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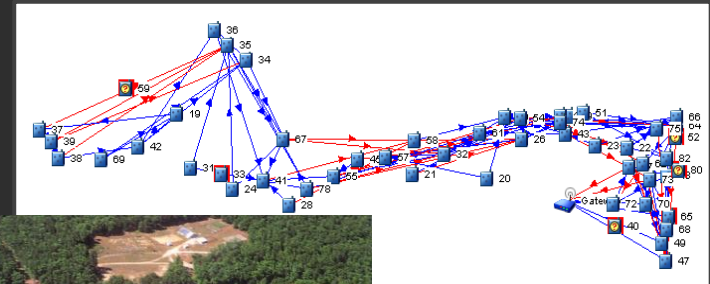
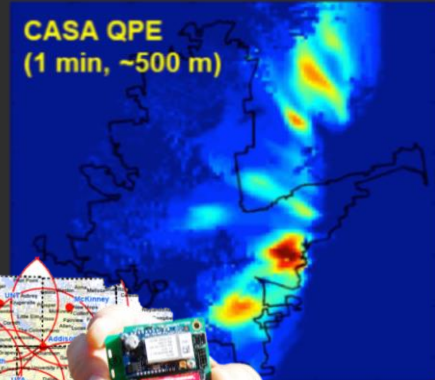
# EVAPORATION ON THE GREAT LAKES



**Kevin Fries**  
UoM CEE

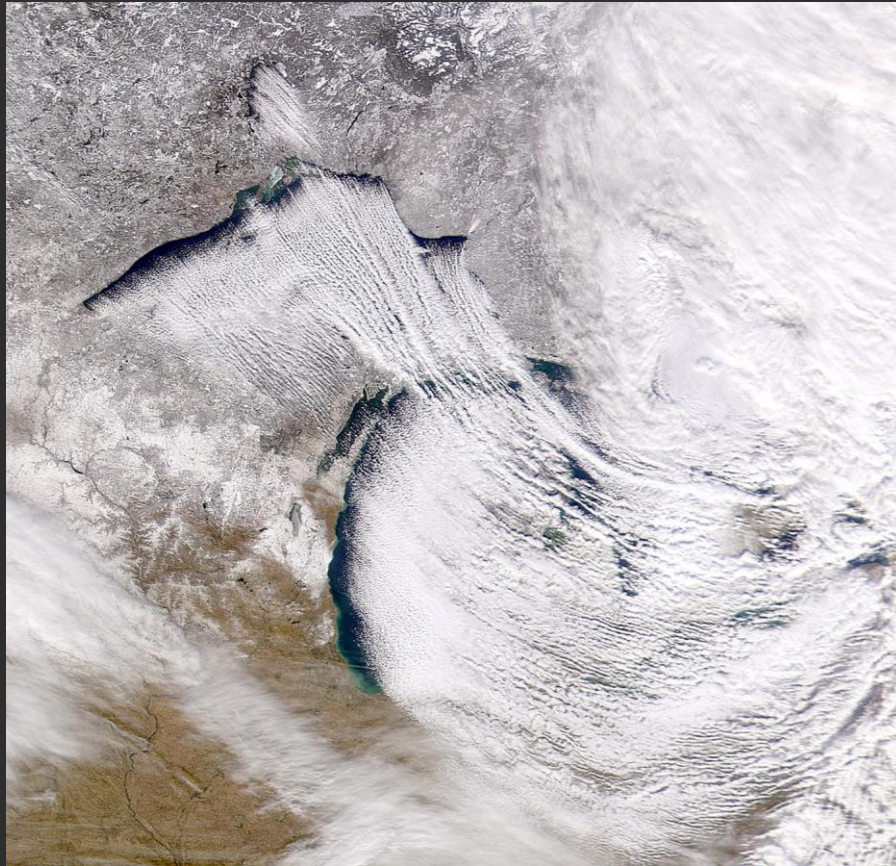
**Branko Kerkez**  
UoM CEE

**Andrew Gronewold**  
NOAA, UoM CEE



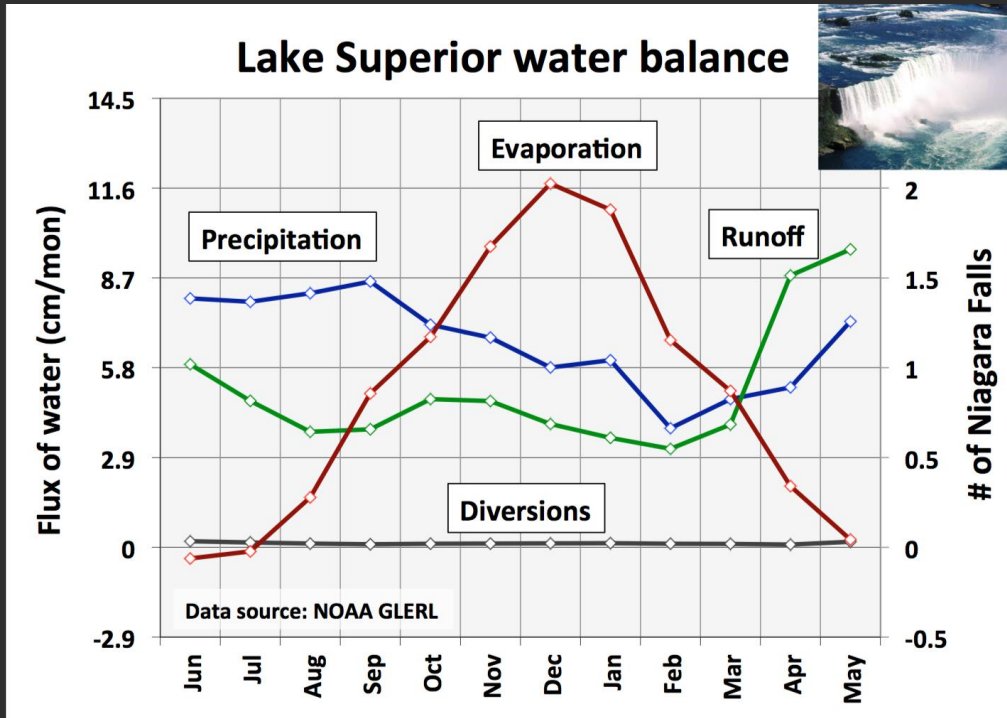
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# Great Lakes Evaporation



Kevin Fries (PhD Student), John Lenters (LimonTech), Andrew (NOAA)

# Water level fluctuations



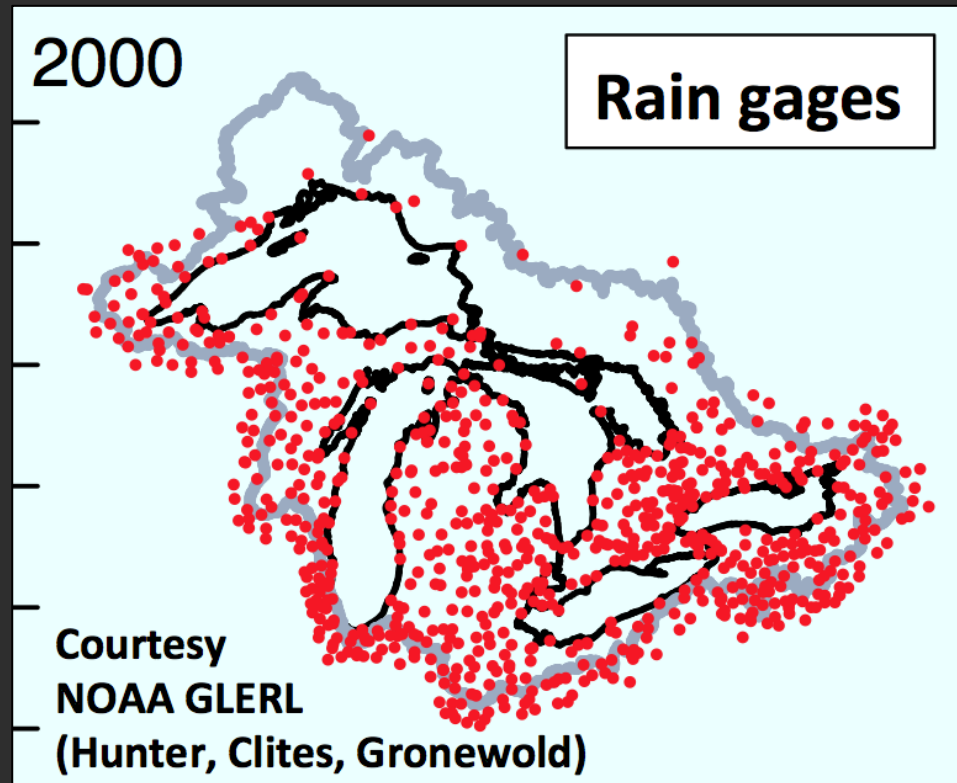
The dipping water levels in Lake Michigan have left docks out of the water and beaches extending hundreds of feet into West Grand Traverse Bay northwest of Traverse City. (John L. Russell / Great Lakes Images)

# Measurements

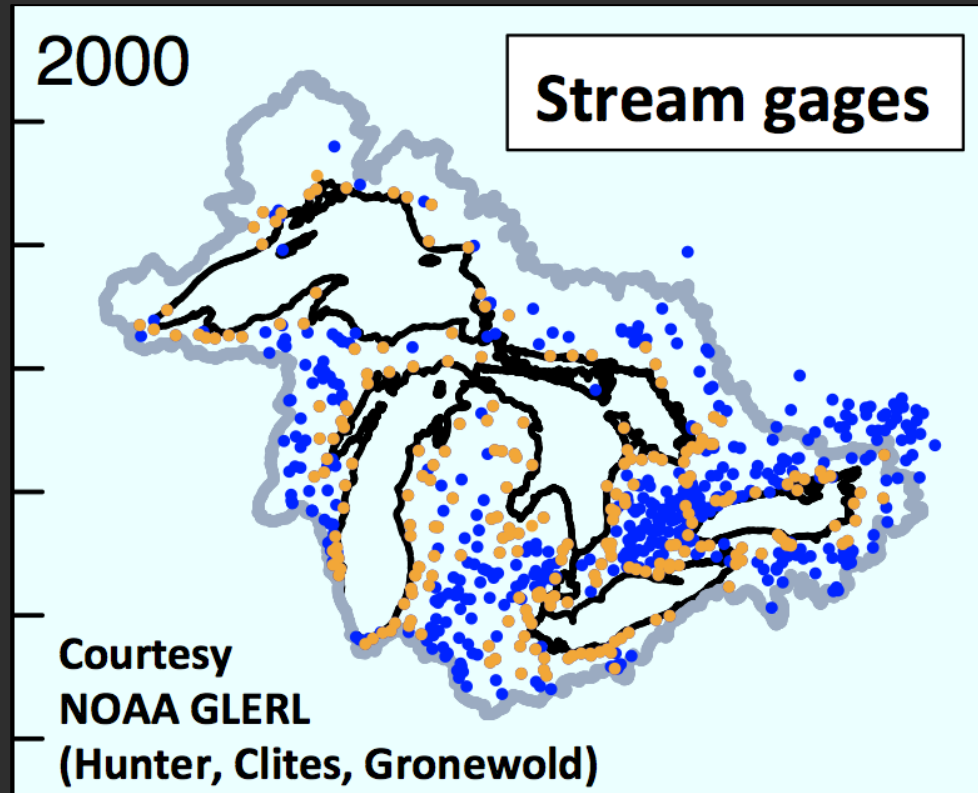


Source: Great Lakes IMDS

# Precipitation



# Flow



# GLEN

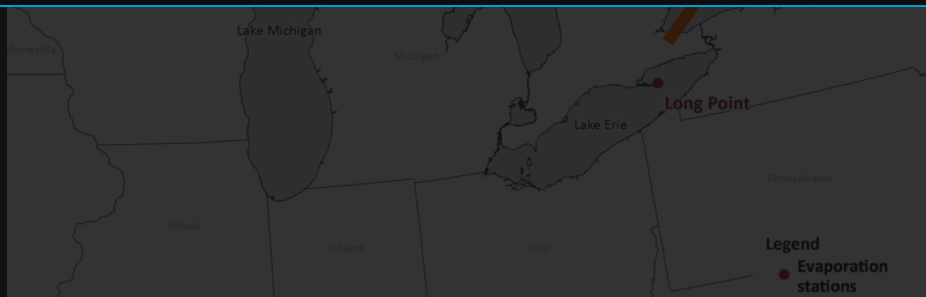




# Great Lakes Evaporation Network



More overlake evaporation  
measurements are needed



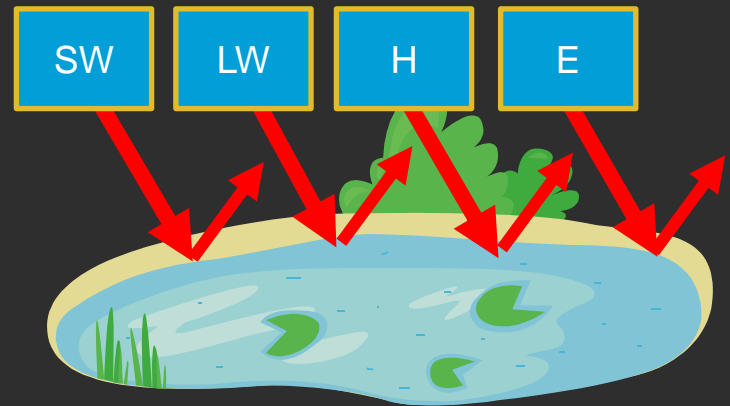
# Measuring Evaporation

## Eddy Covariance



Licor

## Energy Balance



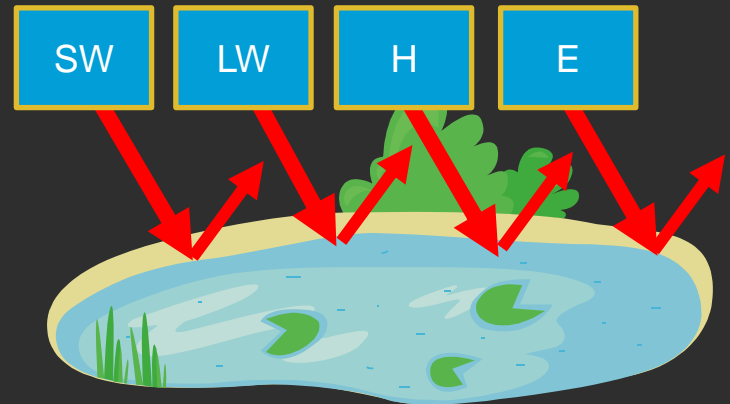
# Measuring Evaporation

## Eddy Covariance



Licor

## Energy Balance



# Eddy Covariance Instrumentation



**Fixed Location  
Very Expensive**

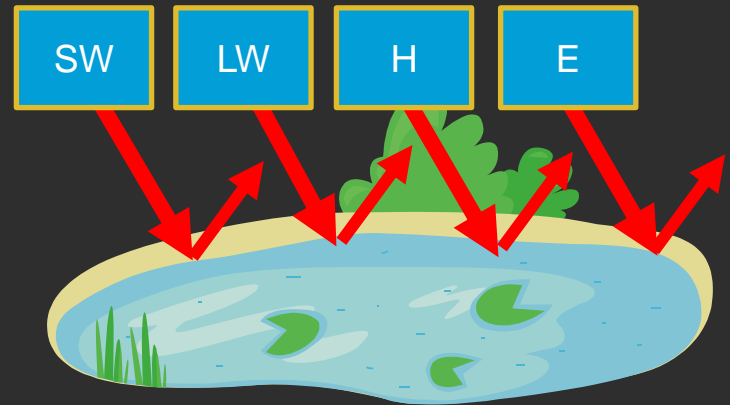
# Measuring Evaporation

## Eddy Covariance



Licor

## Energy Balance

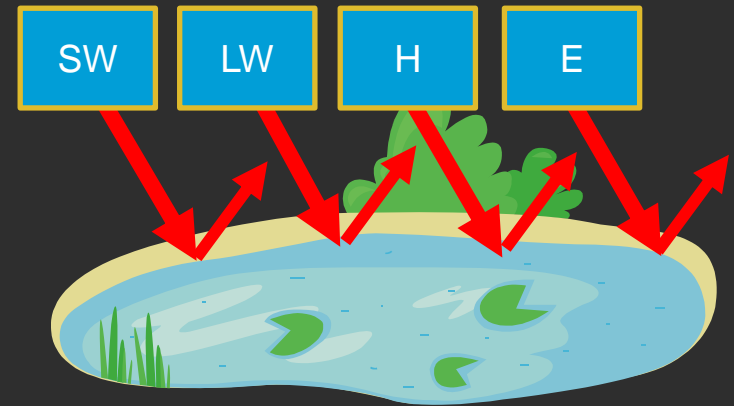


# Energy Balance

Solve for evaporation by measuring energy budget

Can be very accurate (5-10%)

Measure: relative humidity, wind, air and water temperature, radiation



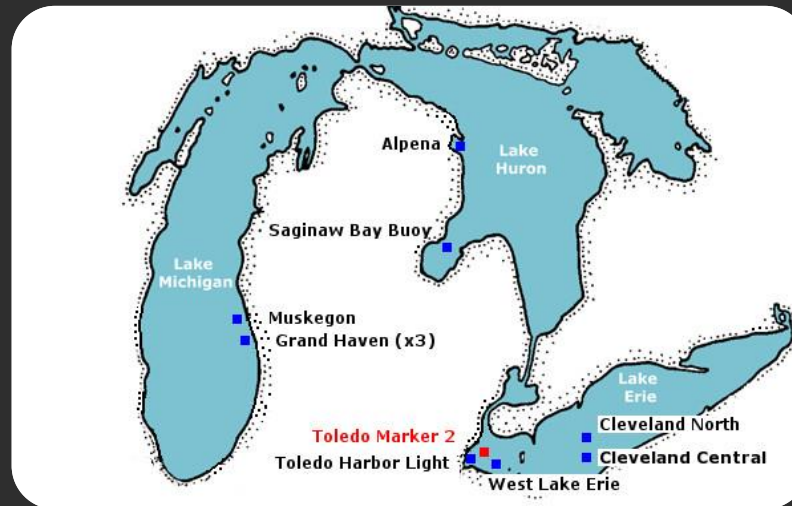
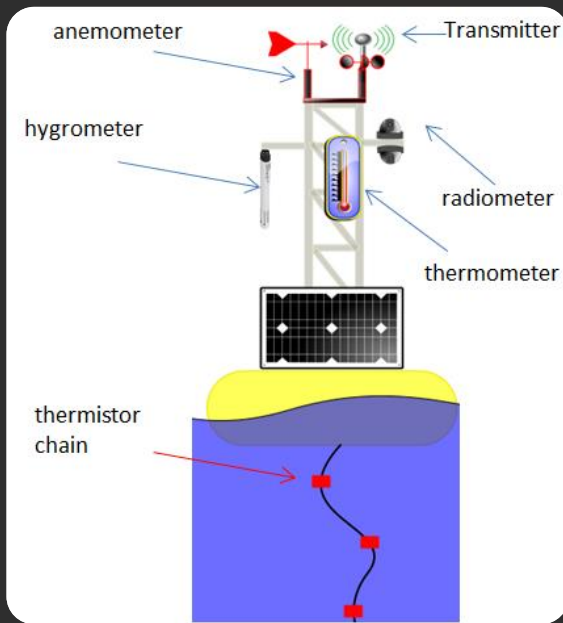
$$E \approx \frac{R_{\text{net}} - S + Q_{\text{sed}}}{1 + B + c_w/L_v(T_s - T_L)}$$

- E: Evaporation rate
- $R_{\text{net}}$ : Net radiation (shortwave and longwave)
- S: Rate of heat storage in lake
- $Q_{\text{sed}}$ : Sediment heat flux
- B: Bowen ratio ( $= k \overline{U \cdot \Delta T} / \overline{U \cdot \Delta e}$ )
- $c_w$ : Specific heat of water
- $L_v$ : Latent heat of vaporization
- $T_s$ : Water surface temperature
- $T_L$ : Average lake temperature

Lenters (2014)

# Energy Balance Buoy

Solve the energy balance in real-time

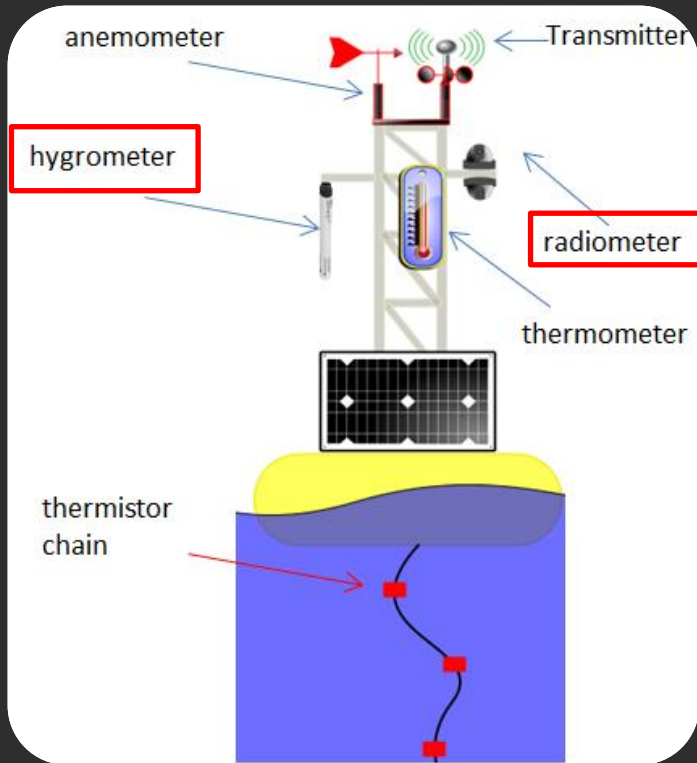


GLERL RECON Buoy Network

[tinyurl.com/bkerkez](http://tinyurl.com/bkerkez)



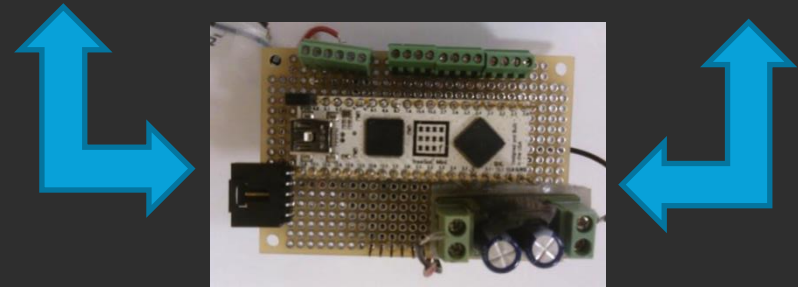
# Buoy



Hukseflux Net Radiometer



Vaisala Hygrometer



$\mu$ C

PSoC5

RS232

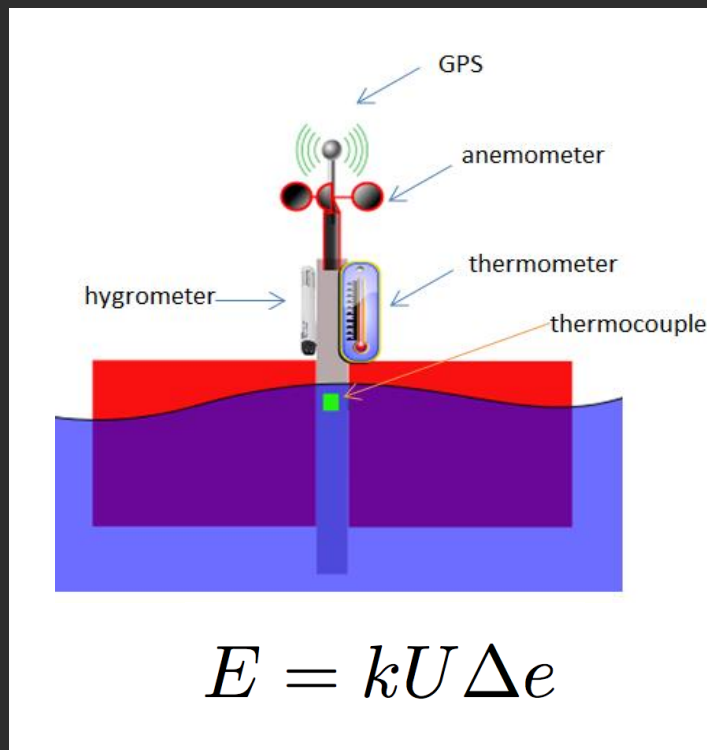
RECON Linux



# Bowen Ratio drifter

Only measures variables related to Bowen Ratio

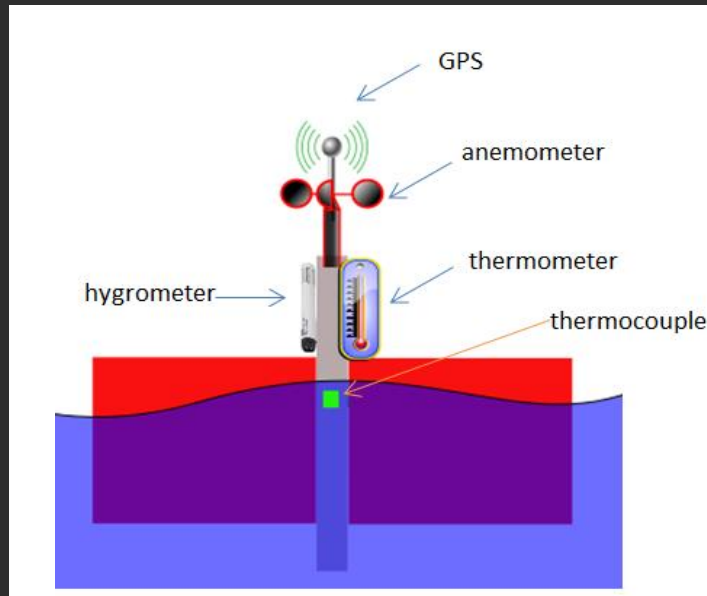
Simpler, cheaper, but requires calibration constant (k)



# Drifter

150WX Wind, Temp/RH

Thermocouple

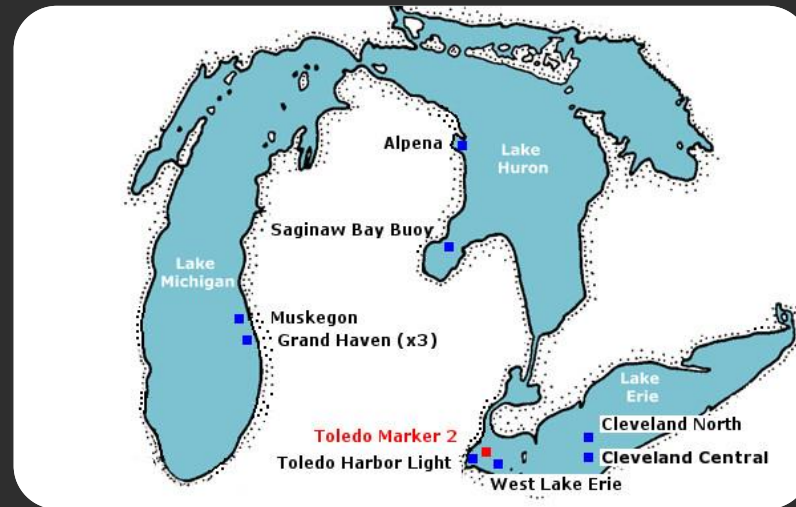


PSoC 5

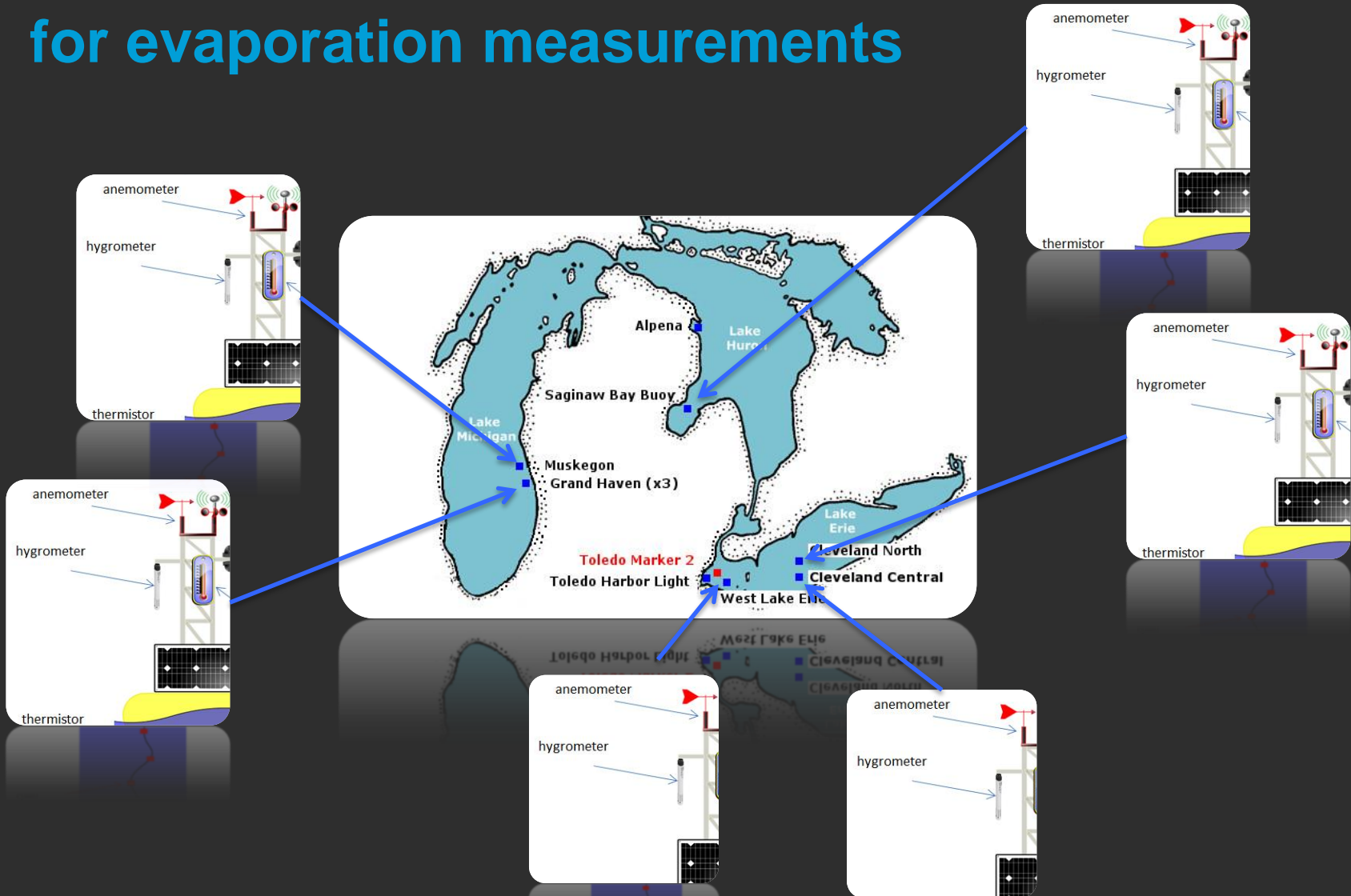


SBD Iridium  
Satellite Module

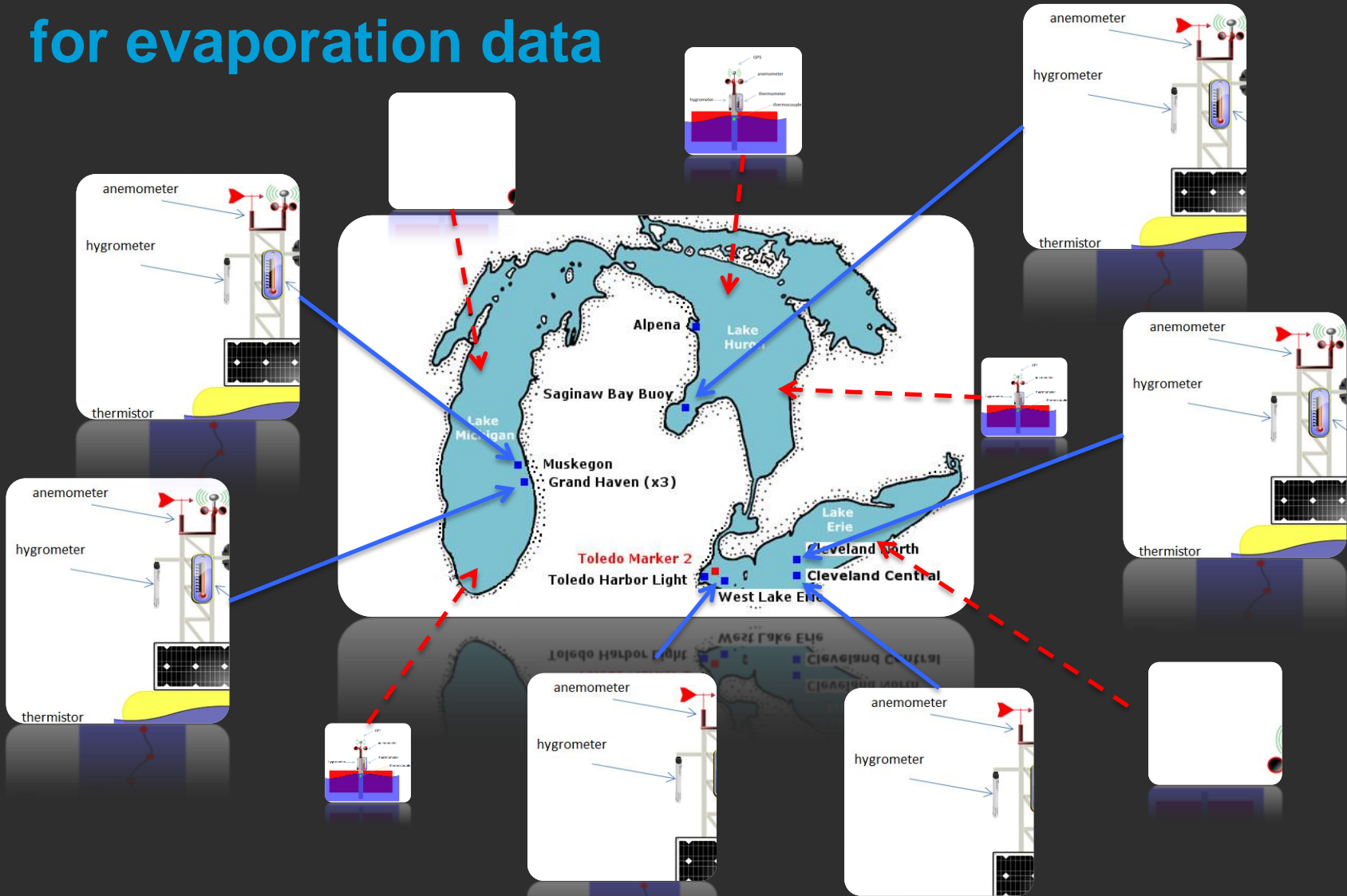
# A Hierarchical architecture for evaporation data



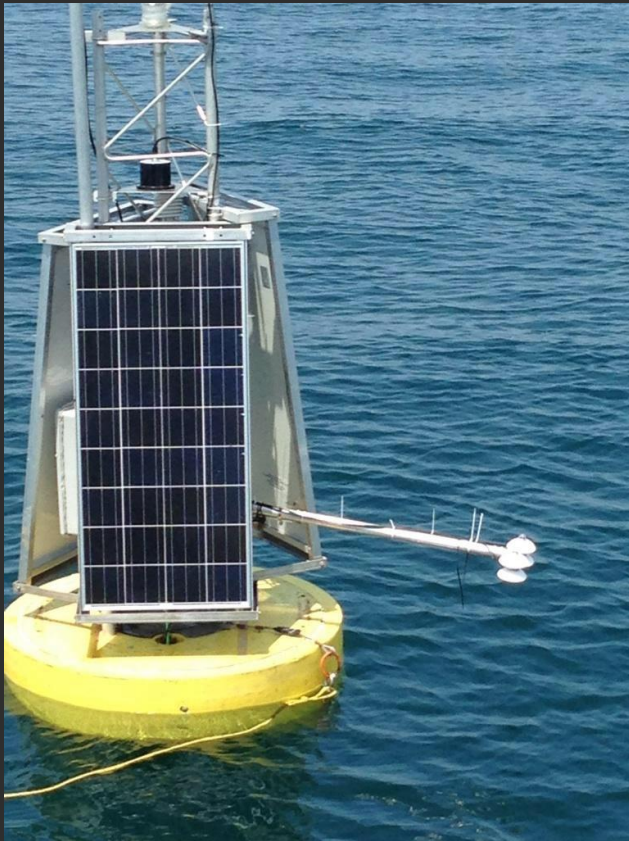
# A Hierarchical architecture for evaporation measurements



# A Hierarchical architecture for evaporation data



# Buoy

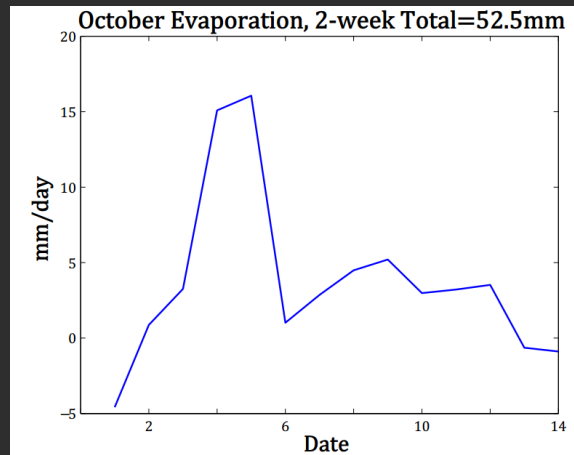
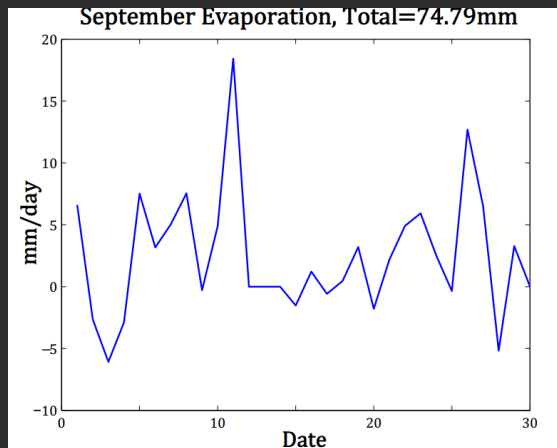
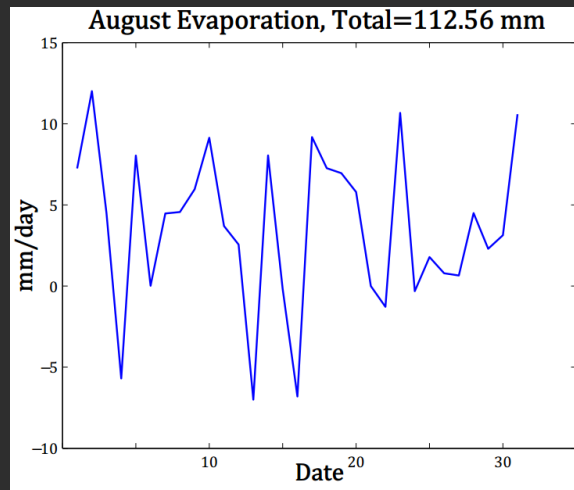


# Drifters



# Preliminary Results

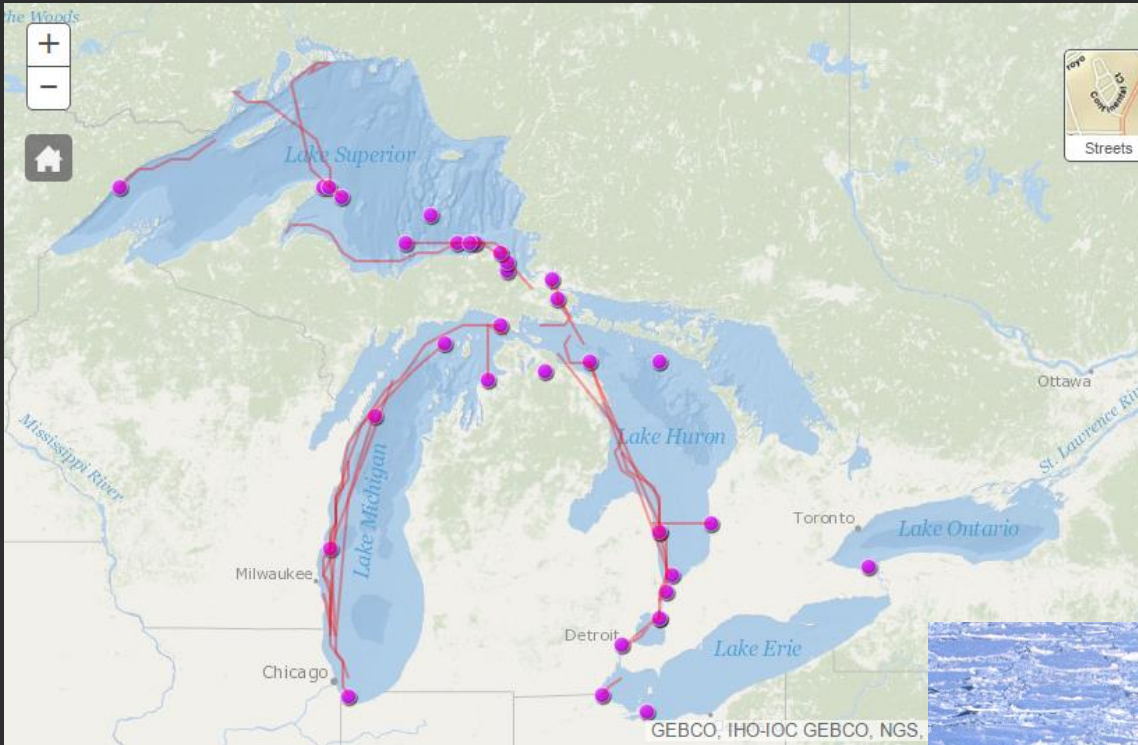
Average	
August	135 mm
September	175 mm
October	205 mm







# Motivation

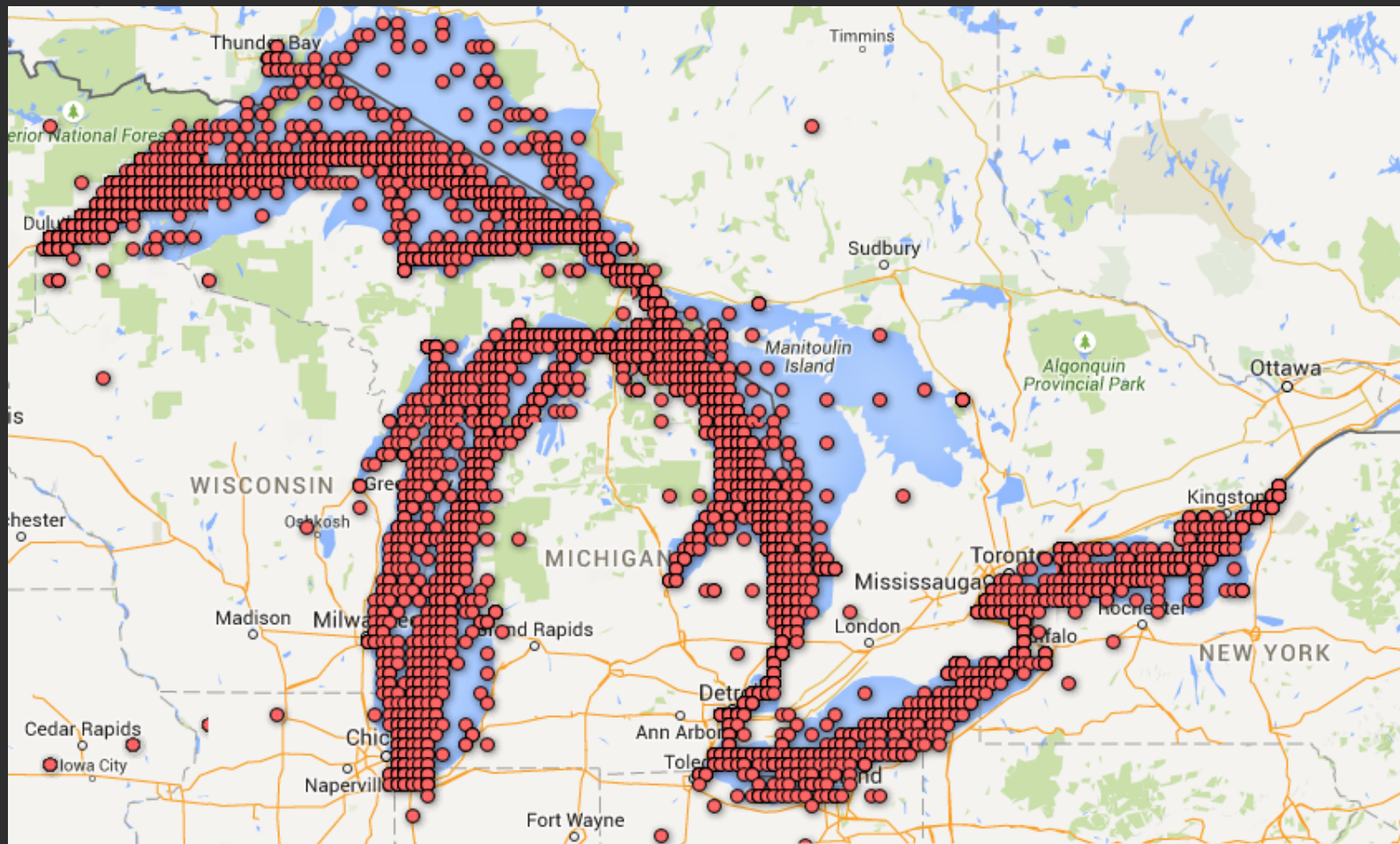


- Temperature
- Dew Point
- Wind Speed
- Wind Direction
- Air Pressure
- SST
- Radiation
- Cloud cover



Source: GLERL CoastWatch

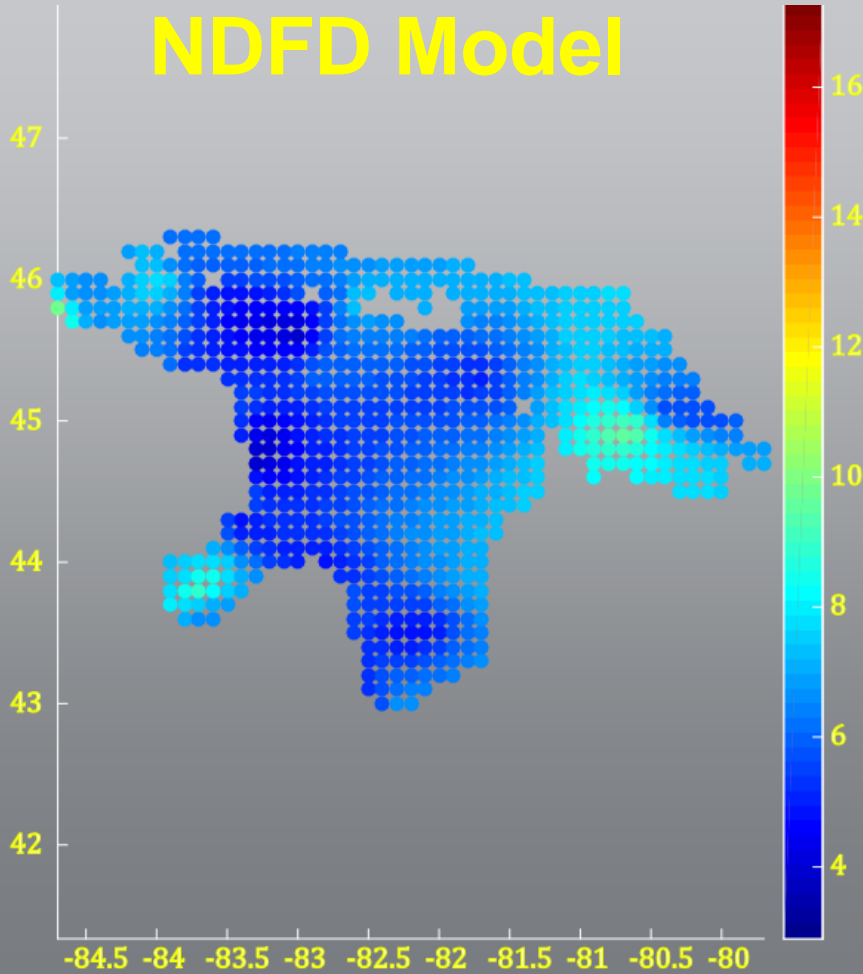
# Motivation



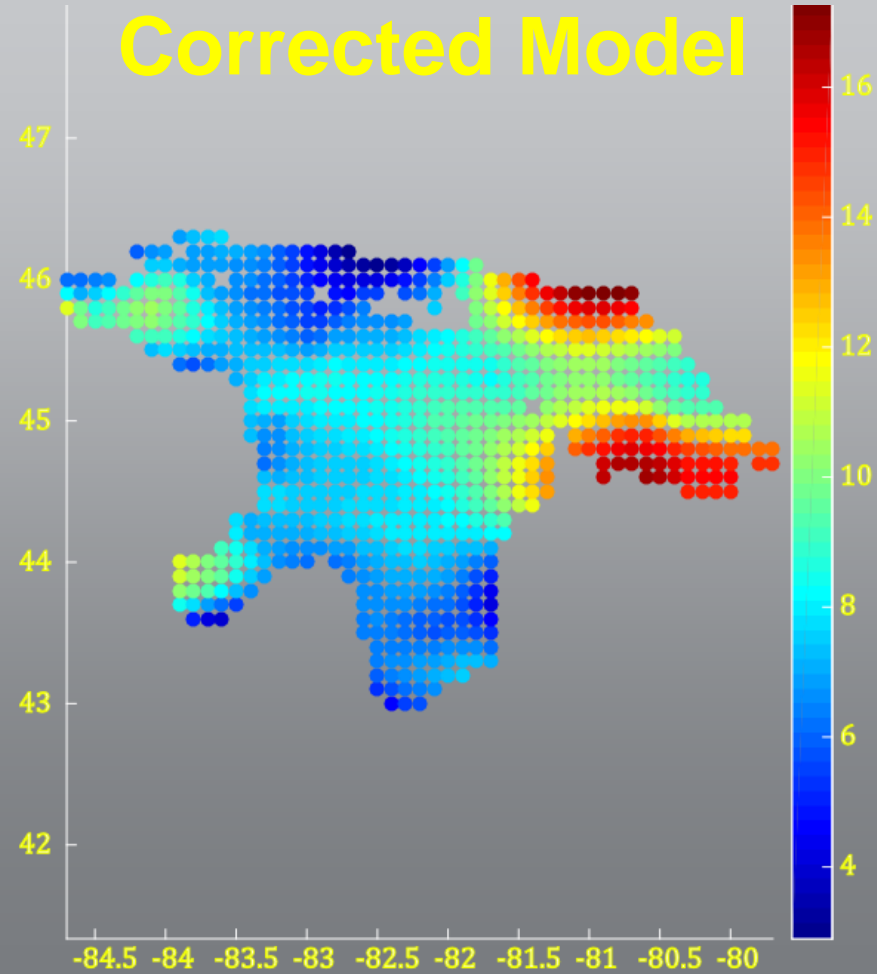
2014: all observations

# July 1, 2014 Wind Speed

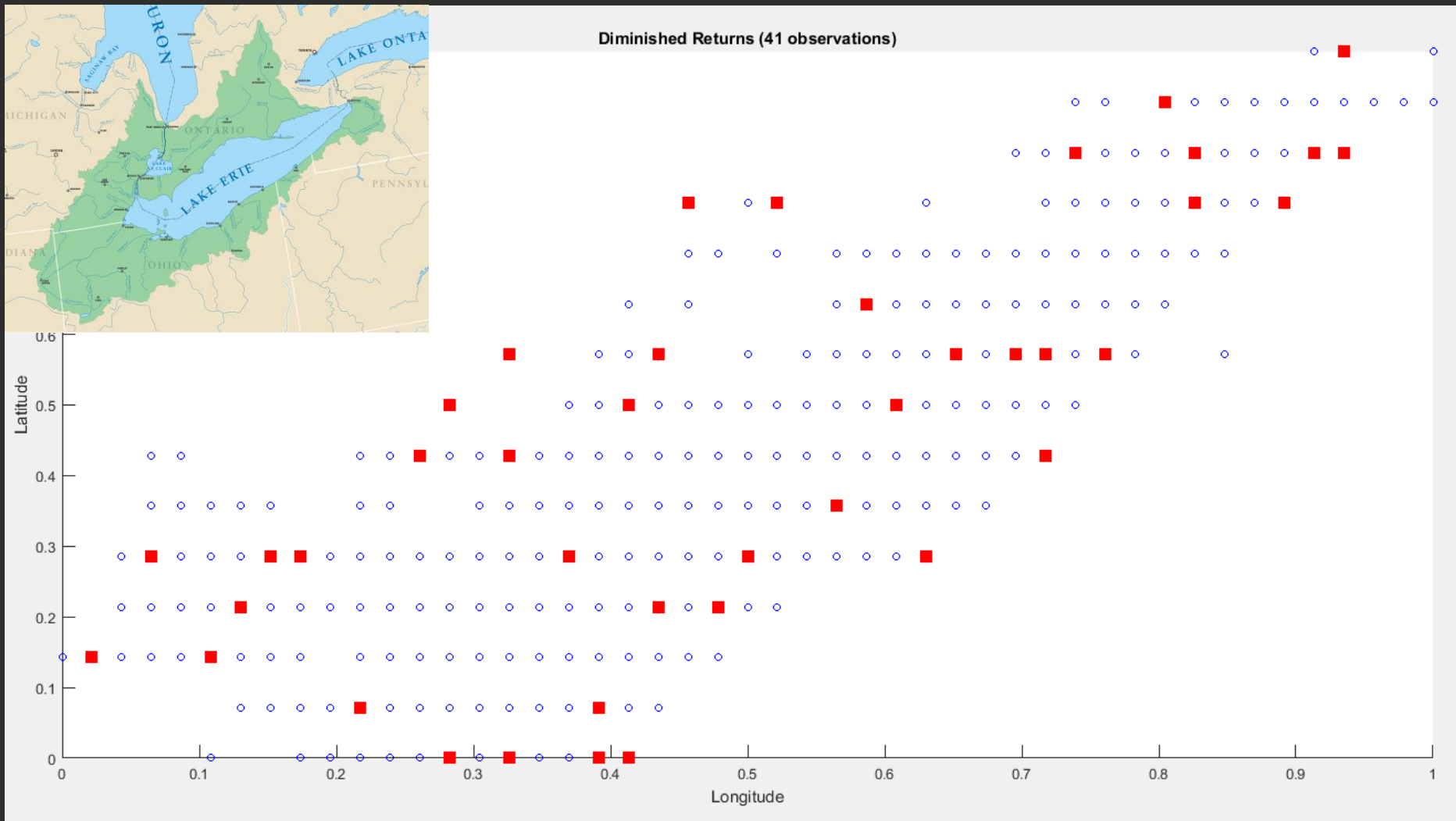
## NDFD Model



## Corrected Model



# Optimal Sensor Placement



# Thank You

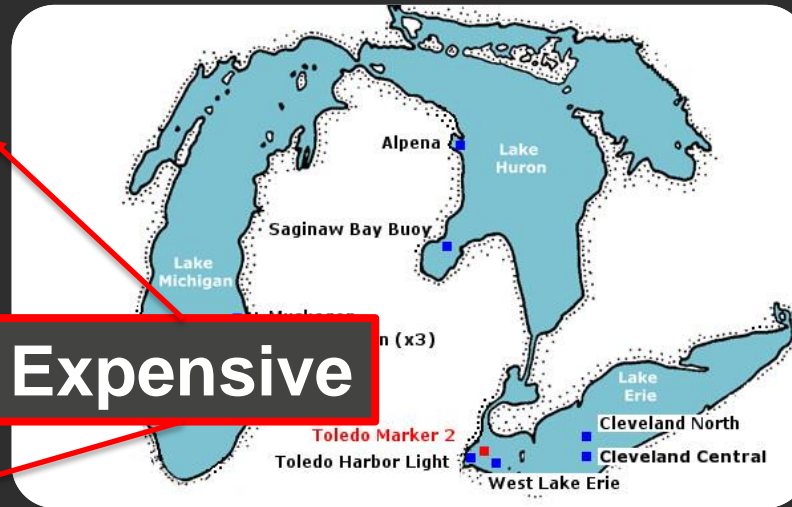
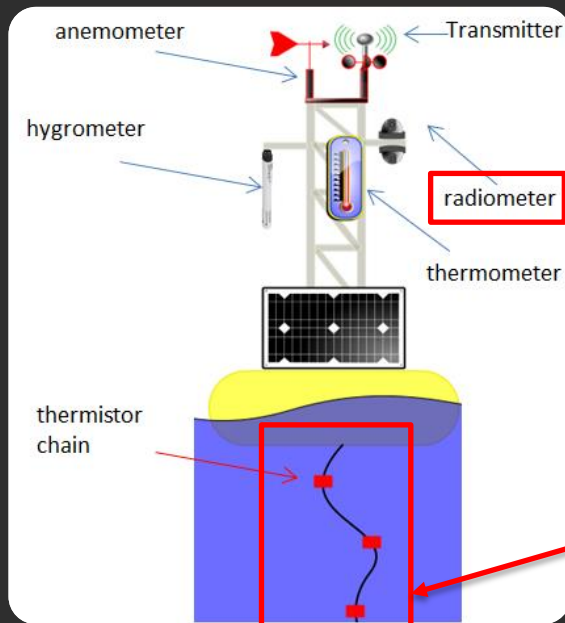


Fred A. and Barbara M.  
Erb Family Foundation



# Energy Balance Buoy

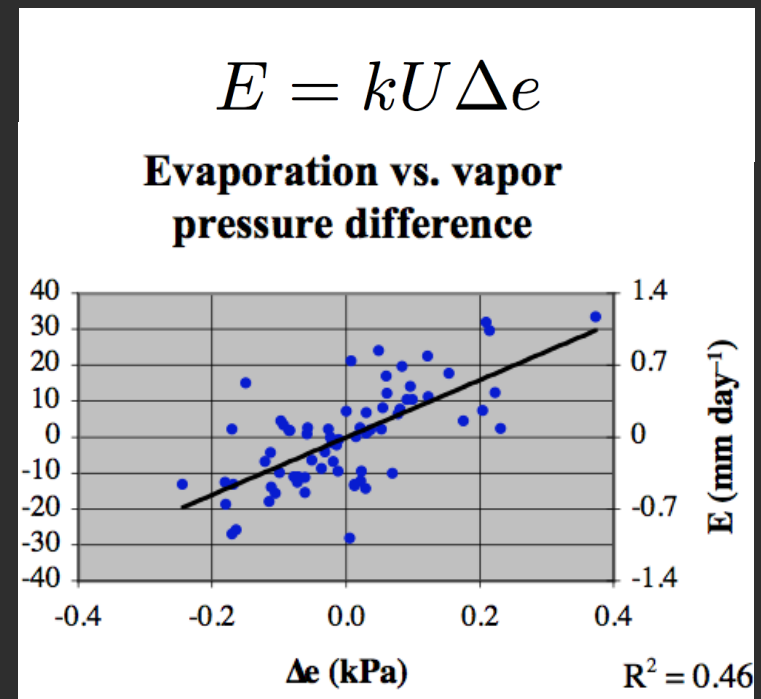
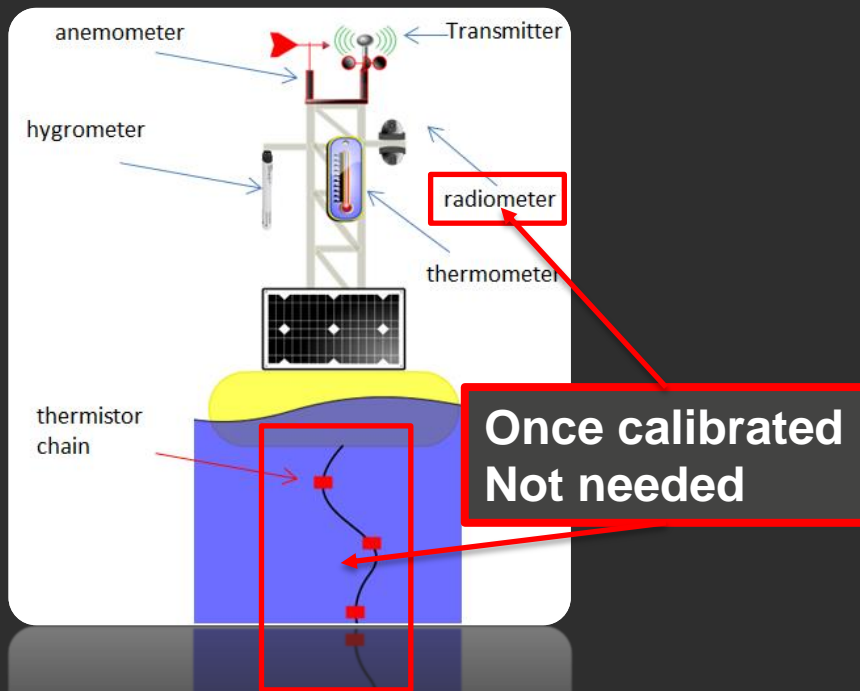
Solve the energy balance in real-time



GLERL RECON Buoy Network

# Calibration constants

Once energy balance is solved, a correlation between evaporation and vapor pressure arises



Lenters (2012, 2014)

# Bowen Ratio Energy Balance (BREB)

Use buoy data to calibrate drifter readings

