Royal Netherlands
Meteorological Institute
*Ministry of Infrastructure
and Water Management*

Measuring Evaporation at Cabauw

E.I.F. (Cisco) de Bruijn [1], Jessica M.I. Strickland [1] Contact: cisco.de.bruijn@knmi.nl

Droughts in the Netherlands are worsening due to climate change, highlighting the need for a better understanding of the hydrological cycle. Evapotranspiration (ET), the sum of evaporation from soil-vegetation surfaces and transpiration through plant leaves, is an essential component of the surface energy balance. Traditionally, the Royal Netherlands Meteorological Institute (KNMI) estimates evaporation based on meteorological conditions, while exploring indirect in-situ methods for observations at the Cabauw Experimental Site, such as a sonic anemometer and a LI-COR delivering eddy-covariance flux measurements, a psychrometer mast applying the Vertical Gradient (VG) method. These long term observations began in 1986, but recently a new direct method for measuring evapotranspiration has been deployed: a smart lysimeter. While lysimeters offer precise measurements of water inflow and outflow from a surface volume, they have spatial limitations, are quite sensitive to variations, and require rigorous validation. Therefore, this study provides an overview of evaporation observations at the Cabauw site and evaluates the lysimeter's performance compared to the established methods. Initial results suggest that integrating validated lysimeter data may improve surface energy balance closure, benefiting hydrological research, models, and environmental policy.

Vertical Gradient method

At the Cabauw site, a psychrometer mast calculates evaporation using the vertical gradient method [1]. Specifically, wet and dry bulb temperature are measured at 1, 2, and 4 m (Figure 1), from which vertical temperature and humidity fluxes are obtained. These measurements have been used to derive latent energy observations spanning four decades, as shown in Figure 2. This figure shows that the warming over the past decades has led to increased ET.

Figure 1: *Psychrometer mast*

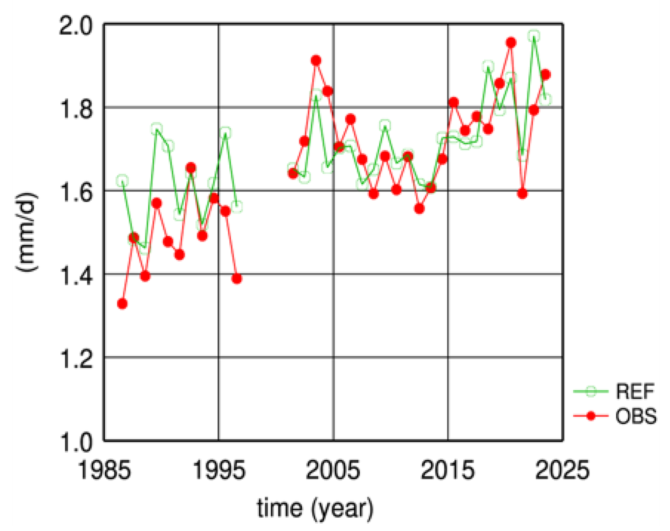

Figure 2: *Yearly-averaged latent energy per day during 1986-2023 determined using the vertical gradient method (OBS) compared to the established Makkink model (REF) [2].*

Eddy Covariance method

Long-term evaporation observations have also been obtained using the established Eddy Covariance (EC) method [3]. Specifically, turbulent moisture fluctuations are obtained from a 3D Sonic anemometer and an open-path liquid vapor analyzer (Figure 3). The vertical moisture fluxes at 3 m are used to infer the latent energy at the surface. This method is sensitive to noise caused by precipitation and the spatial footprint of vegetation.

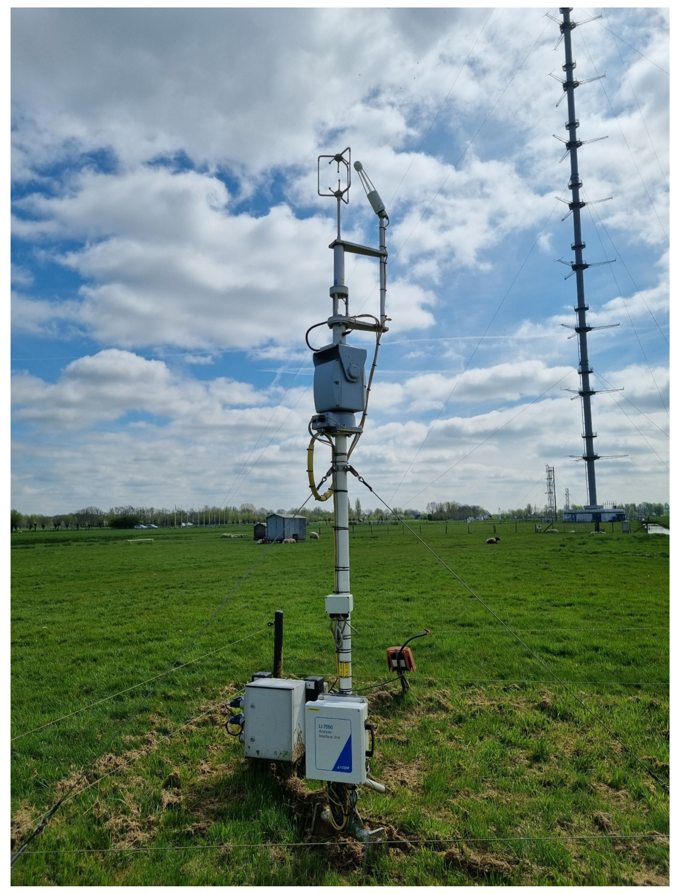

Figure 3: *Gill Sonic anemometer and LI-COR open path analyzer*

Smart Lysimeter method

In contrast to the other two indirect methods which sample the atmosphere above the surface, the lysimeter (shown in Figure 4) measures latent energy fluxes directly at the surface. Specifically, the lysimeter measures the evapotranspiration and precipitation based on the weight change of a representative soil monolith. The monolith is isolated, but an external tensiometer ensures that the moisture of the column is comparable to the surrounding soil. Moreover, an advanced pump system controls the soil moisture inside by wetting or by pumping out the water.

In Figure 5, the daily-averaged rate of latent energy measured by the lysimeter is compared to the Eddy Covariance (EC) method and the established Penman Monteith (PM) model [3]. Overall, we observe relatively good agreement. The PM model overestimates the evaporation in dry periods, because of inaccuracies in soil moisture and stomatal resistance. The EC method indirectly measures the latent heat flux and the non-closure of the energy balance remains an issue applying these measurements. However, the direct lysimeter observations exhibit sensitivity and fluctuations which require filtering and post-processing.

Figure 4: *Smart lysimeter before (upper panel) and after (lower panel) being deployed. Also pictured below is the tensiometer which measures the surrounding field soil water tension.*

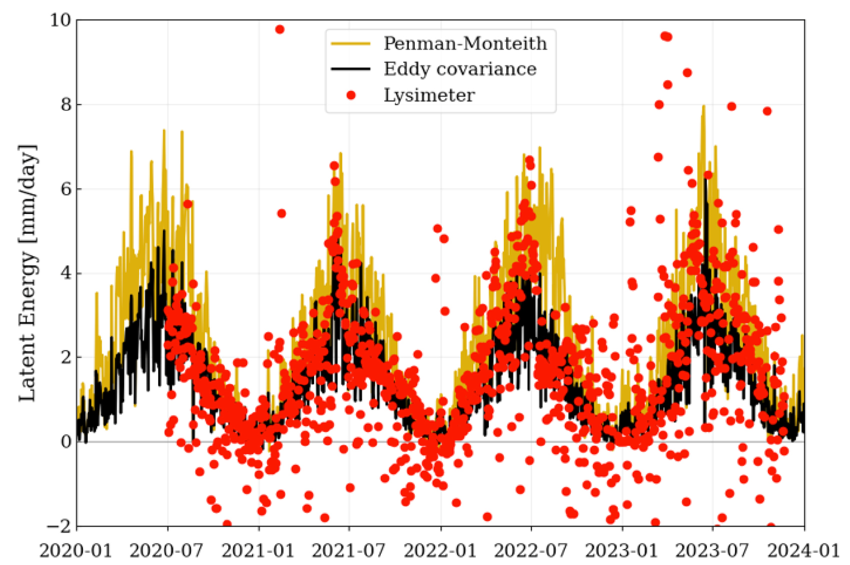

Figure 5: *Comparing three methods for evaporation at Cabauw observational site: Penman Monteith model, Eddy Covariance, and Lysimeter.*

Surface Energy Balance

Evapotranspiration plays a key role in the latent energy component of the surface energy balance (SEB). To eliminate the noise of the lysimeter the raw latent energy data have been processed with a Moving Average (MA) and the Savitzky-Golay (SG) smoothing filter [5,6]. Figure 6 shows the components of the SEB, comparing the lysimeter and EC methods for the Latent Heat Flux (LHF). Each component of the net radiation, as well as the soil heat flux, are measured directly on the same field at the Cabauw site.

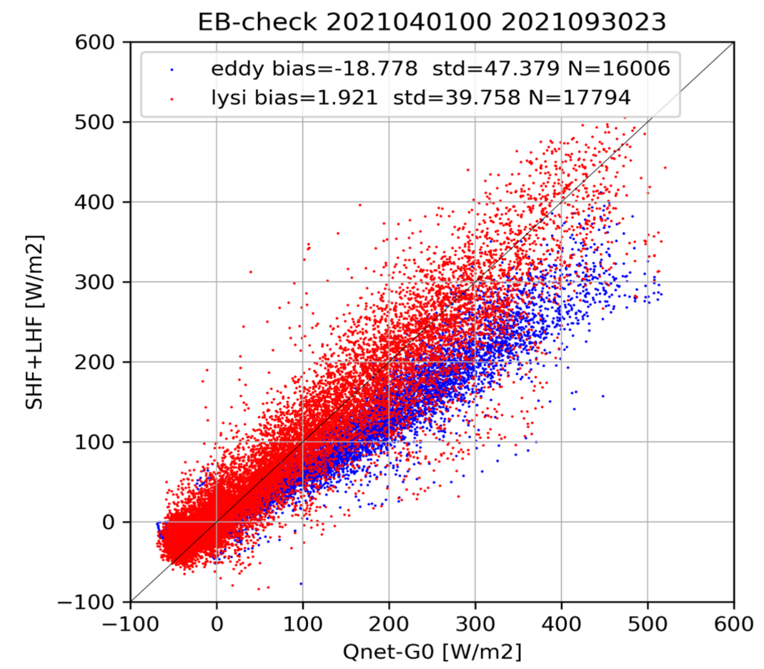

Figure 6: *Scatter plot (April-September, 2021) of Sensible Heat Flux and Latent Heat Flux (SHF+LHF) using the Lysimeter (red) and EC methods (blue) versus the aggregated net radiation minus soil heat flux (Qnet-Go). Each point is a 60-minute average. The lysimeter data are filtered with the Savitzky-Golay filter [4], window=1hr, polynome=6*

We observe the known non-closure of the SEB when the EC method is used for the LHF as the trend deviates from the 1:1 line. However, the balance improves when the lysimeter measurements are used for LHF. Regarding the indirect EC method, the LHF is governed by eddies which are representative of a larger area measured at 3 m above the surface. Meanwhile, the lysimeter measures highly localized LHF values directly at the surface which appears to better correspond with the other in-situ components of the SEB. In this case, we acknowledge that assumptions and factors which impact the other in-situ measurements must be considered in more detail. For example, although there seems to be a better closure, the SHF is still derived from the EC measurements. Furthermore, this comparison is affected by non-representative data which have not yet been filtered out of the raw lysimeter dataset. Nonetheless, the lysimeter performs well at high evaporation rates due to its sensitivity.

References

1 De Bruin, H. A. R., Holtslag, A. A. M. (1982). A simple parameterization of the surface fluxes of sensible and latent heat during daytime compared with the Penman-Monteith concept. *Journal of Applied Meteorology and Climatology*, 21(11), 1610-1621.

2 Makkink, G. F. (1957). Testing the Penman formula by means of lysimeters. Journal of the Institution of Water Engineers, 11, 277–288.

3 Monteith, J. L. (1965). Evaporation and environment. In G.E. Fogg (Ed.), The state and movement of water in living organism. 19th Symposium of the Society for Experimental Biology, Cambridge University Press, 205–234.

4 Bosveld, F. C., Beljaars, A. C. M., Holtslag, A. A. M. (2020). Fifty Years of Atmospheric Boundary-Layer Research at Cabauw Serving Weather, Air Quality and Climate. Boundary-Layer Meteorology, 177(23), 583612.

5 Peters, A., Nehls, T., Schonsky, H., Wessolek, G., 2014. Separating precipitation and evapotranspiration from noise: a new filter routine for high-resolution lysimeter data. *Hydrology and Earth System Sciences* 18, 1189-1198. URL: https://hess.copernicus.org/articles/18/1189/2014/, doi:10.5194/hess-18-1189-2014.

6 Savitzky, A., Golay, M.S., 1964. Smoothing and differentiation of data by simplified least squares procedures. *Anal Chem*, 36, 1627-1639. doi:10.1021/ac60214a047

[1] *R&D Department of Observations and Data Technology, Royal Netherlands Meteorological Institute. PO Box 201, 3730 AE De Bilt, The Netherlands.*