# Evaporation from Lake Kasumigaura
## Bulk Coefficients and Spatial Distribution of Latent Heat Flux

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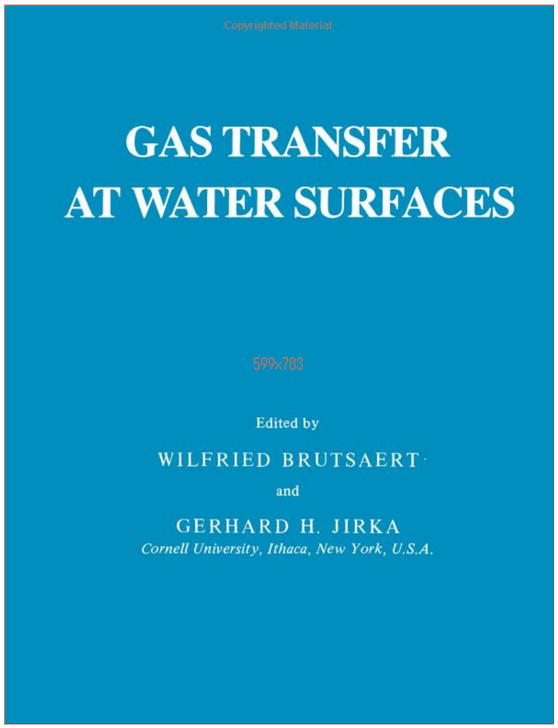
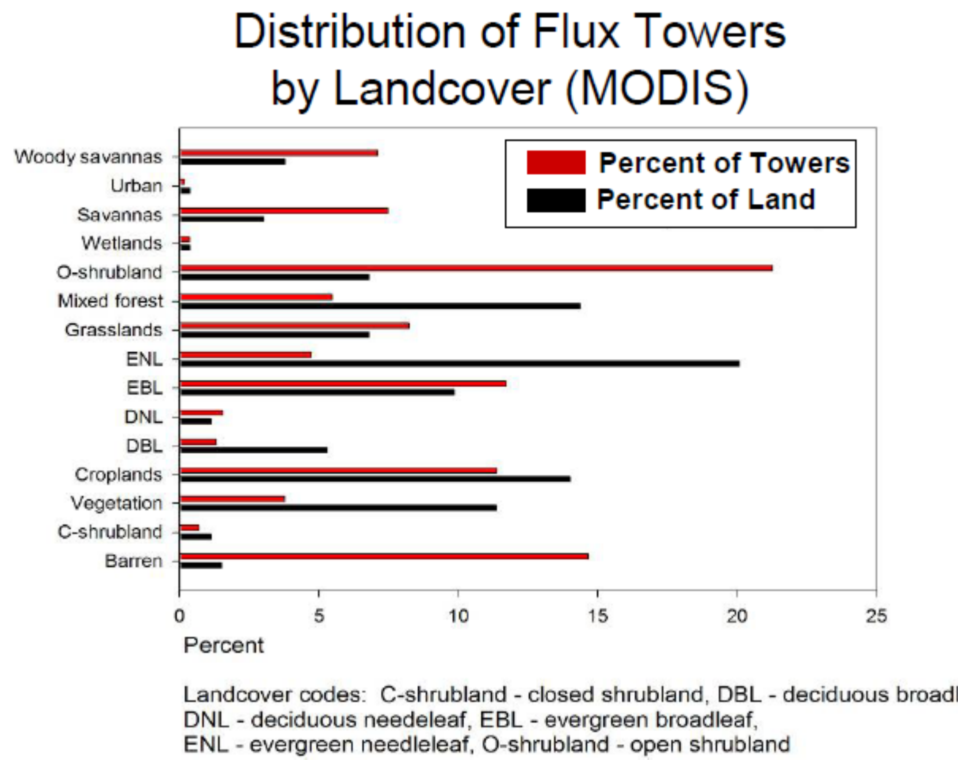



2nd Minneapolis, USA, 1990
3rd Heidelberg, Germany, 1995
4th Miami, USA, 2000
5th Liège, Belgium, 2005
6th Kyoto, Japan, 2010

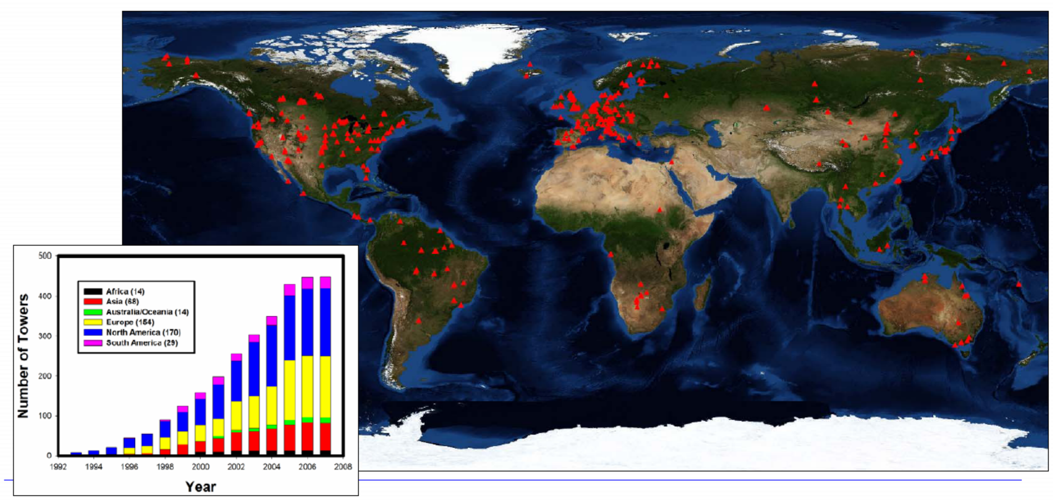
# Tower flux measurements

- Vegetated surface
- Almost no water surface




Distribution of Flux Towers Worlc

More than 550 towers from >10 regional networks and 46 countries worldwide




4

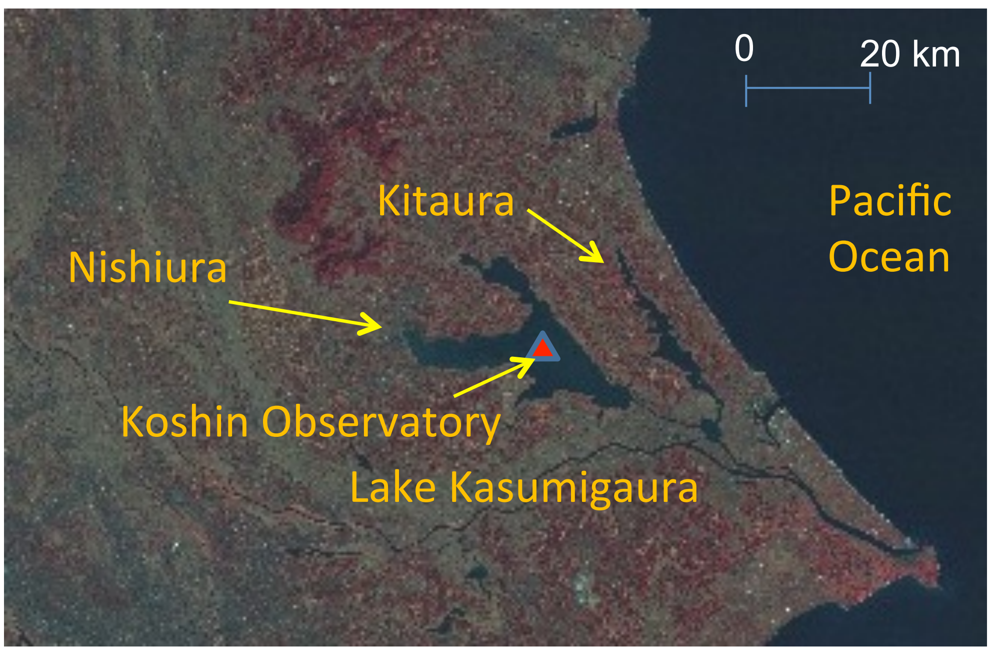
source: Fluxnet webiste

Observation

360° degree "panorama" view from the tower

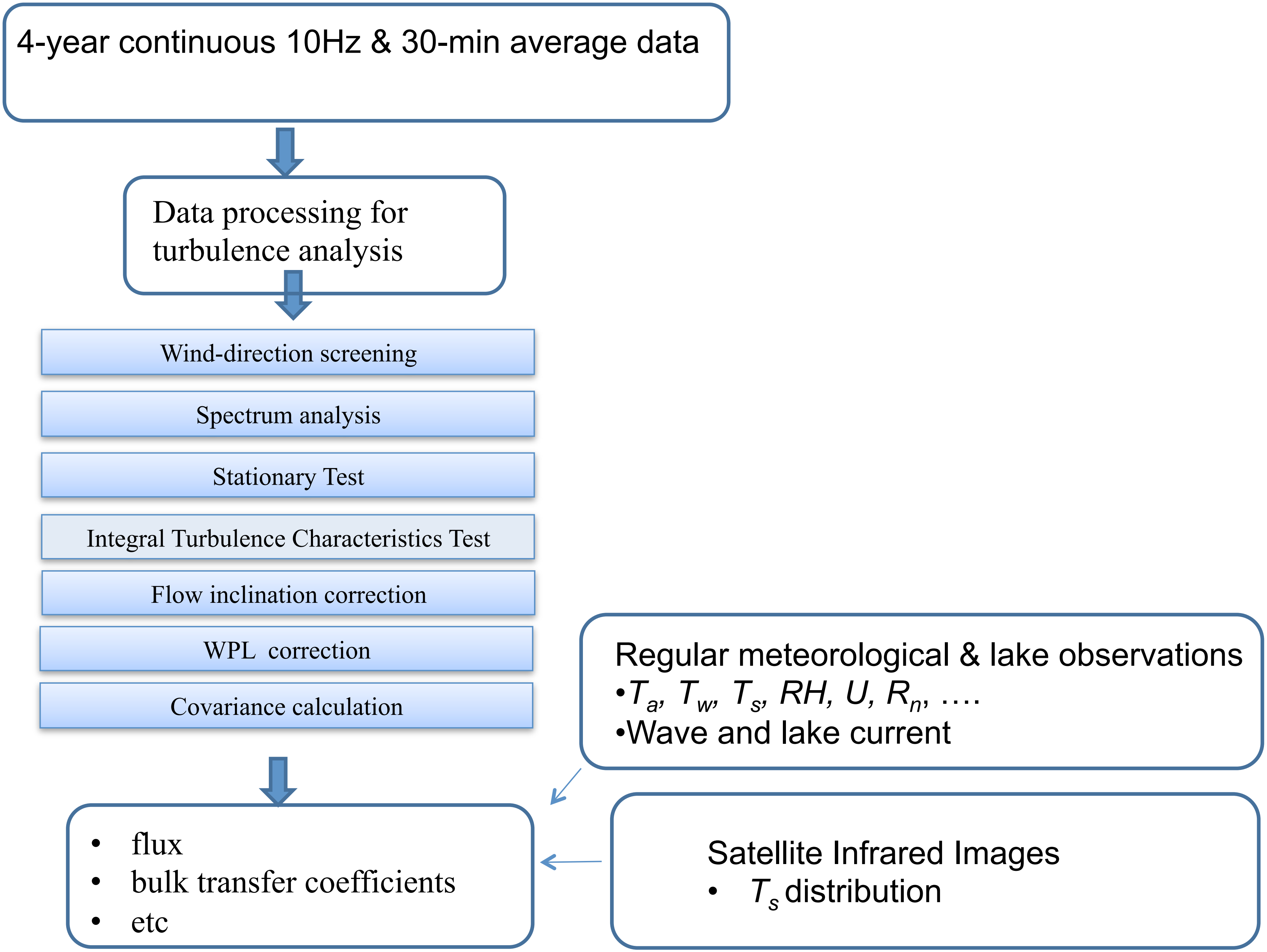
## Lake Kasumigaura (Nishiura)

- Lake surface area: 220 km$^2$ (Nishiura: 172 km$^2$ ), 2$^{nd}$ largest in Japan
- Depth: 4 m (mean) and 7 m (maximum)
- Fetch of Koshin Observatory
  - 10+ km (W and SE)
  - <8 km (other directions)

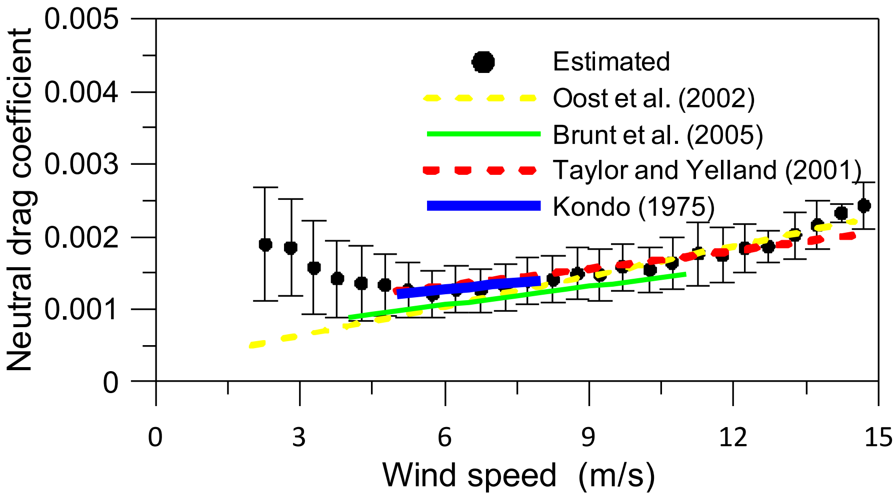



Eddy correlation system

Koshin Observatory


4-year continuous 10Hz & 30-min average data
Data processing for turbulence analysis
Wind-direction screening
Spectrum analysis
Stationary Test
Integral Turbulence Characteristics Test
Flow inclination correction
WPL correction
Covariance calculation
Regular meteorological & lake observations
•$T_a$, $T_w$, $T_s$, $RH$, $U$, $R_n$, ….
•Wave and lake current
• flux
• bulk transfer coefficients
• etc
Satellite Infrared Images
• $T_s$ distribution

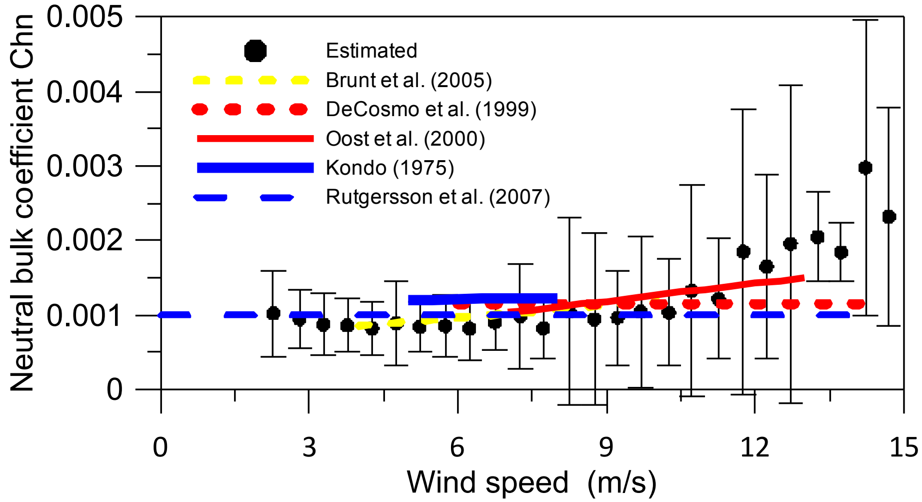
# Bulk transfer coefficients:

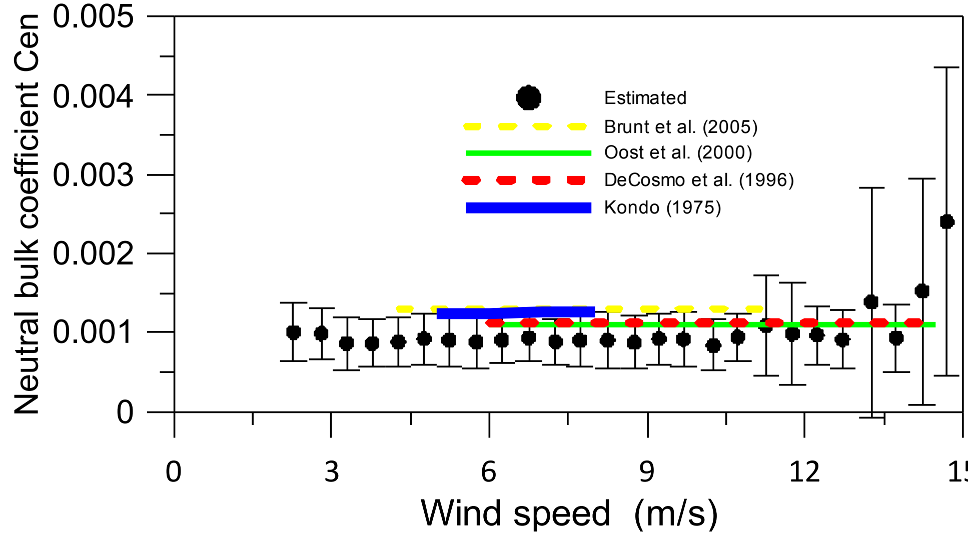



$$u_*^2 = C_d \cdot U^2$$

$$\overline{w't'} = H / (\rho c_p) = C_h \cdot U \cdot (T_s - T_a)$$

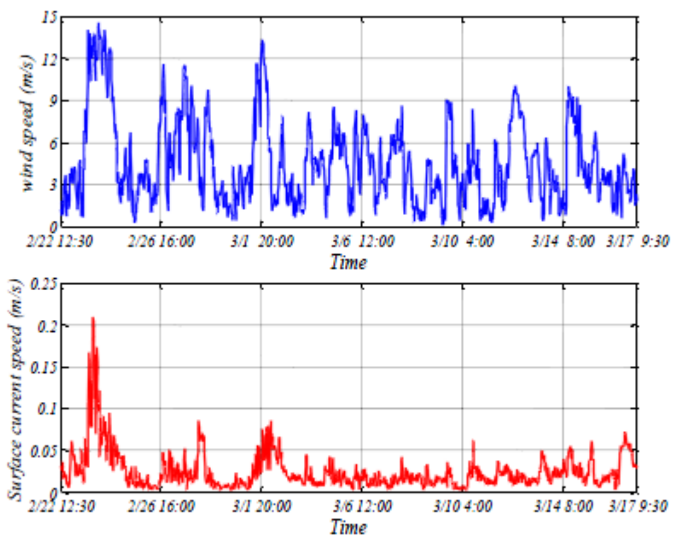
$$\overline{w'q'} = E / \rho = Ce \cdot U \cdot (qs - q)$$



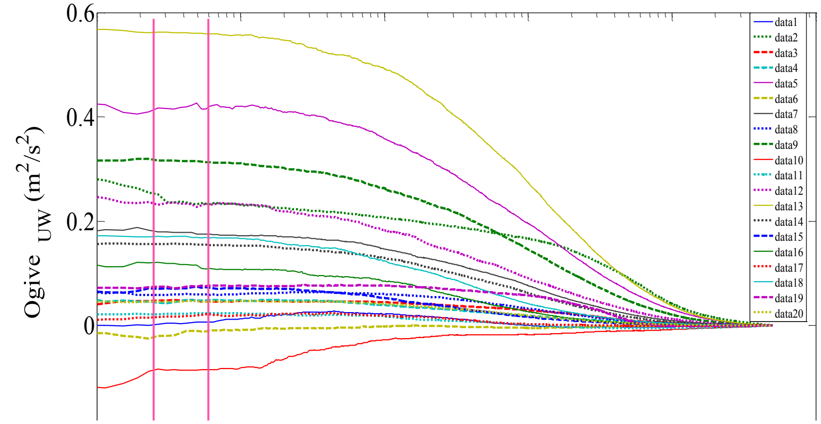
# Some concern in calm wind condition (smooth surface)

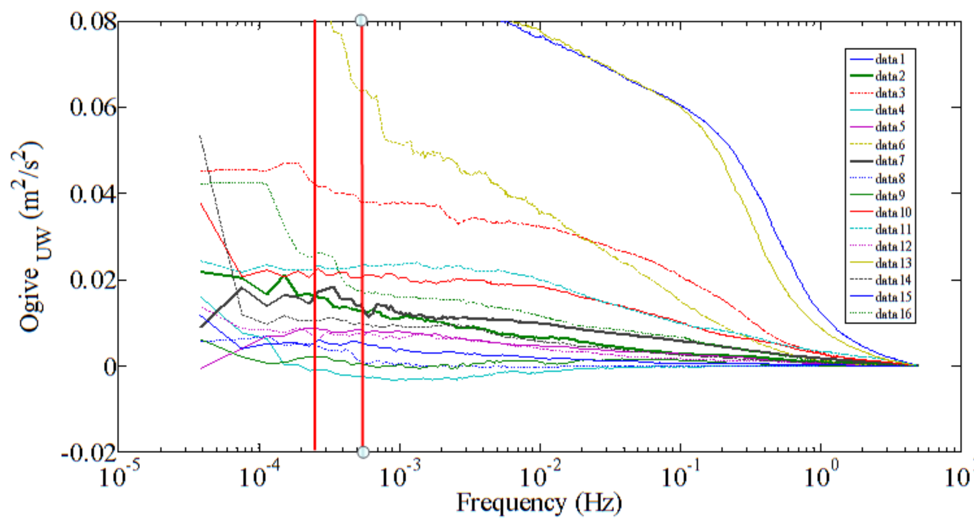
- Lake current → probably negligible
  $U_s << U$
- Contribution of larger-scale circulation




Wind speed (top ≈10 m/s) and lake current (bottom ≈0.1 m/s)

1 h 30 min




Ogive plot of uw for moderate wind (top) and weak wind (bottom)

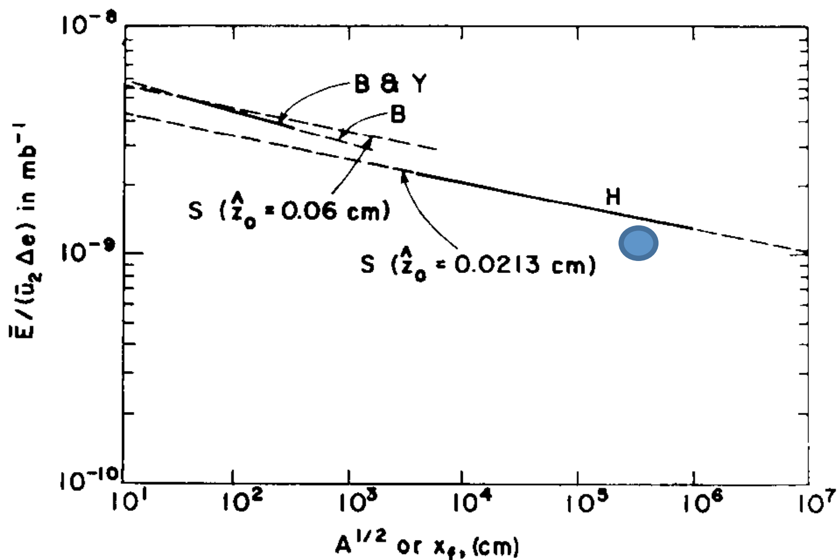



Fig. 7.5

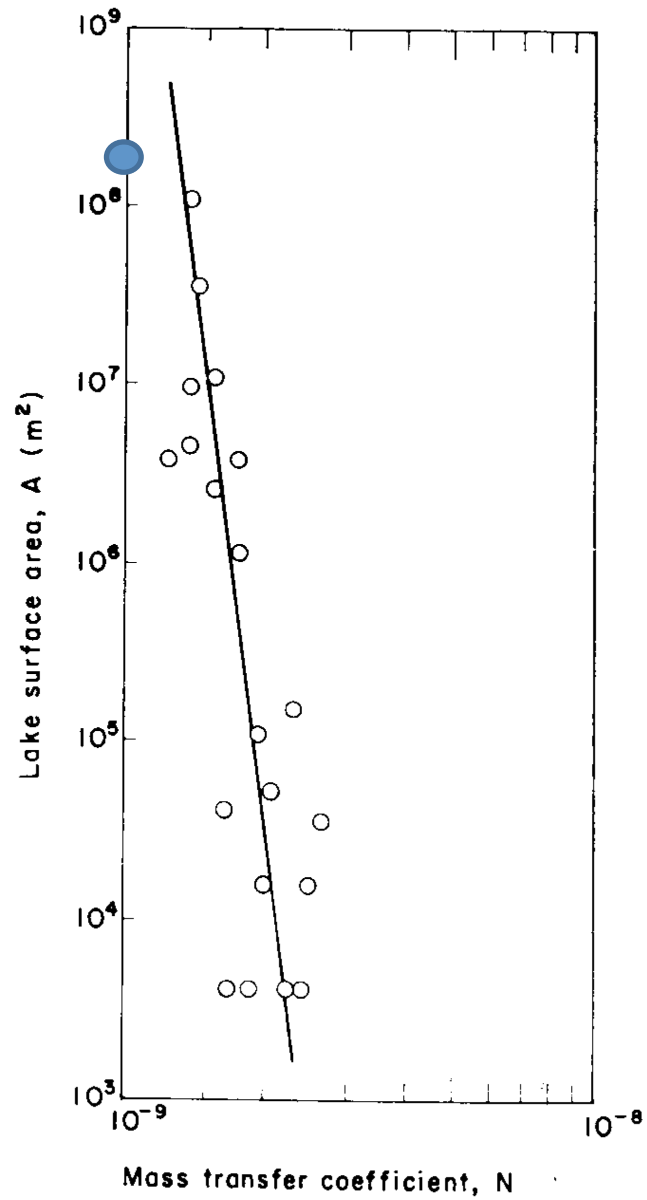
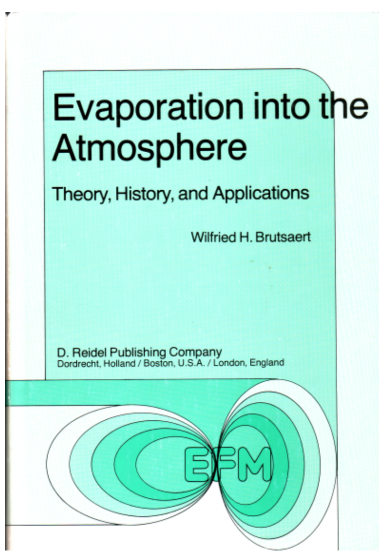



Fig. 7.4 (adopted from Harbeck, 1962)




$$E = N u_2 (e_s - e_a)$$

*N*: bulk transfer coefficient in terms of water vapor pressure
*A*: lake surface area

# Estimation of flux distribution

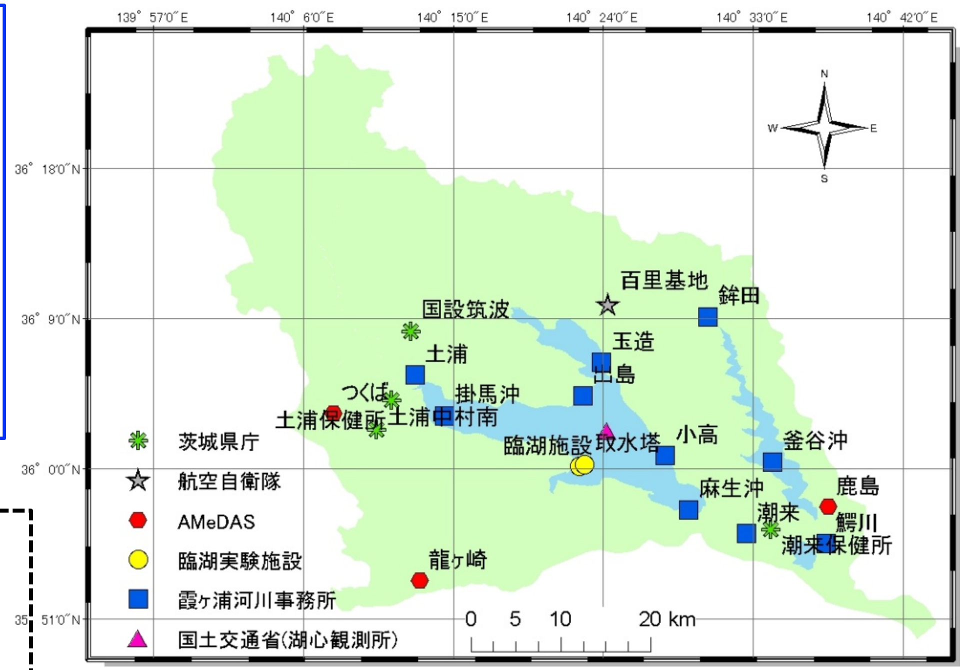
## Method: bulk (mass) transfer equation

$$\overline{w'q'} = E/(\rho l) = C_e \cdot U \cdot (q_s - q)$$

$T_s$ map from satellite infrared image

Interpolation (Kriging) to produce spatial map

$E$ : evaporation
$C_e$ :bulk coefficient
$U$ : Wind speed
$q$ : specific humidity
$q_s$ : : specific humidity of lake water surface (=f (Ts))
$R_f$ : bulk Richardson's number
$T_s$ : surface temperature




Stations distribution in/ around Lake Kasumigaura

**【Data analyzed】**

- 32 cases (1999～2009年)
  - ASTER (14)
    - Landsat-TM (1)
    - Landsat7-ETM+ (17)

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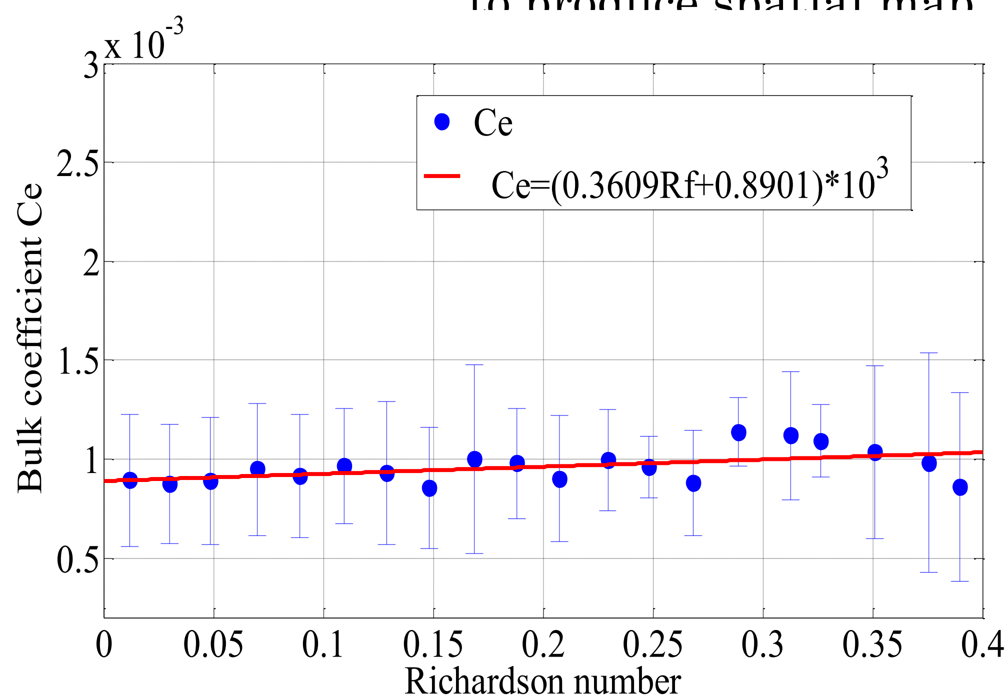


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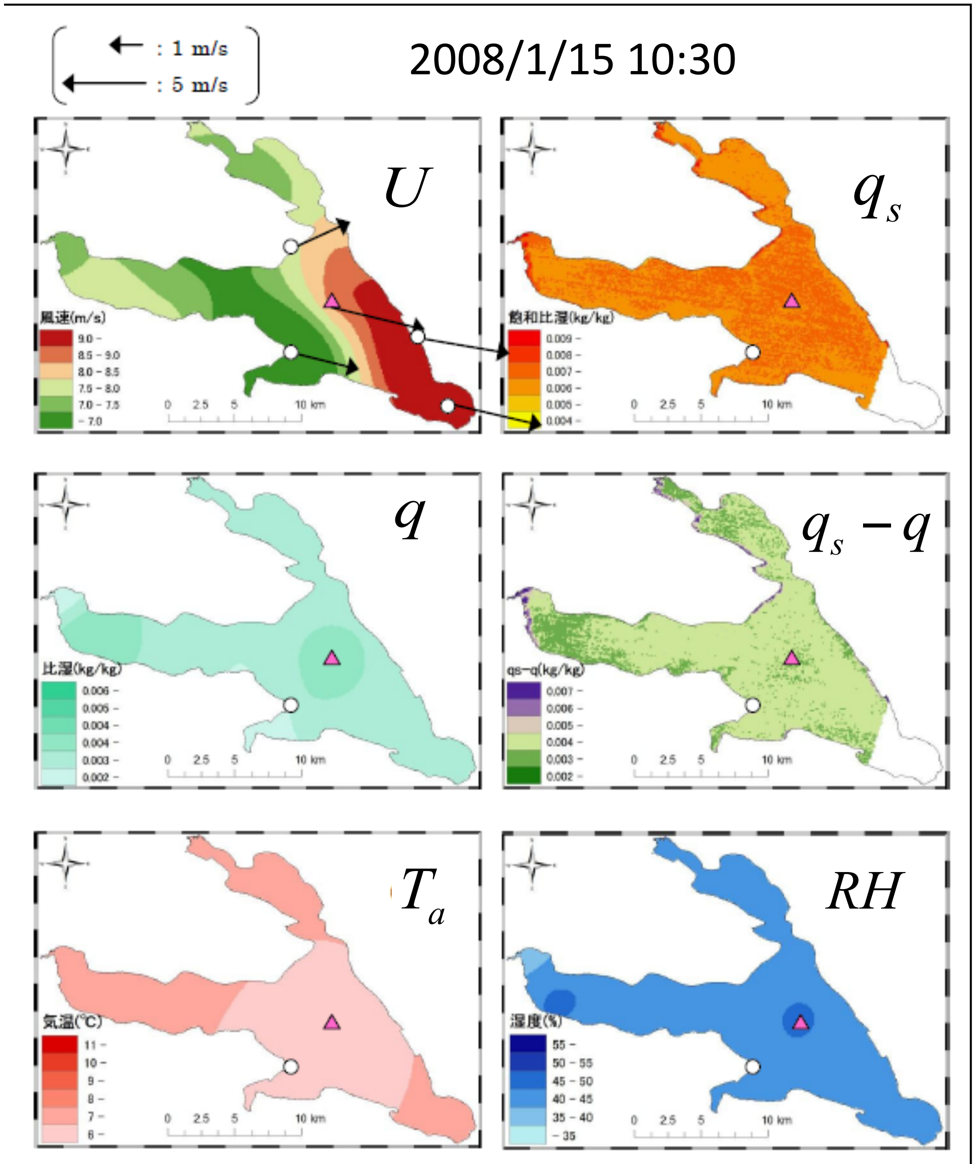
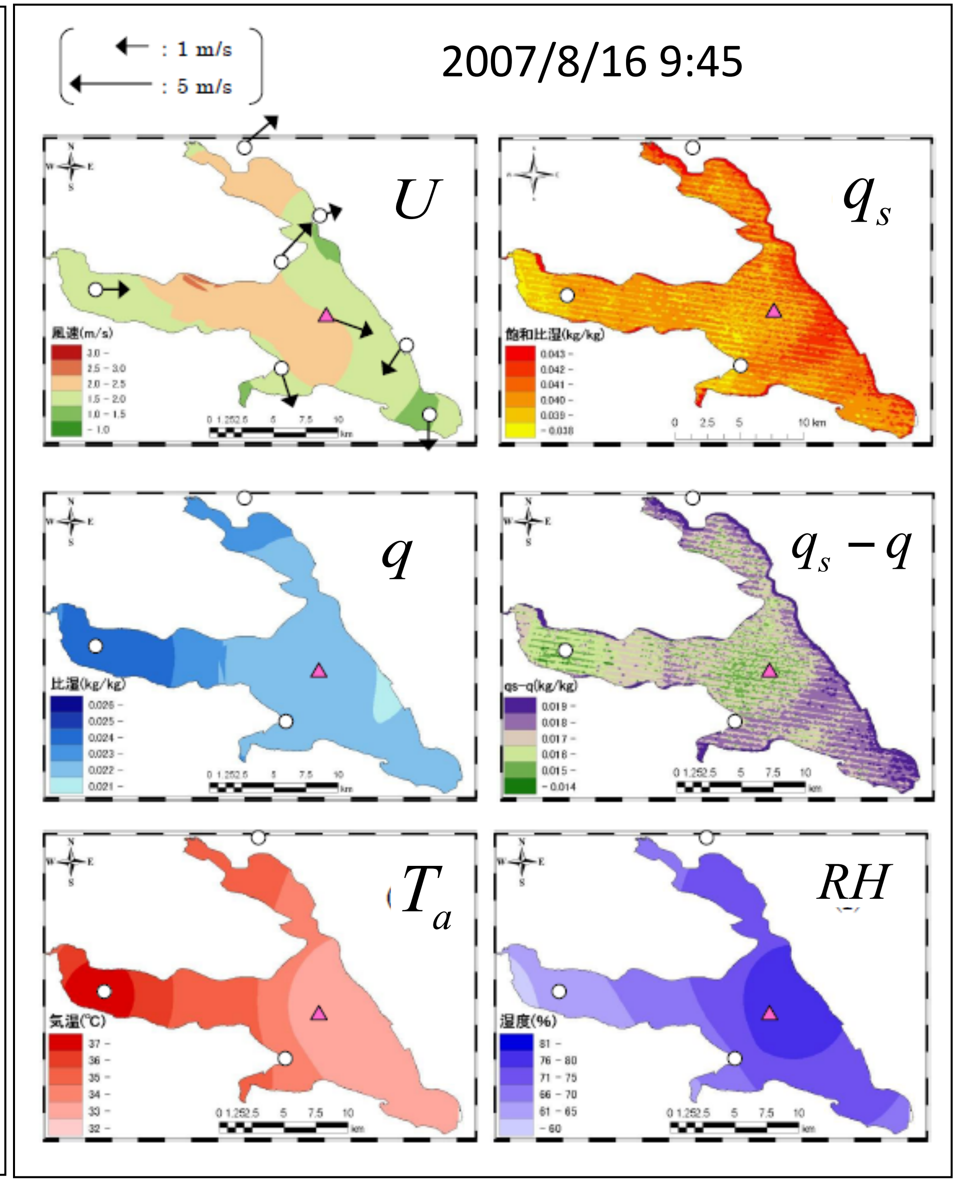
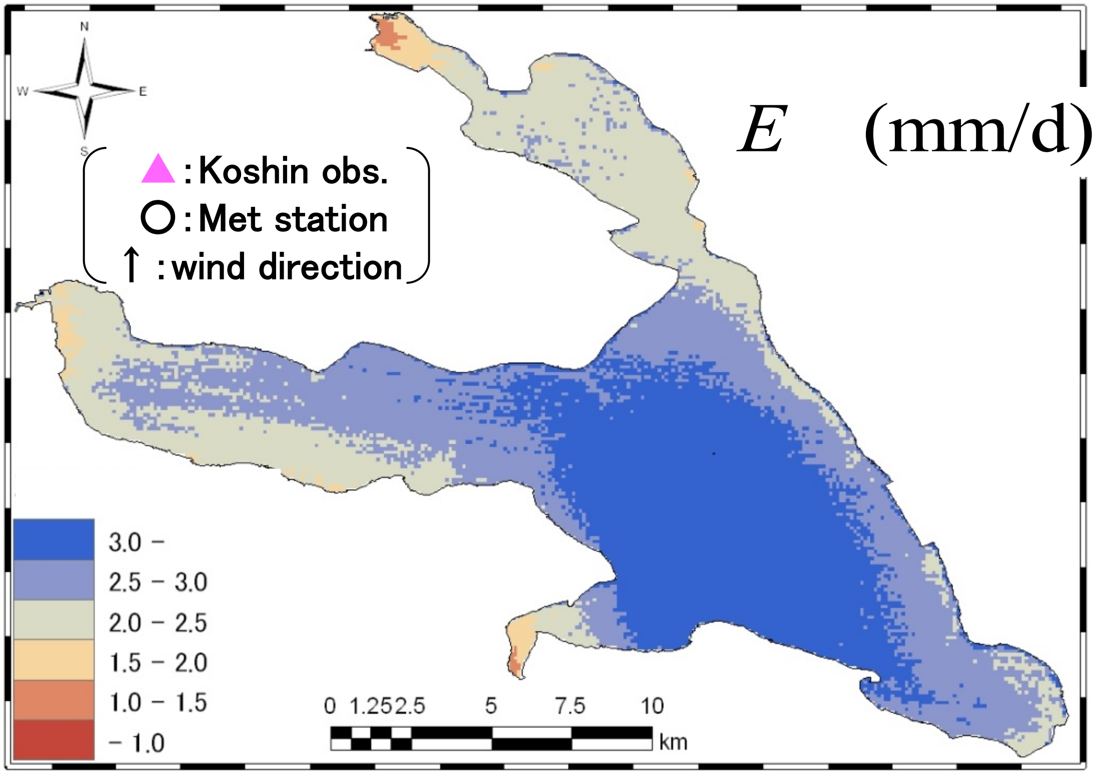
Interpolated meteorological variables $\overline{w'q'} = E/\rho = C_e \cdot U \cdot (q_s - q)$



## Evaporation distribution

$$\overline{w'q'} = E/\rho = C_e \cdot U \cdot (q_s - q)$$




2007/11/21 10:30 am
Evaporation= 2.9 ±0.7 (mm/d)

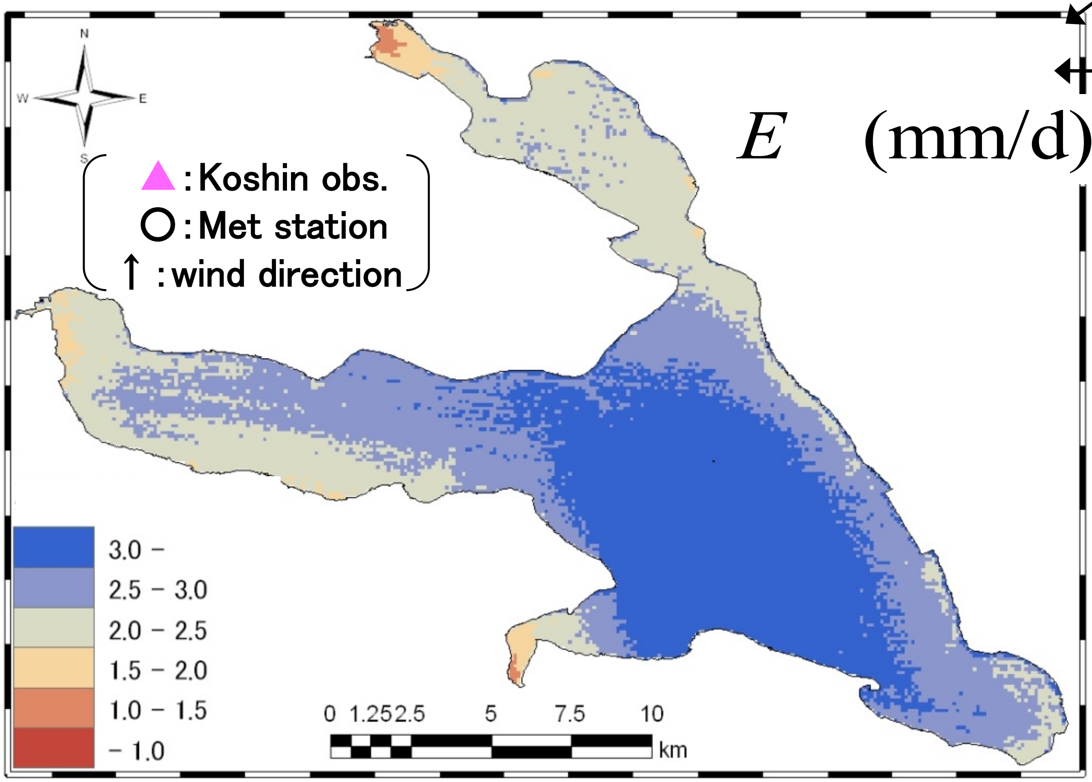
Distribution of $E$ reflects mostly $U$ and not ($q_s - q$)

$U$ (m/s)

$q_s - q$

# Evaporation distribution

$$\overline{w'q'} = E/\rho = C_e \cdot U \cdot (q_s - q)$$

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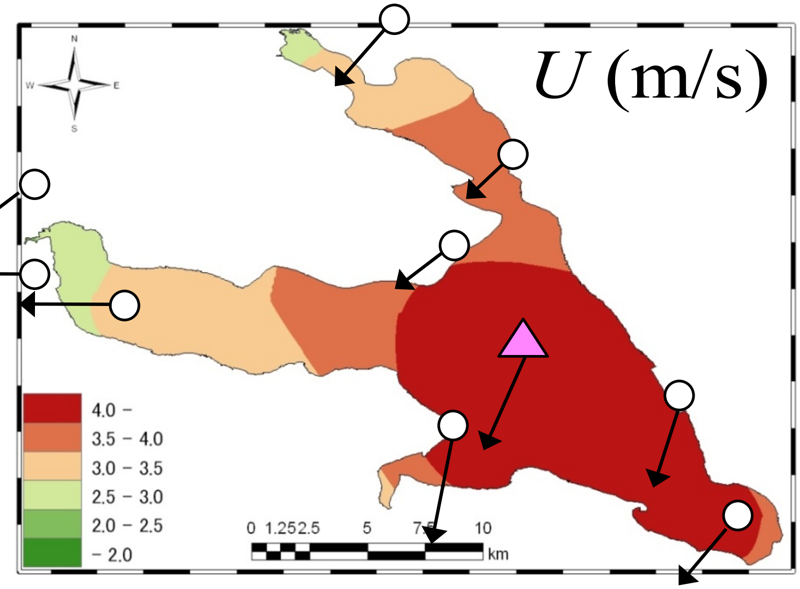
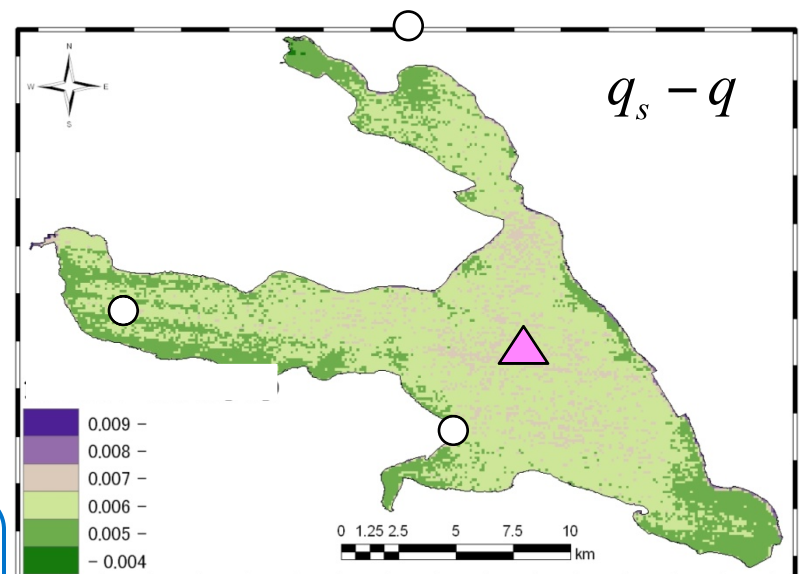



Wind speed= 3.4 ±0.5 (m/s)

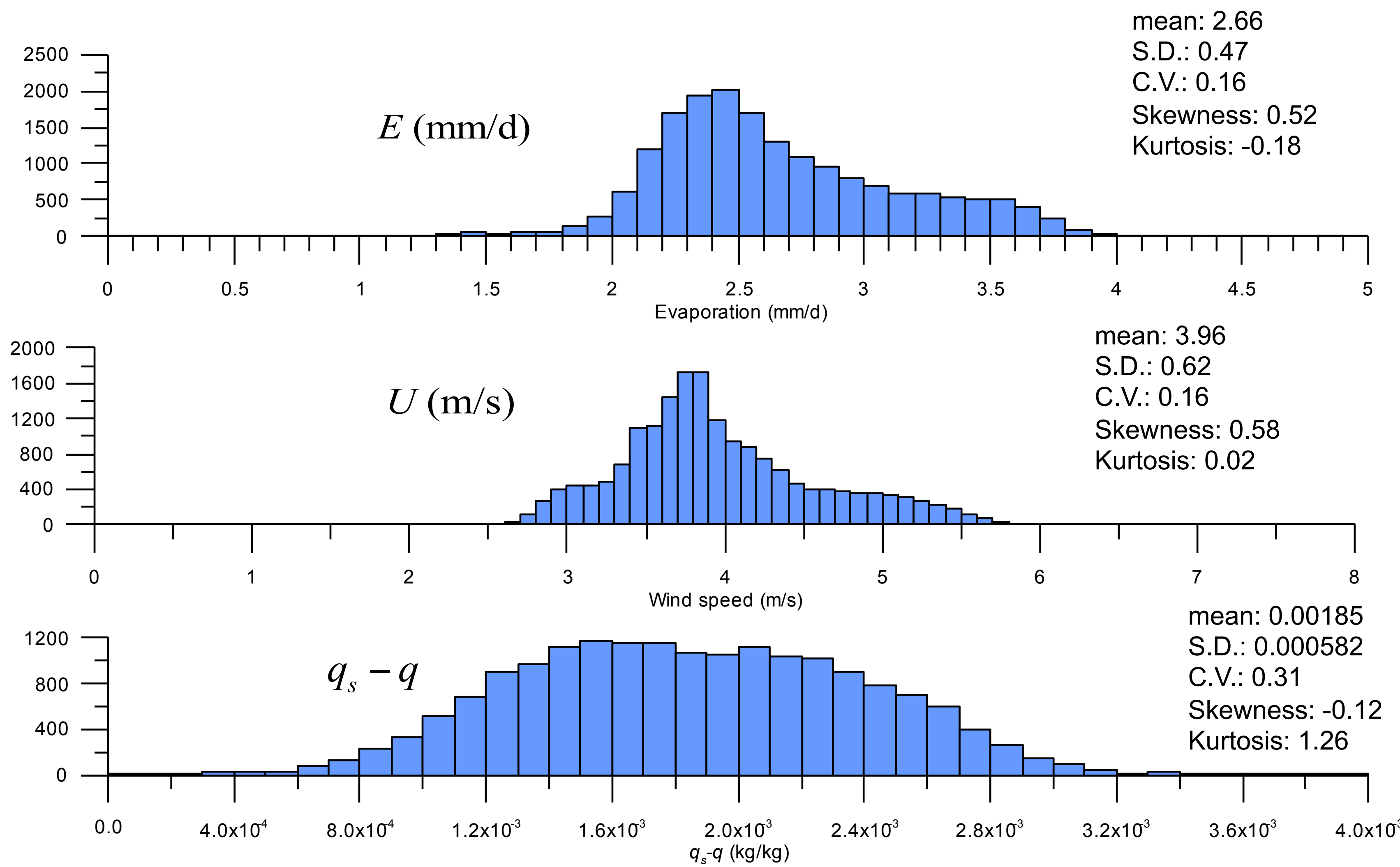



$q_s$-$q$= 4.0 ±0.4 (g/kg)

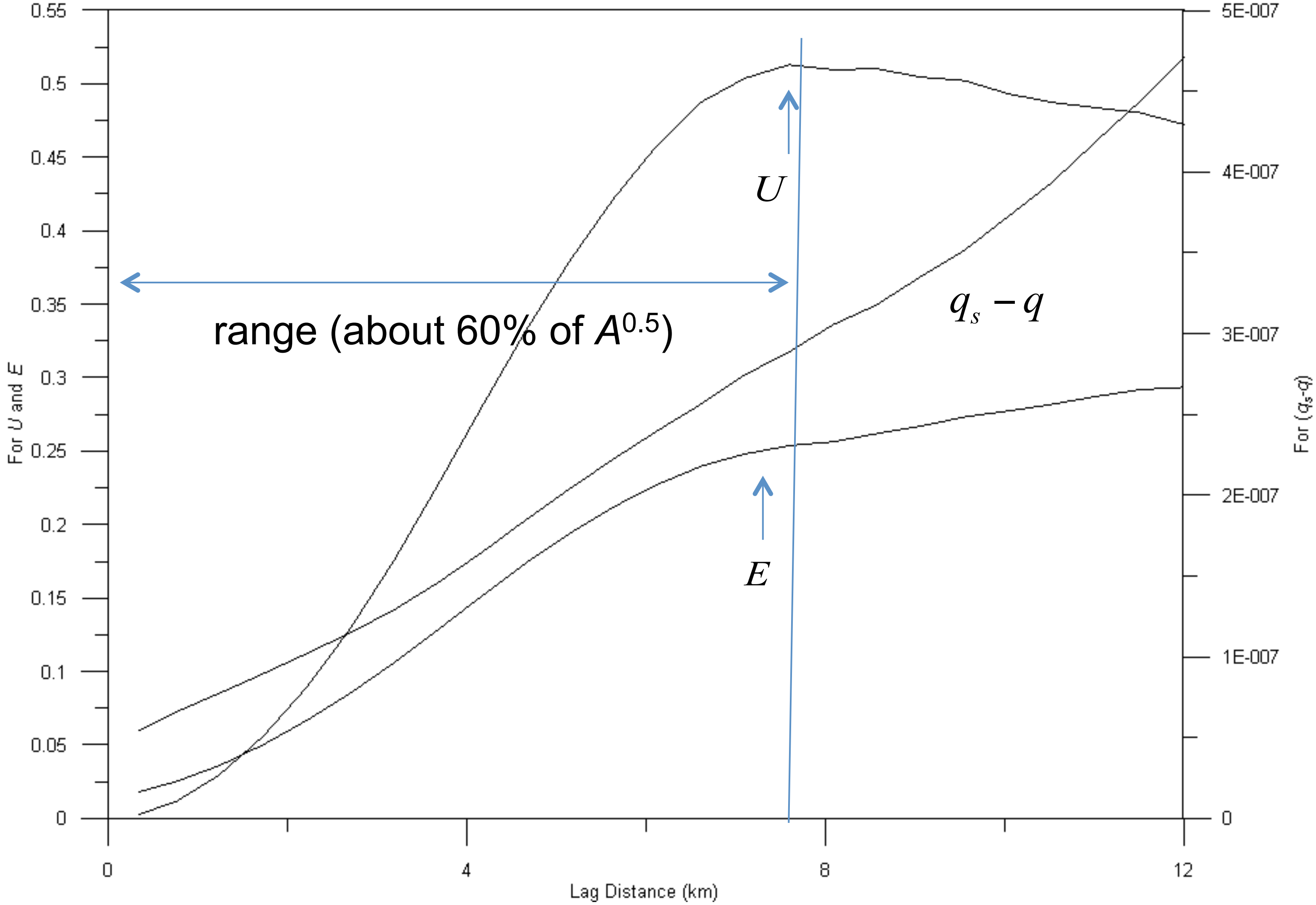
Distribution of $E$ reflects mostly $U$ and not ($q_s$–$q$)

Frequency distribution
2007/11/21 10:30 am

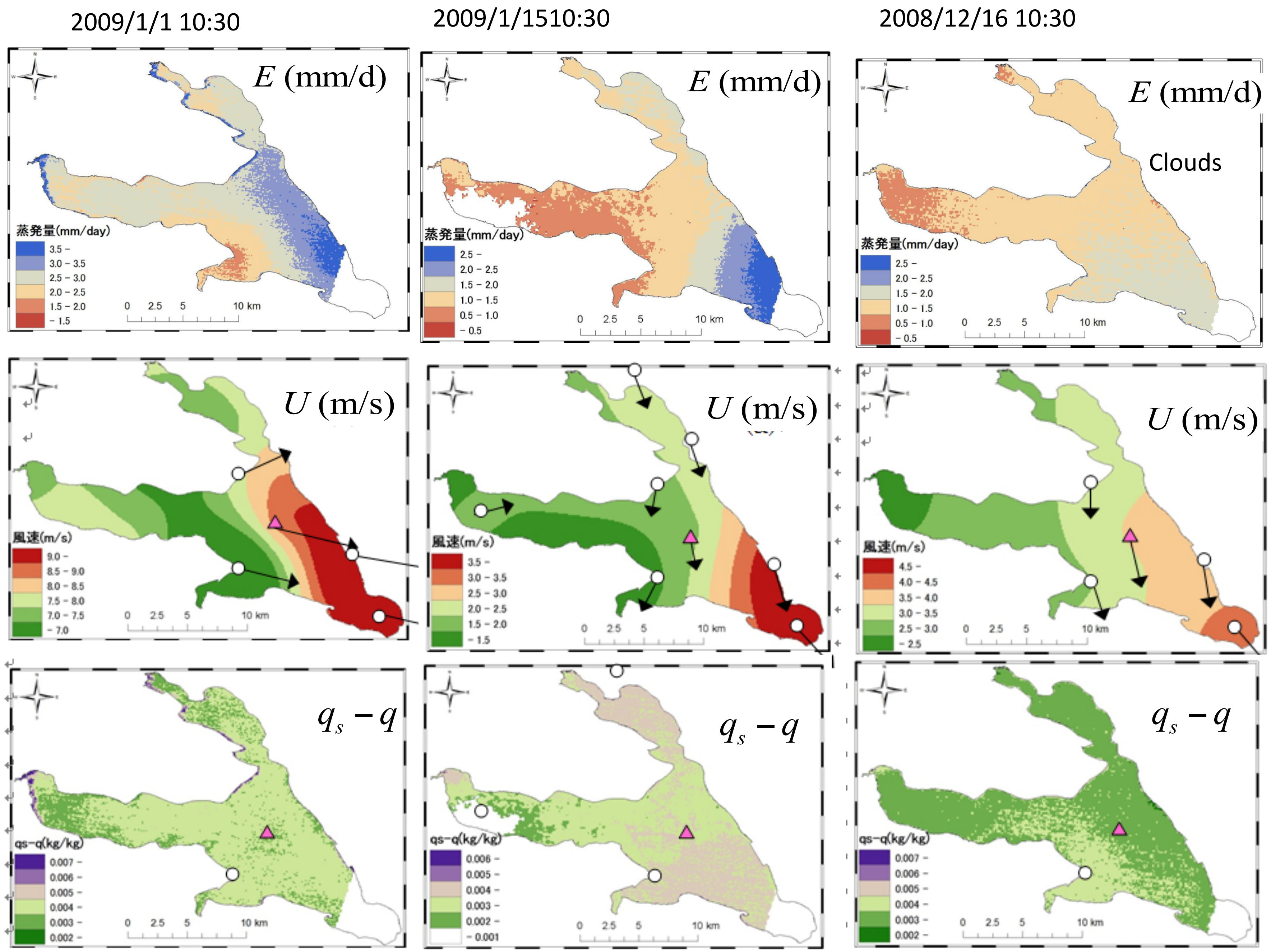
$$\overline{w'q'} = E / \rho = C_e \cdot U \cdot (q_s - q)$$



Variogram (structure function)
2007/11/21 10:30 am



# Other examples



# Spatial distribution of annual lake evaporation

$T_s$ at Koshin observatory

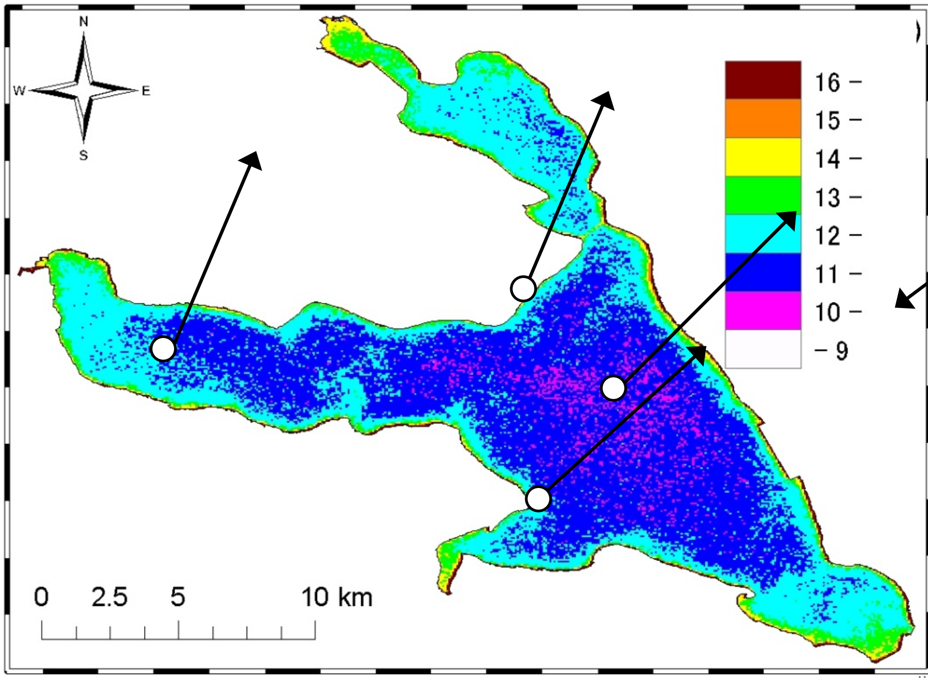
$$E = \rho C_e \cdot U \cdot (q_s - q)$$

Interpolation (Kriging) to produce spatial map

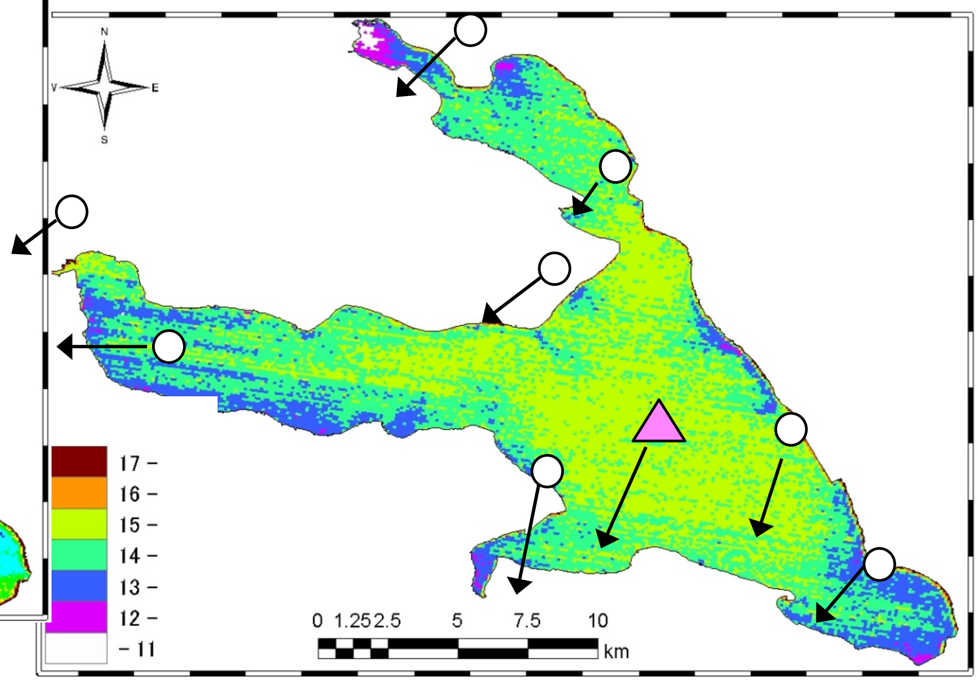
- $U$ and $q$ : interporated from observation of meteorological stations
- $q_s$ : represented by obs. at Koshin observatory
- $C_e$ : estimated from interpolated $U$, $T_s$ *and* $T_a$
- Target year: 2008
- Time resolution: 3 hours

## Lake surface temperature estimated from satellite infrared channel data

$$\overline{w'q'} = E/\rho = C_e \cdot U \cdot (q_s - q)$$




2000/3/29 10:30 am
Strong wind case (~15 m/s)
Surface temp.= 11.0±1.26 (ºC)




2007/11/21 10:30 am
Moderate wind case (~5 m/s)
Surface temp.= 13.5±0.62 (ºC )

**【Analyzed data】**

- 32 cases (1999～2009年)
  - ASTER (14)
  - Landsat-TM (1)
  - Landsat7-ETM+ (17)

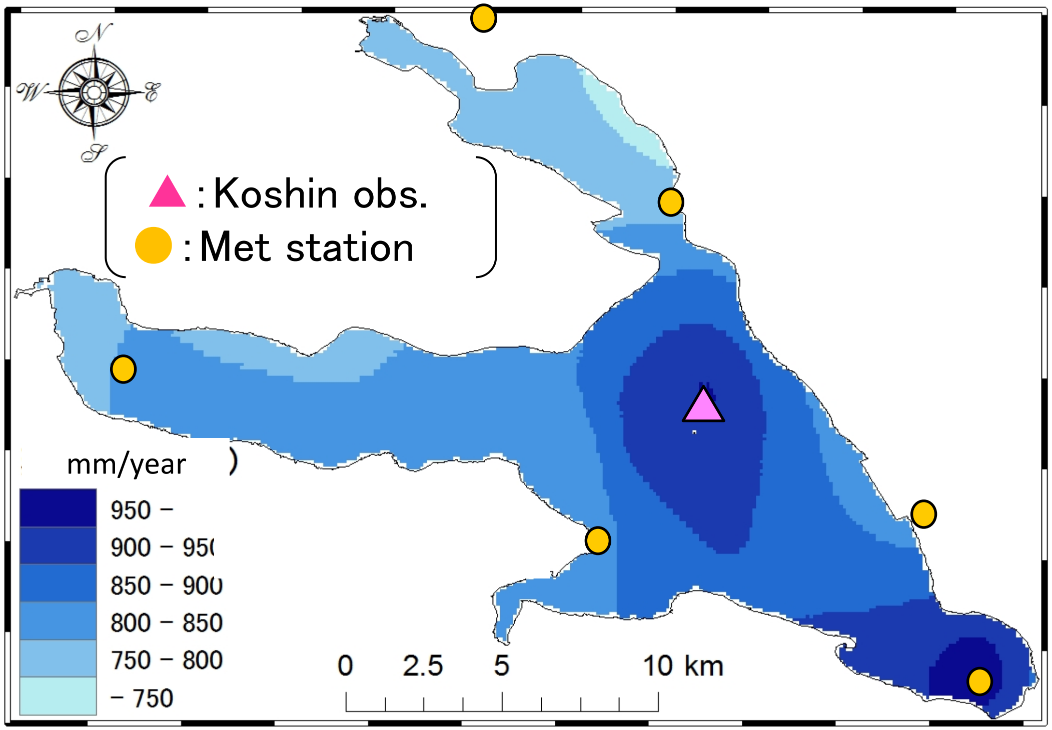
**【Results】**

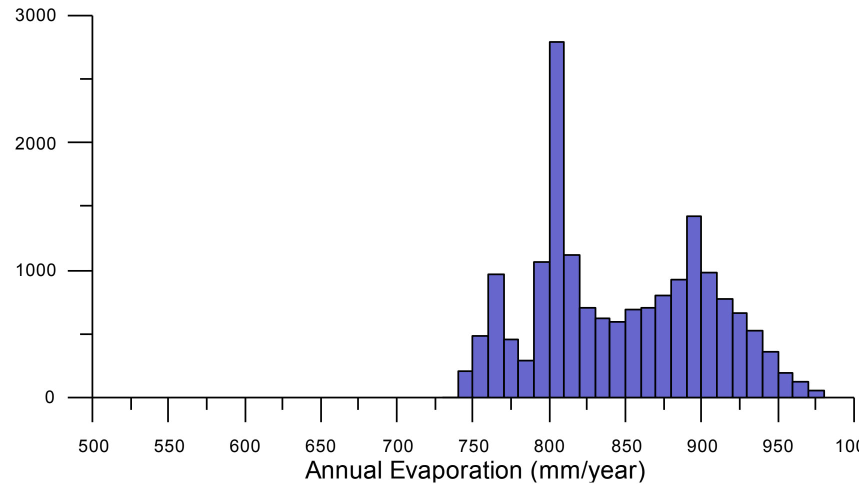
- Spring & Summer: Standard deviation (S.D.) <1-2 ºC
- Fall & Winter: S.D.< 1ºC

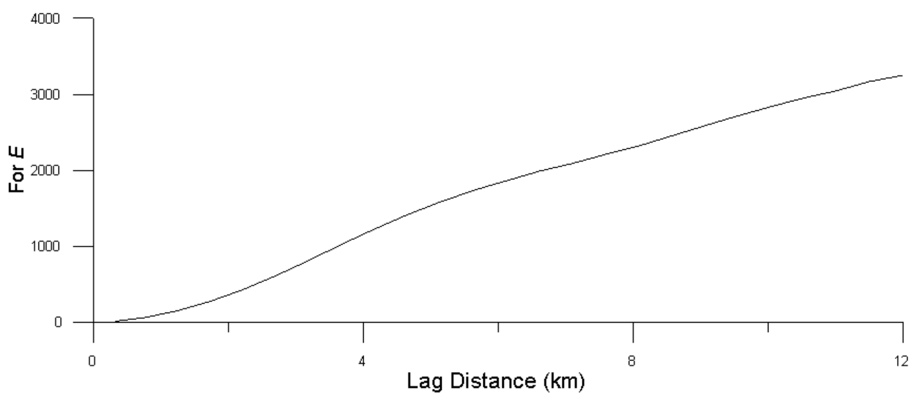
- <<($T_s$-$T_a$) =5~10ºC
- Shallow lake: well-mixed water body

Annual evaporation in 2008

- Target year: 2008
- Time resolution: 3 hours

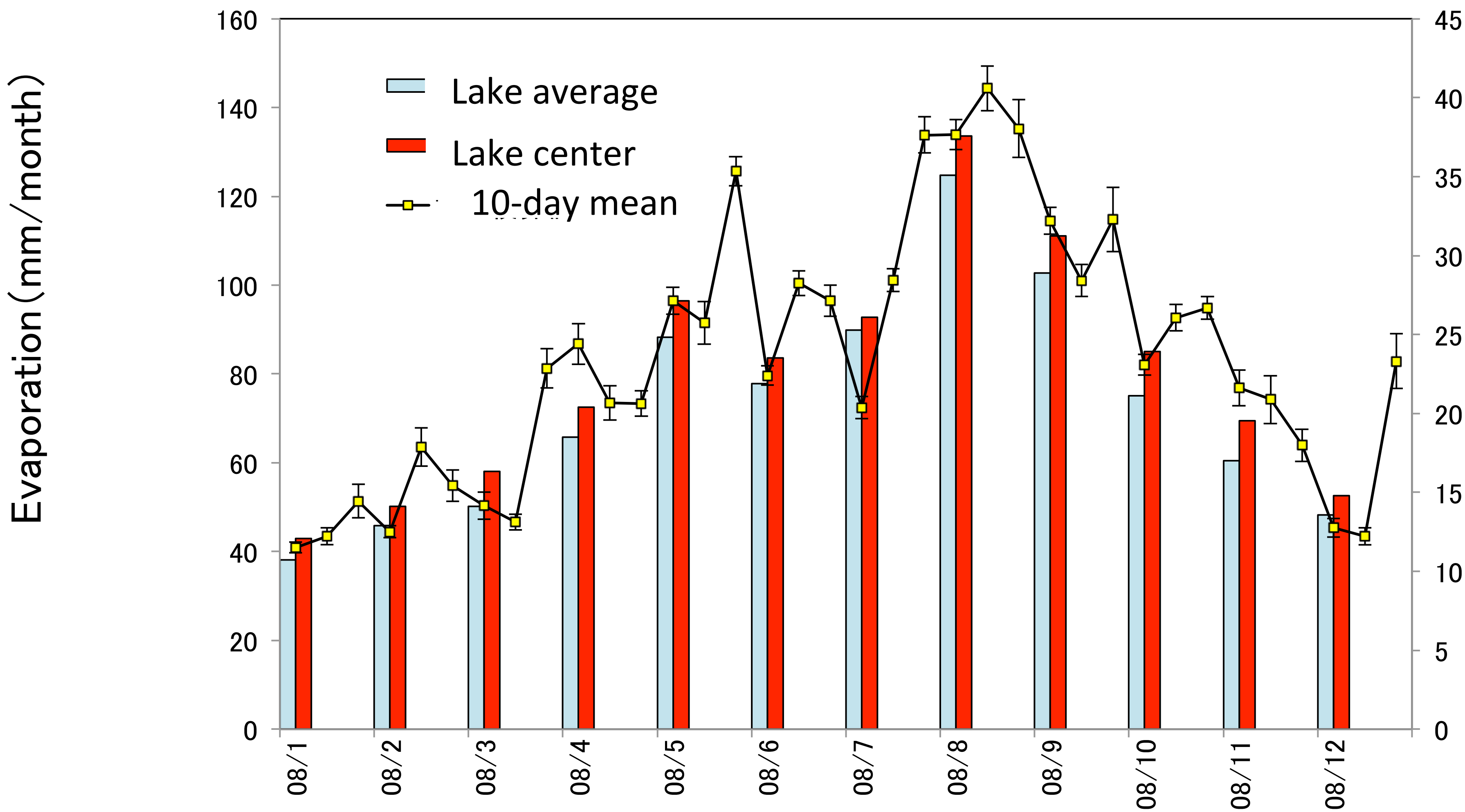



Statistics:
Mean and S.D.: 847 ± 56 (mm/y)
max:: 987 (mm/y)  ±15% of mean
min: 739 (mm/y)

Monthly changes of lake evaporation




2008

# Evaporation from Lake Kasumigaura

## Bulk Coefficients and Spatial Distribution of Latent Heat Flux

- Bulk coefficients are in agreement those reported in the literature except for low wind speed.
- Horizontal variation of lake evaporation is mainly caused by wind speed distribution over Lake Kasumigaura.
- Typical "range" is around 8 km (about 60% of $A^{0.5}$) for both wind speed and evaporation variogram, while the humidity field appears to have longer range than the lake extent.
- Mean annul evaporation is 847 ± 56 (mm/y). So we need to consider spatial variation to make accurate lake evaporation.