7A.3 The Longevity of the Dvorak TC Intensity Technique in the Pacific and Indian Ocean Regions

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1. *Background*. The Dvorak TC Intensity Technique (Dvorak 1975, 1984) has been used at the Joint Typhoon Warning Center (JTWC) for the last three decades and for at least the last two decades at many of the other TC warning centers in the western Pacific Ocean and the Indian Ocean. This technique has unequivocally been the primary method for ascertaining TC intensity in most of the world. As such, it has likely saved tens-, if not, hundreds-of-thousands of lives over the last 30 years in a region where over one billion people are directly affected by tropical cyclones (TC). In fact, it is difficult to think of any other single meteorological technique that has had the life-saving impact of the Dvorak technique. One reason for its tremendous impact has been its longevity. It is amazing, given the multitude of advances in technology over the last 30 years that a superior technique has not been developed to ascertain TC intensity from satellite data. This paper is not meant to be a scientific assessment of the technique but a reflection on the reasons for its durability and success.

2. *Technique discussion*. The brilliance of the Dvorak technique, aside from its relatively good accuracy, is its reproducibility and relative simplicity. It provides the necessary mix of absolute accuracy and internal consistency required of operationally successful techniques, and its capabilities have not deteriorated despite the advances in technology. In fact, they have improved with many of those technological advances. This empirical technique is genius in that it tells the story of the entire life of the TC, from birth to death. And it provides a conceptual model of TC evolution that has held up for 3 decades. To do this, it relates TC intensity to the combination of three distinct properties that produce patterns that relate well to TC intensity. But keep in mind, it was the patterns, not the properties that were important to Dvorak. Two of these properties are kinematic in nature; they are vorticity and shear. The third is thermodynamic and can be referred to as convective vigor. It is impossible to know exactly what was going through Mr. Dvorak's mind as he developed his technique, but it appears that he did not confuse the issue by requiring that his observations and the technique conform to existing theory. In fact, it is theory that has conformed to his technique over the years. The aforementioned properties deserve some discussion.

a. Vorticity. The strength and distribution of the circular winds in a TC impart rotation on the cloud elements that organize them into specific patterns that can be related to the maximum surface wind speed. This kinematic effect is basically imparted internally, and is reflected in the relatively circular patterns of TCs.

b. Shear. Shear is a force that acts to distort the vorticity. Dvorak found that the degree of shear was also related to the maximum surface winds. This kinematic effect is primarily imparted externally, and is reflected in the elongated patterns especially evident at the cyclone's periphery, or in more extreme cases, the decoupling of the deep convection and the low-level circulation.

c. Convective vigor. In TCs, the most vigorous convective activity generally occurs in the inner core eye wall structure. In the Dvorak technique, the depth and the thickness of the eye wall convection are related to the maximum surface winds. Convective vigor also plays an important, but less over-riding role in the bands of the outer core of the cyclone. In the technique, eye temperature and eye distinctness relate to the intensity, with warmer eye temperatures and sharper, more distinct eye edges relating to stronger intensities. The eye characteristics are themselves a reflection of convective vigor in the eye wall. In 1977, Dvorak (1977) modified his technique with the addition of the Enhanced Infrared method, expanding intensity analysis to the nighttime hours. With this method, the convective vigor, especially in the intense TCs, became the dominant influence, with vorticity and shear taking on more subtle roles.

3. *Sources of error*. There are two basic sources of error associated with the technique. The first is the physical limitations of the technique due to the natural range of variability between the basic patterns and the observed surface wind speed. The second results from the misapplication of the technique. While the technique requires some skill, one of its strongest points is its reproducibility. While a 0.5 T (tropical)-number difference between independent analyses is generally deemed acceptable, these differences can occasionally exceed 1.5 T-numbers-numbers, which is unacceptable. In its early application, the initial observation had to be a

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T1.0. Since a T0.5, a T1.0, and a T1.5 all correspond to 25 knots, the T0.5 and the T1.5 were meant to be used for subsequent adjustments to identify slower or faster than normal development, allowing an intensity trend or Model Expected T-number (MET) to be established. This adjustment allowed for the variability observed in the pace of TC development. In more recent times, a common error in the application is to treat a T1.5 as 27.5 knots—better developed—rather than 25 knots. The rule is that if the image looks better than a T1.0, it's a T2.0, not a T1.5. As the T-numbers get higher, they cover a larger range of intensities. Thus, by getting behind early, the analyst is often left chasing the actual intensity and having to break the model in order to catch up. The technique bases change on a 24-hour change in the pattern, and thus assumes that the 24-hour old T-number was correct. At many analysis centers, the 24-hour old picture is rarely reevaluated and changed, if necessary. Instead, today's derived T-number is merely compared to yesterday's T-number to assess the trend. When Dvorak developed the EIR method, he did not replace the visual method. However, it has become very convenient to default to a single analysis method. In many respects, the visual method is superior to the EIR method, and should be used to help calibrate the EIR method before dark. The visual method is especially superior in the T3.5 to T5.0 range (pre-visible eye), where the location of the center or eye is not apparent in the infrared. The visual method, due to its higher resolution, is also superior for ascertaining the intensity characteristics of midget TCs. The technique also provides a forecast capability using the current trend and a set of rules to help anticipate future change. The resulting matrix of about 25 different choices provides a level of complexity that led to some miss-use and eventual non-use of the forecast portion of the technique. Despite these apparent shortfalls, the technique remains Number One.

4. *Challenges in the Pacific and Indian Oceans.* There are a few significant differences between the Pacific and Indian Ocean basins and the Atlantic basin, the basin where the technique was primarily developed. Many of the differences are discussed in more detail in Guard et al (1992). The major difference is the large monsoonal influence in the Pacific and Indian Oceans. Colder cloud-top temperatures are also observed in the Pacific and Indian Ocean basins. In fact, cloud top temperatures colder than –100ºC are not that uncommon, but they do not appear to affect the technique results. Another challenge is the number and frequency of TCs that undergo rapid intensification. In 1997, 11 western North Pacific typhoons attained super typhoon intensity, all undergoing some period of rapid intensification. All TC warning centers in the western North Pacific and Indian Ocean basins, except for the JTWC, base their warnings on a 10-minute average wind. Several centers did not realize that the Dvorak technique was based on a 1-minute average wind and did not make appropriate adjustments in the wind. And, some centers modified the technique output by applying different wind-pressure relationships to derive different "Dvorak" wind values. While this has resulted in occasional large intensity discrepancies between some warning centers, the discrepancies should not be attributed to the technique as it was designed.

5. *Impacts of the technique:* From 1974-2002, there have been some 75,250 fixes made in direct support of the JTWC in the western North Pacific. Similarly, from 1979-2002, there were 5,476 fixes in the North Indian Ocean, and from 1987-2002, there were 34,673 fixes in the Southwest Pacific and the South Indian Ocean. So for JTWC alone, there were some 115,400 fixes produced. Another 10 major analysis and/or forecast centers in the North and South Pacific and Indian Oceans and the Tropical Analysis Branch at NESDIS have produced at least as many fixes as JTWC over the last three decades for the regions. Since about half of the fixes contained a Dvorak analysis, this places the total number of Dvorak intensity analyses for just the eastern hemisphere region at a staggering 115,000 for an equally staggering 2,500 TCs. While there has been a dramatic reduction in the number of deaths in most Pacific and Indian Ocean nations since 1980 , it is difficult to quantify the number of lives that have been saved solely due to the information provided by the Dvorak technique. However, it has certainly added immense credibility to TC warnings based on satellite data. This added credibility has greatly improved readiness and responsiveness for the protection of lives and property.

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