8A.1 GLOBALISATION, CALIBRATION AND OPPORTUNITIES FOR FUTURE ENHANCEMENT OF THE DVORAK TECHNIQUE

Bruce A. Harper*
Systems Engineering Australia Pty Ltd, Brisbane, Australia.

1. INTRODUCTION

The Dvorak (1984) technique for estimating the intensity of tropical cyclones, which emerged in 1973,has not only been a critical forecasting tool for the past 30 years but, with the growth of the best track datasets, has also formed the cornerstone for the worldwide estimation of risks for a diverse range of downstream applications. These include the essential engineering design conditions for offshore oil and gas facilities, coastal management and storm surge prediction, public evacuation, long term building and planning regimes, climate change assessments and insurance loss studies.

Australia, with its vast tropical coastline and without weather reconnaissance services, was amongst the first to eagerly embrace the new technique. The 1970s was the most active decade on record and produced a series of devastating cyclones (*Ada* 1970; *Althea* 1971; *Tracy* 1974; *Trixie* 1974; *Joan* 1975; *Ted* 1976; *Hazel* 1978; *Amy* 1979). The advent of satellite data in the 1960s had already produced a stepped improvement in the quality of the Australian database resulting in an immediate reduction in the estimated average central pressures of 11 hPa during the 1970s (Holland 1981).

2. THE DECADE OF DEVELOPMENT

The first real-time application of Dvorak in Australia is thought to have been *Tracy*, and many storms during the early 1970s were also post-analysed using the new method. The 1970s represented an extremely active period of development of knowledge in Australia of all matters involving tropical cyclones. One of the lasting measures of this knowledge-building was the *Australian Tropical Cyclone Forecasting Manual* (BoM 1978). This comprehensive treatment of cyclone behaviour at the time included the Dvorak method as its intensity-estimation centrepiece and served as a valuable reference text for more than a decade after its publication. In spirit it survives now as the *Global Guide to Tropical Cyclone Forecasting* (WMO 1993).

In 1979, Australia was fortunate to have access to NOAA resources under *Project Storm Fury* (Sheets and Holland 1981) and tropical cyclone *Kerry* off the North Queensland coast became one of the first test cases where aircraft observations were compared with real time (independent) Dvorak analysis. Unfortunately this lead to exposing some of the deficiencies in the method at that time, but provided forecasters with valuable extra knowledge to apply in future interpretations.

A landmark paper by Holland (1980) set out to formalise some of the concepts arising from BoM (1978) and brought together for the first time an explicit comparison of the empirical wind-pressure relationships embodied in the Dvorak method with a simple structural model of geostrophic balance. While the “Holland model” was eagerly adopted by the global risk modelling community during subsequent decades, the practical significance of the climatological link to the Dvorak intensity estimation process was until recently largely overlooked.

3. THE DECADE OF EXPERIMENTATION

As experience and confidence in the Dvorak method gathered pace in the 1980s, forecasters considered adding regional variations. One of the earliest modifications was the conversion of the nominal 1 min sustained maximum wind to the local 10 min standard. A number of wind-pressure relationships that predated the Dvorak method had been in regular use in Australia and the 1982 update of the method had already replaced the original NW Pacific wind-pressure relationship with the proposal by Atkinson and Holliday (A&H). In Queensland, local experience with Coral Sea cyclones lead to a preference for a slightly modified form of A&H for low storm intensities and survives today as the operational standard, while Western Australia favoured the A&H approach. The most significant Australian modification to the method was in the Northern Territory region, where a procedure was developed to better classify the small, rapidly developing and intense storms that appeared to be dominating the region and causing considerable difficulty for forecasters, at least since *Tracy* in 1974. In some ways, this represented a means of circumventing the Dvorak rate of intensification limits. Significantly, this form of wind-pressure relationship, which permits higher pressures than the Atlantic relationship, has been used to characterise the majority of storms in the northern region since that time.

4. THE DECADE OF INFORMATION

Notwithstanding some changes to wind-pressure relationships, the Dvorak rules *per se* were strictly implemented by Australian forecasters throughout the 1980s and early 1990s. The rate of intensification rule, in particular, was only questioned by the more courageous forecaster. However, as knowledge increased from improving US reconnaissance and the identification of dynamical structure changes, such as concentric eyewalls, reviews were prompted of some of the more significant events of the past. This allowed reinterpretation with regard to what could now be explained by the new information, and lead to a more relaxed interpretation of some of the Dvorak rules.

By the end of the 1990s, the increasing role of the internet, the availability of satellite microwave sensors, scatterometers, the steadily improving AWS network, radar coverage and numerical guidance resulted in a wide

*Corresponding author address: Bruce A. Harper, Systems Engineering Australia Pty Ltd, 7 Mercury Court, Bridgeman Downs, QLD 4035, Australia; Email: seng@uq.net.au.

array of additional tools. However, the Dvorak method has remained as the cornerstone of Australian intensity forecasting because it provides a practical and consistent procedural framework.

5. CHALLENGES AND OPPORTUNITIES

The growth of knowledge in meteorology over the past 30 years has also been paralleled by similar advances in oceanography, engineering and numerical and statistical applications that have been of critical importance in quantifying the impacts of tropical cyclones. The increasing demand for greater certainty of environmental risk has pushed the prediction horizon beyond the acceptable 50 and 100 year return period of the 1970s to 1000 years in the 1980s and now to 10,000 years (annual exceedance of 10^{-4}) for the offshore industry. While deterministic models of the various processes have steadily improved, the probabilistic components have been limited by a paucity of mainly meteorological data, which has now become the principal roadblock.

In response to meeting the challenge of producing reliable risk estimates to the 10^{-4} level in Australia's Timor Sea region, Woodside Energy Ltd commissioned a recent review (Harper 2002), with the active cooperation of the Bureau of Meteorology. The review looked critically at the potential for systematic bias in the historical datasets, whether due to procedural or technical causes, and also considered opportunities to improve the present and future quality of the archive. Some of the potentially contentious issues which emerged from the review included:

- The historical datasets have unavoidably inherited any biases that are implicit in the method;
- Present V_{max} estimates might be more reasonably regarded as peak gust proxies;
- V_{max} contributions from vortex balance and storm motion should be separately estimated;
- The natural variability of inner-core wind-pressure balance in any single storm is likely to be much greater than the presently assumed differences between the NW Pacific and Atlantic relationships;
- Important spatial information such as R, R_{OCI}, R_{gales} had not been systematically estimated or recorded;

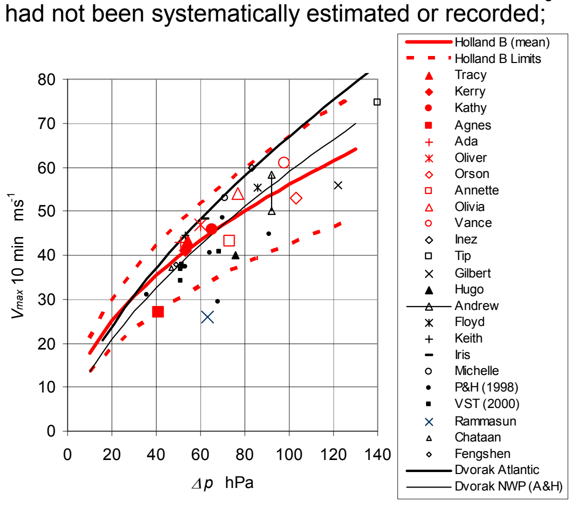

Figure 1 Climatological Wind-Pressure Space

- An absolute storm scale classification system, possibly based on R_{gales}/R might enable *a priori* selection of the expected wind-pressure regime;
- Rate of intensification is likely to significantly influence the dynamics of the wind-presssure balance;
- The Holland model *B* parameter could be used as a proxy for parameterising the variability of inner-vortex wind-pressure balance and avoid the need for the present fixed NW Pacific and Atlantic regional mean wind-pressure relationships (e.g. Figure 1);
- National data archives must ensure that all possible storm parameters are documented and retained for future reanalysis needs (e.g. Dvorak *T* and *CI* numbers, B, p_n, R, R_{OCI}, R_{gales} etc).

6. CONCLUSIONS

The Dvorak method has been the fundamental tool behind the growth of our highly valuable present day tropical cyclone archives. Its practical appeal and demonstrated skill in the face of unimaginable complexity must place it amongst the greatest inventions of our time. Ironically though, its simplicity and modest documentation demands have probably acted to limit the amount of detail which now occupies the archive. This oversight by the meteorological community means that the information pool that could now be actively being used to improve the technique has been much diminished. Empirical techniques such as the Dvorak method intrinsically rely on access to *objective* datasets so they can be continuously improved. They also need champions to ensure they survive and prosper. The Dvorak method of the future is of vital interest to the Australian community and its continued improvement ranks as a national priority.

Thanks are due to Greg Holland, Jeff Callaghan and Rex Falls for their input to this review and to Woodside Energy Ltd and their project participants.

7. REFERENCES

BoM, 1978: Australian tropical cyclone forecasting manual. Preliminary edition, Bureau of Meteorology.

Dvorak, V.F., 1984: Tropical cyclone intensity analysis using satellite data. NOAA Tech Rep NESDIS 11.

Harper, B.A., 2002: Tropical cyclone parameter estimation in the Australian region: wind-pressure relationships and related issues for engineering planning and design – a discussion paper. Systems Engineering Australia Pty Ltd for Woodside Energy Ltd, Nov. [http://www.uq.net.au/seng/download/]

Holland, G.J., 1980: An analytic model of the wind and pressure profiles in hurricanes. Mon. Wea. Rev., 108.

Holland, G.J., 1981: On the quality of the Australian tropical cyclone data base. Aust.Met.Mag.,29.

Sheets, R.C. and Holland, G.J., 1981: Australian tropical cyclones Kerry and Rosa,1979. NOAA Technical Memorandum, ERL-AOML-46, 138pp.

WMO 1993: Global guide to tropical cyclone forecasting. Tropical Cyclone Programme Report No. TCP-31, *World Meteorological Organization*, WMO/TD – No. 560, Geneva. http://www.bom.gov.au/bmrc/pubs /tcguide/global_guide_intro.htm]