3.15 THE APPLICATION OF SYNOPTIC STRATIFICATION TO THE STATISTICAL FORECASTING OF RAINFALL AND SURFACE WIND

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1. INTRODUCTION

As a means of identifying common characteristics for a meteorological phenomenon, or weather regime, synoptic data stratification has been a useful conceptual tool for operational meteorologists in trying to establish the essence of a forecasting problem. Based upon this concept of synoptic stratification, two statistical prediction schemes are described in this paper. The first was designed to predict rainfall in the trade wind flow at the coastal boundary of northeastern Queensland, Australia (Fig. 1), during periods where trade wind flow predominated. The second scheme was designed to provide hourly surface wind vectors for Sydney Harbour (Fig. 1) In both schemes, historical NWP model data is partitioned according to synoptic criteria during the development stage of the model.

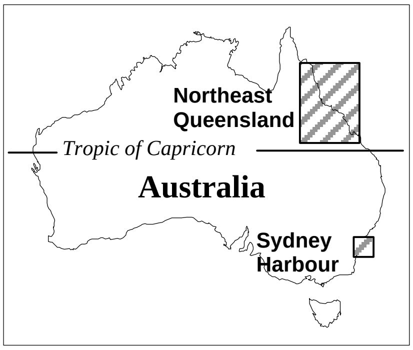

Figure 1 Location map of the areas for which synoptic stratification schemes were developed

The difficult task of rainfall prediction beyond the range of 12 h is increasingly being assigned to objective methods based upon numerical model output. Precipitation forecasts may be directly obtained from NWP model output, or a statistical relationship may be derived from a learning sample of observed rainfall data and NWP parameters (MOS or Perfect Prognosis). A weakness of the statistical approaches to precipitation forecasting is that the dependent variable is generally treated unilaterally – without reference to the mechanism that causes the precipitation.

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Clearly, different meteorological parameters would be influential in, for instance, rainfall from maritime-based convection advected onto a coastal region – when compared to rainfall from an upper-level cloudband.

Observational studies in the Hawaiian region have related trade wind precipitation on windward locations with inversion height (Chen and Feng 1995), and wind strength in the middle of a trade wind layer (Takehashi 1986). Recent studies into trade wind precipitation (Connor and Bonell 1998; Carbone et al. 1998; Connor and Woodcock 2000) reveal a more intricate relationship between rainfall and meteorological parameters. These studies have noted several influential factors affecting precipitation, for regions exposed to the onshore trade flow. These include: topographic profile, trade wind layer depth, perturbations in the horizontal wind field, thermal circulations and the vertical distribution of wind speed, humidity, and stability. The amount of daily rainfall variance explained by each of these factors is dependent on the synoptic setting.

Synoptic stratification offers the opportunity to more closely align the forecast parameter with the actual mechanism(s) responsible for the parameter variation. Improvements in predictive skill have previously been achieved with schemes stratified on a synoptic basis, for a variety of weather phenomena. For example: Paegle (1974) in precipitation forecasts stratified on 500 hPa flow type; Jarrel et al. (1975) for tropical cyclone movement forecasts using surface analogue patterns; Woodcock (1980) for temperature prediction using surface pattern analogues; Stern (1980) and Dahni and Stern (1995) for general weather forecasts based upon surface and mid-tropospheric analogue pattern recognition; and Reap (1994) for lightning activity forecasts objectively stratified by pattern classification of low-level flow.

However, despite the success of the analogue approaches to data stratification outlined above, the techniques based solely upon wind field pattern recognition were considered to be less suitable for precipitation prediction in tropical locations. In the tropical environment, where precipitation amounts often vary according to subtle changes in moisture, diabatic heating or ageostrophic flow; a more sensitive method of data classification is required.

By emulating the synoptic regime sorting process that operational forecasters generally undertake, an objective rainfall prediction scheme has been developed that embraces some of the complexity of the precipitation processes that occur in the trade wind regime. Section 2 describes this technique where NWP model data is synoptically stratified prior to the application of stochastic-dynamic methods. The forecasting scheme is suitably robust for operational use; and has displayed superior skill to other objective forecasting techniques for the determination of significant rainfall events.

Section 3 presents the results of a statistical wind prediction scheme where the NWP development data is firstly stratified according to the gradient wind (900 m) prognosis. The scheme was used operationally for the prediction of surface wind in both offshore and onshore locations, for sailing events during the 2000 Olympic Games in Sydney, Australia. Section 4 briefly discusses further applications and extensions of the synoptic stratification technique.

2. RAINFALL PREDICTION

As the prime focus of this synoptically stratified prediction scheme (SYNS) was on trade wind precipitation, the development sample was derived from data for the period March through to November. In this period, trade winds are the dominant weather regime (Lyons and Bonell 1992). The 1129-day development dataset was based around the Australian operational Model Output Statistics (MOS) archive which, in turn, was extracted from available grid point data from the Australian Limited Area Prediction Scheme (LAPS) (Puri et al. 1998) from June 1993 to August 1997. The 226-day independent dataset used for evaluation of the scheme extended from mid-March through to October 1998.

Fifty potential predictors were offered to the SYNS prediction scheme. The predictors were selected according to the amount of precipitation variance explained by each predictor in preliminary screening regression trials with the development data. The development data was objectively partitioned into synoptic precipitation regimes prior to the generation of Probability of Precipitation (PoP) and Quantative Precipitation Forecasting (QPF) equations (0-24 h and 24-48 h) through screening regression. The four synoptic regimes used for the data stratification were:

- *Upper-level moisture uplift probable* (UPPER-LEVEL)
- *Continental-based afternoon convection probable* (CONT_CONVECTION)
- *Maritime-based overnight or morning convection probable* (MAR_CONVECTION)
- *Offshore flow, or onshore dry flow probable* ("DRY" FLOW).

A detailed discussion on the rainfall dataset, precipitation regime selection process, and predictor specifications is presented in Connor and Woodcock (2000). Some aspects of the results are discussed below.

The regional and individual city forecasts were evaluated over a network of stations. The importance of verifying rainfall at multiple sites is illustrated in Fig. 2, where, the conditional probability of the detection of rainfall for three cities (Townsville, Cairns and Mackay - within the northeast Queensland study area) is presented as a function of the number of stations present in the rainfall network.

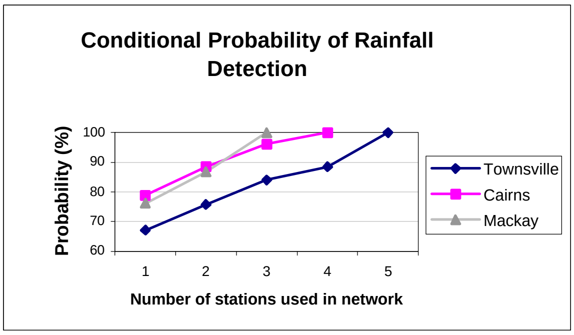


Figure 2 The conditional probability of a rain day (≥0.2 mm) being detected, provided that a rain day was recorded within the rainfall network, for each city. Station 1 is the reference station in each city with subsequent stations listed in order of distance from station 1. The 1355 days of data used in this survey combined the development and verifying periods of this investigation.

In the most extreme case, Townsville, only 67% of the rainfall events (within 10 km of the city) were captured by the official rainfall reference station. For the verification of precipitation events in a city to be meaningful, when considering precipitation arising from sub-synoptic scale phenomena, a network of stations must be used. Through areal aggregation, the mesoscale variability of convective rainfall can be recognized.

The skill of the SYNS rainfall prediction equations was compared with seasonally stratified equations (SEAS), Regional model rainfall output (LAPS), the Bureau of Meteorology operational forecast (ABoM – In Table 1) and the reference forecasts of persistence and climatology. The Brier Skill Score with respect to climatology (BSSc) (Brier 1950) and the percentage of correct forecasts is used for comparative verification in Table 1; and the Hanssen and Kuipers (1965) discriminant (*V*) or True Skill Statistic (TSS) was used to measure skill for the binary rainfall forecasts in Table 2.

METHOD	All Cities (n=596) %	BSSc
0-24 h		
SYNS	***80***	0.49
SEAS	***79***	0.48
LAPS	***75***	0.37
ABoM	***81***	0.54
PERS	***74***	0.37
	All Cities (n=336)	
24-48 h		
SYNS	***79***	0.43
SEAS	***76***	0.37
LAPS	***72***	0.26
ABoM	***65***	0.08
PERS	***63***	0.02

Table 1 Forecast skill for rain occurrence (≥ 0.2 mm d^{-1}) within a city. The data from three cities (Cairns/Townsville/Mackay) is combined in the 0-24-h section. Due to lack of data, only two cities (Cairns/Townsville) were considered in the 24-48-h section. The performance of the synoptically stratified (SYNS), seasonally stratified (SEAS), numerical model precipitation (LAPS), the Bureau of Meteorology operational forecast (ABoM), and persistence (PERS) methods, are shown. The number of cases verified is indicated in parentheses. The measures used for comparitive evaluation are the percentage of correct forecasts (%) and Brier Skill Score (BSSc). The methodology used in assigning binary forecasts to the worded ABoM forecasts is discussed in detail in Connor and Woodcock (2000).

METHOD	Rain occurrence ≥ 0.2 mm d^{-1} ***V***	LOWER LIMIT	UPPER LIMIT	Rain occurrence ≥ 2.5 mm d^{-1} ***V***	LOWER LIMIT	UPPER LIMIT
0-24 h						
SYNS	***0.55***	0.49	0.62	***0.54***	0.46	0.63
SEAS	***0.54***	0.47	0.60	***0.35***	0.26	0.44
LAPS	***0.45***	0.38	0.52	***0.35***	0.25	0.44
PERS	***0.46***	0.39	0.53	***0.32***	0.23	0.41
CLIM	***0.10***	0.03	0.18	***0.18***	0.09	0.28
24-48 h						
SYNS	***0.49***	0.42	0.56	***0.47***	0.39	0.56
SEAS	***0.43***	0.36	0.50	***0.24***	0.15	0.33
PERS	***0.21***	0.14	0.28	***0.15***	0.05	0.24
CLIM	***0.10***	0.02	0.18	***0.17***	0.07	0.26

Table 2 Forecast skill for both rain occurrence (≥ 0.2 mm d^{-1}) and significant rain occurrence (≥ 2.5 mm d^{-1}) for the combined three-city dataset. The performance of the synoptically stratified (SYNS), seasonally stratified (SEAS), numerical model precipitation (LAPS, 0-24-h data only), persistence (PERS), and climatology (CLIM) methods, is compared for the 678 event (226 x 3) data set for 0-24-h forecasts; and the 675 event dataset for 24-48-h data. The Hanssen and Kuipers' discriminant (*V*) is given with the lower and upper limits of *V* at the 95% confidence interval.

In Table 1, for the 0-24-h forecasts, the skill of all objective methods was equal to or greater than that of persistence for most cities. However, the ABoM forecasts displayed slightly superior skill for this interval. As the Mackay ABoM forecasts were only valid for 36 h beyond their issue, the comparison of 24-48-h forecasts was only possible for the cities of Cairns and Townsville. For these longer-term forecasts, the objective methods (SYNS, SEAS, and LAPS) were superior in skill to both the ABoM and persistence forecasts.

In Table 2, the SYNS method exhibits higher skill than other techniques. However, for the 0-24-h rain occurrence results, the distributions of *V* for the objective methods (SYNS, SEAS, and LAPS) overlap at the 95% confidence interval. Therefore, no significant indication on relative performance can be made from the data presented. All objective methods have achieved significantly skill improvements over climatology for rainfall occurrence prediction but show no significant skill over the persistence control forecast at the 95% confidence interval. For the 24-48-h forecasts, the statistical methods (SYNS and SEAS) significantly out-perform the reference forecasts of persistence and climatology. However, it is not possible to separate the distributions pertaining to the skill of these statistical methods, for individual comparison, at the 95% confidence interval.

Forecasting for rain occurrence at the 2.5 mm d^{-1} threshold, Table 2 reveals that the SYNS method is superior in skill to the SEAS technique and all other methods. The skill differential exists at both the 0-24-h and 24-48-h projection. These results are statistically significant at the 95% level.

3. SURFACE WIND PREDICTION

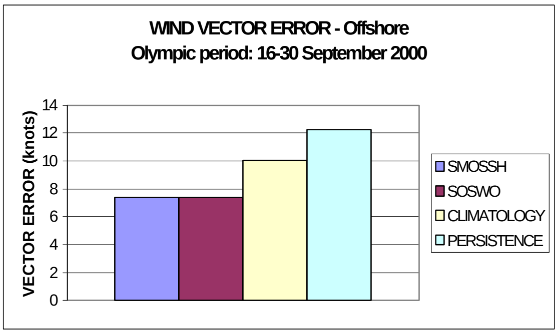
Synoptic stratification was also applied to a matched observed-surface-wind/NWP dataset for the development of a wind prediction scheme for application to the sailing events of the 2000 Olympic and Paralympic games. The Stratified MOS Sydney Harbour scheme (SMOSSH) was derived from a historical data set (Aug/Sep/Oct/Nov) of observed and LAPS data (from the previous evening 2200 LST model run) from the years 1993-1999, and was designed to provide hourly wind vectors for offshore and inshore locations with a lead time suitable for operational use. Prior to the development of wind prediction equations through screening regression, the dataset was stratified into samples based upon the NWP model forecast 1000 LST gradient wind (900 m) direction.

Surface winds on Sydney Harbour are notoriously complex. The interaction between synoptic wind, terrain, tidal effects, and the local sea-breeze circulation – in a region of strong baroclinicity, presents an intricate forecast problem. Previous studies have linked the sea-breeze circulation with the gradient wind (Crooks and Brooks 1987; Houghton 1992) and the sea/land temperature contrast (Zhong and Takle 1992; Connor 1997). Predictors were selected for their meteorological relevance and included NWP wind parameters, sea surface temperature, inland maximum temperature, lapse rates and a number of combined parameters that were known to be relevant to the sea-breeze circulation (Connor 1997).

The SMOSSH wind output was evaluated at several locations near the Olympic yachting courses. Fort Denison is located inside Sydney Harbour and the Offshore station lies 3 km to the east of the entrance to the harbour in an exposed location. The skill of the SMOSSH scheme was verified using the mean vector error for hourly forecasts between 0900 and 1700 LST; and compared with several other forecasts:

- SOSWO – (Sydney Olympic Sailing Weather Office) – The official Bureau of Meteorology hourly wind forecast used by both the Race Management committee (for course selection and alignment) and the athletes and coaches (for race tactics and boat tuning). Forecasts were based upon NWP and statistical guidance.
- Climatology – (CLIM) – An hourly site-specific climatology based upon observed winds during August/September/October/Early November.
- Persistence – (PERS) – Verification site-based wind speed and direction - 24 hours prior to the forecast time.

A comparative evaluation of skill is shown in Figure 3.



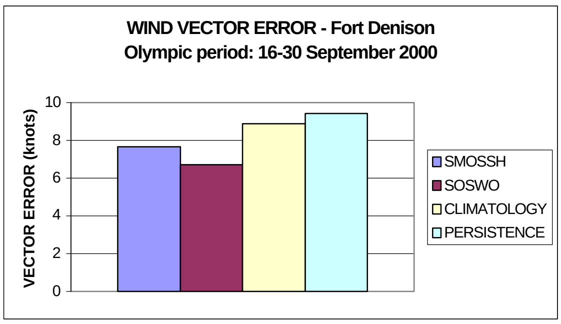


Figure 3 A comparative evaluation of mean wind vector error for the stratified MOS scheme (SMOSSH), Official Bureau of Meteorology forecasts (SOSWO), and the reference methods of climatology and persistence. The upper figure displays wind prediction errors at an offshore (3 km) location and the lower figure shows errors at a location inside Sydney Harbour.

Both SMOSSH and the official forecasts (SOSWO) attained higher skill than climatology and persistence during the 17-day Olympic period. Although the skill of SOSWO and SMOSSH were comparable for the offshore location, a slight skill advantage was maintained by SOSWO for the Fort Denison Harbour forecast.

4. SUMMARY AND FUTURE INVESTIGATION

In a statistical sense, the methodology of synoptic stratification describes the development of procedures that reduce the complexity of the weather forecast problem through the classification of weather situations by synoptic characteristics. Statistical schemes that use synoptic stratification to align the predictor selection process more closely with the meteorology of the predictand, have been discussed. Predictors emerge from the regression process that are particularly relevant to each synoptic category.

The applicability of the synoptic stratification procedures to rainfall and surface wind forecasting has been demonstrated using MOS-type prediction schemes. However, the continual up-grading of NWP models limit the MOS schemes to relatively short datasets. Future synoptic stratification schemes will be developed on a "Perfect Prognosis" basis – the much larger anlaysis datasets available will allow stratification of data into synoptic types, in addition to the more common method of partitioning NWP-statistical datasets on a seasonal basis.

REFERENCES

Brier, G. W., 1950: Verification of forecasts expressed in terms of probability. *Mon. Wea. Rev.,* **78**, 1-3.

Carbone, R. E., J. D. Tuttle, W. A. Cooper, V. Grubisic, and W. C. Lee, 1998: Trade wind rainfall near the windward coast of Hawaii. *Mon. Wea. Rev*., **126**, 2847-2863.

Chen, Y. L., and J. Feng, 1995: The influences of inversion height on precipitation and airflow over the island of Hawaii. *Mon. Wea. Rev*., **123**, 1660-1677.

Connor, G. J. 1997: Statistical short-term forecasting technique for wind and temperature in a coastal tropical location. *Aust. Meteor. Mag*., **46**, 257-265.

Connor, G. J., and M. Bonell, 1998: Air mass and dynamic parameters affecting trade wind precipitation on the northeast Queensland tropical coast. *Int. J. Climatol.,* **18,** 1357-1372.

Connor, G. J., and F. Woodcock, 2000: The application of synoptic stratification to precipitation forecasting in the trade wind regime. *Wea. Forecasting,* **15,** 276-297.

Crooks, G., and B. Brooks, 1987: Sea front winds near Adelaide. *Met.Note,* **176**, 14 pp. [Available from Bureau of Meteorology, GPO Box 1289K, Melbourne 3001, Australia.]

Dahni, R. R. and Stern, H. 1995. The development of a generalised UNIX version of the Victorian Regional Office's operational analogue statistics model. *BMRC Res. Rep. 47,* 34 pp. [Available from Bureau of Meteorology, GPO Box 1289K, Melbourne 3001, Australia.]

Hanssen, A. W., and W. J. A. Kuipers, 1965: On the relationship between the frequency of rain and various meteorological parameters. *Koninklijke Nederlands Meteorlogisch Institut, Meded. Verhand*., **81**, 2-15.

Houghton, D., 1992: *Wind Strategy.* Fernhurst Books, Arundel, West Sussex, 91 pp.

Jarrel, J. D., C.J. Mauck, and R.J. Renard, 1975: Forecasting tropical cyclone motion over the northeastern Pacific Ocean by an analog scheme. *Mon. Weath. Rev*., **103**, 674-684.

Lyons, W. F., and M. Bonell, 1992: Daily mesoscale rainfall in the tropical wet/dry climate of the Townsville area, north-eastern Queensland during the 1988-1989 wet season: synoptic-scale airflow considerations. *Int. J. Climatol.,* **12,** 655-684.

Paegle, J. N., 1974: Prediction of precipitation probability based on 500-mb flow types. *J. Appl. Meteor.,* **13**, 213-220.

Puri, K., G. S. Dietachmayer, G. A. Mills, N.E. Davidson, R. Bowen, and L. W. Logan, 1998: The new BMRC Limited Area Prediction System (LAPS). *Aust. Meteor. Mag*., **47,** 203-223.

Reap, R. M., 1994: Analysis and prediction of lightning strike distributions associated with synoptic map types over Florida. *Mon. Wea. Rev.*, **122**, 1698–1715.

Stern, H. 1980: A system for automated forecasting guidance. *Aust. Meteor. Mag,* **28**, 141-154.

Takehashi, T., 1986: Wind shear effects on water accumulation and rain duration in Hawaiian warm clouds. *J. met. Soc. Japan*, **64**, 575-584.

Woodcock, F. 1980: On the use of analogues to improve regression forecasts. *Mon. Wea . Rev*., **108**, 292-297.

Zhong, S., and E. S. Takle, 1992: An observational study of sea and land breeze circulation in an area of complex coastal heating. *J. Appl. Meteor.,* **31**, 1426-1438.