Evaporation and seasonal temperature changes in lakes of the Iberian Peninsula

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SUMMARY

The present study aims at estimating seasonal changes of temperature in idealised lakes (lagoons) of the Iberian Peninsular and of the evaporation from the lake surface. The sensitivity of the annual temperature cycle and of the evaporation to climatological changes is examined. To this end, two one-dimensional fresh-water lake models are applied. A series of numerical experiments is performed for lakes that differ in terms of their mean depth. The models are forced with the meteorological data from the ECMWF ERA-40 reanalysis. Results from simulations are compared with observational data. A comparison shows that both models are able to simulate the annual cycle of temperature in lakes of varying depth and to predict the evaporation rates with a fair degree of realism. Analysis of the evaporation rates over an idealised grid box of a general circulation model that is partially covered by lakes suggests that the effect of sub-grid scale lakes should be taken into account.

1. INTRODUCTION

Lakes significantly affect the structure of the atmospheric surface layer and therefore the surface fluxes of heat, water vapour and momentum. This effect has not been systematically studied so far and is poorly understood. In most numerical models used for weather prediction, climate studies and for other environmental applications, the effect of lakes is either entirely ignored or is parameterised very crudely. General circulation models (GCM) usually do not account for the effect of small sub-grid-scale lakes. For larger lakes, that are grid-scale features in GCMs, the lake surface temperature is typically prescribed as a monthly-mean climatology.

In the present work, we apply two fresh-water lake models, FLAKE (Mironov et al. 2003, Mironov 2005, http://nwpi.krc.karelia.ru/flake) and LAKE (Stepanenko and Lykosov 2005), to simulate the annual temperature cycle in lakes (lagoons) in the Iberian Peninsula and to estimate the evaporation rates over an idealised GCM grid box partially covered by lakes. We examine the sensitivity of the model results to the atmospheric forcing and to the mean lake depth. The evaporation rates predicted with FLAKE and LAKE are compared with those predicted with the land surface model TESSEL (ECMWF land surface model), where a monthly mean climatology is used for the lake surface temperature. This comparison helps to estimate the effect of lakes on the total evaporation over a GCM grid box.

2. THE MODELS

The lake model FLAKE is a bulk model capable of predicting the surface temperature in lakes of various depths on time scales from a few hours to a year. FLAKE is based on a two-layer parameterisation of the temperature profile, where the structure of the stratified layer between the upper mixed layer and the basin bottom, the lake thermocline, is described using the concept of self-similarity (assumed shape) of the evolving temperature profile. The same concept is used to describe the interaction of the water column with bottom sediments and the evolution of the ice and snow cover. In order to compute fluxes of momentum, and of sensible and latent heat at the lake surface, a parameterization scheme is used that accounts for the specific features of the surface air layer over lakes.

The model LAKE computes the one-dimensional structure of the lake properties by solving partial differential equations (in depth and time) on a finite-difference grid. The main physical processes described by the model are the heat and moisture exchange at the surface, the phase transformations (water-ice), the gravitational infiltration of water in snow and soil, and the drift currents.

The land surface model TESSEL (Van den Hurk et al. 2000) has four prognostic layers in the soil for temperature and water, with free drainage and zero heat fluxes as the bottom boundary conditions. The model is used in offline mode to calculate the land surface response to the atmospheric forcing. TESSEL also calculates the surface fluxes over sea (or lake) by prescribing the sea (lake) surface temperature as a monthly mean climatology.

3. ATMOSPHERIC DATA

The ERA-40 reanalysis data (Uppala et al. 2005) are used to force the lake models over the period from 1990 to 2002. Data from the grid-point nearest to the Monte Novo lagoon (38º42’ N, 7º30’ W) are used. The meteorological data include air temperature, wind speed and specific humidity form the first model level; the surface pressure, and the downward fluxes of the long-wave and of the short-wave (solar) radiation. The wind speed recorded at the heights of 2 metres and of 6 metres above the underlying surface over the period from 13.10.1997 to 31.12.2002 at the Portel station (near the Monte Novo lagoon) was used to validate and correct the ERA-40 wind. The observed 10-metre wind was calculated from the winds at 2 metres and at 6 metres using the logarithmic wind profile.

Figures 1 and 2 compare the monthly-mean diurnal cycle of 10-m temperature and of 10-m wind from ERA-40 and from observations. The ERA-40 temperature data are in good agreement with observations. A considerable difference between the observed 10-m wind speed and that from ERA-40 is evident from Figure 2, the ERA-40 wind being underestimated. Using this difference in wind speed and considering that the evaporation rate (typically) increases with the increasing wind speed, we have generated three different forcing scenarios, namely,

- ERA-40 with its original 10-m wind,
- ERA-40 with the 10-m wind corrected to best fit the observed monthly-mean diurnal cycle at the Portel station (bias corrected wind), and
- ERA-40 with the 10-m wind corrected to best fit the observed monthly diurnal mean wind at the Portel station (bias correct wind with no diurnal cycle).

From the ECMWF land use data, we have retrieved the information on the lake fractional coverage for each grid-box of the ERA-40 reanalysis. The grid-point considered here appears to have 3.2% of its area covered by lake water. This lake fraction of the grid-box is used to estimate the effect of lakes on the grid-box mean evaporative rate. In order to assess this effect, we have run TESSEL and FLAKE with the same forcing. The grid-box mean evaporation rate is then computed as the weighed-mean of evaporation rates computed by TESSEL and by FLAKE, using the land area fraction and the lake area fraction as the respective weights.

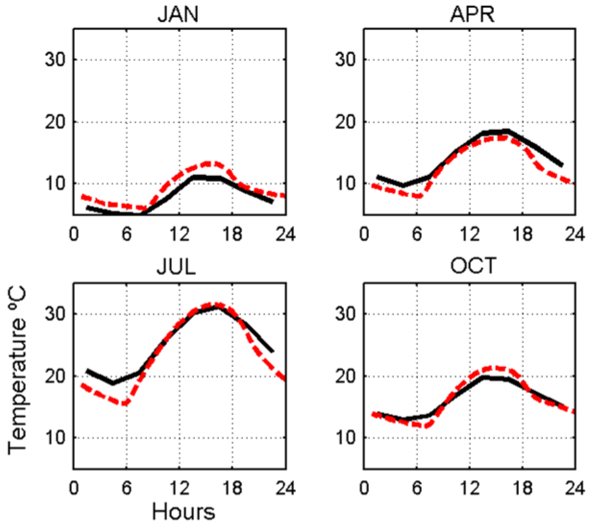

Figure 1. Monthly mean diurnal cycles of 10-m air temperature from ERA-40 (solid lines) and from the observations at the Portel station (dashed lines).

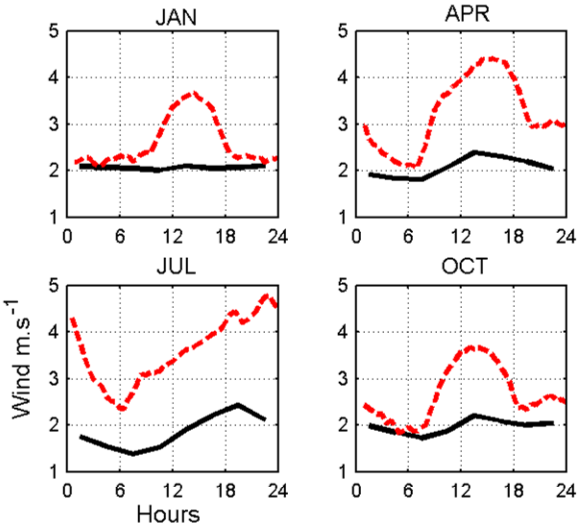

Figure 2. Monthly-mean diurnal cycle of 10-m wind speed from ERA-40 (solid lines) and from the observations at the Portel station (dashed lines).

Data on the water temperature measured at 0.5 to 1 metre below the water surface in the Monte Novo lagoon are the only data used to validate FLAKE results. Since the model results are sensitive to the lake depth, 17 FLAKE runs are performed with the lake depth ranging from 6 m to 14 m 0.5 m apart.

4. RESULTS

Figures 3 and 4 show the water temperature just below the surface computed with FLAKE versus observations in the Monte Novo lagoon. As Figure 3 suggests, the water temperature is systematically overestimated during summer in the ERA-40 forcing with its original wind is used. This is in contrast with Figure 4, where the model results obtained with the bias corrected show a better agreement with empirical data. This suggests that realistic estimates of wind speed are required to correctly simulate the lake temperature. The result is not unexpected as the wind speed strongly controls the mixed-layer depth and hence its temperature. During winter, FLAKE tends to slightly underestimate the near-surface water temperature. With both forcing scenarios, the amplitude of temperature variations on the diurnal time scale reaches 4 K, which is likely to have a significant impact on the daily-mean surface fluxes. A comparison of Figures 4 and 5 shows that FLAKE and LAKE responds to the atmospheric forcing in a similar way and simulate similar seasonal temperature cycles.

The sensitivity of the lake temperature distribution in the seasonal cycle to the lake depth, as computed by FLAKE forced with the ERA-40 with original and bias corrected wind, is illustrated in Figures 6 and 7. The lake is well mixed during most of the winter. During summer, the water column is strongly stratified except for the upper mixed layer that is 2-3 metre deep. Notice peculiar patterns of the temperature distribution in Figures 6 as the lake depth is about 10 m.

The effect of enhanced wind speed on the evaporation rate is illustrated in Figure 8, indicating that the use of a bias corrected wind increases the evaporation rate by about 13% (compare solid and dotted lines in both panels). The inter-annual variability of evaporation (a result of inter-annual variations in the ERA-40 forcing) is reduced. The evaporation computed with TESSEL for the grid-box, whose area is of the type “land”, is about 55% smaller than the evaporation computed with FLAKE, especially during summer and autumn. This is due to a reduced soil water availability in summer. Larger values of evaporation during 1996 – 1998 are related to an increased precipitation and a consequent increase of the soil water availability.

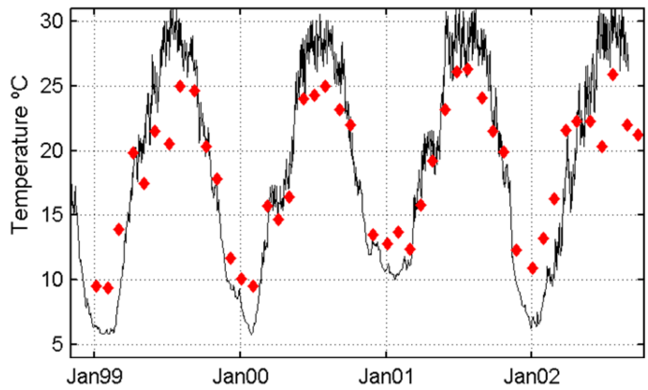

Figure 3. Time series of lake temperature computed with FLAKE (line) vs. observations (points). The water temperature at the Monte Novo lagoon was measured at the depth of 0.5 to 1 m below the lake surface. FLAKE was run over the period from 1990 to 2002 using the ERA-40 forcing. FLAKE temperature at 0.75 m below the lake surface is the result of averaging over 17 runs with the lake depth ranging from 6 m to 14 m 0.5 m apart.

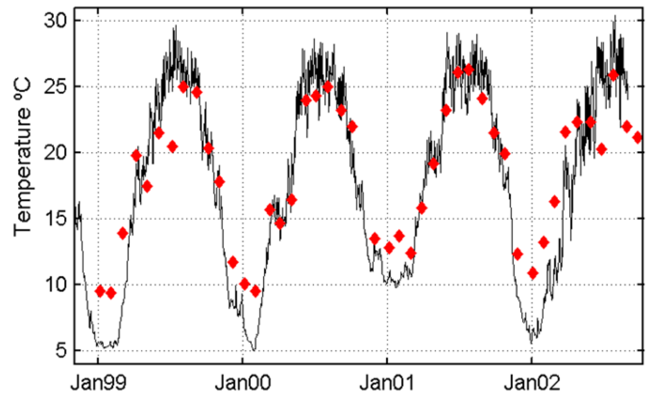

Figure 4. Same as in Figure 3 but FLAKE was forced with the bias corrected wind.

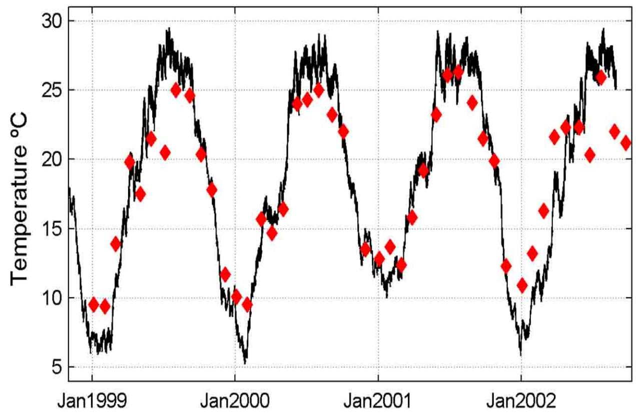

Figure 5. Same as in Figure 4 but the line is computed with the model LAKE and is a result of a single run for the lake whose depth is 10 m.

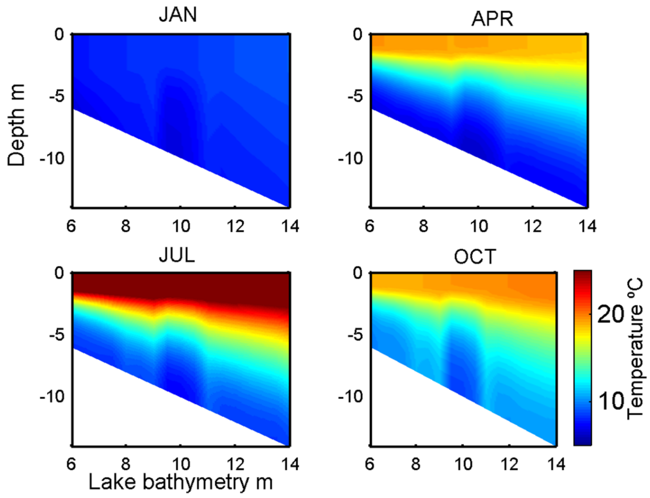

Figure 6. Monthly-mean lake temperature versus depth as computed with FLAKE using the ERA-40 forcing. Plots are the results of averaging over the period from 1990 to 2002. The x-axis indicates the lake depth, ranging from 6 m to 14 m.

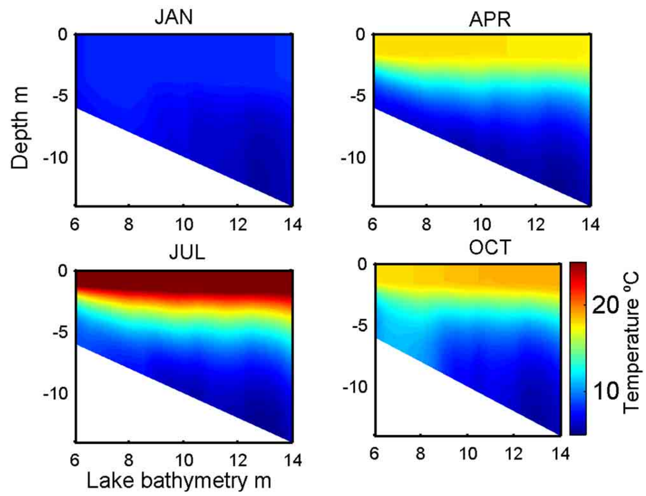

Figure 7. Same as in Figure 6 but the temperature distributions are computed with FLAKE using the bias corrected wind.

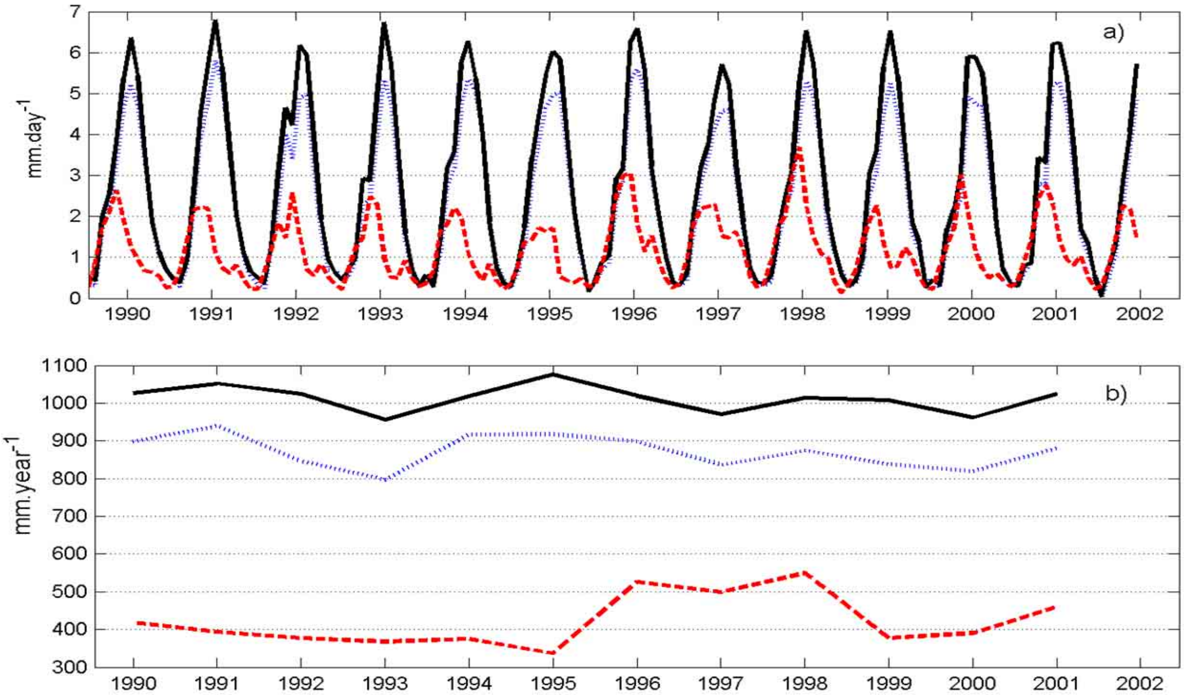

Figure 8. Monthly-mean values of the evaporation rates in mm per day (a) and the annual mean values of evaporation (b). Dotted lines show the evaporation computed with FLAKE and the ERA-40 forcing data. Solid lines show the results of FLAKE computations with the bias corrected wind. Dashed lines show the evaporation computed with TESSEL that is forced with the ERA-40 data.

Figure 9 illustrates the effect of wind speed on the diurnal cycle of evaporation. The use of bias corrected wind leads to pronounced diurnal variations of the evaporation rate. This should strongly affect the structure of the atmospheric surface layer and hence the surface fluxes of heat and momentum. The evaporation rates computed with the model LAKE (not shown) are similar to those computed with FLAKE.

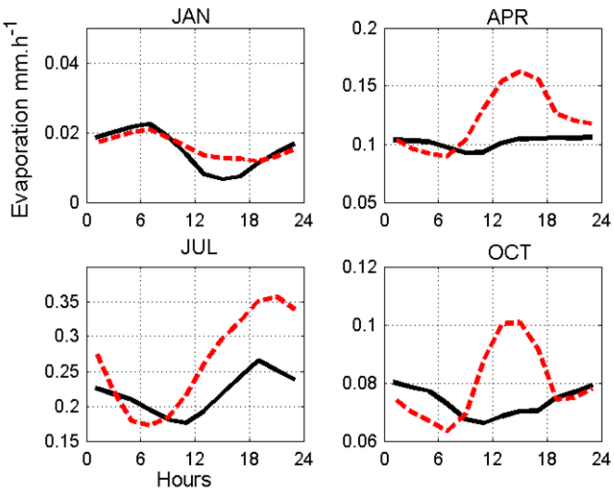

Figure 9. Monthly-mean diurnal cycle of evaporation rate. Solid lines show the evaporation rates computed with FLAKE forced with the ERA-40 data. Dashed lines show evaporation rates computed with the bias corrected wind. Plots are the results of averaging over the period from 1990 to 2002.

Table 1 summarizes the annual-mean evaporation computed with LAKE, FLAKE and TESSEL. The numbers are the result of averaging over the period from 1990 to 2002. TESSEL (sea) treats the grid-box as a sea point, prescribing the water surface temperature from FLAKE runs as annual monthly mean. TESSEL (land) treats the grid-box as a lad point. The last line, TESSEL+FLAKE, represents an estimate of the annual-mean evaporation if FLAKE and TESSEL are used together, with the former providing the evaporation over the lake surface and the latter providing the evaporation over the land surface, and the grid-box mean evaporation being computed as 0.968*TESSEL+0.032* FLAKE. The percentages in bold indicate the increase in evaporation with respect to TESSEL (land).

Table 1. Annual-mean evaporation computed with different models and with different forcing scenarios. A – ERA-40, B-ERA-40 with the bias corrected wind, C – ERA-40 with the bias corrected wind with no diurnal cycle.

	A Evap. (mm.year^{-1})	B Evap. (mm.year^{-1})	C Evap. (mm.year^{-1})
LAKE	884	987	982
FLAKE	871	1012	997
TESSEL (sea)	1064	1079	1078
TESSEL (land)	425	426	426
TESSEL+FLAKE	439 **(+3,4%)**	445 **(+4,5%)**	444 **(+4,4%)**

Differences between the column A and the columns B and C quantify the sensitivity of evaporation to the wind speed. For LAKE and FLAKE, the annual-mean evaporation increases for the forcing scenarios B and C, the increase being nearly linear in the wind speed. The run with TESSEL as a sea point shows the importance of a lake model. A prescribed water surface temperature does not seem to be a good approximation to the actual temperature. The diurnal to seasonal temperature changes considerably affect the evaporation on these time scales. It should be recalled that the prescribed sea (lake) surface temperature used in TESSEL was obtained from FLAKE, as an annual monthly mean, an approach that would not have been generally available for sub-grid scale lakes.

5. CONCLUSIONS

The lake model FLAKE proves to realistically predict the evolution of the lake surface temperature on the annual time scale. It responds to the atmospheric forcing in a similar way as a more sophisticated model LAKE. Estimates of the evaporation rates are sensitive to the wind speed. A reliable estimate of wind speed is necessary to obtain a reliable estimate of the evaporation rate. The FLAKE results significantly depend on the mean lake depth. This should be considered when modelling a specific lagoon. At Iberian latitudes, evaporation from the lake surface should be accounted for, especially in summer, when estimating mean evaporation rates over a GCM grid box partially covered by lakes. The main reason is that the evaporation from the land surface is limited by the water availability whereas the evaporation from the water surface is not.

Future work should include a thorough validation of FLAKE and LAKE in offline mode as well as the two-way coupling of FLAKE/LAKE with a 3D atmospheric model in order to examine the response of the atmosphere to the presence of lakes with time-dependent surface temperature, the various feedbacks in the atmosphere-lake system, and the impact of changes in the evaporation rate on low clouds and on the boundary-layer structure.

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