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Development of Hourly THI Climatology Products for Livestock Producers in the MINK Region

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1. INTRODUCTION

Livestock are subject to stress when high temperatures and high humidity combine to limit the ability of cattle to dissipate excess heat (Hahn et al., 2001; Mader et al., 2001). The Temperature-Humidity Index (THI), originally developed to characterize heat stress for humans (Thom 1959), has been used as a basis for communicating the level of heat stress hazard for feedlot cattle for over 30 years. Three categories of THI have been developed and used as an operational environmental management tool for feedlot operators, alert (THI from 75 - 78), danger (THI from 79-83) and emergency (THI greater than 84). In addition, declines in rates of animal production, feedlot cattle deaths, and heat wave categories have been defined based on THI magnitude and/or the length of high THI periods. A goal of this research effort is to improve our understanding of heat and humidity as an environmental hazard for livestock.

The subject of environmental hazards has been informed and shaped by a variety of contributors (Burton et al., 1978; Cutter, 2001, Mitchell, 1989; Tobin White, 1974). In addition to a pragmatic desire to inform decision makers, assist in development of better public policy, and improve the management of natural resources, hazards researchers are examining aspects of the oldest of traditions within academic geography, the character of human and environment interactions (Mitchell 1989). A major subset of hazards research deals with climatic hazards (1), such as floods, droughts, blizzards, severe thunderstorms, and heat waves, and the impact of these hazards on human health and well-being. As a result, there is considerable sharing of intellectual ideas and research findings among hazards researchers and biometeorologists or bioclimatologists.

Bioclimatology "deals with the relations of climate and life, especially the effects of climate on the health and activity of human beings ... and on animals and plants" (Glickman, 2000). Biometeorology or bioclimatic research can incorporate contributions from a number of academic perspectives, including agronomy, animal science, botany, climatology, entomology, geography, meteorology, and zoology.

Geographic research dealing with applied climatology and environmental hazards has tended to examine stress and risks to humans directly (and not necessarily to other animals); the emphasis on humans follows clearly from the geographic synthesis domain addressing environmental-societal dynamics (Wilbanks et al., 1997). A few social scientists within the hazards research community have incorporated indirect effects associated with stressful conditions, such as economic losses associated with a hazard.

Extreme environmental variations are a major stressor or hazard to wild and domesticated plants and animals. According to Kalkstein (1991), the sensitivity of organisms to varying levels of stress is a major component of bioclimatic research. The stresses to non-human organisms have a major human/societal impact when the affected organisms are linked to an important economic system, such as food production. In this paper, the emphasis is on the development of bioclimatic indicators to assist livestock producers.

2. LIVESTOCK AND HEAT STRESS

This paper reports on one aspect of a multi-year research project, 'Evaluating Models Predicting Livestock Output Due to Climate Change,' that is being funded by the Great Plains Regional Center of the US DOE National Institute for Global Environmental Change (NIGEC). A mission for NIGEC is to provide regionally-conceived and academically-based research that can aid the United States' response to environmental change. A focus of the effort at Kansas State University is the development of a number of applied climate products designed to help test the validity of existing statistical/conceptual models that relate livestock production and health to accumulating heat stress.

In prior NIGEC funded work, Frank et al. (2001) and Frank (2001) identified a number of empirical algorithms relating weather/climate variables to livestock performance. Selected conceptual, statistical, and process-related models or relationships were derived from relevant, recent National Research Council publications covering the impacts of heat, humidity, and other environmental factors on the voluntary feed intake for beef cattle, dairy cattle, and swine (NRC, 1989; NRC 1996; NRC, 1998). Relationships identified by Fox and Tylutki (1998) also informed the development of statistical models. Using GCM output from the Canadian Climate

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Centre and the Hadley Center for Climate Prediction and Research, scenarios for current and future climate were tested using the empirical models. In general, these future warm season climate scenarios suggest marked reductions in production (increased days to reach market weight or declines in daily milk production) for animals not impacted by adjustment in management strategies.

High heat and humidity levels are important inhibitors of optimal livestock performance and most previous work has used daily averages of temperature and humidity in developing a THI statistic to compare with animal performance. Recently, studies on selected extreme events have used hourly THI calculations to examine how the magnitude of the temperature anomaly and/or the temporal extent of high THI periods are related to declines in rates of animal production and increases in feedlot cattle deaths (Mader et al., 2001). In addition, initial development of heat wave categories for livestock have been defined based on hourly THI statistics (Hahn et al., 2001). This study is using available hourly data from weather stations in the central Great Plains to develop long-term data base on THI variations for the region. A goal is to provide a better understanding of the range climatic conditions and the associated risk or hazard for livestock production in the area.

3. DATA AND METHODS

Climate data selected for this analysis are from the National Climatic Data Center's Surface Airways data set; stations with hourly observations of temperature and humidity from weather stations in the MINK region - Missouri, Iowa, Nebraska, and Kansas (Easterling et al., 1993) have been selected. For each station with more than 20 years of recorded data (Table 1), hourly temperature and relative humidity data are extracted and then THI is calculated (Thom, 1959).

Table 1. Weather stations selected for analysis.

Kansas	Nebraska
Concodia	Grand Island
Dodge City	Lincoln
Goodland	Norfolk
Russell	North Platte
Topeka	Omaha
Wichita	Scottsbluff
	Valentine

Iowa	Missouri
Des Moines	Columbia
Dubuque	Kansas City
Mason City	St Louis
Sioux City	Springfield
Waterloo	

Hourly THI values of 65 or greater and being retained for assessment of diurnal, month-to-month, and inter-annual variations. In addition, we are able to examine the data record for multiple day runs with THI exceeding a selected threshold.

A statistic used in bioclimatic assessment of weather severity for livestock is THI hours. THI hours are calculated in a manner similar to heating degree days or growing degree days, and a base value or threshold (e.g., 75) is used in THI hour the calculation. If the THI value at 3:00 pm on a given summer day is 81.5, then there would be 6.5 THI (base 75) hours (81.5 - 75 = 6.5) for that observation time. The number of THI hours is generally summed for a daily interval to give an indication of cumulative heat stress for that 24 hour period. Longer periods can also be used for accumulating THI hours, such as: a three day run, a week, a month, or a year. In this study, summary statistics being generated include: THI hours (above the base values or thresholds of 75, 79, and 84) per day, per month, and per year.

4. RESULTS AND DISCUSSION

Results for Wichita, Kansas, from 1954 indicate that THI hours (based on exceeding a threshold at 75 or 79) can occur at any hour throughout the day (Table 2). The diurnal pattern is highly similar to the classic asymmetrical daily temperature cycle, with greatest likelihood of THI hours in mid-afternoon (3:00 pm) and lowest frequency in the hours near sunrise (at 6:00 and 7:00 am). The classic, asymmetrical, diurnal pattern occurs whether or not THI hours are calculated with 75, 79, or 84 as the base statistic for accumulating hours.

Almost 70 percent of all THI hours occured between 11:00 am and 7:00 pm, whereas less than 10 percent of all THI hours occur between midnight and 9 am local time. However, these relatively few times when conditions remain stressful overnight are most critical for livestock, since nighttime recovery is either limited or nonexistent. With the threshold for calculating THI hours set at 84, occurrences were most common in mid-afternoon and a frequency of zero was recorded for both 7:00 and 8:00 am. For the Wichita observing station, 1954 and 1980 are the two warmest years in the data record. It is likely that a similar diurnal pattern would be observed in other years; the magnitude of the hourly values is reduced in cooler years, however.

The highest frequency of THI alert conditions (THI base 75) occurs in July; August is the month of second highest frequency (Table 3). Data in Table 3 are for 1954, a very warm year, and for 1961, a less stressful year. There is a tendency during abnormally hot summers to have the anomaly get established in late June or July and then persist into August; this tendency is evident in the high value of August THI hours in 1954

The data on THI hours for 1954 and 1961 for the danger category (THI > 79) also indicate that August is the month of second highest frequency (Figure 3). However, with this statistic it is clear that July is the month of peak risk to livestock.

Table 2. Diurnal variation in THI hours at Wichita in 1954 for three different THI base levels.

Time	THI-75	THI-79	THI-84
100	148.6	34.6	5.1
200	110.3	27.4	3.8
300	73.8	19.3	0.8
400	64.1	19.0	1.2
500	47.7	14.0	2.2
600	32.2	8.7	1.2
700	36.7	8.5	0
800	89.0	12.2	0
900	221.0	55.7	2.4
1000	369.4	127.8	19.2
1100	496.8	208.9	48.4
1200	610.8	280.3	68.4
1300	679.9	315.4	74.6
1400	763.0	366.7	87.9
1500	792.2	370.9	82.6
1600	809.6	393.4	87.2
1700	770.0	372.7	87.2
1800	708.8	328.12	80.8
1900	633.0	276.5	67.1
2000	476.0	179.7	34.6
2100	356.4	122.1	19.7
2200	279.9	73.7	10.7
2300	225.9	53.1	7.0
2400	177.3	41.5	6.0

Table 3. Monthly totals of hourly THI values (THI base 75 and 79) at Wichita for 1954 and 1961.

	THI (base 75)		THI (base 79)	
Month	1954	1961	1954	1961
April	84.5	39.8	5.2	0.8
May	125.0	83.0	41.4	2.0
June	1508.8	580.2	517.0	123.1
July	3371.4	1310.6	1574.1	356.3
August	3351.9	865.5	1168.3	138.1
September	918.0	323.6	231.0	55.7
October	363.0	10.6	173.2	0.0

For either the alert (THI >75) or danger categories (THI > 79), the three summer months (June, July, and August) are the period with highest probability of having hazardous conditions. For the years analyzed, at least 85 percent of all THI alert and THI danger hours occurred in one of the three summer months.

Additional data summaries will include analysis of monthly probabilities for various heat events, measures that assess cattle production impacts of heat wave duration by summing THI over several days, and an assessment of nighttime recovery potential using minimum THI values during the diurnal cycle. Plans call for an assessment of how well animals acclimate to high heat and humidity by comparing the impact of early season heat events with similar magnitude events later in the summer.

Assessment of year-to-year variation in THI hours indicates that this measure of livestock stress can differ by more than 50 percent (Figure 1). In the vast majority of years, THI hours occur less than half as often as they did in either 1954 or 1980. The hot summer of 1964 generated only about 65 percent of the number of THI hours as occurred in 1954. Data for 1980 had frequencies of alert and danger categories (96 and 88 percent, respectively) that come closer to the extreme conditions of 1954.

This paper has presented initial hourly THI climatology products based on analysis of data for Wichita, Kansas. We also identify additional THI based statistics that will be used to examine the risk to livestock. It is anticipated that the frequency and magnitude of the heat and humidity hazard to livestock will decline as data from stations in drier and cooler areas to the west and north are analyzed. It will be interesting to examine the relative roles of warmth versus atmospheric moisture in generating the THI hazard to livestock in more humid areas to the east and north.

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Figure 1. Inter-Annual Variation in THI Hours (Base 75) for Wichita, KS