Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

Modelling Electric Fields In Ireland And UK For Space Weather Applications

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[4] Dublin Institute for Advanced Studies (DIAS)

Met Office

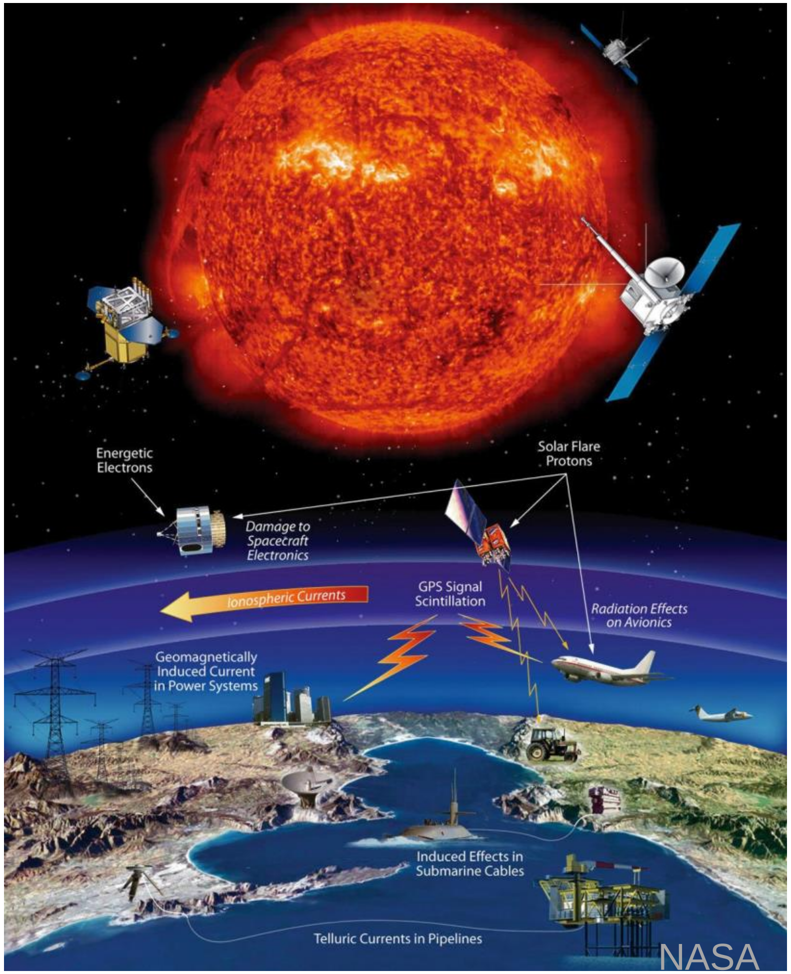
DIAS
Institiúid Ard-Léinn Bhaile Átha Cliath
Dublin Institute for Advanced Studies

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

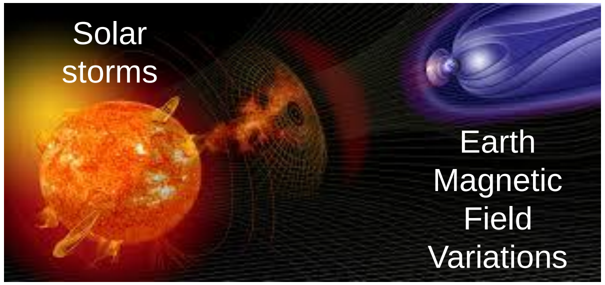
IRISH RESEARCH COUNCIL
An Chomhairle um Thaighde in Éirinn

Why do we want to model the electric fields?

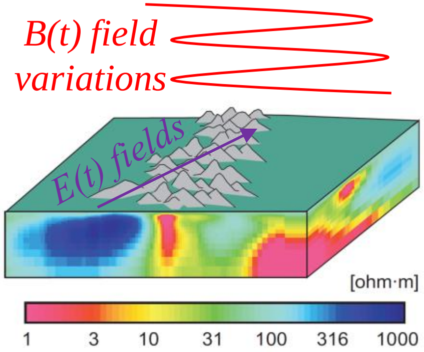
Geomagnetic Induced Currents (GICs)



- Solar Activity



- Induced Electric Fields



Faraday's law

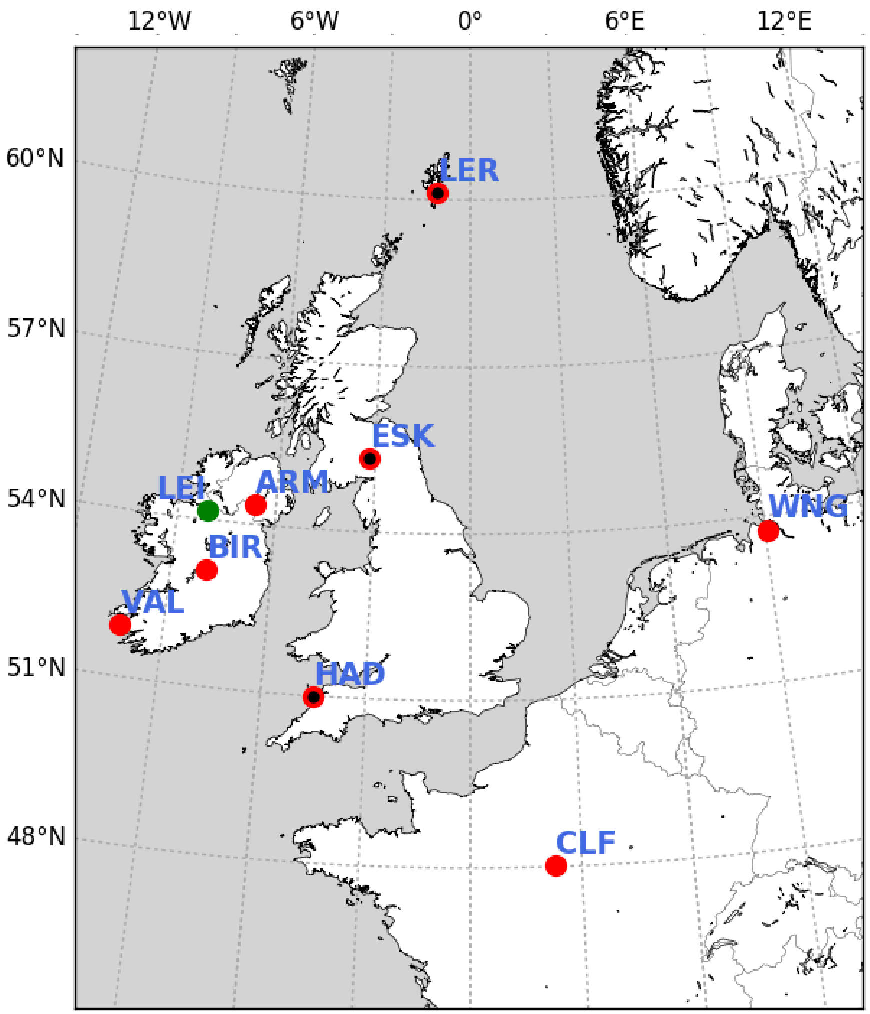
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

- Power Transmission Network

Induced Electric Currents

Area of Interest

Ireland and UK

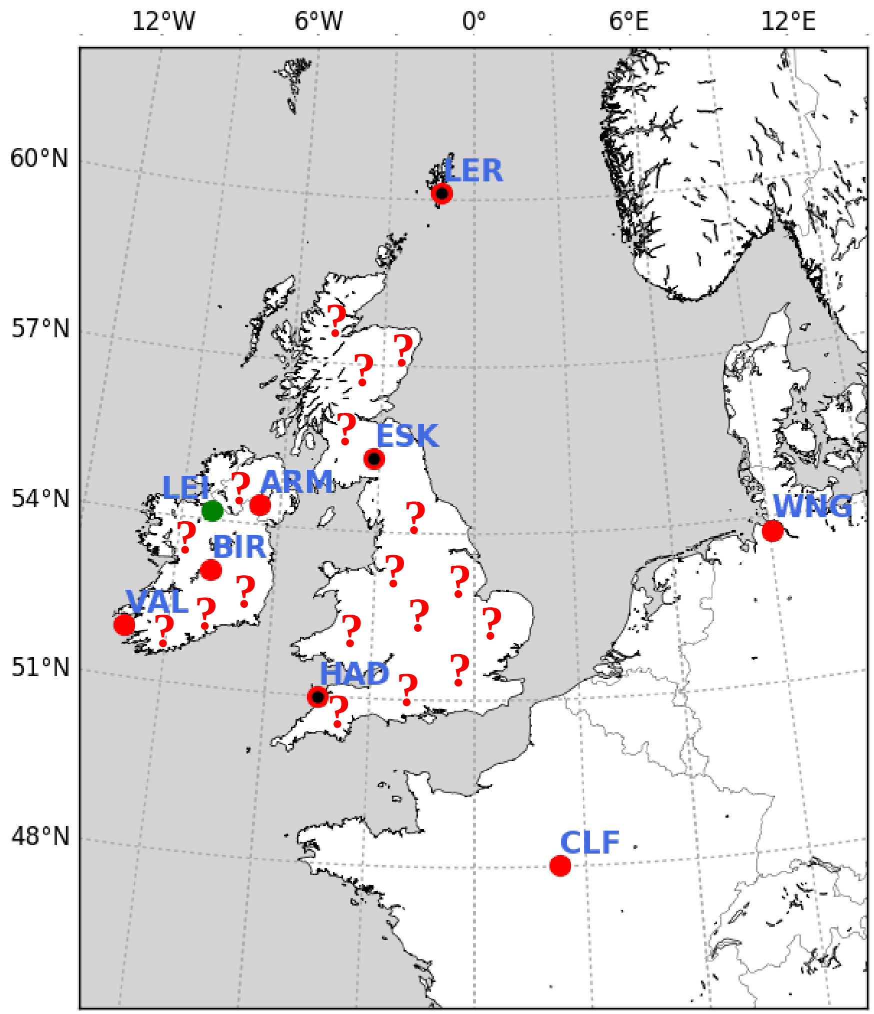


- Permanent Magnetic Observatories (red)
- Permanent Electric Observatories (black)
- Temporary site (electrics and magnetics) (green)

INTERMAGNET & MagIE

Area of Interest

Ireland and UK



- Permanent Magnetic Observatories
- Permanent Electric Observatories
- Temporary site (electrics and magnetics)

How accurate can we model the electric fields at sites with no permanent recordings?

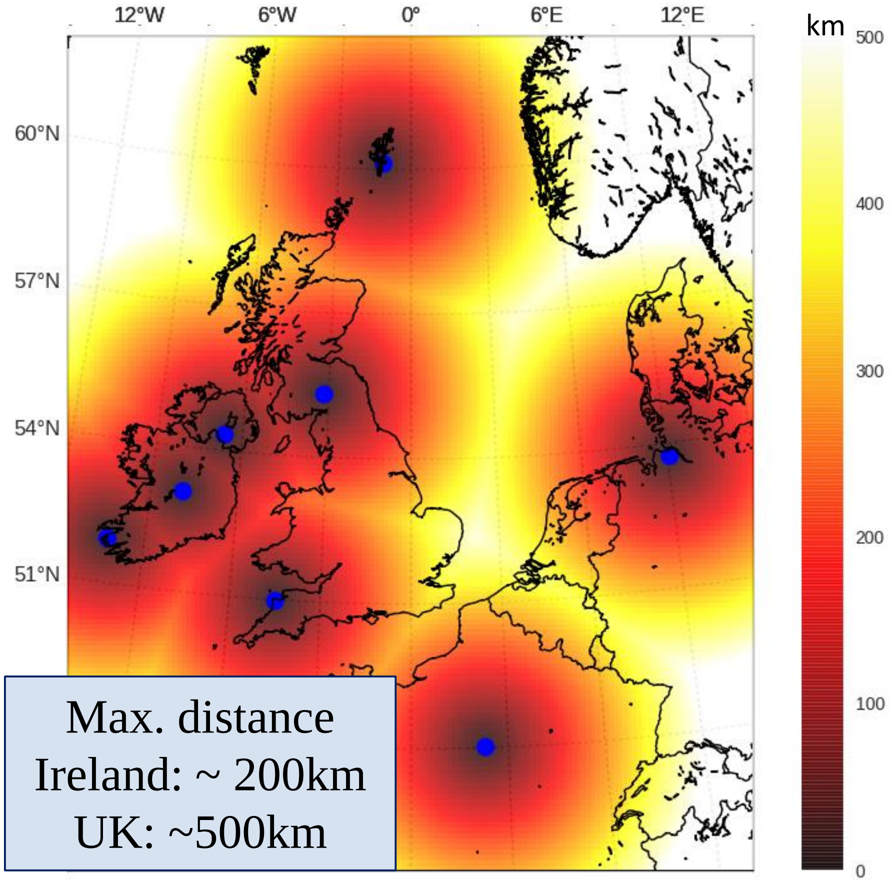
INTERMAGNET & MagIE

Sources of EM fields

Primary Magnetic Field & Influence of the Subsurface Geology

Primary magnetic field

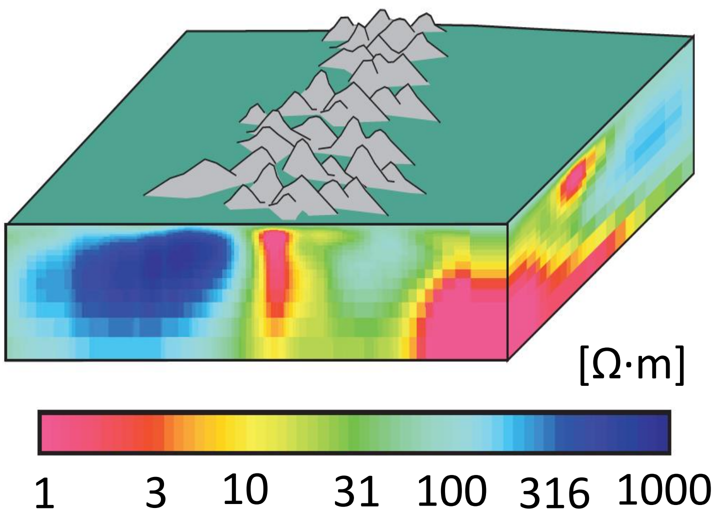
(Interpolate between Magnetic Observatories)



Max. distance
Ireland: ~ 200km
UK: ~500km

Influence of the geology

(Magnetotelluric geophysical method:
Tensor relationships relating EM fields)



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Primary Magnetic Field & Influence of the Subsurface Geology

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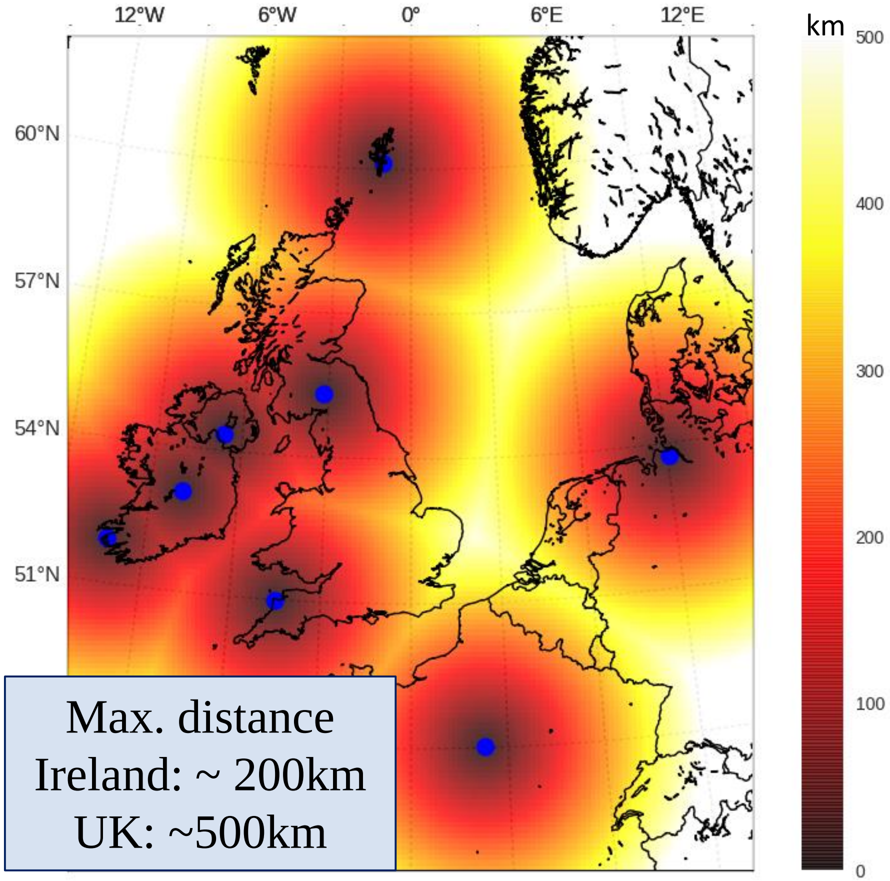

Max. distance
Ireland: ~ 200km
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- Spherical elementary current systems (SECS, ionospheric currents)
- Linear interpolation
- Cubic interpolation

Sources of EM fields

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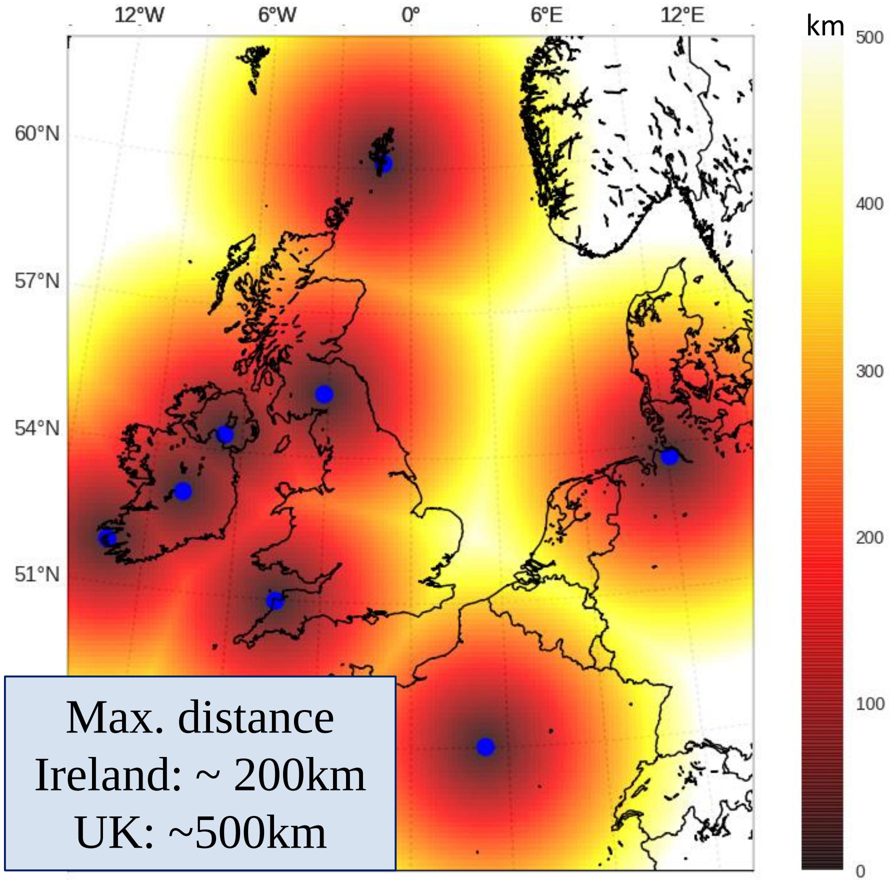

Max. distance
Ireland: ~ 200km
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- Spherical elementary current systems (SECS, ionospheric currents)
- ~~Linear interpolation~~
- ~~Cubic interpolation~~

Linear and Cubic interpolation are NOT accurate during storms

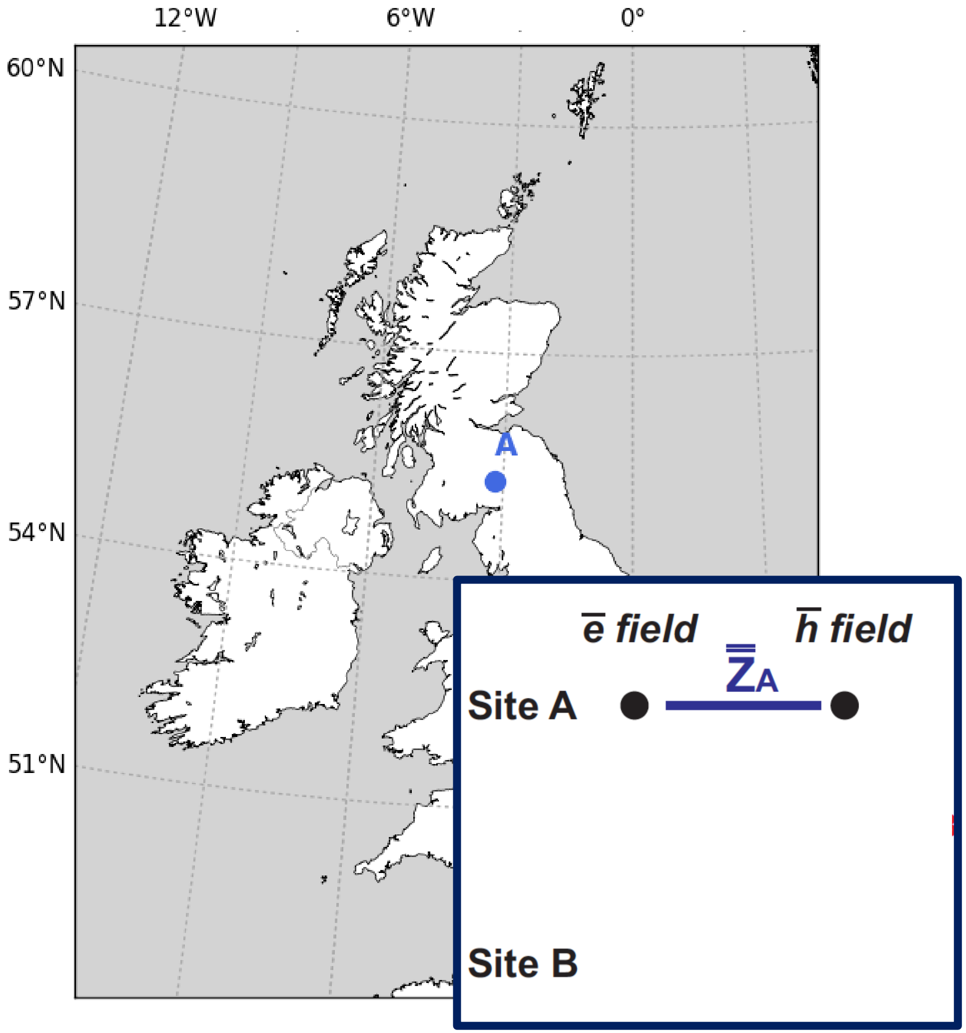
Sources of EM fields

Primary Magnetic Field & Influence of the Subsurface Geology

Tensor relationships

MT Impedance Tensor, ***Z*** (local)

$$\begin{pmatrix} e_x^A(\omega) \\ e_y^A(\omega) \end{pmatrix} = \begin{pmatrix} Z_{xx}(\omega) & Z_{xy}(\omega) \\ Z_{yx}(\omega) & Z_{yy}(\omega) \end{pmatrix} \begin{pmatrix} h_x^A(\omega) \\ h_y^A(\omega) \end{pmatrix}$$



(ω): Frequency dependence

Sources of EM fields

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Inter-station Impedance Tensor, ***Z’***

$$\begin{pmatrix} e_x^A(\omega) \\ e_y^A(\omega) \end{pmatrix} = \begin{pmatrix} Z'_{xx}(\omega) & Z'_{xy}(\omega) \\ Z'_{yx}(\omega) & Z'_{yy}(\omega) \end{pmatrix} \begin{pmatrix} h_x^B(\omega) \\ h_y^B(\omega) \end{pmatrix}$$

Reference site

Inter-station Horizontal Magnetic, ***M’***

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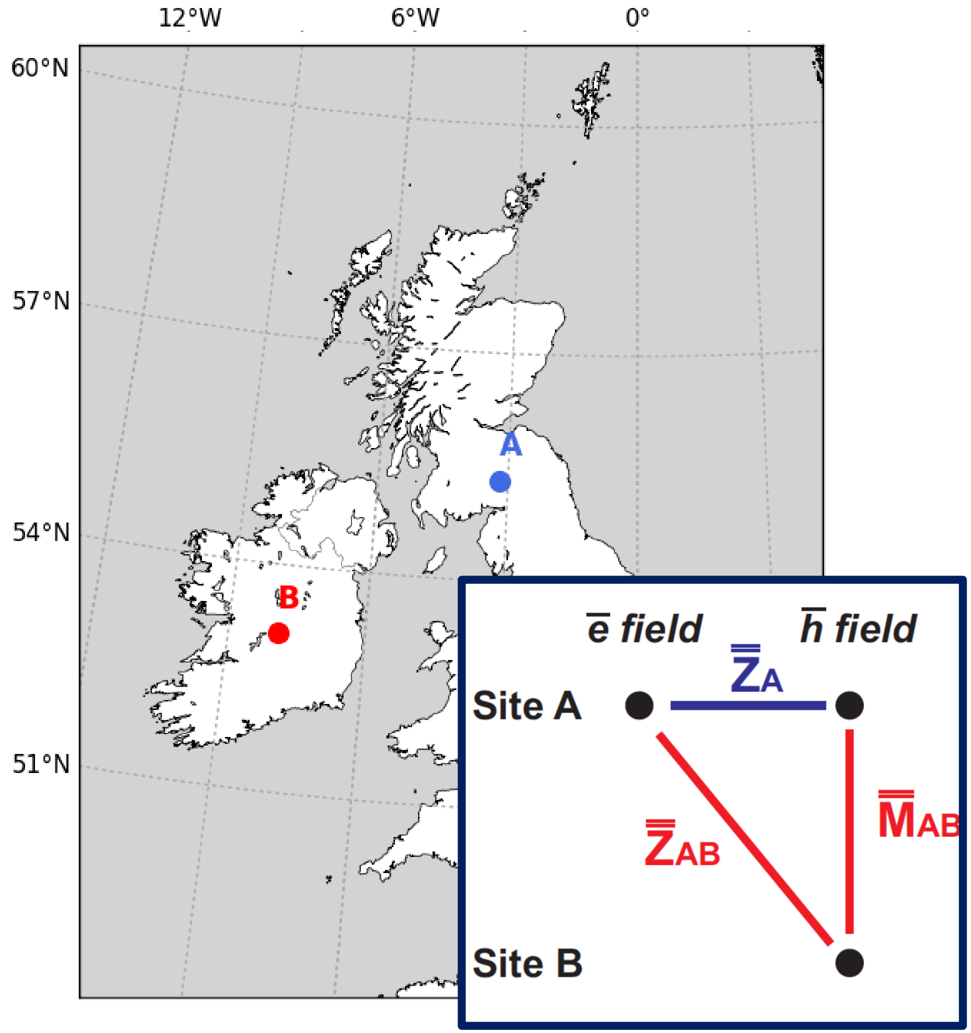

(ω): Frequency dependence

Sources of EM fields

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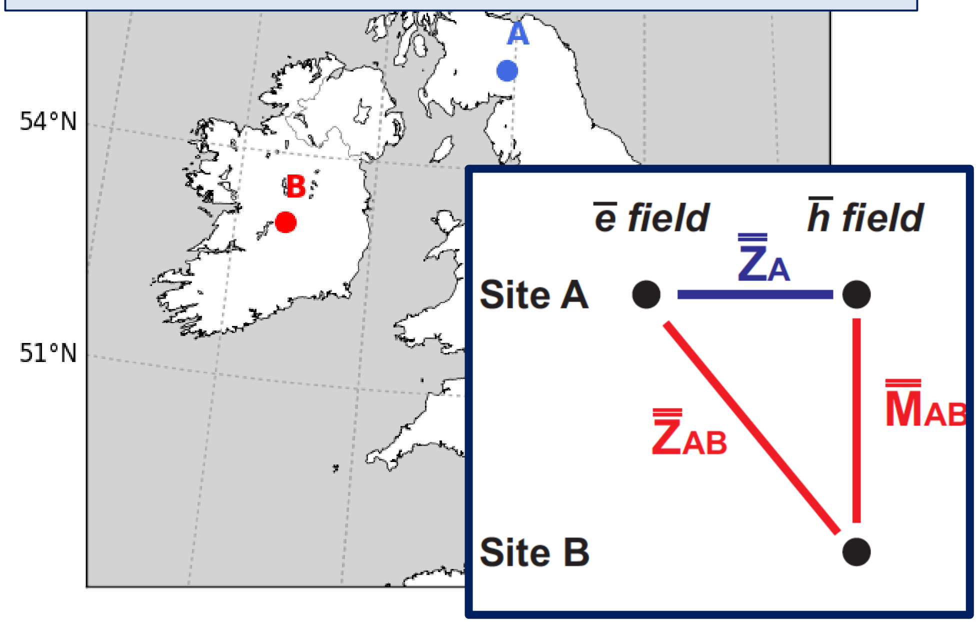
Reference site

(ω): Frequency dependence

- Data needs to be measured at least ones at the site of interest to compute the Tensor relationships

- Works under the Plane-Wave approximation: similar primary magnetic field in both sites

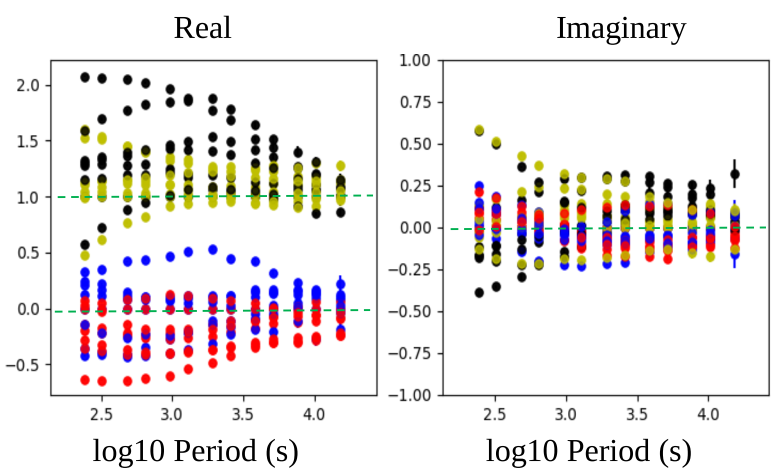


Sources of EM fields

Primary Magnetic Field & Influence of the Subsurface Geology

Influence of the geology on the magnetic field (Secondary/Induced magnetic field)

Tensor Relationship between magnetic fields
(*assuming same magnetic source for all the sites*)



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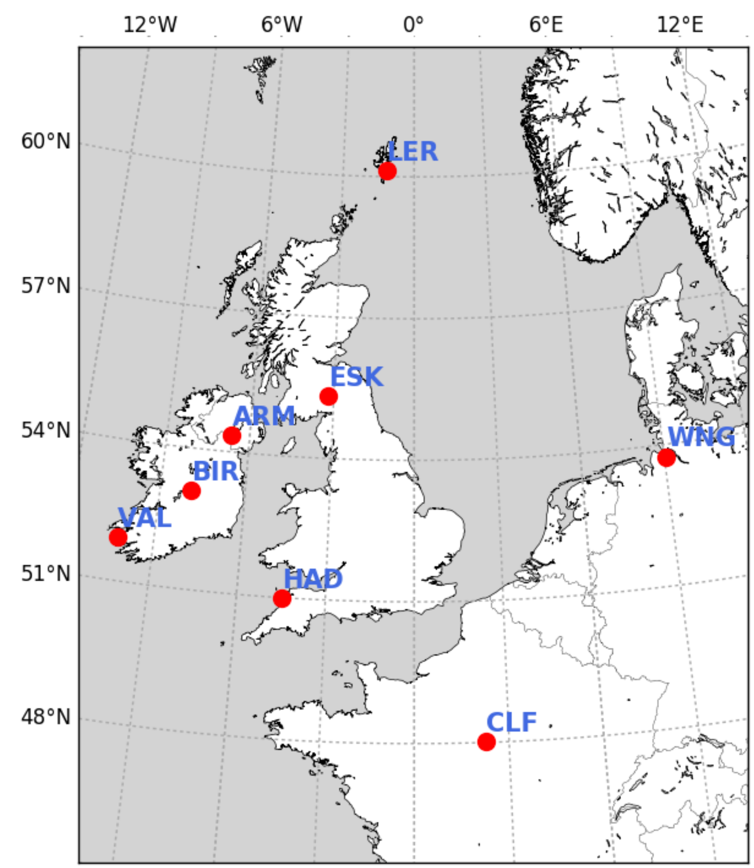

Site A: *ESK* **Site B:** *HAD, ESK, LER, VAL, BIR, ARM*

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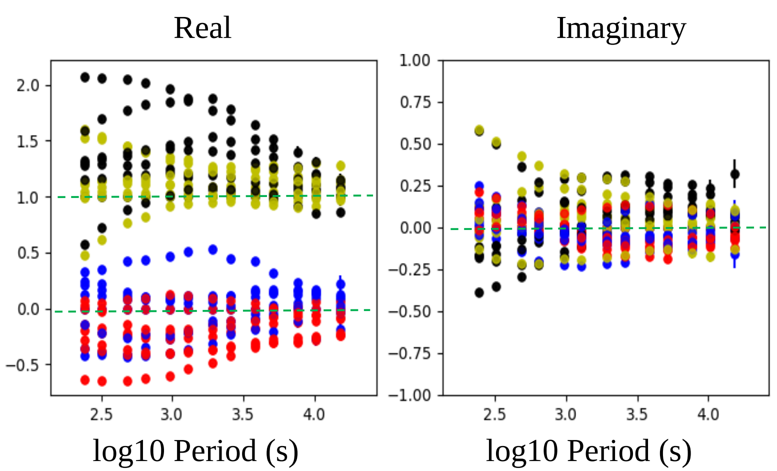

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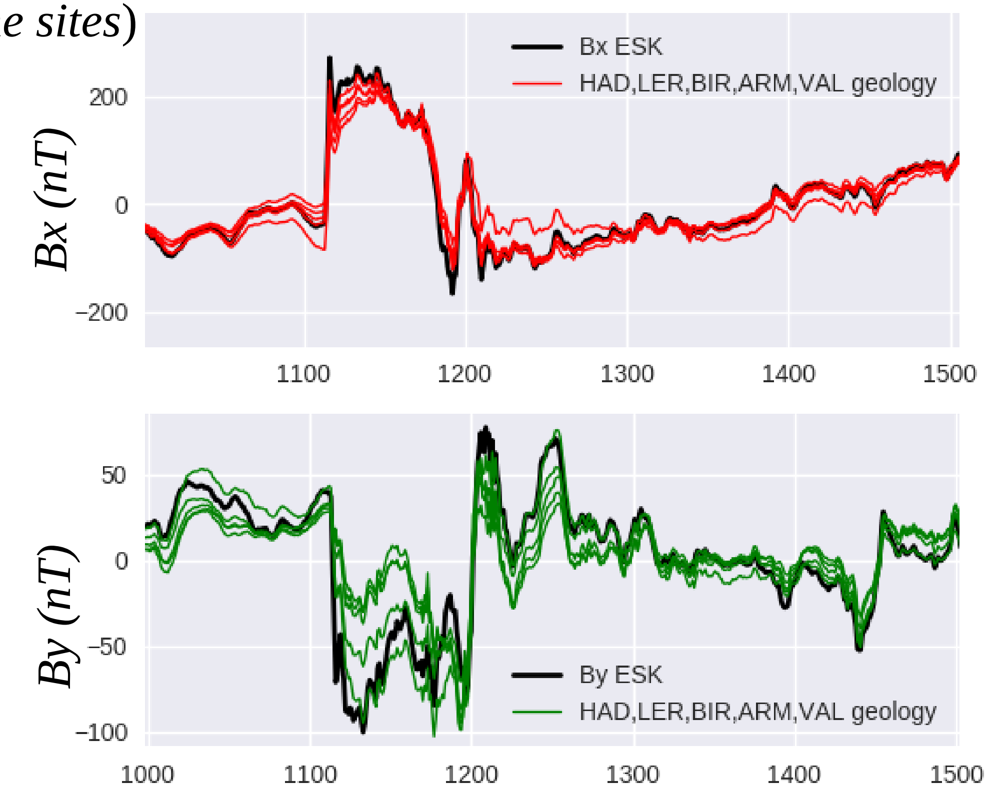
Site A: *ESK*   **Site B:** *HAD, ESK, LER, VAL, BIR, ARM*

22-23 June 2015 storm



Time (minutes)

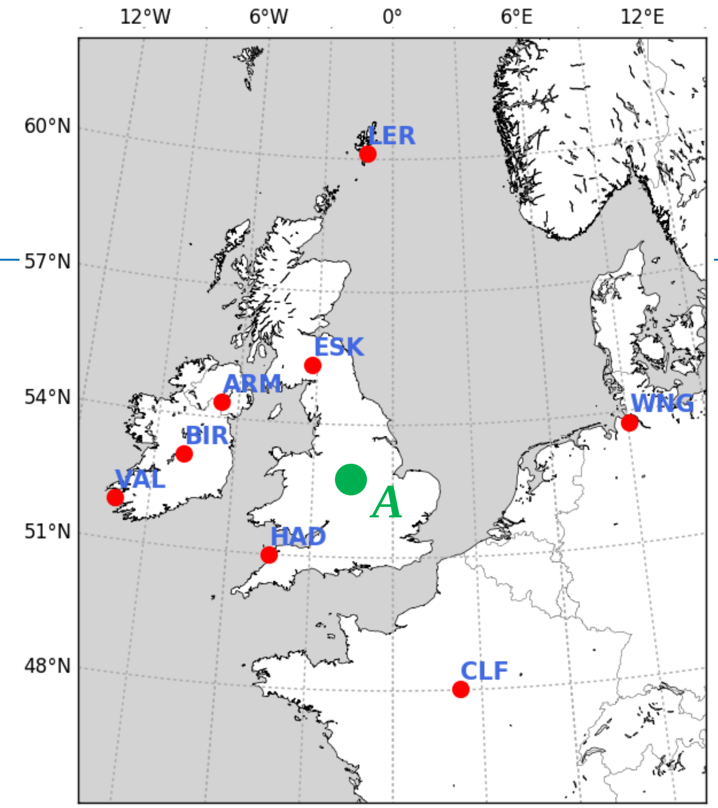
Modelling E fields

Testing different approaches

Method 1

$$E_T^A = Z^A B^A$$

B^A as a result of SECS interpolation using measured magnetic fields as inputs



Modelling E fields

Testing different approaches

Method 1

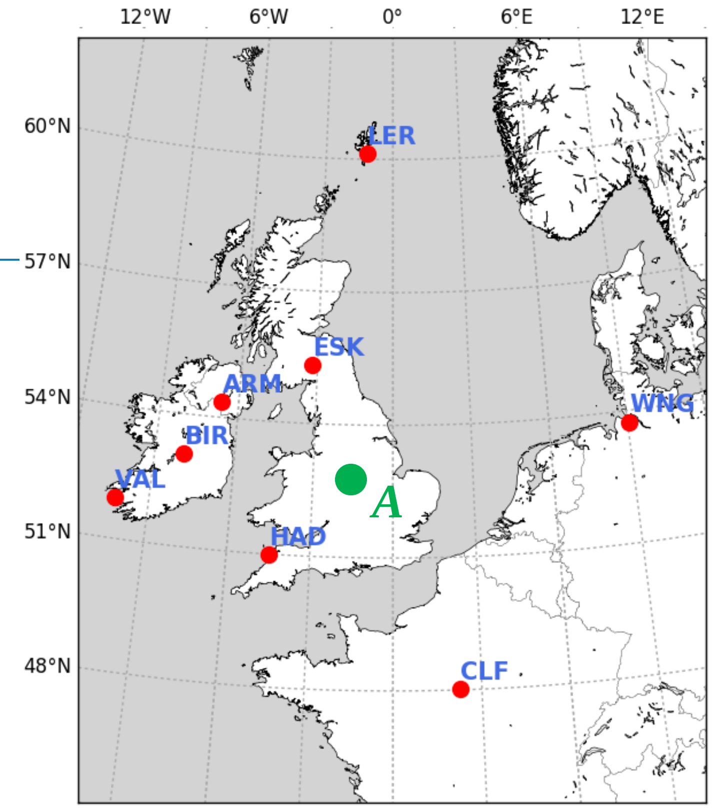
$$E_T^A = Z^A B^A$$

B^A as a result of SECS interpolation using measured magnetic fields as inputs

Method 2

"*Total*" = "*regional*" + "*local*"

$$E_T^A = E_{reg}^A + E_{loc}^A$$



Modelling E fields

Testing different approaches

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B^A as a result of SECS interpolation using measured magnetic fields as inputs

Method 2

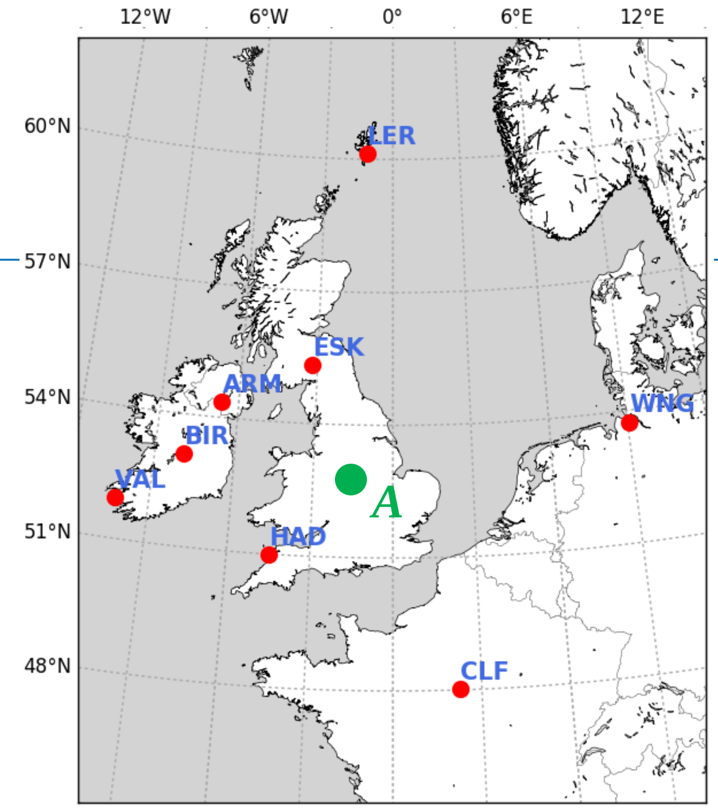
"Total" = "regional" + "local"

$$E_T^A = E_{reg}^A + E_{loc}^A$$

"regional"

$$E_{reg}^A = Z^{AMr} B^{Mr}$$

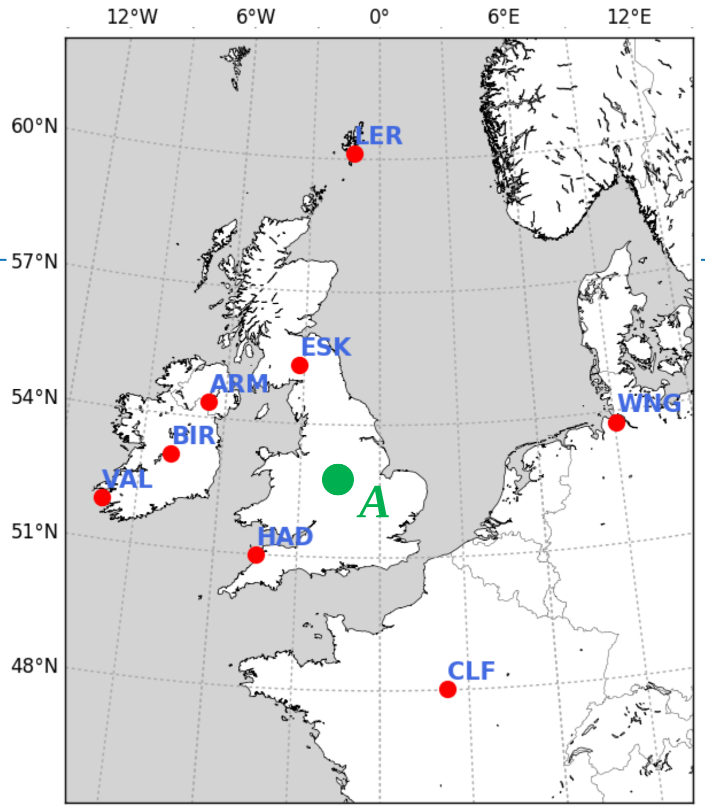
Not account for different magnetic sources (plane wave approx.)



Mr: Magnetic Reference site, such as CLF (less affected by local storms)

Modelling E fields

Testing different approaches



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$$E_T^A = E_{reg}^A + E_{loc}^A$$

"regional"

$$E_{reg}^A = Z^{AMr} B^{Mr}$$

Not account for different magnetic sources (plane wave approx.)

"local"

$$E_{loc}^A = Z^A B_{loc}^A$$

Correction for local storms

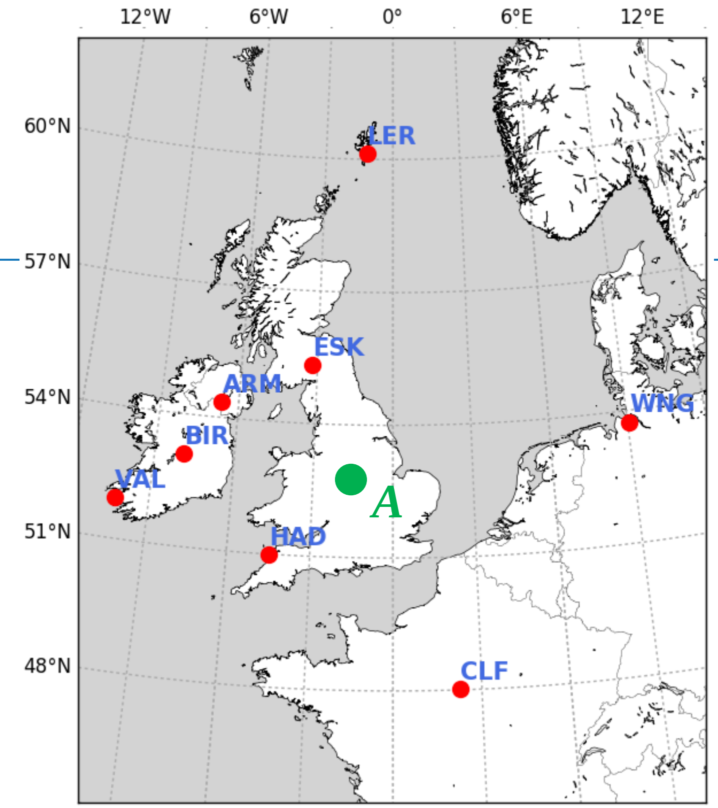
B_{loc}^A as a result SECS interpolation using local magnetic storms as input (B_{loc}^i for $i =$ VAL, BIR, ARM, LER, ESK, HAD ...).

$$B_{loc}^i = B^i - M^{iMr} B^{Mr}$$

Mr: Magnetic Reference site, such as CLF (less affected by local storms)

Modelling E fields

Testing different approaches



Method 1

$$E_T^A = Z^A B^A$$

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"regional"

$$E_{reg}^A = Z^{AMr} B^{Mr}$$

Not account for different magnetic sources (plane wave approx.)

"local"

$$E_{loc}^A = Z^A B_{loc}^A$$

Correction for local storms

using

for $i =$

Mr: Magnetic R

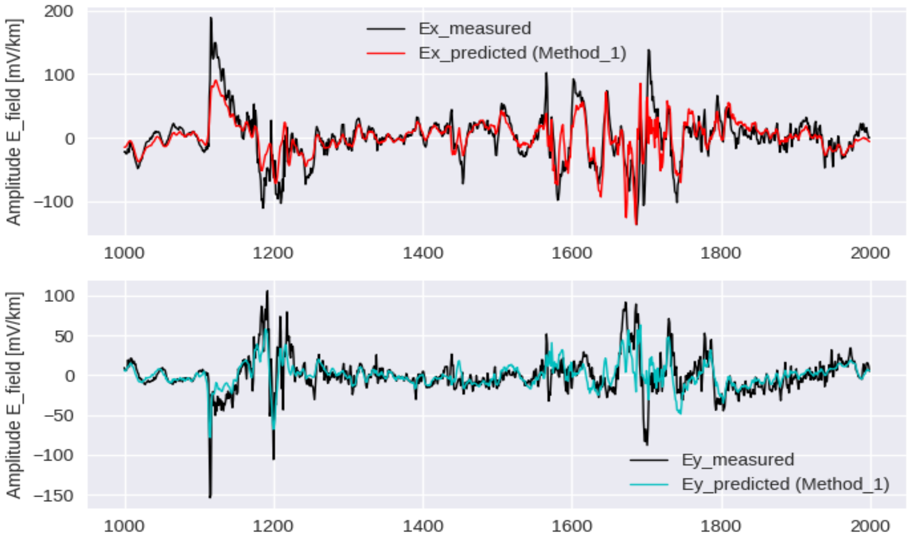
(less affected by local storms)

We aim to reduce the influence of the interpolation methods

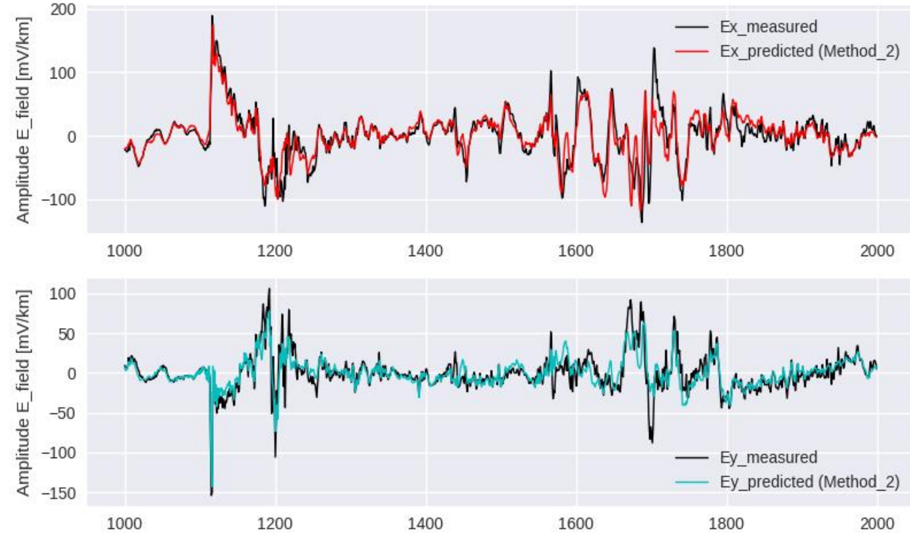
Modelling E fields

22-23 June 2015 Storm, ESK Observatory

Method 1



Method 2



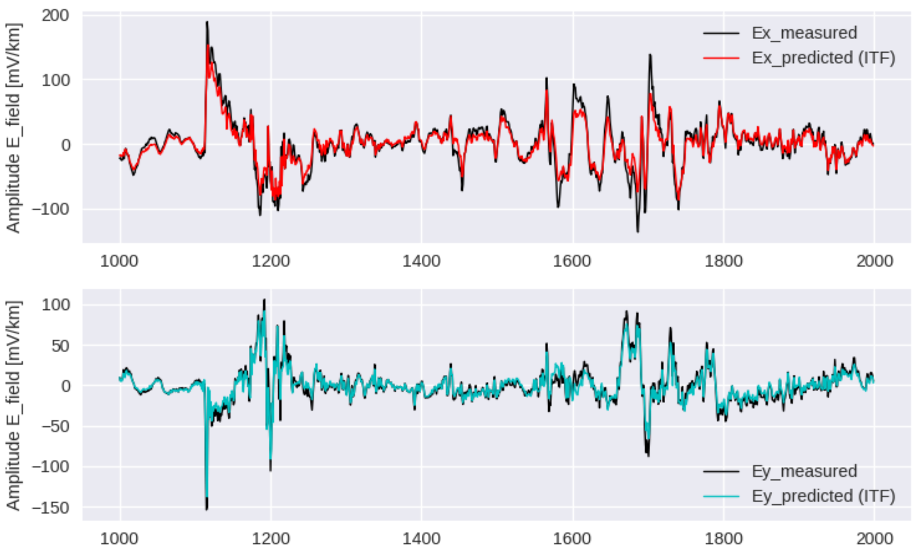
	Ex	Ey
Coherence	0.81	0.76
RMS	12.65	7.29
Pp	0.40	0.34

	Ex	Ey
Coherence	0.86	0.80
RMS	10.32	6.31
Pp	0.47	0.39

Modelling E fields

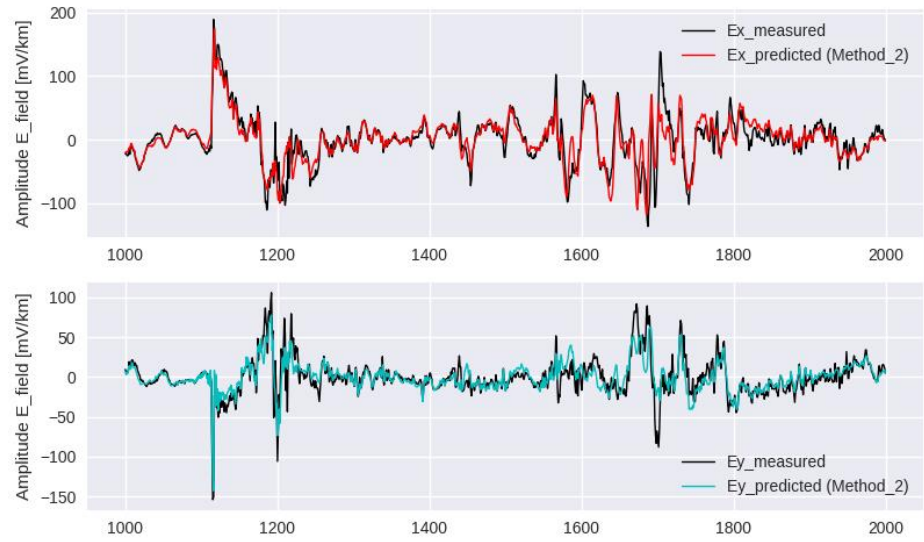
22-23 June 2015 Storm, ESK Observatory

MT with B$_{ESK}$



	Ex	Ey
Coherence	0.97	0.98
RMS	7.22	2.99
Pp	0.68	0.76

Method 2



	Ex	Ey
Coherence	0.86	0.80
RMS	10.32	6.31
Pp	0.47	0.39

Modelling E fields

ESK and LEI sites for two different storms

17-18 March, 2015

	Method_1			Method_2			Local B			Dist. Obs.
	Coh	RMS	Pp	Coh	RMS	Pp	Coh	RMS	Pp	[km]
ESK	0.64	7.12	0.24	0.72	6.60	0.30	0.98	3.35	0.73	400
LEI	0.86	2.61	0.37	0.87	1.86	0.43	0.98	0.98	0.69	125

*ARM Observatory stop recording

22-23 June, 2015

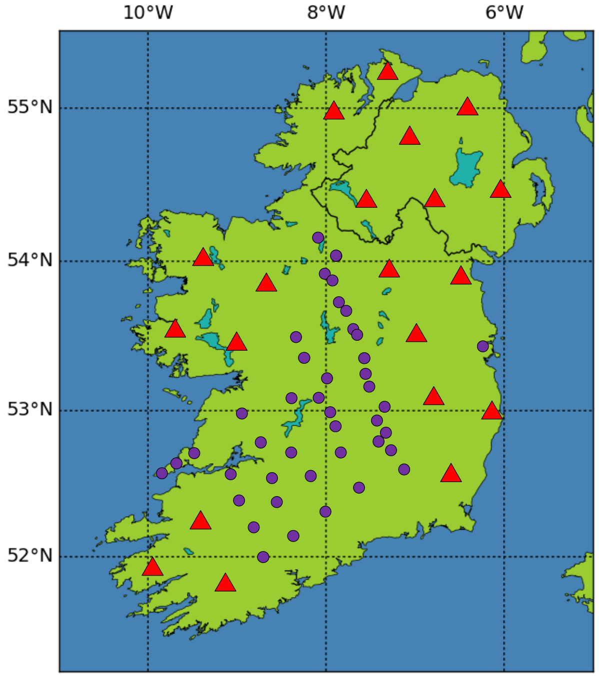
	Method_1			Method_2			Local B			Dist. Obs.
	Coh	RMS	Pp	Coh	RMS	Pp	Coh	RMS	Pp	[km]
ESK	0.79	9.92	0.37	0.83	8.21	0.44	0.97	4.67	0.72	250
LEI	0.93	1.42	0.56	0.93	1.21	0.60	0.96	1.11	0.64	95

$1 \geq |\text{Coherence (Coh)}| \geq 0$

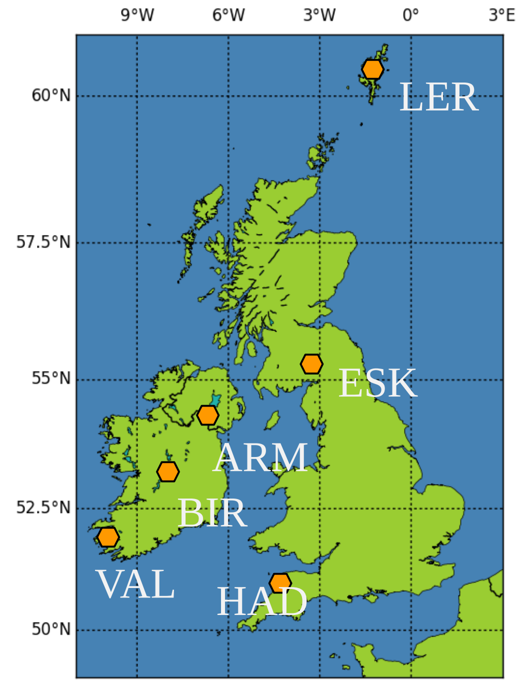
$1 \geq \text{Performance Parameter (Pp)} \geq 0$

New EM data

Ireland and UK



▲ New EM Sites ● Sites already acquired



Permanent magnetic observatories

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

DIAS
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National Oceanography Centre Southampton
UNIVERSITY OF SOUTHAMPTON AND NATURAL ENVIRONMENT RESEARCH COUNCIL

Conclusions
Modelling electric fields in Ireland and UK

- **New approach for modelling E fields (*Method 2*)**
  - Higher accuracy
  - Differentiate between local and regional signal

e-mail: joan.campanya@tcd.ie

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Modelling electric fields in Ireland and UK

- **New approach for modelling E fields (*Method 2*)**
  - Higher accuracy
  - Differentiate between local and regional signal

- **Constrained levels of accuracy (approx.):**
  - Ireland: Coh $\geq$ 0.8; Pp $\geq$ 0.4
  - UK: Coh $\geq$ 0.65; Pp $\geq$ 0.3
  - RMS depends on the storm; larger storms larger RMS

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Modelling electric fields in Ireland and UK

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- **New EM data in Ireland and UK**
  - Modelling EM fields at country scale.

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Modelling electric fields in Ireland and UK

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- **New EM data in Ireland and UK**
  - Modelling EM fields at country scale.

- **Computational costs**
  - Over 7 min with standard PC, mostly to calculate SECS, which is not ideal for monitoring (Machine learning?)

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