Statistical analysis of TIDs and SuperDARN NREs

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Introduction

The Super Dual Auroral Radar Network (SuperDARN) forms a global network of coherent high frequency (HF, 8-20 MHz) radars located at mid-to-high latitudes. **Fig 1** shows that each radar has 16 beams, and each beam has 75 gates of 45 km range resolution, starting from 180 km downrange. The radar's beams are narrow (~3°) but the vertical extent of the beams is large with a maximum power transmitted near 30° elevation. The radars normally scan all beams every 1 or 2 minutes. The exchange of energy and momentum between the charged and neutral components of the Earth's upper atmosphere are manifested in ionospheric phenomena such as Travelling Ionospheric Disturbances (TIDs) and Gradient Drift Instabilities (GDIs) focused on in this work. TIDs and GDIs can be detected by SuperDARN radars. TIDs can propagate in any direction (vertically or horizontally). The radar can show if the TIDs propagate away (positive slope of wavefronts) or toward the radar (negative slope of wavefronts) by inspecting a SuperDARN Range Time Plot, an example of which is in **Fig 2**. TIDs are normally observed in the F-region far range gates at around 300 km in altitude. Near Range Echoes (NREs), which are thought to be associated with GDIs in this study, are generated much lower down in the ionosphere at around 100 km altitude and are normally received by the near range gates 0 - 3 (between 180 and 315 km slant range). We present a statistical analysis of TIDs and NREs during their simultaneous occurrence on 22 November 2013 using the Zhongshan HF radar in Antarctica. We used 50 gates (for TIDs) and 16 gates (i.e. gate 0 of each beam) (for NREs) in this analysis. For the first time, we show that TIDs and NREs backscatter power are linked by a moderate correlation based on Spearman rank Correlation Coefficient.

Methods

Fig 2 shows 13 TIDs (labelled) and NREs observed by beam 15 of Zhongshan HF radar on 22 November 2013 for 0 - 4 UT. We assume that TIDs travel linearly from the F-region of the ionosphere downwards towards the radar into the E-region where they may interact with the NREs. The average phase velocities of the TIDs along beam 15 are 220 - 280 m/s. The TIDs took ~40 min to propagate from ~1300 km range in the F-region to ~180 km in the E-region. This time lag was taken into account for the statistical analysis. We investigated the Cross-correlation (CC) (**Fig 3)**, the Spearman rank Correlation Coefficient (SCC), Linear Regression Correlation Coefficient (LRCC), and P-values (**Fig 4)** between NREs and TIDs. Only CC above/below +/- 0.5 are analysed further. SCC is the ratio between the covariance of NREs and TIDs and the product of their standard deviations. P-values are computed to test the statistical significance of the correlation coefficients. When the P-value is less than 5%, the null hypothesis (stating that there is no relationship between TIDs and NREs) is rejected. Only P-values less than 5% are considered here.

Beams and gates of a SuperDARN HF radar

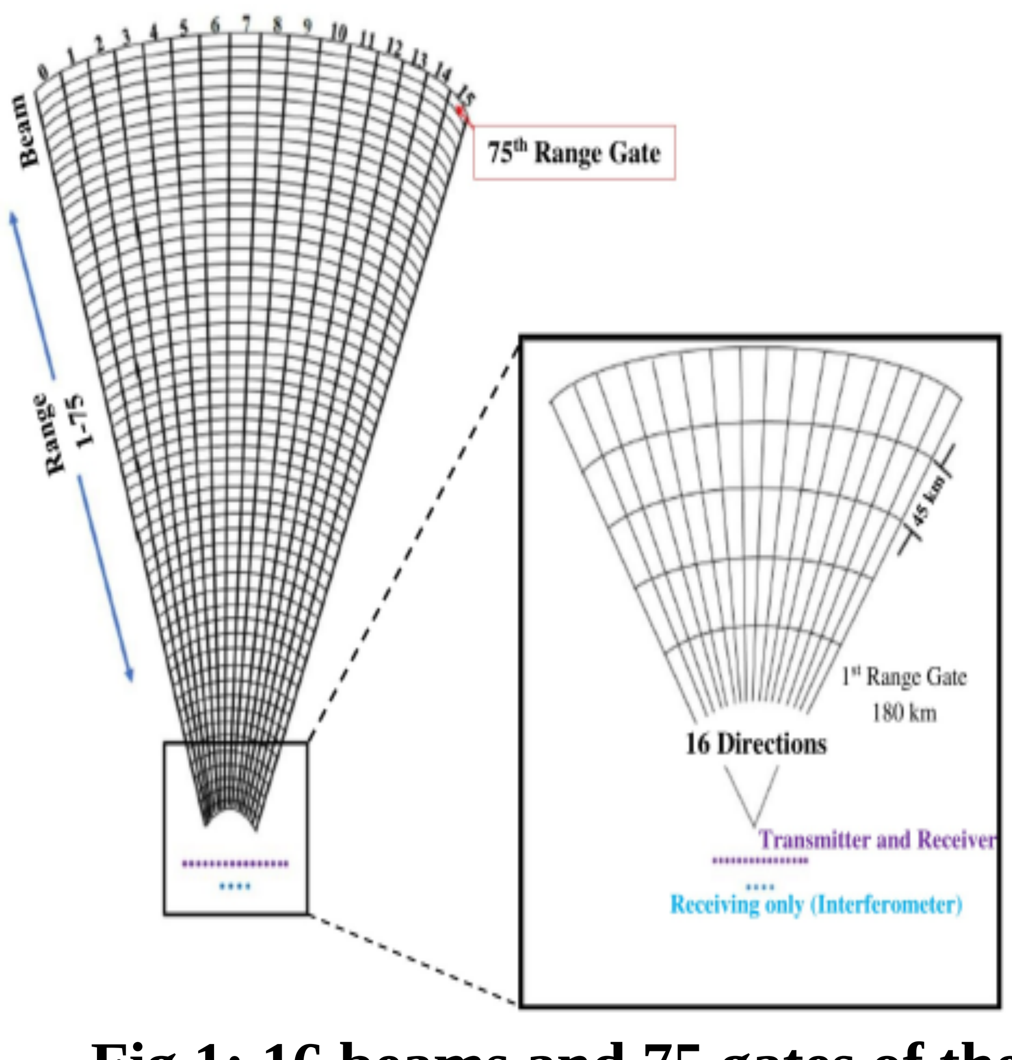

Fig 1: 16 beams and 75 gates of the radar, from beam 0 to 15 (clockwise direction).

Cross correlation between NREs and TIDs

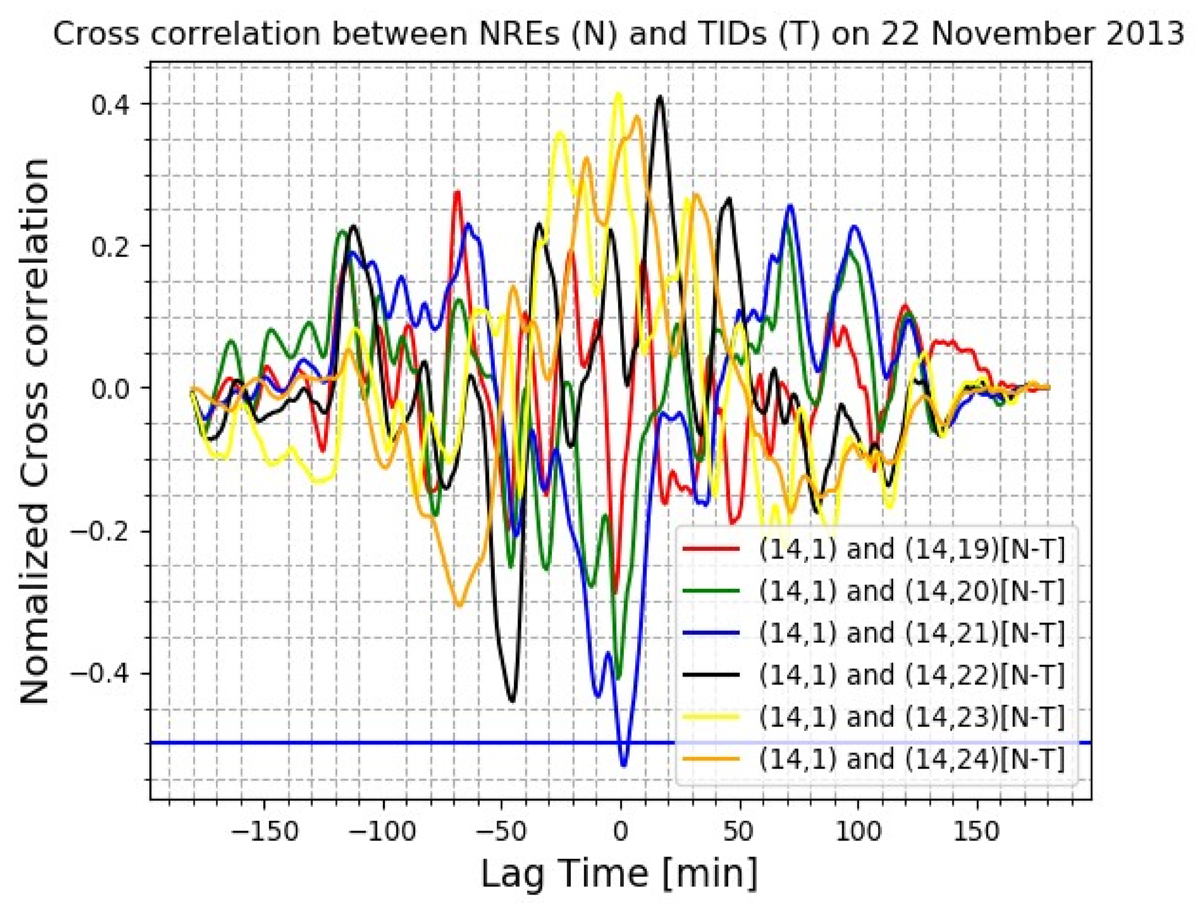

Fig 3: Normalized Cross Correlation Coefficients of gate 1 and gates 19-24 of beam 14

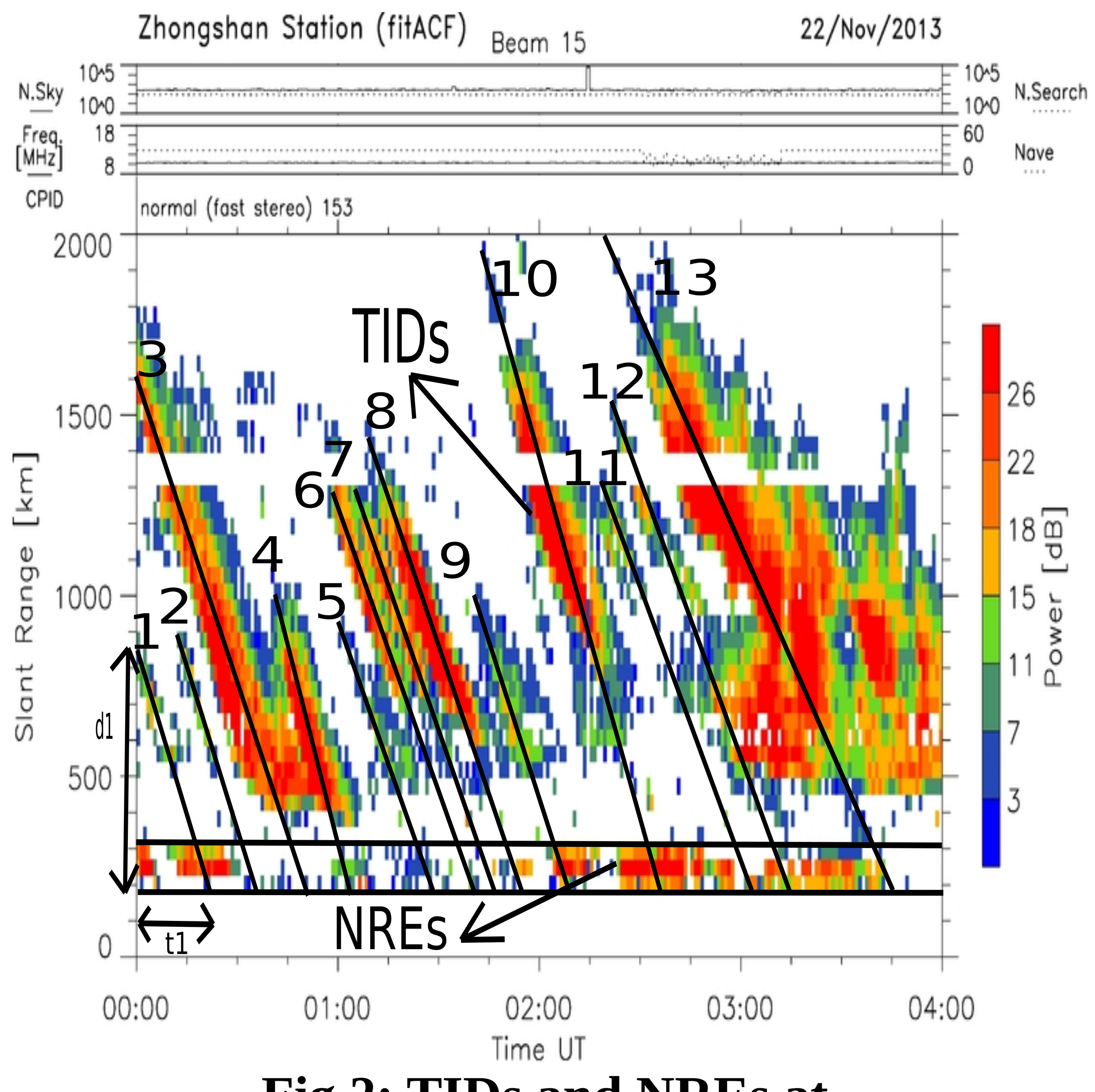

Fig 2: TIDs and NREs at Zhongshan

SCC, LRCC and P-values of NREs and TIDs

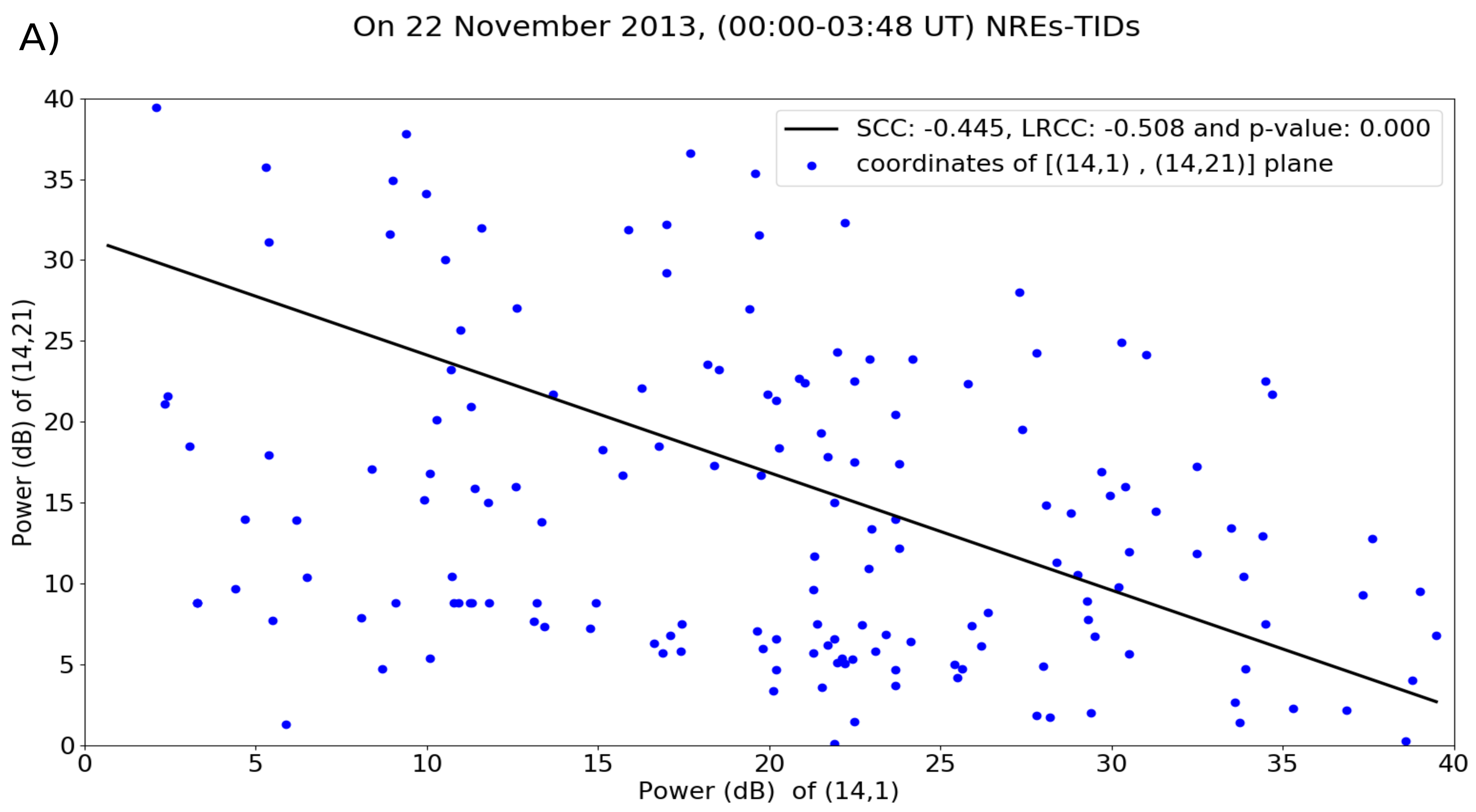

Fig 4: SCC, LRCC and P-value between gates 1 and 21 of beam 14 observed over 4 hours at 1-minute resolution

Fig 3 shows that CC between the backscatter power of gates 1 (for NREs) and 21 (for TIDs) of beam 14 is below -0.5 (blue). **Fig 4** shows that the SCC between the power of gates 1 (NREs) and 21 (TIDs) of beam 14, is -0.445. The LRCC and P-values are -0.508 and 0.00, respectively. This indicates a moderate correlation between TIDs and NREs that is significant.

Conclusions

Similar analysis to the example shown in **Fig 3** and **Fig 4** was done for 50 gates representing the TIDs and 16 gates representing the NREs of all beams. We found a moderate correlation indicating that the TIDs observed by the Zhongshan HF radar in its far range gates contributed ~20% on average to the backscatter power variation received in its near range gates (NREs) when the appropriate time lag is applied.
NREs are thought to be generated by the Gradient Drift Instability (GDI), which itself is generated when the ionospheric electric is parallel to plasma density gradients. GDI results in E-region plasma density irregularities that meet the SuperDARN Bragg scatter condition, which are observed as NREs. TIDs generate local polarisation electric fields, which modulate the GDI locally, which then result in modulated NREs. We have observed the link between TIDs and NREs for the first time.

Selected references

1. Rauf, Abdur, et al. "Investigation of PMSE dependence on high energy particle precipitation during their simultaneous occurrence." Advances Space Res. 63.1 (2019)
2. Tsunoda, Roland T., Shoichiro Fukao, and Mamoru Yamamoto. "On the origin of quasi-periodic radar backscatter from midlatitude sporadic E." Radio Sci. 29.01 (1994)
3. St.-Maurice, J-P., and N. Nishitani. "On the Origin of Far-Aspect Angle Irregularity Regions Seen by HF Radars at 100-km Altitude." J.Geophysical Res. 125.6 (2020)