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Geomagnetically induced currents in the Dutch high voltage power grid

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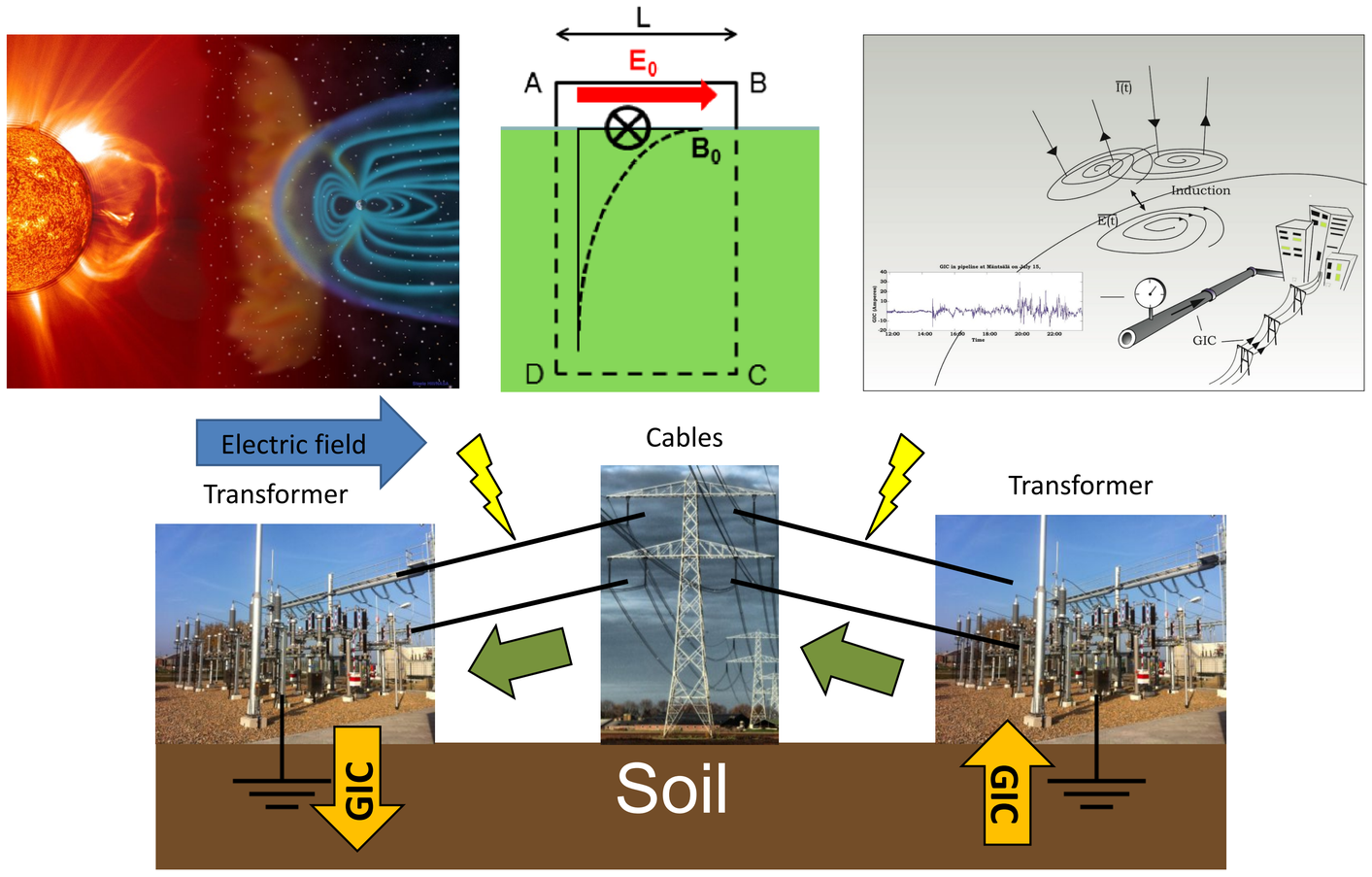
Applied geoscience questions

- Space weather is driven by the magnetic activity of the Sun
- Solar flares and the solar wind perturb the magnetosphere and ionosphere causing geomagnetic storms.
- The response of the Earth results in inductive electric fields and currents that potentially affect power grids. These so-called geomagnetically induced currents (GICs) are difficult to calculate.
- An empirically derived index[1] (GIC index) suggest that the Dutch power grid is susceptible to effects of space weather. To check this we investigated the following aspects:
    1. The Netherlands have no geomagnetic observatory so an interpolation algorithm was build and validated to obtain the magnetic field over the Dutch power grid
    2. The Dutch power grid was modelled and geomagnetically induced electric field were applied. The impact of the following aspects was assessed:
        a) Extent power grid
        b) Magnitude of GICs
        c) Conductivity of Earth's crust and surface

- Halloween storms (29th - 31st October 2003): geomagnetic storms that damaged transformer stations in England[2] and Sweden[3]
- The GIC index indicated **a 65% risk for the Dutch power grid**. Therefore, the effect of these storms was modelled in detail for the Dutch power grid.
- KNMI has been tasked to operate an space weather alert to warn the Dutch vital sectors for disturbing space weather conditions. It is in this context this research was conducted



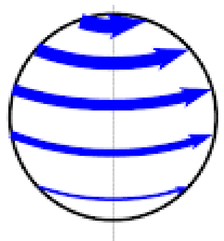
Left panel: Sun-Earth interaction. Middle panel: magnetic field (B) is converted to electric field (E). Right panel: interaction of the variable solar magnetic field introduces ionospheric currents that introduce induced electric field is power grids and pipelines. Panel below: geomagnetically induced currents run through the power lines and through the Earth. The circuit closes through the transformer stations in the network. If the current is too large transformers may be damaged.

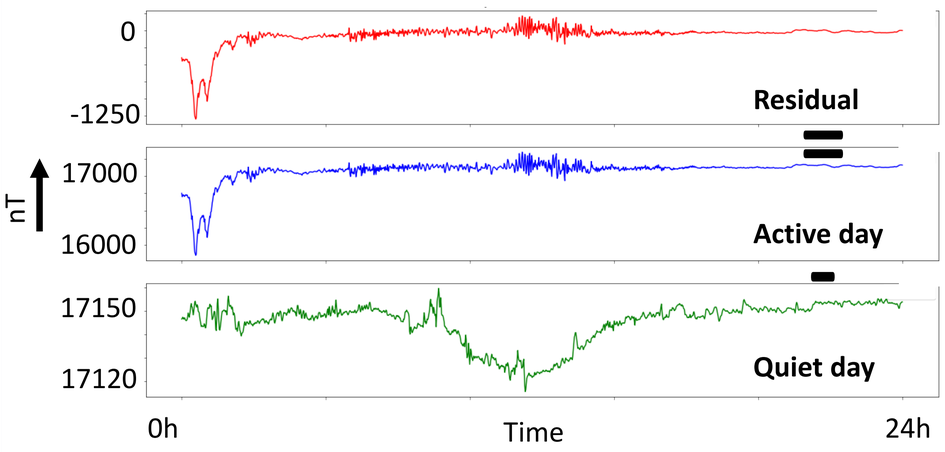
Results

Magnetic field variations in the Netherlands

1. Use observations of surrounding geomagnetic observatories (see lower figure)
2. Fit a synthetic ionospheric current distribution, a so-called Spherical Elementary Current System[4] (see figure to the right)
3. Project this distribution back to the Dutch power grid

Divergence-free elementary system

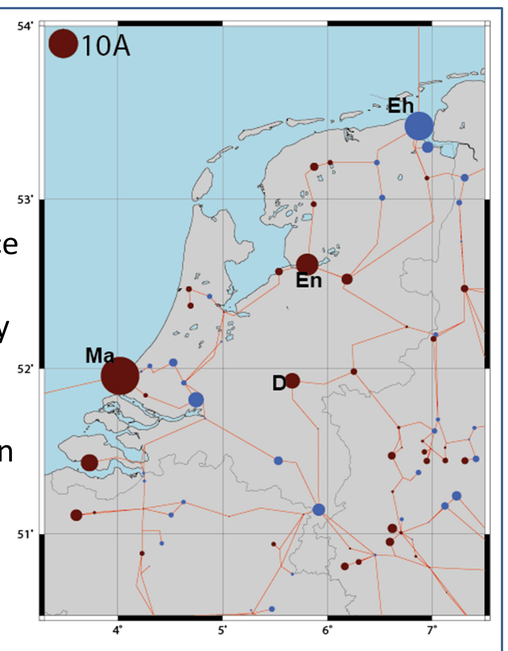


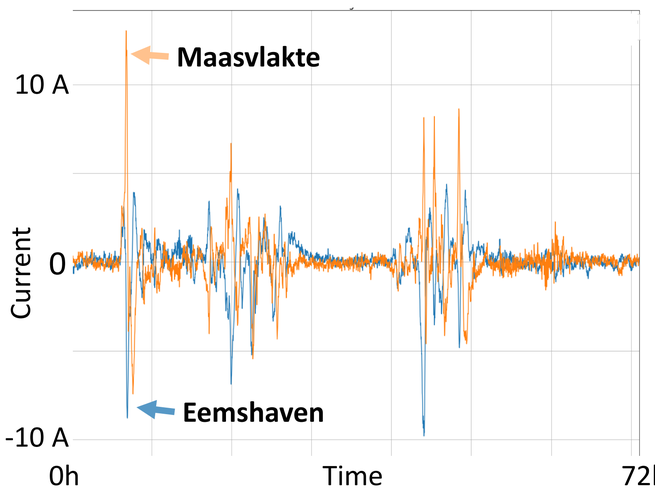


Data from Dourbes Magnetic observatory (intermagnet.org)

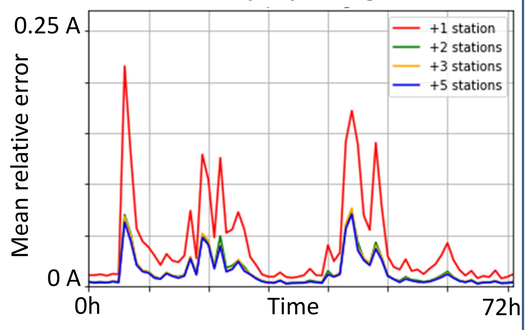
From electric field to Geomagnetically Induced Current

- The electric field induces a current in a transmission line
- From there the current searches a low resistance path back to the Earth, via transformer stations
- The size of this current is determined roughly by applying V = I R to the modelled power grid (solving Kirchhoff)
- Boundary effects were studied by adding foreign stations (see lower right figure)





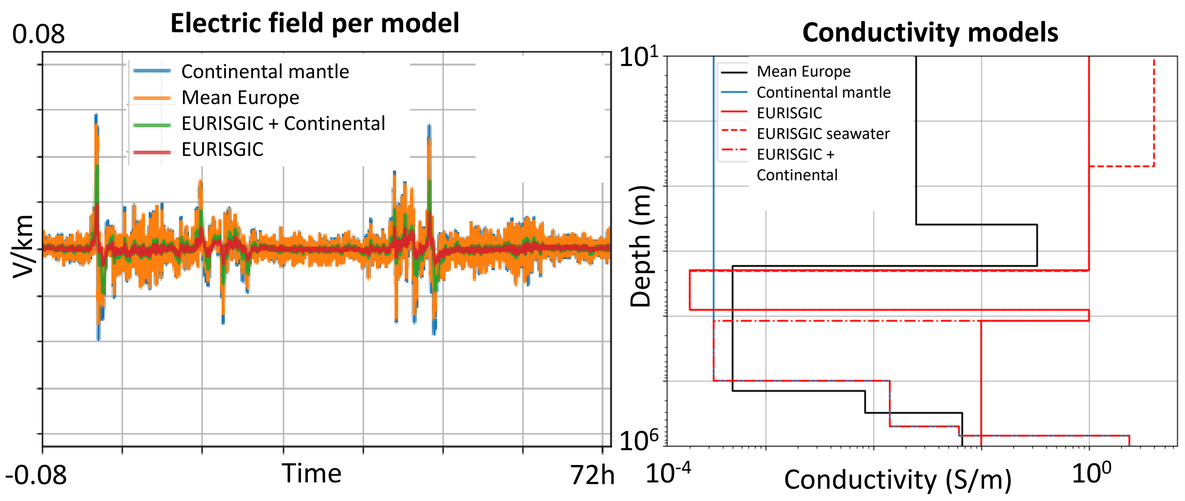
Mean error per power grid model



Left: Maximum GICs during the Halloween storms were 13 A. End nodes like Maasvlakte and Eemshaven experience largest GICs. Right: errors through boundary effects by foreign stations

The role of surface and crust conductivity for electric fields

- To convert magnetic field variations to an electric field, we need Maxwell's equations
- The conductivity of the crust/mantle is necessary for this calculation
- We assumed different 1D-conductivity profiles
- For the Netherlands this 1D-profile is poorly known (see lower figures)



Conclusions

- A model was developed to calculate d**B**/dt for the Netherlands based on foreign geomagnetic stations using Spherical Elementary Current Systems[4]
- The Dutch high-voltage power grid was modelled[2] so that the effects of geomagnetic disturbances in the power grid can be studied during the Halloween storm period (29th -31st October 2003)
- Results indicate that the maximum GIC during Halloween was **13 A**
- An empirically derived risk index (GIC index) overestimates the potential risk to the Dutch power grid
- Our method has been verified against previous studies[3] and is scalable. Together with TenneT it will be investigated at which space weather level the Dutch power grid will be at risk
- Better data for 1D electrical conductivity profiles in The Netherlands are needed

For further information
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References
1. Marshall, R., Smith, E., Francis, M., Waters, C., and Scier, M. (2011). A preliminary risk assessment of the Australian region power network to space weather. Space Weather, 9(10):1-18.
2. Beggan, C. D., Beamish, D., Richards, A., Kelly, G. S., and Thomson, A. W. (2013). Prediction of extreme geomagnetically induced currents in the UK high-voltage network. Space Weather, 11(7):407-419.
3. Viljanen, A., Pirjola, R., Pracser, E., Ahmadzai, S., and Singh, V. (2013). Geomagnetically induced currents in Europe: characteristics based on a local power grid model. Space Weather, 11(10):575-584.
4. Amm, O. and Viljanen, A. (1999). Ionospheric disturbance magnetic field continuation from the ground to the ionosphere using spherical elementary current systems. Earth, Planets and Space, 51(6):431-440.