Evaporation measurements by eddy covariance from a tropical urban water reservoir

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Introduction

One of the major problems in the management of water reservoirs is the accurate estimation of water loss due to evaporation. The availability of accurate estimates of evaporation rates and knowledge about their dependence on weather conditions, e.g., incoming solar radiation, water and air temperature, humidity and wind speed) allows managers to maximize reservoir efficiency. This is particularly important for countries where the water supply relies on imported and recycled water, seawater desalination, and rainfall collected in reservoirs, such as in Singapore.

Within this context, an eddy covariance (EC) system was deployed on the shore of an urban water body in Singapore (Bedok reservoir) with sufficient fetch to measure the upwind evaporation during a period of two weeks. This was likely the first such study for a small urban water catchment located in a tropical climate.

Fig. 1. Location of Singapore’s reservoirs. The red circle indicates Bedok reservoir.

Methodology & instrumentation

The EC approach provides a direct measurement of the water vapor flux. The water vapor flux (in units of g m⁻² s⁻¹) can then be converted into units of evaporation rate (e.g., in units of mm h⁻¹ or mm d⁻¹). This approach is preferred as it is “direct”, involves few assumptions and measures the evaporation from a large portion of the actual reservoir.

Figure 2 shows the instrumentation and EC set-up used in this study. The EC system consists basically of two co-located fast-response sensors to simultaneously measure wind and humidity. Multiplying fluctuations in vertical wind speed and humidity obtained at 3 m by the average wind velocity integrated over a 15-min interval provides the evaporation flux.

The measurements were conducted between 5-19 October, 2009. This period coincided with the end of the SW monsoon season, which is the reason why the EC system was located on the reservoir’s north shore. A total of 1249 15-min periods were measured of which 67% fulfilled data quality (statistical characteristics and stationarity) and fetch (i.e. source area within the reservoir) criteria.

The source area has an elliptic shape and is located upwind of the observation point (Figure 3). Its size depends on the height at which the instruments are installed above the water surface and ambient meteorological conditions, in particular the stability of the atmosphere. Using actual values (sensor height = 1.6 m, roughness length = 0.3 mm) the 90% fetch area extended to 226 m (1,803 m) for a stability (z/L) of -0.1 (+0.1) using the source area model of Hsieh et al. (2000).

Fig. 2. Instrumentation and EC set-up. (1) Sonic anemometer (CSAT3), (2) IRGA open path infrared gas analyzer (LI-7500), (3) net radiometer (REBS 21-G), (4) temperature and RH sensor (HMP45C), (5) cup anemometer (Met One CS100A), (6) temperature and RH data logger (HOBO U23), (7) net-gauge (HOBO RG3), and (8) infrared temperature sensor (Euseline Infraozone 4000). Picture in the upper right corner shows a close-up of the sonic anemometer and IRGA.

Fig. 3. Sensors location and observed fetch. The EC system was located at the north shore (close to red site), area enclosed by red solid line is fetch for favorable (very unstable) and red dashed line for unfavorable (stable) conditions assuming wind is from the South (bottom of image). Blue line includes acceptable wind direction sector for this sensor location.

Results

Evaporation was found to follow a clear diurnal pattern, ranging from 0.03 mm h⁻¹ during nighttime to an early afternoon peak of 0.25 mm h⁻¹, with a daily mean of 2.71±1.18 mm d⁻¹ (Fig. 4a). These values are similar to the summertime evaporation rates reported for larger lakes in subtropical or mid-latitude locations (e.g. 3.1 mm d⁻¹ over Sparkling Lake, Wisconsin (Lenters et al. 2005) and 5.5 mm d⁻¹ over Eshtol reservoir, Israel (Tanny et al. 2008)).

The evaporation shows a strong correlation with atmospheric turbulence u* (friction velocity) which is related to wind speed (Fig. 4b). However, the ∆Q* (heat stored) in the water appears to be the main parameter driving the evaporation from the reservoir because of the relatively calm winds (< 2.5 m s⁻¹) observed during most of the study. The surface water temperature was consistently (between 2 - 3.5 °C) warmer than air temperature throughout the diurnal course (Fig. 4c). Much of the net radiation received during daytime is channeled into heating the water which results in the higher water temperatures (Fig. 4d). The high humidity (> 65%) during the study appears, on the other hand, to work to reduce evaporation.

Fig. 4. Average diurnal pattern of evaporation and ambient parameters. (a) Evaporation rate or water vapor flux, (b) turbulence parameter u* (°C) air and water surface temperature, (c) energy balance components (sensible heat (Qs), latent heat (QL) and net radiation (Qr)), the residual (∆Q = Qs + Ql + Qr) is the heat stored in the reservoir. The colored areas represent ±1 standard deviation of the mean fluxes and give an indication of the day-to-day variability in each phase of the daily cycle.

Summary

These preliminary results are useful to demonstrate the feasibility of the EC technique to measure evaporation rates from a small urban tropical water reservoir. A longer observation period, however, is needed to be able to carry out a more thorough analysis.

In future work, the observations of this study are going to be used to test simple predictive evaporation models based on similarity theory and which require only basic meteorological input data.

Acknowledgments: The field measurements were supported by PUB, Singapore’s national water agency and Singapore-MIT Alliance for Research and Technology (SMART). Singapore-AIT Alliance for Research and Technology (SMART) (evelasco@i-smart.nus.edu.sg)