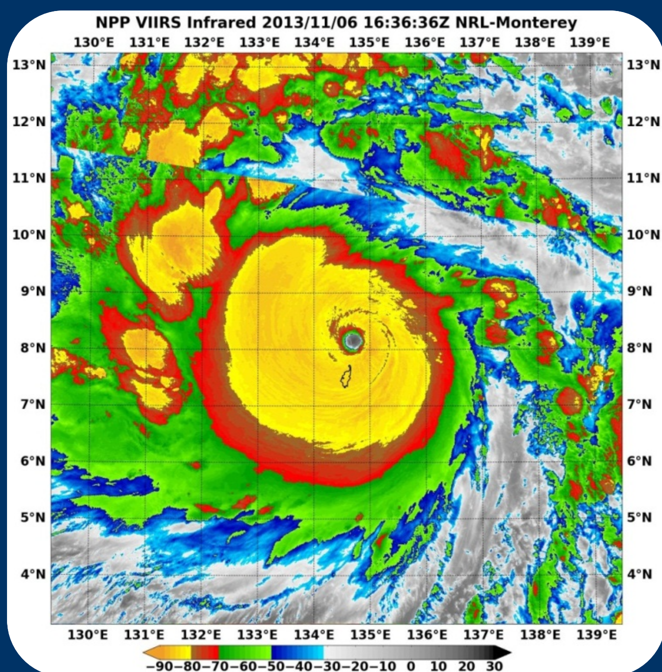
Annual Tropical Cyclone Report
2013



ASHLEY D. EVANS
Captain, United States Navy
Commanding Officer

ROBERT J. FALVEY
Director, Joint Typhoon Warning Center

Cover: NPP VIIRS Infrared image of Super Typhoon 31W (Haiyan). 06 November 2013 as its eye passed just north of Palau with wind speeds of 150 kts. Imagery courtesy of Jeff Hawkins- NRL. http://www.nrlmry.navy.mil/TC.html

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/Navy organization formally under the operational command of the Commanding Officer, Joint Typhoon Warning Center.

The original JTWC was established on 1 May 1959 by the Commander-in- Chief, US Pacific Command (USCINCPAC) to provide a single tropical cyclone warning center for the western North Pacific region. USCINCPAC delegated the tropical cyclone forecast and warning mission to Commander, Pacific Fleet. A subsequent USCINCPAC directive further tasked Commander, Pacific Air Force to provide for tropical cyclone (TC) reconnaissance support to the JTWC. Currently, JTWC operations are guided by USPACOM Instruction 0539.1 and Pacific Air Forces Instruction 15-101.

This edition of the ATCR documents the 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 technique development that members of JTWC were involved.

For the first time since 2004, above average tropical cyclone activity was observed in the western North Pacific Ocean, with only 33 TCs observed compared to the long term average of 31. There were five cyclones that reached super typhoon intensity, with Super Typhoon 31W (Haiyan) being one of the strongest cyclones on record for the western North Pacific basin. Major DoD installations experienced minimal impacts, with only one typhoon (23W) and one depression (13W) passing just north of Okinawa. Guam experienced a direct hit by Tropical Storm 25W (Wipha) while it was a tropical depression. Department of Defense bases in South Korea were not impacted and mainland Japan was impacted by two tropical storms, 15W and 16W.

The Southern Hemisphere activity remained below the long term average of 28, with 16 cyclones in the south Indian Ocean / western Australia region and 8 in the south Pacific / eastern Australia region. The Northern Indian Ocean experienced slightly above normal activity with 6 cyclones, with one in the Arabian Sea and five in the Bay of Bengal. The most significant cyclone in the north Indian Ocean was Tropical Cyclone 20B (Phalin), which reached a peak intensity of 140 knots.

Weather satellite data remained the mainstay of the TC reconnaissance mission to support the JTWC. Satellite analysts exploited a wide variety of conventional and microwave satellite data to produce over 9,280 position and intensity estimates (fixes), primarily using the USAF Mark IVB and the USN FMQ-17 satellite 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 and the Naval Research Lab Monterey were also used by JTWC to make TC fixes thus providing additional data for TC location and intensity.

JTWC also continues to utilize radar derived TC position information from numerous U.S. owned/operated weather radars as well as from international sources. However, budget challenges have delayed the replacement of the WSR-88D Doppler Weather Radar at Kadena AB.

JTWC continued to collaborate with TC forecast support and research organizations such as the Fleet Numerical Meteorology and Oceanography Center (FNMOC), Naval Research Laboratory, Monterey (NRLMRY), Naval Post Graduate School, the Office of Naval Research, Air Force Weather Agency (AFWA), and NOAA Line Offices for continued development of TC reconnaissance tools, numerical models and forecast aids.

The Techniques Development (TECHDEV) remained the voice of JTWC to the research and development community. They worked with researchers from the University of Hawaii, University of Arizona, Naval Post Graduate School and other agencies on a variety of promising projects. In collaboration with other Typhoon Duty Officers , TECHDEV developed a cyclone phase checklist to help forecasters assess whether a cyclone is tropical, subtropical or extratropical. This process and checklist was presented at the 2013 AMS Conference on Hurricanes and Tropical Meteorology in San Diego, CA.

Behind all these efforts are the dedicated team of men and women, military and civilian at JTWC. Special thanks to the entire JTWC N6 Department for their outstanding IT support and the administrative and budget staff who worked tirelessly to ensure JTWC had the necessary resources to get the mission done in extremely volatile financial times.

A Special thanks also to: FNMOC for their operational data and modeling support; ONR for continuing to provide funding to basic and applied research in tropical cyclones in a very challenging fiscal environment, NRLMRY for its dedicated TC research, including providing real-time access to cutting edge satellite imagery on their Tropical Cyclone Page and improvements to the COAMPS-TC model; the National Oceanic and Atmospheric Administration National Environmental Satellite, Data, and Information Service for satellite reconnaissance support; Dr. John Knaff, Mr. Jeff Hawkins, Dr. Mark DeMaria, Mr. Chris Velden and Mr. Derrick Herndon for their continuing efforts to exploit remote sensing technologies in new and innovative ways; Mr. Charles R. “Buck” Sampson, Ms. Ann Schrader, and Mr. Mike Frost for their outstanding support and continued development of the ATCF system.

JTWC Personnel 2013

<u>Staff</u>
Mr. Robert Falvey, *Director*
LT Chad Geis, *Operations Officer*
Mr. Edward Fukada, *Technical Advisor*
Mr. Matt Kucas
Mr. Brian Strahl
Mr. James Darlow

<u>Typhoon Duty Officers (TDO)</u>
Maj Jay Neese
LT Thomas Mills
LT Joshua Carter
LT Chad Geis
LT Thai Phung
Mr. Matt Kucas
Mr. Stephen Barlow
Mr. Brian Strahl
Mr. Richard Ballucanag
Mr. Aaron Lana

<u>Satellite Operations</u>
Maj Jay Neese, *OIC Satellite Operations*
Capt Brenda Arincorayan, *OIC Satellite Operations*
TSgt Jeffrey Quast, *Analyst/NCOIC*
SrA Brittany Bermea, *Analyst*
SrA Andrew Casper, *Analyst*
SrA Karen Long, *Analyst*
SrA Cody Newcomer, *Analyst*
SrA Kolby Rapp, *Analyst*
SrA Terrance Schalin, *Analyst*
Mr. James Darlow, *Analyst*
Mr. Dana Uehara, *Analyst*

<u>Geophysical Technician (GT)</u>
AG1 Jamaine Parks
MC2 Vaughan Dill
AG2 James Spruill
AG2 Candice Sullivan
AG2 Nicholas Vojak
AG3 Heather Johnston
AG3 Jack Tracey
AG3 Christian Wilcox
AGAA Bristol Rigby
AGAA Jake Wilson

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Table 1-1

WESTERN NORTH PACIFIC SIGNIFICANT TROPICAL CYCLONES FOR 2013
(01 JAN 2013 - 31 DEC 2013)

TC	NAME*	PERIOD**		WARNINGS ISSUED	EST MAX SFC WINDS KTS
01W	Sonamu	03 Jan / 1200Z	08 Jan / 1800Z	22	40
02W	Shanshan	19 Feb / 0000Z	21 Feb / 0000Z	10	25
03W	Yagi	8 Jun / 1200Z	12 Jun / 1200Z	17	55
04W	Leepi	17 Jun / 1800Z	20 Jun / 1800Z	13	35
05W	Bebinca	20 Jun / 1200Z	23 Jun / 0600Z	12	35
06W	Rumbia	28 Jun / 0000Z	02 Jul / 0000Z	17	70
07W	Soulik	07 Jul / 1800Z	13 Jul / 1200Z	24	125
08W	Cimaron	15 Jul / 1800Z	18 Jul / 1200Z	12	40
09W	Jebi	31 Jul / 0000Z	03 Aug / 0600Z	14	60
10W	Mangkhut	05 Aug / 1800Z	07 Aug / 1800Z	9	45
11W	Utor	08 Aug/ 1800Z	14 Aug / 1200Z	24	130
12W	Trami	17 Aug / 0000Z	21 Aug / 1800Z	20	75
13W	-	17 Aug / 0000Z	17 Aug / 1800Z	4	30
14W	Kong-Rey	26 Aug / 0000Z	31 Aug / 0000Z	21	50
15W	Toraji	01 Sep /1200Z	04 Sep / 0000Z	11	50
16W	Man-Yi	12 Sep / 1800Z	16 Sep / 0600Z	15	60
17W	Usagi	16 Sep / 1800Z	22 Sep / 1200Z	24	135
18W	-	18 Sep / 0600Z	18 Sep / 1800Z	3	25
19W	Pabuk	21 Sep / 0000Z	26 Sep / 0600Z	22	90
20W	Wutip	26 Sep / 1800Z	30 Sep / 1200Z	16	100
21W	Sepat	30 Sep / 0000Z	02 Oct / 0000Z	9	40
22W	Fitow	30 Sep / 0600Z	06 Oct / 1800Z	27	90
23W	Danas	03 Oct /1200Z	08 Oct /1200Z	21	120
24W	Nari	08 Oct / 1800Z	15 Oct / 0000Z	26	100
25W	Wipha	10 Oct / 1200Z	15 Oct / 1800Z	22	120
26W	Francisco	16 Oct / 0000Z	25 Oct / 1800Z	40	140
27W	-	19 Oct / 0600Z	20 Oct / 0600Z	5	30
28W	Lekima	20 Oct /1200Z	26 Oct / 0600Z	24	140
29W	Krosa	29 Oct / 0000Z	04 Nov / 0000Z	25	105
30W	-	03 Nov / 0600Z	06 Nov / 0600Z	17	35
31W	Haiyan	03 Nov / 0600Z	11 Nov / 0000Z	32	170
32W	Podul	14 Nov / 1200Z	15 Nov / 0000Z	3	30
33W	-	3 Dec /1200Z	4 Dec 0000Z	3	30

* As designated by the responsible RSMC

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

Table 1-2

DISTRIBUTION OF WESTERN NORTH PACIFIC TROPICAL CYCLONES FOR 1959 - 2013

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS	Total ≥64kt	Total 34-63kt	Total ≤33 kt
1959	0	1	1	1	0	1	3	8	9	3	2	2	31			
	0 0 0	0 1 0	0 1 1	1 0 0	0 0 0	0 0 1	1 1 1	5 1 2	4 2 3	2 1 0	2 0 0	2 0 0		17	7	7
1960	1	0	1	1	1	3	3	9	5	4	1	1	30			
	0 0 1	0 0 0	0 0 1	1 0 0	0 1 0	2 1 0	2 1 0	8 1 0	0 4 1	4 0 0	1 0 0	1 0 0		19	8	3
1961	1	1	1	1	4	6	5	7	6	7	2	1	42			
	0 1 0	0 1 0	1 0 0	0 1 0	2 1 1	1 1 4	3 2 0	3 1 3	5 1 0	3 2 2	1 0 1	1 0 0		20	11	11
1962	0	1	0	1	3	0	8	8	7	5	4	2	39			
	0 0 0	0 1 0	0 0 0	1 0 0	2 0 1	0 0 0	5 1 2	7 0 1	3 1 3	3 1 1	3 0 1	0 2 0		24	6	9
1963	0	0	1	1	0	4	5	4	4	6	0	3	28			
	0 0 0	0 0 0	0 0 1	1 0 0	0 0 0	3 1 0	3 1 1	3 0 1	2 2 0	5 1 0	0 0 0	2 1 0		19	6	3
1964	0	0	0	0	3	2	8	8	8	7	6	2	44			
	0 0 0	0 0 0	0 0 0	0 0 0	2 0 1	2 0 0	6 1 1	3 5 0	5 2 1	3 3 1	4 2 0	1 0 1		26	13	5
1965	2	2	1	1	2	4	6	7	9	3	2	1	40			
	1 1 0	0 2 0	0 1 0	1 0 0	1 0 1	3 1 0	4 1 1	3 2 2	5 3 1	2 0 1	1 1 0	0 1 0		21	13	6
1966	0	0	0	1	2	1	4	9	10	4	5	2	38			
	0 0 0	0 0 0	0 0 0	1 0 0	2 0 0	1 0 0	3 1 0	5 3 1	5 3 2	1 1 2	1 2 2	1 0 1		20	10	8
1967	1	0	2	1	1	1	8	10	8	4	4	1	41			
	0 1 0	0 0 0	1 1 0	1 0 0	0 1 0	1 0 0	3 3 2	3 4 3	5 3 0	2 1 1	4 0 0	0 1 0		20	15	6
1968	0	1	0	1	0	4	3	8	4	6	4	0	31			
	0 0 0	0 0 1	0 0 0	1 0 0	0 0 0	2 0 2	1 2 0	3 4 1	4 0 0	5 1 0	4 0 0	0 0 0		20	7	4
1969	1	0	1	1	0	0	3	3	6	5	2	1	23			
	1 0 0	0 0 0	0 1 0	1 0 0	0 0 0	0 0 0	2 1 0	2 1 0	2 0 4	4 1 0	1 1 0	0 1 0		13	6	4
1970	0	1	0	0	0	2	3	7	4	6	4	0	27			
	0 0 0	1 0 0	0 0 0	0 0 0	0 0 0	1 1 0	0 2 1	4 2 1	2 2 0	3 2 1	1 3 0	0 0 0		12	12	3
1971	1	0	1	2	5	2	8	5	7	4	2	0	37			
	0 1 0	0 0 0	0 1 0	2 0 0	2 3 0	2 0 0	6 2 0	3 1 1	5 1 1	3 1 0	1 1 0	0 0 0		24	11	2
1972	1	0	1	0	0	4	5	5	6	5	2	3	32			
	1 0 0	0 0 0	0 0 1	0 0 0	0 0 0	2 2 0	4 1 0	3 2 0	4 1 1	4 1 0	2 0 0	2 1 0		22	8	2
1973	0	0	0	0	0	0	7	6	3	4	3	0	23			
	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	4 3 0	2 3 1	2 0 1	4 0 0	0 3 0	0 0 0		12	9	2
1974	1	0	1	1	1	4	5	7	5	4	4	2	35			
	0 1 0	0 0 0	0 1 0	0 1 0	1 0 0	1 2 1	2 3 0	2 3 2	3 2 0	4 0 0	2 2 0	0 2 0		15	17	3
1975	1	0	0	1	0	0	1	6	5	6	3	2	25			
	1 0 0	0 0 0	0 0 0	0 0 1	0 0 0	0 0 0	0 1 0	4 1 1	4 1 0	3 2 1	2 1 0	0 2 0		14	8	3
1976	1	1	0	2	2	2	4	4	5	0	2	2	25			
	1 0 0	0 1 0	0 0 0	1 1 0	2 0 0	2 0 0	2 2 0	1 3 0	4 1 0	0 0 0	1 1 0	0 2 0		14	11	10
1977	0	0	1	0	1	1	4	2	5	4	2	1	21			
	0 0 0	0 0 0	0 1 0	0 0 0	0 0 1	0 1 0	3 0 1	0 2 0	2 3 0	3 1 0	2 0 0	1 0 0		11	8	2
1978	1	0	0	1	0	3	4	8	4	7	4	0	32			
	0 1 0	0 0 0	0 0 0	1 0 0	0 0 0	0 3 0	3 1 0	3 4 1	3 1 0	4 1 2	1 2 1	0 0 0		15	13	4
1979	1	0	1	1	2	0	5	4	6	3	2	3	28			
	1 0 0	0 0 0	1 0 0	1 0 0	0 1 1	0 0 0	2 2 1	2 0 2	3 3 0	2 1 0	1 1 0	1 1 1		14	9	5
1980	0	0	1	1	4	1	5	3	7	4	1	1	28			
	0 0 0	0 0 0	0 0 1	0 1 0	2 2 0	0 1 0	3 1 1	2 0 1	5 1 1	2 2 0	1 0 0	0 1 0		15	9	4
1981	0	0	1	1	1	2	5	8	4	2	3	2	29			
	0 0 0	0 0 0	1 0 0	0 1 0	0 1 0	2 0 0	2 3 0	2 5 1	4 0 0	1 1 0	2 1 0	2 0 0		16	12	1
1982	0	0	3	0	1	3	4	5	6	4	1	1	28			
	0 0 0	0 0 0	2 1 0	0 0 0	1 0 0	1 2 0	2 2 0	5 0 0	3 2 1	3 0 1	1 0 0	1 0 0		19	7	2
1983	0	0	0	0	0	1	3	6	3	5	5	2	25			
	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 1 0	3 0 0	2 3 1	1 1 1	3 2 0	3 2 0	0 2 0		12	11	2
1984	0	0	0	0	0	2	5	7	4	8	3	1	30			
	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 2 0	4 1 0	2 3 2	1 3 0	5 4 1	3 0 0	1 0 0		16	13	3
1985	2	0	0	0	1	3	1	7	5	5	1	2	27			
	0 2 0	0 0 0	0 0 0	0 0 0	1 0 0	2 0 1	1 0 0	5 2 0	3 2 0	4 1 0	0 1 0	1 1 0		17	9	1
1986	0	1	0	1	2	2	2	5	2	5	4	3	27			
	0 0 0	1 0 0	0 0 0	1 0 0	1 1 0	1 1 0	2 0 0	4 1 0	2 0 0	3 2 0	2 2 0	2 1 0		19	8	0
1987	1	0	0	1	0	2	4	4	7	2	3	1	25			
	1 0 0	0 0 0	0 0 0	0 1 0	0 0 0	1 1 0	4 0 0	3 1 0	5 1 1	2 0 0	1 2 0	1 0 0		18	6	1
1988	1	0	0	0	1	3	2	5	8	4	2	1	27			
	1 0 0	0 0 0	0 0 0	0 0 0	1 0 0	1 1 1	1 1 0	2 3 0	2 6 0	4 0 0	2 0 0	0 1 0		14	12	1
1989	1	0	0	1	2	2	6	8	4	6	3	2	35			
	0 1 0	0 0 0	0 0 0	1 0 0	2 0 0	1 1 0	2 3 1	3 3 2	2 2 0	6 0 0	3 0 0	1 0 1		21	10	4
1990	1	0	0	1	2	4	4	5	5	5	4	1	32			
	1 0 0	0 0 0	0 0 0	0 1 0	1 1 0	2 1 1	2 2 0	5 0 0	4 1 0	2 3 0	3 1 0	1 0 0		21	10	1
1991	0	0	2	1	1	1	4	8	6	3	6	0	32			
	0 0 0	0 0 0	1 1 0	0 1 0	1 0 0	1 0 10	4 0 0	3 3 2	4 2 0	3 0 0	3 3 0	0 0 0		20	10	2
1992	1	1	0	0	0	3	4	8	5	6	5	0	33			
	1 0 0	0 1 0	0 0 0	0 0 0	0 0 0	2 1 0	2 2 0	4 4 0	4 1 0	5 1 0	3 1 1	0 0 0		21	11	11
1993	0	0	2	2	1	2	5	8	5	6	4	3	38			
	0 0 0	0 0 0	0 1 1	0 0 2	0 1 0	1 0 1	3 2 0	6 1 1	4 1 0	3 2 1	1 1 2	3 0 0		21	9	8
1994	1	0	1	0	2	2	9	9	8	7	0	2	41			
	0 0 1	0 0 0	1 0 0	0 0 0	1 0 1	0 2 0	3 4 2	6 3 0	4 4 0	5 1 1	0 0 0	1 1 0		21	15	5
1995	1	0	0	0	1	2	3	7	7	8	2	3	34			
	0 0 1	0 0 0	0 0 0	0 0 0	0 1 0	0 2 0	2 1 0	4 2 1	4 1 2	5 1 2	0 2 0	0 1 2		15	11	8
1996	1	1	0	2	2	0	7	10	7	5	6	3	44			
	0 0 1	0 0 1	0 0 0	0 1 1	1 1 0	0 0 0	6 1 0	4 3 3	6 1 0	2 1 2	1 3 2	1 1 1		21	12	11
1997	1	0	0	2	3	3	4	8	4	6	1	1	33			
	0 1 0	0 0 0	0 0 0	1 1 0	1 2 0	3 0 0	3 1 0	6 1 1	3 1 0	4 1 1	1 0 0	1 0 0		23	8	2
1998	0	0	0	0	0	0	3	3	8	6	3	4	27			
	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 1 2	2 1 0	4 1 3	2 1 3	0 3 0	1 1 2		9	8	10
1999	1	1	0	3	0	1	5	9	6	2	3	3	34			
	0 1 0	0 1 0	0 0 0	2 1 0	0 0 0	1 0 0	1 1 3	4 2 3	2 4 0	1 1 0	1 1 1	0 0 3		12	12	10
2000	0	0	0	0	4	0	8	9	6	3	3	1	34			
	0 0 0	0 0 0	0 0 0	0 0 0	1 1 2	0 0 0	2 3 3	4 3 2	4 1 1	2 1 0	1 1 1	1 0 0		15	10	9
2001	0	1	0	1	1	2	6	7	5	3	3	4	33			
	0 0 0	0 0 1	0 0 0	0 0 1	0 1 0	2 0 0	4 1 1	3 3 1	5 0 0	3 0 0	1 2 0	2 2 0		20	9	4
2002	1	1	1	1	2	3	6	8	3	5	1	1	33			
	0 1 0	1 0 0	0 0 1	0 0 1	1 0 1	3 0 0	3 2 1	4 3 1	1 2 0	3 0 2	1 0 0	1 0 0		18	8	7
2003	1	0	0	1	3	2	2	5	3	6	3	1	27			
	0 1 0	0 0 0	0 0 0	1 0 0	1 1 1	1 1 0	2 0 0	4 1 0	3 0 0	2 1 3	3 0 0	0 1 0		17	6	4
2004	0	1	1	1	3	5	2	9	3	3	2	2	32			
	0 0 0	0 1 0	0 1 0	1 0 0	2 1 0	5 0 0	1 1 0	6 2 1	1 1 1	3 0 0	2 0 0	0 2 0		21	9	2
2005	1	0	1	1	0	1	4	6	5	3	2	1	25			
	1 0 0	0 0 0	1 0 0	1 0 0	0 0 0	1 0 0	1 3 0	6 0 0	4 1 0	2 0 1	1 1 0	0 1 0		18	6	1
2006	0	0	1	0	1	1	3	8	5	4	2	2	27			
	0 0 0	0 0 0	0 1 0	0 0 0	1 0 0	0 1 0	2 1 0	3 4 1	3 0 2	2 1 1	2 0 0	1 0 1		14	8	5
2007	0	0	1	0	1	0	3	6	5	5	6	0	27			
	0 0 0	0 0 0	1 0 0	0 0 0	1 0 0	0 0 0	2 1 0	3 2 1	2 2 1	3 2 0	3 1 2	0 0 0		15	8	4
2008	1	0	0	1	4	1	2	5	6	3	3	1	27			
	0 1 0	0 0 0	0 0 0	1 0 0	3 1 0	1 0 0	2 0 0	1 4 0	3 3 0	0 3 0	0 3 0	1 0 0		12	15	0
2009	0	0	0	0	2	2	3	5	7	4	4	1	28			
	0 0 0	0 0 0	0 0 0	0 0 0	2 0 0	1 1 0	1 1 1	3 2 0	4 1 2	3 1 0	1 1 2	0 0 1		15	7	6
2010	1	0	1	0	0	0	2	5	4	4	1	1	19			
	0 0 1	0 0 0	0 0 1	0 0 0	0 0 0	0 0 0	2 0 0	2 3 0	3 1 0	2 2 0	0 0 1	0 0 1		9	6	4
2011	0	0	0	2	2	3	4	4	7	1	1	3	27			
	0 0 0	0 0 0	0 0 0	0 0 2	1 1 0	0 2 1	2 1 1	2 1 1	2 5 0	0 0 1	0 0 1	0 1 2		7	11	9
2012	0	1	1	0	1	4	4	5	3	5	2	1	27			
	0 0 0	0 0 1	0 1 0	0 0 0	1 0 0	2 2 0	3 1 0	4 1 0	2 1 0	2 3 0	1 0 1	0 1 0		15	10	2
2013	1	1	0	0	0	4	3	5	8	7	3	1	33			
	0 1 0	0 0 1	0 0 0	0 0 0	0 0 0	1 3 0	1 2 0	2 2 1	4 3 1	6 0 1	1 1 1	0 0 1		15	12	6

1) If a tropical cyclone was warned on prior to the last two days of a month, it was attributed to the first month, regardless of how long the system lasted.

2) If a tropical cyclone began on the last day of the month and ended on the first day of the next month, that system was attributed to the first month. However, if a tropical cyclone began on the last day of the month and continued into the next month for only two days, it was attributed to the second month.

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 - 2013)													
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN	0.2	0.1	0.2	0.4	0.7	1.1	2.5	3.5	3.3	2.9	1.5	0.6	17.0
CASES	11	3	10	23	41	59	137	190	180	162	83	35	934
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 - 2013)													
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN	0.5	0.2	0.4	0.6	1.2	1.8	3.9	5.5	4.9	4.0	2.5	1.2	26.7
CASES	26	12	24	34	64	98	212	305	272	221	136	67	1471

TABLE 1-4 TROPICAL CYCLONE FORMATION ALERTS FOR THE WESTERN NORTH PACIFIC OCEAN 1976 - 2013					
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%
MEAN	35	28	30	21%	93%
CASES	1322	1050	1129		
* Percentage of initial TCFAs not followed by warnings.					

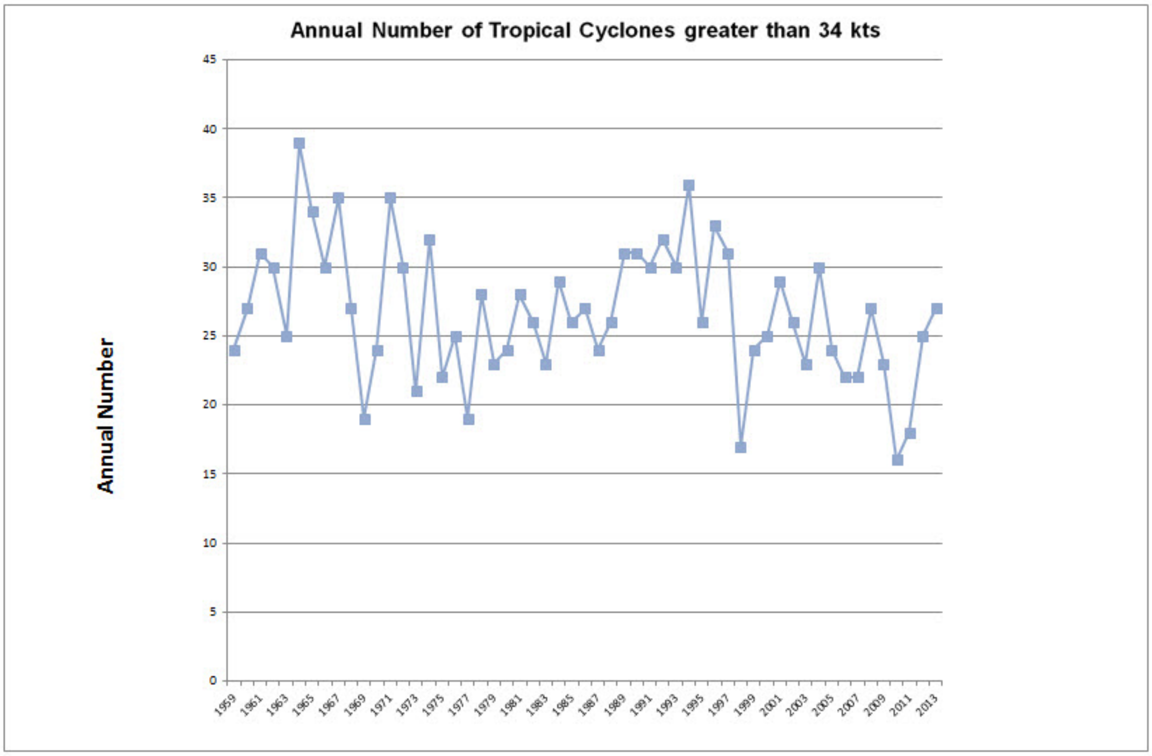


Figure 1-1. Annual number of western North Pacific TCs greater than 34 knots intensity.

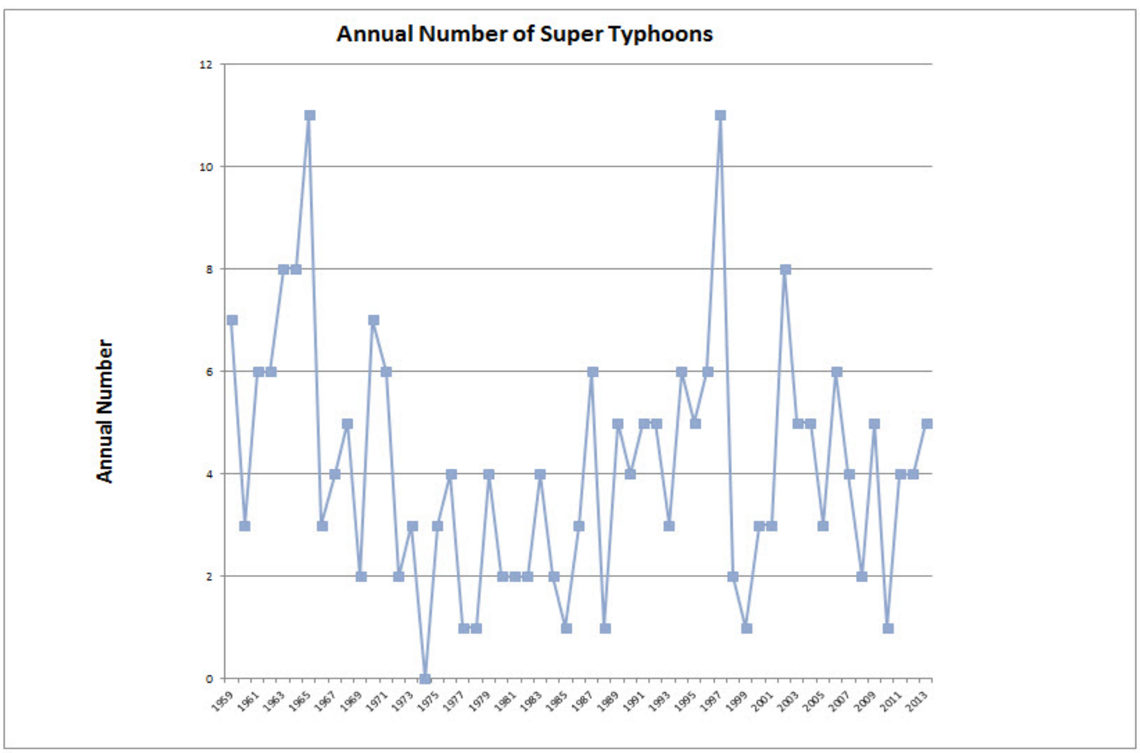
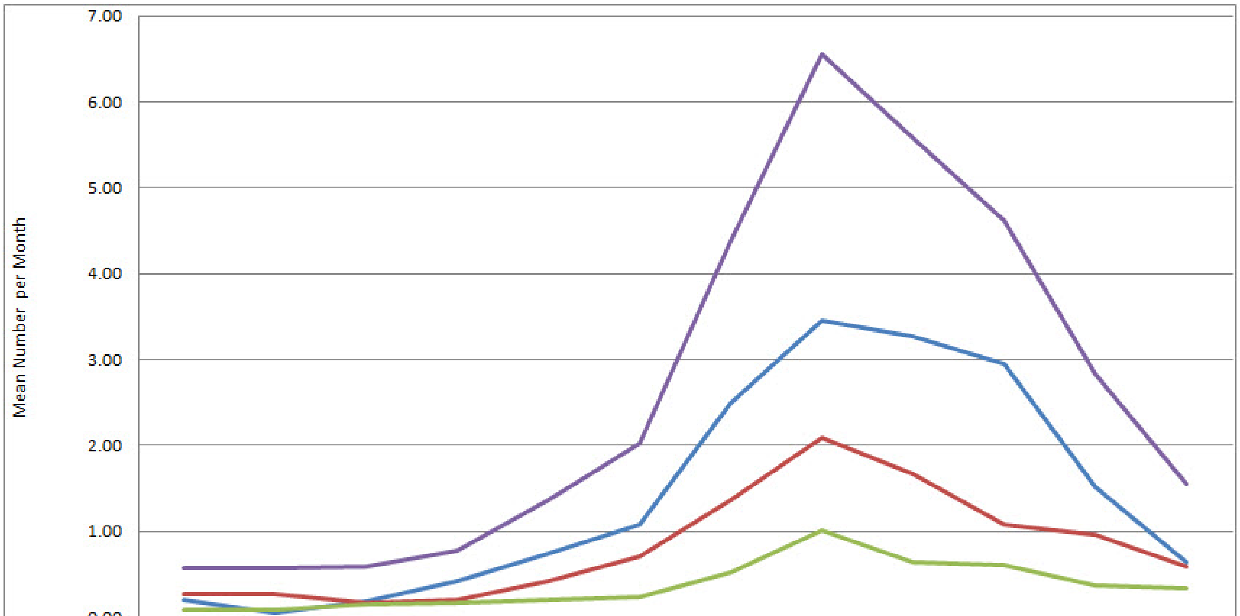


Figure 1-2. Annual number of western North Pacific TCs greater than 129 knots intensity.



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
TY AVG	0.20	0.05	0.18	0.42	0.75	1.07	2.49	3.45	3.27	2.95	1.51	0.64
TS AVG	0.27	0.27	0.16	0.20	0.42	0.71	1.36	2.09	1.67	1.07	0.96	0.58
TD AVG	0.09	0.09	0.15	0.16	0.20	0.24	0.53	1.02	0.64	0.60	0.36	0.33
All AVG	0.56	0.56	0.58	0.78	1.36	2.02	4.38	6.56	5.58	4.62	2.84	1.55

Figure 1-3. Average number of western North Pacific TCs (all intensities) by month 1959-2013.

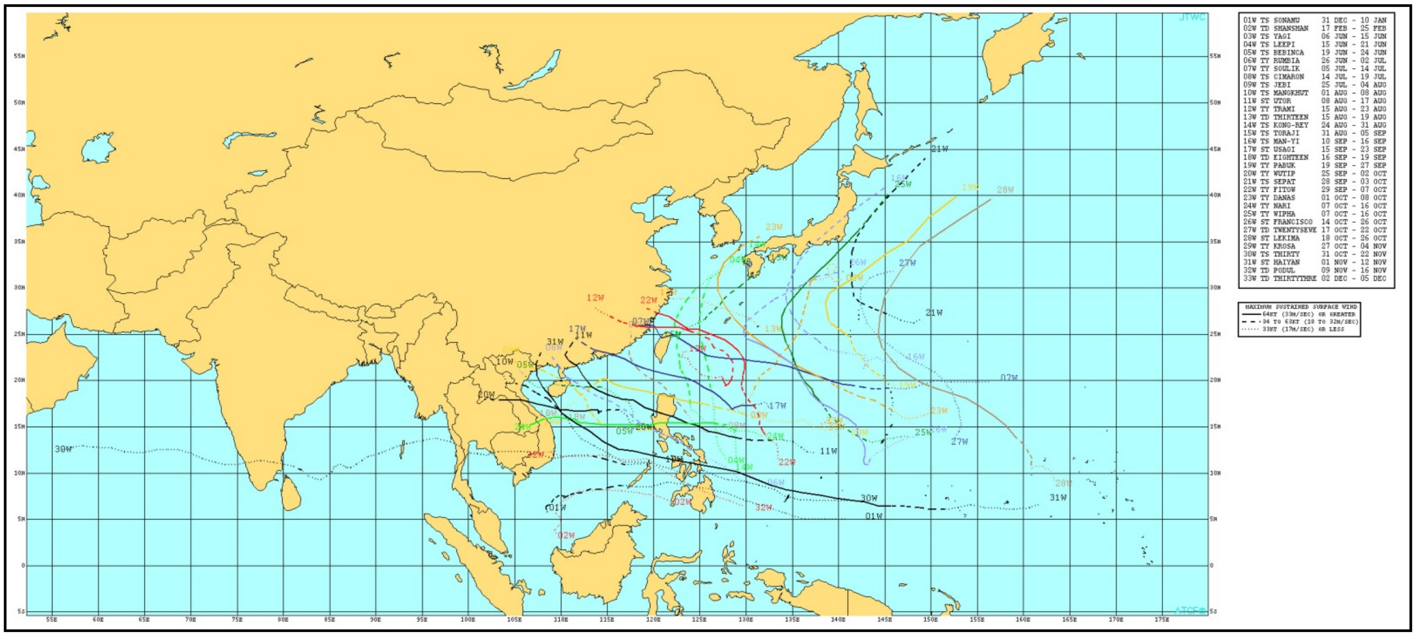


Figure 1-4. Western North Pacific Tropical Cyclones 01W – 33W.

Section 2 Cyclone Summaries

This section presents a synopsis of each cyclone that occurred during 2013 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.

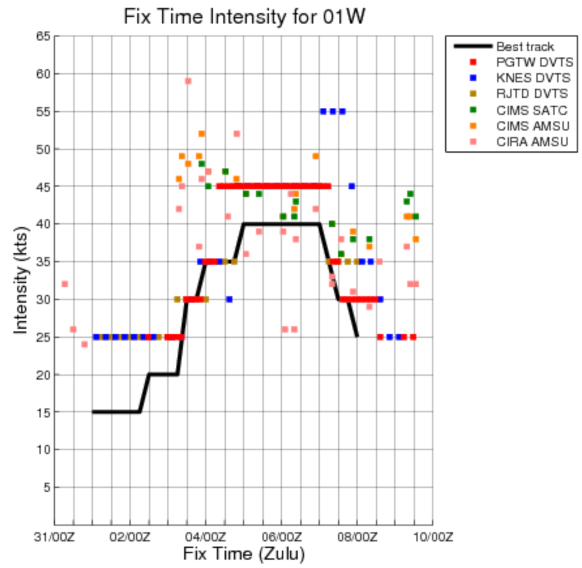
The JTWC post-event reanalysis best track is also provided for each cyclone. Data included on the best track are position and intensity noted with cyclone symbols and color coded track. Best track position labels include the date-time, track speed in knots, and maximum wind speed in knots. A graph of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

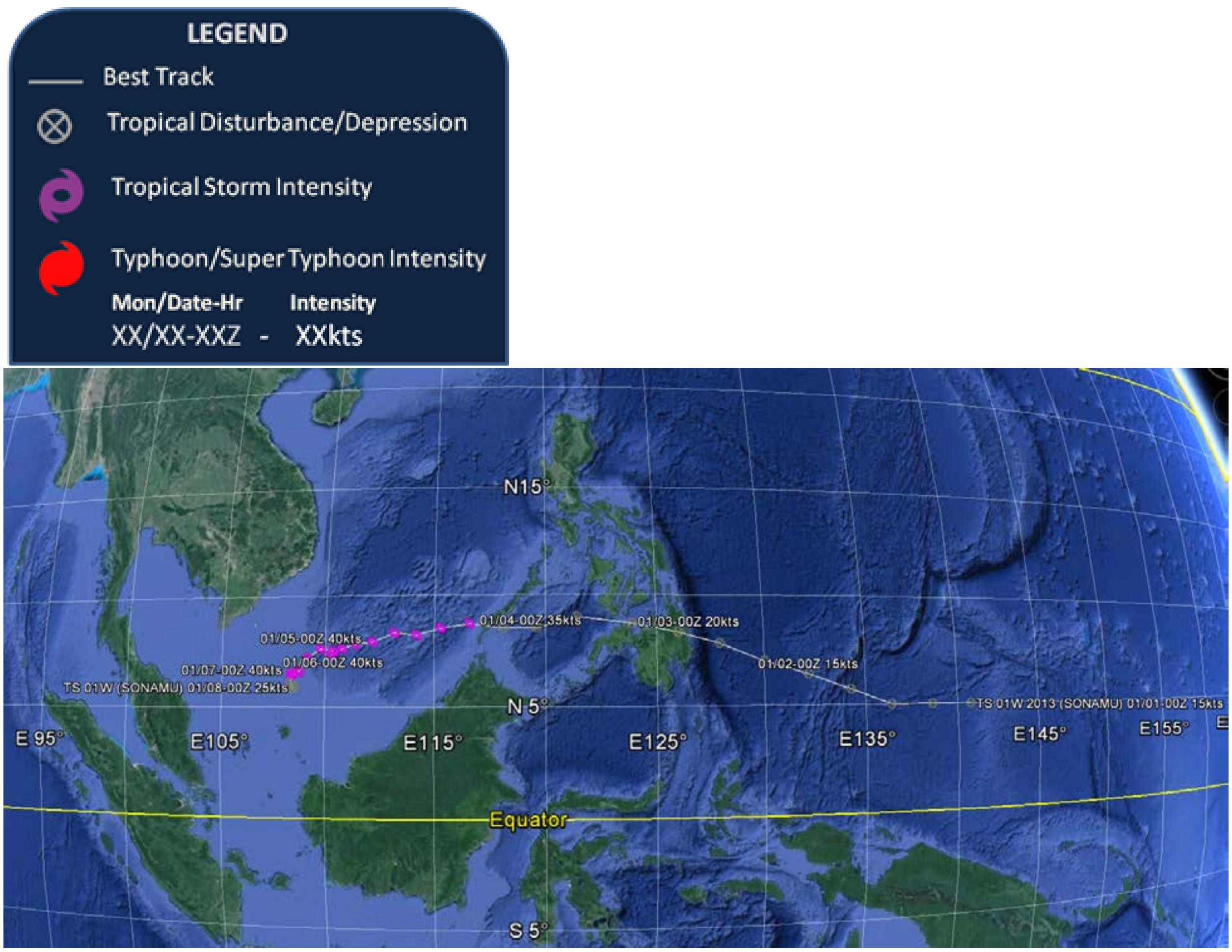
In addition, if this document is viewed as a pdf, each map has been hyperlinked to the appropriate keyhole markup language (kmz) file that will allow the reader to access and view the

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:
http://www.usno.navy.mil/NOOC/nmfc-ph/RSS/jtwc/best_tracks/2013/2013-kmzs/

01W Tropical Storm Sonamu

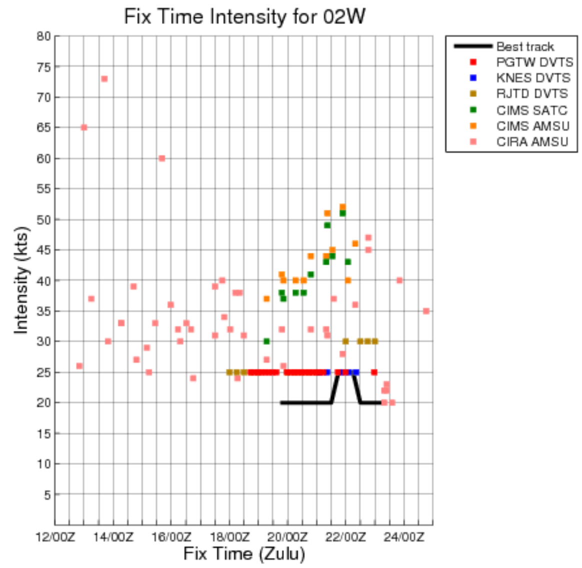
ISSUED LOW:	N/A
ISSUED MED:	02 Jan / 1300Z
FIRST TCFA:	02 Jan / 2130Z
FIRST WARNING:	03 Jan / 1200Z
LAST WARNING:	08 Jan / 1800Z MAX
INTENSITY:	40
WARNINGS:	22

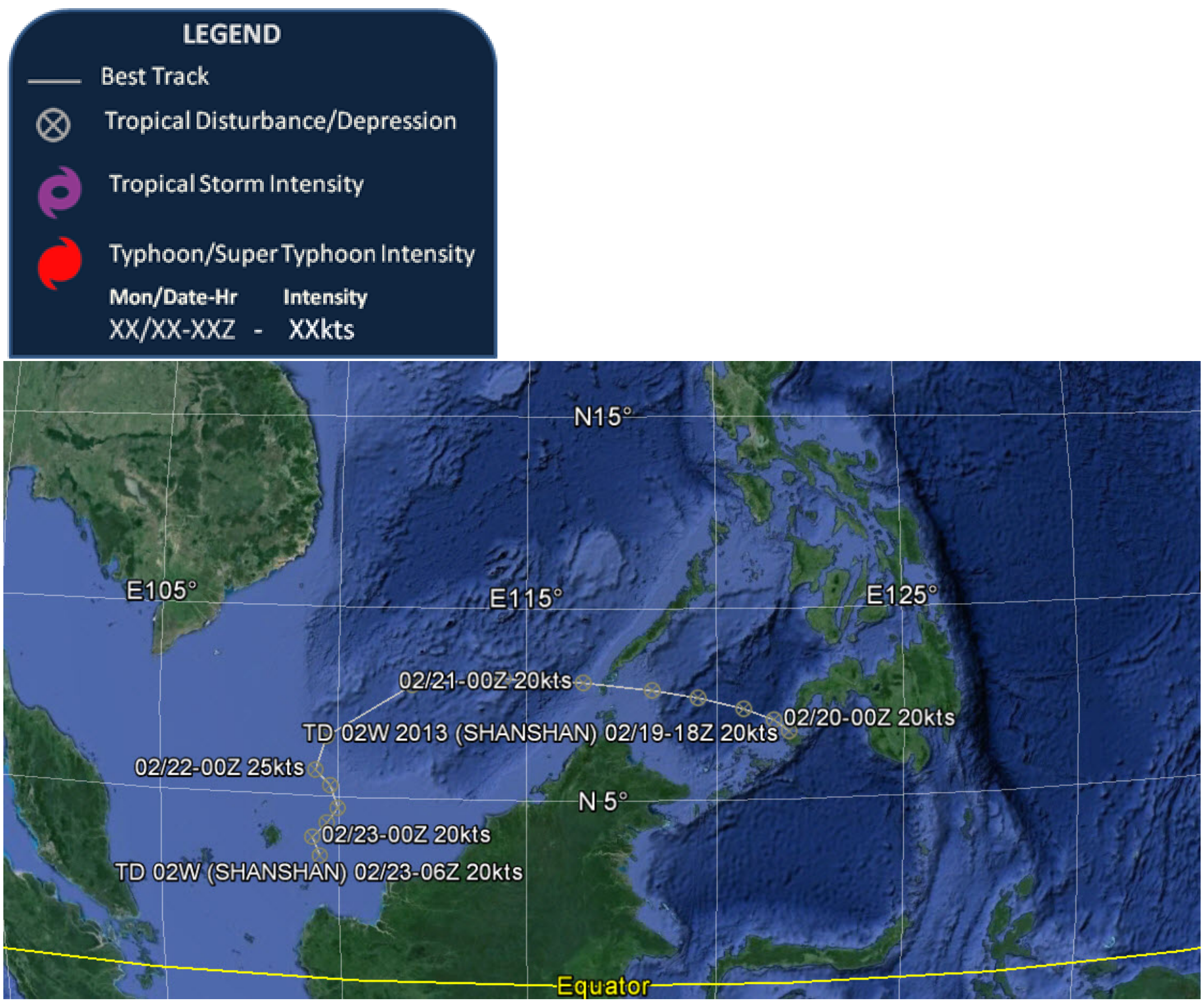




02W Tropical Depression Shanshan

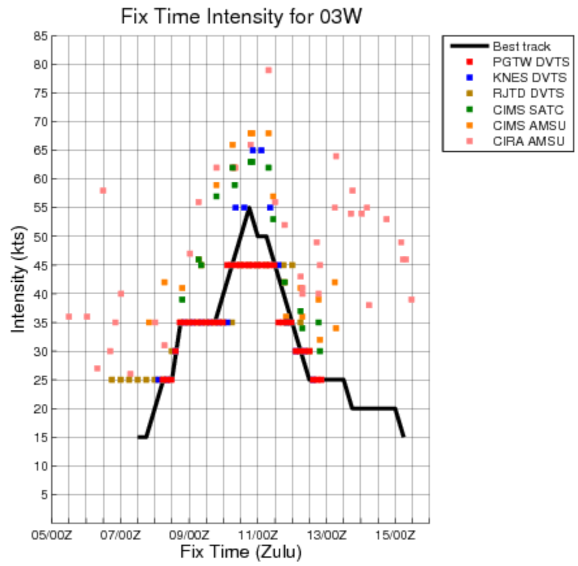
ISSUED LOW:	17 Feb / 0600Z
ISSUED MED:	18 Feb / 0600Z
FIRST TCFA:	18 Feb / 1700Z
FIRST WARNING:	19 Feb / 0000Z
LAST WARNING:	21 Feb / 0000Z
MAX INTENSITY:	25
WARNINGS:	10

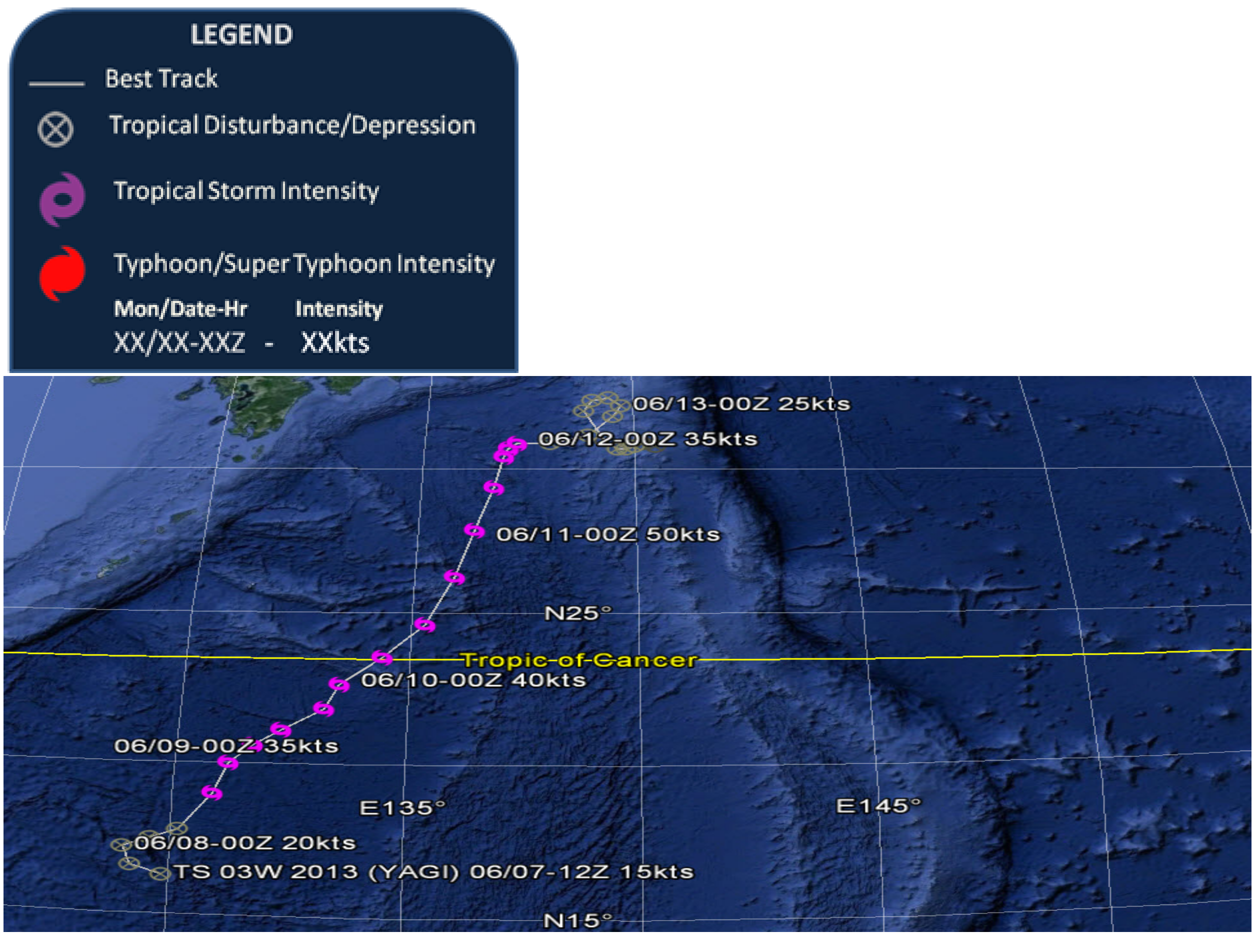




03W Tropical Storm Yagi

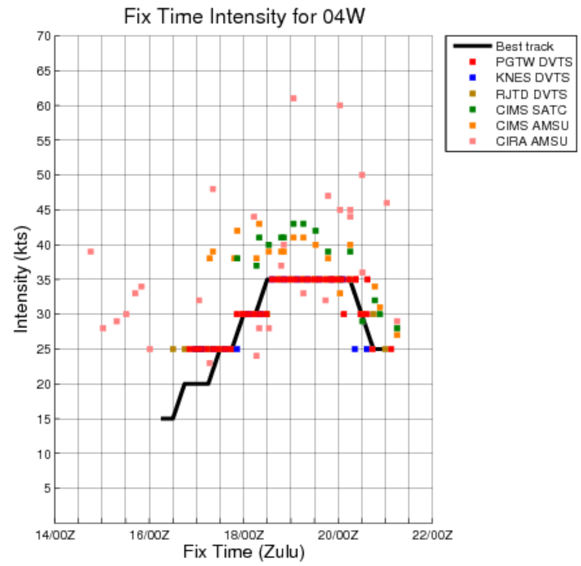
ISSUED LOW:	06 Jun / 1500Z
ISSUED MED:	06 Jun / 2330Z
FIRST TCFA:	07 Jun / 2230Z
FIRST WARNING:	08 Jun / 1200Z
LAST WARNING:	12 Jun / 1200Z
MAX INTENSITY:	55
WARNINGS:	17

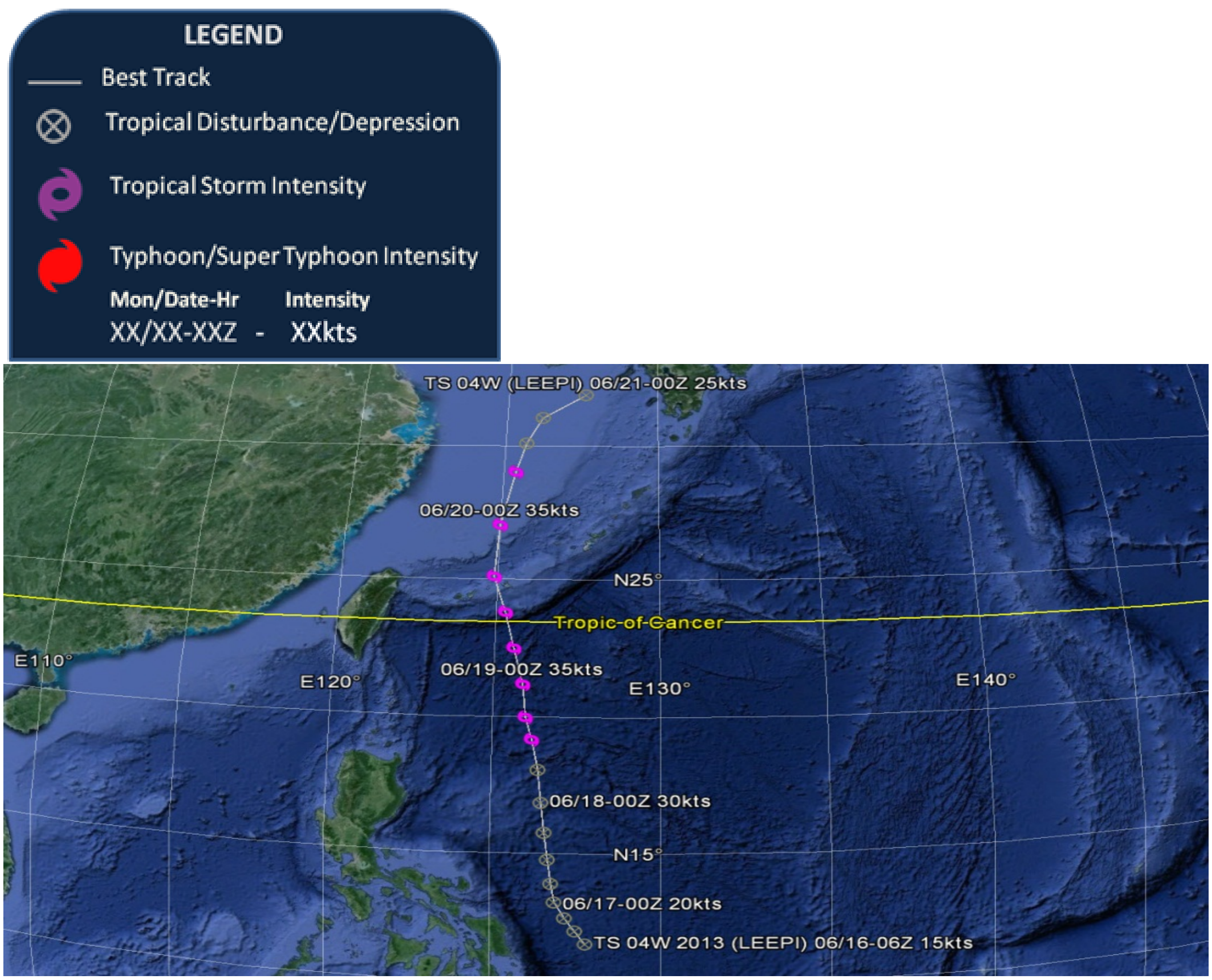




04W Tropical Storm Leepi

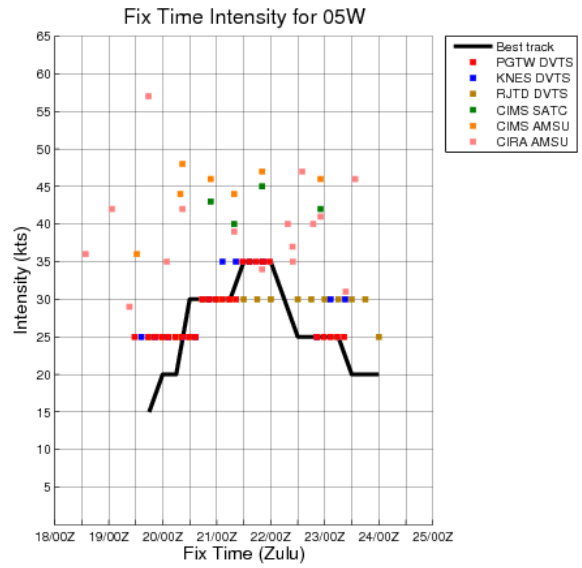
ISSUED LOW:	15 Jun / 2000Z
ISSUED MED:	16 Jun / 1830Z
FIRST TCFA:	16 Jun / 2200Z
FIRST WARNING:	17 Jun / 1800Z
LAST WARNING:	20 Jun / 1800Z
MAX INTENSITY:	35
WARNINGS:	13

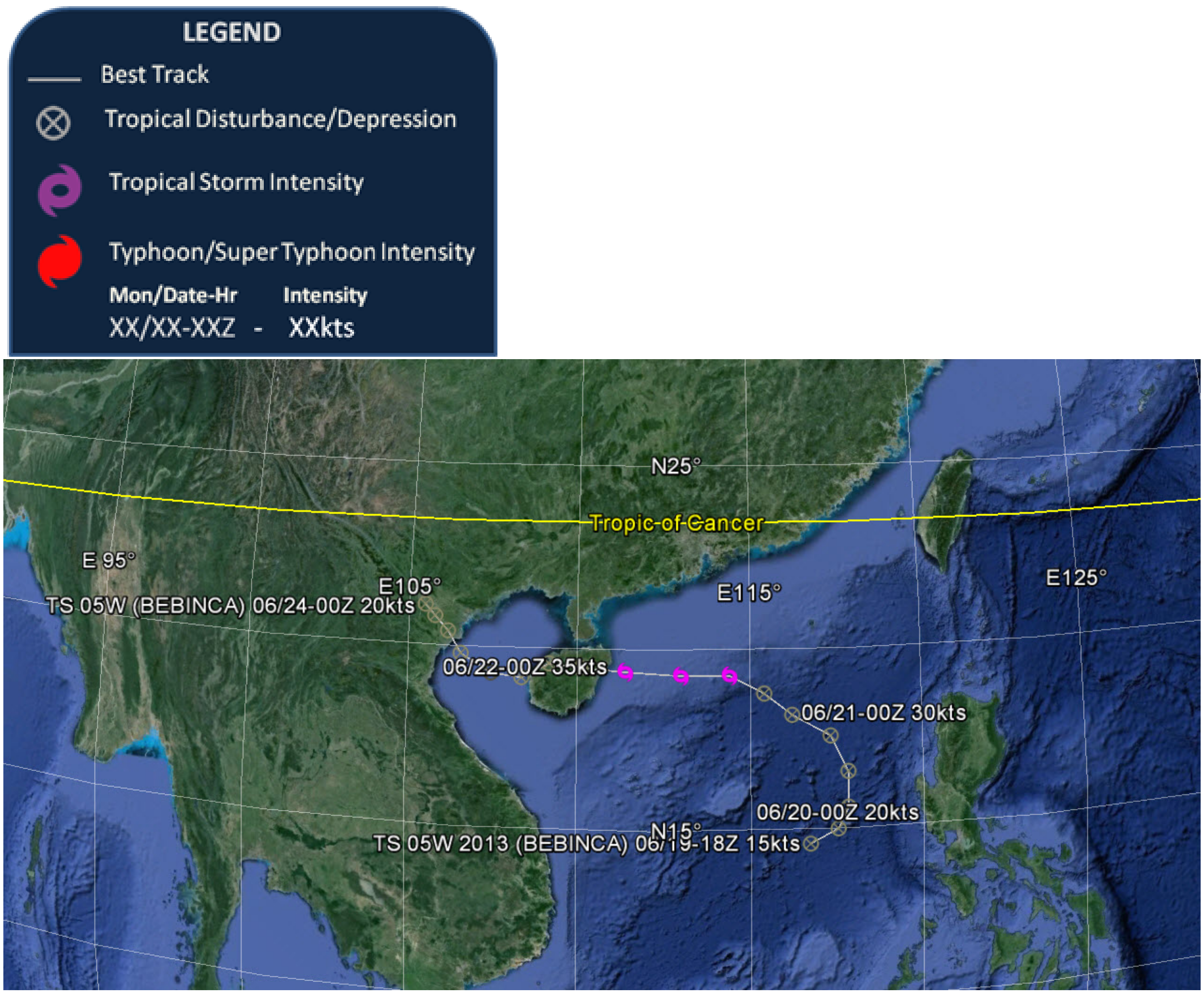




05W Tropical Storm Bebinca

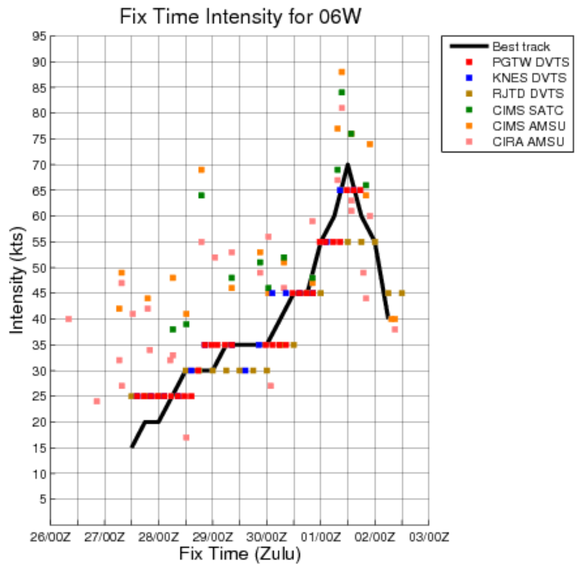
ISSUED LOW:	18 Jun / 2200Z
ISSUED MED:	19 Jun / 1700Z
FIRST TCFA:	20 Jun / 0430Z
FIRST WARNING:	20 Jun / 1200Z
LAST WARNING:	23 Jun / 0600Z
MAX INTENSITY:	35
WARNINGS:	12

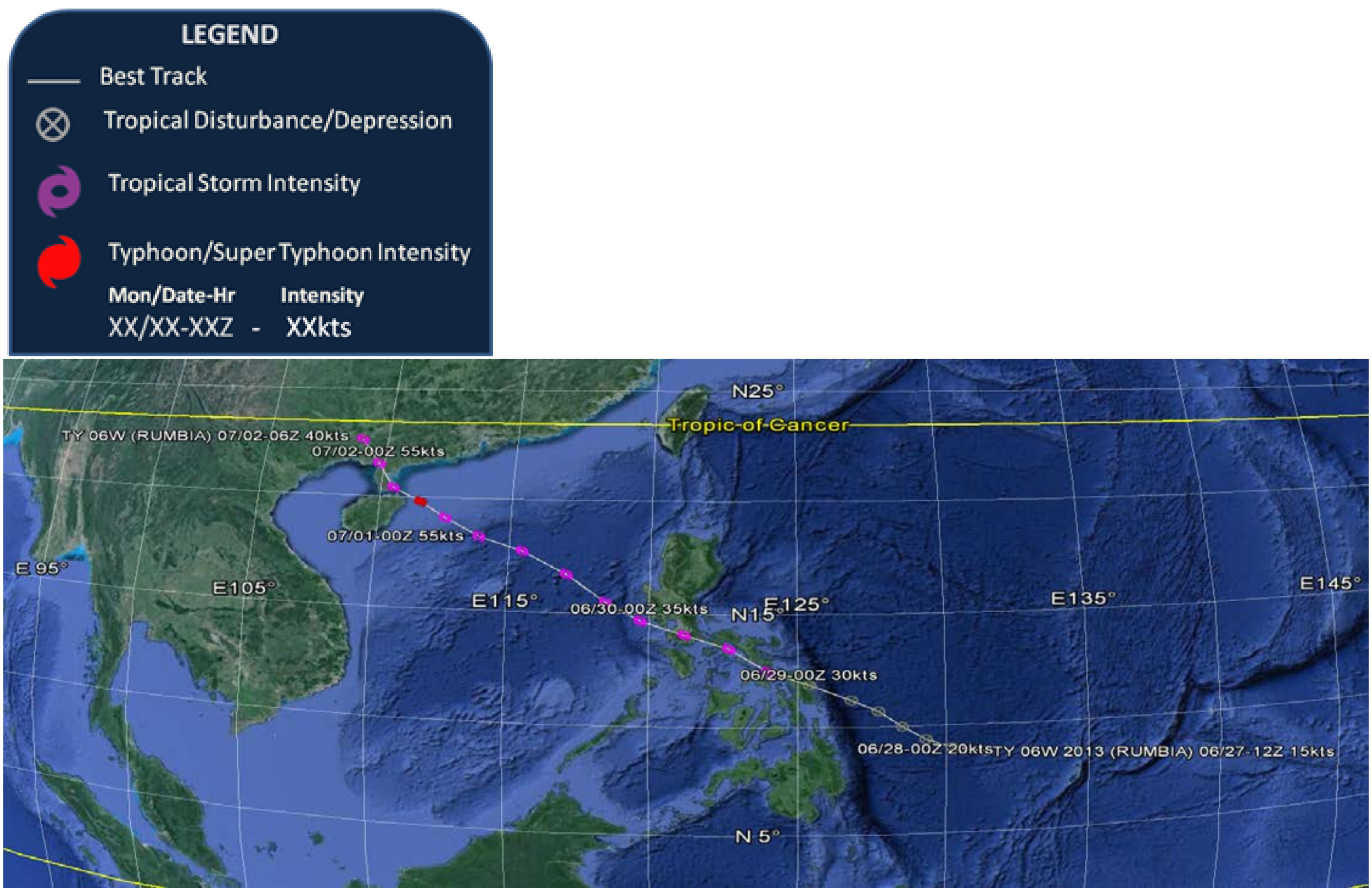




06W Typhoon Rumbia

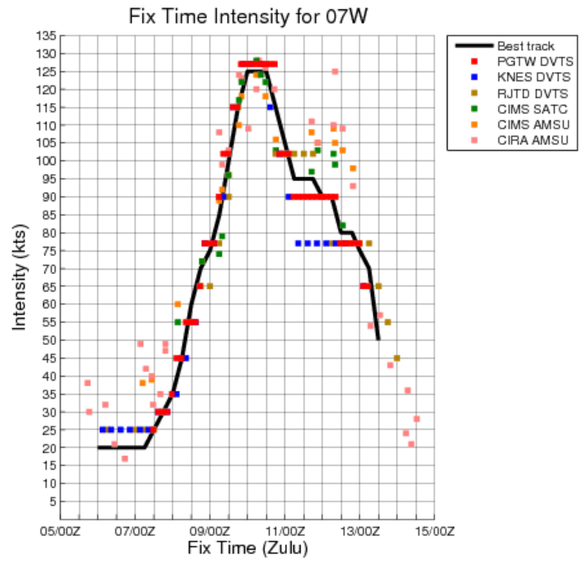
ISSUED LOW:	27 Jun / 0230Z
ISSUED MED:	27Jun / 1400Z
FIRST TCFA:	27 Jun /1930Z
FIRST WARNING:	28 Jun / 0000Z
LAST WARNING:	02 Jul / 0000Z
MAX INTENSITY:	70
WARNINGS:	17

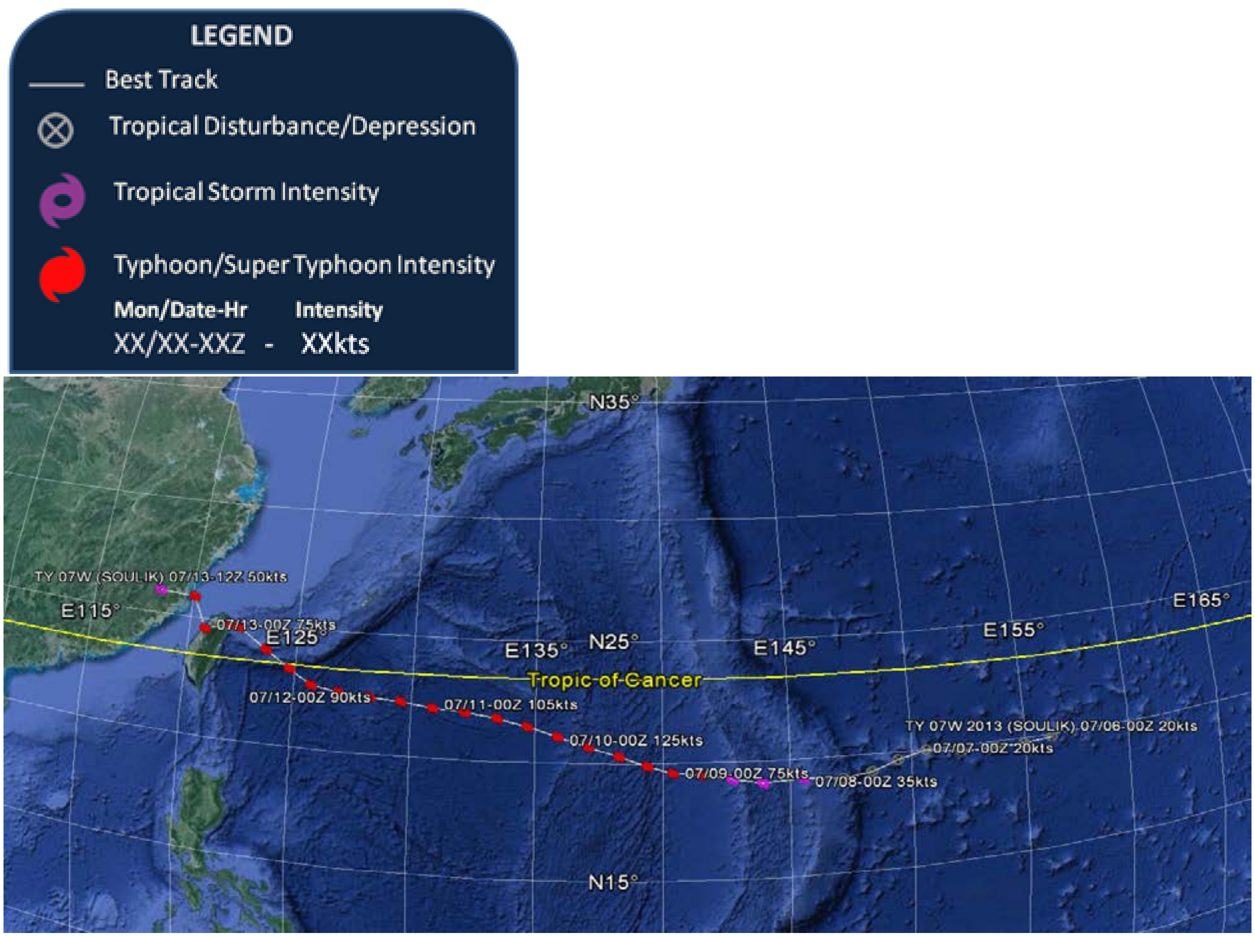




07W Typhoon Soulik

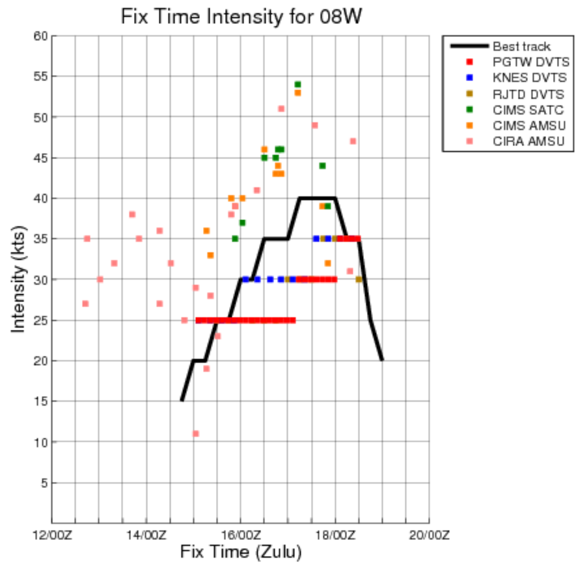
ISSUED LOW:	06 Jul / 0600Z
ISSUED MED:	07 Jul / 0600Z
FIRST TCFA:	07 Jul / 1430Z
FIRST WARNING:	07 Jul / 2100Z
LAST WARNING:	13 Jul / 1200Z
MAX INTENSITY:	125
WARNINGS:	24

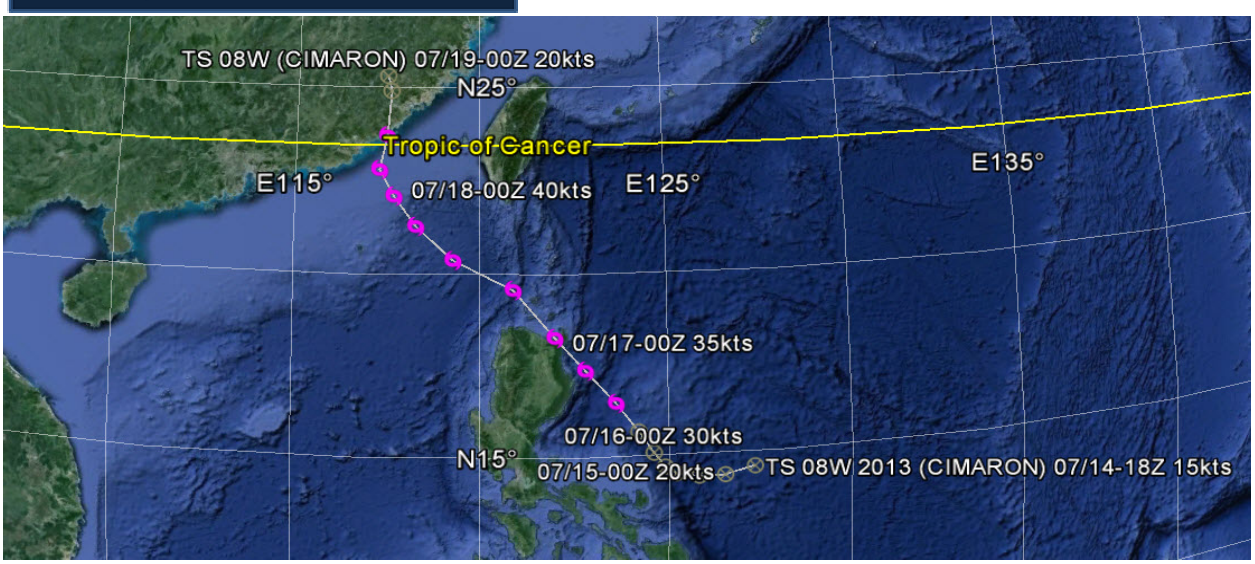




08W Tropical Storm Cimaron

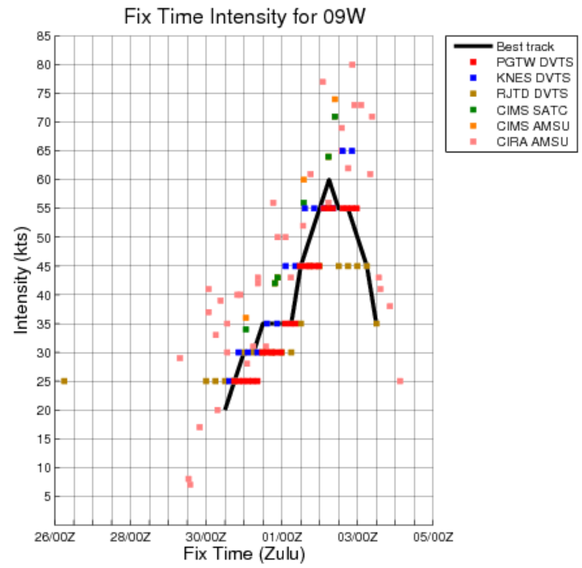
ISSUED LOW: 13 Jul / 0000Z
ISSUED MED: 14 Jul / 2200Z
FIRST TCFA: 15 Jul / 0600Z
FIRST WARNING: 15 Jul / 1800Z
LAST WARNING: 18 Jul / 1200Z
MAX INTENSITY: 40
WARNINGS: 12

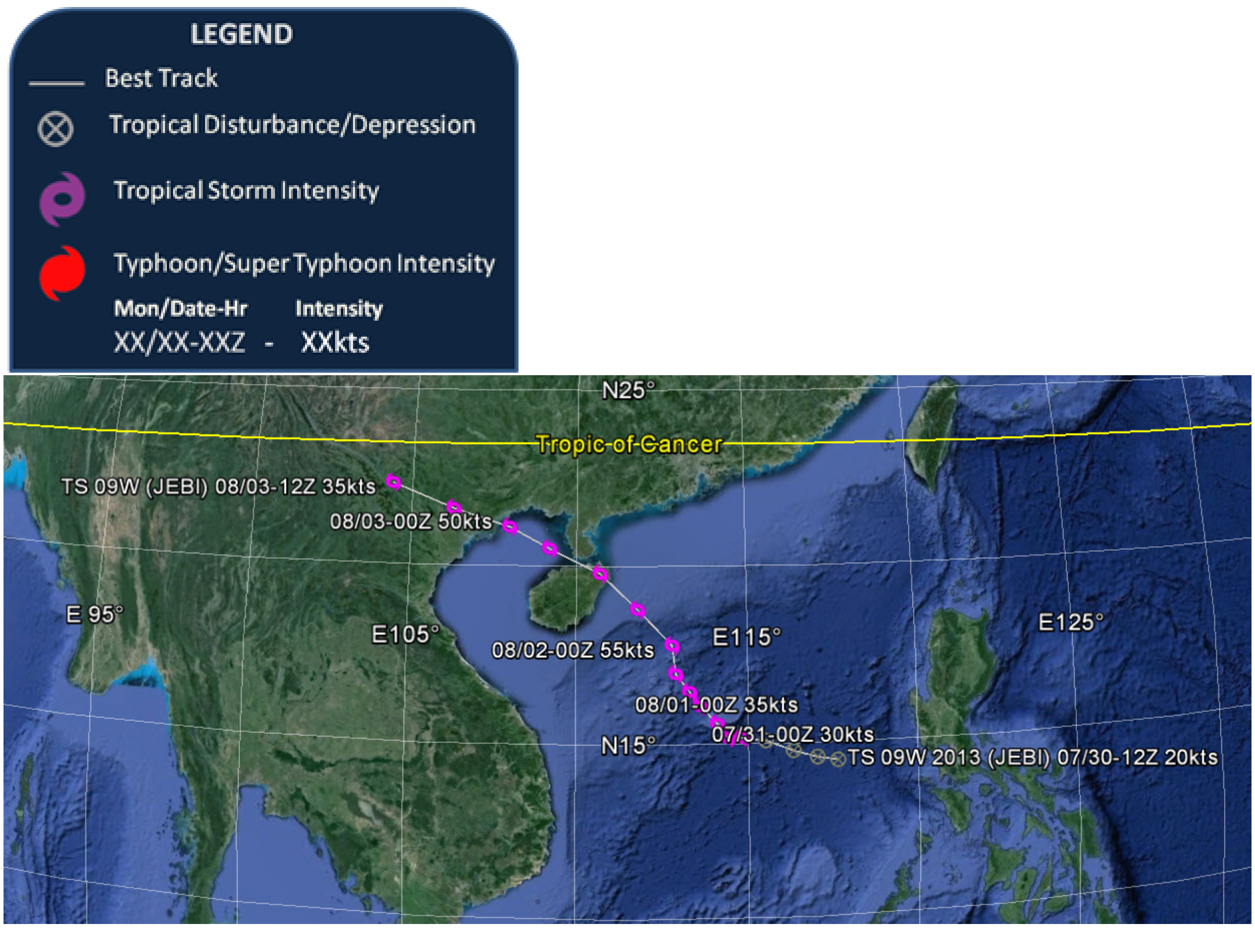




09W Tropical Storm Jebi

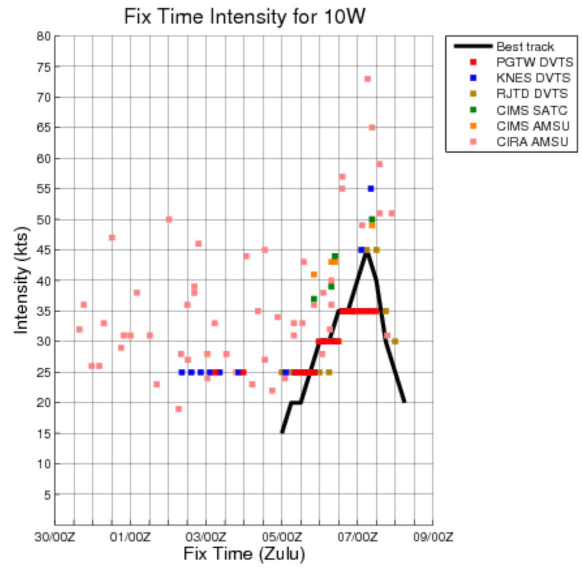
ISSUED LOW:	26 Jul / 0230Z
ISSUED MED:	26 Jul / 0600Z
FIRST TCFA:	30 Jul / 1900Z
FIRST WARNING:	31 Jul / 0000Z
LAST WARNING:	03 Aug / 0600Z
MAX INTENSITY:	60
WARNINGS:	14

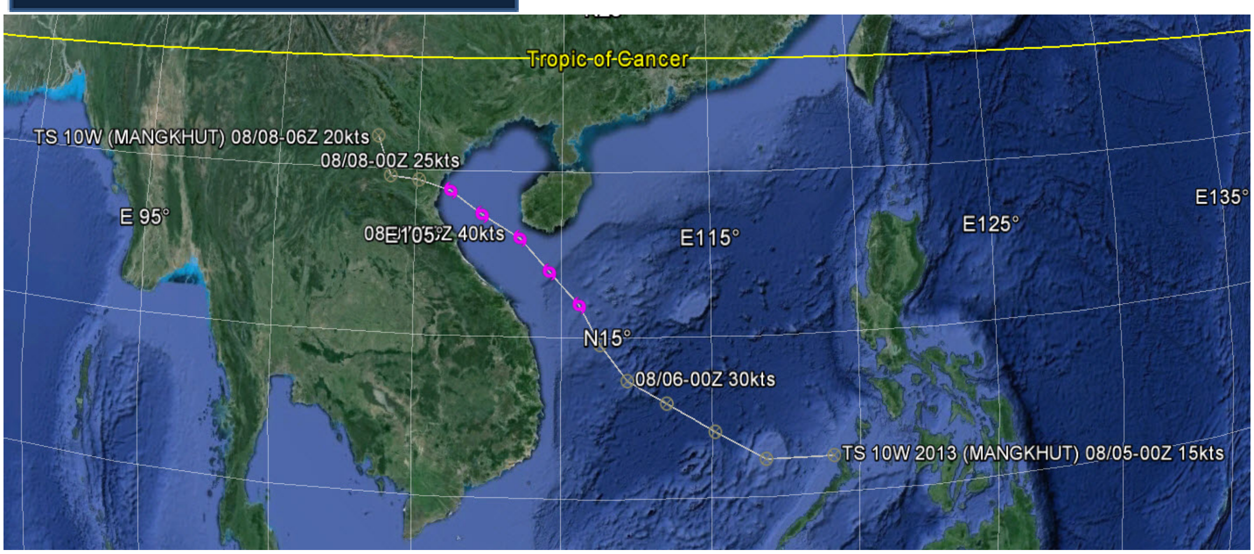




10W Tropical Storm Mangkhut

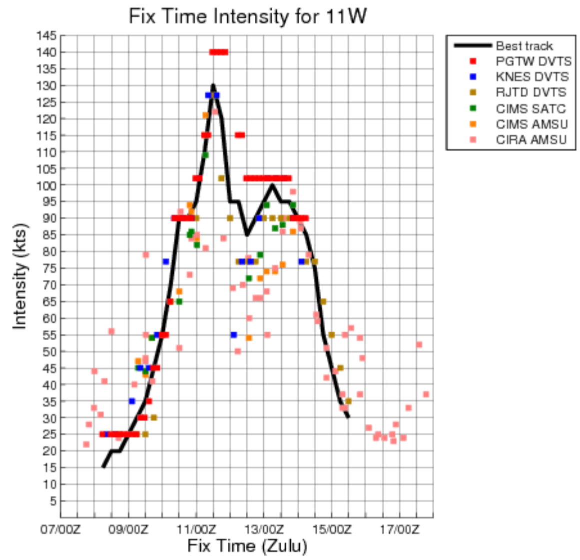
ISSUED LOW:	02 Aug / 0600Z
ISSUED MED:	04 Aug / 0600Z
FIRST TCFA:	05 Aug / 0900Z
FIRST WARNING:	05 Aug / 1800Z
LAST WARNING:	07 Aug / 1800Z
MAX INTENSITY:	45
WARNINGS:	9

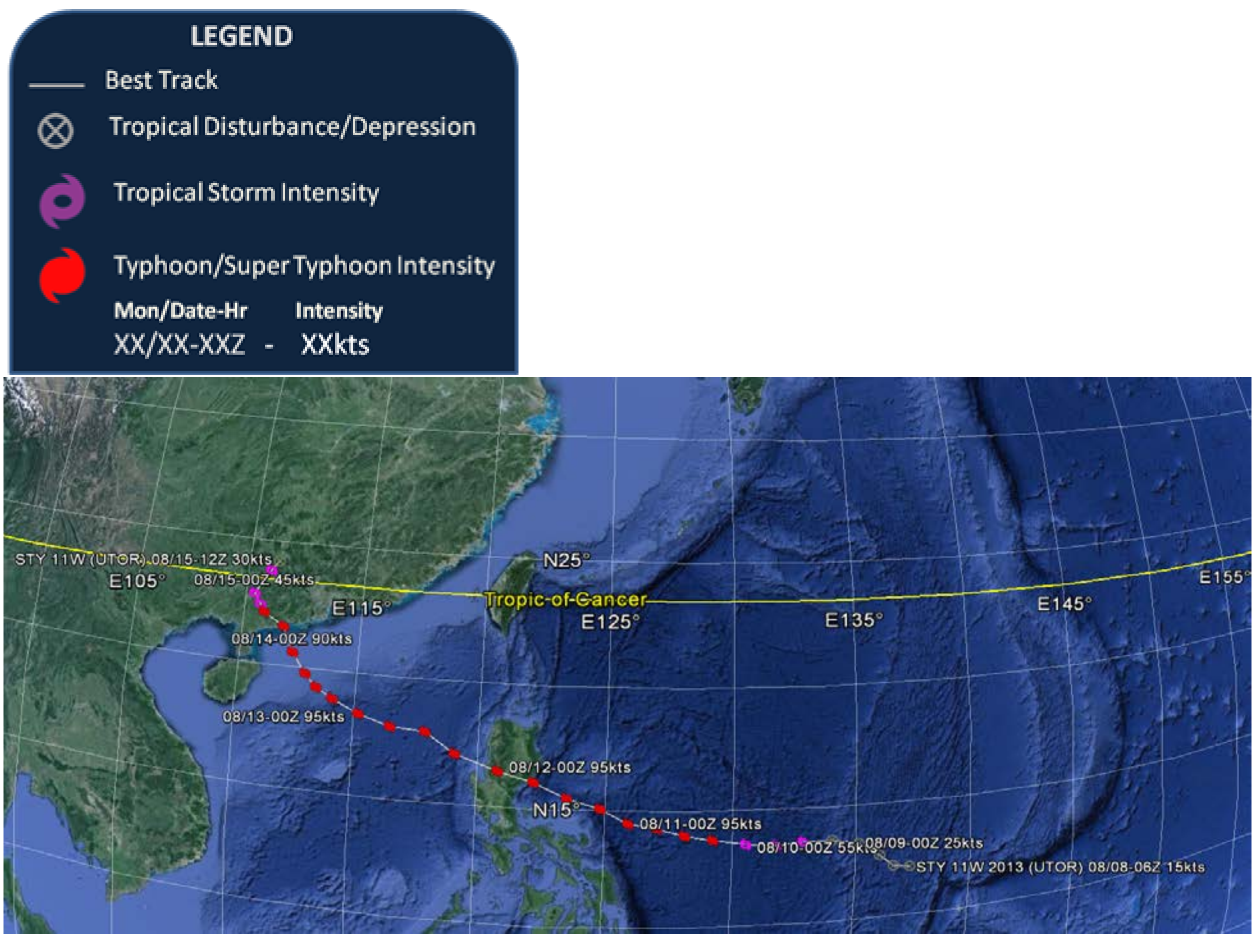




11W Super Typhoon Utor

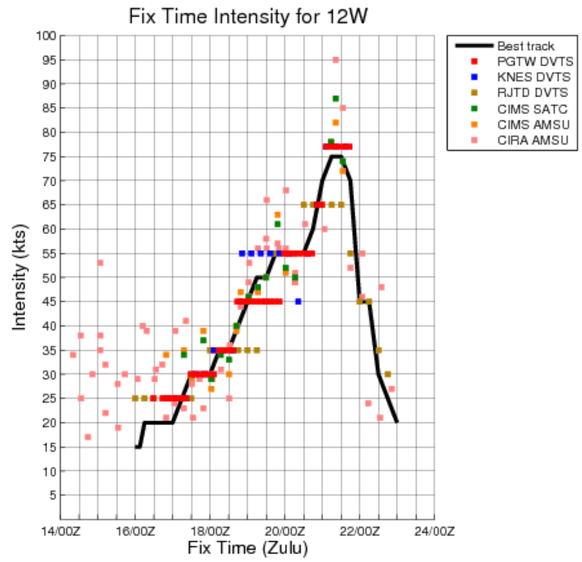
ISSUED LOW:	08 Aug/ 0600Z
ISSUED MED:	08 Aug/ 1200Z
FIRST TCFA:	08 Aug / 1630Z
FIRST WARNING:	08 Aug/ 1800Z
LAST WARNING:	14 Aug / 1200Z
MAX INTENSITY:	130
WARNINGS:	24

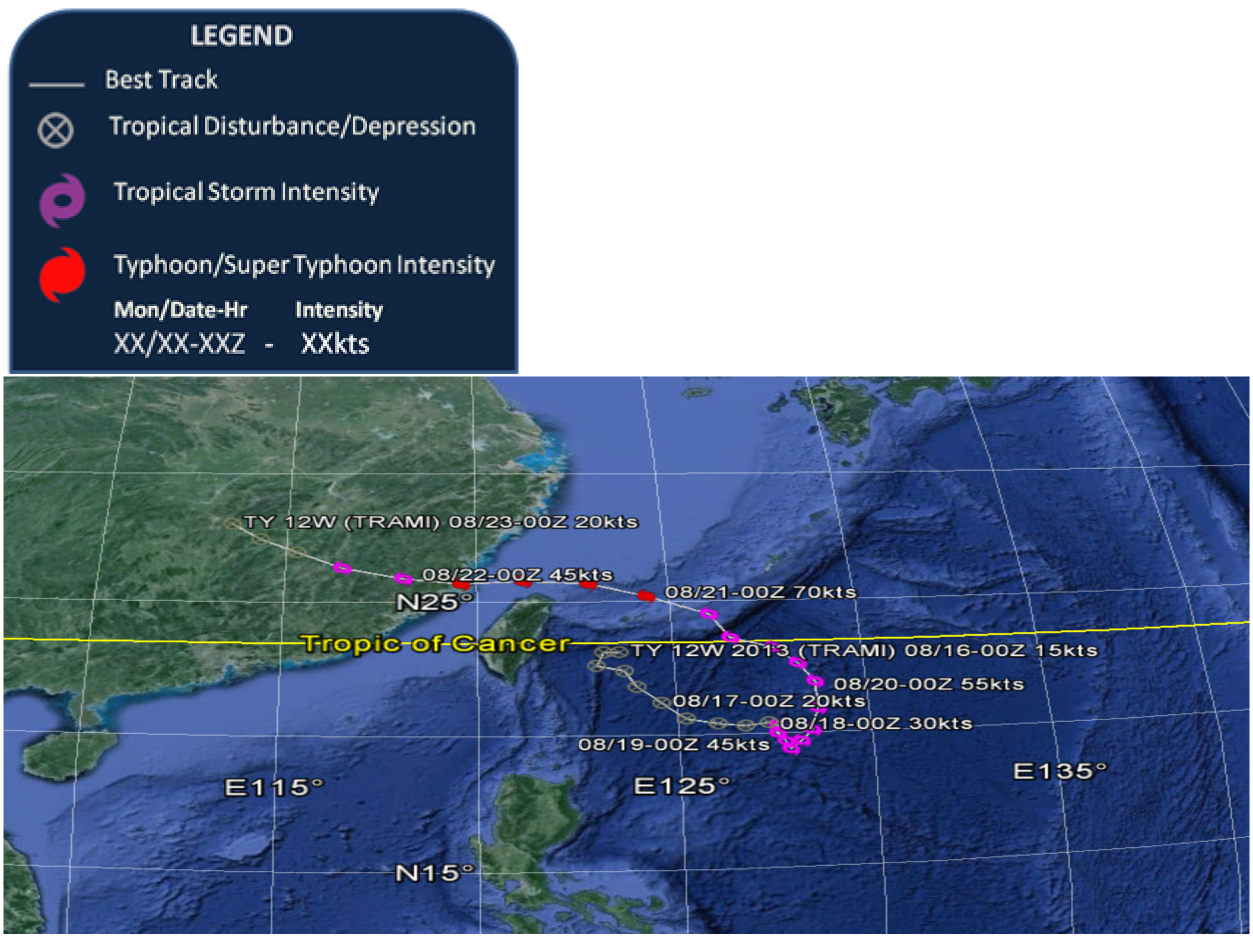




12W Typhoon Trami

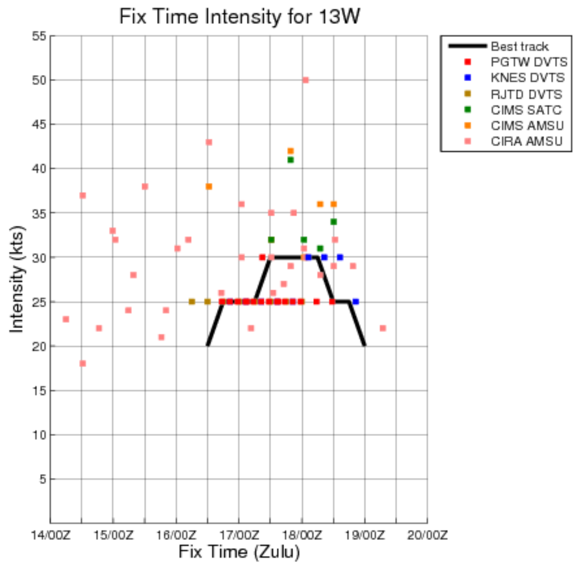
ISSUED LOW:	16 Aug / 0200Z
ISSUED MED:	16 Aug / 1330Z
FIRST TCFA:	16 Aug / 2000Z
FIRST WARNING:	17 Aug / 0000Z
LAST WARNING:	21 Aug / 1800Z
MAX INTENSITY:	75
WARNINGS:	20

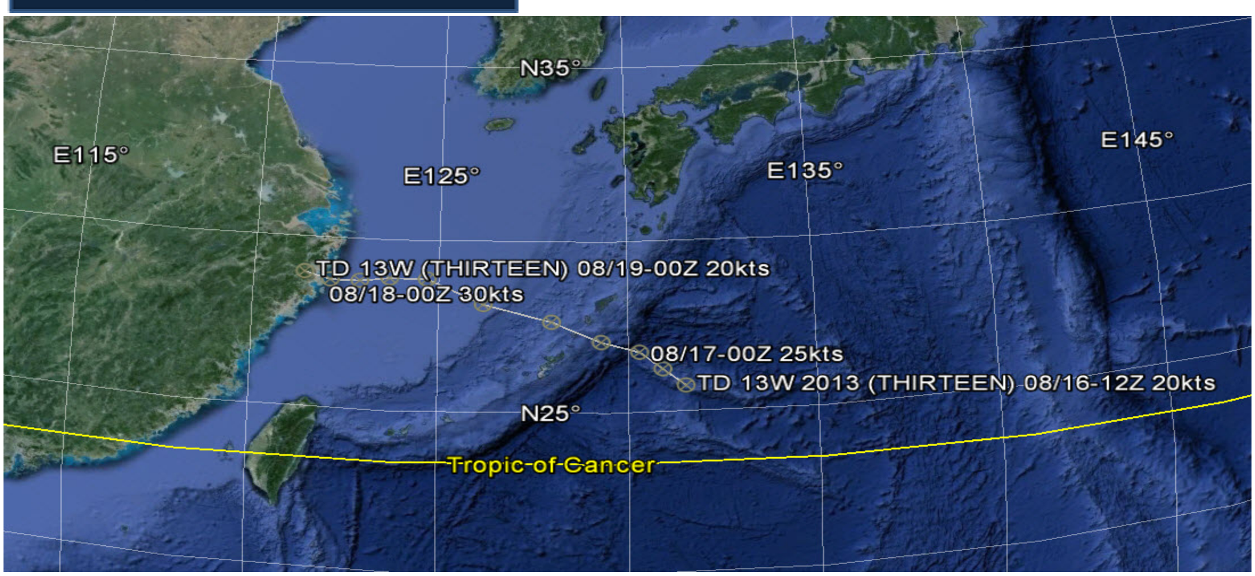




13W Tropical Depression

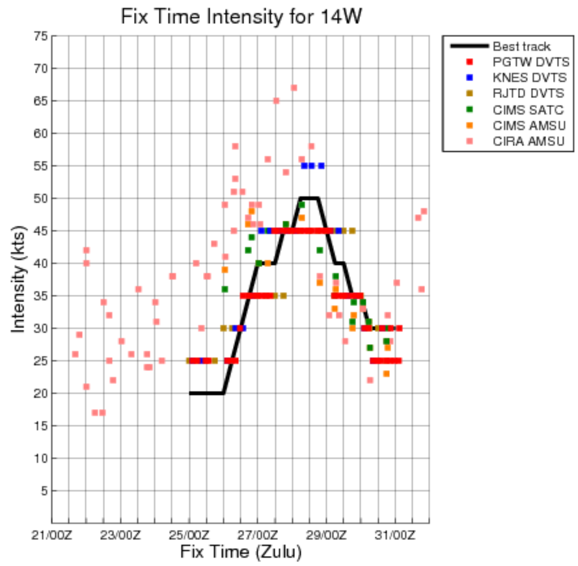
ISSUED LOW: 16 Aug / 0200Z
ISSUED MED: 16 Aug / 1330Z
FIRST TCFA: 16 Aug / 2030Z
FIRST WARNING: 17 Aug / 0000Z
LAST WARNING: 17 Aug / 1800Z
MAX INTENSITY: 30
WARNINGS: 4

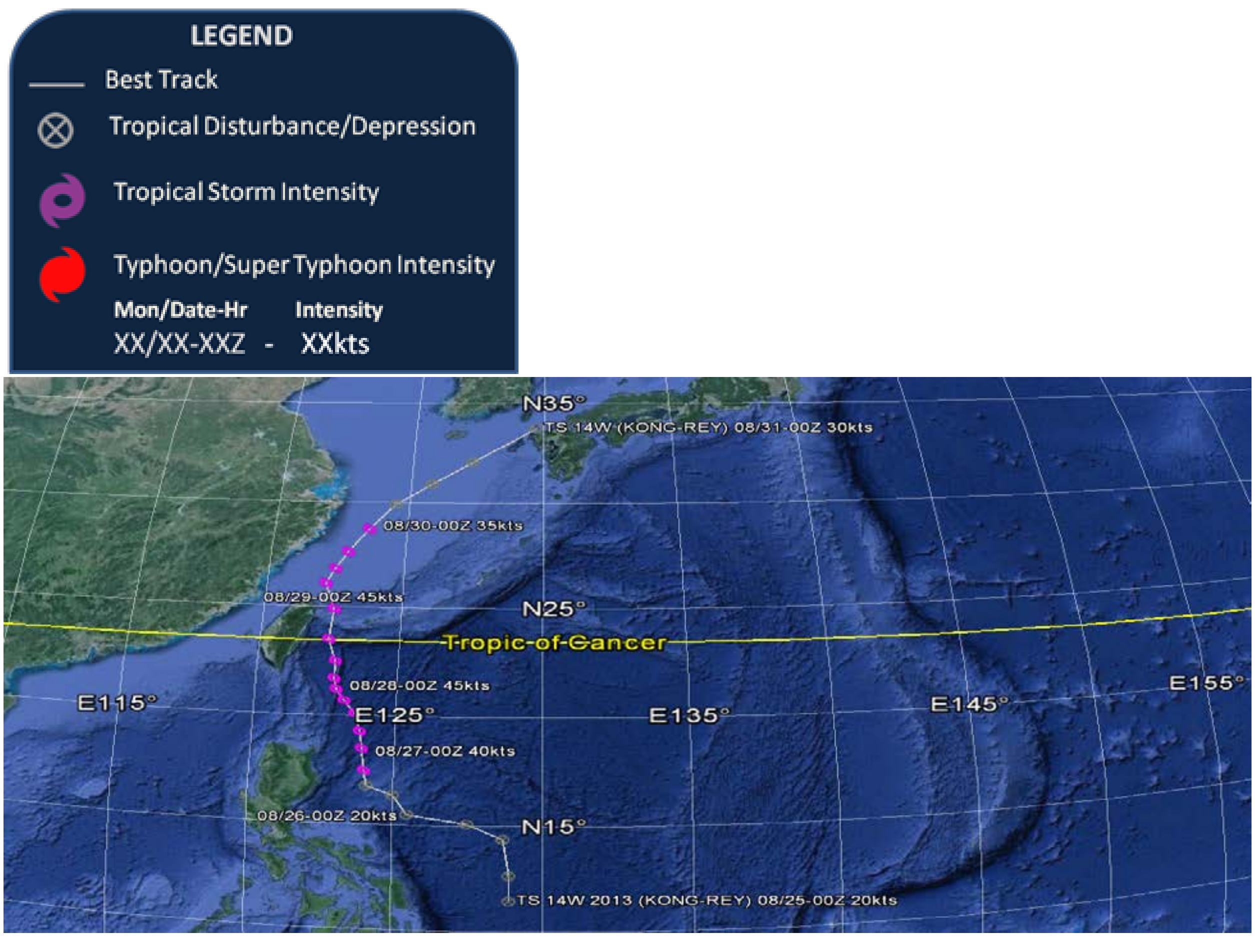




14W Tropical Storm Kong-Rey

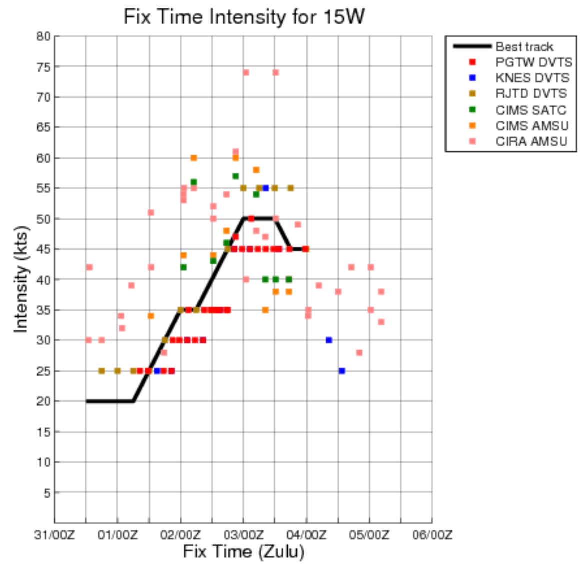
ISSUED LOW:	23 Aug / 0600Z
ISSUED MED:	24 Aug / 1500Z
FIRST TCFA:	25 Aug / 0130Z
FIRST WARNING:	26 Aug / 0000Z
LAST WARNING:	31 Aug / 0000Z
MAX INTENSITY:	50
WARNINGS:	21

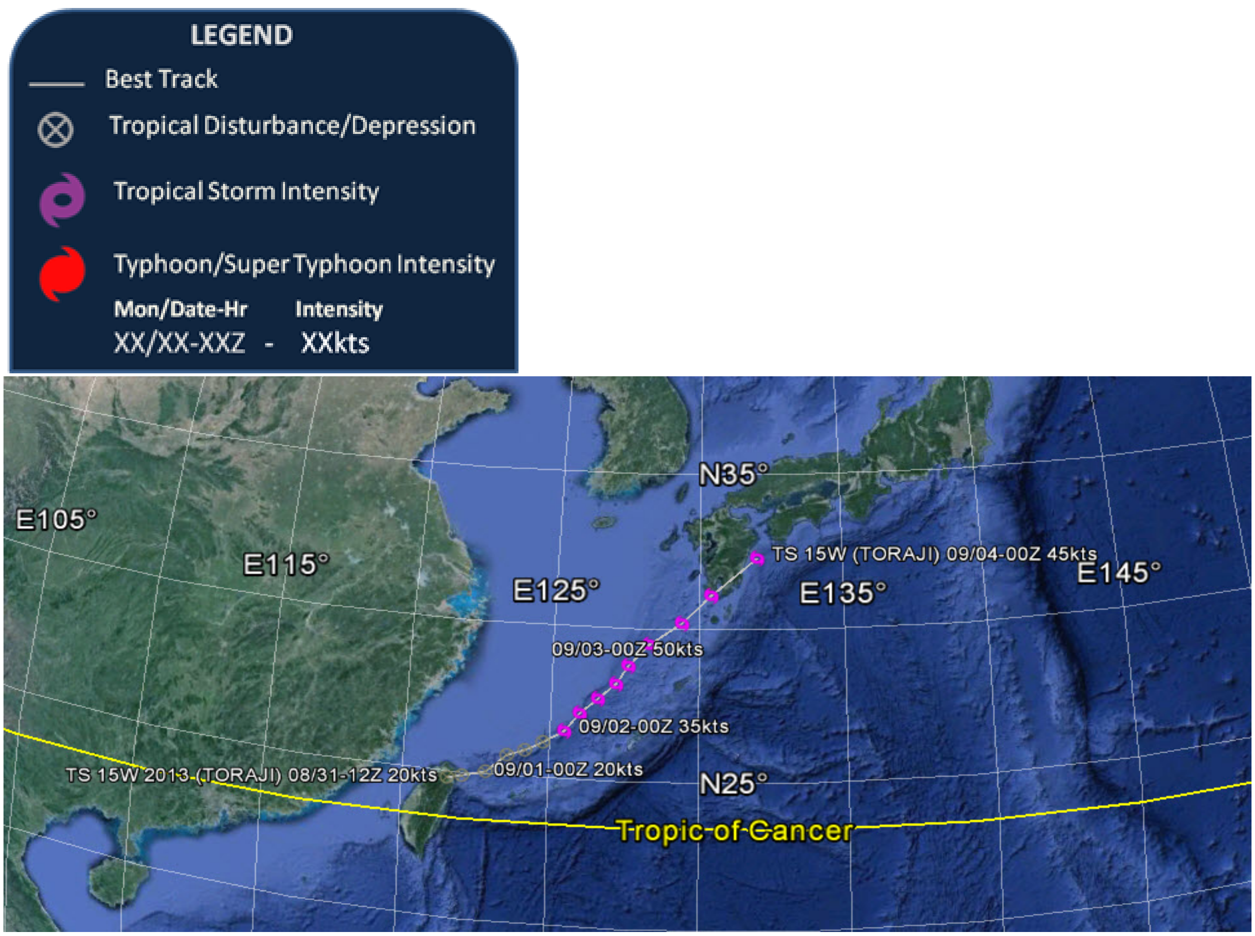




15W Tropical Storm Toraji

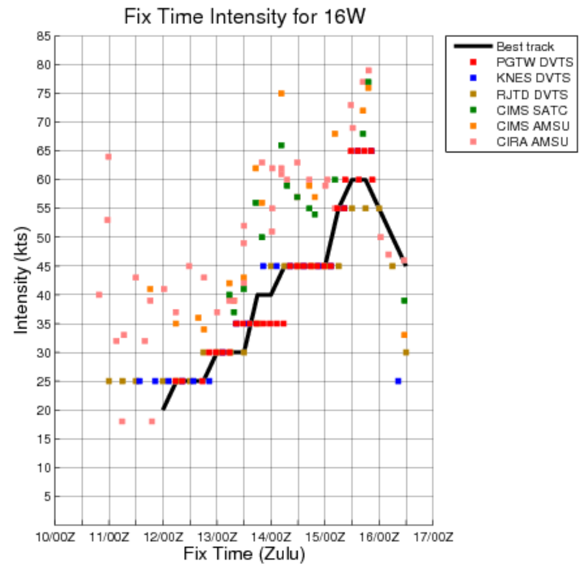
ISSUED LOW:	31 Aug / 2100Z
ISSUED MED:	01 Sep / 0600Z
FIRST TCFA:	01 Sep / 0930Z
FIRST WARNING:	01 Sep /1200Z
LAST WARNING:	04 Sep / 0000Z
MAX INTENSITY:	50
WARNINGS:	11

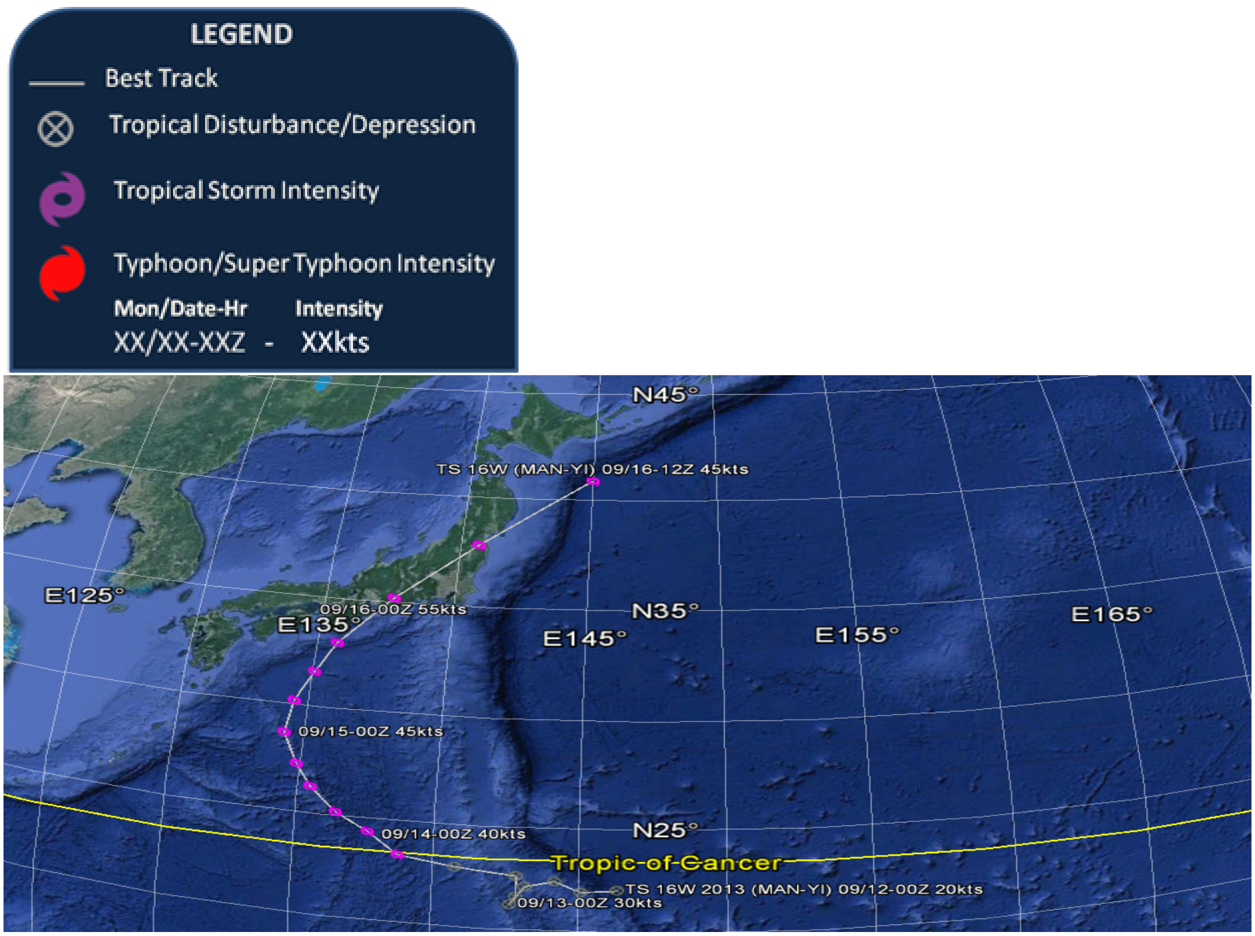




16W Tropical Storm Man-Yi

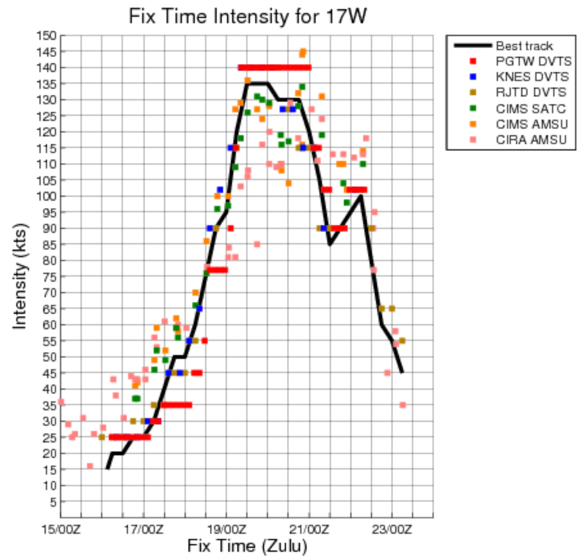
ISSUED LOW: N/A
ISSUED MED: 11 Sep / 0130Z
FIRST TCFA: 11 Sep / 1400Z
FIRST WARNING: 12 Sep / 1800Z
LAST WARNING: 16 Sep / 0600Z
MAX INTENSITY: 60
WARNINGS: 15

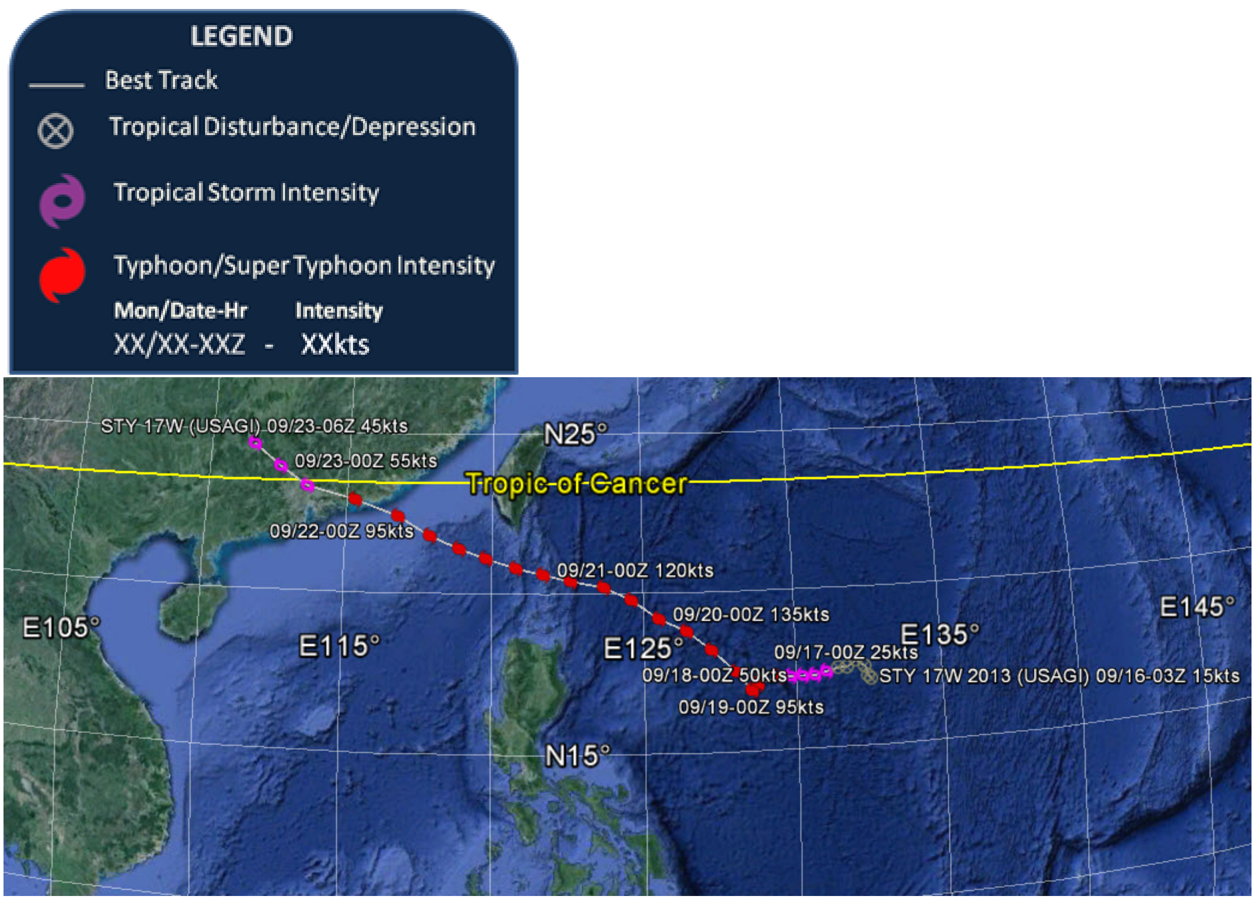




17W Super Typhoon Usagi

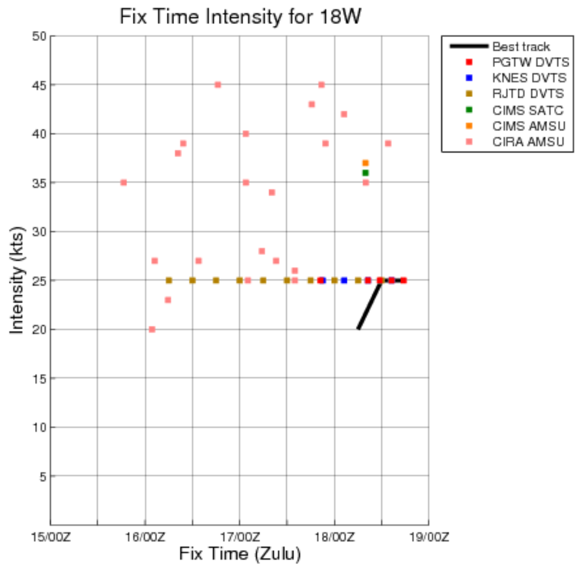
ISSUED LOW:	15 Sep / 2230Z
ISSUED MED:	N/A
FIRST TCFA:	16 Sep / 0430Z
FIRST WARNING:	16 Sep / 1800Z
LAST WARNING:	22 Sep / 1200Z
MAX INTENSITY:	135
WARNINGS:	24





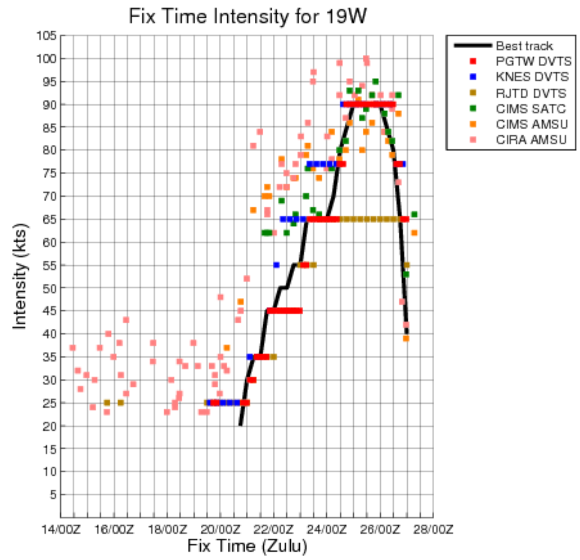
18W Tropical Depression

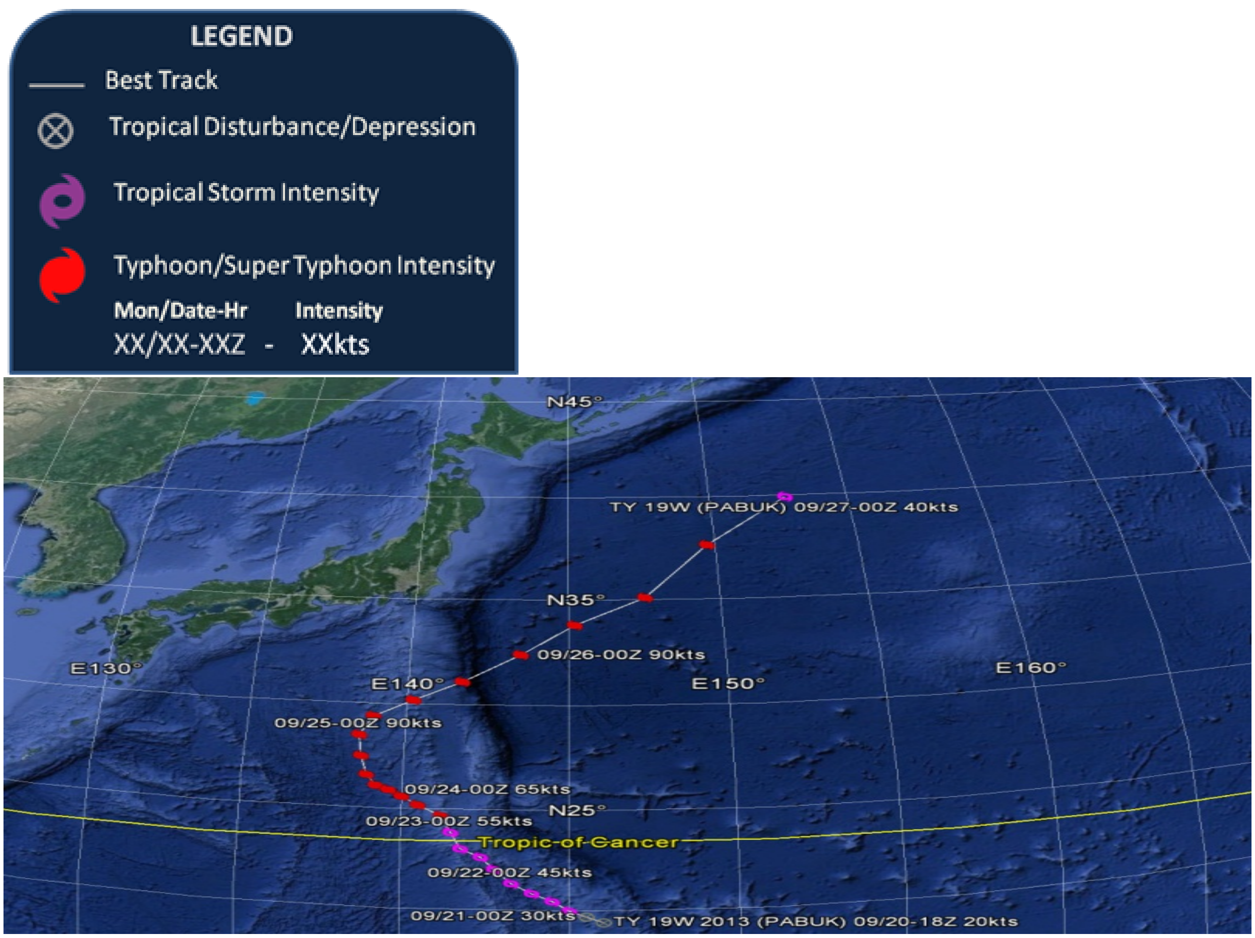
ISSUED LOW:	N/A
ISSUED MED:	16 Sep/0600z
FIRST TCFA:	17 Sep / 2030Z
FIRST WARNING:	18 Sep / 0600Z
LAST WARNING:	18 Sep / 1800Z
MAX INTENSITY:	25
WARNINGS:	3



19W Typhoon Pabuk

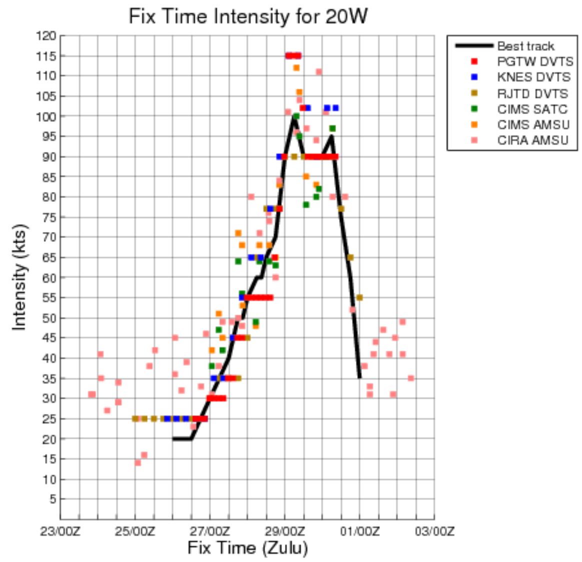
ISSUED LOW:	18 Sep / 1000Z
ISSUED MED:	18 Sep / 2130Z
FIRST TCFA:	19 Sep / 1700Z
FIRST WARNING:	21 Sep / 0000Z
LAST WARNING:	26 Sep / 0600Z
MAX INTENSITY:	90
WARNINGS:	22

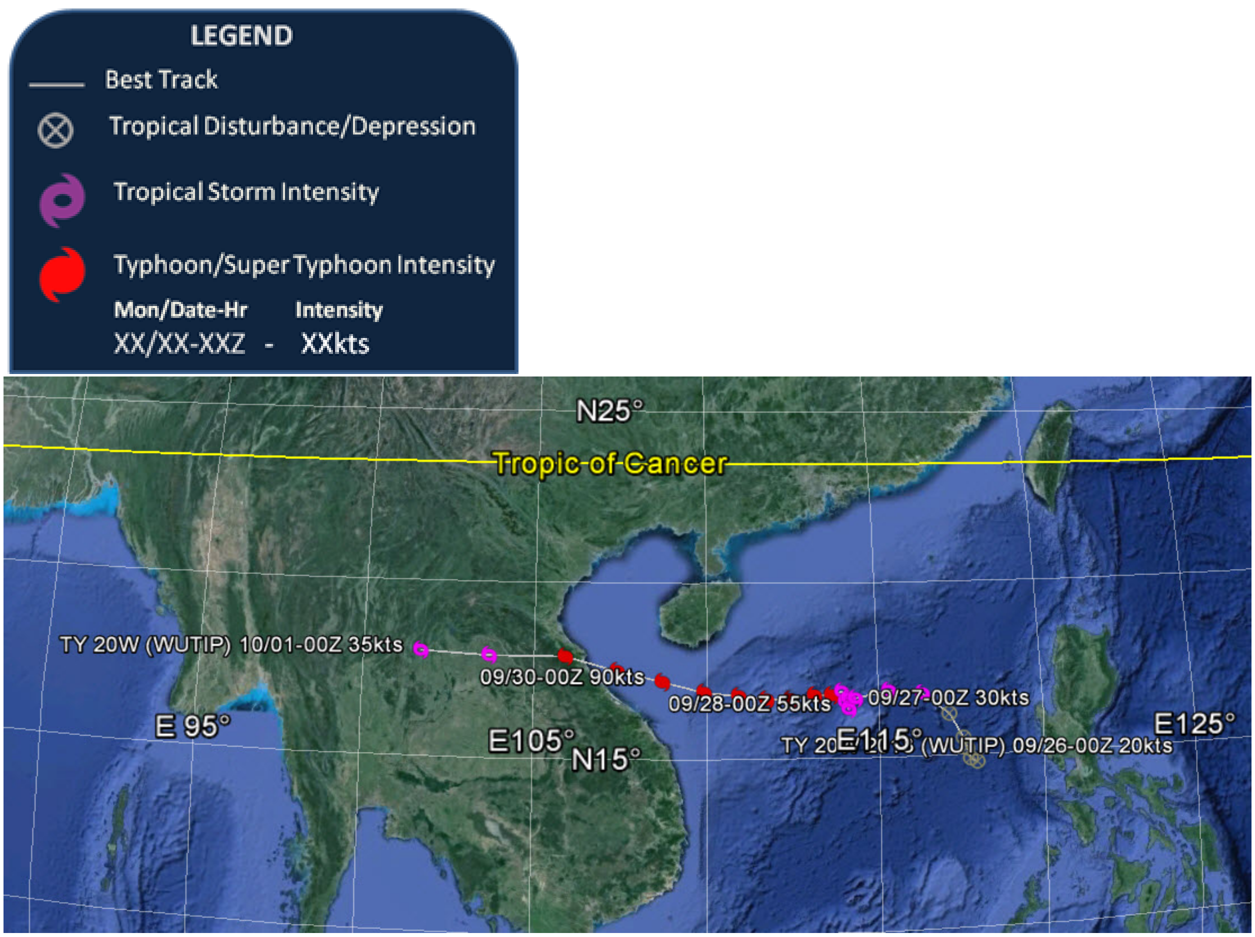




20W Typhoon Wutip

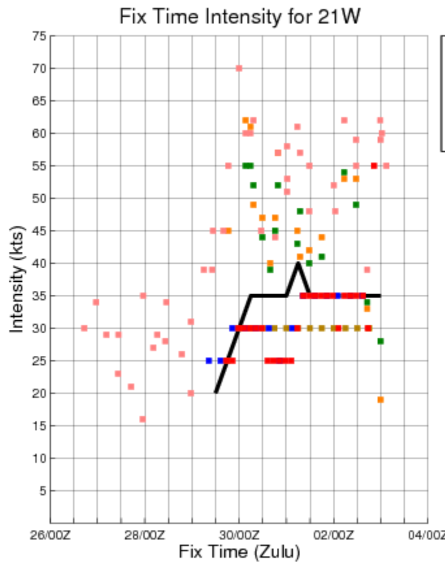
ISSUED LOW:	25 Sep / 0600Z
ISSUED MED:	25 Sep / 2100Z
FIRST TCFA:	26 Sep / 0800Z
FIRST WARNING:	26 Sep / 1800Z
LAST WARNING:	30 Sep / 1200Z
MAX INTENSITY:	100
WARNINGS:	16

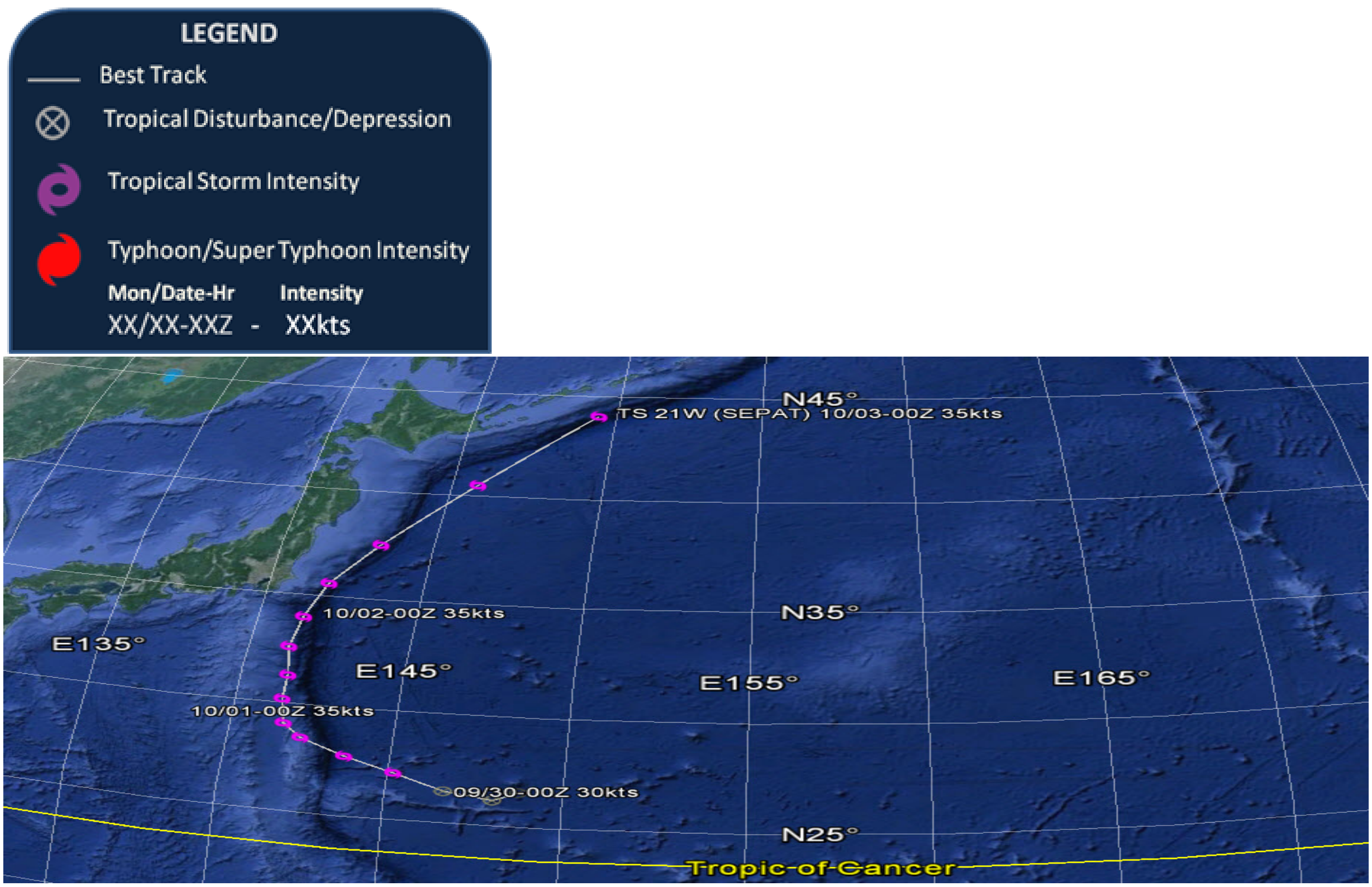




21W Tropical Storm Sepat

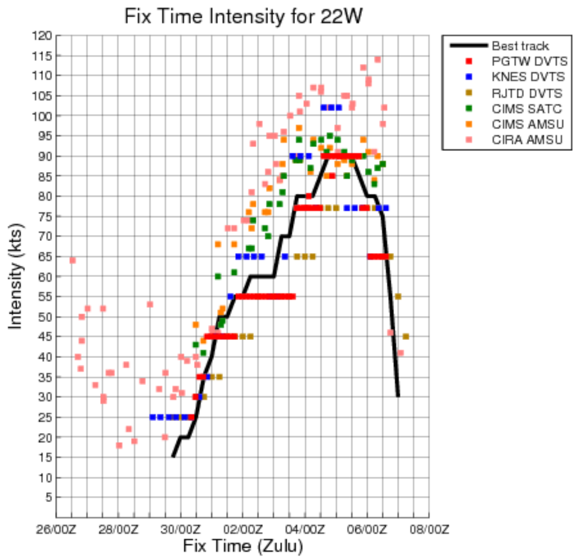
ISSUED LOW: 28 Sep / 0600Z
ISSUED MED: N/A
FIRST TCFA: 29 Sep / 1730Z
FIRST WARNING: 30 Sep / 0000Z
LAST WARNING: 02 Oct / 0000Z
MAX INTENSITY: 40
WARNINGS: 9

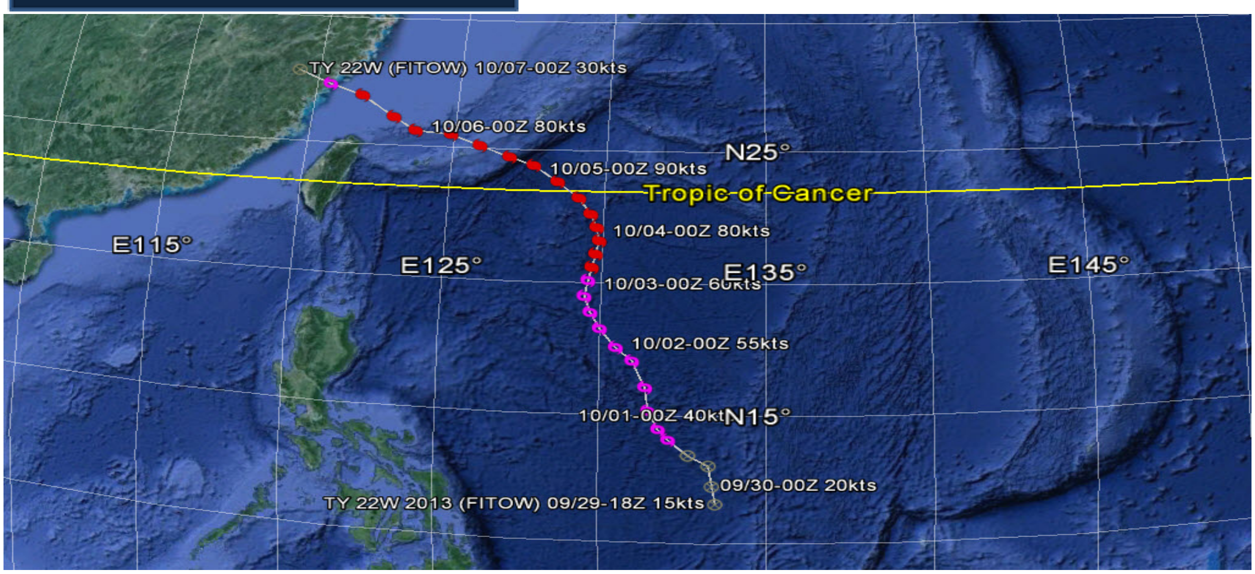




22W Typhoon Fitow

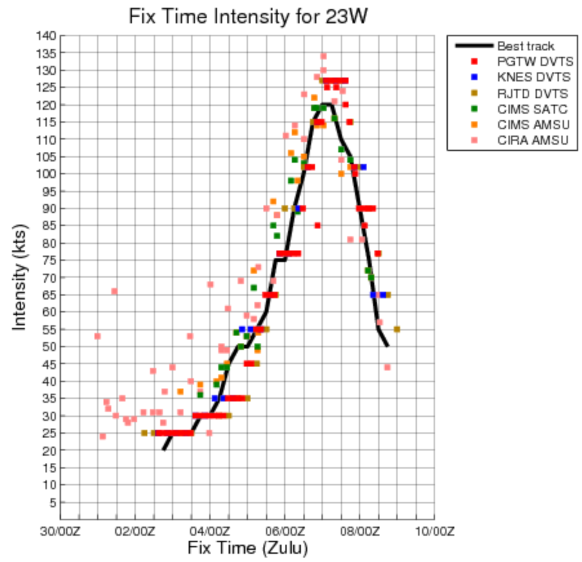
ISSUED LOW:	26 Sep / 2200Z
ISSUED MED:	27 Sep / 0600Z
FIRST TCFA:	28 Sep / 2330Z
FIRST WARNING:	30 Sep / 0600Z
LAST WARNING:	06 Oct / 1800Z
MAX INTENSITY:	90
WARNINGS:	27

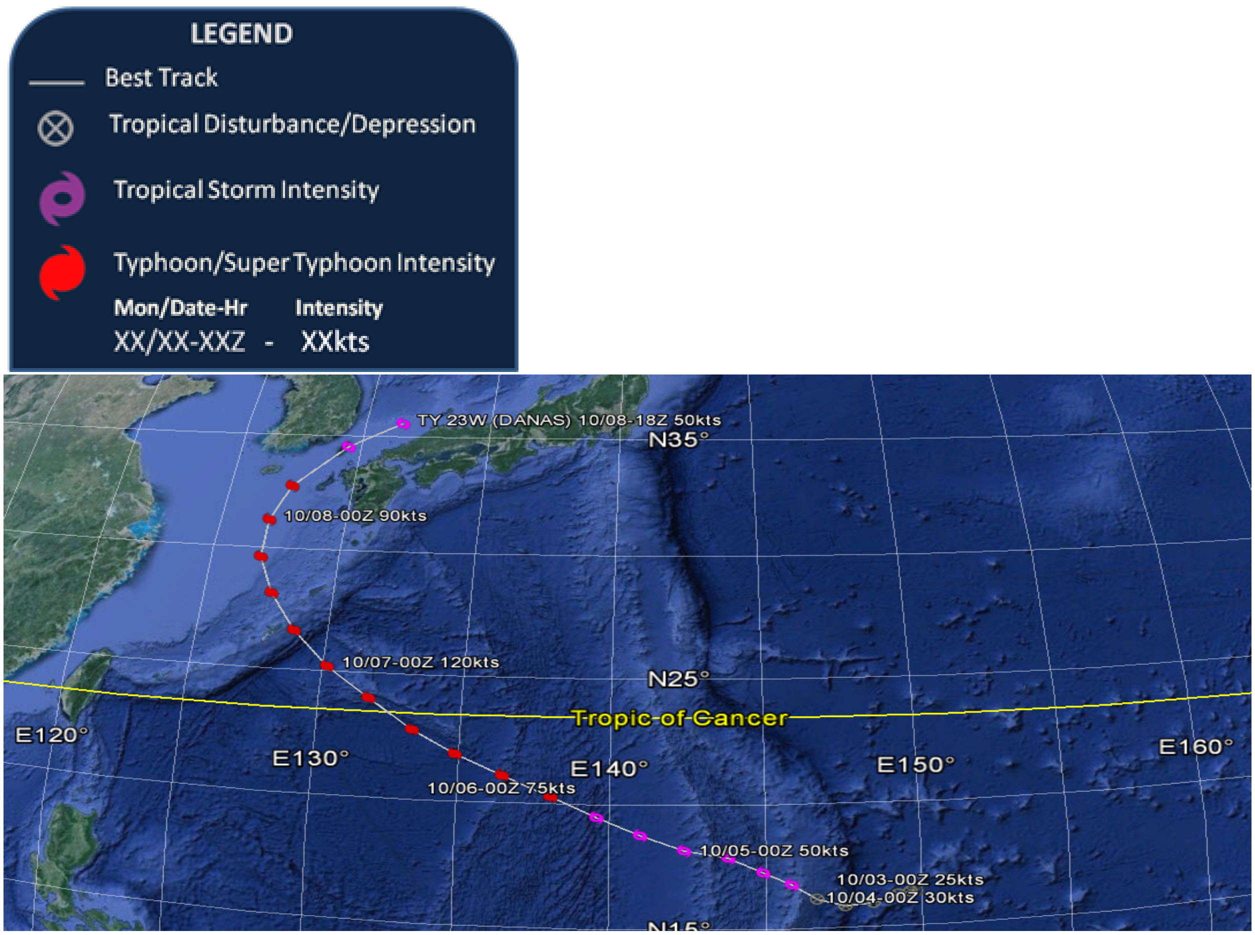




23W Typhoon Danas

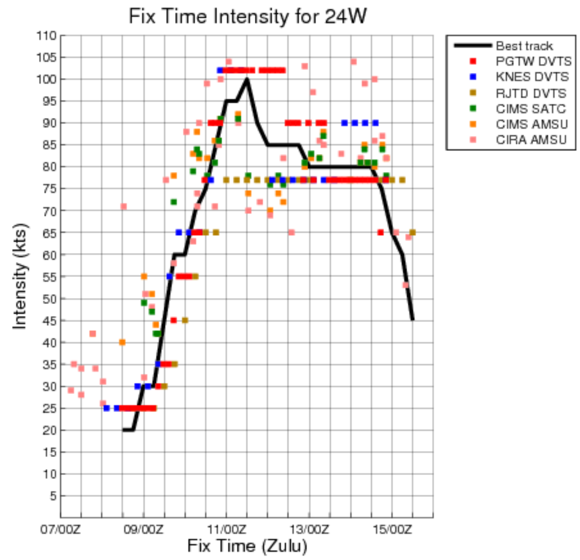
ISSUED LOW:	01 Oct/0600Z
ISSUED MED:	02 Oct/0600z
FIRST TCFA:	02 Oct / 2330Z
FIRST WARNING:	03 Oct /1200Z
LAST WARNING:	08 Oct /1200Z
MAX INTENSITY:	120
WARNINGS:	21

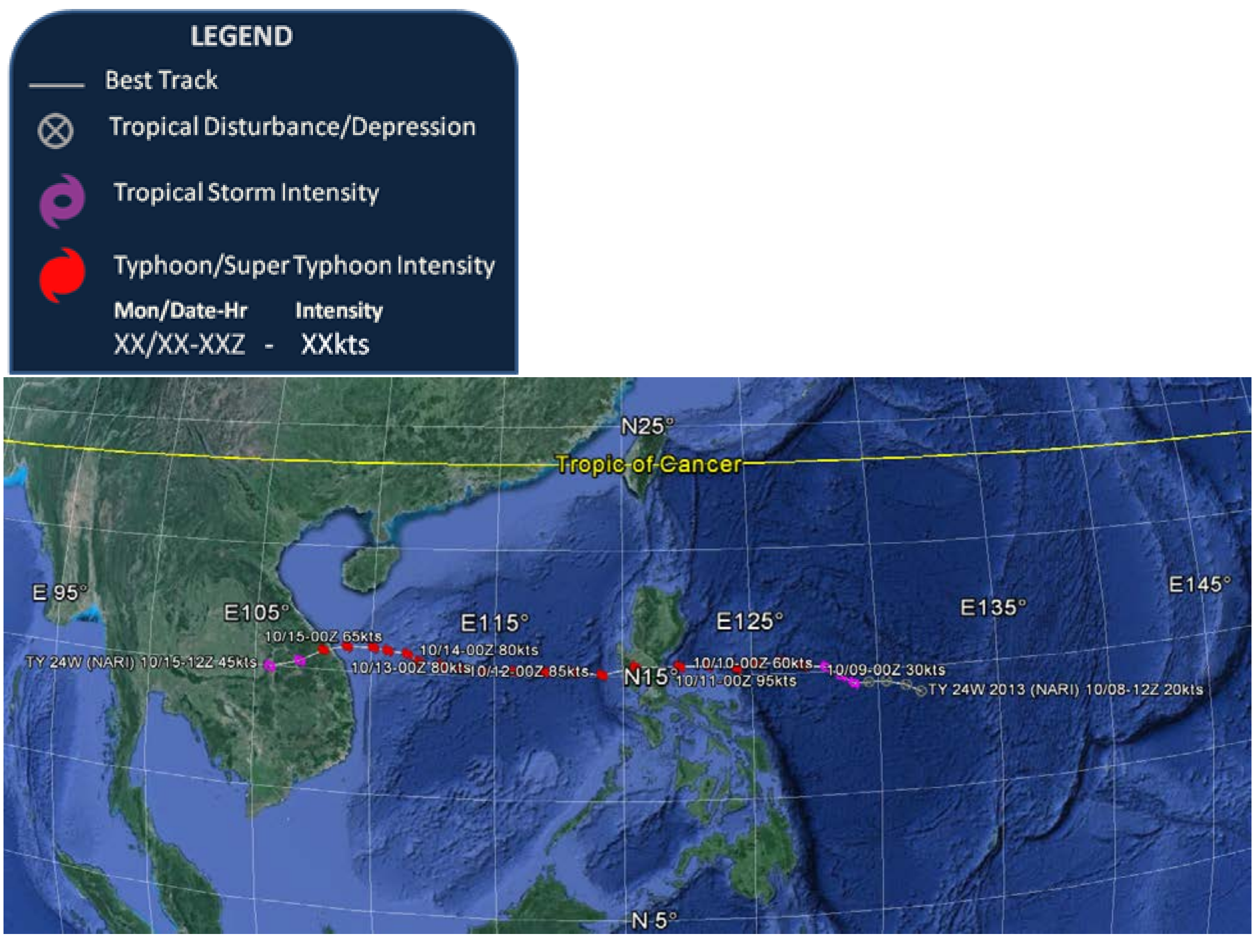




24W Typhoon Nari

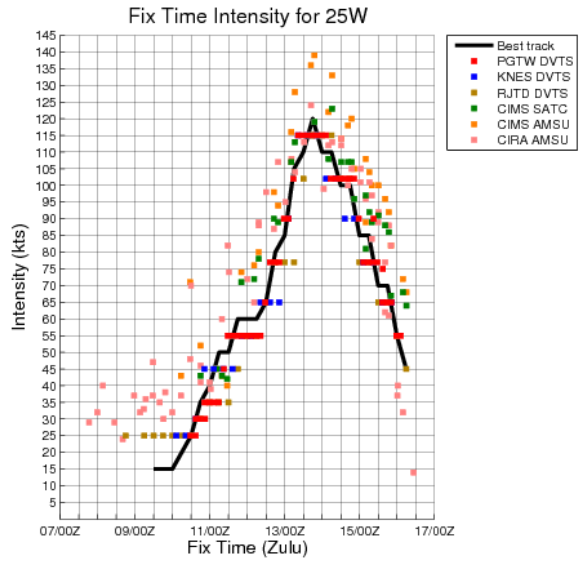
ISSUED LOW: 08 Oct / 0000Z
ISSUED MED: 08 Oct / 0600Z
FIRST TCFA: 08 Oct / 0800Z
FIRST WARNING: 08 Oct / 1800Z
LAST WARNING: 15 Oct / 0000Z
MAX INTENSITY: 100
WARNINGS: 26

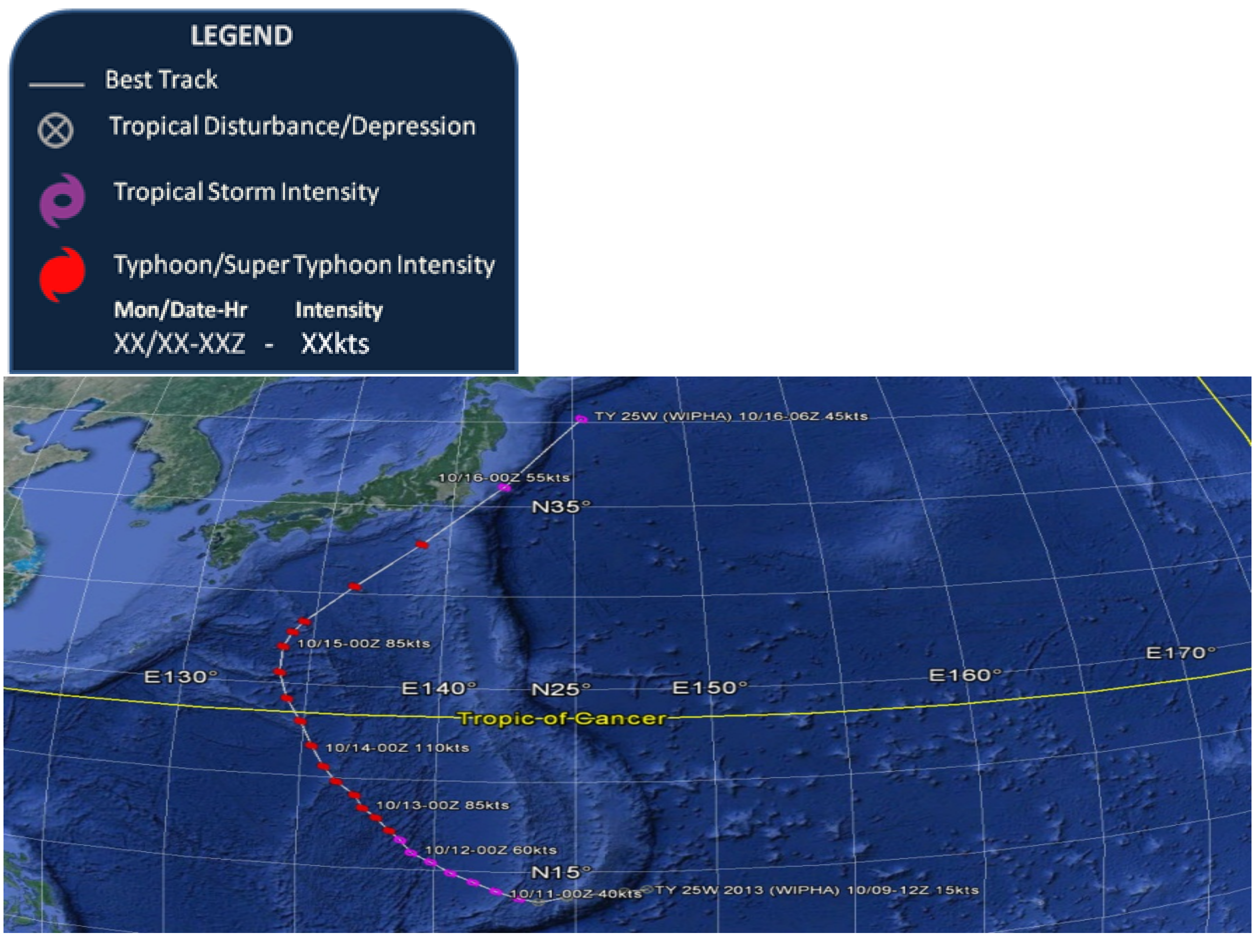




25W Typhoon Wipha

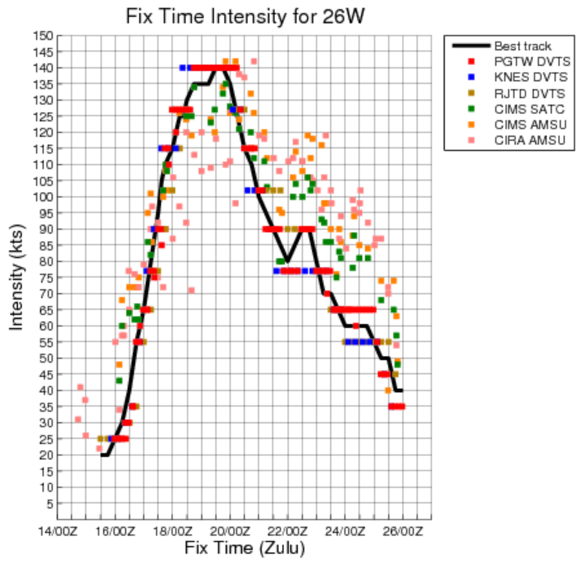
ISSUED LOW:	08 Oct / 0000Z
ISSUED MED:	08 Oct / 2300Z
FIRST TCFA:	09 Oct / 1000Z
FIRST WARNING:	10 Oct / 1200Z
LAST WARNING:	15 Oct / 1800Z
MAX INTENSITY:	120
WARNINGS:	22

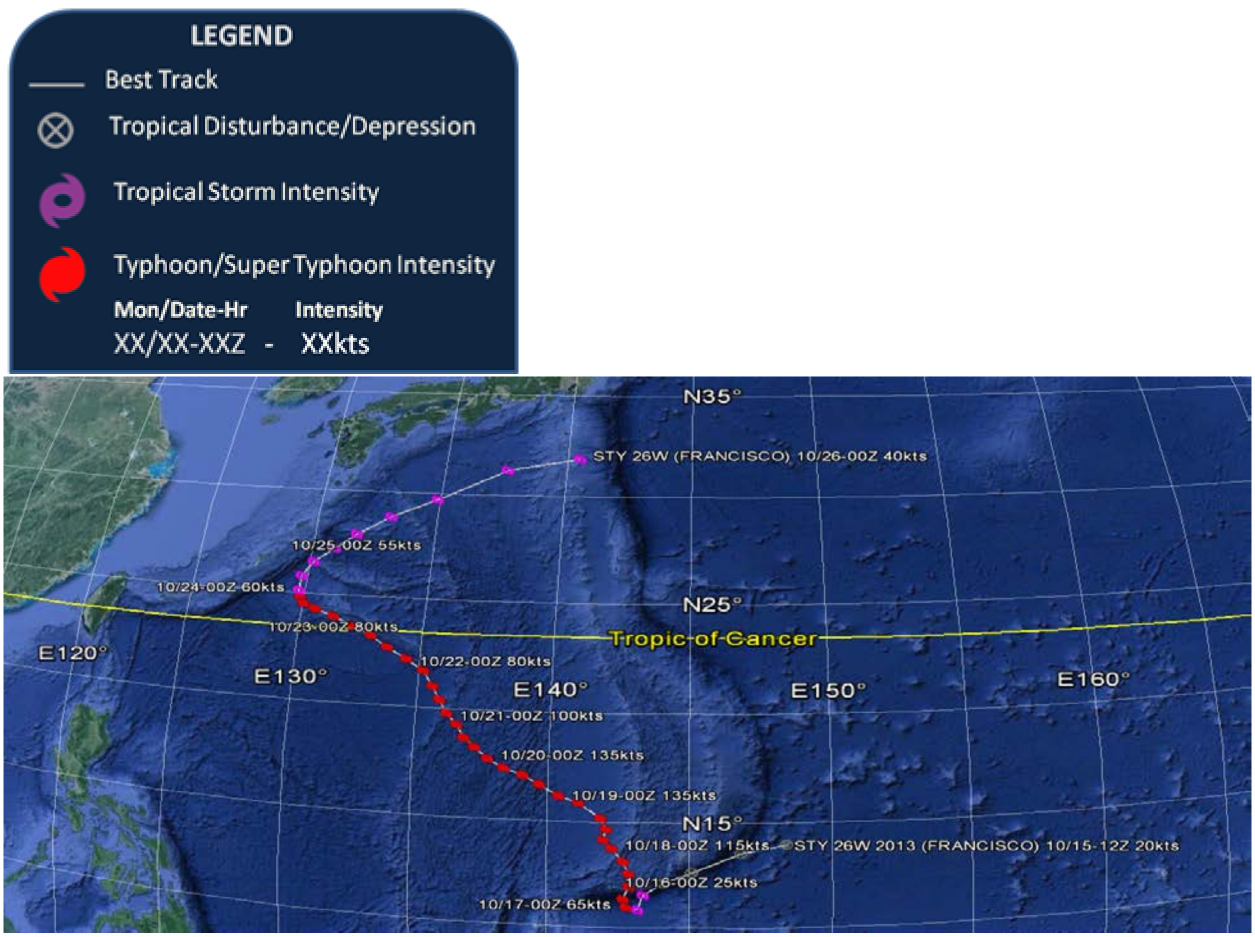




26W Super Typhoon Francisco

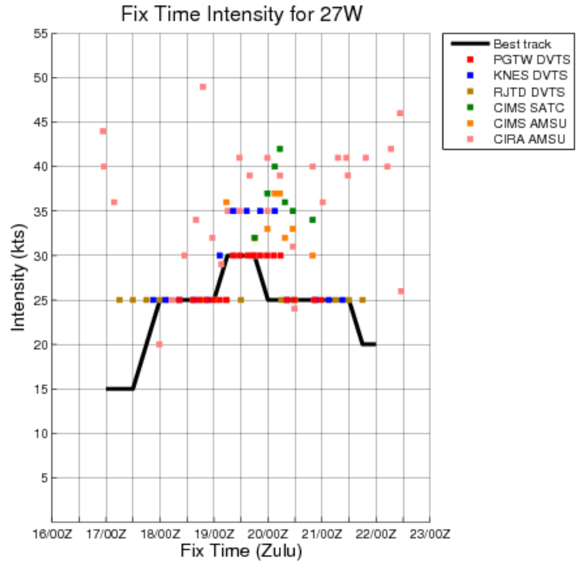
ISSUED LOW: N/A
ISSUED MED: 15 Oct / 0300Z
FIRST TCFA: 15 Oct / 2100Z
FIRST WARNING: 16 Oct / 0000Z
LAST WARNING: 25 Oct / 1800Z
MAX INTENSITY: 140
WARNINGS: 40

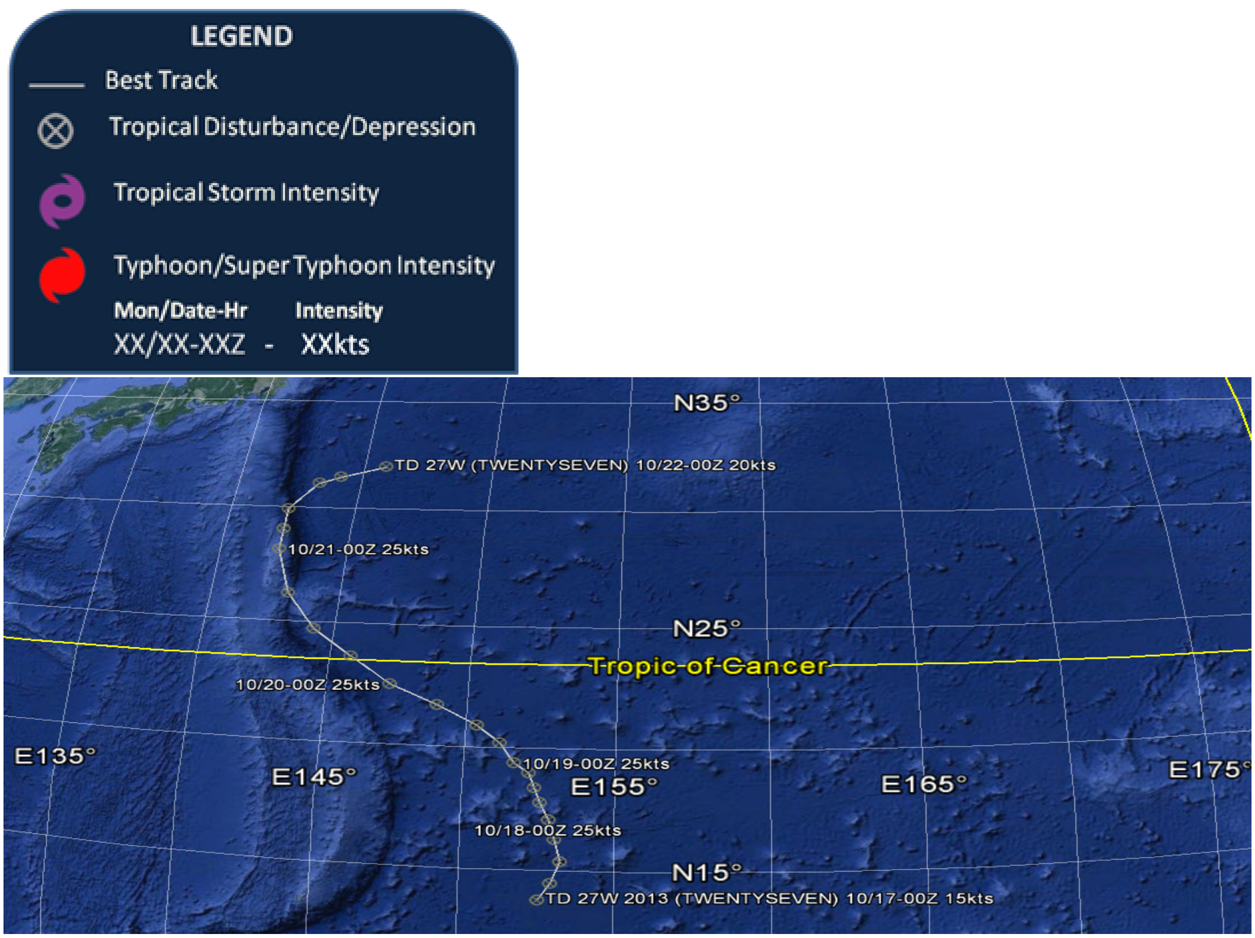




27W Tropical Depression

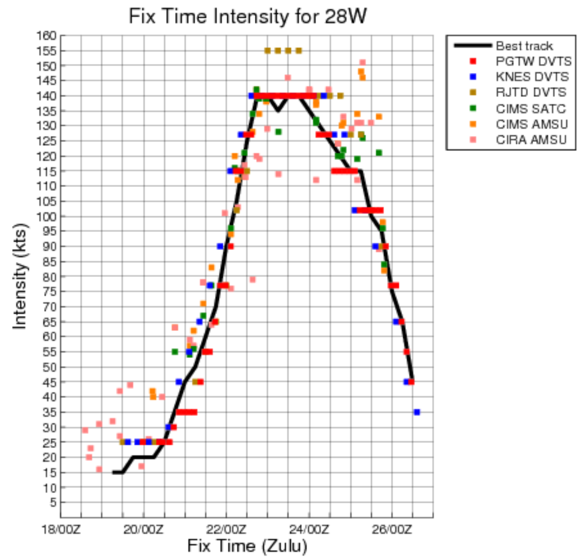
ISSUED LOW:	N/A
ISSUED MED:	18 Oct / 1900Z
FIRST TCFA:	N/A
FIRST WARNING:	19 Oct / 0600Z
LAST WARNING:	20 Oct / 0600Z
MAX INTENSITY:	30
WARNINGS:	5

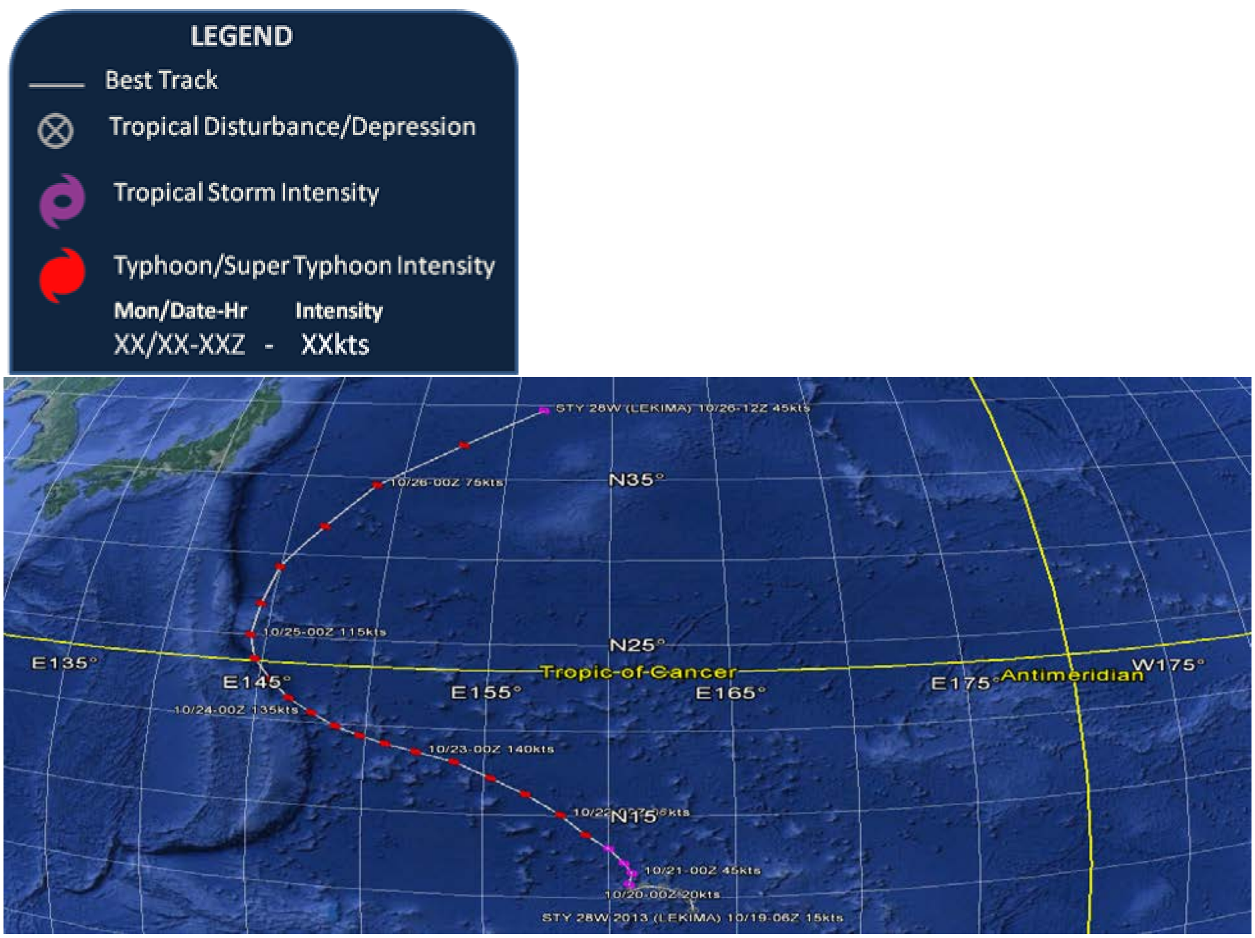




28W Super Typhoon Lekima

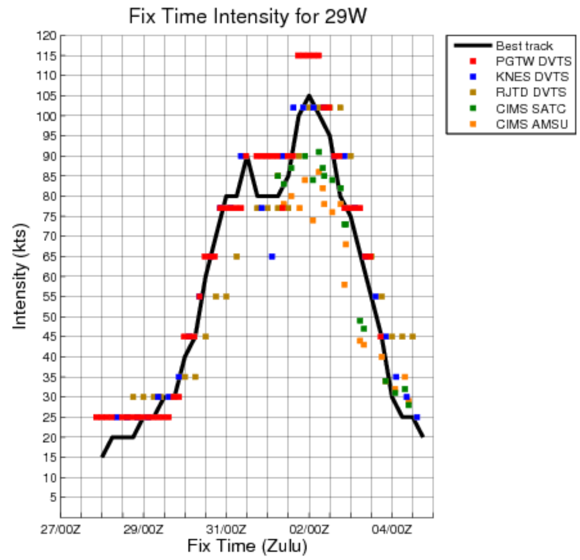
ISSUED LOW:	18 Oct/2100Z
ISSUED MED:	N/A
FIRST TCFA:	19 Oct / 2200Z
FIRST WARNING:	20 Oct /1200Z
LAST WARNING:	26 Oct / 0600Z
MAX INTENSITY:	140
WARNINGS:	24

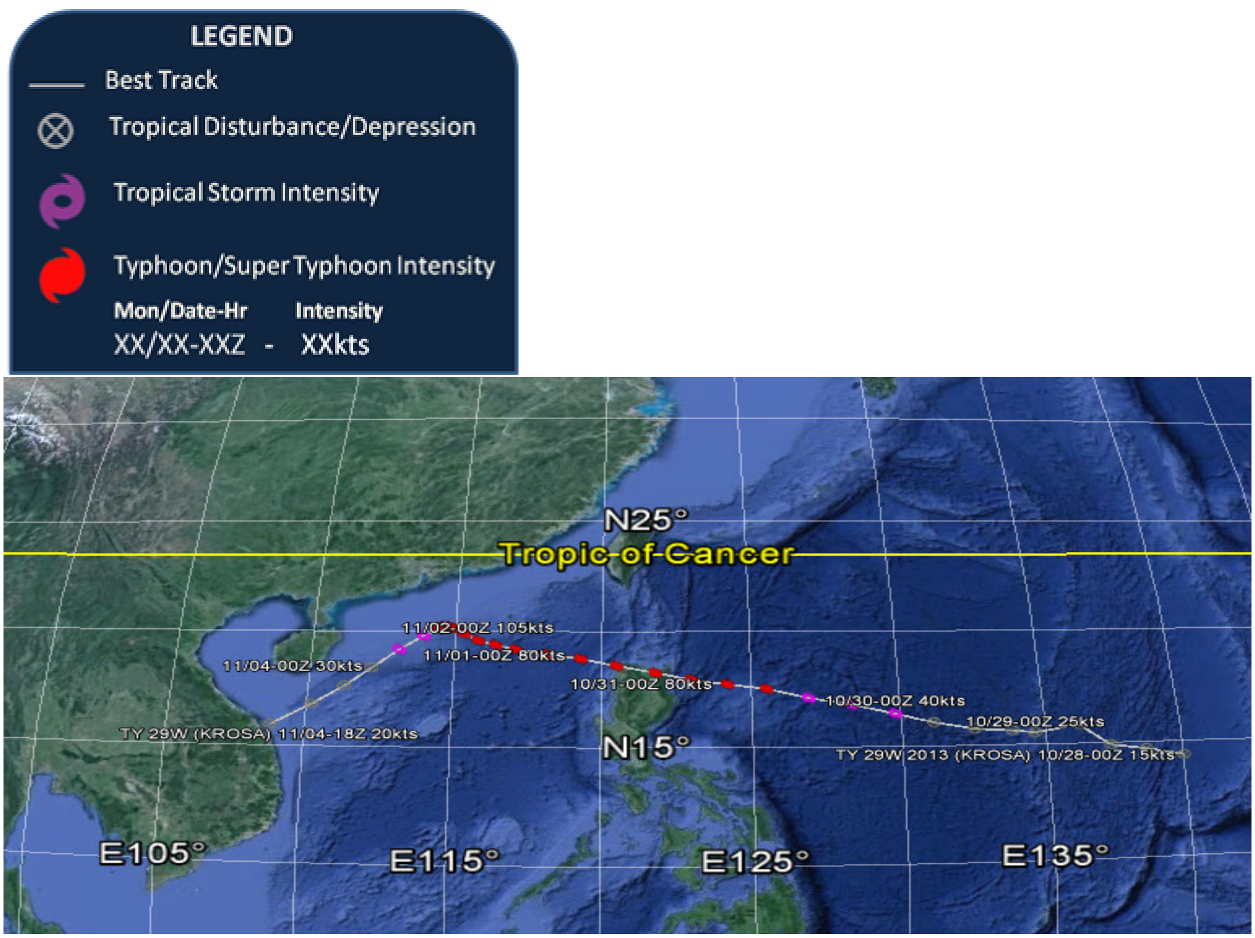




29W Typhoon Krosa

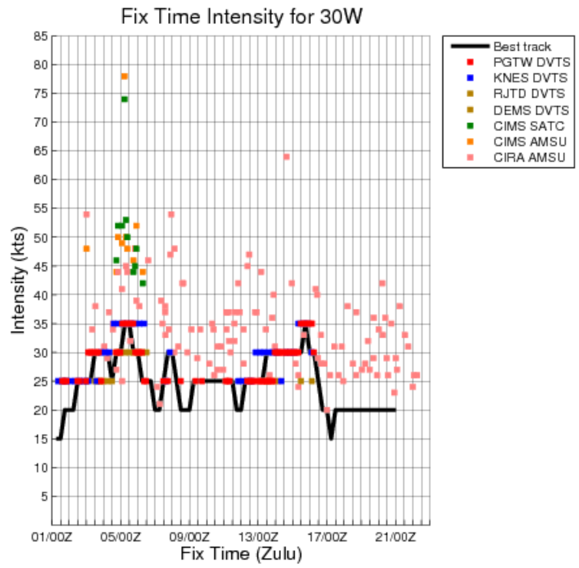
ISSUED LOW:	27 Oct / 1100Z
ISSUED MED:	27 Oct / 1830Z
FIRST TCFA:	28 Oct / 1100Z
FIRST WARNING:	29 Oct / 0000Z
LAST WARNING:	04 Nov / 0000Z
MAX INTENSITY:	105
WARNINGS:	25

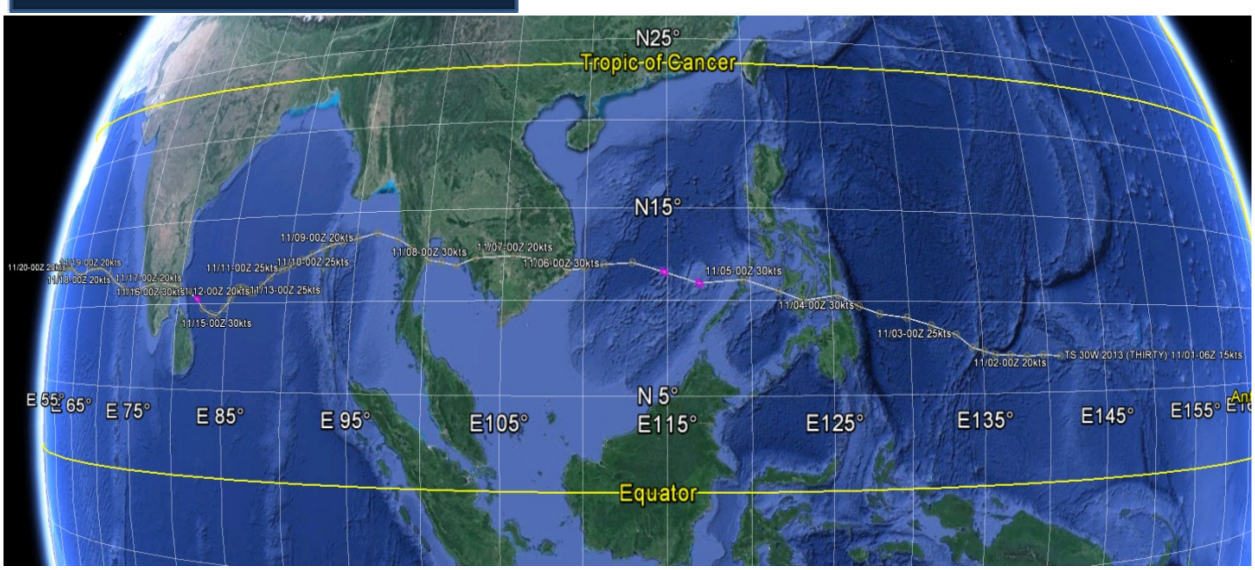




30W Tropical Storm

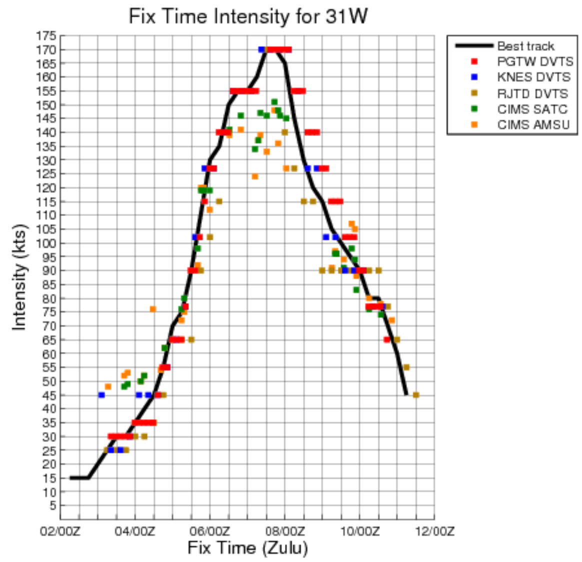
ISSUED LOW:	01 Nov / 0100Z
ISSUED MED:	03 Nov / 0230Z
FIRST TCFA:	03 Nov / 0530Z
FIRST WARNING:	03 Nov / 0600Z
LAST WARNING:	16 Nov / 0600Z
MAX INTENSITY:	35
WARNINGS:	17

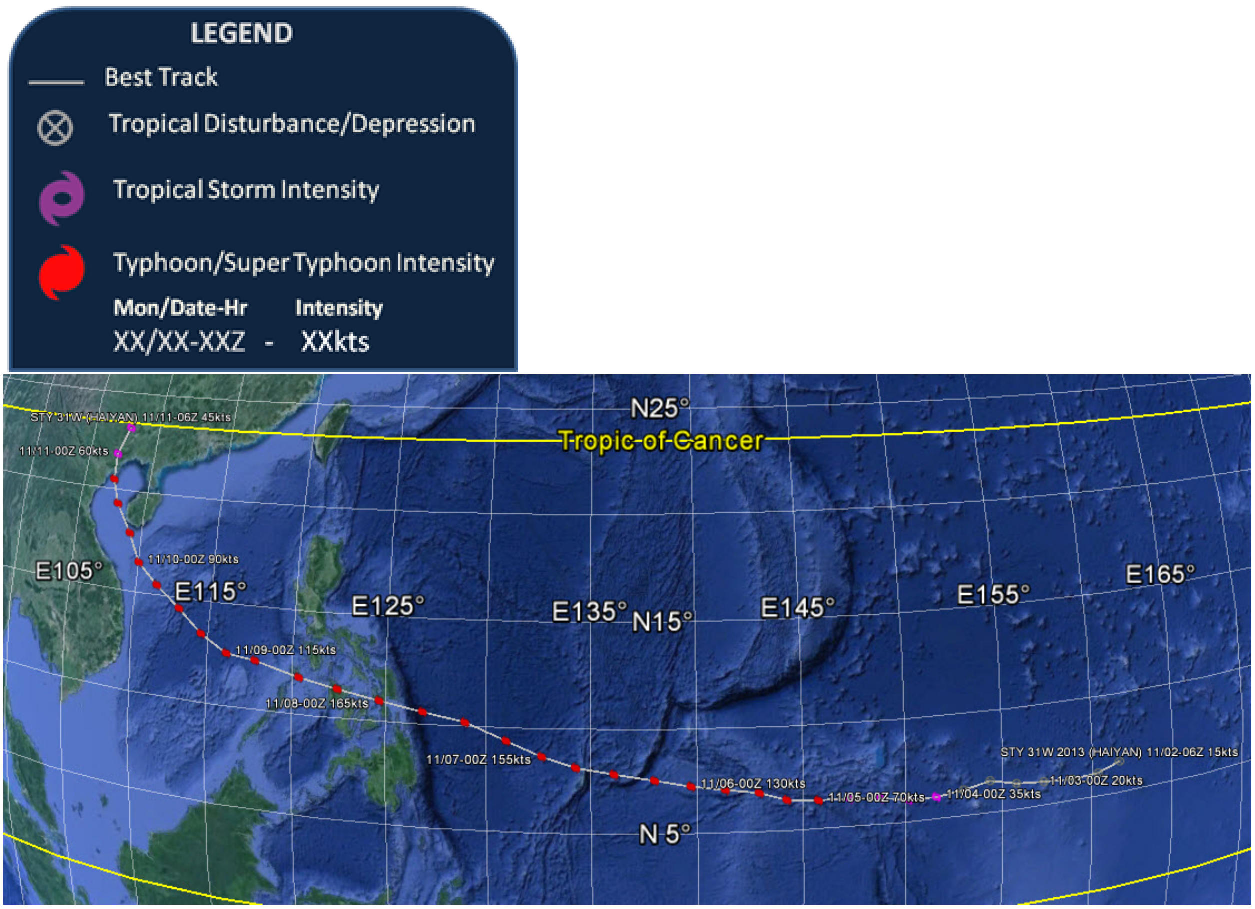




31W Super Typhoon Haiyan

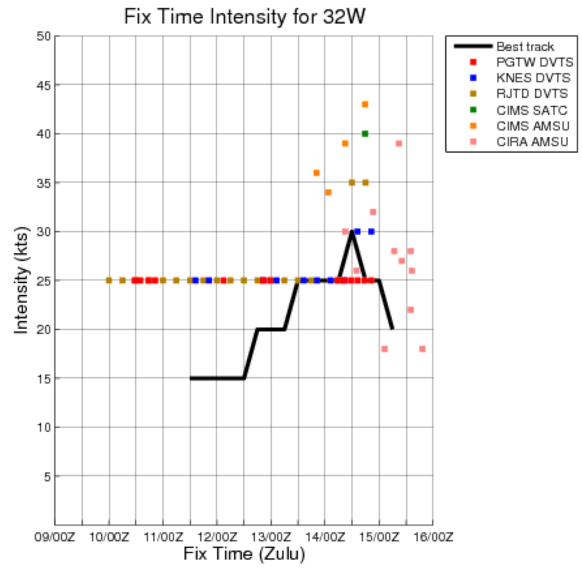
ISSUED LOW:	02 Nov / 0600Z
ISSUED MED:	03 Nov / 0230Z
FIRST TCFA:	03 Nov / 0530Z
FIRST WARNING:	03 Nov / 0600Z
LAST WARNING:	11 Nov / 0000Z
MAX INTENSITY:	170
WARNINGS:	32

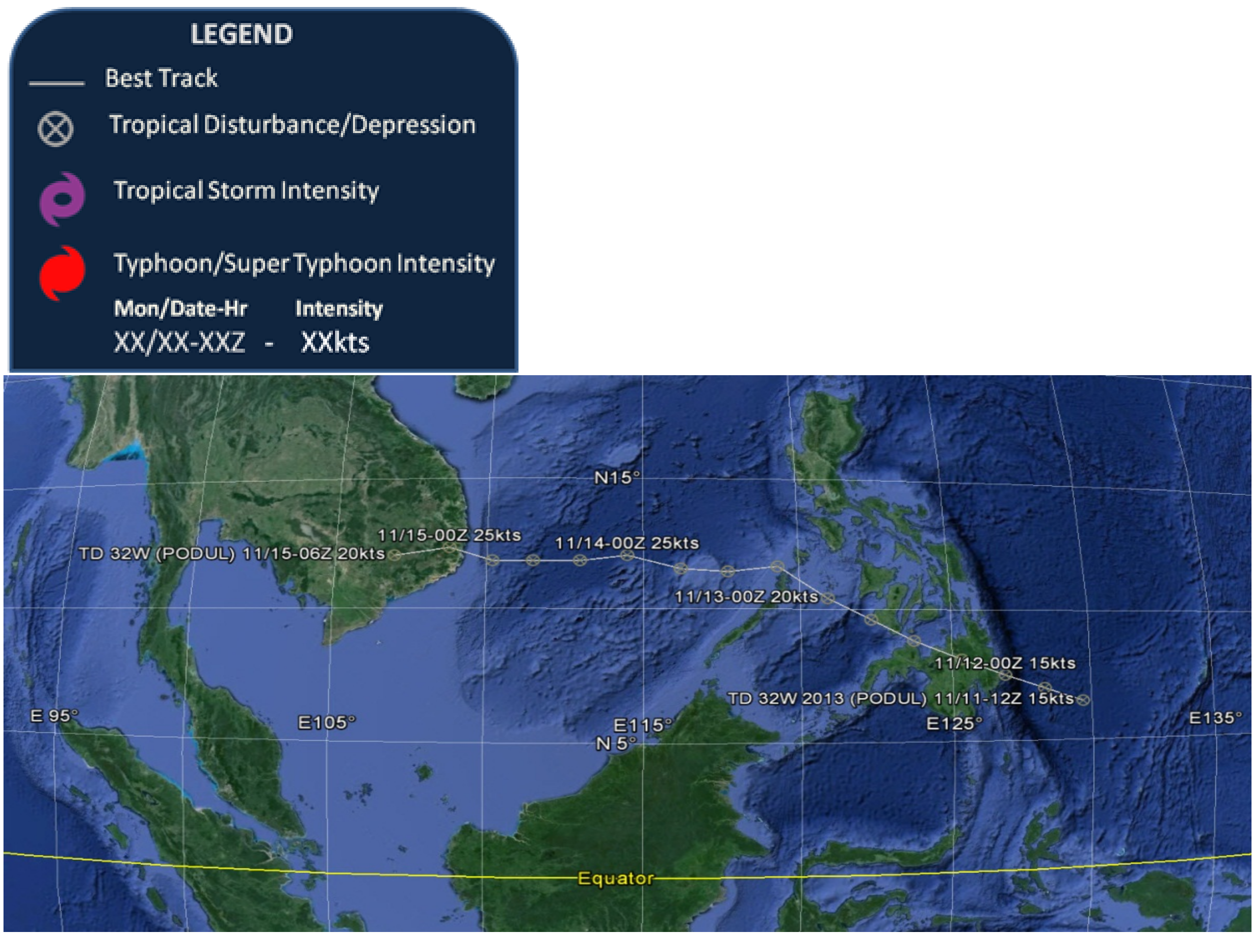




32W Tropical Depression Podul

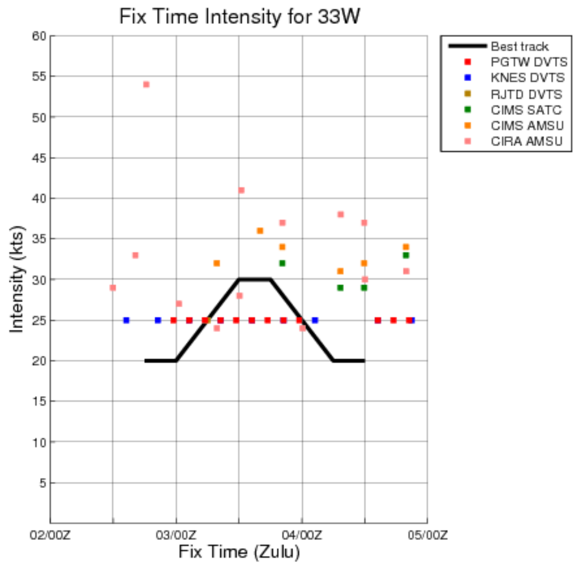
ISSUED LOW: 09 Nov / 0600Z
ISSUED MED: 10 Nov / 0130Z
FIRST TCFA: 14 Nov / 1200Z
FIRST WARNING: 14 Nov / 1200Z
LAST WARNING: 15 Nov / 0000Z
MAX INTENSITY: 30
WARNINGS: 3

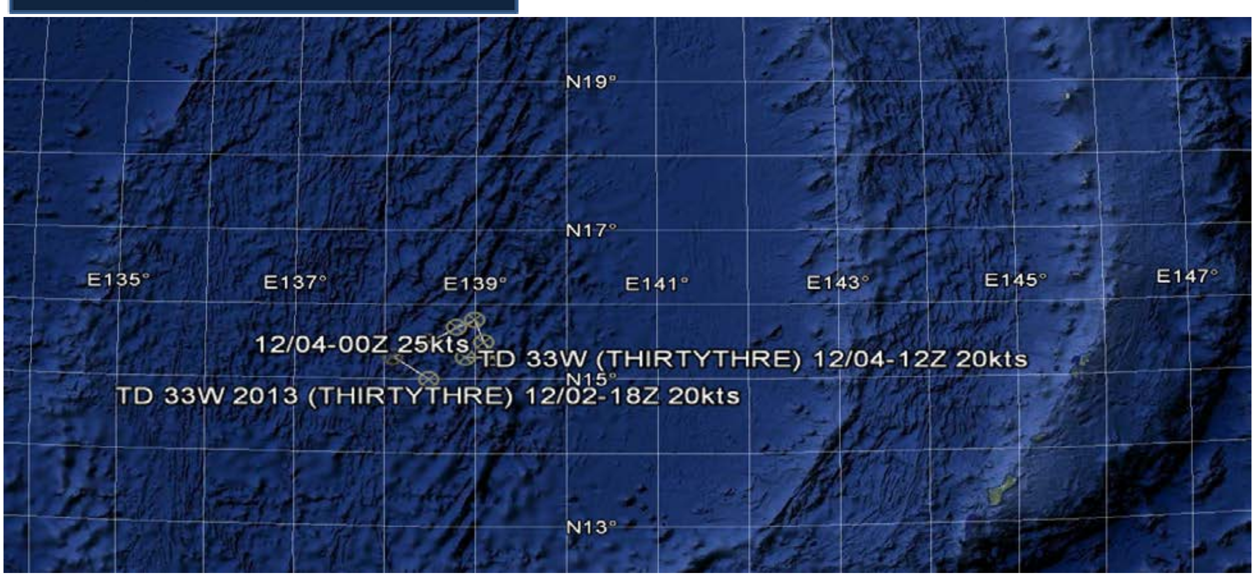




33W Tropical Depression

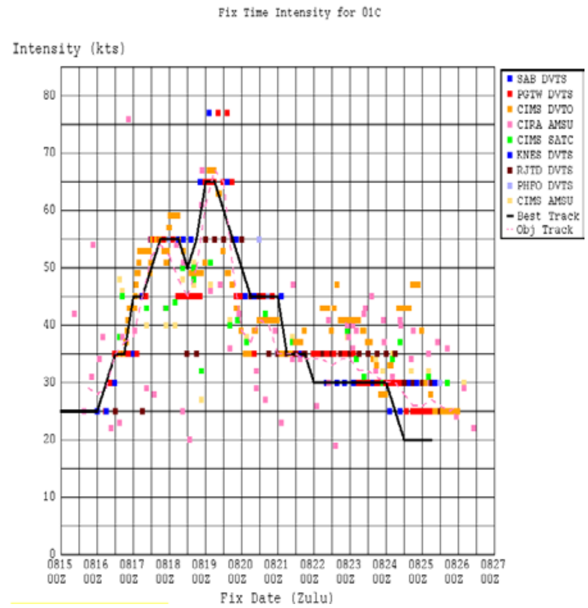
ISSUED LOW:	N/A
ISSUED MED:	03 Dec / 0000Z
FIRST TCFA:	N/A
FIRST WARNING:	03 Dec / 1200Z
LAST WARNING:	04 Dec / 0000Z
MAX INTENSITY:	30
WARNINGS:	3





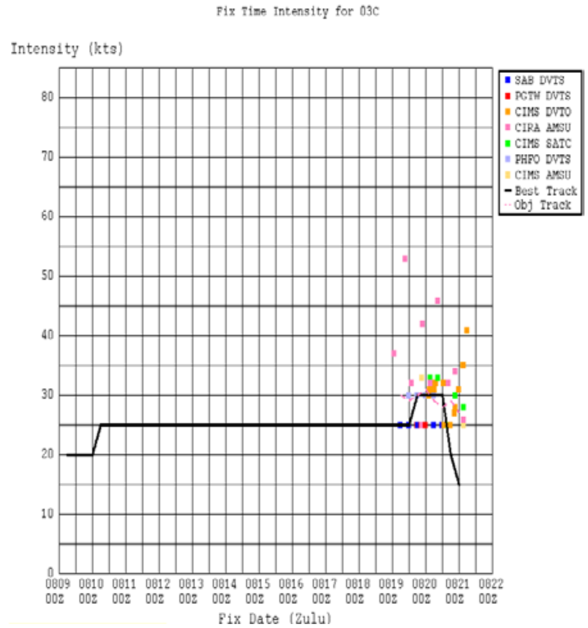
01C Hurricane Pewa

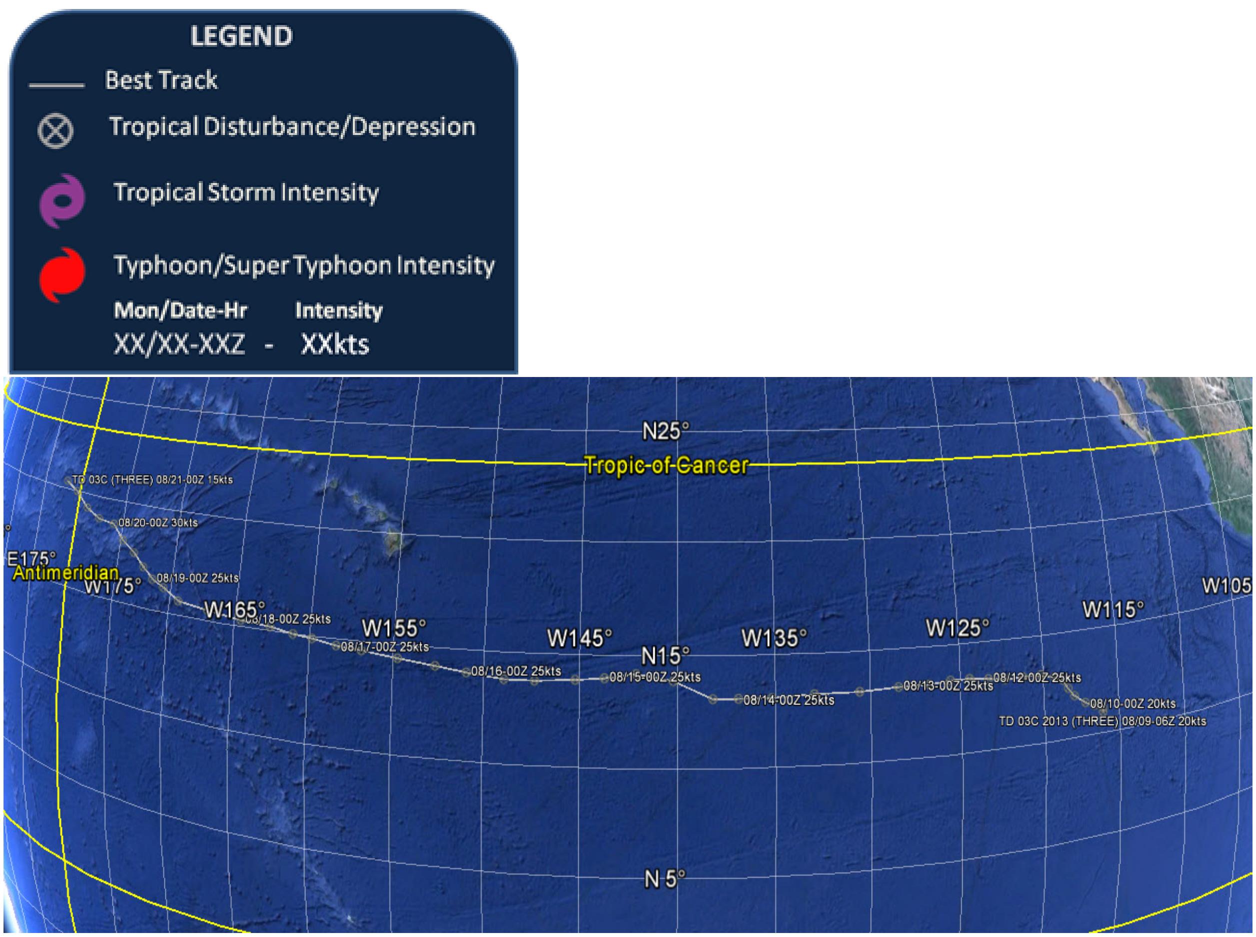
ISSUED LOW: N/A
ISSUED MED: N/A
FIRST TCFA: 15 Aug /2300Z
FIRST WARNING: 16 Aug /1200Z
LAST WARNING: 22 Aug / 0000Z
MAX INTENSITY: 65
WARNINGS: 23



03C Tropical Depression

ISSUED LOW:	N/A
ISSUED MED:	N/A
FIRST TCFA:	N/A
FIRST WARNING:	19 Aug / 1800Z
LAST WARNING:	20 Aug / 1800Z
MAX INTENSITY:	30
WARNINGS:	5





This section highlights operationally or meteorologically significant cyclones noted within the JTWC AOR. Details are provided to describe operational impacts from tropical cyclones as well as significant challenges and/or shortfalls in the TC warning system. These details are provided to serve as input for future research and development efforts.

Typhoon 22W (FITOW)

I. Overview

Typhoon (TY) 22W (FITOW) formed in the east Philippine Sea in late September 2013. The cyclone steadily intensified while tracking poleward toward the East China Sea under the steering influence of a subtropical ridge to the east. TY 22W presented major track forecasting challenges early in its lifecycle. A large degree of track forecast uncertainty arose as dynamic models struggled to accurately represent the passage of a fast-moving, deep mid-latitude shortwave trough to the northwest of the cyclone. Evolution of the mid-latitude flow pattern induced initial weakening of the subtropical steering ridge and a consequent poleward flow pattern between 09/30/06Z and 10/04/00Z. Later, as the aforementioned deep mid-latitude shortwave trough translated quickly northeastward, allowing a building subtropical ridge over the East China Sea and Japan to steer TY 22W west-northwestward.

TY 22W highlighted the following forecasting challenges:

- Properly attributing a large spread in model track forecasts to a track bifurcation scenario rather than simply to “high uncertainty” within a single forecast track scenario
- Accurately quantifying the probability that a tropical cyclone will follow a particular track in a bifurcation scenario
- Selecting the correct track forecast direction/speed in a bifurcation scenario
- Optimally communicating track forecast uncertainty to customers in bifurcation scenarios

The following sections of this case study address the preceding points by highlighting consensus track model forecast performance, available probabilistic guidance including single model ensemble forecasts, and methods applied to identify and communicate track forecast uncertainty for TY 22W. A discussion of procedures that may have improved forecasts and communication of forecast uncertainty in this case, applicable to analogous future cases, follows this analysis.

II. Consensus forecast model performance

The 2013 JTWC track consensus consisted of global and mesoscale deterministic forecast models and single-model ensemble mean track and intensity forecasts. Consensus model guidance early in the cyclone’s lifecycle failed to converge on either a continuous poleward track toward the base of the passing mid-latitude trough or on the west-northwestward track that was eventually observed. Consequently, this large spread in model solutions and abrupt shifts in individual model

guidance from run to run indicated a possible track forecast bifurcation. The JTWC multi-model consensus (CONW), a simple arithmetic average of member model track forecasts, "split" the two primary model clusters at several forecast times. As a result, CONW track forecasts were unrepresentative of the likely track of TY 22W. Several of the early JTWC forecasts favored the incorrect poleward track grouping. Since CONW split the two track guidance clusters and JTWC chose the poleward cluster, CONW average forecast track errors were lower relative to JTWC (Table 1). The UKMET (EGRI) and NAVGEM (NVGI) models, for which a greater proportion of forecasts correctly predicted a west-northwestward track forecast scenario, had the lowest average extended forecast track errors (FTE) for TY 22W.

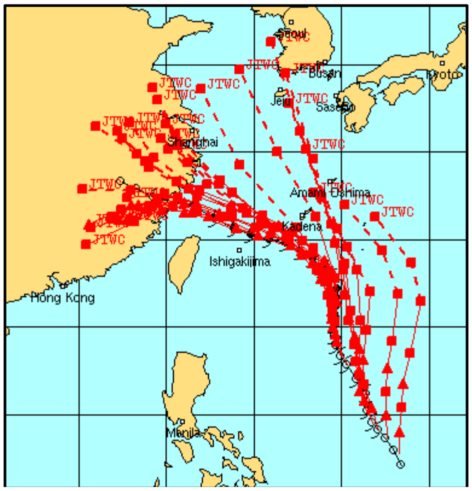


Figure 1-5: All JTWC track forecasts for TY 22W.

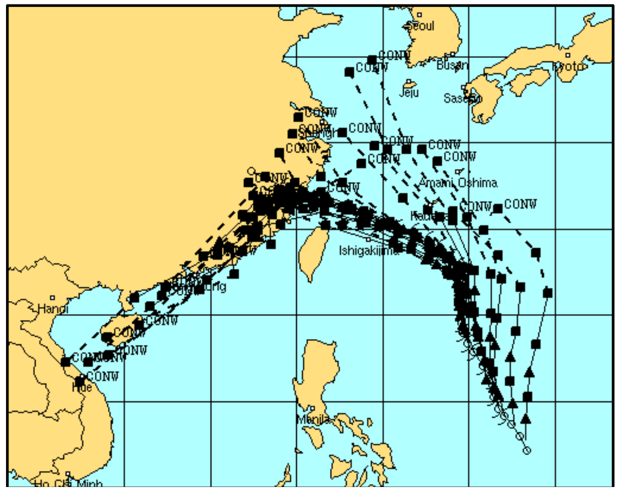


Figure 1-6: All CONW track forecasts for TY 22W.

Initial JTWC forecast tracks for TY 22W favored a slow poleward track followed by a subtle turn northwestward, but shifted to a faster poleward track into the Yellow Sea at 10/01/06Z (Figure 1-5). After 10/01/18Z, the JTWC forecast track gradually walked westward, lagging coincident westward shifts in CONW (Figure 1-6), toward central eastern China.

	24	**36**	**48**	**72**	**96**	**120**
JTWC	41	52	69	92 (96)	185 (142)	392 (234)
CONW	35	44	58	58 (90)	121 (137)	260 (214)
AVNI	53	77	104	**173** (99)	**367** (137)	**670** (235)
EGRI	51	53	66	114 (126)	171 (212)	233 (327)
ECMI	26	41	61	117 (117)	286 (187)	567 (290)
GFNI	67	90	136	216 (179)	227 (232)	294 (256)
NVGI	50	61	82	**119** (118)	**143** (176)	**213** (214)
HWFI	50	65	91	128 (103)	194 (149)	350 (208)
CTCI	78	114	167	235 (192)	414 (295)	804 (522)
JGSI	53	70	90	140	N/A	N/A
# CASES	9	9	8	6 (76)	4 (48)	4 (29)

Table 1-5: Average FTE (nautical miles) for JTWC subjective track forecasts, the 2013 track consensus (CONW), and deterministic models included in CONW (homogeneous comparison) for TY 22W and all 2013 NWPAC cases for forecast taus 72 to 120 in parentheses.

Somewhat surprisingly, although GFS maintained the best average FTE of any individual CONW deterministic model over the 2013 NWPAC season, as shown in red in Table 1-5, GFS (AVNI) performed relatively poorly for TY 22W, with the largest Tau 72, Tau 96 and Tau 120 FTE of the deterministic subset, 173 nm, 367 nm and 670 nm, respectively. In contrast and highlighted in green,

NAVGEM (NVGI) performed quite well in the extended Taus (119 nm, 143 nm, and 213 nm at Taus 72, 96, and 120, respectively). Figures 1-7 and 1-8 highlight the major differences between track forecasts from the two models during the 10/1/12Z to 10/02/18Z period, just as DoD assets in Okinawa were determining appropriate resource protection actions in preparation for potential impacts from the cyclone. A head-to-head comparison of GFS and NAVGEM forecasts for TY 22W, including an overview of synoptic features related to the noted differences, is provided in the following section of this report.

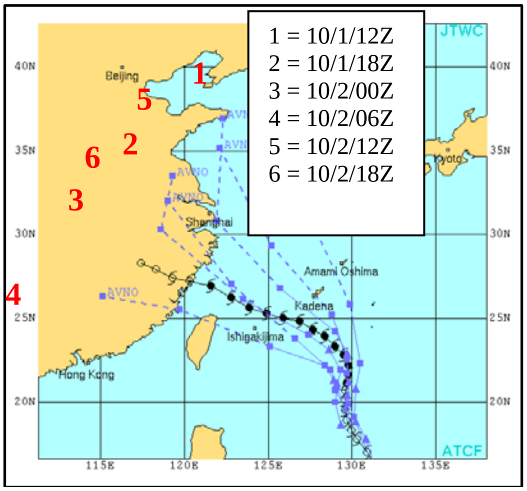


Figure 1-7: Uninterpolated GFS (AVNO) track forecasts for TY 22W (6-hourly from 10/1/12Z to 10/2/18Z).

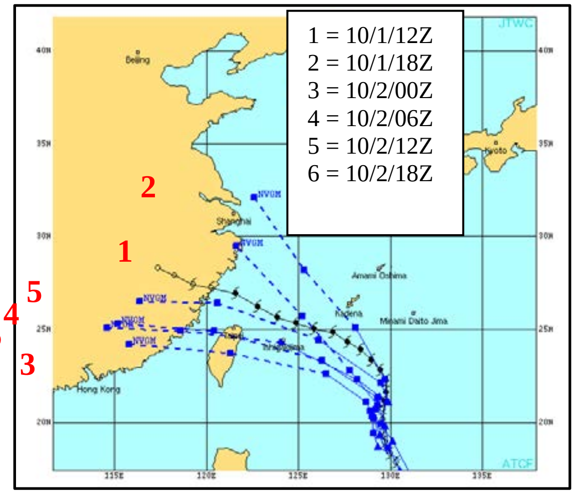


Figure 1-8: Uninterpolated NAVGEM (NVGM) track forecasts for TY 22W (6-hourly from 10/1/12Z to 10/2/18Z).

Inspection of CONW ensemble model mean forecast statistics reveals similar relationships to those noted for the deterministic model subset. The Japanese Typhoon Ensemble Prediction System (TEPS) ensemble mean tracker (JENI), highlighted in green in Table 1-6, provided accurate guidance and verified well (particularly at tau 120) against JTWC and CONW for this system, even though JTWC and CONW outperformed JENI for the 2013 season. In contrast, the GEFS ensemble mean forecast tracker (AEMI), highlighted in red, performed quite poorly compared to JTWC official forecasts and CONW tracks for TY 22W despite "competitive performance" for the season as a whole. Strong performance of the Japanese ensemble and poor performance of the GFS Ensemble Forecast System (GEFS) ensemble mean (AEMI) are consistent with the relative performance of their parent deterministic models (JGSM and GFS, respectively) in this case. Thus, a mean of single-model ensemble solutions did not offer a better alternative to the deterministic forecasts for this case. However, probabilistic guidance derived from individual ensemble *members* signaled the potential for track bifurcation and associated probabilities for each track scenario. A discussion of probabilistic guidance for TY 22W is provided in Section IV of this report.

	24	**36**	**48**	**72**	**96**	**120**
JTWC	32	43	59	90 (99)	190 (142)	398 (218)
CONW	26	35	51	65 (96)	145 (138)	356 (219)
JENI	53	87	120	**155** (167)	**129** (214)	**104** (236)
AEMI	37	54	77	**135** (114)	**305** (160)	**705** (233)
#CASES	19	17	15	11 (189)	7 (114)	3 (61)

Table 1-6: Average FTE (nautical miles) for JTWC subjective track forecasts, the 2013 track consensus (CONW), and single-model ensemble means included in CONW (homogeneous comparison) for TY 22W and all 2013 NWPAC cases for forecast taus 72 to 120 in parentheses.

III. Deterministic forecast guidance: Diagnosis of GFS and NAVGEM steering patterns

It is often difficult to identify the root causes of poor model track forecast performance, but it is nonetheless an imperative effort for cases like TY 22W. TY 07W (2008) formed in the same area as TY 22W (2013) and exhibited similar large model forecast errors. As noted by the JTWC Director, Robert Falvey, in his 2009 Tropical Cyclone Conference *2008 Year in Review* presentation, "10% of the JTWC 120 hour track error was due to 07W" (Falvey 2009). Both systems occurred in a region of US military interests and resulted in significant asset protection efforts that cost DoD multi-millions of dollars as well as the tremendous costs to civilians. These systems have a major impact on operations, and comprise a significant percentage of seasonal forecast track error. Here, we attempt to highlight key differences in the forecast fields between two deterministic models associated with very different forecast tracks and associated forecast track performance for TY 22W. Further numerical investigation is required to verify and explain the trends diagnosed here.

An in-depth review of NAVGEM and GFS model fields for the 10/01/12Z to 10/02/18Z period identified major differences in the 500 mb height fields over Eastern China and the East China Sea associated with very different GFS and NAVGEM track forecasts introduced in the previous section of this report. A detailed explanation of the 10/01/12Z model run highlights these differences, and is generally representative of the trend noted in the following model runs through 10/02/18Z. The 10/01/12Z model run, at forecast tau 48, GFS depicts both a deeper, sharper trough (outlined by the 5820m height line in Figures 1-9 and 1-10) over the East China Sea and a wider closed height line around TY 22W than NAVGEM. GFS also predicts an area of cold air advection (CAA) associated with the approaching mid-latitude shortwave trough, while NAVGEM depicts only weak or neutral temperature advection to support the shortwave trough. The deepening trough evident in the GFS model forecasts develops as a strong mid-latitude low that propagates northeastward as a mid-latitude ridge builds into Eastern Asia. Given that these factors would otherwise favor eastward translation of the shortwave trough and ridge building to the north of TY 22W, it appears that the noted height falls in GFS-modeled trough may be related to the relatively large forecasted size of the TY 22W, as approximated by the 5880m height line at 500 mb.

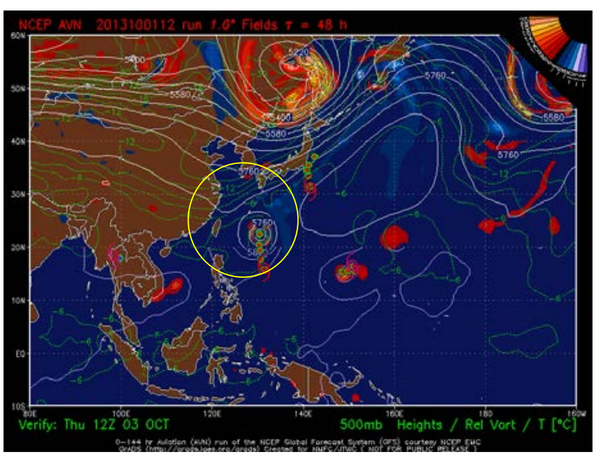


Figure 1-9: GFS 500mb prognosis from the 10/01/12Z forecast (Tau 48).

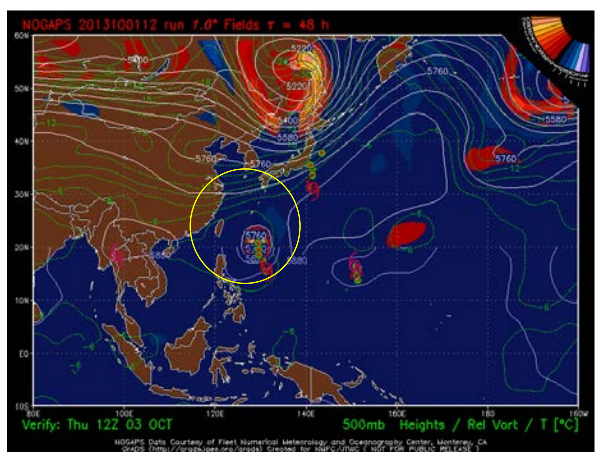


Figure 1-10: NAVGEM 500mb prognosis from the 10/01/12Z forecast (Tau 48).

This apparent interaction between a deeper modeled trough and larger tropical cyclone circulation in the GFS model resulted in the 10/01/12Z forecast prediction of a merging of TY 22W with the shortwave trough's 5820m height field by forecast Tau 72, and a subsequent poleward track (Figure 1-11). In contrast, NAVGEM maintains separation between the shortwave trough and the typhoon circulation, as indicated by the closed, symmetric 5820m height contour around 22W in Figure 1-12. NAVGEM appears to build the ridge into western Japan, evident as a westward extension of the 5820m height contour associated with the subtropical ridge to the east and an area

of warm air advection (WAA) present north of the system. Interestingly, GFS also forecasts WAA and a building ridge over western Japan. However, GFS forecasts an area of CAA to the northwest, which would support simultaneous deepening of the shortwave trough.

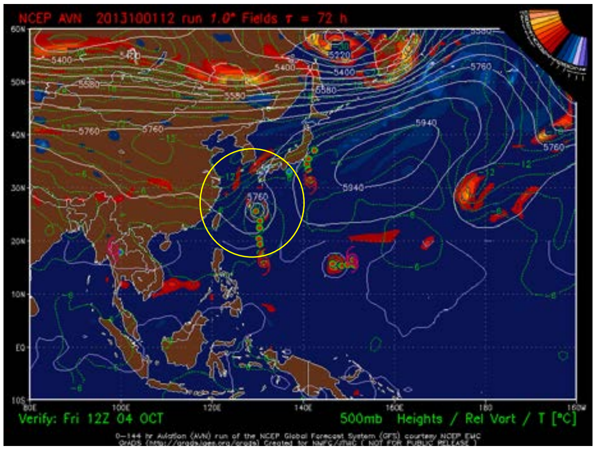


Figure 1-11: GFS 500mb prognosis from the 10/01/12Z forecast (Tau 72).

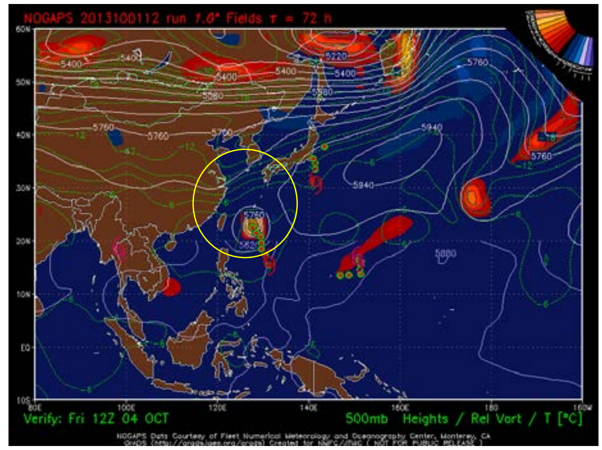


Figure 1-12: NAVGEM 500mb prognosis from the 10/01/12Z forecast (Tau 72).

By forecast Tau 96, both models build the subtropical ridge to the north and east of TY 22W, but the western edge of the ridge extends farther westward across Japan in the NAVGEM forecasts and the tropical cyclone remains embedded within the 5820m height line in the GFS forecast (Figures 1-13 and 1-14). Consequently, TY 22W is predicted to continue poleward in the GFS forecast, while turning northwestward in the NAVGEM forecast.

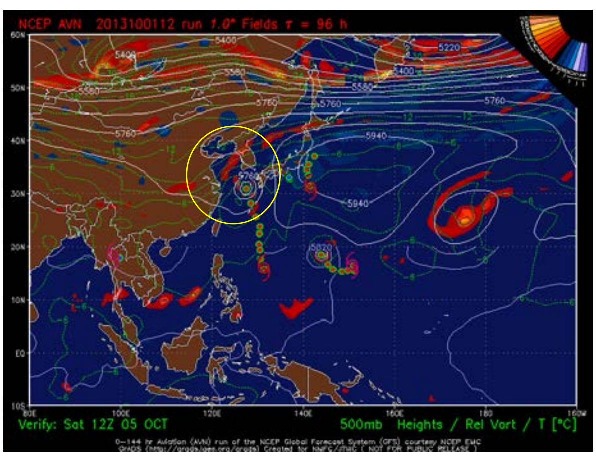


Figure 1-13: GFS 500mb prognosis from the 10/01/12Z forecast (Tau 96).

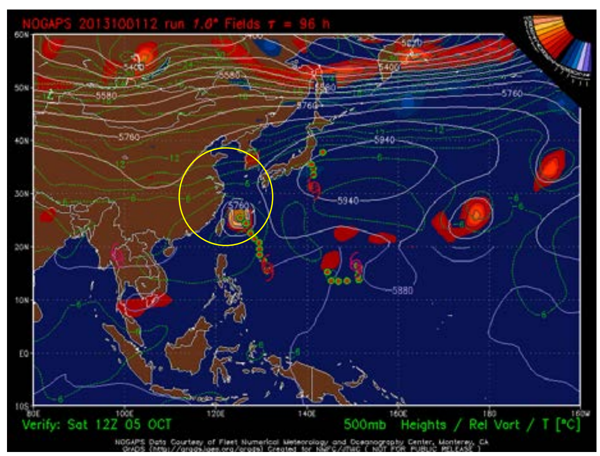


Figure 1-14: NAVGEM 500mb prognosis from the 10/01/12Z forecast (Tau 96).

At Tau 120, GFS continues to shift the steering ridge and tropical cyclone poleward, with a very slight north-northwestward track deflection. Major differences in the 500mb height field are noticeable to the northwest of TY 22W.

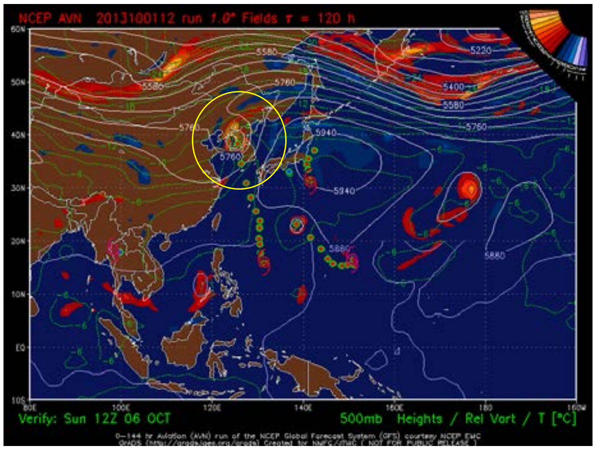


Figure 1-15: GFS 500mb prognosis from the 10/01/12Z forecast (Tau 120).

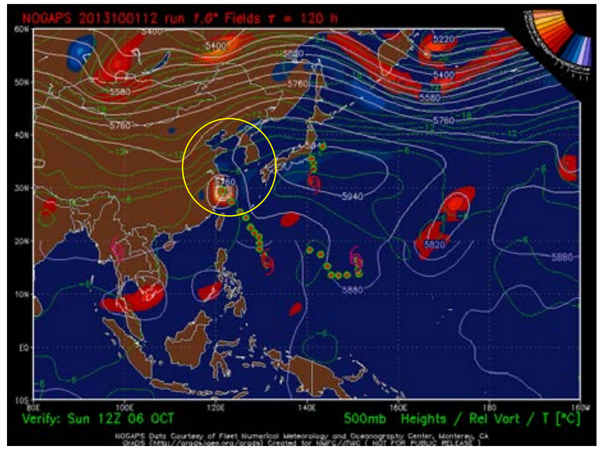


Figure 1-16: NAVGEM 500mb prognosis from the 10/01/12Z forecast (Tau 120).

Post analysis reveals several features in the GFS model forecast that hint at potential errors in the predicted poleward track scenario:

- Deepening of a subtropical shortwave trough while a strong mid-latitude ridge builds to the north is unlikely, especially if it occurs in relatively close proximity to a tropical cyclone, since this deepening may be driven in part by excessive interaction between the shortwave trough and the cyclone.
- Excessive mid-latitude cyclogenesis appears to be more pronounced in the GFS model and may be, in this case, related to the large cyclone size depicted in the model fields.

Identifying these potential model errors in real-time is particularly difficult. In this case, it would have been nearly impossible to "rule out" the poleward track scenario even if these error mechanisms had been identified. Probabilistic guidance identified a poleward track scenario as significantly more likely than a west-northwestward track, as discussed in the following section.

IV. Probabilistic track forecast guidance

Probabilistic forecast track guidance indicated a track forecast bifurcation early in TY 22W's life cycle. This guidance generally favored a poleward track with a significant (~30%) probability of an alternative, westward to west-northwestward track. Experimental strike probability graphics based on consensus model guidance illustrate this trend (Figure 1-17). Forecast graphics for 10/01/12Z and 10/01/18Z show two distinct track possibilities (poleward and west-northwestward) with the consensus track average (CONW) "splitting" the two track scenarios along a track not physically represented by any deterministic model solutions. At 10/02/00Z, the distinction between track scenarios is less obvious, but by the following forecast time (10/02/06Z), the guidance has effectively shifted to favor a west-northwestward track.

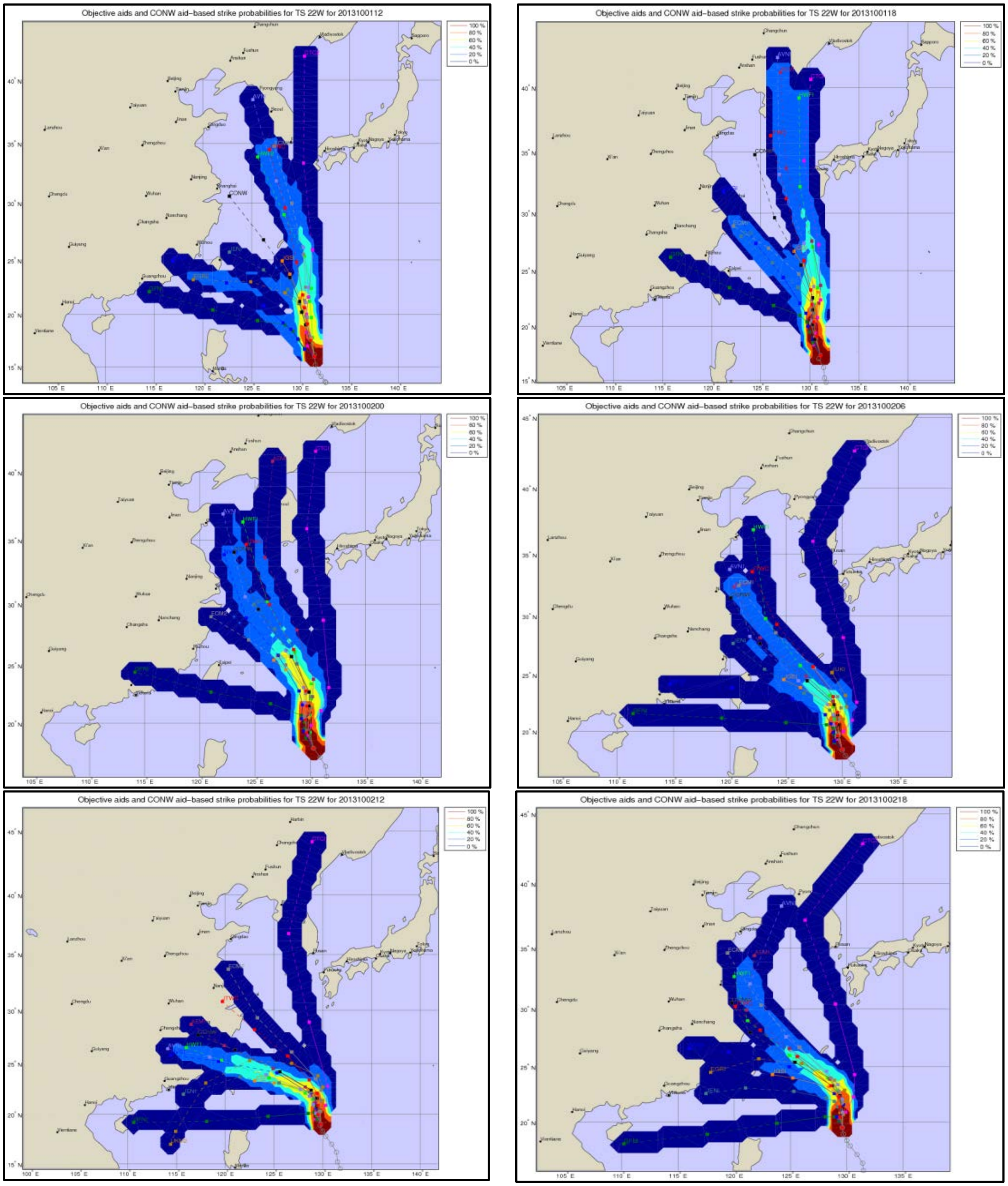


Figure 1-17: Experimental consensus model-based strike probability graphic for the 10/01/12Z (top left), 10/01/18Z (top right), 10/02/00Z (middle left), 10/02/06Z (middle right), 10/02/12Z (bottom left), and 10/02/18Z (bottom right) (cumulative probabilities to tau 120).

Probabilistic track forecast guidance derived from single-model ensembles provided a consistent representation of the bifurcation scenario for TY 22W. For example, ECMWF ensemble "track cluster" products, developed at the Naval Postgraduate School (Dr. Russ Elsberry, Dr. Hsiao-Chung Tsai and Ms. Mary Jordan), showed discrete cluster mean forecast tracks associated with the potential poleward and west-northwestward track scenarios. These products group each track forecast from the ECMWF's 51-member ensemble (available through the TIGGE data outlet) into 1 of 6 discrete "track clusters" derived from ECMWF ensemble five-day forecast tracks from the August

2008 to September 2012 period. Each cluster represents a distinct environmental steering scenario and is assigned a probability that the cyclone will follow the path represented by each cluster during the forecast period, based on the percentage of ensemble members (X out of 51 total members) that fall within each cluster (Tsai and Elsberry 2013, Hsiao-Chung Tsai personal communication).

Track clusters indicated a potential track bifurcation on 10/1/12Z (Figure 1-18). 19.6% of ensemble track forecasts fell within a west-northwestward track cluster (Cluster 1) at 10/1/12Z, increasing to 29.4% of ensemble members by 10/2/00Z (Figure 1-19). Although poleward track scenario “membership” was significantly higher than west-northwestward cluster membership at 78.4% to 62.7%, the decreasing number of members in the poleward group suggested an increasingly likely west-northwestward alternate track scenario. By 10/2/12Z (Figure 1-20), track membership for either a west-northwestward or westward track (Cluster 3) increased to a cumulative 37.2% (Figure 1-21). Figure 1-22 summarizes the changes in the poleward and westward cluster membership over this period, highlighting a steady decrease in members favoring the poleward scenario and coincident increase in members favoring a westward scenario during this period. These signals, in conjunction with consensus model guidance, suggested a shift from the poleward to west-northwestward track scenario, and may have supported more optimal adjustment to the JTWC forecast track and improved communication of forecast uncertainty to customers. This topic is discussed further in the following section.

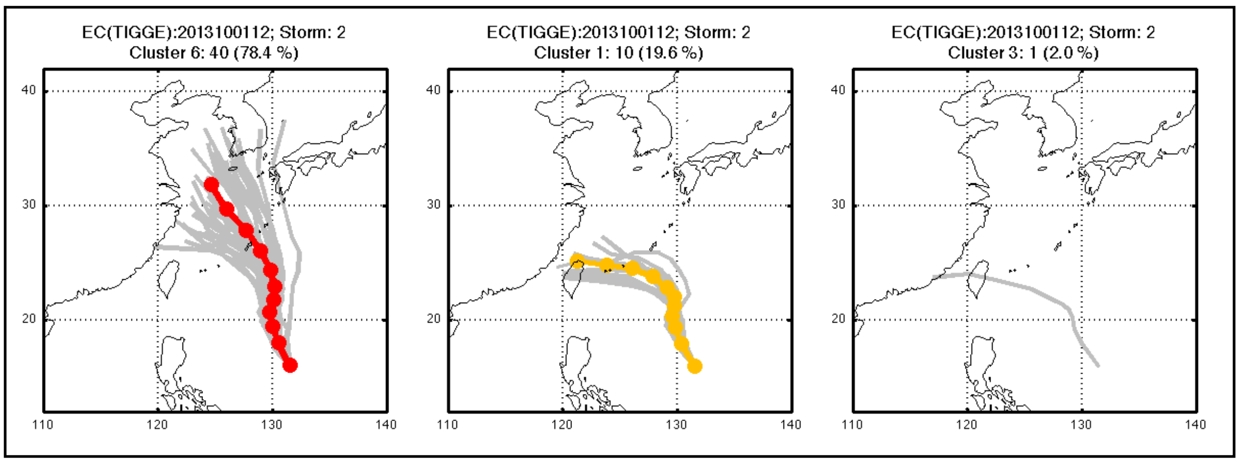


Figure 1-18: ECMWF TC ensemble track clusters from the 10/01/12Z forecast

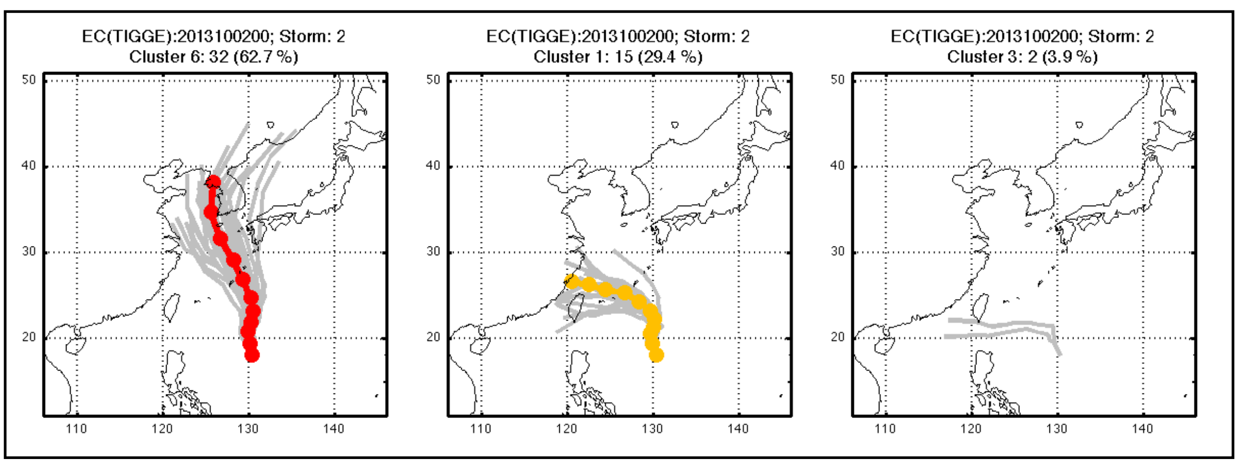


Figure 1-19: ECMWF TC ensemble track clusters for the 10/02/00Z forecast

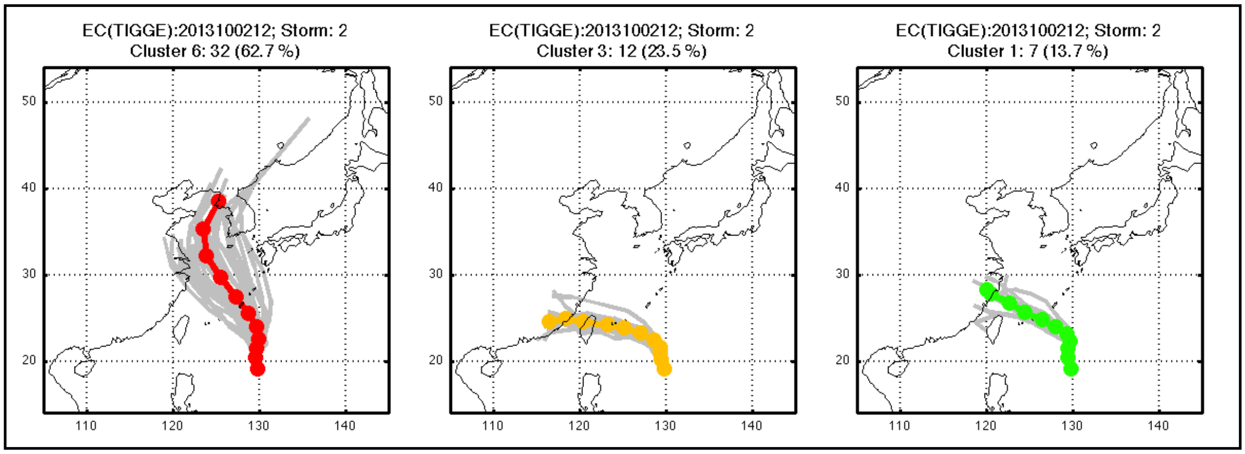


Figure 1-20: ECMWF TC ensemble track clusters for the 10/02/12Z forecast.

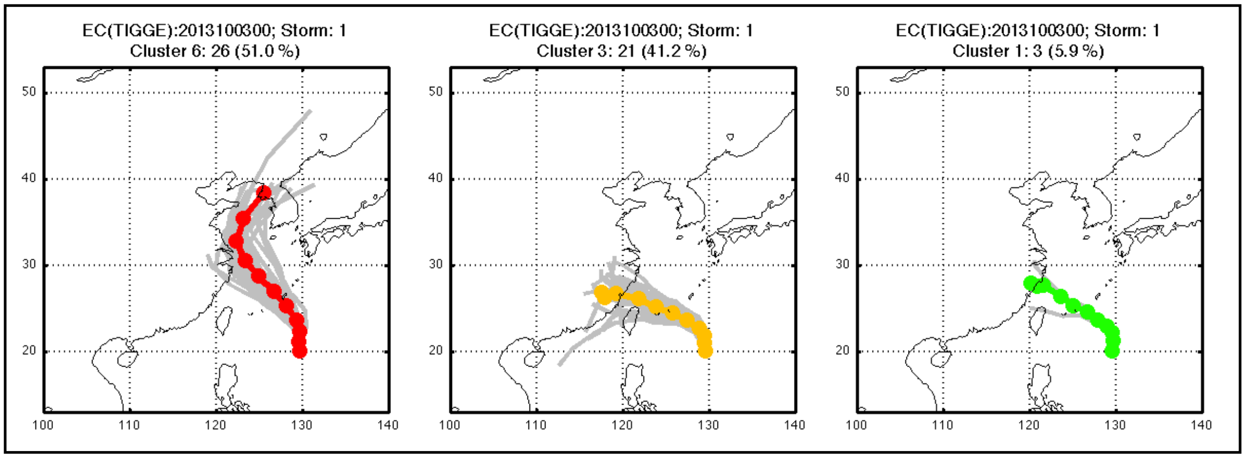


Figure 1-21: ECMWF TC ensemble track clusters for the 10/03/00Z forecast.

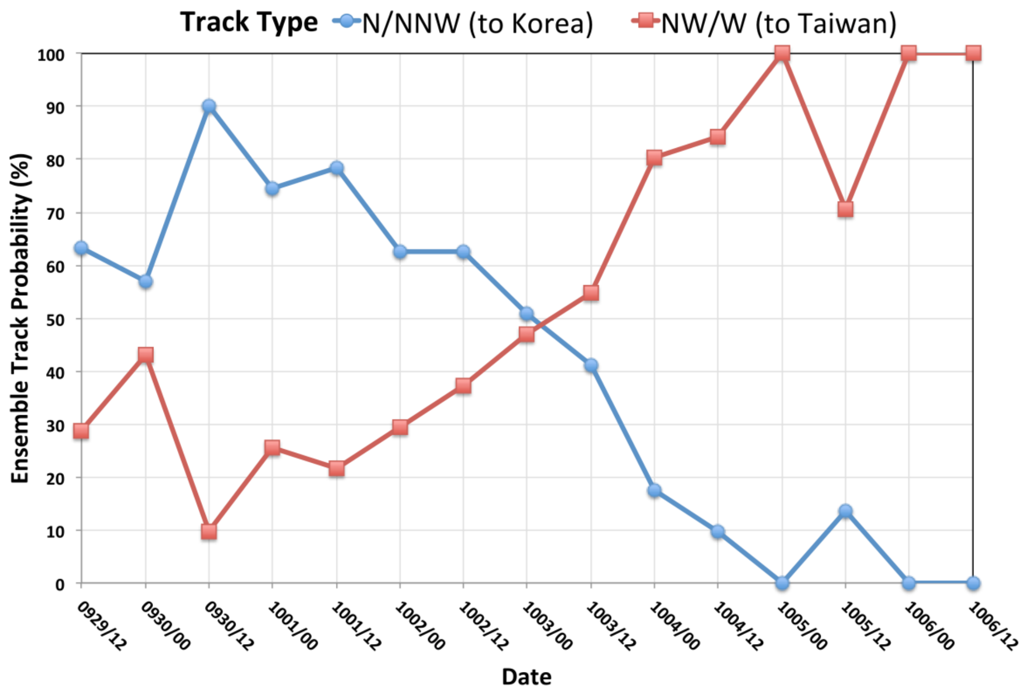


Figure 1-22: ECMWF ensemble track forecast cluster analysis probabilities (cluster membership) for the poleward track scenario (cluster 6) toward the Korean peninsula and westward track scenario toward Taiwan (clusters 3 and 1 combined). The data indicate a steady decrease in the probability of the poleward track scenario and coincident increase in the probability of the westward track scenario between 10/01/12Z and 10/05/00Z (image provided by Dr. Hsiao-Chung Tsai).

Finally, strike probabilities derived from multiple single-model track forecasts further supported the track bifurcation scenario and subsequent shift of the highest probability scenario to the west-northwestward trajectory. Figure 1-22 shows the evolution of 168 hour strike probabilities for TY 22W derived from NCEP, Canadian, US Navy, ECMWF, and UKMET single model ensemble track forecasts (courtesy NCEP Environmental Modeling Center). These products show potential tropical cyclone trajectories based on a set of 133 member forecasts (Figure 1-23).

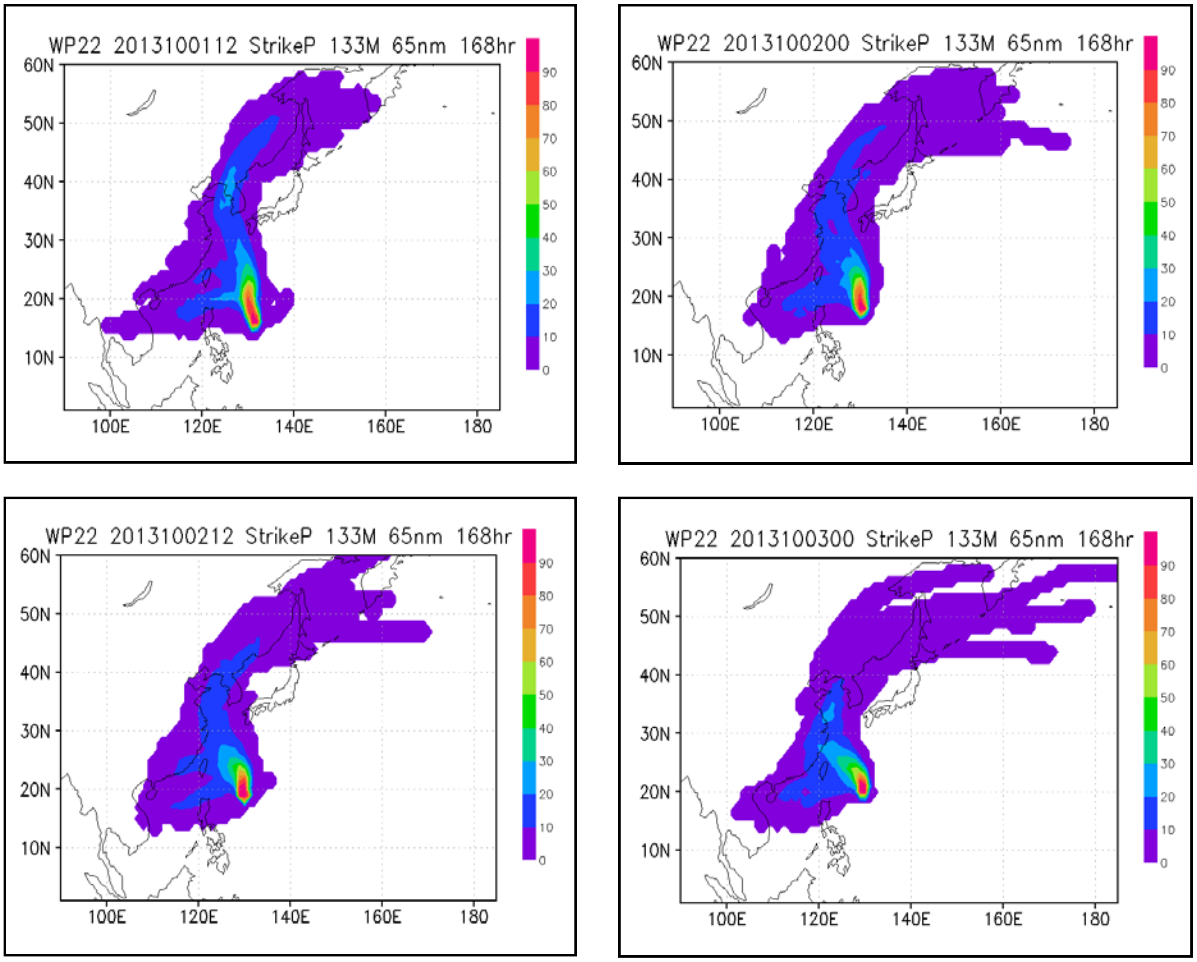


Figure 1-23: Multiple model ensemble TC strike probability graphics (133 total members) for 10/01/12Z (top left), 10/02/00Z (top right), 10/02/12Z (bottom left), and 10/03/00Z (bottom right) (courtesy NCEP EMC).

V. Forecast presentation and discussions

JTWC regularly presents forecast track uncertainty to customers via three tropical products in the center's cyclone warning suite: warning graphics, wind probability graphics, and forecast discussions (prognostic reasoning messages for western North Pacific cyclones). Forecast uncertainty presented in both the warning and wind probability products is derived from historical, subjective track forecast errors, with no additional adjustment based on either subjective or objective forecast uncertainty for the current tropical cyclone (JTWC 2014, DeMaria et al 2009). Qualitative, storm-specific track uncertainty is presented in text-based forecast discussions. Within these discussions, forecasters subjectively classify track forecast confidence as either "high" or "low" depending on analysis of the synoptic steering environment, predicted storm intensity change, and spread in objective forecast guidance. Track forecast bifurcations, characterized as two potential forecast tracks driven by distinctly different synoptic steering mechanisms, are also presented in these forecast discussions. When a bifurcation scenario is identified, the forecaster typically favors the higher probability grouping for the official forecast track, and presents the second track grouping as an "alternate forecast scenario."

For TY 22W, forecasters correctly identified and appropriately described the track forecast bifurcation at 10/01/12Z, stating in the associated forecast discussion:

"MODEL GUIDANCE, INCLUDING ENSEMBLES AND THE MULTI-MODEL CONSENSUS ARE IN POOR AGREEMENT, AS A BIFURCATION HAS DEVELOPED PAST TAU 72. THE WESTERN GROUPING, WHICH INCLUDES NAVGEM, EGRR, JGSM AND GFDN, SHOWS A STRONG STR BUILDING IN, WHICH WOULD TURN THE SYSTEM TOWARDS TAIWAN. THE EASTERN AND MORE POLEWARD GROUP, WHICH INCLUDES ECMWF, GFS, HWRF, AND COAMPS-TC, SHOWS A MORE INTENSE SYSTEM AND A WEAKER STR, WHICH WILL ALLOW FOR A MORE POLEWARD TRACK TOWARDS SOUTHERN JAPAN. THE JTWC FORECAST TRACK IS CLOSE TO MULTI-MODEL CONSENSUS IN THE EARLY TAUS AND FAVORS THE EASTERN GROUPING IN THE EXTENDED TAUS AS THIS GUIDANCE HAS PROVED MORE CONSISTENT."

Subsequent discussions correctly diagnosed the track bifurcation until the forecast guidance came into better agreement on a west-northwestward track. Note, however, that no *quantitative* estimates of track probabilities were provided in any of the forecast discussions.

The official track forecast favored the poleward track scenario through 10/02/06Z, finally shifting to the west-northwestward trajectory at subsequent synoptic times. Unfortunately, the JTWC forecast track gradually "walked" westward, lagging westward shifts in the consensus track, CONW, during this transition period. The slow change in the agency forecast track contributed to larger forecast track errors at extended taus (Table 1-5). In hindsight, a more abrupt shift to the west-northwestward track scenario would have reduced forecast track errors, but a reliable and repeatable process to determine how and when to "dramatically" shift between track forecast scenarios was not available at the time. To address this challenge, the following section proposes a pathway to improve applications of probabilistic track forecast data during the warning process and enhance communication of uncertainty to customers in analogous future cases.

VI. Probabilistic forecasting: An updated paradigm

Optimized procedures to apply probabilistic forecast track data would facilitate quantitative identification of bifurcation scenarios, abrupt adjustment of the forecast track from one likely scenario to another as probabilistic guidance evolves, and accurate presentation of forecast uncertainty to customers throughout a cyclone's lifecycle. Forecasters correctly diagnosed track forecast bifurcation early in the lifecycle of TY 22W and selected the more probable forecast scenario based on deterministic and probabilistic single-model ensemble guidance. However, the *quantitative* probability of each forecast scenario was neither closely tracked nor described by the forecast team on warning discussion products. New products, such as deterministic model-based strike probabilities and ECMWF ensemble track clusters presented in section IV, make it possible to quantify and track probabilities associated with each of two divergent track scenarios. Further in-house studies will explore the viability of a track forecast probability "tracking system" that will identify track probability trends and "break points" that reliably support abrupt forecast track shifts, and explore methods to better present quantitative track probabilities to customers.

As mentioned in section V of this report, the area of uncertainty presented on the JTWC warning graphic is based on historical, subjective track forecast errors. More specifically, the area of uncertainty at each forecast tau is equal to the five year running mean JTWC forecast track error plus the forecasted 34-knot wind radius at each forecast tau. Therefore, the area of uncertainty essentially represents the over-water geographic area that may experience 34-knot winds based on the current track and wind field forecast and historic forecast track errors (JTWC 2014). Storm-specific data, such as ensemble-derived strike probability data, are not included in the calculation. Thus, for cases such as TY 22W, the area of uncertainty can be quite unrepresentative of "true" forecast track uncertainty based on the synoptic environment and available objective guidance (Figure 1-24).

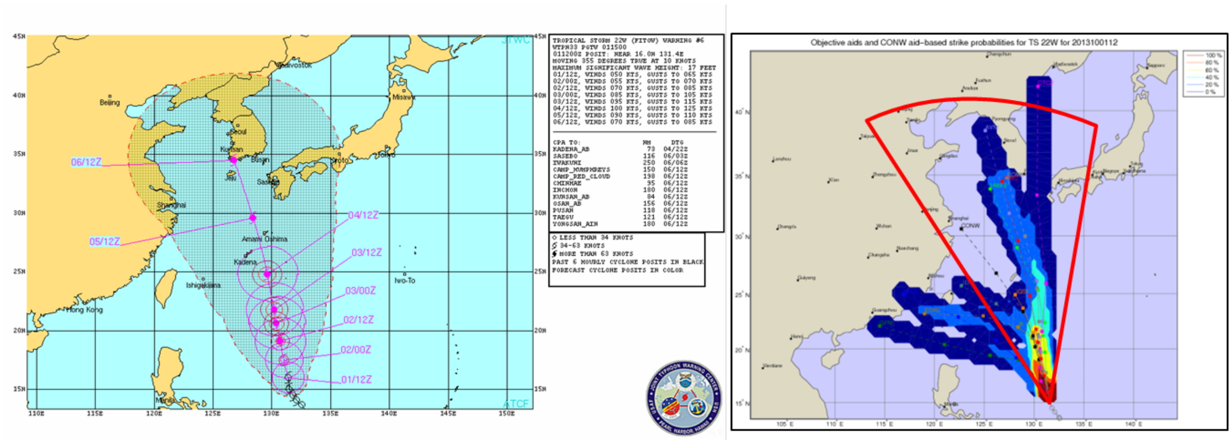


Figure 1-24: Left: JTWC warning graphic for TY 22W, 10/01/12Z. Hashing represents 34-kt wind forecast uncertainty area. Right: Experimental consensus model strike probability graphic for TY 22W, 10/01/12Z, with approximate area of uncertainty from warning graphic highlighted in red. The operational area of uncertainty on the warning forecast graphic excludes a significant portion of the west-northwestward track scenario highlighted in the strike probability graphic.

Regional forecast centers, such as the Japanese Meteorological Agency, base graphical track forecast uncertainty on the spread in numerical model forecast track guidance (Kishimoto 2012). A similar approach using consensus model-based guidance (Goerss 2007; Hansen et al 2011) or single-model ensemble forecast probabilities may have provided a better representation of the area of uncertainty for TY 22W. An ideal method would present the area of uncertainty for TY 22W and analogous cases as bimodal. For TY 22W, such a bimodal distribution would present poleward and west-northwestward track uncertainty "lobes." More work is needed to determine how to best represent this information for JTWC forecasts, whether through adjustment of the existing operational area of uncertainty or through development of a separate product that highlights objective, model-based probabilities. Additionally, education and training of the vast JTWC customer base would be necessary to ensure probabilistic uncertainty products are fully understood and correctly applied by military decision makers.

VII. References

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Super Typhoon 31W (HAIYAN)

I. Overview

Super Typhoon (STY) 31W (Haiyan) was initially analyzed as a tropical disturbance developing within the monsoon trough, just south of Pohnpei, on 02 November 2013. The disturbance consolidated into a single low-level circulation center (LLCC) within 24 hours while tracking westward to the south of Chuuk Atoll. JTWC issued its first warning when the cyclone's maximum sustained wind speed reached 25 knots at 0600Z on 03 November 2013. Over the subsequent 48 hour period, STY 31W intensified at an above average rate as it passed well south of Guam, attaining tropical storm intensity (35 knots) around 0000Z on 04 November and typhoon intensity (70 knots) by 0000Z on 05 November. A period of explosive deepening followed, when the intensity increased from 70 knots to 130 knots in 24 hours (0000Z on 05 November to 0000Z on 06 November).

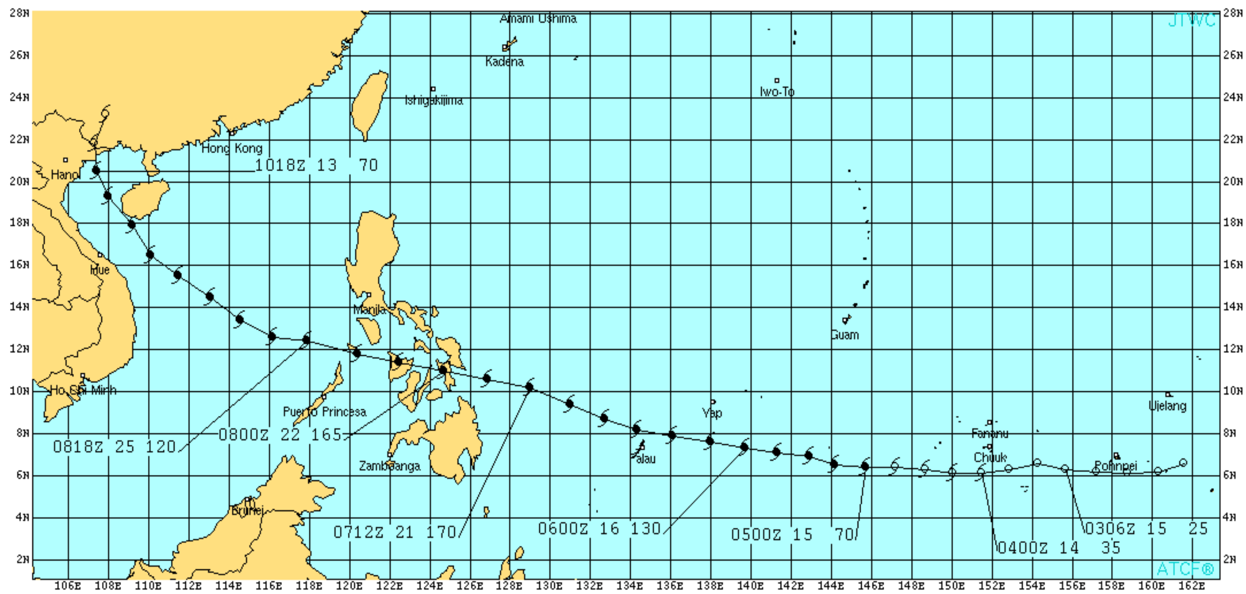


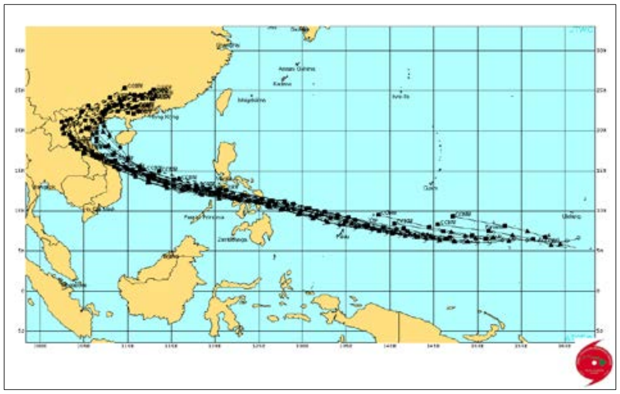
Figure 1-25: Best track positions and intensities for STY 31W (Haiyan). The date-time, speed of movement, and intensity are labeled for key locations and times discussed in this report.

STY 31W intensified to 135 knots approximately 115 nautical miles south of the island of Yap and to 150 knots as it passed over Kyangel Island, Republic of Palau approximately 12 hours later. The cyclone entered the Philippine Islands near Guian, Eastern Samar before passing over Leyte Island near the municipality of Tolosa at around 0000Z on 08 November 2013. Maximum sustained wind speed at landfall was estimated from satellite at 165 knots. The cyclone then moved quickly through the Philippine Islands before reemerging in the South China Sea as a 120 knot cyclone. At 0000Z on 09 November 2013, STY 31W turned poleward and weakened, moving through the Gulf of Tonkin. Just after 1800Z on 10 November 2013, STY 31W made landfall in northeastern Vietnam at typhoon strength (70 knots), and continued to move inland into southern China where it rapidly dissipated due to the frictional effects of land and increasing vertical wind shear (VWS).

II. Steering and Intensity Mechanisms

A deep-layered and persistent STR centered near Guam and extending west into the South China Sea was the primary steering mechanism for this cyclone. The persistence of this synoptic

feature resulted in the dynamic model track guidance and the JTWC forecasts being in close agreement throughout the life of STY 31W, as indicated in Figures 1-26 and 1-27.



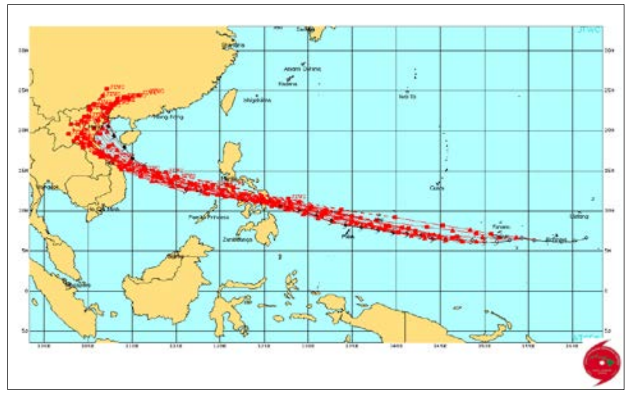


Figure 1-26 (left): All model consensus (CONW) forecasts for STY 31W.
Figure 1-27 (right): All JTWC track forecasts for STY 31W.

Environmental conditions favored development of a very intense cyclone from the beginning of Haiyan's lifecycle. Warm sea surface temperatures (SSTs) were observed along the entire forecast track. As indicated in Figure 1-28, SSTs exceeded 29^{o} C along the track from the cyclone's position southeast of Guam to the east coast of the Philippines.

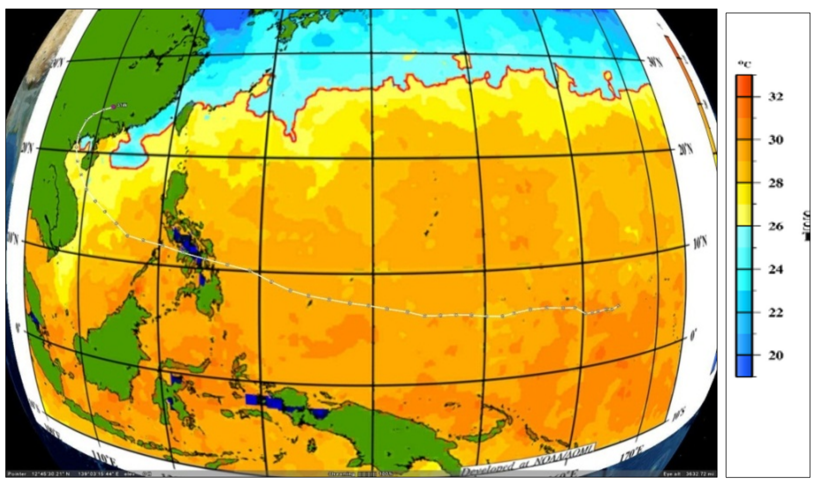


Figure 1-28: NOAA/AOML SST map 05 November 2013 overlaid with the STY 31W track.

Along-track ocean heat content (OHC) was also very high, indicating that warm water extended fairly deep into the upper-ocean along the cyclone's path. High along-track OHC and STY 31W's relatively rapid translational speed may have allowed the cyclone to avoid the negative intensity influence associated with cool water upwelling. Figure 1-29, below, shows along-track OHC values.

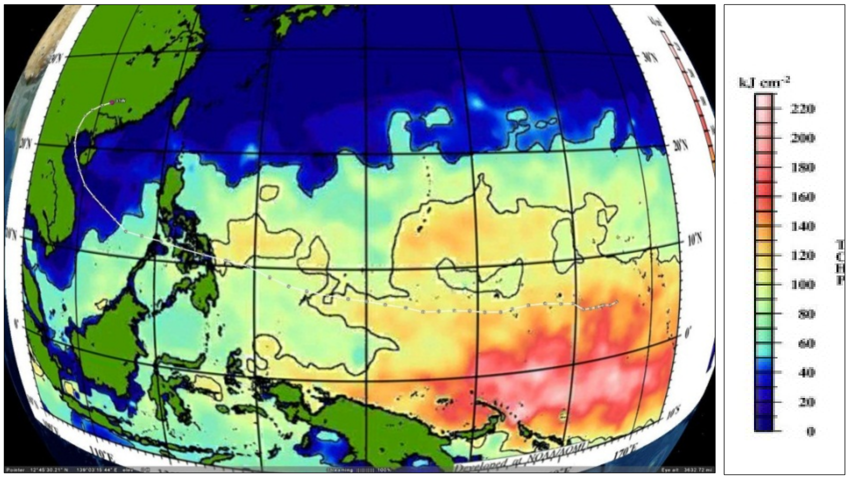


Figure 1-29: NOAA/AOML OHC map from 05 November 2013 overlaid with the STY 31W track.

Satellite-derived upper-level wind field products from the University of Wisconsin Cooperative Institute for Meteorological Satellite Studies (CIMMS) indicated low vertical wind shear (VWS) and strong upper-level diffluence along the track. The CIMMS deep layer shear analysis product from 06 November 2013 at 1200Z (Figure 1-30) indicates 5 to 10 knots of VWS in the vicinity of the storm.

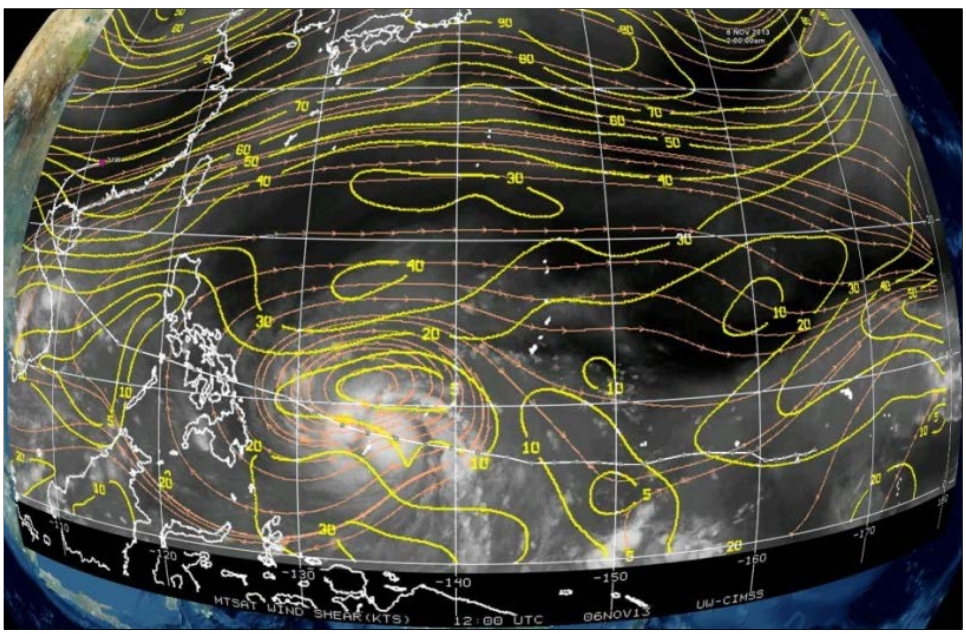


Figure 1-30: CIMMS deep layer shear analysis from 06 November 2013 at 1200Z overlaid with the STY 31W track.

Upper-level radial outflow developed directly over the LLCC and persisted as the cyclone intensified into a tropical storm by 04 November at 1200Z and rapidly intensified into a typhoon by 05 November at 0000Z (Figure 1-31). Strong radial outflow, low VWS, and warm ocean waters provided favorable conditions for the initial rapid intensification to typhoon strength, and subsequent explosive deepening from minimal typhoon intensity (70 knots) to super typhoon intensity (130 kts) during the following 24 hours.

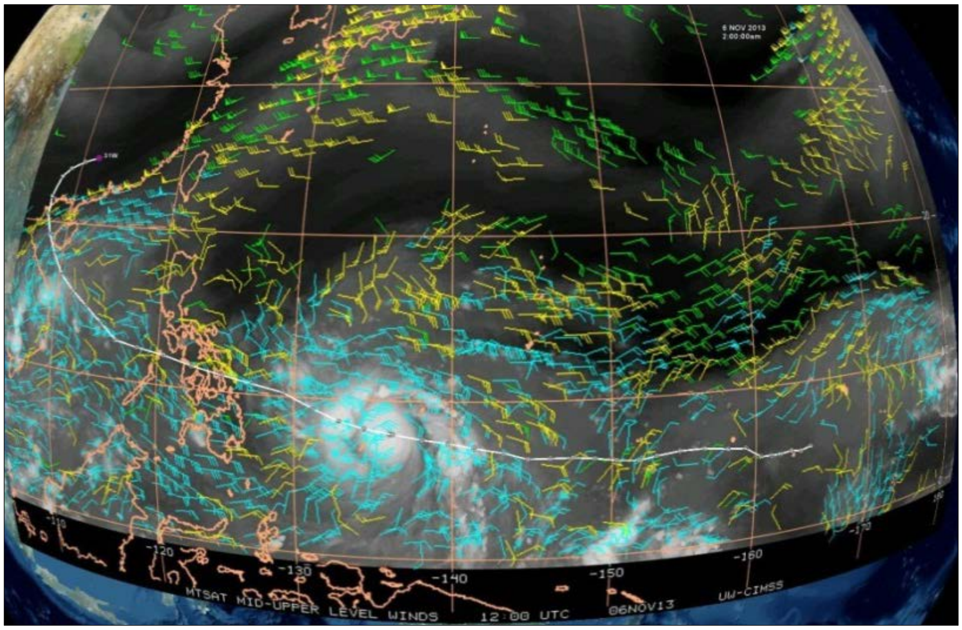
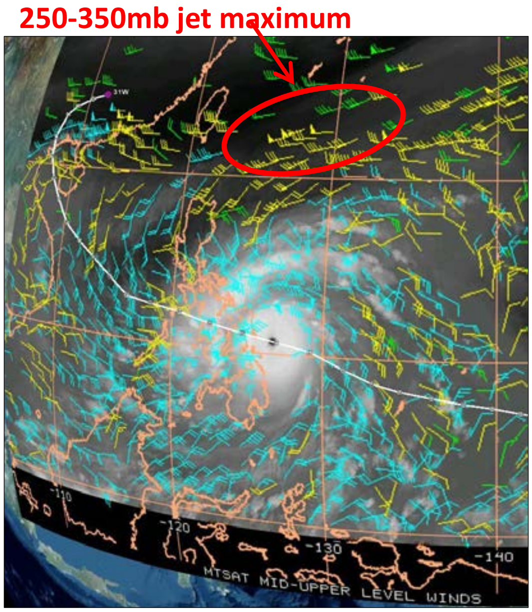


Figure 1-31: CIMMS mid-upper level wind analysis from 06 November 2013 at 1200Z overlaid with the STY 31W track.

Following the rapid jump to super typhoon intensity, a more gradual intensification trend was observed. Intensity increased to 150 knots as the system made landfall on Kyangel Island around 1800Z on 06 November 2013. Media reports indicated severe flooding on the island and wind speeds nearly matching the best track estimate of 150 knots.[1] After passing over Kyangel Island, STY 31W experienced a final period of intensification, likely due to enhanced outflow from a 250-350 milibar jet maximum located across the Luzon Strait, to the northwest of the cyclone, as indicated in Figure 1-32A. At 0832Z on 07 November 2013, satellite analysts at JTWC assessed the Dvorak intensity at T8.0, the highest T-number allowed in the Dvorak technique. By 1200Z, all meteorological satellite fixing agencies (JMA, NESDIS, and JTWC) indicated a subjective Dvorak technique analysis of T8.0, prompting JTWC to set the cyclone intensity at 165 knots. Six hours later, the intensity was adjusted upward to 170 knots as STY 31W approached the Philippine archipelago. The current intensity (CI) would remain T8.0 for the next 18 hours, indicating the extreme nature of the cyclone. Two-kilometer resolution infrared (IR) satellite imagery, with BD curve enhancement (Figure 1-32B), shows the structure of STY 31W at the peak Dvorak final T-number with a sharply defined and symmetrical eye, cold-dark grey banding within a well-defined and circular ring of deep convection, and extensive banding feature to the northwest.



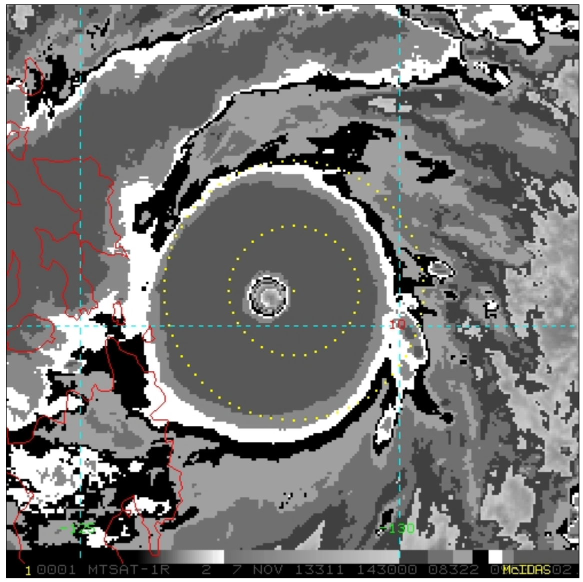


Figure 1-32A (left): 250-350 milibar jet maximum highlighted on CIMMS wind plot from 07 November 2013 at 1800Z with STY 31W track.

Figure 1-32B (right): The 2 km storm relative IR imagery with BD enhancement curve from MTSAT-1R at 1430Z on 07 November 2013.

Microwave satellite imagery highlighted the convective structure of STY 31W as it approached the east coast of the Philippines. Figure 1-33A through-1-33C, below, shows a sequence of 91GHz SSMIS images indicating improving central convective structure as the system moved ashore. Important distinguishing features evident in these images include the dissipation of a very large feeder band in the northwest quadrant, increasing size of the central convective ring surrounding the eyewall, and the contracting, symmetric embedded eye.

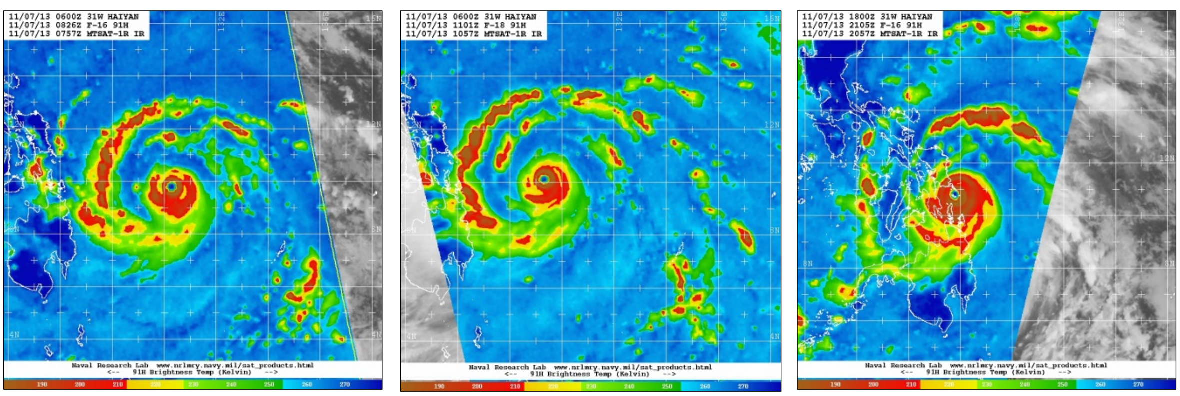
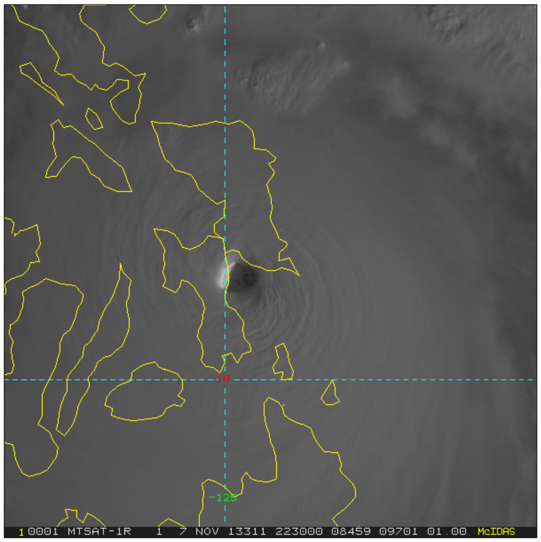


Figure 1-33: Storm-centered, 91GHz SSMIS microwave imagery of STY 31W prior to landfall from11/07/13 0826Z (**Figure 1-33A** - left), 11/07/13 1101Z (**Figure 1-33B** – center), and 11/07/13 2105Z (**Figure 1-33C** – right). Imagery provided by NRL, Monterey.

STY 31W devastated the Visayan Islands of the Central Philippines, bringing strong winds and storm surge as it made landfall at approximately 07 November at 2230Z on Leyte Island. The Philippine National Disaster Risk Reduction and Management Council[2] reported fatalities of over 6000 people, with greater than 28,000 people injured and over 1700 people missing. Figure 1-34A shows a geostationary infrared image of the eyewall as it moved ashore near the municipality of Tolosa. The cyclone slowly weakened as it tracked across the Philippine Archipelago and moved into the South China Sea (Figure 1-34B) as a 125 knot cyclone, just below super typhoon intensity.



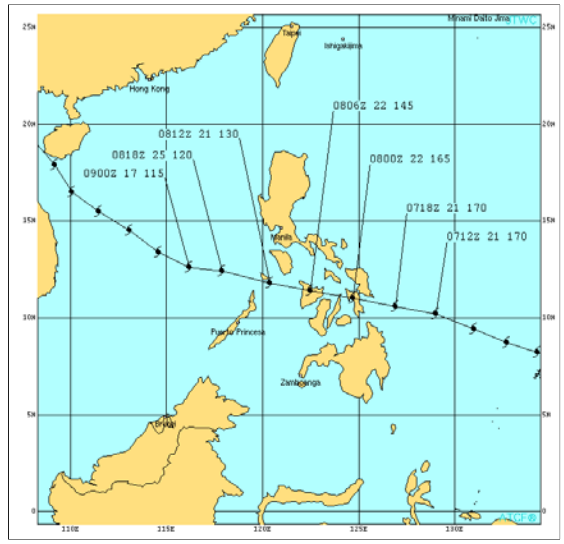


Figure 1-34A (top-left): Storm-relative 1 km geostationary IR imagery from MTSAT-1R at 2230Z on 07 November 2013. Figure 1-34B (top-right): Best track (position, time, speed-of movement and intensities) data for STY 31W (Haiyan) as it crossed over the Philippine Islands.

Decreasing SSTs and increasing VWS continued the weakening trend as STY 31W turned northwestward towards northern Vietnam. Figure 1-35 shows degradation of the cyclone's eye during this period.

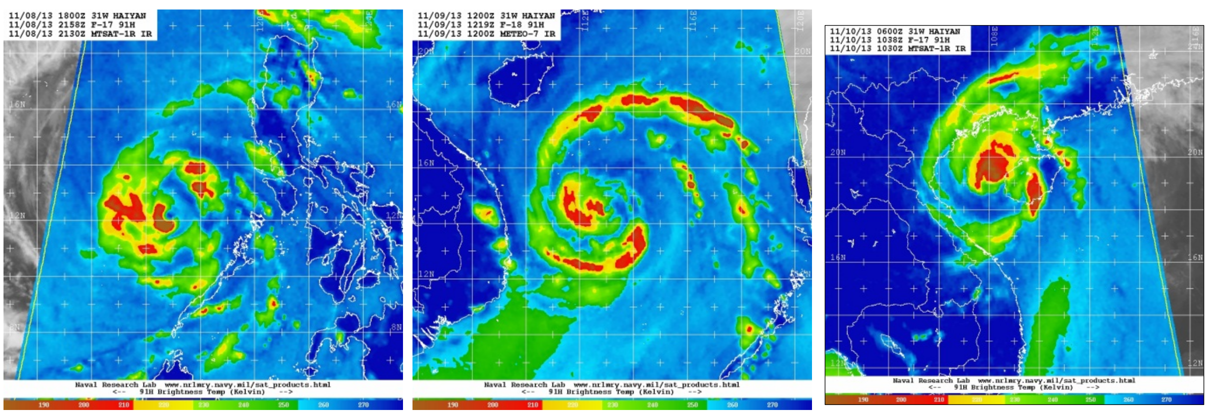


Figure 1-35: Storm-centered, 91GHz SSMIS microwave imagery of STY 31W in the South China Sea 08/2158Z (**Figure 1-35A** - left), 09/1219Z (**Figure 1-35B** – center), and 10/1038Z (**Figure 1-35C** – right). Imagery provided by NRL.

STY 31W moved poleward through the Gulf of Tonkin before making landfall in northeastern Vietnam near the Chinese border. The cyclone moved ashore around 2100Z on 10 November 2013 at typhoon intensity and weakened significantly as it curved northeastward into southern China, then dissipated a day later (11 November 2013 at 12Z) as detailed in Figure 1-36.

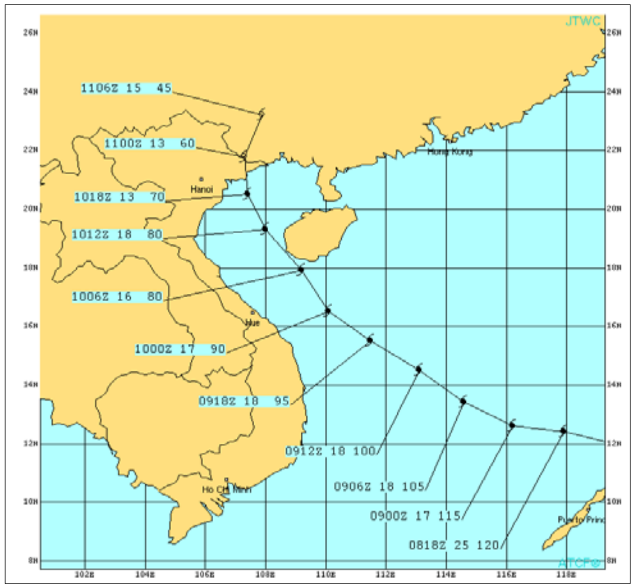


Figure 1-36: Best track positions and associated intensities for STY 31W (Haiyan) as the cyclone weakened while moving across the South China Sea and dissipated over southern China.

Dynamical and statistical-dynamical intensity model guidance indicated significant intensification early in the life of STY 31W, although the predicted intensity change was slower and to a much lower peak intensity than was subsequently observed. Figure 1-37, shows the best track intensities and intensity forecast guidance from dynamical and statistical-dynamical models from the first warning time until 0600Z on 07 November 2013, as STY 31W approached the east coast of the Philippine Islands. A detailed analysis of the synoptic environment led JTWC forecasters to predict intensities above the numerical and statistical dynamical guidance for the most of the Philippine Sea intensification period. However, these JTWC forecasts did not adequately represent the observed explosive rapid intensification.

The noted low VWS, extensive upper-level outflow, and high SSTs appear to have been the primary mechanisms for the intensification of STY 31W as it moved through the Philippine Sea. It is thought, however (from post analysis), that the high along-track OHC and noted upper tropospheric jet max near the Luzon Strait provided additional enhancements that allowed this cyclone to reach its maximum intensity.

A relatively new intensity forecast guidance, SHIPS-RI[3], did predict high rapid intensification probabilities, well above the basin long-term averages for STY 31W (Figure 1-38) throughout the STY 31W intensification phase. Process improvements to optimally incorporate new skilled intensity forecast guidance (e.g. SHIPS-RI) into the subjective forecast process are being explored at JTWC to improve forecast skill of extreme intensification events as observed in STY 31W.

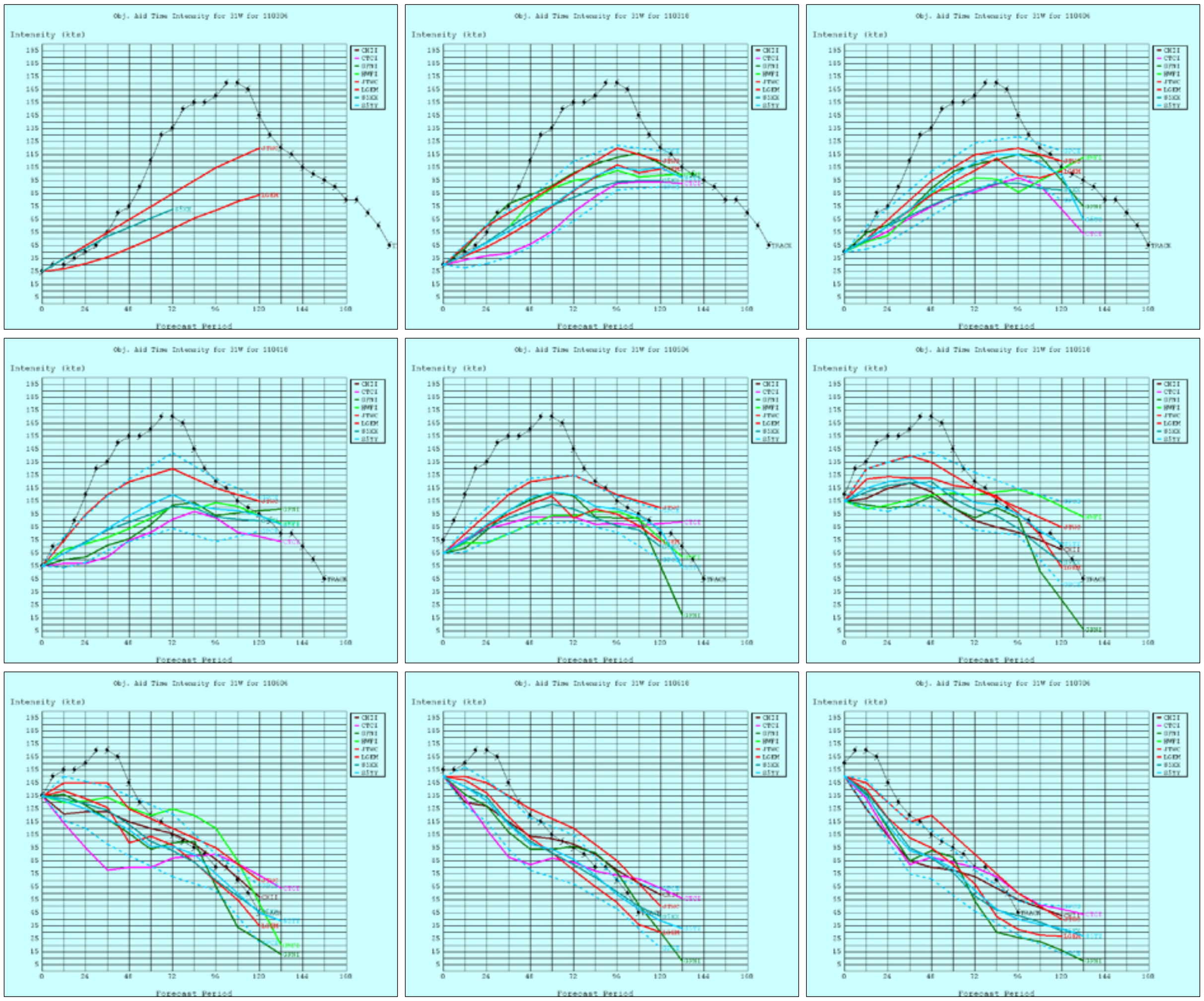


Figure 1-37: JTWC best track intensity with the interpolated dynamical intensity forecasts and statistical-dynamical intensity forecasts for STY 31W from initial warning to 07/0600Z (best track intensities in black).

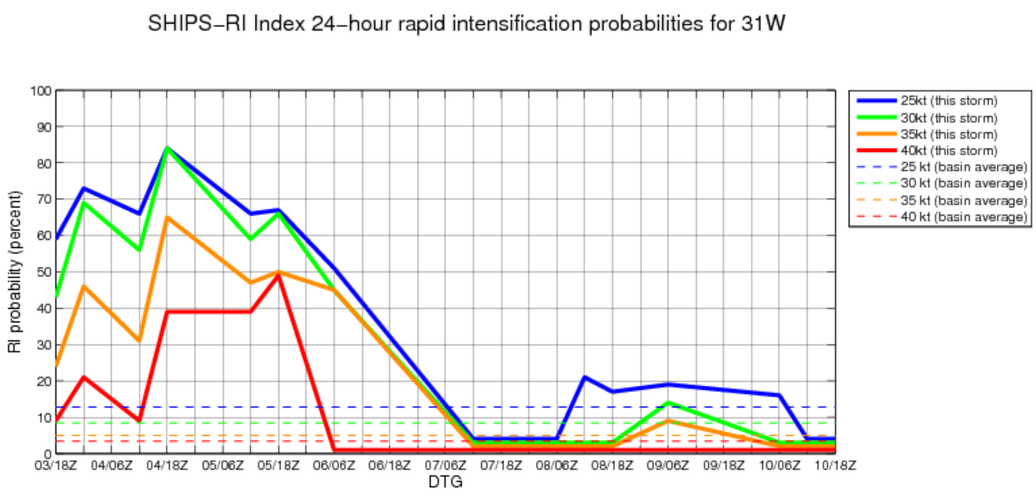


Figure 1-38: SHIPS-RI Index rapid intensification probability values for STY 31W.

JTWC track forecast errors for STY 31W outperformed the JTWC 5-year average errors at all forecast times, including 25-30 percent improvements for the 96 and 120 hour forecasts. JTWC track forecasts outperformed numerical model consensus guidance by 7-10 percent at all forecast times. Although JTWC intensity forecast errors slightly exceeded the JTWC 5-year average through 72

hours, extended intensity forecasts outperformed forecast averages, including a 37 percent improvement at 120 hours. JTWC intensity forecasts were more accurate than numerical and statistical forecast guidance out to 96 hours, beating guidance by 22 to 34 percent.

A final noteworthy characteristic of STY Haiyan was the cyclone's translational speed. The JTWC best track indicates relatively fast forward motion ranging from 15 to 23 knots. Along with the size and intensity of the storm, these rapid track speeds may have contributed to the very unique and devastating storm surge observed as came ashore in the Philippine Islands. Instead of witnessing a gradual rise in sea level and coincident flooding that is often associated with storm surge events, a devastating tsunami-like wave was observed at Tacloban, Leyte. Tsunami-like waves driven by atmospheric phenomena, as observed in this case, are referred to as "meteotsunamis" [4]. These tsunami-like waves are thought to be induced by traveling air pressure disturbances such as gravity waves, pressure jumps, frontal passages, squalls, or tropical cyclones.

III. References

"Palau assesses damage after Super Typhoon Haiyan". *ABC News*. November 7, 2013.

"SitRep No. 104 Effects of Typhoon "Yolanda" (Haiyan)" (PDF). *National Disaster Risk Reduction and Management Council*. January 29, 2014.

Kaplan, J., M. DeMaria, and J.A. Knaff, 2010: A revised tropical cyclone rapid intensification index for the Atlantic and eastern North Pacific basins. *Wea. Forecasting*, **25**, 220-241.

Monserrat, S., I. Vilibíc, and A.B. Rabinovich, 2006. Meteotsunamis: atmospherically induced destructive ocean waves in the tsunami frequency band. *Natural Hazards and Earth System Sciences*, **6,** 1035–1051.

Chapter 2 North Indian Ocean Tropical Cyclones

This chapter contains information on north Indian Ocean TC activity during 2013 and the monthly distribution of TC activity summarized for 1975 - 2013. 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 2013 season. Six cyclones occurred in 2013, with four systems reaching an intensity greater than 64 knots. Table 2-2 shows the monthly distribution of Tropical Cyclone activity for 1975 - 2013.

Table 2-1

NORTH INDIAN OCEAN SIGNIFICANT TROPICAL CYCLONES FOR 2013

(01 JAN 2013- 31 DEC 2013)

TC	NAME*	PERIOD**		WARNINGS ISSUED	EST MAX SFC WINDS KTS
01B	Mahasen	10 May / 0600Z	16 May / 0600Z	25	45
02B	Phailin	09 Oct / 0000Z	12 Oct / 1800Z	16	140
03A	-	08 Nov / 1800Z	11 Nov / 0000Z	10	45
04B	Helen	19 Nov / 1200Z	22 Nov / 0600Z	12	70
05B	Lehar	23 Nov / 0600Z	28 Nov / 0600Z	21	75
06B	Madi	06 Dec / 0000Z	12 Dec / 0000Z	25	85

* As designated by the responsible RSMC

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

Table 2 - 2 DISTRIBUTION OF NORTH INDIAN OCEAN TROPICAL CYCLONES FOR 1975 - 2013													Total		
													≥64kt	34-63kt	≤33 kt
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	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
							(1975-2013)								
MEAN	0.2	0.1	0.0	0.2	0.7	0.6	0.1	0.0	0.3	1.0	1.4	0.6	5.1		
CASES	6	2	1	7	28	22	2	1	13	40	54	23	199		

1) If a tropical cyclone was warned on prior to the last two days of a month, it was attributed to the first month, regardless of how long the system lasted.
2) If a tropical cyclone began on the last day of the month and ended on the first day of the next month, that system was attributed to the first month. However, if a tropical cyclone began on the last day of the month and continued into the next month for only two days, it was attributed to the second month.

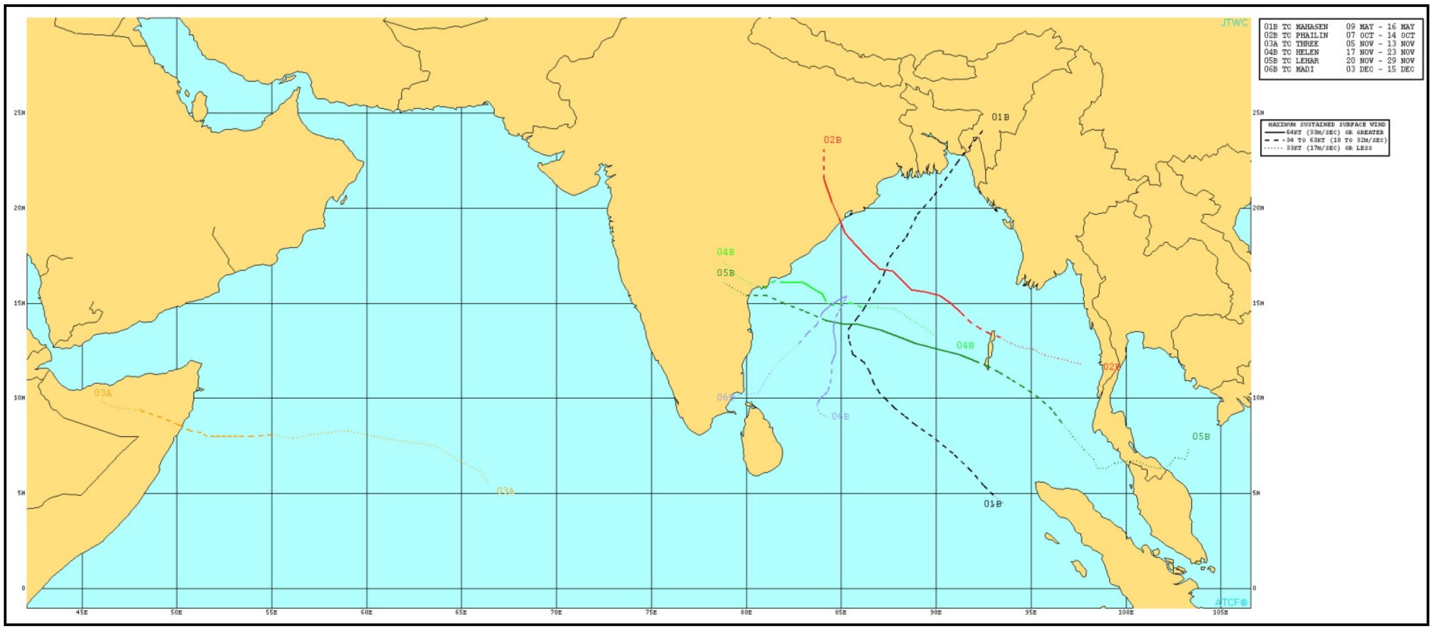


Figure 2-1. North Indian Ocean Tropical Cyclones.

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[1] stages of development:

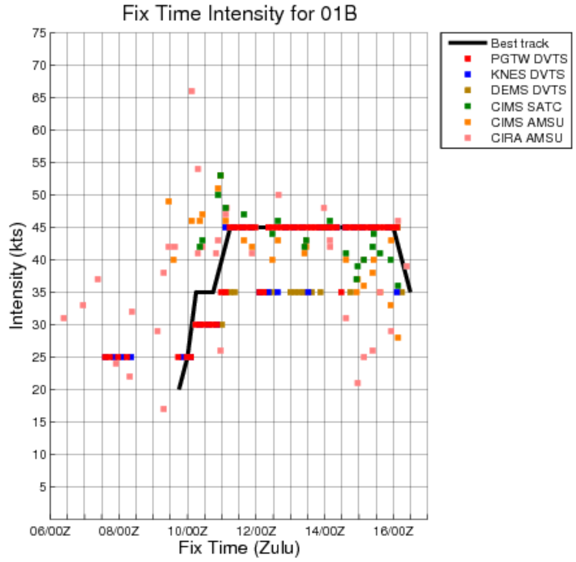
The first Tropical Cyclone Formation Alert (TCFA) and the initial and final warning dates are also presented with the number of warnings issued by JTWC. Landfall over major landmasses with approximate locations is presented as well.

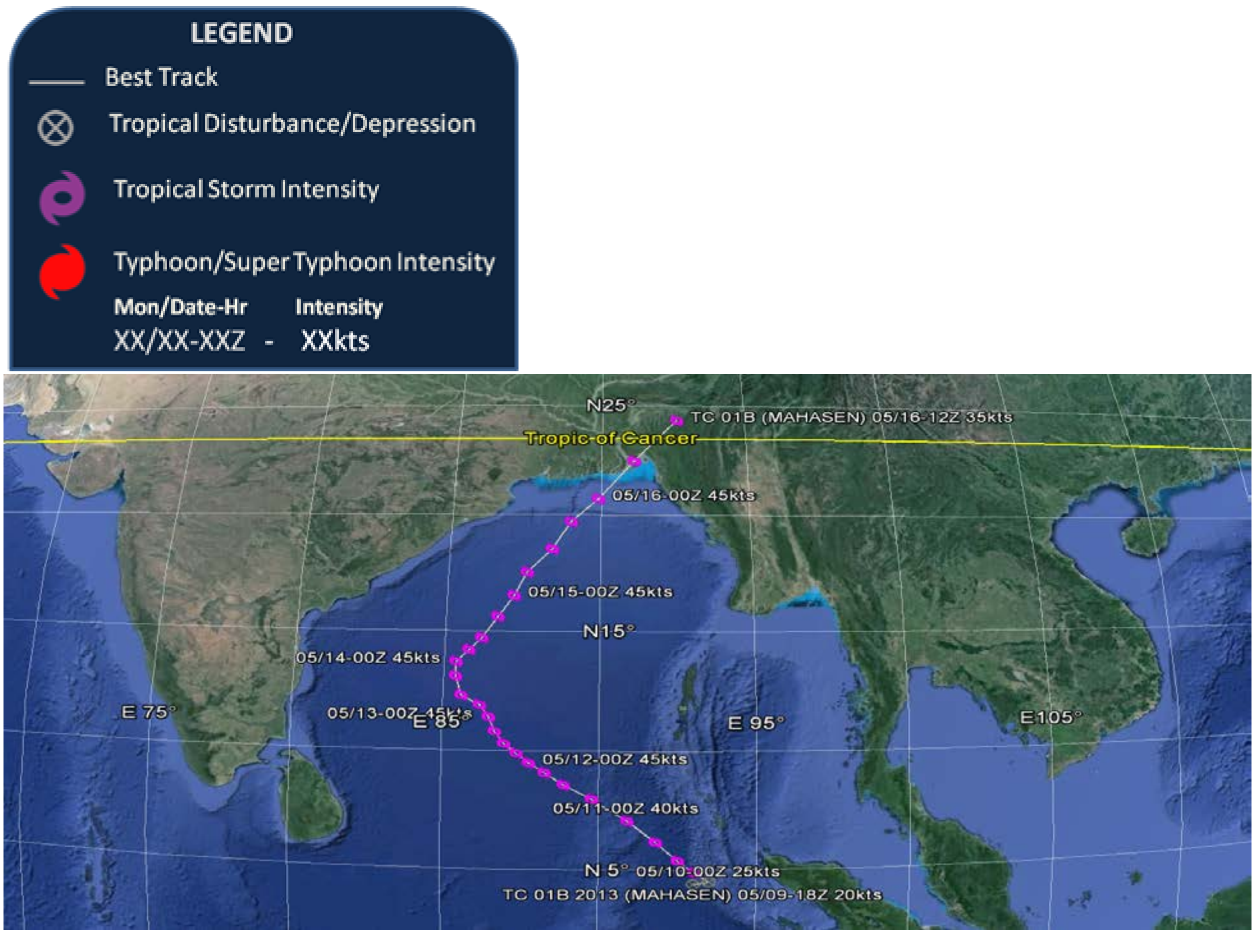
The JTWC post-event reanalysis best track is also provided for each cyclone. Data included on the best track are position and intensity noted with cyclone symbols and color coded track. Best track position labels include the date-time, track speed in knots, and maximum wind speed in knots. A graph of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

In addition, if 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:
http://www.usno.navy.mil/NOOC/nmfc-ph/RSS/jtwc/best_tracks/2013/2013-kmzs/

01B Tropical Cyclone Mahasen

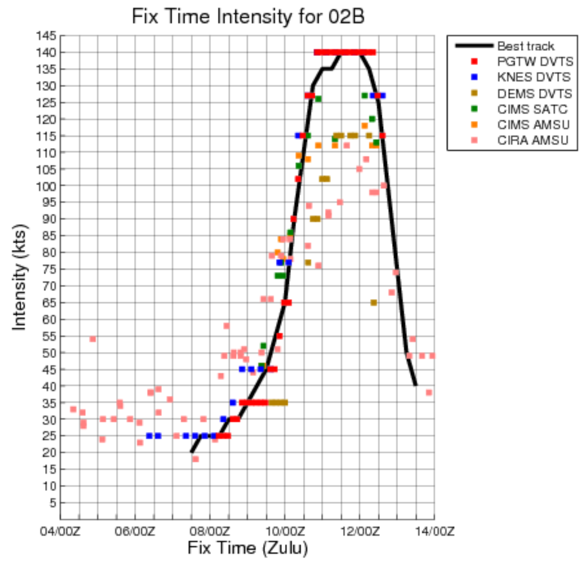
ISSUED LOW:	07 May / 1800Z
ISSUED MED:	08 May / 0230Z
FIRST TCFA:	10 May / 0200Z
FIRST WARNING:	10 May / 0600Z
LAST WARNING:	16 May / 0600Z
MAX INTENSITY:	45
WARNINGS:	25





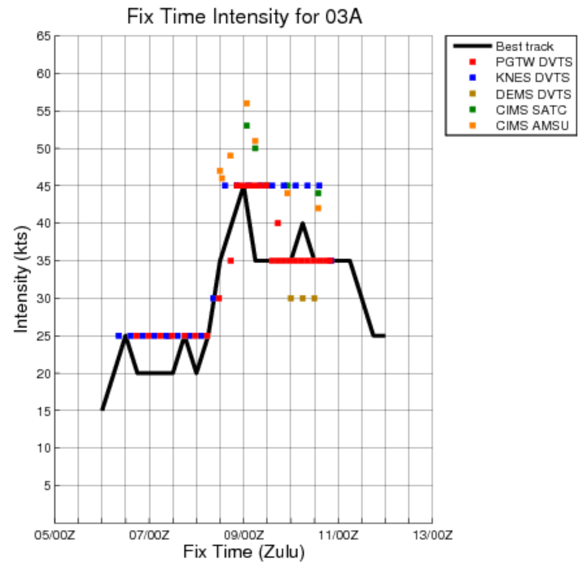
02B Tropical Cyclone Phailin

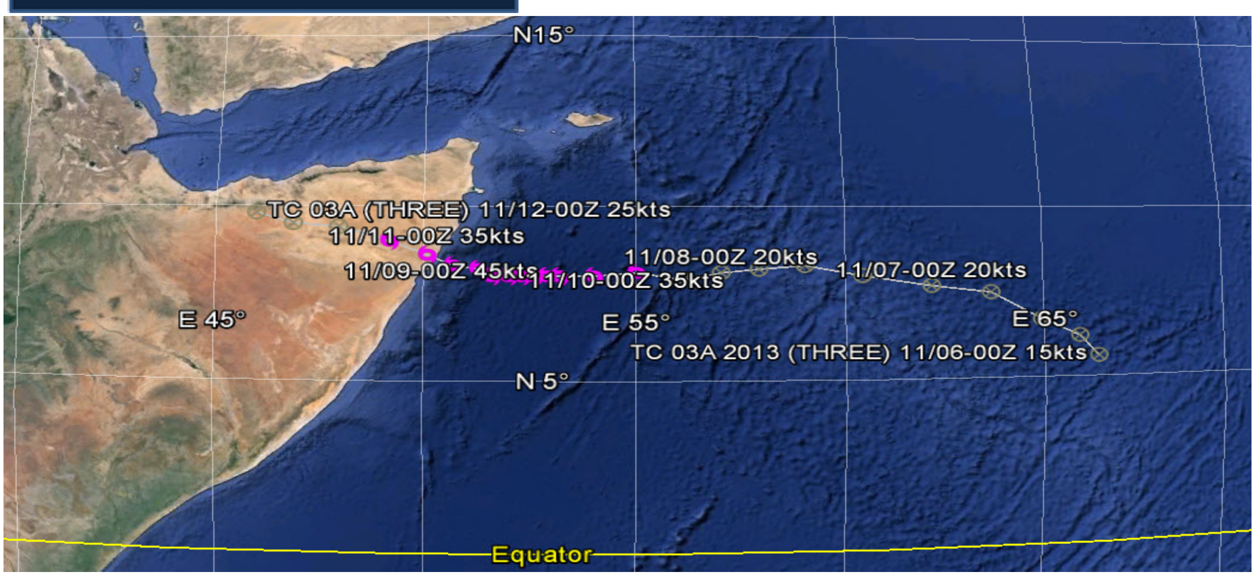
ISSUED LOW:	05 Oct / 1300Z
ISSUED MED:	07 Oct / 1800Z
FIRST TCFA:	08 Oct / 1000Z
FIRST WARNING:	09 Oct / 0000Z
LAST WARNING:	12 Oct / 1800Z
MAX INTENSITY:	140
WARNINGS:	16



03A Tropical Cyclone

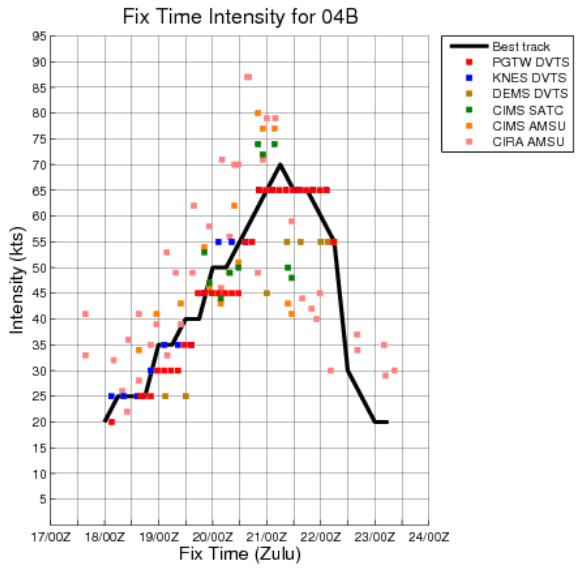
ISSUED LOW:	06 Nov / 1000Z
ISSUED MED:	08 Nov / 0600Z
FIRST TCFA:	08 Nov / 1200Z
FIRST WARNING:	08 Nov / 1800Z
LAST WARNING:	11 Nov / 0000Z
MAX INTENSITY:	45
WARNINGS:	10

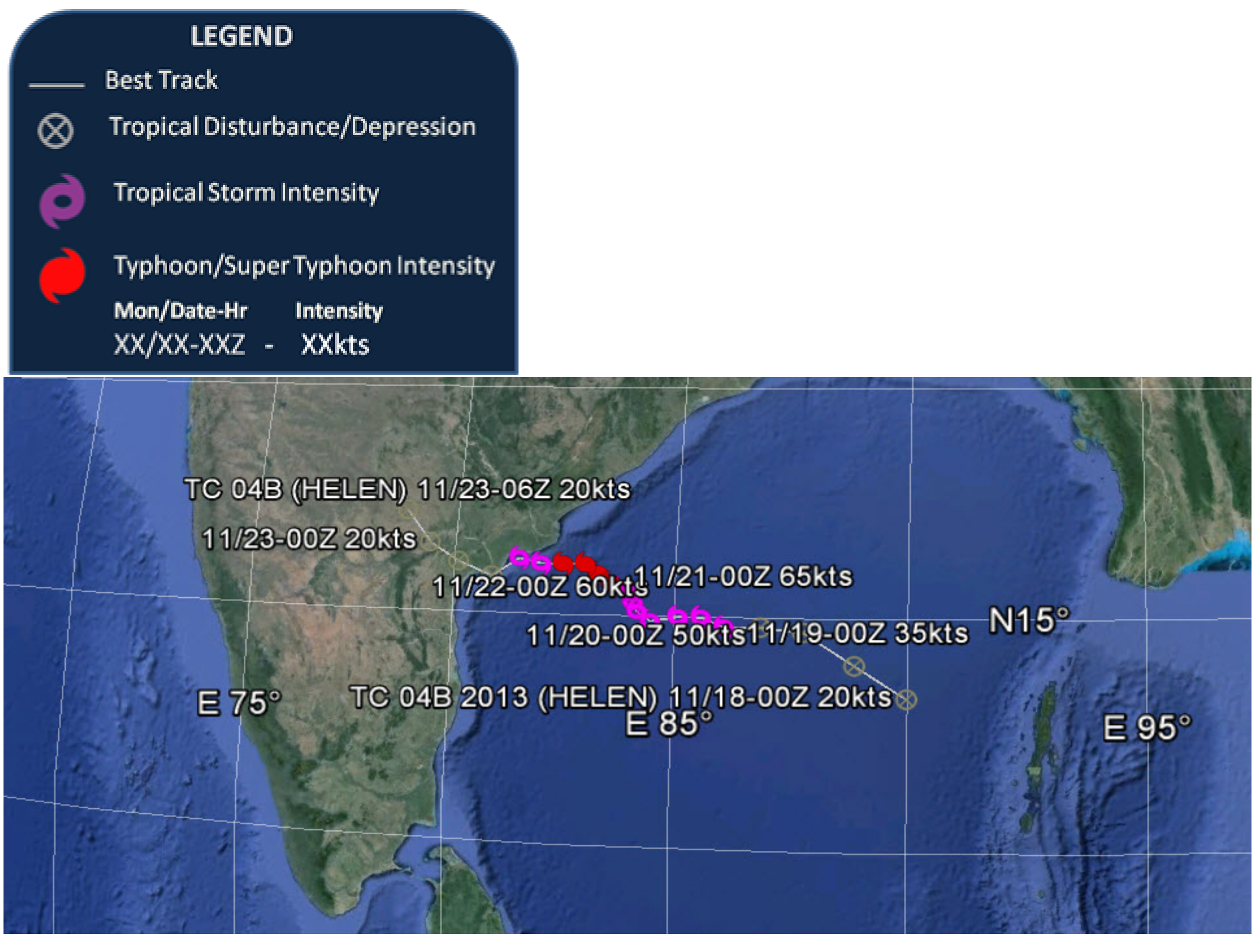




04B Tropical Cyclone Helen

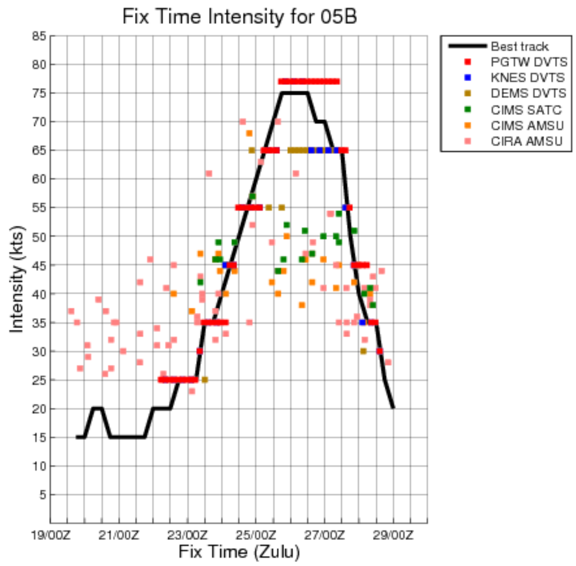
ISSUED LOW:	18 Nov / 0630Z
ISSUED MED:	18 Nov / 1800Z
FIRST TCFA:	19 Nov / 0200Z
FIRST WARNING:	19 Nov / 1200Z
LAST WARNING:	22 Nov / 0600Z
MAX INTENSITY:	70
WARNINGS:	12

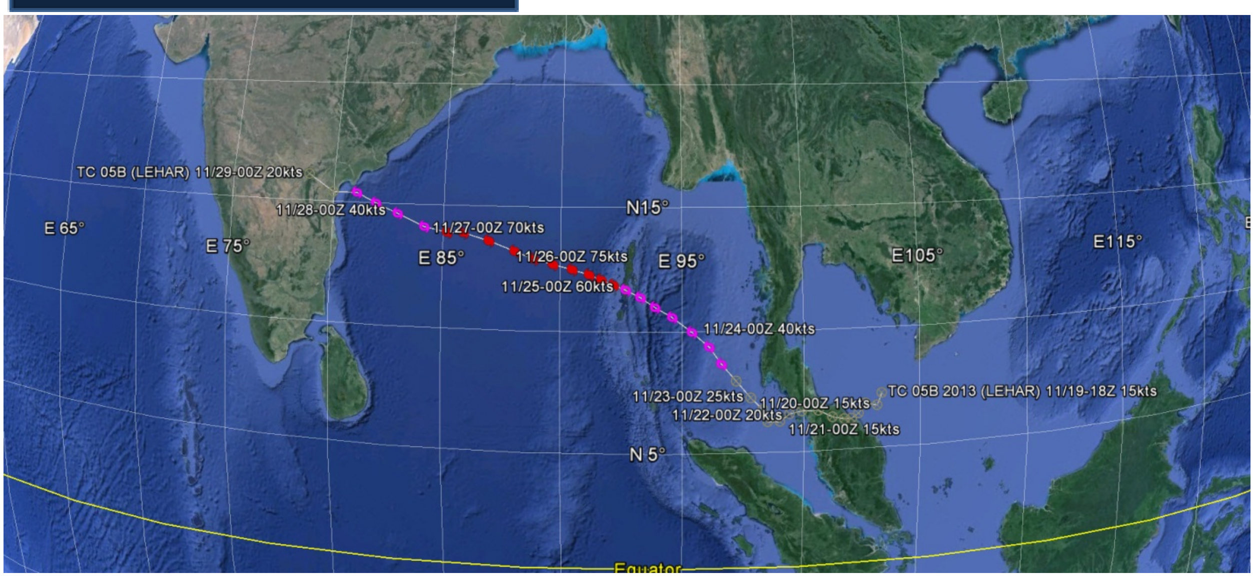




05B Tropical Cyclone Lehar

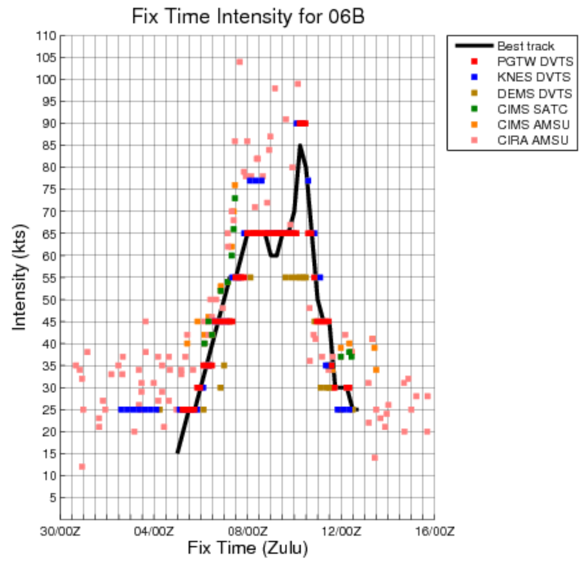
ISSUED LOW:	N/A
ISSUED MED:	21 Nov / 1330Z
FIRST TCFA:	22 Nov / 0930Z
FIRST WARNING:	23 Nov / 0600Z
LAST WARNING:	28 Nov / 0600Z
MAX INTENSITY:	75
WARNINGS:	21

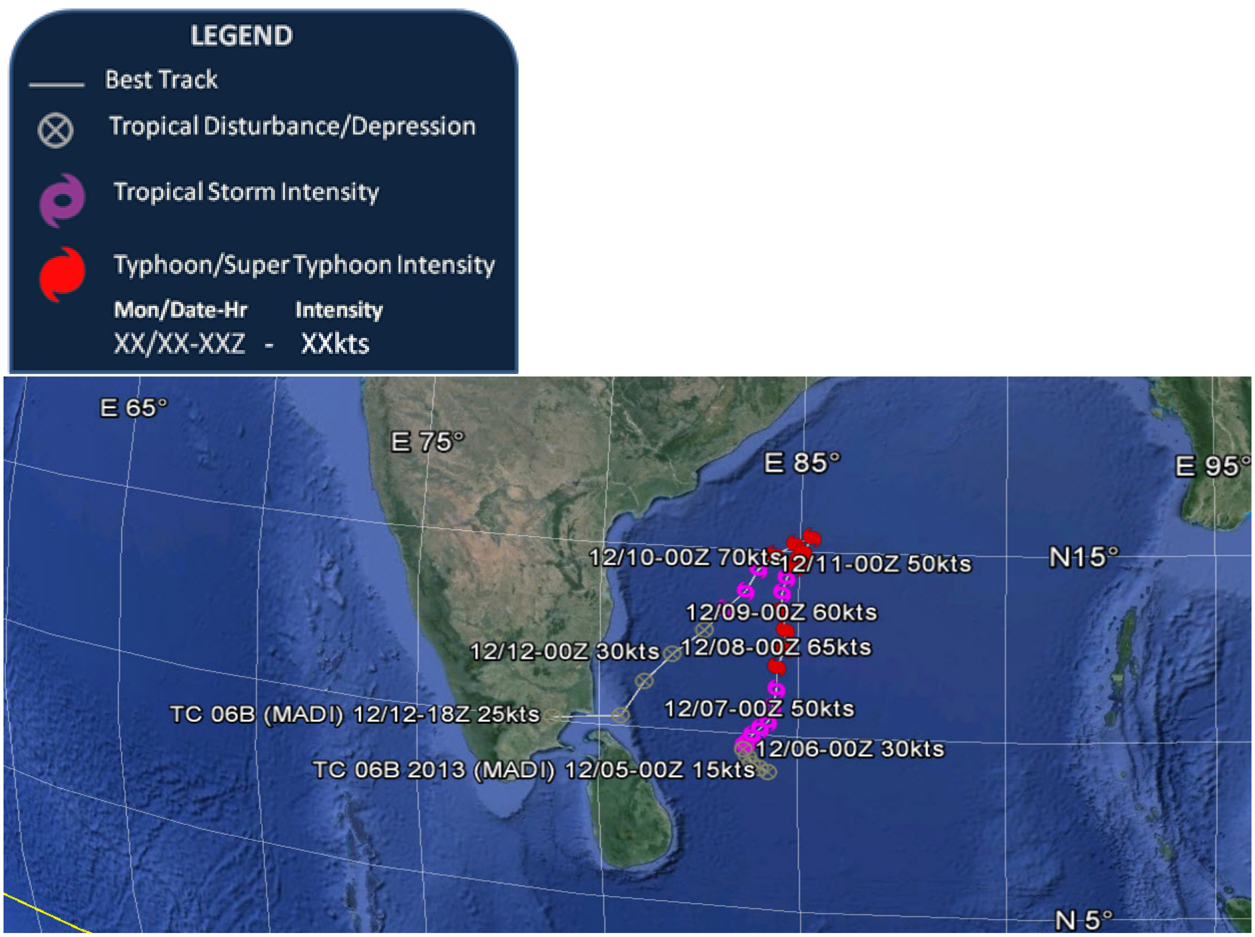




06B Tropical Cyclone Madi

ISSUED LOW:	01 Dec / 1800Z
ISSUED MED:	04 Dec / 0830Z
FIRST TCFA:	05 Dec / 1500
FIRST WARNING:	06 Dec / 0000Z
LAST WARNING:	12 Dec / 0000Z
MAX INTENSITY:	85
WARNINGS:	25





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 2013 tropical cyclone season (1 July 2012 – 30 June 2013) and the monthly distribution of TC activity summarized for 1975 - 2013.

Section 1 Informational Tables

Table 3-1 is a summary of TC activity in the Southern Hemisphere during the 2013 season.

Table 3-1

SOUTHERN HEMISPHERE TROPICAL CYCLONES FOR 2013

(01 JULY 2012- 30 JUNE 2013)

TC	NAME*	PERIOD**		WARNINGS ISSUED	EST MAX SFC WINDS KTS
01S	Anais	12 Oct / 1200Z	17 Oct / 1200Z	11	115
02S	Boldwin	24 Nov / 0600Z	25 Nov / 1800Z	4	55
03S	Claudia	06 Dec / 1200Z	13 Dec / 0000Z	14	115
04P	Evan	11 Dec / 1800Z	19 Dec / 1800Z	22	125
05P	Freda	28 Dec / 1200Z	02 Jan / 0000Z	10	110
06S	Mitchell	28 Dec / 1800Z	30 Dec / 0600Z	7	45
07S	Dumile	31 Dec / 1800Z	05 Jan / 0600Z	10	75
08S	Narelle	07 Jan / 1800Z	14 Jan / 1800Z	26	120
09S	Emang	12 Jan 1800Z	17 Jan / 0600Z	10	35
10P	Garry	20 Jan / 1200Z	27 Jan / 0600Z	16	125
11P	Oswald	21 Jan / 0600Z	21 Jan / 1800Z	2	45
12S	Peta	22 Jan / 1800Z	23 Jan / 1200Z	4	35
13S	Felleng	26 Jan / 1500Z	3 Feb / 1800Z	18	115
14P	Haley	10 Feb / 0000Z	11 Feb / 0000Z	3	45
15S	Gino	11 Feb / 0000Z	15 Feb / 1200Z	10	90
16S	Haruna	19 Feb / 0000Z	25 Feb / 0000Z	13	105
17S	Rusty	24 Feb / 0000Z	27 Feb / 1200Z	14	100
18S	-	24 Feb / 1200Z	27 Feb / 0000Z	6	40
19P	Sandra	07 Mar / 1200Z	14 Mar / 0000Z	14	110
20P	Tim	13 Mar / 1800Z	17 Mar / 1800Z	9	50
21S	Imelda	06 Apr / 0600Z	16 Apr / 0600Z	21	85
22S	Victoria	09 Apr / 0000Z	12 Apr / 0000Z	7	75
23P	Zane	30 Apr / 0000Z	01 May / 2100Z	5	65
24S	Jamala	08 May / 1200Z	11 May / 1800Z	8	45

* As designated by the responsible RSMC

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

Table 3-2 provides the monthly distribution of Tropical Cyclone activity summarized for 1975 - 2013.

Table 3-2 DISTRIBUTION OF SOUTH PACIFIC AND SOUTH INDIAN OCEAN TROPICAL CYCLONES FOR 1958 - 2013													
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 - 2013													
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
(1981 - 2013)													
MEAN	0.3	0.1	0.3	0.7	1.5	3.2	5.9	6.2	4.8	3.0	0.8	0.2	26.9
CASES	9	3	9	22	51	105	195	206	157	98	26	8	889
* (GRAY, 1978)													

1) If a tropical cyclone was warned on prior to the last two days of a month, it was attributed to the first month, regardless of how long the system lasted.
2) If a tropical cyclone began on the last day of the month and ended on the first day of the next month, that system was attributed to the first month. However, if a tropical cyclone began on the last day of the month and continued into the next month for only two days, it was attributed to the second month.

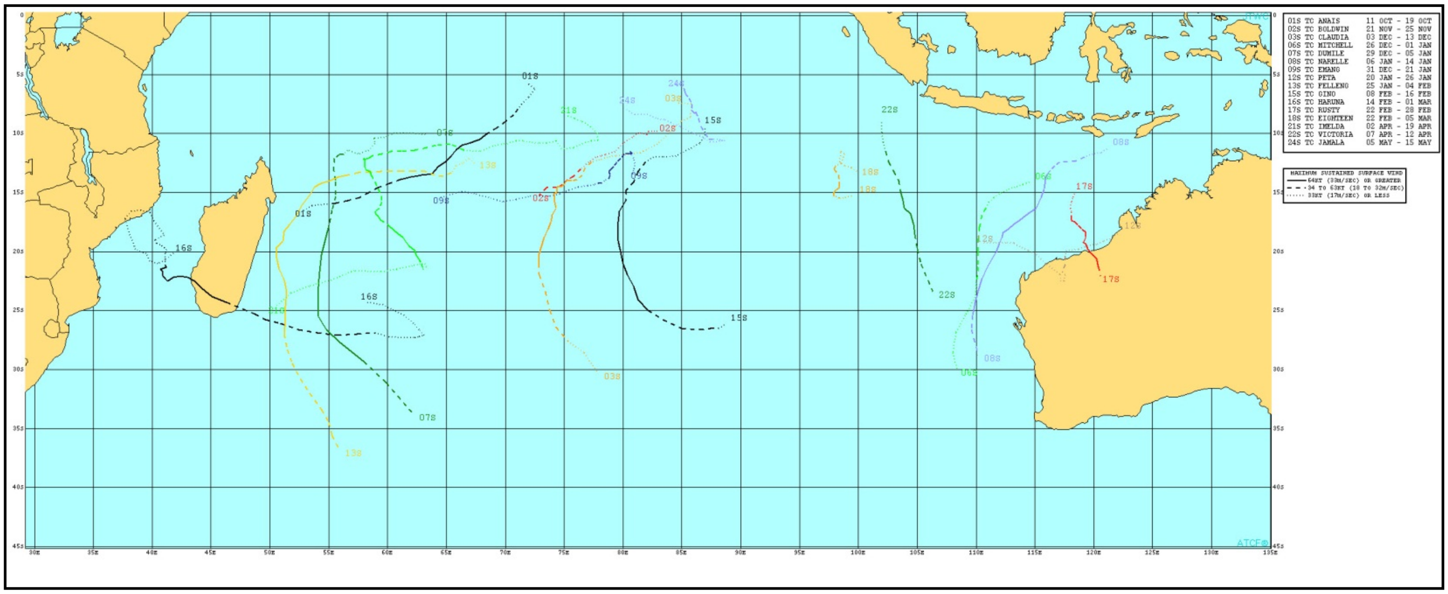


Figure 3-1. Southern Indian Ocean Tropical Cyclones.

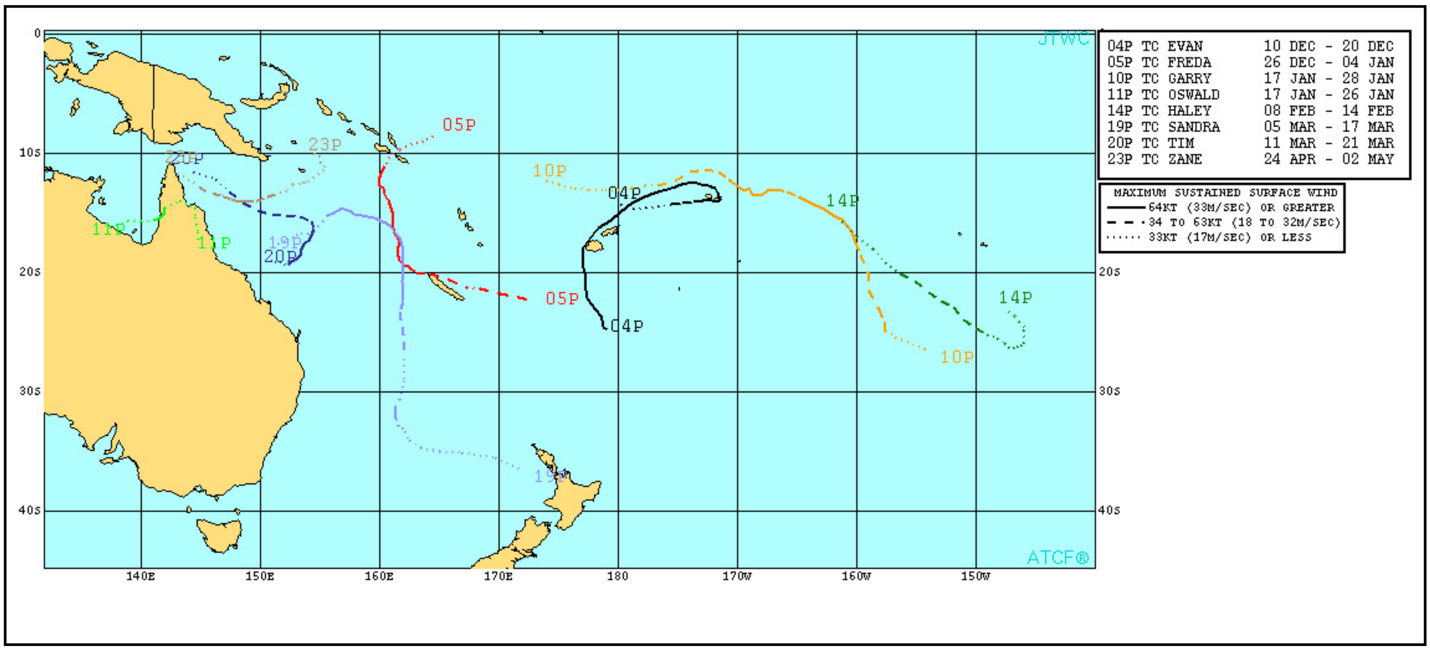


Figure 3-2. Southeast Pacific Ocean Tropical Cyclones.

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.

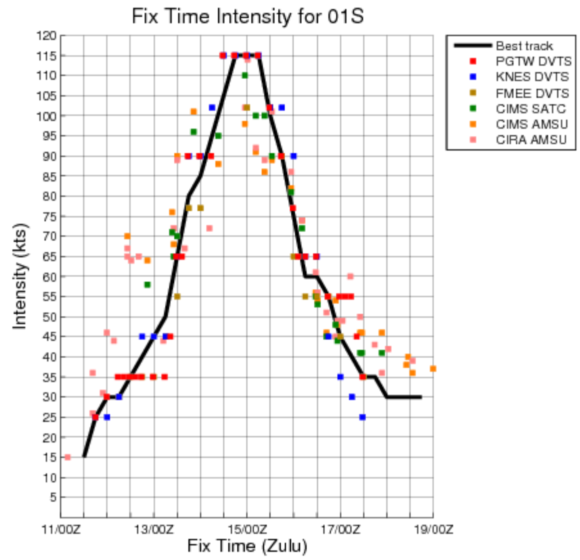
The first Tropical Cyclone Formation Alert (TCFA) and the initial and final warning dates are also presented with the number of warnings issued by JTWC. Landfall over major landmasses with approximate locations is presented as well.

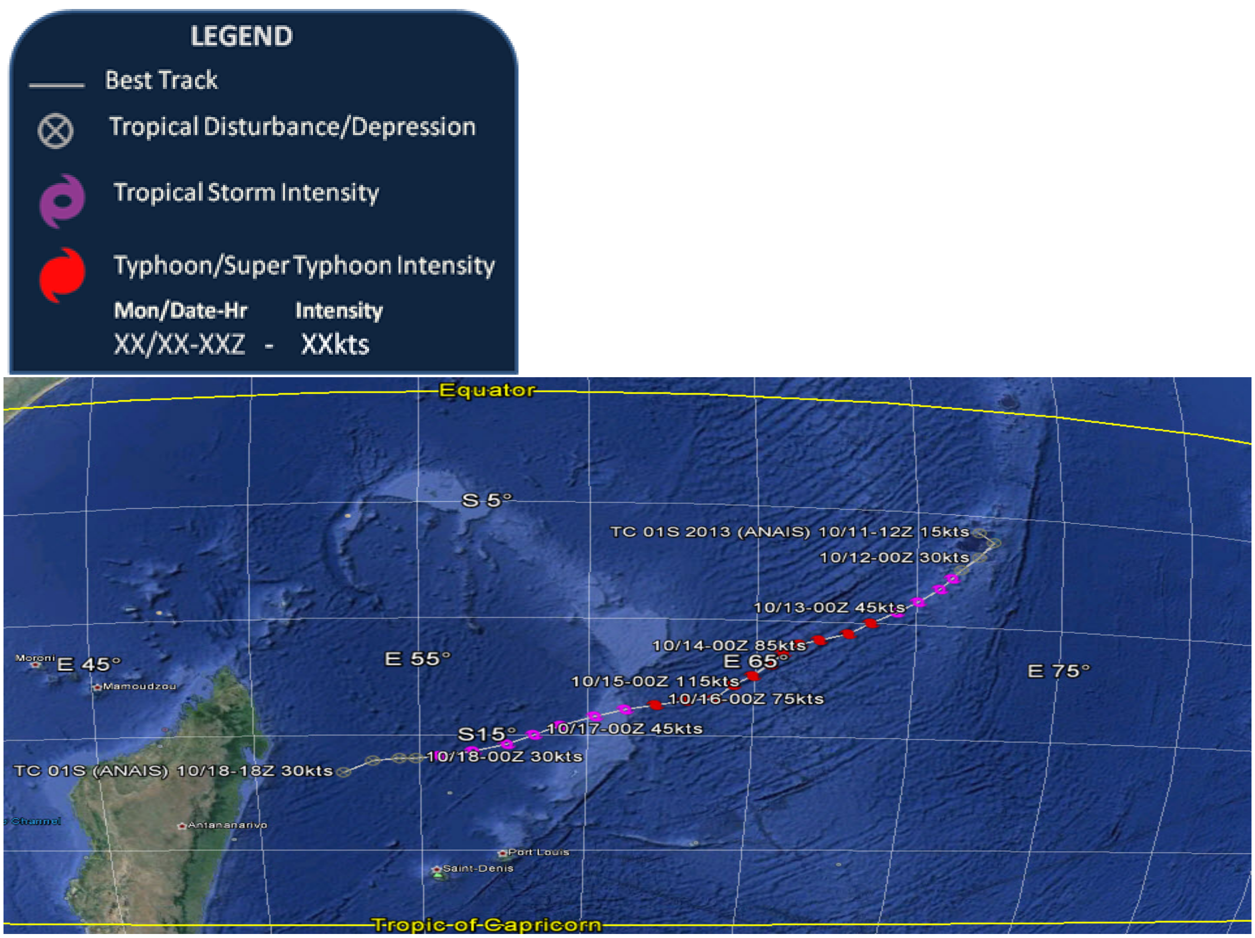
Data included on the best track are position and intensity noted with cyclone symbols and color coded track. Best track position labels include the date-time, track speed in knots, and maximum wind speed in knots. A graph of best track intensity versus time is presented. Fix plots on this graph are color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

In addition, if 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:
http://www.usno.navy.mil/NOOC/nmfc-ph/RSS/jtwc/best_tracks/2013/2013-kmzs/

01S Tropical Cyclone Anais

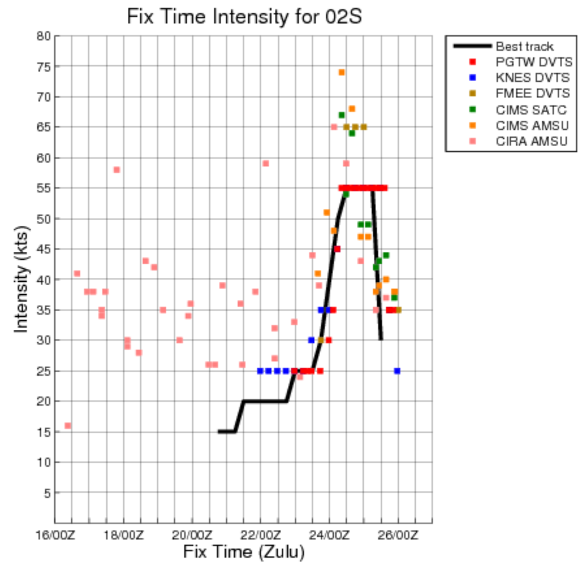
ISSUED LOW:	11 Oct 1800Z
ISSUED MED:	11 Oct 2300Z
FIRST TCFA:	12 Oct / 0500Z
FIRST WARNING:	12 Oct / 1200Z
LAST WARNING:	17 Oct / 1200Z
MAX INTENSITY:	115
WARNINGS:	11

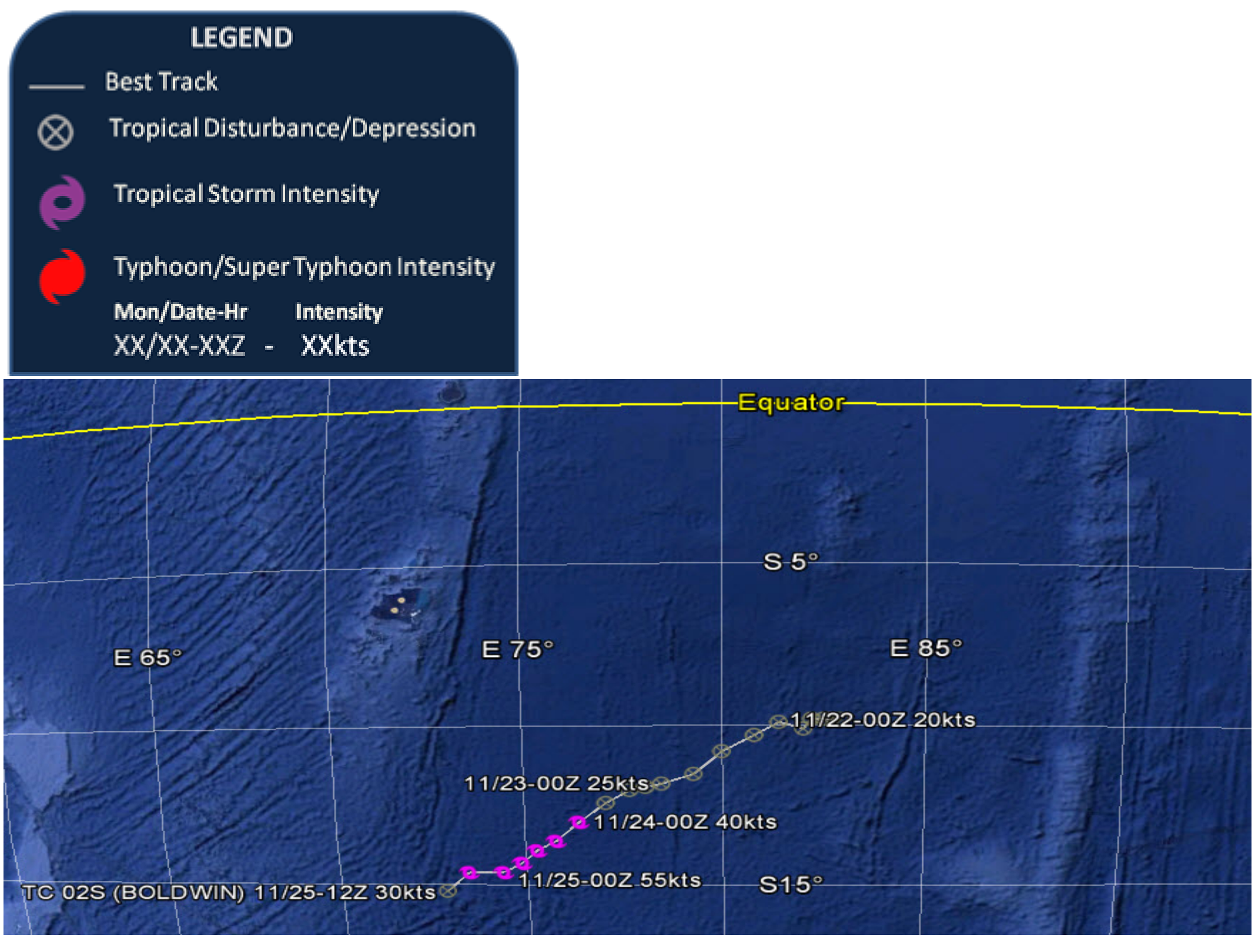




02S Tropical Cyclone Boldwin

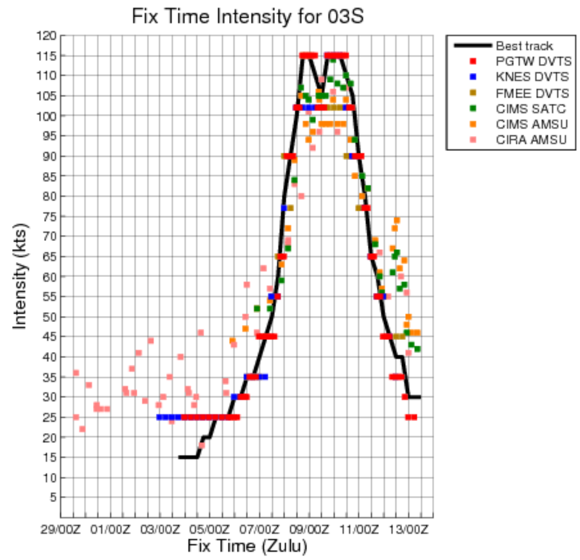
ISSUED LOW: N/A
ISSUED MED: 23 Nov 1000Z
FIRST TCFA: 24 Nov 0230Z
FIRST WARNING: 24 Nov 0600Z
LAST WARNING: 25 Nov / 1800Z
MAX INTENSITY: 55
WARNINGS: 4

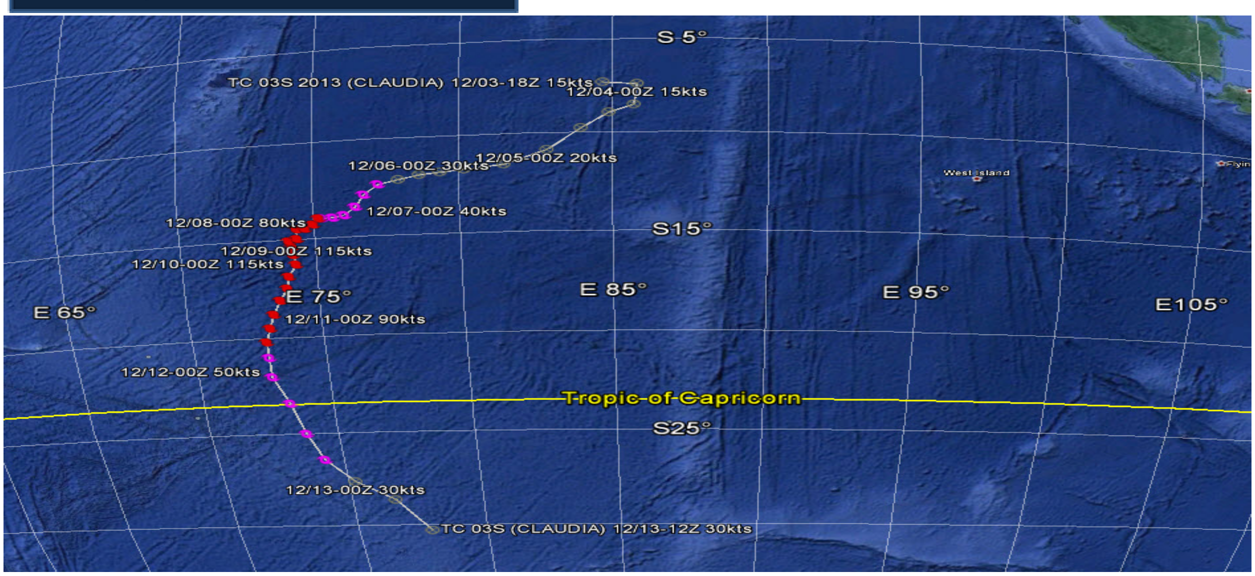




03S Tropical Cyclone Claudia

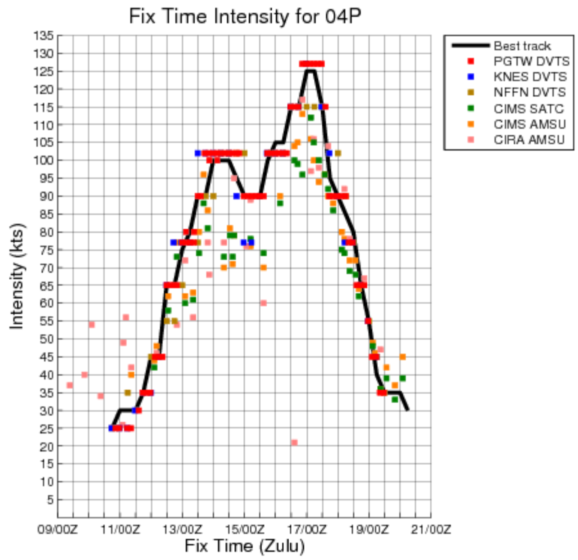
ISSUED LOW:	04 Dec / 0000Z
ISSUED MED:	05 Dec / 0600Z
FIRST TCFA:	06 Dec / 0230Z
FIRST WARNING:	06 Dec / 1200Z
LAST WARNING:	13 Dec / 0000Z
MAX INTENSITY:	115
WARNINGS:	14

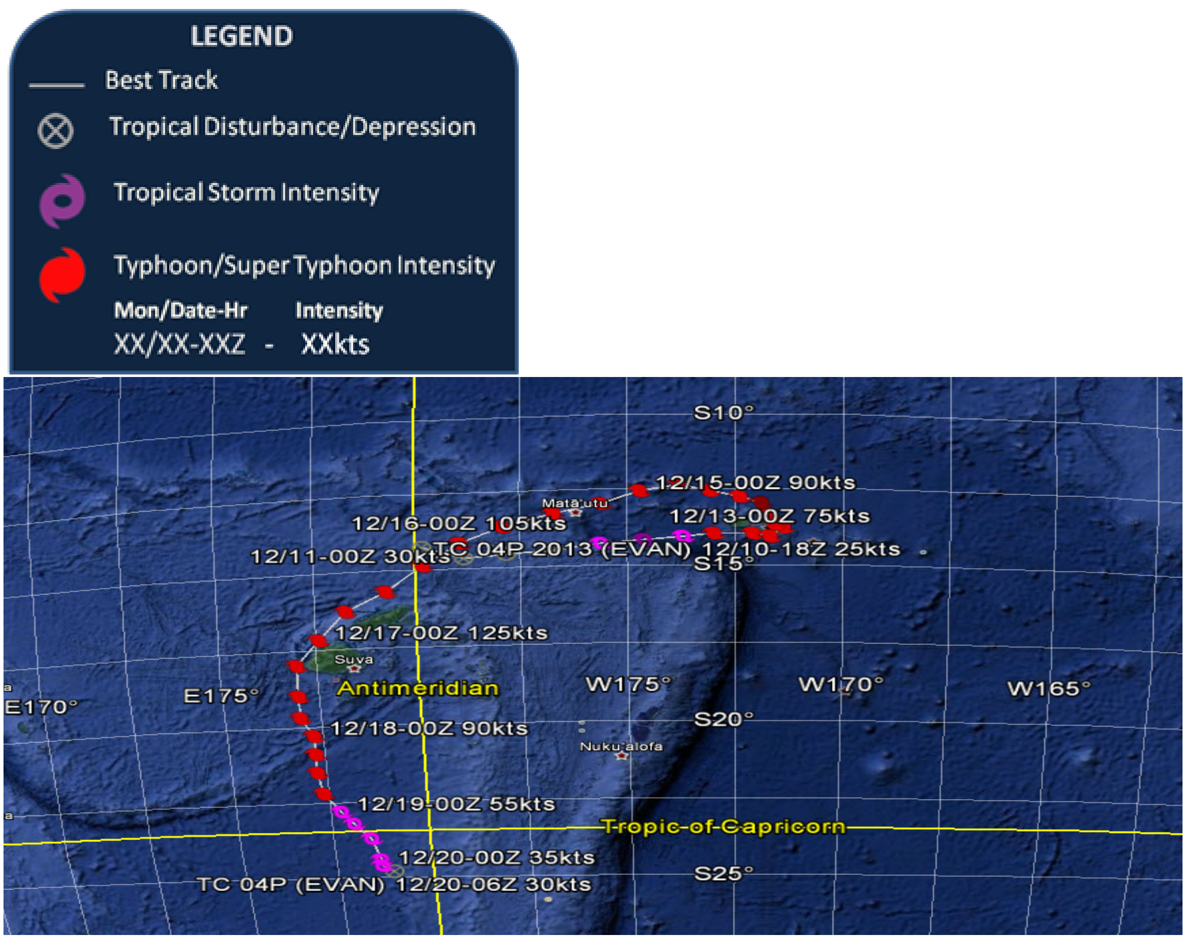




04P Tropical Cyclone Evan

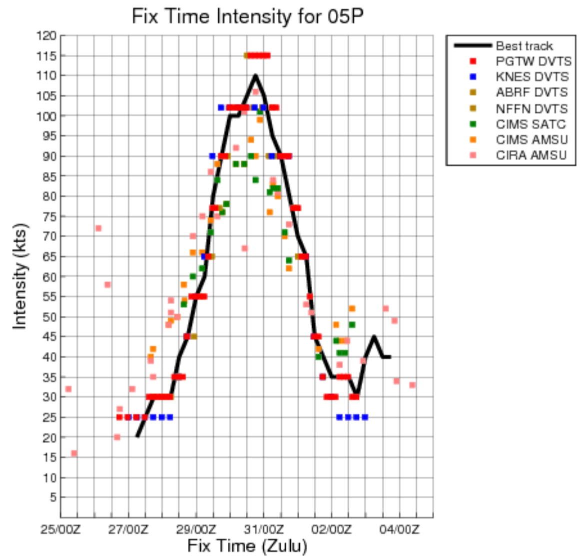
ISSUED LOW:	10 Dec / 1000Z
ISSUED MED:	N/A
FIRST TCFA:	11 Dec / 0500Z
FIRST WARNING:	11 Dec / 1800Z
LAST WARNING:	19 Dec / 1800Z
MAX INTENSITY:	125
WARNINGS:	22

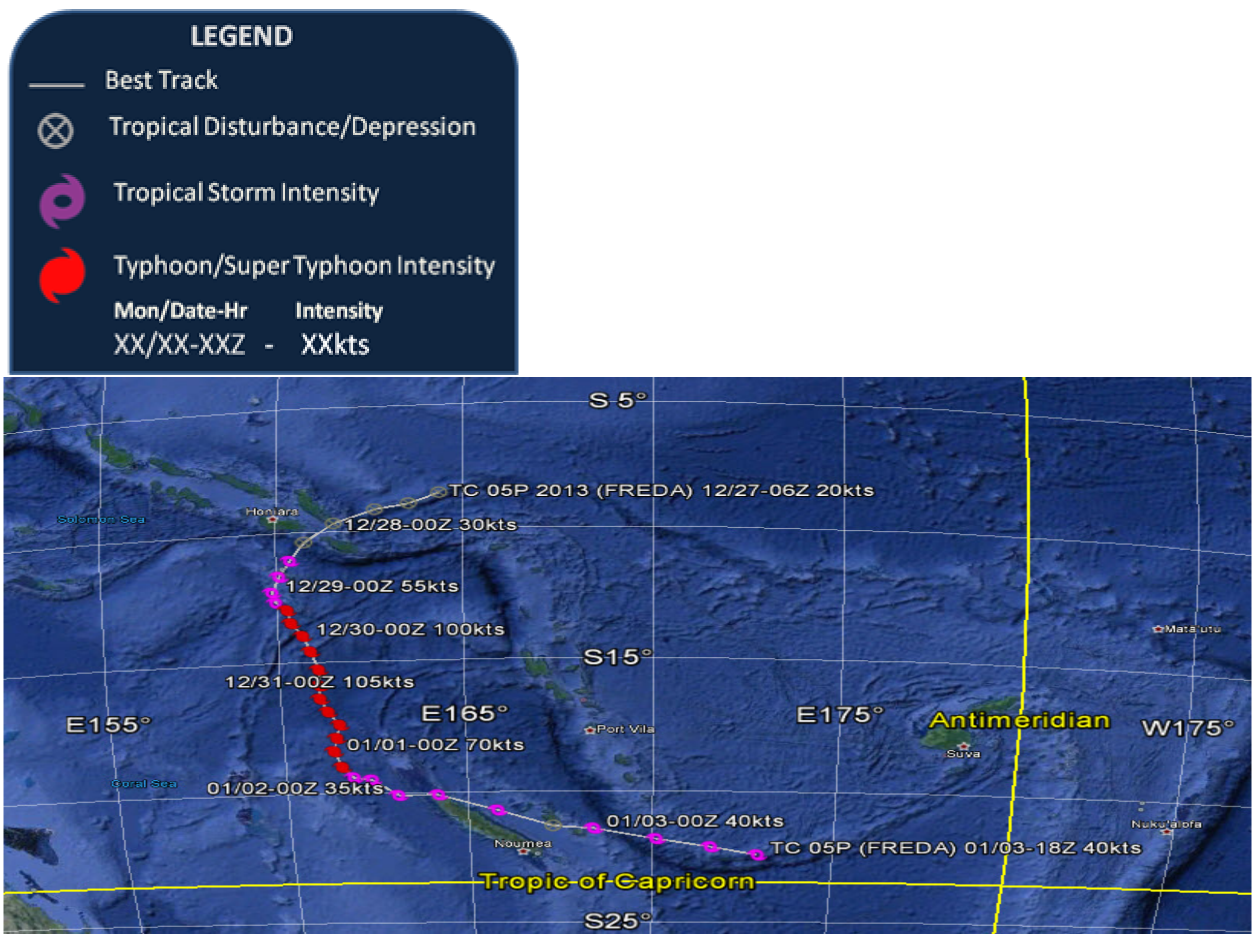




05P Tropical Cyclone Freda

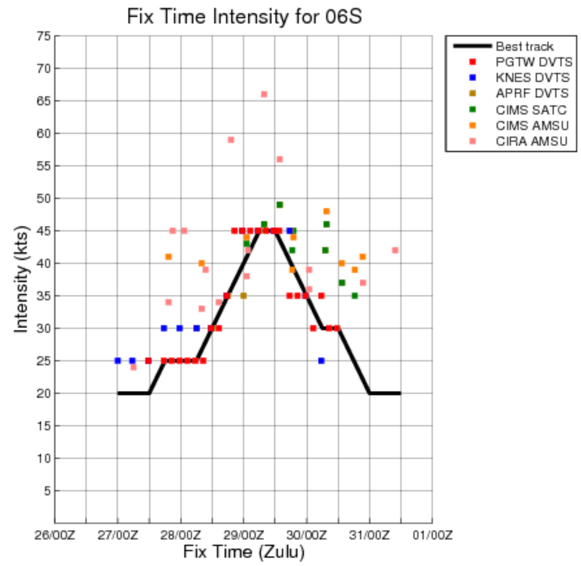
ISSUED LOW:	26 Dec 1200Z
ISSUED MED:	27 Dec 0600Z
FIRST TCFA:	27 Dec / 1430Z
FIRST WARNING:	28 Dec / 1200Z
LAST WARNING:	02 Jan 0000Z
MAX INTENSITY:	110
WARNINGS:	10





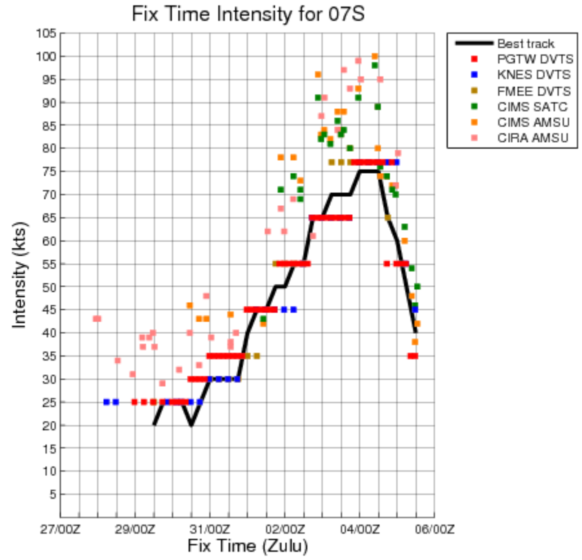
06S Tropical Cyclone Mitchell

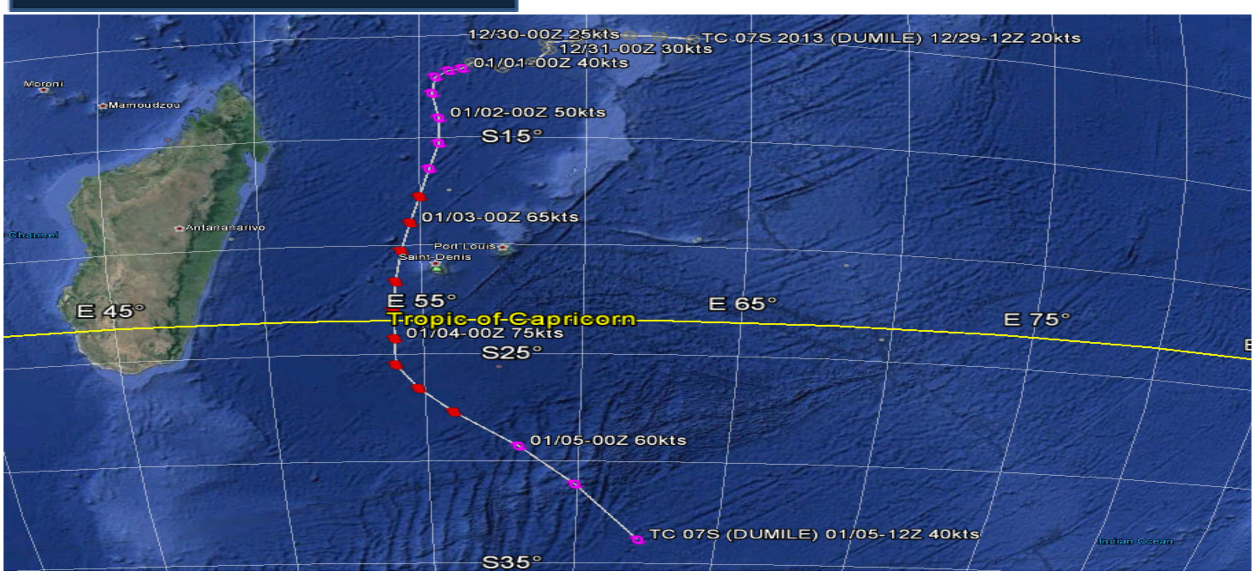
ISSUED LOW:	27 Dec / 1330Z
ISSUED MED:	28 Dec / 0130Z
FIRST TCFA:	28 Dec / 0930Z
FIRST WARNING:	28 Dec / 1800Z
LAST WARNING:	30 Dec / 0600Z
MAX INTENSITY:	45
WARNINGS:	7



07S Tropical Cyclone Dumile

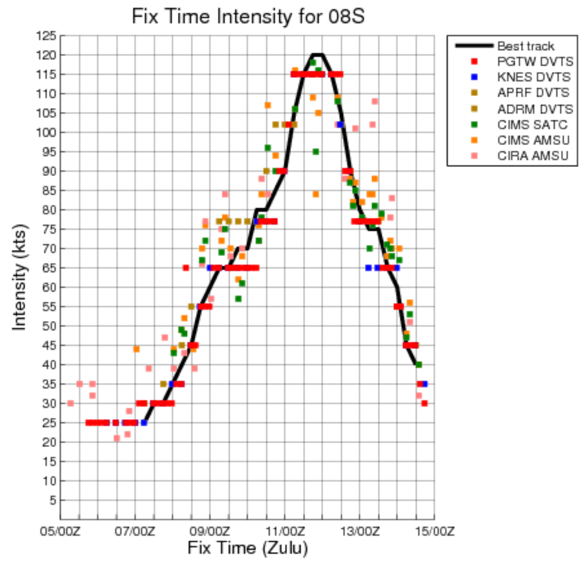
ISSUED LOW:	28 Dec /.1030Z
ISSUED MED:	28 Dec / 1800Z
FIRST TCFA:	30 Dec / 0000Z
FIRST WARNING:	31 Dec / 1800Z
LAST WARNING:	05 Jan / 0600Z
MAX INTENSITY:	75
WARNINGS:	10





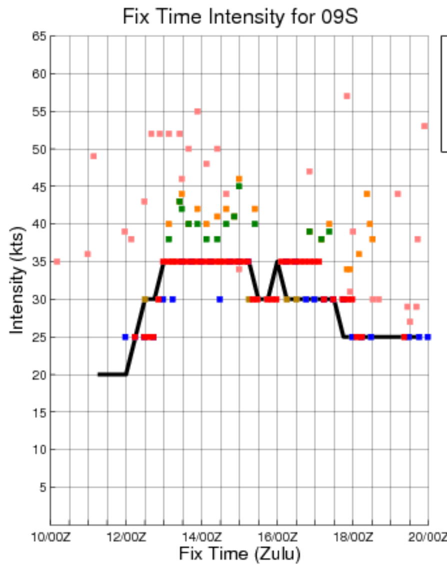
08S Tropical Cyclone Narelle

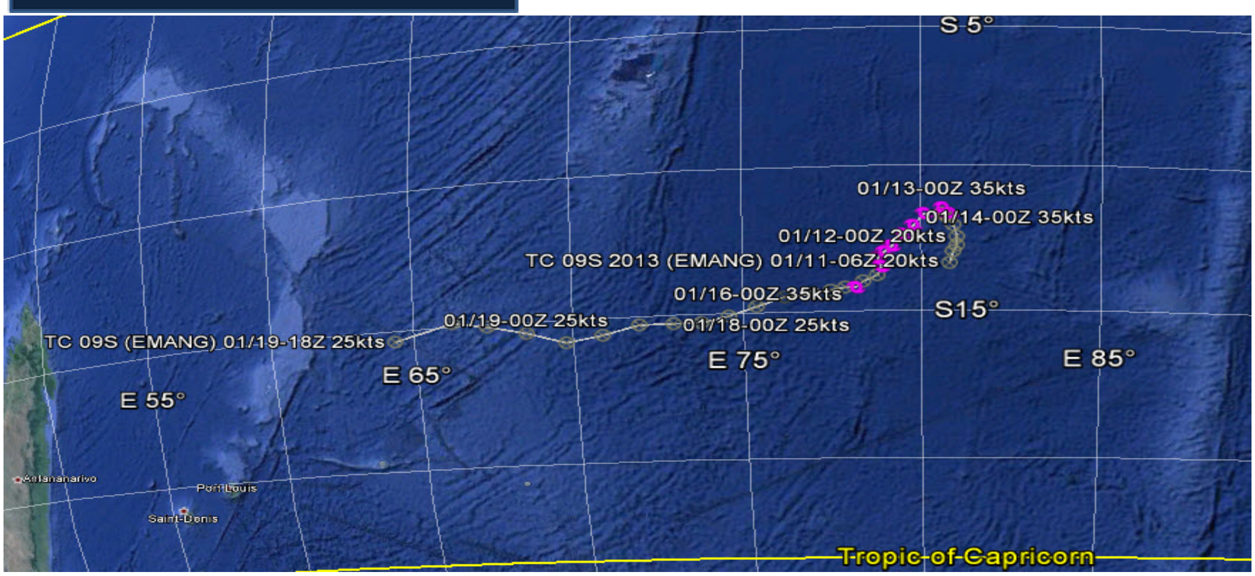
ISSUED LOW: N/A
ISSUED MED: 05 Jan / 2200Z
FIRST TCFA: 07 Jan / 1100Z
FIRST WARNING: 07 Jan / 1800Z
LAST WARNING: 14 Jan / 1800Z
MAX INTENSITY: 120
WARNINGS: 26



09S Tropical Cyclone Emang

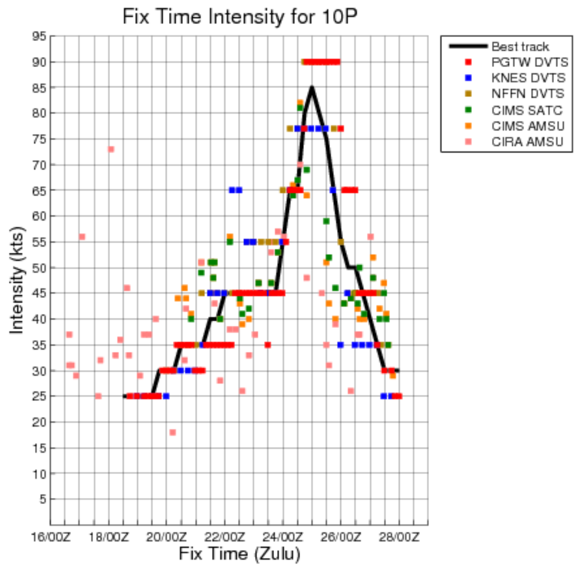
ISSUED LOW:	28 Dec / 1030Z
ISSUED MED:	31 Dec 0300Z
FIRST TCFA:	1 Jan / 2330Z
FIRST WARNING:	12 Jan 1800Z
LAST WARNING:	17 Jan 0600Z
MAX INTENSITY:	35
WARNINGS:	10

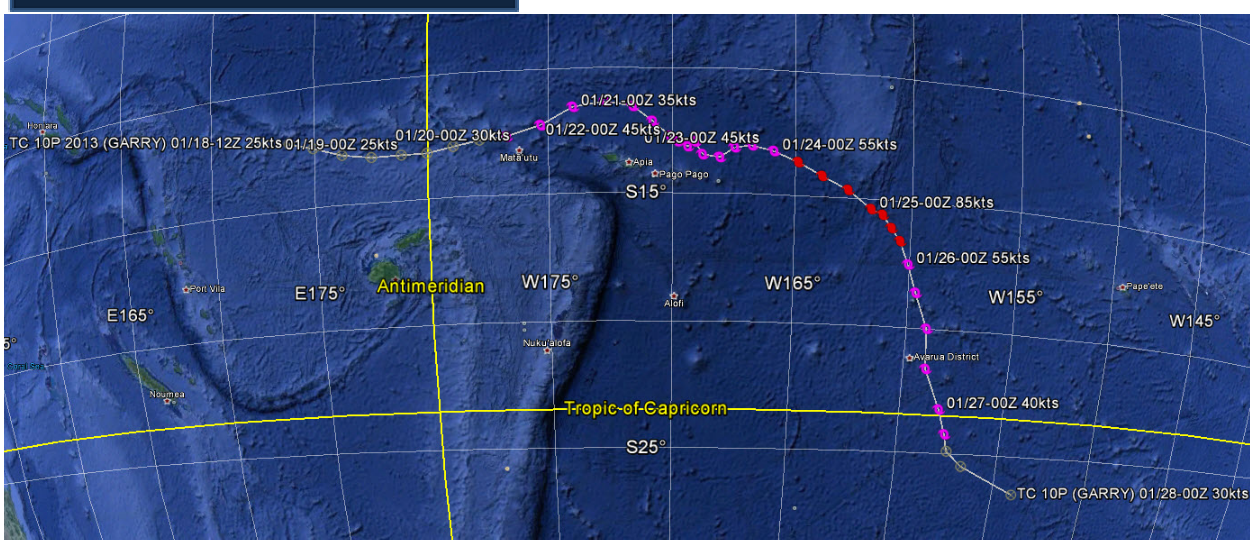




10P Tropical Cyclone Garry

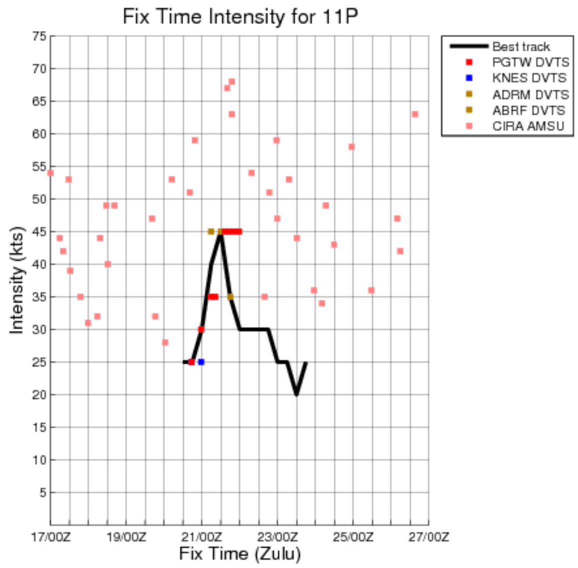
ISSUED LOW:	18 Jan / 0600Z
ISSUED MED:	18 Jan /1430Z
FIRST TCFA:	19 Jan / 2000Z
FIRST WARNING:	20 Jan / 1200Z
LAST WARNING:	27 Jan / 0600Z
MAX INTENSITY:	85
WARNINGS:	16

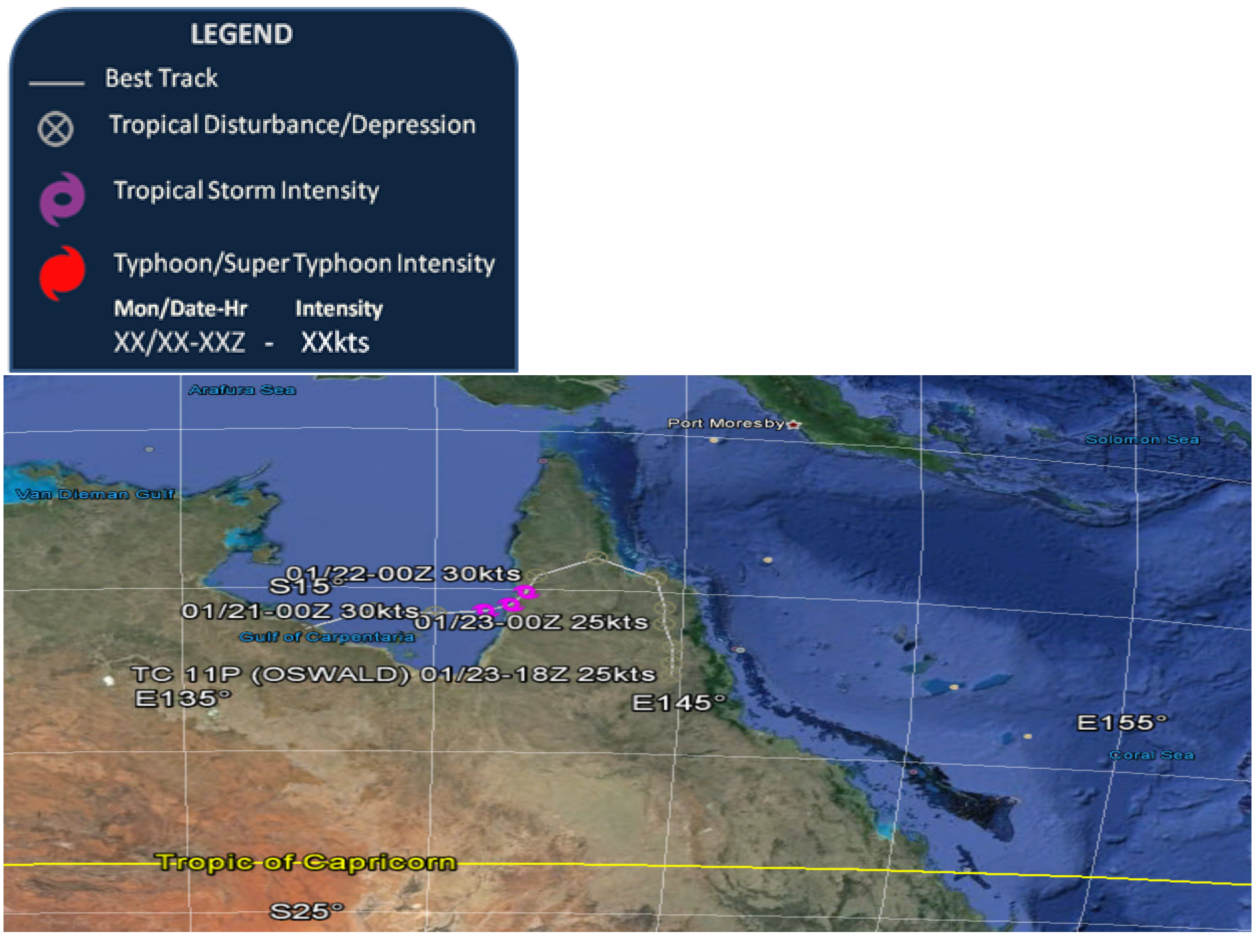




11P Tropical Cyclone Oswald

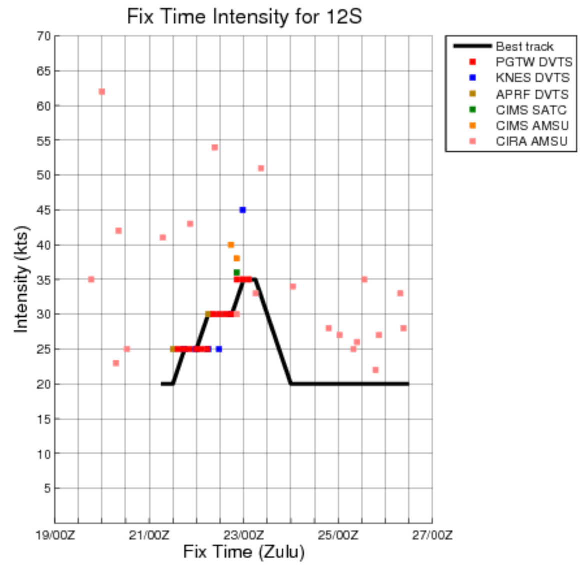
ISSUED LOW:	17 Jan / 0200Z
ISSUED MED:	20 Jan / 1400Z
FIRST TCFA:	21 Jan / 0430Z
FIRST WARNING:	21 Jan / 0600Z
LAST WARNING:	21 Jan / 1800Z
MAX INTENSITY:	45
WARNINGS:	2





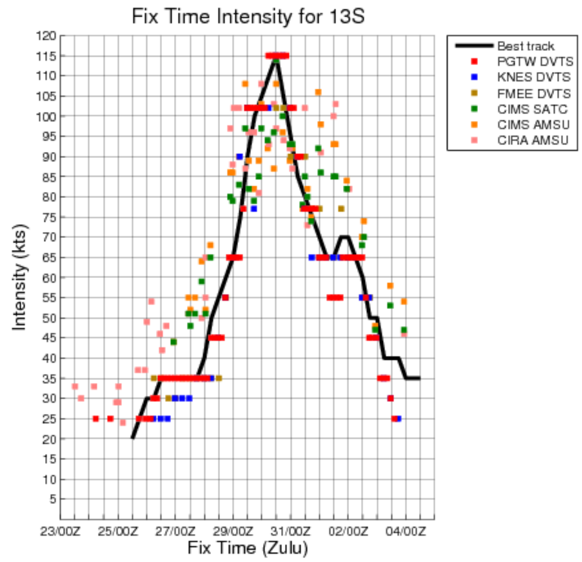
12S Tropical Cyclone Peta

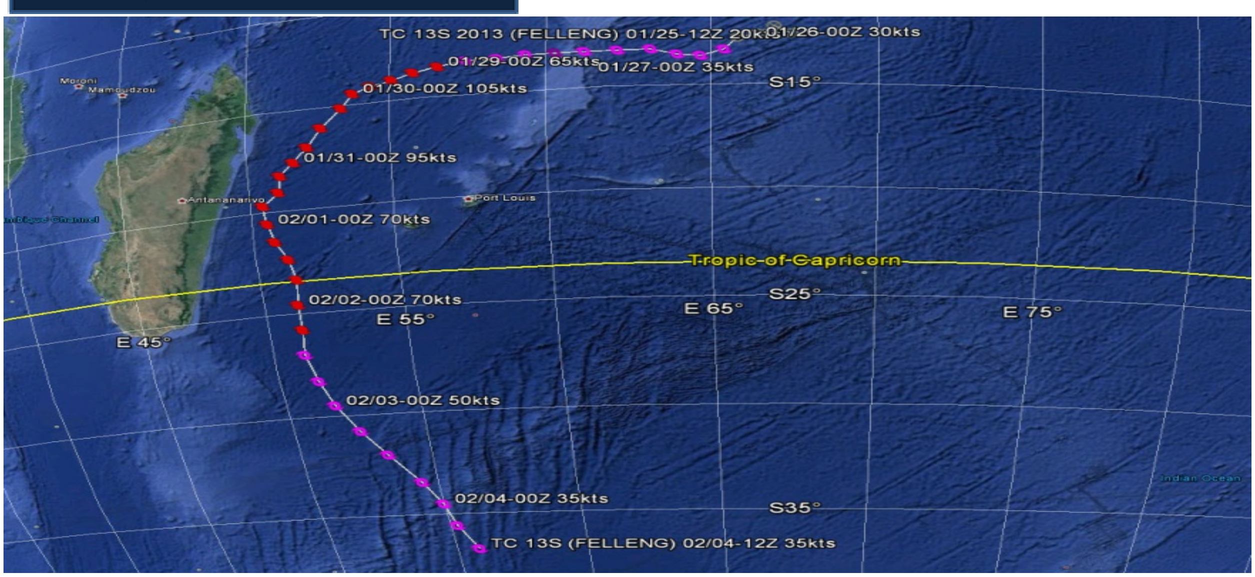
ISSUED LOW:	N/A
ISSUED MED:	21 Jan / 1030Z
FIRST TCFA:	21 Jan / 2200Z
FIRST WARNING:	22 Jan / 1800Z
LAST WARNING:	23 Jan / 1200Z
MAX INTENSITY:	35
WARNINGS:	4



13S Tropical Cyclone Felleng

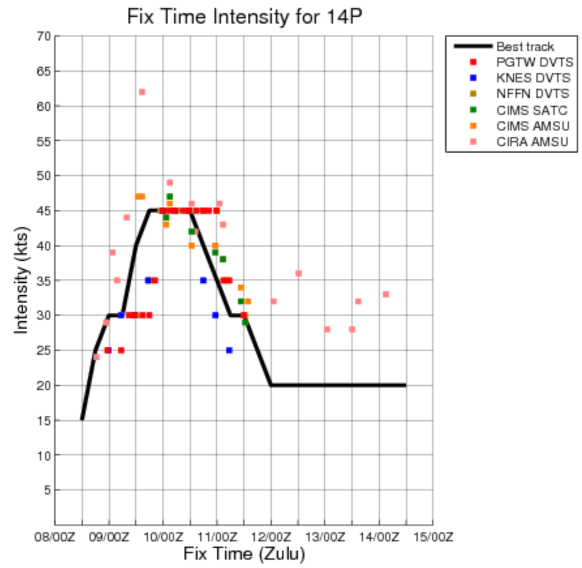
ISSUED LOW:	25 Jan / 1800Z
ISSUED MED:	26 Jan / 0300Z
FIRST TCFA:	26 Jan / 0930Z
FIRST WARNING:	26 Jan / 1500Z
LAST WARNING:	3 Feb / 1800Z
MAX INTENSITY:	115
WARNINGS:	18

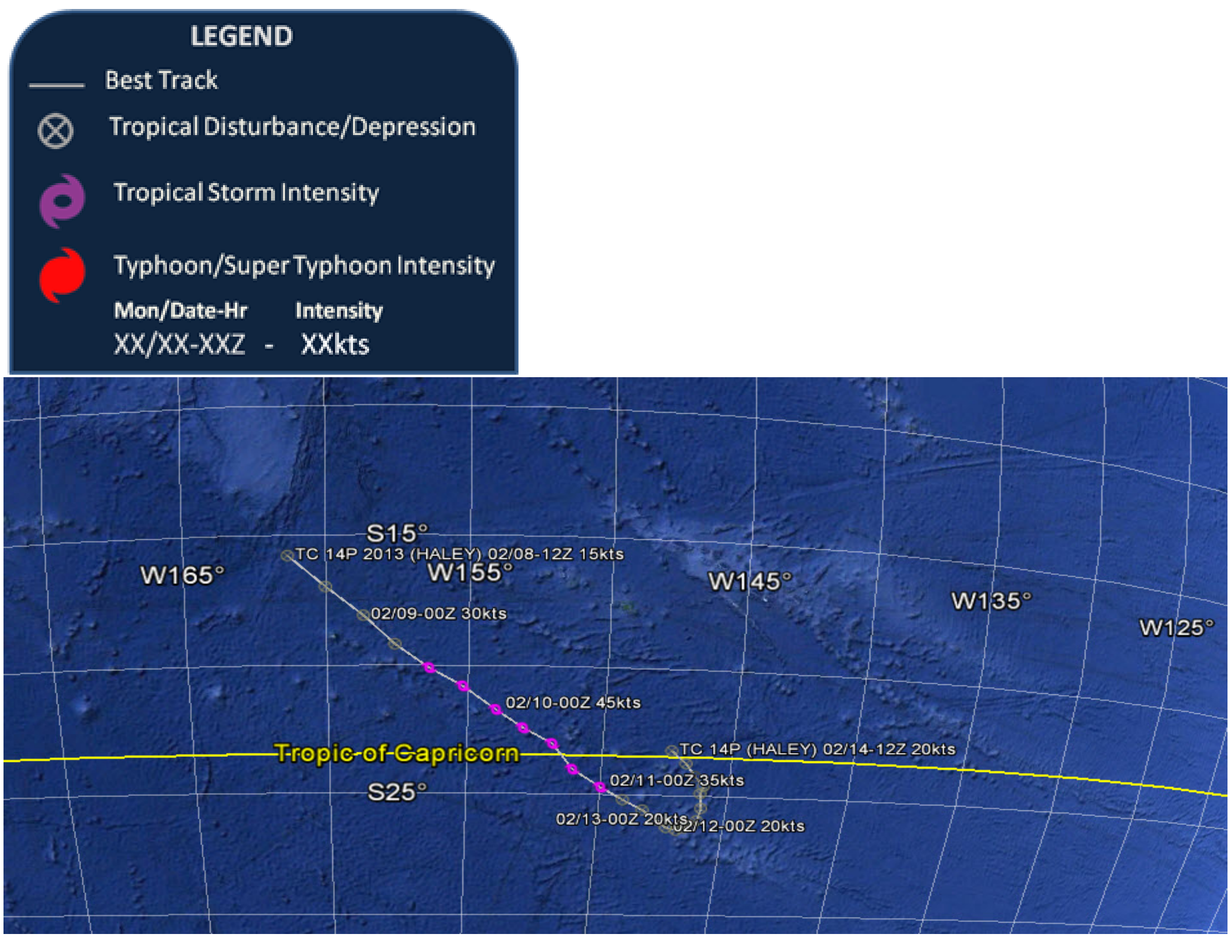




14P Tropical Cyclone Haley

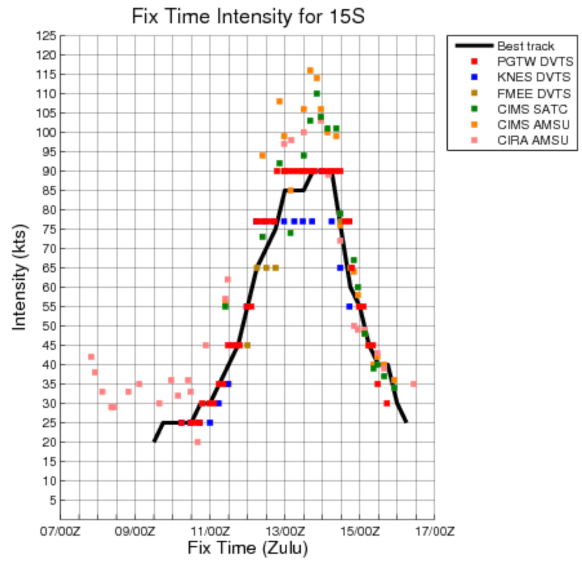
ISSUED LOW:	N/A
ISSUED MED:	09 Feb / 0600Z
FIRST TCFA:	09 Feb / 1000Z
FIRST WARNING:	10 Feb / 0000Z
LAST WARNING:	11 Feb / 0000Z
MAX INTENSITY:	45
WARNINGS:	3

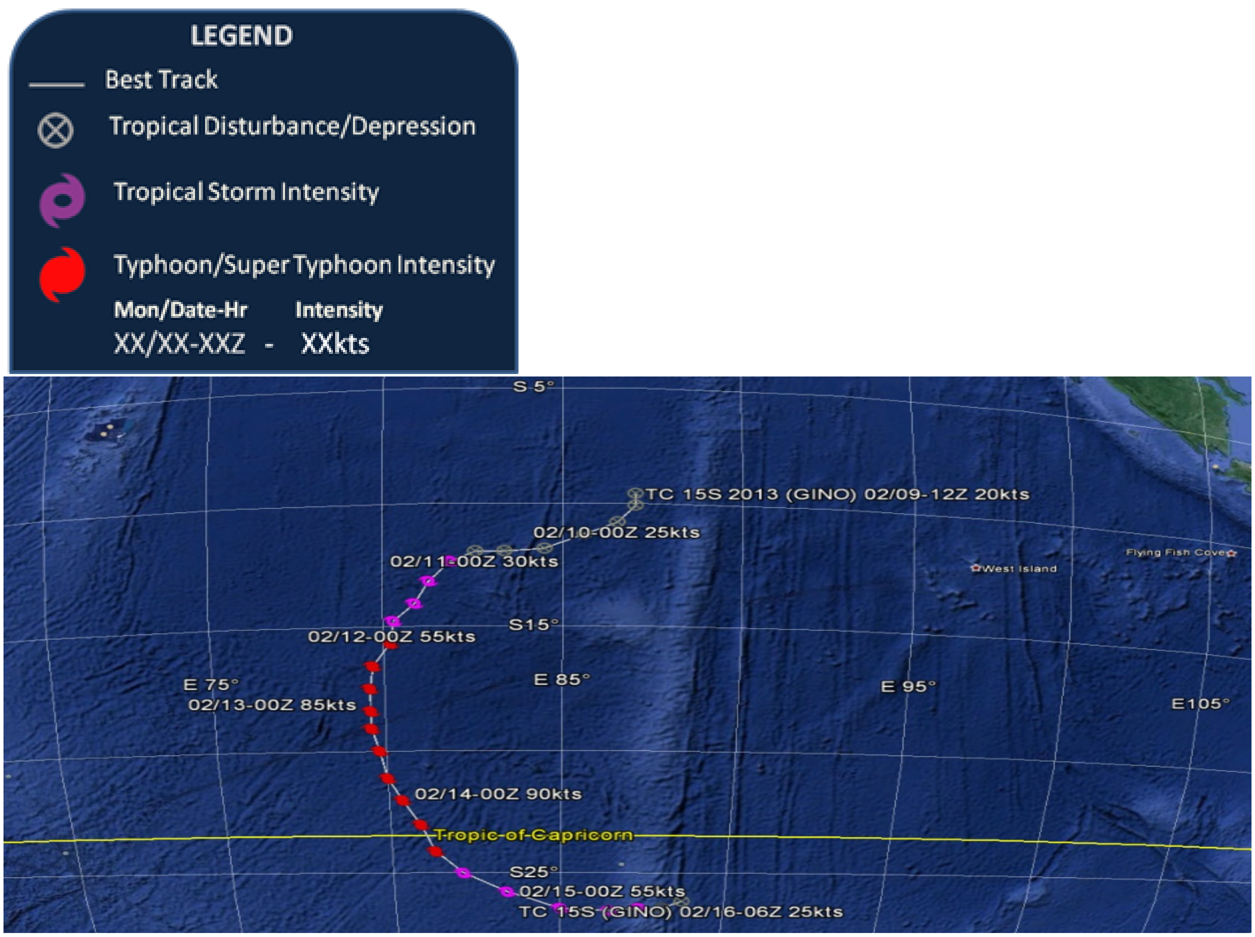




15S Tropical Cyclone Gino

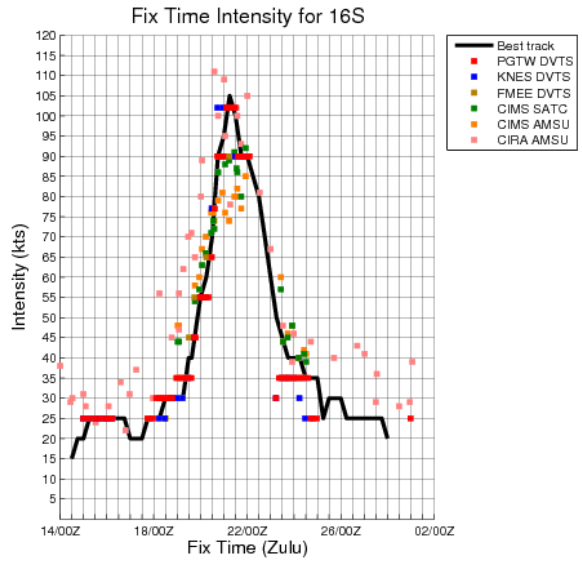
ISSUED LOW:	08 Feb / 1500Z
ISSUED MED:	09 Feb / 1800Z
FIRST TCFA:	10 Feb / 0000Z
FIRST WARNING:	11 Feb 0000Z
LAST WARNING:	15 Feb 1200Z
MAX INTENSITY:	90
WARNINGS:	10

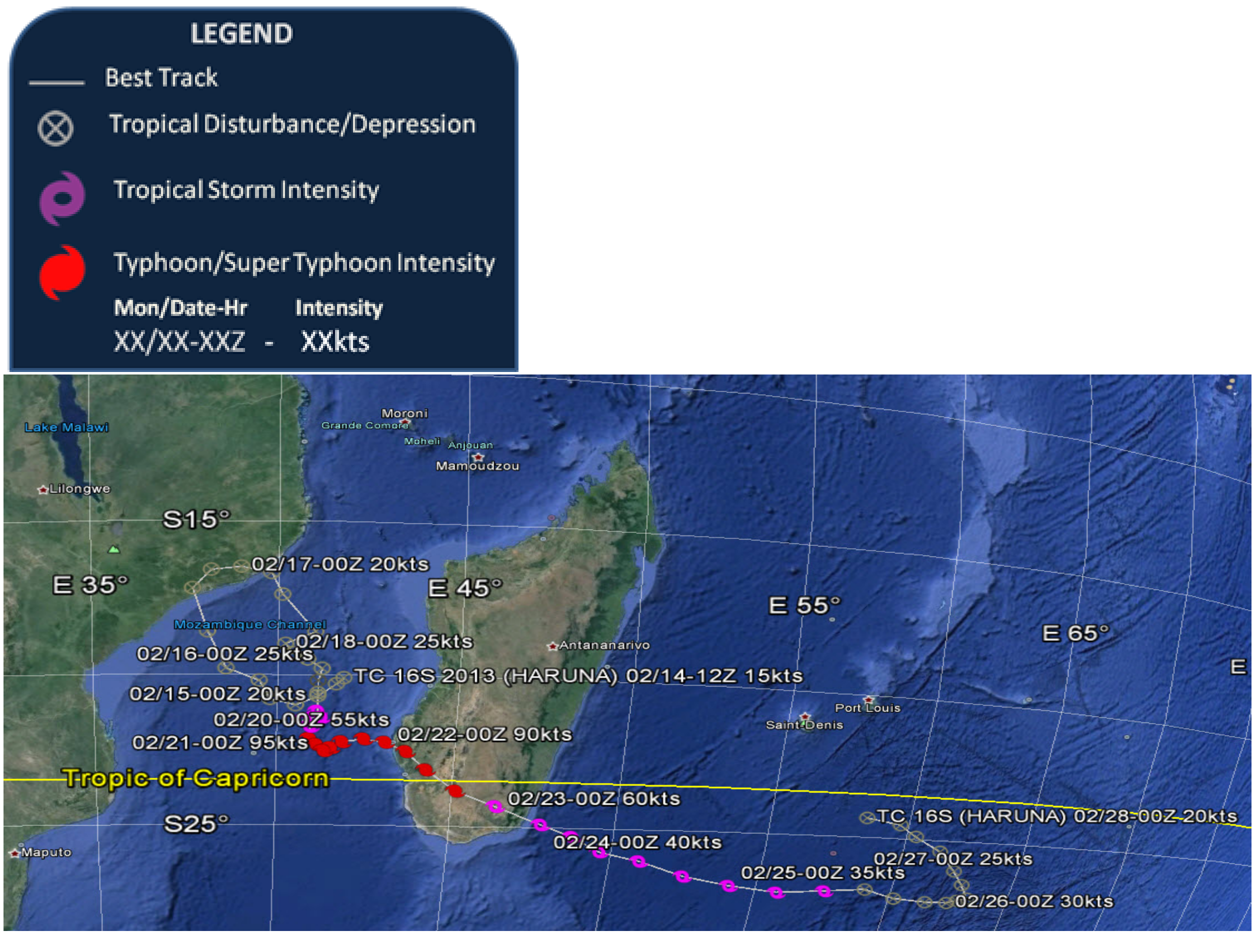




16S Tropical Cyclone Haruna

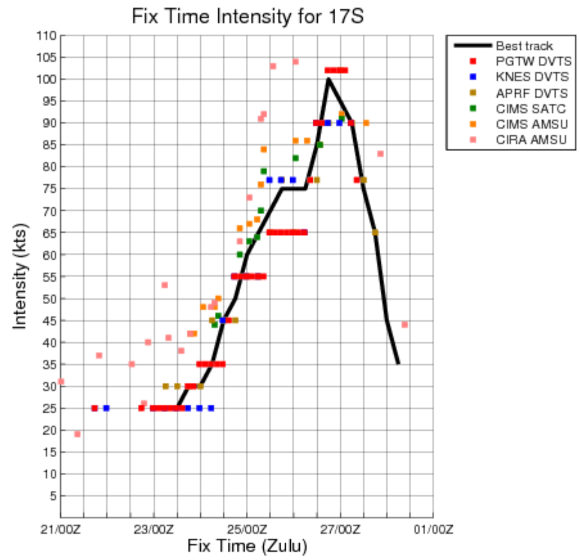
ISSUED LOW:	15 Feb / 0930Z
ISSUED MED:	16 Feb / 2300Z
FIRST TCFA:	18 Feb / 0130Z
FIRST WARNING:	19 Feb / 0000Z
LAST WARNING:	25 Feb / 0000Z
MAX INTENSITY:	105
WARNINGS:	13





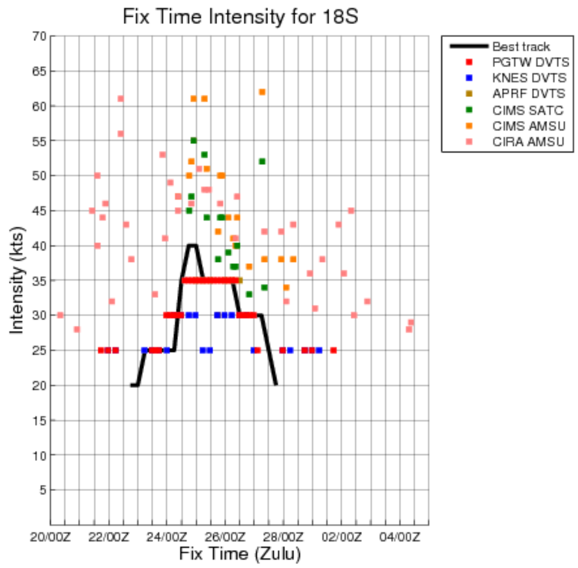
<u>**17S Tropical Cyclone Rusty**</u>

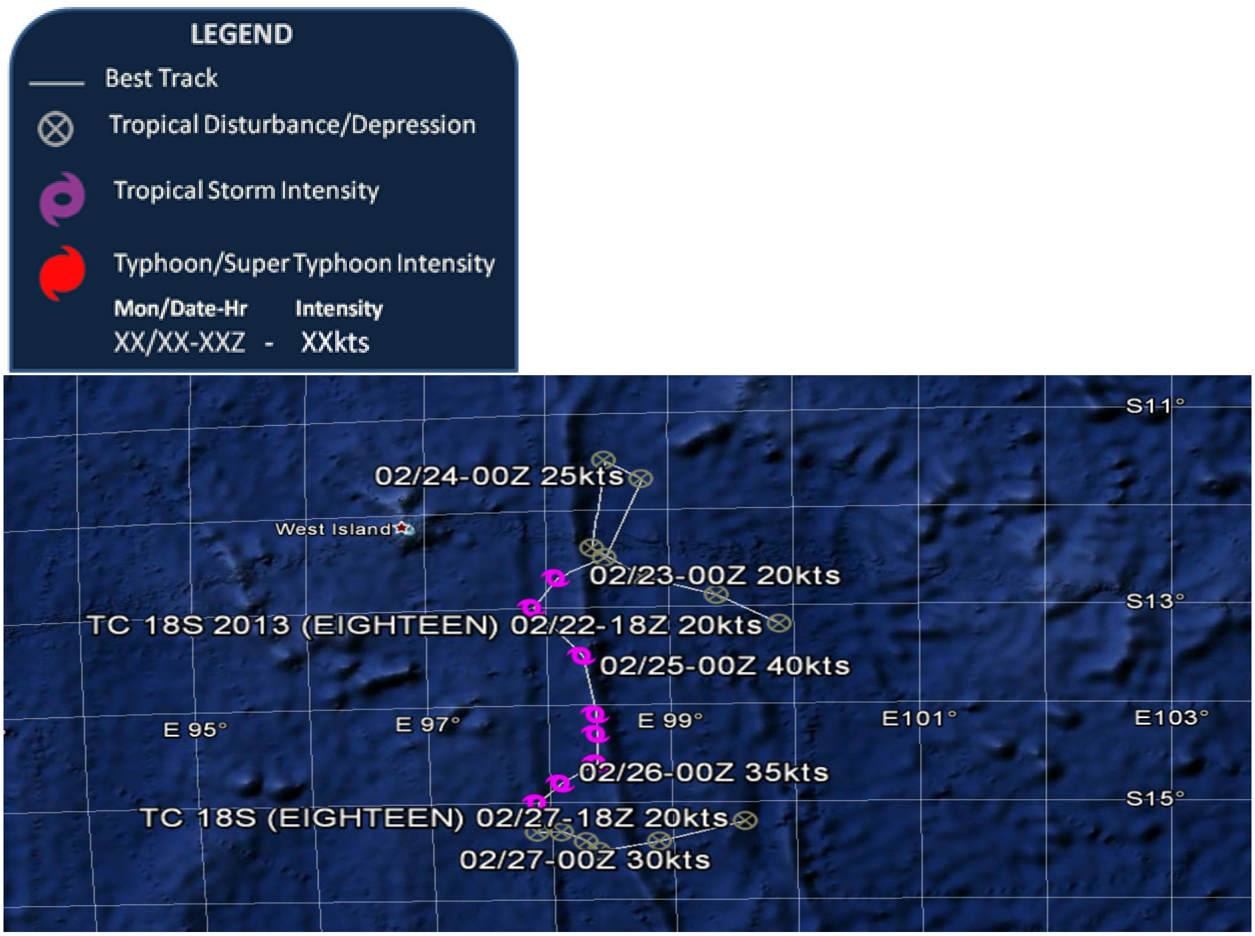
ISSUED LOW:	N/A
ISSUED MED:	22 Feb / 1800Z
FIRST TCFA:	23 Feb / 0300Z
FIRST WARNING:	24 Feb / 0000Z
LAST WARNING:	27 Feb / 1200Z
MAX INTENSITY:	100
WARNINGS:	14



18S Tropical Cyclone

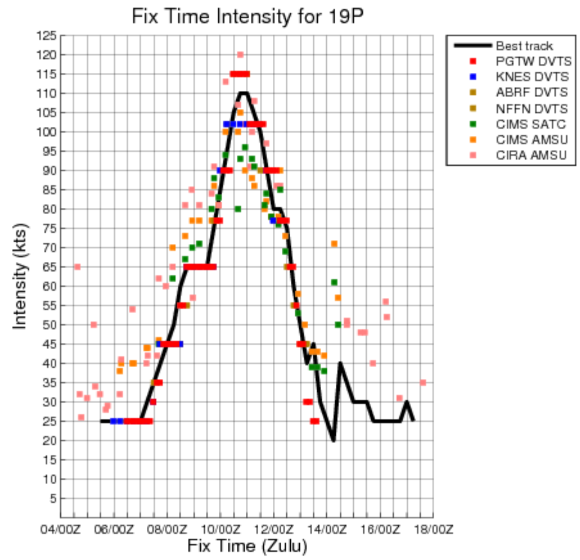
ISSUED LOW:	N/A
ISSUED MED:	22 Feb / 1800Z
FIRST TCFA:	24 Feb / 0200Z
FIRST WARNING:	24 Feb / 1200Z
LAST WARNING:	27 Feb / 0000Z
MAX INTENSITY:	40
WARNINGS:	6

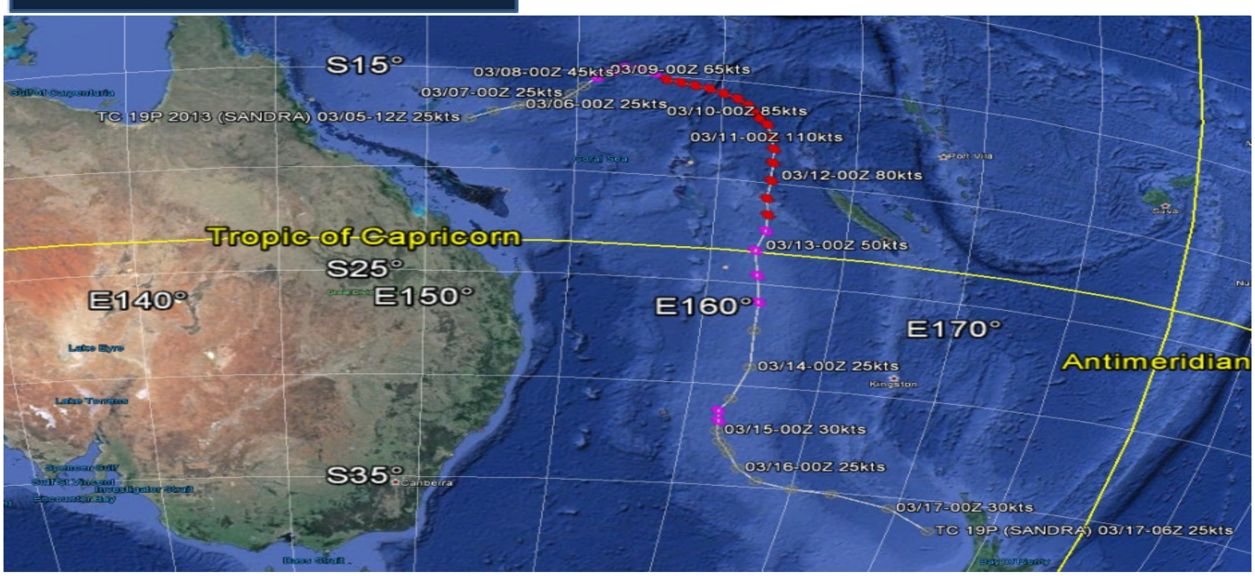




19P Tropical Cyclone Sandra

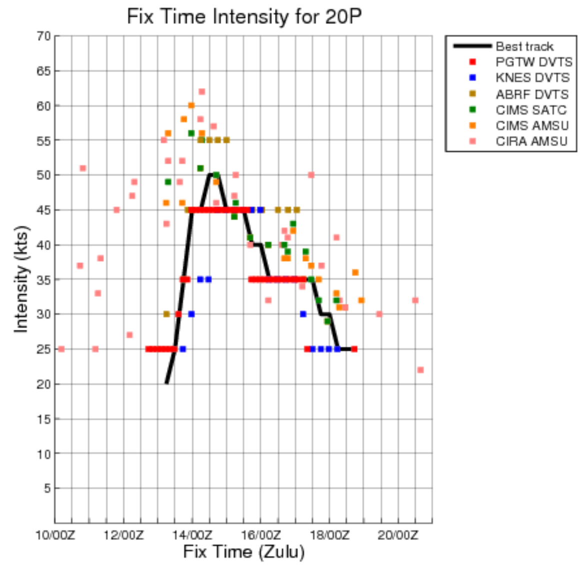
ISSUED LOW:	N/A
ISSUED MED:	05 Mar / 0600Z
FIRST TCFA:	06 Mar / 0300Z
FIRST WARNING:	07 Mar / 1200Z
LAST WARNING:	14 Mar / 0000Z
MAX INTENSITY:	110
WARNINGS:	14

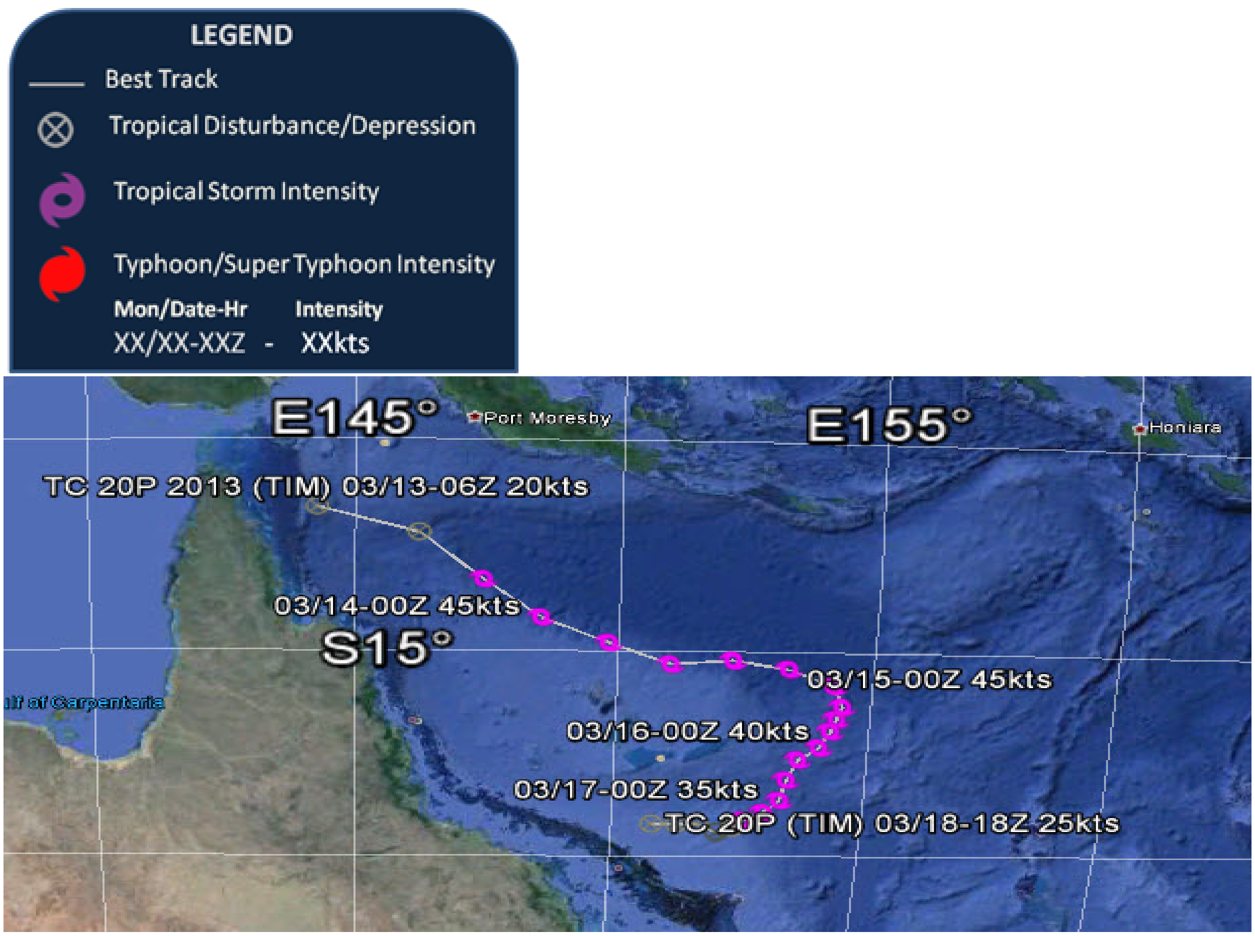




20P Tropical Cyclone Tim

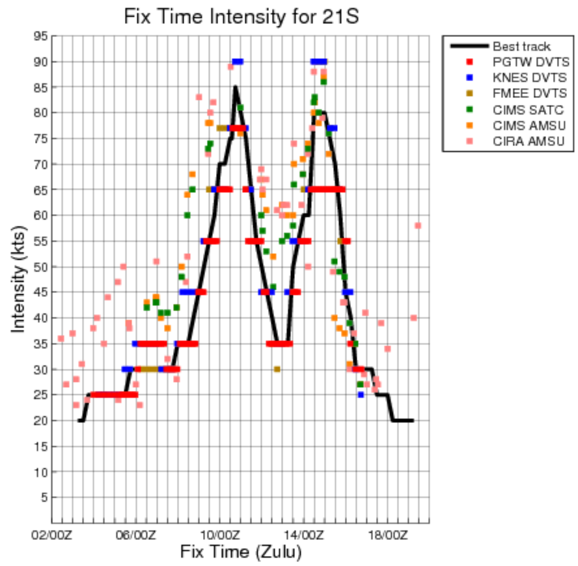
ISSUED LOW:	10 Mar / 2300Z
ISSUED MED:	11 Mar / 1900Z
FIRST TCFA:	12 Mar / 2100Z
FIRST WARNING:	13 Mar / 1800Z
LAST WARNING:	17 Mar / 1800Z
MAX INTENSITY:	50
WARNINGS:	9

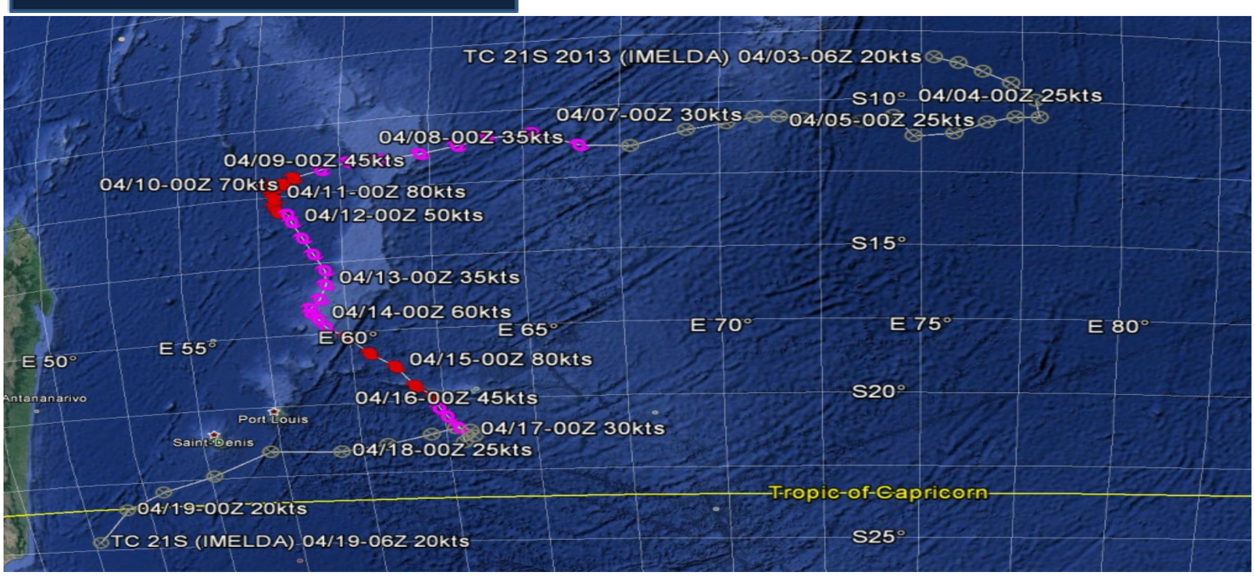




21S Tropical Cyclone Imelda

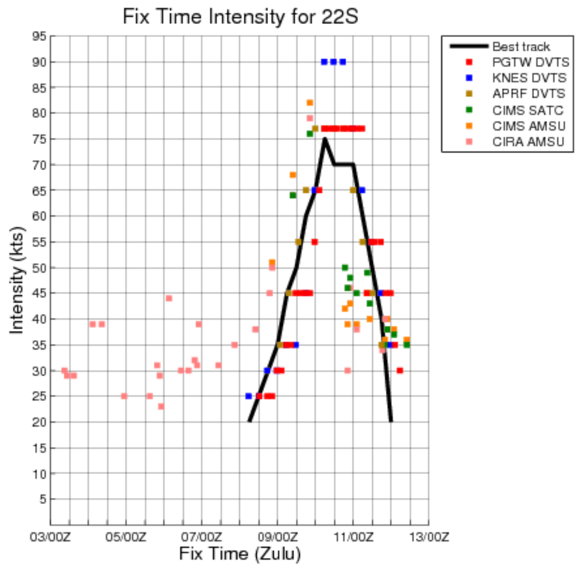
ISSUED LOW:	03 Apr / 1300Z
ISSUED MED:	04 Apr / 1300Z
FIRST TCFA:	05 Apr / 1200Z
FIRST WARNING:	06 Apr / 0600Z
LAST WARNING:	16 Apr / 0600Z
MAX INTENSITY:	85
WARNINGS:	21

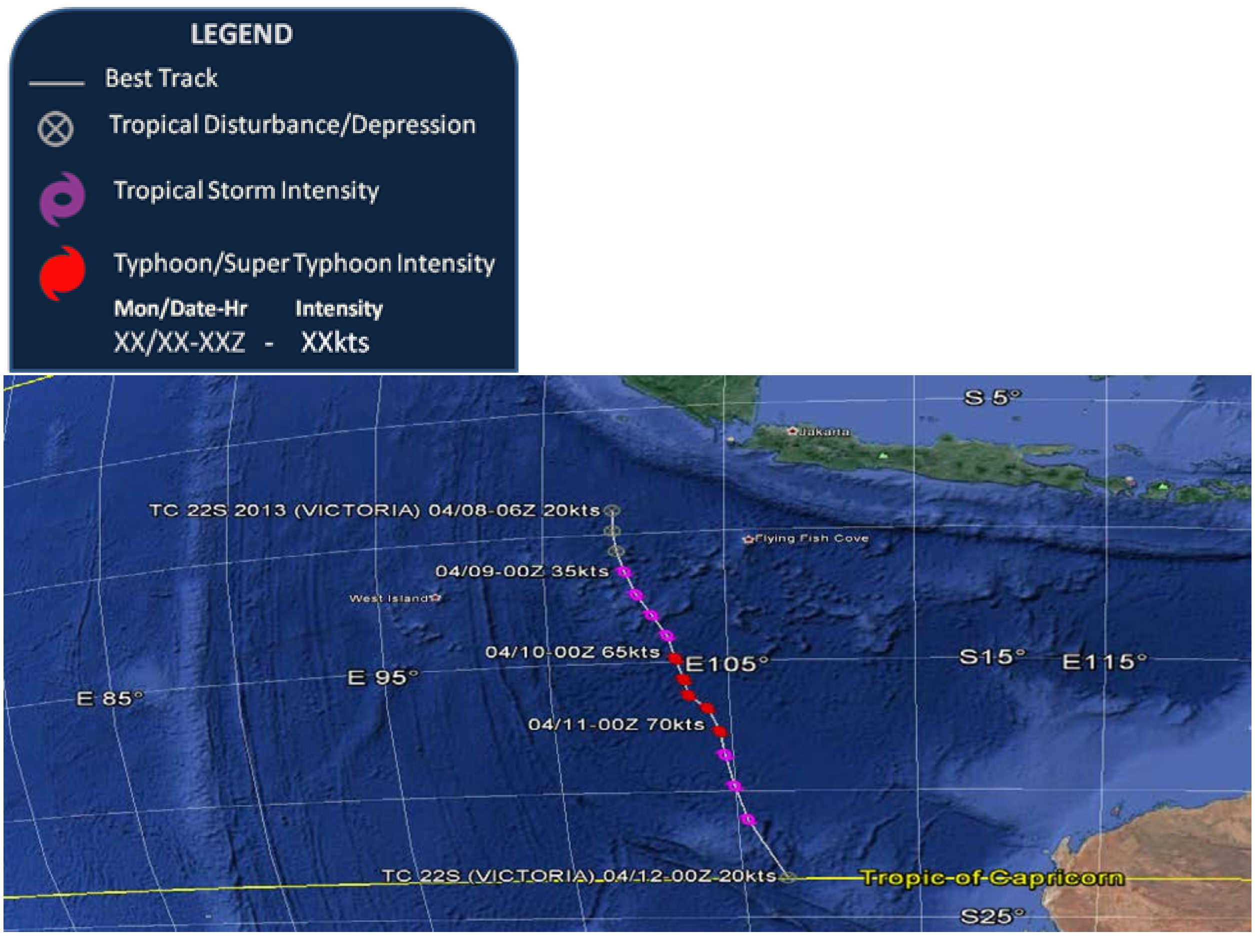




22S Tropical Cyclone Victoria

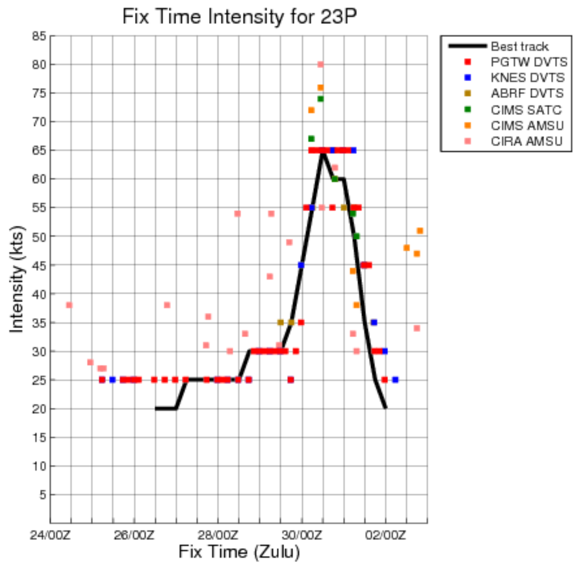
ISSUED LOW:	07 Apr / 0200Z
ISSUED MED:	08 Apr / 1400Z
FIRST TCFA:	08 Apr / 2230Z
FIRST WARNING:	09 Apr / 0000Z
LAST WARNING:	12 Apr / 0000Z
MAX INTENSITY:	75
WARNINGS:	7

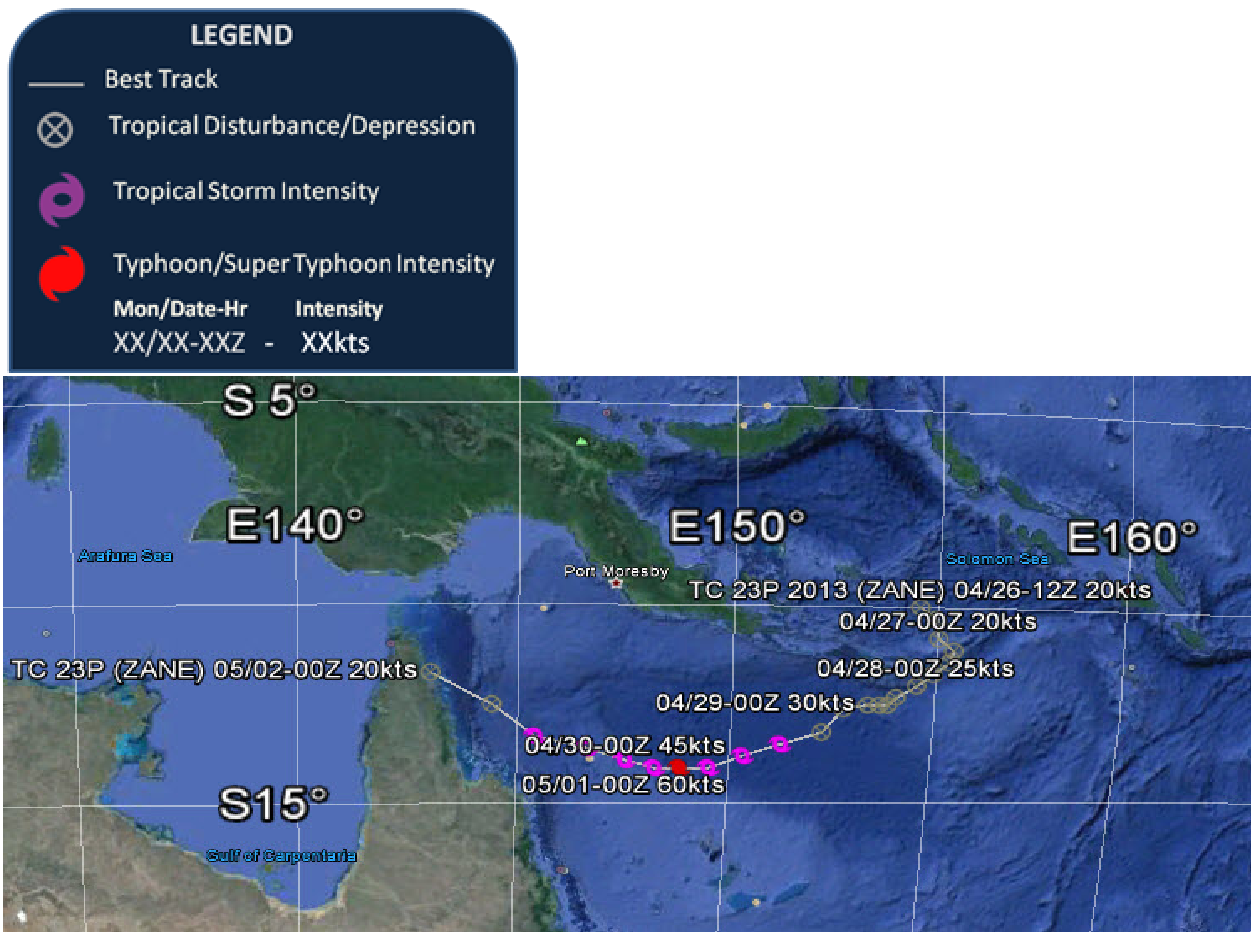




23P Tropical Cyclone Zane

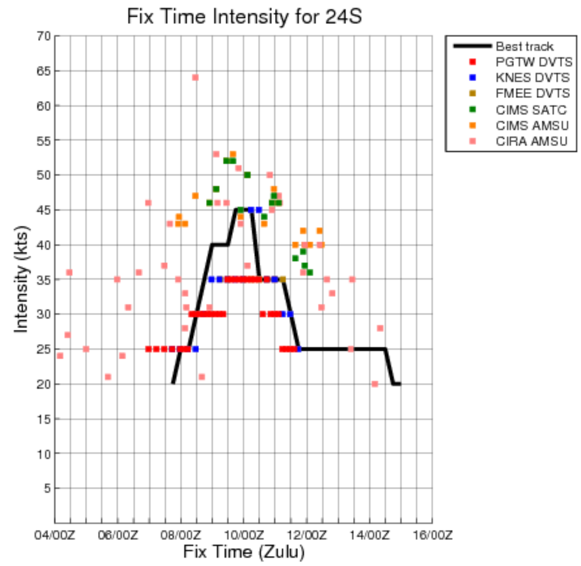
ISSUED LOW: 25 Apr / 0600Z
ISSUED MED: 25 Apr / 1000Z
FIRST TCFA: 28 Apr / 2230Z
FIRST WARNING: 30 Apr / 0000Z
LAST WARNING: 01 May / 2100Z
MAX INTENSITY: 65
WARNINGS: 5

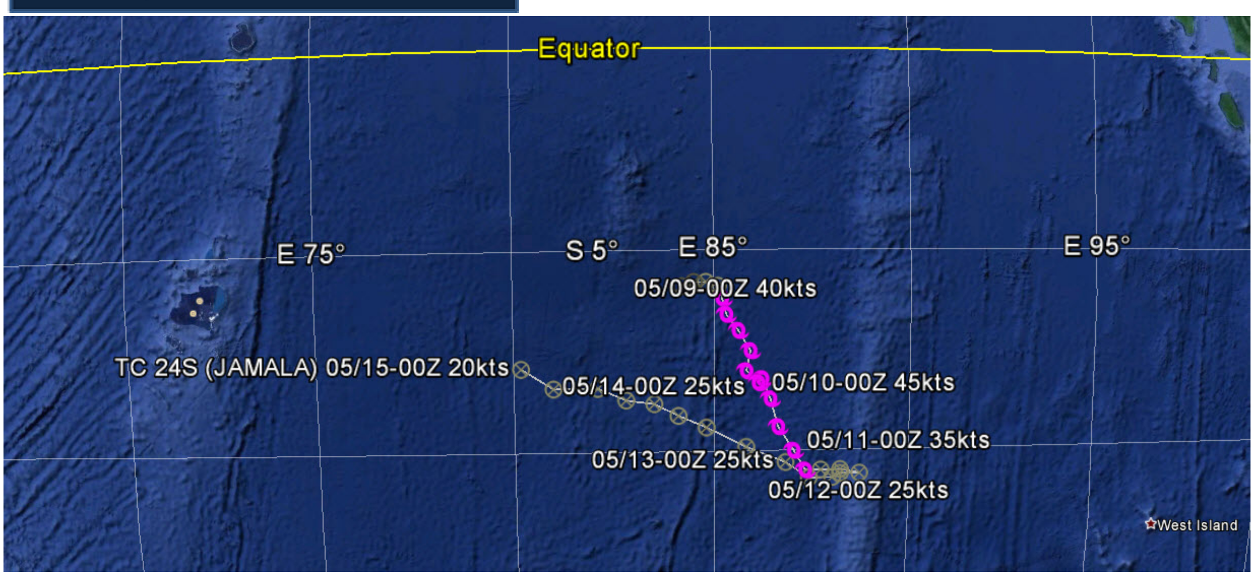




24S Tropical Cyclone Jamala

ISSUED LOW:	04 May / 0200Z
ISSUED MED:	06 May / 1230Z
FIRST TCFA:	08 May / 0200Z
FIRST WARNING:	08 May / 1200Z
LAST WARNING:	11 May / 1800Z
MAX INTENSITY:	45
WARNINGS:	8





Chapter 4 Tropical Cyclone Fix Data

Section 1 Background

Weather satellite data continued to be the mainstay for the TC reconnaissance mission at JTWC. JTWC satellite analysts produced 11,405 position and intensity estimates. A total of 6,913 of those 11,405 fixes were made using microwave imagery, amounting to over 60 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 was 1,216 for all basins, which accounts for approximately 10% of all fixes in 2013.

Section 2 Fix summary by basin

TABLE 4-1

WESTERN NORTH PACIFIC OCEAN FIX SUMMARY FOR 2013

Tropical Cyclone		Visible/Infrared	Microwave/Scatterometry	Total
01W	Sonamu	56	111	167
02W	Shanshan	39	98	137
03W	Yagi	58	130	188
04W	Leepi	36	44	80
05W	Bebinca	36	50	86
06W	Rumbia	41	56	97
07W	Soulik	52	79	131
08W	Cimaron	33	33	66
09W	Jebi	35	44	79
10W	Mangkhut	26	30	56
11W	Utor	71	132	203
12W	Trami	55	68	123
13W		22	33	55
14W	Kong-Rey	48	97	145
15W	Toraji	26	48	74
16W	Man-Yi	43	81	124
17W	Usagi	56	128	184
18W		21	24	45
19W	Pabuk	63	109	172
20W	Wutip	41	82	123
21W	Sepat	27	57	84
22W	Fitow	56	124	180
23W	Danas	56	135	191
24W	Nari	57	118	175
25W	Wipha	47	101	148
26W	Francisco	84	192	276
27W		31	80	111
28W	Lekima	58	121	179
29W	Krosa	67	116	183
30W		141	188	329
31W	Haiyan	69	135	204
32W	Podul	25	38	63
33W		16	27	43
DND		113	79	192
Totals		1705	2988	4693
Percentage of Total		36.33%	63.67%	100

TABLE 4-2

NORTH INDIAN OCEAN (BAY OF BENGAL/ARABIAN SEA)
FIX SUMMARY FOR 2013

Tropical Cyclone		Visible/Infrared	Microwave/Scatterometry	Total
01A	Mahasen	64	90	154
02B	Phailin	46	95	141
03B		49	50	99
04A	Helen	40	61	101
05B	Lehar	55	87	142
06B	Madi	69	109	178
DND		89	34	123
Totals		412	526	938
Percentage of Total		43.92%	56.08%	100

TABLE 4-3

SOUTH PACIFIC & SOUTH INDIAN OCEAN FIX SUMMARY FOR 2013

Tropical Cyclone		Visible/Infrared	Microwave/Scatterometry	Total
01S	Anais	60	73	133
02S	Boldwin	34	62	96
03S	Claudia	77	131	208
04P	Evan	75	109	184
05P	Freda	42	66	108
06S	Mitchell	37	84	121
07S	Dumile	36	53	89
08S	Narelle	70	94	164
09S	Emang	110	144	254
10P	Garry	75	106	181
11P	Oswald	50	20	70
12S	Peta	45	77	122
13S	Felleng	85	143	228
14P	Haley	45	54	99
15S	Gino	60	65	125
16S	Haruna	115	181	296
17S	Rusty	50	55	105
18S		92	164	256
19P	Sandra	159	264	423
20P	Tim	104	179	283
21S	Imelda	157	287	444
22S	Victoria	88	174	262
23P	Zane	114	203	317
24S	Jamala	123	182	305
DND		472	429	901
Totals		2375	3399	5774
Percentage of Total		41.13%	58.87%	100

Section 3: 2013 Automated Fix Assessment

In an effort to assess the utility of automated satellite position and intensity fixes, the JTWC Techniques Development team and Satellite Operations Flight analyzed data from 2010 - 2013 for the western Pacific Ocean and Indian Ocean basins. Subjective Dvorak fix data from PGTW and KNES along with objective Dvorak fix data from Advanced Dvorak Technique (ADT), CIRA AMSU, CIMMS AMSU, and SATCON were compared to JTWC official best track data. Our assessment is that automated fixes have continued to improve over the past three years, and each fix method can be used to aid the JTWC analysis and forecast process. However, due to various errors and biases of each product based on intensity and basin, the application of objective fix data varies for different TC scenarios. Therefore, a process is underway to develop rules of thumb for determining where and when analysts and forecasters can effectively use each objective method.

Section 1: Overview

The JTWC Technical Development (Tech Dev) team helps improve TC analyses and forecasts through scientific study, techniques development, information technology exploitation, data evaluation, process improvement and research to operations efforts. 2013 featured many fruitful, collaborative efforts between the Tech Dev team and supporting researchers, including several recently completed projects:

- Mr. Owen Shieh (JTWC US Pacific Command Student Volunteer Intern), Mr. Matt Kucas (Techniques Development Team Chief), Dr. Bin Wang (University of Hawaii) and Dr. Mike Fiorino (Earth Systems Research Laboratory) coauthored and published a case study of the rapid intensification of Typhoon Vicente in the South China Sea. This study showcased the interaction between Typhoon Vicente and an adjacent upper-level low, which coincided with a poleward track stair-step and explosive deepening (Shieh et al. 2013). The findings of this study set the stage for Mr. Shieh's prospective dissertation research, which will quantify relationships between TC intensity and tropical upper-level flow patterns in order to improve real-time prediction of TC intensity change.

- Tech Dev coordinated with Air Force Institute of Technology graduate student, 2d Lt Coy Fischer. 2d Lt Fischer successfully completed a Master's thesis entitled "Sensitivity of 96 and 120-hour numerical model tropical cyclone position forecasts to initial position errors." 2d Lt Fischer's work related TC position and intensity analysis errors to forecast position errors through tau 120. The findings of this analysis establish a numerical framework to optimize tropical cyclone bogus input and diagnose potential model track forecast errors in an operational setting (Fischer 2014).

- Tech Dev facilitated a study correlating tropical cyclone formation probabilities to Dvorak fix analyses conducted by Florida State University graduate student Mr. Josh Cossuth (PhDc) (Poster presentation, 31st AMS Conference on Hurricanes and Tropical Meteorology). Tech Dev will apply probabilistic relationships established in this study to improve Low/Medium/High invest classification procedures.

Additional, ongoing collaborative projects are detailed in the scientific and operational development sections (2 and 3). Section 4 previews future development work.

Section 2: 2013 Scientific development projects

Operational review of Genesis Potential Index

In 2013, Tech Dev began running the 2012 version of the Genesis Potential Index (GPI) model developed by the research team at NRL (Dr. Melinda Peng) and UH (Drs. Tim Li, Bing Fu, and Duane Stevens) in the JTWC development environment in order to continue evaluation for use in operations. The GPI model applies a numerical algorithm to quantify tropical cyclogenesis potential for designated invest areas based on three parameters: 850 mb maximum relative vorticity from the NAVGEM global forecast model, 750 du/dy from the NAVGEM model, and TRMM 3B42RT 3-hourly

average rainfall data (Huffman et al. 2007). Genesis potential index (GPI) values exceeding a threshold value indicate that TC formation from a designated disturbance is likely to occur within a 24 to 48 hour forecast period, while values below the threshold indicate that development is unlikely. Six-hourly, near real-time GPI output from the 2012 model, and a time series plot illustrating the evolution of these data, were made available to JTWC forecasters in mixed text and graphical format for designated invests during the 2013 calendar year (Figure 5-1). These data were generated for invests in the western North Pacific, South Pacific, and Indian Oceans.

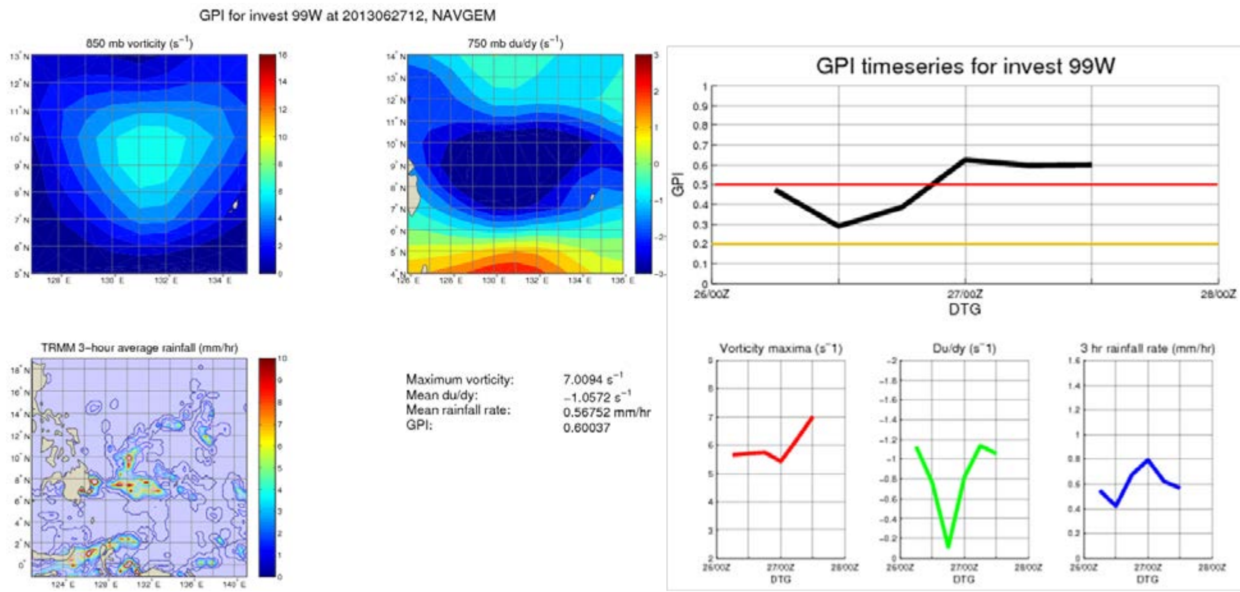


Figure 5-1: GPI model graphics provided to JTWC forecasters for evaluation in near real-time. The graphics provide geographical, numerical, and temporal values of the three parameters included in the 2012 GPI model algorithm.

The GPI research team ran an experimental version of the GPI model for designated invest areas from June through September 2013. This experimental algorithm applies 800 mb maximum relative vorticity from the NAVGEM global forecast model, 1000-400 mb layer-averaged du/dy from the NAVGEM model, and TMI sea surface temperature (Wentz et al. 2000). Tech Dev evaluated output from both the 2012 GPI model and the experimental version. Near real-time and after-the-fact evaluation again confirmed that GPI trends provide actionable signals of either imminent TC formation or dissipation of non-developing disturbances. Our post-facto analysis indicated a high probability of detecting TC formation (above 90%) in both versions of the GPI model. However, false alarm rates were slightly smaller for the 2012 version. Further improvements to the model routine are anticipated as fruitful collaboration between with the GPI research team and JTWC Tech Dev continues. GPI data from the 2012 GPI model are under consideration for inclusion in JTWC's Low/Medium/High (LMH) TC formation potential classification worksheet (Kucas and Darlow 2012). Additionally, GPI predictions will be incorporated into JTWCs weekly (Wednesday) Global Tropics Hazards Outlook / two-week TC formation overview, which is conducted during the morning forecast discussion (METCON).

ECMWF ensemble track clusters

Naval Postgraduate School researchers Dr. Russ Elsberry, Dr. Hsiao-Chung Tsai and Ms. Mary Jordan have developed a technique to group similar forecast tracks for western North Pacific (WestPac) tropical cyclones into a set of "track clusters." Through statistical analysis of historical WestPac tropical cyclone track forecasts from the 51-member ECMWF ensemble (available through the THORPEX Interactive Grand Global Ensemble, TIGGE), the researchers identified six common

tropical cyclone track clusters, illustrated in Figure 5-2. Each cluster is associated with a distinct environmental steering scenario.

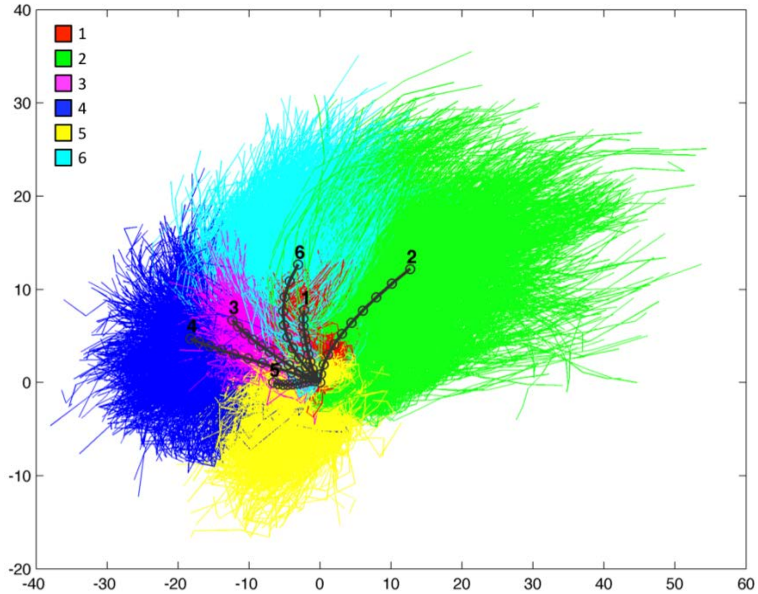


Figure 5-2: Common historical track clusters for western North Pacific tropical cyclones. Each colored line represents a historical tropical cyclone best track. Colors correspond to six different track clusters, or groups of historical tracks with statistically similar direction and speed. Numbered black lines with open circles indicate the weighted-mean vector motion track for the historical data contained within each cluster (Tsai and Elsberry 2013; image courtesy Dr. Hsiao-Chung Tsai).

The NPS research team performs a near real-time cluster analysis of WestPac tropical cyclone track and intensity forecasts from the twice-daily ECMWF ensemble, and provides resultant forecast products to JTWC Tech Dev for evaluation. To generate these products, each of the 51 tropical cyclone track forecasts derived from the ECMWF TIGGE ensemble is assigned to one of the six track clusters shown in Figure 5-3. Weighted-mean vector motion mean (WMVM) track and intensity forecasts are calculated from the data contained within each cluster. These WMVM tracks, and the percentage of ensemble members that fall within each cluster, are presented for each of the "top three" clusters. Statistical analysis indicates that WMVM tracks derived from clusters that contain 70% or more of the available ensemble track forecast solutions outperform (on average) the WMVM track derived from all available ensemble forecasts. Additionally, the presence of a relatively large percentage of ensemble forecasts within separate track clusters is a potentially useful indicator of alternate track scenarios (Tsai and Elsberry 2013). Tech Dev is collaborating with the NPS research team to determine optimal application of these forecast products to predict tropical track and intensity and alternate forecast scenarios. Additional discussion of these products is provided in the TY 22W case study included in this ATCR.

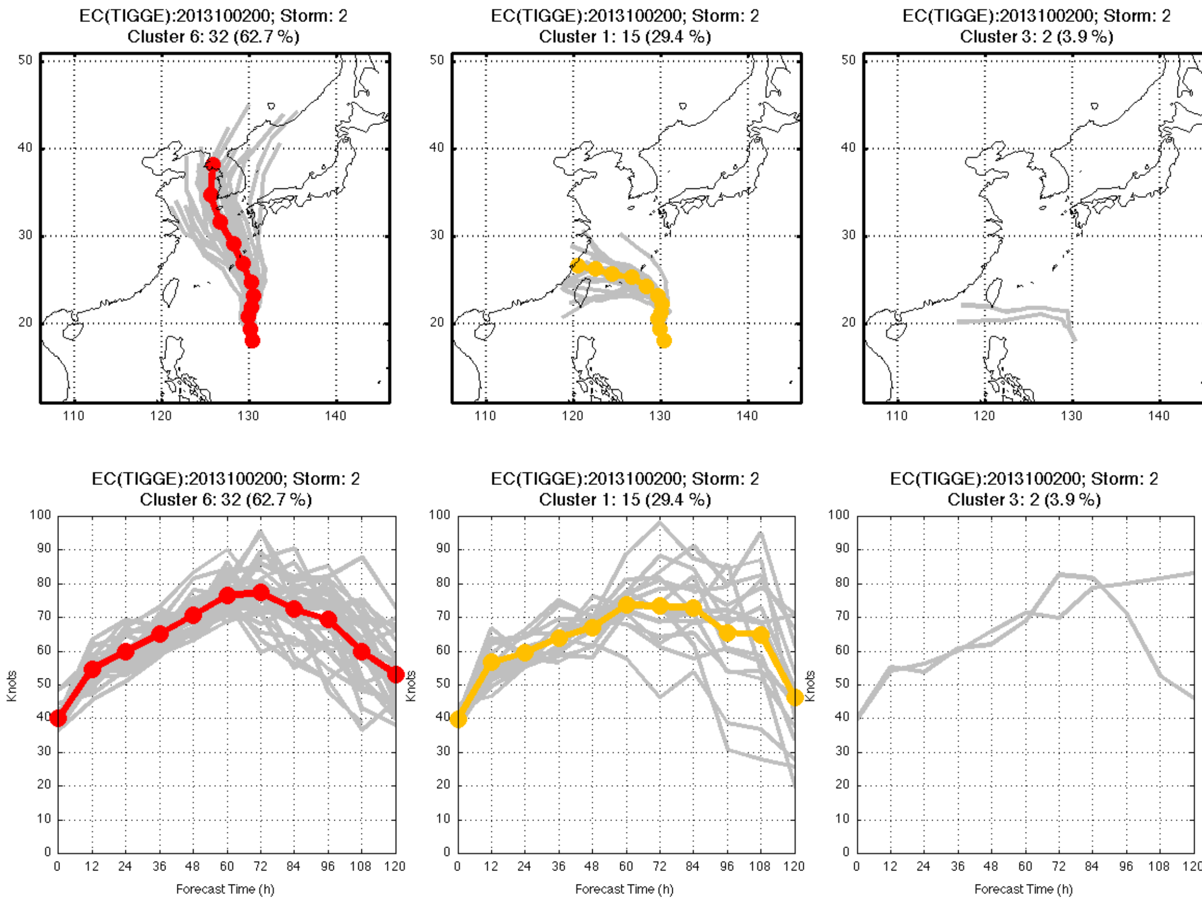


Figure 5-3: ECMWF ensemble track cluster forecasts for TY 22W, 2013 (Fitow) (image courtesy NPS). The top three forecast clusters represented by the 2013100200 ensemble run fall within pre-determined (refer to Figure 5-2) cluster 2 (62.7% of ensemble track forecasts), cluster 1 (29.4% of ensemble track forecasts), and cluster 3 (3.9% of ensemble track forecasts). Ensemble member forecasts that fall within each cluster are shown in light gray (track – top, intensity – bottom) and the mean track / intensity of forecasts falling within each cluster are shown in color.

Situation-Dependent Intensity Prediction (SDIP)

Dr. Russ Elsberry and Dr. Hsiao-Chung Tsai (NPS) have developed a method to calculate intensity forecast skill and spread guidance for designated TC tracks based on situation-dependent analogs in the multi-decadal, historical best track dataset. Track and intensity analogs are selected by comparing the time of year, track speed and direction, and initial intensity of the designated TC track with storms in the historical record (Elsberry and Tsai 2014). An experimental method to derive intensity guidance for western North Pacific and southern hemisphere cyclones based on JTWC forecast analogs followed from the initial SDIP study. This “Weighted Analog Intensity (WANI)” forecast technique (weighted to favor historical tracks that most closely match the current JTWC forecast) is under evaluation for potential operational application at JTWC. An example WANI intensity forecast for TY03W is presented in Figure 5-4. WANI forecasts are also included in experimental intensity forecast range products introduced in the future work section of this report.

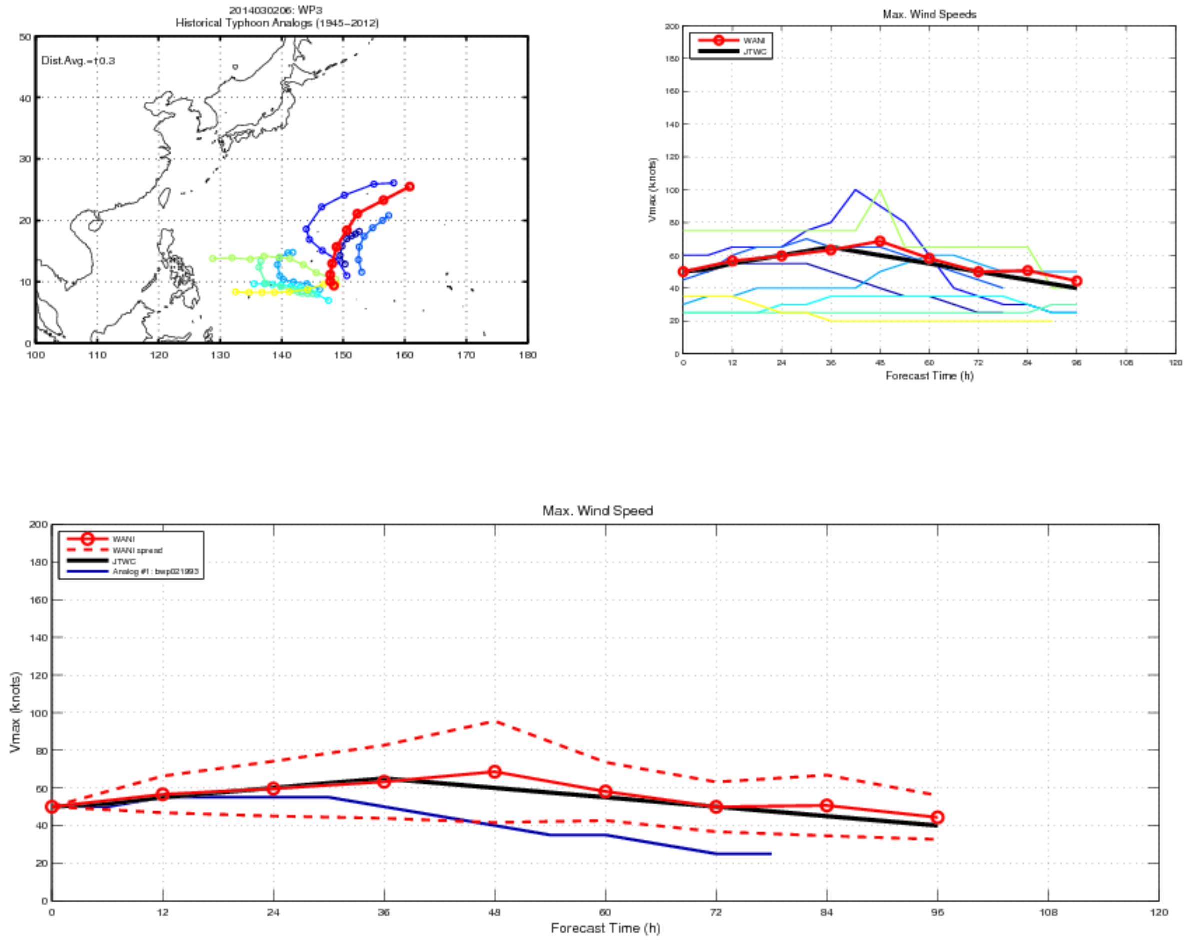


Figure 5-4: Example WANI intensity guidance graphic for TY 03W (03/02/06Z forecast). Top left: JTWC forecast track (red) and analogous tracks from the historical best track dataset (other colors). Top right: WANI intensity forecast (red), JTWC intensity forecast (black), and analog case intensities. Bottom: WANI (solid red), JTWC (black), and closest matching analog intensity (blue) forecasts with WANI intensity spread based on available analogs (bounded by red dotted lines).

Deviation Angle Variance (DAV) technique

Evaluation of the DAV technique developed at the University of Arizona (Piñeros et al. 2010; Piñeros et al. 2010) continued in 2013. Tech Dev implemented a beta version of the DAV routine for real-time analysis of invest areas with support from the DAV research team, particularly Dr. Oscar Rodriguez. Efforts to improve the technique, such as implementing a DAV area "tracker" developed at U of A, will continue through 2014.

Section 3 2013 Operational Development Projects

Multi-model track and intensity consensus updates

In late June 2013, JTWC modified the official tropical cyclone track consensus (CONW) based on recommendations from NRL-Monterey's (NRL-MRY) annual review of CONW performance. COAMPS-TC run with GFS lateral boundary conditions (CTCX), HWRF, the GFS Ensemble Forecast System (GEFS) ensemble mean (AEMN), and the Japan TC-EPS ensemble mean (JENS) vortex trackers were added to CONW, and the Weber Barotropic Model (WBAR) was removed, producing a

CONW with up to ten members. In addition to the four aforementioned models, the full CONW suite includes vortex tracker data from NAVGEM (NVGM), GFDN, GFS (AVNO), ECMWF (ECMF), UKMET model (EGRR), and Japanese Global Spectral Model (JGSM). Numerous model upgrades, including replacement of NOGAPS with the Navy Global Environmental Model (NAVGEM) in March 2013, positively impacted individual consensus member forecasts. A few additional highlights of CONW mesoscale forecast model developments follow:

- **HWRF:** NOAA/NWS's Environmental Modeling Center (EMC) provided Hurricane WRF model forecasts for western North Pacific Ocean (WESTPAC) and North Indian Ocean (IO) tropical cyclones throughout 2013, under the auspices of the Hurricane Forecast Improvement Program (HFIP). In early 2014, EMC extended operational HWRF forecasts to Southern Hemisphere (SH) tropical cyclones, providing global coverage. Although HWRF forecasts for JTWC basins rely on HFIP computing resources, the model's reliability, accurate forecast performance and timely delivery of associated vortex track data led JTWC to add HWRF to CONW in 2013. Additionally, the 2013 post-season intensity consensus review conducted by NRL-MRY determined that HWRF would also add skill and reduce bias in the intensity consensus, S5YY. As a result, HWRF intensities will be added to S5YY in 2014. The HWRF configuration for WESTPAC, IO and SH does not include ocean coupling, but the model is otherwise the same as that used operationally in the Atlantic Basin, with a storm-following inner grid at 3 km horizontal resolution (Tallapragada et al. 2014b).

- **COAMPS-TC:** In 2013, FNMOC transitioned the COAMPS-TC model (COTC), initialized with NAVGEM boundary conditions, into operations. NRL Monterey continued to distribute forecast data from the developmental COAMPS-TC model (CTCX), initialized with lateral boundary conditions from GFS. The current configuration of both versions of the COAMPS-TC model features a storm-following inner nest with 5 km horizontal resolution (Doyle et al. 2012). Given the larger sample size available for review, the developmental CTCX vortex tracker was selected for addition to CONW and S5YY in 2013. However, both versions of the model were routinely evaluated in daily forecast operations. The 2013 post-season analysis by NRL-Monterey concluded that both versions of the model would have a nearly equivalent impact on the consensus (Buck Sampson, personal communication). Therefore, the 2014 CONW and S5YY will switch to the 24x-7 operational COTC in place of CTCX. .

- **GFDN:** The operational GFDN model was upgraded in 2013 to match the 2012 version of the GFDL model. FNMOC runs GFDN for all JTWC basins with NAVGEM initial and boundary conditions, while NCEP runs GFDL for National Hurricane Center forecast basins using the GFS for initial boundary conditions. Both GFDL and GFDN feature a storm-following inner nest at approximately 9 km horizontal resolution. GFDN remains the only three dimensionally ocean-coupled model available to JTWC. A significant resolution and physics upgrade is planned for GFDL in June 2014, and this upgrade will likely be transitioned to the GFDN model by FNMOC later in the year. Retrospective testing for three Atlantic tropical cyclone seasons, encompassing nearly 1,000 cases, revealed an almost 15% improvement in 5-day forecast intensity skill in the prospective upgrade versus the current version of the GFDL model (Bender et al. 2014).

JTWC's operational intensity consensus is a blend of statistical and dynamical model intensities computed within ATCF output (Schubert et al. 2012). The 2013 western North Pacific intensity consensus, S5YY, included the Statistical Hurricane Intensity Prediction System (SHIPS) (DeMaria et al. 2005) and the Logistic Growth Equation Model (LGEM) (DeMaria 2008) components, as well as interpolated intensity forecasts from GFDN, COAMPS-TC, and the Coupled Hurricane Intensity

Prediction System (CHIPS) (Emanuel et al. 2004). NRL Monterey's annual review of consensus performance indicated that adding SHIPS and LGEM in S5YY resulted in the largest improvement in day-2 and -3 intensity forecast skill in more than a decade (Buck Sampson, personal communication). The operational intensity consensus for Indian Ocean and southern hemisphere cyclones, S5XX, includes STIPS statistical-dynamical model components plus interpolated intensity forecasts from GFDN, COAMPS-TC, and the CHIPS model. JTWC expects S5YY will be available for all basins in 2014 as the SHIPS and LGEM code becomes globally unified (Schumacher et al. 2013). Although JTWC forecast model statistics indicate that, on average, statistical-dynamical intensity prediction methods traditionally provide the most skillful guidance available, HWRF performance in 2013 and retrospective testing of 2014 COAMPS-TC and GFDL models suggest promising improvements to intensity forecast guidance from mesoscale models (Bender et al. 2014; Doyle et. al. 2014; Tallapragada et al. 2014a).

JTWC's current version of the SHIPS model uses dynamical input from the NAVGEM and GFS global models. The globalization of SHIPS will allow the model to run with additional global and mesoscale models inputs in 2014 and beyond (K. Musgrave, personal communication), providing future opportunities to improve the intensity consensus.

Several other models are under consideration for operational application and potential inclusion in the track and/or intensity forecast consensuses, including:

- **ACCESS-TC**: TC forecasts from The Australian Community Climate and Earth-System Simulator (ACCESS-TC) model are provided by the Australian Bureau of Meteorology (ABoM) for systems near Australia and in the WESTPAC. ACCESS-TC is a non-hydrostatic tropical cyclone model nested within the ACCESS-G domain of the Australian Bureau of Meteorology's operational modeling system. ACCESS-TC runs twice daily, at 00Z and 12Z. The model incorporates TC bogus data provided by ABoM forecasters for cyclones near Australia, but runs "unbogussed" in other basins. Horizontal grid resolution is approximately 12 km. Vortex trackers include both track and intensity forecast data (ABOM 2010).

- **AFWA MEPS**: In coordination with Tech Dev, the Air Force Weather Agency implemented an operational tropical cyclone vortex tracker for the Mesoscale Ensemble Prediction System (MEPS) (Hacker et al. 2011). These data include twice-daily tropical cyclone track and intensity forecasts from the 20 km ensemble, and from the 4 km ensemble upon request, for all disturbances and cyclones tracked by JTWC from initial best track time to final warning. This provision of forecast data for up to ten 20 km MEPS ensemble members more than doubled the amount of consistently available track and intensity guidance for pre-formation disturbances. MEPS ensemble forecasts may be included in experimental probabilistic track forecast guidance (see section 4 of this report). In addition, the ensemble mean vortex tracker is under consideration for incorporation into the JTWC multi-model consensus, the center's primary tool for tropical cyclone forecasting, as well as a mesoscale model consensus for intensity forecasting. Preliminary results indicate promising track forecast performance. Efforts to verify MEPS ensemble forecasts and incorporate additional MEPS forecast capabilities into JTWC's Decision Support mission are ongoing.

- **Arpege:** Arpege is Météo-France's global modeling system. Tropical cyclone track forecast data from the Arpege model were graciously provided to JTWC through an FTP site hosted by Météo -France as well as via email for all cyclones in the La Réunion forecast area-of-responsibility. Performance during the 2012 and 2013 seasons was promising, and evaluation will continue throughout 2014.

- **FIM9:** Developed and run by the NOAA Earth Systems Research Laboratory (ESRL), the Flow-following Finite-volume Icosahedral Global Model (FIM), features advanced numerical prediction schemes, an icosahedral horizontal grid, and 64 hybrid theta-sigma vertical levels (Michael Fiorino, personal communication). ESRL provided JTWC vortex tracker data from the FIM9 model (15 km horizontal resolution) for invests and tropical cyclones beginning in 2013. Evaluation of FIM9 tropical cyclone forecasts will continue throughout 2014.

- **SHIPS-RI Index:** NRL and JTWC implemented an experimental version of the SHIPS Rapid Intensification Index (SHIPS-RII) for WESTPAC TCs in 2013. This index provides probabilities of 25, 30, 35 or 40 knot intensification during a 24 hour forecast period for active tropical cyclones (Kaplan et al. 2010). The index is generated in ATCF and available for forecaster interrogation during every forecast cycle.

- **TWRF:** TWRF is an adaption of the WRF-ARW model tuned specifically for TC rainfall over Taiwan by the Taiwan Central Weather Bureau (CWB). This model has fixed nests of 5 and 15 km horizontal resolution centered over Taiwan and a larger 45 km nest covering the WESTPAC (Hsiao, L.-F. et al. 2012). Although primarily designed to improve TC-related precipitation forecasting, the CWB has provided tropical cyclone vortex trackers from the TWRF 45 km forecast domain to JTWC for evaluation.

GIS products and tools

JTWC developed and began distributing real-time, KMZ-based Tropical Cyclone Formation Alert (TCFA) and warning products in 2013. These products may be downloaded from JTWC's public website and other outlets. Each graphic enables users to display and interrogate forecast data in geospatial display platforms alongside existing datasets.

In addition to developing KMZ-based end products, JTWC advanced operational application of geospatial data for analysis and forecasting. The fast ops-tempo at JTWC affords forecasters limited time to access and evaluate the large amount of available tropical cyclone analysis and forecast data. Forecasters have traditionally interrogated static web-based products with no inherent capability for overlay alongside JTWC satellite fixes and best tracks. This year, JTWC forecasters were provided the capability to leverage Google Earth (GE) capabilities to display, overlay, interrogate, and animate data by incorporating real-time satellite fixes, best tracks, forecast aids, and warning products from ATCF with NRL satellite imagery, model output, streamline analyses, scatterometry data, buoy data, observations, radar imagery, CIMSS analyses, SST, and a growing list of additional products. Automated scripts collate and refresh these data every ten minutes, ensuring forecasters can access the most up-to-date information. KML-formatted data, such as files produced by NRL TC Web, NDBC, and CIMSS, can be seamlessly integrated into the JTWC Google Earth toolkit. Use of GE at JTWC will enable forecasters to take full advantage of KML-based analysis and forecast products introduced by these and other agencies in the years ahead.

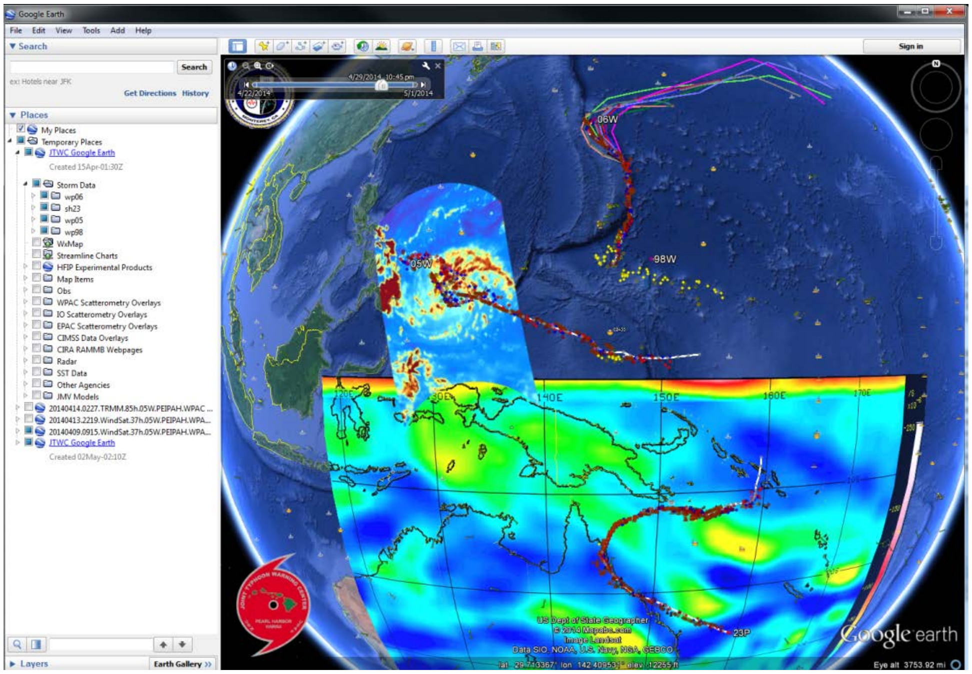


Figure 5-5: JTWC KML toolkit image of TC position fixes, best track, and forecast aids from ATCF overlaid with sample NRL TC Web, CIMSS and NDBC products.

JTWC is also producing a KML-based interface to interrogate historical best track data archives. A climatology of over 1,100 individual search criteria displayable in Google Earth has been generated for the WESTPAC, providing easy access to storm information in a customizable graphical format. Similar climatology tools for the Indian Ocean and Southern Hemisphere are under development.

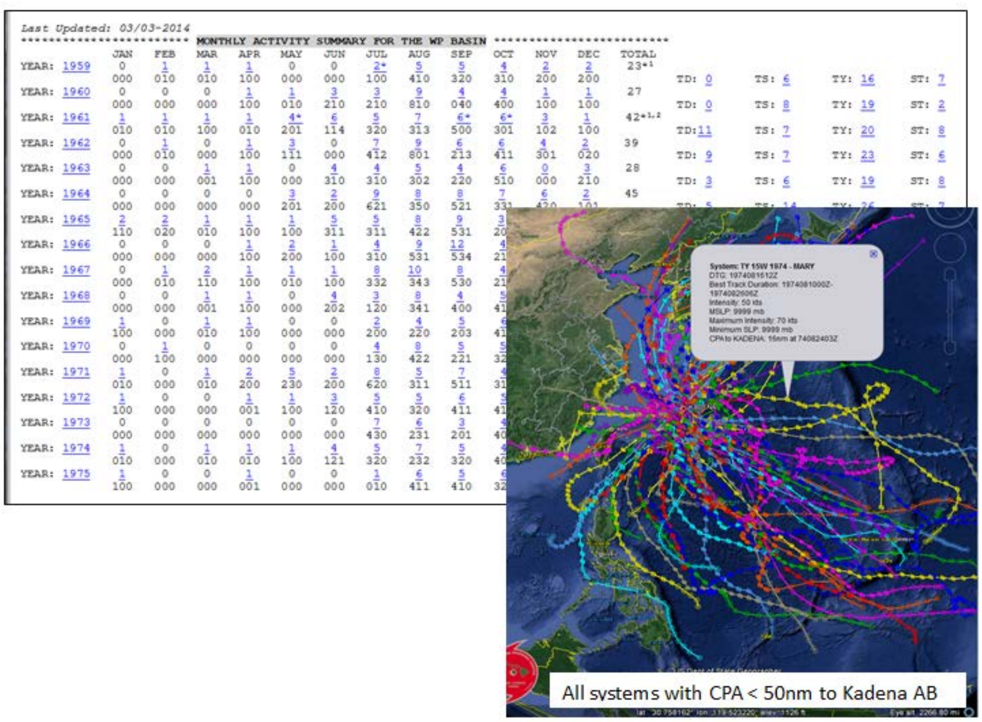


Figure 5-6: Example KML-based climatological data display developed at JTWC.

Cyclone phase classification and subtropical cyclone analysis
(Adapted excerpt from Kucas et al. 2014)

Subtropical cyclones present unique challenges to JTWC (Barlow and Payne 2012; Kucas 2010). Analysis and forecasting procedures for subtropical and tropical cyclones can differ significantly. Because US Government partners rely upon JTWC analyses and forecasts to tailor meteorological products for impacted customers, accurately distinguishing subtropical cyclones from tropical and extratropical cyclones is essential. Of course, cyclones located in the subtropics often exhibit well-documented physical characteristics common to both extratropical and tropical cyclones (OFCM 2013). A universal, subjective analysis method to differentiate these cyclones in ambiguous, real-world situations has not been established by the research community. To address this shortcoming, JTWC developed a cyclone phase classification method that synthesizes available remote sensing datasets and numerical model analysis fields to systematically guide the forecaster through the classification process. This adaptable method reduces the inconsistency that results from a purely subjective approach and provides customers a clear representation of how these classifications are determined.

Based on a thorough review of the literature and forecaster experience, the authors generated a list of 13 observable criteria related to cyclone phase for which associated, near real-time data are routinely available:

- Moisture signature (total precipitable water)
- Symmetry of the low level circulation center (LLCC)
- Radius of maximum winds
- Symmetry of the 850 mb vorticity signature
- 850 mb maximum vorticity
- Deep convection structure
- Size of convective envelope
- Vertical wind shear
- Sea surface temperature
- Baroclinicity
- Core temperature anomaly
- LLCC position relative to the 500 mb subtropical ridge axis
- LLCC position relative to upper low

These criteria are included in an initial version of the cyclone phase classification worksheet. Forecasters access the cyclone phase classification worksheet through a PHP-based web-interface hosted on a JTWC computer server. To complete the worksheet, the forecaster enters data into a series of input boxes and drop down menus. After completing the worksheet, the forecaster receives a summary of data entered and is prompted for his or her subjective assessment of the cyclone's phase (tropical, subtropical, or extratropical) along with any relevant notes or comments before he/she clicks the command button "Assess Cyclone Phase". The calculated assessment is withheld at this point to facilitate the collection of unbiased, subjective assessments. These assessments will be considered during future adjustments to the worksheet criteria, value bins, and formulas. The final screen provides a summary of the assessment and notes entered by the forecaster along with the final score and assessment according to the worksheet parameters and formulas (Figure 5-7).

CYCLONE PHASE CLASSIFICATION WORKSHEET RESULTS

Invest/TC number:	01W
Moisture structure:	Symmetric DRY (< 48mm)
Surface wind field	
Symmetry:	Greater than 2
RMW:	50 to 100 nm
850mb vorticity	
Symmetry:	1.5 to 2
Value:	Greater than 75
Convective structure	
Deep convection:	Greater than 80% located poleward and east of center
Size of convective envelope:	Cloud system width 600-900nm
Vertical wind shear:	20 to 30 kts
Sea surface temperature:	24C to 26C
Baroclinicity:	Moderate temperature gradient
Core temperature anomaly:	Warm anomaly at tropopause with cold core in lower troposphere
Position relative to STR:	Near Axis of STR (but under an upper low or subtropical westerlies)
Upper low position:	Low offset from LLCC
Classification score:	0.15384615384615
Classification assessment:	SUBTROPICAL
Forecaster initials:	ABC
Subjective assessment:	SUBTROPICAL
Notes / comments:	System displays subtropical characteristics.

Click here to run another cyclone phase classification worksheet

Figure 5-7: Example final assessment and summary of data provided by the phase classification worksheet.

More details are available from Kucas et al. (2014).

Tropical cyclone data plots

Tech Dev automated the production and dissemination of multiple tropical cyclone decision support data products to the Center's Naval Oceanography Portal and Collaboration websites using original MATLAB® and Unix-based scripts (Fig 5-8). This automated process replaces time-consuming manual product generation procedures, provides flexible data display options and enables efficient and effective presentation of supplemental analysis and forecast data.

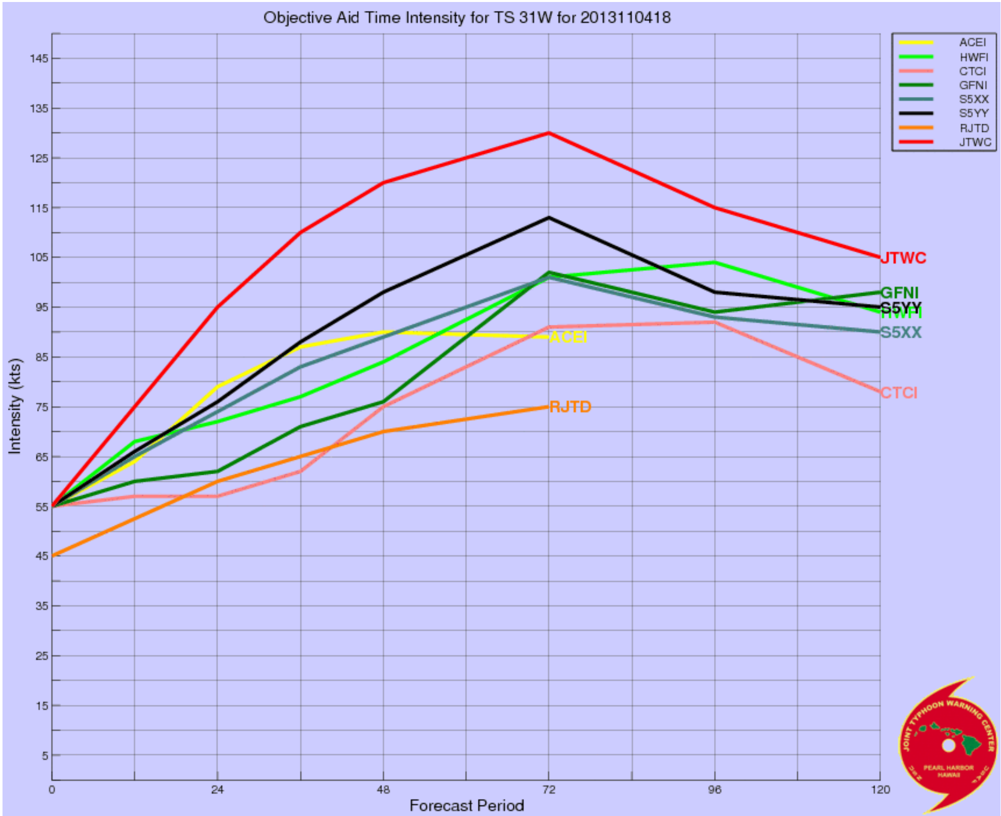


Figure 5-8: Example intensity forecast graphic for 31W (Haiyan) auto-generated by MATLAB® software routines composed by the JTWC Tech Dev team.

Electronic streamline analysis

The Tech Dev team recommended procurement of digital drawing tablets, composed procedures, and conducted extensive training to facilitate application of this new equipment to analyze streamline charts. These new tools and procedures replaced a resource-intensive process involving printing, hand analysis and scanning of large paper charts. The use of digital technology has cut the time required to hand-draw streamlines by an average of 30 minutes, improved the look and feel of the streamline products, and enabled generation of streamline analysis “layers” available for overlay in geospatial data display systems such as Google Earth. Figure 5-9 shows an example streamline chart prepared using the new digital analysis method and tools.

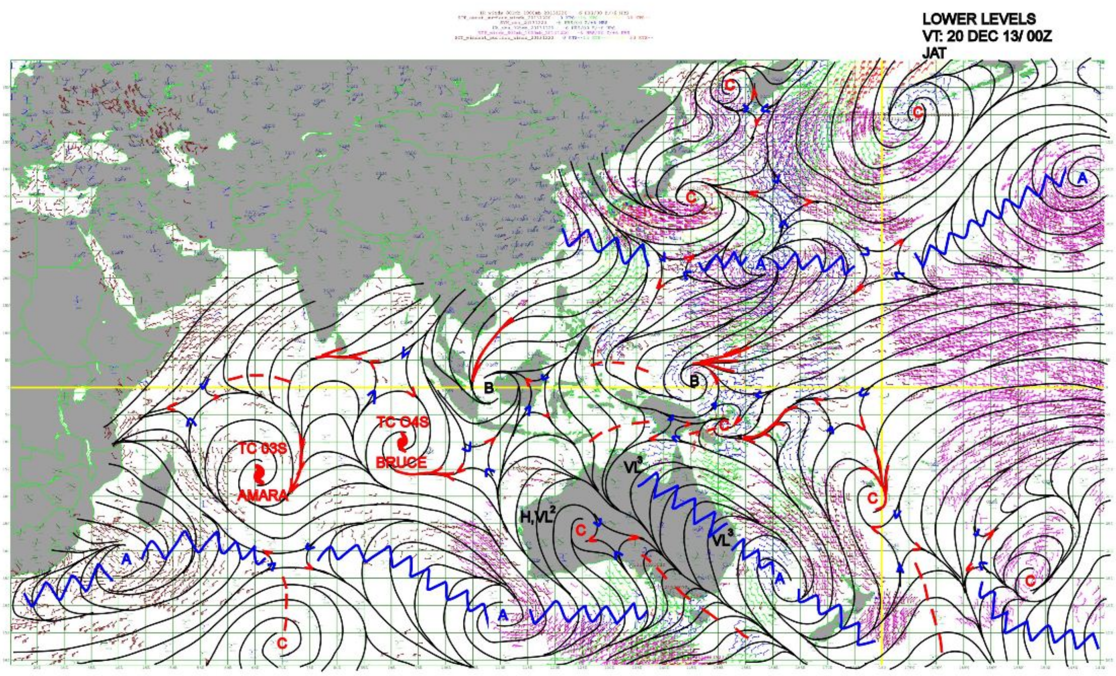


Figure 5-9: JTWC gradient-level streamline analysis for 0000Z on 20 December 2013 (analyzed by JTWC Geophysical Technician Jack Tracey).

Global Tropics Hazards Outlook

Tech Dev, in collaboration with NOAA organizations, the Naval Postgraduate School, the University of Albany, the Australia Bureau of Meteorology, and the Taiwan Central Weather Bureau, once again provide input to the week one and two tropical cyclone forecasts produced by NOAA/NWS's Climate Prediction Center's (CPC) weekly Global Tropics Hazards (GTH) Assessment. This assessment, published weekly by Wednesday at 0000Z, is available directly from CPC's GTH website (http://www.cpc.ncep.noaa.gov/products/precip/CWlink/ghazards/), and is also accessible from a hyperlink provided on JTWC's public webpage.

Section 4 Future work

Probabilistic TC track and intensity forecasting techniques

Tech Dev is exploring methods to derive practical, probabilistic forecast guidance from newly-available intensity forecast products, such as GPCE (Goerss and Sampson 2014) and WANI (Elsberry and Tsai 2014) intensity forecast spreads, and deterministic model track forecasts. Experimental products, including "overlapping intensity forecast ranges" and tropical cyclone strike probabilities from consensus model track forecasts are currently under evaluation for application as in-house forecasting aids (Figures 5-10 and 5-11). Future work will verify the accuracy of these products and optimize both presentation and interpretability. New methods to interpret and communicate probabilistic forecast data will be explored in depth. See the TY 22W (Fitow) case study included in this ATCR for a summary of current probabilistic track forecasting difficulties, customer communication issues, and plans for future development efforts.

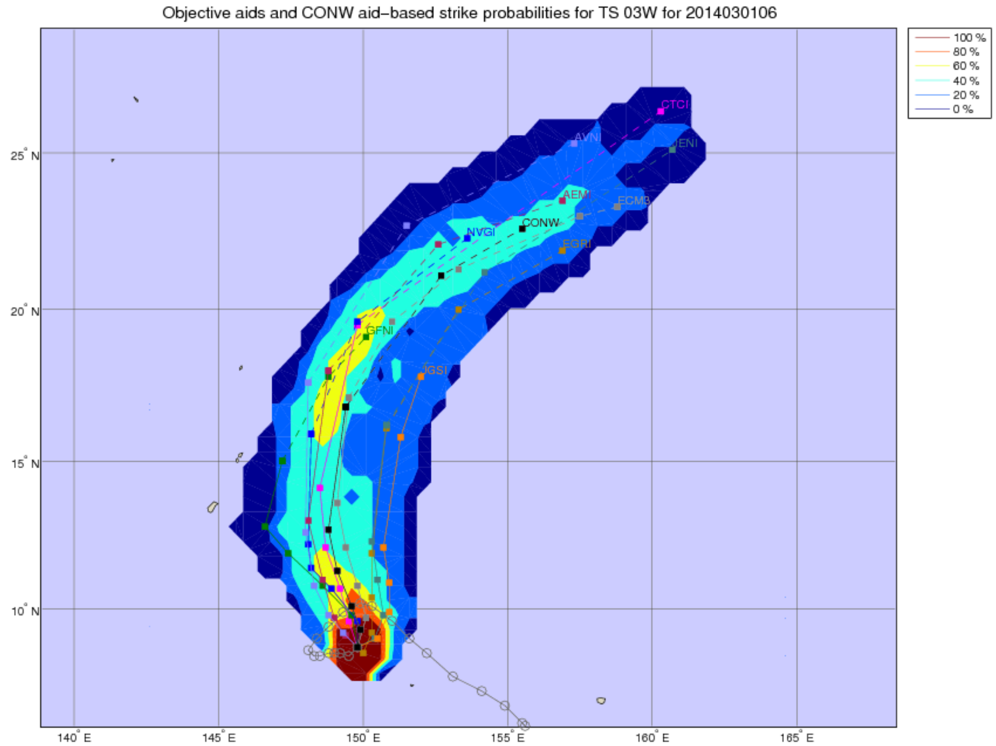


Figure 5-10: Experimental tropical cyclone track forecast probability product for TS 03W (2014). Shading represents the percent probability that the center of TS 03W, 2014 will fall within 60 nautical miles of shaded locations within 120 hours based on available consensus member track data from the 0600Z forecast on March 1, 2014.

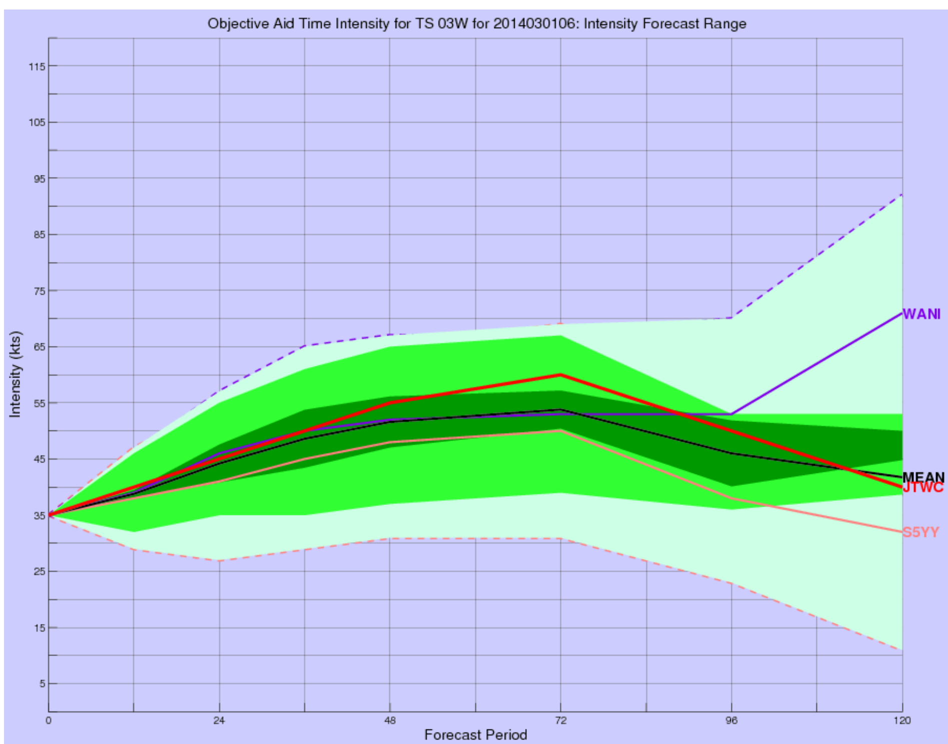


Figure 5-11: Experimental tropical cyclone intensity forecast range product for TS 03W (2014), based on the 0600Z forecast on March 1, 2014. Green shading represents forecast intensity values falling within the WANI, GPCE, and Mean forecast ranges. Areas where these forecast ranges overlap are shaded darker green.

Two-week subjective tropical cyclone formation outlooks

Tech Dev conducted an in-house effort to subjectively forecast tropical cyclone formation across the JTWC AOR within a two-week prediction window. "Pre-invest" forecasts, highlighting locations for potential TC formation with associated development timelines and subjectively-derived formation probabilities, were prepared twice per week from June 2013 to present. The current forecast process leverages available numerical model forecast guidance and intra-seasonal climate data from the NOAA/NWS's Climate Prediction Center and other sources, as well as newly-available experimental guidance such as ECMWF 15 and 32-day outlooks provided by NPS (Elsberry et al. 2011) and the NPS long-lead tropical cyclone formation model (Meyer and Murphree 2012). An evaluation of forecast performance and refinement of the prediction technique will be conducted in 2014. Preliminary plans to expand this effort include tracking objective and subjective formation probabilities associated with designated "pre-invest" areas and gathering associated pre-formation track and intensity forecast data. The goal of this effort is to provide forecasters a "continuum" of pre-formation forecasts to facilitate issuance of timely and accurate Low/Medium/High invest classifications and initial warnings on newly-developed tropical cyclones.

GIS products

Following the successful implementation of GIS-enabled TCFA and warning products in 2013, JTWC is developing an experimental, KML-based Significant Tropical Weather Bulletin integrating real-time graphic representations and text-based discussions for all current classified invest areas, TCFAs, and warnings throughout the JTWC AOR in a single Google Earth layer. When opened, the product will automatically update all relevant position, intensity, and status information for all classified areas, providing customers with up-to-date information in one central location.

Automated track and intensity analysis

Tech Dev will develop automated tropical cyclone track and intensity analysis guidance to expand upon the Automated Tropical Cyclone Forecasting (ATCF) system's objective best track (OBT) routine, developed at the Naval Research Laboratory by Mr. Buck Sampson and Ms. Ann Schrader. This effort will involve a detailed statistical analysis of tropical cyclone position and intensity fix data to build upon the existing OBT technique.

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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 2013 season, and contrasts it with annual verification statistics from previous years.

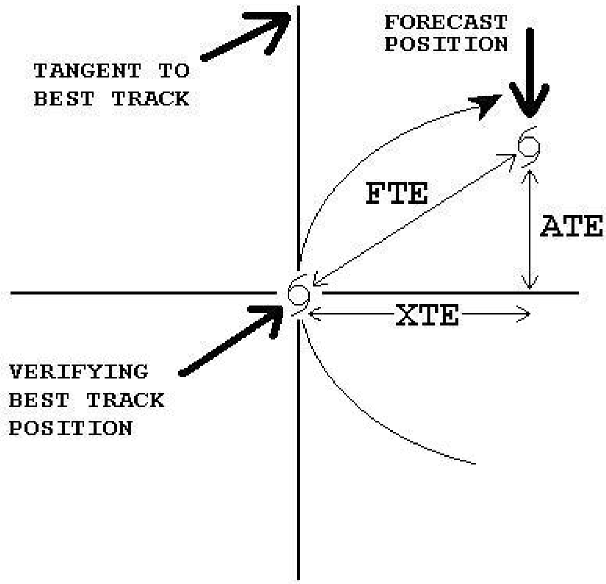

Figure 6-1. Definition of cross-track error (XTE), along track error (ATE), and forecast track error (FTE). In this example, the forecast position is ahead of and to the right of the verifying best track position. Therefore, the XTE is positive (to the right of track) and the ATE is positive (ahead of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

TABLE 6-1
MEAN FORECAST ERRORS (NM) FOR WESTERN NORTH PACIFIC TROPICAL CYCLONES FROM 1959 - 2013

	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
Avg (1978-2013)	575	85	94	54	66	462	165	176	100	123	363	258	263	148	185	195	157	220	119	159	140	213	294	156	212
5yr Avg	438	49	56	33	39	345	88	96	56	66	261	134	140	80	97	179	157	195	111	136	131	213	259	146	178

(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.

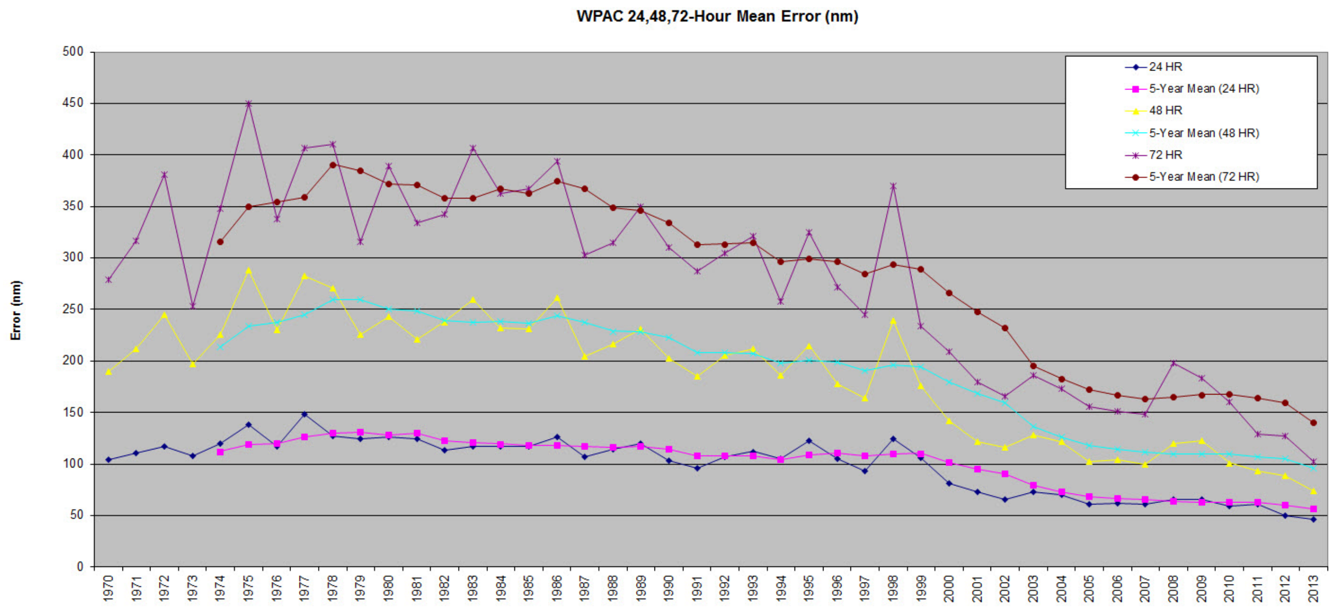

Figure 6-2. Graph of JTWC forecast errors and five year running mean errors for the western North Pacific at 24, 48, and 72 hours.

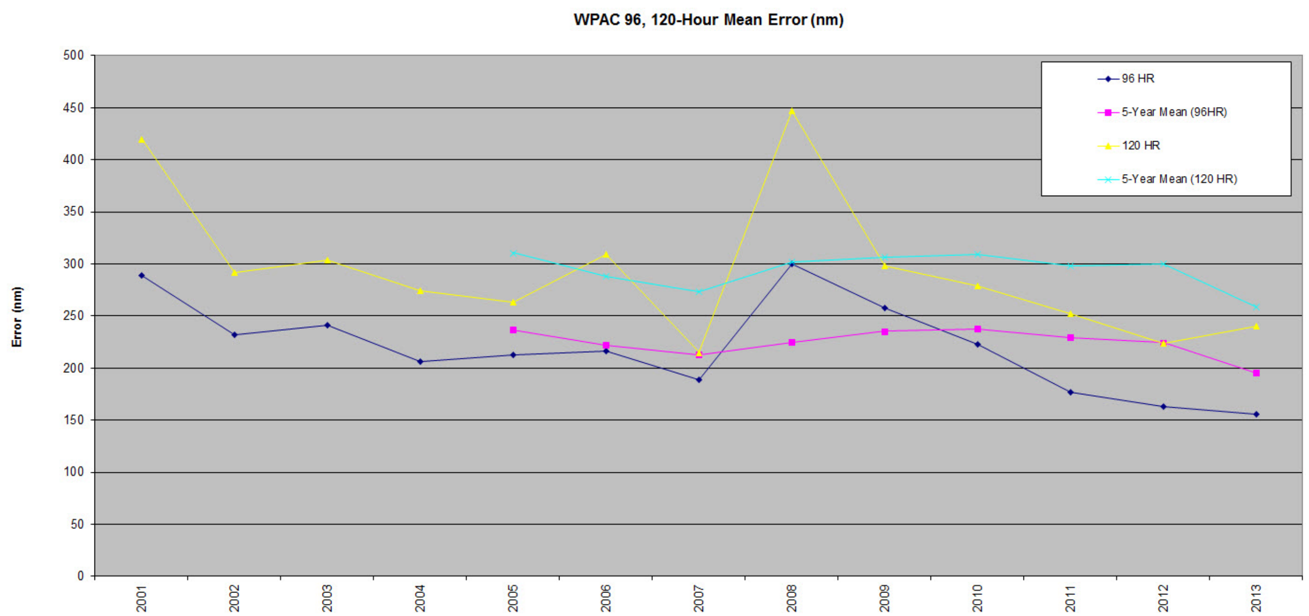

Figure 6-3. Graph of JTWC forecast errors and five year running mean errors for the western North Pacific at 96 and 120 hours.

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

TROPICAL CYCLONES FROM 1985-2013

	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	(1)							
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
Avg (1985-2010)	48	94	66	53	31	160	109	93	17	247	169	140								
5Yr Avg	50	63	35	44	34	105	55	75	20	161	72	126								

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

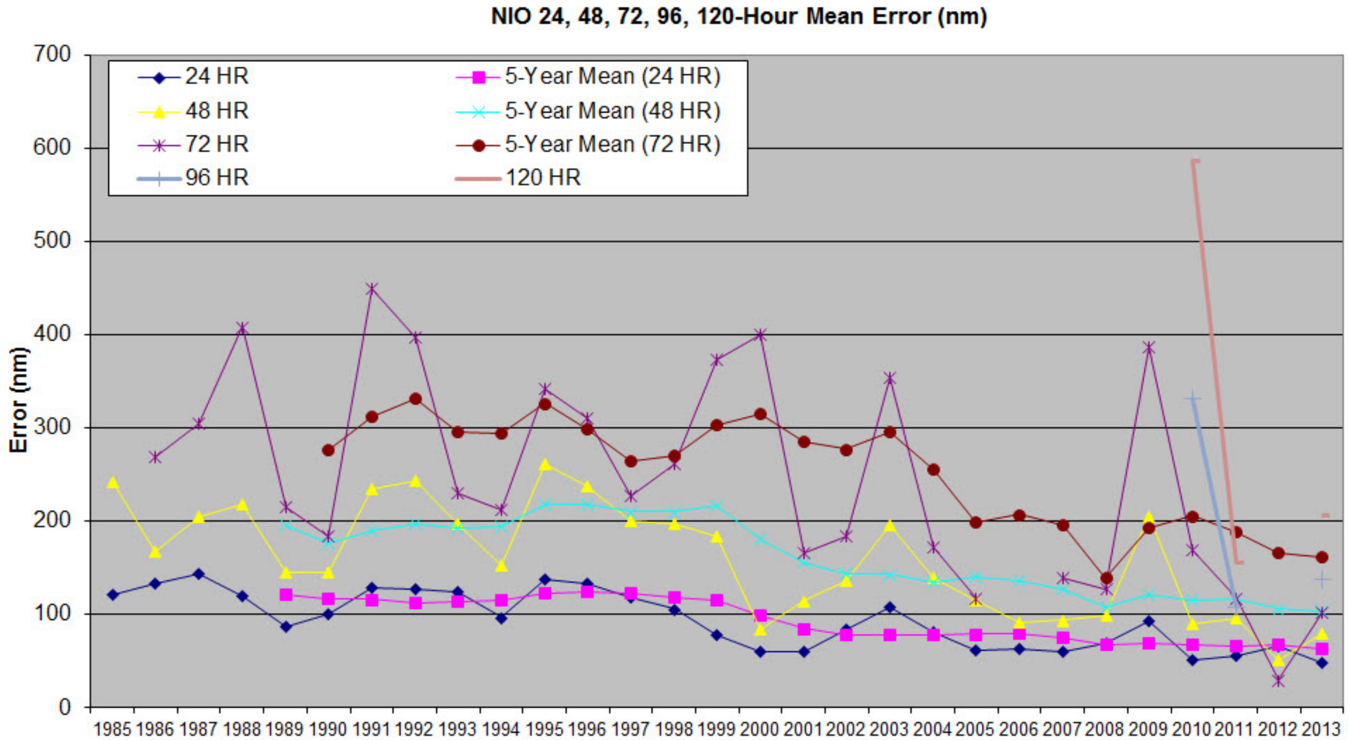

Figure 6-4. Graph of JTWC forecast errors and five year running mean errors for the north Indian Ocean at 24, 48, 72, 96, and 120 hours.

TABLE 6-3
MEAN FORECAST ERRORS (NM) FOR SOUTHERN HEMISPHERE
TROPICAL CYCLONES 1985 - 2013

	24-Hour				48-Hour				72-Hour				96-Hour				120-Hour			
Year (Notes)	Cases	Mean Error	Cross Track Mean Error	Along Track Mean Error	Cases	Mean Error	Cross Track Mean Error	Along Track Mean Error	Cases	Mean Error	Cross Track Mean Error	Along Track Mean Error	Cases	Mean Error	Cross Track Mean Error	Along Track Mean Error	Cases	Mean Error	Cross Track Mean Error	Along Track Mean Error
1985	257	134	79	92	193	236	132	169												
1986	227	129	77	86	171	262	164	169												
1987	138	145	90	94	101	280	138	153												
1988	99	146	83	98	48	290	144	246												
1989	242	124	73	84	186	240	136	166												
1990	228	143	74	105	177	263	152	178												
1991	231	115	69	75	185	220	129	152												
1992	230	124	64	91	208	240	129	177												
1993	225	102	57	74	176	199	114	142												
1994	345	115	68	77	282	224	134	147												
1995	222	108	55	82	175	198	108	144	53	291	190	169								
1996	298	125	67	90	237	240	129	174	46	277	133	221								
1997	499	109	72	82	442	210	135	163	150	288	175	248								
1998	305	111	52	85	245	219	108	169	81	349	171	261								
1999	322	113	64	80	245	226	132	159	59	286	164	198								
2000	313	72	45	47	245	135	86	84	58	180	139	94								
2001	147	84	44	61	113	148	86	105	11	248	197	133								
2002	200	82	43	60	146	133	75	93	5	102	41	91								
2003	279	74	37	57	221	127	68	90	37	123	54	99								
2004	277	77	45	52	233	142	89	92	47	210	102	162								
2005	214	70	44	44	170	116	77	72	41	199	117	136								
2006	191	65	37	46	140	116	69	79	32	201	101	151								
2007	186	74.9	41	52	131	147	80	105	3	173	146	73								
2008	269	61	38	40	211	106	64	72	27	97	53	65								
2009	166	74	42	51	118	128	74	89	14	114	89	54	(1)							
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
Avg (1985-2010)	237	97	55	68	186	180	102	125	60	193	113	133								
5Yr Avg	188	60	35	41	145	99	58	65	97	127	72	87								

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

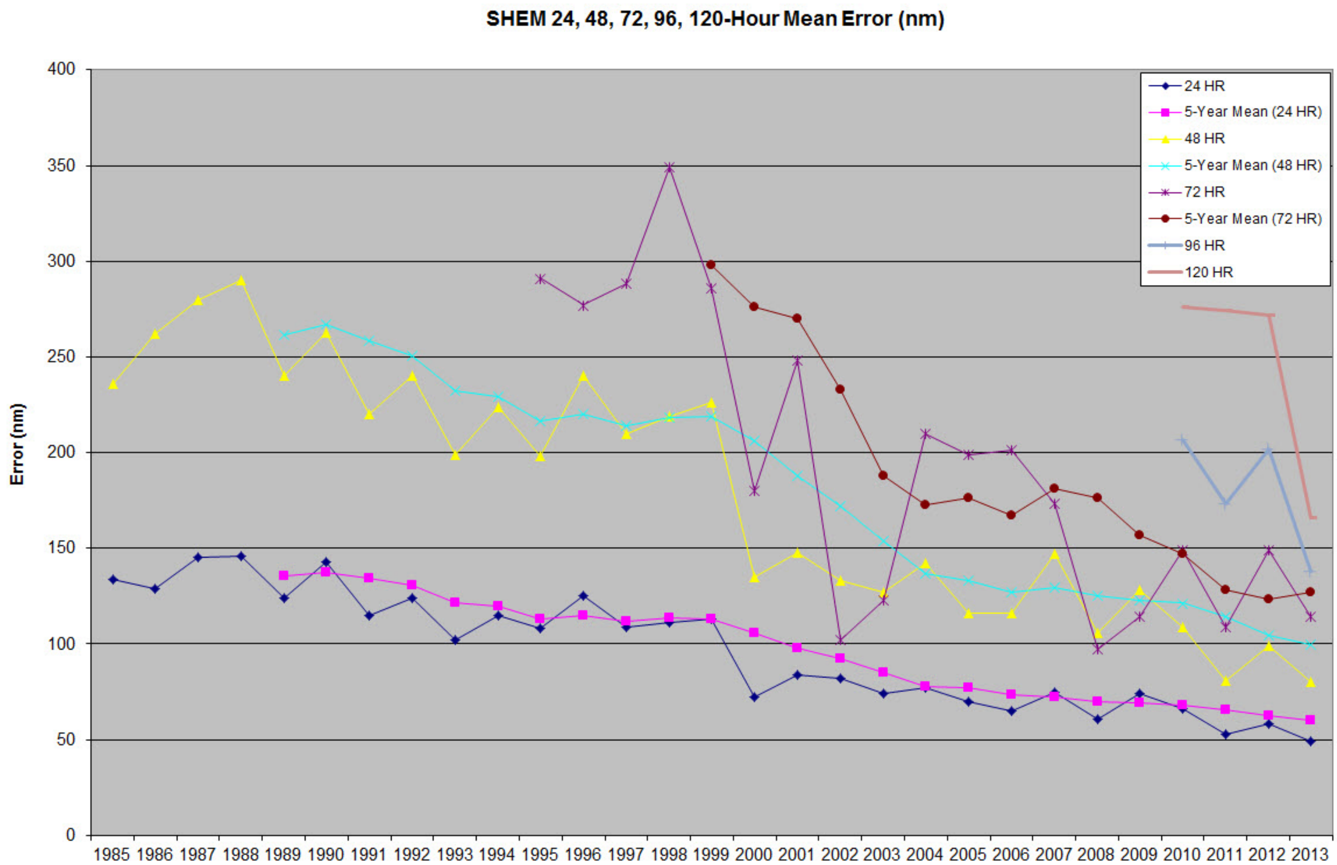

Figure 6-5. Graph of JTWC forecast errors for the Southern Hemisphere at 24, 48, 72, 96, and 120 hours.

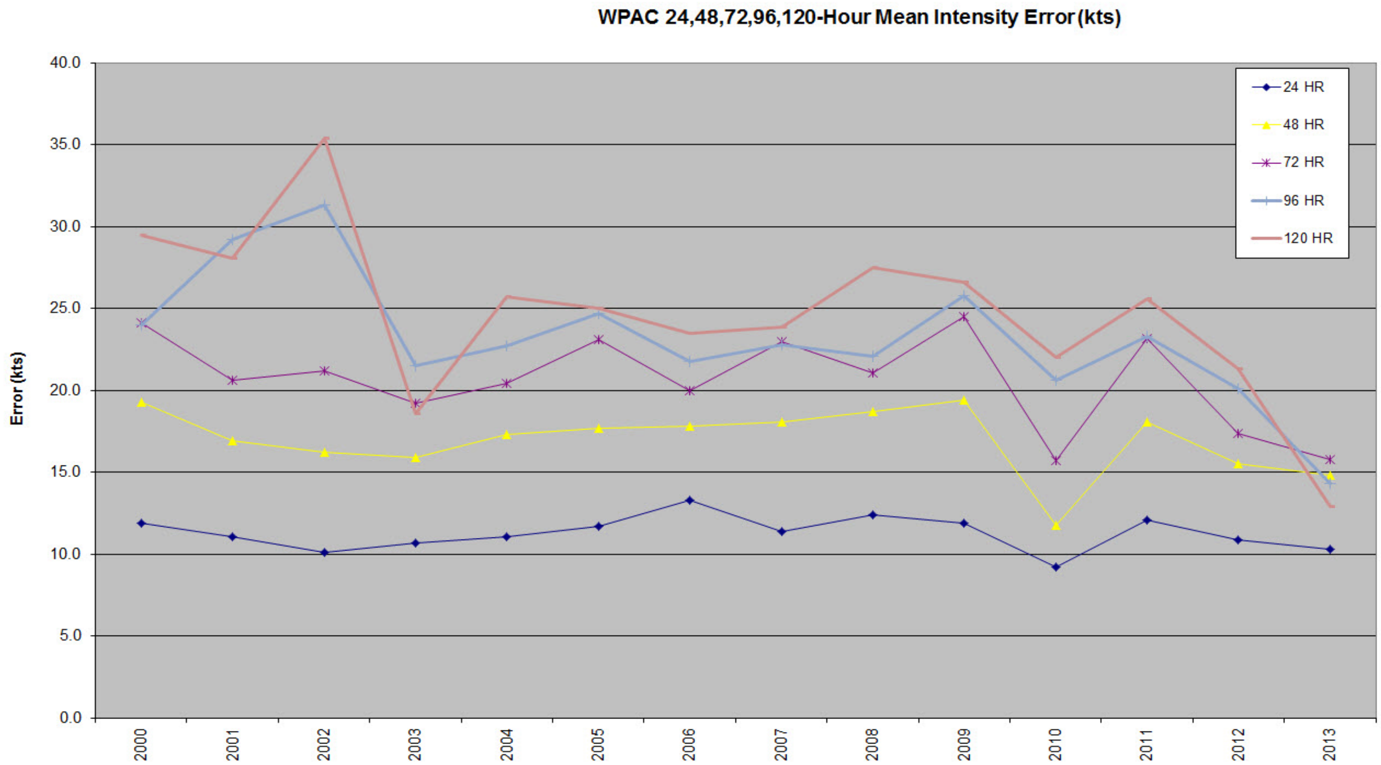

Figure 6-6. Graph of JTWC intensity forecast errors for the western North Pacific at 24, 48, 72, 96, and 120 hours.

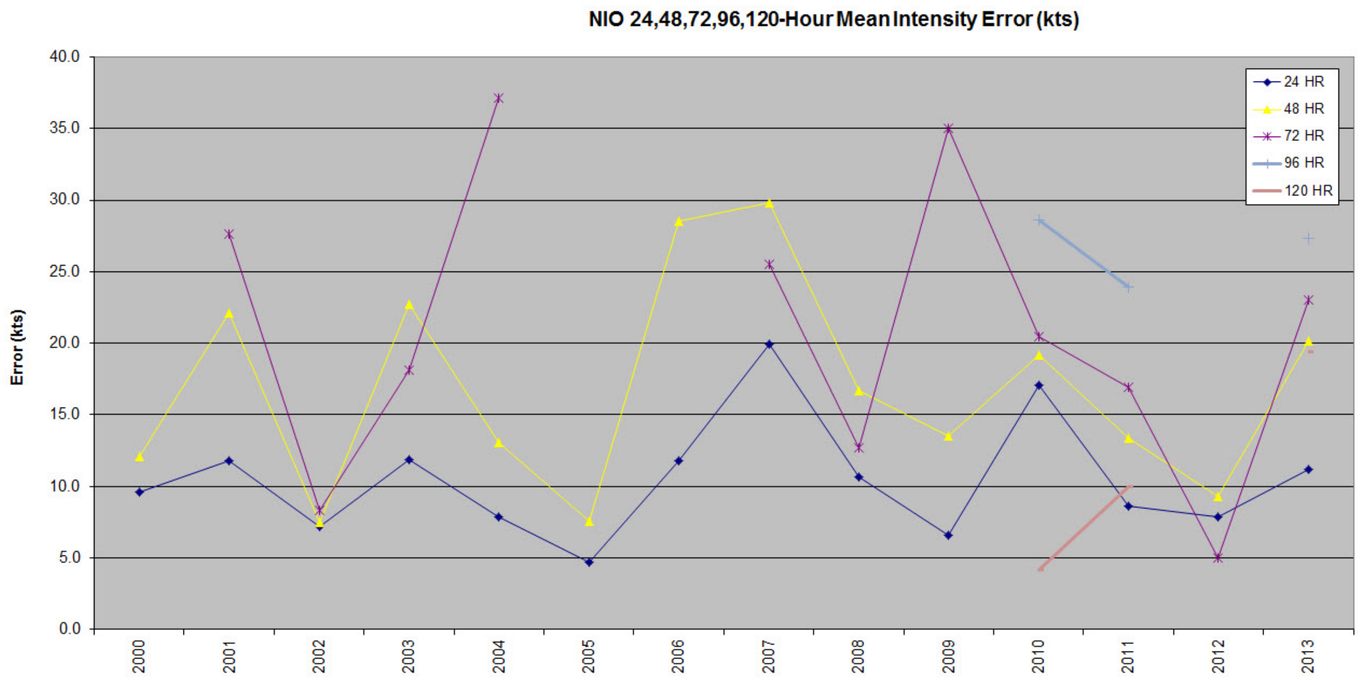

Figure 6-7. Graph of JTWC intensity forecast errors for the North Indian Ocean at 24, 48, 72, 96, and 120 hours.

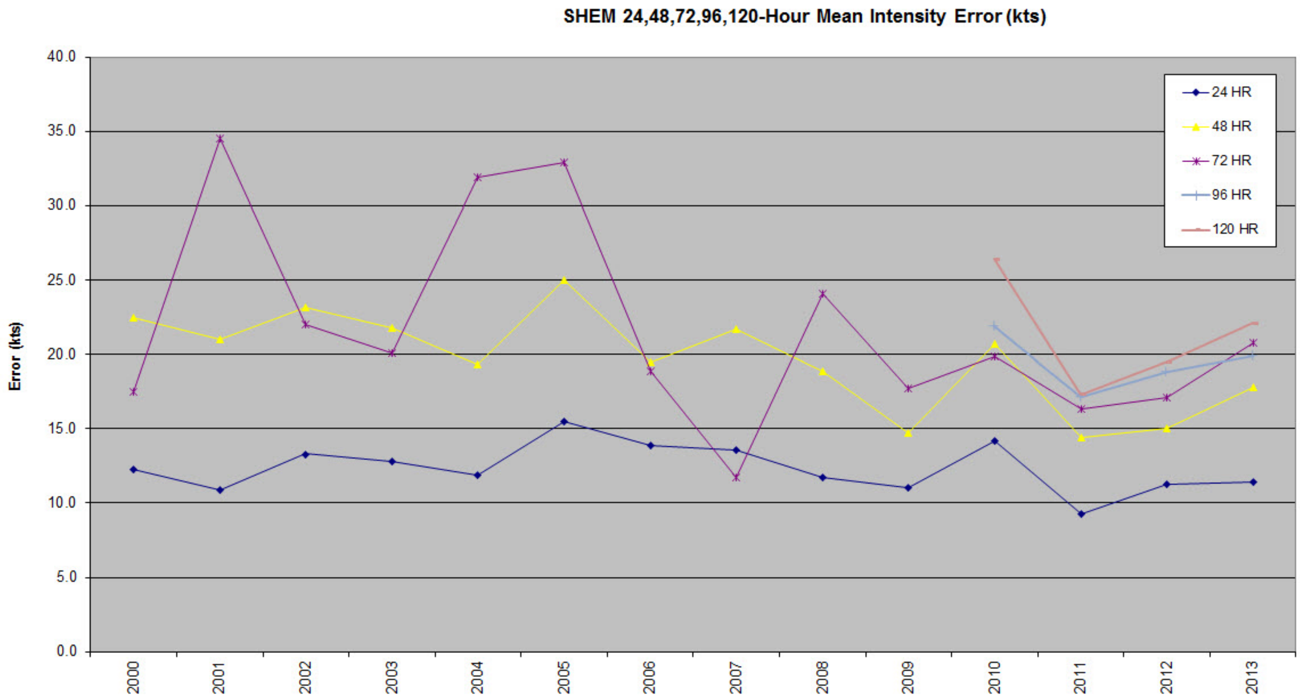

Figure 6-8. Graph of JTWC intensity forecast errors for the Southern Hemisphere at 24, 48, 72, 96, and 120 hours.