SPATIAL AND TEMPORAL VARIABILITY OF ALBEDO FROM ENHANCED RADIATION MEASUREMENTS IN OKLAHOMA

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ABSTRACT

In 1999, the Oklahoma Atmospheric Surface-layer Instrumentation System (OASIS) project placed instrumentation focused on observing the surface energy budget at 89 Oklahoma Mesonet stations. At any given time, 10 stations (designated “super sites”), were outfitted with additional instrumentation including a four component net radiometer with the capability to observe incoming and outgoing shortwave (solar) and longwave radiation. Data are available from the beginning of 2000 until October 2008. This data was filtered to remove observations non-representative of the days albedo (e.g. sunrise and sunset periods, cloudy days, and erroneous instrument readings) and monthly averages were computed for each of the super sites in order to develop a better understanding of the spatial and temporal variability of albedo in Oklahoma.

1. INTRODUCTION

Albedo, the percentage of the Sun’s radiation reflected by the Earth’s surface, is a significant component of the Earth’s surface energy balance and thus, measurements of albedo are of great importance. Understanding the spatial and temporal variability of albedo across the state of Oklahoma will allow improvements in many meteorological applications. The American Society of Civil Engineers (ASCE) guidelines for the computation of potential evapotranspiration include the recommendation to use a constant albedo value of 0.23 for all applications irrespective of latitude, land cover, or other important factors. (American Society of Civil Engineers, 2005) While this may be reasonable for broad based estimates, it is desirable to have a more exact albedo estimate for this computation. Moreover, the Weather Research and Forecasting (WRF) model (http://www.mmm.ucar.edu/wrf /users/docs/arw_v3.pdf) does allow for albedo values that vary with time of year, but comparisons of these values with in-situ measurements of albedo may help refine these variances for the state of Oklahoma.

2. BACKGROUND

Estimations of the albedo of the Earth and it’s surfaces are not new, with Frank W. Very in the early 20th century analyzing Earthshine on the moon to make estimates of the Earth’s albedo (Very, 1913). Henderson- Sellers and Wilson (1983) recommended albedo estimations of no less than a +/- 0.05 accuracy for applications in global climate modeling; this was later revised to +/- 0.02 (Sellers, 1993). Many studies have been undertaken that take part in moving current knowledge toward meeting that goal for all of Earth’s surfaces, including comparing ground based albedo measurements with those of satellites (Lucht et al., 2000; Barnesly et al., 2000). Such comparisons are necessary due to the fact that satellite estimates require extensive calibration as a result of the optical effects of the atmosphere to derive a surface albedo from the top of atmosphere albedo (Brest and Goward, 1987; Carrer et al., 2010; Cesscatti et al., 2012). These estimates report a reasonable level of accuracy, but such validations can only be made at point sites. Another method for estimating albedo is to assign albedo values to land cover types derived from satellite land cover classification schemes, as the WRF does, but this method does not incorporate seasonal or latitudinal changes. Through the analysis of radiation measurements from enhanced surface observation stations, a better estimate of

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Oklahoma's spatial and temporal albedo variability was obtained, which would allow for comparison to estimates based on the above methods.

3. DATA

The Oklahoma Mesonet is an automated network of 120 remote, meteorological stations across Oklahoma (Brock et al., 1995; Shafer et al., 2000; McPherson et al., 2007). Each station measures core parameters that include: air temperature and relative humidity at 1.5 m, wind speed and direction at 10 m, atmospheric pressure, downwelling solar radiation, rainfall, and bare and vegetated soil temperatures at 10 cm below ground level. In addition, over 100 sites measure air temperature at 9 m. In an effort to avoid anthropogenic influences, most Oklahoma Mesonet sites are located in rural areas. Mesonet data is collected and transmitted to a central point every 5 minutes where they are quality controlled, distributed and archived (Shafer et al., 2000; McPherson et al., 2007).

The Oklahoma Atmospheric Surface-layer Instrumentation System (OASIS) project outfitted 89 Oklahoma Mesonet stations with additional instrumentation designed to monitor surface energy balance parameters beginning in April 1999 (Brotgze et al., 1999). Until the end of the project in September 2008, a minimum of 10 sites included further additional instrumentation including a four component net radiometer. These sites (designated "Super Sites") were located in Alva, Bessie, Boise City, Burneyville, Foraker, Grandfield, Idabel, Marena, Norman, Stigler, and Washington, with at least one station in each of Oklahoma's climate divisions (Figure 1). The Bessie site ceased operation as a super site in September 2002, at the same time as Washington began collecting data. Furthermore, the location of the Norman site was moved southeast 2.79 km, but the two sites have been combined into one for the purposes of this analysis due to the geographical proximity as well as the same prairie grass landcover at both sites.

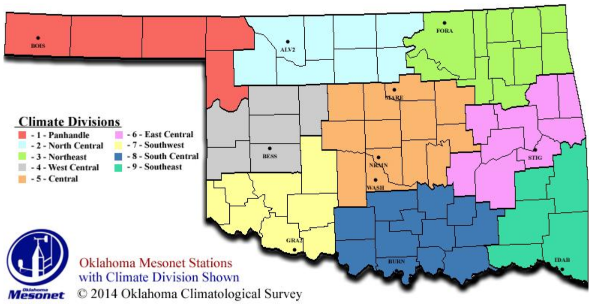


Figure 1. Map of the eleven mesonet sites outfitted as "super sites" and their corresponding Climate division.

The radiometer installed for the project, the Kipp-Zonen CNR1, measures each component of net radiation: shortwave in (SWIN), shortwave out (SWOU), longwave in (LWIN), and longwave out (LWOU). The shortwave components of this system have a spectral range of 305-2800nm (Kipp-Zonen CNR1 Manual, Page 22, Section 2.2.3), which effectively encompasses the solar spectrum. The instrument meets the second class standards of the International Organization for Standardization (ISO) for shortwave in radiometers (pyranometers). The pyranometer converts the solar radiation incident upon it into electric current via a thermopile (e.g., a material that converts thermal energy to electrical energy) and relates the amount of voltage generated to the amount of solar radiation incident on the sensor. The largest source of potential error in the instrument, as used to measure albedo, results from variability in sun angle throughout the day and is addressed in the methodology section. The upward and downward facing pyranometers both have a theoretical field of view of 180 degrees.

Quality assurance (QA) of the super site data set was limited, but some important tests were performed on the raw data. These included a requirement that the net radiation measurement from the net radiometer installed as part of the broader OASIS project was within 50 W/m^2 of the net radiation calculated from the four component radiometer installed as part of the super site upgrades. Likewise, data were flagged if the solar radiation measurement from the Mesonet's radiometer was not within 50 W/m^2 of the measurement taken by the SWIN component of the four component radiometer. These were the only QA procedures performed, which led to the need for additional procedures to arrive at a dataset with which to calculate monthly albedo, described in the next section.

4. METHODOLOGY

Albedo was calculated as the ratio of SWIN over SWOU. However, a simple application of this formula to the entire dataset would not have produced strong results. This was due to such things as non-zero SWIN measurements in the middle of the night and sunrise and sunset periods where low sun angles cause errors in sensor measurements (Figure 2a). The CNR1 radiometer instruction manual cautions to never use data from

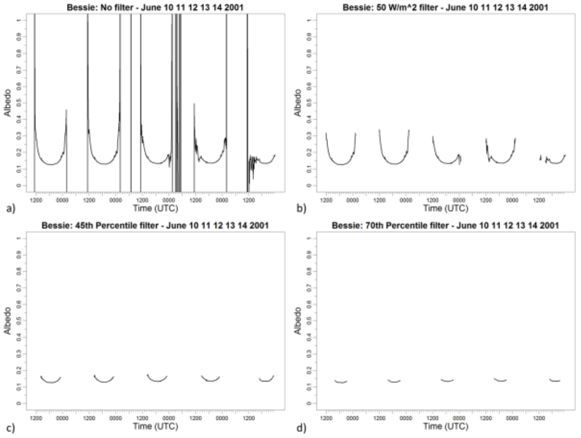


Figure 2. Sample time series of albedo for June 10th, 11th, 12th ,13th , and 14th 2001 at Bessie with a) no filter applied ; b) only albedo values associated with SW_{IN} values above 50 W/m^2 shown ; c) only albedo values associated with SW_{IN} values above the 45th percentile of SWIN values above 50 W/m^2 ; d) only albedo values associated with SW_{IN} values above the 70th percentile of SW_{IN} values above 50 W/m^2, this time series represents a sample of the final post filter dataset.

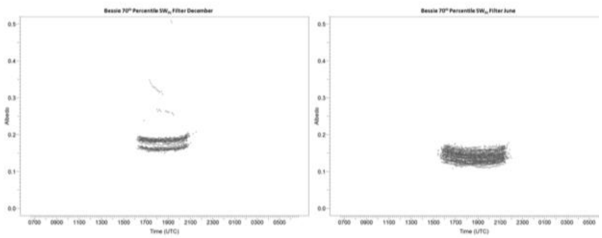
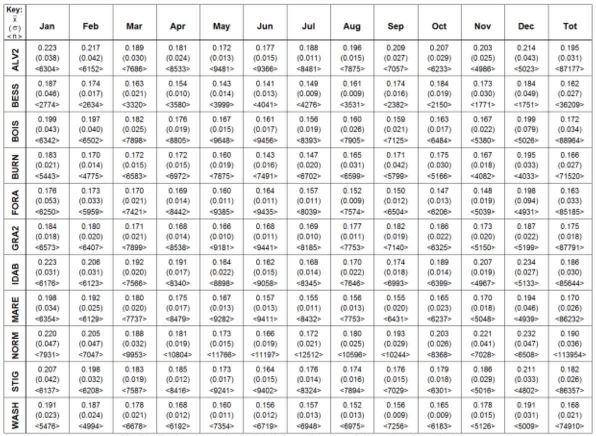


Figure 3. Scatterplot of post filter albedo data and time for summer (June) and winter (December) at Bessie. Note the distinct difference between two different Decembers.

times when the sun is below ten degrees above the horizon (Kipp-Zonen CNR1 ManualPage 13, Section 1.1.2.4). These data points were not reliable and often result in albedo values above one or less than zero. Additionally, the sunrise (or sunset) period results in large variations in measured albedo as the sun moves farther away from (or closer to) the horizon. Thus, all such non-representative data points were removed from this analysis.

To do this, the data for each station was put through an objective filter. First the data were filtered to remove all data points with a SWIN value less than 50 W/m^2 (Figure 2b). This value was chosen as it removed all albedo values falsely above one and also removed most instances where the albedo was measured at near or less than zero due to a non-daytime SWIN or SWOU measurement. 50 W/m^2 also is not a significant percentage of the maximum wintertime SWIN distribution which peaks at ~600-800 W/m^2 with variance due to station latitude and variability in cloud cover between stations. After this filter was applied, the data still retained large peaks in albedo in the morning and evening which correspond to the sunrise and sunset periods. To remove these peaks and only utilize the albedo data from the middle of the day when the sun was highest and the data therefore the most reliable, a percentile threshold was set on the SWIN values for each month. This percentile is of the data that remains after the 50 W/m^2 filter was applied. A percentile allows for seasonal variations to be accounted, as the wintertime distribution of SWIN peaks at a much lower value (~600-800 W/m^2) than the summertime distribution (~1000-1200 W/m^2). An example time series for a 45th percentile filter is shown in figure 2c. Analysis of several different possible threshold percentiles allowed for the discovery of the 70th percentile as the threshold at which the significant morning and evening tails disappeared and the only data that remained is that at the (relatively) flat bottom of the curve (Figure 2d). This procedure generally resulted in ~900 observations per month per station marked as valid at a minimum. Figure 3 presents examples of this post-filtered dataset in the form of a scatterplot of albedo vs. time for June and December at Bessie. With these data, monthly averages, standard deviations,



Key: $\bar{x}$ (σ) <n>	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot
ALV2	0.223 (0.038) <6304>	0.217 (0.042) <6152>	0.189 (0.030) <7686>	0.181 (0.024) <8533>	0.172 (0.013) <9481>	0.177 (0.015) <9366>	0.188 (0.011) <8481>	0.196 (0.015) <7875>	0.209 (0.027) <7057>	0.207 (0.029) <6233>	0.203 (0.025) <4986>	0.214 (0.043) <5023>	0.195 (0.031) <87177>
BESS	0.187 (0.046) <2774>	0.174 (0.017) <2634>	0.163 (0.021) <3320>	0.154 (0.010) <3580>	0.143 (0.014) <3999>	0.141 (0.013) <4041>	0.149 (0.009) <4276>	0.161 (0.009) <3531>	0.174 (0.016) <2382>	0.184 (0.019) <2150>	0.173 (0.030) <1771>	0.184 (0.049) <1751>	0.162 (0.027) <36209>
BOIS	0.199 (0.043) <6342>	0.197 (0.040) <6502>	0.182 (0.025) <7898>	0.176 (0.019) <8805>	0.167 (0.015) <9648>	0.161 (0.017) <9456>	0.156 (0.019) <8393>	0.160 (0.026) <7905>	0.159 (0.021) <7125>	0.163 (0.017) <6484>	0.167 (0.022) <5380>	0.199 (0.079) <5026>	0.172 (0.034) <88964>
BURN	0.183 (0.021) <5443>	0.170 (0.014) <4775>	0.172 (0.015) <6583>	0.172 (0.015) <6972>	0.160 (0.019) <7875>	0.143 (0.016) <7491>	0.147 (0.020) <6702>	0.165 (0.031) <6599>	0.171 (0.042) <5799>	0.175 (0.030) <5166>	0.167 (0.018) <4062>	0.195 (0.033) <4033>	0.166 (0.027) <71520>
FORA	0.176 (0.053) <6250>	0.173 (0.033) <5959>	0.170 (0.021) <7421>	0.169 (0.014) <8442>	0.160 (0.011) <9385>	0.164 (0.011) <9435>	0.157 (0.011) <8039>	0.152 (0.009) <7574>	0.150 (0.012) <6504>	0.147 (0.013) <6206>	0.148 (0.019) <5039>	0.198 (0.094) <4931>	0.163 (0.033) <85185>
GRA2	0.184 (0.018) <6573>	0.180 (0.020) <6407>	0.171 (0.021) <7899>	0.168 (0.014) <8538>	0.166 (0.010) <9181>	0.168 (0.011) <9441>	0.169 (0.010) <8185>	0.177 (0.011) <7753>	0.182 (0.019) <7140>	0.186 (0.022) <6325>	0.173 (0.020) <5150>	0.187 (0.022) <5199>	0.175 (0.018) <87791>
IDAB	0.223 (0.031) <6176>	0.206 (0.031) <6123>	0.192 (0.020) <7566>	0.191 (0.017) <8340>	0.164 (0.022) <8898>	0.162 (0.015) <9058>	0.168 (0.014) <8345>	0.170 (0.022) <7646>	0.174 (0.018) <6993>	0.189 (0.014) <6399>	0.207 (0.019) <4967>	0.234 (0.027) <5133>	0.186 (0.030) <85644>
MARE	0.198 (0.034) <6354>	0.192 (0.025) <6129>	0.180 (0.020) <7737>	0.175 (0.017) <8479>	0.167 (0.013) <9282>	0.157 (0.013) <9411>	0.155 (0.011) <8432>	0.156 (0.013) <7753>	0.155 (0.020) <6431>	0.165 (0.023) <6237>	0.170 (0.018) <5048>	0.194 (0.046) <4939>	0.170 (0.026) <86232>
NORM	0.220 (0.047) <7931>	0.205 (0.047) <7047>	0.188 (0.032) <9953>	0.181 (0.019) <10804>	0.173 (0.015) <11766>	0.166 (0.019) <11197>	0.172 (0.021) <12512>	0.180 (0.025) <10596>	0.193 (0.029) <10244>	0.203 (0.026) <8368>	0.221 (0.041) <7028>	0.232 (0.047) <6508>	0.190 (0.036) <113954>
STIG	0.207 (0.042) <6137>	0.198 (0.032) <6208>	0.183 (0.019) <7587>	0.185 (0.012) <8416>	0.173 (0.017) <9241>	0.164 (0.015) <9402>	0.176 (0.014) <8324>	0.174 (0.016) <7894>	0.176 (0.015) <7029>	0.179 (0.018) <6301>	0.186 (0.029) <5016>	0.211 (0.033) <4802>	0.182 (0.026) <86357>
WASH	0.191 (0.023) <5476>	0.187 (0.024) <4994>	0.178 (0.021) <6678>	0.168 (0.012) <6192>	0.160 (0.011) <7354>	0.156 (0.012) <6719>	0.157 (0.013) <6948>	0.152 (0.013) <6975>	0.156 (0.009) <7256>	0.165 (0.009) <6183>	0.178 (0.015) <5126>	0.191 (0.031) <5009>	0.168 (0.021) <74910>

Monthly albedo average, standard deviation and number of observations for each station

Figure 4. Table of albedo averages, standard deviations (in parentheses), and total number of observations used to produce the result (in greater than/less than signs).

maximums and minimums were computed for each of the 12 stations. Because of these data procedures that selected for albedo from the relatively flat bottom of the curve when sun angles were highest off the horizon, albedo was not normalized for sun angle. Furthermore, since this project aims to report the actual albedo as recorded, and this value does in fact change throughout the day with sun angle, the daily variations that do exist in the dataset were regarded as integrally part of the final results.

5. RESULTS

A table of monthly averages, standard deviations, and total number of observations of albedo for each station is presented (Figure 4). Overall the albedo averages are in the range of 0.15 and 0.22. The results show that an annual maximum of albedo occurs in the winter, when vegetation is dormant, and an annual minimum occurs in late spring and early summer when the vegetation is greenest. There is also a secondary max in late summer, a climatologically dry time of year for Oklahoma. Figure 5 shows the month to month averages of albedo for five stations in the central tier of Oklahoma’s climate divisions (4, 5 and 6) throughout the project. Standard deviations for these stations for the same time span are presented in figure 6. The highest standard deviations of close to 0.05 (in January and February) are caused by snow dramatically increasing the albedo over what would otherwise be present on those days. The lowest standard deviations are found in summer when the character of the vegetation is not changing significantly.

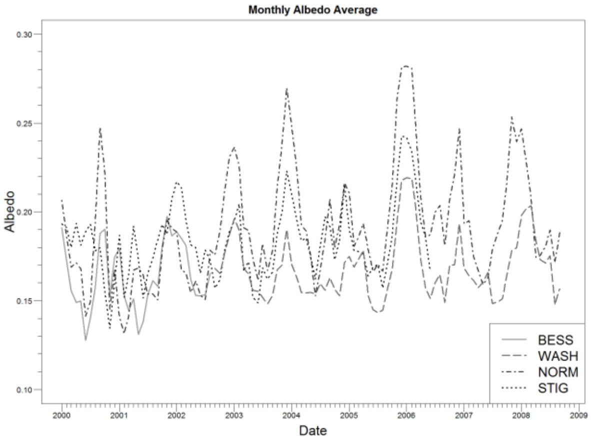


Figure 5. Monthly averages for the five stations in the central tier of climate divisions, showing the month to month variability in albedo average. Note the strong winter peaks outside of the growing season.

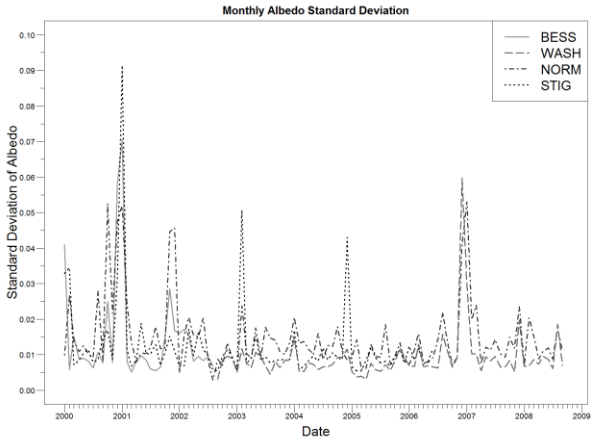


Figure 6. Monthly averages for the five stations in the central tier of climate divisions, showing the month to month standard deviation in albedo average. Note the spikes in the winter particularly for the stations with climatologically more snow.

Significant station to station variability was also found, as can be seen in Figure 7. This figure show the monthly albedo average for the northern, central, and southern tiers of Oklahoma’s climate divisions respectively. The variability between the stations did not appear to follow any strong geographic pattern, and a qualitative analysis using imagery of the sites reveals that these differences are likely partially attributable to soil color. Greenness of vegetation is another major

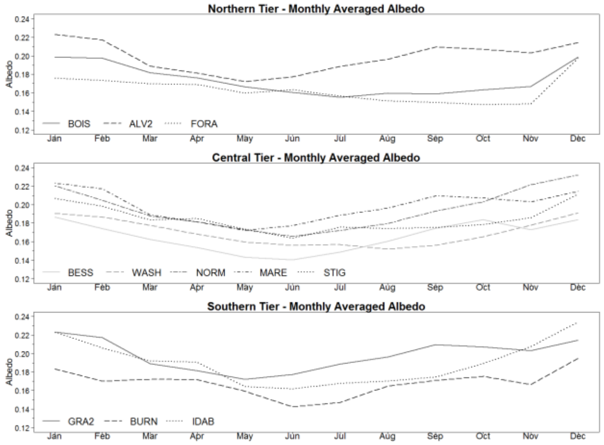


Figure 7. Albedo averages for each tier of climate divisions. Albedo is shown to be below 0.23 for averages in each month at all stations. Also, note the significant seasonality.

factor in the measured albedo, and this varies significantly from season to season as mentioned above. Furthermore albedo is related to soil water amounts for bare soil as well (Idso et al., 1975). All of these elements contribute to changes in albedo between the stations.

6. CONCLUSIONS

The average albedos are all below the 0.23 constant set by the American Society of Civil Engineers, indicating that current potential evapotranspiration estimates made using this number would not be indicative of the true potential evaporation at the sites analyzed. The results also show a range of albedos across generally the same landcover type (prairie grass) that is found at many of the Mesonet stations, indicating that schemes that do nothing more than assign albedo values based on a landcover scheme may not be accurate. However, it should be kept in mind that all results presented are for native vegatation, and considered accordingly. Surrounding farm fields may impact the results somewhat, as the pyranometer field of view is 180 degrees, but the strongest influence on the readings comes from immediately beneath the pyranometer. Thus, the farm fields surrounding the sites may not be well represented in the dataset, which is especially important to note in the winter wheat belt of Oklahoma, where the maximum of greenness occurs in late spring, then when the fields are harvested in June they lay bare until the next fall’s planting season. Nonetheless, the results presented here are valuable in their continuity in time and geographical spread across the state of Oklahoma.

7. ACKNOWLEDGEMENTS

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