Signal and Imaging Processing Final Project

Preliminary Detection of Neutron Monitor Forbush Decrease (FD) Events from Cross-Correlation with Historical FD Data

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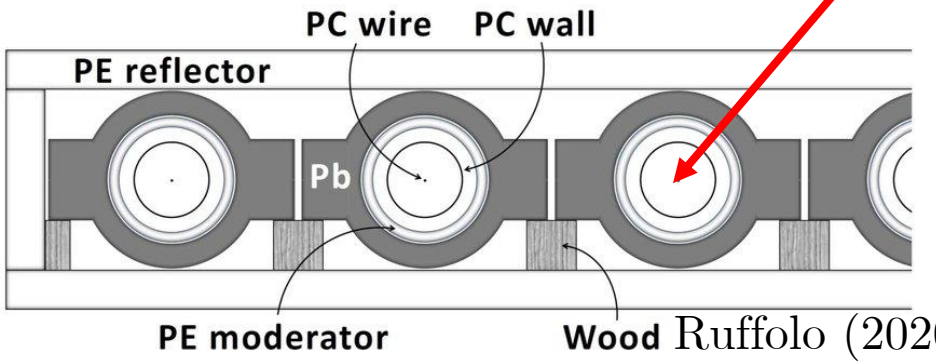
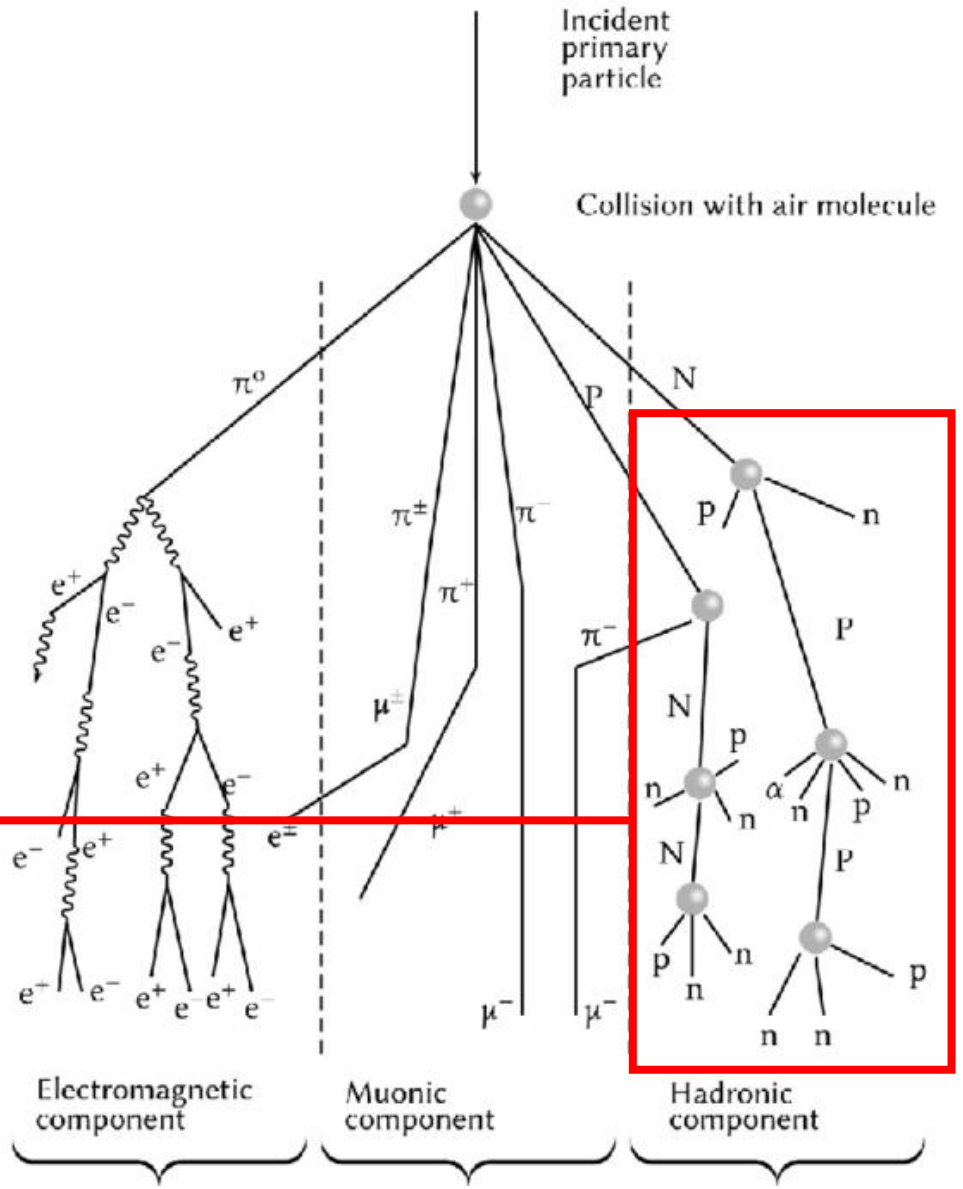
Cosmic Rays

- High-energy particles from outer space
- They collide with air particles in the atmosphere to form "air showers."
- Cosmic rays can be detected with **neutron monitors** (NM).



Ruffolo (2020)

Barrantes, et al. (2018)

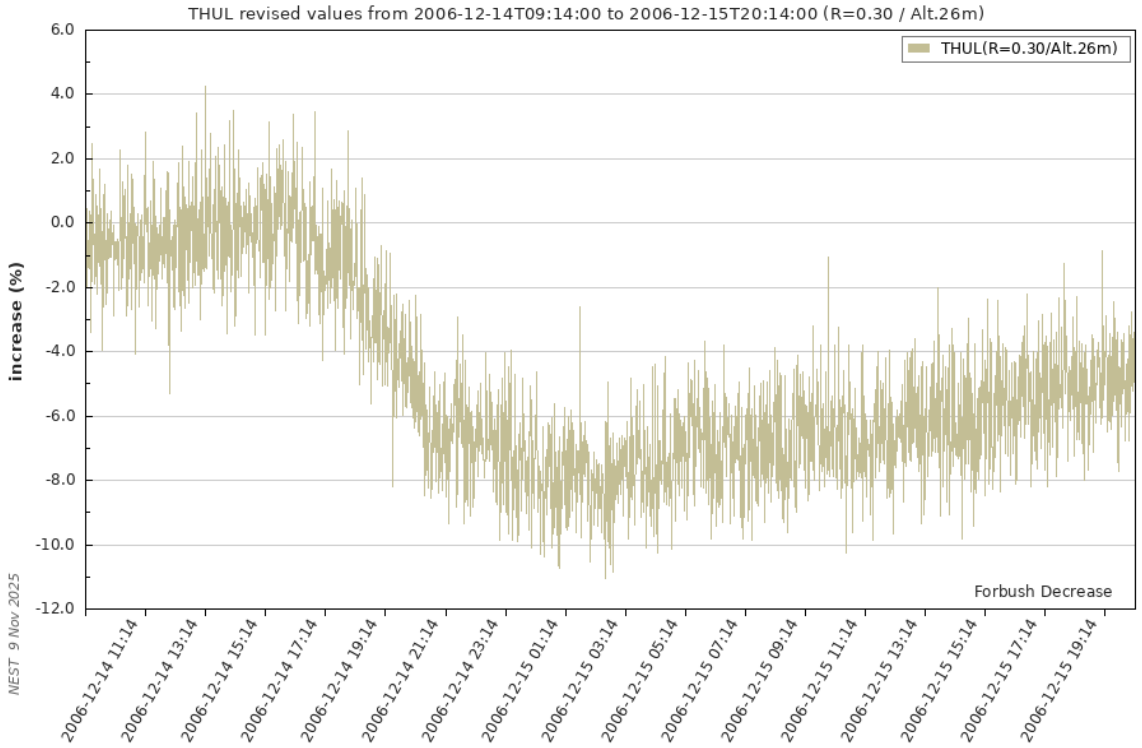


Source: Barrantes, et al. (2018)

Forbush Decreases (FD)

- Rapid decrease in observed cosmic ray intensity (up to 20%)
- Occurs due to plasma ejections from the Sun sweeping cosmic rays away from Earth.

Retrieved from nmdb NEST

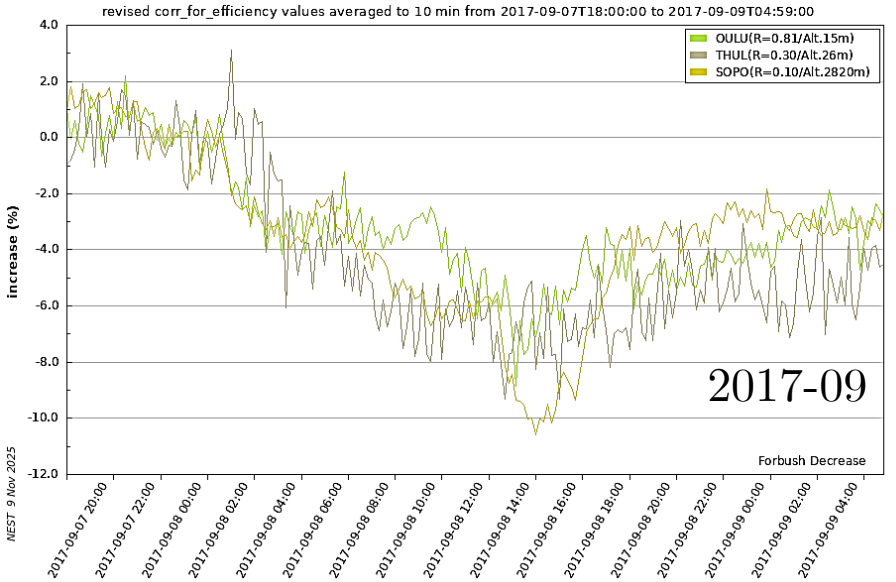


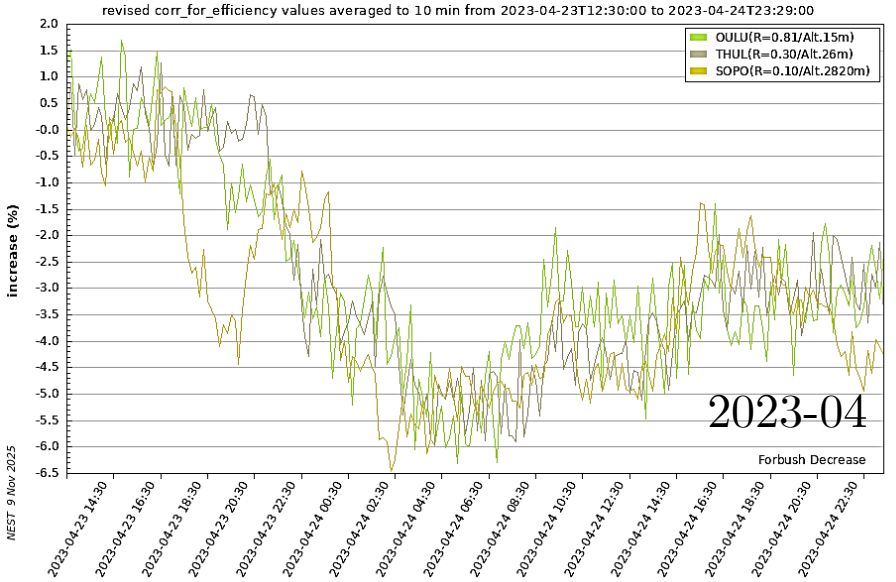
Source: Barrantes, et al. (2018)

SIP Project Overview

- NM data retrieval: nmdb NEST
- Stations: OULU, THUL, SOPO, AATB, LMKS
- Data resolution: 2 minutes
- To-do: Cross-correlate FD data from 2015 on data across entire years of 2005, 2022, 2023 and 2024.
- Evaluate performance (TP/FP/FN)

FD graphs retrieved from nmdb NEST



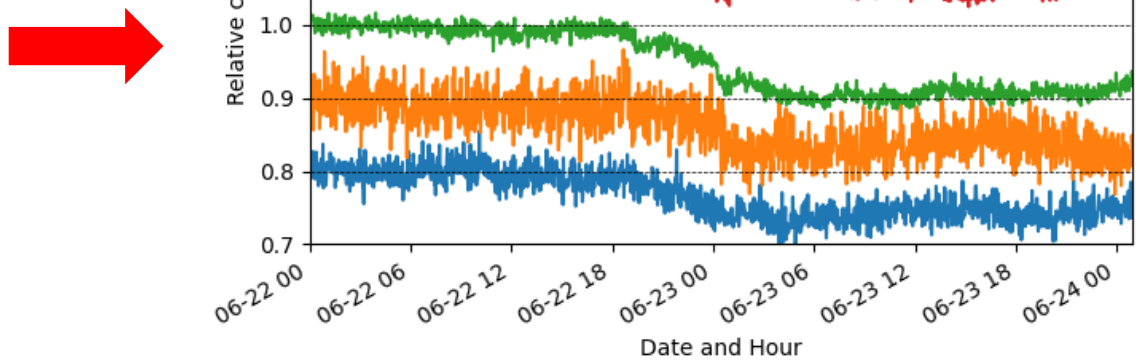


NM Data Retrieval

- Read and clean data downloaded from nmdb

	OULU	THUL	SOPO
2015-06-22 00:00:00	102.038	119.735	null
2015-06-22 00:02:00	102.889	119.045	null
2015-06-22 00:04:00	103.342	116.435	null
2015-06-22 00:06:00	102.001	119.230	null
2015-06-22 00:08:00	103.745	117.120	null
2015-06-22 00:10:00	103.543	115.990	null
2015-06-22 00:12:00	104.774	120.020	294.005
2015-06-22 00:14:00	104.340	113.295	292.080
2015-06-22 00:16:00	100.984	122.365	290.730
2015-06-22 00:18:00	103.903	120.150	289.195
2015-06-22 00:20:00	101.322	120.275	286.975
2015-06-22 00:22:00	100.929	117.170	290.770
2015-06-22 00:24:00	104.688	119.455	287.715
2015-06-22 00:26:00	101.851	116.785	292.685
2015-06-22 00:28:00	102.964	120.180	289.505
2015-06-22 00:30:00	101.334	116.505	292.910
2015-06-22 00:32:00	99.981	118.460	288.870
2015-06-22 00:34:00	103.091	121.430	292.700

	AATB	LMKS
2015-06-22 00:00:00	1255.450	444.087
2015-06-22 00:02:00	1291.550	444.619
2015-06-22 00:04:00	1280.100	447.861
2015-06-22 00:06:00	1298.200	445.234
2015-06-22 00:08:00	1280.650	452.167
2015-06-22 00:10:00	1253.550	455.095
2015-06-22 00:12:00	1283.550	448.875
2015-06-22 00:14:00	1279.700	449.202
2015-06-22 00:16:00	1295.800	452.268
2015-06-22 00:18:00	1265.850	449.059
2015-06-22 00:20:00	1278.250	450.544
2015-06-22 00:22:00	1299.250	451.377
2015-06-22 00:24:00	1278.750	441.420
2015-06-22 00:26:00	1299.750	449.877
2015-06-22 00:28:00	1276.200	446.990
2015-06-22 00:30:00	null	447.890
2015-06-22 00:32:00	1275.400	450.739
2015-06-22 00:34:00	1291.400	445.320

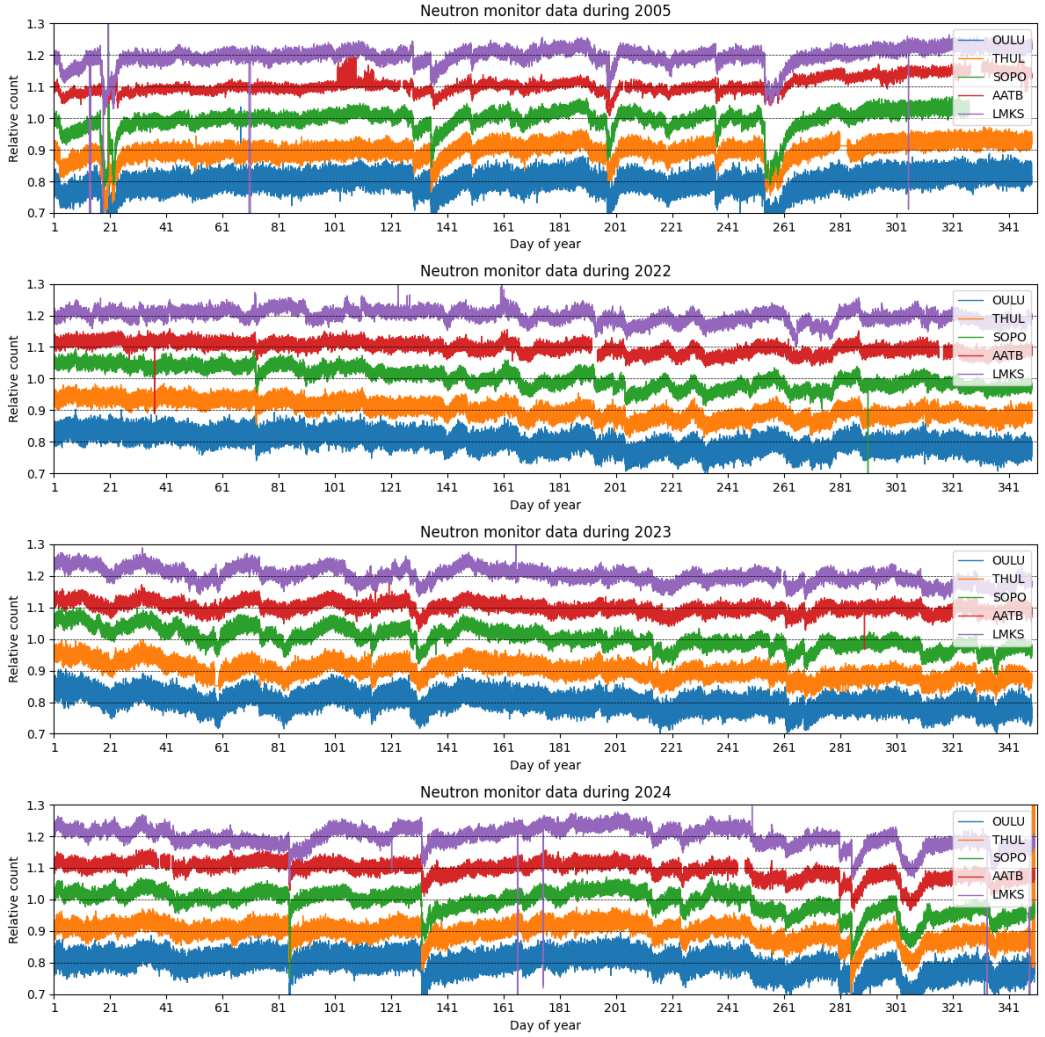


NM Data Retrieval

- Read and clean nmdb data

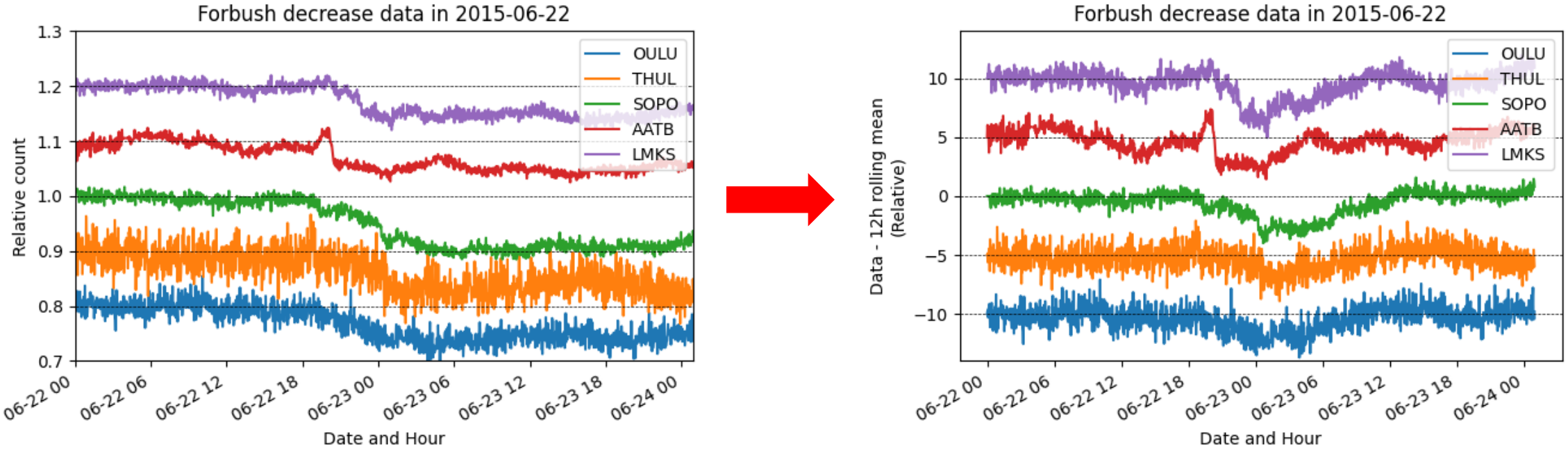
```
                     OULU     THUL     SOPO
2005-01-01 00:00:00;102.878;115.610;287.055
2005-01-01 00:02:00;101.313;114.330;286.695
2005-01-01 00:04:00;103.435;116.180;284.750
2005-01-01 00:06:00;100.498;115.440;284.735
2005-01-01 00:08:00;100.452;116.925;286.435
2005-01-01 00:10:00;100.702;115.230;287.175
2005-01-01 00:12:00;100.584;116.905;287.835
2005-01-01 00:14:00;102.475;118.135;289.385
2005-01-01 00:16:00;103.008;115.660;284.775
2005-01-01 00:18:00;100.594;115.995;285.685
2005-01-01 00:20:00; 99.444;115.125;282.890
2005-01-01 00:22:00;100.279;113.060;284.860
2005-01-01 00:24:00;100.533;114.050;284.555
2005-01-01 00:26:00;101.997;114.445;288.205
2005-01-01 00:28:00;101.216;116.570;284.140
2005-01-01 00:30:00;101.309;116.895;288.835
2005-01-01 00:32:00;105.054;116.175;286.175
2005-01-01 00:34:00;101.189;118.135;281.610
2005-01-01 00:36:00;101.729;115.970;288.560
2005-01-01 00:38:00;103.166;118.235;285.925
2005-01-01 00:40:00;101.295;116.130;284.340
2005-01-01 00:42:00;100.188;115.405;287.065
2005-01-01 00:44:00;101.715;117.935;286.545
2005-01-01 00:46:00;100.997;114.725;283.735
2005-01-01 00:48:00;101.758;116.900;284.750
2005-01-01 00:50:00; 99.768;117.025;286.395
2005-01-01 00:52:00;101.956;115.465;285.845
2005-01-01 00:54:00;103.540;115.170;288.375
2005-01-01 00:56:00;101.392;114.290;287.160
2005-01-01 00:58:00;104.162;116.435;287.005
2005-01-01 01:00:00;104.183;114.585;284.995
```

	datetime	OULU	THUL	SOPO	AATB	LMKS
0	2005-01-01 00:00:00	102.878	115.610	287.055	1368.85	422.034
1	2005-01-01 00:02:00	101.313	114.330	286.695	1395.75	422.425
2	2005-01-01 00:04:00	103.435	116.180	284.750	1374.85	430.050
3	2005-01-01 00:06:00	100.498	115.440	284.735	1377.65	438.716
4	2005-01-01 00:08:00	100.452	116.925	286.435	1383.70	425.375
...	...	...	...	...	...	...
250555	2005-12-14 23:50:00	105.435	121.250	NaN	1443.90	449.992
250556	2005-12-14 23:52:00	104.610	122.380	NaN	1436.60	446.092
250557	2005-12-14 23:54:00	106.469	120.665	NaN	1433.85	446.350
250558	2005-12-14 23:56:00	106.546	122.065	NaN	1449.35	444.250
250559	2005-12-14 23:58:00	104.500	119.460	NaN	1433.40	442.575



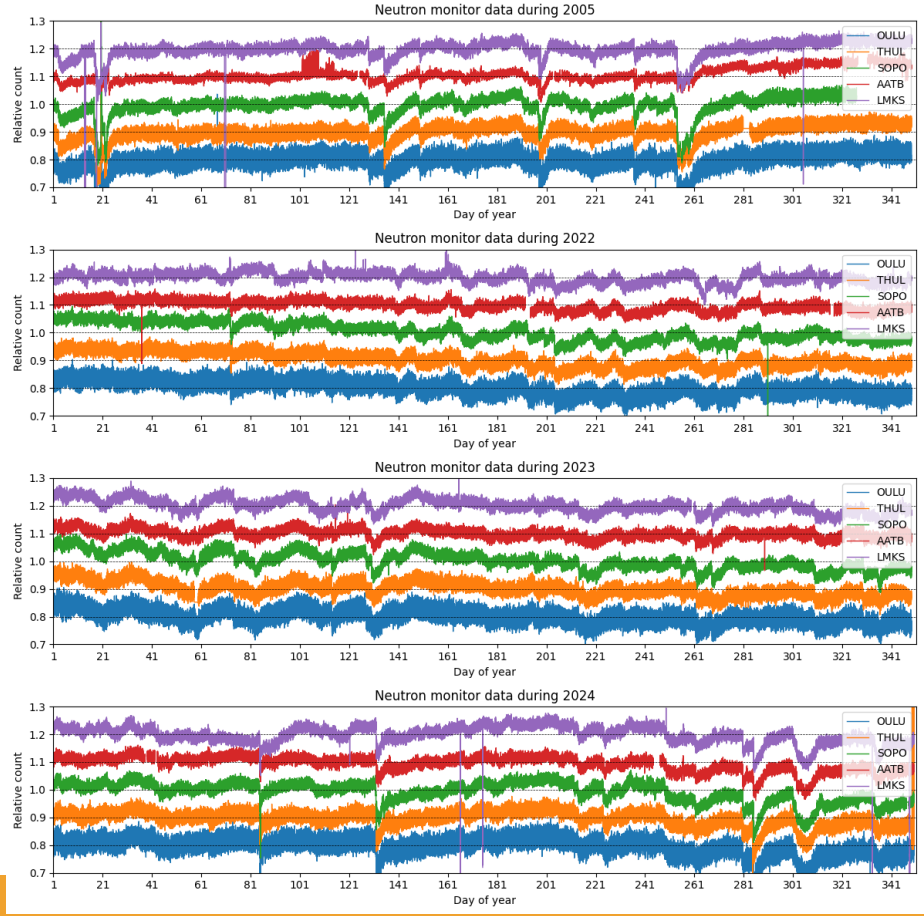
Long-term Trend Removal

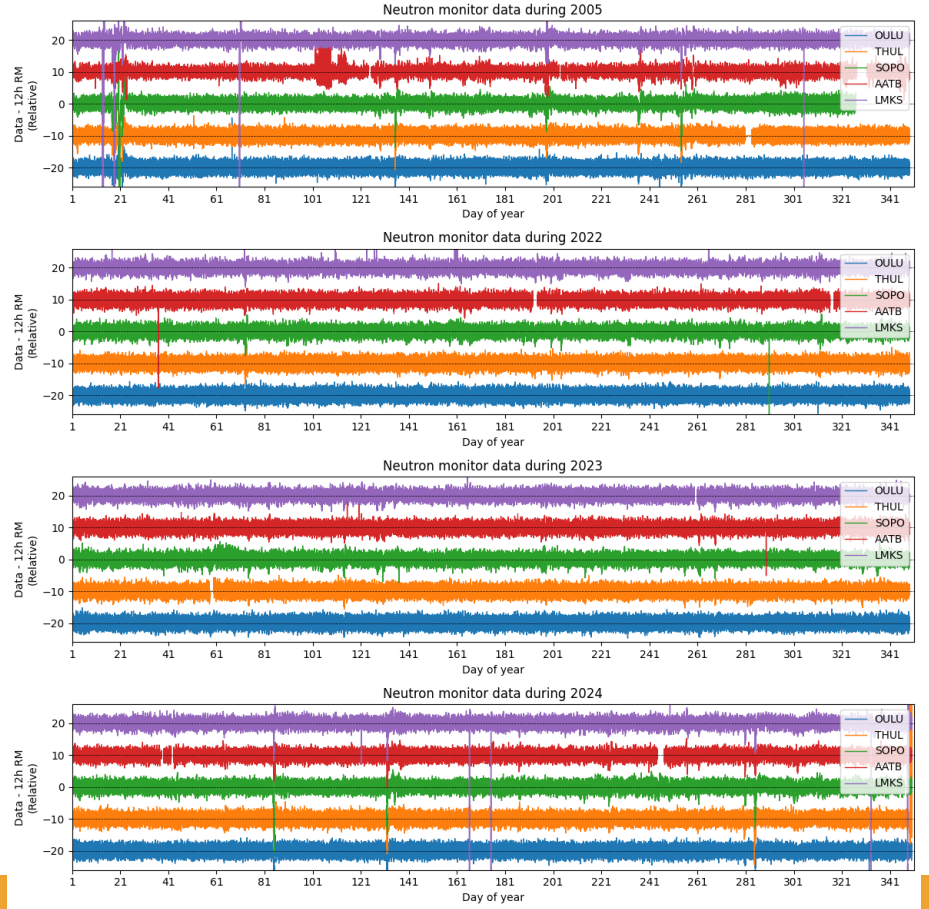
- Data - 12-hour moving average
- Flattens long-term trends, but leaves out short-term changes



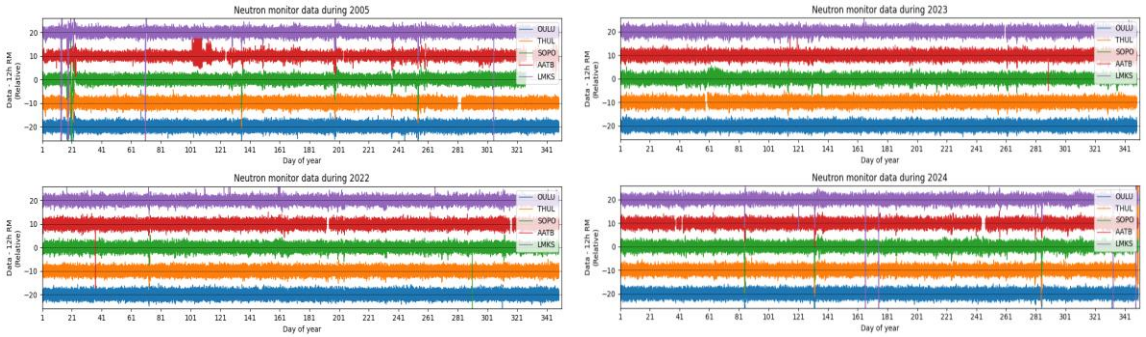
Long-term Trend Removal

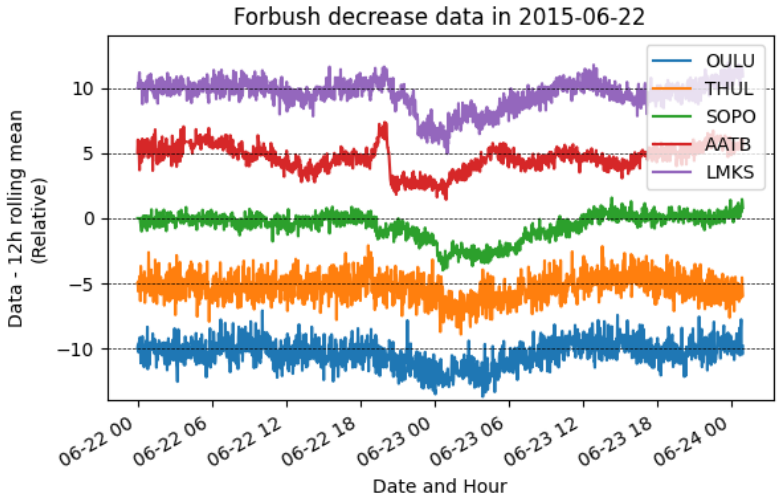
- Data - 12-hour moving average

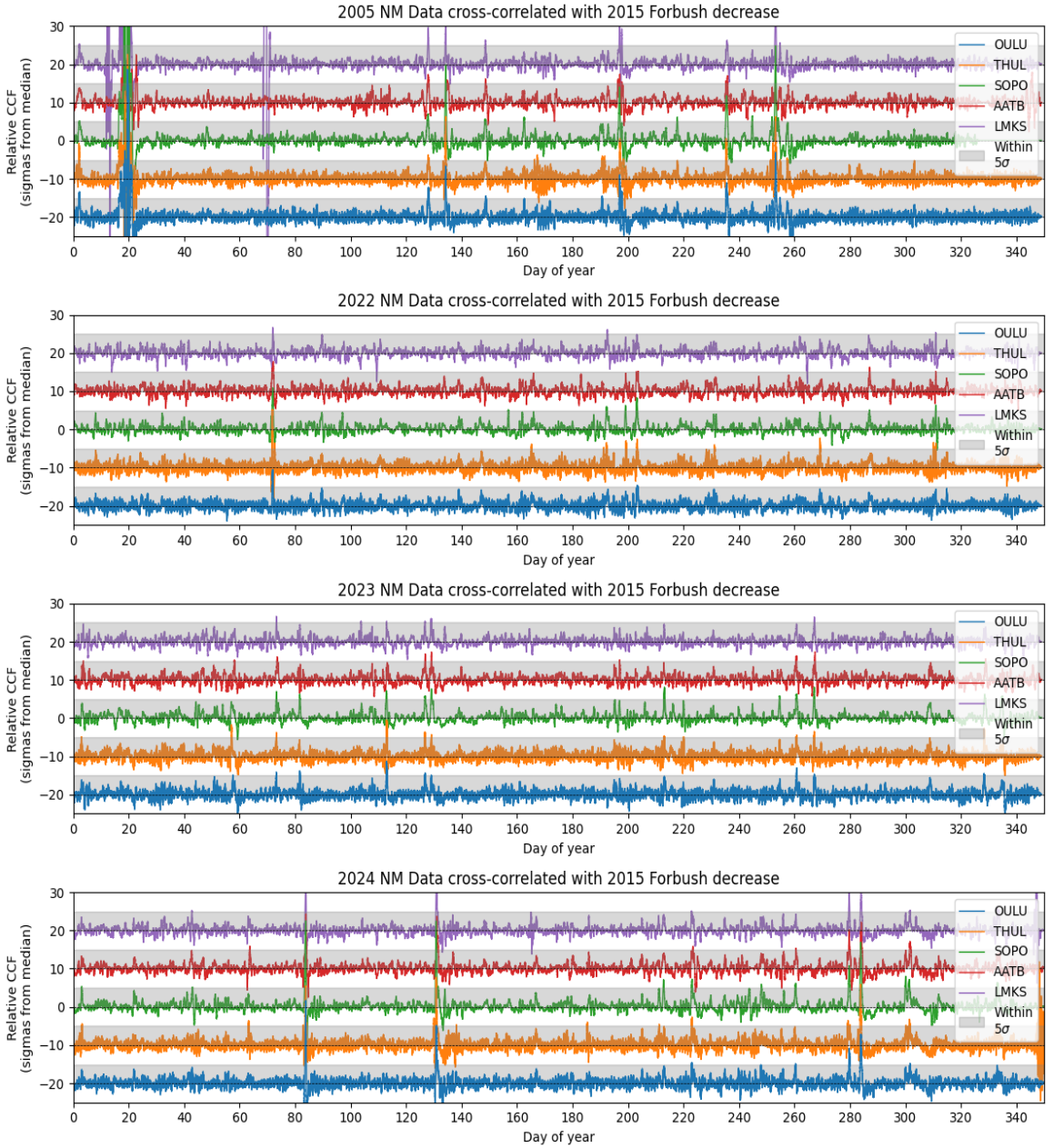




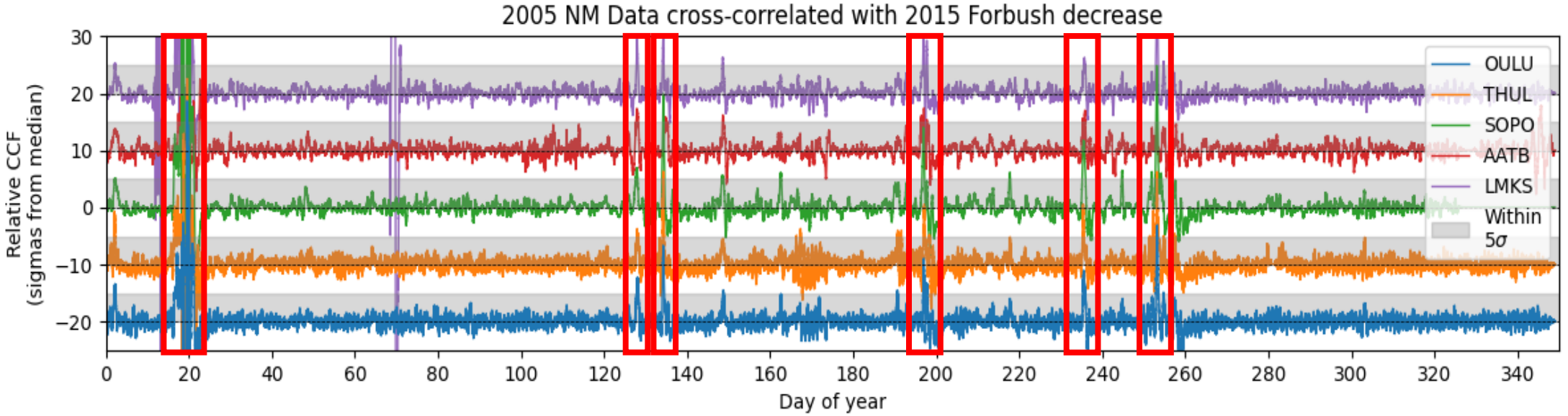
Cross-correlation







Forbush Decrease Detection



Forbush Decrease "detected" if CCF is $+5\sigma$ from its median, simultaneously across 5 stations

Results

- Dates with actual FDs

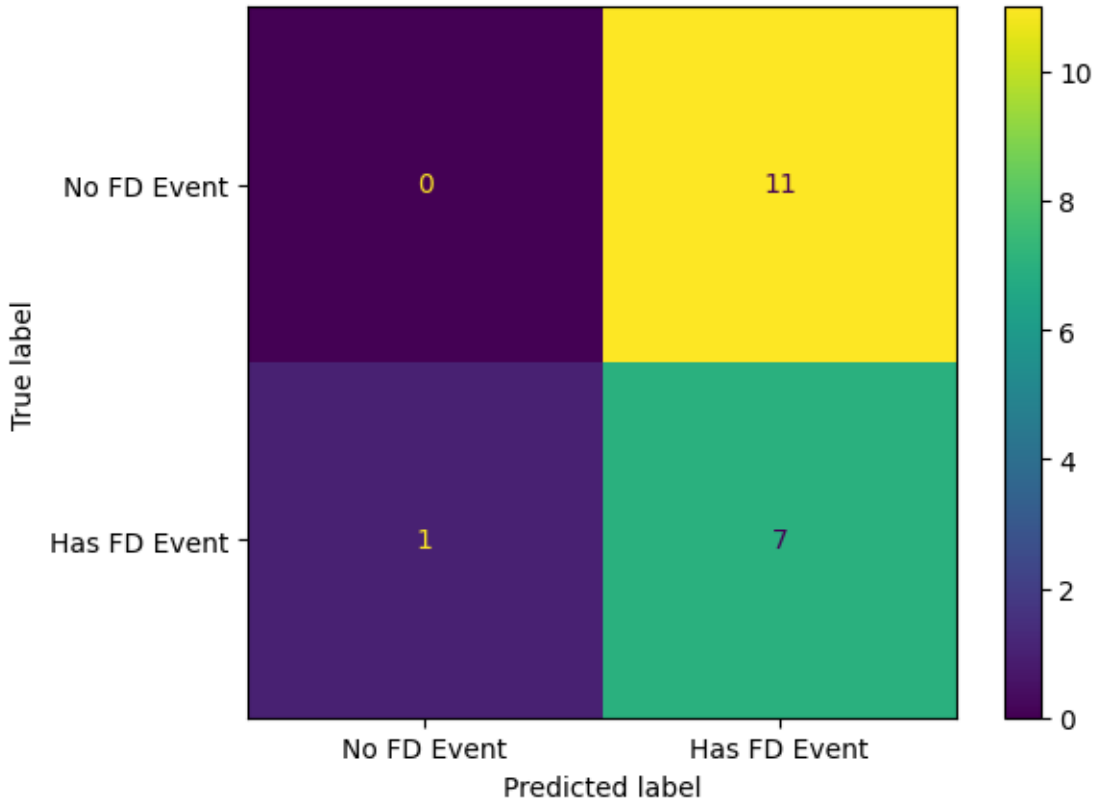
2005-01-18
2005-01-21
2005-05-15
2005-08-24
2005-09-11
2023-04-23
2024-03-24
2024-05-10

- Dates with ‘detected’ FDs

2005-01-18	**2005-01-21**
2005-05-08	**2005-05-15**
2005-07-16	**2005-08-24**
2005-09-11	2022-03-13
2023-03-15	2023-05-07
2023-05-09	2023-09-25
2024-03-24	**2024-05-10**
2024-08-10	2024-10-06
2024-10-10	2014-10-28

Results

- Confusion Matrix



(https://www.labelf.ai/blog/what-is-accuracy-precision-recall-and-f1-score)

$$precision = \frac{true\ positives}{true\ positives + false\ positives}$$

$$recall = \frac{true\ positives}{true\ positives + false\ negatives}$$

$$F1 = 2 \cdot \frac{precision \cdot recall}{precision + recall}$$

True Positives: 7
False Negatives: 1
False Positives: 11

Precision: 0.389
Recall: 0.875
F1 score: 0.538

Conclusion

- Cross-correlation of year-round and historical FD data from neutron monitors can detect FD events with great recall, but leaves many false positives.
- Neutron monitor data alone is not sufficient for FD detection.
- FDs are often associated with stronger interplanetary magnetic fields or disturbances in Earth's magnetic field (Belov 2008), so the associated data may help remove false positives.

References

- Barrantes M, Valdés-Galicia JF, Musalem O, Hurtado A, Anzorena M, García R, et al. Atmospheric corrections of the cosmic ray fluxes detected by the Solar Neutron Telescope at the Summit of the Sierra Negra Volcano in Mexico. Geofis Int. 2018;57(4):253–75. Available from: http://dx.doi.org/10.22201/igeof.00167169p.2018.57.4.2105
- Belov AV. Forbush effects and their connection with solar, interplanetary and geomagnetic phenomena. Proc Int Astron Union 2008;4(S257):439–50. Available from: http://dx.doi.org/10.1017/s1743921309029676