EARTH'S MAGNETIC FIELD AND ANOMALIES

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OVERVIEW

- Introduction
- Data and Methodology
- Result
- Conclusion
- Solar Flares

SOUTH ATLANTIC ANOMALY (SAA)

- It is an area between South America and the southern Atlantic Ocean, which **Van Allen belt** comes closer to the earth's surface than other areas.

- Inside it has a lot of **high-energy protons** from **solar flare** and the **cosmic radiation**.

- It is in the low earth orbit (LEO).

SOUTH ATLANTIC ANOMALY (SAA)

- This phenomenon was firstly happened 8 to 11 million years ago; however, it started to **split from a single valley into two cells** these days.

- the high-energy particles **does not affect life** on the earth, but either **data** or **equipment of the satellites and spacecrafts** passing through the areas can be damaged.

- All satellites and spacecrafts shut down their systems while they are passing these areas to avoid either the temporary or permanent loss.

OBJECTIVE

- **Identify and measure** economic **risk** focusing on the communication satellites in the LEO associated with the growing of the SAA
- Find **the possible mitigation plan** to immunize the possible economic risk in the future.

Variable	Description (Unit)	Data Source
R	The annual revenue from three companies that providing the communication satellite services (USD)	- https://www.wsj.com/market-data/quotes/GSAT/financials/annual/income-statement - https://www.wsj.com/market-data/quotes/IRDM/financials/annual/income-statement - https://www.wsj.com/market-data/quotes/SATS,EK,UEIC,VOXX,MCZ,NIVS,LOJN,LRAD,IGOI/financials/annual/income-statement
E_o	The annual other expense for communication satellite (USD)	
L	The loss occurring when the anomalies damaged a communication satellite	- https://www.space.com/6839-space-forecast-predicts-satellite-production-boom.html
I	The initial investment sum of launching communication satellites (USD)	- https://www.space.com/6839-space-forecast-predicts-satellite-production-boom.html - https://talkingpointsmemo.com/idealab/satellites-earth-orbit

Variable	Distribution	Value (in million)
I	Uniform	Cost of launching = (weight ~ Uniform [1,6]) * 11.3 Cost of producing = 51
R	Uniform	[780.1670,1215.2893]
E_0	Uniform	[477.8237,867.8147]
i	Constant	3%
k	Constant	1, 2, 3, 4..., 10
L	Normal	L ~ $N(\mu = 105, \sigma^2 = 105 * p)$ OR L = 0
p	Constant	0.3, 0.5 and 0.7

METHODOLOGY

- Using **Monte Carlo simulation** (10,000 times) calculated the economic performance indicator's **distribution** and used the distribution to **evaluated risk** using the risk indictor

- Economic Performance Indicator is **Net Present Value (NPV).**

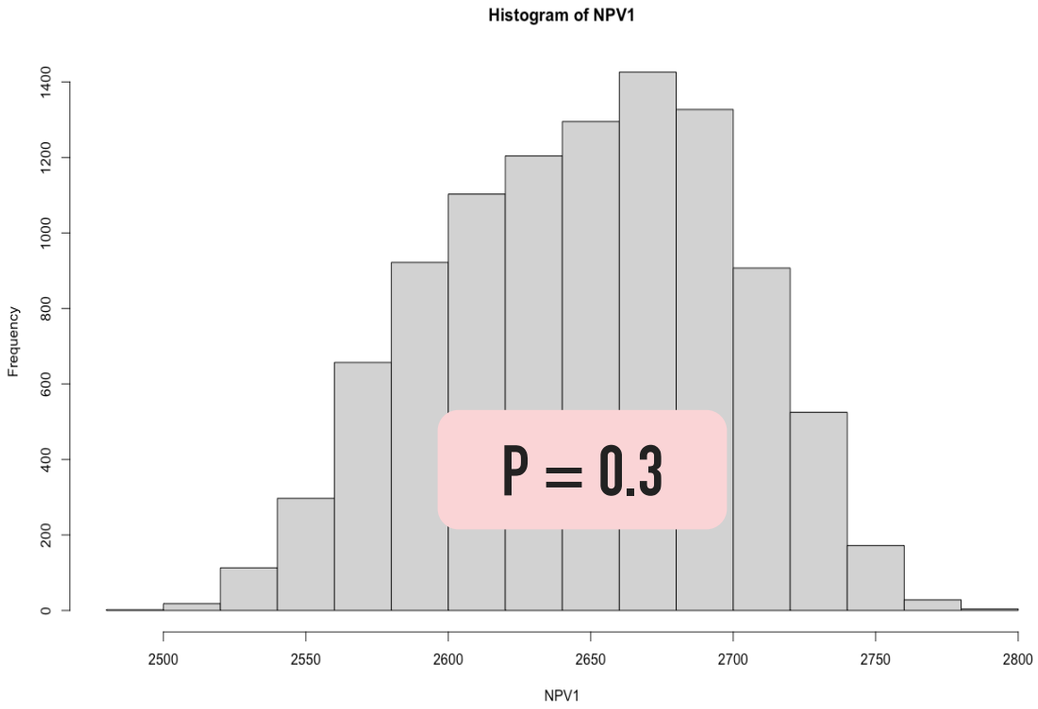
$$NPV = -I + \sum_{k=1}^{10} \frac{R - E_0}{(1+i)^k} - \frac{L}{(1+i)^{10}}$$

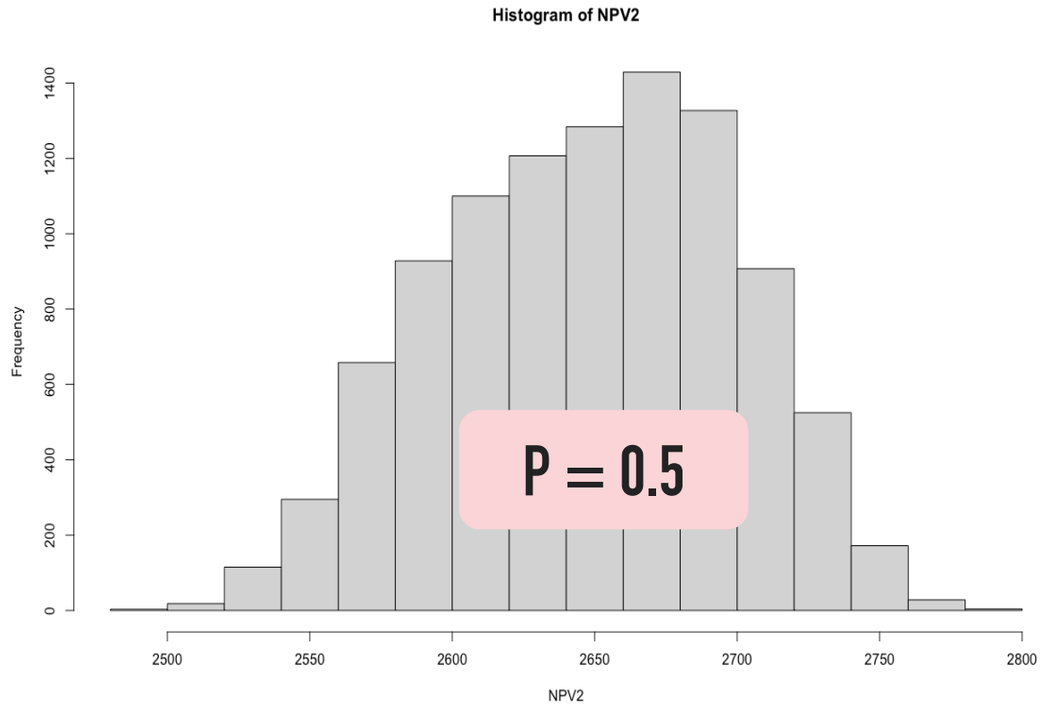
- Risk Indicator is **Value At Risk (VaR)** with 95% level of confidence.

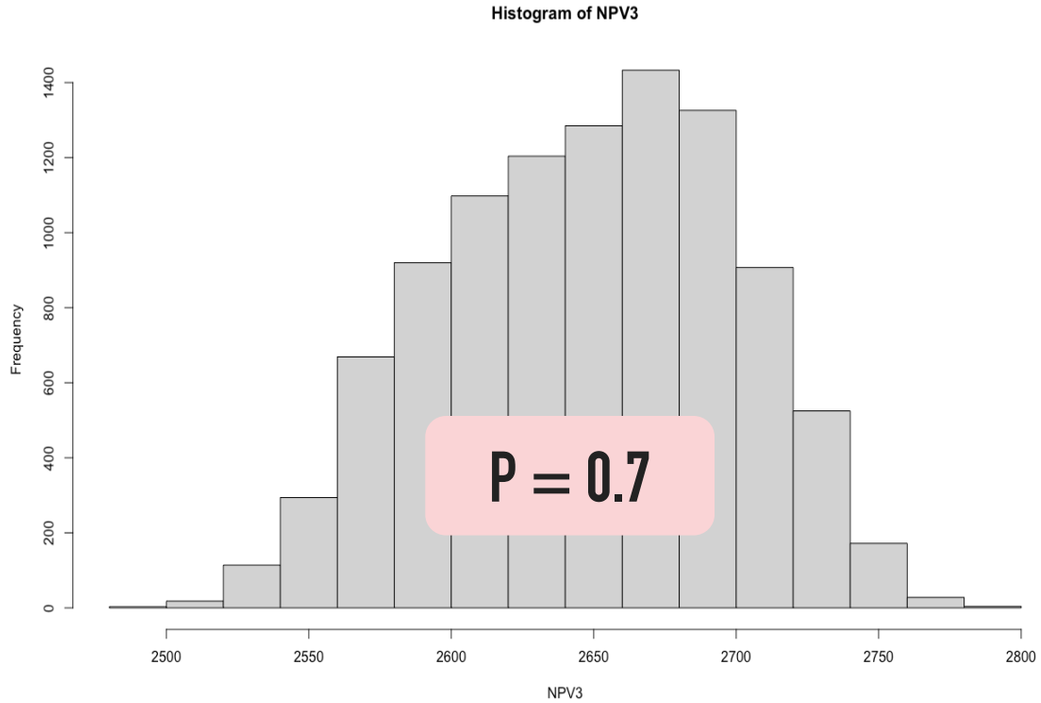
THE FIRST TEN SIMULATED DATA BY R

	I	accumPV_Net	loss_1	loss_2	loss_3	i	NPV1	NPV2	NPV3
1	78.54813	2739.158	0.00000	0.00000	0.00000	0.03	2660.609	2660.609	2660.609
2	106.83924	2806.515	103.70813	103.33221	103.02664	0.03	2622.507	2622.787	2623.014
3	85.40720	2769.273	0.00000	0.00000	0.00000	0.03	2683.866	2683.866	2683.866
4	112.19048	2796.767	0.00000	0.00000	0.00000	0.03	2684.576	2684.576	2684.576
5	115.43640	2759.074	0.00000	0.00000	0.00000	0.03	2643.637	2643.637	2643.637
6	64.87394	2731.401	114.62578	117.42683	119.70362	0.03	2581.234	2579.150	2577.456
7	92.13796	2757.964	0.00000	0.00000	0.00000	0.03	2665.826	2665.826	2665.826
8	112.72168	2814.404	0.00000	0.00000	0.00000	0.03	2701.683	2701.683	2701.683
9	93.45608	2824.842	0.00000	0.00000	0.00000	0.03	2731.386	2731.386	2731.386
10	88.09873	2690.672	0.00000	0.00000	0.00000	0.03	2602.573	2602.573	2602.573

HISTOGRAM PLOT OF NET PRESENT VALUE







RESULT

Scenario no.	p	The average of NPV	The standard deviation of NPV	VaR at 95%
1	0.3	2,647.620	50.96746	-2,726.106
2	0.5	2,647.618	51.01740	-2,726.106
3	0.7	2,647.616	51.06706	-2,726.106

CONCLUSION

- the scenario **no. 1**, which is p = 0.3, performed **the best** among all three scenarios.

- **Adding the lightweight shield** on the satellites might be a mitigation plan to immunize the risk.

- Because **less weight** of satellites will provide **higher average NPV.**

- But the increasing the weight **does not create** that high impact of the change of net present value.

FIXING THE INITIAL INVESTMENT

Weight of the satellite (tons)	The average of NPV	The standard deviation of NPV
1	2,675.732	52.45278
2	2,664.432	52.45278
3	2,653.132	52.45278
4	2,641.832	52.45278
5	2,630.532	52.45278
6	2,619.232	52.45278

THE SOLAR FLARES

- The solar storms are the **form of highly energetic particles** occurred by the activities on the Sun's surface.
- There are **four types**: solar flares, coronal mass ejections (CME), high-speed solar wind and solar energetic particles.
- The solar flares take about 8 mins while the CME takes about 30 mins to an hour to Earth.
- A worst-case scenario that solar flare **shut down the electricity for nine hours** in Quebec, Canada, which affected 6 million people in 1989.

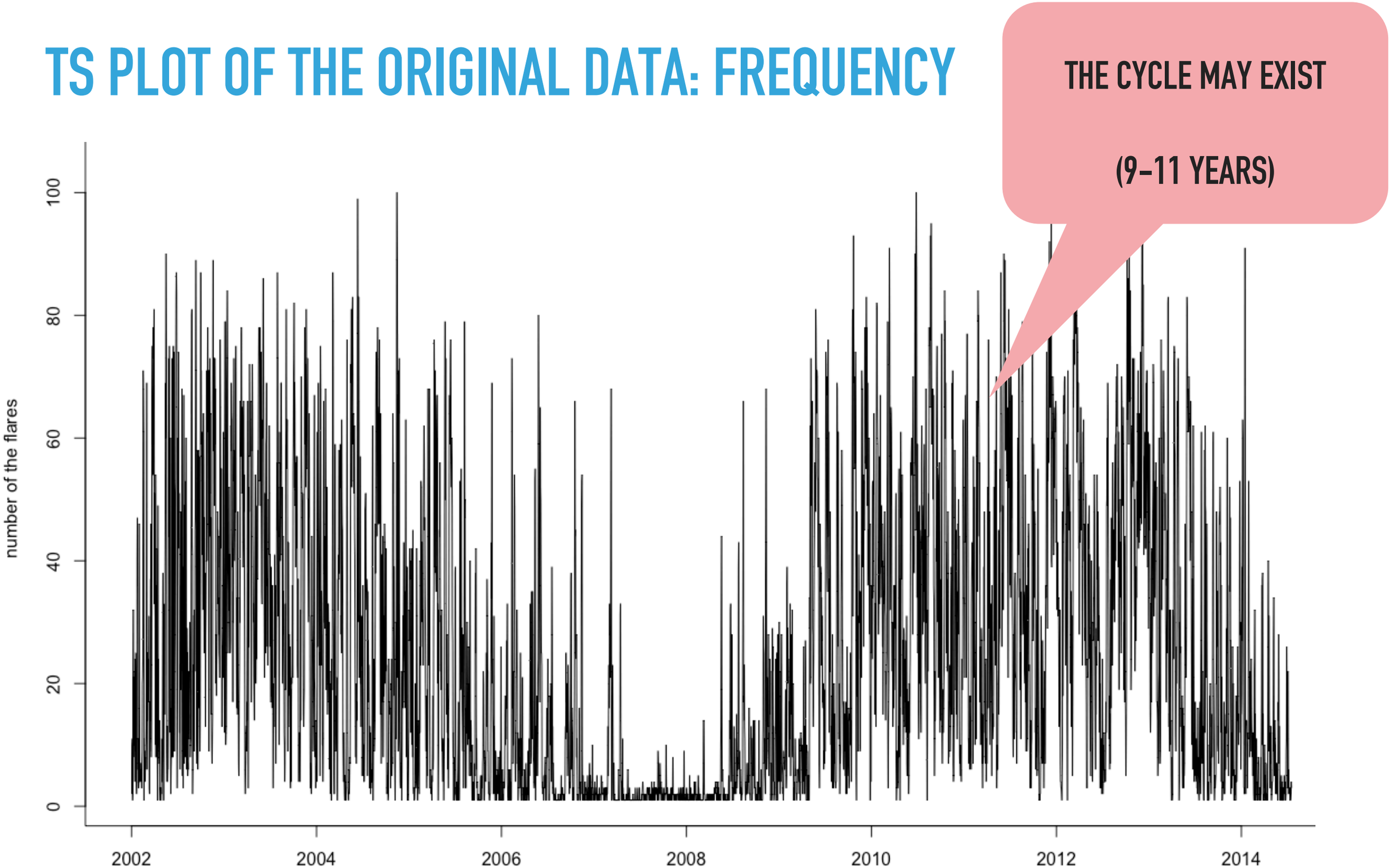
THE SOLAR FLARES

- The quantification of the flares **associated with the number of sunspots**. The flares are happening followed **the cycle ~ 11 years.**

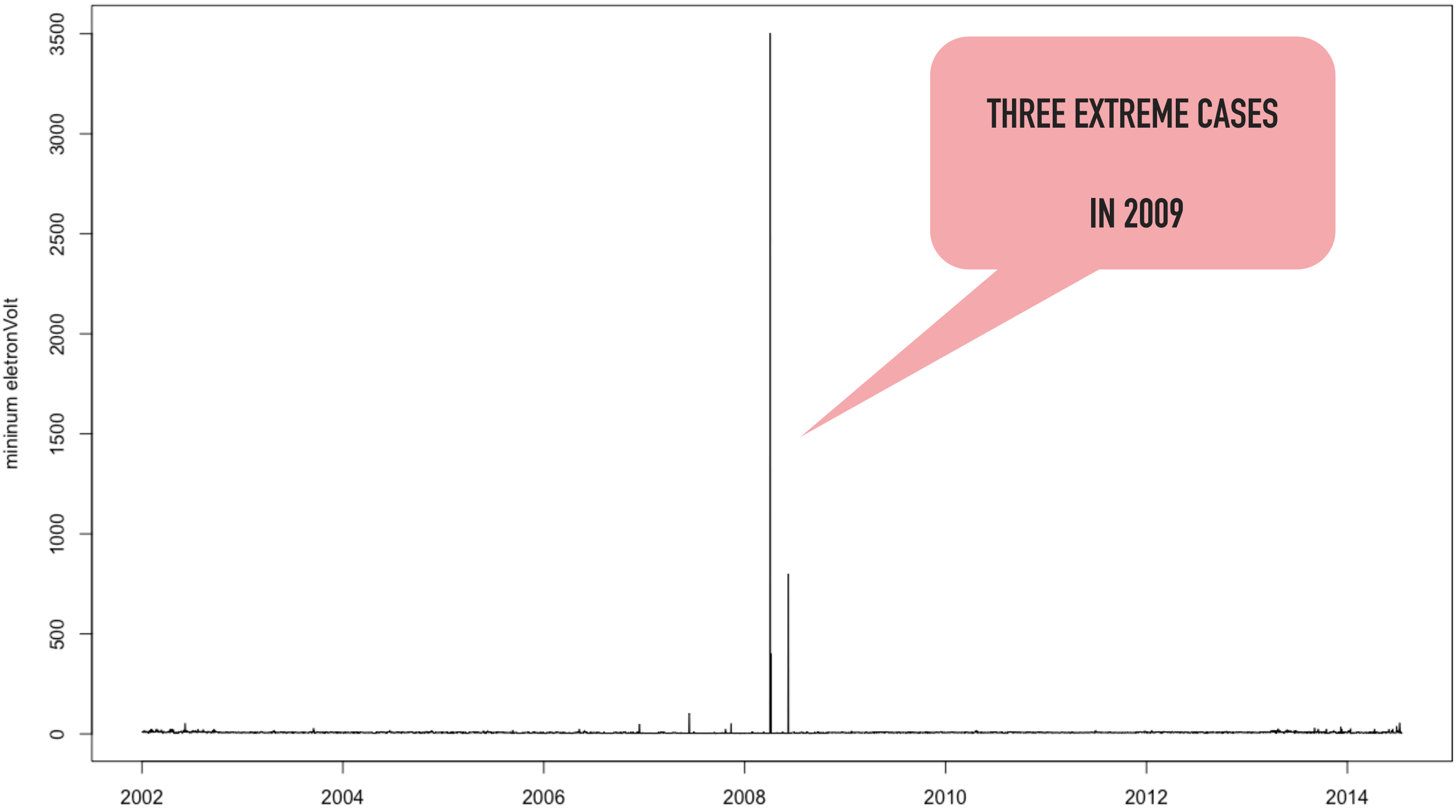
- The more accurate prediction of the flares means the better mitigation plan that people can prepare in order to prevent all risks.

- The statistical method to forecast the flares is **Time series**.

TS PLOT OF THE ORIGINAL DATA: FREQUENCY



TS PLOT OF THE ORIGINAL DATA: MIN SEVERITIES



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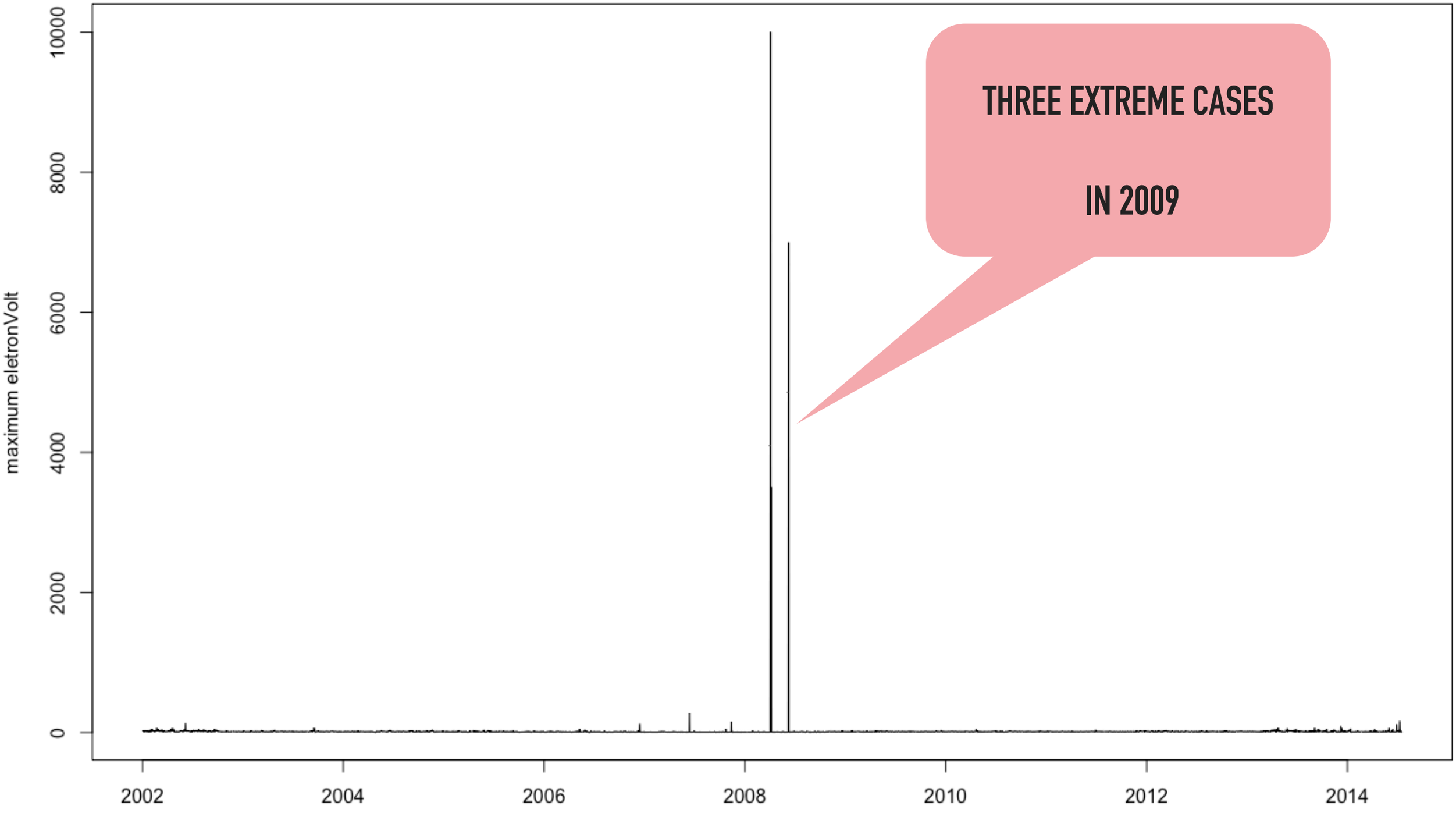


DETAIL OF THE DATA SET

- From kaggle.com
- Collected from February 2002 to December 2016
- 113,942 data points – about 4,581 days in total
- Adjusted to be daily and average of min/max electron volt
- Focused on minimum and maximum the energy produced by the flare (kV/m)
- Training set = 4,343 data points and Test set = 235 data points

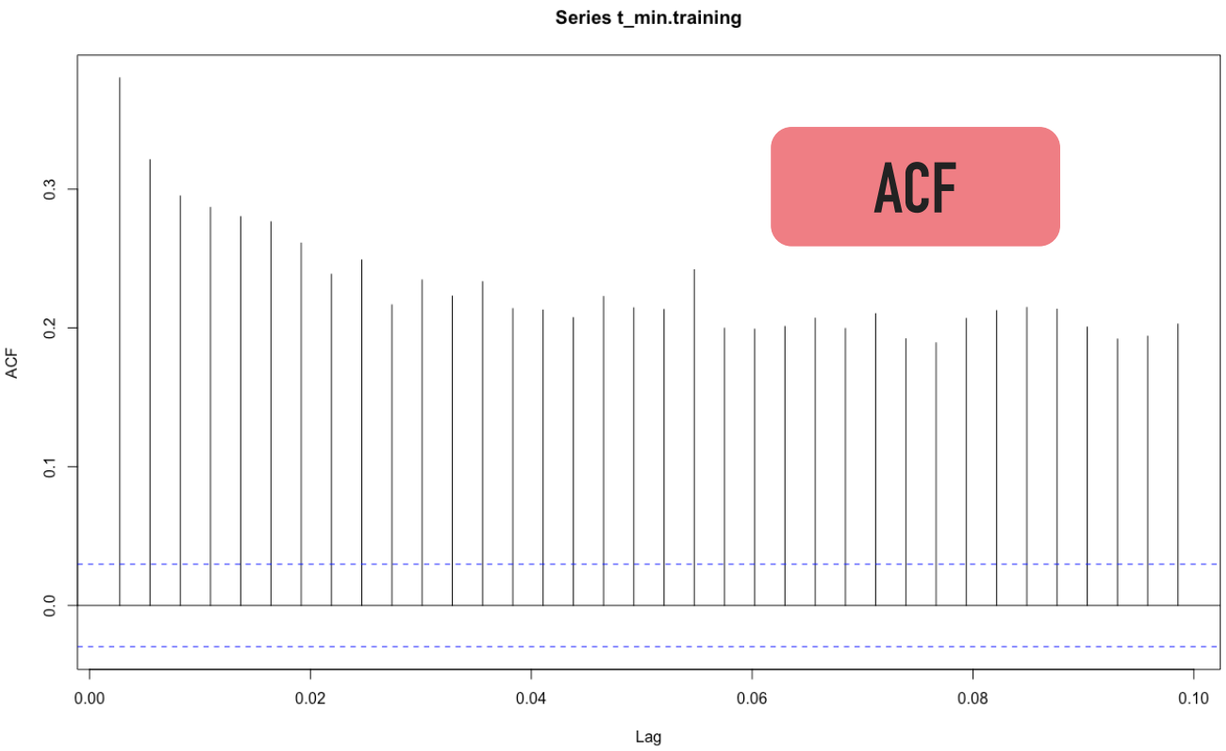
MODEL SPECIFICATION – FOR BOTH MINIMUM AND MAXIMUM

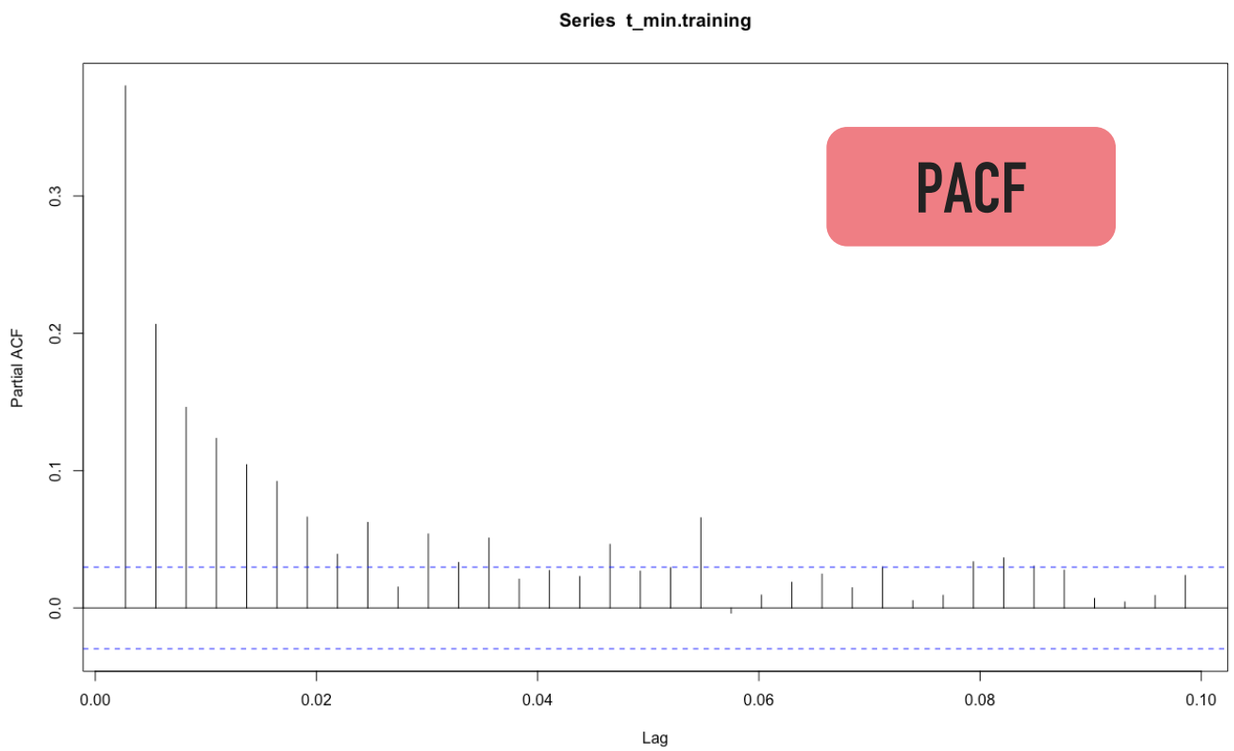
- It is **stationary** because p-value of the dickey-Fuller Test for minimum energy is smaller (less than 0.01)

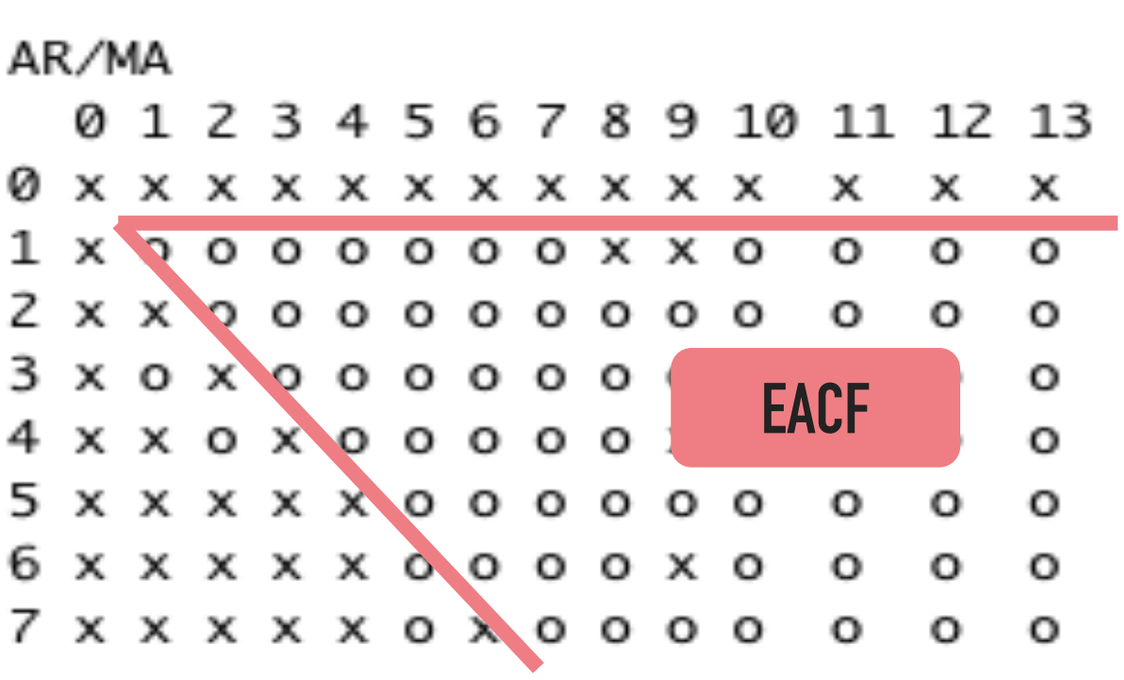
- Doing the autocorrelation (ACF), partial autocorrelation (PACF) and extended autocorrelation (EACF) plot – seasonal trend **does not exist** and **ARMA (1,1)** is recommended model.

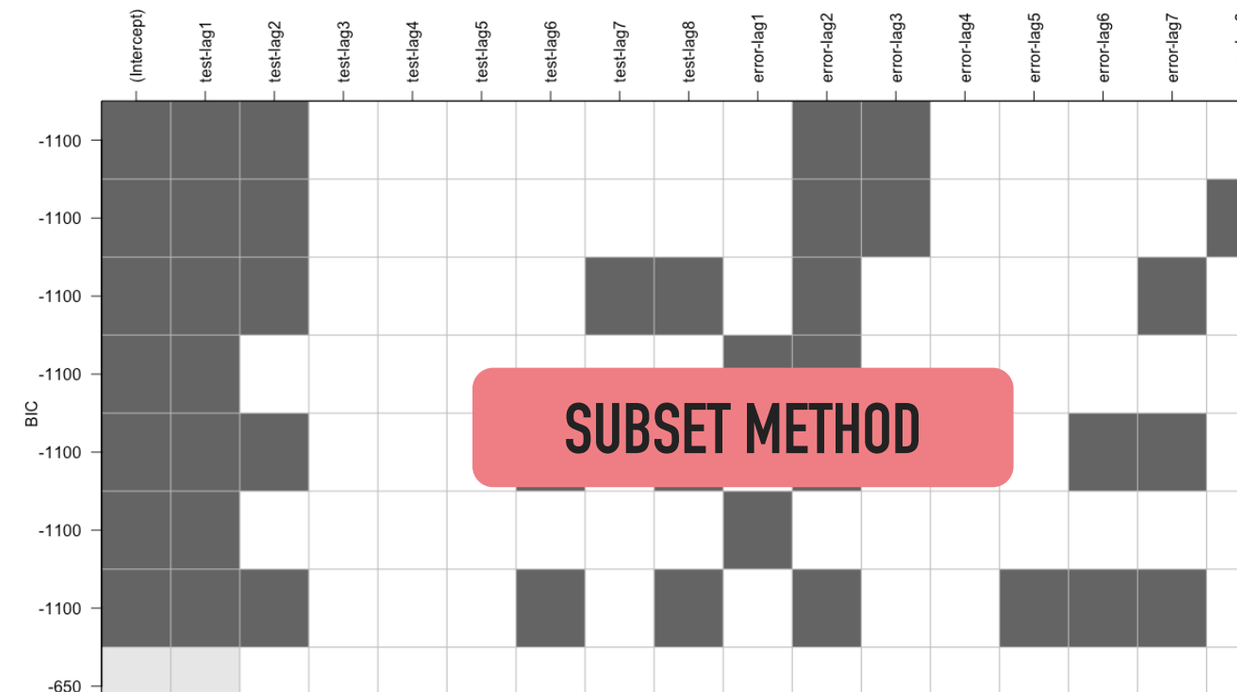
- The subset method recommended **ARMA (2,3).**

MODEL SPECIFICATION – MINIMUM SEVERITY

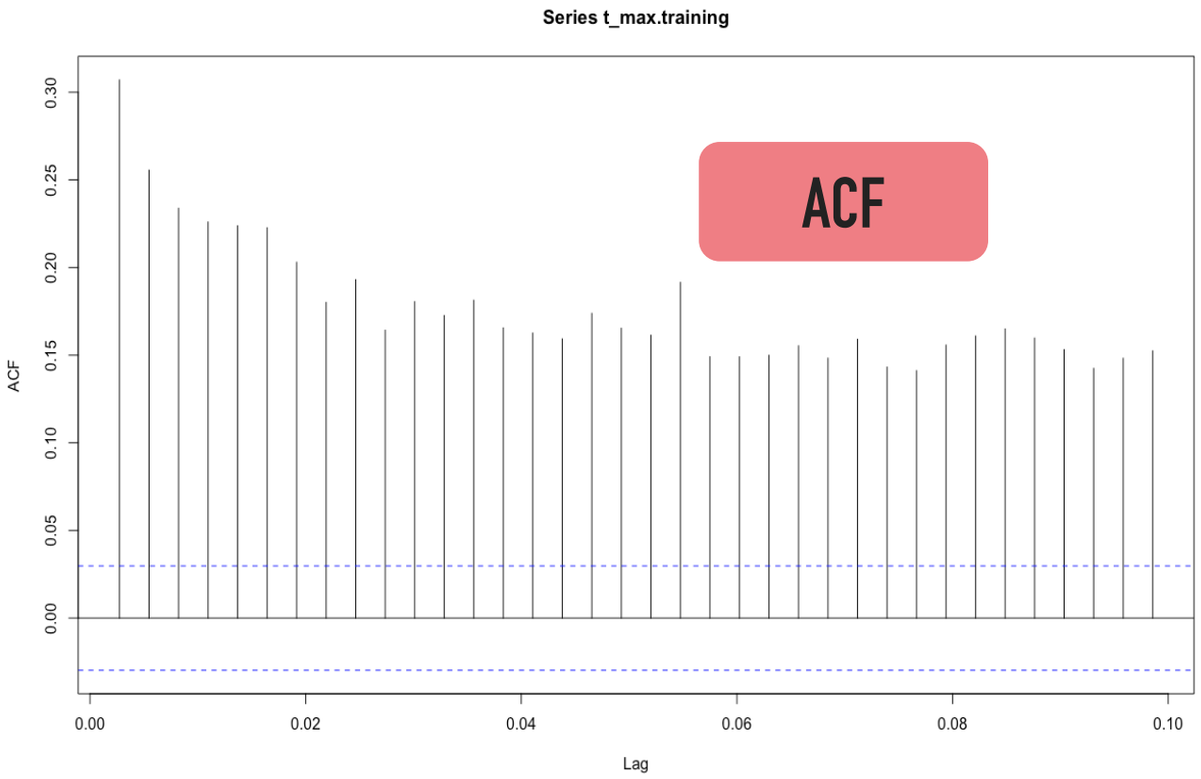




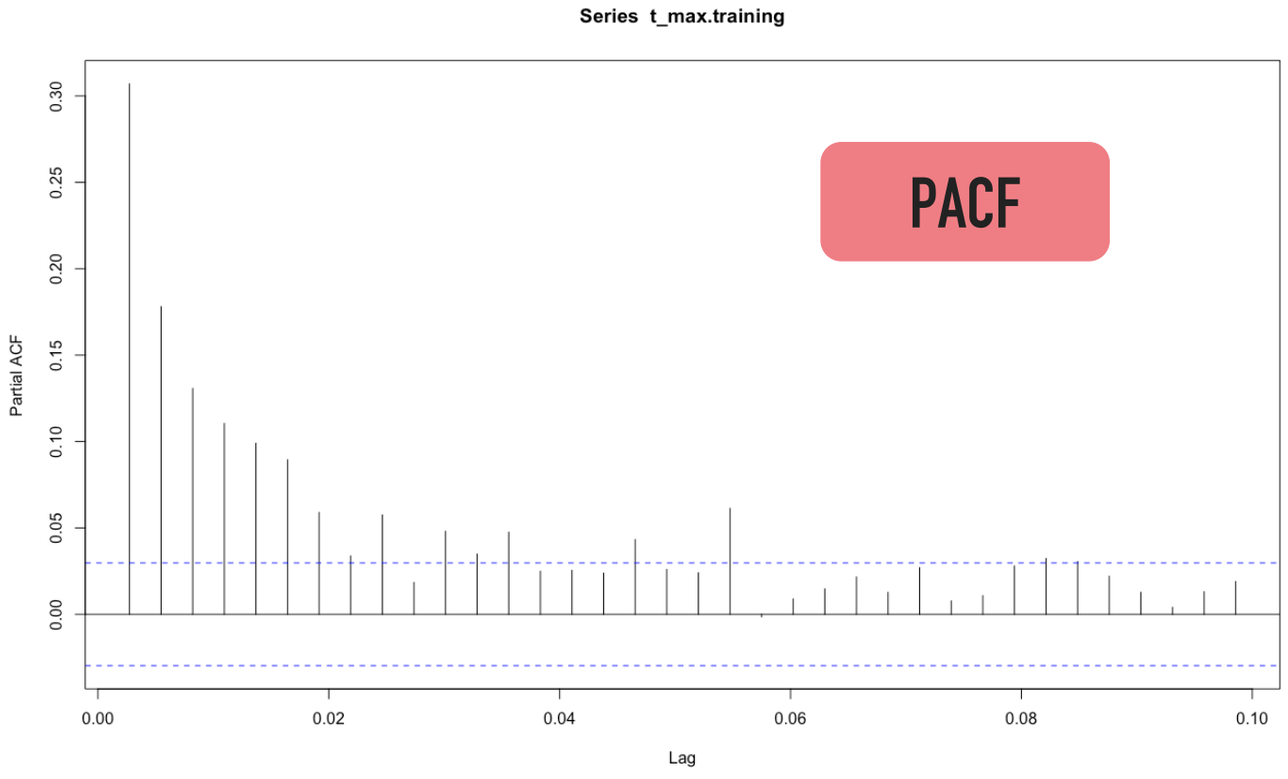




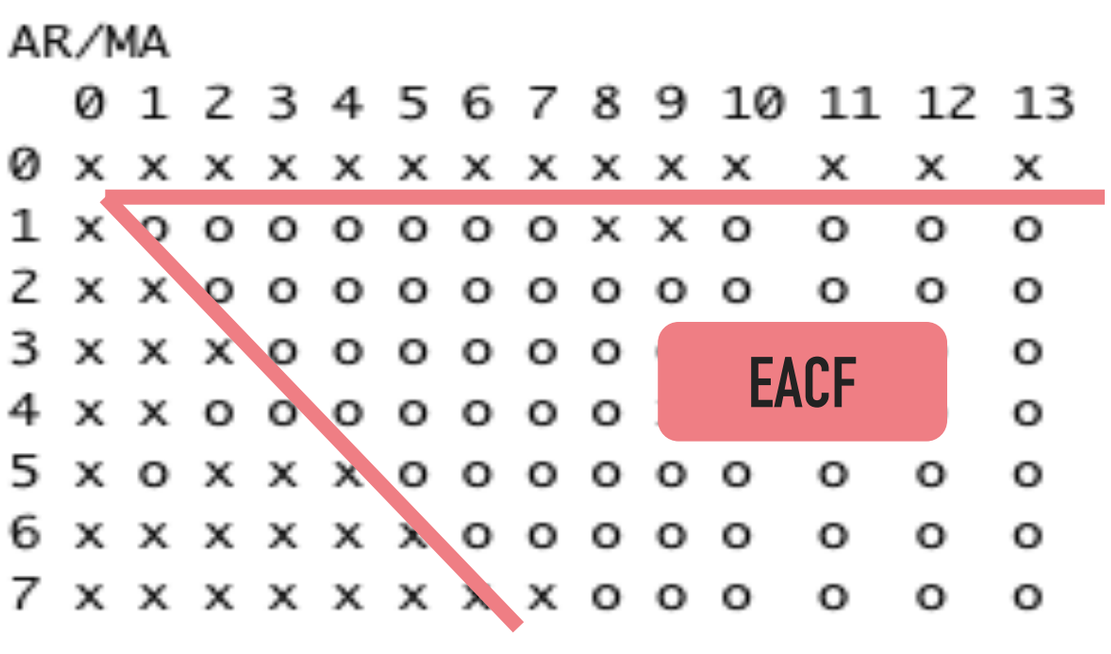
MODEL SPECIFICATION – MAXIMUM SEVERITY



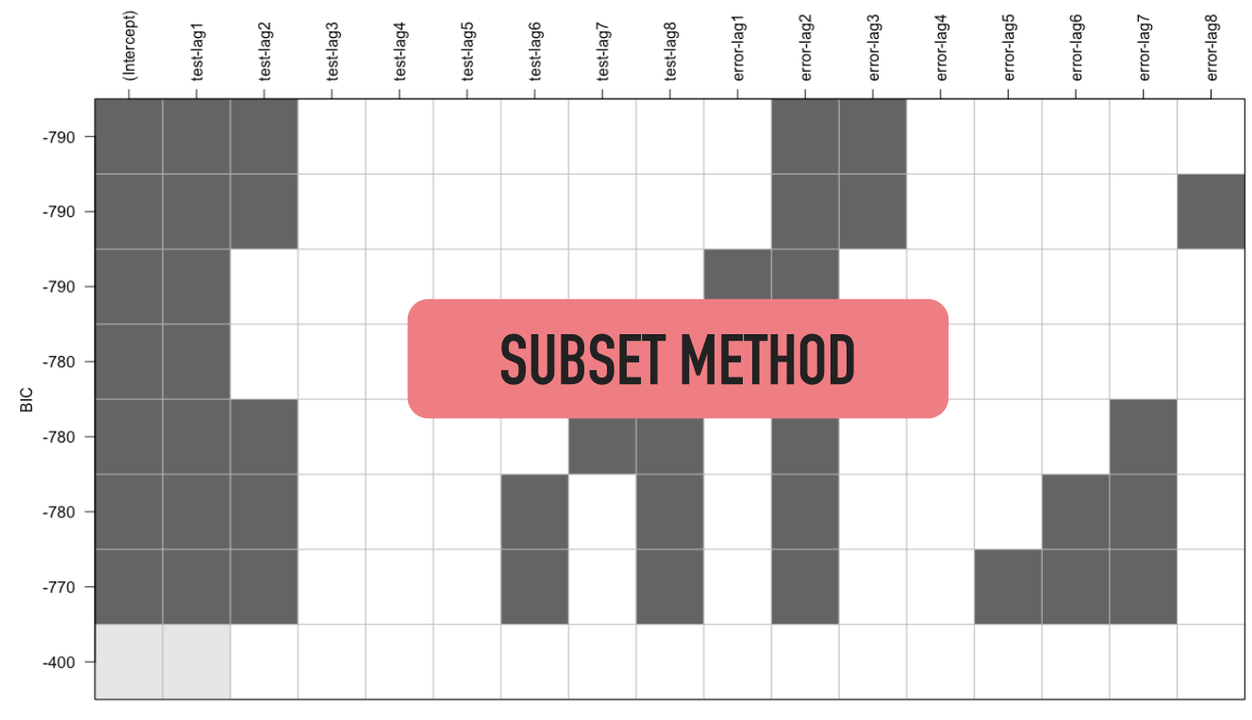
ACF



PACF



EACF



SUBSET METHOD

MODEL FITTING AND RESIDUAL ANALYSIS – MINIMUM SEVERITY

- Overfitting ARMA(1,1) – it suggested **ARMA(2,1)** because all coefficient are significant, and the AIC is smaller.

- Residual analysis: white noise -- around zero-horizontal line, not normal and Ljung-Box test -- residuals are uncorrelated.

- Then, trying the log-transformation – the result were worse.

- $Y_t = 1.1689Y_{t-1} - 0.1714\,Y_{t-2} + e_t - 0.9604e_{t-1} + 6.7416$

MODEL FITTING AND RESIDUAL ANALYSIS – MINIMUM SEVERITY

- Overfitting ARMA(2,3) – it suggested **ARMA(2,2)** because all coefficient are significant, and the AIC is smaller.

- Residual analysis: white noise -- around zero-horizontal line, not normal and Ljung-Box test -- residuals are uncorrelated.

- Then, trying the log-transformation – the result were worse.

- $Y_t = 1.7495Y_{t-1} - 0.7495\,Y_{t-2} + e_t - 1.5753e_{t-1} + 0.5817e_{t-2} + 6.7743$

MODEL FITTING – MAXIMUM SEVERITY

- Overfitting ARMA(1,1) – it suggested **ARMA(2,1)** because all coefficient are significant, and the AIC is smaller.

- Residual analysis: white noise -- around zero-horizontal line, not normal and Ljung-Box test -- residuals are uncorrelated.

- Then, trying the log-transformation – the result were worse.

- $Y_t = 1.1378Y_{t-1} - 0.1403\,Y_{t-2} + e_t - 0.9660e_{t-1} + 13.7655$

RESIDUAL ANALYSIS – MAXIMUM SEVERITY

- Overfitting ARMA(2,3) – it suggested **ARMA(2,2)** because all coefficient are significant, and the AIC is smaller.

- Residual analysis: white noise -- around zero-horizontal line, not normal and Ljung-Box test -- residuals are uncorrelated.

- Then, trying the log-transformation – the result were worse.

- $Y_t = 1.4807Y_{t-1} - 0.4855\,Y_{t-2} + e_t - 1.3101e_{t-1} + 0.3392e_{t-2} + 13.7980$

FINAL MODEL

	Minimum Energy		Maximum Energy	
	Model 1	Model 2	Model 1	Model 2
MSE	32.2679	31.8913	227.3252	229.5163
PMAD	0.3578	0.3942	0.3982	0.3754

Q & A