GICs: where do we stand in Portugal?

Joana Alves Ribeiro on behalf of MAG-GIC team

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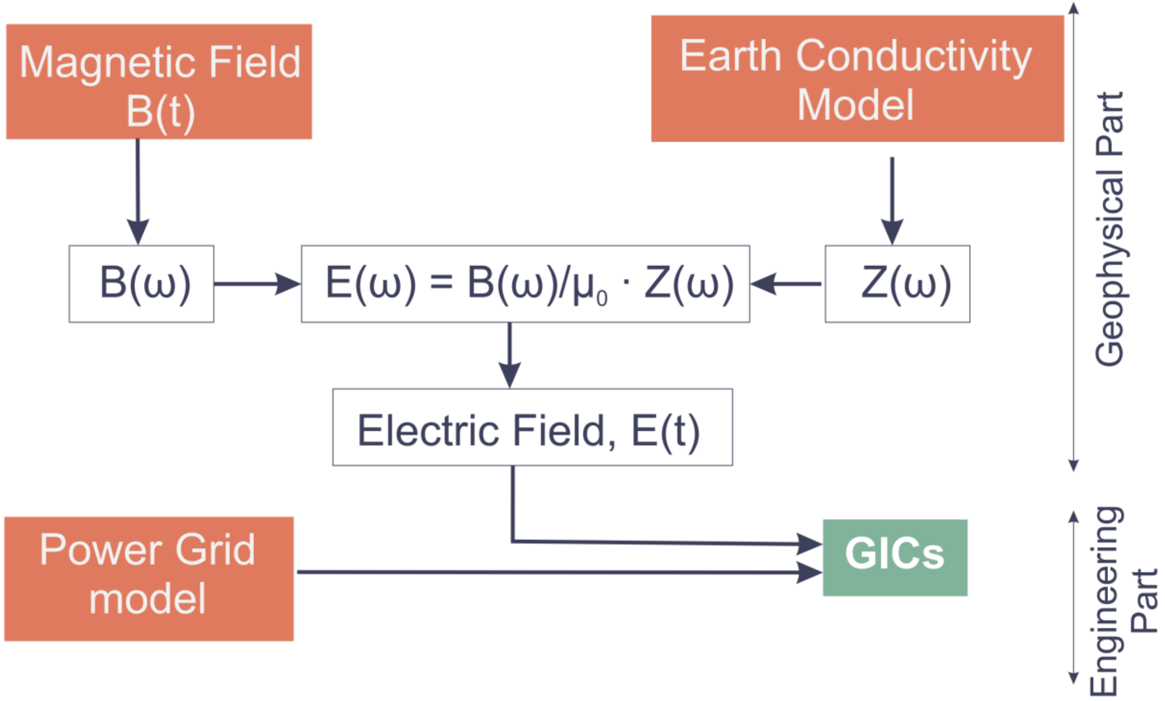
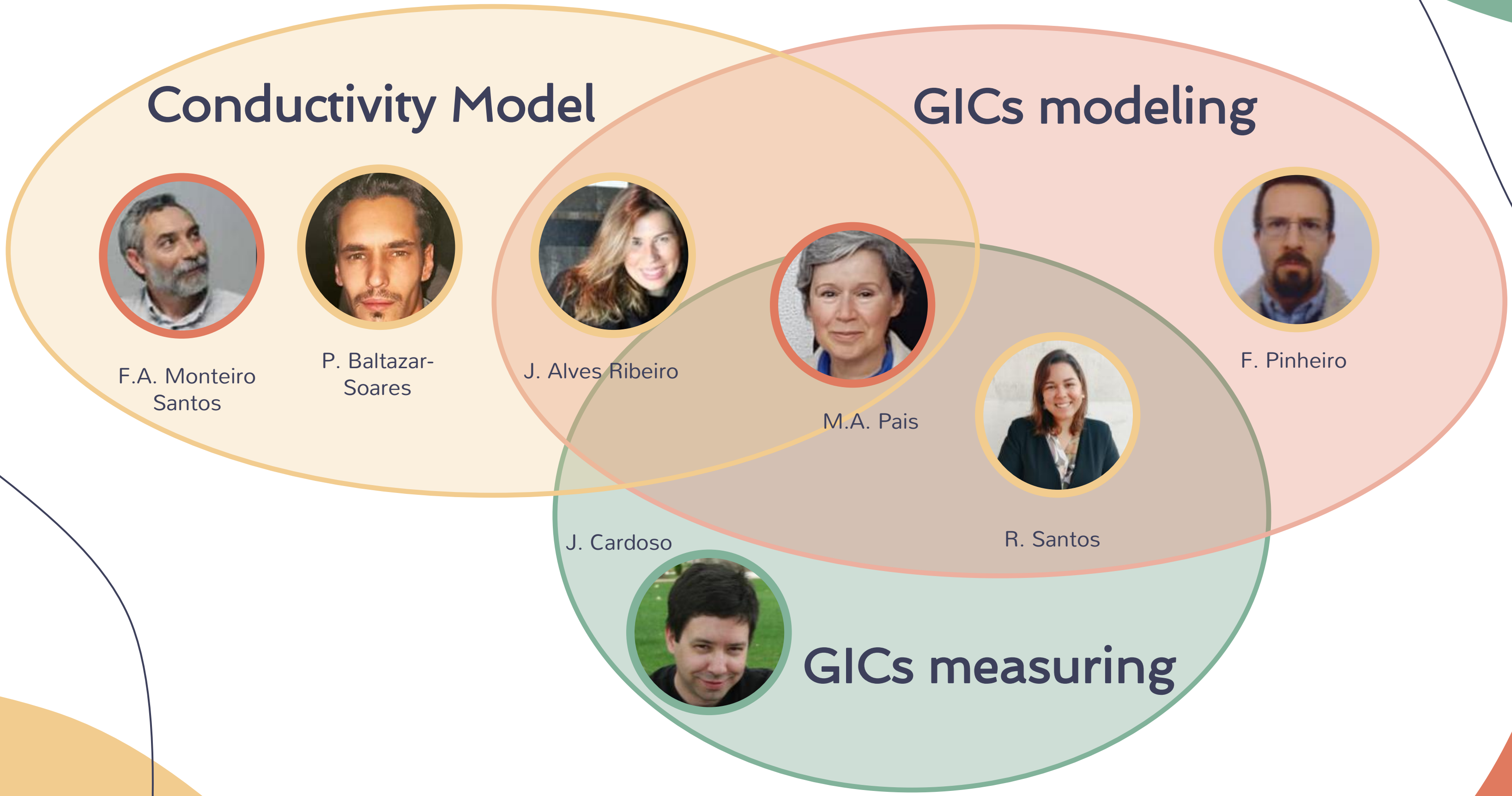
GIC – Mini Meeting
2nd February 2023


Magnetic Field
B(t)
Earth Conductivity
Model
B(ω)
E(ω) = B(ω)/μ0 · Z(ω)
Z(ω)
Electric Field, E(t)
Power Grid
model
GICs
Geophysical Part
Engineering
Part

MULTIDISCIPLINARY TEAM



PT GIC HISTORY

2019

Beginning

Collecting necessary information from the national power operator (REN)

2020

1st GIC estimations for the South of Portugal

April - GIC estimations for 1 V/km
October – 1st paper accepted
Based on true grid parameters and 3D simplified conductivity models

MT soundings acquisition

2021

3D conductivity model + GIC sensor

April – 1st 3D conductivity model for Portugal mainland
July – GIC estimation for the whole Portugal mainland
August – Hall sensor Installation

Working on the shield wires influence

2022

GIC estimation for Portugal mainland

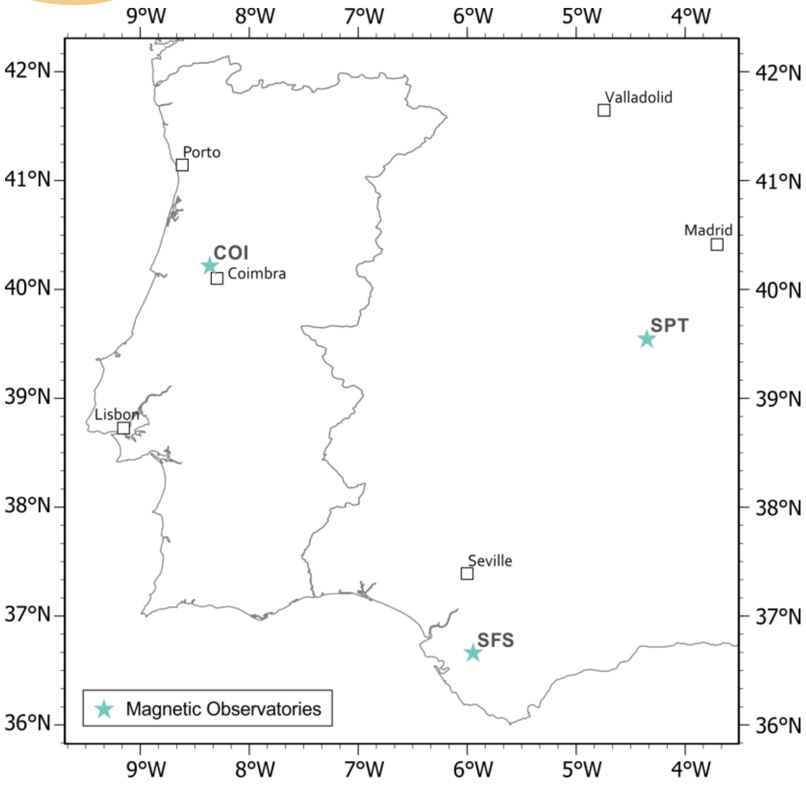
June – 2nd paper accepted – Shield wires
October –REN best thesis award
End of MAG-GIC and search for new funding

Working on GIC uncertainties

GICs in this work are computed using the **Lehtinen-Pirjola method.**

We utilized the GEOMAGICA code in Python, developed by Rachel Bailey, based on the ComputeGIC.m code from C. Beggan at the British Geological Survey (BGS), which was itself an adaptation of K. Turnbull's original Fortran code.

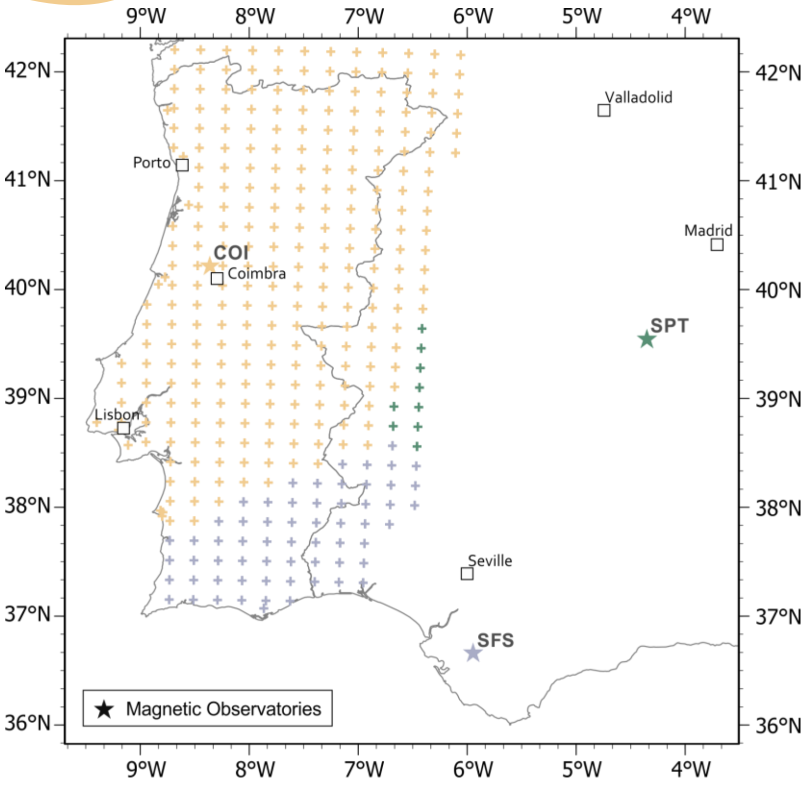
MAGNETIC FIELD



Coimbra Magnetic Observatory - COI

How can we retrieve GIC source data from analogic records?

MAGNETIC FIELD



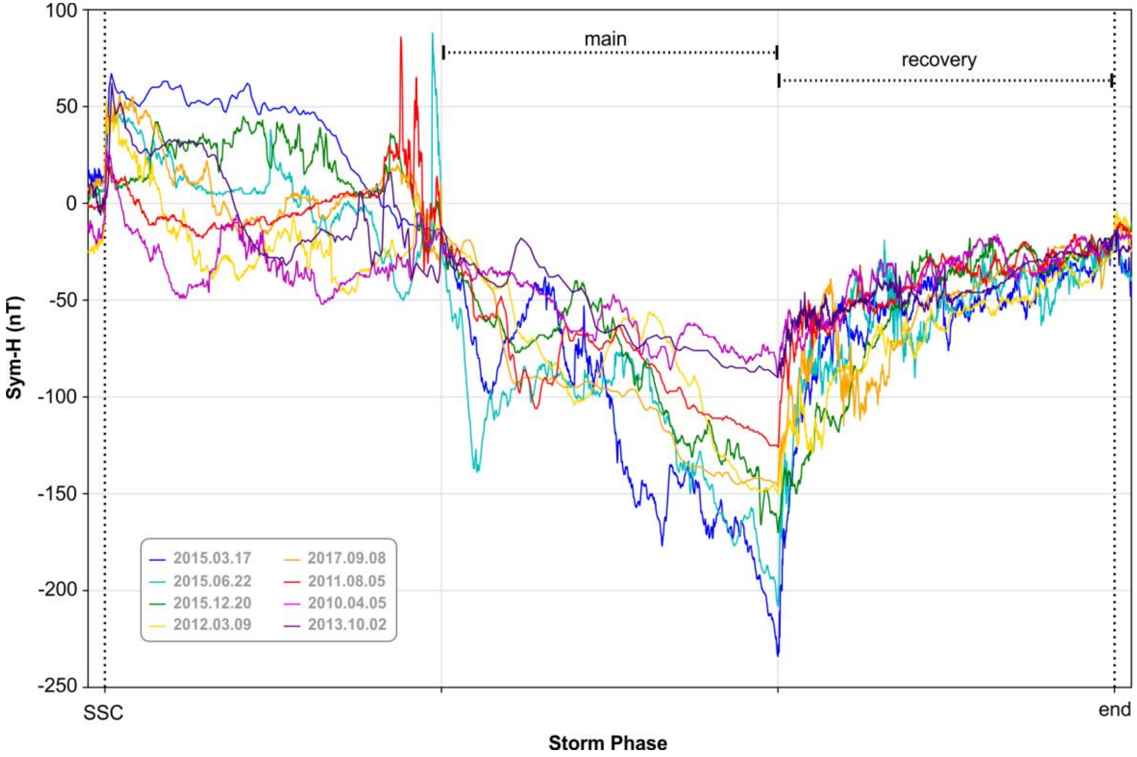
Nearest neighbour method

GIC source gradients are **higher along the south-north** than along the west-east directions

Ngwira et al. (2009)

MAGNETIC FIELD

Definition of the geomagnetic storms' duration



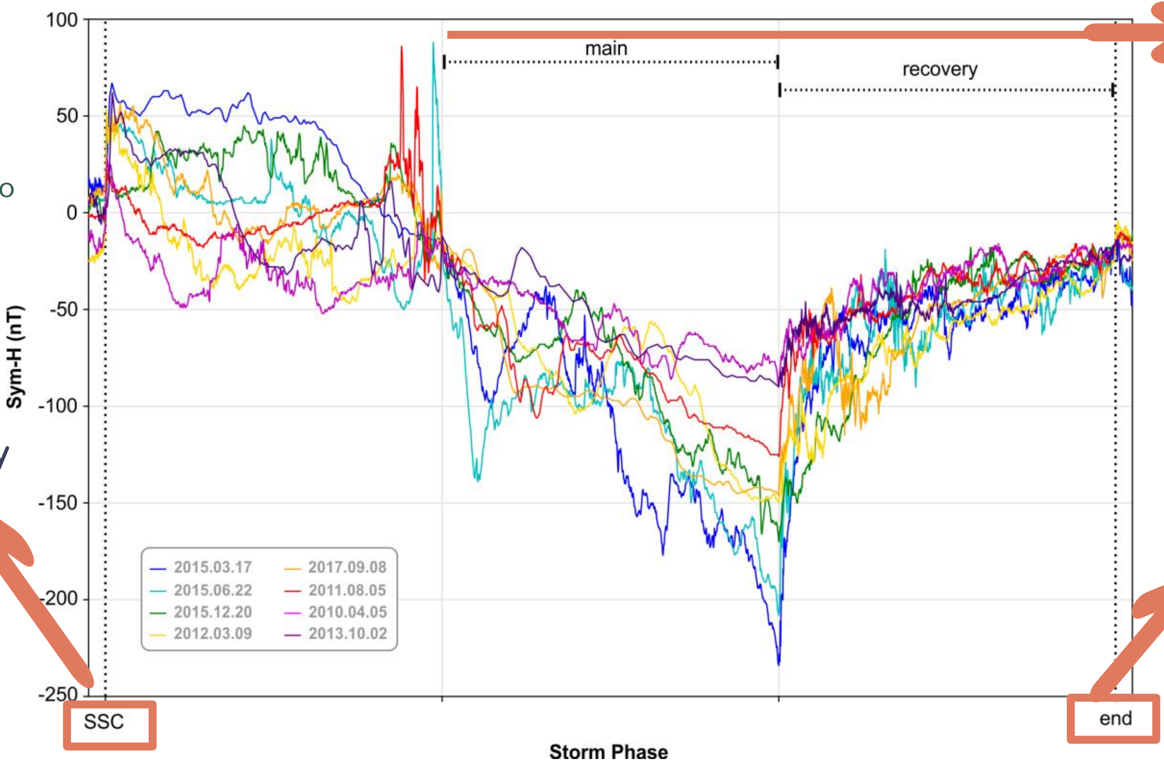
What is your definition?

MAGNETIC FIELD

Definition of the geomagnetic storms' duration

Walach and Grocott (2019)

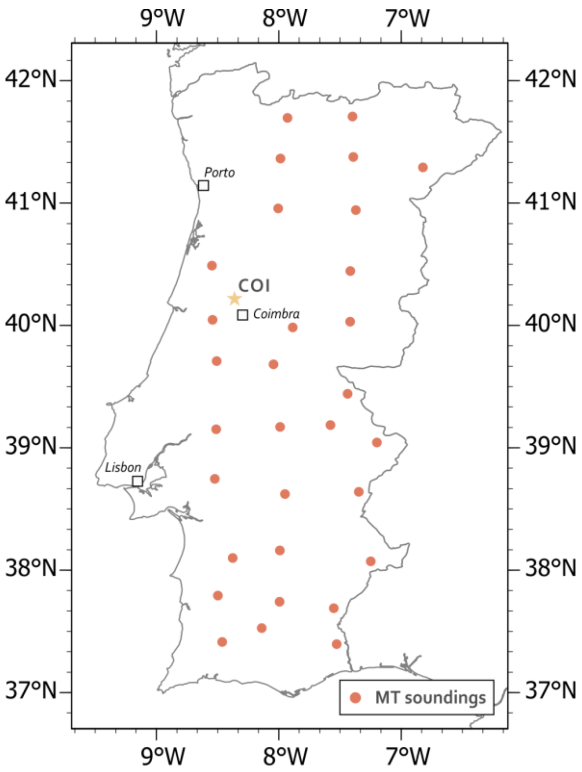
What if we see no SSC?



Ebre Observatory

Hutchinson et al. (2011)

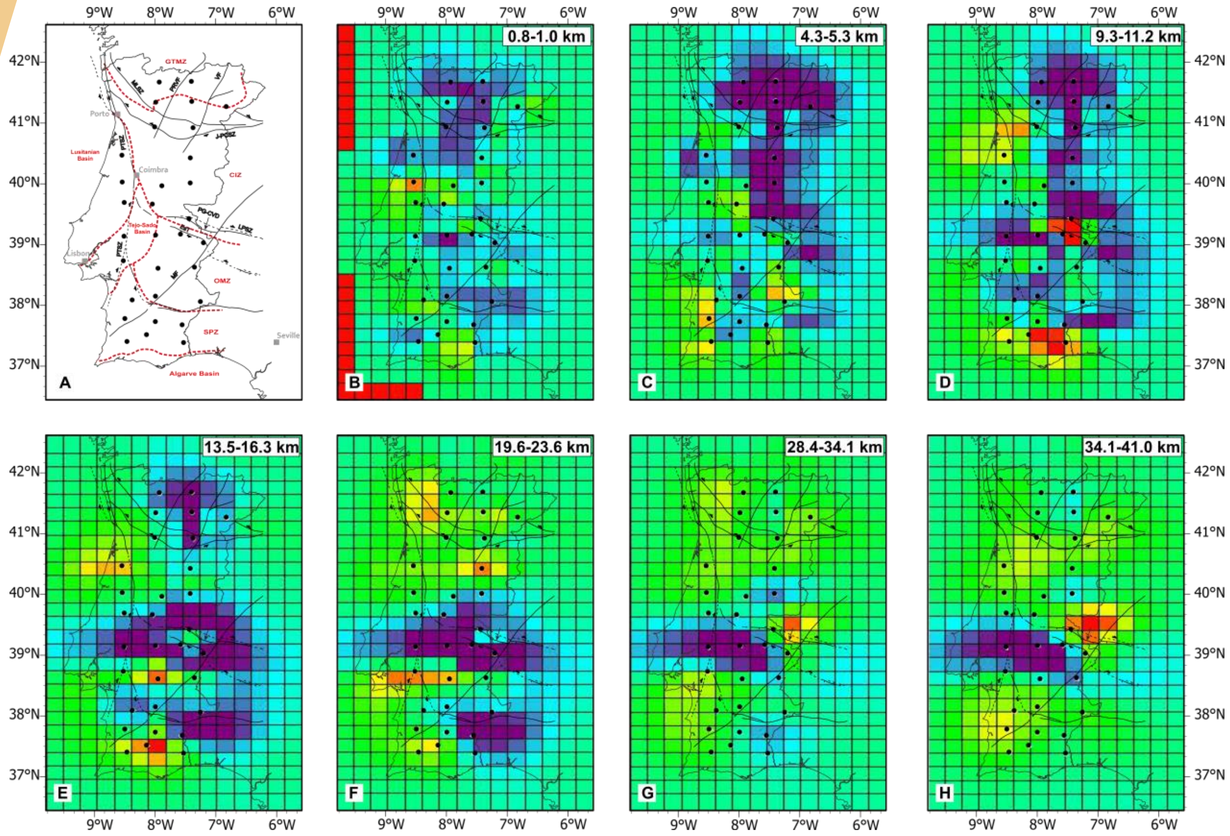
EARTH CONDUCTIVITY MODEL



31 Magnetotelluric Soundings (MT)

- Adquired from:
  - 1997 – 2002 *(8 MT soundings)*
  - 2020 – 2021 *(23 MT soundings)*
- ≈ 50 x 50 km MT sounding grid
- GMS-06 and GMS-07 system (Metronix)
- 48h of acquisition

EARTH CONDUCTIVITY MODEL



ModEM

(Egbert & Kelbert 2012; Kelbert et al., 2014)

- Bathymetry of Atlantic Ocean and the Mediterranean Sea

  (Amante & Eakins, 2009)

- Z_{xy} and Z_{yx}

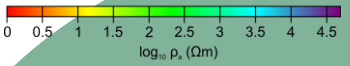
  Error floor of 5%

  Error of computation of $\sqrt{|Z_{xy} \times Z_{yx}|}$

- No tipper

- The exit criteria for the inversion

  RMS < 1.05 or λ < 10E-8 during model update
  No. maximum iterations = 120.

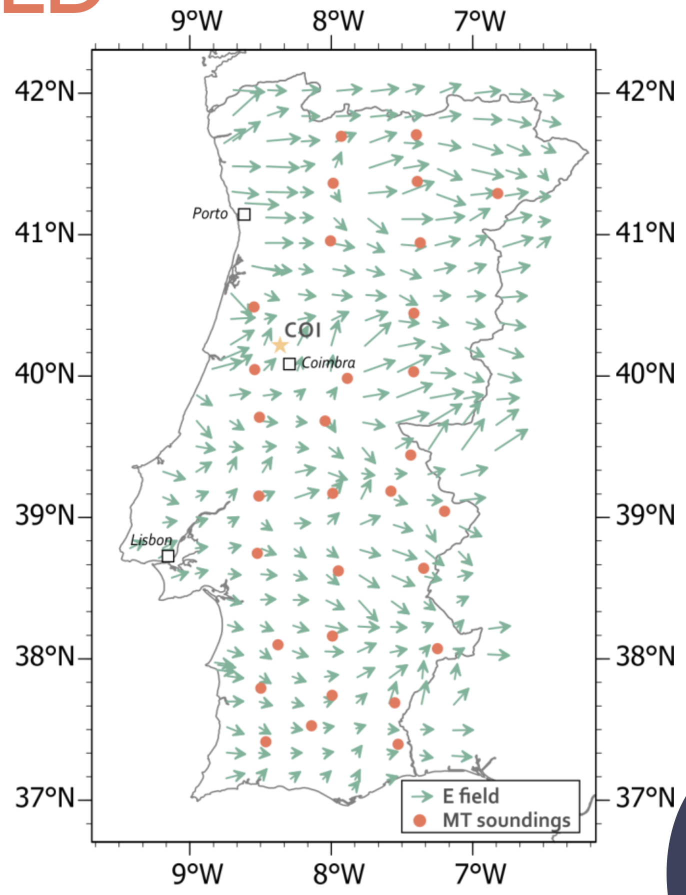


INDUCED ELECTRIC FIELD

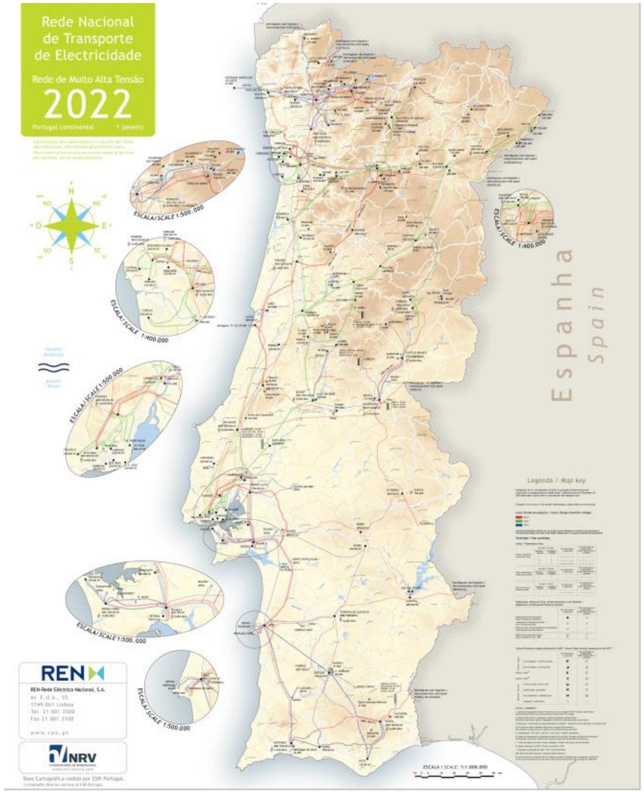
$$E_{x,y}(\omega) = \frac{1}{\mu_0}\mathbb{Z}(\omega) \times B_{x,y}(\omega)$$

Transition from the highly conducting ocean to the resistive mainland, an enhancement of the induced electric field is observed inland, approximately perpendicular to the coastline (coast effect).

Effect of main geological structures



POWER GRID MODEL



Credits: REN

FULL COLLABORATION

- Location of **substations** and values of their grounding resistances;
- Characterization of each **transformer** (type, winding resistance for high and low voltages);
- **Transmission line** information (length and line resistance).

POWER GRID MODEL

139 Substations

- 1 to 7 transformers
- 1 up to 16 line connections
- 9 line connections with REE

How to deal with missing information from neighbouring power grids?

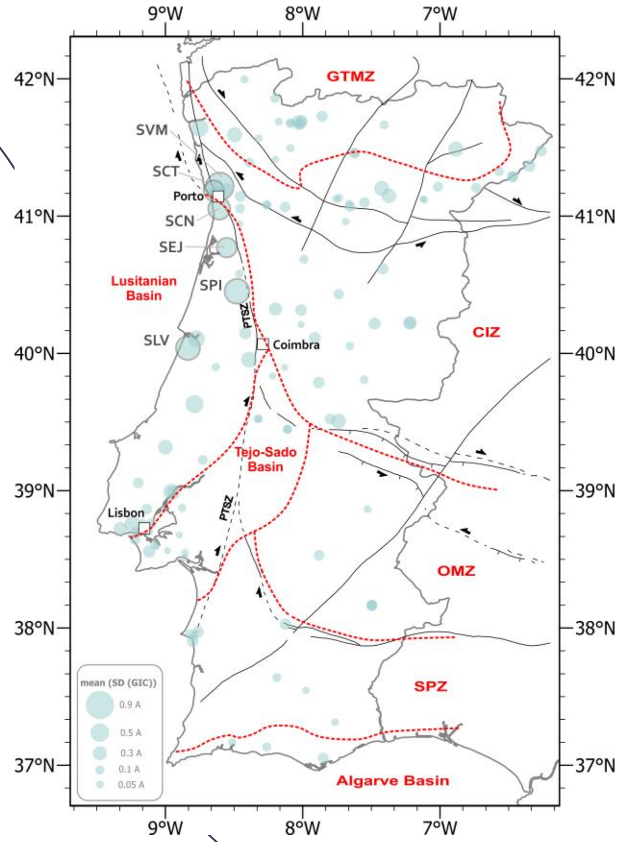
286 Transmission Lines

321 Transformers

3 Line Voltages

- 150 Kv
- 220 kV
- 400 kV

GICs SIMULATIONS



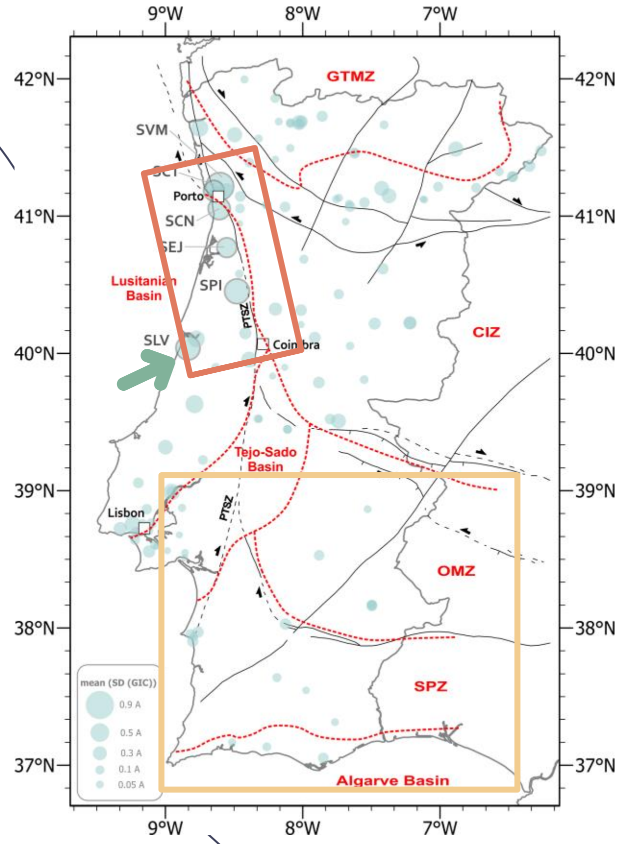
Mean of SD(GIC) values, computed from the 8 most intense geomagnetic storms of cycle 24

Why we use SD(GIC)?

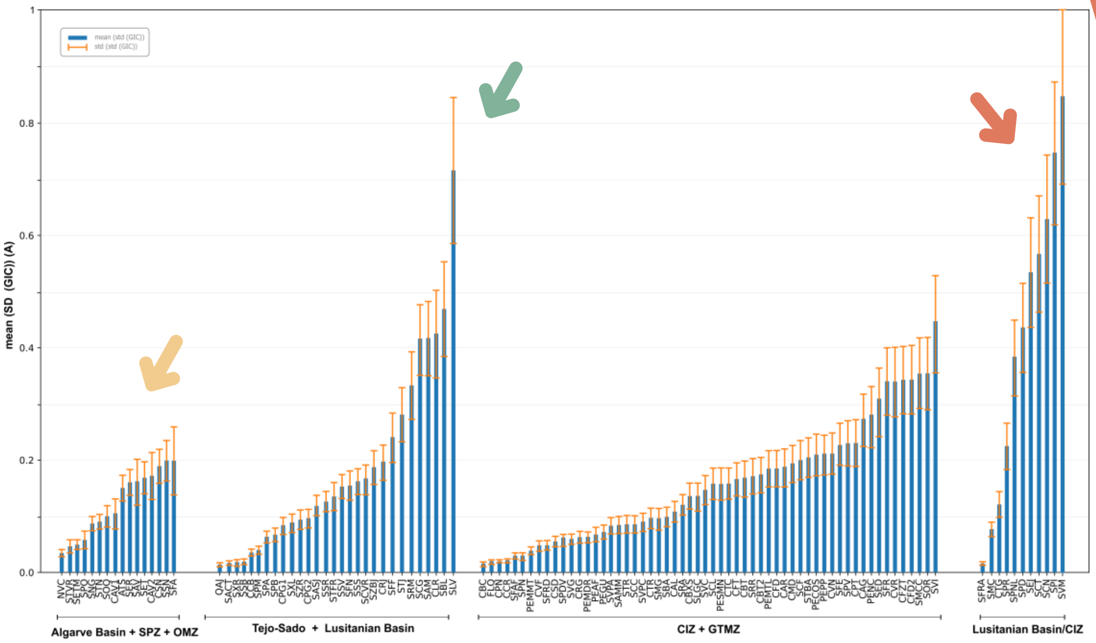
- maximum value may not occur at the same time for different substations
- maximum is not a statistically robust quantity as it is more susceptible to outliers.

Mean of SD(GIC) values, computed from the 8 most intense geomagnetic storms of cycle 24. Substations with mean (SD(GIC)) > 0.5 A are highlighted with a dark contour. Black lines represent the major thrust faults in the study region. Dashed red lines separate different tectonic units. Abbreviations: GTMZ - Galicia-Tras-os-Montes zone; CIZ - Central Iberian Zone; OMZ - Ossa Morena Zone; SPZ - South Portuguese Zone; PTSZ - Porto-Tomar Shear Zone.

GICs SIMULATIONS



Distribution of the mean of SD(GIC) values (blue bars) over substations grouped into four large geotectonic units, for the 8 most intense geomagnetic storms of solar cycle 24. Orange bars for the standard deviation of SD(GIC) values.



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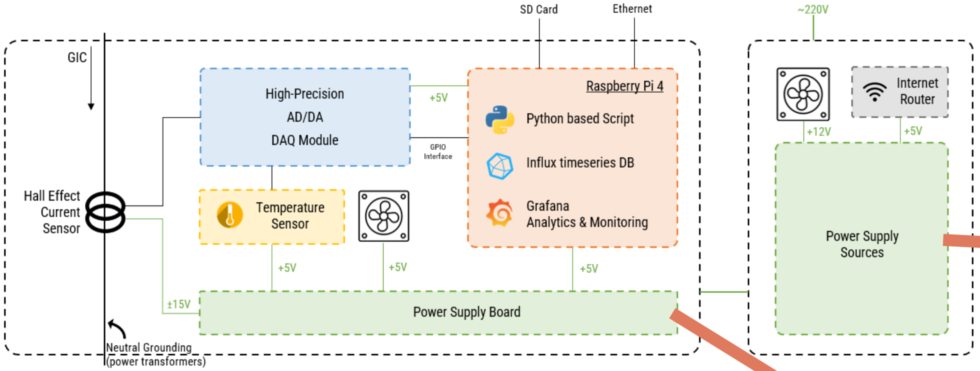
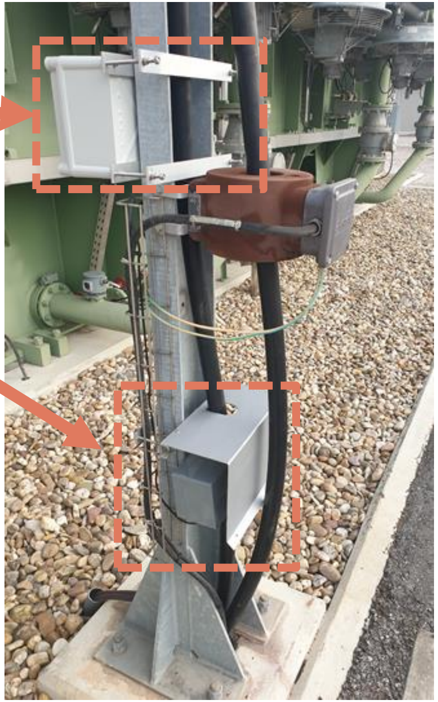
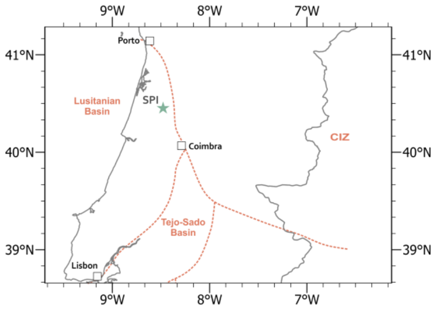
HOW CAN WE VALIDATE THE MODELS?

GIC MEASURING SYSTEM





SPI Substation



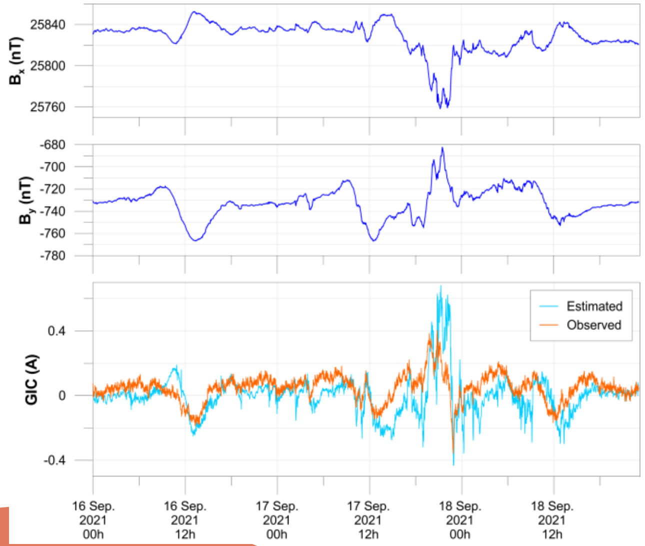
Since August 2021

GIC MEASURING SYSTEM

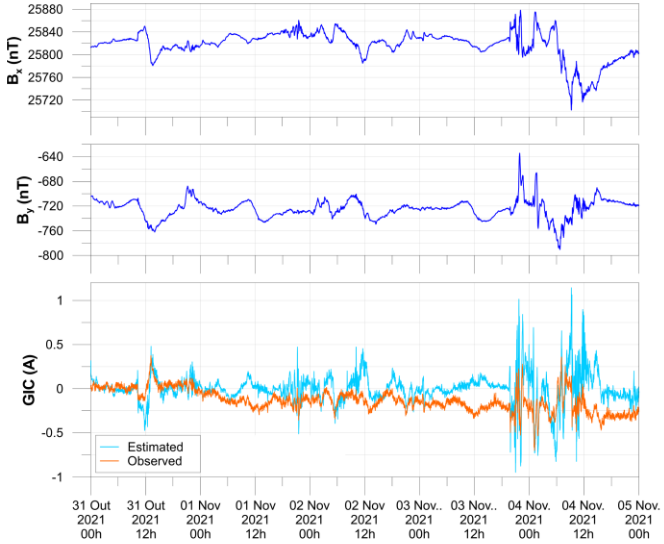
SPI Substation

Small geomagnetic storms, but we can already see a **good correlation**!
(Pearson's coefficient ≈ 0.6)

17th September 2021

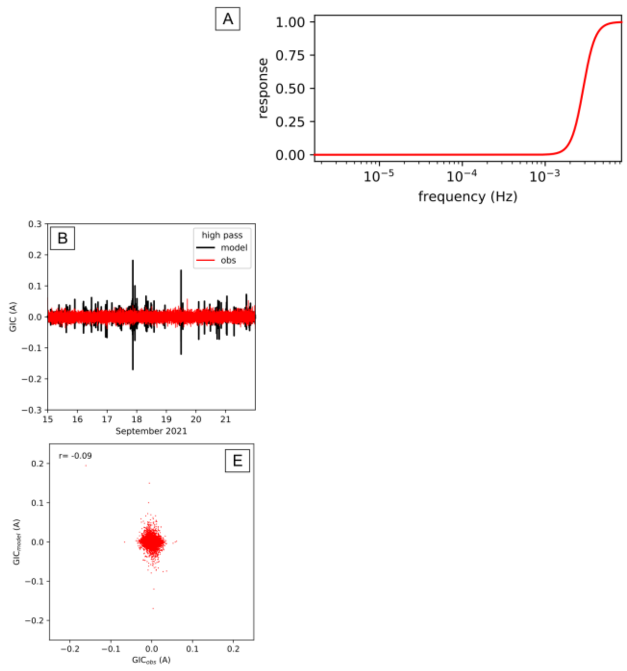


4th November 2021



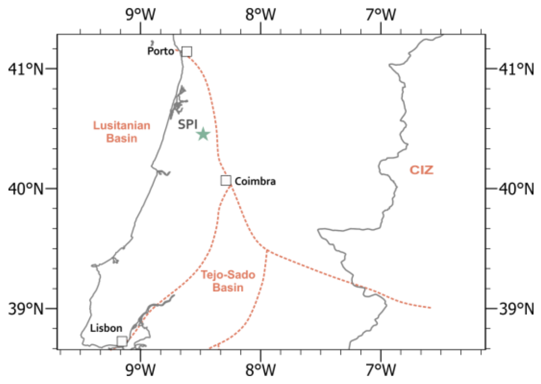
UNCERTAINTIES:
POSSIBLE SOURCES

CONDUCTIVITY MODEL



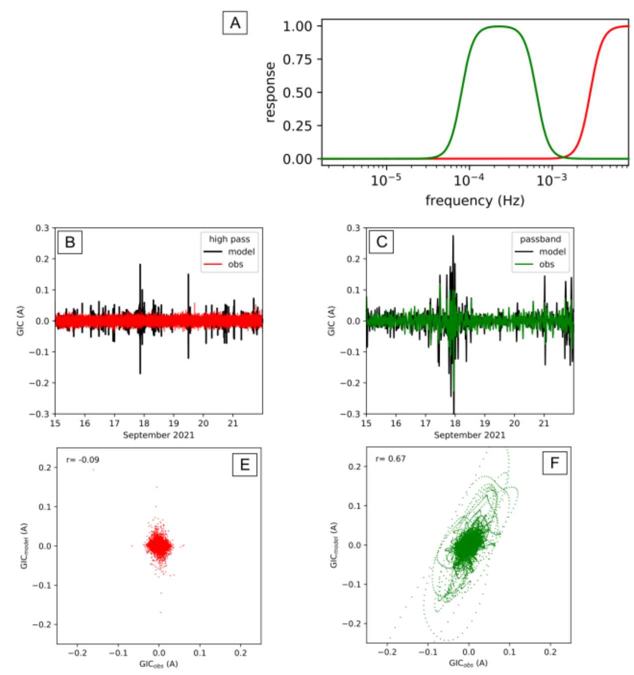
The geomagnetic storm of 17th September 2021, at Paraimo. Comparison between observed and simulated GIC signals in different frequency bands, after using a high-pass (B, E), band-pass (C, F) and low-pass (D, G) Butterworth filters (A).

SPI Substation



Instrumental noise

CONDUCTIVITY MODEL



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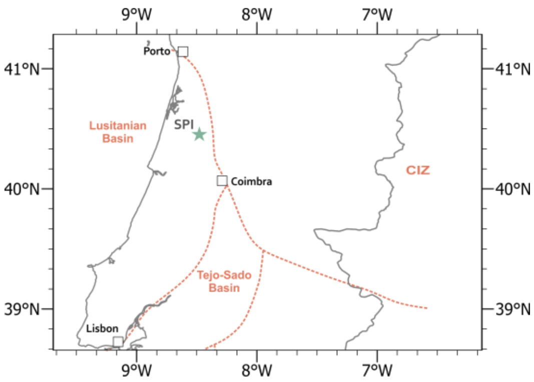
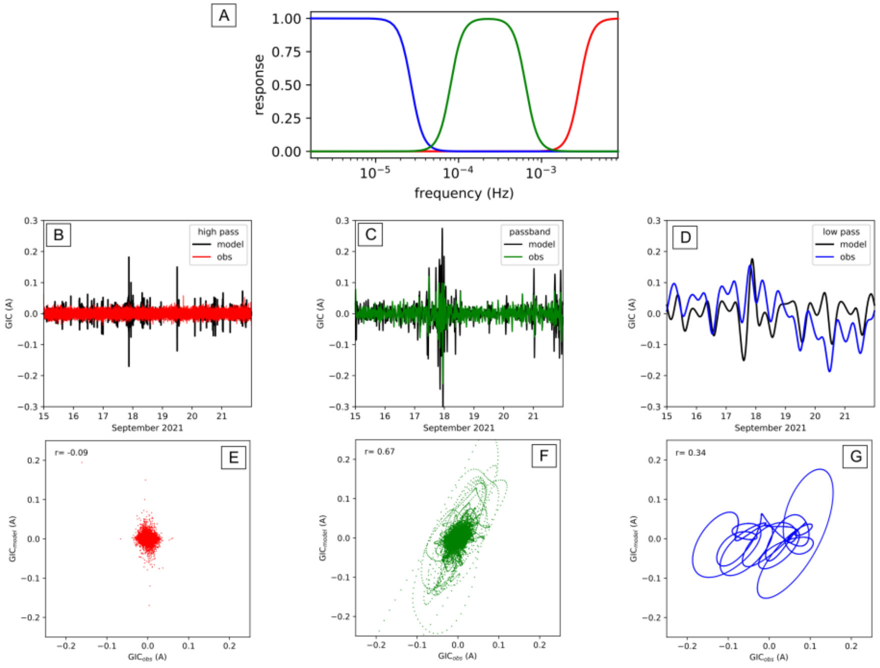


CONDUCTIVITY MODEL



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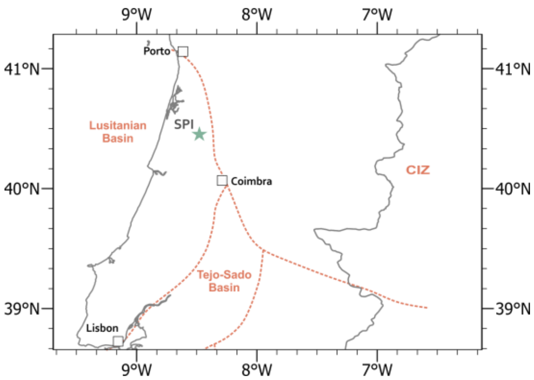
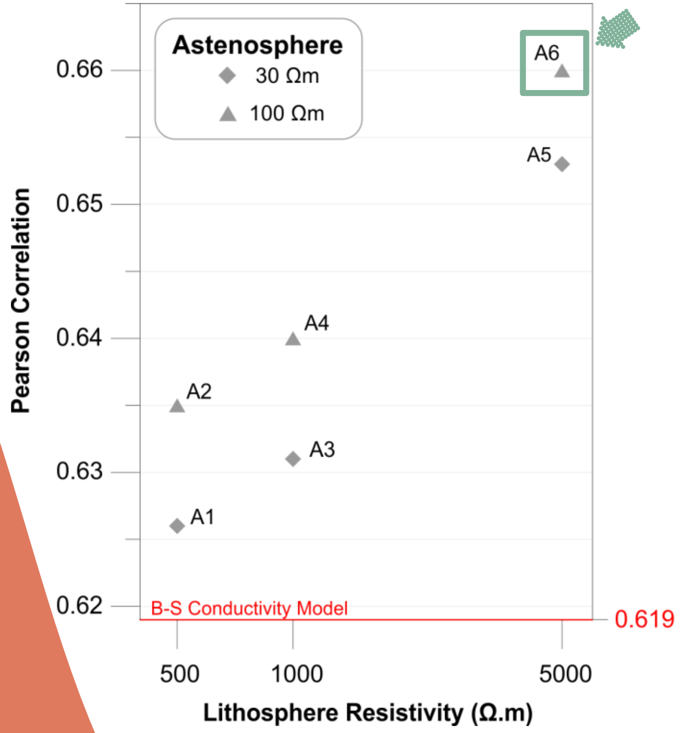
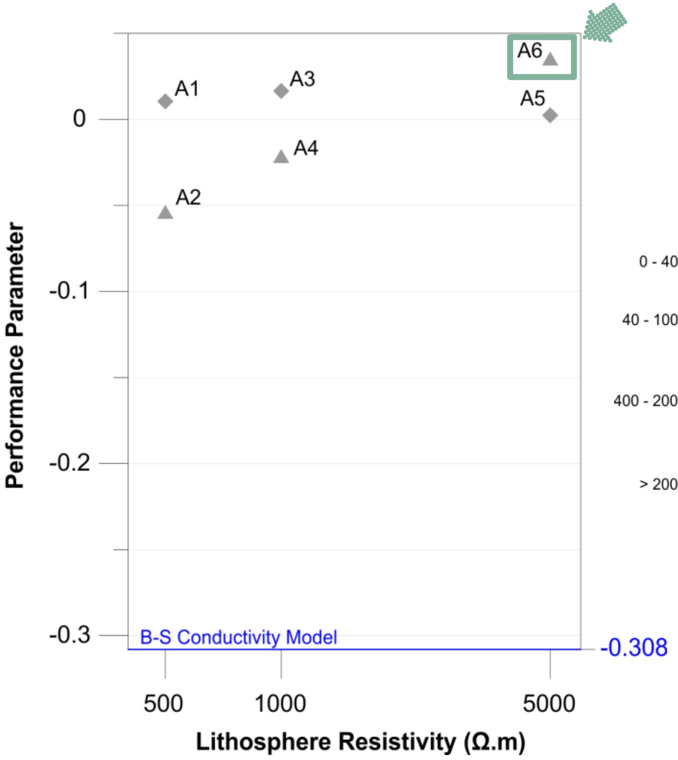


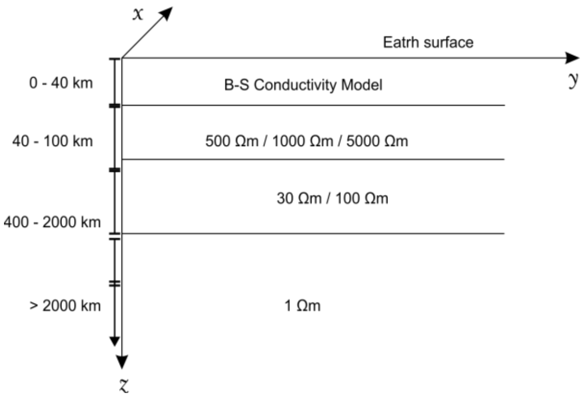
problems with MT model at greater depths

CONDUCTIVITY MODEL





SPI Substation



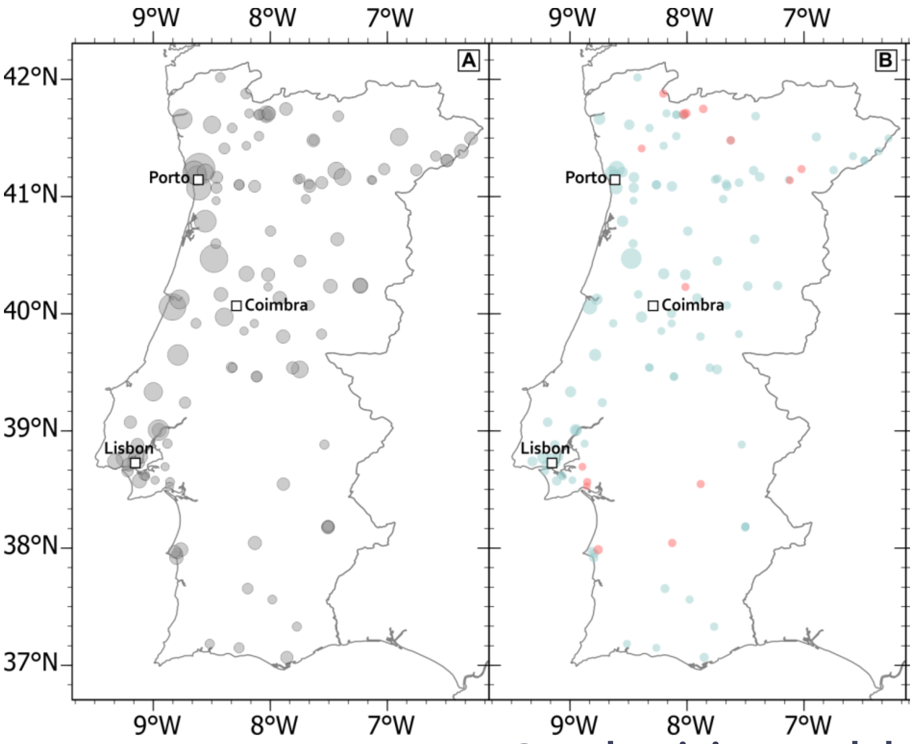
UNCERTAINTIES

Geomagnetic storm
17th March 2015

(A) SD(GIC) in the power network

Differences in SD(GIC) when replacing:

(B) the B-S conductivity model for A6 (crust – B-S model; lithosphere 5000 Ωm asthenosphere of 100 Ωm);



Conductivity model ≈ 50% of estimated SD(GIC)

GROUNDING RESISTANCES

REN substation

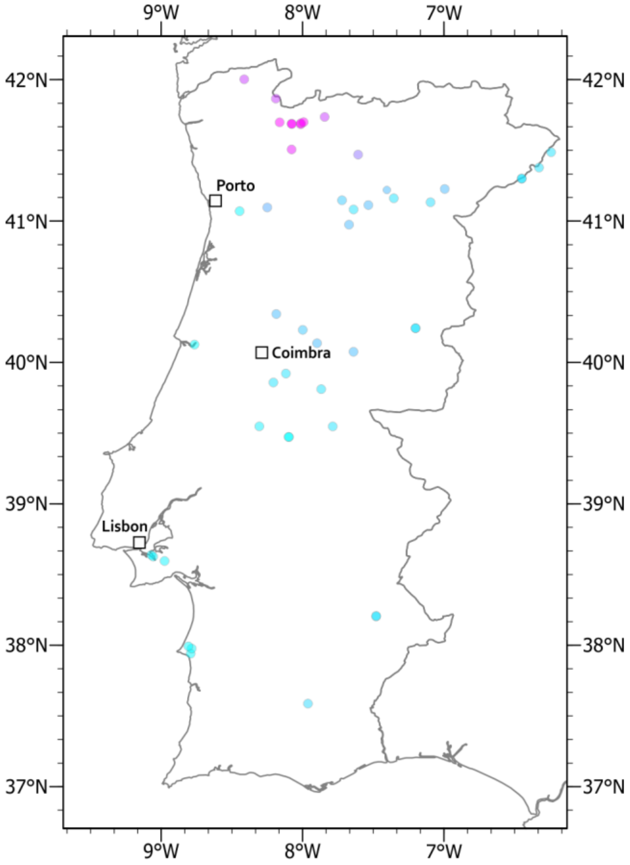
Real values

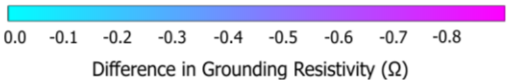
Non-REN substation

0.2 Ω

REN substation located in the vicinity, inside the same geological unit

Difference





For each non-REN substation, representation of differences between the grounding resistance standard value (0.2 Ω) and the grounding resistance at the nearest REN substation.

Geomagnetic storm
17th March 2015

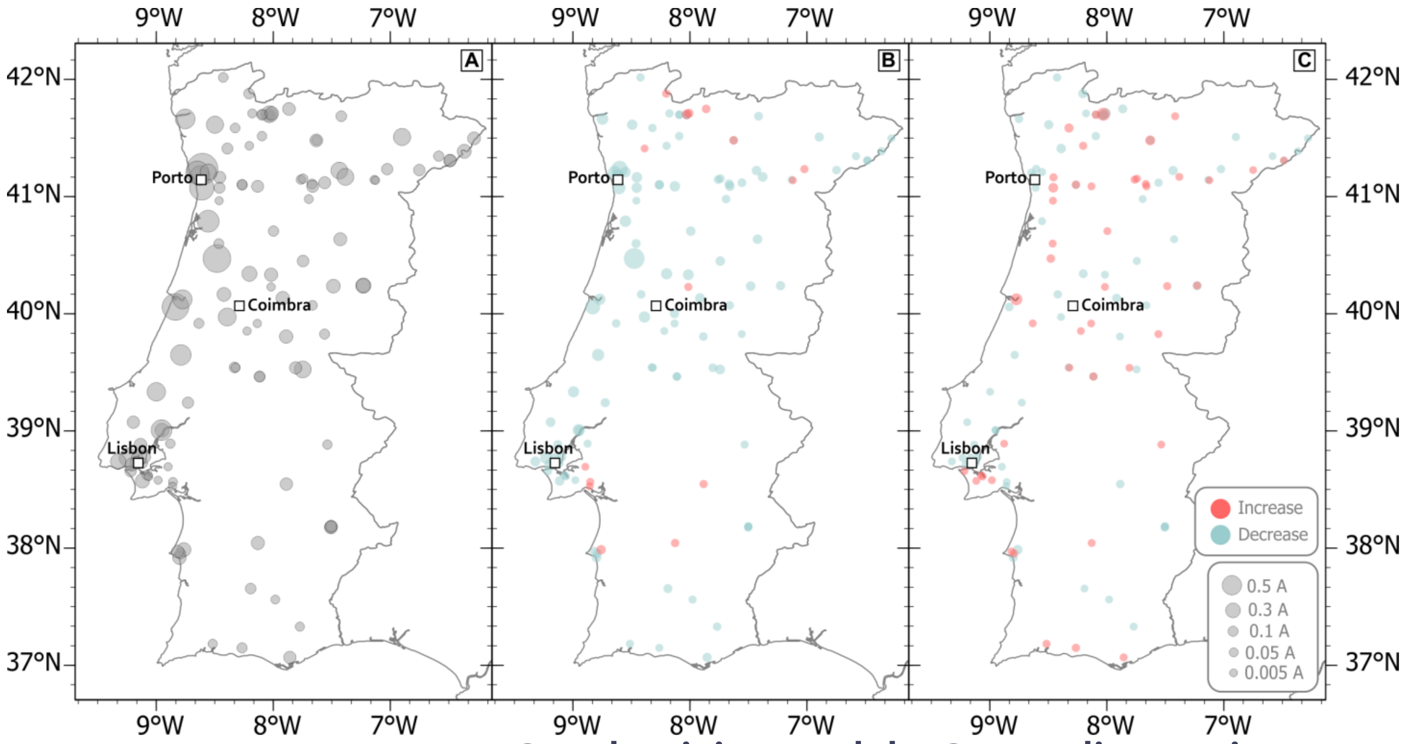
UNCERTAINTIES

(A) SD(GIC) in the power network

Differences in SD(GIC) when replacing:

(B) the B-S conductivity model for A6 (crust – B-S model; lithosphere 5000 Ωm asthenosphere of 100 Ωm);

(C) the standard grounding resistance of non-REN substations for values of the nearest REN substations inside the same geological unit.

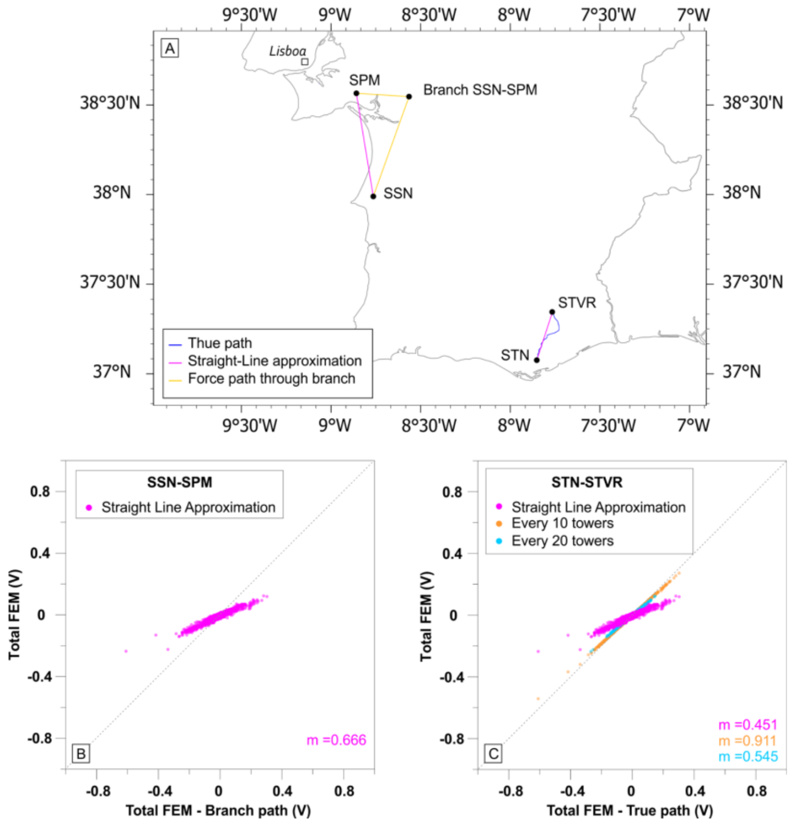


Conductivity model
≈ 50% of estimated SD(GIC)

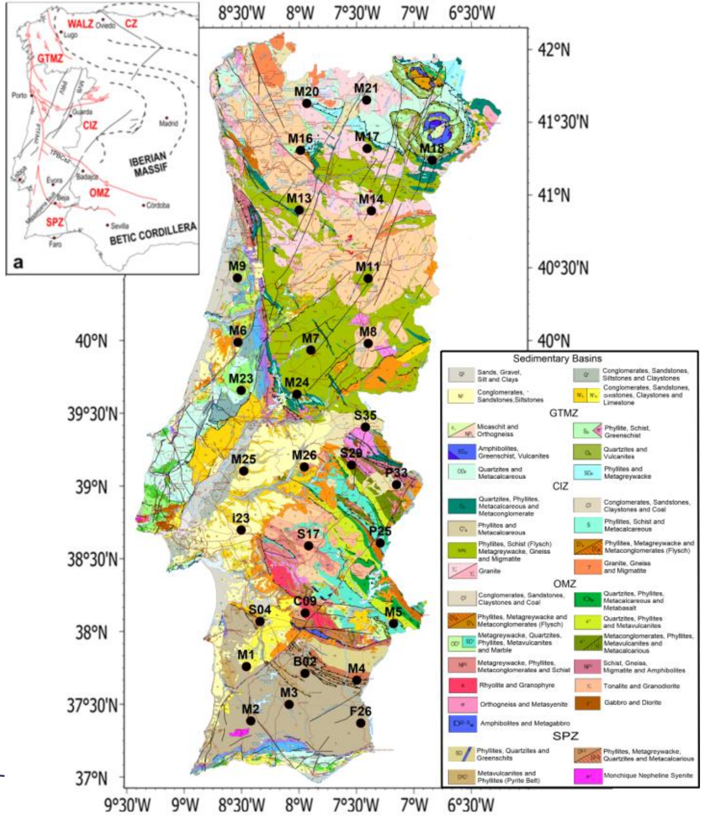
Grounding resistance
≈ 20% of estimated SD(GIC)

STRAIGHT PATH VS REAL PATH

Electromotive forces (emf) generated along different paths



STRAIGHT PATH VS REAL PATH



Consequences of emf when crossing different geological structures?

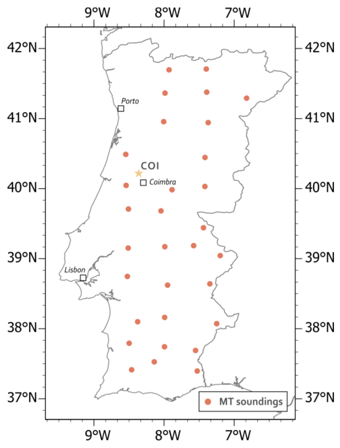
Geological map of Portugal mainland. a – Geotectonic units of the Iberian Massif; b – Lithological units; black points correspond to the MT stations. The solid black lines represent fault zones. The tectonostratigraphic units are represented by the red dashed lines. CA – Cantabrian Zone; WALZ – West Asturian-Leonese Zone; GTMZ – Galicia Trás-os-Montes Zone; CIZ – Central Iberian Zone; OMZ – Ossa Morena Zone; SPZ – South Portuguese Zone. Source: Laboratório Nacional de Energia e Geologia (LNEG), geological map scale 1:1000000

WHAT's NEXT?

FUTURE IMPROVEMENTS

New MT soundings

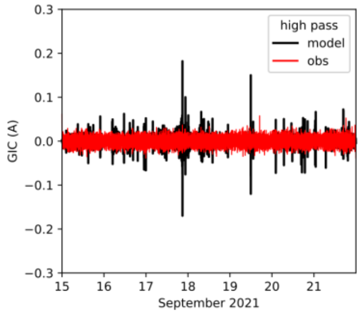
- Tighter grid
- Long Period soundings



Install more sensors on others substations

Best criteria to choose where to instal?

- Improve GIC sensor sensitivity



GICs IN PIPELINES

Credits: REN

"**The risk to pipelines from space weather** arises because GIC can result in such cathodic protection (CP) being overridden and the pipe-to-soil potential (PSP) becoming positive."

(Ingham & Rodger, 2018)

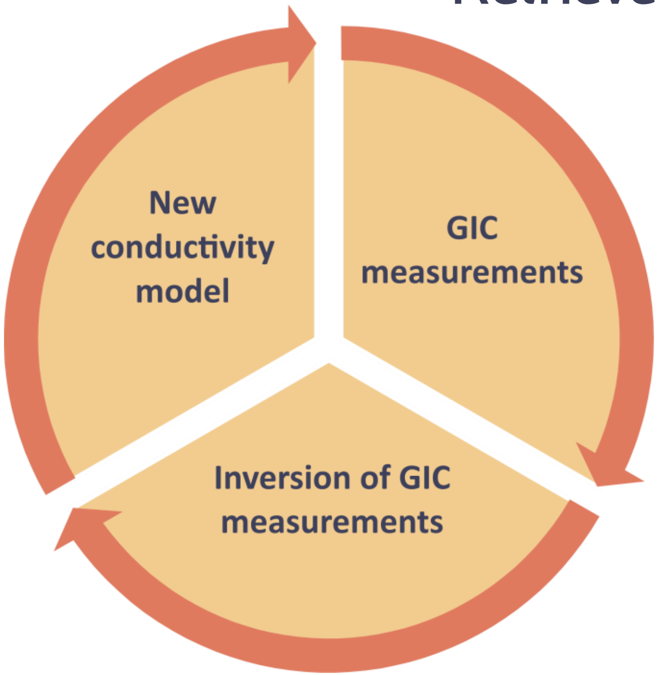
"Large variations which allow the pipe to become more negative than –1.2 V with respect to ground may lead to 'disbanding'—the loss of adhesion between the insulating coating and the pipe."

(Ingham, 2022)

- Estimate GICs
- Measure GICs

WHAT IF WE COULD…?

Retrieve more information from GICs measurements?



GIC measurements also contain information on local conductivity effects and may accordingly provide fundamental knowledge on the Earth interior

THANK YOU!

DO YOU HAVE ANY QUESTIONS?

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https://www.uc.pt/en/org/maggic