Local-scale Validation of the Surface Observation Gridding System with *In Situ* Weather Observations in a Semiarid Environment

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ABSTRACT

While the Surface Observation Gridding System (SOGS) provides spatially continuous models of meteorological conditions, little work has been done to independently validate SOGS data for site-specific research and as a result, a single nearby weather station is commonly selected instead. This study sought to determine 1) local-scale accuracy of SOGS data through correlation with independent, *in situ* weather station measurements, and 2) local-scale accuracy of SOGS data relative to a nearby weather station. Correlations between SOGS data and *in situ* weather observations and between *in situ* weather observations and a nearby weather station were examined in a semi-arid environment of southeastern Idaho over the 2006 growing season. Results indicate both SOGS and nearby weather station data were significantly correlated with *in situ* weather station measurements. While temperature correlations between *in situ* and the nearby weather station were slightly greater compared to SOGS, SOGS data appeared to be a better predictor of precipitation. This suggests the use of a nearby weather station is appropriate for local temperature parameters, but precipitation parameters are better estimated using SOGS data. Overall, the validation of the SOGS weather models closely agreed with independent, *in situ* weather measurements and as a result, greater confidence can be placed in the accuracy of the productivity, biomass, and global climate change models derived from these data.

KEYWORDS: raster, climate, SOGS, global climate change

INTRODUCTION

Models of climate and meteorological conditions are important to our understanding of various ecosystem processes and driver variables like primary productivity. However, accurate spatially-continuous climate models with high-temporal resolution (e.g. daily) are rare (Running *et al.* 1987, Thornton *et al.* 2000) leaving research scientists no alternative but to use 'locally' available weather station data. These data are assumed to accurately characterize 'nearby' study sites, but this assumption may go untested. In some cases, the assumption is valid especially where the study site is reasonably close to the weather station and in areas of minimal topographic relief. In other cases, this assumption is questionable when study sites are more distant from weather stations and in mountainous areas of high topographic relief. In such areas, temperature, humidity, and precipitation are all influenced by differences in elevation resulting in weather events that are sometimes vastly different than those found at 'nearby' weather station.

The most recent development of spatially-continuous, global primary productivity models are those derived from the Moderate-resolution Imaging Spectroradiometer (MODIS). MODIS is a high-temporal resolution sensor aboard the National Aeronautics and Space Administration (NASA) Earth Observing System Terra and Aqua satellites which were launched into space in 1999 and 2002, respectively. The MODIS sensor captures data in 36 spectral bands (0.4 µm to 14.4 µm) and at various spatial resolutions ranging from 250 m to 1000 m. MODIS images the entire Earth every 1 to 2 days and was designed to provide broad-scale measurements of global dynamics (NASA 2007a). As a result of these advances, the reliable production of repeatable and consistent measures of the global terrestrial ecosystem began (Running *et al.* 2004).

With the availability of satellite measurements of global vegetation, weekly global gross primary productivity (GPP) models became possible (Running *et al.* 2004). Subsequently, weekly GPP could then be used to calculate global annual net primary productivity (NPP) (Running *et al.* 2004). These products are relevant to global climate change as more than one climate study has suggested that temperature increases due to the radiative forcing caused by increased atmospheric carbon may lead to changes in ecosystem production (e.g., NPP) and plant species composition (Berry and Bjorkman 1980, Bounoua et al 1999). Such changes will necessarily alter primary productivity curves and may cascade other effects throughout the environment. For this reason, accurate climate and meteorological inputs are ever more important.

The NASA Data Assimilation Office (DAO) collects global surface weather data from all available weather sources and interpolates these point data to produce a raster dataset of the global climatic conditions at 1º by 1.25º resolution. This dataset is then used by MODIS algorithms to generate 1) daily 24-hour average temperature, 2) daily 24-hour minimum temperature, 3) actual vapor pressure, and 4) incident shortwave solar radiation (Running *et al.* 2004). These meteorological data are then used to generate daily GPP estimate at 1 km^2 resolution. The meteorological data, however, have not been well validated, especially at local scales, although other MODIS products have been validated including the MODIS-derived albedo values (Barnsley *et al.* 2000), MODIS bidirectional reflectance distribution function (BRDF), broadband albedos, nadir BRDF-adjusted reflectance (Liang *et al.* 2002), MODIS-based sea surface temperature (Minnett *et al.* 2002), MODIS Normalized Difference Vegetation Index, Leaf Area Index, fraction of absorbed photosynthetically active radiation (Huemmrich *et al.* 2005), and gross primary productivity (Heinsch *et al.* 2006).

Heinsch *et al.* (2006) demonstrated that the NASA DAOs GPP estimates had 28% error and noted that the DAOs global meteorological dataset plays an important role in the accuracy of the GPP algorithm (Heinsch *et al.* 2006). Moreover, another recent study indicated that the NASA DAOs GPP and NPP estimates were considerably different compared to other GPP and NPP estimates driven by meteorological data from European Centre for Medium-Range Weather Forecasts and National Centres for Environmental Prediction/National Centre for Atmospheric Centre (Zhao and Running 2006). This study also concluded that inaccurate meteorological data can introduce substantial error in the accuracy of the GPP and NPP estimates and emphasized the need to minimize these errors. Zhao *et al.* (2005) suggested that the difference in spatial resolution between the MODIS products and DAOs meteorological dataset had significant impacts on the GPP and NPP estimates and interpolated the DAOs meteorological data to the 1-km MODIS pixel level to improve the accuracy of the MODIS products.

Today, several important products derived from MODIS imagery (gross primary productivity [GPP] and net primary productivity [NPP]) use the Surface Observation Gridding System (SOGS) dataset (NTSG 2007). Jolly *et al.* (2005) first suggested the SOGS approach to improve the availability and accuracy of meteorological data. This approach uses a relational database to store point information and interpolates the meteorological conditions from point-source data to provide spatially-continuous meteorological raster layers (1000m x 1000m) such as daily minimum temperature, maximum temperature, precipitation, humidity, and solar input. The SOGS estimates are considered experimental (NASA 2007b) and thus far, SOGS as well as other meteorological inputs used to calculate MODIS products have only been evaluated and validated across the United States indirectly (i.e., using other derived models) and at coarse scales (Zhao *et al.* 2005, Jolly *et al.* 2005). While the reported accuracy of the validated meteorological inputs may be acceptable at regional or global scales, large inaccuracies might exist at a local scale, especially in terrain with large topographic variation or areas located along abrupt climatic gradient zones (Zhao *et al.* 2005). Consequently, site-specific, local-scale validation of the SOGS model is needed, especially in mountainous, semi-arid environments such as those found in southeastern Idaho.

Southeastern Idaho is a region where relatively flat high-desert plains exist (the Snake River Plain) alongside mountain ranges. The economy of this semi-arid region is varied, but geographically dominated by agriculture and ranching industries. For these reasons, southeastern Idaho is especially appealing for researchers concerned with the effects of drought, global climate change, and desertification on rangeland ecosystems. To fully understand these diverse rangelands and to enable accurate forecast of rangeland conditions, accurate weather models are imperative.

The objectives of this study were: 1) to determine the accuracy of SOGS meteorological data for site-specific, local-scale research projects in southeastern Idaho using independent, *in situ* weather station measurements, and 2) to determine if SOGS data are more accurate and, therefore, more appropriate to use, relative to meteorological data from a nearby weather station. The nearby weather station was also independent of the SOGS dataset and the data from this station was not used as part of the SOGS network. We present this paper as a case study that might be useful in further validating the recentlydeveloped SOGS meteorological data at a local scale. This case study may also assist other local-scale studies choose the appropriate meteorological data as inputs for other models.

METHODS

Study Area

Data were collected at the O'Neal Ecological Reserve, an area of sagebrush-steppe rangelands in southeastern Idaho approximately 30 km southeast of Pocatello, Idaho (42° 42' 25''N 112° 13' 0'' W), where many local-scale rangeland studies are being conducted (Figure 1). The O'Neal Ecological Reserve (http://www.isu.edu/departments/CERE/o'neil.htm) was donated to the Department of Biological Sciences, Idaho State University by Robin O'Neal. This 50 ha site, located along the Portneuf River, contains riparian areas in contrast with typical sagebrush steppe upland areas located on higher elevation lava benches. The O'Neal Ecological Reserve receives <0.38 m of precipitation annually (primarily in the winter) and is relatively flat with an elevation of approximately 1400 m. The dominant plant species include big sagebrush (*Artemisia tridentata*) with various native and non-native grasses and forbs, including indian rice grass (*Oryzopsis hymenoides*) and needle-and-thread (*Stipa comata*).

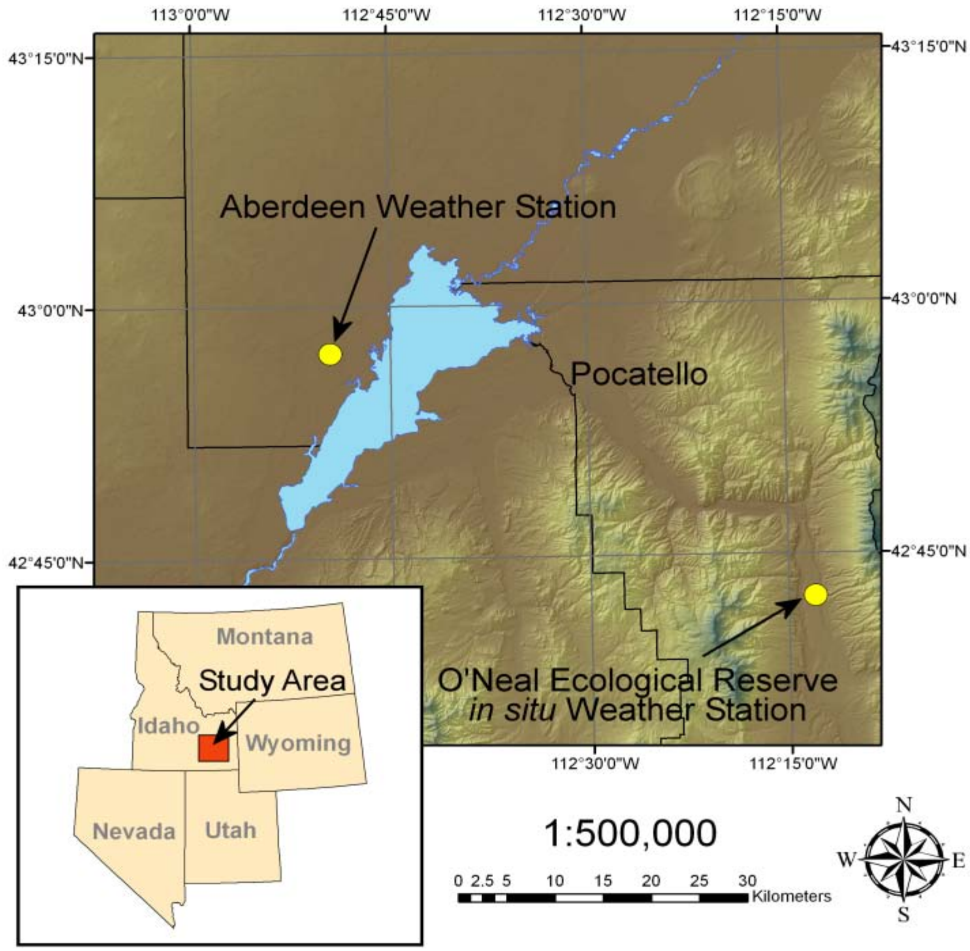

Figure 1. Location of the two independent weather stations used in this study.

In Situ Weather Station

Part of the instrumentation present at the O'Neal Ecological Reserve is a Davis Weather Station (http://www.davisnet.com). The Davis Vantage Pro2 sensor meets or exceeds the specifications set forth by the GLOBE program (http://www.globe.gov). GLOBE is an international science and education program that promotes the investigation of earth and environmental systems science by students, teachers, and scientists. To accomplish this vision, GLOBE has designed a number of data collection protocols, which include the collection of weather observations with Davis and other alternative equipment.

Since June-2006, the O'Neal weather station has measured and recorded observations every two hours describing temperature, humidity, barometric pressure, wind speed and direction, precipitation, solar radiation, solar energy, and soil moisture. In addition, the Vantage Pro2 weather sensor also calculates dew point, various heat indices, and evapotranspiration (ET_0). Evapotranspiration is calculated and recorded as hourly potential ET_0 (in mm) using measured and calculated variables (Jensen *et al.* 1990, Davis 2006). Specifications for all data measurement are given in Table 1. We used a 100-day sampling period beginning on 14-June-2006 and ending on 21-September-2006 for the comparison of SOGS weather data and the *in situ* weather data. This sampling period covered much of the growing season and captured peak biomass production.

Table 1. Specifications for the weather sensors used at the O'Neal Ecological Reserve (Davis Vantage Pro 2) and Aberdeen weather station, Idaho USA.

	O'Neal Ecological Reserve			Aberdeen Weather Station		
Measurement	**Setting**	**Resolution**	**Accuracy**	**Setting**	**Resolution**	**Accuracy**
Temperature	Celsius (˚C)	0.1 ˚C	+/-0.5˚C	Fahrenheit (˚F)	0.01 ˚F	+/-0.1 ˚F
Humidity	Percent (%)	1.0%	+/-5.0%	Percent (%)	0.01%	+/- 3.0%
Barometric pressure	Inches of mercury (Hg)	0.01" Hg	+/-0.03" Hg	---	---	---
Wind speed	Meters/second (m/s)	0.1 m/s	+/- 5.0%	Miles/ hour (mph)	0.01 mph	+/- 1.0%
Precipitation	Millimeters (mm)	0.2 mm	+/- 4.0%	Inches (In)	0.01"	+/- 0.5%
Solar radiation (global and diffuse)	Watt/square meter (W/m^2)	1 W/m^2	+/- 5.0%	Langleys (Ly)	0.01 Ly	+/- 5.0%
Solar energy	Langleys (Ly)	0.1 Ly	+/- 5.0 %	---	---	---

Aberdeen Weather Station

The Aberdeen weather station in southeastern Idaho was used as the independent, nearby weather station in this study. It is a part of Agrimet and the Pacific Northwest Cooperative Weather Network (http://www.usbr.gov/pn/agrimet/) and has been in operation since 20-March-1991. The station is located approximately 34 km northwest of Pocatello, Idaho (42° 57' 12"N 112° 49' 36" W, Elevation: 1341 m) and 57 km northwest of the O'Neal Ecological Reserve (Figure 1). The Aberdeen weather station is within an area of flat topography immediately adjacent to agricultural fields. The instrumentation present at the Aberdeen weather station measures temperature, relative humidity, wind speed and direction, precipitation, solar radiation, soil moisture, and soil temperature (http://www.usbr.gov/pn/agrimet/aginfo/station_params.html#abei). In addition, the Aberdeen weather station also calculates evapotranspiration using the 1982 Kimberly-Pennman equation (Penman 1948, Penman 1956, Wright 1982, Norihiro *et al.* 2002). Specifications for all data measurements at this station are given in Table 1. For the comparison of the *in situ* weather data and the Aberdeen weather data, we used a sampling period of 100 days beginning on 14-June-2006.

SOGS Data and Imagery

SOGS raster layers (1000m x 1000m pixels) were acquired through the Numerical Terradynamic Simulation Group (NTSG) at the University of Montana. The acquisition included daily predictions of temperature, precipitation, dew point, and solar radiation models derived from the SOGS algorithms. Each of these raster layers was delivered in Universal Transverse Mercator (UTM) NAD 83 projection and datum. All analyses were completed in the 'as-delivered' format using the values from the pixel containing the weather station's location.

Data Analysis

The location (point vector data) of the *in situ* weather station and Aberdeen weather station were projected into UTM NAD 83 using ESRIs ArcGIS 9.2 to match the geographic reference system used by the SOGS raster layers. Daily minimum, maximum, and average temperatures, daily total precipitation, and daily total solar energy were calculated from the two-hour recordings made by the Davis Vantage Pro2 weather sensor at the O'Neal Ecological Reserve using the ArcGIS 9.2 summarize function. The SOGS algorithm for solar radiation is an expression of solar energy in MegaJoules per square meter per day ($MJ/m^2/day$). To better compare solar energy values, the Davis Vantage Pro2 weather station data (recorded in Langleys (Ly) and calculated as Ly/day) was converted to $MJ/m^2/day$ using 1 Ly/day = 0.0419 $MJ/m^2/day$ (Ward and Trimble 2004). To compare the observed *in situ* weather data with the predicted SOGS data, corresponding SOGS pixel values (n = 100, 14-June-2006 through 21-September-2006) were extracted using the ArcGIS 9.2 data extraction tool (sample). This routine was completed for the six meteorological variables of interest: daily minimum temperature, daily maximum temperature, daily average temperature, precipitation, dew point, and solar radiation. The extracted data were saved to database tables and then imported into SPSS 14.0 for statistical analysis.

We first compared the observed *in situ* values of the six meteorological variables (daily minimum temperature, daily maximum temperature, daily average temperature, precipitation, dew point, and solar radiation) with the SOGS-predicted values to determine the accuracy of the SOGS meteorological data at a local scale. We built a linear regression model for each of the six variables of interest. The observed *in situ* values (n=100) for each variable were the response variables, while the SOGS-predicted values were the predictor variables.

We then compared the observed *in situ* values of daily minimum, maximum, and average temperatures, and precipitation with the observed weather data at the Aberdeen weather station. We again built a separate linear regression model for each of the four meteorological variables of interest. The observed values at the *in situ* weather station (*n*=100) for each variable were the response variables, while the observed values at the Aberdeen weather station were the predictor variables for each model. The objective of this modeling exercise was to determine if the meteorological data from a nearby station was more or less accurate than the SOGS-predicted data. To compare the predictive accuracies and to inform preferences between SOGS meteorological data and the nearby weather station data, we compared the mean squared deviation (MSD; the sum of squared deviations between predicted and observed values, divided by the number of observations) in addition to the coefficient of determination (R^2 or the proportion of variability explained by the model) of each model. MSD has been suggested to be more informative in model comparisons and model evaluations than coefficient of determination (Freund and Simon 1991, Gauch *et al.* 2003).

RESULTS

When the observed *in situ* values were examined with the SOGS-predicted values, average daily temperature had the highest coefficient of determination (0.93) and the SOGS values were a significant predictor variable (Table 2). Dew point, daily maximum temperature, and precipitation had the next highest coefficients of determination and the SOGS-generated estimates were all statistically significant as predictor variables (Table 2). SOGS daily minimum temperature was also a statistically significant predictor variable, but had a lower coefficient of determination of 0.79 compared to these variables. Solar energy had a low coefficient of determination of 0.24, although it was a significant predictor variable.

Table 2. Results of linear regression analysis (P < 0.0001) between *in situ* weather conditions (O'Neal Ecological Reserve, Idaho, USA), predicted SOGS values (*n* = 100), and the Aberdeen weather station, Idaho USA (*n* = 196).

	O'Neal Ecological Reserve and SOGS		O'Neal Ecological Reserve and Aberdeen Weather Station	
Weather variable	**Coefficient of determination (R^2)**	**Mean Squared Deviation (MSD)**	**Coefficient of determination (R^2)**	**Mean Squared Deviation (MSD)**
Minimum temperature	0.79	3.42	0.96	2.62
Maximum temperature	0.87	3.62	0.98	2.69
Average temperature	0.93	1.42	0.98	1.76
Precipitation	0.83	0.87	0.33	4.72
Dew point	0.90	1.49	---	---
Solar energy	0.24	20.37	---	---

When the observed *in situ* values were compared to the weather data from a nearby weather station, all predictor variables were also statistically significant (Table 2). Minimum, maximum, and average daily temperatures had high coefficients of determination of 0.96, 0.98, and 0.98, respectively. However, precipitation had an adjusted R^2 of only 0.33, although it was statistically significant (Table 2). Compared to the SOGS-predicted average temperature values, the Aberdeen weather station daily average temperature had greater correlation with the observed daily average temperature values at the O'Neal *in situ* weather station (R^2 of 0.98 versus 0.93). However, the SOGS-predicted daily average temperature produced a lower MSD compared to the Aberdeen weather station daily average temperature (1.76 versus 1.42). Daily minimum and maximum temperatures at the Aberdeen weather station also had greater correlation, compared to the SOGS-predicted values, with the observed *in situ* values. Aberdeen weather station daily minimum and maximum temperatures also produced lower MSD compared to the SOGS-predicted values, indicating that the regression models with Aberdeen weather station data performed better than the SOGS-based models (Table 2). In contrast with the temperature variables, the SOGS-predicted precipitation values had much greater correlation, compared to the Aberdeen weather station precipitation values, with the observed *in situ* precipitation values. The SOGS-based regression model of precipitation predictions also produced much lower MSD compared to the Aberdeen weather station precipitation predictions (Table 2) indicating that SOGS precipitation prediction performed much better than the nearby station data.

DISCUSSION

Our results indicate that SOGS predictions of daily average, maximum, and minimum temperature, dew point, and precipitation performed well at a local scale. While the SOGS predictions of solar energy did not perform well at a local scale, the low coefficient of determination was not surprising. The SOGS algorithm models solar energy as incident shortwave radiation (100-2000nm) and these data are not sensor-derived (Zhang *et al.* 2004). Rather, the solar energy model represents a derived surface-meteorological variable which is required for several MODIS algorithms such as gross primary productivity. As there generally are no daily measured solar radiation data from standard weather stations, the SOGS solar energy model is semi-empirically derived using elevation, latitude, and several spatially-interpolated environmental variables including the range of daily diurnal temperature, humidity, and precipitation (Thornton and Running 1999, Jolly *et al.* 2005).

Data from the *in situ* weather station, the Aberdeen weather station, and SOGS dataset are given in Figure 2 for comparison. Most of the graphs exhibit very similar curves illustrating the high correlations calculated in these analyses with the solar energy curves perhaps being the most interesting (Figure 2b). An offset was observed between weather values during the first two weeks in which the *in situ* weather station was in operation (13-June to 3-July). This offset may be explained as the new solar radiation sensor requires a break-in period before it functioned correctly. After the initial break-in period, the correlation between the datasets was much improved (R^2=0.56). Temperature curves were very similar for all three datasets (Figure 2d-f) as well as the dew point curves for the *in situ* weather station and SOGS dataset (Figure 2a)(note: dewpoint was not reported for the Aberdeen weather station). Figure 2c illustrates a better correlation between *in situ* weather station precipitation data and SOGS precipitation data compared to the correlation between *in situ* weather station precipitation data and the Aberdeen weather station precipitation data. The relationship curves reveal relatively good correspondence for the date when the precipitation events occurred but a low correspondence in the quantity of precipitation recorded for each event. This suggests that the weather stations were in close enough proximity to receive rainfall from the same weather events, but the differences in terrain may have caused differences in the actual amount of precipitation received.

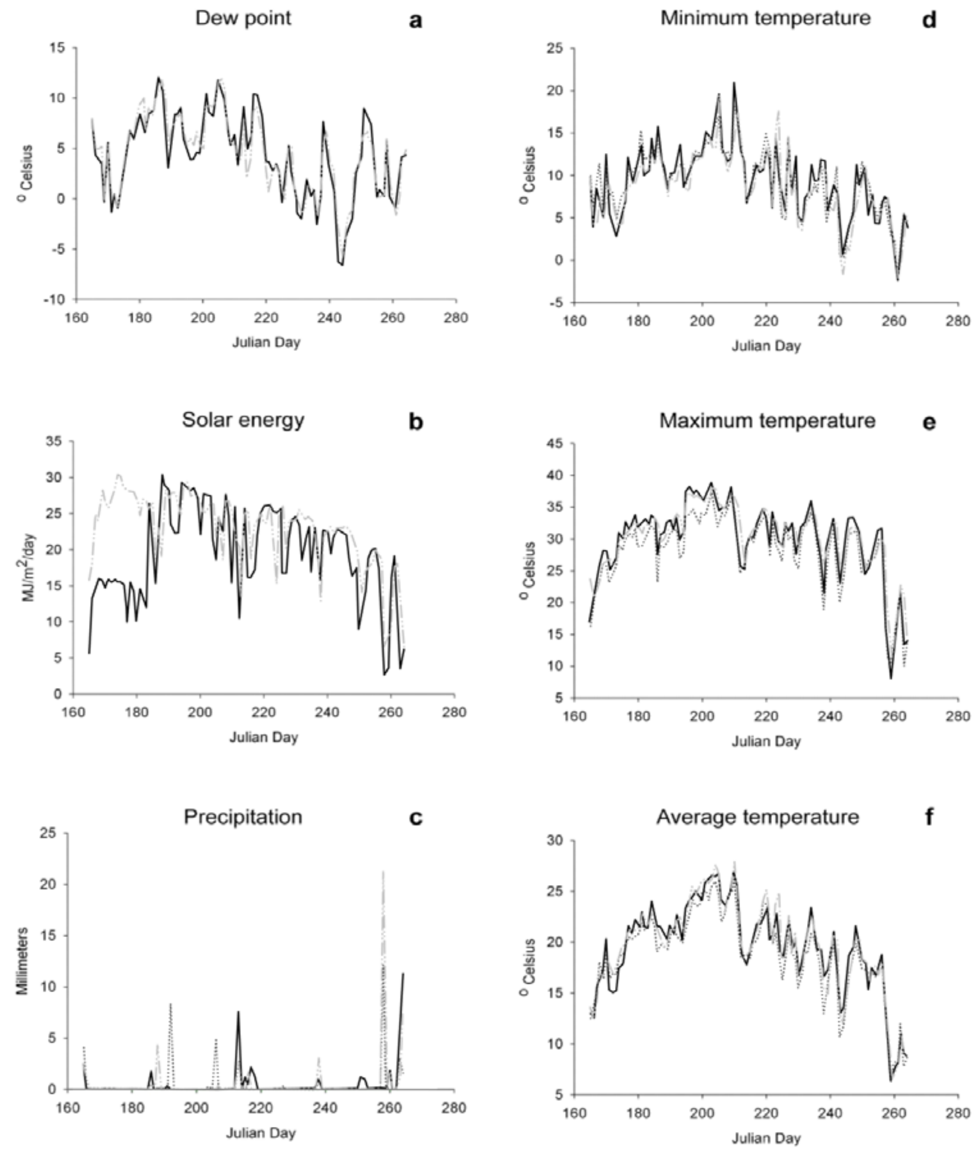

Figure 2. Temporal comparison between weather variables from the O'Neal Ecological Reserve (Idaho, USA) *in situ* weather station (solid black line), the predicted SOGS data (dashed grey line), and the nearby weather station in Aberdeen, Idaho (USA) (dotted grey line). Dew point and solar energy data were not available for the Aberdeen weather station and so are not shown in a or b.

Model comparisons indicate the Aberdeen weather station predictions of daily minimum and maximum temperatures were better than the SOGS predictions. These results suggest that site-specific, local-scale research at the O'Neal Ecological Reserve could use the daily minimum and maximum temperature measurements from the nearby weather station rather than the SOGS predictions. However, the SOGS predictions of precipitation at the O'Neal Ecological Reserve were far better than the precipitation predictions from the Aberdeen weather station data. This suggests that in the semi-arid rangelands of southeastern Idaho with variable terrain between the nearby weather station and research site, the SOGS prediction of precipitation should be used. This validation result of the SOGS precipitation prediction at a local scale is consistent with validation results of SOGS precipitation predictions for the broader-scale, continental United States (Jolly *et al.* 2005). Our regression models and model comparisons did not indicate a clear preference in daily average temperature predictions between the SOGS data and the nearby weather station data. It appears that both predictions had high correlation with the *in situ* measurements suggesting either prediction could be used. In general, it might seem that an *in situ* weather station is the better data source, but the authors suspect that for spatially-extensive study areas, data from a single weather station might introduce similar inaccuracies as demonstrated with the nearby weather station data used in this study. For this reason, there exists a need for a spatially-continuous and accurate weather dataset. The SOGS dataset provides one such source. In addition to the accuracy issues, the authors also note that the use of the SOGS dataset ensures a consistent data source.

The results presented in this paper indicate SOGS is an accurate spatially-continuous dataset well suited to modeling primary productivity at local scales. In addition, the SOGS dataset appears to offer great potential for climate change modeling. However, future studies should first validate the correspondence between these same weather parameters over increasingly larger areas before applying SOGS data to model climate change at continental scales.

CONCLUSIONS

This study examined the correlation between SOGS data and *in situ* weather observations and the correlation between a nearby weather station and *in situ* weather observations over the 2006 growing season at the O'Neal Ecological Reserve in southeastern Idaho. The results of this study indicate nearby weather station data has a slightly better correlation with *in situ* observations for most weather variables, while SOGS data has better correlations with *in situ* precipitation observations.

Modeling climate change and ecological processes frequently requires the use of weather data as a primary data input. The use of nearby weather stations may be acceptable in some cases, but the proximity of the nearby weather station to the study area and terrain characteristics between the weather station and study area might affect prediction accuracy especially those related to precipitation. In such cases, SOGS data could be used to improve results. The best solution to collect weather data input for modeling purposes might be the use of an *in situ* weather station, but for spatially extensive study areas, single point observations extrapolated over large areas will introduce the same inaccuracies as demonstrated with the nearby weather station used in this study. In contrast, the use of SOGS data ensures a consistency in source data that is spatially continuous.

Overall, the validation of the SOGS weather models closely agreed with the independent, *in situ* weather measurements. With these data, more accurate models of productivity and biomass are possible. In addition, the spatially-continuous SOGS data can fill an important niche in global climate change and environmental modeling efforts for local, regional, continental, and global scales providing accurate spatial and temporal weather data. However, further analysis is required to generalize these results over an entire year and across different spatial scales.

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LIERATURE CITED

Barnsley, M.J., P.D. Hobson, A.H. Hyman, W. Lucht, J.P. Muller and A. H. Strahler. 2000. Characterizing the Spatial Variability of Broadband Albedo in a Semi-desert Environment for MODIS Validation. Remote Sensing of Environment, 74: 58 – 8

Barrett, E.C. and L. F. Curtis. 1992. Introduction to Environmental Remote Sensing (London, England: Chapman & Hall, 3rd ed.) 426 pp.

Davis, 2006. Derived Variables in Davis Weather Products, Davis Corporation. Application note 28.

Freud, J.E. and G.A. Simon, 1991. Statistics: A First Course (Englewood Cliffs, New Jersey, USA: Prentice-Hall, 5th ed.) 584 pp.

Gauch, Jr. H.G., J.T.G. Hwang, and G.W. Fick, 2003. Model Evaluation by Comparison of Model-based Predictions and Measured Values. Agronomy Journal, 95: 1442 – 1446

Heinsch, F.A., M. Zhao, S.W. Running, J.S. Kimball, R.R. Nemani, K.J. Davis, P.V. Bolstad, B.D. Cook, A.R. Desai, D.M. Ricciuto, B.E. Law, W.C. Oechel, H. Kwon, H. Luo, S.C. Wofsy, A.L. Dunn, J.W. Munger, D.D. Baldocchi, L. Xu, D.Y. Hollinger, A.D. Richardson, P.C. Stoy, M.B.S. Siqueira, R.K. Monson, S.P. Burns, and L.B. Flanagan, 2006. Evaluation of Remote Sensing Based Terrestrial Productivity from MODIS Using Regional Tower Eddy Flux Network Observations. IEEE Transactions on Geoscience and Remote Sensing, 44: 1908 – 1925

Huemmrich, K.F., J.L. Privette, M. Mukelabai, R.B. Myneni, and Y. Knyazikhin, 2005. Time-series Validation of MODIS Land Biophysical Products in a Kalahari Woodland, Africa. International Journal of Remote Sensing, 26: 4381 – 4398

Jensen, M.E., R.D. Burman, and R.G. Allen, 1990. Evapotranspiration and Irrigation Water Requirements. ASCE Manuals and Reports on Engineering Practice, 70

Jolly, W.M., J.M. Graham, A. Michaelis, R. Nemani, and S.W. Running, 2005. A Flexible, Integrated System for Generating Meteorological Surfaces Derived from Point Sources Across Multiple Geographic Scales. Environmental Modeling and Software, 20: 873 – 882

Liang, S., H. Fang, M. Cheng, C.J. Shuey, C. Walthall, C. Daughtry, J. Moriesette, C. Schaaf, and A. Strahler, 2002. Validating MODIS Land Surface Reflectance and Albedo Products: Methods and Preliminary Results. Remote Sensing of Environment, 83: 149 – 162

Lillesand, T.M. and R.W. Kiefer, 2000. Remote Sensing and Image Interpretation (New York, USA: John Wiley and Sons, 4th ed.) 724 pp.

Minnett, P.J., R.H. Evans, E.J. Kearns, and O.B. Brown, 2002. Sea-surface Temperature Measured by the Moderate Resolution Imaging Spectroradiometer (MODIS). In Proceedings of the IEEE Geosciences and Remote Sensing Symposium, Toronto, Canada, 2002. IGARSS '02. 2002 IEEE International**,** pp. 1177-1179, vol.2

NASA, 2007a. MODIS Website, National Aeronautics and Space Administration. URL = http://modis. gsfc.nasa.gov/ visited 01-October-2007

NASA, 2007b. Ecocast – Products, National Aeronautics and Space Administration. URL = http://ecocast. arc.nasa.gov/content/view/104/131/ visited 25-October-2007

Norihiro, K., K. Yasunori, and M. Takeshi, 2002. A Study of the Penmans Potential Evapotranspiration and the Real Evapotranspiration. Research Reports of the Kochi University, 51: 77-115

NTSG, 2007. Images Website – News Archive. Numerical Terradynamic Simulation Group. URL = http://images.ntsg.umt.edu/news_archive.php?page=1&numbRecords=8 visited 23-August-2007

Penman, H.L., 1948. Natural Evaporation from Open Water, Bare Soil, and Grass. In Proceedings of the Royal Society of London, A (194):120 – 145

Penman, H.L., 1956. Estimating Evaporation. Transactions of the Trans-American Geosphysica.Union. 37: 43 – 50

Running, S.W., R.R. Nemani, and R.D. Hungerford, 1987. Extrapolation of Synoptic Meteorological Data in Mountainous Terrain and its use for Simulating Forest Evaporation and Photosynthesis. Canadian Journal of Forest Research, 17: 472 – 483

Running, S.W., R.R. Nemani, F.A. Heinsch, M. Zhao, M. Reeves, and H. Hashimoto, 2004. A Continuous Satellite-derived Measure of Global Terrestrial Primary Production. BioScience, 54: 547–560

Thornton, P.E. and S.W. Running, 1999. An Improved Algorithm for Estimating Incident Daily Solar Radiation from Measurements of Temperature, Humidity, and Precipitation. Agricultural and Forest Meteorology, 93: 211 – 228

Thornton, P.E., H. Hasenhauer, and M.A. White, 2000. Simultaneous Estimation of Daily Solar Radiation and Humidity from Observed Temperature and Precipitation: An Application over Complex Terrain in Austria. Agricultural and Forest Meteorology, 104: 255 – 271

Ward, A.D. and S.W. Trimble, 2004. Environmental Hydrology (Boca Raton, Florida, USA: Taylor and Francis-CRC Press

Wright, J.L., 1982. New Evapotranspiration Crop Coefficients. Journal of Irrigation and Drainage Division -ASCE, 108: 57 – 74

Zhang, Y., W.B. Rossow, A.A. Lacis, V. Oinas, and M.I. Mischenko, 2004. Calculation of Radiative Fluxes from the Surface to Top of Atmosphere Based on ISCCP and other Global Data Sets: Refinements of the Radiative Transfer Model and the Input Data. Journal of Geophysical Research-Atmospheres, 109: D19105

Zhao, M., F.A. Heinsch, R.R. Nemani, and S.W. Running, 2005. Improvement of the MODIS Terrestrial Gross and Net Primary Production Global Data Set. Remote Sensing of Environment, 95: 164 – 176

Zhao, M. and S.W. Running, 2006. Sensivity of Moderate Resolution Imaging Spectroradiometer Terrestrial Primary Production to the Accuracy of Meteorological Reanalyses. Journal of Geophysical Research, 111: 1 – 1

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