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**ASTRONOMICAL SEEING CONDITIONS AND
CLEAR AIR TURBULENCE**

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ABSTRACT

A decade of extremes of astronomical seeing is studied in connection with atmospheric conditions. An attempt is made to relate seeing to turbulence parameters, especially those parameters favouring turbulence at tropopause levels. The gravity wave-vertical shear mechanism is found to be significantly related to poor seeing conditions, suggesting that clear air turbulence is strongly involved in poor astronomical seeing.

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ASTRONOMICAL SEEING CONDITIONS AND CLEAR AIR TURBULENCE

by

Anthony Wankiewicz

1. INTRODUCTION

Astronomical observations are hindered in a cloudless atmosphere in two ways, firstly, by dust, smoke and haze. Secondly, bad seeing conditions are caused by shimmer and scintillation. This problem is considered in the paper.

Shimmer involves random changes in apparent direction (wandering and dancing) and in size (pulsation) of heavenly bodies. Scintillation or "twinkling" refers to brightness changes of point light sources such as stars. The higher frequency scintillation is thought to originate at tropopause levels since it can only be observed in extraterrestrial bodies (3). Shimmer and low frequency scintillation is attributed to nocturnal lower level (less than 1000 ft) effects (see Stock and Keller, 1) and to observatory and instrument convection (Winibush, 2). These latter conclusions have resulted from studies of observatory and telescope construction techniques (2), and from observations of terrestrial objects.

It would seem reasonable to assume that the combined effect of turbulence and inversion would be small-scale density gradients of a substantial magnitude; these would give rise to variations of index of refraction of the air and thus distortions of the light path. The importance of the inversion-turbulence mechanism has been verified in studies of optical scintillation over a snow surface (Rysnar, 4). The tropopause is the location of a permanent inversion and the occasional moderate to severe clear air turbulence situation and thus could be the region of the density fluctuations which cause scintillation.

Therefore, the object of this investigation is to compare nights of good and bad seeing with respect to those parameters favourable to clear air turbulence. The parameters considered in this connection are the gravity wave-vertical shear mechanism which, according to Clodman (5), is the principal mechanism for building up clear air turbulence over land.

The primary sources of turbulent energy in this mechanism are standing gravity waves extending to the tropopause and vertical wind shear in the vicinity of the jet stream. Heavy turbulence results from the Reynolds stresses associated with the interaction of the waves and vertical shear.

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TEC- 500
13 Jan. 64.

2. DATA

Column one of table one is a list of twenty-one nights with extremes of good and bad seeing conditions. These observations were taken at the David Dunlap Observatory, near Richmond Hill, during the period 1950-58. The average duration of bad seeing is five hours with a standard deviation or SD of three hours. Parametric values for the atmosphere above Richmond Hill were interpolated for the appropriate dates from rawinsonde and radiosonde reports of surrounding stations. Historical surface, 500-mb, and 300-mb charts were also used. The seasonal distribution of twenty-one useful cases is shown below.

SEEING

Season	Good	Bad
Aug - Nov	9	2
Dec - May	1	9
TOTAL	10	11

TABLE 2

Because good seeing apparently predominates in autumn and bad seeing in winter-spring, it is necessary to recognize that a correlation between seeing conditions and some parameters may not be causal in nature but merely due to the fact that the parameters in question and the true causal influences may both have similar seasonal fluctuations.

3. ANALYSIS OF DATA

The data were analyzed by the check list method shown in table one. Each parameter (except jet distance) was given one check if it was present on the night of good or bad seeing. Because of the importance of the jet stream proximity to tropopause turbulence, one, two, or three checks were given depending on distance from the jet stream. The ten parameters used in table one are selected from those that give conditions favourable to clear air turbulence according to the Clodman Gravity Wave - Vertical Shear Mechanism. All the parameters were used that were readily available to this investigation, the first six involve gravity-wave effects and the remainder are influential at the site of the turbulence.

Gravity Wave Parameters

Clodman states that "terrain with small obstacles is very significant in high level clear air turbulence". A hill, five miles to the north of Richmond Hill, is shown on the contour map in figure one. It has a rise of 300 feet and a width of 16 miles. This feature can be viewed to more advantage when the North-South profile map through Richmond Hill in figure two is compared with the East-West profile in figure three. It may be assumed that the influence on the airflow of this obstacle or the more complex features of the surrounding terrain could result in gravity waves.

Since the height of the rise to the north of Richmond Hill is 1040 ft MSL, the 1000 ft level was chosen as the most significant in relation to wind direction and speed for the check list. Most gravity waves are found when the wind is within 30° of the normal to the ridge. (Alaska, 6). This means in this instance, that the wind must come from the north or the north-west. A check was entered in column two of the checklist if the wind blew from the directions most likely to result in gravity waves. These data are summarized in Table 3.

TABLE 3 Wind Direction Favourable for Gravity Waves

	Wind direction	
	favourable	unfavourable
Good seeing	3	7
Bad seeing	7	4

Since those directions favourable to gravity waves represent only one-sixth of all directions, one would expect the wind to come mostly from the directions less favourable to gravity waves. This distribution is seen in good seeing nights but the reverse is the case for bad seeing nights.

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TEC-500
13 Jan. 64.

Column three of the check list was given a check if the 1000 ft wind speed was not less than 15 mph (13 kts.). An intermediate stable layer (col. 4); low level unstable air (col. 5); increasing wind speed with height (col. 6); and little turning of wind with height (col. 7), were all given checks if they were present on any of the nights listed.

The results for the gravity wave parameters (cols. 2-7) are shown below.

TABLE 4 Gravity Wave Parameters

NUMBER OF CHECKS	0	1	2	3	4	5	6	7
nights of good seeing	0	5	5	0	0	0	0	0
nights of bad seeing	0	0	0	3	4	4	0	0

It is noteworthy that all the good seeing nights have less than three checks while all the bad seeing nights have three or more checks. The average number of checks on good nights is 1.5 with a standard deviation (SD) of 0.5. The average number on bad nights is 4.1 checks (SD = 0.9). The difference between these means is shown by the "student's t" test to be significant at the 0.1% level

High Level Parameters Involved in Clear Air Turbulence

Tropopause Wind Speeds

Wind speeds rather than wind shears were examined for two reasons. Firstly, high winds imply high shears. Secondly, direct wind shear measurements were not readily available. The number of occurrences in certain wind speed intervals for good or bad seeing nights are shown in table five.

TABLE 5 Wind Speed at the Tropopause

Nights of	KNOTS			
	0 - 39	40 - 79	80 - 119	120 +
Good Seeing	8	2	0	0
Bad Seeing	1	7	2	1

CIR- 3965
TEC- 500
13 Jan. 64.

The mean for good seeing nights is 30 knots with a standard deviation (SD) of 10, in contrast to a normal autumn mean of 50 knots (SD = 10). This difference between the two means is highly significant (0.1% level). Good seeing nights, therefore, have tropopause wind speeds much below normal.

The bad seeing nights' mean is 65 knots (SD = 25) as compared with a winter-spring mean of 70 knots (SD = 15). The bad nights thus follow the seasonal trend.

Distance to the Jet Stream

This factor should have a clearer relationship than tropopause wind speed for two reasons. (a) Nearness to the jet stream would imply a high wind shear overhead, during some period of the night. The rawinsonde readings, on the other hand, may not be representative of the whole night. (b) The jet stream is a well-known location of clear air turbulence associated with its high winds and shears.

Figure four is a histogram of distances from Richmond Hill to the nearest jet stream. The average jet distance on nights of bad seeing is only 120 miles (SD = 130). On nights of good seeing, the average distance is 600 miles (SD = 120).

A population variance was taken from a list of forty-five random sample nights. For the random samples, the mean jet distance was 260 miles (SD = 190). Using this variance, the test of significance for a normal population showed that the jet stream distance was significantly less for nights of bad seeing than for nights of good seeing (0.1% level).

To determine the seasonal effect on this difference, the autumn and winter-spring averages (see Data, section two) were computed from the random samples. The mean for autumn nights is 300 miles (SD = 230) and for winter-spring nights, 230 miles (SD = 160). The random samples indicate that seasonal differences are relatively small.

In summary:

(a) Extremely bad seeing conditions seem to occur when the jet stream is relatively close.

(b) Very good seeing conditions are found when the jet stream is further away than normal.

The number of checks entered in column eight of the check list depends on the type of horizontal shear and on the magnitude of the jet distance.

CIR-3965

TEC-500

13 Jan. 64.

For a core speed of 160 knots (a typical winter jet), the half-speed distances (distance from core to where the speed falls to one-half) are 100 and 300 miles for the cyclonic and anticyclonic sides of the jet respectively. Thus with cyclonic shear; three, two, or one check(s) were awarded for jet distances of 0-30, 31-60, 61-100 miles respectively. With anticyclonic shear, the respective jet distance intervals for three, two or one check(s) are 0-100, 101-200, 201-300 miles.

Based on the findings of a number of jet stream investigations (5), checks were also entered if the maps showed that:

- (a) Richmond Hill was on the cyclonic side of a jet,
- (b) There was cyclonic curvature overhead at 500 mb,
- (c) There was a high lapse rate just below the tropopause.

Check List Results

The results of the complete check list analysis (table one) are summarized in figure five. The cross-hatched boxes are nights of very bad seeing and the white boxes are those of very good seeing. The bad night average is 7.9 checks (SD = 1.8). The good night average is 2.2 checks (SD = 0.8). The significance of this difference is above the 0.1% level.

A summary of each of the ten parameters considered is given in table six. The numbers indicate the percentage of good nights or of bad nights on which the parameter in question was present. The relative importance of each parameter can be seen from this table.

TABLE 6

CHECK LIST COL.	PARAMETER	percentage of	
		GOOD NIGHTS	BAD NIGHTS
2	winds perpendicular to hill	30%	64%
3	strong low level winds	20	73
4	Intermediate stable layer	60	100
5	low level unstable air	10	55
6	increasing wind with height	0	64
7	little turning of wind with height	40	82
8	jet stream distance	0	82
9	cyclonic side of jet	0	55
10	cyclonic curvature	10	82
11	high lapse rate just below trop.	50	64

4.

CONCLUSION

Extremely bad seeing conditions are well-correlated with a high wind shear situation (jet stream neighbourhood) and to a lesser extent with conditions favourable to a gravity wave. In very good seeing conditions, both these factors tend to be absent. Since the gravity wave-vertical shear mechanism was found by Clodman to be likely the major cause of high level turbulence mechanism over land, this suggests that clear air turbulence is frequently associated with bad astronomical seeing conditions. It would appear likely that the usual site of the atmospheric conditions causing the bad seeing would be just above the tropopause since this is both a level of maximum occurrence of clear air turbulence and of strong temperature inversions. A corollary of the above is that the relationship between bad seeing and the wind shear-gravity wave parameters can be considered as supportive evidence for the importance of this mechanism in clear air turbulence.

Although low level turbulence and observatory convective turbulence may also be important, their time scales would tend to be short. This is especially true of low level turbulence since the turbulence would soon destroy the nocturnal inversion necessary for bad seeing. The mechanism under consideration above has a relatively long time scale since jet stream proximity and gravity waves may persist for several hours.

Since even modest obstacles, such as those found in Southern Ontario, can cause gravity waves, this may account for the fact that scintillation problems occur over much of the world. The better seeing conditions in equatorial regions could be due to the absence of jet streams or the high level of the tropopause in those areas. It would appear inadvisable to neglect consideration of clear air turbulence in the siting of astronomical observatories.

5.

ACKNOWLEDGMENTS

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APPROVED,



J. R. H. Noble,
Acting Director.

6.

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FIG. 1 - CONTOUR MAP

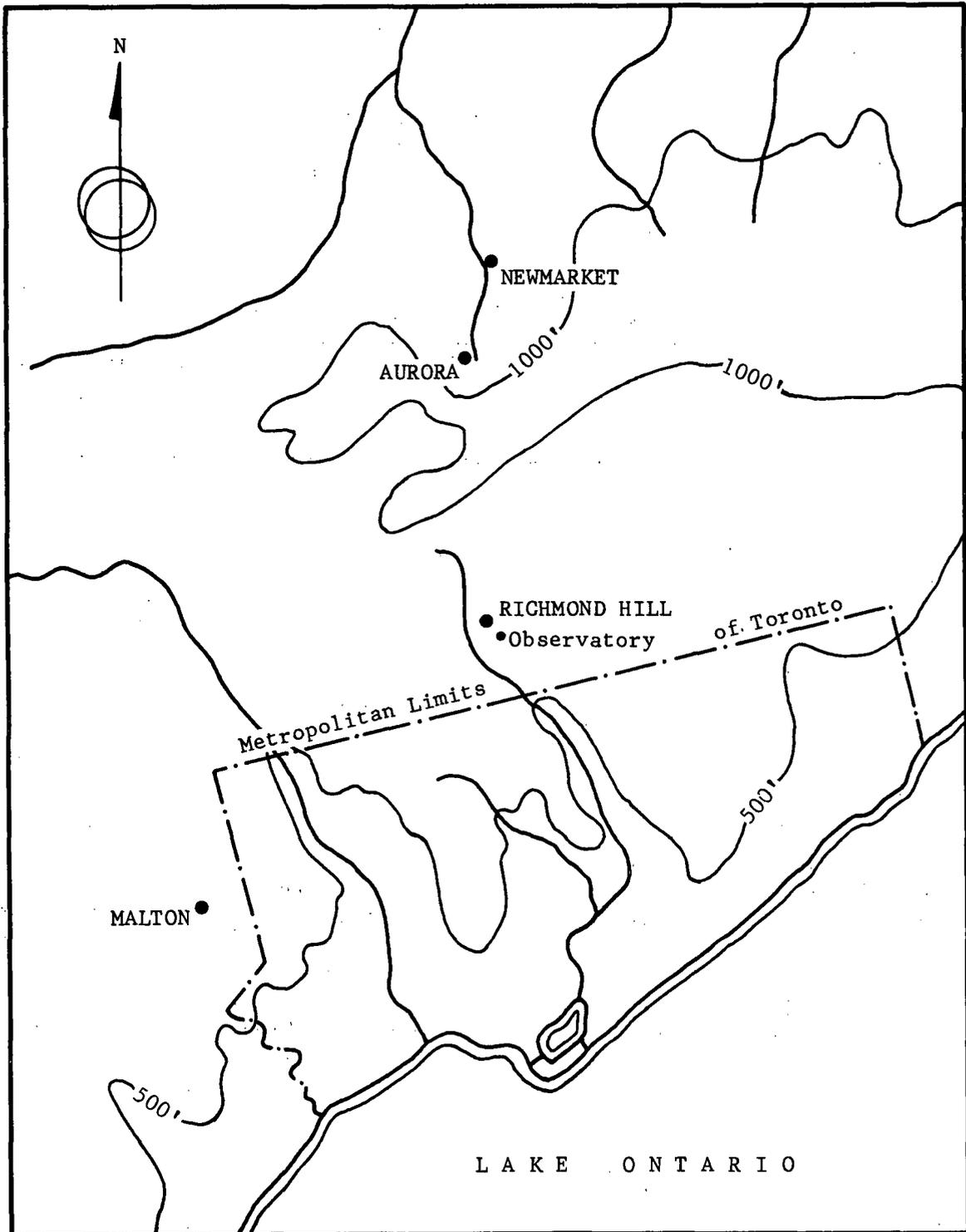


FIG. 2 - NORTH-SOUTH PROFILE

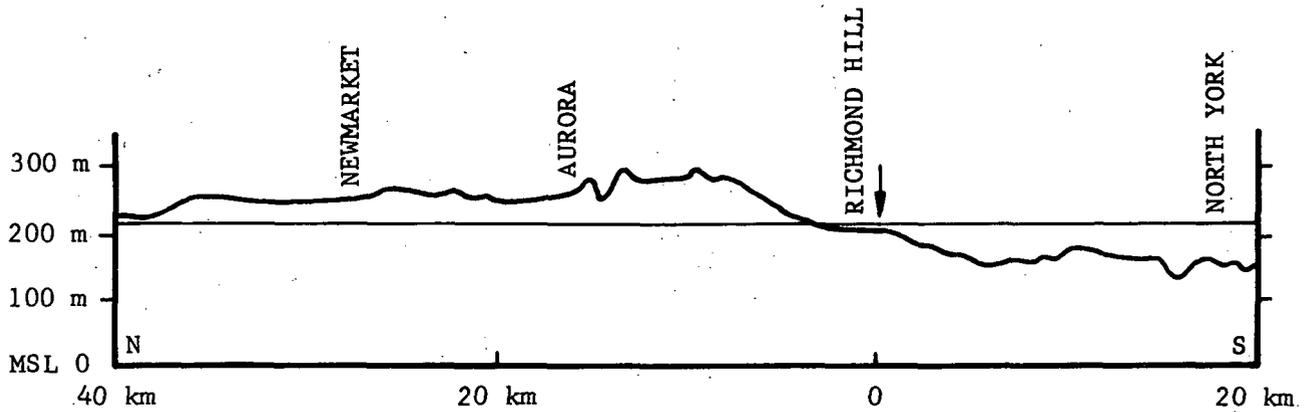


FIG. 3 - WEST-EAST PROFILE

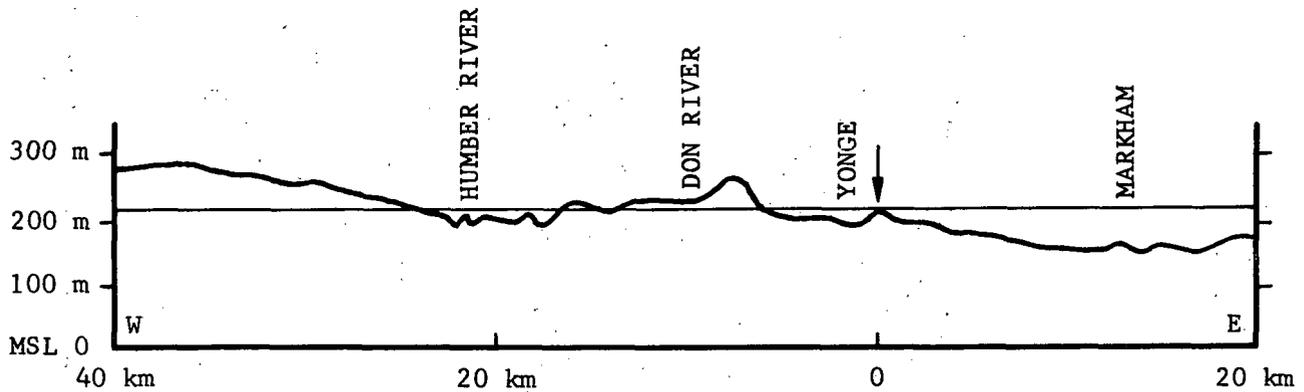
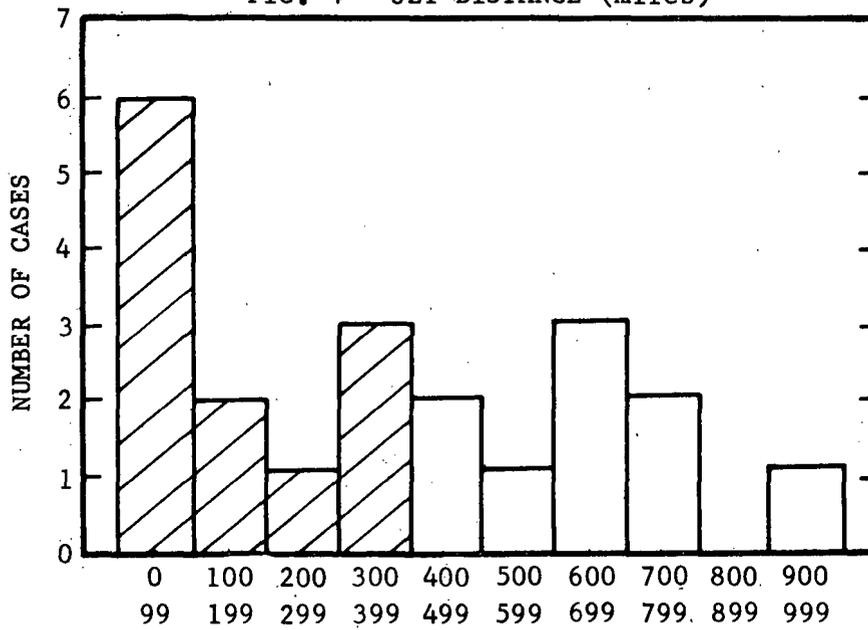
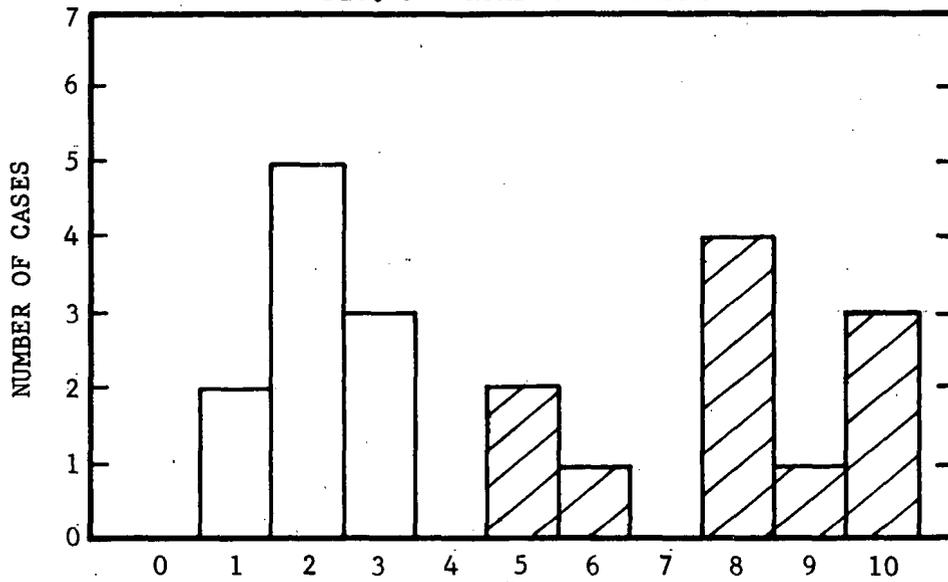


FIG. 4 - JET DISTANCE (miles)



nights of bad seeing  nights of good seeing 

FIG. 5 - NUMBER OF CHECKS



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13 JAN 64

TABLE 1: CHECK LIST

		GRAVITY WAVE PARAMETERS						HIGH LEVEL PARAMETERS				
	1	2	3	4	5	6	7	8	9	10	11	12
	DATE	1000 ft. wind 30° to hill axis	1000 ft. winds ≥13 kts.	intermediate stable layer	low level unstable air	increasing wind speed with height	little turning of wind with height	jet stream distance	cyclonic shear	cyclonic curvature	high speed rate just below trop.	total number checks for each night
NIGHTS OF GOOD SEEING	25-26 AUG. 51			✓								1
	15-16 OCT. 51	✓		✓							✓	3
	25-26 OCT. 51			✓								1
	9-10 SEPT. 52	✓					✓				✓	3
	27-28 SEPT. 52		✓	✓							✓	3
	1-2 SEPT. 53			✓			✓					2
	9-10 OCT. 53	✓								✓	✓	3
	17-18 NOV. 53			✓			✓					2
	17-18 SEPT. 55						✓				✓	2
18-19 APR. 58		✓			✓						2	
NIGHTS OF BAD SEEING	23-24 FEB. 50		✓	✓	✓	✓	✓		✓	✓	✓	8
	2-3 FEB. 51		✓	✓	✓	✓	✓	✓✓✓	✓	✓		10
	8-9 FEB. 51		✓	✓	✓	✓	✓	✓		✓		6
	13-14 FEB. 52	✓		✓	✓	✓	✓	✓✓	✓	✓		9
	16-17 APR. 52	✓		✓			✓			✓	✓	5
	30-31 MAR. 54	✓		✓		✓	✓	✓✓✓	✓	✓	✓	10
	19-20 SEPT. 54		✓	✓		✓	✓	✓✓		✓	✓	8
	16-17 MAY 55	✓	✓	✓				✓			✓	5
	19-20 DEC. 55	✓		✓	✓	✓	✓	✓✓	✓	✓	✓	10
	13-14 JAN. 56	✓		✓	✓		✓	✓✓✓	✓			8
	5-6 OCT. 58	✓		✓	✓			✓✓✓		✓	✓	8

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