JP1.23 THE IMPACT OF A CONTROLLED BURN ON SURFACE AND ATMOSPHERIC CONDITIONS ON A TALLGRASS PRAIRIE

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1. INTRODUCTION

This study focused on the impact of a controlled burn on surface and atmospheric conditions in the field that contains the El Reno Mesonet site (ELRE). Data were collected from ELRE and 4 portable sites placed on the property. During the controlled burn, the portable sites were removed from the property and replaced the following day. Conversely, a firebreak was cut around ELRE, so the site was undisturbed. Figure 1 is a map of Oklahoma showing the location of ELRE. Figure 2 is a map of the area affected by the burn and the locations of the PARMS sites in relation to the Mesonet site. Figure 3a-c shows photographs of PARMS 4 on the tallgrass prairie before the burn, on the day after the burn, and a few weeks after the burn.

2. BACKGROUND

2.1. Energy

Energy is transferred within the atmosphere in four different ways. The first is through conduction, where heat from one molecule is transferred to another within a substance. The second method of transfer is convection, which refers to the transfer of heat by the mass movement of a fluid. Another form is evaporation and other forms of latent heating. The final method is through electromagnetic radiation; radiation does not require a physical means for transport (Geiger 1995).

Surface energy balance refers to the balance between net radiation, energy flow from the surface of the Earth into the ground (or vice versa), energy flow from the ground to the air above it (or vice versa), evaporation, precipitation, and advection. All variables must sum to zero, according to the conservation of energy. The energy exchange equation for ground that is free of vegetation is:

Figure 1. A map of Oklahoma showing the location of the El Reno Mesonet site.

$$S + B + L + V + Q + N = 0 \quad (1)$$

where S represents the net radiation, B is the flow of energy from within the ground to the surface, the air above the ground is L, V is evaporation, Q represents advection, and N is precipitation; often, Q and N are neglected. Thus the final equation (Geiger 1995) becomes:

$$S + B + L + V = 0 \quad (2)$$

2.2. Heat

There are several types of heat. Latent heat is described as the heat energy required to change a substance from one state to another. Evaporation and condensation are examples of latent heat (Ahrens 2003). Sensible heat, also known as enthalpy, is the heat energy that is absorbed or transmitted by a substance during a change of temperature that is not accompanied by a change of state. Sensible heat can be described as the heat you "feel" (Stull 2000). In meteorology, the available energy at the land surface is often partitioned mainly between sensible heat and latent heat (Arctic 2005). According to Oke (1987), sensible heat flux, the direction of heat transfer, is estimated by measuring the air temperature and vertical wind velocity, where both variables are directly proportional to the instantaneous heat flux.

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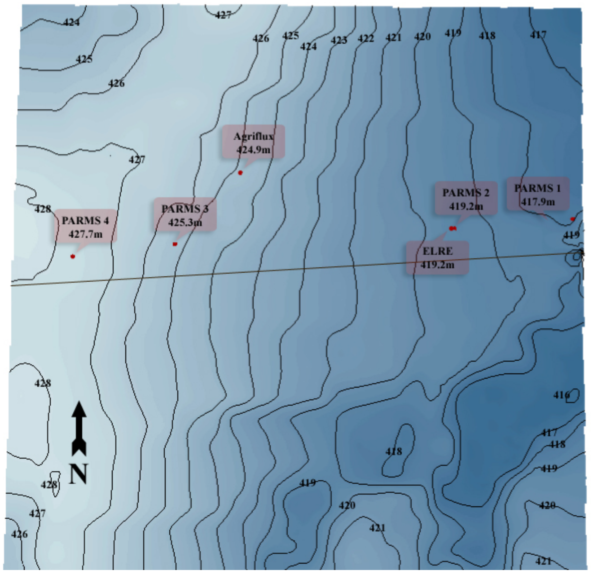

Figure 2. A map of the deployment locations of the four PARMS sites.

Further, the sign of the sensible heat flux in inversely proportional to the sign of the temperature gradient (Oke 1987).

2.3. Temperature

The temperature of the air just above the ground is influenced by the nature of the soil, which is dependent on the amount of energy transported into it and on its ability to absorb energy (Geiger 1995). According to nasa.gov, skin temperature refers to the temperature of the surface of the Earth, where the atmosphere ends and the surface begins. This is in contrast to the meteorological definition of surface temperature, which is measured at approximately 1.5 to 2 meters above the surface. Because of solar heating, surface skin temperature can experience large fluctuations between day and night readings (NASA 2005).

2.4. Electromagnetic Radiation

Radiation is the energy source that drives atmospheric circulations (Ahrens 2003). Radiation travels in the form of waves that release energy when they are absorbed by an object. Because these waves have electrical and magnetic properties, they are called electromagnetic waves. The wavelength, represented by λ, is the distance measured along a wave from one crest to another (Ahrens 2003).

All objects whose temperature is above absolute zero emit radiation (Geiger 1995). Objects with higher temperatures emit radiation at a higher intensity and shorter wavelength. Therefore, as an object's temperature increases, the total amount of emitted radiation per second increases (Ahrens 2003). Kirchhoff's law states that if an object absorbs well at a given wavelength, it will also emit well at that wavelength (Geiger 1995).

A black body is a substance that absorbs all radiation incident upon it and perfectly emits radiation in a continuous spectrum. According to the Stefan-Boltzmann law of radiation, all black bodies radiate such that the flux density of emitted radiation (summed over all wavelengths) is proportional to the fourth power of the absolute surface temperature in Kelvin. This can be written as:

$$E = \sigma * T^4 \qquad (3)$$

where σ is the Stefan-Boltzmann constant ($5.670*10^{-8}$ J K^{-4} m^{-2} s^{-1} Geiger 1995).

Incoming radiation from the sun arrives at the Earth's surface in the form of shortwave radiation. Solar radiation that reaches the surface of the earth consists of direct-beam solar radiation (I) and diffuse solar radiation (H). Diffuse radiation is radiation that is scattered by clouds, gas molecules, and particulates. The sum of I and H is termed global solar radiation. On average, approximately 49 percent of the total solar

Figure 3a-c. PARMS 4 (a) just before the burn, (b) on the day after the burn, and (c) two months after the burn.

radiation reaches the surface, and approximately 3 percent of that radiation is reflected. Nearly 30 percent of the total solar radiation is not absorbed by the earth-atmosphere system and is reflected back to space (Geiger 1995).

Direct beam solar radiation and diffuse solar radiation, two forms of shortwave radiation, are included in the radiation balance equation, as well as two forms of longwave radiation (Stull 2000). One form of longwave radiation is emitted by the atmosphere; it is termed counterradiation or atmospheric radiation. The other form is emitted by the surface of the earth and is referred to as terrestrial radiation. The terrestrial radiation will be reduced at a given surface temperature based upon the value of that surface's emissivity. Emissivity refers to a material's ability to absorb and radiate energy and is the ratio of radiation emitted by the material to the energy radiated by a black body at the same temperature (Geiger 1995).

To maintain thermal equilibrium, the earth system attempts to balance radiation. Thus, the radiation balance refers to the balance between the radiation absorbed and the radiation emitted. If the incoming radiation is greater than the outgoing radiation, the balance is positive; if it is less, the balance is negative or a net loss of radiation. The radiation balance equation is:

$$S = I + H + G - \sigma * T^4 - R \tag{4}$$

where I + H refers to global solar radiation; G refers to atmospheric radiation σ * T^4 is the Stefan-Boltzmann law, and R refers to terrestrial radiation (Geiger 1995).

The albedo of an object is the ratio of the reflected solar radiation to the incident solar radiation; it is also known as the reflection coefficient. Albedo can be expressed as a percentage or as a fraction and is influenced by the nature of the surface and by its moisture content. Because the state of the surface undergoes daily changes, there are corresponding periods of variation in albedo (Geiger 1995).

Vegetation occupies the space between the surface and the atmosphere and acts as a transition zone. For surfaces with vegetation, the magnitude of downwelling radiation is the same as for surfaces without it, but the magnitude of reflected radiation can vary. The albedo of soil varies greatly depending upon particle size, mineral composition, moisture and organic matter content, and surface roughness (Geiger 1995). Similarly, the albedo of vegetation is also quite variable due to vegetation type, color, canopy geometry, moisture content, percentage of the ground covered, leaf area, and the stage of the plant's growth (Geiger 1995).

3.0 INSTRUMENTATION

3.1. The Oklahoma Mesonet

The Oklahoma Mesonet is a research quality network of automated stations that measure a number of meteorological, hydrological, and agricultural variables (Brock et al. 1995). In addition, the data is collected in real time and is transmitted every 5 minutes through a radio link to the nearest terminal of the Oklahoma Law Enforcement Telecommunications System (OLETS); from there, it is relayed to the Oklahoma Climatological Society in Norman, OK. There are currently 116 stations placed across Oklahoma with at least one site in every county (Brock et al. 1995).

3.2. PARMS

Portable Automated Research Micrometeorological Stations, or PARMS, are used to study atmospheric conditions at various spatial and temporal scales. One PARMS can be deployed or removed in approximately 30 minutes and transported in the back of a standard pickup truck. Each PARMS site measures air temperature, relative humidity, downwelling solar radiation, reflected solar radiation, net radiation, surface skin temperature, and the horizontal and vertical wind components (OCS 2005).

4. CONTROLLED BURNING

Controlled burning, also known as prescribed burning, stimulates germination and creates fire control (Answers.com 2005). Nutrients may take months or years to decay on their own but are available within seconds of being burned. The nutrients are turned to ash and are in a form usable to plants. In addition, sunlight warms the blackened ground and stimulates dormant plants to sprout and grow (Tallgrass Prairie National Preserve 2005). A controlled burn was conducted at ELRE on 8 March 2005 because the site is located on a tallgrass prairie and, to keep the area's ecosystem vigorous and to rid the area of flammable materials, the area needed to be burned or grazed (Schneider 2005).

Tallgrass prairies are lands that are too wet to be deserts, too dry to be forests, and have thousands of plant and animal species living in

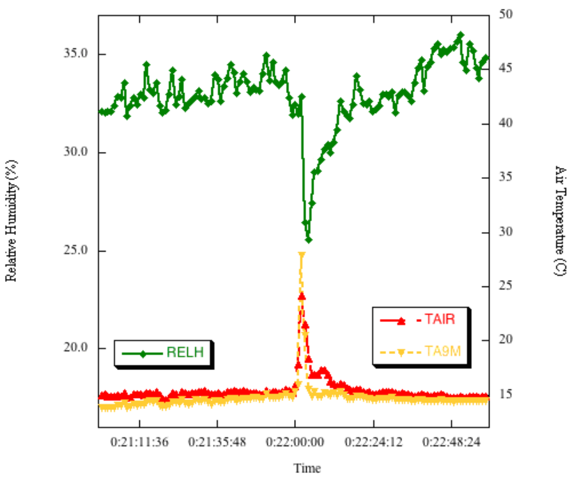

Figure 4. Relative humidity and air temperature during the 8 Mar 2005 controlled burn at ELRE (1-minute data).

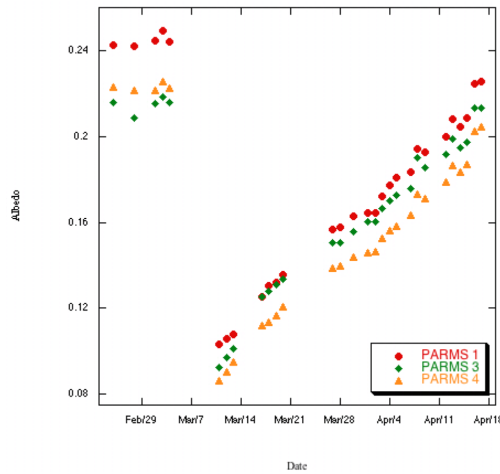

Figure 5. Albedo for PARMS 1, 3, and 4 from 25 Feb to 17 Apr 2005.

them (Tallgrass Prairie National Preserve 2005). This sea of grass was prevalent in the mid-continent of North America; the area they cover has been greatly diminished due to urbanization and human activities. These areas have complex ecosystems, only being surpassed by the rainforests in Brazil, and they quickly accumulate a large amount of biomass. By the end of a year, dead leaf litter creates a thick thatch over the ground making it increasingly difficult for new shoots to obtain the sunlight they greatly need. As this litter accumulates, the prairie plants actually weaken and smother. Fire is nature's way of starting over, but rejuvenation can be aided if the area is grazed (Tallgrass Prairie National Preserve 2005).

5. RESULTS

5.1. During the burn

Observations were obtained from the ELRE Mesonet site on 8 March 2005. For this portion of the study, data sets were utilized: a data file with 1-minute average values and a data file with 5-minute average values. The controlled burn was conducted from approximately 2100-2300 UTC; the only noticeable meteorological changes occurred in the air temperature at 1.5 m and 9 m and relative humidity at 1.5 m. A sudden spike in temperature and drop in relative humidity began at approximately 2200 UTC and lasted nearly 10 minutes (Fig. 4).

When a fire occurs, local heating

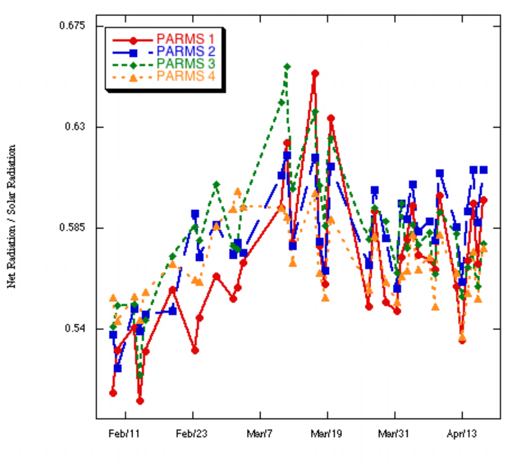

Figure 6. Normalized net radiation values for PARMS 1-4 from 9 Feb to 17 Apr 2005.

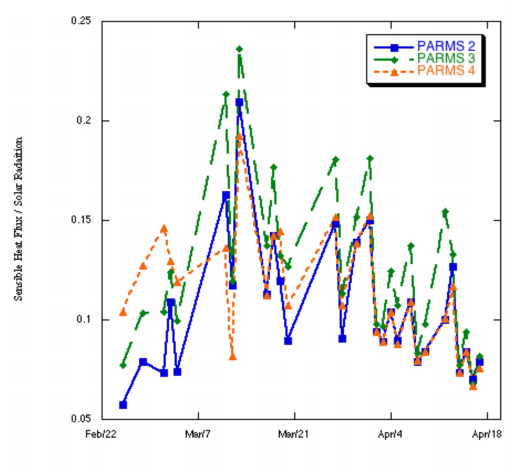

Figure 7. Normalized sensible heat flux values for PARMS 2-4 from 25 Feb to 17 Apr 2005.

increases the temperature. Relative humidity is defined as the amount of moisture in the air divided by the maximum amount of moisture that could exist in the air at a given temperature (i.e., a ratio of vapor pressure to saturation vapor pressure). Because the temperature increased, the saturation vapor pressure increased and the relative humidity decreased. However, after the spike, the relative humidity quickly increased. This feature likely occurred because before the fire was started, the area around the ELRE site was sprayed down with water. Thus, the water evaporated after the fire and increased the amount of moisture in the air and, when coupled with the decreasing air temperature, increased the relative humidity.

5.2 Before and after the burn

Observations were also obtained from 4 Portable Automated Research Micro-meteorological Station (PARMS) sites that were placed across the property from 5 February 2005 to 19 April 2005; The PARMS sites were removed during the fire and replaced soon afterwards. For days with adequate sunshine (at least 75% of the possible solar radiation reaching the surface), an "afternoon" average (from 1700-2100 UTC) of the observed variables was obtained.

Before the PARMS were ever deployed to ELRE, a series of intercomparisons was conducted to ensure that all stations were operating correctly. Furthermore, when instruments were not functioning properly during the study, the data from those instruments were discarded. As such, some graphs do not include observations from all 4 PARMS.

Many calculations were completed during the data analysis. First, to compensate for the annual cycle of net radiation (RNET) and solar radiation (SRAD), RNET was normalized by dividing by SRAD. The sensible heat flux calculations were also normalized by dividing by SRAD. To analyze the impact the fire had on temperature, the difference between air temperature at 1.5 m and surface skin temperature was calculated. Finally, the albedo for the sites was also calculated.

The analyses revealed that significant meteorological changes occurred in the albedo, net radiation, and sensible heat flux. Immediately following the burn, the albedo decreased significantly but steadily increased back to near its initial value by the end of the study period. Conversely, net radiation and sensible heat flux peaked a few days after the burn but began to decline soon after. Finally, a minor deviation was observed in the difference between surface skin temperature and the air temperature at 1.5 m, but it wasn't as pronounced as the changes observed in other variables (Figs. 5-7).

Additional analyses were completed comparing the albedo values at PARMS 3 and 4 to other variables at the same sites to quantify the relationship between the change in the surface characteristics and the impacts on the observed energy and radiation values. The linear regressions revealed that the coefficient of determination for PARMS 3 was much higher for all of the comparisons than it was for PARMS 4 (Table 1). This shows that the relationship between the albedo and the other variables for that site are not as closely correlated as expected (Fig. 8a-b).

6. CONCLUSION

A controlled burn on a tallgrass prairie impacted surface and atmospheric conditions throughout the field near the El Reno, OK Mesonet site. As expected, the albedo decreased significantly and gradually increased as new vegetation began to cover the surface. However, the impact of the land surface change on temperature difference, net radiation, and sensible heat flux weren't as dramatic. Furthermore, the correlation between albedo and the other variables measured at the PARMS sites were somewhat weak and varied from location (e.g., PARMS 3 and 4 which were approximately 100 meters apart). The cause of this variability was undetermined, but sensor error was eliminated as a possible cause.

Site	RNET/SRAD	IRTG -TAIR	SH	SH/SRAD	SH/RNET
PARMS 3	0.51	0.02	0.49	0.48	0.39
PARMS 4	0.00	0.10	0.19	0.09	0.10

Table 1. Coefficients of determination (R^2) between albedo and radiation or temperature values for PARMS 3 and 4 from 25 Feb 2005 to 17 Apr 2005.

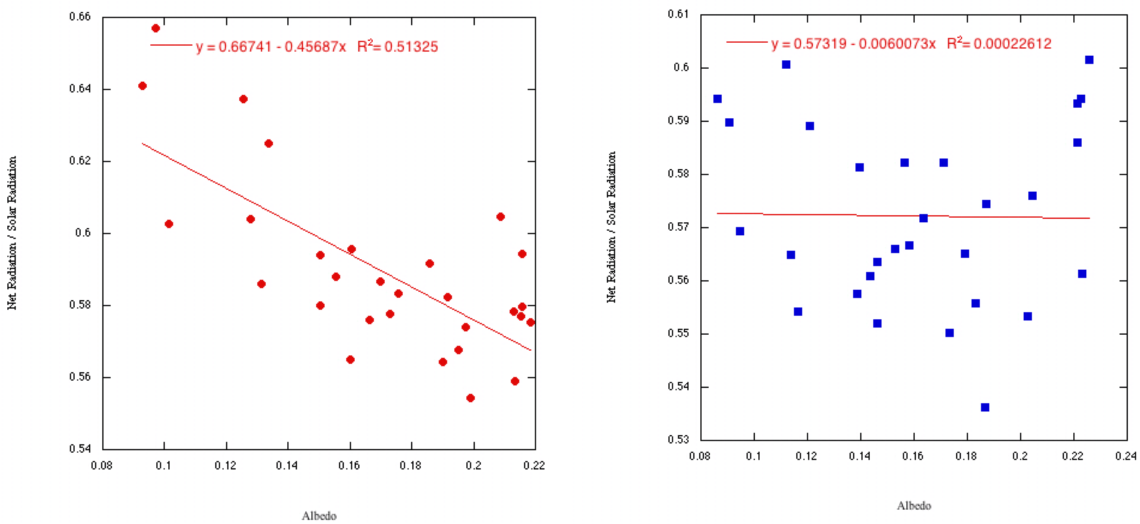

Figure 8a-b. Albedo vs. normalized net radiation for (a) PARMS 3 and (b) PARMS 4 from 25 Feb. to 17 Apr. 2005.

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