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In-situ air temperature and humidity measurements over diverse landcovers in Greenbelt, MD Nov. 2013 – Nov. 2015

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Abstract

As our climate changes through time there is an ever increasing need to quantify how and where it is changing so that mitigation strategies can be implemented. Urban areas have a disproportionate amount of warming due, in part, to the conductive properties of concrete and asphalt surfaces that make up an urban environment. The NASA Climate Adaptation Science Investigation working group at Goddard Space Flight Center in Greenbelt MD conducted a study to collect temperature and humidity data at 15 minute intervals from 12 sites on center. These sites represented the major surface types on center: asphalt, building roof, grass field, forest, and rain garden. The data show a strong distinction in the thermal properties of these surfaces on the center and the difference between the average value for the center compared to a local meteorological station. The data have been submitted to Oak Ridge National Laboratory Distributed Active Archive Center (ORNL-DAAC) for archival in comma separated value (csv) file format http://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1319.

Keywords

Remote sensing, urban heat island, temperature, field data, microclimate.

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Introduction

While leaders around the world are deliberating about the best ways to slow the rate of climate change through reductions in greenhouse gas emissions, the time to develop and implement adaptation strategies is now. Executive Order (EO) 13693 directs Federal agencies to incorporate climate-resilient design and management elements into the operation, repair, and renovation of existing agency buildings and the design of new agency buildings. Climate change in the Washington DC metro area will impact facility operations (e.g., stormwater management, energy supply and demand, cost of utilities), natural resource management (e.g., forest maintenance, invasive species control), mission infrastructure (e.g., labs, testing facilities, and computing capabilities), as well as the quality of life in the community (e.g., drinking water availability, wildfire risk). It is critical to plan for climate change impacts as part of established planning and budgeting cycles within and beyond NASA. US government agencies will need to implement short-term tactical changes while simultaneously planning for longer-term strategic adaptation measures. The Climate Adaptation Science Investigator (CASI) initiative focuses on bringing together NASA scientific expertise with its facilities and environmental planning organizations to ensure that the Center develops adaptation strategies for a changing climate.

The CASI working group was formed in 2010 with representatives from each center. The CASI team at Goddard Space Flight Center (GSFC) Greenbelt began working together in the fall of 2011 to discuss and consider problems and solutions for climate change impacts at GSFC-Greenbelt. This team meets monthly to consider how CASI can have a positive impact on the Center. After reviewing the information from other CASI workshops, the GSFC-CASI team concluded that there were two aspects of climate change that posed a direct and tangible risk to the ability of the Center to meet its mission in the future: the impact of rising temperatures on energy needs and the potential increase in frequency of high-intensity rainfall events. We held a

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two-day workshop to address these concerns with internal stakeholders at the GSFC Greenbelt campus. The primary goal of the workshop was to identify a path forward that would integrate climate change considerations in the Center Facilities Master Plan.

Based on climate predictions from NASA Goddard Institute for Space Studies (GISS), it is likely that GSFC-Greenbelt will experience increased temperatures and intensifying rainfall events. These two stresses will exacerbate problems with energy sustainability and with stormwater management (Table 1).

Table 1. Qualitative Changes in Extreme Events for GSFC Based on global climate model simulations, published literature, and expert judgment. Source: NASA GISS Likelihood definitions based on IPCC: >90% Very likely, >66% Likely, >50% More likely than not, 33 to 66% About as likely as not (Rosenzweig et al. 2014).

Event	Direction of Change	Likelihood
Heat Stress	Increase	Very Likely
Ice storms/freezing rain	Increase	About as likely as not
Snowfall frequency and amount	Decrease	Likely
Intense Precipitation Events	Increase	Likely
Drought	Increase	More likely than not

While the impacts of atmospheric climate change have been the subject of significant research, Urban Heat Island effects have been demonstrated to be equal in magnitude to climate change effects. The GSFC-CASI team performed a study to collect data to evaluate the contribution of various land cover types at the GSFC facility to urban heat island formation.

An urban heat island occurs when dense concentrations of built surfaces retain heat differently than their suburban or rural surroundings. Numerous studies have investigated this phenomena on large cities using satellite data and models (Chun and Guldmann 2014; Sun and

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Augenbroe 2014; Zhang et al. 2012), however these studies yield little information to support specific interventions on the local scale that would reduce urban heating. To improve understanding of urban heating, and potential mitigation strategies on the campus scale, we deployed and monitored 12 environmental monitoring sensors (temperature and relative humidity) on 5 different surface types around the center. The UHI study served as a bridging activity between the other GSFC-CASI activities related to building energy management analysis and the stormwater hydrological analysis. The goals of the UHI study were to collect data for a minimum of 1 year and have duplicate measurements over representative surface types on center.

Study site and equipment

NASA Goddard Space Flight Center is a controlled access facility (i.e. requires a badge to enter) located in the heavily developed suburbs of Washington, DC. Greenbelt, MD, is a mixed use area with retail and commercial office space intermixed with residential, both high density and single family homes (figure 1). The center itself is comprised of approximately 1300 acres with 5 main land cover types: urban/building, urban/road, forest, grass/field, wetland. The National Land Cover Database (NLCD; Homer et al., 2015) was used for land cover analysis. This dataset is designed to provide decadal land cover data for the conterminous United States. It is primarily based on decision-tree classification of Landsat data and is available at 30 m spatial resolution. In this study, the NLCD 2011 was downloaded and cropped to GSFC using property boundary shapefiles provided by the GSFC facilities management division. The area of each significant (≥5% of total area) land cover class represented in GSFC is displayed in Table 2, and the relative areas of each significant class are displayed in a pie chart in figure 2.

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Table 2: Total area of each land cover type for GSFC as determined by the NLCD.

Class	Loggers	Area (acres)
Developed, Open Space	5,6	184.14
Developed, Low Intensity	1,3,7	155.45
Developed, Medium Intensity		130.1
Developed, High Intensity	2,4,8,9	68.94
Deciduous Forest	12	346.49
Evergreen Forest	11	138.33
Mixed Forest	10	158.57
Other		113.2

For this study we purchased 12 "HOBO U23 Pro v2 External Temperature/Relative Humidity Data Logger - U23-002" to record data on the center. The loggers were programmed to record temperature and humidity at 15 minute intervals beginning at the start of an hour. In this way all loggers were recording at the same time. The loggers were mounted on posts at 2 meters height above the ground with the actual logger mounted inside a radiation shield to minimize direct sunlight on the probe (figure 3). The twelve loggers were deployed on 5 different surface types (figure 1) around the center: asphalt parking lot, bright surface roof, grass field, forest, and stormwater mitigation feature.

Data

The loggers were initialized in the office in September 2013. They were placed in a box with ventilation for 2 weeks on a shelf in the office to assess the amount of agreement between the loggers in a controlled environment. The box was moved to a garage with no temperature controls for an additional 2 weeks prior to being deployed in the field in late October, 2013. Data was downloaded every 2 – 3 weeks. A portable data shuttle was used to download data in the field and transfer it to a PC and a log of observations and dates of download was maintained (Appendix A). The loggers were retrieved in November 2015 after collecting data for 2 years continuously. Upon retrieval the loggers were placed in a box and stored in the same garage as

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prior to being deployed for 2 weeks. The box was moved to the climate controlled office for 2 more weeks after which data collection stopped. The information collecting during the pre- and post- deployment can be used to determine sensor to sensor agreement both before deployment and after retrieval. This will allow a user to assess the impact of 2 years in the field on sensor agreement and to put appropriate error bars on the analysis of the data.

Direct logger data is stored in proprietary file format with one file per logger per download. These data were converted to Microsoft Excel file format and compiled to a single data file with all 12 loggers and all dates for ease of use. The data are stored in 5 files 1 for each significant period of collection: office pre-calibration, garage pre-calibration, live data collection, garage post-calibration, and office post-calibration.

The full log of events is in the table in Appendix A but several notable events during the data collection are listed here:

- Data gap for all loggers occurred in January 2014 due to failure of data retrieval device
- Data gap for logger 6 occurred in April 2015
- Parking lot loggers were moved several times for safety during winter storm events
- Field loggers moved due to special event
- Effort was made to find suitable alternate location during each event

Discussion

GSFC-Greenbelt is a controlled access facility which means that admission is granted for official business only and is not open to the general public. This creates an ideal environment to take long running measurements on various surface types with minimal concern for vandalism and unintended interference from the general population. If a similar network was deployed in a

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typical urban environment the loggers could be exposed to more human interaction and generally a greater level of activity from vehicle and pedestrian traffic.

The period during which the data were collected was ideal for capturing a wide range of temperature conditions. The East coast experienced record cold as well as very warm conditions during 2014 (Trenary et al. 2015). Summer temperatures in 2015 were the hottest on record, although the weather in the Greenbelt area was only slightly above average.

Three diagnostic plots were generated to display the characteristics of the temperature and relative humidity data collected from the loggers. These plots represent 1) relative difference between GSFC and a local meteorological station; 2) relative difference between the loggers based on land cover type; 3) the min, max, and mean values for the center regardless of surface type.

The loggers were programmed to record data at 15 minute intervals. To analyze the data, the mean, maximum, and minimum were calculated individually for each logger. The results for all 12 loggers were then averaged to generate one set of summary data for GSFC. These are displayed in figure 4 a-b for the second year of data collection, and the mean values served as the GSFC data for figure 4 c-d. The other data used for figure 4 c-d was a local meteorological dataset, collected at the Beltsville Agricultural Research Center (BARC; http://www.ba.ars.usda.gov/weather/ba-weather). BARC maintains seven meteorological stations, and for this analysis data from the closest of these, Station #3 which is approximately 4 km from GSFC, was used. This data is also collected at 15 minute intervals, but daily summary statistics are available from the BARC data portal, so daily mean values were downloaded for the time period of the GSFC dataset. The difference between the average daily mean values for all of GSFC and the daily mean values for BARC was calculated, and the results are shown in figure 4 c-d for the second year of GSFC data collection. These plots show only the second year to improve readability, but it should be noted that the first year contains a data gap of approximately one month in length that is therefore not displayed. Finally, as described above, each logger was deployed in a distinct land cover type. The daily means were averaged together according to land cover, meaning that each value is the average of the daily mean values for all of the loggers deployed in that land cover type. The difference between this land cover average and the average value for all of the GSFC loggers was then calculated, and these results are displayed in figure 4 e-f for the second year of GSFC data collection.

Figure 4 shows, in general terms, what the data can describe. The data have been submitted to Oak Ridge National Laboratory Distributed Active Archive Center (ORNL-DAAC) for archival in comma separated value (csv) file format http://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1319. The data could be used as a validation dataset for a satellite-based study or could be used as a stand-alone study of the impact of surface type on heating in a campus setting.

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Date	Time	Offload?	Action	Comments
10/31/2013		X	Collection01: 10/28/13-10/31/13	
11/14/2013	12:51pm		Loggers 2&4 moved to field	
11/19/2013	9:15am		Loggers 2&4 moved back to lot	
11/19/2013		X	Collection02: 10/31/13-11/19/13	
12/04/21013		X	Collection03: 11/19/13-12/04/13	
12/18/2013		X	Collection04: 12/04/13-12/18/13	
1/2/2014	4:18pm		Loggers 2&4 moved to field	
1/6/2014	8:28am		Loggers 2&4 moved back to lot	
1/15/2014		X	Collection05: 12/18-1/15	
12/18/2013-01/03/2014			missing data	
1/20/2014	6:52-6:54pm		Loggers 2&4 moved to field	
1/27/2014	2:54pm		Loggers 2&4 moved back to lot	
1/30/2014	10:32am		Relaunched shuttle	
1/30/2014		X	Collection06: 01/15/14-01/30/14	
2/12/2014	4:35pm		Loggers 2&4 moved to field	
2/18/2014	1:00pm		Loggers 2&4 moved back to lot (not yet in correct spot)	
2/18/2014	1:30pm		Loggers 2&4 moved to spots in lot	
2/18/2014			Logger 2 surrounded by ice until 2/19?	
2/20/2014			Logger 3 (salt dome pond) observed being frozen over	
2/20/2014		X	Collection07: 01/30/14-02/20/14	
2/24/2014	9:03-9:27am		Logger 2 out of commission (Joel fixed tilt)	
3/2/2014	12:00pm		Loggers 2&4 moved to field	
3/4/2014	11:30am		Loggers 2&4 moved back to lot	
3/12/2014	2:45-2:50pm		Logger 3 down (Joel restood)	
3/14/2014		X	Collection08: 02/20/14-03/14/14	
4/2/2014			Logger 9 observed missing shield	
4/2/2014		X	Collection09: 03/14/14-04/02/14	
4/23/2014		X	Collection10: 04/02/14-04/23/14	
5/1/2014	11:22-11:26am		Replaced shield on Logger 9	
5/15/2014		X	Collection11: 04/23/14-05/15/14	
6/18/2014		X	Collection12: 05/15/14-06/08/14	
6/18/2014			USB to shuttle broke off, sent to HOBO for repair	

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7/22/2014		X	Collection13: 06/18/14-07/22/14	
8/27/2014		X	Collection14: 07/22/14-08/27/14	
10/1/2014		X	Collection15: 08/27/14-10/01/14	
11/6/2014		X	Collection16: 10/01/14-11/06/14	
12/8/2014	1:45-3:25 pm		Joel drilled holes in bases (drainage) and secured solar shields	
12/10/2014		X	Collection17: 11/06/14-12/10/14	
1/13/2015	9:18am		Loggers2&4 moved to field (construction)	
1/15/2015		X	Collection18: 12/10/14-01/15/15	
1/15/2015			Noticed pond frozen, probably been so for a few weeks	
1/21/2015			Snowfall beginning around 12:15pm	
1/22/2015	11:40am		Loggers2&4 moved back to lot, but switched locations*	* loggers 2&4 remained switched for the remainder of data record
2/25/2015		X	Collection19: 01/15/15-02/25/15	
4/7/2015		X	Collection20: 02/25/15-04/07/15	Logger 6 for collection20: no data (data was corrupt)
5/26/2015		X	Collection21: 04/07/15-05/26/15	
5/28/2015	1:23pm		Loggers5&6 moved from field	
5/28/2015	2:00pm		Loggers5&6 moved to field by Goddard Day Care temporarily	
7/1/2015		X	Collection22: 05/26/15-07/01/15	
8/6/2015	2:25-2:35pm		Logger6 moved back to field	
8/6/2015		X	Collection23: 07/01/15-08/06/15	
9/2/2015		X	Collection24: 08/06/15-09/02/15	
9/3/2015	9:00-9:20am		Logger5 moved back to field	
9/8/2015	12:23-12:28pm		Loggers2&4 moved to lot parking between B6 and B11	
10/20/2015		X	Collection25: 09/02/15-10/20/15	
11/19/2015		X	Collection26: 10/20/15-11/19/15	
	indicates loggers	were moved	from or back to usual spot	

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Figures

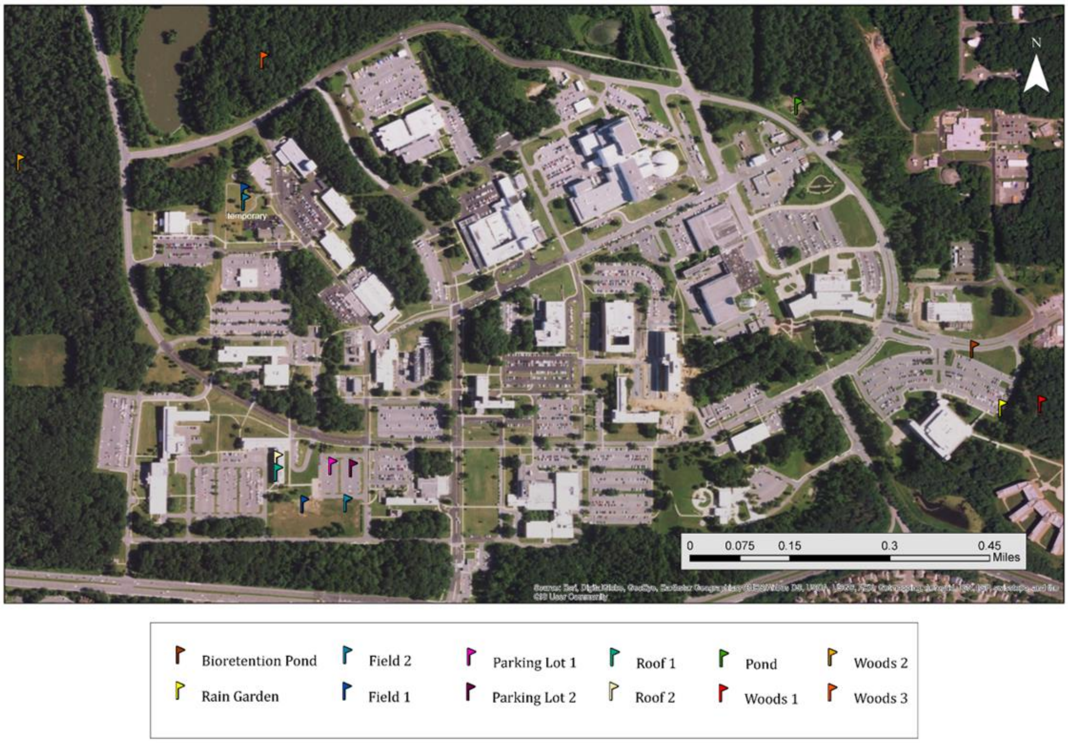

Figure 1 Map of Goddard Space Flight Center. Flags indicate locations for logger placement on center. Loggers were strategically placed in low traffic areas of the center to minimize the potential for disturbance.

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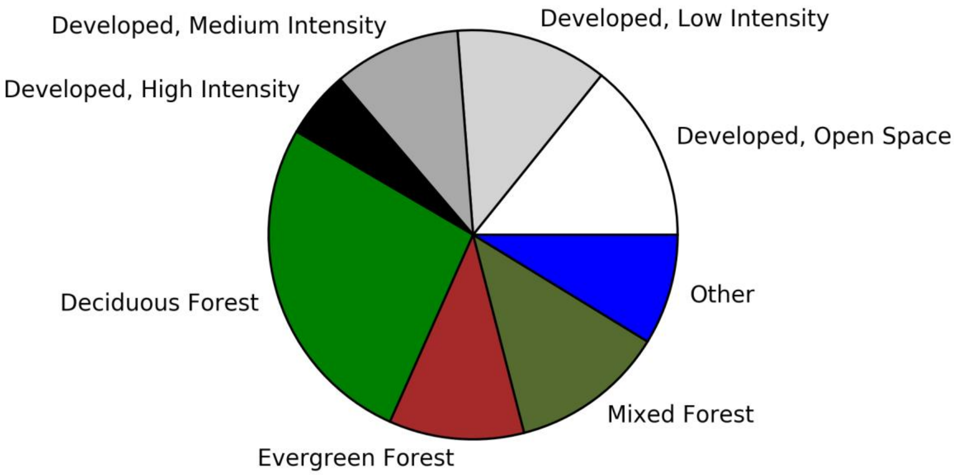

Figure 2 Distribution of land cover types on Goddard Space Flight Center as determined by the National Land Cover Dataset (NLCD).

Figure 3 Photo of logger installed in rain garden adjacent to parking lot for building 32 at NASA-GSFC.

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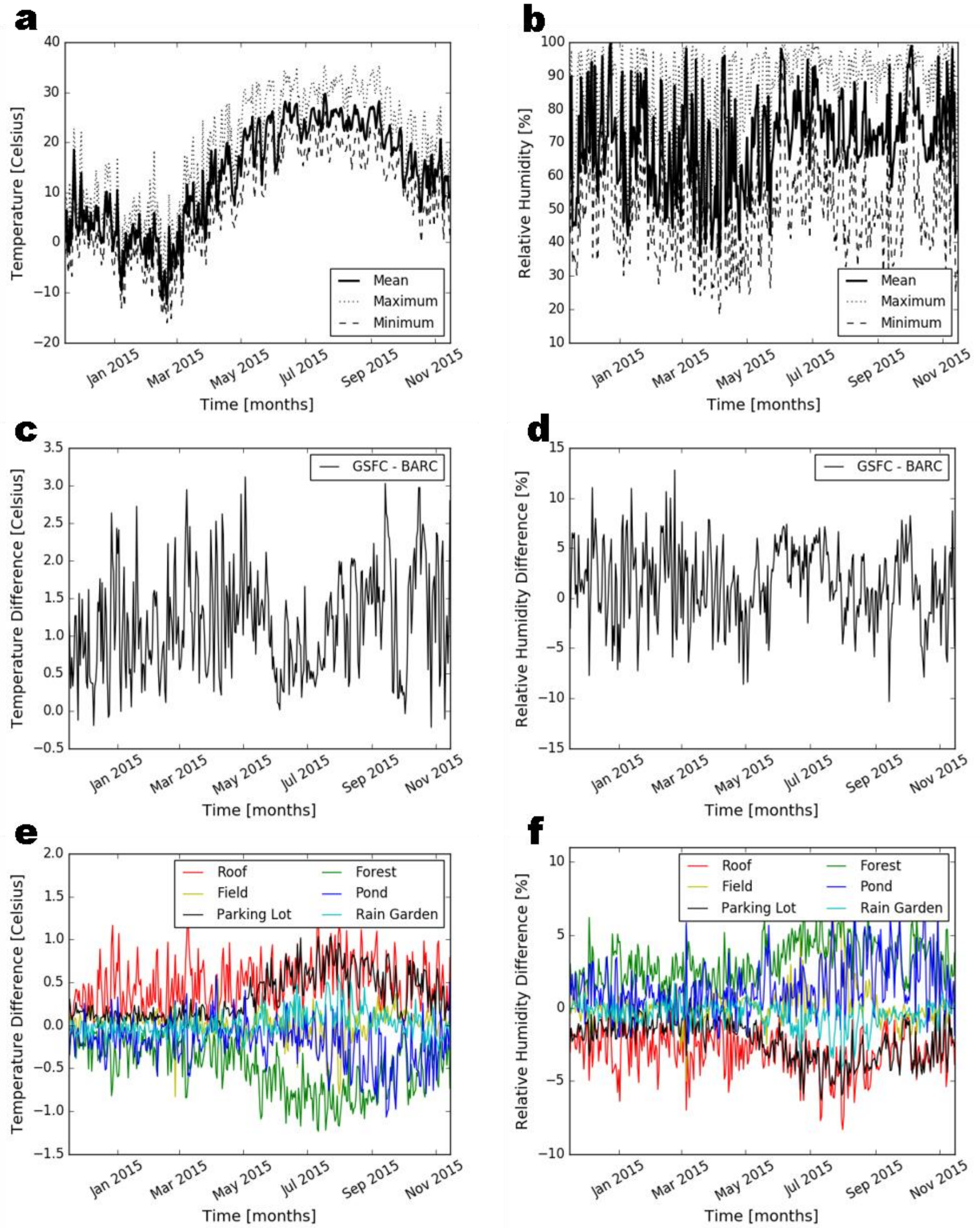

Figure 4 Plot of logger data for year 2 of data collection from November 2014 - November 2015. Figures in the left column show temperature features in Celsius while figures on the right show relative humidity in percent.