An holistic monitoring system for measurement of the atmospheric electric field over the ocean - the SAIL campaign

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***Abstract*—The atmospheric electric field is a key characteristic of the Earth system. Despite its relevance, oceanic measurements of the atmospheric electric field are scarce, as typically oceanic measurements tend to be focused on ocean properties rather than on the atmosphere above. This motivated the set-up of an innovative campaign on board the sail ship NRP Sagres focused on the measurement of the atmospheric electric field in the marine boundary layer. This paper describes the monitoring system that was developed to measure the atmospheric electric field during the planned circumnavigation expedition of the sail ship NRP Sagres.**

***Index Terms*—electric field, marine boundary layer, climate, monitoring**

I. Introduction

The marine boundary layer, the part of the atmosphere directly influenced by the ocean, is critical for the Earth's climate. Despite the enormous advances enabled by remote sensing observations, knowledge on marine boundary layer processes is still very incomplete due to the lack of direct, in-situ observations of the marine atmosphere.

Project SAIL (Space-Atmosphere-Ocean Interactions in the marine boundary Layer) [1] aimed to increase understanding on the physical processes at the marine boundary layer focusing on the electrical properties of the atmosphere. The global nature of the atmospheric electric field was unveiled in the early 20th century by measurements performed by the survey vessel Carnegie [2]. The impact of these measurements endures today, as what became known as the Carnegie curve remains the reference against which current atmospheric electricity measurements are still compared. Despite the fundamental importance of the Carnegie curve, no comparable measurements have been performed again over the global ocean. In a climate change context, however, the need of such observations is even more compelling, as the electrical conductivity of the ocean air is clearly linked to global atmospheric pollution and aerosol content. In the spirit of the Carnegie expeditions, project SAIL aimed to provide, 100 years later, an updated and detailed picture of the atmospheric electric field over the ocean, by setting-up an innovative monitoring campaign on board the tall ship NRP Sagres.

This paper presents the monitoring system that was developed to measure the atmospheric electric field during the planned circumnavigation expedition of the sail ship NRP Sagres. As the electrical properties of the atmosphere are linked to space-earth interactions, the campaign also included detailed monitoring of environmental radioactivity and atmospheric ionization. The atmospheric measurements were complemented by the underwater monitoring of the ocean state (temperature, conductivity, dissolved oxygen, pH, spectral radiance) for a detailed study of ocean-atmosphere fluxes and surface-atmosphere interactions. All the observations, in air as well as underwater, have been linked to the same rigorous temporal and spatial reference frame.

The monitoring system is described in section II, the results obtained are illustrated in section III and concluding remarks are provided in section IV.

II. Monitoring system

A. Atmospheric instrumentation

The monitoring system includes a comprehensive suite of instruments for atmospheric measurements, focusing on the electrical properties of the atmosphere. This is an unparalleled installation on a sailboat, enabling for the first time the joint measurement of the electric field, ions, and radiation in the marine boundary layer. The atmospheric measurement system is composed by the following instruments:

- two identical atmospheric electric field sensors (Campbell Scientific, CS110) installed on the same mast, but at different heights (22 m and 5 m), measuring the vertical component of the electric field by means of a rotating grounded shutter.
- a visibility sensor (Biral, SWS050) providing the meteorological optical range and the atmospheric extinction coefficient.
- a NaI(Tl) scintillator (Scionix, 76B76/3M-HV–E3–X3) measuring total gamma radiation in the range 475 keV - 3 MeV.
- shortwave incoming (Apogee, SP-510) and outgoing (Apogee, SP-610) solar radiation sensors.
- a cluster ions counter (Airel, CIC), measuring the total concentration of both positive and negative cluster ions as well as providing information on the ions mobility distribution.

All the instruments were installed on the same (mizzen) mast of the ship (Fig. 1). All the sensors provide measurements at a rate of 1 Hz, except for the visibility sensor with measurements every 1-minute.

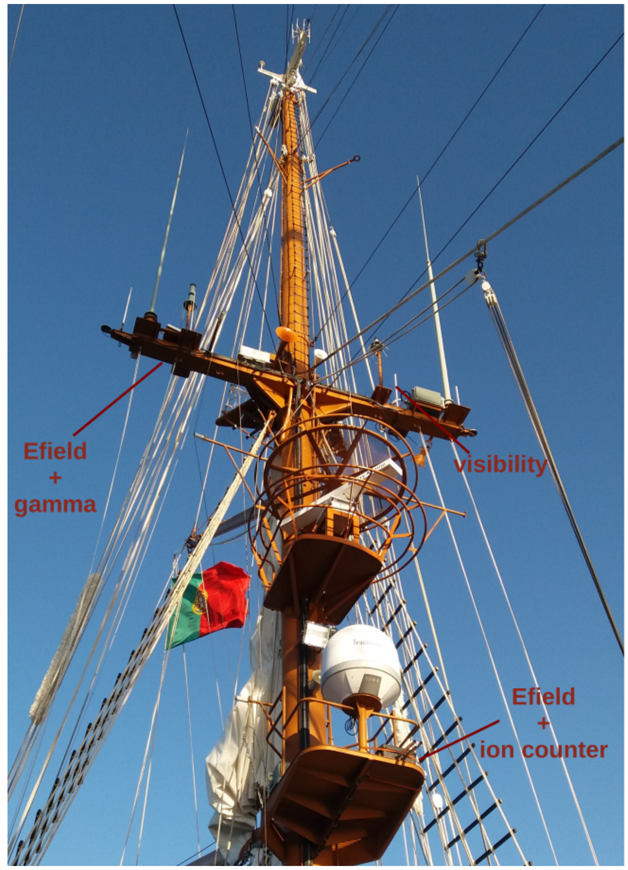

Fig. 1. Ship mast with installed instruments.

B. Oceanographic instrumentation

Oceanographic measurements were performed with a in-house built submarine system (Fig. 2).The system (tow-fish) was towed by the sail ship over several days, recording continuously the properties of sea water. It housed a Seven 310 multiparameter CTD (Idronaut) and a Trilux multiparameter algae sensor (ctg Ltd), providing information on pressure, temperature, conductivity, salinity, oxygen (% and ppm), pH, chlorophil(a), Turbidity and Phycoerythrin.

Fig. 2. Tow-fish housing CTD and algae sensors.

C. Hardware

The main hardware of the monitoring system includes:

- industrial computer running a Linux Ubuntu 18.04 LTS (with a redundant computer) both with Solid State Drive storage.
- 40 Tbytes Network attached Storage (NAS) with a high level of redundancy.
- 16 port RS422/RS232 Mux.

  These peripherals are connected by a Gigabit switch.

D. System operation

A log service was implemented for each instrument. For every log service a configuration file was created including specific serial communication details such as : serial device, baud rate, stop bits, parity, end line delimiters and frame format. After start-up, the computer starts to collect the data from each sensor (in the same format as it is sent by the instrument) based on these configurations.

Every measure is tagged with a timestamp with microsecond precision based on the system clock. The system clock is corrected by the PPS signal available from the GNSS. In order to ensure data integrity the operating system clock is always maintained in Universal Time Clock (UTC). Because the PPS signal cannot reach every sensor and some sensors don't have an internal clock, the timestamp is obtained on the first interaction between the sensor and the operating system after the current acquisition. This can lower the time resolution to the milliseconds. In case a sensor has a Real Time Clock (RTC), this clock is adjusted with the operating system time and the time value is also saved along with the sensor sample.

The log files are split into hourly files and saved in a dedicated directory named from the date (year, mount and day) and name of the sensor. The log service writes every detail about it's current state and sensor state in special memory blocks shared with the rest of the operating system. These memory blocks can be read by any application.

The data from the previous day is backed up into the NAS system at 01:00 UTC every day. This process is managed by the operating system crond services and consists in compressing the data for the current day and sending this data into the NAS. The data currently copied to the NAS is not immediately deleted being maintained in the computer until the space is needed, and/or someone ensures no problems had occurred.

E. System interface

The monitoring system was designed to run without human intervention collecting data for long periods of time and ensuring its preservation even in the absence of communications or direct access to the on board computer. However, a system interface was developed to enable checking of the status of all sensors either remotely or locally (e.g by the ship's crew). Since the available ship internet connection was via a satellite link with low bandwidth, a simple ncurses interface was implemented. The SAIL tool interface interacts with the log services via the special memory blocks and enables either remote or local visualization of the state of the monitoring system (Fig. 3).

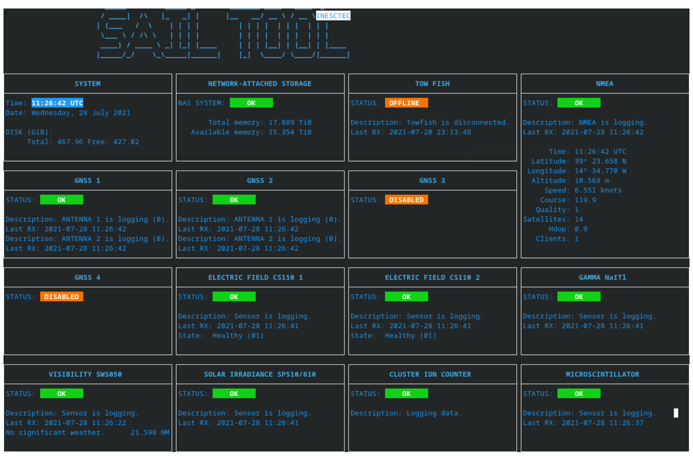

Fig. 3. Sailtool interface.

III. Results

The monitoring system was operational during the circumnavigation expedition of the ship NRP Sagres in 2020. The ship departed from Lisbon towards South America, with stops in Tenerife, Cape Verde, Rio de Janeiro, Montevideo and Buenos Aires. Then it crossed the South Atlantic to Cape Town, but instead of pursuing the planned trip into the Indian Ocean returned northward to Lisbon (Fig. 4). Data were collected since the departure of the ship from Lisbon, in January 5th, up to its early return to Lisbon due to the restrictions resulting from the covid pandemic, in May 10th 2020. During this 126-days period of navigation in the Atlantic ocean , about 98% of the data were successfully retrieved, attesting the robustness of the monitoring system. The resulting dataset contains more than 300 files per day, and an average size of 10 GB per day.

As an illustration of the collected data, the atmospheric and oceanographic data collected over a day are displayed in Fig. 5 and Fig. 6, respectively.Both electric field sensors record high variability of the potential gradient from around 12:00 to 16:00 UTC, consistent with disturbed weather as the visibility is reduced in the same period. After $\sim 16:00$ UTC the electric field decreases to typical fair-weather values (consistent with high visibility) but the variance of the measurements remains higher than in the morning. Interestingly the ocean measurements of temperature and conductivity also display higher variability than the morning measurements, although such a change in data dispersion between morning and afternoon is not observed for turbidity or the algae measurements (chlorophyll and phycoerythrin).

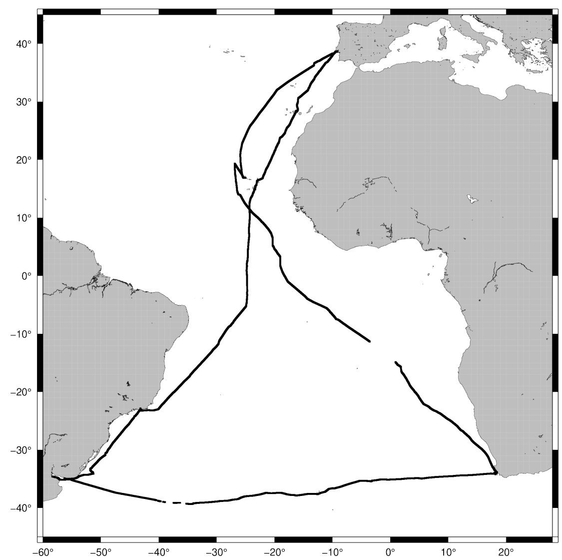

Fig. 4. Ship trajectory retrieved from the GNSS measurements.

Time series of 1-minute potential gradient obtained from aggregation of the raw electric field measurements are displayed in Fig. 7. The potential gradient has the opposite sign of the atmospheric electric field in order to comply with the sign convention denoting the potential gradient as positive under undisturbed atmospheric electrical conditions. Both sensors display large oscillations associated with disturbed weather conditions (hydrometeors, lightning, fog,...). The potential gradient (PG) data are thus processed in order to flag and remove the values associated with non-fair weather conditions: i) negative PG values (corresponding to $< 2\%$ and $< 10\%$ of the upper and lower sensors values, respectively); and ii) positive PG values exceeding 150 V/m (corresponding to $< 2\%$ and $< 0.5\%$ of the upper and lower sensors values, respectively). The resulting time series of pre-processed potential gradient values is displayed in Fig. 8.

The sensor at the lower height in the mast typically displays

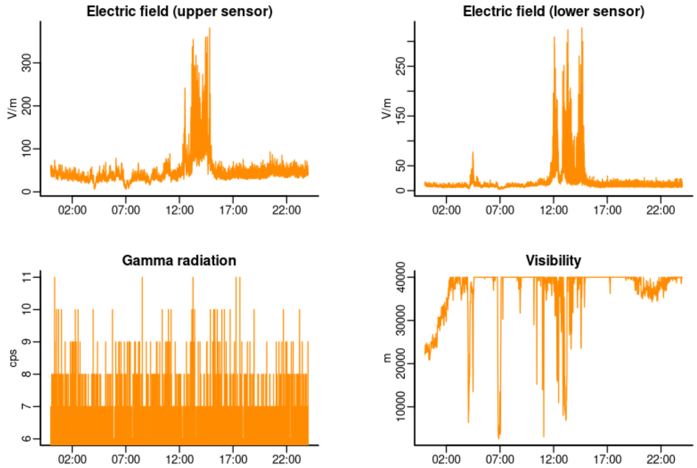

Fig. 5. Atmospheric 1-second data.

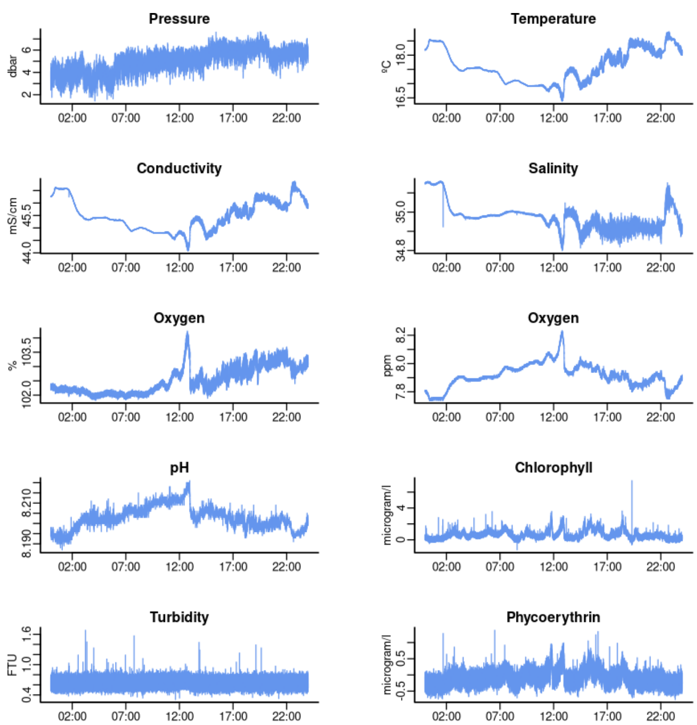

Fig. 6. Oceanographic 1-second data.

lower PG values, though the temporal variability is consistent with the upper sensor. Checks of the sensor's reference zero cover field yielded values of the atmospheric electric field below 1 V/m. Thus differences between the sensors are not related to a systematic instrumental bias but a local effect reducing the electric field measurements at the lower height. The lower sensor is more affected by screening effects associated with the position of the sensor in the mast and its proximity to the ship's structure and sails, while the upper sensor is in a less obstructed position.

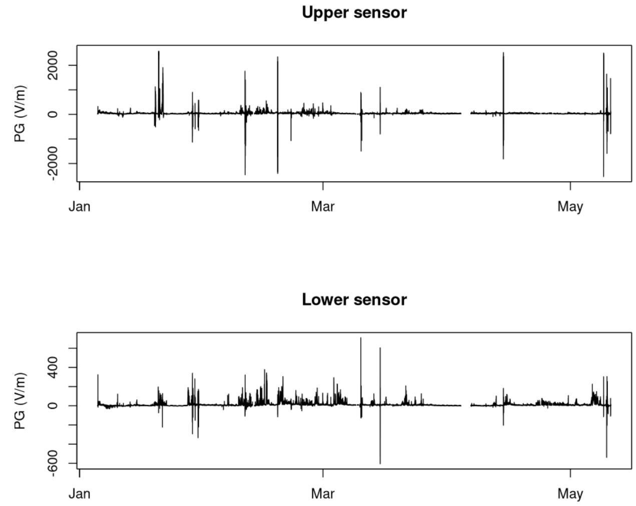

Fig. 7. Time series of 1-min potential gradient values.

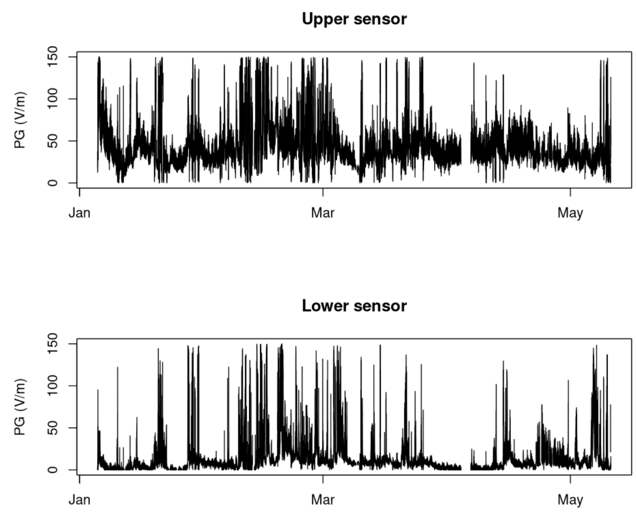

Fig. 8. Time series of 1-min potential gradient values after removal of outlying values associated with disturbed weather.

IV. Conclusions

The monitoring system installed on board the sail ship NRP Sagres enabled to measure the atmospheric electric field with unprecedented accuracy over the Atlantic Ocean. These 21st century measurements, 100-years after the Carnegie expeditions, are an unique contribution, not only by providing updated quantitative information on the electrical properties of the atmosphere, but also related parameters (e.g. gamma radiation) associated with space-earth interactions.

All the collected data will be dully preserved to enable initially unforeseen uses of the data and to guarantee fully-documented and reproducible research based on the dataset, supporting reuse of the data in multiple environmental domains and for different applications [3]. The raw data [4] are available from the INESC TEC institutional repository (https://rdm.inesctec.pt).

Acknowledgment

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References

[1] S. Barbosa et al., "The SAIL data infrastructure - Open and FAIR research data from the SAIL campaign" Zenodo. http://doi.org/10.5281/zenodo.3575111.

[2] R. G. Harrison, "The Carnegie curve," Surveys in Geophysics, vol. 34, pp. 209–232, 2013.

[3] S. Barbosa and Yulia Karimova. SAIL Data Management Plan (Version 2.0.0), DOI: 10.5281/zenodo.4286209, 2021.

[4] S. Barbosa et al., "Raw data collected onboard the Sagres ship during the SAIL project campaign [dataset]". INESC TEC research data repository. DOI: https://doi.org/10.25747/b2ff-kg31. 07 jul 2021.