4.9 CHARACTERIZATION OF CHANGING PRECIPITATION REGIMES

John Hallett[1] * and Roy Rasmussen[2]
[1]Desert Research Institute, Reno Nevada
[2]National Center for Atmospheric Research, Boulder Colorado

1. INTRODUCTION

Measurement to characterize a changing climate requires assessment of changes of instrumentation and its deployment throughout the spatial and temporal scale of interest. Radiosondes may be subject to decadal changes of design and deployment (Sherwood et al. 2005); surface measurements, while subject to somewhat less instrument variability are subject to a variety of changes as trees grow and whither away to be replaced by parking lots and street canyons. Measurement of precipitation has a much longer history than upper air sensing; however the longer sets of historical data available provide challenges in sorting out reality (long scale, long time) and local effects (of changing roughness, tree growth, heat islands and cold air trapping).

Considerations of changing climate do not have major impact on instrument design, construction and detailed deployment. Current technology tends to dominate – as the availability of mercury for pressure and temperature a few centuries ago or the current incorporation of microsensors under microprocessor control. Similarly, current economics and manufacturing techniques have more influence on measurement systems than we may be willing to acknowledge. Fashions come and go in our subject as in any other.

2. MEASUREMENT OF PRECIPITATION

2.1 Concept

Herein is described an instrument designed initially to measure airport snow precipitation for deicing operations. It is based on a simple physical concept that measurement of latent heat required to evaporate falling snow or rain or supercooled rain (or a mix thereof) provides high resolution data capable of transmission and analysis in near real time. It provides ultimately data of quality and robustness, defined here as being able to withstand minor perturbations of both design changes and deployment protocol. This is not a new idea; it has been used for many years in instruments for measuring water and ice content of clouds from aircraft (Hallett 1980; Korolev et al. 1998; King et al. 1978; King and Turvey 1986). What is new is to apply the idea to a flat plate with real time wind correction and to utilize a resolution such that the rates are only limited by the inherent statistical properties of the precipitation itself.

* *Corresponding author address:* John Hallett, Desert Research Institute, Division of Atmospheric Sciences, 2215 Raggio Parkway., Reno, NV 89512-1095; e-mail: John.Hallett@dri.edu.

The guiding design principle has been of minimizing complexity of the sensor, incorporating thermal, mechanical and electrical simplicity.

Further, minimizing the complexity of its deployment and prescribing a minimum deployment space is necessary in a complex terrain. Thus changes, as inevitably occur, must follow the original concepts to provide data capable of combination over a long time and space, keeping as closely as possible the basic physical principles used in the initial design. We discuss here the protocol for such a design and derived data analysis to provide a quantitative measure of changing precipitation regimes.

2.2 Design Criteria

The instrument schematic, Fig. 1, illustrates the following: two identical horizontal plates, heated independently, collocated one above the other and thermally isolated. They may be center mounted (as shown here) or side mounted. Each is maintained at a predetermined constant temperature (the same or slightly different) controlled and measured by the resistance of the heating elements. The plates are supported such that even at high winds they do not vibrate or blow away, with behavior independent of wind direction. The power for each plate is recorded from the control system (in a separate unit) and averaged over selected intervals, typically 1 minute. Under zero precipitation, the difference in power between top and bottom plate is defined as zero; this is not quite the case as the heat loss of the top and bottom plates are not quite equal (the convective heat loss is slightly more for the bottom plate; the wind loss in a typical boundary wind profile is slightly more from the top plate). With precipitation, the top plate power, differenced from the bottom plate power, taking into account the slight asymmetry, gives precipitation from knowledge of air temperature, plate temperature and a knowledge of the phase related to temperature. Since the latent heat of evaporation dominates, the phase (ice/water) and air temperature correction are of second order. The size of the plate (13 cm diameter) is such that the Poisson statistics of particle capture give reasonable values for snow and rain rate over one minute, which is in excess of the thermal time constant of the plates and their control (<20 seconds). For practical purposes the operating temperature is of order 100°C, which has the merit of discouraging birds and insects. This can be made sufficiently high to evaporate both water and ice particles as they impact; for high rate regimes the temperatures may be higher. As a bonus, the bottom plate heat loss gives wind speed and its variance. Edge and intermediate rings Figs. 1 a, b, c, d) inhibit loss of particles that skid in the prevailing wind or drop splash. Thus two units mounted at different levels give momentum flux and differentiation between falling and blowing snow. There is a reference temperature sensor. Resting power is typically 20 watts per plate.

2.3 Data display

The display system conveniently provides a rolling one minute portrayal of precipitation rate; total precipitation from an arbitrary start point, as midnight (Figs. 2-5 a). Derived data (Figs. 2-5 b, c) are conveniently displayed as the probability functions between two arbitrary times, as the fraction of precipitation falling at different rates and the fraction falling at different times, excluding selected intervals with zero precipitation. Ancillary data, wind speed, air temperature, and other parameters are provided by collocated measurements as Figs. 2-5 d. The crucial graph here is the rate frequency which has the potential of being a function for characterization of the system, either as a storm, front, sequence of systems, or over a season or decade. Figs. 2, 3, 4 show three snowstorm Nov 2004, Jan. 2005 and corresponding distributions; the color is temperature representing rain (red), or melting mix (green), or snow (blue). Fig. 5 shows data from an-all rain storm. Fig. 6 a, b shows the totals of the probability graphs from the three snow storms together.

3. OTHER CONSIDERATIONS

There is a lower limit of measurement of <1/100 inch/hr, resulting from turbulence related noise. Other problems arise because of radiation effects: sunlight gives potential interpretation as continuous drizzle, a negative precipitation rate, which software can remove; a cold night sky is more problematical as it gives a fortuitous positive continuous drizzle. An offset suitably calibrated by direct measurement of plate surface temperature provides a second order correction for the influence of this radiative flux and appears to cover these eventualities. More interesting is the measurement under strong wind. With modest winds, 5 m/s, the rate limit with the current system (Fig. 1 d) is near 1 inch/hr, and requires calibration. This can be more than doubled by increase of power in the design shown in Figs. 1 a, b, c. Under such wind speed conditions calibration is required; reasonable agreement has been found with other types of gauge (Rasmussen et al. 2002). With a horizontal wind many times the fall velocity of drops, their trajectory is near horizontal with respect to the plate surface and a different set of physics is necessary as drops are carried away from the top plate, analogous to the Jevons effect for buckets gauges (Glossary of Meteorology 2000). Drops fall on to the plate through the ambient turbulence, more above rather than below, rather than the mean velocity of the drops. In the extreme case this is the hurricane condition and has yet to be explored.

The most effective correction for the plate system is not to have any shield at all, as the velocity – wind correction has an unknown effect in the plate in a shield, particularly under turbulence. This simplifies things as the gauge now has no moving parts and without a shield simplifies deployment.

4. EXPECTATIONS

The ability to measure one minute data of precipitation rate under a variety of atmospheric conditions and particle size and phase, together with collocated meteorological properties opens up a number of possibilities. Inference of the probability precipitation rate functions deduced from radar rates (Amitai et al. 2004), necessarily encompass a larger sampling volume requiring a time delay from the fallout leading to more specific comparison with collocation of systems. Simple considerations tell us that enhanced water cycle activity results from higher cloud base temperatures (more water substance available) as well as a changing stability (more widespread and intense convection) together with a higher Ultra Giant Nuclei concentration resulting from high wind speed over the ocean, to release rain at higher temperatures. The challenge comes from adequate microphysical modeling of these processes together with a likely functional relationship with the frequency-precipitation rate curve over suitable areas and times.

Of special interest are the outliers of high rates of precipitation rate frequency plots, Figs. 2 b, 3 b, 4 b and 5 b, and the single or multiple peaks in these plots. The challenge of design is to increase the measurement rates so that the high continuing rates reported from tipping bucket gauge (as Burt 2005, Golding et al. 2005 and others) may be compared under extreme conditions. From simple physical considerations, splashing and shaking can potentially lead to under or over reporting, as possibly exists for the hotplate itself under such extreme conditions. The effect of turbulent drop transport is relevant to all systems and needs much more systematic evaluation under high wind speed.

The combination of the data from the three snow storm as shown in Fig. 6 leads to rate and time frequency plots which seem to be settling down. The frequency of extreme events, from one minute to tens of minutes is evident from an even cursory examination of the plots (Figs. 2-5 a). Comparison shows that the three storms (although giving comparable local societal disruption), differ significantly in the rate probabilities, and need to be placed within a synoptic setting. This requires data from a synoptic scale distribution of gauges – obviously location with respect to storm track is critical. One is reminded of the Marshall-Palmer distributions which needed several seasons data to settle down to an empiricism to be useful in such a long term but often quite unhelpful in application to a short term single event (which does not prevent their use!). The occurrence of rain gushes has long been debated – as Vonnegut suggested a half century ago, as possibly related to a sudden loss of electric potential following a lightning discharge, although sudden removal of the updraft source and or a rapidly changing coalescence process is also a possibility. The physical processes here are still unclear; measurements of such events in high resolution can lead to assessment of potential cloud physical mechanisms for their generation and continuance, whether of dynamical, electrical or microphysical origin. The advantage of the system demonstrated here is its high resolution, inherent simplicity and its straight-forward physics. Although the use at high wind velocity may strain the idea beyond such simplicity because of the need for a turbulent flow to impact drops on the upper plate. However, data obtained so far gives rise for optimism.

5. CONCLUSIONS

Its is demonstrated through one minute precipitation data that the probability plots may converge on a storm scale and possibly on a longer seasonal scale. More importantly is whether such convergence provides a useful measure of changing precipitation physics through changing availability of water substance and possibly nuclei. This requires measurements on a time scale of hours to decades to fully investigate the approach.

6. ACKNOWLEDGEMENT

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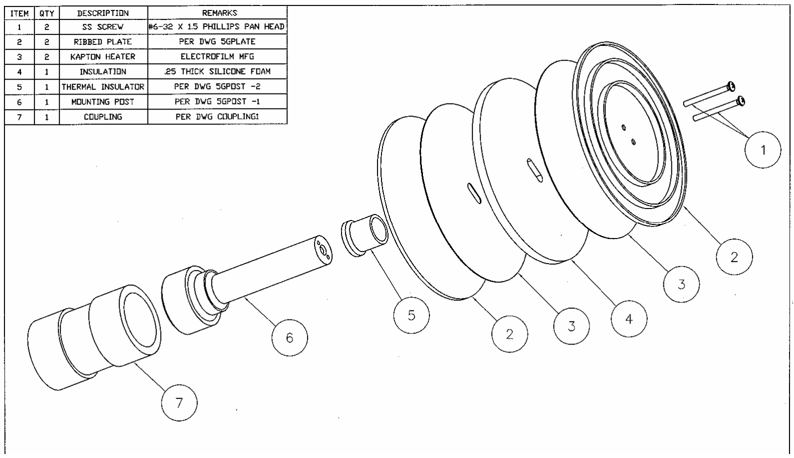


ITEM	QTY	DESCRIPTION	REMARKS
1	2	SS SCREW	#6-32 X 1.5 PHILLIPS PAN HEAD
2	2	RIBBED PLATE	PER DWG 5GPLATE
3	2	KAPTON HEATER	ELECTROFILM MFG
4	1	INSULATION	.25 THICK SILICONE FOAM
5	1	THERMAL INSULATOR	PER DWG 5GPOST -2
6	1	MOUNTING POST	PER DWG 5GPOST -1
7	1	COUPLING	PER DWG COUPLING1

Fig. 1 . Schematic of hot plate with center mount.

Fig. 1 a

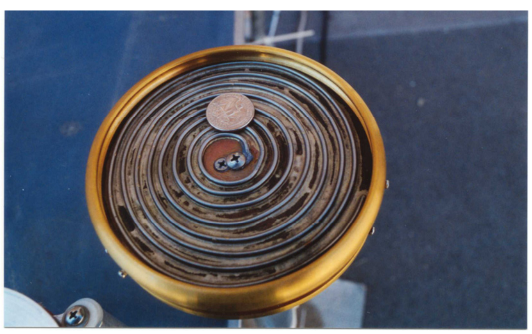
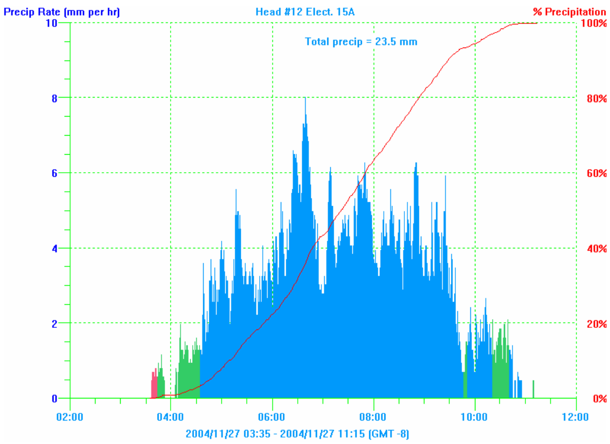


Fig. 1 b

Fig. 1 c

Fig. 1 d

Fig 1. The hot plate precipitation gauge designed for measurements of rain, supercooled or above 0°C snow, and water-ice mixtures. The plate is maintained at constant temperature, with the power providing a measure of the precipitation rate through the appropriate latent heat of evaporation. For high rates, the heating element, two stranded and shorted at one end, is internal to the outer grounded sheath, brazed to the copper plate, Fig. 1 a, b, c. For lower rates as snow, a thin film heater contacts the inside surface of each aluminum plate, Fig. 1 d, used for the snow data. The plate is center mounted (to remove any wind speed directional effects), with power leads running down the post to the control circuitry, located elsewhere. An edge shield is added to capture ice particles being swept along the surface under windy conditions. The shielded reference plate is identical but subject to air at approximately the same wind speed and temperature as the top plate, is located beneath the upper sensor plate, separated by a thermal insulating layer to minimize heat flow between the two plates. The lower plate, shielded from precipitation, provides a measure of wind speed through heat loss at the ambient temperature.



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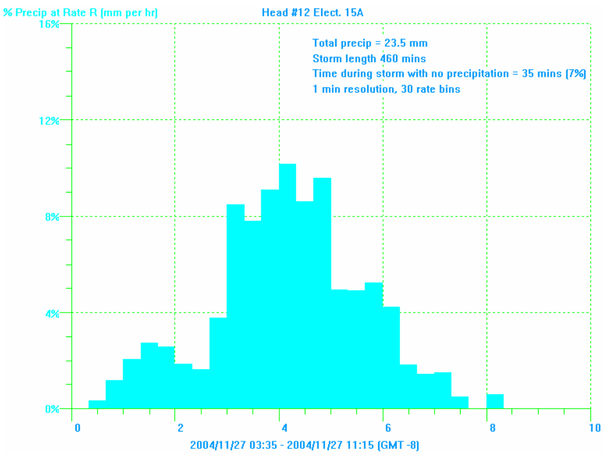

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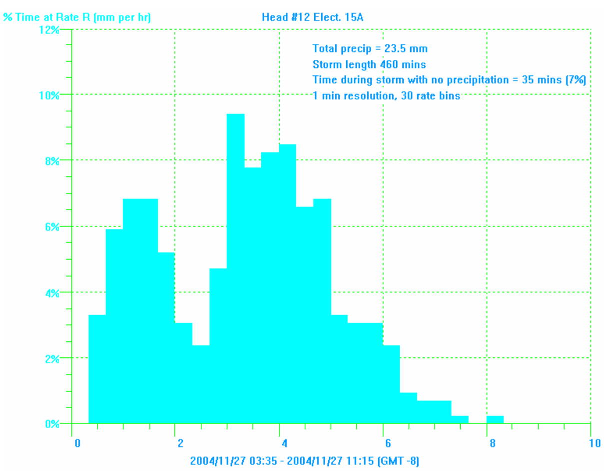

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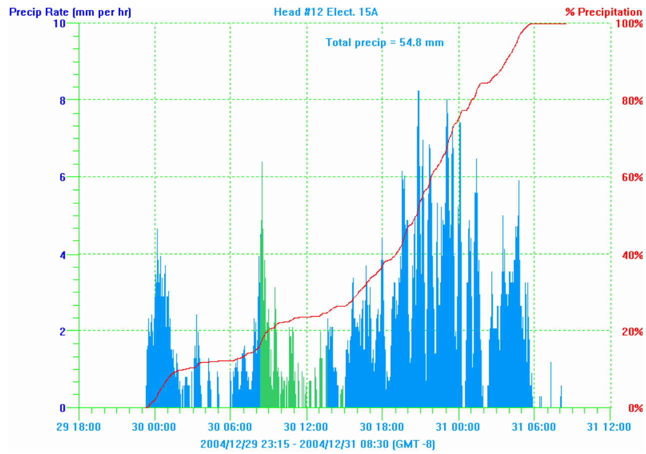
Fig. 2 a, b, c



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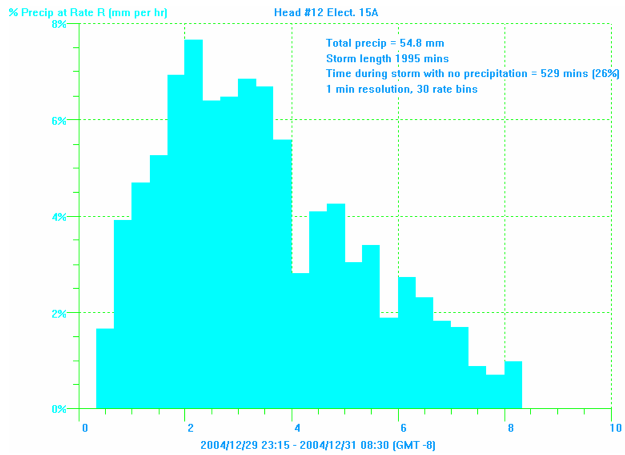

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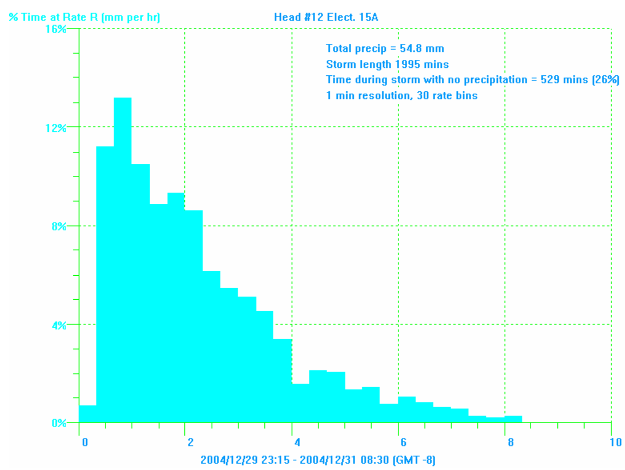

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Fig. 3 a, b, c.

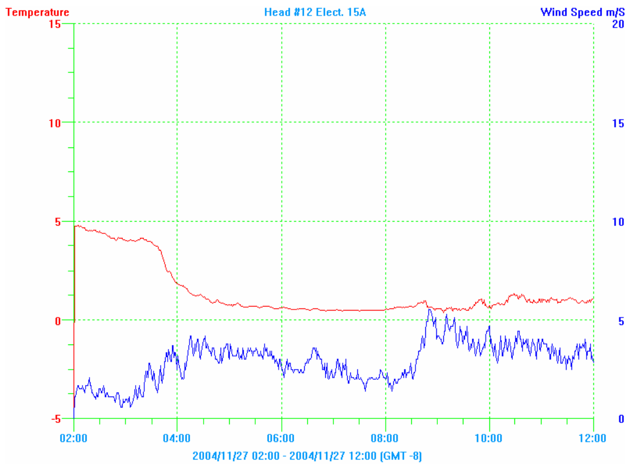


Fig. 2 d

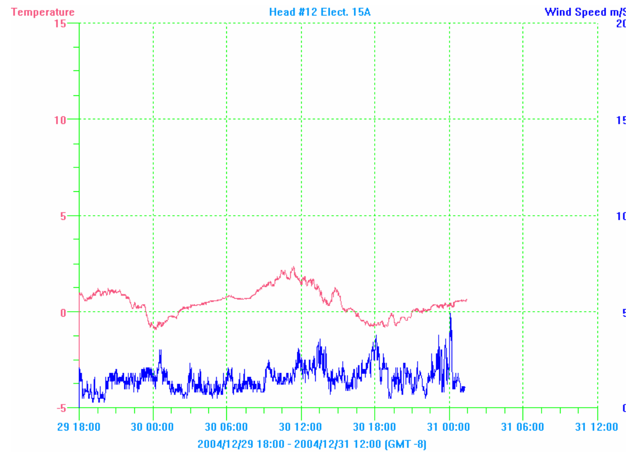


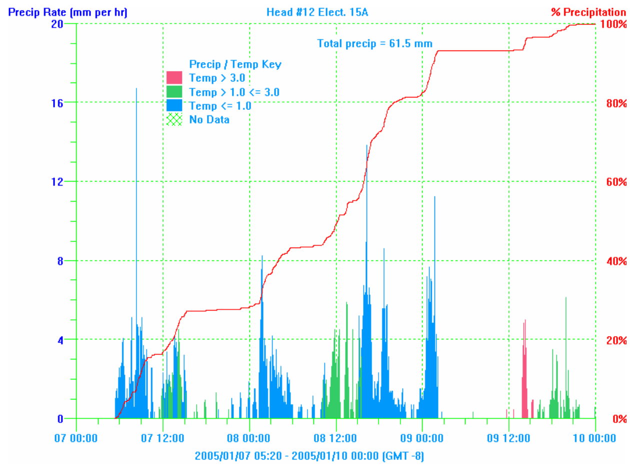
Fig. 3 d

Fig. 2 a shows precipitation rates computed for one minute intervals for an instrument located outside the Ice Physics Laboratory, DRI in Reno for a snow storm 2004/1 1 /27 with integrated amount over the storm period, about 7 hours. The colors are chosen for rain (red), melting snow (green) and snow (blue). Peaks (and dips) in rate are clearly defined on a 1 minute scale as are longer periods of tens of minutes. Fig 2b shows, for the same period, the amount (%) of precipitation falling at different rates and Fig 2c the time (%) at different rates. Fig. 2d shows windspeed form the bottom plate power and air temperature from a collocated sensor.

Fig. 3, 4 Measurements for snow storms later in the season, averaged for convenience over different periods, each showing a differing detail of precipitation microstructure; Fig. 5 a rain storm at temperatures well above 0°C.

Note:

- The occasional peaks in one minute precipitation rates in Figs. 2 – 5 a;
- The decreasing variability with the longer data sets of rate distribution;
- Longer rate periods are 5 - 10 minutes;
- The approximate exponential form of the time rates; and
- The distribution of the precipitation rates are definable through the width of the peak over which 2/3rd of the precipitation fell, when a clear maximum exits.



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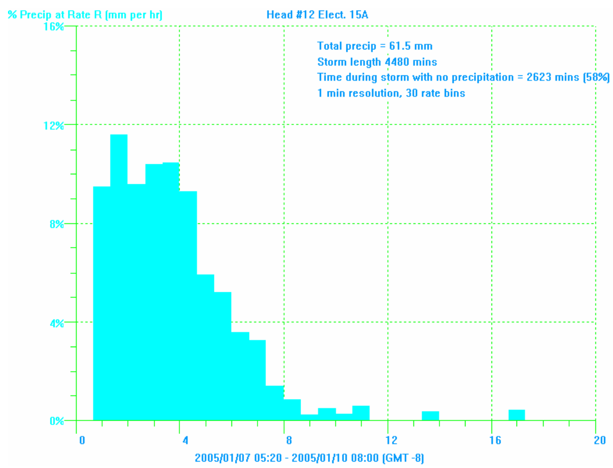

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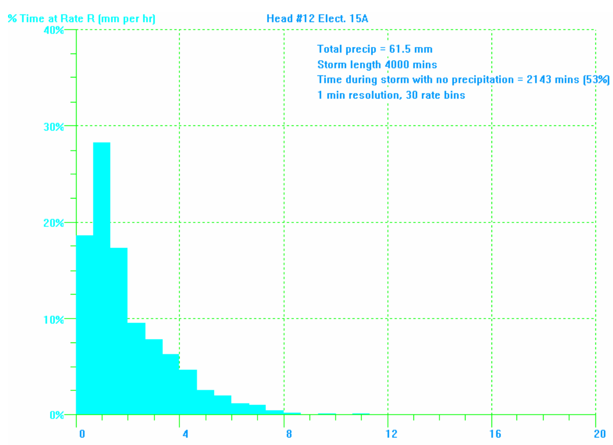

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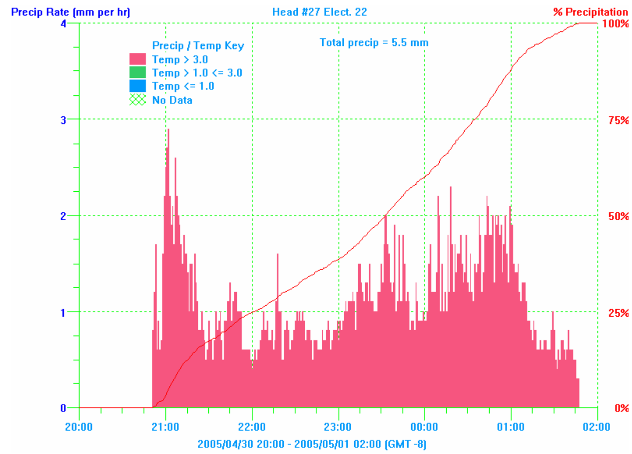
Fig. 4 a, b, c



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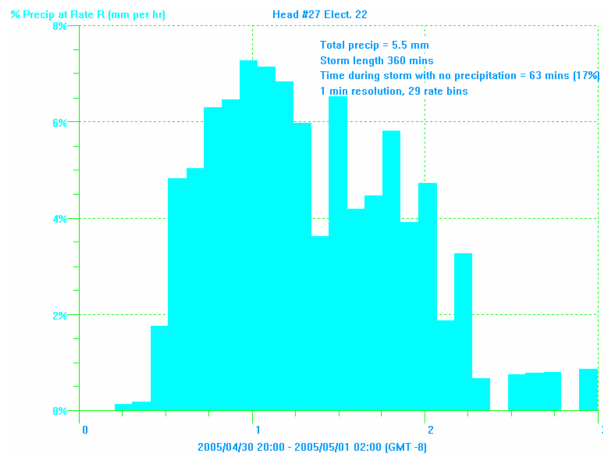

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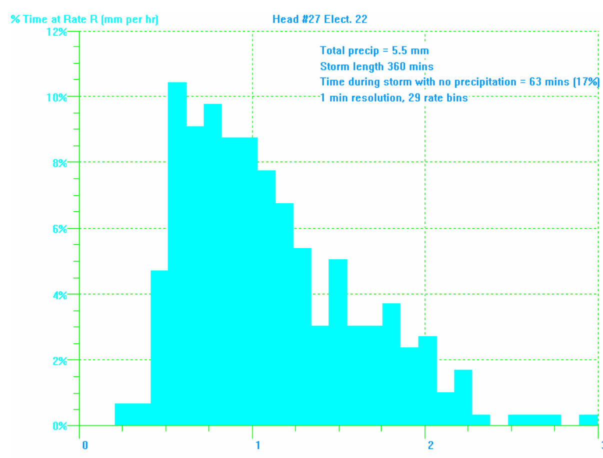

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Fig. 5 a, b, c

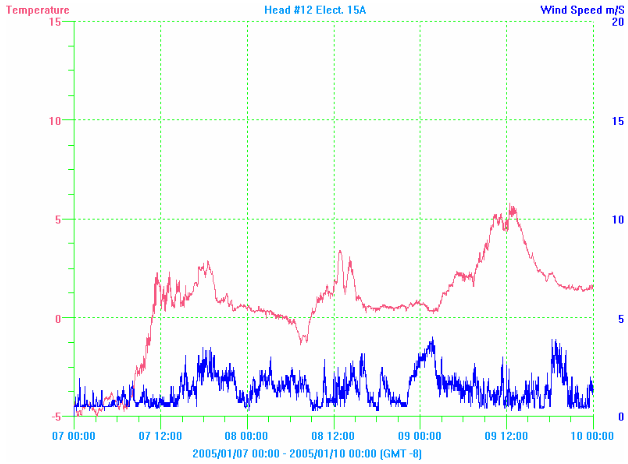

Fig. 4 d

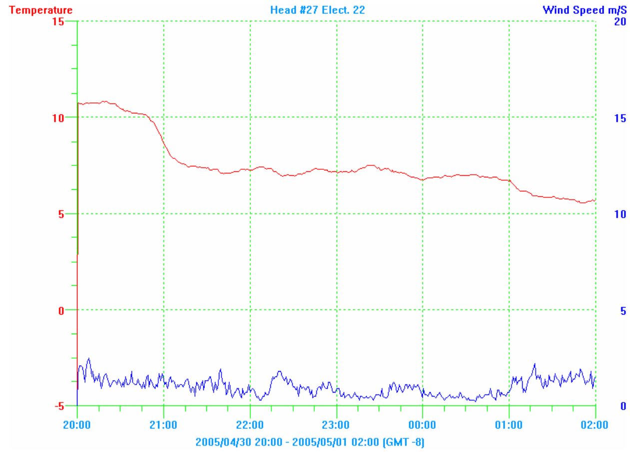

Fig. 5 d

Figs. 4-5. Temperature and wind data for previous page.

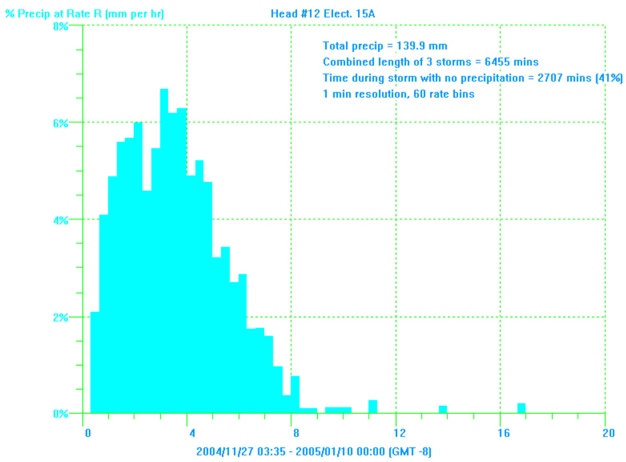

Fig. 6 a

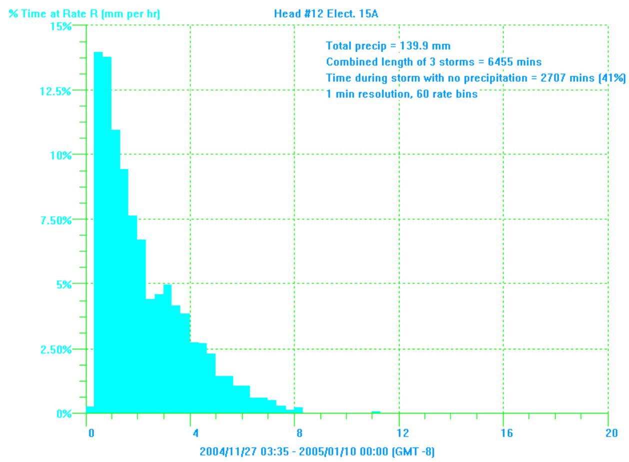

Fig. 6 b

Fig. 6 a, b. Combination of all data from the three snow storms suggesting specific analytical relationships for parameterization.