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Forecasting Intense Tropical Cyclones Using 700-MB Equivalent Potential Temperature Ar Central Sea-Level Pressure

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Sikora (1976), et al., suggests that the equivalent potential temperature at 700 mb in a developing tropical cyclone is an excellent parameter to measure the total thermodynamic energy of the tropical cyclone at a particular time. He further suggests that abnormally high values of equivalent potential temperature ($\lesssim$ 370°K) can herald a period of subsequent explosive deepening. This note expands on that idea to propose a technique for forecasting the development of intense tropical cyclones (minimum sea-level

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pressure <925 mb) based on the relationship of the total thermodynamic field, as measured by the tropical cyclone's central 700-mb equivalent potential temperature, and the kinematic field, as measured by the tropical cyclone's central sea-level pressure. One hundred seven tropical cyclones which occurred in the north Western Pacific and north Central Pacific Ocean were evaluated using 700-mb temperature, 700-mb dewpoint and sea-level pressure data which were available from past Annual Typhoon Reports (1975-1980). These data were used to develop a forecast technique whereby the tropical cyclone forecaster may anticipate significant development in a tropical cyclone by monitoring the central sea-level pressure and 700-mb equivalent potential temperature provided by aircraft reconnaissance.

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ABSTRACT

Sikora (1976), et al., suggests that the equivalent potential temperature at 700 mb in a developing tropical cyclone is an excellent parameter to measure the total thermodynamic energy of the tropical cyclone at a particular time. He further suggests that abnormally high values of equivalent potential temperature ($\geq$ 370°K) can herald a period of subsequent explosive deepening. This note expands on that idea to propose a technique for forecasting the development of intense tropical cyclones (minimum sea-level pressure <925 mb) based on the relationship of the total thermodynamic field, as measured by the tropical cyclone's central 700-mb equivalent potential temperature, and the kinematic field, as measured by the tropical cyclone's central sea-level pressure. One hundred seven tropical cyclones which occurred in the north Western Pacific and north Central Pacific Ocean were evaluated using 700-mb temperature, 700-mb dewpoint and sea-level pressure data which were available from past Annual Typhoon Reports (1975-1980). These data were used to develop a forecast technique whereby the tropical cyclone forecaster may anticipate significant development in a tropical cyclone by monitoring the central sea-level pressure and 700-mb equivalent potential temperature provided by aircraft reconnaissance.

FORECASTING INTENSE TROPICAL CYCLONES USING 700-MB EQUIVALENT POTENTIAL TEMPERATURE AND CENTRAL SEA-LEVEL PRESSURE

I. INTRODUCTION

There are two parts to tropical cyclone forecasting: track forecasting and intensity forecasting. Much attention has been given to statistical and dynamic models to provide the operational forecaster with the track forecast, but little research has been directed to intensity forecasting.

An intensity forecast technique is useful in real time if it uses, as input, only data that are routinely available to the operational forecaster. Over the years, it has been the philosophy of the Joint Typhoon Warning Center (JTWC) to task the 54th Weather Reconnaissance Squadron for at least two aircraft penetrations per day on tropical cyclones within aircraft range. Thus, JTWC has been receiving and should continue to receive, 700-mb temperature, 700-mb dewpoint and central sea-level pressure (CSLP) data approximately two times per day on tropical cyclones in the western North Pacific. This constitutes "routinely" available data which can be used by the operational forecaster as input to an intensity forecast technique.

Sikora (1976), et al., has suggested that the 700-mb equivalent potential temperature (θ_{e7}) is one measure of the total thermodynamic energy of a tropical cyclone because it accounts for both sensible and latent heat. Sikora found from an evaluation of 12 typhoons during the 1973-1975 period that θ_{e7} increases steadily with the continued development of a tropical cyclone. Dramatic increases were noted when rapid intensification occurred. Rapid intensification (deepening) was defined by Holliday and Thompson (1979) as a decrease of 30 mb per 24 hours (or -1.25 mb/hr). Sikora (1976) also stated that "from the data evaluated, the observation of values of θ_{e7} greater than 370°K appears to correlate well with subsequent explosive intensification." Explosive intensification (deepening) was defined by Holliday and Thompson (1979) as -2.5 mb/hr over 12 hours or -5.0 mb/hr for 6 hours.

This technical note proposes a technique for forecasting the development of intense tropical cyclones (defined as minimum sea-level pressure (MSLP) <925 mb) using θ_{e7} and CSLP data.

II. DATA AND METHODOLOGY

Aircraft reconnaissance data obtained from the Annual Typhoon Reports were evaluated for 160 tropical cyclones which occurred in the western and central North Pacific during the period 1975-1980. Fifty-three of these tropical cyclones were rejected for this study due to insufficient 700-mb data. From the 107 remaining tropical cyclones, 20 were chosen which had minimum sea-level pressures (MSLP) below 925 mb. Tropical cyclones with a MSLP below 925 mb were defined for this note as intense typhoons.

Then, CSLP versus time and θ_{e7} versus time graphs[1] were constructed for each of the 20 tropical cyclones and evaluated for possible relationships. As Sikora (1976) noted, θ_{e7} increased as the CSLP of the tropical cyclone decreased. Next, the total sea-level pressure drop (Δp) was determined[2] and a mid-point CSLP (P_m) was determined for each tropical cyclone. P_m is defined as

$$P_m = MSLP+\tfrac{1}{2}\Delta p$$

Finally, the mid-point θ_{e7} was extracted from the θ_{e7} versus time graph at the time P_m was observed.

Table 1 summarizes data for each of the 20 tropical cyclones that intensified to below 925 mb. Evaluation of the data in Table 1 yielded a mean P_m of 950 mb and a mean θ_{e7} of 360°K. The relatively small standard deviations of 7.6 mb for P_m and 4.5°K for θ_{e7} indicate that an intensification mechanism may be initiated in a tropical cyclone when the CSLP reaches 950 mb at the same time that its θ_{e7} reaches 360°K. With this in mind, a graph was constructed (Fig. 1) which allowed both CSLP and θ_{e7} to be plotted as a function of time. The left ordinate is CSLP, the right ordinate is θ_{e7}, and the abscissa is time. The scales were oriented so the critical values of 950 mb and 360°K were located on the same line. The ranges of the CSLP and θ_{e7} scales were chosen to permit the plotting of all expected values of both CSLP and θ_{e7} on one graph. The CSLP and θ_{e7} curves for each of the 20 selected tropical cyclones were replotted on the graph. In each case, the CSLP and θ_{e7} traces intersected near the 950 mb/360°K line. After intersection, θ_{e7} generally continued to increase as the CSLP decreased to a minimum value that was approximately equal to $P_m-\tfrac{1}{2}$ p. The average MSLP for the 20 cyclones was 903 mb. A sample trace is illustrated in Fig. 2.

The next step was to evaluate the CSLP/θ_{e7} relationships of the remaining 87 tropical cyclones chosen for this study.

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[1]Derived from 700-mb temperature, dewpoint, and sea-level pressure data provided by aircraft reconnaissance. Standard tables were used to convert 700-mb temperature and dewpoint to θ_{e7}.

[2]The total sea-level pressure drop (Δp) is defined as the difference between the initial CSLP (ISLP) and the minimum sea-level pressure (MSLP) observed by aircraft reconnaissance during the tropical cyclone's existence. In addition, ISLP is defined as either 1000 mb or the CSLP of the tropical cyclone just before the CSLP began to decrease at a rate of at least 1.0 mb/hr, whichever occurs last.

TROPICAL CYCLONE NAME	YEAR	PM (MB)	$\theta_e 7$ AT TIME OF PM (°K)	MAX WIND (KT)	ΔP (MB)	ΔT (HRS)	ISLP (MB)	MSLP (MB)
WYNNE	1980	945	362	150	110	62	1000	890
KIM	1980	954	367	130	92	64	1000	908
TIP	1979	935	361	165	130	110	1000	870
HOPE	1979	948	367	130	96	60	996	90[illegible]
JUDY	1979	942	357	135	111	70	998	887
VERA	1979	954	361	140	79	60	994	915
OWEN	1979	959	357	110	82	62	1000	918
RITA	1978	940	358	155	119	108	1000	881
VIOLA	1978	952	358	125	85	84	995	910
LUCY	1977	956	361	115	73	48	992	919
BABE	1977	943	364	130	74	42	980	906
KIM	1977	956	356	125	77	72	995	918
PAMELA	1976	959	360	130	78	102	998	920
THERESE	1976	947	360	135	86	33	990	904
SALLY	1976	961	365	115	75	62	999	924
FRAN	1976	956	365	130	84	54	998	914
LOUISE	1976	948	347	140	106	66	1000	895
BILLIE	1976	953	358	125	79	72	993	914
ELSIE	1975	950	357	135	100	58	1000	900
JUNE	1975	936	360	160	120	81	996	876
AV (SD)		950 (7.6)	360 (4.5)	134 (14.5)	93 (17.6)	68 (20.2)	996 (4.9)	903 (15.7)

TABLE 1. DATA USED TO DEVELOP THE θ_{E7} / CSLP GRAPH. TWENTY (20) TROPICAL CYCLONES FROM 1975-1980.

CYCLONE__________ **THETA E TRACE** MONTH__________

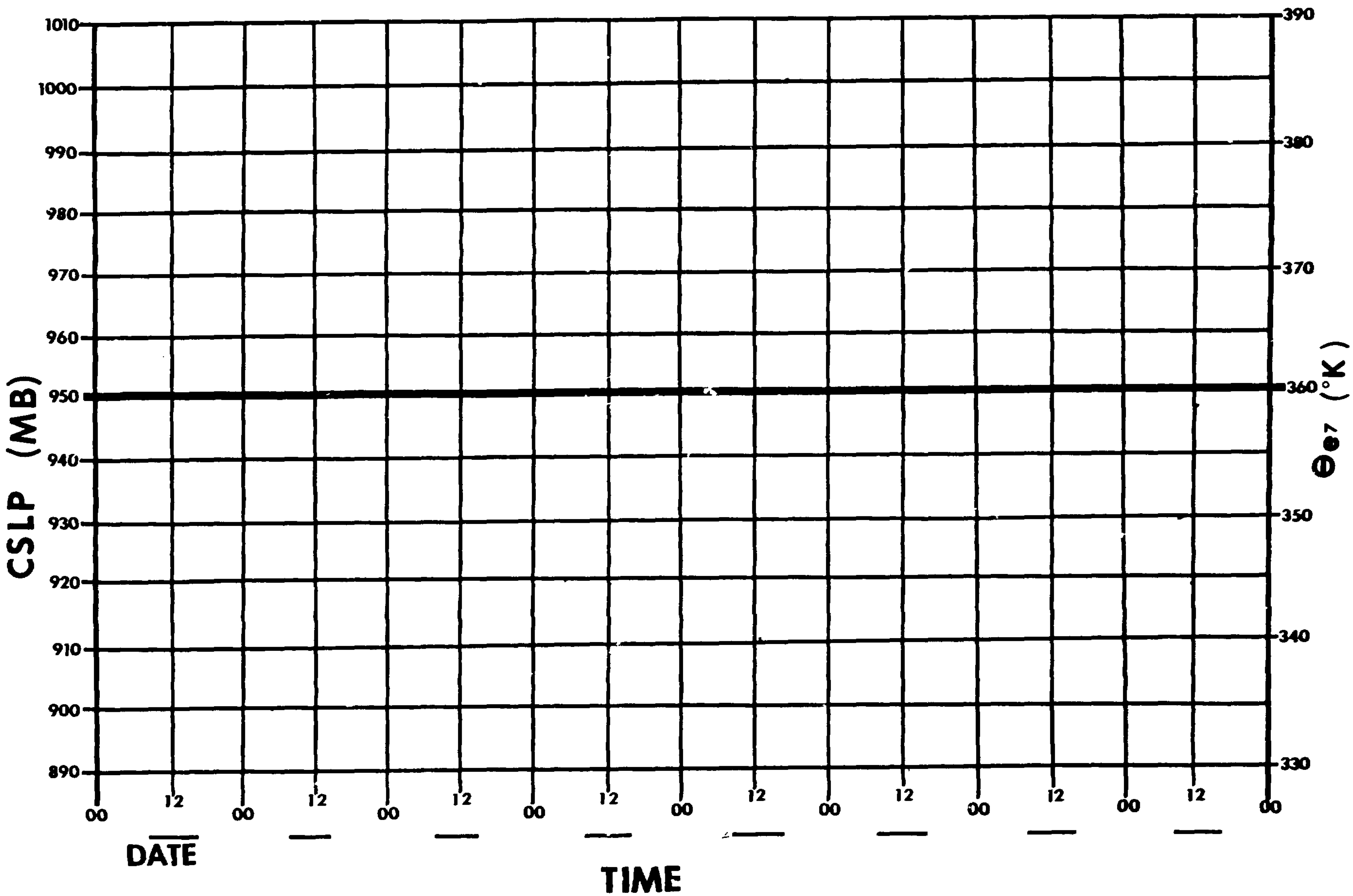


FIGURE 1. CSLP/ θ_{E7} /TIME GRAPH.

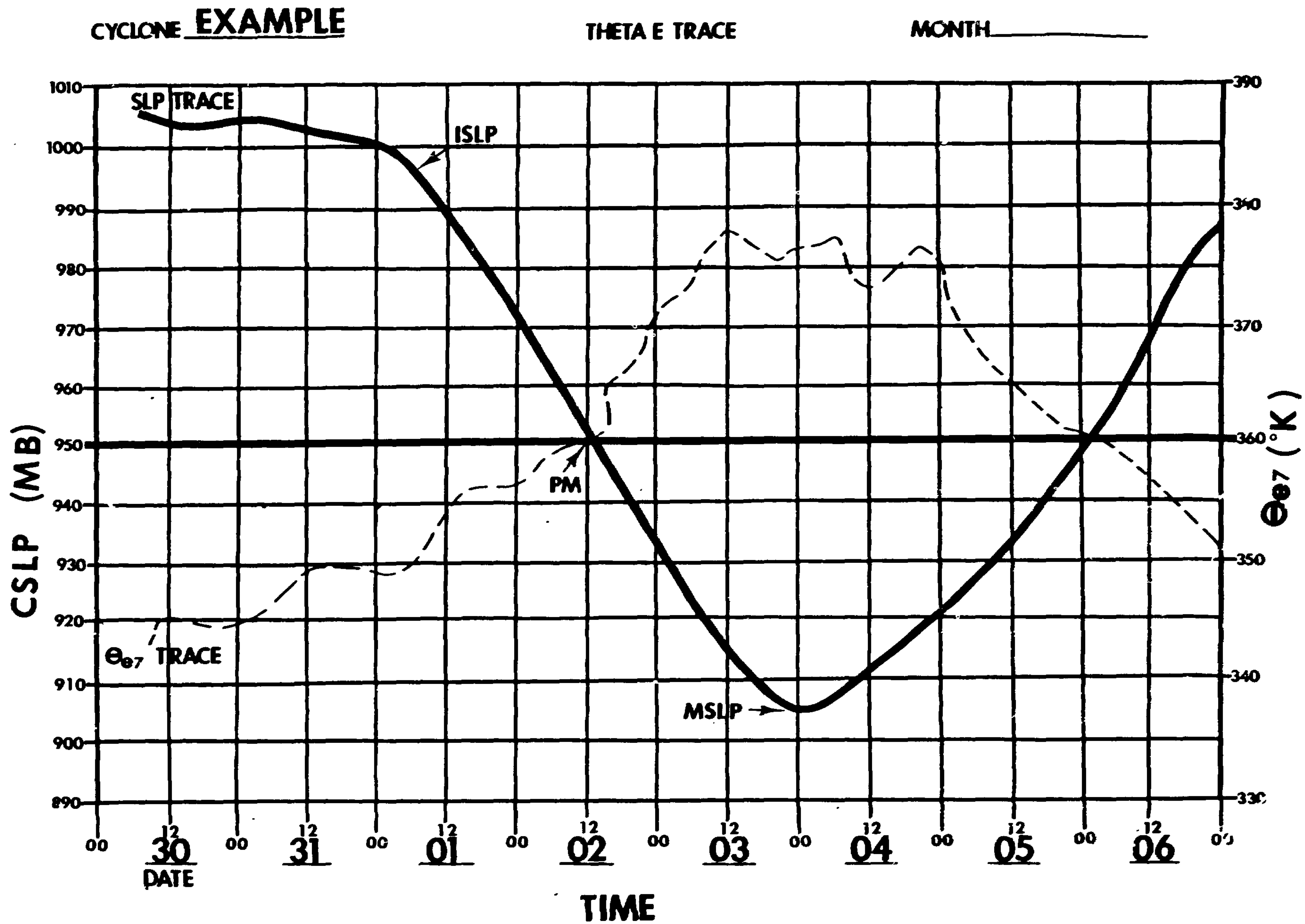


FIGURE 2. SAMPLE CSLP/ θ_{E7} /TIME TRACE.

III. RESULTS

Of the 87 tropical cyclones evaluated, 65 had CSLP/θ_{e7} traces which did not intersect. None of these 65 tropical cyclones deepened to below 925 mb. The CSLP/θ_{e7} traces of the remaining 22 cyclones did intersect, but 6 of the 22 made landfall shortly after intersection and 12 intersected as the tropical cyclones were accelerating rapidly to the north or northeast prior to extratropical transition. The remaining 4 tropical cyclones continued to deepen after trace intersection, but had MSLP's in the 926-931 mb range (Table 2). Therefore, of the 42 total cases of trace intersection, 20 or 48% deepened to at least 925 mb, 22 or 52% did not deepen to below 925 mb. It should be noted again that 18 or 82% of these 22 cyclones were in the process of recurving or were about to make landfall. These 18 cyclones may very well have attained a MSLP below 925 mb if they had been able to remain in a favorable tropical environment for a longer period of time. The remaining 4 tropical cyclones (18%) which did not intensify below 925 mb, deepened to at least 931 mb, which is still a respectable intensity.

IV. SUMMARY

As previously stated, θ_{e7} provides a good measure of thermodynamic energy and CSLP is a good measure of the kinematic energy in a tropical cyclone. Thus, changes in a tropical cyclone's total energy should be reflected by changes in the relative values of these parameters. With this in mind, the following procedure is suggested as a technique for forecasting the short-term intensification of intense typhoons (MSLP<925 mb):

1. Initiate graphs of CSLP and θ_{e7} versus time as soon as aircraft reconnaissance data become available.

2. Forecast intensification to below 925 mb if the CSLP and θ_{e7} traces intersect. The following intensification trend can be expected:

   a. The decrease in CSLP from the point of intersection (P_m) to MSLP will be approximately equal to the pressure drop that has occurred from ISLP to P_m. The average decrease will be about 47 mb (Fig. 2).

   b. The time period from the trace intersection to MSLP will average 34 hours, but it could vary based upon whether the tropical cyclone is undergoing normal, rapid or explosive deepening. Generally, this time period is somewhat shorter than the period from ISLP to P_m.

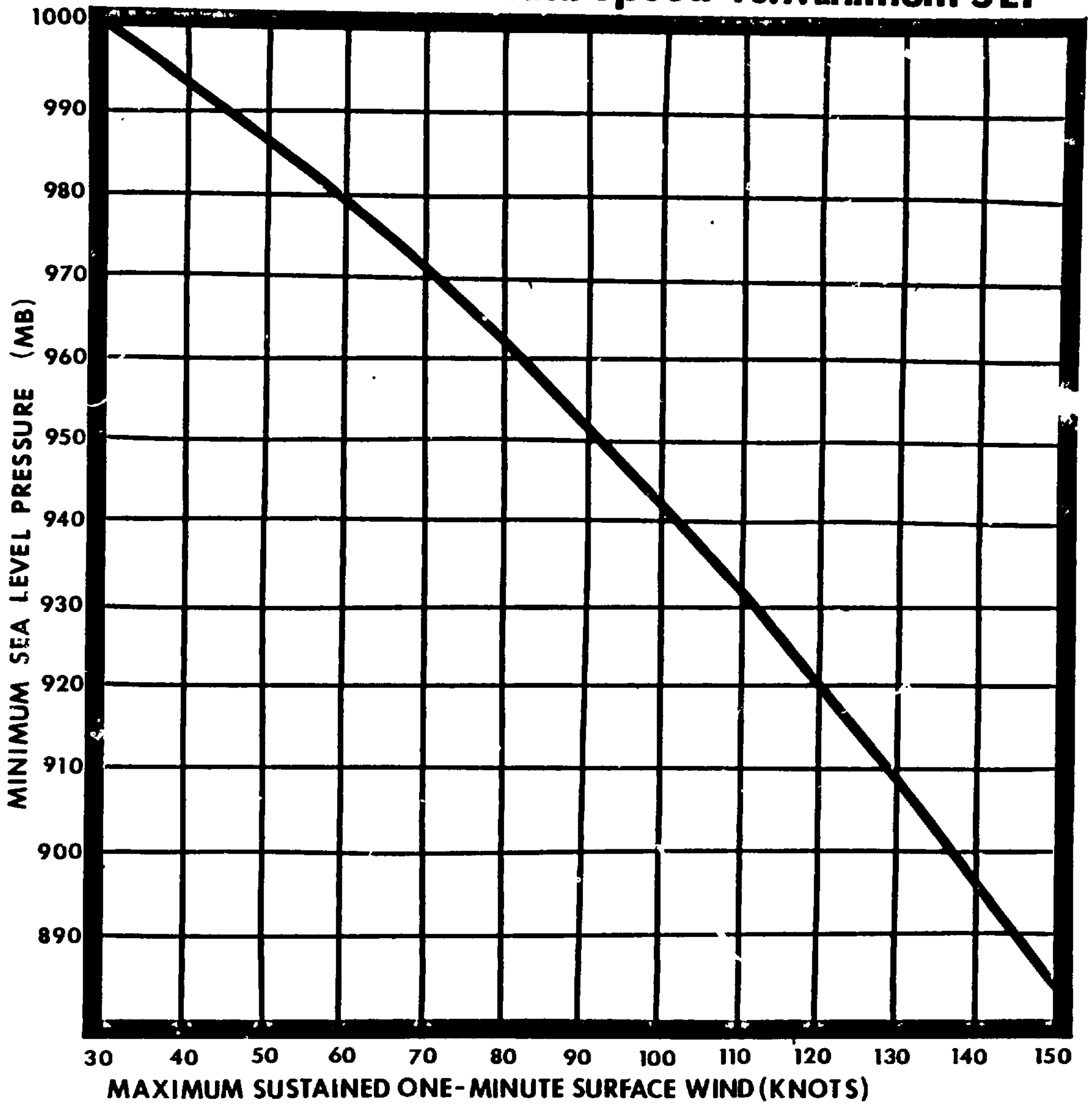
3. Correlate the forecast MSLP with a forecast maximum sustained wind speed using the maximum wind/minimum sea-level pressure relationship developed by Atkinson and Holliday (1977) (Fig. 3).

	θ_{E7} AND CSLP TRACES INTERSECTED	θ_{E7} AND CSLP DID NOT INTERSECT
INTENSIFIED TO BELOW 925 MB	20	Ø
DID NOT INTENSIFY TO BELOW 925 MB	4: 925 MB $\leq$ CSLP $\leq$ 931 MB 6: MADE LANDFALL 12: RECURVED DURING INTENSIFICATION 22: TOTAL	65

TABLE 2. VERIFICATION MATRIX FOR INTENSIFYING AND NON-INTENSIFYING TROPICAL CYCLONES

FIGURE 3.

Sustained Surface Wind Speed Vs. Minimum SLP



4. Evaluate each particular situation to determine which intensity trend (normal, rapid, or explosive) is most probable when the technique is applied. Likewise, the technique should not be applied when the tropical cyclone is beginning to accelerate northward, or when landfall is expected within 36 hours.

This intensity forecast technique is very restrictive because it only identifies those tropical cyclones which can be expected to develop into intense typhoons. However, it is precisely these systems which are the most difficult to forecast.

Some general information is available from any CSLP/θ_{e7} versus time trace. For example, if the CSLP and θ_{e7} traces remain far apart, significant deepening should not be expected to occur in the near future. On the other hand, if the CSLP and θ_{e7} traces begin to approach each other, then the forecaster must be alert to the possibility of significant intensification. If the CSLP decreases and θ_{e7} increases at a steady rate, it may be possible for the forecaster to extrapolate the traces forward in time to predict the intersection point and then to apply the technique to obtain a forecast MSLP.

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