# NEGATIVE SPACE-CHARGE DENSITY OVER ALQUEVA RESERVOIR (PORTUGAL) RETRIEVED FROM ATMOSPHERIC ELECTRIC FIELD MEASUREMENTS

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# LABORATORY OF ATMOSPHERIC ELECTRICITY

- Main research objectives
  - Aerosols (pollution)
  - Radioactivity (natural and artificial)
- Instruments
  - 3 Atmospheric electric field sensors
  - 2 Alpha particle detectors
  - 1 Ion counter
- Historical records
  - Portela meteorological station (Lisbon)
  - Observatório do Pilar (Oporto)

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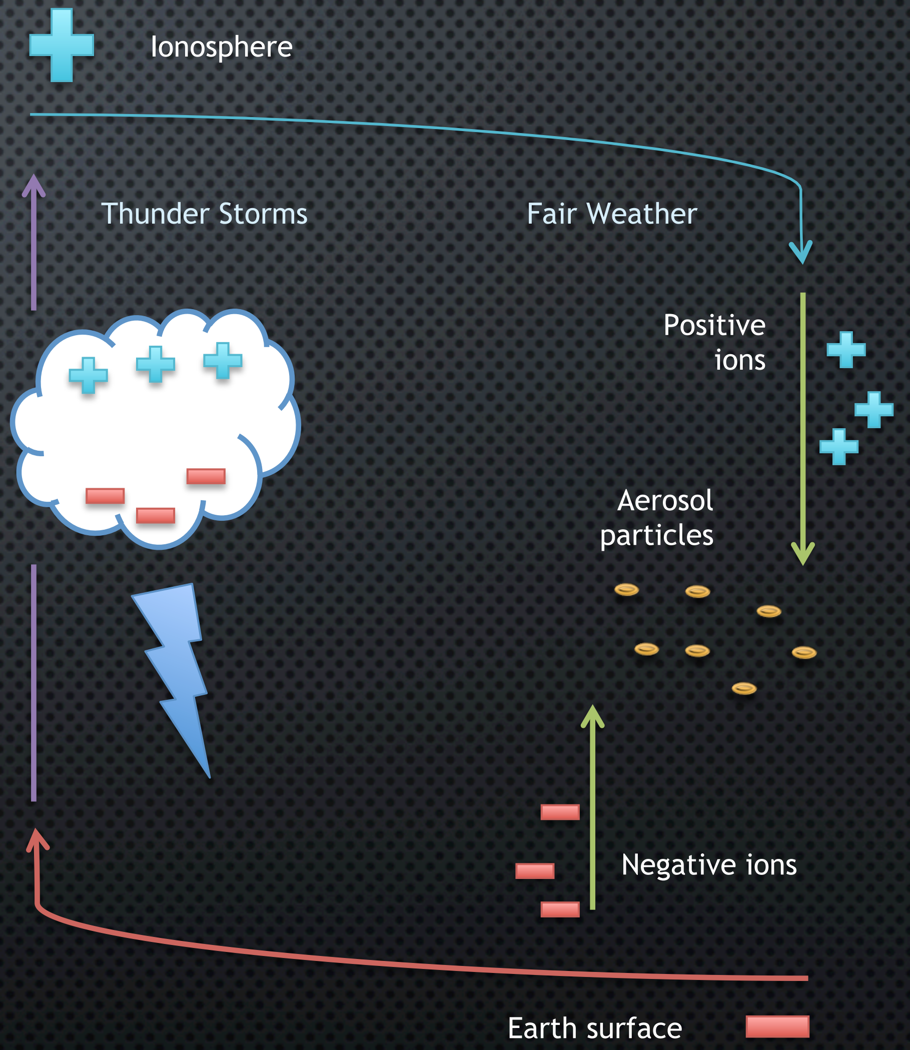
# ATMOSPHERIC ELECTRICITY

- The basic concept of Atmospheric Electricity is the existence of a **Global Electric Circuit** influencing all the planet. The global thunderstorm activity act as a voltage source and imposes a potential difference ($V_I$) between the ionosphere (positively charged) and the Earth's surface (negatively charged) of about 300 kV.
- Such potential difference is discharged through the **poorly conducting atmosphere in the fair-weather regions** and creates a Potential Gradient (PG) in those regions of ~ 100 V/m. A convention is used that $PG = dV_I/dz$ defined to be positive for fair-weather days and is related with the vertical component of the atmospheric electric field by $E_z = -PG$.
- **Atmospheric ions are responsible for most of the air-conductivity.** On the one hand, they are created mainly by cosmic rays and the particles emitted by the decay of radioactive elements (e.g. radon). On the other hand, they are lost by ion-ion recombination and ion-aerosol attachment.



# OVERVIEW

## INTRODUCTION

- Motivation;
- Theory Formulation;
- Measuring Locations;
- Geographic Background;
- In Situ Stations;

## RESULTS – BEJA & AMIEIRA

- PG;
- Temperature and Wind Speed;
- Wind Directions;
- Wind Speed and Friction (Lake);
- Space Charge;
- Space Charge VS. Wind Speed;

# MOTIVATION

- Measurements of the atmospheric potential gradient (PG) near the Alqueva Lake (Portugal) have been carried out during the ALEX2014 summer campaign.
- The objective is to study the possible impact of the Alqueva reservoir on the local PG by comparing measurements both in-land and close to the lake during a period of 27 days of fair-weather.
- The development of negative space charge density over the water surface can affect the local region.
- The physical mechanisms behind such phenomena are presented and discussed.

# THEORY FORMULATION

- Indication that a negative space-charge density is developed over fresh-water Lake Superior (USA) was observed, Gathman and Hoppel (1970); Similar verifications was found near fresh-water waterfalls, e.g. Austrian Alps (Kolarz et al., 2012);

- Negative space-charge density is mostly linked with the breaking/splashing of fresh water waves promoting a multiple source of negative charges dispersed over the lake region;

- Most probably the mechanism of bursting bubbles is responsible for the negative electrification over lakes (Gathman and Hoppel (1970); Laboratory experiments support this theory since the formation of negatively charged nanoparticles produced by splashing of water was observed by Tammet et al. (2009);

- The formation of a space-charge density, either positive or negative, alters considerably the local PG. This means that any variation in the latter can be seen as a proxy for the development of such space-charges;

- Additionally, air convection and turbulent mixing processes near the Earth's surface due to air temperature changes (*the sunrise effect*) can also disturb the PG. The sunrise effect can be the result of the convection of the positive space-charges developed by the known electrode effect.

# THEORY FORMULATION

- Negative space-charge over Alqueva Lake can be retrieved by using Potential Gradient measurements made near the lake, $F_{lake}$, and away from the lake in a land station, $F_{land}$.

$$\frac{dF}{dz} = -\frac{\rho(z)}{\varepsilon_0}$$

+

$$\rho(z) = \rho_0 \exp\left(-\frac{z^2}{2\xi^2}\right)$$

(Gathman and Hoppel, 1970)

$$\Delta\rho_0 \approx \frac{\varepsilon_0}{\xi}\sqrt{\frac{2}{\pi}}\left(F_{lake} - F_{land}\right)$$

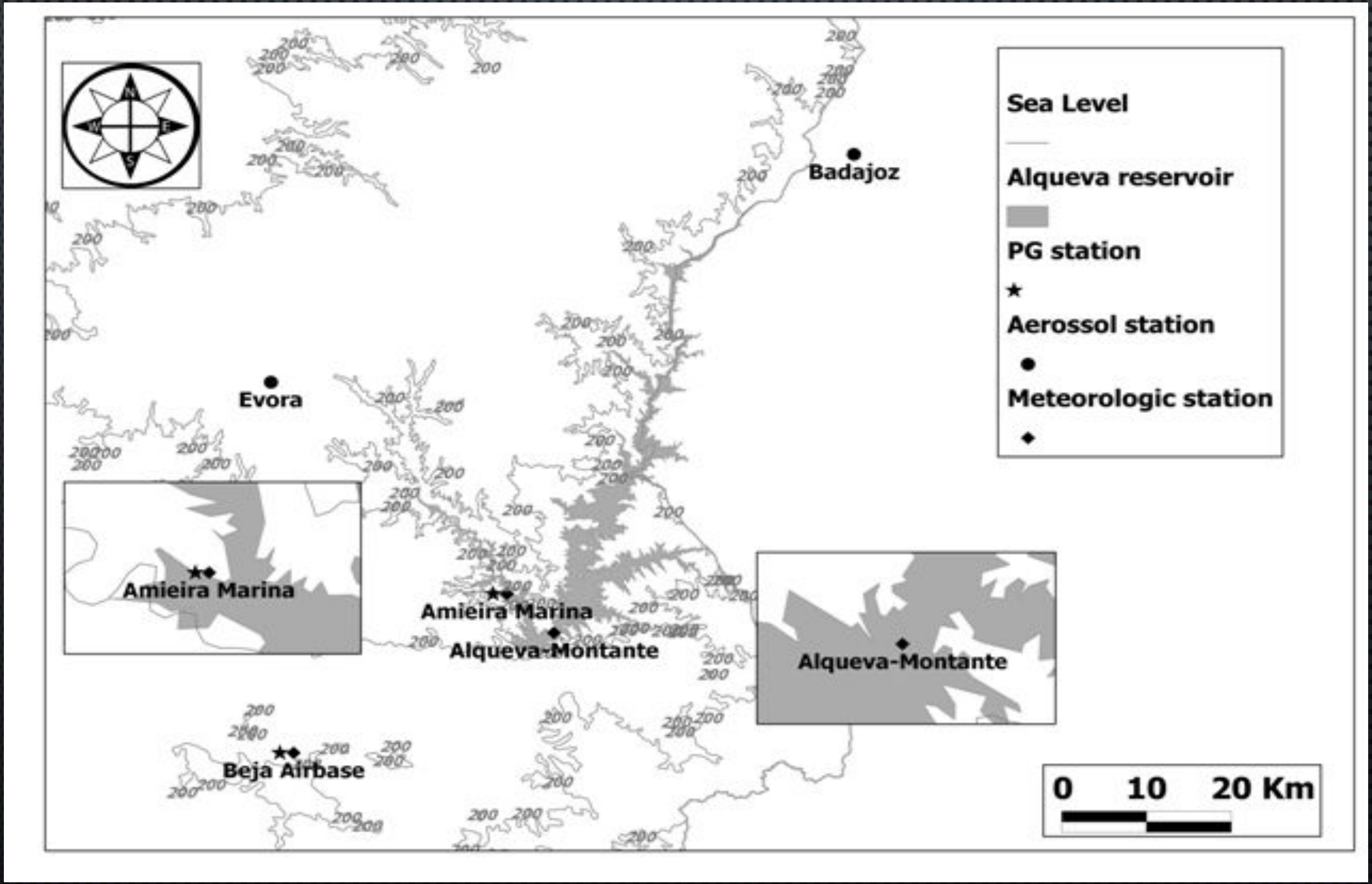
$$\rho_0 = e(n_+ - n_-)$$

$$\sigma_0 \approx e\mu(n_+ + n_-)$$

$$\Delta n_+ \approx \frac{J_z}{2e\mu}\left(\frac{1}{F_{lake}} - \frac{1}{F_{land}}\right) + \frac{\varepsilon_0}{e\xi\sqrt{2\pi}}\left(F_{lake} - F_{land}\right)$$

$$\Delta n_- \approx \frac{J_z}{2e\mu}\left(\frac{1}{F_{lake}} - \frac{1}{F_{land}}\right) - \frac{\varepsilon_0}{e\xi\sqrt{2\pi}}\left(F_{lake} - F_{land}\right)$$

# MEASURING LOCATIONS



# GEOGRAPHIC BACKGROUND

## BEJA AIRBASE (BA)

- ~40 km away from the Alqueva Lake;
- Located outside the city of Beja, i.e., is less affected by urban pollution;
- Used as in land reference for PG and meteorological measurements;
- Strong wind from the North ("Nortada") with an increase during the afternoon;
- High temperature gradient between land-air (local air convection systems);

| Table 1 | AOD 440 Mean / median | AOD 870 Mean / median |
|---|---|---|
| Évora | 0.11 / 0.08 | 0.04 / 0.03 |
| Badajoz | 0.12 / 0.09 | 0.04 / 0.03 |

## AMIEIRA (AMI)

- Located on the shore of the southern part of the Alqueva Lake;
- PG and meteorological stations are set upon a hill ~30 m from the lake water level;
- Low vegetation in the surroundings;
- Low pollution levels;
- Strong wind from the North ("Nortada") with an increase during the afternoon;
- Development of a lake breeze systens linked with the difference in temperatures of the lake and the surrounding land;

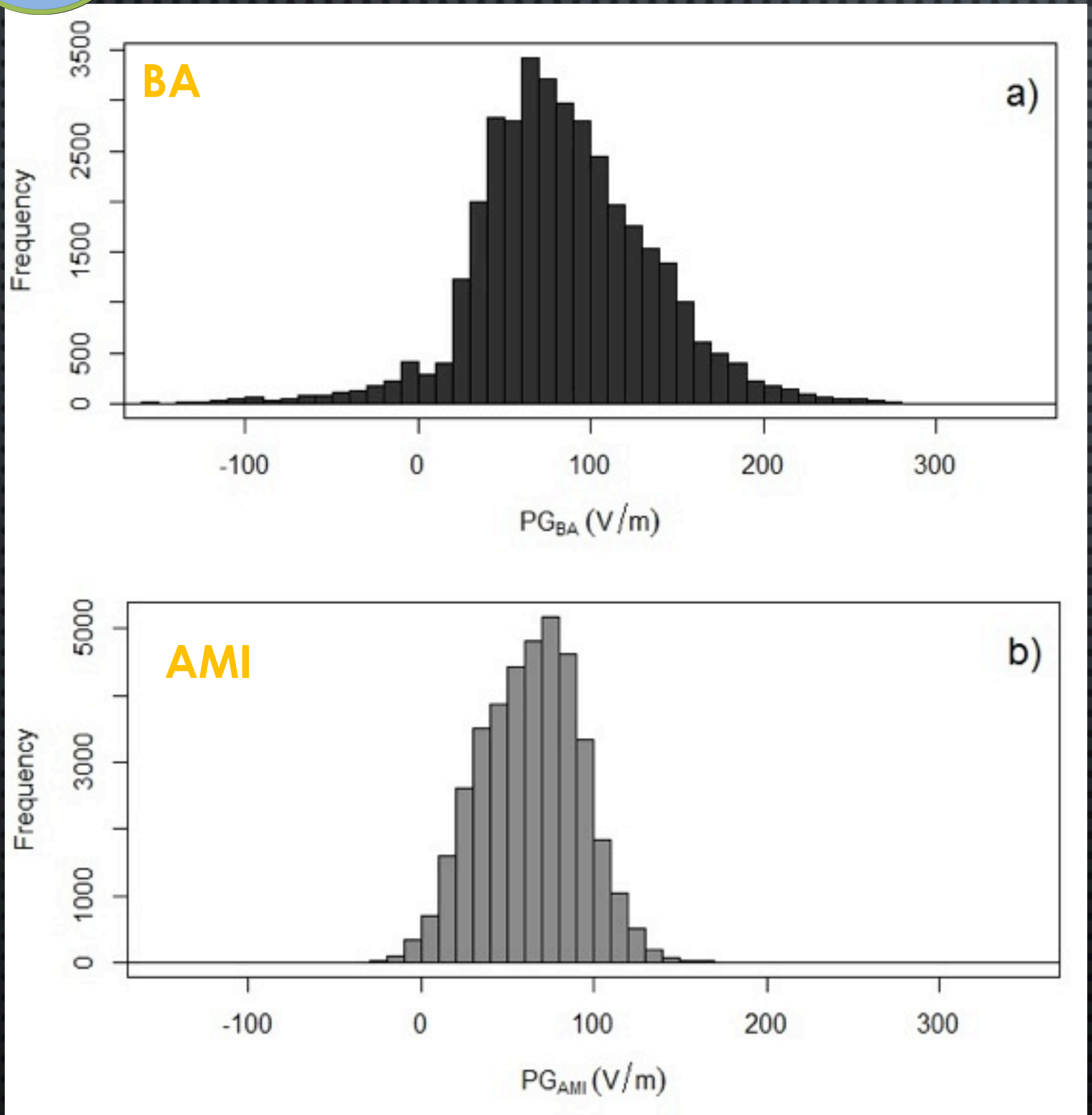
# IN SITU STATIONS

Amieira Marina – Potential Gradient

Amieira Marina – Meteorological

Alqueva-montante – Meteorological

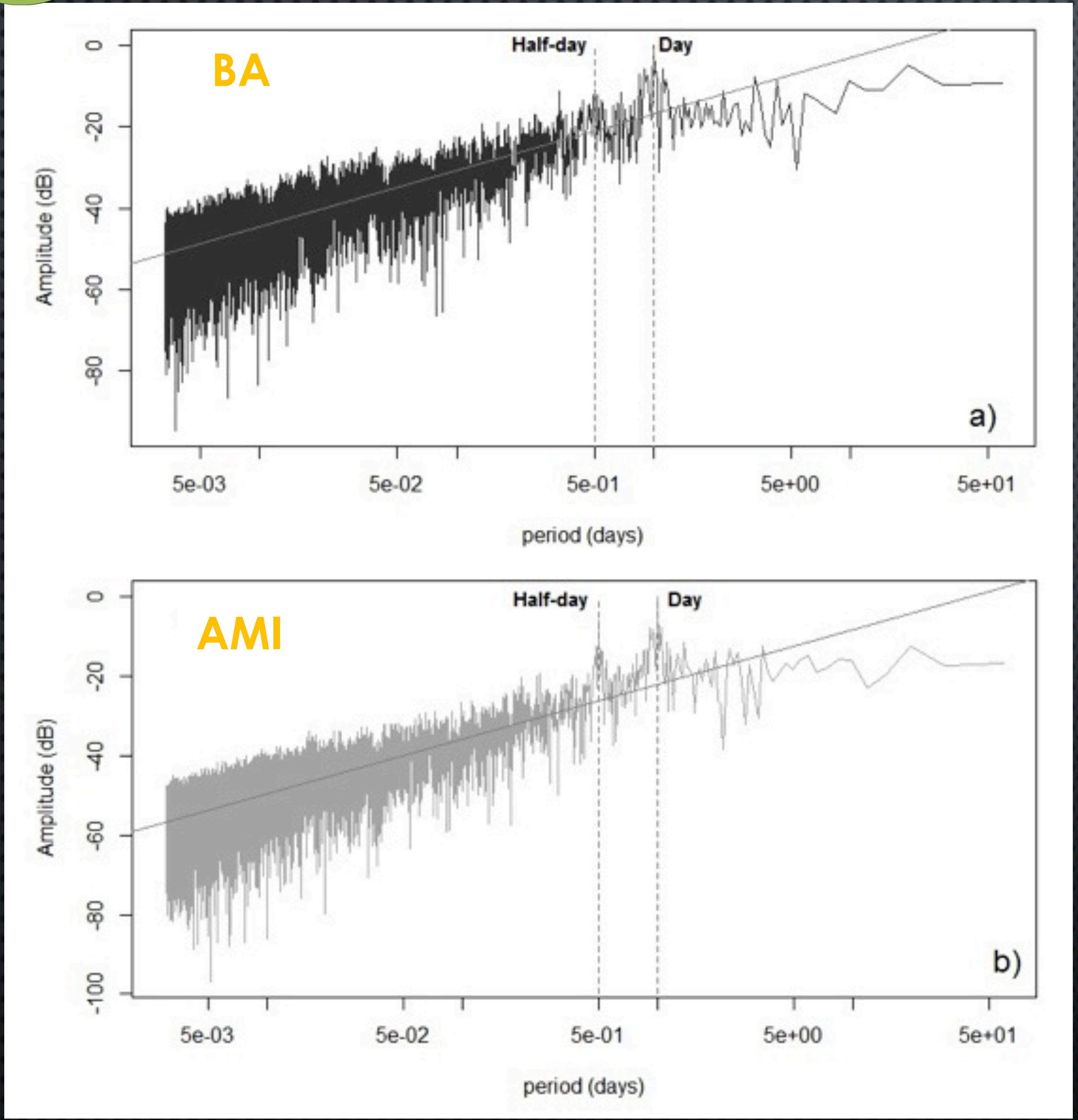
# RESULTS - $PG_{BA}$ & $PG_{AMI}$




| Table 2 | BA | AMI |
|---|---|---|
| Mean (V/m) | 84.36 | 63.41 |
| Median (V/m) | 80.90 | 64.70 |
| MAD (V/m) | 45.52 | 30.69 |
| Skewness | -0.15 | -0.07 |
| Kurtosis | 2.99 | -0.11 |
| Number of FW days | 25 | 27 |

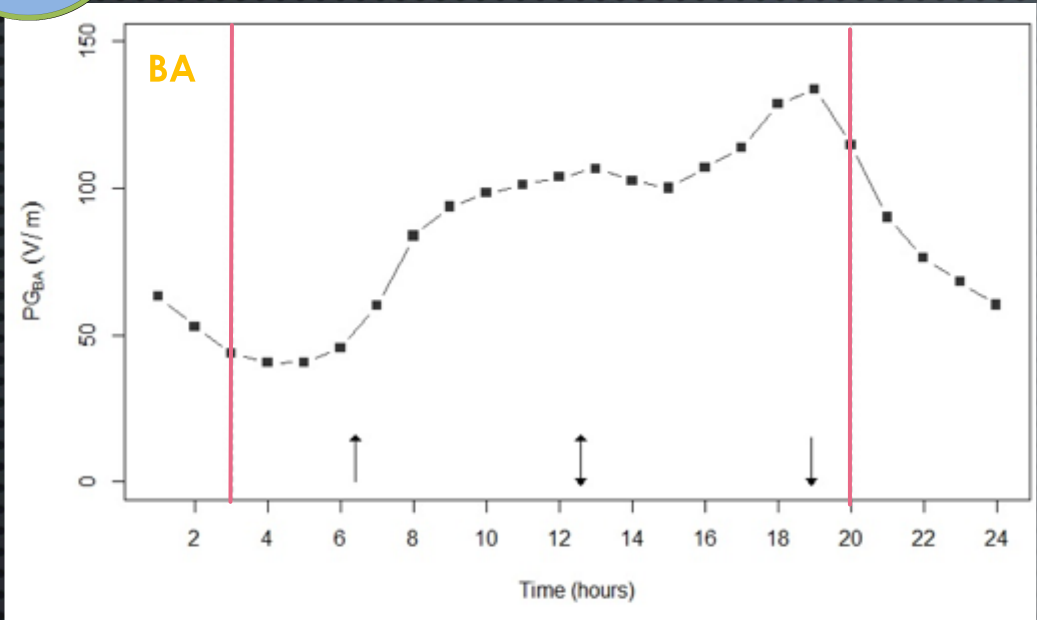
- $PG_{AMI}$ is less influenced by secondary variables, which are present in urban environments and lead to a lower variability of the PG (smaller MAD).

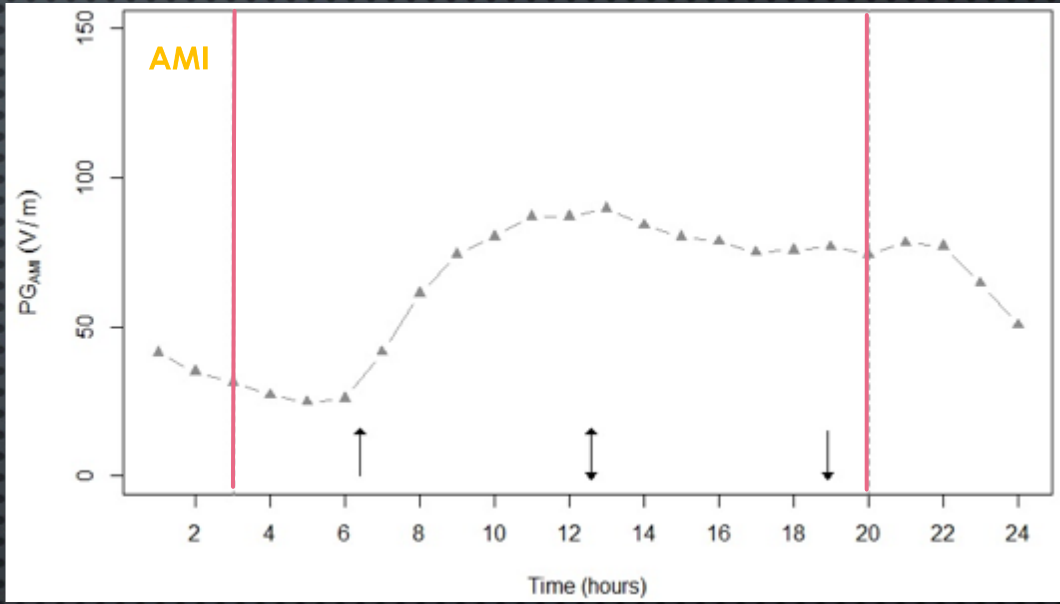
# RESULTS - $PG_{BA}$ & $PG_{AMI}$




- Lomb-Scargle Periodograms with slopes of the linear fit, for periods below the semi-diurnal cycle, with 1.38 and 1.37 for BA and AMI, respectively;
- Possible relation between the PG data and a meteorological variable (most likely the wind): n~1.667 (Lumley and Panofsky, 1964);
- Diurnal and semi-diurnal peaks are present in both series;
- Diurnal peak follows the diurnal behavior of the **Global Electrical Circuit**;
- Semi-diurnal peak can be a sub-harmonic of the main 1-day period (Xu et al., 2013), since measurements are performed under very low pollution levels (Table 1);

# RESULTS - $PG_{BA}$ & $PG_{AMI}$



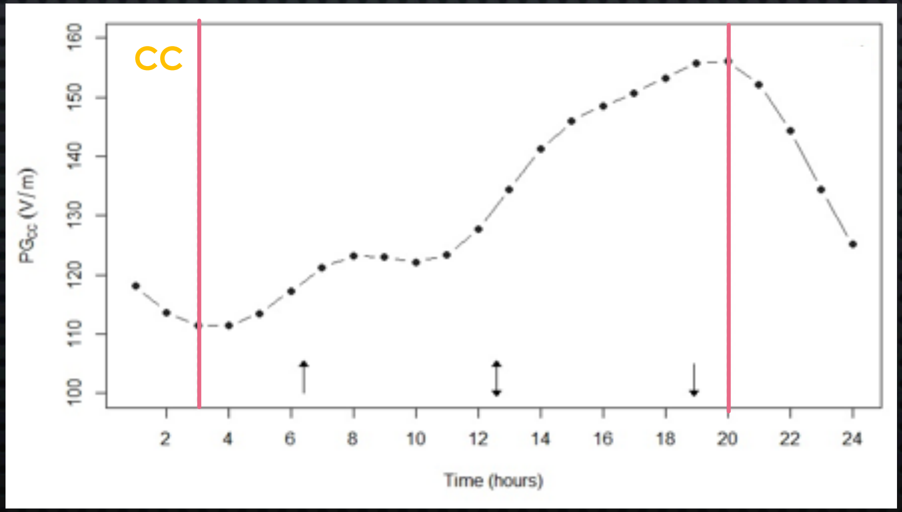




Reference of the Global Electric Circuit

**Carnegie Curve (CC)**

**Minimum: 111.4 V/m (3-4 UTC)**

**Maximum: 156.1 V/m (20 UTC)**



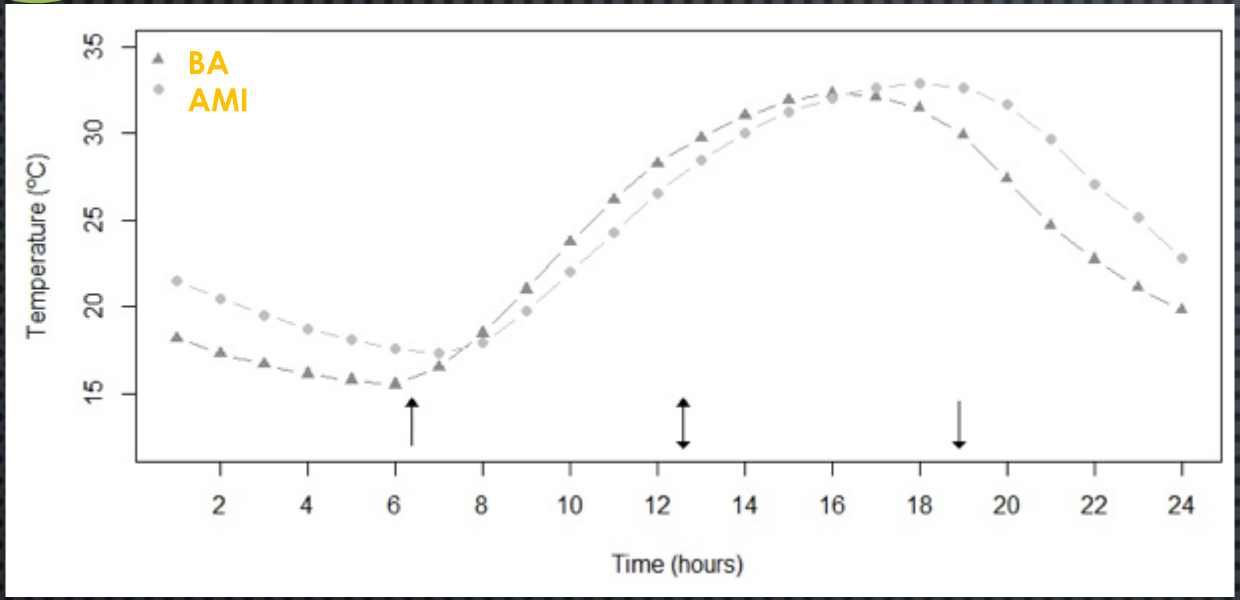

**AMI**

**Sunrise: 6.4 ± 0.3 UTC**

**Solar max.: 12.6 ± 0.2 UTC**

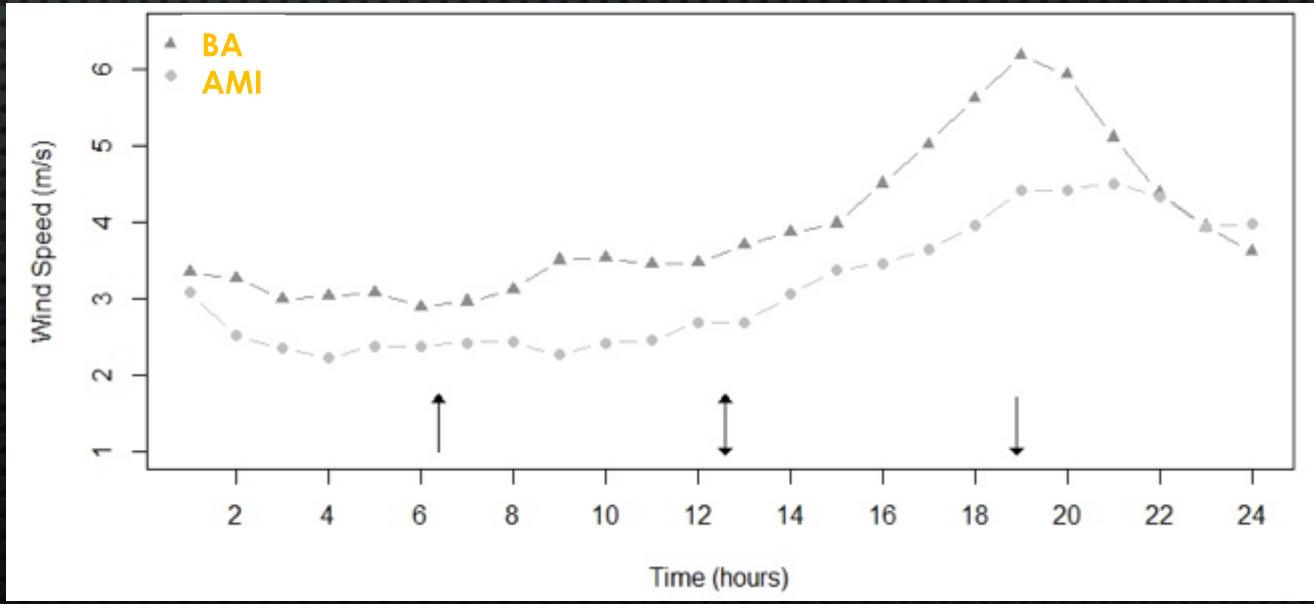
**Sunset: 18.9 ± 0.1 UTC**

# RESULTS - TEMPERATURE / WIND SPEED, BEJA & AMIEIRA

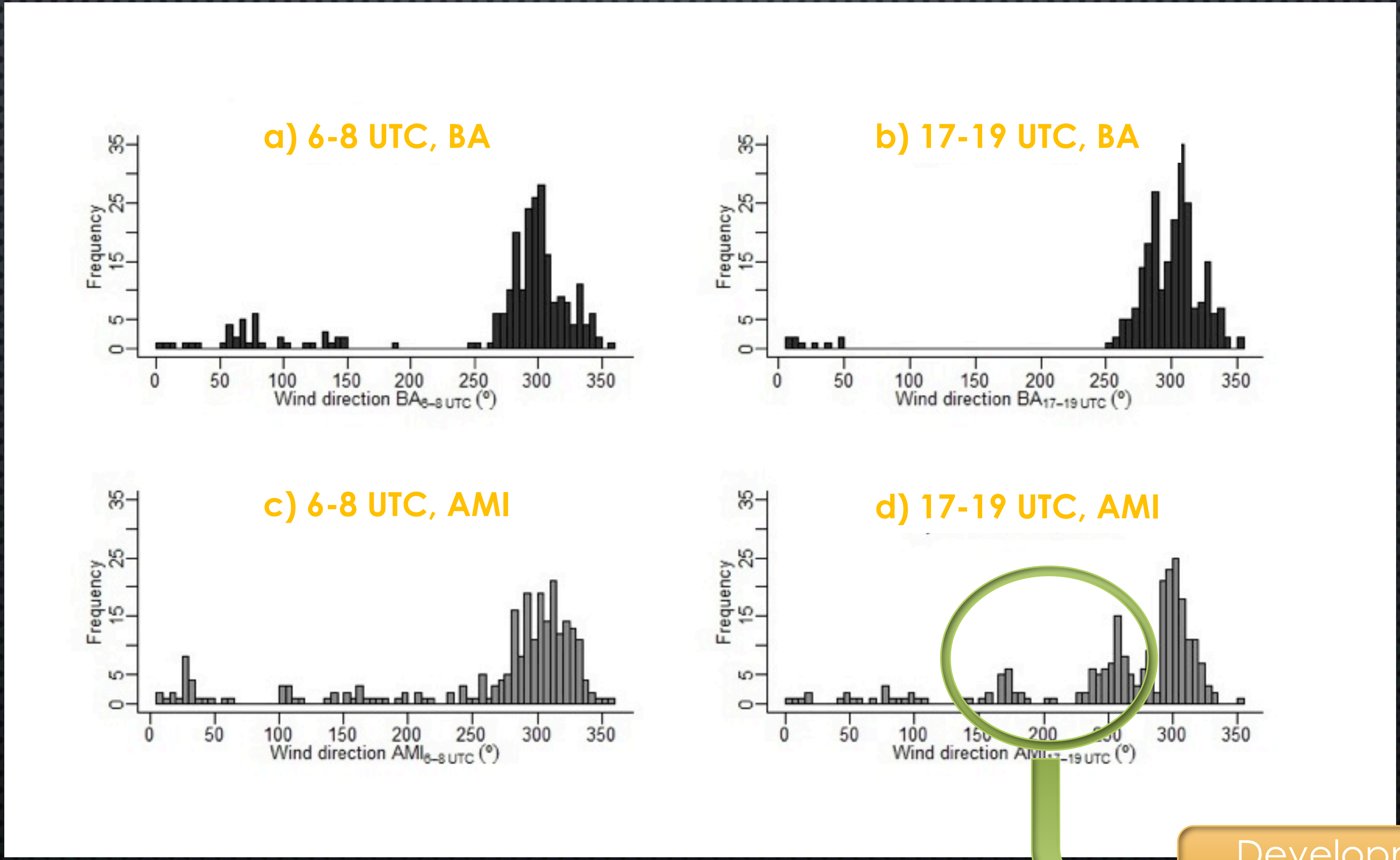



- Temperature in the reference land station (BA) and the temperature in the lake station (AMI) shows a similar behavior. AMI has a lower temperature amplitude as compared with BA. The maximum at BA is at 18 UTC one hour later then BA. This could be a result from the lake climatology.

- Some differences are noticeable in the wind speeds from BA and AMI. Strong winds are developed in BA probably related with strong conventions caused by the high temperatures in that region. This effect is reduced in AMI most likely because of the action of the lake.



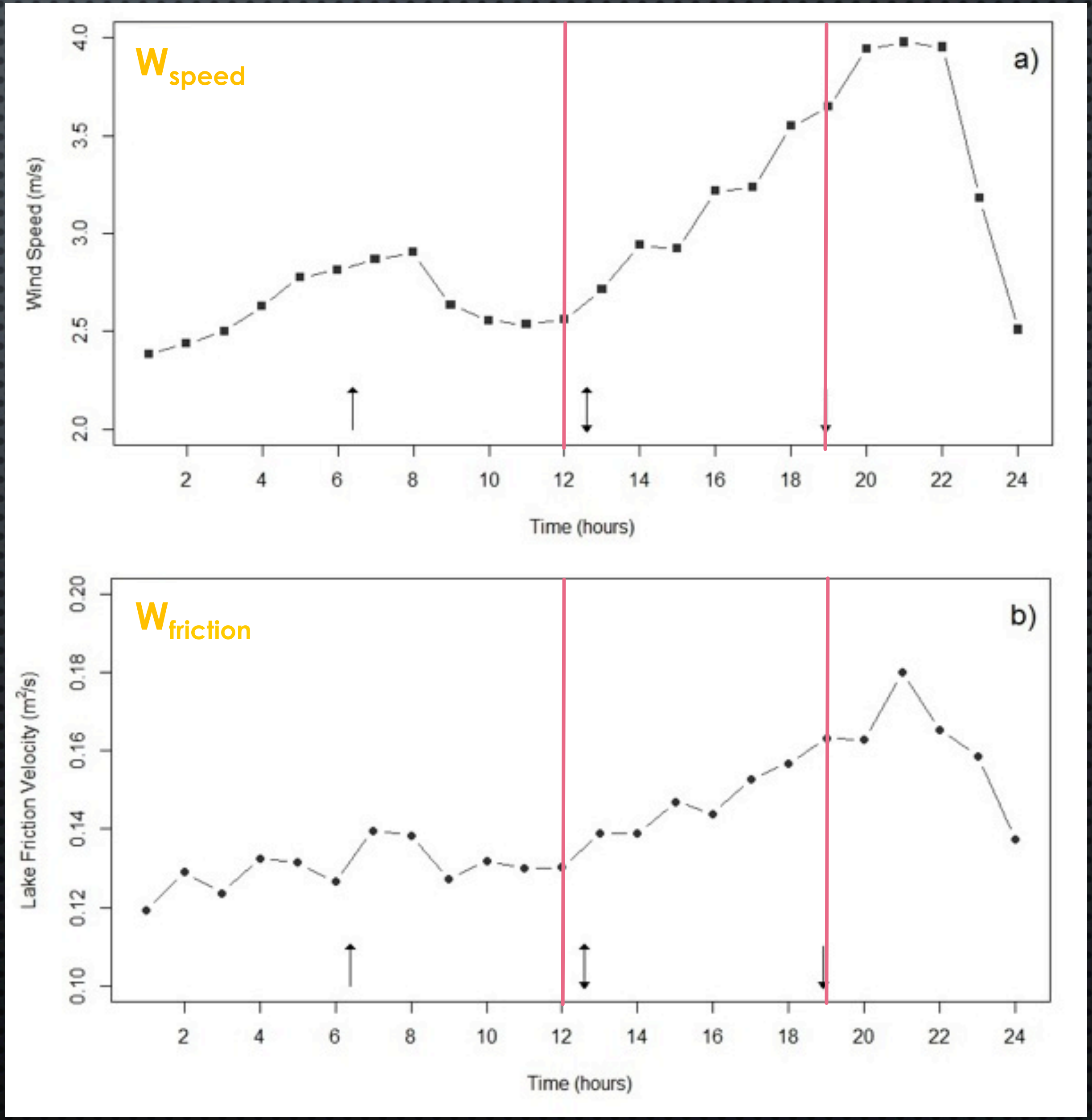
# RESULTS - WIND DIRECTIONS, BEJA & AMIEIRA



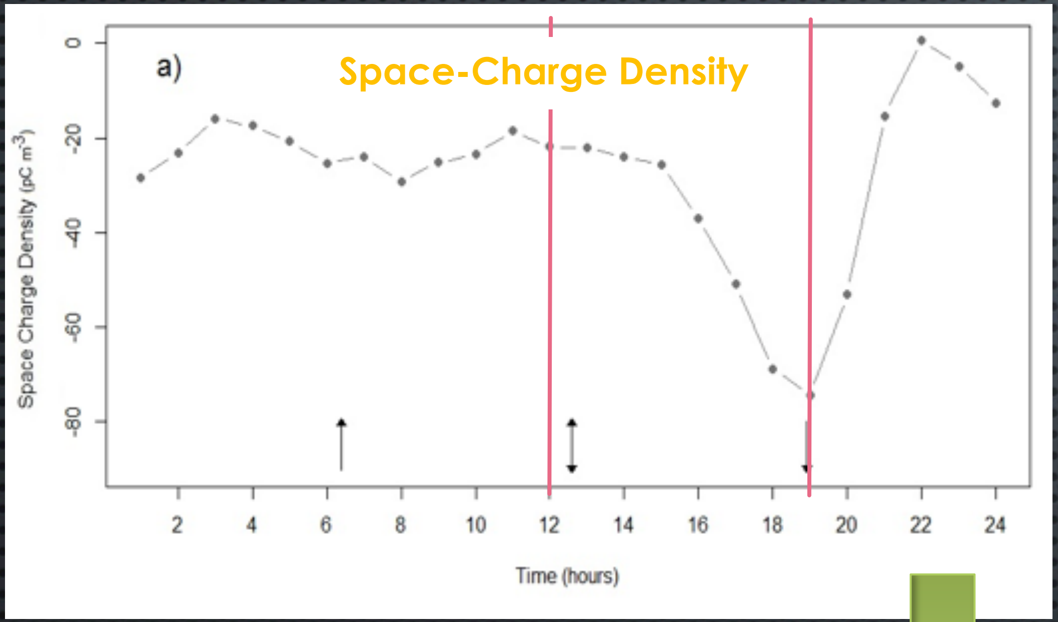

Development of the Lake Breeze

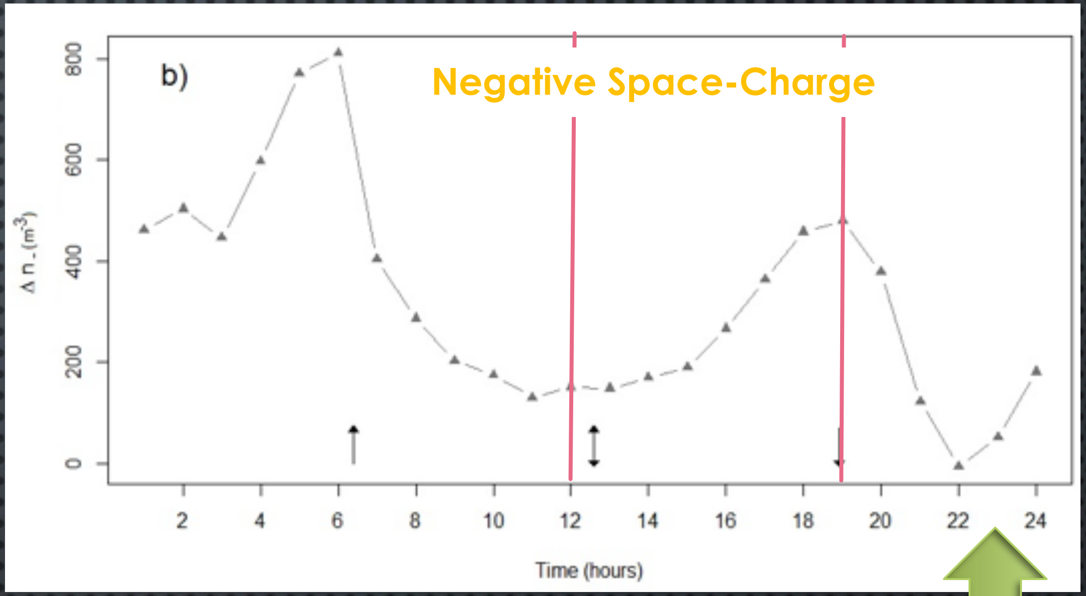
# RESULTS - WIND SPEED / FRICTION, LAKE

- The average daily variation of lake wind speed and friction velocity is represented for fair-weather days. A weak lake breeze forms during the afternoon, bringing air from the lake to land. In the afternoon an increase in the lake  wind speed and friction velocity is observed.
- Such increase is related with lake-land temperature difference and has a maximum value around 21:00 UTC.



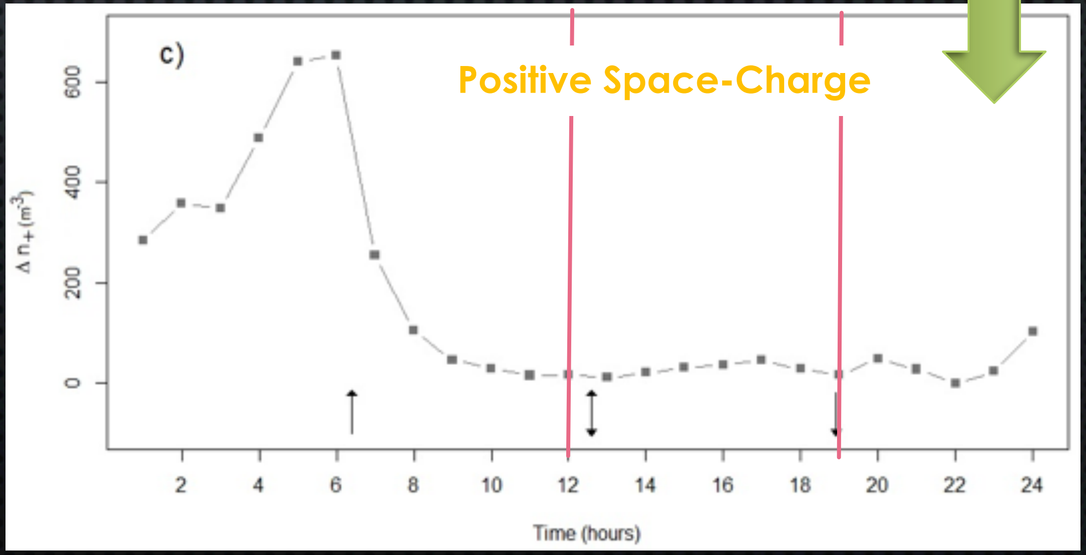
# RESULTS - SPACE CHARGE, BEJA & AMIEIRA



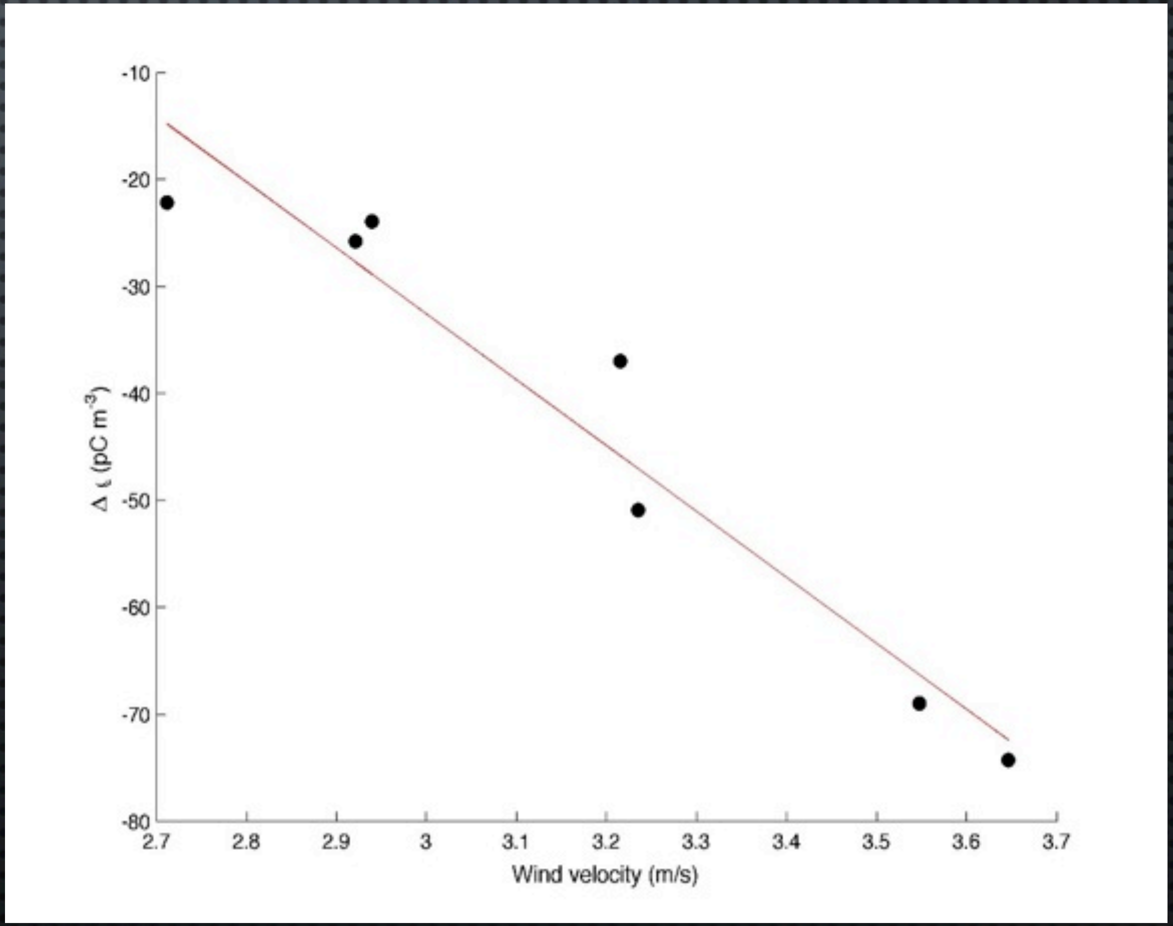

- The evolution of the negative space-charge seems to depend on wind speed over the lake;
- More wind implies more splashing at the shore and more bubble bursting and as a consequence the dispersion of negatively charged small drops;

$$2H_2O \rightleftharpoons H_3O^+ + OH^-$$



# RESULTS - SPACE CHARGE & WIND SPEED

- A first relation between the wind speed in the lake and the space-charge at AMI is made in the period of 13:00 and 19:00 UTC.
- The space-charge is represented against wind speed completing 7 points in the period above.
- The plot shows a good linearity with **$r^2$~0.93**.
- This is a good indication of the impact that the lake has in the space-charge.
- Next step would be to calculate the average hour values of $PG_{BA}$, $PG_{AMI}$, and lake wind for each of the fair-weather days.
- This will result in 7 similar points to the ones represented in this plot for each day allowing for a more statistically representative fit.



# FINAL REMARKS

- The formulation developed (not shown here in detail) to calculate the space-charge is innovative.

- The PG changes observed in AMI are related with the development of a negative space-charge related with the wind speed in the lake;

- In the afternoon the joint effect of wind speed in the lake and the presence of the lake breeze developed the mentioned negative space-charge resulting in the suppression of the PG at AMI  as compared with the BA and the Global Behavior;

- The significant correlation coefficient between the space-charge and the wind velocity in the lake indicates that the Alqueva Lake is the source of negative ions that create the negative space-charge;

- This is an original result: very few reports of negative space-charge over lakes exists in the literature.

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