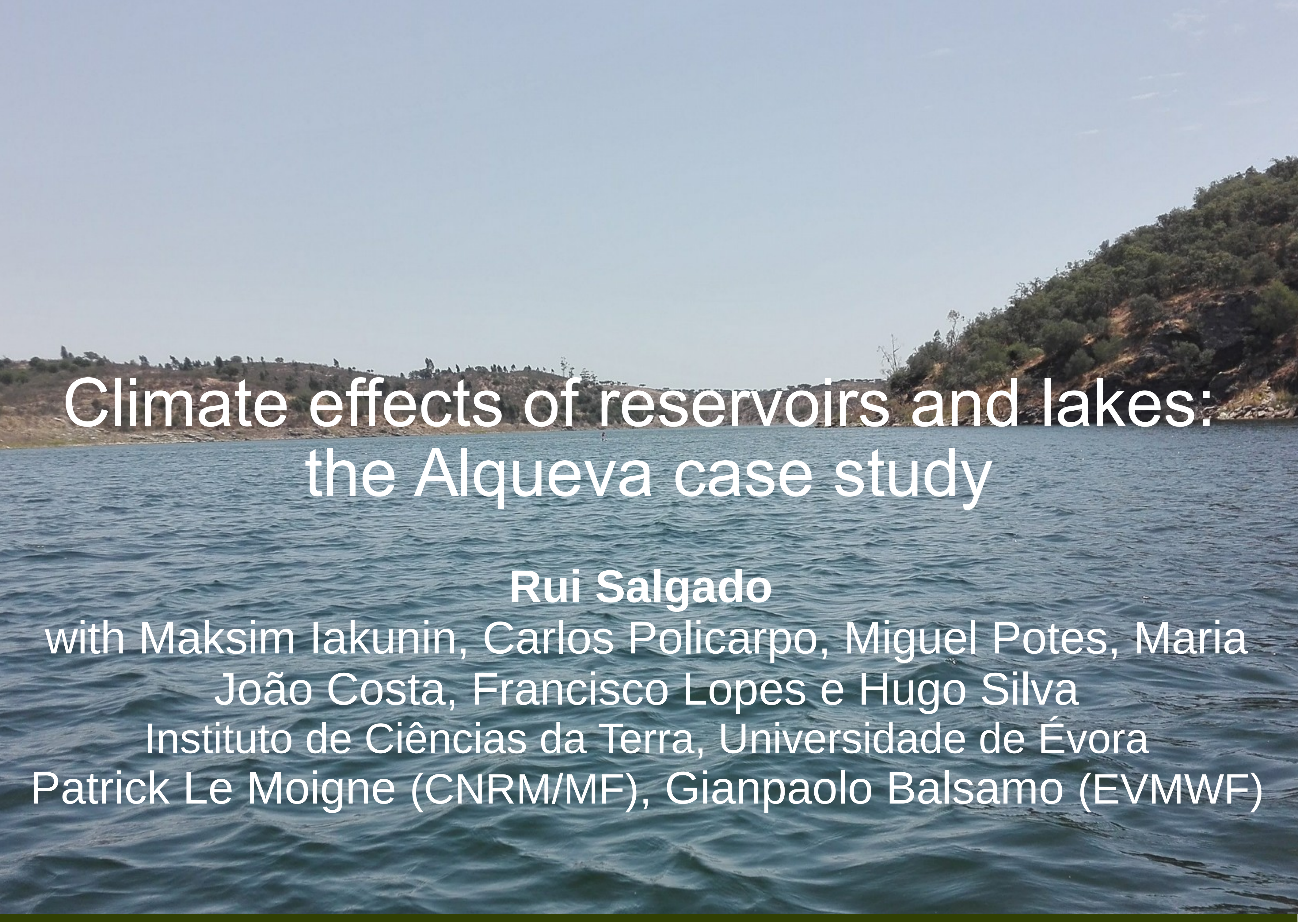
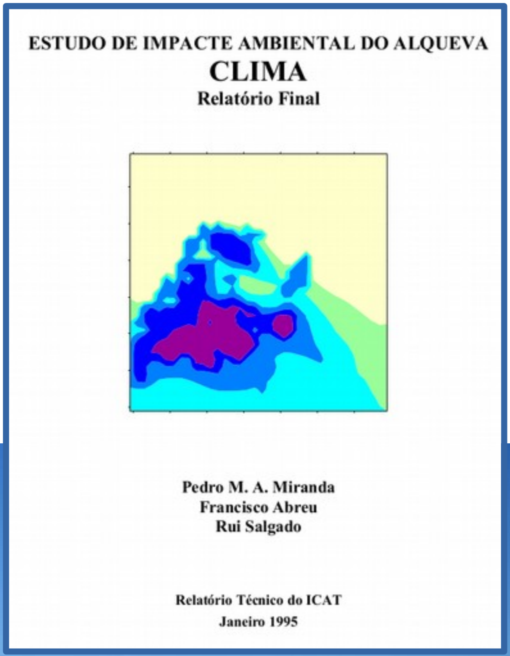


Climate effects of reservoirs and lakes: the Alqueva case study

Rui Salgado
with Maksim Iakunin, Carlos Policarpo, Miguel Potes, Maria João Costa, Francisco Lopes e Hugo Silva
Instituto de Ciências da Terra, Universidade de Évora
Patrick Le Moigne (CNRM/MF), Gianpaolo Balsamo (EVMWF)

Motivation (1)

- Construction of Alqueva dam
  - Project from the fifties
  - works began in 1975, than interrupted
  - In 1994, the environmental impact study includes an estimation of the climate impact (Miranda et al., 1995)
    - Pedro Miranda (FCUL) was the PI of this study
    - … I was his master student ...



ESTUDO DE IMPACTE AMBIENTAL DO ALQUEVA

CLIMA

Relatório Final

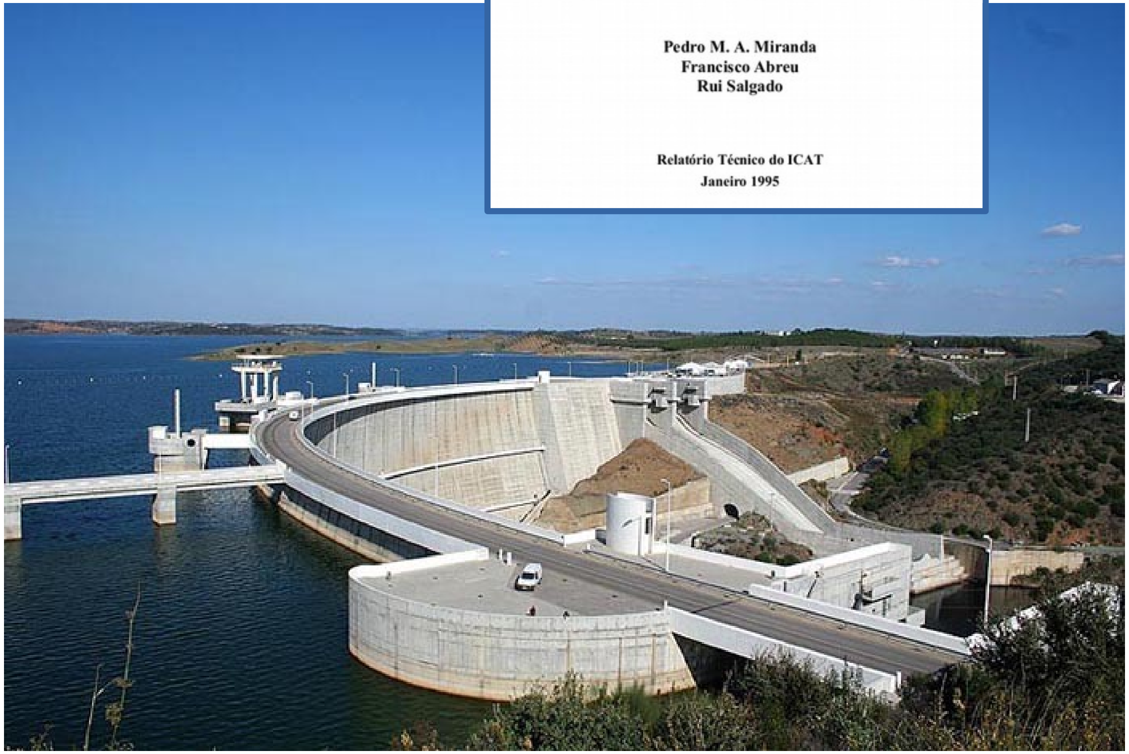
Pedro M. A. Miranda

Francisco Abreu

Rui Salgado

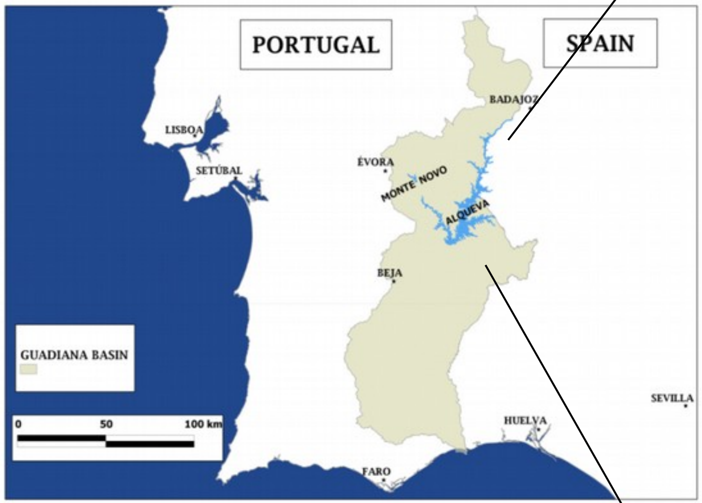
Relatório Técnico do ICAT

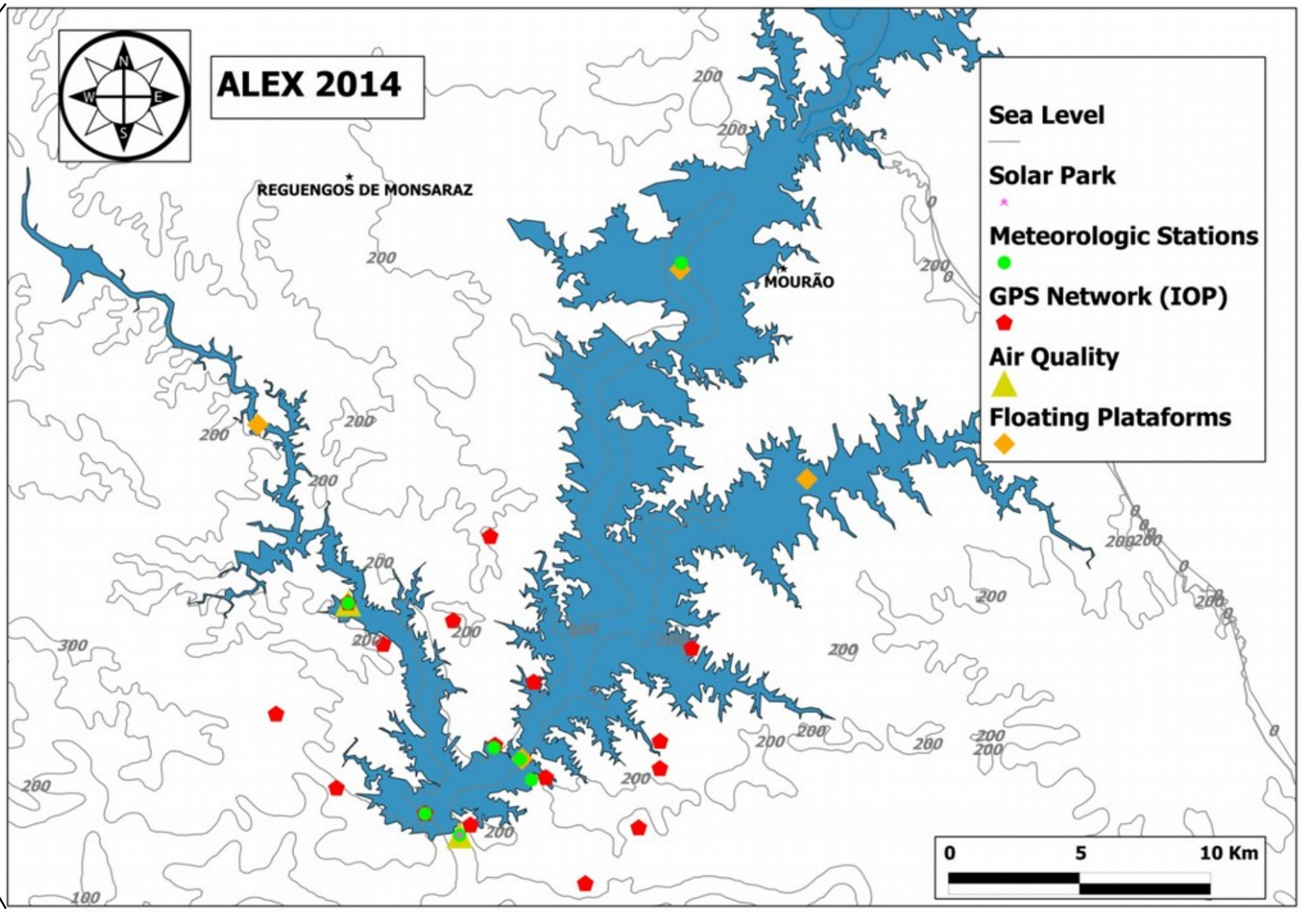
Janeiro 1995



The Dam is not do big, but...

The Alqueva and the region



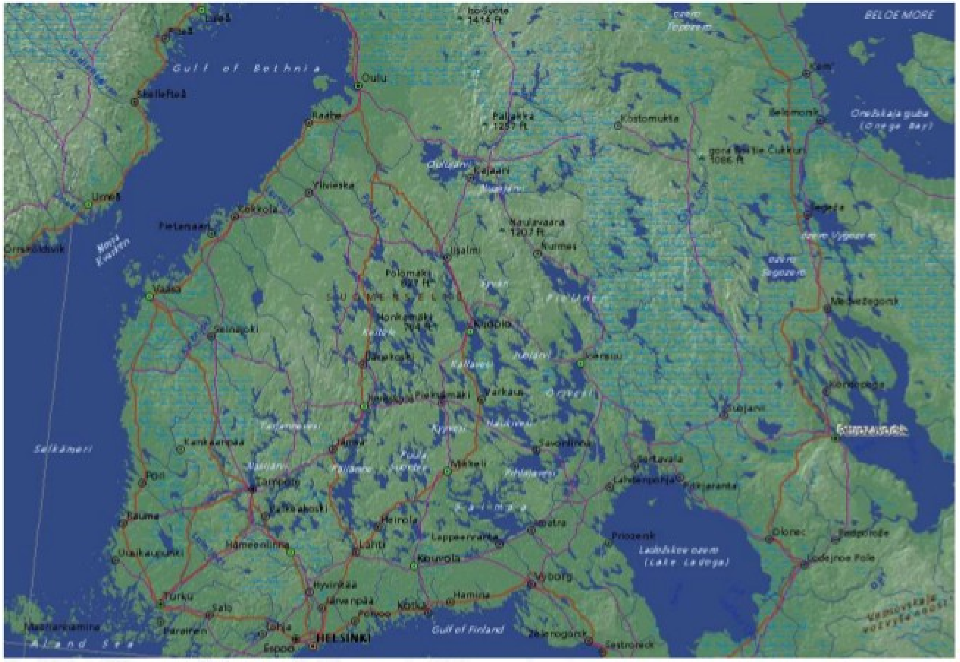


Surface area of 250 km^2
Gates were closed in 2002

Motivation 2: Lakes and NWP

- Some regions can be highly influenced by the presence of lakes
  - The boreal zone (9.2% of the area of Sweden and 10% of the area of Finland are covered by lakes)
  - Eastern Africa and of the American Great Lakes region
  - In many regions (Mediterranean, Brasil, ...), dams and reservoirs have been constructed.

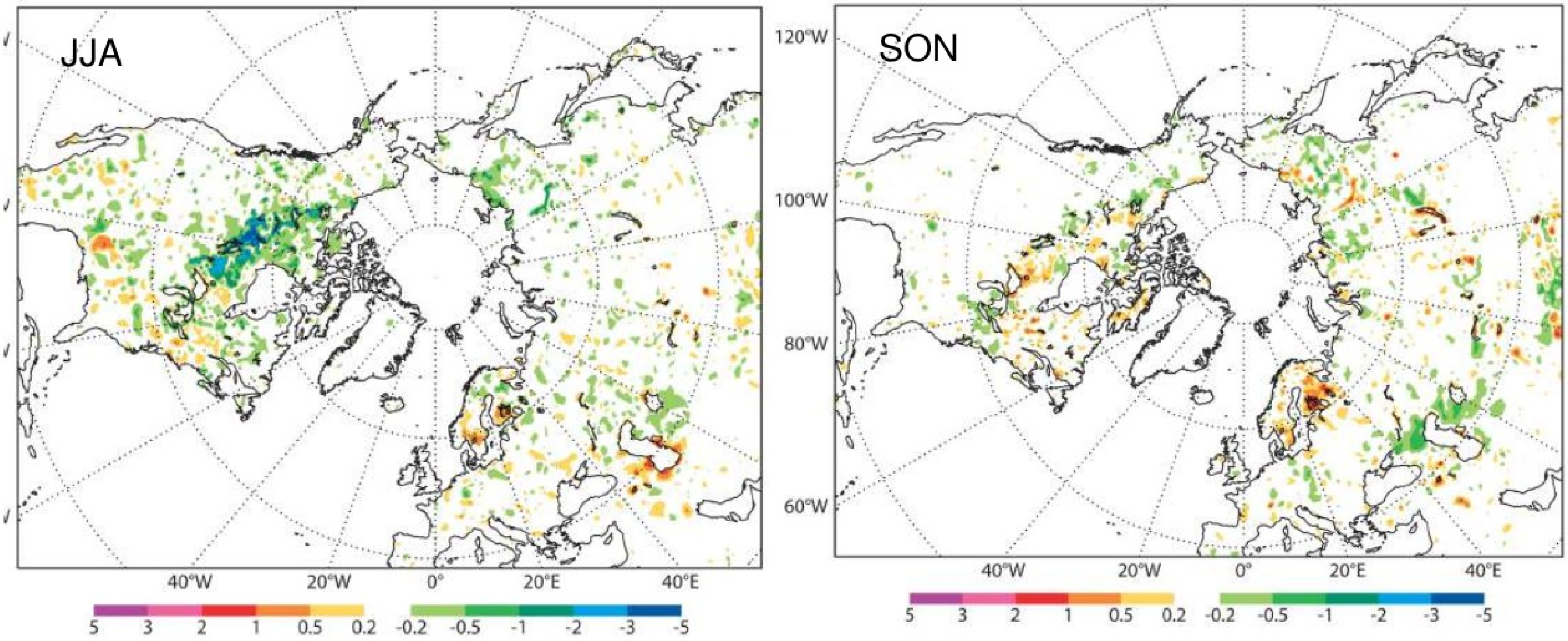
An accurate prescription of lake surface temperatures becomes more important as the horizontal resolution of the weather forecast models increases.



Lake Regions: Finland, Karelia

How Important is the lake representation?

Example from first tests in ECMWF



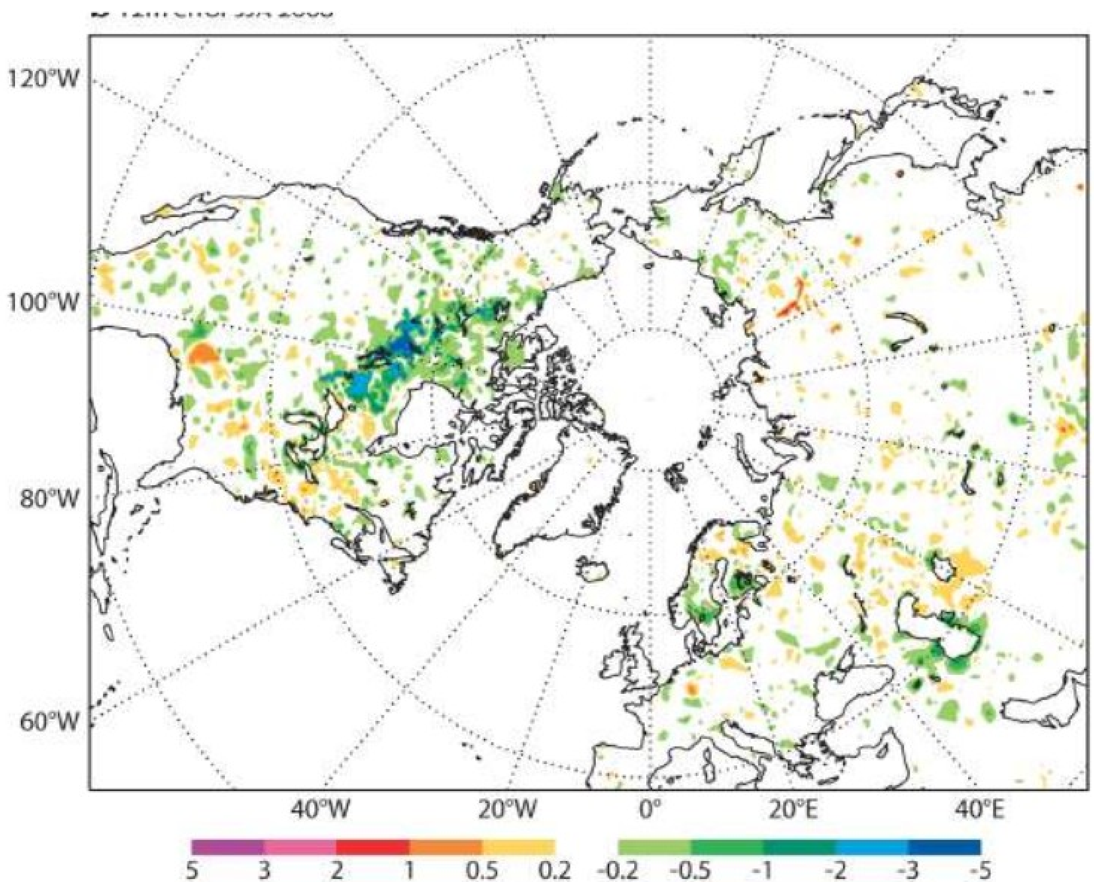
Sensitivity of 48-hour near surface temperature forecast (LAKE – NOLAKE)
- Sets of 10-day forecasts covering one full year (1988) at 50 km resolution with the operational IFS. Two experiments were performed with (LAKE) and without (NOLAKE) FLake activated.

Balsamo, G., R. Salgado, E. Dutra, S. Boussetta, T. Stockdale, M. Potes, (2012). Tellus

How Important is the lake representation?

Example from first tests in ECMWF (in climate mode)
Impact of interactive lakes on the T2m

- *A positive impact in spring and summer particularly over the North American lakes region and the European large lakes areas.*
- *In Winter, deteriorates T2m over central Canada while it improves in the eastern North America*
- *In Autumn the impact is milder, with improvement over Scandinavia*
- *Overall the impact is positive*



Impact of 48-hour T2m forecasts (valid at 00 UTC) for LAKE compared to NOLAKE, verified against the ECMWF T2m analysis: Mean Absolute Error difference for JJA 2008. Negative values indicate an improvement (MAE reduction)

Field campaigns in ALqueva (ALEX and ALOP)

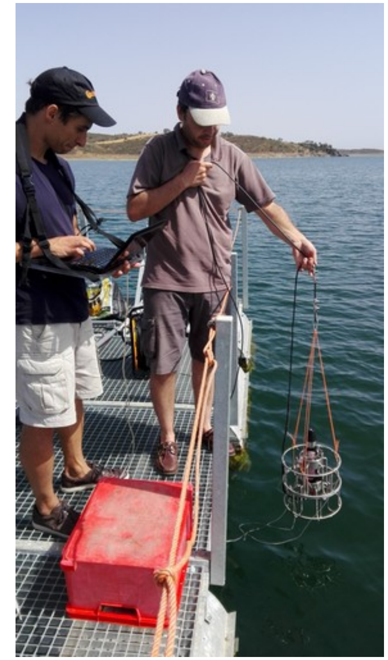
Understanding and predicting the complex interactions between climate, hydrology, ecosystem processes, water quality and biodiversity form the basis for a future sustainable management of Mediterranean systems and are important to:

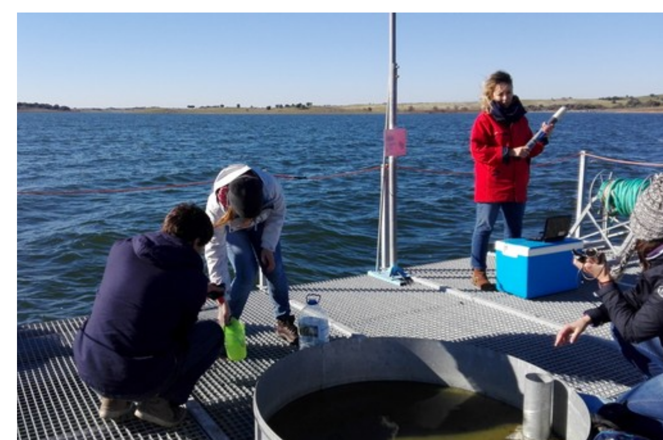
- **Study the climate effects of Alqueva**
- Improve the representations of lakes in NWP models (improve weather forecast and access climate impacts of man made lakes)
- Fulfil the requirements of the Water Framework Directive
- Improve the environmental management of the reservoir.

Now we are running a 2 year Experiment

- ALOP
- Observations in Water and atmosphere





Summary

Among the various effects of ALqueva (and lakes and reservoirs) on the local climate, this presentation is about:

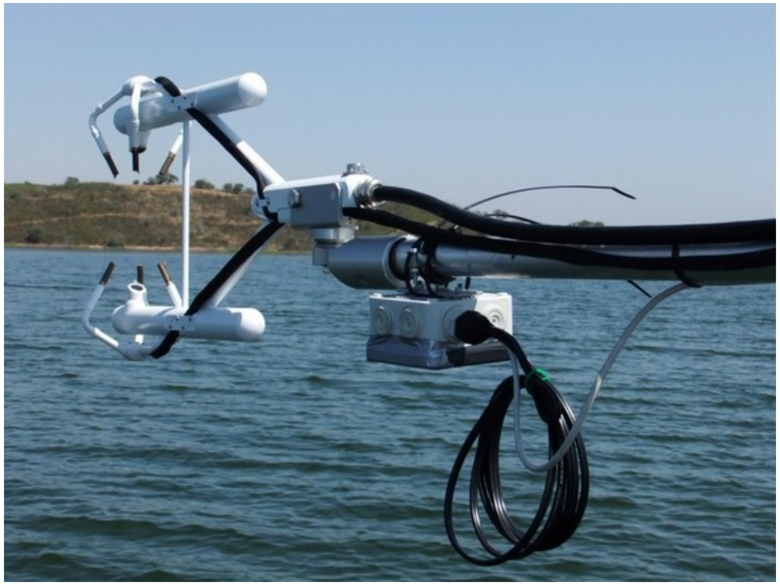
- The surface energy balance and partition
- effects on air temperature, moisture and electrical field
- Development of lake breeze
- The impact on fog
- The impact on the boundary layer

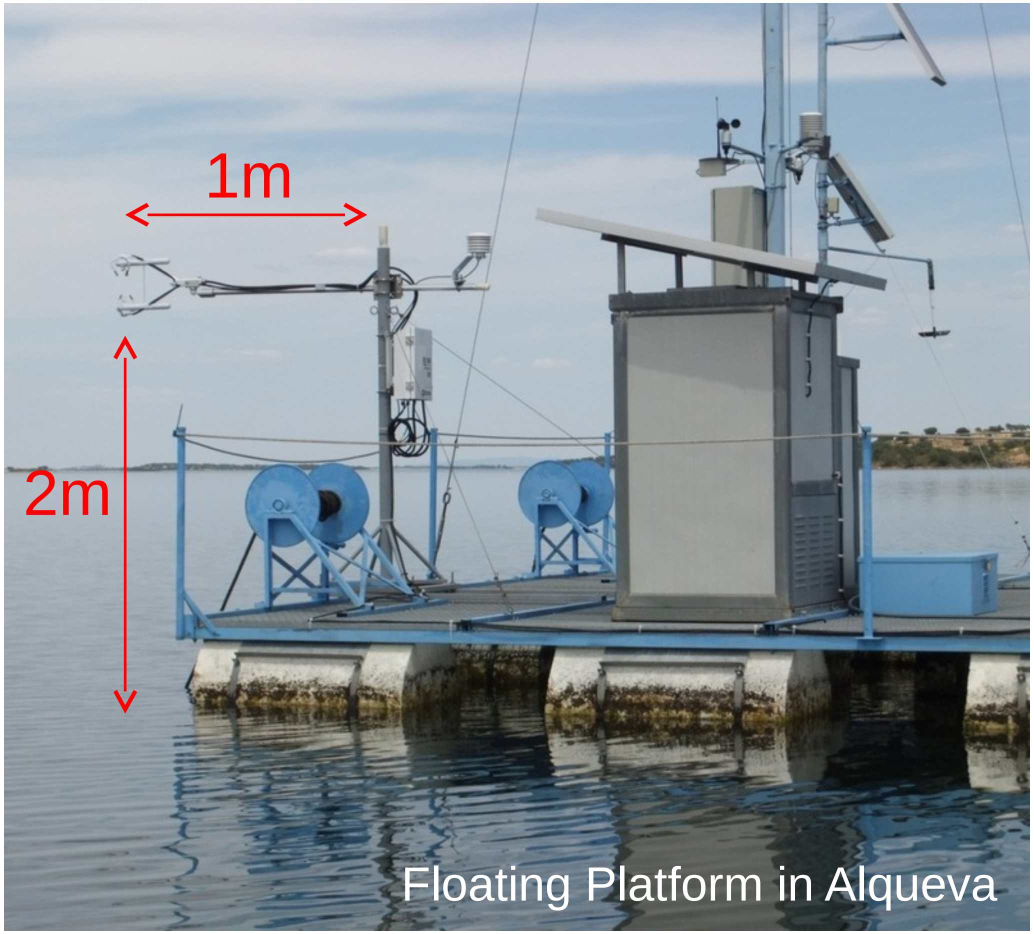
Alqueva reservoir is our natural laboratory. The methodology is based on:

- Measurements ALEX / ALOP and others
- Simulations with the Meso-NH model

Eddy covariance measurements

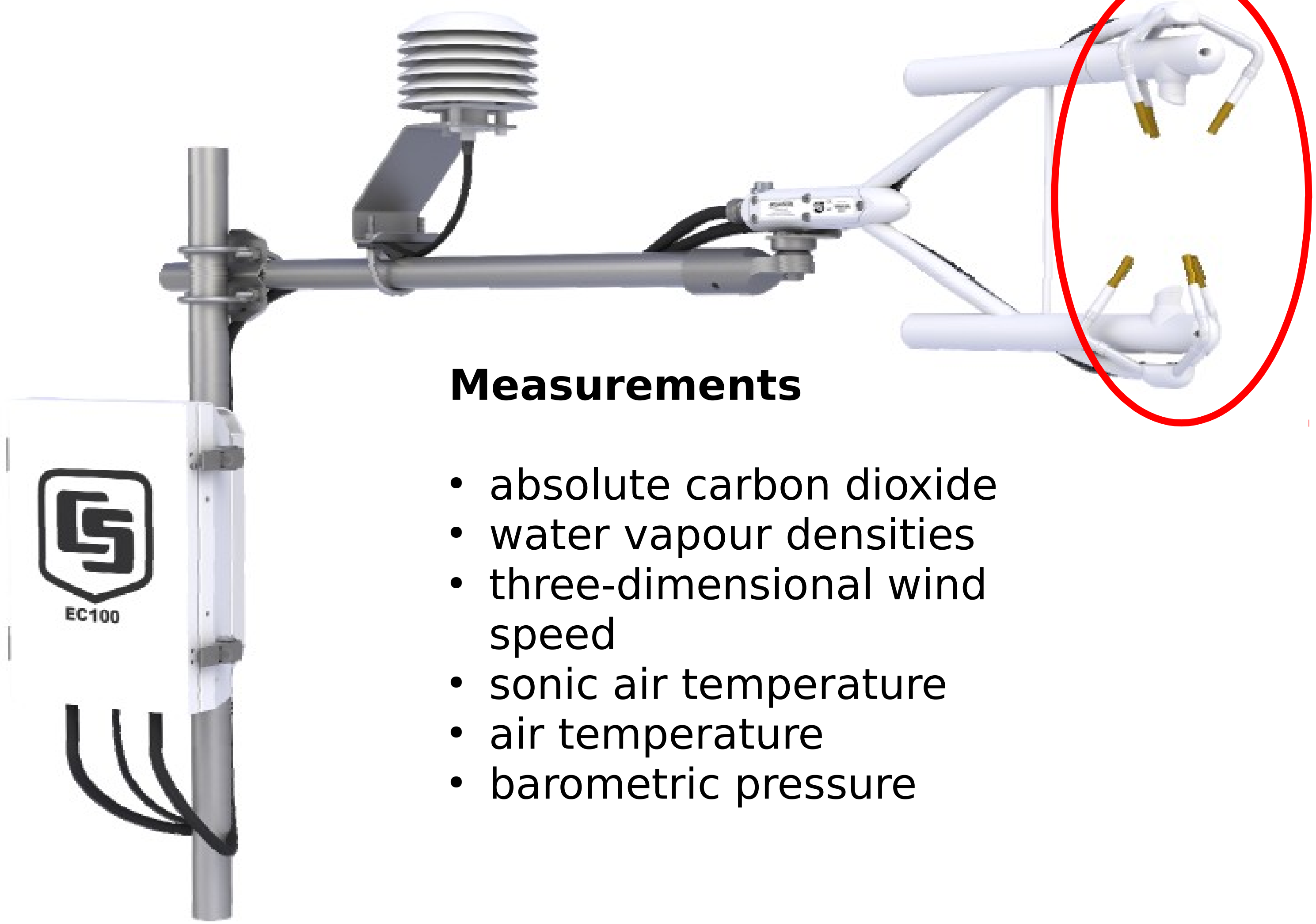
- Central point is a floating platform
- Energy fluxes (radiative and sensible and latent heat), CO2 and H2O over the reservoir
- water temperature at 14 levels





Potes et al., 2017

Integrated CO_2/H_2O Open-Path Gas Analyzer and 3D Sonic Anemometer

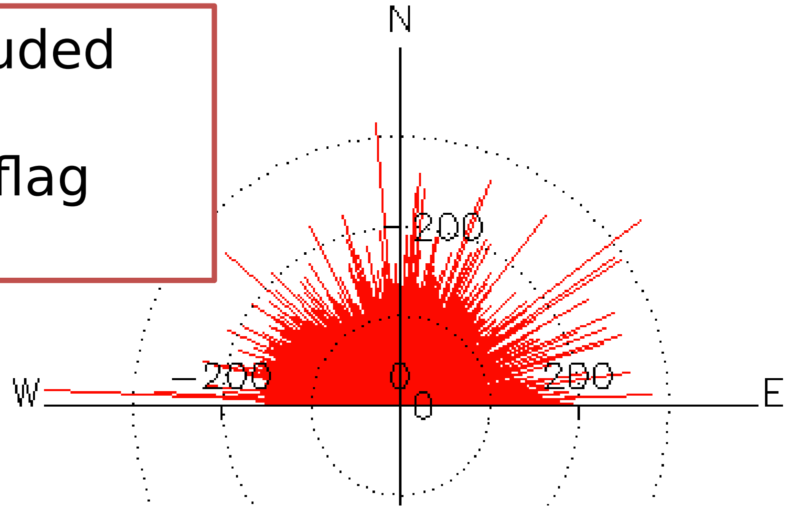


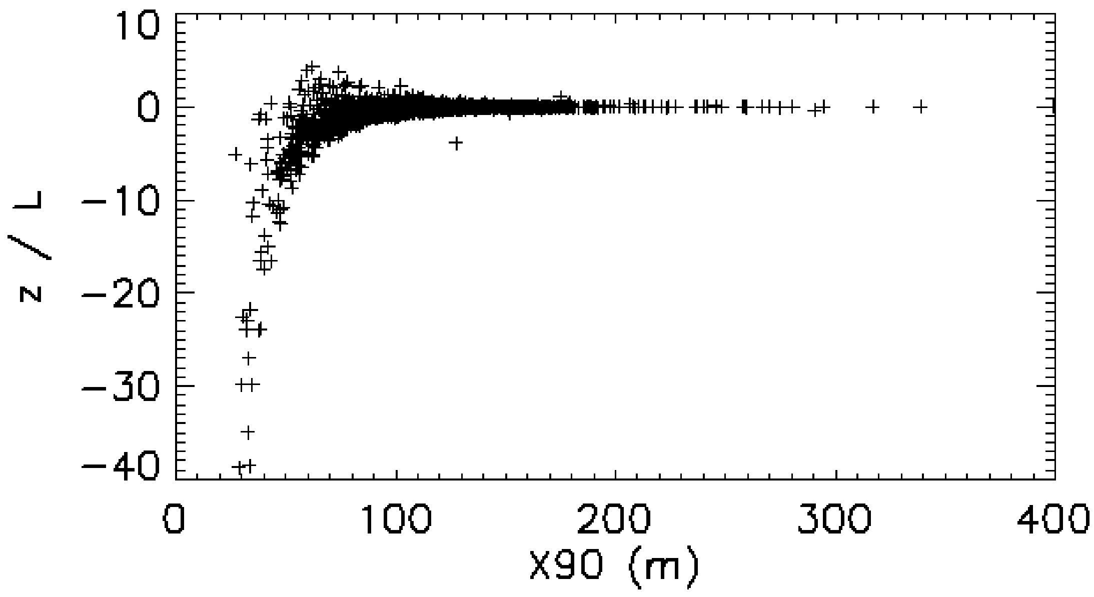
Measurements

- absolute carbon dioxide
- water vapour densities
- three-dimensional wind speed
- sonic air temperature
- air temperature
- barometric pressure

EC data treatment

35% excluded by wind direction flag





Coordinate transformation

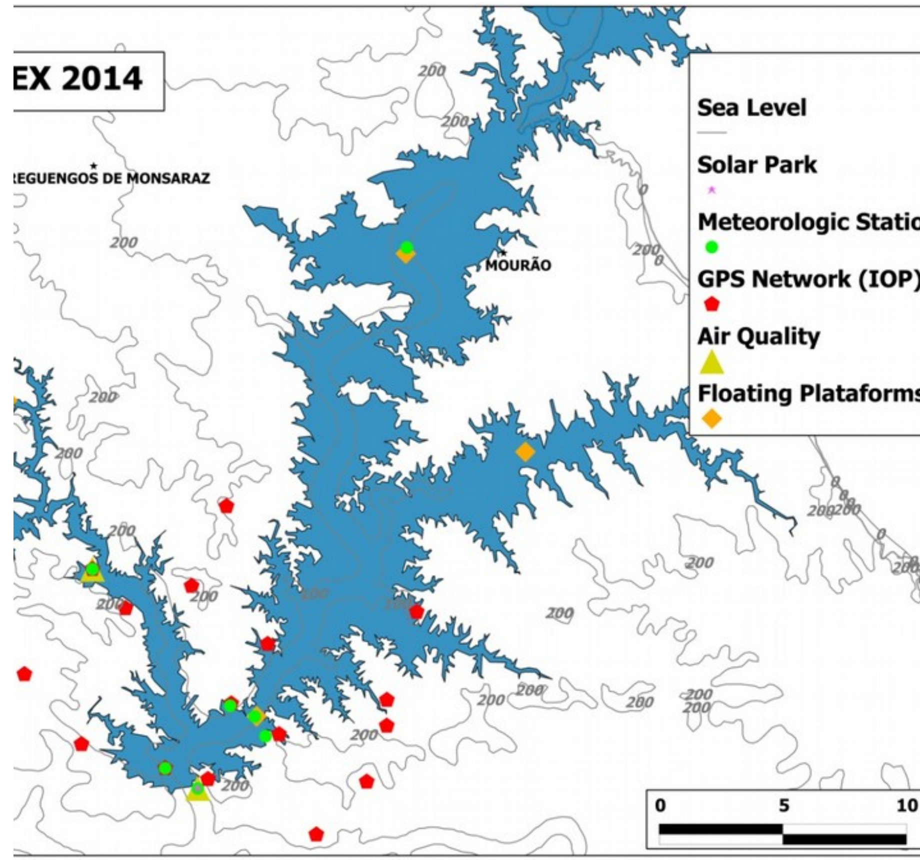
WPL correction were made for 30 minutes fluxes calculations

Footprint analysis according Kljun et al. 2004

Average X90 : 106.2 m
Average Z / L : -0.48

Relation between stability (Z/L) and footprint length (90% - X90)

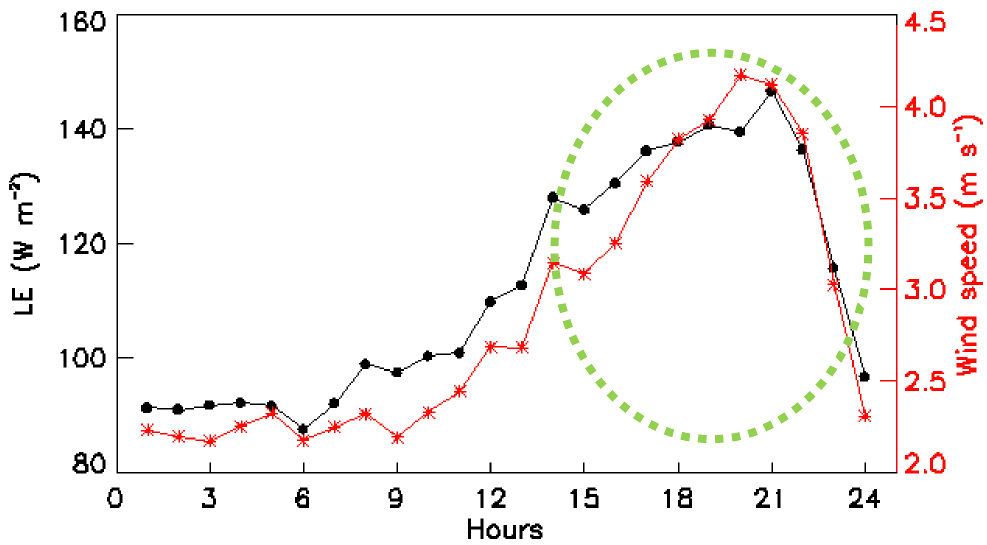
Weather stations

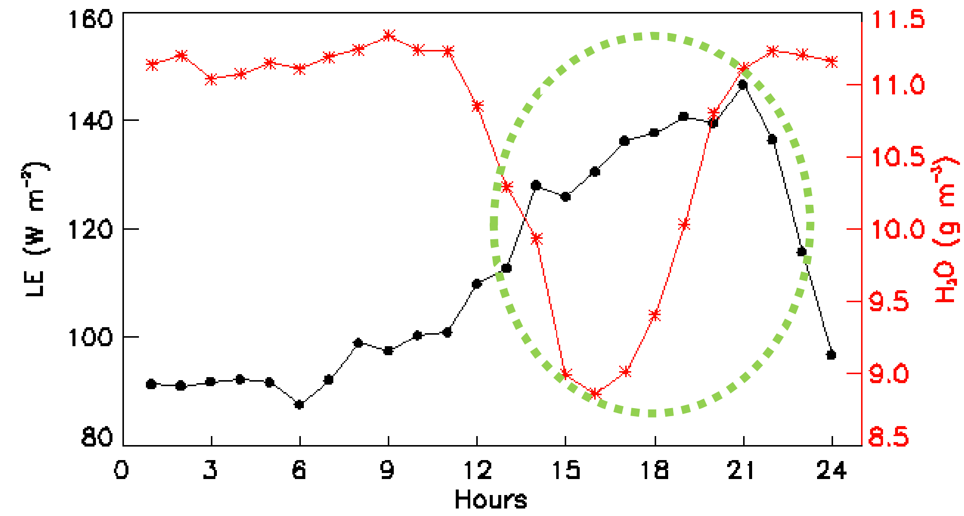


- near surface meteorological stations: temperature, humidity, wind, precipitation and pressure.
- automatic weather stations were in place
    - upwind and downwind

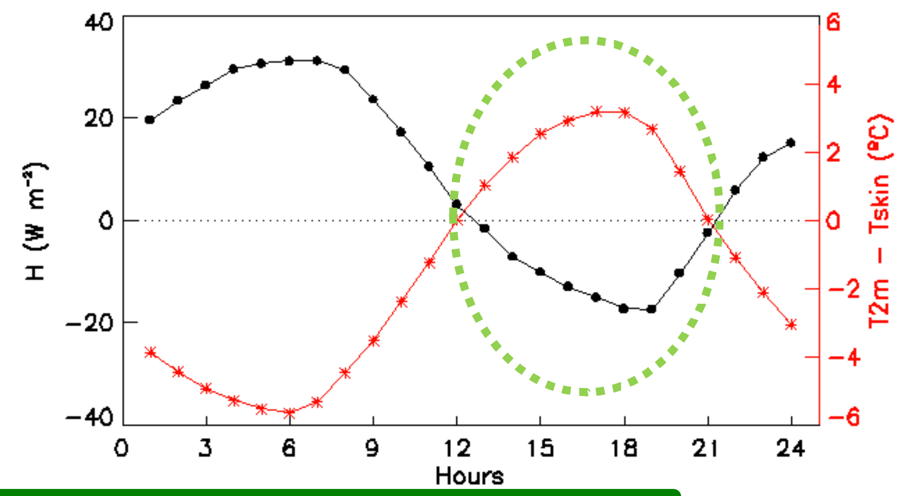
Heat fluxes over the reservoir

ALOP



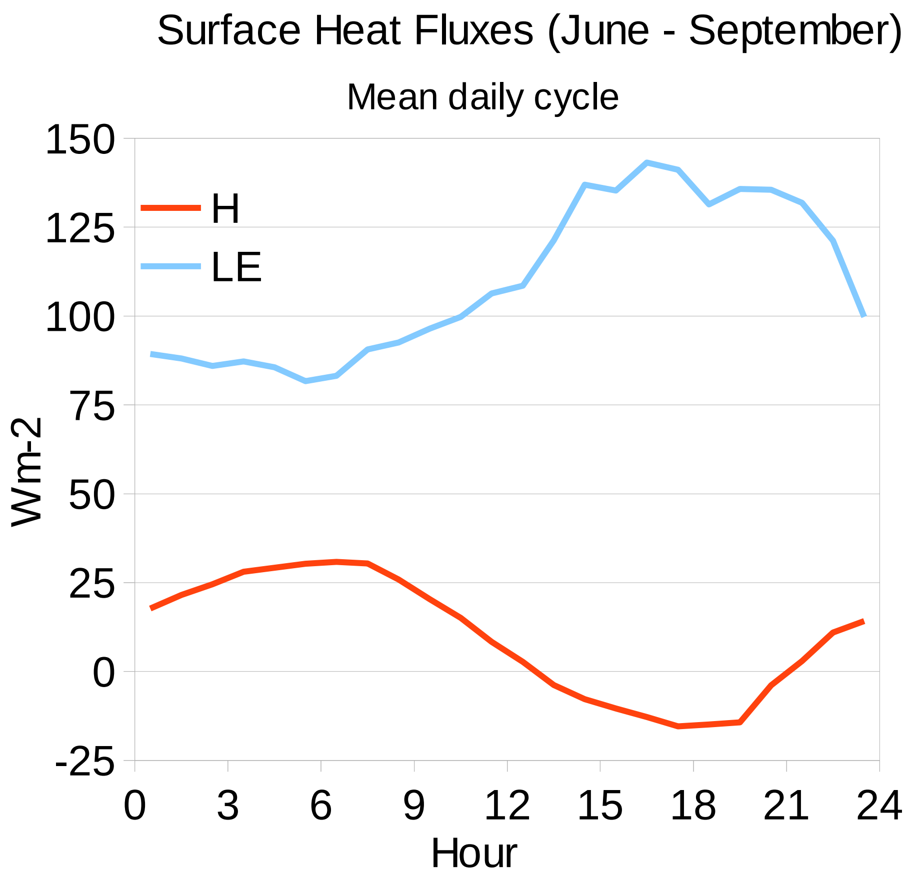


During the afternoon, between 12 and 21 hours, the air temperature is hotter then reservoir surface and lake breeze is developed allowing the subsidence of upper dry air leading to an increase of latent heat and forcing a negative sensible heat flux.



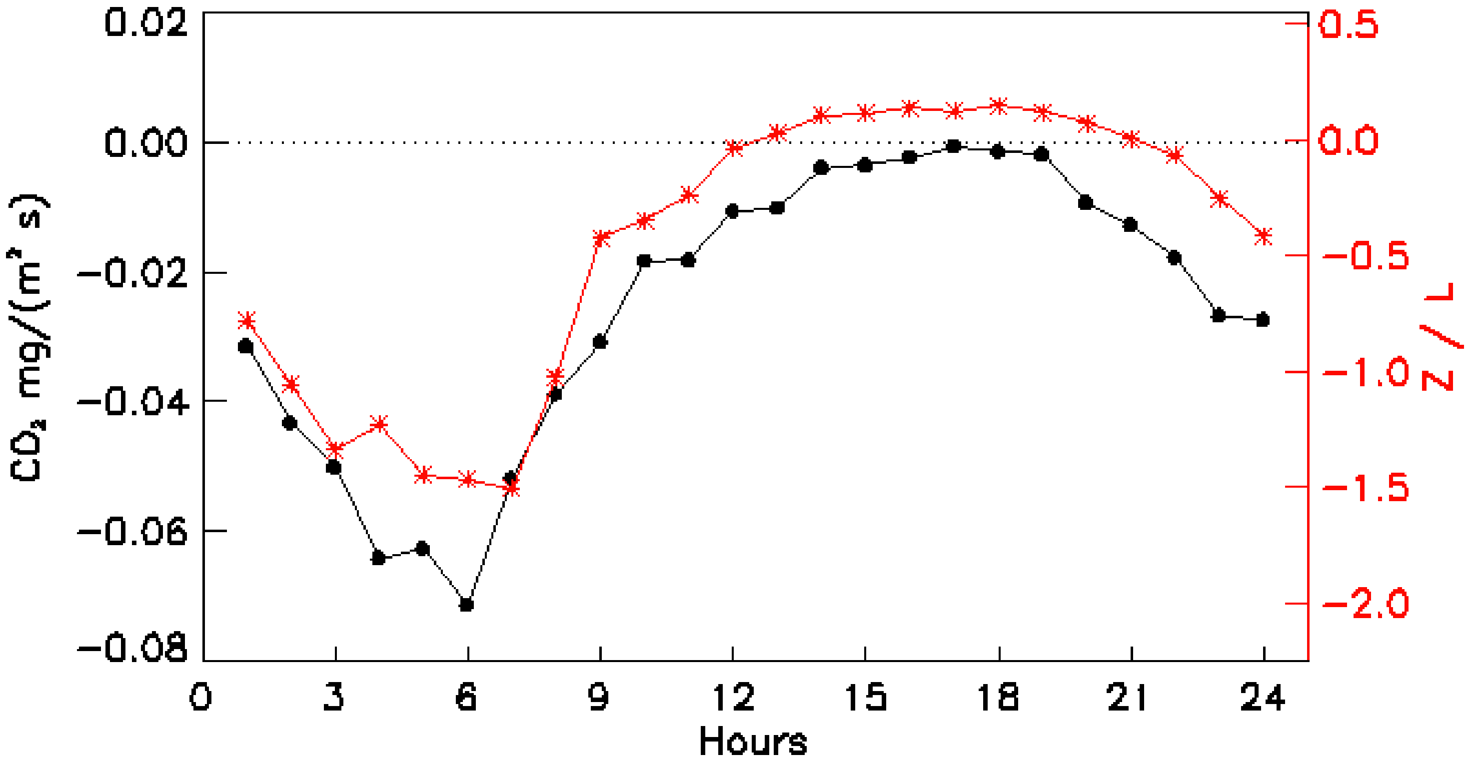
Summer average values: June to September 2014

Surface energy Balance



- The H is generally small (usually less than 30 Wm-2), with a maximum at sunrise. In the afternoon it is normally slightly negative.
- In average, the latent heat flux is always positive, reaching the highest values in the afternoon, when the wind speed is higher. In the evening, the values are, on average, about 150 Wm-2,

CO2 over reservoir (June to September)



Greater uptake occurs under instability (Z / L) < -0.1

CO2 over reservoir (June to September)

At night – CO_2 plants respiration

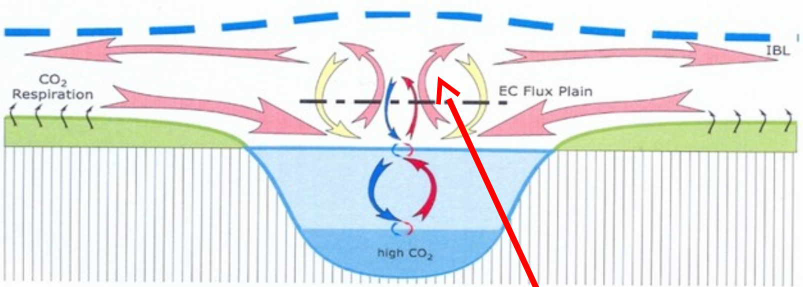


Figure 14. Processes influencing the eddy covariance (EC) flux measurements above a lake surface at night. Because EC measurements cannot be performed directly at the air-water interface, the CO_2 exchange with the lake (blue and red arrows) at EC reference height (black dash-dotted line) is measured together with the exchange flux of CO_2-rich air from the land surrounding the lake (pink and yellow arrows) where CO_2 originates from respiration of soils and vegetation (black arrows). This local lake-breeze type circulation is expected to be restricted in its vertical extent by an internal boundary layer (IBL).

During day – CO_2 plants photosynthesis

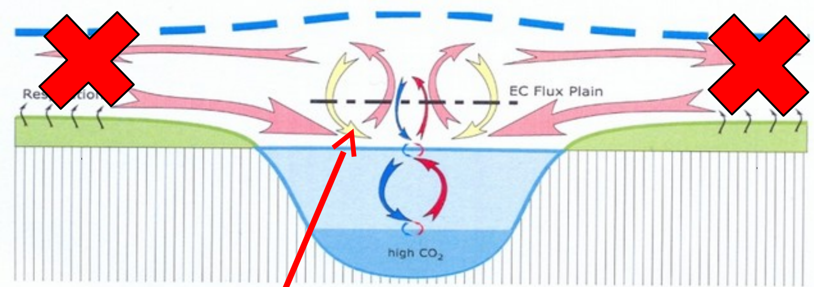
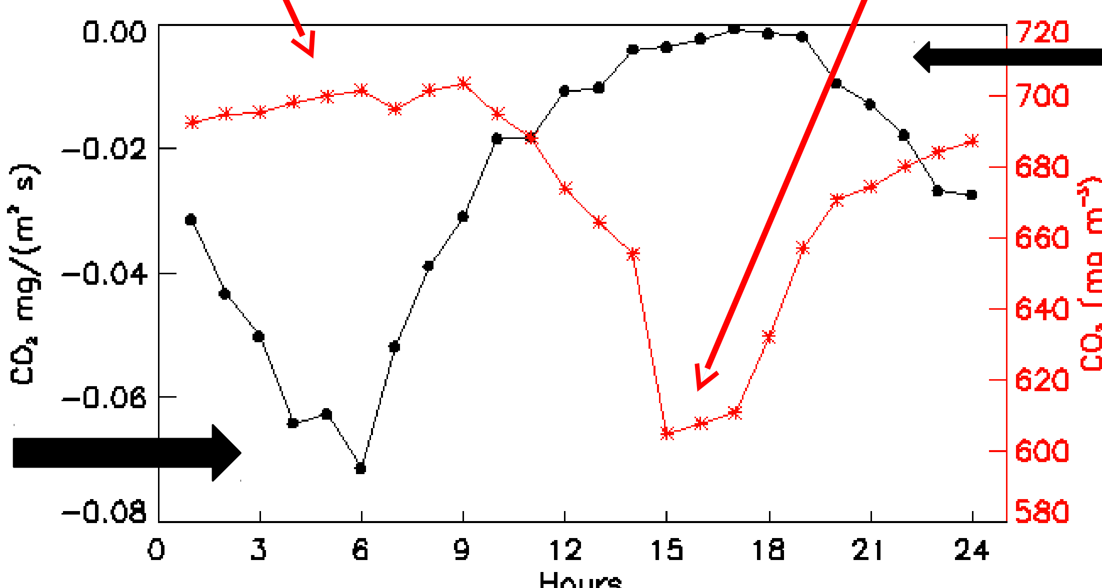


Figure 14. Processes influencing the eddy covariance (EC) flux measurements above a lake surface at night. Because EC measurements cannot be performed directly at the air-water interface, the CO_2 exchange with the lake (blue and red arrows) at EC reference height (black dash-dotted line) is measured together with the exchange flux of CO_2-rich air from the land surrounding the lake (pink and yellow arrows) where CO_2 originates from respiration of soils and vegetation (black arrows). This local lake-breeze type circulation is expected to be restricted in its vertical extent by an internal boundary layer (IBL).

Greater uptake by the reservoir during night – high negative flux



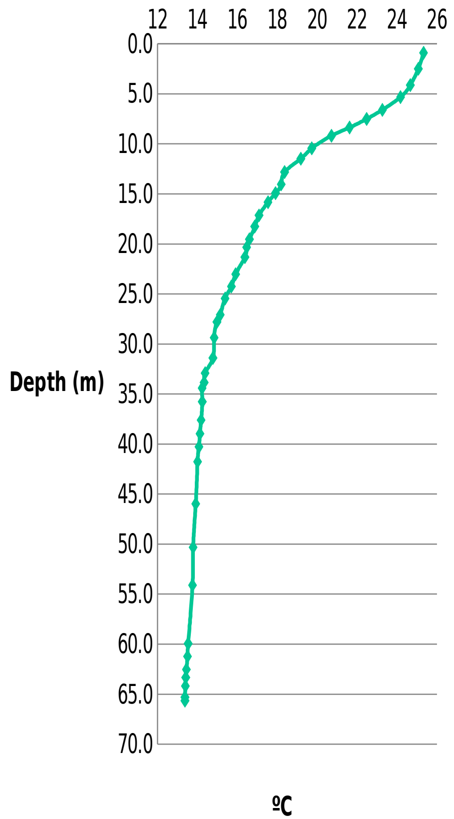
Lower uptake by the reservoir during day – weaker flux, still negative

In black flux

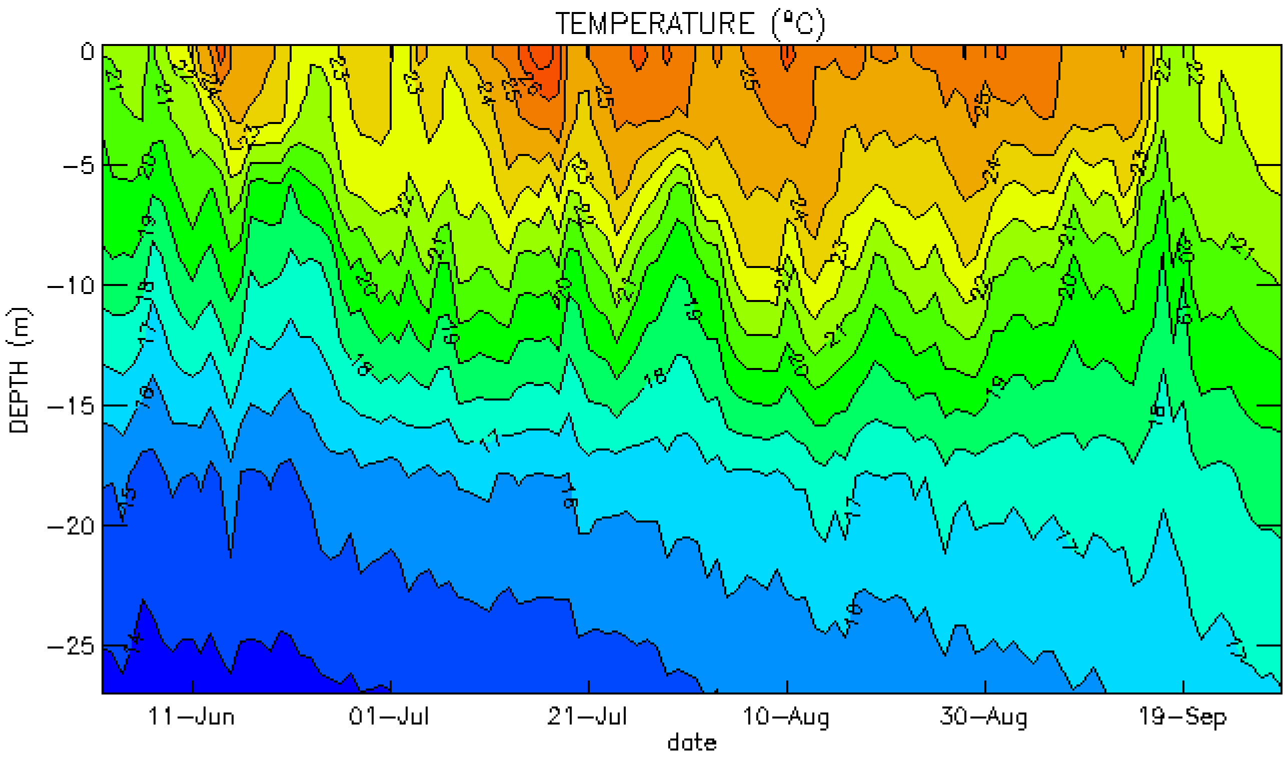
In red concentration (air)

Water Temperature

Ponctual temperature profiles up to bottom



Continuous measurements up to 27 meters depth during the 4 months

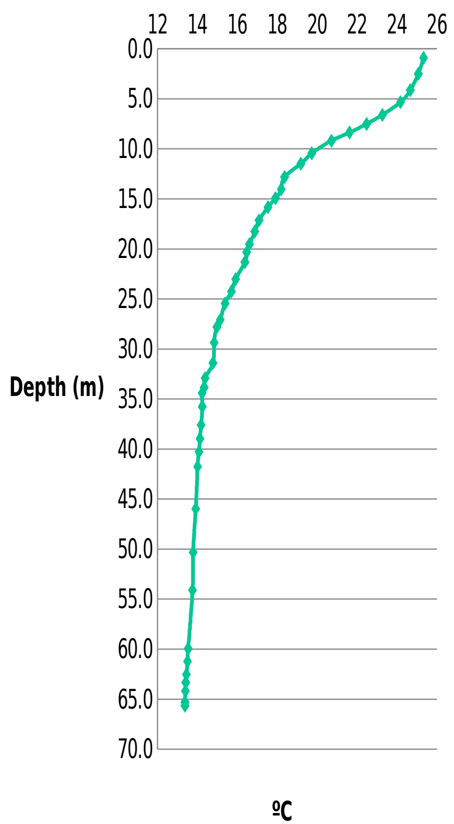


Thermocline between 5 and 15 meters. Also visible in the right graph.

It shows the diurnal warming in the first meters and progressive increase of temperature in deeper layers (below 10 meters)

Water Temperature

Ponctual temperature profiles up to bottom



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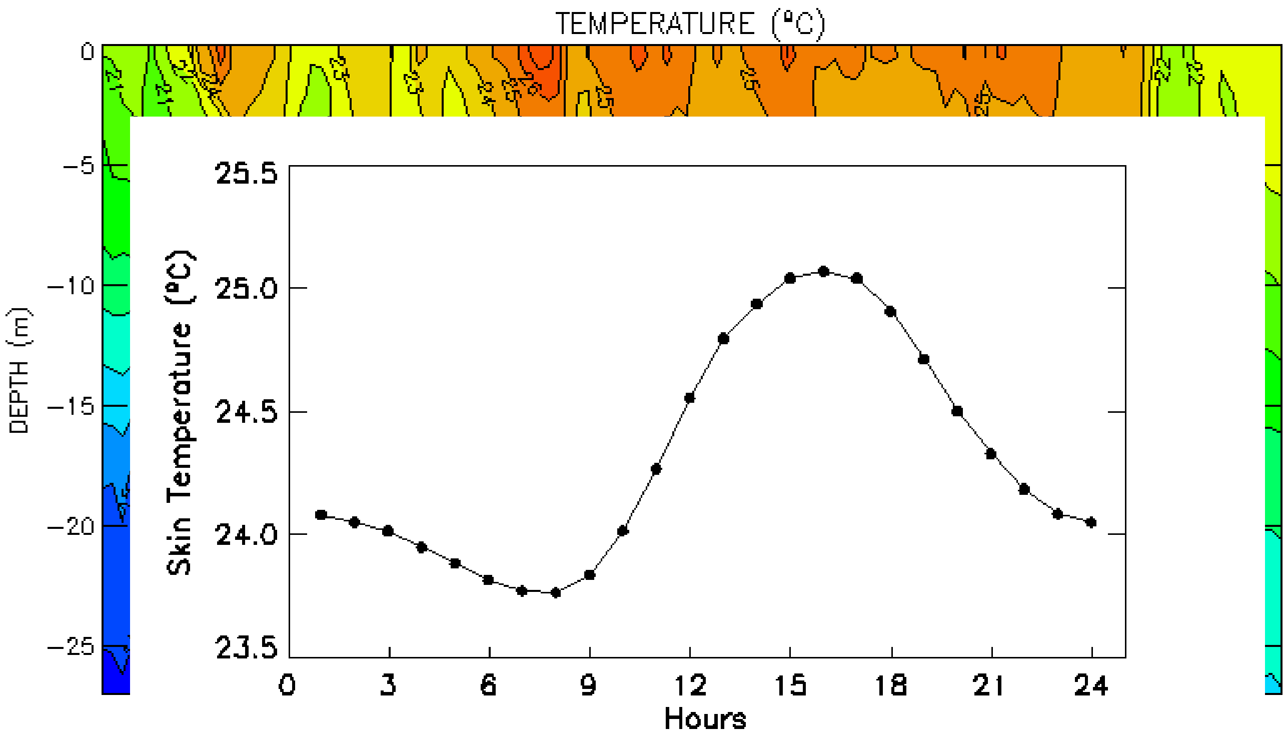
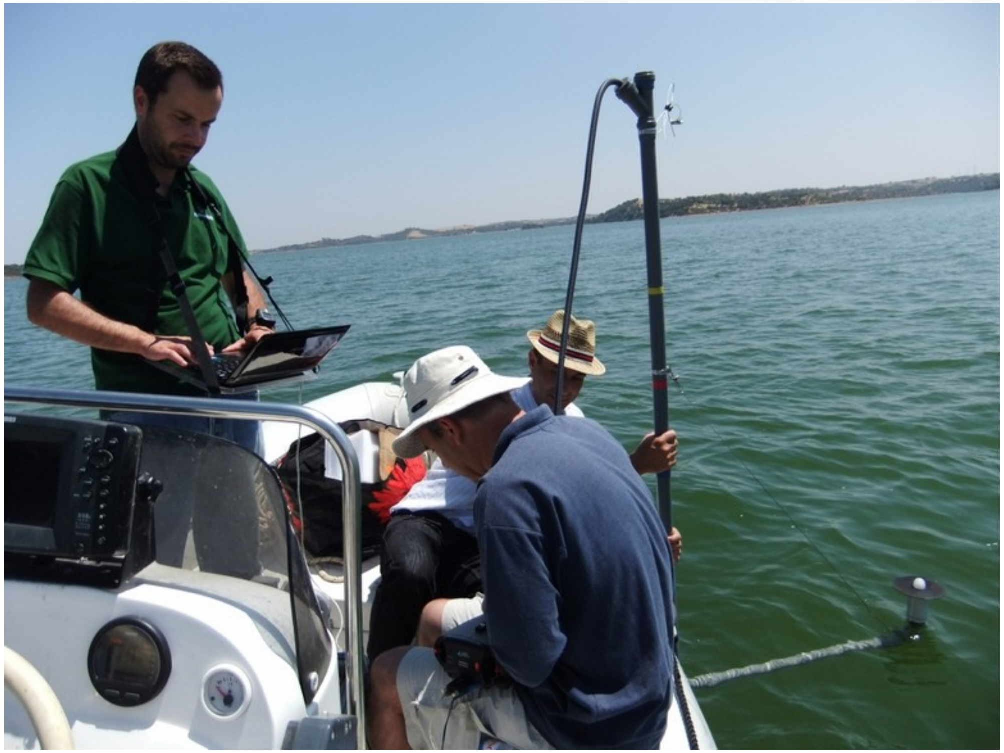


It shows the diurnal warming in the first meters and progressive increase of temperature in deeper layers (below 10 meters)

Underwater irradiance system



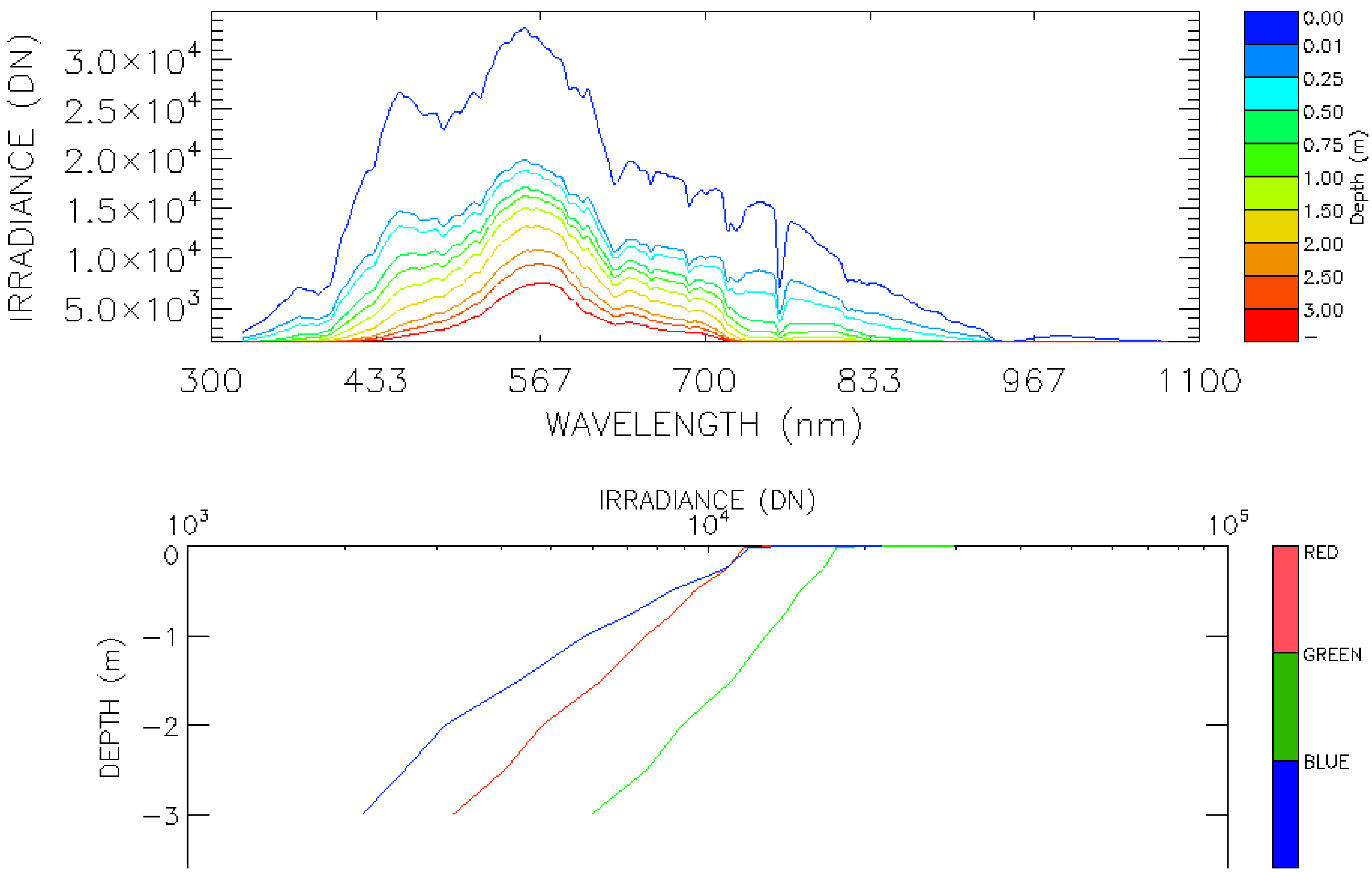
FieldSpec UV/VNIR da ASD coupled to an optical cable and a cosine receptor

- Wavelengths between 325 – 1075 nm
- Spectral resolution of 3 nm
- 180º of FOV
- Maximum depth of 3 m

Turbidity measurements

Potes et al., 2013

Underwater irradiance profiles



IOP 23 July
Clear Sky
Low wind

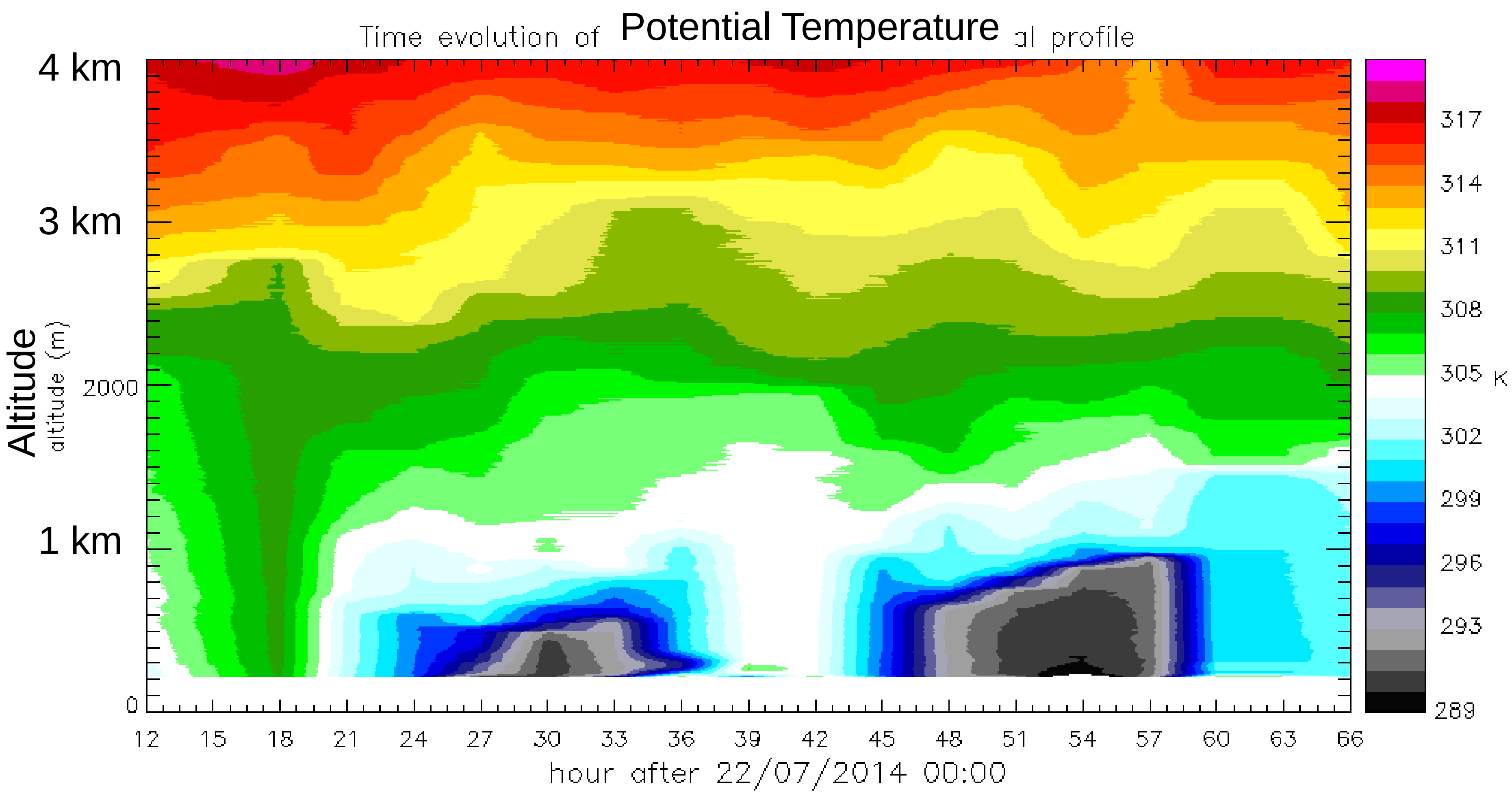
Profiles of the sum of irradiance between 400-500, 500-600 and 600-700 nm.

Intensive Observation Periods

IOP 2014: 22, 23 and 24 of July 2014, during which:

- 18 meteorological balloons with meteorological radiosondes were launched.
- every 3 hours

IOP Atmospheric Radiosondes



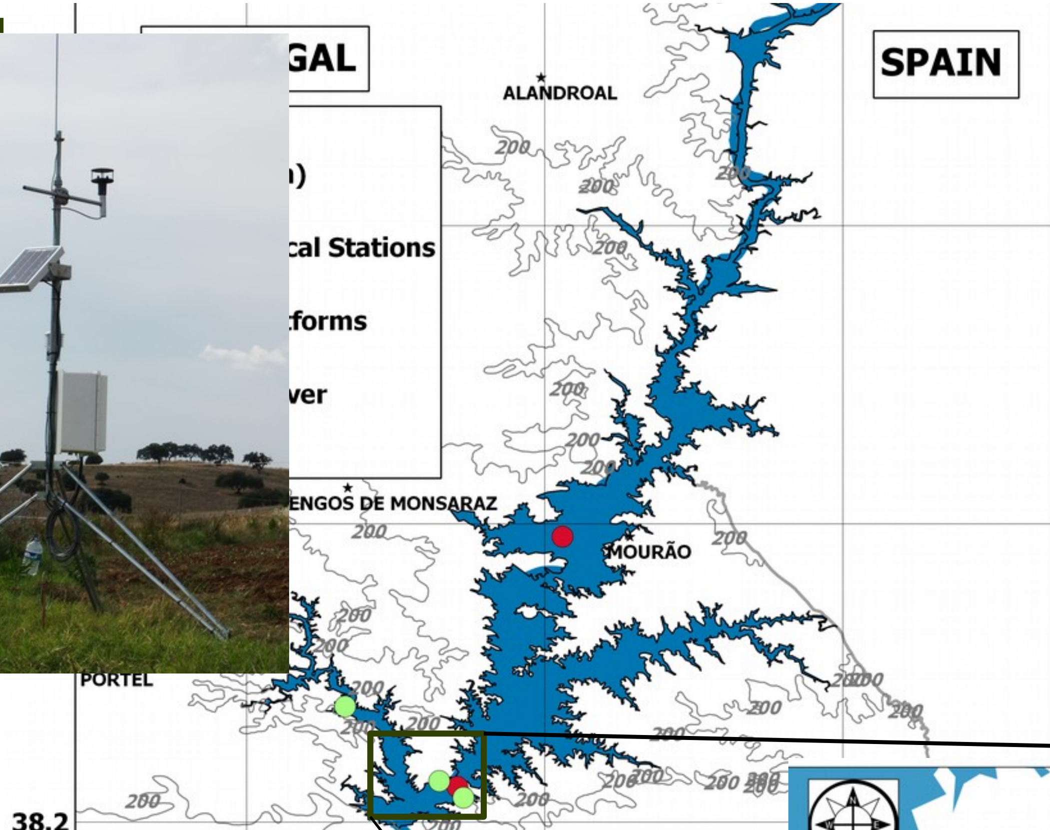
Characterization of the vertical structure and synoptic conditions

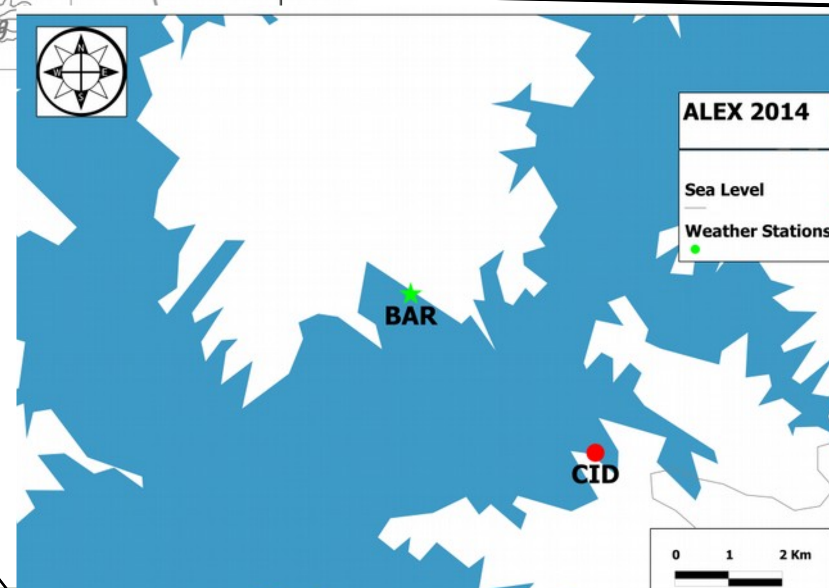
- Anticyclonic conditions
- Boundary layer well developed (more than 2500m deep in 1st day)
- Instable surface layer in the region (over land) with high values of sensible heat flux
- Near surface temperatures greater than 35ºC (1st day)

atmospheric ionization profile

- Geigersondes (Harrison et al., 2012, Reading University) were coupled to the meteorological radiosondes in order to obtain the atmospheric ionization profile
  - based on two miniature Geiger tubes
  - using a digital interface system, the radiosonde's meteorological data are also be retained.

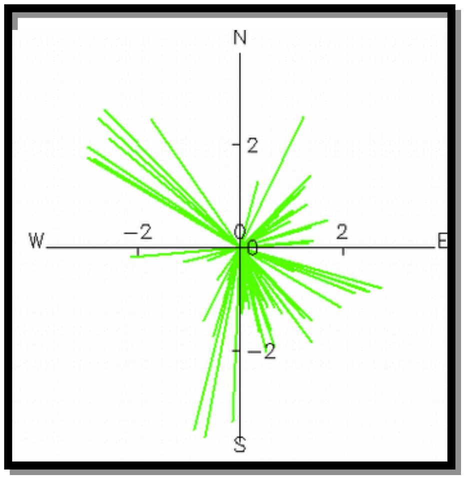
Sea Breeze: Observations



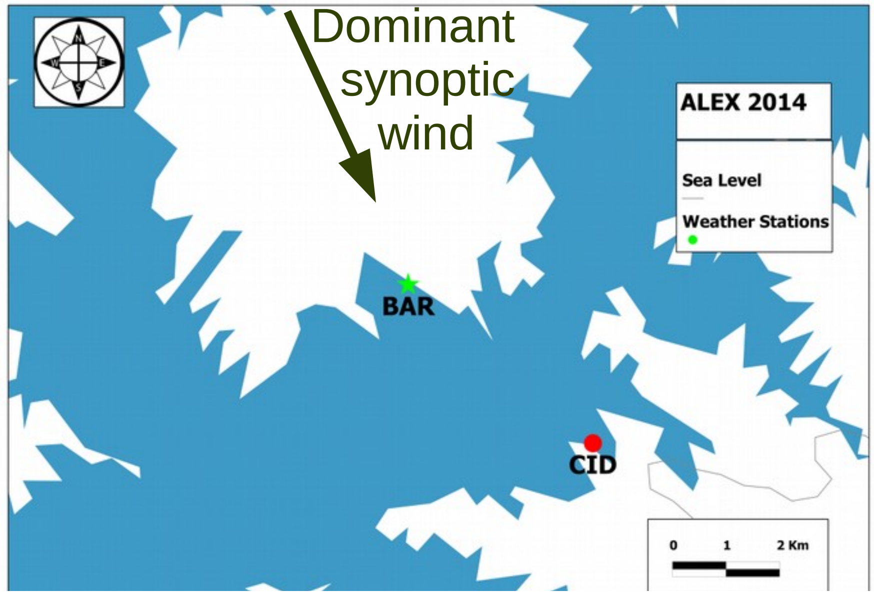


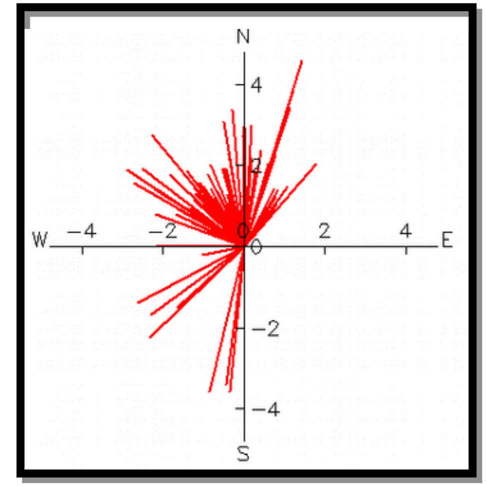
Potes, M. Salgado, R., Costa M.J., Morais, M., Bortoli, D., Kostadinov, I. and Mammarella, I. (2017). Lake–atmosphere interactions at alqueva reservoir: a case study in the summer of 2014. Tellus A 2016, 00, 1272787, http://dx.doi.org/10.1080/16000870.2016.1272787

Sea Breeze: What says observations

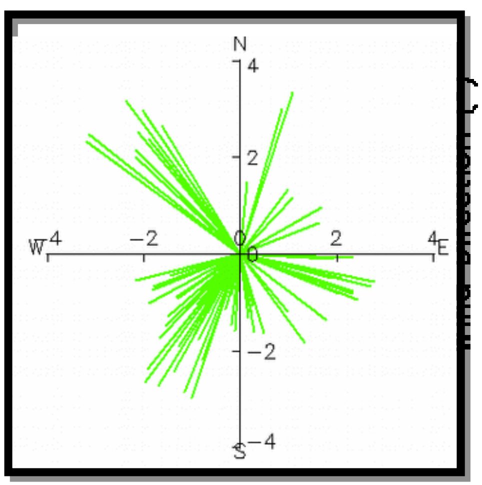


BAR:10-12 UTC

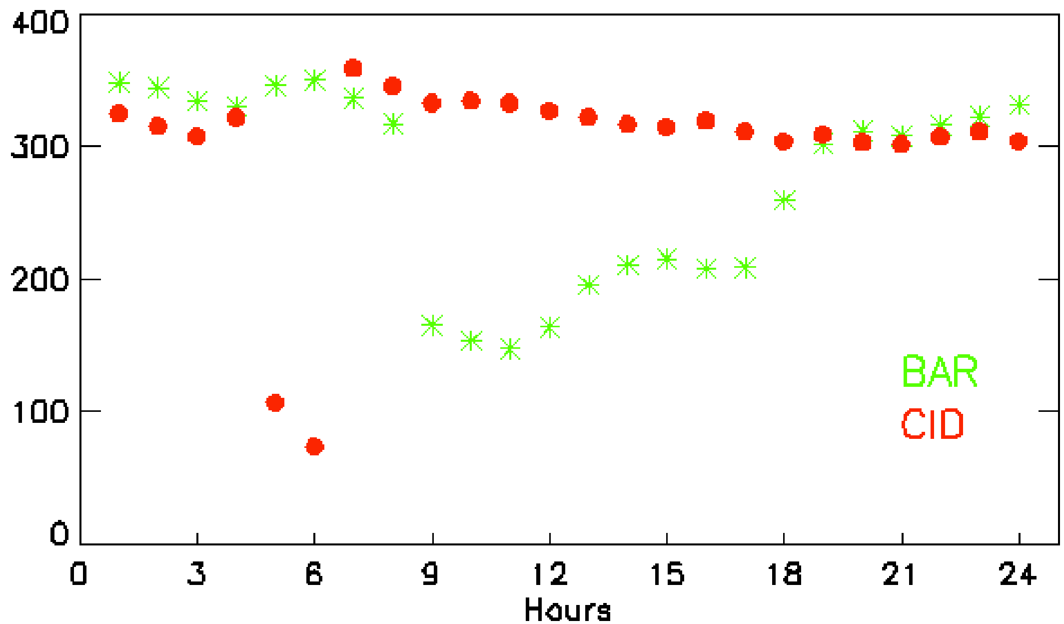


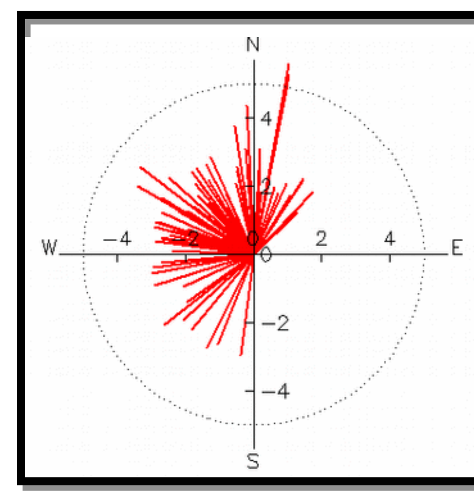


CID: 10-12 UTC



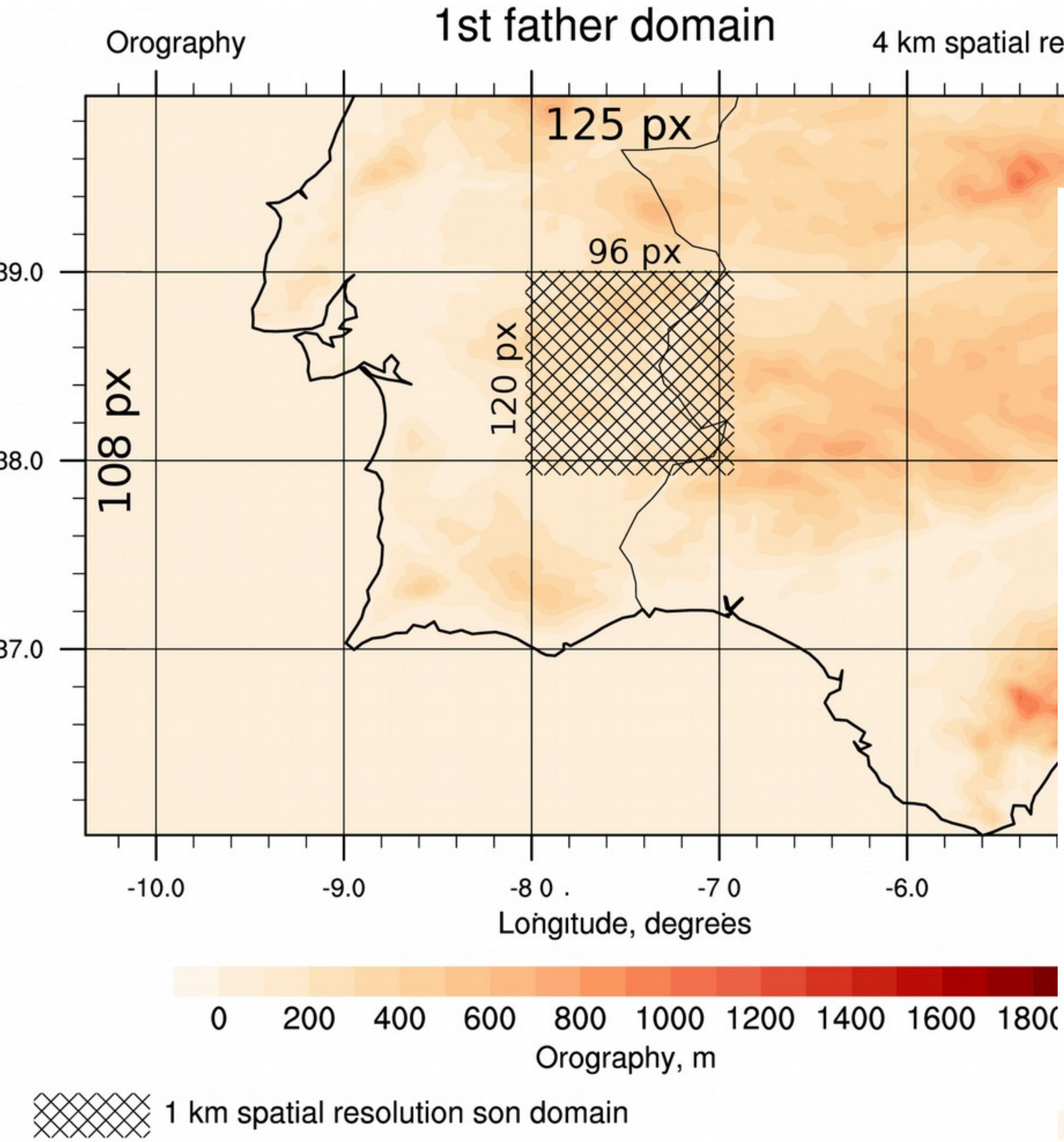
BAR:13-15 UTC

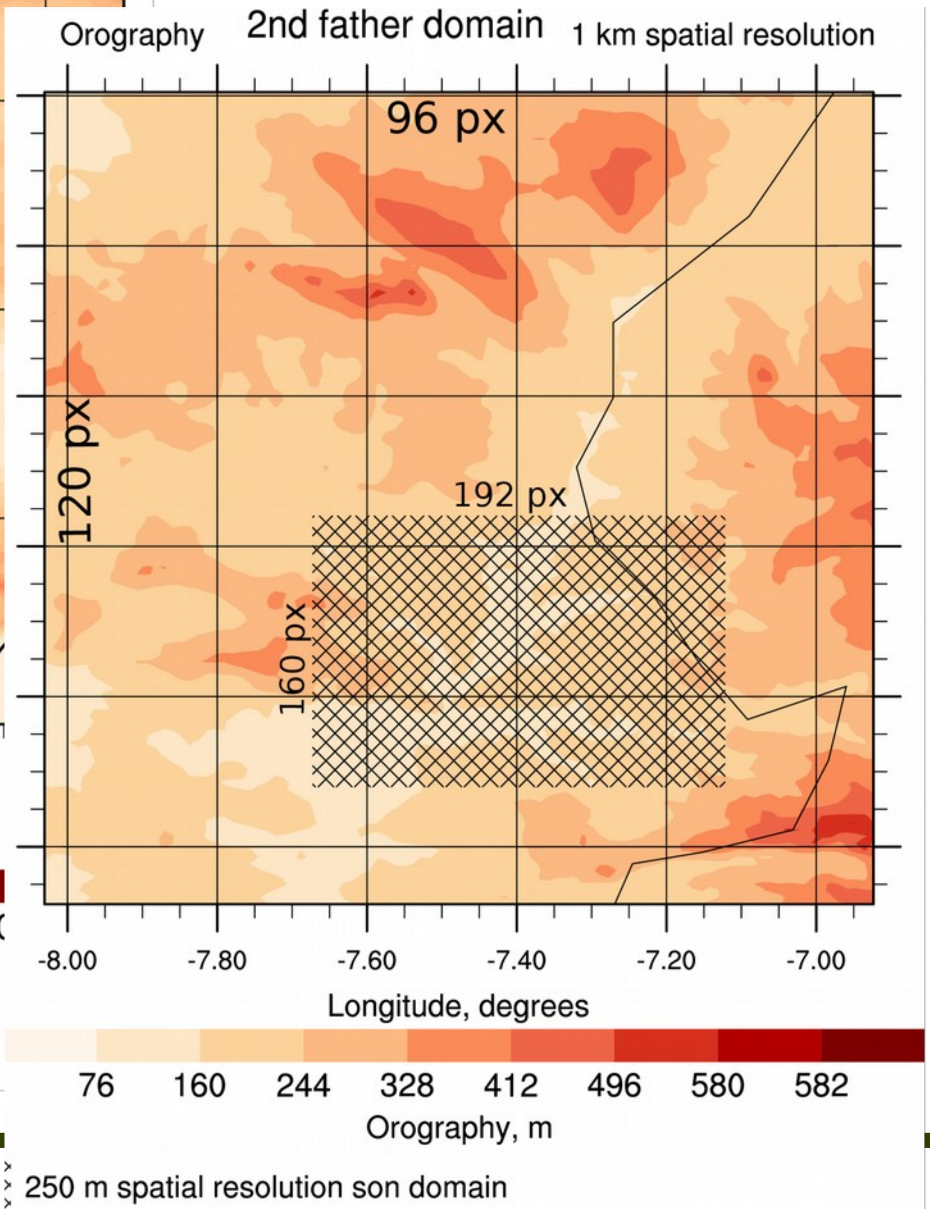




CID: 13-15 UTC

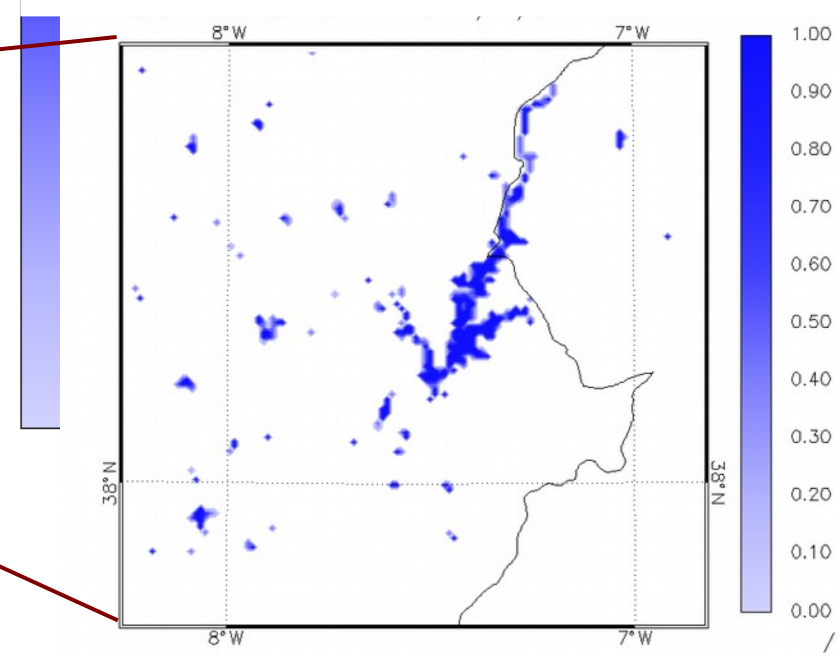
Lake Breeze simulation: Domains 1 & 2





Simulation Setup

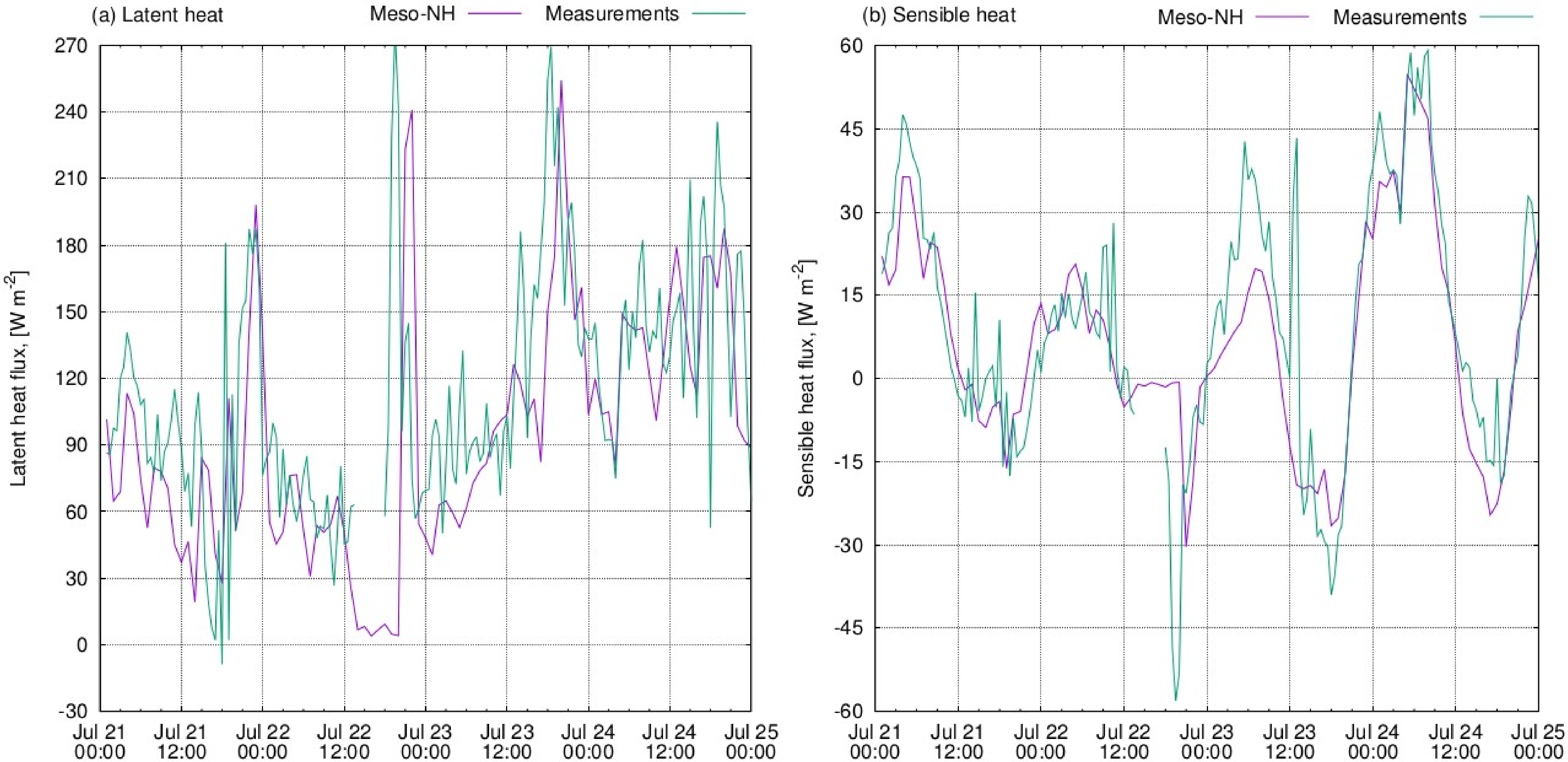
MesoNH v5.3.0 + FLake scheme;
3 nesting levels: 4 km – 1 km – 250 m;
Inicialized & forced by ECMWF analysis;
Ecoclimap (updated to include Alqueva);
Two simulations: with and without lake;
Turbulence: TKEL (1D);
No deep convection, but EDKF;
XTSTEP: 20 s, 10s and 1s.;
68 vertical levels, 36 for boundary layer;
21-25 July 2014 simulation;



Numerical surface water fraction

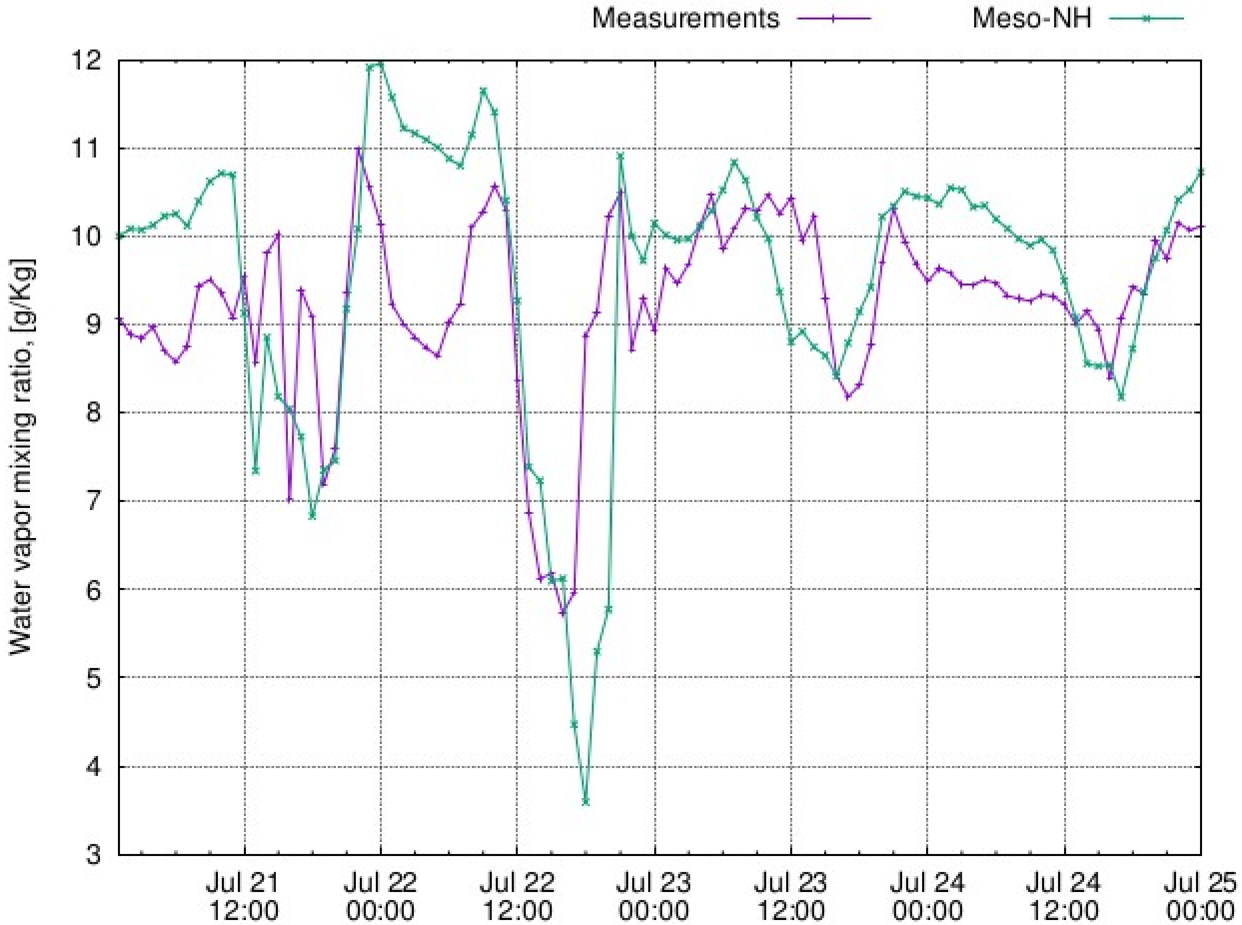
Validation: Latent and Sensible heat flux over the water

- Fluxes over Alqueva, computed with the Meso-NH model | comparison with observations on a floating platform, July 2014



Iakunin et al. 2018

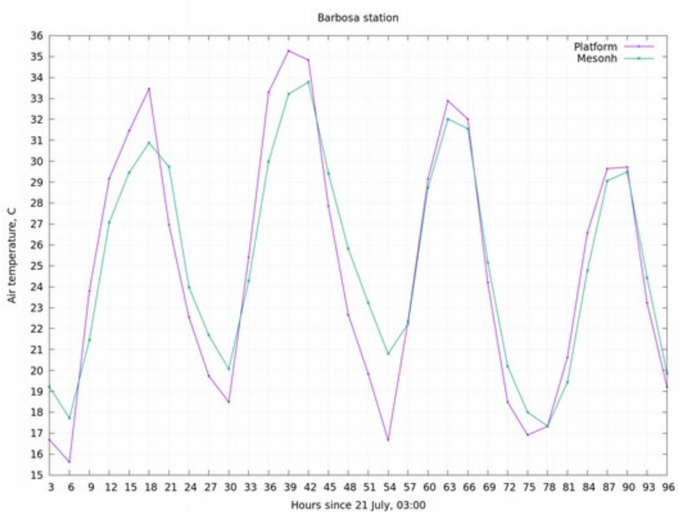
Water vapor mixing

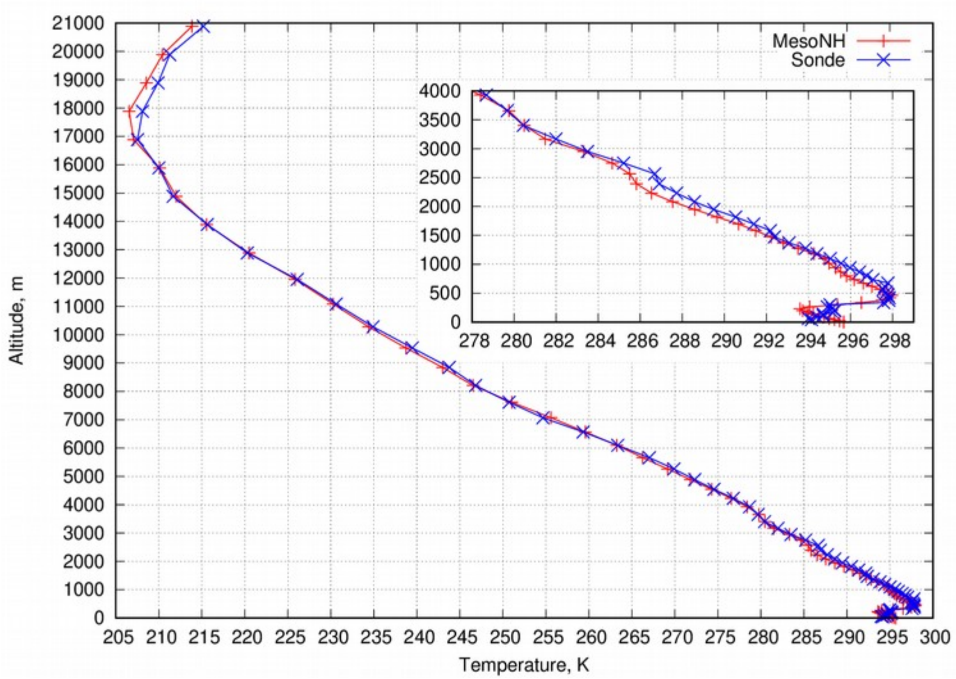


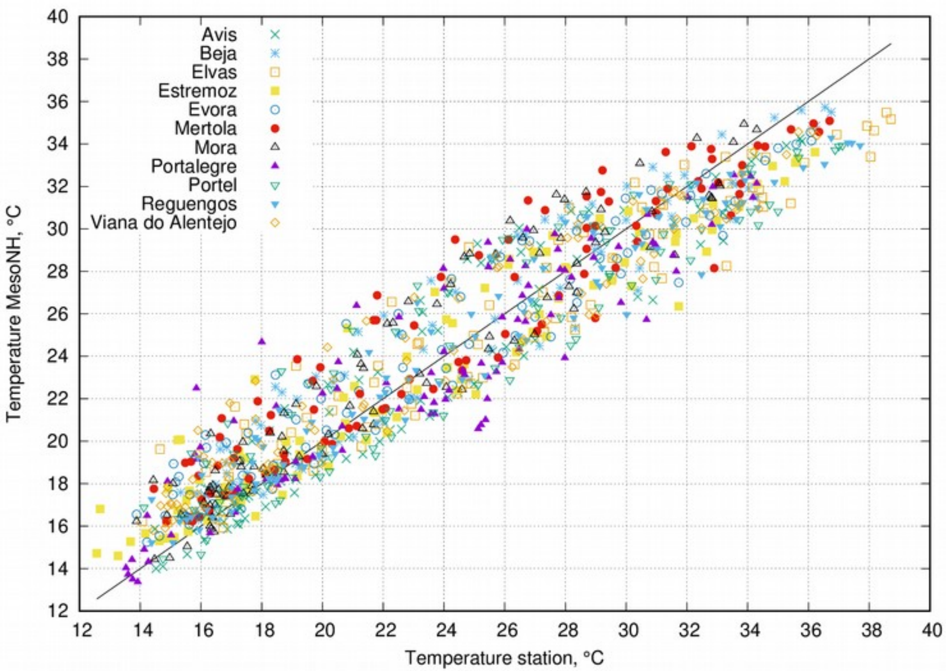
Iakunin et al. 2018

Lake Breeze simulation: Validation

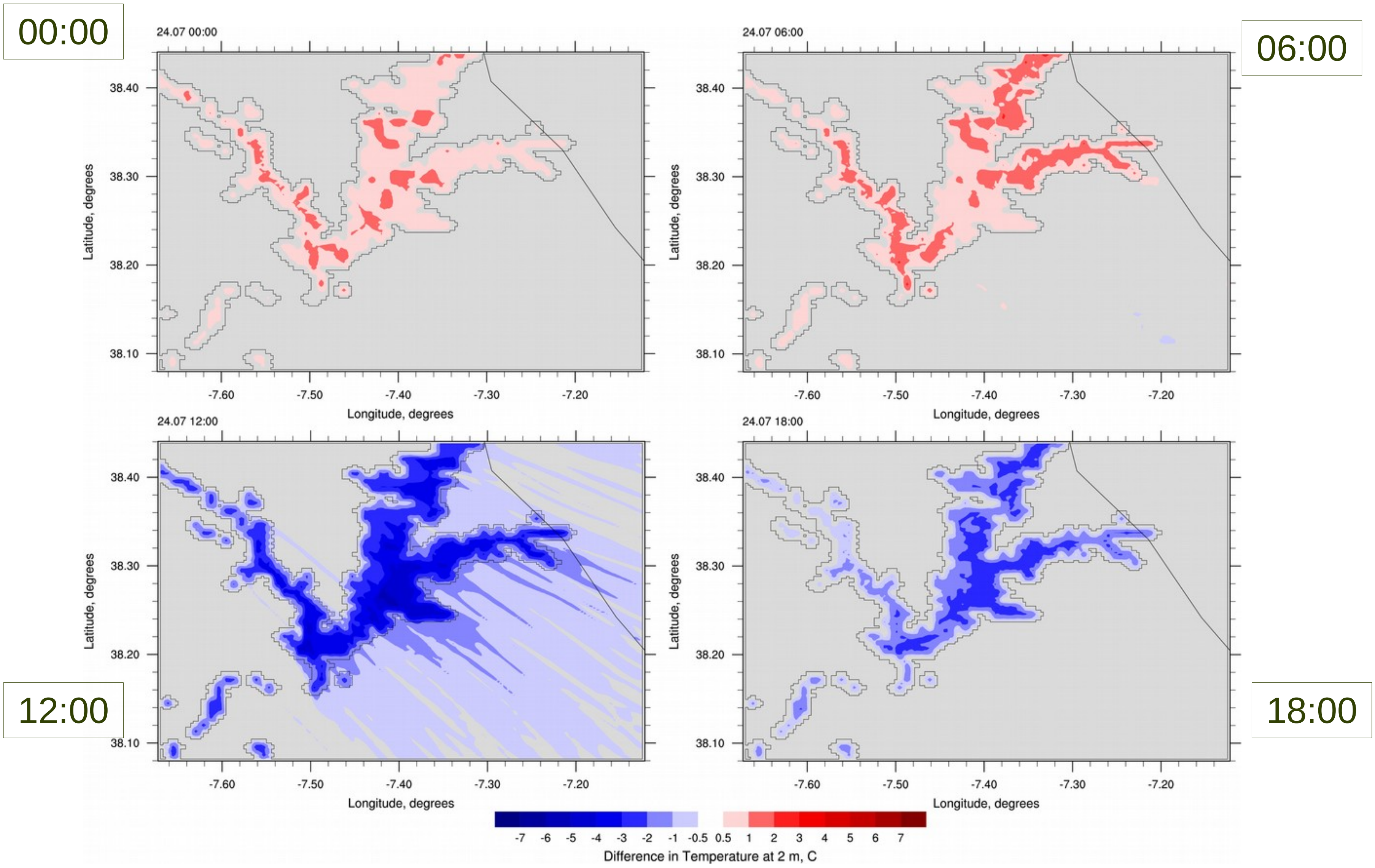
- Simulation data were compared with
  - National meteorological network
  - ALEX meteorological stations
  - radiosonds







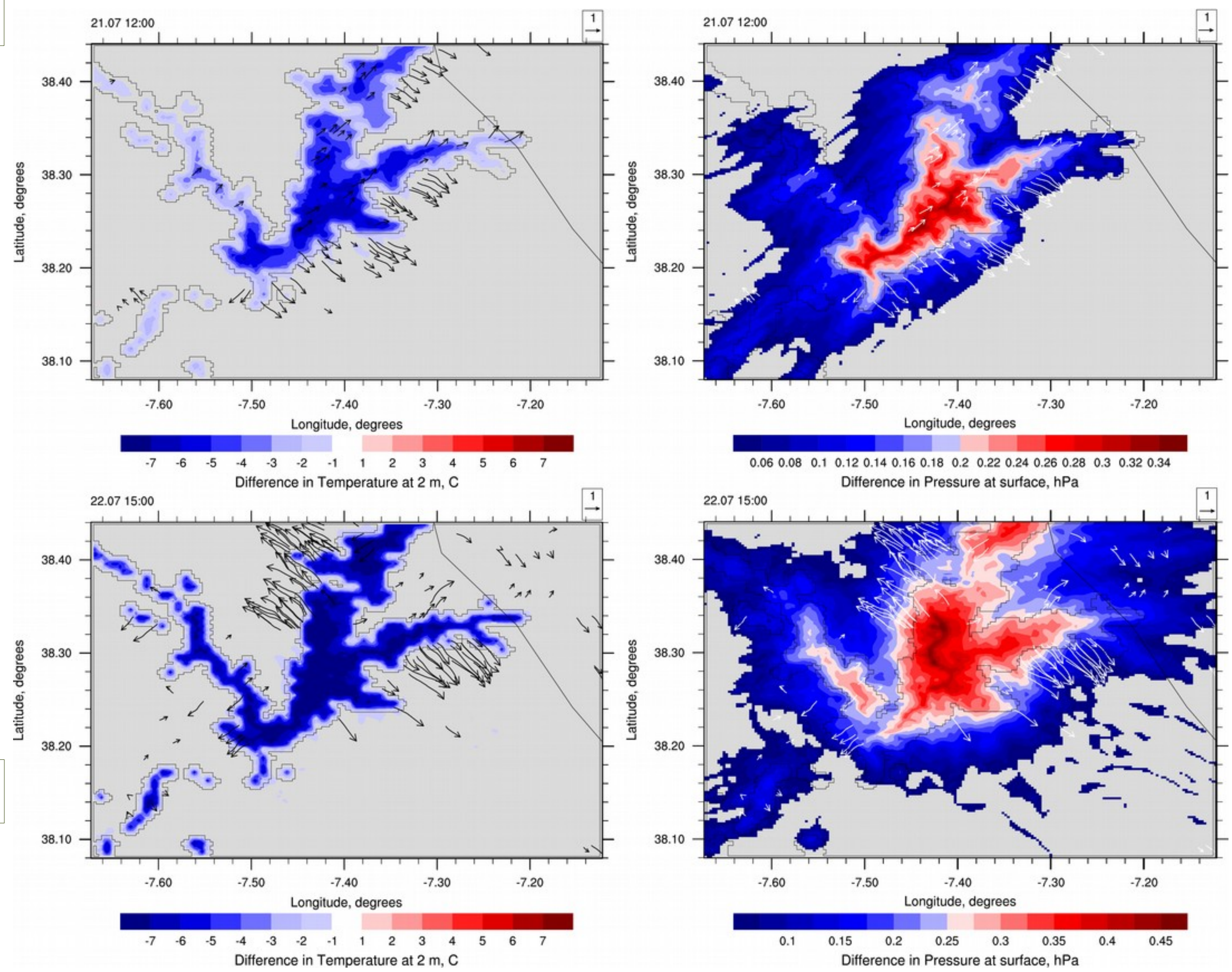
Impact of the Lake: Air Temperature



Impact of the Lake: Temperature and Pressure

12:00

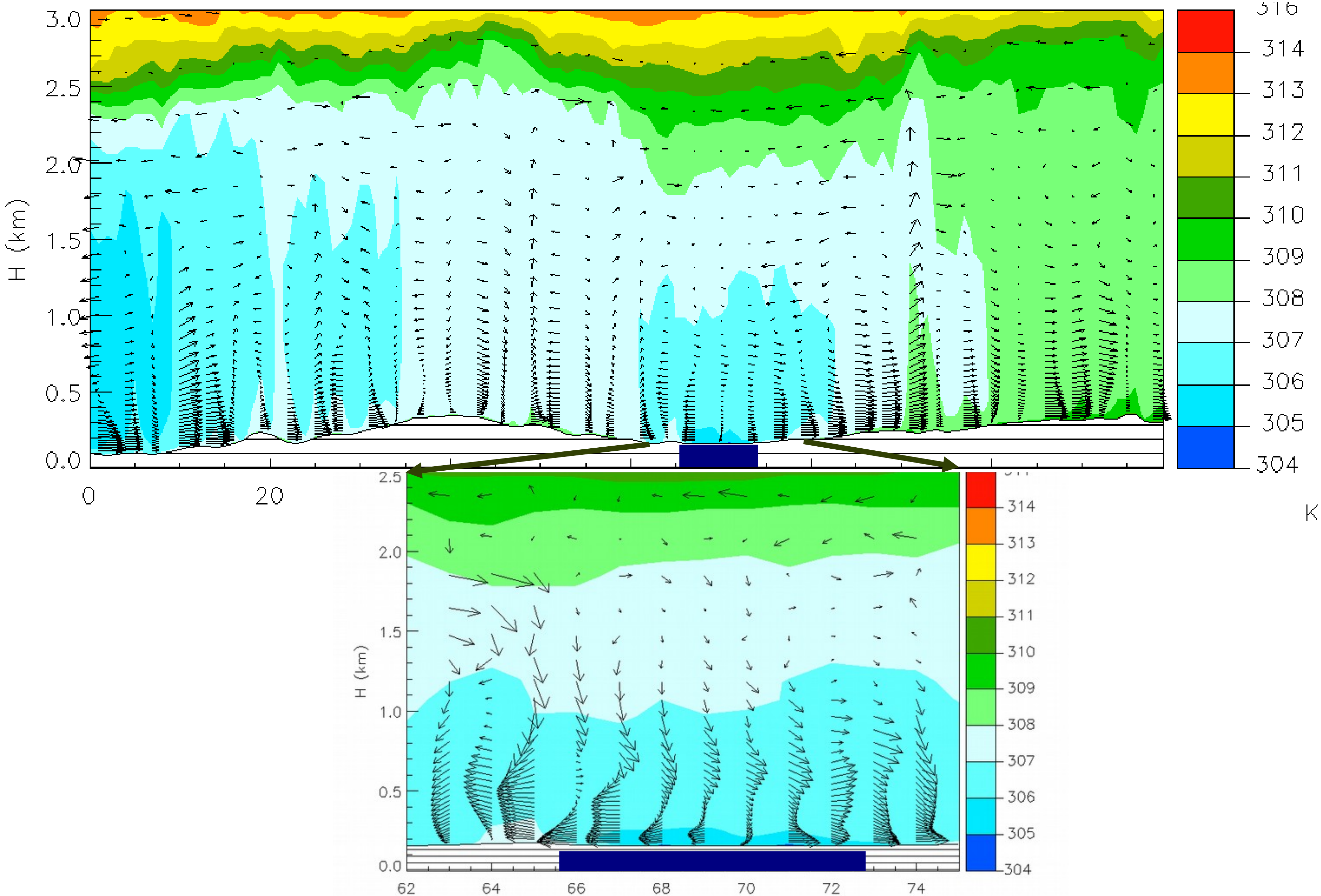
12:00



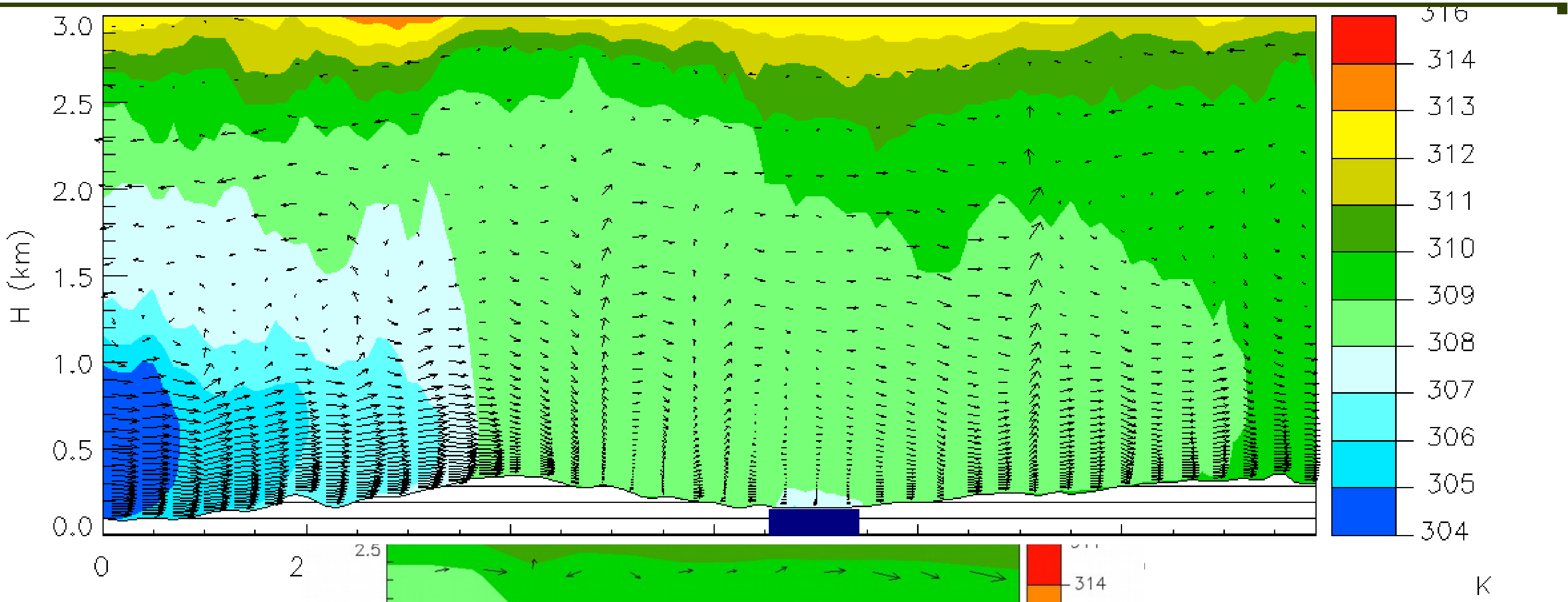
18:00

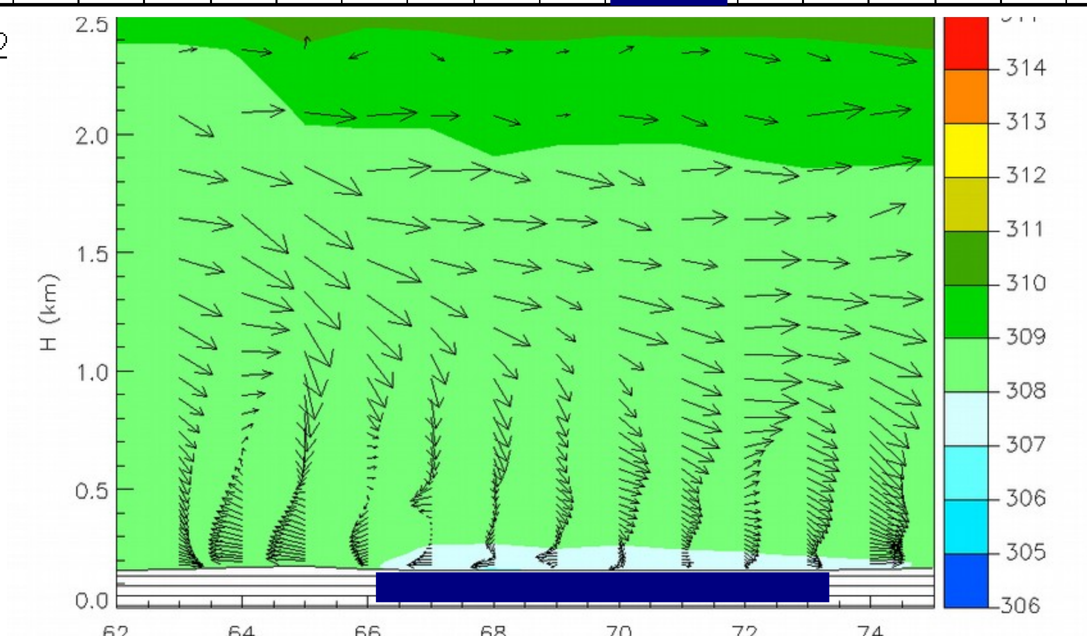
18:00

Lake breeze 15 TU

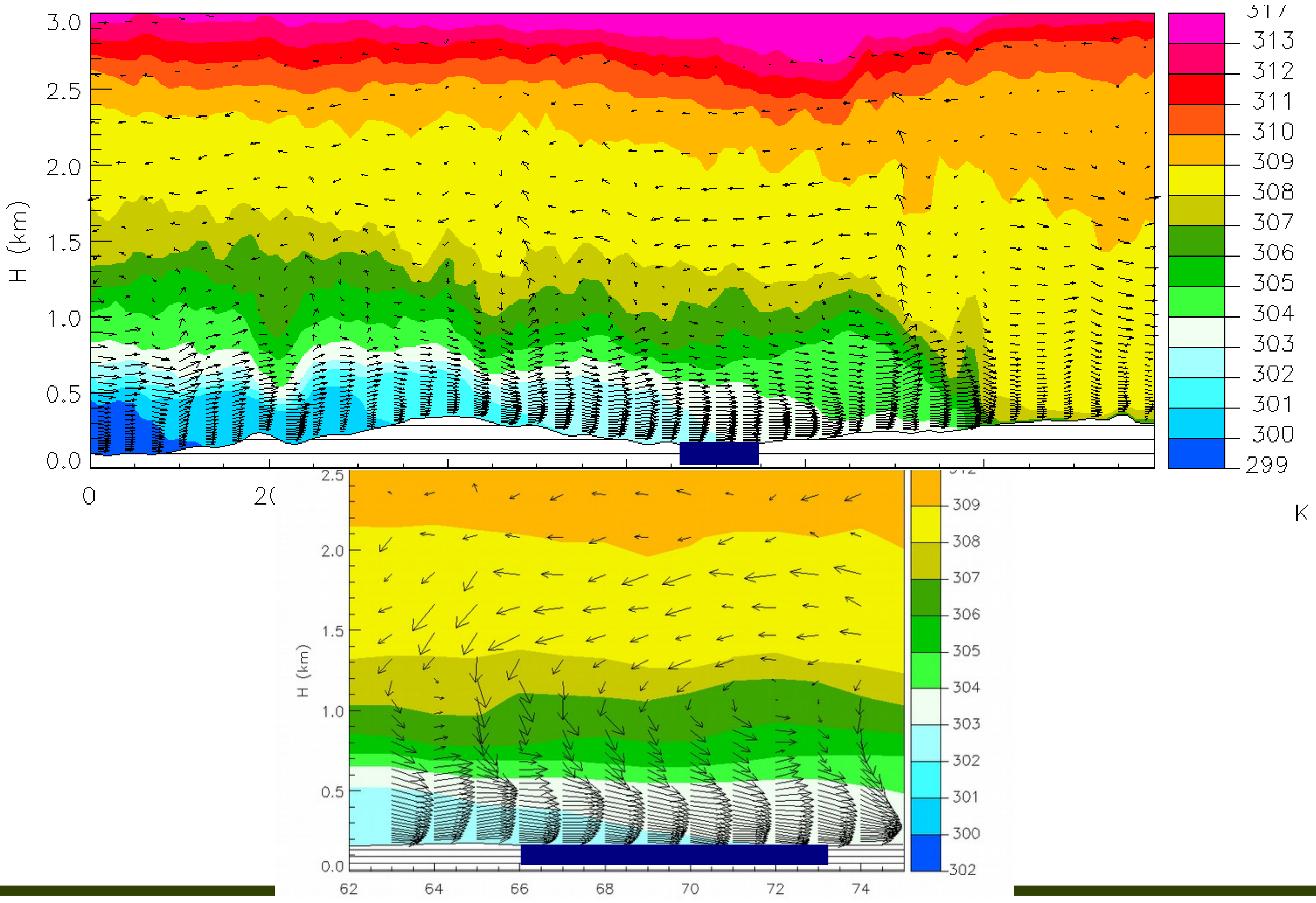


Lake breeze 18 TU

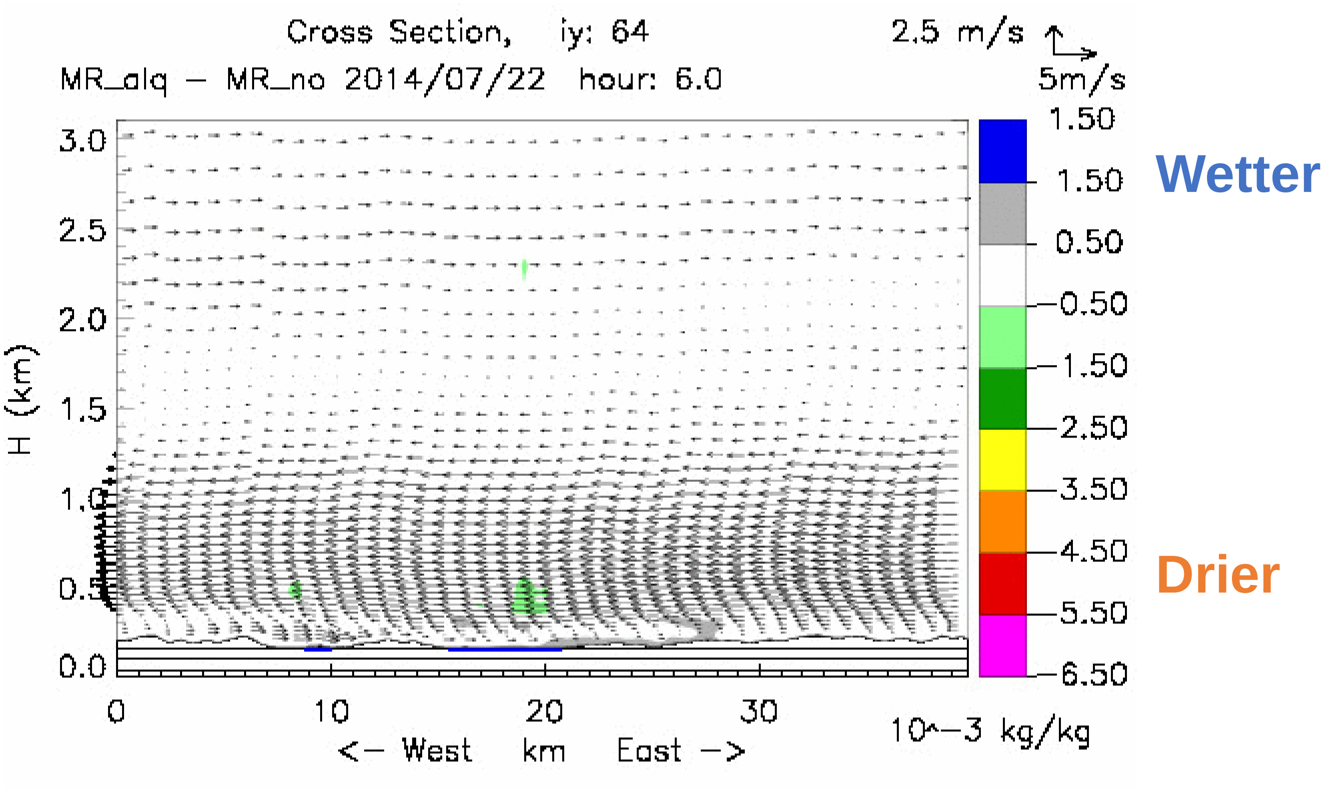




Sea Breeze 21 TU

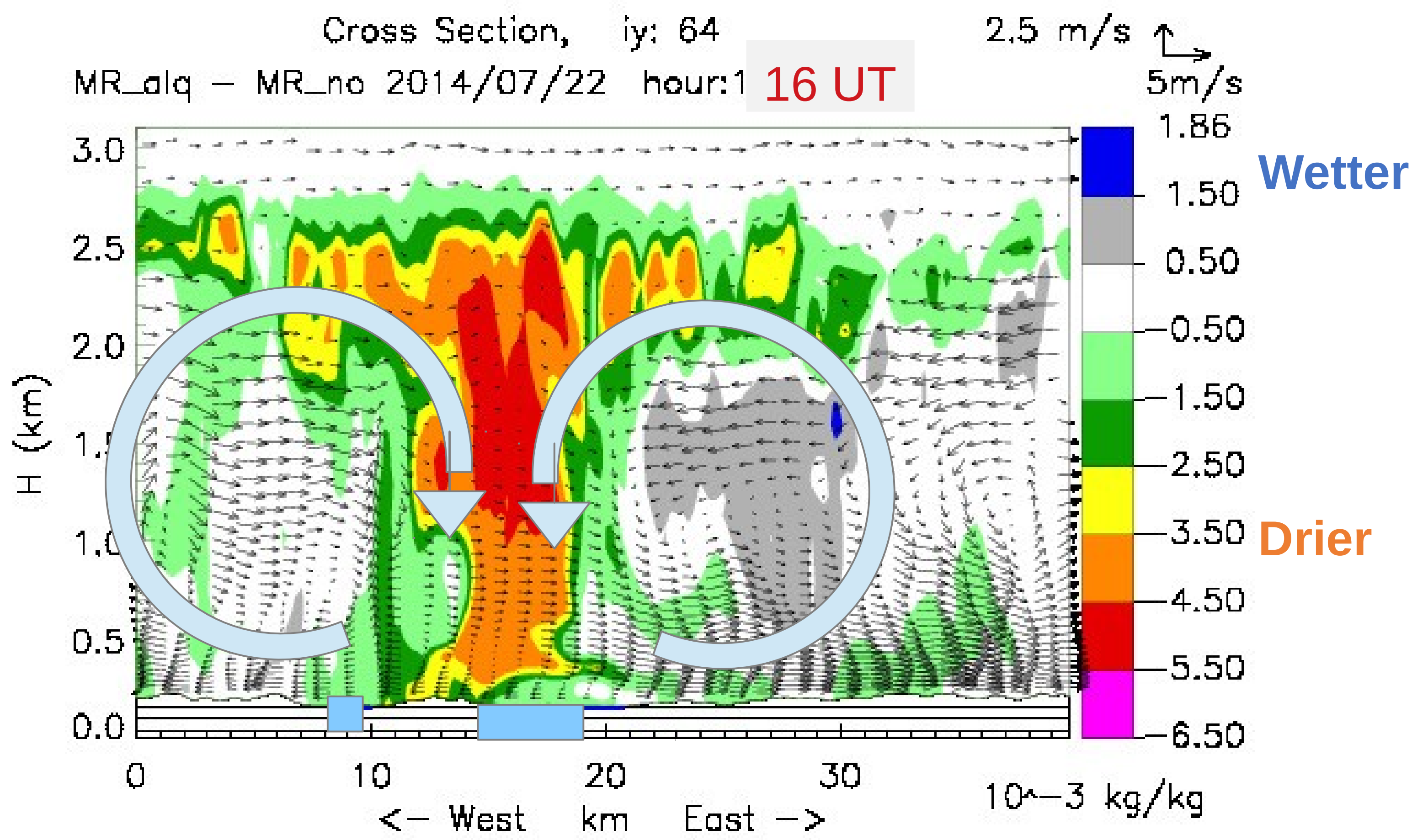


Alqueva impact on atmospheric moisture



- Alqueva – NoAlqueva water vapor anomaly and wind in Alqueva case
- 250 m resolution, West-Est crosssection, crossing the reservoir
- Afternoon decrease of mixing ratio over the water reservoir

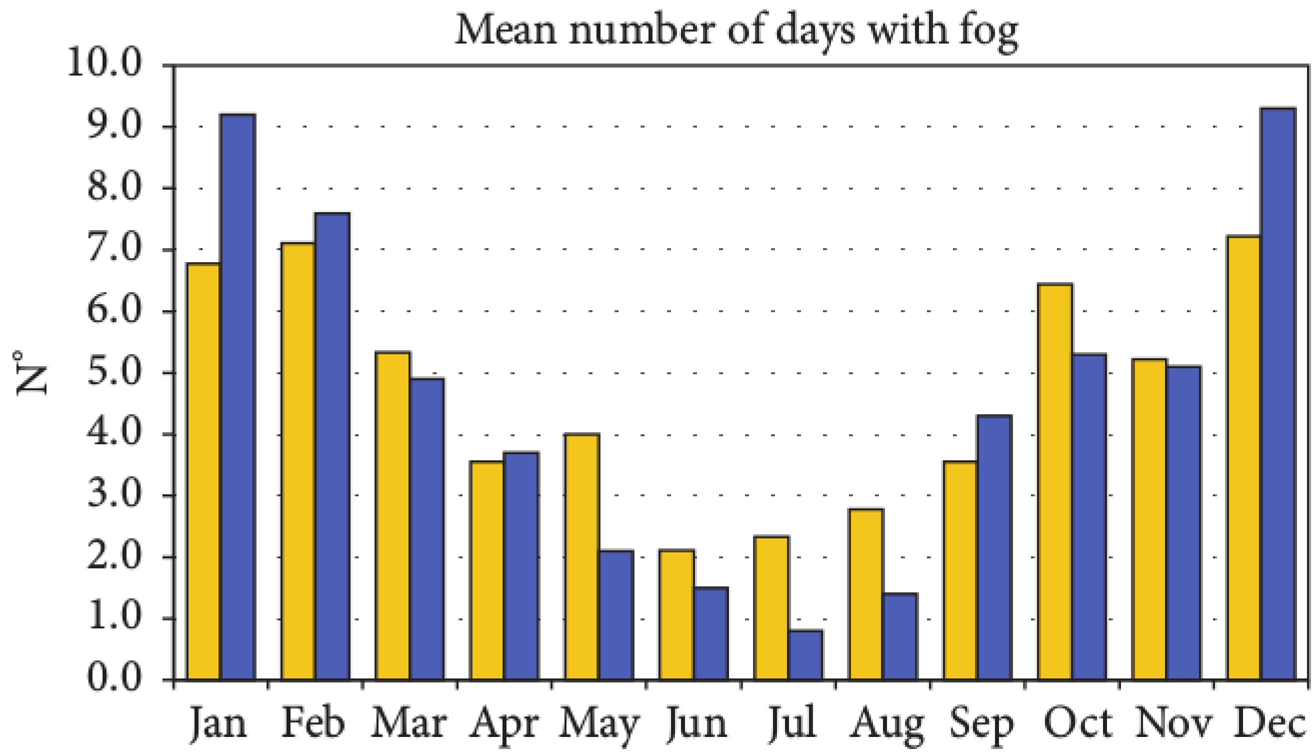
Alqueva impact on atmospheric moisture



- Alqueva – NoAlqueva water vapor anomaly and wind in Alqueva case
- 250 m resolution, West-Est crosssection, crossing the reservoir
- Afternoon decrease of mixing ratio over the water reservoir

Fog: What says the observations?

- it seems that there is an increase in the number of days with fog in the winter
- and a decrease in May - August
- Suggest the existence of a slight impact caused by Alqueva in the increasing of the number of foggy days during winter.
- On the contrary, the decrease in the average number of foggy days in May-August is difficulty attributed to a specific regional effect, being mainly due to synoptic conditions



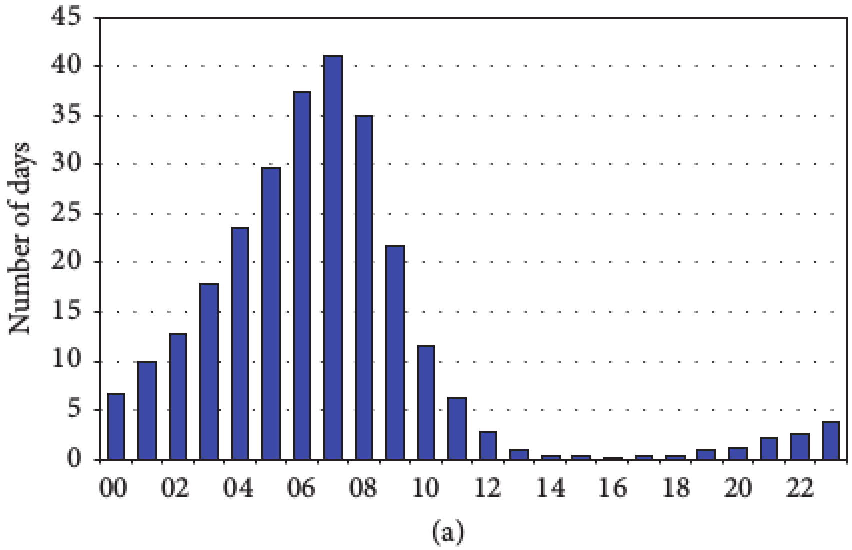
Monthly mean days of Fog in Beja Air Base in the 9 years periods:

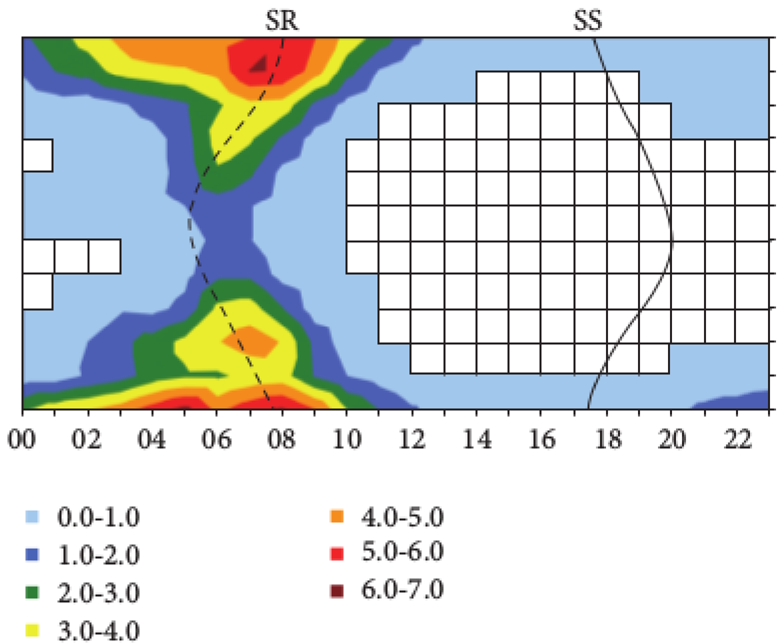
- 1994–2002
- 2003–2012

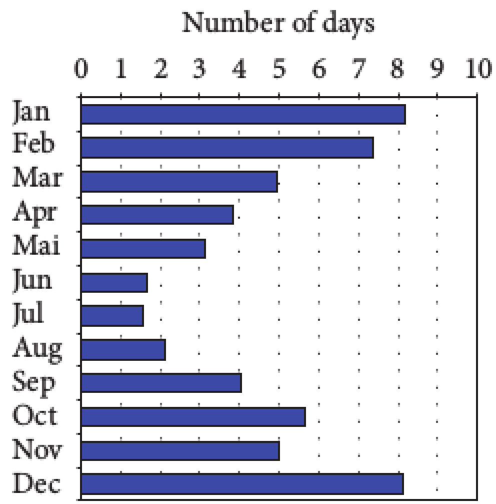
Policarpo et al., 2017

Fog Climatology

Mean number of days with fog over the entire year in Beja Air Base (2006–2012) by hour, hour and month, and month. Hours in UTC. SR: sunrise; SS: sunset.





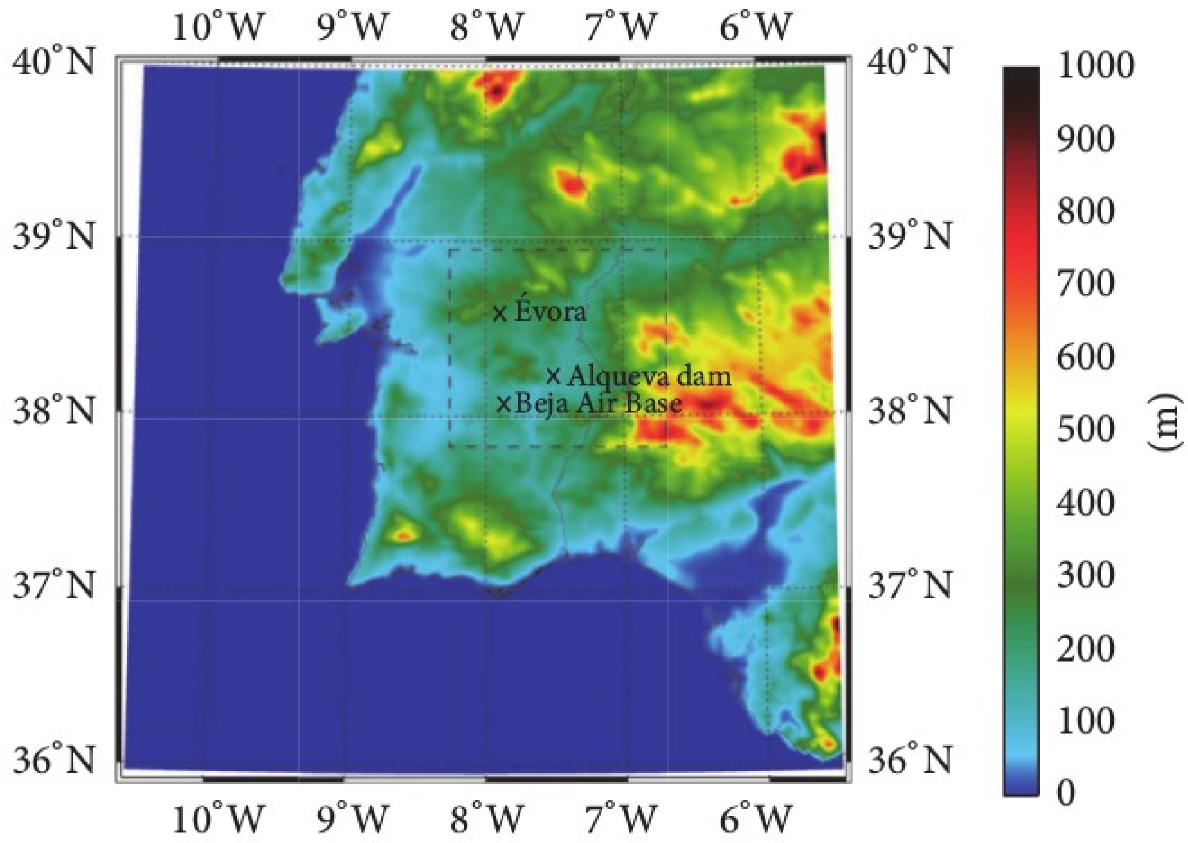


- More frequent in winter
- mostly between 04 and 10 UTC
- more than 40 days with fog at 07 UTC
- In Winter, the majority are radiation fog
- advection fogs occur in the remaining seasons.

Fog: Model Setup

- Physics schemes:
  - Radiation: ECMWF
  - Turbulence: Quasi-1D
  - microphysics: ICE3
  - No convection
  - SURFEX with FLake
- Initialization and forcing: ECMWF analysis
- vertical grid with 55 levels, with the lowest level at 5 m
- ECOCLIMAP v2.0 database, improved to include Alqueva reservoir
- Temperature of the Alqueva water surface was initialized from MODIS satellite data

Two domains:
Largest: 150 × 150 points, spatial resolution of 3 km
Smallest: 120 × 120 points, spatial resolution of 1km, includes Alqueva reservoir and Beja Air Base.
Two-way grid nesting technique



Case studies

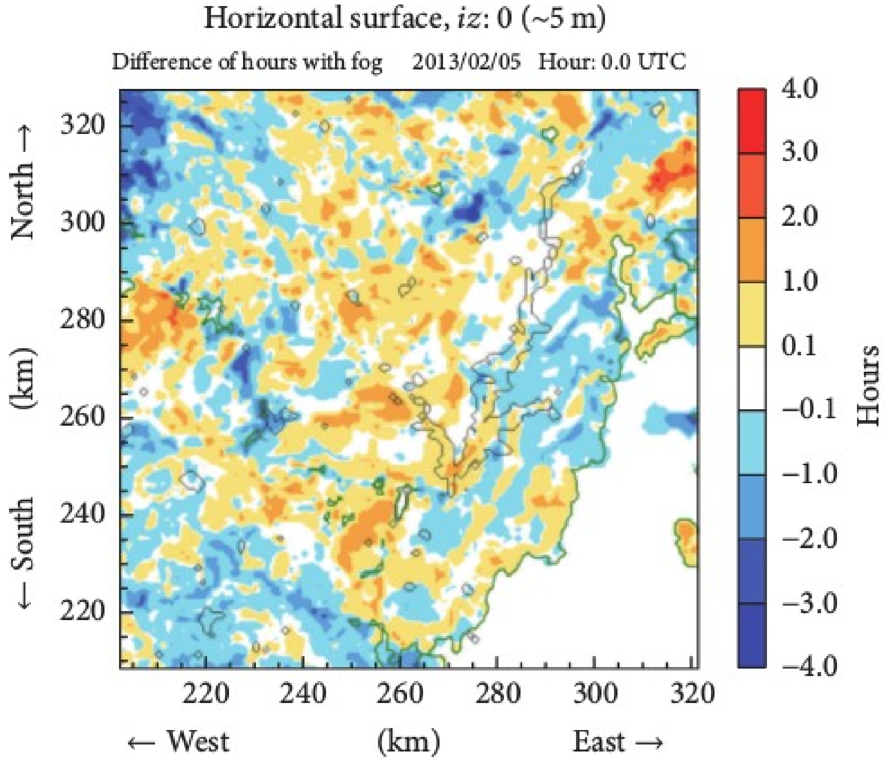
- The period considered: December 2012 and Ju:ly 2013. In Beja Air Base, 47 fog events were registered. Among these, five events were selected
- **Two simulations, one with Alqueva and the other without were performed**

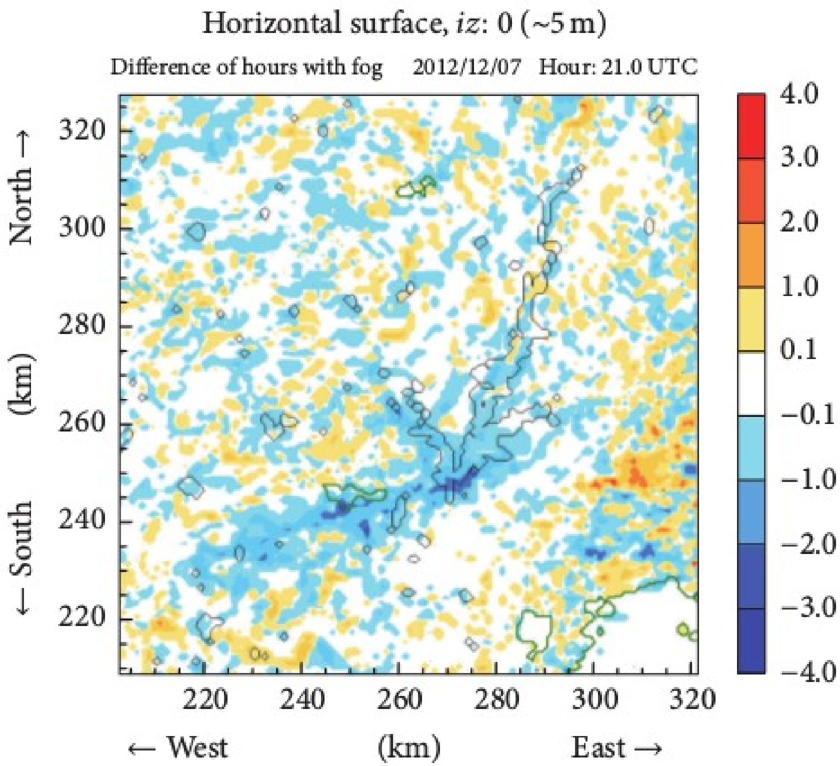
TABLE 3: Simulation periods for the selected case studies.

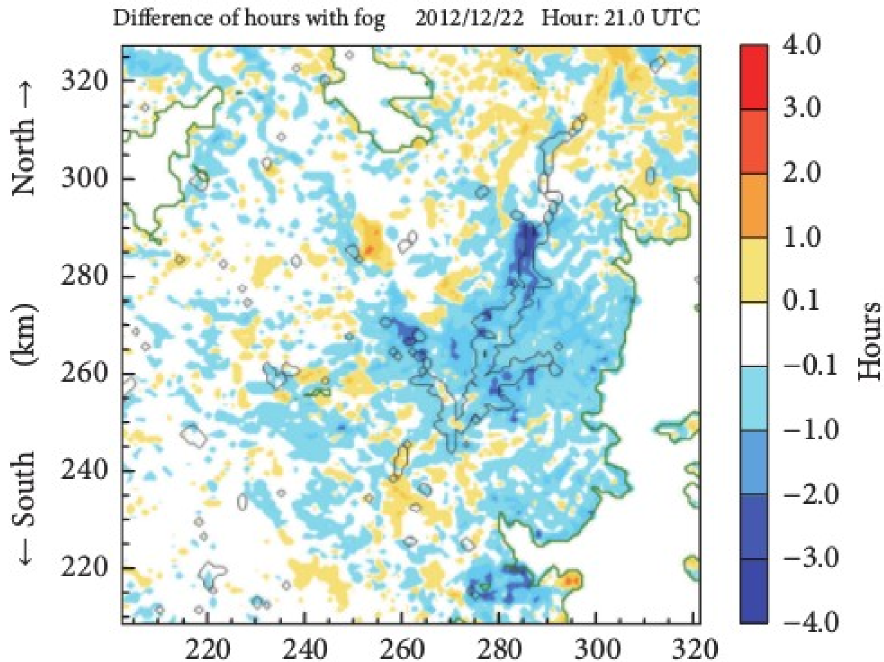
Date	Simulations	Study periods
2012-12-08	07 18:00–08 18:00 UTC	07 21:00–08 15:00 UTC
2012-12-23	22 18:00–23 18:00 UTC	22 21:00–23 15:00 UTC
2013-02-05	04 12:00–05 18:00 UTC	05 00:00–05 15:00 UTC
2013-07-16	15 18:00–16 12:00 UTC	15 21:00–16 12:00 UTC
2013-07-18	17 18:00–18 12:00 UTC	17 21:00–18 12:00 UTC

Winter case studies

- Difference between the "number of hours with fog", with and without Alqueva from 21:00 to 15:00 UTC in son domain. Fog occupation boundaries with Alqueva (green line), color scale: 2012/12/08, 2012/12/23, and 2013/02/05

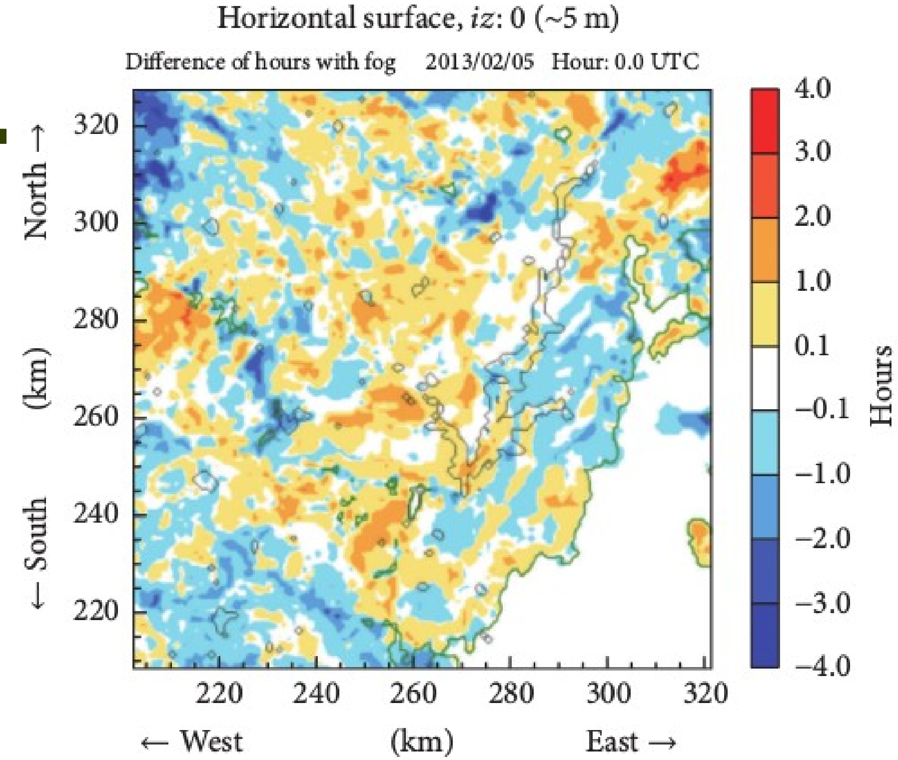


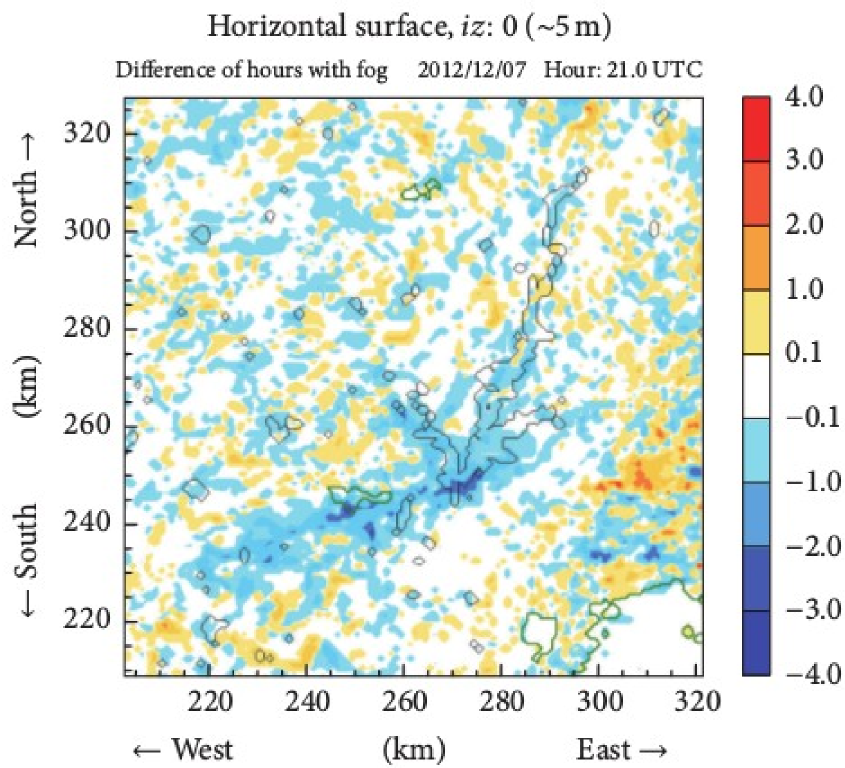


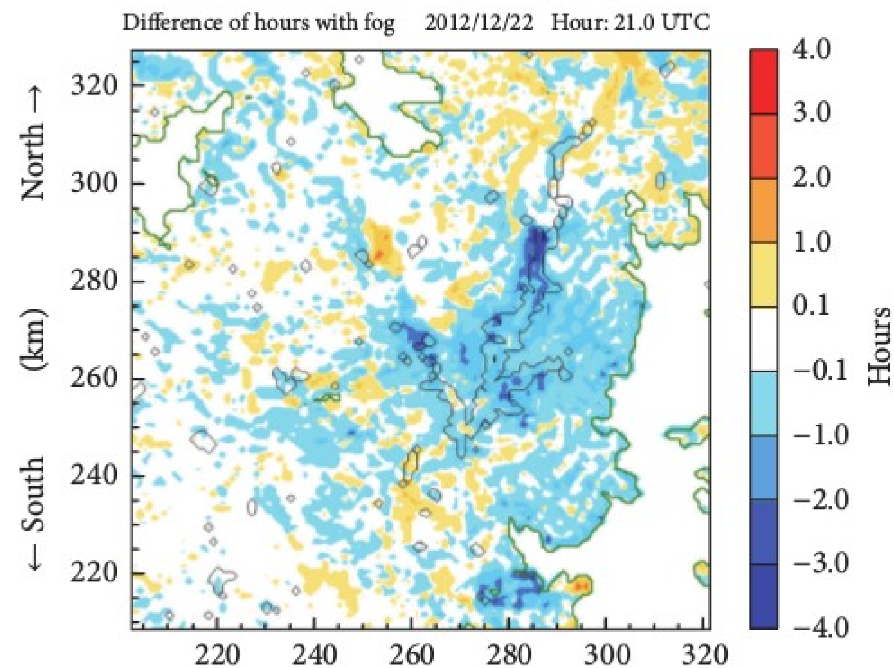


Winter case studies

- In winter cases the impact was visible
- depending the direction and wind speed, different effects may become dominant
- The fog duration over the reservoir had a shorter duration in the simulations with Alqueva during December, suggesting that its existence inhibited the fog formation and evolution.
- In the situation of February there has been a slight increase in the fog duration over the Alqueva reservoir, possibly due to the weak flow



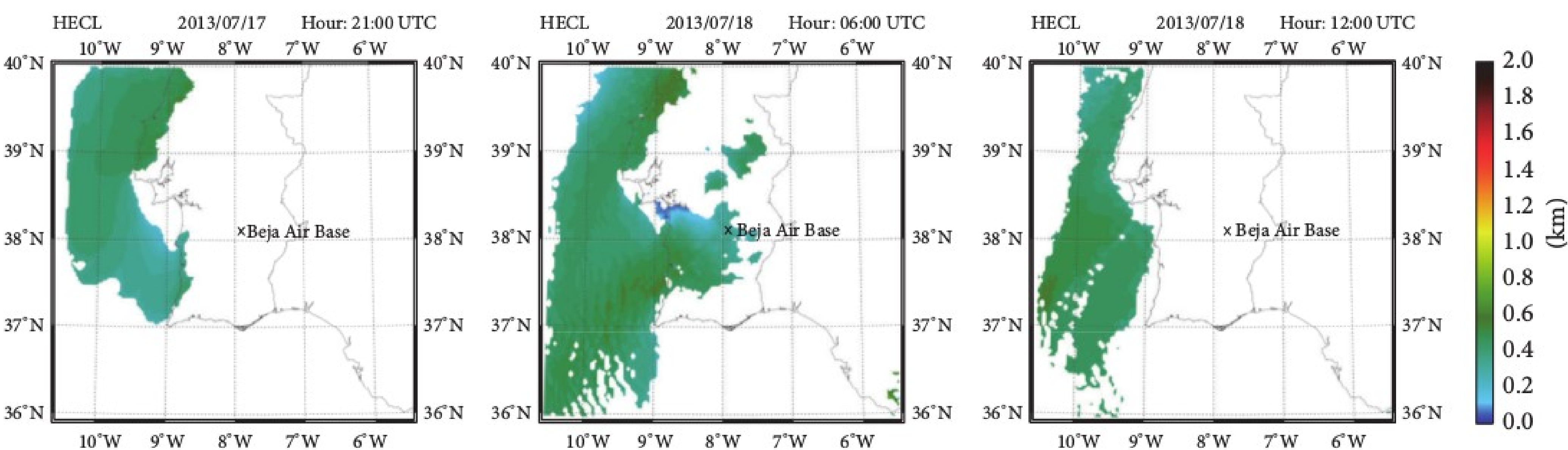




Summer cases

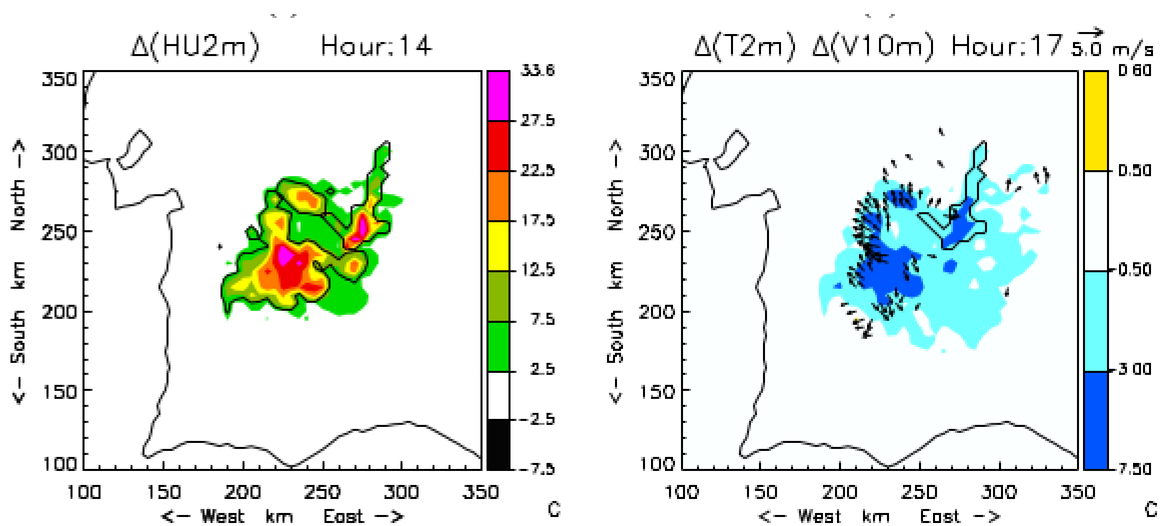
- For summer cases, there were no significant differences between simulations with and without Alqueva, due to the fact that they correspond to events of advection fog, originated in the Atlantic Coast, and that they have not reached Alqueva reservoir.

(a)



Alqueva e o Clima local

- impacto nos campos da temperatura e humidade do ar → evaporação



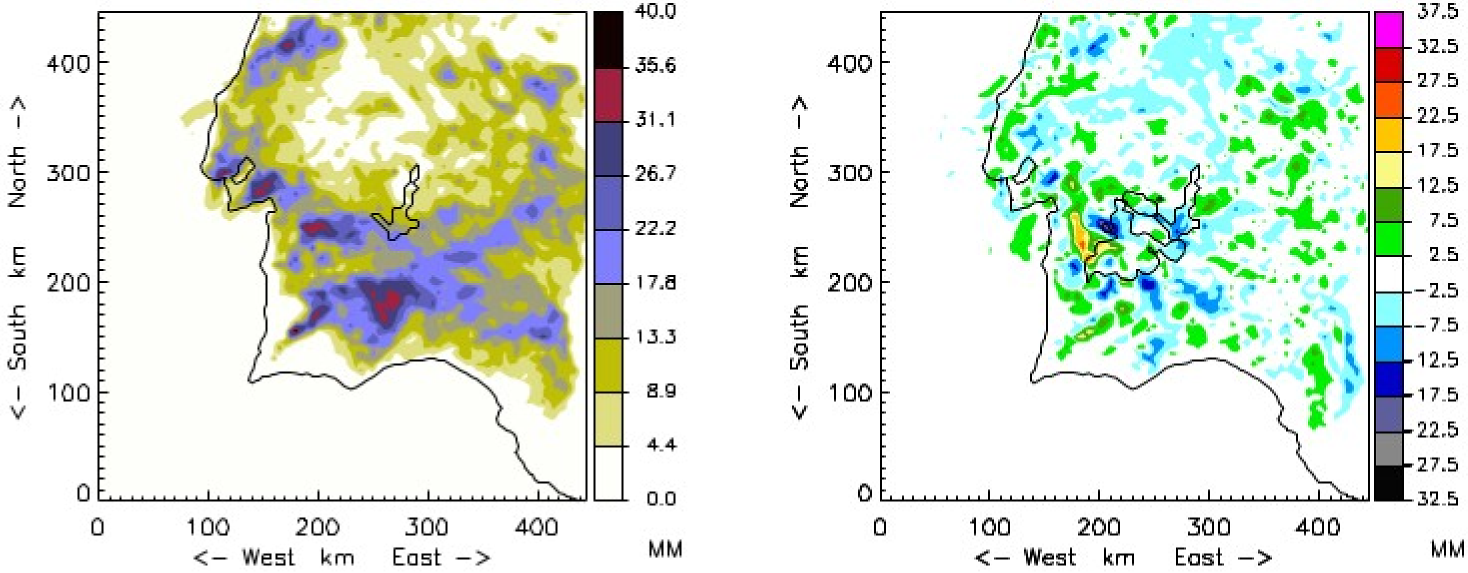
Resultado de simulações numéricas de casos de estudo representativos do estado do tempo no Verão.

Salgado. 2006

- na escala regional os efeitos mais acentuados resultam da criação doperímetro de rega e não da introdução do lago.

Alqueva e o Clima local (Precipitação)

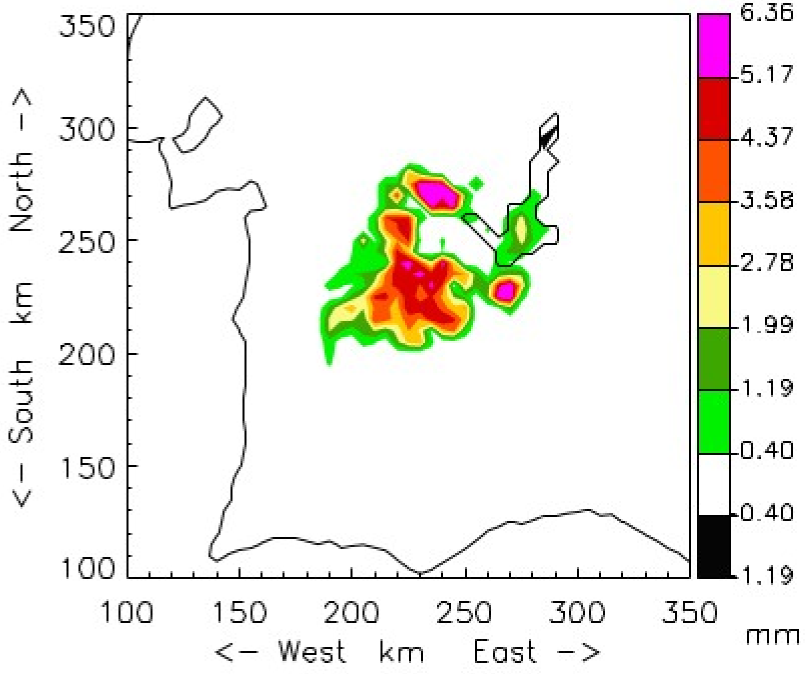
- impacto na precipitação



  - É marginal. Simulações indicam ligeira diminuição sobre a albufeira e zona irrigada e ligeiro aumento na vizinhança. Aparentemente, não existe reciclagem da água evaporada na região.

Alqueva e o Clima local (Evaporação)

- Resultado de simulação de caso de estudo: Anomalia na evaporação: depende das culturas, mas pode corresponder a cerca de 8 kg/m2 de área irrigada (cálculos para culturas com LAI=4)
  - Salgado, 2006
- Evaporação da albufeira.



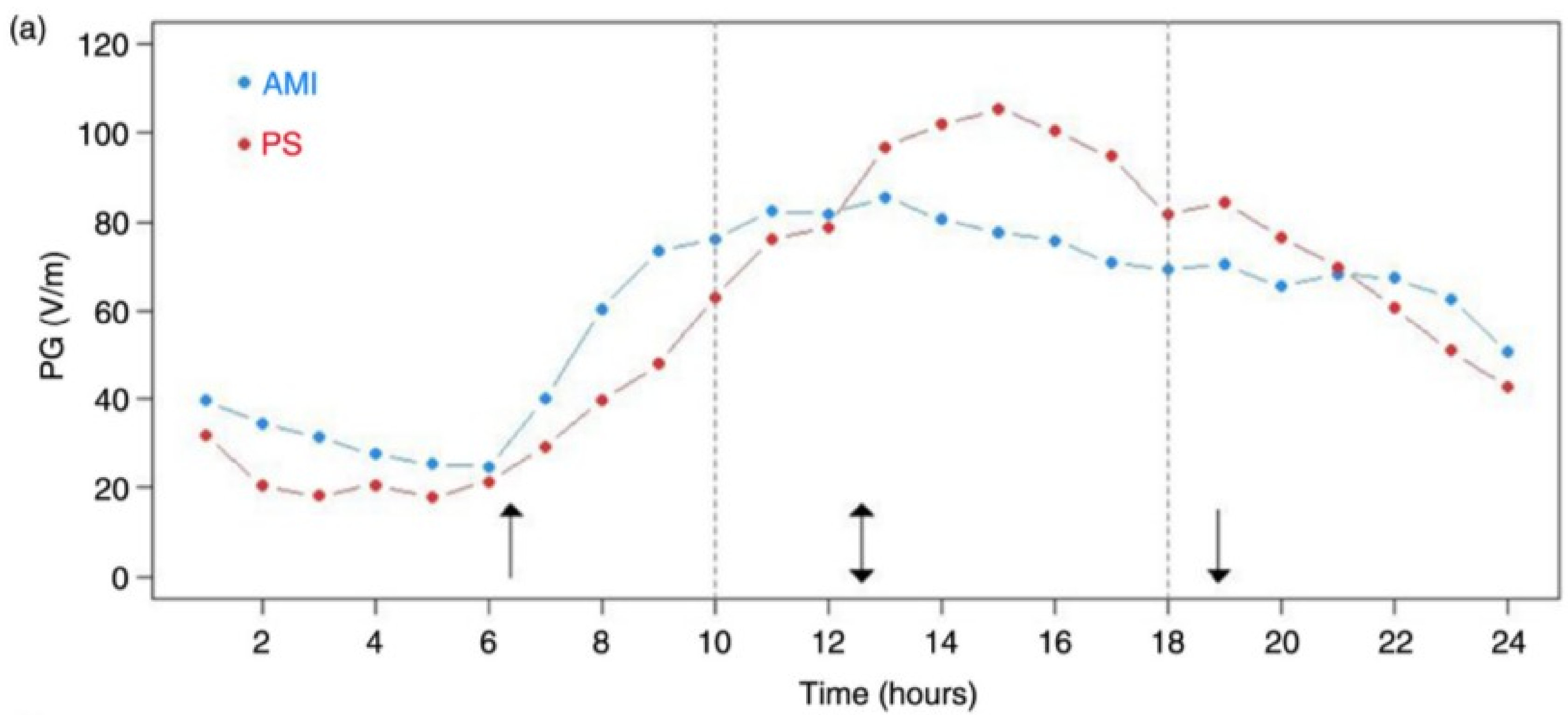
Atmospheric electrical field measurements

- Two ALEX2014 stations 10 km apart were used
  - located up and down-wind of the lake (Amieira and Parque Solar, respectively), in reference to the dominant northwestern wind direction.
  - measurements of atmospheric electrical field in terms of potencial gradiente: *PG = dV / dz (V is the electrical potential)*
  - using two identical electrostatic field mills, JCI 131F
- Seventeen days of Fair Weather were chosen, based on local undisturbed daily solar radiation curves, cloud-free days and the availability of PG data in both stations.

Lopes et al., 2016

Effects of the lake in the atmospheric electrical field

- Measurements in both stations indicates that the presence of the lake has a local signature on the atmospheric electricPG
- The up-wind station shows lower atmospheric electric potential gradient values than the ones observed in the down-wind station between 12 and 20 UTC, when the breeze is fully developed



Hourly mean diurnal variation of potential gradient (V/m) at the two measuring locations, AMI and PS


THANKS
alquevaline
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Erasmus+

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