Comments on "Reexamination of Tropical Cyclone Wind–Pressure Relationship"

SHYAMNATH VEERASAMY

Mauritius Meteorological Services, Vacoas, Mauritius

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ABSTRACT

In their study on the wind–pressure relationship (WPR) that exists in tropical cyclones, Knaff and Zehr presented results of the use of the Dvorak Atlantic WPR for estimating central pressure and maximum wind speed of tropical cyclones. These show some fairly large departures of estimated central pressure and maximum surface winds from observed values. Based on a study carried out in the southwest Indian Ocean (SWIO), it is believed that improvements in the use of the Dvorak WPR can be achieved by using the size of a closed isobar (it is the 1004-hPa closed isobar in the SWIO) to determine whether to use the North Atlantic (NA), the western North Pacific (WNP), or a mean of the NA and WNP Dvorak WPR for estimating central pressure and maximum wind speed in tropical cyclones.

1. Introduction

Knaff and Zehr (2007, hereinafter KZ07) presented some very interesting and important results from their study of the wind–pressure relationship (WPR) that exists in tropical cyclones (TCs). In the southwest Indian Ocean (SWIO), analysis of TC is carried out by using the Dvorak technique (1984), which, because of the severe lack of data, is the only tool available for operational use.

I would like to comment on the Dvorak WPR (D-WPR) in use in the SWIO and the term "environmental pressure" (P_{env}) used by KZ07. In addition, I shall discuss the performance of the North Atlantic (NA) Dvorak wind–pressure relationship (NA D-WPR) in relation to Hurricanes Katrina, Rita, and Wilma of the 2005 hurricane season and suggest some improvements in the use of the D-WPR.

2. Wind–pressure relationship in the southwest Indian Ocean

a. The WPR adopted in the SWIO

In KZ07, mention is made of the Atkinson and Holliday (1977) wind–pressure relationship adopted by the Regional Specialized Meteorological Center (RSMC), situated on La Réunion Island (overseas department of France) for use in the SWIO. But as no mention is made of this Atkinson and Holliday WPR in Dvorak (1984), and to avoid confusion for users of the SWIO tropical cyclone operational plan, the WPR included in Dvorak (1984) for use in the western North Pacific (WNP) is referred to as the WNP D-WPR. The use of the WNP D-WPR in the SWIO was adopted following a meeting held by the Tropical Cyclone Committee of the Regional Association 1 (TCC RA1) of the World Meteorological Organization in September 1985.

b. Failure of the WNP D-WPR

Data collected during the passage of a few TC over coastal stations and low-lying islands in the SWIO show that the use of only the WNP D-WPR for estimating the central minimum sea level pressure (MSLP) from the 1-min maximum surface wind speed (MWS), and vice versa, leads to erroneous and misleading values when applied to some cyclones. These data show that the WNP D-WPR is suitable for some cyclones and that the NA D-WPR is suitable for others.

Furthermore, those data show that the radii of cyclonic weather associated with TC whose WPR satisfy the NA D-WPR are small when compared with those associated with TC whose WPR satisfy the WNP D-WPR. These aspects, which are very important for tropical cyclone preparedness, are not discussed here;

Corresponding author address: Mr. Shyamnath Veerasamy, Mauritius Meteorological Services, St. Paul Road, Vacoas, Mauritius.
E-mail: shyamnath.veera@yahoo.com

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for further details, the readers are referred to Veerasamy (2005).

3. The environmental pressure in KZ07

In section 2 of KZ07, environmental pressure (P_{env}) is defined as "the azimuthal mean pressure in an 800-1000-km annulus surrounding the cyclone center." The P_{env} is different from the usual definition of environmental pressure, P_E, as given for example by Wang (1978) and Holland (1980). To avoid confusion, P_{env} can be replaced by P_{900}. The quantity (MSLP $-$ P_{env}) is better suited than the quantity (MSLP $-$ P_{E}) for calculating the pressure gradient. The (MSLP $-$ P_{env}) is the pressure difference between the center of the TC and the fixed distance 900 $\pm$ 100 km around the cyclone. On the other hand, (MSLP $-$ P_E) is the pressure difference between the center of the TC and the distance of P_E from the center: this is a difficult quantity to handle because both the value of P_E and its distance from the center of the cyclone are variables.

The concept (MSLP $-$ P_{env}) is similar to the one proposed by Veerasamy (2005), namely, the use of the quantity (1004 hPa $-$ MSLP) for the calculation of the pressure gradient between the 1004-hPa isobar and the center of a TC. By measuring the average radius of the 1004-hPa isobar (R4) as described by Cocks and Gray (2002), one can calculate the pressure gradient between the 1004-hPa isobar and the center of the cyclone. The reason for choosing the 1004-hPa isobar is that it is a closed isobar for all TC (even the very large monsoon depression) encountered so far in the SWIO and its size can be assessed fairly accurately.

4. Hurricanes Katrina, Rita, and Wilma

In KZ07 it is seen that although the NA D-WPR could explain about 91% of the variance of the maximum wind speed and of the central pressure of the hurricanes that made up the 2005 dataset, some fairly large departures ($\pm$25–30 kt and $\pm$15–20 hPa) of their estimated values from observations occurred. These large departures are due to the inappropriate use of the NA D-WPR. This is demonstrated for Hurricanes Katrina, Rita, and Wilma. The observations used for this demonstration are chosen so that the impacts that the variation of latitude and the movement of tropical cyclones have on WPR are considerably reduced. For example, data for Hurricanes Emily and Wilma are chosen when both of them were near latitude 16°N and were moving west-northwest, thus eliminating almost completely the impacts of difference in latitude and direction of motion of the cyclones on the WPR.

The data used are available on the National Oceanic and Atmospheric Administration (NOAA) Web site. They are measured MSLP and aircraft reconnaissance maximum wind speed obtained at flight levels of 700 and 850 hPa. The MWS is obtained by using the adjustment factor 0.87 for the 700-hPa winds and 0.83 for the 850-hPa winds. These adjustment factors are blends of the values used by the U.S. National Hurricane Center for the 2005 Hurricanes Emily, Katrina, Rita, and Wilma. The observations showed that the use of the NA D-WPR was inappropriate for Wilma and for part of the existence of Katrina and Rita. KZ07 also reported that their Eqs. (7) and (8) had problems with Rita and Wilma during part of their existence.

At 1700 UTC 16 July 2005, Hurricane Emily was centered near 16.5°N, 78.5°W and moving toward the west-northwest at about 16 kt. The measured MSLP was 937 hPa; the maximum wind speed at flight level 700 hPa was 151 kt and the MWS was 132 kt. This 132-kt/937-hPa WPR satisfies the NA D-WPR.

At about 0500 UTC 19 October 2005, Hurricane Wilma was situated near 17.0°N, 82.0°W and was moving toward the west-northwest at about 7 kt. The measured MSLP was 901 hPa; the maximum wind speed at flight level 850 hPa was 162 kt and the MWS was 135 kt. This 135-kt/901-hPa WPR does not satisfy the NA D-WPR; instead it satisfies the WNP D-WPR. Even if the 135-kt wind of Wilma is reduced to the 130-kt wind of Emily, the MSLP of Wilma would still be, at most, 908 hPa, compared with the 937 hPa of Emily—a difference of 29 hPa for the same MWS. Even more spectacular is the MSLP of 884 hPa at 0900 UTC 19 October, and a wind speed of 168 kt at flight level 700 hPa—that is an MWS of about 147 kt. On the NA D-WPR, an MSLP of 884 hPa would give an MWS of 175 kt; on the WNP D-WPR, this would give 150 kt. It is clear that, for Wilma, the WNP D-WPR was more appropriate than the NA D-WPR.

Similarly, at 1200 UTC 28 August 2005, Hurricane Katrina was situated near 25.5°N , 87.5°W. The measured MSLP was 908 hPa, with a 153-kt wind at flight level 700 hPa; that is an MWS of 133 kt. On the NA D-WPR, an MSLP of 908 hPa corresponds to an MWS of about 153 kt; on the WNP D-WPR, the corresponding MWS is about 132 kt. Again, the WNP D-WPR was more appropriate than the NA D-WPR.

The case of Hurricane Rita is most interesting. The examples start with the WPR of Rita satisfying the NA D-WPR and end with the WPR satisfying the WNP D-WPR. This change in the characteristic of the WPR of a cyclone has also been noted in the SWIO. At 1800 UTC 20 September 2005, Rita was situated near 24.0°N, 81.5°W. The measured MSLP was 978 hPa and

TABLE 1. Comparison between observed and estimated MSLP. Estimated MSLP is obtained from the observed MWS, using the Dvorak NA, WNP, and average WPR. Asterisk indicates that the MSLP was extrapolated. "Average WPR" is obtained by averaging the MSLP of the NA and WNP MSLP.

					Estimated MSLP (hPa), using the Dvorak			
Cyclones	Year	R4 (° lat)	Types	Obs MWS (km h^{-1})	NA WPR	WNP WPR	Avg WPR	Obs MSLP (hPa)
Gervaise	1975	5.6	C_P	174	967	950	959	949
Celine	1979	4.8	C_P	174	967	950	959	953*
Claudette	1979	1.8	C_A	177	965	948	957	963
Ditra	1985	3.0	C_A	145	977	964	971	978
Firinga	1989	3.4	C_M	174	967	950	959	962
Colina	1993	3.0	C_A	157	973	959	966	975
Hansella	1996	6.5	C_P	143	978	965	972	965

the MWS was about 85 kt. An MWS of 85 kt corresponds to about 973 hPa on the NA D-WPR and to about 959 hPa on the WNP D-WPR; clearly, this '85-kt/978-hPa WPR satisfies the NA D-WPR. At 0600 UTC 22 September 2005, Rita was situated near 25.0°N, 87.5°W. The MSLP was 898 hPa and the MWS was about 145 kt. An MWS of 145 kt corresponds to an MSLP of 915 hPa on the NA D-WPR and to 890 hPa on the WNP D-WPR. It is interesting to note that the average of 915 hPa and 890 hPa is 902 hPa; this average value is closer to 898 hPa than either 915 hPa or 890hPa. At about 0600 UTC 23 September, Rita was near 26.5°N, 90.5°W. The MSLP was 927 hPa, with a maximum wind speed of 130 kt at flight level 700 hPa; that is an MWS of about 113 kt. On the WNP D-WPR, 927 hPa corresponds to an MWS of about 115 kt, but it corresponds to about 135 kt on the NA D-WPR. This shows that the NA D-WPR was inappropriate. At 0300 UTC 24 September, Rita was near 29.0°N, 93.0°W. The MSLP was about 930 hPa and the maximum wind at flight level 700 hPa was about 125 kt, which gives an MWS of about 110 kt. On the NA D-WPR, 930 hPa corresponds to an MWS of about 130 kt, while on the WNP D-WPR it corresponds to an MWS of about 112 kt. Again, the NA D-WPR was inappropriate.

5. Improving the use of the Dvorak wind–pressure relationship

The existence of cyclones with the same MSLP but with different MWS, and vice versa, is consistent with the gradient wind equation. Veerasamy (2005, hereafter V05), by using the gradient wind equation, showed that if there are two cyclones C1 and C2 with equal MWS but with their MSLP being, respectively, P_0 and $(P_0 - \Delta P)$, then the average radius of the closed isobar 1004 hPa (R4) of C1 is smaller than that of C2. Furthermore, he showed that the environmental pressure (P_E) within which C1 evolves is higher than for C2. Because, on average, the P_E in the NA is higher than in WNP (Atkinson and Holliday 1977), then for a given MWS, the R4 of tropical cyclones whose WPR satisfy the NA D-WPR are expected to be smaller than those satisfying the WNP D-WPR.

This result was used to differentiate between cyclones whose WPR satisfies the NA D-WPR (hereafter type C_A cyclones) and those satisfying the WNP D-WPR (hereafter type C_P cyclones). The study was carried out on SWIO TCs whose current intensity (CI) were greater than 3.5 and that evolved between latitudes 10° and 20°S. V05 inferred that (i) the R4 of C_A cyclones are less than 3.3° latitude, (ii) the R4 of C_P cyclones are greater than 4.5° latitude, and (iii) TC whose R4 lie between 3.3° and 4.5° latitude (hereafter C_M type) are those whose MSLP is equal to the average of the MSLP of the WNP and the NA D-WPR. It is to be noted that R4 were calculated for 1200 UTC (that is 1600 local time); at 1600 local time, sea level pressure is a minimum because of diurnal variation. The MWS is obtained by dividing the observed maximum gust by 1.24, as required by the tropical cyclone operational plan of the SWIO. It is true that the values of R4 for C_A, C_P, and C_M are based on the few cases when both the MSLP and the highest gusts were measured. Nonetheless, as shown in Table 1 above, the results are instructive.

It can be seen from Table 1 that TC Claudette, with its R4 being less than 3.3° latitude, is classified as a C_A cyclone. Its observed MWS was 177 km h^{-1} and its observed MSLP was 963 hPa. The estimated MSLP using the NA D-WPR, the WNP D-WPR, and the average of the MSLP of the NA and WNP is, respectively, 965, 948, and 957 hPa. It is clear that the observed MSLP of Claudette (963 hPa) agrees best with the estimated MSLP using the NA D-WPR. Similarly, the R4 of Ditra and Colina were less than 3.3° latitude. They are C_A cyclones and their observed MSLP agree best with the estimated MSLP using the NA D-WPR. The

R4 of TC Gervaise, Celine, and Hansella were greater than 4.5° latitude. They are C_P cyclones and their observed MSLP agree best with the estimated MSLP using the WNP D-WPR. The R4 of cyclone Firinga was 3.4° latitude and is a borderline case. It can be considered a C_M cyclone; its observed MSLP agrees best with the estimated MSLP obtained by averaging the MSLP of the NA and the WNP D-WPR.

6. Final remarks

From Table 1 and the above discussion, it can be seen that in the SWIO, satisfactory estimates of MSLP and MWS can be obtained by using the Dvorak WPR, provided that the cyclones are first classified according to the size of the R4.

The work of KZ07 is very important, but because of the lack of observation in the SWIO, it is very difficult to apply their procedures. It is much easier and quicker to determine whether a cyclone belongs to type C_A, C_P, or C_M than calculating V_{500} and P_{env}. The results of V05, although tested on a small sample, are encouraging. But it would be very helpful and instructive to test the procedures of V05 on the dataset of KZ07 or on any sufficiently large dataset.

It is worthwhile to point out that the values of R4 for C_A, C_P, and C_M in NA are different from those in the SWIO. Analysis of a few surface charts for Katrina, Rita, and Wilma (no other charts are available here) showed that their R4 were ≥3.0° latitude (compared with R4 being ≥4.5° in SWIO) when their WPR satisfied the WNP D-WPR. It may also be that in the NA, the 1006- or 1008-hPa isobar could be more appropriate than the 1004-hPa isobar.

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