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DUST FROM AUSTRALIA — A REAPPRAISAL

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Abstract

This paper reviews the meteorological events of October 1928 associated with severe duststorms in Australia and subsequent transport of dust to New Zealand. In the light of contemporary knowledge of the jet streams, and from reappraisal of the original synoptic charts, reported meteorological conditions and press reports pertaining to these duststorms, it is postulated that for dust to be deposited upon New Zealand within 24 hours of duststorms in Australia it presumably travelled via the jet stream region of the middle and upper troposphere.

INTRODUCTION

Visual fall of dust over New Zealand is a rare phenomenon. Between 6th-9th October, 1928, falls of red-brown dust were observed over an extensive part of the country. The samples collected were analysed by Marshall (1929) and showed a high degree of similarity. In size few particles were larger than 4 microns (i.e. clay size), and all grains were tinted by red-brown iron oxides. According to Marshall (1929) the dust samples were "quite distinct from New Zealand material" and were presumably of Australian origin.

The period between the 30th September and 10th October, 1928, was remarkable for the very disturbed weather prevailing over southeastern Australia, the Tasman Sea and New Zealand. Severe gales were of almost daily occurrence. It was in these circumstances that large amounts of dust were transported from Australia to New Zealand.

The following discussion reviews Kidson's (1929) report of the meteorological conditions associated with the transport of this dust, and the pattern of dust deposition in New Zealand. In the light of current knowledge, certain inconsistencies evident in Kidson's explanation of the transport of dust are pointed out. On the basis of contemporary knowledge of jet stream patterns over this area, it is postulated that for the dust to have arrived in New Zealand within 24 hours of duststorms in Australia, a certain amount of dust travelled within the jet stream region of the middle and upper troposphere. Accordingly a mechanism for the transport of dust in this manner is suggested.

METEOROLOGICAL CONDITIONS ASSOCIATED WITH THE TRANSPORT OF DUST DURING OCTOBER 1928

The weather conditions associated with the transport of dust have been summarised in Table 1, and Figure 1. Information contained in the table was obtained from perusal of the original meteorological archive charts and accompanying press reports held by the Commonwealth Bureau of Meteorology in Melbourne.

In summary, there were 3 major periods of unsettled dust movement.

	Meteorological Conditions	Reports of Dust Storms in Australia
Tuesday 2nd October	According to the Sydney Meteorological office, all S.E. Australia was within the scope of an intense cyclone (A) "- the biggest for a long time -" centred off the western entrance to Bass Strait. Severe S.W. gales blew over South Australia and western New South Wales. Local conditions caused willy-willies.	Severe dust storms were reported in western and northern South Australia, southwestern Queensland and western New South Wales (Broken Hill).
Wednesday 3rd	The cyclone had moved to the east of Bass Strait and was still very intense. Strong and squally S to SW winds blew over eastern South Australia, western New South Wales and Victoria.	In the early afternoon Brisbane and surrounding districts became completely mantled in thick yellow dust. Visibility was limited to within 1 mile. This could not be termed a dust "storm". It was attributed to dust from the interior being carried in the lower atmosphere by the general westerly drift over subtropical Queensland. Notably dust was grey coloured at Gympie but yellow at Brisbane and Southport. The thick smothering dust was also reported as enveloping Kandanga, Kolroy, Eumondi, Esk, and Wallangara - all in S.W. Queensland.
Thursday 4th	Pressure rose over the south Tasman Sea but rough weather was still general between Tasmania and New Zealand with the cyclone still centred in the south Tasman Sea. A series of low pressure systems over the southern oceans gave unsettled weather to the southern states although winds had generally decreased over S.E. Australia. An anticyclone formed over Queensland.	A few dust storms were reported again over the southern states.
Friday 5th	By morning a secondary depression (B) had developed in the rear of the cyclone (A) (whose centre had now moved southward). An associated low pressure trough was over South Australia. Beaufort force 6-8 (35-49 mph) N.W. winds prevailed over central and S.E. Australia and the Tasman Sea.	Scattered dust storms reported in southern Queensland. The situation was considered by Kidson to be ideal for the transport of air from the interior of Australia to New Zealand.
Saturday 6th	Pressures remained very low in the south. Winds over S.E. Australia were squally and stronger than on the 5th. Strong W-NW gales blew over the Tasman Sea.	Dust storms again reported severe and widespread over Central and S.E. Australia. Kidson assumes but quotes no evidence of the main dust deposit travelling across the central Tasman Sea.
Sunday 7th	A new cyclone centre (C) formed near Hobart. Conditions over S.E. Australia remained squally. Winds remained N.W. from Australia to New Zealand.	"Great volumes" of dust reported in S.E. Australia, especially Victoria, New South Wales and Queensland. Severe dust storms were reported at Canberra and Sydney throughout the day, generally in association with very high winds, and followed by rain (as at Finley, Doake and Millewa in western New South Wales). Notably this dust was red and appeared to originate from the Mallee-Wimmera-Riverina region. At Yallourn in Victoria "red rain" fell.
Monday 8th	N.W.-W. gales reached their greatest intensity over New Zealand, especially in the South Island. Rain falling in New Zealand contained dust.	Conditions in Australia ameliorated.
Tuesday 9th	Conditions improved in Australia, but remained stormy over New Zealand, the North Island now experiencing the strongest gales.	

In the first period violent duststorms occurred over South Australia, and western Victoria on Friday 28th September. Resulting from a strong flow of tropical air traceable from Darwin to Bass Strait, temperatures in southeastern Australia were raised (giving Melbourne a September record 88.6° F. and Adelaide 90.2° F.). These strong northerly winds, which occurred after a long dry spell, caused the first phase of severe duststorms. According to the press reports, the heaviest duststorms occurred in the Wimmera-Mallee-Riverina region of the Murray Basin. Following this day of severe dust blowing, the passage of a deep trough of low pressure and associated front during the weekend (29th, 30th September) caused very heavy rain over southeastern Australia — the first for several weeks. [At this time (1929) methods of frontal analysis had not been implemented into operational practice in Australia or New Zealand (Kidson, 1935; Kidson and Holmboe, 1935) although the concept had previously been outlined by Kidson (1924).]

The second period of duststorms occurred during Tuesday 2nd October and the morning of Wednesday 3rd (Table 1). At this time severe gales lashed Victoria and South Australia causing structural damage in many areas. The accompanying duststorms, often occurring as local "willy-willies", appear to have been caused by the very strong gusty and squally winds in the wake of the cyclone (and associated fast moving front) which moved through Bass Strait. After passage of the rapidly moving front, dust was (apparently) left suspended in the lower troposphere over the northeastern Murray Basin. On the afternoon of October 3rd it wafted in over southern Queensland and Brisbane on remarkable

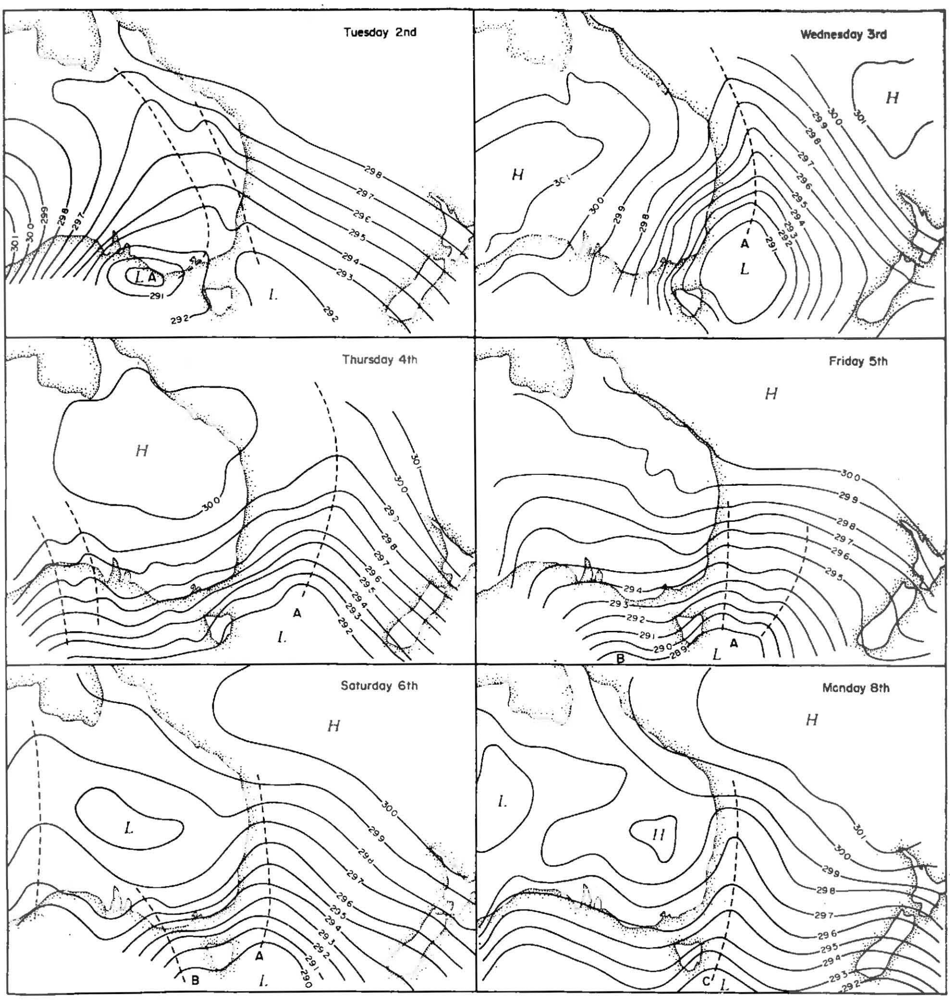

Figure 1. Daily weather charts for 2-8 October, 1928. (Extracted from archive charts held by the Commonwealth Bureau of Meteorology, Melbourne.)

mild southwesterly winds forerunning an anticyclone (Figure 1). According to the Brisbane *Mail* the envelopment of Brisbane and surrounds by this dust "could in no way be called a duststorm . . . " For this situation the term "dust fog" (Loewe, 1943) seems appropriate.

A third period of vicious duststorms occurred from late Friday 5th; increasing in intensity during Saturday 6th and Sunday 7th (Table 1). From the press reports it appeared that the major portion of this dust originated from the Wimmera-Malee-Riverina areas of the Murray Basin. Scattered duststorms also occurred in central Australia and southern Queensland on the Friday. These duststorms appear to have been caused by the strong northwesterly winds preceding the passage of a deep trough of low pressure and front extending from an intense depression to the south of the continent (Figure 1). The front moved across southeastern Australia during the night of the 5th and morning of the 6th. Severe gusty winds following passage of the front again caused severe duststorms on the 6th and 7th over southeastern Australia (Table 1).

DEPOSITION AND REPORTS OF DUST IN NEW ZEALAND

The principal deposit of dust fell on south Canterbury, Otago and Southland on the afternoon (3 - 4 p.m.) of the 6th October. Falls in Central Otago and Southland were "extraordinarily heavy". Further falls occurred during that night. On the early morning of the 7th falls were first recorded in northern Westland (Greymouth). "All this dust appears to have been associated with the same air mass or storm" (Kidson, 1929; p. 298).

A similar deposit, though of a lesser intensity, was recorded by stations in central New Zealand on the 8th. This deposit was heavy in parts of South Taranaki and the Manawatu, but otherwise fairly light, and decreased in intensity northwards.

Three other points concerning the dust in New Zealand are pertinent (Figure 2) :

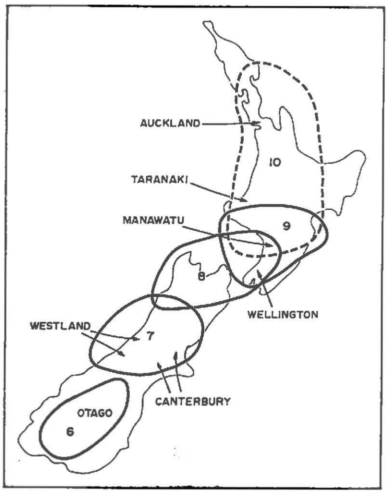

Figure 2. Major zones of atmospheric dust activity over New Zealand from 6-10 October, 1928. The dotted line indicates high level haze only; the solid line indicates deposition of dust. [Based on Kidson (1929).]

(i) The zone of greatest atmospheric dust concentraction moved northward from Central Otago and Southland on the 6th, to central districts on the 7th. Dust was observed by more northern stations (in the southern and central North Island) on the 8th and 9th, and in the north of the North Island on the 10th.

(ii) The intensity of dust deposition decreased from south to north. Falls in Central Otago on the 6th were "extraordinarily heavy". However, falls in the central districts of the country were somewhat lighter. Apparently no deposits were recorded in the northern part of the North Island although dust was seen in the air, on the 9th. Although northern part of the North Island indicate that considerable quantities of no dust was actually recorded on the 10th, the very hazy conditions in the atmospheric dust were present.

(iii) A remarkable feature of the period was the number of thunderstorms recorded. In accordance with the patterns of atmospheric dust concentration and intensity of dust deposition over this period the zone of highest frequency of thunderstorm occurrence moved up the country from south to north. In this, the pattern of thunderstorm activity also resembled that of the gale winds. The thunderstorms, in many places remarkably severe, were almost certainly associated with the presence of dust in the atmosphere (Kidson, 1929).

Kidson's Explanation of the Dust Transportation to New Zealand

From 2nd - 8th duststorms and reports of dust haze were numerous and severe over southern central and eastern Australia. At the same time "it is clear that the high winds and dry conditions led to an unusual quantity of dust being raised into the air, while the strong convection currents carried it to great heights . . . much of this dust would be carried northwards into the interior of Australia" (Kidson, 1929; p. 293). There was, Kidson felt, a continual accumulation of dust in the atmosphere over the regions of the interior, where light winds prevailed.

On the 4th October cyclone (A) (Figure 1) was centred in the south Tasman Sea. Winds from Central Australia to New Zealand were westerly to north-westerly and "it is probable that some of the dust commenced its journey to New Zealand during the day" (Kidson, 1929). By the morning of the 5th conditions were ideal for the transport of air from the interior of Australia to New Zealand . . . "The dust that fell on the South Island from the afternoon of the 6th to the morning of the 7th was now well on its way" (Kidson, 1929; p. 293). The speed probably varied from 25 - 40 miles per hour.

Deposition of dust in Southland, Otago and Westland appears to have been associated with the same general air mass and storm. The dust deposit recorded by the more northerly Stations was evidently brought in by a separate air mass and by a different storm.

Kidson felt that southern and central Australia as well as Queensland and New South Wales contributed significantly to the supply of dust, and that the large amount of aerosol matter in the atmosphere at the time could only have been maintained by replenishment during the course of several days.

Some Puzzling Aspects of Kidson's Explanation

Kidson is not explicit on the exact mode of dust transportation from Australia to New Zealand. Initially he suggested that dust accumulation at high levels over Central Australia contributed to dust deposits experienced in New Zealand. However, his later observations indicate that massive volumes of dust moved from eastern Australia across the Tasman Sea to New Zealand *at substantially lower levels.* For instance he comments that on October 6th, heavy rain-type clouds passed over Sydney and that "many coastal stations observed dust clouds passing out to sea" (Kidson, 1929; p. 299). That much dust was incorporated in heavy rain clouds is evidenced in the reports that "red rain" fell at Yallourn (Victoria) while on October 7th great volumes of dust from inland districts were smothering Sydney causing extremely poor visibility.

There are two reports of this dust at sea. The steamer *Hatkhola* which arrived at Newcastle on Tuesday, October 9th, was reported in the Melbourne *Age* as encountering a duststorm 200 miles from port. Similarly the schooner *Margaret W* (according to the Sydney *Herald*) arrived at Sydney on Wednesday, October 10th, having observed thick red dust clouds 400 miles from the Australian coast. Obviously the reports refer to the same dust cloud which both vessels would have encountered on Monday, October 8th — *not* on Friday, October 5th as presumed by Kidson (1929). This dust would appear to be related to the most violent storms and dust raising which occurred over southeastern Australia on Sunday, October 7th.

Significantly, no such dust clouds were reported advancing on New Zealand from the Tasman Sea. Indeed it seems unlikely that dense low level dust clouds could persist for the duration of a Tasman crossing without either dispersing, settling upon, or being precipitated into the sea.

Perhaps more anomalous is the relationship between the time of most severe duststorms in Australia — October 7th — and the most intense deposit of dust in New Zealand — on October 6th !

Other remarkable features are :

(i) Dust deposits were reported in South Canterbury, Otago and Southland on the 6th whereas they were not reported as being deposited in Westland until the 7th.

(ii) Dust was deposited without rain at Napier and Taihape (in the central North Island), but was apparently precipitated within rain in Taranaki and Manawatu, and in the South Island.

(iii) As noted by Kidson, it is remarkable that dust should have been so locally concentrated in the atmosphere after the 1600 to 1800 mile journey from Australia.

A POSSIBLE MECHANISM FOR THE TRANSPORT OF DUST TO NEW ZEALAND

Of the three major periods of duststorms in southeastern Australia, it is felt by the writer that the third probably accounted for the principal dust deposition over New Zealand.

First reports of severe dust blowing were on Friday, September 28; eight days prior to dust being observed in New Zealand. It is unlikely that this dust took eight days to traverse the Tasman Sea, without being observed, and was then precipitated over a localised area in New Zealand. Nevertheless, it is possible that some of this dust was raised into the stratosphere by a mechanism of strong vertical motions accompanying the passage of fast-moving cold fronts (Sutton, 1931; Loewe, 1944; Sawyer, 1956; Eliassen, 1960; Reiter, 1963) and/or by vertical circulations associated with the tropopause discontinuity and baroclinic zone in the region of the jet-stream (Arakawa, 1951; Lee, 1956; Newell, 1963). That much dust did at some stage actually enter the upper troposphere and stratosphere is shown by the widespread upper level dust haze observed over northern New Zealand on October 8, 9 and 10. However, it appears that much of this dust was confined to the troposphere, for dust haze was removed by thunderstorms (Kidson, 1929). Dust injected into the stratosphere would certainly have contributed to the brilliantly colourful sunsets observed in the region during the following months (Kidson, 1930).

It is unlikely, as envisaged by Kidson (1929), that dust from this first period of storms was raised to high levels forming a concentrated reservoir of continual dust accumulation. Significantly these upper tropospheric and lower stratosphere levels over the interior of Australia are influenced by the quasi-permanent subtropical jet-stream and occasionally by an incursive mid-latitude jet. Although Kidson's hypothesis as stated appears unlikely, it is possible that dust may become trapped in certain layers of the atmosphere. As shown by Weinert (1967) volcanic dust from the eruption of Mt. Agung, Bali, in March 1963, apparently became suspended in a zone of atmospheric calm between the tropospheric westerlies and the stratospheric easterlies. This seemed to be the only explanation of the month-long traverse of concentrated high-level dust haze across Australia after the Bali eruption (Weinert, 1967). It is thus possible that the first period of duststorms contributed to high-level haze observed over northern New Zealand on October 8, 9, and 10, 1928. Some larger dust particles (about

8 microns diameter), which have a greater settling velocity as defined by Stokes Law, when released from the calm area into the fast-moving westerlies below, travelled at a much faster rate across Australia (Mossop, 1964; Weinert, 1967).

The second period of duststorms in Australia is also unlikely to have contributed to dust deposition on the New Zealand scene. Again it is probable that some of the buoyant finer dust would be carried into the high troposphere, perhaps by convective turbulence, and ejected into the stratosphere by vertical circulations reaching up to the jet-stream. Such material would possibly contribute to high-level dust haze some days later over New Zealand. However, the more spectacular event from this period of dust blowing was the intense blanketing of Brisbane and southern Queensland by a "dust fog" on Wednesday, October 3. This low-level dust, controlled then by mild southerly winds, could only have travelled in a northerly direction (Figures 3 - 6) where it presumably dispersed over or was absorbed into the Pacific Ocean. There is no conceivable way this dust could have been deposited on New Zealand. Furthermore, this yellow-grey dust was of a distinctly different character to the red-brown iron oxide-tinted dust which fell on Central Otago (Marshall, 1929).

It would thus appear that it was the third period of dust blowing in Australia which resulted in dust being transported to, and deposited upon, New Zealand. These duststorms occurred in association with the passage of a deep trough of low pressure across southeastern Australia during the night of October 5 and early morning of October 6. The trough was located just west of Adelaide at 9 a.m. on October 5, and off the eastern coastline, aligned meridionally along 160°E. at 9 a.m. on October 6 (Figure 1). Hence the front crossed the main area of dust origin sometime during the late afternoon and evening of October 5, probably between the hours 4 - 9 p.m. Preceding the front during the afternoon of October 5 were strong northwesterly winds of 35 - 50 m.p.h. (30-43 knots) at the surface. Dust was first deposited on Otago and Southland between 3 - 4 p.m. (N.Z. time) on October 6. Accordingly the dust must have traversed the Tasman at very high speeds. Assuming the dust originated from the Mallee-Wimmera-Riverina area then it must have been transported 1700 miles within 17 - 22 hours. In other words the maximum average speed necessary to transport the dust was between 77 and 100 m.p.h. (67-87 knots) — i.e., jet-stream conditions. Such winds would normally only occur in the mid to upper troposphere associated with a jet stream.

One mechanism for raising dust to great heights would seem to be related to strong vertical velocities often associated with cold fronts (Farquharson, 1937; Reiter, 1963). Loewe (1943) attributed such strong vertical velocities to turbulence increasing simultaneously with increase of wind velocity in the squall line thus leading to a strong and sudden increase in the vertical wind components. Significantly, of the many individual examples of duststorms quoted by Loewe (1943), the majority occur in situations almost identical to the one recounted here, especially in association with the passage of a cold front across the Wimmera-Mallee-Riverina area.

Upon being raised to levels between the mid and upper troposphere, the dust would be injected into the jet-stream system for transportation across the Tasman. In such extreme "bad" weather situations jet-stream intensity winds extend down to quite low levels (e.g. 300-500 mb). This is the level which according to Reiter (1963) and recently Stevenson (1969) mainly influences the trajectories of the dust particles. The jet concerned is probably not the subtropical jet but rather a mid- to high-latitude jet which commonly appears on the maximum wind charts prepared by the Central Analysis Office of the Commonwealth Bureau of Meteorology (see also Phillpot, 1962; and Gibbs, 1965). Figure 3 illustrates an analogous

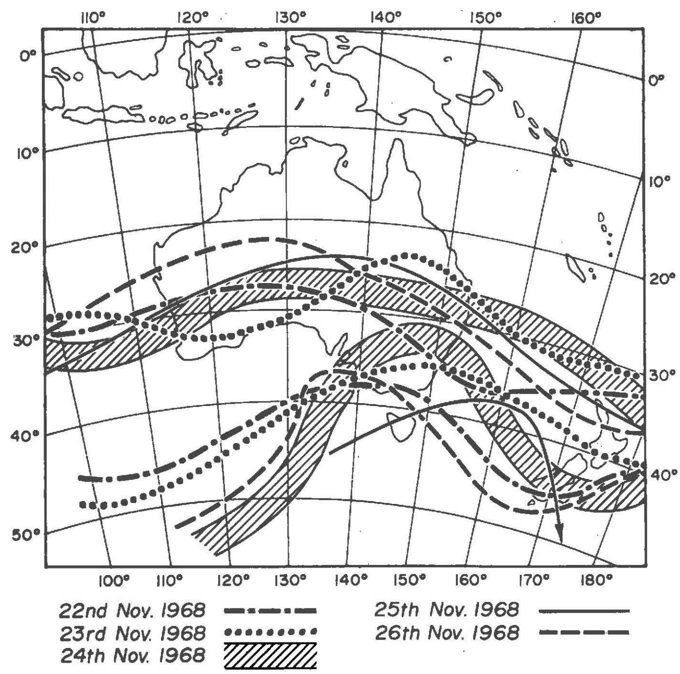

Figure 3. Jet stream patterns of 22-26 November, 1968. (Extracted from Daily Maximum Wind Analysis Charts, Central Analysis Office, Commonwealth Bureau of Meteorology, Melbourne.)

jet-stream pattern of November 24, 1968, which shows broad agreement with the deep surface trough illustrated in Figure 1. This pattern occurred in conjunction with very strong surface winds and severe squally weather. In addition the jet-stream patterns for the period November 22 - 26, 1968, are shown. Of interest is the near standing wave situation attained by the mid-latitude jet. A similar situation may be envisaged during October 5 - 9, 1928. Jet-stream maxima wind velocities in this stationary wave type of situation are commonly between 100-150 knots. Although this is somewhat higher than the 81-95 km per hour (43-52 knots) average rates quoted by Reiter (1963) for transport of dust by jet streams, the situation of October 1929 is an extreme one, and thus jet-stream maxima wind speeds of 100 - 150 knots are reasonably realistic.

Transfer of dust out of the jet stream and subsequent deposition over a localised area may be achieved by two, perhaps not mutually exclusive ways. Dust deposits travelling within the jet stream have been found to be confined to the leading edge of a deep upper trough (Reiter, 1963). The leading edge of a jet stream is a zone of convergence and thus decelerating air (Murray and Daniels, 1953). It is also the zone of strongest subsidence (Reed and Sanders, 1953). As dust deposits first fell in New Zealand within torrential rainfall it is possible that the causative cumulo-nimbus clouds reached high into the troposphere. In this event dust may be envisaged as being "sucked" down from the mid-troposphere by strong downdraughts within the cumulo-nimbus. On the other hand there are apparent vertical motions present in the stratosphere which so far have not been adequately accounted for (Murray and Daniels, 1953; Reiter, 1963). In the region of strong jet-stream development, air within the baroclinic zone is sinking out of the stratosphere (Newell, 1963; Reiter, 1963). "Because of their vertical circulations the jet streams become a very important factor of mass exchange, which may bring particles originally suspended in the stratosphere and in the upper troposphere down to the earth's surface within a short time" (Reiter, 1963; p. 373). For example, such vertical motions seem necessary to explain the drift of radioactive dust to New Zealand from the British nuclear bomb test at Woomera in October, 1953 (Gabites, 1954).

Another point lending credence to the hypothesis proposed here is that the Mallee-Wimmera-Riverina area is the area shown by Loewe (1943) as lying in the zone of greatest duststorm frequency. Loewe's conclusions show that highest average frequency of duststorms does not occur in the most arid parts of Australia, but rather in the slightly moister regions of marginal agriculture (for example the Wimmera, Mallee and Riverina). The wind-distributed parna soils found over a large portion of these areas are characterised by red-brown iron oxide colourations (Butler, 1956).

In addition, transport of dust from the Sahara to the European Alps has often been associated with a standing wave type of jet-stream maximum (Reiter, 1963). The jet-stream patterns simulated here for the transport of dust suggest the slow eastward progression of a well-formed wave trough across New Zealand

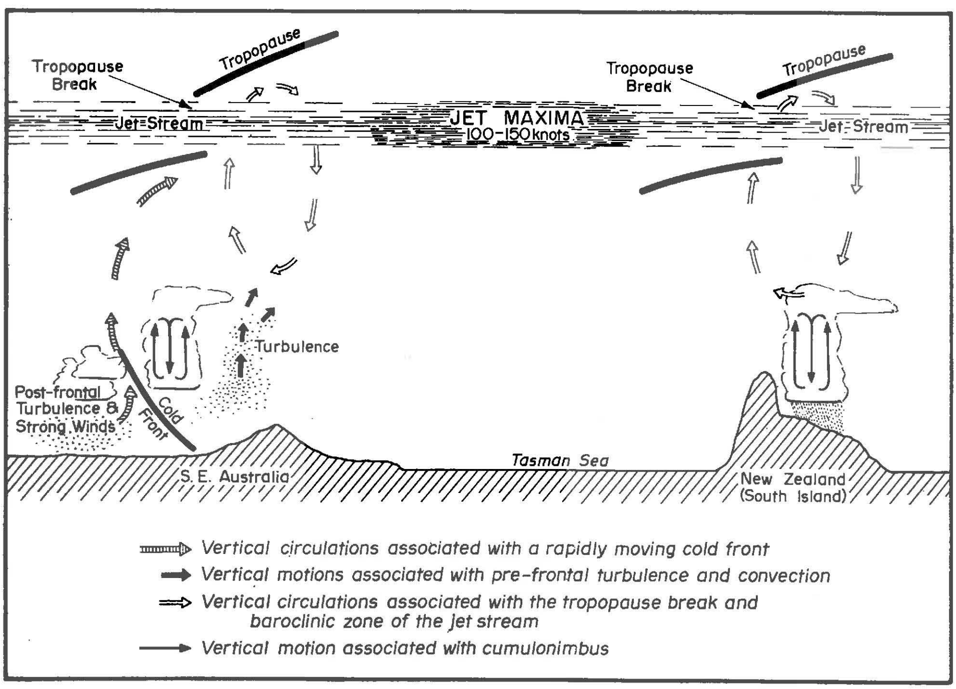

Figure 4. Schematic Representation of a mechanism foı transport of dust from Australia to New Zealand.

between October 6 - 8. This would account for the deposition of dust clouds without rain at Napier and the central North Island localities on October 8. It would also explain the movement northward of the major zone of gale winds, dust activity and thunderstorms during the same period (Kidson, 1929).

Apart from the mechanism for rapid transit of dust across the Tasman, the problem of intermittent deposition of dust over New Zealand from October 6 - 9, and the replenishment of dust supply also need comment. As noted previously the third period of dust raising in Australia was the most severe. In this period duststorms were caused initially by the passage of a cold front. Dust raising was protracted until October 7 by strong south-southwesterly winds in the rear of the front as well as by the rapid passage of minor fronts (Figure 1).

In New Zealand dust was deposited from October 6 - 9. Hence at least some of the dust travelled at slower average speeds than the maximum jet-stream rates derived above. Speculatively, this could be due to lack of rapid vertical motion either before or subsequent to transit of the dust within the jet stream.

CONCLUSION

Although paucity of surface data and absence of upper air data precludes unequivocal determination of the exact mechanism of dust transportation, and its source, the evidence reviewed and presented strongly suggests that an explanation incorporating rapid transit of dust from southeastern Australia to New Zealand via a jet-stream type situation is distinctly plausible. Nevertheless it would also seem likely that during all periods of dust raising over Australia, normal turbulence and convection processes raised the dust to the upper troposphere. Undoubtedly some of this dust was carried into the stratosphere by vertical circulations associated with the baroclinic zone of the jet stream. These extensive concentrations of dust at high levels would have contributed to the widespread high-level haze, and later brilliant sunsets. Recent work by Prospero (1968) and Stevenson (1969) on the transport of dust from the Sahara support the hypothesis of dust transport by strong wind flow in the mid to upper troposphere. It thus appears that the hypothesis outlined above (Figure 4) allows for many of the puzzling features evident in the contemporary report by Kidson (1929).

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Table 1. Storm conditions and reports.