



UNIVERSIDADE D
COIMBRA



Towards an improved proxy for geomagnetically induced currents (GICs)

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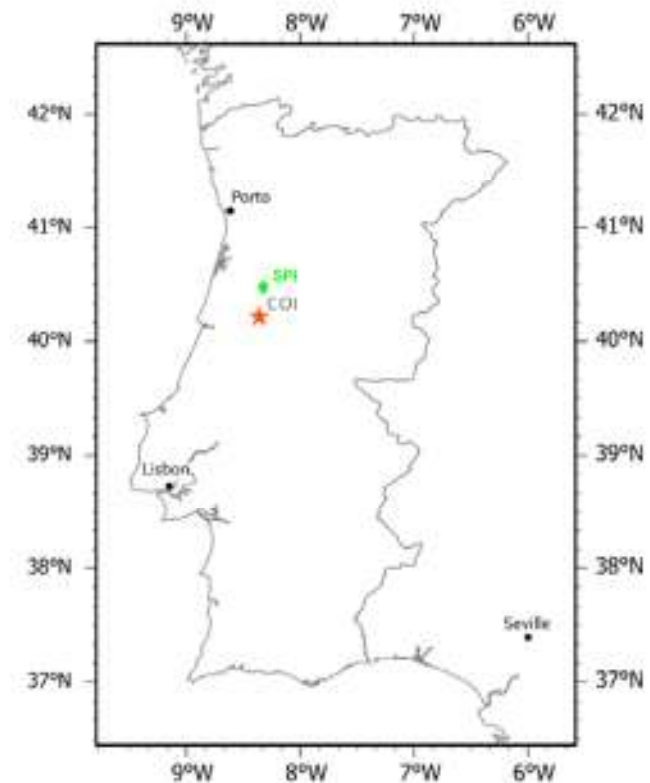
⁵Department of Physics, LIBPhys- University of Coimbra, Coimbra, Portugal

GIC Measurements

Installed on 30th August 2021



Installation of the sensor at Paraimo substation on the TRF6 transformer.

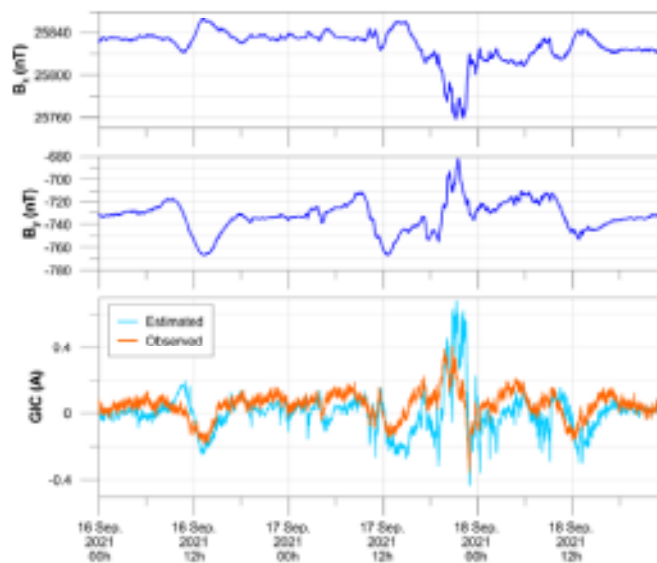


Location of the Paraimo (SPI) substation, in green, where the first GIC measuring sensor was installed.

Geomagnetic Storms Registered on GIC sensor

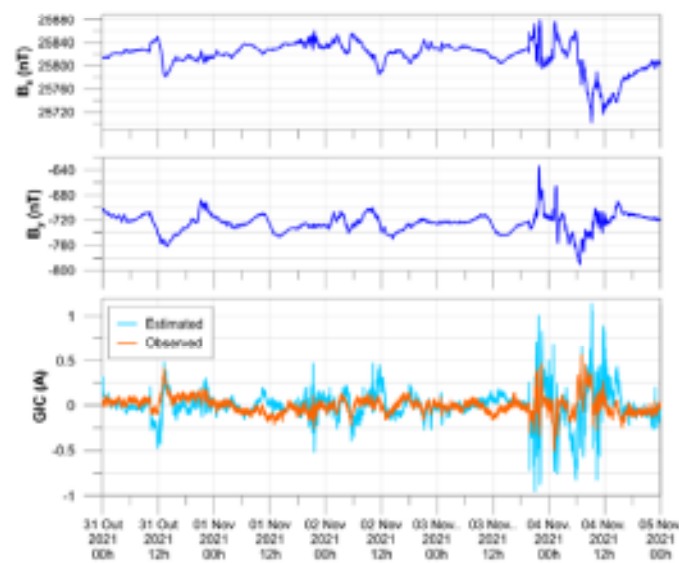
17th September 2021

Dst = -64 nT



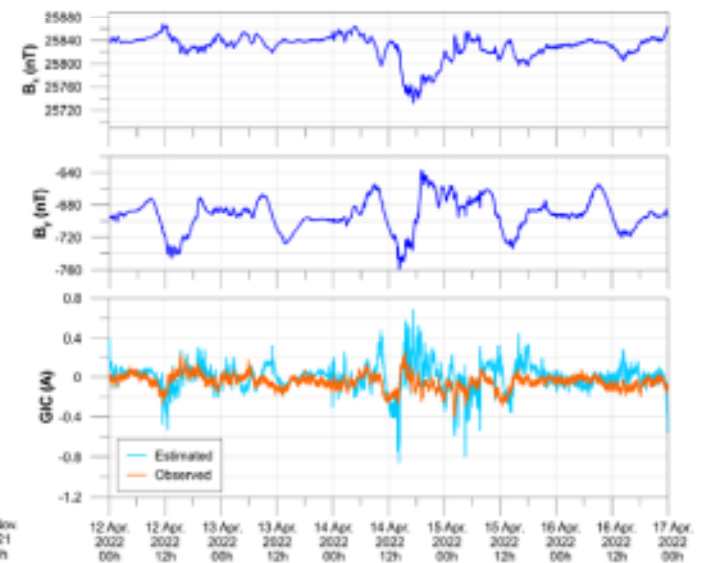
4th November 2021

Dst = -105 nT



14th April 2022

Dst = -81 nT

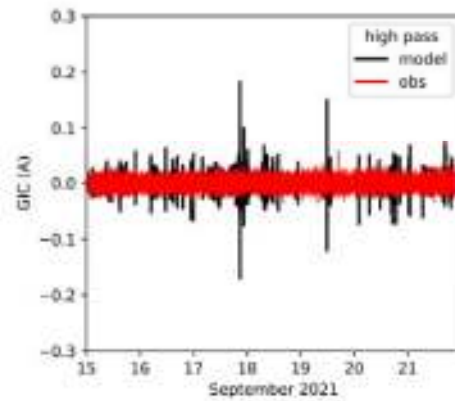
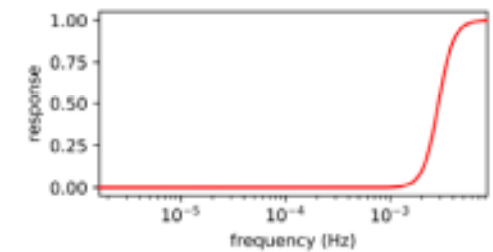


Why work with filtered data?

Butterworth filters

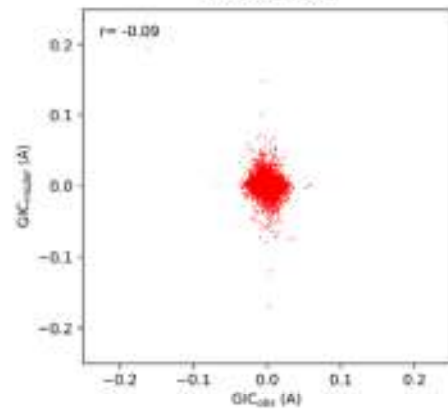
cutoff 1/5min

signal dominated by instrumental noise



Butterworth:

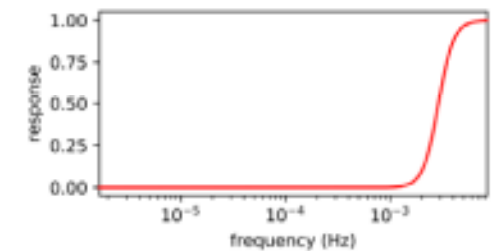
$$high - pass \ filter = \frac{1}{\left(1 + C \times \frac{R_{DZ}}{freq(k)}\right)^{2N}}$$



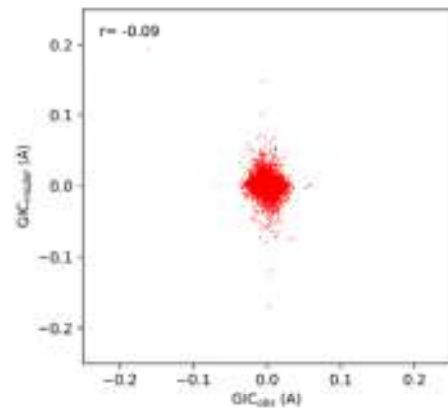
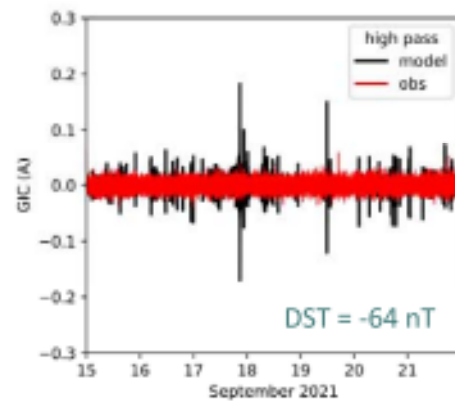
Why work with filtered data?

Butterworth filters

cutoff 1/5min



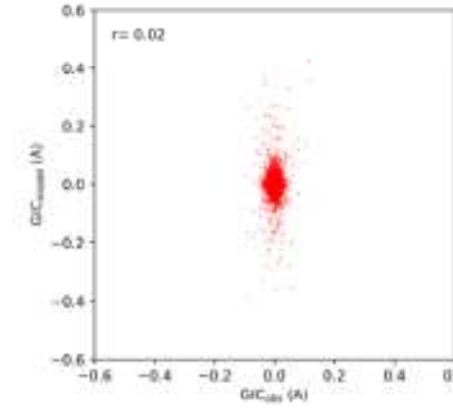
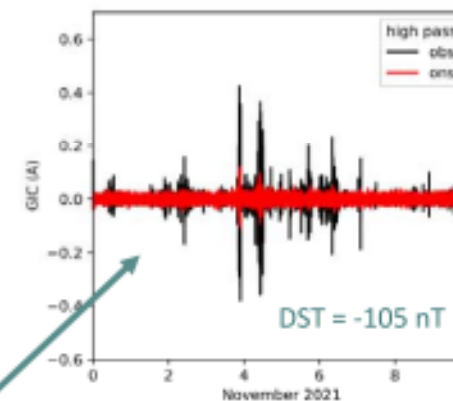
signal dominated by instrumental noise



Butterworth:

$$high - pass \ filter = \frac{1}{\left(1 + C \times \frac{R_{02}}{freq(k)}\right)^{2N}}$$

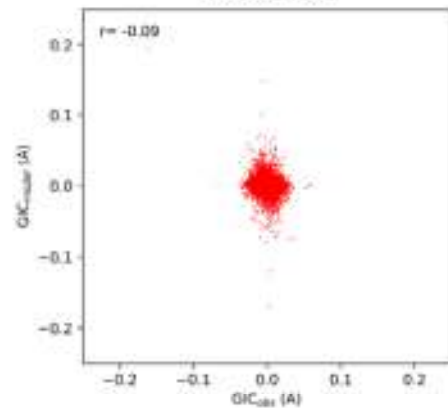
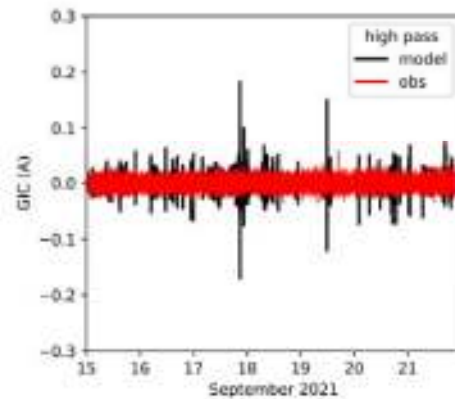
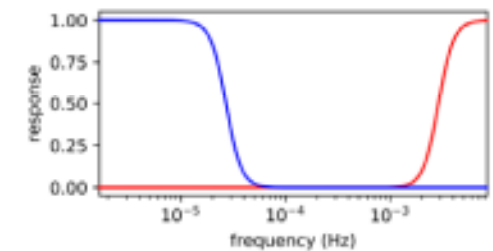
Stronger events
↓
GIC signal present



Why work with filtered data?

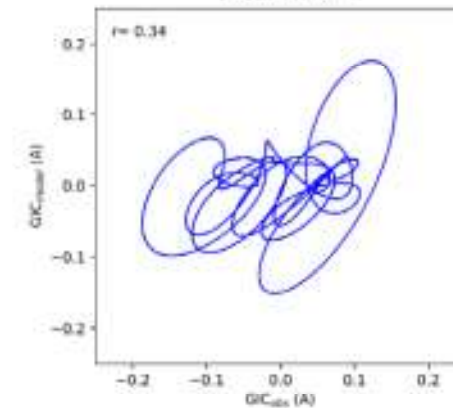
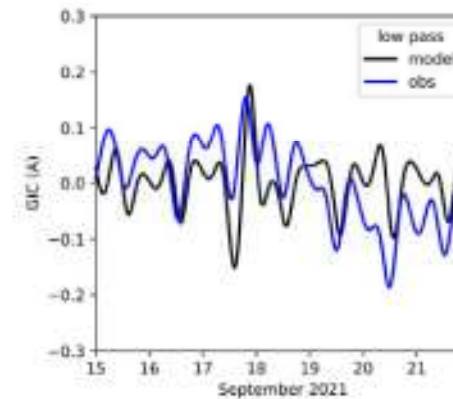
Butterworth filters

cutoff > 12h



Butterworth:

$$\text{low-pass filter} = \frac{1}{\left(1 + C \times \frac{\text{freq}(k)}{k_0}\right)^{2N}}$$

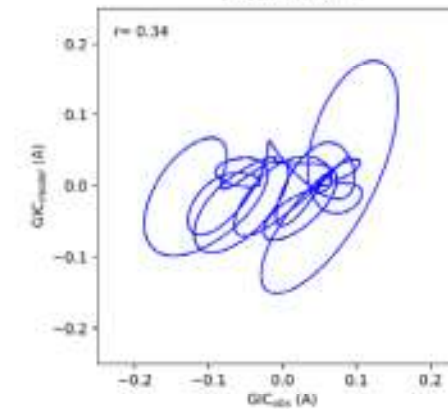
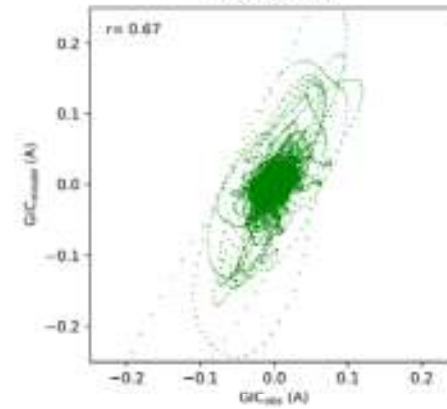
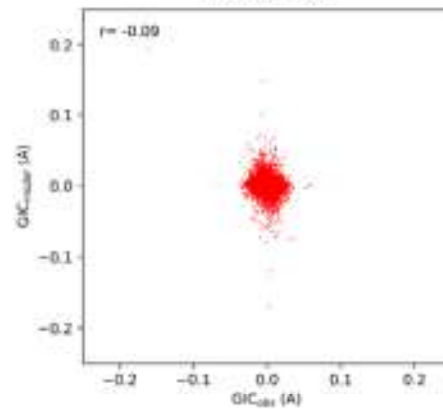
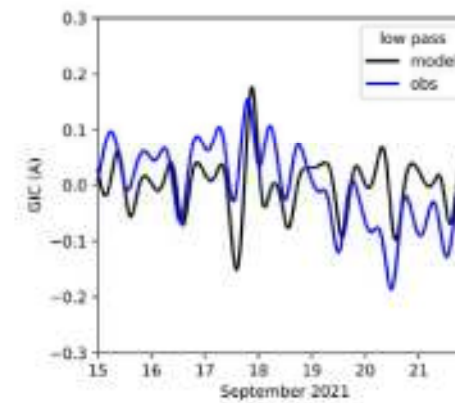
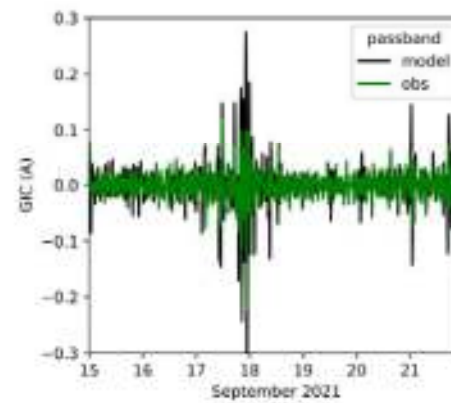
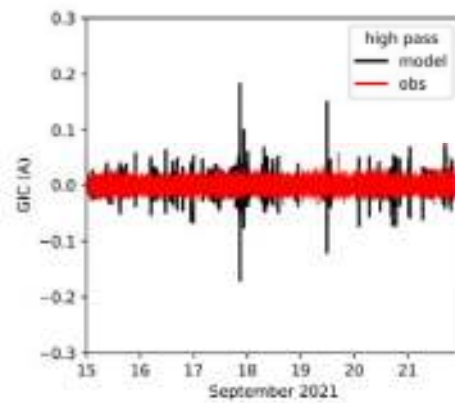
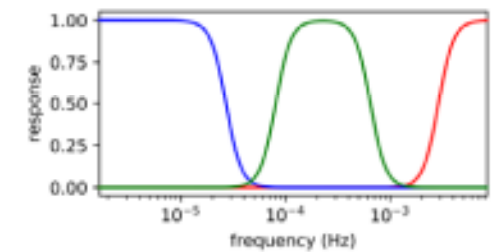


Limitation in the conductivity model, for deep layers

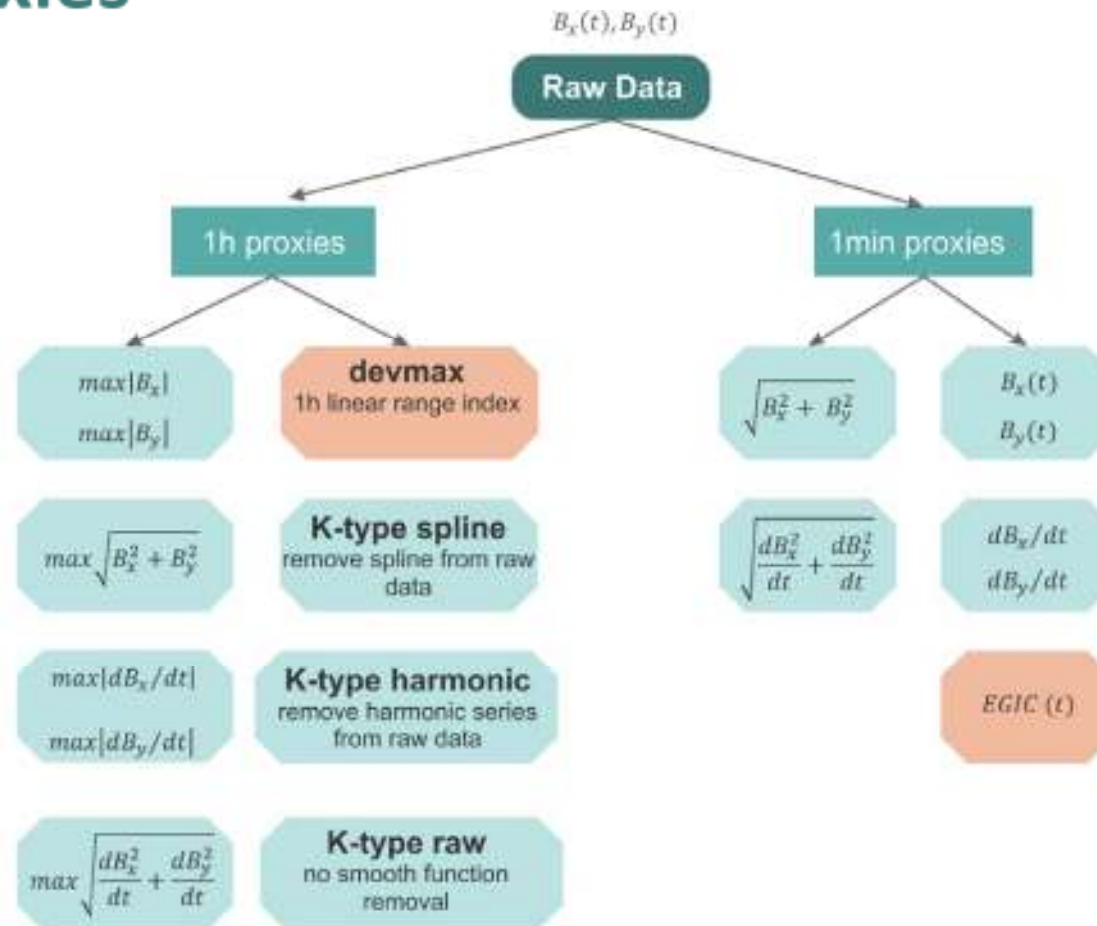
Why work with filtered data?

Butterworth filters

cutoff 30min – 3h



Tested proxies

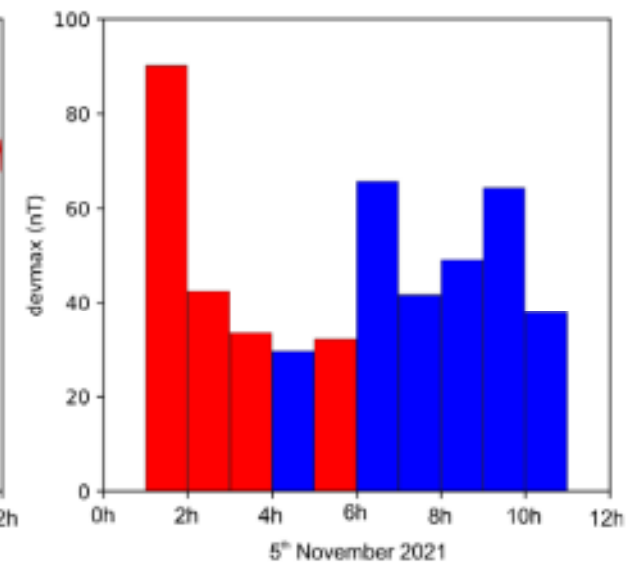
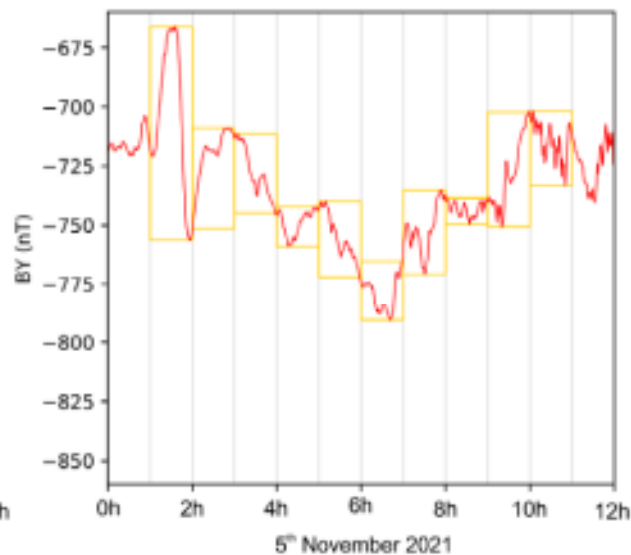
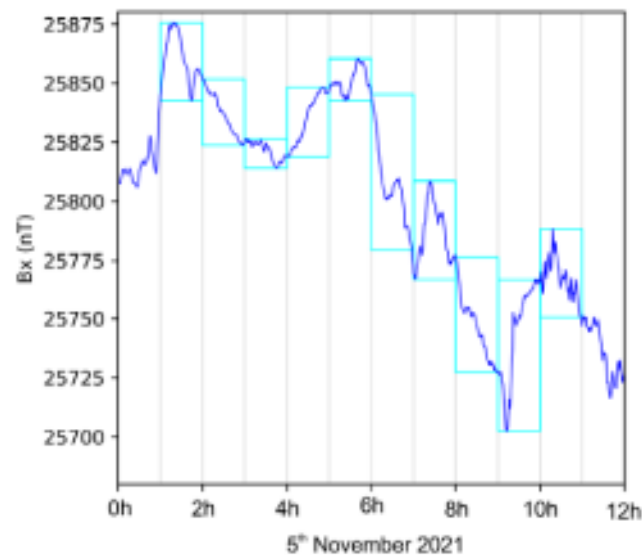


Flowchart of proxies used to compare with GICs, for different time resolutions: the whole geomagnetic storm duration, 1 hour and 1 minute.

1-hr proxies

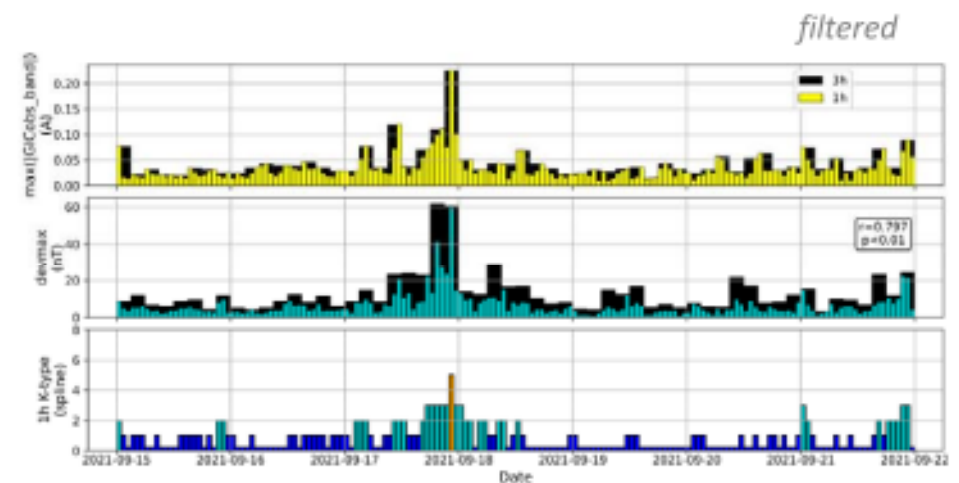
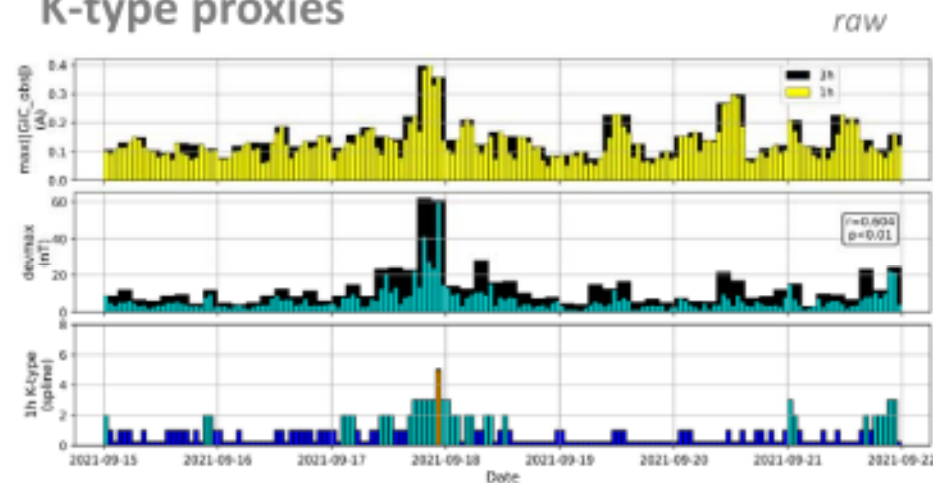
devmax explanation

Linear index that measures the maximum range in Bx or By values during 1 hour interval



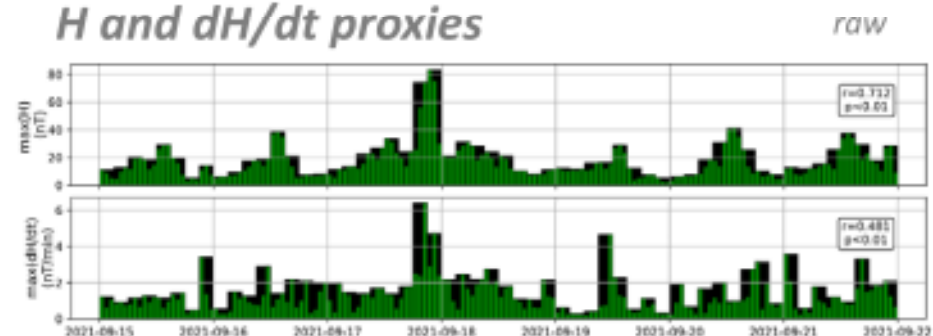
1-hr proxies

K-type proxies



1-hr K-type indices, for the 17th September 2021 storm. *devmax* is a linear index that measures the maximum range in Bx or By values for 1 hour interval

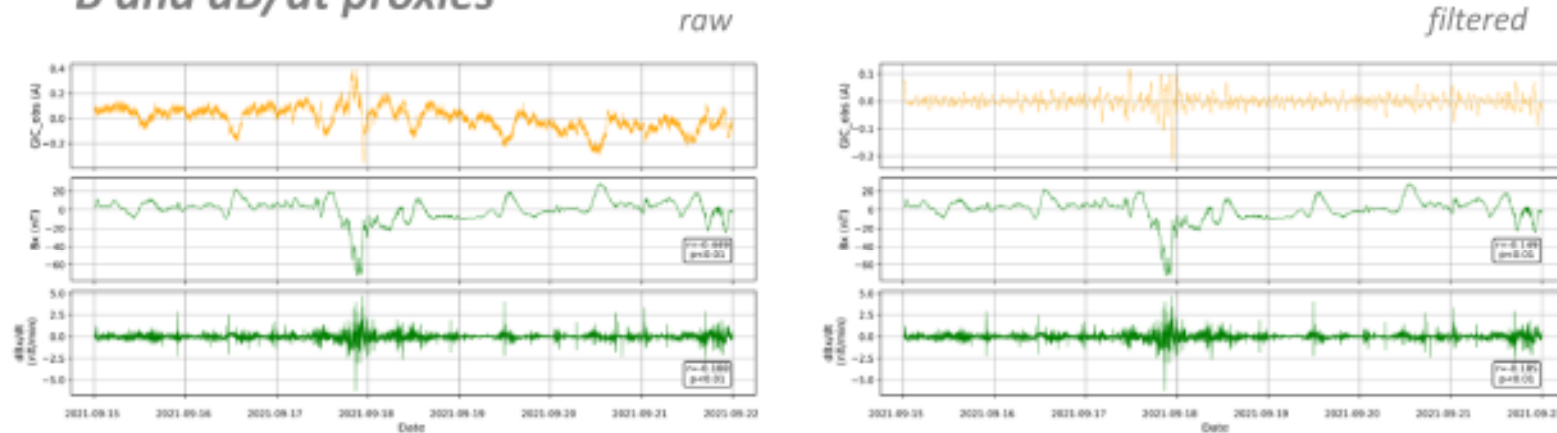
H and dH/dt proxies



Correlation of |GIC| with 1-hr maximum absolute values of horizontal components(|Bx| and |By|), with their combination into H and with absolute values of time derivatives

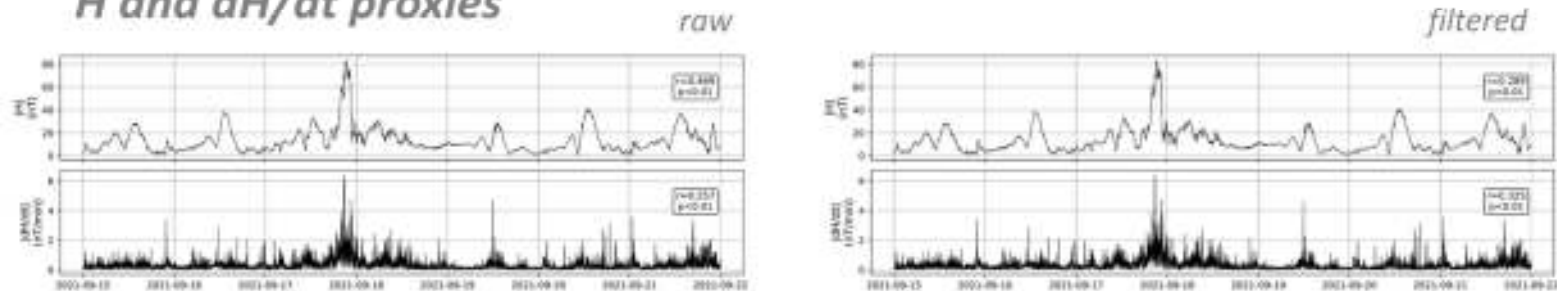
1-min proxies

B and dB/dt proxies



Correlation between GIC and B_x (green)

H and dH/dt proxies

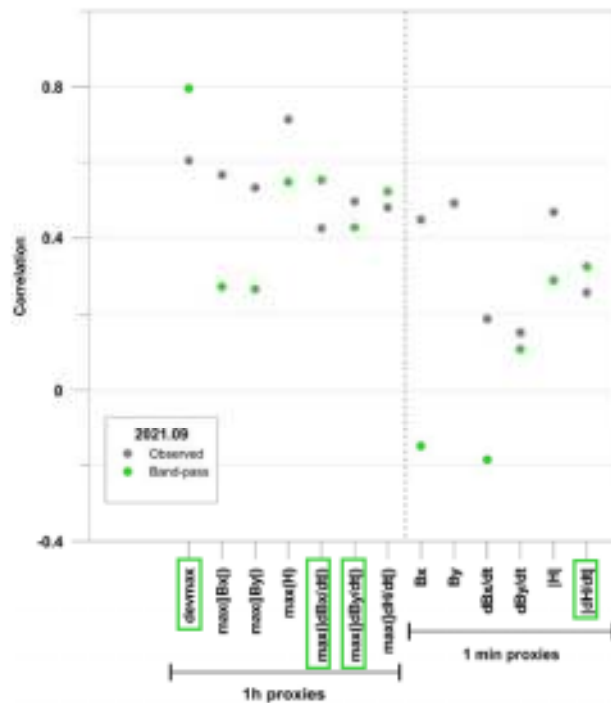


Correlation of $|GIC|$ with the magnitude of the horizontal component $H = \sqrt{B_x^2 + B_y^2}$ and with the magnitude of the time derivative of H

Comparison of all studied proxies

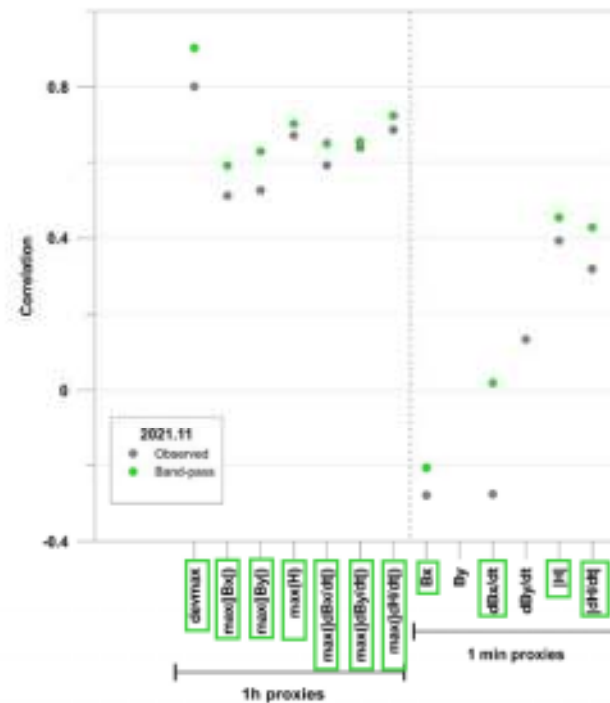
17th September 2021

Dst = -64 nT



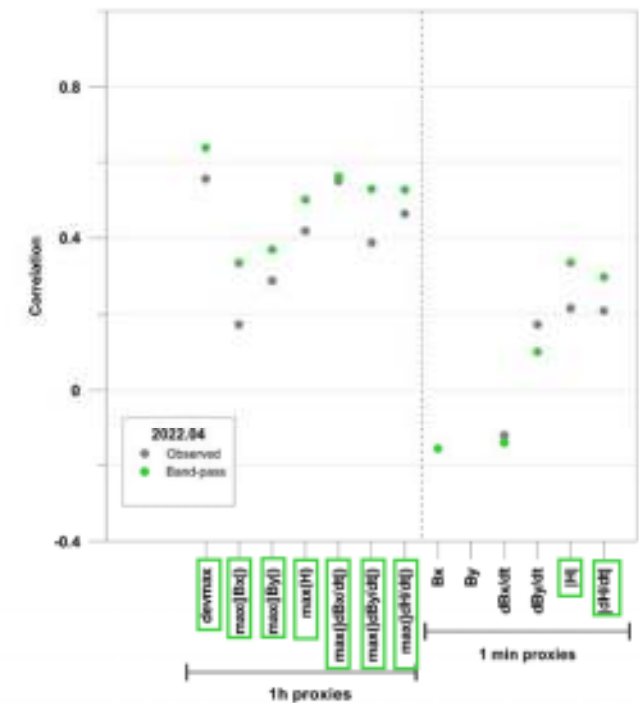
4th November 2021

Dst = -105 nT



14th April 2022

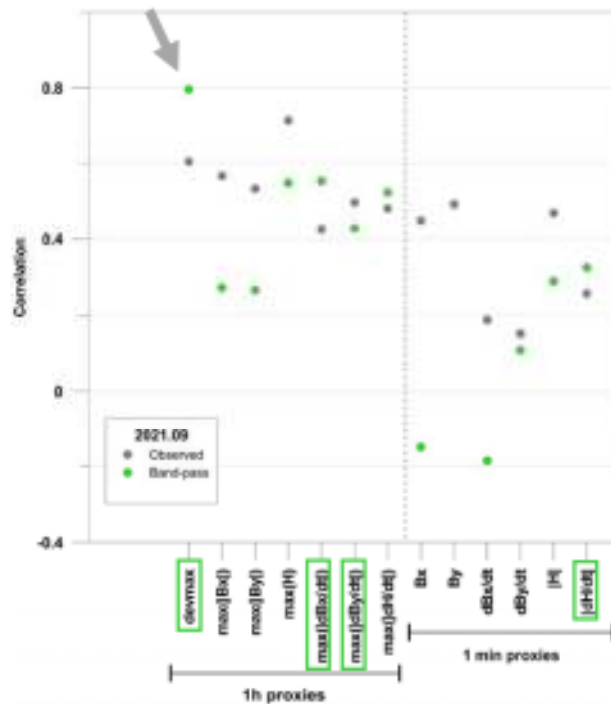
Dst = -81 nT



Comparison of all studied proxies

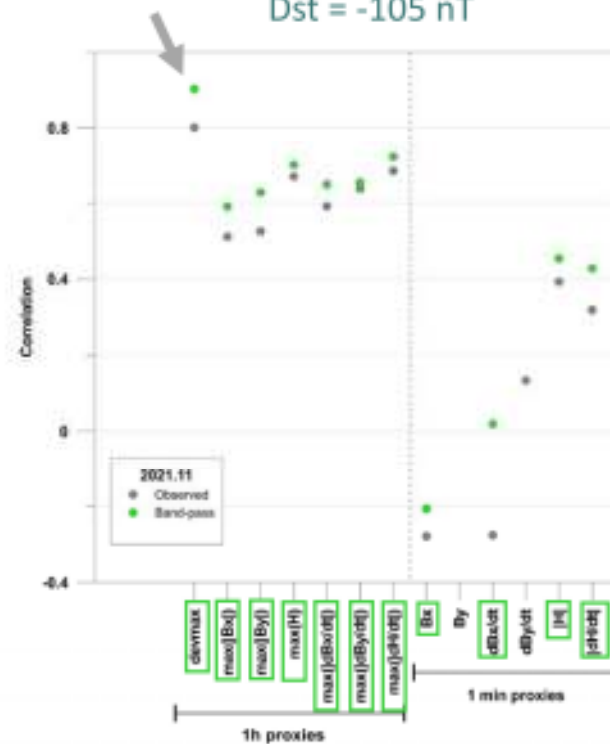
17th September 2021

Dst = -64 nT



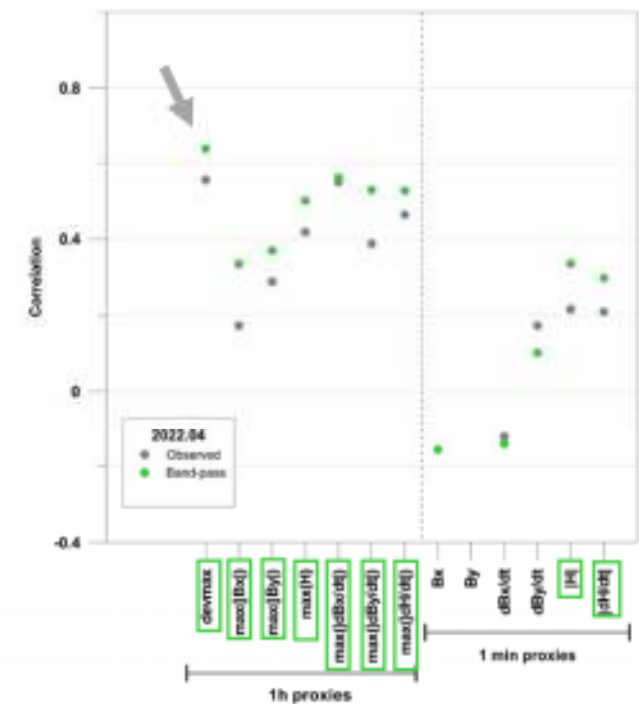
4th November 2021

Dst = -105 nT



14th April 2022

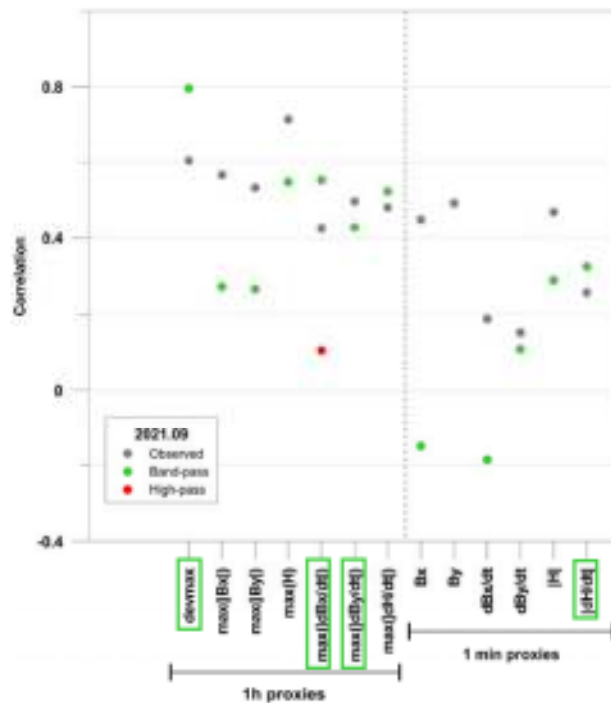
Dst = -81 nT



Comparison of all studied proxies

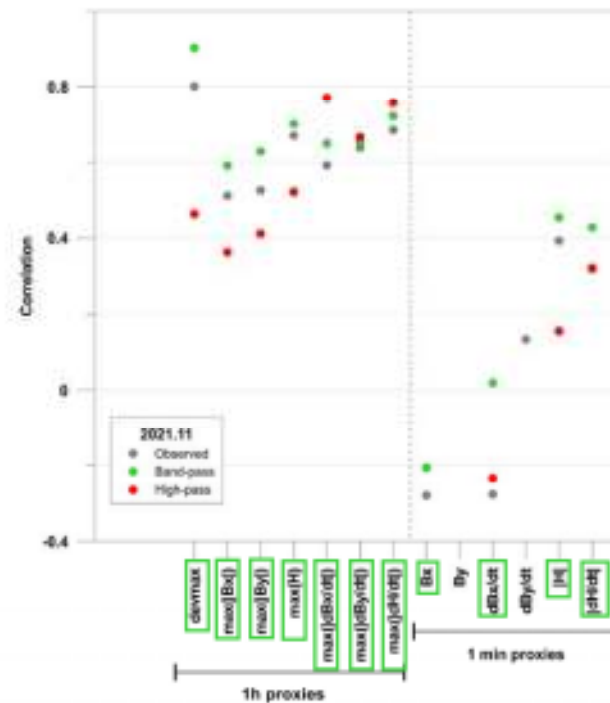
17th September 2021

Dst = -64 nT



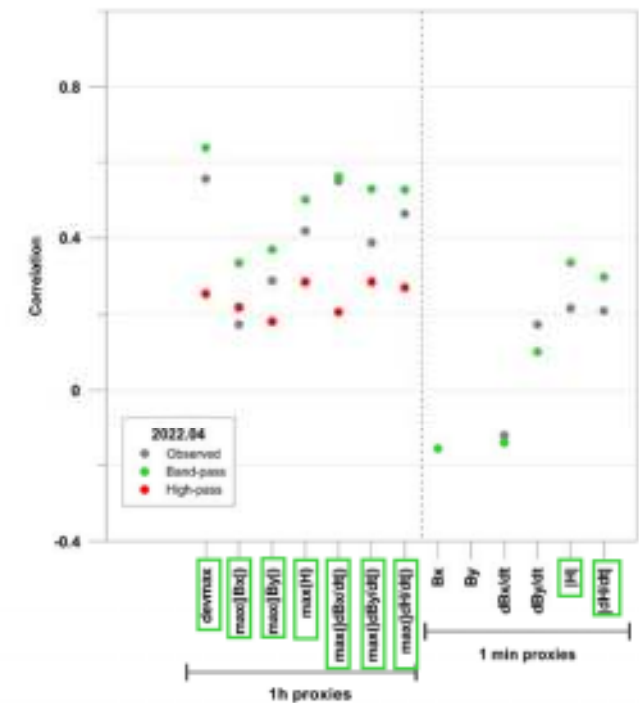
4th November 2021

Dst = -105 nT



14th April 2022

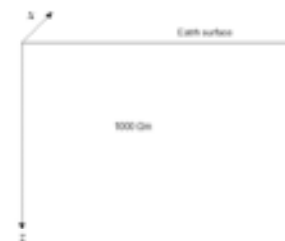
Dst = -81 nT



EGIC-Index

How it is estimated?

1. Calculate E_x & E_y from a uniform half-space of 1000 $\Omega.m$



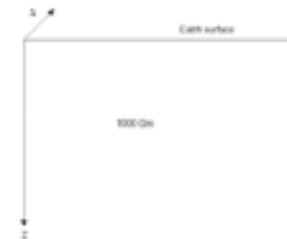
EGIC-Index

How it is estimated?

1. Calculate E_x & E_y from a uniform half-space of 1000 $\Omega.m$
2. Calculate fitted coefficients as a function of E

$$GIC = A.E_x + B.E_y$$

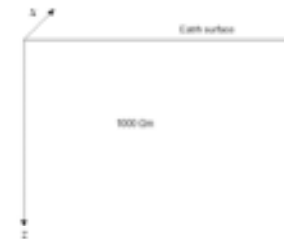
Measured or estimated



EGIC-Index

How it is estimated?

1. Calculate E_x & E_y from a uniform half-space of 1000 $\Omega.m$



2. Calculate coefficients fitted to the observations/estimations, for each substation and geomagnetic storm

$$GIC = A.E_x + B.E_y$$

Measured or estimated

3. Calculate EGIC for any geomagnetic storm and a given substation

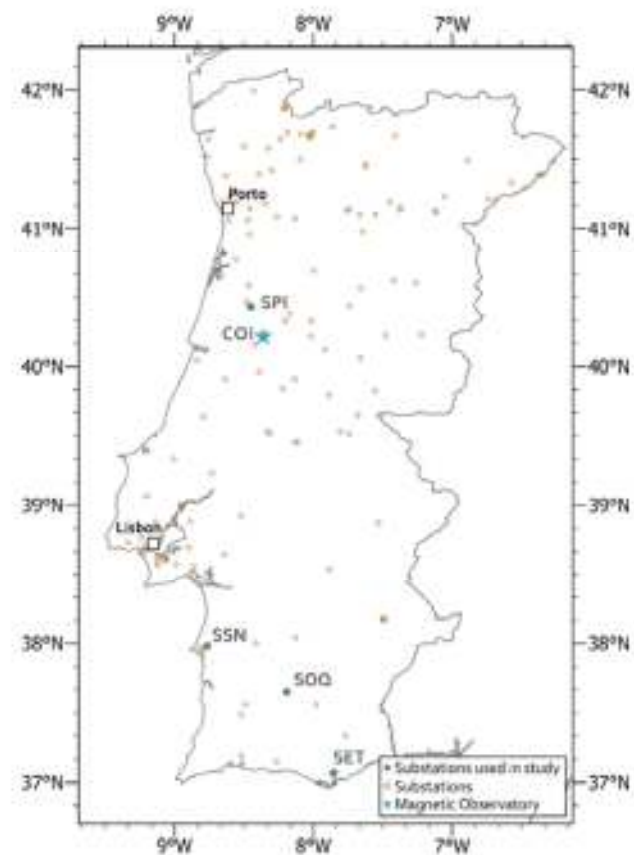
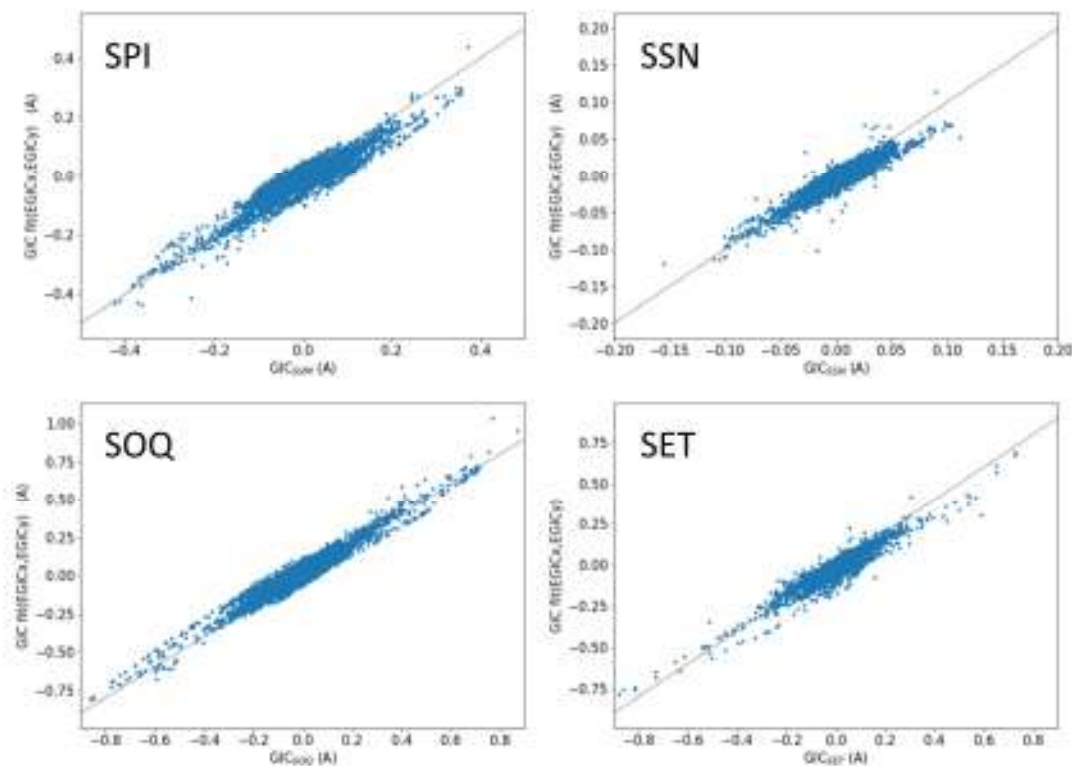
$$EGIC = \bar{A}.E_x + \bar{B}.E_y$$

$$\vec{E} = \frac{1}{\sqrt{\pi\mu_0}} \hat{k} \wedge \int_0^\infty \frac{1}{\sqrt{\tau}} \frac{d\vec{H}(t-\tau)}{d\tau} d\tau$$

EGIC-Index

15th March 2015

Correlation with (raw) estimates

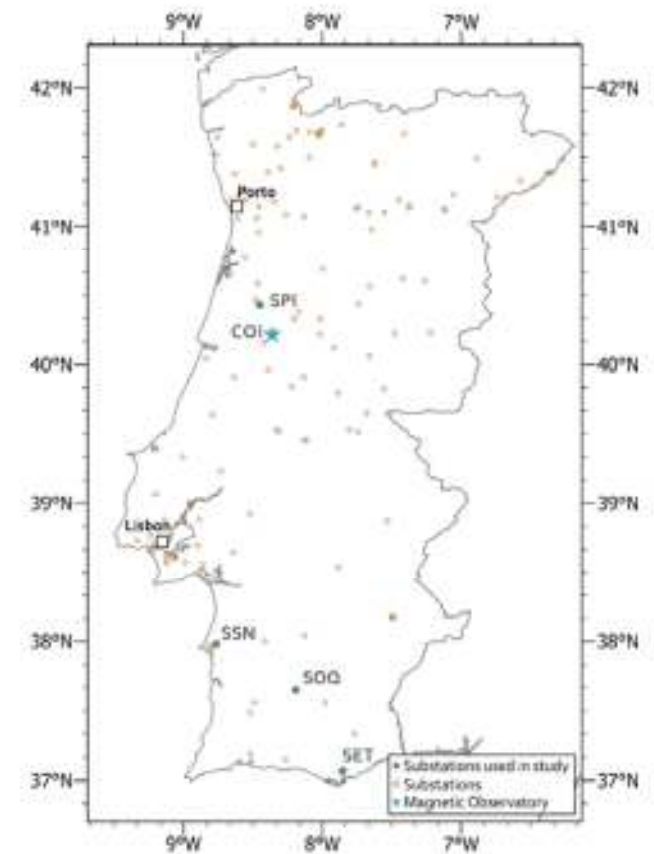
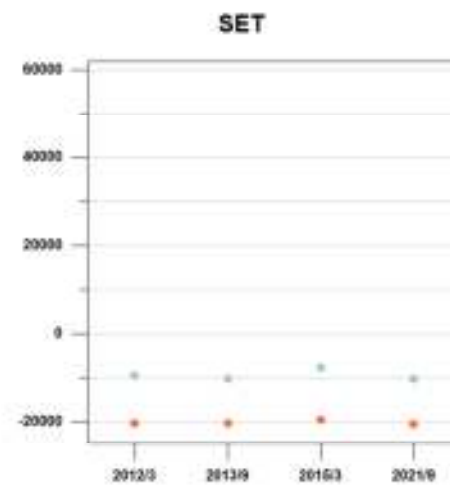
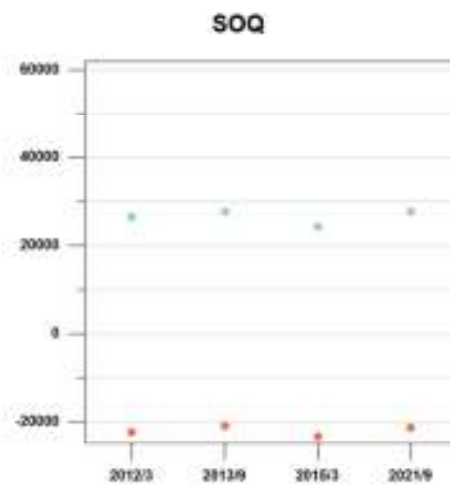
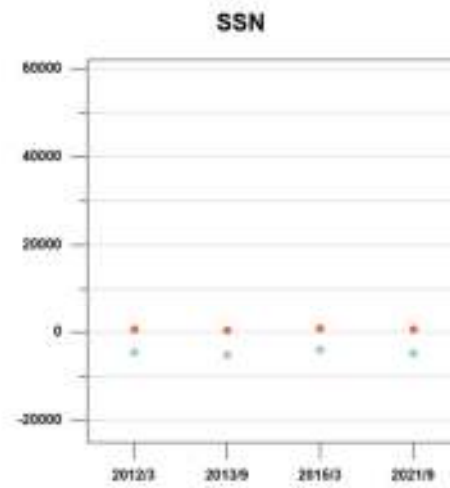
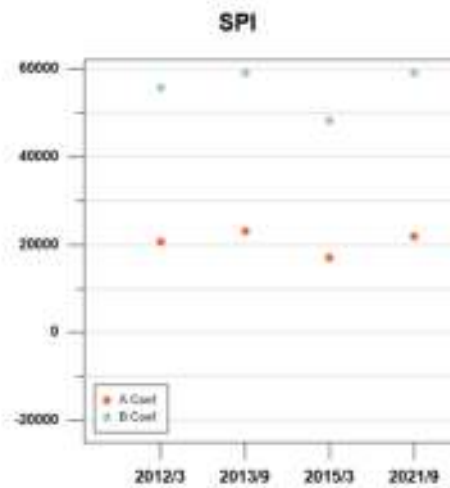


EGIC-Index

Coef	2012/3	2013/9	2015/3	2021/9	mean	stdev
SPI_A	20791.2	23142.3	17124.7	21947.4	20751.4	2252.9
SPI_B	55648.7	59139.4	48261.	59050.	55524.8	4423.5
SSN_A	630.3	422.6	854.3	551.8	614.8	156.9
SSN_B	-4546.6	-5131.6	-4048.2	-4786.3	-4628.2	394.
SOQ_A	-22347.6	-21033.8	-23424.6	-21276.1	-22020.5	949.5
SOQB	26544.7	27779.8	24309.9	27692.1	26581.6	1399.2
SET_A	-20306.7	-20235.9	-19449.8	-20534.3	-20131.7	408.8
SET_B	-9514.7	-10354.9	-7600.6	-10264.6	-9433.7	1107.5

EGIC-Index

From estimated data



EGIC-Index @ Paraimo substation

17th September 2021

Model

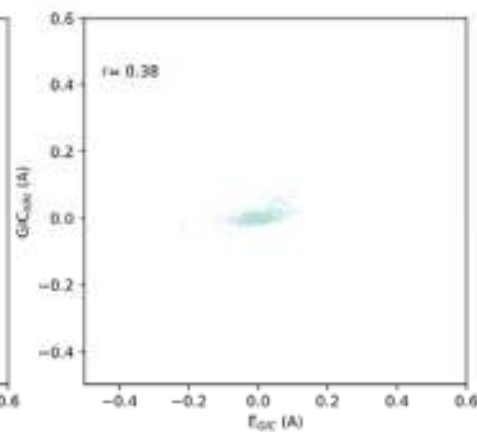
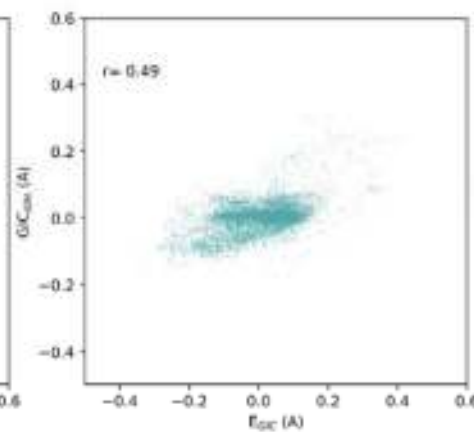
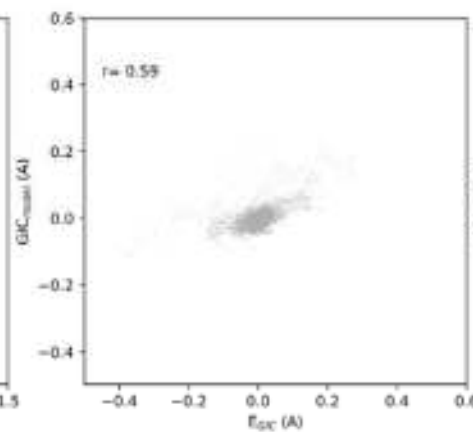
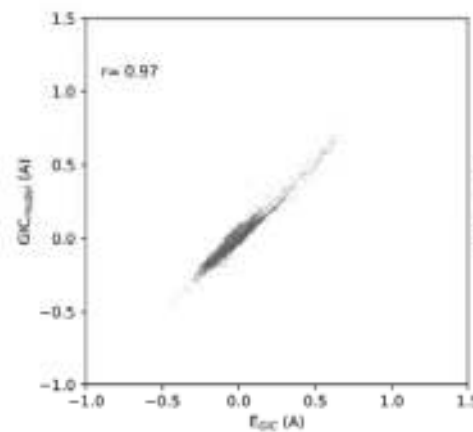
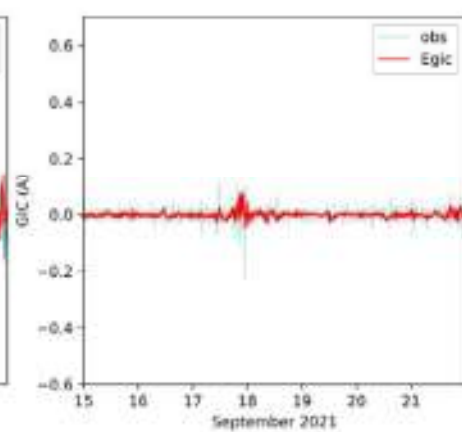
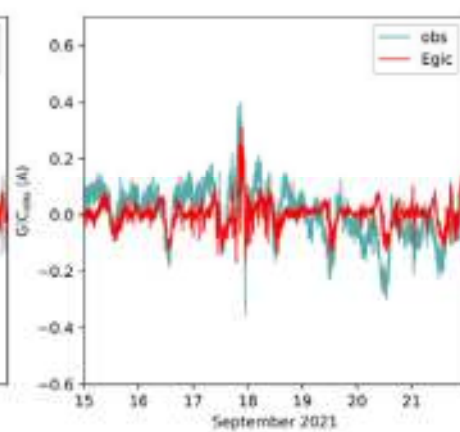
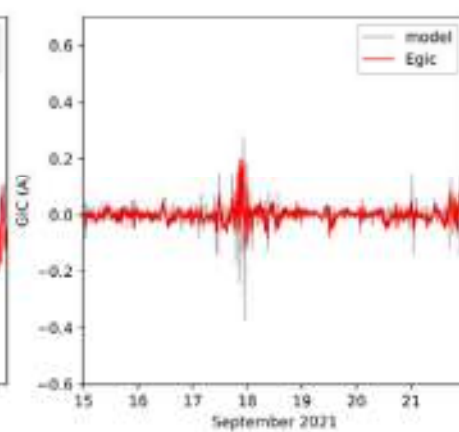
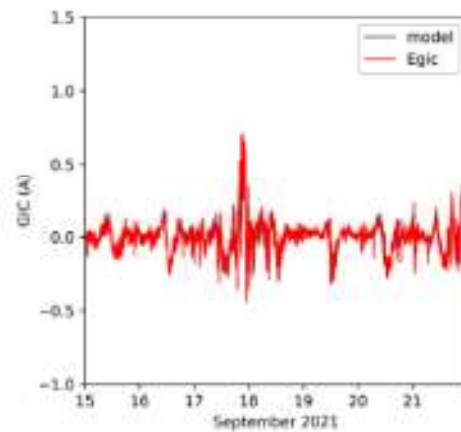
Observations

raw

filtered

raw

filtered



EGIC-Index @ Paraimo substation

4th November 2021

Model

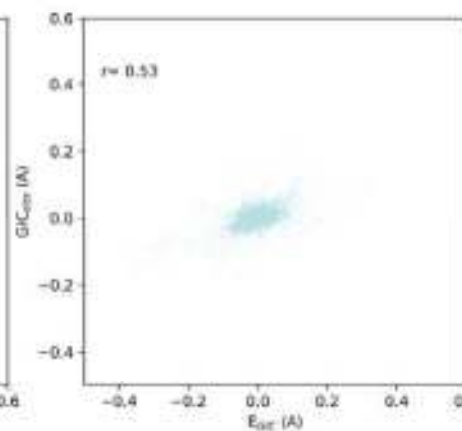
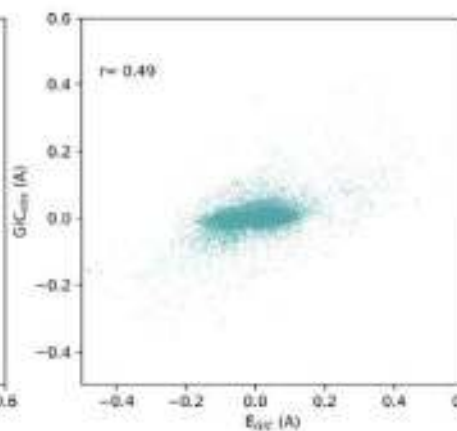
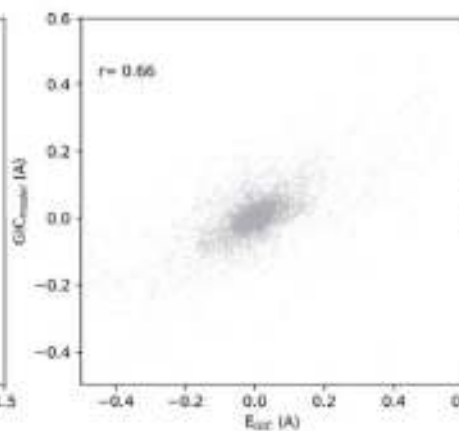
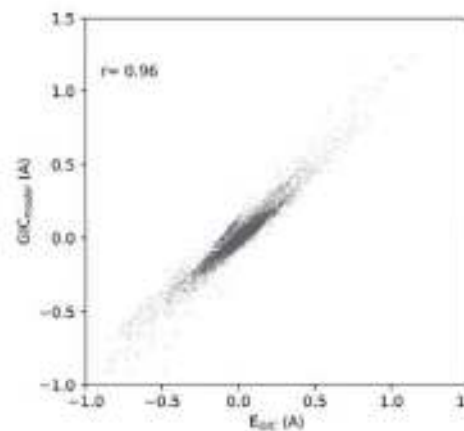
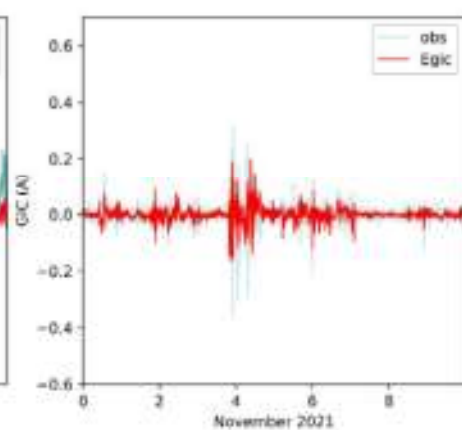
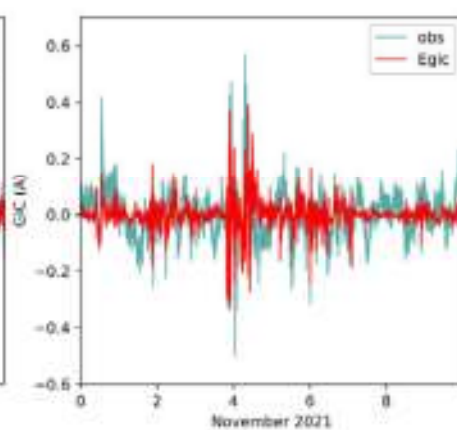
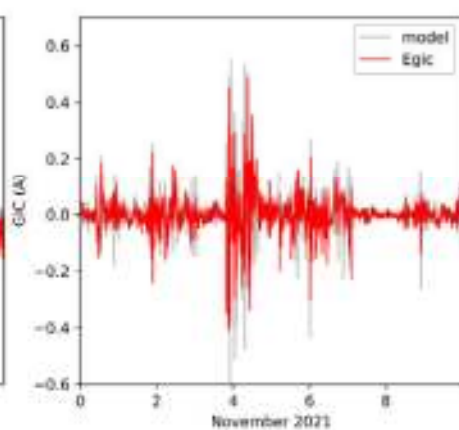
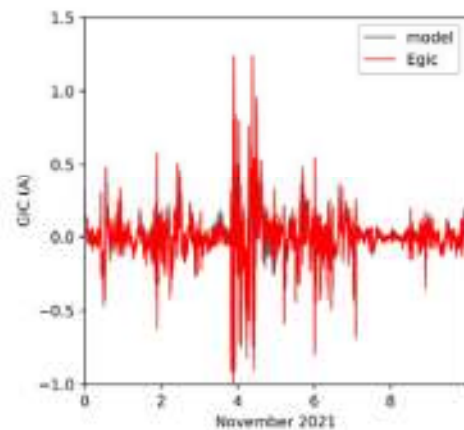
Observations

raw

filtered

raw

filtered



EGIC-Index @ Paraimo substation

14th April 2022

Model

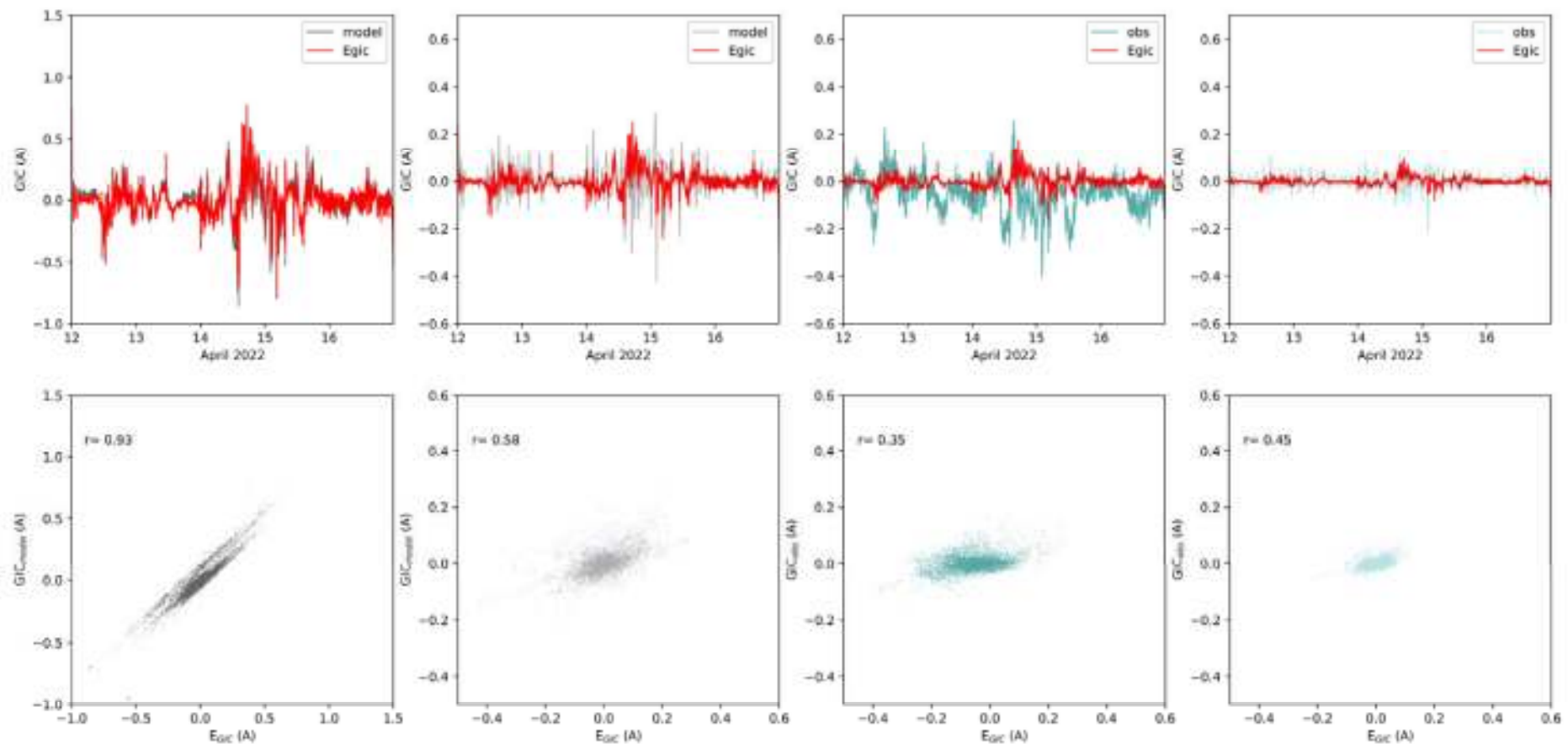
Observations

raw

filtered

raw

filtered



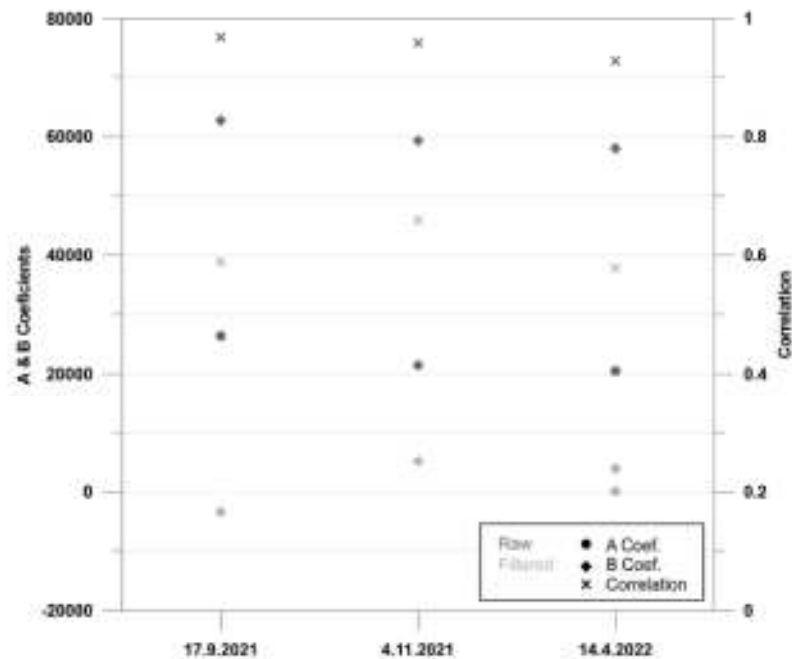
EGIC-Index @ Paraimo substation

	Estimated GICs						Observed GICs					
	Raw			Filtered			Raw			Filtered		
	A	B	r	A	B	r	A	B	r	A	B	r
2021.09.17	26430	62696	0.97	-3448	19997	0.59	22547	18782	0.49	-1319	7816	0.38
2021.11.04	21477	59300	0.96	5113	23042	0.66	4695	18565	0.49	2492	9385	0.53
2022.04.14	20500	57983	0.93	3879	18529	0.58	2186	12688	0.35	-69	7004	0.45

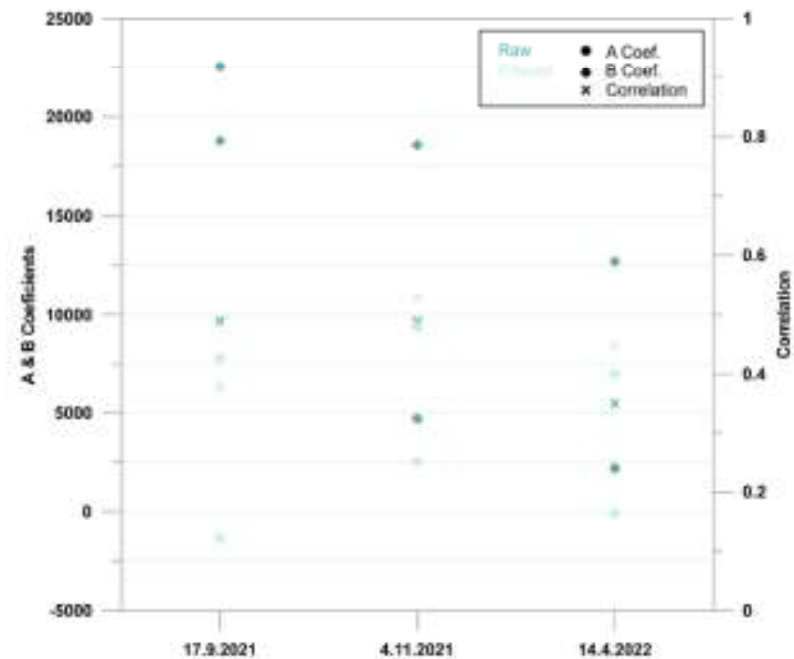
MP0

EGIC-Index @ Paraimo substation

Model

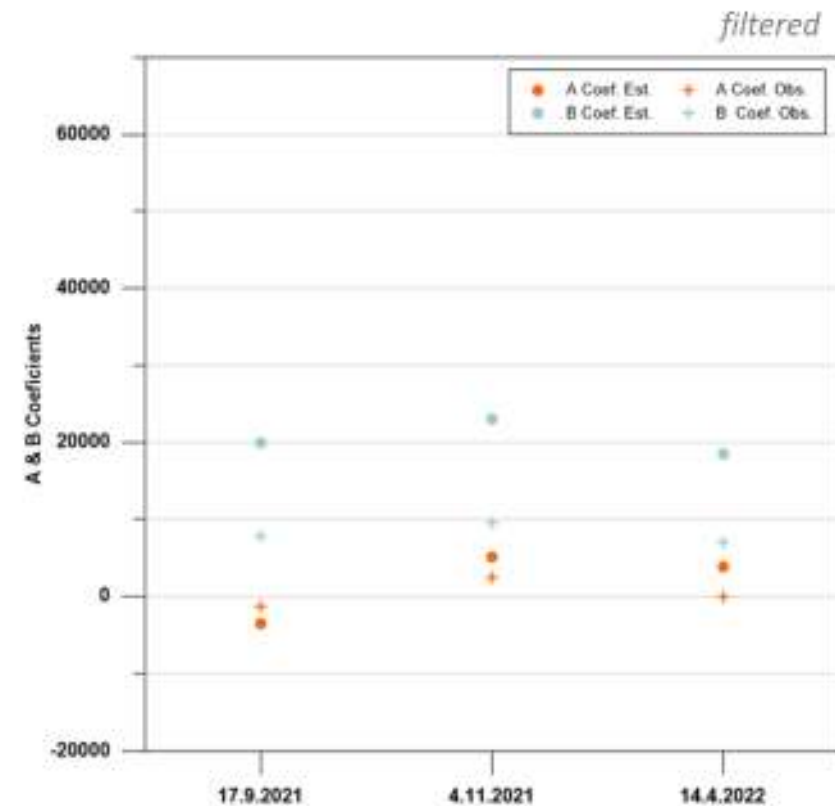
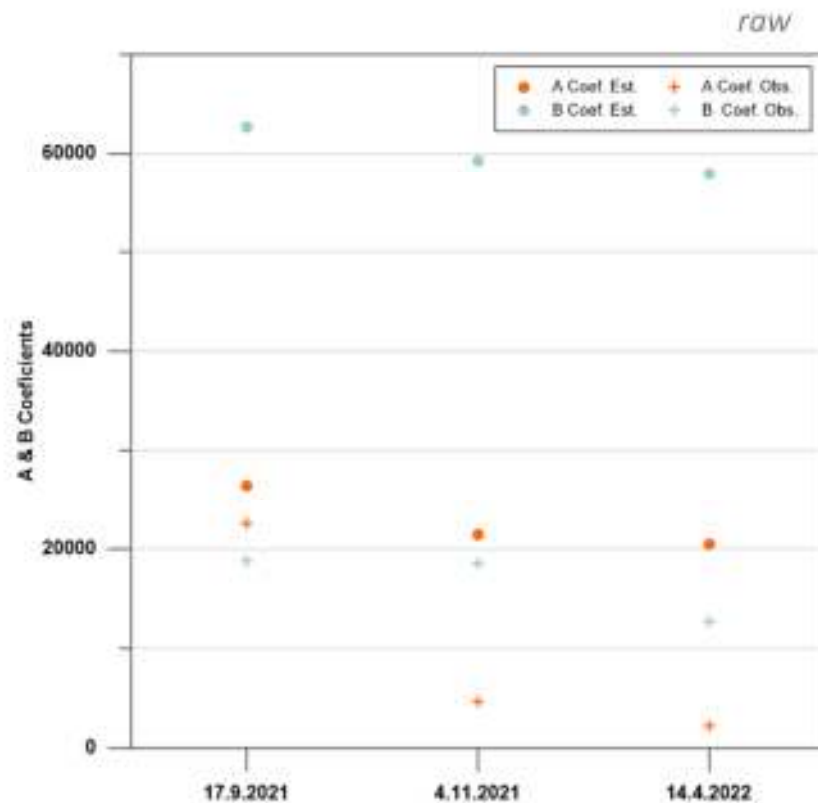


Observations



EGIC-Index @ Paraimo substation

Estimated Vs Observations



Summary

- First GIC measurements allow to test GIC model;
- Filtering data helps to understand differences between estimations & observations;
- For 1-hr proxies, filtering improved correlations between GIC proxies and observations;
- *devmax* was the best 1-hr proxy;
- For 1-min proxies, EGIC needs to be improved.

Next steps:

- Improve conductivity model for deeper layers (long period MT soundings);
- Improve GIC sensor resolution (meanwhile, waiting for stronger events...);
- Improve the E model in EGIC, mainly for the E_x component

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