VARIABILITY OF PRECIPITATION IN WESTERN OREGON AS REVEALED BY RADAR ECHO PATTERNS

by

LAURENCE DAVID MENDENHALL

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APPROVED:

[redacted]

Associate Professor of Physics

In Charge of Major

[redacted]

Chairman of Department of Physics

[redacted]

Chairman of School Graduate Committee

[redacted]

Dean of Graduate School

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VARIABILITY OF PRECIPITATION IN WESTERN OREGON AS REVEALED BY RADAR ECHO PATTERNS

INTRODUCTION

The wide variation in mean annual precipitation amounts in western Oregon directs attention to the probable factors causing this variability. Locations only a few miles from the main Willamette Valley receive over 120 inches of rainfall annually compared to the 35 to 40 inch mean annual precipitation recorded in the central portion of the valley. The average effect of the Coast and Cascade Range mountain barrier on the precipitation pattern is shown in Table I where the zones used in this study are identified and the mean annual precipitation for each station is given. Plate I shows the locations of the stations and the general topographic features within the area under consideration.

After observing the remarkable contrast in annual amounts between the various zones one is inclined to say that coast range stations, for example, always receive more precipitation than valley stations. However, this assumption is not always true. There are wide variations in the precipitation anomalies between various zones. Some precipitating systems will deposit more or equal amounts of precipitation on valley stations than on coast range stations. On other occasions, coastal stations receive more precipitation than the coast range stations. The magnitude of the differences varies considerably also.

The objective of this study is to determine what radar echo characteristics and patterns are uniquely associated with variations in precipitation amounts between zones. Little is reported in the literature regarding echo characteristics associated with variations due to orographic effects. This is so partly because most weather radars are located in areas where no appreciable orographic effects can or do exist. The location of the AN/CPS-9 weather radar set on 2200 foot McCulloch Peak in the Oregon Coast Range provides an unusual opportunity to study this variability, especially as it relates to orographic effects.

Studied in detail are two general types of precipitation variation. One type concerns the cases where the coast range stations receive more precipitation than do stations in surrounding zones. The other type deals with the cases in which the Willamette Valley receives as much or more precipitation than the coast range stations.

PROCEDURE FOR ANALYSIS OF DATA

The method used by one in the analysis of the large quantities of radar data available for a study such as this is most difficult to select. Those familiar with the inherent capabilities and limitations of radar know of the difficulty in extracting useful and meaningful data from the PPI (Plan Position Indicator) scope or the RHI (Range-Height Indicator) scope. Several previous investigators noticed on occasion that radar echoes took on an organized appearance. Clem and Moxon (5, p.38) investigated in detail the appearance of banded structures in radar echoes, but did not relate these structures to precipitation characteristics; nor did they find any relationship between these structures and the underlying topographic features. Fujiwara (I:33-39), however, studied the formation of stationary rainbands and related the formation of these to topographic features. Ligda (14, 1274-1275) states that, ". . . there are no unique features in this type (orographic) of precipitation except that on occasion it can be fairly uniform."

None of the above mentioned characteristics appear to be commonly present on the radar scope. In fact, most of the time there seems to be a constantly changing pattern. Since radar detects precipitation and since it is the quantity being investigated it seems logical to start a study of this type by first looking at the precipitation data. To determine from the radar data when there is a significant change in the echo pattern corresponding to some change in the precipitation anomaly is too subjective. For these reasons the precipitation pattern is analyzed first in this study.

For purposes of this study, only precipitation data from recording rain gages in Oregon within 125 miles of the radar are used. Table I identifies the stations and groups them into nine zones. The stations are zoned according to their mean annual precipitation and geographic location. Plate I shows the locations of all 59 numbered stations used in this study.

The periods of precipitation analyzed were selected out of the approximately 350 hours of radar film data collected between 22 August and 31 December 1960. Hourly precipitation data for this period for all 59 stations was then tabulated on ledger form. Next the three-hourly amounts for each station are totaled and the zonal three-hourly mean computed. Using Zone C as the base for all zones it is determined whether each zone has more, equal, or less precipitation than Zone C. These other zones are then marked with either +, -, or N (equal).

With this information at hand adjacent three-hourly periods are compared. When a change occurs, i.e. from +to

- in one or more of the zones in relation to Zone C, the period for that particular precipitation regime ends and the comparison with the next three-hourly period begins. Thus, a certain precipitation regime may last from three hours to any multiple thereof. Generally, if the regime lasted for more than 12 hours, it was broken down into smaller intervals of time, especially if there appeared a marked change in rainfall intensity during the period.

Selection of three-hourly periods for the initial grouping came about for the following reasons: (1) the Fergusson weighing gages used at 56 of the stations do not provide accurate hourly amounts, but three-hourly amounts are more reliable; (2) all zones should be affected by the atmospheric process or processes taking place in the three-hourly period but probably not for shorter intervals of time. Indeed, in nearly all cases, the maximum precipitation amount for a given three-hourly period occurred during that period for all zones, except usually not in Zone I. Larger intervals of time are likely to smooth over any variation in the precipitation pattern that might occur within that time.

The procedure used to classify the radar echo pattern and characteristics corresponding to the two general precipitation regimes evolved after first checking the radar film for the two most contrasting cases. The best example of the most pronounced orographic effect was found in the case of 23 November 1960 between 1900 and 2100. During this period Zone A showed a mean three-hourly precipitation amount of 0.07, Zone C0.62, Zone E0.11, and Zone G0.32. At the other extreme, for the cases where the Willamette Valley (Zones E and F) receives more precipitation than, or equal amounts to, the coast range (Zone C), the best example occurred in the case of 8 October 1960 between 1300 and 1800P.

These two cases were then analyzed very closely in order that any differences in the echo pattern might be detected, and that then these same characteristics would be looked for in the remainder of the data selected for analysis. Echo characteristics especially looked for were direction and movement of cells and lines, horizontal extent, character of the echoes, i.e., stratiform or cellular, streaks (length, width, spacing between longitudinal axis) and life times of the echoes.

The most pronounced differences between the two cases selected above were: (1) character of echoes and (2) the dissipation of echoes as they moved across the coast range into the Willamette Valley on the 23 November case. The echoes were of cellular character for the 8 October case, while for the 23 November case the echo pattern appeared wholly stratiform in nature.

The problem then became one of adopting a procedure for the analysis of the radar film data that would reveal these differences in the other cases selected, if they were present. The matter of echo character determination is subjective and consequently became a relatively easy characteristic to determine, one that is determined by appearance only. To detect whether or not the echoes dissipate as they move across the coast range into the Willamette Valley, a method of determining relative areas covered by echo in the various zones evolved. A grid system composed of squares 25 miles on a side was set up by drawing north-south and east-west lines tangent to the 25 mile range markers. The grid extended to the 75 mile range markers directly east and west of the radar. Thus, there are eight zones, seven of which correspond roughly to one of the zones listed at the end of Table VI.

This phase of the study required two people, one to operate a movie projector and to record the data and the other to make the echo measurements. Echo characteristics measured were: (1) percentage of echo coverage in each of the eight echo measuring zones defined in Table II; (2) echo type (stratiform, S, or cellular, C); (3) echo movement (direction from which the echo moves); and, (4) the mean range that echo appeared during the time period involved for four azimuths (north, N; south, S; west, W; and east, E).

The summary of mean three-hourly zonal precipitation and mean zonal echo coverage appears in Table VI for the case of plus coast range anomaly and in Table VII for coast range minus anomaly. For all columns, except those headed by D, O' and I, the mean three-hourly precipitation is the top figure listed in the column and the lower figure is the mean echo coverage for the period in question.

Computations from the Salem, Oregon rawinsonde sounding for the 12-hourly periods during and immediately adjacent to the times selected for study appear in Table II for the coast range plus anomaly and in Table III for the coast range minus anomaly. Computations of temperature difference between 1000 and 850 millibars, 850 and 700 millibars, and 700 and 500 millibars appear as a rough measure of stability in the lower layers of the atmosphere. The other parameters listed will be mentioned when appropriate in later sections.

The general surface synoptic conditions for the area within 400 miles of the radar are listed in Table IV for the coast range plus anomaly and in Table V for the coast range minus anomaly.

All echo measurements listed are for antenna tilts of 2.5 or 3.0 degrees in order to eliminate the ground clutter from the measurements. Plate II shows the ground clutter as obtained for antenna tilts of 1 and 2.5 degrees.

COAST RANGE PLUS ANOMALY

The most illustrative example of orographic precipitation resulting in a much higher mean in Zone C than for other zones appears in Plates III through V. During the period 1900 - 2100P on 23 November 1960 the mean three-hourly precipitation for Zone C was 0.62 inch while Zone A received 0.07 and Zone E received 0.11. Zone G, the north Cascade zone immediately east of Zone E, shows an increase again over the valley. However, the echo coverage did not show an increase, probably due to range attenuation factors resulting from the heavy precipitation. The echo character during this period was stratiform.

Plate III shows the echo pattern at a plus one degree antenna tilt at the top and a plus 3.5 degree antenna tilt in the lower photograph. The significant echo features in this photograph are: (1) the stratiform nature of the echo; (2) the distance that the echo extends to the east compared to the distance to the west, an indication that the air is starting to lift as it crosses the coast line and more lifting as it crosses the Cascades: (3) the void space over the Willamette Valley, especially noticeable in the lower photograph, indicating that the precipitation decreases markedly in intensity as it crosses the valley. These three characteristics are apparent in 65 percent of the cases of the coast range plus anomaly.

Plates IV and V show the same echo characteristics persisting nearly one and two hours later, respectively.

For coast range amounts less than 0.15 inch but still more than Willamette Valley amounts, the relationships are less apparent than for the amounts above 0.30 inch. Table VI, Part B shows the summary for Zone C amounts less than 0.15 inch. The most significant change is in the character of the echo. In the case for Zone C amounts above 0.30 inch, the predominant character was stratiform. In this case, the cellular characteristic is more pronounced, indicative of more convection taking place (2, 78-84), and thus making it more likely that the valley stations can receive as much precipitation as the coast range stations.

No significant correlation exists between any of the factors listed in Table II with the intensity of the orographic anomaly. Thus, radar appears to detect the orographic effect more vividly than can any of the routine synoptic or air-mass analyses techniques commonly used. 11 of the coast range plus anomaly cases occurred with a cold front or occluded front in the area, while two cases occurred immediately after the passage of a cold front. The other 11 cases apparently occurred in the absence of any frontal effect.

COAST RANGE MINUS ANOMALY

Nine cases for which the mean three-hourly precipitation for the coast range was less than for the Willamette Valley are listed in Table VII. The cases are listed in order of decreasing contrast between Zone C amounts and Zone E amounts. The echo character is cellular in nature for eight out of the nine cases, although there appeared stratiform type along with the cellular type in seven of the cases.

The correlation between a change in mean precipitation from one adjacent zone to another is not quite as good as in the case for the coast range plus anomaly. For an increase in precipitation from Zone A to Zone C in four cases, there existed a corresponding increase in percentage of echo coverage in three of the cases. For an increase of precipitation from Zone C to E in six cases, radar echo showed a corresponding increase in four cases. For an increase in precipitation from Zone E to G in five cases, a corresponding increase in echo from the same zones occurred in four cases.

Plate VI illustrates the case of an echo pattern during which Zones G and H received more precipitation than Zone C. The scope pattern for 5 October at the top of the page shows the frontal band over the coast and then later, in the bottom picture, over the valley, with no decrease in areal extent. In fact there is a slight increase shown as listed in Table VII.

Cold fronts were present in two out of the nine cases analyzed for this anomaly. Again, no obvious correlation existed with any of the parameters listed in Table III.

CONCLUSIONS

This study demonstrated that radar can successfully detect the occurrence of orographic precipitation, especially in the most extreme cases of a large plus anomaly for Zone C. For an increase in precipitation from Zone A to Zone C in 11 cases, a corresponding increase in radar echo coverage occurred in the same 11 cases. 11 cases showed a decrease in precipitation from Zone C to E with a corresponding decrease in the radar echo in nine of the same cases.

The correlation between a change in the precipitation amount from a given zone to another zone and the corresponding like change in the echo pattern between the same zones is not nearly as good for the southern zones (zones south of the radar), probably because of the more complicated topographic features. A much better correlation can probably be obtained if stepped-gain is used for the radar receiver. In one zone the echo may exceed saturation but have the same percentage of coverage as the echo that is not to saturation in another zone, and consequently the correlation may turn up less.

RECOMMENDATIONS FOR FURTHER RESEARCH

Presenting the radar echo on the PPI scope is a very crude method of presenting certain kinds of data for use by the observer. For instance, signal intensity information is much more meaningful if presented on an A scope instead of on the PPI where it is difficult to detect gradations of brightness as related to the strength of the returned signal. Intensity information coupled with measurement of areal extent of echo as done in this study could make feasible the estimation of areal amounts of precipitation. This is a necessary step to take if more work is done on precipitation variability and estimation of amounts.

Another type of data provided by the AN/CPS-9 but not used in this study is the depiction of the vertical structure of the precipitation as provided by the RHI scope. Due to operational difficulties with the RHI during the period under study and consequently very little data obtained from it, no data from the RHI is presented here. However, the RHI scope provides invaluable information on the vertical extent of precipitation and should be exploited as much as possible.

Stepped-gain control is another method used to determine relative intensities and should be used for a study of this type. An accurately calibrated radar system coupled with stepped-gain can reveal even more clearly some of the processes taking place over a mountain range, for instance.

Finally, detailed examination of the precipitation pattern around Marys Peak with another radar set at the same time that the AN/CPS-9 is operating at McCulloch Peak surveying the larger scale precipitation pattern, could provide additional insight into the physical processes occurring during various stages of a certain precipitation regime. By investigating some of the aforementioned problems maximum utilization of the unique advantages available for weather radar research conducted at McCulloch Peak will come closer to reality.

TABLE I

IDENTIFICATION OF STATIONS AND ZONES

Zone	No.	Station Name		Station Elev. Ft.	Years[4] of Record	Mean Annual Precip., In.
	01	Astoria WBAP (AST)	+	8	*	76.30
	02	Seaside	+	10	*	79.86
A	03	Nehalem		75	18	81.90
	04	Yaquina Head Lgt. Sta.		87	11	64.87
				M_e=45		Mp=75.74 SD=6.56
	05	Florence 3 NNW		49	7	60.22
B	06	Allegany		50	13	86.50
	07	Bandon	+	15	*	55.54
				M_e=38		Mp=67.42 SD=11.42
	08	Lees Camp		595	12	109.50
	09	Tillamook 12 E		320	10	103.18
C	10	Carlton 13 W		1950	9	90.30
	11	Valsetz	+	1135	4	124.90
				M_e=1000		Mp=106.97 SD=12.41
	12	Clatskanie	+	92	9	59.40
	13	Jewell Guard Sta.	+	491	6	72.70
D	14	Haskins Dam	+	840	*	75.19
	15	Grand Ronde		340	0	59.44
				M_e=441		Mp=66.68 SD=6.84
	16	Goble 6 SW		493	17	43.40
	17	Vernonia	+	490	7	47.48
	18	Sauvies Island		40	17	41.30
	19	Portland WBAP (PDX)	+	21	*	35.38
	20	Portland WB City	+	30	*	40.09
	21	Buxton		325	19	50.10
E	22	Buxton Mountaindale		360	14	49.50
	23	Glenwood		805	12	60.78
	24	Rex 1 S	+	490	18	40.40
	25	Colton		714	16	42.60
	26	Silverton 3 SSE	+	870	17	49.00
	27	Salem WBAP (SLE)	+	195	*	40.02
	28	Jefferson		248	14	40.60
				M_e=391		Mp=44.67 SD=4.70

IDENTIFICATION OF STATIONS AND ZONES - Continued

	29	Lacomb 1 WNW	+	665	18		46.10
	30	Oregon State University[2]	+	320	*		37.27
	31	Bellfountain		450	6		44.50
	32	Noti 2 ESE	+	450	17		52.50
	33	Drain 10 NNW		750	14		64.10
F	34	Eugene WBAP (EUG)	+	361	*		37.67
	35	Fern Ridge Dam	+	380	16		38.40
	36	Lookout Point Dam	+	712	5		40.60
	37	Dorena Dam	+	757	11		56.40
	38	Oakridge Salmon Hatchery	+	1225	*		43.64
	39	Cottage Grove Dam	+	831	15		46.40
	40	Blackbutte 1 N	+	1001	16		55.20
	41	Roseburg WBAP (RBG)[5]	+	505			
				M_e=637		Mp=46.92 SD=8.13	
	42	Bonneville Dam	+	85	15		67.00
	43	Estacada 24 SE		2214	15		57.25
	44	Detroit	+	1586	*		75.24
G	45	Detroit Dam Power House	+	1300	5		81.81
	46	Marion Forks Fish Hatchery	+	2475	8		71.71
	47	Government Camp	+	3900	7		93.20
				M_e=1927		Mp=74.37 SD=11.51	
	48	Cascadia Ranger Station	+	796	*		61.25
	49	Santiam Junction		3780	5		67.54
	50	Marcola		530	18		58.10
	51	Blue River[2]		1040			
H	52	McKenzie Bridge Ranger Sta.	+	1375	*		69.99
	53	Sutherlin 14 ENE		1035	4		58.20
	54	Disston 1 NE Laying Creek	+	1218	*		52.74
	55	Steamboat Ranger Station		1200	4		51.12
	56	Upper Steamboat Creek		1855	4		52.79
				M_e=1425		Mp=58.97 SD=18.42	
	57	Hood River Exp. Sta.	+	500	*		29.54
	58	Simnasho	+	2400	7		12.25
I	59	Redmond	+	2994	*		8.54
	60	Bend	+	3599	*		12.25
				M_e=2384		Mp=15.67 SD=8.15	

IDENTIFICATION OF STATIONS AND ZONES - Continued

1 Mean taken from Newport located about two miles south-southeast of the station.

2 Mean taken from Corvallis State University located about one mile northeast of station. Tipping-bucket gage.

3 Tipping-bucket gage operated by Oregon State University. No annual means available.

4 The number of years of record used in computing the mean annual precipitation for those station means not marked with an asterisk.

5 Roseburg WBAP not used in this study; not used in computation of zonal mean.

+ Indicates station also equipped with standard rain gage. Annual totals from the standard rain gage used where possible when record missing from recording gage.

* Mean as published by the Weather Bureau. For those stations designated by Weather Bureau Airport or Weather Bureau City in the station name, the means are based on the period 1921-1950 adjusted to represent observations taken at the present location. All other stations have means based on the period 1931-1955.

M_e Mean station elevation for zone.

Mp Mean annual precipitation for zone.

SD Standard deviation of mean annual precipitation for stations within zone.

TABLE II

Date / Time	ΔT_1	ΔT_2	ΔT_3	Stability Index	Freezing Level, Ft.	Absolutely Unstable Base, mb	Absolutely Unstable Top, mb	Neutral Stability Base, mb	Neutral Stability Top, mb	$\Delta\theta$	Potential Instability Base	Potential Instability Top	Lifting Req., Ft.	Inversions Base, mb	Inversions Top, mb	ΔT
22 Aug. 1900 - 2400P																
22/1600P	11	11	15	+5	7200	—	—	—	—	0.4	—	—	—	—	—	+4
23/0400P	8	9	14	+7	7500	—	—	1010	1000	0.4	560	530	2000	—	—	0
23 Aug. 1300 - 1700P																
23/1600P	10	10	14	+5	8000	1010	990	—	—	—	—	—	—	—	—	0
5 Oct. 2200 - 2400P																
5/1600P	8	14	15	+4	11000	1000	970	—	—	—	—	—	—	—	—	-2
6/0400P	6	8	16	+4	8600	670	640	—	—	—	—	—	—	960	970	+9
7 Oct. 0400 - 0900P																
7 Oct. 1000 - 1200P																
7/0400P	8	8	18	+2	6800	540	535	—	—	—	—	—	—	—	—	-3
7/1600P	10	9	14	+2	5500	1010	1000	—	—	—	—	—	4700	555	520	0
8 Oct. 0100 - 1200P																
8/0400P	7	10	15	+7	5000	—	—	—	—	0.5	700	690	4700	1000	960	-1
8/1600P	9	11	8	+13	5000	1010	1000	—	—	—	—	—	—	555	520	0

TABLE II - Continued

23 Oct. 1500 - 2400P 24 Oct. 0100 - 1600P																
23/1600P	9	9	17	+0	7500	—	—	—	—	—	—	—	—	—	—	-5
24/0400P	10	12	8	+12	5000	720	700	—	—	2.0	710	680	1000	690	660	-5
24/1600P	13	1	12	+16	11200	1010	980	495	465	1.5	800	790	5000	740	710	+3
26 Oct. 1000 - 1500P 26 Oct. 1600 - 2400P																
26/0400P	11	9	9	+3	5000	620	590	—	—	—	—	—	—	475	460	-6
26/1600P	11	12	12	+9	5300	—	—	1020	990	0.8	650	625	5000	625	590	0
27/0400P	8	9	9	+13	5300	—	—	—	—	—	—	—	—	690	675	-1
27 Oct. 1000 - 1800P																
27/1600P	7	8	14	+7	8500	—	—	1010	960	—	—	—	—	—	—	+2
28/0400P	5	8	16	+3	7500	700	630	1010	990	—	—	—	—	980	970	+3
30 Oct.-31 Oct. 1900 - 1200P																
30/1600P	1	9	14	+3	9000	660	650	—	—	—	—	—	—	590	570	+2
31/0400P	5	7	17	+3	9800	—	—	770	750	1.5	530	500	2000	800	770	-1
31/1600P	9	11	12	+6	8500	750	690	—	—	0.9	525	500	1500	—	—	-2
31 Oct.-1 Nov. 1900 - 1500P																
11/0400P	10	8	8	+17	5400	—	—	—	—	—	—	—	—	590	570	-3
1/1600P	12	7	11	+14	5500	750	735	—	—	—	—	—	—	740	710	0

TABLE II - Continued

23 Nov. 0100 - 1200P																
24 Nov. 1900 - 2400P																
24 Nov. 0100 - 0900P																
24 Nov. 1000 - 1200P																
24 Nov. 1300 - 1800P																
23/0400P	5	8	17	+4	5750	—	—	—	—	—	—	—	—	590	570	+1
														710	690	
23/1600P	7	7	17	+6	6600	—	—	—	—	—	—	—	—	—	—	0
24/0400P	6	6	18	+6	10500	590	545	—	—	—	—	—	—	800	760	+4
24/1600P	8	8	10	+12	4500	—	—	—	—	—	—	—	—	—	—	-4
25/0400P	6	11	14	+7	4500	—	—	—	—	—	—	—	—	950	930	-8
16 Dec. 1900 - 2400P																
16/1600P	1	10	19	+1	6250	—	—	—	—	—	—	—	—	985	965	-1
17/0400P	3	9	15	+7	5000	—	—	780	755	1.9	780	755	2750	1000	965	0
17 Dec.-18 Dec. 2200 - 0600P																
18 Dec. 0700 - 1500P																
18 Dec. 1600 - 2400P																
17/1600P	6	7	14	+8	5500	—	—	—	—	—	—	—	—	1015	990	-1
18/0400P	7	6	16	+8	7000	—	—	—	—	—	—	—	—	740	700	+3
18/1600P	10	10	18	+3	5000	—	—	—	—	—	—	—	—	—	—	0
19/0400P	10	9	14	+10	4000	—	—	—	—	0.8	850	820	3000	1025	1000	-6

TABLE III

Date / Time	ΔT_1	ΔT_2	ΔT_3	Stability Index	Freezing Level, Ft.	Absolutely Unstable Base, mb	Absolutely Unstable Top, mb	Neutral Stability Base, mb	Neutral Stability Top, mb	$\Delta\theta_e$	Potential Instability Base, mb	Potential Instability Top, mb	Lifting Req., Ft.	Inversions Base, mb	Inversions Top, mb	ΔT
3 Sept. 1600 - 2200P																
3/1600P	7	10	9	+1	11000	—	—	—	—	—	—	—	—	—	—	-3
4/0400P	6	10	15	+1	7200	1010	1000	—	—	—	—	—	—	1000	950	-8
6 Oct. 0100 - 0900P																
6/0400	6	8	16	+4	8600	—	—	—	—	—	—	—	—	—	—	+9
7 Oct. 1300 - 1800P																
7/1600P	10	9	14	+2	5500	540	535	—	—	—	—	—	—	—	—	-4
						1010	1000									
8 Oct. 1300 - 1800P																
8/1600P	19	11	8	+13	5000	1010	1000	—	—	—	—	—	—	550	520	0
24 Nov. 1900 - 2400P																
24/1600P	8	8	10	+12	4500	—	—	—	—	—	—	—	—	950	930	-8
25/0400P	6	11	14	+7	4500	—	—	—	—	—	—	—	—	—	—	-1
1 Dec.-2 Dec. 1600 - 0300P																
1/1600P	9	9	16	+5	6500	—	—	1000	940	—	—	—	—	925	910	-3
2/0400P	7	8	17	+6	4500	—	—	635	600	—	—	—	—	795	775	-2

TABLE III - Continued

16 Dec. 1000 - 1800P																	
16/1600P	1	10	19	+1	6250	——	——	——	——	——	——	——	——	985	965	-1	

Explanation of Symbols Used in Tables II and III

ΔT_1, ΔT_2, ΔT_3 - temperature difference between 1000 - 350 millibars, 850 - 700 millibars, and 700 - 500 millibars, respectively.

$\Delta \theta_e$ - equivalent potential temperature difference between the top and bottom of the potentially unstable layer.

ΔT - the 12-hour temperature change at the 850 millibar level. + indicates warming; - cooling.

—— indicates that the layer does not have the type of instability or stability indicated and other quantities listed in connection with that stability type are therefore not listed. Under "inversions" indicates no inversions present.

Note: That part of the sounding above 500 millibars disregarded in this study. All computations made from soundings plotted on the USAF Skew T - log p diagrams furnished OSU by the weather detachment, Adair AFS, Corvallis.

TABLE IV

Date / Time	Azimuth[1]	Range[2] Miles	Orientation[3] Degrees	Frontal[4] Type
22 Aug. 1900 - 2400P				Triple
22/2200P	300	400	——	Point
23/0400P	300	275	30	Occluded
23 Aug. 1300 - 1700P				
23/1600P	150	100	60	Occluded
5 Oct. 2200 - 2400P				
5/2200P	Over Station	0	10	Cold
7 Oct. 0400 - 0900P				
7 Oct. 1000 - 1200P				
7/0400P	None	——	——	
7/1000P	150	350	60	Stationary
7/1600P	150	350	60	Stationary
8 Oct. 0100 - 1200P	None	——	——	——
11 Oct. 1300 - 2100P				
11/1000P	290	125	20	Cold
11/1600P	Over Station	0	20	Cold
11/2200P	090	250	360	Cold
23 Oct. 1500 - 2400P				
24 Oct. 0100 - 0600P				
23/1000P	270	50	10	Cold
23/1600P	090	25	10	Cold
23/2200P	090	300	10	Cold
24/0400P	None			
26 Oct. 1000 - 1500P				
26 Oct. 1600 - 2400P				
26/1000P	110	400	20	Cold
26/1600P	None	——	——	——
26/2200P	None	——	——	——
27/0400P	None	——	——	——
27 Oct. 1000 - 1800P				
27/1000P	310	400	60	Cold
27/1600P	Missing	——	——	——
27/2200P	150	50	60	Cold

TABLE IV - Continued

30 Oct. 1900 - 31 Oct. 1200P					
	30/1600P	360	200	90	Warm
	30/2200P	30	100	110	Warm
	31/0400P	30	100	110	Warm
	31/1000P	320	100	05050	Cold
		10	200	——	Triple Point
	31/1600P	330	40	50	Cold
		30	200	——	Triple Point
31 Oct. 1900 - 1 Nov. 1500P					
	31/2200P	Over Station	0	70	Cold
	1/0400P	170	50	90	Cold
	1/1000P	None			
	1/1600P	150	200	50	Stationary
23 Nov. 0100 - 1200P					
	23/0400P	130	200	25	Cold
	23/1000P	210	150	50	Cold
23 Nov. 1900 - 2400P					
24 Nov. 0100 - 0900P					
24 Nov. 1000 - 1200P					
24 Nov. 1300 - 1800P					
	23/1600P	150	200	50	Stationary
	23/2200P	130	225	30	Occluded
		180	150	90	Warm
	24/0400P	330	50	40	
		10	100	——	Triple Point
	24/1000P	250	125	340	Occluded
		30	125	——	Triple Point
	24/1600P	180	100	20	Cold
	24/2200P	110	90	20	Cold
25 Nov. 0100 - 0600P		130	200	30	Cold
	25/0400P	130	200	30	Cold
	25/1000P	10	400	90	Stationary
16 Dec. 1900 - 2400P		None	——	——	——
17 Dec. 2200 - 18 Dec. 0600P					
	17/2200P	270	250	020	Cold
	18/0400P	270	30	0	Cold
18 Dec. 0700 - 1500P					
18 Dec. 1600 - 2400P					
	18/1000P	Over Station	0	10	Cold
	18/1600P	130	200	20	Cold
	18/2200P	180	400	80	Cold

TABLE V

3 Sept. 1600 - 2200P				
3/1600P	310	380	45	Cold
3/2200P	290	250	45	Cold
7 Oct. 1300 - 1800P				
7/1000P	150	350	60	Stationary
7/1600P	150	350	60	Stationary
8 Oct. 1300 - 1800P				
8/1000P	None	----	----	----
8/1600P	250	350	150	Warm
21 Oct. 0100 - 1500P				
20/2200P	300	300	30	Cold
21/0400P	150	100	70	Stationary
21/1000P	150	100	70	Stationary
21/1600P	340	20	70	Stationary
24 Nov. 1900 - 2400P				
24/1600P	180	100	20	Cold
24/2200P	110	90	20	Cold
25 Nov. 0600 - 1200P				
25/0400P	130	200	30	Cold
25/1000P	10	400	90	Stationary
1 Dec. 1600 - 2 Dec. 0200P				
1/1600P	80	300	150	Stationary
1/2200P	70	300	150	Stationary
2/0400P	50	300	150	Cold
16 Dec. 1000 - 1800P	None			

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1 The azimuth from the radar to the closest point on the front listed under "Frontal Type."

2 The range in statute miles to the front along the given azimuth.

3 The orientation of the front at the azimuth listed in (1) above, given by a number in the 180° sector from north (360°) to south (180°) through east.

4 The type of front appearing within the 400 mile range of the radar. Triple point refers to the point of occlusion.

All data obtained from the six-hourly surface synoptic facsimile charts produced by the U.S. Weather Bureau.

TABLE VI
Part A

Date / Time	A_1/A	C_1/C	D	E_1/E	G_1/G	C^1	B_1/B	F_1/F^1	H_1/H	I	Echo Type	Echo Movement Degrees	Mean Range Echo Detected N	S	W	E
23 Nov. 1900 – 2100P	07/02	62/34	26	11/07	32/07	03	15/35	30/50	63/50	27	S	240	48	72	32	72
27 Oct. 1000 – 1800P	26/33	35/60	19	07/28	05/27	28	08/37	03/06	05/04	01	S	270–290	59	60	69	53
23 Oct. 1500P – 2400P	09/16	48/43	18	11/30	13/23	11	07/32	09/27	10/17	01	S/C	250–220	68	54	49	65
18 Dec. 0700 – 1500P	09/19	39/42	23	13/24	20/24	17	26/46	37/41	18/32	06	S/C	210–250	62	63	63	54
18 Dec. 1600 – 2400P	08/18	39/37	19	17/24	20/17	08	03/27	09/14	08/08	08	S/C	250–260	58	47	48	52
17 Dec. 2200 – 18 Dec. 0600P	16/34	43/46	28	16/41	12/34	33	13/47	08/37	10/26	03	S	240	52	50	54	52
7 Oct. 1000 – 1200 P	10/13	40/43	11	18/58	24/58	08	07/33	21/58	29/42	02	S	235–250	37	108	58	70
24 Nov. 0100 – 0900P	40/24	84/54	54	42/58	63/59	21	33/56	35/48	35/31	22	S	240	61	59	65	59

TABLE VI - A — Continued

16 Dec. 1900 - 2400P	18/23	34/46	18	19/34	12/25	12	13/37	14/39	07/21	01	S/S,C	240	58	52	51	54
23 Nov. 0100 - 1200P	25/12	47/33	30	25/25	18/13	18	44/33	17/32	17/18	05	S,C/S	210-240	35	46	46	47
24 Nov. 1300 - 1800P	46/65	58/74	35	32/73	51/68	63	78/66	51/68	48/55	10	S	240	68	71	74	73
24 Nov. 1000 - 1200P	14/60	91/73	56	81/68	63/52	40	33/62	67/57	20/18	22	S	240	29	53	75	60

TABLE VI
Part B

5 Oct. 2200 - 2400P	09/50	21/55	10	T/12	02/30	45	43/35	08/20	03/30	0	S	180	65	82	90	108
24 Oct. 0100 - 0600P	03/03	10/14	02	01/05	02/03	03	0/09	01/02	01/02	01	C	220-250	38	16	26	24
25 Nov. 0100 - 0600P	04/12	07/32	08	01/30	M/26	19	14/54	17/67	17/38	04	S	250	35	87	85	51
22 Aug. 1900 - 2400P	04/0	06/04	01	02/02	05/02	0	03/02	02/01	07/01	0	---	275-240	18	9	19	24
30 Oct. 1900 - 31/1200P	02/06	04/09	01	01/03	09/09	12	03/14	01/10	05/15	T	S,C	270	43	54	94	53

TABLE VI - B — Continued

11 Oct. 1300 - 2100P	07/04	13/35	05	04/21	09/16		08/25	06/22	09/25	0	S/C	235-270	51	43	28	46
26 Oct. 1600 - 2400P	01/T	06/05	02	02/03	04/04	T	0/04	01/06	03/08	02	C	260-270	32	27	13	28
7 Oct. 0400 - 0900P	05/03	05/07	11	02/02	12/20	07	14/28	11/20	20/17	01	S	235-250	35	83	53	75
31 Oct. 1900 - 1 Nov. 1500P	03	04	02	02	05		05	02	04	01						
23 Aug. 1300 - 1700P	11/01	16/03	06	08/03	07/02	0	01/0	02/0	04/01	01	C	240-235	33	0	40	75
26 Oct. 1000 - 1500P	05/14	13/38	14	07/21	13/17	14	02/26	04/18	07/16	04	C	260	72	53	59	64
8 Oct. 0100 - 1200P	04/04	05/19	06	03/11	09/06		01/15	04/15	05/09	01	C	270-290	48	35	49	50

Zones for Echo Analysis: A^1- north coast C^1- north coast range E^1- north Willamette Valley G^1- north Cascades O^1- south ocean area B^1-south coast F^1- south Willamette Valley H^1- south Cascades
(See text for description of boundaries used in echo analysis)

Explanation of Tables VI and VII: Column headings $\frac{A}{A^1}$, $\frac{C}{C^1}$, D, etc. refer to the zones as identified in Table I.
The lower letters in the cases of one letter on top of the other refers to the zones used in the radar echo analysis.

Column headings N, S, W, E, under "Mean Range Echo Detected" are abbreviations for north, south, west and east, respectively.

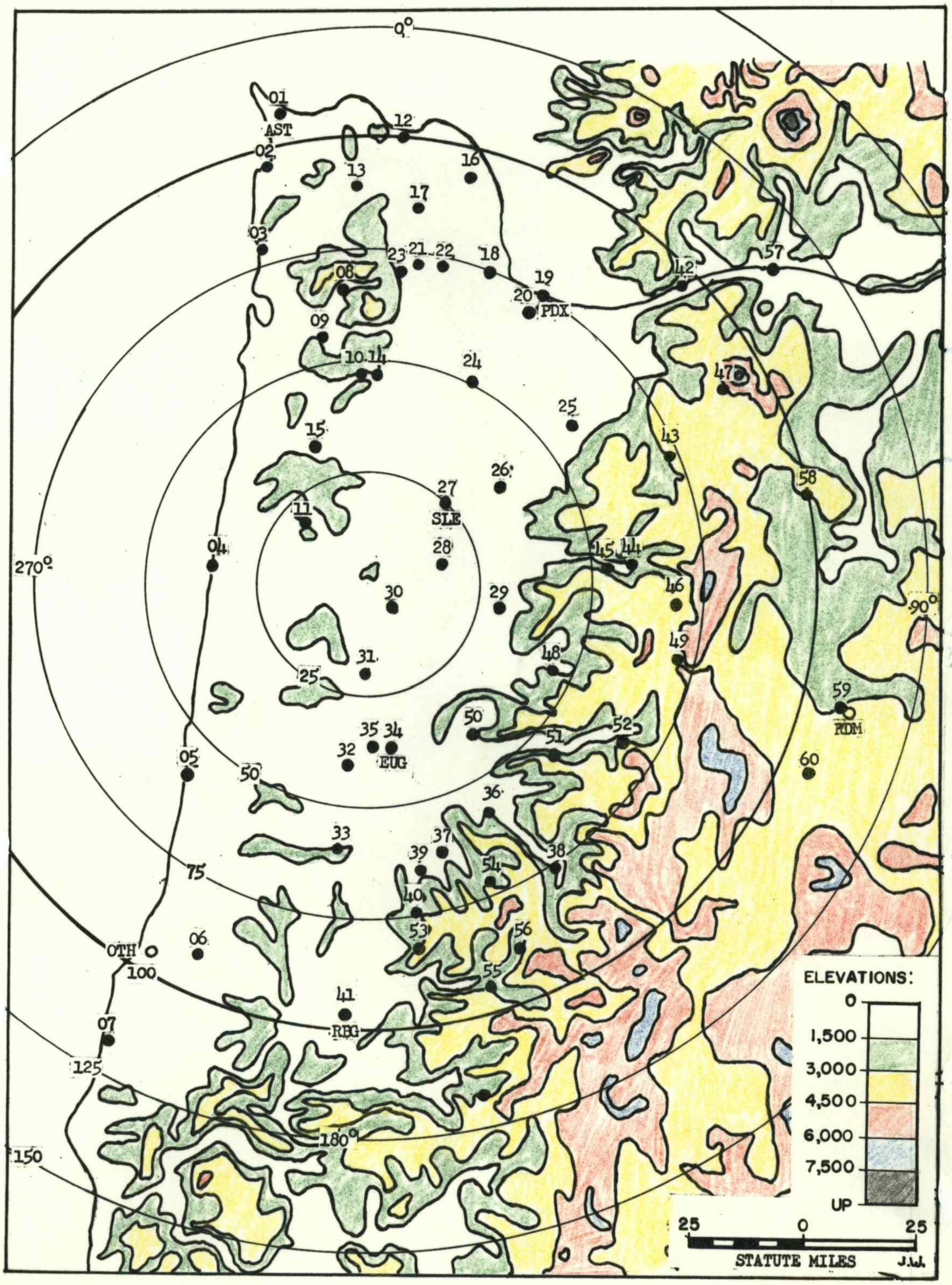
Explanation of Tables VI and VII - Continued

Under "Echo Type", S indicates predominately stratiform type and C indicates predominately cellular type. $\frac{S}{C}$ indicates stratiform predominated during first part of period and cellular echoes predominated during last part of period. S,C indicates that both echo types are equally present.

See text for further explanation of tables and table entries.

TABLE VII

Date / Time	$\frac{A_1}{A^1}$	$\frac{C_1}{C^1}$	D	$\frac{E_1}{E^1}$	$\frac{G_1}{G^1}$	O^1	$\frac{B_1}{B^1}$	$\frac{F_1}{F^1}$	$\frac{H_1}{H^1}$	I	Echo Type	Echo Movement Degrees	Mean Echo N	S	Range Detected W	E
8 Oct. 1300 - 1800P	0/0	01/06	02	05/09	05/08	0	0/05	03/12	06/05	0	C	310	41	42	23	49
3 Sept. 1600 - 2200P	02/T	04/05	12	12/06	17/04	0	08/04	13/04	07/01	02	C_1S	170	38	39	22	48
7 Oct. 1300 - 1800P	03/07	03/09	02	06/08	11/10	06	T/19	07/14	09/11	01	C_1S	270	64	55	63	56
16 Dec. 1000 - 1800P	03/16	02/21	04	04/22	02/17	16	07/31	03/21	01/08	01	SC	210	44	54	56	39
1 Dec. 1600P - 2 Dec. 0300P	0/01	01/T	0	02/10	11/20	T	02/04	06/19	10/19	04	S/C	180-270	23	38	19	45
25 Nov. 0700 - 1200P	13/15	06/30	02	01/04	01/05	14	0/25	09/20	09/13	04	SC/C	230-240	54	49	58	34
24 Nov. 1900 - 2400P	10/14	07/36	12	07/56	11/60	60	23/76	29/83	29/73	09	S	240	65	87	71	76
6 Oct. 0100 - 0900P	11/05	12/14	08	12/24	23/37	01	03/11	12/14	22/32	04	S/C_1S	220-180	64	67	38	76
21 Oct. 0100 - 1500P	04/17	02/18	03	02/13	0/09	08	0/04	0/05	0/09	0	S_1C	230-250	53	22	57	33



0°
90°
180°
270°
50
75
100
125
150
01
AST
02
03
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EUG
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RBG
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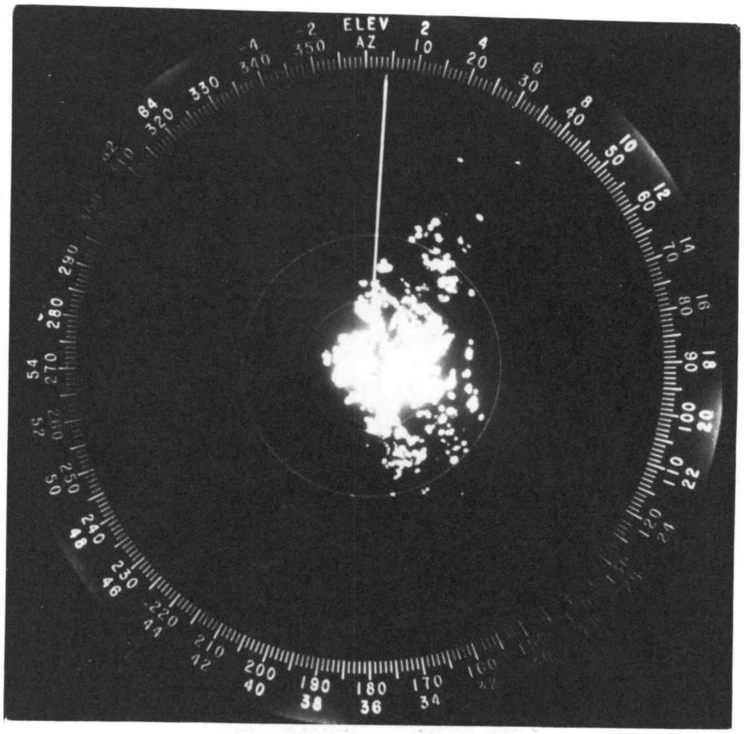
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
RDM
60
OTH
ELEVATIONS:
0
1,500
3,000
4,500
6,000
7,500
UP
25
0
25
STATUTE MILES
J.W.

PLATE I

200 Mile Range +1° Tilt



200 Mile Range +2.5° Tilt

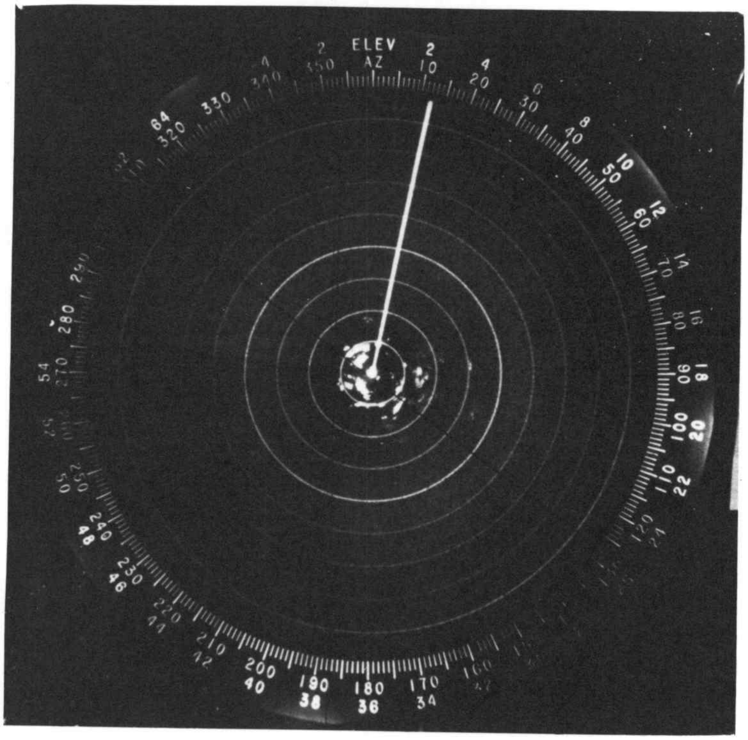
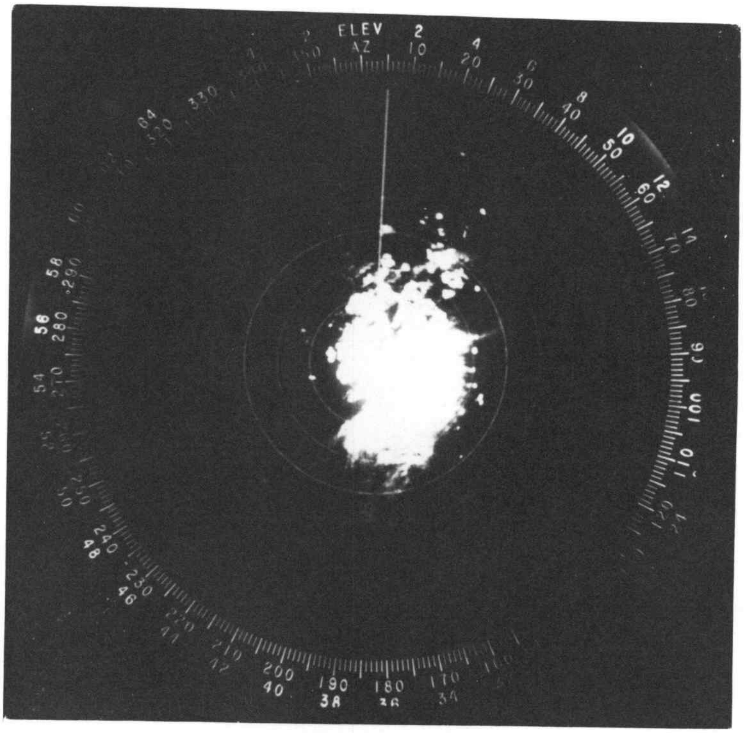


PLATE II

23 November 1960 1902P



23 November 1960 1904P

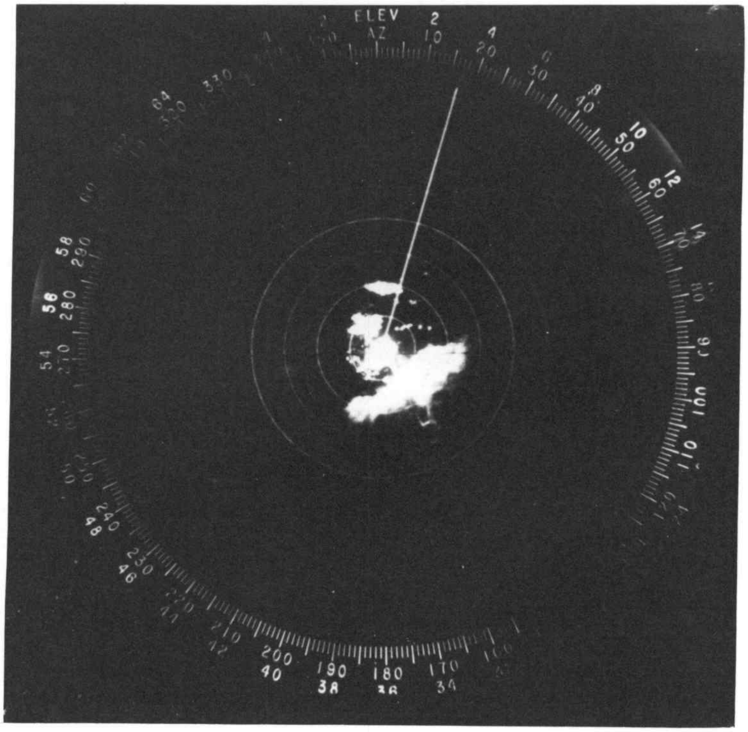
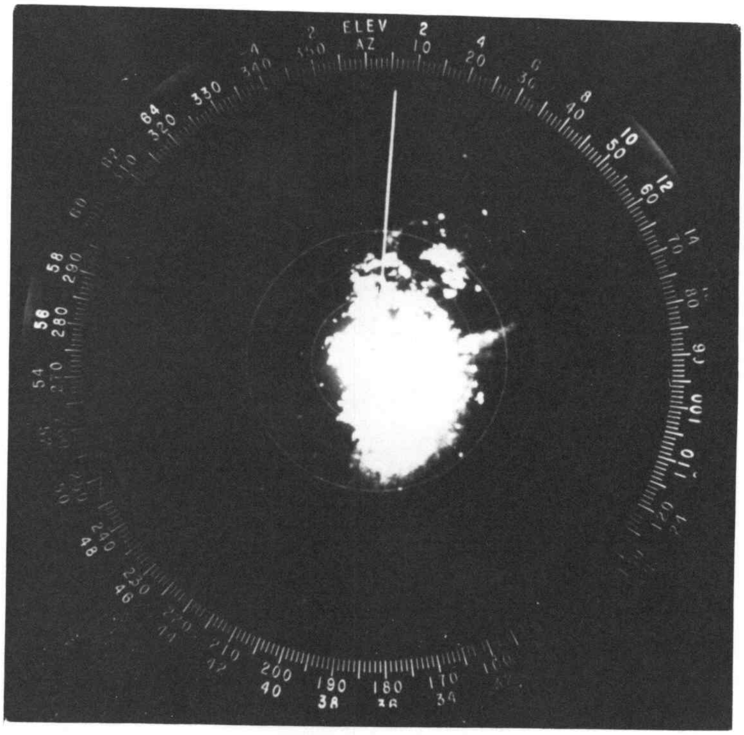


PLATE III

23 November 1960 1958P



23 November 1960 1957P

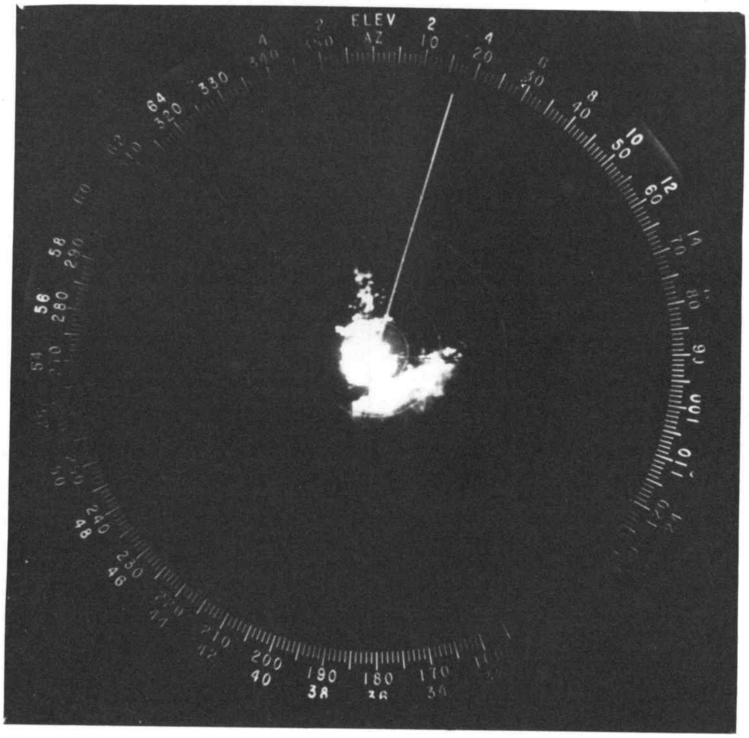
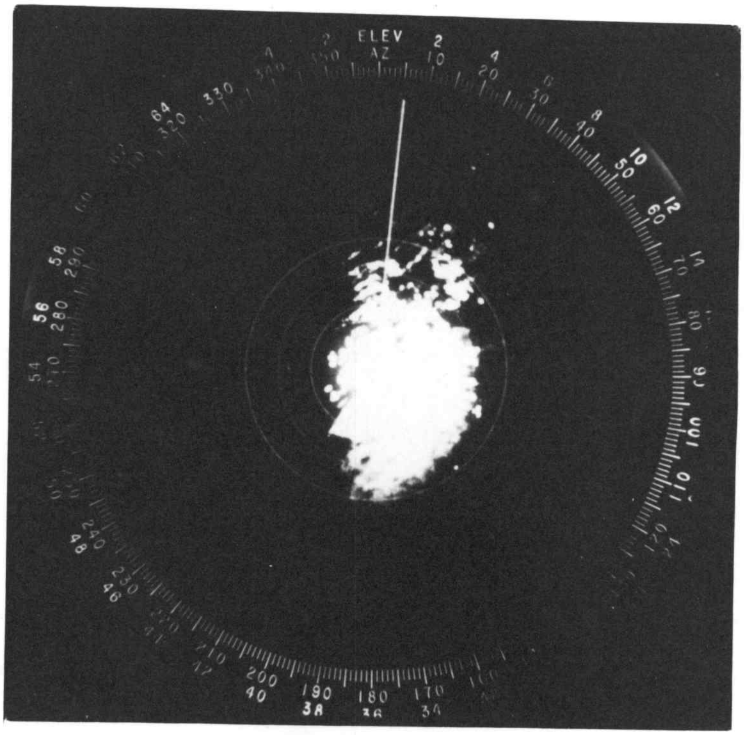


PLATE IV

23 November 1960 2043P



23 November 1960 2045P

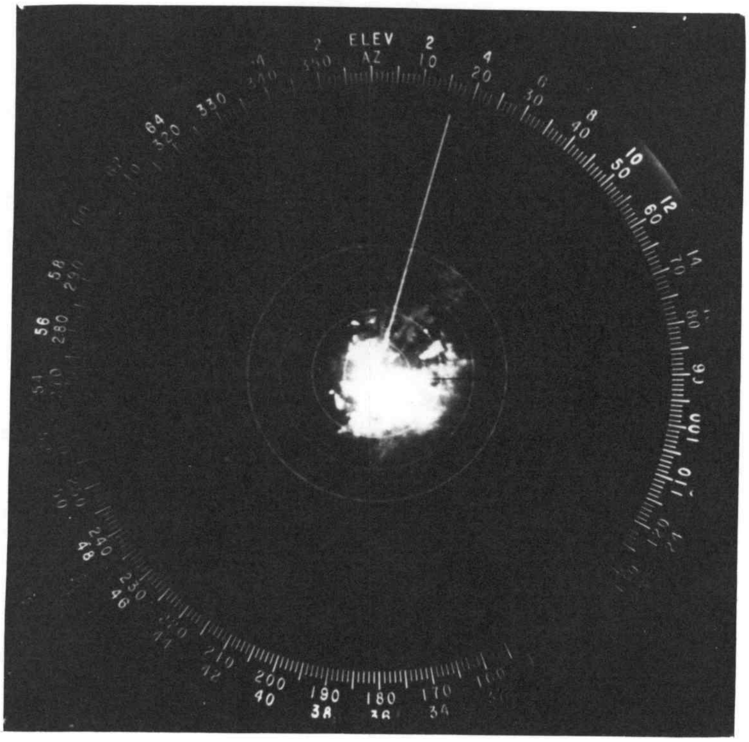
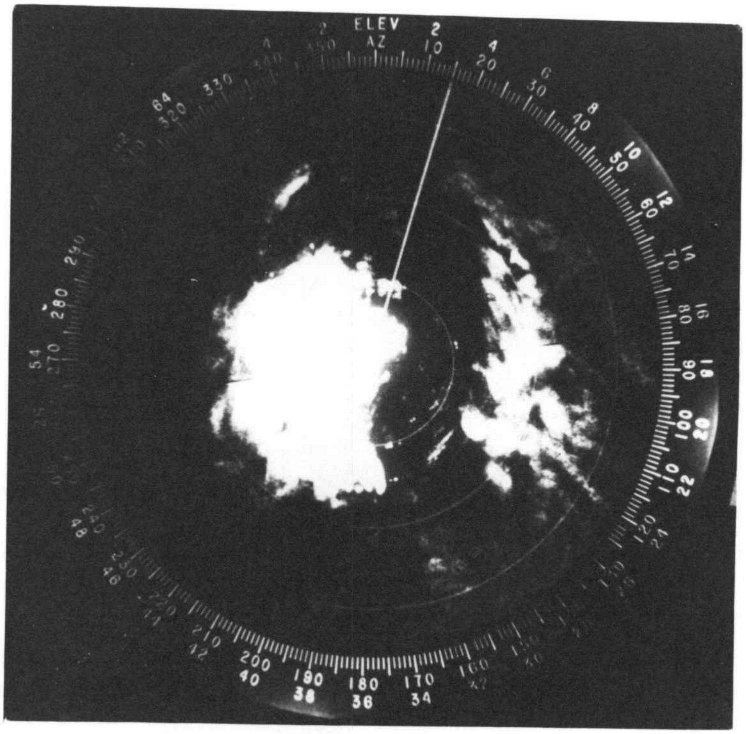


PLATE V

5 October 1960 2258P 25 Mile Range Markers



6 October 1960 0234P 25 Mile Range Markers

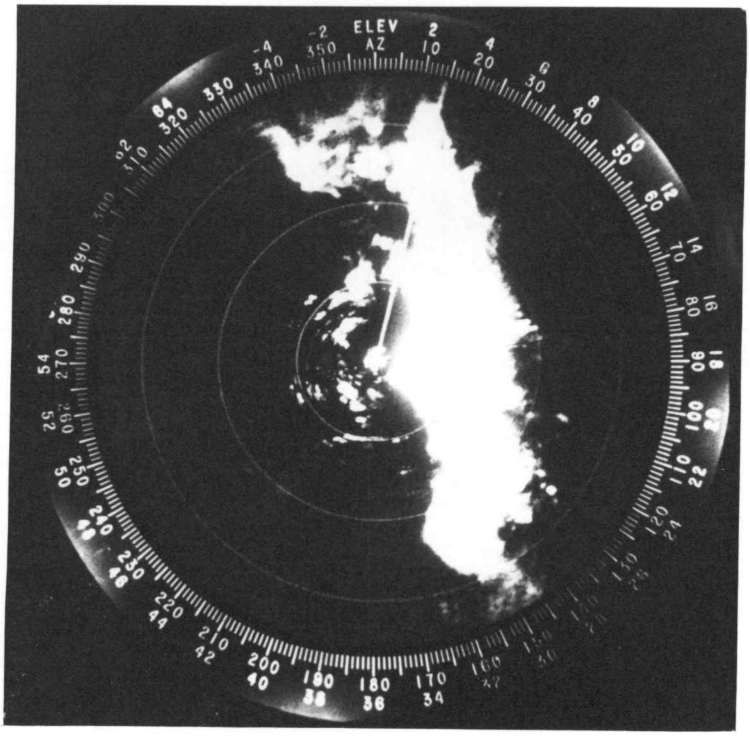


PLATE VI

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