14A.4 WESTERN NORTH PACIFIC TROPICAL CYCLONE INTENSITY CLIMATOLOGY AND JTWC INTENSITY FORECAST ERROR STUDY

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1. INTRODUCTION

As part of ongoing efforts to improve tropical cyclone (TC) intensity forecast capability, two tasks were conducted at JTWC. A climatology of 24-hour intensity changes was computed using 30 years (1977-2006) of JTWC best track data, which covers 915 TCs. Intensity forecast errors during the 2002-2006 NWPAC seasons were also examined.

Results of the 2nd effort indicate that during 2002-2006, the average absolute intensity errors have not improved. Furthermore, preliminary 2007 errors shown in Table 1 indicate the same trend.

Preliminary results using the Pearson product-moment coefficient of linear correlation, Spearman rank correlation and Kendall's τ indicate that there is no statistically significant correlation between the JTWC intensity forecast error magnitude and geographical location, initial intensity, or 6-hour motion of the TC.

	Tau 24	Tau 48	Tau 72	Tau 96	Tau 120
2007	11.0	18.0	23.1	23.5	26.4
2002-2006	11.2	16.9	20.7	24.4	26.0

Table 1: Average JTWC Absolute Intensity Error (knots)

2. DATA AND ANALYSIS METHOD

An intensification climatology was created using JTWC's official archive of tropical cyclone track data or "best tracks" from 1977 to 2006 to describe 24-hour intensity changes noted with the data. The 24-hour intensification rates were calculated using the 6-hourly TC intensity values ($\geq$ 25 knots) from the best tracks; these intensity values represent the 1-minute mean sustained 10-meter wind speeds. Refer to Chu (2002) for more detailed information on the JTWC best track data. For the purpose of this study, the rapid and explosive intensification thresholds were set at 30-45 knots and $\geq$ 50 knots, respectively, based on the relatively low frequencies of occurrence (9.1% and 1.8%).

JTWC intensity forecast errors were calculated for all NWPAC TCs for the period 2002-2006 using the Automated Tropical Cyclone Forecast System's single model error (SME) statistical function. JTWC SME was first calculated for each year then merged into a single database, which provided the 6-hourly date/time, latitude, longitude, initial intensity and the intensity forecast error at each significant forecast period. Storm motion was calculated using the ATAN2 (Δlat, Δlon) and converting from radians into degrees. Intensity error characteristics were examined for the 24, 36, 48, 72, 96 and 120 hour forecasts.

3. RESULTS

3.1 24-hour Intensification Rate: For TCs of all initial intensities $\geq$ 25 knots and a 24-hour intensification rate $\geq$ 0 knots, 58.6% (8,146) of the cases occurred at a rate of 0-10 knots per 24 hours, including 22.0% (3,056) which indicated no change in intensity, while 30.7% (4,250) of the cases were at a rate of 15-25 knots per 24 hours. Figure 1 reflects this rapid decrease in the percent occurrence of intensification rates above 10 knots per 24 hours. In general, the Dvorak model forecast intensification rate varies markedly based on the TC initial intensity with a greater 24-hour intensification rate expected for increasing TC initial intensity (Dvorak, 1975). The Dvorak model "typical" rate of 1 T-number per day varies from 5 (T1.0 to 2.0) to 30 (T7.0 to 8.0) knots per day—71.1% of the cases

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occurred at a rate of 5-30 knots. The Dvorak model "slow" rate of 0.5 T-number per day varies from 0 to 15 knots per day (comprised 72.3% of the cases); and the "rapid" rate varies from 10 to 40 knots per day (comprised 57.0% of the cases).

Rate (knots/ 24 hours)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
Cases	3056	2563	2527	1927	1477	856	523	327	270	134	106	56	37	22	15	4	5	3
% Occurrence	22.0	18.4	18.2	13.9	10.6	6.2	3.8	2.4	1.9	1.0	0.8	0.4	0.3	0.2	0.1	0	0	0

Table 2: Summary of 24-Hour Intensification Rates for TCs of all Initial Intensities (1977-2006)

Intensification rates continued to decrease at and above 30 knots with rapid intensification cases (30-45 knots) comprising 9.1% (1,254) of the total cases and explosive intensification (≥ 50 knots) only 1.8% (248).

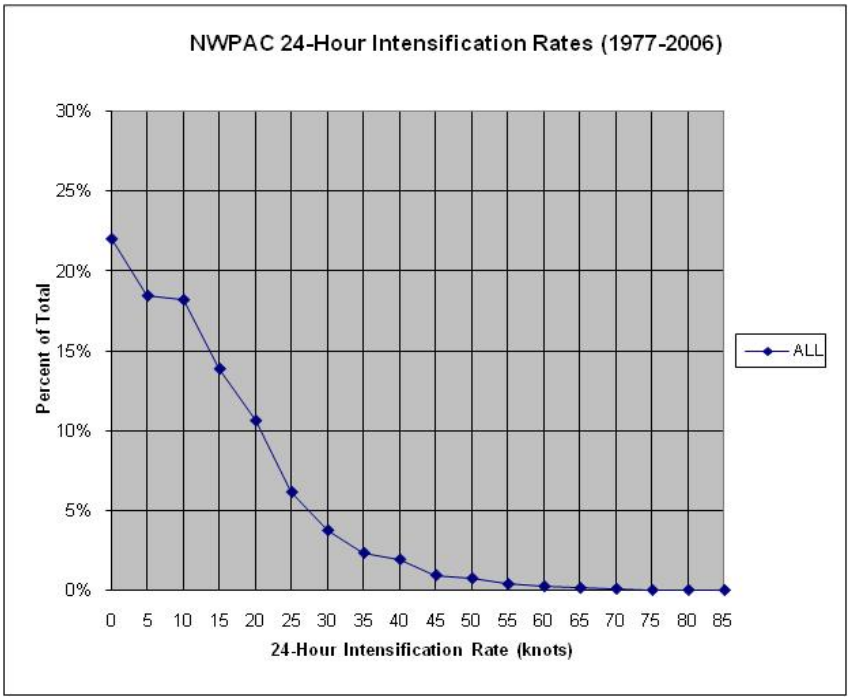


Figure 1: Percent Occurrence of Intensification Rates for all TCs (1977-2006)

The Dvorak model rates have proved difficult to use operationally as a forecast tool, therefore, a more detailed examination of 24-hour intensification rates was completed. The data was binned and is summarized in Table 3. There were significant differences in frequency of occurrence based on the TC's initial intensity. Weak systems (25-40 knots) had a higher percentage (81.4%) of slow intensification events (0-15 knots / 24hours), while moderate intensity systems (45-100 knots) had a higher percentage of rapid intensification events--the frequency of these events increased from 12.2% (initial intensity of 45-60 knots) to a peak of 19.9% (initial intensity of 85-100 knots). Systems with initial intensity ranging from 65-100 knots had the highest percentage of explosive intensification ranging from 2.3% for 45-60 knot systems to a peak of 6.4% for 65-80 knot systems.

RATE	ALL	25-40 KTS	45-60 KTS	65-80 KTS	85-100 KTS	105-120 KTS	≥ 125 KTS
0	22.0%	25.4%	16.1%	15.3%	22.4%	19.4%	45.0%
+5	18.4%	22.0%	14.8%	11.7%	12.7%	15.1%	16.8%
+10	18.2%	19.8%	17.6%	15.5%	12.7%	16.0%	16.8%
+15	13.9%	14.2%	14.7%	13.6%	10.4%	14.9%	12.2%
+20	10.6%	9.4%	14.9%	10.7%	7.9%	13.4%	5.0%
+25	6.2%	4.5%	7.4%	9.0%	9.6%	10.2%	1.7%
+30	3.8%	2.7%	5.0%	4.7%	7.5%	3.6%	2.1%
+35	2.4%	1.0%	3.0%	5.4%	5.3%	4.0%	0.4%
+40	1.9%	0.7%	2.7%	4.8%	4.5%	2.6%	0.0%
+45	1.0%	0.1%	1.5%	3.0%	2.6%	0.2%	0.0%
+50	0.8%	0.1%	0.8%	2.7%	2.6%	0.4%	0.0%
+55	0.4%	0.1%	0.6%	1.5%	0.7%	0.2%	0.0%
+60	0.3%	0.1%	0.3%	1.1%	0.4%	0.0%	0.0%
+65	0.2%	0.0%	0.3%	0.4%	0.4%	0.0%	0.0%
+70	0.1%	0.0%	0.2%	0.4%	0.1%	0.0%	0.0%
+75	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
+80	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%
+85	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%

Table 3: 24-Hour Intensification Rates Stratified By TC Initial Intensity (1977-2006)

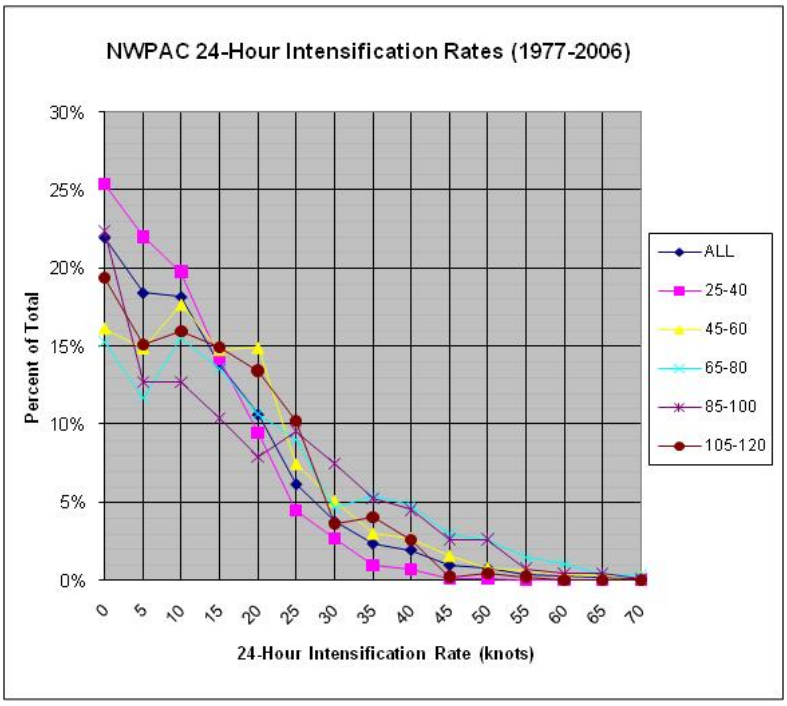
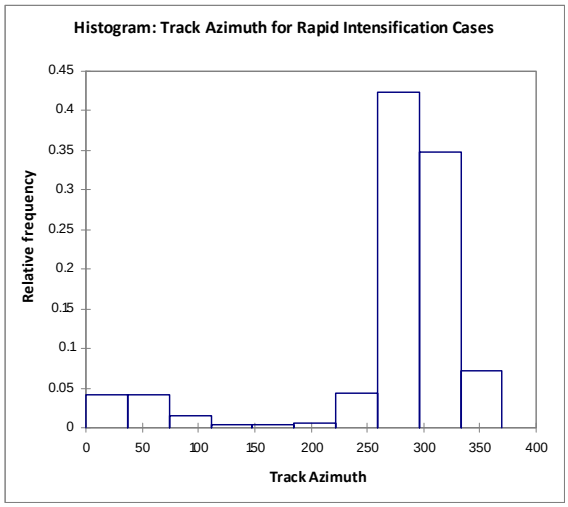
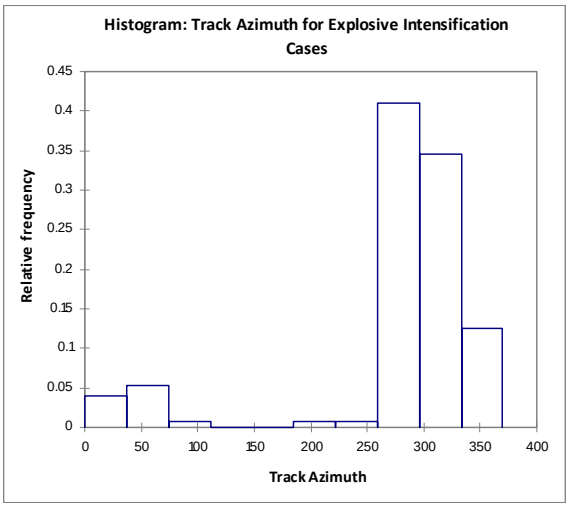


Figure 2: Percent Occurrence of Intensification Rates (1977-2006)

The 24-hour intensification rates were further stratified by TC track azimuth (6-hour storm motion), latitude, and longitude. In general, rapid intensification occurred more frequently with TCs tracking toward 259-296 degrees (relative frequency of 42.3%) or toward 296-333 (relative frequency of 34.8%). TCs tracking toward 111-222 degrees had the lowest frequency of occurrence ranging from 0.3% to 0.7% (total of 1.4%). Similarly, TCs tracking toward 259-333 were more likely to experience explosive intensification (75.7%). TCs tracking toward 333-360 were more likely to experience explosive vice rapid intensification (7.1% vs. 12.6%).





Figures 3a,b: Track Azimuth Histogram for Rapid and Explosive Intensification Cases

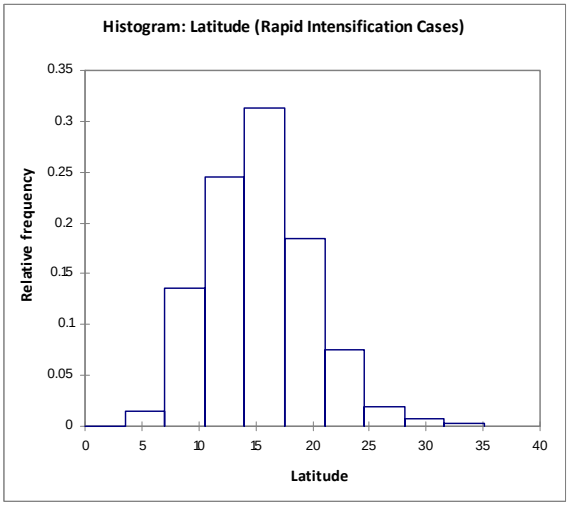
Begin Azimuth	End Azimuth	Frequency	Relative frequency
0	37	52	4.2%
37	74	51	4.2%
74	111	19	1.6%
111	148	5	0.4%
148	185	4	0.3%
185	222	8	0.7%
222	259	54	4.4%
259	296	518	42.3%
296	333	426	34.8%
333	370	87	7.1%

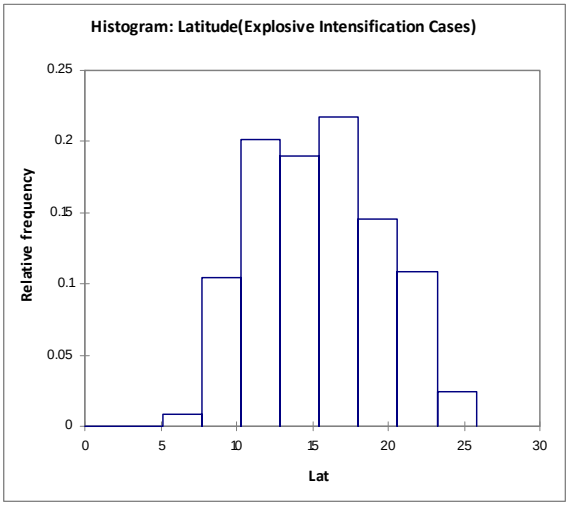
Begin Azimuth	End Azimuth	Frequency	Relative frequency
0	37	10	4.1%
37	74	13	5.3%
74	111	2	0.8%
111	148	0	0.0%
148	185	0	0.0%
185	222	2	0.8%
222	259	2	0.8%
259	296	101	41.1%
296	333	85	34.6%
333	360	31	12.6%

Tables 4a,b: Track Azimuth Frequency (cases) and relative frequency (%) of Rapid and Explosive Intensification

In general, TCs located between 10N-21N had a higher frequency of rapid intensification with the majority of cases occurring between 10.53-17.55N (55.9%).

Explosive intensification occurred primarily between 10-18N with 61% of the cases occurring between 10.32-18.06N.





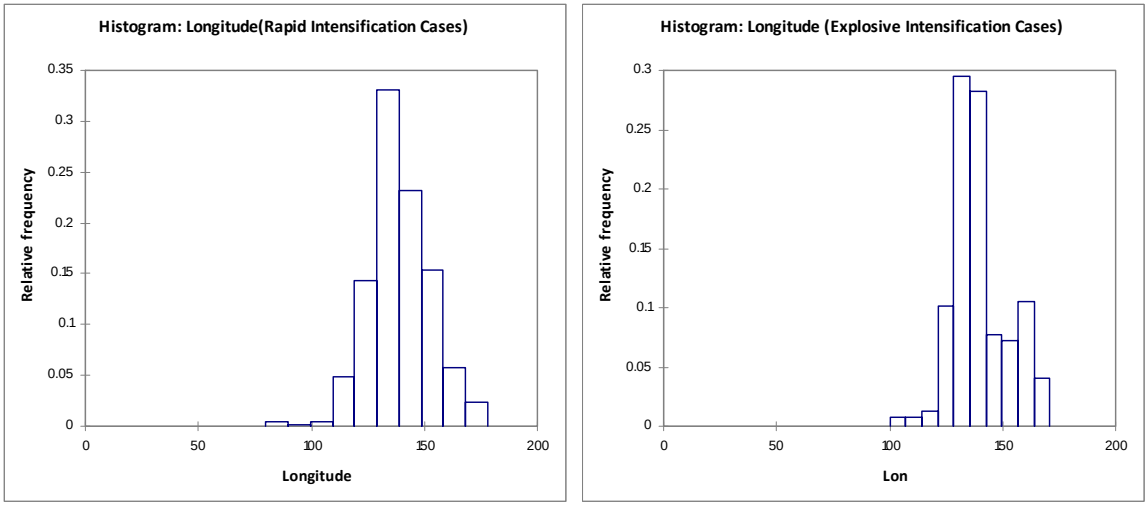
Figures 4a,b: Latitude Histogram for Rapid and Explosive Intensification Cases

Begin Lat	End Lat	Frequency	Relative frequency
0	3.51	0	0.0%
3.51	7.02	18	1.4%
7.02	10.53	170	13.6%
10.53	14.04	308	24.6%
14.04	17.55	393	31.3%
17.55	21.06	232	18.5%
21.06	24.57	95	7.6%
24.57	28.08	25	2.0%
28.08	31.59	10	0.8%
31.59	35.1	3	0.2%

Begin Lat	End Lat	Frequency	Relative frequency
0	2.58	0	0.0%
2.58	5.16	0	0.0%
5.16	7.74	2	0.8%
7.74	10.32	26	10.5%
10.32	12.9	50	20.2%
12.9	15.48	47	19.0%
15.48	18.06	54	21.8%
18.06	20.64	36	14.5%
20.64	23.22	27	10.9%
23.22	25.8	6	2.4%

Tables 5a,b: Latitude Frequency (cases) and relative frequency (%) of Rapid and Explosive Intensification

TCs located east of the Philippines intensified at the highest rates. Systems located between 129-148.6E longitude had the highest occurrence of rapid intensification (56.3%) while 86.1% occurred between 119.2-158.4E. The majority of explosive intensification cases occurred between 128.4-142.6E (57.6%).



Figures 5a,b: Longitude Histograms for Rapid and Explosive Intensification Cases

Begin Lon	End Lon	Frequency	Relative frequency
80	89.8	5	0.4%
89.8	99.6	1	0.1%
99.6	109.4	5	0.4%
109.4	119.2	62	4.9%
119.2	129	180	14.4%
129	138.8	415	33.1%
138.8	148.6	291	23.2%
148.6	158.4	193	15.4%
158.4	168.2	72	5.7%
168.2	178	30	2.4%

Begin Lon	End Lon	Frequency	Relative frequency
100	107.1	2	0.8%
107.1	114.2	2	0.8%
114.2	121.3	3	1.2%
121.3	128.4	25	10.1%
128.4	135.5	73	29.4%
135.5	142.6	70	28.2%
142.6	149.7	19	7.7%
149.7	156.8	18	7.3%
156.8	163.9	26	10.5%
163.9	171	10	4.0%

Tables 6a,b: Longitude Frequency (cases) and relative frequency (%) of Rapid and Explosive Intensification

The annual number of rapid intensification (RI) and explosive intensification (EI) cases varied significantly year-to-year. The RI occurrence trend increased from 1977-1997 and then decreased, with two maximum peaks in 1992 and 1997. EI had a peak in 1997 as well, but the increasing trend is not as apparent.

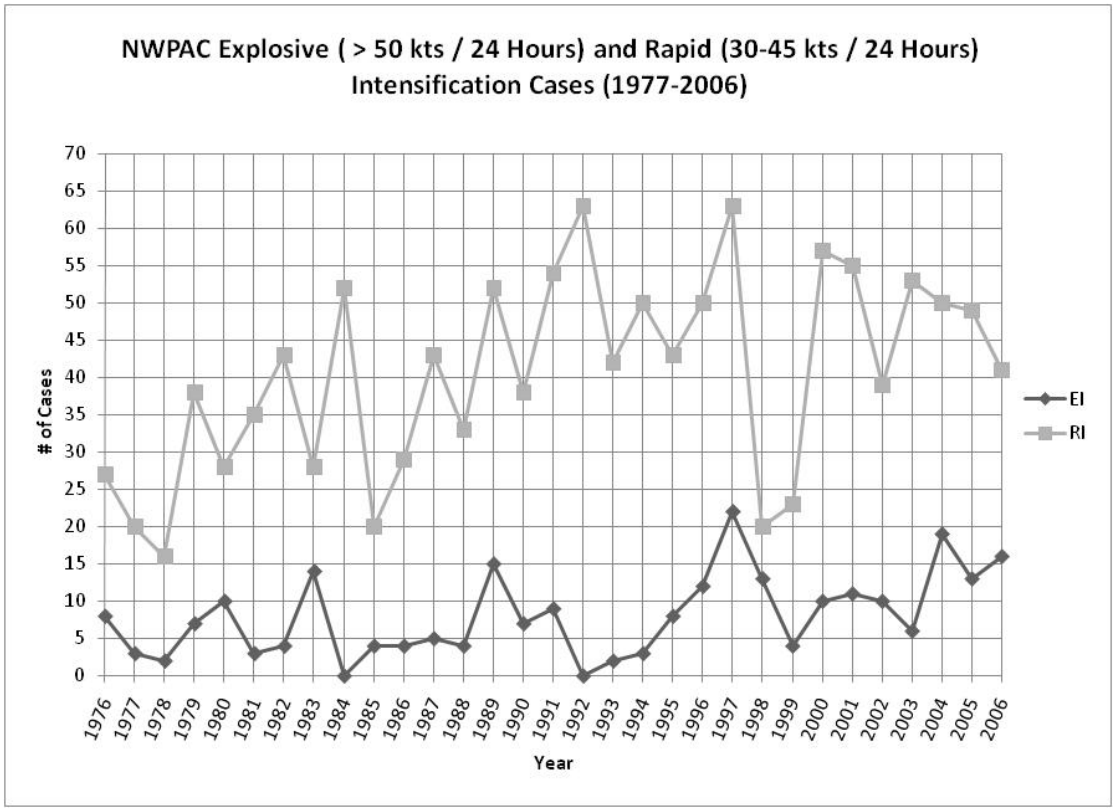


Figure 6: Annual Cases of Rapid and Explosive Intensification (1977-2006)

The geographic distribution of both rapid and explosive intensification cases are highlighted in Figure 7 and 8. RI occurred from 110E to the dateline between 5-35N, with the highest concentration of occurrences between 6-25N and 125-165E and a secondary maximum between 10-20N, 110-120E.

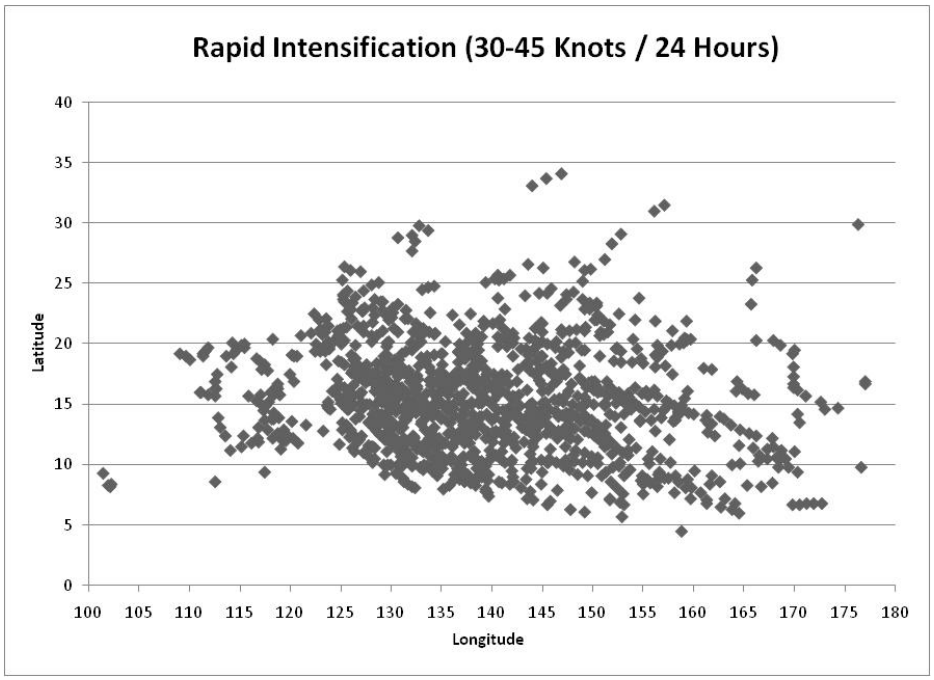


Figure 7: Rapid Intensification Cases (1977-2006)

Explosive intensification tended to be more clustered within the region 10-25N, 125-145E, with a secondary maximum between 155-165E.

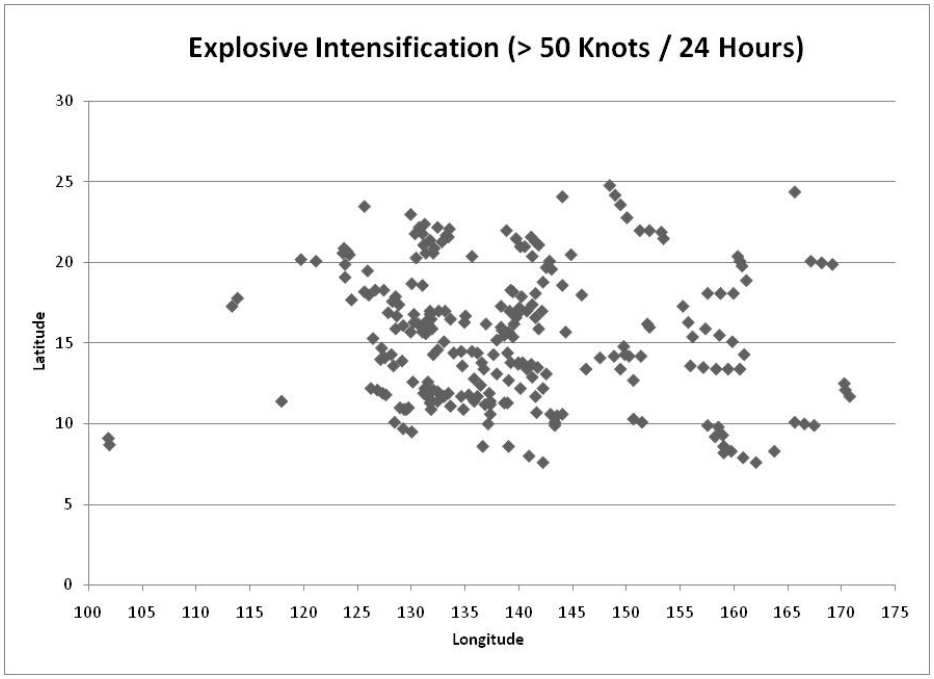
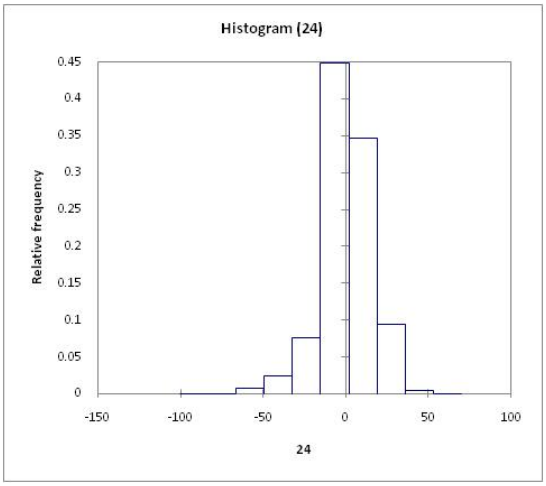


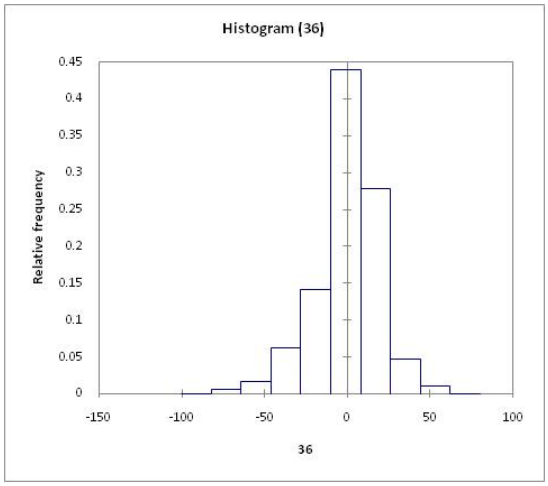
Figure 8: Explosive Intensification Cases (1977-2006)

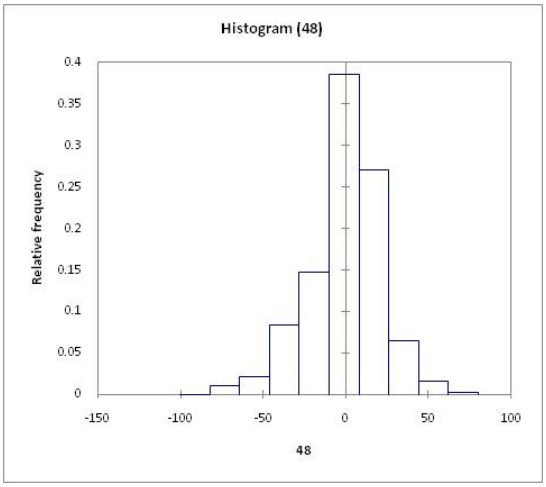
3.2 Five-Year (2002-2006) Analysis of JTWC Intensity Forecast Error Trends: The data showed a slight tendency to over forecast intensity for 24, 36 and 120 hours and to under forecast for 72 and 96 hours.

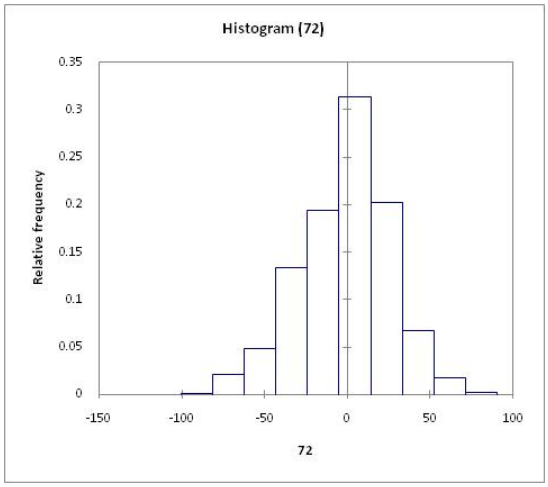
EXACT	TAU 24		TAU 36		TAU 48		TAU 72		TAU 96		TAU 120		TOTAL	
FORECAST	CASES	%	CASES	%	CASES	%	CASES	%	CASES	%	CASES	%	CASES	%
TOTAL (0)	457	15.9%	326	12.5%	264	11.3%	169	9.1%	68	5.7%	47	5.4%	1331	11.3%
OVER	TAU 24		TAU 36		TAU 48		TAU 72		TAU 96		TAU 120		TOTAL	
FORECAST	CASES	%	CASES	%	CASES	%	CASES	%	CASES	%	CASES	%	CASES	%
+5	385	13.4%	289	11.1%	208	8.9%	137	7.4%	68	5.7%	50	5.8%	1137	6.2%
+10	352	12.3%	264	10.2%	213	9.1%	141	7.6%	57	4.8%	57	6.6%	1084	5.9%
+15	255	8.9%	197	7.6%	162	6.9%	115	6.2%	51	4.3%	41	4.7%	821	4.5%
+20	143	5.0%	157	6.0%	146	6.2%	98	5.3%	65	5.4%	43	5.0%	652	3.6%
+25	72	2.5%	104	4.0%	110	4.7%	85	4.6%	56	4.7%	29	3.3%	456	2.5%
+30	34	1.2%	67	2.6%	68	2.9%	78	4.2%	44	3.7%	28	3.2%	319	1.7%
+35	20	0.7%	32	1.2%	45	1.9%	61	3.3%	52	4.3%	33	3.8%	243	1.3%
+40	10	0.3%	24	0.9%	38	1.6%	29	1.6%	36	3.0%	26	3.0%	163	0.9%
+45	2	0.1%	15	0.6%	13	0.6%	19	1.0%	23	1.9%	21	2.4%	93	0.5%
+50	1	0.0%	7	0.3%	14	0.6%	17	0.9%	14	1.2%	21	2.4%	74	0.4%
+55	1	0.0%	2	0.1%	5	0.2%	14	0.8%	11	0.9%	18	2.1%	51	0.3%
+60	1	0.0%	2	0.1%	5	0.2%	7	0.4%	16	1.3%	13	1.5%	44	0.2%
+65	0	0.0%	0	0.0%	3	0.1%	8	0.4%	12	1.0%	8	0.9%	31	0.2%
+70	0	0.0%	1	0.0%	1	0.0%	4	0.2%	10	0.8%	16	1.8%	32	0.2%
+75	0	0.0%	0	0.0%	1	0.0%	3	0.2%	4	0.3%	9	1.0%	17	0.1%
+80	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4	0.3%	3	0.3%	7	0.0%
+85	0	0.0%	0	0.0%	0	0.0%	1	0.1%	0	0.0%	6	0.7%	7	0.0%
+90	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	2	0.2%	2	0.0%
+95	0	0.0%	0	0.0%	0	0.0%	0	0.0%	3	0.3%	3	0.3%	6	0.0%
TOTAL (+)	1276	44.5%	1161	44.7%	1032	44.1%	817	43.9%	526	43.9%	427	49.3%	5239	44.7%
UNDER	TAU 24		TAU 36		TAU 48		TAU 72		TAU 96		TAU 120		TOTAL	
FORECAST	CASES	%	CASES	%	CASES	%	CASES	%	CASES	%	CASES	%	CASES	%
-5	381	13.3%	307	11.8%	223	9.5%	136	7.3%	95	7.9%	64	7.4%	1206	6.6%
-10	256	8.9%	220	8.5%	205	8.8%	129	6.9%	98	8.2%	58	6.7%	966	5.3%
-15	191	6.7%	170	6.5%	142	6.1%	123	6.6%	77	6.4%	51	5.9%	754	4.1%
-20	122	4.3%	121	4.7%	116	5.0%	108	5.8%	69	5.8%	51	5.9%	587	3.2%
-25	55	1.9%	76	2.9%	86	3.7%	98	5.3%	52	4.3%	50	5.8%	417	2.3%
-30	42	1.5%	66	2.5%	73	3.1%	72	3.9%	46	3.8%	25	2.9%	324	1.8%
-35	33	1.2%	46	1.8%	52	2.2%	44	2.4%	36	3.0%	19	2.2%	230	1.3%
-40	13	0.5%	27	1.0%	52	2.2%	34	1.8%	32	2.7%	16	1.8%	174	0.9%
-45	22	0.8%	24	0.9%	18	0.8%	31	1.7%	28	2.3%	10	1.2%	133	0.7%
-50	12	0.4%	24	0.9%	17	0.7%	22	1.2%	22	1.8%	12	1.4%	109	0.6%
-55	1	0.0%	6	0.2%	17	0.7%	21	1.1%	17	1.4%	10	1.2%	72	0.4%
-60	5	0.2%	12	0.5%	17	0.7%	17	0.9%	7	0.6%	14	1.6%	72	0.4%
-65	3	0.1%	8	0.3%	7	0.3%	15	0.8%	8	0.7%	8	0.9%	49	0.3%
-70	0	0.0%	6	0.2%	9	0.4%	11	0.6%	8	0.7%	1	0.1%	35	0.2%
-75	0	0.0%	0	0.0%	3	0.1%	2	0.1%	5	0.4%	3	0.3%	13	0.1%
-80	0	0.0%	0	0.0%	5	0.2%	11	0.6%	2	0.2%	0	0.0%	18	0.1%
-85	0	0.0%	0	0.0%	0	0.0%	1	0.1%	1	0.1%	0	0.0%	2	0.0%
-90	0	0.0%	0	0.0%	0	0.0%	1	0.1%	1	0.1%	0	0.0%	2	0.0%
TOTAL (-)	1136	39.6%	1113	42.8%	1042	44.6%	876	47.0%	604	50.4%	392	45.3%	5163	44.0%
TOTAL (ALL)	2869		2600		2338		1862		1198		866		11733	

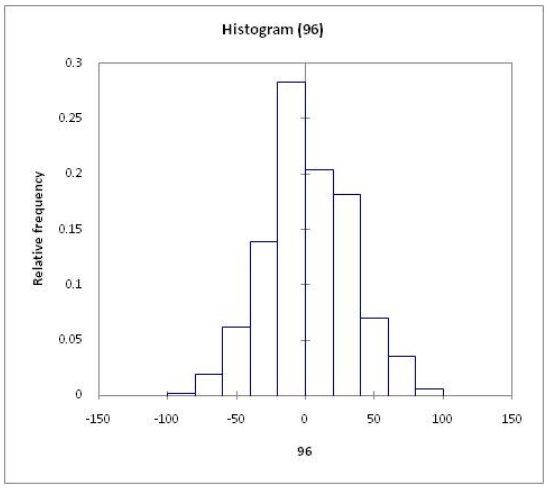
Intensity forecast bias are graphically depicted in figures 9a-f for each forecast period (tau) and indicate the biases discussed above.

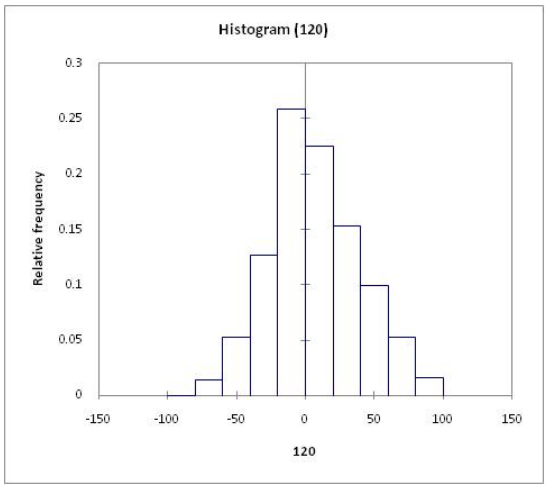












Figures 9a-f: Intensity Forecast Error Histograms at 24, 36, 48, 72, 96 and 120 Hours.

Forecast intensities at all taus were binned by latitude, longitude, initial intensity, and storm motion, but no useful trend information was found.

4. SUMMARY AND CONCLUSIONS

This 30-year analysis of intensity trends was the first step towards understanding climatological TC development rates for possible use as a forecasting tool

to supplement intensity model guidance. Results indicate that there are significant differences in how TCs intensify that correspond to their current intensity, geographical position and motion. Only 11% of all cases with $\geq$ 0 knots per 24 hour intensification rate showed RI or EI. RI cases can occur over a large portion of the NWPAC while EI cases had a lower frequency of occurrence and tended to occur near the East Philippine Sea and the Marshall Islands. Additionally, large year-to-year variability in the occurrence of RI and EI was apparent. Further analysis is needed to understand the reasons for this variability.

JTWC forecast error tendencies over a 5-year period showed a tendency to over forecast for the 24, 36, and 120 hour period while under forecasting for the 72-96 hour period. An analysis of correlation between the magnitude of the intensity forecast error and latitude, longitude, initial intensity and storm motion was completed using several robust methods and indicated weak correlation at best.

5. REFERENCES

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