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14. ABSTRACT
The Defense University Research Instrumentation Program (DURIP) is designed to improve the capabilities of U.S. Universities to conduct research and to educate scientists and engineers in selected technical areas of importance to national defense. DURIP funding provides for the acquisition of research equipment and instrumentation for this purpose.
This proposal is for the purchase of a system of ground-based measuring devices including a CO2/H2O analyzer, a

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Report Title

Final Report: Instrumentation for Exploring Surface Energy Balance using a combination of Satellite and Ground Based Observations

ABSTRACT

The Defense University Research Instrumentation Program (DURIP) is designed to improve the capabilities of U.S. Universities to conduct research and to educate scientists and engineers in selected technical areas of importance to national defense. DURIP funding provides for the acquisition of research equipment and instrumentation for this purpose.
This proposal is for the purchase of a system of ground-based measuring devices including a CO2/H2O analyzer, a soil flux system, a sonic anemometer, a heavy duty tripod, a biomet system, a cellular communication system, and a latent and sensible heat flux system.
In order to understand these forcing factors, reliable sources of information in various spatial scales including ground-based measurements and satellite observations are needed. Ground-based measurements can be used to validate models in smaller scales and to enhance our understanding of surface heat properties in higher spatial resolutions. Soil moisture, soil temperature, snow water equivalence, evapotranspiration, wind and net radiation are among most important parameters that need to be measured. Moreover, satellite-based observations are utilized when acquisition of data in regional and global scales is not feasible.
The New York City College of Technology, use the equipment to augment and enhance research capabilities in the exploration and characterization of surface energy fluxes in urban and non-urban environments.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

orouzi, H, Vant-Hull, B, and Ramamurphy, P., CHARACTERIZING SURFACE ENERGY BUDGET COMPONENTS IN URBAN REGIONS USING COMBINATION OF FLUX TOWER OBSERVATIONS AND SATELLITE REMOTE SENSING MEASUREMENTS, American Geophysical Union (AGU) Fall Meeting, Will be presented in Dec. 2016.

Two Journal Publications are under preparation.

Number of Presentations: 1.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received	Book

TOTAL:

Received	Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Post Doctorates

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Faculty Supported

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FTE Equivalent:
Total Number:

Names of Under Graduate students supported

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FTE Equivalent:
Total Number:

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME　　PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

See Attachment

Technology Transfer

Table of Content

Instrumentation for Exploring Surface Energy Balance using a combination of Satellite and Ground-Based Observations

Hamidreza Norouzi - Principal Investigator

Reginald Blake - Senior Investigator

Abstract

This grant provided ground-based instrumentation to develop a new research study in surface energy fluxes and to augment existing research studies and facilities.

Knowledge of the Surface Energy Balance of urban and non-urban surfaces has great potential in water resources, health, biodiversity, and air quality studies as high-risk applications. There have been several attempts to derive land surface energy fluxes through different available satellite and ground observations in the past. However, the lack in adequacy of ground truth observations has made the validation and integration of such models challenging.

Partitioning and estimating the turbulent fluxes requires information about surface properties, wind, humidity, surface roughness, and temperature. In order to understand these forcing factors, reliable sources of information in various spatial scales including ground-based measurements and satellite observations are needed.

The equipment was purchased through the funding and it took several months to be utilized. Several urban surfaces such as concrete and asphalt pavements have been targeted so far and there is a plan to expanding to other surfaces such as rooftops. The results also form the Cary Institute of Ecosystem Studies are used as surfaces for non-urban region. Additionally, we investigated carbon dioxide exchange in response to land and atmospheric conditions and explore short-term response of soil moisture-temperature-CO2 interactions to extreme weather events based on diurnal in-situ measurements by purchased LI 8100 equipment. The study area is at the San Joaquin Marsh Reserve (SJMR), CA. Both undergraduate and graduate students have used and worked with the equipment. It is expected that equipment on average to be used for at least seven years before being upgraded.

Statement of Problem

As the solar energy is expended, some of it is stored in the ground, some returns to atmosphere by warming the air, and the remaining is used to evaporate surface water. Therefore, the surface energy balance equation can be written as:

$$(1-r)\,S\downarrow + L\downarrow = L\uparrow + H + \lambda E + G \qquad (1)$$

$(1-r)S\downarrow$ is the absorbed solar radiation, where $rS\downarrow$ is the incident radiation onto the surface and r is the albedo, defined as the fraction of $S\downarrow$ that is reflected by the surface. ($L\downarrow$) downward longwave radiation, ($L\uparrow$) emitted upward longwave radiation, (H) sensible heat, (λE) latent heat, and (G) the heat exchange by conduction. Expressed in a different manner, the net radiation absorbed by an object can be written as:

$$R_n = (1-r)\,S\downarrow + (L\downarrow - L\uparrow) = H + \lambda E + G \qquad (2)$$

Surface condition in terms of material and its properties can affect any of the above factors, and a comprehensive spatial knowledge about these properties such as heat capacity and heat conductivity is required to understand the balance of energy at the surface level. Surface energy flux varies between day and night. Typically, during the day, surface energy balance is positive when net shortwave exceeds the net longwave loss. However, at nighttime there is no incoming solar shortwave, and this changes the sign of the remaining heat energy of the surface balance equation. The surface emits energy during daytime, while it needs more energy at night and causes to have downward latent and sensible heat flux from atmosphere to the surface. The difference between maxima and minima air temperature on a daily basis is an indicator of the response of the surface to the change in energy flux.

With the equipment that was obtained through this grant, surface heat energy balance study is performed: The study involves both ground measurements and satellite observations.

The research is divided into two sections; ground measurement study and satellite-based energy balance study.

To achieve the above-mentioned goals, equipment was requested to measure the parameters/components of surface energy balance. They were deployed in various land cover types with variety of vegetation and moisture states in non-urban regions and urban regions with different pavement material such as asphalt, concrete, rooftops, and etc.

The study area for ground measurements at this point is our tri-state region (100 miles around New York City). City Tech is located in Brooklyn NY with variety of urban surface types. This will allow us to have complete understanding of energy balance components in urban regions. So far the equipment has been used at the Bronx and Brooklyn, NY on asphalt and concrete surfaces. The plan is to collect the data from other surfaces such as rooftops and non-urban regions.

List and Specification of Equipment

The requested equipment through this grant consists of some equipment to perform ground measurements to investigate heat energy balance. The list of equipment and devices with their detailed specifications are provided in this section.

These devices are:

- **LI-7500A Open Path CO2/H2O Analyzer from LI-COR**:

The LI-7500A is a high speed, high precision, non-dispersive infrared gas analyzer that accurately measures densities of carbon dioxide and water vapor in situ. With the eddy covariance technique, these data are used in conjunction with sonic anemometer wind speed to determine ecosystem level fluxes of CO2 and H2O.

The LI-7500A accepts analog data from a sonic anemometer and logs complete data sets to a removable USB storage device. It includes:

  - LI-7550 Analyzer Interface Unit

- LI-7540 Analyzer Head
- 3-Year Extended Warranty
- 15% discount on consumables during warranty period, (1) free calibration

- **LEEF Soil Flux System from LI-COR:**

Although the main purpose of this device is to measure CO2 fluxes, it also provides survey measurements of soil temperature and soil moisture instantly. It means that the device is easily portable and the soil moisture and temperature can be measured where multiple sites are targeted. The device also is very user friendly and students can be trained easily and can collect the field data. This device includes:

- **LI-8100A Analyzer Control Unit:** The gas analysis, data storage and communication center of theLI-8100A System.
- **Survey Chamber, 20 cm diameter:** Connects directly to the Analyzer Control Unit. Includes Soil Temperature Probe, gasket kit, spares kit, and six Soil Collars
- **Theta Soil Moisture Probe:** with bare leads for direct connection to the Analyzer Control Unit
- **Trace Gas Sampling Kit:** Used to collect samples from the same air stream used to measure CO_2flux for further trace gas analysis
- **Eight additional Soil Collars:** to use with the Survey Chamber
- **Three Rechargeable Batteries and a Battery Charger:** One battery needed to operate the LI-8100A. Each battery provides approximately 3 hours of battery life
- **CO_2 Mapping Kit:** used to measure and map carbon dioxide emissions over a large area
- **8100App Wireless Package:** Includes 32 GB iPod, iPod Micro Case, Cisco® Wireless (802.11b) Card, and serial cable for IP configuration
- Windows® and Apple iOS interface Software, Mapping software, and Data Analysis software
- **Two-Year Extended Warranty:** Extends the standard one-year warranty of the LI-8100A to a total of three years
- **Five sets of Training DVDs:** A two-DVD set each. Great for new users of theLI-8100A
- Full Scientific and Technical support

- **Gill WindMaster Sonic Anemometer from LI-COR**

This instrument measure wind and are used along LI 7500A gas analyzer. It includes mounting post.

- **7900-300 Tripod from LI-COR**

The 7900-300 Heavy Duty Adjustable Tripod is a sturdy instrument platform for eddy covariance systems, communication antennas, meteorological sensors, and enclosures. It provides mounting heights up to 4 m (13 ft) with individually adjustable legs for deployment on uneven terrain.

Additional cross arms and hardware components are available to mount gas analyzers, radiation sensors, and other sensors to the tripod.

  - Includes cross arm, guy cable kit, earth anchors, lightning rod, grounding hardware, foot stakes, and UV-resistant cable ties

- **7900-101 Biomet from LI-COR**

LI-COR® eddy covariance systems support a full complement of additional biomet sensors. Data from these sensors are time synchronized with gas analyzer and sonic anemometer data and logged in GHG eddy covariance data files, so they can be used for gap filling and interpreting flux results. They are summarized with EddyPro® output and also can be evaluated independently of the eddy covariance data set.

The biomet system includes a datalogger (Sutron Corp., Sterling, VA) and a pre-configured enclosure with mounting hardware. Installed components include circuit breakers, relay switches, terminal blocks, and grounding connections. It has an Ethernet connection for data transfer and collection on the LI-7550. Space is also available for the addition of network switches and/or cell modem communication devices. It includes:

+(1) 7900-144 Net Radiometer (Kipp & Zonen CNR4).
+(1) 7900-130 Humidity and Temperature sensor (Vaisala HMP155).
+(1) 7900-135 Radiation Shield (RM Young 41005-5) for above.

+(3) 7900-150 Soil Heat Flux sensors (Hukseflux HFP01).
+(3) 7900-180 Soil Temperature thermistors (LI-COR).
+(3) 7900-170 Soil Moisture probes (Delta-T ML2x).
+(1) 7900-190 Quantum Sensor (LI-COR LI-190SL-50).
+(1) 7900-160 Rain/Precipitation gauge (Texas Electronics TR-525USW).
+(1) 7900-120 Data logger (Sutron Xlite 9210) with (2) 7900-124 Modules (10-channel).
+(1) 7900-125 Pre-configured Biomet Enclosure 36 x 41 cm (LI-COR)

- **7900-703 Cellular Communication from LI-COR**

It includes a cellular modem, high-gain antenna, Ethernet switch, power cables, data cables, and hardware to mount the module inside a LI-COR 7900 Biomet System enclosure. It supports a GHG eddy covariance system (LI-7500A or LI-7200), 7900 Biomet System, and an optional LI-7700 Open Path CH4Analyzer. It enables us to collect the data for long-term measurements without going into the field.

- **7550-200 SMARTFlux from LI-COR**

The SMARTFlux™ System (Synchronization, Management and Real Time flux system) is a powerful tool that provides fully corrected flux results in real time at the research site.

The SMARTFlux System is fully integrated with the LI-7550 Analyzer Interface Unit, the hub of LI-COR's greenhouse gas and energy flux systems.

SMARTFlux is the only system available that provides:

- Fully corrected fluxes of sensible heat, latent heat, evapotranspiration, CO_2, H_2O, and CH_4 at the site and in real time
- Advanced, site-specific raw data processing (in situ spectral correction, planar fit, etc.)
- GPS time synchronization prevents clock drift and keeps instrument clocks in sync within and across sites

Experimental Setup

The overall goal is to study the surface energy budget of individual urban materials (asphalt, concrete, black roofs and white roofs). To facilitate this process, we have begun to install a complete energy balance station over these distinct individual materials. The footprint of these stations will be restricted to the individual materials. The energy balance stations monitor the sensible and latent heat fluxes through eddy covariance method. These instruments correlate the fluctuate in the velocity field to the fluctuations in the temperature and humidity fields. To account for the incoming and outgoing radiation, a 4-component radiometer is used that can observe both incoming and outgoing longwave and shortwave radiation. Finally the storage term is estimated through the method of residuals. In addition to the primary components of the surface energy budget, the stations also monitor basic meteorological variables such as air temperature, relative humidity, barometric pressure and precipitation. These variables can be directly used to force urban land surface models. The flux instruments sample data at very high temporal resolution, around 20 Hz. The instruments are also operated continuously.

Two flux towers purchased from money leveraged from the Department of Defense (DoD), the Defense University Research Instrumentation Program (*DURIP*) grant and an internal funding through the City University of New York, the Graduate Research Technology Initiative (*GRTI*). They were installed to measure flux properties of test slabs of asphalt and concrete at Riverdale, the Bronx, NYC; a site more representative of most urban areas than Manhattan itself. Sensors were placed less than half a meter above the middle of each slab so that the measurements are less likely to incorporate fluxes from outside materials. The goal is to survey all surface types found in the city, including rooftops and parkland. Prediction of the fluxes from these surfaces can be used to model air temperature by linear combination of surface types and area fractions that influence surface parcels of air (Ramamurthy et al, 2014).

Following parameters/components of surface energy are acquired through field measurements:

Turbulent Fluxes: Fluxes by the surface are sensible heat and latent heat (ET). These parameters are estimated using LI-COR 7500A and LEEF Flux System.

Net Radiation: at each site net radiation is measured using LI-COR 7900-101.

Ground heat flux: the ground heat flux is monitored continuously using LI-COR 8100 and LI-COR 7900-101 through measurement of soil temperature. Moreover, soil temperature sensors at three different depths will allow us to understand the heat conduction at the locations that soil is permeable and is not paved surface.

Eddy Covariance: in large-scale analysis, in order to understand how the energy is exchanged between the surface and atmosphere, other than a vertical dimension a horizontal dimension is also added to the equation.

A sample of these flux measurements appears in Figure 2, showing hourly averages of sensible and latent heat vertical fluxes compared to air temperature over asphalt. For clarity the more directly measured radiative fluxes and other weather variables have been omitted. The causal relationship between sensible flux and changes in air temperature are evident for all days except June 9, which may have been cooled by regional flow off the ocean. The connection between dewpoint/humidity (not shown) and latent heat flux is less evident in the data, likely because these surfaces are not strong moisture sources.

Modeled fluxes of urban landscapes based on this campaign of measurements when combined with regional forecasts should provide a more accurate prediction of surface air temperature and humidity than regional forecasts alone.

Figure 1: Flux towers installed at Manhattan College. Left: Asphalt. Right: Concrete.

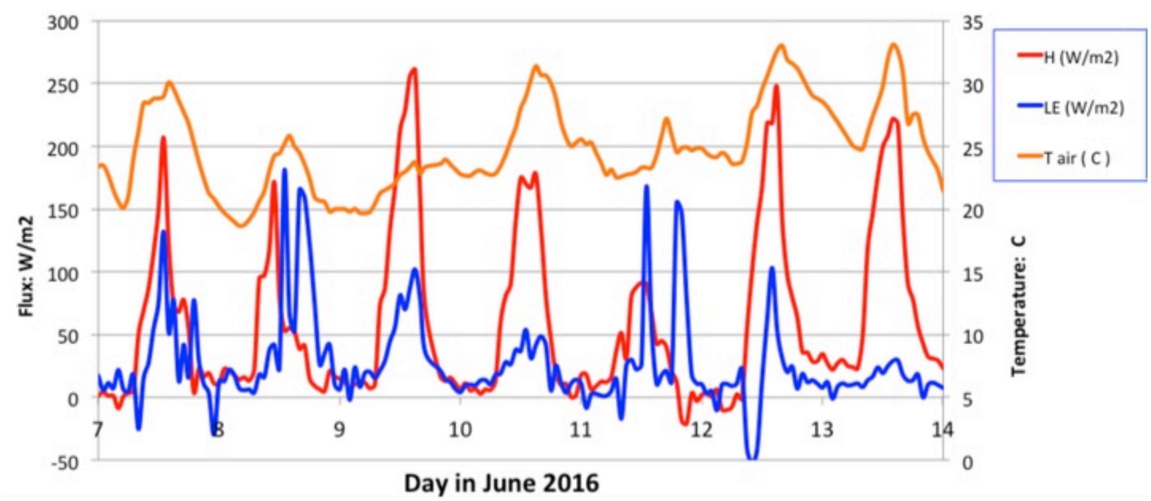

Figure 2: vertical fluxes of sensible and latent heat for the week of June 7-14, 2016.

This project aimed to initiate efforts to study surface energy balance components in urban and non-urban regions. Synergetic use of ground observations, satellite measurements, and urban canopy modeling results revealed a great potential to expand the knowledge with promising findings.

The LI 8100 equipment was also used to investigate carbon dioxide exchange in response to land and atmospheric conditions and explore short-term response of soil moisture-temperature-CO2 interactions to extreme weather events based on diurnal (~5 measurements an hour) in-situ measurements at University of California, Irvine.

The study area of this research is located at the San Joaquin Marsh Reserve (SJMR) (Phase 2, Ponds and Seasonal Marsh), which is close to the University of California, Irvine (UCI) (Figure 3). It is adjacent to the UCI main campus and bordered to the south by the San Diego Creek (SDC). The region experiences a Mediterranean climate with an average annual temperature of 17 °C and a mean annual precipitation of 300 mm (P. Bowler, 2007).

The SJMR is one of the reserves of the University of California Natural Reserve System (UCNRS) with an area of 817,500 m2. It is subdivided into different sections, including man-made areas, i.e. ponds (shown by the green solid line in Figure 3), Phase II (shown by yellow solid line), and untouched, i.e. Seasonal Marsh (shown by red solid line). The measurements gauge is located in the Seasonal Marsh (33° 39’32.7” N latitude, 117° 50’55.9” W longitude) at an elevation of 2 m above sea level (Figure 3 solid red line).

Soil CO2 flux and additional measurements

Diurnal soil respiration was measured from February 5th to November 4th, 2016 using an automated soil CO2 flux system (LI-8100A, LI-COR, Inc., Lincoln, Nebraska, USA) with one LI-8100A-104C long-term transparent chamber (Figure 4). The measurement device was mounted on a collar and five measurements with an observation period of two minutes were made every hour.

Figure 3: Study area (blue solid line) at Seasonal Marsh (red solid line) at the San Joaquin Marsh Reserve (SJMR).

Simultaneously, soil temperature and soil volumetric water content near the chamber at 5 cm depth below ground were observed using an auxiliary soil temperature thermistor (LI-COR, Inc., Lincoln, NE, USA) and an ECH2O model EC-5 (Decagon Devices, Inc., Pullman, WA, USA), respectively. Soil temperature and soil moisture sensors were attached to the LI-8100A analyzer control unit. The EC-5 determines the volumetric water content by measuring the dielectric constant media using capacitance domain technology (Kočárek and Kodešová, 2012). The system was powered with a 55 Ah/12 Volt battery and a 60 Watt solar panel in the beginning, during which the system ran out of power for a few short periods (i.e. during long cloudy days).

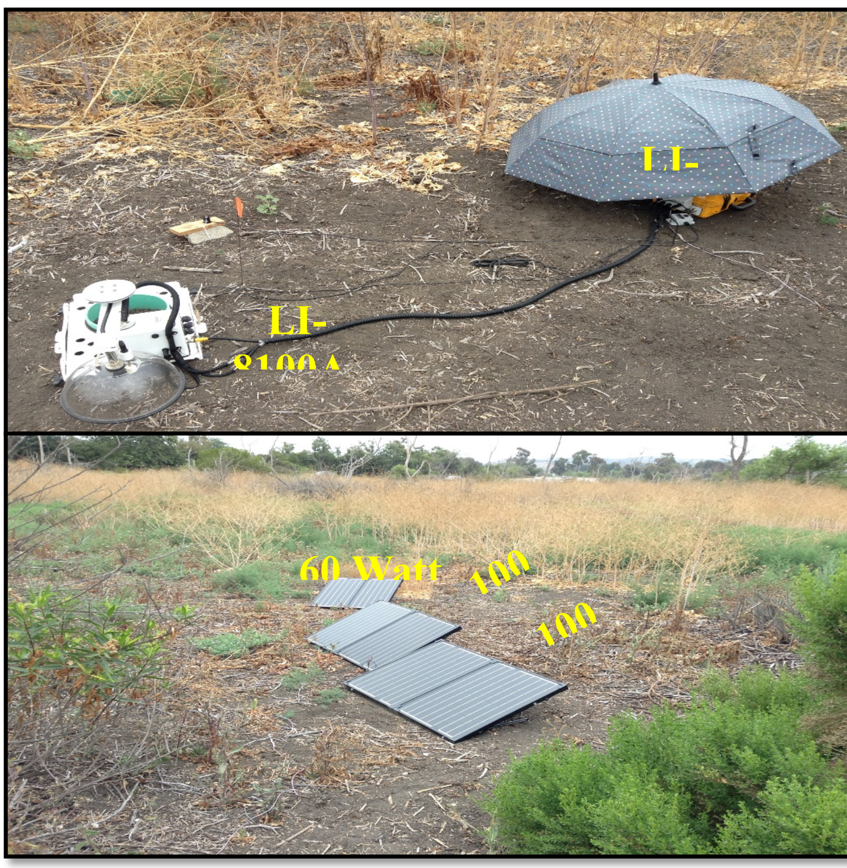

Figure 4: Device LI 8100A-104C and three solar panels in Seasonal Marsh at SMJR.

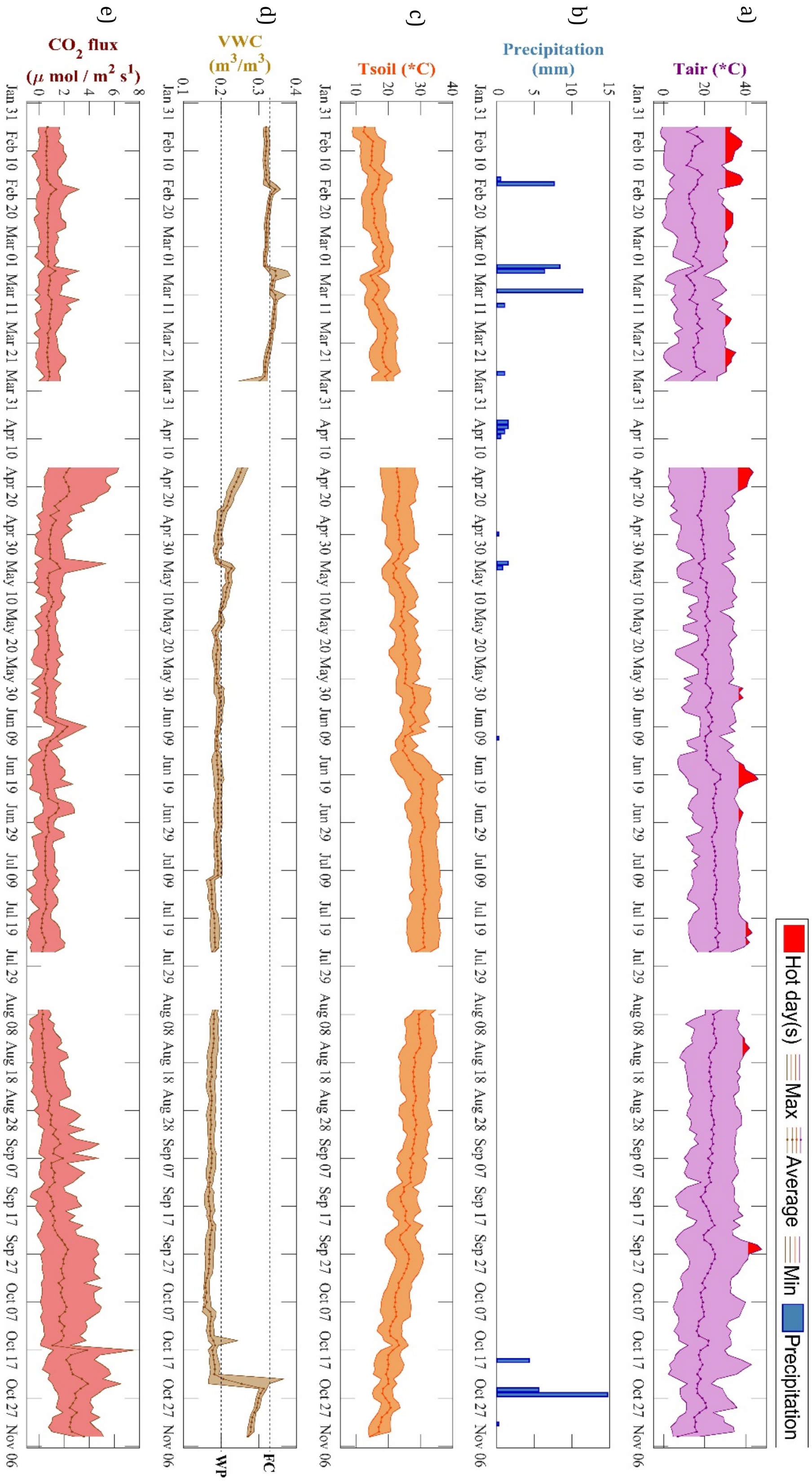

Figure 5: Five Parameters of meteorological and Rs data

Figure 5a shows maximum, average and minimum air temperature. The bias-corrected hot day threshold is defined as the 85th percentile of the maximum air temperature of the long-term climatology for each month. Hot days are illustrated with red areas and warm spells are red areas with at least three consecutive hot days. We found 58 hot days including nine warm spells with different durations and intensities. During the study period, the study area received ~69 mm of rainfall (Figure 5b). Soil temperature follows the seasonal air temperature pattern (Figure 5c). The observation shows that in most cases precipitation causes the CO2 flux to increase, which is compatible with Deng et al., 2012 and Yan et al., 2014.

Equipment / Instruments Maintenance and Lifetime

Equipment obtained through this grant includes 5 years of warranty in their prices. Based on LI-COR Company, the vendor for ground-based measurements, the equipment should last for at least 15 years. So far except one issue, all equipment are working fine. The equipment was sent for repair and it is fixed. University through Center for Remote Sensing and Earth Systems Science (ReSESS) will be responsible for maintaining the equipment beyond the grant period. Additionally, the university provided a funding to purchase another set of equipment similar to those obtained through this grant to expand the number of different surfaces that can be measured.

Equipment Operation Training

The PI and senior person of this project attended a 3-day workshop are provided by LI-COR at Lincoln, Nebraska. Free training session trained us how to operate and assemble the equipment in the field. Currently, trained researchers transfer their information to other faculty members and students.

Educational Activities

Several graduate and undergraduate students have been affected and used the equipment provided by this grant. One graduate student used LI 8100 at University of California, Irvine to obtain carbon and water fluxes at wetland in Orange County, CA. Another graduate student is using data measurements at the urban regions to better understand the surface energy balance at the City College of New York under supervision of Dr. Prathap Ramamurphy, collaborator on this project. City Tech as a senior under-graduate level academic institution is a Minority Serving University. As part of its mission, the college is committed to enhance undergraduate research especially for under-represented students. To pursue this mission college has several programs and grants to encourage student to perform research in STEM field. These grants are supported by different agencies such as NASA, National Science Foundation, National Oceanic Atmospheric Administration (NOAA), and Department of Education. Several students participating in these grants have experienced or learned about this research experiment. ReSESS faculty members are also involved actively in some these programs.

At City Tech, students have shown more interest in hands-on learning activities. A significant portion of the planned research in Surface Energy Balance is dedicated to ground measurement field campaign. Students at some classes have learned about the process and importance of surface energy balance and they have visited the flux tower that is currently deployed at a parking lot on a concrete surface at New York City College of Technology. The plan is to continue engaging students in this project by performing satellite-based remote sensing studies or data collection using equipment.

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