Atmospheric Research 89 (2008) 243–251

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

The daily and annual effects of dew, frost, and snow on a non-ventilated net radiometer

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ARTICLE INFO

Article history:
Received 31 August 2007
Accepted 3 February 2008

Keywords:
Dew
Frost snow
Ventilated
Unventilated net radiometer

ABSTRACT

The formation of dew, deposition of frost and accumulation of snow mainly on the upper domes of a non-ventilated net radiometer seriously affect the measurement of available energy (net radiation). Net radiometers measure radiation, and energy balances and are widely used for estimation of evapotranspiration throughout the world. To study the effects of dew, frost, and snow on a non-ventilated net radiometer, a radiation station was set up which uses 2 CM21 Kipp & Zonen pyranometers (one inverted), 2 CG1 Kipp & Zonen pyrgeometers (one inverted), along with a Q*7.1 net radiometer (Radiation & Energy Balance Systems, Inc.; REBS) in a semi-arid mountainous valley in Logan, Utah, U.S.A. The pyranometers and pyrgeometers were ventilated using 4 CV2 Kipp & Zonen ventilation systems. The net radiometer was not ventilated. The ventilation of pyranometers and pyrgeometers prevents dew and frost deposition and snow accumulation which otherwise would disturb measurements. All sensors were installed at about 3.0 m above the ground, which was covered with natural vegetation during the growing season (May–September). The incoming and outgoing solar or shortwave radiation, the incoming (atmospheric) and outgoing (terrestrial) longwave radiation, and the net radiation have been continuously measured by pyranometers, pyrgeometers and a net radiometer, respectively, since 1995. These parameters have been measured every 2 s and averaged into 20 min. To evaluate the effects of dew, frost, and snow, three days were chosen: 26 April 2004 with early morning dew, 6 January 2005 with an early morning frost, and the snowy day of 24 February 2005. Dew formation, frost deposition, and snow accumulation occurred mainly on the upper dome of the non-ventilated Q*7.1 net radiometer on the related days, while the ventilated Kipp & Zonen system was free of dew, frost and snow. Net radiation measured by the non-ventilated net radiometer $R_{n,unvent.}$ during dew and frost periods of the above-mentioned days was greater than ventilated ones $R_{n,vent.}$ (−0.2 MJ m^{-2} vs. −0.8 MJ m^{-2} during almost 4 h on 26 April 2004, and −0.2 MJ m^{-2} vs. −0.7 MJ m^{-2} during almost 6.5 h on 6 January 2005). The reason for higher reading by the non-ventilated net radiometer during dew and frost periods was due to emission of additional longwave radiation from water and ice crystals formed mainly on the upper dome of the Q*7.1 net radiometer. In contrast, during the snowy day of 24 February 2005, the $R_{n,unvent.}$ was less than $R_{n,vent.}$ (−4.00 MJ m^{-2} vs. 0.77 MJ m^{-2}, mainly from sunrise to sunset). The extremely low $R_{n,unvent.}$ measured by the non-ventilated net radiometer on 24 February 2005 is due to blocking of the incoming solar radiation (mainly diffuse radiation) by the snow-covered upper dome.

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1. Introduction

Dew, frost and snow are very important sources of moisture in many parts of the world. When using a non-ventilated net radiometer, these parameters seriously affect the measurement of available energy (net radiation). Net radiometers measure radiation and energy balances, and are widely used for the estimation of crop water requirements. Many researchers have worked on the radiation and energy balances and dew formation in different ecosystems. Malek et al. (1999) used the Bowen ratio system for computation of the downward flux of

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0169-8095/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.atmosres.2008.02.006

water vapor (dew) and reported the dew contribution to the annual water balances in semi-arid desert valleys. Oerlemans and Knap (1998) related the one-year downward and upward solar radiation data for computation of albedo of snow, firn and ice in the ablation zone of Morteratschgletscher, Switzerland. McKenzie et al. (1998) studied effects of snow cover on UV irradiance and surface albedo. Malek and Bingham (1997) worked on the partitioning of radiation and energy balance components in an inhomogeneous desert valley. Steffen and DeMaria (1996) reported the surface energy fluxes of Arctic winter sea ice in Barrow Strait. Pluss and Ohmura (1997) worked on the longwave radiation on snow-covered mountainous surfaces. Ma et al. (1992) studied the energy balance of a snow cover in the western Tien Shan Mountains, China. Eaton and Wendler (1982) reported the heat balance during the snowmelt season for a permafrost watershed in interior Alaska, U.S.A. Brotzge and Duchon (2000) compared a domeless net radiometer, two four-component net radiometers, and a domed net radiometer. In their thorough study, they examined problems associated with calibration, precipitation, and wind induced error among these net radiometers. Malek et al. (2002) worked on the evaluation of annual radiation and windiness a playa.

While many researchers have addressed the radiation and energy balance and albedo of different surfaces such as desert, glaciers, sea ice and snow-covered areas, there is little detailed information on the effects of dew formation, frost deposition, and snow accumulation on the measurement of net radiation by a non-ventilated net radiometer compared to ventilated sensors. This subject will be addressed in this article.

2. Instruments and methods

This experiment has been conducted in Logan (41° 47′ N, 111° 51′ W, 1460 m above mean sea level), Utah, U.S.A., since October, 1995, to evaluate the radiation and energy budget components, pollution, and parameterization of clouds in this semi-arid valley (Malek, 1997; Malek et al., 1999; Malek et al., 2006; Malek, in press). The experimental site is far away from any obstacle and is located in the middle of a field covered mostly by cheatgrass (*Bromus tectorum* L.). Two CM21 Kipp & Zonen pyranometers (one inverted) were used to measure the solar or shortwave radiation. The facing-up pyranometer measured the incoming (R_{si}) shortwave or solar radiation, and the inverted one measured the outgoing (R_{so}) or reflected shortwave radiation. Two CG1 Kipp & Zonen pyrgeometers (one inverted) were used to measure the longwave radiation. The facing-up pyrgeometer measured the incoming longwave (R_{li}) or atmospheric radiation, and the inverted one measured the outgoing longwave (R_{lo}) or terrestrial radiation. Both pyrgeometers have a field of view of about 150°. The pyranometers and pyrgeometers were equipped with 4 CV2 Kipp & Zonen CVB1 ventilation systems. The ventilation air was heated at the rate of 5 W to prevent accumulation of dew and frost, and to aid the evaporation of light to moderate rain and snow before reaching the upper pyranometer and pyrgeometer, which otherwise would disturb the measurement, and to suppress the infrared offset, which is produced by the cooling down of the glass domes under calm, clear sky conditions.

The radiation balance equation for any site can be expressed as:

$$R_n = R_{si} - R_{so} - R_{lo} + R_{li} \quad (1)$$

where R_n is the net radiation, R_{si} and R_{so} are the incoming and outgoing solar or shortwave radiation, respectively; and R_{li} and R_{lo} are the incoming (atmospheric) and outgoing (terrestrial) longwave radiation, respectively. All energy terms in Eq. (1) are in W m^{-2}. The net radiation measured by the Kipp & Zonen radiation system is referred to as $R_{n,vent.}$.

We also used a non-ventilated Q*7.1 net radiometer (Radiation Energy Balance System, Inc. (REBS)) to measure the

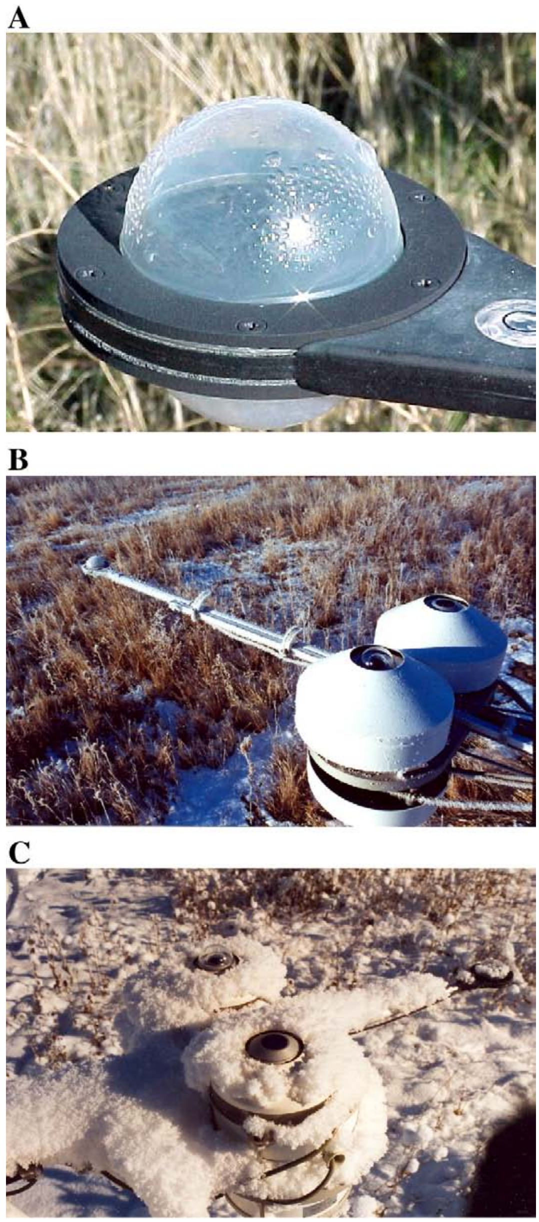

Fig. 1. The top panel a dew-covered net radiometer, the middle panel a frosty fall morning, and the bottom panel a morning after a snowy day at the experimental site, in Logan, Utah, USA.