AIRCURRENTS

CHANGING THE WAY WE MEASURE HURRICANE INTENSITY

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EDITOR'S NOTE: In this article, Dr. Peter Sousounis discusses the advantages, disadvantages, and likely evolution of the Dvorak Technique for measuring tropical cyclone intensity.

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Research scientists and forecasters have been flying into hurricanes since 1944. While this might seem a brute-force tactic, aircraft reconnaissance remains to this day the most reliable method for analyzing hurricane intensity. Dropwindsondes—tubes containing sophisticated instrument packages—are released from planes and, as they fall, record a multitude of atmospheric parameters, including temperature, pressure, humidity and wind speeds, all the way to the surface. Wind speeds are measured using a GPS system that tracks the horizontal displacement per unit of time. Wind speed errors are small in relative terms: an estimated 4 kts at flight level and less than 10 kts at the surface.

Flying through hurricanes may seem like a glamorous and exciting job, but it is a dangerous one. Since 1944, four planes and their crews have been lost, three in the Pacific and one in the Atlantic.[1] And while it has been more than 30 years since the last plane went down, there have been many bumpy rides and even a few close calls since. It is also an expensive proposition, at an estimated $12,000-$15,000 per flight hour.

For obvious practical reasons, an alternate strategy for diagnosing tropical cyclone intensity—one based on the analysis of satellite images—has become increasingly widespread. In fact, the Dvorak Technique replaced aerial reconnaissance in the Northwest Pacific basin in 1987. In this most active basin worldwide, only special field studies and exceptional circumstances now allow for aircraft-based wind speed measurements—measurements that are in fact critical to validating and calibrating the Dvorak Technique itself.

THE DVORAK TECHNIQUE—AN OVERVIEW

By the late 1960s, polar orbiting satellites were providing tropical cyclone forecasters with frequent, albeit coarse-resolution satellite images in real time. In the early 1970s a NOAA scientist, Vernon Dvorak, along with colleagues, developed an empirical technique that used those images to assess hurricane intensity based on cloud pattern recognition (Dvorak 1972, Dvorak 1974, Dvorak 1975).

In the simplest terms, the technique assigns a "T" (tropical) number to a particular cloud pattern as shown in Figure 1. Based on characteristics of cloud evolution, the T-number is then converted into a Current Intensity (CI) number. A standard table is then used to convert the CI number to maximum sustained winds. Finally, a wind-pressure relationship may be used to also assign a minimum sea-level pressure.

In its purest form, the Dvorak Technique is subjective. This is both an advantage and a disadvantage. The fact that it can be applied without any special equipment or software means that the technique is available to anyone with access to satellite images (which today means anyone with access to the internet) and knowledge of the technique. On the down side is the fact that the images are subject to different interpretations by different analysts. Despite this, however, studies have shown that over 50% of T-number classifications for the same event are within 0.5 T-number.

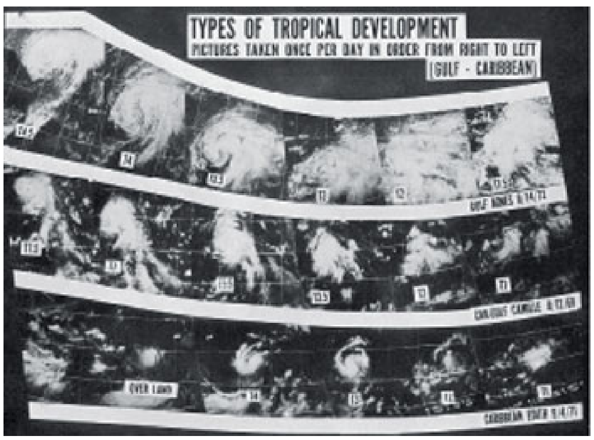

Figure 1. Characteristic Tropical Cyclone Cloud Patterns (from Dvorak, 1973)

A more significant disadvantage is that the technique does not actually measure wind speed—even though the primary purpose is to determine tropical cyclone intensity. Its success is instead based on the premise that weak tropical cyclones appear a certain way and that, as they intensify, their appearance changes in a predictable manner. Yet, interestingly, one of the first verification studies (Erickson 1972) of the Dvorak Technique revealed the need for separate versions for the Atlantic and Pacific basins. Using aerial reconnaissance data, it was discovered that storms with the same minimum sea-level pressure in the Atlantic and Northwest Pacific basins did not share the same wind speeds. In fact, the differences were found to be quite significant for intense storms (see, for example, Figure 2).

In the 1980s, the Objective Dvorak Technique (ODT) was created to leverage infrared (IR) satellite imagery in an attempt to improve the earlier visible version and to form the basis for the future development of an automated version (e.g., Dvorak 1982, Dvorak 1984, Dvorak 1995, Velden et al. 1998) . In its simplest form, the ODT used high resolution IR satellite imagery to measure brightness temperature differences between the eye and the surrounding eyewall to determine intensity at the surface. Assuming the eye can be identified as a clear area, the temperature measured will be that of the ocean water. The temperature of the eyewall will depend on the height of the convective cloud top (CCT). Because environmental atmospheric temperature decreases with height in the troposphere, the higher the CCT, the lower will be the CCT temperature. And the more intense the convection, the argument goes, the higher will be the CCT height. Finally, the more intense the convection, the more intense the rotational winds will be. So, there is a direct correlation between maximum sustained winds and the eye-to-eyewall temperature difference.

CI	MSW (kt)	Atlantic MSLP (hPa)	WestPac MSLP (hPa)
1.0	25		
1.5	25		
2.0	30	1009	1000
2.5	35	1005	997
3.0	45	1000	991
3.5	55	994	984
4.0	65	987	976
4.5	77	979	966
5.0	90	970	954
5.5	102	960	941
6.0	115	948	927
6.5	127	935	914
7.0	140	921	898
7.5	155	906	879
8.0	170	890	858

Figure 2. Summary of the Dvorak (1984) Atlantic and WestPacific wind-pressure relationship. MSLP=Minimum Sea Level Pressure. (Source: Adapted from Velden et al., 2006)

The pair of satellite images in Fig. 3 for Typhoon Krosa 2007 illustrates the advantage of using enhanced IR imagery. The visible satellite image on the left shows Krosa on its approach towards Taiwan with a well-developed eye, but there is no way of knowing what that eye means in terms of intensity. The enhanced IR image on the right shows Krosa with a relatively warm eye. The Warm Medium Gray of the eye means a temperature greater than 9 degrees C. The coldest cloud in the eyewall that completely surrounds the eye is White—corresponding to a cloud top temperature of about -70 degrees C. Using the ODT, this IR temperature difference corresponds to a T-number of 6.5 with maximum sustained winds of 127 kts. Indeed the Joint Typhoon

Warning Center measured Krosa at this time using a more advanced form of the ODT with 125 kt winds.

While conceptually the notion of the ODT may be straightforward, there are some basic constraints that have precluded full and automated implementation thus far. For example, the ODT can only be applied to storms that possess a minimum intensity of hurricane/typhoon strength. Additionally, the ODT requires a storm center location to be manually (and subjectively) selected by an analyst prior to algorithm execution. Thus, in its current operational form, for example at the Joint Typhoon Warning Center (JTWC), the Dvorak Technique is still subjectively applied using visible and IR satellite imagery—even after several decades of operational use (Guard 2004) to monitor tropical cyclone activity in the eastern and western Pacific.

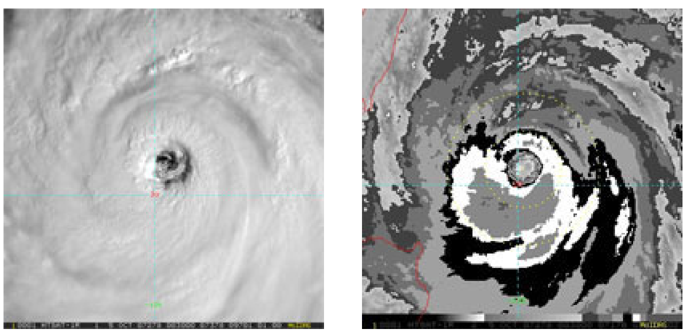

Figure 3. Visible (left) and enhanced infrared (right) satellite images for typhoon Krosa valid at 0030 UTC 05 Oct 2007. The various shades of gray in the right panel correspond to different cloud top temperatures. (Source: RAMMB-CIRA)

The good news is that the Dvorak Technique continues to evolve and improve. Work has been ongoing for a number of years to develop a completely automated form. The Advanced Objective Dvorak Technique—or AODT as described by Olander and Velden (2007) provides some recent enhancements to the ODT. Specifically, the AODT can automatically locate the center of circulation and identify weaker storm signatures. The latest version of the AODT can definitely compete in terms of accuracy with the current operational form. Other research, for example by Hoshino and Nakazawa (2007) at the Japan Meteorological Agency (JMA), is being conducted to improve the relationship between brightness temperatures and typhoon intensity. It is very likely that, after some additional testing and refinements, a completely automated form of the Dvorak Technique will become operational at hurricane and typhoon forecast centers.

REMAINING CHALLENGES OF INTERPRETATION

The Dvorak Technique was originally developed using data from the Northwest Pacific basin. Ironically, however, the technique is not designed to handle some of the unique aspects of Northwest Pacific basin tropical cyclones. Features such as monsoon depressions, monsoon gyres, and midget tropical cyclones (Lander 2004), to name a few, can cause difficulties for the current form of the Dvorak Technique. To further complicate matters, the JTWC and the JMA—two reporting agencies that provide real-time and best-track data for storms in that region—use different versions of the technique to measure the intensity of the same storm. This results in differences in deduced intensity that cannot be explained simply by the subjective implementation of the same technique. The differences stem from the conversion of the T-number to the CI number. The JMA developed a technique that was tuned based on storms impacting Japan, while the JTWC version was developed using a larger set of storms spanning the entire Northwest Pacific Basin.

At best, this practice can be a source of confusion for the layperson interested in real-time hurricane reports. At worst, the discrepancy can and does cause difficulty in analyzing best track data from the different agencies. Typhoon Man-Yi (2007) provides a recent example. As Man-Yi was rounding Okinawa, Japan, the JTWC reported a rather strong storm, with 1-minute maximum sustained winds of 125 kts. In contrast, for the same time period, the JMA reported a moderately strong storm with 1-minute maximum sustained winds of just 108 kts.[2] Differences of this magnitude tend to be the rule rather than the exception. It is ironic that the Dvorak Technique has operationally replaced reconnaissance-based intensity measurements, yet the only way to further improve the technique will be through verification from continued or resurrected aircraft-reconnaissance data.

IMPLICATIONS FOR RESEARCH ON THE FREQUENCY OF TROPICAL CYCLONES

Another significant controversy has been spawned because of the discrepancy. Studies using either JTWC or JMA best track data to evaluate possible changes in typhoon frequency and intensity in the Northwest Pacific—whether from climate change or otherwise—have found a significant increase in the last three decades in total days of intense typhoons, defined here as Saffir-Simpson Category 2 storms or greater. However, depending on the dataset used, the driver of the apparent increase differs. For example, using the JTWC data and comparing adjacent 15-year periods, Kamahori et al. (2006) found that the primary cause for the increase lies with the significant increase in Category 4 and 5 storms. But using the JMA data, they found that the primary cause for the increase lies with an increase of Cat 2 and 3 storms. Additionally, they found that the JMA data actually indicated a decrease in Category 4 and 5 storms.

The Dvorak Technique is also influencing the way tropical cyclone activity is measured in the Atlantic, which is the only basin where regularly scheduled reconnaissance flights still occur. It was largely due to the Dvorak Technique that 2007's Karen was given hurricane status—albeit in a post-season reanalysis. At 0000 UTC on September 27, a Hurricane Hunter mission estimated Karen's intensity at 60 kts—just below hurricane status. However, a comparison with satellite imagery from twelve hours earlier, which actually showed a weak eye, suggested that Karen had become less organized by the time of the reconnaissance measurements. Thus, Karen's status at 1200 and 1800 UTC 26 September was upgraded from a strong tropical storm to a weak Category 1 status, with winds estimated at 65 kts.

CONCLUSION

The Dvorak Technique has certainly revolutionized tropical cyclone forecasting and research, and evolution of the technique will continue. Future versions are likely to account not only for basin-specific storm characteristics, but also for storm-specific features, which will help eliminate discrepancies between different reporting agencies. Archived information from past storms may be recalibrated to yield improvements to current best track data sets. Finally, new interpretations of these best track data may yield new information about trends and/or cycles in tropical storm frequency and intensity.

[1] http://www.usatoday.com/weather/hurricane/2003-07-16-flying-hurricanes_x.htm. Also http://docs.lib.noaa.gov/rescue/mwr/083/mwr-083-12-0315.pdf (page 321).

[2] The JMA reports wind speeds as 10-minute sustained. As Man-Yi skirted Okinawa, the JMA reported 10-minute sustained winds of 95 kts. This converts to 1-minute sustained winds of 108 kts.

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