Improved Precipitation Measurement in Wintertime Snowstorms

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Final Report

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Abstract-

It is widely acknowledged that precipitation measurements can be biased by an assortment of uncertainties. Measurement of snowfall is especially problematic. Independent of the type of measurement system employed, uncertainty due to wind-induced error is inherent to all snowfall measurements. Also, when using conventional gauges, uncertainty due to loss of material (sublimation and evaporation), and gauge capping, can also occur. Minimization of these uncertainties requires improved snow precipitation sensors. Applications requiring improved precipitation sensors include weather advisory, hydrometeorology and biogeochemistry.

The focus of his research has been an upgraded version the hotplate precipitation sensor manufactured by Yankee Environmental Systems. A hotplate data processing algorithm was developed, calibration studies were conducted, and the hotplate and a conventional precipitation gauge were compared during wintertime field experiments. The algorithm considers all relevant terms in the hotplate's heat budget (sensible, latent and radiative effects). One M.S. student was supported by the project and the upgraded hotplate precipitation sensor is now available for snow precipitation measurements.

Conference Presentation Supported by this WWDC Funding -

Wettlaufer, A., The Hotplate Precipitation Rate Sensor, Young Scientists Symposium, Colorado State University, October, 2012

Thesis Supported by this WWDC Funding -

Wettlaufer, A., Calibration and Operation of a Fully-compensated Hotplate Precipitation Gauge, in progress, thesis defense planned for August, 2013

Publications supported by this WWDC Funding -

Wolfe, J.P., and J.R.Snider, Reply to "Comments on 'A Relationship between Reflectivity and Snow Rate for a High-Altitude S-Band Radar'", J. Appl. Meteor. Climatol., 52, 730–731, 2013, PDF

Publication supported by Previous WWDC Funding-

Wolfe, J.P., and J.R.Snider, A Relationship between Reflectivity and Snow Rate for a High-Altitude S-Band Radar. J. Appl. Meteor. Climatol., 51, 1111–1128, 2012, PDF

Theses supported by Previous WWDC Funding-

Wolfe, J.P., Radar-estimated Upslope Snowfall Rates in Southeastern Wyoming, MS thesis, Dept. of Atmospheric Science, University of Wyoming, 2007

Borkhuu, B., Snowfall at a high-elevation site: A comparison of six measurement techniques, MS thesis, Dept. of Atmospheric Science, University of Wyoming, 2009

Overview -

With funding from this grant we upgraded a hotplate precipitation sensor and developed calibration methodologies and a hotplate data processing algorithm. The hardware upgrade was performed by the company that manufacturers the hotplate (Yankee Environmental Systems). The upgrade provided sensors for the longwave and shortwave radiant fluxes and two additional meteorological sensors (pressure and relative humidity). As we discussed in our grant application, the addition of radiation sensors makes it possible to account for a bias in the hotplate's estimation of precipitation rate. This bias can lead to substantial uncertainty in estimates of the liquid-equivalent accumulation. The accumulation uncertainty is especially problematic during winter in the Rocky Mountains where typically the liquid-equivalent precipitation rate (≤2 mm/hr) is only a factor of five larger than the magnitude of the radiation-induced bias. Further complicating is the fact that the sign of the bias shifts from positive to negative over a 24 hour day-to-night cycle.

Our approach is similar to the instrument development work performed by Borkhuu (2009) but with the distinction that we now have access to the longwave and shortwave radiant fluxes. In addition, this grant supported the development of the data acquisition system we used for data recording.

Algorithm Development and Laboratory Calibration -

During laboratory and field experiments we recorded the data signals output by the hotplate. The most fundamental of these is the hotplate's top-plate power; this was recorded with measurements of temperature, wind speed, and the shortwave and longwave fluxes. Our data processing algorithm assimilates these measurements, applies calibration constants, and outputs the precipitation rate.

The following steady-state energy budget is the basis for our analysis:

$0 =$	Implied Steady-state Balance
$\dot{Q}_{plate}$	Electrical Power Supplied to Top Plate
$- L \cdot K \cdot (T_{hp} - T) \cdot (\alpha \cdot Re^{\beta} + \gamma)$	Outgoing Sensible Heat
$- a \cdot \varepsilon_{hp} \cdot \sigma \cdot T_{hp}^{4}$	Outgoing Longwave Radiant Heat
$+ a \cdot \varepsilon_{hp} \cdot (LW + \sigma \cdot T^{4})$	Incoming Longwave Radiant Heat
$+ a \cdot \left(1 - r_{hp}\right) \cdot SW$	Incoming Shortwave Radiant Heat
$- a \cdot \rho_{\ell} \cdot \xi \cdot E \cdot P$	Precipitation

In this equation we see that there are six terms in the hotplate's energy budget. Most of these are expressed in terms of measurements (e.g., plate power and ambient temperature). We obtained some of the factors by reviewing the heat transfer literature (emissivity and reflectance) and some we evaluated experimentally. In the latter category there are four parameters; these are the hotplate temperature (T_{hp}) and the sensible heat parameters (α , β and γ). These four appear in the sensible heat term; also, T_{hp} appears in the outgoing longwave term. Values for these parameters, and descriptions of how they were evaluated, are provided in Adam Wettluafer's thesis. Because the sensible heat is one of two dominant terms in the heat budget (the other is the top-plate power), its determination, and its dependence on temperature and wind speed is essential for accurate determination of the precipitation rate.

Field Measurements -

During 2012 and 2013 we calibrated and deployed two hotplates; both were upgraded by the manufacturer. Because of the upgrade we have measurements of the longwave and shortwave fluxes which complement the measurements of the top-plate power and temperature. In the sensible heat term we see a temperature difference ($T_{hp} - T$) and a ventilation term $(\alpha \cdot Re^{\beta} + \gamma)$. The latter relates the nondimensional sensible heat - formulated as a Nusselt number (Nu) - to a nondimensional wind speed. The latter is expressed as a Reynolds number (Re).

Two Nu - Re relations are shown in Figure 1. Data used in these plots were recorded in the Sierra Madre Mountains (NCAR hotplate) and at a site located north of the city of Laramie (UWyo hotplate). We see that the shape of the Nu - Re function is different for the two hotplates, and consequently, the fitting coefficients, shown at the top of the graphs, are also different. At the present time, it is not obvious if these differences are instrument-dependent, location-dependent, or a mixture of both effects. Also evident is the occurrence of larger wind speed (larger Re) and the associated larger variability, at the north Laramie site. Ancillary results, not shown here, indicate that Nu - Re function can shift subsequent to repair work conducted by the hotplate manufacturer. Twice during this research, in both 2012 and in 2013, we returned the hotplate to the manufacturer to have them repair failed electronic components. Subsequently, we recalibrated α, β and γ.

In addition to the hotplates, we also worked with conventional precipitation gauges. At the Sierra Madre and Glacier Lakes Ecosystem Experiments Site (GLEES) we have the ETI gauges as comparators. These are maintained by NCAR. At the north Laramie site we worked with a gauge manufactured by Vaisala. The latter is known as the Vaisala Rain Gauge (VRG). We have the four VRGs that were used in the first two years of the Wyoming Weather Modification Pilot Project. These were replaced by ETI gauges. We have made plans to donate the VRGs to the Laramie Junior High School (contact person Heath Brown). All four VRGs were tested in our laboratory; test results are shown in Figures 2. These figures illustrate the VRGs response to the addition of a fixed mass (3.75 g). The mass was not added instantaneously; as a rate the mass addition is equivalent to 1.12 mm/hr precipitation rate. The figures shown some variability in the detection of the mass addition, but for all four VRG's the results are reasonable.

Field testing of one of the VRGs, at the north Laramie site, has not been very encouraging. Pictures of the site is provided in Figure 3. On the left is the UWyo hotplate and on right is one of the VRGs. In March and April of 2013 we recorded four major snow events at this site. The one advantage of operating at the north Laramie site is that line power is more reliable that the power at the GLEES site. As we discuss above, we conducted gauge intercomparison studies at GLESS in 2012.

The VRGs sensitivity to temperature precludes a quantification of the snowfall at the north Laramie site. We have had discussions with Vaisala and they recently agreed to replace the sensor unit in one of the four VRGs. At the present time we are waiting for Vaisala to return the new sensor unit.

Outlook –

The research described here is an ongoing effort. Currently we are focused on writing a journal article with Ms.Bujidmaa Borkhuu and finishing Adam Wettluafer's thesis. The paper will report on the gauge intercomparisons conducted at GLEES, in 2008 and 2012, and will describe Adam's method for calibrating and analyzing the hotplate measurements. Also, we have funding support from NSF (P.I. Bart Geerts) to deploy the UWyo hotplate during a winter precipitation study planned for western New York state in 2014.

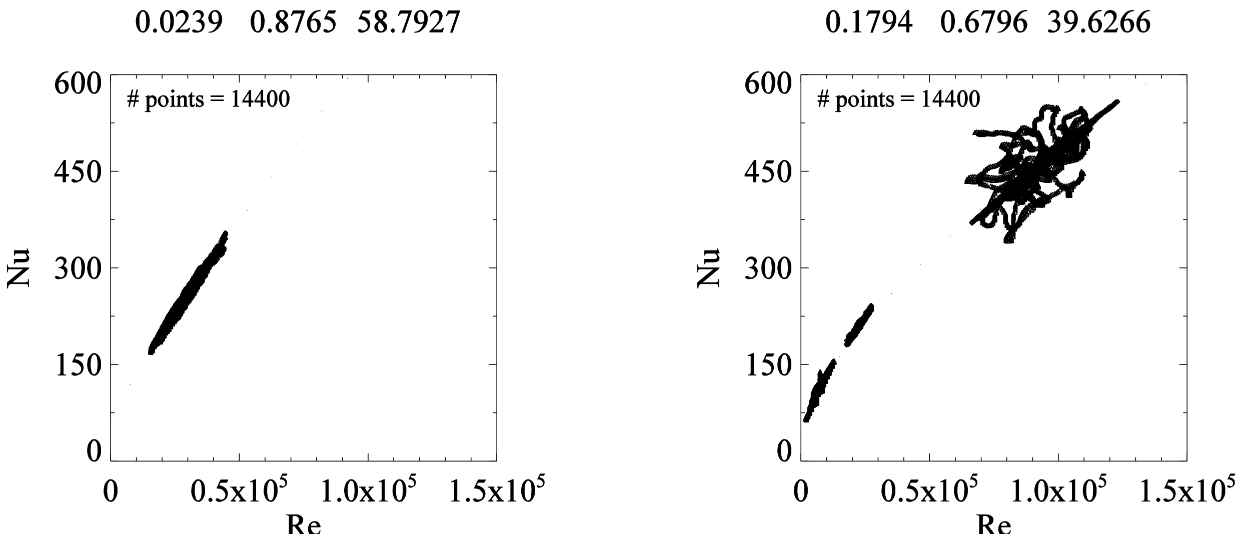

Figure 1 – Nondimensionalized plots of sensible heat (*Nu*) and wind velocity (*Re*) from a hotplate operated in the Sierra Madre Mountains (left panel, NCAR hotplate) and at the north Laramie site (right panel, UWyo hotplate). See text for details.

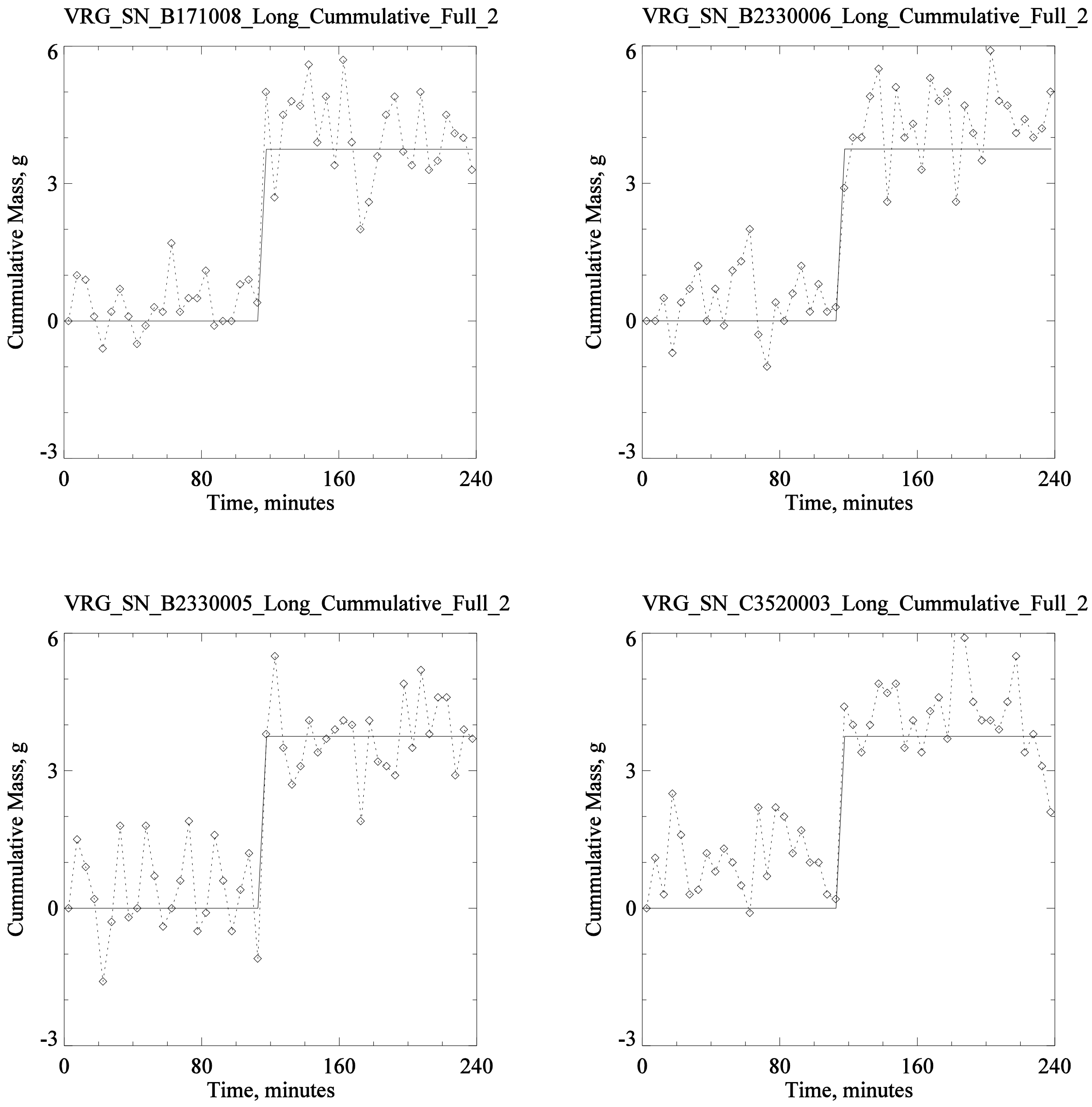

Figure 2 – VRGs response to the addition of a fixed mass (3.75 g) (dotted line connecting diamonds) and the expected response (solid line step function at time ~ 120 minutes). See text for details.

Figure 3 – The UWyo hotplate and a VRG located at the north Laramie site. Measurements were started in early March 2013 and continued into May 2013. See text for details.

Bibliography -

Borkhuu, B., Snowfall at a High Elevation Site: Comparisons of Six Measurement Techniques, M.S. Thesis, Department of Atmospheric Science, University of Wyoming, 2009