6.7 CONCEPTUAL MODELS OF SYNOPTIC-SCALE CYCLONES IN THE NEW ZEALAND – AUSTRALIA AREA

Peter V. Kreft*, Mark A. Schwarz, Gabriele H. Thompson and Christopher S. Webster
Meteorological Service of New Zealand Limited, Wellington, New Zealand

1. INTRODUCTION

This paper discusses a mobile "open wave" cyclone that developed over New Zealand and moved east-southeast into the Southwest Pacific Ocean early in October 2001. While neither the Norwegian nor the Shapiro-Keyser cyclone model described the system perfectly, the cyclone had a deep seclusion of warm air at its centre similar to that described by the Shapiro-Keyser model. However, the secluded air appeared to be of warm sector origin, unlike the example discussed by Neiman and Shapiro in 1993 (hereafter, N93).

Over a few days prior to the event, a large and intense anticyclone moved slowly away to the east of New Zealand. This feature blocked the upstream flow, resulting in the formation of a "graveyard" meridional baroclinic zone and trough over the Tasman Sea – New Zealand area. Cyclogenesis occurred downstream of the upper trough and beneath the equatorward entrance of an anticyclonically curved departing jet, with a second weaker jet entering the equatorward sector of the cyclone later. In terms of the cyclogenesis classes described by Sinclair and Revell in 2000 (hereafter, SR00), this was a "Class E" event.

2. DATA

Besides surface and upper air observations and GMS satellite imagery, this case study used operational numerical analysis data from the 60 km model run by the UK Met Office.

The mean sea level pressure, 850 hPa wet-bulb potential temperature and 1000 hPa geostrophic relative vorticity analyses from this latter data set were compared with those from the AVN model run by the National Centers for Environmental Prediction (NCEP) for 0000 UTC and 1200 UTC throughout the period studied. The models' depictions of synoptic detail were very similar.

For much of the period studied, the cyclone centre was distant from places where conventional observations are made. However, New Zealand – based S1 skill scores of the mean sea level pressure analyses from the 60 km model run by the UK Met Office (not shown) suggest the model analyses were in substantial agreement with observations, thereby providing consistent and reliable detail on the synoptic scale.

3. CYCLONE IDENTIFICATION

Sinclair (1995) describes a method of cyclone identification based on geostrophic relative vorticity ζ_g. This method is well suited to "open wave" cyclones, which can possess large relative vorticity, but which are also very mobile and consequently often do not have many closed isobars. In this study, the centre of the surface cyclone was taken to be the local minimum of model-analysed 1000 hPa ζ_g. There was also a local minimum of mean sea level pressure within about 120 nautical miles southeast of the vorticity centre.

4. SYSTEM-RELATIVE FLOW

The six-hour mean velocity of the 1000 hPa vorticity centre showed little variation throughout the period for which system-relative flow was calculated. For simplicity, therefore, a single 24-hour mean velocity of the 1000 hPa vorticity centre was used in calculations. System-relative flow, as shown by the white arrows in Figure 1, was calculated by subtracting the mean surface cyclone velocity vector from the local wind at a number of levels between the surface and 500 hPa. Two flows are depicted: warm to the east of and encircling the cyclone, with θ_w = 11 to 12º C; and cold to the west and south of the cyclone, with θ_w = 6º C.

5. EVOLUTION

5.1 *Incipient broad baroclinic phase*

Between 0000 UTC and 1200 UTC 06-Oct-01 the cyclone formed west of New Zealand's North Island in a broad and shallow pressure trough, and on the warm side of a baroclinic zone.

5.2 *Frontal fracture phase*

The only significant deepening of the cyclone occurred between 1200 UTC 06-Oct-01 and 0000 UTC 07-Oct-01, with the 1000 hPa ζ_g decreasing from $-12 \times 10^{-5} s^{-1}$ to $-35 \times 10^{-5} s^{-1}$ and the central pressure falling from 1005 hPa to 999 hPa. It is likely that the cyclone redeveloped into the orographic trough east of New Zealand's North Island.

Frontal fracture began during the deepening phase of the cyclone and is evident by 1200 UTC 07-Oct-01 (Figure 1 (a)). Baroclinicity within about 500 km north of the vorticity centre was significantly less than in any other part of the cyclone's frontal system. At this time the warm conveyor belt was split, with one branch turning west into the developing circulation. There was no clear sign of a cold conveyor belt as in, for example, Browning and Mason (1981).

Figure 2(a) shows cross-sections of wind speed and θ_w perpendicular to the bent-back front. The cross-section axis, line A-A' in Figure 1(a), has its eastern end at Chatham Islands, near the centre of a developing seclusion. In this Eulerian frame of reference, the front had a small eastward component of motion and was followed by low-level cold advection. However, the front had the gentle slope characteristic of a warm or quasi-stationary front and there was a system-relative warm flow rearward of the surface cyclone.

5.3 *T-bone and warm seclusion phase*

The cyclone was probably at its peak intensity at 0000 UTC

* *Corresponding author address:* Peter V. Kreft,
Meteorological Service of New Zealand Limited,
30 Salamanca Road, Wellington, New Zealand.
E-mail: peter.kreft@metservice.com

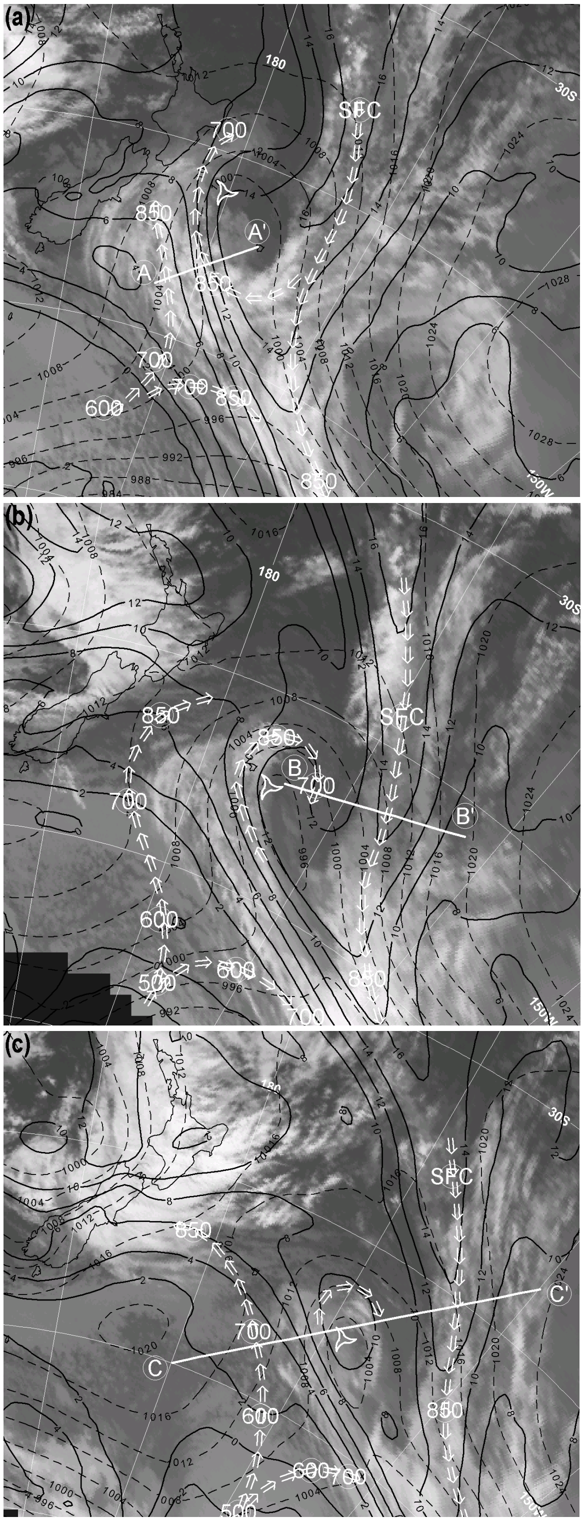

FIG. 1. Operational numerical analyses of 850 hPa θ_w (bold lines) and mean sea level pressure (dashed lines) from the 60 km model run by the UK Met Office, laid over GMS infra-red satellite imagery.
Minimum (most cyclonic) 1000 hPa ζ_g is marked with a vorticity symbol. Lines A-A', etc., are axes along which vertical cross-sections were computed. Open arrows denote system-relative constant-θ_w flows; flow height in hPa is defined by θ_w = 11º C in the warm air and θ_w = 6º C in the cold air.
(a) 1200 UTC 07-Oct-01; (b) 0000 UTC 08-Oct-01; (c) 1200 UTC 08-Oct-01.

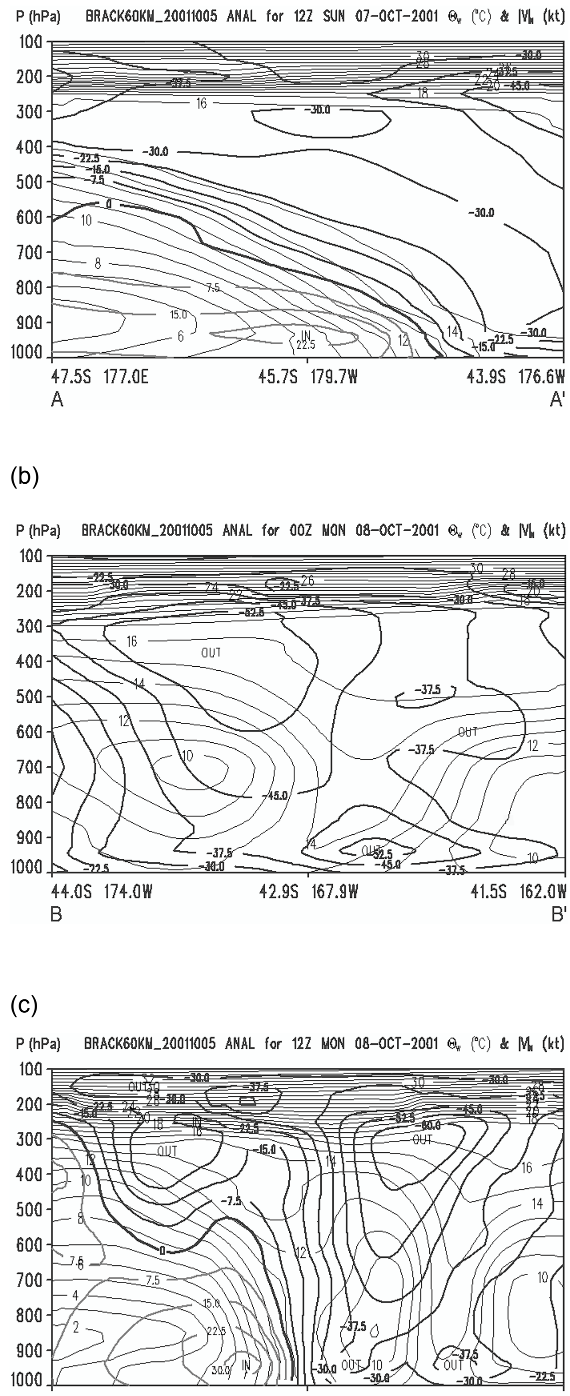

FIG. 2. Vertical cross-sections, using data from the 60 km model run by the UK Met Office, of wet-bulb potential temperature (ºC; thin lines) and wind speed normal to the cross-section (kt; bold lines).
Wind maxima and their directions are marked: "IN" means into the page (isotachs in grey); "OUT" means out of the page.
(a) 1200 UTC 07-Oct-01, along line A-A' in Fig 1(a); (b) 0000 UTC 08-Oct-01, along line B-B' in Fig 1(b); (c) 0000 UTC 08-Oct-01, along line C-C' in Fig 1(c).

07-Oct-01. At both 1200 UTC 07-Oct-01 and 0000 UTC 08-Oct-01, "central" 1000 hPa ζ_g was –28 x 10^{-5} s^{-1}; it became less negative thereafter.

At 0000 UTC 08-Oct-01, the warm air near the vorticity centre was surrounded on three sides by colder air (Figure 1(b)). The baroclinic zone of the bent-back front was broader at this time because of the approach of a mass of cooler air from the southwest.

System-relative flow south of the vorticity centre at 0000 UTC 08-Oct-01 was towards the northwest and of warm origin. Its link with the warm conveyor belt was now broken, suggesting the development of the seclusion was well under way. This contrasts with the post-cold-frontal origin of the seclusion studied in N93. The thermodynamic diagram for Chatham Islands at 0000 UTC 07-Oct-01 (Figure 3; grey trace) confirms that air in the layer from the surface to about 750 hPa was of warm origin, with a wet-bulb potential temperature of at least 11º C. Despite large changes in the low-level wind direction that took place between 0000 UTC 07-Oct-01 and 0000 UTC 08-Oct-01 (not shown), the low-level air mass over Chatham Islands (Figure 3; black trace) changed little.

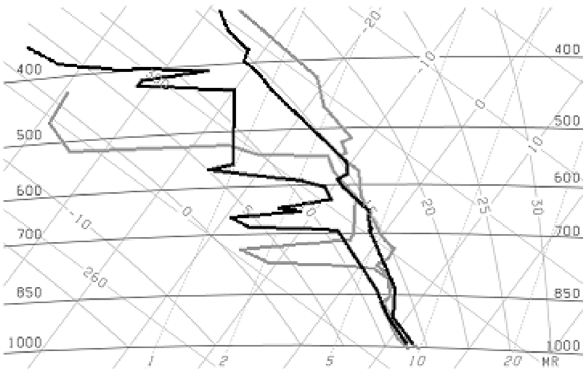

FIG. 3. Chatham Islands tephigrams for 0000 UTC 07-Oct-01 (grey) and 0000 UTC 08-Oct-01 (black).

In the satellite imagery for 0000 UTC 08-Oct-01, the cloud of the cold front can be seen approaching the cloud of the bent-back front at an angle of perhaps 70º. Overall, the cloud system strongly resembled the T-bone structure. However, a curve denoting the leading edge of the cold air assumed a "reverse-S" shape around the cyclone.

Figure 2(b) shows a cross-section perpendicular to the fractured cold front. The cross-section axis, line B-B' in Figure 1(b), has its western end near the centre of the maturing seclusion. West of the warm conveyor belt, baroclinicity is greatest at around 700 hPa and reduces markedly towards the surface.

By 1200 UTC 08-Oct-01, complete seclusion of the cyclone had occurred. The cold and warm system-relative flows were completely separated and a partial θ_w = 11º C "whirl" lay between them. The cold front now had a T-bone shape, with the triple point near 50ºS 157ºW, approximately 800 km southeast of the vorticity centre. This zonal elongation is consistent with SR00's observations of "Class E" cyclones. In 1998, Schultz, Keyser and Bosart (hereafter, SKB98) observed and modelled cases of cyclones which, in an environment of large-scale confluence, evolved in a manner consistent with the Shapiro-Keyser model. In this case, the nature of the large-scale environment as SKB98 describe it, is not entirely clear.

Figure 2(c) shows a cross-section at 1200 UTC 08-Oct-01, approximately perpendicular to the bent-back front, through the centre of the warm seclusion and approximately perpendicular to the fractured cold front. The cross-section axis, line C-C' in Figure 1(c), is analogous to lines A-A' and B-B' joined together. East of the warm seclusion, the coldest air had descended from near 700 hPa to near 850 hPa. The cross-sections in Figures 2(b) and (c), allowing for the difference in horizontal scale, show the warm conveyor belt had become progressively narrower as the cyclone approached seclusion.

6. SUMMARY AND CONCLUSIONS

Arguably, system-relative moist-isentropic analysis is the most powerful way of conceptualising cyclone structure. For this reason, the authors have resisted the temptation to draw fronts in Figure 1.

This cyclone was distinctive for having secluded air of *warm sector* origin at its centre, in contrast to the findings in N93. Consistent with this, the system-relative moist-isentropic analysis revealed a *branching* warm conveyor belt early in the seclusion process.

While the cyclogenesis event itself falls comfortably into the "Class E" class defined in SR00, the authors found the diffluent/confluent environment criteria described in SKB98 hard to apply. Until more case studies are done, it is unknown how effective the criteria in SR00 and SKB98 are in predicting cyclone structure.

7. REFERENCES

Browning, K.A., and Sir J. Mason, 1981: Air motion and precipitation growth in frontal systems. Pure and Applied Geophysics: Vol. 119, no. 3, pp. 577-593.

Neiman, Paul J., M.A. Shapiro, 1993: The Life Cycle of an Extratropical Marine Cyclone. Part I: Frontal-Cyclone Evolution and Thermodynamic Air-Sea Interaction. Monthly Weather Review: Vol. 121, No. 8, pp. 2153–2176.

Shapiro, M.A., and D. Keyser, 1990: Fronts, jet streams and the tropopause. Extratropical Cyclones, The Erik Palmén Memorial Volume, C.W. Newton and E. Holopainen, Eds., Amer. Meteoro. Soc., 167–191.

Schultz, David M., Daniel Keyser, Lance F. Bosart, 1998: The Effect of Large-Scale Flow on Low-Level Frontal Structure and Evolution in Midlatitude Cyclones. Monthly Weather Review: Vol. 126, No. 7, pp. 1767–1791.

Sinclair, Mark R., 1995: A Climatology of Cyclogenesis for the Southern Hemisphere. Monthly Weather Review: Vol. 123, No. 6, pp. 1601–1619.

Sinclair, Mark R., Michael J. Revell, 2000: Classification and Composite Diagnosis of Extratropical Cyclogenesis Events in the Southwest Pacific. Monthly Weather Review: Vol. 128, No. 4, pp. 1089–1105.