MEMO #28

TO: W. BRUCKMAN DATE: AUGUST 22, 1990

FROM: P. CHEIMETS

SUBJECT: MEASUREMENT OF WIND AT MAUNA KEA SITE

CC: G. NYSTROM
R. DIAS
L. COYLE

SCOPE:

The lack of good applicable wind spectrum data leads us to conclude that a set of measurements must be made at the proposed Mauna Kea site to use in predicting the antenna pointing and tracking performance. We wish to associate these measurements with an existing body of measured climate information for the area. This requires that spectrum measurements at the proposed site be coordinated with average weather condition measurements at one of the easterly summits.

Two sources of general wind information were reviewed, one from a Mauna Kea site survey performed for the University of Hawaii and the other from the the USAF Climatic Center at Hilo. These show a year round prevailing easterly flow, though the pattern is less pronounced in the winter. The site survey presents wind data taken on the three peaks that surround the proposed SMA site. The data seems to show that the two upwind (easterly) peaks disrupt the wind pattern measured at the downwind peak, and presumably in the valley between. Unfortunately the data was taken on the three peaks at different times, and therefore are inconclusive.

A proposed wind experiment is described, complete with the data logging hardware.

INTRODUCTION:

We are developing a SMA antenna pointing and tracking model to assist in the preparation of an overall system specification. Key to a successful model is an understanding of the influences and disturbances that the antenna is subject to. In this case the single largest external, non-systematic pointing disturbance is the wind. As mentioned elsewhere the wind causes problems in two frequency domains, first continuous flows cause a tracking offset, and second, wind variations with a frequency component near the position servo bandwidth will cause oscillations.

We have attempted to find useful wind speed data from the literature, and though this has yielded useful information on the average wind speed at the Mauna Kea site, all attempts to acquire accurate spectrum information have failed. Furthermore, there is not enough general information about mountain top climates to make a meaningful estimate extrapolating from measurements elsewhere. Using the general formulae for wind spectrum with rough values for the free parameters can result in a spectrum that is as much as 10 times different than the true spectrum. Therefore, a test to measure the wind spectrum at the proposed has been proposed.

The wind literature that we reviewed all conclude that a minimal amount of data is required to characterize the wind speed spectrum at a given location. A single spectrum determined from 100-500 seconds of rapidly sampled wind velocity data is enough to determine the general spectrum for a particular wind direction at that site. For sites that have no unsymmetrical features this single measurement will tell you all you need to know about the wind in all directions.

The proposed SMA site is surrounded by several wind-effecting features that can, and the available data suggest, do influence the wind average speed and spectrum. There are two peaks to the east and a single summit to the west. These peaks are 100-200m higher than the plane that the antennas are to sit on and only 500-750m away.

In performing a wind spectrum measurement we would like to determine two things:

1) What is the worst wind spectrum we are likely to encounter within the precise and degraded operating range (wind speed <15 m/s),

2) What is the wind speed spectrum of the prevailing, or most likely wind.

These questions are separate because the site presents different features to the wind when approached from different directions. The first question can be answered by measuring wind spectra for winds in all directions. The second question is a little more difficult since the wind pattern at the site has not been measured enough to determine what the prevailing patterns are. We can make the assumption though, that the wind at the site during a period of prevailing wind at the summit is the prevailing wind. This suggests a simultaneous measurement of average wind speed at one of the eastern summits while the spectrum measurements are being made.

We spoke with the Hawaiian Bureau of Land Development to get wind direction data on the Mauna Kea site that would tell us what the prevailing winds were and in what season they were most likely to occur. This would indicate the most favorable time to perform the survey. They sent us two compilations of wind data from the island of Hawaii. Both are appended to this memo and summarized below.

The first survey is a listing of wind measurements taken over Hilo airport at an altitude of 3050 m, during the 11 year period between 1950 and 1961. These indicate a prevailing easterly flow at an average speed of 5.3-6.8 m/s throughout the year. The wind speed is below 10 m/s 90 % of the time, except in the winter when it exceeds this value 20 % of the time. The flow is within 22 deg of east 50 % of the time in the summer and fall, dropping to 30 ^

in the winter. In the winter and spring the wind is westerly 20 % of the time, it is hardly ever westerly in the summer and fall.

The second source of information on the mountain climate is a Mauna Kea site survey made over a year period between 1965-1966. This survey tracked winds on the three summits that immediately surround the proposed site. The data seem to show a tendency for the eastern summits to divert the flow, changing the apparent wind direction at the third summit, which is on the other side of the site; the implication being that the wind in the valley between is also affected. Unfortunately the data cannot be used to say anything that strongly since the periods during which the measurements were made on the three summits do not overlap. The measurements at the easterly summits were made during the months from April to December while the wind speed and direction were measured to the west between November and March, thus only overlapping a month, December and only measuring in the west during the least representative time during the year, winter. The fact that the western peak showed little easterly wind while the eastern peak showed a lot can be partially explained by the timing of the measurements.

It is still fair to say that the proposed site is not a general site with relationship to the wind, its direction or spectrum. There is still reason to believe that the plateau is in the wake of the two eastern summits and that they will cause a change in the apparent wind direction, average speed and spectrum. Furthermore an argument can be made that the apparent wind direction at the site will vary with wind speed at the summit without the apparent wind direction at the summit varying. If this condition is true then the spectrum is also a function on the summit wind speed, since this implies that the site is falling in and out of the wind wake of the eastern summits.

A test program that is intended to determine the likely wind induced disturbances to the antennas must take all these possibilities into account as well as the location on the site where the antenna might be. We are therefore proposing to measure at various points in the site and at various summit wind conditions.

TEST OUTLINE:

The test is a simple one, sample the wind speed at a short sampling period for 100 or so seconds under a variety of summit conditions. In order to produce meaningful information about wind speed variation up to the system bandwidth (in this case 10 Hz) the sensor must be able to respond to variations in excess of that rate and the signal must be sampled at at least twice the bandwidth, about a frequency of 20 Hz.

This relatively high frequency rules out the use of most wind sensors. The standard 3-cup anemometer responds up to about .5 Hz, the standard hot wire responds to variations up to 2 Hz. This limited the search to very thin hot wire or film probes, or a pitot tube mounted on a fast pressure transducer.

Most of the hot wires are mounted in directional mounts and have to be pointed into the wind just like a pitot tube. The hot films, though they do not have to be pointed up wind are very expensive, and like the wires, can be damaged by rain. It was decided therefore that the sensor would be a pitot tube connected to an inexpensive pressure transducer, a semiconductor type made by SENSYM, and costing $75 including conditioning electronics. The pitot tube is mounted on a wind vane that points it up into the wind.

The data gathering strategy is simple, two local computers, synchronized with each other, constantly track the wind speed and direction. One is on one of the summits at Mauna Kea the other is somewhere on the proposed site. When a certain condition is observed for the first time by the computer at the site, e.g. 5 m/s wind from the southeast, the computer begins to log data from our weather station, taking data at 20 Hz for about 100 seconds (2000 data points). This condition is then removed from the list of trigger conditions and the system awaits another trigger condition. Between trigger conditions the computer at the summit and the data logging computer take weather data every minute or so. By correlating the data gathered at the summit with that taken at the site we will be able to compare conditions at the proposed site to the years of weather data collected at the summit and above the island, and relate the measured spectrum to known prevailing conditions.

There is a potential problem with this approach, it assumes that there is a weather station at the summit that can be interfaced to the computer. This issue is unresolved at this time, we are looking into it. Since there is a prohibition against radio transmitters in the science preserve we have structured the data logging to be triggered by a condition at the site. This avoids the two computers having to communicate remotely. There is the possibility of some ambiguity resulting from this approach, but that will become apparent quickly.

TRANSDUCER PERFORMANCE

The pressure transducer must posses two attributes, high resolution to track the very small pressure fluctuation that result from wind speed variations, and rapid response. To determine that the selected transducer met these requirements several simple tests were run. First the high pressure port on the differential transducer was connected to an oil manometer. The manometer is a Dwyer product specifically designed for use with wind measuring pitot tubes. A syringe was inserted into the connecting tube and used to pressurize the inside to the desired levels, as determined from the manometer. The pressure transducer was calibrated and various intermediate pressures were placed on it. The absolute accuracy was found to be about .7 m/s with resolution and repeatability better than .5 m/s. There seems to be a slight nonlinearity through the calibration range, this can be removed by look up tables.

The test of the transducer to a dynamic input was performed by connecting a tube to the high pressure port of the transducer, crimping the far end shut, and rapidly squeezing and releasing it. The squeezing action was performed by rotating an eccentric over the tube at various RPM. The output of the transducer was tracked with a storage scope. The output measured between 60 and 62 mV for crimping rates between 5 and 20 Hz. This correspond to a pressure change of around 2522 Pa, determined from calibration. This compares to an expected pressure variation of 2580 Pa, virtually identical.

WIND VANE:

The wind speed is measured by comparing the dynamic to the static pressure. This is done by putting one pressure tap directly into the wind while having another one always perpendicular to the wind (see Figure). In the present experiment the proposed method is to use a simple weather vane to point the dynamic tap or pitot tube into the wind and a downward pointing tap to register static pressure. The taps will each be connected to one of the ports of a differential pressure transducer.

The vane consists of a pitot tube and split tail mounted on a pivot, the wind forcing it to point upwind. The dynamic pressure is carried from the moving vane to a stationary tube through a lightly loaded oring in the pivot bearing. The tail is split to increase the restoring torque caused by a given wind. An internal cavity in the slip joint can be filled with a high viscosity fluid to increase damping, if this becomes necessary.

DATA LOGGER:

Presently we propose to use one of a variety of very low power computers designed specifically for the purpose of recording data in the field. The computers require very little power and can run for weeks without intervention, given that the amount of data that is being taken does not exceed the on board storage capacity. In our case the total data storage requirement is easy to calculate. Static ram boards are added until the memory requirements are met.

The computer will be enclosed in a weather tight container, probably made from a modified standard equipment case. If we determine that the power requirements are greater than the battery pack we may include a solar panel to recharge the batteries.

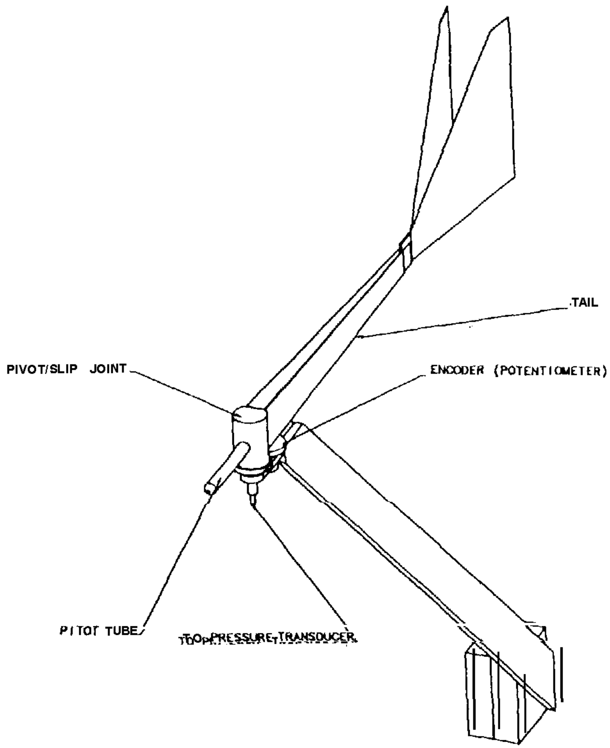

FIGURE SCHEMATIC OF WEATHER VANE

DATA REDUCTION:

Data reduction can be handled in a number of ways. The most likely approa ch is to perform a Fourier transform on the data and smooth it to remove spikes and drop outs. Then we can compare it to 50 years worth of accumulate wind spectrum data to determine the relevant modelling parameters, this will help ensure that we have good, consistent data. More simply we can use the measured data, as is, as an input to a control model of the antenna. This will give us an estimate of pointing performance immediately. Different pointing control methods can be examined to determine those that have the most likelihood of achieving the desired specification.

Data ...sing Division
2150th Weather Squadron

PERCENTAGE / FREQUENCY OF DIF... ...NS BY SPEED GROUPS

WINDS ALOFT SUMMARY

STATION	STATION NAME	MO OR SEASON	TYPE OF OBSERVATION	LEVEL
21504	HILO, HAWAII IH WBAP	WINTER	RAWINS	700 MB 10,000 ft

YEARS: 50 51 52 53 54 55 56 47 58 59 60 61

SPEED / DIR	M/S 1-4 / KNOTS 1-9 / M.P.H. 1-10	5-10 / 10-19 / 11-22	11-15 / 20-29 / 23-33	16-20 / 30-39 / 34-45	21-25 / 40-49 / 46-56	26-30 / 50-59 / 57-68	31-38 / 60-74 / 69-85	39-51 / 75-99 / 86-114	52-77 / 100-149 / 115-172	78-102 / 150-199 / 173-229	≥ 103 / ≥ 200 / ≥ 230	TOTAL ALL OBS. OBS.	TOTAL ALL OBS. %	SPEED (KNOTS) SUM	SPEED (KNOTS) MEAN
N	52	57	6	1								116	5.3	1243	10.7
NNE	44	54	15	1								114	5.2	1333	11.7
NE	36	84	20	6	1							147	6.7	2137	14.5
ENE	58	100	28	10								196	8.9	2832	14.5
E	55	164	55	13	2							289	13.1	4581	15.8
ESE	48	118	26	2								194	8.8	2712	14.0
SE	39	68	8	1								116	5.3	1375	11.9
SSE	37	61	7	3								108	4.9	1267	11.7
S	42	56	15	5	1							119	5.4	1537	12.9
SSW	29	52	17	5								103	4.7	1426	13.8
SW	46	71	19	8	5	1	1					151	6.8	2327	15.4
WSW	37	74	25	12	1							149	6.8	2319	15.6
W	49	77	27	10	1							164	7.4	2413	14.7
WNW	30	35	7	2								74	3.4	832	11.9
NW	38	48	5	2								93	4.2	1006	10.8
NNW	28	28	3	1								60	2.7	645	10.7
CALM												12	.5		
TOTALS	668	1147	283	82	11	1	1					2205	-	30036	13.6
PERCENT	30.3	52.0	12.8	3.7	.5	.0	.0					-	100.0		
MEAN SPEED (KNOTS) BY GROUP	5.7	13.9	24.4	34.0	43.4	51.0	70.0								

θ 112	V_r 2.2744	σ_v 15.660	ΣXY 50138.049	ΣV^2 551876.313	* $N\sigma_y/\Sigma X$ 4.464	** σ_v/V_r 6.89	σ_a 12.816	σ_b 8.999	σ_s 8.048
N 2205	$\Sigma X/N$ 2.113	σ_x 12.500	SUM OF E COMPONENTS(ΣX) 4659.445	ΣX^2 354239.503	* $N\sigma_x/\Sigma X$ 5.916	** σ_v/σ_s 1.95	r .208	* e 1.424	
ψ 18	$\Sigma Y/N$ .841-	σ_y 9.432	SUM OF N COMPONENTS(ΣY) 1854.739-	ΣY^2 197636.797	* $N\sigma_y/\Sigma Y$ 11.213-	** $V_r/\bar{v}$ .17	ΣV 30036	$\bar{v}$ 13.6	

σ_x Standard devation of east components

σ_y Standard deviation of north components

σ_v Standard vector deviaton of wind velocity

r Correlation coefficient of north and east components

$\bar{v}$ Average wind speed

V Scalar wnd speed

e Ratio of standard deviations $=\sigma_a/\sigma_b$

σ_a Standard deviation of wind components along the major axis of the distribution

σ_b Standard deviation of wind components perpendicular to the major axis of the distribution

ψ Angle of rotation of the major axis of the wind distribution counter-clockwise from E-W direction

θ Resultant wind direction

V_r Resultant wind speed

σ_s Standard deviaton of wind speeds

* Wherever ratio ~1000.0000, printed 999.9999

** Wherever ratio ≥100.00, printed 99.99

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2150th Weather Squadron

{PERCENTAGE / FREQUENCY} OF DIF NS BY SPEED GROUPS

WINDS ALOFT """"MARY

21504 HILO, HAWAII IH WBAP — STATION / STATION NAME

SPRING — MO. OR SEASON

RAWINS — TYPE OF OBSERVATION

700 MB — LEVEL

50, 51 52 53 54 55 56 57 58 5Y 60 61 — YEARS

SPEED M/S	1-4	5-10	11-15	16-20	21-25	26-30	31-38	39-51	52-77	78-102	≥ 103	TOTAL ALL OBS.		SPEED (KNOTS)	
KNOTS	1-9	10-19	20-29	30-39	40-49	50-59	60-74	75-99	100-149	150-199	≥ 200				
DIR / M.P.H.	1-10	11-22	23-33	34-45	46-56	57-68	69-85	86-114	115-172	173-229	≥ 230	OBS.	%	SUM	MEAN
N	49	42	4	1								96	4.1	894	9.3
NNE	67	47	3									117	5.0	1010	8.6
NE	58	79	5	1								143	6.1	1496	10.5
ENE	79	151	29	5								264	11.3	3372	12.8
E	96	199	47	4	1							347	14.8	4641	13.4
ESE	75	108	13	2								198	8.4	2304	11.6
SE	59	65	8	1								133	5.7	1426	10.7
SSE	43	37	2	1								83	3.5	808	9.7
S	37	44	5	1								87	3.7	923	10.6
SSW	41	40	5	2								88	3.8	971	11.0
SW	46	65	29	6								146	6.2	2018	13.8
WSW	54	69	24	5								152	6.5	2051	13.5
W	71	83	28	3	1							186	7.9	2370	12.7
WNW	59	47	6									112	4.8	1049	9.4
NW	66	30	3									99	4.2	816	8.2
NNW	45	38	2	1								86	3.7	802	9.3
CALM												8	.3		
TOTALS	945	1144	213	33	2							2345	-	26951	11.5
PERCENT	40.3	48.8	9.1	1.4	.1							-	100.0		
MEAN SPEED (KNOTS) BY GROUP	5.5	13.5	24.3	33.4	44.7										

θ	V_r	σ_v	ΣXY	ΣV^2	* $N\sigma_v/\Sigma X$	** σ_v/V_r	σ_a	σ_b	σ_s
99	2.0437	13.212	32070.444	418952.353	3.674	6.46	11.077	7.202	6.826
N	**$\Sigma X/N$**	**σ_x**	**SUM OF E COMPONENTS(ΣX)**	**ΣX^2**	*** $N\sigma_x/\Sigma X$**	**** σ_v/σ_s**	**r**	*** σ**	
2345	2.017	10.939	4729.474	290013.230	5.424	1.94	.177	1.538	
ψ	**$\Sigma Y/N$**	**σ_y**	**SUM OF N COMPONENTS(ΣY)**	**ΣY^2**	*** $N\sigma_y/\Sigma Y$**	**** $V_r/\bar{v}$**	**ΣV**	**$\bar{v}$**	
12	.330-	7.409	774.153-	128939.112	22.444-	.18	26951	11.5	

σ_x Standard deviation of east components

σ_y Standard deviation of north components

σ_v Standard vector deviation of wind velocity

r Correlation coefficient of north and east components

$\bar{v}$ Average wind speed

V Scaler wnd speed

Ratio of standard deviations $= \sigma_a/\sigma_b$

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θ Resultant wind direction

V_r Resultant wind speed

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** Wherever ratio E100.00, printed 99.99

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MATS 60-66

Data ˈ ˈassing Division
2150. Weather Squadron

{FREQUENCY} OF DIP⁻⁻TIONS BY SPEED GROUP

WINDS ALOFT SUMMARY

21504 HILO, HAWAII TH WBAP — STATION / STATION NAME
SUMMER — MO. OR SEASON
RAWINS — TYPE OF OBSERVATION
700 MB — LEVEL

50 51 52 53 54 95 56 97 50 59 60 61
YEARS

SPEED M/S	1-1	5-10	11-15	16-20	21-25	26-30	31-38	39-51	52-77	78-102	≥ 103	TOTAL ALL OBS.		SPEED (KNOTS)	
KNOTS	1-B	10-15	20-29	30-39	40-49	50-59	60-74	75-99	100-149	150-199	≥ 200				
DIR M.P.H.	1-1D	11-22	23-33	34-45	46-56	57-68	69-85	86-114	115-172	173-229	≥ 230	OBS.	%	SUM	MEAN
N	44	47	2									93	4.0	849	9.1
NNE	66	45	7	1								119	5.2	1105	9.3
NE	85	106	10									201	8.7	2129	10.6
ENE	105	204	33	1	1			1				345	15.0	4390	12.7
E	135	363	77	8								583	25.4	7834	13.4
ESE	84	194	25									303	13.2	3722	12.3
SE	70	113	10	1								194	8.4	2154	11.1
SSE	44	47	4	2								97	4.2	989	10.2
S	48	34	2	1								85	3.7	742	8.7
SSW	27	24	1									52	2.3	497	9.6
SW	22	12										34	1.5	264	7.8
WSW	24	10										34	1.5	225	6.6
W	29	12										41	1.8	282	6.9
WNW	27	9										36	1.6	266	7.4
NW	22	6	1									29	1.3	212	7.3
NNW	28	16	1									45	2.0	369	8.2
CALM												8	.3		
TOTALS	860	1242	173	14	1			1				2299	-	26030	11.3
PERCENT	37.4	54.0	7.5	.6	.0			.0				-	100.0		
MEAN SPEED (KNOTS) BY GROUP	5.6	13.3	23.5	33.9	67.0			07.0							

θ 89	V_r 7.7242	σ_v 10.419	ΣXY 7963.768	ΣV^2 386621.334	* $N\sigma_y/\Sigma X$ .865	** σ_v/V_r 1.35	σ_a 8.011	σ_b 6.662	σ_s 6.324
N 2299	$\Sigma X/N$ 7.723	σ_x 7.992	SUM OF E COMPONENTS(ΣX) 17755.135	ΣX^2 283913.144	* $N\sigma_x/\Sigma X$ 1.035	** σ_v/σ_s 1.65	r .045	◦ 1.203	
ψ 7	$\Sigma Y/N$ .136	σ_y 6.684	SUM OF N COMPONENTS(ΣY) 312.461	ΣY^2 102708.178	* $N\sigma_y/\Sigma Y$ 49.179	** $V_r/\bar{v}$ .68	ΣV 26030	$\bar{v}$ 11.3	

σ_x Standard devation of east components
σ_y Standard deviation of north components
σ_v Standard vector deviaton of wind velocity
r Correlation coefficient of northand e ast components
$\bar{v}$ Average wind speed
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Data [illegible]ssing Division
2150[illegible] Weather Squadron

{PERCENTAGE / FREQUENCY} OF DIR[illegible]IONS BY SPEED GROUPS

WINDS ALOFT S[illegible]MMARY.

21504	HILO, HAWAII TH WBAP	AUTUMN	RAWINS	700 MB
STATION	STATION NAME	MO. OR SEASON	TYPE OF OBSERVATION	LEVEL.

50 51 32 53 54 55 56 57 58 59 60

YEARS

SPEED M/S / DIR	1-4	5-10	11-15	16-20	21-25	26-30	31-38	39-51	52-77	78-102	> 103	TOTAL ALL OBS. OBS.	TOTAL ALL OBS. %	SPEED (KNOTS) SUM	SPEED (KNOTS) MEAN
KNOTS	1-9	10-19	20-29	30-39	40-49	50-59	60-74	75-99	100-149	150-199	≥ 200				
M.P.H.	1-10	11-22	23-33	34-45	46-56	57-68	69-85	86-114	115-172	173-229	≥ 230				
N	68	45				1						114	4.8	981	8.6
NNE	69	54	4									127	5.3	1142	9.0
NE	89	116	8									213	9.0	2205	10.4
ENE	91	236	50	3								380	16.0	5016	13.2
E	136	259	47	7								449	18.9	5730	12.8
ESE	77	118	16	1								212	8.9	2364	11.2
SE	75	67	2									144	6.1	1317	9.1
SSE	49	40	1									90	3.8	793	8.8
S	46	53	5									104	4.4	1072	10.3
SW	4a	34	4	2								82	3.5	822	10.0
WSW	33	44 39	8	2								93	3.9	956	10.3
'		43	1									77	3.2	769	10.0
W	56	47	6									111	4.7	1127	10.2
NNW	32	13										45	1.9	334	7.4
NW	38	18	2									58	2.4	455	7.8
NNW	40	22										62	2.6	456	7.4
CALM												15	.6		
TOTALS	985	1204	156	14		1						2376		- 25539	10.7
PERCENT	41.5	50.7	6.6	.6		.0							100.0		
MEAN SPEED BY GROUP	5.5	13.2	23.7	34.4		54.0									

θ 85	V_r 5.1301	σ_v 11.247	ΣXY 34549.465	ΣY^2 362980.597	* $N\sigma_y/\Sigma X$ 1.330	** σ_v/V_r 2.19	σ_a 9.182	σ_b 6.496	σ_s 6.104
N 2376	ΣX/N 5.112	σ_x 8.961	SUM OF E COMPONENTS(ΣX) 12146.755	ΣX^2 252795.733	* $N\sigma_x/\Sigma X$ 1.753	** σ_v/σ_s 1.84	r .203	* e 1.413	
ψ 18	ΣY/N .428	σ_y 6.798	SUM OF N COMPONENTS(ΣY) 1015.880	ΣY^2 110184.853	* $N\sigma_y/\Sigma Y$ 15.899	** $V_r/\bar{v}$ .48	ΣV 25539	$\bar{v}$ 10.7	

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σ_a Standard deviation of wind components along the major axis of the distribution

σ_b Standard deviation of wind components perpendicular to the major axis of the distribution

ψ Angle of rotation of the major axis of tha wind distribution counter-clockwise from E-W direction

θ Resultant wind direction

V_r Resultant wind speed

σ_s Standard deviaton of wind speeds

* Wherever ratio ≥1000.0000, printed 999.9999

** Wherever ratio ≥100.00, printed 99.99

AWS HQ FORM MAY 59 O-46 PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE.

STANLOCK [illegible]

MATS 60 66