Snow Surface Temperature Variation Near a Snow Pit

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ABSTRACT

Snow surface temperatures were observed to increase approaching a depression. This thermal increase appears to be the result of a complex convective exchange between the atmosphere and the depression. These temperature changes can affect energy balance exchange observations and can possibly be used as a thermal indicator of anthropengic influence .

INTRODUCTION

Observation within snow environs - for military or scientific purposes - most often includes snow surface temperature collected from remote infrared instruments [Jordan et al. 1986]. These thermal observations of the snow surface reflect the thermal exchanges at the boundary interface and may identify anthropogenic modifications of the surface [Jordan et al. 1987; Albert et al. 1992].

During field collection of energy balance exchange components over a seasonal snow cover at Silverton, Colorado, snow surface temperatures were observed to vary spatially. Using a hand held Everest Infrared Thermometer [IRT] surface temperatures were observed to increase as the instrument was moved toward the access path used to establish the micrometeorological instrument platform. The temperature variation was sufficiently large enough and spatially wide enough to require covering the access path to assure valid observation of the snow surface, and normal surficial heat exchange.

A separate snow pit, approximately one meter square and sixty centimeters deep, was emplaced near the instrument platform to allow for observation of this phenomena. Surface temperature observations were then collected at ten centimeter intervals - and at five centimeters next to the edges - along two transects - north/south and east/west - which radiated outward from the center of the pit. Hourly observations were collected from 1100 through 1600 hours, and at 2100 and 0800 hours beginning on the 9th of January 1991. The atmosphere was stable and precipitation free throughout the twenty hour study period.

The focus of this impromptu research was to determine 1) What was expected? 2) What was the heat source? 3) What was the spatial variation? 4) What was the vertical variation? and 5) What was the temporal variation? of this snow surface temperature anomaly. Critical to this research was the implications on scientific and military observation of this phenomena.

Undisturbed Snow Temperatures

Using the atmospheric temperature at 10 centimeters above the ground (Ta) and IRT snow surface temperature (Ts) from the micrometeorological instrument platform over an uninterrupted surface:

$$Ts = -4.6225 + 0.8798\ Ta \qquad (1)$$
$$se = 0.7921 \quad F = 8995 \quad adj\ r^2 = 0.9908$$

The strong correlation between the air temperature includes both the expected relationship of air to ground and the strong influence of the diurnal cycle.

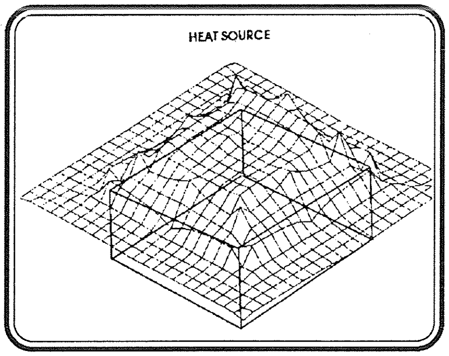

Figure 1. 3D surface temperature

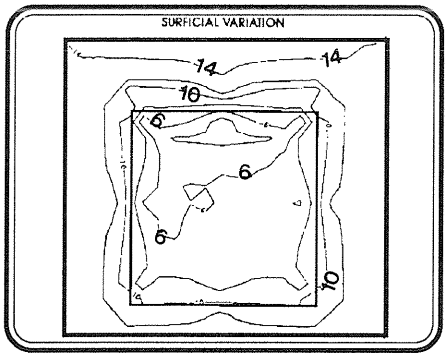

Figure 2. Aggregate surficial temperatures

Heat Source

When looking at the aggregate snow surface temperature around the snow pit (Ts') it is the aggregate temperature of the exposed ground which fits best.

$$Ts' = -1.8404 + 1.1784\ Tg \qquad (2)$$

$$se = 3.0223 \quad F = 1996 \quad \text{adj}\ r^2 = 0.8281$$

The area adjacent to the snow pit is therefore primarily affected by the newly exposed heat source - the ground.

The primary implication of this comparison is that exposure of a heat source can affect adjacent surface temperatures to include warming adjacent vertical or horizontal snow surfaces. This excess heat can affect energy balance studies by adding heat and can also contribute to military observation of snow environs by providing a thermal record of change(s).

Surficial Variation

As first observed at the fixed micrometeorological instrument site, surficial temperatures rapidly decrease as one moves away from the heat source depression as shown in Figures 1 and 2. Using the simple linear relationship relating surface temperature (Ts') with the exposed ground temperature (Tg) in equation 2; new intercept (a) and slope (b) values were calculated as a function of distance from the snow pit (d) in centimeters. Table 1 lists these coefficients and associated statistical values. Both the a and b coefficients vary inversely with distance. Replacing the original intercept and slope values with the new inverse relationships provides:

$$Ts' = -7.0940 + [13.4479/d] + [1.4992Tg] + [0.0350Tg/d] \qquad (3)$$

There is no statistical difference between equation 2 and 3. The relationship between ground temperature and distance is significant. The observed thermal change is no more then a simple inverse distance decay function.

Effectively the influence of the ground's heat diminishes to zero at about one meter. During instrument emplacement for energy balance exchange it is important to return the adjacent snow surface to near normal conditions. When looking for thermal changes it is now important to reognize the rapid thermal decay and look for small changes on the order of one-half degree Celsius over a very short distance of 50 to 100 centimeters.

Table 1. Intercept and slope coefficient variation with distance.

d	a	b	se	F	adj r2
05	-2.2181	1.3347	1.2516	1149	0.9728
10	-3.2719	1.2968	1.0754	1470	0.9786
20	-4.0366	1.2813	1.0329	1556	0.9797
30	-3.7655	1.2871	1.0517	1514	0.9792
40	-4.2203	1.2806	1.0250	1578	0.9800
50	-4.3488	1.2805	.0.9764	1739	0.9818

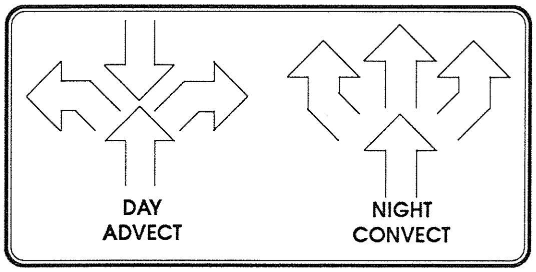

Figure 3. Convective forcing

Vertical Variation

Knowing that the ground is providing extra heat which advectively decays rapidly is important to the further define the heat exchange mechanism. Using the observed wall temperatures along with the ground and air temperatures it is possible to calculate convective heat exchange rates (Oke, 1978) within the pit and over the snow surface.

$$Qh = -\rho\ c_p\ kh\ [\Delta T\ /\ \Delta z] \qquad (4)$$

$\rho = 2.5058 - 0.0044T$

$kg/m^3 * 10^{-3}$ Density

$cp = 1.01$

$J/kg*K*10^3$ Specific Heat

$kh = -15.8106 + 0.1341T$

$m^2/s * 10^{-6}$ Thermal Diffusivity

Table 2 shows the convective forcing of the atmosphere and pit during each of the observation periods. The pit is always losing heat to the atmosphere.

The atmosphere from 1100 through 1500 hours experiences an inversion with highly stable air. During the daytime period the dominant downward movement of the atmosphere forces the upwardly moving excess heat from the pit to displace advectively.The result of these two forces is increased advection during the day. During the night the inversion layer lifts and convection dominates, see Figure 4.

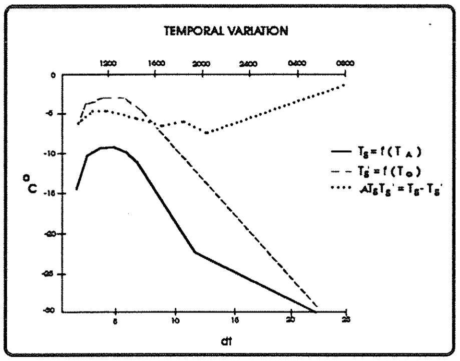

Figure 4. Thermal variation over time.

Site selection for sensitive energy balance studies must include consideration of microclimatic influences such as adjacent depressions with potential differential heat exchanges. For military observations it is critical to know atmospheric, surficial, and underlying heat source temperatures.

Temporal Variation

The final perspective is concerned with change over time. By looking at the difference between what was expected - i.e. that Ts is a function of Ta - and what was observed - i.e. Ts' is a function of Tg - it should be possible to identify any influence of time [Figure 4]. The expected relationship includes the influence of the diurnal cycle (t) where the observed relationship appears to decreases with time (dt).

$$dTsTs' = Ts - Ts' \qquad (5)$$

$$dTsTs' = -11.4772 + (8051/t) + (-2.6337/dt^2) \qquad (6)$$

Once again the influence of the diurnal cycle is present implying a growing influence of air temperature and a decreasing influence of ground temperature. The time from exposure (dt) is inversely squared indicating a strong initial influence which rapidly decreases possibly as the ground equalizes with the overlying atmosphere.

Table 2. Advective/Convective exchanges over time.

Time	1100	1200	1300	1400	1500	1600	2100	0800
Air (Ha)	0.76	1.50	.098	1.10	1.25	-1.67	-0.55	-1.07
Pit (Hp)	-0.10	-0.08	-0.09	-0.09	-0.06	-0.12	-0.28	-0.41
DHaHp	0.65	1.42	0.89	1.01	1.19	-1.80	-1.35	-1.49
Forcing	Down	Down	Down	Down	Down	Up	Up	Up
Process	Advect	Advect	Advect	Advect	Advect	Convect	Convect	Convect

The difference between observed and predicted decreases over time. This change withtime indicates a need to ignore initial thermal observations for energy balance exchanges or to use a multidimensional snow model [Albert 1983; Jordan et al. 1986; Jordan et al. 1987, Albert et al. 1992]. For observation of the environ this thermal difference can with knowing Ta, Ts, and Tg provide a temporal record of when the snow surface change occurred.

CONCLUSIONS

Traditonally snow insulates the ground. The heat exchange is therefore primarily conductive. The intentional or unintentional exposure of an underlying heat source can create a convective thermal exchange. This exchange is the result of removing, or reducing, the conductive path and inducing a thermal differential at the ground or snow interface with the air. This surficial thermal differential - due to exposure of shortened conductive path - concurrently creates a convective exchange with the overlying atmosphere. The excess heat will attempt to convectively rise. During stable conditions the warmer air can be forced to move advectively thus creating differential surface temperatures which decrease inversely with distance and possibly over time as the exposed or venting heat source decays to thermal equilibrium. This process can have a direct impact on scientific and military observation of snow environs.

When conducting micrometeorological energy balance exchange studies it becomes important to recognize the potential impact of adjacent surficial changes. During the conduct of this impromptu study the exposed heat source became the dominant local influence. This influence created abnormally high surface temperatures which decrease over both distance and time indicating a need to return the adjacent surfaces to normal conditions, and to ignore the initial observations.

When observing snow environs for change small disruptions can create thermal signatures. These signatures identify both the size and time of disruption. However to recognize these signatures air, surface, and ground temperatures must be continuously collected and thermal differences of one-half degree Celsius over half meter distances must be observed.

Future research must consider longer time periods, different heat source - to include cold seeps - temperatures, and spatial location of thermal samplers and remote sensing instruments.

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