Breeze effects at a large artificial lake: summer case study

Authors' responses to the Reviewer 1 comments

Maksim Iakunin[1], Rui Salgado[1], Miguel Potes[1]
miakunin@uevora.pt

[1]Department of Physics, ICT, Institute of Earth Sciences, University of Évora, 7000 Évora, Portugal

Contents

Introduction. Document structure

This document contains authors' responses to the comments of the Reviewer. The document structure is the following:

- Reviewer's comments are numbered and given in *italic font*. General, specific, and technical comments come separately.
- Authors' response follows the comment and starts after **"Response:"** with normal font.
- The text from the article itself (if some changes were done, and if it is reasonable to provide it) is typed with `typewriter font` and separated from the response with an extra blank line.
- *Technical comments and mistakes* are not numbered, and authors' response follows immediately.

Reviewed manuscript with all the corrections is given after all responses. It contains the changes and proposals of **two** Reviewers and was prepared using LaTeXdiff package for better understanding of what was added or removed.

Anonymous Referee 1

General comments

This paper studies the lake breeze effects caused by the Alqueva reservoir (Portugal), which is the largest artificial lake in Western Europe. The paper concentrates to a 3 days long modeling case study done with the Meso-NH model. Simulations are done with and without the reservoir and different kind of measurements are used to evaluate the skill of the model. The results show the existence of a lake breeze and how it influences the local areas. The paper links nicely to previous studies and support their analysis of the breeze effects. I think the paper fits in the scope of HESS and should be published after some modifications. There are some specific areas that need more analysis and modifications. The language of the manuscript should be improved as there are too many sections when the text is rather difficult to follow. I have marked some points to the "Technical corrections" section, but the list is not comprehensive. I suggest that the authors get editing help from someone with full professional proficiency in English.

Response: We thank the Reviewer for the positive comments about the text. The paper was edited very carefully and modifications and improvements were made. Below, we address every comment and explain the corresponding changes in the manuscript.

Specific comments

Comment 1

P1, line 11: Does "It" at the end of the sentence link to the lake breeze or to the Atlantic breeze system? This part is unclear without reading the text.

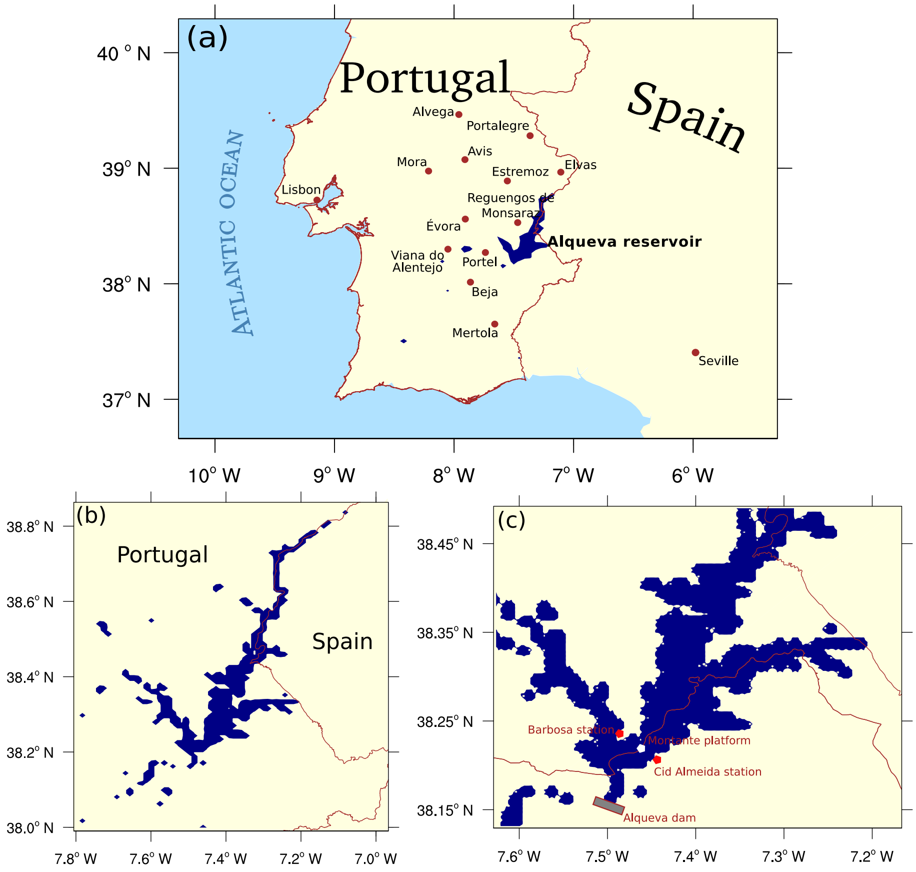
Response: Indeed, after mentioning two different breeze systems in previous sentence, `"it"` here looks confusing. To avoid this the sentence was rewritten:

`The descending branch of the lake breeze circulation brings dry air from higher atmospheric layers (2-2.5 km) and redistributes it over the lake.`

Comment 2

Figure 1: The text in the a) part is too small. Please consider saying grid boxes instead of pixels. Also, would be more informative if the pictures would actually show the grid boxes, i.e. the resolution would be more visible. The underlying map could be surface orography, like in Figure 9.

Response: Font size for towns was increased on Fig. 1 (a) as well as the figure itself was enlarged. We were trying to add some extra layer to provide more information about the domain, but in this case locations of stations become difficult to read, and this does not make figure more useful. Same problem appears if we add grid to the maps: grid points are small and lines appear to be too dense making the figure uninformative. So we decided to keep all three figures (a, b, c) in same style.



Following the suggestions of the reviewer, the caption of the figure was changed to:

`Nested domains used in the simulations: (a) Father domain at 4 km horizontal resolution with 100` × `108 grid points, with location of the 12 IPMA synoptic stations used for validation, (b) intermediate 1 km horizontal resolution domain, 96` × `72 grid points, (c) finer 250 m` resolution domain comprising 160 × 160 grid points, together with the location of the ALEX land stations, the Montante floating platform and the dam.

Pixels were replaced by grid points.

Comment 3

The units used in this manuscript seem to have slightly different font than the main text. Is there a reason for this?

Response: Indeed, the font of the units looks slightly different. The reason for this is that we used a HESS LaTeX template where indicated:

```
%%% PHYSICAL UNITS
%%% Please use \unit{} and apply the exponential notation
```

This command could make unit fonts look a little bit different.

Comment 4

P4, lines 14-15: You discuss here about the dataset (the main dataset for this work). It would be clearer to talk about "the measurement data". The modeling data is also a dataset.

Response: That is true, and we agree that speaking of measurement data we named them "main dataset" which is not correct in this context. Later we introduce the results of modeling which are part of the dataset as well as measurements. To make it clearer, section 3 was renamed to **Measurement data**, and corresponding corrections in that section was made.

Comment 5

P6, lines 15-16: This small chapter could merged with the first chapter of section 4.1. Also, you mention that ECMWF data is used at the lateral boundaries with an update frequency of 6 hours and in chapter 4.1 that the model is capable of doing multi-scale grid nesting techniques. It would be nice to know more how the simulations were really done. I would assume that ECMWF data was used only for the 4-km resolution (even then 6-hourly boundary forcing seems to be a bit coarse) and the higher resolution used some kind of nesting to this (e.g. 1-km was nested to 4-km and 250-m was nested to 1-km). If this is the case, what was the later boundary update frequency of the nests? Overall, more details about the modeling structure are needed.

Response: Agreed, this small paragraph fits better in the end of the section's **4.1** first paragraph. As for nesting technique. The model is able to conduct simulations on various spatial scales. Since we are interested in atmospheric processes in particular region on the background of some large-scale processes, we can use grid nesting. We set "father" domain to take the larger peninsular scale processes into account and put smaller "son" domain with higher spatial resolution inside. The model runs using a two-way grid nesting technique, in which the results of the simulation in "son" domain are used as a forcing back in the "father's" domain. Each "son" domain may have its own "son" domains, in Meso-NH the "depth" of nested domains is limited to eight.

ECMWF analysis are used to initialise the model and provide up-to-date information about the atmospheric conditions on the boundaries. This is working only for the "father" domain because for all "sons" domains initial and boundary conditions are calculated by the model itself. This information is interpolated from the results of the "father" domain simulation on every timestep. In this work, we use only analysis as boundary conditions and not forecasts, and ECMWF provides analysis only every six hours.

Corresponding additions were made to the paragraph:

In this work, three nesting domains were used: 400×432 km^2 domain with 4 km horizontal resolution to take into account the large scale circulations, namely the influence of the sea breeze (Fig. 1 (a)), an intermediate 96×72 km^2 domain with 1 km horizontal resolution centered at the Alqueva reservoir (Fig. 1 (b)), and a finer 40×40 km^2 domain with 250 m spatial resolution to track the small scale effects of the lake (Fig. 1 (c)). Hereinafter we denote this three domains A, B, and C correspondingly. The two-way nesting technique used in Meso-NH allows to conduct simulations on different horizontal resolutions at the same time. Domain A is a "father" domain for B, which means that simulation results on domain A are interpolated and used as initial and boundary conditions for domain B. Same scheme applies for domains B/C. European Centre for Medium-Range Weather Forecast (ECMWF) operational analyses, updated every six hours, were used for Meso-NH initialization and domain A boundary forcing.

Comment 6

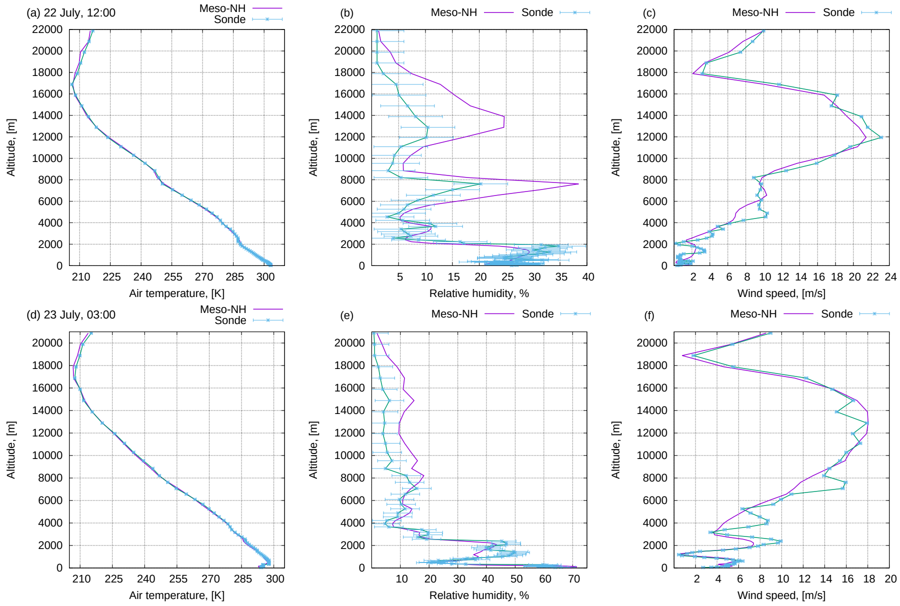
P7, line 14: Do you have a citation for value used for attenuation coefficient?

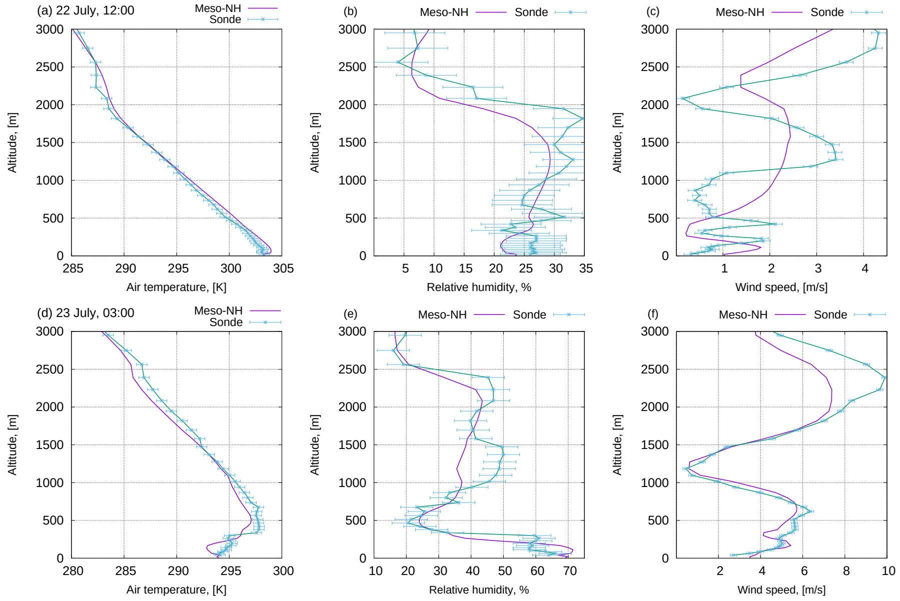
Response: Yes, thank you for noticing that. Citation was added (Potes et al., 2017).

Comment 7

P9, lines 5-6: Did you try to include the radiosonde accuracy limits in Figure 4? This could improve the plots.

Response: Yes, we tried, but it does not improve the plots. Errors in air temperature and wind speed are too small in comparison with the ranges of these variables, so errorbars in this case are not useful. As for relative humidity, it changes very rapidly in lower lower layer of the atmosphere, so errorbars only make plot less informative. You can see that on the example below:





Comment 8

P9: You mention the supplementary material, but not the numbers of the figures you are referring to. Please add these to the text.

Response: That is true, references to these figures in supplementary materials were missed. Now corresponding references were added.

Comment 9

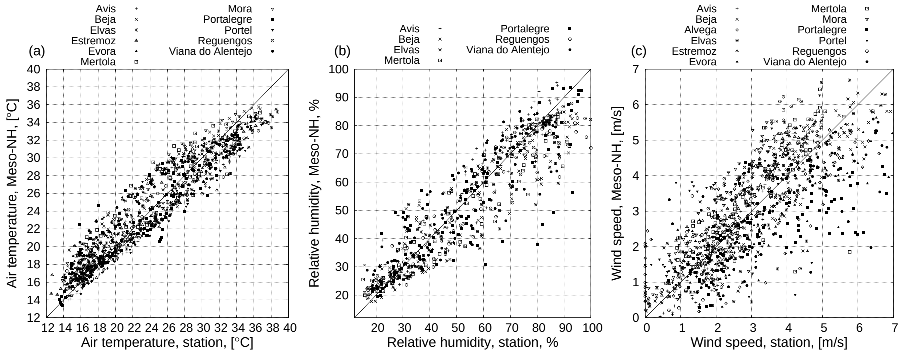
P10, lines 10-11 and P12, lines 10-11: The comparison of wind speed is interesting in Fig. 4, but what information does it bring to compare the 10-meter wind speed from the model against the measured 2-m wind speed (Figures 5 and 6)? Did you try to convert the 2-m wind speed to 10 m height (or vice versa)? You mention this possibility, but why was it not done? Comparing the same variable on different heights requires more explanation in the text.

Response: Yes, we did the interpolation of the model output data from 10 meters to 2, which slightly improved the results of the comparison (correlations and biases). Sections **5.2** and **5.3** were revised in accordance with the new results.

Comment 10

P11, Fig. 5. The text font is quite small. Please increase it.

Response: Font size of the legend and axis labels was increased, now the figure should be more readable.



Comment 11

P12, lines 14-15: Are the simulated results more smooth due to difference in plotting frequency (modeled output 1-hourly, what about the measurements? I could not find the information from page 5 for latent and sensible heat fluxes; I assume it is the same as for the variables listed in P5L1). Are the model outputs accumulated over the output frequency? What about measurements? The peak difference seems to be quite large, especially on July 22nd and there should be more discussion about this.

Response: Yes, model output data is 1-hourly, but it is not accumulated over this period. Measurements of latent and sensible heat fluxes were done with 30-minutes timestep (information about this was added to page 5, where we speak about Irgason eddy-covariance system). For the validation, measurement data was 1-hourly averaged (this applies to all data, both with 1-minute and 30-minutes timestep), so the timestep was equal. The modelled curve is more smooth for the reason that the model itself is more conservative and usually prevents variables from quick changes.

The paragraph with the discussion of fluxes comparison was expanded:

More detailed analysis of Fig 7 (a) shows that the lowest heat flux values usually occur during the afternoon (12:00 – 18:00 UTC), under windless conditions, and high peaks in the early evening (20:00 – 21:00 UTC). The simulation reproduces these peaks with 1-2 hour delay which are related to the delay on the simulated wind speed. The magnitude of the latent heat flux daily maximum (order of 200 – 250 Wm^{-2}) is well captured by the model. The delay in the simulation of the peaks reduces the value of the correlation coefficient and is a manifestation of the so-called double-penalty that penalize high-resolution model scores. As seen in the Fig. 7 (b) the simulated latent heat flux is almost zero between 14:00 and 16:00

`UTC of July 22. As pointed before, there is a gap in the measurements of the flux during this period, but data from the day before indicates that the results are realistic. This effect of almost zero evaporation from water on a very hot day is contrary to common sense and will be discussed later.`

Comment 12

P12, line 14: What are you trying to say with "Dynamic"?

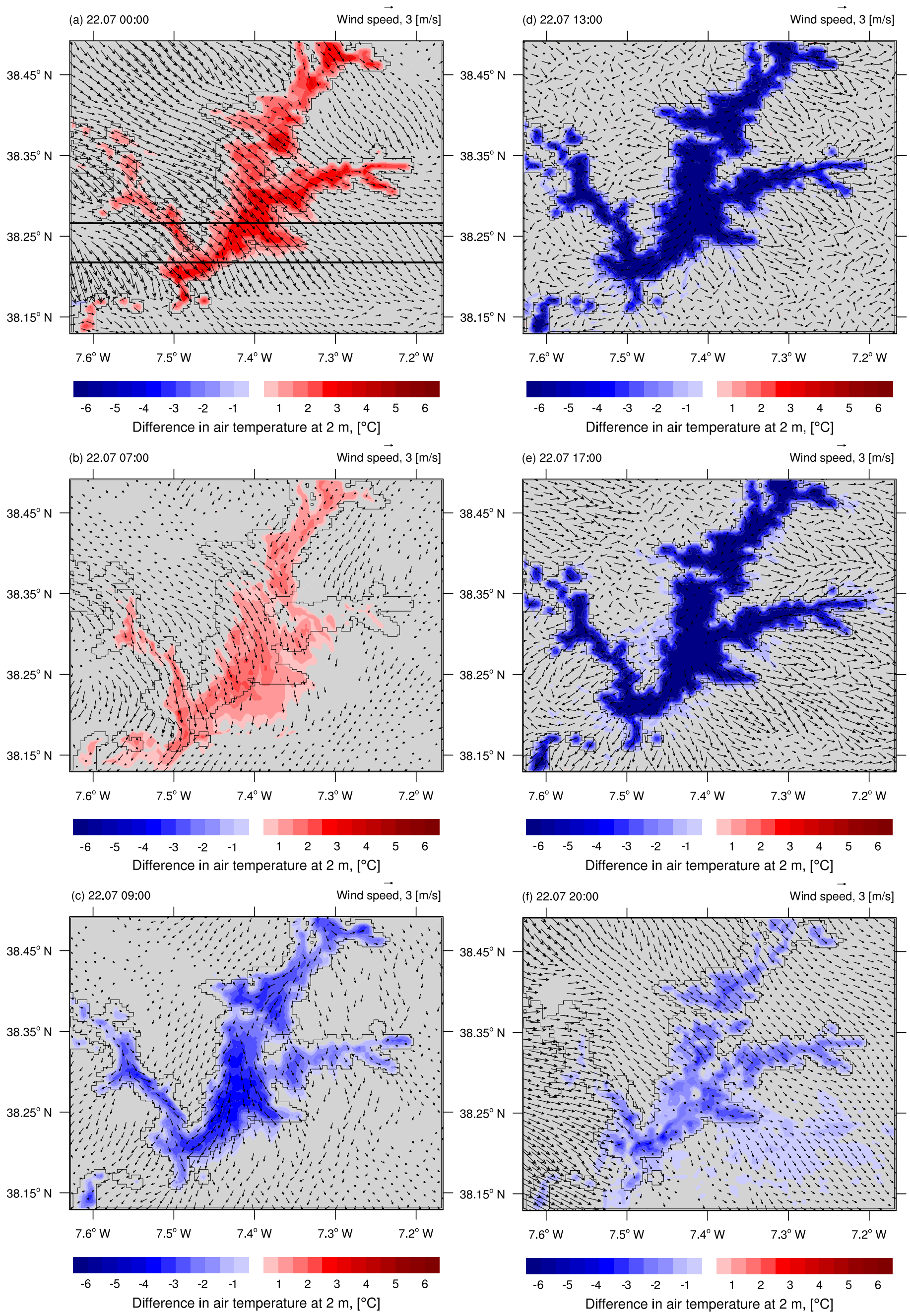
Response: In this sentence the word "Dynamic" should be interpreted as "temporal evolution". The sentence was changed to:

`The temporal evolution of simulated and observed latent and sensible heat fluxes...`

Comment 13

P16, lines 1-9 and Figure 10: Please change the colorbar scale as currently it is too coarse. Perhaps you could try using the limits -5 to 5 degrees with 0.25 degree.

Response: Colorbar stride was reduced to 0.5 and the range changed to $-6.5 \ldots 6.5$. Now the temperature anomalies are more detailed. Reducing the colorbar stride to 0.25 makes the internal structure of the thermal impact too smooth.



Comment 14

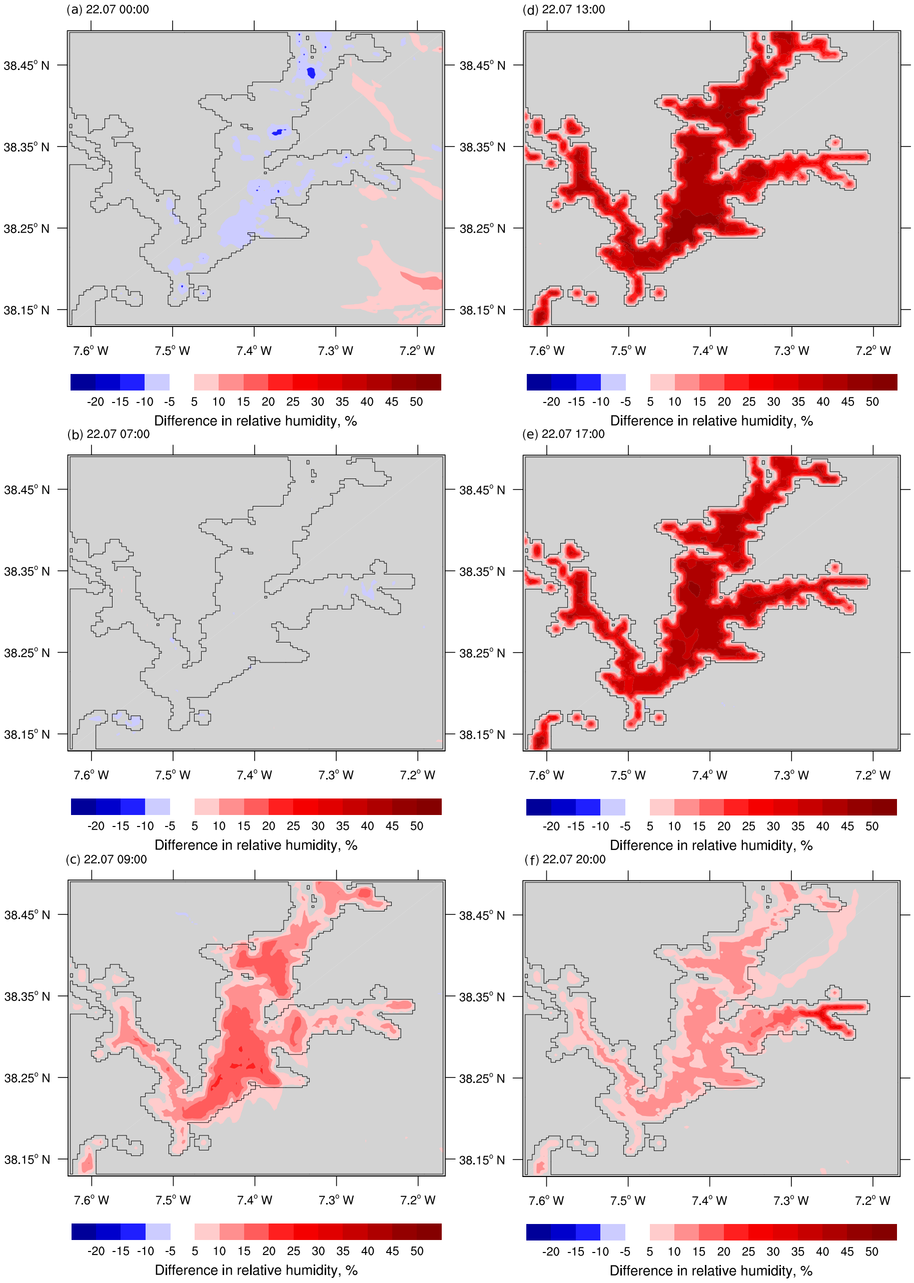
P16, line 32: You can use the word "lake" instead of "mass body".

Response: Yes, “mass body” was replaced by “lake”.

Comment 15

P17, line 34 – P18, line 2 and Fig 12: Like with Fig 10, I think you are using too coarse colorbar in your plots (-10 to 10 % difference are not shown) to see the effect of transport (and night-time differences). Please try to improve the figure in this respect and update the text accordingly.

Response: As well as in the response to *Comment 13*, colorbar was improved. Unfortunately, night-time differences are too weak to trace. Only at midnight (and at 1-2 a.m.) some negative impact can bee seen (Figure below, (a)), and its magnitude is not higher than 20%, while daytime anomalies does not differ noticeably. Corresponding updates to the article were made (section **6 Lake impact**). 5



Comment 16

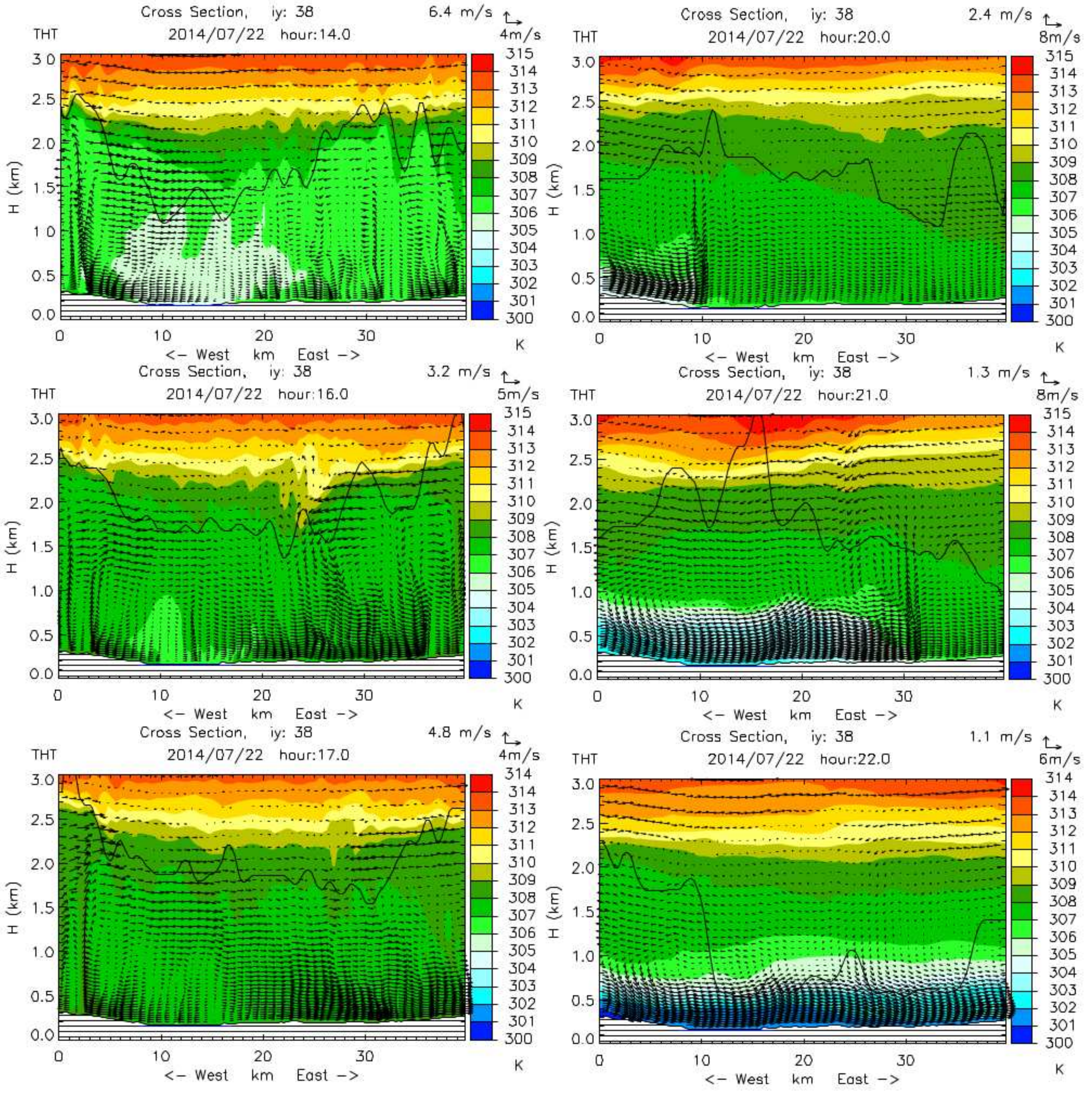
P17, Fig 12: Could you please name the cross-sections (e.g. I and II) and inform about this in the caption. Also, please refer to this naming in the text when discussing about the cross-section results. 10

Response: Yes, that makes sense. Cross-sections are named S1 and S2, and corresponding corrections and references are made in section **6 Lake impact**.

Comment 17

P18, Figure 11: Could you add to the plot the BL height as seen by the model? Please also increase the font size.

Response: In Meso-NH version 5.3.0 (which we used in this work) it is a known issue that boundary layer top is not calculated correctly. We tried to put it to the figures (as you can see on the example below), but as we are not sure of the results, we decided to keep this figure without it.



Comment 18

P18, line 9: The water vapor mixing ratio indeed has a minimum around 14:00-15:00 o'clock, but the values are higher than 7-8 g/km on July 23rd and 24th (8-9 g/kg). So the minimum values are not between 7-8 g/kg every day.

Response: True, these values were revised, and then the part of paragraph was rewritten:

This dry downstream is confirmed by the measurements of water vapor mixing ratio at the Montante platform. As can be seen in Fig. 13 the observed and the simulated mixing ratio of water vapor have a daily minimum with average values of about 8-8.5 g kg^{-1} around 14:00-16:00. During the afternoon of July 22, the day with a strong lake breeze, the minimum reached a value lower than 6 g kg^{-1}. Out of the period in which the air over the lake subsides, the water vapor mixing ratio returns beck to 9-10.5 g kg^{-1}. The presence of this dry downstream was proposed as a hypothesis by Potes et al. (2017) and is proved through the performed simulations. In the same Fig. 13 it is clearly seen that the model tends to overestimating the mixing ratio, except in the afternoon of July 22.

Comment 19

P20, line 2: Where is the dam exactly? Please mark it to the maps.

Response: The location of the dam now is mentioned in the end of the first paragraph of section **2 Object of study**:

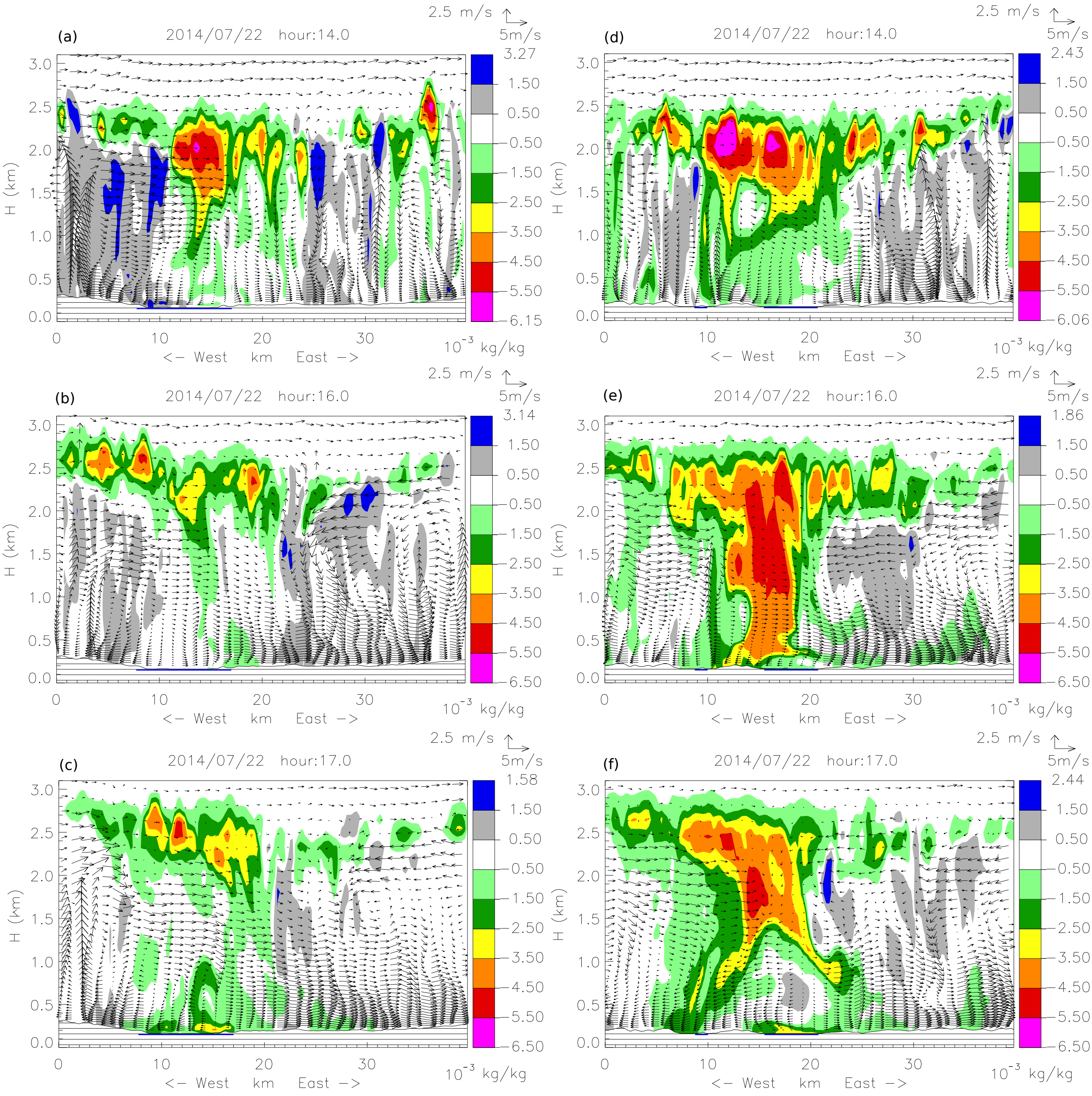
The dam is located in the southern part of the reservoir (Fig 1 (c)).

Corresponding adjustments are made in Fig. 1 (see *Comment 2*).

Comment 20

P20, Fig 13: Please increase the font size.

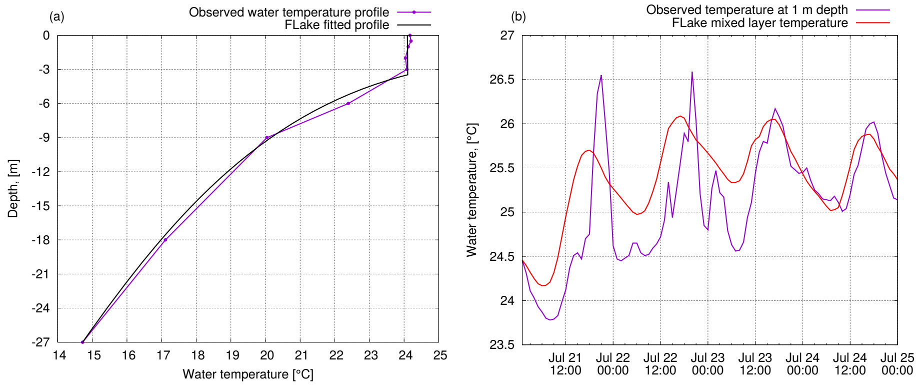
Response: Figure was enlarged:



Comment 21

Could you have done any lake water temperature (surface) comparison between the measurements and the model? Although the simulation period is short, the comparison would give some information how good your initial conditions were and how well you model the lake dynamics and the atmosphere-lake interactions.

Response: Yes, we performed this comparison. The results added to Fig. 2. Also the corresponding text added to the end of **4.2** section:



The comparison between measurements of water temperature near surface (at 1 meter depth) and FLake simulated values of mixed layer temperature are shown in Fig. 2 (b). Sensor at 1 meter depth was chosen because it always stays in mixed layer and is not affected by surface "skin" effects. Modelled values are close to measurements which indicates that the initial conditions were realistically imposed.

Comment 22

Conclusions: You list the main results of your work (basically the lake breeze effects), but I would like to see a bit more discussion about their implications.

Response: Section **Conclusions** was expanded and more comments were added:

This work is dedicated to the studies of the formation and magnitude of the summer lake breeze at the Alqueva reservoir, South Portugal, one of the impacts of the artificial lake on the local weather. The study was based on Meso-NH simulations of a well documented case study of 22-24 July 2014. This period was taken for several reasons. First, a large volume of meteorological data was collected during these days, which allowed for a validation of the simulation results. Secondly, this period was hot and dry, which is typical for most summer days in this region.

The model allowed to conduct the simulation with horizontal resolution of 250 meters which is fine enough to resolve such relatively small scale lake breeze and to spot the impact of the reservoir on the detailed local boundary layer structure. Due to the "youth" of the Alqueva reservoir it is possible to run atmospheric model with the surface conditions prevailing before the filling of the reservoir. Two simulations, one with Alqueva and another one without it, allow to evaluate the raw impact of the lake on the local weather regime.

Formation and dissipation of the daytime breeze system induced by the reservoir are described in the work. On hot summer mornings the difference between air temperatures above water and neighbouring land surfaces induces the radial movement of air from the lake. The breeze system starts to form in the morning and the peak of the wind speed reaches 6 m/s in the late afternoon. Simulation results show that the lake breeze could be detected at a distance of more than 6 km away from the the shores and on altitudes up to 300 m above water surface. In late afternoon the dissipation stage of the lake breeze system anticipated with the arrival of the larger scale sea breeze from the Portuguese west Atlantic coast. In early evening (19:00 – 20:00 UTC) the local lake breeze system can not be detected anymore. No reverse land breeze is detected during the night.

During daytime, the simulation testify the observed very low evaporation from water surface ($0 - 120$ Wm^{-2} in terms of sensible heat flux), due to weak winds and the stable stratification of the internal atmospheric surface layer. A night-time, the strong winds associated with the Peninsular larger-scale circulation induced by the sea-land contrasts, induce a very high evaporation rate ($200 - 250$ Wm^{-2}).

The cooling effect of the reservoir can decrease the air temperature up to 7 °C, nevertheless is limited by the lake borders and normally can not be seen farther than few kilometers away from the shore mostly in southeast direction. The cooling can be found up to 1200 m above the lake surface.

Lake breeze system brings dry air from upper atmospheric layers (2-2.5 km) to near surface levels above the reservoir. This effect leads to the fact that the air above the surface of the lake becomes more dry in terms of water vapor mixing ratio, in spite of its relative humidity can increase up to 50% due to the decrease in air temperature.

Further work implies two directions. The first is tuning the lake model and its initialization in order to obtain more accurate results and reduce validation biases. The second is to carry out a longer experiment, which would cover a 12-month period. Such simulation could reveal seasonal aspects of the impact of Alqueva on local weather.

Technical comments

P1, line 1: "could" to "can"
Corrected.

P1, lines 1-2: rewrite the end of the sentence starting from "but usually".
The end of the sentence was rewritten:

Natural lakes and big artificial reservoirs can affect the weather regime of surrounding areas but, usually, consideration of all aspects of this impact and their quantification is a difficult task.

P1, line 2: "lakes" to "lake"
Corrected.

P1, line 5: comma after "reservoir"
Added.

P1, line 6: here FLake scheme is used, later FLake model (e.g. P2, lines 26-27). Please be consistent with the description (model is widely used).
Corrected, now "model" is used throughout the text.

P1, line 7: "this" to "these".
Corrected.

P1, line 8: the reservoir.
Corrected.

P1, line 18: "0.35 %" to "0.35%".
Corrected.

P1, line 26: "the warm summer period" to "warm summer periods".
Corrected.

P1, line 26: ", forcing" to "leading to".
The sentence was rewritten:

`During the warm summer periods relatively colder lake surface interacts with the atmosphere above, which leads to a reduction of clouds and precipitation.`

P2, lines 3-4: Consider changing to "These regional lake effects have been seen in previous studies".
Replaced.

P2, lines 10-11: remove ", and others" and use "and" before "terrain types…".
Removed and replaced.

P2, line 12: "In this work,"
Corrected.

P2, line 14: "A first report" to "The first report".
Corrected.

P2, line 15: "as part of" to "as a part of".
Corrected.

P2, lines 16-19: The sentence starting "They concluded, " is very hard to follow. Please rewrite and make it clearer.
The sentence was split into two and rewritten:

`It was concluded that the climate impact of the multi-purpose Alqueva project should be merely due to the irrigation of surrounding area. The influence of the reservoir itself was unclear as at that time it was not possible to perform high resolution simulations.`

P2, line 20: "were done" to "was done".
Corrected.

P2, lines 22-24: Sentence starting "Later," should be improved.
The sentence was rewritten:

`Later on, Policarpo et al. (2017), used observations data from two periods of ten years (before and after Alqueva reservoir) combined with Meso-NH simulations, and showed a slight increase in the average number of days with fog during the winter (about 4 days per winter after 2003 in a downwind site)`

P2, lines 25-28: this chapter needs to be rewritten.
This paragraph was removed from the article.

P2, lines 29-33: This chapter needs also to be improved. Especially the first sentence and the end of the chapter requires some attention.
The paragraph was rewritten:

Mesoscale atmospheric models, such as Meso-NH, allow to obtain results with sufficient horizontal resolution (250 m in present study) for studying the local effects of air temperature changes and the generation of small-scale circulations under different large-scale atmospheric situations. In this work simulations have been done for the Intensive Observation Period (IOP) of ALEX project (ALqueva hydro-meteorological EXperiment, http://www.alex2014.cge.uevora.pt/). Data collected during this experiment were used to validate the numerical simulations.

P2, line 34: Is "the object of current study" really needed?
Not really. Removed.

P3, line 1: move "used in this work" after "numerical models".
Corrected.

P3, line 7: "if" to "of".
Corrected.

P4, line 5: Consider starting a new sentence with "An average annual...".
Rewritten:

The normal (1981-2010) average annual precipitation in the city of Beja (40 km from Alqueva reservoir) is 558 mm (www.ipma.pt).

P4, line 8: remove "inside it".
Removed.

P4, line 16: "has last" to "lasted".
Corrected.

P4, line 16: remove "included" and replace it with something like "was to utilize".
The sentence was rewritten:

One of the aims of this project was to perform a wide set of measurements of chemical, physical, and biological parameters in the water, air columns, and over the water-atmosphere interface.

P4, line 27: Add comma after "also".
Added.

P4, lines 30-31: Consider changing the end to "while the floating platform Montante situated

in the middle".
Changed.

P5, line 9: "has last" to "lasted".
Corrected.

P5, line 10: "have been" to "were".
Corrected.

P5, line 13: consider writing "because the atmosphere was mostly stable and anticyclonic conditions were present".
Rewritten:

This period, 22-24 July, was chosen for a case study in the this work,as it is an well documented period with typical anticyclonic conditions, hot, dry and low near surface wind speed.

P5, lines 20-21: Add the first sentence to the first chapter, i.e. remove the gap (line break).
Removed. Now it is one paragraph.

P5, line 22: please add ", and" after "precipitation".
Added.

P5, line 24: "platforms" to "platform".
Corrected.

P6, Table 1: "Deep convction" to "Deep convection".
Corrected.

P6, lines 4-6: The sentence starting with "Mixed microphysical..." should be rewritten. A suggestion: "A mixed-phase microphysical sheme...", leave out "and explicit precipitation" and add to the end "was used". The next sentence could start with "The model solves longwave and...".
Sentences were rewritten:

A mixed-phase microphysical scheme for stratiform clouds and explicit precipitation (Cohard and Pinty, 2000; Cuxart et al. 2000)) which distinguishes six classes of hydrometeors (water vapor, cloud water droplets, liquid water, ice, snow, and graupel) was used. Longwave and shortwave radiative transfer equations are solved for independent air columns (Fouquart and Bonnel, 1980; Morcrette, 1991).

P6, line 8: "exchange is controlled"?
Rewritten:

Atmosphere-surface exchanges are taken into account through physical parametrizations…

P6, lines 11-14: The end of the chapter should be improved. For example, for the 1-km and 250m domains it is better to say something like "the resolution is high enough for the deep/shallow convection to be solved explicitly" Also, the reference to Table 1 is missing the number and the

brackets are left open. The list is missing "and" from the end.
The sentence that describes domains and used schemes was rewritten:

Deep and shallow convection parametrization schemes were activated in the coarser domain A. 1-km and 250-m resolutions of domains B and C are high enough for the deep/shallow convection to be represented explicitly.

Number for the reference to the table was added, and mistakes were corrected.

P6, lines 15-16: remove "files" and ending should be improved (e.g. "for lateral boundary forcing with an update frequency of 6-hours").
Moved to another paragraph and rewritten:

European Centre for Medium-Range Weather Forecast (ECMWF) operational analyses, updated every six hours, were used for Meso-NH initialization and domain A boundary forcing

P6, line 17: "the one" to "one"
Corrected.

P6, line 19: remove "-"
Removed.

P6, line 20: "have covered" to "covered".
Corrected.

P7, line 5: "the freshwater lake..."
Corrected.

P7, line 6: "were" to "was".
Corrected.

P7, line 15: A new chapter starts so better to say "The initial parameters used in FLake are".
There are several sets of parameters that are required, so the beginning of the sentence was rewritten:

FLake model requires at least the following sets of variables and parameters to run…

P7, line 29: rewrite, a suggestion "the depth of the artificial lakes varies spatially, because".
Rewritten:

The depth of the artificial lakes varies decreases rapidly from the center to the shore, because the bottom of the reservoirs used to be valleys.

P8, lines 8: "to compare" to "analyzed".
Changed.

P8, line 10: "of" to "took place between" (and remove second "took place").

Rewritten:

The ALEX2014 IOP took place between 22 – 24 of July 2014 at the Alqueva reservoir.

P8, line 13: merge this chapter with the first one in section 5.1.
Merged.

P8, line 14: comma after "point".
Added.

P8, line 17: rewrite the end of the sentence, e.g. "22 km height; thus, to build a corresponding profile, three..."
Rewritten:

Radiosondes reached the altitude of the top of the model (about 22 km) in about 2.5 hours. Therefore in order to build the simulated profile, three consecutive hourly outputs from the model were used.

P9, line 6: "95.5 %" to "95.5%"
Corrected.

P9, line 17: "11.26 %" to "11.26%"
Corrected.

P9, line 14: "magnitude are" to "magnitude is"
Corrected.

P9, lines 11 and 15: "suplementary" to "supplementary"
Corrected.

P9, lines 15 onwards: make a real list of the statistical values ("following: temperature average bias. . ., humidity average. . ., and for the wind speeds...")
The sentence was rewritten:

Statistical results for them are the following: temperature average bias is -0.13 °C, RMSE is 1.49 °C, and correlation coefficient is 0.99; relative humidity average bias is 0.59%, RMSE is 11.26%, and correlation coefficient is 0.87; and for the wind speed average bias is 0.05 m/s, RMSE is 2.07 m/s, and correlation coefficient is 0.90.

P10, line 1: "accordance" to "accord"
Corrected.

P10, line 6: "are" is missing. Also, you could add "It should be mentioned that not all...".
Added both.

P10, line 8: "visible in" should be change to e.g. "which can be seen from".
Changed.

P10, lines 10-11: this small chapter can be merged with the previous one.
Accepted, now it is one paragraph.

P10, line 10: "100 %" to "100%"
Corrected.

P12, line 1: This seems to be a new chapter and yet you referrer to "these stations", please correct.
Rewritten:

Figure 6 shows the time evolution of simulated and observed air temperature and wind speed at Cid Almeida, Barbosa, and Montante sites.

P12, lines 23-24: Please rephrase this sentence (starting "Measurements").
The sentence was rewritten:

Wind direction at ALEX stations is represented in Fig. 8. Different behaviour in wind direction between the two station from 21 to 23 of July is clearly seen from measurements data (green dots). In Barbosa station the wind changes from northwest to south regime during daytime while in Cid Almeida this effect is not observed. In the simulations this difference is not so clear, but is still visible during the afternoon on July 22. Barbosa station, located on the northwest shore of the lake, indicates the presence of the lake breeze because its direction is the opposite to the dominant wind. However, at Cid Almeida station on the southeast shore breeze is co-directed with the dominant wind in the area, so, its appearance is difficult to track.

P15, line 1: Rephrase, e.g. "To study. . . affects the surrounding area, the following. . . were analyzed in this work:"
The paragraph was rewritten:

To analyse the impact of the Alqueva reservoir on local area the changes of the following atmospheric variables, such as air temperature and potential temperature, relative humidity and water mixing ratio, and vertical and horizontal wind speed, were considered. In this section only B and C domain datasets were used.

P15, lines 2-5: Is the sentence starting with "Overall, simulation result..." necessary?
The sentence was removed. Rewritten version of this paragraph can be found above.

P15, line 6: A comma after "During daytime" and add "the" before water temperature and air temperature.
Corrected.

P16, line 1: A new chapter and you refer with "its" to? Lake breeze should be mentioned here.
The sentence was rewritten:

The lower layers of air are the first to be affected by the presence of water.

P16, lines 12-15: Please rephrase the sentence starting with "Maximum of the temperature" It

is too long and complicated.
The sentence was split into two and rewritten:

The highest impact on the air temperature can be observed in the early afternoon (12:00 – 14:00 UTC). The boundary layer is cooling down and its height decreases from more than 2 km above the land outside to values close to 1 km over the lake surface (Fig. 10 (a)).

P16, line 22: "nighttime" to "night-time" and you could move the part in brackets to be before the comma.
Corrected:

During the night, the large-scale circulation (Fig. 9 (a), (b)), driven…

P16, line 31: A new chapter starts, where does "this" referrer to?
Corrected:

The breeze intensifies during the afternoon…

P18, line 3: use "the cross-sections"
Rewritten:

Cross-sections S1 and S2 presented in Fig. 12 show…

P18, line 9 and Fig. 14: "g/Kg" to "g/kg".
Corrected.

P19, line 3: "increase" to "increases".
Corrected.

P20, line 1: "this zones" to "These zones".
Corrected.

P20, line 5: "proeminent" to "prominent".
Corrected.

P20, Figure 13: "KG/KG" to "kg/kg"
Corrected (see *Comment 20*).

P21, line 5: "figure out" to "resolve".
Changed.

References

Breeze effects at a large artificial lake: summer case study

Maksim Iakunin[1], Rui Salgado[1], and Miguel Potes[1]

[1]Department of Physics, ICT, Institute of Earth Sciences, University of Évora, 7000 Évora, Portugal

Correspondence to: Maksim Iakunin (miakunin@uevora.pt)

Abstract. Natural lakes and big artificial reservoirs ~~could~~ can affect the weather regime of surrounding areas but~~usually it is difficult to track~~ , usually, consideration of all aspects of this impact and ~~evaluate its magnitude~~their quantification is a difficult task. Alqueva reservoir, the largest artificial ~~lakes~~ lake in Western Europe located on the ~~South-East~~ southeast of Portugal, was filled in 2004. This makes it a large laboratory and allows to study the changes in ~~hydrological and geological structures~~ the surface and in the landscape and how they affect the weather in the region. This paper is focused on a case study of ~~the~~ a 3 days intensive observation period of 22-24 July 2014. In order to quantify the breeze effects induced by Alqueva reservoir, two simulations with the mesoscale atmospheric model Meso-NH coupled to FLake freshwater lake ~~scheme~~ model has been done. The principal difference of ~~this~~ these two simulations is in the presence of the reservoir in the input surface data. Comparing two simulations datasets: with and without the reservoir, net results of the lake impact were obtained. Magnitude of the impact on the air temperature, relative humidity, and other atmospheric ~~parameters~~ variables is shown. Clear effect of a lake breeze (5-7 $\mathrm{m/s}$) can be observed during the daytime on the distances up to 6 km away from the shores and up to 300 m over the lake surface. ~~Breeze~~ Lake breeze system starts to form at 9:00 UTC and dissipates at 18:00-19:00 UTC with the arrival of ~~major Atlantic breezesystem. It induces specific air circulation that captures the~~ a larger scale Atlantic breeze. The descending branch of the lake breeze circulation brings dry air from ~~the upper atmosphere~~ higher atmospheric layers (2-2.5 km) ~~which follows the downstream and redistributes~~ and redistributes it over the lake. It is also shown that ~~the although the impact can be relatively intensive, its area is limited by several~~ despite its significant intensity the effect is limited to a couple of kilometers away from the lake borders.

1 Introduction

Human ~~activity~~activities, such as urbanization, deforestation or water reservoirs building ~~, changes surface properties~~ change the properties of the surface (vegetation cover, emissivity, albedo) which ~~determine~~ rule the surface energy fluxes (Cotton and Pielke, 2007). As a consequence, changes in surface energy fluxes affect local weather and climate. Lakes and reservoirs contains about 0.35% of global freshwater storage (Hartmann, 1994) and cover only 2% of continental surface area (Segal et al., 1997). ~~However, they play a huge societal role.~~ Thermal circulations triggered by lake/land thermal contrast have an impact on dispersion of air pollution and lake catchment transport (Lee et al., 2014). Big lakes being a significant source of atmospheric moisture can intensify storm formation (Samuelsson et al., 2006; Zhao et al., 2012). Lakes and reservoirs~~can be characterized by increased~~ , compared to land surfaces, have higher thermal inertia and heat capacity, ~~small~~ and lower albedo and roughness length~~compared to vegetated land surfaces~~ (Bonan, 1995). They can affect meteorological conditions and atmospheric processes at meso and synoptic scales (Pielke, 1974; Bates et al., 1993; Pielke, 2013).

Normally, ~~surface moisture~~ near surface relative humidity is increased while daily air temperature ~~near the surface is decreased in lake~~ is decreased above lake and shore areas. During the warm summer ~~period~~ periods relatively colder lake surface ~~balances~~ interacts with the atmosphere above, ~~forcing~~ which leads to a reduction of clouds and precipitation. Formation of the local high pressure areas over the lake surface in summer season supports atmospheric circulation, which can be observed as a lake breeze (Bates et al., 1993). In autumn and winter it has the opposite effect: due to the ~~warmer air above lake surface:~~ fact that water is warmer than the air above, increase of evaporation and cloud formation can be observed (Ekhtiari et al., 2017). These ~~lake effects on the regional climate regime find confirmation~~ regional lake effects have been seen in previous studies, e.g. Elqui Valley reservoir in Chile (Bischoff-Gauß et al., 2006) and the great African lakes (Thiery et al., 2014).

~~Despite the fact that~~ Although the theoretical aspects of formation of the lake breezes are clear, in practice, they remain not well documented. Difficulties in studies of lake breeze are due to the diversity and complexity of lake shapes and surrounding landscapes, and the ~~using of coarse spatial resolutionobservations data~~inexistence of observational data at sufficiently fine spatial resolution (Segal et al., 1997).

Lake breezes are mainly determined by ~~geophysical variables~~ the landscape and weather conditions. Formation and intensity of the breeze depend on the set of parameters such as large scale winds, sensible heat flux, geometry of the lake ~~,~~ and terrain types of the surrounding area~~, and others~~ (Segal et al., 1997; Drobinski and Dubos, 2009; Crosman and Horel, 2012).

In this work, the focus is on the study of the lake ~~of Alqueva~~ breeze at the Alqueva reservoir and its impact on atmospheric parameters of the surrounding area. This large artificial reservoir has been filled in 2004 which makes it a big natural laboratory for studying physical, chemical, and biological effects. Few studies about the influence of Alqueva on atmosphere and climate were published. ~~A~~ The first report, in Portuguese, was published even before the construction of the dam by Miranda et al. (1995), as a part of the environmental impact study of the reservoir ~~. They concluded,~~ on the basis of numerical simulations performed with the NH3D ~~model Miranda and James (1992)~~ (non-hydrostatic 3-dimensional) mesoscale model from Miranda and James (1992). It was concluded that the climate impact of the ~~the~~ multi-purpose Alqueva project should be ~~essentially~~ merely due to the ~~projected irrigation area and pay little attention to~~ irrigation of surrounding area. The influence of the reservoir itself ~~as at the~~ was unclear as at that time it was not possible to perform high resolution simulations. The studies were continued and improved by Salgado (2006) ~~in his PhD thesis, also in Portuguese, in which a~~ who did the first attempt to quantify the direct effect of the reservoir on the local climate, in particular on winter fog~~, were done~~. Using the Meso-NH (non-hydrostatic mesoscale atmospheric model) model, the author concluded that the introduction of the reservoir should increase slightly the winter fog in the ~~neighborhood~~surrounding area, but decrease over the filled area. Later on, Policarpo et al. (2017)~~used observations for two periods .~~, used observations data from two periods of ten years (before and after Alqueva ~~)~~ ~~and also~~ reservoir) combined with Meso-NH simulations, ~~showing~~ and showed a slight increase in the average number of days with fog during the winter (~~DJF), of~~ about 4 days per winter after 2003 in a downwind site~~and reinforcing previous findings.~~).

~~On the other hand, data collected in and above the Alqueva reservoir allowed the characterization of energy and mass transfers between the water and the air (Salgado and Le Moigne, 2010; Potes et al., 2012) and were used to calibrate the FLake~~

~~model (Mironov, 2008) and to validate its integration in the SURFEX platform of surface models Masson et al. (2013) used among other atmospheric models by Meso-NH.~~

~~Using a mesoscale atmospheric model~~ Mesoscale atmospheric models, such as Meso-NH~~allows to gain the~~ , allow to obtain results with sufficient horizontal resolution (~~up to~~ 250~~m) to track~~ m in present study) for studying the local effects of air temperature changes and the generation of small-scale ~~winds on the background of~~ circulations under different large-scale atmospheric ~~motions. Simulation has~~ situations. In this work simulations have been done for the Intensive Observation Period (IOP) of ~~an in-situ measurement field campaign on the lake area (ALEX2014 —~~ ALEX project (ALqueva hydro-meteorological EXperiment, http://www.alex2014.cge.uevora.pt/)~~, so it allowed~~ . Data collected during this experiment were used to validate the ~~acquired results with different datasets~~numerical simulations.

The article outline is the following. Section 2 provides a brief description of the Alqueva reservoir~~, the object of current study~~. Section 3 reveals information about ~~ALEX2014 experiment and dataset~~ ALEX experiment and the measurement data used in this paper ~~:~~ such as meteorological stations, observations, and measurements. Section 4 contains a brief description of the numerical models ~~: Meso-NH and FLake,~~ used in this work: Meso-NH and FLake. Sections 5 and 6 are dedicated to the case study on 22-24 July 2014: validation of simulation results using in-situ measurements and the studies of the lake effects respectively, with an illustration and discussion of the magnitude of the impact and intensity of a lake breeze. Section 7 summarizes the results and conclusions.

2 Object of study

Alqueva reservoir established in 2002 is an artificial lake located in the ~~South-East~~ southeast part of Portugal. It spreads along 83 km over the Guadiana river valley covering~~the total~~ , when completely filled, an area of 250 km^2 with ~~the total capacity if~~ a capacity of 4.15 km^3, which makes it the largest artificial lake in Western Europe (Fig. 1 (a)). The maximum and average depths of the reservoir are ~~92.0~~92 m and 16.6 m respectively. The dam is located in the southern part of the reservoir (Fig 1 (c)).

Alqueva reservoir is mainly used to provide water supply, irrigation, and hydroelectric power. ~~Surrounding region~~ The region where it is located is known for the irregularity of its hydrological resources, with ~~the~~ long periods of drought that could last for more than one consecutive year (Silva et al., 2014). This region ~~is characterised as Csa according to the Köppen climate classification (~~has an Mediterranean climate with dry and hot summers (Csa according to the Köppen climate classification), with a small area within of the mid-latitude steppe (BSk) category. During summer, the maximum air temperature ranges between 31 and 35 °C on average (July and August), often reaching values close to 40 °C, or even higher. The incident solar radiation ~~on the surface level~~ at the surface is of the highest in Europe, with mean daily values (integrated over 24 hours) of about 300 $\mathrm{W m^{-2}}$ and the daily maximum of July often can reach 1000 $\mathrm{W m^{-2}}$. Rainfall periods are seasonal and last from October to April~~, an~~ . The normal (1981-2010) average annual precipitation ~~registered~~ in the city of Beja (40 km from Alqueva reservoir) ~~over 1981-2010~~ is 558 mm (www.ipma.pt).

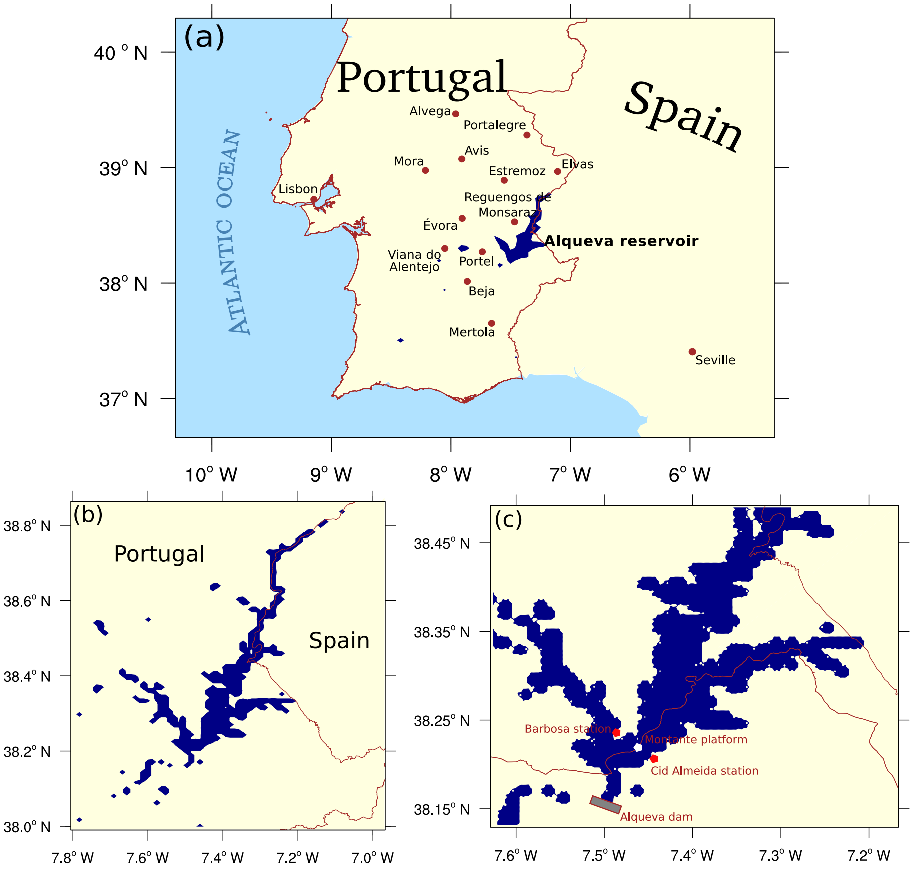


Figure 1. ~~Maps of the nesting~~ Nested domains used in the simulations: **(a)** Father domain at 4 km horizontal resolution ~~, 100×108 pixels~~with 100 × 108 grid points, with location of the 12 IPMA synoptic stations used for validation~~process ,~~, **(b)** intermediate 1 km horizontal resolution domain, ~~96×72 pixels~~96 × 72 grid points, **(c)** finer 250~~m horizontal~~ m resolution domain comprising 160 × 160 grid points, ~~160×160 pixels,~~ together with ~~ALEX2014~~ the location of the ALEX land stations~~and~~, the Montante floating platform ~~Montante location~~and the dam.

Two major factors determine synoptic circulations over the region during the summer period: the shape and location of the Azores anticyclone, and the frequent establishment of a low-pressure system over the Iberian Peninsula~~inside it~~, induced by the ~~the~~ land-ocean thermal contrasts. The sea breeze system controls the transport of the maritime air masses from the Atlantic ~~coast of the peninsula to its internal areas~~ to Iberian Peninsula, on distances more than 100 km reaching the Alqueva region in the late afternoon. This phenomenon is known as the Iberian thermal low (Hoinka and Castro, 2003) and is characterized by a westward change of the wind direction (prevailing wind directions are from the ~~North-West~~ northwest quadrant). As a result, this effect is observed in the local increase in wind intensity and in its rotation (Salgado et al., 2015).

3 ~~Dataset~~Measurement data

The ~~main dataset for this work has been~~ measured data used in this work were obtained during the ~~ALEX2014~~ ALEX campaign — a multidisciplinary observational experiment at the Alqueva reservoir which ~~has last~~ lasted from June to October 2014. ~~The aim~~ One of the aims of this project ~~included~~ was to perform a wide set of measurements of chemical, physical, and biological parameters in the water, air columns, and over the water-atmosphere interface. To reach this goal the project operated the following facilities:

- 7 sites with meteorological measurements: 2 ~~Platforms~~ platforms (Montante and Mourão); 1 permanent weather station ~~in the island~~ located in a small island nearby the dam (Alquilha), 2 dedicated weather stations (Barbosa and Cid Almeida), two compact weather stations in the Solar Park and Amieira;
- 4 floating platforms where water quality and biological sampling were done: Montante, Mourão, Captação, and Alcarrache;
- 3 weather stations of Instituto de Ciências da Terra (ICT), located in Mitra, Portel, and at the University of Évora;
- 2 Air quality mobile units: Amieira and ~~at~~ Solar Park;
- 3 Atmospheric Electricity stations: Amieira, Solar Park, and Beja.

Also, data from 42 IPMA (Portuguese Institue of Sea and Atmosphere) meteorological stations located ~~over all nearby regions~~ in the region were integrated into ALEX database. They provided ~~basic set of parameters~~typical set of variables, e.g. air temperature, relative humidity, pressure, horizontal wind speed.

Two land weather stations (Barbosa and Cid Almeida) were ~~located on the opposite shores and~~ installed on opposite shores (38.2235° N, 7.4595° W and 38.2164° N, 7.4545° W, correspondingly) while the floating platform Montante is situated in the middle (38.2276° N, 7.4708° W, Fig. 1 (c)). This ~~locaton allowed to monitor~~ locations allowed the characterization of the lake effects ~~in real time during the observations~~on a fine scale. Land stations collected ~~the following data with~~ data with an 1-minute time resolution ~~:~~ including horizontal wind speed, relative humidity, air temperature, and downwelling short-wave radiation~~, and precipitation. The floating platform Alqueva Montante~~ . Montante floating platform was the principal experimental site inside the reservoir. The following equipment was installed there ~~and collected data since~~ on 2 June 2014 and data has been collected until the end of the campaign:

- ~~Irgason~~ an eddy-covariance system which provides data for ~~:~~ pressure, temperature, water vapor and carbon dioxide concentrations, 3D wind components, momentum flux, sensible and latent heat fluxes (with 30 minutes timestep), carbon dioxide flux, evaporation;
- one albedometer and one pirradiometer in order to measure upwelling and downwelling shortwave and total radiative fluxes;
- 9 thermistors to measure water temperature profile.

The ~~most intensive observational part~~ intensive observation period of the ALEX project ~~has last~~ lasted 3 days (22-24 July) and included launches of meteorological balloons every 3 hours. ~~For that TOTEX meteorological balloons (600) were used.~~ In total, 18 radiosondes ~~have been~~ were launched: 2 from the boat over the lake and 16 from the land. Atmospheric profiles of air temperature, relative humidity, wind, and pressure were obtained~~with the use of Vaisala Radiosondes model RS92-SGP~~. This period, 22-24 July, was chosen for a case study in the this work,~~because it was a period with mostly atmospheric stability and anticyclonic conditions~~as it is an well documented period with typical anticyclonic conditions, hot, dry and low near surface wind speed.

Data collected during the ~~ALEX2014~~ ALEX field campaign have already been used to study: lake-atmosphere interactions, including the heat and mass ($\mathrm{H_2O}$ and $\mathrm{CO_2}$) fluxes in the interface water-air (Potes et al., 2017); the effects of inland water bodies on the atmospheric electrical field (Lopes et al., 2016); and the evolution of the vertical electrical charge profiles and its relation with the boundary layer transport of moisture, momentum and particulate matter (Nicoll et al., 2018).

4 Simulation setup

4.1 Meso-NH atmospheric model

~~For the study of the breeze effects of the~~ To study the lake breeze effects in Alqueva reservoir the Meso-NH model (Lac et al., 2018) was used.

Meso-NH is a non-hydrostatic mesoscale atmospheric research model. It ~~has a complete set of physical parameterizations, which are particularly advanced for the representation of clouds and precipitation, incorporates a non-hydrostatic system of equations, for dealing with~~ can simulate the evolution of the atmosphere on scales ranging from large (synoptic) to small (large eddy)~~scales while calculating budgets~~, and has a complete set of physical parametrizations. Meso-NH is coupled with SURFEX ~~(Masson et al., 2013) platforms~~ (Surface Externalisée, Masson et al. (2013)) platform of models for the representation of surface-atmosphere interactions by considering different surface types (vegetation, city, ocean, ~~lake), and~~ inland waters).

Meso-NH allows a multi-scale approach through a grid-nesting technique (Stein et al., 2000).

~~Three nesting levels were usedin Meso-NH runs~~In this work, three nesting domains were used: $400 \times 432\,\mathrm{km}^2$ domain with $4\,\mathrm{km}$ ~~spatial~~ horizontal resolution to take into account the large scale circulations, namely the influence of the sea breeze (Fig. 1 (a)), an intermediate $96 \times 72\,\mathrm{km}^2$ domain with $1\,\mathrm{km}$ ~~spatial~~ horizontal resolution centered at the Alqueva reservoir (Fig. 1 (b)), and a ~~small~~ finer $40 \times 40\,\mathrm{km}^2$ domain with $250\,\mathrm{m}$ spatial resolution to track the ~~minor~~ small scale effects of the lake (Fig. 1 (c)). Hereinafter we denote this three domains A, B, and C correspondingly. The two-way nesting technique used in Meso-NH allows to conduct simulations on different horizontal resolutions at the same time. Domain A is a "father" domain for B, which means that simulation results on domain A are interpolated and used as initial and boundary conditions for domain B. Same scheme applies for domains B/C. European Centre for Medium-Range Weather Forecast (ECMWF) operational analyses, updated every six hours, were used for Meso-NH initialization and domain A boundary forcing.

For ~~the~~ surface and orography, ECOCLIMAP II (Faroux et al., 2013) and SRTM ~~(Jarvis et al., 2008)~~ (Shuttle Radar Topography Mission, Jarvis et al. (2008)) databases were used, respectively, both updated with the ~~presence~~ inclusion of Alqueva reservoir

Table 1. Summary of the Meso-NH physical schemes used in the simulations.

Schemes and parameters	~~4-km domain~~ A	~~1-km domain~~ Domains B	~~250-m domain~~ C
Deep ~~convetion~~ convection	KAFR	NONE	NONE
Shallow convection	EDKF	EDKF	NONE
Turbulence	BL89 1 dimension	DEAR 3 dimensions	DEAR 3 dimensions
Radiation transfer	ECMW	ECMW	ECMW
Advection	WENO	WENO	WENO
Clouds	ICE3	ICE3	ICE3
Timestep	20 s	5 s	1 s

by Policarpo et al. (2017). All model domains had 68 vertical levels starting with 20 m and up to 22 km~~at the top~~, including 36 levels for the lower atmospheric level (2 km). The model configuration included ~~the~~ a turbulent scheme based on a one-dimensional 1.5 closure (Bougeault and Lacarrere, 1989). ~~Mixed~~ A mixed-phase microphysical scheme for stratiform clouds and explicit precipitation (Cohard and Pinty, 2000; Cuxart et al., 2000) which ~~distinguish 6~~ distinguishes six classes of hydrometeors (water vapor, cloud water droplets, liquid water, ice, snow, and graupel) was used. Longwave and shortwave radiative transfer equations are solved for independent air columns (Fouquart and Bonnel, 1980; Morcrette, 1991). Atmosphere-surface ~~flux exchange controlled by physical parametrisations~~exchanges are taken into account through physical parametrizations: the surface soil and vegetation are described by the Interface Soil Biosphere Atmosphere (ISBA) model (Noilhan and Mahfouf, 1996); the town energy balance was handled according to Masson (2000). Basic parameters for each model domain are shown in the Table 1. ~~4-horizontal resolution in the first domain is coarse enough to use deep~~ Deep and shallow convection ~~schemes in simulation~~parametrization schemes were activated in the coarser domain A. 1-km ~~resolution of the second domain already required deep~~and 250-m resolutions of domains B and C are high enough for the deep/shallow convection to be ~~resolved explicitly. 250-resolution is fine so both schemes can not be applicable. Used schemes~~ represented explicitly. The following schemes were used (see Table ~~are the following~~1): KAFR (Kain and Fritsch, 1990; Bechtold et al., 2001), EDKF (Pergaud et al., 2009), WENO (Lunet et al., 2017), and ICE3 (Pinty and Jabouille, 1998).

~~European Centre for Medium-Range Weather Forecast (ECMWF) operational analyses data files were used for Meso-NH initialization and lateral boundary forcing, updated every six hours.~~

To track the ~~direct~~ impact of the reservoir on the weather conditions, ~~a set of~~ two numerical simulation were performed: ~~the~~ one with the surface input files updated to ~~Alqueva reservoir presence~~ include the Alqueva reservoir (ECOCLIMAP database version updated by ~~Policarpo et al. (2017)~~Policarpo et al., 2017) and another ~~—~~with the previous version of this database where the reservoir does not exist yet. In order to distinguish these simulations hereinafter we denote them LAKE1 and LAKE0, correspondingly. Both simulations ~~have~~ covered the case study period, 22-24 July 2014, with 1 hour output. To reproduce the atmospheric conditions more ~~realistic the simulation included~~ realistically the simulations included the previous 24 hours (21 July), so ~~, overall the model covered~~ the model was integrated for 96 hours. The differences between these two simulations were then computed, with the aim of evaluating the direct influence of the ~~presence of the~~ lake on the ~~environment~~atmosphere.

4.2 FLake ~~scheme~~model

In order to ~~represent the presence and~~ better represent the evolution of the lake ~~more realistically, freshwater lake model FLake (Mironov, 2008) were~~ surface temperature and therefore the water-air heat fluxes, FLake (Freshwater Lake) model (Mironov, 2008) was used. FLake is a bulk-type model capable to predict the evolution of the lake water temperature at different depth on time scales from a few hours to many years. For ~~the~~ an unfrozen lake it uses a two-layer approach: upper mixing layer with ~~the~~ a constant water temperature ~~from the surface~~ and the thermocline ~~level~~ beneath it where the temperature decreases with depth. Parametrization of the thermocline ~~layer~~ profile is based on the concept of self-similarity assuming that such approach could be applied to all natural and artificial freshwater lakes.

~~The following parameters are required to runthe FLake model~~FLake model requires at least the following sets of variables and parameters to run: four initial parameters ~~of~~ to describe the lake temperature structure, six atmospheric ~~parameters for each calculation~~ input variables for each timestep, and two ~~constants~~ parameters — lake depth and the attenuation coefficient of light ~~into~~ in the water. This coefficient ~~represents~~ is used to compute the penetration of the solar radiation in the water body. In this work, the attenuation coefficient was set to 0.85 ~~corresponding the~~ based on in-situ measurements carried out in Alqueva by Potes et al. (2017).

~~Initial parameters~~ The FLake prognostic variables that need to be initialized are: water temperature at the bottom, temperature and depth of the mixing layer, and shape factor C_f — ~~specific~~ a parameter that describes the shape of the the thermocline curve. In the parametrization proposed by Mironov (2008) for the normalized temperature profile ~~and depth~~ it varies from 0.5 to 0.8. The initial values of the shape factor C_f, ~~temperature of the~~ a water mixing layer ~~and its~~ temperature, and depth were determined using ~~fitting technique of real~~ a fitting technique applied to the observed water temperature profile ~~data from~~ at a given time in Montante platform (Fig. 2 ~~). FLake model is~~ (a)). Short term FLake model runs are very sensitive to initial parameters~~, and this~~. The fitting technique is based on the assumption that the bottom temperature is fixed and given by the value of the lowermost sensor. Thereby, the other three parameters could vary within some range until the best set ~~of them~~ is found. The ~~set of parameters for this case study is~~initial conditions for our simulations were obtained following this technique: $C_f = 0.8$, mixed layer temperature is 23.8 °~~,~~ C and depth is 3.4 m. ~~Water temperature profile on July 21, 00:00 at Montante platform.~~ Test simulation with these set of inputs was done using stand-alone version of FLake model (not in couple with Meso-NH). The results of the comparison of water mixing layer temperature is shown in Fig. 2 (b). The maximum difference does not exceed 0.8 °C which is a very good result for such short-term simulation.

~~In view of the fact that the~~ The observed daytime temperature profiles showed strong skin effects (higher temperatures ~~of the upper (up to~~ in first 10 cm) ~~water layer)~~ and could not be ~~correctly fitted ,~~ well fitted by a FLake type temperature profile, which

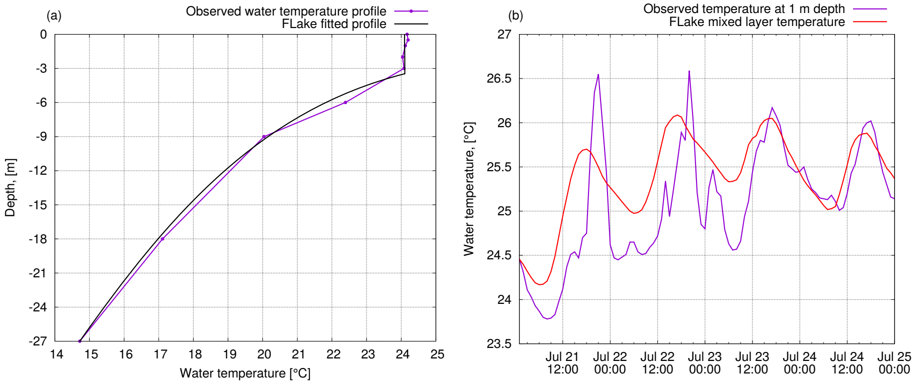


Figure 2. Water temperature observed and fitted profiles on July 21, 00:00 at the Montante platform (a) and comparison of upper level water temperature between measurements and FLake results (b)

assumes a constant temperature in the mixed layer. Thus, the midnight profile was used as an initial one and the simulation started at midnight, 21 July 2014.

~~Required atmospheric parameters: horizontal wind speed, air temperature, special humidity, longwave and shortwave downwelling radiation, and atmospheric pressure were taken directly~~ The required atmospheric variables were taken interactively from Meso-NH simulation since FLake was implemented in SURFEX model ~~(Salgado and Le Moigne, 2010)~~by Salgado and Le Moigne (2010)

~~Typically, the~~ The depth of the artificial lakes ~~characterized by strong spatial variability~~varies decreases rapidly from the center to the shore, because the ~~lake bottom of these lakes~~ bottom of the reservoirs used to be ~~a valley~~valleys. In case of Alqueva, when completely filled, the mean depth is of about 17 m (http://www.edia.pt/). On the other hand, the local depth at Montante platform can reach 70 m. As an 1D bulk model, FLake has only one depth value which should be seen as an effective depth and is not easy to assess. Moreover, FLake ~~scheme~~ model is not capable to represent deep lakes, ~~the scheme~~ it works well for depths from 20 to 50 m with the sediments routine ~~switched off~~switched-off. After a series of a sensitivity tests of short-term (2-4 days) and long-term (2-4 months) simulation it was found that the best simulations results can be obtained with the bottom depth value of 20-30 m. Thus, since the ~~last profile sensor was~~ deepest temperature probe was installed at the depth of 27 m, this value was chosen for the effective lake depth in this work. The comparison between measurements of water temperature near surface (at 1 meter depth) and FLake simulated values of mixed layer temperature are shown in Fig. 2 (b). Sensor at 1 meter depth was chosen because it always stays in mixed layer and is not affected by surface "skin" effects. Modelled values are close to measurements which indicates that the initial conditions were realistically imposed.

5 Validation

The simulation LAKE1 results were validated against radiosondes data (vertical profiles) and meteorological ~~stations data :~~ data from ALEX and IPMA ~~synoptic stations and~~ stations located on land and in the floating platforms. ~~In this process all~~ All three domains were ~~used. Size~~ considered in the validation. The size of the domain A was enough to consider 12 ~~meteorological~~

~~stations~~ synoptic stations located in the region, domain B was used to track the radiosondes trajectory, and domain C ~~data was used for the validation against stations at~~results were validated against stations installed on the lake shores and on the Montante floating platform. The ~~parameters to compare are:~~ variables under analysis were air temperature, relative humidity, wind speed, sensible and latent heat fluxes.

5.1 Comparison with radiosondes data

The ALEX ~~2014 IOP of~~ IOP took place between 22 ~~–~~and 24 of July 2014 ~~took place~~ at the Alqueva reservoir. ~~They included balloon launches~~ It included the launch of 18 meteorological balloon every 3 hours~~, and overall 18 launches have been done. Balloons radiosonde data provided~~ . The radiosondes took measurements of air temperature, humidity, pressure, and wind speed.

~~Due to the fact that the trajectory of the balloons was not vertical but resembled a spiral and balloons~~ As the balloons did not ascent vertically and flew several kilometers away from the launching point~~it was decided to make~~ , a trajectory profile comparison was performed. Each balloon had a GPS-tracker to register its coordinates every 2 seconds, which was used to build a corresponding ~~trajectory inside~~ numerical trajectory on the simulation domain. Radiosondes ~~have~~ reached the altitude of ~~≈ 35 km, but since the upper layer~~ the top of the model ~~is limited to~~ (about 22 km~~, the profiles were built up to this altitude. For sondes it took~~) in about 2.5 hours~~to reach 22 height so to build a corresponding profilethree consecutive timestep arrays of the model data~~ . Therefore in order to build the simulated profile, three consecutive hourly outputs from the model were used. ~~This comparison is done in 1 horizontal resolution domain.~~

Figures 3 (a, b, c) represent examples of the daytime profiles ~~for~~ of air temperature, relative humidity, and horizontal wind speed. Examples of ~~corresponding~~ night profiles can be found ~~on~~ in figures 3 (d, e, f). ~~All night profiles demonstrate~~ In general, the night simulated profiles show slightly better accordance with model results~~because atmosphere is more stable during the nighttime.~~ .

Figure 4 ~~represents~~ shows the same profiles, but for the lower ~~atmospheric~~ troposphere level (3000 m altitude). Simulation ~~results~~ are in good accordance with ~~measured values under the radiosonde accurace~~ observations. The simulation results are within the confidence interval of the measurements as given by the radiosonde accuracy (±0.5°C, ±5% relative humidity, and ±0.15 m/s wind speed with 2-sigma confidence level (95.5%)).

The principal features of the ~~curve profiles as well as the dynamics~~ profiles trend are well represented by the model. ~~On air temperature curves (and , to a lesser extent, on the relative humidity and wind speed curves), one can observe a characteristic fracture~~ During daytime, air temperature and relative humidity curves indicate that the model tends to well represent the height of the boundary layer at 2-2.5 km altitude ~~during daytime, which denotes the top of the boundary layer~~(around 2 km in Fig. 4 (a), (b)). Overall, Meso-NH ~~better represents air temperature in the layer from 2.5 to 10-12 , while the worst values are in the lower lever near the surface during the period of 06~~reproduces the air temperature above the surface layer (over 500 m) very well. Near surface, the Meso-NH tends to anticipate the development of the unstable boundary layer in the morning (9:00 ~~–~~and 12:00 UTC~~(presented in suplementary material~~), simulating higher temperatures in the lower levels. In the late afternoon (18:00

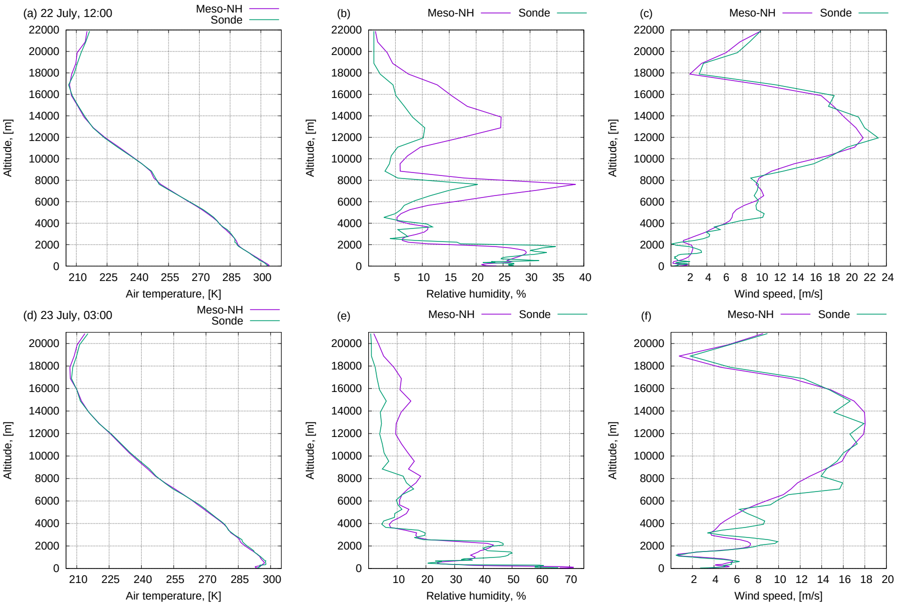


Figure 3. Examples of observed and simulated vertical profiles for July 22, 12:00 and July 23, 3:00 of air temperature (a, d), relative humidity (b, e), and wind speed (c, f).

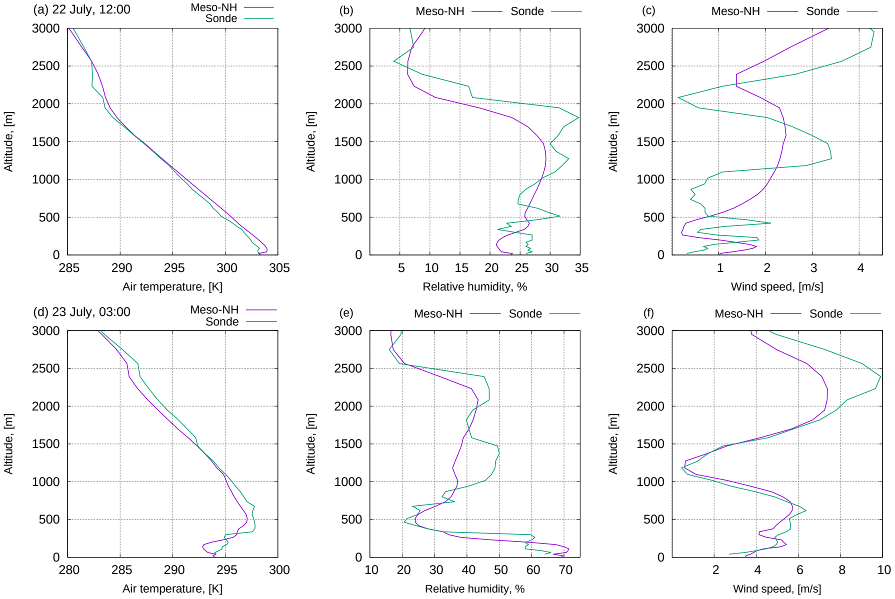


Figure 4. ~~Lower atmospheric level profiles for~~ Profiles of air temperature, relative humidity, and wind speed ~~.~~in low atmosphere on 22 July 12:00 and 23 July 03:00.

and 21:00 UTC) the model also tends to anticipate the decrease of the temperature in the surface layer (see the supplementary material, Fig. S1).

~~Patterns~~ The patterns of relative humidity and wind speed are good, as observed and modelled curves look similar, nevertheless simulations tend to be more conservative and their values do not change so quick. ~~For example,~~ Nocturnal low level jets ~~can be found on night profiles~~ at the edge of the boundary ~~level (Fig. 4 (f)). These jets~~ layer are represented by the model~~as well~~, but their magnitude ~~are~~ is slightly weaker than the observed~~values. All 18~~. All the profiles can be found in the ~~suplementary material .~~ supplementary material (Fig. S3). The moisture vertical profile in the boundary layer is well reproduced by the model, as can be seen in the graphs of the relative humidity (Fig. 4 (b), (e), and S2 in the supplementary materials). Above the boundary layer the radiosondes show a dry layer, which is also well simulated. From July 23 the observations show the appearance of a moist layer close to the troposphere, which magnitude is overestimated by the model. On July 24 at dawn the radiosondes and the model indicate the existence of a very moist layer close to the surface, with the formation of low clouds that were not formed in the simulations.

Statistical results for them are ~~following. Temperature~~ the following: temperature average bias is -0.13~~, RMSE~~ °C, RMSE is 1.49 °C, and correlation coefficient is 0.99~~. Humidity~~; relative humidity average bias is 0.59%~~RMSE of~~, RMSE is 11.26%~~and 0.87 correlation coefficient . For wind speed these values are:~~, and correlation coefficient is 0.87; and for the wind speed average bias is 0.05 m/s~~average bias~~, RMSE is 2.07 m/s, and correlation coefficient is 0.90. ~~All these values show~~ These values testify that the simulation is in a good ~~accordance~~ accord with the observations, ~~and~~ in line with similar studies of Meso-NH validation against radiosondes data (e.g., Masciadri et al., 2013).

5.2 Comparison with IPMA stations data

~~We also validated the model data~~ The model was also validated against 12 IPMA automatic meteorological stations. For this comparison ~~data of 4-domain~~ the output of the bigger domain A were used. Geographical positions of the stations can be found ~~on~~ in Fig. 1 (a). Scatter plots of air temperature, relative humidity, and wind speed ~~shown on~~ are shown in Fig. 5. ~~Not~~ It should be mentioned that not all stations provided the same set of ~~parameters. These scatter plots represent~~ variables. The scatter plots show the intercomparison of the model data (X axis) and the measured values (Y axis) over ~~the case study period~~ all the simulated period and all the stations. The model tends to overestimate lower values of air temperature (14-24 °C) and slightly underestimate higher values (>30 °C), ~~visible in~~ as can be seen from Fig. 5 (a).

~~For relative humidity the model shows lower values~~ Over some stations and in several times, the model simulates lower values of relative humidity within the range from 40 to 100% ~~. Wind speed is overestimated~~ (Fig. 5 (b)). Fig. 5 (c) indicates that the wind speed is slightly underestimated by the model~~as the output is set to 10 above the surface and measurements are at 2~~.

Statistical parameters (~~biases~~bias, mean absolute ~~errors~~error, root mean ~~square~~squar, and correlation ~~coefficients) of this comparison~~ coefficient) for each station are shown in Table 2. ~~Comparison of air temperature showed high correlation~~ Simulated and observed air temperature are highly correlated (correlation coefficient is higher that 0.91) with ~~biases absolute values lesser~~ bias always less than 1 degree. The ~~worse result~~ worst results are observed in ~~comparison against Portalegre data (see for~~

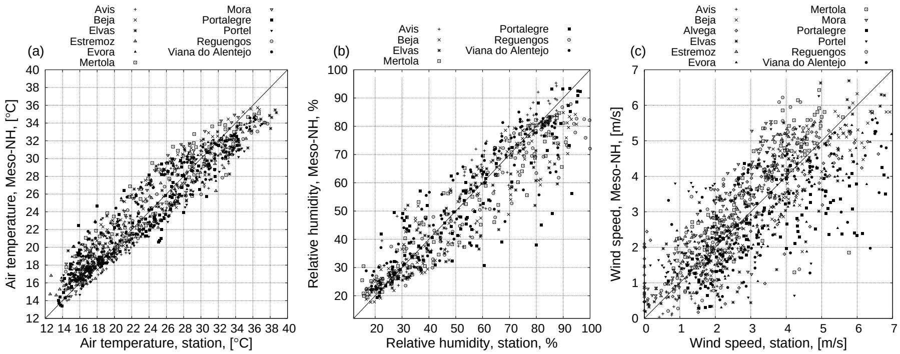


Figure 5. Scatter plots of the comparison ~~with~~ between Meso-NH sumulation LAKE1 and measured values at synoptic stations. Air temperature **(a)**, relative humidity **(b)**, and horizontal wind speed **(c)**.

Table 2. Statistics for the hourly values of the station validation.

Stations:		Alvega	Avis	Beja	Elvas	Estrem.	Évora	Mert.	Mora	Portal.
Temp., °C	Bias:	—	-0.08	0.68	-0.39	0.00	0.56	0.85	0.9	-0.08
	MAE:	—	1.49	1.60	1.76	1.65	1.60	1.71	1.54	1.82
	RMS:	—	1.84	1.96	2.18	2.02	1.96	2.20	1.93	2.38
	Corr:	—	0.95	0.96	0.96	0.96	0.96	0.95	0.96	0.91
Rel. hum., %	Bias:	—	0.53	-2.98	-3.42	—	—	-1.29	-4.19	-2.79
	MAE:	—	5.80	7.48	5.87	—	—	6.61	6.88	7.83
	RMS:	—	7.41	9.49	8.61	—	—	8.49	8.43	11.91
	Corr:	—	0.93	0.93	0.93	—	—	0.94	0.94	0.86
Wind speed, m/s	Bias:	~~0.49~~ -0.46	~~0.31~~ -0.34	~~0.17~~ -0.16	~~0.07~~ -0.09	~~0.89~~ -0.91	~~-0.36~~ 0.27	~~1.08~~ -1.11	~~1.19~~ -1.09	~~-0.66~~ 0.53
	MAE:	~~0.91~~ 2.33	~~0.60~~ 0.26	~~0.60~~ 0.22	~~0.74~~ 0.88	~~0.97~~ 1.28	~~0.80~~ 0.44	~~1.25~~ 0.74	~~1.30~~ 1.19	~~1.05~~ 0.68
	RMS:	~~1.15~~ 1.01	~~0.77~~ 0.73	~~0.77~~ 0.74	~~0.99~~ 1.01	~~1.11~~ 0.69	~~1.01~~ 0.94	~~1.42~~ 0.93	~~1.52~~ 0.93	~~1.36~~ 1.12
	Corr:	0.85	0.92	0.91	0.86	~~0.93~~ 0.92	0.82	~~0.82~~ 0.81	~~0.84~~ 0.85	~~0.65~~ 0.68

~~example the~~ Portalegre (square points in relative humidity plot ~~on~~ in Fig. 5 (b))~~: this station is located~~, and a possible reason for this relies on the location of the station which is installed in small mountain area~~which makes the meteorological situation more difficult to predict. Validation of~~. Regarding the wind speed~~shown the~~, Table 2 shows small biases, in general lower than 1 m/s, and relatively high correlation coefficients for wind simulations (0.68 - 0.92). The lowest correlation coefficient ~~(0.65 in Portalegre, 0.82 average) due to its high variability over time~~is also obtained in Portalegre. Overall, simulation results are in good agreement with synoptic stations data~~. Other works represent the similar results of~~, and the statistical parameters are similar to other published works done with Meso-NH~~validation against data from meteostations~~ (e.g., Lascaux et al., 2013, 2015).

5.3 Comparison with data from ALEX ~~Lake platform and stations~~database

In addition to the validation against the IPMA synoptic stations, comparisons were made with data obtained at ~~ALEX2014 dedicated stations : Montante platform (38.2235° N, 7.4595° W) and two stations: Cid Almeida~~ ALEX stations (~~38.2164° N, 7.4545° W) and Barbosa (38.2276° N, 7.4708° W) (Fig. 1 (c)). These~~ Barbosa, Cid Almeida and Montante platform). Their coordinates were used to locate ~~the stations on the 250-output. Another criteria which was used for this was water fraction variable: land stations can not be found over the water , so the nearest land grid-point was used~~corresponding grid points on the C domain output. In the case of land stations with grid point associated to water fraction, the nearest land grid point was chosen.

Figure 6 ~~represents the evolution in time of~~ shows the time evolution of simulated and observed air temperature and wind speed ~~for these stations and the comparison to the corresponding simulated parameters. Meso-NH underestimation of air temperature in the afternoon time is opposite of wind speedoverestimation at the same period.Values of wind speed show higher amplitude which may can be partlially explained by the same fact that modelwind corresponds to the 10 height while sensors at the station are at a height of 2 .~~ at Cid Almeida, Barbosa, and Montante sites. Overall, the simulation results are slightly more conservative (except wind speed over the Montante platform), but in general, the patterns are well represented. The model could not represent well the maximum and minimum temperatures, especially in land stations where the temperature range is larger. Regarding wind speed, the model underestimates the maximum values at land stations and at Montante platform (Fig. 6 (d)), on the contrary, the wind speed is overestimated by the model, but the principal features of the curve is represented. Statistical values for this validation are the following. For Barbosa: air temperature ~~maximum absolute error (MAE) is 3.6 with RMSE of~~ average bias is 0.23 °C, RMSE is 1.37 °C and correlation coefficient is 0.98, ~~and~~ for wind speed ~~: 4.4 is maximum absolute bias , 2.13~~ these values are: average bias is 0.55 m/s~~RMSE, and 0.67 correlation coefficient~~, RMSE is 1.08 m/s, and correlation coefficient is 0.73. For Cid Almeida: ~~MAE 4.9 , RMSE~~ temperature average bias is 0.5 °C, RMSE is 1.57~~,~~ °C, and correlation coefficient is 0.98, wind speed ~~MAE is 5.9~~ average bias is -0.36 m/s, RMSE is ~~1.56~~ 1.24 m/s~~wid the correlation coefficient of 0.63~~, and correlation coefficient is 0.69. For Montante platform~~these values are following. Air temperature MAE is 3.2 , RMSE~~: air temperature average bias is -0.1 °C, RMSE is 1.22 °C, correlation is 0.98, wind speed ~~MAE 4.95~~ average bias is -0.97 m/s, RMSE ~~1.76~~ is 1.55 m/s, and correlation coefficient is ~~0.63. Wind speed in the simulation input is given at 10 meters high while the stations are installed to measure it at 2 meters. Interpolation of the model results for 2 meters can reduce biases and improve the comparison. All maximums of the biases can be found on the peaks of the temperature or wind speed which is explained by the fact that the model is more conservative.~~ 0.61.

~~Dynamic of~~ The temporal evolution of simulated and observed latent and sensible heat fluxes at Montante platform is shown ~~on~~ in Fig. 7 (a, b). Overall patterns of ~~these~~ the curves are similar but ~~simulated results are more smoothwhile observed values changes more quickly~~the simulated one is more smooth. Comparison between measurements and simulated results demonstrates that for latent heat the RMSE is 57.34 $\mathrm{W m^{-2}}$ with correlation coefficient of 0.47, and for sensible heat the RMSE is 13.39 $\mathrm{W m^{-2}}$ with the correlation of 0.82. ~~It should be noted here~~

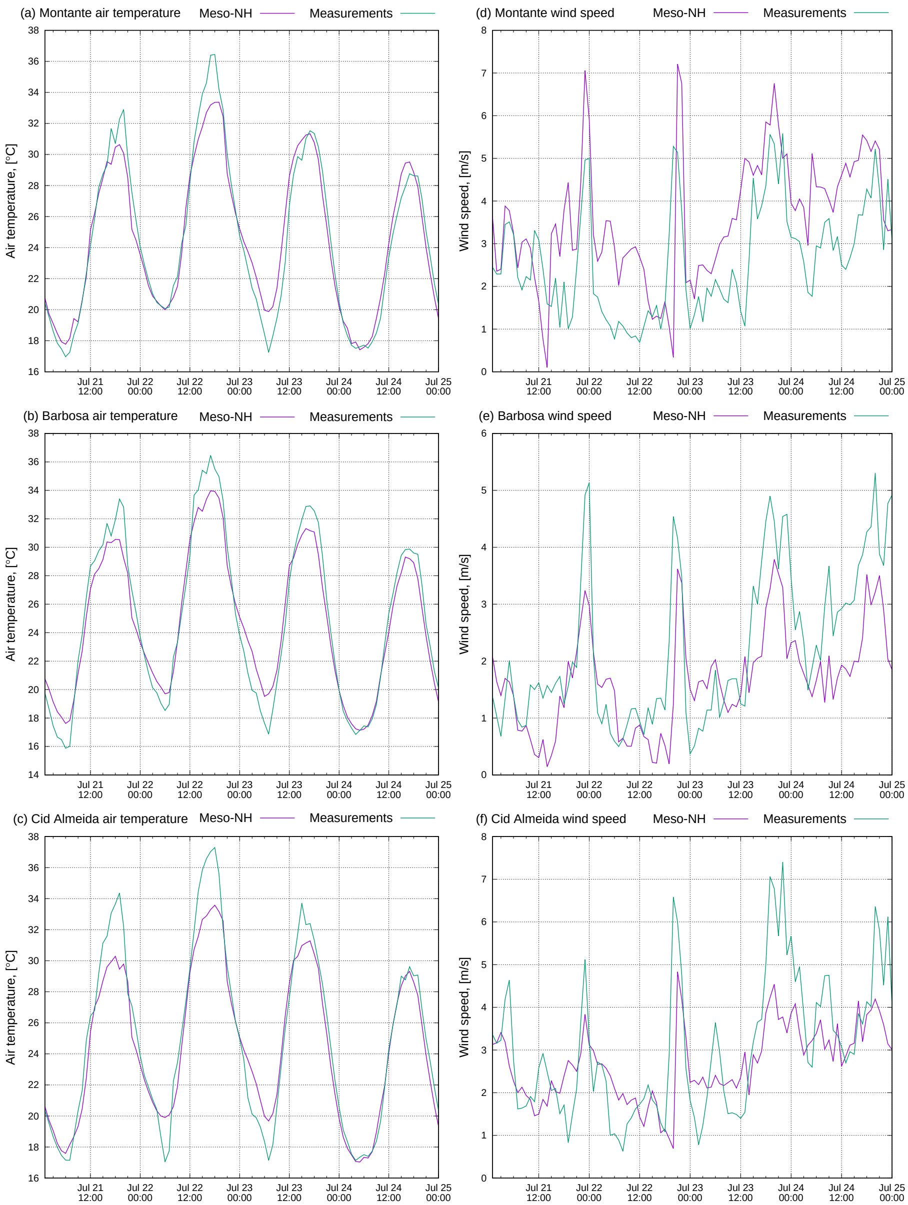


Figure 6. ~~Comparison of~~ Observed and simulated air temperature and wind speed at 2 meters for ALEX stations: Montante platform (a, d), Barbosa (b, e), and Cid Almeida (c, f) sites.

Both observed and simulated curves of Fig. 7 (a) reveal that sensible heat flux has two different periods during the day, positive when air-water temperature difference is negative, and vice-versa, showing that during daytime the water gets energy from the air and during night-time the water warms the nearby air. The transition between the two regimes is well captured by the model. Fig. 7 (b) also shows that the magnitude of the sensible heat flux is relatively small when compared with the other

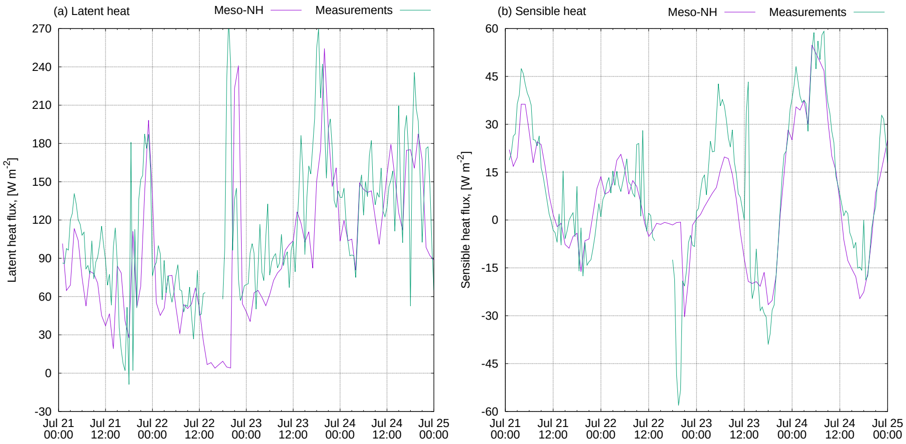


Figure 7. Observed and simulated latent (a) and sensible (b) heat fluxes at Montante floating platform.

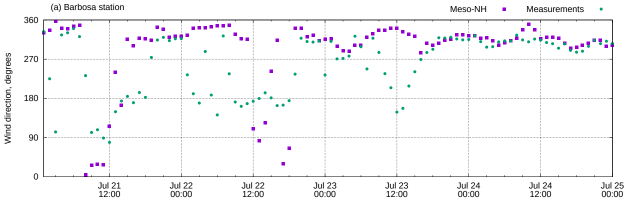
terms of the energy balance. Daily maximum positive (negative) fluxes between 30 and 60 $\mathrm{Wm^{-2}}$ (-15 and -30 $\mathrm{Wm^{-2}}$) are well reproduced by the model. An apparently strange behavior appears on July 22 afternoon, with the sensible heat flux being almost zero. This effect, unfortunately not documented due to the lack of data, will be discussed later and is linked to the fact that the wind is very weak during this period (see Fig. 6 (d)).

More detailed analysis of ~~these curves shows that measurements have minimums of latent heat in the daytime~~ Fig 7 (a) shows that the lowest heat flux values usually occur during the afternoon (12:00 – 18:00 UTC), under windless conditions, and high peaks in the early evening (20:00 – 21:00 ~~). Simulation~~ UTC). The simulation reproduces these peaks with 1-2 hour delay which are related to the delay on the simulated wind speed. ~~Unfortunately, there is no data about fluxes for~~ The magnitude of the latent heat flux daily maximum (order of 200 – 250 $\mathrm{Wm^{-2}}$) is well captured by the model. The delay in the simulation of the peaks reduces the value of the correlation coefficient and is a manifestation of the so-called double-penalty that penalize high-resolution model scores. As seen in the Fig. 7 (b) the simulated latent heat flux is almost zero between 14:00 ~~–~~ and 16:00 ~~, 22 of July , but according to the model results both fluxes are tend to be around 0 $^{-2}$~~ UTC of July 22. As pointed before, there is a gap in the measurements of the flux during this period, but data from the day before indicates that the results are realistic. This effect of almost zero evaporation from water on a very hot day is contrary to common sense and will be discussed later.

~~Wind direction on Barbosa and Cid Almeida stations.~~

Wind direction at ALEX stations is represented ~~on the~~ in Fig. 8. ~~Measurements show how wind direction changes to the opposite due to the lake breeze effect during the daytime between~~ Different behaviour in wind direction between the two station from 21 ~~and~~ to 23 of July ~~, not clearly seen on the simulation results on the grid-points near the ALEX stations. The structure of the simulated breeze will be discussed later.~~ is clearly seen from measurements data (green dots). In Barbosa station the wind changes from northwest to south regime during daytime while in Cid Almeida this effect is not observed. In the simulations this difference is not so clear, but is still visible during the afternoon on July 22. Barbosa station, located on the ~~North-West~~ northwest shore of the lake, indicates the presence of the lake breeze because its direction is the opposite to the

(a) Barbosa station



(b) Cid Almeida station

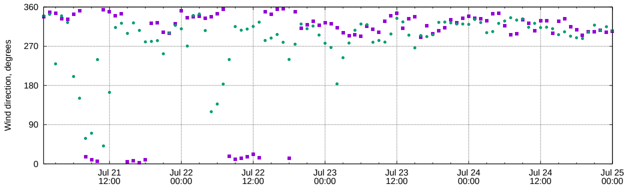


Figure 8. Observed and simulated wind direction on Barbosa and Cid Almeida stations.

dominant wind~~in this area~~. However, at Cid Almeida station on the ~~South-East~~ southeast shore breeze is co-directed with the dominant wind in the area, so, its appearance is difficult to track.

6 Lake ~~effects~~impact

To ~~study how the Alqueva lake affects the~~ analyse the impact of the Alqueva reservoir on local area the ~~following atmospheric parameters were used in this work:~~ changes of the following atmospheric variables, such as air temperature and potential temperature, relative humidity and water mixing ratio, and vertical and horizontal wind speed~~. Overall, simulation result is a 3 sets of 96 output files (for each horizontal resolution) of 1-hour timestep consisting of required atmospheric parameters. Only 1-and 250-resolution~~ , were considered. In this section only B and C domain datasets were used~~in this section.~~

~~During daytime water temperature is lower than air temperature, which is associated to a very weak air circulation over the water surface which leads to very low evaporation from the lake (refer to low latent heat flux values on Fig. 7 (a)). At this time period evaporation over the land is even higher that over the water. By late afternoon when the dominant sea breeze system reaches the region, smooth water surface significantly enhances the North-West wind. As the result, evaporation from the lake becomes very intensive.~~

~~Figure ?? shows an example of wind regime on the 1 domain in the morning (07:00 UTC). Dark blue color represents the lake area over the orography. At this time of the day before the establishment of the lake breeze, North-West wind prevails in the area with the magnitude of 3-5~~ . ~~Simulated 10 wind (vectors) over orography (color scale) at 07:00 UT 22 July 2014; results from the 1 resolution domain.~~

6.1 Impact on air temperature and relative humidity

The ~~first level of air above the lake surface is the most affected by its impact. Fig. 9 illustrates the air temperature difference caused by~~ lower layers of air are the first to be affected by the presence of ~~the reservoir~~ water. Differences in air temperature at 2 meters ~~height~~ during 22 July ~~2014. We focus on this day because air temperature was the highest and the lake breeze expected to be strong and well distinguishable~~are shown in Fig. 9, the warmest day of the IOP and the one when the breeze was stronger. Positive anomaly (up to 3-4~~K~~ °C) can be traced during the period from 1 hour after the sunset (21:00 UTC) ~~until~~ to 1 hour after the sunrise (07:00 UTC). ~~Examples of this~~ By positive and negative anomalies here we mean the differences between LAKE1 and LAKE0 simulations. Examples of the positive night anomalies are illustrated in Fig. 9 (a, b). Night ~~North-West~~ northwest wind transports warm air from the lake to the ~~South-East~~ southeast part of the reservoir for up to 2~~km~~ km away from the shore. Daytime period is characterized by the negative temperature anomaly up to 7 °C (Fig. 9 (c-f)). This effect is essentially limited by the lake borders. When the large-scale sea breeze system arrives~~to the Alqueva area~~, temperature trace of the lake impact ~~are followed~~ is advected by the wind and can be found in 10-12 km away from the ~~South-East~~ southeast part of the reservoir (Fig. 9 (f)).

Vertical cross-sections ~~can~~ help to illustrate the processes in the atmosphere on different altitudes. ~~Such East-West~~ Two different cross-sections ~~along 38.215 °N (Fig. 10, position of this cross-section is indicated by a lower horizontal line on~~ S1 and S2 (the first one crosses the lake near Montante platform and the second in the middle, exact locations are indicated in Fig. 9, (a)) are shown to provide a better visualization of the three-dimensional structure of air circulation above the lake. Cross-sections S1 along 38.215 °N (Fig. 10) show the evolution of wind and the potential temperature during the 22 July in the

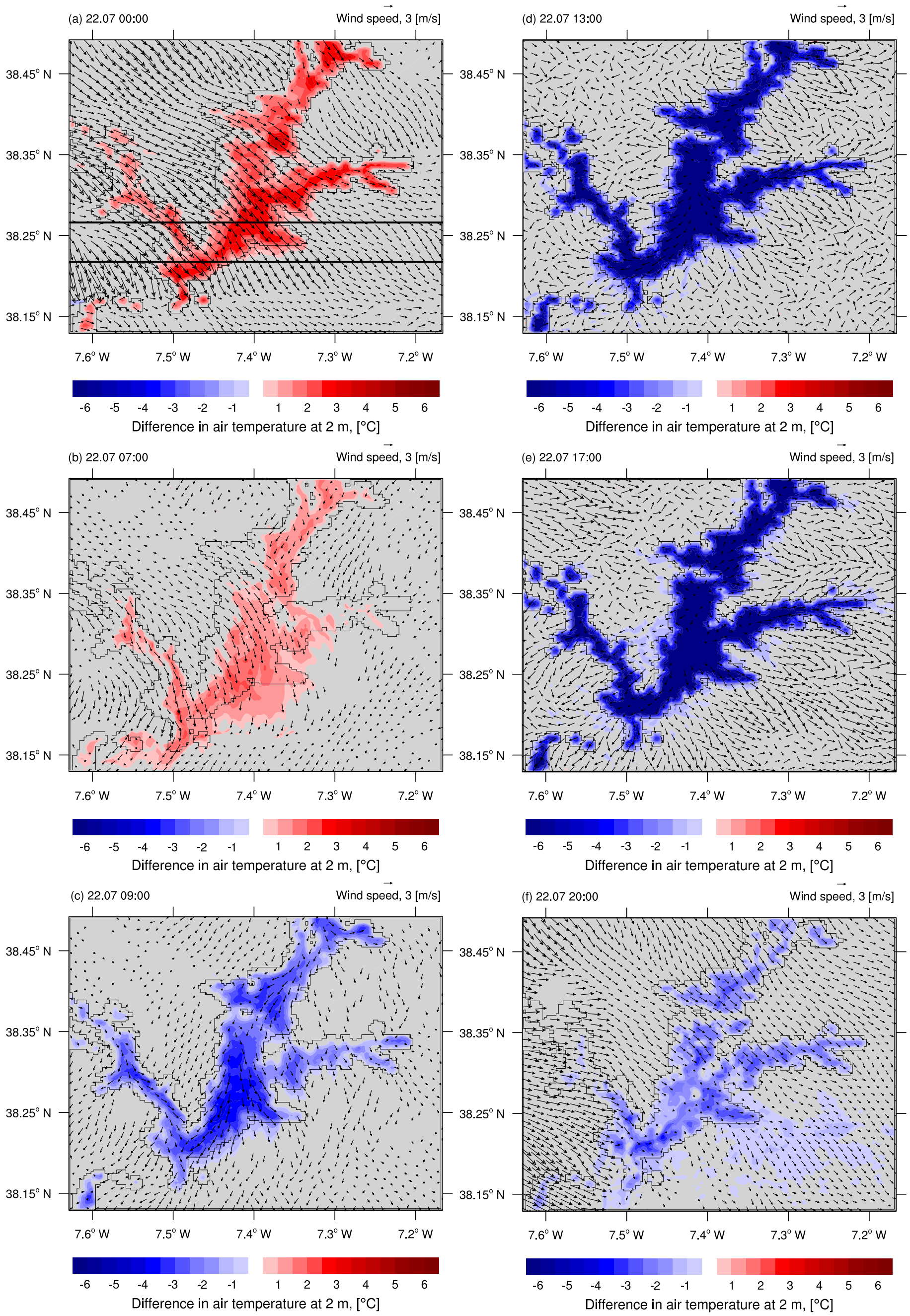


Figure 9. Anomalies in air temperature at 2 m ~~temperature anomaly~~ (~~difference between LAKE1 and LAKE0 experiments)~~ in filled contours) and horizontal wind in LAKE1 experiment (arrays, the scale is indicated in the upper rigth corner of each figure) of the reservoir on 22 of July 2014 on ~~the 250 resolution~~ domain C. Horizontal lines on (a) indicate the location of cross-sections S1 (southern) and S2 (northern).

experiment with the reservoir (simulation LAKE1). ~~Maximum of the temperature impact of the lake can be found~~ The highest impact on the air temperature can be observed in the early afternoon ~~, at~~ (12:00 – 14:00 ~~on the altitudes up to 1-1.2 , cooling all the boundary layer , which depth decreases (very clear seen on Fig. 10 (a))~~ UTC). The boundary layer is cooling down and its height decreases from more than 2 km above the ~~surface outside the zone of influence of Alqueva,~~ land outside to values close to 1 km over the ~~water reservoir~~lake surface (Fig. 10 (a)). The thermal anomaly induced by the presence of the reservoir seems to affect an area greater than ~~that~~ what was identified at the surface, especially in the middle of the boundary layer. Later on, at 19:00 – 20:00 UTC the powerful ocean breeze system reaches the area and cools the lower (1~~km~~ km) layer of air by 6-7 K. The progression of the sea breeze front is impressively well shown ~~on~~ in Fig. 10 (d) (20:00 ~~UT~~UTC), when it reaches the border of the reservoir, and ~~on~~ in Fig. 10 (e), (f) (21:00 ~~UT~~- 22:00 UTC), when it is already beyond the east bank of the Alqueva ~~lake~~reservoir.

Alqueva causes a similar anomaly on 2 m relative humidity which is shown in Fig. 11. At night when the temperature impact is negative some small negative differences in relative humidity can be seen over the lake surface (Fig. 11 (a)). There are also traces of daytime positive impact, essentially due to the decrease of air temperature, advected by the sea breeze in the southeast direction. In the morning, however, the difference of relative humidity can not be detected because the thermal impact is not strong enough (Fig. 11 (b)). Figures 11 (c), (d), and (e) show how relative humidity increases during the daytime over the water surface. The peak of the difference can reach 50% in the afternoon (Fig. 11 (f)). In general, lake impact on relative humidity is limited by the area of the reservoir and does not spread over the surrounding land.

6.2 Breeze effects

Differences in near surface sensible heat fluxes and ~~consequentely in air temperature~~ contrast of the air temperature over the land and water surfaces during the daytime ~~induces~~ induce the formation of the lake breeze system. The development of the lake breeze is illustrated ~~on~~ in Fig. 9 ~~. Wind arrows corresponding to~~ (arrows that corresponds to the wind speed lesser than 0.5 m/s are not ~~ploted. During nighttime~~ plotted). During the night, the large-scale circulation (Fig. 9 (a), (b)) ~~large-scale circulation, driven by the peninsular scale sea breeze system~~ is dominant in the area~~but after the sunrise when the temperature anomalies near surface changes to negative, winds blowing out of the the lake shores can be observed.~~ . After the sunrise (07:00 – 08:00 UTC) the air temperature over the water surface becomes lower than the air temperature over the surrounding areas, which induce a thermal circulation directed from the center of the lake to its shores. The breeze intensifies during the afternoon reaching 6 m/s in some areas (Fig 9 (d), (e)).

Daytime cross-sections ~~on~~ S1 in Fig. 10 (a, b, c) indicates that the direct lake breeze can be found on ~~the~~ altitudes up to 300 meters above ~~lake surface. Breeze wind speed in that case can reach 5-7 . Spreading of the lake breeze in horizontal plane~~ the lake, with a divergent flow over the water surface. The lake breeze intensity and pattern depends on the local orography, but usually the traces ~~of it~~ can be found ~~in~~ 4-6 km away from the lake shores (Fig. 10 (c)). ~~An~~ In altitude, a return flow is visible in the eastward wind component over the west shore and a westward component in the east of the reservoir which causes an upper-level ~~convergent return circulation can be noticed (~~convergence which can be seen in Fig. 10 (a, b, c)~~) by an increase of eastward component over the west shore, and an westward motion to East of the reservoir~~. We will return to this features

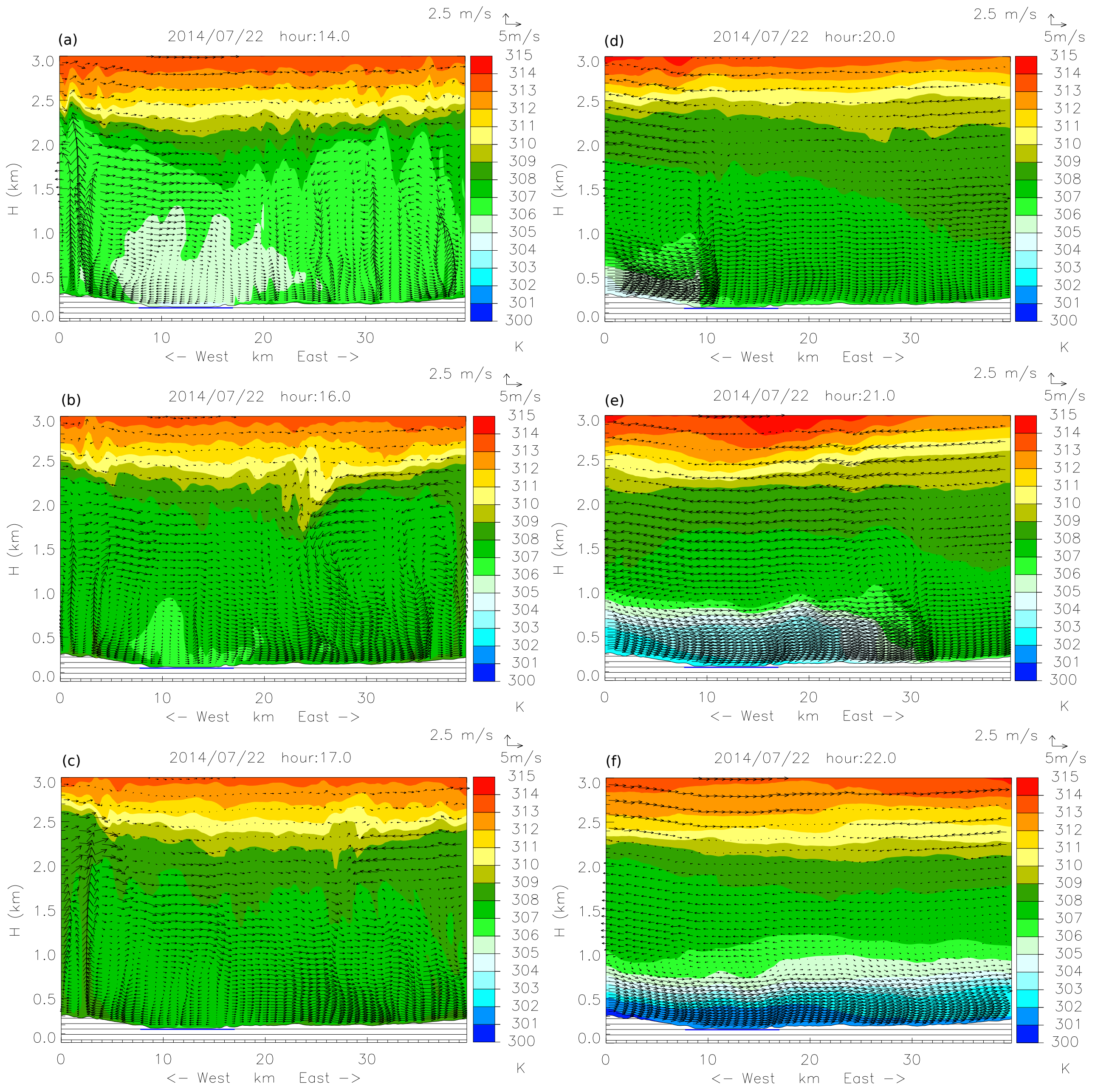


Figure 10. ~~East-West~~ East-west direction cross-sectons along 38.215 °N (S1, crosses the lake near Montante platform, ~~southernmost straight line in~~ Fig. 9 (a)) of potential temperature (filled contours) and ~~projection of~~ wind vectors in the plane of the cross-section (~~arrays~~arrows), at different ~~times~~ hours (indicated in the top of each figure) in LAKE1 experiment at 250 m horizontal resolution. The wind vertical and horizontal scales are indicated in the upper right corner of each figure. Blue line on the surface level indicates the location of the reservoir.

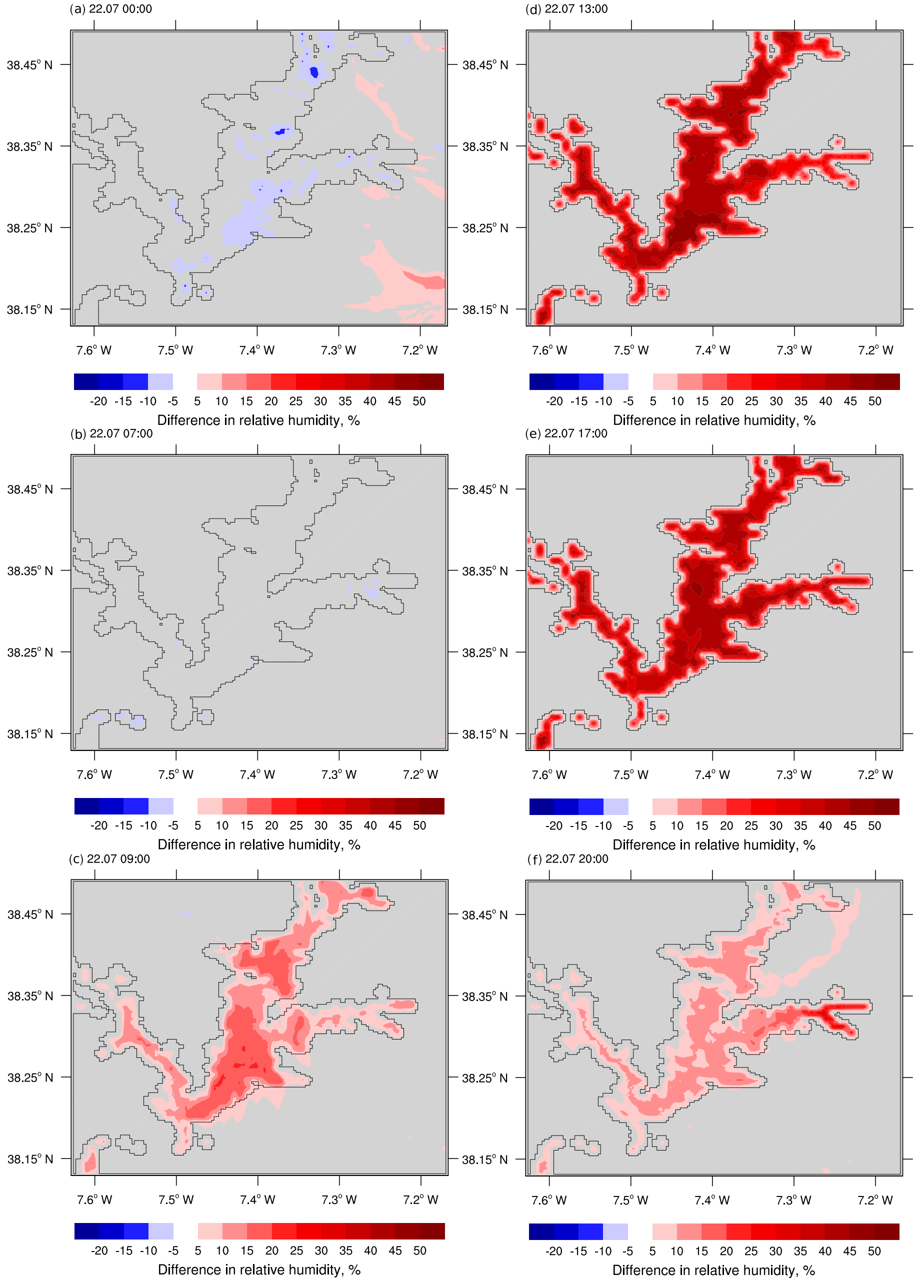


Figure 11. 2 m relative humidity anomalies (in filled contours) on 22 of July 2014 on domain C.

later ~~, during~~ together with the discussion of the ~~impacts of the teservoir~~ effects of the reservoir on the moisture field, ~~showing another cross-section,~~ in which the structure of the lake breeze system is more visible.

~~This breeze wind intensifes until~~ In the late afternoon (~~Fig. 9 (e)) when the wind speed can reach 7 . When~~ 18:00 UTC) the negative temperature anomaly due to the presence of the ~~mass body~~ lake is getting weaker, and breeze system starts to wane and dissipate. At 19:00 – 20:00 ~~when~~ the ocean breeze arrives to the area ~~, lake breeze already can not be traced~~ and overlaps the local circulations (Fig. 10 (d, e, f)).

~~Alqueva impact on the relative humidity at 2 height is shown on Fig. 11. 2 relative humidity anomaly (difference between LAKE1 and LAKE0 experiments) in filled contours on 22 of July 2014 on 250 resolution domain. The lake increases relative humidity up to 50% during the daytime while at night its influence is insignificant. The positive anomaly is limited by the area of the lake and does not spread over the surrounding land. It should be noted that the increase in the relative humidity is mainly due to the decrease in air temperature.~~

~~In fact, cross-sections presented on~~ Cross-sections S1 and S2 presented in Fig. 12 ~~(the position of the cross-sections are indicated with horizontal lines on Fig. 9 (a))~~ show that the lake breeze system includes a descending branch over the ~~lake area~~ reservoir that carries dry air from a height of about 2-2.5 km and redistribute it over the lake surface. ~~Two different locations of cross-sections (the first one is near Montante platform and the second one is in the middle of the lake) are shown to provide a better vizualization of the three-dimensional structure of air circulation above the lake.~~ This dry downstream ~~effect~~ is confirmed by the ~~results of measurement~~ measurements of water vapor mixing ratio at ~~Montante platform as~~ the Montante platform. As can be seen in Fig. 13 ~~, in which simulation results are compared with observations: it decreases to a minimum of about 7-8~~the observed and the simulated mixing ratio of water vapor have a daily minimum with average values of about 8-8.5 g kg^{-1} ~~every day after noon~~ around 14:~~00-15:00 and reaches a minimum~~ 00-16:00. During the afternoon of July 22, the day with a strong lake breeze, the minimum reached a value lower than 6 g kg^{-1}~~during the afternoon of the day of stonger lake breeze (July 22)~~. Out of the period in which the air ~~subside~~ over the lake ~~, the~~ subsides, the water vapor mixing ratio returns ~~to previous values of~~ beck to 9-10.5 g kg^{-1}. The presence of this dry downstream was proposed as a hypothesis by Potes et al. (2017) and is proved through the ~~simulations done in this study.~~ performed simulations. In the same Fig. 13 it is clearly seen that the model tends to overestimating the mixing ratio, except in the afternoon of July 22.

On the other hand, Fig. 12 also shows that outside the reservoir there ~~exist~~ are zones of low-level convergence and upward motion ~~which~~ that increase the moisture of the boundary layer ~~. this zones correspond to~~ and form some kind of lake breeze fronts. The complex shape of the reservoir implies an also complex 3D structure of the breeze system. Towards the ~~Southernmost~~ southernmost part, near the dam, the low level divergent breeze circulation is very clear, but the convergence upper-level return current is weaker (Fig. 12 (a, b, ~~and~~ c)). In contrary, near the ~~midle~~ middle of the reservoir (cross-section S2 in Fig. 12 (d, e, ~~and~~ f)) where two water branches exist, the circulation near the surface is more complex due to the presence of a land ~~band~~ area inbetween, but the subsidence motion is more ~~proeminent~~prominent, inducing a decrease in mixing ratio through the boundary layer, which reaches a magnitude of about 4 g kg^{-1} at 16:00 (Fig. 12 (f)).

Figure 14 illustrates this process in a horizontal plane. At midnight (Fig 14 (b)) the reservoir does not directly affect vapour mixing ratio in the air. In the morning hours, when the sun has risen, but the breeze system has not yet formed, a positive impact on the moisture over the lake can be seen due to the increase of the evaporation. This anomaly affects the air above central and southern part of the reservoir and is advected to other nearby areas (Fig 14 (c)). Later in the afternoon, with the

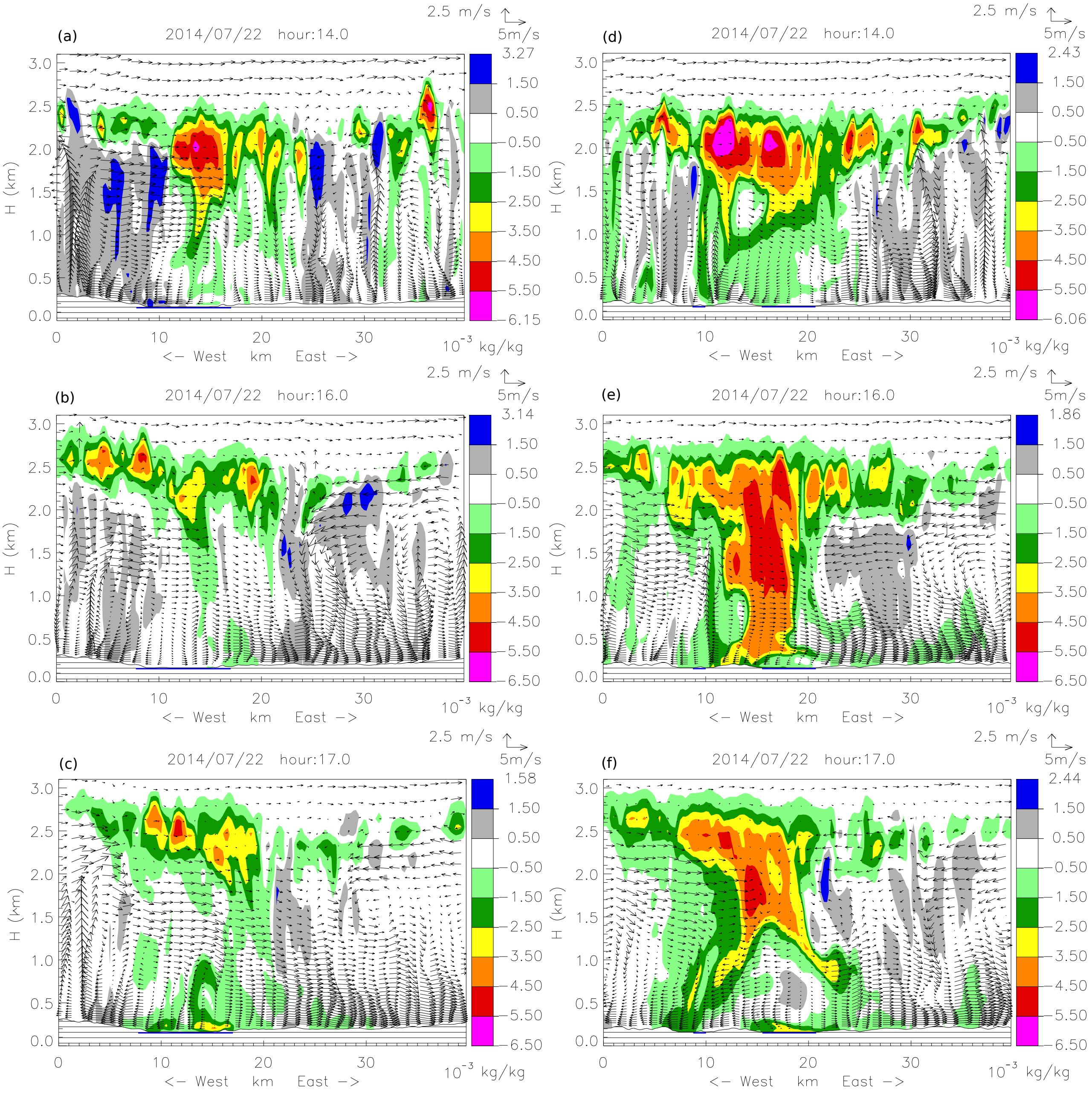


Figure 12. ~~East-West~~ East-west direction cross-sections S1 along 38.215 °N (a,b,c) and S2 along 38.274 °N (d, e, f) ~~(horizontal lines on Fig. 9 (a))~~ with the difference (LAKE1 and LAKE0 simulations) of water mixing ratio (filled contours), and ~~projection of~~ wind vectors in the plane of the cross-section (~~arrays~~arrows) in LAKE1 experiment at 250 m horizontal resolution at different times (indicated in the top of each figure). Blue line on the surface level indicates the location of the reservoir.

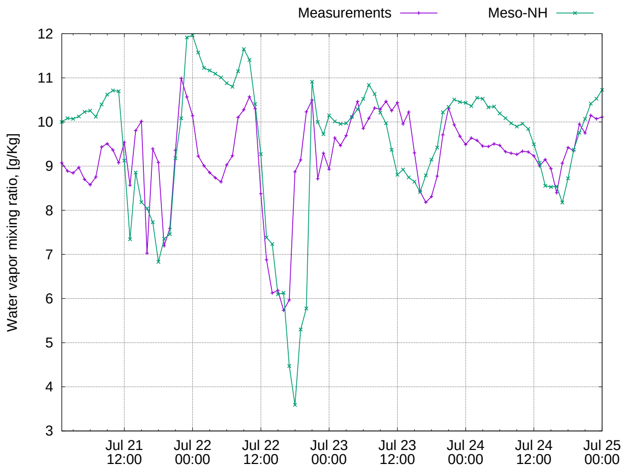


Figure 13. ~~Water~~ Observed and simulated water vapor mixing ratio over the Montante platform.

formation of the lake breeze, a negative impact can be traced over the water surface due to the descending branches of the local circulation (Fig. 14 (d, e)). This explains the afternoon decrease of the water vapour mixing ratio observed at the Montante platform as seen in Fig 13. The localization of the area of this negative anomaly changes in time, but predominantly it is over the larger southern part of the reservoir. With the dissipation of the local lake breeze system and the arriving of the stronger large scale northwestern wind, the negative moisture anomaly over the reservoir disappears and a positive effect is visible on the downwind region (Fig. 14 (a, f)), due to the increase of evaporation (note that Fig. 14 (a) corresponds to the night of July 21 to 22, when the effect was more noticeable).

During daytime, the water temperature is lower than the air temperature, which is associated to a very weak air circulation over the water surface which leads to very low evaporation from the lake (refer to low latent heat flux values in Fig. 7 (a)). At this time period evaporation over the land is even higher that over the water. By late afternoon when the dominant sea breeze system reaches the region, the northwestern wind accelerates significantly, passing over the smooth surface of the lake. As result, evaporation from the lake becomes very intense.

7 Conclusions

~~In this work we studied~~ This work is dedicated to the studies of the formation and magnitude of the summer lake breeze at the Alqueva reservoir, South Portugal, ~~and the impact~~ one of the impacts of the artificial lake on the local weather. The study was based on Meso-NH simulations of ~~an~~ a well documented case study of 22-24 July 2014. This period was taken for several reasons. First, a large volume of meteorological data was collected during these days, which allowed for a validation of the simulation results. Secondly, this period was hot and dry, which is typical for most summer days in this region.

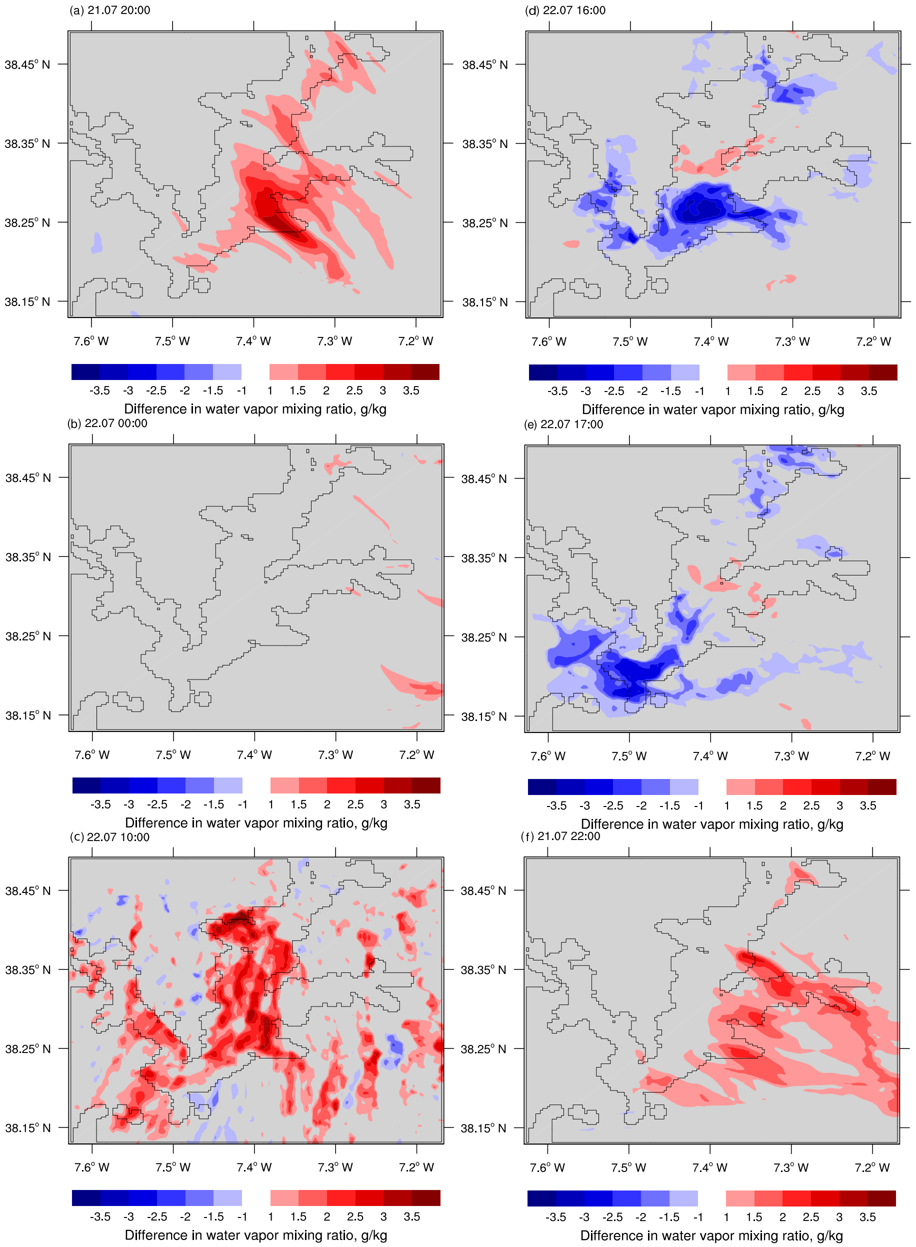


Figure 14. Observed and simulated water vapor mixing ratio anomalies in filled contours on 22 of July 2014 on domain C for selected hours

The model allowed to conduct the simulation with horizontal resolution of 250 meters which is fine enough to ~~figure out~~ resolve such relatively small scale lake breeze and to spot the impact of the reservoir on the detailed local boundary layer structure.

Due to the “youth” of the Alqueva reservoir it is possible to run atmospheric model with the surface conditions prevailing before the filling of the reservoir. Two simulations, one with ~~the~~ Alqueva and another one without it, allow to evaluate the ~~impact~~raw impact of the lake on the local weather regime.

~~We described the formation of~~Formation and dissipation of the daytime breeze system induced by the reservoir are described in the work. On hot summer mornings the difference between air temperatures above water and neighbouring land surfaces induces the radial movement of air from the lake. The breeze system starts to form in the morning and the ~~lake breeze system during the daytime and its dissipation in late afternoon anticipated by the arrival of the larger scale sea breeze generated at the Portuguese west Atlantic coast. The magnitude of~~ peak of the wind speed reaches 6 $\mathrm{m/s}$ in the late afternoon. Simulation results show that the lake breeze ~~can reach 6 . It can be traced at about~~ could be detected at a distance of more than 6 km away from the ~~lake shore~~ the shores and on altitudes up to 300 m above ~~the lake surface. Daytime lake regime can be characterized by~~ water surface. In late afternoon the dissipation stage of the lake breeze system anticipated with the arrival of the larger scale sea breeze from the Portuguese west Atlantic coast. In early evening (19:00 – 20:00 UTC) the local lake breeze system can not be detected anymore. No reverse land breeze is detected during the night.

During daytime, the simulation testify the observed very low evaporation ~~rate~~ from water surface ~~, while at nighttime major sea breeze induces~~ (0 – 120 $\mathrm{Wm^{-2}}$ in terms of sensible heat flux), due to weak winds and the stable stratification of the internal atmospheric surface layer. A night-time, the strong winds associated with the Peninsular larger-scale circulation induced by the sea-land contrasts, induce a very high evaporation rate (200 – 250 $\mathrm{Wm^{-2}}$).

~~Cooling~~ The cooling effect of the ~~lake expressed in lower air temperatures (~~reservoir can decrease the air temperature up to 7~~) but~~ °C, nevertheless is limited by the lake borders and normally ~~not~~ can not be seen farther than few kilometers away from the shore mostly in ~~South-East direction. Altitude effect of the~~ southeast direction. The cooling can be found ~~at the~~ up to 1200 m above the lake surface.

~~The lower layer of the air over the lake usually are more wet during the daytime, but the presence of the lake makes a negative impact on the humidity at higher altitudes. Downward circulation induced by the lake breeze~~ Lake breeze system brings dry air from ~~the upper atmospheric layer~~ upper atmospheric layers (2-2.5 km) to near surface levels above the reservoir. This effect leads to the fact that the air above the surface of the lake becomes more dry in terms of water vapor mixing ratio, in spite of its relative humidity can increase up to 50% due to the decrease in air temperature.

Further work implies two directions. The first is tuning the lake model and its initialization in order to obtain more accurate results and reduce validation biases. The second is to carry out a longer experiment, which would cover a 12-month period. Such simulation could reveal seasonal aspects of the impact of Alqueva on local weather.

Competing interests. The authors declare that they have no conflict of interest.

Acknowledgements. The work is co-funded by the European Union through the European Regional Development Fund, included in the COMPETE 2020 (Operational Program Competitiveness and Internationalization) through the ICT project (UID / GEO / 04683/2013) with the reference POCI-01-0145-FEDER-007690 and also through the ALOP project (ALT20-03-0145-FEDER-000004). Experiments were accomplished during the field campaign funded by FCT and FEDER-COMPETE: ALEX ~~2014~~ (EXPL/GEO-MET/1422/2013) FCOMP-01-0124-FEDER-041840.

References

Bates, G. T., Giorgi, F., and Hostetler, S. W.: Toward the Simulation of the Effects of the Great Lakes on Regional Climate, Monthly Weather Review, 121, 1373–1387, https://doi.org/10.1175/1520-0493(1993)121<1373:TTSOTE>2.0.CO;2, 1993.

Bechtold, P., Bazile, E., Guichard, F., Mascart, P., and Richard, E.: A mass-flux convection scheme for regional and global models, Quarterly Journal of the Royal Meteorological Society, 127, 869–886, https://doi.org/10.1002/qj.49712757309, 2001.

Bischoff-Gauß, I., Kalthoff, N., and Fiebig-Wittmaack, M.: The influence of a storage lake in the Arid Elqui Valley in Chile on local climate, Theoretical and Applied Climatology, 85, 227–241, https://doi.org/10.1007/s00704-005-0190-8, 2006.

Bonan, G. B.: Sensitivity of a GCM Simulation to Inclusion of Inland Water Surfaces, Journal of Climate, 8, 2691–2704, https://doi.org/10.1175/1520-0442(1995)008<2691:SOAGST>2.0.CO;2, 1995.

Bougeault, P. and Lacarrere, P.: Parameterization of Orography-Induced Turbulence in a Mesobeta–Scale Model, Monthly Weather Review, 117, 1872–1890, https://doi.org/10.1175/1520-0493(1989)117<1872:POOITI>2.0.CO;2, 1989.

Cohard, J.-M. and Pinty, J.-P.: A comprehensive two-moment warm microphysical bulk scheme. I: Description and tests, Quarterly Journal of the Royal Meteorological Society, 126, 1815–1842, https://doi.org/10.1002/qj.49712656613, 2000.

Cotton, W. R. and Pielke, R. A. S.: Human Impacts on Weather and Climate, Cambridge University Press, 2nd edn., 2007.

Crosman, E. T. and Horel, J. D.: Idealized Large-Eddy Simulations of Sea and Lake Breezes: Sensitivity to Lake Diameter, Heat Flux and Stability, Boundary-Layer Meteorology, 144, 309–328, https://doi.org/10.1007/s10546-012-9721-x, 2012.

Cuxart, J., Bougeault, P., and Redelsperger, J.-L.: A turbulence scheme allowing for mesoscale and large-eddy simulations, Quarterly Journal of the Royal Meteorological Society, 126, 1–30, https://doi.org/10.1002/qj.49712656202, 2000.

Drobinski, P. and Dubos, T.: Linear breeze scaling: from large-scale land/sea breezes to mesoscale inland breezes, Quarterly Journal of the Royal Meteorological Society, 135, 1766–1775, https://doi.org/10.1002/qj.496, 2009.

Ekhtiari, N., Grossman-Clarke, S., Koch, H., Souza, W. M., Donner, R. V., and Volkholz, J.: Effects of the Lake Sobradinho Reservoir (Northeastern Brazil) on the Regional Climate, Climate, 5, https://doi.org/10.3390/cli5030050, 2017.

Faroux, S., Kaptué Tchuenté, A. T., Roujean, J.-L., Masson, V., Martin, E., and Le Moigne, P.: ECOCLIMAP-II/Europe: a twofold database of ecosystems and surface parameters at 1 km resolution based on satellite information for use in land surface, meteorological and climate models, Geoscientific Model Development, 6, 563–582, https://doi.org/10.5194/gmd-6-563-2013, 2013.

Fouquart, Y. and Bonnel, B.: Computations of Solar Heating of the Earth's Atmosphere — A New Parameterization., Beitrage zur Physik der Atmosphare, 53, 35–62, 1980.

Hartmann, D. L.: Global physical climatology, International geophysics, 1994.

Hoinka, K. P. and Castro, M. D.: The Iberian Peninsula thermal low, Q. J. Roy. Meteorol. Soc., 129(590), 1491–1511, 2003.

Jarvis, A., Guevara, E., Reuter, H. I., , and Nelson, A. D.: Hole - filled SRTM for the globe : version 4 : data grid, published by CGIAR-CSI on 19 August 2008., 2008.

Kain, J. S. and Fritsch, M. J.: A One-Dimensional Entraining/Detraining Plume Model and Its Application in Convective Parameterization, Journal of the Atmospheric Sciences, 47, 2784–2802, https://doi.org/10.1175/1520-0469(1990)047<2784:AODEPM>2.0.CO;2, 1990.

Lac, C., Chaboureau, J.-P., Masson, V., Pinty, J.-P., Tulet, P., Escobar, J., Leriche, M., Barthe, C., Aouizerats, B., Augros, C., Aumond, P., Auguste, F., Bechtold, P., Berthet, S., Bieilli, S., Bosseur, F., Caumont, O., Cohard, J.-M., Colin, J., Couvreux, F., Cuxart, J., Delautier, G., Dauhut, T., Ducrocq, V., Filippi, J.-B., Gazen, D., Geoffroy, O., Gheusi, F., Honnert, R., Lafore, J.-P., Lebeaupin Brossier, C., Libois, Q., Lunet, T., Mari, C., Maric, T., Mascart, P., Mogé, M., Molinié, G., Nuissier, O., Pantillon, F., Peyrillé, P., Pergaud, J., Perraud, E., Pianezze, J., Redelsperger, J.-L., Ricard, D., Richard, E., Riette, S., Rodier, Q., Schoetter, R., Seyfried, L., Stein, J., Suhre, K., Thouron, O., Turner, S., Verrelle, A., Vié, B., Visentin, F., Vionnet, V., and Wautelet, P.: Overview of the Meso-NH model version 5.4 and its applications, Geoscientific Model Development Discussions, 2018, 1–66, https://doi.org/10.5194/gmd-2017-297, 2018.

Lascaux, F., Masciadri, E., and Fini, L.: MOSE: operational forecast of the optical turbulence and atmospheric parameters at European Southern Observatory ground-based sites — II. Atmospheric parameters in the surface layer 0-30 m, Monthly Notices of the Royal Astronomical Society, 436, 3147–3166, https://doi.org/10.1093/mnras/stt1803, 2013.

Lascaux, F., Masciadri, E., and Fini, L.: Forecast of surface layer meteorological parameters at Cerro Paranal with a mesoscale atmospherical model, Monthly Notices of the Royal Astronomical Society, 449, 1664–1678, https://doi.org/10.1093/mnras/stv332, 2015.

Lee, X., Liu, S., Xiao, W., Wang, W., Gao, Z., Cao, C., Hu, C., Hu, Z., Shen, S., Wang, Y., Wen, X., Xiao, Q., Xu, J., Yang, J., and Zhang, M.: The Taihu Eddy Flux Network: An Observational Program on Energy, Water, and Greenhouse Gas Fluxes of a Large Freshwater Lake, Bulletin of the American Meteorological Society, 95, 1583–1594, https://doi.org/10.1175/BAMS-D-13-00136.1, 2014.

Lopes, F., Silva, H. G., Salgado, R., Potes, M., Nicoll, K. A., and Harrison, R. G.: Atmospheric electrical field measurements near a fresh water reservoir and the formation of the lake breeze, Tellus A: Dynamic Meteorology and Oceanography, 68, 31 592, https://doi.org/10.3402/tellusa.v68.31592, 2016.

Lunet, L., Lac, C., Auguste, F., Visentin, F., Masson, V., and Escobar, J.: Combination of WENO and Explicit Runge–Kutta Methods for Wind Transport in the Meso-NH Model, Monthly Weather Review, 145, 3817–3838, https://doi.org/10.1175/MWR-D-16-0343.1, 2017.

Masciadri, E., Lascaux, F., and Fini, L.: MOSE: operational forecast of the optical turbulence and atmospheric parameters at European Southern Observatory ground-based sites — I. Overview and vertical stratification of atmospheric parameters at 0-20 km, Monthly Notices of the Royal Astronomical Society, 436, 1968–1985, https://doi.org/10.1093/mnras/stt1708, 2013.

Masson, V.: A Physically-Based Scheme For The Urban Energy Budget In Atmospheric Models, Boundary-Layer Meteorology, 94, 357–397, https://doi.org/10.1023/A:1002463829265, 2000.

Masson, V., Le Moigne, P., Martin, E., Faroux, S., Alias, A., Alkama, R., Belamari, S., Barbu, A., Boone, A., Bouyssel, F., Brousseau, P., Brun, E., Calvet, J.-C., Carrer, D., Decharme, B., Delire, C., Donier, S., Essaouini, K., Gibelin, A.-L., Giordani, H., Habets, F., Jidane, M., Kerdraon, G., Kourzeneva, E., Lafaysse, M., Lafont, S., Lebeaupin Brossier, C., Lemonsu, A., Mahfouf, J.-F., Marguinaud, P., Mokhtari, M., Morin, S., Pigeon, G., Salgado, R., Seity, Y., Taillefer, F., Tanguy, G., Tulet, P., Vincendon, B., Vionnet, V., and Voldoire, A.: The SURFEXv7.2 land and ocean surface platform for coupled or offline simulation of earth surface variables and fluxes, Geoscientific Model Development, 6, 929–960, https://doi.org/10.5194/gmd-6-929-2013, 2013.

Miranda, P., Abreu, F., and Salgado, R.: Estudo de Impacte Ambiental do Alqueva, Tech. rep., Instituto de ciencia aplicada e tecnologia, Faculdade de Ciências, Universidade de Lisboa, 1995.

Miranda, P. M. and James, I. N.: Non-linear three-dimensional effects on gravity-wave drag: Splitting flow and breaking waves, Quarterly J. Royal Meteorological Society, 118, 1057–1081, 1992.

Mironov, D.: Parameterization of lakes in numerical weather prediction. Description of a lake model. COSMO Technical Report, Deutscher Wetterdienst, 11, Pp. 41, 2008.

Morcrette, J.-J.: Radiation and cloud radiative properties in the European Centre for Medium Range Weather Forecasts forecasting system, Journal of Geophysical Research: Atmospheres, 96, 9121–9132, https://doi.org/10.1029/89JD01597, 1991.

Nicoll, K. A., Harrison, R. G., Silva, H. G., Salgado, R., Melgâo, M., and Bortoli, D.: Electrical sensing of the dynamical structure of the planetary boundary layer, Atmospheric Research, 202, 81–95, https://doi.org/https://doi.org/10.1016/j.atmosres.2017.11.009, 2018.

Noilhan, J. and Mahfouf, J.-F.: The ISBA land surface parameterisation scheme, Global and Planetary Change, 13, 145 – 159, https://doi.org/10.1016/0921-8181(95)00043-7, soil Moisture Simulation, 1996.

Pergaud, J., Masson, V., Malardel, S., and Couvreux, F.: A Parameterization of Dry Thermals and Shallow Cumuli for Mesoscale Numerical Weather Prediction, Boundary-Layer Meteorology, 132, 83, https://doi.org/10.1007/s10546-009-9388-0, 2009.

Pielke, R. A.: A Three-Dimensional Numerical Model of the Sea Breezes Over South Florida, Monthly Weather Review, 102, 115–139, https://doi.org/10.1175/1520-0493(1974)102<0115:ATDNMO>2.0.CO;2, 1974.

Pielke, R. A. S.: Mesoscale Meteorological Modeling, Academic Press, 3rd edn., 2013.

Pinty, J.-P. and Jabouille, P.: A mixed-phase cloud parameterization for use in mesoscale non-hydrostatic model: simulations of a squall line and of orographic precipitations., Proc. Conf. of Cloud Physics, Everett, WA, USA, Amer. Meteor. soc., pp. 217–220, 1998.

Policarpo, C., Salgado, R., and ao C., M. J.: Numerical Simulations of Fog Events in Southern Portugal, Advances in Meteorology, 2017, 16, 2017.

Potes, M., Costa, J. M., and Salgado, R.: Satellite remote sensing of water turbidity in Alqueva reservoir and implications on lake modelling, Hydrol. Earth Syst. Sci., 16, 1623–1633, https://doi.org/doi:10.5194/hess-16-1623-2012, 2012.

Potes, M., Salgado, R., Costa, M. J., Morais, M., Bortoli, D., Kostadinov, I., and Mammarella, I.: Lake–atmosphere interactions at Alqueva reservoir: a case study in the summer of 2014, Tellus A: Dynamic Meteorology and Oceanography, 69, 1272 787, https://doi.org/10.1080/16000870.2016.1272787, 2017.

Salgado, R.: Interacção solo-atmosfera em clima semi-àrido, Ph.D. thesis, Universidade de Èvora, 2006.

Salgado, R. and Le Moigne, P.: Coupling of the FLake model to the Surfex externalized surface model, Boreal Environ. Res., 15, 231–244, 2010.

Salgado, R., Miranda, P. M. A., Lacarrère, P., and Noilhan, J.: Boundary layer development and summer circulation in Southern Portugal, Tethys, 12, 33–44, https://doi.org/10.3369/tethys.2015.12.03, 2015.

Samuelsson, P., Kourzeneva, E., and Mironov, D.: The impact of lakes on the European climate as simulated by a regional climate model, Boreal Environment Research, 15, 113–129, http://www.borenv.net/BER/pdfs/ber15/ber15-113.pdf, 2006.

Segal, M., Leuthold, M., Arritt, R. W., Anderson, C., and Shen, J.: Small Lake Daytime Breezes: Some Observational and Conceptual Evaluations, Bulletin of the American Meteorological Society, 78, 1135–1147, https://doi.org/10.1175/1520-0477(1997)078<1135:SLDBSO>2.0.CO;2, 1997.

Silva, A., De Lima, I., Santo, F., and V., P.: Assessing changes in drought and wetness episodes in drainage basins using the Standardized Precipitation Index, Bodenkultur, 65 (3-4), 31–37, 2014.

Stein, J., Richard, E., Lafore, J. P., Pinty, J. P., Asencio, N., and Cosma, S.: High-Resolution Non-Hydrostatic Simulations of Flash-Flood Episodes with Grid-Nesting and Ice-Phase Parameterization, Meteorology and Atmospheric Physics, 72, 203–221, https://doi.org/10.1007/s007030050016, 2000.

Thiery, W., Martynov, A., Darchambeau, F., Descy, J.-P., Plisnier, P.-D., Sushama, L., and van Lipzig, N. P. M.: Understanding the performance of the FLake model over two African Great Lakes, Geoscientific Model Development, 7, 317–337, https://doi.org/10.5194/gmd-7-317-2014, 2014.

Zhao, L., Jin, J., Wang, S.-Y., and Ek, M. B.: Integration of remote-sensing data with WRF to improve lake-effect precipitation simulations over the Great Lakes region, Journal of Geophysical Research: Atmospheres, 117, https://doi.org/10.1029/2011JD016979, d09102, 2012.