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AUSTRALIAN NATIONAL UNIVERSITY

MT. STROMLO OBSERVATORY

ASTRONOMICAL SITE TESTS AT

SIDING SPRING OBSERVATORY AND MOUNT SERLE

MAY 1964 - JUNE 1965

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December 1965

SIDING SPRING AND MT. SERLE

May 1964 - June 1965

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SIDING SPRING AND MT. SERLE

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LIST OF TABLES AND FIGURES

I. OUTLINE OF TESTS

Early in 1964 preparations were commenced to make astronomical site tests at Siding Spring Observatory (longitude 149°03'E, latitude 31°16'S, elevation 3800 ft.) and Mt. Serle (longitude 138°53'E, latitude 30°30'S, elevation 3060 ft.). It was considered most desirable that the tests should be carried out at each place over approximately the same period in order to minimise any such effects that could be introduced by testing one place in, say, a generally dry season and the other in a generally wet season. For various reasons including loss of staff, illness, etc. it was not possible to carry out this intention completely, but a fair degree of sampling at each place over the period has been achieved.

The installation of the station and its operation at Mt. Serle were in the hands of Mr. A.V. Williamson, initially assisted by Mr. R. Johnson. Mr. Johnson resigned in May and the maintenance of the station was left solely in the hands of Mr. Williamson. At Siding Spring Observatory equipment was installed and operated by Mr. G. Foxall until October 1964 - later Mr. A.G. Samuels took over the operation and maintenance of the station. During my absence overseas (May - October 1964) the work was under direction of Dr. A.W. Rodgers.

MT. SERLE STATION The installation of the Mt. Serle Station commenced in mid-March 1964. The S.A. Government cooperated by preparing a track suitable for a four-wheeled vehicle part of the way to the summit and a foot track for the remaining 700 foot climb. A base tent for general storage was established at the end of the vehicle track, a galvanized iron hut and equipment were carried to the summit of the mountain with the aid of aboriginal residents in the area. A helicopter provided by the Department of Supply lifted oil fuel, some stores, and a refrigerator to the summit.

The following measurements were carried out at Mt. Serle for various periods :-

a) Seeing estimates (Danjon scale) with an 8" reflector (Astrola II) mounted in a small dome
b) Image motion measures with a double beam telescope (on loan from National Science Foundation, U.S.A.)
c) Air temperature records (at summit and at foot of mountain)
d) Relative humidity records (at summit)
e) Ground surface temperature records
f) Wind velocity records, at first with a cup anemometer recording every ten miles of wind, later with a pressure tube recorder
g) Net radiation records as an index of cloud cover
h) Eye observations of wind direction, cloud and other phenomena.

SIDING SPRING OBSERVATORY The equipment at Mt. Serle was largely duplicated at Siding Spring. The Danjon tests were made with a similar reflector (Astrola I) and the image motion observations with a double beam telescope purchased from Boller and Chivens. Wind records were initially obtained from a recording cup anemometer, but later a combined velocity and direction recorder was brought into use.

II. COMPARISON OF RESULTS

A. CLOUD DATA

The cloud data comprise visual observations of the amount of cloud at 9 p.m. from which is derived the frequency of occurrence of nights when the cloud more than 10° above the horizon is 1/8th or less. Because of interruptions to this (and other) records on Mt. Serle, use has been made of extensive and critical observations carried out by Mrs. Snell and Miss Flowers at Angepena station which is close to Mt. Serle. The results over the period of occupation are given in Table I.

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TABLE I

FREQUENCY OF "A" CLOUD NIGHTS

(Cloud less than 1/8 at 21 h.)

		SIDING SPRING		ANGEPENA (MT. SERLE)	
1964	June	36%	(25)	46%	(30)
	July	27	(30)	42	(31)
	Aug	31	(29)	55	(31)
	Sep	44	(27)	37	(30)
	Oct	39	(28)	48	(31)
	Nov	47	(19)	43	(30)
	Dec	63	(24)	70	(31)
1965	Jan	59	(17)	81	(31)
	Feb	57	(28)	61	(28)
	Mar	73	(31)	60	(30)
	Apr	67	(27)	60	(30)
	May	39	(28)	46	(24)
	June	56	(27)	48	(25)
	MEAN :	49.0%		53.8%	

The small difference is nominally in favour of Angepena, but an application of a t-test indicates that such a difference could be expected to occur as the result of random fluctuations in about one in five pairs of samples of the same population.

Night cloud observations were carried out in Coonabarabran during 1960-1963 (inclusive). These have been combined with results obtained at Siding Spring during 1964 giving the five-year mean shown under the heading "Coonabarabran" in Table II. There they are compared with an extensive series due mainly to the careful observations of Miss Flowers at Angepena. These again show a slight margin in favour of Angepena and presumably Mt. Serle over Siding Spring Observatory. The margin is more apparent in the "winter" months. Both sets of observations indicate clearer night conditions around the time of the equinoxes. This effect is also shown in a twenty-year series of 3 a.m. observations at Broken Hill, N.S.W., which site appears comparable with Mt. Serle.

The use of a single "spot" reading to characterise conditions during the complete night is, of course, theoretically open to objection, but a comparison of the 9 p.m. cloud results for individual nights in January-June 1965, with the actual "photoelectric" hours of use of the 40-inch r reflector at Siding Spring shows that a good statistical correlation exists between the two quantities (Fig. 1).

Using this relation suggests that the minimum number of photoelectric hours at the two sites computed from "A" nights at 21 hrs are :-

Siding Spring	1410 hours per year
Mt. Serle	1540 hours per year

or, if allowance is made for nights when the cloud lies between 1/8 and 4/8 (clearing after 21 hr) :-

Siding Spring	1500 hrs p.a. (derived)
Mt. Serle	1690 hrs p.a. (derived)

The recorded value at Siding Spring (from log entries at the 40" telescope) for the twelve months ending 30 June 1965 was -

Siding Spring	1554 hrs p.a. (recorded).

TABLE II

CLOUD AT COONABARABRAN AND ANGEPENA

9 p.m. observations 1960-1964 (incl.)

Mean Frequency of occurrence of nights with 1/8th cloud or less

1960-1964 (incl)	COONABARABRAN %F	ANGEPENA %F
Jan	54	48
Feb	62*	53
March	66	60
April	50	46
May	40	47
June	55	58
July	46	50
Aug	47	54
Sept	57	64
Oct	56	67
Nov	50	51
Dec	50	51
Mean Sept-March	56.4	56.3
Mean April-Aug	47.6	51.0
Mean Year	52.8	54.1

* No results available for February 1965

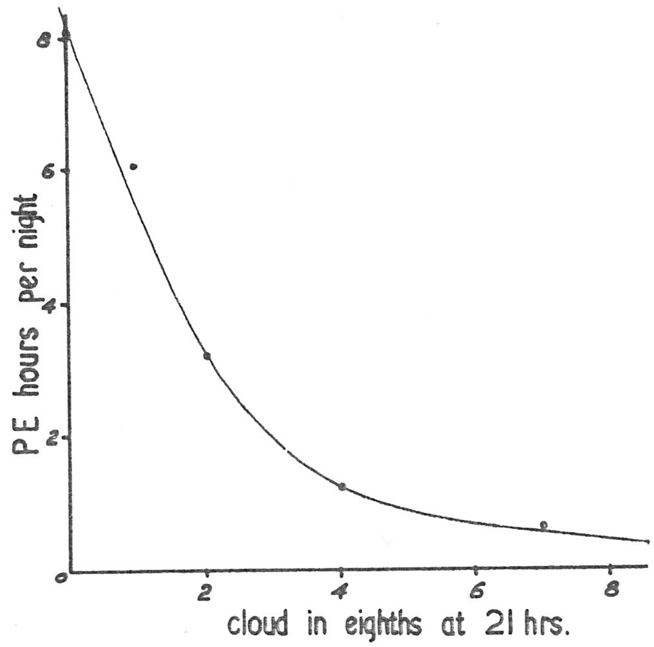

FIG 1

CLOUD & PE HOURS — SIDING SPRING

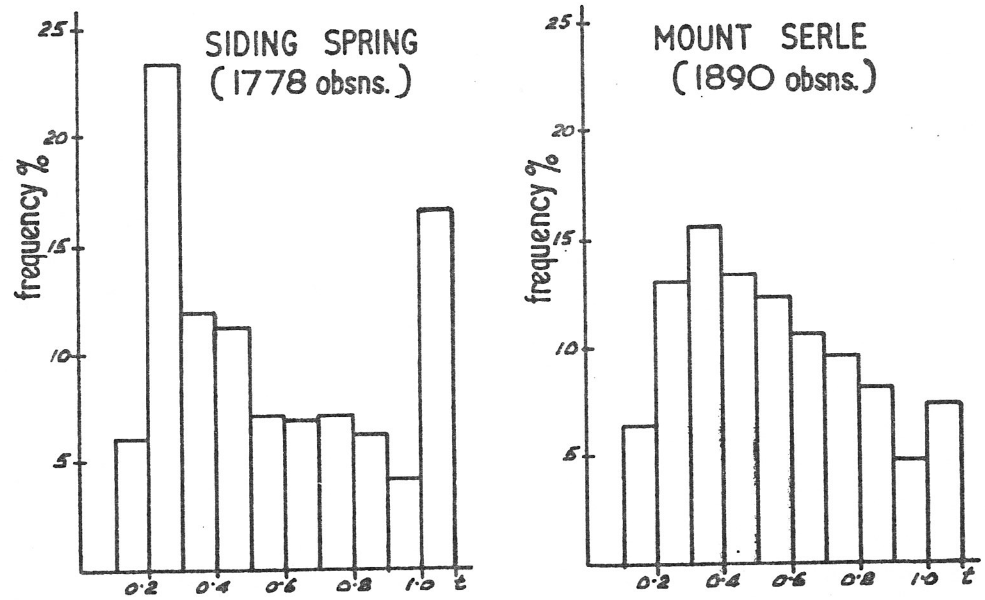

FIG 2 FREQUENCY DISTRIBUTION OF t FOR STARS AT AIR MASS < 1·2

B. SEEING - IMAGE QUALITY AND IMAGE MOTION

(i) Methods The comparison between the two sites is based mainly on the Danjon tests made by A.G. Samuels and A.V. Williamson. The Danjon test, as described in earlier reports, in intended to give a nominal figure for the semi-amplitude of the image motion in seconds of arc reduced to the zenith (t_o''). The actual observation is of the quality of the star image and its diffraction pattern as observed in a small telescope and expressed on a scale of 1 to 5. The seeing index is converted to the turbulence index t_o'' (for the zenith) or t(for any zenith distance.)

As observers were not interchanged it was necessary to compare their results using the same telescope. A test series was run at Siding Spring Observatory in December 1964 using an instrument designated as Astrola I. The telescope having been directed to a star each observer made his own independent estimate of the Danjon index from which was calculated the "turbulence index" t, no correction here being necessary for zenith distance. The grouped means resulting from this and other comparisons made in June and November 1965 are shown in Table III. There is some scatter in the results for the poorer seeing conditions, but apart from this, the general statistical agreement is good over the central part of the scale and it has not been considered worthwhile applying observer corrections. The two reflectors were compared in 1962 by G. Foxall and A.V. Williamson with the results shown in Table IV. In the sequel all the results have been brought to the scale of Astrola II, using the smoothed values of Table IV.

(ii) Comparison of seeing results In seeking a single figure to characterize long-term seeing conditions at a particular site, an obvious, even if somewhat impracticable solution, is to take the mean of a completely continuous record extending over many years. In practice usually only scattered results are available and means derived from these, if used for the comparison of two or more places, can be misleading, for

TABLE III

COMPARISON OF OBSERVERS' ESTIMATES OF t"

Series	Observer	t" in units of 0".01 and number of observations				
1964 Dec	AVW	115	73	41	24	15
	AGS	110	73	49	23	18
	No.	45	35	21	13	10
1965 June	AVW	110	73	40	26	-
	AGS	98	62	39	26	-
	No.	74	84	42	40	-
1965 Nov	AVW	110	68	42	25	15
	AGS	120	64	43	26	16
	No.	20	22	26	30	25
M E A N	AVW	111	72	41	26	15
	AGS	95	65	43	25	16
	No.	142	141	89	83	35

TABLE IV

COMPARISON OF ASTROLA I and ASTROLA II

(a) Observed means

t_I	0".39	0".44	0".49	0".57	0".71
$t_I - t_{II}$	0.05	0.075	0.08	0.090	0.12
n	4	4	4	4	3

(b) Smoothed Values

t_I	0".30	0".40	0".50	0".60	0".70
$t_I - t_{II}$	0.03	0.06	0.08	0.10	0.12

quite apart from any random fluctuations, selection effects in the presence of systematic nocturnal, annual or secular variations may influence the results. For example, comparative readings of seeing at, say, 21hr at two places obviously will not truly reflect the average seeing at the two sites throughout the night if, for instance, the seeing is a maximum at 21hr at one place and at 3hr at the other. Such effects may be eliminated by using continuous records throughout the night or minimized by comparing night means derived from observations made at several appointed times during the night. Similarly, the effect of any systematic month to month (annual) variation may be removed by comparing only whole years and the effect of secular variations minimized by ensuring that the observations at the two places are taken concurrently.

In the present case it has not been possible to comply with all the foregoing desiderata. Apart from interruptions due to weather conditions, the resignation of one observer, the illness of another and storm damage to equipment have combined to bring about breaks in the continuity of the observations as shown in Table V which gives the monthly averages of t_o. Series A is derived from night means using all observations; Series B comes from those nights when four (or in a very few cases three) or sets of measures were secured at the set hours and thus should be substantially free from any regular nocturnal variation effects. Weighted and straight means of these monthly averages are shown (a) for all months and (b) for those months for which five or more nightly averages were obtained when the stations were operating continuously. Three sets of these grand means give an apparent indication that the seeing is slightly better at Mt. Serle than at Siding Spring, the fourth favours Siding Spring. As none of the grand means conforms strictly to the requirements mentioned earlier, they have, in desperation, been averaged to give the following figures :-

Siding Spring Observatory	$\bar{t}_o'' = 0.48$
Mt. Serle	$\bar{t}_o'' = 0.45$

TABLE V : DANJON SEEING TESTS t''_o - SIDING SPRING AND MT. SERLE

1964 June - 1965 June

	SIDING SPRING				MT. SERLE			
	Series A		Series B		Series A		Series B	
	t''_o	n	t''_o	n	t''_o	n	t''_o	n
1964 June	0.37	1	-	-	0.58	11	0.65	5
July	0.44	2	0.44	1	0.31	10	0.41	3
Aug	0.51	3	-	-	0.51	9	0.46	5
Sept	-	-	-	-	0.65	4	0.48	3
Oct	-	-	-	-	0.45	20	0.42	9
Nov	-	-	-	-	0.60	17	0.57	5
Dec	0.52	8	0.55	1	0.69	1	0.69	1
1965 Jan	0.58	25	0.52	9	0.45	10	0.52	4
Feb	0.37	15	0.35	7	0.45	9	0.53	3
March	0.44	19	0.44	8	-	-	-	-
April	0.48	19	0.47	4	0.34	5	0.35	5
May	0.54	21	0.55	12	0.45	22	0.34	13
June	0.48	11	0.43	5	1.12	2	1.12	2
MEANS:								
(1) Weighted								
(a)	0.49		0.48		0.48		0.48	
(b)	0.51		0.48		0.44		0.39	
(2) Straight								
(a)	0.47		0.48		0.50		0.46	
(b)	0.49		0.47		0.43		0.44	

NOTES: In this table all observations have been brought to the scale of Astrola II. Series A refers to means of nightly averages of t_{θ} using all observations irrespective of the hour at which they were taken. Series B refers to means of nights for which four (or occasionally three) sets of observations at standard hours were used. Grand means are (1) weighted according to the number of nights used in their formation or (2) are straight means of the monthly figures. The means noted as (a) are derived from all the available monthly averages (except that the June result at Mt. Serle has been excluded from the straight mean) and those noted as (b) are from the monthly means which have been derived from five or more nightly averages when the stations were operating concurrently.

These figures conventionally represent the semi-angular amplitude of the image tremor in seconds of arc as determined by the Danjon method and taken at their face value suggest that the average seeing at Mt. Serle is slightly better than at Siding Spring. However, even taking the case of the means which display the largest difference (Series B, Means 1-b) the difference Siding Spring minus Mt. Serle comes out at $\Delta t_o = 0.09 \pm 0.06$ which is not statistically significant. There is, of course, some hesitation in applying the ordinary tests of significance to these observations which have a markedly non-Gaussian distribution (see (iv) below). On the whole it is likely that the observations indicate no real difference in mean seeing (image quality) between the two sites.

(iii) Maximum seeing conditions As the best seeing observed at a given site is an important characteristic, average values of t_o for the 20 best nights at the two stations have been computed.

Siding Spring	t_{max}	= 0".24	(20 nights)
Mt. Serle	t_{max}	= 0".24	(20 nights)

The best conditions are equal at the two sites, which, considering their general similarity in latitude, altitude and topography, is not altogether surprising.

(iv) Frequency distribution The seeing observations at the two sites may also be compared as frequency distributions. For this purpose 1778 observations of stars with an air mass of 1.2 or less at Siding Spring were compared with 1890 observations of stars with an air mass of 1.2 or less at Mt. Serle. As the air mass correction averages only about 0.05 units of t_o'' per unit air mass these results (Fig. 2) are effectively for zenith seeing. The ordinates in this histogram represent the frequency of occurrence of seeing with $0.1 < t_o < 0.2$ etc. It will be noted that the seeing distribution at Mt. Serle is roughly a Poisson curve, whilst at Siding Spring the seeing tends to extremes, a large amount of good seeing being offset by a considerable amount of poor seeing.

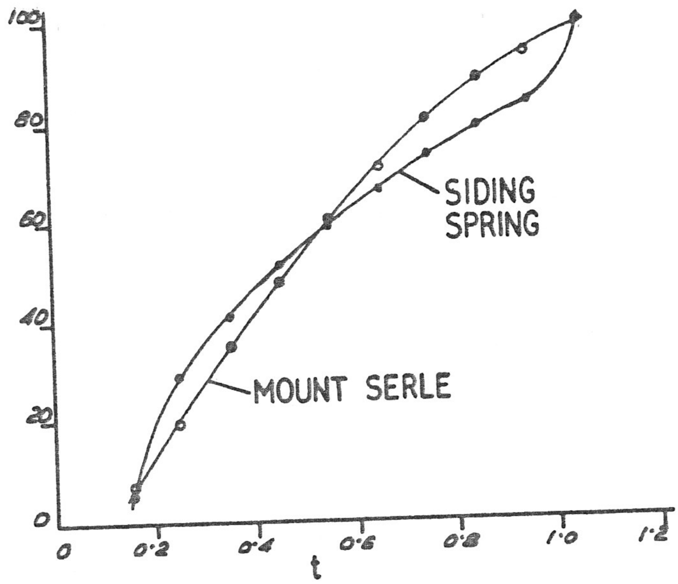

FIG 3 CUMULATIVE FREQUENCY OF t LESS THAN STATED AMOUNT

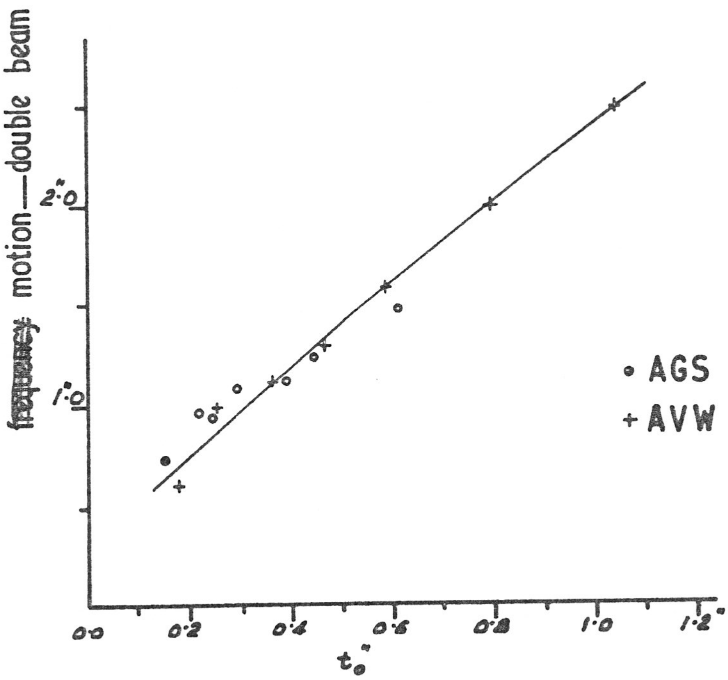

FIG 4 COMPARISON OF DANJON AND DOUBLE BEAM METHODS

These results may also be displayed in an integrated curve, showing the percentage of the time for which t (air mass less than 1.2) falls below $0''.1$, $0''.2$, etc. These curves indicate a somewhat higher frequency of better seeing ($t'' < 0.3$) at Siding Spring than at Mt. Serle, but this is counterbalanced by a greater frequency of very poor seeing at Siding Spring. How far this result is affected by the fact of the two sets of observations having been carried out over different periods is an open question.

(v) <u>Seasonal variations</u> The mean values of t''_o for Summer (D,J,F), Autumn (M, A, M), Winter (J, J, A) and Spring (S, O, N) are shown in Table VI. Unfortunately, the Siding Spring results are badly distributed throughout the year and the figures for Winter have been obtained only by combining the few observations obtained in both 1964 and 1965. Whether the seeing at Siding Spring, like that at Mt. Serle, falls off during the Spring is an open question. At Mt. Serle there is perhaps a tendency for the best seeing to occur during the Autumn and the worst during the Spring.

(vi) <u>Nocturnal variations</u> The seeing observations have been attempted at the following times :- 2045, 2245, 0045 and 0245hr. Mean values of t''_o at these hours have been formed for the nights when the sets were complete. The values shown in Table VII have been tabulated as at 21^h, 23^h, 01^h and 03^h for convenience and show the number of complete sets (n) and the means. (N.B. The grand means vary slightly from those shown in Table V because part nights have been omitted.) In both cases the seeing tends to worsen as the night proceeds, particularly at Siding Spring, the best seeing being encountered in the early part of the night. A similar state of affairs was found at Mt. Singleton in 1963 (AST/64/30), the results being repeated in the present Table VII. Earlier results at Mt. Burges (W.A.) also displayed a similar trend (AST/39/63) and the phenomenon may well be characteristic of such mountain sites. A shorter series of observations at Mt. Grey (W.A.) failed to display the variation, but Mt. Grey is more of a knoll than a mountain.

TABLE VI

SEASONAL VARIATIONS OF t''_o

	SIDING SPRING		MT. SERLE	
	t''_o	n	t''_o	n
Summer (D, J, F)	0.49	48	0.46	20
Autumn (M, A, M)	0.51	59	0.43	27
Winter (J, J, A)	0.50	44	0.48	30
Spring (S, O, N)	-	-	0.53	41

TABLE VII

NOCTURNAL VARIATIONS OF t''_o

Hour	21^h	23^h	01^h	03^h	Mean	n
Siding Spring	0.38	0.43	0.47	0.51	0"45	54
Mt. Serle	0.44	0.47	0.50	0.51	0.48	69
Mt. Singleton (1963)	0.54	0.60	0.61	0.65	0.60	44

(vii) Optical turbulence and image motion Each site was ultimately provided with a double beam telescope (J. Stock, I.A.U. Symposium No.19 (1962) p.48 ≐ Bull. Astron. Obs. Paris XXIV fasc 2-3) having two 6-inch objectives (f.l. = 42 inch) separated by 60 inches. One of these instruments (that at Mt. Serle) was on loan from the U.S. National Science Foundation and had been used at Kitt Peak. It was erected in the open. The instrument used at Siding Spring was a more recent model purchased from Boller and Chivens and was housed in a caravan with an opening roof. This caravan, which had been used in the AURA survey, gave a degree of wind protection to the observer, but rather restricted the motion of the double beam instrument.

The double beam instruments were used to obtain a calibration of the optical turbulence (t_o) measures in terms of relative image motion. Comparisons were made using the same stars at near the same time, so as to eliminate the need for the rather uncertain air mass corrections. The results of the two independent sets of observations reduced to the scale of Astrola II are displayed in Table VIII as means of n grouped observations and plotted in Fig.4 which shows a very good agreement between the results of the two observers at well separated stations using different instruments. Mean values of image motion, derived from the more extensive t_o observations by using Fig.4, are as follows :-

	Relative Image Motion
Siding Spring Observatory	1".3
Mt. Serle	1".3
Mt. Singleton (1962)	1".6

TABLE VIII

OPTICAL TURBULENCE (t_o, DANJON TEST) AND IMAGE MOTION (d, DOUBLE BEAM TELESCOPE)

t_o measures reduced to scale of Astrola II

SIDING SPRING A.G.S.			MT. SERLE A.V.W.		
t_o	d	n	t_o	d	n
0".15	0".75	6	0".18	0".61	4
0.21	0.99	11	0.25	1.00	11
0.24	0.90	7	0.36	1.12	16
0.29	1.06	14	0.46	1.32	13
0.39	1.12	4	0.59	1.57	9
0.44	1.25	2	0.80	1.92	11
0.61	1.50	3	1.08	2.26	5

C. WIND

i) Observations at 21^h. The most regular sets of wind observations taken at the two sites were the estimates of wind force (Beaufort Scale) and direction made at 21^h. For purposes of tabulation the mean Beaufort numbers have been converted into m.p.h. (Australian Meteorological Observers Handbook 1954) and shown in Table IX. The mean frequency (f) with which the wind blows from the various octants is shown in Table X together with the mean velocity $\overline{v}$ of the wind from these directions. This table is based on the same observations as those shown in Table IX.

The observations at Siding Spring show that the wind blows from the SE quadrant (E, SE, or S) for nearly two-thirds of the time. The strongest winds also come from this quarter or the NE, the westerlies being relatively slower. The results refer to observations made generally in the vicinity of the 16-inch reflector; how far they reflect the motion of the air over the mountain is perhaps an open question.

At Mt. Serle, where the observations were made from a quite exposed situation near the summit, the mean shows that the strongest winds came from the north, but these were relatively infrequent. The maximum wind force at 21hr was estimated at 8 on the Beaufort scale, i.e. equivalent to a steady wind of 40-45 m.p.h.

(ii) Integrating cup anemometer records At Siding Spring a contact cup anemometer was arranged on the tank stand at a height of about 9 m. so as to give a record every ten miles of wind on the net radiometer chart. This instrument operated with a fair degree of continuity, over the period March-August 1964, at effectively the highest and most exposed point on the mountain. A similar arrangement was installed at Mt. Serle also in a well exposed position on the crest of the ridge, again using the net radiometer chart to receive the record.

A summary of the records giving the mean velocity in m.p.h. averaged over two-hourly periods for the night hours is shown in Table XI. This table also gives the average wind velocity during the "night" (18h-06h)