7.2 DEVELOPMENT OF A METEOROLOGICAL PARTICLE SENSOR FOR THE OBSERVATION OF DRIZZLE

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1. INTRODUCTION

The National Weather Service (NWS) and Federal Aviation Administration (FAA) are jointly participating in a Product Improvement Program to improve the capabilities of the of Automated Surface Observing Systems (ASOS). The greatest challenge in the ASOS was to automate the visual elements of the observation; sky conditions, visibility and type of weather. Despite achieving some success in this area, limitations in the reporting capabilities of the ASOS remain. As currently configured, the ASOS uses a Precipitation Identifier that can only identify two precipitation types, rain and snow. A goal of the Product Improvement program is to replace the current PI sensor with one that can identify additional precipitation types of importance to aviation. Highest priority is being given to implementing capabilities of identifying ice pellets and drizzle. The preliminary testing in the effort to automate the drizzle portion of the observation were described in an earlier paper, Automating the Observation of Drizzle (Lewis, 2002). This paper discusses the results of three years of field testing of a sensor that was developed to differentiate drizzle from rain.

2. DEFINITION OF DRIZZLE

The National Weather Service Handbook No. 7, Surface Weather Observations and Reports (NOAA, 1996) defines drizzle as:

> “Fairly uniform precipitation composed exclusively of fine drops with diameters of less than 0.5mm very close together. Drizzle appears to float while following air currents, although unlike fog droplets, it falls to the ground.”

The definition of drizzle in the Glossary of Meteorology (American Meteorological Society, 1959) is:

> “Very small, numerous, and uniformly dispersed, water drops that may appear to float while following air currents. Unlike fog droplets, drizzle falls to the ground. It usually falls from low stratus clouds and is frequently accompanied by low visibility and fog.
>
> In weather observations, drizzle is classified as (a) “very light”, comprised of scattered drops that do not completely wet an exposed surface, regardless of duration; (b) “light,” the rate of fall being from a trace to 0.25 mm per hour: (c) “moderate,” the rate of fall being 0.25-0.50 mm per hour:(d) “heavy” the rate of fall being more than 0.5 mm per hour. When the precipitation equals or exceeds 1mm per hour, all or part of the precipitation is usually rain; however, true drizzle falling as heavily as 1.25 mm per hour has been observed. By convention, drizzle drops are 0.5mm or less in diameter”

Whichever definition is used, there is necessarily some subjectivity in the identification of drizzle. It is also difficult to measure the low accumulation rates to determine the intensity based on the rate of accumulation criteria.

3. HUMAN OBSERVATIONS OF DRIZZLE

While the observation of drizzle is obviously difficult to automate, it is generally straightforward for an observer to visually assess when drops are too small to be rain drops. It then becomes a question of whether the drops are suspended in air (fog) or falling (drizzle). This is typically done by determining whether the drops can be observed to collect on horizontal surfaces.

Such subjective definitions inevitably cause problems when attempting to develop a specification for an instrument to detect drizzle. It is preferable to have a reference instrument that is accepted by vendors whose products will be evaluated by the government for potential inclusion in the ASOS. Many meteorological measurements can be evaluated in the field against instruments whose calibration is traceable to the National Institutes of Standards and Technology (e.g. temperature). Unfortunately there is no traceable reference for instruments that measure subjective weather elements (sky conditions, visibility, and type of weather).

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4. ASOS PRECIPITATION IDENTIFICATION (PI) SENSOR

The ASOS PI Sensor is the Optical Scientific Inc. (OSI) Model OWI-240, also called the light emitting diode weather identifier (LEDWI) is shown in figure 1. Its precipitation identification measurement is based on the optical sensing of weather particle-induced scintillations in a partially coherent source (i.e., an infrared light emitting diode). The temporal frequency spectrum of the induced scintillation varies according to the size and velocity of the falling precipitant. By measuring the energy in two frequency bands and comparing their ratios, the state of precipitation (yes/no) and the type (rain/snow) can be identified. An estimate of precipitation intensity is also derived for discriminating the three intensity levels of light, moderate, or heavy. As particle size and/ or number of particles decreases, the signal level also decreases and becomes too weak to differentiate the signal from naturally occurring background scintillation which is associated with bright sun and/ or turbulence. For this reason the LEDWI is not capable of detecting very small, slow falling drizzle particles.

Figure 1. OWI-240 LEDWI

5. REFERENCE SENSOR FOR DRIZZLE

5.1 Meteorological Performance Criteria

The obvious requirements for a reference sensor for drizzle are contained in the definitions cited in section 2. If the number, size and fall velocity of the atmospheric particles can be measured, it should be possible to differentiate drizzle from rain, fog or other types of weather. To determine if such technologies existed, the government in 2000 initiated a competitive solicitation to identify any vendors that could provide a sensor that makes the necessary measurements. After a proposal evaluation, a vendor was selected based on the technical merits of their current product line, their technical proposal for supplying a sensor that will meet the government's requirements, and their final cost for delivering the sensor. The successful bidder on this solicitation was Droplet Measurement Technologies, Inc. of Boulder, Colorado, delivering a sensor to be henceforth called the Meteorological Particle Sensor (MPS).

5.2 Meteorological Particle Sensor

The Meteorological Particle Sensor (MPS), shown in figure 2, is designed to directly measure precipitation shapes, sizes and fall velocities. In post processing, rainfall rates and statistical data on the intensity of the rainfall can be derived. The Particle Analysis and Collection System (PACS), a graphical user interface at the host computer, provides control of measurement parameters, while simultaneously displaying real-time size distributions.

The MPS is installed on a rotating mount with a wind vane that keeps the axis of the projected laser beam directed parallel to the prevailing wind. The incident laser beam is focused on particles ranging in size from 50 micrometers to 3100 micrometers, which are magnified by a factor of four, onto a 64 element photo-sensitive diode array (each diode is therefore a 0.05mm width bin). After a sufficient number of particles have been sampled by the sensor, the digital signal processor stores the cumulative number of particles of each size.

Figure 2. Meteorological Particle Sensor

6. MPS ALGORITHM FOR DRIZZLE DETECTION AND INTENSITY

While the MPS provides key information about the size, number density, and fall velocity of particles, an algorithm had to be developed to use this information to determine if the particles that are falling meet the definition of drizzle.

In essence, the algorithm first determines if precipitation is occurring. The criteria that was ultimately chosen was that four or more particles must be detected in one minute to validate the occurrence of precipitation.

The number of drizzle size particles ($N_{dz} \leq 0.5$mm) and the number of raindrop size particles ($N_{ra} > 0.5$mm) are then determined. Then the ratio:

$$R = N_{dz}/(N_{dz}+N_{ra}) \qquad (1)$$

is used to differentiate drizzle from rain. The higher the percentage, the greater the likelihood that the precipitation type is drizzle (DZ). After three years of intercomparing MPS measurements against human observations, a ratio of 0.95 or greater was chosen as the indicator for drizzle. All other precipitation was considered rain (RA). If fewer than 4 particles in one minute were detected, the designation was no precipitation (NP). The identification algorithm is described in greater detail in the Appendix.

An additional objective of this effort was to determine the accumulation rate due to drizzle. Since the MPS sizes all the drops that pass through its sample area, a straightforward computation of the volume of (assumed spherical) drops can be used to determine the cumulative volume of water V_w passing through the sample area A to compute precipitation P for an interval of time (e.g. each minute) whereby:

$$P = V_w/A \qquad (2)$$

The precipitation accumulation derived in this manner can be compared against a high resolution rain gauge (HRRG) (measuring to the nearest 0.0025mm) to assess the accuracy of the method. The results of comparing the accumulation derived using this equation and simultaneous accumulation measurements from a nearby HRRG were that the MPS derived measurements were too high in drizzle and too low in rain. To improve the comparability, a logarithmic equation was developed to adjust the drop size before performing the accumulation calculation. The details of the drop size adjustment and precipitation accumulation calculation are given in the Appendix.

7. RESULTS

Table 1 provides a summary of MPS performance in terms of percent comparability with a human observer and percent of derived accumulation compared to an HRRG.

The percent of correct detection is excellent, close to 100%. The derived precipitation is also very close to the HRRG, generally within 10%, with overall difference of only 1%.

Table 1. MPS performance vs. human observation

Date	Weather (Human minutes)		Percent of correct detection	Percent of measured accum.
	RA	DZ		
12/16/00	104	75	99%	97%
1/30/01	85	17	100%	90%
12/14/01	182	241	100%	104%
03/15/01	275	0	100%	101%
05/21/01	5	273	100%	100%
06/01/01	5	108	100%	107%
09/14/01	92	0	100%	98%
01/23/02	133	0	100%	101%
03/26/02	0	608	100%	119%
06/14/02	154	18	100%	105%
08/28/02	530	0	100%	91%
09/26/02	542	0	97%	107%
09/27/02	124	359	100%	107%
10/10/02	511	0	100%	92%
10/11/02	465	0	98%	92%
10/16/02	502	57	99%	92%
10/28/02	164	97	98%	104%
11/05/02	67	0	99%	94%
03/06/03	94	245	99%	102%
04/08/03	86	331	99%	95%
04/09/03	71	41	100%	93%
04/11/03	147	348	100%	101%
04/18/03	0	294	100%	118%
overall	2288	2310	99.4%	101%

8. CONCLUSIONS

With the completion of MPS testing, the results demonstrate the capability of the MPS to accurately differentiate drizzle from rain and to provide a good estimate of real-time rate of precipitation accumulation and consequently precipitation intensity. This intensity measurement can thus be used to quite accurately estimate drizzle intensity based on a rate of accumulation criteria.

With this capability demonstrated, it is concluded that the MPS can be used as a reference sensor for differentiating drizzle from rain.

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APPENDIX: MPS DRIZZLE OCCURRENCE AND INTENSITY ALGORITHMS

The algorithm used to differentiate drizzle from rain or other larger precipitation particles is as follows:

1. Count the total number of particles sampled by the sensor in one minute.
2. If fewer than 4 particles are counted, there is no precipitation (NP). If 4 or more particles are counted, derive the ratio (A) of the number of particles equal to or less than 0.5mm in diameter to the total number of particles. Then derive the ratio (B) of the number of particles less than or equal to 1 mm in diameter to the total number of particles. Then if A<95% and B<99%, the precipitation type is drizzle (DZ). Otherwise the precipitation type is “other than drizzle” which for the purposes of this analysis is identified as rain (RA).

Use the following empirically derived equation to determine the intensity of precipitation:

The drop diameter X in millimeters measured by the MPS is converted to an adjusted drop diameter (A) by the equation:

$$A = [0.25 * \ln(X) + 1.125] * X \qquad (1)$$

Then the equation for the volume of a sphere is used to calculate the liquid water content of the drop using adjusted drop size:

$$V = \frac{4}{3} * \pi * \left(\frac{A}{2}\right)^3 \qquad (2)$$

Then knowing the distance between the MPS projector and detector (200 mm) and the width of the projected beam (3.2 mm), the cumulative drop volume can be converted to equivalent depth of water (D in millimeters) that has passed through the sampling area by the equation:

$$D = \frac{V}{(200 * 3.2)} \qquad (3)$$

This calculation is performed each minute and a running ten minute total (D_{10}) is maintained to derive rate of accumulation (R_a) in millimeters per hour by the equation:

$$R_a = D_{10} * 6 \qquad (4)$$

Then for determining intensity of drizzle:

if Ra $\leq$ 0.25 the intensity is light
If 0.25 < $R_a \leq$ 0.50 the intensity is moderate
If R_a > 0.50 the intensity is heavy

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