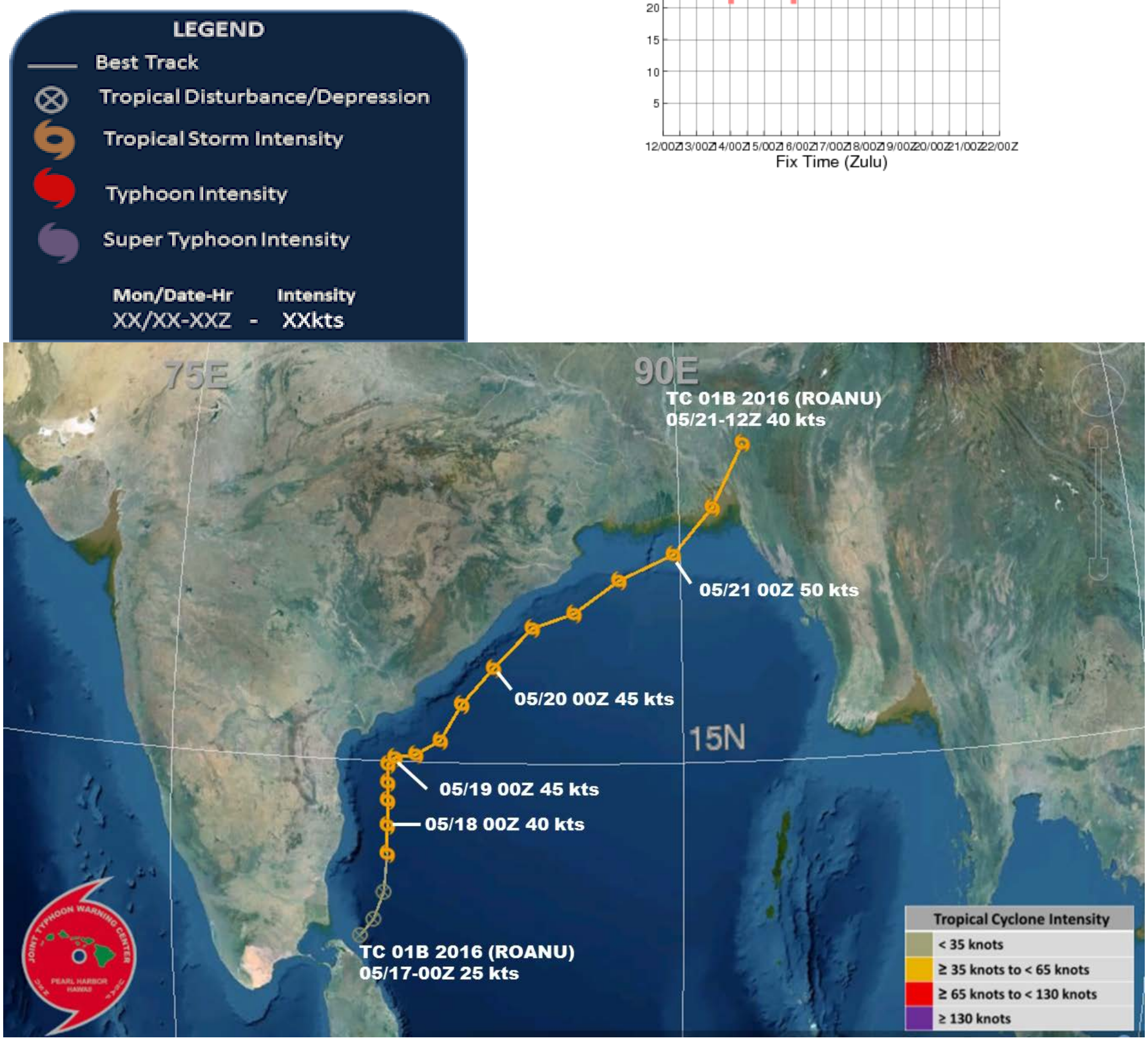
The JTWC post-event reanalysis best track is also provided for each cyclone. Data included on the best track are position and intensity noted with cyclone symbols and color coded track. Best track position labels include the date-time, track speed in knots, and maximum wind speed in knots. A graph of best track intensity versus time is presented. Fix plots on this graph are color coded by fixing agency.

In addition, when this document is viewed as a pdf, each map has been hyperlinked to the appropriate keyhole markup language (kmz) file that will allow the reader to access and view the best-track data interactively on their computer using Google Earth software. Simply hold the control button and click the map image; the link will open allowing the reader to download and open the file.
Users may also retrieve kmz files for the entire season from:
https://metoc.ndbc.noaa.gov/ProductFeeds-portlet/img/jtwc/best_tracks/2016/2016s-bio/IO_besttracks_2016-2016.kmz

01B TROPICAL CYCLONE ROANU

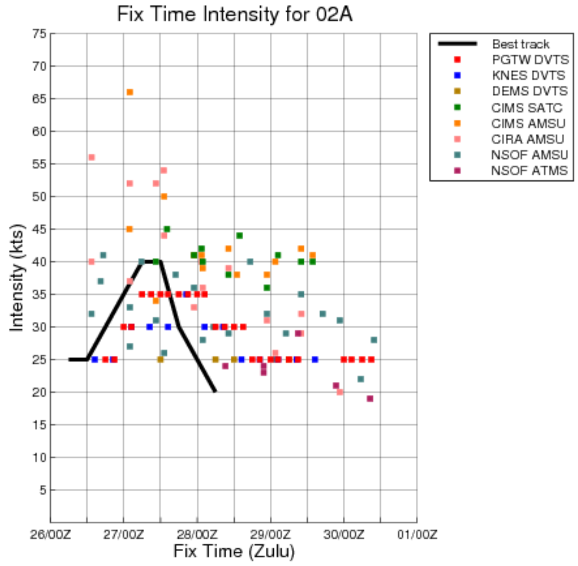
ISSUED LOW:	13 May / 0230Z
ISSUED MED:	14 May / 1800Z
FIRST TCFA:	17 May / 2300Z
FIRST WARNING:	18 May / 0600Z
LAST WARNING:	21 May / 1200Z
MAX INTENSITY:	60
WARNINGS:	14

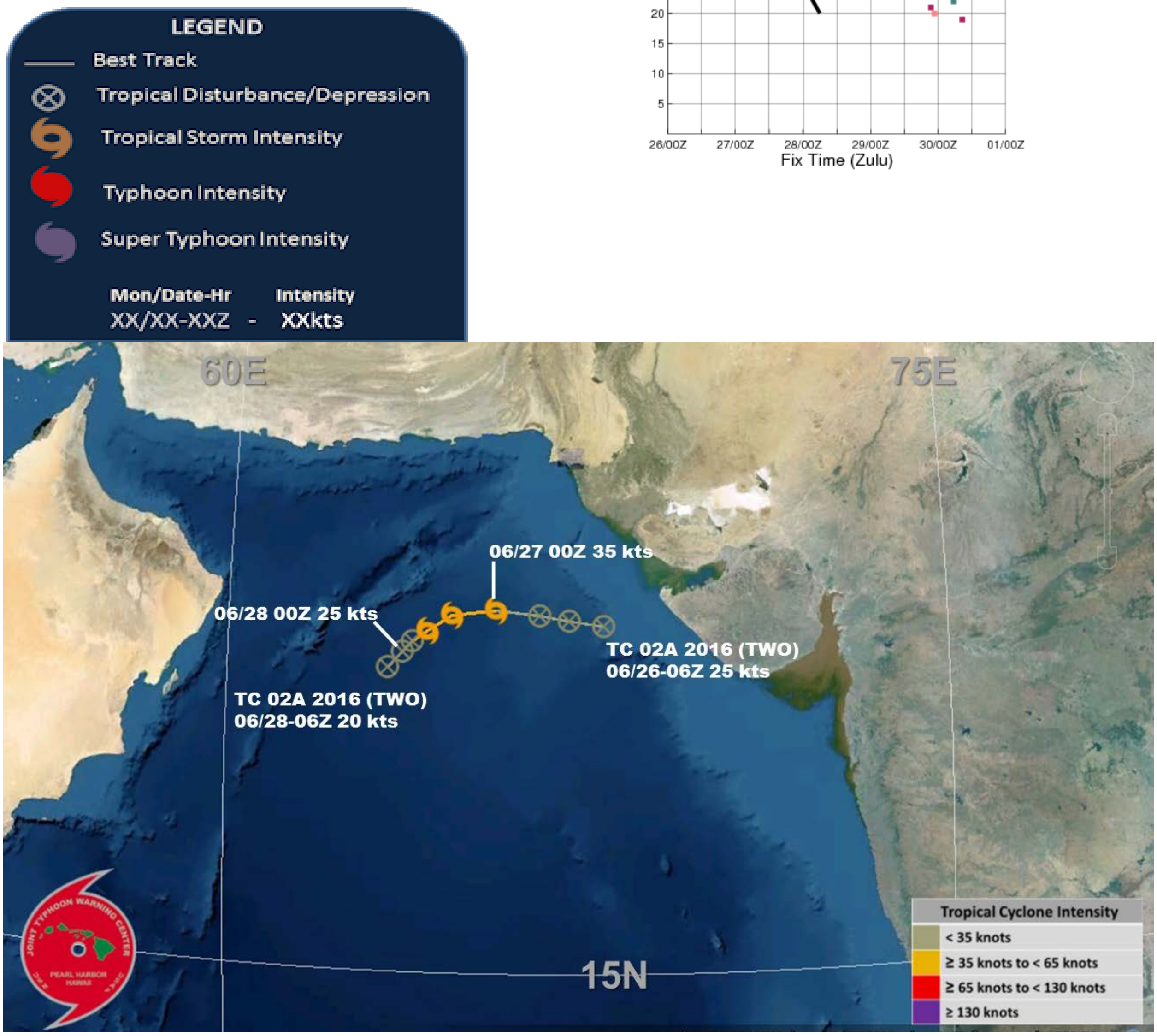




02A TROPICAL CYCLONE TWO

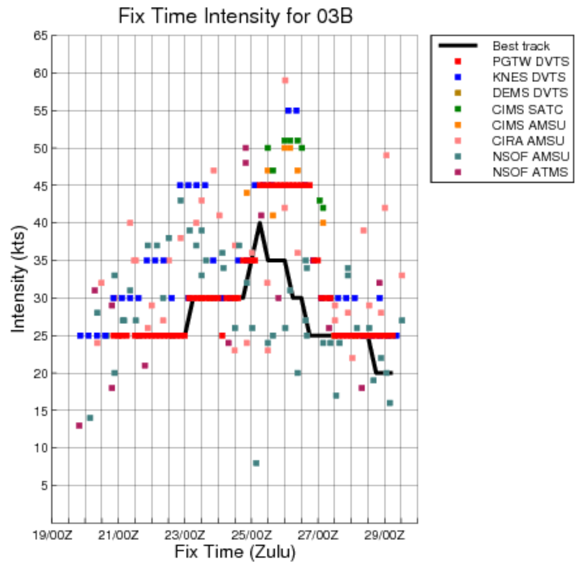
ISSUED LOW:	26 Jun / 1800Z
ISSUED MED:	None
FIRST TCFA:	26 Jun / 2030Z
FIRST WARNING:	27 Jun / 0000Z
LAST WARNING:	28 Jun / 1800Z
MAX INTENSITY:	40
WARNINGS:	8

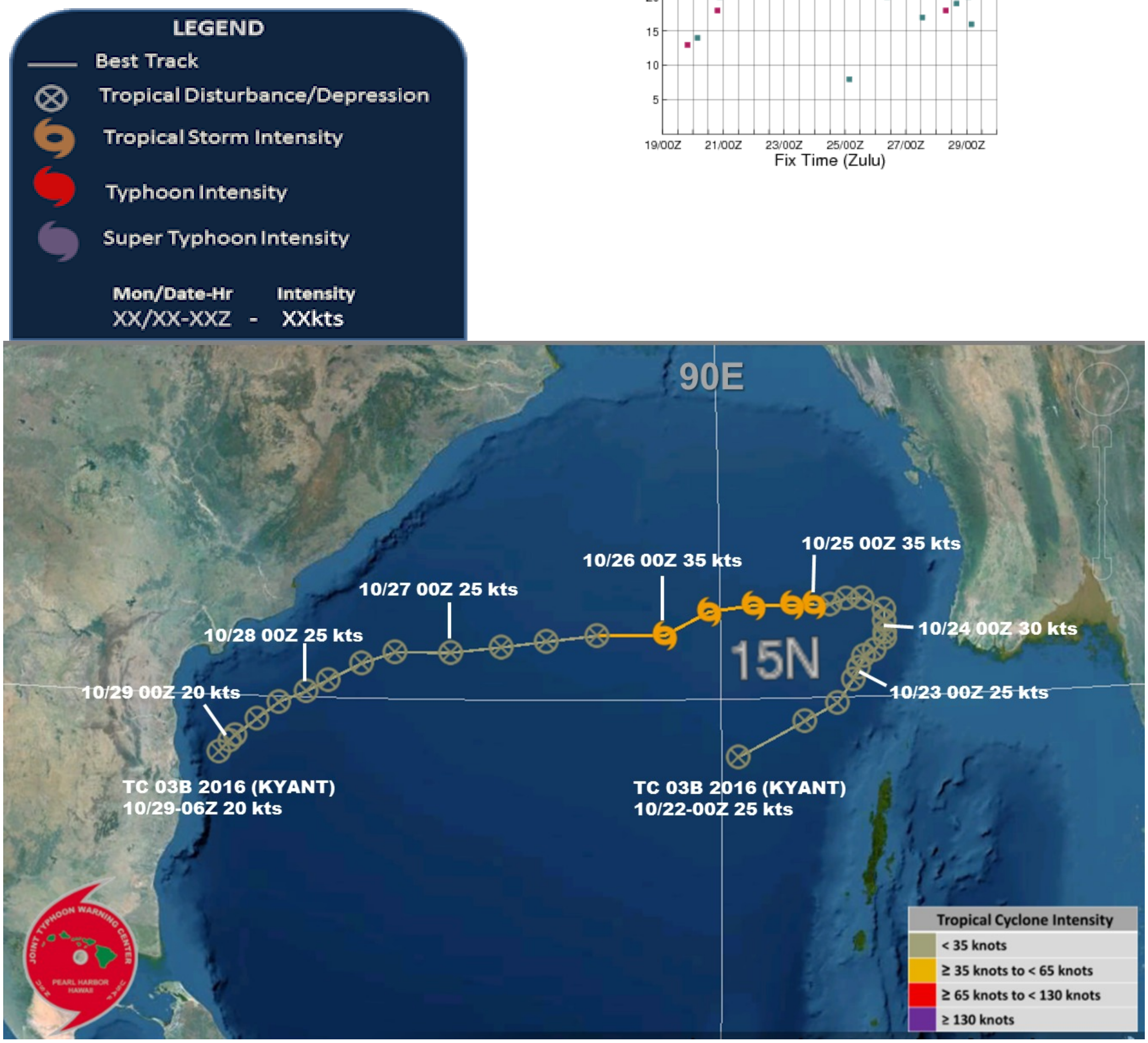




03B TROPICAL CYCLONE KYANT

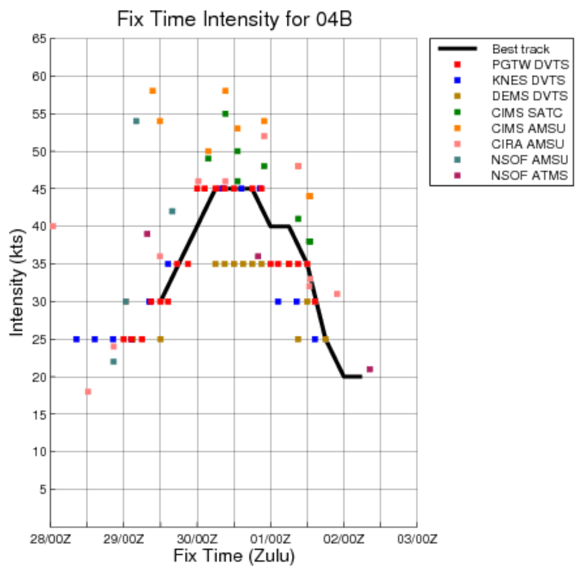
ISSUED LOW:	19 Oct / 1800Z
ISSUED MED:	20 Oct / 1800Z
FIRST TCFA:	23 Oct / 0800Z
FIRST WARNING:	25 Oct / 0000Z
LAST WARNING:	26 Oct / 1800Z
MAX INTENSITY:	40
WARNINGS:	8

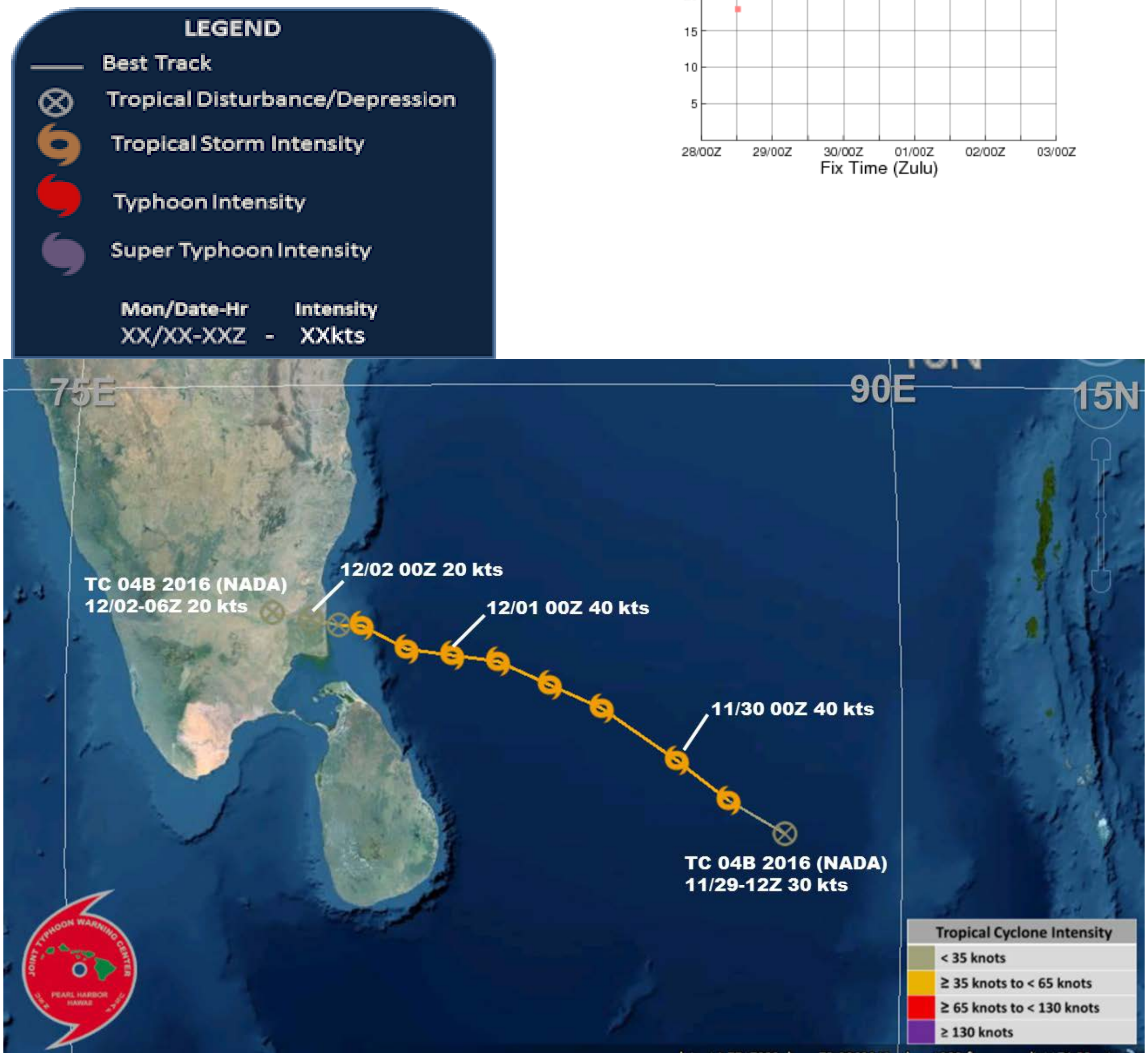




04B TROPICAL CYCLONE NADA

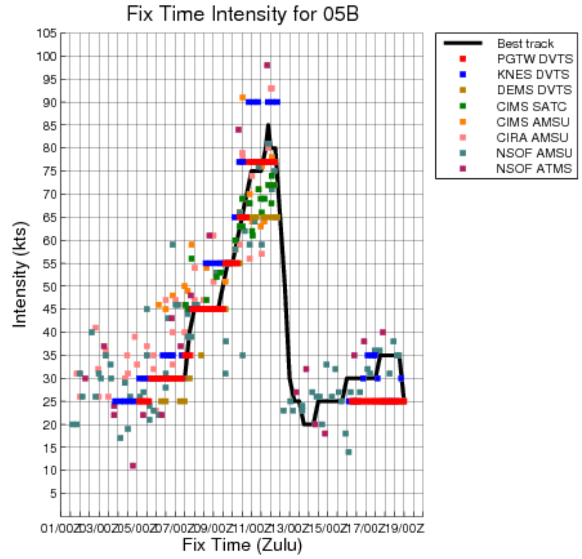
ISSUED LOW:	28 Nov / 1800Z
ISSUED MED:	29 Nov / 0200Z
FIRST TCFA:	29 Nov / 1000Z
FIRST WARNING:	29 Nov / 1800Z
LAST WARNING:	01 Dec / 1200Z
MAX INTENSITY:	45
WARNINGS:	8

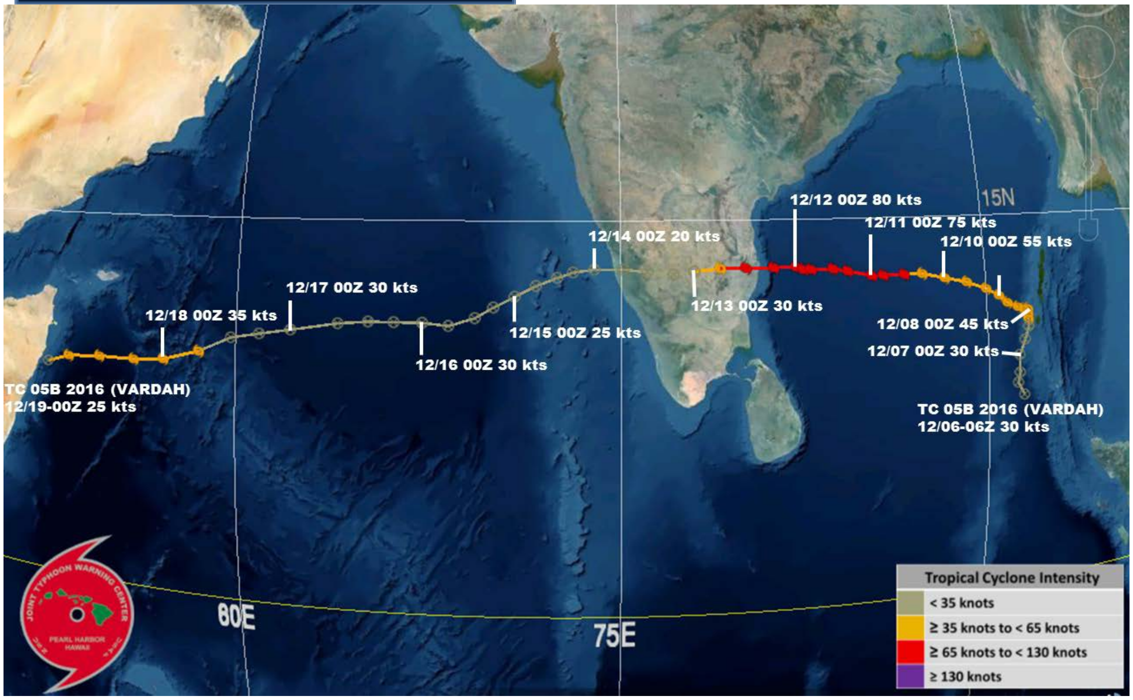




05B TROPICAL CYCLONE VARDAH

ISSUED LOW:	03 Dec / 0100Z
ISSUED MED:	03 Dec / 1800Z
FIRST TCFA:	06 Dec / 1600Z
FIRST WARNING:	07 Dec / 1200Z
LAST WARNING:	12 Dec / 0600Z
MAX INTENSITY:	85
WARNINGS:	20





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 2016 tropical cyclone season (1 July 2015 – 30 June 2016) and the monthly distribution of TC activity summarized for 1975 - 2016.

Section 1 Informational Tables

Table 3-1 is a summary of TC activity in the Southern Hemisphere during the 2016 season.

Table 3-1

SOUTHERN HEMISPHERE TROPICAL CYCLONES

(01 JULY 2015- 30 JUNE 2016)

TC	NAME*	PERIOD**		WARNINGS ISSUED	EST MAX SFC WINDS KTS
01P	ONE	02 Aug / 1800Z	03 Aug / 1800Z	3	40
02P	TWO	15 Oct / 1800Z	17 Oct / 1800Z	5	35
03S	ANNABELLE	20 Nov / 1200Z	24 Nov / 1200Z	9	60
04P	TUNI	27 Nov / 1800Z	29 Nov / 1800Z	8	40
05S	BOHALE	10 Dec / 0600Z	12 Dec / 0600Z	5	35
06P	ULA	30 Dec / 0600Z	12 Jan / 1800Z	28	120
07P	VICTOR	14 Jan / 1800Z	22 Jan / 1800Z	17	90
08S	CORENTIN	21 Jan / 1200Z	25 Jan / 1200Z	9	80
09S	STAN	29 Jan / 0000Z	30 Jan / 1800Z	8	65
10S	DAYA	10 Feb / 1200Z	12 Feb / 0000Z	4	50
11P	WINSTON	10 Feb / 1200Z	24 Feb / 1800Z	47	155
12P	TATIANA	10 Feb / 1800Z	13 Feb / 1800Z	7	55
13S	URIAH	13 Feb / 1200Z	20 Feb / 0000Z	14	130
14P	YALO	25 Feb / 0000Z	26 Feb / 1200Z	4	55
15S	EMERAUDE	15 Mar / 1800Z	22 Mar / 0600Z	14	125
16P	SIXTEEN	16 Mar / 0000Z	16 Mar / 1200Z	2	40
17S	SEVENTEEN	28 Mar / 1800Z	30 Mar / 0600Z	4	45
18P	ZENA	05 Apr / 0600Z	07 Apr / 0600Z	8	90
19S	FANTALA	11 Apr / 1800Z	24 Apr / 0600Z	26	155
20P	AMOS	20 Apr / 0000Z	24 Apr / 1800Z	20	90

* As designated by the responsible RSMC

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

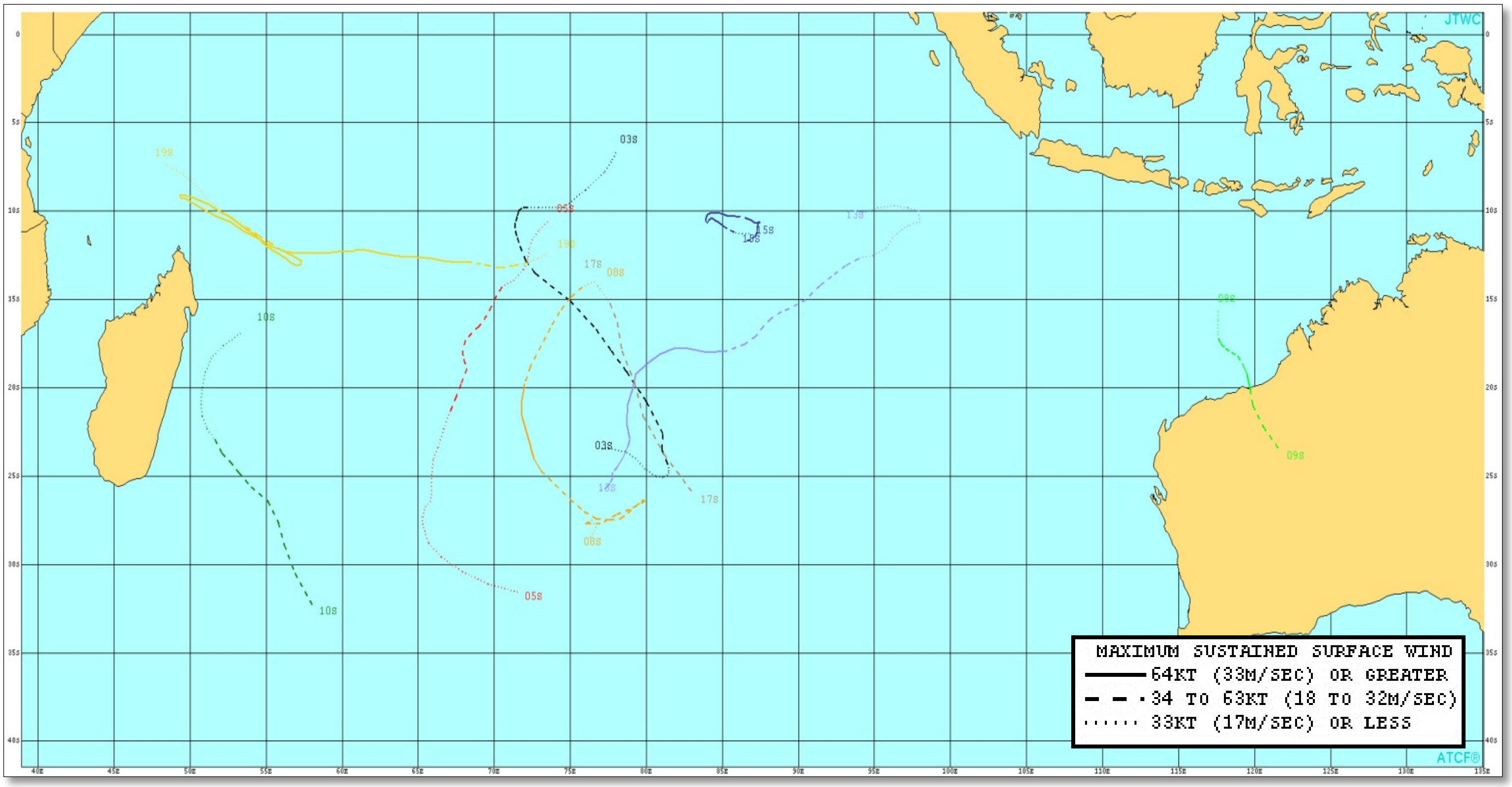


Figure 3-1. Southern Indian Ocean Tropical Cyclones

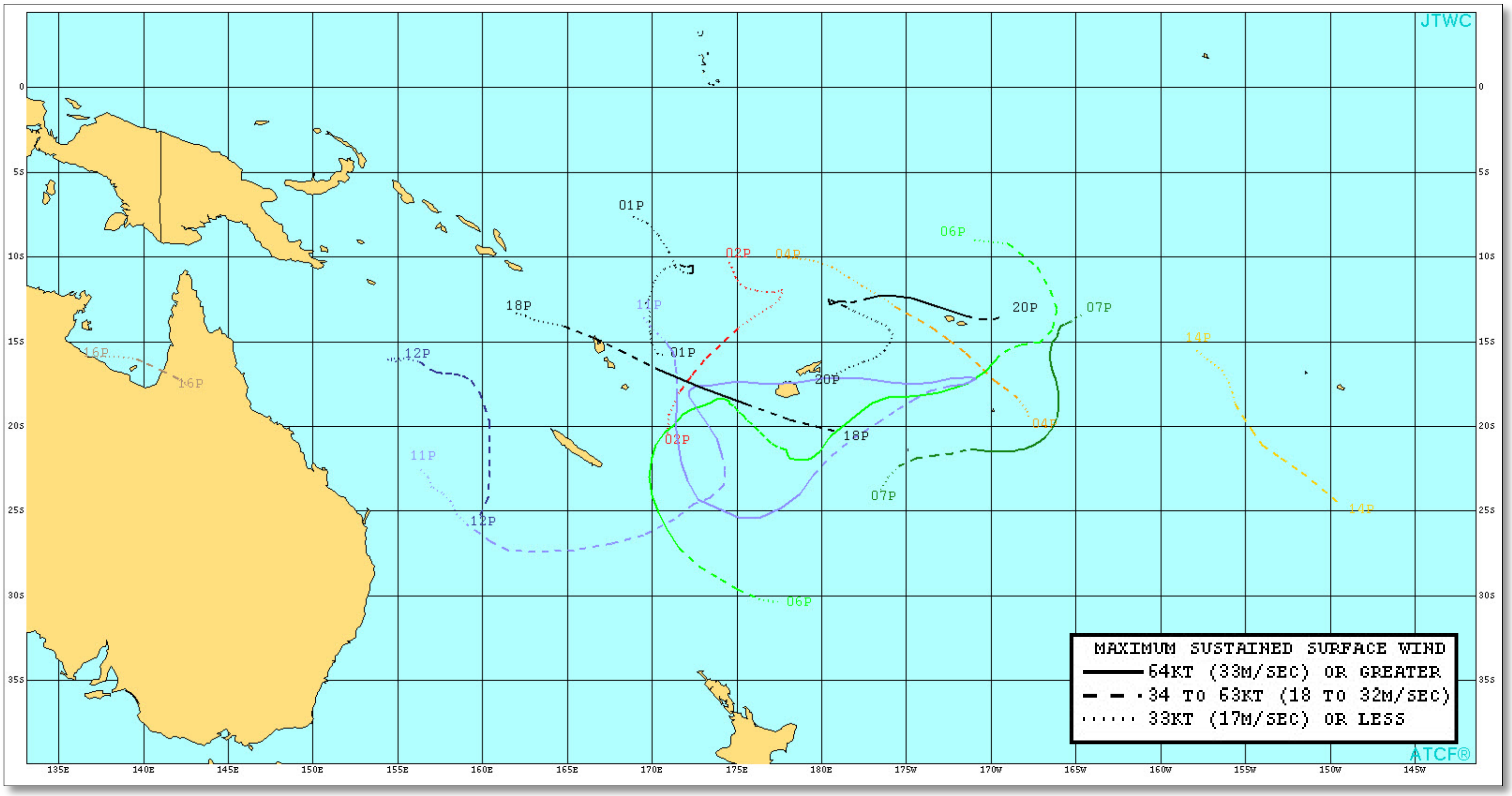


Figure 3-2. Southern Pacific Tropical Cyclones**.**

Table 3-2													
DISTRIBUTION OF SOUTH PACIFIC AND SOUTH INDIAN OCEAN TROPICAL CYCLONES FOR 1958 - 2016													
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 - 2016													
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
(1981 - 2016)													
MEAN	0.3	0.1	0.3	0.7	1.5	3.2	5.9	6.1	4.8	3.0	0.7	0.3	26.8
CASES	9	3	9	23	54	111	205	215	169	105	26	9	938
* (GRAY, 1978)													

Table 3-2 Monthly distribution of Tropical Cyclone activity summarized for 1975 - 2016.

Section 2 Cyclone Summaries

Each cyclone is presented, with the number and basin identifier assigned by JTWC, along with the RSMC assigned cyclone name. Dates are also listed when JTWC first designated various stages of development.

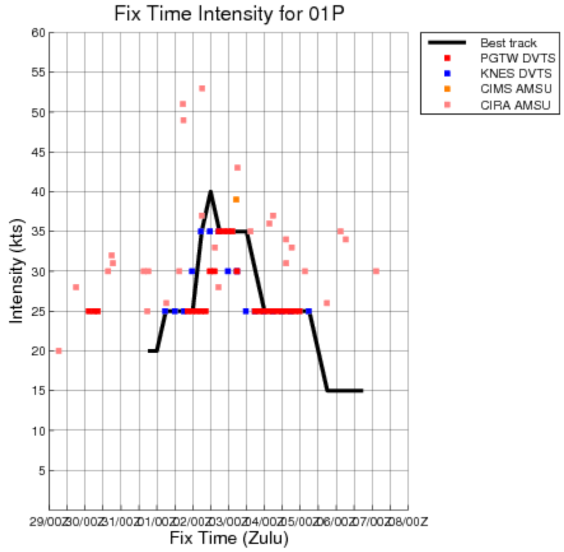
The first Tropical Cyclone Formation Alert (TCFA) and the initial and final warning dates are also presented with the number of warnings issued by JTWC. Landfall over major landmasses with approximate locations are presented as well.

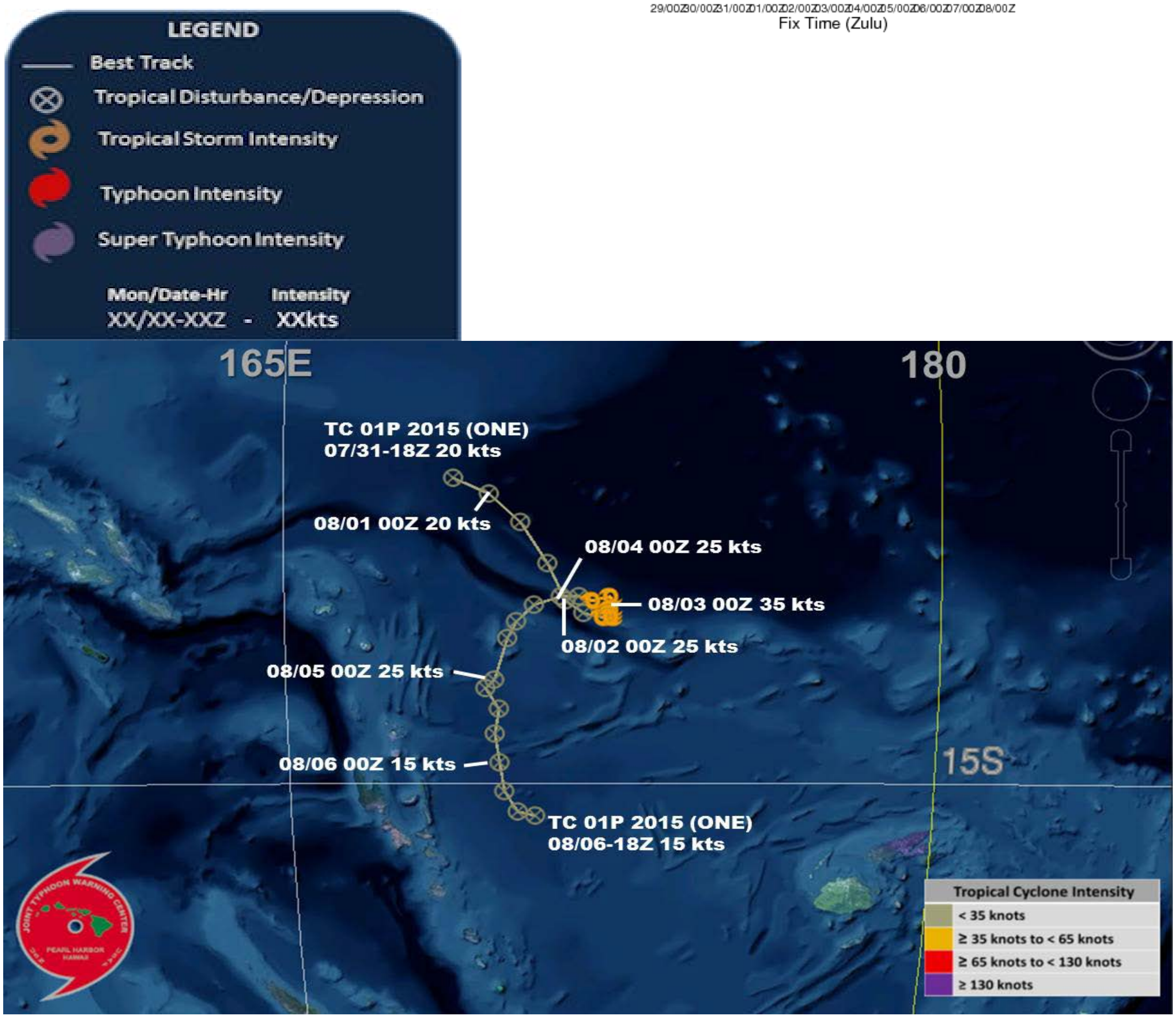
Data included on the best track are position and intensity noted with cyclone symbols and color coded track. Best track position labels include the date-time, track speed in knots, and maximum wind speed in knots. A graph of best track intensity versus time is presented. Fix plots on this graph are color coded by fixing agency.

In addition, when this document is viewed as a pdf, each map has been hyperlinked to the appropriate keyhole markup language (kmz) file that will allow the reader to access and view the best-track data interactively on their computer using Google Earth software. Simply hold the control button and click the map image; the link will open allowing the reader to download and open the file.
Users may also retrieve kmz files for the entire season from:
https://metoc.ndbc.noaa.gov/ProductFeeds-portlet/img/jtwc/best_tracks/2016/2016s-bsh/SH_besttracks_2016-2016.kmz

01P TROPICAL CYCLONE ONE

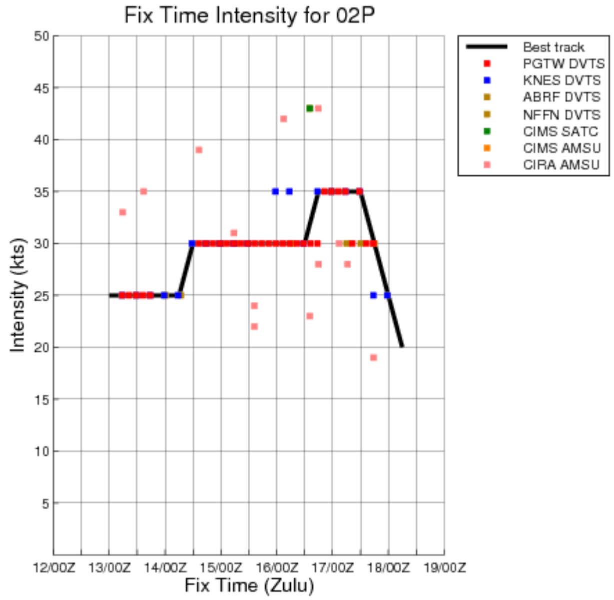
ISSUED LOW:	29 Jul / 0600Z
ISSUED MED:	30 Jul / 0230Z
FIRST TCFA:	02 Aug / 0830Z
FIRST WARNING:	02 Aug / 1800Z
LAST WARNING:	03 Aug / 1800Z
MAX INTENSITY:	40
WARNINGS:	3

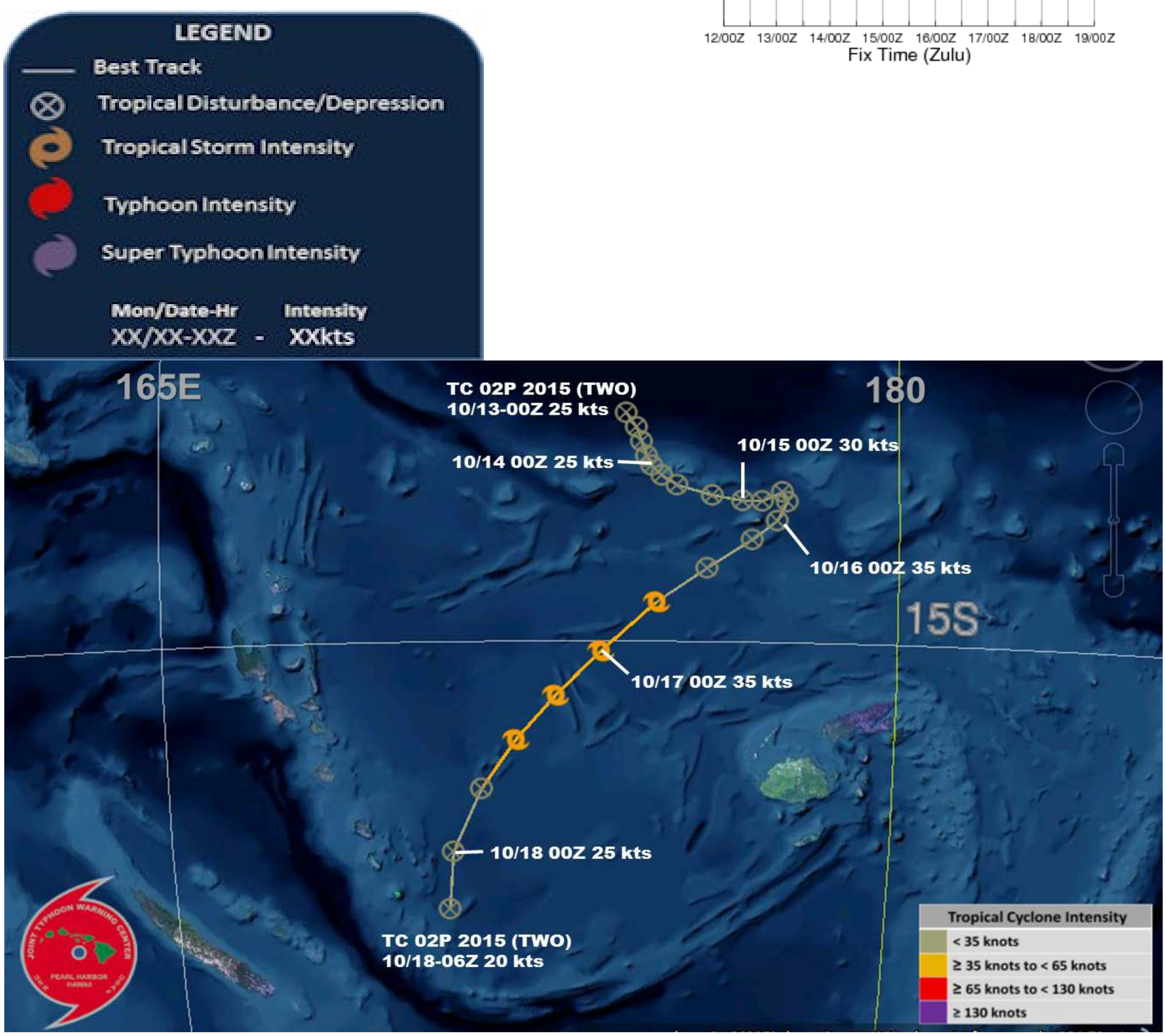




02P TROPICAL CYCLONE TWO

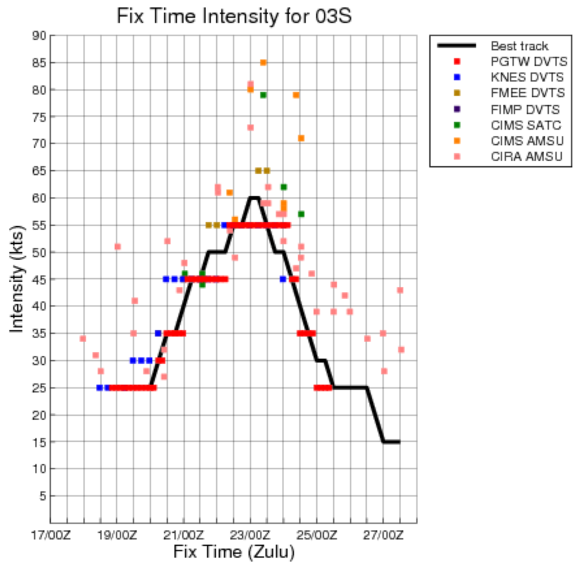
ISSUED LOW:	None
ISSUED MED:	13 Oct 0600Z
FIRST TCFA:	14 Oct / 1930Z
FIRST WARNING:	15 Oct / 1800Z
LAST WARNING:	17 Oct / 1800Z
MAX INTENSITY:	35
WARNINGS:	5

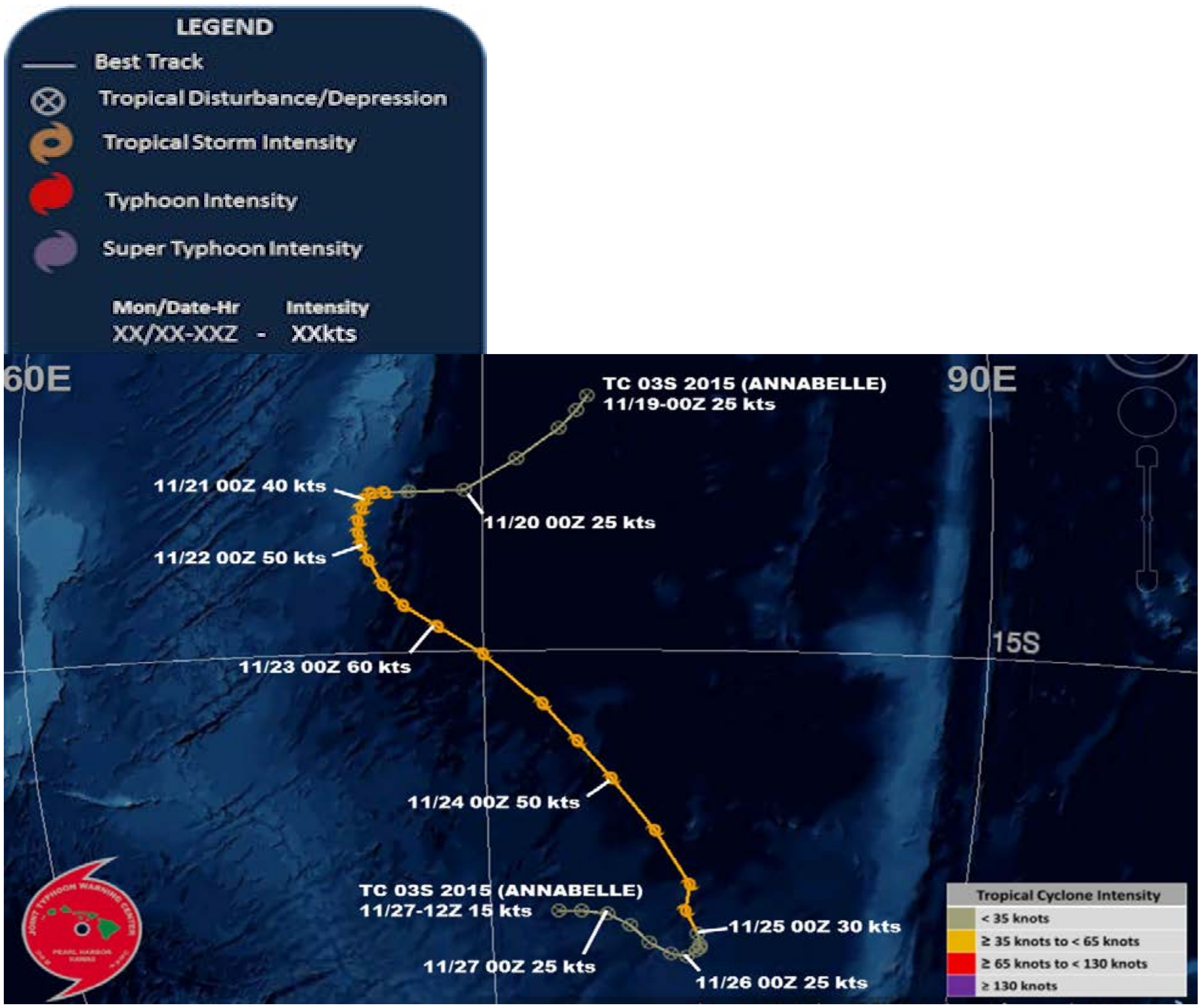




03S TROPICAL CYCLONE ANNABELLE

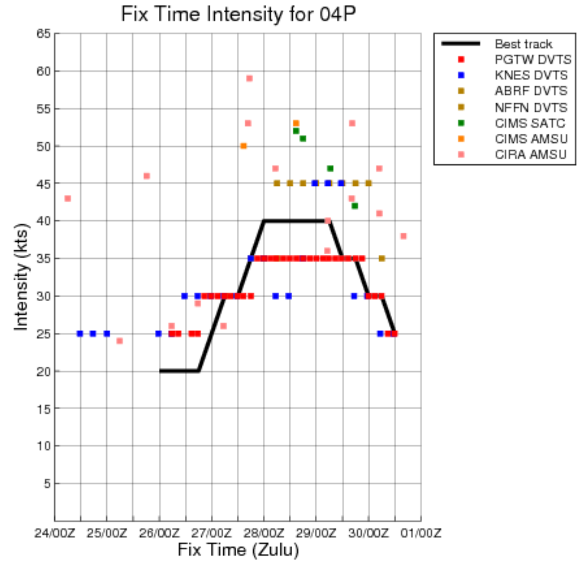
ISSUED LOW:	17 Nov / 1800Z
ISSUED MED:	18 Nov / 1800Z
FIRST TCFA:	20 Nov / 0730Z
FIRST WARNING:	20 Nov / 1200Z
LAST WARNING:	24 Nov / 1200Z
MAX INTENSITY:	60
WARNINGS:	9

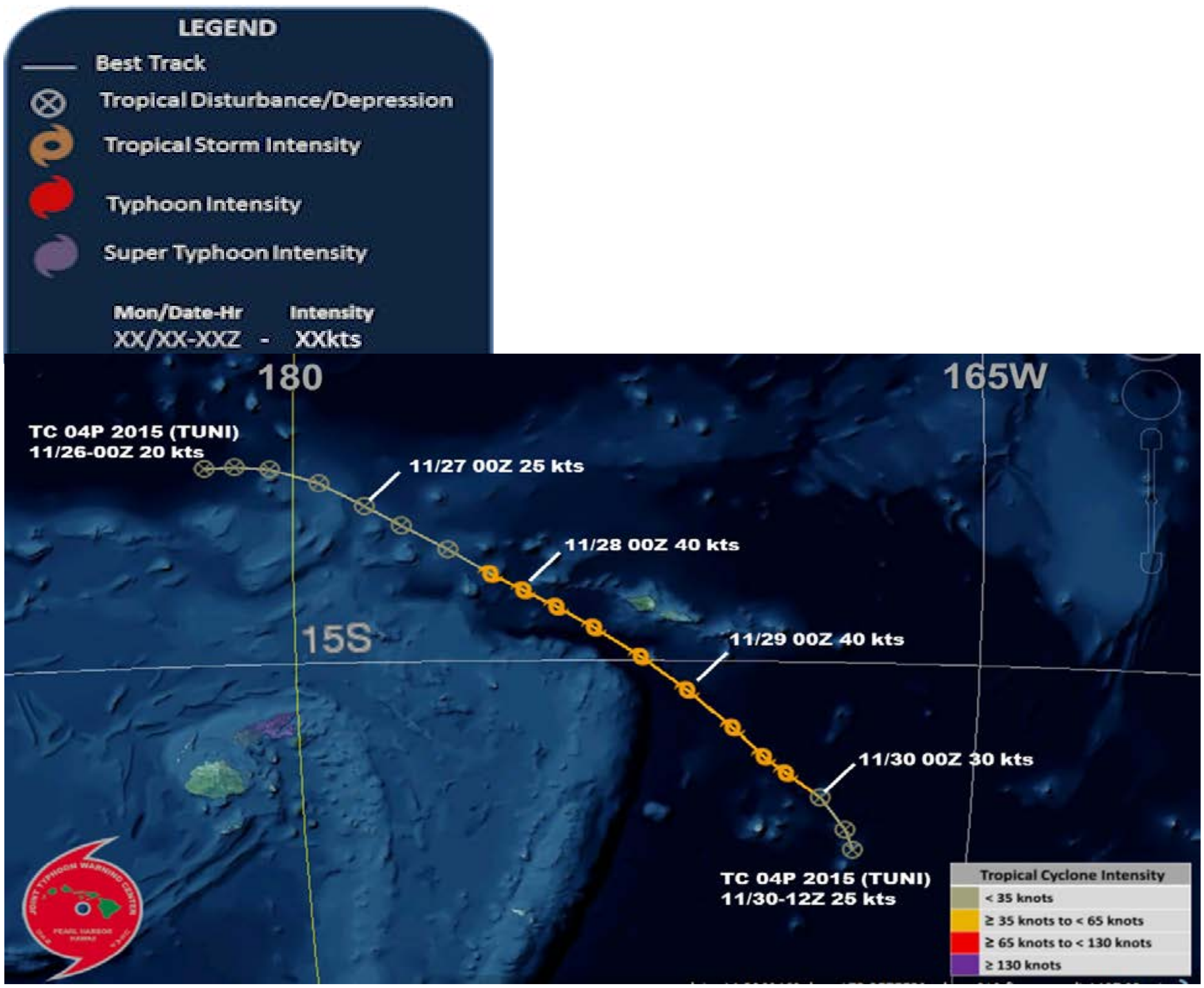




04P TROPICAL CYCLONE TUNI

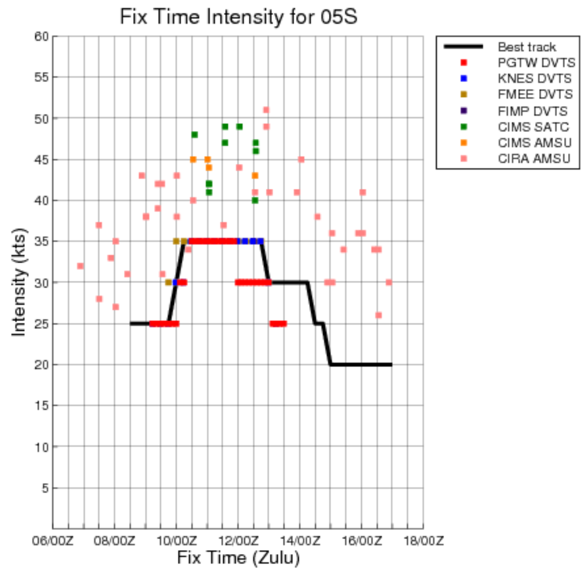
ISSUED LOW:	26 Nov / 0300Z
ISSUED MED:	26 Nov / 1400Z
FIRST TCFA:	26 Nov / 1930Z
FIRST WARNING:	27 Nov / 1800Z
LAST WARNING:	29 Nov / 1800Z
MAX INTENSITY:	40
WARNINGS:	8

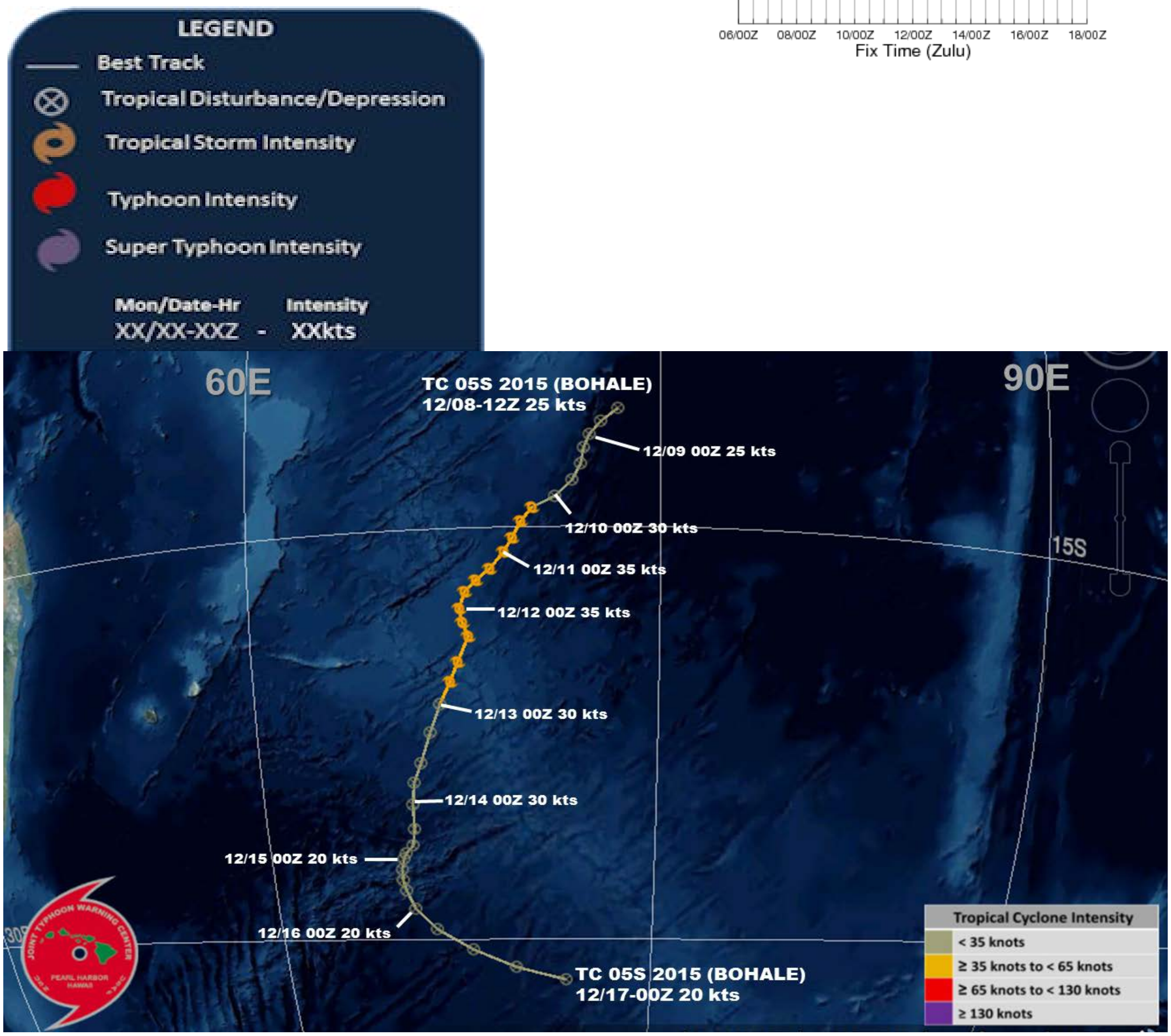




05S TROPICAL CYCLONE BOHALE

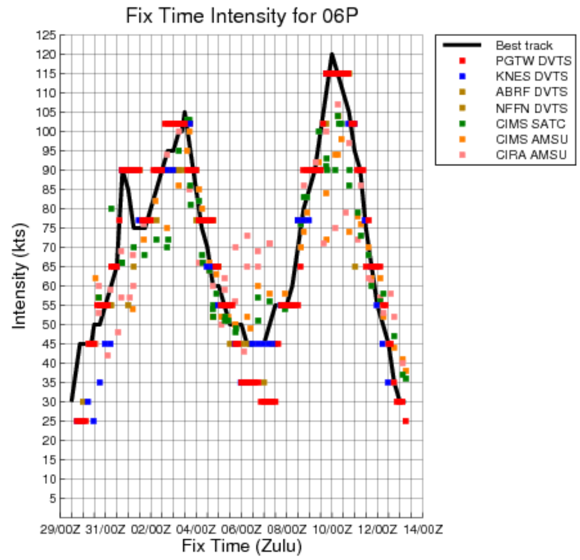
ISSUED LOW:	07 Dec / 0230Z
ISSUED MED:	08 Dec / 2200Z
FIRST TCFA:	09 Dec / 2300Z
FIRST WARNING:	10 Dec / 0600Z
LAST WARNING:	12 Dec / 0600Z
MAX INTENSITY:	35
WARNINGS:	5

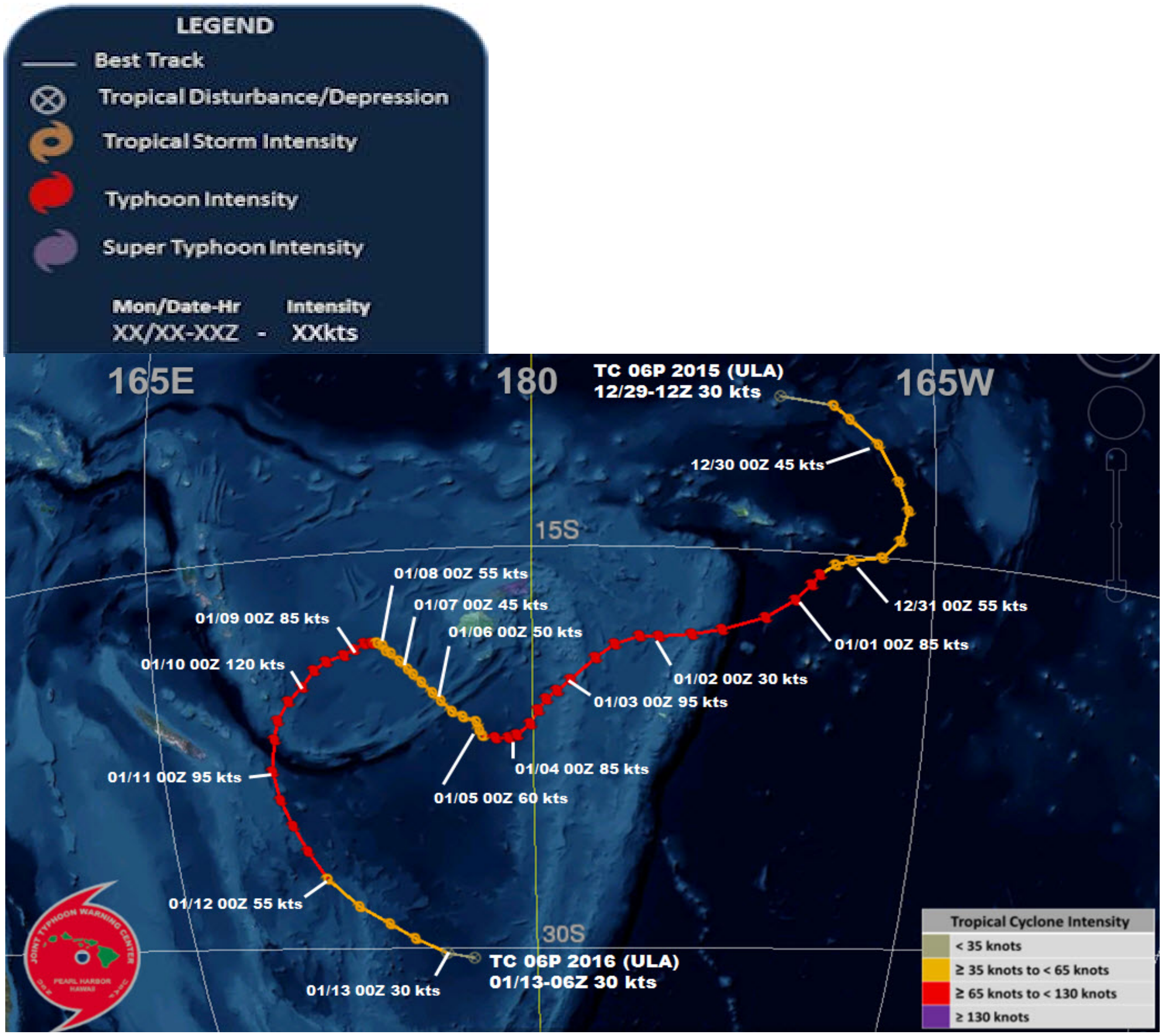




06P TROPICAL CYCLONE ULA

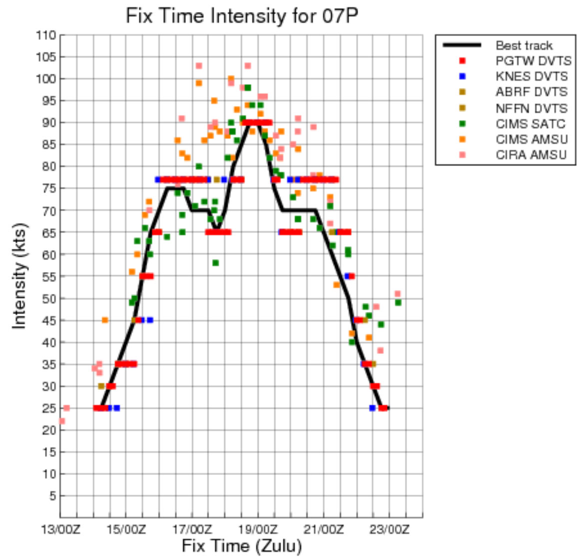
ISSUED LOW:	None
ISSUED MED:	29 Dec / 2000Z
FIRST TCFA:	30 Dec / 0100Z
FIRST WARNING:	30 Dec / 0600Z
LAST WARNING:	12 Jan / 1800Z
MAX INTENSITY:	120
WARNINGS:	28

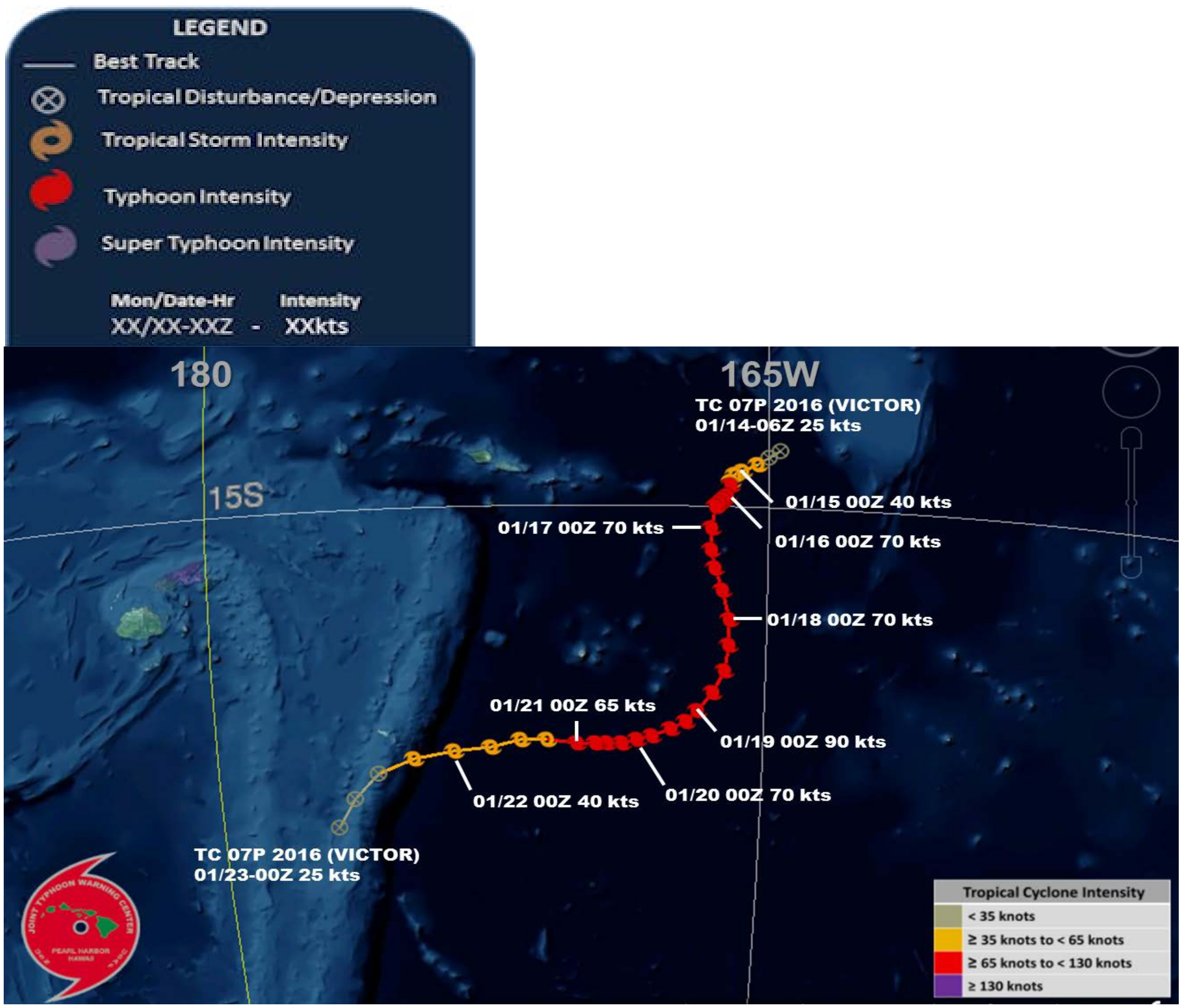




07P TROPICAL CYCLONE VICTOR

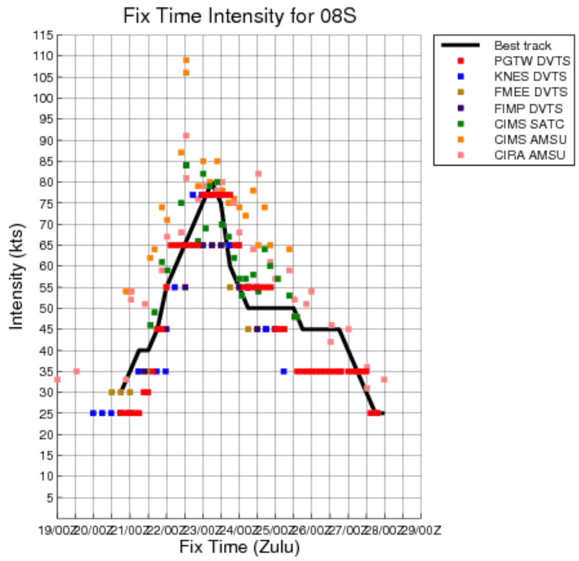
ISSUED LOW:	13 Jan / 0600Z
ISSUED MED:	13 Jan / 2330Z
FIRST TCFA:	14 Jan / 1030Z
FIRST WARNING:	14 Jan / 1800Z
LAST WARNING:	22 Jan / 1800Z
MAX INTENSITY:	90
WARNINGS:	17

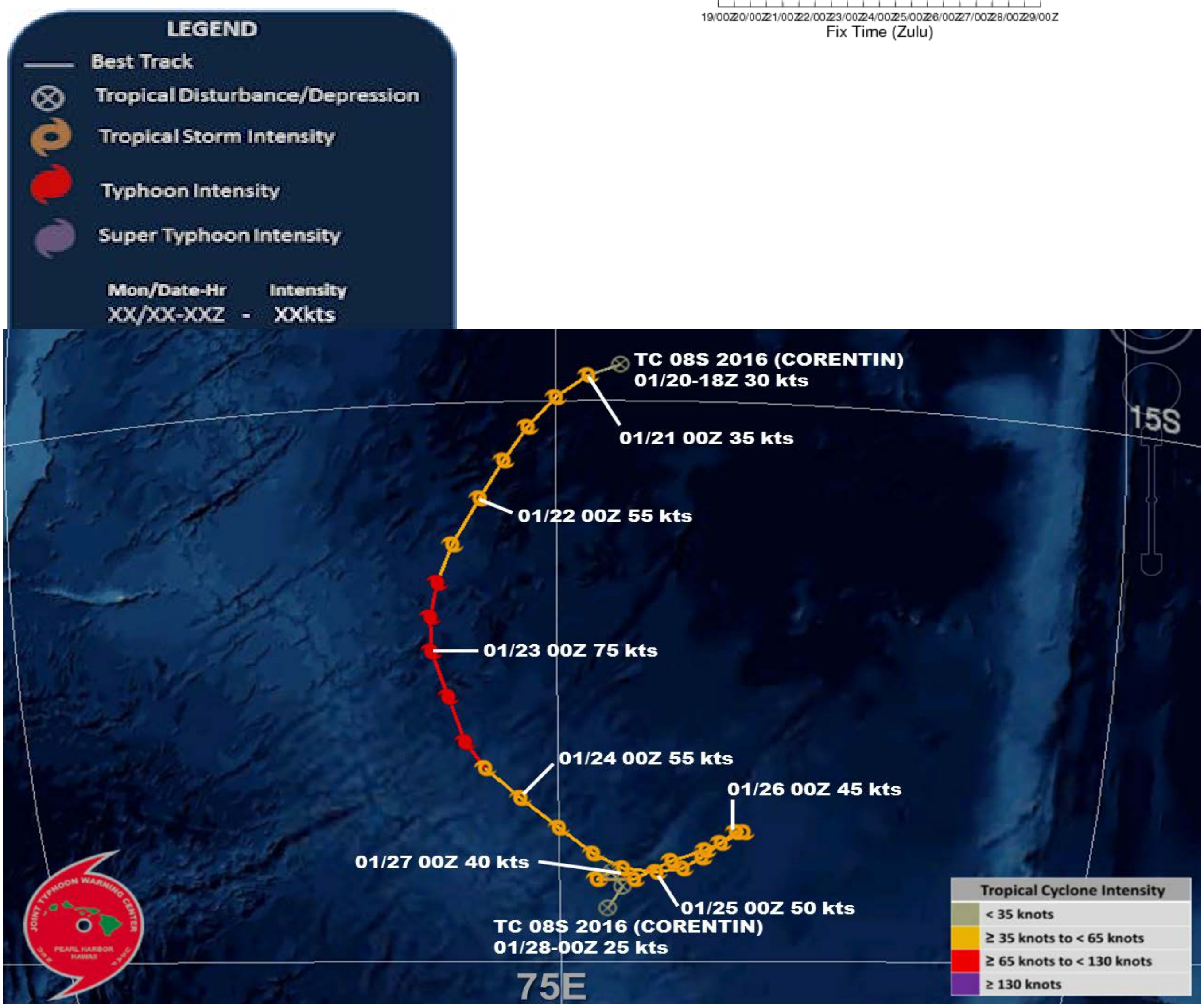




08S TROPICAL CYCLONE CORENTIN

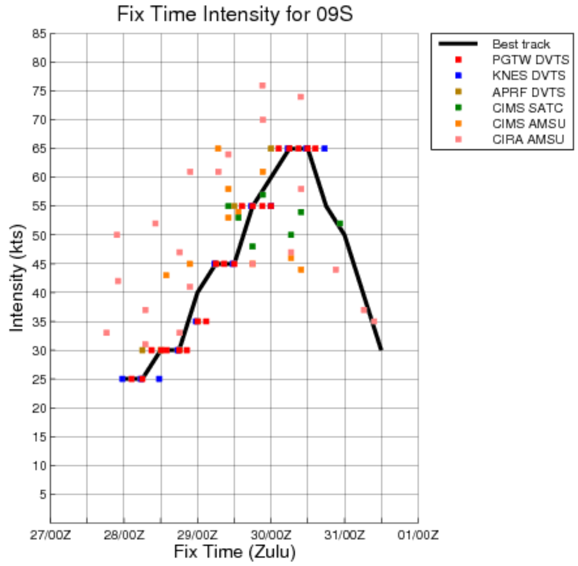
ISSUED LOW:	19 Jan / 1800Z
ISSUED MED:	20 Jan / 0530Z
FIRST TCFA:	20 Jan / 1500Z
FIRST WARNING:	21 Jan / 1200Z
LAST WARNING:	25 Jan / 1200Z
MAX INTENSITY:	80
WARNINGS:	9

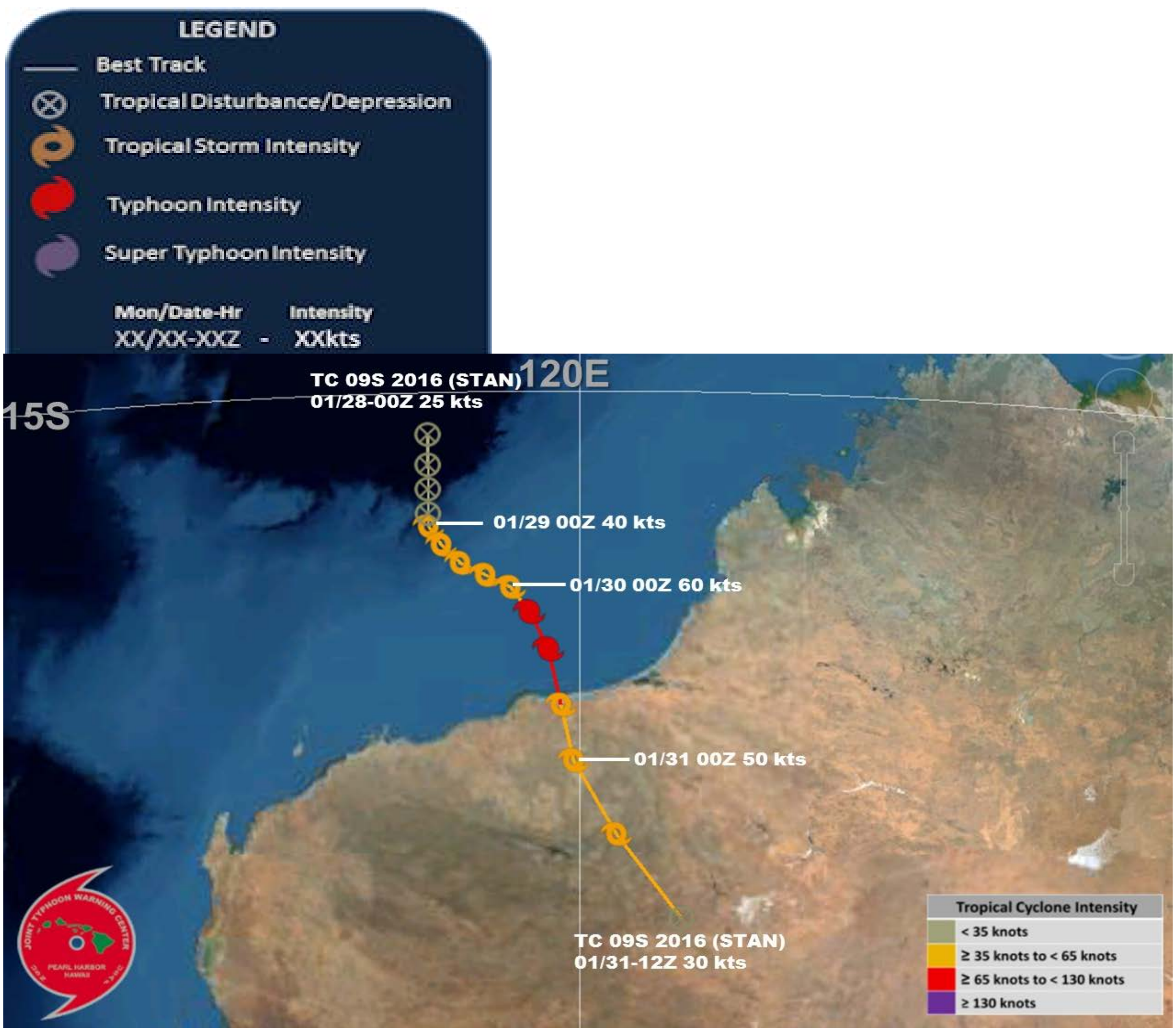




09S TROPICAL CYCLONE STAN

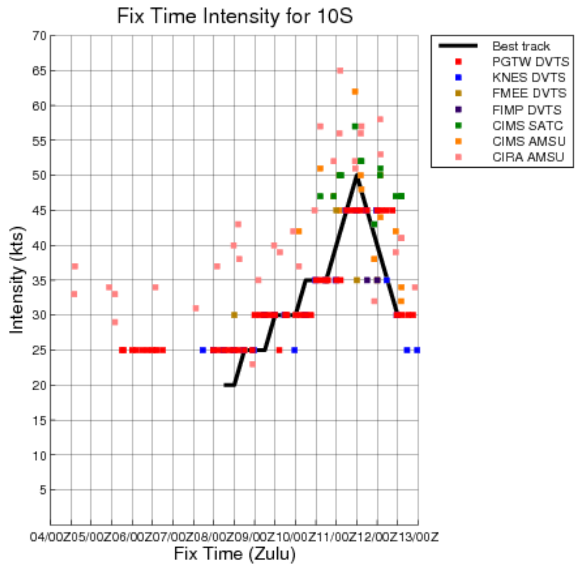
ISSUED LOW:	27 Jan / 2030Z
ISSUED MED:	28 Jan / 0500Z
FIRST TCFA:	28 Jan / 1030Z
FIRST WARNING:	29 Jan / 0000Z
LAST WARNING:	30 Jan / 1800Z
MAX INTENSITY:	65
WARNINGS:	8

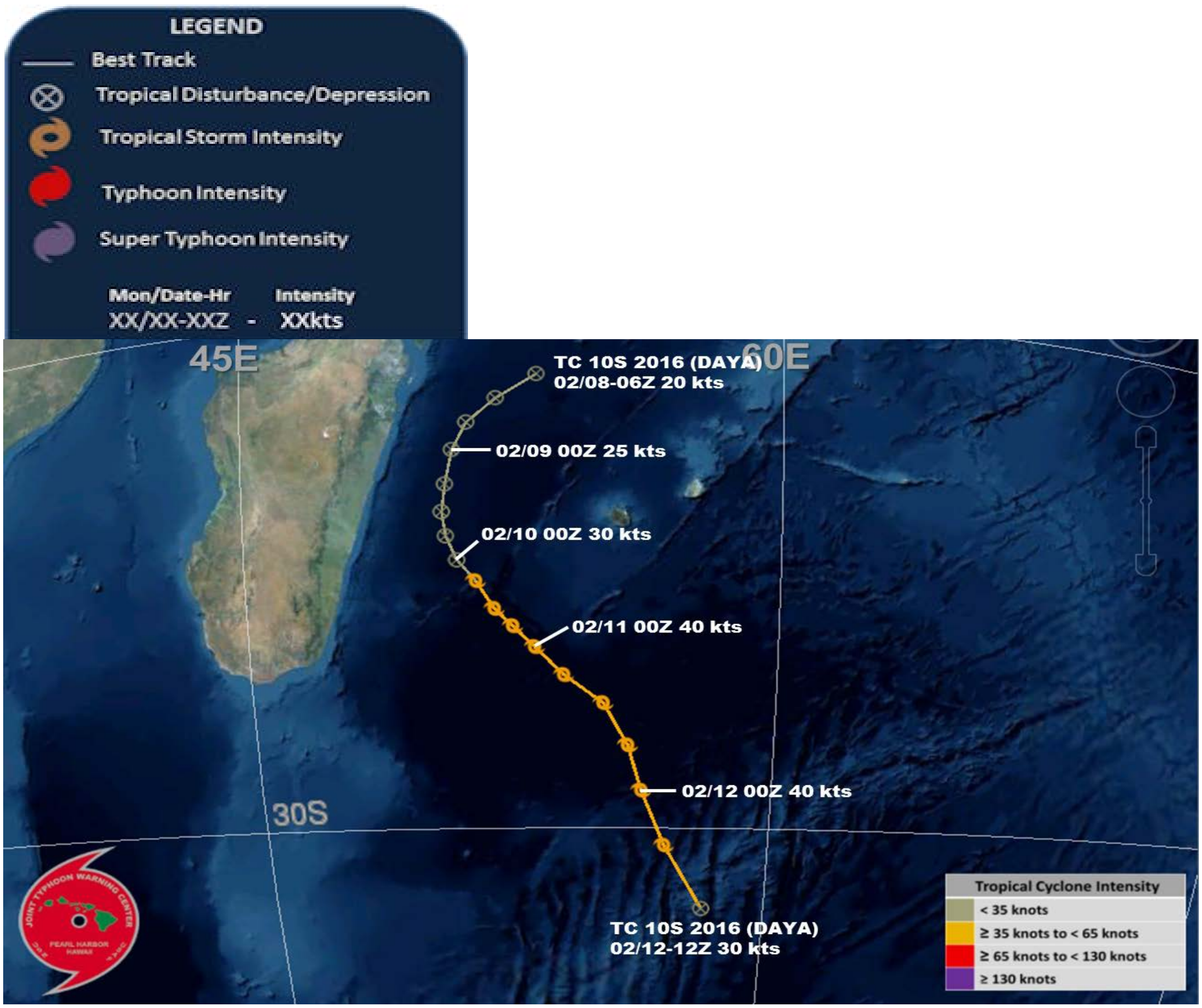




10S TROPICAL CYCLONE DAYA

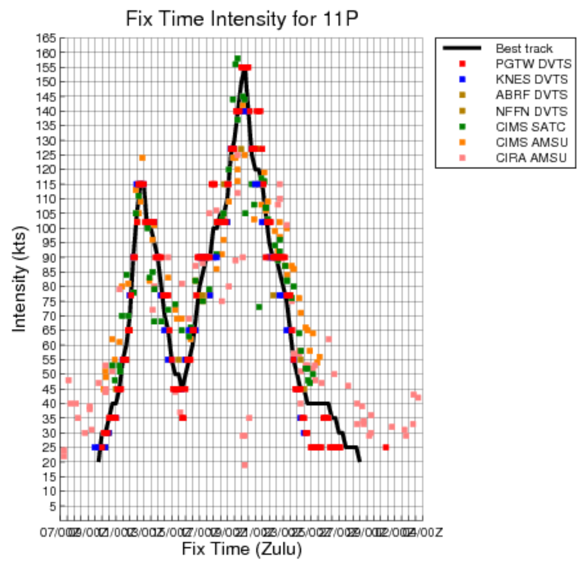
ISSUED LOW:	08 Feb / 1100Z
ISSUED MED:	08 Feb / 1800Z
FIRST TCFA:	09 Feb / 0200Z
FIRST WARNING:	10 Feb / 1200Z
LAST WARNING:	12 Feb / 0000Z
MAX INTENSITY:	50
WARNINGS:	4

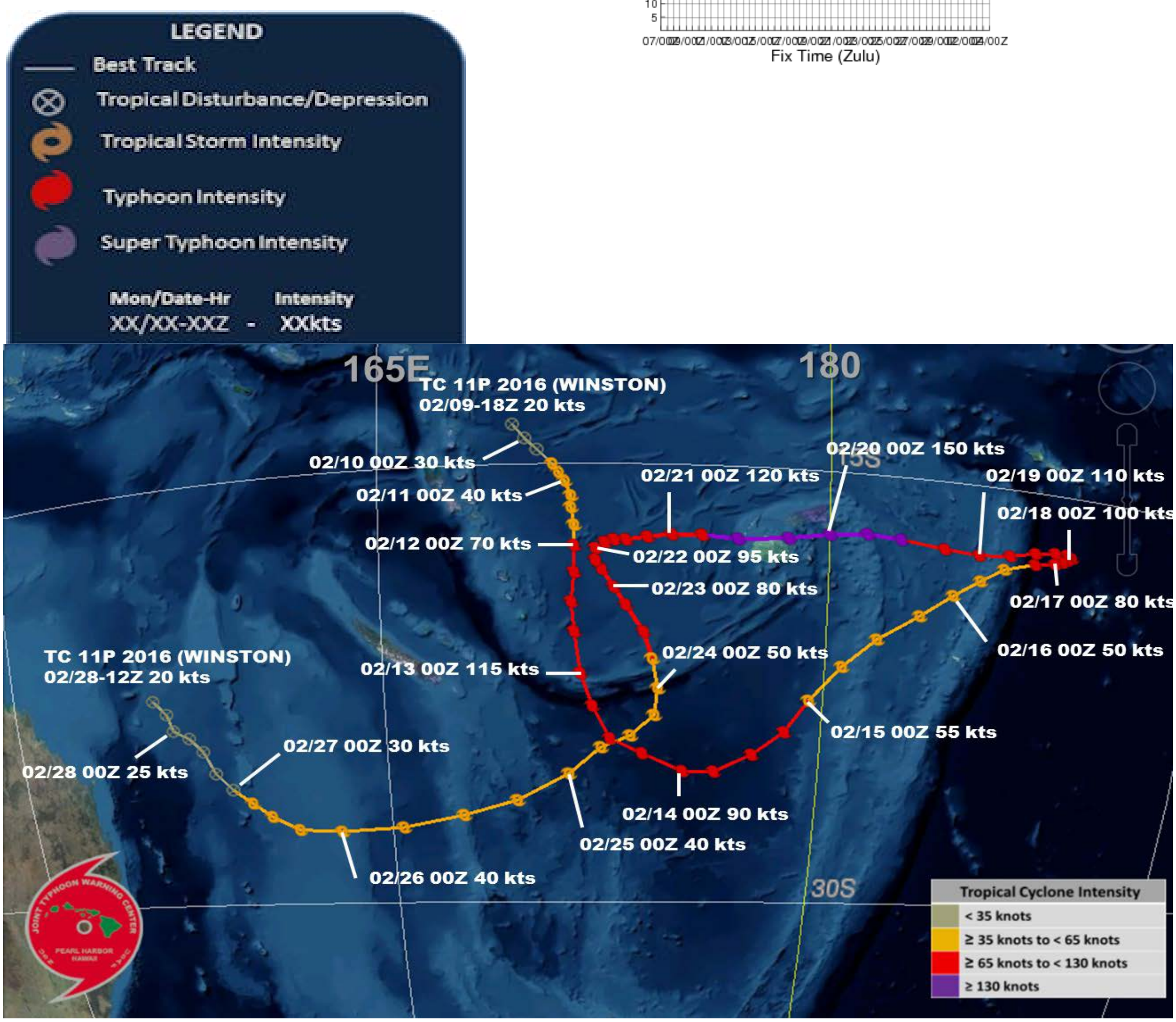




11P TROPICAL CYCLONE WINSTON

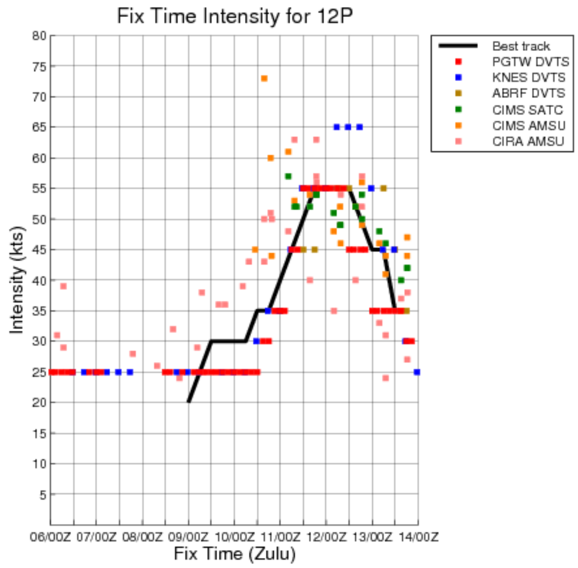
ISSUED LOW:	08 Feb / 1400Z
ISSUED MED:	10 Feb / 0230Z
FIRST TCFA:	10 Feb / 0500Z
FIRST WARNING:	10 Feb / 1200Z
LAST WARNING:	24 Feb / 1800Z
MAX INTENSITY:	155
WARNINGS:	47

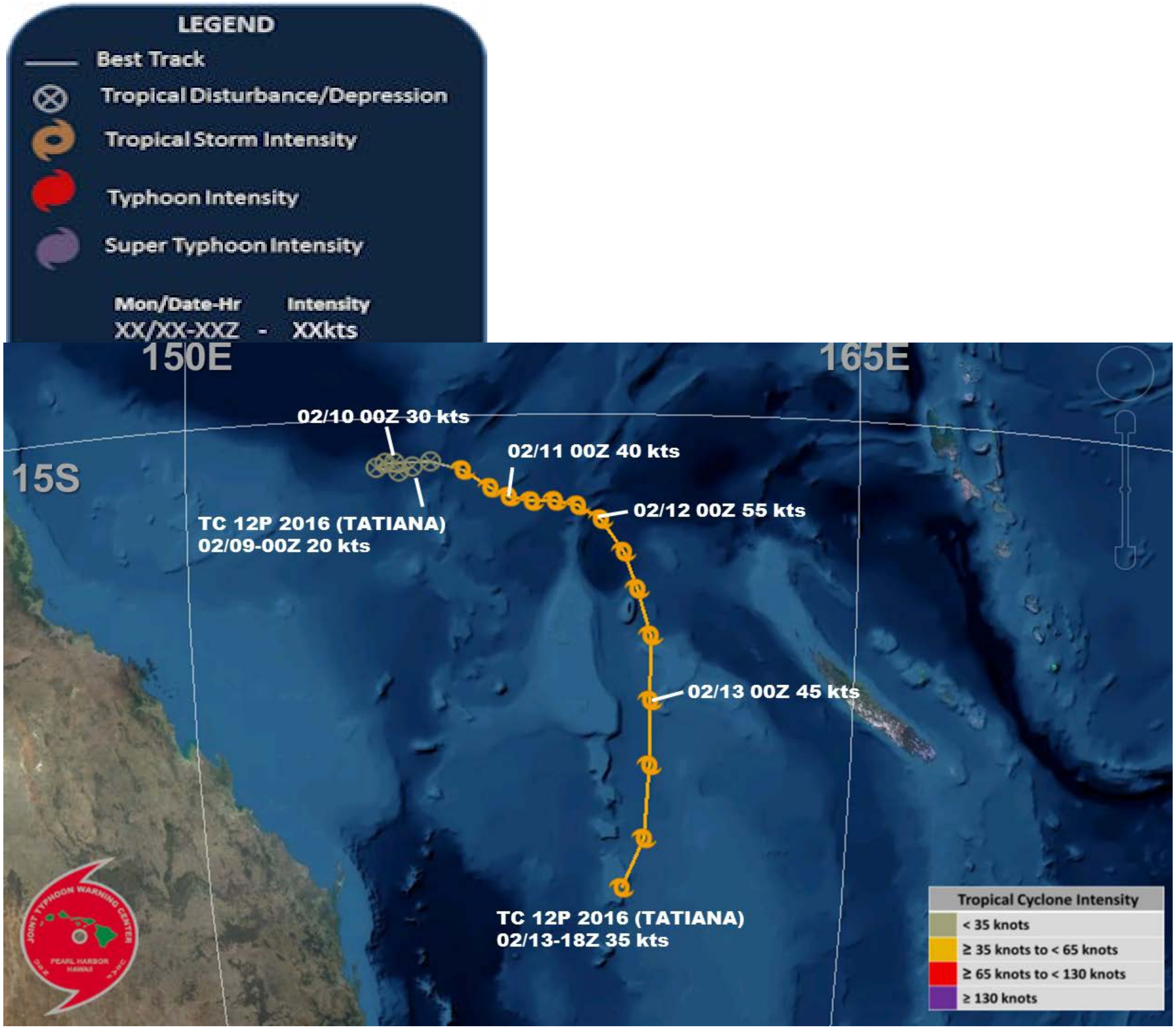




12P TROPICAL CYCLONE TATIANA

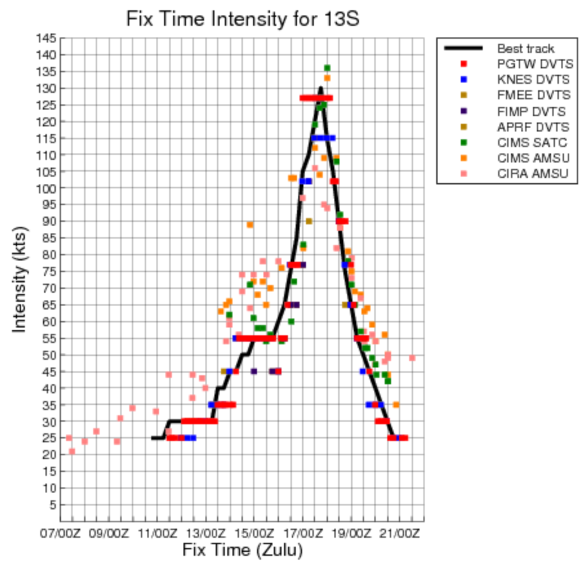
ISSUED LOW:	08 Feb / 1400Z
ISSUED MED:	09 Feb / 0600Z
FIRST TCFA:	10 Feb / 0130Z
FIRST WARNING:	10 Feb / 1800Z
LAST WARNING:	13 Feb / 1800Z
MAX INTENSITY:	55
WARNINGS:	7

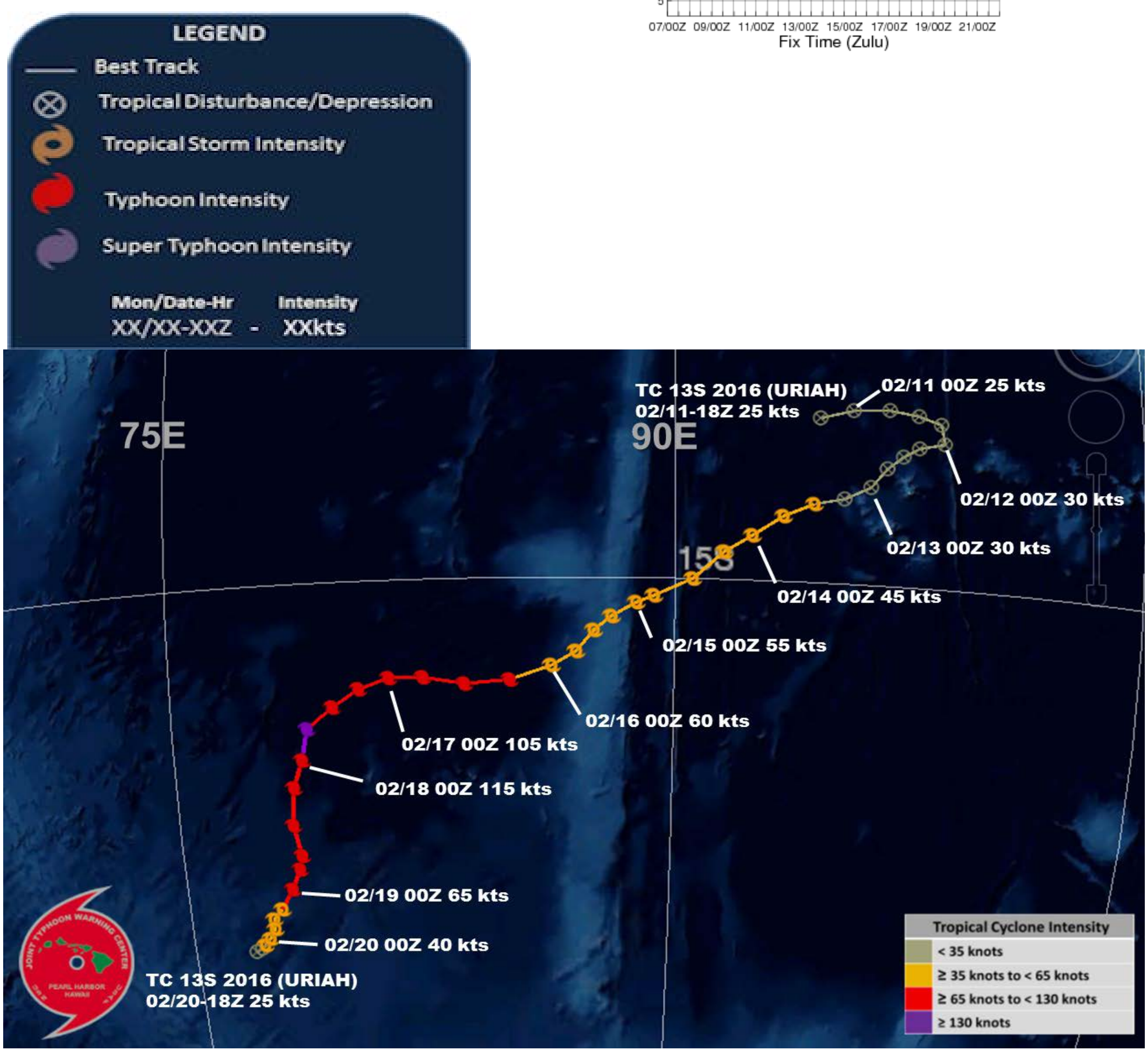




13S TROPICAL CYCLONE URIAH

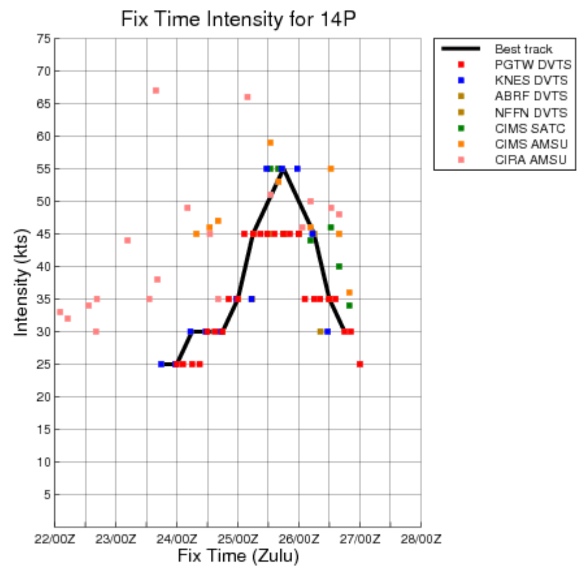
ISSUED LOW:	09 Feb / 1800Z
ISSUED MED:	11 Feb / 0000Z
FIRST TCFA:	12 Feb / 0430Z
FIRST WARNING:	13 Feb / 1200Z
LAST WARNING:	20 Feb / 0000Z
MAX INTENSITY:	130
WARNINGS:	14

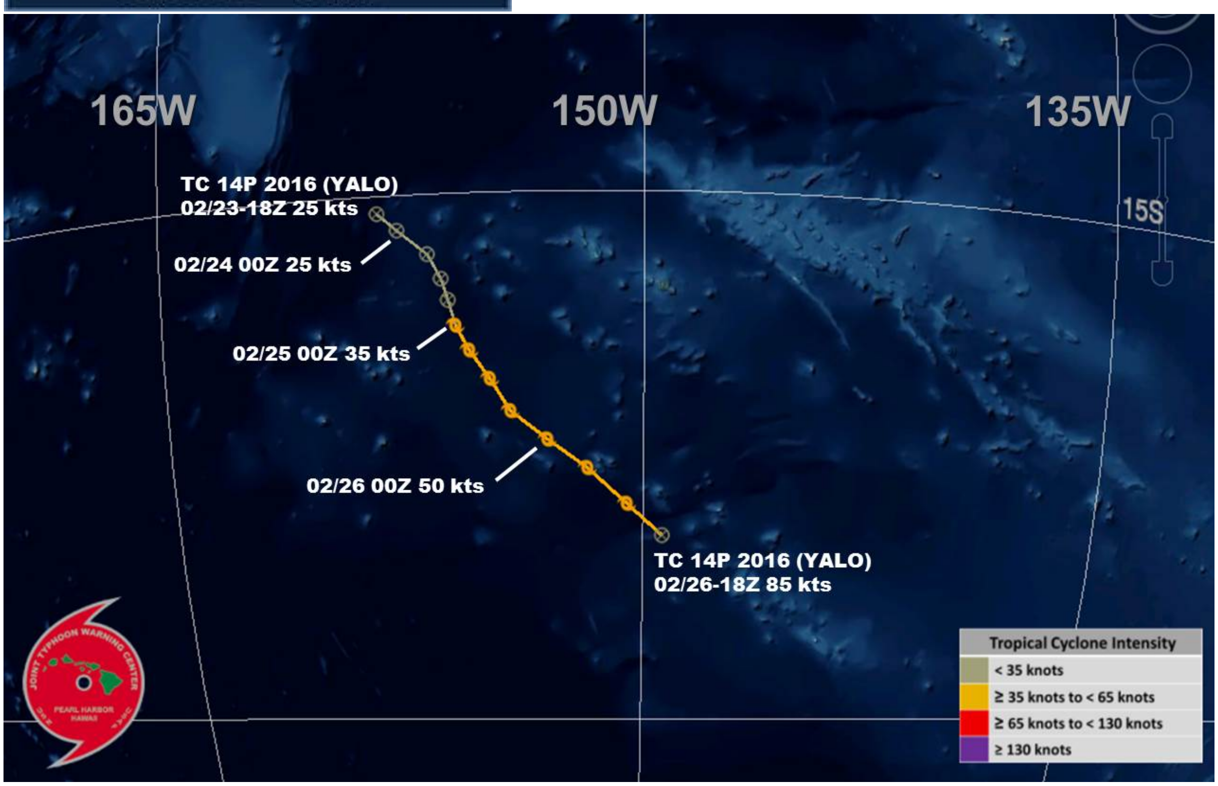




14P TROPICAL CYCLONE YALO

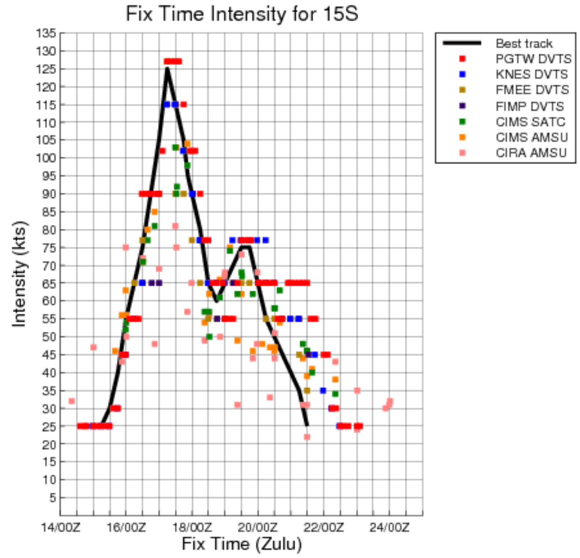
ISSUED LOW:	22 Feb / 1400Z
ISSUED MED:	23 Feb / 0600Z
FIRST TCFA:	24 Feb / 0730Z
FIRST WARNING:	25 Feb / 0000Z
LAST WARNING:	26 Feb / 1200Z
MAX INTENSITY:	55
WARNINGS:	4

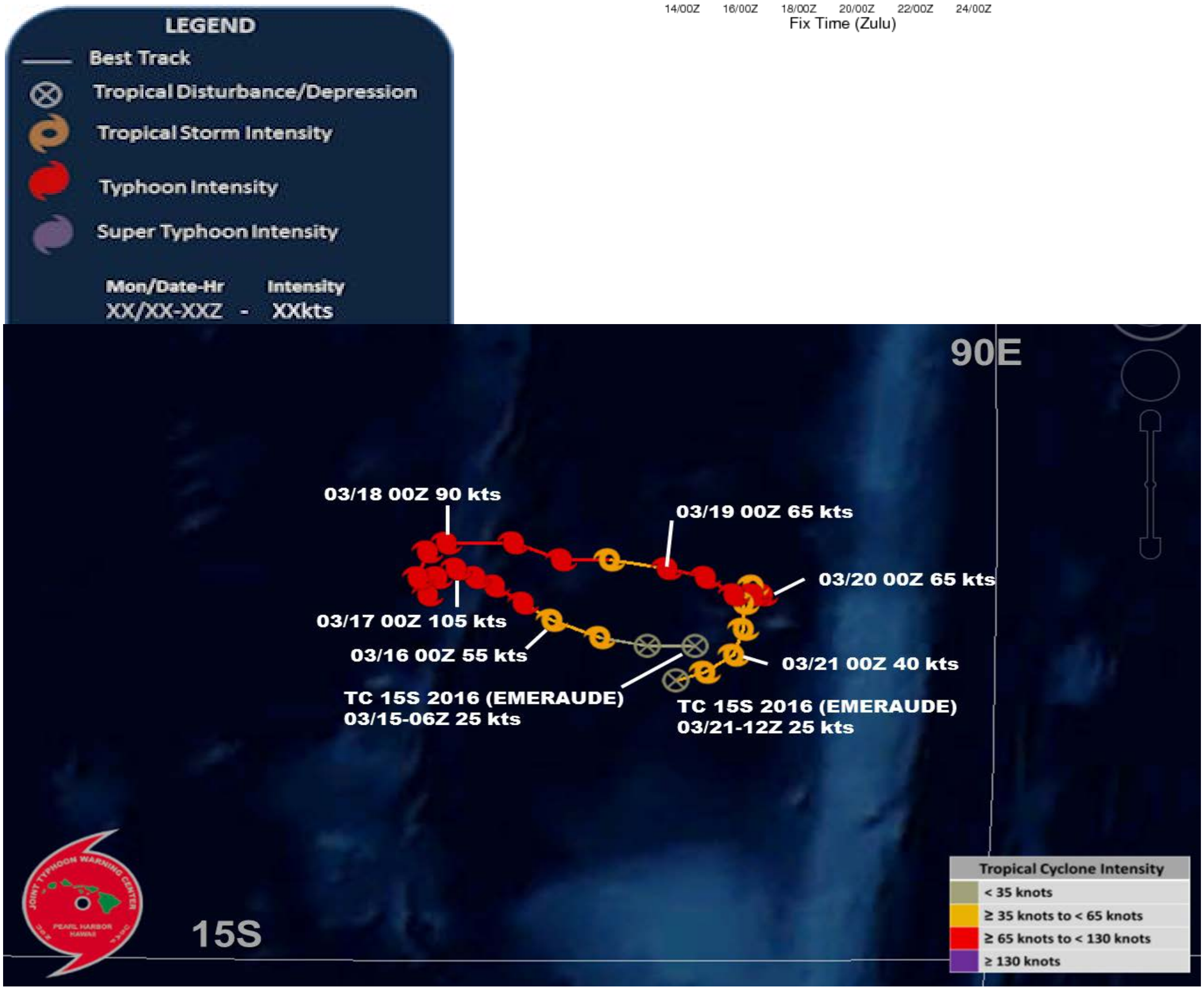




15S TROPICAL CYCLONE EMERAUDE

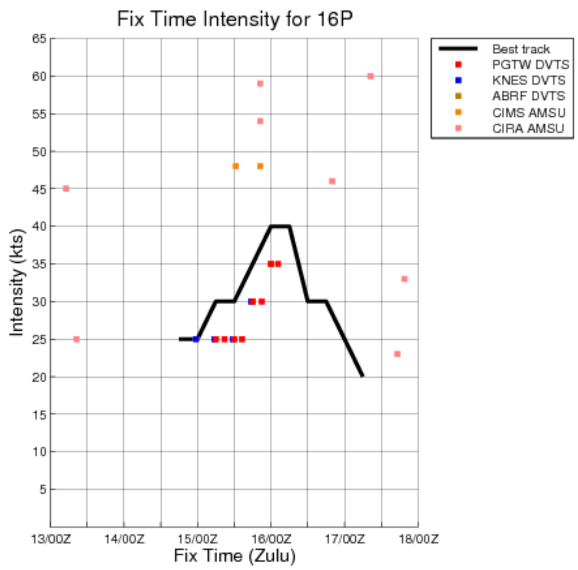
ISSUED LOW:	14 Mar / 1800Z
ISSUED MED:	15 Mar / 0430Z
FIRST TCFA:	15 Mar / 1700Z
FIRST WARNING:	15 Mar / 1800Z
LAST WARNING:	22 Mar / 0600Z
MAX INTENSITY:	125
WARNINGS:	14

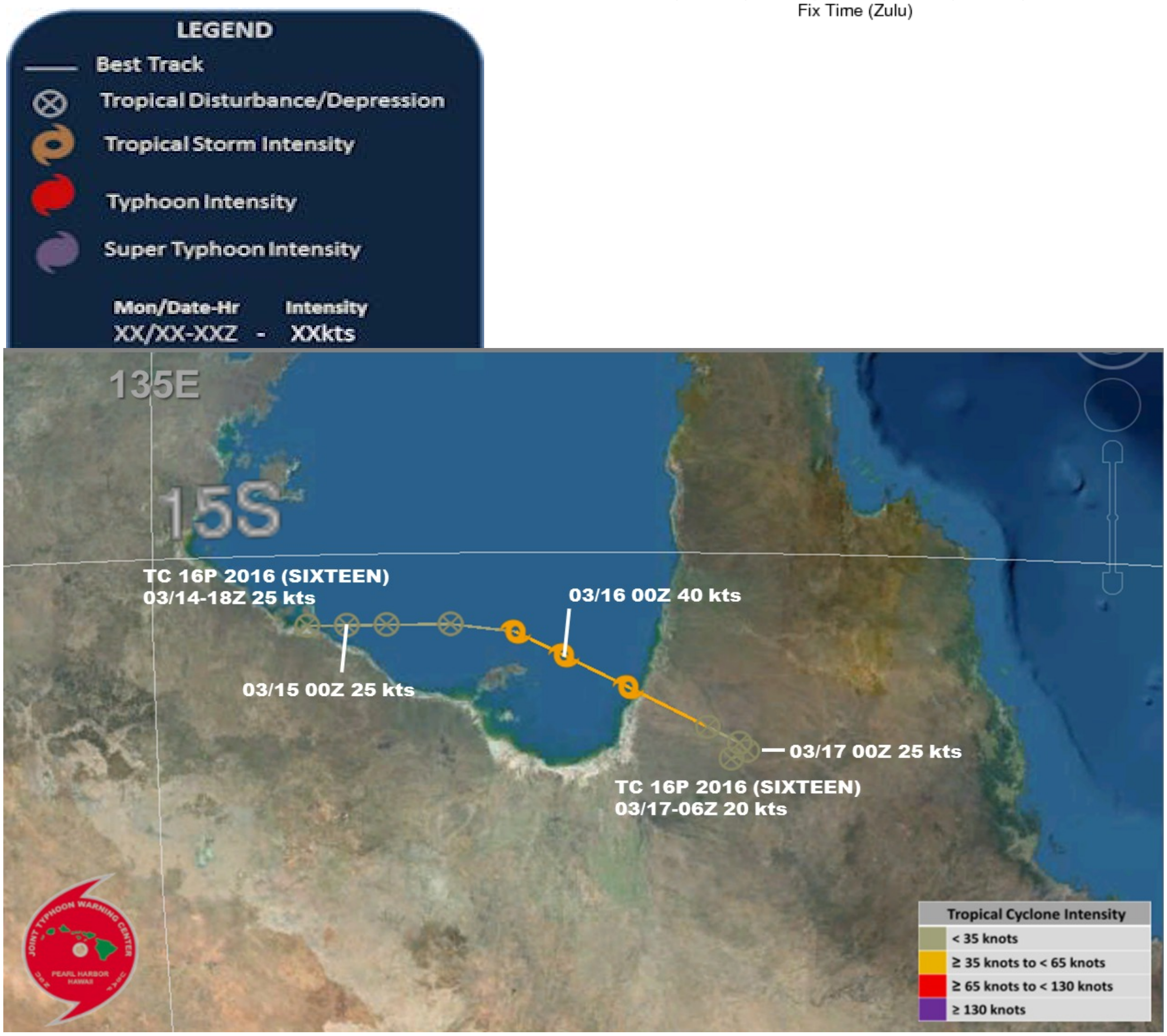




16P TROPICAL CYCLONE SIXTEEN

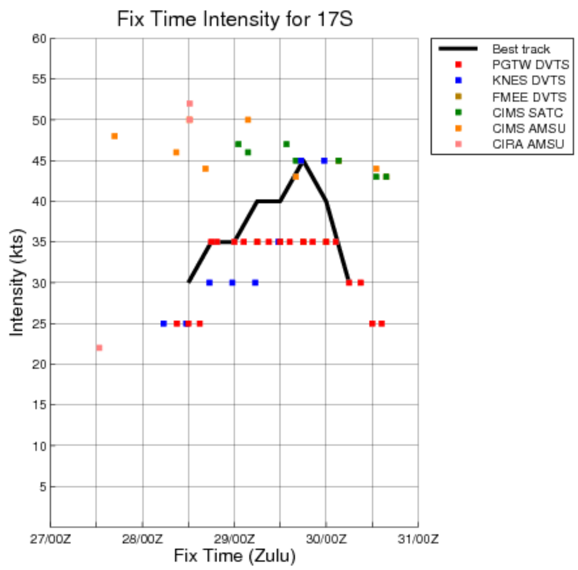
ISSUED LOW:	14 Mar / 0600Z
ISSUED MED:	15 Mar / 0130Z
FIRST TCFA:	15 Mar / 2000Z
FIRST WARNING:	16 Mar / 0000Z
LAST WARNING:	16 Mar / 1200Z
MAX INTENSITY:	40
WARNINGS:	2

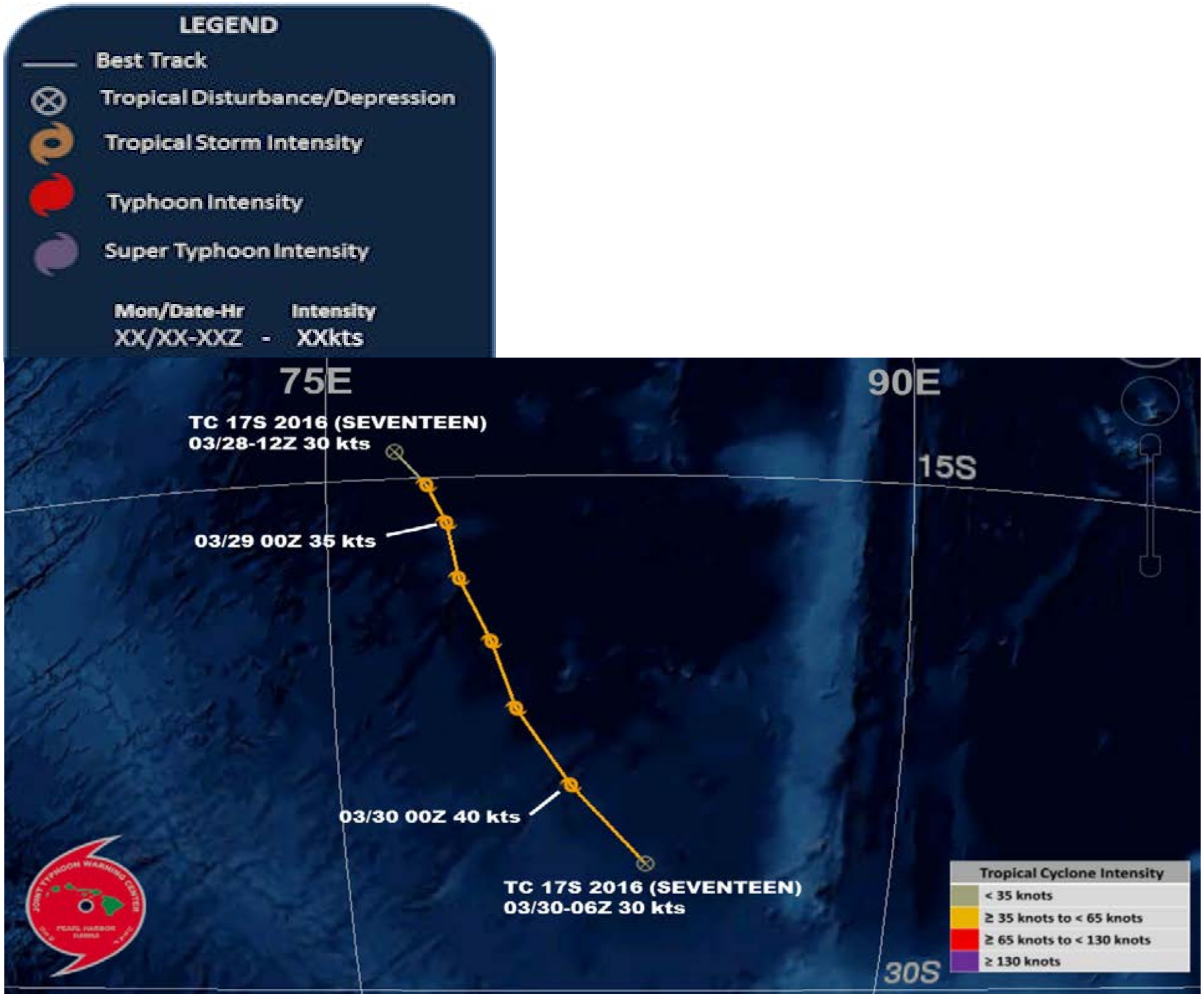




17S TROPICAL CYCLONE SEVENTEEN

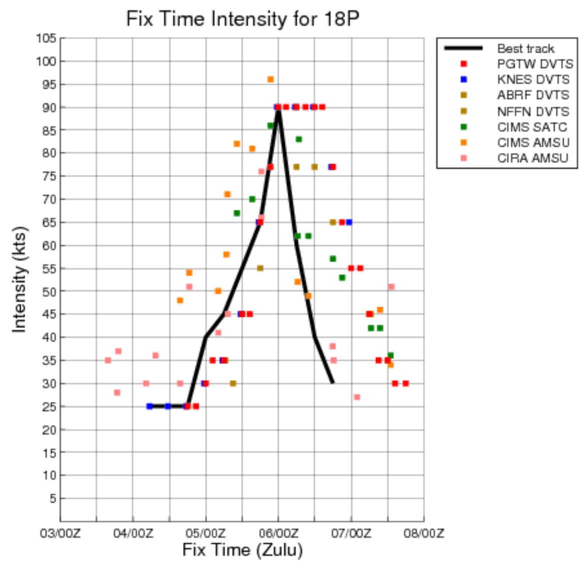
ISSUED LOW:	None
ISSUED MED:	28 Mar / 1130Z
FIRST TCFA:	28 Mar / 1430Z
FIRST WARNING:	28 Mar / 1800Z
LAST WARNING:	30 Mar / 0600Z
MAX INTENSITY:	45
WARNINGS:	4

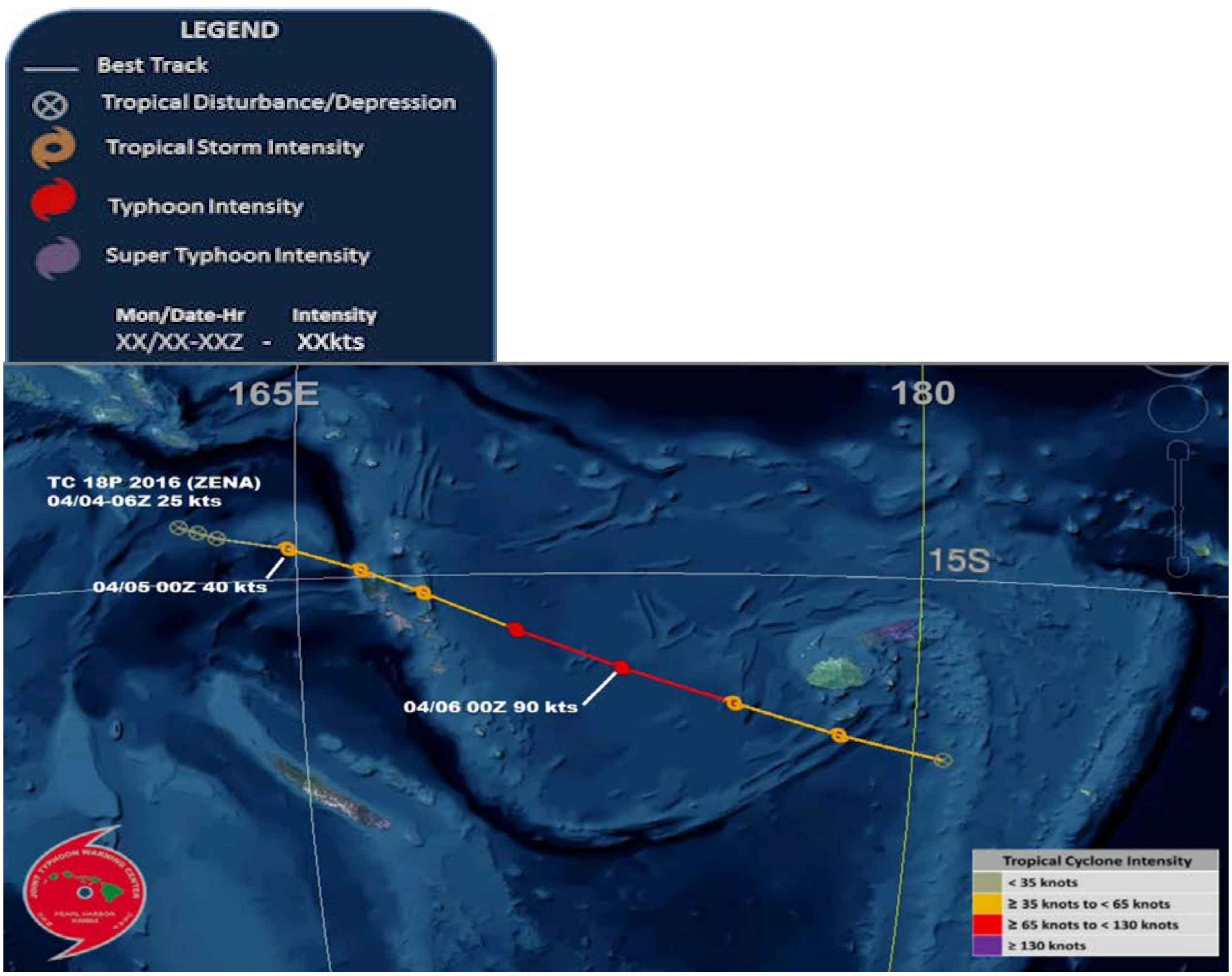




18P TROPICAL CYCLONE ZENA

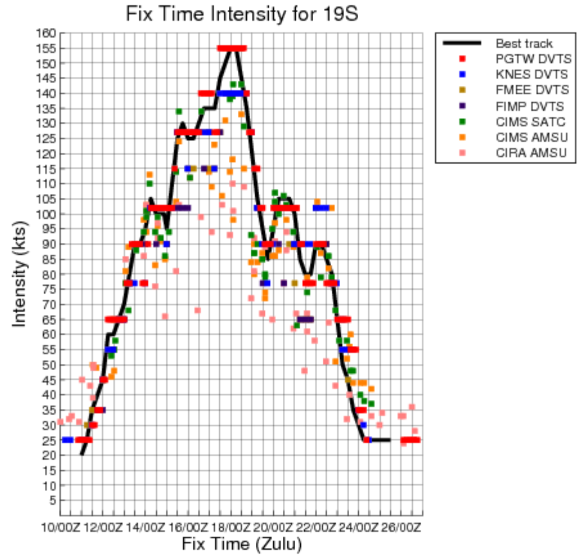
ISSUED LOW:	04 Apr / 0330Z
ISSUED MED:	None
FIRST TCFA:	04 Apr / 2130Z
FIRST WARNING:	05 Apr / 0600Z
LAST WARNING:	07 Apr / 0600Z
MAX INTENSITY:	90
WARNINGS:	8

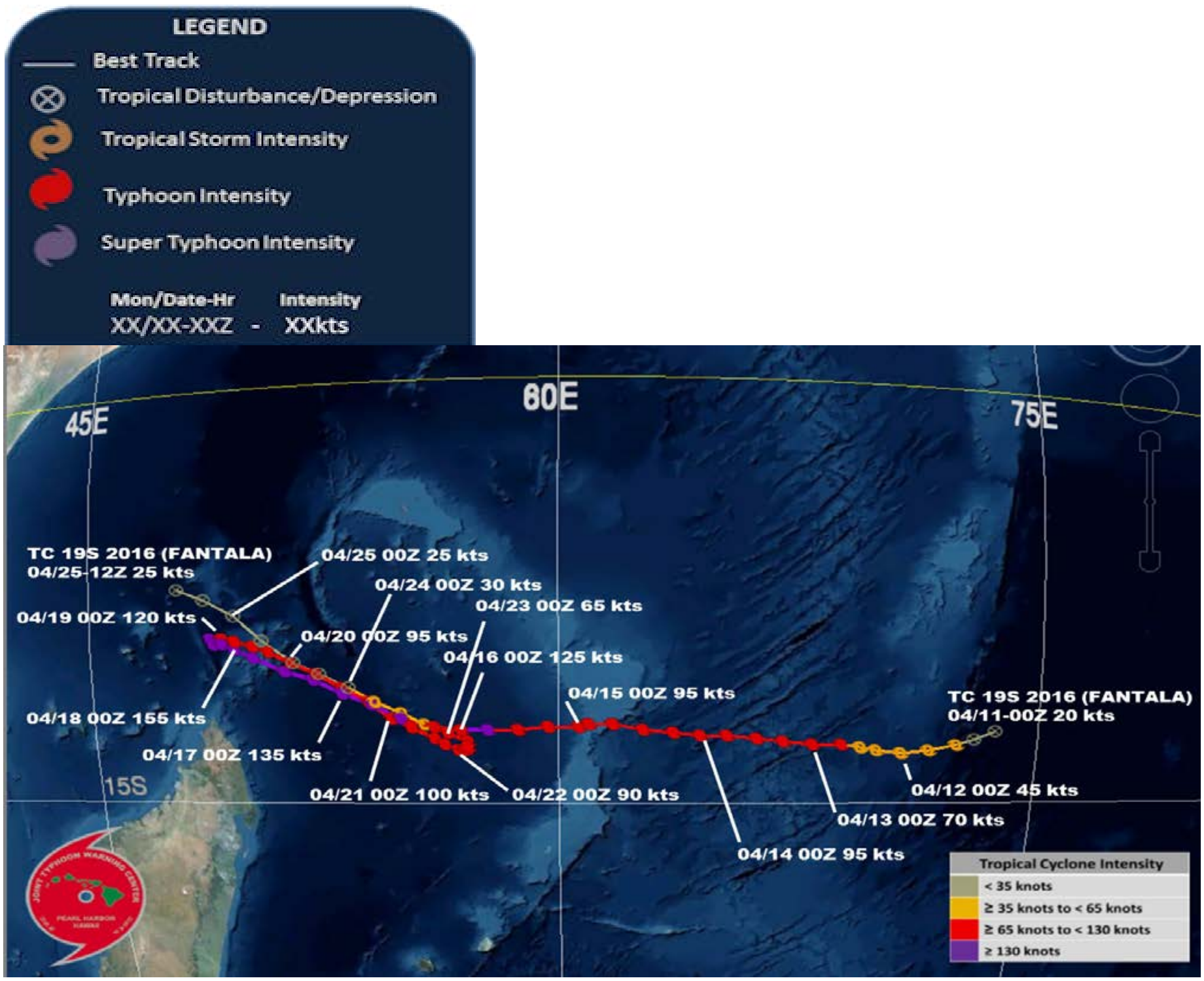




19S TROPICAL CYCLONE FANTALA

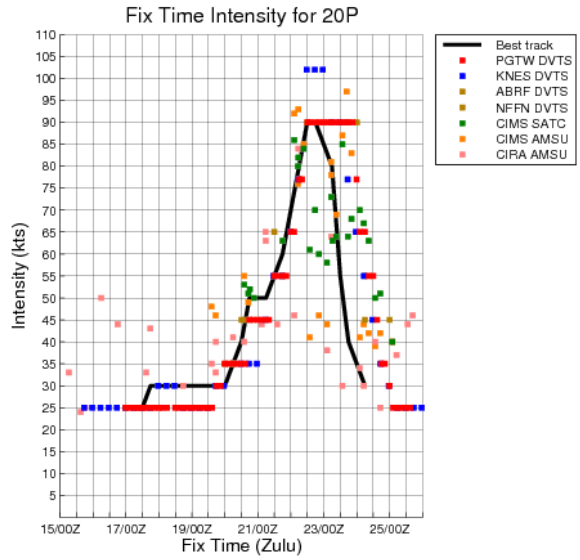
ISSUED LOW:	10 Apr / 1800Z
ISSUED MED:	11 Apr / 0500Z
FIRST TCFA:	11 Apr / 1300Z
FIRST WARNING:	11 Apr / 1800Z
LAST WARNING:	24 Apr / 0600Z
MAX INTENSITY:	155
WARNINGS:	26

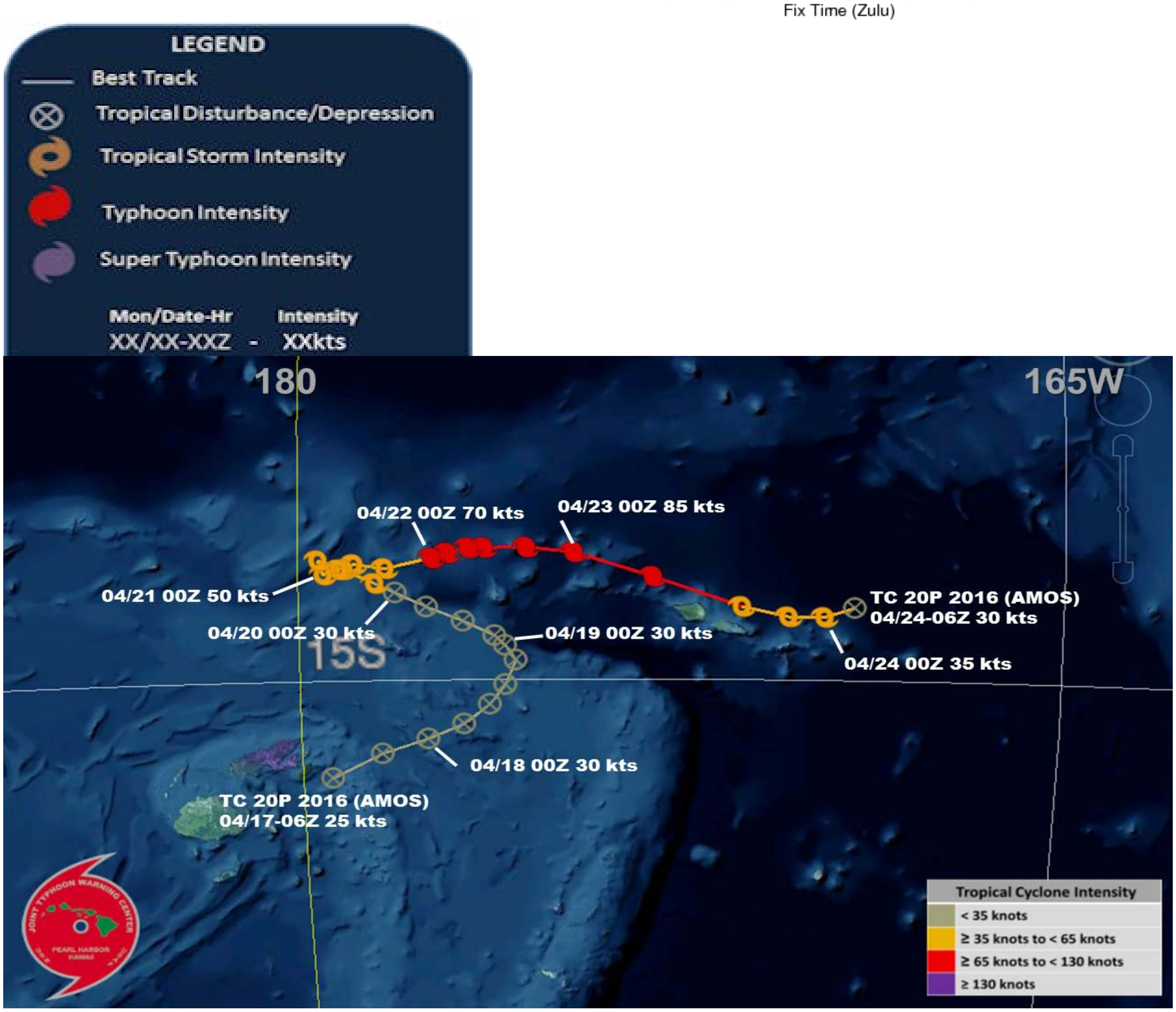




20P TROPICAL CYCLONE AMOS

ISSUED LOW:	None
ISSUED MED:	15 Apr / 1330Z
FIRST TCFA:	18 Apr / 0400Z
FIRST WARNING:	20 Apr / 0000Z
LAST WARNING:	24 Apr / 1800Z
MAX INTENSITY:	90
WARNINGS:	20





Section 3 Detailed Cyclone Reviews

Tropical Cyclone 11P (Winston)

I. Overview

Tropical Cyclone (TC) 11P (Winston) formed in the South Pacific Ocean, approximately 220 nautical miles to the northeast of Port Vila, Vanuatu, on 10 February 2016. This system was one of the world's most intense land-falling TCs, and the most intense TC to hit Fiji, since records began. TC Winston is also notable for its long duration (20 days), highly atypical track, and large variation in intensity throughout its lifecycle, all of which presented major forecast challenges. Figure 3-3 below chronicles the long, erratic track of TC Winston. Overall, dynamic model guidance handled the system poorly, often misrepresenting and misdiagnosing key steering influences, which consequently had a negative impact on the intensity forecasts. TC Winston reached a peak intensity of 155 knots (178 mph) at 06Z on 20 February 2016, just prior to making landfall along Fiji's northern coastline (Figure 3-3).

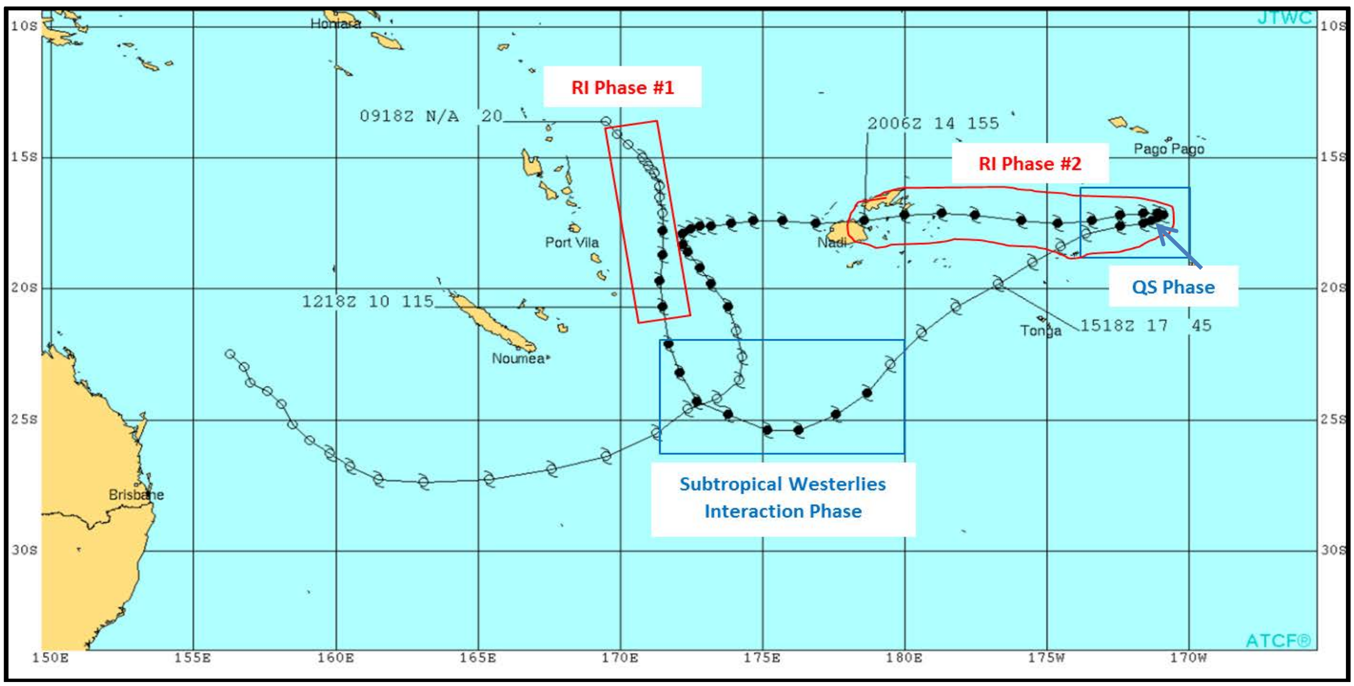


Figure 3-3: JTWC best track for TC 11P (Winston).

II. Steering and Intensity Mechanisms

TC Winston initially tracked southward along the western periphery of a subtropical ridge (STR) to the east. Between 9 and 12 February, the system underwent a phase of steady to rapid intensification (RI), with best track intensities increasing from 20 knots to 115 knots (Figure 3-4). The JTWC defines RI as an increase in TC intensity of 30 knots or greater during a 24-hour period (Kaplan and DeMaria, 2003). Environmental conditions supported intensification with radial outflow, low (5 to 10 knots) vertical wind shear (VWS), and very warm (30 to 31°C) sea-surface temperatures (SSTs). By 12 February at 18Z, the STR had reoriented and shifted equatorward as a meridionally-oriented mid-latitude trough, positioned to the southeast, began to dig equatorward. In response to the reoriented steering environment, over the next two days, TC Winston tracked to the east and northeast along the outer periphery of the subtropical westerlies (Figures 3-3 and 3-5). During this phase of interaction with the subtropical westerlies, TC Winston underwent rapid weakening, dropping from a 115-knot system to a 45-knot system, as outflow became restricted and VWS increased to unfavorable levels. However, as Winston tracked northeastward, environmental conditions once again improved, leading to a second period of more pronounced intensification (Figures 3-4 and 3-5).

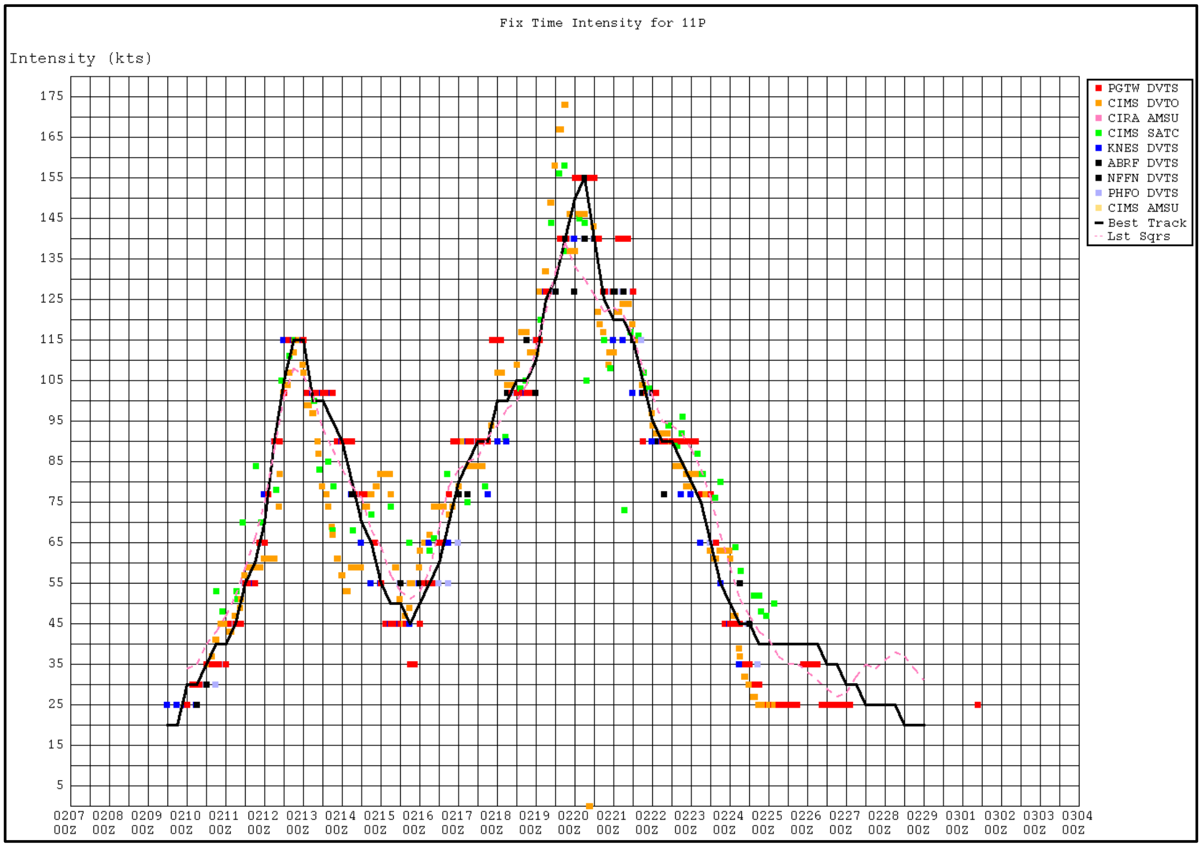


Figure 3-4: TC Winston Fix Intensity vs. Time graph showing the bi-modal distribution of intensity change, with two phases of rapid intensification and weakening.

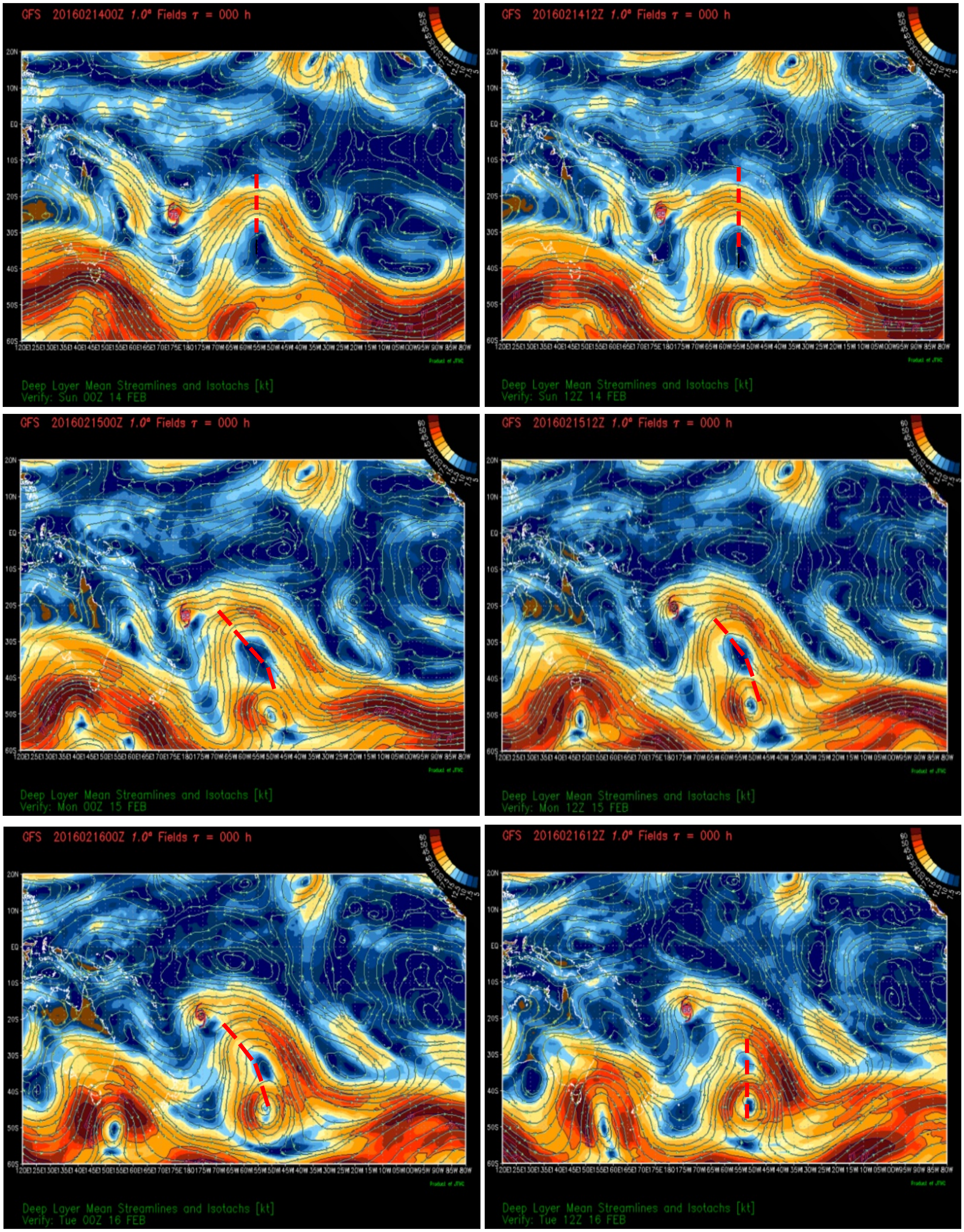


Figure 3-5: GFS deep layer mean streamline and isotach analyses for the 14 February 0000Z through 16 February 1200Z period. TC Winston remained on the periphery of stronger westerly flow as it followed an unusual eastward to northeastward track toward a more favorable environment during this period.

From 17 to 18 February, TC Winston became quasi-stationary as it entered a col region between two competing steering ridges: 1) a near-equatorial ridge (NER) to the northeast and 2) a subtropical ridge to the south and west of the system. There was a high degree of uncertainty in the overall synoptic steering pattern during this period, particularly regarding which ridge feature would become the dominant steering mechanism. The NER to the north was initially expected to build southward and, consequently, turn TC Winston sharply south to southeastward after the quasi-stationary phase. JTWC forecasts called for the system to quickly recurve poleward after it meandered well east of Fiji, in response to both this NER and an approaching upper-level trough to the west (Figure 3-6). Due to the known dependency of intensity mechanisms on TC track, there was high uncertainty in the JTWC intensity forecast as well (Bhatia et al. 2013 and Emanuel et al. 2016). Dry air entrainment, limited outflow and upwelling were expected to negatively impact Winston's intensity during this period.

Contrary to predictions, during the post-QS phase the deep layered STR to the south of TC Winston ultimately became the dominant steering mechanism (Figure 3-9). This STR pushed the storm on a westward track towards Fiji, and across very warm (30°C) SSTs. Note the large JTWC track forecast changes evident in Figure 3-6, which reflect a general westward trend toward Fiji over time. An upper-level reflection of this steering ridge feature, in concert with an upper-level point source to the north, and upper-level troughing to the southeast of TC Winston, provided a favorable upper-level environment for intensification by establishing low VWS and dual-channel outflow (Figure 3-7). TC Winston underwent steady to rapid intensification over the course of a few days, evolving from a 45 knot system on 15 February to a Southern Hemisphere record 155-knot system (tied with TC Monica (2006) on 20 February, just prior to landfall over Viti Levu, Fiji (Figure 3-8).

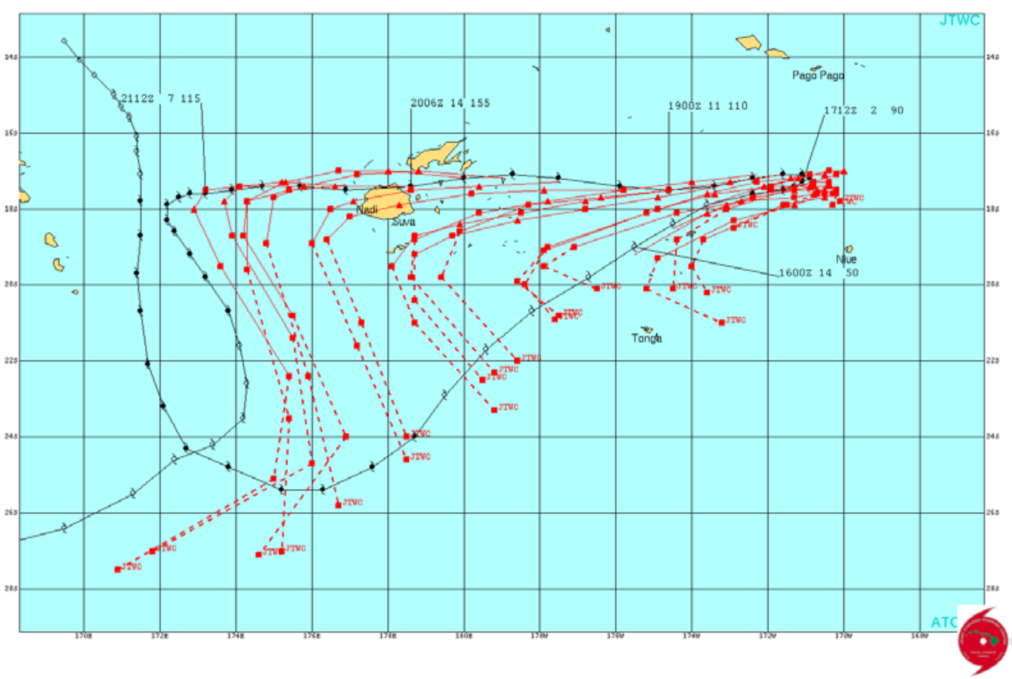


Figure 3-6: TC 11P best track and JTWC track forecasts from 16 Feb 2016 at 0000Z through 21 Feb 2016 at 1200Z. JTWC forecasts walked westward as forecasters struggled to identify the correct primary steering influence.

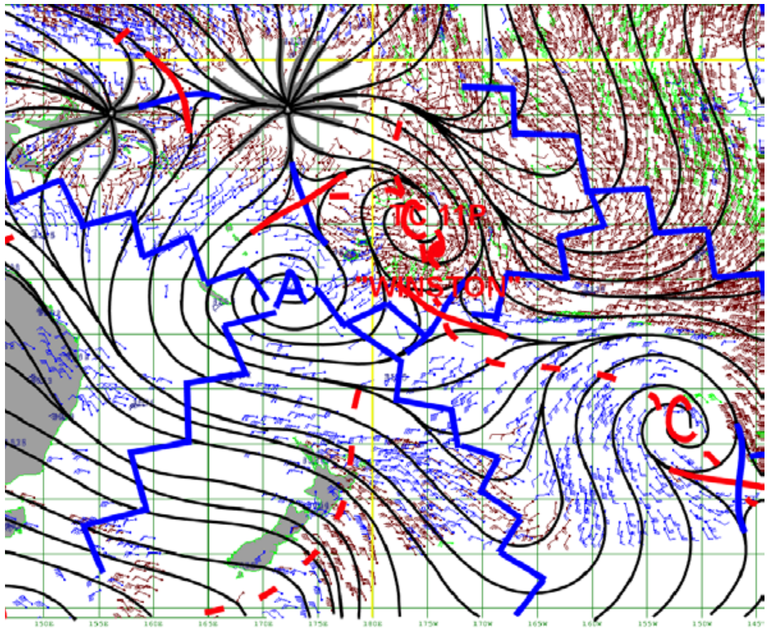


Figure 3-7: Upper-level streamline analysis in the vicinity of TC Winston on 17 Feb 2016 at 1200Z.

The onset of rapid intensification on 19 February was preceded by a cyan ring feature evident in a 37 GHz microwave image from the Coriolis satellite platform on 18 February at 1752Z (see Fig 3-8). Based on research from Kieper and Jiang (2012), this cyan ring could have provided an early signal to forecasters of the impending intensity changes. Model guidance and JTWC forecasts significantly under-forecasted the peak intensity of TC Winston.

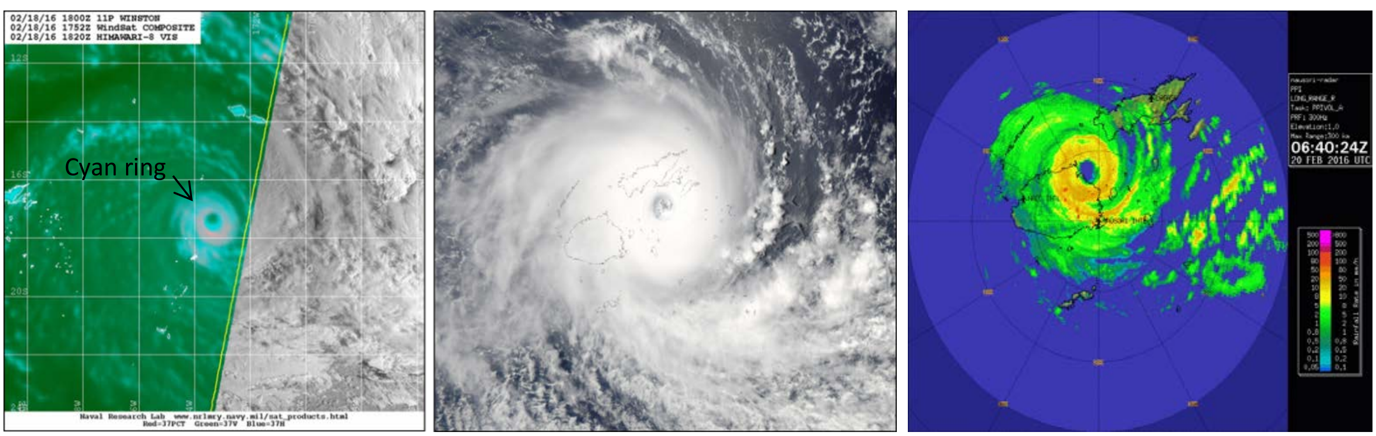


Figure 3-8: Left image: 18 Feb 2016 1752Z Coriolis 37 GHZ composite image depicting a microwave eye feature with cyan ring outlining the eyewall. The storm was positioned several hundred miles to the east of Fiji (image source: NRL TC webpage). **Center image**: 20 Feb 2016 0130Z natural color image of TC Winston from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite, just prior to landfall (image source: NASA). **Right image:** 20 Feb 2016 0640Z radar base reflectivity showing the cyclone's landfall upon Fiji's northeast coast (image source: Fiji Meteorological Service).

III. Model Forecast Performance

Numerical model forecasts for TC Winston exhibited large track forecast errors, especially beyond 48 hours (Figure 3-10). The largest degree of uncertainty within the models occurred from 16 through 18 February when the system tracked equatorward, stalled, and then reversed course westward towards Fiji. This was a period marked by exceptionally poor agreement on the synoptic steering pattern and an overemphasis of the magnitude of the NER to the north and an upper-level trough to the southeast of TC Winston. Meanwhile, the magnitude of the deep-layered STR to the south of system was significantly under-forecast. The STR ultimately became the dominant steering mechanism during the 16 to 18 February period (Figure 3-9).

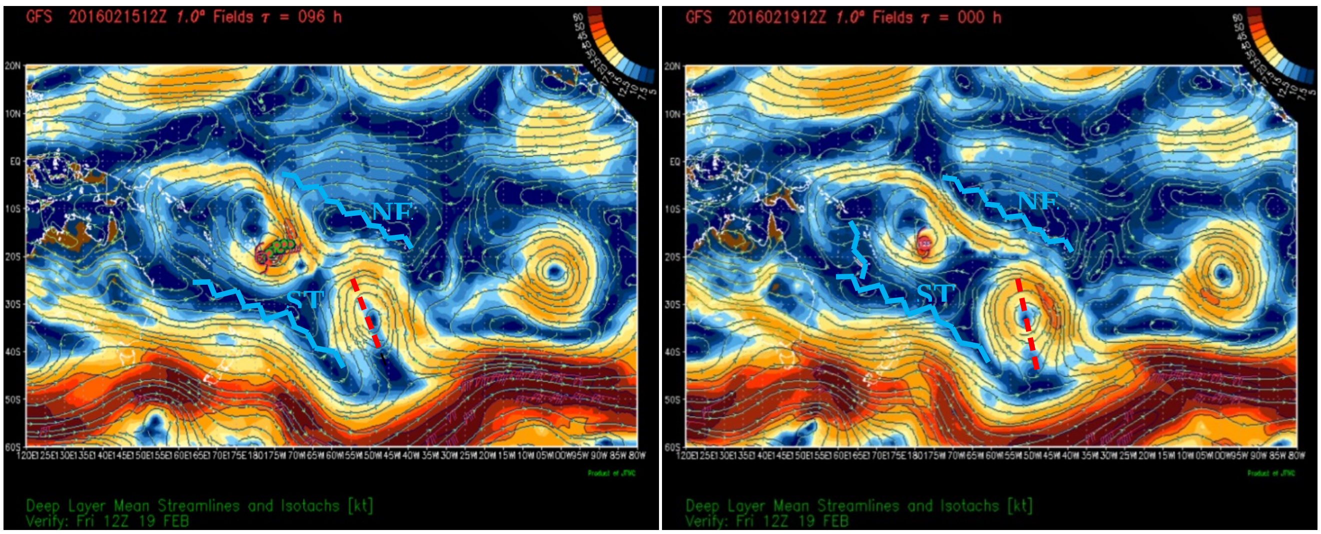


Figure 3-9: Deep-layer mean streamlines and isotachs. The left panel is the GFS model 96-hr forecast for 19 Feb 2016 at 1200Z, and the right panel is the GFS model analysis on 19 Feb 2016 a 1200Z. Major steering features are annotated in both panels, highlighting the differences in positioning and magnitude that ultimately influenced the track of TC Winston. The STR (not the NER, as initially predicted) became the dominant steering influence following the QS phase.

The interpolated HWRF (HWFI) and GFS (AVNI) model trackers provided the most accurate forecasts during the life-cycle of TC Winston, with their statistical mean errors beating both model consensus (CONW) and JTWC at all forecast times. The interpolated UKMET (EGRI) was also remarkably accurate, compared to the other model trackers, in the short-term forecast. This is evident in changes to the model forecast that occurred between 18 February 2016 at 1200Z and 21 February 2016 at 1200Z, when the model began to accurately resolve the strength of the STR to the south, and the associated model vortex tracker indicated a consequent westward movement of TC Winston. Interpolated GFS (AEMI) and ECMWF (EEMI) ensembles produced more accurate forecasts overall than a majority of the other trackers for all forecast times. Table 3-3 shows the individual model tracker performance statistics for the entire lifecycle of TC Winston.

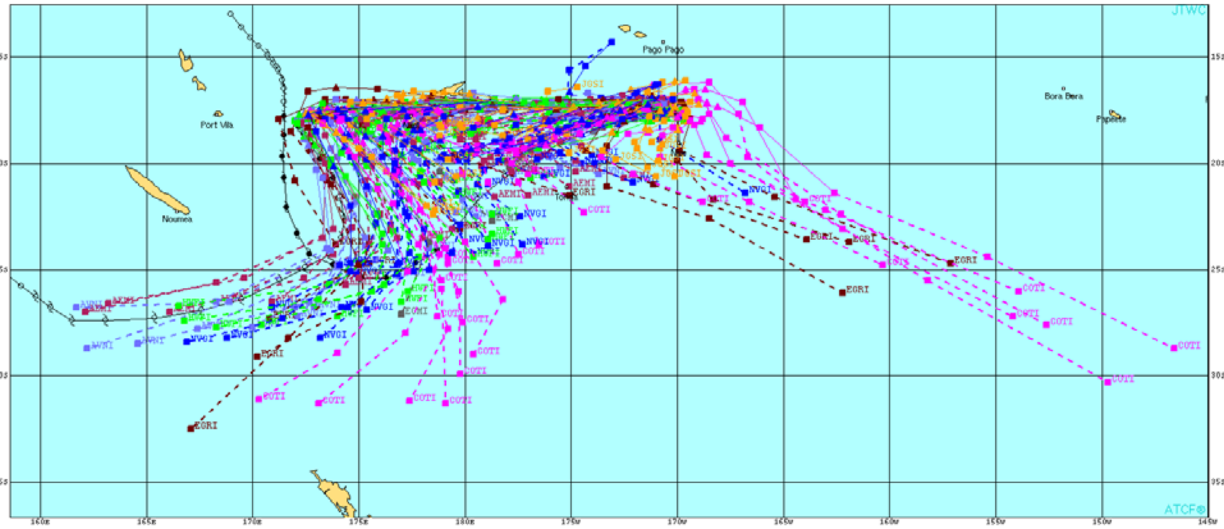


Figure 3-10: Dynamic model track forecasts from 16 Feb 2016 at 0000Z through 21 Feb 2016 at 1200Z. A majority of dynamic model guidance was erratic, indicating a less-pronounced westward track toward Fiji than was subsequently observed.

average track errors (NM) FOR HOMOGENEOUS SAMPLE								
	00	12	24	36	48	72	96	120
CONW	9.8	29.8	59.8	96.1	145.9	241.4	299.0	472.9
JTWC	9.8	31.7	66.4	102.1	145.8	238.6	300.4	444.1
AEMI	10.1	33.3	69.8	109.7	157.3	234.3	262.2	390.0
AVNI	10.1	25.8	52.3	82.3	119.1	167.8	187.4	284.7
COTI	10.1	43.5	81.8	122.0	170.8	286.8	516.2	869.9
ECMI	10.1	30.1	69.5	115.0	175.7	294.2	352.5	439.5
EEMI	10.1	33.2	72.8	117.0	172.5	257.0	311.9	408.1
EGRI	10.1	25.6	47.4	71.7	108.4	217.6	393.5	659.1
GFNI	10.1	40.6	74.4	103.0	136.0	207.3	305.2	434.7
HWFI	10.1	21.6	38.3	62.6	93.5	132.6	201.8	313.8
NVGI	10.1	42.5	90.2	140.7	200.3	307.2	434.2	567.4
#CASES	23	23	23	23	21	21	16	12

Table 3-3: Homogeneous forecast track error statistics for TC Winston. Overall model performance was poor, with a few noteworthy exceptions highlighted in green.

I

average track errors (NM) FOR HOMOGENEOUS SAMPLE								
	00	12	24	36	48	72	96	120
CONW	13.0	32.0	50.2	72.4	96.1	155.7	216.8	301.3
JTWC	12.8	33.6	51.2	70.0	90.1	154.1	216.8	281.7
AEMI	12.8	33.1	52.4	73.6	93.8	144.5	199.6	274.4
AVNI	12.8	31.9	49.7	68.6	86.3	126.8	158.4	207.8
COTI	12.8	39.5	66.6	97.5	128.0	198.5	294.3	454.4
ECMI	12.8	32.9	55.4	81.9	109.6	173.1	263.4	333.5
EGRI	12.8	33.1	56.2	79.5	100.2	174.9	292.2	408.1
GFNI	12.8	39.6	69.4	96.2	119.2	176.4	254.6	351.7
HWFI	12.8	30.6	47.9	67.0	89.0	137.9	202.3	274.1
NVGI	12.8	40.2	70.0	106.1	140.0	203.6	289.1	372.9
#CASES	135	130	120	110	95	77	59	43

Table 3-4: Overall model track performance during the 2016 Southern Hemisphere tropical cyclone season. Track forecasts from the HWRF mesoscale model outperformed all of the global models, with the exception of the GFS.

AVERAGE INTENSITY ERRORS (KT) FOR HOMOGENEOUS SAMPLE								
	00	12	24	36	48	72	96	120
JTWC	3.3	7.0	13.1	16.2	21.2	24.9	21.3	18.5
COTI	3.4	8.0	15.5	20.5	23.4	25.3	25.6	25.9
GFNI	3.4	11.4	19.7	25.5	26.7	26.8	26.1	28.2
HWFI	3.4	9.7	17.1	20.1	23.9	21.3	23.4	27.5
DSHA	3.4	8.2	12.9	16.8	21.6	23.6	21.9	21.9
DSHN	3.4	7.7	11.4	15.0	18.0	19.6	19.0	20.0
#CASES	43	43	42	42	38	36	35	31

AVG BIAS (KT) FOR HOMOGENEOUS SAMPLE								
	00	12	24	36	48	72	96	120
JTWC	0.5	1.6	1.7	1.7	2.5	-2.1	-5.6	-8.2
COTI	0.6	-0.9	-5.5	-8.7	-12.4	-17.0	-16.5	-17.8
GFNI	0.6	-8.3	-14.5	-16.7	-17.5	-13.2	-9.9	-11.5
HWFI	0.6	4.0	6.6	7.2	8.2	6.5	7.5	12.3
DSHA	0.6	-2.3	-5.3	-8.2	-11.0	-11.0	-5.7	-4.4
DSHN	0.6	-1.5	-3.5	-5.5	-7.7	-12.1	-12.0	-11.2
#CASES	43	43	42	42	38	36	35	31

Tables 3-5 (top) and 3-6 (bottom): Official (JTWC) and model intensity forecast statistics for TC Winston. COTI, GFNI, HWFI, DSHA, and DSHN are the COAMPS-TC (interpolated), GFDN (interpolated), HWRF (interpolated), decay-SHIPS with GFS environmental conditions, and decay-SHIPS with NAVGEM environmental conditions, respectively. Intensity forecast errors among the mesoscale models (COTI, GFNI, HWFI) are above average at forecast taus 24-48. An over-forecast bias is evident in HWRF forecasts (lower table) and an under-forecast bias is evident in all other models' forecasts. These trends are also evident in an equivalent statistical analysis for the entire 2016 southern hemisphere TC season (not shown).

V. Conclusion

TC Winston was a unique Southern Hemisphere storm noteworthy for its track, intensity, and duration. Numerical weather models and JTWC forecasters struggled to diagnose and predict this complex forecast scenario, which led to large forecast errors and limited preparation time prior to the storm's landfall in Fiji. Better resolution of key steering features may have prevented the large track errors recorded by the JTWC. Forecasters were somewhat hindered by the absence of available data sources. The limited number of radiosonde launching stations across the data-sparse South Pacific, for example, is problematic for global models. Addressing the declining number of low Earth orbiting satellites by launching new platforms carrying next-generation high-resolution microwave imagers and sounders could help alleviate this challenge by increasing data available for assimilation of derived parameters such as vertical profiles of temperature, pressure, and moisture.

Several prospective actions could address the track and intensity forecasting challenges noted in this report. For example, increasing the number of skillful model ensemble track and intensity forecasts available to JTWC could lead to higher forecast accuracy, particularly given that highly-accurate ensemble mean forecasts can be derived from a robust suite of individual ensemble members (Goerss 2000). Examining the superior TC track forecast performance of the GFS and HWRF compared to other models, the multi-model consensus (CONW), and JTWC forecasts during TC Winston (Table 3-4) and throughout the 2016 Southern Hemisphere tropical season (Tables 3-5 and 1-8) may also provide insight applicable to future cases. Identifying and correcting biases in model-derived TC intensity forecasts could limit medium-range intensity forecast errors, which were higher than average among mesoscale model forecasts for TC Winston (see Tables 3-5 and 3-6). Finally, increasing the application of emerging intensity prediction methods, especially those that incorporate information on TC core structure, could help forecasters improve prediction of rapid intensity change.

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Tropical Cyclone 06P (Ula)
I. Overview

JTWC's first warning for Tropical Cyclone (TC) 06P (Ula) was issued on 30 Dec 2015 at 0600Z, when the circulation was located approximately 280 nautical miles east-northeast of Pago Pago, American Samoa. TC Ula gradually intensified while initially tracking poleward under the steering influence of a near-equatorial ridge to the northeast. After about 12 hours, the cyclone turned sharply west-southwestward as a subtropical ridge (STR) to the south became the primary steering mechanism. This STR was weakened occasionally by transitory mid-latitude troughs, but rebuilt each time to remain the dominant steering mechanism throughout the remainder of the cyclone's lifespan. In response to changes in the orientation of the STR, TC Ula followed a meandering path, threatening several island nations including Samoa, Niue, Tonga, Fiji, Vanuatu, and New Caledonia, before finally recurving southeastward and dissipating in a cold baroclinic air mass to the north of New Zealand.

TC Ula underwent three distinct periods of intensification, including two periods of rapid intensification, defined here as greater than 30 knots of intensification within 24 hours (Kaplan and DeMaria, 2003). Fortunately, due to the cyclone's winding track around many populated islands, major damage was avoided and only localized impacts were reported. This review highlights the rapid intensity changes observed during the lifecycle of TC 06P, with a focus on the second RI event. Noteworthy differences in model intensity forecast performance, particularly the relative accuracy of the HWRF model, are also discussed.

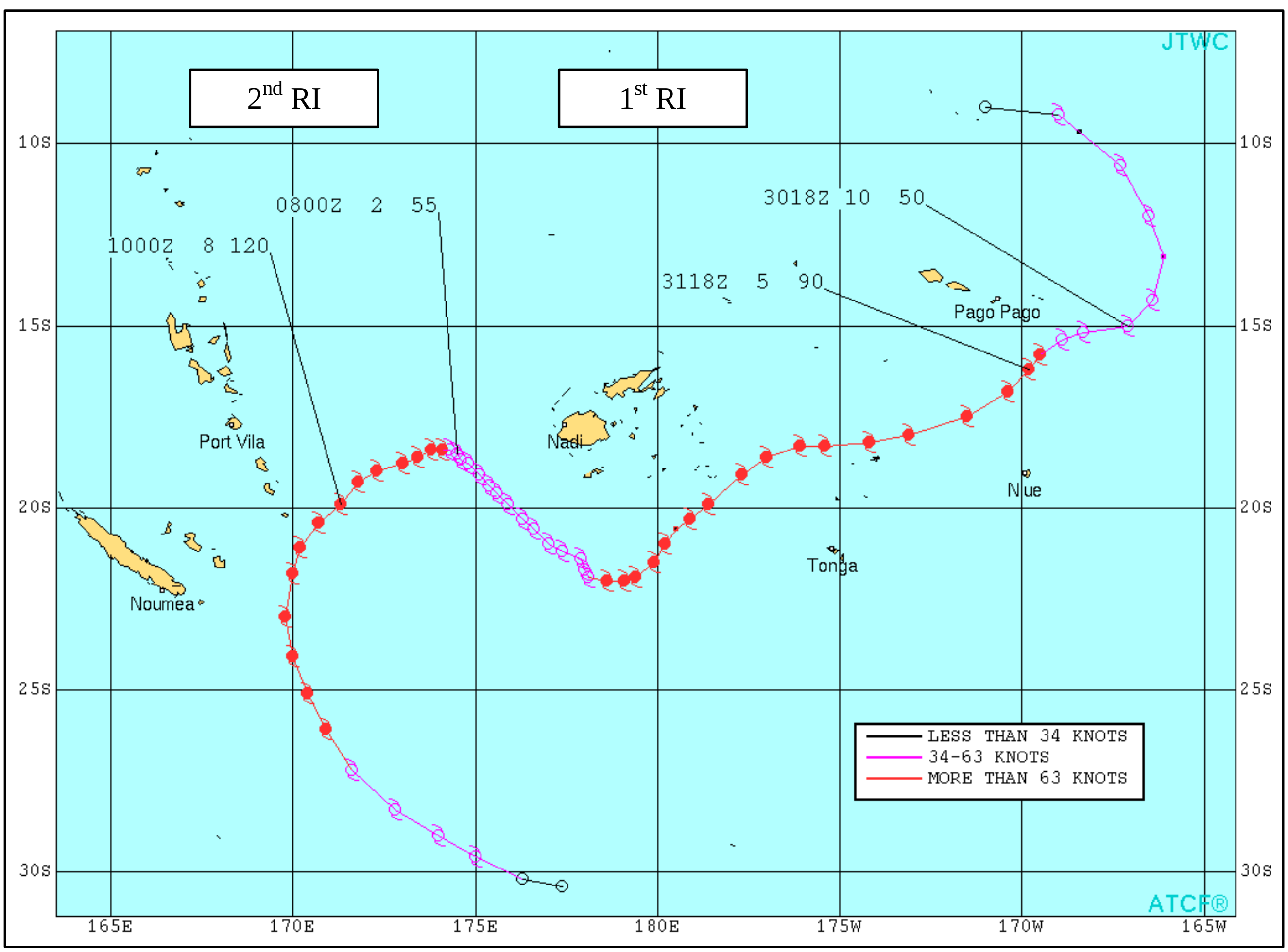

Figure 3-11: TC 06P (Ula) best track with notable RI events delineated.

Despite TC Ula's complex track, JTWC average forecast track errors (Table 3-7: Homogeneous comparison to the multi-model consensus, CONW) were quite accurate overall. Official track forecast errors were particularly low in the extended period, during which JTWC outperformed CONW by 6% at tau 72, 15% at tau 96 and 39% at tau 120.

	Tau 24	Tau 48	Tau 72	Tau 96	Tau 120
JTWC	34	57	**88**	**127**	**99**
CONW	33	55	**94**	**150**	**162**
# Cases	*27*	*24*	*22*	*14*	*6*

Table 3-7: Forecast track error (nm): homogeneous comparison (JTWC vs. CONW).

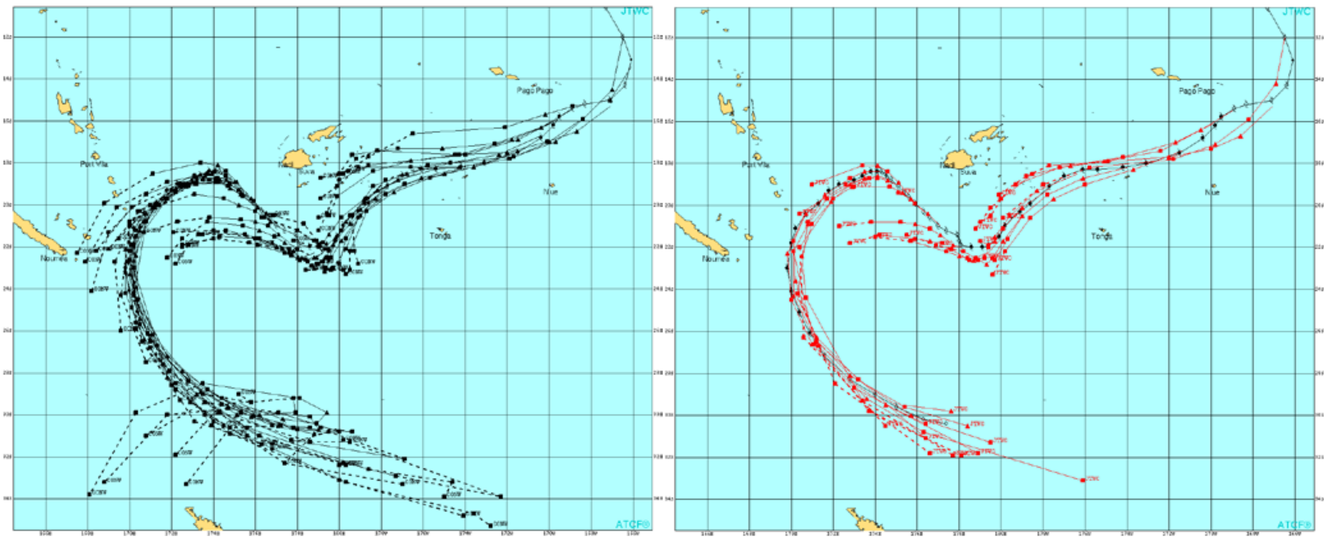

Figure 3-12: Final best track and all JTWC (left) and CONW (right) track forecasts from the coincident timeframe for TC Ula.

With a few exceptions, JTWC forecasts accurately predicted the unusual equatorward track change that preceded the second RI event (see Figures 3-11 and 3-12), as well as the subsequent sharp re-curvature that followed. Generally, performance by the models comprising the multi-model consensus (CONW) varied considerably, with a large range of forecast track error values evident in a basic statistical analysis. Although JTWC track forecasts for TC Ula were quite accurate overall, with tau 48 to tau 120 errors approximately 40% to 65% lower than 2016 southern hemisphere seasonal averages, intensity changes were not as well-predicted. Both numerical model and JTWC official intensity forecasts for the second RI event, which followed a sustained weakening phase evident in Figure 3-13, were particularly inaccurate. However, intensity forecasts from the Hurricane Weather Research and Forecast (HWRF) model noticeably outperformed other model guidance, as well as JTWC official forecasts, for that period and for most forecast taus throughout the full lifecycle of TC Ula. The following sections of this review discuss these differences in further detail.

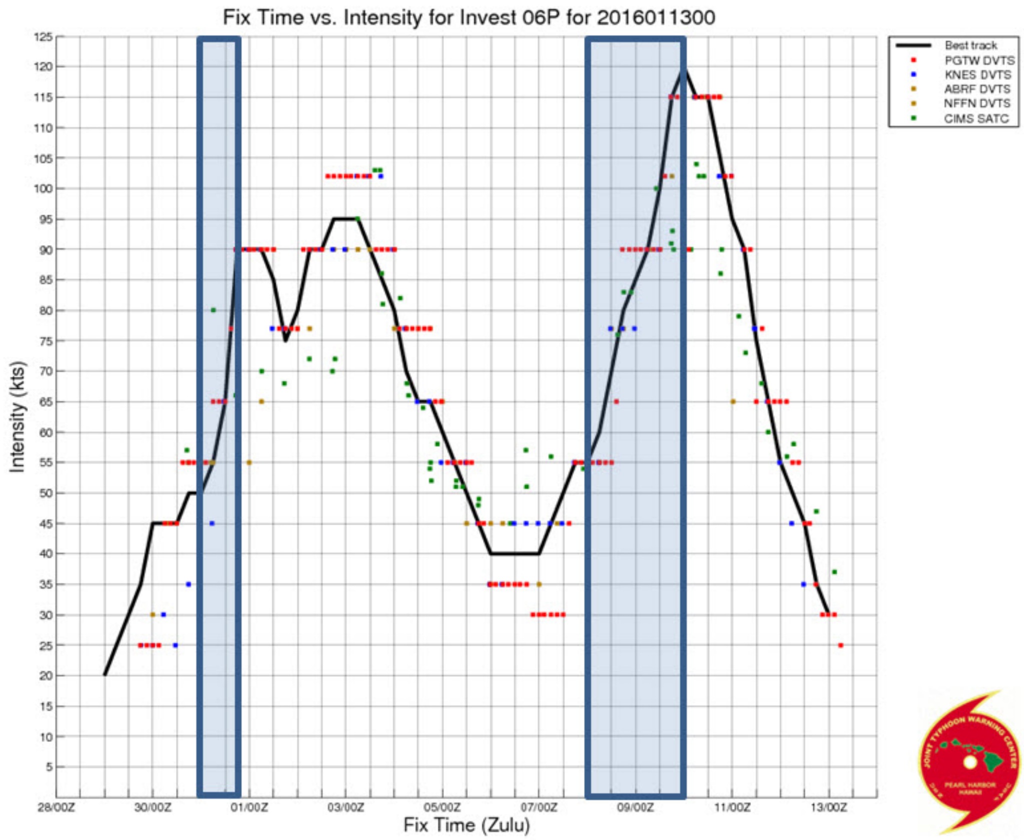

Figure 3-13: Fix and best track intensity history for TC 06P (Ula) indicating three distinct intensification events, including two periods of rapid intensification highlighted by the shaded boxes, and a period of steady weakening around the mid-point of the cyclone's lifecycle.

II. Rapid Intensification

TC Ula underwent three periods of significant intensification, two of which were classified as rapid intensification (RI) events. The first RI event occurred between 30 Dec 2015 at 1800Z and 31 Dec 2015 at 1800Z, when the TC passed to the southeast of American Samoa and intensified from 50 to 90 knots. The second RI event occurred during the 48-hour period extending from 08 Jan 2016 at 0000Z to 10 Jan 2016 at 0000Z, during which time the system intensified from 55 knots to its peak of 120 knots while tracking to the west of Fiji and approaching Vanuatu (Figure 3-13). As previously noted, large JTWC forecast intensity errors occurred during this second RI event.

Predicting TC intensity change is an ongoing challenge for forecast agencies, including JTWC. Forecasting the onset, duration and cessation of RI is arguably the most challenging aspect of TC intensity forecasting. In general, RI occurs over varying timescales, takes place in an exceptionally favorable environment and is more likely to occur in certain geographic areas. In the JTWC AOR, these areas include the Philippine Sea, Mozambique Channel and the Gulf of Carpentaria, among others. RI is particularly likely when a TC develops dual outflow channels (Chen and Gray, 1985), especially when the dual outflow pattern coincides with an area of exceptionally warm sea surface temperature (SST), typically greater than 28°C, and/or high ocean heat content (OHC), typically greater than 50 kJ/cm^2 (Shay et al. 2000). These conditions were present during TC 06P's first RI event, but not during the second RI period.

A TC with an accompanying single-channel outflow (e.g., poleward channel) may also rapidly intensify when additional environmental conditions are conducive. One common single-outflow RI setup can develop as TCs approach the STR axis, where the translation speed of the tropical cyclone decreases, vertical wind shear (VWS) is usually low to moderate, and the underlying SSTs/OHC are sufficiently warm/high to support a period of intensification. These conditions were present during the second RI event (Figure 3-14).

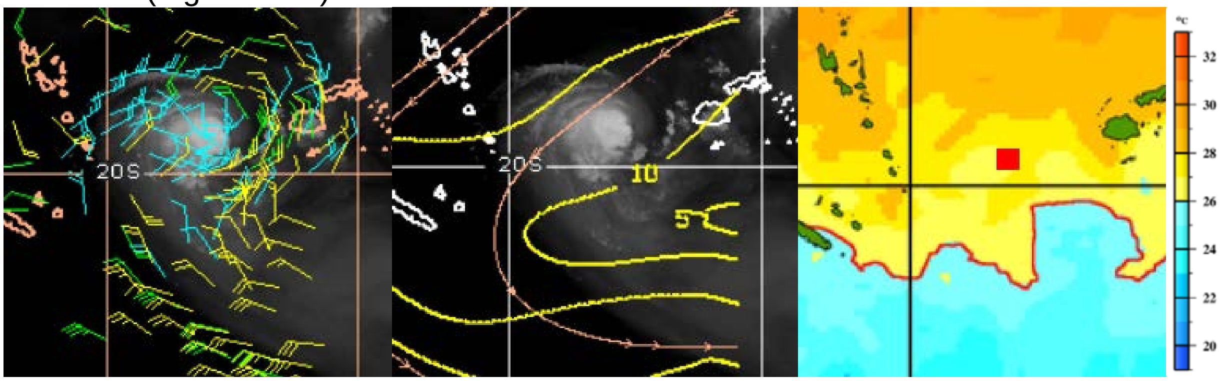

Figure 3-14: Upper-level satellite feature track winds and Himawari satellite image (left – courtesy CIMSS), vertical wind shear and Himawari satellite image (center - courtesy CIMSS) and sea surface temperature (right; red box marks the approximate location of the TC center – courtesy AOML, NOAA) for TC Ula at 08 January 0000Z.

III. Consensus Intensity Forecasting

JTWC forecasters use a suite of statistical-dynamical and dynamical (mainly mesoscale) models as the primary toolset for TC intensity prediction. The consensus of models previously used to forecast the intensity of southern hemisphere TCs (including during TC 06P's lifecycle), was known as S5XX. S5XX was a numerical average of intensity predictions from the Statistical Typhoon Intensity Prediction Scheme (STIPS), as well as the COAMPS-TC, GFDN, HWRF and CHIPS dynamic models. A homogeneous statistical comparison of average model and official (JTWC) forecast intensity errors for the complete lifespan of TC 06P indicates that the interpolated HWRF TC vortex tracker (HWFI) was the best overall performer for the short-range and medium-range forecast taus (Table 3-8).

AVERAGE INTENSITY ERRORS (KT) FOR HOMOGENEOUS SAMPLE

	00	12	24	36	48	72	96	120
JTWC	3.5	9.8	13.1	13.4	15.5	26.3	27.7	16.3
COTI	3.5	10.9	15.8	21.2	20.9	21.7	24.6	6.3
GFNI	3.5	12.0	18.1	23.3	23.7	21.8	23.2	9.3
HWFI	3.5	8.2	11.0	13.4	14.3	17.9	16.5	17.0
CHII	3.5	15.5	20.8	24.3	28.3	29.7	26.7	11.0
S5XX	3.5	10.0	13.0	14.5	16.9	18.7	20.9	12.8
S5YY	3.5	9.9	13.8	16.1	18.9	21.7	20.3	3.8
WANI	3.5	11.6	17.3	21.0	22.8	20.2	20.9	15.5
#CASES	26	24	24	22	21	19	11	4

AVG BIAS (KT) FOR HOMOGENEOUS SAMPLE

	00	12	24	36	48	72	96	120
JTWC	-1.9	-2.3	-4.8	-8.0	-15.0	-24.7	-24.1	-13.8
COTI	-1.9	-6.4	-12.0	-17.7	-17.9	-16.1	-19.7	-0.8
GFNI	-1.9	-7.7	-14.4	-20.7	-20.6	-17.8	-15.0	5.8
HWFI	-1.9	-3.0	-2.1	-0.9	-1.5	-5.9	-10.8	2.0
CHII	-1.9	-12.3	-15.7	-17.7	-21.3	-25.2	-17.8	1.5
S5XX	-1.9	-5.8	-10.0	-11.5	-11.2	-13.6	-12.2	11.8
S5YY	-1.9	-6.3	-9.5	-12.9	-15.0	-16.5	-17.0	-0.8
WANI	-1.9	1.0	1.2	0.5	-3.4	-16.0	-15.6	-6.0
#CASES	26	24	24	22	21	19	11	4

Table 3-8. Average forecast intensity errors for TC Ula (2016) (top) and biases (bottom) (homogeneous comparison).

AVERAGE INTENSITY ERRORS (KT) FOR HOMOGENEOUS SAMPLE

	00	12	24	36	48	72	96	120
JTWC	2.7	6.2	10.4	16.0	21.7	35.6	46.7	0.0
COTI	2.7	7.1	12.9	19.1	20.7	23.0	45.7	0.0
GFNI	2.7	11.2	20.5	27.9	30.6	31.4	37.7	0.0
HWFI	2.7	5.5	9.7	15.5	17.3	17.8	20.3	0.0
CHII	2.7	14.2	20.5	27.9	36.1	41.8	47.7	0.0
S5XX	2.7	8.0	14.1	19.8	25.0	30.3	41.0	0.0
S5YY	2.7	7.7	12.9	19.5	23.2	26.1	39.3	0.0
WANI	2.7	10.1	16.1	22.9	25.4	23.8	33.0	0.0
#CASES	15	13	12	10	9	8	3	0

AVG BIAS (KT) FOR HOMOGENEOUS SAMPLE

	00	12	24	36	48	72	96	120
JTWC	-2.0	-2.3	-7.1	-13.0	-21.7	-31.9	-46.7	0.0
COTI	-2.0	-4.5	-11.4	-18.3	-20.7	-21.8	-45.7	0.0
GFNI	-2.0	-8.8	-19.8	-27.9	-30.3	-31.4	-37.7	0.0
HWFI	-2.0	-2.7	-3.0	-2.9	-3.6	-8.8	-20.3	0.0
CHII	-2.0	-13.4	-20.3	-27.3	-36.1	-41.8	-47.7	0.0
S5XX	-2.0	-6.6	-13.8	-19.4	-24.1	-30.3	-41.0	0.0
S5YY	-2.0	-6.5	-12.1	-18.5	-23.0	-25.9	-39.3	0.0
WANI	-2.0	1.5	-1.3	-5.9	-13.0	-22.5	-33.0	0.0
#CASES	15	13	12	10	9	8	3	0

Table 3-9. Average forecast intensity errors (top) and biases (bottom) for TC 06P (2016) for the period from 04 January 0000Z – 11 January 1800Z (homogeneous comparison).

IV. Second RI Event, 010800-011000 (55-120 knots)

Table 1-11 shows homogeneous intensity forecast statistics for the second RI event, during which TC 06P tracked equatorward, rapidly intensified, and re-curved poleward. HWFI was the far superior performer during this period, partially due to more accurate forecasts for the RI period. JTWC forecasts were also more accurate than the consensus methods, S5XX and S5YY, in the near- to medium-term (12-48 hour) forecast taus (Table 3-9).

While JTWC forecasters recognized a favorable environment for intensification prior to the second RI event, they anticipated a “slow period of development” in the 08 January 2016 0600Z forecast. The recent intensity trend (nearly steady for the previous 18 hours), unusual equatorward track, and inconsistent model intensity forecasts made it difficult to predict a rapid rate of intensification. Most of the dynamic and statistical-dynamic models that comprise the multi-model intensity forecast consensus did not predict significant intensification. On the other hand, HWRF consistently called for a steady to rapid intensification trend in the 08 Jan 0600Z, 08 Jan 1200Z, and 08 Jan 1800Z forecasts (see Figures 3-15 and 3-16). COAMPS-TC also predicted intensification at 08 Jan 0600Z and 08 Jan 1200Z, but the timing and extent of the intensification trend were less accurate. Recognizing that HWRF had provided the best depiction of the ongoing intensity trend despite its status as a significant “outlier,” JTWC forecasters adjusted the official forecast to closely follow HWRF guidance at 08 Jan 1800Z. That official forecast called for the cyclone to intensify to 110 knots from the observed 80 knot intensity within 36 hours, only 10 knots shy of the final storm maximum estimated intensity of 120 knots, which was observed at 10 Jan 0000Z (30 hours later).

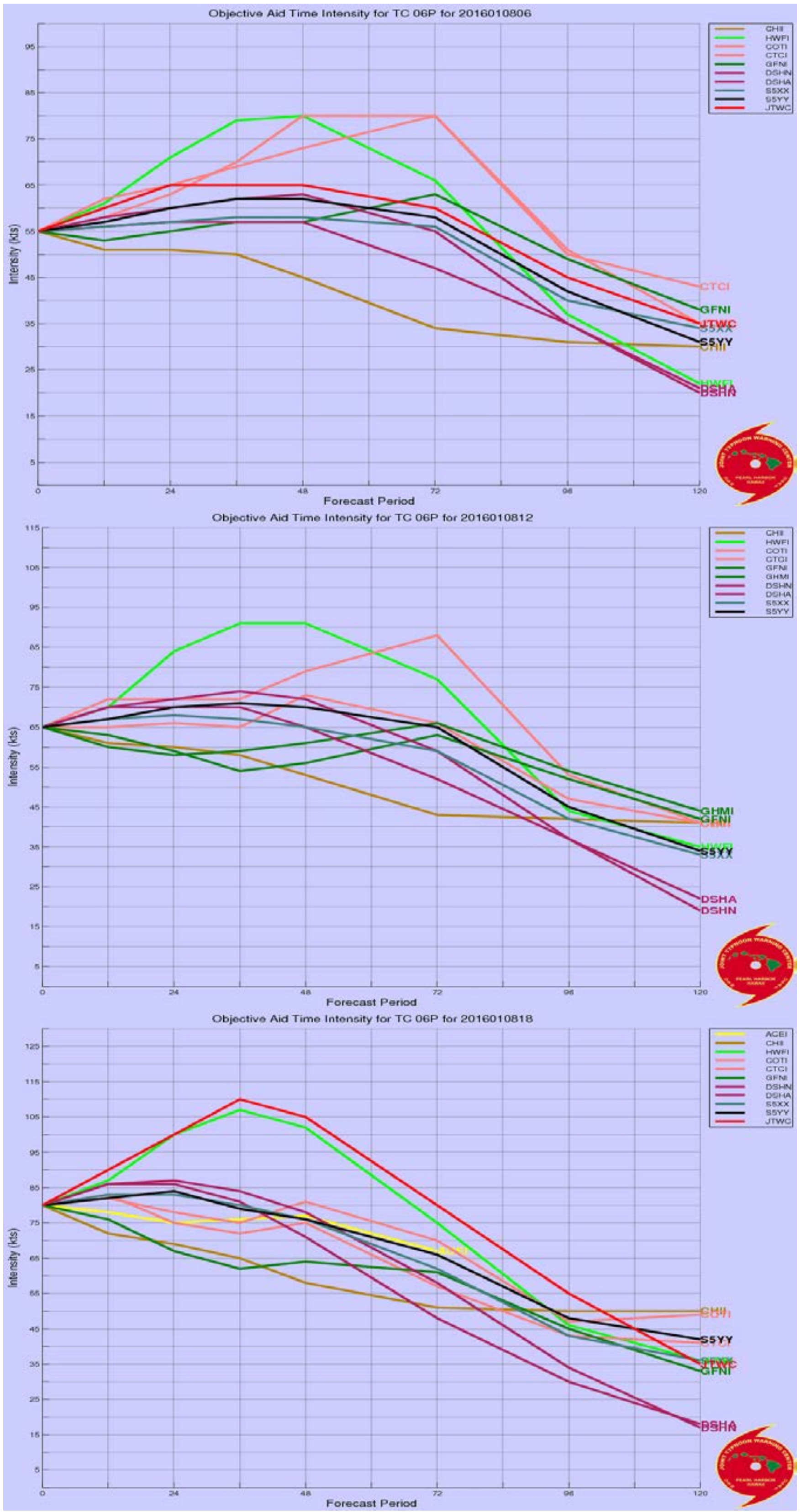

Figure 3-15: Intensity consensus model and JTWC official forecasts for TC Ula from the 08 Jan 0600Z (top) through 08 Jan 1800Z (bottom) period. Note that interpolated HWRF model intensity forecasts (HWFI – light green) lie above the primary consensus model grouping at each forecast time, particularly at 08 Jan 1800Z.

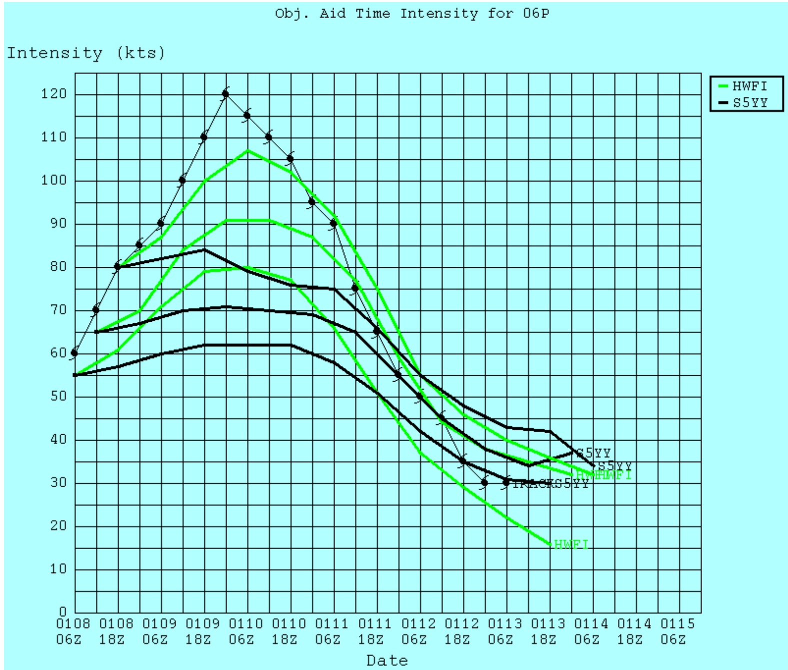

Figure 3-16: HWFI and S5YY consensus intensity forecasts for TC Ula from the 08 Jan 0600Z through 08 Jan 1800Z period.

V. Conclusion

Forecasting the intensity of TC Ula was clearly a challenge for JTWC forecasters and objective methods alike. HWRF forecasts were more consistent and accurate than other model forecasts, particularly during the second RI period discussed in this report. It is worth noting that the HWRF model has provided forecasters "signals" of rapid intensification prior to observed events in many instances. The root causes for the model's superior performance during TC Ula were not apparent from an inspection of model forecast fields and other environmental data. However, further study of this case, perhaps through retrospective modeling, may yield valuable insights regarding specific factors that influence model intensity forecasts prior to RI events.

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Chapter 4 Tropical Cyclone Fix Data

Section 1 Background

Meteorological satellite data continued to be the mainstay for the TC reconnaissance mission at JTWC. JTWC satellite analysts produced 8,100 position and intensity estimates. A total of 4,464 of those 8,100 fixes were made using microwave imagery, amounting to just over 55 percent of the total number of fixes. A total of 575 of those 8,100 fixes were scatterometry fixes amounting to just over 7 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 count of DND fixes for all basins was 1,233. Which account for approximately 15% of all fixes in 2016 .

During 2016, JTWC received authorization to install and use the Gibson Ridge Software, LLC GRLevel2 and GRLevel3 software to perform TC reconnaissance using U. S. WSR-88D Doppler Weather Radars installed in Guam, Okinawa, South Korea, and Hawaii. This software provides significant capability for surveillance when TCs are within range of these radar systems. JTWC also continues to use radar information available via the Internet from nations around the Pacific and Indian Oceans.

Section 2 Fix Summary by Basin

TABLE 4-1 WESTERN NORTH PACIFIC OCEAN FIX SUMMARY FOR 2016				
Tropical Cyclone	Name	Visible/Infrared	Microwave/Scatterometry	Total
01W	ONE	11	9	20
02W	NEPARTAK	59	42	101
03W	THREE	22	14	36
04W	LUPIT	15	28	43
05W	MIRINAE	31	30	61
06W	NIDA	41	46	87
07W	OMAIS	38	63	101
08W	CONSON	53	72	125
09W	CHANTHU	48	62	110
10W	MINDULLE	46	72	118
11W	DIANMU	19	8	27
12W	LIONROCK	110	181	291
13W	KOMPASU	22	27	49
14W	FOURTEEN	19	16	35
15W	NAMTHEUN	42	56	98
16W	MERANTI	57	68	125
17W	SEVENTEEN	26	25	51
18W	MALAKAS	84	112	196
19W	RAI	23	11	34
20W	MEGI	60	59	119
21W	CHABA	81	116	197
22W	AERE	79	74	153
23W	SONGDA	76	97	173
24W	SARIKA	61	69	130
25W	HAIMA	68	93	161
26W	MEARI	66	85	151
27W	MA-ON	42	48	90
28W	TWENTYEIGHT	25	22	47
29W	TOKAGE	36	39	75
30W	NOCK-TEN	63	97	160
DND	-	179	128	307
Totals	**-**	**1602**	**1869**	**3471**
Percentage of Total	**-**	**46.15%**	**53.85%**	**100**

TABLE 4-2 NORTH INDIAN OCEAN (BAY OF BENGAL/ARABIAN SEA) FIX SUMMARY FOR 2016				
Tropical Cyclone	**Name**	**Visible/Infrared**	**Microwave/Scatterometry**	**Total**
01B	ROANU	44	48	92
02A	TWO	31	33	64
03B	KYANT	77	105	182
04B	NADA	30	32	62
05B	VARDAH	111	115	226
DND	-	51	52	103
Totals	**-**	**344**	**385**	**729**
Percentage of Total	**-**	**47.19%**	**52.81%**	**100**

TABLE 4-3 SOUTH PACIFIC & SOUTH INDIAN OCEAN FIX SUMMARY FOR 2016				
Tropical Cyclone	**Name**	**Visible/Infrared**	**Microwave/Scatterometry**	**Total**
01P	ONE	38	100	138
02P	TWO	33	41	74
03S	ANNABELLE	73	106	179
04P	TUNI	36	59	95
05S	BOHALE	64	104	168
06P	ULA	118	182	300
07P	VICTOR	72	126	198
08S	CORENTIN	62	112	174
09S	STAN	27	38	65
10S	DAYA	51	55	106
11P	WINSTON	177	252	429
12P	TATIANA	62	66	128
13S	URIAH	86	147	233
14P	YALO	26	42	68
15S	EMERAUDE	72	76	148
16P	SIXTEEN	20	6	26
17S	SEVENTEEN	20	23	43
18P	ZENA	25	27	52
19S	FANTALA	130	166	296
20P	AMOS	72	85	157
DND	-	426	397	823
Totals	**-**	**1690**	**2210**	**3900**
Percentage of Total	**-**	**43.33%**	**56.67%**	**100**

Chapter 5 Technical Development Summary

Section 1 Operational Priorities

The top operational priority of the Joint Typhoon Warning Center remains the sustained development and support of the Automated Tropical Cyclone Forecast System (ATCF). ATCF is the DoD's **ONLY** 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 is used to track all invest areas (developing disturbances) and TC activity, processes objective forecasting aids, produce TC formation alerts, warning text and graphical products and provide core capabilities for analyzing TCs and their environment. Additionally, ATCF offers JTWC Contingency of Operations Plan (COOP) backup capabilities to Fleet Weather Center (FWC)-Norfolk and analytic support to FWC-San Diego for tasks such as setting Tropical Cyclone Conditions of Readiness (TCCOR), forecasting on-station wind speed, designating Optimum Track Ship Routing (OTSR) "MODSTORM" locations, and preparing diverts and advisories. JTWC upgraded to the latest version of ATCF (v5.8) in September 2016. In addition to improving analysis, display and processing efficiency, this upgrade introduced new consensus-based tools for wind radii analysis and forecasting, which enabled JTWC to produce operational 5-day forecasts of TC wind radii starting in the fall of 2016. The latest release, v5.8.3, scheduled for implementation in summer 2017, incorporates numerous new guidance products and visualization tools to further improve JTWC's analysis and forecast capabilities and accuracy. These new features are highlighted in Section 3.

JTWC has also prioritized integrating a state-of-the-art platform to facilitate visualization and evaluation of meteorological data. In 2015, the Commander, US Navy Meteorology Oceanography Command authorized acquisition of the National Weather Service (NWS) Advanced Weather Interactive Processing System (AWIPS-II) as the Navy's next-generation weather display and analysis system for JTWC, FWC-Norfolk and FWC-San Diego. JTWC received the AWIPS system in June, 2017, and technical services staff will facilitate incorporation of AWIPS-II into operations by developing standard operating procedures and site-specific applications in the months ahead. Attainment of initial operating capability (IOC), originally anticipated to occur in 2017, is now projected to follow in mid-2018. AWIPS-II promises many enhanced data synthesis capabilities that are expected to supplement JTWC data visualization and fusion. However, replicating the functionality, cost-effectiveness, and long-term research to operations (R2O) efficiency of the ATCF system 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.

Section 2   Research and Development Priorities

The top 6 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 2017 Interdepartmental Hurricane Conference, are presented in Table 5-1. Developing guidance to accurately forecast TC intensity change, particularly the onset, duration, and magnitude of rapid intensity change remains the highest R&D priority. In 2016, 50% of all WESTPAC tropical cyclones reaching tropical storm intensity or higher experienced at least one period of 30-knot intensification over a 24-hour period.

JTWC has moved TC structure specification improvement to its number two priority. The radius of 34-knot winds (R34) impacts the specification of the 34-knot danger swath, wind speed probabilities, TCCOR, and wave forecasting. Additionally, new research by Bender et al. (2017) indicates that improved R34 inputs to the GFDL TC model, using objective best track wind radii (OBTK) described in section 3, reduced intensity forecast error for tropical cyclones undergoing rapid intensification by 14 to 17% in the 1-2 day forecast lead times in the western North Pacific, while reducing negative intensity bias by 25-75% for 12 to 72-hour lead times.

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. 2017 JTWC R&D priorities

Section 3 Technical Development Projects

JTWC personnel have collaborated on numerous efforts to evaluate promising R&D efforts and to transfer mature projects into operations.

1. TC Wind Structure

a. TC wind structure post-analysis QA/QC

JTWC best track post-analysis has historically been limited to position and intensity due to limited manpower resources and the lack of an "off-season" during which to perform the post-analysis. In 2015, NRL-Monterey and JTWC initiated an effort to post-analyze TC 34-knot wind radii (R34) in the western North Pacific basin for 2014 and 2015. The fruits of this effort include the development of new techniques, highlighted in the following sections, which are designed to improve the accuracy of JTWC TC wind structure and to automate the lengthy process of recording these data. Continued funding for improvements to these techniques allowed for post-analysis of R34 again for 2016, as well as a re-analysis of 2013 R34 data. The quality controlled R34 data have not previously been publicly released; however, the 2016 public best track datasets will include post-analyzed R34 values, and the 2013-2015 best track archives will be updated and released as well. R50 and R64 values will be derived via linear regression from the R34 value. JTWC is seeking funding to continue post-analysis of wind structure, and to extend this work to other basins.

b. Forecast Wind Radii Consensus (RVCN)

For many years, the wind radii climatology and persistence model, DRCL (Knaff et al., 2007), was the JTWC's primary operational forecast wind radii guidance. The DRCL model was initially developed using a training dataset of operational wind radii estimates set by forecasters in near real-time. No post-storm, quality controlled best track wind radii data were available during the development of this statistical model. The operational datasets that were applied to train the DRCL model exhibited a systematic, small bias. This bias in the training dataset, in-turn, resulted in a systematic under-forecast bias in the DRCL model, particularly for large tropical cyclones such as those forming from monsoon depressions.

In an effort to improve JTWC's objective wind radii forecast guidance suite, a new consensus-based wind radii forecast aid (RVCN) was incorporated into JTWC's ATCF system for evaluation in the western North Pacific, Indian Ocean, and southern hemisphere in 2015. The RVCN consensus became operational with the v5.8 upgrade in September, 2016. Initially, the consensus was comprised of interpolated wind radii forecasts from four dynamical models: GFS, GFDL, HWRF, and ECMWF. COAMPS-TC was found to add value to the consensus as was subsequently incorporated into the RVCN consensus. Recently, interpolated GFDL wind radii forecasts were removed from the RVCN consensus because operational application of that model has ended.

A new SHIPS-based wind radii aid, DSWR (Knaff et al. 2016) has been tested and shown to further improve the RVCN. Additionally, the DRCL has been re-derived using 2013-2016 post-analyzed best track data, yielding a significant reduction in the previously-noted small bias. Both DSWR and DRCL will be added to the RVCN with the next ATCF update. Verification data for the 2016 RVCN performance in the western North Pacific is presented in Figure 5-1.

Finally, a wind radii GPCE has been developed for RVCN to provide statistical confidence information based on the consensus spread. This GPCE will be produced experimentally in 2017 and stored in ATCF e-deck files under the objective aid name RVCN. Radii GPCE display capabilities will be added in the CY2018 ATCF update.

RVCN 2016	RVCN 2017
AHNI	AHNI
GHTI	HHFI
HHFI	EMXI
EMXI	CHTI
CHTI	DSWR
	DRCL

Table 5-2. Primary objective aids comprising the operational JTWC TC wind radii consensus (RVCN)

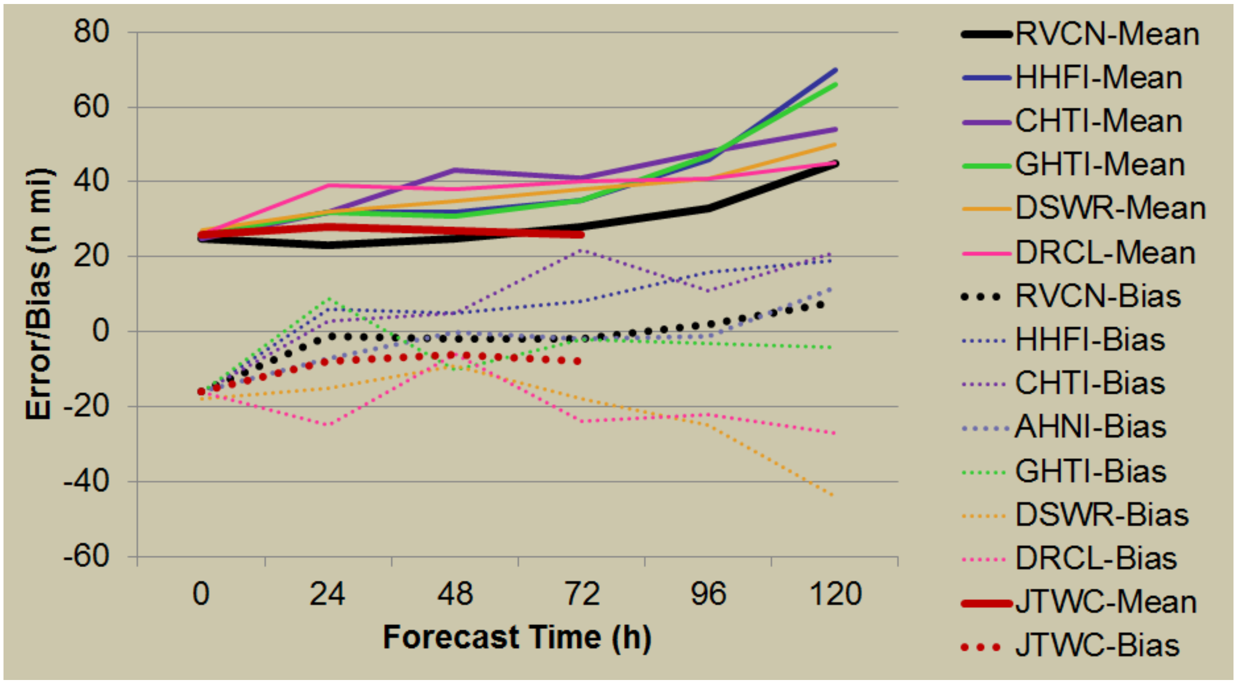

Figure 5-1. 2016 RVCN performance (western North Pacific) versus objective best track (OBTK) with NRL ASCAT (see section 3.1.c. below)

c. Objective ASCAT fix generation

The pending ATCF v5.8.3 upgrade includes an objective scatterometry-based R34 fix algorithm implemented by NRL-MRY. The fixes further refine the objective best track wind radii estimates described in the next section, particularly for cases with limited consensus members (e.g., early in the TC lifecycle), adding stability to OBTK estimates.

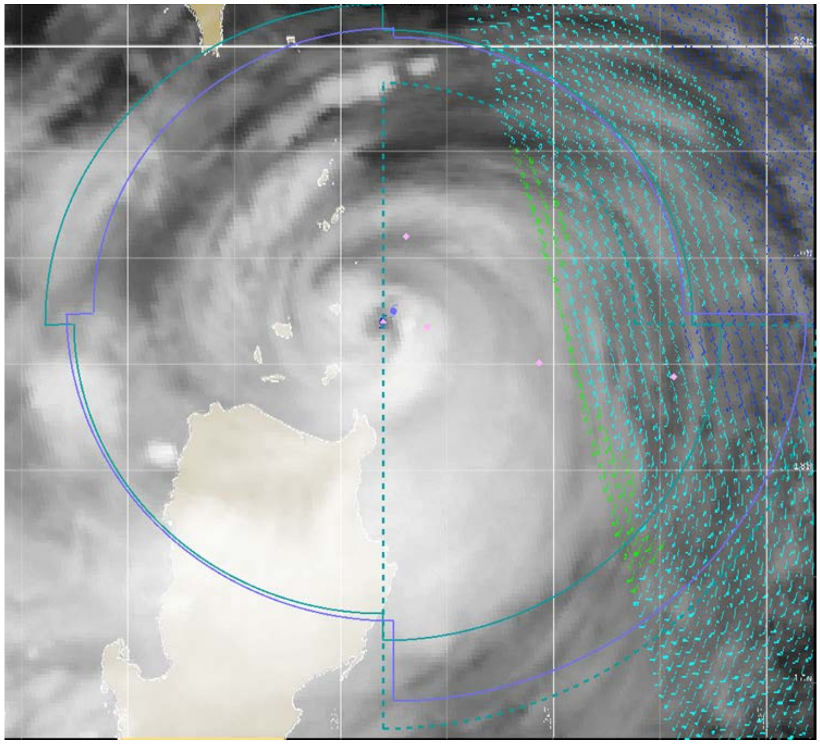

Figure 5-2. Example objective scatterometry fix (dashed line) versus OBTK (blue line) and working best track estimate (green line) for Typhoon Goni, WP162015

d. Objective Best Track Wind Radii (OBTK)

Analyzed TC structure parameters (e.g. R34, R50, and R64) are critical numerical weather prediction inputs, and form the basis for subsequent forecast wind radii values that are used to generate the swath of potential 34-knot winds depicted on JTWC warning graphics, as well as TCCOR setting guidance, wind probabilities and wave forecasts. Due to infrequent and/or incomplete scatterometer overpasses and the lack of in-situ observational data throughout the JTWC AOR, TC structure analysis has a high degree of uncertainty, resulting in a well-known historical small bias for large TCs and frequent step function-like growth in the non-quality controlled, operational best track wind radii data. An equally weighted average of R34 estimates (OBTK; Sampson et al. 2017) was developed from 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), and 6-hour NWP forecasts (Sampson et al. 2017), which became operational with the v5.8 upgrade to ATCF.

Verification for 2014-2016 (Figure 5-3) indicates the OBTK has lower mean errors than any of the individual members of the consensus, greatly reducing the previously-observed small bias and rendering smooth the individual storm growth curves. As noted in the preceding section, the OBTK will be updated in 2017 to include objective ASCAT fixes (ASCT).

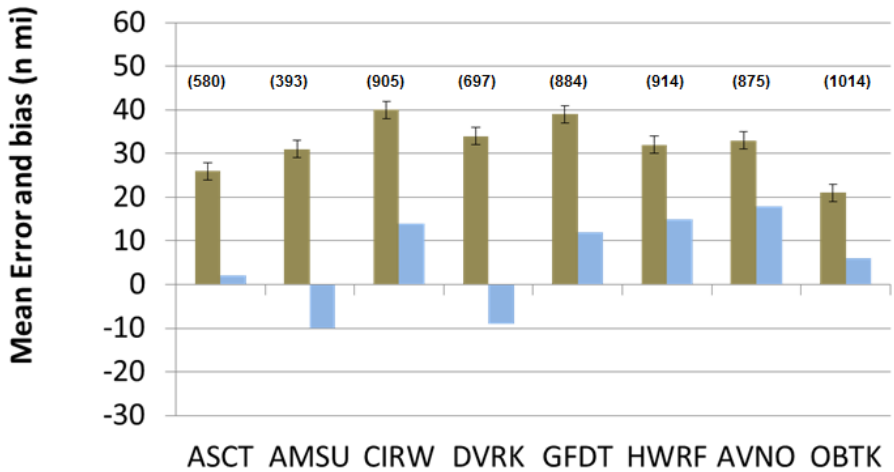

Figure 5-3. 34-knot wind radii fix mean errors (brown) and biases (blue) relative to JTWC 2014-2016 best tracks coincident with ASCAT. Standard error is indicated by the black error bars that overlap the means.

e. Deterministic rapid intensity forecast guidance

A version of the SHIPS-RI rapid intensity model, RI30, was available to JTWC in 2016. This guidance was produced when the probability of 30-knot intensification in a 24-hours forecast period exceeded 40%. Although incorporating RI30 reduced intensity consensus forecast error by approximately 10% at times when the aid was available, the 40% threshold was met in less than 1% of forecasts during the year. In 2017, JTWC employed new methods to provide guidance for rapidly intensifying tropical cyclones in the western North Pacific. These methods, developed by NESDIS and its partners at CIRA/CSU and NRL-Monterey, will become operational with the pending ATCF v5.8.3 upgrade. The new guidance uses probabilistic forecasts based on two methods (linear discriminant analysis and logistic regression) to forecast the likelihood of 25, 30, 35, and 40 knots of intensification within a 24-hour forecast period, 45 and 55 knots of intensification within a 36-hour forecast period and 70 knots of intensification within a 48-hour forecast period. 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 period, a separate deterministic forecast will be triggered for each forecast lead. These short-term, deterministic rapid intensification forecasts will be 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. During testing, deterministic forecasts were triggered approximately 20%-25% of the time in the RI-conducive western North Pacific. Additionally, the intensity GPCE was re-derived to account for the new RI guidance, providing a more realistic spread in potential RI cases.

f. Dynamically sized swath of potential gale force winds based on GPCE

The swath of potential-34 knot winds that accompanies JTWC TC forecasts is a function of TC forecast wind radii and climatological forecast track errors. A dynamically-sized swath that adjusted the swath radius by the ratio of GPCE climatology to GPCE was tested in 2015 (Strahl et al. 2016). This study indicated that applying the traditional GPCE method yielded JTWC swath sizes that were appropriately scaled in high certainty scenarios. However, in cases of extreme uncertainty, e.g., during recurvature, the swath size could become unrealistically large. In light of these results, an effort was funded to update and improve the along/across track version of the GPCE, i.e., GPCE-AX. Once completed, dynamically-sized swaths will be recomputed using the GPCE-AX data. It is hypothesized that weighting the swath by the appropriate along-track and across-track components will yield a more realistic swath size for highly uncertain forecast scenarios.

2. Tropical cyclone intensity change

a. ICNW

JTWC's intensity consensuses were officially renamed from S5YY and S5XX to ICNW and ICNX, respectively, in 2016. ICNW was previously designated as the official, multi-model intensity consensus for tropical cyclone forecasting in the western North Pacific Ocean basin, and ICNX was designated as the intensity consensus for Indian Ocean and Southern Hemisphere cyclones. Recent statistical analyses indicate that ICNW is, on average, more accurate than ICNX in all forecast basins. Thus, ICNW has been designated as the official intensity consensus for cyclones in all basins. The interpolated GFDN intensity forecast was recently removed from the ICNW consensus because operational application of that model has ended. Otherwise, ICNW consensus members have not changed since 2016. Current ICNW members listed in table 5-2.

ICNW 2016	ICNW 2017
DSHN (SHIPS)	DSHN (SHIPS)
DSHA (SHIPS)	DSHA (SHIPS)
GFNI	COTI
COTI	CHII
CHII	HWFI
HWFI	RI30 *
RI30	

Table 5-3. Primary objective aids comprising the operational JTWC tropical cyclone intensity (ICNW) consensus (as of June 2017). * RI30 will soon be replaced in the ICNW consensus with new, deterministic RI guidance discussed in section 3.1.e. of this report.

3. Application of environmental satellite data

a. Incorporation of automated intensity fix estimates

JTWC is processing new, automated TC intensity estimates derived from ATMS and SSMI/S sensor data into operational datasets, enabling examination and application by analysts and forecasters (Herndon et al. 2012; Galina et al. 2015; Demuth et al. 2004). These data are provided by the National Environmental Satellite, Data, and Information Service (NESDIS) and the Cooperative Institute for Meteorological Satellite Studies (CIMSS), respectively. SSMI/S intensity estimates are a component of the CIMSS automated satellite consensus (SATCON) (Velden et al. 2006). A full statistical evaluation of these data is pending, but preliminary results indicate promising performance for both methods.

4. Improved and extended tropical cyclone forecast track guidance

a. CONW

JTWC continuously evaluates model forecast data provided by various U.S. and international forecast agencies in order to both improve operational forecasts and to modify the official consensus for optimal forecast accuracy. NRL and JTWC evaluate model performance statistics on an annual basis, and adjust the track, intensity, and wind radii consensuses to include a subset of the most accurate and timely guidance available. The track consensus was updated to include ECMWF ensemble mean track forecasts in 2016. Interpolated GFDN track forecasts have been removed from the CONW consensus because operational application of that model has ended. Current members are listed in table 5-4.

Model	CONW Tracker	Model Type
NAVGEM	NVGI	Global
GFS	AVNI	Global
UKMET Office Global Model	EGRI	Global
JMA Global Spectral Model	JGSI	Global
ECMWF Global Model	ECMI	Global
COAMPS-TC	COTI	Mesoscale
HWRF	HWFI	Mesoscale
GEFS	AEMI	Ensemble
JMA TC Ensemble	JENI	Ensemble
ECMWF EPS	EEMI	Ensemble

Table 5-4. Primary objective aids comprising the operational JTWC tropical cyclone track (CONW) consensus (as of June 2017).

In addition to the CONW forecast models, JTWC evaluates TC track forecasts from GALWEM (see next section), ACCESS-TC, TWRF, CMC, ARPEGE, MEPS, the NRL Monterrey experimental COAMPS-TC (using GFS initial and boundary conditions), and the UK Met Office global ensemble

(MOGREPS). A COAMPS-TC ensemble is expected to be available to JTWC forecasters beginning in 2017.

b. Acquisition and evaluation of the Air Force Global Air-Land Weather Exploitation Model (GALWEM)

JTWC began processing the GALWEM vortex tracker for operational application during calendar year 2016. GALWEM is the US Air Force's global atmospheric model, an adaptation of the UK Met Office's Unified Model. A post-season evaluation indicated that average track forecast accuracy for the GALWEM model is on-par with other consensus models, and it is therefore a candidate for incorporation into the JTWC track forecast consensus.

c. Two-week subjective TC formation outlooks

JTWC continued providing weekly input to the Climate Prediction Center's Global Tropics Hazards / Benefits Outlook throughout 2016. Additionally, JTWC expanded the in-house, two-week TC forecasting process highlighted in the 2014 Annual Tropical Cyclone Report (JTWC 2014). The Technical Service team prepares these two-week tropical cyclone formation outlooks for JTWC forecasters on a daily (Monday through Friday) basis. Each candidate area for TC formation, designated as a "preinvest," is monitored until either TC formation occurs or formation is no longer anticipated. Recent improvements to this process follow.

- Acquired and processed ECMWF medium-range deterministic and ensemble model forecast vortex trackers for designated preinvests
- Processed available vortex tracker data into the Automated Tropical Cyclone Forecast (ATCF) system running on JTWC's development server
- Transitioned weighted-motion vector mean (WMVM) plotting scripts for ensemble data developed at Naval Postgrad School (Ms. Mary Jordan)
- Produced shapefiles and KMLs for display in Mark-IVB, Google Maps
- Provided forecasters easy access to forecast plots via clickable interface
- Applied Weighted Analog Intensity technique to preinvest areas
- Retooled track and intensity forecast plotting code to increase efficiency and improve data presentation (Figure 5-4)

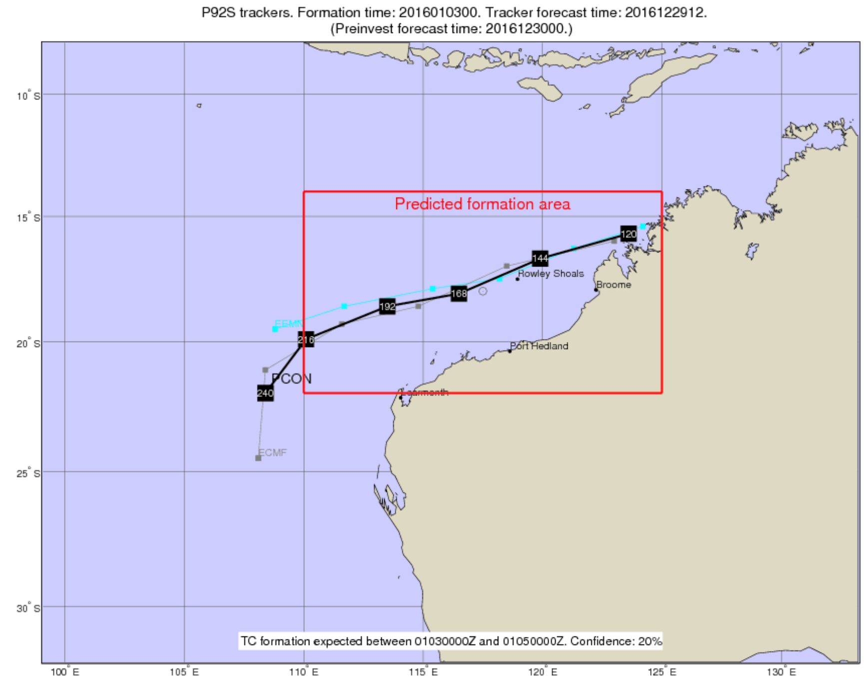

Figure 5-4. Example numerical model vortex tracker forecast graphic for a designated preinvest area.

Further advancements to the two-week forecasting process are planned for the remainder of 2017, including expansion of the numerical model track and intensity forecast suite, increased automation of the preinvest forecasting process (including location, timing, and probability of formation), and potential provision of preinvest forecast data to a selected set of external customers.

d. Decision support tools

JTWC developed 7-day objective aid track forecast and track versus time graphics to supplement the decision support product suite available to the center's US Government and research partners (Figures 5-5 and 5-6). JTWC continues to study the viability of issuing 7-day tropical cyclone forecasts. While the center plans to maintain the 5-day limit for official forecasts for the foreseeable future, these 7-day decision support products are intended to provide situational awareness of potential forecast outcomes during the 5-day to 7-day period. The graphics will be made available through JTWC's decision support product suite on an operational basis, for developing disturbances and existing tropical cyclones, in the summer of 2017.

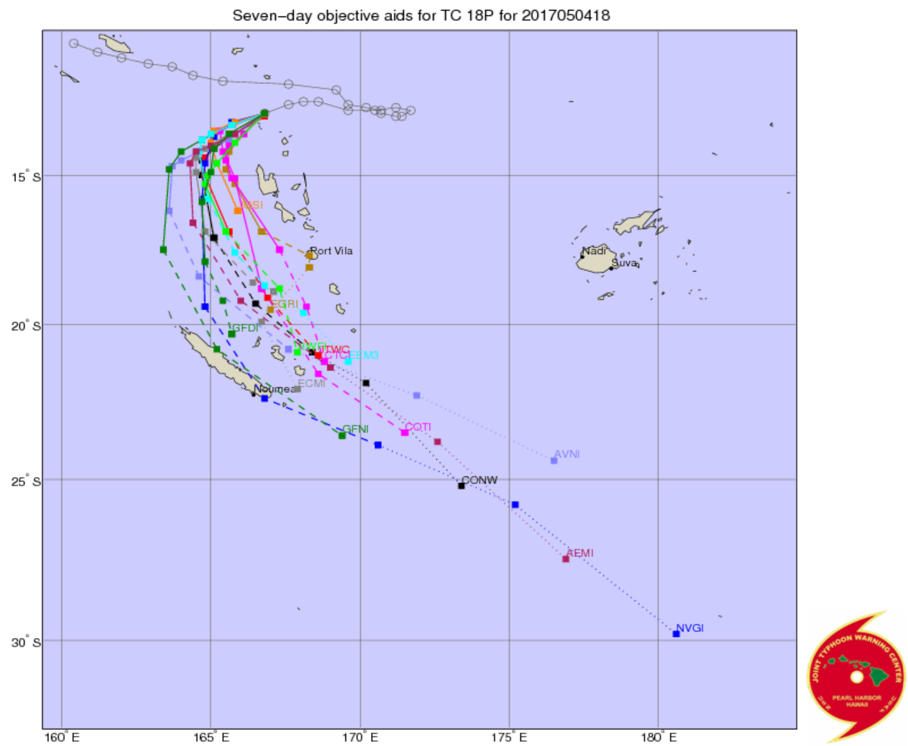

Figure 5-5. Example 7-day objective aid track forecast graphic for TC 18P (2017).

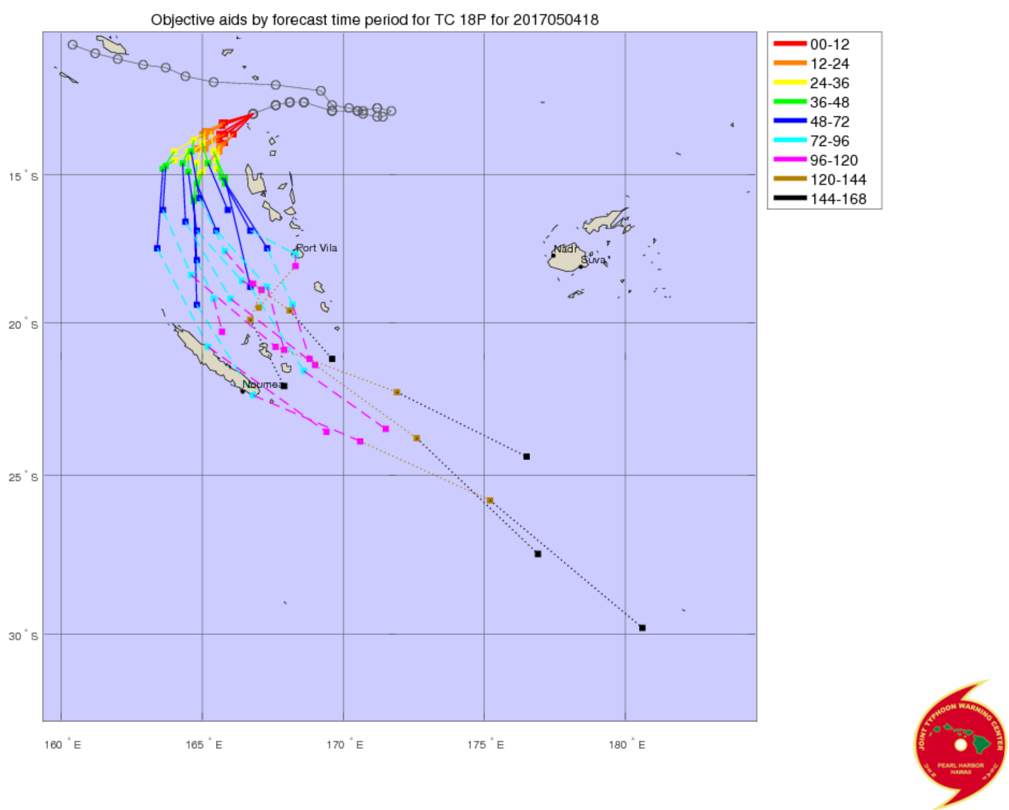

Figure 5-6. Example 7-day objective aid track versus time forecast graphic for TC 18P (2017).

Section 4 Other Scientific Collaborations

1. Joint Hurricane Testbed

JTWC is collaborating with principal investigators of two 2015-2017 JHT funded projects.

a. Passive Microwave Data Exploitation via the NRL Tropical Cyclone Webpage (R. Bankert, J. Cossuth, and K. Richardson (NRL-MRY))

The goal of this project is to improve the utility of the NRL TC webpage used by JTWC, NHC, CPHC, and other global TC forecast agencies and researchers, via the following efforts:

- Enhance the near-realtime 37 and 85/89/91 GHz H/V/PCT/color imagery products for all global TCs
- Populate an archive of historical passive microwave data since 1987; A standardized database of both digital data and image products will be generated and made available to the TC community to compliment the near-realtime data.
- A study and application of a more sophisticated parallax correction scheme will be created to provide increased confidence in the initialization of the TC center.
- Color tables will be revised to improve visualization of TCs.

b. Improvement and Implementation of the Probability-based Microwave Ring Rapid Intensification Index for NHC/JTWC Forecast Basins (H. Jiang (FIU) and K. Musgrave (CSU/CIRA))

The goals of this project include adding two additional 37 GHz predictors to the probability-based RI index, as well as implementing and tuning this product to all JTWC forecast basins. The research team is providing trial, near real-time estimates to JTWC forecasters through the web and via email. This effort builds upon the 37 GHz ring pattern recognition study conducted by Kieper and Jiang (2012).

2. Hurricane Forecast Improvement Project (HFIP)

JTWC has significantly benefited from work performed under the auspices of the HFIP, particularly with respect to the significant 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 COAMPS-TC, HWRF, and GFDL. JTWC hopes to receive experimental results from the new, HFIP-developed, “Hurricanes in a Multi-scale Ocean-coupled Non-hydrostatic” (HMON) model in 2017. The HMON will become operational at NCEP for the Atlantic, Eastern Pacific, and Central Pacific basins during the 2017 season.

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 2016 conference attendance and technical exchange meetings follows.

- PACOM Joint Tropical Cyclone Forecasting Program Assembly (Feb 2016)
- WMO Typhoon Committee 48th Annual Meeting (Feb 2016)
- 70th Interdepartmental Hurricane Conference (Mar 2016)
- NRL 6.2/6.4 Program Review (Apr 2016)
- 32nd AMS Conference on Hurricanes and Tropical Meteorology (Apr 2016)
- 7th NCEP Ensemble Users Workshop (Jun 2016)
- WMO Typhoon Committee 11th Integrated Workshop (Oct 2016)
- NCEP Production Suite Review (Dec 2016)

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Kieper, M., and Jiang, H., 2012: Predicting tropical cyclone rapid intensification using the 37 GHz ring pattern identified from passive microwave measurements. *Geophys. Res. Lett.*, 39, 1-7.

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Knaff, J.A., C.R. Sampson, M. DeMaria, T.P. Marchok, J.M. Gross, and C.J. McAdie, 2007: Statistical tropical cyclone wind radii prediction using climatology and persistence. *Wea. Forecasting*, 22, 781–791, doi: 10.1175/WAF1026.1.

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Chapter 6 Summary of Forecast Verification

Verification of warning position and intensities at 24-, 48-, and 72-, 96-, 120-hour forecast periods are made against the final best track. The (scalar) track forecast, along-track and cross track errors (illustrated in Figure 6-1) were calculated for each verifying JTWC forecast. These data are included in this chapter. This section summarizes verification data for the 2016 season, and contrasts it with annual verification statistics from previous years.

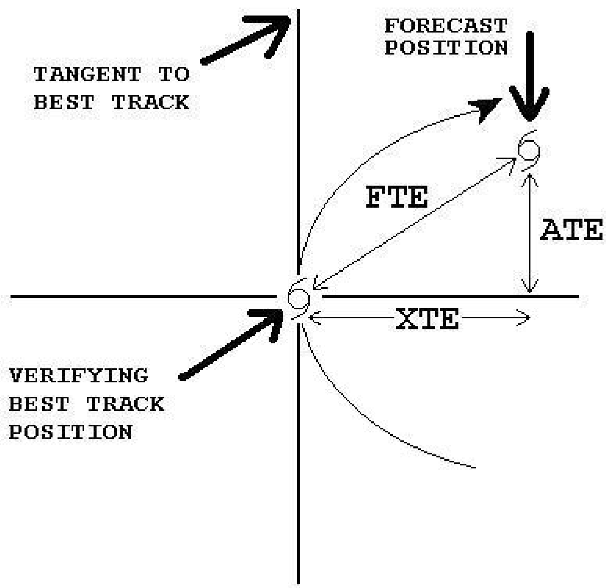

Figure 6-1. Definition of cross-track error (XTE), along track error (ATE), and forecast track error (FTE). In this example, the forecast position is ahead of and to the right of the verifying best track position. Therefore, the XTE is positive (to the right of track) and the ATE is positive (ahead of 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 - 2016

	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	403	33	46	29	30	310	66	84	50	57	230	102	131	74	94	157	131	177	105	123	102	248	228	124	160
Avg (1978-2016)	567	81	91	52	63	456	158	168	96	118	358	246	252	142	177	204	149	209	114	150	148	213	279	150	200
5yr Avg	492	40	47	29	32	401	70	79	48	53	306	104	116	66	82	228	147	160	92	111	163	221	221	125	155

(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.

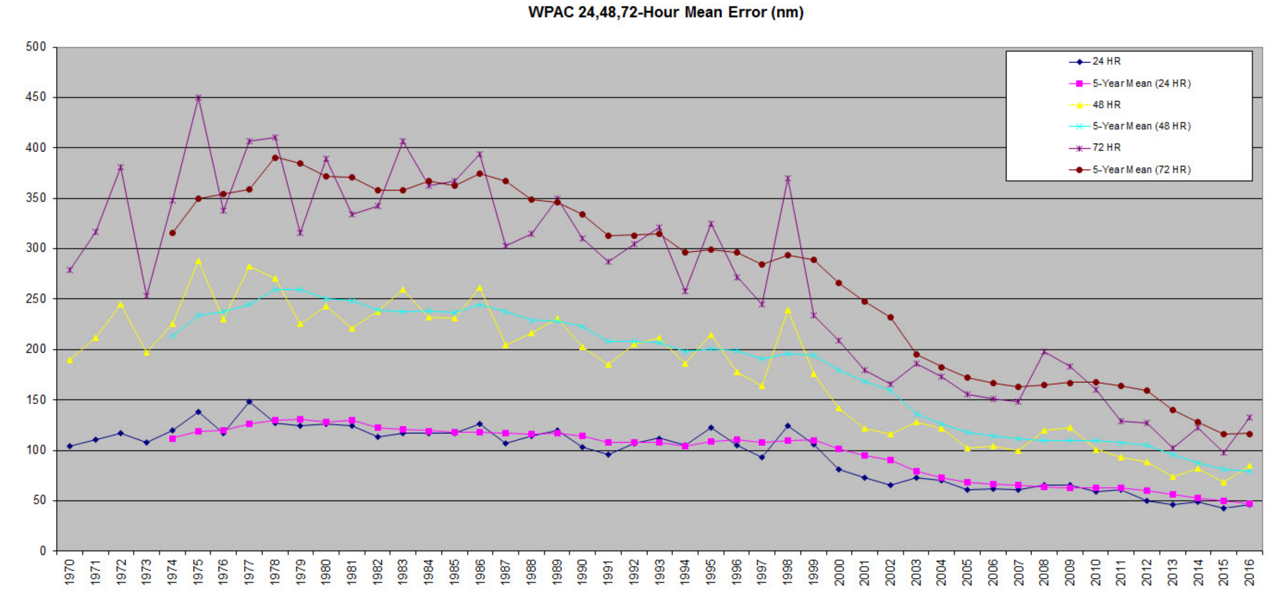

Figure 6-2. Graph of JTWC forecast errors and five year running mean errors for the western North Pacific at 24, 48, and 72 hours.

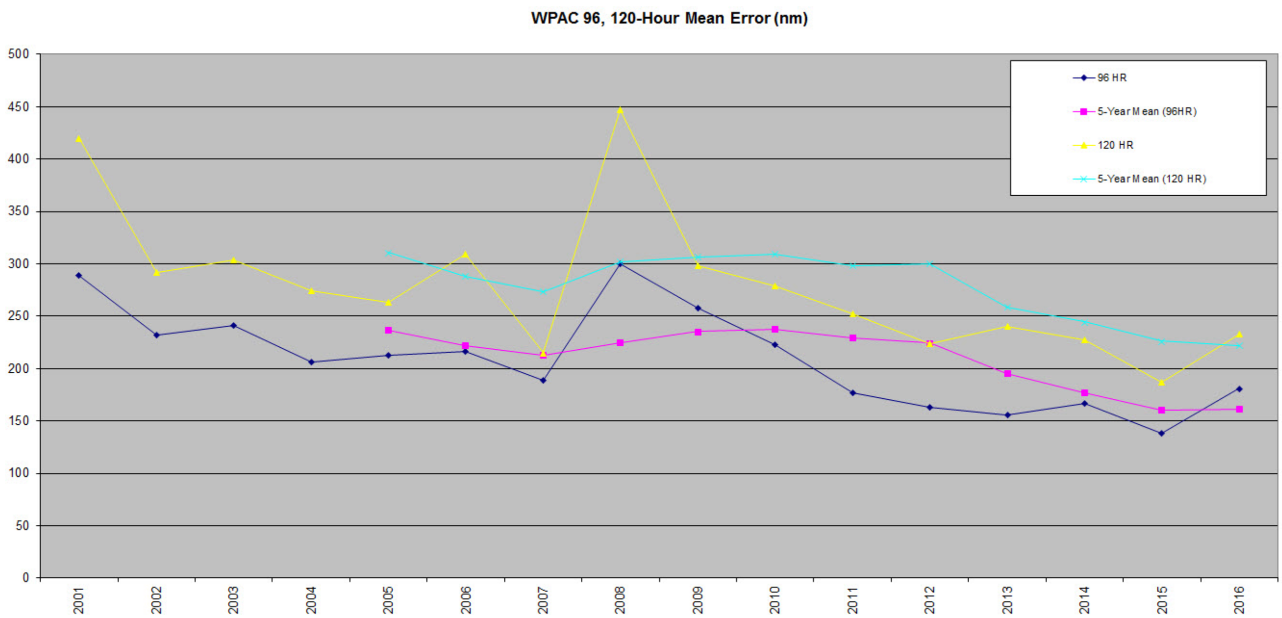

Figure 6-3. Graph of JTWC forecast errors and five year running mean errors for the western North Pacific at 96 and 120 hours.

Table 6-2
MEAN FORECAST TRACK ERRORS (NM) FOR NORTH INDIAN OCEAN
TROPICAL CYCLONES FROM 1985-2016

	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
Avg (1985-2016)	49	90	63	51	32	152	103	88	18	232	159	132	14	169	105	116	7	253	131	192
5Yr Avg	57	49	29	34	39	69	41	46	26	85	58	49	15	144	103	85	7	194	142	123

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

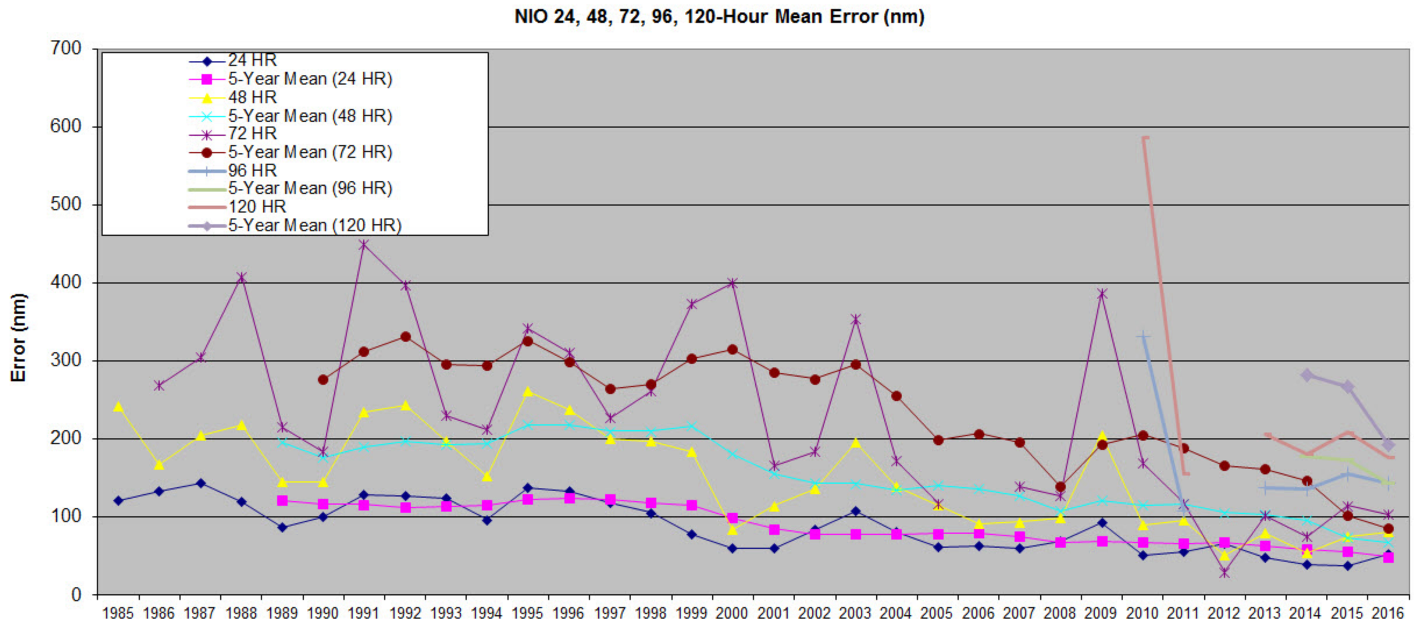

Figure 6-4. Graph of JTWC forecast errors and five year running mean errors for the north Indian Ocean at 24, 48, 72, 96, and 120 hours. (Note: No 96 HR, 120 HR data for 2012)

TABLE 6-3
MEAN FORECAST ERRORS (NM) FOR SOUTHERN HEMISPHERE TROPICAL CYCLONES 1985 - 2016

Year (Notes)	24-Hour				48-Hour				72-Hour				96-Hour				120-Hour			
	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
Avg (1985-2016)	233	92	52	65	182	171	97	120	65	185	107	129	79	184	101	130	54	253	151	166
5Yr Avg	193	53	28	38	149	90	47	65	112	133	67	98	82	181	96	131	57	244	139	164

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

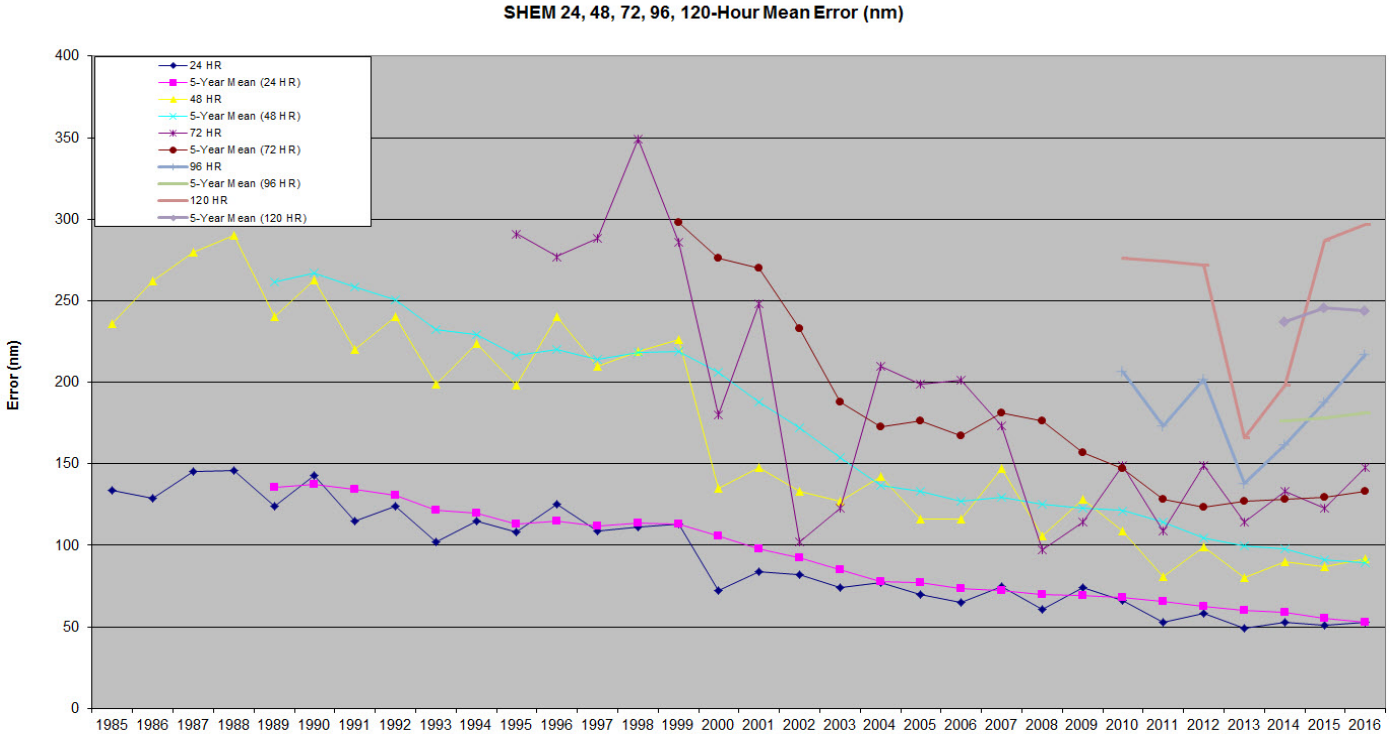

Figure 6-5. Graph of JTWC forecast errors for the Southern Hemisphere at 24, 48, 72, 96, and 120 hours.

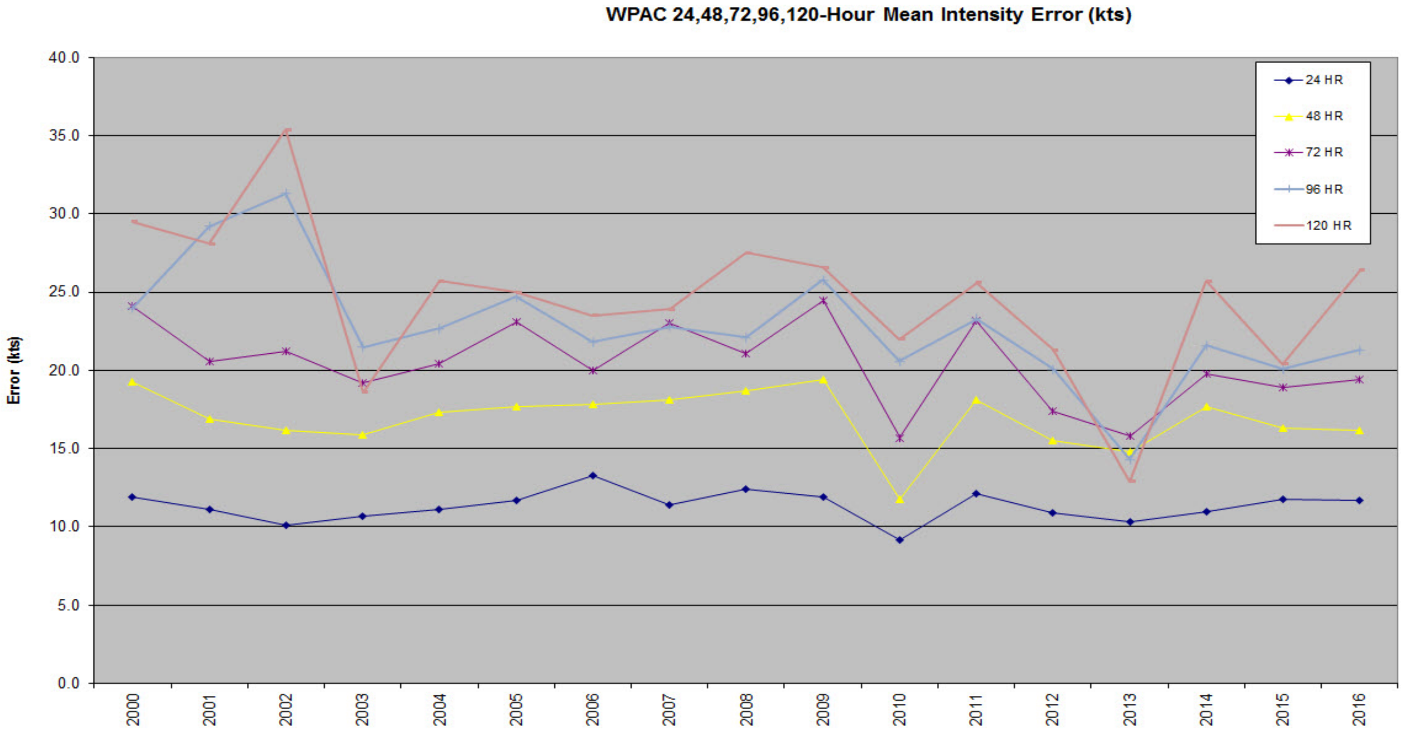

Figure 6-6. Graph of JTWC intensity forecast errors for the western North Pacific at 24, 48, 72, 96, and 120 hours.

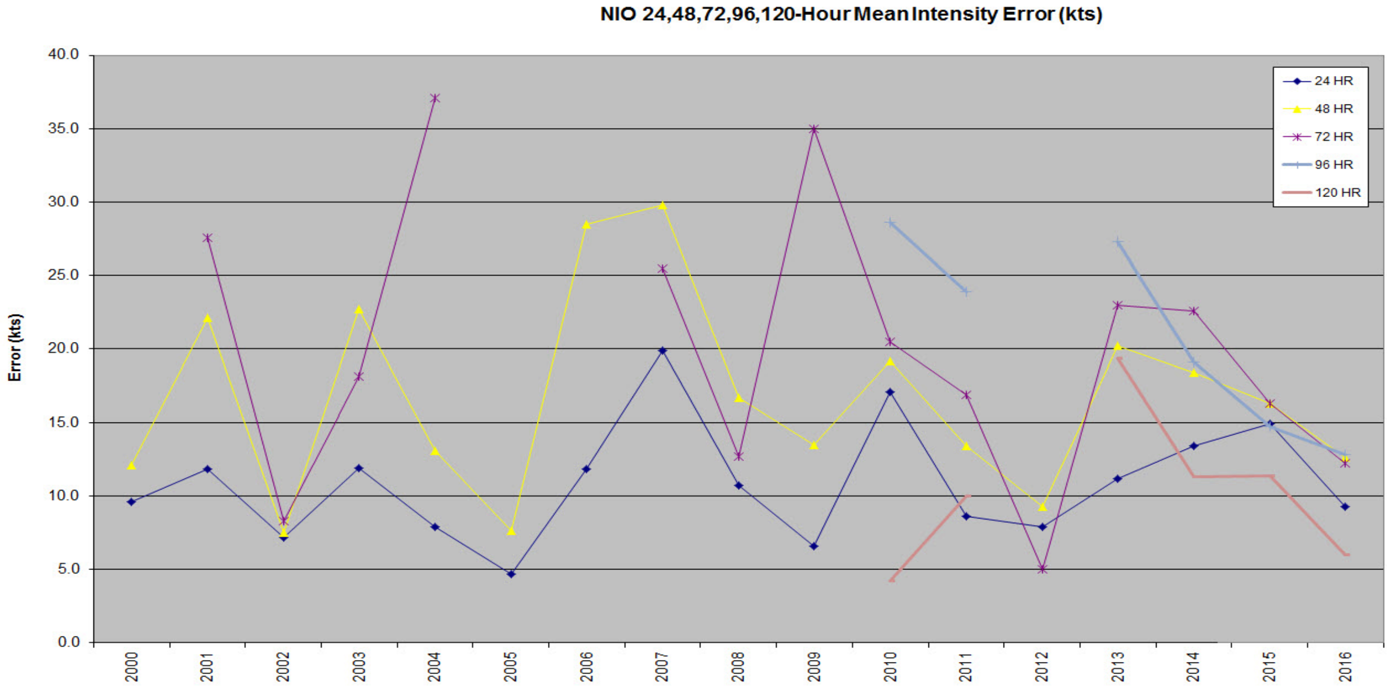

Figure 6-7. Graph of JTWC intensity forecast errors for the North Indian Ocean at 24, 48, 72, 96, and 120 hours. (Note: No 96 HR, 120 HR data for 2012)

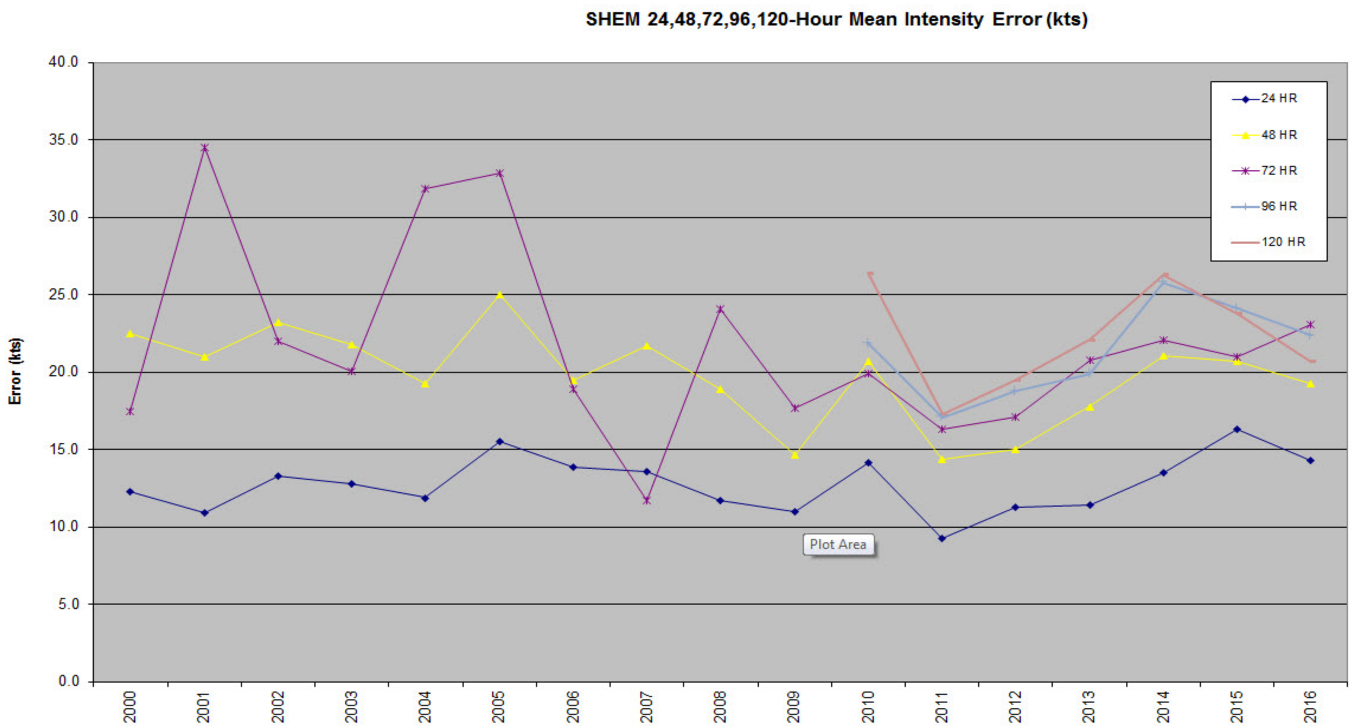

Figure 6-8. Graph of JTWC intensity forecast errors for the Southern Hemisphere at 24, 48, 72, 96, and 120 hours.