Transmission Dynamics®

Modern Approaches to Pantograph-OLE Dynamic Interaction Monitoring

Comparing Dynamic Contact Force Measurements with Acceleration-Based Diagnostics

J. Rosinski, June 2025

About Transmission Dynamics

Transmission Dynamics is an award-winning AI engineering company specialising in the monitoring, diagnosis, and optimisation of critical assets and infrastructure.

For nearly three decades, the company has helped organisations solve complex engineering challenges by providing a deeper understanding of how assets behave, perform, and deteriorate in service. Combining engineering expertise with innovative monitoring technologies, Transmission Dynamics delivers the insight needed to improve reliability, enhance safety, reduce downtime, and extend asset life.

Its work spans some of the world's most demanding industries, including rail, energy, mining, defence, aerospace, renewable energy, and heavy industry. Whether monitoring overhead line equipment, rolling stock, rotating machinery, or structural assets, the company focuses on turning complex engineering data into practical knowledge that supports better operational and maintenance decisions.

Company achievements include Design Team of the Year at the Engineering & Manufacturing Awards 2023; Remarkable Innovation SME at the Dynamites Awards 2024; The Best Use of Data and AI at the Dynamite Awards 2025; the Railway Industry Association RISE Award for Innovation 2025; and The King's Award for Enterprise for Innovation in 2025.

About the Author

Professor Jarek Rosinski

Executive Chairman at Transmission Dynamics

Professor Jarek Rosinski is widely recognised as one of the pioneers shaping the future of intelligent engineering systems, with a career dedicated to redefining how industry understands, monitors, and manages critical machinery.

With an MSc in Vibroacoustics and a PhD in Machine Dynamics, Jarek began his career in academia, first in Kraków and later at Newcastle University's National Gear Technology Centre. There, he combined rigorous research with deep industrial engagement, building an international reputation for solving complex, high-stakes challenges in machine dynamics and power transmission.

In 1996, he founded Transmission Dynamics - anticipating the convergence of sensing, connectivity, and data long before it became mainstream. Under his leadership, the company has grown into a globally respected innovator in Industrial IoT, delivering advanced condition monitoring and predictive maintenance systems that integrate sensor design, electronics, and intelligent analytics.

A defining element of Jarek's vision is captured in the concept he coined - “Trains with Brains” - a powerful expression of how intelligent, self-aware systems can transform the rail industry. This thinking reflects a broader shift he has championed: from reactive maintenance to predictive, insight-driven operations, and increasingly towards autonomous, self-diagnosing assets.

Today, this transformation is influencing industries ranging from energy and transport to defence and aerospace, with clients including Siemens, GE, BMW, Ford, Network Rail, the MoD, and NASA.

Beyond business, Jarek has played a significant role in advancing engineering knowledge and practice. He has delivered specialist industrial training for the British Gear Association for over three decades and was recently appointed Professor in Practice at Durham University, reflecting his commitment to bridging academia and industry.

His contributions have been recognised through numerous national and international awards, including the King's Award for Enterprise in Innovation.

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Introduction

The monitoring of pantograph and Overhead Line Equipment (OLE) interaction has historically relied upon instrumented pantographs designed to measure contact forces in accordance with EN50137 methodologies. These systems typically employ strain gauges, Fibre Bragg Gratings (FBGs), or load cells mounted within the pantograph head assembly to estimate contact forces between the carbon strip and the contact wire.

Whilst such methods can provide valuable information under static or quasi-static conditions, the accurate measurement of dynamic contact forces presents considerably greater challenges due to the complex dynamic behaviour of the pantograph structure itself. Increasing train speeds, higher-frequency excitation mechanisms, and the growing requirement for continuous infrastructure monitoring are exposing limitations in traditional force-based measurement approaches.

At the same time, advances in compact accelerometer technology, edge processing, machine learning, and distributed train-borne monitoring systems have enabled alternative approaches capable of providing highly sensitive and operationally scalable diagnostics of pantograph–OLE interaction.

Static and Dynamic Contact Force Measurements

Under static conditions, contact force measurement is relatively straightforward. Instrumented pantographs equipped with calibrated sensing systems can accurately determine uplift forces and mean contact loads. These approaches are particularly effective when assessing average contact force values or performing controlled acceptance testing.

However, such systems are inherently complex and operationally demanding. Instrumented pantographs typically require specialised installation, complex calibration procedures, careful maintenance, and pantograph-specific instrumentation arrangements.

Recent advances in Machine Learning (ML) provide an alternative method for estimating mean contact force by analysing the deflection of compliant pantograph components such as spring systems on Bracknell Willis pantographs or torsion bars on Siemens pantographs.

Challenges of Dynamic Contact Force Measurements

The principal challenge associated with dynamic contact force measurements is that the true contact force cannot be measured directly at the interface between the carbon strip and the contact wire.

Instead, force measurements are inferred from sensors positioned elsewhere within the pantograph structure, such as carbon carriers, suspension elements, support frames, or structural members.

Under dynamic conditions, the pantograph head no longer behaves as a rigid body. Instead, it behaves as a flexible continuous structure exhibiting multiple vibration modes and frequency-dependent dynamic behaviour.

As a consequence, the relationship between local strain measurements and actual contact force becomes highly dependent upon the dynamic response of the system.

Dynamic Behaviour of Pantograph Systems

The dynamic behaviour of pantograph systems can be understood by considering the concept of apparent dynamic mass (see Appendix A):

$$\text{Apparent Dynamic Mass} = F / a$$

As train speed increases, spatial irregularities within the OLE system are translated into higher excitation frequencies. This progressively moves the pantograph response deeper into the stiffness-controlled dynamic regime.

Below resonance:

- acceleration sensitivity increases strongly with frequency,
- while force measurements may lose diagnostic sensitivity.

Above resonance, the system progressively approaches Newtonian behaviour:

$$F = ma$$

However, many diagnostically important pantograph–OLE interactions occur within or near stiffness-controlled regions and structural resonances, where acceleration-based monitoring provides significantly enhanced sensitivity to excitation events.

Operational Correlation with Mentor Train Measurements

To assess practical correlation between force-based and acceleration-based monitoring systems, a set of high-contact-force events identified by the Mentor measuring train were analysed against historical PANDAS-V® impact event datasets (see fig. 1).

The comparison demonstrated that:

- all Mentor-reported events were successfully identified by PANDAS-V®;
- multiple locations corresponded to persistent impact clusters;
- and some locations exhibited several hundred repeated impact detections over time.

This operational evidence demonstrates strong correlation between force-based event identification and acceleration-based diagnostics.

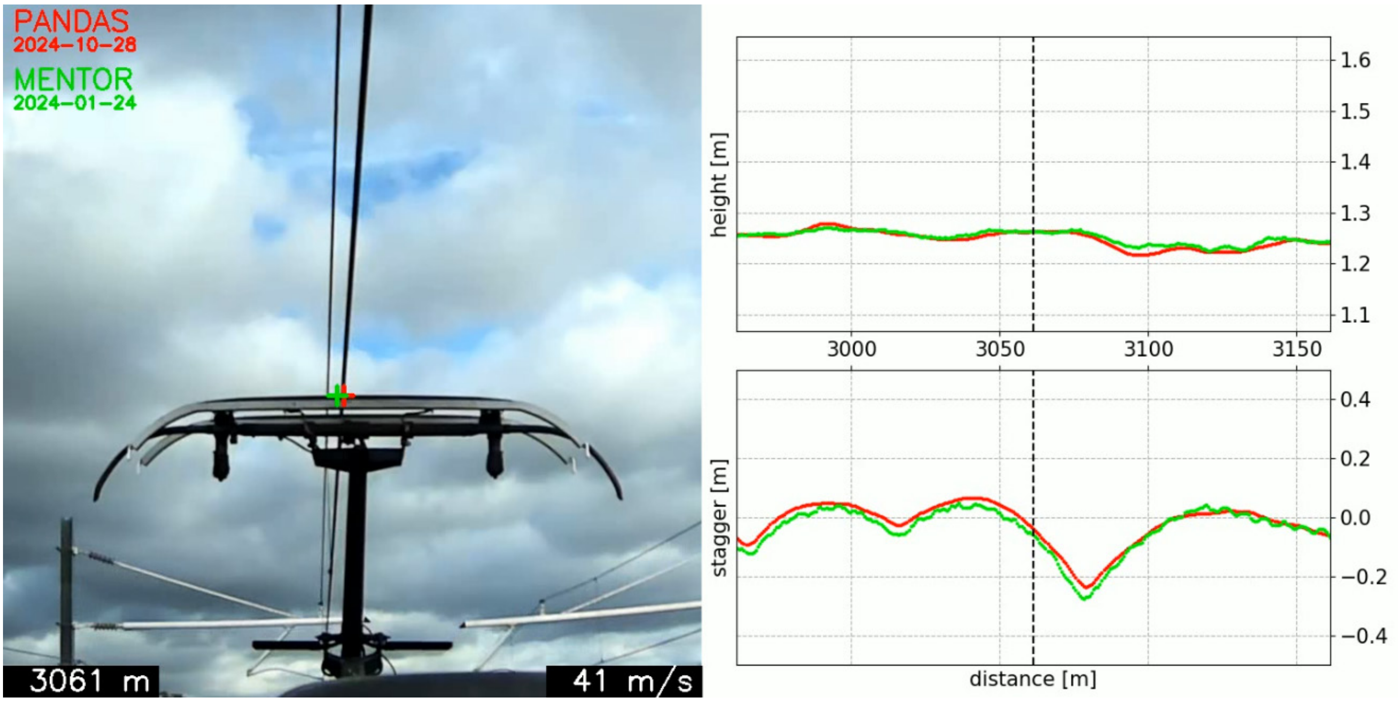


Fig. 1 Analysis of Mentor train and PANDAS-V® impact event datasets.

Advantages of Acceleration-Based Monitoring

Modern accelerometers provide several important practical and technical advantages for dynamic pantograph–OLE monitoring.

Acceleration measurements are highly sensitive to:

- hard spots,
- contact wire irregularities,
- broken droppers,
- registration arm impacts,
- poorly aligned neutral sections,
- and other transient excitation events.

Continuous monitoring systems deployed across operational fleets can scan infrastructure continuously, detect emerging defects rapidly, provide near-real-time alerts, and monitor defect progression over time.

Conclusion

Traditional pantograph contact force measurements remain valuable for static assessments, calibration activities, and controlled acceptance testing.

However, dynamic force measurements are fundamentally constrained by indirect sensing locations, structural modal behaviour, frequency-dependent response characteristics, and operational deployment limitations.

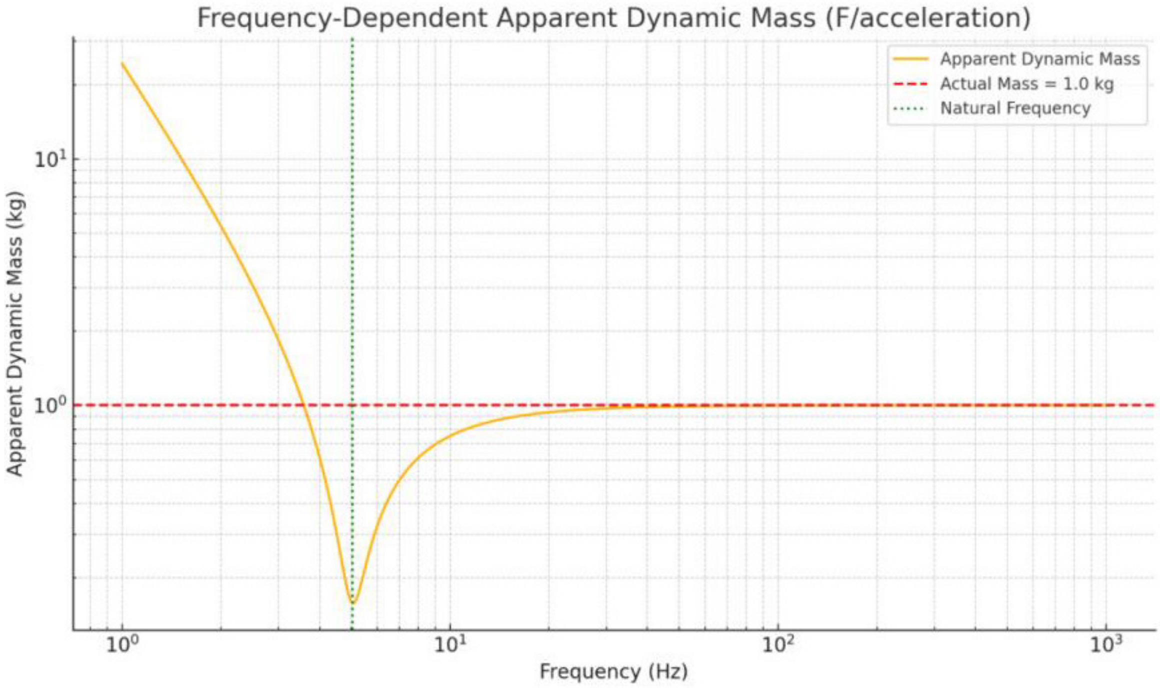
Acceleration-based monitoring systems provide several important advantages for modern OLE condition monitoring, particularly for high-frequency anomaly detection, continuous network surveillance, trend monitoring, and distributed operational deployment.

As railway systems continue to evolve toward condition-based maintenance and real-time infrastructure monitoring, acceleration-based diagnostics supported by Machine Learning offer a practical, scalable, and dynamically sensitive approach for monitoring pantograph–OLE interaction in modern rail networks.

Appendices

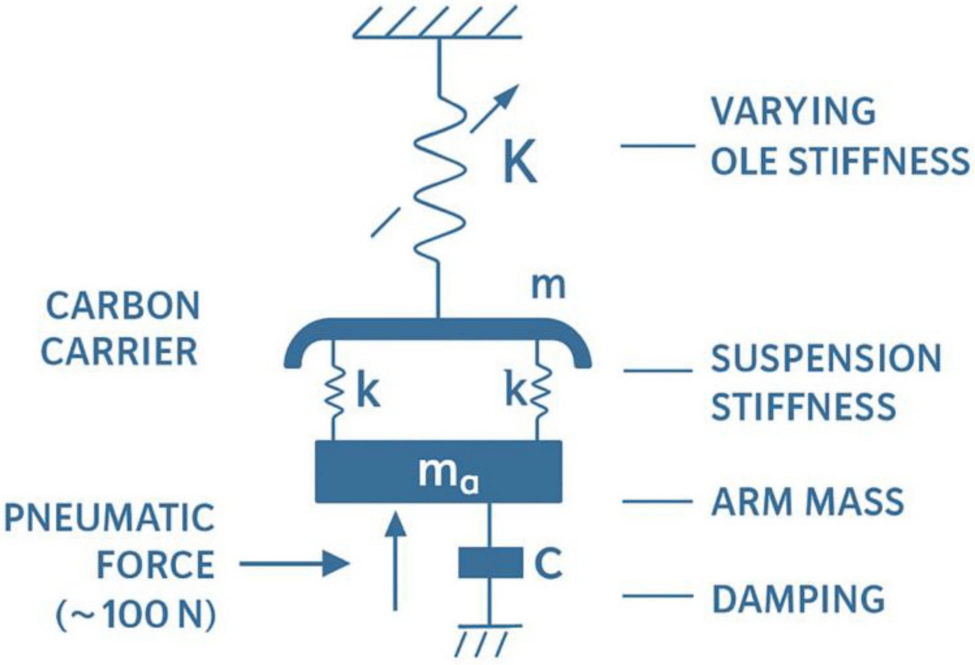
Appendix A

Example of Apparent Dynamic Mass {FRF}
The figures and operational correlation data included below illustrate the strong agreement between conventional force-based monitoring and acceleration-derived diagnostics, whilst highlighting the enhanced sensitivity and scalability of distributed acceleration-based systems.



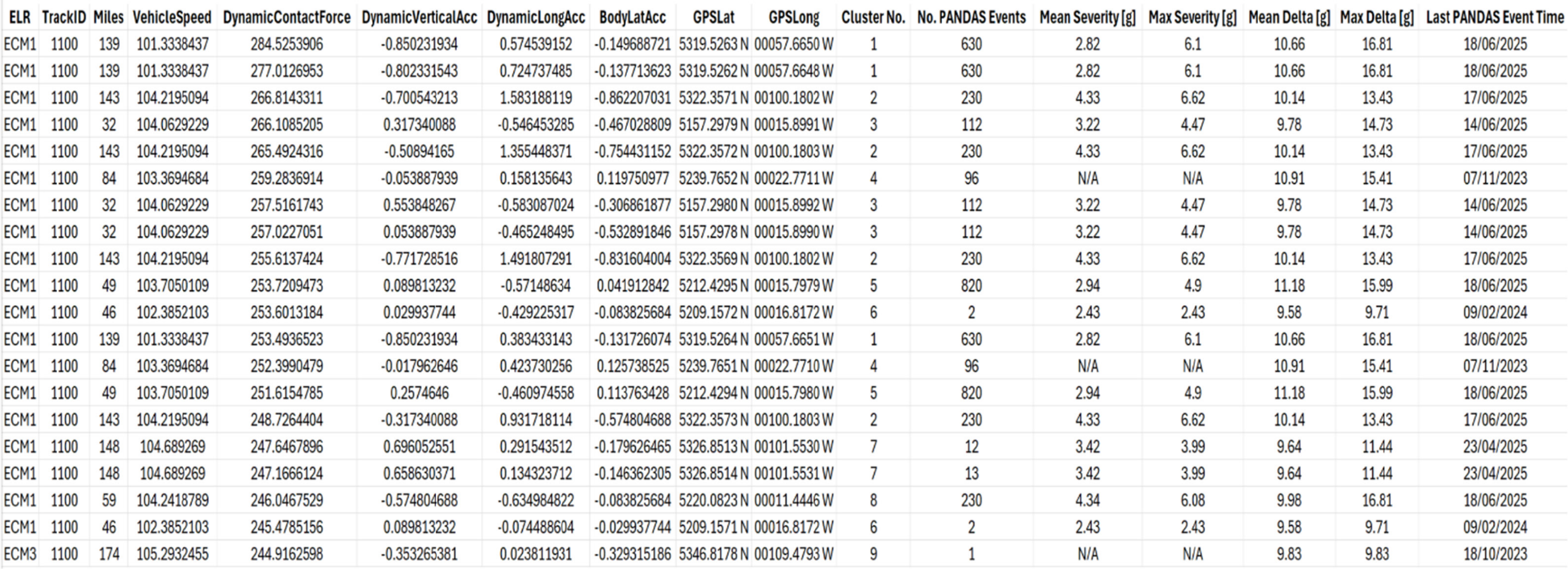
Appendix B

Dynamic model of the pantograph



Appendix C

Table showing correlation between Mentor train force events and historical PANDAS-V® impact event clusters



ELR	TrackID	Miles	VehicleSpeed	DynamicContactForce	DynamicVerticalAcc	DynamicLongAcc	BodyLatAcc	GPSLat	GPSLong	Cluster No.	No. PANDAS Events	Mean Severity [g]	Max Severity [g]	Mean Delta [g]	Max Delta [g]	Last PANDAS Event Time
ECM1	1100	139	101.3338437	284.5253906	-0.850231934	0.574539152	-0.149688721	5319.5263 N	00057.6650 W	1	630	2.82	6.1	10.66	16.81	18/06/2025
ECM1	1100	139	101.3338437	277.0126953	-0.802331543	0.724737485	-0.137713623	5319.5262 N	00057.6648 W	1	630	2.82	6.1	10.66	16.81	18/06/2025
ECM1	1100	143	104.2195094	266.8143311	-0.700543213	1.583188119	-0.862207031	5322.3571 N	00100.1802 W	2	230	4.33	6.62	10.14	13.43	17/06/2025
ECM1	1100	32	104.0629229	266.1085205	0.317340088	-0.546453285	-0.467028809	5157.2979 N	00015.8991 W	3	112	3.22	4.47	9.78	14.73	14/06/2025
ECM1	1100	143	104.2195094	265.4924316	-0.50894165	1.355448371	-0.754431152	5322.3572 N	00100.1803 W	2	230	4.33	6.62	10.14	13.43	17/06/2025
ECM1	1100	84	103.3694684	259.2836914	-0.053887939	0.158135643	0.119750977	5239.7652 N	00022.7711 W	4	96	N/A	N/A	10.91	15.41	07/11/2023
ECM1	1100	32	104.0629229	257.5161743	0.553848267	-0.583087024	-0.306861877	5157.2980 N	00015.8992 W	3	112	3.22	4.47	9.78	14.73	14/06/2025
ECM1	1100	32	104.0629229	257.0227051	0.053887939	-0.465248495	-0.532891846	5157.2978 N	00015.8990 W	3	112	3.22	4.47	9.78	14.73	14/06/2025
ECM1	1100	143	104.2195094	255.6137424	-0.771728516	1.491807291	-0.831604004	5322.3569 N	00100.1802 W	2	230	4.33	6.62	10.14	13.43	17/06/2025
ECM1	1100	49	103.7050109	253.7209473	0.089813232	-0.57148634	0.041912842	5212.4295 N	00015.7979 W	5	820	2.94	4.9	11.18	15.99	18/06/2025
ECM1	1100	46	102.3852103	253.6013184	0.029937744	-0.429225317	-0.083825684	5209.1572 N	00016.8172 W	6	2	2.43	2.43	9.58	9.71	09/02/2024
ECM1	1100	139	101.3338437	253.4936523	-0.850231934	0.383433143	-0.131726074	5319.5264 N	00057.6651 W	1	630	2.82	6.1	10.66	16.81	18/06/2025
ECM1	1100	84	103.3694684	252.3990479	-0.017962646	0.423730256	0.125738525	5239.7651 N	00022.7710 W	4	96	N/A	N/A	10.91	15.41	07/11/2023
ECM1	1100	49	103.7050109	251.6154785	0.2574646	-0.460974558	0.113763428	5212.4294 N	00015.7980 W	5	820	2.94	4.9	11.18	15.99	18/06/2025
ECM1	1100	143	104.2195094	248.7264404	-0.317340088	0.931718114	-0.574804688	5322.3573 N	00100.1803 W	2	230	4.33	6.62	10.14	13.43	17/06/2025
ECM1	1100	148	104.689269	247.6467896	0.696052551	0.291543512	-0.179626465	5326.8513 N	00101.5530 W	7	12	3.42	3.99	9.64	11.44	23/04/2025
ECM1	1100	148	104.689269	247.1666124	0.658630371	0.134323712	-0.146362305	5326.8514 N	00101.5531 W	7	13	3.42	3.99	9.64	11.44	23/04/2025
ECM1	1100	59	104.2418789	246.0467529	-0.574804688	-0.634984822	-0.083825684	5220.0823 N	00011.4446 W	8	230	4.34	6.08	9.98	16.81	18/06/2025
ECM1	1100	46	102.3852103	245.4785156	0.089813232	-0.074488604	-0.029937744	5209.1571 N	00016.8172 W	6	2	2.43	2.43	9.58	9.71	09/02/2024
ECM3	1100	174	105.2932455	244.9162598	-0.353265381	0.023811931	-0.329315186	5346.8178 N	00109.4793 W	9	1	N/A	N/A	9.83	9.83	18/10/2023

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