NOAA Technical Memorandum NWS WR- 143

THE DEPTH OF THE MARINE LAYER AT SAN DIEGO AS RELATED TO SUBSEQUENT COOL SEASON PRECIPITATION EPISODES IN ARIZONA

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May 1979

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This Technical Memorandum has been reviewed and is approved for publication by Scientific Services Division, Western Region.

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CONTENTS

FIGURES

THE DEPTH OF THE MARINE LAYER AT SAN DIEGO AS RELATED TO SUBSEQUENT COOL SEASON PRECIPITATION EPISODES IN ARIZONA

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ABSTRACT. The relationship between the depth of the marine layer at San Diego, California, and potential precipitation episodes in Arizona during the cool season is studied. It is shown that a marine layer from the surface to at least the 700-mb level is generally necessary for consideration of a subsequent widespread precipitation episode in Arizona. The relationship of the height of this marine inversion to the current vertical motion field is also discussed.

I. INTRODUCTION

It has long been subjectively recognized by Arizona forecasters that a correlation exists during the cool season (October-April) between the depth of the marine layer at San Diego (MYF) and potential precipitation episodes in Arizona. This is logical since MYF would be directly upstream from Arizona in the southwesterly flow preceding an advancing upper level trough.

It is felt that the height of the top of the marine layer is proportionate to the intensity of the vertical-motion field being superimposed on the area as an upper trough approaches. All too frequently, a vertical-motion field sufficiently strong to produce precipitation west of the coastal mountains is insufficient for widespread precipitation in Arizona. The theory being tested is that the vertical motion field west of the coastal range must be strong enough to raise the top of the marine layer to at least the 700-mb level in order to consider a widespread precipitation episode in Arizona. Numerous articles have been written on the subject of the quantitative effects of Positive Vorticity Advection (PVA) and subsequent vertical-motion fields. Two of the more pertinent articles for Arizona include Brenner (1979) and Rosendal (1976). However, it must be realized that the magnitude of the PVA/vertical-motion field necessary to deepen the MYF marine inversion through at least the 700-mb level during a given time interval will vary since, among other things, it will be a function of the available initial moisture values. The objective of this study was to demonstrate that the depth of the marine layer at MYF can be used on a real-time basis as a means for indirectly, but nevertheless reliably, measuring the relative magnitude of the current vertical-motion field ahead of an approaching upper trough.

During 1977 and 1978, an investigation was conducted to try and determine a more precise relationship between the observed vertical moisture profile at MYF and subsequent precipitation (as well as nonprecipitation) episodes in Arizona. Plotted data from balloon releases (RAOBS) dating from March

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1971 through December 1975, were graciously loaned by the San Diego Weather Service Office for use as the developmental data base. The period of study involved data for the months of October through April only. Therefore, a total of thirty-three months of RAOBS comprised the developmental sample. With RAOBS for both 0000 and 1200 GMT available for nearly every day, approximately two thousand cases completed the developmental data base.

II. DEVELOPMENTAL DATA BASE STRATIFICATION

Moisture distributions were sampled in terms of the summation of the temperature-dew point spread inventoried every 50 mb through a predetermined column:

$$(1) \quad A = (T\text{-}Td)_x + (T\text{-}Td)_{x-50} + \ldots + (T\text{-}Td)_y$$

where (T-Td) is the temperature-dew point spread at a given level, $x = 1000$ mb, $y = 850$ mb.

$$(2) \quad B = (T\text{-}Td)_x + (T\text{-}Td)_{x-50} + \ldots + (T\text{-}Td)_z$$

where (T-Td) is the temperature-dew point spread at a given level, $x = 1000$ mb, $z = 700$ mb.

The initial column stratifications (referred to as <u>Types</u> in the text) were selected as follows:

Type 1 equal $A \leq 10°C$ and $B \leq 25°C$.

Type 2 equal $A \leq 10°C$ and $B > 25°C$.

Type 3 equal $11°C \leq A \leq 30°C$ and $11°C \leq B \leq 60°$.

Type 4 equal $11°C \leq A \leq 30°C$ and $B > 60°C$.

Type 5 All remaining cases.

Types 1 and 2 sampled all the available cases where a nearly saturated column of air existed in at least the lower 5000 feet. This was most frequently associated with a deep marine layer. Type 1 was designed to examine cases where the vertical-motion field was sufficiently strong to bring this layer through at least the 700-mb level, while Type 2 assumed the marine layer top short of 700 mb, but above 850 mb.

The theory being tested by Types 1 and 2, as mentioned earlier, was that the vertical-motion field west of the coastal range must be strong enough to deepen the marine layer through at least the 700-mb level in order to consider a widespread precipitation episode in Arizona. This same basic theory was tested by Types 3 and 4 also, but the required amounts of available moisture at MYF were scaled down. All remaining cases were included in Type 5.

III. DEVELOPMENTAL DATA SAMPLE ANALYSIS

All the available MYF RAOBS from March 1971 through December 1975 (October through April only) were examined and separated into the various Types described earlier. Data from 0000 GMT RAOBS were analyzed apart from that of 1200 GMT. Data sheets for each Type were prepared and the dates of the respective RAOBS corresponding to each Type were recorded. Then four consecutive 12-hour periods (Figure 1) were individually examined for each date to determine if precipitation occurred at Phoenix (PHX, elevation 1100 ft) or Flagstaff (FLG, elevation 7000 ft). Throughout the remainder of this article, these four periods will simply be referred to as "Period 1, Period 2, etc.". However, when reference is made to the periods used by the National Weather Service for forecasts and comparison with Model Output Statistic (MOS) probabilities, the terms "FP Period 1, FP Period 2, etc." will be used. After tabulation, the number of measurable cases of precipitation only, and then the number of measurable and trace cases were totaled for each Type. Percent occurrences (in effect, conditional climatological probabilities for Periods 1-4 of this sample) were then computed for each. The results are shown in Figures 2a-e. Enough curiousity was raised to try and determine the percent of total measurable, as well as total measurable and trace cases that were caught by the combined Types 1-4. It was hoped that the percentage would be high enough to consider any adverse effects from rapidly changing conditions at balloon release times to be only an occasional compromising factor to the overall study. Figure 3 shows the results for Periods 1-4.

An analysis of Figure 3a reveals that in general, Types 1-4 for the 1200 GMT RAOBS caught on the order of 80-90% of the total measurable cases in the study for Period 1, 70-80% of the cases for Period 2, 60-70% for Period 3, and 50-60% for Period 4. The 0000 GMT RAOBS did not perform as well, indicating basically 70-80% for Period 1, 60-70% for Period 2, 50-60% for Period 3, and 40-50% for Period 4. An overall decrease in reliability occurred, as observed in Figure 3b, when the measurable and trace cases were considered. This was expected, since trace cases can frequently occur with middle and/or high-level moisture only. Perhaps another reason would be due to troughs approaching from a more northerly trajectory. Nevertheless, considering the overall rarity of precipitation events in Arizona and the fact that only one parameter (moisture at a fixed location) was being tested, it was felt that Types 1-4 locked in on those measurable events that did occur quite well. This was particularly true in Periods 1 and 2. One should be reminded at this point that this is only a climatological study, and although it would appear that this study has considerable prognostic value, it should be primarily viewed from a diagnostic standpoint when used operationally.

As mentioned earlier, 1200 GMT RAOBS outperformed the 0000 GMT RAOB data in the analysis of Figure 3. This diurnal conflict is intriguing. The 0000 GMT RAOBS had nearly 100 less cases per period in the total sample size for the combined Types 1-4 than the 1200 GMT RAOBS. Considerably more precipitation events occurred in Type 5 using 0000 GMT RAOBS as opposed to 1200 GMT data. One could speculate here that the problem is likely related to afternoon heating and mixing resulting in larger temperature-dew point spreads in the 1000- to 850-mb layer. Therefore, even though on a given day the vertical-motion field might still be strong enough to give widespread precipitation in Arizona, the 0000 GMT RAOB may occasionally fail to satisfy the criteria for any of Types 1-4.

A graphical representation of the data presented in Figures 2a-e is shown in Figures 4a,b. Note that of the five Types for both PHX and FLG at 0000 GMT as well as 1200 GMT, the two Types involving high moisture values concentrated in at least the 1000-mb - 700-mb layer yielded the highest probabilities (Types 1 and 3). Types 2 and 4, which have high moisture only up to 850 mb, yielded lower probabilities (significantly lower for PHX) than those obtained by Types 1 and 3. This strongly suggests that high moisture values below 850 mbs, complimented by moisture in the 850-mb - 700-mb layer, is necessary for consideration of widespread precipitation in Arizona. This point is additionally supported by a comparison of Types 3 and 4. Type 4 involved the scaled-down moisture criteria in the 1000-mb - 850-mb layer and "dry" conditions between 850 mb and 700 mb. This, in itself, resulted in relatively low probabilities. The addition of moisture to the 850-mb - 700-mb layer to this, as shown in Type 4, with no change below 850 mb, sharply increased the probabilities (see the graphs of Type 3 for FLG and PHX).

Interest was then aroused as to the potential additional effects of high moisture above the 700-mb level. Therefore, Types 1 and 2 were tested for the effects of varying moisture supply above 700 mb. The criteria used was as follows:

$$(3) \quad C = (T\text{-}Td)_z + (T\text{-}Td)_{z-50} + \ldots + (T\text{-}Td)_v$$

where (T-Td) is the temperature-dew point spread at a given level, z = 700 mb, v = 400 mb.

These were segregated such that:

Sub-Type 1a equal Type 1 and $C \leq 60°C$.

Sub-Type 1b equal Type 1 and $C > 60°C$.

Sub-Type 2a equal Type 2 and $C \leq 60°C$.

Sub-Type 2b equal Type 2 and $C > 60°C$.

Sub-Type 3a equal Type 3 and $C \leq 60°C$.

Sub-Type 3b equal Type 3 and $C > 60°C$.

Sub-Type 4a equal Type 4 and $C \leq 60°C$.

Sub-Type 4b equal Type 4 and $C > 60°C$.

Climatological probabilities for these Sub-Types (hereafter called "breakdown pops") were then derived and are displayed in Figure 5a-d with the original combined (or non-substratified) probabilities from Figure 2 a-e for comparison. The Sub-Typing resulted in data samples generally too small to be considered representative. Despite this, in most instances, the presence of high moisture values above 700 mb increased the probabilities from that of the original combined values, while the absence of this moisture had the opposite effect.

IV. INDEPENDENT TEST DATA

The months of October 1977 through April 1978 were utilized as test data. This provided a total sample size of 414 cases. Brier scores were totaled using the original combined pops for measurable precipitation (POPA) from Figures 2a-e as well as the breakdown pops (POPB). Comparisons were then made to the corresponding Final Model Output Statistics (MOS) Brier score in each of the three National Weather Service's FP periods. The results are listed in Figure 6a-d. Brier scores are rounded off and the decimal points displaced for convenience. As can be seen, the usage of the breakdown pops (POPB) generally degraded the results (increased the Brier scores) from those obtained by POPA. This was quite likely due to the problem of small sample size alluded to earlier. The breakdown pops did have a positive influence in a few cases. In general, the number of cases used to derive the breakdown probability for the presence of upper level moisture was too small to seriously consider the results reliable.

The comparison of POPA to MOS Brier scores displayed a few significant areas where the MOS forecasts could possibly be improved upon on an operational basis. Those listed below include periods where POPA Brier scores were less than or equal to the MOS Brier score in any period, or where POPA was less than 30 units above the MOS score in Periods 1 or 2 (indicating MOS was only slightly better than conditional climatology in the short term).

MOS WEAKNESS LIST #1

	RAOB TIME	STATION	TYPE	FP PERIOD	SAMPLE SIZE PER PERIOD
1.	0000GMT	PHX	2	1,2,3	11
2.	0000GMT	FLG	2	2,3	11
3.	0000GMT	PHX	1	2,3	12
4.	0000GMT	FLG	1	1,2,3	12
5.	1200GMT	PHX	1	1,2	20
6.	1200GMT	FLG	1	1,2	20
7.	0000GMT	PHX	4	1	26
8.	1200GMT	PHX	4	1,2,3	27
9.	1200GMT	PHX	3	1,2	11
10.	1200GMT	FLG	3	1	11

Of special interest here is that for Type 1, the wettest and most important of the Types in terms of precipitation events, MOS commonly was only slightly better or actually worse than the conditional climatological pops from the study (POPA). This was true at both RAOB times and for both PHX and FLG. A review of the appropriate data indicated that MOS had a definite tendency for forecasting rather low probabilities (0-30%)--many on which precipitation occurred.

A more detailed examination of the possible weaknesses in the MOS forecasts for the above MOS WEAKNESS LIST #1 is found in Appendix A and labeled WEAKNESS LIST #1. The numbers of the 1-10 in WEAKNESS LIST #1 correspond to the same numbers in the above MOS WEAKNESS LIST #1.

A return to Figure 3 brings forth another interesting point. The best results for measurable as well as measurable plus trace cases were in Periods 1 and 2. Perhaps the operational forecaster could also be served by this study in terms of an updating tool. The analysis of Brier scores just examined from Figure 6 involved a comparison of data from a given RAOB to the MOS run from the same time as the RAOB. However, the RAOB is nearly 10 hours old by the time the first FP period begins. In actuality, a given RAOB is received almost at the beginning time of the first FP period MOS probabilities from the previous run. For example, the 1200GMT RAOB is received and plotted by the time the first FP period MOS pop from the previous 0000GMT run is only about 2 hours old. The utility of this study, examined from the standpoint of an updating aid, is tabulated in Figure 7a-d.

The comparison of POPA to MOS Brier scores for purposes of updating also indicated areas where MOS forecasts from the previous runs were potentially weak. Opportunities for improvement upon MOS forecasts existed in the following categories:

MOS WEAKNESS LIST #2

	RAOB TIME	STATION	TYPE	FP PERIOD	SAMPLE SIZE PER PERIOD
1.	0000GMT	PHX	2	1,2,3	11
2.	0000GMT	FLG	2	1,2,3	11
3.	0000GMT	PHX	1	1,2,3	12
4.	0000GMT	FLG	1	1,2,3	12
5.	1200GMT	PHX	1	1,2	20
6.	1200GMT	FLG	1	1,2,3	20
7.	0000GMT	PHX	4	2,3	26
8.	0000GMT	FLG	4	1, 3	26
9.	1200GMT	PHX	4	1,2,3	27
10.	1200GMT	FLG	4	1	27
11.	1200GMT	PHX	3	2,3	11
12.	1200GMT	FLG	3	3	11

Note here also that Type 1 showed up again at both RAOB times and for both PHX and FLG. As with MOS WEAKNESS LIST #1, an investigation of the data revealed that the MOS tendency to forecast rather low probabilities, on which precipitation occurred, persisted. Appendix B uses a format similar to Appendix A for further describing the possible MOS weaknesses corresponding to MOS WEAKNESS LIST #2.

V. CONCLUSIONS

This conditional climatological study was considered to be a beneficial diagnostic forecast aid for PHX WSFO. Even if used strictly from an objective standpoint, the study yielded excellent results. The added usage of a limited amount of subjective reasoning and modification will improve the operational results even further. The utility of the study extended beyond the capacity of making three-period probability forecasts. It was found that the study also served the forecaster successfully as an updating tool.

The developmental data sample did not stratify precipitation episodes at PHX or FLG by storm origin or trajectory. Despite this, results, particularly using 1200GMT MYF RAOBS, still displayed a definite relationship between the depth of the marine layer at MYF and subsequent widespread precipitation episodes in Arizona. It is felt that on an operational basis, subjective evaluation can be made to the study probabilities for cases where storms approach from a more northerly direction or when an unusually strong influx of tropical moisture is involved.

This investigation gave strong supportive evidence that high moisture content (i.e., a high marine inversion) at MYF from the surface to at least 700 mb is generally necessary for widespread precipitation episodes in Arizona. It is the opinion of the author that when the top of the marine layer at MYF is lifted to at least the 700-mb level ahead of an upper-level trough, the vertical-motion field will generally remain strong enough to produce widespread precipitation upon reaching Arizona.

Although not conclusive from this study, it would appear subjectively that additional high moisture values in the 700-mb - 400-mb layer enhance the probabilities of precipitation even further.

A fringe benefit of this study was the identification of potentially weak areas in the MOS probability forecasts. With reasonable discretion, forecasters can successfully use the results listed in the INDEPENDENT TEST DATA section to identify and hopefully improve upon available corresponding MOS forecasts.

VI. ACKNOWLEDGMENTS

Appreciation is extended to the San Diego Weather Service Office for use of their plotted RAOBS and to Mrs. Tommie McCabe and Mrs. Evelyn Allan for their conscientious typing efforts.

VII. REFERENCES

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APPENDIX A

WEAKNESS LIST #1

An analysis of the data from MOS WEAKNESS LIST #1 revealed the following information (Numbers 1-10 refer to the corresponding numbers in MOS WEAKNESS LIST #1):

1. MOS frequently forecast pops of 30% or greater with no cases of measurable precipitation occurring.

2. Measurable precipitation fell on more than half the cases when MOS forecast pops between and including 5% and 20%. Also, no measurable precipitation fell on MOS pops of 70% or greater.

3. No measurable precipitation fell on MOS pops of 70% or greater. Also measurable precipitation fell on half the cases where MOS pops were 20% or less.

4. A large amount of measurable precipitation events occurred on MOS pops of 30% or less.

5. Measurable precipitation fell on one half of the cases where MOS forecast pops of 5% - 20%.

6. Measurable precipitation fell on most of the cases where MOS forecast pops of 5% - 30%.

7. No measurable precipitation fell on MOS pops of 30% or greater.

8. No measurable precipitation fell on MOS pops of 20% - 60%.

9. Measurable precipitation fell on a 0% in FP Period 1. No measurable precipitation fell on MOS pops of 50% or greater in FP Period 2.

10. Several incidents where measurable precipitation fell were on MOS pops of 20% or less.

APPENDIX B

An analysis of this data from MOS WEAKNESS LIST #2 revealed the following:

1. MOS frequently forecast pops of 30% or greater, and, excepting one case of .08 in. on a 60% pop, no other measurable precipitation occurred. For FP Period 1, MOS got precipitation on half of the 0% and 5%s.
2. Measurable precipitation fell on more than half the cases when MOS forecast pops from 5% and 20%. Also, no measurable precipitation fell on MOS pops 70% or greater in FP Period 3.
3. No measurable precipitation fell 2 out of 3 times on MOS pops of 70% or greater. Measurable precipitation fell on half of the pops of 20% or less.
4. A large amount of measurable precipitaiton events occurred on MOS pops of 30% or less.
5. Measurable precipitation fell on half the cases where MOS forecast pops of 5% to 20%.
6. Measurable precipitation fell on most cases where MOS forecast pops of 5% to 30%.
7. No measurable precipitation fell on MOS pops of 40% or greater.
8. No measurable precipitation fell on MOS pops 50% or greater. Measurable precipitation fell on half the cases of MOS pops of 2%.
9. No measurable precipitation fell, excepting one case of .01 inch on a 20% MOS pop, on MOS pops in the 20-60% bracket.
10. No measurable precipitation fell, excepting one case, on MOS pops 50% or greater.
11. Measurable precipitation fell on a 0% in FP Period 2. No measurable precipitation fell on MOS pops of 50% or greater in FP Period 3.
12. No measurable precipitation fell on MOS pops of 50% or greater.

0000 GMT RAOB		
PERIOD NUMBER USED IN STUDY	TIME INTERVAL (GMT)	CORRESPONDING FP PERIOD
1	0000 - 1200	
2	1200 - 0000	1
3	0000 - 1200	2
4	1200 - 0000	3

1200 GMT RAOB		
PERIOD NUMBER USED IN STUDY	TIME INTERVAL (GMT)	CORRESPONDING FP PERIOD
1	1200 - 0000	
2	0000 - 1200	1
3	1200 - 0000	2
4	0000 - 1200	3

Figure 1. Time Interval of Periods Utilized in this Study.

0000 GMT RAOB

TYPE 1	STN	PHX				SAMPLE SIZE FOR TYPE 1	FLG			
	PD	1	2	3	4		1	2	3	4
MEASURABLE CASES		11	9	9	4	25	18	19	17	12
MEASURABLE AND TRACE CASES		15	12	10	5	25	23	21	20	13
PERCENT MEASURABLE		44	36	36	16		72	76	68	48
PERCENT MEASURABLE AND TRACE		60	48	40	20		92	84	80	52

1200 GMT RAOB

TYPE 1	STN	PHX				SAMPLE SIZE FOR TYPE 1	FLG			
	PD	1	2	3	4		1	2	3	4
MEASURABLE CASES		19	16	6	6	41	35	27	19	15
MEASURABLE AND TRACE CASES		25	22	11	8	41	40	33	23	23
PERCENT MEASURABLE		46	39	15	15		85	66	46	37
PERCENT MEASURABLE AND TRACE		61	54	27	20		98	81	56	56

0000 GMT RAOB

TYPE 2	STN	PHX				SAMPLE SIZE FOR TYPE 2	FLG			
	PD	1	2	3	4		1	2	3	4
MEASURABLE CASES		4	9	5	5	37	22	22	20	12
MEASURABLE AND TRACE CASES		14	16	11	8	37	27	25	23	15
PERCENT MEASURABLE		11	24	14	14		59	59	54	32
PERCENT MEASURABLE AND TRACE		38	43	30	22		73	68	62	41

1200 GMT RAOB

TYPE 2	STN	PHX				SAMPLE SIZE FOR TYPE 2	FLG			
	PD	1	2	3	4		1	2	3	4
MEASURABLE CASES		13	17	17	15	112	55	46	47	40
MEASURABLE AND TRACE CASES		25	28	30	22	112	74	64	57	50
PERCENT MEASURABLE		12	15	15	13		49	41	42	36
PERCENT MEASURABLE AND TRACE		22	25	27	20		66	57	51	45

0000 GMT RAOB

TYPE 3	STN	PHX				SAMPLE SIZE FOR TYPE 3	FLG			
	PD	1	2	3	4		1	2	3	4
MEASURABLE CASES		20	11	8	8	50	35	30	20	22
MEASURABLE AND TRACE CASES		27	17	14	12	50	40	36	27	27
PERCENT MEASURABLE		40	22	16	16		70	60	40	44
PERCENT MEASURABLE AND TRACE		54	34	28	24		80	72	54	54

1200 GMT RAOB

TYPE 3	STN	PHX				SAMPLE SIZE FOR TYPE 3	FLG			
	PD	1	2	3	4		1	2	3	4
MEASURABLE CASES		13	8	9	7	42	33	26	14	11
MEASURABLE AND TRACE CASES		26	19	13	11	42	34	35	21	15
PERCENT MEASURABLE		31	19	21	17		79	62	33	26
PERCENT MEASURABLE AND TRACE		62	45	31	26		81	83	50	36

0000 GMT RAOB

TYPE 4	STN	PHX				SAMPLE SIZE FOR TYPE 4	FLG			
	PD	1	2	3	4		1	2	3	4
MEASURABLE CASES		16	12	14	9	109	35	37	33	31
MEASURABLE AND TRACE CASES		23	23	28	18	109	51	52	44	37
PERCENT MEASURABLE		15	11	13	8		32	34	30	28
PERCENT MEASURABLE AND TRACE		21	21	26	17		47	48	40	34

1200 GMT RAOB

TYPE 4	STN	PHX				SAMPLE SIZE FOR TYPE 4	FLG			
	PD	1	2	3	4		1	2	3	4
MEASURABLE CASES		7	4	7	6	123	23	23	29	30
MEASURABLE AND TRACE CASES		11	17	16	17	123	34	36	37	41
PERCENT MEASURABLE		6	3	6	5		19	19	24	24
PERCENT MEASURABLE AND TRACE		9	14	13	14		28	29	30	33

0000 GMT RAOB

TYPE 5	STN	PHX				SAMPLE SIZE FOR TYPE 5	FLG			
	PD	1	2	3	4		1	2	3	4
MEASURABLE CASES		14	20	27	38	781	50	63	73	90
MEASURABLE AND TRACE CASES		41	42	52	66	781	93	98	125	133
PERCENT MEASURABLE		2	3	4	5		6	8	9	12
PERCENT MEASURABLE AND TRACE		5	5	7	8		12	13	16	17

1200 GMT RAOB

TYPE 5	STN	PHX				SAMPLE SIZE FOR TYPE 5	FLG			
	PD	1	2	3	4		1	2	3	4
MEASURABLE CASES		7	15	24	25	684	28	38	63	63
MEASURABLE AND TRACE CASES		23	29	44	51	684	50	73	92	104
PERCENT MEASURABLE		1	2	4	4		4	6	9	9
PERCENT MEASURABLE AND TRACE		3	4	6	8		7	11	13	15

Figures 2a-e: Probability of Precipitation Events at PHX and FLG by Periods for Types 1-5 from 0000 GMT and 1200 GMT RAOBS.

RELIABILITY
MEASURABLE PRECIPITATION
FIGURE 3A

		1200 GMT						0000 GMT				
	PERIOD	1	2	3	4	TOTAL SAMPLE SIZE PER PD	PERIOD	1	2	3	4	TOTAL SAMPLE SIZE PER PD
TOTAL NUMBER OF EVENTS CAUGHT BY TYPES 1-4	PHX	52	45	39	34	318	PHX	51	41	36	26	221
	FLG	146	122	109	96		FLG	110	109	90	77	
TOTAL NUMBER OF EVENTS IN STUDY	PHX	59	60	63	59	1002	PHX	65	61	63	64	1002
	FLG	174	160	172	159		FLG	160	172	163	167	
PERCENT OF TOTAL EVENTS WHICH OCCURRED IN TYPES 1-4	PHX	88%	75%	62%	58%		PHX	78%	67%	57%	41%	
	FLG	84%	76%	63%	60%		FLG	69%	63%	55%	46%	

RELIABILITY
MEASURABLE AND TRACE
FIGURE 3B

		1200 GMT						0000 GMT				
	PERIOD	1	2	3	4	TOTAL SAMPLE SIZE PER PD	PERIOD	1	2	3	4	TOTAL SAMPLE SIZE PER PD
TOTAL NUMBER OF EVENTS CAUGHT BY TYPES 1-4	PHX	87	86	70	58	318	PHX	79	68	63	43	221
	FLG	182	168	138	129		FLG	141	134	114	92	
TOTAL NUMBER OF EVENTS IN STUDY	PHX	110	115	114	109	1002	PHX	120	110	115	109	1002
	FLG	232	241	230	235		FLG	234	232	239	225	
PERCENT OF TOTAL EVENTS WHICH OCCURRED IN TYPES 1-4	PHX	79%	75%	61%	53%		PHX	66%	62%	55%	39%	
	FLG	78%	70%	60%	55%		FLG	60%	58%	48%	41%	

FIGURES 3A and 3B: Probability of Precipitation Events at PHX and FLG by Periods for Types 1-5 from 0000 GMT and 1200 GMT RAOBS.

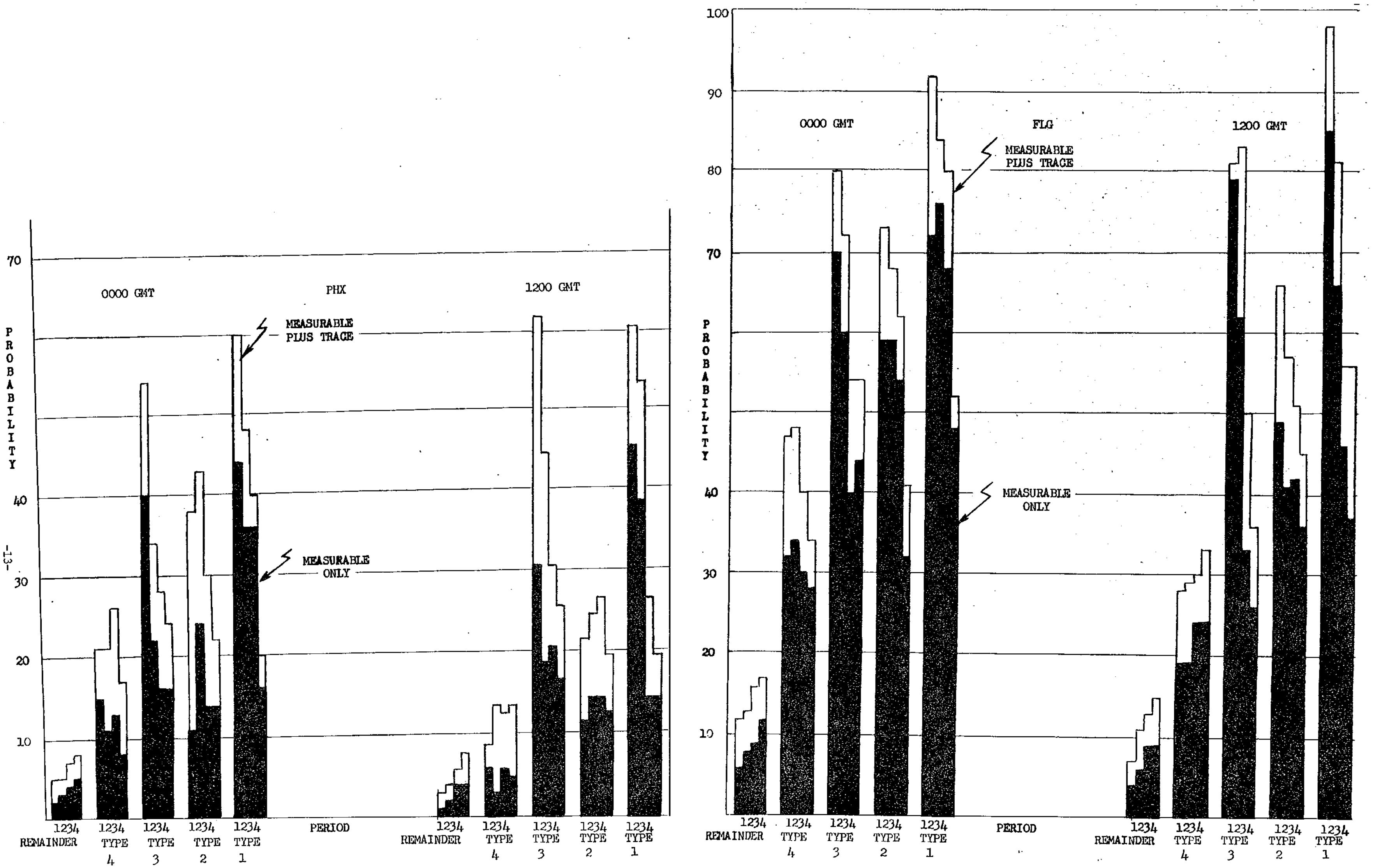

Figure 4a-b: Graphical Representation of the Probability of Precipitation Events by Periods at PHX and FLG for Types 1-5. RAOBS at 0000 GMT and 1200 GMT.

PROBABILITY OF MEASURABLE PRECIPITATION

TYPE 1

PHX

0000 GMT						1200 GMT					
	N	PD1	PD2	PD3	PD4		N	PD1	PD2	PD3	PD4
WITH UPPER LEVEL MOISTURE	14	50	50	36	21	WITH UPPER LEVEL MOISTURE	13	62	54	23	15
COMBINED	25	44	36	36	16	COMBINED	41	46	39	15	15
WITHOUT UPPER LEVEL MOISTURE	11	36	18	36	9	WITHOUT UPPER LEVEL MOISTURE	28	39	32	11	14

FLG

0000 GMT						1200 GMT					
	N	PD1	PD2	PD3	PD4		N	PD1	PD2	PD3	PD4
WITH UPPER LEVEL MOISTURE	14	79	79	64	50	WITH UPPER LEVEL MOISTURE	13	92	69	54	38
COMBINED	25	72	76	68	48	COMBINED	41	85	66	46	37
WITHOUT UPPER LEVEL MOISTURE	11	64	73	73	45	WITHOUT UPPER LEVEL MOISTURE	28	82	64	43	36

PROBABILITY OF MEASURABLE PRECIPITATION

TYPE 2

PHX

0000 GMT						1200 GMT					
	N	PD1	PD2	PD3	PD4		N	PD1	PD2	PD3	PD4
WITH UPPER LEVEL MOISTURE	7	43	71	14	43	WITH UPPER LEVEL MOISTURE	10	20	40	20	0
COMBINED	37	11	24	14	14	COMBINED	112	12	15	15	13
WITHOUT UPPER LEVEL MOISTURE	30	3	20	13	7	WITHOUT UPPER LEVEL MOISTURE	102	12	13	15	15

FLG

0000 GMT						1200 GMT					
	N	PD1	PD2	PD3	PD4		N	PD1	PD2	PD3	PD4
WITH UPPER LEVEL MOISTURE	7	86	86	71	57	WITH UPPER LEVEL MOISTURE	10	60	60	60	40
COMBINED	37	59	59	54	32	COMBINED	112	49	41	42	36
WITHOUT UPPER LEVEL MOISTURE	30	53	53	50	27	WITHOUT UPPER LEVEL MOISTURE	102	48	39	40	35

PROBABILITY OF MEASURABLE PRECIPITATION

TYPE 3

PHX

0000 GMT						1200 GMT					
	N	PD1	PD2	PD3	PD4		N	PD1	PD2	PD3	PD4
WITH UPPER LEVEL MOISTURE	10	40	20	20	10	WITH UPPER LEVEL MOISTURE	15	27	27	47	27
COMBINED	50	40	22	16	16	COMBINED	42	31	19	21	17
WITHOUT UPPER LEVEL MOISTURE	40	40	23	15	18	WITHOUT UPPER LEVEL MOISTURE	27	33	15	7	11

FLG

0000 GMT						1200 GMT					
	N	PD1	PD2	PD3	PD4		N	PD1	PD2	PD3	PD4
WITH UPPER LEVEL MOISTURE	10	90	80	30	30	WITH UPPER LEVEL MOISTURE	15	87	73	47	40
COMBINED	50	70	60	40	44	COMBINED	42	79	62	33	26
WITHOUT UPPER LEVEL MOISTURE	40	65	55	43	48	WITHOUT UPPER LEVEL MOISTURE	27	74	56	26	19

PROBABILITY OF MEASURABLE PRECIPITATION

TYPE 4

PHX

0000 GMT						1200 GMT					
	N	PD1	PD2	PD3	PD4		N	PD1	PD2	PD3	PD4
WITH UPPER LEVEL MOISTURE	9	33	56	33	11	WITH UPPER LEVEL MOISTURE	3	33	33	33	0
COMBINED	109	15	11	13	8	COMBINED	123	6	3	6	5
WITHOUT UPPER LEVEL MOISTURE	100	13	7	11	8	WITHOUT UPPER LEVEL MOISTURE	120	5	3	5	5

FLG

0000 GMT						1200 GMT					
	N	PD1	PD2	PD3	PD4		N	PD1	PD2	PD3	PD4
WITH UPPER LEVEL MOISTURE	9	56	67	44	44	WITH UPPER LEVEL MOISTURE	3	33	67	67	67
COMBINED	109	32	34	30	28	COMBINED	123	19	19	24	24
WITHOUT UPPER LEVEL MOISTURE	100	30	31	29	27	WITHOUT UPPER LEVEL MOISTURE	120	18	18	23	23

FIGURE 5A-D: BREAKDOWN PROBABILITIES OF MEASURABLE PRECIPITATION EVENTS FOR THE PRESENCE OR LACK OF MOISTURE ABOVE 700 MB BY PERIODS AT PHX AND FLG FOR TYPES 1-4. RAOBS AT 0000 GMT AND 1200 GMT.

COMPARISON OF TOTAL BRIER SCORES FOR BOTH ORIGINAL POPS (POPA) AND BREAKDOWN POPS (POPB) TO CURRENT MOS POPS

CURRENT 0000 GMT RAOB
CURRENT 0000 GMT MOS

TYPE 1 - N=12

	PHX			FLG		
	PD1(FP)	PD2(FP)	PD3(FP)	PD1(FP)	PD2(FP)	PD3(FP)
POPA	372	332	288	168	228	300
POPB	495	332	313	193	237	300
MOS	209	345	324	217	299	388

CURRENT 0000 GMT RAOB
CURRENT 0000 GMT MOS

TYPE 2 - N=11

	PHX			FLG		
	PD1(FP)	PD2(FP)	PD3(FP)	PD1(FP)	PD2(FP)	PD3(FP)
POPA	104	91	91	276	275	259
POPB	104	91	91	276	275	259
MOS	100	125	182	238	396	301

COMPARISON OF TOTAL BRIER SCORES FOR BOTH ORIGINAL POPS (POPA) AND BREAKDOWN POPS (POPB) TO CURRENT MOS POPS

CURRENT 0000 GMT RAOB
CURRENT 0000 GMT MOS

TYPE 3 - N=25

	PHX			FLG		
	PD1(FP)	PD2(FP)	PD3(FP)	PD1(FP)	PD2(FP)	PD3(FP)
POPA	520	520	400	600	600	540
POPB	580	520	433	672	617	681
MOS	294	346	231	356	301	230

CURRENT 0000 GMT RAOB
CURRENT 0000 GMT MOS

TYPE 4 - N=26

	PHX			FLG		
	PD1(FP)	PD2(FP)	PD3(FP)	PD1(FP)	PD2(FP)	PD3(FP)
POPA	106	266	266	354	394	474
POPB	58	242	266	354	388	468
MOS	121	176	124	185	227	223

COMPARISON OF TOTAL BRIER SCORES FOR BOTH ORIGINAL POPS (POPA) AND BREAKDOWN POPS (POPB) TO CURRENT MOS POPS

CURRENT 1200 GMT RAOB
CURRENT 1200 GMT MOS

TYPE 1 - N=20

	PHX			FLG		
	PD1(FP)	PD2(FP)	PD3(FP)	PD1(FP)	PD2(FP)	PD3(FP)
POPA	520	500	380	340	500	500
POPB	500	510	450	350	530	500
MOS	567	483	366	434	476	352

CURRENT 1200 GMT RAOB
CURRENT 1200 GMT MOS

TYPE 2 - N=17

	PHX			FLG		
	PD1(FP)	PD2(FP)	PD3(FP)	PD1(FP)	PD2(FP)	PD3(FP)
POPA	368	428	257	412	392	392
POPB	372	428	284	412	372	372
MOS	251	175	236	179	147	226

COMPARISON OF TOTAL BRIER SCORES FOR BOTH ORIGINAL POPS (POPA) AND BREAKDOWN POPS (POPB) TO CURRENT MOS POPS

CURRENT 1200 GMT RAOB
CURRENT 1200 GMT MOS

TYPE 3 - N=11

	PHX			FLG		
	PD1(FP)	PD2(FP)	PD3(FP)	PD1(FP)	PD2(FP)	PD3(FP)
POPA	164	164	224	316	179	299
POPB	169	207	219	329	195	316
MOS	147	172	191	291	118	241

CURRENT 1200 GMT RAOB
CURRENT 1200 GMT MOS

TYPE 4 - N=27

	PHX			FLG		
	PD1(FP)	PD2(FP)	PD3(FP)	PD1(FP)	PD2(FP)	PD3(FP)
POPA	97	97	97	408	408	288
POPB	97	97	97	408	408	288
MOS	127	137	199	352	257	279

FIGURE 6a-d. COMPARISONS OF TEST DATA BRIER SCORES DERIVED FROM ORIGINAL (POPA) AND BREAKDOWN (POPB) PROBABILITIES OF MEASURABLE PRECIPITATION TO THOSE FROM FINAL MOS PROBABILITIES OF THE COMPUTER RUN CONCURRENT WITH RAOB TIME.

COMPARISON OF TOTAL BRIER SCORES FOR BOTH ORIGINAL POPS
(POPA) AND BREAKDOWN POPS (POPB) TO PREVIOUS MOS POPS

CURRENT 0000 GMT RAOB
CURRENT 0000 GMT MOS

TYPE 1 - N=12

	PHX			FLG		
	PD1	PD2(FP PD1)	PD3(FP PD2)	PD1	PD2(FP PD1)	PD3(FP PD2)
POPA	372	372	332	148	168	228
POPB	335	495	332	128	193	237
MOS	590	374	332	509	301	289

CURRENT 0000 GMT RAOB
CURRENT 1200 GMT MOS

TYPE 2 - N=11

	PHX			FLG		
	PD1	PD2(FP PD1)	PD3(FP PD2)	PD1	PD2(FP PD1)	PD3(FP PD2)
POPA	251	104	91	236	276	275
POPB	288	104	91	275	276	275
MOS	222	142	158	518	318	324

COMPARISON OF TOTAL BRIER SCORES FOR BOTH ORIGINAL POPS
(POPA) AND BREAKDOWN POPS (POPB) TO PREVIOUS MOS POPS

CURRENT 0000 GMT RAOB
PREVIOUS 1200 GMT MOS

TYPE 3 - N=25

	PHX			FLG		
	PD1	PD2(FP PD1)	PD3(FP PD2)	PD1	PD2(FP PD1)	PD3(FP PD2)
POPA	520	520	520	785	600	600
POPB	520	580	520	913	672	617
MOS	436	411	446	376	447	431

CURRENT 0000 GMT RAOB
PREVIOUS 1200 GMT MOS

TYPE 4 - N=26

	PHX			FLG		
	PD1	PD2(FP PD1)	PD3(FP PD2)	PD1	PD2(FP PD1)	PD3(FP PD2)
POPA	284	106	266	336	354	394
POPB	282	58	242	348	354	388
MOS	131	159	282	414	262	394

COMPARISON OF TOTAL BRIER SCORES FOR BOTH ORIGINAL POPS
(POPA) AND BREAKDOWN POPS (POPB) TO PREVIOUS MOS POPS

CURRENT 1200 GMT RAOB
PREVIOUS 0000 GMT MOS

TYPE 1 - N=20

	PHX			FLG		
	PD1	PD2(FP PD1)	PD3(FP PD2)	PD1	PD2(FP PD1)	PD3(FP PD2)
POPA	500	520	500	260	340	500
POPB	320	372	428	416	412	372
MOS	481	581	180	329	207	130

CURRENT 1200 GMT RAOB
PREVIOUS 0000 GMT MOS

TYPE 2 - N=17

	PHX			FLG		
	PD1	PD2(FP PD1)	PD3(FP PD2)	PD1	PD2(FP PD1)	PD3(FP PD2)
POPA	337	368	428	425	412	392
POPB	320	372	428	416	412	372
MOS	180	259	180	329	207	130

COMPARISON OF TOTAL BRIER SCORES FOR BOTH ORIGINAL POPS
(POPA) AND BREAKDOWN POPS (POPB) TO PREVIOUS MOS POPS

CURRENT 1200 GMT RAOB
PREVIOUS 0000 GMT MOS

TYPE 3 - N=11

	PHX			FLG		
	PD1	PD2(FP PD1)	PD3(FP PD2)	PD1	PD2(FP PD1)	PD3(FP PD2)
POPA	219	164	164	284	316	179
POPB	219	169	207	291	329	195
MOS	106	146	231	163	223	181

CURRENT 1200 GMT RAOB
PREVIOUS 0000 GMT MOS

TYPE 4 - N=17

	PHX			FLG		
	PD1	PD2(FP PD1)	PD3(FP PD2)	PD1	PD2(FP PD1)	PD3(FP PD2)
POPA	7	97	97	228	408	408
POPB	7	97	97	228	408	408
MOS	43	117	145	310	365	292

FIGURE 7a-d. COMPARISONS OF TEST DATA BRIER SCORES DERIVED FROM ORIGINAL (POPA) AND BREAKDOWN (POPB) PROBABILITIES OF MEASURABLE PRECIPITATION TO THOSE FROM FINAL MOS PROBABILITIES OF THE COMPUTER RUN 12 HOURS PREVIOUS TO RAOB TIME.

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