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AVIATION AUTOMATED WEATHER OBSERVATION SYSTEM (AV-AWOS).(U)

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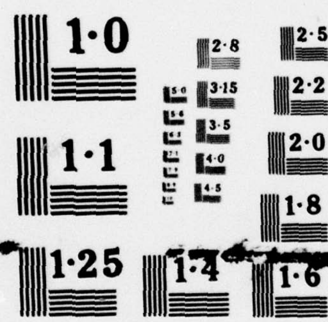

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Report No. FAA-RD-79-63

AVIATION AUTOMATED WEATHER OBSERVATION SYSTEM (AV-AWOS)

National Weather Service
National Oceanic and Atmospheric Administration
Department of Commerce

March 1979

Final Report

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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
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16. Abstract

The test results of the Aviation Automated Weather Observation System (AV-AWOS) at Newport News, Virginia, are presented. The rationale for the cloud and visibility algorithms is discussed. Verification of these algorithms is presented. The algorithms for converting sensor data to automated observations of cloud height, sky cover, and visibility are specified. Tabulation of the user reactions to an automated observation is presented.

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METRIC CONVERSION FACTORS

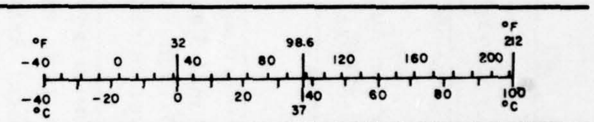
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



AV-AWOS EXECUTIVE SUMMARY

In June of 1973 a program to develop an Aviation Automated Weather Observation System (AV-AWOS) was initiated under Interagency Agreement DOT-FA73WAI-394 between the National Weather Service (NWS) and the Federal Aviation Administration (FAA).

At that time most of the weather parameters could be observed automatically, however, the most important parameters of an aviation weather observation--clouds, visibility and present weather, e.g., hail, freezing rain, thunderstorms, still required a subjective judgement of an observer.

The major emphasis of the AV-AWOS development was directed toward solving the cloud and visibility problems and the integration of these efforts into an automated station.

The technical approach involved the definition and requirements of an AV-AWOS system. This included the design and selection of best available sensors, development of processing algorithms, hardware design of sensor interfaces, the processing functions and the output communications. The AV-AWOS system would be tested at a medium sized airport which was at Newport News, Virginia (PHF). This operational test was evaluated for the acceptance by users and for the acceptance of the automated report as a certified weather observation.

Several significant contributions have been realized during this program. Some of the most important are as follows:

a) A determination of the magnitude of the requirements for a totally automated station.

b) The development of the initial sensor processing algorithms of the subjective type of weather observations.

c) The investigation into several types of sensors for various weather parameters.

d) The intensive investigation into the laser ceilometer status, which indicated the true status of such sensors.

e) The initiation of the development of utilizing a laser sensor for present weather indicators (such as fog, snow, rain, etc.).

f) The internal error checking and data quality control function usually performed by an observer.

g) What the aviation public objected to and what they applauded in an automated observation.

h) Realizing all of the above factors, realistic models have been developed utilizing the latest electronic technologies (microprocessors) to produce a more economical and more reliable totally automated system.

The AV-AWOS program pointed out many of the major deficiencies in all aspects of developing totally automated systems. This has lead to intensified programs within NWS, FAA and other agencies in the development of ceilometers, visibility and present weather sensors realizing what is truly required for aviation services.

Even though the major part of the AV-AWOS program is completed it is still planned to use the remaining funds to support some evaluation efforts required with these new sensors as they become available.

This report covers the final phases of the AV-AWOS program and includes technical information required to system specifications and user evaluation results from the Patrick Henry tests.

TEST AND EVALUATION DIVISION REPORT NO. 2-78

AUTOMATING CLOUD AND VISIBILITY OBSERVATIONS

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NOVEMBER 1978

MANAGEMENT SUMMARY

AV-AWOS is the acronym for Aviation Automated Weather Observation System. The overall system is designed to totally automate the aviation surface weather observation. The work element discussed in this report deals only with the development and test of methods for automated observing techniques for cloud height, sky cover and visibility. This report is intended to be part of a specification prepared by the Equipment Development Laboratory (part of the National Weather Service's Systems Development Office) for the Federal Aviation Administration.

Programs for the development of automated observing techniques have been conducted for several years by the Office of Technical Services' Test and Evaluation Division. Algorithms for automated observations of sky and visibility have been conceived based on a relatively small data sample from a sensor network surrounding Dulles International Airport. During the period January to May 1978, fully automated weather observations were used in an operational test at Patrick Henry International Airport, Newport News, Virginia. There, the automated observations were compared with routine observations made by the duty flight service specialist. Test results showed favorable comparisons with the observer. Several weaknesses were noted, almost exclusively, related to sensor performance.

The cloud and visibility algorithms are considered *operative*. This report specifies the manner in which the algorithms can be used, and their limitations.

The results of the development and test of the automated observing technique can be summarized as follows:

Visibility Observations

- The operational definition of visibility focuses on the human observer. Human observations of visibility, however, have many limiting factors. For example, point of observation, and the nature and number of visibility markers impart unique characteristics to each observation.

- The visibility sensor used in these tests (Videograph) has a limited sampling volume: 13 ft.^{3}. The unit, however, samples a relatively large volume compared to other types of single-ended visibility sensors currently marketed. Because of this volume, "grab" samples of 2 to 30 per minute show no significant differences when averaged over a time period of 6 to 10 minutes.

- When using three visibility sensors, sensor derived prevailing visibility had only fair agreement with human visibility during these tests. We believe this to be related to the limitations of subjective observing techniques, differences between human and automated concepts of observing, and reactions of the Videograph during certain obstruction to visibility situations.

- The inability of a single visibility sensor to report sector visibility may be a limitation in some operational applications. But with appropriate processing, a single sensor can produce a useful index of visibility. By definition, a single sensor could never report prevailing visibility. It could be used to report "station" visibility at smaller or limited service airfields.

Cloud Observations

- The operational definition of sky condition is based on the presence of a human observer with inherent limitations.

- Test results show that our computer-generated observations are in agreement with human observations. Our data sampling, averaging times and network configuration, while not unique, are appropriate for use in automated surface observations.

- Our program for observing total and partial obscurations is marginal. No sensors are currently available that measure the amount of sky obscured or vertical visibility into an obscuration. Until such equipment is developed, adequate algorithms for partial and total obscurations cannot be generated. Our algorithms for obscurations are the weakest part of our program. Under some combinations of weather conditions, unrepresentative observations of obscuration can be output by the automated system.

- The three sensor cloud algorithm shows good agreement with human observations. Variances are largely related to differences in human and automated concepts of observing.

- The inability of a single cloud sensor to report directional bias cloud remarks may be a limitation in some operational applications. Our tests, however, showed excellent agreement between two separated single sensors as well as between network and single sensor observations.

MANAGEMENT SUMMARY (Concluded)

Network Size and Siting

- If prevailing visibility is required, three visibility sensors are needed - more, if there are unusual local problems. In normal situations, the three sensors should be installed at the vertices of an equilateral triangle having approximately three mile legs. The required point of observation should be at the triangle's center.

- If an index of visibility is required, one visibility sensor is needed - more, if there are local visibility problems.

- In most situations, one ceilometer would be adequate. More would be needed if directional bias is present. If three ceilometers are needed for more representative information, they should be installed at the vertices of an equilateral triangle having 6 to 8 mile legs. The required point of observation should be at the triangle's center.

- We do not believe that the algorithm test results would be affected by small changes in network configurations.

- Installation of an automated weather system should proceed in a manner typical of other major aviation facilities. This includes an initial period of investigation to define the required network configuration. Continued review, after commissioning, is also needed.

TABLE OF CONTENTS

TABLE OF CONTENTS (Concluded)

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

AV-AWOS is the acronym for Aviation Automated Weather Observation System. The overall system is designed to totally automate the aviation surface weather observation. The work element discussed in this report deals only with the development and tests of methods for automated observing techniques for cloud height, sky cover and visibility. This report is intended to be part of a specification prepared by the National Weather Service's Equipment Development Laboratory for the Federal Aviation Administration.

Cited in this report is the rationale for the algorithms, and test results at two airport locations. An important feature is the discussion of automated observation limitations due, in part, to instrument deficiencies. Other sections include information on sensor network configurations and how siting requirements should be determined. Finally, the algorithms by which sensor input is converted to automated observations of cloud height, sky cover and visibility are specified in the appendices.

2. VISIBILITY OBSERVATIONS

Federal Meteorological Handbook #1 (FMH-1) (NOAA-National Weather Service, 1970) describes three types of visibility observations: runway visual range (RVR), runway visibility (RVV), and prevailing visibility (PV). The first two are highly specialized and have an accepted method of derivation from transmissometer measurements (Lefkowitz and Schlatter, 1966). The third type (PV) is based on the subjective visual impressions of a human observer scanning the apparent horizon. By using the technique of "sensor equivalent visibility" (SEV), developed by George and Lefkowitz (1972), we have been able to process measurements from a network of sensors to produce an equivalent of PV.

Prevailing visibility is the most difficult subjective observation parameter to automate. Attempting to put an individual's visual impressions in logic form is ambitious. The basic types of visibility sensors available today are a limiting factor. Most measure within a limited sampling volume. This spot measurement is extrapolated to larger volumes with the assumption of homogeneity (George and Lefkowitz, 1972; Chisholm and Kruse, 1974b).

One purpose of the tests was to use limited sampling sensors in the development of automated PV. We tried to satisfy the space averaging requirements of PV by employing a three sensor network with appropriate data processing. Time averaging was also an input to sensor derived PV. We also tested to determine the feasibility of using only one sensor as an index of PV (for use at limited service locations).

In this report, we describe techniques used for determining time averages and data sampling rates for sensor PV. While these averages were developed using a specific sensor type, the techniques are generalized and will apply to most visibility sensors.

2.1 SEV

SEV is defined as any equivalent of human visibility derived from instrumental measurements. In practice, the sensor from which SEV was derived required uniform visibility for an accurate calibration. Once calibrated, a sensor was then used to determine visibility under all conditions.

In our experiments, sensor visibility was measured by a backscatter sensor. This instrument relates visibility to the amount of projected light reflected back into the detector by particles in the air. The output of this instrument is converted to SEV by using an empirical relationship established by Hochreiter (1973). While backscatter sensors were used in our tests, a SEV calibration can be developed for any type of visibility sensor.

2.2 Prevailing Visibility (PV)

FMH-1 specifies the manner in which human observations of visibility are to be taken and reported. It defines PV as, "The greatest visibility equaled or exceeded throughout at least half of the horizon circle which need not necessarily be continuous." PV is determined at either the usual site(s) of observation or from the control tower level.

SEV and PV have different principles of observation. SEV is based on measurement of a small volume sample with extrapolation to overall areal visibility. PV, as determined by a human, relies on sensory information integrated over a relatively extensive area. SEV, based on a point sensor, usually has strongest relationships with PV during homogeneous conditions. It is important to note that the definition of PV, written for human observers as it is, could very well require an infinite number of sensors for automation to duplicate the human observation; however, practical and economic considerations dictate the use of as few sensors as will supply a useful product.

3. VISIBILITY INSTRUMENTATION

The ideal visibility instrument should have a direct relationship to the characteristics of human visibility. To our knowledge, such a sensor is not available for field use. The Videograph was selected for the visibility tests because it was readily available, was capable of field operation with little maintenance and had a traceable calibration.

3.1 Videograph

The Videograph is a backscatter visibility sensor. The instrument consists of a projector and receiver contained in a single housing mounted on a pedestal. The projector uses a xenon lamp that emits high intensity, short duration (1 μs) pulses of blue-white light into the atmosphere at a 3 Hz rate. The receiver measures the amount of projected light scattered back into a detector by particles in the atmosphere. The detector uses a reverse-biased PIN silicone photodiode. The Videograph output ranges from 0 to 999 μA with a system time constant of about 3 minutes.

The optical axis of the projector is inclined upwards at 3° so that it intersects the horizontal axis of the receiver optics at 17 feet. The common volume of the system extends about 600 feet from this point of intersection, although most of the backscattering occurs within the first 5 to 100 feet (Curcio and Knestrick, 1958). Using the 100-foot sampling length, the volume of atmosphere that can be sampled at any one time is about 13 $ft.^3$.

The μA output of the Videograph detector is converted to SEV using the empirically determined curves described by Hochreiter (1973). He established two conversions from μA to SEV values: one for daytime use and one for night. The values are:

Visibility	Day μA	Night μA
1/4 mi.	900	999
1 mi.	470	530
2 mi.	340	380
3 mi.	280	310
5 mi.	220	250
7 mi.	190	210

Conversion equations can also be developed for different types of obstruction to vision (Sheppard, 1977). In our work, however, we did not differentiate between different obstructions to vision.

The Videographs are calibrated against a collocated standard Videograph which is referenced against human visibility. Using paired measurements of sensor vs. standard, these data are grouped into classes ranging from 1/4 mile to 7 miles. Within each class, the mean difference between the sensor and standard must be less than 10% of the standard's output for the sensor to be considered calibrated. We checked the Videographs used at PHF before and after the four-month operational test. All had stayed within the alloted ± 10%.

3.2 Network Spacing

The length of each leg in our visibility triangle for both IAD and PHF tests was about 3 miles with a Videograph located at each vertex: the human observer was at the nominal center (Figures 1 and 2). Since visibility is a fragile parameter subject to small scale temporal changes and physical modification, the network was kept relatively small. The decision to use 3-mile legs was predicated on the need to supply the aviation community with visibility information over a large area around an airport while keeping within the same visibility universe. Use of three sensors was a pragmatic choice based on resources, difficulties in obtaining sites and complexity of installing data lines across great distances. A more comprehensive method might have been to test many sensor arrays of varying size. Economic and time constraints doomed that approach. We feel our network is appropriate for determining PV, but we do not believe it is unique.

4. VISIBILITY PROCESSING STRATEGY

Processing strategies for determining PV using a network of sensors must take into account the temporal and spatial variability of the atmosphere, as well as the characteristics and sampling volume of the sensor in use. In the subsequent paragraphs, we assess the role of these factors in developing a technique that will be sensor independent.

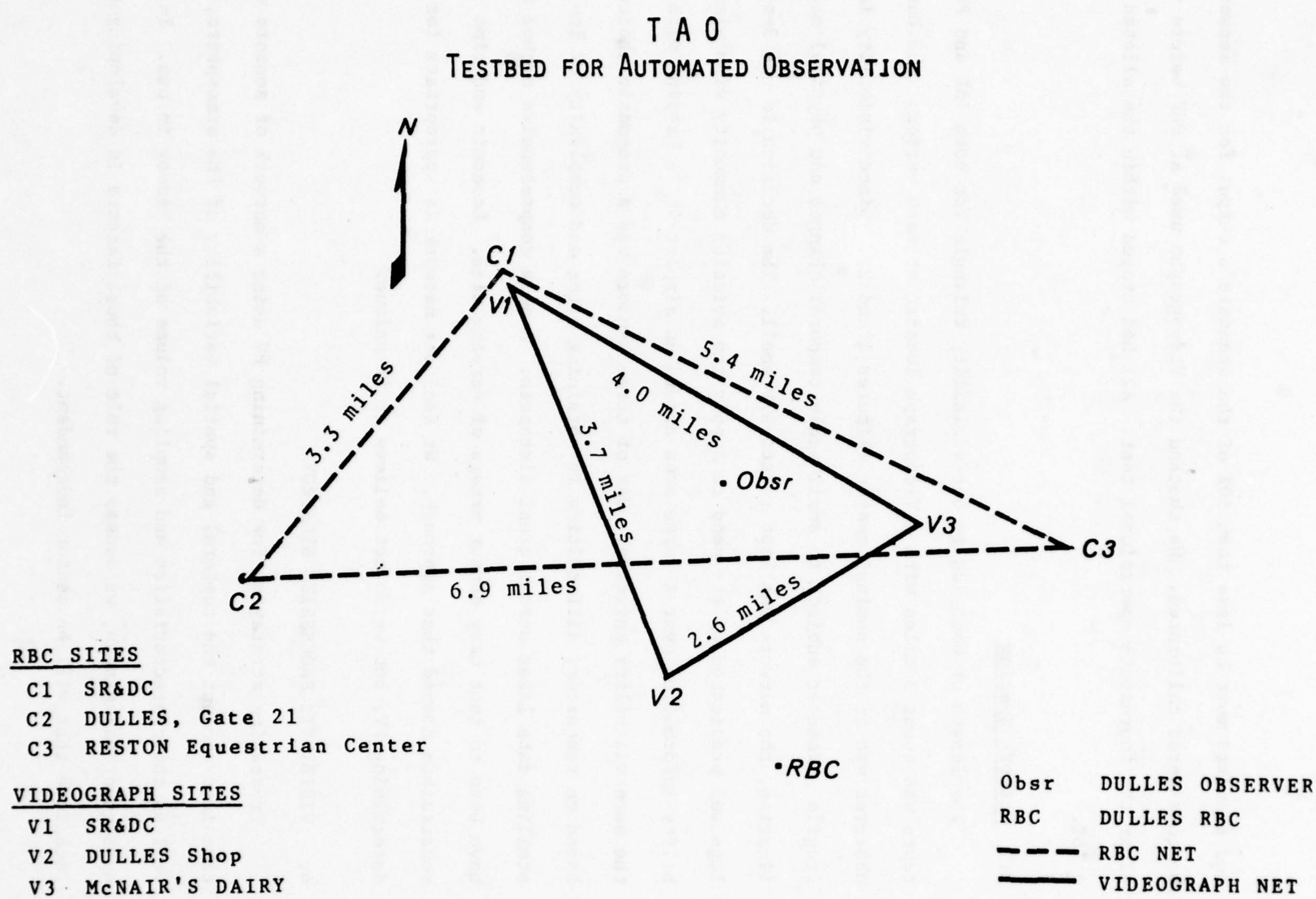


Figure 1. AV-AWOS Test Network at Dulles International Airport, Chantilly, Virginia

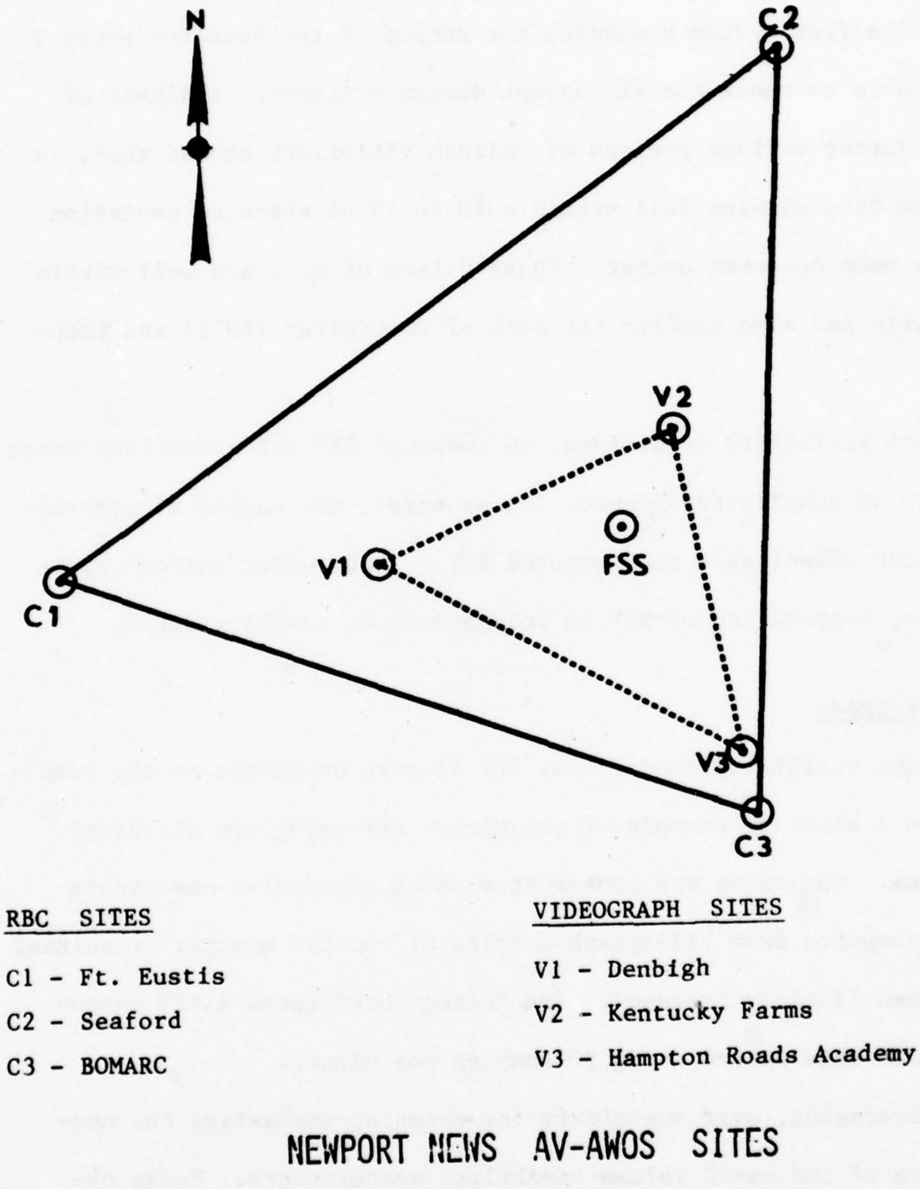


Figure 2. AV-AWOS Test Network at Patrick Henry International Airport, Newport News, Virginia

4.1 Sensor Processing

The output of the Videograph detector is designed to oscillate over a range of 2% of full scale (999 μA) as the amplifier searches for equilibrium. With our data collection system recording the output of the detector every 2 seconds, we are able to check the Videograph design criteria. Analysis of data sets taken during various periods of uniform visibility showed that, in each episode, the data samples fell within a 10 to 15 μA standard deviation (S.D.) about the mean detector output. These values of S.D. are well within the design criteria and also confirm the work of Hochreiter (1973) and Sheppard (1977).

Under uniform visibility conditions, we computed SEV using sampling rates varying from 2 to 30 samples per minute. As expected, the number of samples averaged had little effect upon the computed SEV. Thus, under uniform visibility conditions, computation of SEV is independent of sampling rates.

4.2 Temporal Averaging

During varying visibility conditions, SEV is more dependent on the sampling rate. Figure 3 shows an example of one-minute SEV using two different processing schemes. One curve was constructed using successive one-minute averages of SEV computed from Videograph samples of two per minute: resultant μA values have been linearly averaged. The dotted curve shows a SEV computation for the same data period using 30 samples per minute.

Short-term averaging, over one-minute for example, emphasized the nonhomogeneous nature of the small volume visibility measurements. Human observers tend to integrate these characteristics. In order to emulate human methods and provide a more appropriate observation, we tested various averaging schemes from 5 to 20 minutes. We concluded that averaging intervals of

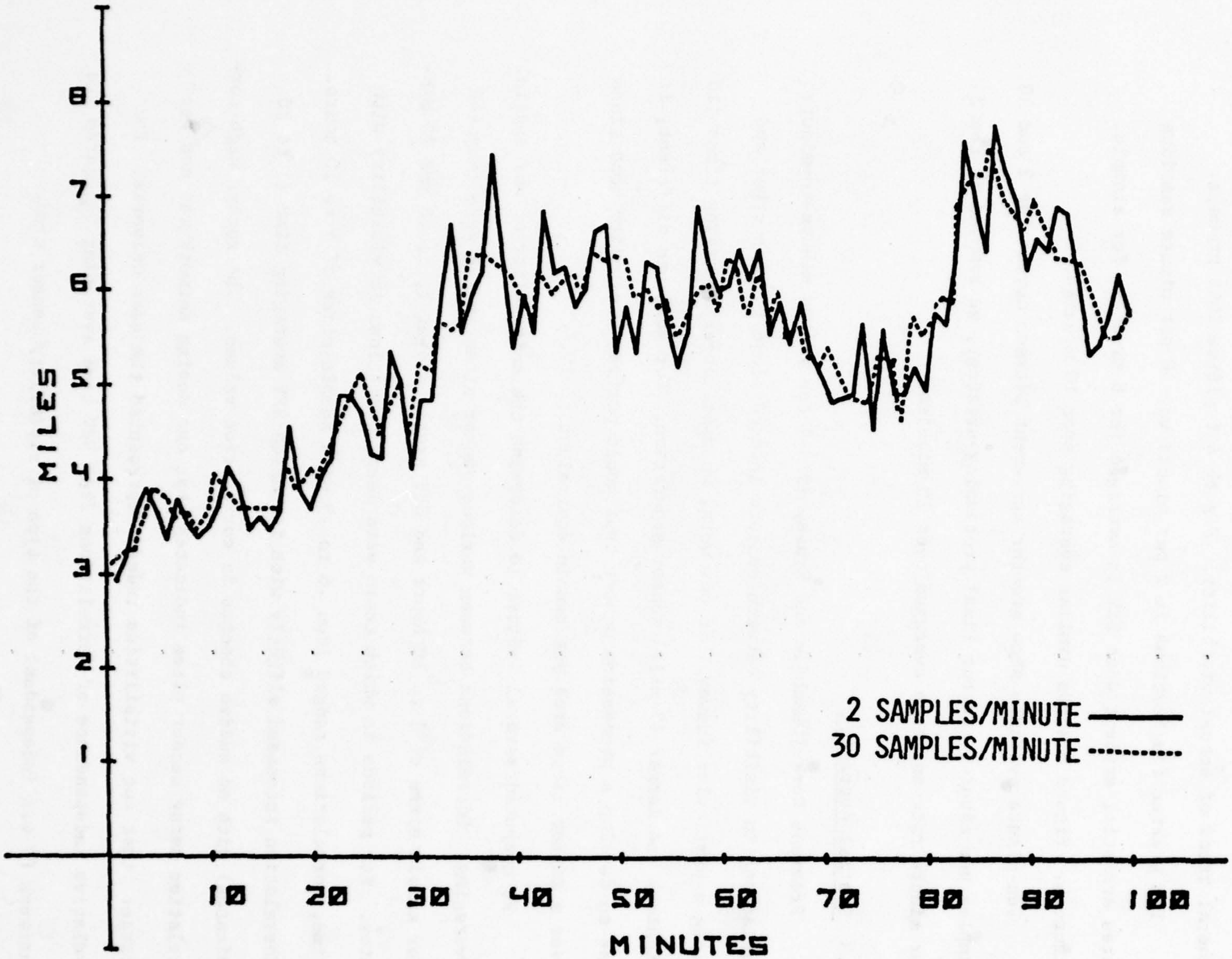


Figure 3. Time Plots of 1 Minute SEV Values Computed Using 2 and 30 Videograph Samples/Minute.

from 6 to 10 minutes generate the best compromise between smoothing to remove short-term sampling or temporal fluctuations and speed to respond to the general trend of actual visibility. Figure 4 typifies this process.

The greater fluctuations in 2 per minute vs. 30 per minute sampling rates are still evident when SEV is averaged for 6 minutes, for example, Figure 5. Figure 6 shows similar averaging over 10 minutes.

Ten-minute averages show greater agreement between curves for 2 and 30 samples per minute. In our final processing strategy, we sampled at the 2 per minute rate and then averaged over 10 minutes.

4.3 Spatial Averaging

Previous work (Chisholm and Kruse, 1974a) considered minute-to-minute variations in visibility between sensors located close to each other and along a particular runway. In our work, we used longer averaging times (10 minutes) and larger (3 mile) sensor separation. Our goal was different; it was to develop a processing scheme that would portray visibility conditions over a rather large area yet remain equivalent to PV.

We computed several indices to determine the suitability of our spatial averaging. Correlations between various sensor sites at PHF were computed for sample sizes of 1 to 10 hours and SEV averaged over 1, 5, 10 and 20 minutes. For periods in which there were large variations in visibility with time, correlations ranged from .6 to .9 with sample sizes of 5 to 10 hours. Correlation increased slightly with increased SEV averaging time (1 to 20 minutes) with no sudden changes in correlation values. The rather high correlation among sensor sites indicated that our design network was not too large: that our visibilities indeed represented the same universe. The relative independence of correlations from SEV time averaging indicated the network PV was independent of the type of visibility sensor used.

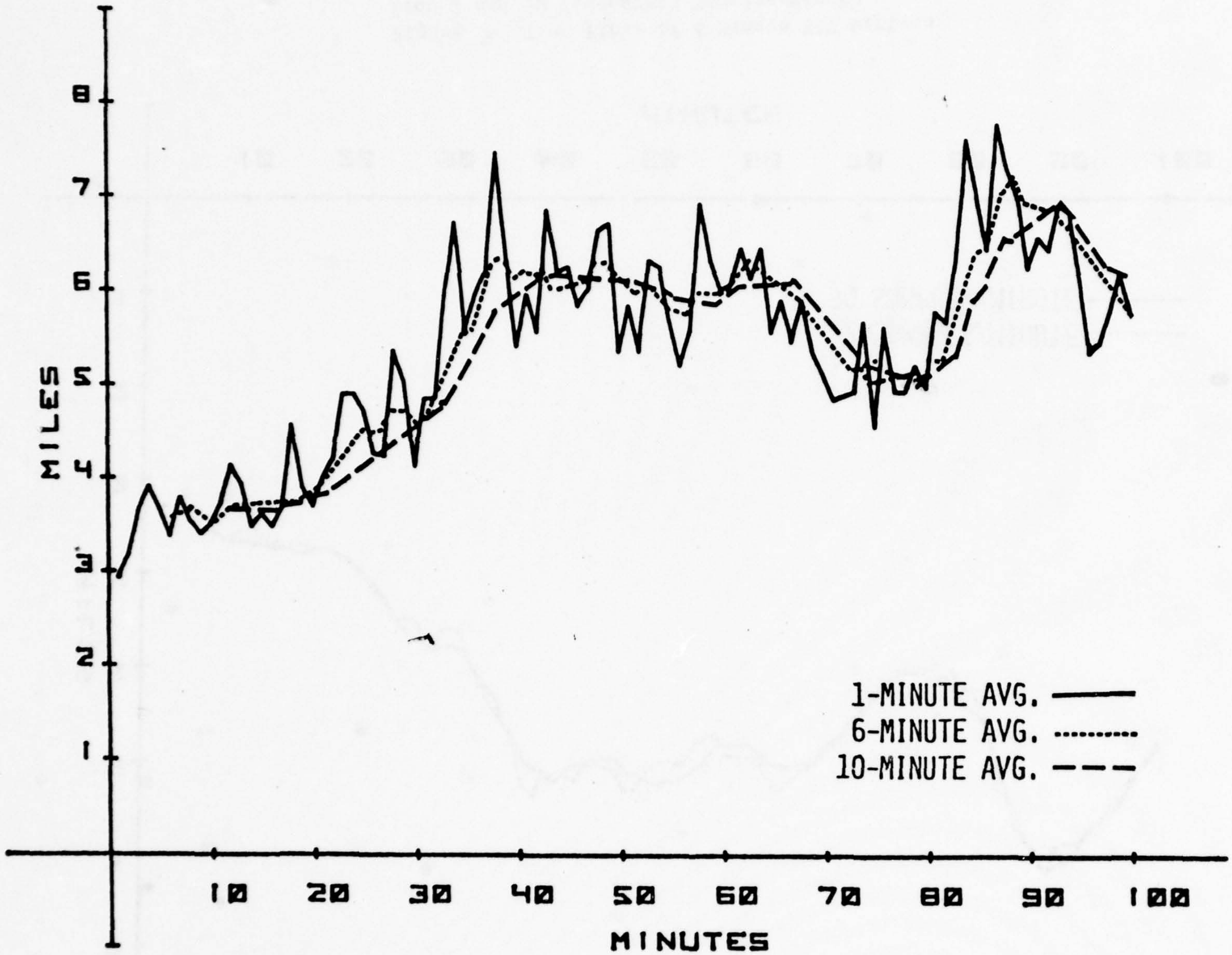


Figure 4. Time Plots of SEV Averaged Over 6 and 10 Minutes.

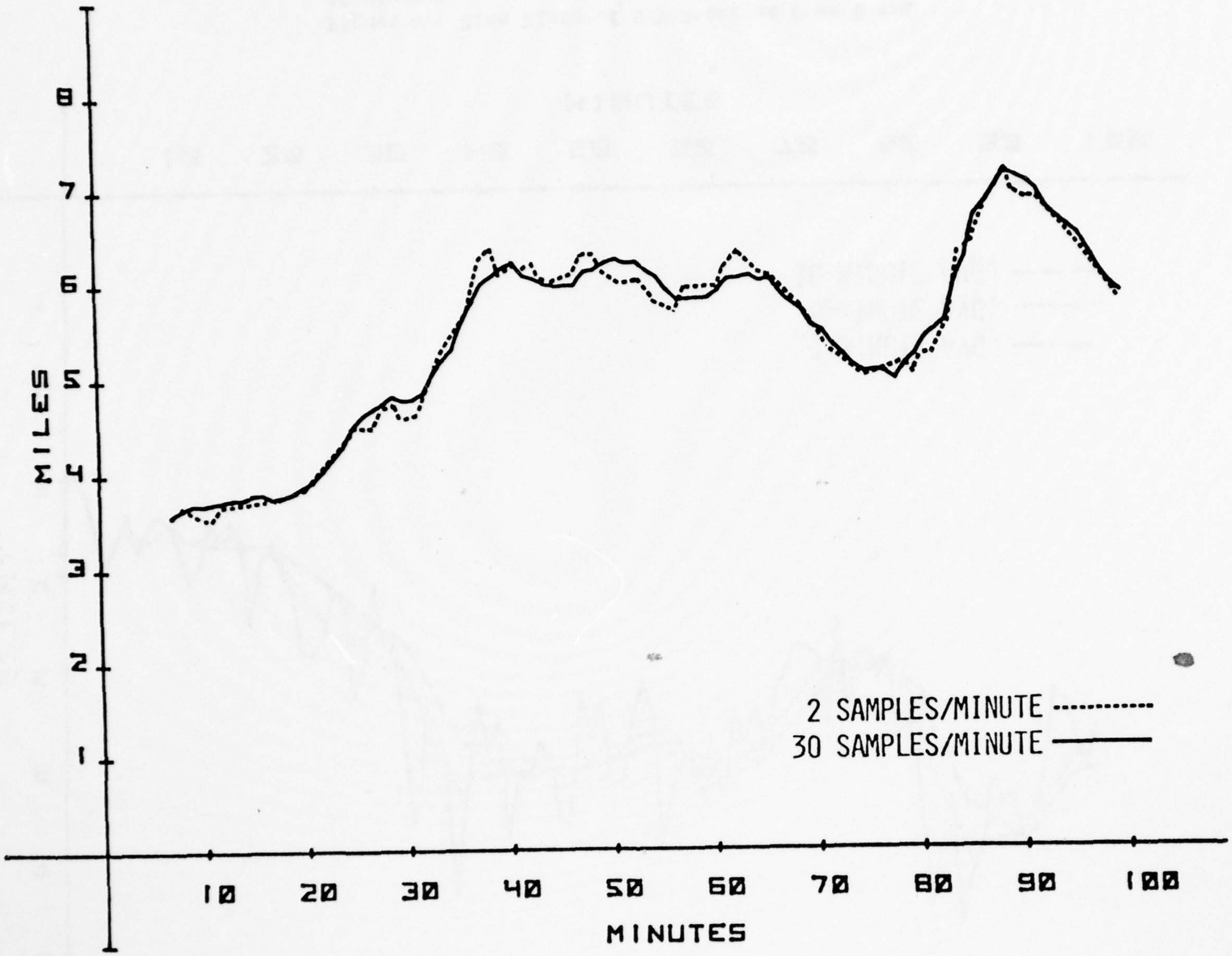


Figure 5. Time Plots of 6 Minute SEV Derived from 2 and 30 Videograph Samples/Minute.

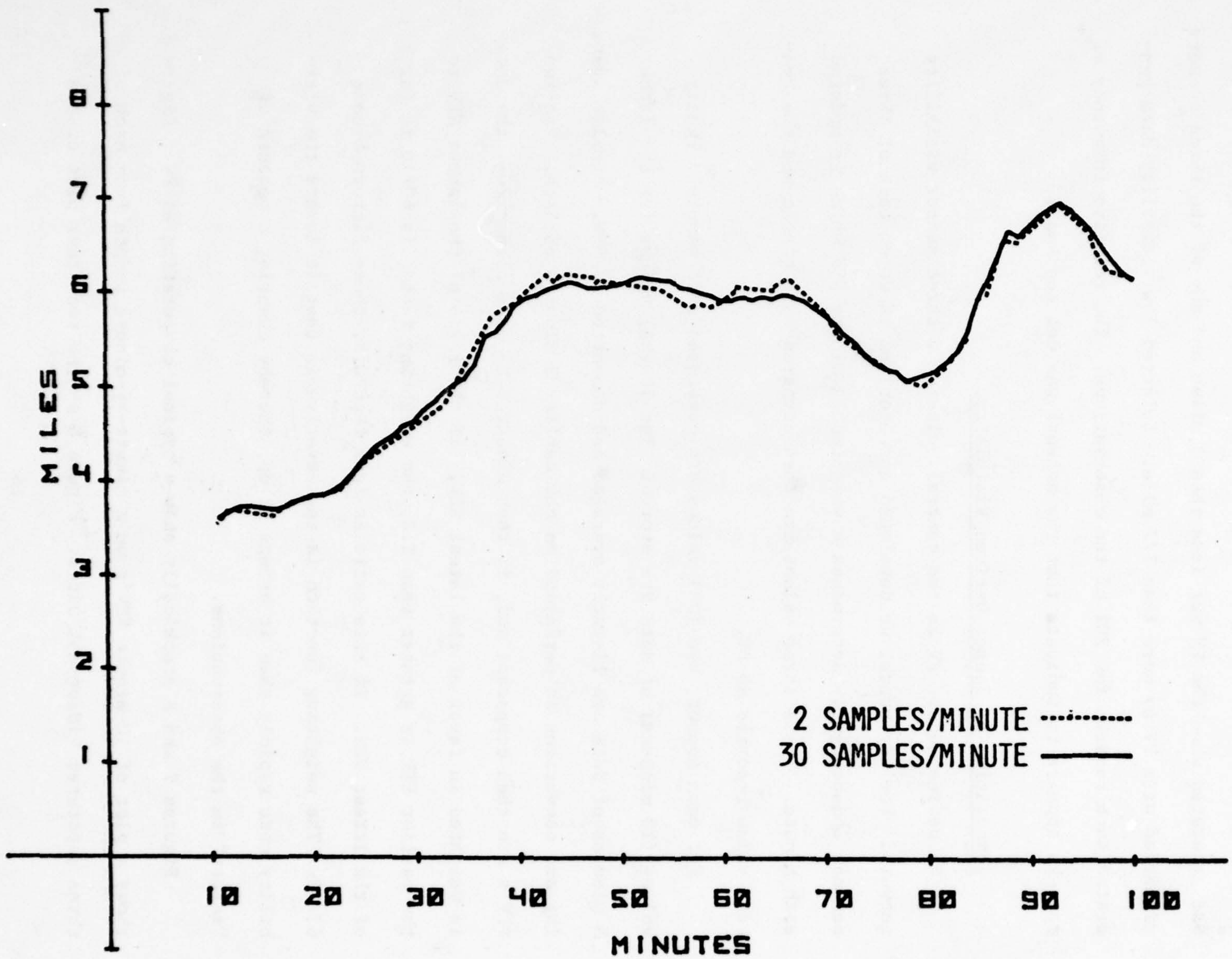


Figure 6. Time Plots of 10 Minute SEV Derived from 2 and 30 Videograph Samples/Minute.

Another index we used was how often a remark of sector visibility (e.g., VSBY NE1/2) was generated by the PV algorithm. For our algorithm, a remark was generated when the PV was less than 3 miles and any of the three sensors disagreed with PV by more than 1/2 mile. Selected low visibility data generated such remarks for 20% of the observations. The relative frequency of remarks appears to indicate that the network was not too small.

4.4 Computation of Sensor Derived Visibility

We define sensor PV as the central value of a three sensor visibility network. For our tests, we developed an algorithm in which each of three sensors independently determines a weighted 10-minute SEV which is updated each minute. These three values are then compared each minute and the central value reported as PV.

For each sensor, two (μA) values are generated each minute. Twenty values (10 minutes) of data are stored. The 10 (μA) values for the latest 5 minutes of data are linearly averaged and converted to SEV. Similar averaging and conversion is performed on the earlier 5 minutes of data. The two SEV's are then compared; and, if they disagree by more than ± 20%, the data is weighted in favor of the latest SEV. If the ratio of the latest SEV to the earlier SEV is greater than 1.2, the weighting factor is 60/40 in favor of the latest SEV. If this ratio is less than 0.8, these factors become 67/33. The weighting function is conservative in that it lowers the visibility more rapidly than it brings it up, thereby ensuring a measure of "safety" in the observations.

Figures 7 and 8 graphically show a typical computation of PV. Figure 7 shows a plot of 10-minute SEV's on a minute-by-minute update from each of three separated Videograph sites. Figure 8 is the resultant plot of the

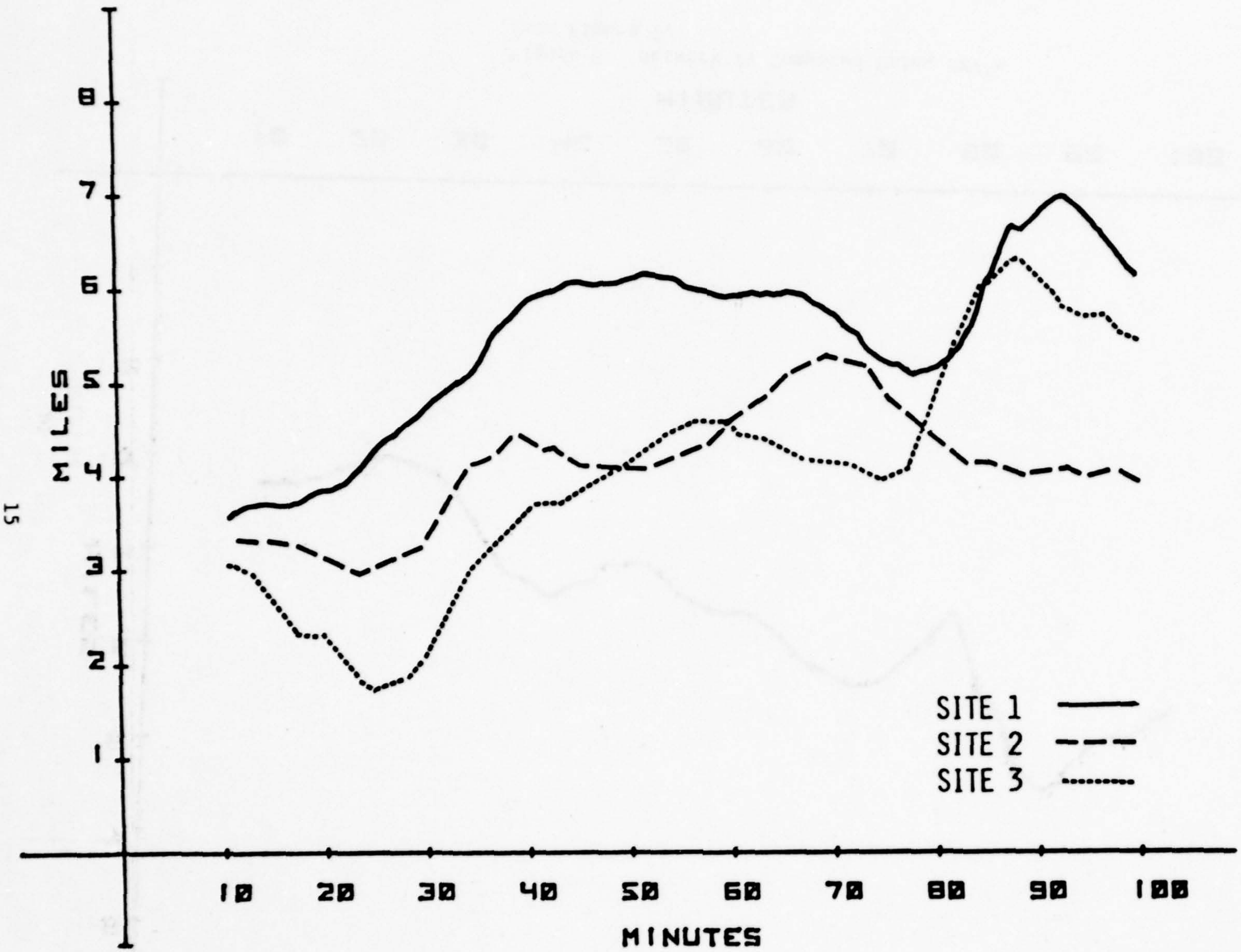


Figure 7.. Time Plots of 10 Minute SEV at 3 Locations in the PHF Net.

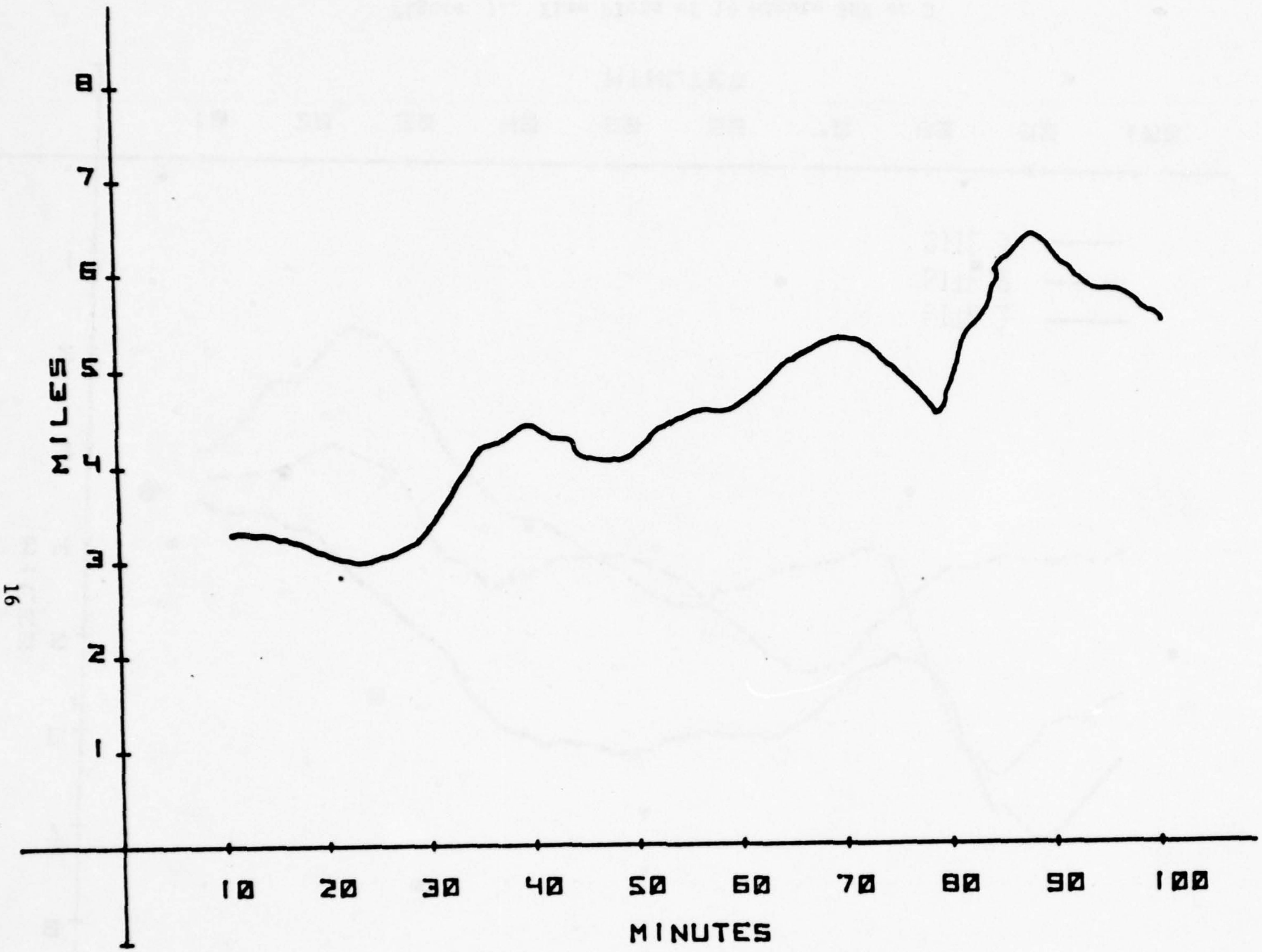


Figure 8. Network PV Computed Using SEV's from Figure 7.

central value of these SEV's and is defined as the sensor derived PV. If individual site SEV's differ from the PV by more than one-half mile, a sector visibility remark is generated.

For some applications, only one visibility sensor is required. In this case, station visibility (SV) is calculated in a manner identical to PV with one exception: the "compare" program step, that is, selecting the central visibility value from three choices, is skipped. Therefore, only one visibility measurement is generated for the observation, and sector visibility remarks are not available.

5. CLOUD OBSERVATIONS

The manner in which the subjective aviation surface weather observation is taken is prescribed by FMH-1. It states that "a complete evaluation of sky condition includes the type of clouds or obscuring phenomena present, their stratification; amount, opacity, direction of movement, height of bases and the effect on vertical visibility of surface-based obscuring phenomena."

In our objective techniques we limit these parameters to cloud height, amount, stratification and opacity. Currently there is no known production instrument to objectively measure the extent and depth of obscuring phenomena nor to identify cloud type.

5.1 The Human Observation

Describing the state of the sky is one of the more difficult tasks for weather observers. An observer must scan the entire sky from horizon to horizon, identify the cloud layers, estimate the height of each layer and then determine the percentage of sky coverage: the amount of the sky which is covered by clouds up to and including that layer. The observer must also determine the amount of sky hidden by surface based obscurations, and in some cases, the vertical visibility in the obscuring phenomena.

This task must be done despite the limitations to vision such as precipitation, airlight and darkness. Frequently, the observer's view of the horizon is limited by physical obstructions typified by an airport terminal and office buildings.

The cloud sensor most relied upon at National Weather Service observing stations is the rotating beam ceilometer (RBC). This instrument, described in Section 6, measures the height of a cloud element directly over its detector. A record of these measurements can help the observer to determine cloud layers and ascribe representative heights. The RBC, however, is only a tool. Since the RBC site is often a mile or more from the observer's location, the observer is required to determine through visual observation that the RBC measurements are representative of clouds in the overall observing area.

In some instances, the observer can deduce from the RBC record the amount of sky cover. But there is no direct instrumental means to obtain this information. The observer must rely primarily on a subjective sensory observation. Because of this, there is a natural variability among observers. For example, Galligan (1953) noted that the largest differences between observers in a test group occurred when reporting from 0.3 to 0.7 of cloud cover, with a maximum standard deviation of 0.123. She interprets this to mean, "...if the true cloud amount was for example, 0.5, 95% of the possible recordings for this amount could be expected to fall between 0.25 sky cover and 0.75 sky cover..." This range includes the critical ceiling/no ceiling point.

The major reason for the difference between objective and subjective cloud amounts is the "packing effect" noted in Figure 9. The observer is

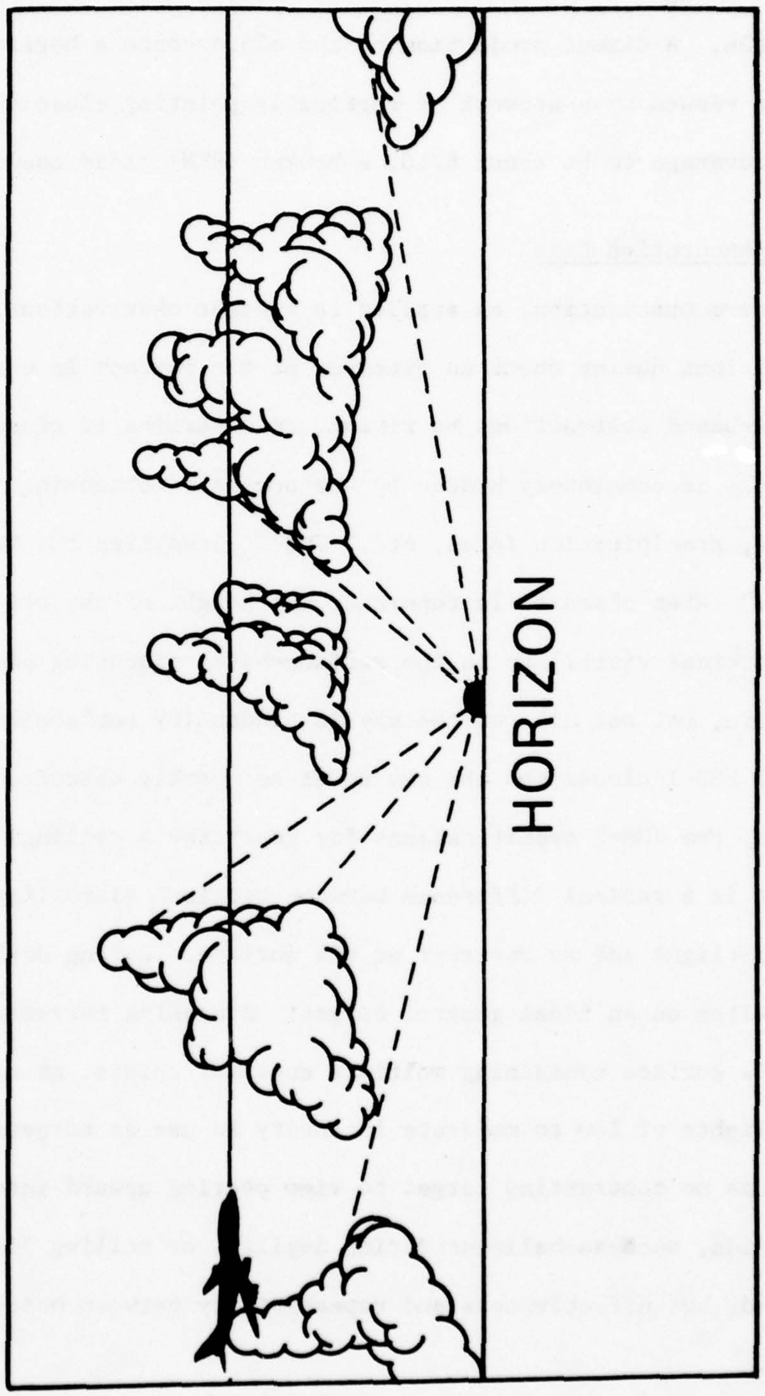


Figure 9. Packing Effect
(Observed Sky Cover 10/10)

directed to include in his evaluation of cloud cover the visibile vertical development of clouds, and would report 10/10 overcast (OVC) condition in that example. A direct projection of the clouds onto a horizon plane, in the manner viewed by a network of vertically pointing cloud sensors, would indicate coverage to be about 8/10, a broken (BKN) cloud condition.

5.2 The Obscuration Case

The term obscuration, as applied to weather observations, generally infers conditions during which an observer at the surface is unable, because of surface-based obstructions to vision, to determine if clouds are present. When the sky is completely hidden by surface-based obscuring phenomena (e.g., fog, smoke, precipitation forms, etc.) FMH-1 classifies the sky cover as "obscured." When obscured is reported, the height of the ceiling is defined as "the vertical visibility in the surface-based obscuring phenomena." When 1/10 or more, but not all, of the sky is hidden (by surface-based obscuring phenomena) FMH-1 classifies the sky cover as "partly obscured" (which does not satisfy the FMH-1 specifications for reporting a ceiling).

There is a radical difference between vertical visibility as viewed by a pilot in flight and an observer at the surface. During daylight, the pilot usually relies on an ideal general target: a massive terrestrial object - the earth's surface containing multiple contrast points; at night, the pilot may have lights of low to moderate intensity to use as targets. The observer, however, has no contrasting target to view peering upward into the obscuring medium. Aids, such as balloons during daylight or ceiling light at night, can be used, but effectiveness and repeatability between observers is uncertain.

We know of no instrument capable of quantitatively measuring the extent of partial obscuration, total obscuration or vertical visibility. Yet, despite the weaknesses in objective or subjective methods of making such observations, FMH-1 defines a ceiling in part as "the vertical visibility in a surface-based obscuring phenomena." Because of this FMH-1 specification, we've devised a technique to give an inferred partial obscuration or vertical visibility observation using a combination of cloud measurements, horizontal visibility and air temperature. This subprogram in our algorithms is based on a review of some human observations in obscuration conditions, but there has been insufficient data to fully test it. In an extreme case, virtually no clouds within ceilometer range for the latter portion of the sampling period and visibility below about 1 1/2 miles, the algorithm can indicate a total obscuration.

The obscuration case is the weakest element in the automated cloud observation. The method, perhaps, can be revised to reduce some inadequacies. But there'll not be a truly objective observation of this phenomena until an appropriate sensor is available.

Two subprograms are described in the Appendices. One generates partial obscuration and assumes .2 of the sky is obscured. The other produces several levels of vertical visibility into a total obscuration.

The success of automating cloud observations is not strictly contingent upon duplicating the human observation. Although reliable, the exact repeatability and precision of human observations has yet to be determined. While there are some differences in basic techniques, in a comparison between automated and human observations, neither is "more correct." Instead, both are similar means of describing physical conditions for which there is, as yet, no ground truth.

6. CLOUD INSTRUMENTATION

The RBC was used for data acquisition in these tests. Their sheer bulk, long baselines and hearty installations made changes in network configuration impractical. Still other problems with this sensor (not designed for automation) dictate little future for it in operational AV-AWOS networks. Sensor performance was adequate in our test mode.

6.1 Rotating Beam Ceilometer

The standard RBC is the most widely used cloud height indicator (CHI) today. This instrument consists of a rotating projector and a vertically pointing detector. The baseline is usually 400, 800 or 1200 feet: we use 800 feet. The standard RBC projector sweeps the detector's verticam beam of receptivity once every 6 seconds, with the measuring scan (0° to 90°) requiring 3 seconds. Its efficient height range is nominally up to 10 times the baseline. Because of pragmatic sensor and trigonometric limitations, cloud heights in our tests were limited to measurements below 7000 feet.

For our experiments, several modifications were made to the standard RBC. An optical zero switch was added to reduce alignment errors, thus giving greater accuracy at higher cloud heights. An electronic circuit was designed to allow only one projector lamp to be used, thereby reducing the measurement cycle to once every 12 seconds. This sampling interval was more than ample for our data collection needs since the AV-AWOS algorithm used just two scans per minute. The output of the RBC, normally analog, was routed through a digitizing system to detect peak amplitude signals, which indicated the presence of cloud bases.

6.2 Network Spacing

The design length of each leg of the ceilometer triangle was about 7 miles. Assuming the observer can see only to within 8° of the horizon when cloud bases are at 3000 feet, the observer's diameter of view is about 8 miles.

The number of CHI's to use represents a difficult choice. Although an infinite number of sensors in the network area would provide near perfect sampling, that approach was impractical. However, one CHI was located at each vertex of the network triangle. The decision was based on economic considerations and the availability of sensors. We were also influenced by the work done by Duda, et al., (1971).

7. CLOUD PROCESSING STRATEGY

Processing strategies for producing an automated cloud observation must consider the temporal and spatial variability of cloud elements, and the characteristics and sampling volume of the sensor in use. In subsequent paragraphs, we assess these factors to develop a technique that is sensor independent. While sensor independent, the technique assumes the use of a vertically pointing cloud height indicator (e.g., RBC, laser ceilometer, fixed-beam ceilometer).

7.1 Clustering

Clustering is first done independently for each network RBC. The AV-AWOS computer maintains a 30-minute running file of cloud heights reported at each site. At designated intervals, the program clusters these stored heights into layers and determines the height of each individual layer. This clustering procedure enables us to mathematically combine differing cloud height measurements into representative levels.

The method we use is "hierarchical clustering" as described by Duda, et al., (1971). In this technique, we initially consider our (n) cloud height measurements (from 30 minutes of data) to be a set of n clusters which we order in increasing height (h) so that $h_1 \leq h_2 \leq h_3 \leq h_n$. The step from n to n-1 clusters is made by computing a least square distance between adjacent clusters and then merging the closest pair. The iteration process continues and could conceivably end with all data in one final cluster. Figure 10 is an example of the hierarchical clustering procedure for each ceilometer. In this example, we started with a total of nine clusters, each a single cloud height arranged in ascending order.

In our technique, clustering stops at five cloud layers. We then determine if there should be any additional combining of these layers using various meteorological considerations, such as the distance between adjacent cloud layers. In our tests at Dulles International Airport, Chantilly, Virginia, (IAD), we found this combination of techniques saved computer processing time and yielded number of layers and layer separations more representative of human observations.

Figure 11 illustrates the clustering technique applied to cloud heights from an RBC site 7 miles NE of Patrick Henry International Airport, Newport News, Virginia, (PHF). We plotted the lowest cloud height reported each minute from that site. At the beginning of the data period, the cloud heights grouped naturally into layers - one about 1500 feet and the other at 3500 feet. Near the end of the period, the upper layer lowered to 3000 feet while the lower layer became less evident. Using only the data set from this particular RBC, the automated observation would be:

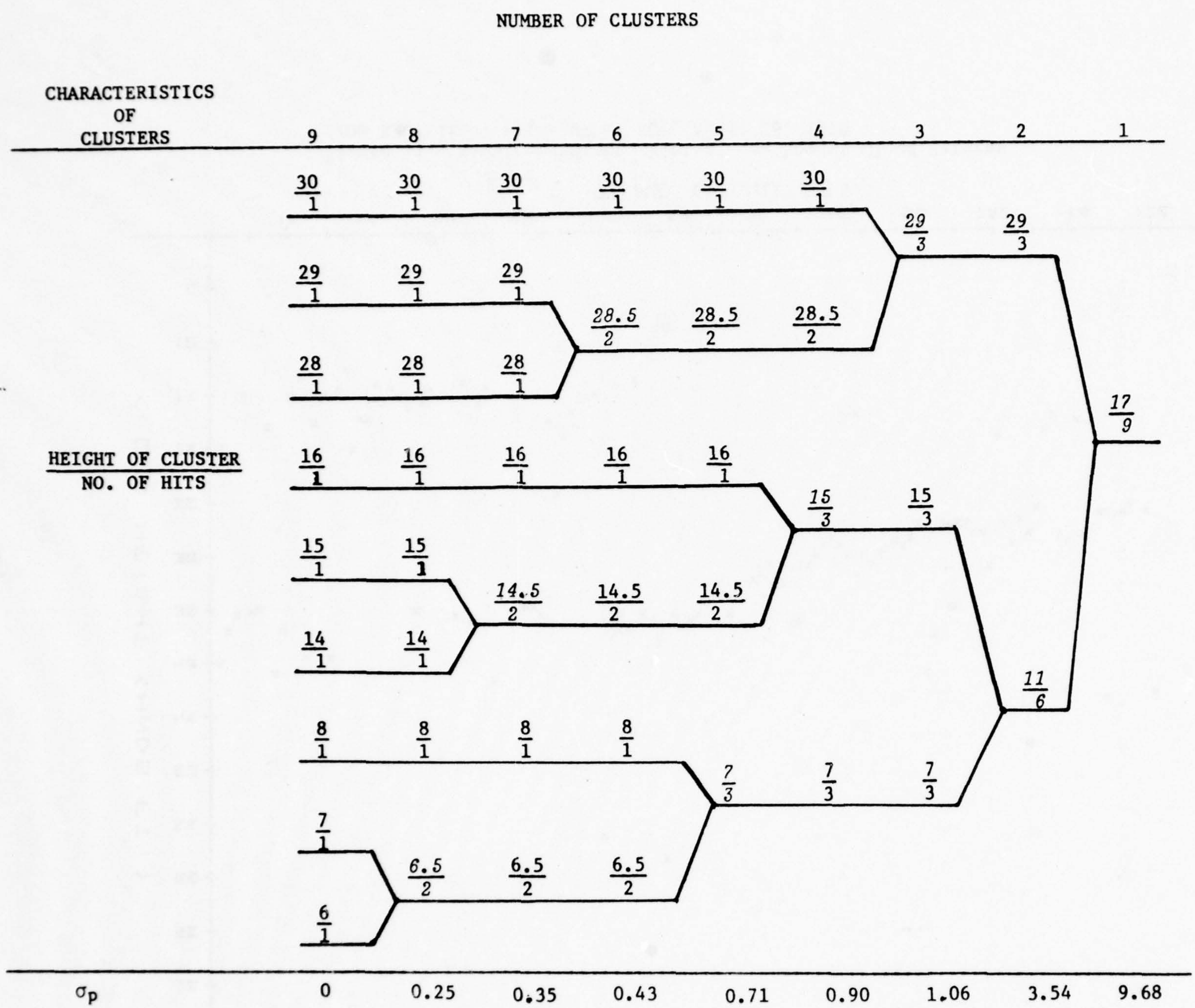


Figure 10. Example of Hierarchical Clustering

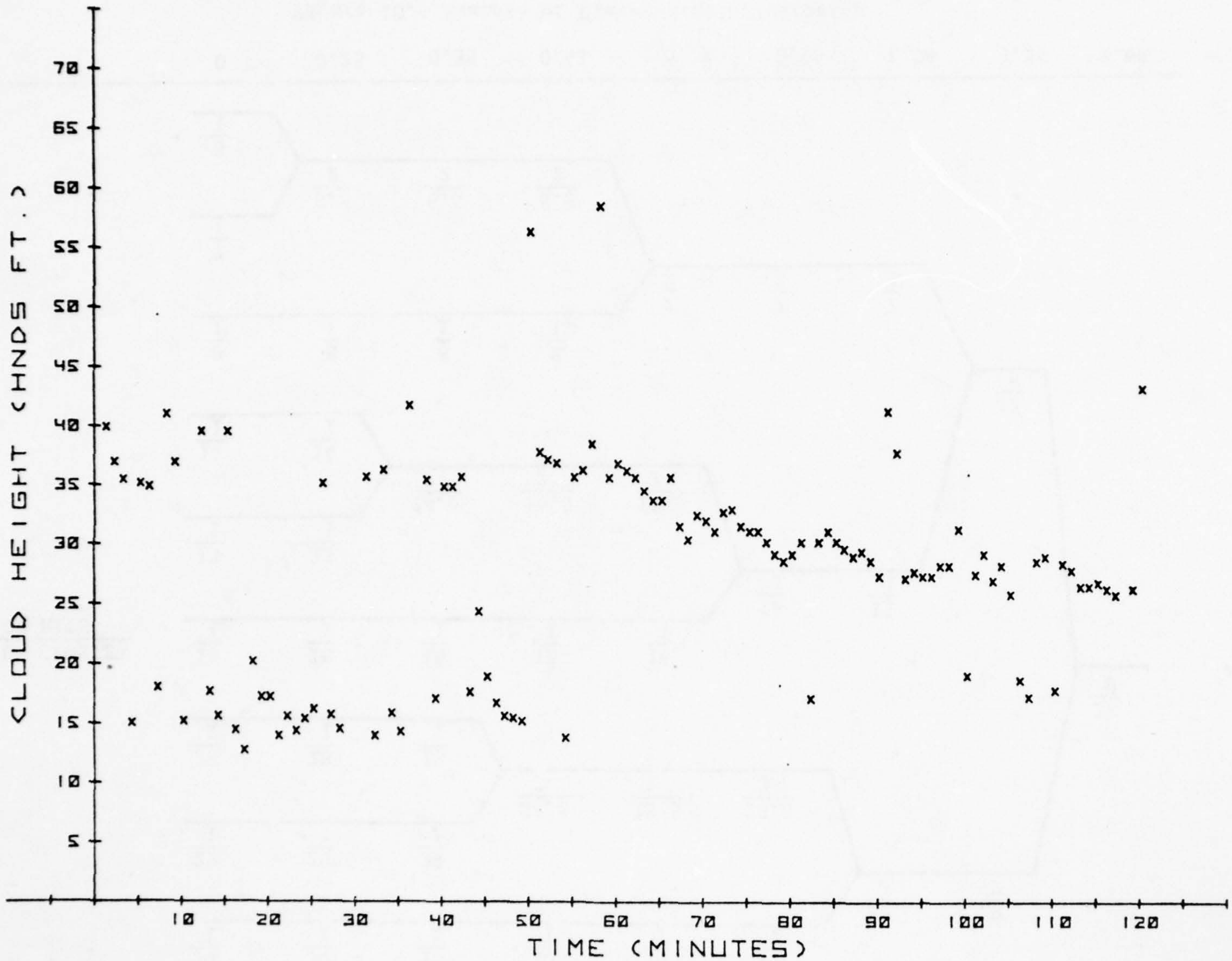


Figure 11. Minute-by-Minute Plot of the Lowest Cloud Returns from RBC Site 7 Miles NE of PHF, April 26, 1978

Time	Observation
30 minutes	15 SCT M37 OVC
60 minutes	16 SCT M36 BKN
90 minutes	M30 BKN 35 OVC

The layers, as determined from each of the three ceilometer sites, are then merged into a common pool and tested again to see if they can be (meteorologically) combined. The algorithm then selects the most significant layers (up to 3) based upon cloud information (height and amount) and outputs these layers as the automated cloud observation. The precedence for significant layers begins with the lowest scattered (SCT) layer, followed by the lowest BKN layer and then various combinations of layer types and heights. The AV-AWOS computer maintains a history of the cloud hits from each ceilometer site. These data are used to compute and format remarks such as "CIG LWR NE" or CIG 20V26."

Except for one step, the single ceilometer algorithm processes data in virtually the same manner as the three ceilometer algorithm. When a single ceilometer is used, double weight is given to the last 10 minutes of the 30-minute sample. Since the overall sample and sampling area is smaller, we've added this recency weighing for the determination of cloud layers. Directional cloud variation remarks are not generated.

7.2 Determination of Cloud Amount

Cloud amount is determined by dividing the number of hits in each layer by the total possible hits (60) during the 30-minute sampling period. For the lowest layer, the ratio of the hits to the total possible hits in that layer only determines whether that layer is classified as SCT, BKN or OVC. Summation totals of all hits, up to and including that level, are used to classify the higher layers.

In our algorithms we use observed population proportions of .05, .55, and .87 as break points for SCT, BKN and OVC with a sample size of 60 independent measurements. In this manner, we can be 90% confident that our observed proportions are within $\pm.1$ of the population proportions.

7.3 Determination of Sky Conditions During Obscuration

The cloud algorithm was designed to separately treat those cases in which all or part of the sky is hidden by surface-based obscuring phenomena. This is typical in the case of fog, and occasionally true for precipitation, particularly snow. The algorithm reports a partial obscuration when cloud layers are detected and visibility is below about 1 1/2 miles: an arbitrary 0.2 cloud amount is added to the summation total and -X placed before the first layer. To satisfy the requirement that vertical visibility be determined when the sky is completely hidden by a surface-based obscuration, we've formulated this procedure - when less than five cloud measurements are recorded in the last 10 minutes of the sampling period and visibility is below about 1 1/2 miles, the obscuration subprogram is called up. The subprogram overrides the report from the cloud algorithm and outputs "WAX" as the indication of total obscuration. "A" represents vertical visibility. Selection of a value is based on considerations such as visibility and air temperature.

Comparisons of human vs. automated observations have not been made using this procedure. The technique has been improvised solely to satisfy the requirements for determination of vertical visibility and extent of obscuration. It is the weakest of the AV-AWOS methods.

8. FIELD TESTS

Fully automated weather observations were used in an operational test at PHF during the period January 6 - May 10, 1978. Algorithms had been developed based on data acquired from an earlier test program at IAD from mid-1976 through early 1977.

In these tests, the automated observations were compared with routine observations made by the duty observers. Although the observers were dedicated and diligent, their time was shared with other, sometimes more insistent, demands. The PHF point of observation did not facilitate visibility observations. Visibility markers were few and not evenly distributed about the horizon. To those reading this report who are familiar with the vicissitudes of weather observing, more need not be written.

8.1 Results of Automated Cloud Observation Tests

An automated sky condition observation was generated each minute, but we limited our test data set to the number of "record" hourly (human) observations available. This set was further limited to periods during which the human observer reported clouds on several consecutive observations. The final data set totaled over 600 observations. Some comparisons are made with earlier results obtained on our network at IAD (Bradley et al., 1978).

In the following comparisons, "AV-AWOS" means that the data is derived from our three sensor CHI network and processed by the AV-AWOS cloud algorithms. "Two separated RBC's" means that the data from two RBC's in our network are processed separately as if each was a complete and independent three sensor CHI network.

Table 1 shows a comparison of cloud layers reported by various methods; the number of cloud layers reported for each observation was put into one of four categories (0, 1, 2, 3 layers). The number of observations in each category was then computed for ordered pairs of observations obtained by several different methods (e.g., human vs. AV-AWOS algorithm) and a 4x4 matrix formed for each pair. Agreement to ± 1 layer means, for example, that a human report of 1 layer would be compared with the number of observations in the 0, 1, and 2 layer categories of the appropriate paired sensor.

TABLE 1

NUMBER OF CLOUD LAYERS: COMPARISON OF METHODS

Methods	% Agreement ± 1 Layer
AV-AWOS/IAD Observer	74%
AV-AWOS/PHF Observer	87%
Two Separated RBC's-IAD	89%
Two Separated RBC's-PHF	92%
AV-AWOS/Separated RBC-PHF	85%

Table 1 tests our hierarchical clustering techniques. The general agreement among methods indicates that we are indeed clustering data derived from various sources in a consistent manner. The strong agreement between the AV-AWOS/PHF observer comparisons (87%) indicates that the clustering technique is consistent; and the clusters themselves are similar to those reported by the human observer. The lower level of agreement for AV-AWOS/IAD observer reflects earlier problems when spurious layers were generated by RBC system noise. The program was later modified to reject that type of false RBC measurement.

In Table 2, joint reports of ceilings occurred in upwards of about 78% of the cases regardless of the method used. The agreement between "two separated RBC's-PHF" (78%) would likely be higher in a fully operational network, since in this category we suffered the loss of some data in line transmissions across our test network. As with the cloud layer comparisons, the agreements between AV-AWOS and the PHF observer indicate that the methods are consistent and in general agreement with human results.

TABLE 2

OCCURRENCE OF CEILING REPORTS: COMPARISON OF METHODS

Methods	% of Joint Occurrence*
AV-AWOS/IAD Observer	78%
AV-AWOS/PHF Observer	82%
Two Separated RBC's-IAD	81%
Two Separated RBC's-PHF	78%
AV-AWOS/Separated RBC's-PHF	86%

*Occurrence = either method reports ceiling.

Table 3 summarizes results of ceiling height comparisons. Agreement between methods is better at the lower, more critical cloud heights but falls off at greater heights. This is probably due to the characteristics of the RBC (small errors at low altitude tend to increase with height). Many of the cases in which the differences were greater than 200 feet occurred either during nighttime or precipitation periods. This was particularly the case at PHF where testing was conducted in an operational mode. Tests at IAD were developmental.

We believe the cloud height and sky cover algorithm to be complete. This excludes partial and total obscuration for which the algorithm is inferred rather than empirical. Given a more reliable sensor, less prone to height and communication error than an RBC, the scores in Tables 1, 2, and 3 would be still higher.

8.2 Results of Automated Visibility Observation Tests

FAA observers at PHF took routine visibility observations at ground level. When visibility dropped below 4 miles, observations were also taken at the airport control tower level of 45 feet, a standard procedure. In

TABLE 3

CEILING HEIGHT VALUES: COMPARISON OF METHODS

1. Ceiling: 100 to 1000 feet

Methods	% Agreement to ± 200 feet
AV-AWOS/IAD Observer	96%
AV-AWOS/PHF Observer	75%
Two Separated RBC's-IAD	82%
Two Separated RBC's-PHF	85%
AV-AWOS/Separated RBC-PHF	92%

2. Ceiling: 1100 to 3000 feet

Methods	% Agreement to ± 400 feet
AV-AWOS/IAD Observer	63%
AV-AWOS/PHF Observer	53%
Two Separated RBC's-IAD	82%
Two Separated RBC's-PHF	75%
AV-AWOS/Separated RBC-PHF	74%

both cases, distribution of visibility targets was limited by circumstance. The only adequate visibility marker for visibilities greater than 2 miles was a 500-foot smokestack 7 miles to the north of the observer. In our analyses, we used only the visibility reported by the ground observer.

Our three Videographs were sited to avoid local sources of moisture and fog. However, local sources of pollution, particularly automotive emissions, appears to have affected one of the sites. Two of the Videographs were located on low roofs while the third was at ground level.

For the following comparisons, both sensor and human visibility values were first rounded to the nearest mile. The number of visibility observations in each of nine categories (0, 1, ..., 7, 7+) was then computed for pairs of observations obtained by different methods (e.g., sensor vs. sensor, human vs. sensor), and a 9x9 matrix formed for each pair. Tables 4 and 5 were prepared from these matrices. In these tables, agreement to ± 1 mile means, for example, that a visibility category of 3 miles for a method based on human PV would be compared with observations in the 2, 3 and 4 mile range categories of the appropriate paired sensor. While a sensor PV was generated each minute (1440 per day), our data set was limited to the number of "record" human observations available (24 per day). We further limited this set to those days on which the human reported an obstruction to visibility. The final data set totaled 490 observations.

Table 4 shows the results of comparisons between totally objective sensor derived visibility observations. First, sensor observations from two of the three Videograph sites were compared with each other and level of agreement recorded. Then a sensor PV observation derived from the three sensor network was compared with a similar observation from one arbitrarily chosen network sensor.

TABLE 4

VISIBILITY OBSERVATIONS: SENSOR vs. SENSOR

Methods	Agreement ± 1 Mile
1. All Visibility Values:	
2 Separated Sensors-PHF	87%
2 Separated Sensors-IAD	89%
Sensor PV/Single Sensor-PHF	92%
2. Sensor Visibility Below 5 Miles:	
2 Separated Sensors-PHF	90%
2 Separated Sensors-IAD	90%
Sensor PV/Single Sensor-PHF	93%

Results demonstrate consistently high and stable relationships between objective visibilities derived from individual sensors in the visibility network. The experiment was conducted at both IAD and PHF with almost identical effect.

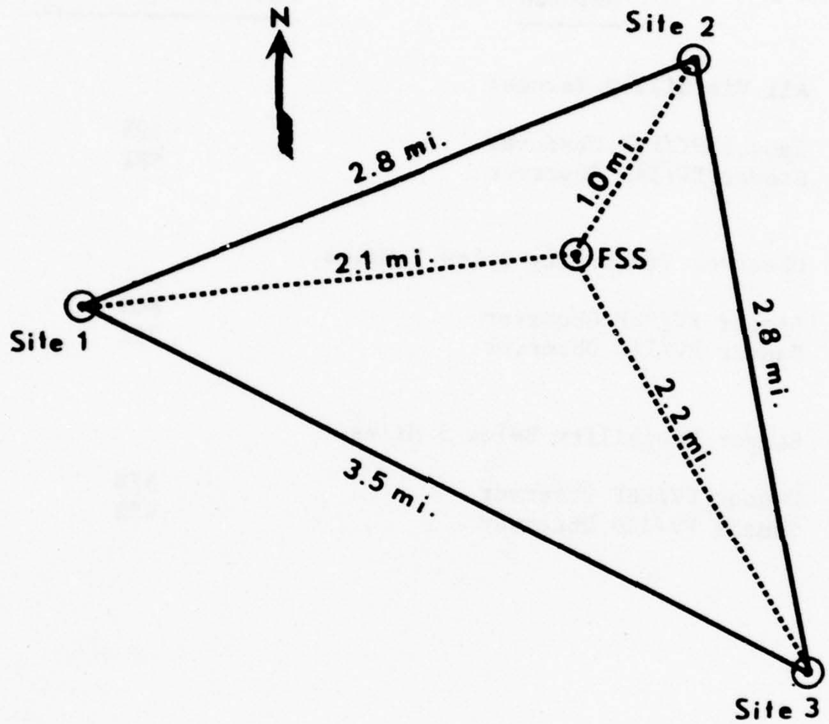
The results in Table 4 show the intercomparisons of sensor derived objective visibility observations, are not duplicated when human subjective observations are introduced. Table 5 shows comparisons of objectively and subjectively derived visibility observations. Greatest agreement occurs when the observer records visibility below 5 miles. But strength of comparisons weakens for the other examples.

In another visibility test, a single visibility sensor was located at PHF on a roof about 35 feet directly above the normal FSS point of observation. Figure 12 shows the spatial relationships between this site and the three remote network sites. Visibility was derived by averaging 10

TABLE 5

VISIBILITY OBSERVATIONS: HUMAN vs. SENSOR

Methods	Agreement ± 1 Mile
1. All Visibility Values:	
Sensor PV/PHF Observer	69%
Sensor PV/IAD Observer	58%
2. Observer Visibility Below 5 Miles	
Sensor PV/PHF Observer	80%
Sensor PV/IAD Observer	72%
3. Sensor Visibility Below 5 Miles	
Sensor PV/PHF Observer	57%
Sensor PV/IAD Observer	45%



Site 1 - Denbigh - West site. Near a heavily travelled traffic intersection; on a roof with projector and detector about 30 ft. above ground.

Site 2 - Kentucky Farms - Northeast site, pointing toward an open field. Elevation about 10 ft. above ground.

Site 3 - Hampton Roads Academy - Southeast site. About 1.2 miles west of a city trash incinerator smokestack. About 20 ft. above ground pointing over a soccer field.

Figure 12. Visibility Site Locations at Newport News

once-per-minute Videograph output values and converting this value to visibility based on day or night conversion equations. Results were also separated on the basis of whether precipitation was occurring.

Table 6 shows the results of intercomparisons between the roof Videograph and AV-AWOS sites. Best agreement is between the roof Videograph and human observer during the day.

Psychophysical and other limitations are often associated with subjective observations. The influence of human factors is discussed in detail by Lefkowitz (1966) for another type of objective visibility observation (RVR). Human limitations include, but are not limited to, visual illuminance threshold, visual contrast threshold, dark adaption, availability of appropriate visibility targets, and pressure of other duties.

There appears to be the effect of a "non-linear" human/backscatter sensor relationship. We noted strong relationships between human and Videograph derived visibility in the presence of hydrometeors (e.g., rain, drizzle, snow). When lithometeors (e.g., haze, smoke, dust) reduced visibility, the visibility algorithm (using Videograph measurements as input) characteristically produced lower visibilities than those reported by the human observer (Table 7). Although we believe the visibility algorithm performance to be effective, performance of the Videograph needs review.

9. SENSOR NETWORK CONFIGURATION

The earliest elements considered in the AV-AWOS work were sensor network size and number of cloud and visibility sensors. Some guidance was available from a study funded by the FAA (Duda et al., 1971). The study, using several assumptions, indicated that three cloud sensors could be used to produce cloud observations comparable to those made by humans.

TABLE 6

VISIBILITY COMPARISONS BETWEEN VARIOUS REPORTING SYSTEMS

A. % Agreement Between Roof Videograph and Simultaneous Observation Within ± 1 Mile

	All Cases	Precip Day	No Precip Day	Precip Night	No Precip Night
Human	67%	74%	75%	60%	63%
AV-AWOS	69%	68%	70%	80%	65%
Site 1	70%	72%	73%	73%	66%
Site 2	68%	65%	77%	78%	60%
Site 3	61%	70%	69%	68%	51%

B. % Roof Videograph > Simultaneous Observation Outside of ± 1/2 Mile

	All Cases	Precip Day	No Precip Day	Precip Night	No Precip Night
Human	35%	48%	32%	47%	32%
AV-AWOS	53%	49%	49%	50%	57%
Site 1	49%	49%	42%	48%	54%
Site 2	53%	48%	41%	54%	63%
Site 3	65%	50%	53%	61%	77%

C. % Roof Videograph < Simultaneous Observation Outside of ± 1/2 Mile

	All Cases	Precip Day	No Precip Day	Precip Night	No Precip Night
Human	34%	16%	25%	32%	44%
AV-AWOS	7%	11%	7%	7%	7%
Site 1	11%	20%	14%	14%	7%
Site 2	10%	16%	11%	12%	6%
Site 3	7%	12%	9%	11%	3%

TABLE 7

VISIBILITY OBSERVATIONS: A COMPARISON OF METHODS

Methods	Agreement $\pm$ 1 Mile
1. Sensor Visibility Below 5 Miles:	
Sensor PV/PHF Observer	
- All Cases	57%
- Precip Occurring	86%
- Fog Reported by Human	88%
- No Precipitation	43%
Sensor vs Sensor	
- All Cases	90%
2. Sensor Visibility 1 Mile or Less:	
Sensor PV/PHF Observer	
- All Cases	95%
3. All Sensor Visibility Values	
Sensor PV/PHF Observer	
- All Cases	69%

At first, the NWS program manager specified a ceilometer triangle having legs of 12 to 15 miles. He wrote, "My concern is that operational aviation, as distinguished from the 'flight standards' and 'safety' matters, will be wanting assurances that our system won't give pessimistic information when it is clearly safe to descend through breaks in clouds within the operational proximity of the airport and make a normal visual flight rules (VFR) approach." Due to FAA concern, he later agreed to a triangle with 8 mile legs. He believed, however, that no fixed-size triangle should be specified. That is, should multiple sensors be required, the shortest triangle legs at which data remained valid should be selected. He believed, at that time, that network size would be a sensitive factor.

The choice of a visibility network configuration followed. Since visibility is a less stable phenomena than clouds, we decided to keep the sensors relatively close to the airport operational area, and used a smaller triangle than the one used for the ceilometer network.

Original plans called for portable visibility sensors and lidar ceilometers. Sensor networks were to be varied in size and configuration to determine sensitivity of those factors. The lidar ceilometers were not delivered as expected, and we were forced to use the non-portable RBC. The fixed nature of the RBC and the general difficulty of obtaining sensor sites with qualified data lines doomed the variable configuration experiments.

9.1 Number of Sensors

We conducted several tests to determine the number of visibility and cloud sensors that would be needed to produce an automated observation comparable to a human observation.

a. Visibility

In our first visibility test, we located three backscatter visibility sensors next to each other at SR&DC and processed each output separately through AV-AWOS visibility algorithm. For 158 independent samples, the correlation coefficient between the sensors exceeded .98. We then placed the sensors at the vertices of our visibility network around IAD (Figure 1). For 103 independent samples taken during June-July 1976 with the sensors spread 3 to 4 miles apart, the correlation coefficient between the sensor at SR&DC and the individual sensors at the other sites ranged from .79 to .96. Denoting the sensor at SR&DC as our standard, we then compared differences in visibility between each remote site and our standard. The worst case situation of the two data sets is shown in Table 8. Even in this case, the differences between visibilities from our standard and from our remote sites were ± 1/2 mile or less on 86% of the observations.

Table 9 shows a similar plot for PHF data. In this set, visibility data from two separated sites were compared every one-half hour for May 4-6, 1978. While there is some bias towards higher visibility at sensor 2, the spread in the data shows most of the comparisons grouped with ± 1/2 mile of some central value.

At PHF we located the three Videographs at sites selected to be climatologically favorable for detecting the onset of lower visibility during varying synoptic weather conditions. We then examined two 30-day data periods (720 observations each): one for the winter season, another for the spring season. Using the SEV from each of the three Videograph sites, a "remark" (supplemental comment required by FMH-1) was generated if a sensor visibility differed from the PV by more than 1/2 mile. The results are

TABLE 8

Visibilities at Site 2 (IAD Network)
Compared With Visibilities at Site 1 as Standard

VISIBILITY REPORTED BY SENSOR 1 (Miles)	DIFFERENCE IN VISIBILITY (Miles) (SENSOR 1 — SENSOR 2) -3	-2	-1	-1/2	-1/4	+1/4	+1/2	+1	+2
0-1/2					2				
1/2-1									
1-2				2	13	19	1		
2-3			1	1	5	10	3		
3-4		1	2	4	5	4	1		1
4-5		2	1	2		1			
5-6		1		1					
6-7		1							
7		2							

TABLE 9

Visibilities at Site 2 (PHF Network) Compared
With Visibilities at Site 1 as Standard, May 4-6, 1978

DIFFERENCE IN VISIBILITY (Miles)
(SENSOR 1 — SENSOR 2)

VISIBILITY REPORTED BY SENSOR 1 (Miles)	-3	-2	-1	-1/2	-1/4	±0	+1/4	+1/2	+1	+2	+3	+4
0-1/2												
1/2-1												
1-2			3	1	1	2	1	4	1			
2-3					1	1	6	6	4	4		
3-4				1	1	1	1	4	7	3	1	
4-5		1	2				1	4	6	7		1
5-6		2							4	4	1	
6-7			1	1				1	1	4		
7										1	1	4

summarized in Figure 13. The distribution of remarks can better be explained by local variations in ground fog and urban pollution than by any variation in the synoptic scale elements. As an example, the ten cases of lower visibility at the west (Denbigh) site in the winter period were due to enhanced backscatter due to smog pollution on mornings with temperatures near or below freezing. The absence of low visibility remarks at Denbigh in the spring season was due to the presence of ground fog at the other two sites-sites situated in less developed areas.

The question of how many visibility sensors are needed in an automated system should be based on the nature of the visibility observations needed at the observation site. As stated earlier, FMH-1 defines prevailing (human) visibility as, "The greatest visibility equaled or exceeded throughout at least half of the horizon circle which need not necessarily be continuous." The only off-the-shelf visibility sensors now available have very limited volume sampling areas. Therefore, it appears that one sensor will not satisfy the FMH-1 definition of prevailing visibility. Three sensors, then, appear to be the minimum needed for prevailing visibility. If a lesser form of visibility is acceptable, e.g., station visibility (index of visibility), one sensor will do. In both cases, data would be processed as indicated by the algorithms in the appendices.

b. Clouds

In the PHF and IAD tests, two RBC's, separated by a distance of 8 miles, jointly reported the occurrence of a ceiling in upwards of 78% of the observations in which either RBC reported a ceiling. With the ceiling reported at or below 1000 feet, ceiling heights agreed to $\pm$ 200 feet in 82% to 85% of the observations. During two test periods at PHF (Figure 13),

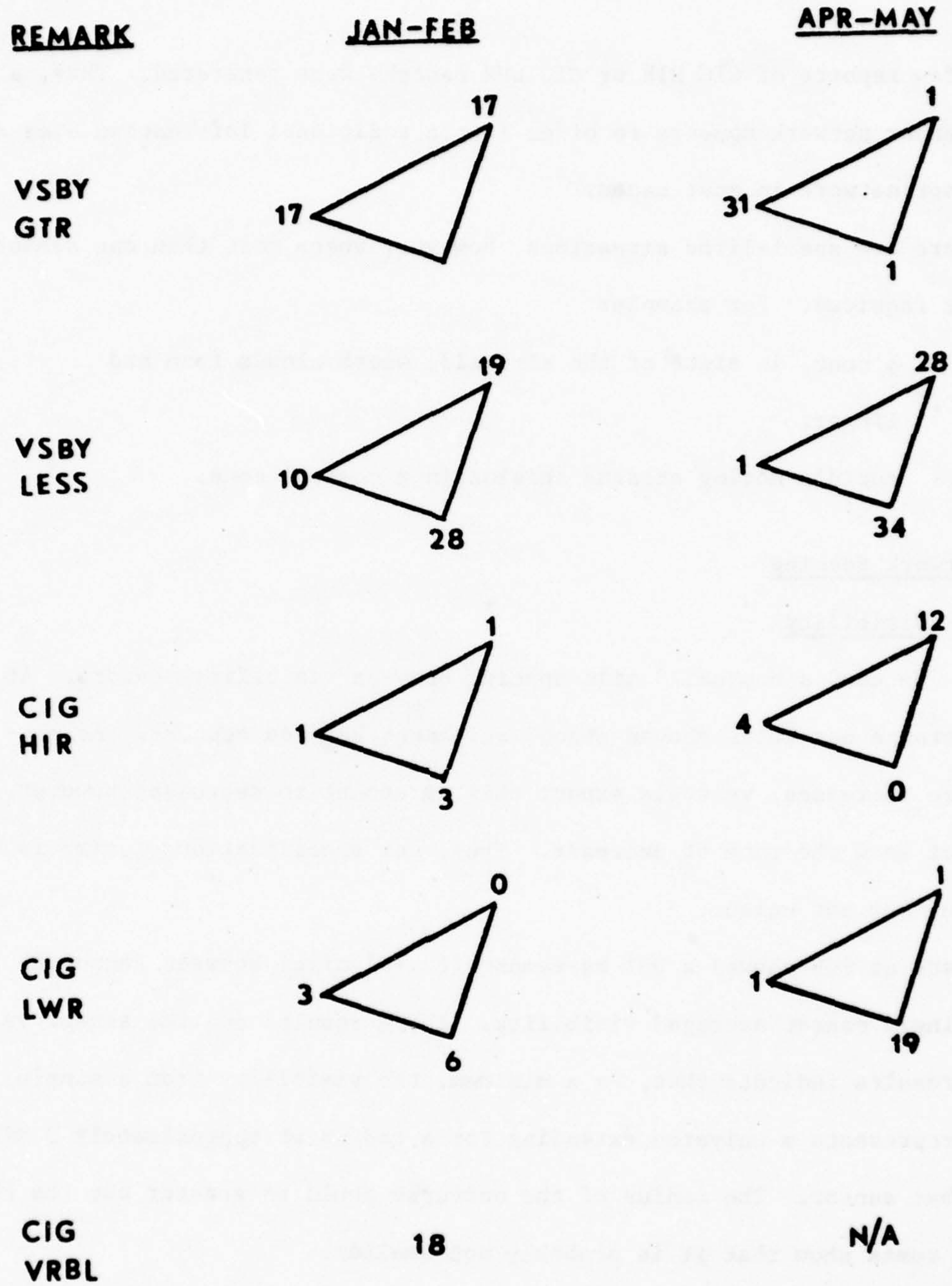


Figure 13. Distribution of Remarks for Clouds and Visibility at Each Sensor Site at PHF. Amount is Indicated at Site.

only a few reports of CIG HIR or CIG LWR remarks were generated. Thus, a three sensor network appears to offer little additional information over a one sensor network in most cases.

There are specialized situations, however, where more than one sensor would be required. For example:

- a zone, in sight of the airfield, where clouds form and linger.
- rapidly moving stratus shields in a coastal zone.

9.2 Network Spacing

a. Visibility

We used a nominal 3 mile spacing between visibility sensors. At that distance our tests showed a good agreement between sensors. As network size increases, we would expect this agreement to decrease; however, we do not know the rate of decrease. Thus, our specification of size is adequate, but not unique.

Tests at PHF showed a 92% agreement (to $\pm$ 1 mile) between sensor PV and a single sensor averaged visibility. These results and the sensor vs. sensor results indicate that, as a minimum, the visibility from a single sensor represents a universe extending for a radius of approximately 3 miles about that sensor. The radius of the universe could be greater but the PHF and IAD tests show that it is probably not smaller.

b. Clouds

The AV-AWOS cloud report at PHF and a cloud observation generated by a single sensor showed joint occurrence of a ceiling on 86% of the observations. Ceiling heights agreed to within $\pm$ 200 feet on 92% of the observations. Coupled with the results from two separated RBC's, we conclude that at 8 miles separation, clouds sampled by one RBC come from the same universe as clouds sampled by a second separated RBC. The cloud reports from a single sensor RBC thus represent a universe extending up to about 8 miles in radius about said sensor. Since the joint agreement is only 80%, we do not believe this 8 mile radius should be extended. A circle with a 6 mile radius would probably be more representative.

10. SENSOR SITING

Our experiences at IAD and PHF have pointed up the need for preliminary site surveys before installing sensor networks at airports.

The primary purpose of a detailed site survey would be to identify unique conditions that might influence judgments on the number of sensors needed and configuration. For example, if fog or stratus tends to move in rapidly from a specific sector, sensors would be located in their path to provide early warning. In such cases, algorithms may have to be modified. The best source for information on local peculiarities should be experienced observers at the stations. Climatological records and local geography should also be evaluated as part of the site survey.

In some cases, three sensor arrays may be required. In particular, if prevailing visibility is considered a requirement at a station, a triangular network will have to be set up. Particular attention should be given to avoiding highly localized sources of pollution or fog. For example, in the PHF area, heavy vehicular traffic near one site occasionally lowered visibility indications from that sector (a more representative sector visibility could have been obtained by moving that Videograph about a quarter mile). Other locations to be avoided are low spots where pockets of fog tend to form or locations very close to smokestacks. Also, to avoid ground fog

(< 20 feet deep), sensors should be located 20 to 30 feet above ground. The exact height is uncertain, since FMH-1 no longer specifies the height of the visibility observing plane. The 14-foot height the FAA specifies for the RVR transmissometer may be appropriate.

Other considerations for siting of visibility sensors depend on the type of sensor used. Specifically, in our tests, we used a backscatter instrument, the Videograph, which requires about 100 yards of cleared space in front of it. This meant that open areas such as parks or farmland were most desirable. When we had to go into developed areas, rooftop sites were generally the only suitable locations. No matter what sensor is used, the availability of nearby power and data transmission lines must be assured before a site is selected.

Siting of cloud height indicators should not be a problem if laser ceilometers are used. However, requirements to site RBC's are expensive and require considerable real estate. If a site survey indicates the need for a remote site away from the airport, that site must be selected to avoid localized conditions. For example, at Newport News were forced to locate an RBC within 1/2 mile of a smokestack. We found that on a few occasions a smoke layer at that site would cause an indication of scattered clouds in our PHF cloud report. Although the layer could be seen from the airport, it did not cover 1/10 of the sky. If single ended laser ceilometers had been available, the flexibility in site selection would have been greatly increased. RBC's require line-of-site between detector and projector, underground signal cables, and stable concrete bases for both projector and detector. If secure government-owned land is not available, it is often very difficult to find private property owners willing to permit such an installation.

11. FURTHER INVESTIGATIONS

Although we consider the algorithms for objective cloud and visibility observations to be operational, some weaknesses are present as discussed earlier in this report. Since there has been no assessment of the precision and accuracy of subjective human observations, it's difficult to specify standards for automated observations. Therefore, we're uncertain as to the "perfection" that can or should be achieved in objective automated observations. We propose that further investigations, such as those proposed below, be conducted to resolve uncertainties (they've been limited to cloud and visibility observation techniques):

- Determine why the Videograph showed lower than human visibilities during the tests at PHF.
- Seek improvement in the obscuration automation method. This may include additional sensor input not part of the original AV-AWOS program.
- "Fine tune" the cloud and visibility observations with a larger and more certain data sample than thus far acquired.
- When suitable ceilometers become available, check the sensitivity of sensor network configurations.
- Investigate variations in data preprocessing that may be needed for new sensor characteristics, sampling method, sampling volume and response time.
- Determine how newly-developed sensors (laser weather identifier, for example) can be used to improve automated cloud and visibility observation performance.

- Assess the performance of the AV-AWOS system, thus far limited to PHF and IAD, to more extreme meteorological conditions.
- Determine the precision (and accuracy, if feasible) of human weather observers.

An operational approach to network size and siting should be established (as it might be for the construction of a new airport or installation of an ILS system). These steps, for example, might be followed:

- Form a multidisciplined committee. (Meteorologists, climatologists, engineers, airport experts, and perhaps, members of the user groups).
- Examine all meteorological data possible to determine local weather effects, advection characteristics, directional weather characteristics, terrain influence, weather features that should be included in the observation, etc.
- Based on the foregoing, legal requirements and the nature of observation needed, select number of sensors and design configuration.
- Procure needed property, hardware and software, and install the system.
- Run the system in a test mode through all seasons of weather as long as possible before commissioning is needed. Verify that the system is responsive to requirements and local characteristics. If not, correct and retest.
- Commission the system, continue retesting in accordance with a predetermined program.

12. SUMMARY

This summary is based on tests and experiences at IAD and PHF. In addition, we had valuable input from the observers, both National Weather Service and Federal Aviation Administration, who participated in the program at PHF.

12.1 Visibility Observations

- The Human Observation: The operational definition of visibility focuses on the human observer. However, human observations of visibility have many limiting factors. For example, point of observation, nature and number of visibility markers, and the very curvature of the earth impart unique characteristics to each observation.
- Sensor Preprocessing: The Videograph, although it has limiting sampling volume (13 $ft.^3$), samples a relatively large volume compared to other types of single-ended visibility sensors currently marketed. Because of this volume,"grab" samples of 2 to 30 per minute show no significant differences when averaged over a time period of 6 to 10 minutes. A sensor with a faster time constant or smaller sampling volume than the Videograph will require preprocessing at a greater rate than two samples per minute.
- Sensor PV: Sensor derived PV (using three visibility sensors) had only fair agreement with human visibility at IAD and PHF. We believe this to be related to the limitations of subjective observing techniques, differences between human and automated concepts of observing, and reactions of the Videograph during certain obstruction to visibility situations. Because of consistency and timeliness, sensor PV should, in time, replace human visibility as the standards for observations.

- Single Sensor Visibility: The inability of a single sensor to report sector visibility may be a limitation in some operational applications. However, our tests showed excellent agreement between two separated single sensors as well as between sensor PV and single sensor visibility. Thus, a single sensor with appropriate processing can produce a useful index of visibility. By definition, a single sensor could never report PV. It could be used to report "station" visibility at smaller or limited-service airfields.

- The Visibility Algorithm: The visibility algorithm for both a three sensor network (PV) and a single sensor (station visibility) is now at the operational level.

12.2 Cloud Observation Automation

- The Human Observation: The operational definition of sky condition is based on the presence of a human observer with inherent limitations.

- Processing Strategy: Test results show that our processing strategies give consistent results and that our computer-generated observations are in agreement with human observations. Our data sampling, averaging times and network configurations, while not unique, are appropriate for use in automated surface weather observations.

- Obscurations: Our program for observing total and partial obscurations is marginal. No sensors are currently available that measure the amount of sky obscured or vertical visibility into an obscuration. Until such equipment is developed, adequate algorithms for partial and total obscuration cannot be generated. Our algorithms for obscurations are the weakest part of our program. Under some combinations of weather conditions, unrepresentative observations of obscuration can be output by the automated system.

- Three Sensor Observations: Our cloud algorithm based on a three sensor CHI network shows good agreement with human observations. Variances are largely related to differences in human and automated concepts of observing. Because of its consistency and timeliness, sensor-generated cloud observation should, in time, replace human observations as the standard observing practice.

- Single Sensor Observations: The inability of a single CHI to report remarks such as "CIG LWR NW" may be a limitation in some operational applications. However, our tests showed excellent agreement between two separated single sensors as well as between network and single sensor observations.

- The Cloud Algorithms: The cloud algorithms for both a three sensor (AV-AWOS) network and a single sensor application are now at the operational level.

12.3 Network Size and Siting

- If prevailing visibility is required, three visibility sensors are needed - more, if there are unusual local visibility problems.

- Three visibility sensors in normal situations should be installed at the vertices of an equilateral triangle having approximately 3 mile legs. The required point of observation should be at the triangle's center.

- If an index of visibility is required, one visibility sensor is needed - more, if there are local visibility problems.

- In most situations, one ceilometer would be adequate. More would be needed in situations where directional bias is present.

- If three ceilometers are needed for more representative information, they should be installed at the vertices of an equilateral triangle having 6 to 8 mile legs. The required point of observation should be at the triangle's center.

- We do not believe that the algorithm test results would be affected by small changes in network configuration.

- Installation of an automated weather system should proceed in a manner typical of other major aviation facilities. This includes an initial period of investigation to define the required instrument network configuration. Continued review after commissioning will also be needed.

13. ACKNOWLEDGMENTS

AV-AWOS was developed by the National Weather Service as a joint project with the Federal Aviation Administration. Engineering and liasion support were provided by NWS's Equipment Development Laboratory: particularly Douglas Downen and Wayne Huffman. Noteworthy among the fine support received from NWS's Test and Evaluation Division were contributions of Paul Chinn, George Reeves, William Read, and John Blelloch. The tests at PHF were coordinated by Eric Mandel of the FAA. The dedication of the FAA and NWS weather observers during the tests was exemplary.

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APPENDIX A

VISIBILITY ALGORITHM

APPENDIX A

VISIBILITY ALGORITHM

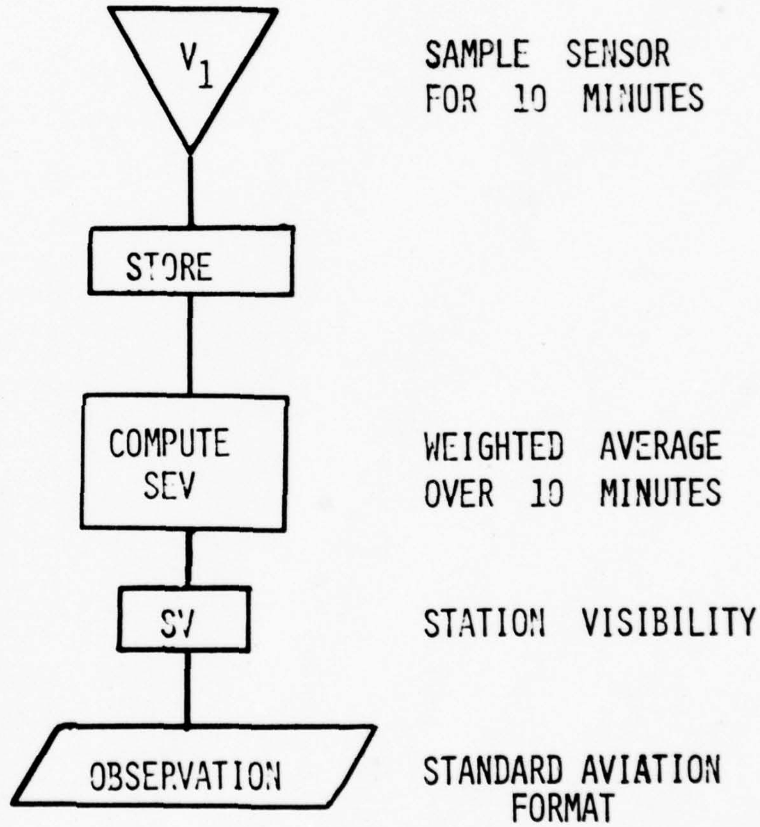
Comments on a Single Sensor Visibility Algorithm

1. The algorithm is essentially the single sensor AV-AWOS algorithm used at PHF and updated by the October '78 three sensor algorithm.
2. We designate the sensor output as station visibility (SV) to distinguish it from the prevailing visibility (PV) determined by a three station network.
3. The adequacy of using a single station as opposed to a three station network must be determined for each location by a site committee.
4. A generalized flow chart is attached.

Comments on the Three Sensor Visibility Algorithm

1. The algorithm is essentially the algorithm as currently programmed in AV-AWOS and used operationally at PHF.
2. In Section 1.4a, we made provision for preprocessing sensor data. While one grab sample per 30 seconds is adequate for the Videograph, a sensor with a shorter time constant might have to be sampled and averaged more often.
3. In 1.4i, we allowed for calibration curves to be inserted for any sensor.
4. We made a technical correction to Section 1.4u to bring it in line with Section 1.4r.
5. Section 1.4z is new. This procedure is our method to avoid oscillating between two values of visibility. It solves the problem of frequent specials because of this oscillation. In one test, 17 oscillations in 2 hours were reduced to 5.

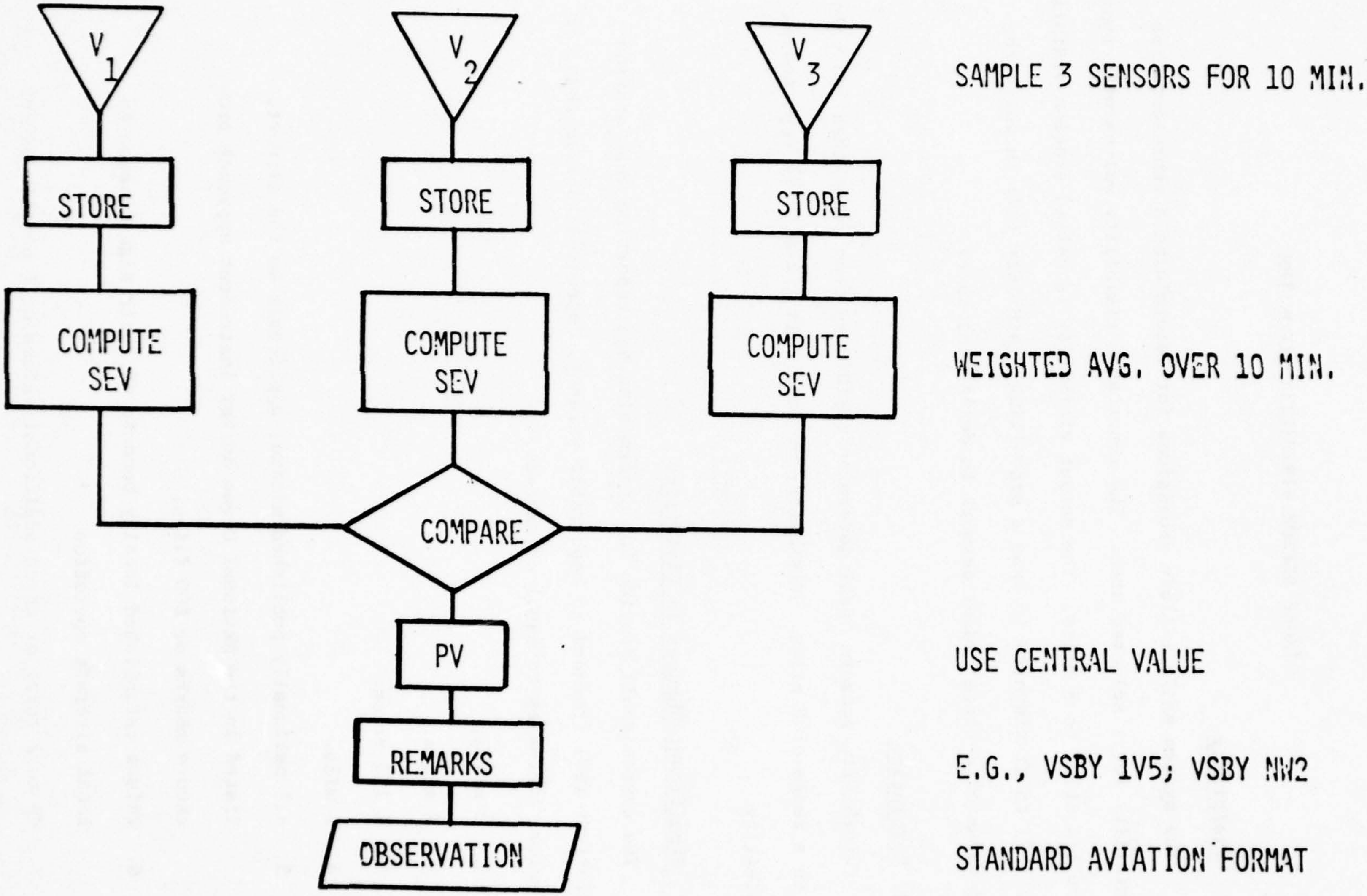
SINGLE SENSOR VISIBILITY ALGORITHM



6. Section 1.4ad is new. This procedure prevents more than one visibility remark at a time from being outputted on Service A. This procedure is needed since we saw excessive remarks being generated during our test at PHF.

7. A generalized flow chart is attached.

THREE SENSOR VISIBILITY ALGORITHM



SINGLE SENSOR VISIBILITY ALGORITHM

1. Visibility

The system shall include provisions for determining a representative visibility for a selected area. The reportable visibility values will range from 1/4 miles to 8 miles. The output visibility is called station visibility (SV) to distinguish it from a prevailing visibility (PV) in which the mid-value of a three sensor network is designated as PV.

1.1 Resolution

Visibility sensors shall determine visibility from "less than 1/4 mile" up to a range of 8 miles. Visibility of less than 1/4 mile is reported as 0 visibility.

1.2 Significant Changes in Visibility

The system shall provide for determining and reporting when station visibility (SV) (rounded to reportable values), decreases to less than, or if below, increases to equal or exceed:

1. 3 miles.
2. 2 miles.
3. 1 1/2 miles.
4. 1 mile.
5. All nationally published minima, applicable to the airport, listed in the National Ocean Survey instrument approach procedure charts or DOD flips.
6. Values established locally because of their significance to local aircraft operation.
7. Up to a total of three additional values will be allowed for conditions 5 and/or 6.

1.3 Number of Sensors

One sensor is used in the determination of station visibility. Location of the sensor will be determined by a site survey.

1.4 Visibility Algorithm

The visibility algorithm shall perform the following functions each minute:

a) Get two readings from the sensor. Sensor data may be preproccessed if necessary to comply with hardware specifications.

b) A check shall be made to determine if a reading is outside sensor limits. If so, the value is bad and the previous good value shall be inserted for up to two consecutive times. The third sonsecutive time a "bad value" key shall be set.

c) Check to see if the day or night sense switch should be set.

d) Store up to 10 minutes of values for the sensor; i.e., 20 values.

e) If less than 20 values are stored for the sensor, a Visibility Estimated Message shall be generated.

f) After 20 values have been collected for the sensor, the new values received shall replace the oldest values stored.

g) The average of the first half of the stored values shall be calculated.

h) The average of the second half of the stored values shall be calculated.

i) Convert the reading for each of the data to sensor equivalent visibility (SEV) in miles. A separate conversion table for day and night conditions must be supplied for each type sensor.

j) If SEV is less than 0.25, store 0.0 for value.

k) If SEV is more than 7.0, store 8.0 for value.

l) The average of second half of data shall be divided by the average of the first half of data for each sensor.

m) If the result is greater than 1.2, the visibility of the sensor shall be computed as:

$$Vm = \frac{1\ (\text{Avg 1st Half Data}) + 1.5\ (\text{Avg 2nd Half Data})}{2.5}$$

n) If the result is less than 0.8, the visibility of the sensor shall be computed as:

$$Vm = \frac{1\ (\text{Avg 1st Half Data}) + 2\ (\text{Avg 2nd Half Data})}{3}$$

o) If the result is equal to or between 0.8 and 1.2, the visibility of the sensor shall be computed as:

$$Vm = \frac{1\ (\text{Avg 1st Half Data}) + 1\ (\text{Avg 2nd Half Data})}{2}$$

where

Vm is a floating point number.

p) The value of Vm, when rounded to the nearest reportable value (Sections r, s, and t), is considered to be SV.

q) If the value of Vm is less than 2.75 miles, a variability check shall be made using the following criteria:

1. Get the last 10 minutes worth of Vm values.
2. Compare each value with its preceding Vm.
3. If $\left| Vm_i - Vm_{i-1} \right|$ is greater than 0.5, then increment a counter.

4. If the counter is equal or greater than 3, report visibility as variable.

5. Output a remark that the visibility is variable followed by the maximum and minimum Vm values generated in the last 10 minutes. The remark must be of the following form:

   VSBY <u>Min Value</u> V <u>Max Value</u>

   Example: VSBY 1/4V11/2.

r) Any visibility must be reported in the following values:

   0, 1/4, 5/16, 3/8, 1/2, 5/8, 3/4, 7/8, 1, 11/8, 11/4, 13/8, 11/2, 15/8, 13/4, 17/8, 2, 21/4, 21/2, 3, 4, 5, 6, 7 and 8+.

s) If the reportable value of Vm as obtained from Section r is 2 miles or less, use the following procedure. If this new Vm has not changed by at least two reportable values from the previously reported SV, continue to use the previous SV as the current SV.

t) If the last reported SV was:

   1. 2 1/4, use 2 1/4 as the current SV if the current Vm is between 2.01 and 2.49;

   2. 2 1/2, use 2 1/2 as the current SV if the current Vm is between 2.26 and 2.99;

   3. 3, use 3 as the current SV if the current Vm is between 2.51 and 3.60.

   Otherwise, use the reportable values as generated in Section 1.4r.

u) A check shall be made to determine if a special message is required by using the following criteria:

   If the present SV, when compared to the last Service "A" visibility, meets any of the criteria listed in Section 1.2, a special counter must be incremented. If the counter is incremented on two successive minutes, a special Service "A" message must be generated and the counter set to zero.

v) The current SV will be reported in the visibility section of the Service "A" message.

w) Remarks, as generated, will be placed at the end of the Service "A" message.

x) A new visibility observation will be generated each minute.

THREE SENSOR VISIBILITY ALGORITHM

1. Visibility

The system shall include provisions for determining a representative visibility for a selected area. The reportable visibility values range from 1/4 miles to 8 miles. The output visibility is called a prevailing visibility (PV) since it chooses the middle value from a three sensor network and designates this value as PV. This choice of the middle value is the algorithm approximation to the FMH-1 requirement of choosing the greatest visibility which is attained or surpassed throughout at least half of the horizon circle.

1.1 Resolution

Visibility sensors shall determine visibility from "less than 1/4 mile" up to a range of 8 miles. Visibility of less than 1/4 mile is reported as 0 visibility.

1.2 Significant Changes in Visibility

The system shall provide for determing and reporting when prevailing visibility (PV) (rounded to reportable values), decreases to less than, or if below, increases to equal or exceeds:

1. 3 miles.
2. 2 miles.
3. 1 1/2 miles.
4. 1 mile
5. All nationally published minima, applicable to the airport, listed in the National Ocean Survey instrument approach procedure charts or DOD flips.
6. Values established locally because of their significance to local aircraft operation.

7. Up to a total of three additional values will be allowed for conditions 5 and/or 6.

1.3 Number of Sensors

Three sensors shall be provided in separate dispersed locations on or near the airport. Location of the sensors will be determined by a site survey.

1.4 Visibility Algorithm

The visibility algorithm shall perform the following functions each minute:

a) Get two readings from each of three sensors. Sensor data may be preprocessed if necessary to comply with hardware specifications.

b) A check shall be made to determine if a reading is outside sensor limits. If so, the value is bad and the previous good value shall be inserted for up to two consecutive times. The third consecutive time a "bad value" key shall be set.

c) Check to see if the day or night sense switch should be set.

d) Store up to 10 minutes of values for each sensor, i.e., 20 values each.

e) If less than 20 values are stored for any sensor, a Visibility Estimated Message shall be generated.

f) After 20 values have been collected for a sensor, the new values received shall replace the oldest values stored.

g) The average of the first half of the stored values of each sensor shall be calculated.

h) The average of the second half of the stored values of each sensor shall be calculated.

i) Convert the reading for each set of data to sensor equivalent visibility (SEV) in miles. A separate conversion for day and night conditions must be supplied for each type of sensor.

j) If SEV is less than 0.25, store 0.0 for value.

k) If SEV is more than 7.0, store 8.0 for value.

l) The average of second half of data shall be divided by the average of the first half of data for each sensor.

m) If the result is greater than 1.2, the visibility of the sensor shall be computed as:

$$V = \frac{1 \text{ (Avg 1st Half Data)} + 1.5 \text{ (Avg 2nd Half Data)}}{2.5}$$

n) If the result is less than 0.8, the visibility of the sensor shall be computed as:

$$V = \frac{1 \text{ (Avg 1st Half Data)} + 2 \text{ (Avg 2nd Half Data)}}{3}$$

o) If the result is equal to or between 0.8 and 1.2, the visibility of the sensor shall be computed as:

$$V = \frac{1 \text{ (Avg 1st Half Data)} + 1 \text{ (Avg 2nd Half Data)}}{2}$$

where

V is a floating point number.

p) The mean visibility (Vm) shall be selected using the following criteria:

1. If three sensors, select central value.
2. If two sensors, select lower value
3. If one sensor, select value.
4. If no sensor, put in a flag to report visibility data is missing.

This value of Vm, when rounded to the nearest reportable value (Sections y, z and aa), is considered to be PV.

q) The lowest average visibility shall be obtained if there is data from all three sensors.

r) A remark shall be generated if the lowest visibility is less than 2.75 miles and if the mean visibility minus the lowest visibility is greater than 0.5 miles.

s) The remark shall state that visibility is lower in a stated direction and give the value of the lowest visibility in reportable values. The remark must be of the form:

VSBY Direction Value

Example: VSBY NE1/2

t) The highest average visibility shall be obtained if there is data from all three sensors.

u) A remark shall be generated if the mean visibility is equal to or less than 2.75 miles and if the highest visibility minus the mean visibility is greater than 0.5 miles.

v) The remark shall state that visibility is higher in a stated direction, and give the value of the highest visibility in reportable values. The remark must be in one of these forms:

VSBY Direction Value, when there is higher visibility, only; or VSBY Direction L Value L Direction H Value H, when there are both higher and lower visibility. Example: VSBY W1/2SE2.

w) If a remark is present for both higher and lower sector visibilit the remark for lower visibility will be reported first.

x) If the mean visibility (Vm) is less than 2.75 miles, a variabilit check shall be made using the following criteria:

1. Get the last 10 minutes worth of Vm values.

2. Compare each value with its preceding Vm.

3. If $\left| Vm_i - Vm_{i-1} \right|$ is greater than 0.5, then increment a counter.

4. If the counter is equal or greater than 3, report visibility as variable.

5. Output a remark that the visibility is variable followed by the maximum and minimum Vm values generated in the last 10 minutes. The remark must be of the following form:

   VSBY <u>Min Value</u> V <u>Max Value</u>

   Example: VSBY 1/4V11/2.

y) Any visibility must be reported in the following values:

0, 1/4, 5/16, 3/8, 1/2, 5/8, 3/4, 7/8, 1, 11/8, 11/4, 13/8, 11/2, 15/8, 13/4, 17/8, 2, 21/4, 21/2, 3, 4, 5, 6, 7 and 8+.

z) If the reportable value of Vm as obtained from Section y is 2 miles or less, use the following procedure. If this new Vm has not changed by at least 2 reportable values from the previously reported PV, continue to use the previous PV as the current PV.

aa) If the last reported PV was:

1. 2 1/4, use 2 1/4 as the current PV if the current Vm is between 2.01 and 2.49;

2. 2 1/2, use 2 1/2 as the current PV if the current Vm is between 2.26 and 2.99;

3. 3, use 3 as the current PV if the current Vm is between 2.51 and 3.60.

Otherwise, use the reportable values as generated in Section 1.4y.

ab) A check shall be made to determine if a special message is required by using the following criteria:

If the present Vm (rounded to reportable values) when compared to the last Service "A" visibility meets any of the criteria listed in Section 1.2, a special counter must be incremented. If the counter is incremented on two successive minutes, a special Service "A" message must be generated and the counter set to zero.

ac) The current PV will be reported in the visibility section of the Service "A" message.

ad) Remarks, as generated, will be placed at the end of the Service "A" message. If two visibility remarks are generated, only one will be reported. A "variable visibility" remark will have precedence over "sector visibility."

ae) A new visibility observation is to be generated each minute.

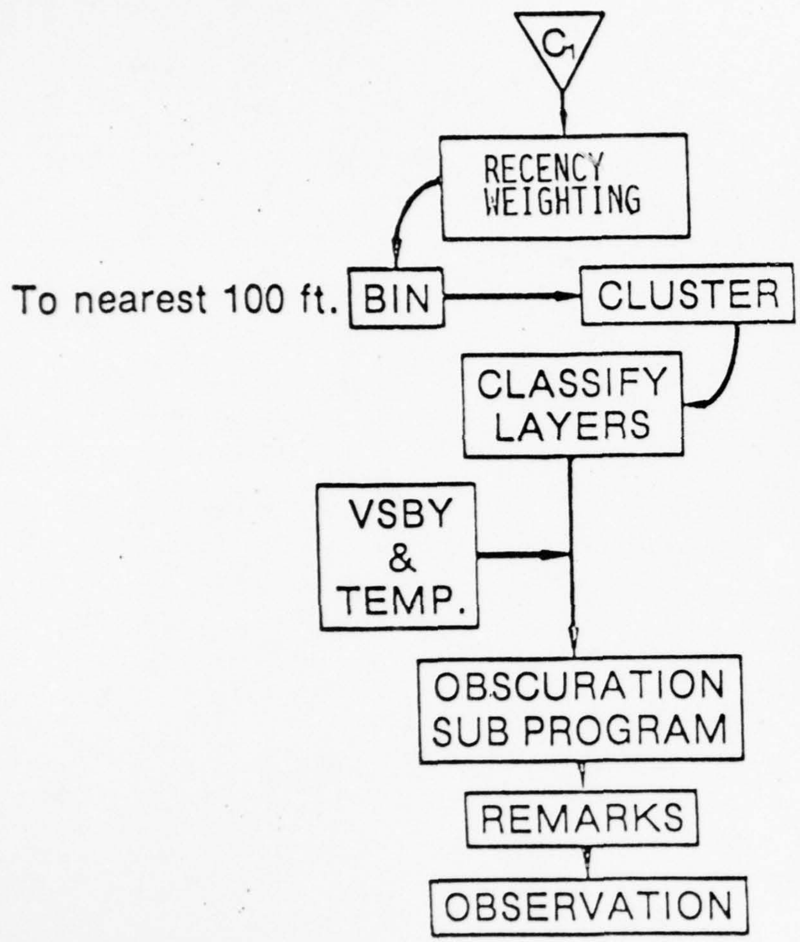
APPENDIX B

CLOUD ALGORITHM

Comments on the Single Sensor Cloud Algorithm

1. The algorithm is essentially the single sensor AV-AWOS algorithm used at PHF and updated by the October 1978 three sensor algorithm.
2. In the single sensor algorithm, we use recency weighting to give greater emphasis to the current cloud data. This is done by giving double weight to the last 10 minutes of cloud data.
3. The adequacy of using a single sensor as opposed to a three sensor network must be determined for each location by a site committee.
4. A generalized flow chart is attached.

SINGLE SENSOR CLOUD ALGORITHM



Sample RBC for 30 min.
(150 samples)

Double weight to last 10 min.
of OB period

Hierarchical Clustering

Tables. each higher layer uses
summation totals

Logic tables

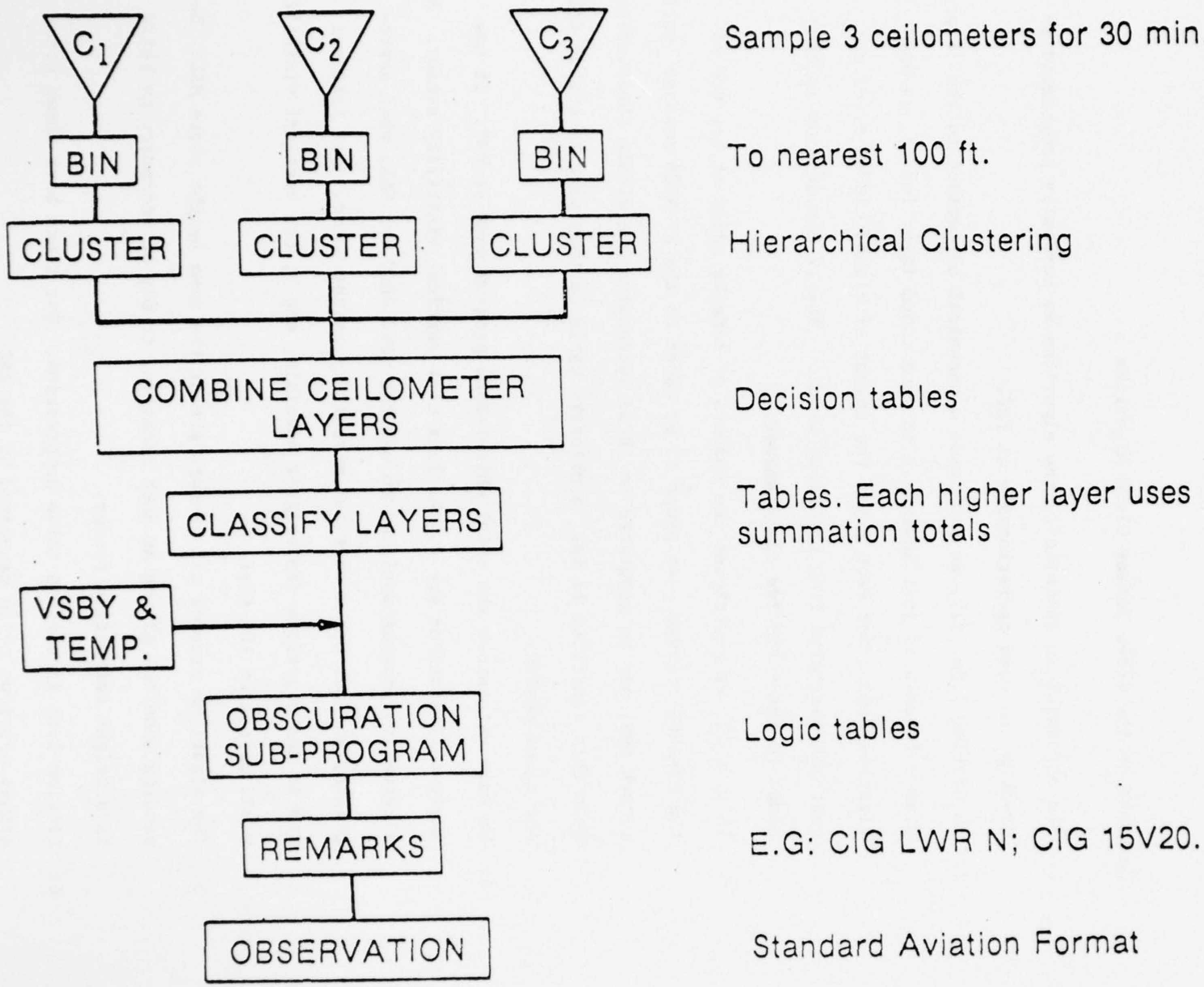
None

Limited Aviation format

Comments on the Three Sensor Cloud Algorithm

1. The algorithm is essentially the algorithm as currently programmed in AV-AWOS and used operationally at PHF.
2. In Section 1.5m 2(2), we have made a technical correction to the -X program. Instead of just adding .2 to each cloud layer for -X, we now first determine for each layer the amount of clouds hidden by -X and subtract the value from the cloud amount. The .2 obscuration is then added to the corrected cloud amount.
3. In 1.5q 12, we restricted the numbers of remarks added at the end of the AV-AWOS message. In order to be added to the AV-AWOS message, each remark must now be generated on three successive one minute observations. When this condition is met, a priority table is then used to output only one cloud remark.
4. We have maintained the total obscuration program used at PHF. It has serious limitations due to the lack of a vertical visibility sensor. An alternative program would be to use the word OBSC for WAX, when appropriate, and not use a vertical visibility height value. For internal use in the algorithm (to trigger specials, etc.), the vertical visibility would be set at 100 feet.
5. The algorithm assumes all sensors are at the same height above MSL. Depending upon the siting at each location, it may be necessary to build in a height correction factor.
6. Section 1.5j is used as noise suppression. Our tests have shown occasional spurious noise generated by the RBC.
7. A generalized flow chart is attached.

THREE SENSOR CLOUD ALGORITHM



SINGLE SENSOR CLOUD ALGORITHM

1. Cloud Cover and Height

The system shall include provisions for determining the amount of cloud cover and cloud heights in the general sensor area.

1.1 Accuracy of Cloud Heights

Sensors shall be provided to determine cloud heights as follows:

±100 feet from 100 feet to 1000 feet,

±10% from 1000 feet to 5000 feet,

±20% above 5000 feet.

1.2 Number of Sensors

A single cloud height sensor shall be provided. A site survey will determine the location of this instrument.

Horizontal visibility and air temperature as determined elsewhere in the automated observation must also be supplied.

1.3 Cloud Cover

Cloud cover shall be determined to the nearest 0.1 coverage from 0.0 to 1.0.

1.4 Significant Changes in Cloud Cover

The system shall provide for the determination and reporting of changes which meet the following criteria:

Ceiling

The ceiling (rounded to reportable values) forms below, decreases to less than, or if below, increases to equal or exceed:

1. 3000 feet.

2. 1000 feet.

3. 500 feet.

4. If the system is located at an airport, all nationally published minima, applicable to the airport, listed in the National Ocean Survey (NOS) instrument approach procedure charts or Department of Defense Flight Information Publication (DOD flips). Up to three additional values will be allowed for these minima.

Sky Condition

A layer of clouds or obscuring phenomena aloft is present below:

1. 1000 feet and no layer below 1000 feet was reported in the last transmitted Service "A" message.

2. The highest instrument minimum applicable to the airfield and no sky cover was reported below this height in the previous Service "A" transmission.

1.5 Cloud Algorithm

The cloud algorithm shall perform the following functions each minute.

a) Get a reading each 30 seconds from each of three ceilometers. Each reading shall have the capability of reporting the two lowest cloud layer heights.

b) Check to determine if the reading is above an upper limit of 7000 feet or below a lower limit of 50 feet. If less than 50 feet, the value is bad and the last good value for that ceilometer shall be inserted. A reading above 7000 feet shall be treated as a "no hit" and not as a bad value. The third consecutive time a bad value is received from the ceilometer, the system shall print an error message.

At that time, data from the ceilometer is excluded from any further data processing, the ceilometer is considered as "off-the-air" and no further cloud message shall be generated.

c) The input value will be the height in feet. Bin each input height as follows:

Surface to 5000 feet: to nearest 100 feet,

5000 feet to 7000 feet: to nearest even 200 feet (e.g., 5000, 5200, 5400 ...).

This binned value shall be used in computing the cloud clusters. However, the actual height value must be maintained.

d) Store up to 30 minutes of cloud heights, two heights of each ceilometer each 30 seconds.

e) Tag the two lowest cloud heights from each cycle scan of the ceilometer as follows:

1. Time of receipt.
2. Class of strike:

<u>Class A</u> = Only one cloud strike on that ceilometer scan cycle or the higher of two strikes.

<u>Class B</u> = The lower strike on a scan where two hits are recorded.

f) Recency Weighting - To give greater emphasis to the more current data, we give double weight to both hits and no hits in last 1/3 of data period. The actual hits are thus computed as the total hits in the first 2/3 of the data period plus twice the hits in the last 1/3 of the data period. The total possible hits are computed using 2.67 times the minutes the ceilometer has been collecting valid data plus 1 times all the Class B hits in first 2/3 of data period plus 2 times Class B hits in last 1/3 of data period. These double weights are binned like regular data and these values used in the remainder of the algorithm.

g) If less than 30 minutes of heights are available, estimate (E) shall prefix a ceiling height. If 30 minutes of heights are available, measured (M) shall prefix a ceiling height.

h) If there is more than one height value recorded in the sampling period, the values shall be tested and, if needed, clustered using the following criteria:

1. A check shall be made to determine if there are five or less clusters (or bins).
2. If there are five or less clusters, go to Step i.
3. The values shall be ordered from lowest to highest heights.
4. The least square distances of all adjacent heights shall be calculated

$$D^2 = \frac{N(J) \times N(K)}{N(J) + N(K)} \times [H(J)-H(K)]^2$$

where:

D = Least square distance.

H = Cluster (bin) height.

N = Number of cloud hits in that cluster.

5. The smallest least square distance shall be found.
6. If there are more than five clusters, the two clusters with the smallest least square distance between them shall be combined.

7. The cluster shall be combined as follows for height:

$$H(L) = \frac{[N(J) \times H(J)] + [N(K) \times H(K)]}{N(J) + N(K)}$$

and as follows for number of samples:

$$N(L) = N(J) + N(K)$$

8. The range of height values in a cluster shall be retained. These are the maximum and minimum values included in the cluster and are actual, not binned, values.

9. The H(L) and N(L) cluster shall replace the H(J), H(K), N(J), and N(K) clusters.

10. The clustering process shall return to Step 1 above and continue.

i) After the clustering has been completed, a test shall be run to determine if clusters from the same ceilometer can be combined:

1. Group the clusters in ascending order.
2. Compute the height difference of all adjacent clusters.
3. If lowest height of pair is less than 1000 feet and the difference between heights is 250 feet or less, combine the clusters; if not, go to the next height.
4. If lowest height of pair is greater than 1000 feet and the difference between heights is 350 feet or less, combine the clusters; if not, go to the next height.
5. If lowest height of pair is greater than 3000 feet and the difference between heights is 450 feet or less, combine the clusters; if not, go to the next height.

6. If the lowest height of pair is 5000 feet or higher and the difference between heights is 600 feet or less, combine the clusters; if not, go to next height.

7. The clusters are combined by the following for height:

$$H(L) = \frac{[H(J)\ N(J)] + [H(K)\ N(K)]}{N(J) + N(K)}$$

and as

$$N(L) = N(J) + N(K)$$

for the number of samples.

8. When two clusters are combined, the range of value of the cluster shall be maintained; the new cluster shall replace the two which were combined; the clusters reordered and the process of combining continued.

9. All adjacent pairs shall be examined until no future combining is required.

j) At the end of this process if any cluster has five hits or less, this cluster is not considered any further in the program and the number of hits is not added to any other cluster. However, the total possible hits (as calculated in Section 1.5e) are not reduced. All cluster heights are now rounded to:

Surface - 5000 feet: nearest 100 feet

5000 feet to 7000 feet: nearest 500 feet

(5000, 5500, 6000, etc.).

k) The sky cover shall be calculated by using the following criteria:

1. The total possible hits shall be obtained from Section 1.5e.

2. The cloud cover factor (R_L) shall be calculated using the following criteria for each layer starting with the lowest cluster (layer):

$$R_L = \frac{\sum_{L=1}^{n} (\text{Total Number of Layer Hits})}{\text{Total Possible Hits}}$$

where n is the cluster order number starting from the lowest layer. For the subsequent (i.e., $L>1$) layers, the summation principle from FMH-1 is applied. That is, if a lower layer at height h_1 has 25 hits, and a higher layer at height h_2 has 13 hits; R_L for h_2 would be computed using 38 divided by the total possible hits.

3. If less than five hits from all ceilometers "CLR BLO 70" shall shall be stored.

4. If five or more hits and $R_L \leq 0.06$ for all L, "CLR BLO 70" shall be stored and a remark of "Few Clouds" and the height of the cluster shall be stored. Example: FEW CLDS 55 for few clouds at 5500 feet.

5. If $R_L \leq 0.55$, height and "scattered" shall be stored.

6. If $R_L \leq 0.87$, height and "broken" shall be stored.

7. If $R_L > 0.87$, height and "overcast" shall be stored.

8. If more than one layer has a $R_L > 0.87$, a remark of higher clouds visible shall be stored. Example: HIR CLDS VSB.

9. For the lowest scattered, broken, and overcast layers, only, divide the total number of Class B strikes up to and including that layer by the total number of (non-zero) hits up to and

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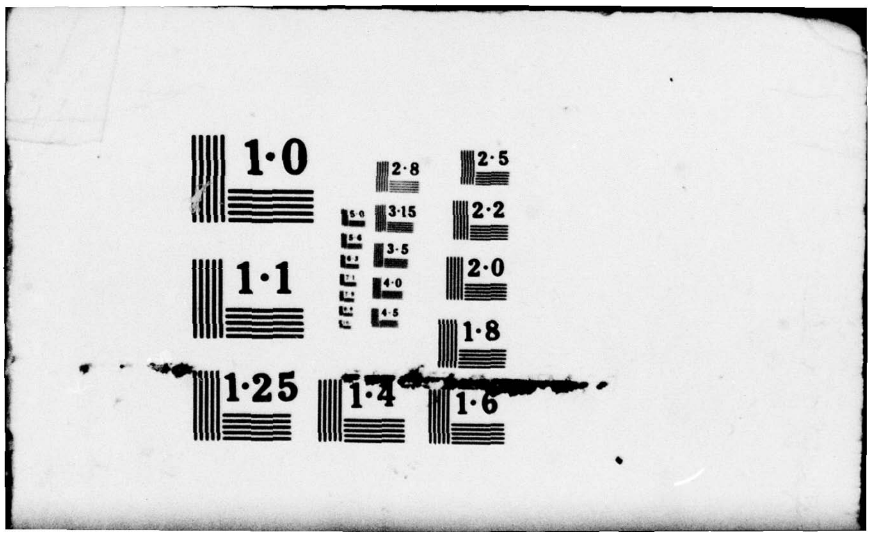
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including that layer. Call this ratio C. If $C \geq 0.5$, store "thin" (-) in front of SCT, BKN, or OVC as appropriate.

1) A test shall be made to determine if the ceiling is variable. The test shall use the following criteria:

   1. If there is a broken or overcast layer, not classified as thin (e.g., W2X is not considered a ceiling layer for variability) below 3000 feet, its standard deviation, using actual, not binned values, shall be calculated:

$$SD = \frac{1}{N} \sqrt{N\Sigma\, H^2 - (\Sigma\, H)^2}$$

      where H is the individual height values that are clustered into the layer.

   2. If there is no broken or overcast layer below 3000 feet, the *variability test is complete.*

   3. If the height is 1000 feet or below and the standard deviation greater than 200, a remark shall be queued.

   4. If the height is between 1000 and 2000 feet and the standard deviation is greater than 300, a remark shall be queued.

   5. If the height is greater than 2000 feet and the standard deviation greater than 400 feet, a remark shall be queued.

   6. If the remark is queued 1 minute in a row, a remark of ceiling variable with minimum and maximum heights (the highest and lowest binned values clustered into that layer) shall be reported and the queue counter set to zero. The form of the remark must be CIG MIN Height V MAX Height. Heights must be reported in hundreds of feet. Example: CIG 15V20.

m) A check shall be made to determine if the sky is obscured. If the visibility (Vm) as furnished elsewhere in the automated observation is 1.8125 miles or below and the cloud sensor has 30 minutes of data, scan last 10 minutes of cloud data.

1. If there are less than five cloud hits in the last 10 minutes output as cloud cover/height =

WAX,

where:

A = 1 if visibility is $\leq$ 1/4 mile

2 if visibility is > 1/4 mile or < 1.5625 miles

7 if visibility is $\geq$ 1.5625 miles and < 1.8125 miles and if the air temperature input is $\leq$ 36°F.

Otherwise continue to Step n.

A is the vertical visibility (in hundreds of feet) and is considered the ceiling height.

2. If there are five or more cloud hits within the last 10 minutes, and if the visibility is < 1.5625 miles, or if the air temperature is $\leq$ 36 F and the visibility is < 1.8125 miles:

1) If $R_L \leq .06$ for all layers, the cloud algorithm shall read -X and nothing else will be reported in the cloud group.

2) If $R_L > .06$, multiply each cloud layer amount by .2. Subtract these values from their respective cloud layers. Add .2 to each cloud layer and use these new cloud layer amounts in the subsequent steps. Prefix

cloud height/cover with -X.

3) If the above conditions are not met, continue to Step n.

n) Obtain the height of the ceiling layer (e.g., A of WAX or height of lowest broken or overcast layer not classified as thin) reported on the last Service "A" message (C_{L_a}). If no ceiling is reported, the ceiling height is assumed to be above 7000 feet.

Obtain the current ceiling height using the same criteria as above. If the current ceiling height differs from the last Service "A" ceiling by any of the criteria reported in Section 1.4 for two consecutive observations, a special Service "A" message shall be generated. In both cases the flow must go to o.

o) A second test shall be made to determine if a special message needs to be generated. If the following conditions are met, a special shall be generated for Service "A":

1. Get lowest scattered, broken or overcast layer less than 1000 feet presently existing.
2. Get lowest scattered, broken or overcast layer less than 1000 feet reported on last Service "A".
3. If a layer less than 1000 feet was reported on the last Service "A", a special shall not be required.
4. If no layer less than 1000 feet was reported on the last Service "A" and a layer less than 1000 feet has been present for 2 minutes, a special Service "A" message shall be generated and the counter set to zero.

p) Cloud data shall be displayed using the following criteria:

1. If obscured, the decision table in m.1 shall be reported.
2. If clear, it shall be reported as "CLR BLO 70" and the remark "few clds hh" added, if appropriate.
3. If one layer, it shall be reported.
4. If two layers, they shall be reported except only one overcast is reported.
5. If three layers, they shall be reported except only one overcast is reported.
6. The reporting shall be from the lowest to the highest layer.
7. If there are more than three layers, a total of three layers shall be reported in the following order or precedence:
   a. The lowest scattered (SCT) layer not classified as thin.
   b. The lowest broken (BKN) layer.
   c. The lowest "thin" SCT layer.
   d. The overcast (OVC) layer.
   e. The lowest "thin" BKN layer.
   f. A "thin" OVC layer.
   g. The second lowest SCT layer.
   h. The second lowest BKN layer.
   i. The highest BKN layer.
   j. The highest SCT layer.
8. 1) If lowest BKN layer has a ratio between .55 and .59, add in remarks "BKN VRBL SCT."

   2) If highest BKN layer reported has a ratio between .85 and .87, add in remarks "BKN VRBL OVC."

   3) If OVC layer reported has a ratio between .87 and .89, add in remarks "OVC VRBL BKN."

9. For lowest BKN or OVC layer prefix height value with an M or E as appropriate (e.g., M12 BKN).

10. -X shall precede the cloud layers as appropriate from m.2.

11. Each layer must be reported with its heights in reportable values in front of the layer type. Example: scattered clouds at 800 feet and broken clouds at 3200 feet are reported a 8 SCT M32 BKN. A blank shall separate the height and the amount designator and will also be used to separate successive cloud groups.

12. Remarks, as generated by the algorithm, shall be added at the end of the observation message.

Each remark must be generated on at least three successive one minute observations before it will be added to the end of the output message. Only one cloud remark shall be added to each message. The priority of these remarks are:

FEW CLD HH (Section 1.5 k 4)

CIG MIN V MAX (Section 1.5 1 6)

BKN VRBL SCT (Section 1.5 p 8(1))

BKN VRBL OVC (Section 1.5 p 8(2))

OVC VRBL BKN (Section 1.5 p 8(3))

HIR CLDS VSB (Section 1.5 k 8).

q) A new observation will be generated each minute.

THREE SENSOR CLOUD ALGORITHM

1. Cloud Cover and Height

The system shall include provisions for determining the amount of cloud cover and cloud heights in the general airport area.

1.1 Accuracy of Cloud Heights

Sensors shall be provided to determine cloud heights as follows:

$\pm$100 feet from 100 feet to 1000 feet,

$\pm$10% from 1000 feet to 5000 feet,

$\pm$20% above 5000 feet.

1.2 Number of Sensors

Three cloud height sensors shall be provided located in separate dispersed locations. A site survey will determine the location of the instruments. Visibility and temperature as determined elsewhere in the automated observation must also be supplied. Sensors should be corrected to the same height.

1.3 Cloud Cover

Cloud cover shall be determined to the nearest 0.1 coverage from 0.0 to 1.0.

1.4 **Significant Changes in Cloud Cover**

The system shall provide for the determination and reporting of changes which meet the following criteria:

Ceiling

The ceiling (rounded to reportable values) forms below, decreases to less than, or if below, increases to equal or exceed:

1. 3000 feet;
2. 1000 feet;
3. 500 feet.
4. All nationally published minima, applicable to the airport, listed in the National Ocean Survey (NOS) instrument approach procedure charts or Department of Defense Flight Information Publication (DOD flips). Up to three additional values will be allowed for these minima.

Sky Conditions

A layer of clouds or obscuring phenomena aloft is present below:

1. 1000 feet and no layer below 1000 feet was reported in the last transmitted Service "A" message.
2. The highest instrument minimum applicable to the airfield and no sky cover was reported below this height in the previous Service "A" transmission.

1.5 Cloud Algorithm

The cloud algorithm shall perform the following functions each minute:

a) Get a reading each 30 seconds from each of three ceilometers. Each reading shall have the capability of reporting the two lowest cloud layer heights.

b) Check to determine if the reading is above an upper limit of 7000 feet or below a lower limit of 50 feet. If less than 50 feet, the value is bad and the last good value for that ceilometer shall be inserted. A reading above 7000 feet shall be treated as a "no hit" and not as a bad value. The third consecutive time a bad value is received from the same ceilometer, the system shall print an error message. At that time, data from this ceilometer is excluded from any further data processing, the ceilometer is considered as "off-the-air" and the total possible number of hits is reduced accordingly.

c) The input value will be the height in feet. Bin each input heights as follows:

   Surface to 5000 feet: to nearest 100 feet.

   5000 feet to 7000 feet: to nearest even 200 feet (e.g., 5000, 5200, 5400 ...).

   This binned value shall be used in computing the cloud clusters.

d) Store up to 30 minutes of cloud heights, two heights of each ceilometer each 30 seconds.

e) Tag the two lowest cloud heights from each cycle scan of each ceilometer as follows:

   1. Ceilometer from which it originated.
   2. Time of receipt.
   3. Class of strike:

      Class A = Only one cloud strike on that ceilometer scan cycle or the higher of two strikes.

      Class B = The lower strike on a scan where two hits are recorded.

   The total possible hits shall be calculated. The total possible hits is two times the minutes ceilometer 1 has been collecting valid data, plus two times the minutes ceilometer 2 has been collecting valid data, plus two times the minutes ceilometer 3 has been collecting valid data, plus the number of hits from the second level from all three ceilometers.

f) If less than 30 minutes of heights are available from any sensor, estimate (E) shall prefix a ceiling height.

g) If 30 minutes of heights are available from all sensors, measured (M) shall prefix a ceiling height.

h) If there is more than one height value recorded from a ceilometer during the sampling period, the values shall be tested and, if needed, clustered using the following criteria for each ceilometer independently:

1. A check shall be made to determine if there are five or less clusters (or bins).

2. If there are five or less clusters, go to Step i.

3. The values shall be ordered from lowest to highest heights.

4. The least square distances of all adjacent heights shall be calculated

$$D^2 = \frac{N(J) \times N(K)}{N(J) + N(K)} \times [H(J) - H(K)]^2$$

where:

D = Least square distance.

H = Cluster (bin) height.

N = Number of cloud hits in that cluster.

5. The smallest least square distance shall be found.

6. If there are more than five clusters, the two clusters with the smallest least square distance between them shall be combined.

7. The cluster shall be combined as follows for height:

$$H(L) = \frac{[N(J) \times H(J)] + [N(K) \times H(K)]}{N(J) + N(K)}$$

and as follows for number of samples

$$N(L) = N(J) + N(K).$$

8. The range of height values in a cluster shall be retained. These are the maximum and minimum values included in the cluster and are actual, not binned, values.

9. The H(L) and N(L) cluster shall replace the H(J), H(K), N(J), and N(K) clusters.

10. The clustering process shall return to Step 1 above and continue.

i) After the clustering has been completed, a test shall be run to determine if clusters from the same ceilometer can be combined. The test shall use the following criteria for combining:

1. Group the clusters in ascending order.
2. Compute the height difference of all adjacent clusters.
3. If lowest height of pair is less than 1000 feet and the difference between heights is 250 feet or less, combine the clusters; if not, go to next height.
4. If lowest height of pair is greater than 1000 feet, and the difference between heights is 350 feet or less, combine the clusters; if not, go to next height.
5. If lowest height of pair is greater than 3000 feet, and the difference between heights is 450 feet or less, combine the clusters; if not, go to next height.

6. If the lowest height of pair is 5000 feet or higher and the difference between heights is 600 feet or less, combine the clusters; if not, go to next height.

7. The clusters are combined by the following for height:

$$H(L) = \frac{[H(J) \cdot N(J)] + [H(K) \cdot N(K)]}{N(J) + N(K)}$$

and as follows for number of samples:

$$N(L) = N(J) + N(K).$$

8. When two clusters are combined the range of value of the cluster shall be maintained, the new cluster shall replace the two which were combined, the clusters reordered and the process of combining continued.

9. All adjacent pairs shall be examined until no future combining is required.

j) After the combining process has been completed, a test shall be run to determine if clusters from the different ceilometers can be combined. To do this, repeat Step i using as input the clusters from all ceilometers.

At the end of this process, if any cluster has five hits or less, this cluster is not considered any further in the program and the number of hits is not added to any other cluster. However, the total possible hits (as calculated in Section 1.5e) are not reduced. All cluster heights are now rounded to:

Surface - 5000 feet: nearest 100 feet.

5000 feet to 7000 feet: nearest 500 feet (5000, 5500, 6000, etc.).

k) The sky cover shall be calculated by using the following criteria:

1. The total possible hits shall be obtained from Section 1.5e.

2. The cloud cover factor (R_L) shall be calculated using the following criteria for each layer, starting with the lowest cluster (layer)

$$R_L = \frac{\sum_{L=1}^{n} \text{(Total Number of Layer Hits)}}{\text{(Total Possible Hits)}}$$

where

n is the cluster order number starting from the lowest layer.

For the subsequent layers (i.e., L>1), the summation principle from FMH-1 is applied. That is, if a lower layer at height h_1 has 25 hits, and a higher layer at height h_2 has 13 hits, R_L for h_2 would be computed using 38 divided by the total possible hits.

3. If less than five hits from all ceilometers, "CLR BLO 70" shall be stored.

4. If five or more hits and $R_L \leq 0.06$ for all L, "CLR BLO 70" shall be stored and a remark of "Few Clouds" and the height of the cluster shall be stored. Example: FEW CLDS 55 for few clouds at 5500 feet.

5. If $R_L \leq 0.55$, height and "scattered" shall be stored.

6. If $R_L < 0.87$, height and "broken" shall be stored.

7. If $R_L > 0.87$, height and "overcast" shall be stored.

8. If more than one layer has a $R_L > 0.87$, a remark of higher clouds visible shall be stored. Example: HIR CLDS VSB.

9. For the lowest scattered, broken, and overcast layers, only, divide the total number of Class B strikes up to and including

that layer by the total number of (non-zero) hits up to and including that layer. Call this ratio C. If $C \geq 0.5$, store "thin" (-) in front of SCT, BKN, or OVC as appropriate.

1) A test shall be made to determine if the ceiling is variable. The test shall use the following criteria:

1. If there is a broken or overcast layer, not classified as thin (e.g., W2X is not considered a ceiling layer for variability), below 3000 feet, its standard deviation, using actual, not binned, values shall be calculated:

$$SD = \frac{1}{N}\sqrt{N\Sigma H^2 - (\Sigma H)^2}$$

where H is the individual height values that are clustered into the layer.

2. If there is no broken or overcast layer below 3000 feet, the variability test is complete.

3. If the height is 1000 feet or below and the standard deviation greater than 200, a remark shall be queued.

4. If the height is between 1000 and 2000 feet and the standard deviation is greater than 300, a remark shall be queued.

5. If the height is greater than 2000 feet, and the standard deviation greater than 400 feet, a remark shall be queued.

6. If the remark is queued 1 minute in a row, a remark of ceiling variable with minimum and maximum heights (the highest and lowest binned value that was clustered into that layer) shall be reported and the queue counter set to zero.

The form of the remark must be CIG MIN Height V MAX Height. Heights must be reported in hundreds of feet. Example: CIG 15V20.

m) A test shall be made to determine if the ceiling is lower and/or higher over the various ceilometers. The following steps must be completed:

1. If there is a broken or overcast layer not classified as thin and all three ceilometers are operational for 30 minutes, the test is made; if not, the test is bypassed.
2. Get the last half of the data from each ceilometer within the range of the ceiling layer (lowest broken or overcast layer not classified thin).
3. Compute the average height of the last half of data in this ceiling layer for each ceilometer. If any ceilometer does not have three or more hits, the high and low tests (4 - 9 below) shall be omitted.
4. Get the lowest average height.
5. Get the highest average height.
6. If the lowest average height and the clustered height of the ceiling layer difference is more than 200 feet, a lower sector exists.
7. A remark is generated that the ceiling is lower in the direction that the ceilometer is located from the airport. Format of remark CIG LWR direction. Example: CIG LWR NW.
8. If the highest average height is greater than 200 feet different from the clustered height, a higher ceiling exists.

9. A remark is generated that the ceiling is higher in the direction that ceilometer is located from the airport. Format of remark CIG HIR direction. Example: CIG HIR SE. Used only if 7 is not used.

n) A check shall be made to determine if the sky is obscured. If the visibility (Vm) as furnished elsewhere in the automated observation is 1.8125 miles or below, and any one of the cloud sensors has 30 minutes of data, scan last 10 minutes of cloud data.

1. If there are less than five cloud hits (from all ceilometers) in the last 10 minutes output as cloud cover/height =

WAX,

where:

A = 1 if visibility is $\leq$ 1/4 mile

2 if visibility is > 1/4 mile and < 1.5625 miles

7 if visibility is $\geq$ 1.5625 miles and < 1.8125 miles and if the air temperature input is $\leq$ 36°F.

Otherwise continue to Step o.

A is the vertical visibility (in hundreds of feet) and is considered the ceiling height.

2. If there are five or more cloud hits (from all ceilometers) within the last 10 minutes, and if the visibility is < 1.5625 miles, or if the air temperature is $\leq$ 36°F and the visibility is < 1.8125 miles:

(1) If $R_L \leq .06$ for all layers, the cloud algorithm shall read -X and nothing else will be reported in the cloud group.

(2) If $R_L > .06$, multiply each cloud layer amount by .2. Subtract these values from their respective cloud layers. Add .2 to each cloud layer and use these new cloud layer amounts in the subsequent steps. Prefix cloud height/cover with -X.

3. If the above conditions are not met, continue to Step o.

o) Obtain the height of the ceiling layer (e.g., A of WAX or height of lowest broken or overcast layer not classified as thin) reported on the last Service "A" message (C_{L_a}). If no ceiling is reported, the ceiling height is assumed to be above 7000 feet. Obtain the current ceiling height using the same criteria as above. If the current ceiling height differs from the last Service "A" ceiling by any of the criteria reported in Section 1.4 for two consecutive observations, a special Service "A" message shall be generated. In both cases, the flow must go to p.

p) A second test shall be made to determine if a special message needs to be generated. If the following conditions are met, a special message shall be generated for Service "A":

1. Get lowest scattered, broken or overcast layer less than 1000 feet presently existing.
2. Get lowest scattered, broken or overcast layer less than 1000 feet reported on last Service "A".
3. If a layer less than 1000 feet was reported on the last Service "A", a special message shall not be required.
4. If no layer less than 1000 feet was reported on the last Service "A" and a layer less than 1000 feet has been present for

2 minutes, a special Service "A" message shall be generated and the counter set to zero.

q) Cloud data shall be displayed using the following criteria:

1. If obscured, the decision table in n.1 shall be reported.
2. If clear, it shall be reported as "CLR BLO 70" and the remark "few clds hh" added, if appropriate.
3. If one layer, it shall be reported.
4. If two layers, they shall be reported except only one overcast is reported.
5. If three layers, they shall be reported except only one overcast is reported.
6. The reporting shall be from the lowest to the highest layer.
7. If there are more than three layers, a total of three layers shall be reported in the following order or precedence:
   a. The lowest scattered (SCT) layer not classified as thin.
   b. The lowest broken (BKN) layer.
   c. The lowest "thin" SCT layer.
   d. The overcast (OVC) layer.
   e. The lowest "thin" BKN layer.
   f. A "thin" OVC layer.
   g. The second lowest SCT layer.
   h. The second lowest BKN layer.
   i. The highest BKN layer.
   j. The highest SCT layer.

8. (1) If lowest BKN layer has a ratio between .55 and .59, add in remarks "BKN VRBL SCT."

   (2) If highest BKN layer reported has a ratio between .85 and .87, add in remarks "BKN VRBL OVC."

   (3) If OVC layer reported has a ratio between .87 and .89, add in remarks "OVC VRBL BKN."

9. For lowest BKN or OVC layer, prefix height value with an M or E as appropriate (e.g., M12 BKN).

10. -X shall precede the cloud layers as appropriate from n.2.

11. Each layer must be reported with its heights in reportable values in front of the layer type. Example: scattered clouds at 800 feet and broken clouds at 3200 feet are reported as 8 SCT M32 BKN. A blank shall separate the height and the amount designator and will also be used to separate successive cloud groups.

12. Remarks, as generated by the algorithm, shall be added at the end of the observation message.

Each remark must be generated on at least three successive one minute observations before it will be added to the end of the output message. Only one cloud remark shall be added to each message. The priority of these remarks are:

FEW CLD HH (Section 1.5 k 4)

CIG LWR DD (Section 1.5 m 7)

CIG MIN V MAX (Section 1.5 1 6)

CIG HIR DD (Section 1.5 m 9)

BKN VRBL SCT (Section 1.5 q 8(1))

BKN VRBL OVC (Section 1.5 q 8(2))

OVC VRBL BKN (Section 1.5 q 8(3))

HIR CLDS VSB (Section 1.5 k 8).

r) A new observation will be generated each minute.

APPENDIX C

AV-AWOS User Assessment Plan Results

Equipment Development Laboratory
Systems Development Office
National Weather Service
Silver Spring, Maryland

November 1978

1. Introduction

The purpose of the AV-AWOS User Assessment Plan at Patrick Henry Airport was to obtain user reaction/acceptability of an automated weather observation. FAA's National Aviation Facilities Experimental Center and NWS's Test and Evaluation Division and Equipment Development Laboratory prepared a questionnaire for use to survey the users of the AV-AWOS observation. A copy of this questionnaire is shown in figure 1. The questionnaire was distributed to the following user groups during the AV-AWOS test period (January - May, 1978) at Newport News, Virginia:

1. General Aviation Pilots
2. Air Carrier Pilots, Dispatchers and Forecasters
3. FSS Briefers
4. Air Traffic Controllers
5. NWS and Military Forecasters/Observers

Results from the questionnaires were tabulated by EDL and are presented in the following section.

The user groups listed in the first question of the survey are self explanatory except for "other." In the results presented in Section 2 questionnaires returned by NWS forecasters at Norfolk, Virginia and Washington, D.C., and military forecasters and observers at Langley Air Force Base, Virginia and Fort Eustis, Virginia are included in the "other" category.

No attempt is made to interpret the results of the User Assessment Plan. The results are just presented for the reader's interpretation and use.

Form Approved. OMB No. 04-S77022. Use Expires 6/1/78

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

AVIATION AUTOMATED WEATHER OBSERVATION SYSTEM (AV–AWOS) USER SURVEY

No.

Part I–USER PROFILE

1. Indicate in which capacity(ies) you used the AV–AWOS
(If more than one, number box to indicate the order of importance (1, 2, 3, etc.).)

1 ☐ General Aviation Pilot
2 ☐ Weather Briefer
3 ☐ Air Carrier Pilot
4 ☐ Air Traffic Controller
5 ☐ Other *(Specify)*

2. Indicate means used to obtain AV–AWOS "observation(s)"
("X" all applicable boxes)

1 ☐ Teletype Line
2 ☐ VOR Automated Voice Broadcast
3 ☐ Air Traffic Controller
4 ☐ Weather Briefer
5 ☐ TV Displays
6 ☐ Electrowriter
7 ☐ Telephone Automated Voice
8 ☐ Other *(Specify)*

Indicate "X" your preference
3. I prefer getting weather information from a –

1 ☐ Human Observer
2 ☐ Automated System
3 ☐ Does not matter

Indicate "X" your opinion
4. The fact that AV–AWOS is an automated system –

1 ☐ Bothers me
2 ☐ Does not bother me

5. Approximate number of times AV–AWOS observations used

1 ☐ 1-5
2 ☐ 6-10
3 ☐ 11-20
4 ☐ Over 20

Part II–USER EVALUATION

1. Weather Data

ITEMS *("X" ONE of the five responses in BOTH Columns (3) and (4). If your function does not involve the use of the data listed, "X" that line in the "N/A" Column.)* (1)	N/A (2)	DESIRABILITY (3) VERY UN-DESIRABLE (a)	UN-DESIRABLE (b)	NEUTRAL (c)	DESIRABLE (d)	VERY DESIRABLE (e)	IMPORTANCE (4) VERY SMALL (a)	SMALL (b)	MODERATE (c)	GREAT (d)	VERY GREAT (e)
a. Height limit of 7,000 feet for cloud observation											
b. Provision of weather observations via TV displays											
c. All visibilities greater than eight (8) miles reported as "8 +"											
d. Provision of weather by automated voice over the telephone											
e. No rain/snow discrimination. Precipitation reported for both											
f. More frequent weather observation updates											
g. Remarks on thunderstorms do not include bearing and movement											
h. Availability of local weather inflight via VOR automated voice											
i. Fewer remarks reported											
j. AV–AWOS considered in its entirety											

1st | Fold

2. Most desirable feature of AV–AWOS *(Explain)*

3. Least desirable feature of AV–AWOS *(Explain)*

4. Automated Voice Data

a. TYPE FEATURE USED: 1 ☐ VOR 2 ☐ Telephone 3 ☐ Both 4 ☐ Neither *(Skip to 5)*

b. QUALITY OF EQUIPMENT

ITEMS *(Based on your experience with the AV–AWOS voice output–rate ("X") the four items below in BOTH Columns (b) and (c).)* (a)	TELEPHONE (b) VERY POOR 1	POOR 2	FAIR 3	GOOD 4	VERY GOOD 5	VOR (c) VERY POOR 1	POOR 2	FAIR 3	GOOD 4	VERY GOOD 5
(1) Intelligibility of words, absence of distortion and noise, fidelity										
(2) Suitability of speaking rate for note taking or copying										
(3) Naturalness of rhythm and intonation, smoothness of flow from word to word										
(4) Overall pleasantness of sound of speech										

Indicate "X" your opinion
5. Suitability of AV–AWOS for widespread field use

1 ☐ SUITABLE, fine as is
2 ☐ SUITABLE, minor changes desirable
3 ☐ MARGINALLY SUITABLE, major changes necessary
4 ☐ UNSUITABLE, extensive redesign
5 ☐ UNSUITABLE, entire concept is inappropriate

6. Remarks

Please fold twice on fold marks and tape where indicated. Thank you for your cooperation.

FAA Form 7950-2 OT (9-77) USE EXPIRES 6/1/78

Figure 1. AV-AWOS Questionnaire

2. Results of User Assessment Plan

This section contains the results of the User Assessment Plan. One-hundred and eighty-one (181) questionnaires were returned and are included in the results presented. The number of questionnaires returned by each user category is as follows:

1.	General Aviation Pilots	21
2.	Weather Briefers	18
3.	Air Carrier Pilots	27
4.	Air Traffic Controllers	54
5.	Other	61
	Total	181

The following abbreviations are used for each user category:

GAP - General Aviation Pilots
WB - Weather Briefers
ACP - Air Carrier Pilots
ATC - Air Traffic Controllers
OT - Other
COMB - Combined Categories

Each user category received the AV-AWOS by the following means:

	GAP	WB	ACP	ATC	OT	COMB
1. Teletype Line	10%	33%	11%	0%	76%	33%
2. VOR Automated Voice Broadcast	10%	0%	77%	0%	2%	13%
3. Air Traffic Controller	10%	0%	4%	4%	0%	3%
4. Weather Briefer	32%	0%	0%	0%	2%	4%
5. TV Display	18%	44%	0%	83%	5%	33%
6. Electrowriter	5%	23%	0%	13%	2%	7%
7. Telephone Automated Voice	10%	0%	4%	0%	8%	4%
8. Other	5%	0%	4%	0%	5%	3%

The automated observation at Patrick Henry Airport was used by each user group the following number of times:

	GAP	WB	ACP	ATC	OT	COMB
1. 1 - 5	52%	5%	86%	13%	13%	28%
2. 6 - 10	10%	11%	7%	4%	7%	7%
3. 11 - 20	5%	17%	0%	4%	11%	7%
4. >20	33%	67%	7%	80%	69%	58%

Each respondee was asked how they preferred receiving weather information. The results from this question are as follows:

	GAP	WB	ACP	ATC	OT	COMB
1. Human Observer	62%	50%	44%	28%	62%	48%
2. Automated System	5%	0%	4%	17%	8%	9%
3. Does Not Matter	33%	50%	52%	55%	30%	43%

To determine a measure of prejudice against an automated observation, users were asked if they were bothered/not bothered by the fact AV-AWOS is an automated system. The results are as follows:

	GAP	WB	ACP	ATC	OT	COMB
1. Bothers	29%	11%	11%	15%	36%	23%
2. Does Not Bother	71%	89%	89%	85%	64%	77%

The unique features of the AV-AWOS system were evaluated via the user's questionnaire. These included the height limitation of 7,000 feet for cloud observations; the availability of the automated observation on TV displays; visibilities greater than 8 miles reported as 8+; the provision of providing weather by automated voice over the telephone; present weather descrimination limited to only precipitation, freezing rain, hail and thunderstorms; more frequent updating of the observation; remarks on thunderstorms do not include bearing and movement; availability of local weather inflight on VOR via automated voice; fewer remarks reported; and the AV-AWOS system considered in its entirety. Users rated these features in terms of desirability, importance or not applicable to their function. Their response to this section of the questionnaire is given below.

Height Limit of 7,000 Feet for Cloud Observation

1. DESIRABILITY

	GAP	WB	ACP	ATC	OT	COMB
a. Very Undesirable/Undesirable	33%	50%	33%	20%	57%	39%
b. Neutral	43%	33%	41%	56%	31%	41%
c. Desirable/Very Desirable	19%	11%	26%	22%	8%	17%
d. N/A or Left Blank	5%	6%	0%	2%	4%	3%

2. IMPORTANCE

	GAP	WB	ACP	ATC	OT	COMB
a. Very Small/Small	23%	39%	55%	22%	20%	28%
b. Moderate	29%	39%	26%	52%	48%	43%
c. Great/Very Great	29%	16%	15%	15%	28%	21%
d. N/A or Left Blank	29%	6%	4%	11%	4%	8%

Provision of Weather Observations Via TV Displays

1. DESIRABILITY

	GAP	WB	ACP	ATC	OT	COMB
a. Very Undesirable/Undesirable	0%	6%	4%	31%	5%	12%
b. Neutral	52%	27%	4%	9%	13%	17%
c. Desirable/Very Desirable	43%	27%	26%	60%	31%	40%
d. N/A or Left Blank	5%	40%	66%	0%	51%	31%

2. IMPORTANCE

	GAP	WB	ACP	ATC	OT	COMB
a. Very Small/Small	29%	28%	4%	13%	18%	17%
b. Moderate	33%	11%	10%	40%	16%	21%
c. Great/Very Great	14%	17%	19%	48%	12%	24%
d. N/A or Left Blank	24%	44%	67%	9%	54%	38%

All Visibilities Greater Than Eight (8) Miles Reported as "8+"

1. DESIRABILITY

	GAP	WB	ACP	ATC	OT	COMB
a. Very Undesirable/Undesirable	15%	0%	10%	9%	18%	12%
b. Neutral	52%	72%	48%	44%	52%	51%
c. Desirable/Very Desirable	33%	17%	38%	41%	28%	33%
d. N/A or Left Blank	0%	11%	4%	6%	2%	4%

2. IMPORTANCE

	GAP	WB	ACP	ATC	OT	COMB
a. Very Small/Small	24%	44%	44%	35%	56%	44%
b. Moderate	43%	28%	30%	37%	30%	33%
c. Great/Very Great	14%	17%	19%	17%	13%	15%
d. N/A or Left Blank	19%	11%	7%	11%	1%	8%

Provision of Weather by Automated Voice Over the Telephone

1. DESIRABILITY

	GAP	WB	ACP	ATC	OT	COMB
a. Very Undesirable/Undesirable	23%	17%	4%	20%	10%	14%
b. Neutral	29%	17%	15%	17%	20%	19%
c. Desirable/Very Desirable	43%	22%	22%	17%	21%	23%
d. N/A or Left Blank	5%	44%	59%	46%	49%	44%

2. IMPORTANCE

	GAP	WB	ACP	ATC	OT	COMB
a. Very Small/Small	24%	28%	11%	15%	20%	18%
b. Moderate	24%	28%	15%	22%	20%	21%
c. Great/Very Great	29%	6%	11%	13%	11%	13%
d. N/A or Left Blank	23%	38%	63%	50%	49%	48%

No Rain/Snow Discrimination - Precipitation Reported for Both

1. DESIRABILITY

	GAP	WB	ACP	ATC	OT	COMB
a. Very Undesirable/Undesirable	86%	83%	82%	84%	92%	86%
b. Neutral	4%	11%	7%	9%	5%	7%
c. Desirable/Very Desirable	10%	0%	0%	5%	3%	4%
d. N/A or Left Blank	0%	6%	11%	2%	0%	3%

2. IMPORTANCE

	GAP	WB	ACP	ATC	OT	COMB
a. Very Small/Small	5%	11%	7%	7%	7%	7%
b. Moderate	19%	17%	22%	26%	8%	18%
c. Great/Very Great	57%	61%	52%	56%	85%	65%
d. N/A or Left Blank	19%	11%	19%	11%	0%	10%

More Frequent Weather Observation Updates

1. DESIRABILITY

	GAP	WB	ACP	ATC	OT	COMB
a. Very Undesirable/Undesirable	5%	28%	11%	19%	8%	13%
b. Neutral	38%	11%	22%	35%	11%	23%
c. Desirable/Very Desirable	52%	50%	63%	46%	76%	60%
d. N/A or Left Blank	5%	11%	4%	0%	5%	4%

2. IMPORTANCE

	GAP	WB	ACP	ATC	OT	COMB
a. Very Small/Small	10%	22%	7%	15%	8%	12%
b. Moderate	24%	22%	15%	41%	18%	25%
c. Great/Very Great	42%	39%	71%	33%	69%	52%
d. N/A or Left Blank	24%	17%	7%	11%	5%	11%

Remarks on Thunderstorms Do Not Include Bearing and Movement

1. DESIRABILITY

	GAP	WB	ACP	ATC	OT	COMB
a. Very Undesirable/Undesirable	67%	44%	70%	51%	74%	62%
b. Neutral	19%	33%	11%	20%	16%	19%
c. Desirable/Very Desirable	10%	6%	11%	22%	5%	12%
d. N/A or Left Blank	4%	17%	8%	7%	5%	7%

2. IMPORTANCE

	GAP	WB	ACP	ATC	OT	COMB
a. Very Small/Small	0%	17%	7%	13%	11%	10%
b. Moderate	19%	44%	26%	33%	21%	28%
c. Great/Very Great	62%	28%	56%	39%	63%	51%
d. N/A or Left Blank	19%	11%	11%	15%	5%	11%

Availability of Local Weather Inflight via VOR Automated Voice

1. DESIRABILITY

	GAP	WB	ACP	ATC	OT	COMB
a. Very Undesirable/Undesirable	0%	5%	7%	7%	3%	5%
b. Neutral	38%	5%	4%	20%	8%	14%
c. Desirable/Very Desirable	57%	33%	82%	42%	23%	42%
d. N/A or Left Blank	5%	57%	7%	31%	66%	39%

2. IMPORTANCE

	GAP	WB	ACP	ATC	OT	COMB
a. Very Small/Small	17%	17%	0%	6%	10%	9%
b. Moderate	10%	17%	26%	33%	7%	19%
c. Great/Very Great	49%	17%	63%	24%	16%	29%
d. N/A or Left Blank	24%	49%	11%	37%	67%	43%

Fewer Remarks Reported

1. DESIRABILITY

	GAP	WB	ACP	ATC	OT	COMB
a. Very Undesirable/Undesirable	38%	33%	41%	37%	59%	44%
b. Neutral	47%	39%	33%	43%	31%	38%
c. Desirable/Very Desirable	5%	11%	7%	13%	7%	9%
d. N/A or Left Blank	10%	17%	19%	7%	3%	9%

2. IMPORTANCE

	GAP	WB	ACP	ATC	OT	COMB
a. Very Small/Small	23%	33%	15%	28%	23%	24%
b. Moderate	29%	28%	44%	33%	39%	36%
c. Great/Very Great	19%	22%	15%	22%	35%	25%
d. N/A or Left Blank	29%	17%	26%	17%	3%	15%

AV-AWOS Considered in its Entirety

1. DESIRABILITY

	GAP	WB	ACP	ATC	OT	COMB
a. Very Undesirable/Undesirable	23%	17%	4%	31%	41%	28%
b. Neutral	38%	22%	19%	20%	26%	24%
c. Desirable/Very Desirable	29%	44%	67%	45%	30%	41%
d. N/A or Left Blank	10%	17%	10%	4%	3%	7%

2. IMPORTANCE

	GAP	WB	ACP	ATC	OT	COMB
a. Very Small/Small	28%	17%	0%	12%	16%	14%
b. Moderate	24%	39%	62%	30%	43%	39%
c. Great/Very Great	24%	22%	19%	41%	36%	33%
d. N/A or Left Blank	24%	22%	19%	17%	5%	14%

Users were next asked to list the most desirable feature and the least desirable feature of AV-AWOS. The most frequent desirable features given were:

Frequent Update
Automated Voice
Cloud and Visibility Observations

Fifty-six (56) percent of the respondees gave the frequent update capability of AV-AWOS as the most desirable feature.

The most frequent least desirable features given were:

Precipitation Type Limitation
AV-AWOS System Downtime
Automated Voice Intelligibility

Forty-one (41) percent of the respondees gave the limitation of the AV-AWOS in reporting precipitation types as the least desirable feature.

Only fifty-five (55) users gave their evaluation of the automated voice capability of AV-AWOS. Instead of listing the response by user category, the responses were combined for all categories.

Telephone

1. INTELLIGIBILITY, DISTORTION, NOISE, FIDELITY

a.	Very Poor/Poor	18%
b.	Fair	29%
c.	Good/Very Good	53%

2. SUITABILITY OF SPEAKING RATE

a.	Very Poor/Poor	6%
b.	Fair	23%
c.	Good/Very Good	71%

3. NATURALNESS OF RHYTHM, SMOOTHNESS

a.	Very Poor/Poor	21%
b.	Fair	24%
c.	Good/Very Good	55%

4. OVERALL PLEASANTNESS

a.	Very Poor/Poor	21%
b.	Fair	36%
c.	Good/Very Good	43%

VOR (VHF Omni Range)

1. INTELLIGIBILITY, DISTORTION, NOISE, FIDELITY

a.	Very Poor/Poor	30%
b.	Fair	40%
c.	Good/Very Good	30%

2. SUITABILITY OF SPEAKING RATE

a.	Very Poor/Poor	7%
b.	Fair	16%
c.	Good/Very Good	77%

3. NATURALNESS OF RHYTHM, SMOOTHNESS

a.	Very Poor/Poor	23%
b.	Fair	23%
c.	Good/Very Good	54%

4. OVERALL PLEASANTNESS

a.	Very Poor/Poor	24%
b.	Fair	30%
c.	Good/Very Good	46%

The overall suitability of AV-AWOS for widespread field use was rated by users of the automated observation. The results by user category are as follows:

1. SUITABLE, FINE AS IS

a.	General Aviation Pilots	0%
b.	Weather Briefers	0%
c.	Air Carrier Pilots	0%
d.	Air Traffic Controllers	2%
e.	Other	2%
f.	Combined	< 1%

2. SUITABLE, MINOR CHANGES DESIRABLE

a.	General Aviation Pilots	55%
b.	Weather Briefers	33%
c.	Air Carrier Pilots	63%
d.	Air Traffic Controllers	46%
e.	Other	26%
f.	Combined	42%

3. **MARGINALLY SUITABLE, MAJOR CHANGES NECESSARY**

a.	General Aviation Pilots	25%
b.	Weather Briefers	61%
c.	Air Carrier Pilots	33%
d.	Air Traffic Controllers	33%
e.	Other	44%
f.	Combined	39%

4. **UNSUITABLE, EXTENSIVE REDESIGN**

a.	General Aviation Pilots	5%
b.	Weather Briefers	0%
c.	Air Carrier Pilots	4%
d.	Air Traffic Controllers	13%
e.	Other	11%
f.	Combined	9%

5. **UNSUITABLE, ENTIRE CONCEPT IS INAPPROPRIATE**

a.	General Aviation Pilots	15%
b.	Weather Briefers	6%
c.	Air Carrier Pilots	0%
d.	Air Traffic Controllers	6%
e.	Other	18%
f.	Combined	10%