COST Action CA15211 "Electronet"

Short-Term Scientific Missions (STSM) final report

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3. STSM PERIOD: 29 March 2017 to 4 April 2017

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STSM Working Plan and Objective

Proposal objective

- Familiarization with the operation of the various instruments that measure atmospheric electricity parameters with a special focus on the conductivity sensor in the Geophysical Observatory in Swider. The Swider observatory is run by the Institute of Geophysics, Polish Academy of Sciences.
- Understanding the theoretical mechanism of air conductivity measurement instruments and the influence of local meteorological variations and other parameters and events on the measured values of the electric parameters.
- Test the implementation of an air conductivity sensor and consideration of uses in various areas of atmospheric electricity research.
- Discussion on implementing and building a conductivity sensor in Israel to measure the air conductivity. Today we measure the conduction current density and the electric field. By measuring the conductivity we will be able to compare actual conductivity results with the theoretical results derived from Ohm's law.

Introduction

The Gerdien condenser device which is the standard device for measuring the conductivity of air is composed of two brass electrodes which are encircled by a hollow stainless steel cylinders which act as an outer electrodes. The outer cylinder electrodes have a finite capacitance which can be derived from Gauss' law. A potential is applied to the electrodes and a fan is ventilating the air into the cylinder. Air Ions of a similar sign as the voltage applied to the outer cylinder are repelled and gathered on the inner brass electrode applying a small current flow which is proportional to the ion concentration and electrical conductivity of the air. Figure 1 shows a schematic of one cylinder tube, if the cylinder for example if connected to the positive side of the battery, positive Ions entering into the cylinder will repel and collect on the central electrode and will generate and current. Negative Ions will be attracted to the outer electrode (the cylinder) and grounded to Earth.

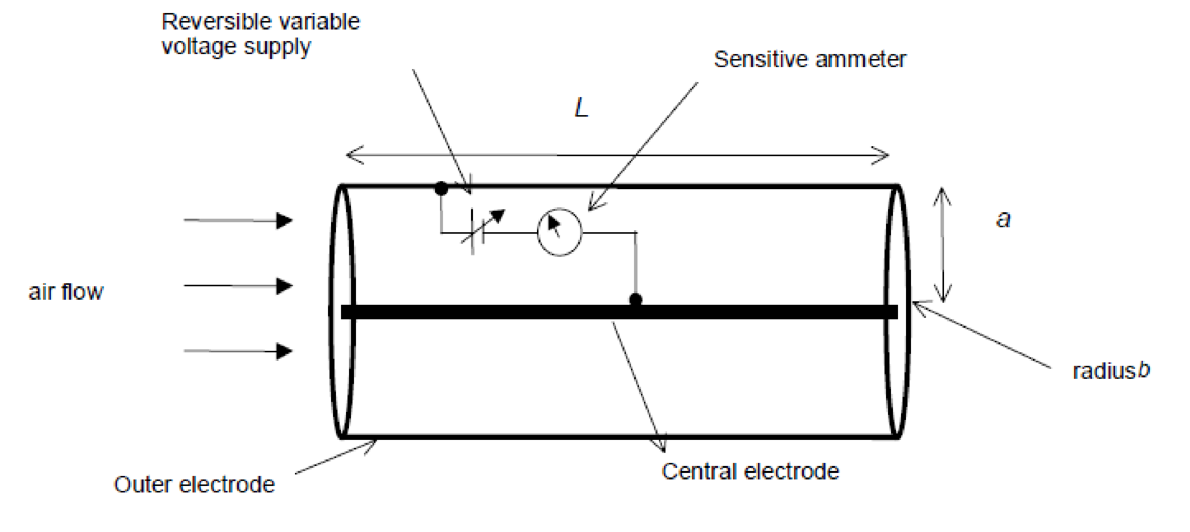

Figure 1 – A Gerdien Condenser – central brass electrode (bold black line) is encircled by a stainless steel cylinder which act as an outer electrode. Air flow from one direction to the other.

The fundamental of the conductivity (σ) measurements carried by a capacitor of surface area (S) through a medium can be defined with Gauss' law that the charge per unit area is proportional to the electric field and to the current density (J) and is given by

Eq. 1 $$J = \frac{\sigma Q}{S\varepsilon_0}$$

Hence the current I for a flow of ions is

Eq. 2 $$i = \frac{\sigma Q}{\varepsilon_0}$$

The current arriving at the central electrode per unit time is defined as (Mcgorman and Rust 1998):

Eq. 3 $$i = \frac{2\pi NkVLe}{ln\left(\frac{b}{a}\right)}$$

V is the voltage on the outer electrode, L is the length of the outer electrode, e is the electron charge, N is the number of ions, k is the mobility, b and a are dimension as can be seen from figure 1. Conductivity is:

Eq. 4 $$\sigma = eNk$$

And therefore Eq. 3 can be substitute so the ion current is proportional to the conductivity so that:

Eq. 5 $$i = \frac{2\pi VL\sigma}{ln\left(\frac{b}{a}\right)}$$

The Capacitance C of a cylindrical capacitor is, from Gauss's law:

Eq. 6 $$C = \frac{2\pi\varepsilon_0 L}{ln\left(\frac{b}{a}\right)}$$

And therefore the current I can be written as

Eq 7. $$i = \frac{CV\sigma}{\varepsilon}$$

So by measuring the current i (typical values are 0.1-2 pAm) from an electromemter we can calculate the conductivity. One time for positive ions and second time for negative ions. The conductivity for each polarity should be:

Eq 8. $\sigma = \frac{\varepsilon i}{CV}$

The total conductivity therefore is:

Eq. 9 $\sigma_t = \sigma_+ + \sigma_-$

Alternate way to measure the conductivity by using volume wind flow, capacitance and voltage is as follow. The conductivity is defined with the mobility (k), Ion concentration (N) and elementary charge (e) and is as seen is Eq. 4:

Eq. 10 $\sigma = eNk$

From Eq. 6, the capacitance per dielectric unit C' of the cylinder can also be defined as the length of the cylinder (L), and radii dimension and is as follows:

Eq. 11 $C' = \frac{C}{4\pi\varepsilon_0} = \frac{L}{2ln\left(\frac{b}{a}\right)}\ [cm]$

Using Eq. 10, we can measure the electrical mobility (k) that is defined as:

Eq. 12 $k = \frac{M}{4\pi C'V} = \frac{M\varepsilon_0}{CV}\ \left[\frac{cm^2}{sec \cdot Volt}\right]$

While C' is calculated from (eq. 11), V is the battery voltage on the outer electrode (~10V) and M is the volume of air flow [cm^3/sec] that is calculated by measuring the surface opening of the a cylinder and the air velocity generated by the fan on the opposite side (with Anemeter).

Eq. 13 $M = V \cdot S\ \left[\frac{cm}{sec} \cdot cm^2\right]$

The ion concentration (N) is defined as:

Eq. 14 $N = \frac{\Delta V}{RMe}$

ΔV is the voltage values measured on the resistor by the electrometer (typical values: ~20-50 mV), R is the resistance of the resistor (1 or 2 GΩ = 10^{11} Ω), M is the volume air flow.

So by measuring the ΔV on the resistor we can calculate the ion concentration N and the conductivity for each cylinder and use Eq. 6 to calculate the total conductivity.

Preliminary Results

The following photos in figure 2 show the Gerdien condenser configuration

Figure 2 – images of the Gerdien condenser ready to be installed. The big black 10Ω resistors that heat the white Teflon insulator. The GΩ transparent tube resistors, the wiring. The inner collecting brass electrode inside the cylinder and the electrometer.

Figure 3 shows the operational station.

Figure 3 – conductivity station. Gerdien condenser, electrometer, the outside tube and the conductive fence to protect the collection from electric fields, so the wind flow will funnel the ions into the cylinders inside.

The outer electrode (cylinders) are connected to a voltage of 10 Volt, one is connected to the positive battery electrode and the second to the negative battery electrode and both are grounded separately. The four 10 Ω resistors are connected to 20 Volt (1 Ampere) power supply which heat the four resistors that keep the insulators warm (and prevent a current leak due to water condensation along the insulator and from the inner electrode).

The current or voltage to measure the conductivity is measured on two 100-1000 GΩ resistors.

Each of the two GΩ resistors is grounded and is connected to a separate electrometer – one for the positive measurements and the other to the negative measurements.

The following tables summaries some of the main components:

Component	Material	Maintenance
Cylinder 10V battery	Regular battery	1 / year replacement
Electrode material	copper	40 cm long, 1.8 cm diameter
Outer cylinder	Stainless steel	12.8 cm diameter
Fan	Stainless steel	
Insulator	Teflon	
Cleaning	The instrument in Swider is cleaned once in several month from dust and insects. In a dusty location it should be cleaned once in two-three month and after a dust storm.	

The instrument is connected to a datalogger which records the data at a sampling frequency of 2Hz and a data acquisition system that can show plots in real time mode and calculated the conductivity from the voltage or current measurements. The raw data in Swider are Ez [V/m], Jz [pAm/m^2], σ+ [X10^{-15} Ω^{-1}m^{-1}], σ- [X10^{-15} Ω^{-1}m^{-1}]. An example of raw data file is seen on figure 4.

Typical values measured in Swider observatory (Latitude: 51^0 6.9' N, Longitude: 21^0 15.18' E, Altitude: 100m a.s.l) are:

The volume air flow is: $M = 4620\ \frac{cm^3}{sec}$, instrument capacitance is: $C' = 14.5\ cm$

And the calculated mobility is: $k = 2.8 \ \frac{cm^2}{V \cdot sec}$.

Typical total electric conductivity values measured in the observatory:

$$\sigma = 0.1 - 20 \cdot 10^{-15} \left[\frac{1}{\Omega \cdot m}\right] or \ [Siemens]$$

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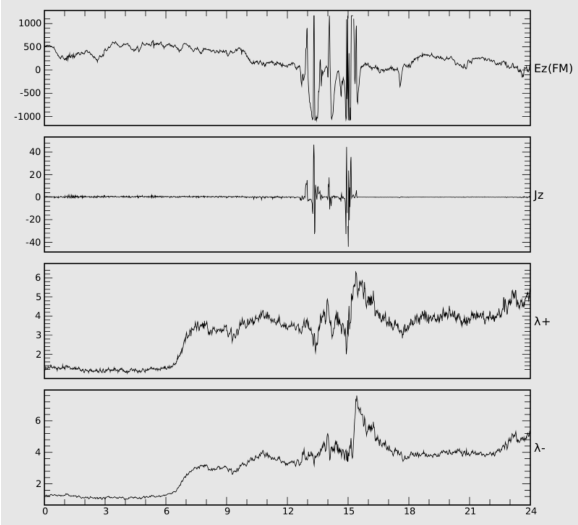
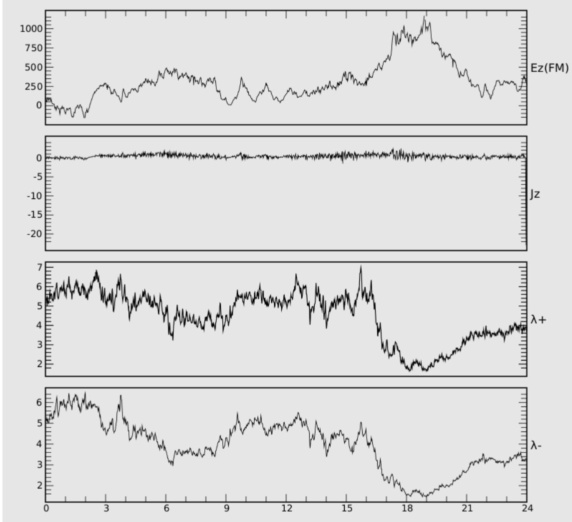
SAMPLE	cond-	cond+	Jz	Ez(FM)
0	*	*	*	*
1	3.4	4.1	0.3	286
2	3.4	4.0	0.1	269
3	3.3	3.8	0.4	278
4	3.4	4.1	0.1	261
5	3.5	4.3	0.3	260
6	3.5	4.3	0.5	265
7	3.5	4.2	0.3	269
8	3.5	4.0	0.5	273
9	3.5	3.9	0.4	288
10	3.5	4.1	0.6	296
11	3.6	4.2	0.4	296
12	3.6	4.4	0.3	292
13	3.7	4.4	0.4	293
14	3.6	4.3	0.3	297
15	3.6	4.3	0.4	292
16	3.5	4.0	0.4	291
17	3.5	3.9	0.3	305
18	3.5	4.2	-0.3	278
19	3.6	4.1	0.2	263
20	3.6	4.3	-0.1	245
21	3.6	4.1	0.1	237
22	3.6	4.1	0.1	228

Figure 4 – An example of the raw data.

Measurements from Wednesday to Friday, 29-31 March 2017 of Ez, Jz and the positive and negative conductivity are presented on figure 5 and show the diurnal curve. Figure 5 top left is 29 March 2017, figure 5 top right is 30 March 2017 and figure 5 bottom left is 31 March 2017.





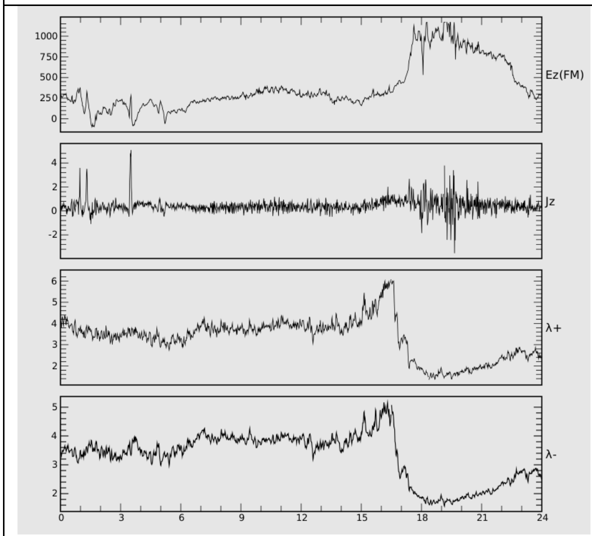


Figure 5 – Three subsequent days from 29 March 2017 (top left) to 31 March 2017 (bottom left) of atmospheric electricity parameters measured in Swider observatory, Poland.

We can see the lightning activity global contribution on the Ez – low values were measured at night and the Ez began to increase. At evening hours of the 29 March a distant CB was observed on the maps and the station measured electrical activity – strong variations on the Ez, Jz and the σ. On 30 and 31 March the weather was partially fair weather with a thin layer of high stratus clouds from time to time. Since the weather was quite cold with moderate wind speed variations were seen on the Ez, Jz and σ. On both days around 18:00 LT, the residents from the surrounding town lit the fireplaces, the concentration of soot in the air was rising and a local aerosol concentration sampler measured 42,800 cc/cm^3. A clear response is seen on the Ez which increases up to 1000 V/m. The positive and negative conductivity measured at the time showed an opposite response with a strong decrease from 4-6 $1X10^{-15}$ $\Omega^{-1}m^{-1}$ to ~$1X10^{-15}$ $\Omega^{-1}m^{-1}$ while the conduction current density (Jz) was constant (~-2pA/m^2).

Summary

Conductivity measurements are performed continuously from Swider, Poland along with conduction current density and the vertical electric field. Preliminary results measured during the STSM show an expected negative correlation between the electric field and the conductivity with respect to ohm's law during the time of high pollution from local source.

We wish to implement a similar instrument in Israel to measure the conductivity in the Negev desert and on Mount Hermon to see a similar effect during sunrise and the uplift of aerosols from the ground in the desert and the decrease of conductivity during the "Austausch effect" that was measured on the Hermon mountain in the early hours [Yaniv et al 2016, Yaniv et al 2017].

References:

MacGorman D.R and Rust W.D, the electrical nature of storms, Oxford University Press, 1998.

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Yaniv, R., Yair, Y., Price, C., Mkrtchyan H., Lynn B., Reymers A., Ground-based measurements of the vertical E-field in mountainous regions and the "Austausch" effect. (Accepted for publication) Atmospheric Research, 2017.