New Zealand Long term Geomagnetically Induced Current Observations:

Peak Current Estimates and Mitigation Approaches for Extreme Geomagnetic Storms

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Space Weather Users Workshop 2017
Camperdown Campus, University of Sydney
Sydney, Australia
0930-0945, Friday 17 November 2017

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Effects of GIC on power systems - local scale

These can be local to a specific transformer in a given substation, potentially destroying a transformer.

New Jersey, March 1989.
USA

courtesy Metatech

South Africa, Oct 2003

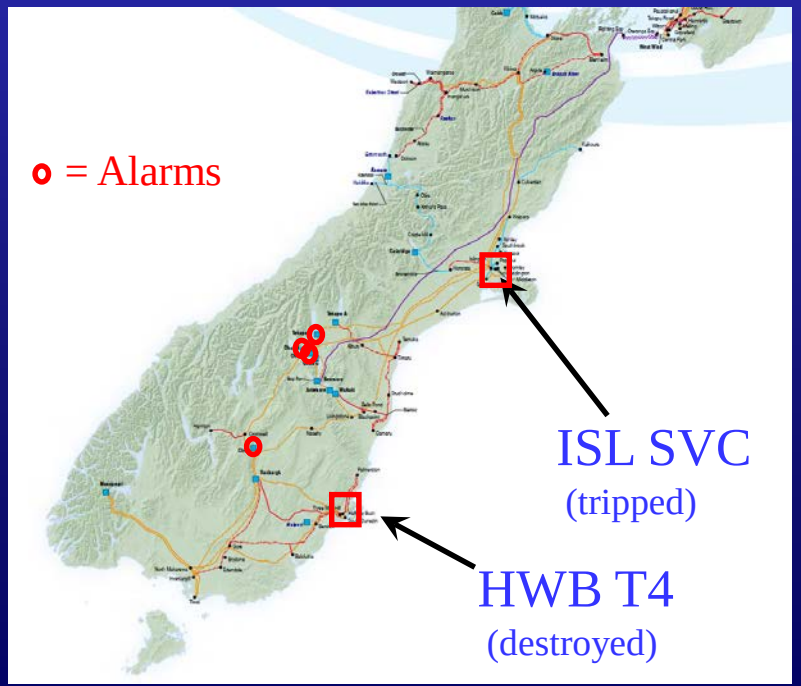
GIC = Geomagnetically induced currents

Effects of GIC on power systems - NZ

A large geomagnetic storm started on 6 November 2001 at ~2:53pm LT (1:53am UT). At this time HWB T4 (Dunedin) tripped, as did systems at ISL (Christchurch). Alarms occurred at multiple locations across the South Island.

The transformer at Dunedin / Halfway Bush (HWB T4) suffered a major internal flashover. A subsequent internal inspection found the transformer was beyond repair - it was subsequently written off (~$2 million value in 2016 NZD).

Halfwaybush Substation, Dunedin.



GIC risk mitigation research in NZ

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HIKINA WHAKATUTUKI

Solar Tsunamis: Mitigating Emerging Risks to New Zealand's Electrical Network

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United Kingdom Team

British Geological Survey
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British Antarctic Survey
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Projected nominally started 1 October 2015

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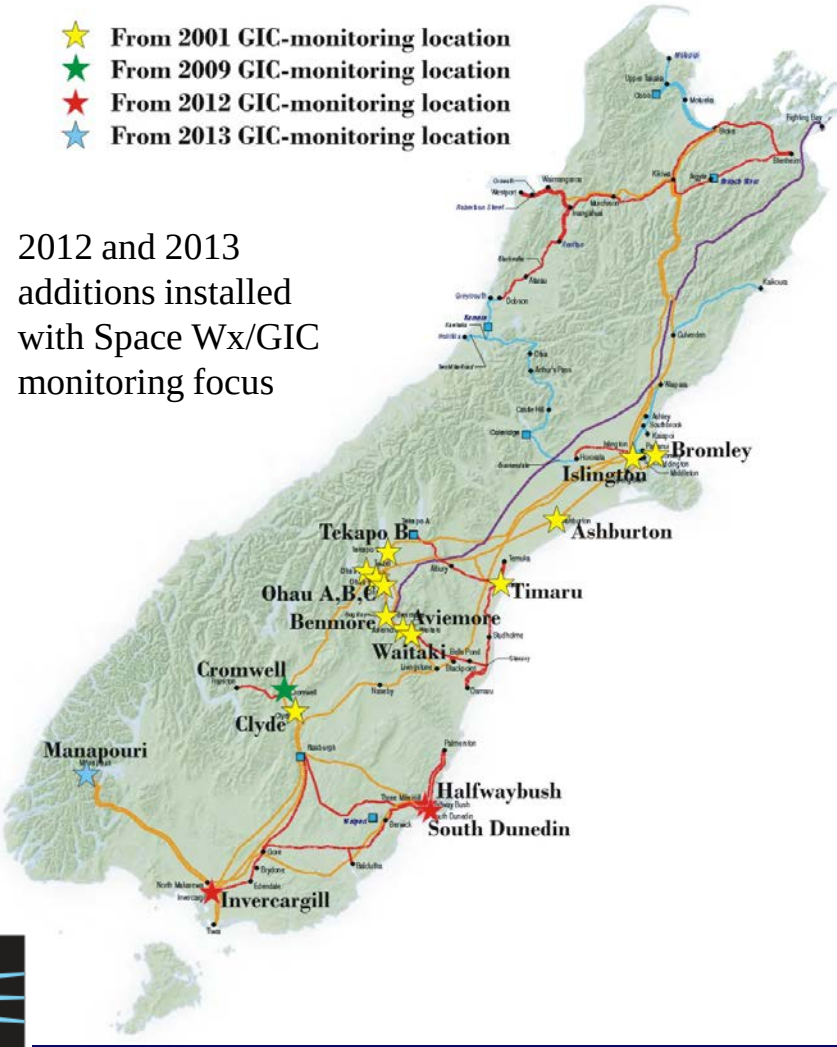
New Zealand GIC observations

Transpower New Zealand Ltd. is measuring, and archiving, observations of transformer neutral current values from DC current measuring devices (LEM) at many transformers. This has occurred from multiple South Island locations for more than 15 years.

Date	Total Transformers Monitored	Total Substations Monitored
Nov 2001	36	12
Jan 2005	37	12
Apr 2005	39	12
Sep 2008	40	12
Mar 2009	42	13
May 2009	43	13
Jul 2010	44	13
Nov 2011	45	13
Sep 2012	44	13
Oct 2012	49	16
Dec 2012	48	16
Feb 2013	56	17
May 2013	57	17
Aug 2013	56	17
Jan 2014	57	17
Jun 2015	58	17



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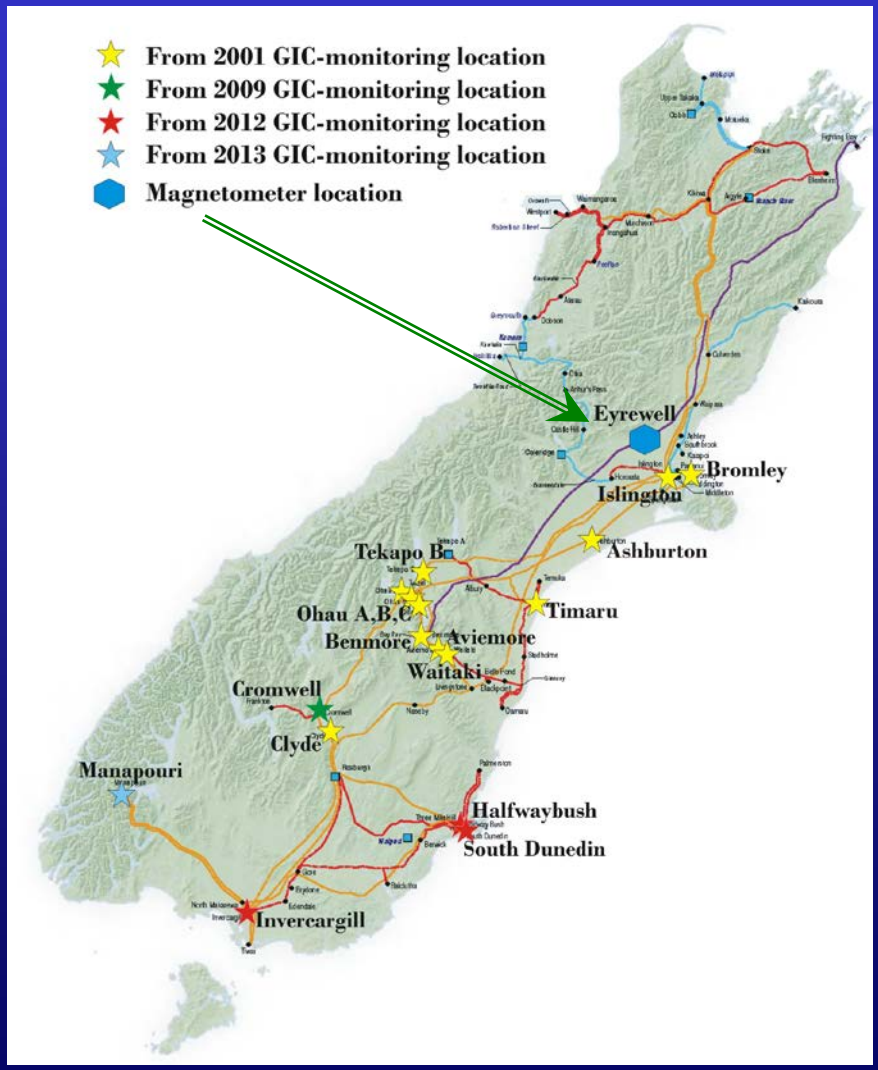
HVDC and Eyrewell magnetometer

Transpower New Zealand Ltd. is measuring, and archiving, observations of transformer neutral current values from DC current measuring devices (LEM) at many transformers. This has occurred from multiple South Island locations for more than 15 years.



Note EYR is located very near the HVDC cable - they correct for HVDC operation [we have checked at times of large HVDC changes and not been able to see any problems]

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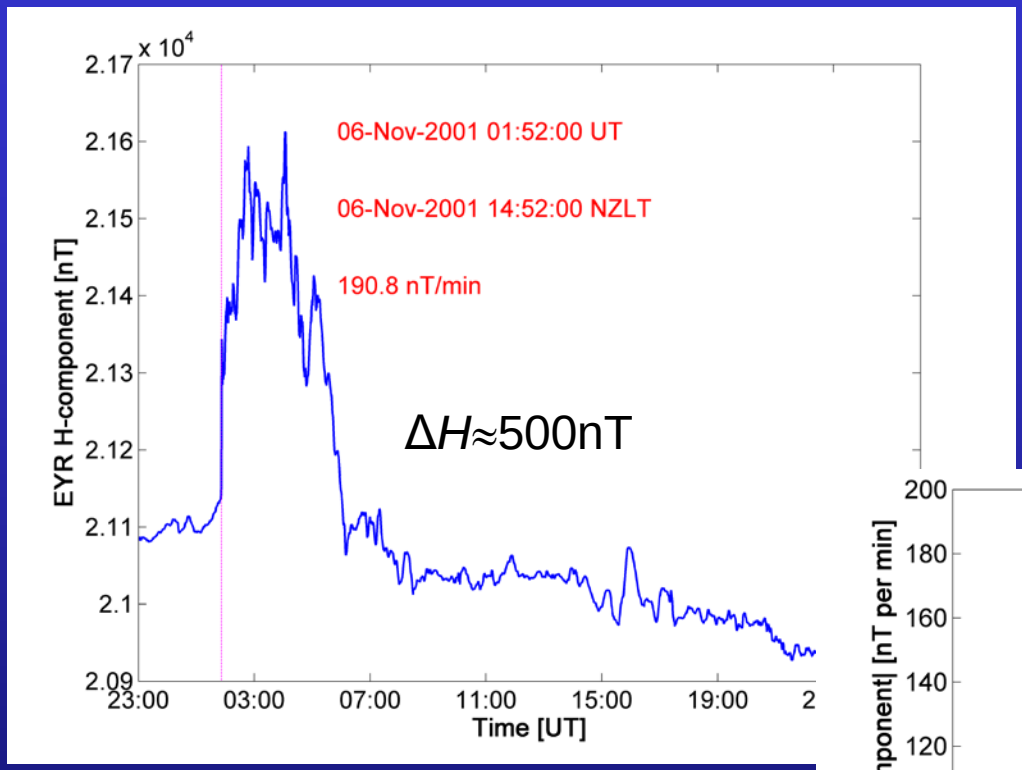
Our project goals

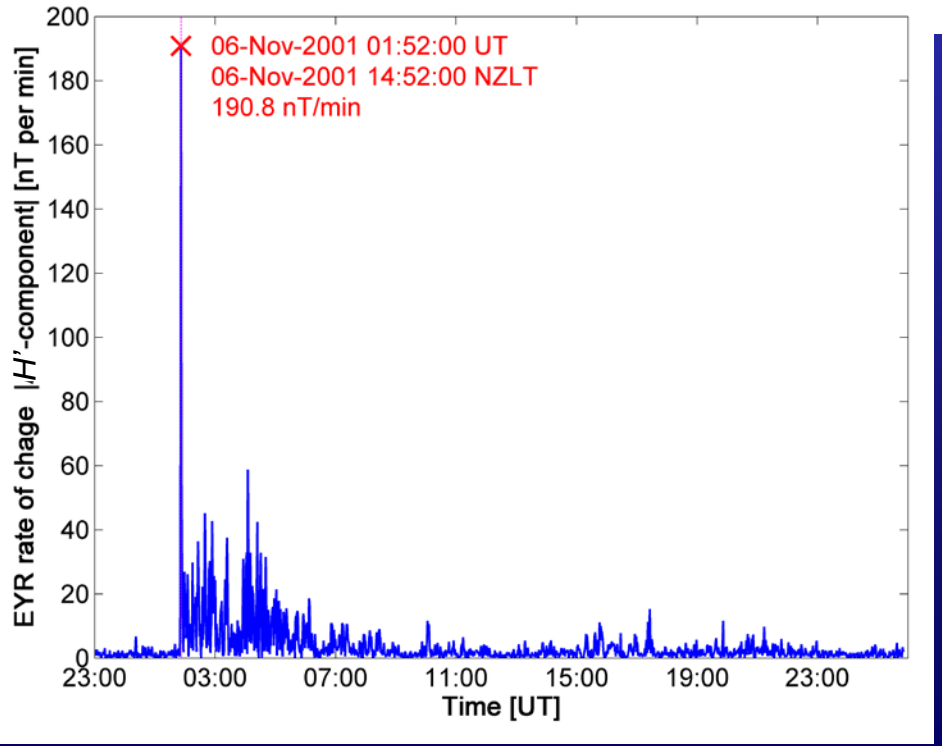
1. Understand the occurrence of GIC in the New Zealand electrical transmission network.

2. Test Transpower's existing GIC mitigation protocols

3. Predict the likely impact of severe/extreme geomagnetic storms in the New Zealand grid.

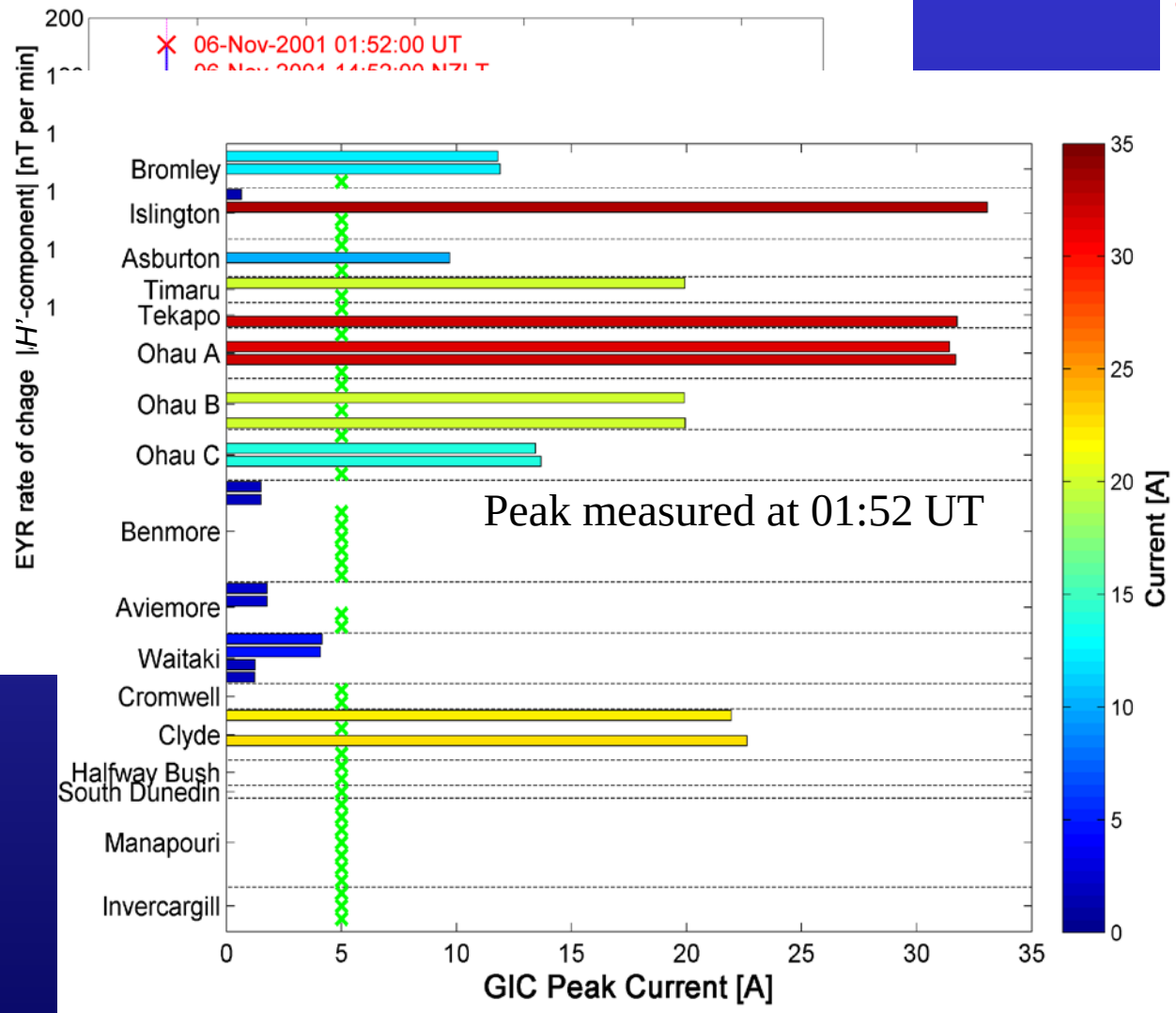
Example of a large geomagnetic storm 6 November 2001

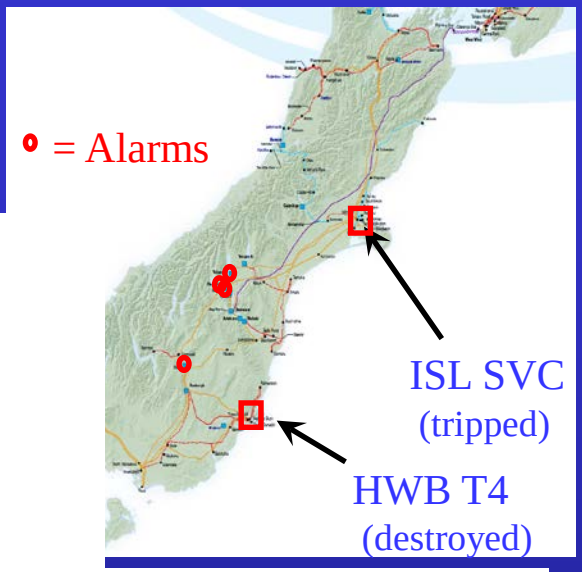


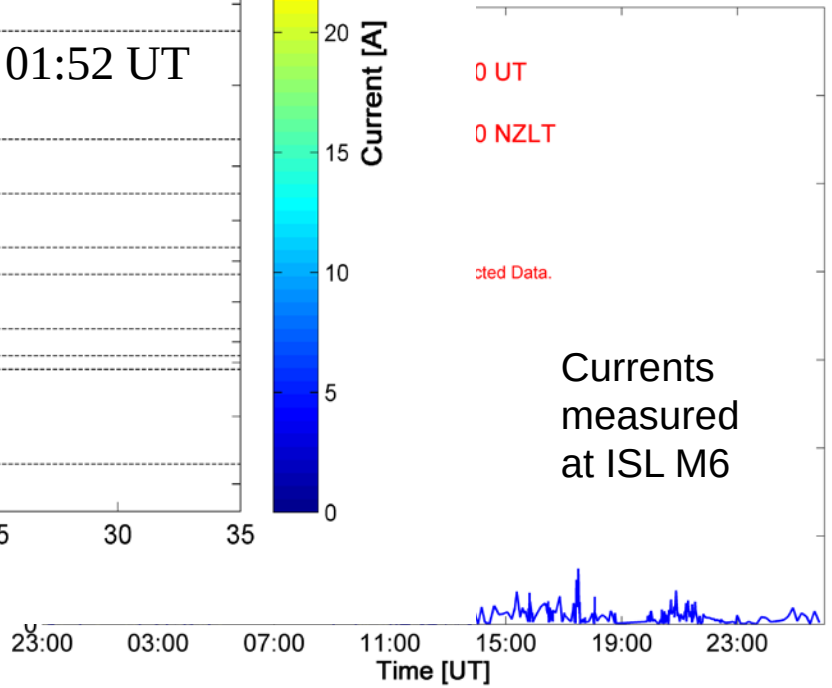


Highest rate of change in *H'* observed in New Zealand from 2001-2016.

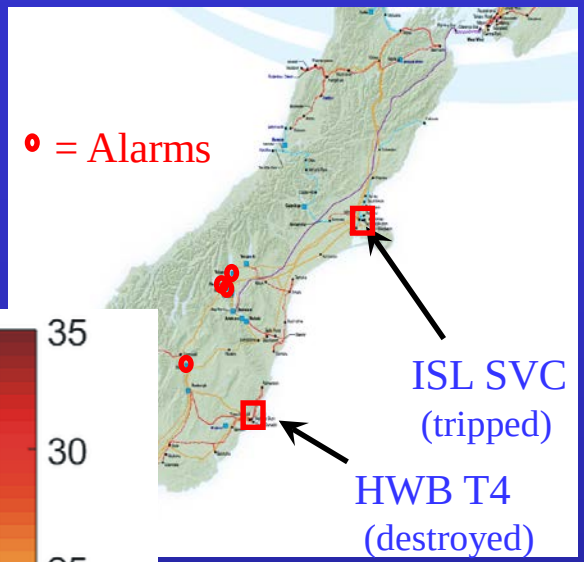
Example of a large geomagnetic storm 6 November 2001

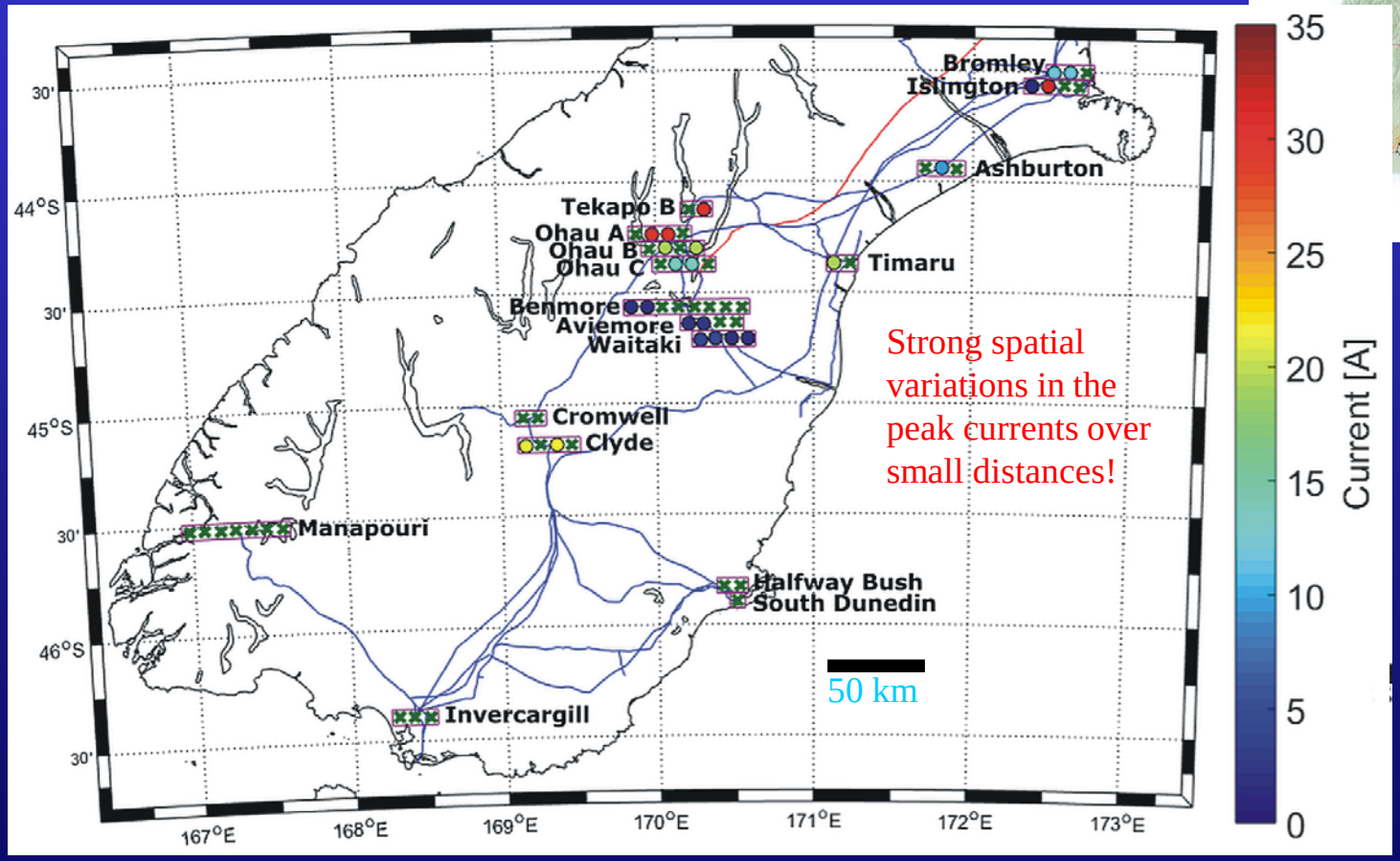






Example of a large geomagnetic storm 6 November 2001





Strong spatial variations in the peak currents over small distances!

Likely caused by network configuration and ground conductivity.

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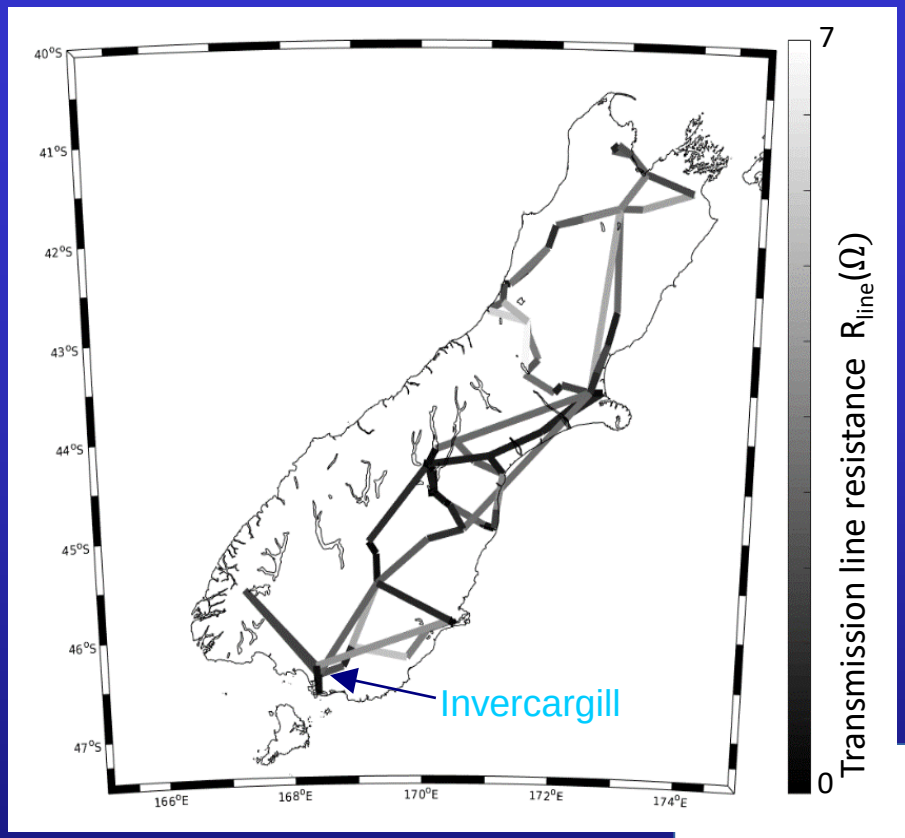
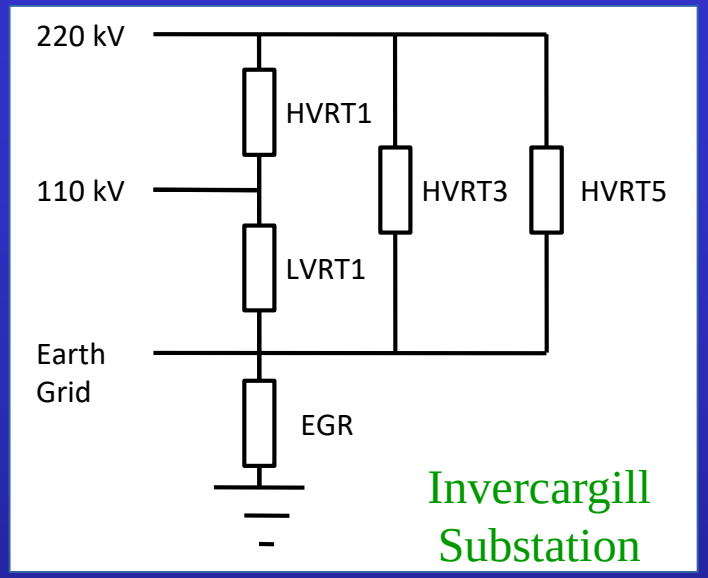
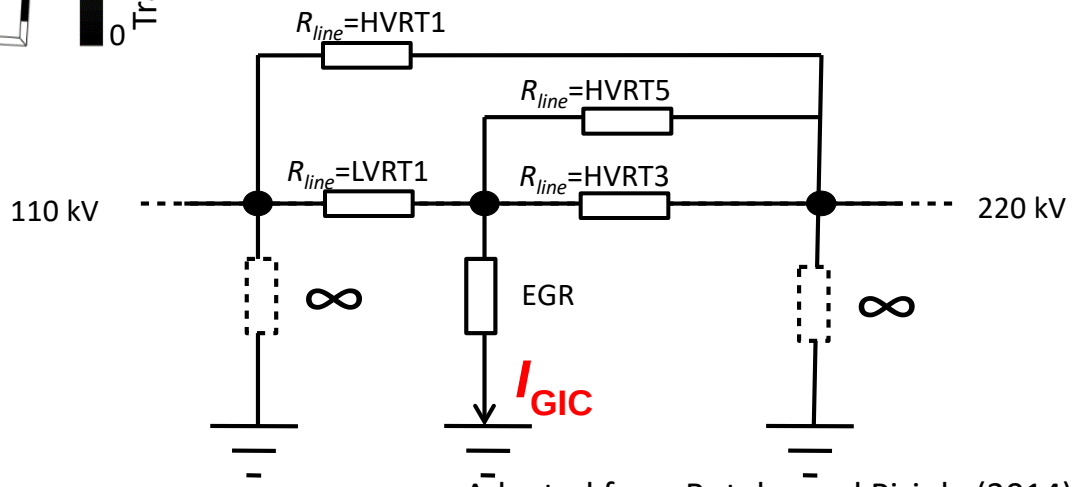
3. Predict the likely impact of severe/extreme geomagnetic storms in the New Zealand grid.

Building a South Island Transmission Grid Model







Adapted from Boteler and Pirjola (2014)

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Looking at GIC mitigation

System Operations Division
Manage Geomagnetic Induced Currents

Document Location Map

Level 3 Document User Domain Procedures

Dispatch (DP) /Real-Time Security

PR-DP-252 Manage Geomagnetic Induced Currents

Document Status: **Approved**

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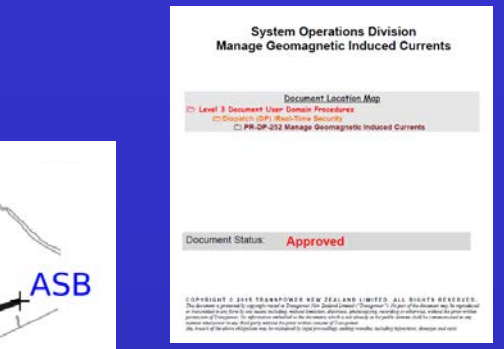
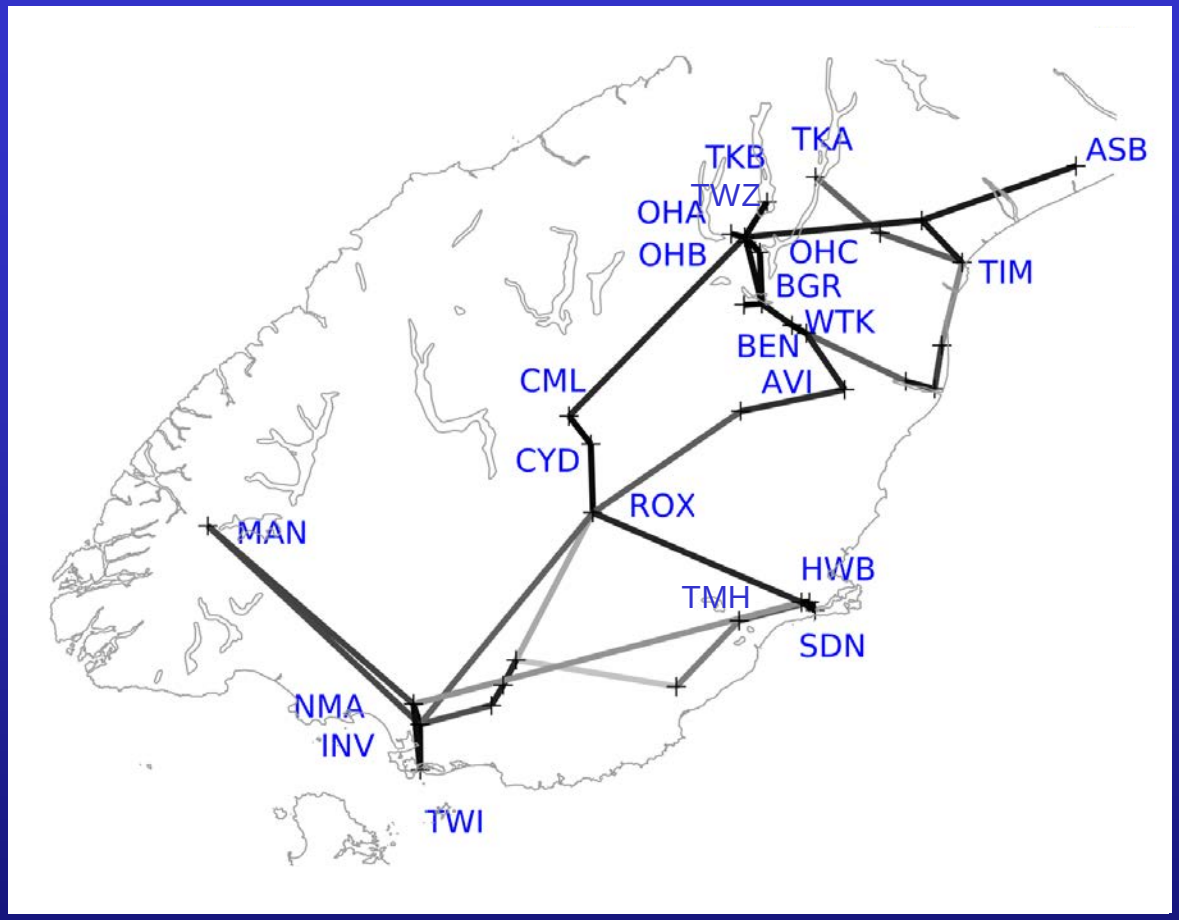
Looking at GIC mitigation





Approximate path of transmission lines as straight

In the event of an event the PR-DP-252 describes the following actions to be undertaken in the lower South Island. **We have looked at what the impact of this would be on GIC magnitudes.**

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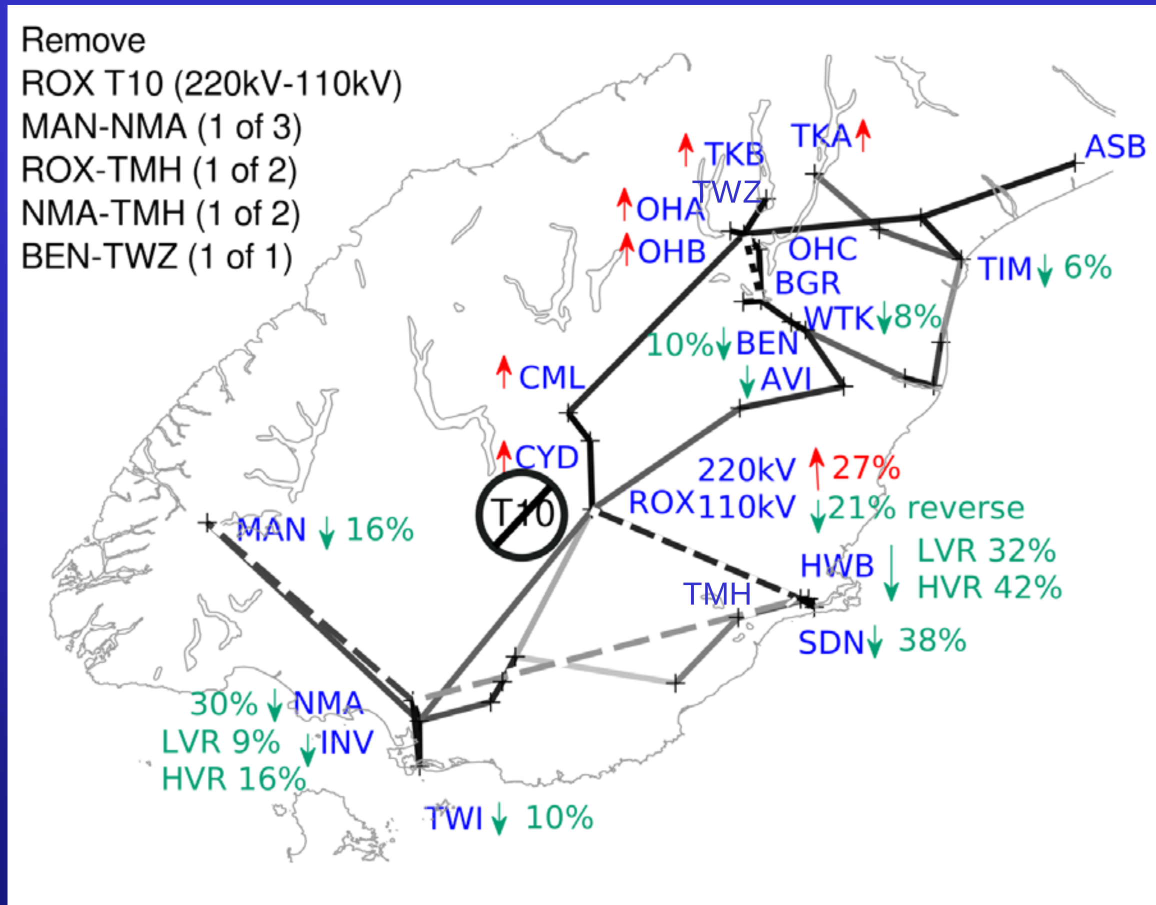
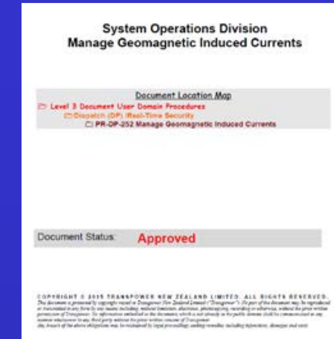
Looking at GIC mitigation





While the GIC magnitude at ROX would go up by ~27%, it would still be slightly smaller than the mitigated GIC magnitudes at HWB and SDN. **Looks good!**

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Our project goals

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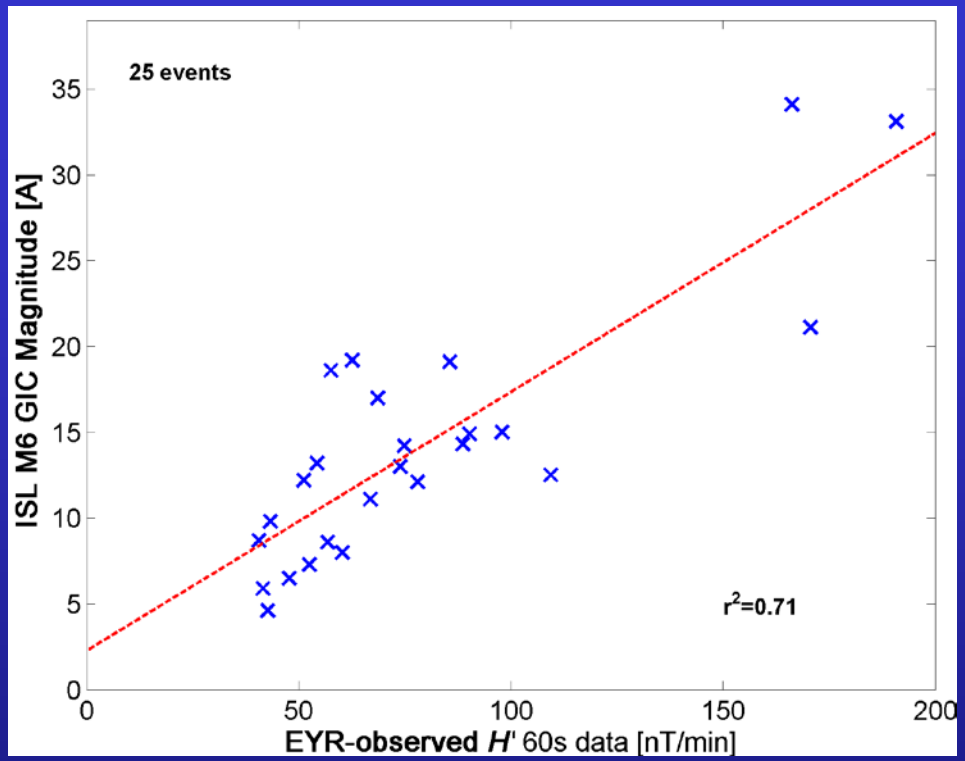
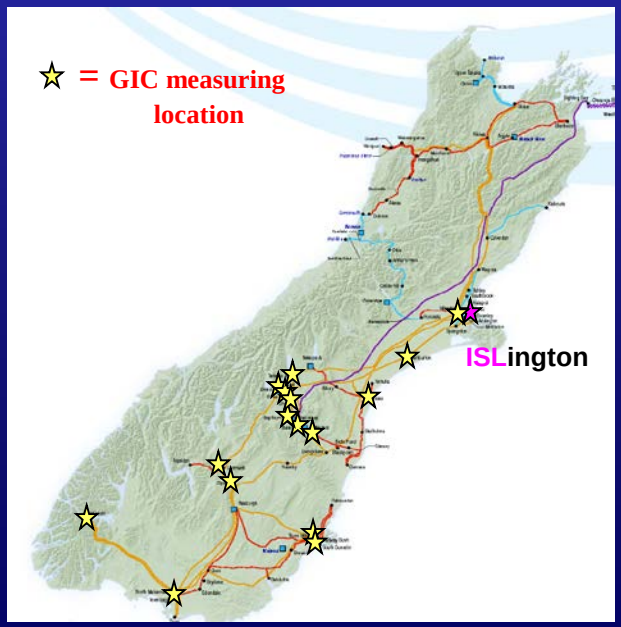
Focus on the Christchurch ISL M6 data



Roughly linear response between the EYR H-component magnetic field rate of change and the ISL M6 peak currents.

NOTE: after HVDC stray current correction!



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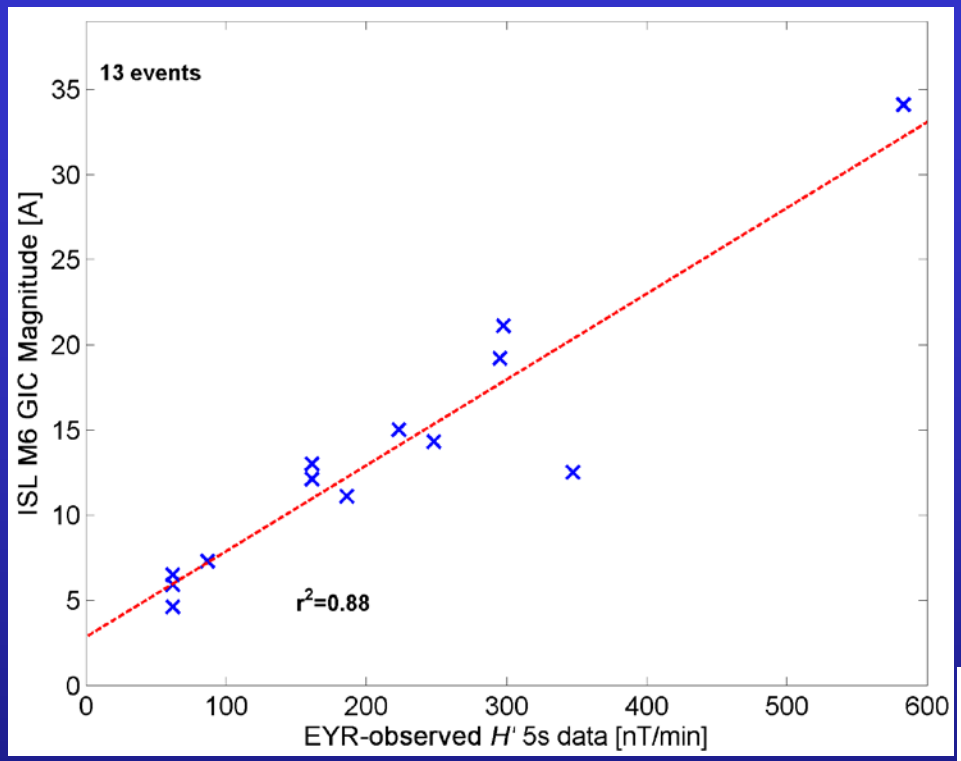
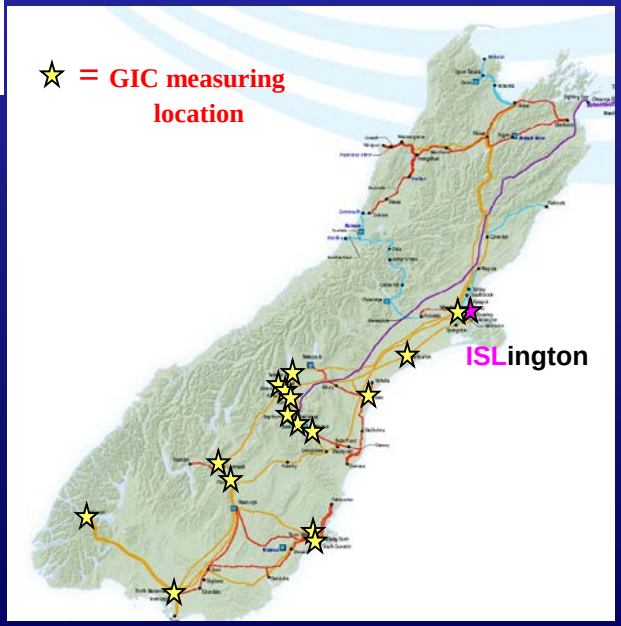
Focus on the Christchurch ISL M6 data



Even more linear response between the 5-s resolution EYR H-component magnetic field rate of change and the 4-s resolution ISL M6 peak currents.

NOTE: after HVDC stray current correction!

These relationships allow us to the extrapolate for a possible "extreme" expected current for a 1 in 100-200 year reutrn period storm.



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What is an extreme storm at mid-lats?

Thomson et al. [2011] and *Cannon et al.* [2013]

Thomson et al. used ~30 years of European magnetometer observations a reasonable "extreme" magnetic storm would be ~1000-6000 nT/min. Cannon et al. took those and provided UK estimates:

100 year return	3000 nT/min
200 year return	5000 nT/min

Thomson et al. (2011), Space Weather, doi:10.1029/ 2011SW000696.

Canon et al. (2013), "Extreme space weather" report, Royal Academy of Engineering

Kelly et al. [2014]

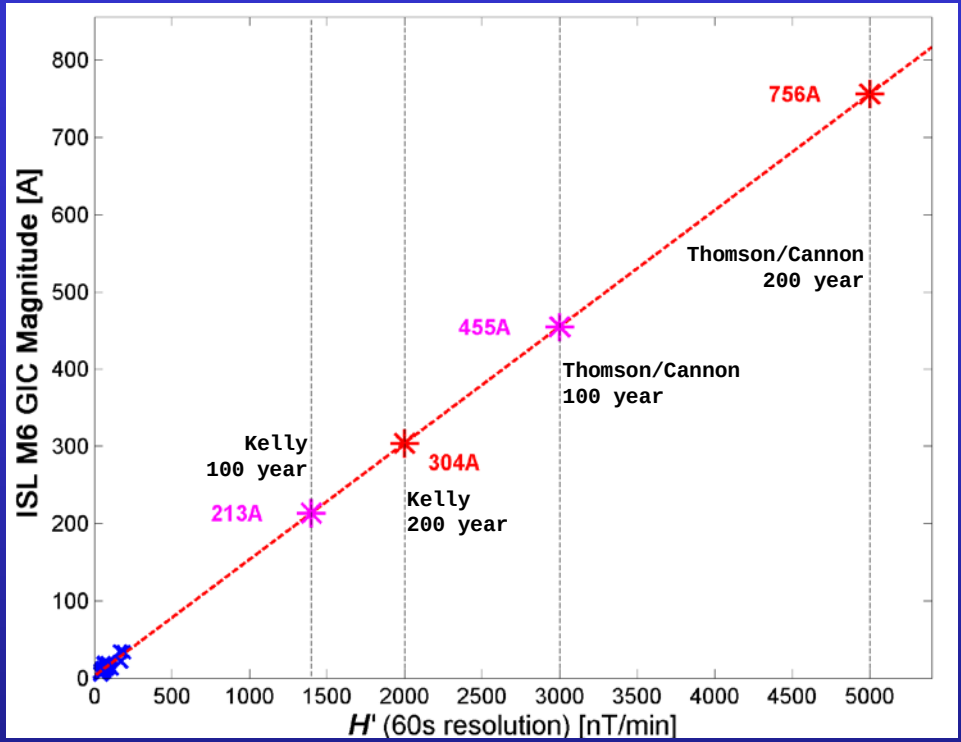
Kelly et al. used ~19 years of EYR digital data and estimated NZ extreme values.

100 year return	1400 nT/min
200 year return	2000 nT/min

Kelly et al. (2014), ESWW11 Poster, doi: 10.13140/ RG.2.1.4681.1124

Note New Zealand is at essentially the same magnetic latitudes as the UK, so one might expect these to be the same!

Focus on the Christchurch ISL M6 data

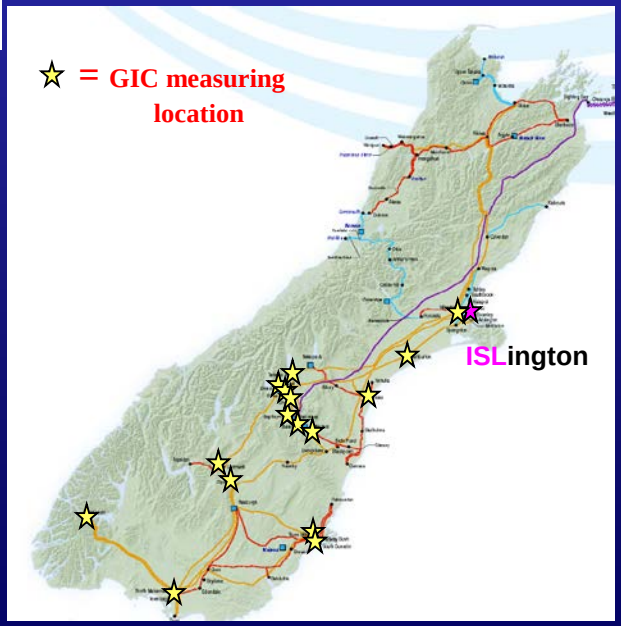


Let us extrapolate our fit to the 25 storms with GIC observed at ISL M6 to an extreme storm case.

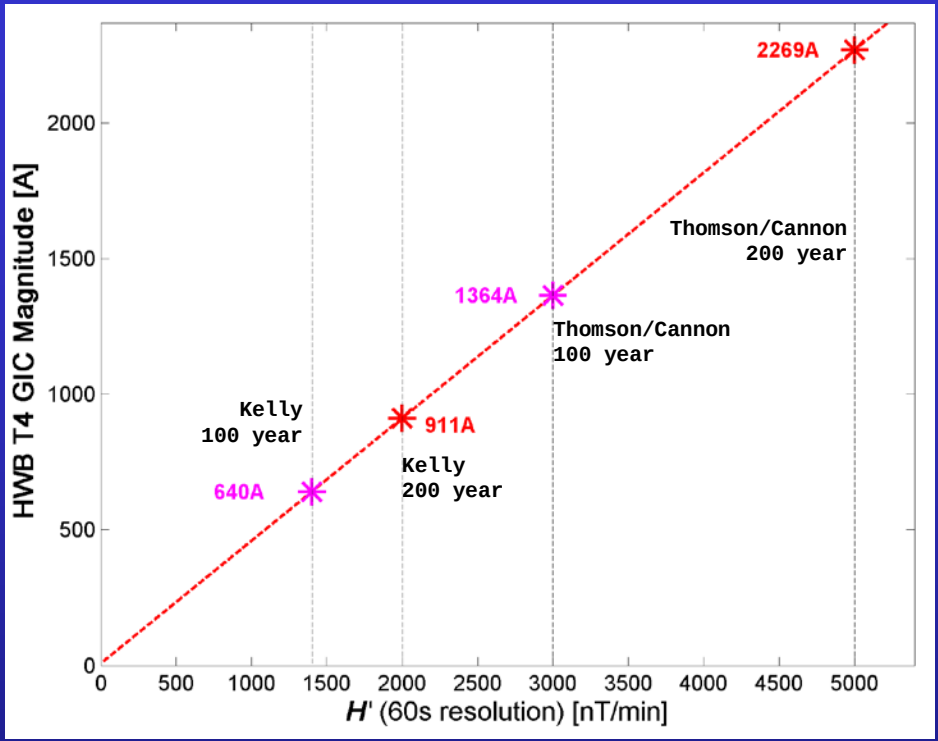
Very rough estimate for big extrapolation!

For ISL M6 a 100 year return period leads to peak currents of ~215-455 A.

For ISL M6 a 200 year return period leads to peak currents of ~305-755 A.



What about HWB T4?



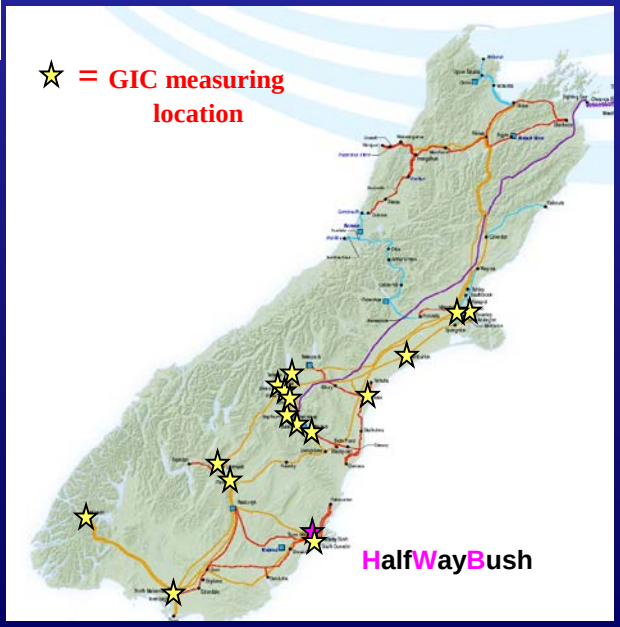
We have a small number of storms for which there were GIC observations at HWB T4 (which was lost in November 2001).

We find that the HWB T4 peak current is ~3 times bigger than the ISL M6 peak current.

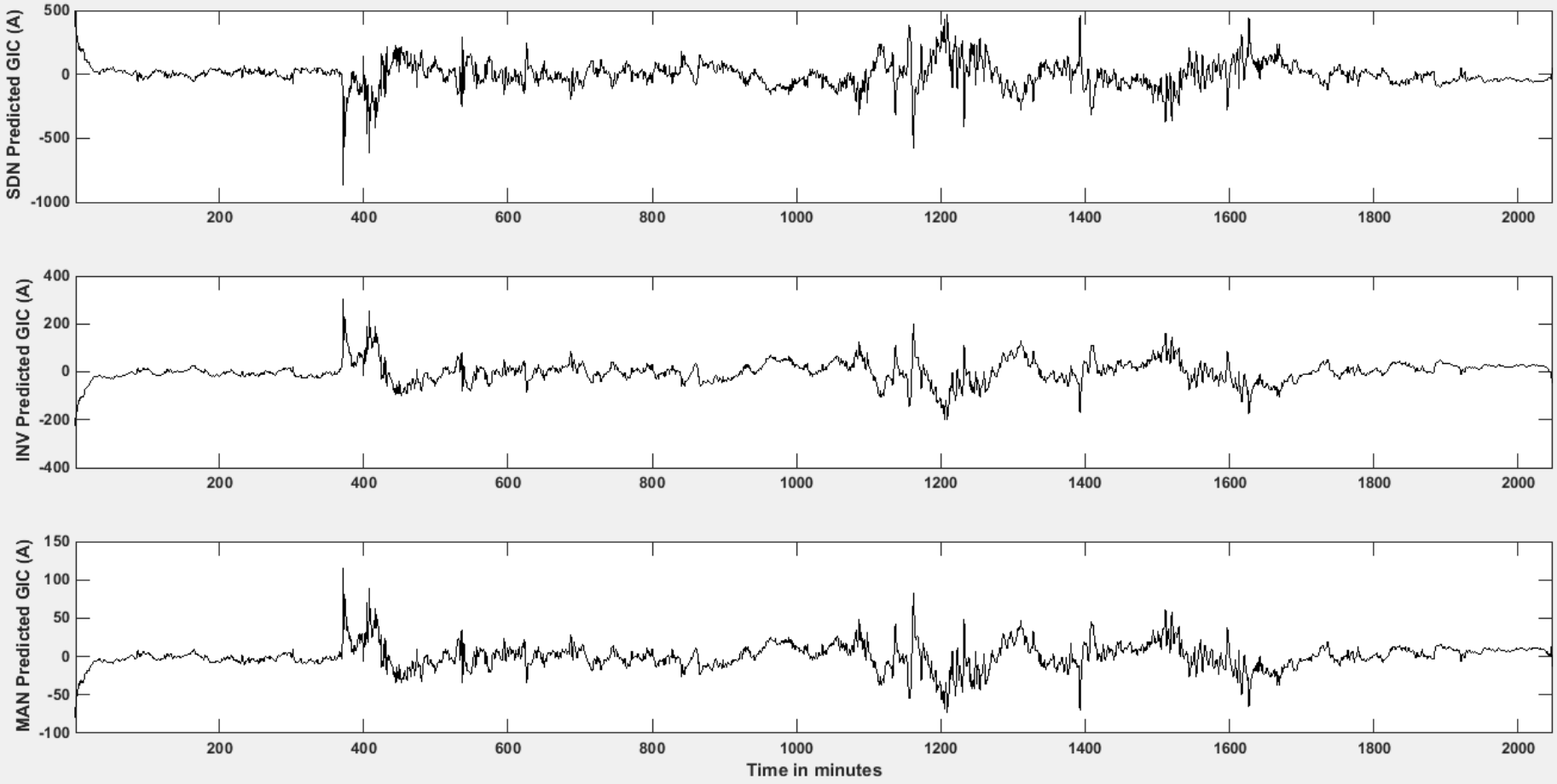
For HWB T4 a 100 year return period leads to peak currents of ~640-1360 A.

For HWB T4 a 100 year return period leads to peak currents of ~910-2300 A.

In contrast, HWB T4 probably failed at ~100A on 6 November 2001.



Using a transfer function analysis to predict GIC in the NZ power system…..including what a Carrington Event size storm might produce.



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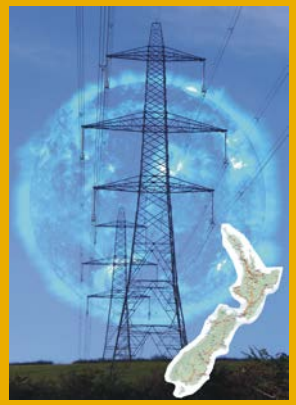
Summary

- We have recently started a research project to analyse the New Zealand GIC dataset in order to better understand the occurrence and impact of GIC to the New Zealand electrical network.
- There are very strong spatial variations in the peak GIC magnitude across the lower South Island.
- We are working with the New Zealand grid operator to examine existing GIC mitigation plans. Initial results suggest these are would help, if enacted in time
- As expected, we find that in most locations and for most times the observed GIC is best correlated with the rate of change of the horizontal component of the geomagnetic field.
- Using the ~14 year dataset and results from previous extreme studies we have estimated the likely extreme GIC magnitude expected at the transformer which was lost in November 2001. This is ~640-2300 A, depending on the storm case used.



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Daniel, Craig and James at the Halfway Bush (HWB) substation in front of HWB T4 which was lost on 6 November 2001 [5 May 2015].

Thankyou!

Are there any questions?

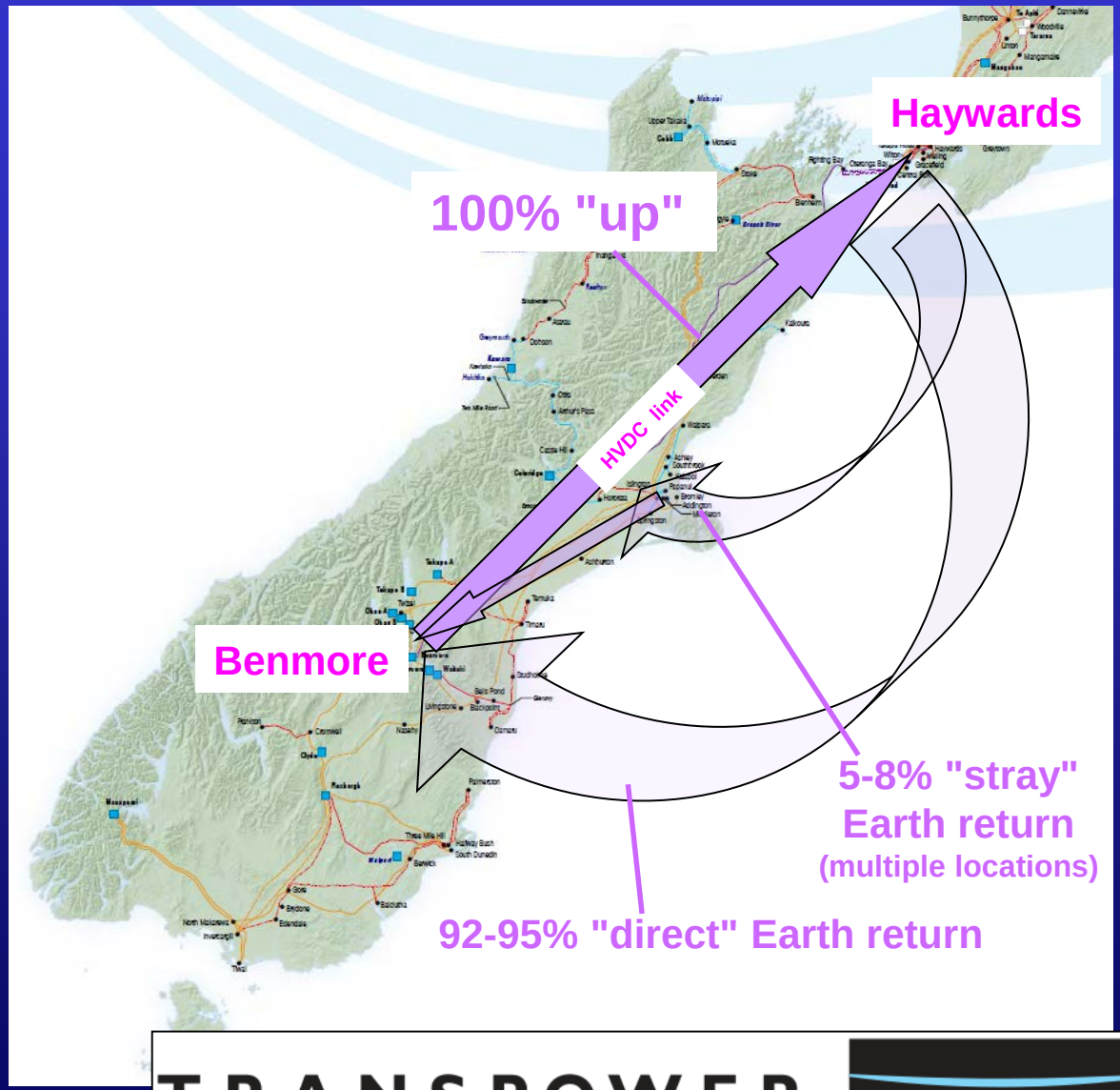
Why so many DC observations at NZ Transformers?

New Zealand has a HVDC link to link the large hydro-generation in the South Island with large population in the North Island.

Often operations in a balanced or "bipolar" mode. But also common to operate in **single wire Earth-return** mode

When in Earth-return mode, ~92-95% of the current returns directly to Benmore.

The other 5-8% first comes into various South Island transformers and then returns to Benmore across the AC power transmission network - we term this “stray Earth return” and it is what the LEMs exist to monitor.



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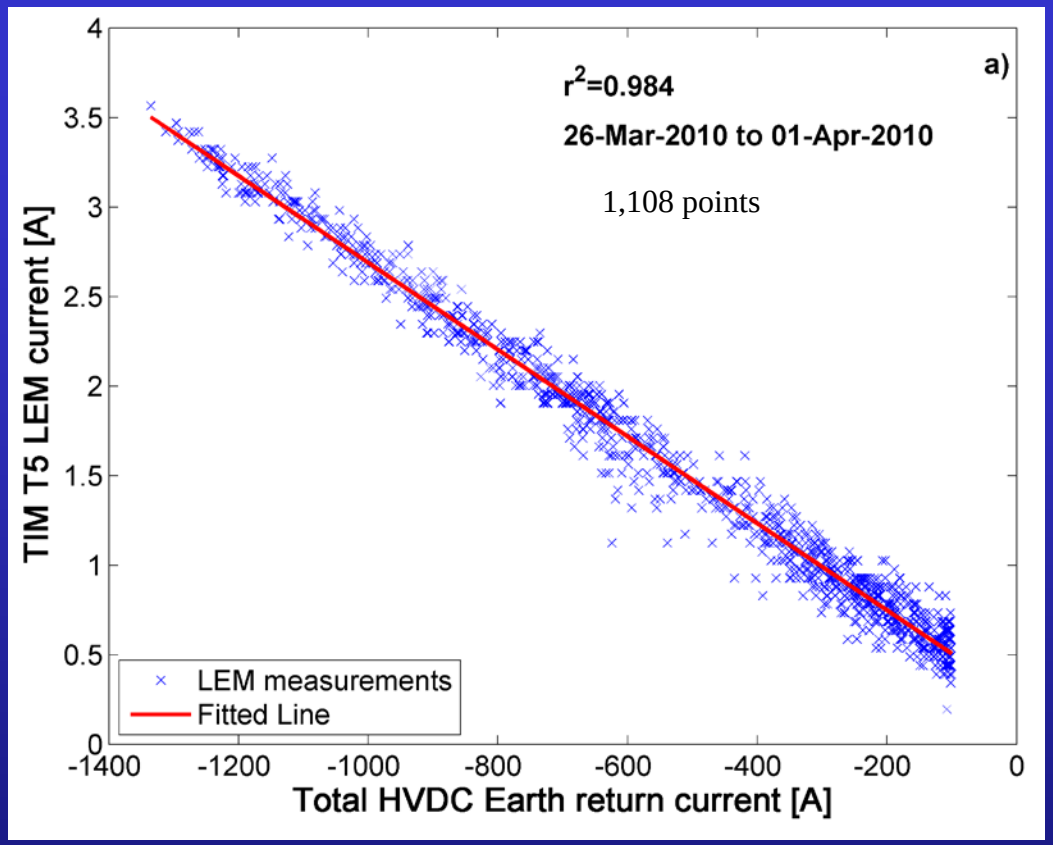
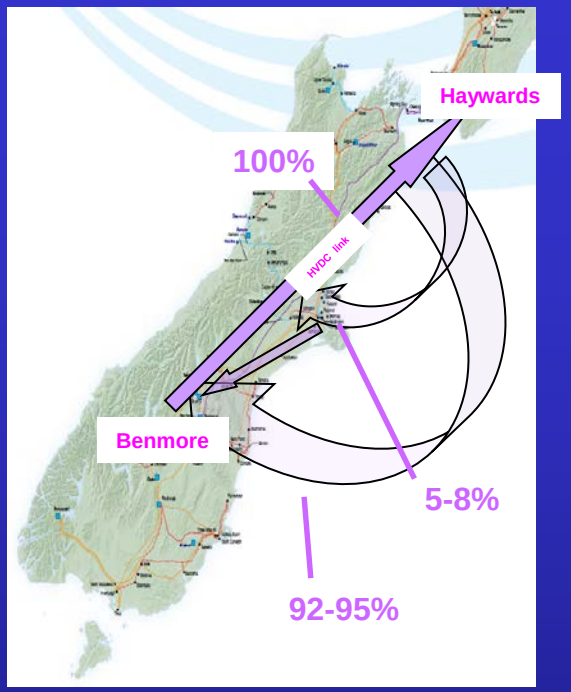
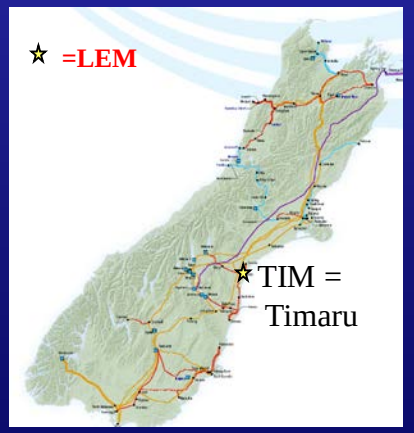
Need to "correct" the LEM data!







Strong linear relationship between the Timaru transformer #5 currents (TIM T5) and the total HVDC current - outside of geomagnetic storm times (EYR K<5) and for large HVDC Earth Return currents (>100A).

So can undertake weekly linear fits over all data to determine slopes, from which we can do a correction.

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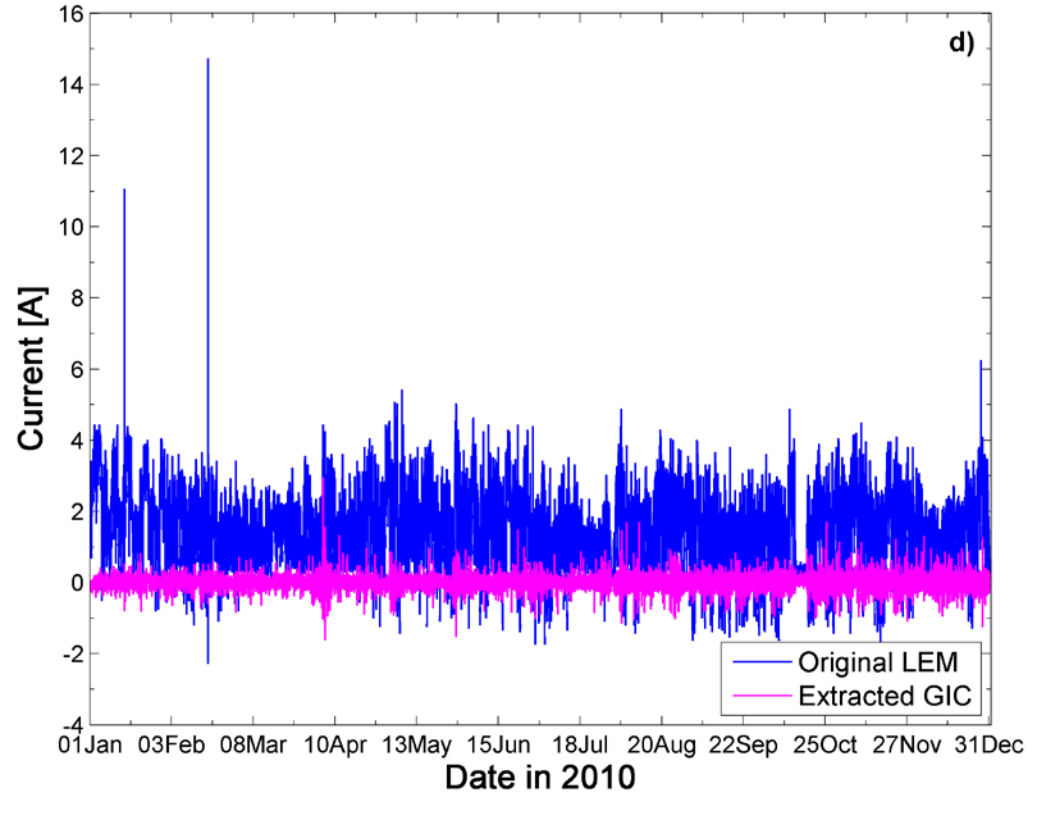
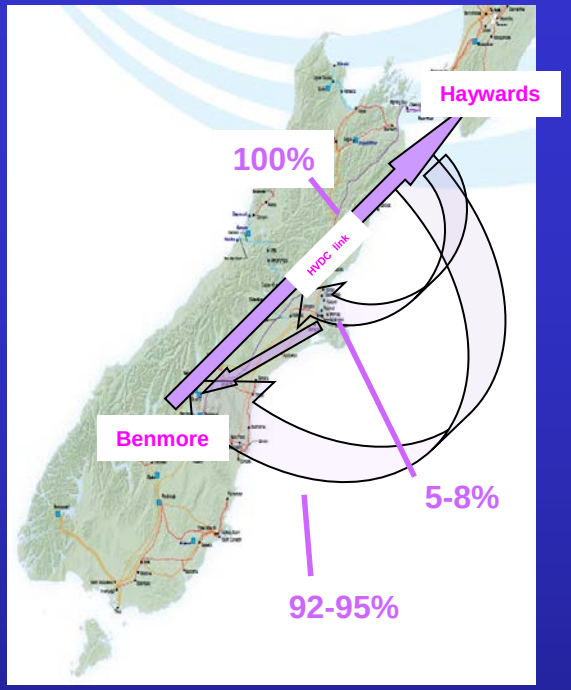
Need to correct the LEM data!





Timaru transformer #5 currents (TIM T5) data after correction.

Having removed the offsets and the stray currents from the LEM measurements, we should just have GIC present.

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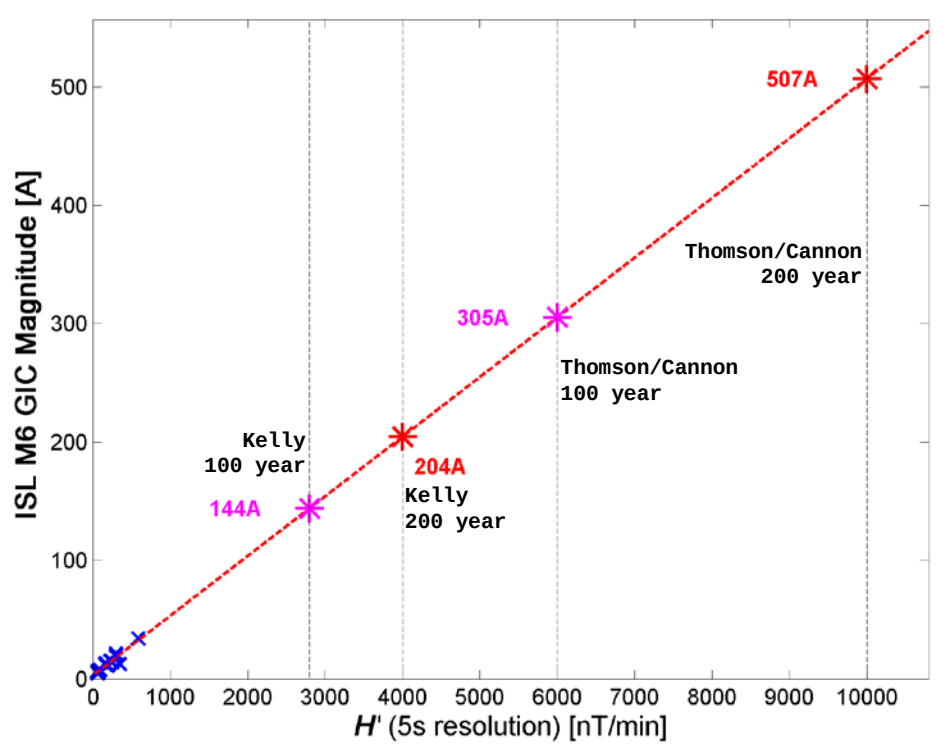
Focus on the Christchurch ISL M6 data



The fit to the 5-s *H* values was of higher quality than we had for 60-s, so try that for the extrapolation to extreme storms.

Assume the extreme storm rates of change on a 5-s cadence will be about twice that for a 60-s cadence.

End up with slightly lower peak GIC at ISL M6.