CHEESEHEAD Experimental Design

Experiment Objective

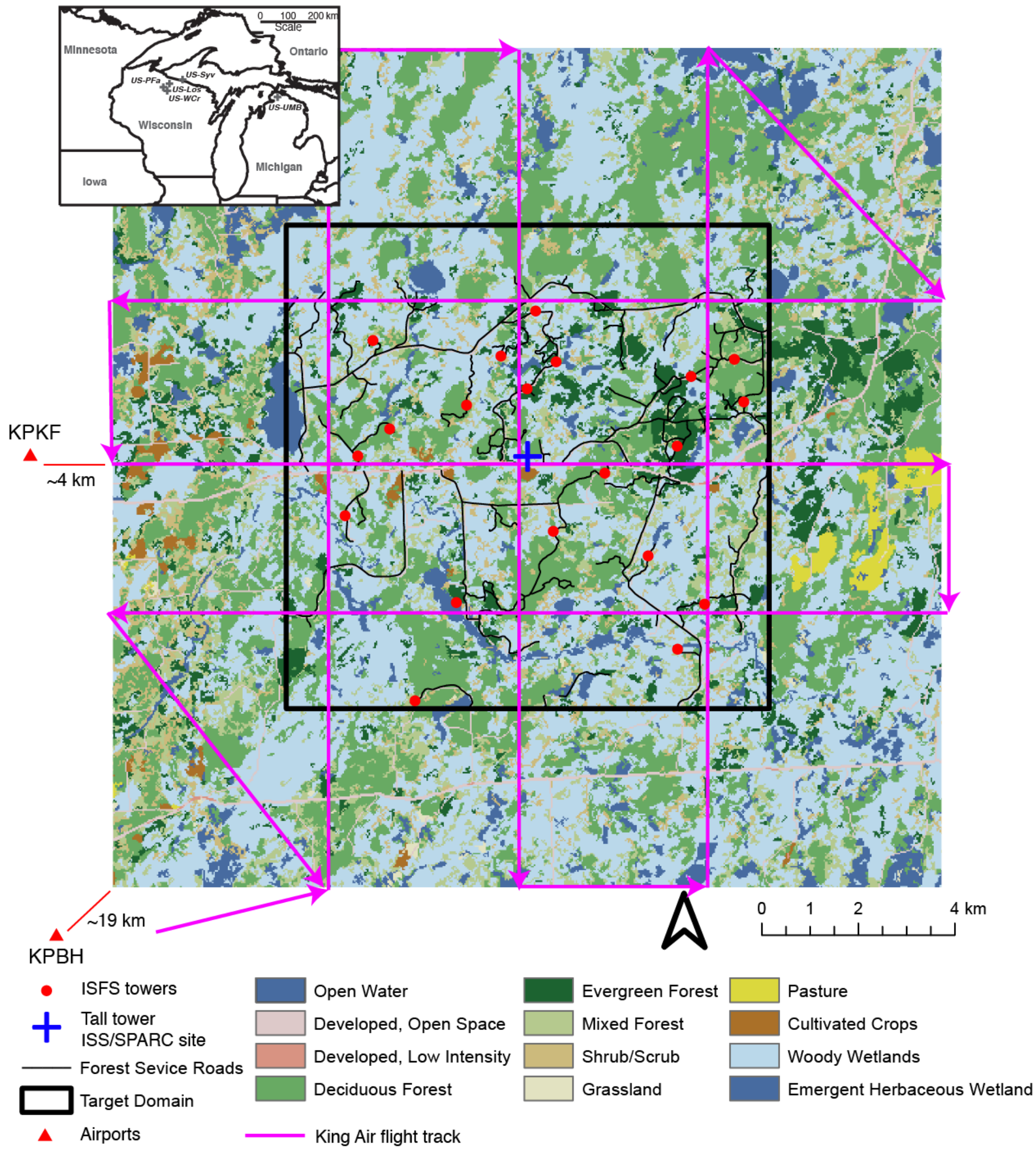


Figure 1 Landcover (National Land Cover Data 2011) map of the surrounding region, 10x10 km study domain (black box), WLEF very tall tower, ISS, SPARC instruments (blue cross), 20 tower locations (red dots), airports (red triangle), and proposed flight pattern for UW King Air (purple lines and arrows), based at KPBH. Flight pattern for the UW ultralight varies, but generally follows the edges of the target domain, flying in from KPKF.

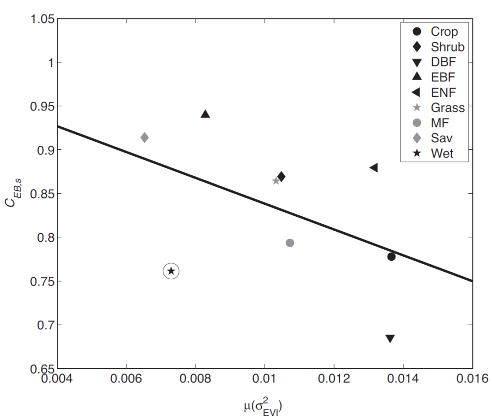
The Chequamegon Heterogenous Ecosystem Energy-balance Study Enabled by a High-Density Extensive Array of Detectors 2019 (CHEESEHEAD19) aims to improve the representation of surface energy balance and atmospheric response to surface heterogeneity in weather and climate models. For this purpose, CHEESEHEAD intensively samples and simulates the surface and boundary layer within the heterogeneous subgrid of a single “grid” cell of such models (i.e., 10x10 km).

Proposed observations (Table 1) are anchored around the NOAA/DOE/NASA/NSF supported WLEF very tall tower (447 m) supersite (Fig. 1), where existing continuous profiles of temperature, moisture, greenhouse gases, and eddy heat, moisture, carbon, and momentum fluxes have been made since 1996. The landscape is a mix of forest, wetland, lakes, and clearings, including a 100 m clearing around the tall tower. NCAR Integrated Sounding System (ISS) was deployed as part of a small experiment at the tower site in the late 1990s and the Space Science and Engineering Center (SSEC) Portable Atmospheric Research Center (SPARC) visited the site in fall 2016. Our proposed analysis is based on mapping variation in surface energy balance and detecting atmospheric response to surface energy balance variability. Statistical models and large eddy simulations (LES) will then be evaluated for scaling and simulating these processes over a three-month period, from mid-summer to early fall. During this time period, we expect the land surface energy balance to transition from a more uniform transpiration (latent heat flux) dominated landscape to a patchy sensible heat flux dominated landscape.

Our primary science question in this experiment is: to what extent does local surface heterogeneity drive local atmospheric circulations, and how does the presence or absence of these circulations influence the reliability and representativeness of single-point eddy covariance flux tower measurements?

Earlier studies have shown, for example, that the daytime energy balance closure (ratio of available net radiation to surface total heat fluxes, which is expected to be 1.0) worsens with increasing surface spatial variation (Fig. 2a, from Stoy et al., 2013). A proposed mechanism for this finding is from Mauder et al (2008) who argued that heterogeneity drives quasi-stationary eddies with positive heat and water flux, at spatial scales that cannot be sampled with a single tower (Fig. 2b). In support of such a mechanism, Xu et al. (in press, Fig. 2c) showed how the WLEF tall tower (US-PFa) net surface fluxes of sensible and latent heat initially behave erraticly when aggregated over an increasing number of mesoscale structures with a statistical model. The area-average mean value ultimately converges, though at model grid scale that substantially exceeds the single-tower observation.

a)



b)

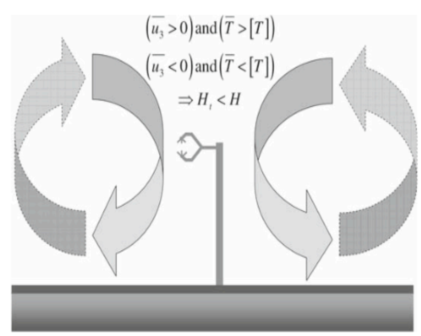


Fig. 1 Schematic showing how quasi-stationary eddies cause an underestimation of the total sensible heat flux H when using the temporal EC method to calculate H_t. The single-point sonic measurement in the centre is not able to resolve quasi-stationary eddies

c)

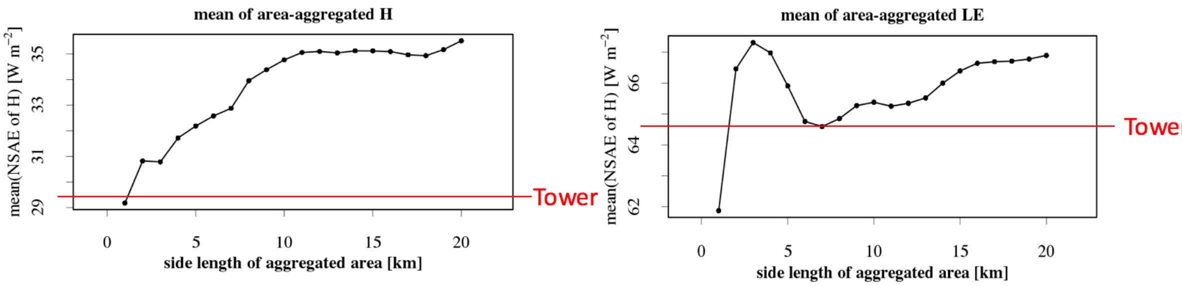


Figure 2. a) from Stoy *et al* (2013), ratio of energy balance closure (turbulent heat fluxes over net available energy) declines as a function of near-field variance in remotely-sensed vegetation greenness, indicating heterogeneity as a driver of under sampled heat fluxes. b) from Mauder *et al* (2008), a potential source of this "missing energy" arises from land surface heterogeneity leading to the presence of stationary long-wave eddies in a convective boundary layer, which can advect positive sensible heat flux to the surface. c) from Xu et al. (in press), showing how WLEF net surface fluxes of sensible and latent heat behave when aggregated over from single-tower toward model grid scale.

The outcomes of the field experiment will be improved understanding of "how homogenous is homogenous enough" for representing landscape variability in Earth system models and "how many distributed observations are enough" for scaling surface-atmosphere flux samples across space? To address these questions CHEESEHEAD uses a high-density network of flux towers, intensive continuous sampling of boundary layer vertical profiles, and airborne mapping of land and atmosphere spatial variability.

The high density of flux towers represents a first-of-its-kind intensive study of sub-mesoscale variation in energy partitioning, fundamental to understanding scaling of non-linear surface-atmosphere interactions. Spatial maps of surface energy balance will be built by a model-data fusion scaling approach, which will be evaluated here through multi-tower cross-validation. Large eddy simulation with have either spatially average homogenous or observed scaled heterogeneous surface forcing and boundary conditions. The model will be forced from airborne and profiler observations and run for each IOP and select cases throughout to evaluate response of atmosphere of heterogeneity based on observed atmospheric boundary-layer properties. Three-month operations will allow for evaluation of interaction of ecological evolution of plant canopies and water use and atmospheric mesoscale patterns and fluxes observed from the very tall tower.

This proposal is a resubmission of a submission to National Science Foundation (NSF) Physical Dynamic Meteorology (PDM) program grant proposal in December 2015 and the NSF/NCAR Observing Facilities Assessment Panel (OFAP) review process in November 2015 and 2016. OFAP and science proposal reviews were positive, though the flux tower deployment was deemed not feasible due to close proximity in timing to another field experiment that needed them in the previous two cycles. As a result, we are resubmitting the proposal for July-October 2019 deployment. We have also addressed comments made in the OFAP summary. These include the following changes:

1.) U Wyoming King Air low-level eddy covariance flight sampling now includes cross-track legs to better sample the environment and leg lengths were lengthened for better eddy covariance flux estimation. Frequency of flights have been kept constant, but there is opportunity for additional samples to be deployed with an ultralight experimental airborne platform at U Wisconsin to be available for this experiment. Flights legs were extended to 30 km.
2.) We have removed the CTEMPS distributed temperature sensing from the funding request as its goal overlap with existing instrumentation. Instead, we will consider purchasing and installing

CTEMPS as a permanent installation with support from U Wisconsin and the AmeriFlux program.

3.) We have conducted a preliminary 14-day field campaign in September 2016 with the SSEC SPARC trailer at the WLEF tall tower site. These data allowed us to test remote sensing configurations, install necessary power connections, and analyze initial results on mesoscale structures.
4.) We conducted a large eddy simulation (LES) study of the domain using an existing cloud-resolving model with a Ph.D. student at the University of Wisconsin. This allowed us to re-do the minimum flux tower requirement test and also evaluate the likelihood of success on the spatial eddy covariance technique. A graduate student is currently pursuing additional LES model runs to evaluate experimental design, to be completed and submitted for peer review by spring 2018.
5.) We removed co-location of the G-LiHT spectrometer with the UWKA, and instead will fly a newly acquired UW hyperspectral spectrometer (Townsend) on a State of Wisconsin plane. We will also request the NSF-funded National Ecological Observatory Network (NEON) mobile deployment pool Airborne Observation Platform to include the CHEESEHEAD domain during its overflight of nearby NEON sites (one NEON Terrestrial Observing System site is right on edge of domain).
6.) To address potential facility conflicts, we have modified the timing of our IOPs in consultation with UWKA schedule and our analysis of flux tower energy balance time series.
7.) Because the NCAR Water Vapor LiDAR is not available for this time period, we are requesting the Karlsruhe Institute of Technology combined Doppler and RAMAN LiDAR for high resolution water vapor and temperature profiles to compute water and heat flux profiles.
8.) We addressed a number of minor comments on data promotion, outreach, and field sampling.

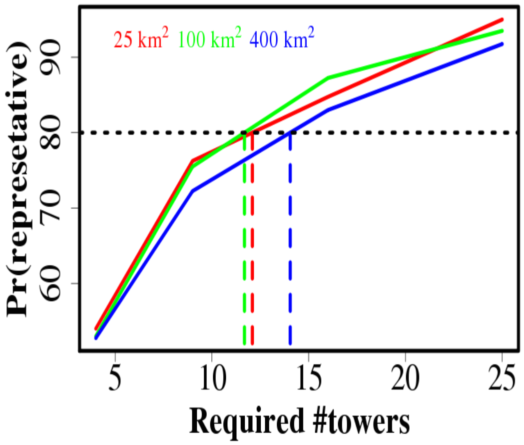
We are aware of the trade-offs that come in sample size and costs, and that both the airborne costs and the tower infrastructure costs are relatively high for this experiment. However, we believe the airborne sampling of the mesoscale environment and mapping fluxes between the towers is essential, and that two campaigns each with four or more days of samples is sufficient to capture the state of the environment. Our goal is not to sample an average environment, but rather the snapshot of the atmosphere in representative states. 30 km flight lines should be sufficient to compute a robust leg average mesoscale eddy flux based on theory of maximum eddy size scaling with PBL depth (~1 km). The long-term run of the flux towers provides the anchor points to test the core hypotheses that are then framed and evaluated against the aircraft.

General Design

The experiment would be held June 24-Ocober 11 2019. Within this three-month time period, we propose two intensive observation periods (IOPs) where airborne sampling, student experiments, and increased balloon launches will allow us to "fill the gaps" in observational density. The IOPs are timed for peak greenness (Jul 1-7) and senescence (Sept 30-Oct 6) with intensive measurement during different surface energy balance spatial variability.

At least 17 NCAR Integrated Surface Flux System FluxPam eddy covariance flux towers, ranging in height from 5-25 m would be placed in a stratified random grid pattern in a 10x10 km box around the WLEF very tall tower and operate from July 1-Oct 6 in a mix forests, several wetlands, and open fields, mostly on US Forest Service land. We have found 12 to be the minimum number of sites needed to adequately represent expected land cover variability in the domain (Fig. 3a), but at least 20 to fully close the energy balance in our LES simulations of random flux towers and spatial eddy covariance techniques (Fig. 3b). A team of student observers will characterize vegetation phenology, canopy leaf area, and soil temperature and moisture weekly throughout the field season at each of the sites. In the 100m grassy clearing around the tall tower or alternatively (if sky view is a factor) at the nearby Park Falls municipal airport, atmospheric profiling instrumentation from three groups (ISS, SPARC, and KIT) as noted in

Table 1 would be installed and daily morning sondes launched to monitor high-resolution vertical profiles of temperature, moisture, winds, and PBL depth during the same time period. Together, these provide the base observations to evaluate atmospheric response to surface energy balance patterns and observations required to derive scaling functions and parameterize the large eddy simulation experiments.



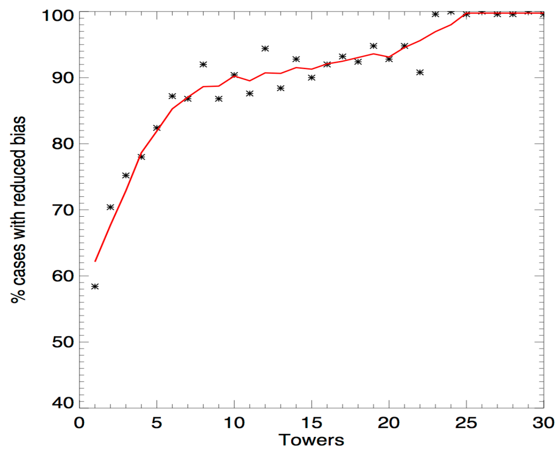


Figure 3. a) While the minimum number of towers to represent the average land cover for 25 km^2 (red), 100 km^2 (green), and 400 km^2 (blue) area around the tower site, based on random sampling of flux tower upscaled regional fluxes is on the order 12, the b) minimum number of towers needed to reduce energy balance closure based on an LES study and a spatial covariance approach is closer to 20. Thus, 20 towers would allow us test these estimates and to stratify sampling across wind direction, land cover type, and canopy height.

During the IOPs, UW would add additional high-resolution, low-altitude, inexpensive WindSond radiosonde profiles at three-hourly interval at multiple locations (including upwind for air trajectory analysis), while SPARC and ISS would launch daytime sondes. The UWyo King Air would fly on two 3.5-hour flights (mid-morning and mid-afternoon) on 4 or 5 of the 6 IOP days. Each 3.5 hour flight will include a series of stacked 30 km legs at 500 ft AGL (300 ft if permission is granted) and 1000 ft above ground level, spaced 8-10 km apart to sample eddy covariance fluxes, lower PBL meteorology both in situ and if available, by downward pointing Raman LiDAR, and PBL depth with the upward looking Wyoming Cloud LiDAR. IOPs would also support student field projects, including low-cost meteorological flow tracking with digital cameras and party balloons. Finally, high resolution (4 m) imaging spectroscopy of visible, near IR, and shortwave IR reflectance will be conducted during each IOP using the UW HySpex imaging spectrometer flown on a separate plane leased from the State of Wisconsin.

Table 1 List of facilities to be deployed for CHEESEHEAD

Surface (mostly distributed in 10x10 km area)	
University of Wisconsin-Madison, Atmospheric and Oceanic Sciences (DESAI)	
Ameriflux/NOAA very tall tower (US-PFa / WLEF)	Continuous, funded by DOE Ameriflux
ChEAS Ameriflux tower network (US-WCr/US-Los)	Continuous, funded by DOE Ameriflux
University of Wisconsin-Milwaukee, Geography (SCHWARTZ)	
Ground-based vegetation/phenology sampling	July-Oct, weekly, campaign/student-based
NCAR EOL Integrated Surface Flux System (ISFS)	
15-20 10-20 m eddy covariance flux towers	July-Oct, above canopy fluxes and met
In-Situ Profiling (mostly at US-PFa Very tall tower)	
NCAR EOL Integrated Sounding System (ISS)	
449 MHz modular wind profiler + RASS	July-Oct, Winds, T/RH profile
Radiosonde	Every morning (12 UTC) July-Oct
UW Space Science and Engineering Center Portable Atmospheric Research Center (SPARC)	
Atmospheric Emitted Radiance Interferometer (AERI)	July-Oct, T and RH profile
HALO Photonics Streamline scanning wind LiDAR	July-Oct, Winds and turbulence
High-Spectral Resolution Lidar (HSRL)	July-Oct, aerosol backscatter
Vaisala Ceilometer	July-Oct, PBL depth
University of Wisconsin-Madison, Atmospheric and Oceanic Sciences (DESAI)	
3-hourly high-resolution PBL sondes during IOPs	Daily during IOPs
Karlsruhe Institute for Technology (MAUDER)	
DIAL/Raman Lidar	July-Oct, T and H2O profile
Airborne	
University of Wyoming King Air	
Eddy covariance, Raman LiDAR, cloud LiDAR (70 hours)	2 IOPs w/ 8 hour ferry + 26 hours sampling
University of Wisconsin Hyperspectral Imager (TOWNSEND)	
Surface mapping of spectra and canopy height	2 IOPs
University of Wisconsin Ultralight (PETTY)	
Boundary-layer heat and water budget of domain	2 IOPs

Instrumentation details

Ameriflux towers: The WLEF US-PFa 447-m very tall tower is a television tower owned by the State of Wisconsin Educational Communications Board (ECB). Since 1995, University and NOAA investigators have made greenhouse gas profile, meteorology, and eddy covariance flux measurements (energy, carbon, momentum) at 30 m, 122 m and 396 m above ground level, in addition to surface meteorology (pressure, temperature, humidity, soil moisture). The instrument trailer has AC power, DSL internet, desktop computers, and gas cylinder storage capability. Two additional towers (US-WCr, 30m in mature forest, and US-Los, 10m in shrub fen wetland) are also operated, and are approximately 20 km to southeast or east from the tall tower, in addition to a NEON sampling site near US-WCr. Desai operates these sites as sole PI and is funded on a facility contract from the Dept of Energy Lawrence Berkeley Laboratory American Network Management Project. A full-time lab manager maintains the facilities for UW, in addition to technical support based at NOAA ESRL in Boulder, CO, and a contract is in place with USGS in Rhinelander, WI for weekly site visits. CalTech/NASA JPL also operate a FTIR solar-pointing spectrometer (TCCON) for total greenhouse column observations.

Vegetation sampling: Co-PI Mark Schwartz at U. Wisconsin-Milwaukee will hire undergraduate observers to characterize vegetation canopy, leaf phenology, and optical leaf area for each of the 20 sites on a weekly or bi-weekly basis, depending on feasibility. Undergraduate students from the primarily undergraduate institution Northland College in Ashland, WI (collaborating partner Jon Martin) will also assist on this project. The goal of this collection is to provide ground-truth data to convert the spectroscopic airborne measurements into maps of plant properties and to document those changes over time, to connect the phenology changes with hypothesized surface energy balance shifts.

ISFF: Integrated Surface Flux Facility (ISFF) FluxPam/CentNet towers can be operated with minimal maintenance in vegetation across the domain, mostly owned by the US Forest Service. Canopy heights range from 0 m to 25 m and tower heights would need to be at least 2 m above vegetation height, preferably 4 m. Each tower will have a 3-dimensional ultrasonic anemometer, and gas analyzer for H_2O and CO_2 at the top. 2-dimensional sonic anemometers mid-canopy will capture wind speed/direction. Three levels of temperature and humidity will be profiled on the tower to measure sub-measurement height airspace storage fluxes and canopy micrometeorology. A 4-componet net radiometer will measuring incoming and outgoing shortwave and longwave broadband radiation. Soil sensors will include soil temperature, soil moisture, soil heat capacity, and soil heat flux, at 5 cm underneath the soil. Each tower will have an independent data logging system, solar panel, battery set, and battery charger. Permitting for wetlands or lakes (at least 4 or 5) may require constructing tower on upland downwind of the wetland site, though alternative approaches (boats, floating docks) may be considered. Proposed sites are noted in Table 2 but will require further site visit and permitting discussion before finalizing. An initial visit for site selection was performed by PI Desai and NCAR scientist Steve Oncley on December 1, 2015.

Table 2 Proposed candidate site coordinates, airborne LiDAR-derived canopy height, and vegetation type (WISCLAND)

Site#	Latitude (degrees N)	Longitude (degrees W)	Canopy height (m)	Vegetation type
1	-90.290	45.918	3.2	Shrub land
2	-90.286	45.922	14.4	Wetland
3	-90.247	45.925	0	Wetland
4	-90.309	45.927	16.8	Forest
5	-90.305	45.933	17.6	Forest
6	-90.266	45.934	20.8	Forest
7	-90.290	45.935	13.6	Wetland
8	-90.212	45.936	25.6	Forest
9	-90.239	45.939	24	Forest
10	-90.290	45.940	15.2	Forest
11	-90.333	45.952	0	Lake
12	-90.293	45.955	20	Forest
13	-90.219	45.956	23.2	Forest
14	-90.232	45.962	20	Forest
15	-90.319	45.966	19.2	Forest
16	-90.267	45.966	18.4	Forest
17	-90.209	45.970	24.8	Forest
18	-90.231	45.973	21.6	Wetland
19	-90.252	45.975	22.4	Forest
20	-90.211	45.976	27.2	Forest

We are aware that significant infrastructure costs are likely with the short-term construction of 15-20 flux towers and that further land cover sampling analyses (Fig. 3a) suggest reduction in slope of representativeness after 8 towers. However, the spatial eddy covariance analysis, whereby multiple towers are used in unison to detect mesoscale eddy contribution to fluxes requires, based on preliminary LES analysis (Fig. 3b), requires closer to 15+ towers. This figure is remarkably similar to the one produced by Steinfeld et al (2007) in a similar “virtual tower” sampling study, whereby the convergence on cases where randomly place flux towers converge on the true space-time heat flux only converges after > 20 towers.

Thus, while for reducing the random error, perhaps 12 towers would be enough (Fig. 4a), more are needed for reducing the systematic error that arises from biased sampling of large eddies, should they exist and persist, one of the overarching goals of our experiment (Fig. 4b). Only with nearly 20 towers can we calculate a spatial covariance instead of a temporal covariance to test this hypothesis, and derive and rigorously evaluate a spatial model for compensating large eddy bias, potentially from even a single tower (Fig. 2c).

We have had extensive discussion with the ISFS team, including an informal site visit last winter. We have considered options including using local students, UW engineering expertise, and being creative with existing tower locations. NCAR has been able to consider various bids from the tower engineers and there may be options for tripod or smaller systems at low height vegetation, which could save time and cost. The USFS has already committed to allowing these tower operations on the site and Desai has had no issues in the past with rapid permitting.

Depending on ISFS availability, we will make additional requests for mobile deployment flux tower platforms available from both the Dept of Energy Ameriflux Network Management Project and the NSF National Ecology Observatory Network (NEON). Desai is an AmeriFlux core site PIm on the NEON Science and Technical Advisory Committee (STEAC), and closely collaborates with the NEON eddy flux team (co-PI Stefan Metzger is based at NEON), and will make these requests after the project is approved for funding.

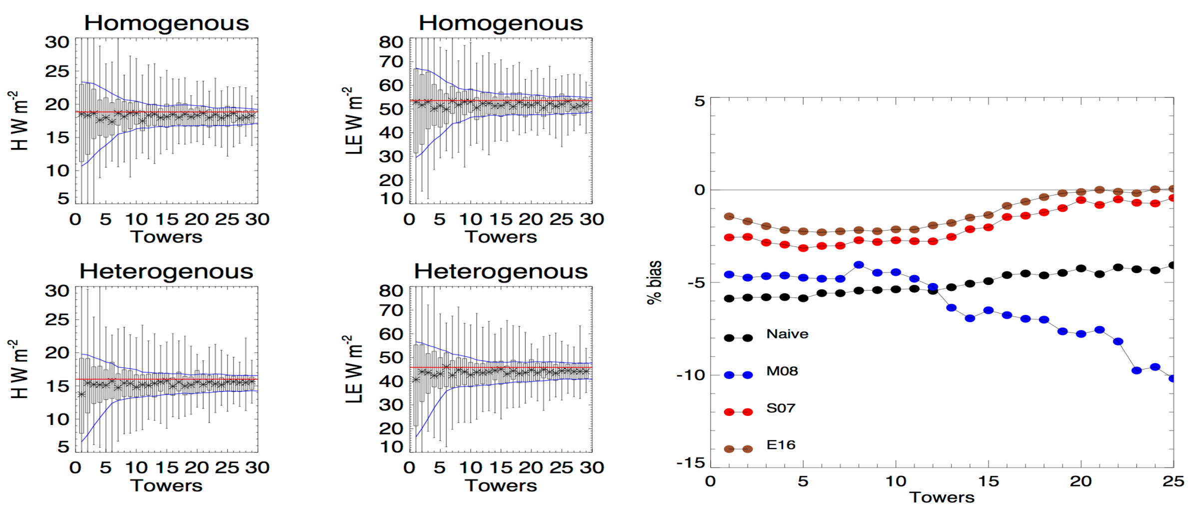


Figure 4. a) Virtual flux towers sampled using time-average Reynolds decomposition in a large eddy simulation study shows persistent underestimation of surface heat flux (red line) that worsen with surface heterogeneity (lower panels) and only slightly improves with more towers. b) However, recently published spatial eddy covariance techniques (blue, red, and brown lines) can close the energy balance when computing the space-time covariance for heat fluxes with 15-20 towers.

ISS: We request the 449 MHz wind profiler and radio acoustic sounding system (RASS) deployed to measure boundary layer winds and virtual temperature operating in low-altitude mode to maximize sample (60 or 100 m resolution) in the first 2 km of the atmosphere at 5-minute intervals. Standard surface meteorology (pressure, temperature, humidity) is requested for inter-calibration with existing tall tower meteorology.

We request a total 105 soundings from the balloon-borne rawinsonde. A single sounding at 12Z will be launched each day. During the IOPs, additional radiosondes from SPARC (42 per IOP, 6 days) and UW (30 per IOP, flight days only) would be launched at approximately 10 Z (sunrise), 12Z, 15Z, 18Z, 21Z, 0Z, and 3Z (sunset) to capture the diurnal cycle. Undergraduate student support from UW-Madison and/or Northland College is available for these launches. The UW Atmospheric and Oceanic Sciences (AOS) sounding system will also be used to capture upwind soundings for trajectory analysis (additional 5 per IOP).

KIT DIAL/Raman LiDAR: Hannes Vogelmann und Ralf Sussmann at the Karlsruhe Institute of Technology (KIT) will assist co-I Matthias Mauder in submitting a proposal to the German DFG to develop and deploy their combination Raman/DIAL LiDAR. The LiDAR is a combination between a DIAL for H_2O and Raman for temperature. The instrument was tested during ScaleX-2016 but still needs some further development. Thus the parallel proposal would support a Ph.D. student in German who would work prior to the experiment on continued development of the instrument prior to deployment. This instrument would provide a unique opportunity when coupled with the SPARC and ISS wind profilers to capture the water vapor and heat flux budget and compare directly to eddy covariance measurements made on the tower, at least for the top height (396 m), which would overlap the first range of the DIAL (300 m, 150m vertical resolution). If this funding is unsuccessful, the instrument would not be usedi n CHEESEHEAD19. However, Mauder will still provide assistance on the LES modeling and all hypotheses can still be addressed with other instrumentation.

SPARC: The UW SSEC SPARC trailer would be co-located with the ISS instrumentation. The Atmospheric Emitted Radiance Interferometer (AERI) would pointed upward to retrieve boundary layer profiles of temperature and humidity, complementing the more qualitative profiles retrieved from the RASS, while the High-Spectral Resolution Lidar (HSRL) would be pointed upward to sample boundary layer aerosol backscatter and depolarization ratio at 532 nm and 1064 nm. A HALO Photonics Streamline XR conical scanning wind LiDAR would provide high-resolution, 5-minute wind profiles to complement the ISS 449 MHz profiler, since the LiDAR has better retrieval quality near the ground and be used to compute boundary layer eddy flux profile. Finally, the Vaisala ceilometer provides a secondary evaluation of PBL depth.

a) b)

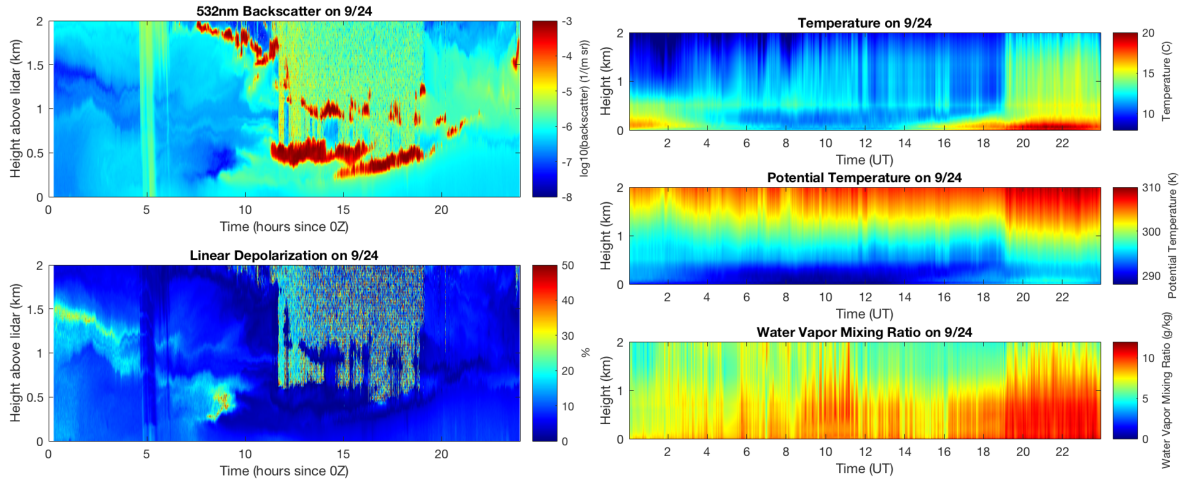


Figure 5. Undergraduate student Kip Nielson thesis results showing a) SPARC HSRL 532 nm backscatter and linear depolarization on Sept 24 and coincident AERI temperature and water vapor retrievals at the WLEF tall tower site during the 2016 test deployment. AERI shows turbulent mixing enhancing surface fluxes and water vapor transport around 20 Z, as clouds clear off earlier in day, as seen on HSRL.

C-TEMPS: While our previous proposal included funding to deploy a field-deployable air temperature fiber-optic distributed temperature sensing system (DTS) from the NSF Center for Transformative Environmental Monitoring Programs (C-TEMPS), based on marginal utility as brought up in reviewer comments and panel review and our own assessment based on consultation with C-TEMPS, we have removed this request. We will instead consider permanent acquisition as part of a facilities upgrade to the tower.

U Wyoming King Air: IOP dates will be selected in close consultation with U. Wyoming King Air availability and weather conditions. We request a total of 70 hours. During the IOPs, the King Air will ferry from Laramie, WY to a nearby airport (likely Price County, Philips, WI) – 3.5 hours. With student forecasting assistance, up to five days will be flown focusing on fair-weather days, with either clear sky or shallow cumulus. On these days, 2 3 to 3.5-hour flights will be conducted, one from 15Z-18Z and another from 20Z-23Z. Each flight will consist of 3 100-km legs roughly perpendicular to mean wind direction (prevailing westerly or south-westerly, and thus typically north-south legs) and a similar 3 in parallel, each located 4 km apart, flown at level altitudes of 500 ft above ground and then 2000 ft above ground. If permission is granted, we request the 500 ft leg to be flown at 300 ft to minimize vertical flux divergence. While 30 km extends beyond the 10 km study domain, it allows for capturing enough eddies and mesoscale variation necessary to properly compute statistics for fluxes and waves using the wavelet decomposition method.

Each altitude will require 5 minutes for sample and 2 minutes per turn, so a single leg will require 20 minutes and the total sample will take 100 minutes (1.6 hours), which will be repeated, for a total 3.2 hours + additional 0.3 hours for taxi, takeoff, and positioning. During flight, CO_2 and H_2O will be sampled by an open-path Licor 7500 and closed-path Licor 6262 or 7000, depending on upgrade progress. The Wyoming upward pointing 355 nm Wyoming Cloud LiDAR, if available, will be used to identify boundary layer depth, otherwise we will rely on soundings and temperature profile. Reverse-flow temperature and gust-probe provide 10 Hz turbulent temperature and wind measurements. A chilled mirror will provide baseline dewpoint measurement. Upward and downward IR and visible radiation will also be analyzed for energy budget calculation. Fluxes will be processed using a wavelet decomposition and flux footprinting method to increase sampling resolution and identify individual surface contributions to the measured eddy flux.

During the 2000 ft AGL leg, we request the Wyoming Compact Raman LiDAR, is available, to be flown downward pointing to map temperature and moisture profiles of the atmosphere, which would allow us to effectively estimate mesoscale development and calculate flux divergence and storage terms. Result from prior experiments suggest the LiDAR has excellent resolution in both daytime and nighttime conditions.

We believe this approach will provide sufficient statistics for computing spatial eddy fluxes and sampling boundary layer meteorological variability based on some preliminary analysis with our large eddy simulation output. Additional allocation for tower surveillance was noted in the last review, which seems reasonable. We also noted in the last review that UWKA team was willing to accommodate the low-level flight legs after tower surveillance is accounted.

UW Ultralight: The University of Wisconsin Ultralight (N13UW) is a new human-piloted airborne instrument platform built in the summer of 2017 from a commercial kit (the Aeromarine Zigolo) by personnel in the Atmospheric and Oceanic Sciences Department (Fig. 6). It is an experimental platform intended primarily for airborne boundary layer measurements. Operating characteristics are in many ways similar to those of fixed-wing drones, but without the associated regulatory restrictions (e.g., line-of-sight operation below 400' only) and without many of the logistical complexities of unmanned autonomous flight. The aircraft would be maintained and operated by co-PI Grant Petty.

CHEESEHEAD will likely be the first major deployment of the aircraft in an experiment outside of testing or educational deployments. The aircraft is notable for short takeoff requirements (< 500 ft), ultra-slow cruise speed (~30–40 mph), and up to 3 hours of on-site air time on one 5 gal. tank of fuel. Because of its light weight (~100 kg empty, ~220 kg maximum takeoff weight) and low speed, the plane can safely cruise and maneuver at extremely low altitudes (100–500 ft) over unpopulated areas as well as flying to higher altitudes when needed. The principal anticipated limitation of the UW Ultralight for the purposes of this experiment is that it cannot be flown during periods of strong or gusty winds.
The standard minimum suite of instruments will log temperature, pressure, humidity, position, and altitude. By the time of the CHEESEHEAD deployment, we anticipate the integration of additional instrumentation to measure turbulent fluxes and winds aloft, a FLIR thermal imaging camera for mapping surface skin temperature, and telemetry for ground monitoring of aircraft position and raw data. During IOPs, the plane will be based at the Park Falls municipal airport, 12 km west of the WLEF US-PFa tall tower. Students will help design the final flight plan, but the preliminary plan is to sample the 10x10 km box in a square pattern at two heights (100 and 300 ft) during King Air deployments to construct a simple boundary layer budget. In addition, measurements will be compared with those from the stationary tower for validation of both instrument performance and spatial homogeneity assumptions.

Figure 6. The 29 August 2017 maiden flight of the UW ultralight in Verona, Wisconsin.

UW hyperspectral imager: HySpex is a compact 400-2500 nm spectrometer, with high spectral resolution (3-5 nm), for mapping surface spectral reflectance that was recently acquired by the University of Wisconsin, and operated by PI Phil Townsend in Forest Ecology. Townsend has an agreement to fly this spectrometer on a Cesna 180J owned by the State of Wisconsin Department of Natural Resources. Acquisition for the 10x10 km in a mapping mode will be acquired at an altitude (~1000 ft) that allows for approximately 1 m spatial resolution during both IOPs, to capture both fully leaf on and partial leaf off. These maps will be connected to the ground based spectra and phenology to provides the boundary conditions of canopy type, activity, and stress, needed for estimating scaling properties. These will also help with scaling of data collected weekly at the field plots, which provide the phenological evolution of the landscape. Phenological observation work has been done in the area for several years now. There also may be opportunity for no-cost additional acquisition from a thermal band and canopy height LiDAR sensor aby coordinating a flyover with the NEON Airborne Observing Platform, which would sample one of the nearby NEON sites during its routine visits, as well as the US-PFa AmeriFlux site as part of a developing agreement between AmeriFlux and NEON.

Logistics

The tall tower is owned by the State of Wisconsin Educational Communication Board (ECB) with whom Desai has had a good working relationship for the past decade. Tall tower climbing support is provided by the OK Tower Company. The clearing around the tower can provide support for trailers and other deployments with permission, and line power and high-speed internet can be accessed from the existing AmeriFlux/NOAA trailer. We successfully deployed SPARC here in fall 2016 and acquired additional electrical hook ups, which will facilitate the full experiment in 2019.

The area around the tower is primarily land in the U.S. Forest Service Chequamegon-Nicolet National Forest. A number of research activities are ongoing in the forest including Ameriflux tower operations. The CNNF research coordinator (Linda Parker) can provide site access and permitting details. Some wetlands and forests may require coordination with the Wisconsin Dept of Natural Resources (DNR) or the Ojibwe Lac Du Flambeau Indian reservation.

The University of Wisconsin operates a field research station approximately 45 minutes away from the tall tower site. The Kemp Natural Resources station has low-cost dormitory-style lodging, high speed internet, dry and wet lab facilities, and shipping/receiving/storage capability. We propose a “field office” be set up at Kemp NRS. Additional student work and lodging space is offered by Northland College.

Adequate runway and hangar facilities are likely available at Phillips Price County airport or alternatively Ashland or Rhinelander airport.

Operational Concerns, Safety, Data Availability

Daytime operations in relative flat, unpopulated areas, with mostly uncontrolled airspace, and with good local options for aviation and lodging suggests limited safety issues. No eye safety issues are present with LiDARs. Desai has worked in this region for over 15 years, has sustained contact with local landowners and permitting authorities, and has a full-time DOE-supported lab manager (Jonathan Thom) to support flux tower operations (and partial salary support here). NCAR ISS staff have operated in this area before and ISFS staff will be soon making a visit to the tall tower site. A full-time postdoctoral scholar will live in the area during the field experiment to supervise students (at least 3 graduate students and 4-5 undergraduates) and scientist interaction. Weekly project teleconferences will begin 9 months prior to operations, during and after. Experts on eddy covariance (Desai), ecohydrology (Stoy), land surface ecology (Schwartz), remote sensing (Townsend), atmospheric radiation (Petty), boundary layer modeling and instrumentation (Mauder) and flux scaling (Metzger) are all committed to training and support of analysis. Desai also has extensive participation in outreach in the area and will teach an undergraduate field instrumentation course in conjunction with the experiment. We intend to make all data (raw high-rate and processed) freely available both through UCAR data archive and also locally at University of Wisconsin as soon as it is available. Ameriflux tower data are made freely available nightly online and archived at DOE ORNL DAAC. We are aware that potential instrument conflicts are always possible, and are willing to adjust timing.

The goal of all field experiments should be to generate broadly applicable observations for the community for science hypothesis testing and evaluation. We support open-access publication of all data in a timely manner (as soon as logistically feasible), and will broadly advertise the dataset in the experiment overview paper (e.g., BAMS), at conferences, on our website, and via social media. We will request a DOI for the dataset and consider a special issue related to the experiment in Agricultural and Forest Meteorology, for which Desai is an editorial board member. Desai has often written public interest newsletter, blog, and web pieces and will consider working with EOL for one focused on this dataset.

Outreach

We expect to support at least 3 graduate students and 2 post-docs at UW-Madison, who will be involved in aspects of outreach, data dissemination, and education. We also budgeted participant travel for a NEON-organized workshop on key data and science objectives of the experiment, in particular on flux scaling, at the American Geophysical Union (AGU) meeting. Four undergrad students will be supported to participate in experiment assistance, including balloon launches, flight forecasting, King Air on-board flight assistance, and supporting student projects. Three undergraduates at UW-Milwaukee will conduct most of the ground based ecology sampling. Desai will teach an Atmospheric and Oceanic Sciences special topics course on CHEESEHEAD (AOS 404: Meteorological Measurements, recently approved by UW). In that class, students will use existing instrumentation at UW-Madison to develop 1 or 2 side project to occur during the experiment, including making additional WindSond profiles, mapping sub-canopy flow with balloons and digital cameras, deployment of a tripod based eddy covariance system and other meteorological sensors, or running of local mesoscale numerical simulations. Desai is also in discussion with the primarily undergraduate and nearby Northland College regarding student participation. Public outreach to school groups is planned for two middle and high schools in vicinity of the tower (Park Falls Class ACT Charter School and Butternut Ridge School), in partnership with the Wisconsin office of the NSF and NASA supported Global Learning and Observation to Benefit the Environment (GLOBE) program. GLOBE personnel (Rose Pertzborn) and supplies are budgeted in this program to provide teacher training, classroom materials, and coordinate classroom visits to the field sites during IOPs. Also, Desai has mentored middle school science students as part of an annual mentoring program run by the Madison Metropolitan School District (which serves students, of whom 57% are non-white and 50% low-income) and will attempt to recruit middle school science students to participate in some component of the project. Desai frequently (4-6 times per year) gives public talks in the region arranged by the UW Speaker's Bureau and also through the Kemp Natural Resources Station and the nearby NSF LTER field station (Trout Lake). Desai will work with SPARC and outreach specialists in SSEC and UWKA to provide tours of the SPARC facility, the UWKA, the US-PFa tall tower, and the UW ultralight during operation.

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