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NOTES ON THE APPLICATION OF THE DVORAK TECHNIQUE

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ABBREVIATIONS

BF	Banding feature
BoM	Australian Bureau of Meteorology
CDO	Central dense overcast
CF	Central feature
CI	Current intensity number
CCC	Central cold cover
CSC	Cloud system centre
DG	Dark grey (shade of the Dvorak EIR enhancement)
DT	Data T-number
E	Eye number
E_{adj}	Eye adjustment factor
EC	Embedded centre

EIR	Enhanced infrared
FT	Final T-number
IR	Infrared band satellite imagery
JTWC	Joint Typhoon Warning Centre (Honolulu)
LLCC	Low-level circulation centre
LLCL	Low-level cloud lines
MET	Model expected T-number
PT	Pattern T-number
TC	Tropical cyclone
TCWC	Tropical Cyclone Warning Centre
VIS	Visible band satellite imagery

NOTES ON THE APPLICATION OF THE DVORAK TECHNIQUE

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INTRODUCTION

The Dvorak technique matured over an extended period and there is no single reference that wholly defines the application of the technique. This document tries to bring together a collection of notes regarding the application of the Dvorak technique as a reference for operational cyclone forecasters. The limitations of the technique are covered, together with common traps for inexperienced analysts, ambiguities in the original texts and some possible modifications to the technique. Most of this material comes straight from the 'standard' Dvorak publications. Some points are derived from later studies or represent a consensus amongst a number of experienced analysts. Priority is given to indications given by Dvorak and all points are referenced to at least one source.

While some familiarity with the technique is assumed it is hoped that these notes will be of use to the novice and expert alike. If you are unfamiliar with the technique it is recommended that you first work through some training material. Dvorak (1995) is recommended. You may also have local training resources available. The Australian Bureau of Meteorology is producing a web-based learning module that may also be of assistance (contact the author via email: A.Burton@bom.gov.au). After working through available training material, supervised on-the-job training is recommended to reach operational standards of proficiency.

GENERAL COMMENTS

1. When available use VIS-IR pairs. Perform at least two VIS analyses per day to check agreement between VIS and IR analyses.
2. When an image can be analysed using more than one pattern perform both analyses and compare the results (Dvorak 1984).
3. Always try to analyse more than one image leading up to the analysis time – then average the resulting DT numbers (Dvorak 1984,1995). This is particularly applicable to shear patterns that often go through a cyclic pattern of convection blow-up near the low-level centre followed by increasing separation of the overcast from the low-level centre. This can lead to rapidly varying DT numbers over several hours.
4. It is good practice to perform a reanalysis of earlier imagery whenever a TC reaches a stage of well-defined intensity (for example when an eye first appears). The dependency of the Dvorak technique on the MET can lead to situations where it appears that model constraints have to be broken, when in fact a reanalysis of previous day's data shows that earlier FTs could have been higher and the analyst(s) has (have) 'got behind the power curve'.

5. Recognise the limitations of the Dvorak technique – it was not designed for monsoon depressions, subtropical systems or systems undergoing extratropical transition (Dvorak 1995). A separate technique exists for the classification of subtropical systems (Herbert and Poteat 1975).
6. The Dvorak technique does not adjust for the effects of system translation on surface winds. It was initially derived using a set of cyclones with an average speed of around 3-12 knots (Brown and Franklin 2004). For systems with close to average translation speeds the error from this will generally be much less than that inherent in the technique itself. For systems with rapid translation speeds the error may be significant, however the effect of translation on surface wind speeds is complex and non-linear and there is no systematic way of incorporating these effects into warning policy.
7. There can be times in a TC's life cycle when no DT can be determined – do not force a DT when no pattern can be applied – use the MET or other observations (e.g. scatterometer data) to help estimate intensity in these circumstances.
8. The winds experienced at the surface vary depending on the presence of deep convection. Thus a weak system that is going through a diurnal maximum in convection will generally have larger areas of more damaging winds than a weak system that is going through a diurnal minimum in convection. This can make the difference between a Category 2 (Australian scale) impact and a Category 1 or weaker impact.
9. Midget cyclones (gale radius < 60 nm) present problems for analysis. Although Dvorak states 'It is the pattern formed by the clouds of a tropical cyclone that is related to the cyclone's intensity and not the amount of clouds in the pattern' (Dvorak 1984), several parts of the technique rely on measurements of size (most noticeably in the CDO pattern, but also when determining BFs). Midget storms tend to intensify and decay more rapidly than larger storms.
10. Whenever Dvorak talks about the 'model' he is referring to the Dvorak model of TC development wherein a cyclone intensifies by one T-number per day.
11. It is a common mistake amongst inexperienced analysts to assume that the MET is the same as the 'Forecast Intensity Number' from 24 hours ago. The first step in determining the MET is to qualitatively compare images 24 hours apart (remove diurnal influences) and decide whether the storm has deepened (D), weakened (W) or remained steady (S). The second step is to add or subtract between 0 and 1.5 from the 24-hour-old FT (not the DT or CI) based on the D, S, W determination (Dvorak 1984, 1995).
12. The pattern T-number (PT) is not independent of the MET – it is an adjustment to the MET (Dvorak 1984). The PT is determined by first establishing the MET, then determining whether the pattern in the current imagery looks 'obviously stronger or weaker' (Dvorak 1984) than the corresponding pattern indicated at step six on the flow chart. The MET can then be adjusted by ±0.5 (no greater adjustment can be made (Dvorak 1995)) and the resulting T-number is called the PT (we could have called it the 'adjusted-MET').
13. Sometimes the Dvorak technique, with its adjustments, will indicate that a tropical cyclone with a ragged eye is only at T3.5. A reasonable rule of thumb is that if an eye is clearly discernible, then regardless of how ragged it is the storm is at a minimum of T4.0.
14. The rules for determining the FT imply that 'the more vague or conflicting the evidence of intensity, the more the estimate should be biased toward the MET' (Dvorak 1995). Even where the DT measurement is clear cut, the FT must be within ±1.0 of the MET (Dvorak 1973, 1984, 1995).

15. Recent comparisons of reconnaissance-based best-track data (Atlantic basin) with Dvorak intensity estimates found that Dvorak intensity estimates of weakening storms showed an overestimation bias. This bias could be virtually removed by using a six-hour rule for holding the CI number during initial weakening rather than the existing 12-hour rule (Brown and Franklin 2004).
16. The same study (Brown and Franklin 2004) found that:
    (a) Dvorak intensity estimates had an RMS error of 11.0 knots;
    (b) 50 per cent of Dvorak intensity estimates were within 5 knots;
    (c) 75 per cent of Dvorak intensity estimates were within 12 knots;
    (d) 90 per cent of Dvorak intensity estimates were within 18 knots;
    (e) for storms moving faster than 12 knots there was a slight underestimation bias.
17. The advent of frequent passive microwave imagery has given tropical cyclone forecasters greater insight into structural and intensity changes in tropical cyclones than can be obtained through IR and VIS imagery alone. The Dvorak technique cannot be validly applied to microwave imagery, however forecasters should use microwave imagery to assist in determining the centre position. Trends in intensity that are evident in sequences of microwave imagery can also inform the analysis process.

CURVED BAND PATTERNS

1. Note the modelled CSC positions in flow diagrams – do not centre the spiral at the CSC in early stages of development.
2. It follows from (1) that intensity analysis is not critically dependent on accuracy of centre location. However the CSC should always lie within the curvature of the band (Dvorak 1973, 1984).
3. Deciding where a band stops and starts is critical to the success of the method. The band does not have to be continuous – you should draw your band axis through small breaks (Fig. 1) (Dvorak 1982). Conversely you should beware of continuing to draw a curved band axis at the outer limit of the band when there is no remaining curvature (Fig. 2). This is usually only a problem in IR imagery where the cirrus outflow can appear to be a continuation of a deep convective band.

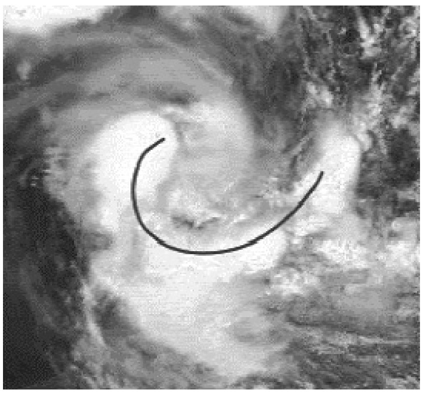


Fig.1 Continuing band axis through small breaks.

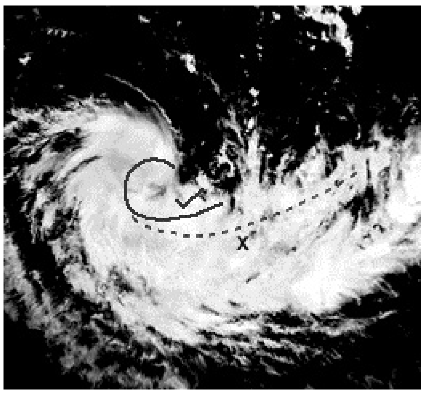


Fig.2 Use of tightest inner curvature compared with linear continuation of band axis.

4. Try to place your band axis parallel to the cold, dense overcast edge nearest the cloud minimum wedge (concave side) (Dvorak 1995). Ideally the axis will be situated one-third into the cloud band from the concave side (Fig. 3).

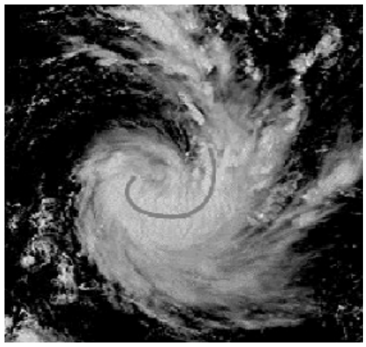
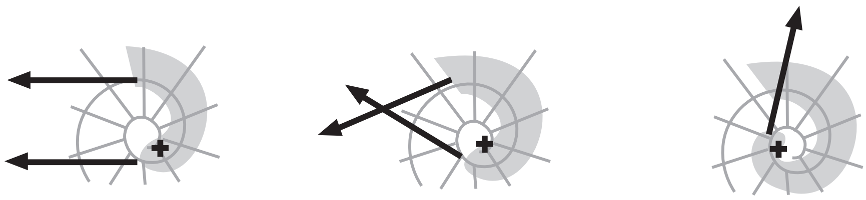


Fig. 3 Placement of curved band axis.

5. Experienced analysts are often able to visually estimate the degree of curvature without counting the tenths of a spiral. Some have developed simple rules and find them a useful adjunct to the 'count the tenths' method.

   For example, consider the figure below covering the curved band pattern over the critical range DT2.5 to DT3.5. We can see that if the DT< 3 then linear extensions of the band axes will never intersect (in fact if the band wrap is 0.55 they will eventually intersect but the precision is sufficient for our purposes). If the DT=3 then the linear extensions of the band axes will intersect. If the DT>3 then the linear extension of the band axis at the 'head' of the band will intersect the band itself (Steve West, personal communication).



DT2.5 DT3.0 DT3.5

Fig. 4 Alternative curved band method.

6. The log10 spiral does not have a physical basis – it was an empirical choice, other spirals, or a circle, can be used (Dvorak 1982). So don't get hung up on fitting your band axis to the spiral exactly.
7. Always go for the band with the tightest inner curvature – this may not be the largest, most noticeable band (Fig. 2).
8. The degree of incursion of the 'cloud minimum wedge' is an also an indication of the intensity of the storm (a corollary to the degree of wrap of the band itself).

EYE PATTERNS

General comments regarding eye patterns

1. The VIS eye technique is not as objective as the EIR technique for intensity estimates (Dvorak 1984, 1995). The EIR technique is also considered to be more 'reliable'. 'The EIR technique should be used instead of the VIS whenever possible for cyclones of hurricane intensity' (Dvorak 1995, p. 5-18).

2. Eye size – there is some slightly conflicting information regarding the delineation between 'small' and 'large' eyes, particularly with respect to the eye adjustment factor (Table 1). When determining the E (eye) number in a VIS eye pattern analysis, a small eye is one <30 nm – this is consistently defined in the various Dvorak publications. However when determining the eye adjustment factor the pre-1982 literature defines a large eye as ≥0.75° (≥45 nm) for VIS imagery and ≥0.6° (>36 nm) for EIR, while Dvorak (1982, 1984) refer to large eyes in EIR imagery as being ≥0.75° (≥45 nm) and do not explicitly define large eyes in VIS. From this information we can at least say that an eye with diameter <30 nm is small for all purposes (E and E_{adj}), and an eye with diameter ≥45 nm is large for all purposes. In between there is some ambiguity, but given the overall precision of the technique it is not a large concern. If this ambiguity leads to an uncertainty of 0.5 in the DT then once again the analyst should be guided by the MET.

Table 1. Definition of large eyes for E_{adj}.

Publication	*VIS Definition*	*EIR Definition*
Feb 1973	≥0.75° (≥45 nm)	N/A
1978-1980	≥0.75° (≥45 nm)	≥0.6° (>36 nm)
1982-1984	Not explicitly defined under E_{adj}	≥0.75° (≥45 nm)

EIR (E + eye adj + (BF adj) = DT)

3. In the EIR technique BF additions are only made when the DT would otherwise be less than the MET (Dvorak 1984, 1995).
4. Do not use the VIS banding feature additions diagram on the flow chart for EIR imagery – that diagram is intended for VIS imagery only (Dvorak 1984). Refer to Dvorak (1982, 1984) for the EIR banding feature diagram.
5. There is no minimum width criterion when determining the surrounding ring temperature for the eye adjustment factor (E_{adj}) (Dvorak 1995).
6. When determining the E (eye) number for a spiral eye, use the average width of the spiral band to determine the minimum width criteria (Dvorak 1984).
7. No 'plus' eye adjustment should be made for large eyes (≥0.75° (≥45 nm) diameter within surrounding grey shade) or elongated eyes (short axis <2/3 the long axis) (Dvorak 1984). For elongated eyes: if no previous subtraction has been made, subtract 0.5 for E (eye) numbers ≥4.5 (Dvorak 1984).

VIS (E + E_{adj} + BF adj = DT)

8. Embedded distance is measured from the centre of the eye for small eyes (<30 nm diameter), otherwise from the inner wall of the eye (Dvorak 1984, 1995).
9. When determining eye size, if the eye is not circular use the longest diameter.
10. Large eye sizes are defined differently for E and E_{adj} (see general comments on eye patterns).
11. Eye adjustment factor (E_{adj}) is determined by eye (Dvorak 1984, 1995):

- Definition – poorly defined=barely visible, well defined=dark;
- Shape – ragged eye=very uneven boundary, little circularity;
- Size – large is ≥45 nm.

12. When an adjustment is not clear cut, use the guidance of the MET to make final decision (Dvorak 1984).
13. The BF is always considered for VIS imagery, not only when DT<MET as with EIR patterns eye (Dvorak 1984, 1995).

SHEAR PATTERNS

1. Works best with VIS imagery where the boundary of the dense overcast is better defined.
2. The Dvorak flow chart suggests the use of DG to define the overcast in IR imagery, however this often does not correspond with the boundary of the overcast suggested by the VIS imagery. When performing a shear analysis overnight (i.e. without VIS imagery), consider looking for the strongest gradient in temperature to define the overcast boundary, rather than sticking to the DG shade.
3. Shear pattern intensity estimates are not determined solely on the distance from the low-level centre to the overcast – they also depend on the definition of the low-level centre and the size of the overcast. To achieve a DT≥2.5 requires that the low-level centre be defined by parallel, circularly curved low cloud lines near or under an overcast with a diameter ≥1.5 degrees latitude (Dvorak 1984). If the LLCC is poorly defined by spiral cloud lines, or if the overcast is <90 nm in diameter then DT is ≤2.0.
4. In a later publication (Dvorak 1995) the shear diagram was modified to allow greater freedom in the assignment of the DT. The previous schematic for DT=2.5 was labelled as DT3 +/-0.5, and the previous schematics for DT=3.0 and 3.5 were not shown. This may indicate an acknowledgment of the difficulty of using shear patterns given that the distance between the LLCC and the deep convection tends to vary significantly over a period of a few hours under a shear regime. However most Tropical Cyclone Warning Centres still use the older flow diagrams.

CDO PATTERNS (CF + BF = DT)

1. Designed for use only with VIS imagery (Dvorak 1982, 1984).
2. Intensity measurement not dependent on centre location (Dvorak 1982, 1984).
3. You can often do a curved band analysis on these images by drawing the axis of the band through the CDO – try both and compare results (Dvorak 1995).
4. Size matters – CF is determined by size (and definition) of overcast, this has implications for analysis of midget cyclones (see general comments).

EMBEDDED CENTRE PATTERNS

1. Intensity estimate dependent on centre location – but accuracy of centre location is often poor (by definition LLCC is covered by overcast) location (Dvorak 1982a; 1984). Often works best when an eye has just disappeared (and so there is relatively high confidence in the centre location). Uncertainty in centre location can be reduced through use of passive microwave imagery and scatterometer data.

2. Susceptible to abuse – remember that embedded centre patterns should only be applied when the 12-hour-old FT is ≥3.5 (Dvorak 1984). Application of the embedded centre pattern type will always yield a DT≥3.5 so it must be applied appropriately.
3. Dvorak says 'Use the DT for the FT when the cloud features are clear cut' (Dvorak 1982, 1984). Dvorak also indicates that 'the more vague or conflicting the evidence of intensity, the more the estimate should be biased toward the MET' (Dvorak 1995). There is nothing clear cut about the cloud features in an embedded centre pattern, and there is an implied vagueness about this intensity estimate because the centre location is generally imprecise, so you will often want to weight the FT towards the MET for these pattern types.
4. Even when the centre location is confidently located via microwave or other imagery there are reasons to be less confident about the accuracy of intensity estimates using the embedded centre technique. A number of experienced southern hemisphere analysts have noted that the temperature ranges used in the embedded centre technique often appear to give higher than warranted DT numbers often resulting in a discontinuous jump in the DT when the embedded centre pattern is used after using some other pattern (based on personal communication with a number of experienced analysts). This is likely the result of two factors relating to tropopause height. TCs tend to occur at lower latitudes in the southern hemisphere compared with the northern hemisphere where the technique was developed. At lower latitudes the tropopause is higher and thus we get colder cloud-top temperatures. Additionally, the southern hemisphere tropics have colder warm season tropopause temperatures than the northern hemisphere tropics (Kossin and Velden 2004). A study comparing Atlantic reconnaissance-based best-track pressure data with Dvorak intensity estimates based on EIR imagery found that EIR-based estimates in the low latitudes of the Atlantic were likely to have a low bias in pressure (Kossin and Velden 2004). However another study (Landsea et al. 2000) has shown a counteracting latitudinal bias in the empirical Atlantic pressure-wind relationship. It is thus difficult to make a statement regarding what bias there may be in maximum wind (Kossin and Velden 2004; Landsea et al. 2000). Notwithstanding that there is a rationale and a body of experience that suggests embedded centre intensity estimates should be treated with caution, particularly in the low latitudes of the southern hemisphere.

CENTRAL COLD COVER PATTERNS

1. This is not a pattern in the same sense as other pattern types – you cannot derive a DT – this is obvious from the Analysis Worksheet. Instead, this pattern is an indicator of 'arrested development' – and has immediate implications for the FT and the ongoing rate of development (Dvorak 1984).
2. This concept applies primarily to IR imagery because with VIS imagery the CDO or curved bands are usually visible beneath the thin cirrus shield (Dvorak 1984, 1995).
3. It is important not to confuse very cold comma patterns with CCC – the former should have some indication of a cloud minimum wedge between comma head and tail (Dvorak 1984).
4. There is also potential for confusion between Embedded Centre patterns and CCCs – use this part of the technique with caution, but do not ignore it .

REFERENCES

Brown, D.P. and Franklin, J.L. 2004. Dvorak tropical cyclone wind speed biases Determined From Reconnaissance-Based 'Best Track' Data (1997-2003). *Proceedings of the 26th AMS Conference on Hurricanes and Tropical Meteorology,* Miami, May 2004. Amer. Met. Soc., 86-7.

Dvorak, V.F. 1972. A technique for the analysis and forecasting of tropical cyclone intensities from satellite pictures. *NOAA Technical Memorandum NESS 36*, NTIS, Springfield, VA 22161, 15 pp.

Dvorak, V.F. 1973. A technique for the analysis and forecasting of tropical cyclone intensities from satellite pictures. *NOAA Technical Memorandum NESS 45*, NTIS, Springfield, VA 22161, 19 pp.

Dvorak, V.F. 1975. Tropical cyclone intensity analysis and forecasting from satellite imagery. *Mon. Weath. Rev.,103(5)*, 420-30.

Dvorak, V.F., May 1982. Tropical cyclone intensity analysis and forecasting from satellite visible or infrared imagery. NOAA National Earth Satellite Service, *Applications Laboratory Training Notes*. NTIS, Springfield, VA 22161, 42 pp.

Dvorak, V.F. 1984. Tropical cyclone intensity analysis using satellite data. *NOAA Technical Report NESDIS 11,* NTIS, Springfield, VA 22161, 45 pp.

Dvorak, V.F. 1995. *Tropical clouds and cloud systems observed in satellite imagery: Tropical cyclones. Workbook Vol. 2* (available from NOAA/NESDIS, 5200 Auth rd. Washington, DC, 20333).

Herbert, P.J. and Poteat, K.O. 1975. A satellite classification technique for subtropical cyclones. *NOAA SR Technical Memorandum 83*, US Dept of Commerce, National Weather Service, Ft Worth, TX 76102, 25 pp.

Jiang Jixi and Dvorak, V.F. 1987. Tropical cyclone centre locations from enhanced infrared satellite imagery. *NOAA Technical Memorandum NESDIS 18.*

Kossin, J. and Velden, C.S. 2004. A pronounced bias in tropical cyclone minimum sea level pressure estimation based on the Dvorak technique. *Mon. Weath. Rev., 132,* 165-73.

Landsea, C.W., Anderson, C., Charles, N., Clark, G., Fernandez-Partagas, J., Hungerford, P., Neumann, C. and Zimmer, M. 2000. The Atlantic hurricane database re-analysis project documentation for 1851-85 addition to the HURDAT database. http://www.aoml.noaa.gov/hrd/hurdat/Documentation.html.