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AN AUTOMATED SYNOPTIC TYPING SYSTEM USING ARCHIVED AND REAL-TIME NWP MODEL OUTPUT

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1. INTRODUCTION

The Australian Bureau of Meteorology (BoM) has developed an automated synoptic typing system using archived and real-time NWP model output. Objective synoptic typing is performed using a pattern recognition scheme with fields of mean sea level pressure (MSLP). Real-time NWP model output is then automatically classified to generate synoptic type guidance for storage in a Forecast Database for accessibility and verification.

The synoptic types are derived using MSLP analyses over the Australian region from the BoM's archived METANAL grids and the NCEP re-analysis dataset. Principal components were first computed to represent the features of the MSLP fields. Reducing the dimensionality of the dataset, the derived variables based on these principal components were then fed to a K-means unsupervised clustering scheme to derive the synoptic types.

Real-time NWP model output extracted from the operational database is then classified using these synoptic types. Synoptic type guidance for a variety of NWP models is generated operationally and stored in the BoM's Forecast Database (under development), a comprehensive real-time database which allows forecasters to flexibly display, assess, manipulate and store all types of observational data, NWP data, and processed data (analyses and forecasts).

The real-time synoptic type guidance is accessible to new software applications used by forecasters, making the applications "context-sensitive" and allowing automatic presentation of statistical summaries of similar situations. Alerts for likely significant weather appropriate to the synoptic type may also be generated.

The BoM's synoptic typing system is unique in that no other operational system exists (to our knowledge) that incorporates both the development of synoptic types and generation of synoptic type guidance from the automatic classification of real-time NWP model output. The system continues to be under development.

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2. BACKGROUND

In Australia, over the last 25 years, there has been significant development of systems for the generation of automated weather forecast guidance using analogue retrieval techniques (Stern, 1980; Stern and Dahni, 1981, 1982; Dahni et al, 1984; Dahni and Stern, 1995; Stern, 1996; and Dahni, 1988). The analogue technique achieved national recognition and operational status through the Australia-wide implementation of the Generalised Analogue Statistics Model (Dahni and Stern, 1995) and the Forecast Guidance System component of the Australian Integrated Forecast System (Kelly and Gigliotti, 1997). The analogue model became an integral part of the forecast process, with the guidance readily available to the forecasters in their operational environment.

Analogues differ from synoptic types in their method of derivation, but they both still represent similar synoptic situations from the past from which useful weather forecast guidance could be derived. Synoptic pattern recognition has been accomplished either subjectively (Stone, 1989; Elliot et al, 2002) or with the aid of objective synoptic typing methods (Jasper and Stern, 1983; Treloar and Stern, 1993; and Dahni and Ebert, 1998).

Weather variables have been associated with these synoptic patterns or types to either generate weather forecast guidance or for verification purposes (Stern et al, 1984; Dahni and Ebert, 1998; Stern and Parkyn, 1999, 2001; Stern, 2002, 2003; Stern and Dawkins, 2003; and Dawkins and Stern, 2003). Grace (1995) proposed to build a computerised library of recognizable synoptic patterns associated with user-defined weather events.

Despite the potential of synoptic typing to provide useful weather forecast guidance in the operational environment, a common problem with all these methods is their lack of operational implementation. This has primarily been due to the difficulties that can be experienced in the transfer of research and development into operations, and systems not yet developed (until now) to automatically classify real-time NWP model output.

3. SYNOPTIC TYPER

The BoM has developed and operationally implemented the Synoptic Typer, an automated synoptic typing system using archived and real-time NWP model output to generate synoptic type guidance for storage in a Forecast Database for accessibility and verification.

3.1 *Version 1*

The Synoptic Typer is both an interactive (GUI-based) and non-interactive (normally run in batch mode) application designed to perform automated objective synoptic typing using a pattern recognition scheme. A history of grid point analyses is used to develop the synoptic types for multiple locations within the Australian region, using both principal component and cluster analysis techniques. Real-time NWP model output (analysis and prognosis grids) is then automatically classified to generate synoptic type forecast guidance for storage in a Forecast Database for accessibility by the MENTOR system (Ryan et al, 2003).

The Synoptic Typer has been developed on the PC (Windows) using the Interactive Data Language (IDL) and implemented (cross-platform) in Windows, Linux and UNIX. An existing C^{++} module is used to extract the NWP grids from the operational (NEONS/ORACLE) database. The Synoptic Typer GUI is presented in Figure 1.

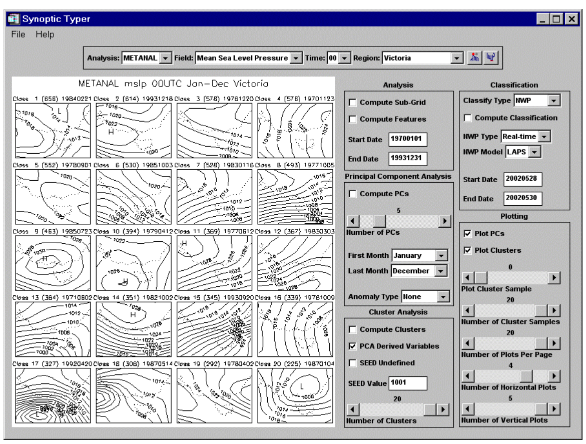

Figure 1 Synoptic Typer GUI

The GUI-based design and cross-platform implementation of the Synoptic Typer allows easy demonstration and investigation of the functionality of the application to promote feedback from both researchers and forecasters. This is essential for the successful, continued development of the system.

3.2 *Methodology*

The Synoptic Typer methodology is based on the synoptic typing work of Dahni and Ebert (1998). They described some initial results from an automated synoptic typing scheme based on MSLP patterns, and applied the synoptic classifications to the problem of identifying systematic errors in NWP QPFs.

Automated objective synoptic typing was performed using a simple pattern recognition scheme with fields of MSLP as input. MSLP was the most obvious field to choose since it gives information on the low-level flow, and because forecasters generally have good knowledge of the particular weather patterns associated with various flow regimes.

The synoptic types were derived from 24 years of 00UTC MSLP analyses (from the BoM's archived METANAL grids) on a 15^{o} latitude/longitude grid centred over Melbourne, Australia, covering the period 1 January 1970 to 31 December 1993.

In order to represent the characteristics of the MSLP fields, principal components were first derived. The first five principal components together represented the majority of the variance in the MSLP patterns. The derived variables based on these five principal components were then fed to a K-means unsupervised clustering scheme that classified the samples into a specified number of clusters, or synoptic types.

The number of synoptic types (clusters) needed to accurately represent the variety of MSLP patterns and needed to be large enough so that the variability within any individual class was not too great, but the number of samples within the cluster large enough so that its statistics (mean and variances of the derived variables) could be reliably determined. It was also advantageous to differentiate between seasonal patterns. The algorithm separated wintertime (mid-April to mid-October) and summertime (mid-October to mid-April) samples, and specified the number of synoptic types to be 20 in each season.

The synoptic classifications were applied to the problem of identifying systematic errors in NWP QPFs. It was concluded that automated synoptic typing appeared to be a useful tool for categorising errors in NWP forecasts. Using the QPF verification results to provide guidance to forecasters would involve classifying the forecast MSLP field, accessing the QPF verification statistics for the appropriate synoptic type, and providing the forecaster with estimated probabilities for over- or under-estimation of rain area and intensity, and likely position errors.

The synoptic typing results of Dahni and Ebert (1998) has finally been extended nationally and implemented in the operational environment, incorporated into the Synoptic Typer.

3.3 Data

Analogue retrieval and synoptic typing methods have always relied upon the availability of a significant history of point or gridded MSLP data.

The BoM's archived METANAL grids contain a history of 00UTC and 12UTC analyses, covering the period 1 January 1970 to 31 December 1993, from the regional (i.e. RASP) model at a resolution of 1.5^{o} over a specific (90.5E-170E, 50S-9.5S) geographical region for a variety of fields (i.e. mean sea level pressure, 850 hPa temperature, 1000, 850, 700, 500, 300 and 250 hPa geopotential height, 500 hPa wind speed). The METANAL grid is presented in Figure 2.

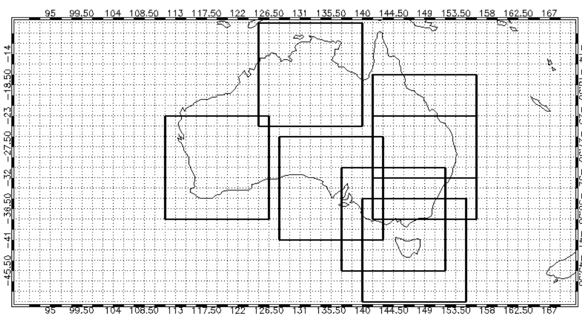

Figure 2 METANAL grid and Synoptic Typer regions

The NCEP re-analysis dataset (i.e. NCEP grids extracted over the Australian region) contain a history of 00UTC, 06UTC, 12UTC and 18UTC analyses, covering the period 1 January 1948 to 31 December 2001, at a resolution of 2.5^{o} over a specific (90E-170E, 50S-7.5S) geographical region for a variety of fields (e.g. mean sea level pressure, 850 hPa temperature, 1000 hPa and 500 hPa geopotential height and wind, precipitable water). The NCEP grid is presented in Figure 3.

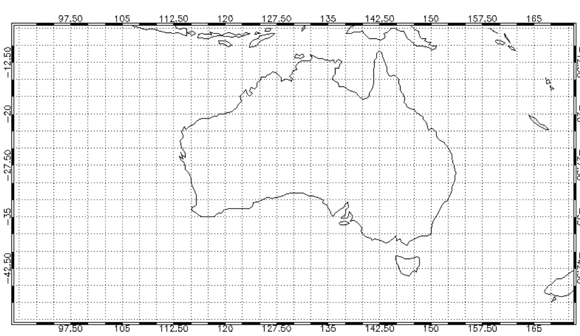

Figure 3 NCEP grid

The Synoptic Typer has been initially developed using the 00UTC METANAL grids for MSLP to enable comparison with the work of Dahni and Ebert (1998). Synoptic types are derived for specific locations (e.g. 15^{o} latitude/longitude box centred near Melbourne) in the Australian region. The Synoptic Typer regions for the METANAL grid are also presented in Figure 2.

3.4 Synoptic Typing

The methodology to derive the synoptic types is also schematically presented in Figure 4.

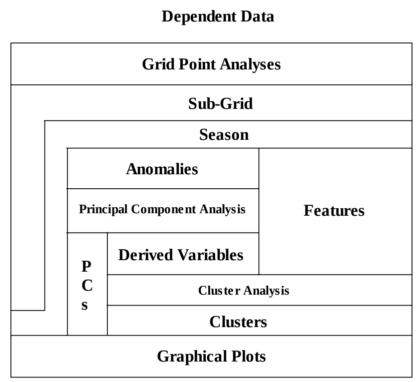

Figure 4 Derivation of synoptic types

In order to represent the characteristics of the MSLP fields, principal components are first derived. An example of the variance in the MSLP patterns explained by the first 10 principal components is presented in Figure 5.

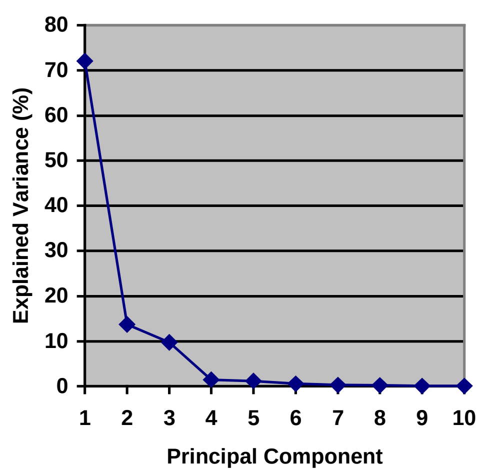

Figure 5 Principal Component Analysis

The derived variables based on the first five principal components (where the explained variance > 1%) are then fed to a K-means unsupervised clustering scheme to classify the samples into a specified number (i.e. 20) of clusters, or synoptic types. An example of the synoptic types for the Victoria region using the METANAL grids is presented in Figure 6.

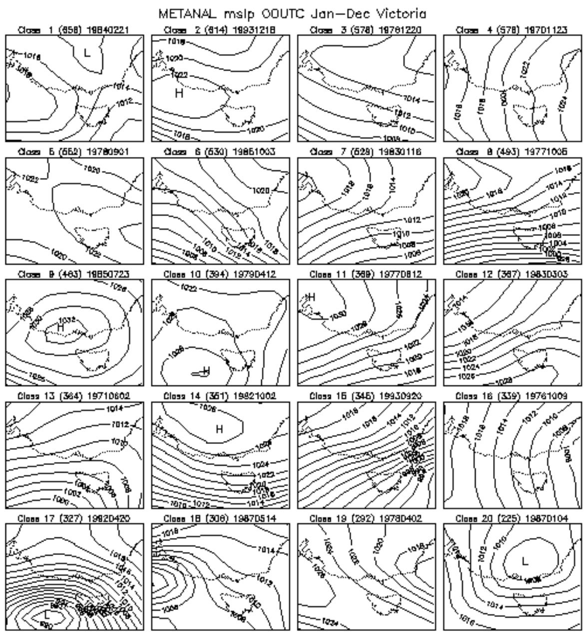

Figure 6 METANAL synoptic types for Victoria

The GUI-based design of the Synoptic Typer allows easy demonstration of the synoptic typing features of the application. The performance of the interactive derivation of synoptic types from the time series of MSLP grids using principal component and cluster analysis techniques is quite impressive, even on modest hardware. This enables the results of different scenarios (e.g. varying the number of principal components or clusters) to be returned immediately.

3.5 Synoptic Type Guidance

The Synoptic Typer accesses real-time NWP model output (analyses and prognoses) from the operational database to automatically classify the output of a variety of NWP models. The methodology to generate the synoptic type guidance is also schematically presented in Figure 7.

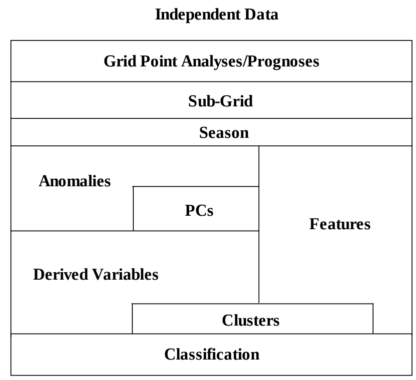

Figure 7 Generation of synoptic type guidance

The Synoptic Typer generates synoptic type guidance for a variety of NWP models in a database friendly format for storage in the Forecast Database. An example of the synoptic type guidance for seven locations throughout Australia generated from the 26/09/2002 00UTC LAPS model run is presented in Figure 8.

STNNUM,	FCST_TIME,	SYNT
086071,	2002092600,	7
086071,	2002092700,	7
086071,	2002092800,	18
066062,	2002092600,	2
066062,	2002092700,	13
066062,	2002092800,	12
040842,	2002092600,	1
040842,	2002092700,	3
040842,	2002092800,	13
014015,	2002092600,	3
014015,	2002092700,	11
014015,	2002092800,	14
009225,	2002092600,	8
009225,	2002092700,	8
009225,	2002092800,	12
023090,	2002092600,	7
023090,	2002092700,	7
023090,	2002092800,	5
094010,	2002092600,	11
094010,	2002092700,	5
094010,	2002092800,	16

Figure 8 Synoptic type guidance

The Synoptic Typer is run on a UNIX server automatically (batch mode) to extract the real-time NWP grids from the operational database, generate the synoptic type guidance, and store it in the Forecast Database. Automatic synoptic type classification is an important element of the MENTOR system (Ryan et al, 2003), the first of the new software applications that utilises the output of the Synoptic Typer.

3.6 *Version 2*

The Synoptic Typer has been subsequently developed using the database of 00UTC, 06UTC, 12UTC and 18UTC MSLP analyses (NCEP grids) covering the period 1 January 1948 to 31 December 2001. An example of the principal component patterns for the Victoria region using the NCEP grids is presented in Figure 9.

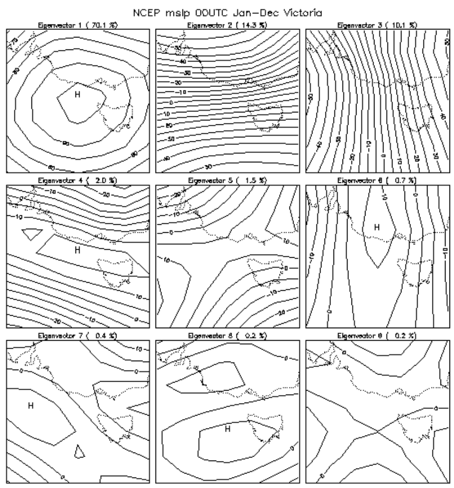

Figure 9 NCEP principal components for Victoria

An example of the synoptic types for the Victoria region using the NCEP grids is presented in Figure 10.

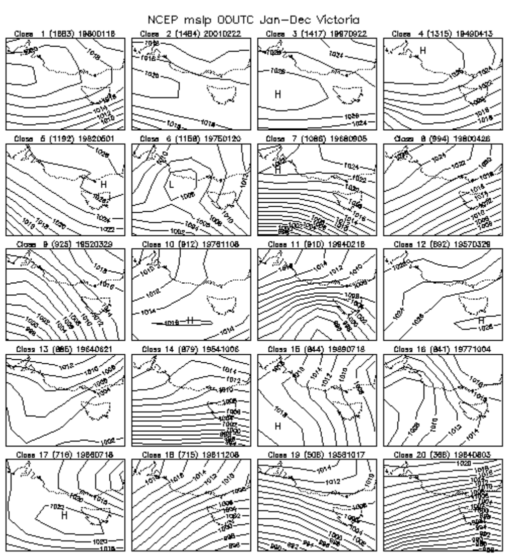

Figure 10 NCEP synoptic types for Victoria

The Synoptic Typer will also use a database of 00UTC and 12UTC MSLP analysis and prognosis grids (from the BoM's archived LAPS grids) covering the period 1 July 1996 to present. The LAPS archive will contain a history of 00UTC and 12UTC analyses for the Australian region at a resolution of 0.75^o over a specific (89.75E-180.5E, 50S-0.25N) geographical region for a variety of fields. The LAPS grid is presented in Figure 11.

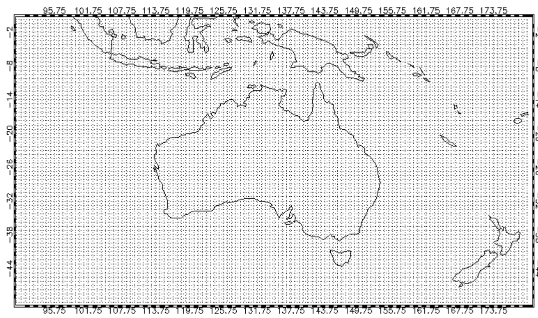

Figure 11 LAPS grid

The LAPS grids will complete the archive of historical and real-time NWP model output, enabling easy independent testing of the synoptic typing methodologies prior to operational implementation.

The synoptic types and NCEP grids are also available for browsing and further manipulation within the new software application Map Browser.

4. MAP BROWSER

Map Browser is an interactive (GUI-based) and non-interactive (batch mode) application that is used to view archived grids (e.g. METANAL and NCEP grids) and synoptic types (e.g. Treloar and Stern, 1993) in the Australian region.

The Map Browser system has been developed on the PC (Windows) using IDL and implemented (cross-platform) in Windows, Linux and UNIX. The Map Browser GUI is presented in Figure 12.

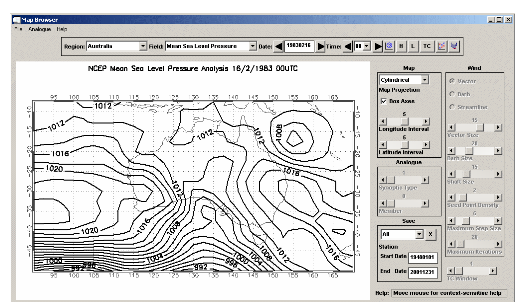

Figure 12 Map Browser GUI

The GUI-based design and cross-platform implementation of the Map Browser allows easy demonstration and investigation of the functionality of the application to promote feedback from both researchers and forecasters. This is essential for the successful, continued development of the system.

The NCEP grids extracted over the Australian region also contain a history of 00UTC, 06UTC, 12UTC and 18UTC analyses for outgoing longwave radiation (OLR) at a resolution of 1.875^{o} x1.905^{o} over a specific (90E-170.625E, 50.4752S-8.5652S) geographical region. The OLR field (despite it being on a different grid to the other NCEP fields) is also available in Map Browser. The NCEP OLR grid is presented in Figure 13.

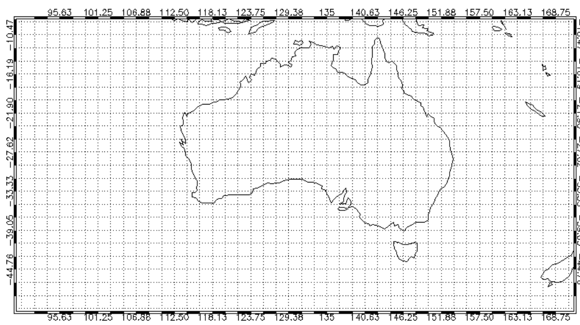

Figure 13 NCEP OLR grid

The synoptic types from the Synoptic Typer are available in Map Browser. Synoptic types from the synoptic classification system for southeastern Australia (Treloar and Stern, 1993) are also available in Map Browser. These synoptic types have been updated using data interpolated from the NCEP grids (Stern, 2003). An example of the mean MSLP field over southeastern Australia calculated from all members of Synoptic Type 39 is presented in Figure 14.

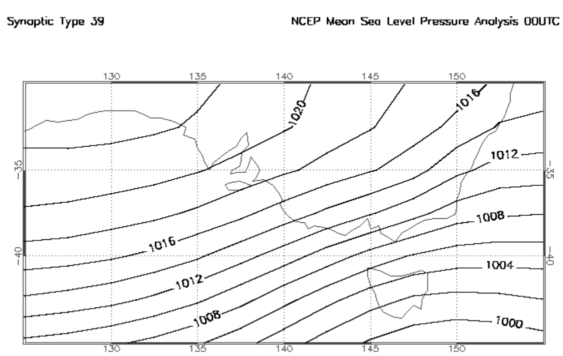

Figure 14 Synoptic Type 39

Map Browser is a valuable application to assist in the interpretation of synoptic types. It continues to be developed as one of the Synoptic Typer suite of tools.

5. EXAMPLE

The value of synoptic types increases through their association with weather variables, particularly significant weather events. Stern et al (1984) presented frequency distributions of weather phenomena, particularly precipitation type, from data associated with synoptic analogues. Elliot et al (2002) produced a Perth Fog Pattern Forecasting web page by relating their subjective synoptic patterns to fog events at Perth Airport.

An example of a useful statistical weather summary associated with synoptic types is presented in Table 1. A frequency analysis of daily rainfall at Launceston Airport (Tasmania) and the Treloar and Stern (1993) synoptic types, updated using the NCEP interpolated data (Stern, 2003), reveal interesting probabilities of occurrence of significant rainfall amounts for particular synoptic types.

Synoptic Type (frequency %)	Daily rainfall > 20mm frequency (%)
39 (8.9)	29.6
37 (5.0)	16.1
41 (4.0)	12.5

Table 1 Significant rainfall and synoptic type

With the capability now to generate synoptic type guidance from the forecast fields of NWP model output, interesting probabilities of occurrence of significant rainfall amounts could be interpreted as forecast probabilities of flood events.

6. FUTURE DEVELOPMENTS

A single data type (i.e. MSLP) has only been used to develop the synoptic typing methods. The Synoptic Typer will be extended to consider multiple input fields.

The Jasper and Stern (1983) correlation method of synoptic typing will also be updated and extended to other locations in the Australia region using data from the NCEP grids. This will enable a comparison with the other synoptic typing methodologies, and add another component (i.e. Synoptic Type Correlate) to the Synoptic Typer suite of tools.

The amount of subsequent work that will be undertaken using synoptic typing will be determined by the successful operational implementation of the various synoptic typing methods, and the results of associating weather variables with synoptic types.

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