Improved methods for surface impedance estimation in modelling of geomagnetically induced currents in power networks

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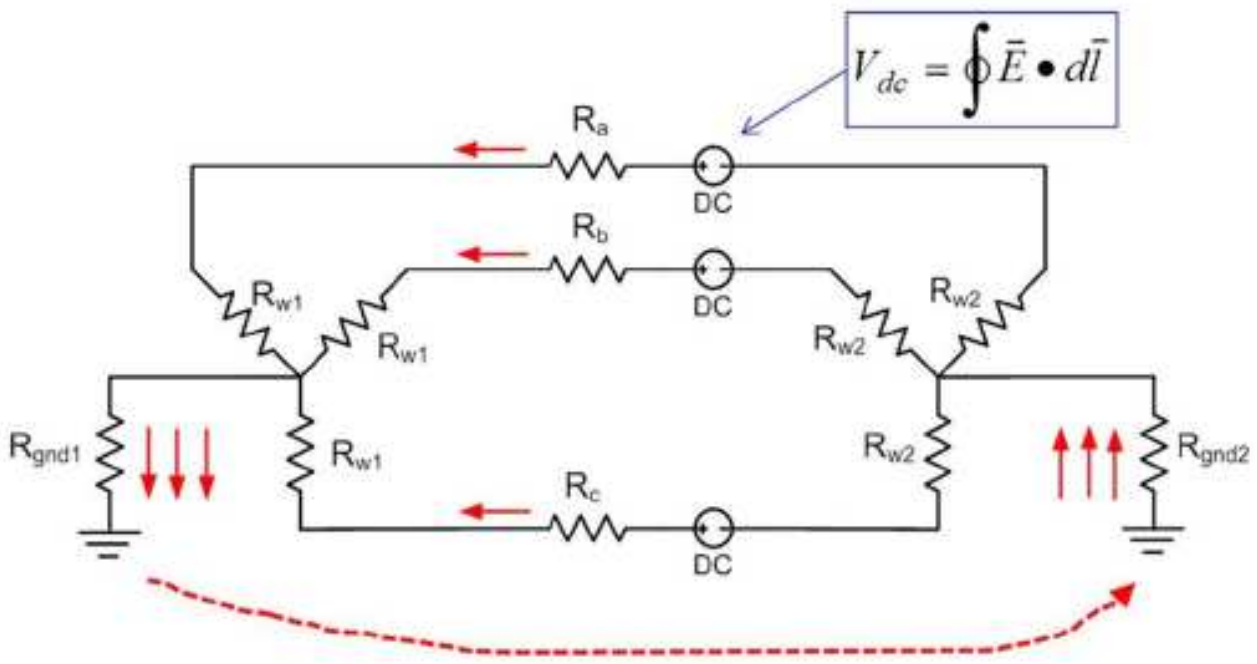
Space weather

- Space Weather related geomagnetic field variations can adversely affect power transmission networks through outages caused by
  - Spurious tripping
  - Temporal or permanent damage to high voltage power transformers
- The prediction of potential GIC hot-spots in a power network should be considered in future planning in order to improve the security and reliability of electricity supply.

Illustration of GIC flow in the power system

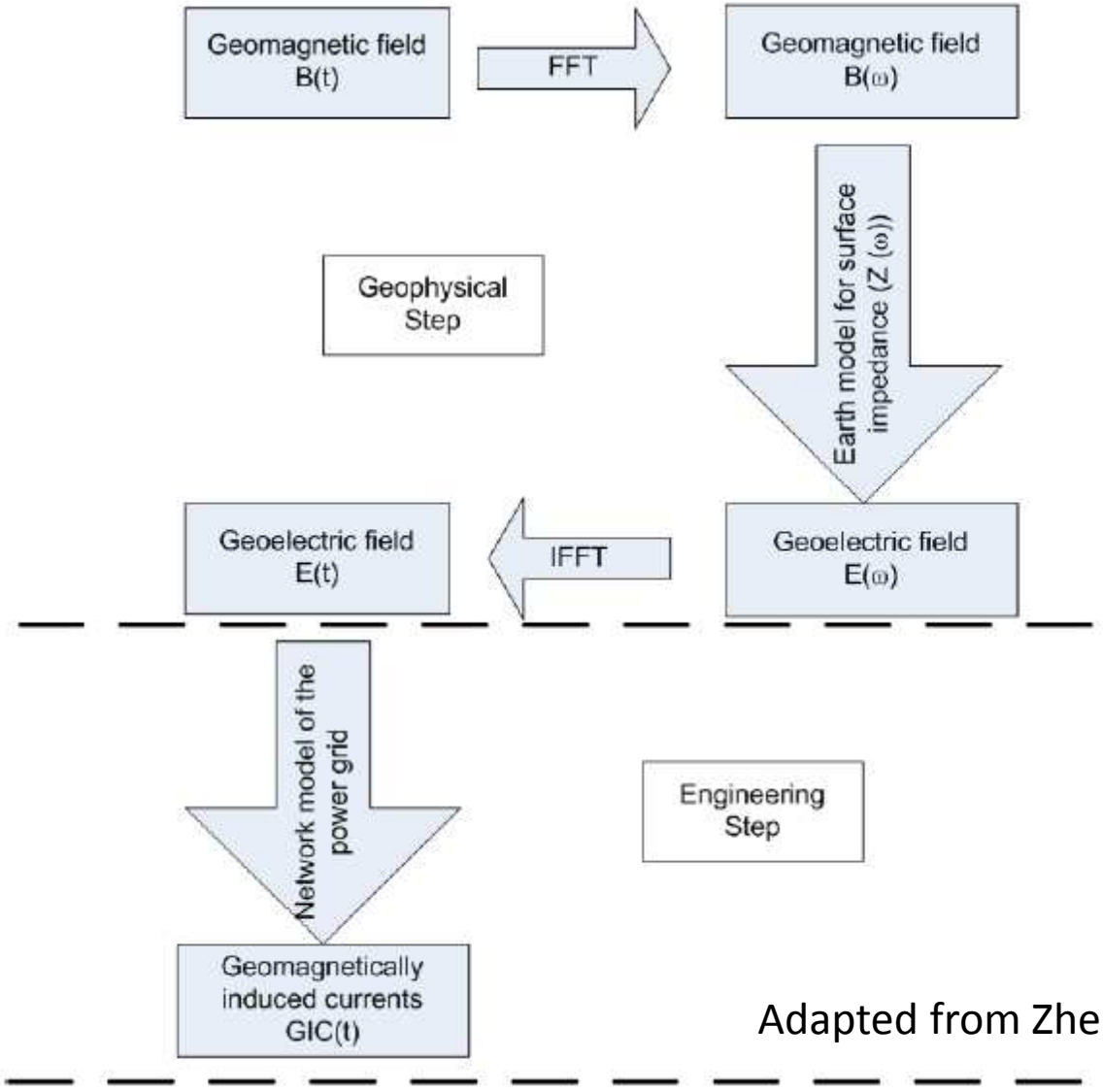


https://www.powerworld.com/files/GICGroundLoop.jpg

E-field calculation

- The estimation of GICs from measurements or predictions of the fluctuations in the geomagnetic field comprises two steps:
  - The *geophysical step:* estimates of the geo-electric field along each power line
  - The *engineering step* which applies these geo-electric field estimates to the network

E-field calculation



Adapted from Zheng et al., 2013.

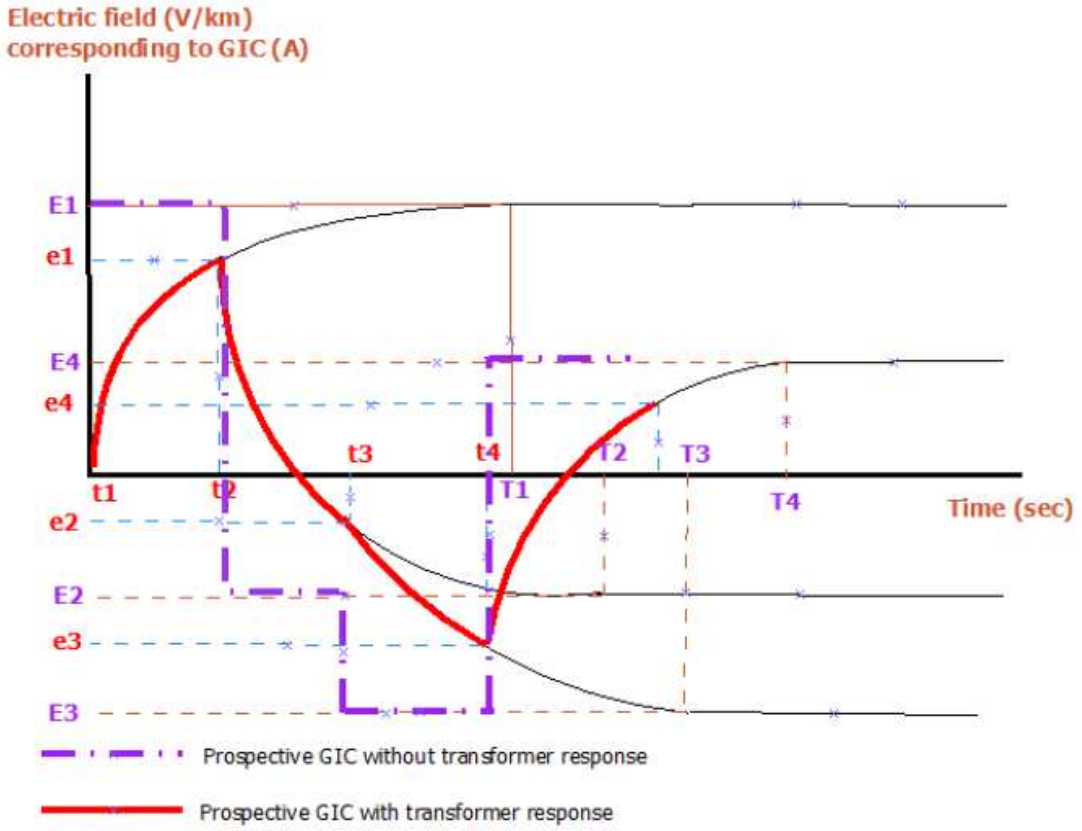
E-field calculation

- The geophysical step: Significant source of error in the modelling chain.

- This stems from the assumption that GICs in networks are related to an induced plane-wave geoelectric field
  - E-field derived using limited knowledge of the Earth's conductivity profile and associated surface impedance.

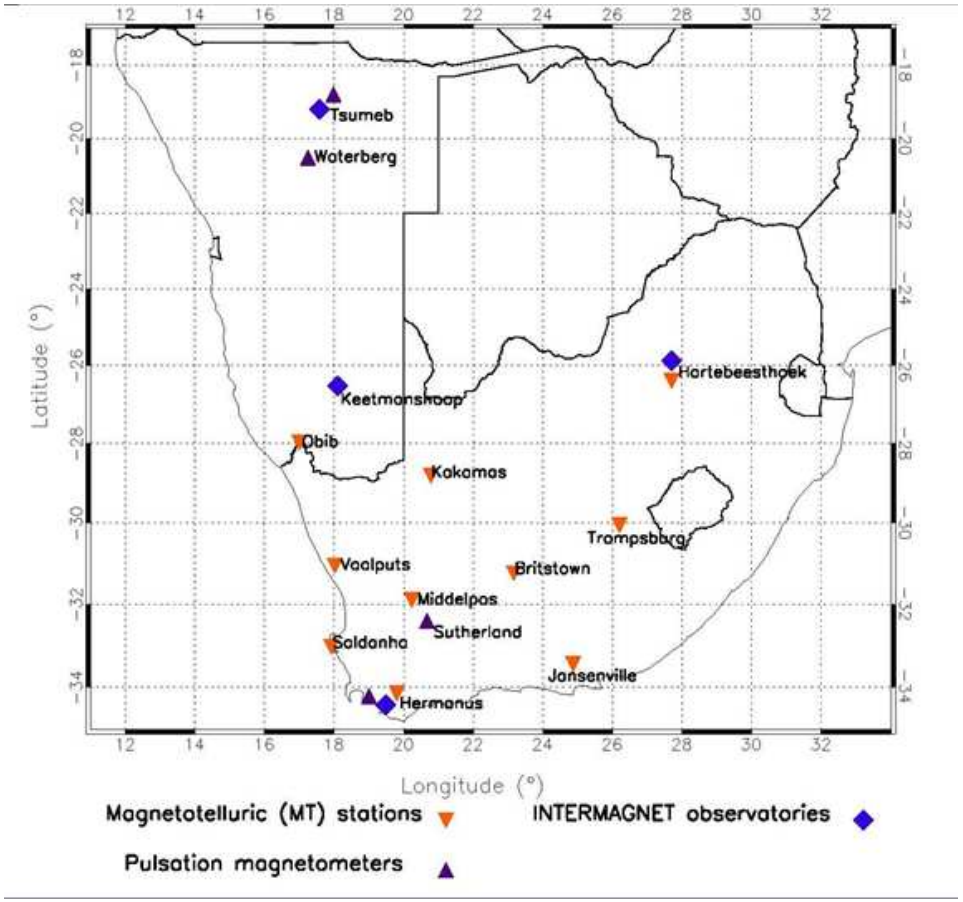
Other sources of modelling error

- Transformer response



DTO Oyedokun, 2015

Magnetic observatories and MT stations



Locations of the INTERMAGNET magnetic observatories and magnetotelluric (MT) stations in Southern Africa which are used for the estimation of the surface impedance tensors at each location.

Interpolation of the B-field

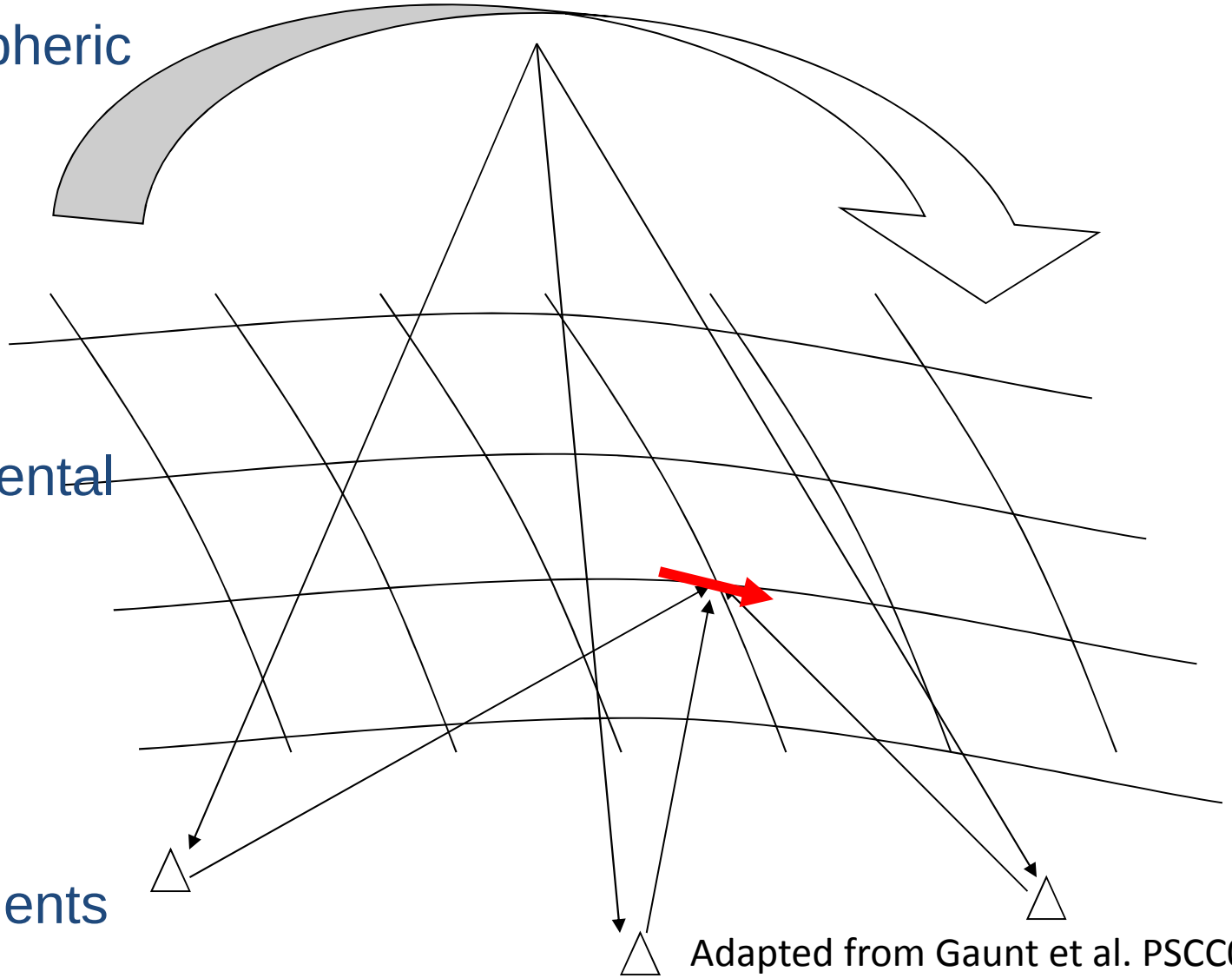
- The Spherical Equivalent Current Systems (SECS) is a commonly used approach to find the magnetic field at the location of the power lines
- Derives the characteristics of a hypothetical array of current elements in the ionosphere based on measurements of the geomagnetic field at several locations on the ground, typically at magnetic observatories.
- The SECS method then applies the Biot-Savart Law to the x- and y- components of the array of currents, to find the B_x, and B_y components, respectively, of the surface *B*-field at any coordinate of interest.

Interpolation of Magnetic field

Actual ionospheric current

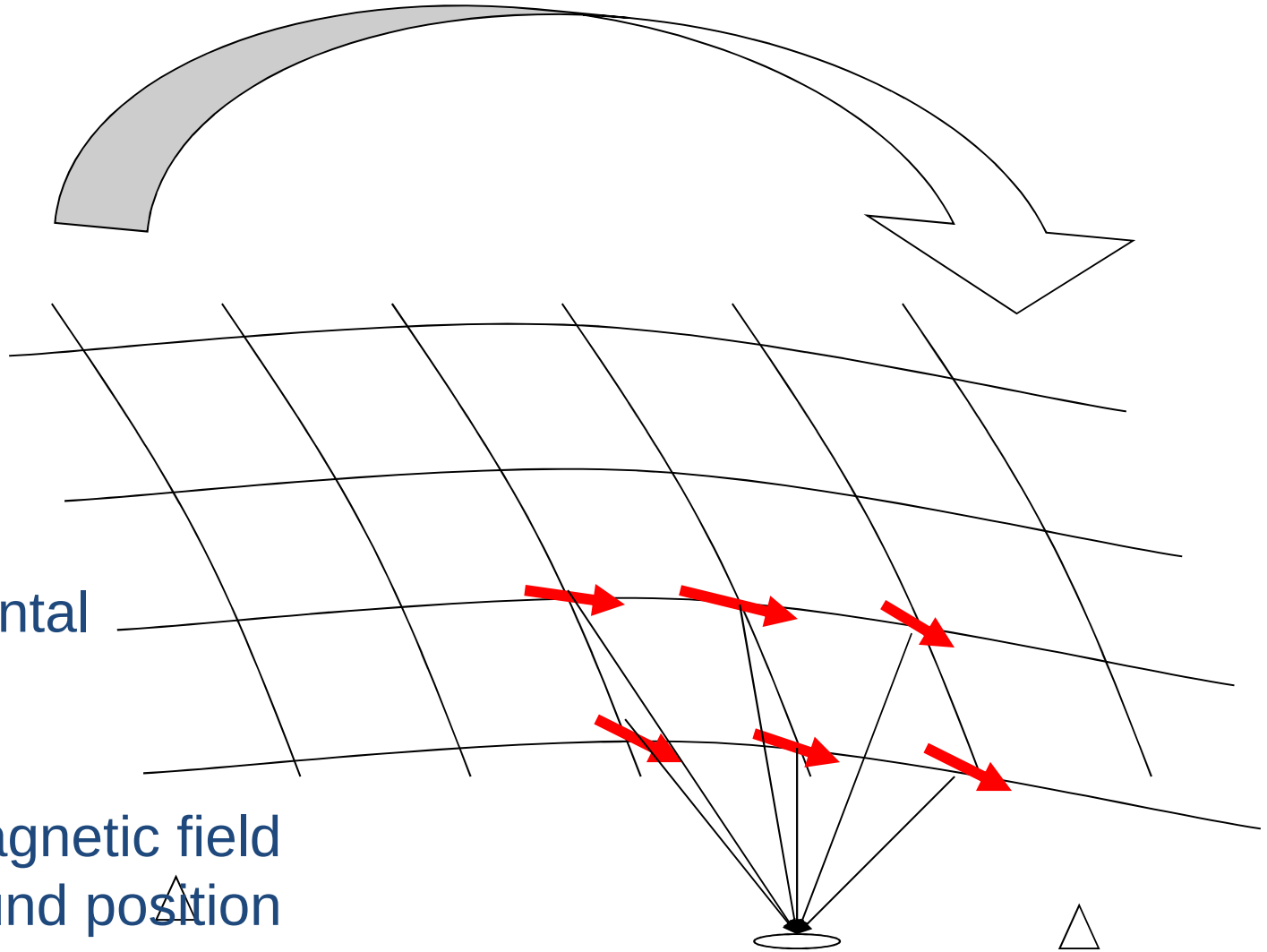
Grid of elemental currents

Ground field measurements



Adapted from Gaunt et al. PSCC08

Interpolation of Magnetic field



Grid of elemental currents

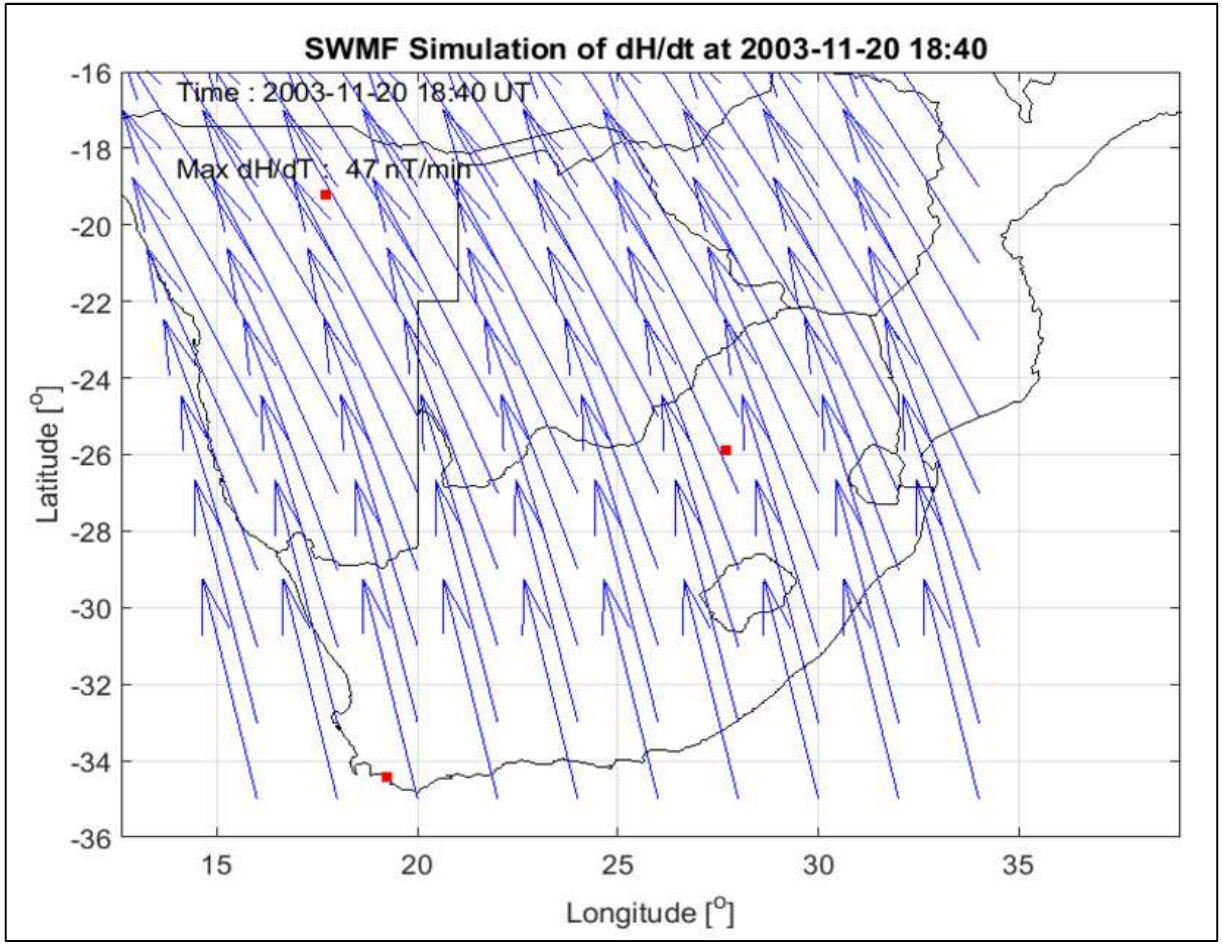
Horizontal magnetic field at any ground position

Adapted from Gaunt et al. PSCC08

Interpolation of the B-field

- Accuracy of the B-field interpolation method was estimated by using a simulated field for a whole day obtained by means of the University of Michigan Space Weather Modelling Forum (SWMF).
- The interpolated field components (dB_x/dt, and dB_y/dt) at a 2 x 2 degree grid of virtual observatories were derived from the simulated vector components of the total field at each of the four geomagnetic observatories in Southern Africa Hermanus (HER, 19.43°E,33.22°S), Hartebeesthoek (HBK, 25.88°E,27.70°S), Tsumeb (TSU, 19.20°E,17.58°S) and Keetmanshoop (KMH, 26.32°E,18.06°S).
- The simulated field was derived from solar wind parameters measured during the geomagnetic storm of 2003-11-20.

Interpolated B-field

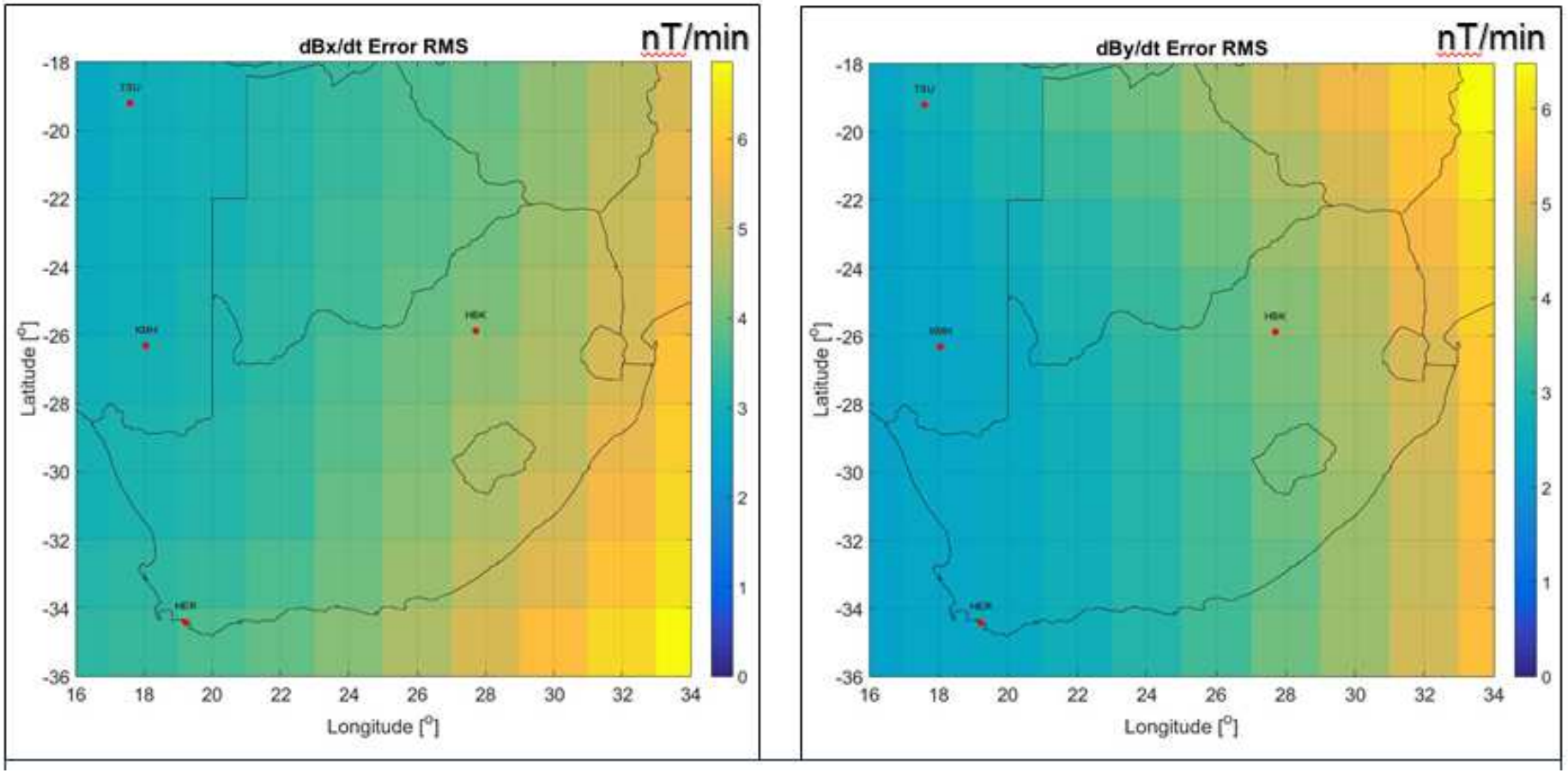


Simulated B field over Southern Africa at 2x2 degree grid points at the peak of the 2003-11-20 storm.

Verification of dB/dt interpolation method

- For the comparison between simulated and interpolated B-field we use dB/dt rather than the absolute values of the field
  - dB/dt is a better proxy of the electric field than the absolute values of the field

Magnetic field (dB/dt) interpolation



Plots of the RMS error, in nT/min, for *dBx/dt* (Left) and *dBy/dt* (Right) , between simulated and interpolated values, averaged over the duration of the geomagnetic storm on 2003-11-20.

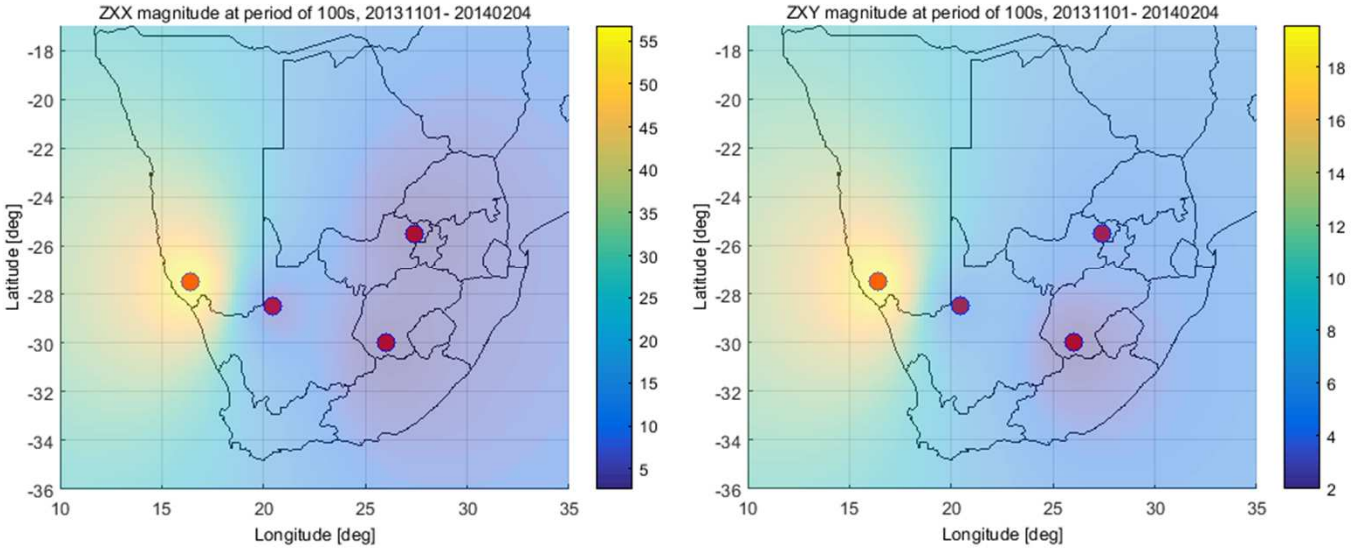
Surface impedance measurement

- Derived from weighted spectra of simultaneous measurement of B-field and E-field
- Sampling interval: 1 s
- Frequency range of interest: 0-8 mHz
- Long-duration observations: Typically 3 weeks to 3 months
- Can also be derived mathematically from conductivity profiles of Earth
- Depends mostly on deep Earth conductivity

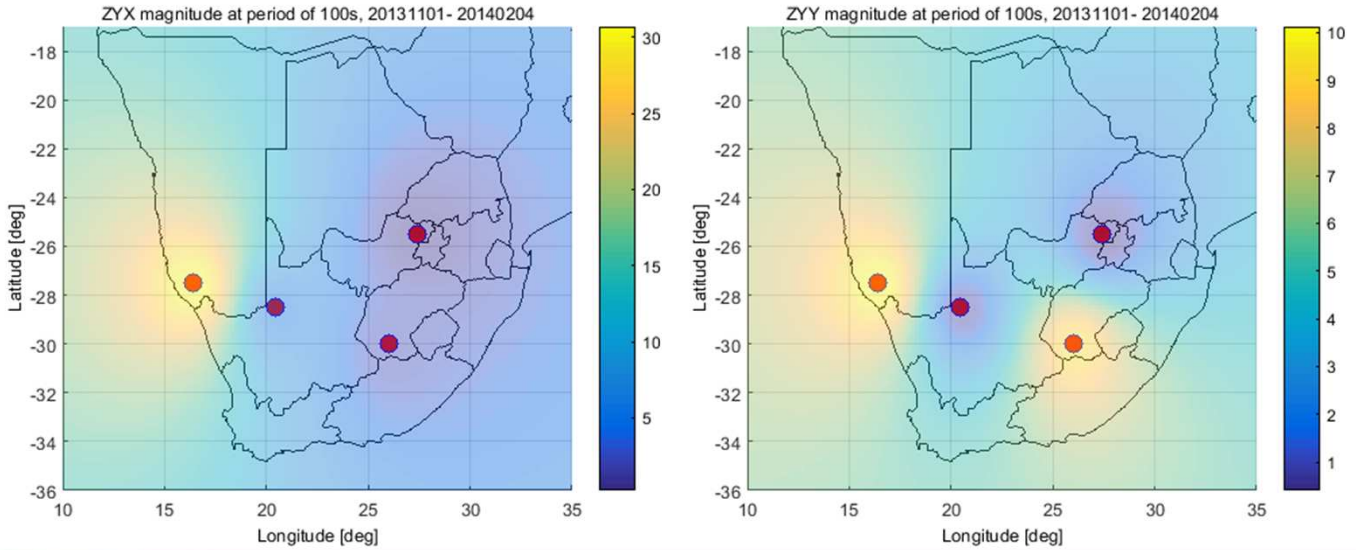
Surface impedance interpolation

- Simultaneous data from 4 MT stations
- Stations selected by data quality and spatial distribution
- 5^{th} order polynomial fit of the measured surface impedance vs. frequency at each station
- Spatial interpolation of polynomial coefficients
- Reconstruction of interpolated Z at each of 1440 frequencies in B-field spectrum.

Interpolation of the surface impedance



f=0.01 Hz



Conclusions

- Feasibility of surface impedance interpolation demonstrated
- Validation to be done with MT data from non-selected sites
- Potential improvement in accuracy of GIC estimation pending availability of measured GIC data
- Progress in GIC estimation can enhance strategies for GIC mitigation

Thank you for your attention