Spatial and Temporal Variability in Microclimate and Evaporation over Lake Kinneret: Experimental Evaluation

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ABSTRACT

Microclimate characteristics and latent and sensible heat fluxes were measured continuously and simultaneously over Lake Kinneret, Israel, during two consecutive summers at the eastern (Ein Gev) and western shores (Sapir) of the lake. The data were used to characterize the variability in basic meteorological variables (air temperature and humidity, water surface temperature, and wind velocity) and in evaporation rates. Analysis of the data on an hourly basis reveals the combined effect of local physical processes occurring during airflow over water surfaces and the diurnal regional phenomena of the inland penetration of the Mediterranean sea breeze downslope into the area during the afternoon hours. The resulting strong, hot and dry westerly winds at the western coast become weaker, cooler, and more humid as they reach the eastern shore after a delay of 1–2 h. Consequently, the maximum evaporation rate at Sapir was occasionally twice the corresponding rate at Ein Gev. The data on a daily basis depicted the influence of synoptic systems on the regional climate. Commonly, the mean evaporation rate from the entire lake is assumed to be equal to that evaluated at a specific site. Considering the observed variability, this assumption might lead to errors as large as 100% on the daily basis and of 15% on the seasonal basis.

1. Introduction

The evaporation from a free water surface is a complex process highly sensitive to the local microclimate characteristics. Dealing with the evaporation from lakes, different methods for both direct and indirect evaluation are available. The direct method consists of applying the eddy correlation flux theory (ECS), which enables a determination of atmospheric turbulent heat fluxes by measuring fluctuations of vertical wind speed, air temperature, and specific humidity. The indirect methods consist of empirical formulas that address some of the physical aspects of the transfer of both mass and heat across the air–water interface. Among these, the energy budget method (EBM) "is considered by many to be the most accurate method available for periods of a month or less" (Rosenberry et al. 1993, p. 2473). The energy balance approach relies on the assumption that the ratio between sensible and latent heat fluxes is computable by means of measurable local microclimatic variables (Bowen 1926). In fact, both the direct and indirect methods rely on on-site measured values of the relevant microclimatic variables appearing in the respective equations. In practice, the number of stations providing the appropriate data is restricted. In the case of shallow lakes, it is possible to locate a station at the center of the lake (Stannard and Rosenberry 1991; Rosenberry et al. 1993). In the case of small lakes, a land station close to the shore and a raft station in the lake can be used, but these generally provide complementary rather than comparative data (Sturrock et al. 1992). However, "it is tempting to use land-based temperature and atmospheric vapor pressure data for estimating evaporation because of the inconvenience and expense in obtaining midlake data" (Rosenberry et al. 1993, p. 2479). Therefore, in the case of large and deep lakes, the stations are generally restricted to shoreline locations (Bolsenga 1975; Derecki 1981).

Great variability in microclimate variables can be generally observed, the effect of which increases as the area represented by a single station is larger.

For a 69-day test period, Keijman (1974) estimated the average difference between evaporation rates measured by sensors located on the shore of a lake and sensors centrally located over the lake to be 0.6 mm per day.

Rosenberry et al. (1993) evaluated the effect of using microclimate data from a land station located

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100 m from the northwestern shore of Williams Lake instead of the data provided from raft-based sensors located near the center of the water body on evaporation rate estimates resulting from energy budgets. Average annual changes in estimates of evaporation ranged from 1% to 7%.

The variability in the microclimate characteristics and the limited number of measuring stations generally available lead to a biased estimation of the overall evaporation from the lake surface. There are cases where an accurate evaluation of the water loss by evaporation is needed. For example, the Lake Kinneret (northern Israel) water budget is characterized by a practically undefined saline ground water inflow. A precise evaluation of this inflow is crucial in order to (i) control the salinity of the lake water; and (ii) understand and model the activity of the complex system of thermosaline springs at the shoreline and the bottom of the lake. The ground water inflow is estimated through the residuals that balance the water, heat, and salt balance equations of the lake (Assouline 1993). On a yearly basis, the evaporation loss is about 270 $\times 10^6$ m^3, and the ground water inflow approximately 90 $\times 10^6$ m^3. Consequently, a 10% error on the evaporation estimate represents an error of 30% on the evaluation of the ground water component. On monthly or daily bases, the errors might be far larger. Winter (1981), in a comprehensive review, has analyzed 23 cases of lake water budgets and found that in most of the studies, the ground water component was calculated as the residual. It is therefore evident that accurate evaluation of evaporation losses is needed, at least when a lake water budget component is evaluated through the residual of the balance equation used. We propose to use Lake Kinneret as a case study of spatial and temporal variability of microclimate and evaporation over lakes.

Evaporation from Lake Kinneret is estimated by means of the energy budget method using meteorological data from a single station (Sapir site) located on the northwestern shore, 200 m offshore. The estimated rates are commonly assumed to be representative of the whole lake area. In the past, differences have been monitored between the western and eastern shores of the lake in terms of wind speed, relative humidity, and pan evaporation data (Serruya 1975; Neumann and Stanhill 1978; Stanhill and Neumann 1978). The eastern shore was characterized by lower wind speeds, cooler and more humid air, and lower pan evaporation rates. Mahrer and Assouline (1993) used the two-dimensional version of a numerical mesoscale model to evaluate the horizontal distribution of the evaporation rate over the lake. The model, whose results were in agreement with the measured values at the western shore station, predicted different trends in the evaporation variability along a west–east transect over the lake. For the climatic conditions prevailing during the experimental period, a concave horizontal distribution of the computed evaporation rates across the lake was obtained. In this study, we will analyze the meteorological and heat fluxes data measured simultaneously at two stations on the western and the eastern shores of Lake Kinneret in order to characterize their variability in time and space.

2. Methods

Lake Kinneret is a small lake in northeastern Israel, with an area of 166 km^2 and a maximum depth of 44 m. The main stream interacting with the lake is the Jordan River, the inlet of which is situated at the northernmost point of the lake, and the outlet at the southernmost point. The lake is situated in the Jordan Valley, a corridor running from north to south, between the Galilee hills in the west and the Golan Heights in the east. Therefore, most of the surroundings of the lake have an elevation of approximately 400 m, while the elevation of the lake surface is -210 m. The evaporation from the lake is evaluated basically using the EBM, and more specifically, using the simultaneous solution of the water, heat, and chloride budgets of the lake (Assouline 1993). The relevant microclimatic variables required for an application of the EBM—that is, air temperature and relative humidity, net radiation and water surface temperature—are measured at a station located 200 m offshore at the Sapir site on the northwestern shore of the lake. Global radiation, wind speed, and wind direction are also continuously monitored. The climatological sensors are placed 4 m above the water surface. The heat storage changes in the lake are estimated by means of biweekly temperature surveys, during which the water temperature distribution with depth at 45 points over the lake area is measured at 0.5-m depth intervals. The net energy flux resulting from heat exchange across the lake bottom and from biological processes is assumed to be negligible. During two periods, from 24 July to 22 September 1992, and from 16 August to 26 September 1993, the sensors of the ECS—that is, a sonic anemometer for vertical wind fluctuations, a thermocouple for air temperature fluctuations, and an absorption hygrometer for air humidity fluctuations—were added to the station. They were mounted on a boom 6 m from the station mast and 1.5 m from the water surface, giving a height to fetch ratio that was adequate for an accurate representation of the vertical fluxes from the water surface. During these periods, a second station including sensors similar to those at the Sapir station was installed on the eastern shore of the lake, at Ein Gev. However, because the eastern part of the lake is characterized by a rapid deepening of the bottom, this station could not be installed offshore as at the Sapir site and was mounted on the shoreline on a pier. Consequently, the ECS sensors were installed with the other sensors 4 m above water level. Since the ECS sensors could not be placed at an adequate height above water level to obtain the required height-to-fetch ratio, only measured fluxes corresponding to periods of basically westerly winds (between 210° and 330°) were used. The position of the stations and the wind directions for which the ECS data are relevant are described in Fig. 1. The sensors at the two stations were switched during the experimental periods.

The errors associated with the different measurements are about 10% for eddy fluxes; 0.5°C for temperatures; 0.5 m s^{-1} for wind velocity; and 2% for air relative humidity. A detailed description of the hydrology of the lake, the instruments used, the sampling procedure, and the different characteristics of the climate over the lake in summer can be found in Assouline (1993) and Assouline and Mahrer (1993).

3. Results and discussion

a. Diurnal variation of microclimate and evaporation

Mean hourly values of the basic meteorological variables for three typical consecutive days during the summer (23–25 August 1992) are depicted in Figs. 2a–e. During the night, there are only slight differences in air temperature and humidity between the two stations. The major differences are in the surface water temperature and the wind direction. The water temperature is 2°C higher at Ein Gev. Westerly winds were measured in Sapir, while they were southeasterly in Ein Gev. After sunrise, and until 1300 LT, an increase in water surface and air temperature with a corresponding decrease in relative humidity is noted. The winds turn easterly in Sapir and southerly in Ein Gev. The south component in the wind at Ein Gev reflects the influence of the channeling effect caused by the Jordan Valley. It is interesting to note that due to easterly winds at Ein Gev, the air at 1200 LT is warmer in Ein Gev by about 3°C and dryer by 15%. The rate of warming of the water at Sapir is greater, and at 1400 LT the difference between the two stations reduces to 0.5°C only. After 1300 LT, strong, hot and dry westerly winds are mea-

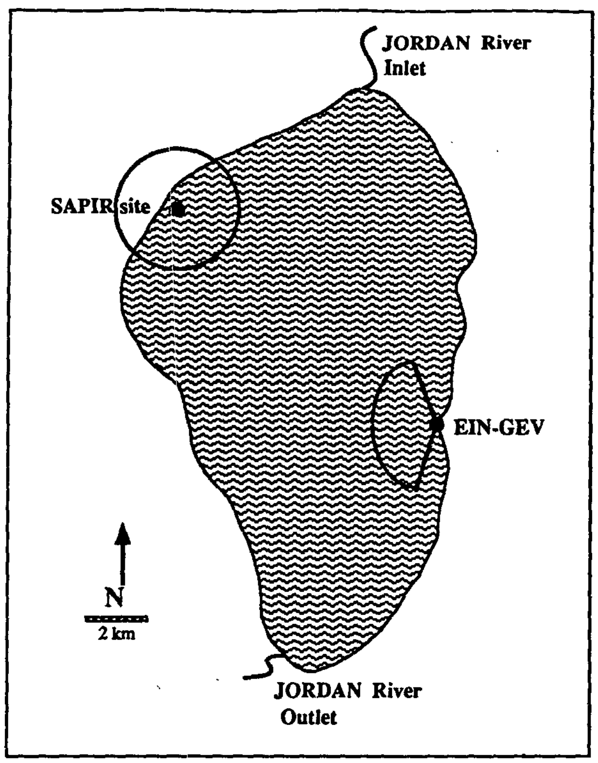

FIG. 1. The location of the micrometeorological stations and the wind directions for which the ECS data are relevant at each station.

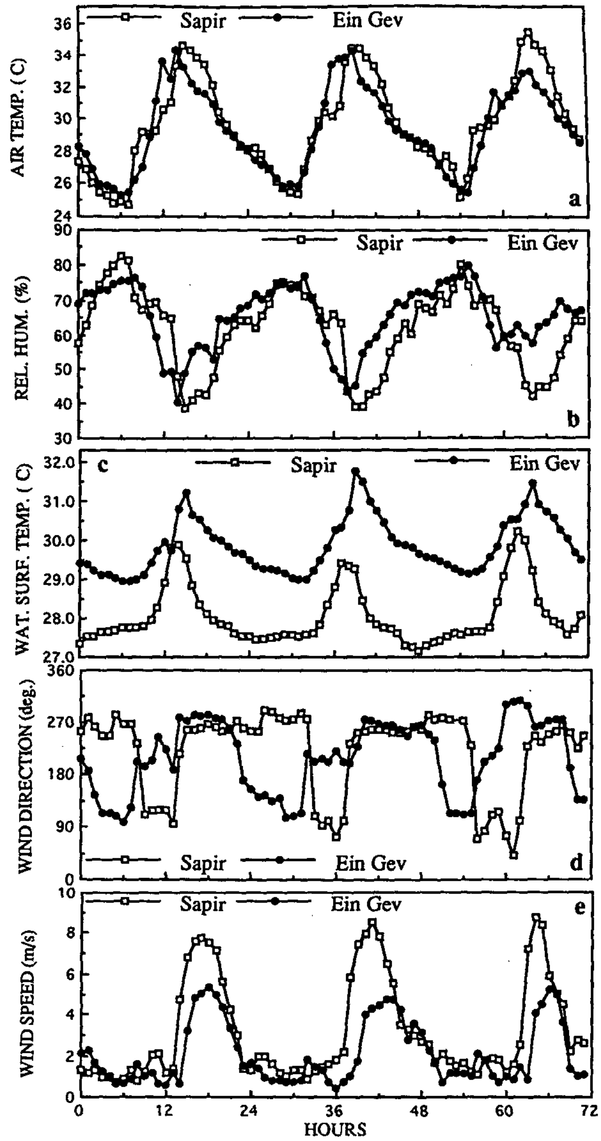

FIG. 2. The mean hourly values of (a) air temperature, (b) relative humidity, (c) water surface temperature, (d) wind direction, and (e) wind speed at Ein Gev and at Sapir during 23–25 August 1992.

sured at Sapir, due to the penetration of the inland Mediterranean sea breeze. These winds reached the eastern shore after a delay of 1–2 h. The winds became weaker, cooler, and more humid due to energy losses and heat and vapor exchanges with the water surface during their flow across the lake. The differences depicted were up to 2°C in air temperature, 15% in humidity and 4 m s^{-1} in wind speed. These strong afternoon westerly winds cause a marked increase of the sensible and latent heat fluxes in Sapir and a more moderate increase in Ein Gev (Fig. 3). Note that in Ein Gev, the measured values of the sensible and latent heat fluxes begin at about 0800 LT when the wind direction became appropriate for ECS measurements. Due to the increased evaporation rate at both stations, a decrease in surface water temperature is observed (Fig. 2c). The differences in the meteorological variables at the two stations affect, as expected, the heat fluxes measured at Ein Gev. Due to the cooler and weaker winds, the measured fluxes were lower and the maximum evaporation rate at Sapir was about twice the corresponding rate at Ein Gev. Consequently, less cooling took place at Ein Gev and the water temperature difference between the two stations rose back to 2°C (Fig. 2c). As a result, one can observe some higher evaporation rates at Ein Gev after 2100 LT due to the more unstable thermal stratification there [air temperature is about equal at both stations at this time (Fig. 2a)].

The measured meteorological parameters and sensible and latent heat fluxes in summer 1993 are depicted in Figs. 4a–e and Fig. 5. To characterize the differences

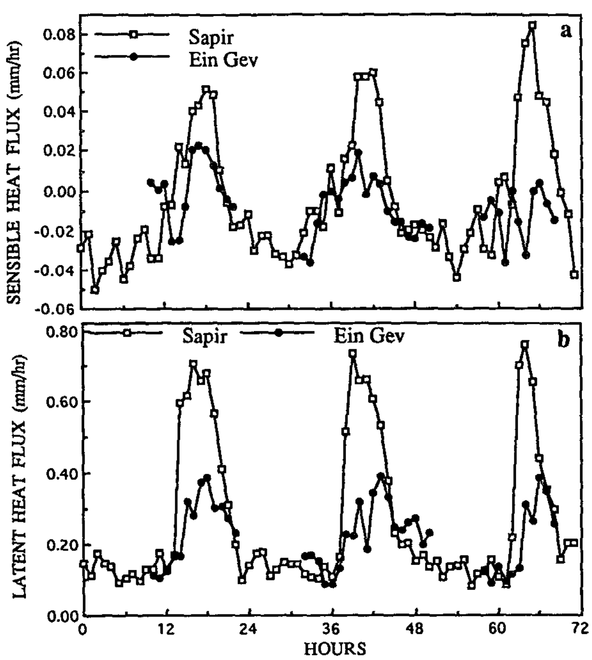

FIG. 3. The mean hourly values of (a) sensible and (b) latent heat fluxes at Ein Gev and at Sapir during 24–26 August 1992.

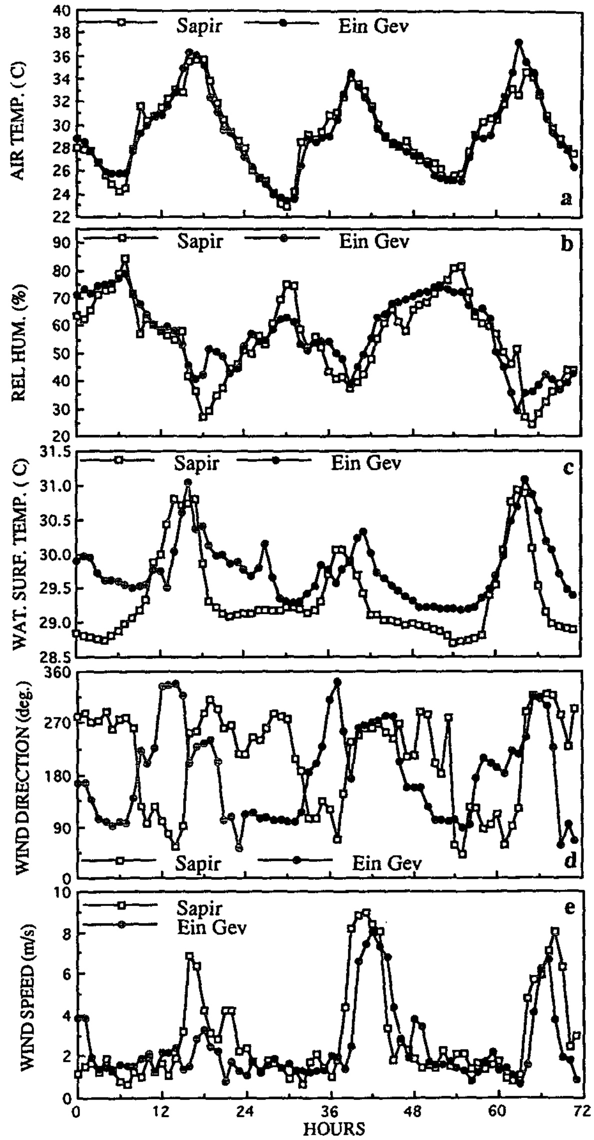

FIG. 4. The mean hourly values of (a) air temperature, (b) relative humidity, (c) water surface temperature, (d) wind direction, and (e) wind speed at Ein Gev and at Sapir during 20–22 September 1993.

between the two experimental periods more specifically, mean monthly values of the main climatic variables measured at Sapir are presented in Table 1. The mean surface water temperature in 1992 was 28.0°C and 29.3°C in 1993; this is a result of the very large inflow of cold water during the exceptionally rainy winter of 1992. Global radiation was nearly identical during the two consecutive summers. Net radiation was higher in 1992, partly because of the lower water surface temperature. Wind speed was larger in 1992. The mean air temperature and relative humidity were similar for both periods. In general, the diurnal cycles during summer 1993 reveal similar main characteristics of

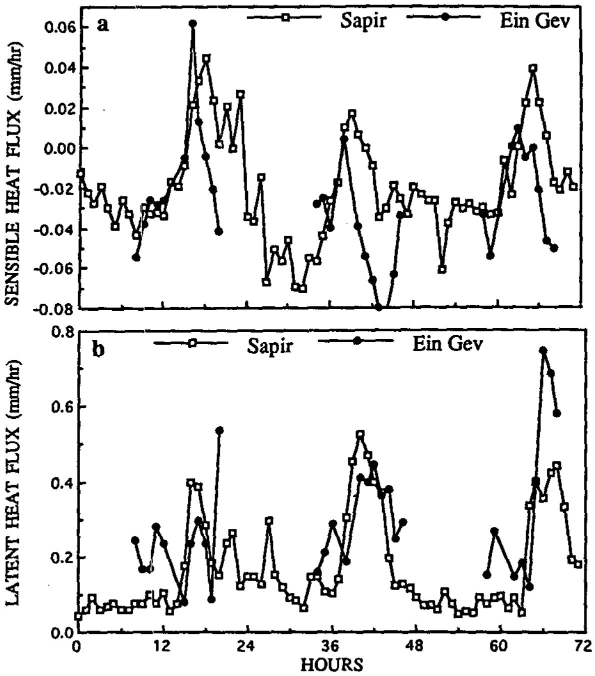

FIG. 5. The mean hourly values of (a) sensible and (b) latent heat fluxes at Ein Gev and at Sapir during 20–22 September 1993.

the flow as those in 1992. However, some distinct differences are apparent due to the above mentioned changes in the basic meteorological variables in the two periods. The differences in water surface temperatures (Fig. 4c) and the differences between the wind speed (Fig. 4e) at the two stations in the afternoon hours (with the penetration of the Mediterranean sea breeze into the lake's area) were much smaller in 1993. Consequently, the sensible and latent heat fluxes during the comparable periods (westerly winds between 210° and 330°) were quite similar at both stations (Fig. 5). During the third day, the latent heat flux at Ein Gev was even higher than at Sapir.

TABLE 1. Mean monthly values of water surface temperature, global and net radiation, air temperature and relative humidity, and wind speed at Sapir station (western shore) during the months of August and September in 1992 and 1993.

	Summer 1992		Summer 1993	
	August	September	August	September
Water surface temperature (°C)	28.5	27.5	29.3	29.2
Global radiation (W m^{-2})	253.9	202.2	253.9	218.1
Net radiation (W m^{-2})	211.1	137.3	191.8	147.7
Air temperature (°C)	30.2	28.7	30.1	28.5
Relative humidity (%)	60.6	52.8	59.5	56.6
Wind speed (m s^{-1})	3.2	2.5	2.8	2.3

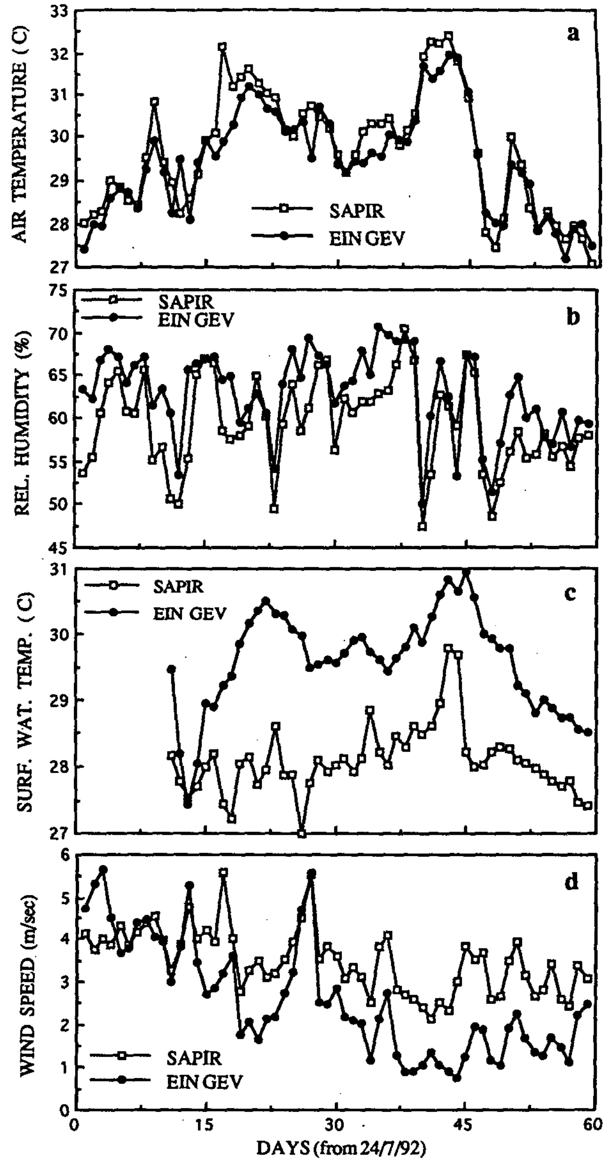

FIG. 6. The mean daily values of (a) air temperature, (b) relative humidity, (c) water surface temperature, and (d) wind speed at Ein Gev and at Sapir during the 1992 experimental period (from 24 July to 22 September).

b. Periodical variation of microclimate and evaporation

Mean daily variations of the meteorological parameters and evaporation rates are illustrated for 1992. Mean daily values of air temperature, relative air humidity, water surface temperature, and wind speed at Ein Gev and Sapir are depicted in Fig. 6. In general, the eastern shore was more temperate, with cooler and more humid air, hotter water, and weaker winds than the western shore. The maximum mean daily air and water surface temperature differences between the two

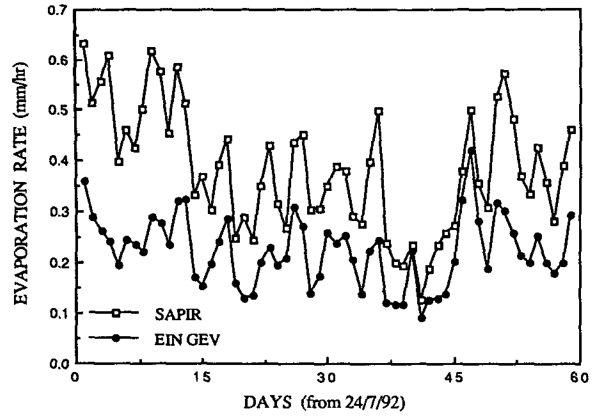

FIG. 7. Mean hourly evaporation rates measured by means of the ECS at Ein Gev and at Sapir during the summer of 1992 (only values measured when the wind direction at Ein Gev was between 210° and 330°, and their corresponding values measured at the Sapir site, were considered).

stations was 2.5°C. Differences of up to 10% in relative humidity and 2.5 m s^{-1} in wind speed were also measured. This is in agreement with earlier observations made by Neumann and Stanhill (1978). However, a detailed analysis of the data reveal some factors affecting the measured variability during the period and between the stations:

(a) Events of hot air intrusion into the region are well depicted in both stations (Fig. 6a) and also affect the relative humidity (Fig. 6b) and the water surface temperature (Fig. 6c). Note that the peaks in water surface temperature occur two or three days after the peaks in air temperature. The correlation between air and water temperature trends was more noticeable at Ein Gev. This is due to the combined effect of two processes characterizing the lake during such periods: (i) the dominant, relatively steady, counterclockwise circulation in the lake (Serruya 1978). Consequently, the Sapir station was much more affected by the cold inflow from the Jordan River inlet at the northernmost part of the lake; (ii) the upwelling of deep colder water at the western shore resulting from the strong westerly winds forcing on the lake surface.

The most drastic event occurred between day 38 and day 45. The synoptic system during that week indicated that advective sharav conditions (a low pressure system from Africa causing hot and easterly winds) dominates the region. Consequently, increase in air and water temperature and decrease in humidity are monitored, leading to the formation of a very stable thermal structure over the lake. Sharav conditions are also characterized by low wind velocities, and the measured values at both stations during these days were the lowest of the whole period.

(b) The decrease of the wind velocities along the experimental period correspond to the end of the summer with its characteristically strong afternoon winds. This trend is accompanied by an increase of the difference between the wind speed measured at the two stations.

These factors also affect the rate of the evaporation process. During the experimental period, latent heat fluxes were directly measured by means of the ECS. As noted above, the position of the sensors at Ein Gev relative to their distance from the eastern shore and their height above the water surface precluded measured values during easterly winds. Therefore, only values measured when the wind direction at Ein Gev was between 210° and 330°, and their corresponding values measured at Sapir were considered. This generally occurred in the afternoon hours. The average daily duration of the period during which the wind direction was within the above limits was 10 h, with a minimum of 5 h and a maximum of 18 h. The mean hourly evaporation rates measured during this daily period are presented in Fig. 7. During the entire experimental period, the evaporation rates were lower at Ein Gev. Here too, increases in evaporation at Sapir correspond to increases at Ein Gev, indicating that changes in the western shore influencing the process are also recorded, albeit more weakly, at the eastern location. The sharav days are clearly depicted. The combination between low wind velocities and stable thermal stratification led to the lowest evaporation rates measured at both stations, and to the smallest difference between the rates at the two stations.

Using the climatic data from the station at Ein Gev and applying the EBM for the whole experimental period leads to 10%–15% lower mean evaporation rate relative to the western station, which is the reference site for Lake Kinneret evaporation estimation. As mentioned earlier, the major differences between the two experimental periods occurred in the surface temperature and wind speed.

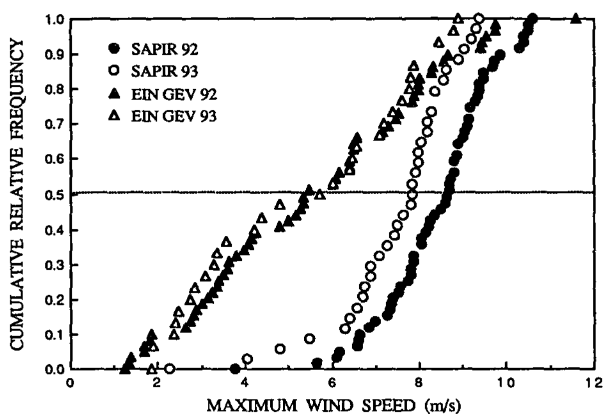

FIG. 8. The cumulative relative frequency distributions of the maximum wind speeds at Sapir and Ein Gev during the summers of 1992 and 1993.

The cumulative relative frequency distributions of the maximum daily wind velocities measured during the two periods at both sites are presented in Fig. 8. The maximum daily wind speed in summer corresponds to westerly winds. Therefore, the weakening of the wind as it crosses the lake is very clear. The nonlinear nature of this process is also depicted. For very weak and very strong winds, the drop in velocity is noticeable yet less remarkable. It seems that the maximal drop occurred for winds of 6–7 m s^{-1}. At the Sapir site, the maximal were systematically lower in 1993, by about 1 m s^{-1} for the high velocities to 2 m s^{-1} for the low values. Such a difference was not observed at Ein Gev. It is interesting to note the difference between the distribution shapes at the two sites. The basic shape seems to be specific to the location since it is similar at each site for both periods, even when the median is shifted to the left, as in the case of the Sapir site winds in 1993.

To illustrate the relationship between the meteorological parameters and the evaporation rates at the two sites in 1993 as compared to 1992, the mean daily values measured at Ein Gev are presented in relation to the corresponding values at Sapir (Fig. 9). The line represents the case in which the values are identical at both stations (1:1 line). Points situated above that line represent values that are higher at the eastern station. In terms of air temperature (Fig. 9a) and relative humidity (Fig. 9b), opposite relationships between the values at the two stations characterized the two consecutive summers. During the summer of 1992, the air was cooler and more humid at the eastern shore. This situation is in agreement with the widely accepted estimation that the climate at the eastern shore in summer is more temperate than that at the western shore. During the summer of 1993, the air was basically warmer and drier at the eastern site. Although this might not be a frequent occurrence, it shows that no unique pattern exists in relating the microclimate at the western shore to that at the eastern one.

In terms of water surface temperature (Fig. 9c), values at Ein Gev were greater than or at least equal to those at Sapir, both in 1992 and in 1993. During the latter summer, the difference between the water surface temperatures at the two sites was smaller (the black points are closer to the 1:1 line). This is mainly due to warmer water at Sapir, whereas no major difference was found between water surface temperatures at Ein Gev for the two periods. In fact, the water surface temperature was exceptionally low in 1992, resulting from the effect of the Jordan River inlet, as noted earlier.

Considering mean daily wind speed (Fig. 9d), the basic trend found in 1992, namely, higher values at Sapir, was also valid in 1993. However, as can also be seen from Fig. 8, the drop in the wind velocity between the two shores was smaller in 1993. This is mainly because of weaker winds at Sapir during that summer, whereas no major changes in the wind speed distribution at Ein Gev between the two periods were monitored. The drop in westerly wind speed between the western and eastern shores is a well-accepted characteristic of the lake microclimate. It has been observed (Serruya 1975) and simulated by mesometeorological models applied to the lake region (Alpert et al. 1982; Mahrer and Assouline 1993).

The hourly mean of the evaporation rates measured by the ECS, for times of the day when the local wind direction at Ein Gev were favorable for this study (i.e., 210°–330°) are depicted in Fig. 9e. Two main features are apparent: (i) in general, the evaporation rates at both sites were lower in 1993 than in 1992. This is due mainly to the lower wind speeds in 1993. (ii) The evaporation rates at the Ein Gev site were higher than those at the Sapir site in 1993, while lower rates at Ein Gev were observed in 1992. With respect to air temperature and relative humidity, this reflects the opposite relationship that characterized the comparison between the two sites for the two consecutive summers seasons. Analysis of the data shows that the episodes characterized by higher evaporation rates in Ein Gev correspond to periods of (a) moderate to strong wind speeds of the same intensity at the two sites; (b) unstable thermal stratification at both the eastern and western shores (the eastern shore characterized, in general, as being more unstable); and (c) higher air temperatures at Ein Gev.

4. Conclusions

The analysis of measured meteorological, heat, and moisture flux data at two locations at Lake Kinneret, Israel, during two consecutive summers show that different factors acting at different timescales shape the spatial and temporal variability of these components. The spatial variability seems to be most affected by factors resulting from analyzing the data hourly (i.e., wind dynamics; physical processes involving mass and energy exchanges during airflow over a water surface; and channeling effects resulting from specific microtopography). The temporal variability is affected by a wider range of timescales (i.e., short term, hourly basis, diurnal meteorological processes such as the sea breeze and mountain and valley flows; and long-term effects—numbers of days—influenced by synoptic systems affecting the regional climate, such as during sharav conditions). From a quantitative point of view, these sources of variability are far from being negligible. When the mean evaporation rate from the entire lake is assumed to be equal to that evaluated at a specific site, the resulting error might be as large as 100% on the daily basis and of 15% on the seasonal basis. Therefore, in order to obtain a more accurate evaluation of the mean evaporation, it is necessary to account for most of the dominant factors leading to spatial and temporal variability. We assume, then, that as a basic approach, a three-dimensional numerical, mesometeorological model that addresses the physical aspects of

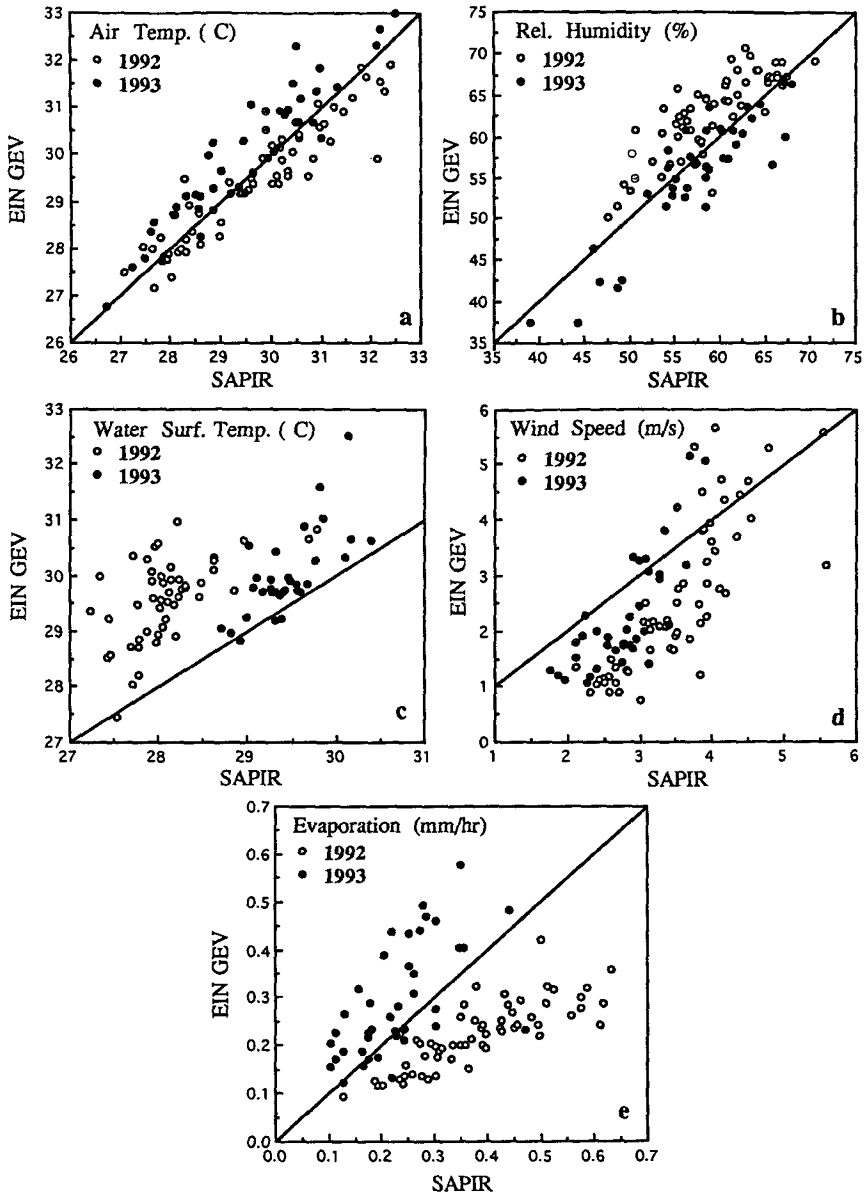

FIG. 9. The relationship between the means daily values at Ein Gev and the corresponding values at Sapir for the summers of 1992 (circles) and 1993 (points): (a) air temperature; (b) relative humidity; (c) water surface temperature, (d) wind speed, and (e) evaporation rates.

airflow, diurnal meteorological processes, microtopography effects, and synoptic conditions should be applied. On a practical basis, and considering the case of Lake Kinneret, datasets from different sites should be used to calibrate and validate a mesoscale model to the lake region. Then, the model would become an integral part of the evaporation monitoring system, supplying predicted temporal and spatial variability of the evaporation rates over the lake that could in turn be used to evaluate the total loss of water from the entire lake surface more accurately.

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REFERENCES

Alpert, P., A. Cohen, J. Neumann, and E. Doron, 1982: A model simulation of the summer circulation from the eastern Mediterranean past Lake Kinneret in the Jordan valley. *Mon. Wea. Rev.*, **110,** 106–118.

Assouline, S., 1993: Estimation of lake hydrologic budget terms using the simultaneous solution of water, heat and salt balances and a Kalman filtering approach—Application to Lake Kinneret. *Water Resour. Res.,* **29,** 3041–3048.

——, and Y. Mahrer, 1993: Evaporation from Lake Kinneret. Part A: Eddy correlation system measurements and energy budget estimates. *Water Resour. Res.,* **29,** 901–910.

Bolsenga, S. J., 1975: Estimating energy budget components to determine Lake Huron evaporation. *Water Resour. Res.,* **11,** 661–666.

Bowen, I. S., 1926: The ratio of heat losses by conduction and by evaporation from any water surface. *Phys. Rev.,* **27,** 779–787.

Derecki, J. A., 1981: Operational estimates of Lake Superior evaporation based on IFYGL findings. *Water Resour. Res.,* **17,** 1453–1462.

Keijman, J. Q., 1974: The estimation of energy balance of a lake from simple weather data. *Bound.-Layer Meteor.,* **5,** 399–407.

Mahrer, Y., and S. Assouline, 1993: Evaporation from Lake Kinneret. Part B: Estimation of the horizontal variability using a two-dimensional numerical mesoscale model. *Water Resour. Res.,* **29,** 911–916.

Neumann, J., and G. Stanhill, 1978: The general meteorological background. *Monogr. Biologicae,* Vol. 32, Junk Publishers, 49–58.

Rosenberry, D. O., A. M. Sturrock, and T. C. Winter, 1993: Evaluation of the energy budget method of determining evaporation at Williams Lake, Minnesota, using alternative instrumentation and study approaches. *Water Resour. Res.,* **29,** 2473–2483.

Serruya, S., 1975: Wind, water and motions in Lake Kinneret. *Verh. Int. Ver. Limnol.,* **19,** 73–87.

——, 1978: The physical environment. Part C. Water motions. *Monogr. Biologicae,* Vol. 32, Junk Publishers, 167–171.

Stanhill, G., and J. Neumann, 1978: Energy balance and evaporation. *Monogr. Biologicae,* Vol. 32, Junk Publishers, 173–181.

Stannard, D. I., and D. O. Rosenberry, 1991: A comparison of short-term measurements of lake evaporation using eddy correlation and energy budget methods. *J. Hydrol.,* **122,** 15–22.

Sturrock, A. M., T. C. Winter, and D. O. Rosenberry, 1992: Energy budget evaporation from Williams Lake: A closed lake in north central Minnesota. *Water Resour. Res.,* **28,** 1605–1617.

Winter, T. C., 1981: Uncertainties in estimating the water balance of lakes. *Water Resour. Bull.,* **17,** 82–115.