O1.1.2

Identifying the causes of the vertical component geomagnetic field anomaly at Eskdalemuir, Scotland

GUANREN WANG, JULIANE HÜBERT & KATHY WHALER

guanren@bgs.ac.uk

British Geological Survey

EMIW2022

25TH EM INDUCTION WORKSHOP

SEPTEMBER 2022 Çeşme, Turkey

THE UNIVERSITY of EDINBURGH

British Geological Survey

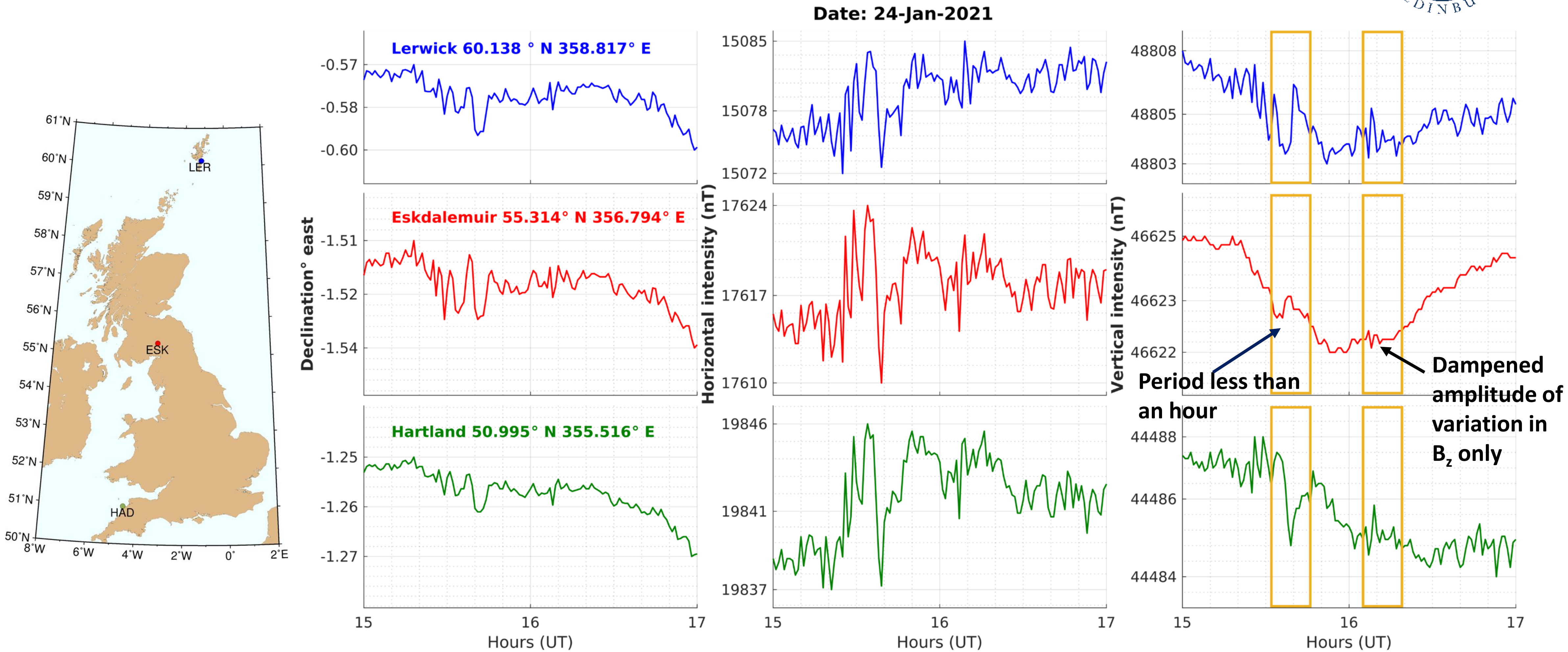
Outline

‘Eskdalemuir Anomaly’: What/where/when?

Motivation:

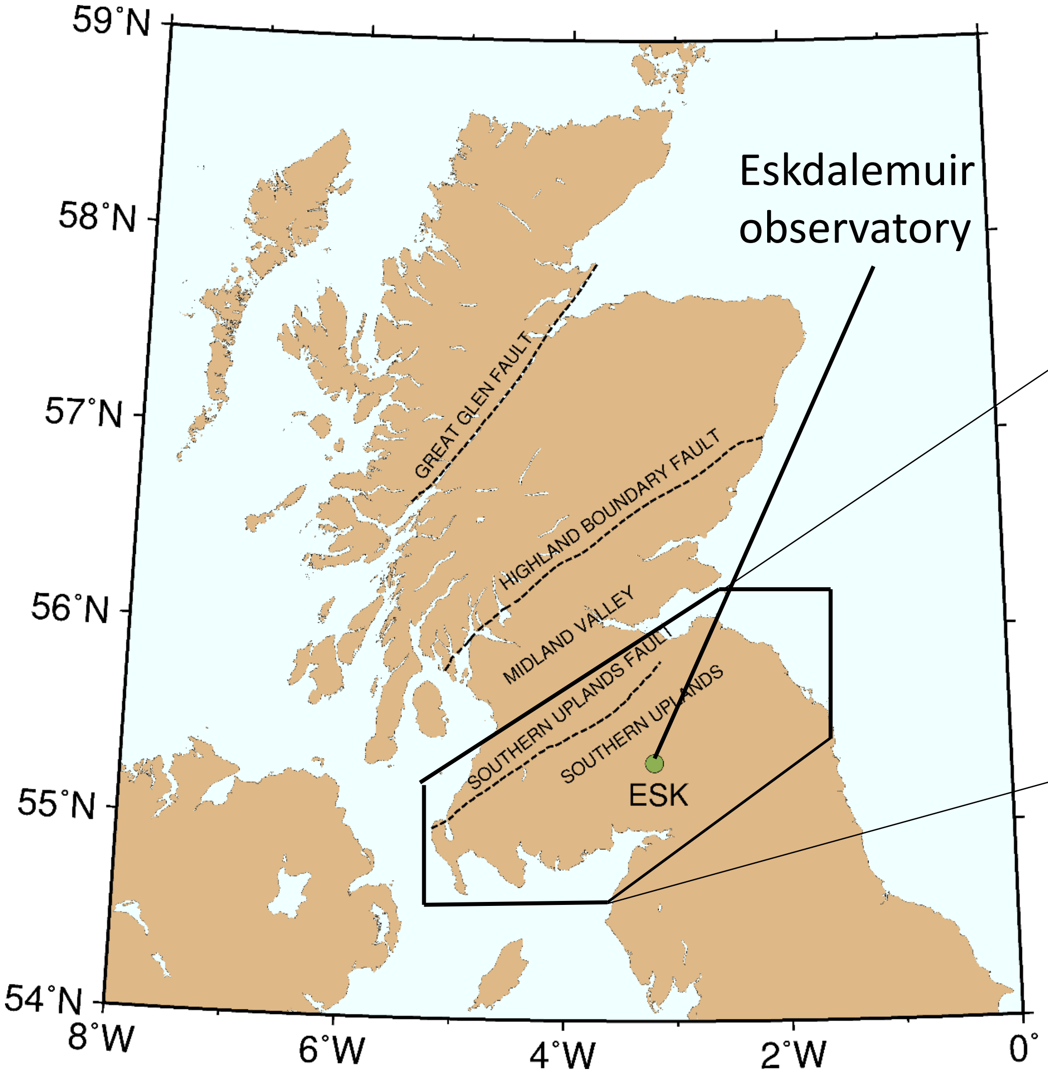
- Temporal variation of the tipper at Eskdalemuir.
- Seasonal variations of the tipper at Eskdalemuir.
- Is the induced B_z only caused by lateral conductivity contrasts, or are there times when it is strongly influenced by space weather?
- What does the tipper estimates from geomagnetically quiet times look like?
- Predict ‘source-effect’ influence from space weather on magnetic field data collected from MT fieldwork campaigns (e.g. two-year MT fieldwork campaign to investigate space weather effect on the power grid in the U.K.; refer to poster P.1.1.03 and P3.3.07).

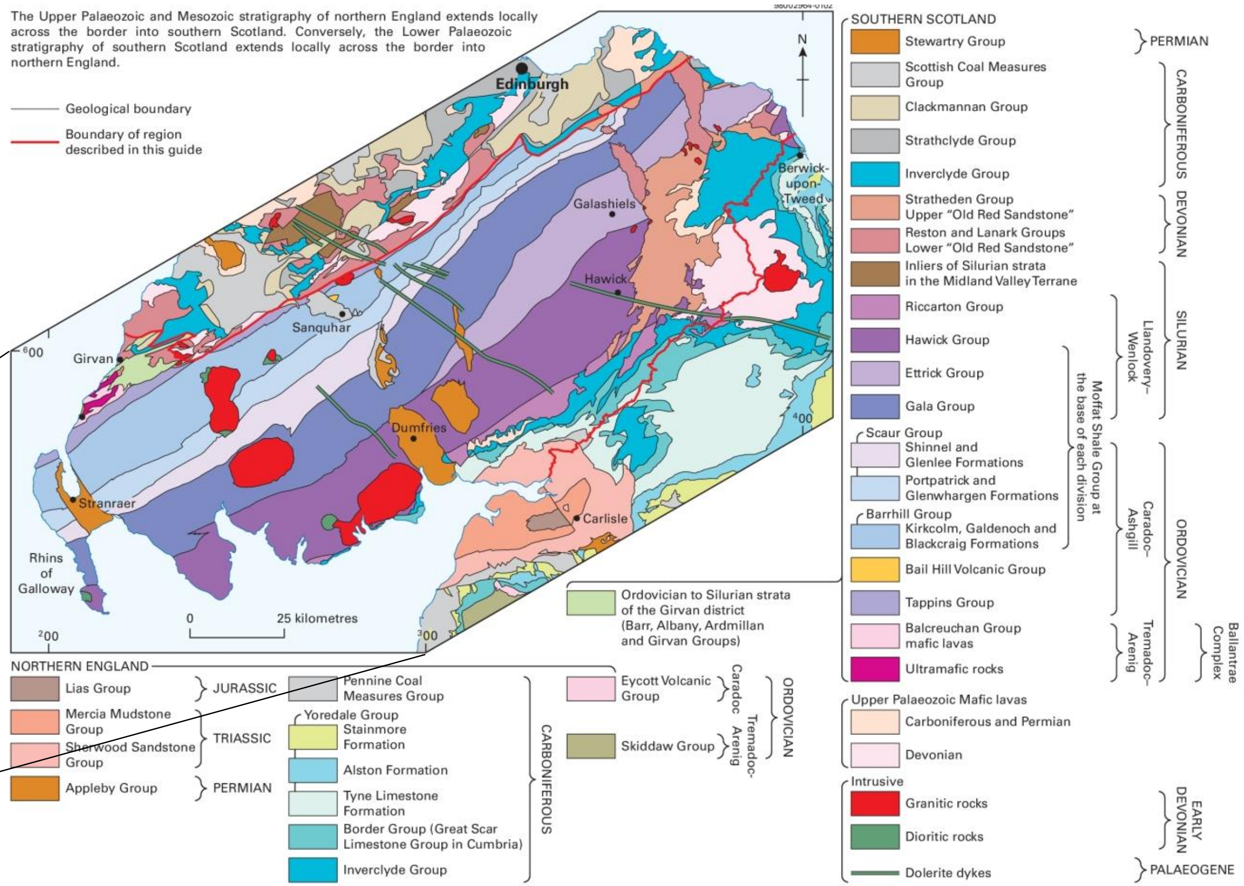
What is the Eskdalemuir Anomaly?



Magnetic declination (first column), horizontal intensity (second column) and vertical intensity (third column) from Lerwick, Eskdalemuir and Hartland (top, middle and bottom) observatories.

Where is the Eskdalemuir Anomaly?

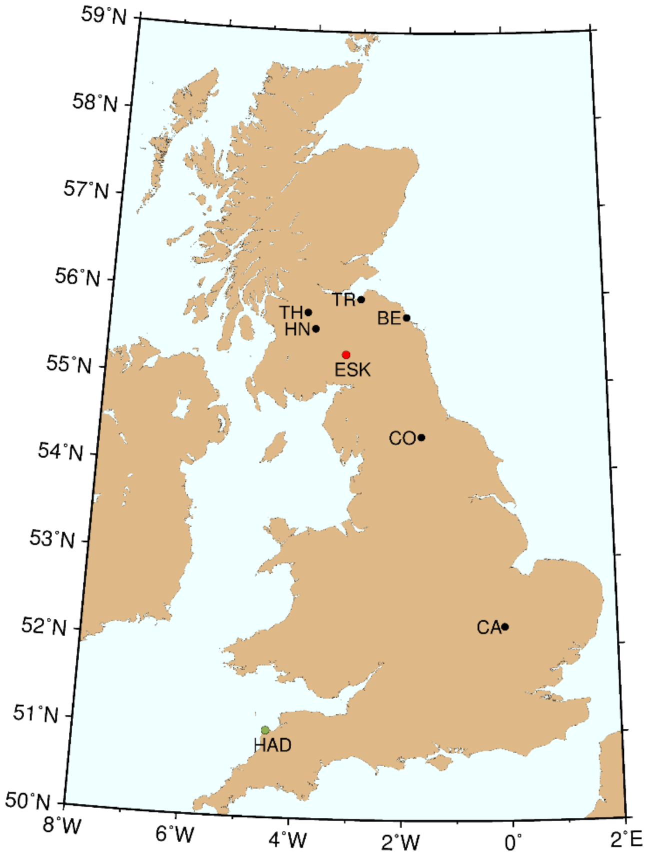


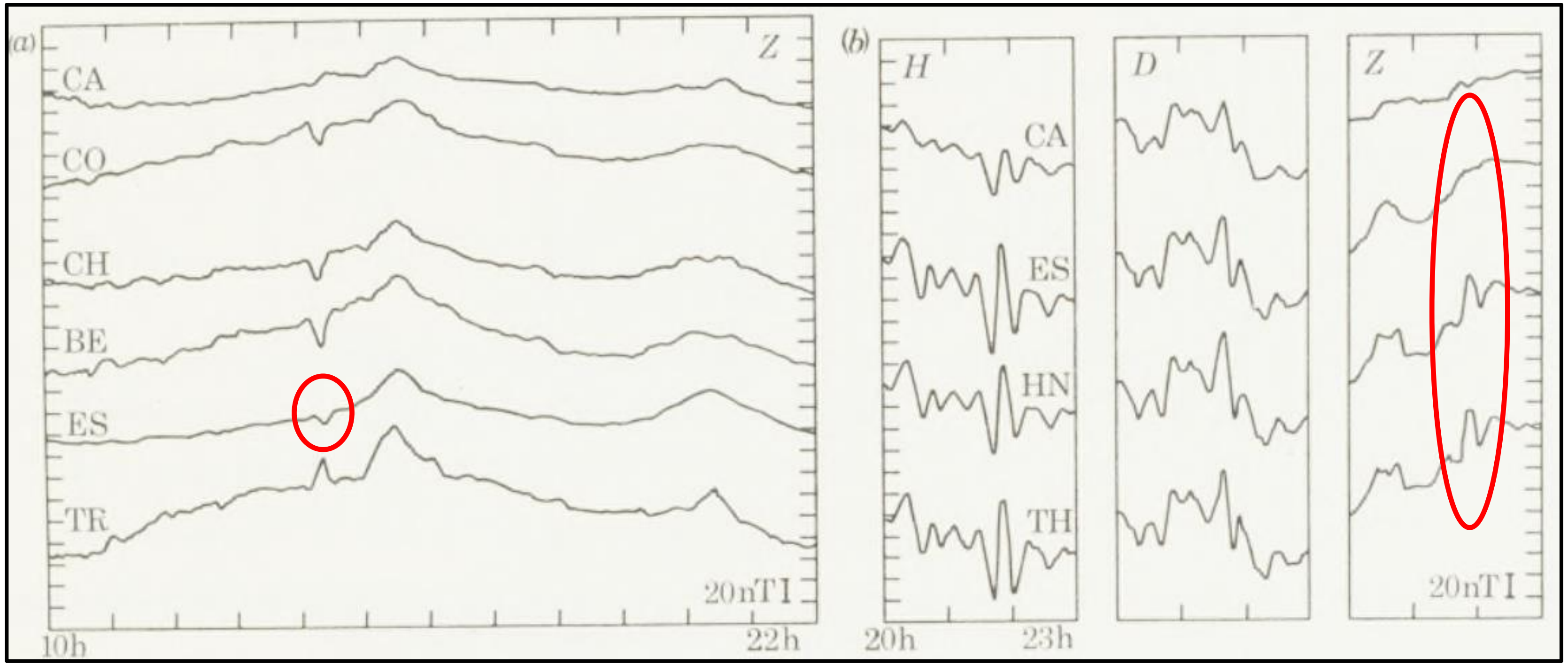


Source: British Geological Survey

Metasandstone and **metamudstone**. Metamorphic bedrock formed during the **Silurian**.

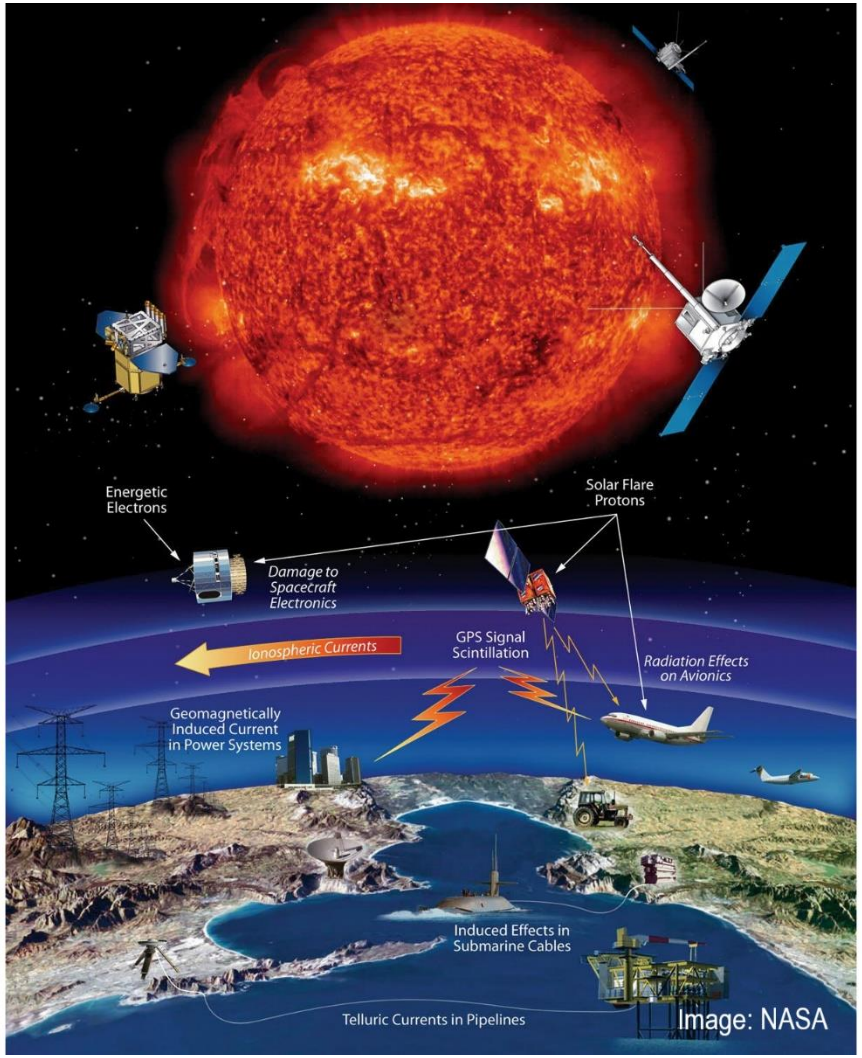
When was this anomaly first observed?





Left: Magnetograms from S-N through ESK (ES) on **11 June, 1967** for Z. ***Note the lower amplitude at ESK compared to Z variations recorded from adjacent sites Berwick (BE) and Tranent (TR).***
Right: Magnetograms from four sites between Cambridge (CA) and Thornton (TH) for **29-September 1967** for D, H and Z. From **Edwards, et al (1971).**

Space Weather Activity Imposing on the Geomagnetic Field Data



Timescales of variations.
Space weather (source effects): Daily
Electrical conductivity due to geology: Millions of years

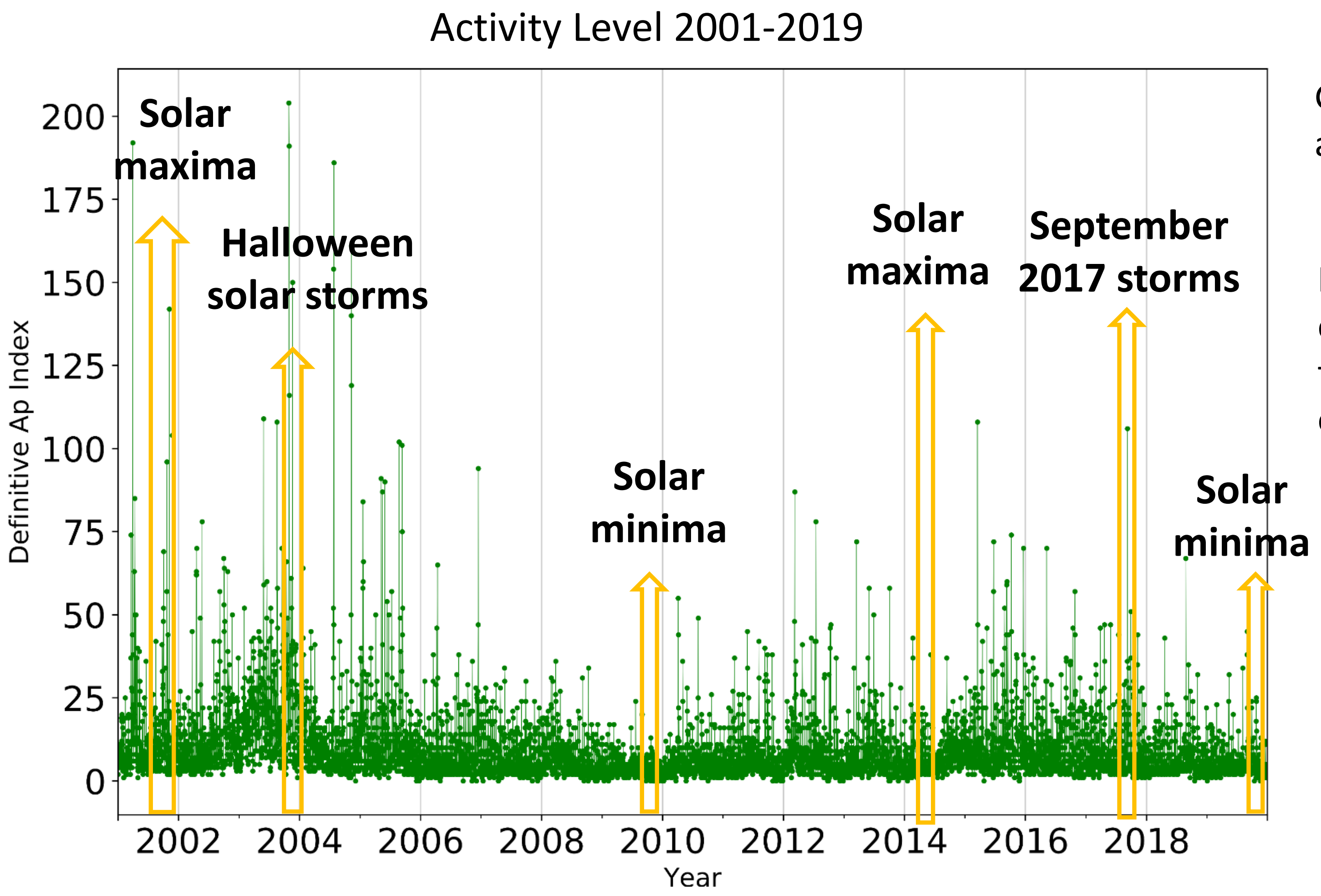
The ‘source effect’ is a separate contribution imposed on the induced magnetic field; it is independent of the contribution from geology. Not accounting for the ‘source effect’ can impact on the accuracy of the tipper we use to infer the conductivity anomaly.

$$\widetilde{B_z}(f) = T_x\widetilde{B_x}(f) + T_y\widetilde{B_y}(f) + \epsilon(f)$$

where frequency $f = \frac{2\pi}{T}$ and T is the period. $\epsilon(f)$ is the the uncorrelated residual.

Where ~indicates the Fourier transform, f is the frequency and $\epsilon(f)$is the uncorrelated residual.

Identify Geomagnetically Quiet Periods for Tipper Estimation



Geomagnetic indices (Kp, Ap) can be considered as proxies for space weather activity levels.

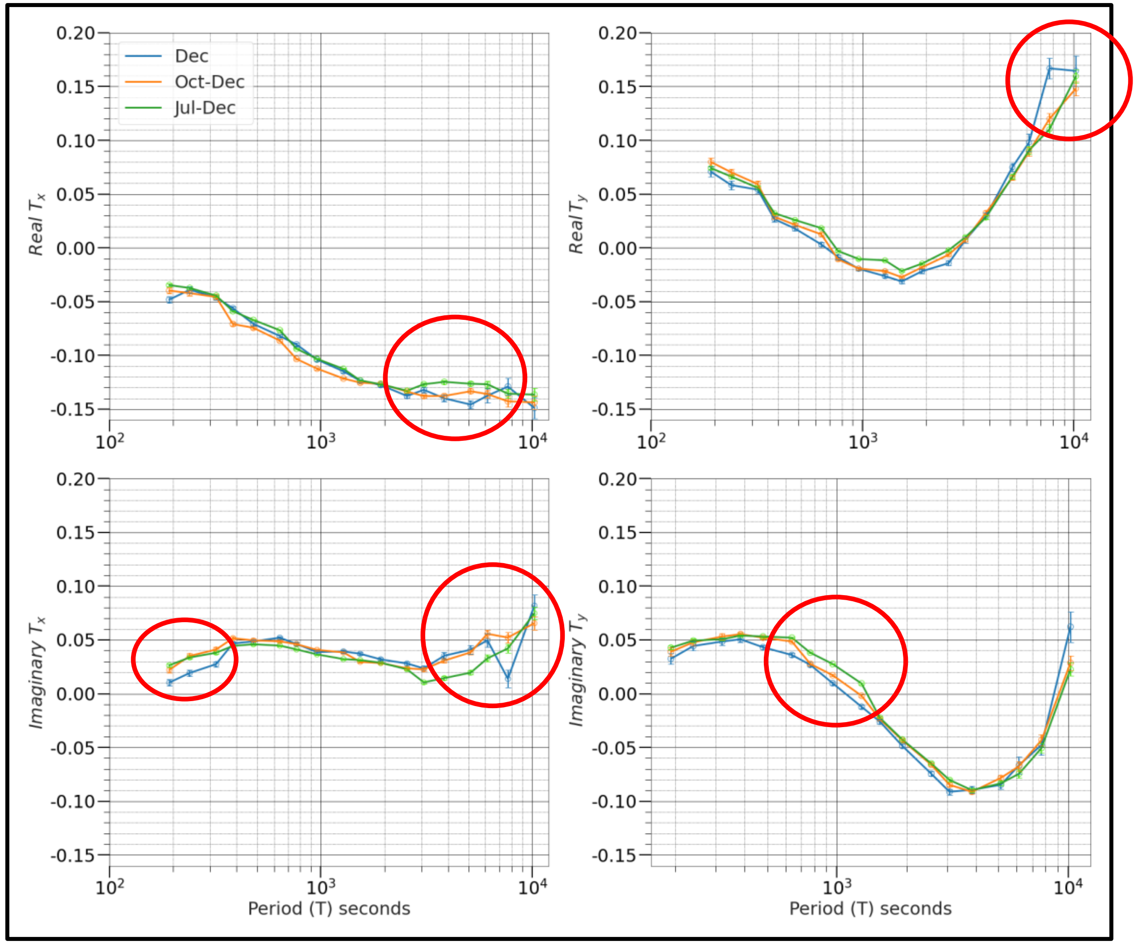
High-level geomagnetic activity on the estimated transfer functions (tipper) can lead to erroneous conclusions of subsurface electrical conductivity.

British Geological Survey

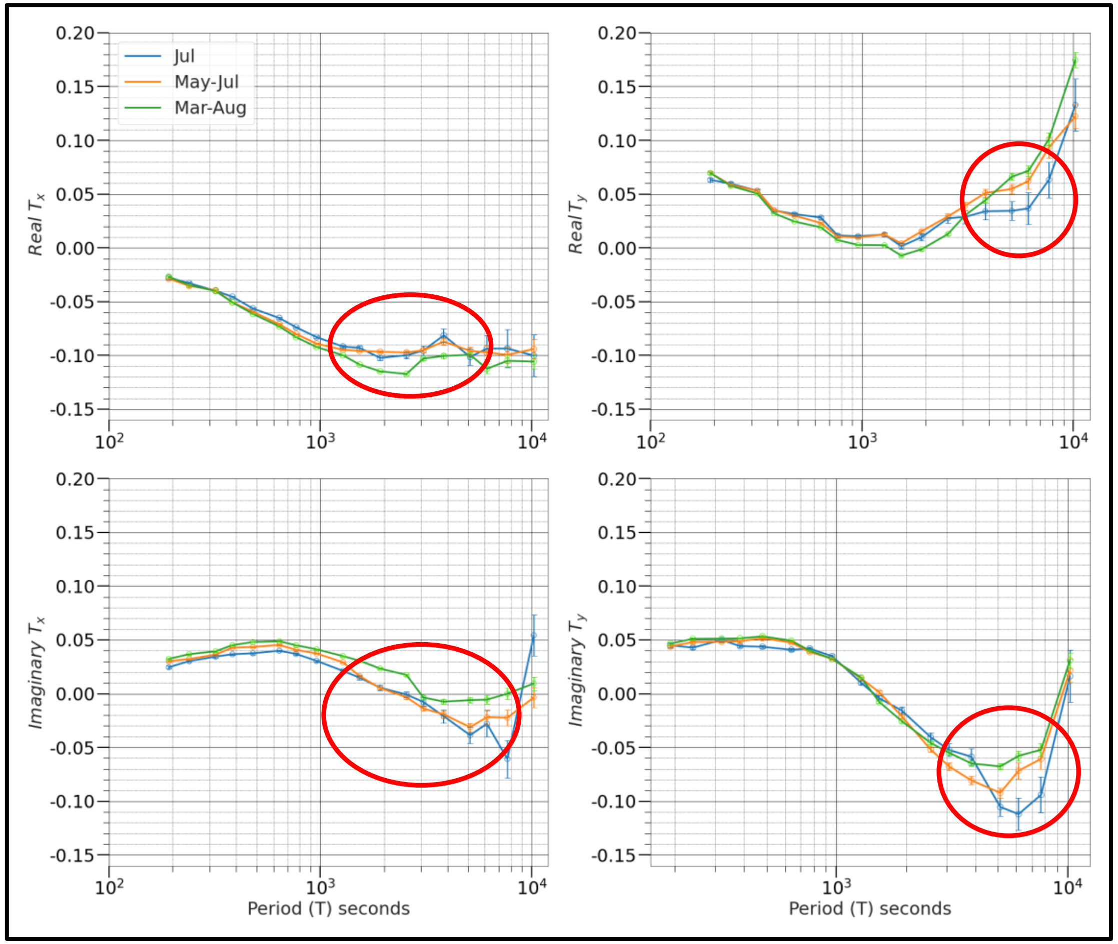
Determine Tipper “Baseline” for Studying Seasonal Variations of the Tipper. one-month vs three-month vs six-month

Used Smirnov (2008) KMSProMT data processing software to compute tipper.

2009



2014



Six-month input data smears out the ‘source effects’. Space weather changes daily so three-month is selected as the baseline.

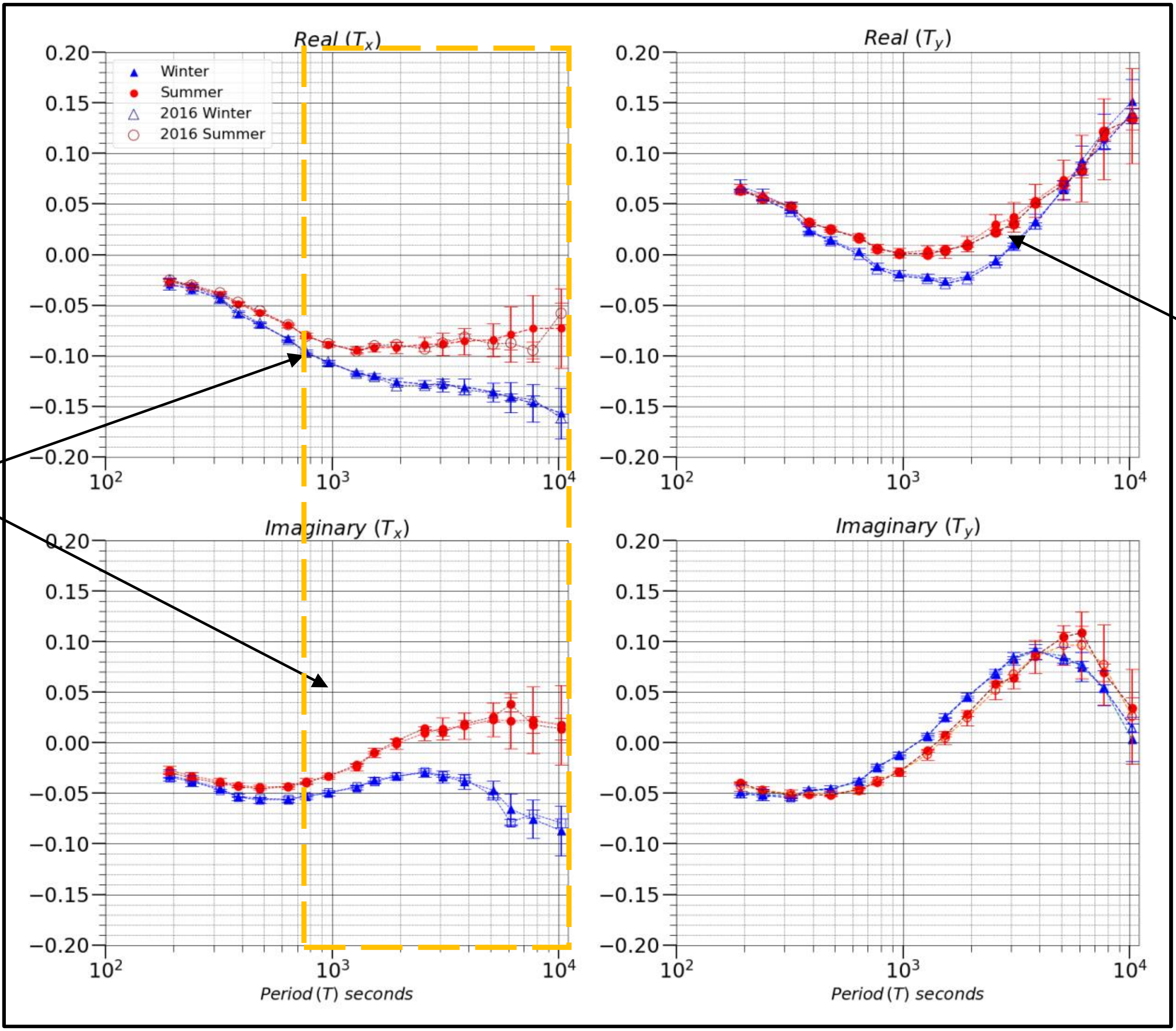
British Geological Survey

2016 Tipper Variations relative to the 2001-2019 Average

There are seasonal variations observed in tipper variations at ESK.

Winter (November-January)

Summer (May-July)



Effect in T_x is systematically occurring in multiple years.

Largest seasonal differences in T_y occur at the intermediate periods.

Empirical Modelling of the Source Effect by Vargas & Ritter (2016)

$$T_{source\ effect}(DOY, F10.7) = C_1 + C_2 sin\left(\frac{2\pi \cdot DOY}{N} + C_3\right) + C_4 cos\left(\frac{4\pi \cdot DOY}{N} + C_5\right) + C_6[F10.7]$$

DOY: Day of the Year.

F10.7: solar emission indicator measured at L1. Proxy for forecasting space weather activity.

C_1 to C_6: unknown parameters in the empirical model to be determined**.**

Use solution of least squares to derive the six coefficients.

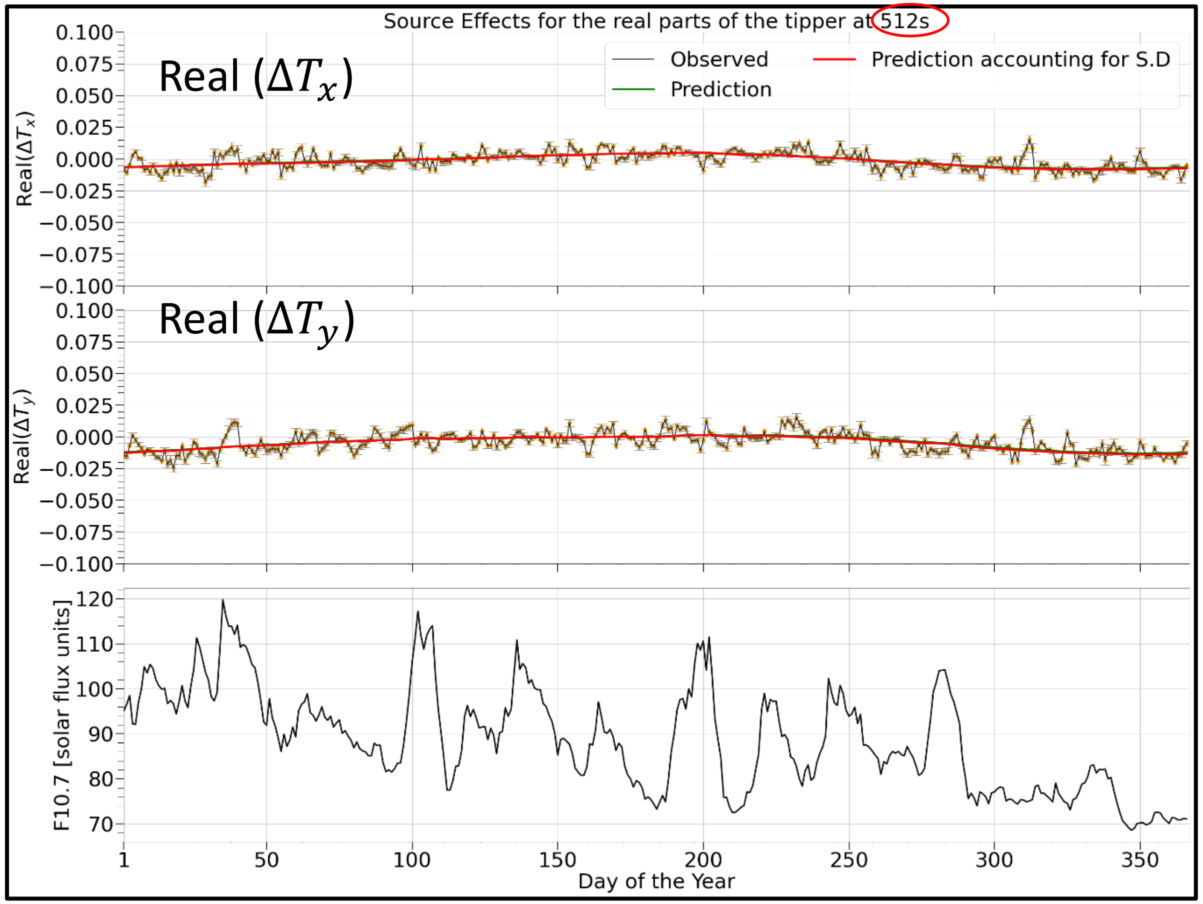
Input data is the tipper deviation (ΔT) for an element of the tipper, where i is the DOY in ΔT.

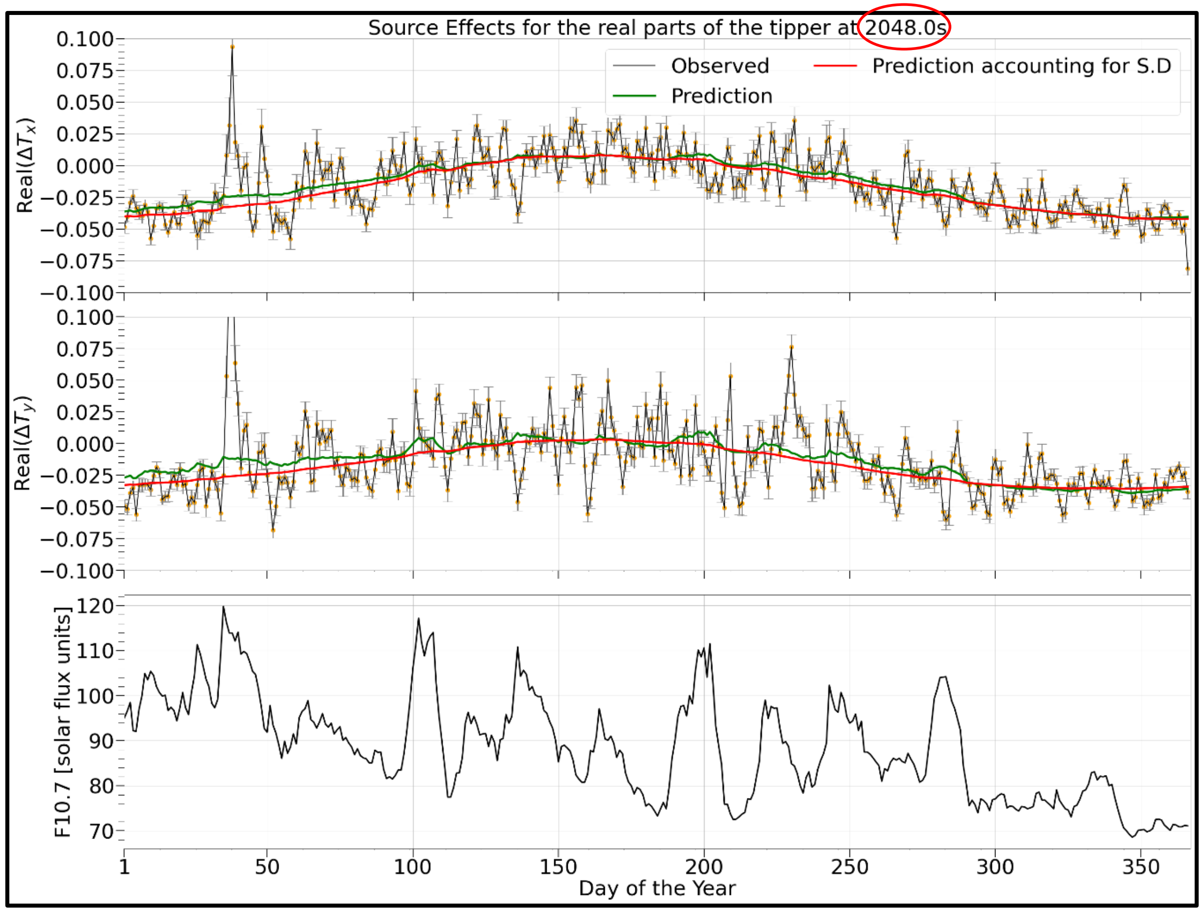
$$\Delta T_i = T_i(t) - (three\text{-}month\ T_i(t))$$

Real (ΔT_x); Real (ΔT_y); Imaginary (ΔT_x); Imaginary (ΔT_y)

Empirical Modelling of the Source Effect

Very small source effect (F10.7) at lower periods compared to longer periods

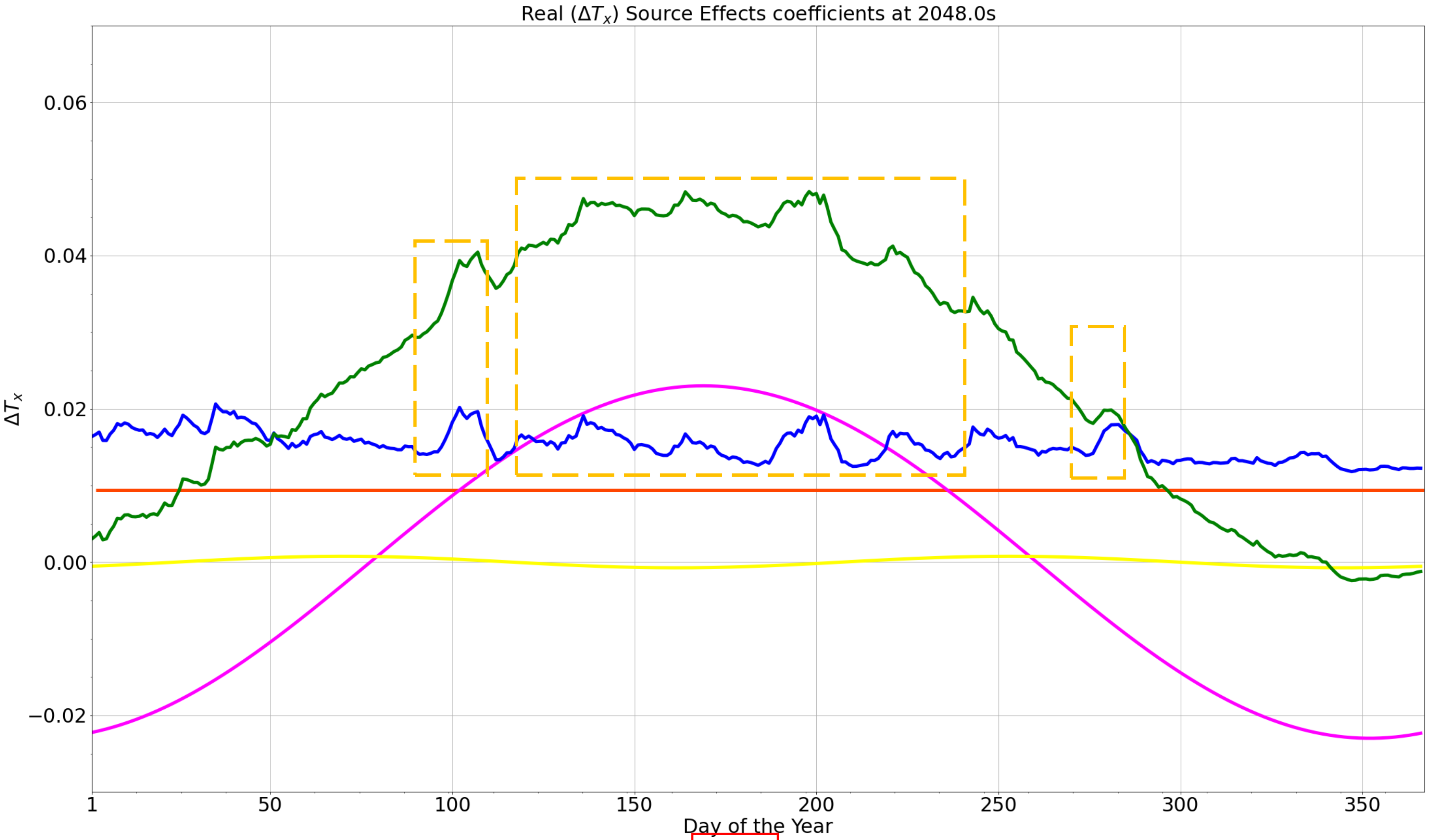




2016 Real part of the tipper source effect prediction at 512s. Baseline tipper from summer 2016. Minimal source effect seen in 512s. Significant levels of source effect at 2048s.

Prediction accounting for the standard deviation (S.D) Source effect prediction Observed $\Delta T \pm 1$ S.D

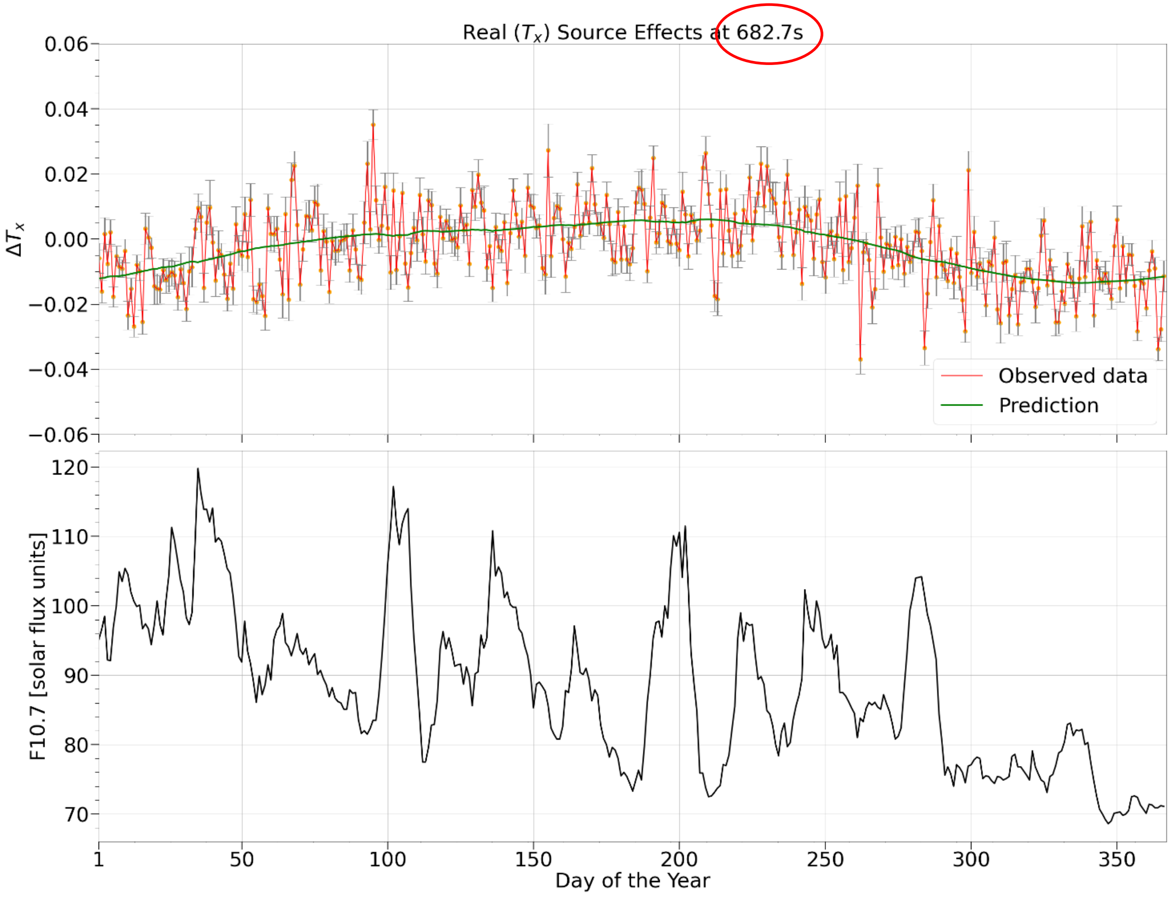
Empirical Modelling of the Source Effect



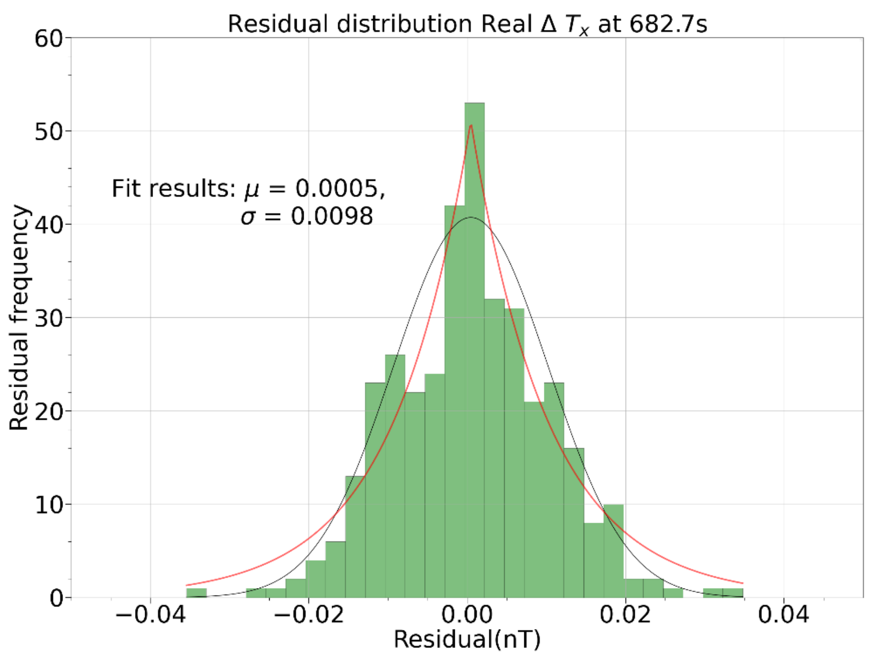
2016 Real (ΔT_x) source effect prediction (green) at 2048s period and offset (red) the annual and semi-annual terms (purple and yellow), and F10.7 components (blue) used to calculate the prediction.

Empirical Modelling of the Source Effect

2016



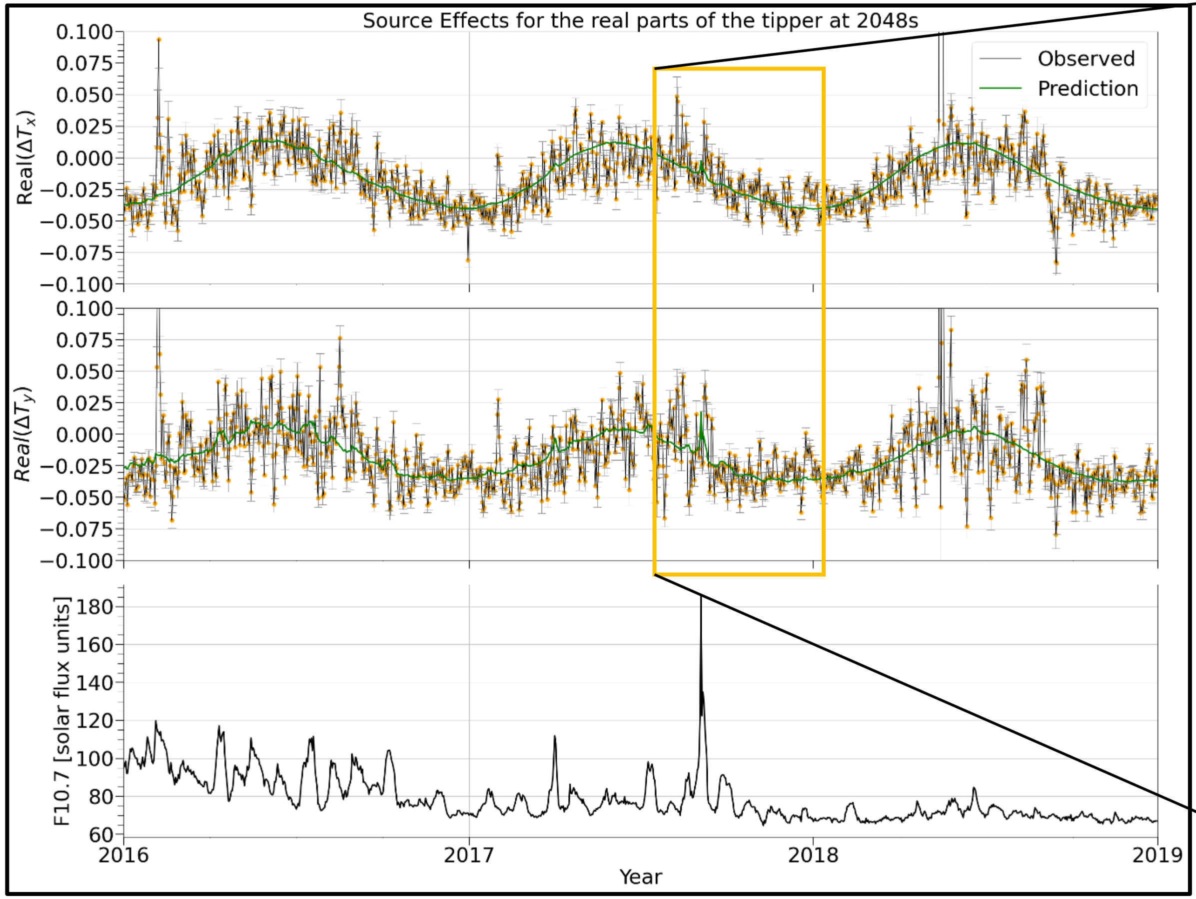
F10.7



2016 Real (ΔT_x) relative to tipper summer baseline.

Empirical Modelling of the Source Effect
Longer-term tipper variations at ESK

Real part @ 2048s

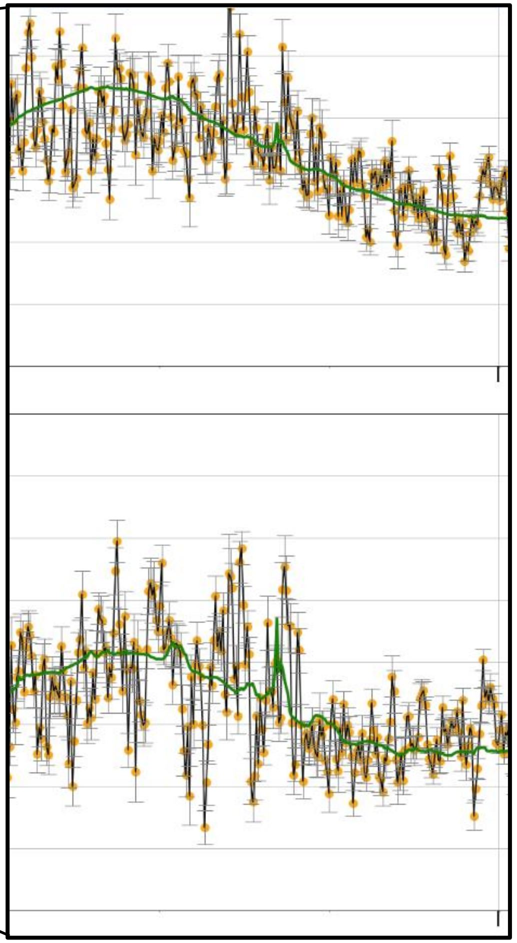


(ΔT_x)

(ΔT_y)

F10.7

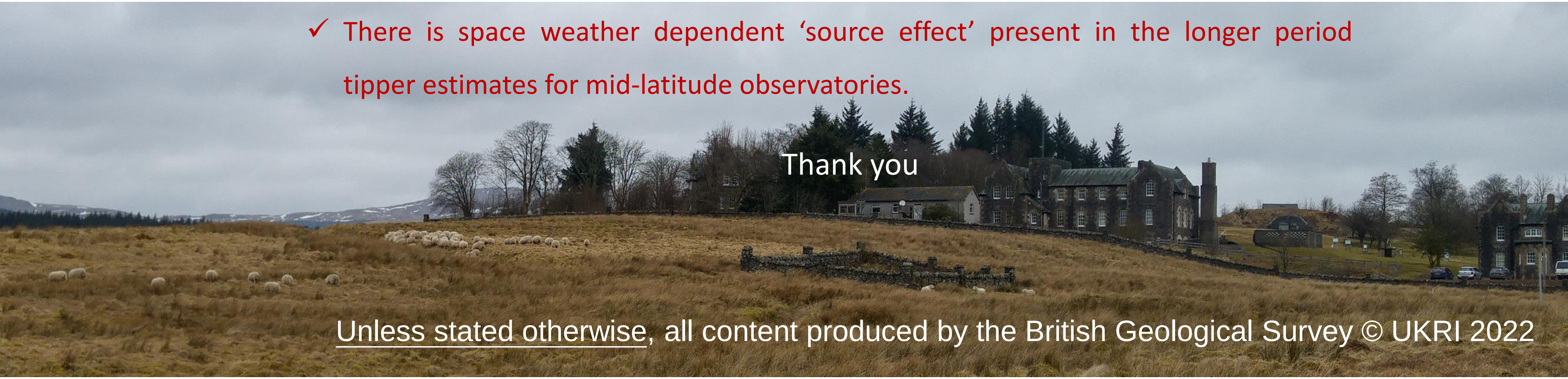
Tipper source effect prediction between the start of 2016 to end of 2018.



September 2017 solar storms picked up in the variation.

Summary

- ✓ Seasonal variation observed in the tipper estimates.
- ✓ Differences between the summer and winter tippers in the T_x components become increasingly large towards the longer periods, and they are observed in multiple years. Systematic differences in T_x are not linked to subsurface conductivity contrasts so need to be accounted for. Implications for larger regional studies.
- ✓ Winter baseline is not necessarily more stable than the summer baseline, vice versa.
- ✓ There is space weather dependent 'source effect' present in the longer period tipper estimates for mid-latitude observatories.



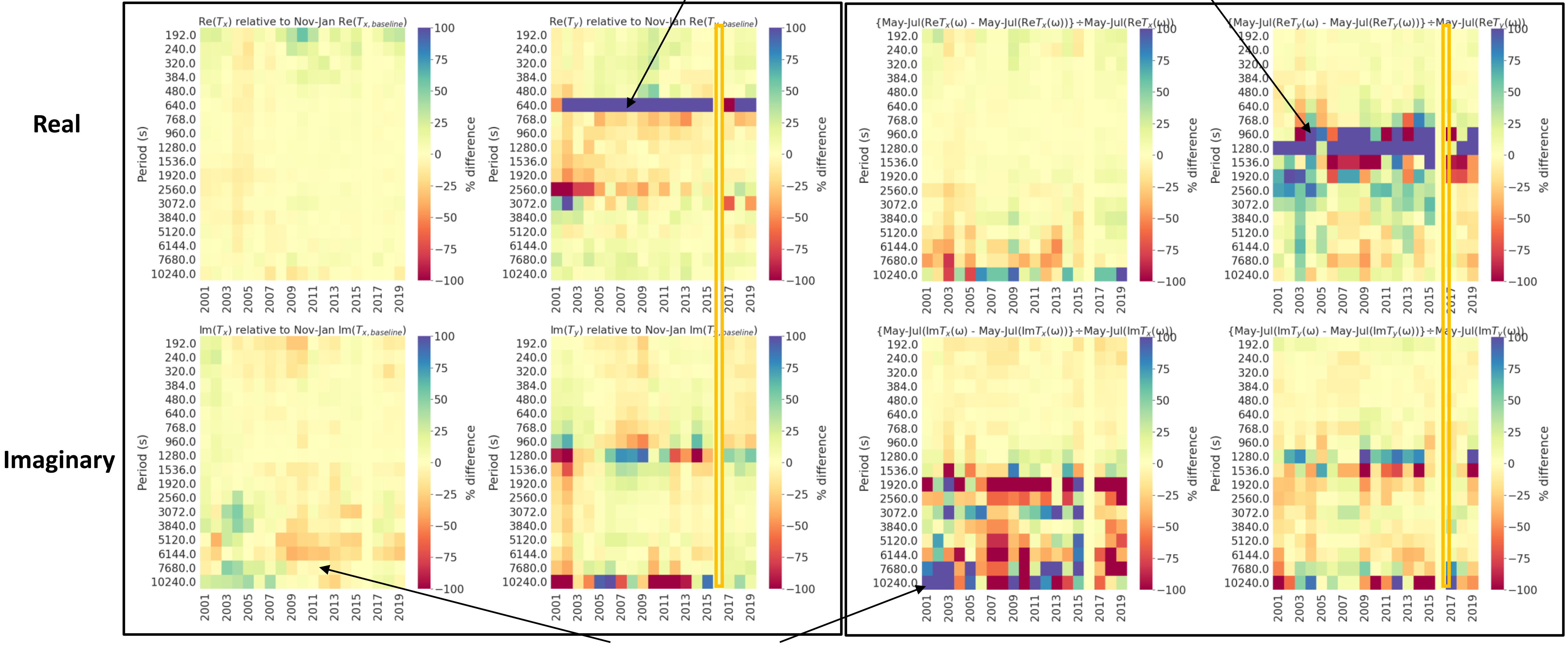
Thank you

Additional Material

The seasonal changes in the tipper: **Year-to-year percentage differences**

Larger than 2016 baseline.
Smaller than 2016 baseline.

Largest % difference at intermediate periods in T_y

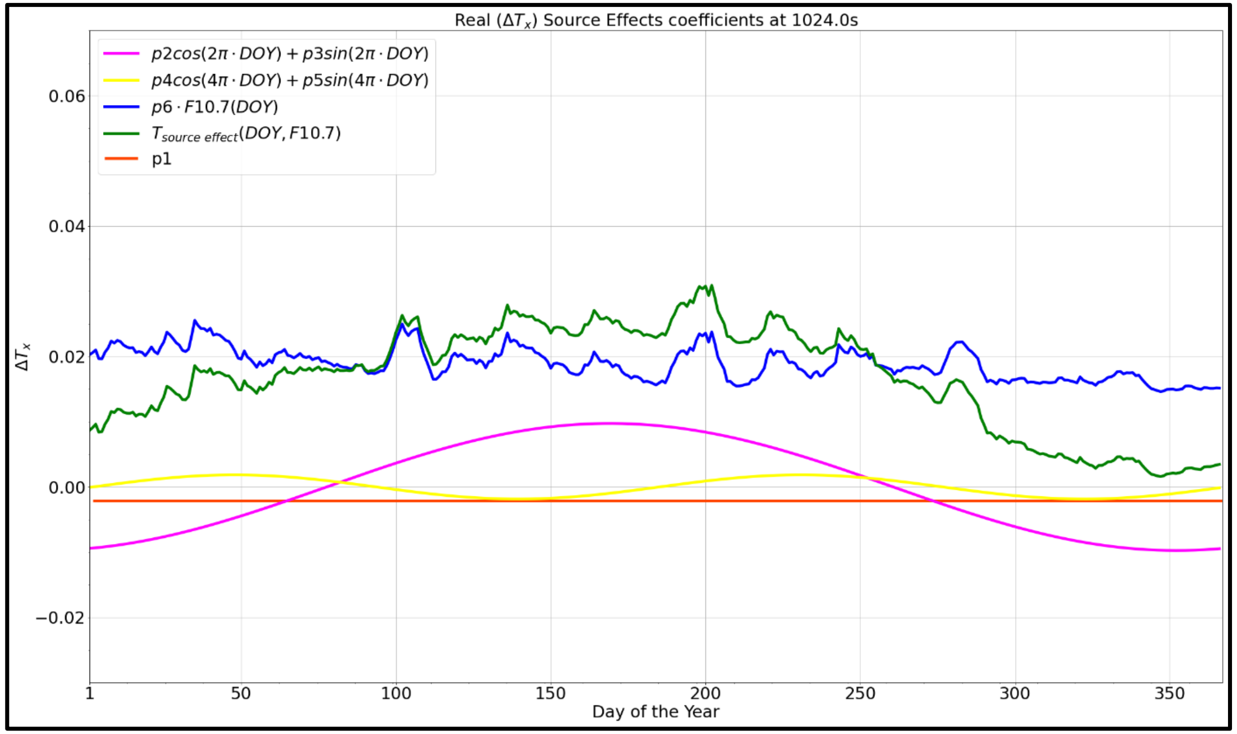


Largest % difference at longer periods in T_x

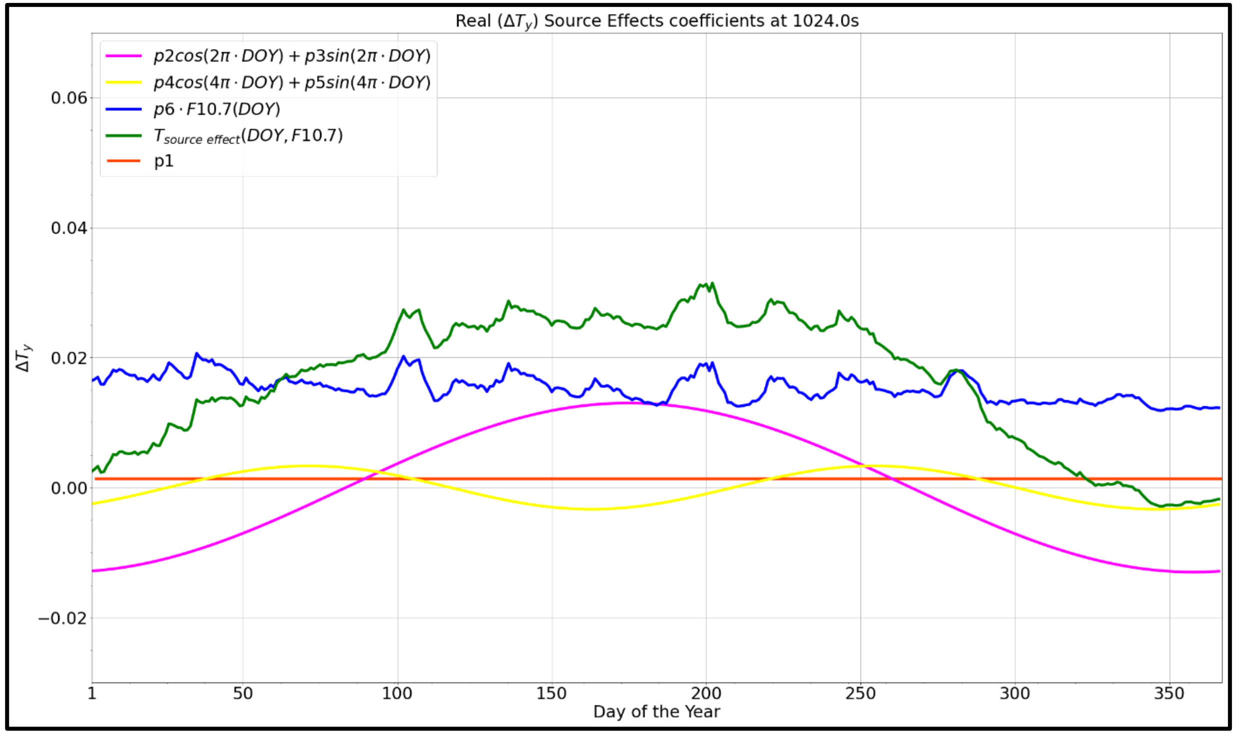
Additional Material

Empirical Modelling of the Source Effect: contribution from different components

2016 Real (ΔT_x) at 1024s



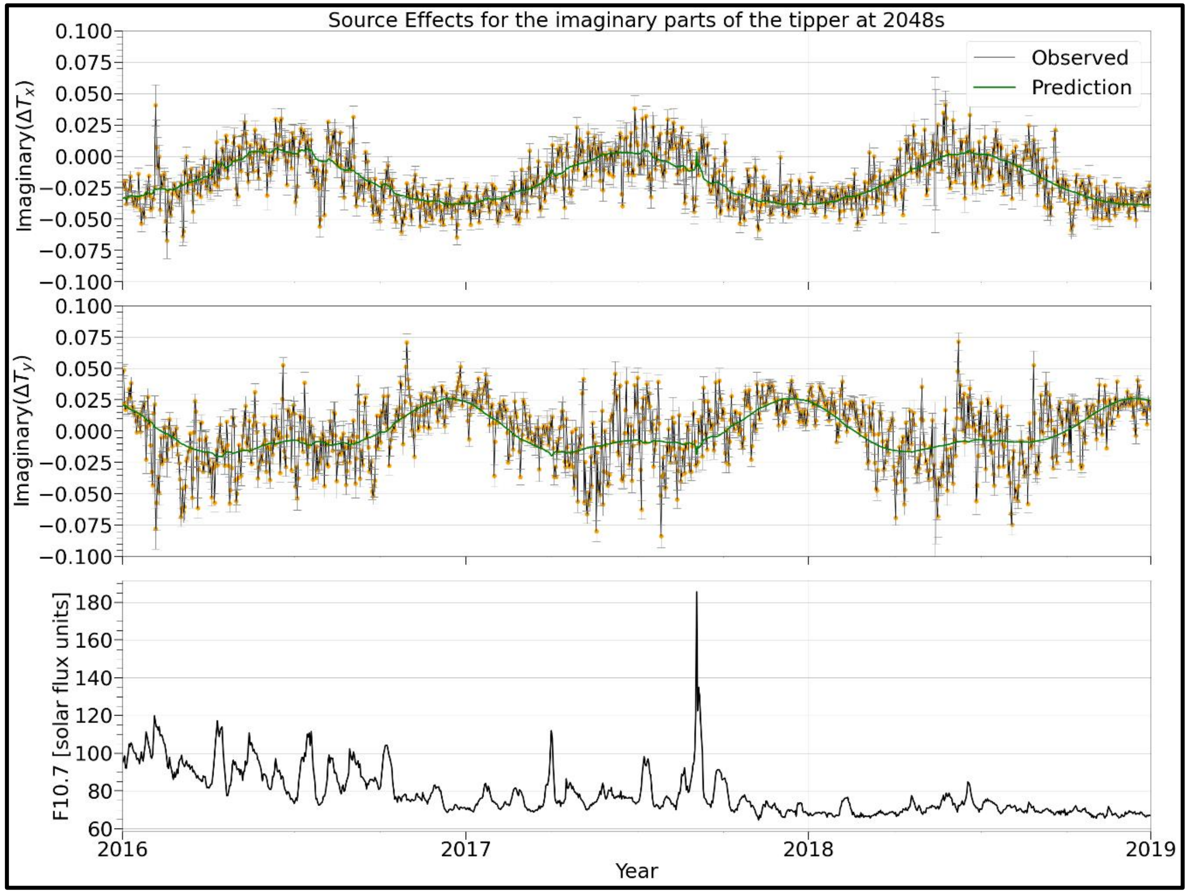
2016 Real (ΔT_y) at 1024s



Additional Material

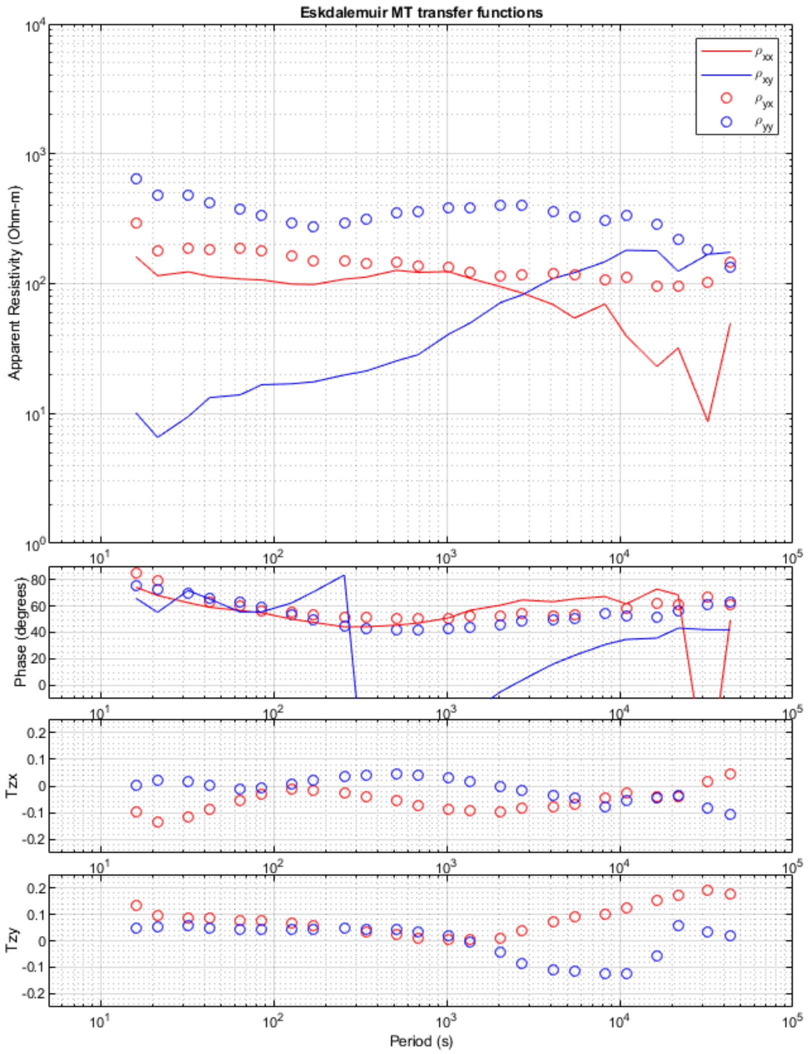
Empirical Modelling of the Source Effect: Longer-term tipper variations at ESK

Imaginary (ΔT) at 2048s

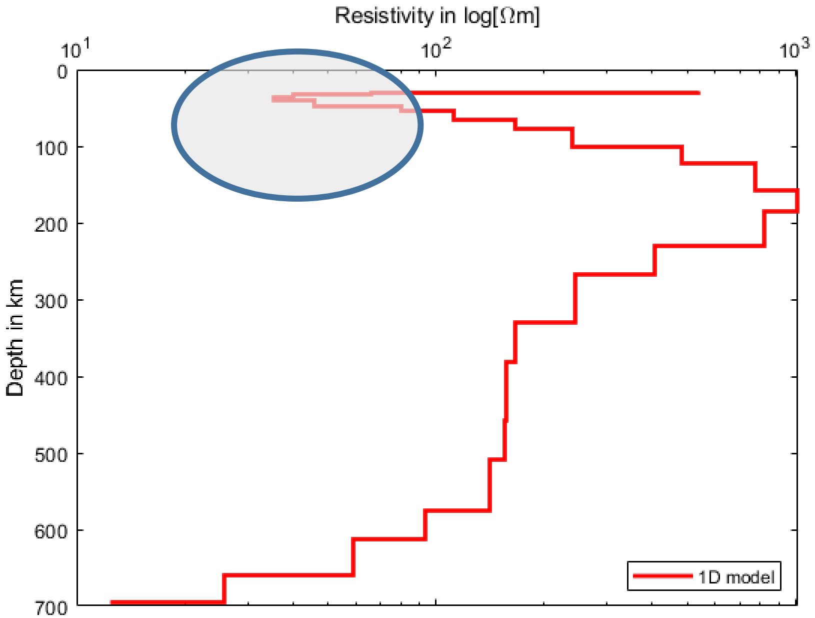


British Geological Survey

Additional Material
MT transfer functions



- MT transfer functions (impedance and tipper) using the electric field time series from 2013-2017.
- 1D model shows crustal conductor at 30 km



1D inversion model for determinant (rho+phs)