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MICROCLIMATE INSIDE AIR TEMPERATURE RADIATION SHIELDS

by

Xiaomao Lin

A DISSERTATION

Presented to the Faculty of

The Graduate College in the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Doctor of Philosophy

Major: Agronomy

Under the Supervision of Professor Kenneth G. Hubbard

Lincoln, Nebraska

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DISSERTATON TITLE

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GRADUATE COLLEGE
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MICROCLIMATE INSIDE AIR TEMPERATURE RADIATION SHIELDS

Xiaomao Lin, Ph. D.

University of Nebraska, 1999

Advisor: Kenneth G. Hubbard

With the replacement of the Cotton Region Shelter (CRS), new air temperature observing systems such as the Automated Surface Observing System (ASOS), Maximum-Minimum Temperature System (MMTS), and the Gill shield temperature system were introduced. All of these systems house the air temperature sensor in radiation shields to prevent radiation loading on the sensors; a side-effect is that the air temperature entering a shield is modified by the interior solar radiation, infrared radiation, air speed, and heat conduction to or from the sensor so that the shield forms its own interior microclimate. The objectives of this study are to: 1. Theoretically investigate air temperature errors inside radiation shields. 2. Experimentally determine the air flow characteristics inside the shields. 3. Develop a physical model to understand the microclimate inside the shields including the interior solar radiation, infrared radiation, and air speed effects on the air (sensor) temperature under day and night conditions. 4. Experimentally estimate the effect of underlying ground surface coverings on the shield's interior solar radiation.

Theoretical investigation, field experiments, and the energy balance modeling of

temperature sensors were methodologies in this study. Parabolic curves described the fraction of solar radiation entering shields during the day light hours. This fraction increased as the ground solar reflectivity increased, except for the ASOS, as a function of time of day. The rank of solar radiation shielding effectiveness was ASOS > CRS > MMTS > Gill. The ASOS dew point sensor extracted heat from the mirror surface and heated or cooled the shield. The rank for the magnitude of unbalanced infrared radiation was ASOS > CRS > MMTS > Gill. Linear equations provided a reliable air speed estimation inside the shields based on the ambient wind speed. The air flow efficiency of shields (exception of ASOS) ranked as MMTS > CRS > Gill when the ambient wind speed was below 1m s^{-1} and ranked as Gill > MMTS > CRS when the ambient wind speed was more than 2 m s^{-1}. For all radiation shields, the air temperature corrected for shield effects was in good agreement between shields while the uncorrected "normal operating" temperatures were more variable from shield to shield.

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Finally, I dedicate this work to my family. I am grateful to my wife Ruiju Yang for her love and support over the years. Thank you.

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CHAPTER 1

INTRODUCTION

How can we find the true temperature signal of global warming? Despite the litany of problems, the instrumented climate record can tell us a great deal about the spatial distribution and secular trends in temperature over many areas of the world (Karl et al., 1989). The magnitude of changes in global mean temperature is one of the cornerstones of the greenhouse warming issue, however, the temperature sensor related biases found by Quayle et al. (1991) are of the same magnitude as the recorded change in global and United States mean temperatures since the turn of the century. Additional challenges in using the historical climate record are issues of calibration, observing practices, urbanization, station changes, data representativeness, data access, and areal coverage (Karl et al., 1986; 1987; 1988; 1989; 1993; Karl and Quayle, 1988; Karl and Jones, 1989). Inhomogeneities in surface weather records can and have produced a number of serious biases in the climate records. Researchers have focused on identifying and removing these biases that result from the above climate monitoring issues.

Changes in station location, instruments, instrument shelters, and the height of the instruments above the ground have lead to biases of 1 °C or more at many stations (Karl et al., 1987). Because of inadequate station meta-data and insufficient side-by-side overlapping comparisons, there has been a lack of sufficient analyses of the instrument shelters that house

thermometers. This is potentially a serious matter because thermometers in the nineteenth century were exposed to the open air on north-facing walls when in the twentieth century the thermometers were exposed inside Cotton Region Shelters (CRS) or Stevenson shelters. New automated weather stations in the 1980's (Hubbard et al., 1983) and the new federal Automated Surface Observing System (ASOS) network of the 1990's both introduced thermometer shelters of yet another design.

Temperature equipment at a weather station consists of a thermometer(s) for sensing **air** temperature and a sensor shelter referred to as the radiation shield. The primary function of the radiation shield is to shield the thermometer(s) from direct radiation that would otherwise raise the thermometer temperature much above the **air** temperature. The radiation shield usually is constructed with louvers--ventilating slits that allow air to circulate past the thermometers. Throughout the history of weather station networks changes in instrumentation have occurred; usually a change in the radiation shield design accompanied a change in sensors. Changes in equipment could potentially result in local biases in the temperature record because radiation shields of different design may not have the same ability to **screen out radiation** and to **ventilate the temperature sensor(s).**

There have been a number of previous studies investigating the characteristics of both air temperature radiation shields and air temperature sensors, including field and wind tunnel tests to determine the errors of air temperature measurement by MacHattie (1965) and Fuchs and Tanner (1965). McKay and McTaggart-Cowan (1977) suggested that air temperature errors caused by radiation shield changes ranged from -0.5 to 1.0°C. McTaggart-Cowan and McKay (1976) performed field comparisons of 14 different shields. They found that using

unaspirated shields without knowledge of other parameters (e.g., radiation and wind) can make relative accuracies uncertain by as much as 1.0°C. and the worst case was a shield that had errors of 2.5°C in light wind conditions. Gill (1983) conducted wind tunnel tests of several radiation shields under high radiation and low wind speed conditions. He found that the Gill shield, a multi-plate plastic shield which currently is in wide service in the automated weather station networks, can introduce +5.2 to 7°C radiation heating errors when the simulated solar intensity is 1080 W m^{-2} at a 0.25 m s^{-1} ambient wind speed. Even with high radiation errors, the Gill was found to be the best of several radiation shields in his experiments. Brock et al. (1995a, 1995b) and Richardson and Brock (1995) explored optimal radiation shield designs and sensor geometry designs with a goal of minimizing both direct and indirect radiation loadings while maximizing the air flow.

In recent years, the National Weather Service (NWS) has gradually replaced the traditional Liquid-in-Glass (LIG) self-registering maximum-minimum thermometers mounted in the CRS with thermistors mounted in plastic multi-plate shields which are called the Maximum-Minimum Temperature System (MMTS). Based on thousands of comparisons of monthly mean temperatures from stations with and without MMTS, Quayle et al. (1991) found that the MMTS temperature system produced maximum temperatures about 0.3°C lower and minimum temperatures about 0.4°C higher than the CRS system. Tanner (1990) stated that it is possible that the Gill shield could produce errors in excess of 5°C over snow covered surfaces with no wind. McKee et al. (1995) reported that systematic temperature differences between ASOS and conventional observations reached -1.2°C for daily maximum and -1.1°C for daily minimum temperatures.

In view of the preceding, it appears each **air** temperature monitoring system creates its own microclimate because of two non-independent factors: **shielding of sensors from radiation** and **ventilation of air** by natural or forced air movement. In this study we monitor the microclimate inside thermometer shelters and describe the microclimate inside the shield as a function of wind condition, solar, and infrared radiation. The overall goal of this study is to investigate the effects of temperature measurement systems (the thermometer and radiation shield) on the normal operating air temperature and to develop a physical model capable of removing such effects. The procedures will include both direct experimentation with an array of temperature equipment that represents major types of temperature systems (CRS, Gill, MMTS, and ASOS) (Figure 1.1) used historically or presently in weather station networks and modeling to increase our physical understanding of air temperature measurement in weather station networks. The specific objectives are to:

1. Theoretically investigate air temperature errors inside radiation shields.
2. Experimentally determine the air flow characteristics inside the shields.
3. Develop a physical model to understand the microclimate inside the shields including the interior solar radiation, infrared radiation, and air flow effects on the air (sensor) temperature under day and night conditions.
4. Experimentally estimate the effect of underlying ground surface coverings on the shield's interior solar radiation.

Each Chapter deals with one objective beginning with Chapter 2.

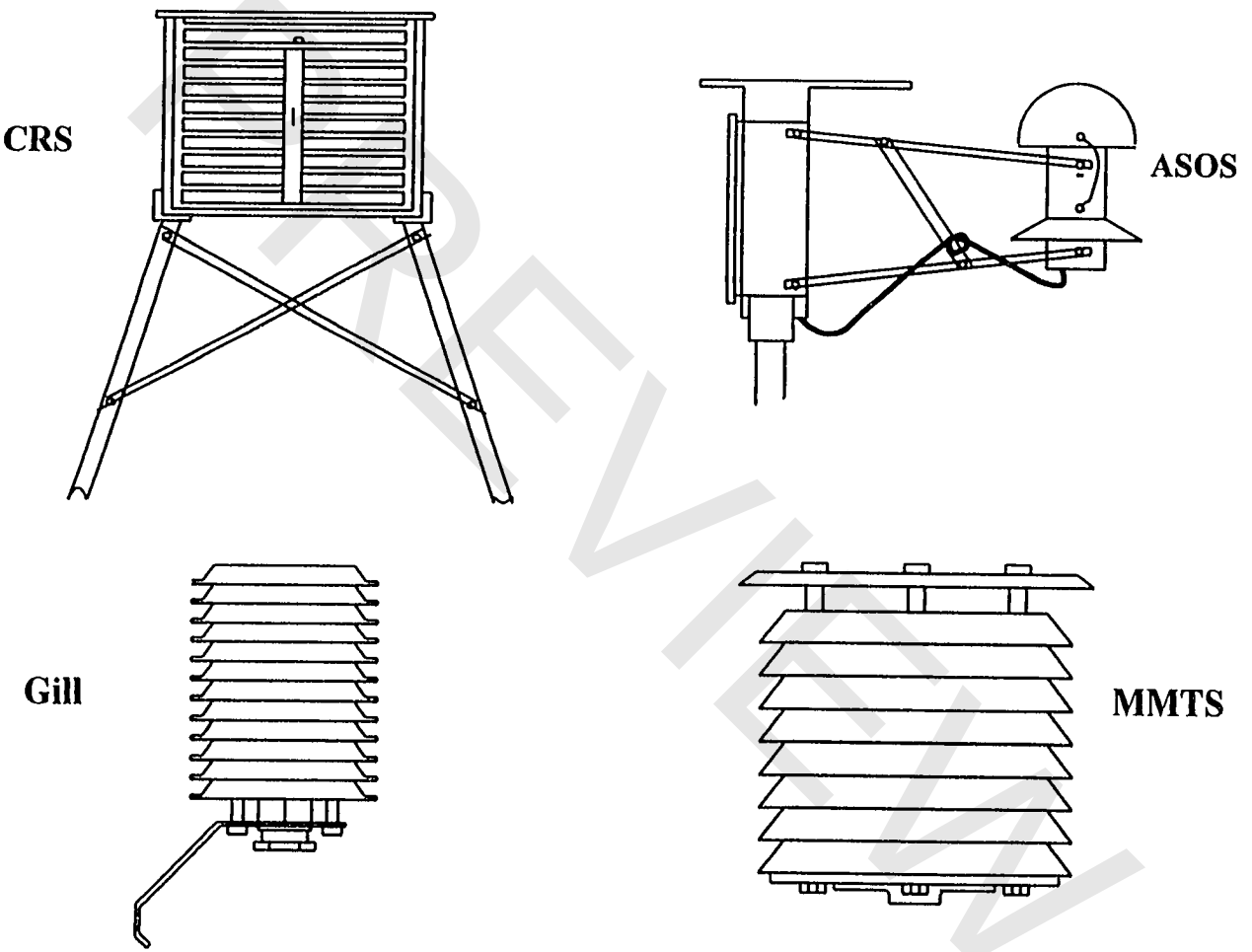

Figure 1.1 Air temperature radiation shields: the standard NWS Cotton Region Shield (CRS); Gill; the Maximum-Minimum Temperature System (MMTS); and the Hygrothermometer of the Automated Surface Observing System (ASOS).

CHAPTER 2

INVESTIGATION OF RADIATIVE ERROR INSIDE AIR TEMPERATURE RADIATION SHIELDS

2.1 INTRODUCTION

2.1.1 Background

An air temperature observation system in a weather station network commonly contains an air temperature sensor and an air temperature radiation shield. The purpose of the air temperature radiation shield is to house the air temperature sensors and in so doing prevent the sun's direct rays from reaching the sensor surface while allowing adequate ventilation and serve as shelter from inclement weather. Advances in semiconductor technology have led to air temperature sensors with accuracies of ±0.1°C in controlled conditions. However, in practice, it has been impossible to achieve this accuracy because air temperature radiation shields do not completely shield solar radiation without retarding natural air flow. Adequate air flow is required in order for the sensors to reach thermal equilibrium with the air. Forced ventilation ensures adequate flow but, requires too much power for remote stations. The greatest source of air temperature measurement error is inadequate coupling with the atmosphere (Brock et al., 1995).

The Cotton Region shield (**CRS**) was used in the U.S. for several decades as the principal air temperature shield. This large wooden structure provides enough space to house