



Australian Government

Bureau of Meteorology

Modelling GICs in Australian Power Networks

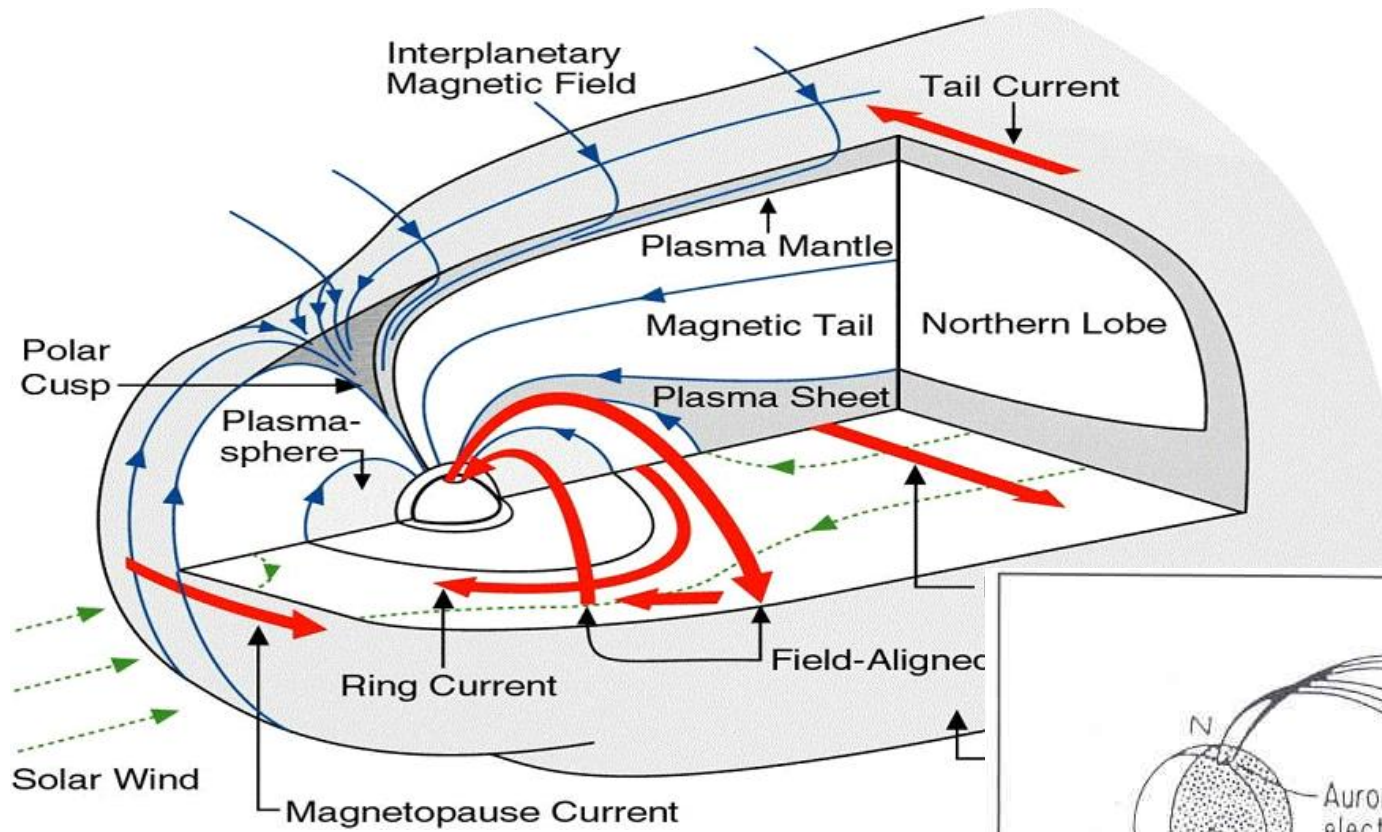
Richard Marshall

Space Weather Services

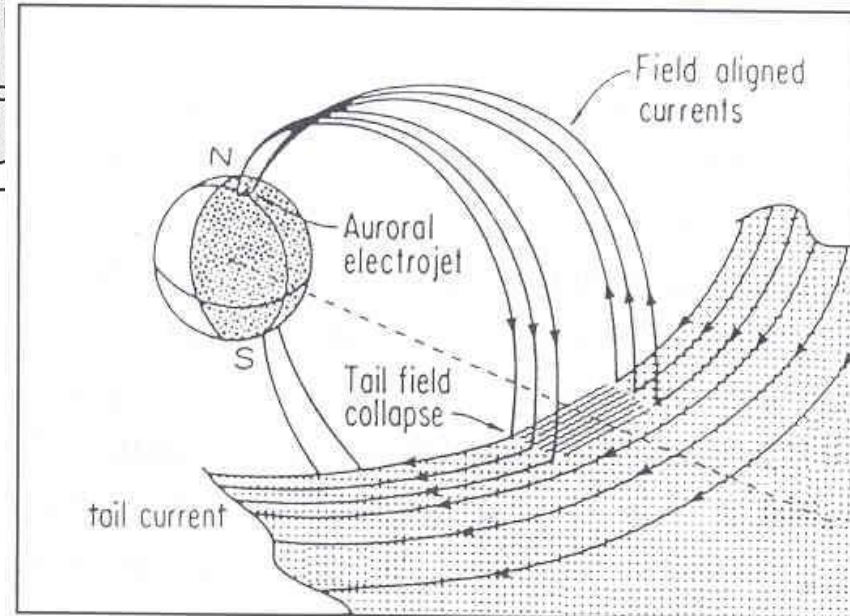
Modelling GICs

- Geoelectric field
- Network analysis

Geomagnetic Storms



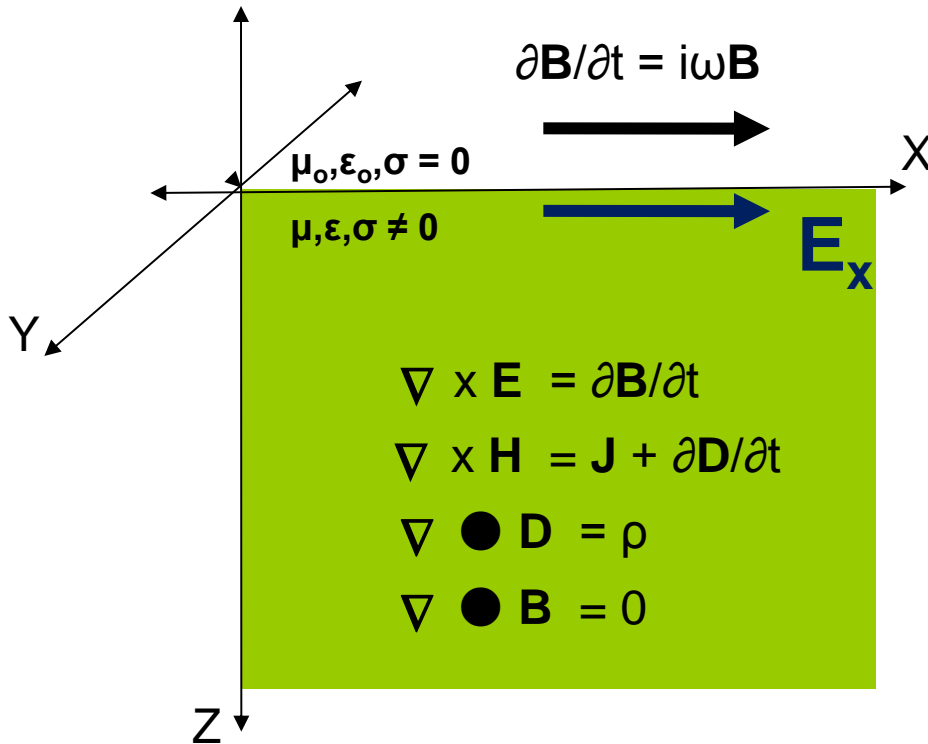
(Kivelson and Russell, 1995)



(McPherron, 1973)

Geoelectric Field – Uniform Cond.

Models: 1-Layer



$$\nabla \times \mathbf{E} = -i\omega\mu\mathbf{H}$$

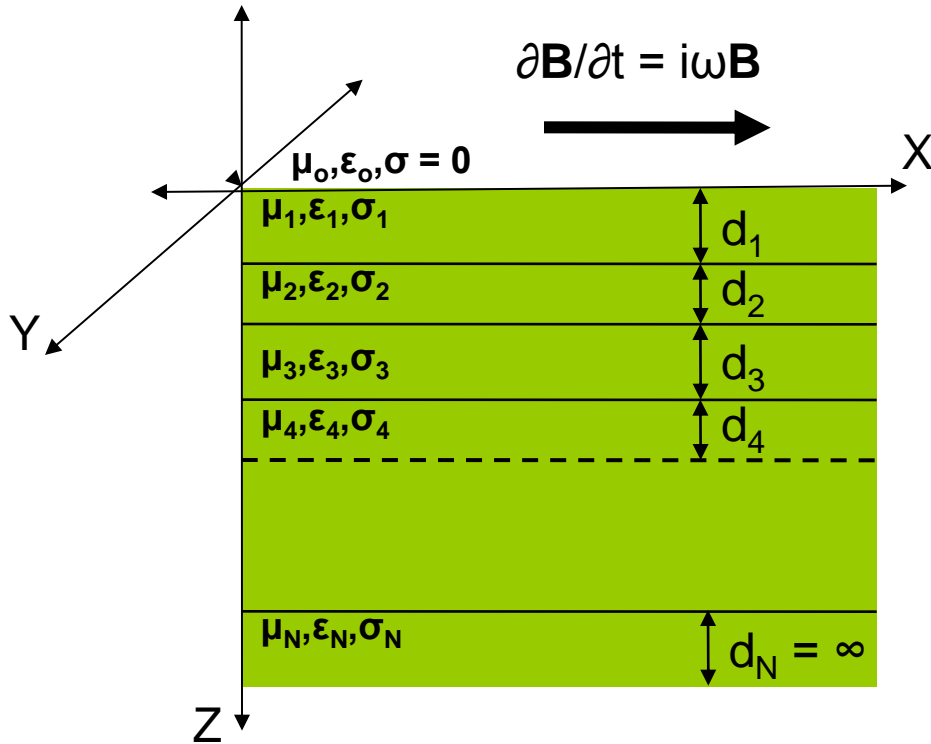
$$\nabla \times \mathbf{H} = (\sigma + i\omega\epsilon)\mathbf{E}$$

$$\nabla \cdot \mathbf{E} = 0$$

$$\nabla \cdot \mathbf{H} = 0$$

$$E_y / H_x = -\sqrt{i\omega\mu / (\sigma + i\omega\epsilon)}$$

Geoelectric Field – 1D



Models: N-Layers

$$E_N = A_N (e^{-kz} + R_N e^{kz})$$

$$H_N = A_N (e^{-kz}/Z_N + R_N e^{kz}/Z_N)$$

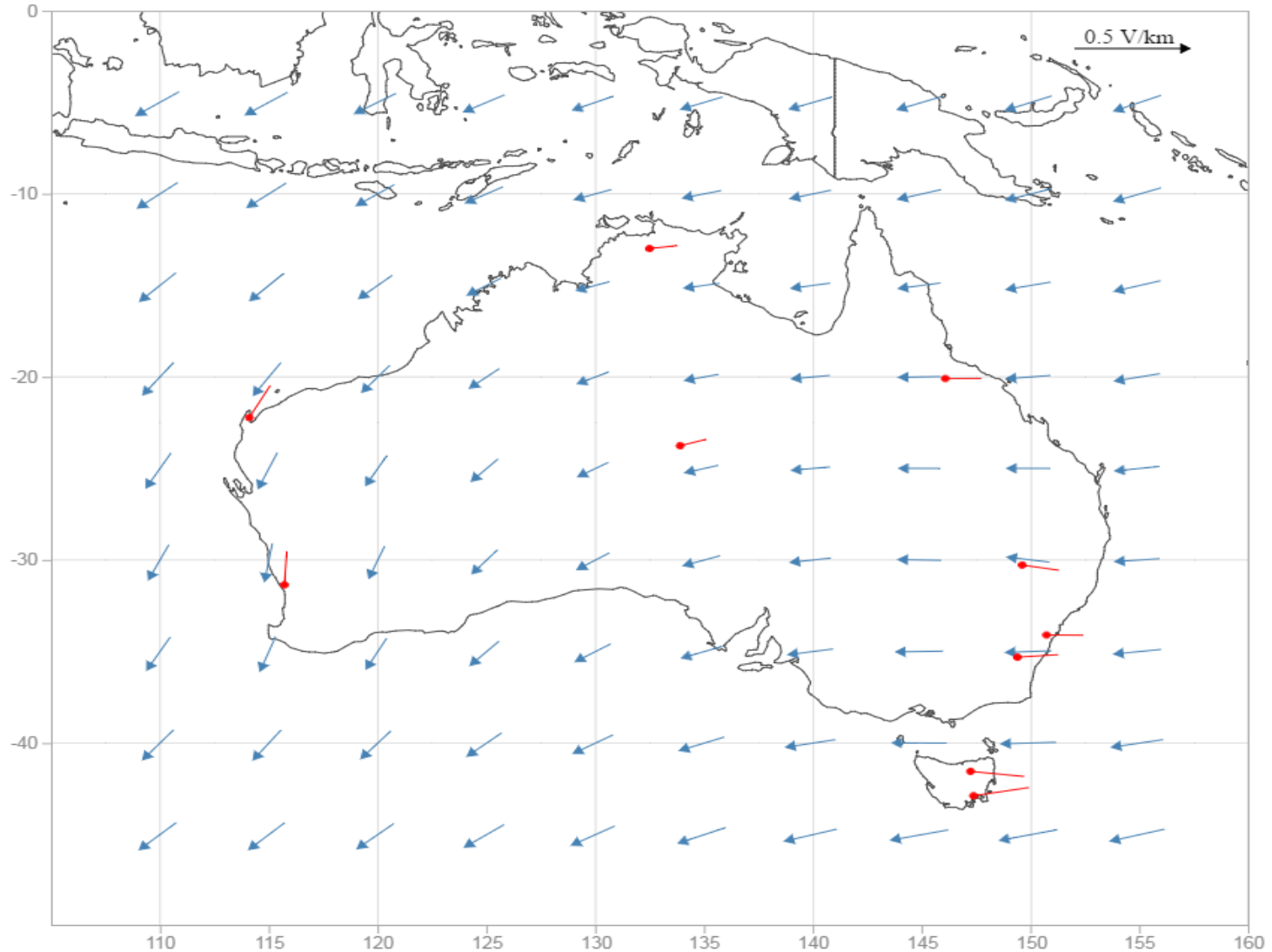
$$E_y/H_x = i\omega\mu \left(1 - r_N e^{-2k_N d_N} / k_N (1 + r_N e^{-2k_N d_N}) \right)$$

(Weaver, 1994)

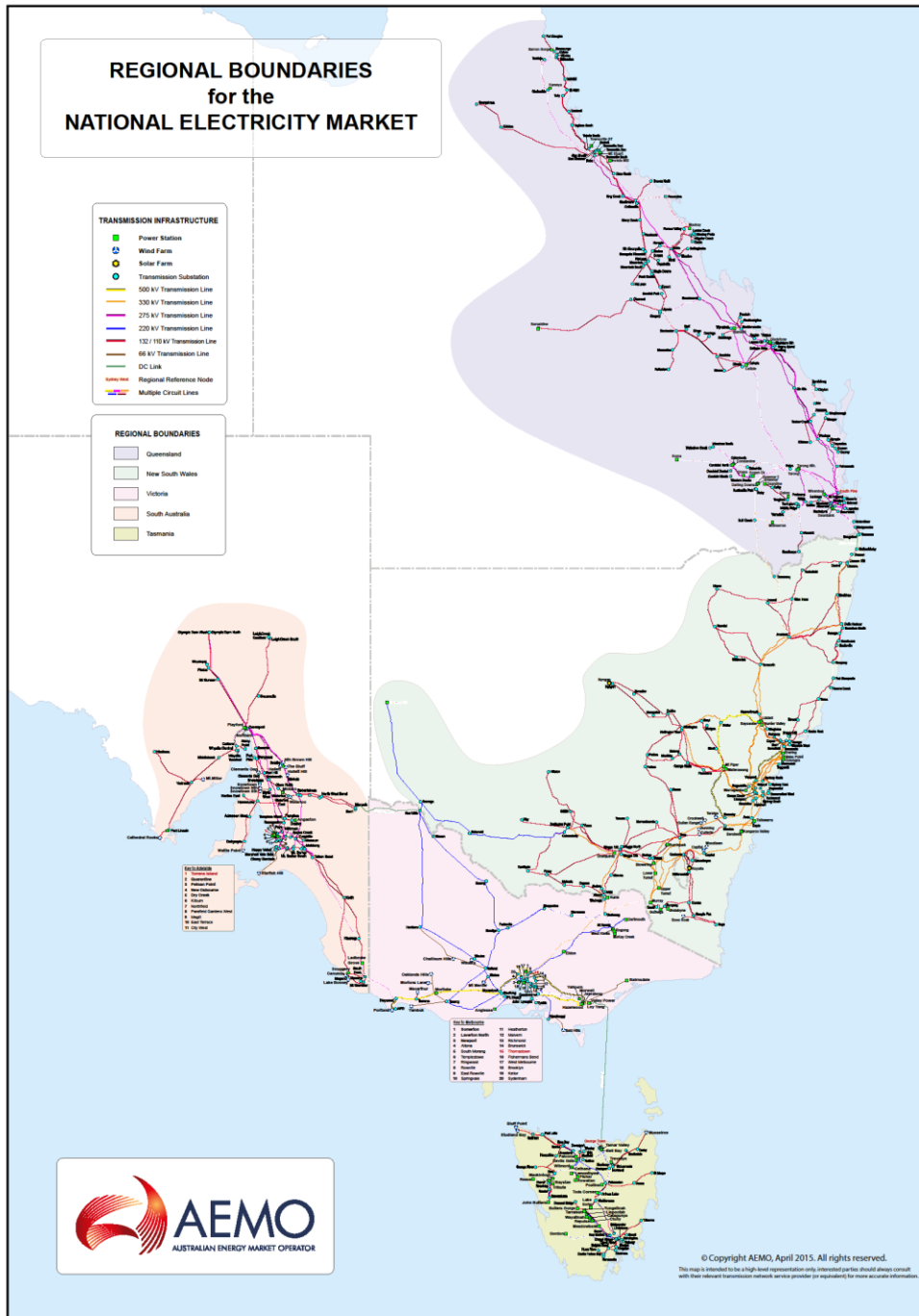
Geoelectric Field Grid – Uniform Cond.

Modelled geoelectric field at 2-Oct-2013 01:57 UT

- Measured geoelectric field at magnetometer sites.
- ← Modelled geoelectric field at 5° grid spacing.



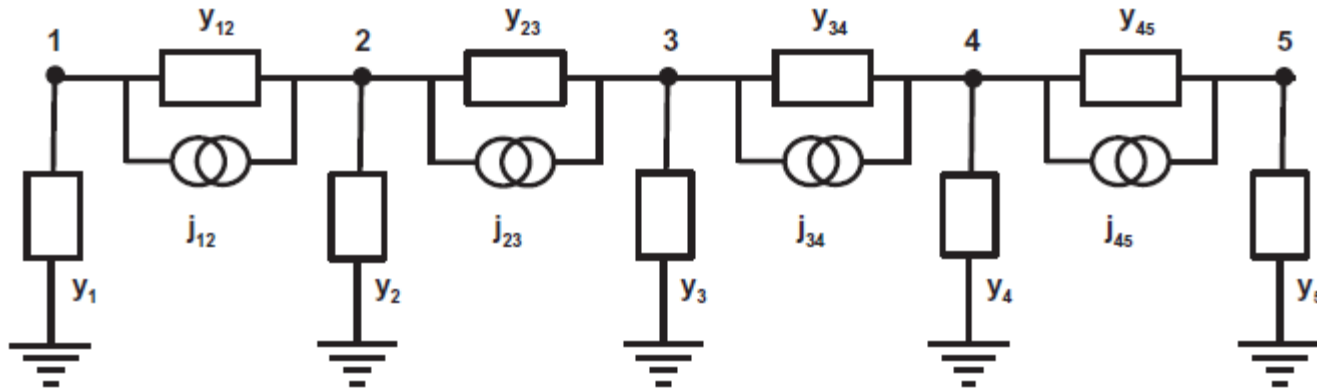
Network



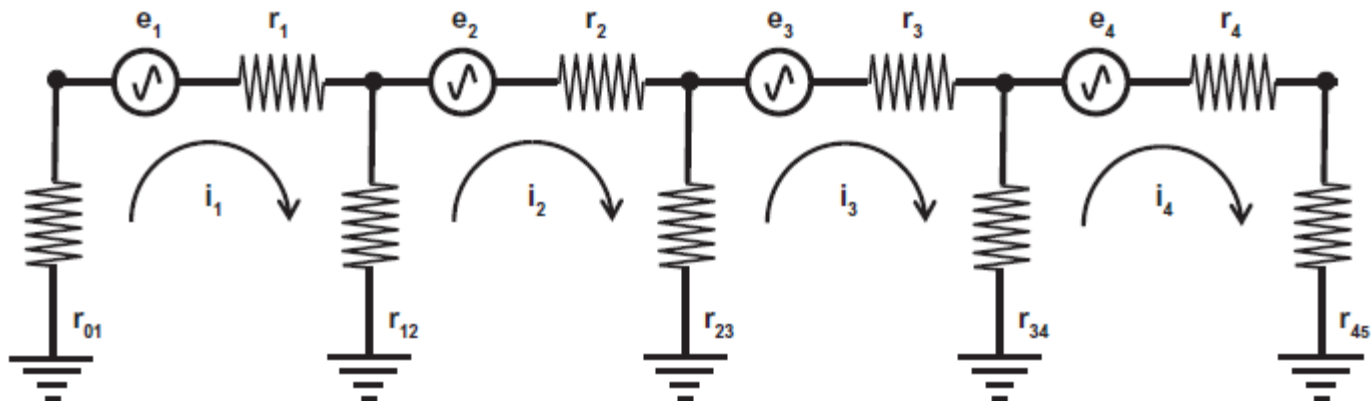
- Operating Voltages of 500, 330, 275, 220, 132, 110, 66, 33, 11 kV
- Over 2000 nodes/buses
- Over 1500 branches
- Over 1000 HV transformers

Network Analysis

Nodal Admittance Matrix method



Mesh Impedance Matrix method



GIC Model

$$\mathbf{I}_e = (\mathbf{U} + \mathbf{Y}_n \mathbf{Z}_e)^{-1} \mathbf{J}_e \quad (\text{Lehtinen and Pirjola, 1985})$$

where \mathbf{U} is an $N \times N$ unit matrix, \mathbf{Y}_n is the $N \times N$ network admittance matrix with

$$Y_{n,ij} = -1/R_{ij}^n \quad (i \neq j)$$

$$Y_{n,ij} = \sum_{k \neq i} 1/R_{ik}^n \quad (i=j)$$

and R_{ij}^n are the line resistances between nodes i and j ,

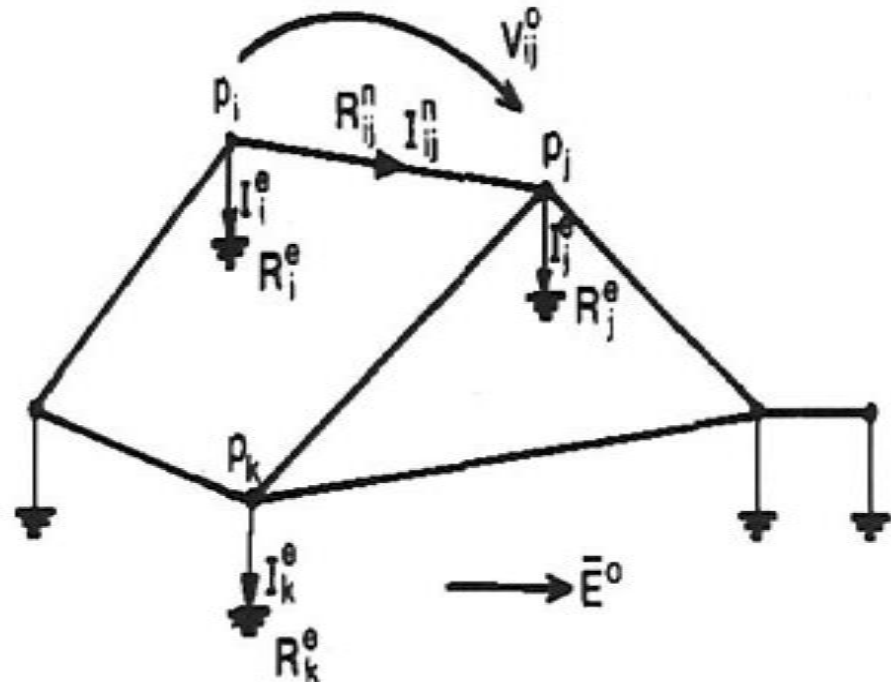
\mathbf{Z}_e is the $N \times N$ earthing impedance matrix

\mathbf{J}_e is a $N \times 1$ column matrix

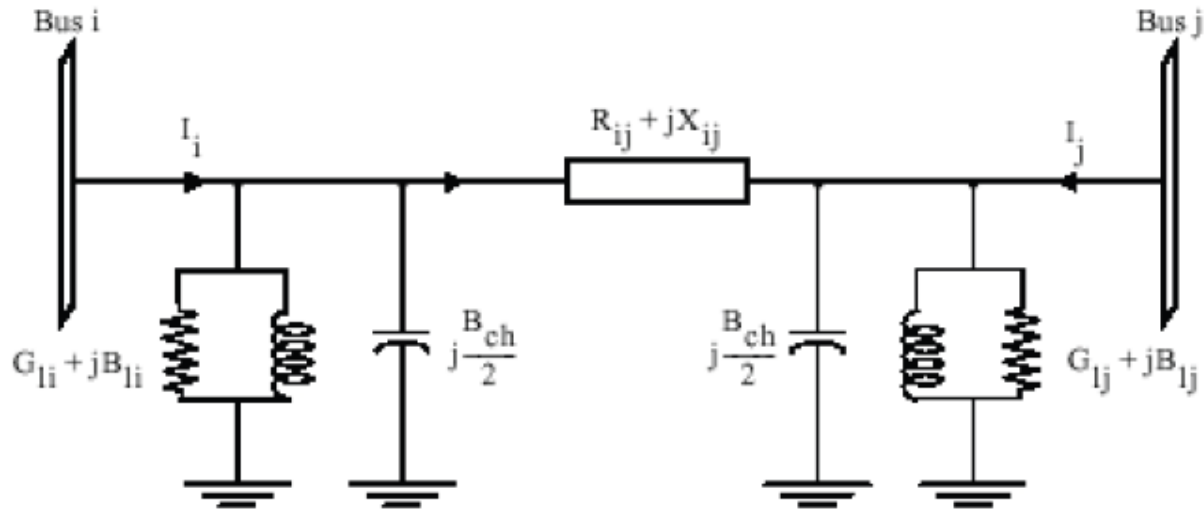
$$J_{e,i} = \sum_{k \neq i} J_{n,ji}$$

$$J_{n,ji} = V_{ij}/R_{ij}^n$$

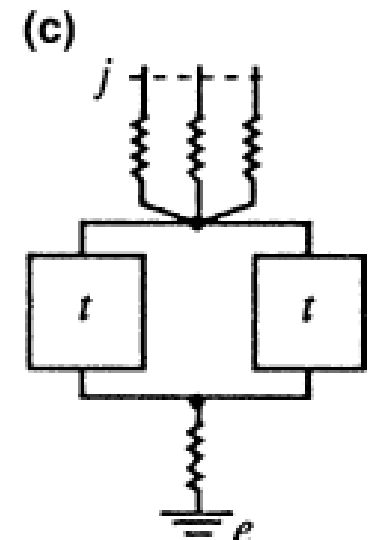
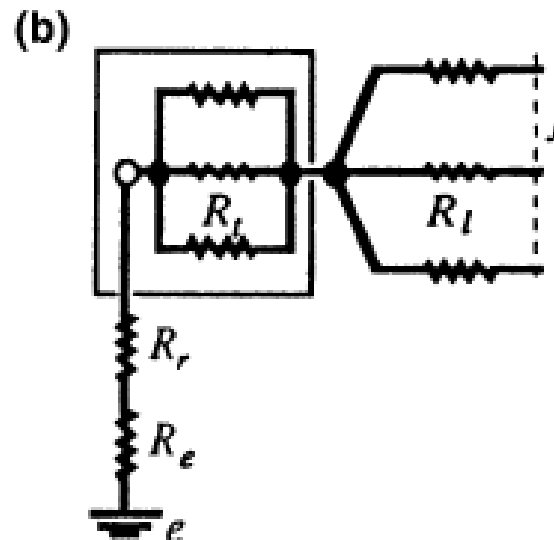
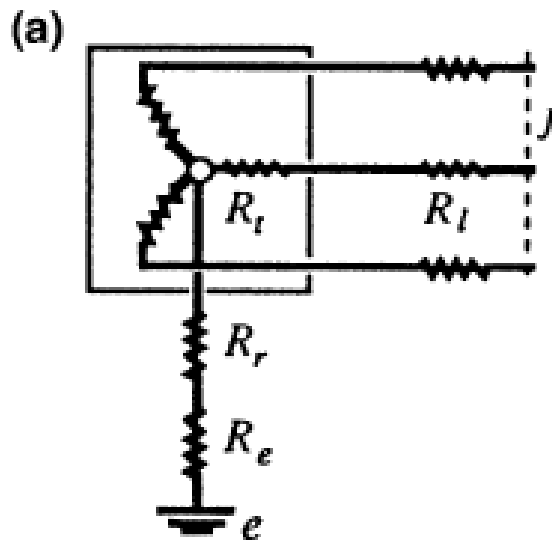
$$V_{ij} = \int_{s_{ij}} \mathbf{E} \cdot d\mathbf{s}$$



Network Models

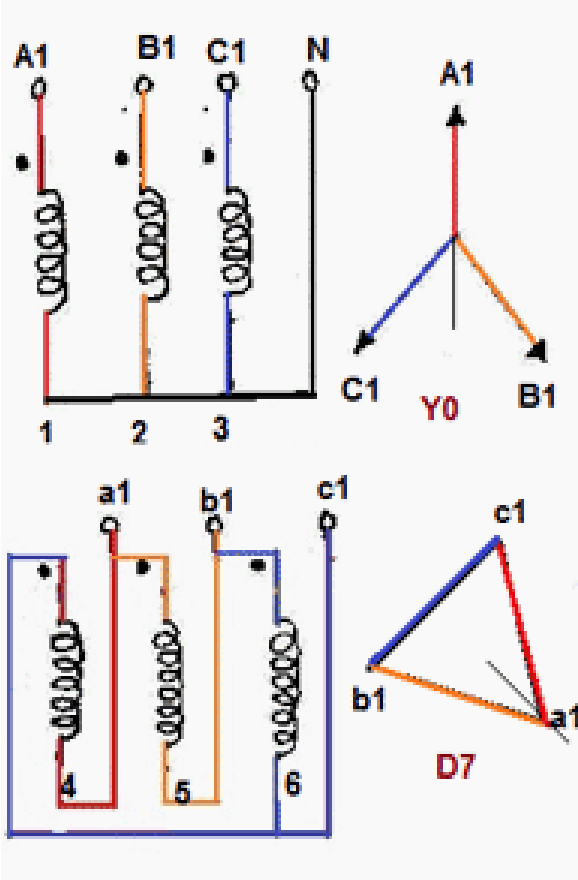


Transmission line
single phase
Pi-model

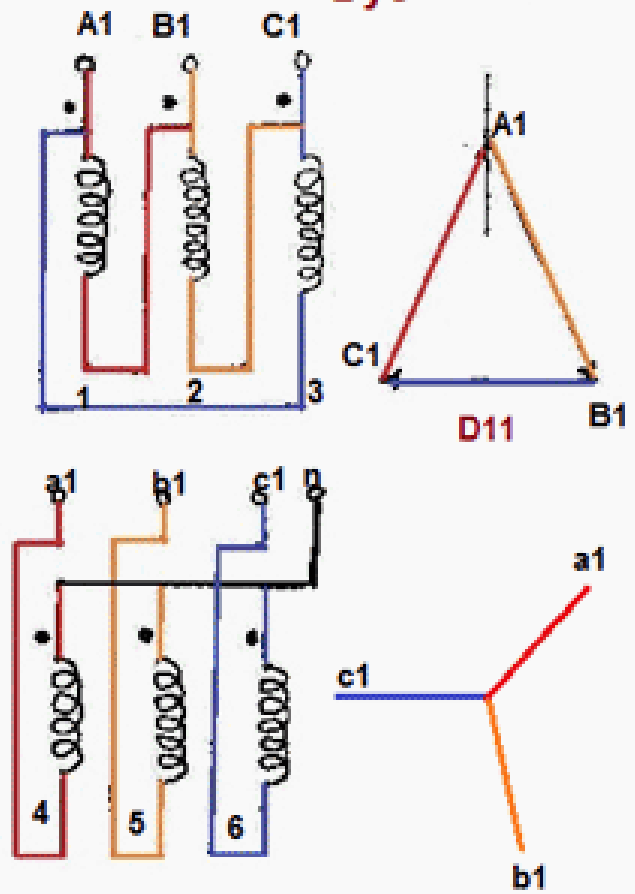


Transformers Configurations

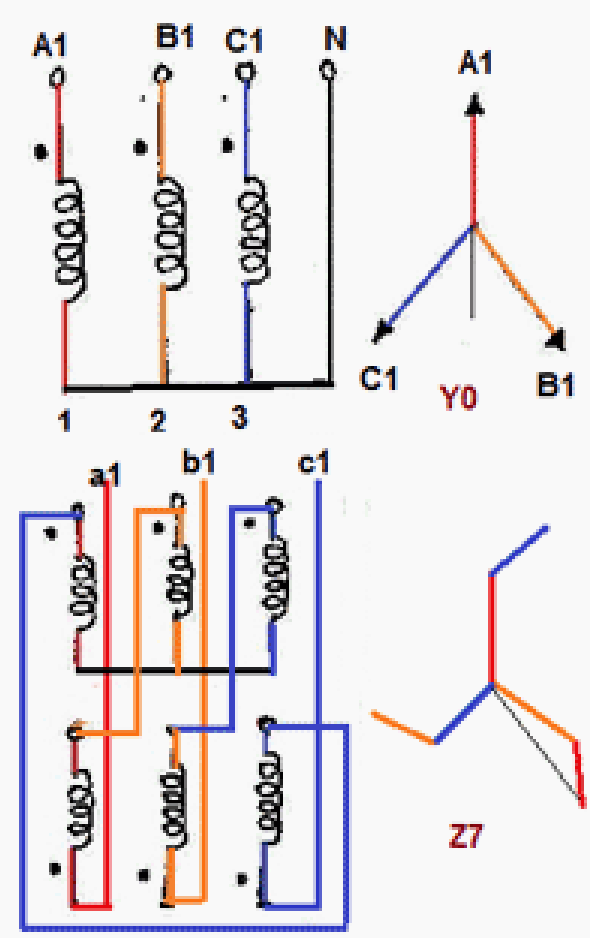
Yd5



Dy5

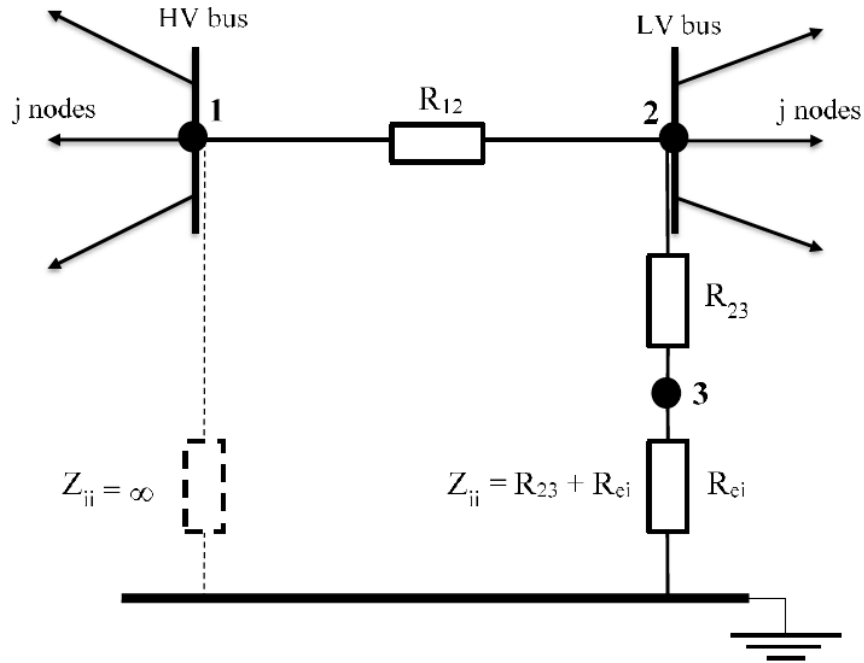


Yz5

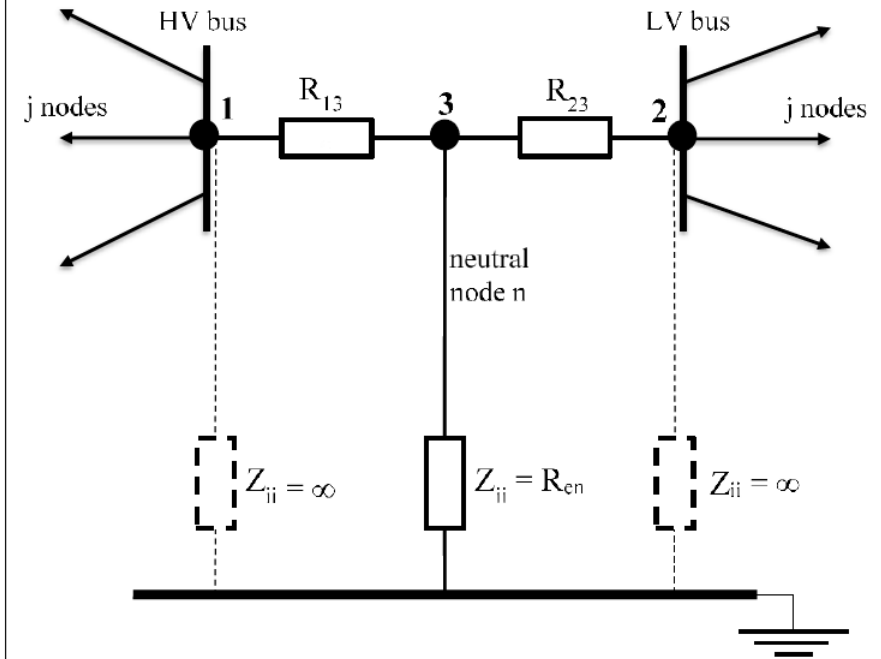


Auto, Star Transformers

Transformer nodes - Auto

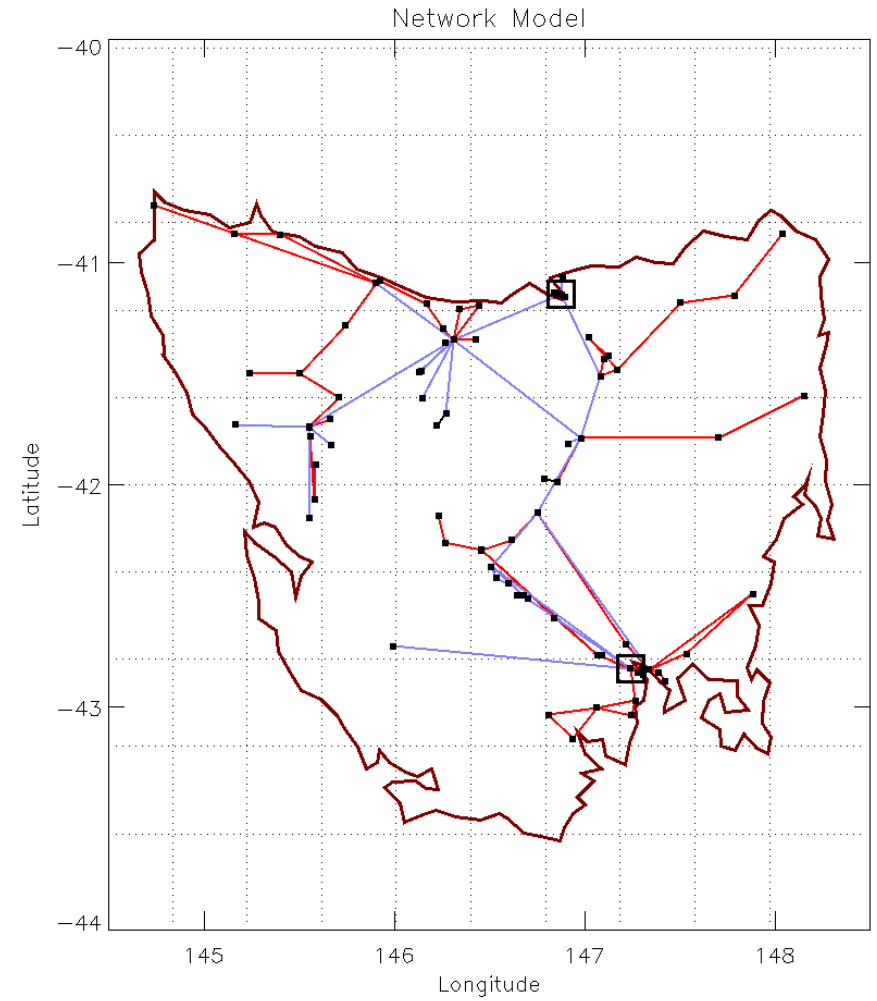
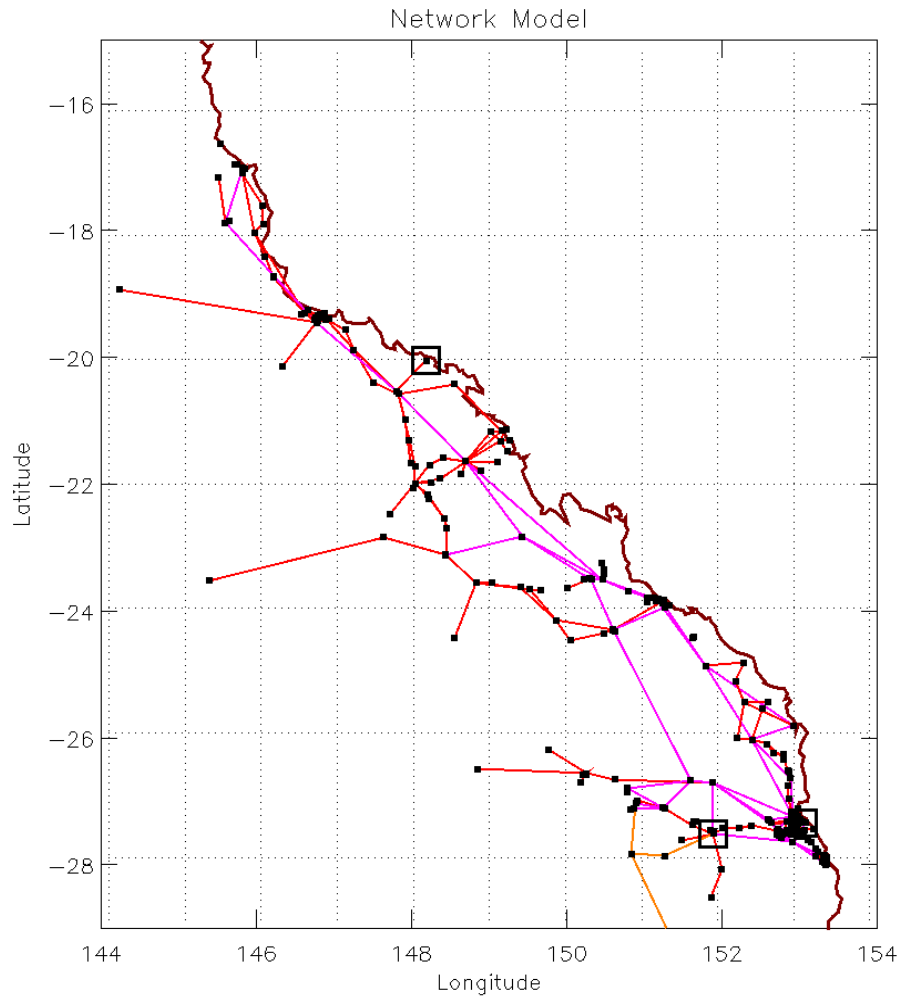


Transformer nodes - Star



(Marshall et al., 2017)

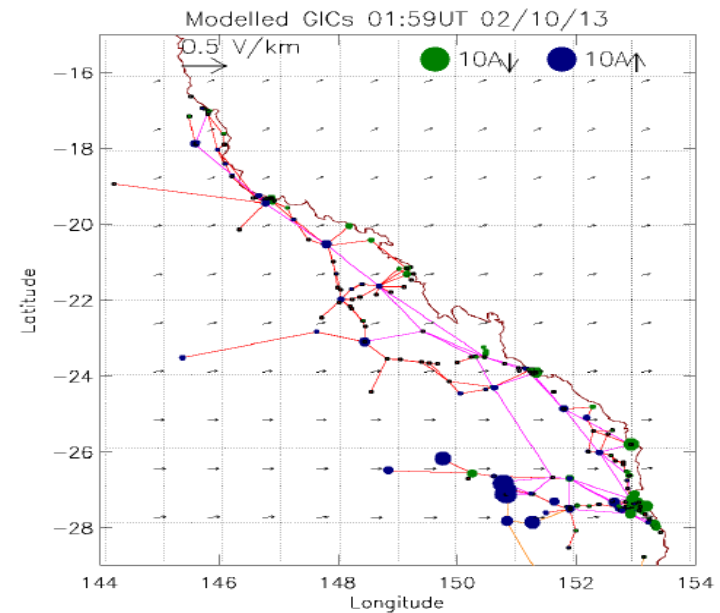
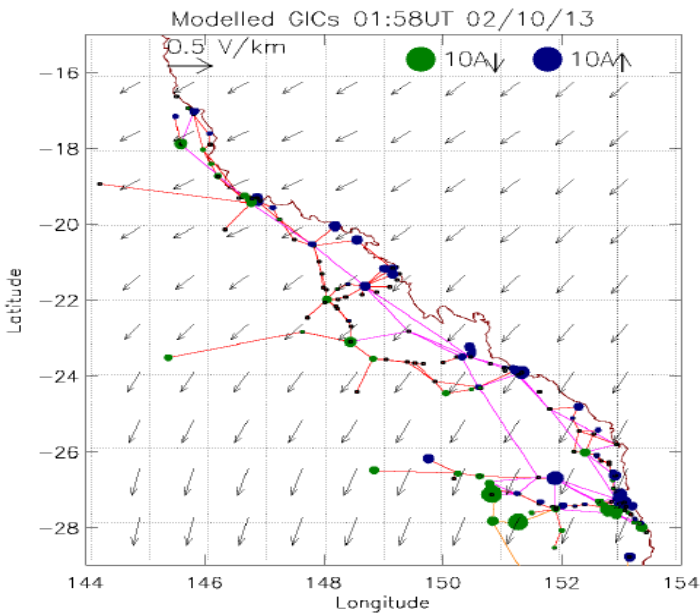
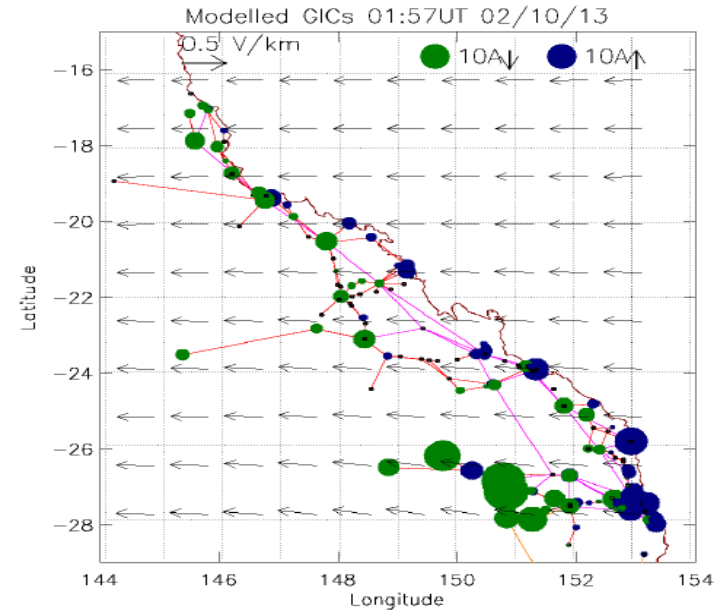
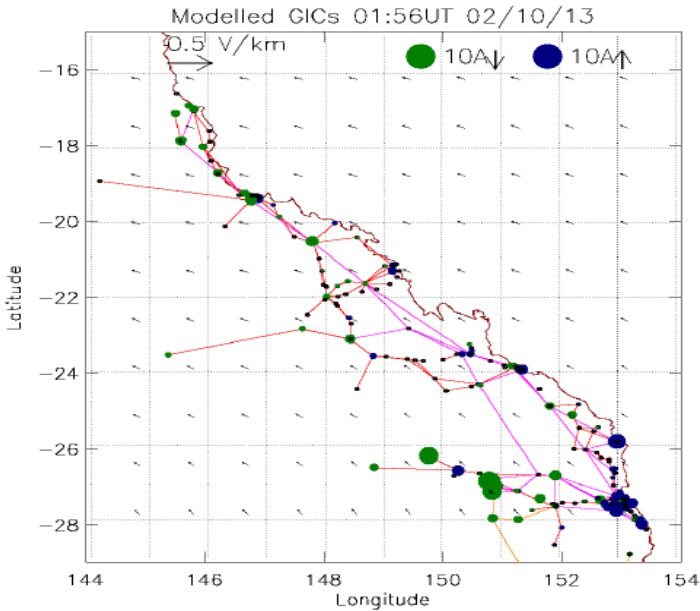
Results!



(Marshall et al., 2017)

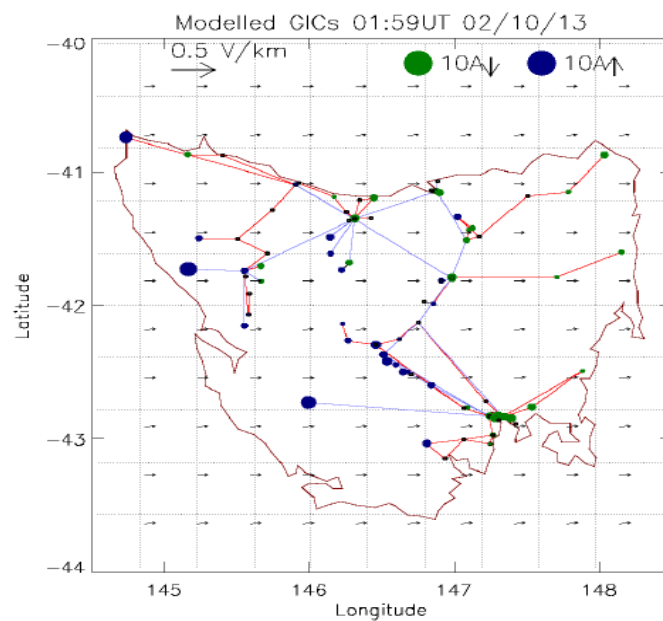
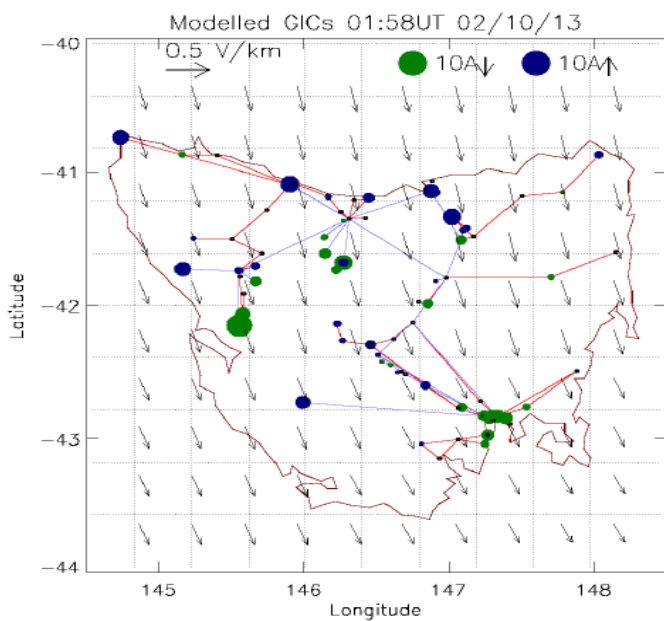
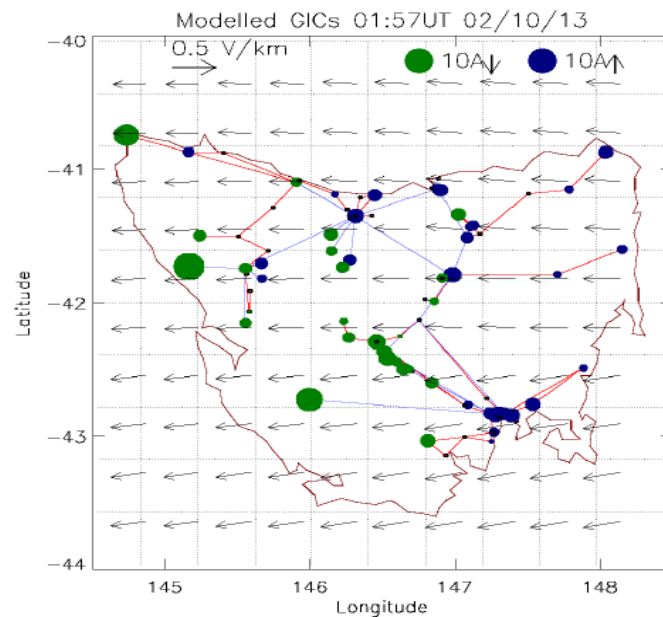
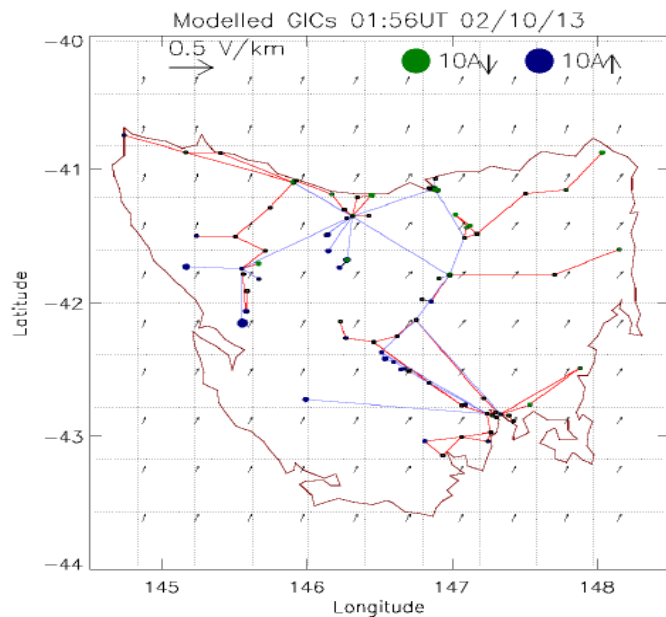
QLD: 2nd October 2013, 0156-0159UT

(Marshall et al., 2017)



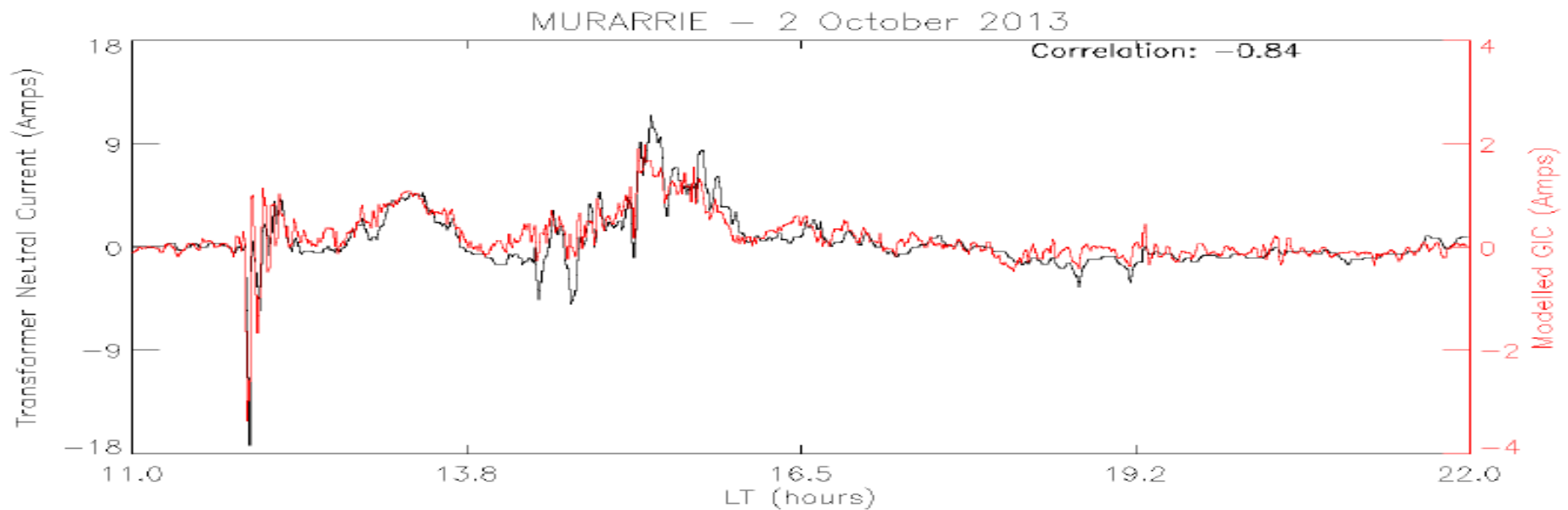
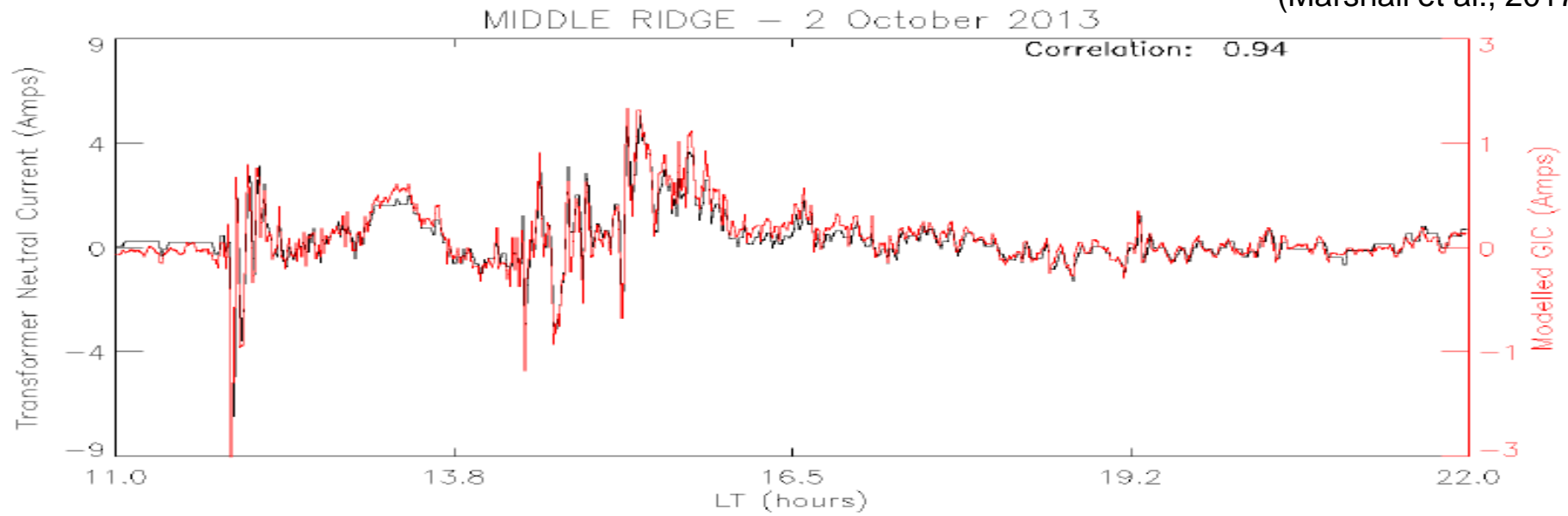
TAS: 2nd October 2013, 0156-0159UT

(Marshall et al., 2017)



Obs vs Model: 2nd October 2013, 11-22LT

(Marshall et al., 2017)

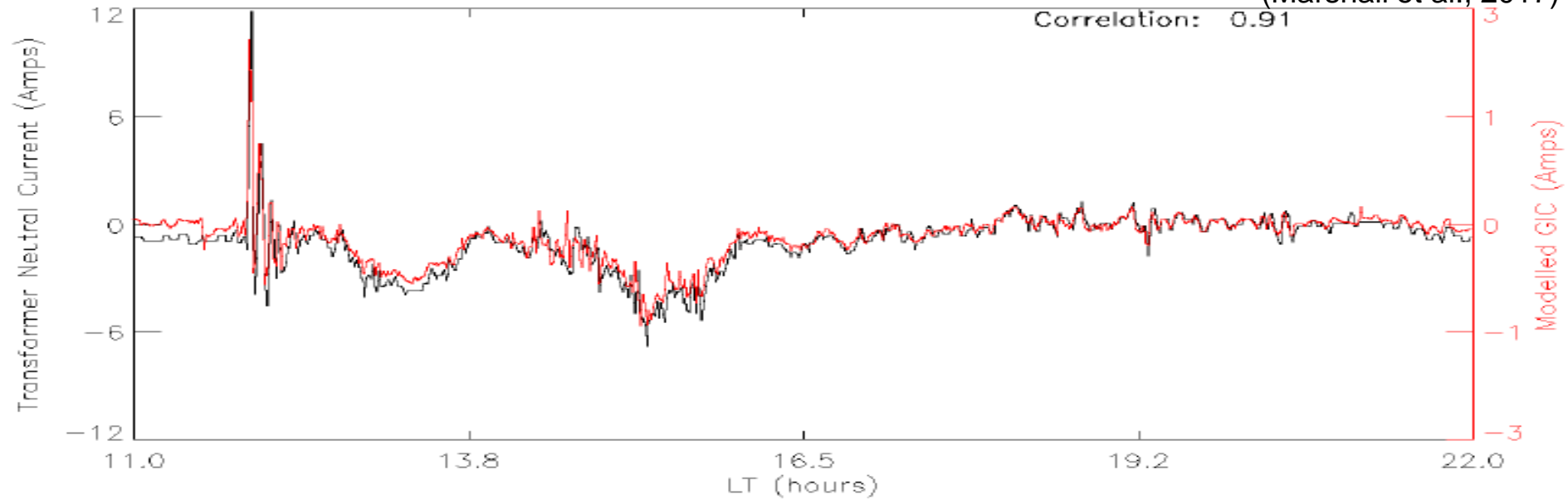


Obs vs Model: 2nd October 2013, 11-22LT

BOWEN NORTH — 2 October 2013

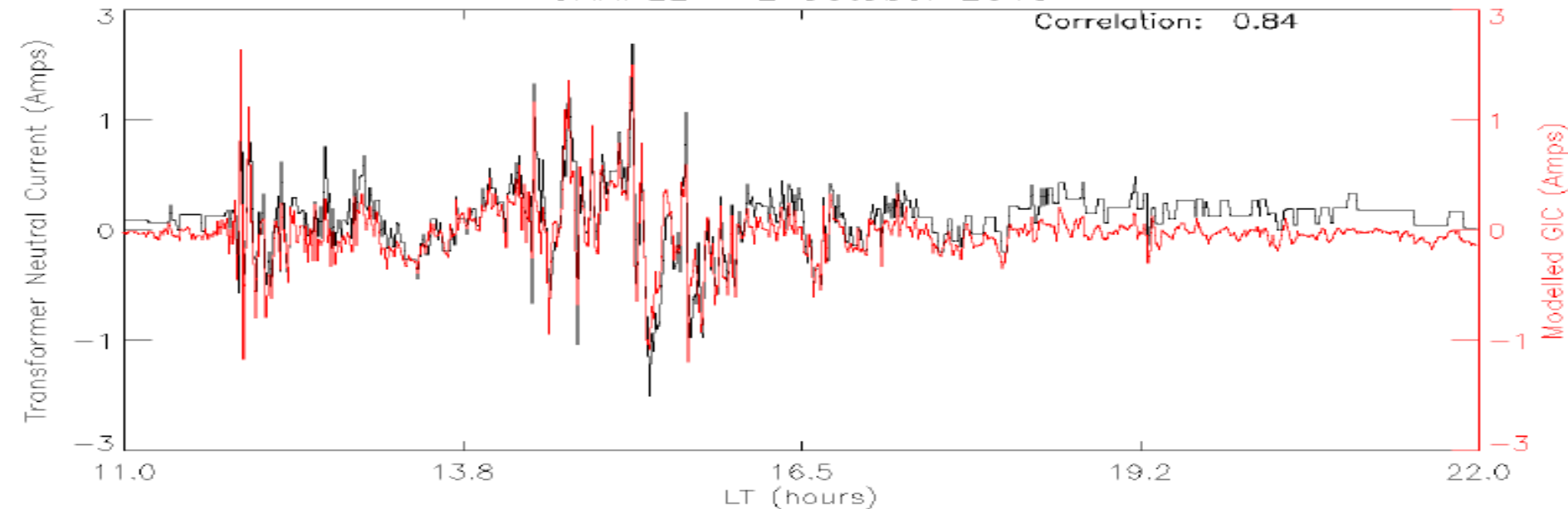
(Marshall et al., 2017)

Correlation: 0.91



CHAPEL — 2 October 2013

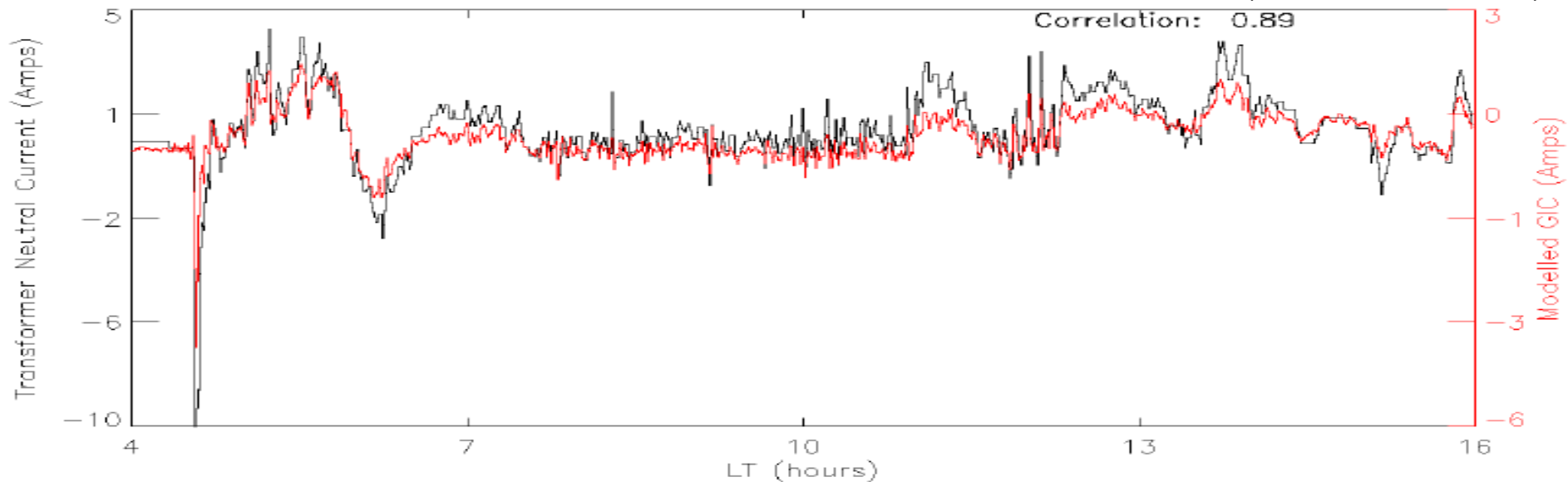
Correlation: 0.84



Obs vs Model: 23 June 2015, 04-16LT

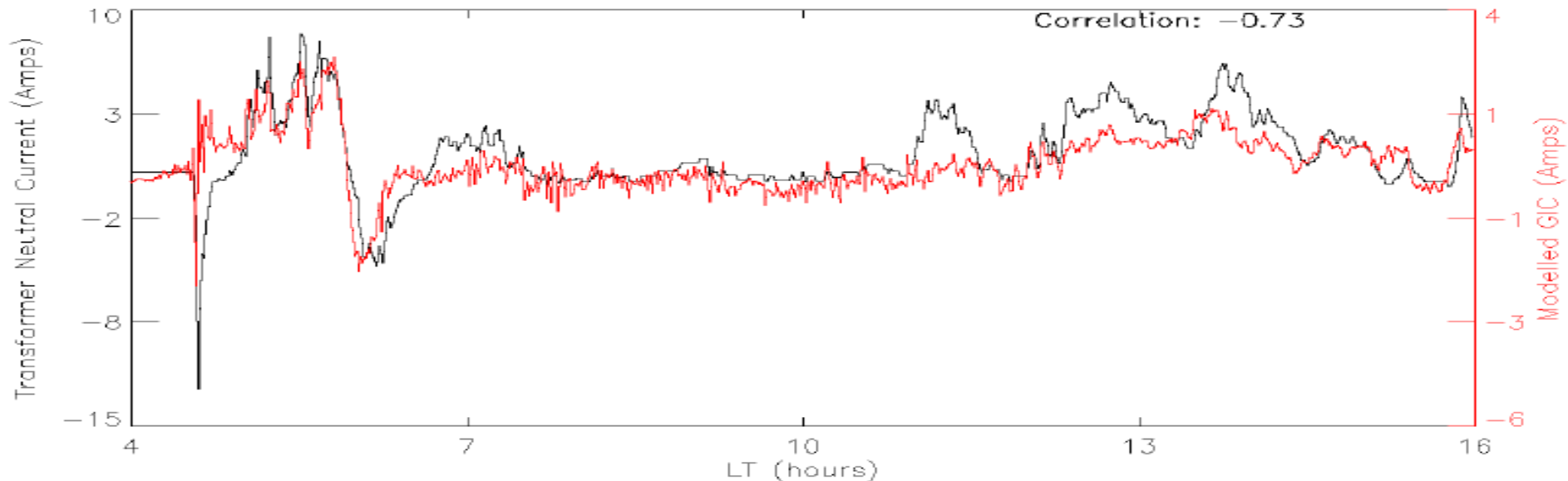
MIDDLE RIDGE – 23 June 2015

(Marshall et al., 2017)



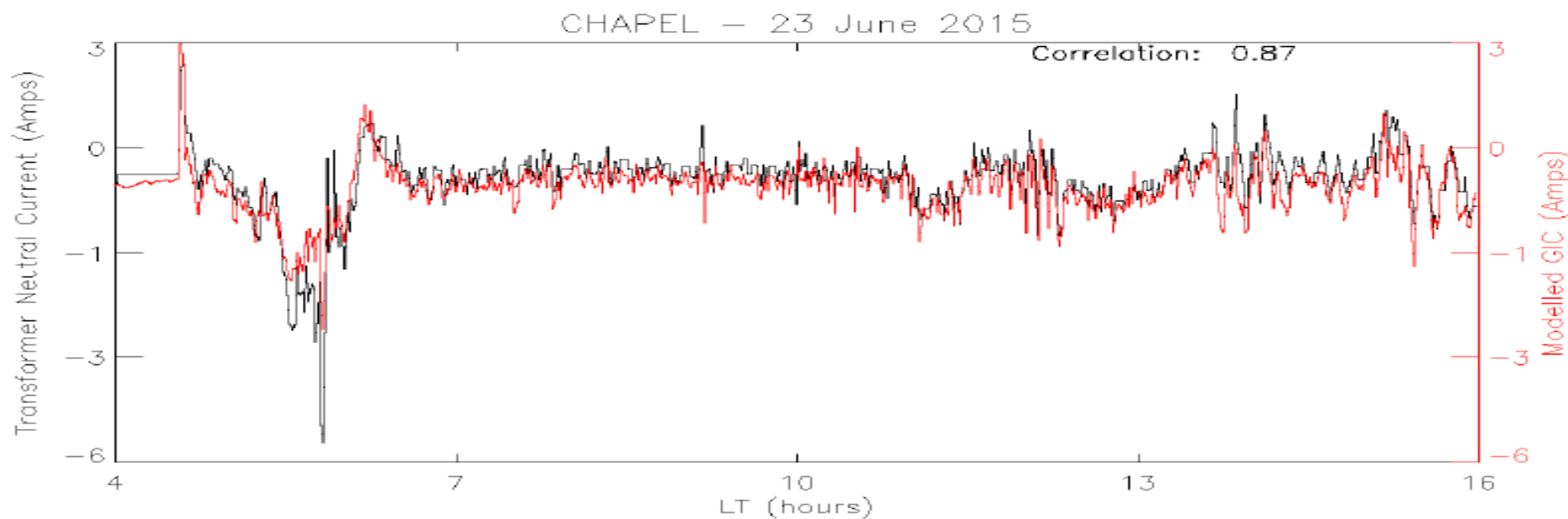
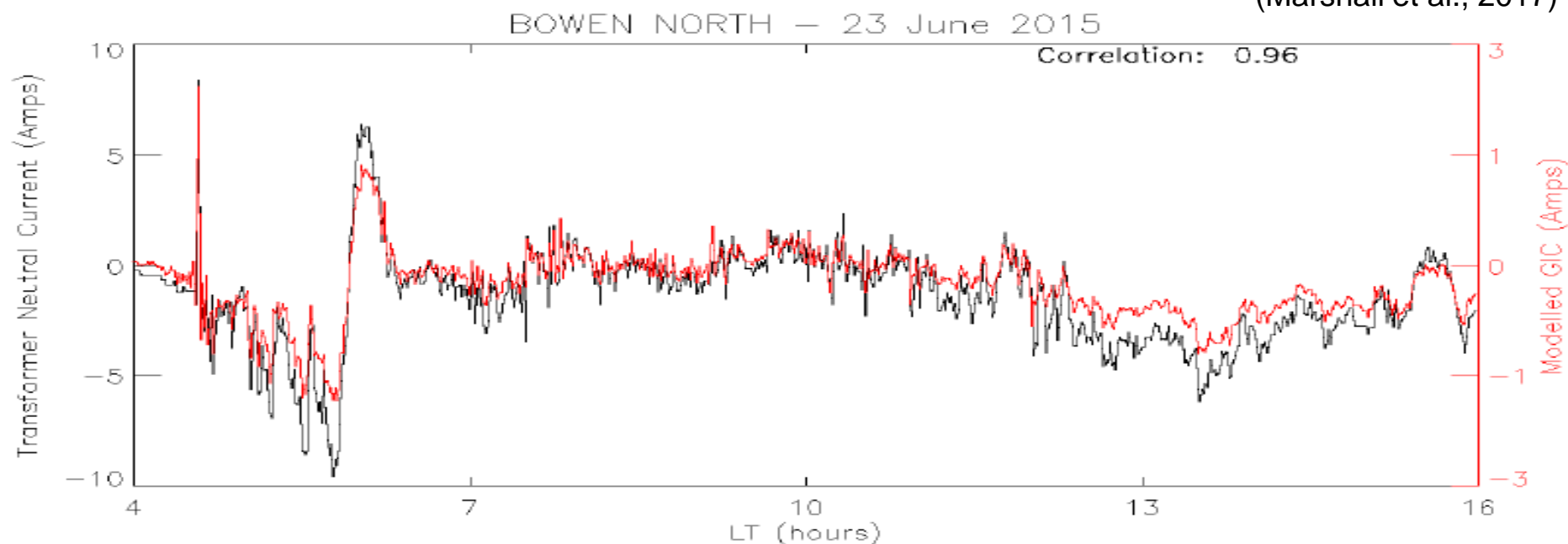
MURARRIE – 23 June 2015

Correlation: -0.73



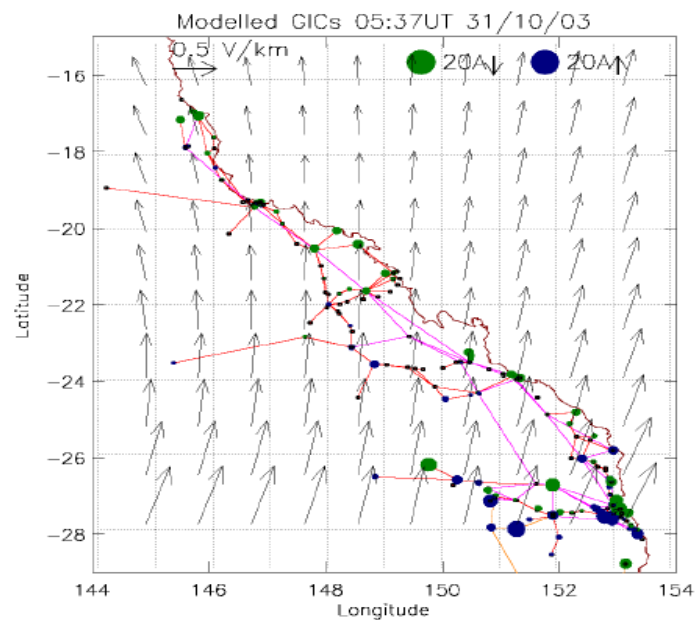
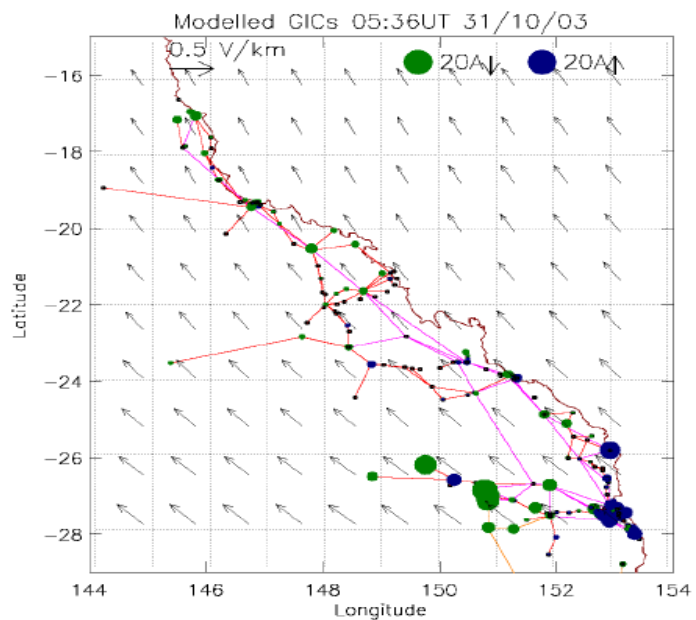
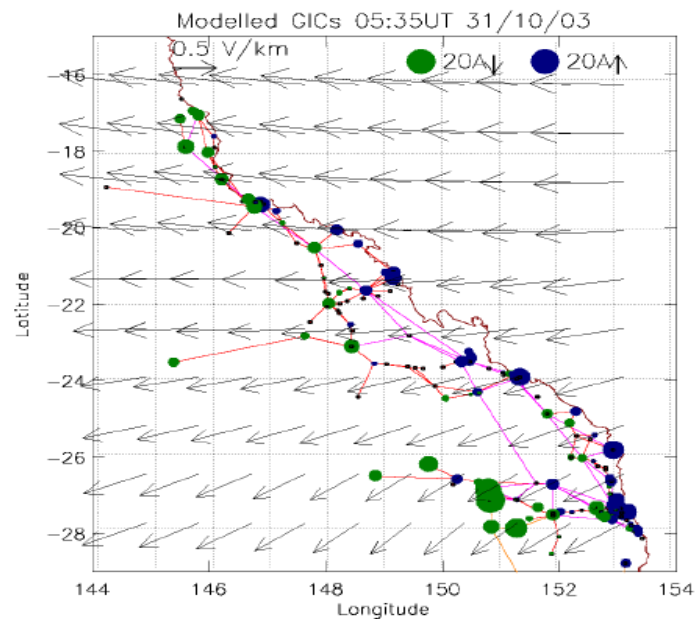
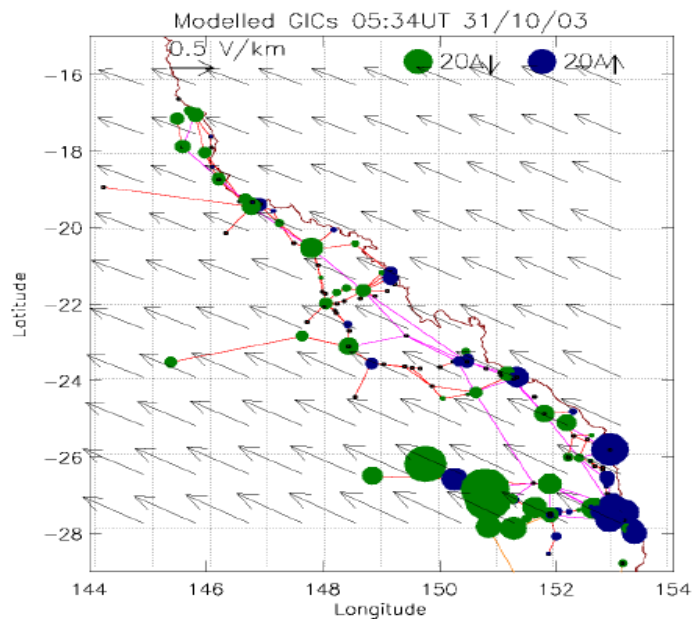
Obs vs Model: 23 June 2015, 04-16LT

(Marshall et al., 2017)



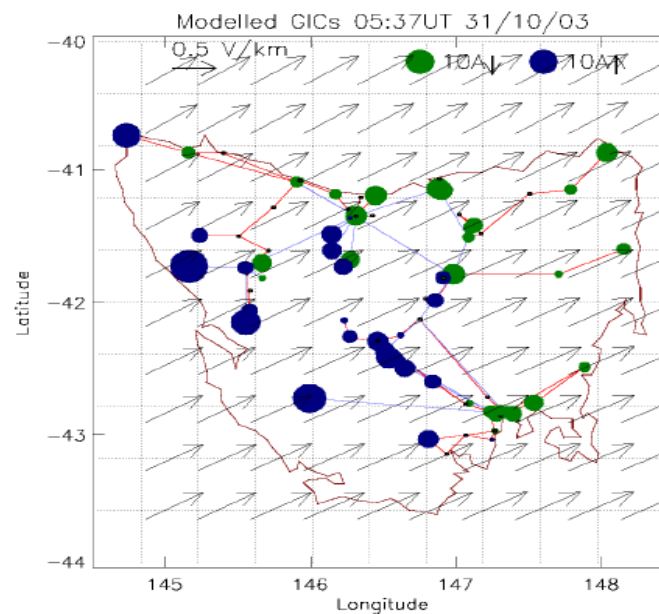
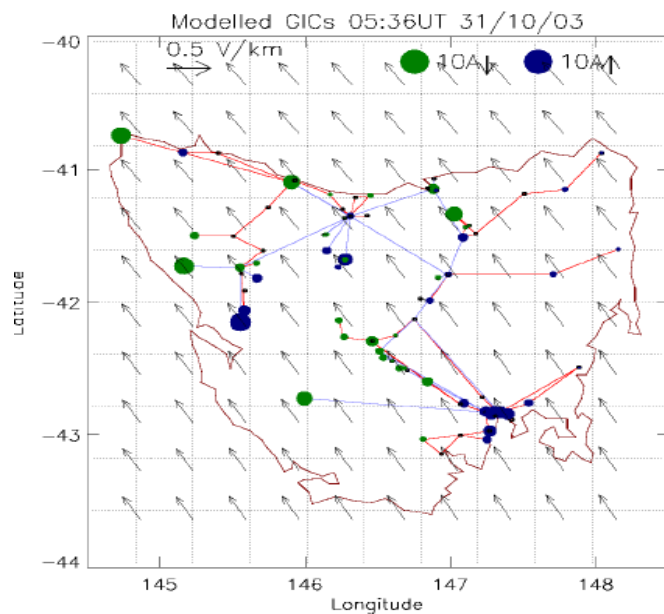
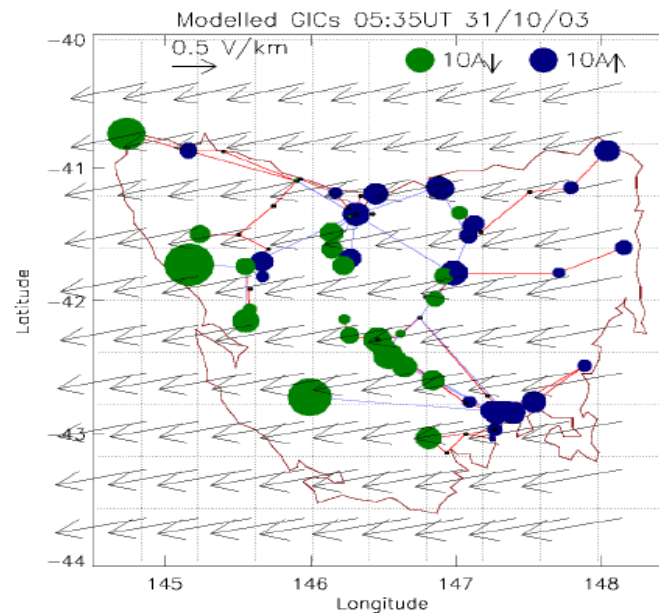
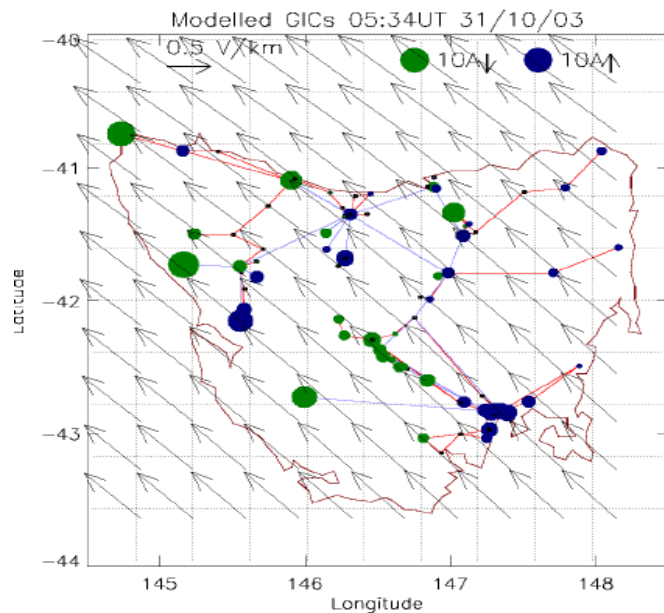
QLD: Halloween 2003, 0534-0537UT

(Marshall et al., 2017)



TAS: Halloween 2003, 0534-0537UT

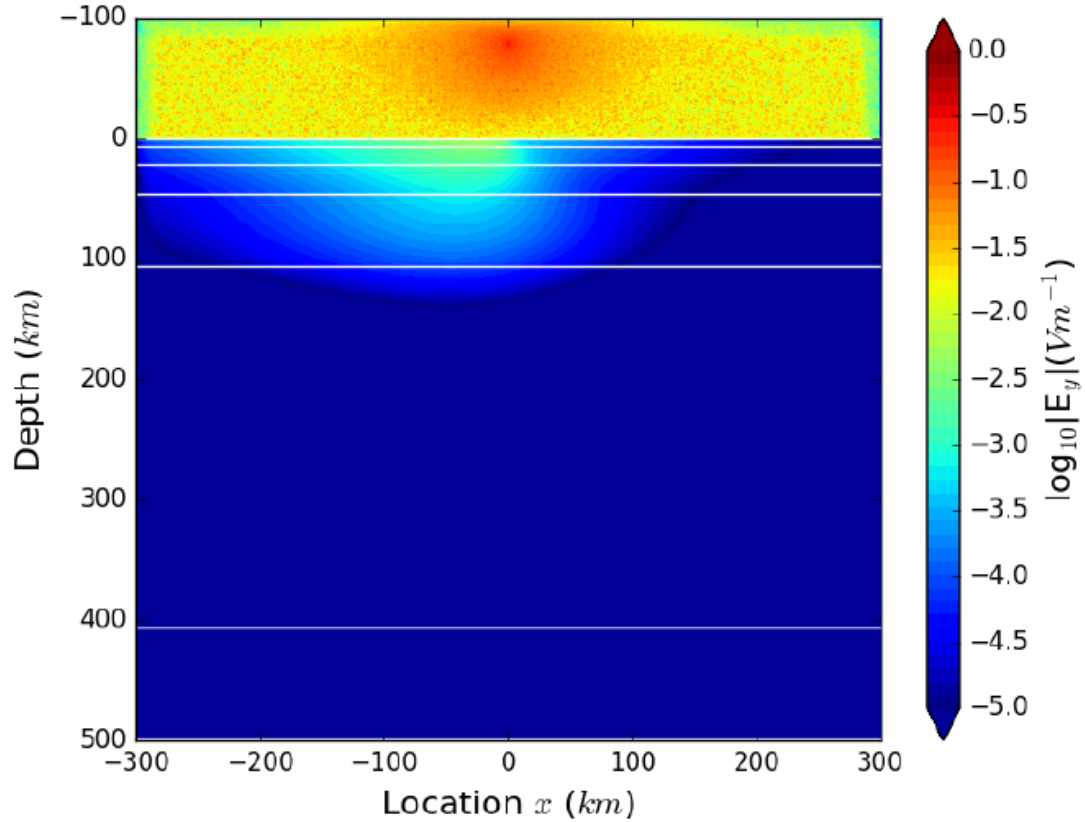
(Marshall et al., 2017)



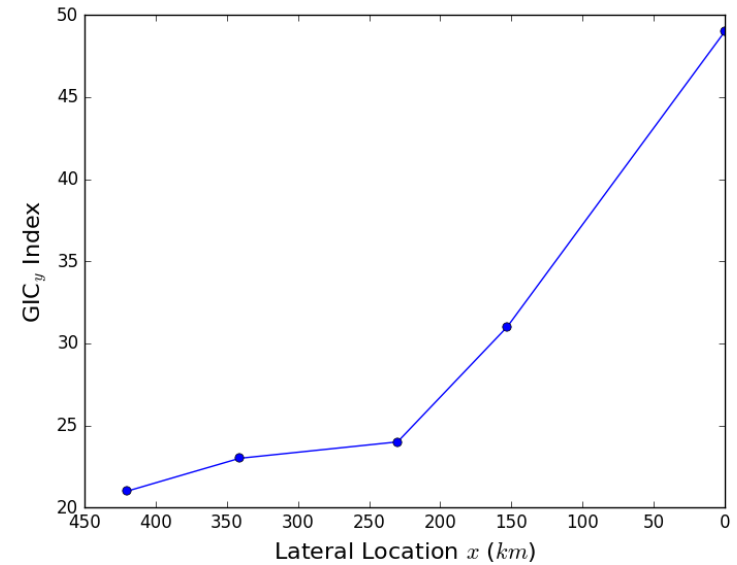
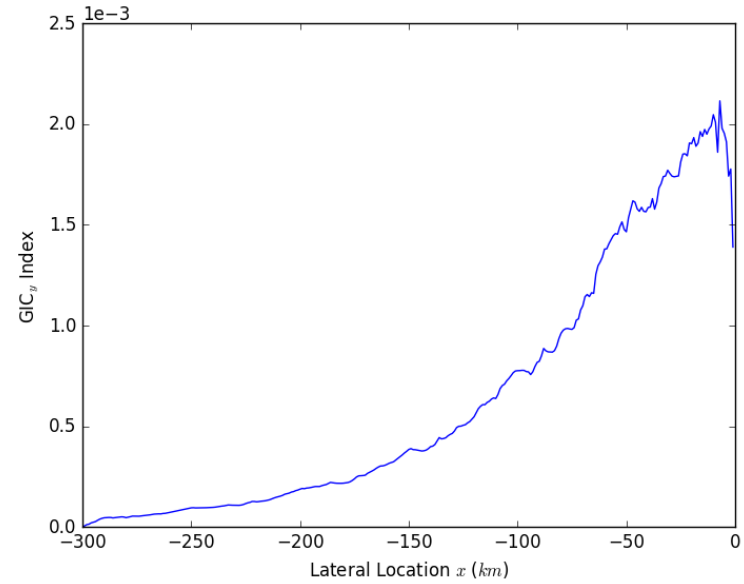
Future

- Obtain additional data for other states and compare model with observations
- Incorporate model results into mitigating procedures
- Operationalize the models to provide near real-time GIC output – in progress
- Incorporate more realistic conductivity models and the derived geoelectric fields

Geoelectric Field – 2D



(Barnett R., 2016)



Geoelectric Field – 3D

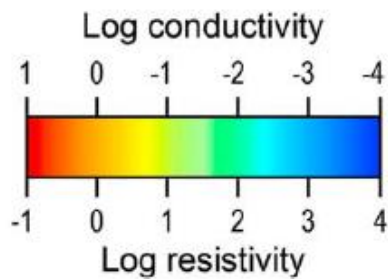
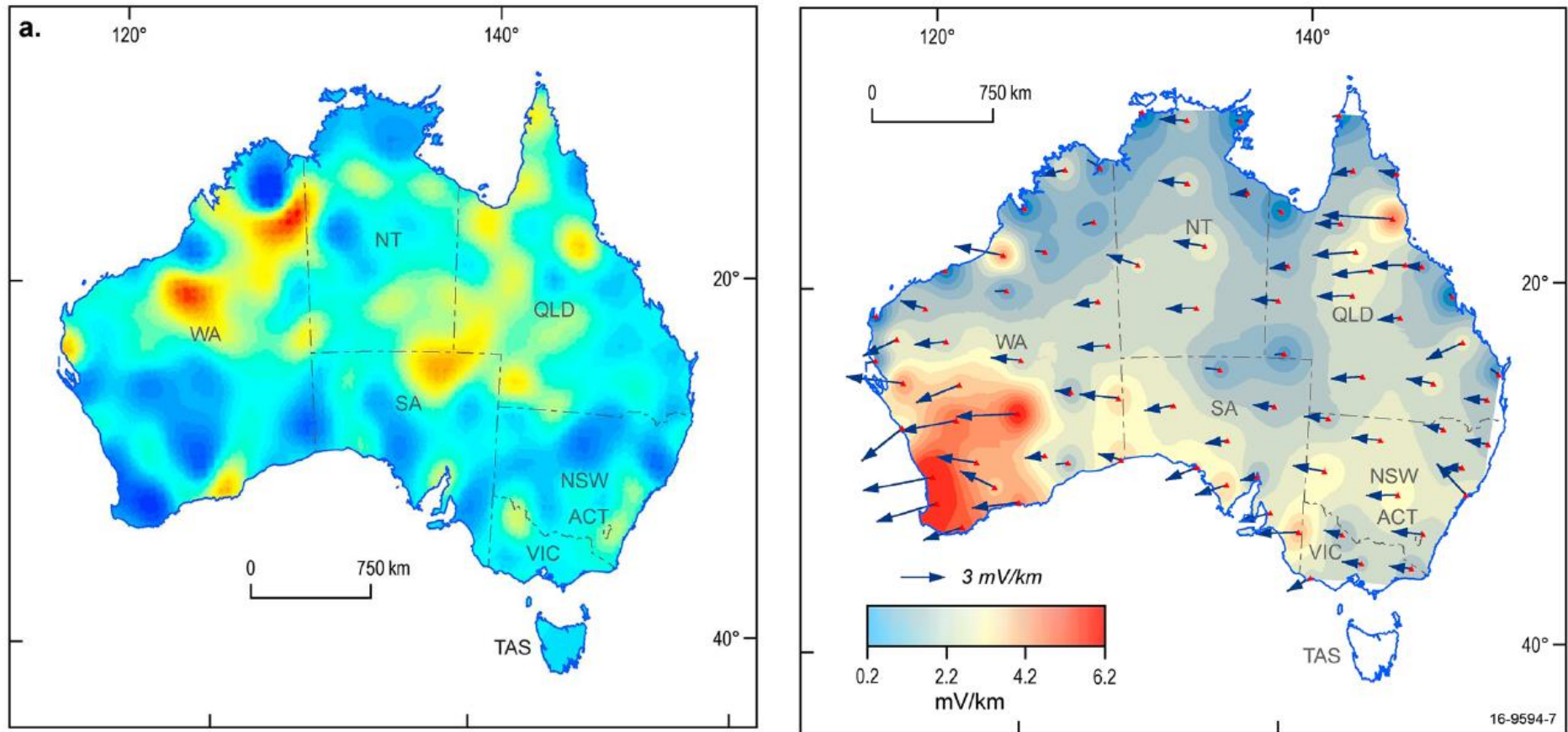


Figure 7. Magnitude of regional electric field component (E_y associated with M_{yx}) and telluric vectors of real e_x for a northerly polarization mode for $|B| = 1$ nT at a period of 360 s.

(Wang et al., 2016, doi:10.1002/2016SW001436)



**T29 –
Postmans
Ridge
(Energex)**

**WED – West End
(Energex)**

**Murarrie
(Powerlink)**

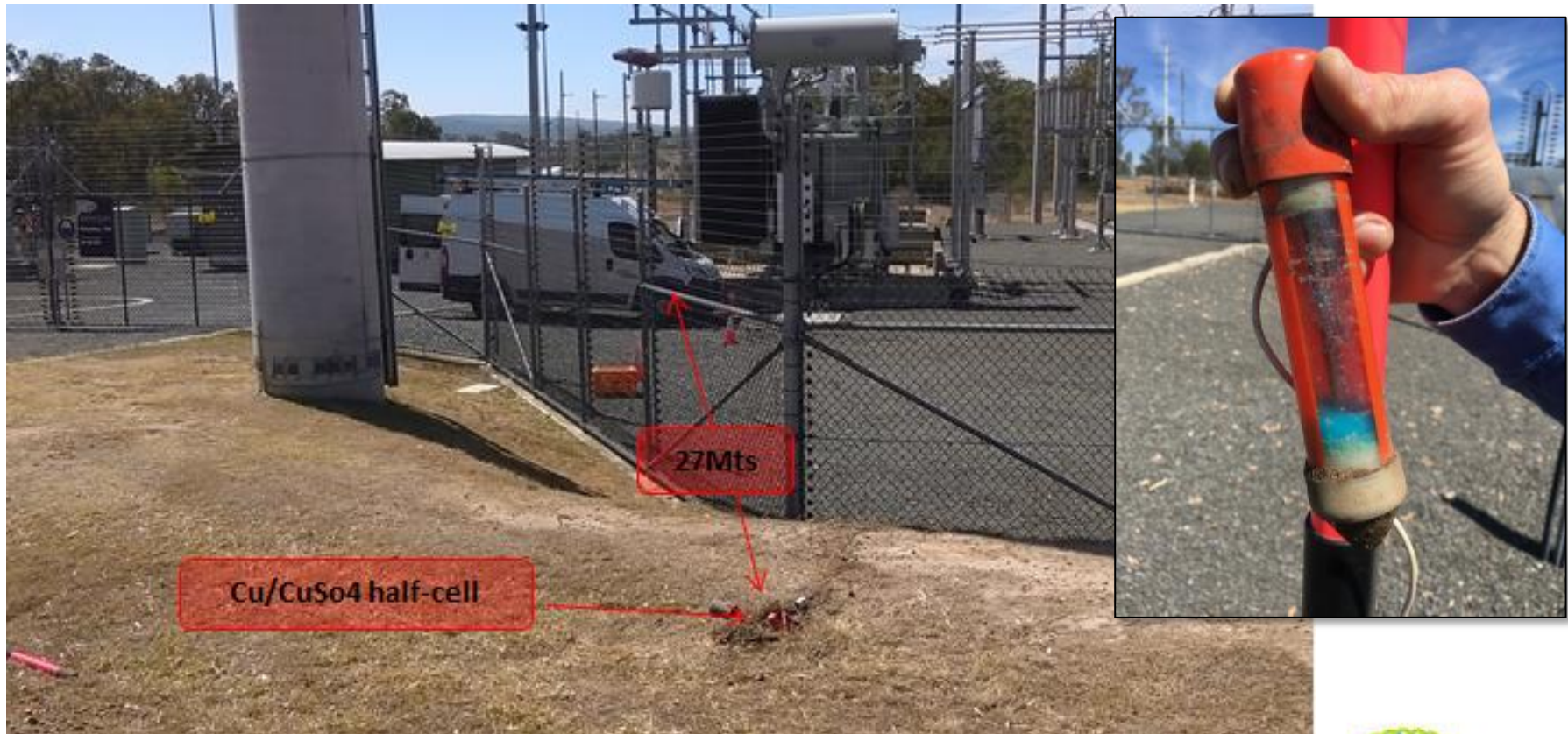
**Middle Ridge
(Powerlink)**

Instrumentation

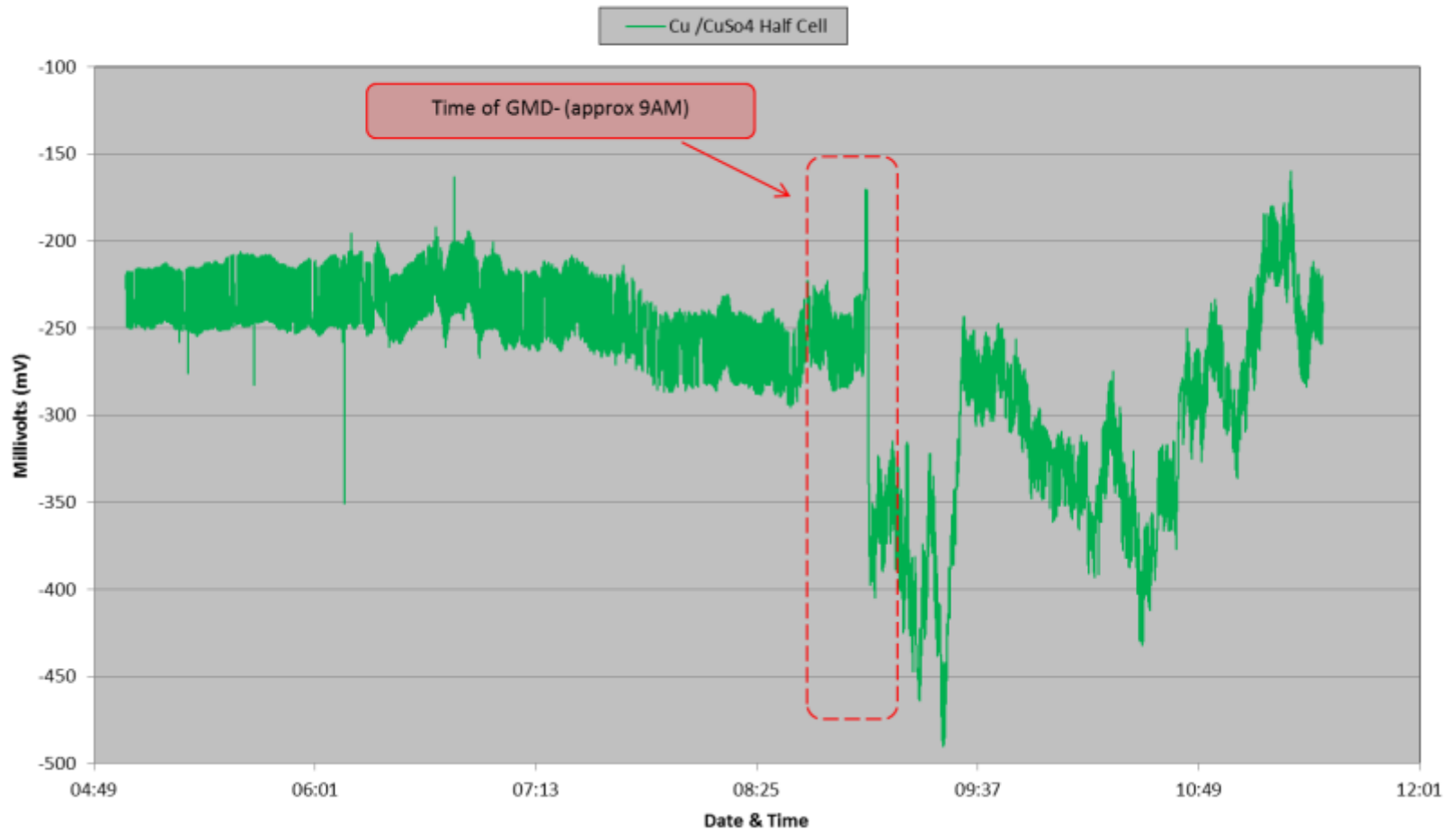
Instrument	Location	Description	Dates
Hioki 8880 serial #151111189	SST29 TR5 Earthing	Both NEX Earth cable AC & DC current & Half Cell reference voltage.	8-9-2017 – 12-9-2017
Eberle PQ 150 serial # 1711-015	SST29 110kV TR5 VT & CT	110kV AC supply at T29 & TR5 Load Current including harmonic distortion (odd & even)	8-9-2017 – 12-9-2017



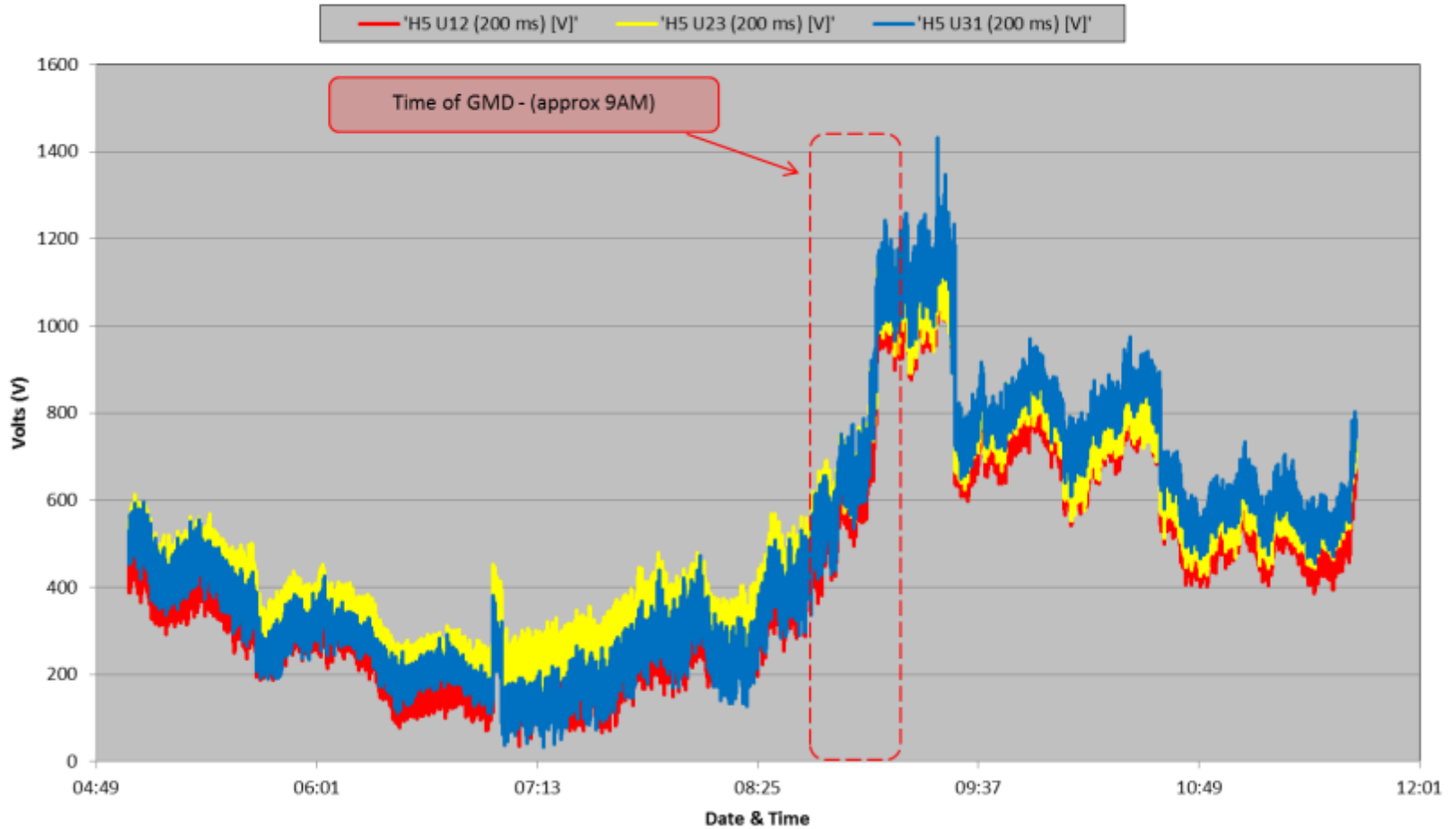
Instrumentation



SST29 Substation Earth - Cu/CuSo4 Halfcell (outside substation fence) 8-9-17 @ 05:00 - 11:30



SST29 110kV transformer (T5) - 8-9-2017 5th Harmonic voltage profile (200msec data)





Australian Government

Bureau of Meteorology

Thank you...

Richard.Marshall@bom.gov.au

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