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TIROS VI PICTURE OF 'FISH-BONE' CLOUD PATTERN

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Abstract: TIROS VI on picture taking orbit 465 at 0721Z 20 October 1962 obtained a picture of an unusual 'fish-bone' cloud pattern at 23°S 120°E (Fig. 1). Although the scope of the analysis was restricted by the rather sparse conventional data available in this region of Western Australia, it is concluded that conditions favoured the formation of Haurwitz billow cloud rolls lying approximately normal to the wind shear in an inversion layer. The wavelength is however much greater than that computed by theory.

1. METEOROLOGICAL SITUATION

The wind field in the vicinity of 23°S 120°E at 0800Z 20 October 1962, can be seen from the 0500Z and 0800Z charts (Fig. 2a, 2b) and from winds (Fig. 3) reported from Onslow (305), Port Hedland (312) and Meekatharra (430). These indicated a S'SW wind flow to a depth of 5000 ft at 2300Z on the morning of the satellite observation and persisted through 0500Z and 1100Z on the 20th at the first two stations. This low-level flow veered to W'NW briefly at Meekatharra in advance of a cold front as shown by the 0500Z winds at that station. The 1100Z winds here showed the stronger post-frontal southwest winds with shear through the frontal inversion layer between 5,000 and 10,000 ft.

In the warm air the low-level S'SW wind flow described above was overlain by warmer NW flow above 7,000 ft at all three stations. Port Hedland (20.5°S 118.5°E) is the nearest radiosonde station to 23°S 120°E but no sounding was available for 20 October. However, the sounding (Fig. 4) for Carnarvon (25°S 114°E) for the preceding day was considered representative of the conditions over the area of interest. It indicates a stable layer in the warm air at 5,000 to 7,000 ft, representing the boundary surface of density discontinuity due to the different wind trajectories above and below this layer. The cold front was penetrated by the Carnarvon sounding of 2300Z 19 October at about 700 mb (Fig. 5). It was identified also by surface observations and wind shears - Meekatharra winds 1100Z (Fig. 3) - and from the satellite nephanalyses (Fig. 6) on frame 10 (Fig. 1) it appears as the broken cloud band in the bottom left-hand corner. Upper level charts showed that this frontal trough merged into a pre-existing major trough. The small isallobaric falls which preceded the front, together with only slight cooling of the warm air above the frontal inversion indicated that no marked divergence and ascent of the warm air occurred in advance of the front. Thus it is reasonable to assume that the inversion was able to persist, although possibly weaker and at higher level, within the warm air over the 'fish-bone' cloud area. Further factors tending to maintain the inversion in the warm air are the gradual frontolysis in an unfavourable field of motion of the warm air at low levels and the moisture gradient in the warm air with lower values inland.

2. THEORY OF FORMATION OF BILLOW CLOUDS

Assuming the validity of the reasoning in the previous section, the warm air in the vicinity of 23°S 120°E on 20 October was characterised by,

(a) an inversion between 5,000 ft and 10,000 ft,

(b) a wind shear in this layer between southwest winds at low levels and northwest winds aloft.

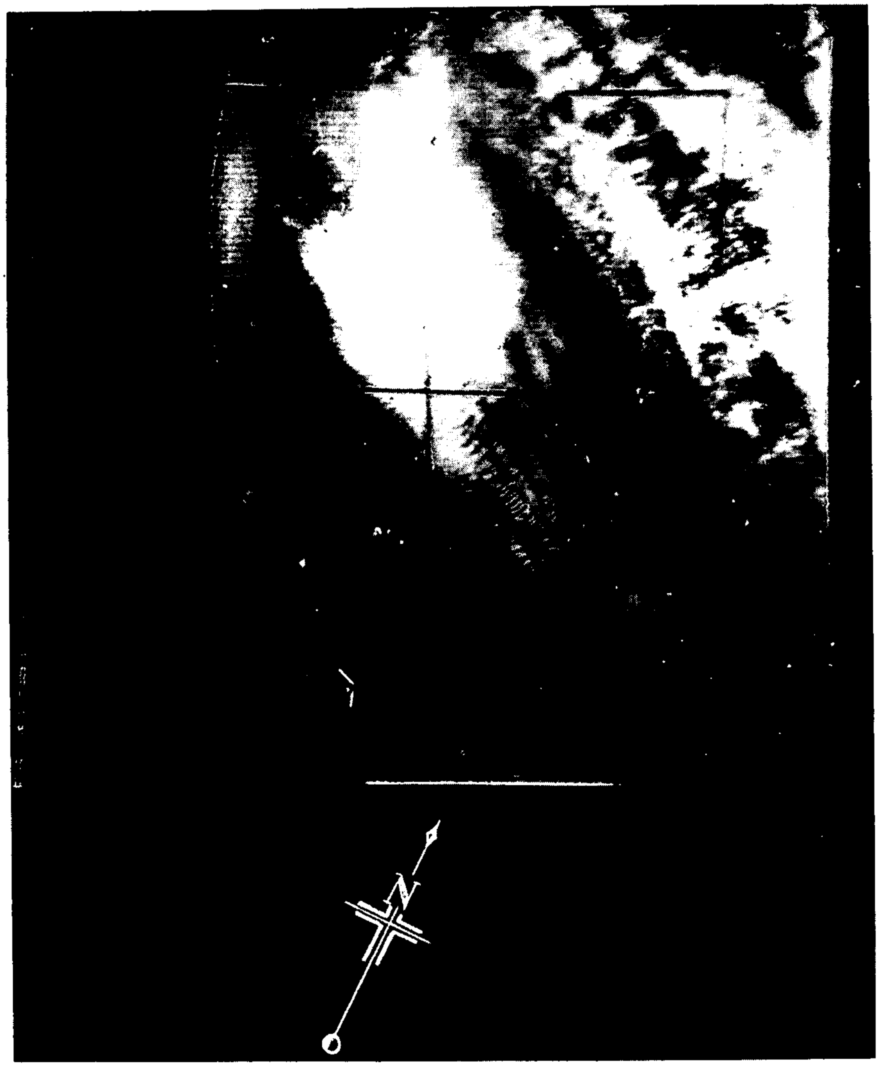

Fig. 1 Tiros $\overline{\underline{VI}}$ picture of 'fish-bone' cloud pattern at 23° S 120° E

[Orbit 465 20 October 1962]

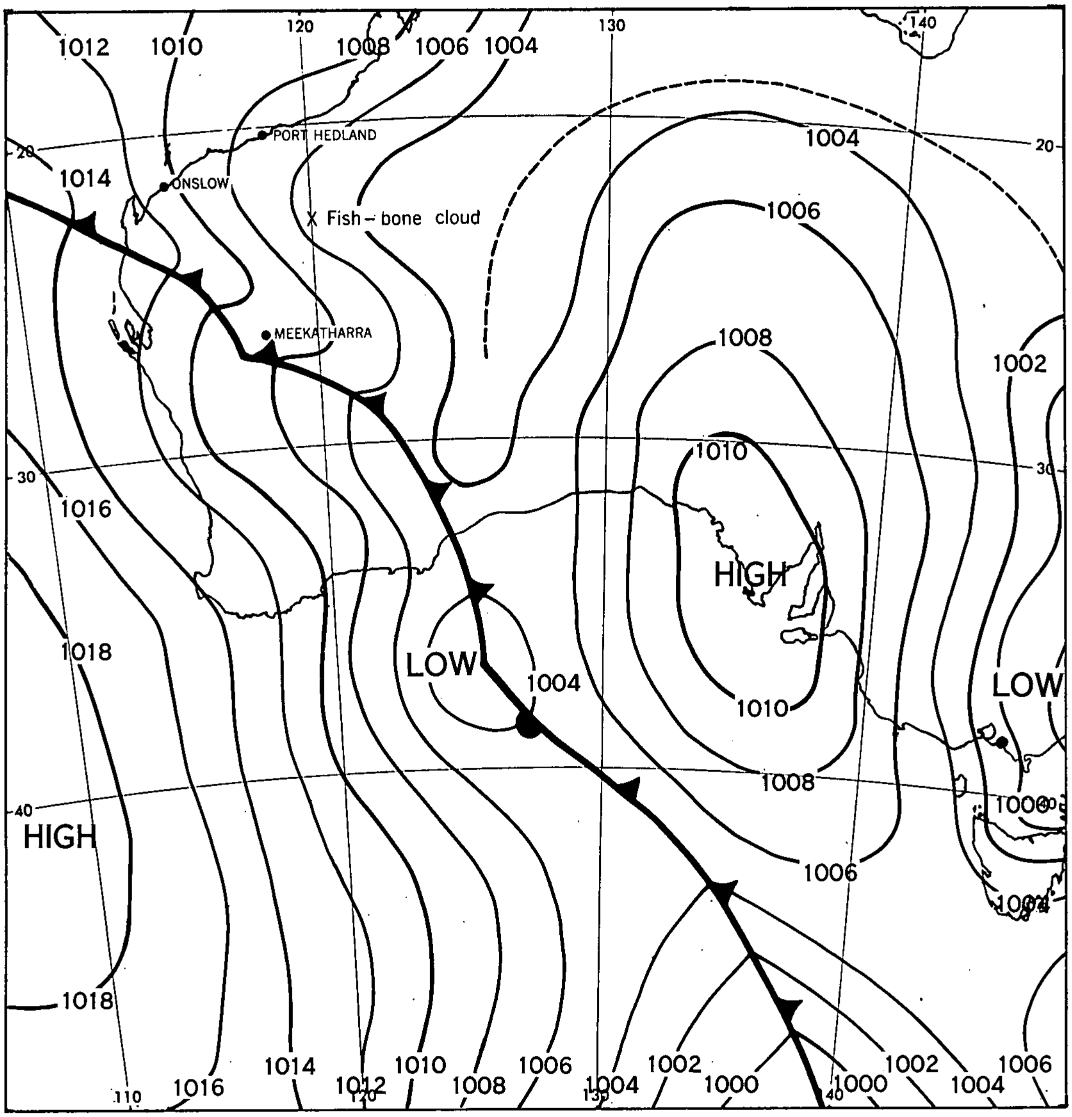

Fig. 2 [a] Mean sea level chart 0500 GMT 20 October 1962.

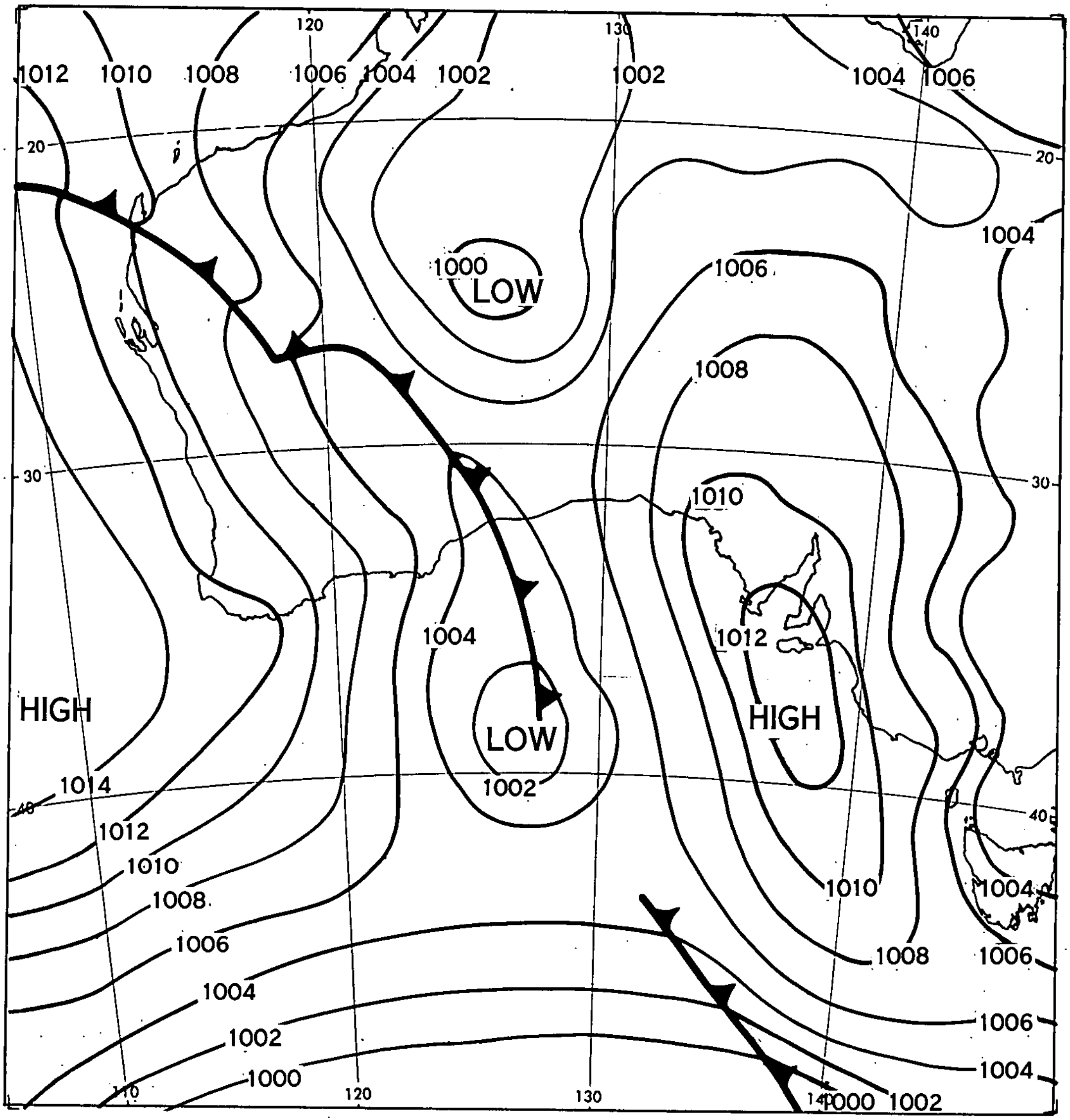

Fig. 2 [b] Mean sea level chart 0800 GMT 20 October 1962.

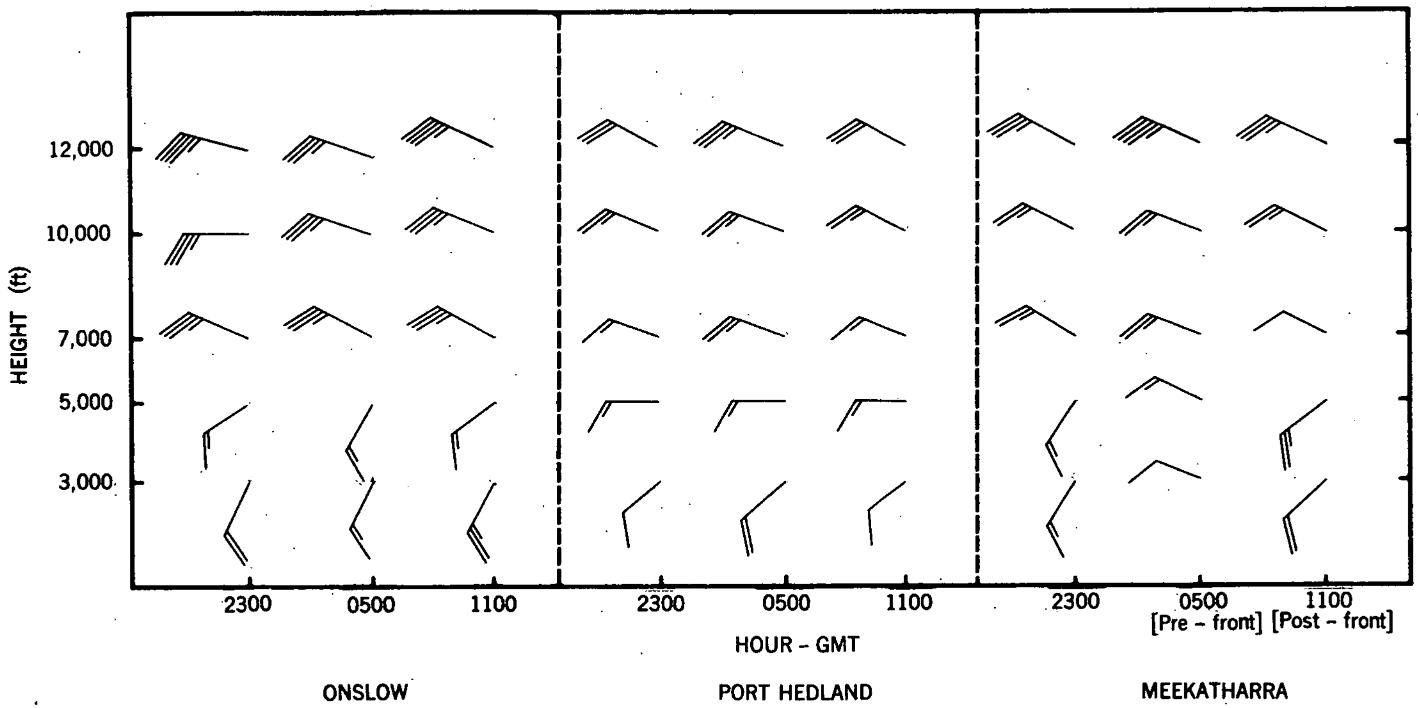

Fig. 3 Upper winds in vicinity of fish - bone cloud pattern.

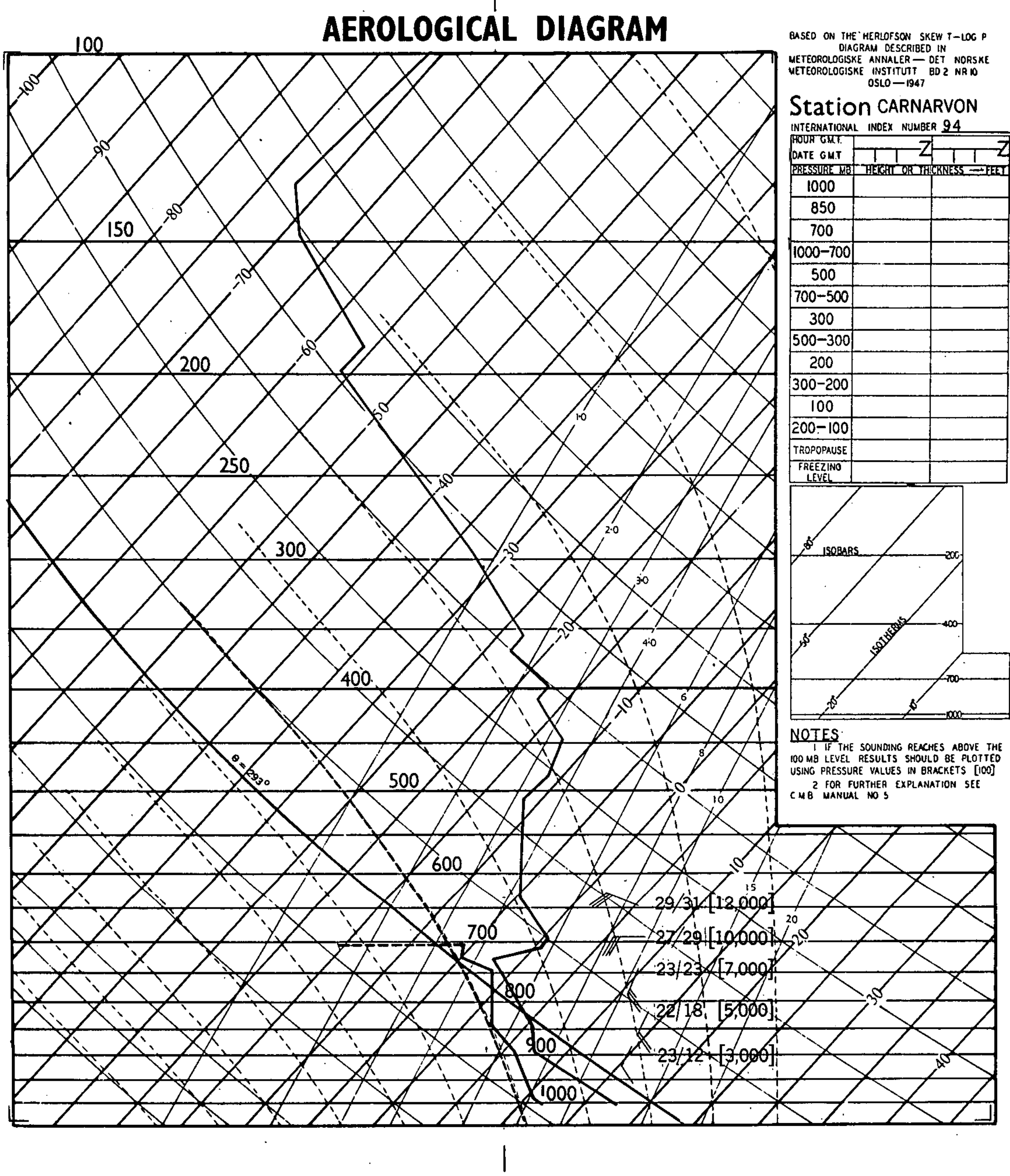

Fig. 5 Carnarvon sounding 2300 GMT, 19 October 1962 showing frontal inversion near 700 mb.

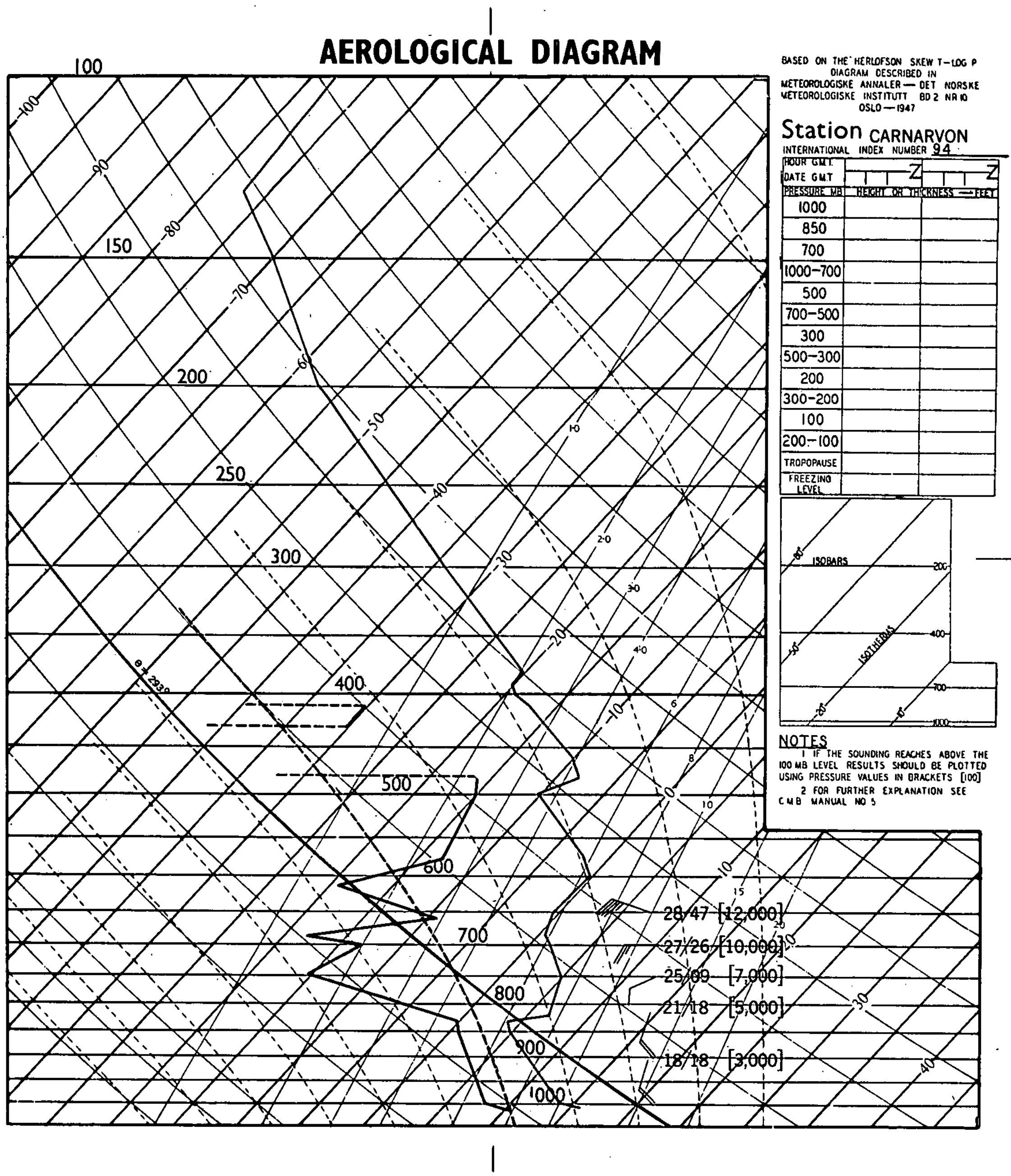

Fig. 4 Carnarvon sounding 2300 GMT, 18 October 1962 with inversion due to overlying westerlies.

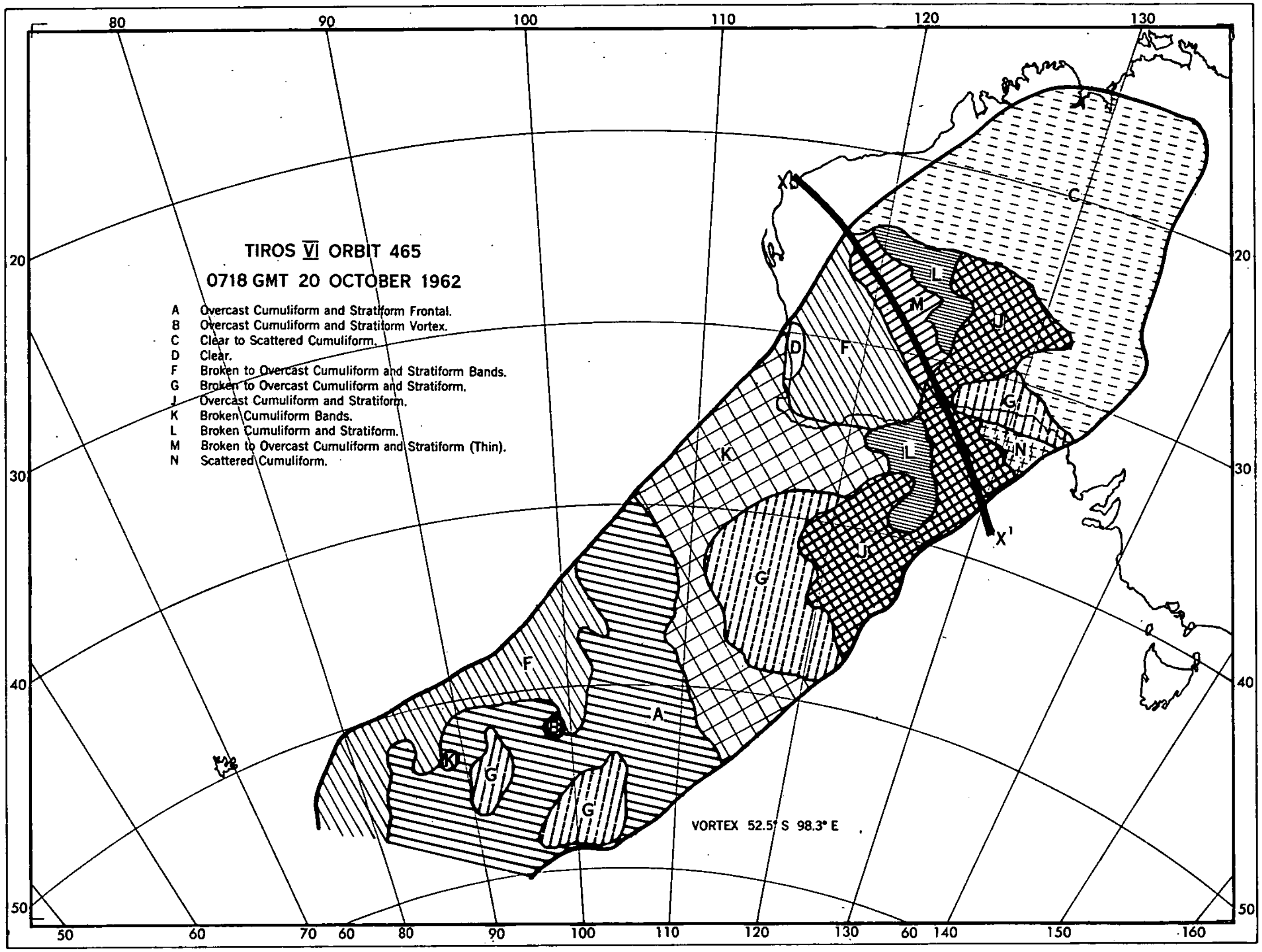

Fig. 6 Nephanalylisis corresponding to Figs. 1, 2[a] and 2[b]. Broken to overcast cumuliform cloud along X—X' corresponds to front and overcast cloud 'J' to trough in easterlies.

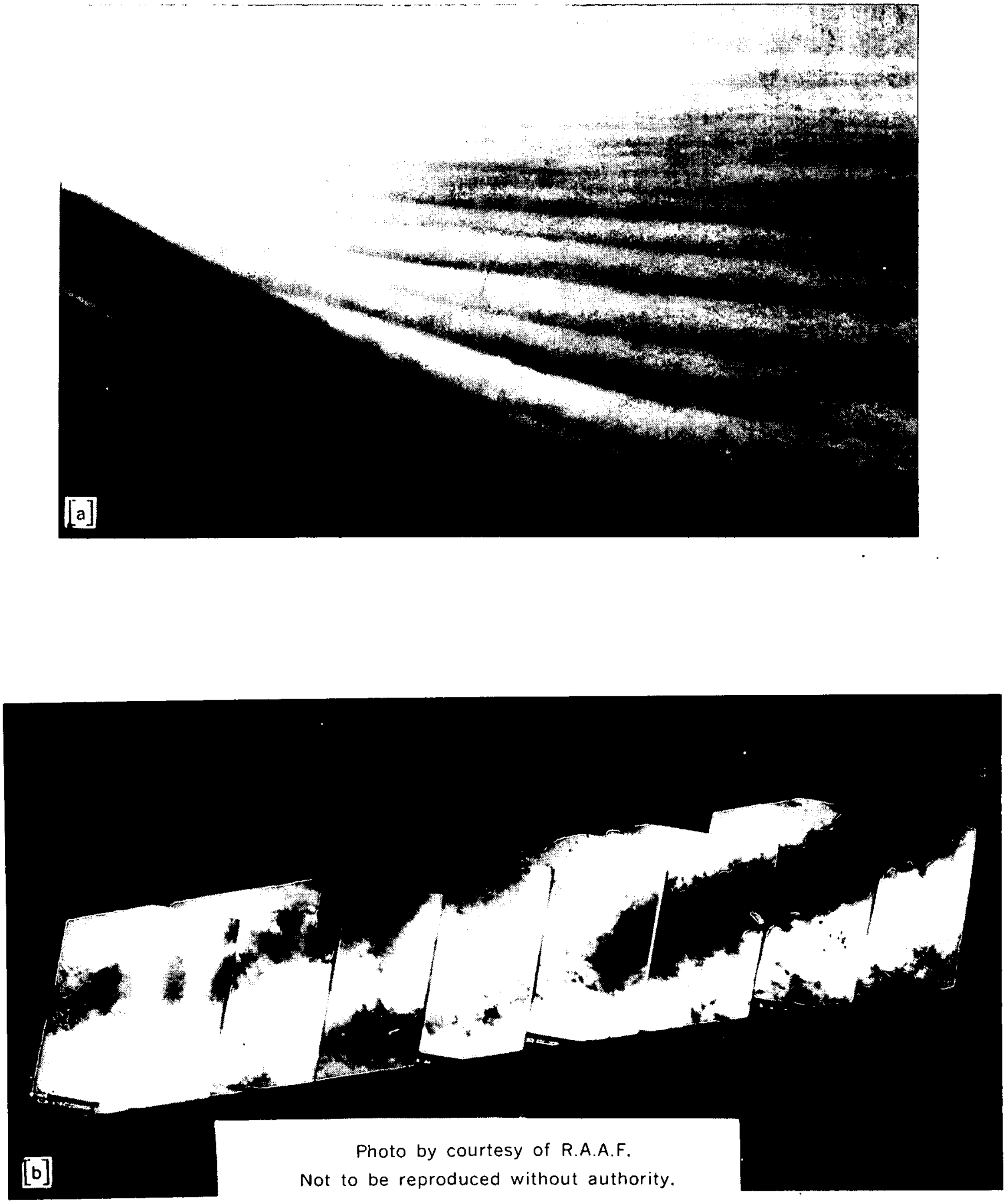

Fig. 7 Billow clouds over S.E. Australia 9 August 1961 photographed from 40,000 ft [a] to starboard [b] vertically below the aircraft.

These are conditions which support Haurwitz's theory (1949) for formation of billow cloud rolls or streets. According to this theory such a pattern tends to form at the boundary surface of a density discontinuity with billows preferably normal to the wind vector shear across the boundary. The cloud elements should have restricted vertical development.

Conventional ground station observations at 0800Z 20 October were available from only eight stations in an area of about 10^5 square miles. These indicated mainly clear skies but one station reported broken middle cloud with scattered Sc at 5, 000 ft. In the satellite picture the elements of cloud comprising the 'fish-bone' pattern appear less bright and may be of smaller vertical development than the broken to overcast brighter cloud mass into which they merge to the southeast. This is, however, not conclusive, since relative brightness is a very crude criterion of cloud thickness. The brighter overcast mass is probably associated with the trough extending southward along meridian 125°E, where large cumuliform cloud and broken Ac As are reported (Fig. 2).

The frame (Fig. 1) can be orientated approximately by alignment of the frontal cloud along the NW/SE direction corresponding to the synoptic analysis (Fig. 2) or nephanalysis (Fig. 6). The billows are then approximately normal to this direction, i. e. NE/SW. The shears through the warm air inversion at Carnarvon, Port Hedland and Meekatharra as measured from wind soundings are 310/28 kt, 300/25 kt, and 290/25 kt respectively, i. e. approximately normal to the billow orientation. Thus the Haurwitz requirements of inversion and wind shear normal to cloud direction appear to be satisfied for billow clouds of limited vertical development as indicated in the satellite frame.

This cloud formation appears to be similar in origin and appearance to a pattern noted in a photograph taken from a Canberra aircraft at 40, 000 ft in August 1961 during a TIROS III interpretation exercise (Fig. 7). On that occasion the TIROS picture taken $1\frac{1}{2}$ hours after the aircraft observation did not reveal the billow formation although the wavelength or size of the cloud elements and their proximity to the principal point was such as to be within the resolution threshold of the satellite camera system. It was concluded that an approaching vigorous cold front had destroyed the inversion conditions required for its formation prior to satellite camera time.

Haurwitz has formulated an equation for the wavelength, L_∞, of rows of infinite lateral extent, viz:-

$$L_\infty = \frac{\pi (\Delta U)^2 \bar{T}/g}{\left(\Delta T^2 + \frac{(\Delta U)^2 \bar{T} (\Gamma - \gamma)}{g}\right)^{\frac{1}{2}}}$$

where ΔU = speed shear across the inversion,

$\bar{T}$ = mean absolute temperature above and below the inversion,

ΔT = temperature difference across the inversion,

Γ = adiabatic lapse rate,

γ = lapse rate of atmosphere, assumed equal above and below the inversion.

The Carnarvon sounding at 2300Z 18 October and mean of wind shears at the three upper wind stations gave values as under:-

ΔU = 12 m sec^{-1}

$\bar{T}$ = 273°K (measured over layers 150 mb thick above and below the inversion),

ΔT = 3°C,

γ = 0.5°C per 100 m (measured as mean of the lapse rates above and below the inversion).

L_{∞} was approximately 2100 m or 1.3 mi.

For waves of finite lateral extent as in the 'fish-bone' patterns,

$$L = \frac{L_{\infty}}{\left(1 + \frac{L^2}{\lambda^2}\right)^{\frac{1}{2}}}$$

where L = wavelength of finite waves

λ = lateral spacing between the cells.

λ appears close to the limits of resolution of the wide angle camera (see Fig. 1) and may be evaluated as 1 mi or 1.5 mi under the favourable conditions near the principal point. With this assumption L was found to be approximately 1 mi, which appears to be considerably less than the wavelength of the pattern estimated at 5 to 10 mi. These estimations are only approximate, since L and λ could not be measured from the pattern in the absence of a latitude/longitude grid.

A similar disparity between observed and computed wavelengths has been noted by Whitney (1961). He has suggested that suppression of some cloud rows has occurred as noted by Riehl et al. (1959) and Conover (1959). Billow clouds rarely are observed to have longer wavelengths than about 2,000 m. This would in many cases be less than the raster-line width of the satellite camera systems, and the billow formations would not be resolvable but appear as a diffuse overcast.

ACKNOWLEDGEMENT

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