Measuring and modelling the geoelectric field using a thin sheet approach

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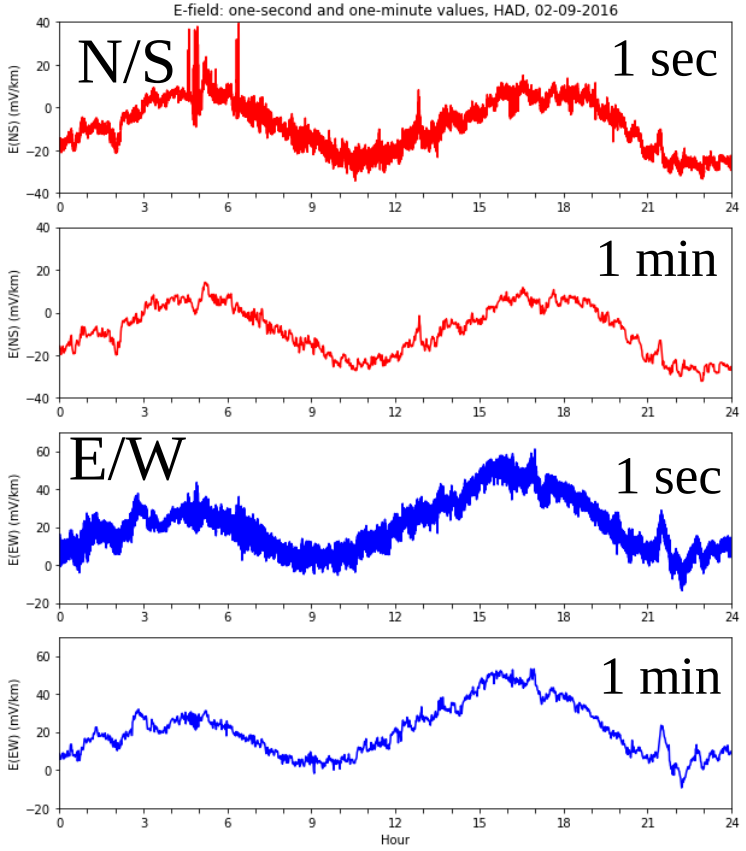
swigs
SPACE WEATHER IMPACT ON GROUND-BASED SYSTEMS

Geoelectric field

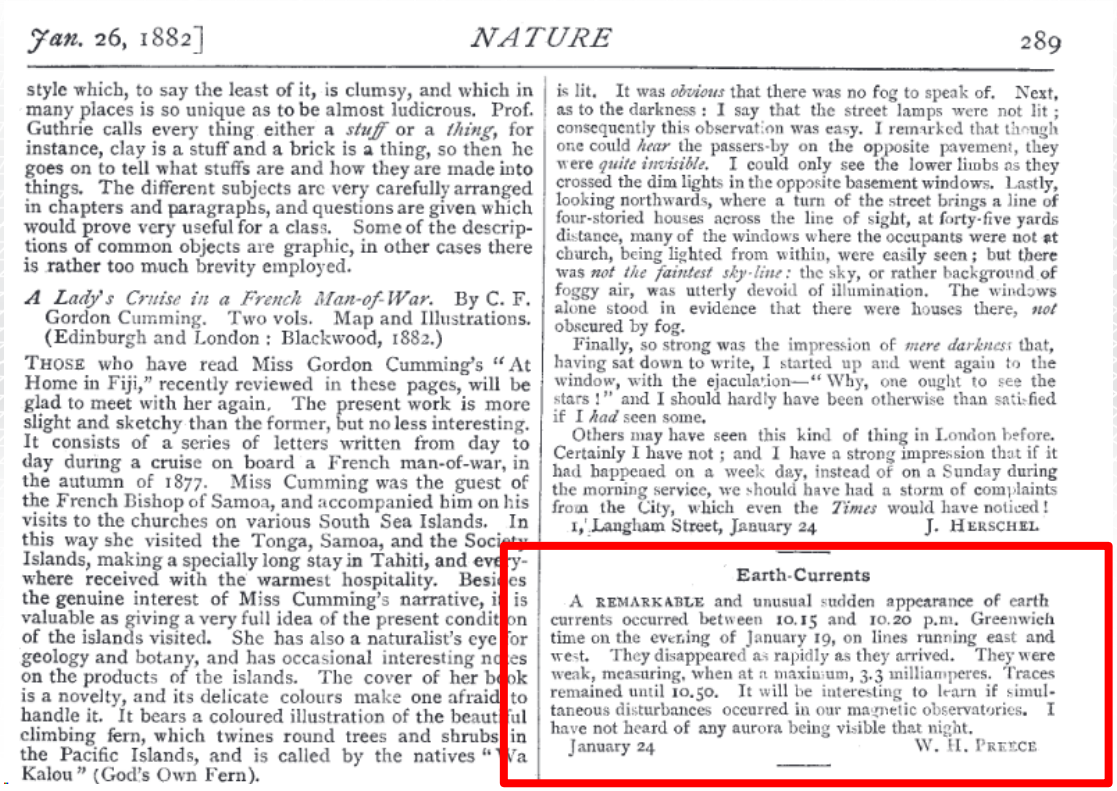
- Why?
  - General curiosity
  - Geophysical property of the Earth
  - Proxy for space weather effects

- Applications?
  - GICs
  - Conductivity at depth (MT)
  - Subsurface properties (fluid flow)
  - Tides

Geoelectric field, Hartland, UK



Historic geoelectric measurements (London)



Jan. 26, 1882] NATURE 289

style which, to say the least of it, is clumsy, and which in many places is so unique as to be almost ludicrous. Prof. Guthrie calls every thing either a *stuff* or a *thing*, for instance, clay is a stuff and a brick is a thing, so then he goes on to tell what stuffs are and how they are made into things. The different subjects are very carefully arranged in chapters and paragraphs, and questions are given which would prove very useful for a class. Some of the descriptions of common objects are graphic, in other cases there is rather too much brevity employed.

A Lady's Cruise in a French Man-of-War. By C. F. Gordon Cumming. Two vols. Map and Illustrations. (Edinburgh and London: Blackwood, 1882.)

THOSE who have read Miss Gordon Cumming's "At Home in Fiji," recently reviewed in these pages, will be glad to meet with her again. The present work is more slight and sketchy than the former, but no less interesting. It consists of a series of letters written from day to day during a cruise on board a French man-of-war, in the autumn of 1877. Miss Cumming was the guest of the French Bishop of Samoa, and accompanied him on his visits to the churches on various South Sea Islands. In this way she visited the Tonga, Samoa, and the Society Islands, making a specially long stay in Tahiti, and everywhere received with the warmest hospitality. Besides the genuine interest of Miss Cumming's narrative, it is valuable as giving a very full idea of the present condition of the islands visited. She has also a naturalist's eye for geology and botany, and has occasional interesting notes on the products of the islands. The cover of her book is a novelty, and its delicate colours make one afraid to handle it. It bears a coloured illustration of the beautiful climbing fern, which twines round trees and shrubs in the Pacific Islands, and is called by the natives "Va Kalou" (God's Own Fern).

is lit. It was *obvious* that there was no fog to speak of. Next, as to the darkness: I say that the street lamps were not lit; consequently this observation was easy. I remarked that though one could *hear* the passers-by on the opposite pavement, they were *quite invisible*. I could only see the lower limbs as they crossed the dim lights in the opposite basement windows. Lastly, looking northwards, where a turn of the street brings a line of four-storied houses across the line of sight, at forty-five yards distance, many of the windows where the occupants were not at church, being lighted from within, were easily seen; but there was *not the faintest sky-line*: the sky, or rather background of foggy air, was utterly devoid of illumination. The windows alone stood in evidence that there were houses there, *not* obscured by fog.

Finally, so strong was the impression of *mere darkness* that, having sat down to write, I started up and went again to the window, with the ejaculation—"Why, one ought to see the stars!" and I should hardly have been otherwise than satisfied if I *had* seen some.

Others may have seen this kind of thing in London before. Certainly I have not; and I have a strong impression that if it had happened on a week day, instead of on a Sunday during the morning service, we should have had a storm of complaints from the City, which even the *Times* would have noticed!

1, Langham Street, January 24 J. HERSCHEL

Earth-Currents

A REMARKABLE and unusual sudden appearance of earth currents occurred between 10.15 and 10.20 p.m. Greenwich time on the evening of January 19, on lines running east and west. They disappeared as rapidly as they arrived. They were weak, measuring, when at a maximum, 3.3 milliamperes. Traces remained until 10.50. It will be interesting to learn if simultaneous disturbances occurred in our magnetic observatories. I have not heard of any aurora being visible that night.

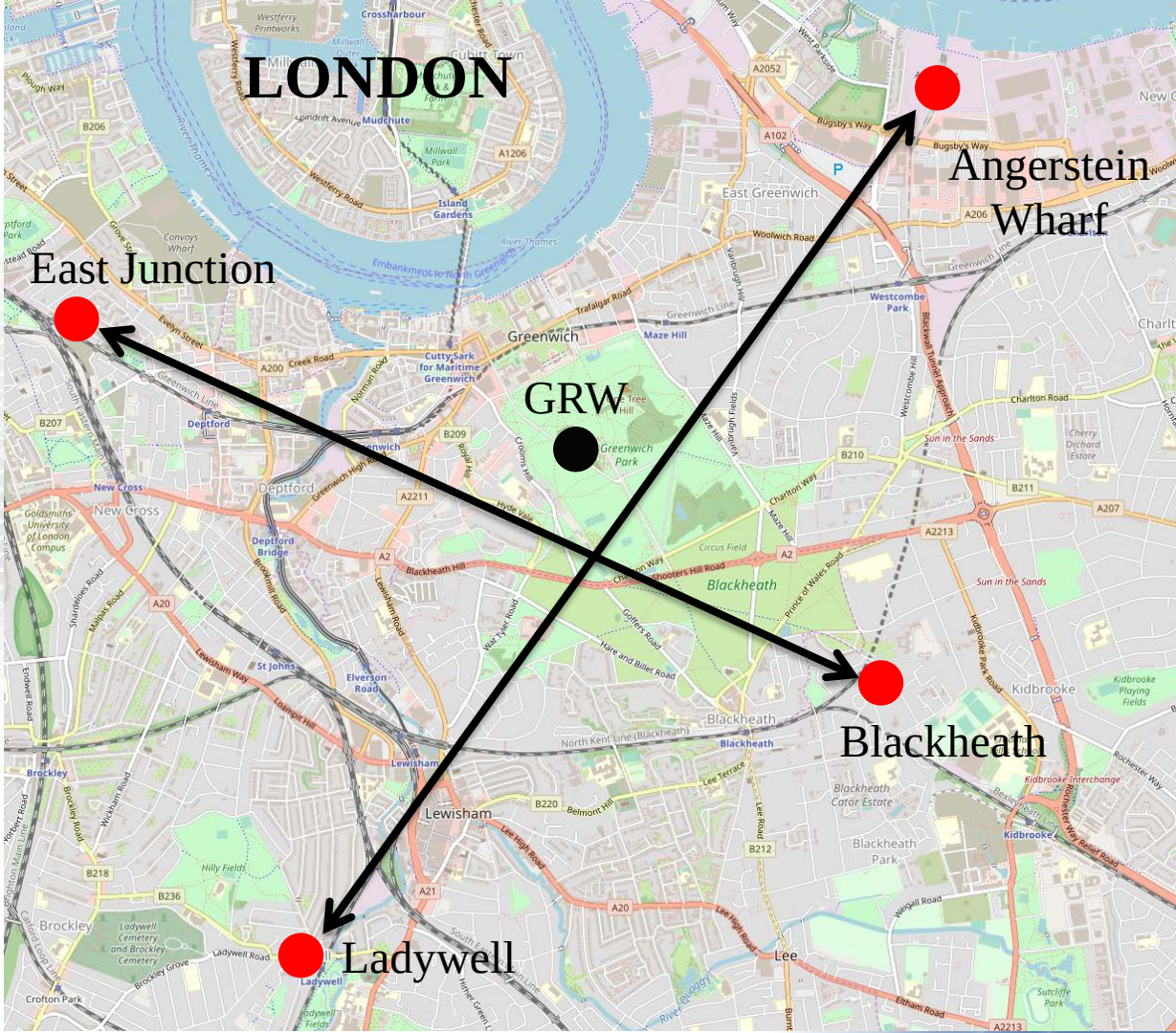
January 24 W. H. PREECE

"A remarkable and unusual appearance of earth currents… were weak, …, at a maximum of 3.3 mA. … I have not heard of any aurora …"

W.H. Preece, *Nature*, Jan 1882

Greenwich (GRW) Earth Current Registers

- Installed 1868-1895
- Wiring ran along the (steam) rail lines
  - NE-SW: ~ 5km
  - NW-SE: ~ 4 km
  - Copper earth plates
- Recorded *deflection* of magnetic needles at GRW
- No conversion to SI units of E-field was made



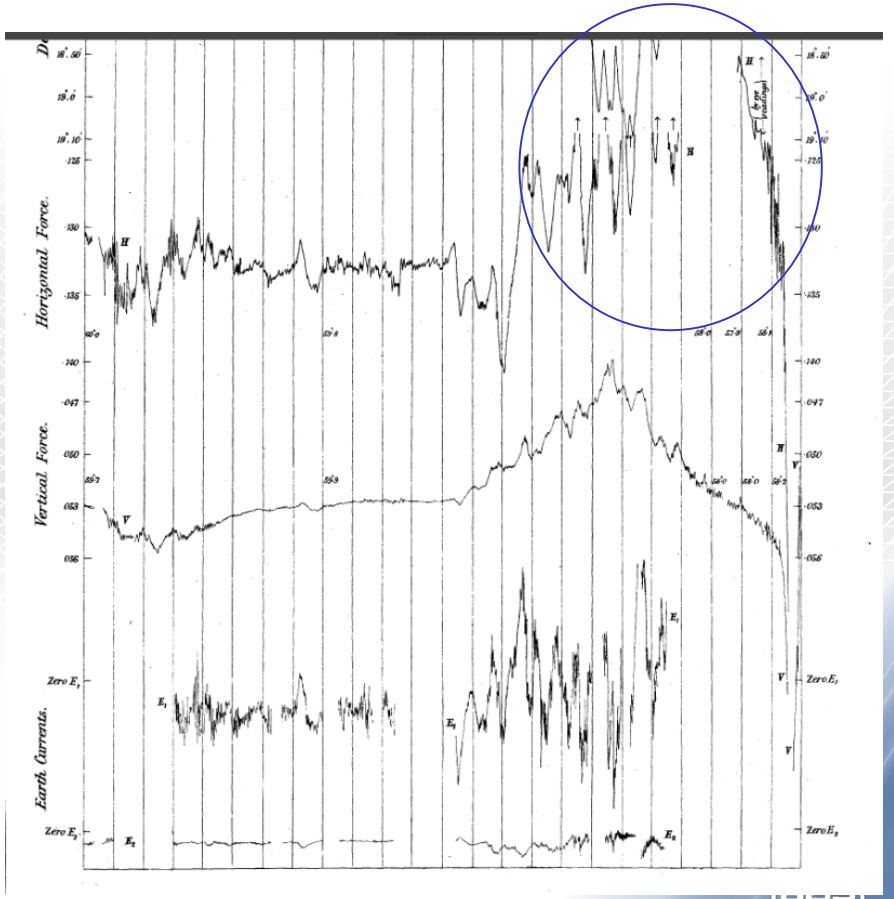
19 Nov 1882 storm

disturbances during the year 1882, affording thereby, it is hoped, facilities for making comparison with solar phenomena.

Referring now again to the plates, it may be remarked that on each day, with few exceptions, five distinct registers are given, viz.: declination, horizontal force, vertical force, and the two earth currents, all necessary information for proper understanding of the plates being given in the notes on page (xxviii). No attempt has been made to determine earth current scales in terms of any electrical unit, but it may be stated that the instrumental conditions are similar for the two circuits, excepting that the communicating wire of the E_1 circuit is longer than that of the E_2 circuit in the proportion of 3 to 2, and that the distances between the earth plates of the former and of the latter are in the proportion of 6 to 5.

The indications of horizontal and vertical force are given precisely as registered;

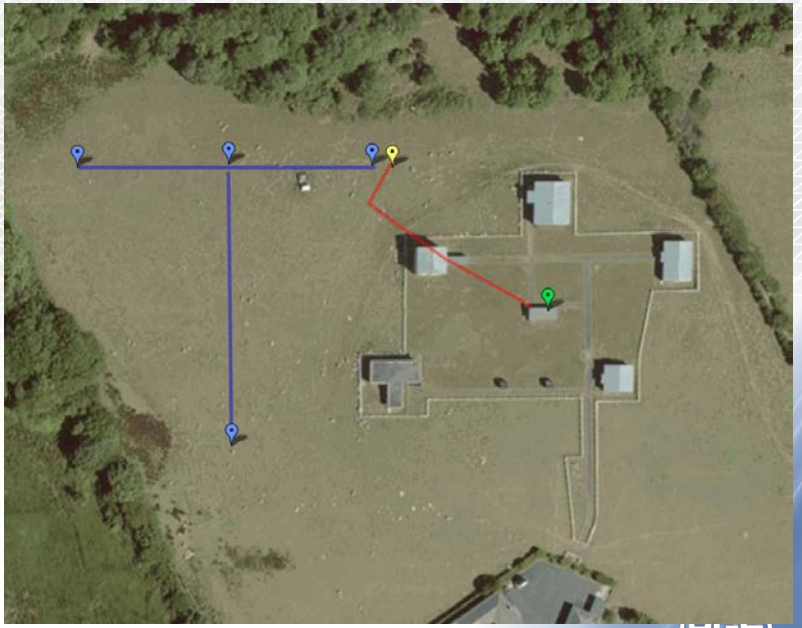
Sadly, the ‘Earth currents’ are unscaled ☹



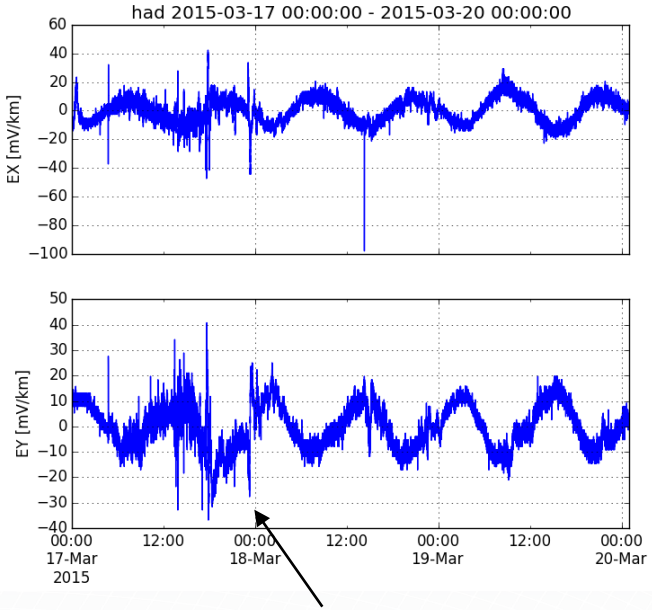
See: https://geomag.bgs.ac.uk/data_service/data/yearbooks/

Modern geoelectric measurements

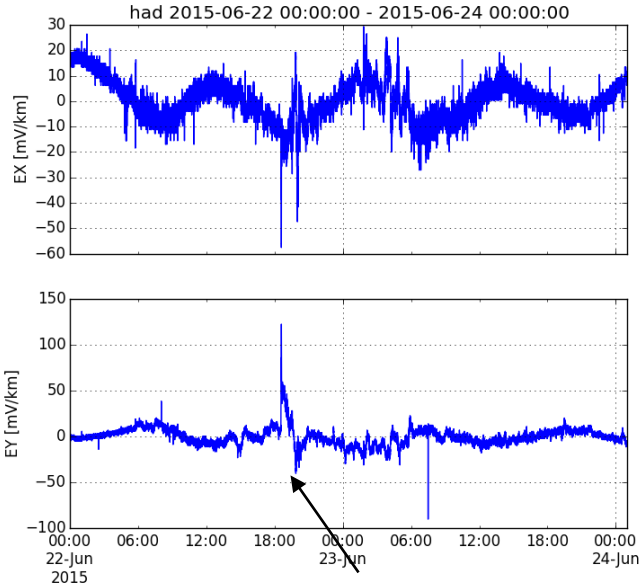
- E-field probes installed at all UK obs in 2012/13
- Electrodes maintained in a ‘neutral’ Cu-$CuSO_4$ clay mixture
- Buried in pits ~ 0.6m deep (helps minimise temperature variation)
- Electrode pairs separated by about 80-100 m
- Shielded cable to minimise pick-up of noise on signal line
- Incomplete/noisy records (environmental, equipment failure, etc.)



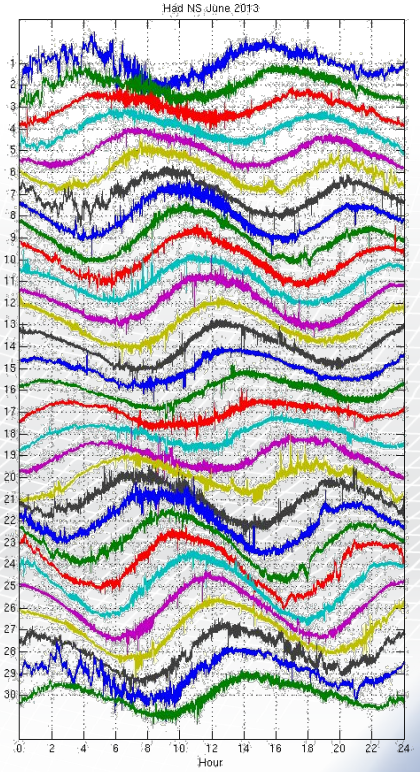
Hartland



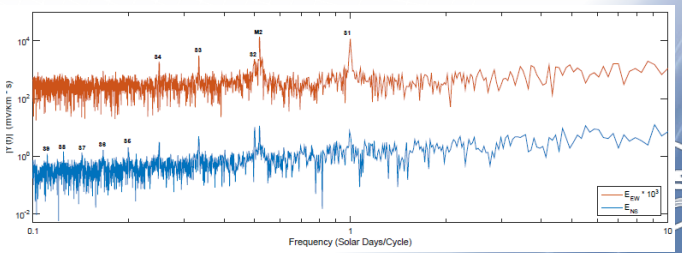
Storm



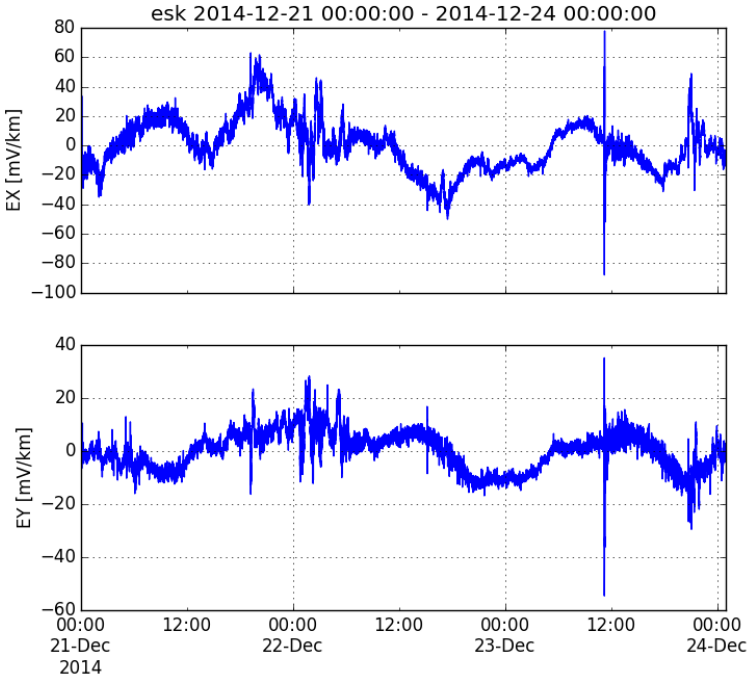
Storm



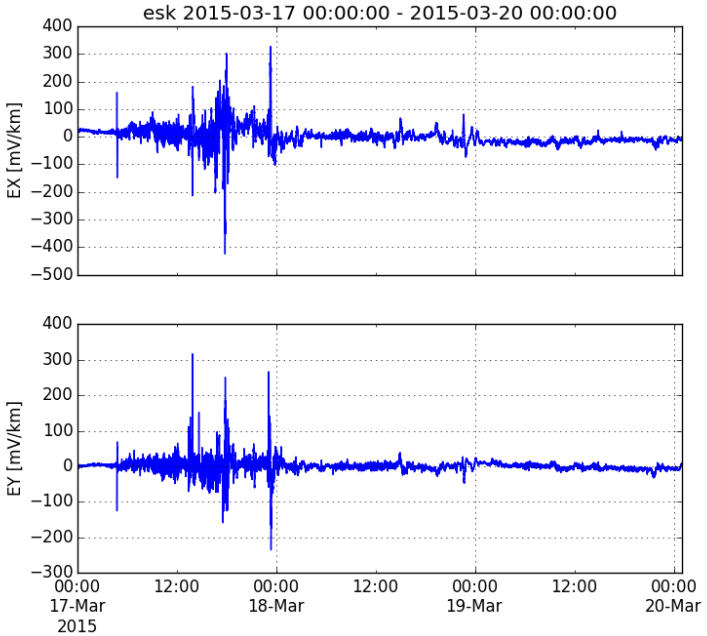
See: **Baillie et al,** Investigation of Tidally Induced Geoelectric Fields at Three Sites in the UK, A19 Poster session



Eskdalemuir

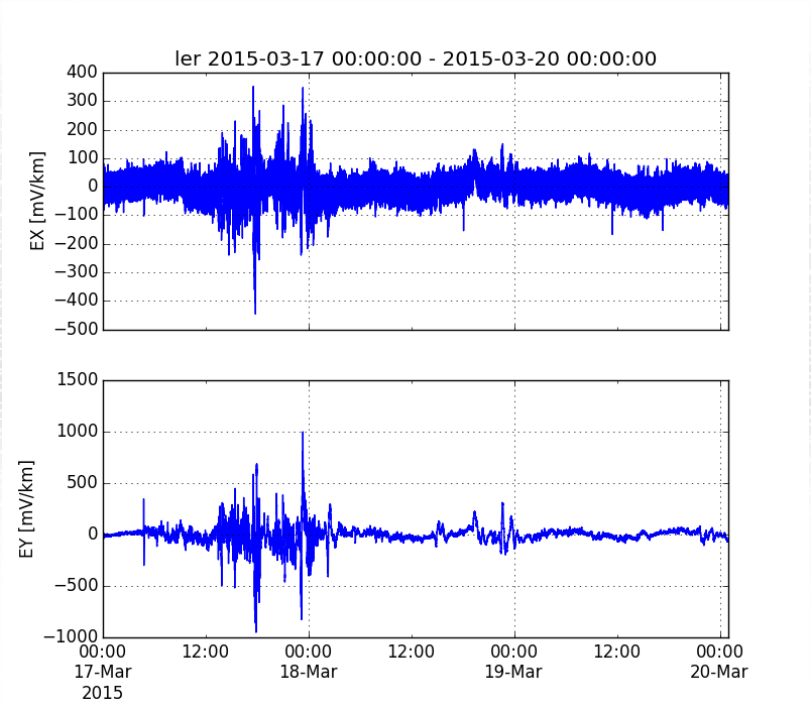


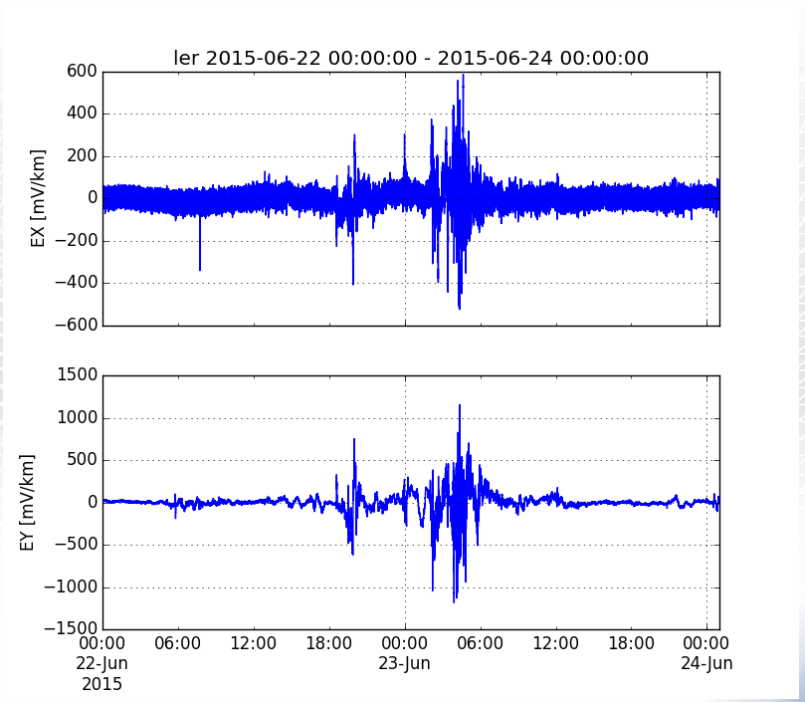
Small storm



Large Storm

Lerwick





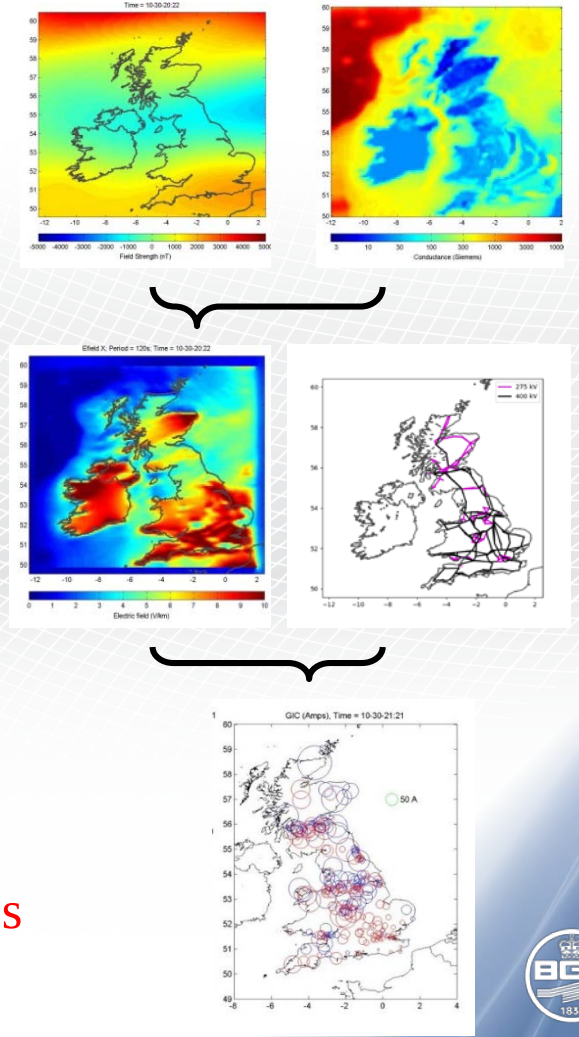
Ex noisier than Ey (local conditions)

GIC modelling steps

Three major steps:

1. Measure magnetic field across the UK
   - Magnetic change across GB
2. Convert to geo-electric field
   - Ground conductivity map
3. Create a model of the UK high voltage grid
   - Location, electrical parameters, connections

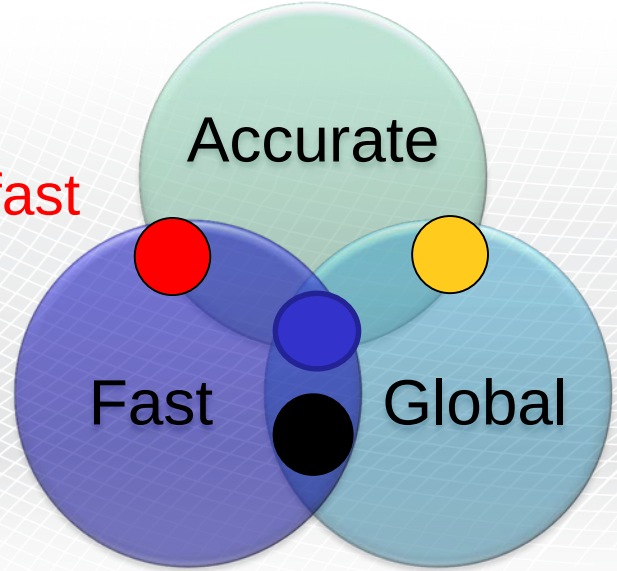
= GICs ✓



Validate the various models and run '**what-if**' scenarios

Modelling geoelectric fields

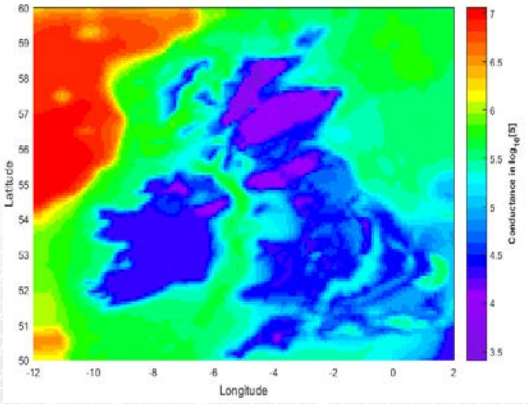
- 1D model (MT tensor) – locally accurate, fast
- 3D FEM – full solution, very slow
- Thin-sheet modelling – loss of accuracy, reasonably fast, global

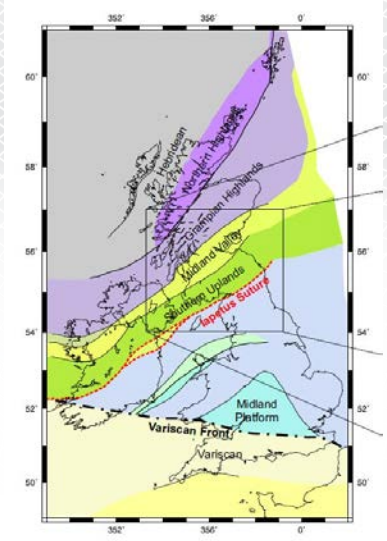


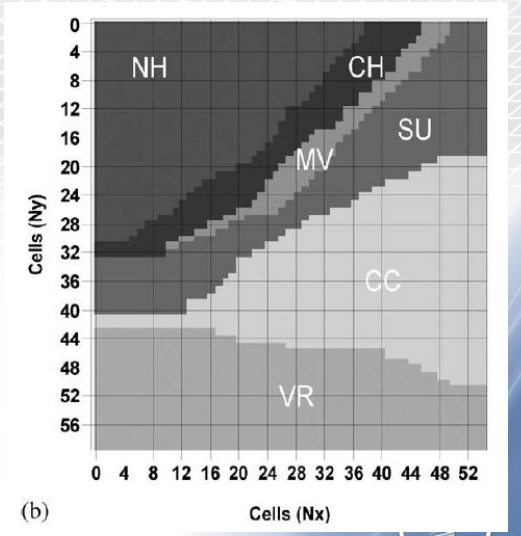
"Two out of three ain't bad", *Meatloaf (1977)*

Thin sheet modelling

- Was is it?
  - Land/sea geology/bathymetry
  - Infinitely thin surface (3km)
  - 1D model below (to 1000 km depth)
  - Non-plane wave B field allowed
  - Assumptions required about cell size vs skin depths
- What is it not?
  - The full and final answer!
  - Useful in all scenarios





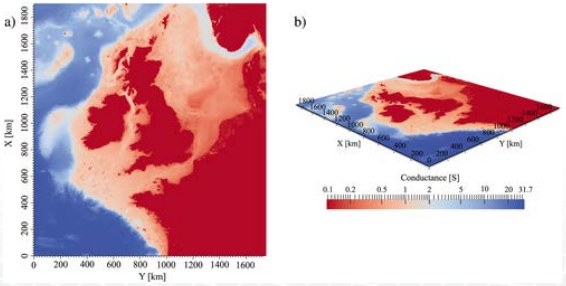


3D versus thin sheet

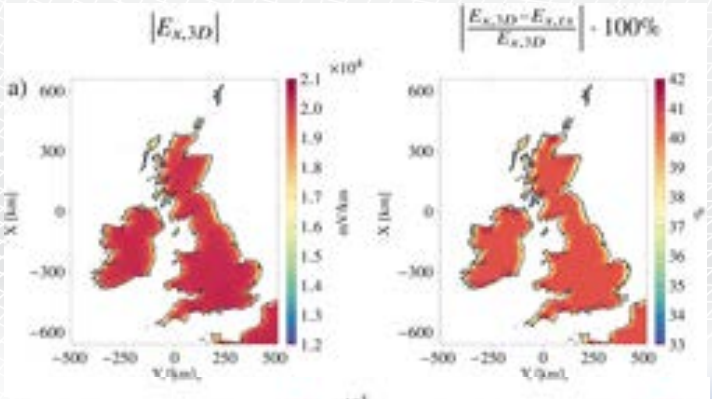
- Ivannikova et al (2017), AGU SW
  - Comparison of 3D vs thinsheet modelling around UK
  - Plane-wave field of 1,257 nT
  - Differences at 2 sec: > 40 %
  - Differences at 50 sec: < 8%

- A useful *approximation* at longer periods

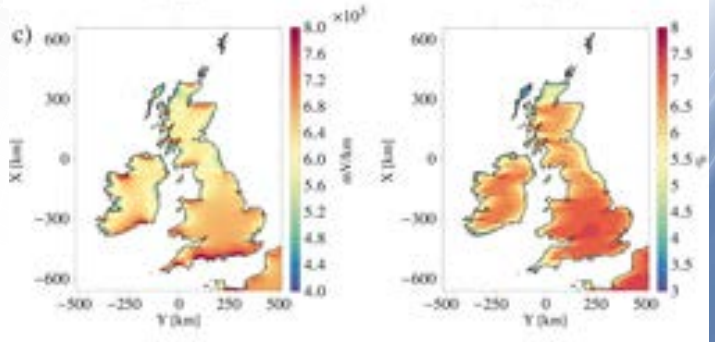
Input



2 seconds



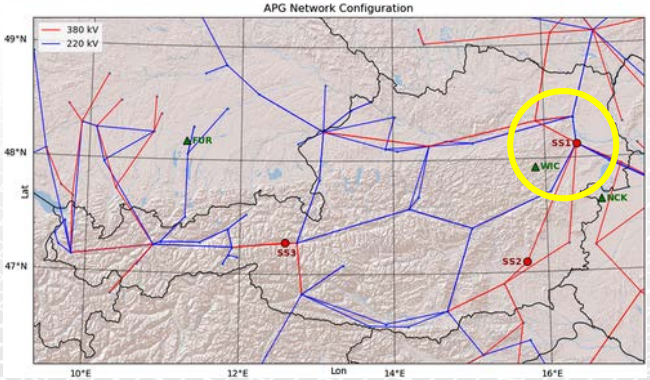
50 seconds

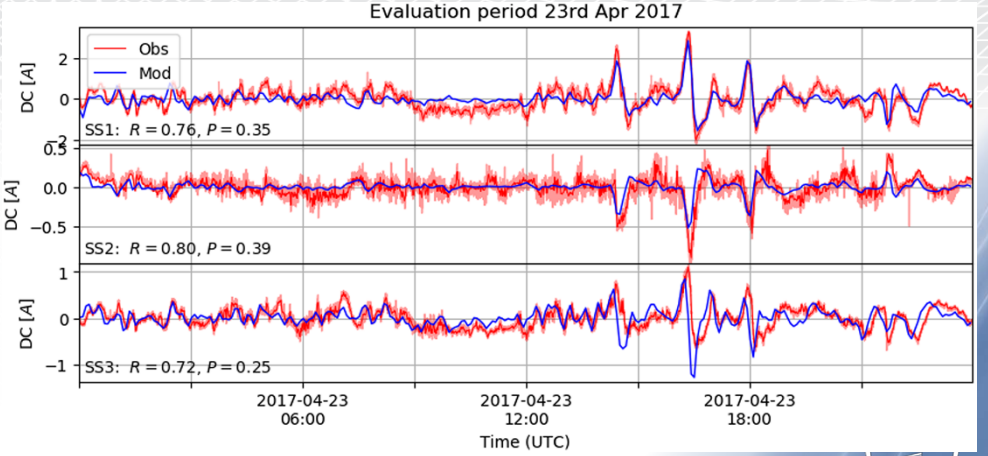


Ivannikova et al (2017) *Space Weather*, doi:10.1002/2017SW001793

GIC validation with thin sheet (Austria)

- Bailey et al (2018), AGU SW
- Thin sheet to compute geoelectric field
- Comparison to transformer GIC in Austria
- Good correlation with dB/dt of 300 seconds
- Parameter study of varying conductivity models



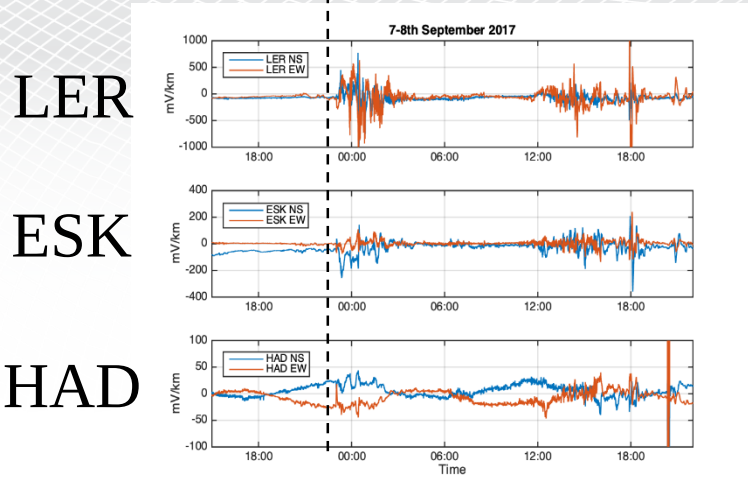


Bailey, R. L et al. (2018), Space Weather, doi:10.1029/2018SW001842

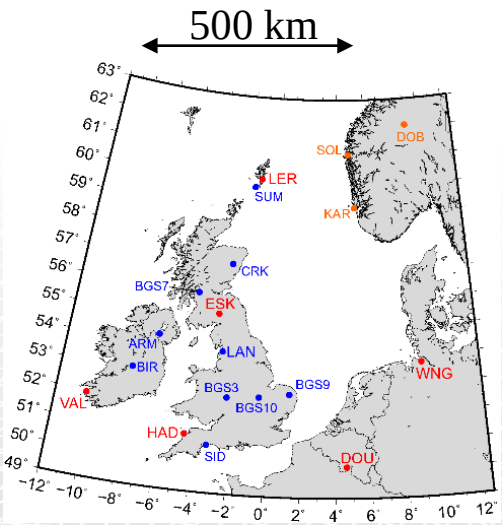
Thin sheet comparison for UK

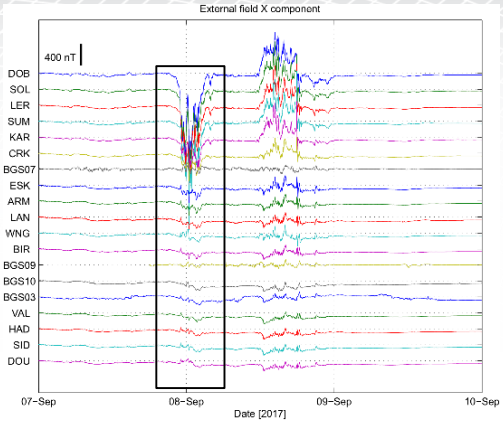
- Examine a large storm:
  - Sep 2017
  - (Mar 2015; Aug 2018)

- Compute geoelectric field using thin sheet model of UK
  - 25 magnetic (minute mean) time-series available
  - Extrapolate using SECS (10 km grid)
  - Use dB/dt of 120 seconds for frequency
  - Bandpass filter the geoelectric data for comparison

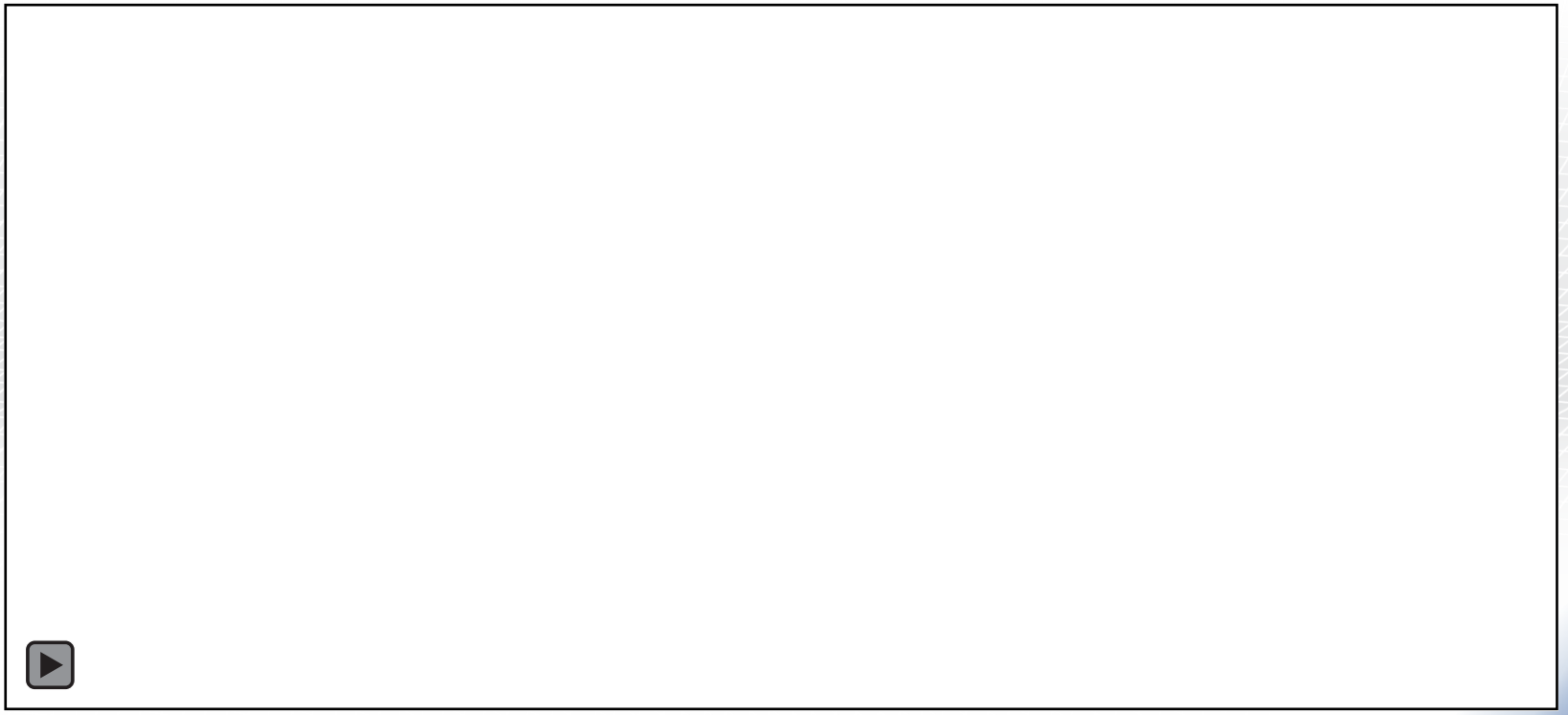


Magnetic field using SECS



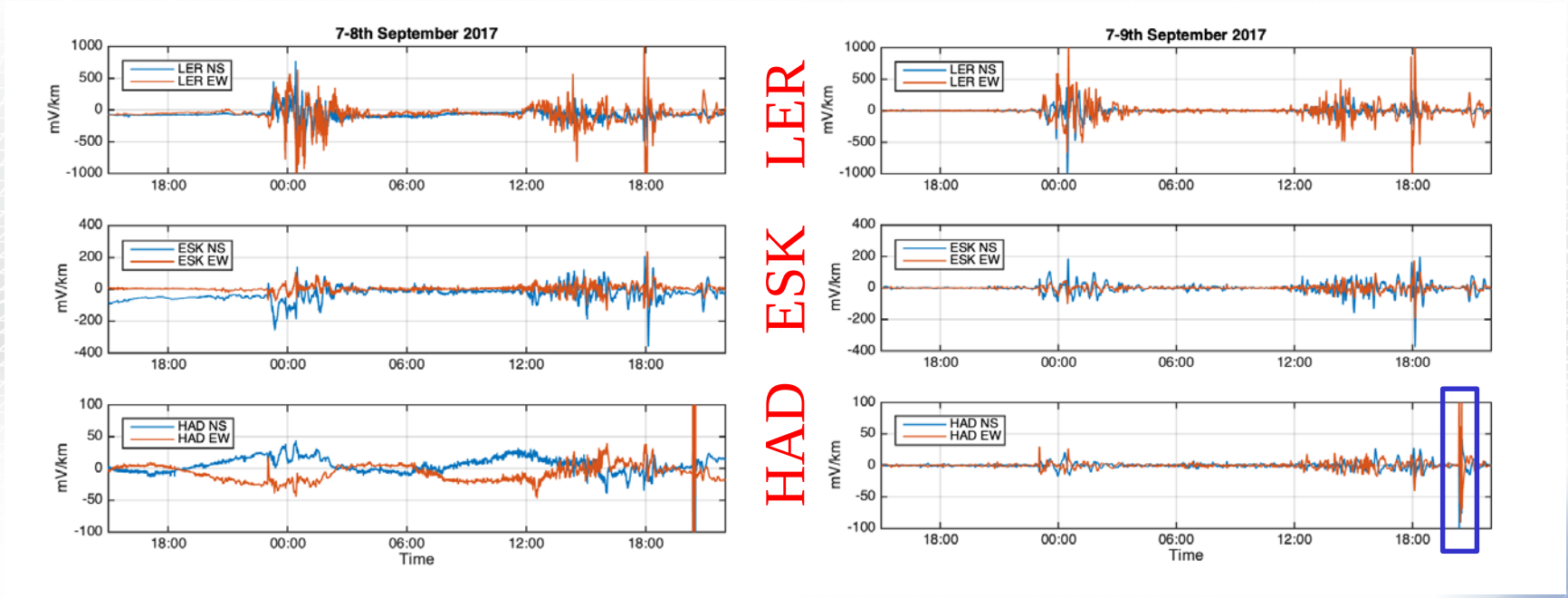


TS modelled geoelectric



Color bar: ±0.5 V/km

7/8th Sep 2017: measured geoelectric field



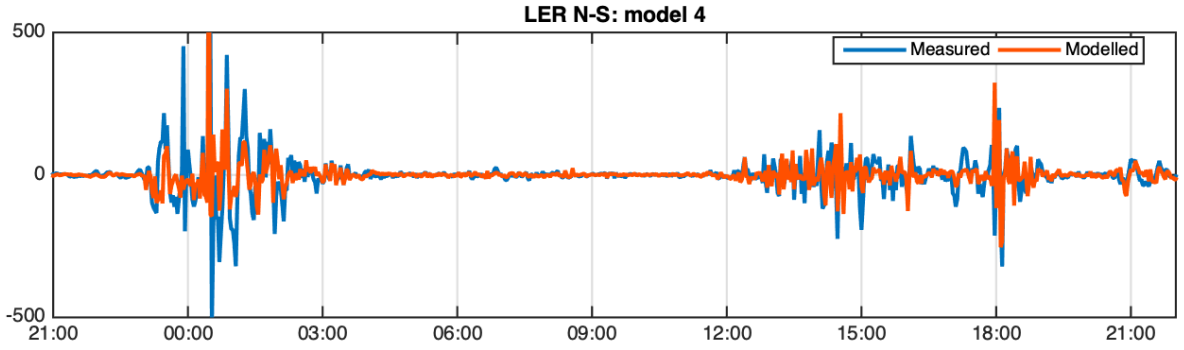
1 second values

Bandpass 2-30 mins

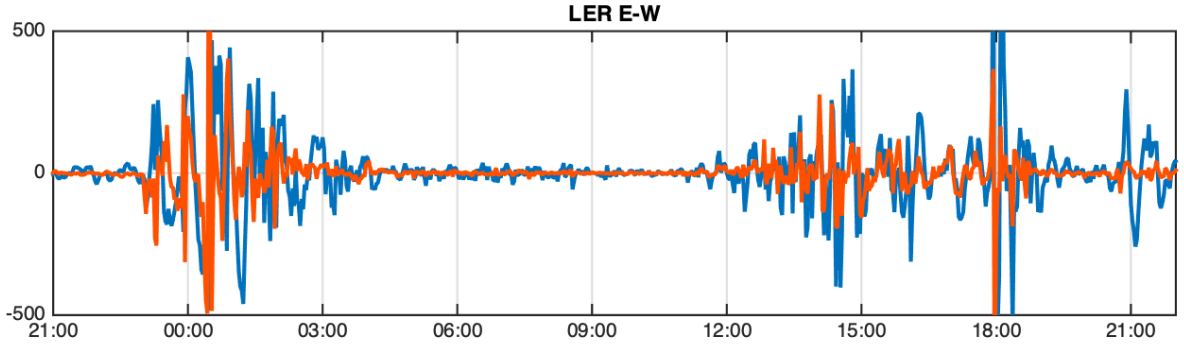
Lerwick

Measured Modelled

Ex



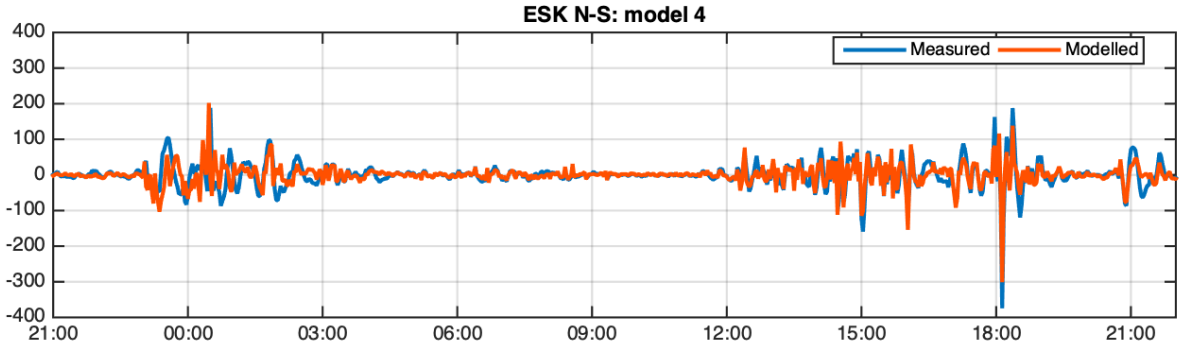
Ey



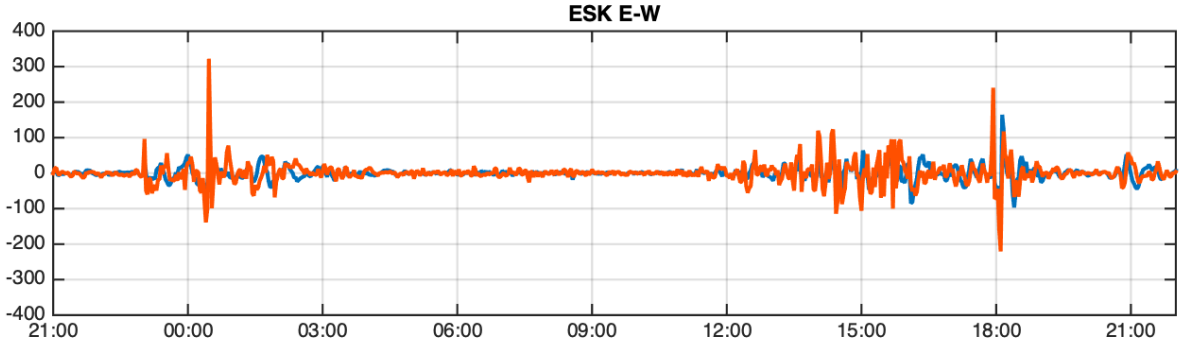
Eskdalemuir

Measured Modelled

Ex



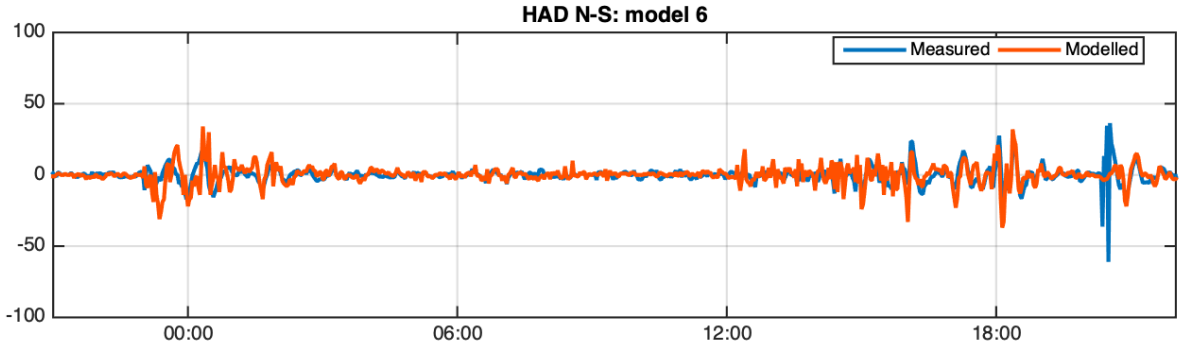
Ey



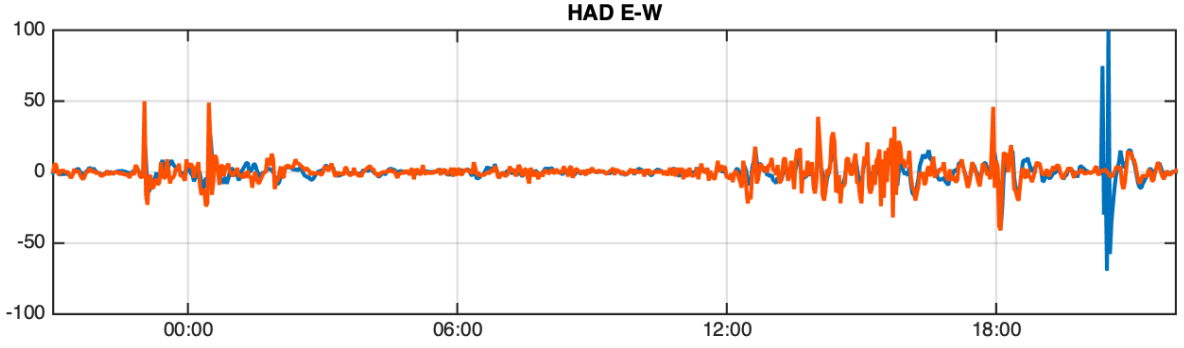
Hartland

Measured Modelled

Ex



Ey



P Metric

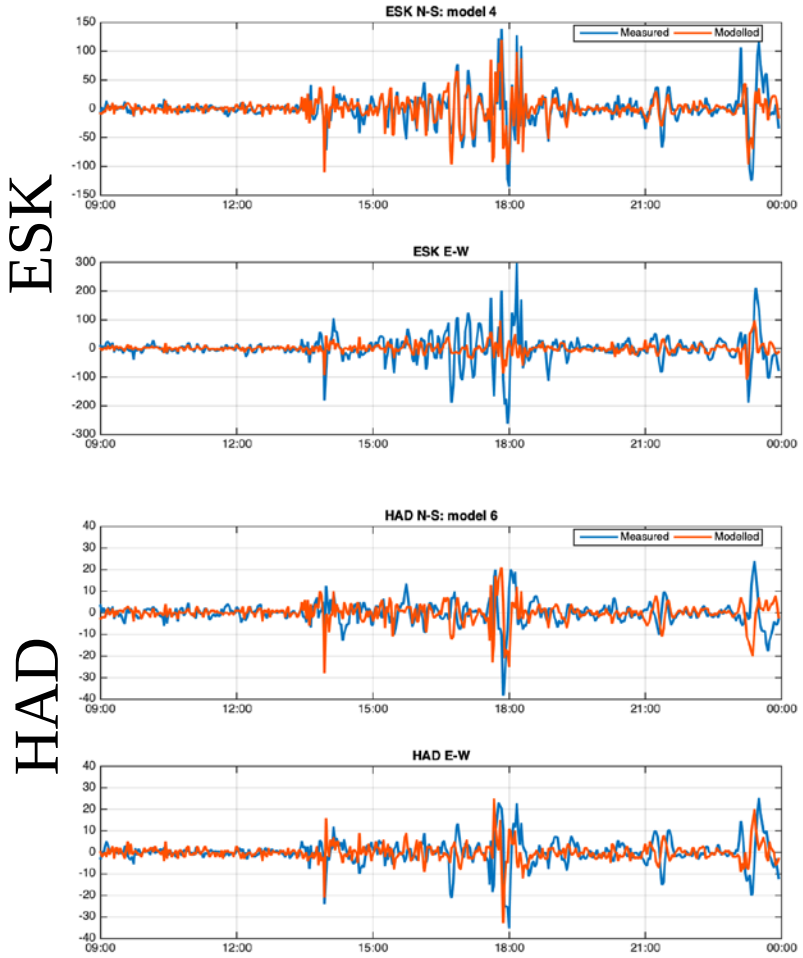
Ex	P (7/8th Sep)	P (substorm 1)	P (substorm 2)
LER	0.226	0.258	0.167
ESK	0.246	0.034	0.447
HAD	0.004	0.005	0.012

Torta et al (2014), EPS: $P = 1 - \frac{\sqrt{\frac{\sum(obs - mod)^2}{N}}}{\sigma_{obs}}$

Mar 2015

SECS: 8 observatories

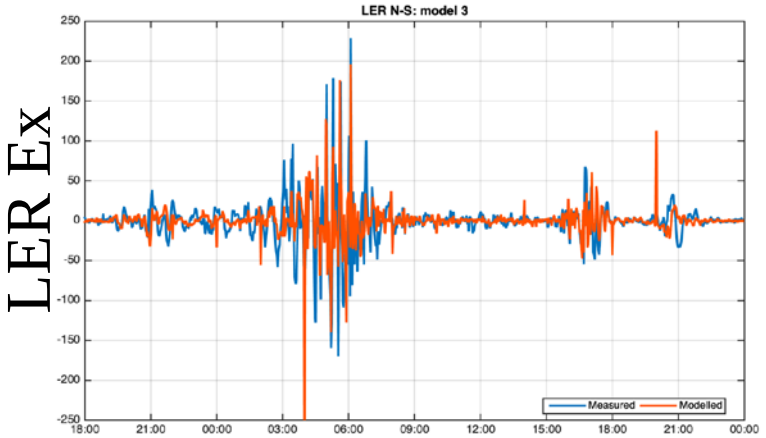
Ex	P (Mar 2015)
LER	0.099
ESK	0.220
HAD	-0.337

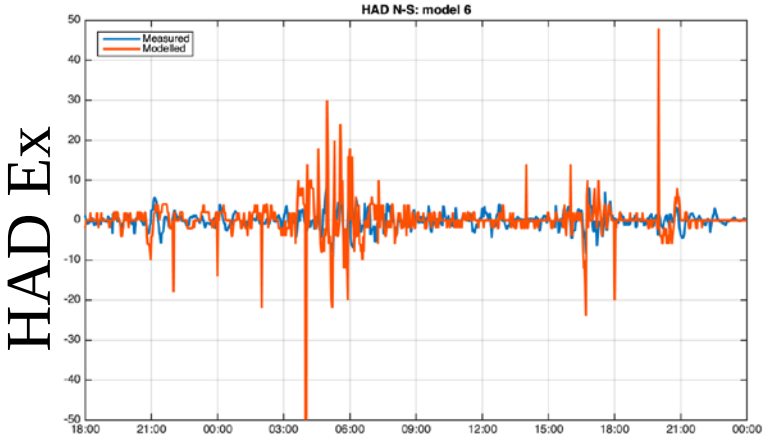


Aug 2018

SECS: 10 observatories

	P (Aug 2018)
LER (Ex)	0.137
ESK (Ey)	0.054
HAD (Ex)	-0.002



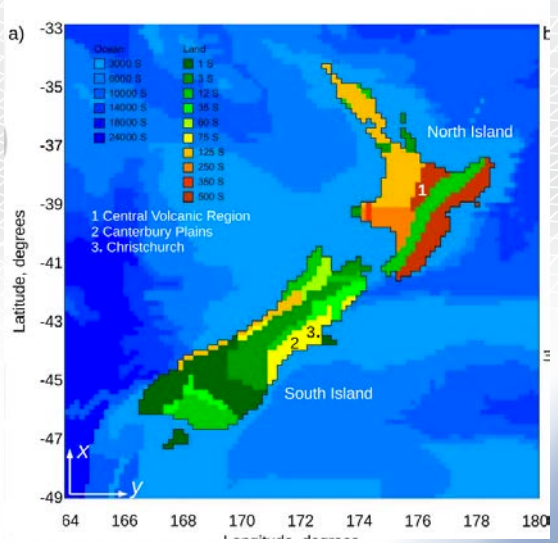


New Zealand

- Island setting
- Similar geomagnetic latitude to UK

- Complex igneous geology / tectonics
  - Volcanic/sedimentary/faults
- Large topographic change
  - Southern Alps (3km) -> offshore trenches (4km)!

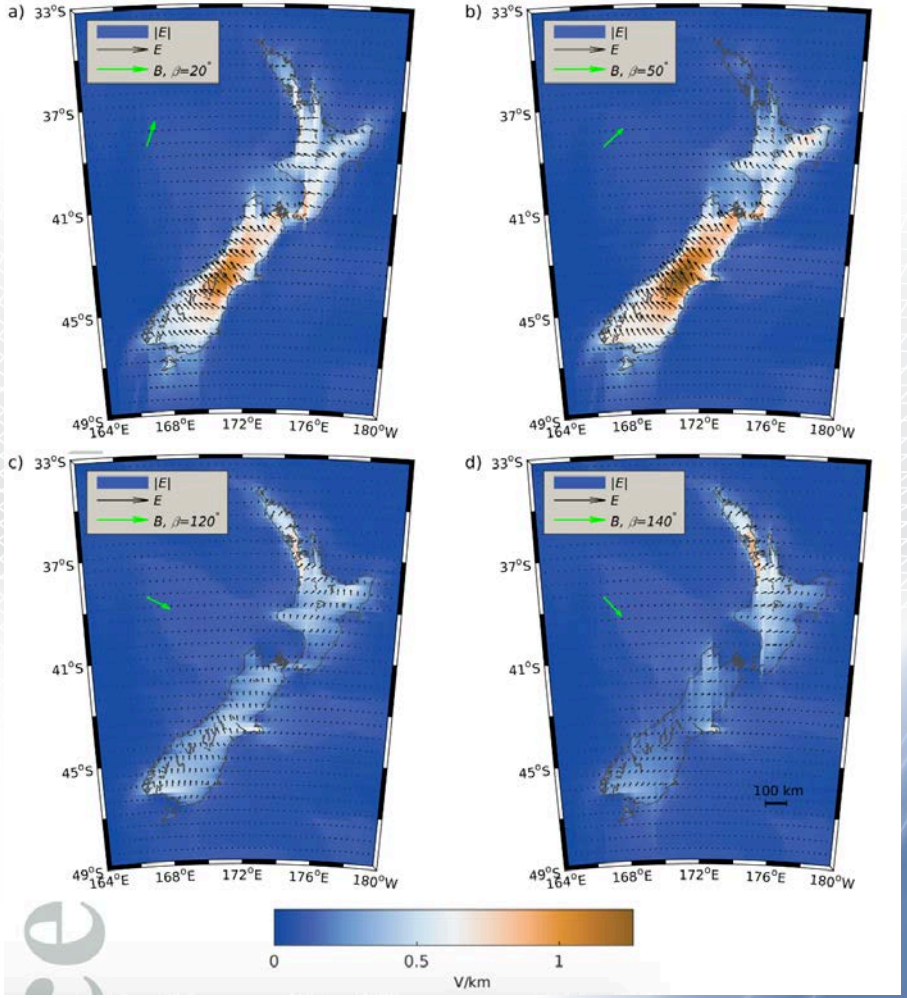
- Stretches some TS assumptions
  - Period ~ 10 mins acceptable



Divett et al (2017)

Thin sheet test field

- Plane wave uniform B field (500 nT)
- Strong coastal effect
  - Penetrates across island
- Direction of E is approx. constant with direction of B



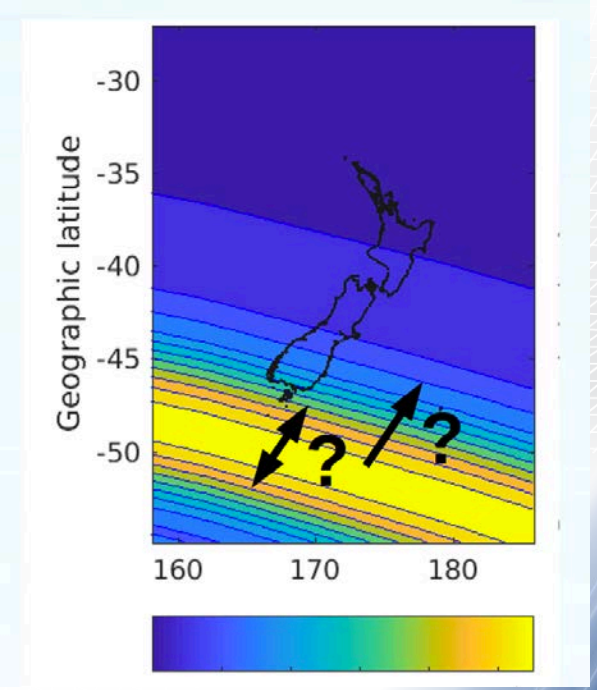
Validation in New Zealand

- On-going work
  - No geoelectric measurements
  - Few magnetic observations

- O*bserved GIC* at 23 transformers in South Island

- Modified TS to use broader spectral response
- Looking to investigate larger storms

17-Mar-2015



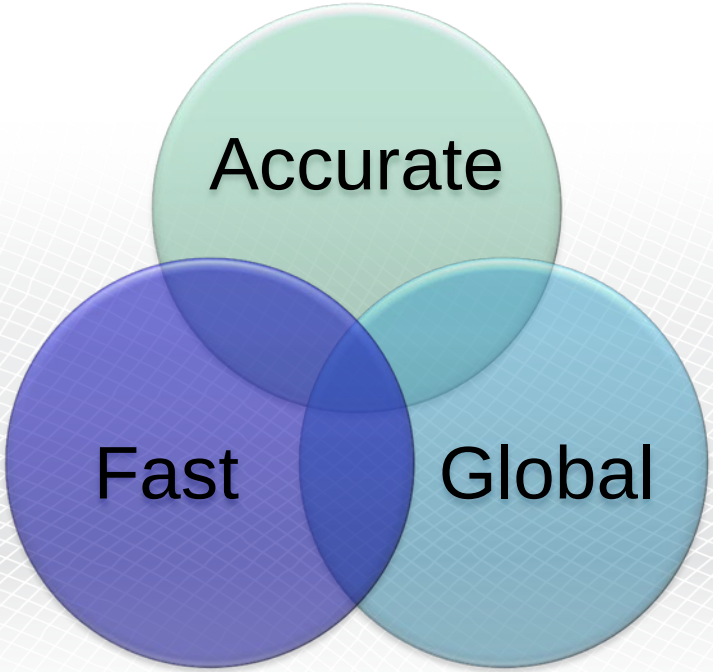
Bx

See Tim's poster in this session (A19p – 257)

Summary

1) Large storms are better modelled than small storms (local vs regional effects)
2) Better results with representative magnetic field
3) Thin sheet caveats apply (Frequency limitations)
4) Topography/Bathymetry is important to consider
5) Future should move toward 3D modelling

Geoelectric fields with TS are *approximate but useful*



“Choose two”

Thank you