Transfer coefficients of momentum, heat and water vapour in the atmospheric surface layer of a large freshwater lake

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Outline

- 1. Introduction
- 2. Methods
- 3. Results and Discussion
- 4. Conclusion

1. Introduction (1)

- Lake is an important land surface type for atmospheric research.
  - There are 304 million lakes in the world, covering 4.2 million km^2 in area.
  - Having lower albedos and larger heat capacity than land, lakes store more solar radiation and have greater capacity to buffer variations of air temperature.
  - Lakes are also sources of atmospheric moisture.
  - Lakes are aerodynamically much smoother than vegetated land surfaces, a factor that contributes to variations of atmospheric flow in the landscape.

(Rouse et al. 2003, 2005; Long et al. 2007; Downing et al. 2006; Herderson-Sellers 1986; Bonan 1995; Betts and Ball 1997; Liu et al. 2005).

1. Introduction (2)

- A critical issue here concerns the accuracy of the **transfer coefficients** because any bias in them will propagate directly to the flux variables.
  - Land-atmosphere interactions are driven by the fluxes of momentum, sensible heat and water vapor between the earth's surface and the atmosphere.
  - Even though frequently used in quantifying these fluxes in dryland ecosystems, eddy covariance is deployed in very few lake-air exchange studies and over short durations

(Chikita et al. 2004; Kebede et al. 2006; Martínez-Alvarez et al. 2011)

1. Introduction (3)

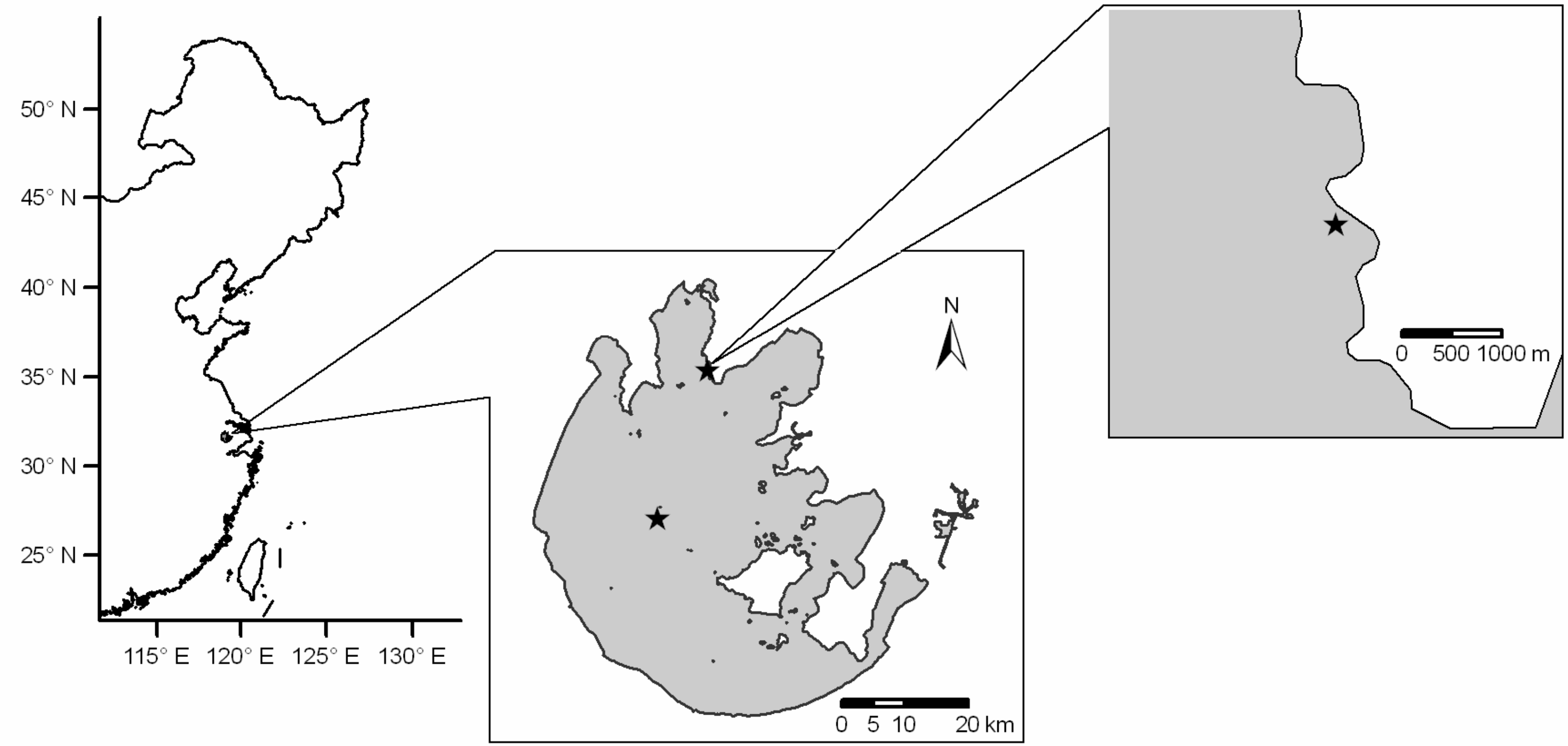
- The inclusion of lakes in numerical weather prediction (NWP) and climate models improves model performance.
  - The exchange coefficients are taken from experimental studies conducted in **open oceans** but we do not know if these coefficients are applicable to lake environments.
  - Although the exchange coefficients have been reported in several lake experimental studies, no research has been conducted on evaluating **the oceanographic parameterizations** for C_D, C_E and C_H with flux observations made in lakes.

(Garrant 1992)

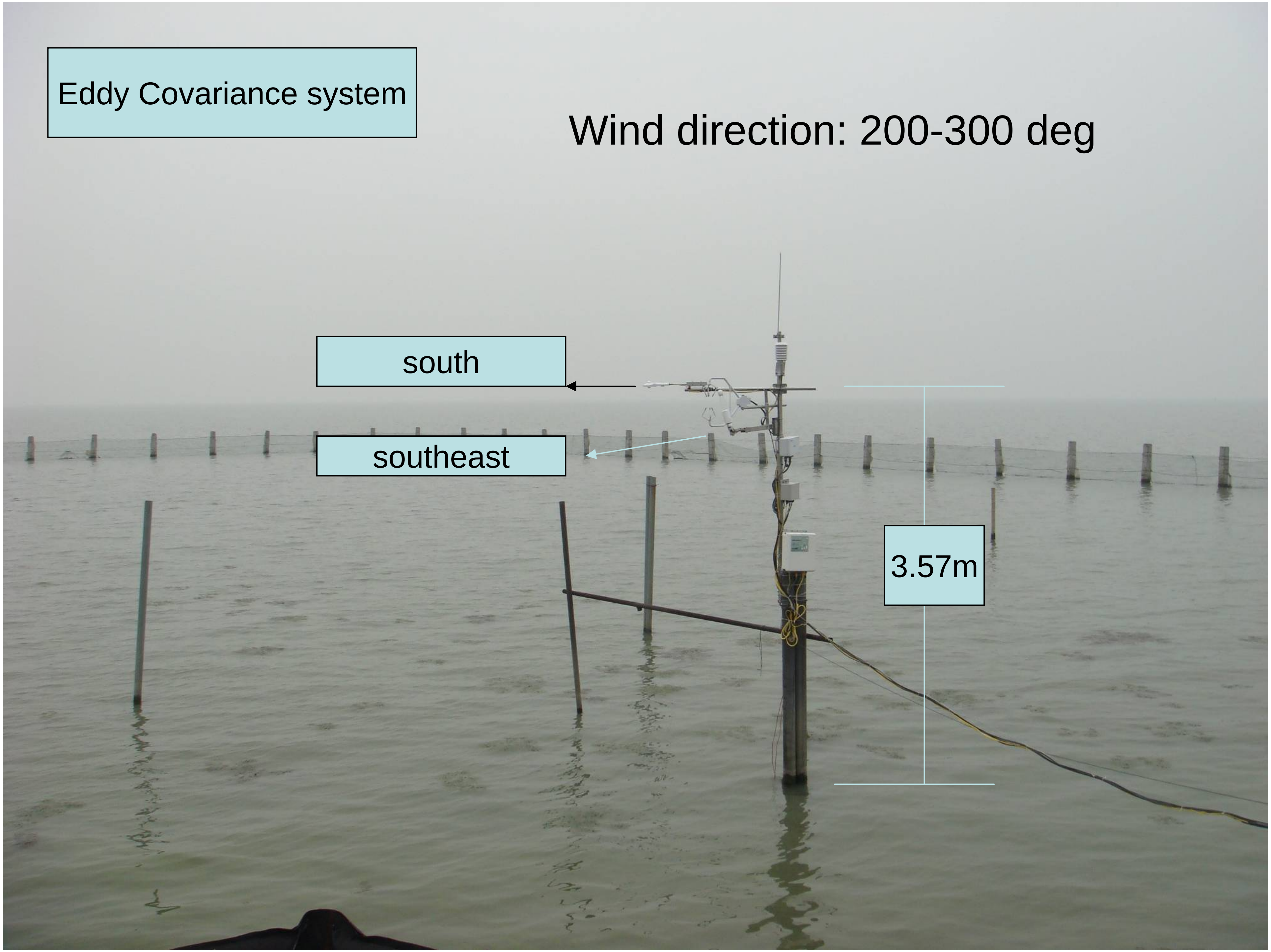
1. Introduction (4)

- Based on the in-situ fluxes measurement using the eddy covariance method on Lake Taihu (a large and shallow lake with area of 2338 km^2 and mean depth of 1.9 m).
  - To identify the transfer coefficients of momentum, moisture and heat on Lake Taihu;
  - To compare the transfer coefficients of Lake Taihu with those of other lakes and oceans;
  - To test the sensitivity of the transfer coefficients to the stability correction and wind speed.

2. Methods- Sites on Lake Taihu



Period: June 14 to December 31, 2010; Fetch: >8km

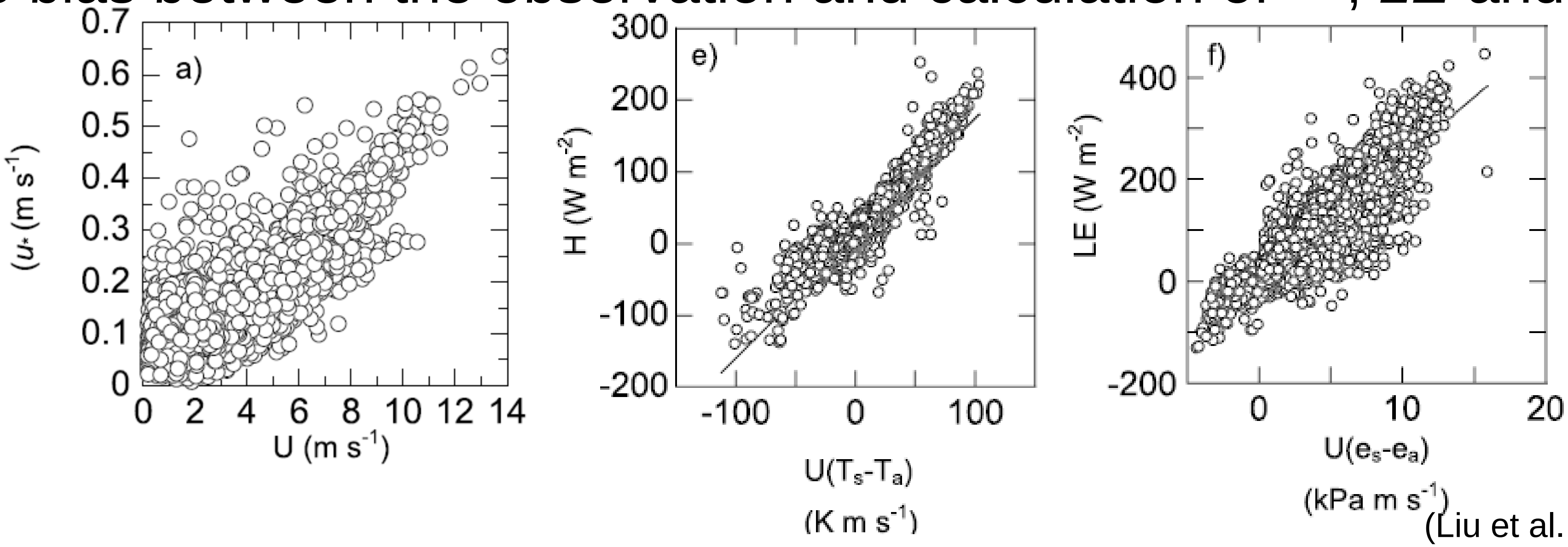


Eddy Covariance system
Wind direction: 200-300 deg
south
southeast
3.57m

2. Methods- Mass transfer equations

Momentum flux	$\tau = \rho_a C_D u^2$	Drag coefficient
Latent heat flux	$LE = \rho_a L_v C_E u(q_s - q_a)$	Transfer coefficient for moisture
Sensible heat flux	$H = \rho_a c_p C_H u(\theta_s - \theta_a)$	Transfer coefficient for heat

The coefficients C_{DN}, C_{EN} and C_{HN} were optimized by minimizing the bias between the observation and calculation of τ, *LE* and *H.*



(Liu et al. 2009)

Transfer coefficients - the surface roughness

$$C_{DN} = k^2 / [\ln(z / z_0)]^2$$

Momentum roughness

$$C_{EN} = k^2 / [\ln(z / z_0) \ln(z / z_q)]$$

Roughness length for water vapor

$$C_{HN} = k^2 / [\ln(z / z_0) \ln(z / z_T)]$$

Roughness length for temperature

The neutral transfer coefficients at the height of 10 m above the water surface

$$C_{D10N} = k^2 / [\ln(10 / z_0)]^2$$

$$C_{E10N} = k^2 / [\ln(10 / z_0) \ln(10 / z_q)]$$

$$C_{H10N} = k^2 / [\ln(10 / z_0) \ln(10 / z_T)]$$

3. Results and Discussion

Lakes	10^3C_{D10N}	10^3C_{E10N}	10^3C_{H10N}	References
Lake Taihu (MLW)	1.52	0.82	1.02	This study
Lake Valkea-Kotinen, Southern Finland	1.21	1.06	1.25	Nordbo et al. (2011)
Lake Tämnaren, Sweden	1.42	0.88	1.13	Heikinheimo et al. (1999)
Ross Rarnett Reservoir, mississippi, USA	1.89	0.97	1.23	Liu et al. (2009)
Great Slave lake	1.66	1.44	0.49	Blanken et al. (2003)
Lake mean	**1.54 (±0 26)**	**1.03 (± 0.24)**	**1.02 (± 0.31)**	

We suggest that errors in T_s are one reason for the scatters in C_{E10N} and C_{H10N} found in the literature.

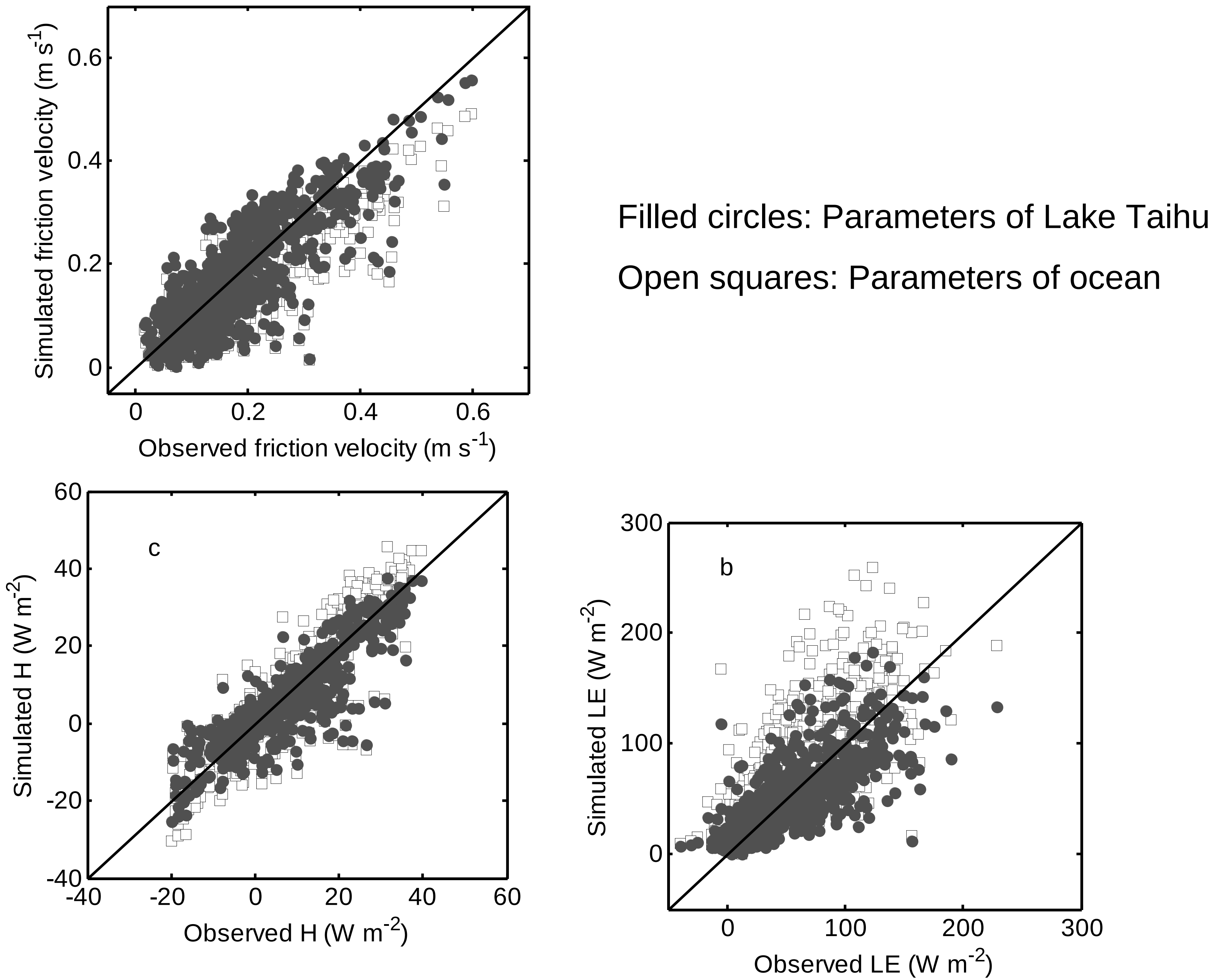
Ocean schemes
-COARE

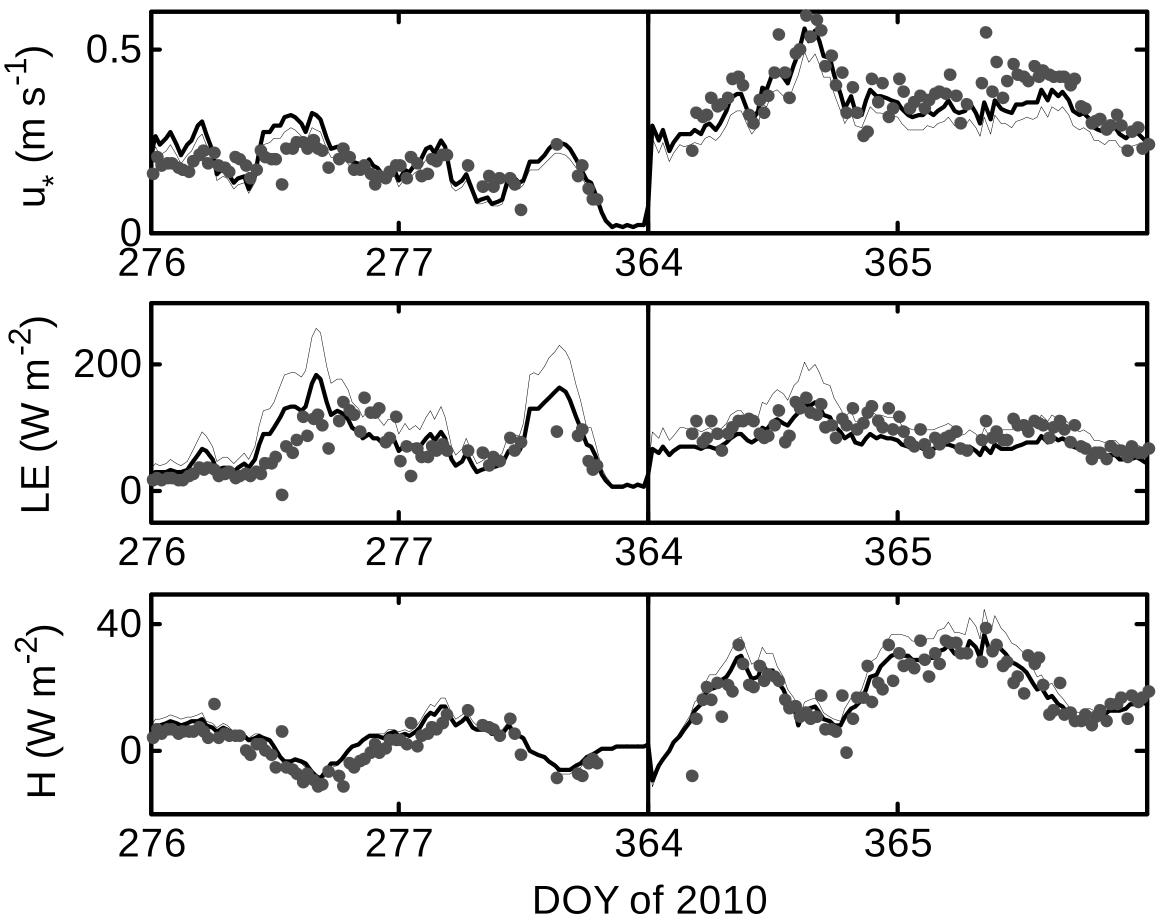
$$z_0 = \frac{a u_*^2}{g} + \frac{0.11 v}{u_*}$$

$$z_T = z_q = \min(1.1 \times 10^{-5} m, 5.5 \times 10^{-5} \mathrm{Re}_*^{-0.6})$$

$$\mathrm{Re}_* = \frac{z_{0m} u_*}{v}$$

Ocean parameterization	$10^3 C_{D10N}$	$10^3 C_{E10N}$	$10^3 C_{H10N}$
BDY	3.89(1.01-248.21)	1.72 (1.19-13.5)	0.70
CCM3 & CAM3	1.46 (1.05-12.57)	1.29 (1.12-3.88)	1.22 (1.06-3.67)
COARE 3.0	1.08 (0.97-1.63)	0.96 (0.91-1.16)	0.96 (0.91-1.16)
ECMWF	1.11 (0.91-1.73)	1.11 (1.07-1.33)	1.07 (1.03-1.27)
GEOS-1	1.15 (0.96-1.56)	1.02 (0.90-1.24)	1.08 (0.93-1.30)
GSSTF-2	1.11 (0.99-1.65)	1.12 (1.06-1.33)	1.02 (1.02-1.26)
HOAPS	1.32 (1.25-1.90)	1.20	1.00
J-OFURO	1.14 (1.14-1.43)	1.19 (1.08-1.57)	2.16(1.97 2.85)
UA	1.32(1.25-1.90)	1.26 (1.19-1.86)	1.26 (1.19-1.86)
Ocean mean	1.21(±0.14) **	1.14(±0.11)	1.22(±0.39)
Lake mean	1.54 (±0 26)	1.03 (±0.24)	1.02 (±0.31)


Filled circles: Parameters of Lake Taihu
Open squares: Parameters of ocean
Simulated friction velocity (m s-1)
Observed friction velocity (m s-1)
0
0.2
0.4
0.6
c
Simulated H (W m-2)
Observed H (W m-2)
-40
-20
0
20
40
60
b
Simulated LE (W m-2)
Observed LE (W m-2)
0
100
200
300



Filled circles: Observation on Lake Taihu

Thick solid line: Calculation with parameters of Lake Taihu

Thin solid lines: Calculation with parameters of ocean

Sensitivity analysis

Paremeterization	Fluxes	Without stability correction		With stability correction	
		RMSE	ME	RMSE	ME
Lake Taihu	u_* (m s^{-1})	0.062	-0.011	0.061	-0.011
	LE (W m^{-2})	26.6	-2.1	25.4	-1.6
	H (W m^{-2})	5.5	-1.1	5.4	-0.7
Oceans mean value	u_* (m s^{-1})	0.066	-0.032	0.066	-0.031
	LE (W m^{-2})	40.6	23.1	41.5	25.6
	H (W m^{-2})	5.9	-0.1	6.1	0.6
Constant coefficients	u_* (m s^{-1})	0.071	-0.040	0.070	-0.040
(COARE)	*LE* (W m^{-2})	28.5	6.3	27.9	7.9
	H (W m^{-2})	5.6	-1.5	5.4	-1.0
Wind-dependent	u_* (m s^{-1})	0.064	-0.036	0.064	-0.036
coefficients	*LE* (W m^{-2})	29.8	7.6	29.2	9.2
(COARE)	*H* (W m^{-2})	5.6	-1.1	5.5	-0.7

stability corrections improved the calculations only marginally

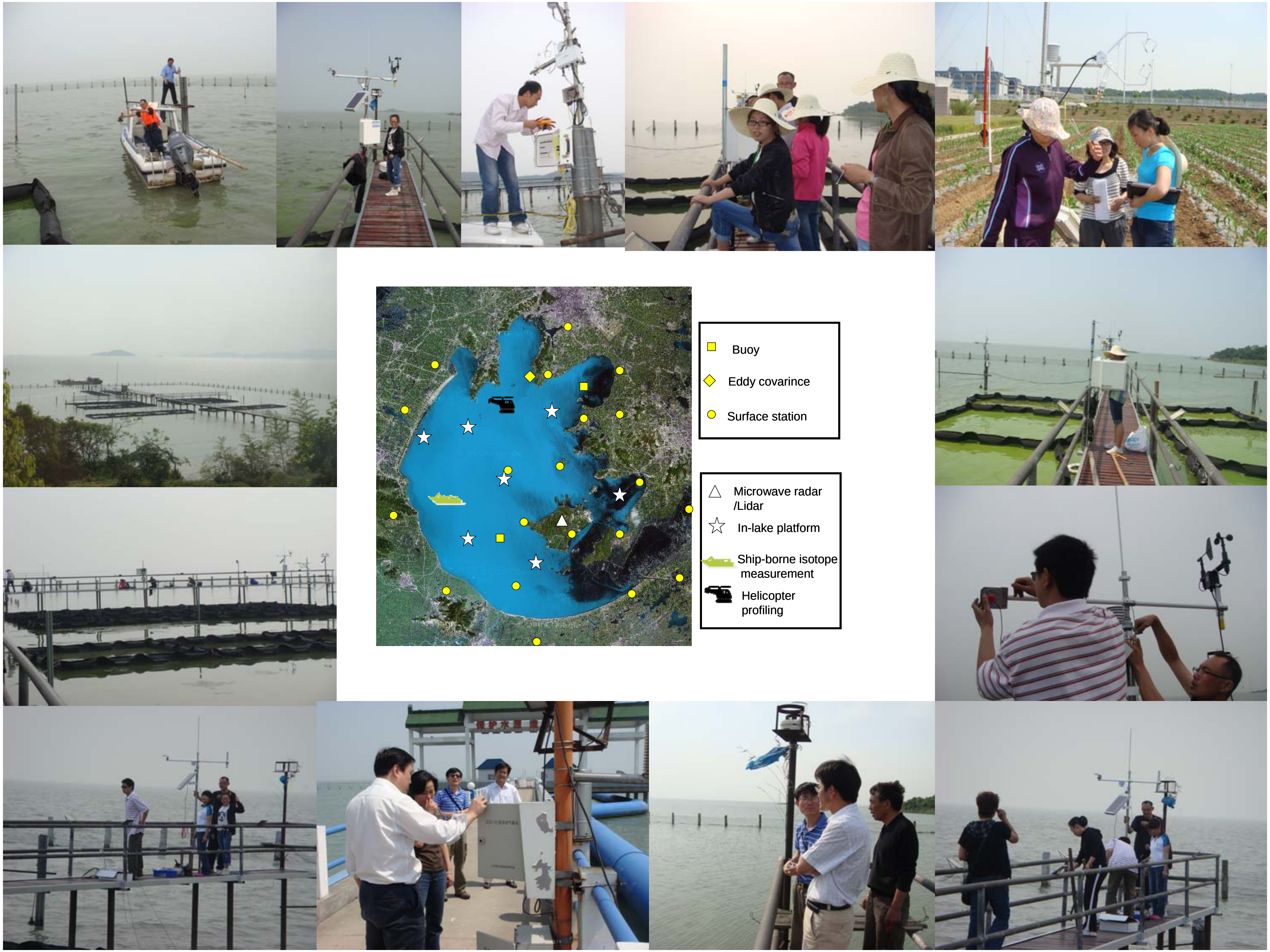
Stability corrections did not bring improvement

The wind-dependent coefficients did not improve the simulation

4. Conclusion

- The drag coefficient of shallow lakes was higher than ocean.

- The effect of stability and wind speed were negligible on the fluxes calculation.



Buoy
Eddy covarince
Surface station
Microwave radar
/Lidar
In-lake platform
Ship-borne isotope
measurement
Helicopter
profiling