BOGAZICI UNIVERSITY

KANDILLI OBSERVATORY AND EARTHQUAKE RESEARCH INSTITUTE

EARTHQUAKE ENGINEERING

EQE 520 – STRONG GROUND MOTION

2020-2021 Fall Term

ASSINGMENT I

(Due December 16, 2020)

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1 Introduction

Samos Earthquake occurred on 30 October 2020 and in the Aegean Sea near Samos Island. The earthquake was felt in Greece as well as in Turkey excessively. In this study, we are expected to retrieve Samos Earthquake raw acceleration recordings of stations that are within 100 km epicentral distance from the AFAD website. Each component of raw data should be corrected with baseline correction. Secondly, Arias Intensity (I_A) and Cumulative Absolute Velocity (CAV) should be calculated to understand the energy of earthquakes. Arias Intensity (I_A) and Cumulative Absolute Velocity (CAV) indicates the potential destructiveness of an earthquake. Significant duration is also another important parameter for an earthquake and is calculated by using accumulated energy in the accelerogram. Significant duration is the time interval between 5% and 95% of I_A. Another important step of the assignment is to calculate the Instrumental Intensity of the earthquake. In this case, Tselentis and Danciu (2008) have a proposition a model to predict Modified Mercalli Intensity (MMI) by using dataset. This dataset has been constituted from earthquakes that happened in Greece during the period between 4 November 1973 and 7 September 1999. Tselentis and Danciu (2008) claim that epicentral distance, accumulated energy, and soil classification but dummy values are proportional to Modified Mercalli Intensity (MMI). They tested their claim in their dataset and came up with a formula to find MMI. In this study, their formula was used to calculate MMI, and calculated MMI has been compared with the MMI which has been already calculated by Kandilli Observatory and Earthquake Research Institute. In the last part of this assignment, Arias Intensity (I_A) and Cumulative Absolute Velocity (CAV) should be predicted from the empirical equation which is presented by Sandıkkaya and Akkar (2016). To predict these values for each recording, Sandıkkaya and Akkar (2016) propose coefficients for moment magnitude (Mw), the average seismic shear-wave velocity from the surface to a depth of 30 meters (Vs_{30}), distance (R_{epi}, R_{hyp}, R_{JB}), and corresponding coefficients. After finding the I_A, MMI can be predicted from I_A which is calculated the previous step.

2 Analysis

2.1 Raw Data, Baseline Correction, Arias Intensity, and Cumulative Absolute Intensity Graphs for Each Recording

Figures from 1 to 26 show that baseline correction has been already implemented to raw acceleration data. Nevertheless, to understand the difference between raw and corrected data, I also implemented baseline correction to retrieved acceleration data. To implement baseline correction, the mean of acceleration data must be found first. Then, mean value must be subtracted from each acceleration value. In addition to that, I want to see that how velocity and displacement change when baseline correction is applied. Corrected acceleration data should be converted to velocity by taking integral. But if it is accepted that constant acceleration method helps to solve integral easily.

Arias Intensity (I_A) is one of the important parameters to be aware of potential destructiveness of an earthquake. Arias Intensity is the sum of the total energy per weight in a set of undamped, elastic, single-degree-of-freedom (SDOF) systems in which frequencies distributed between zero and infinity. The formula is:

$$I_{ax} = \frac{\pi}{2 \times g} \int_0^{T_d} a_x^2(t)dt \quad (1)$$

T_d = the total duration of ground motion
g = gravity
a_x = the acceleration

Cumulative Absolute Intensity (CAV) is another indicator to measure structural damage. CAV is defined as the total area under the absolute ground acceleration a(t) with total duration t. The formula is:

$$CAV = \int_0^t |a(t)|dt \quad (2)$$

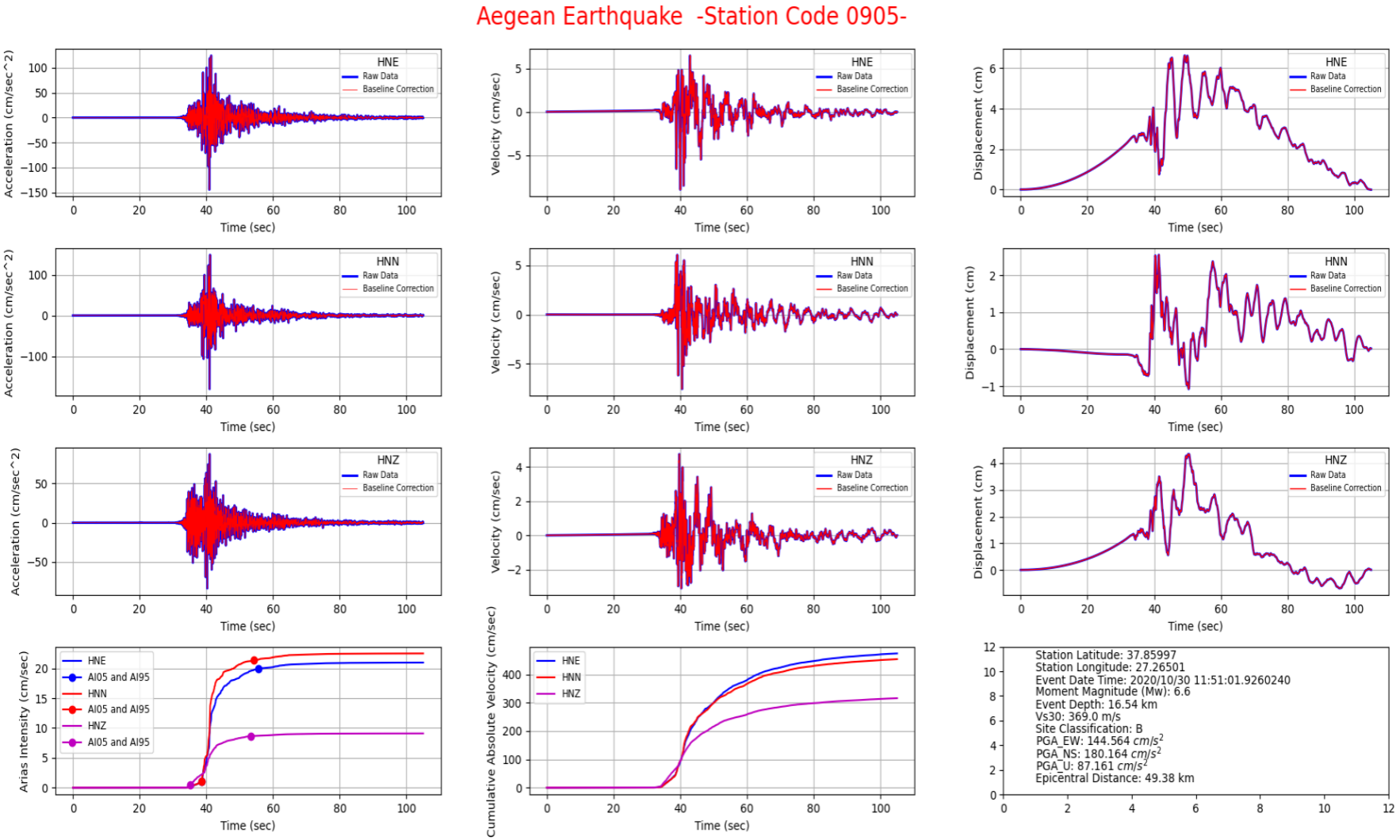
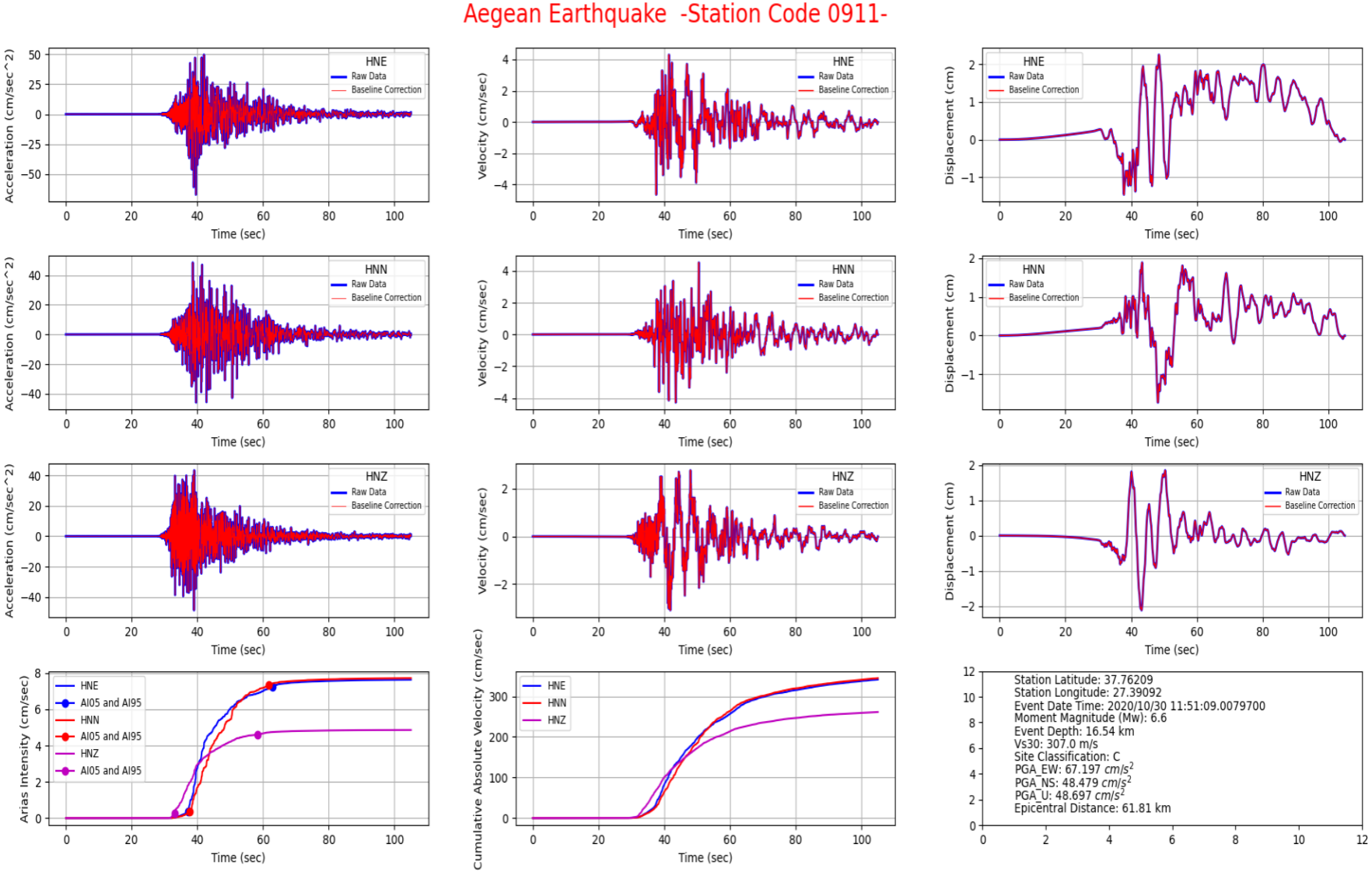


Figure 1 Station 0905



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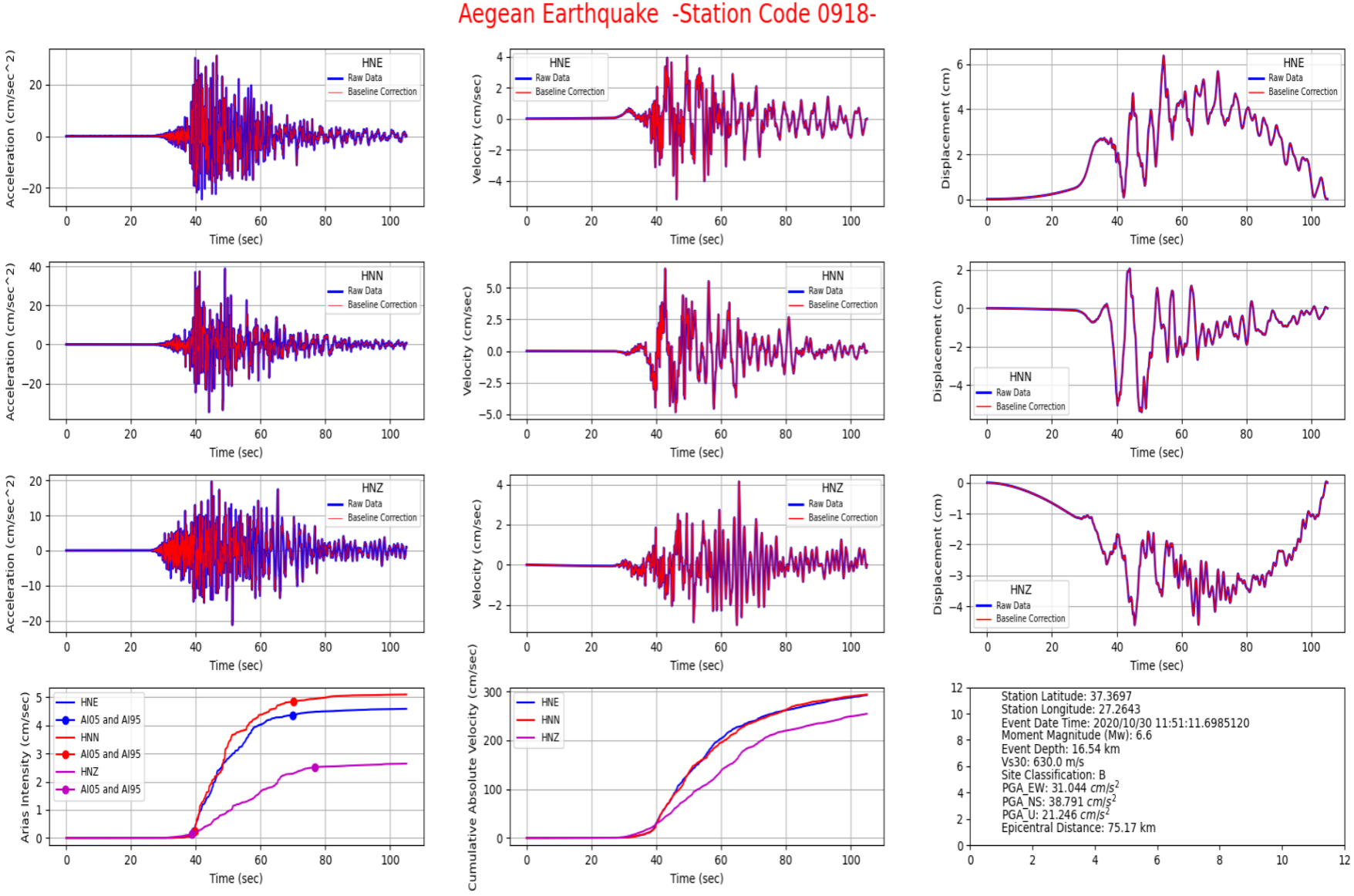

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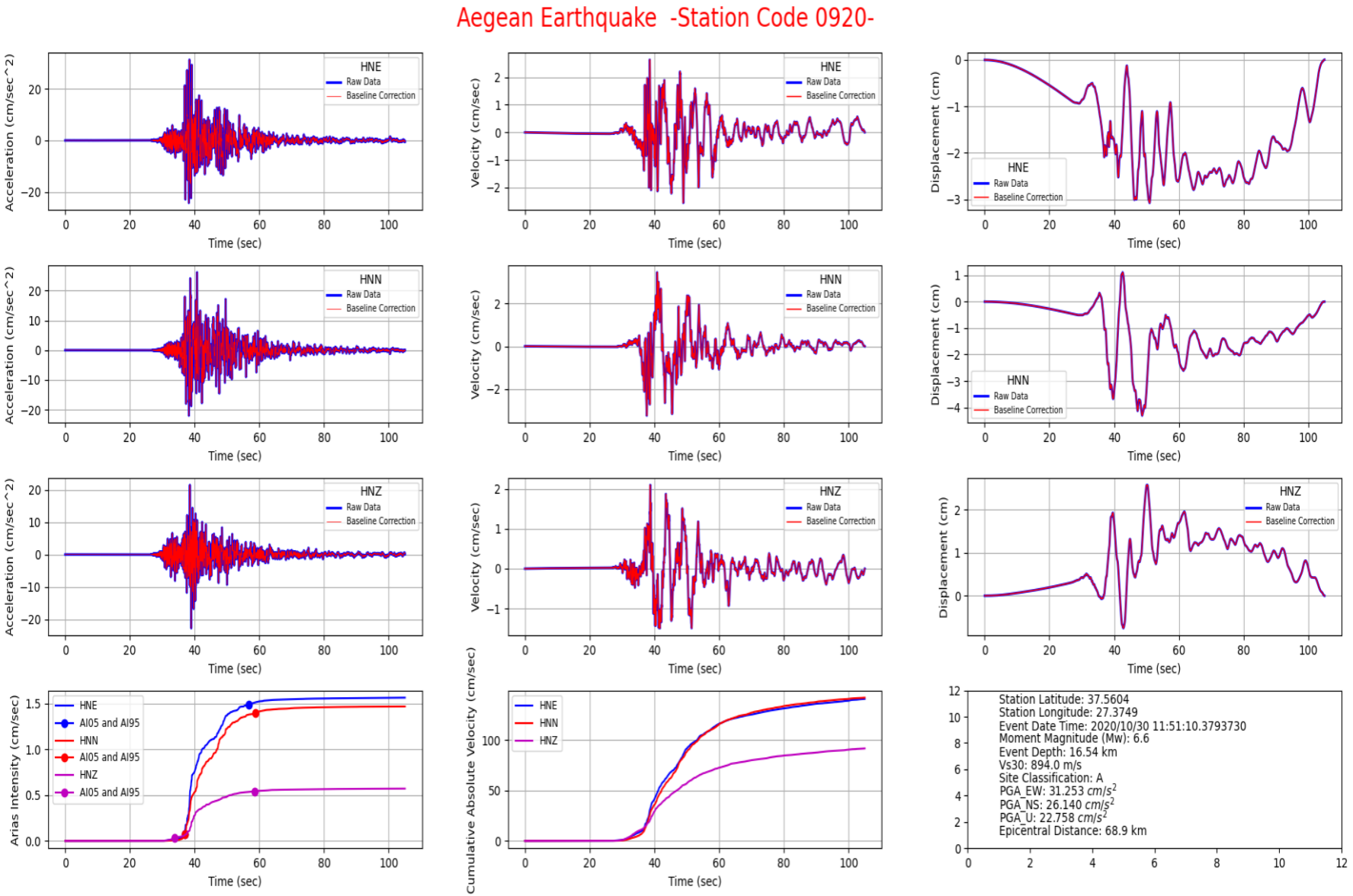

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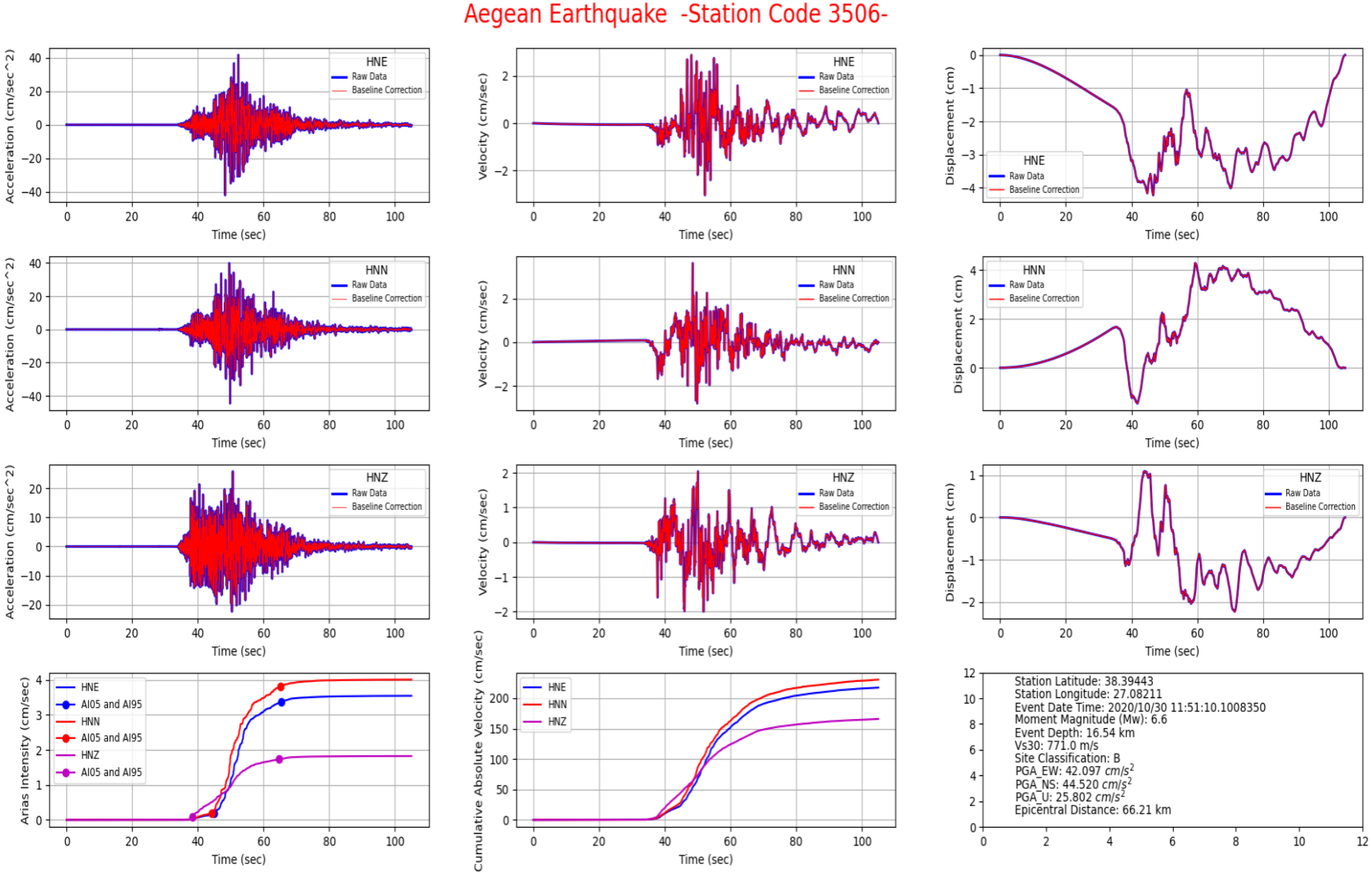

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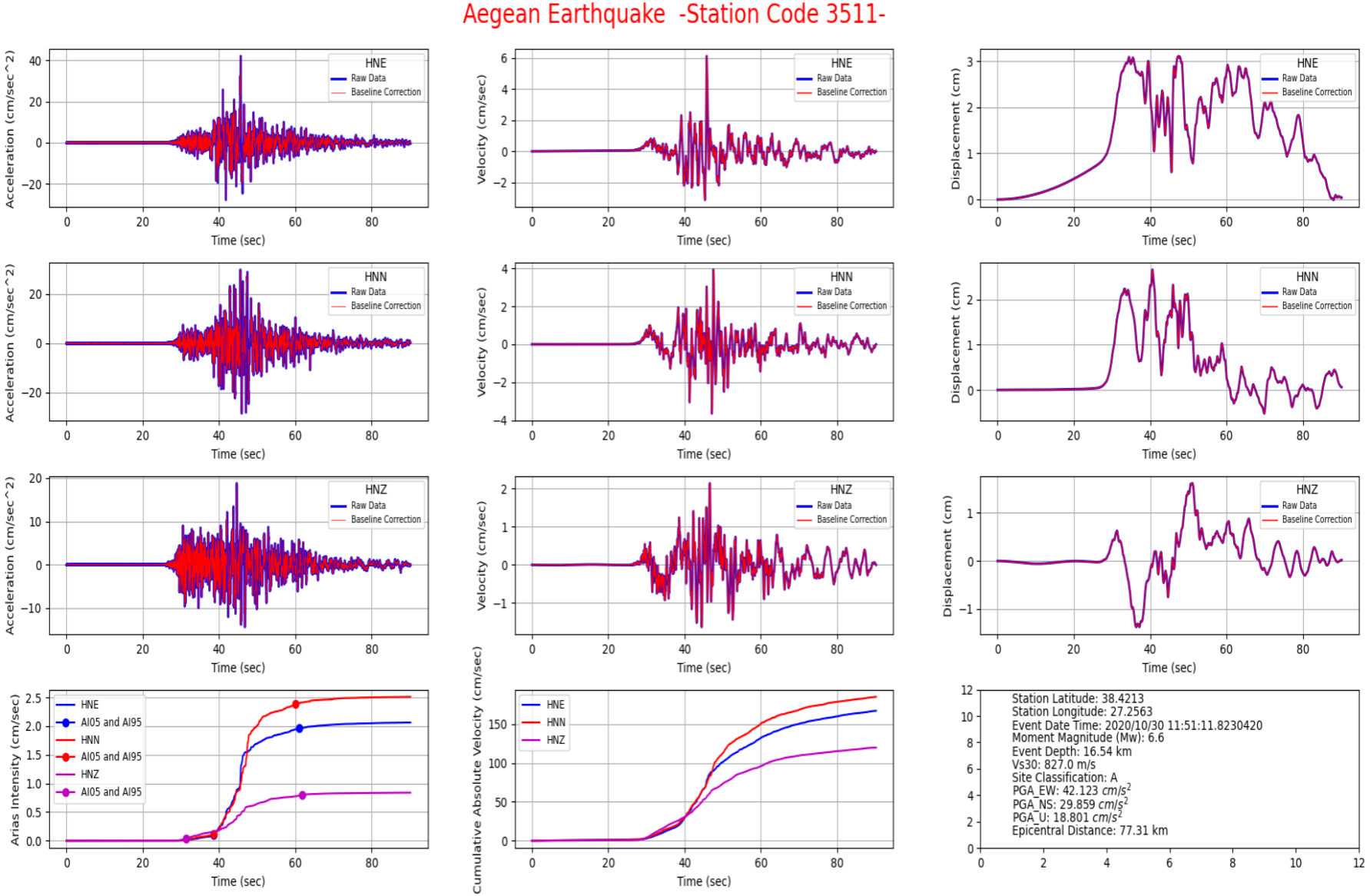

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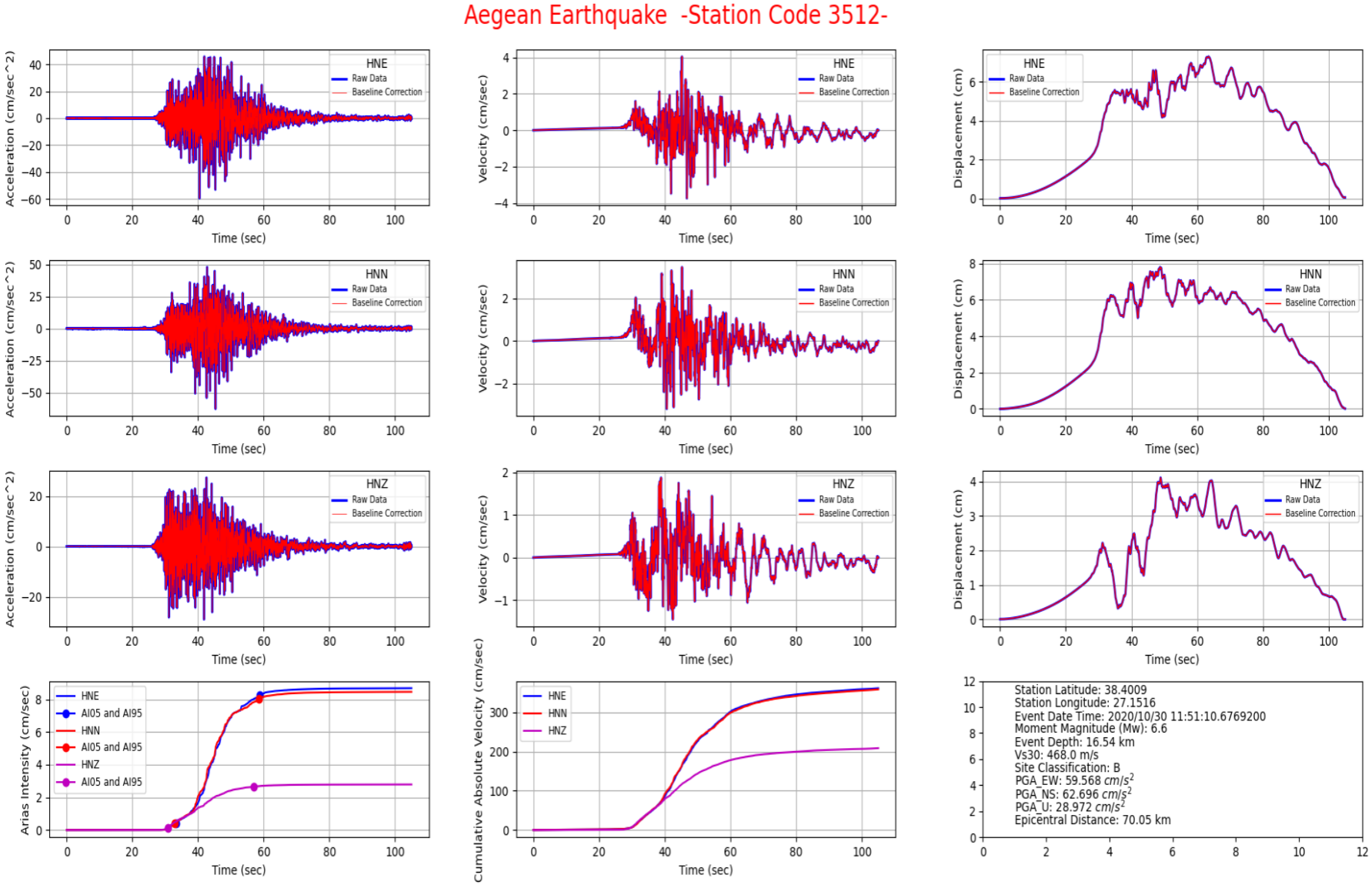

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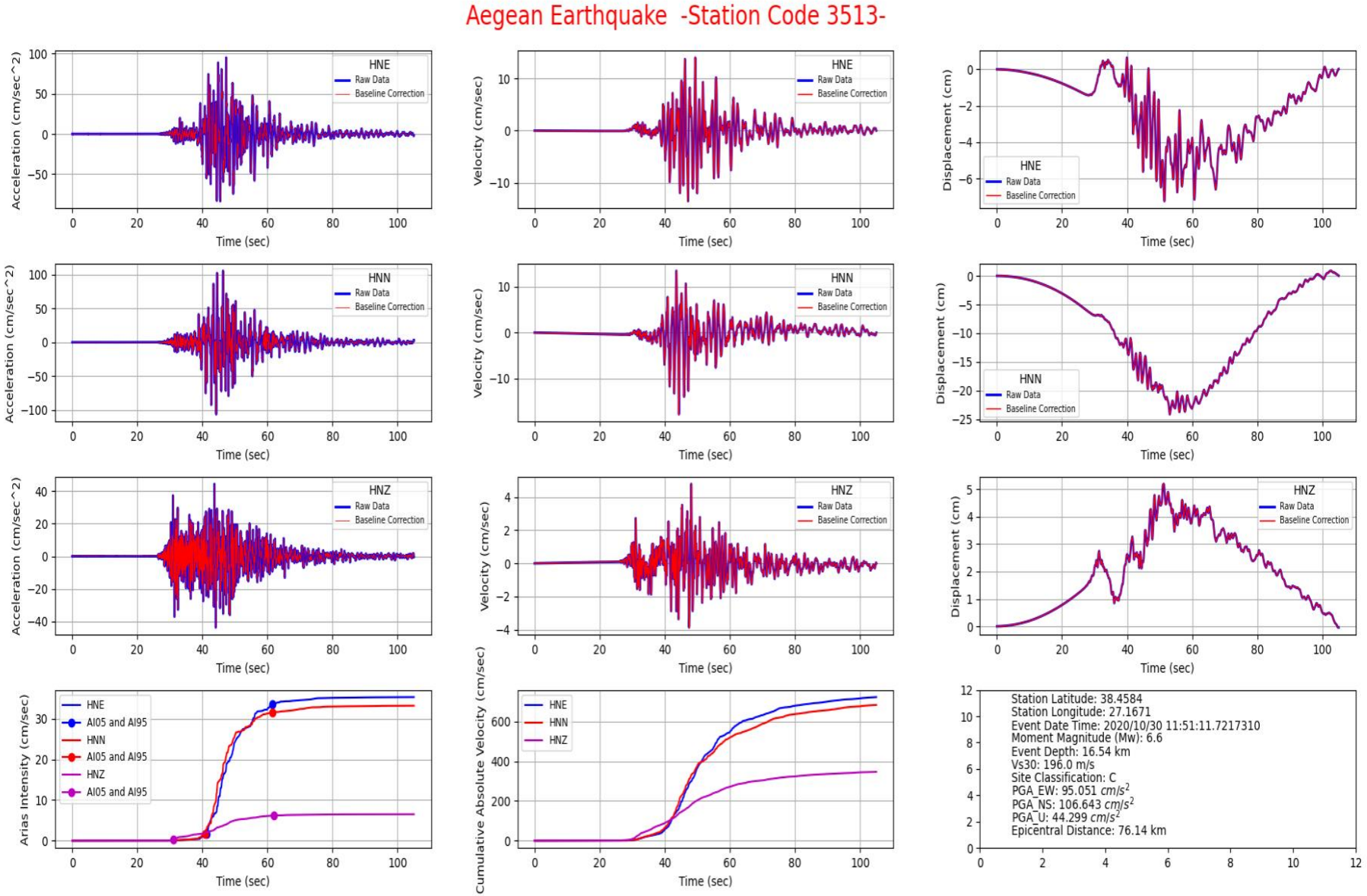

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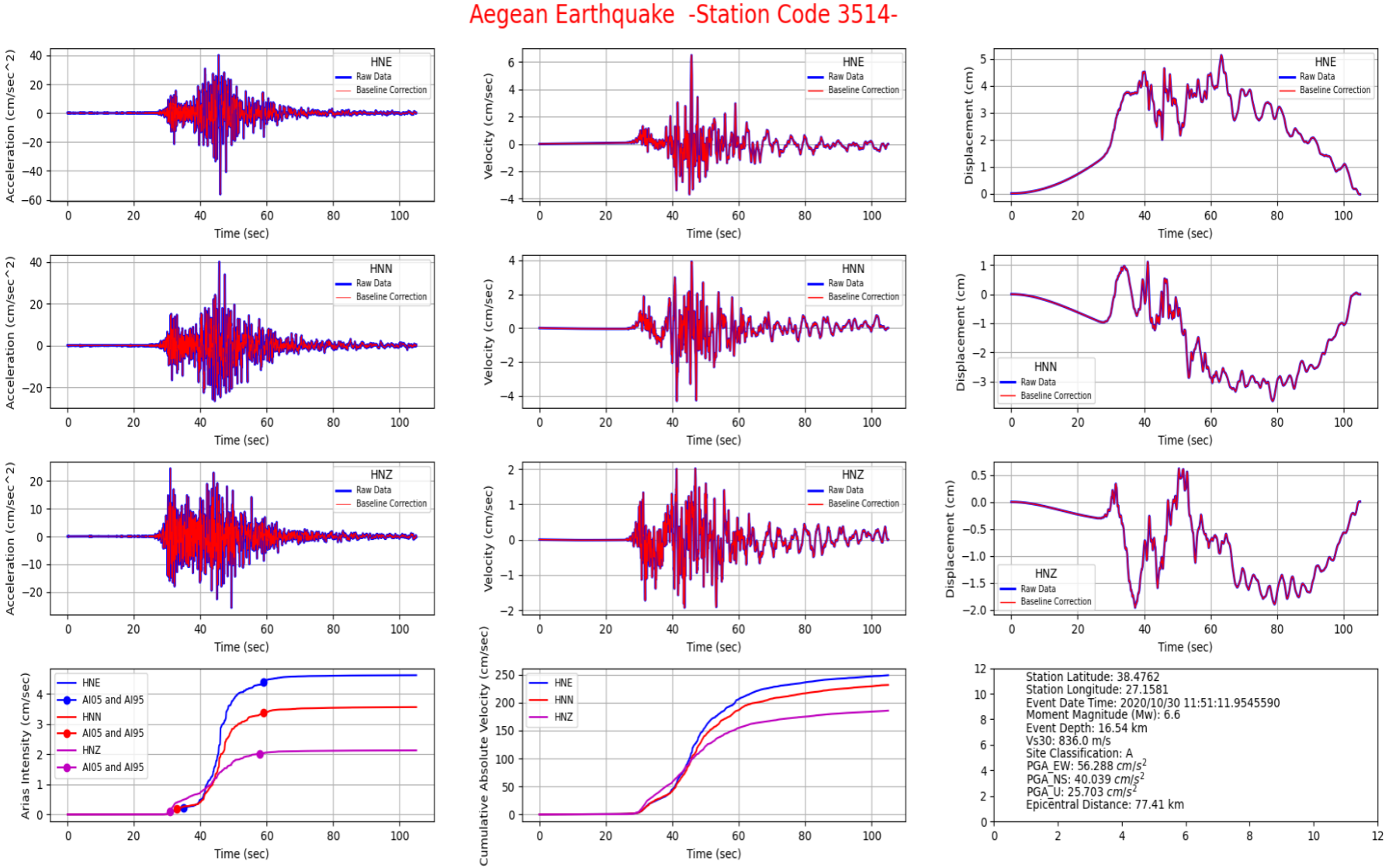

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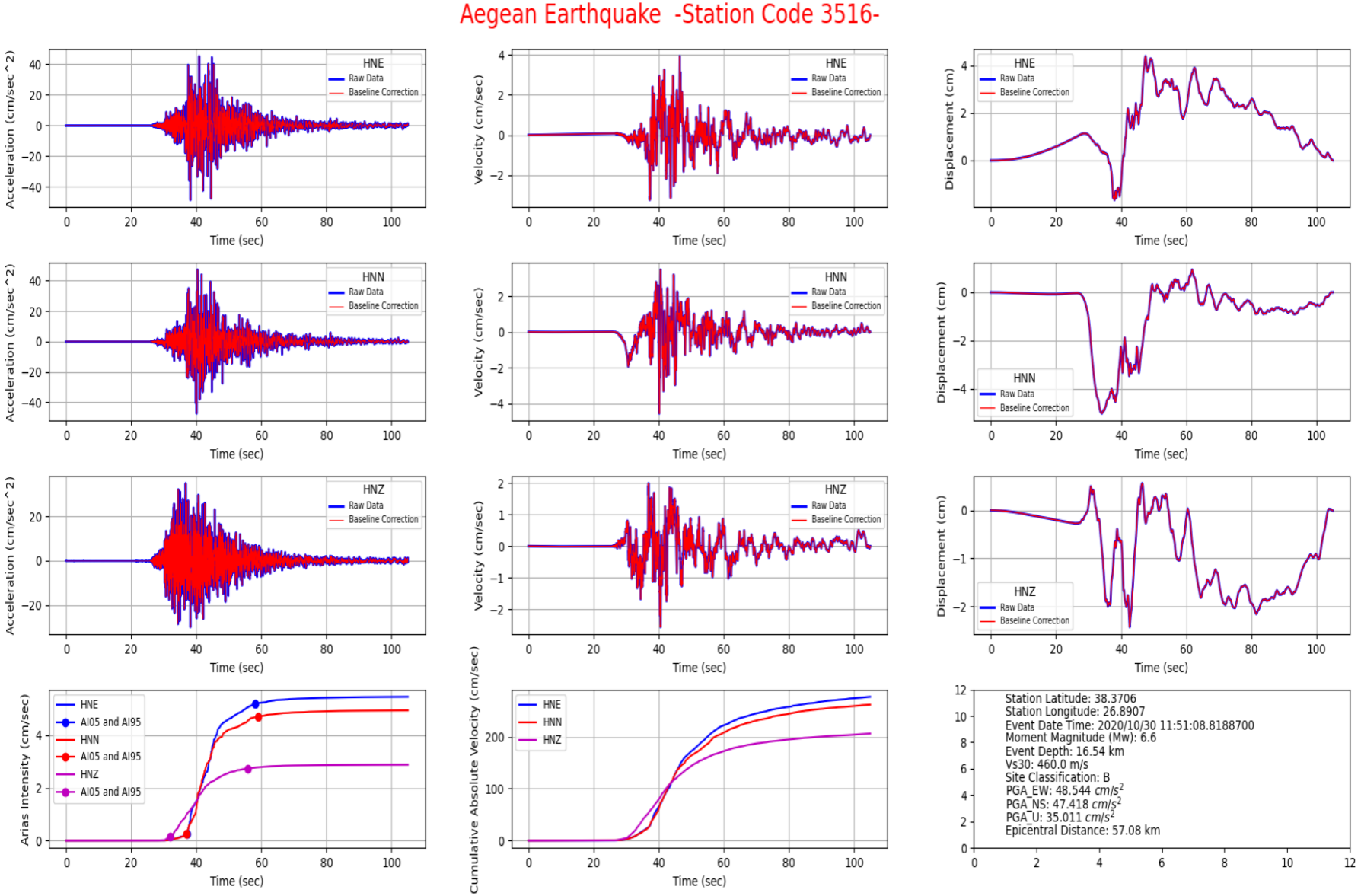

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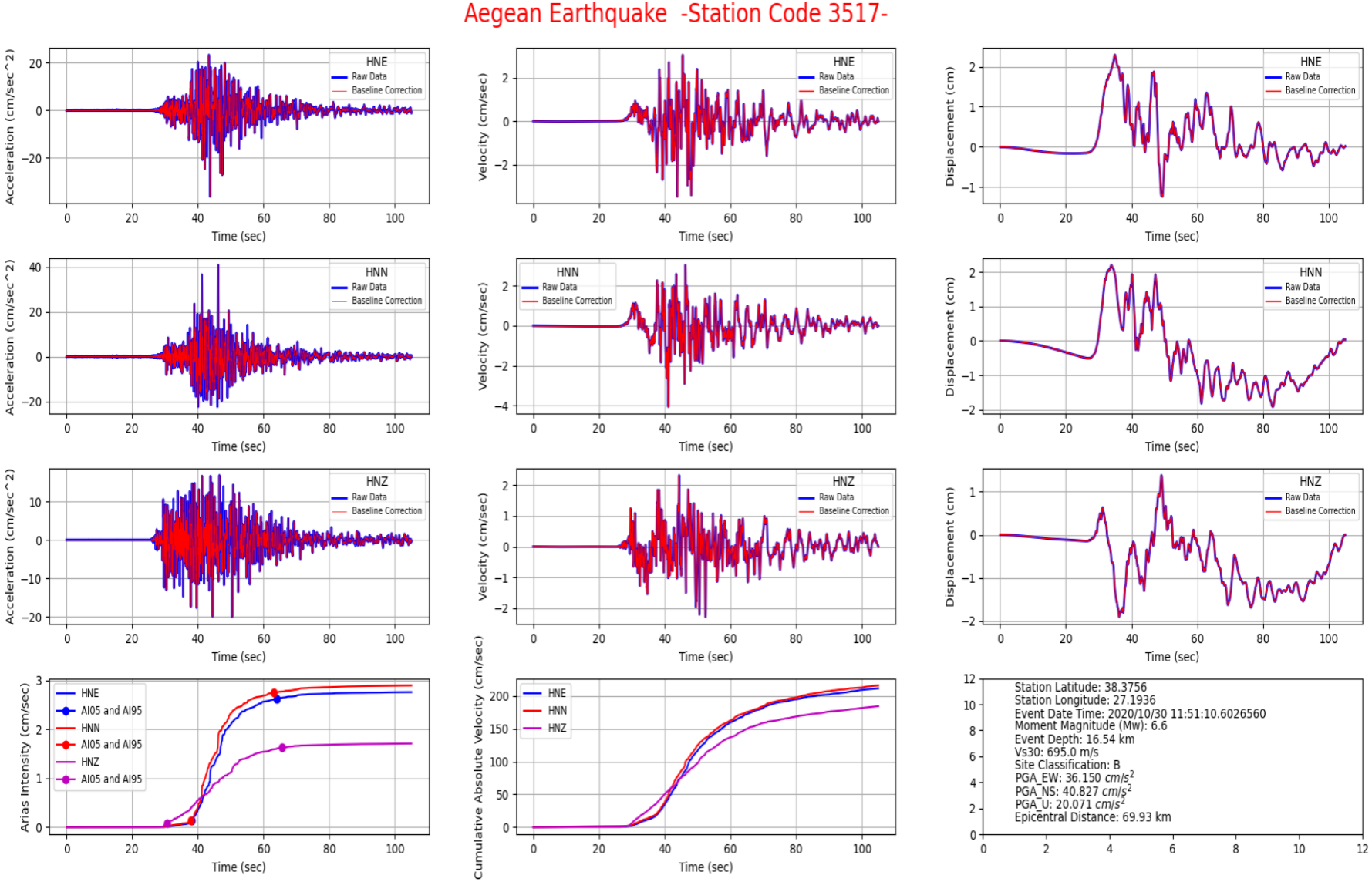

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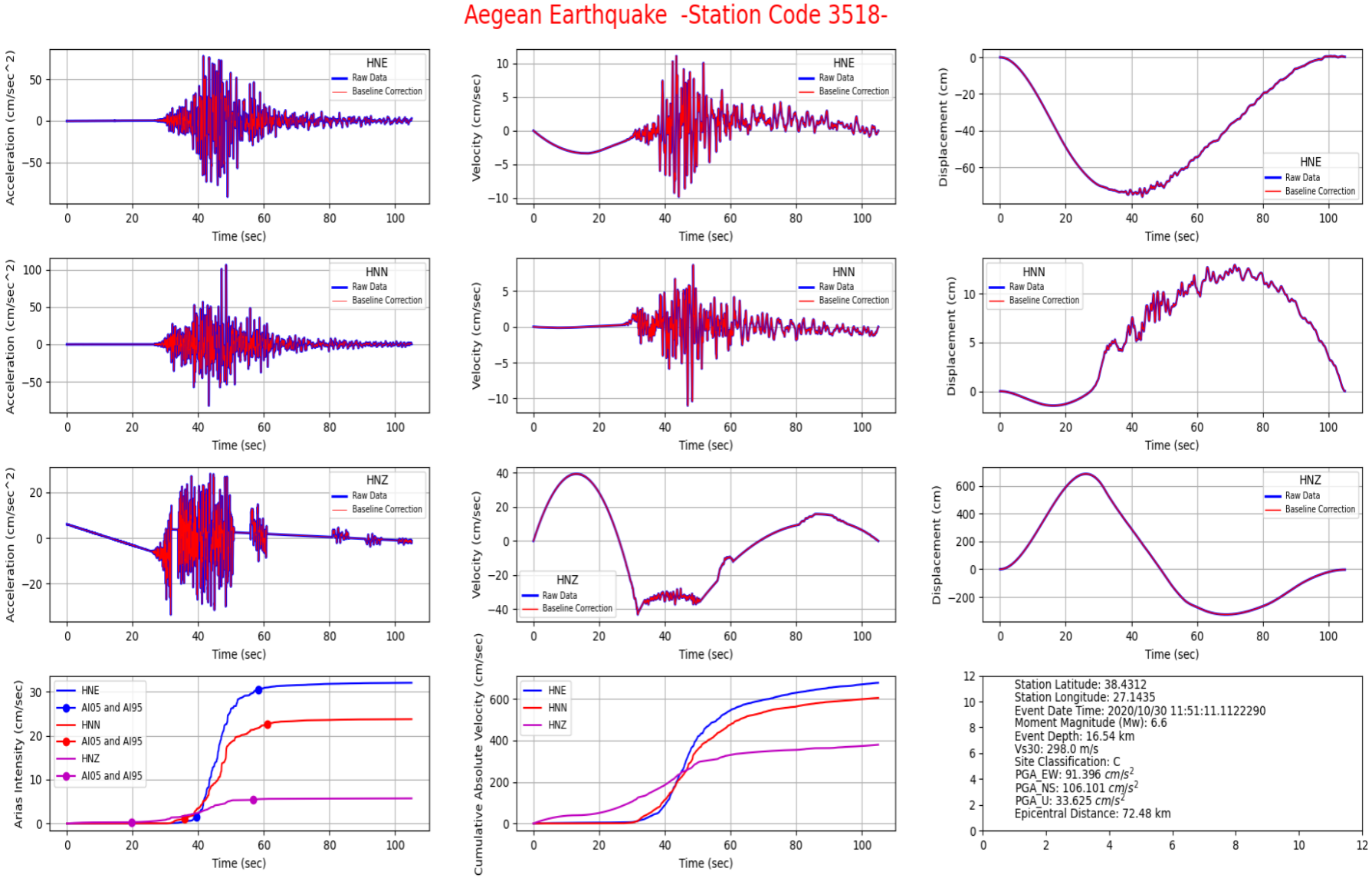

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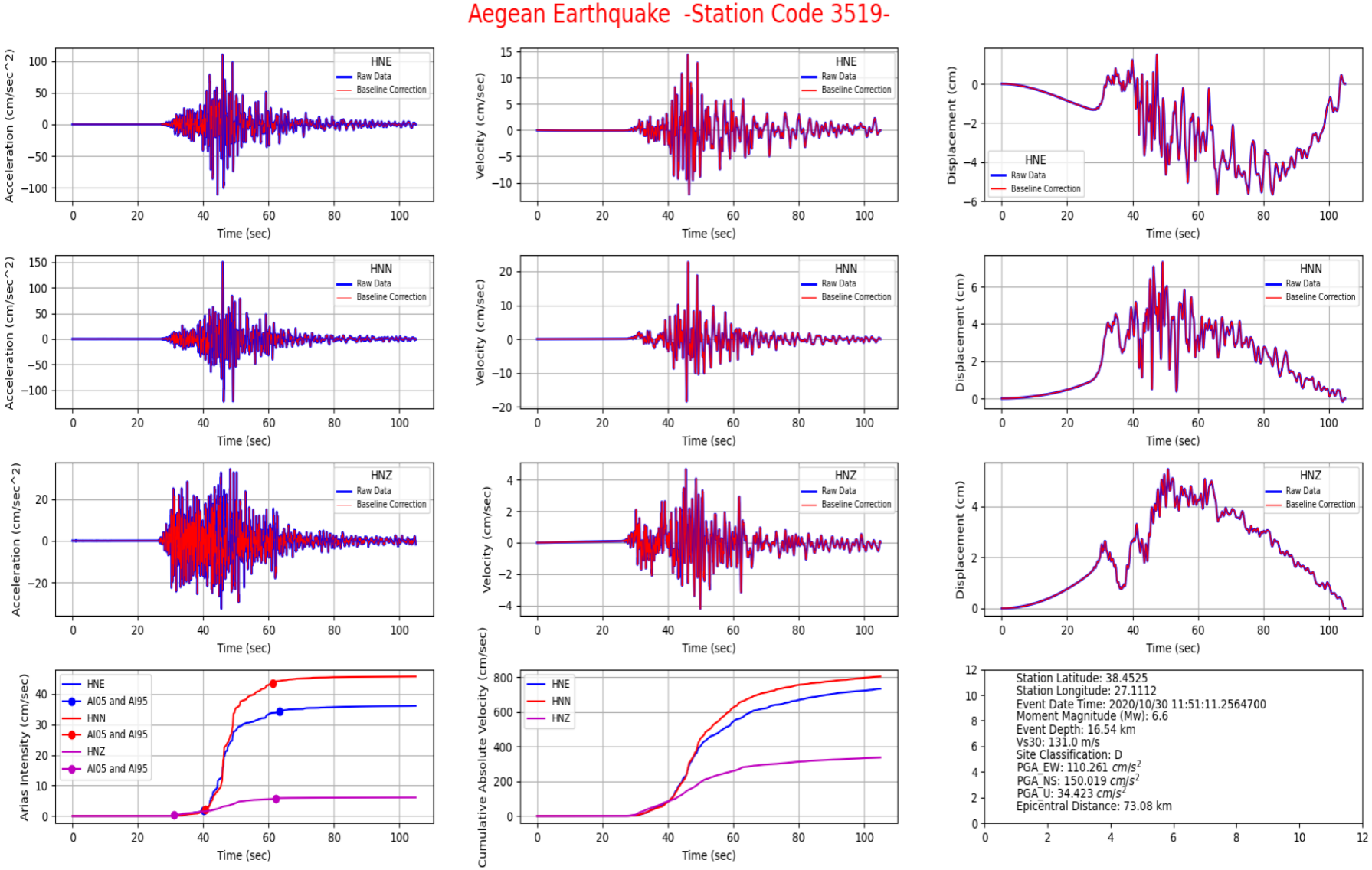

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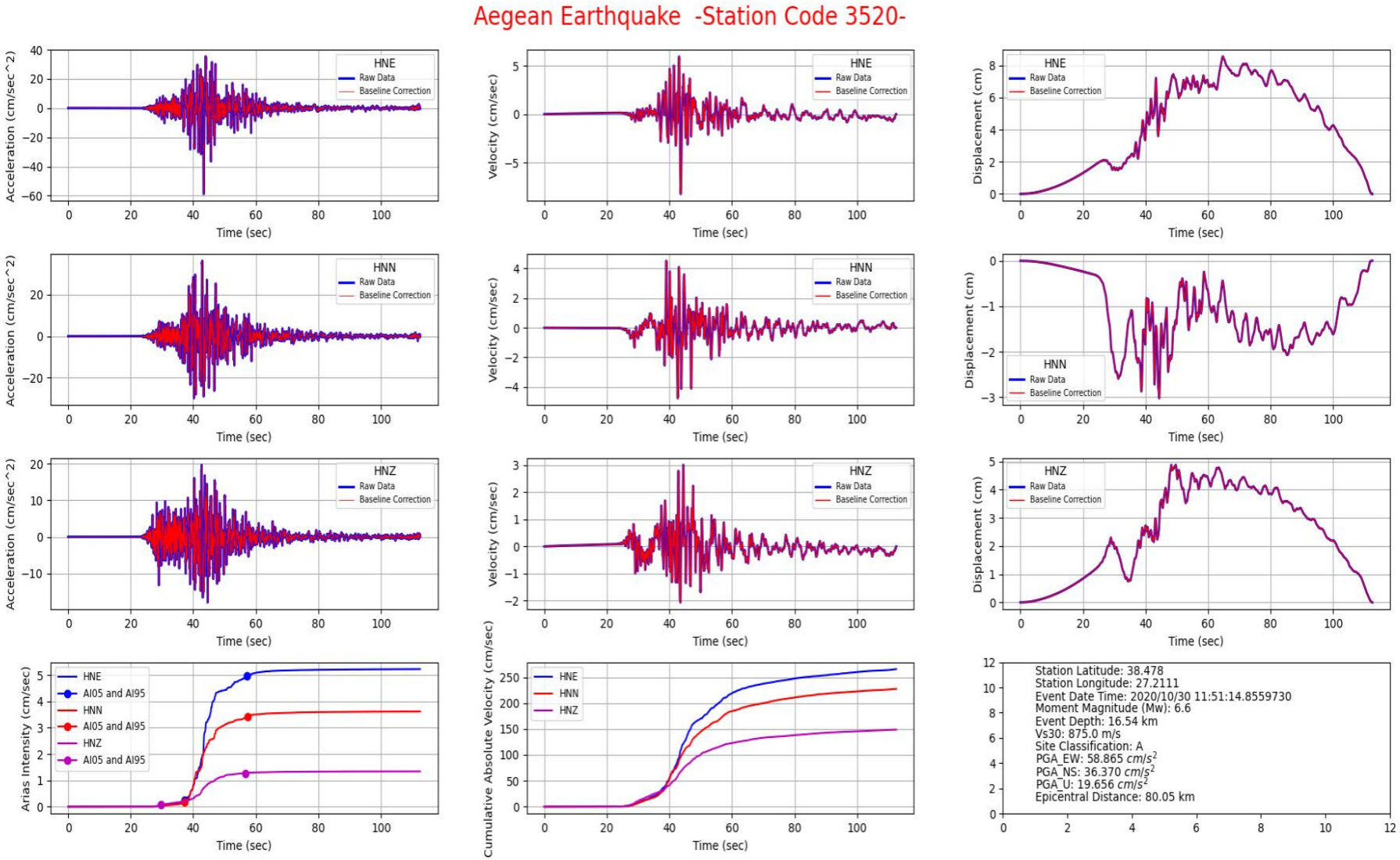

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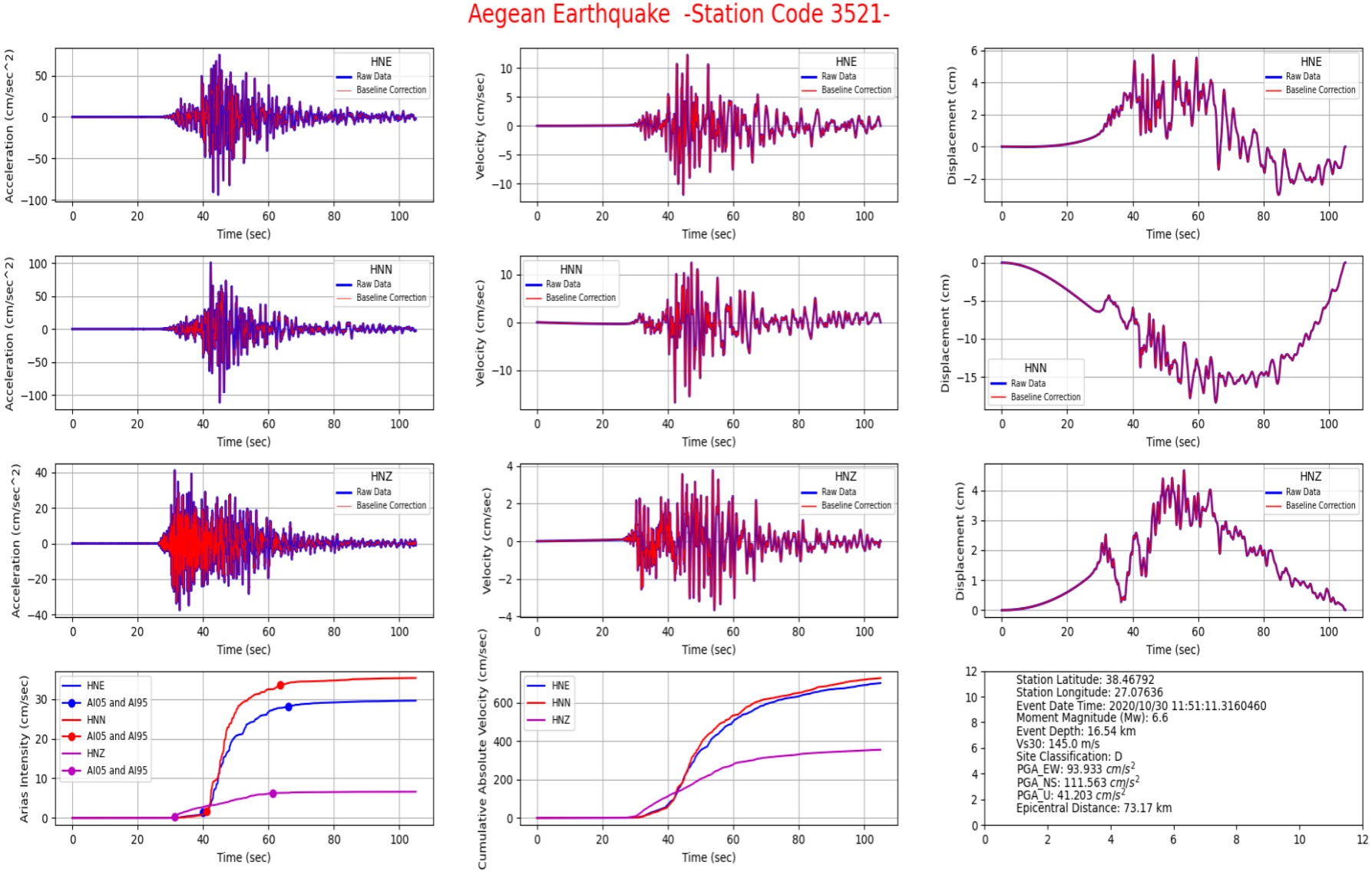

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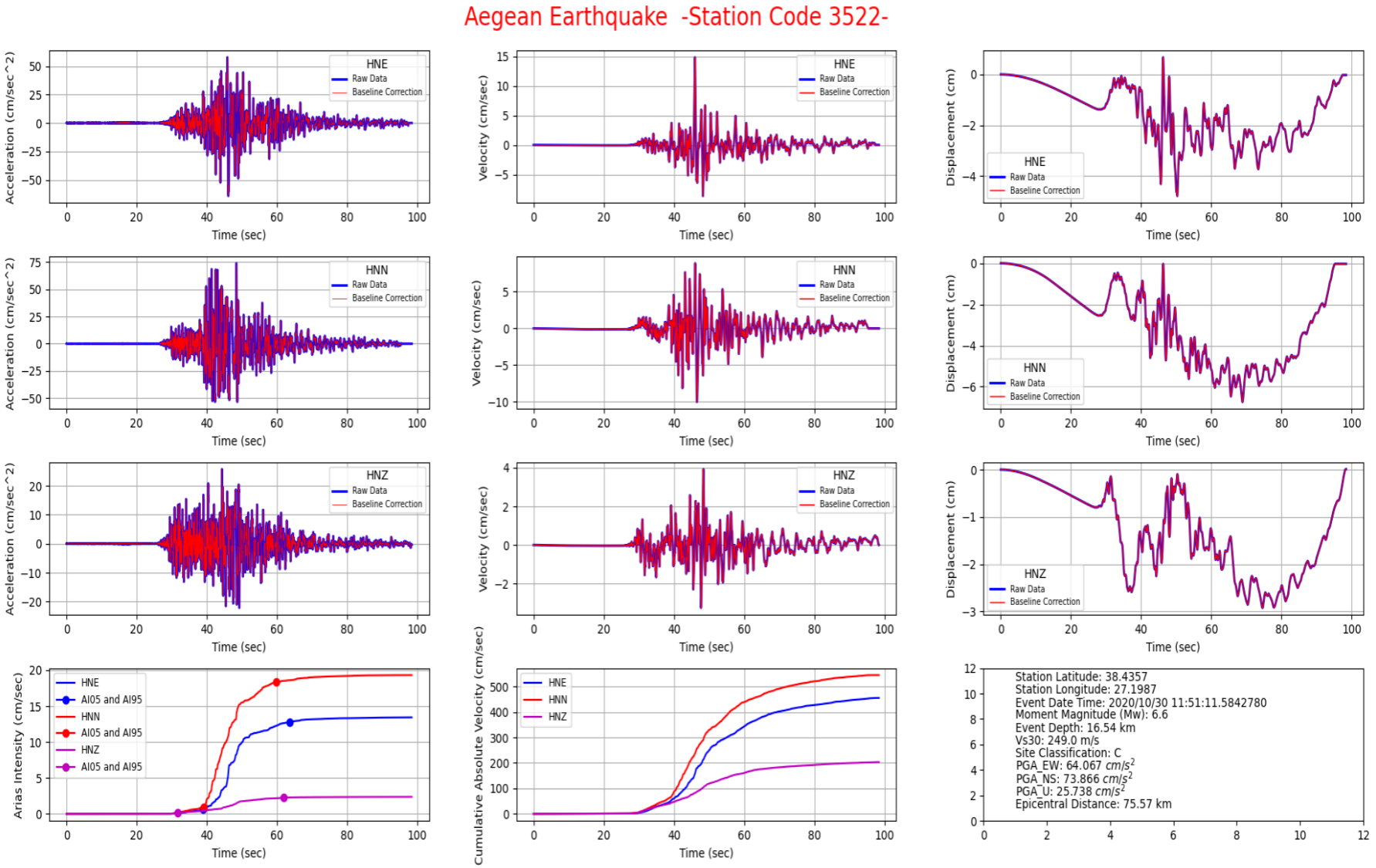

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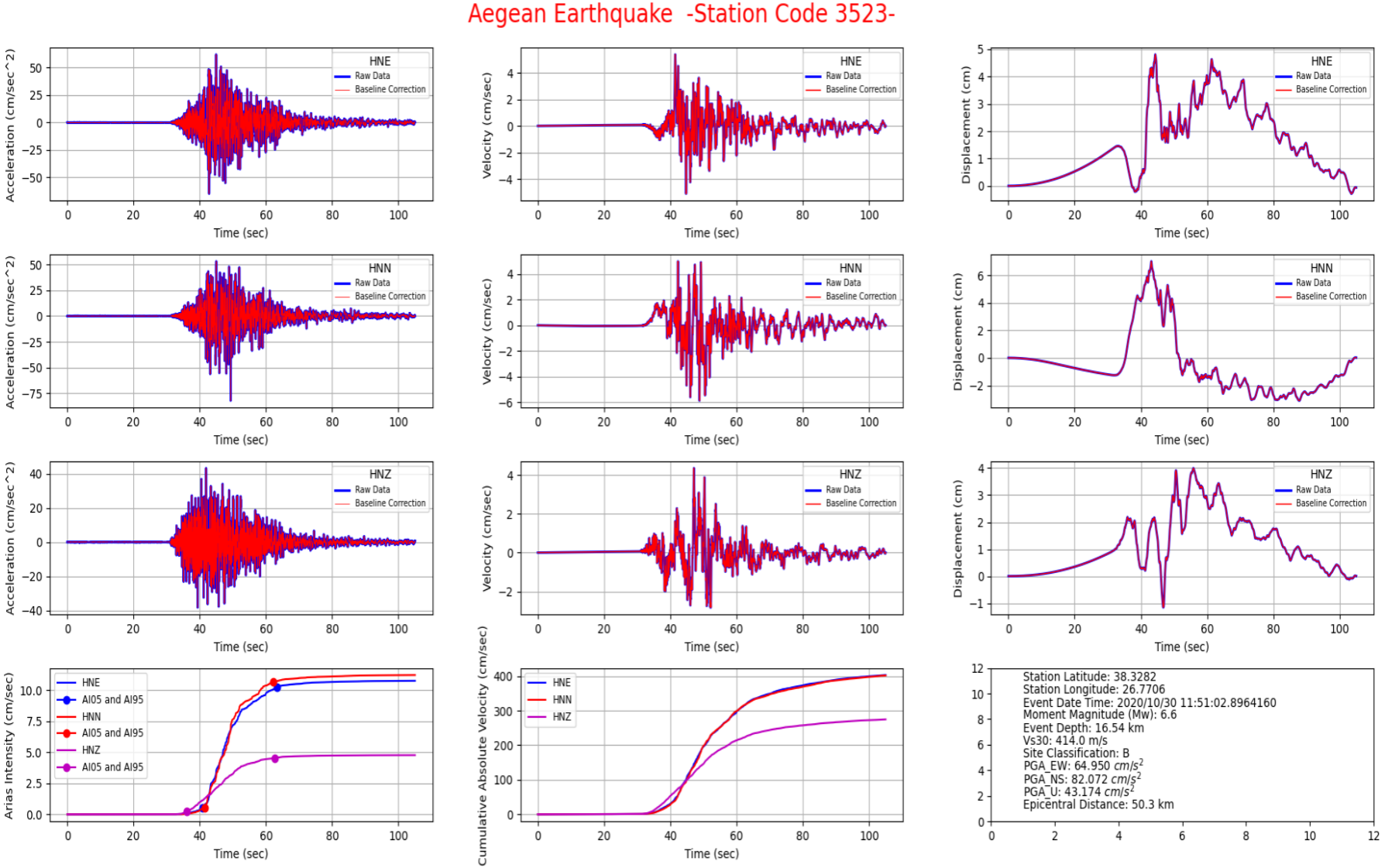

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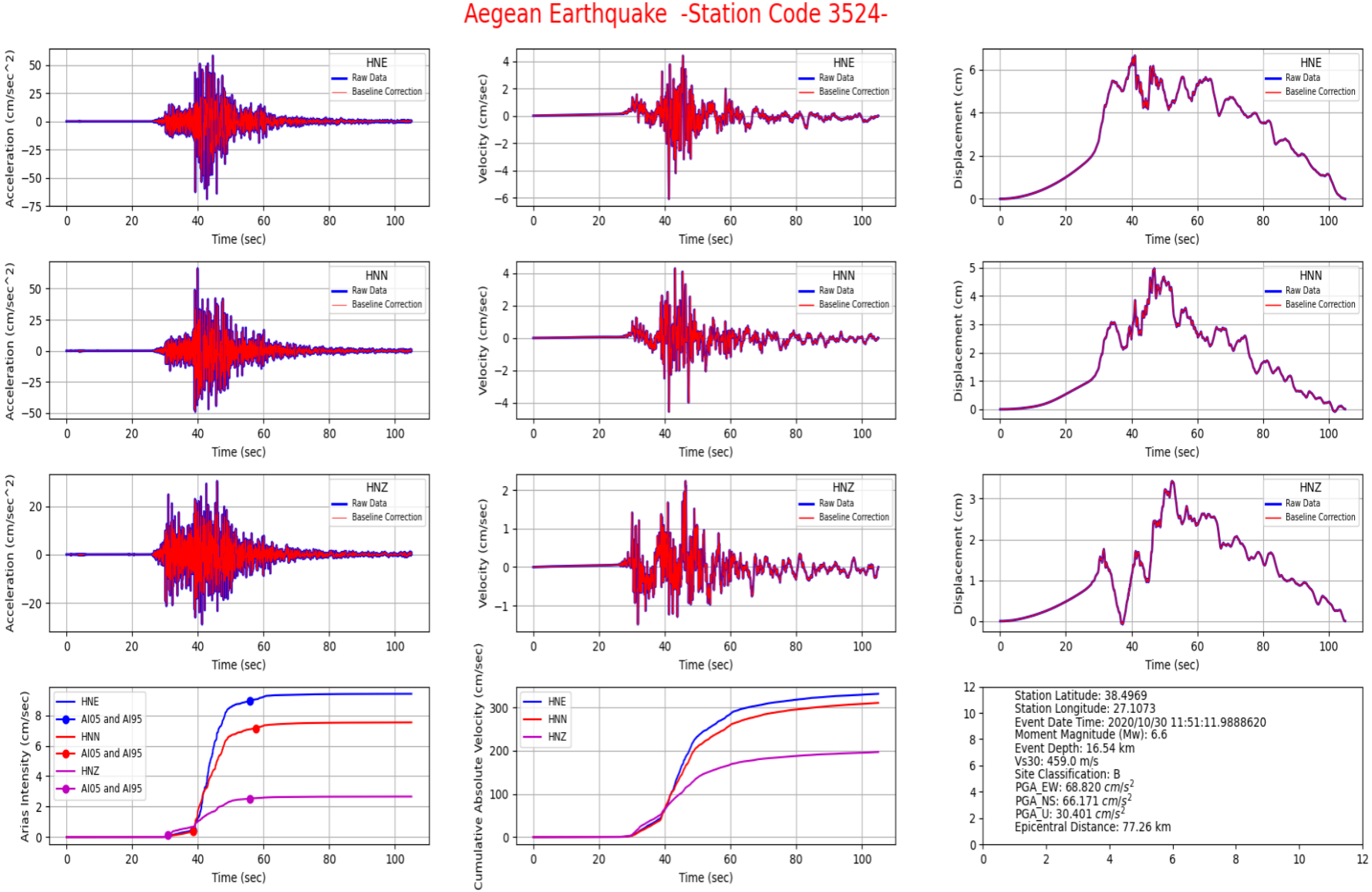

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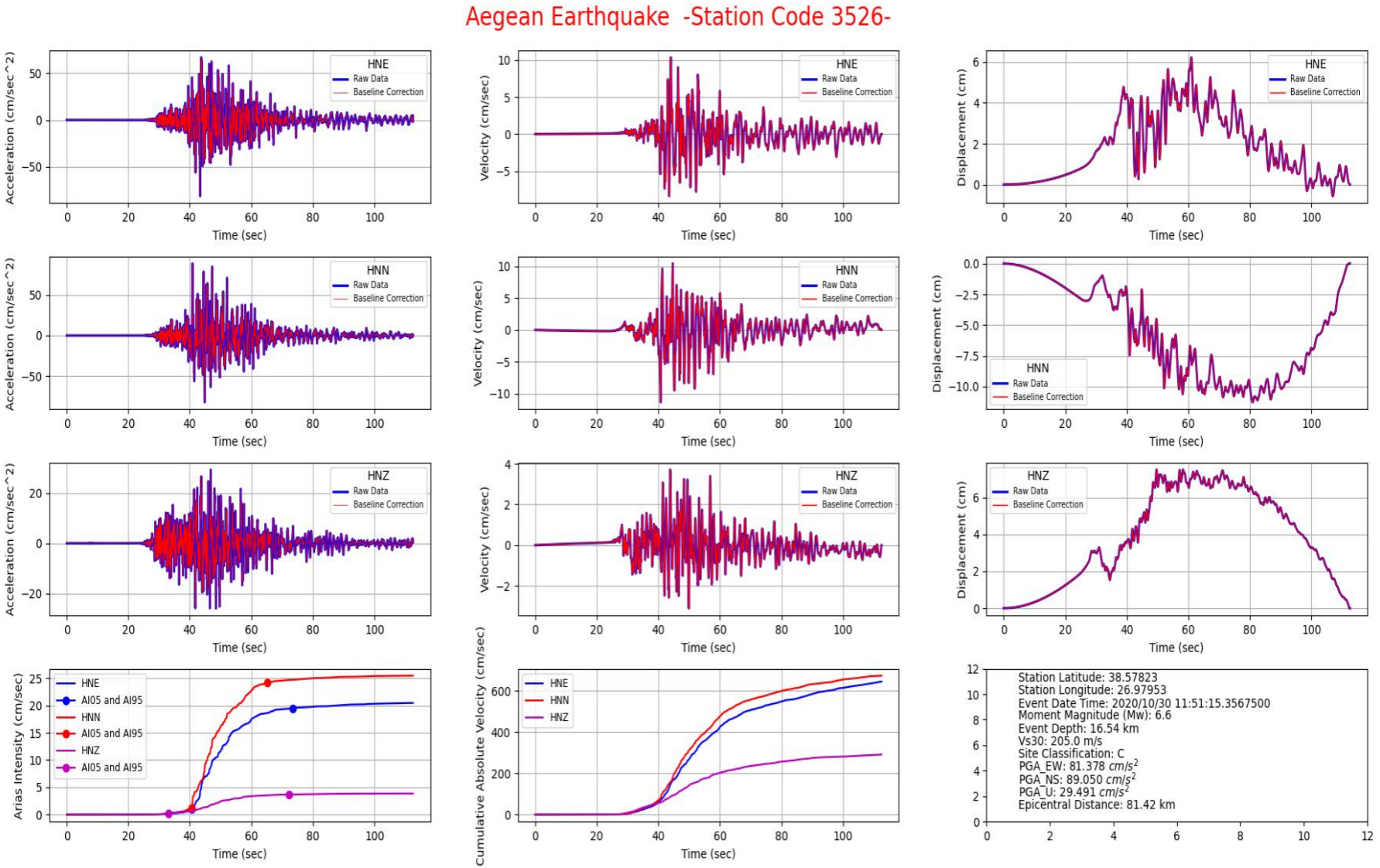

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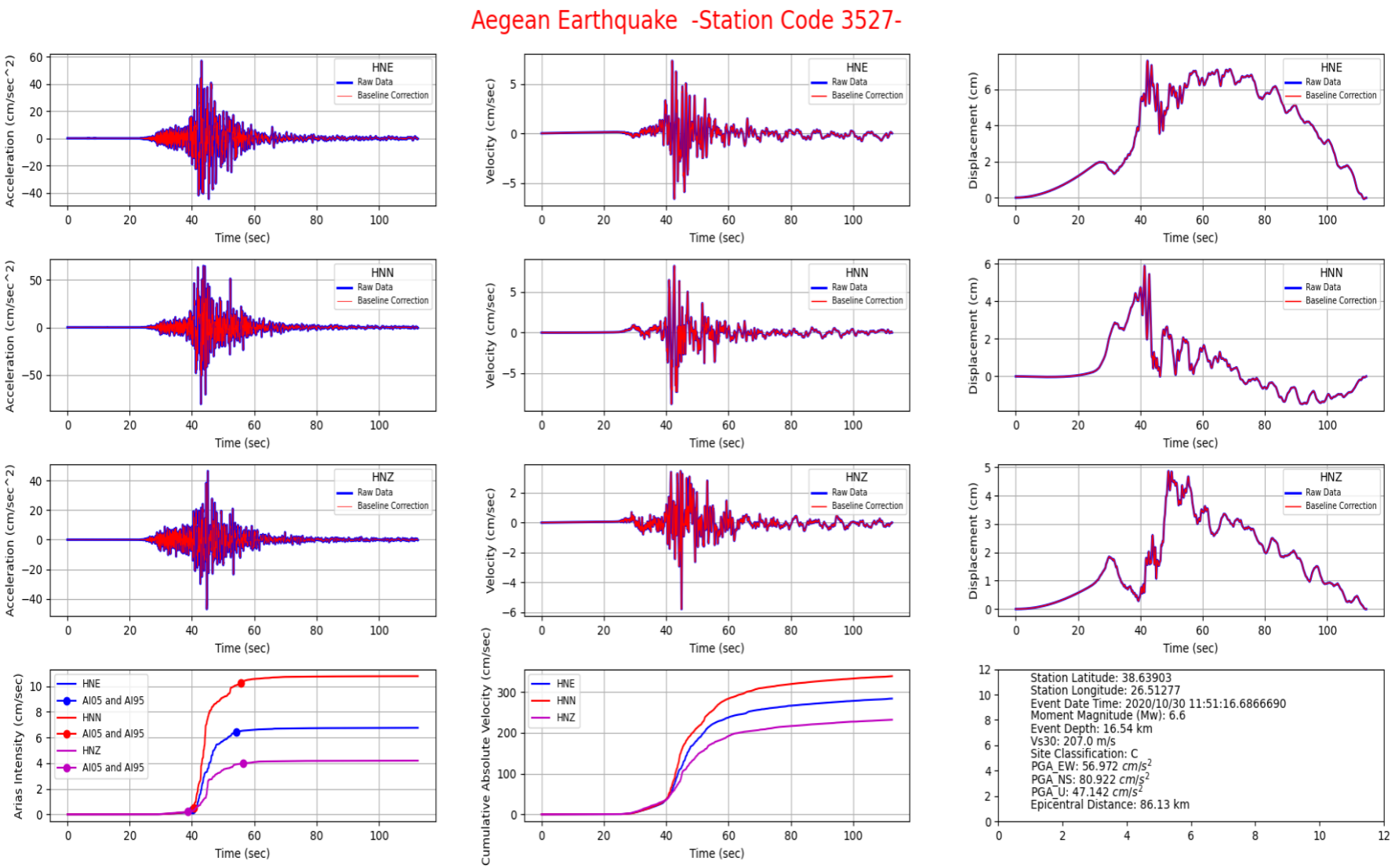

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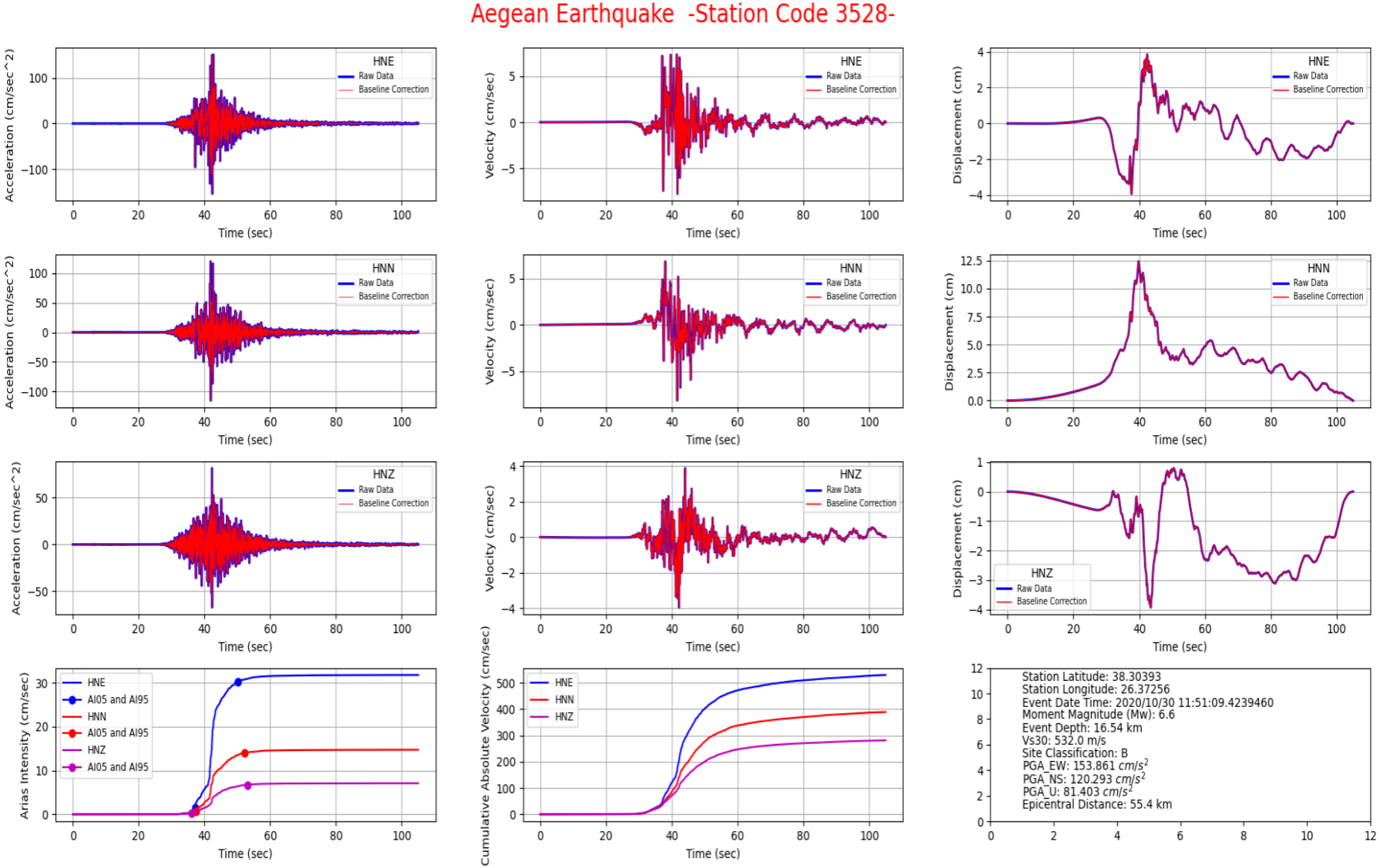

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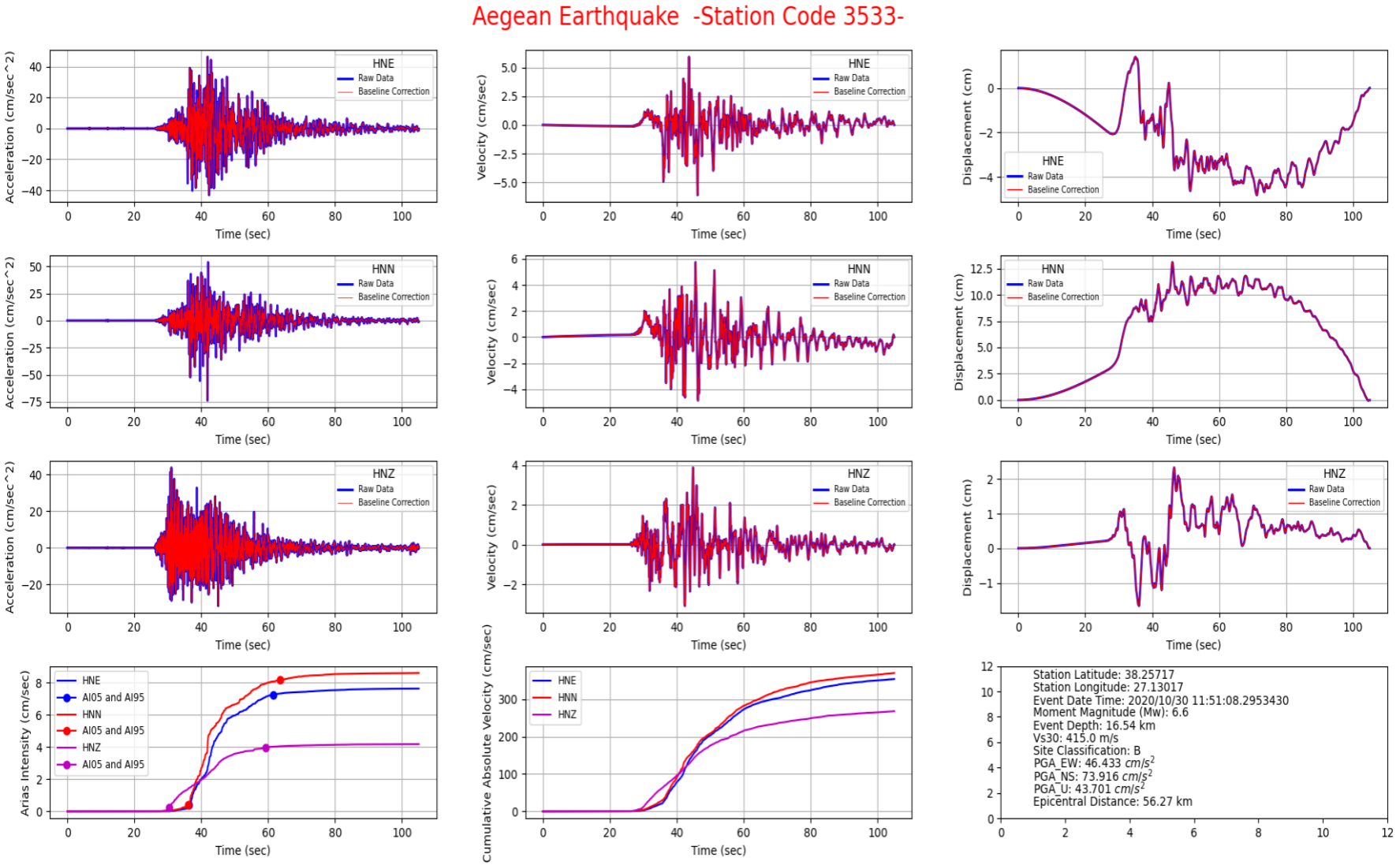

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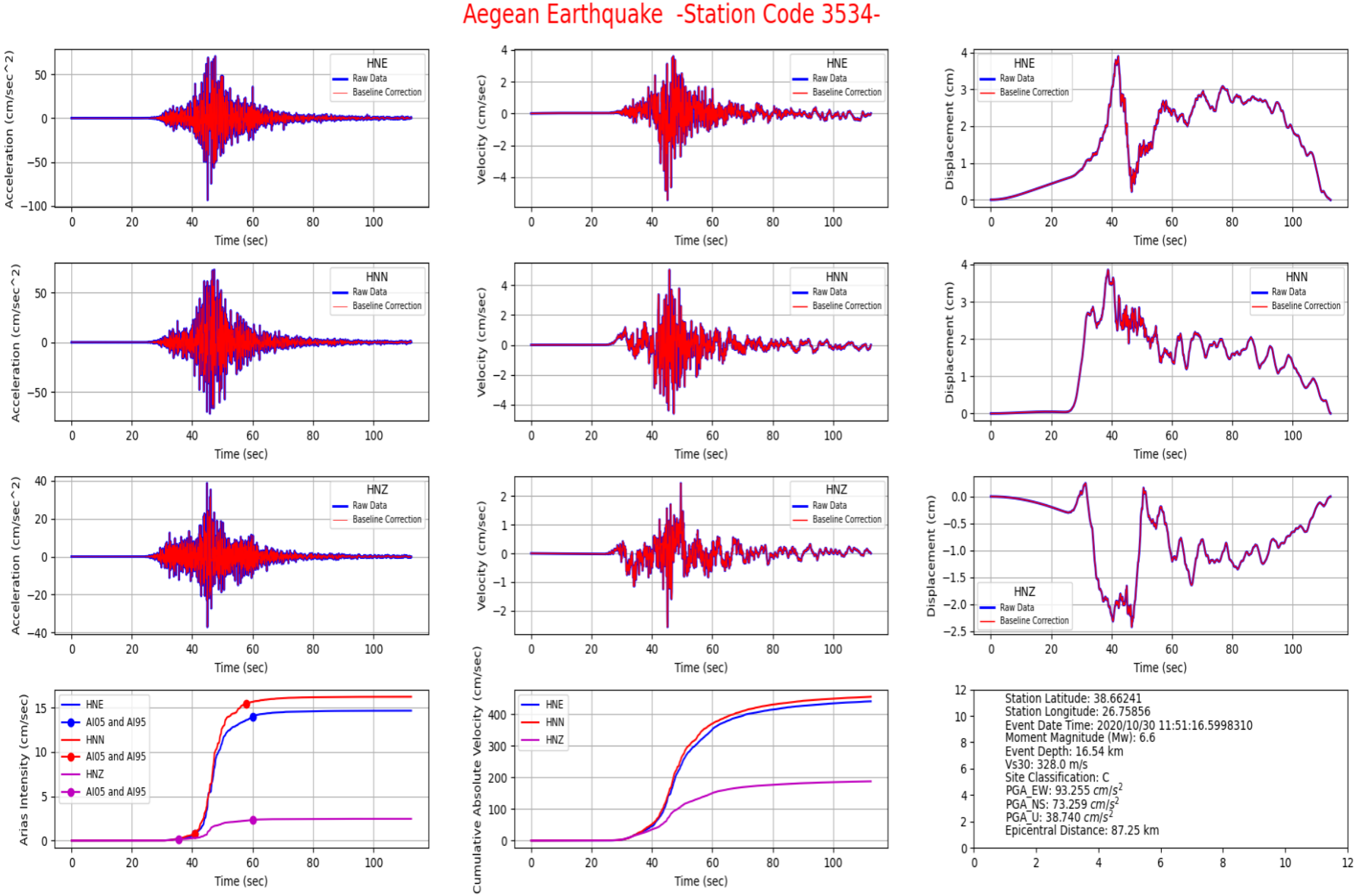

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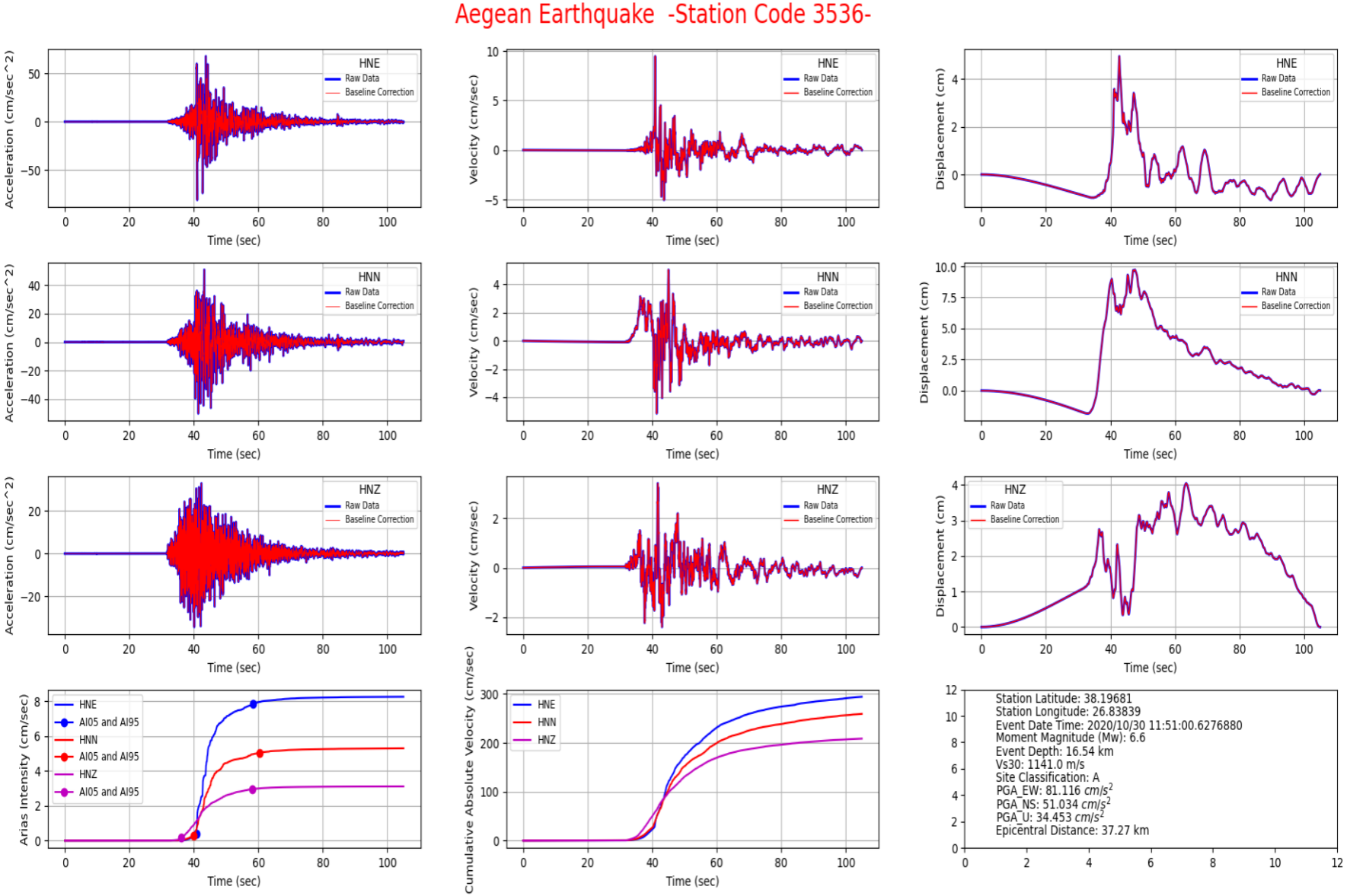

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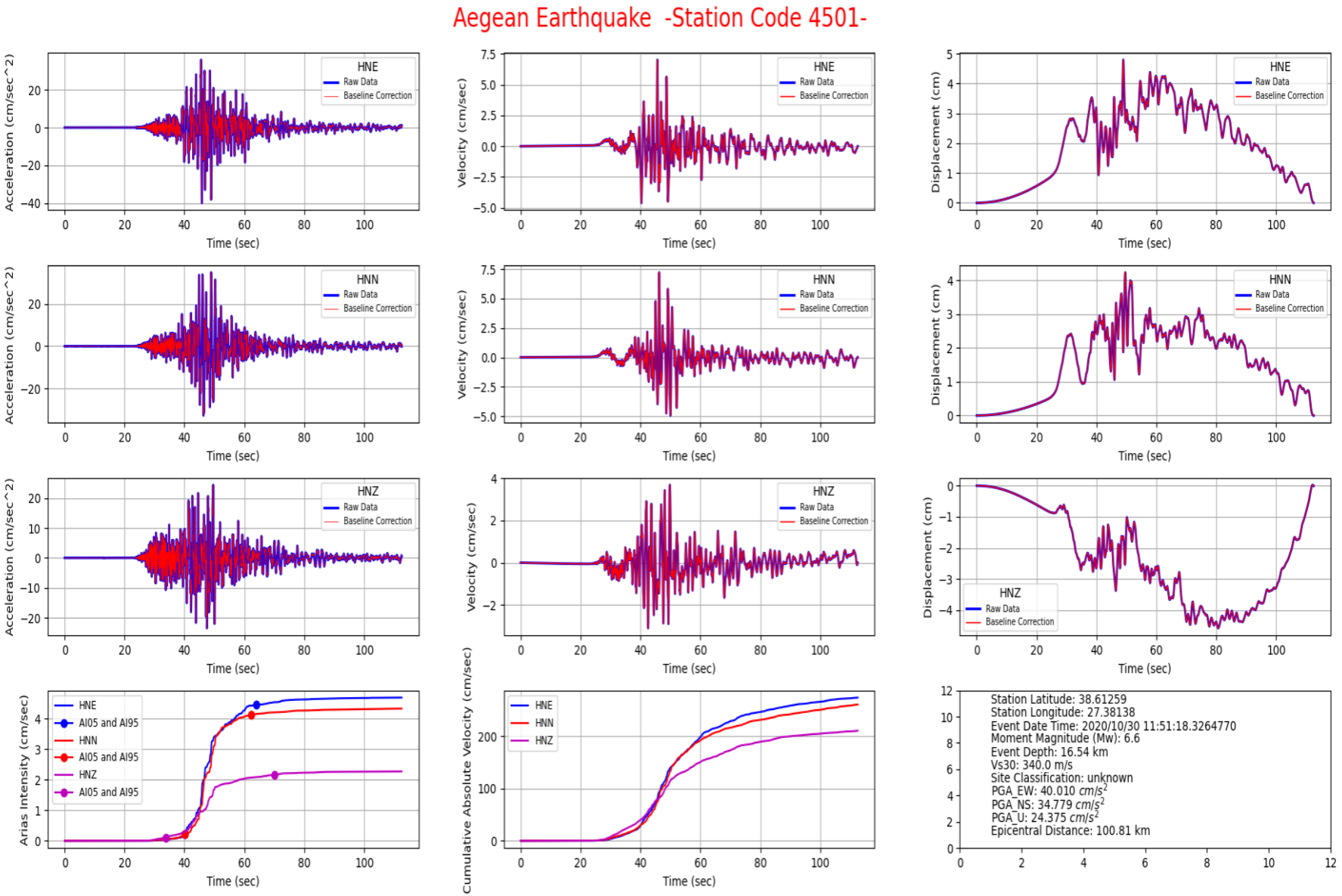

Figure 25 Station 4501

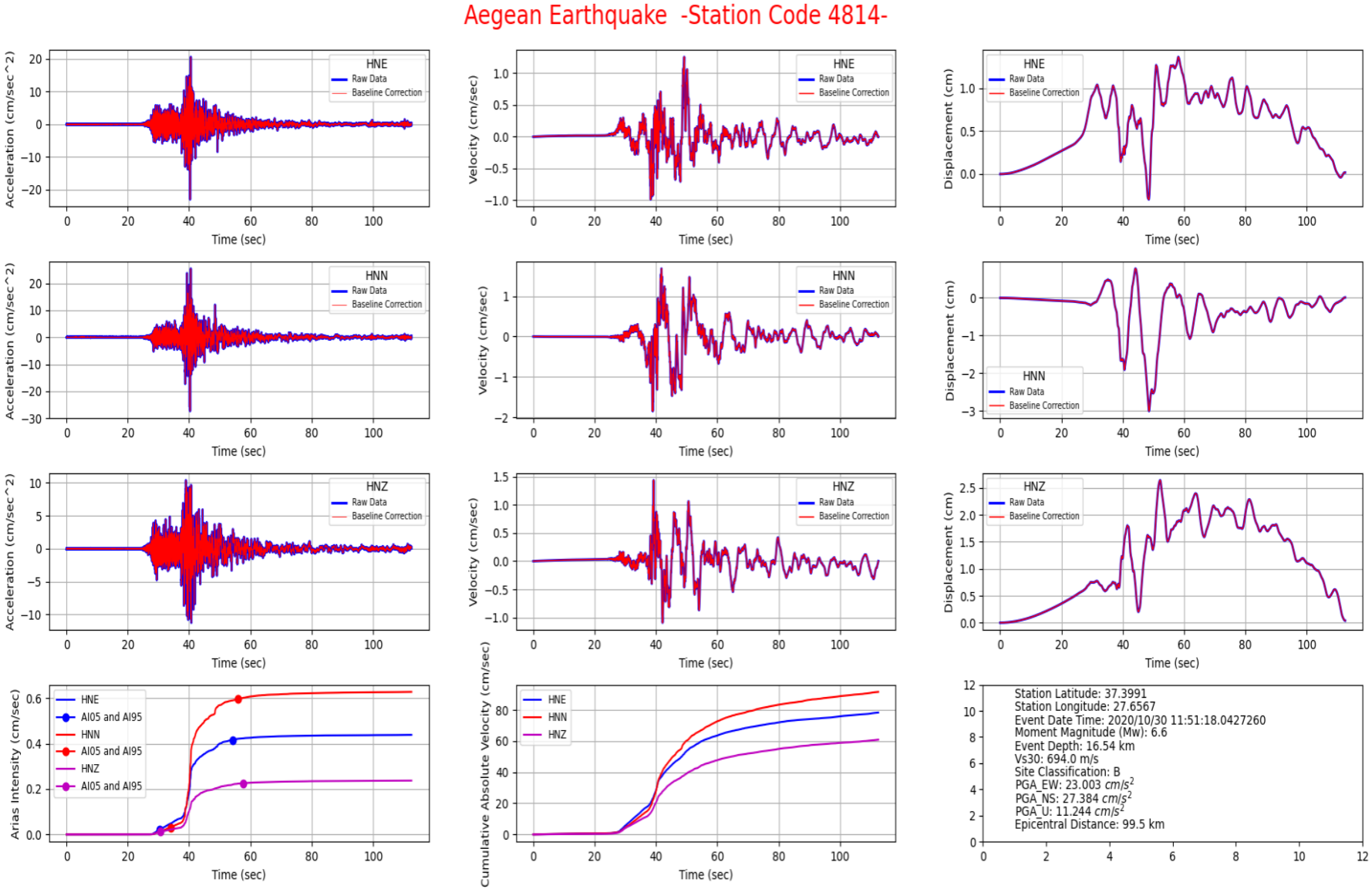

Figure 26 Station 4814

2.2 R - Significant Duration and Vs_{30} – Significant Duration Graphs

There are 4 different duration definition based on the response of structure to earthquake loading. One of them is significant duration. Significant duration is based on the accumulated energy in the accelerogram. This duration is the time interval between 5 percent and 95 percent of accumulated energy. In figure 27, it is clear that while epicentral distance elevates, significant duration also increases. But the same thing cannot be said for Vs_{30} and significant duration relationship. As can be seen, while significant duration is decreasing when Vs_{30} is increasing in the components of east-west and vertical data, significant duration is increasing in the component of north-south. This shows us that the reliability of Vs_{30} – Significant Duration graph will not be enough to say that the relationship between Vs_{30} and Significant Duration is highly observed. Therefore, it is hard to say that these parameters have an interrelation each other. But if we had more records, we would observe more relationship between these parameters. Horizontal componants are integrated with geometric mean to compare with Sandıkkaya and Akkar's method which predict I_A and CAV.

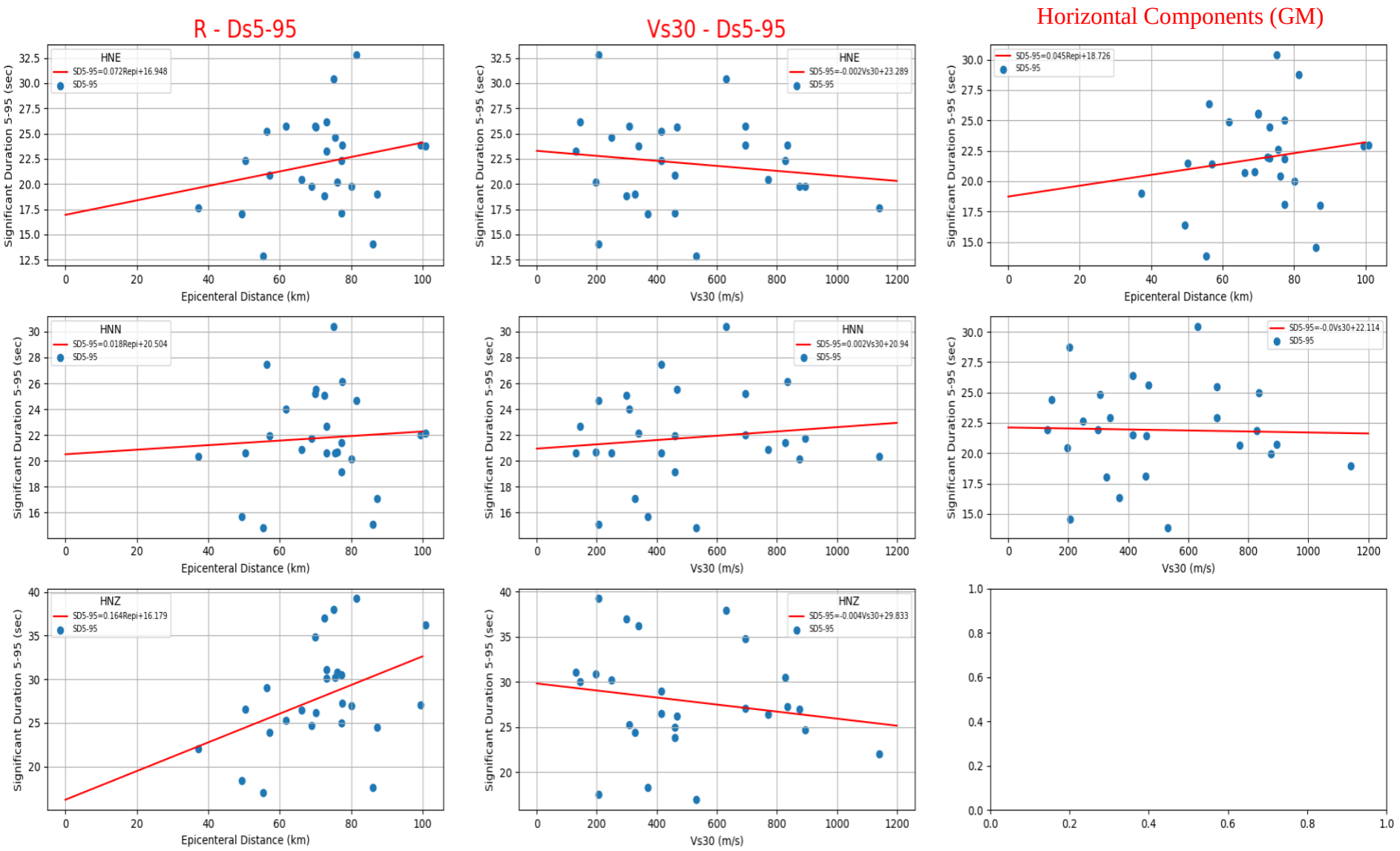

Figure 27 The Variation of Significant Duration According to R and Vs_{30}

2.3 Instrumental Intensity Calculation from Recordings

Tselentis and Danciu propose a method to calculate Instrumental Intensity. They created dataset from 89 earthquake which occurred in Greece. The method can be calculated by using not only Peak Ground Acceleration (PGA) but also PGV, I_A, and CAV. Moment magnitude is significant only MMI predicted from PGA. Otherwise epicentral distance (R), and Soil Classification but dummy variables are important to find MMI. Soil category dummy variable 0 for rock sites and 1 for soft soil sites. In this case, the soft soil is defined (Vs30 = 0–360 m/sec) and rock is defined as (Vs30 > 360 m/sec). The formula is:

$$MMI_{(y=PGA,\, I_A,\, CAV)} = a + b\log_{10}(Y) + r\log_{10}(R) + sS + \varepsilon_{MMI_{(y=PGA,\, I_A,\, CAV)}} \quad (3)$$

Where;

Regression Coefficients of Equation (3) for Predicting MMI from Ground-Motion Parameters (All Data)

$MMI_{(y=PGV,\, CAV)} = a + b\log_{10}(Y) + r\log_{10}(R) + sS + \varepsilon$

Ground-Motion Parameters	Regression Coefficients	Values	Standard Error	t	p Value
PGA (cm/sec^2)	a	2.355	0.383	6.142	0.000
	b	1.384	0.123	11.220	0.000
	m	0.297	0.084	3.537	0.000
	r	−0.832	0.157	−5.309	0.000
	s	−0.108	0.041	−2.625	0.009
	$\sigma_{MMI-PGA}$	0.666			
PGV (cm/sec)	a	5.582	0.167	33.372	0.000
	b	1.397	0.099	14.056	0.000
	r	−0.787	0.100	−7.880	0.000
	s	−0.073	0.041	−1.777	0.077
	$\sigma_{MMI-PGV}$	0.661			
I_a (cm/sec)	a	5.919	0.151	39.180	0.000
	b	0.844	0.057	14.707	0.000
	r	−0.997	0.099	−7.309	0.000
	s	−0.105	0.040	−2.614	0.009
	σ_{MMI-Ia}	0.649			
CAV (cm/sec)	a	3.763	0.280	13.424	0.000
	b	1.409	0.108	13.073	0.000
	r	−0.997	0.099	−10.066	0.000
	s	−0.105	0.042	2.496	0.013
	$\sigma_{MMI-CAV}$	0.679			

Table 1 Tselentis and Danciu's Instrumental Intensity

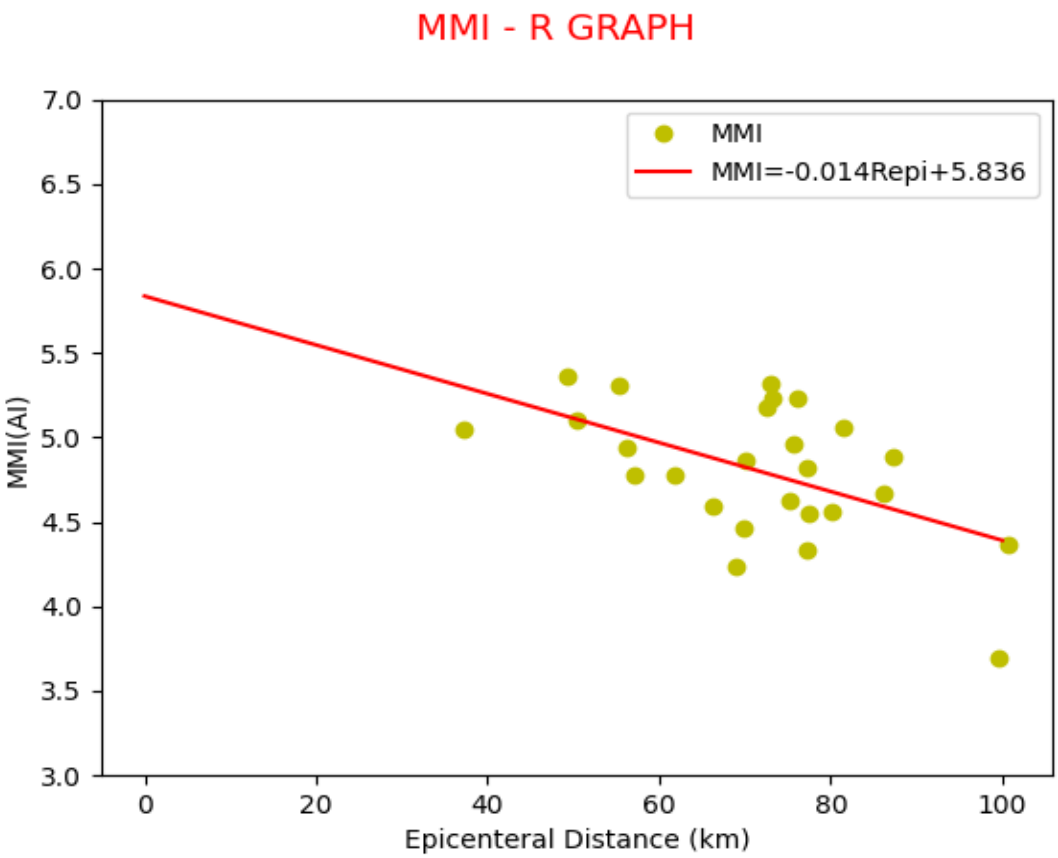

Figure 28 MMI - R Graph

Tselentis and Danciu's formula compose of Arias Intensity (I_A), Epicentral Distance, the dummy values which represent soil classification, and corresponding coefficient. Besides, the geometric mean is used to combine horizontal components of recordings for Arias Intensity (I_A) in order to compare Sandıkkaya and Akkar's method. As can be seen in figure 28, Modified Mercalli Intensity decreases while epicentral distance increases. In the epicenter, the maximum value of instrumental intensity is VI. There is a difference between MMI which I calculated and MMI which Kandilli Observatory and Earthquake Research Institute calculated. I think that the reason for the difference occurs because Tselentis and Danciu's method has consisted of a different dataset. This dataset might not have fitted as much as expected to the Aegean Earthquake, therefore polynomial regression can be used instead of linear regression or the coefficients might have needed to be rearranged according to standard error to fit data.

2.4 Arias Intensity and Cumulative Absolute Velocity Calculations to Predict Instrumental Intensity from an Empirical Equation

Sandıkkaya and Akkar (2016) presented a method to predict Arias Intensity and Cumulative Absolute Velocity. Thus, the destructiveness of an earthquake can be anticipated before the earthquake happen. The horizontal components have been combined with geometric mean. The formula is:

$$\ln(GMIM) = \left\{ \begin{array}{l} a_1 + a_2(M_w - 6.5) + a_3(8.5 - M_w)^2 + [a_4 + a_5(M_W - 6.5)] \ln(\sqrt{R^2 + a_6^2}) + \\ a_7 F_N + a_8 F_R + a_9 \ln\left[\dfrac{\min(V_{S30}, 1000)}{750}\right] + \varepsilon\sigma \end{array} \right\} \quad (4)$$

Where;

	CAV models (cm/s)				I_A models (m/s)		
	R_{JB}	R_{epi}	R_{hyp}		R_{JB}	R_{epi}	R_{hyp}
a_1	8.74378	9.01362	9.44255	a_1	4.8528	5.48044	6.57230
a_2	0.7516	0.7516	0.7516	a_2	0.39645	0.39645	0.39645
a_3	−0.03713	−0.03713	−0.03713	a_3	−0.10684	−0.10684	−0.10684
a_4	−0.88554	−0.93573	−1.0271	a_4	−2.04165	−2.15658	−2.38955
a_5	0.10417	0.10417	0.10417	a_5	0.39202	0.39202	0.39202
a_6	9	9	9	a_6	9	9	9
a_7	0.02738	0.02738	0.02738	a_7	−0.01572	−0.01572	−0.01572
a_8	−0.16629	−0.16629	−0.16629	a_8	−0.09282	−0.09282	−0.09282
a_9	−0.6444	−0.6444	−0.6444	a_9	−1.02908	−1.02908	−1.02908
ϕ	0.5538	0.5584	0.5618	ϕ	1.1229	1.1405	1.1486
τ	0.3033	0.3027	0.2946	τ	0.6339	0.6407	0.6058
σ	0.6314	0.6352	0.6344	σ	1.2895	1.3081	1.2986
	SD_{5-75} models (s)				SD_{5-95} models (s)		
	R_{JB}	R_{epi}	R_{hyp}		R_{JB}	R_{epi}	R_{hyp}
a_1	0.32116	0.18075	−0.17451	a_1	1.51131	1.40098	1.11533
a_2	1.47832	1.47832	1.47832	a_2	1.24873	1.24873	1.24873
a_3	0.06405	0.06405	0.06405	a_3	0.04921	0.04921	0.04921
a_4	0.41638	0.43977	0.51634	a_4	0.30794	0.32626	0.38781
a_5	−0.21769	−0.21769	−0.21769	a_5	−0.19161	−0.19161	−0.19161
a_6	7.5	7.5	7.5	a_6	7.5	7.5	7.5
a_7	0.10532	0.10532	0.10532	a_7	0.06962	0.06962	0.06962
a_8	−0.1326	−0.1326	−0.1326	a_8	−0.18352	−0.18352	−0.18352
a_9	−0.29276	−0.29276	−0.29276	a_9	−0.2957	−0.2957	−0.2957
ϕ	0.5267	0.5314	0.5319	ϕ	0.4492	0.4519	0.4519
τ	0.255	0.264	0.2506	τ	0.1879	0.1989	0.1907
σ	0.5852	0.5934	0.5880	σ	0.4869	0.4937	0.49049

Table 2 Regression Coefficients and Corresponding Coefficients

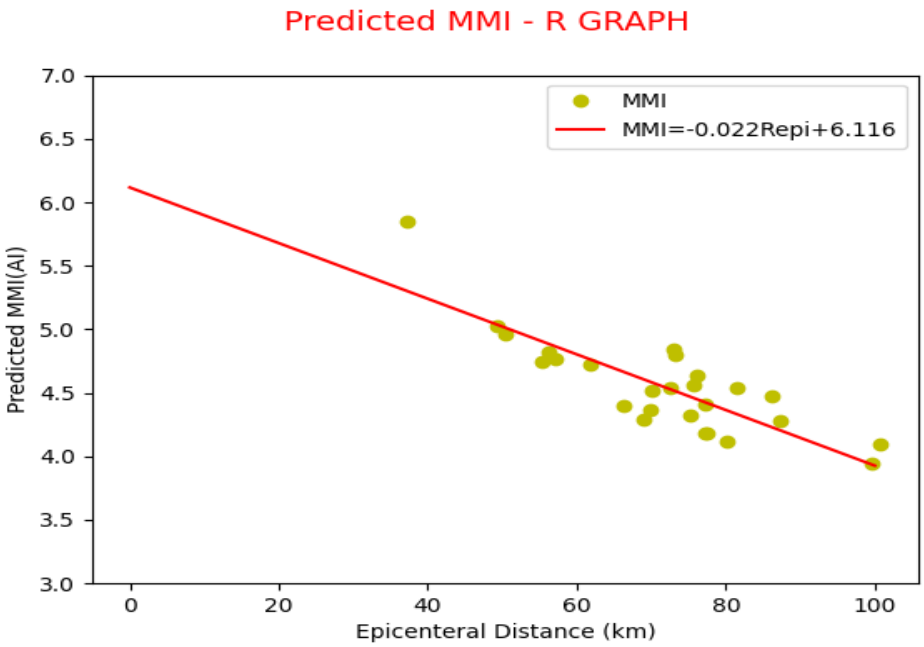

Figure 29 Predicted MMI - R Graph

The interval of predicted Instrumental Intensity has wider range than Instrumental Intensity which is found from recorded data according to epicentral distance. Also, prediction modal fits as the epicentral distance gets smaller. On the other hand, as epicentral distance increases, the prediction model starts to be inappropriate to predict well. As it is mentioned, Kandilli Observatory and Earthquake Research Institute prepared a press bulletin, and in the epicenter, they estimated the Instrumental Intensity VII.

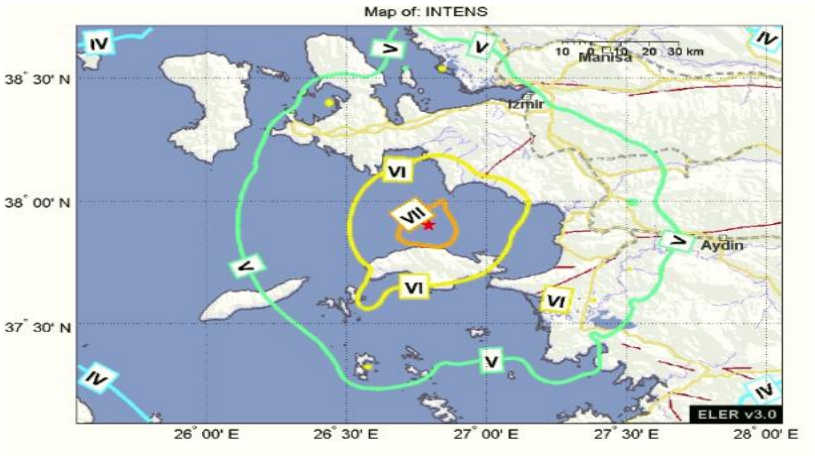

Figure 30 Map of Intensity From KOERI

3 Conclusion and Discussion

Figure 27 shows that significant duration move in the same direction with epicentral distance. It means when epicentral distance increases, significant duration also increases. Another important thing that the figure shows is without enough recording we cannot find the relevance between Vs_{30} and significant duration.

Figure 28, Figure 29, and Figure 30 demonstrate that Predicted MMI's slope is bigger than the recorded MMI, but neither of them fit exactly to MMI prepared by KOERI. As neither Tselentis and Danciu's method nor Sandıkkaya and Akkar' method has the same dataset that we use. Nevertheless, each method is pretty well to anticipate the intensity of the earthquake.

Residual AI and CAV graphs illustrate that if below 25 and above 75 quantiles removed from data, points cluster between 0 and 2. So, it means predicted AI and CAV do not match very well to recorded AI and CAV.

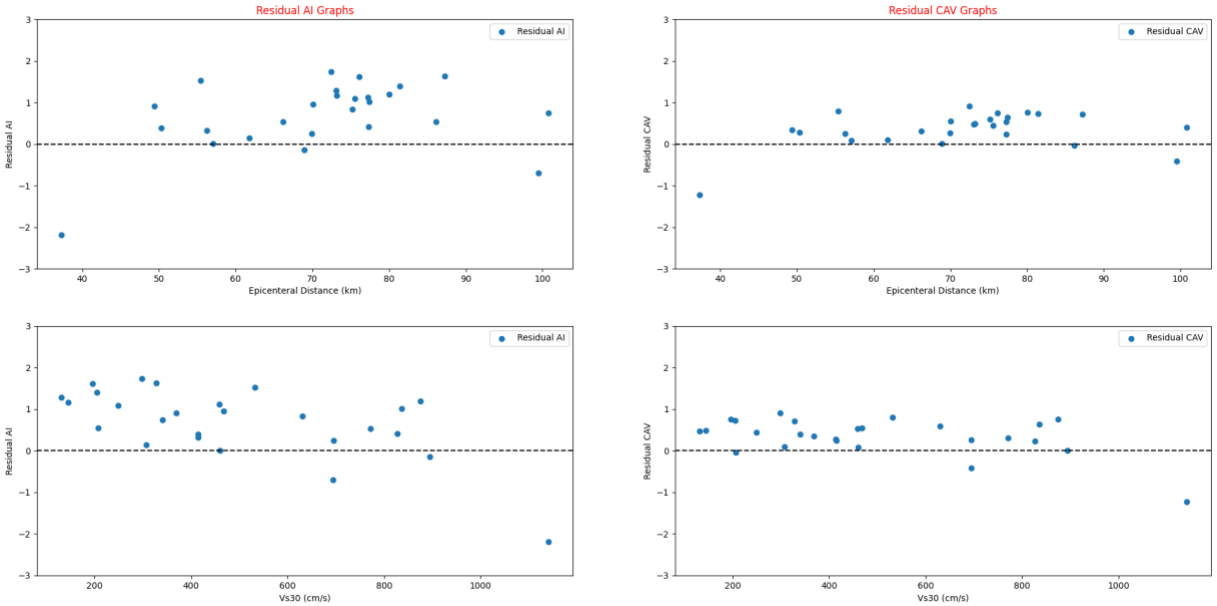

Figure 31 Residual AI and CAV Graphs

Another comparison can be made for Residual Intensity. As it is mentioned before, upper quartile and lower quartile remove from data, recorded Intensity and predicted intensity almost the same. Because residual intensity clustered almost zero. But also, it can be said that while epicentral distance increases, the probability of error is getting higher. On the contrary, Vs_{30} and Residual Intensity has an opposite relationship when considered the relationship of Epicentral Distance (R) and Residual Intensity.

In the conclusion, Sandıkkaya and Akkar (2016) empirical equation predict satisfactorily in terms of intensity.

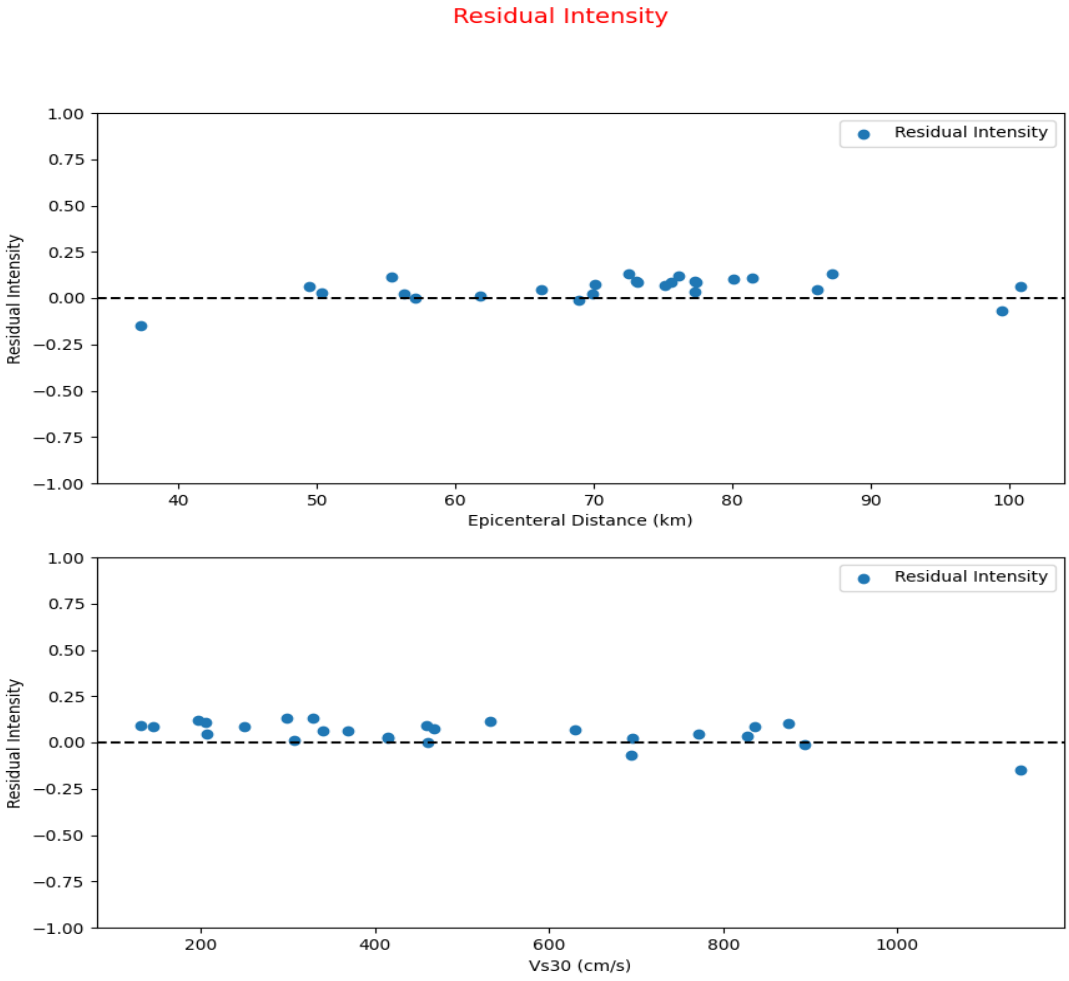

Figure 32 Residual Intensity

4 References

1- Tselentis and Danciu (2008) Empirical Relationships between Modified Mercalli Intensity and Engineering Ground-Motion Parameters in Greece, Bulletin of the Seismological Society of America, Vol. 98, No. 4, pp. 1863–1875, August 2008, doi: 10.1785/0120070172

2- Sandıkkaya and Akkar (2016), Cumulative absolute velocity, Arias intensity and significant duration predictive models from a pan-European strong-motion dataset, Bull Earthquake Eng DOI 10.1007/s10518-016-0066-6

3- http://www.koeri.boun.edu.tr/sismo/2/30-ekim-2020-mw6-9-ege-denizi-izmir-depremi/