Drone-based harmful algae blooms monitoring

A Review and Our Preliminary Research

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Background

- Harmful algae blooms (HABs) is a severe water quality problem
  - Negative effects on ecology, public health and local economy
- The monitoring of HABs is traditionally cost-prohibitive or qualitative
  - Manual water sampling is costly and laborious
  - Community-based approach is often qualitative
    - Volunteer Lake Monitoring Program (VLMP)
- Unmanned aerial vehicles (UAVs) is a new method
  - A promising alternative to repeated in-situ field data collection in a more responsive manner
  - Flexibility in flight scheduling, low costs, and fine spatial resolution

UAVs Platforms and image sensors

- UAVs can be categorized and classified based on different design specifications and purposes
  - Wing structure: fixed-wing vs helicopter
  - Applications: agriculture, military, emergency response
  - Flight parameters: orientation, position, GPS locations and speed
- Spectral imagers or cameras largely decide the quality of image data
  - Multispectral or thermal cameras
  - Lightweight but often most complex (zoom lens, image stabilization)
- The gimbal system used to stabilize an imager’s connection to a UAV
  - Adjust the posture of cameras continually, regardless the position of UAV platform

Comparison with Satellite-based Monitoring

Platform		Spatial resolution (m)	Repeat cycle	Factors affecting image quality
Satellite	MODIS	250/500/1000	16 days	Atmospheric absorption, scattering and reflectance; cloud coverage; weather; terrain relief
	MERIS	300/1200	35 days	
	AVHRR	1100	Daily	
	Landsat TM	TM: 30/120; ETM+:15/30/60; OLI&TIRS:15/30/100	16 days	
	SPOT	SPOT 1-4:10/20; SPOT 5: 2.5/5/10/20; SPOT 6-7: 1.5/6	26 days	
UAV		< 0.5, can reach the level smaller than 0.1	Can be several times each day	Weather; terrain relief

	Advantages	Disadvantages
UAVs	Exceptional spatial resolution, and flexibility in scheduling; lower cost	Limited flying distance
Satellites	Global and regional coverage; lower cost	Relatively coarse spatial and temporal resolutions; atmospheric effects

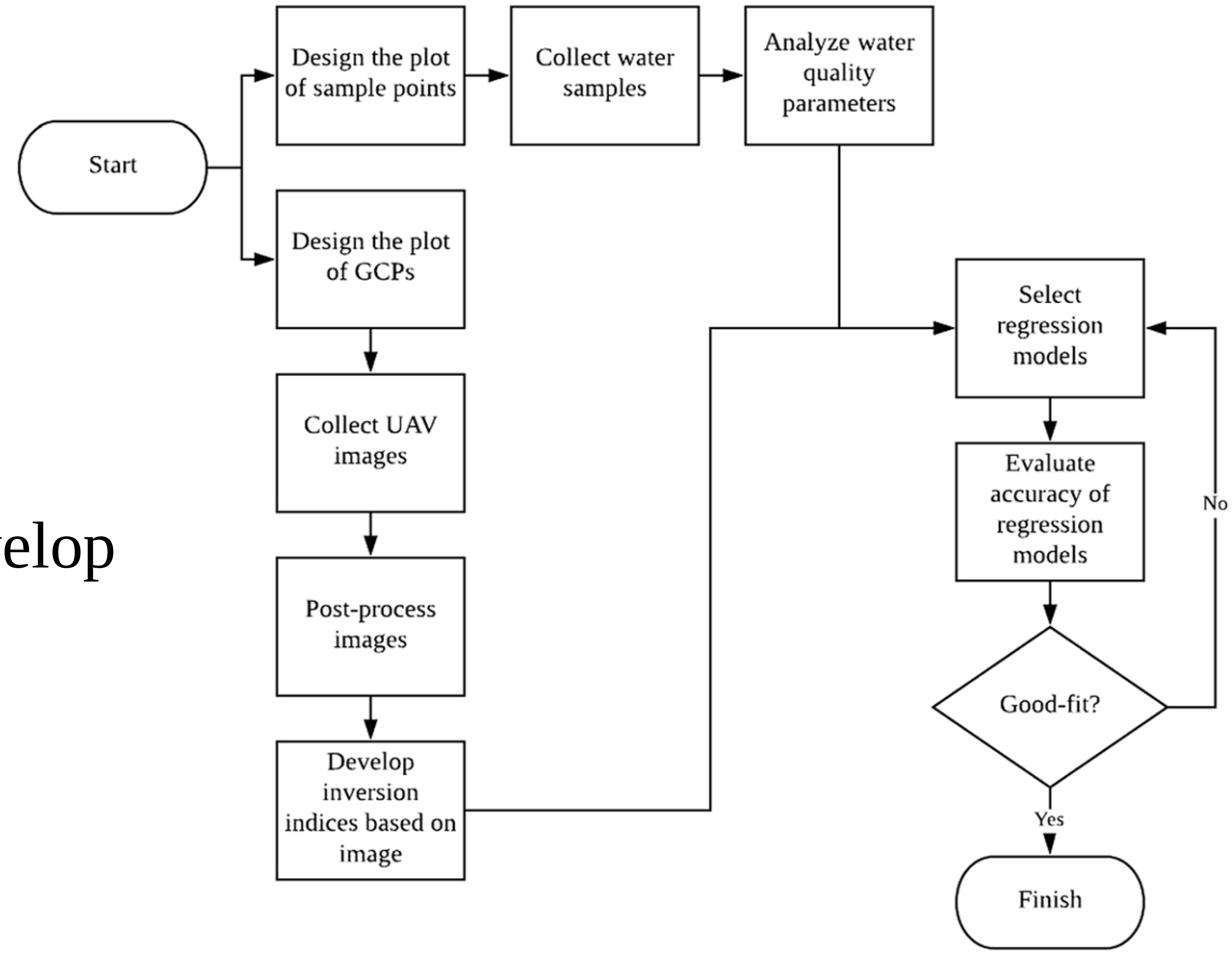
Objective

- Develop a cost-effective UAVs-based harmful algae bloom monitoring model for affected water bodies in Southern Illinois

- This presentation focuses on:
  - A review of current state of the art on drone monitoring for HABs
  - Our current research efforts pending full implementation

UAVs-based methods for HABs monitoring

- Design ground control points
- Collect UAV images
- Image processing
- Generate spectral indices
- Develop regression models
- Apply the selected model to develop a map

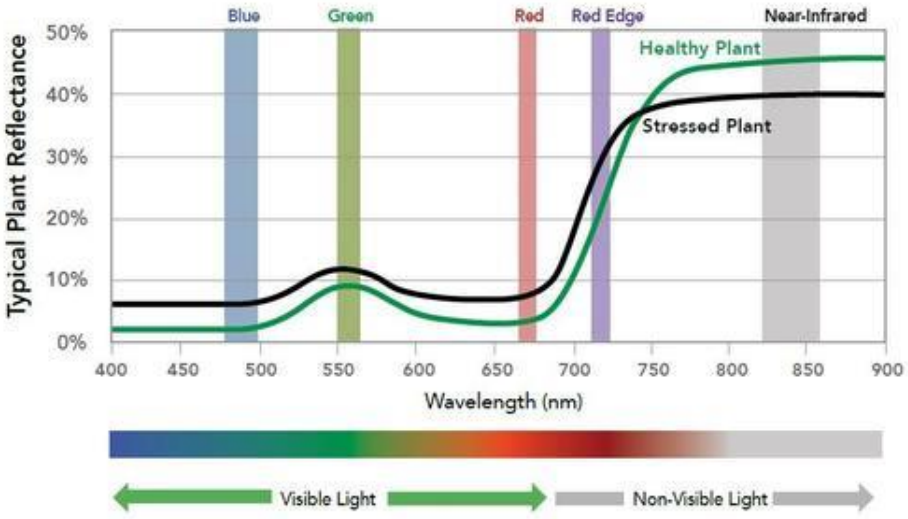


UAVs applications in algae bloom monitoring

Reference	Unmanned aircraft system		Modeling approach	
	UAV	Sensor	Water quality indicator	Image indices
Shang et al. (2017)	LT-150	AvaSpec-dual spectroradiometer with two sensors	Chlorophyll	Wavelength, FLH
Liu et al. (2017)	A fixed-wing UAV	A 25-bands snapshot μHSI sensor	N/A	N/A
Xu et al. (2017b)	DJI Inspire 1		Area of the green tide	NGRDI, NGBDI, GLI
Jang et al. (2016)	SenseFly eBee	Canon Powershot S110 RGB and NIR sensors	Amount of algae cells	AI
Van der Merwe. and Price (2015)	Small UAV	N/A	BPCV	BNDVI
Su and Chou (2015)	A fixed-wing UAV	Canon Powershot S110 RGB and NIR sensors	Chlorophyll-a, Total phosphorous, Secchi disk	NIR/R, R/B, NIR/B
Fráter et al. (2015)	Fixed-wing: a MULTIPLEX Easy Star II and a STYROMAN Smile Helicopter: a TAROT 690S hexacopter	Fixed-wing: FLIP MinoHD type Helicopter: GoPro HD Hero 3+	N/A	N/A
Ngo et al. (2015)	A helicopter UAV	Video camera	Concentration level of the algae	Color component in the RGB and HSV color spaces
Flynn et al. (2014)	Ready-to-fly unmanned multi-rotor VTOL aircraft	GoPro Hero 3 lightweight digital camera	Percent cover range on water surface	N/A
Dugdale (2007)	SmartPlanes SmartOne UAV	Canon IXUS 50/60 camera	Dry biomass	NGRDI, NDVI

Image correction and calibration

- UAVs image postprocessing is needed
  - Radiometric correction
    - Distortion caused by solar angles and atmospheric conditions can be ignored
    - Correction can be achieved by following prescribed procedures from manufacturers
  - Geometric correction
    - Distortion caused by wind and movement of a UAV can be correct by **six degrees of freedom** (6DoF) parameters or gimbal system
    - Distortion caused by terrain relief can be corrected by ground control points



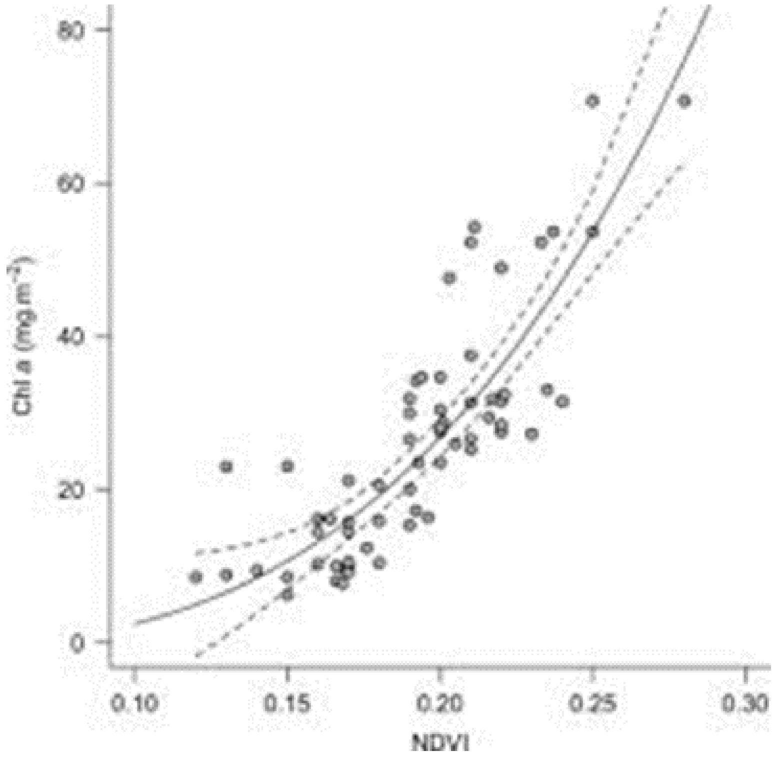
Spectral indices for detecting HABs

- Criteria of spectral indices selection
  - Sensors are able to provide sufficient spectral bands that can be used to arithmetically construct spectral indices indicative of the algae biomass in the water

Index	Equation	Reference
NGRDI	$NGRDI = (G - R)/(G + R)$	Xu et al. (2017b), Dugdale (2007)
NGBDI	$NGBDI = (G - B)/(G + B)$	Xu et al. (2017b)
GLI	$GLI = (2G - R - B)/(2G + R + B)$	
AI	$AI = \frac{R_{850mn} - R_{660nm}}{R_{850mn} + R_{660nm}}$	Jang et al. (2016)
AI_{adjust}	$AI_{adjust} = \frac{R_{850mn} - R_{660nm}}{R_{850mn} + R_{660nm}} + \frac{R_{850mn} - R_{625nm}}{R_{850mn} + R_{625nm}}$	
BNDVI	$BNDVI = (NIR - B)/(NIR + B)$	Van der Merwe and Price (2015)
NDVI	$NDVI = (NIR - R)/(NIR + R)$	Dugdale (2007)

Modeling approaches

- Regression modeling
  - Associate algae biomass with spectral signatures on the UAVs images
  - Linear or non-linear regression
- Empirical image indices
  - Develop them based on previous research experience
  - Simplify the modeling procedures for establishing quantitative relationships between water quality indicators and drone images.



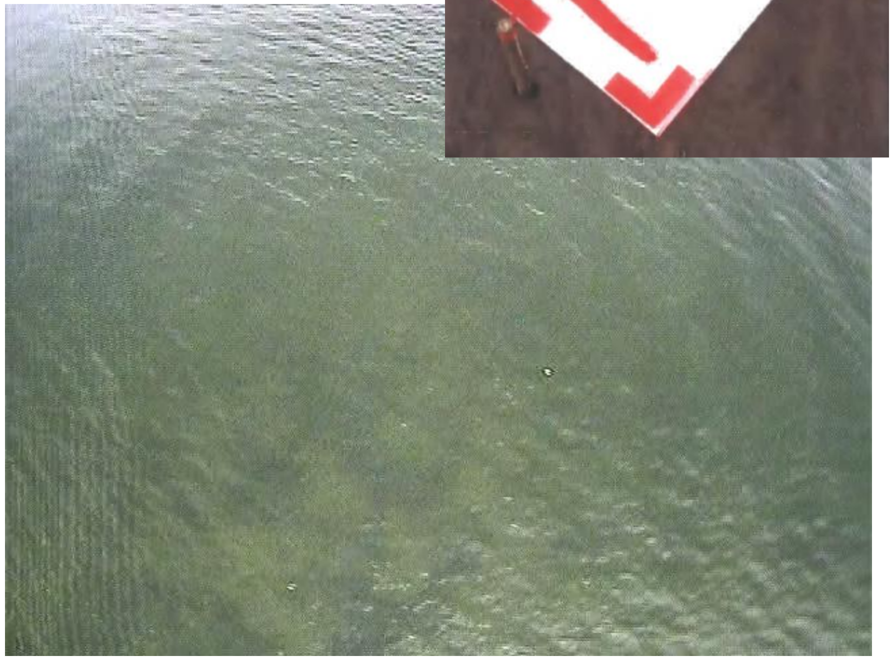
Opportunities and limitations

- Innovative applications
  - Deeper integration of UAVs and other technologies (e.g., automation technologies, Internet of Things, and Artificial Intelligence)
    - Algal bloom removal robotic system (ARROS) (Jung et al. 2017)
    - Collecting water samples (Koparan et al. 2016; Koparan et al. 2018; Wolinsky, 2017)
    - Automatic methods may be available as cloud-based services
- Limitations
  - A trade-off has to be stricken between the battery power capacity and the image resolution
  - Airspace restrictions (e.g., no-fly zones) and the absence of adequate regulations in some countries
  - Undesirable weather conditions

Technical challenges

- Challenges for image registration
  - Difficult to set up ground control points (GCPs) in deep water

- Possible solutions
  - In shallow water, the GCPs were marked on A4 paper-sized panels mounted on the fixed sticks distributed over the water area randomly (Dugdale, 2007)
  - Using area-based algorithms for automatically selecting GCPs from the airborne images that do not present distinctive features in uniform areas (Du et al. 2008)



Technical challenges

- Challenges for image stitching
  - Unique reference features to be used as image overlapping areas do not exist on homogeneous, or rippling water surface for image stitching

- Possible solutions
  - For mosaicking large water-present areas, using a position and orientation system (POS). (Wang et al. 2014)
  - For images with small land or other objects, using a combination of scale-invariant feature transform (SIFT) and Harris algorithms and random sample consensus (RANSAC) algorithm. (Wang et al. 2014)

Our Project


Campus Lake
Carbondale Reservoir
West Frankfort City Lake
West Frankfort Reservoir
Herrin Lake
Sharp Ln
McReynolds Ln
Braggs Ln
Gordon Ln
N Shore Ln
Charley Good Rd
Baseline Rd
E Old Lake Rd
Michalic Ln
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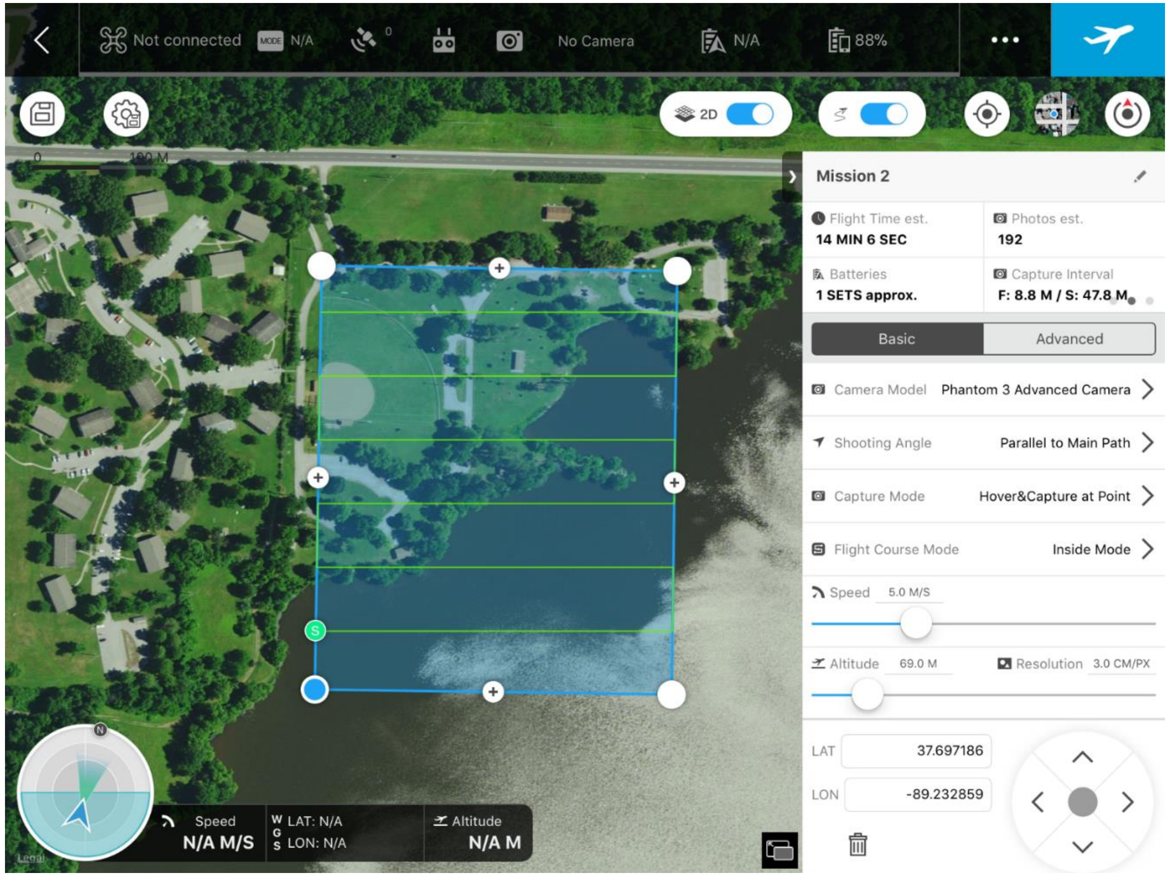
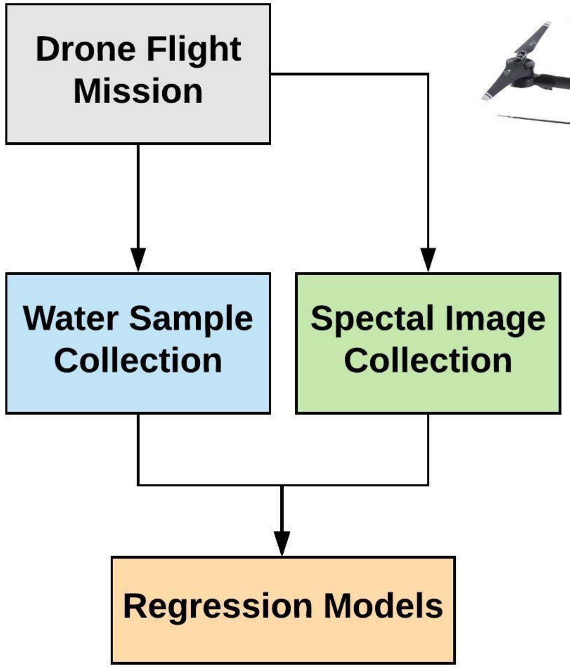
Our Project – Equipment (DJI M100 + RedEdge-M)

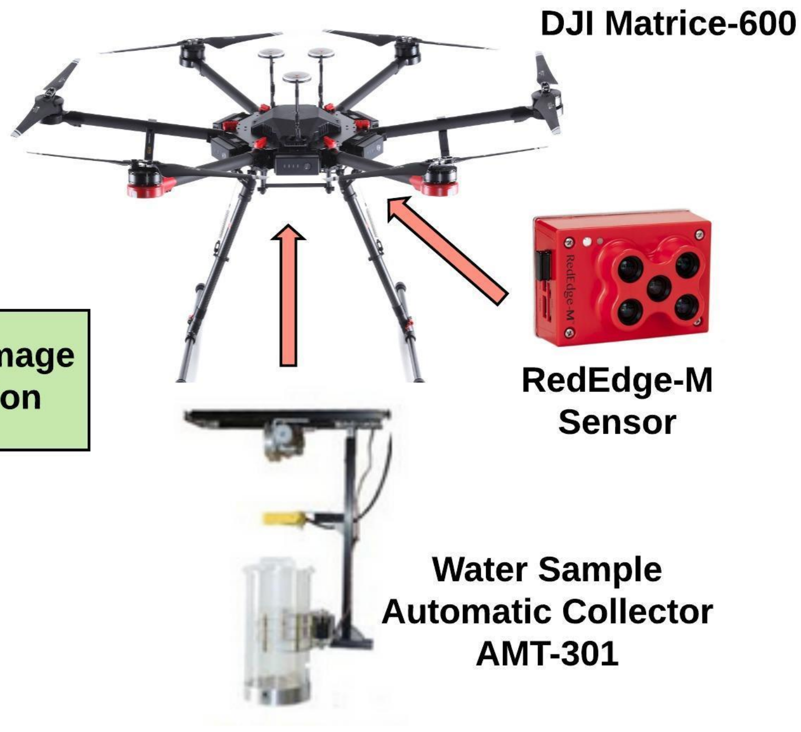


Our Project – Water Sampling

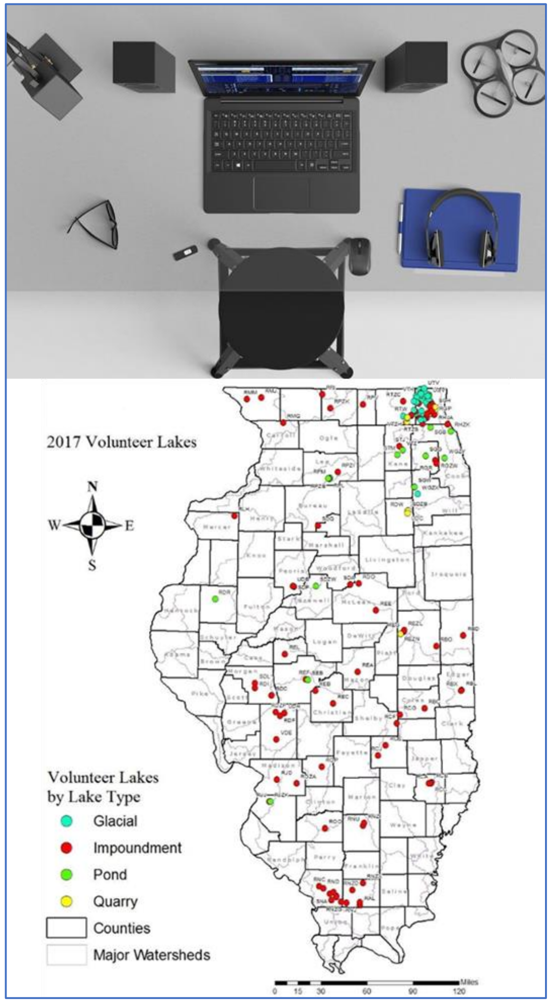
- Sampling points are plotted with a density of 0.01~2.34 points per square kilometer (Zhao et al. 2011; Bonansea et al. 2015)
- A rental boat will be used to collect water samples with survey-grade GPS
- In water sample analysis, we will use quantitative PCR (qPCR) for monitoring the cells of toxic cyanobacteria *Cylindrospermopsis raciborskii* and *Microcystis spp.*
- Lab tests for Chlorophyll-a, another HABs indicator.

Our Project – Future Work





Synchronized Data Collection



Community-based Usable Tool

Summary

- UAVs + onboard sensors appear to be promising methods to help environmental managers monitor algae blooms and develop precautionary warming systems in a timely, accurate, and cost-effective manner.
- With continuous advancement in hardware and modeling algorithms, it is expected more refined and automatic methods may financially and technically affordable to local communities.
- Although limitations still exist affecting broader applications, this emerging technology exhibits tremendous opportunities for community-based HABs monitoring programs.

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Timeline & Acknowledgment

- The work in Southern Illinois is expected to start next May and complete the work by the fall, 2019.

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Questions?

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