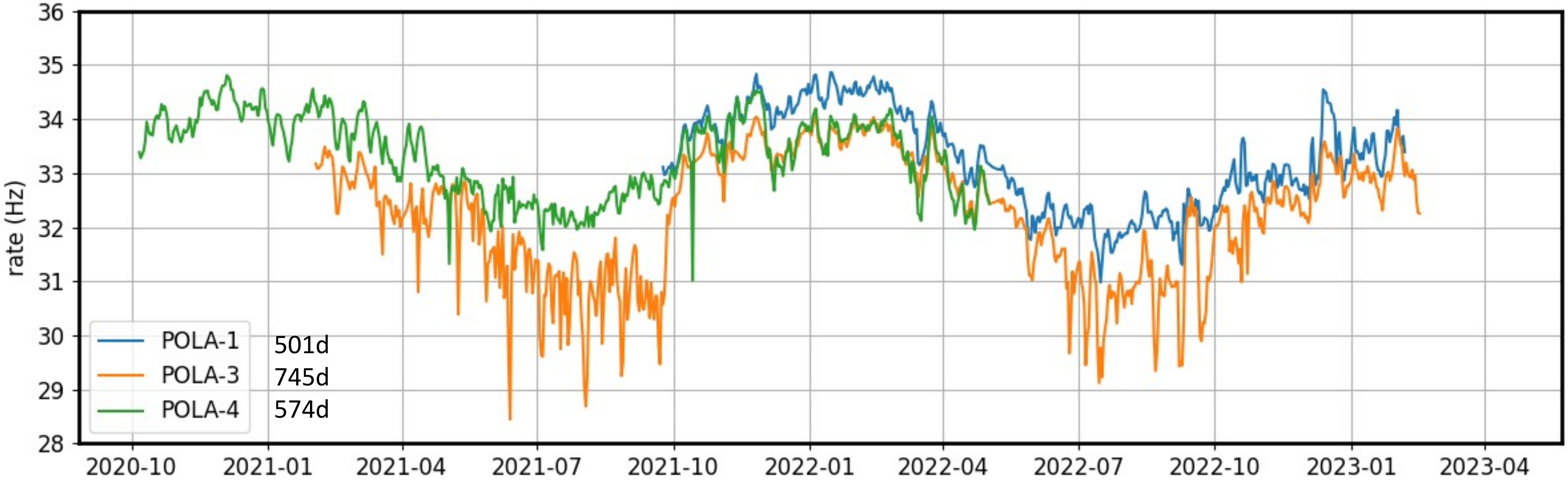
Ricerca di periodicità nei rate a Ny Ålesund

Studio preliminare

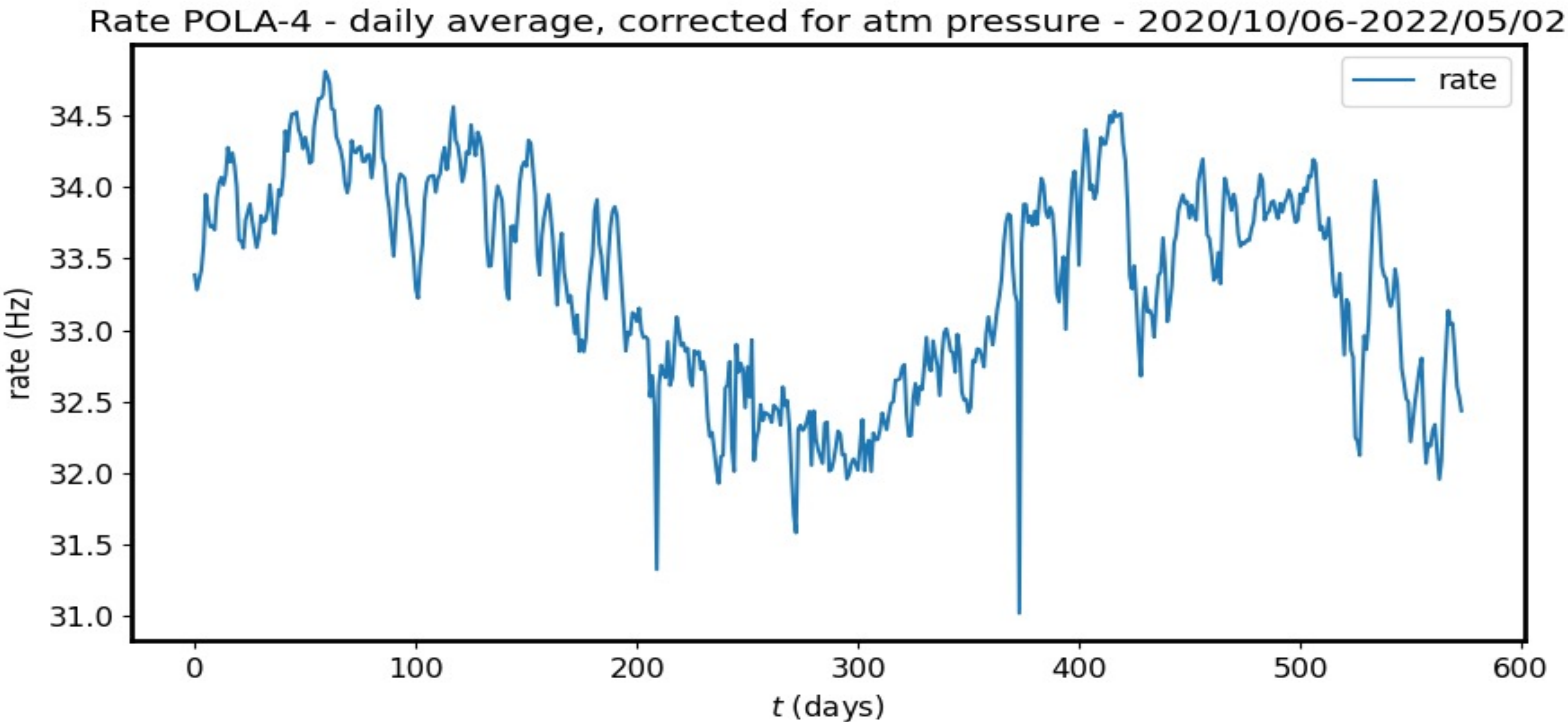
Ombretta Pinazza

4 maggio 2023

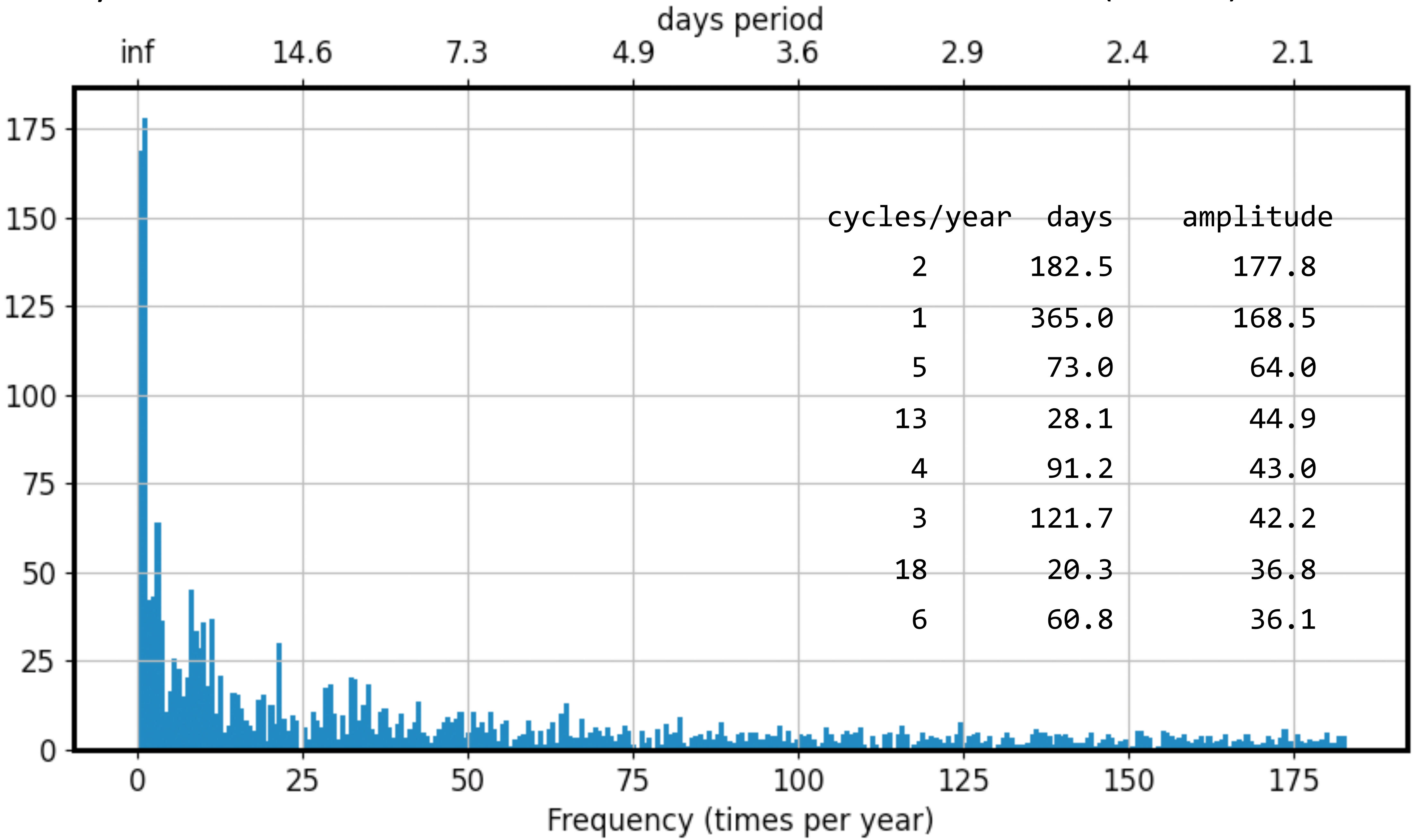
Daily rates, corrected for pressure, long sequences



POLA-4 2020/10/06-2022/05/02 (574d)



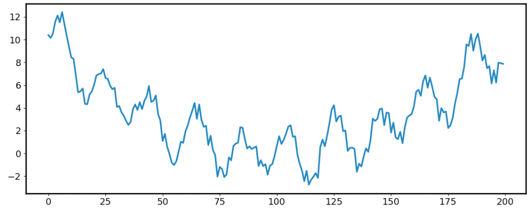
Daily rate POLA-4 FFT – 2020/10/06-2022/05/02 (574d)



cycles/year	days	amplitude
2	182.5	177.8
1	365.0	168.5
5	73.0	64.0
13	28.1	44.9
4	91.2	43.0
3	121.7	42.2
18	20.3	36.8
6	60.8	36.1

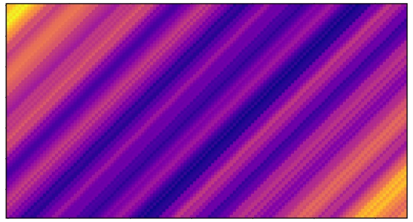
Singular Spectral Analysis (SSA)

- Time series: F(t)
  - discrete $F[0,\dots,N-1]=[f_0,f_1,\dots,f_{N-1}]$



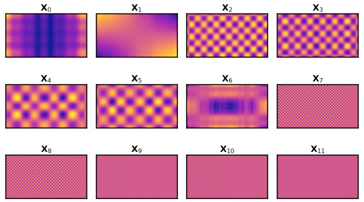
- Trajectory matrix (Hankel), $2 \le \mathbf{L} \le N/2$ (L window length)

$$\mathbf{X} = \begin{bmatrix} f_0 & f_1 & f_2 & f_3 & \cdots & f_{N-L} \\ f_1 & f_2 & f_3 & f_4 & \cdots & f_{N-L+1} \\ f_2 & f_3 & f_4 & f_5 & \cdots & f_{N-L+2} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ f_{L-1} & f_L & f_{L+1} & f_{L+2} & \cdots & f_{N-1} \end{bmatrix}$$

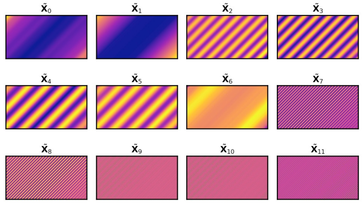


d=rank(X)

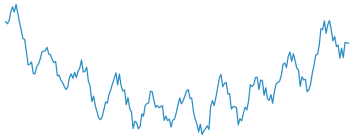
- Singular Value Decomposition: $X = U \times \Sigma \times V^T$
  - U, V sono matrici unitarie
  - Σ matrice diagonale
  - $\{U_i,\sigma_i,V_i\}$ eigentriple
- SVD permette la decomposizione in matrici elementari $\mathbf{X} = \sum_{i=0}^{d-1} \sigma_i U_i V_i^{\mathrm{T}} \equiv \sum_{i=0}^{d-1} \tilde{\mathbf{X}}_i$ hankelizzabili



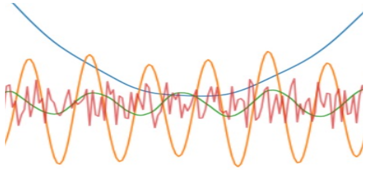
→

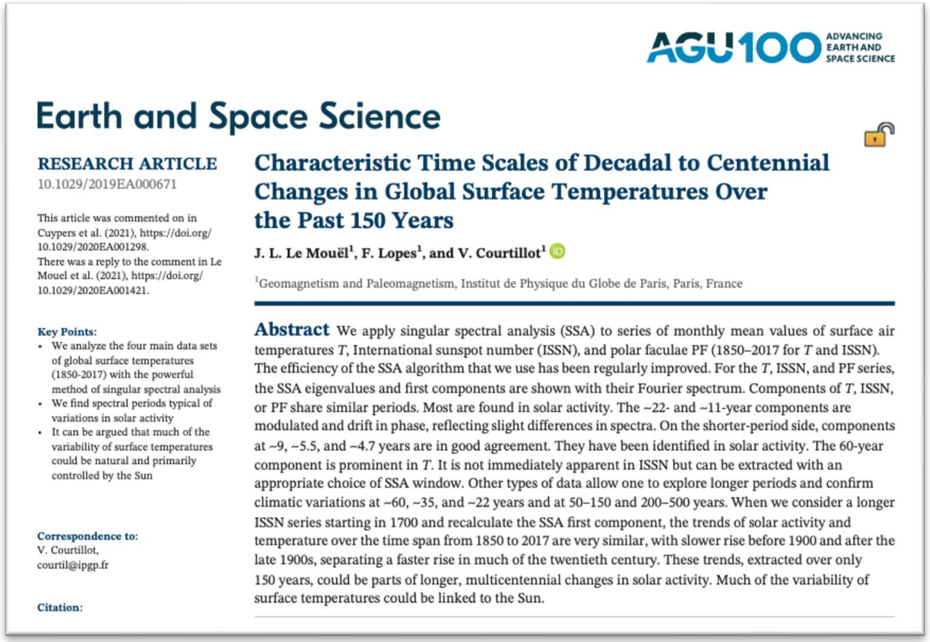


$\rightarrow F(t)=\sum_{i=0}^{d-1} F_i^{\sim}$



→





AGU100 ADVANCING EARTH AND SPACE SCIENCE

Earth and Space Science

RESEARCH ARTICLE
10.1029/2019EA000671

This article was commented on in Cuypers et al. (2021), https://doi.org/10.1029/2020EA001298.
There was a reply to the comment in Le Mouel et al. (2021), https://doi.org/10.1029/2020EA001421.

Characteristic Time Scales of Decadal to Centennial Changes in Global Surface Temperatures Over the Past 150 Years

J. L. Le Mouël[1], F. Lopes[1], and V. Courtillot[1]

[1]Geomagnetism and Paleomagnetism, Institut de Physique du Globe de Paris, Paris, France

Key Points:
- We analyze the four main data sets of global surface temperatures (1850-2017) with the powerful method of singular spectral analysis
- We find spectral periods typical of variations in solar activity
- It can be argued that much of the variability of surface temperatures could be natural and primarily controlled by the Sun

Correspondence to:
V. Courtillot,
courtil@ipgp.fr

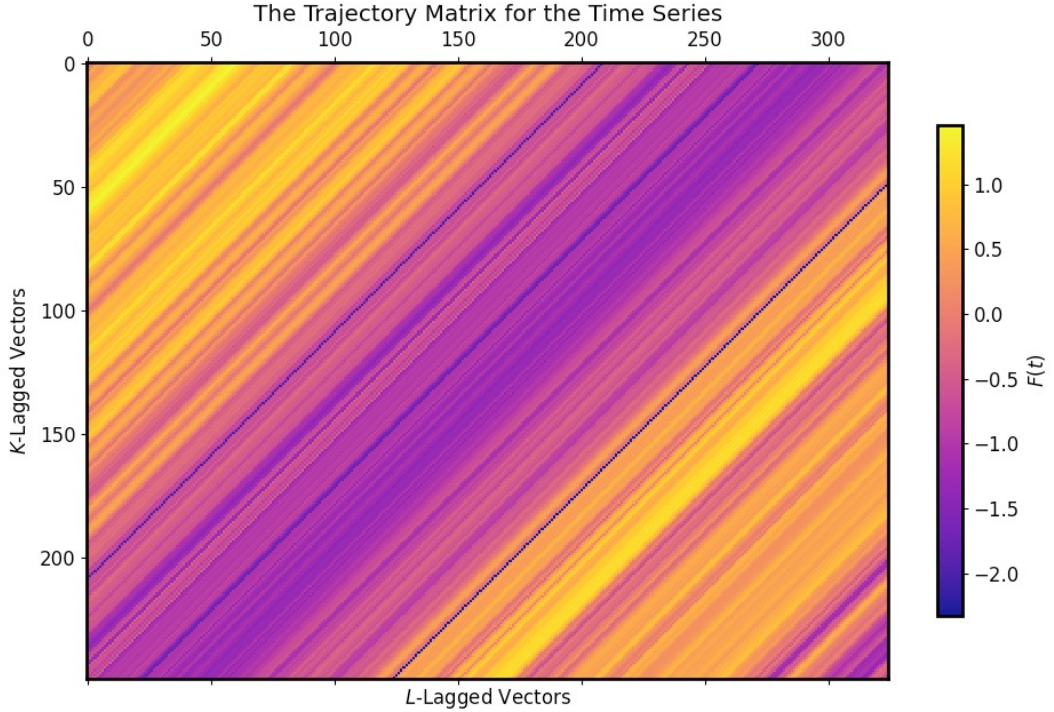
Citation:

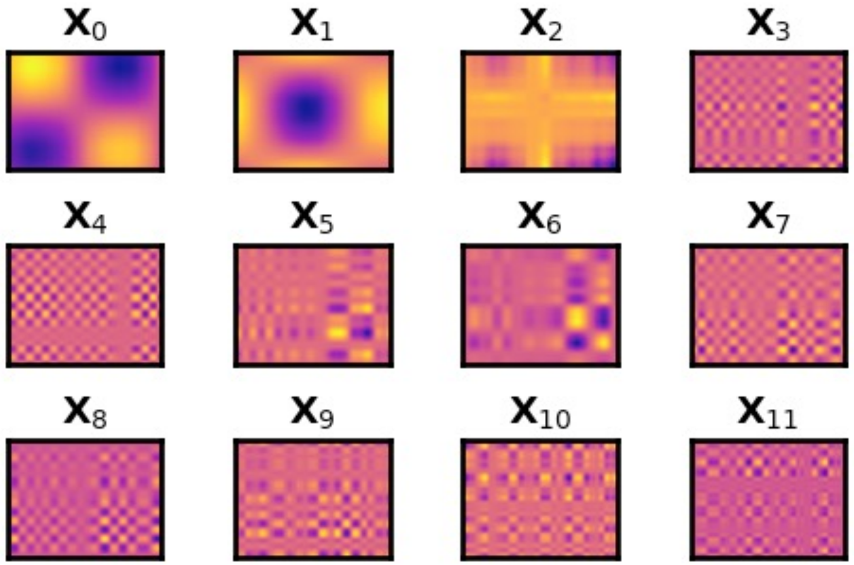
Abstract We apply singular spectral analysis (SSA) to series of monthly mean values of surface air temperatures *T*, International sunspot number (ISSN), and polar faculae PF (1850–2017 for *T* and ISSN). The efficiency of the SSA algorithm that we use has been regularly improved. For the *T*, ISSN, and PF series, the SSA eigenvalues and first components are shown with their Fourier spectrum. Components of *T*, ISSN, or PF share similar periods. Most are found in solar activity. The ~22- and ~11-year components are modulated and drift in phase, reflecting slight differences in spectra. On the shorter-period side, components at ~9, ~5.5, and ~4.7 years are in good agreement. They have been identified in solar activity. The 60-year component is prominent in *T*. It is not immediately apparent in ISSN but can be extracted with an appropriate choice of SSA window. Other types of data allow one to explore longer periods and confirm climatic variations at ~60, ~35, and ~22 years and at 50–150 and 200–500 years. When we consider a longer ISSN series starting in 1700 and recalculate the SSA first component, the trends of solar activity and temperature over the time span from 1850 to 2017 are very similar, with slower rise before 1900 and after the late 1900s, separating a faster rise in much of the twentieth century. These trends, extracted over only 150 years, could be parts of longer, multicentennial changes in solar activity. Much of the variability of surface temperatures could be linked to the Sun.

Applying SSA to POLA-4 [0:574]

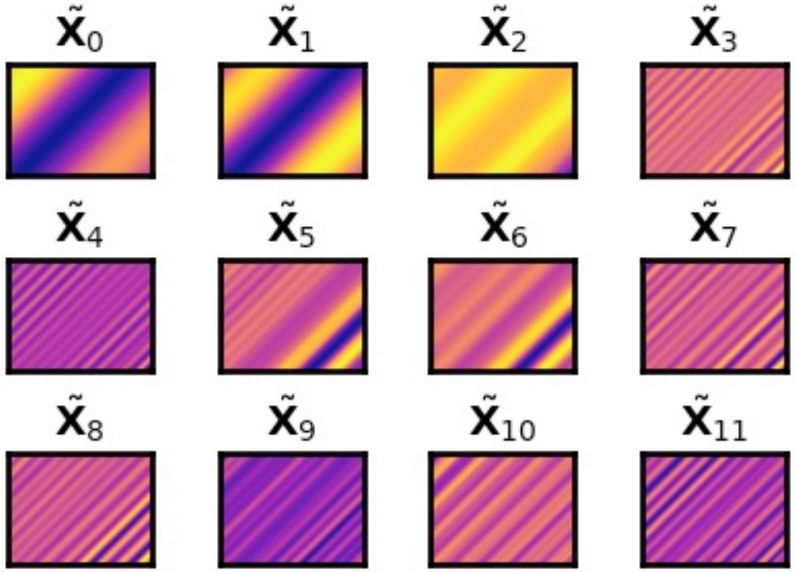
- Trajectory matrix (Hankel matrix) for L=250
- $X = U \times \Sigma \times V^{T.}$ $\rightarrow \sum_i U_i, \sigma_i, V_i$ $\rightarrow \sum_i X_i$ $\rightarrow \sum_i \tilde{X}_i$

- TS $\rightarrow \sum_i \tilde{F}_i$

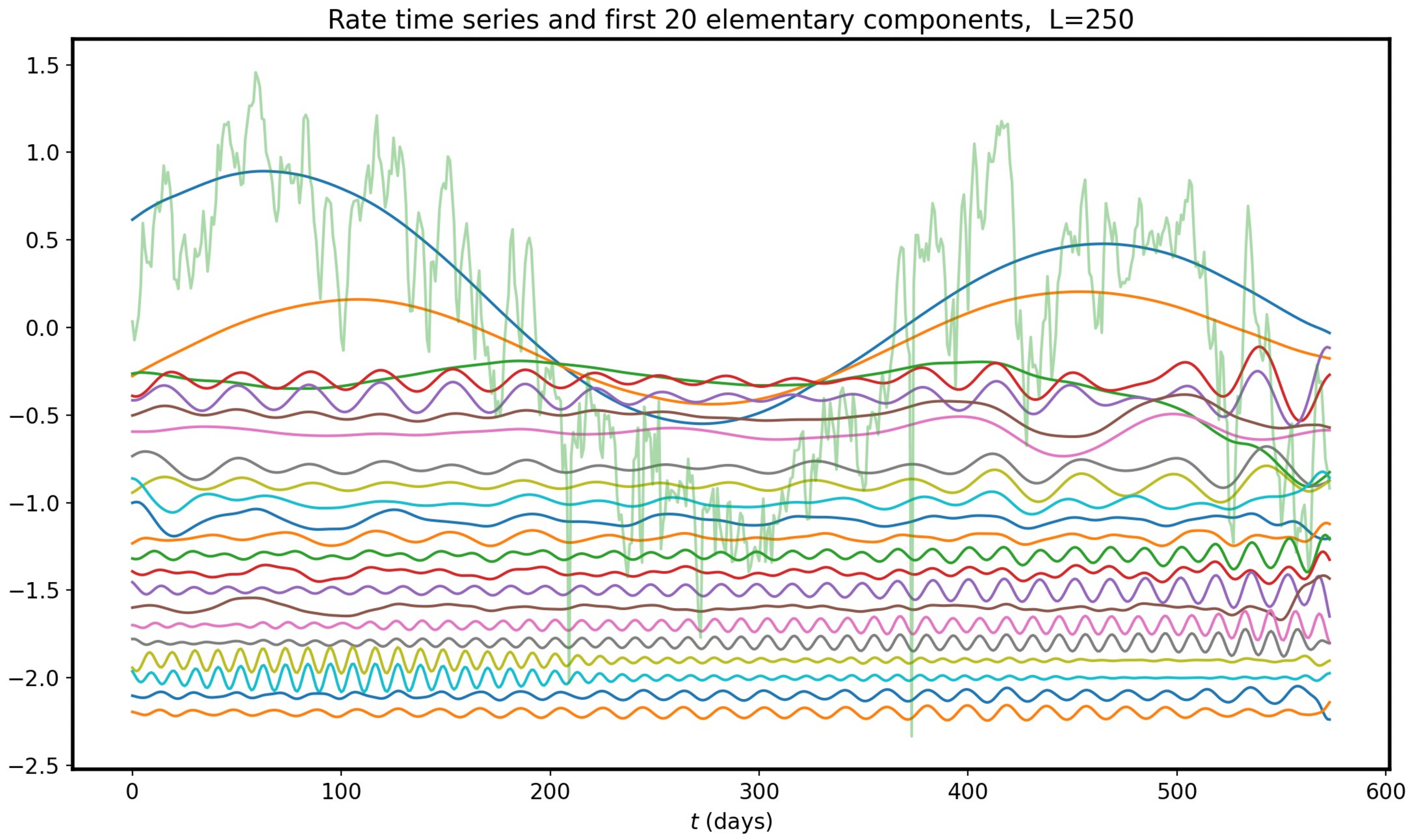




→

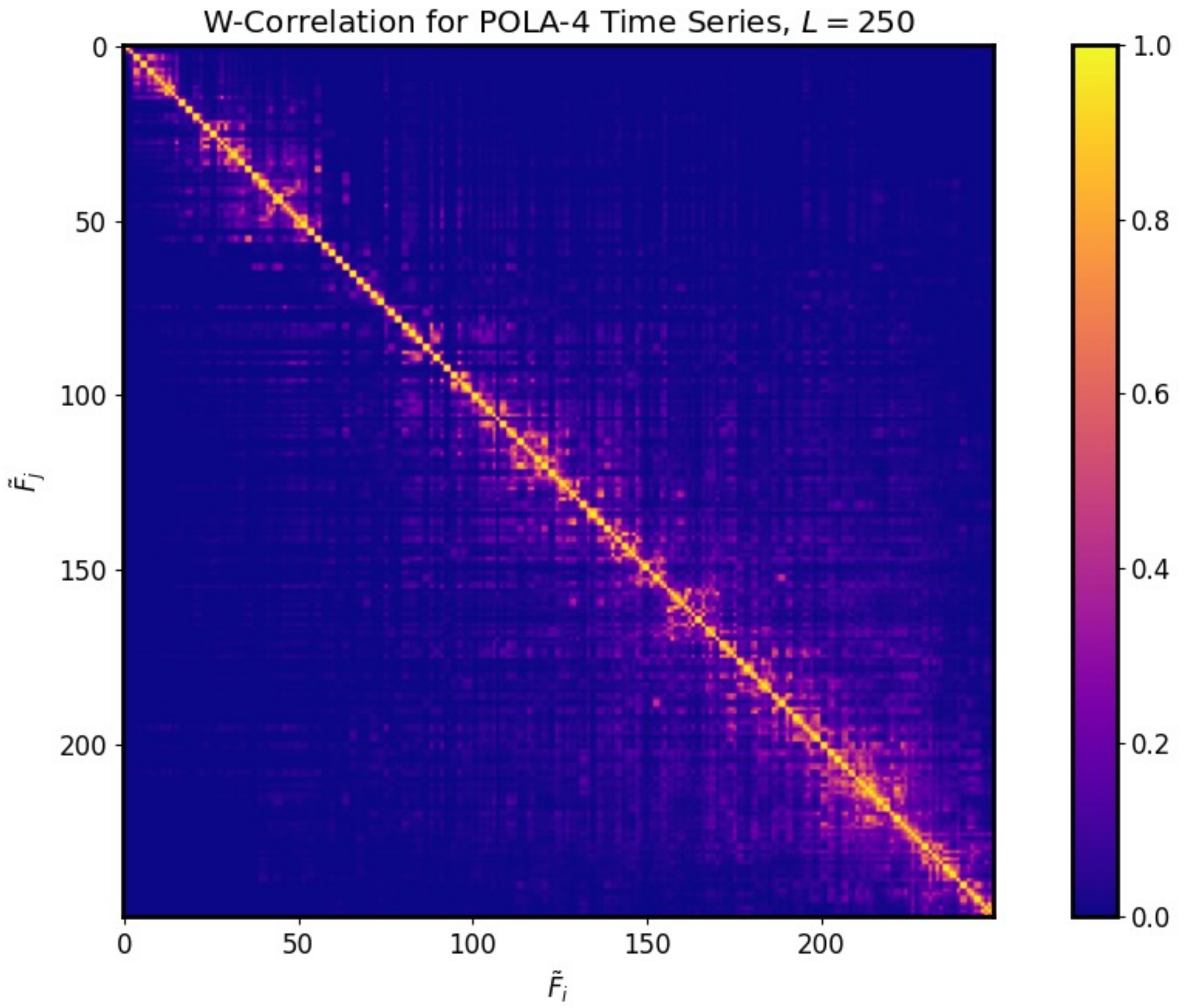


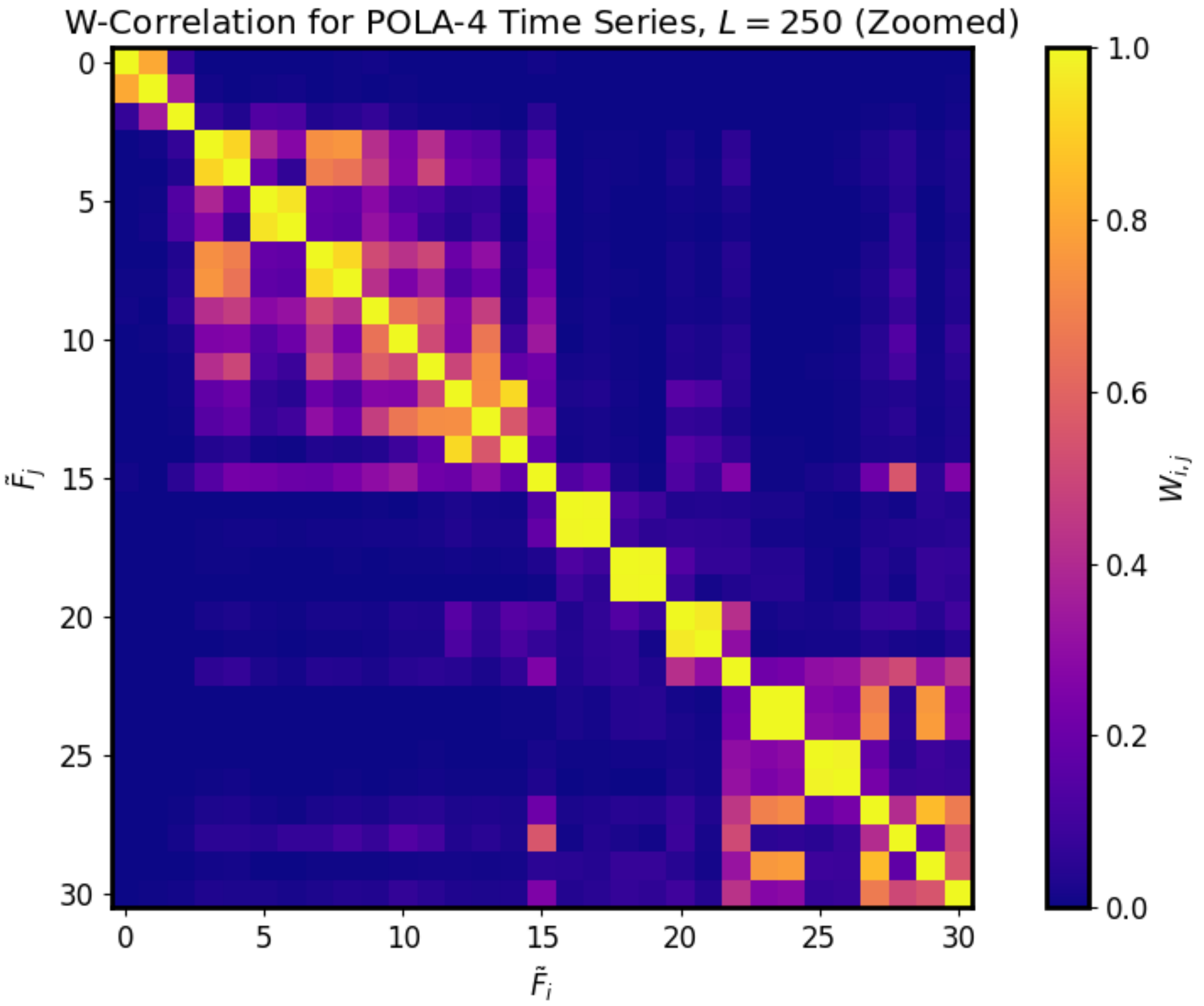
POLA-4 and its $\tilde{F}_i$ components [0:21]



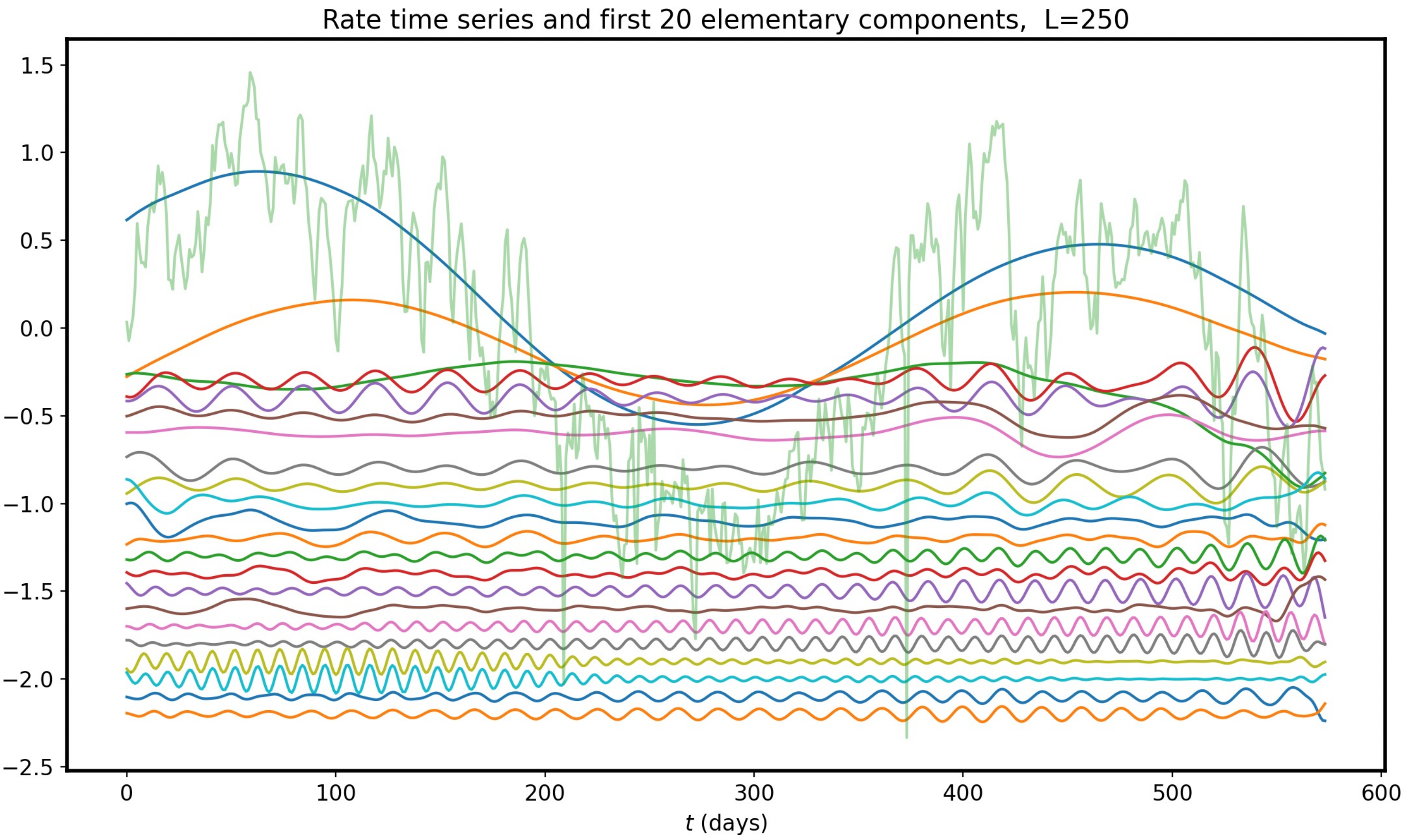
SSA Matrice di correlazione pesata delle F˜$_i$

$$W_{i,j} = \frac{(\tilde{F_i}, \tilde{F_j})_w}{\|\tilde{F_i}\|_w \|\tilde{F_j}\|_w}$$



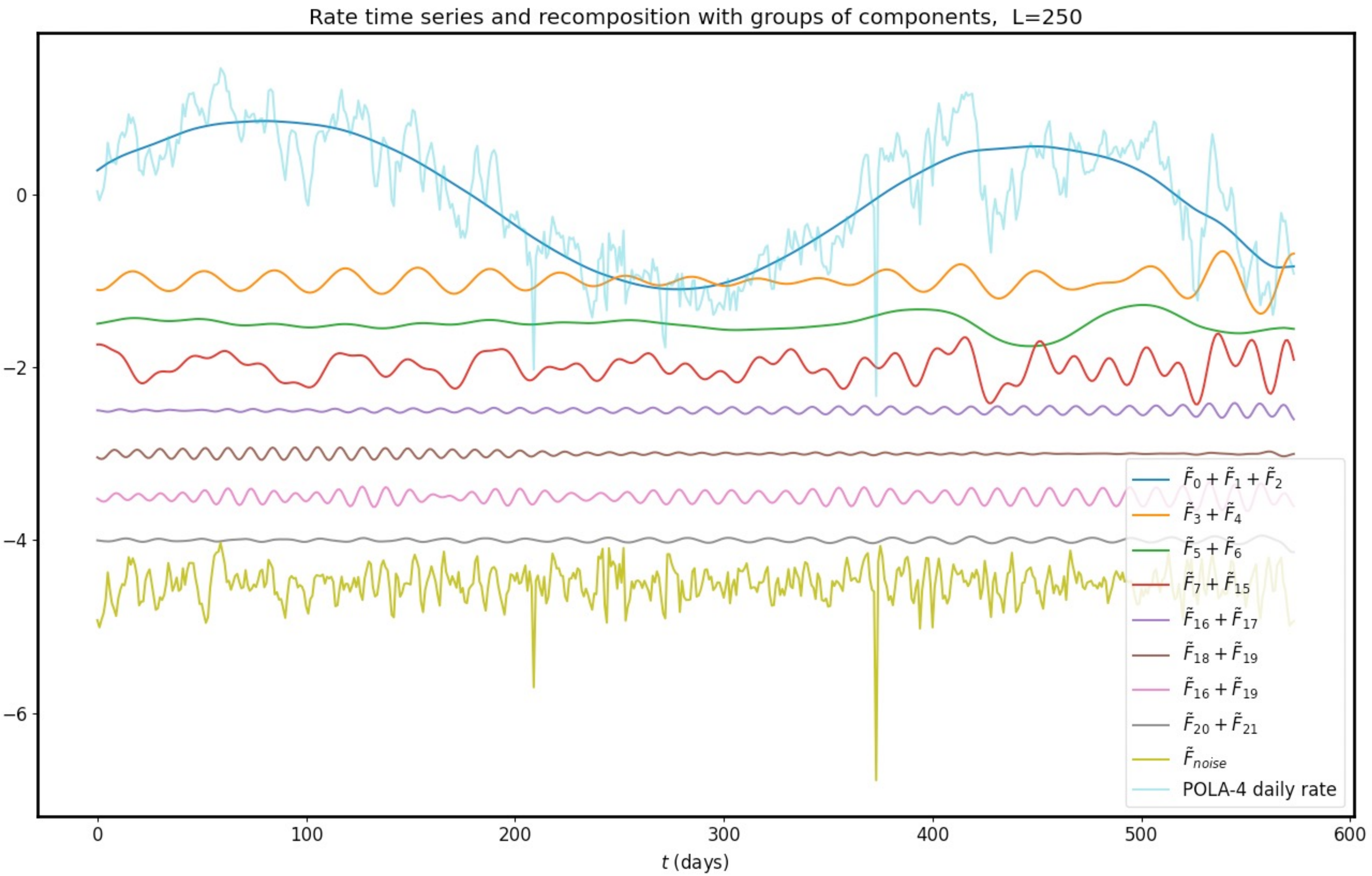


POLA-4 components [0:21] and FFT analysis

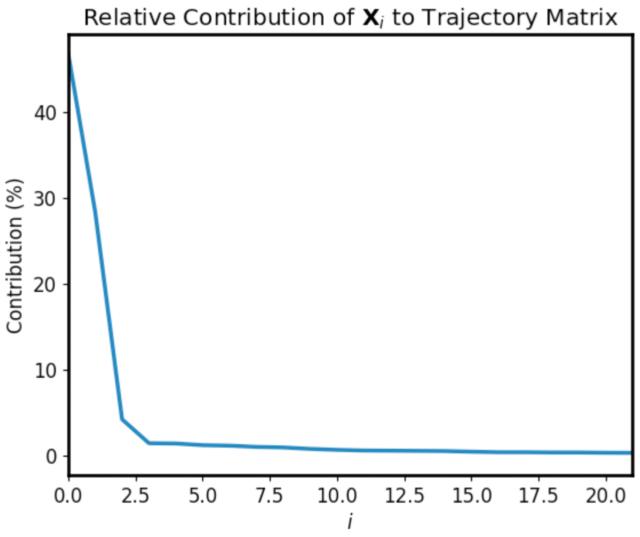


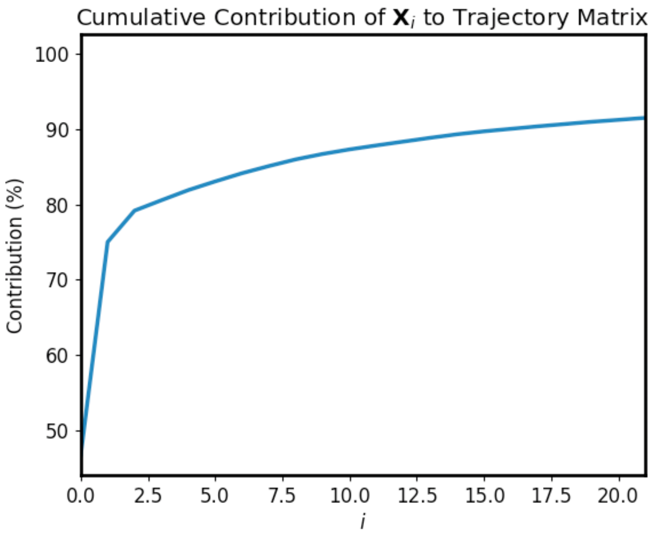
- F_0 365
- F_1 182.5/365
- F_2 365/182.5
- F_3 20.3
- F_4 20.3
- F_5 73.0/91.2
- F_6 73.0
- F_7 28.1
- F_8 28.1/26.1
- F_9 45.6/121.7/20.3
- F_{10} 40.6/45.6
- F_{11} 22.8
- F_{12} 10.7
- F_{13} 40.6/10.7
- F_{14} 10.7
- F_{15} 52.1/40.6
- F_{16} 8.1
- F_{17} 8.1
- F_{18} 6.9
- F_{19} 6.9
- F_{20} 12.2/12.6
- F_{21} 12.2

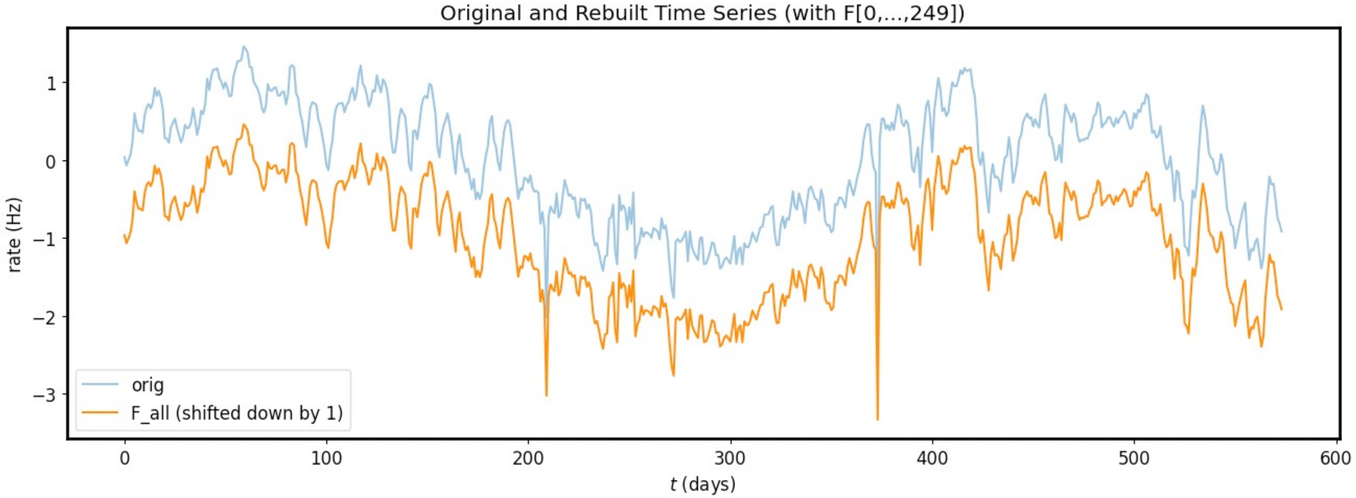
SSA POLA-4: grouping elementary component

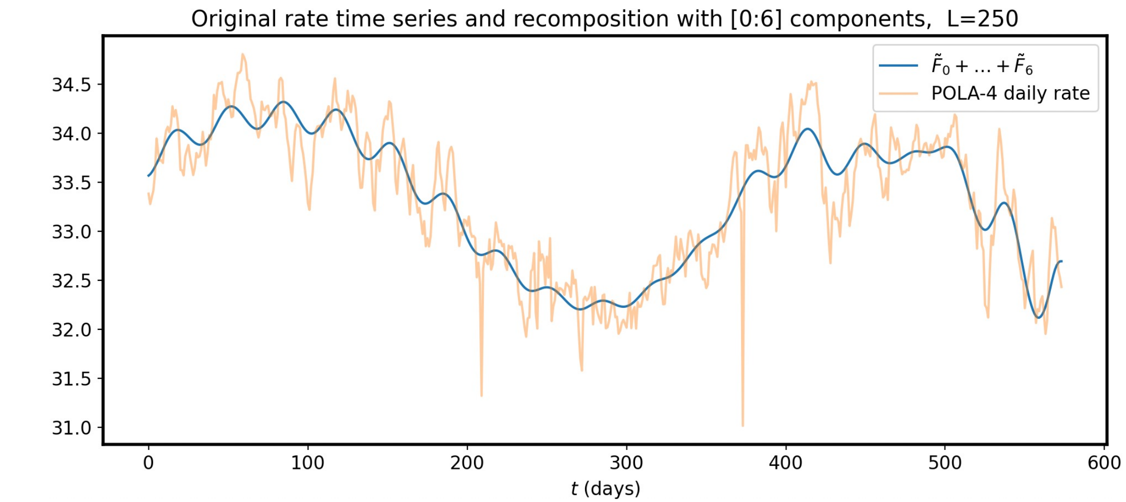


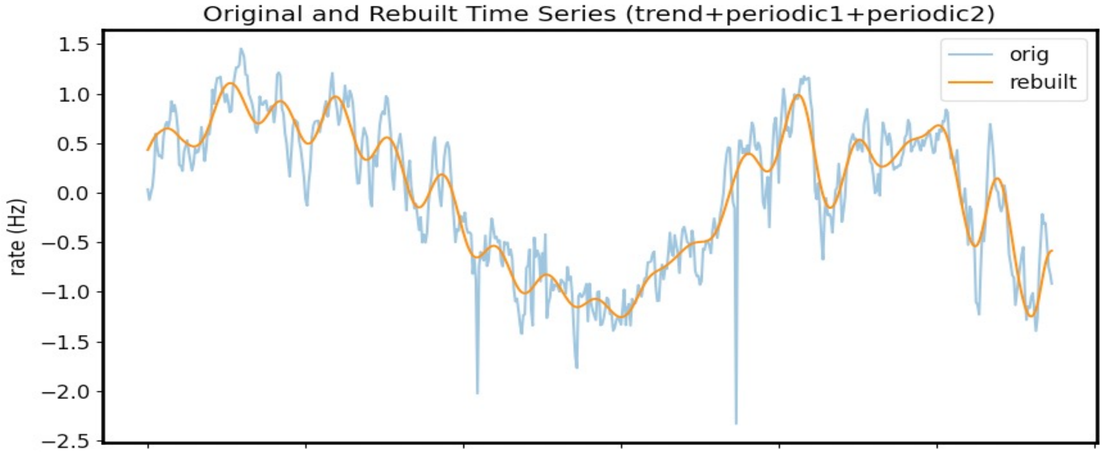
Esempi di diversi livelli di ricostruzione

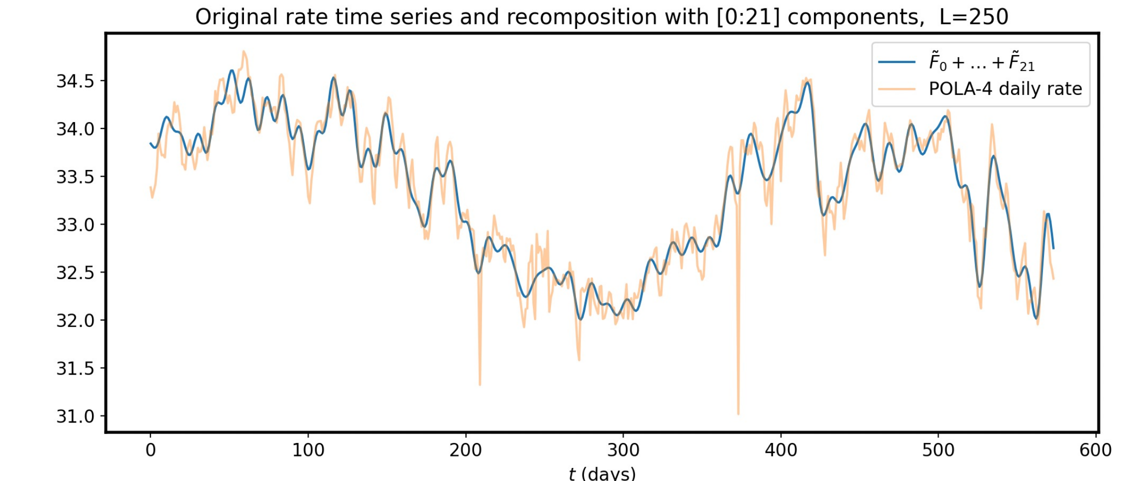




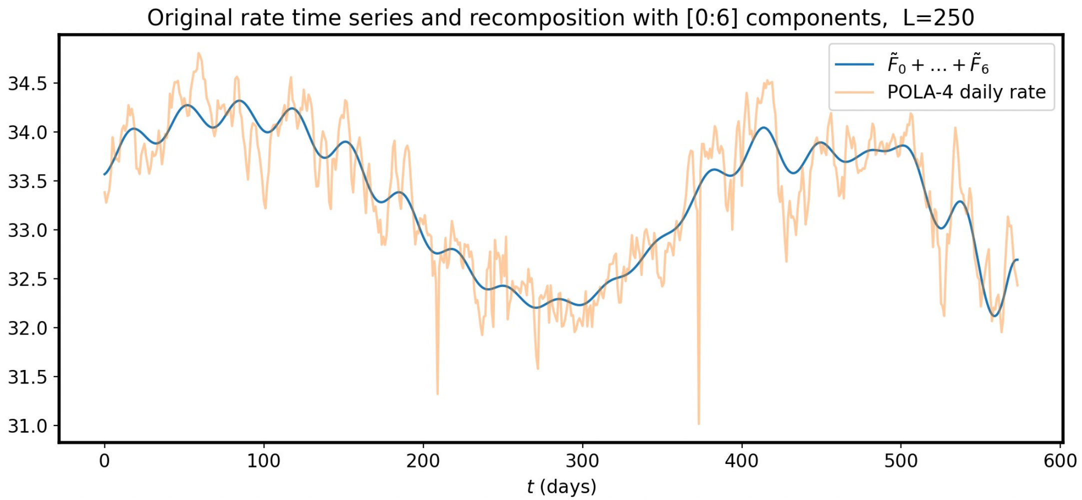


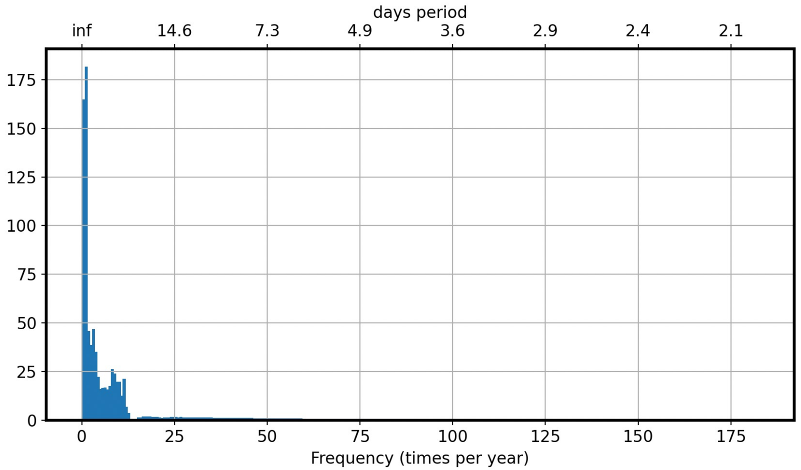




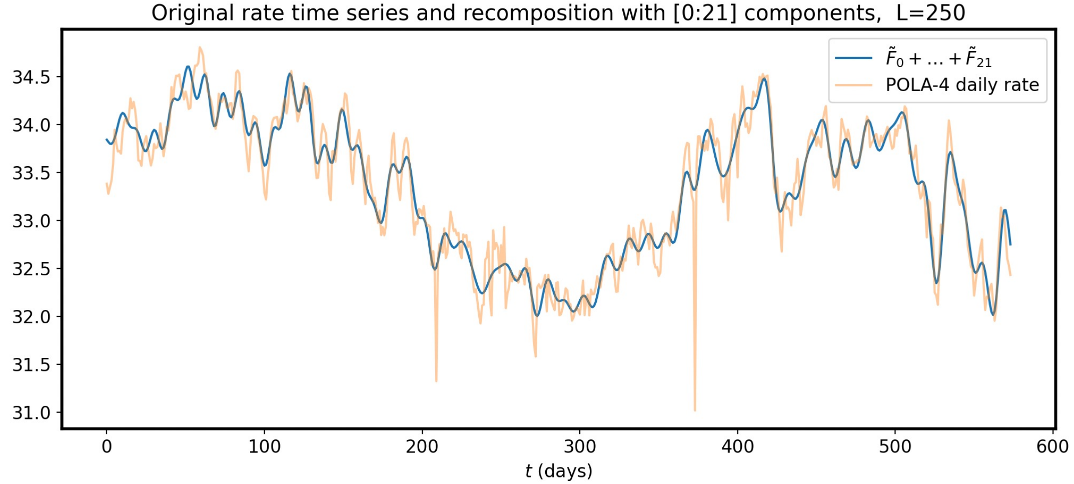


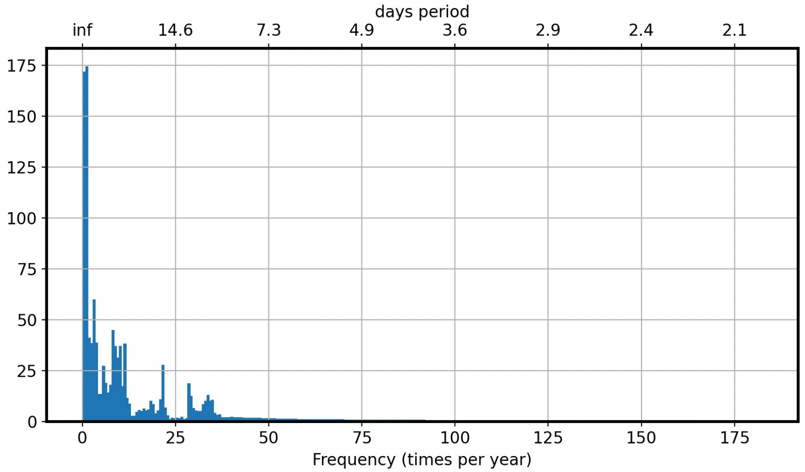
POLA-4 recomposition with [0:6] and [0:21] SSA elements





cycles/year	days	amplitude
2	182.5	181.7
1	365.0	164.8
5	73.0	46.9
3	121.7	45.8
4	91.2	38.8
6	60.8	35.3
13	28.1	26.2
14	26.1	24.0





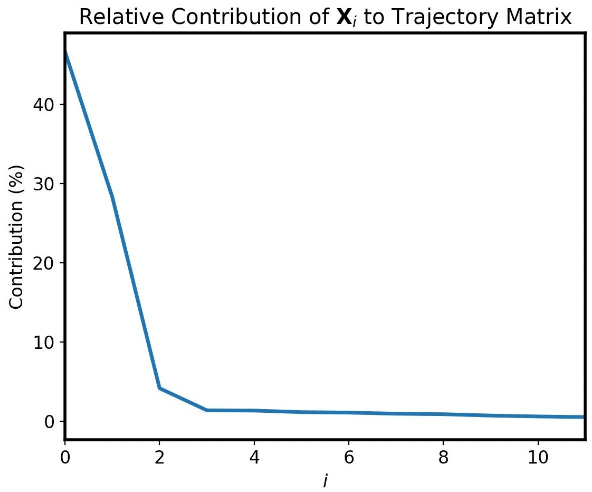
cycles/year	days	amplitude
2	182.5	174.6
1	365.0	172.0
5	73.0	60.0
13	28.1	45.1
3	121.7	41.2
6	60.8	38.8
4	91.2	38.6
18	20.3	38.3

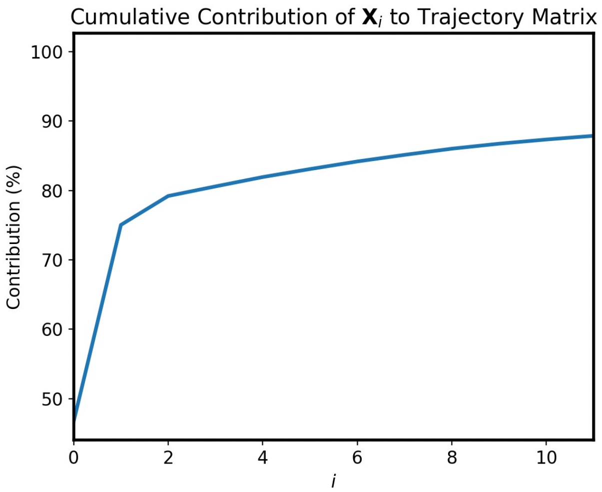
Ricostruzione per gruppi

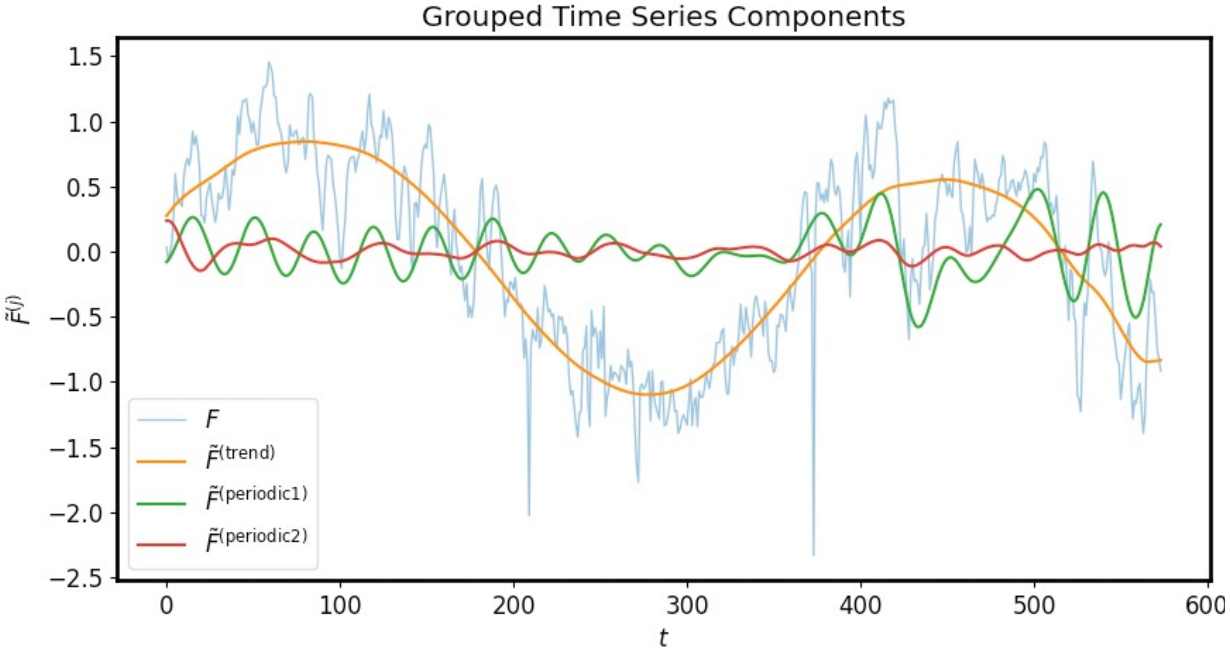
$F_{trend} \leftarrow [0,1,2]$

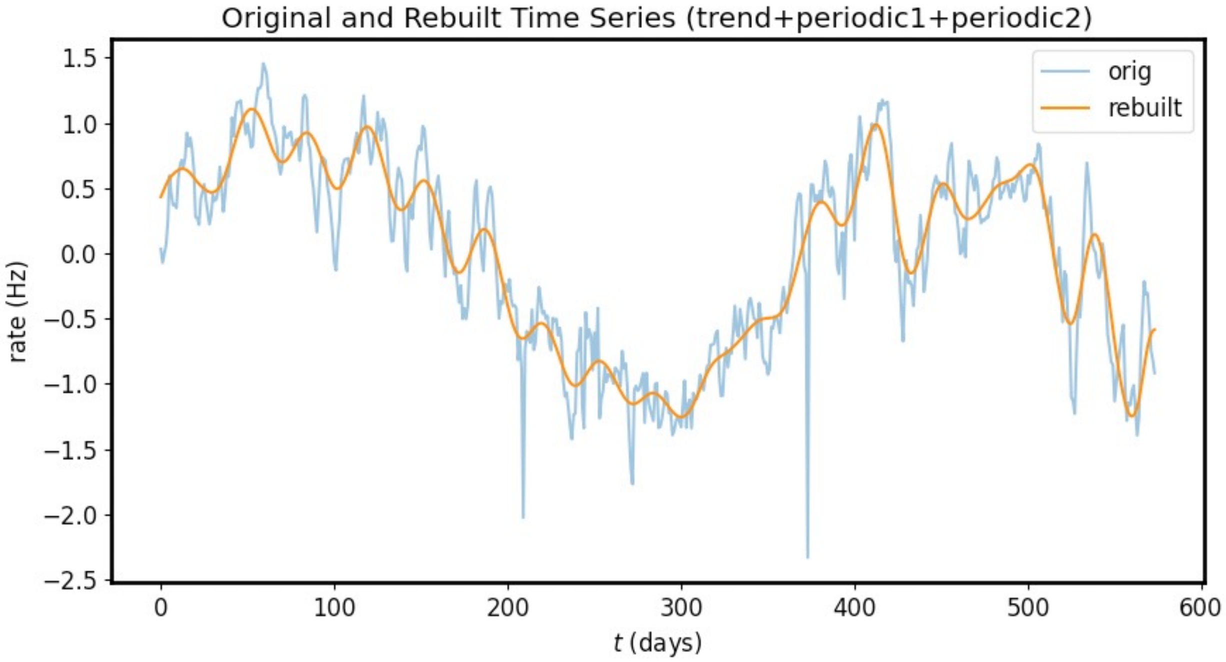
$F_{periodic1} \leftarrow [3,\ldots,8]$

$F_{periodic2} \leftarrow [9,10]$

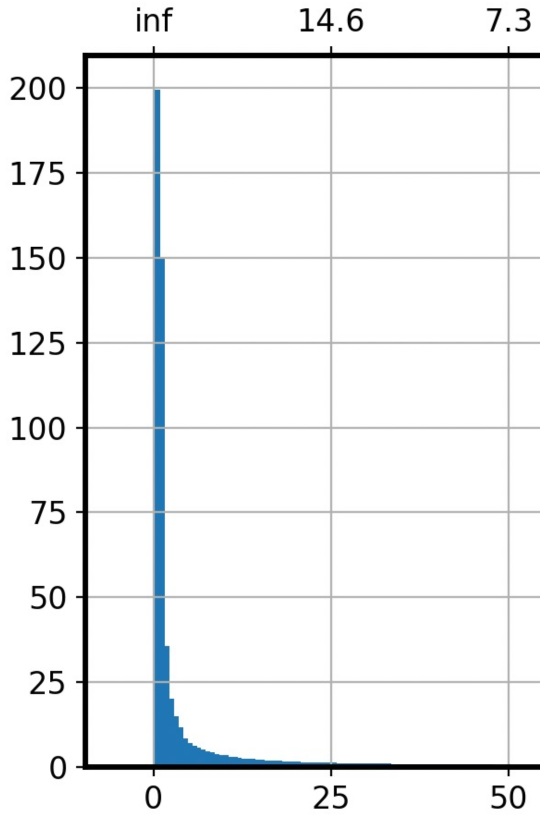






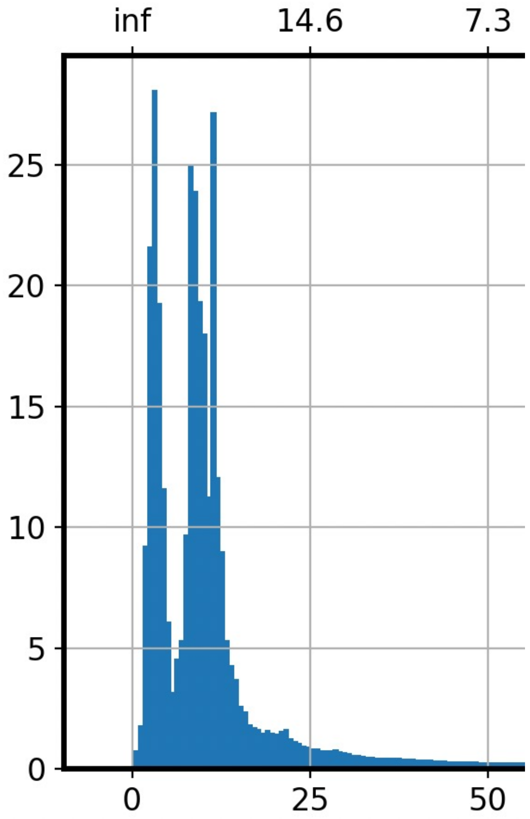


POLA-4: FFT of the 3 components and the rebuilt TS



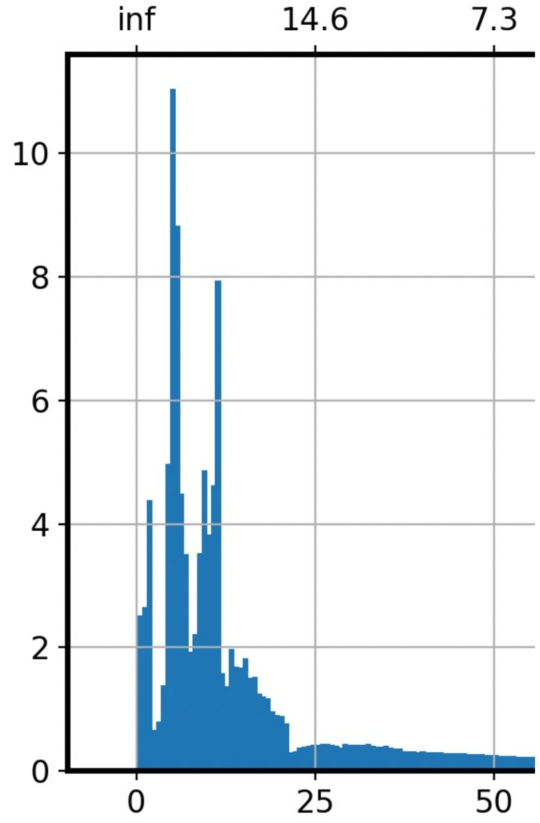
F_trend FFT

cycles/year	days	amplitude
1	365.0	199.6
2	182.5	150.0
3	121.7	35.7
4	91.2	20.2
5	73.0	14.9
6	60.8	11.6
7	52.1	8.4
8	45.6	7.0



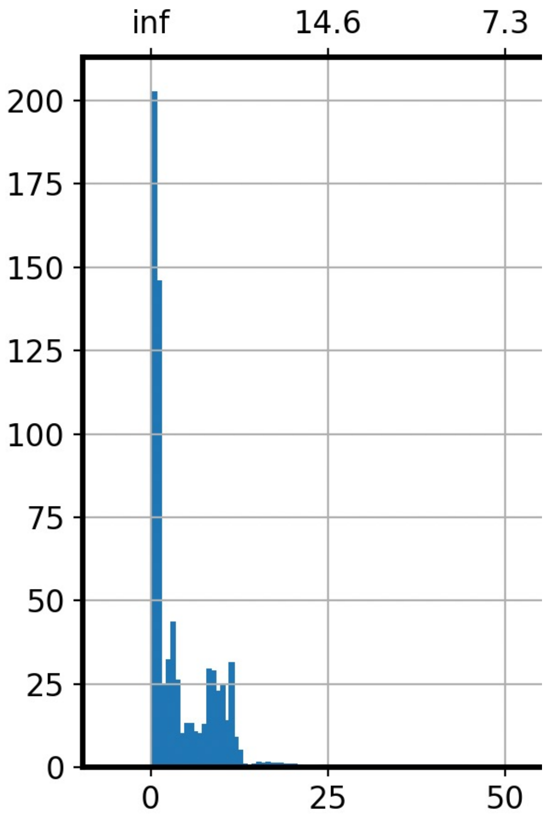
F_period1 FFT

cycles/year	days	amplitude
5	73.0	28.1
18	20.3	27.2
13	28.1	25.0
14	26.1	23.9
4	91.2	21.6
15	24.3	19.3
6	60.8	19.3
16	22.8	18.0



F_period2 FFT

cycles/year	days	amplitude
8	45.6	11.1
9	40.6	8.8
18	20.3	7.9
7	52.1	5.0
15	24.3	4.9
17	21.5	4.6
10	36.5	4.5
3	121.7	4.4



F_rebuilt FFT

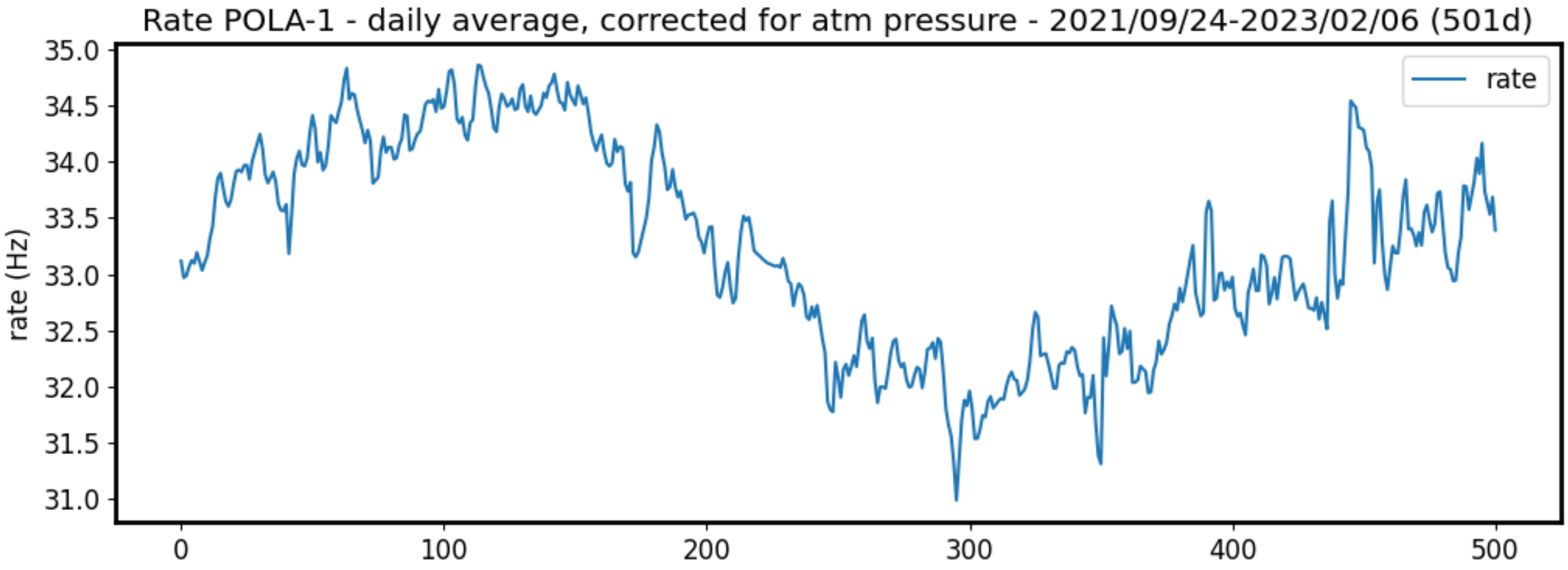
cycles/year	days	amplitude
1	365.0	202.9
2	182.5	146.1
5	73.0	43.7
4	91.2	32.3
18	20.3	31.5
13	28.1	29.5
14	26.1	28.9
6	60.8	26.2

Considerazioni relative a SSA

- Bisogna valutare quali componenti di una particolare time series possono essere separati
- Bisogna trovare la window length L ottimale, per avere la migliore risoluzione:
  - L grande migliora la risoluzione delle componenti elementari e quindi la loro separabilità
  - L determina la maggiore periodicità estraibile tramite SSA
- SSA è più adattabile alla particolare time series rispetto a FFT
  - I componenti elementari non sono semplici funzioni trigonometriche
  - La scelta dei parametri e i principi di raggruppamento dipendono dalla ts

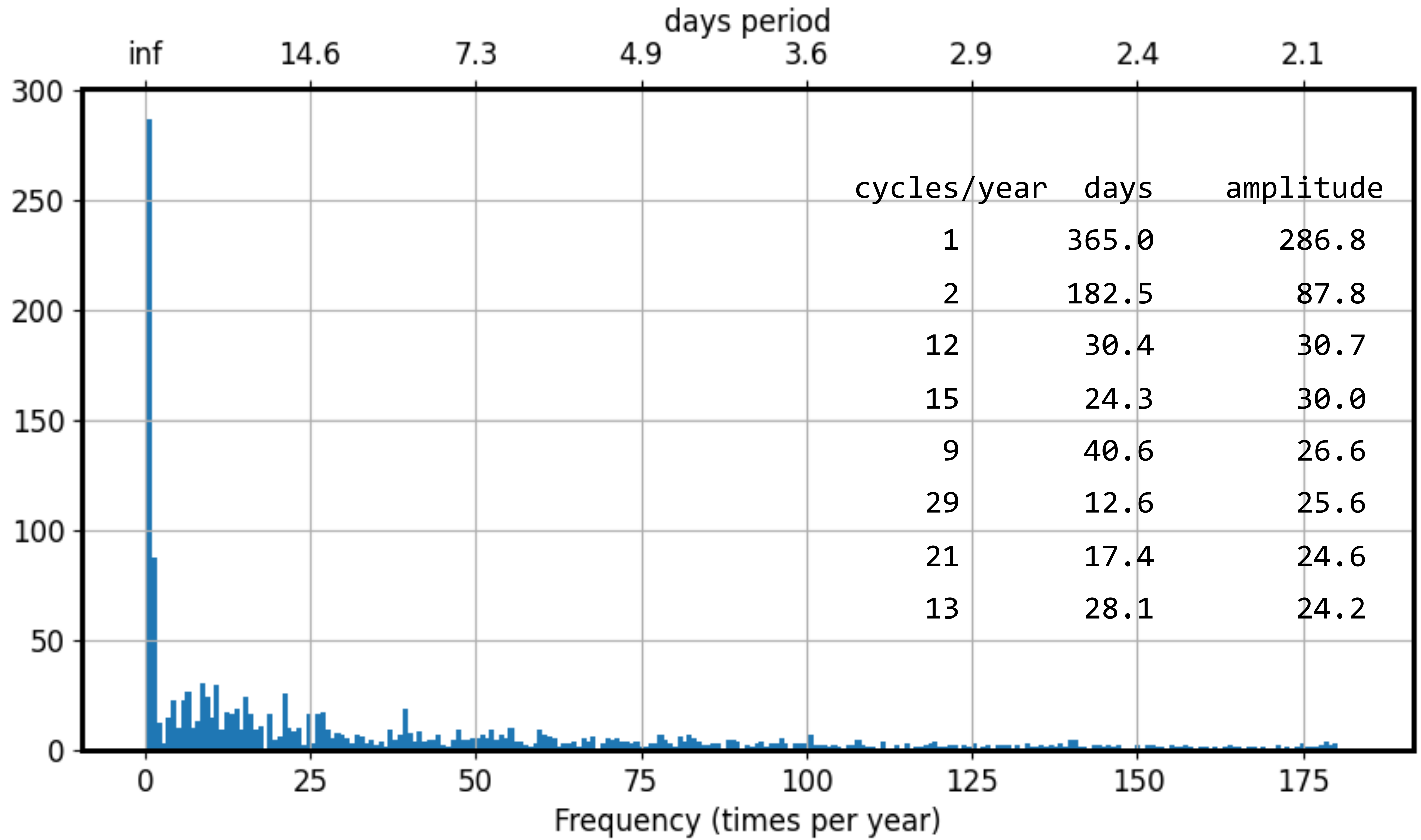
POLA-1 and POLA-3

POLA-1

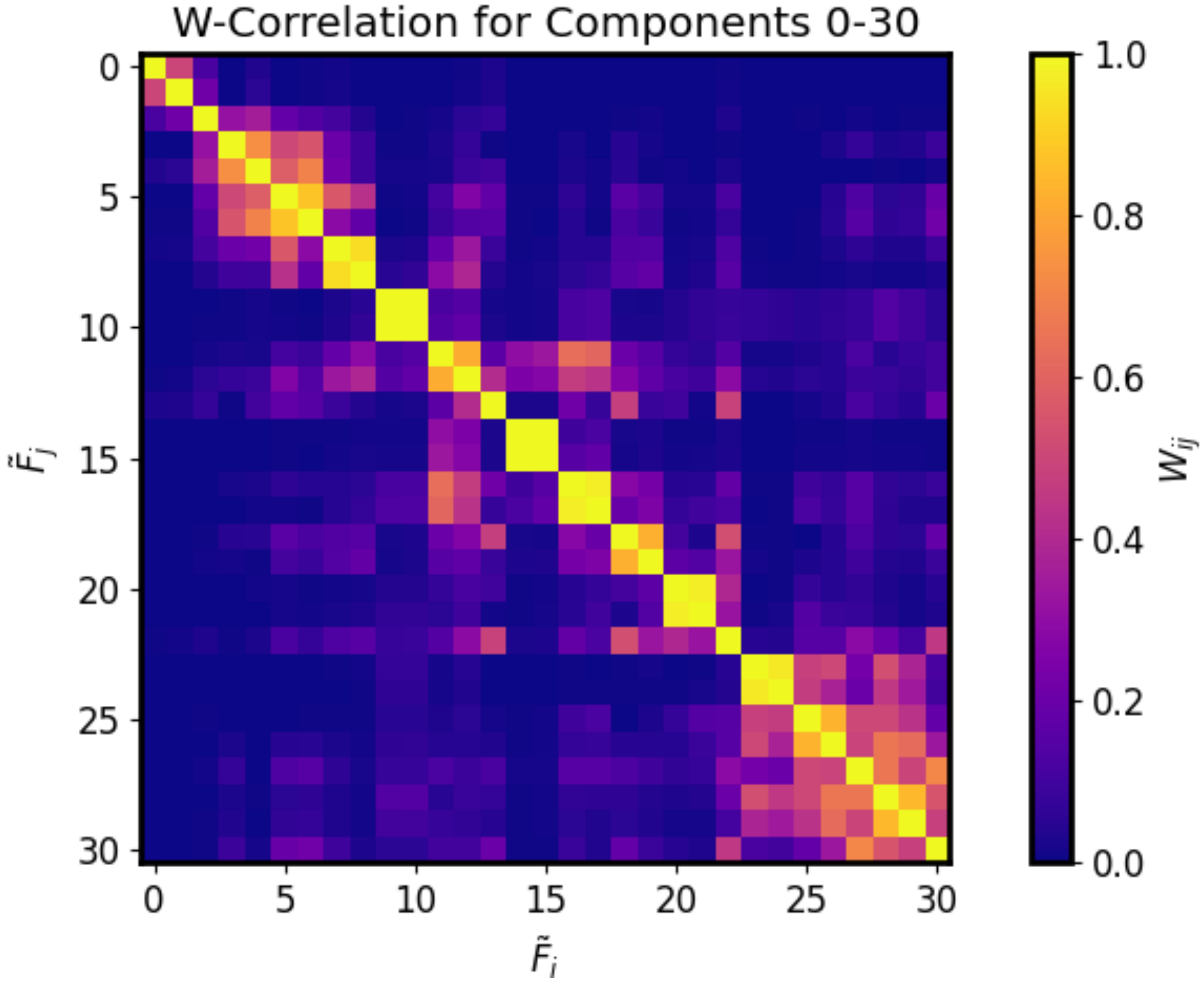


Rate POLA-1 - daily average, corrected for atm pressure - 2021/09/24-2023/02/06 (501d)
rate (Hz)
rate
35.0
34.5
34.0
33.5
33.0
32.5
32.0
31.5
31.0
0
100
200
300
400
500

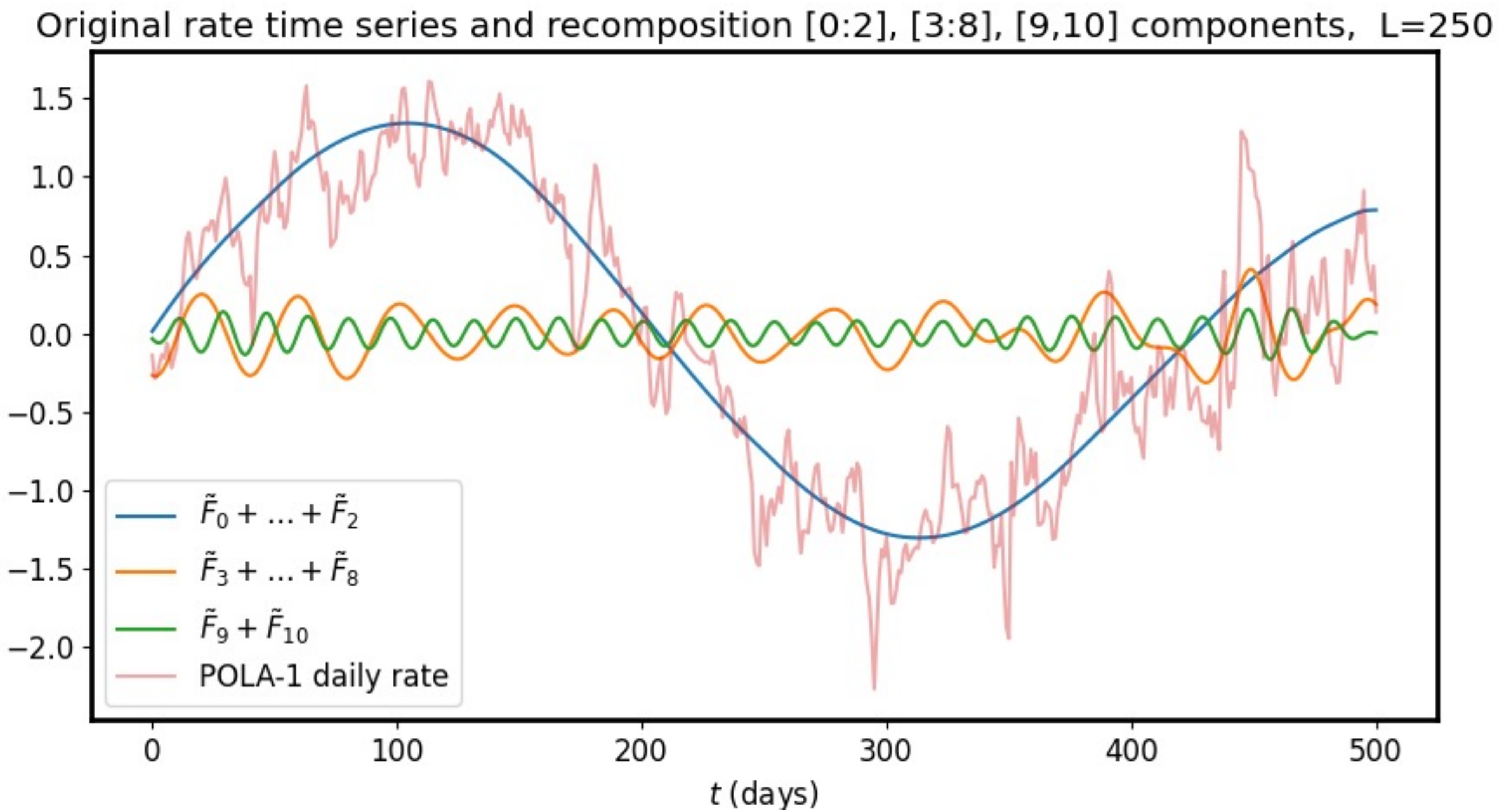
Daily rate POLA-1 FFT – 2021/09/24-2023/02/06 (501d)



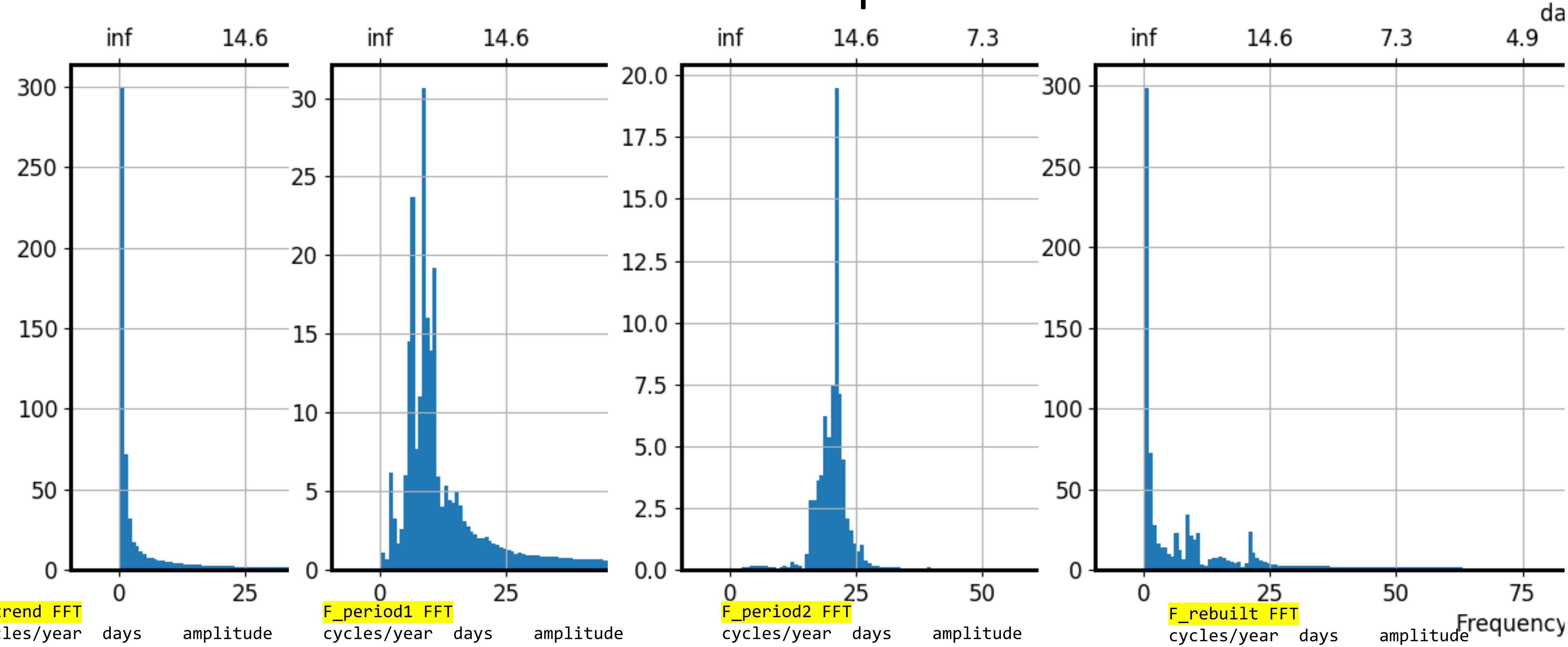
POLA-1 W matrix



Trying with the same POLA-4 groups



POLA-1: FFT of the 3 components



F_trend FFT

cycles/year	days	amplitude
1	365.0	298.9
2	182.5	72.1
3	121.7	31.7
4	91.2	17.3
5	73.0	14.3
6	60.8	11.4
7	52.1	9.4
8	45.6	7.5

F_period1 FFT

cycles/year	days	amplitude
12	30.4	30.6
9	40.6	23.7
15	24.3	19.2
13	28.1	16.1
8	45.6	14.5
14	26.1	13.9
11	33.2	11.0
10	36.5	7.6

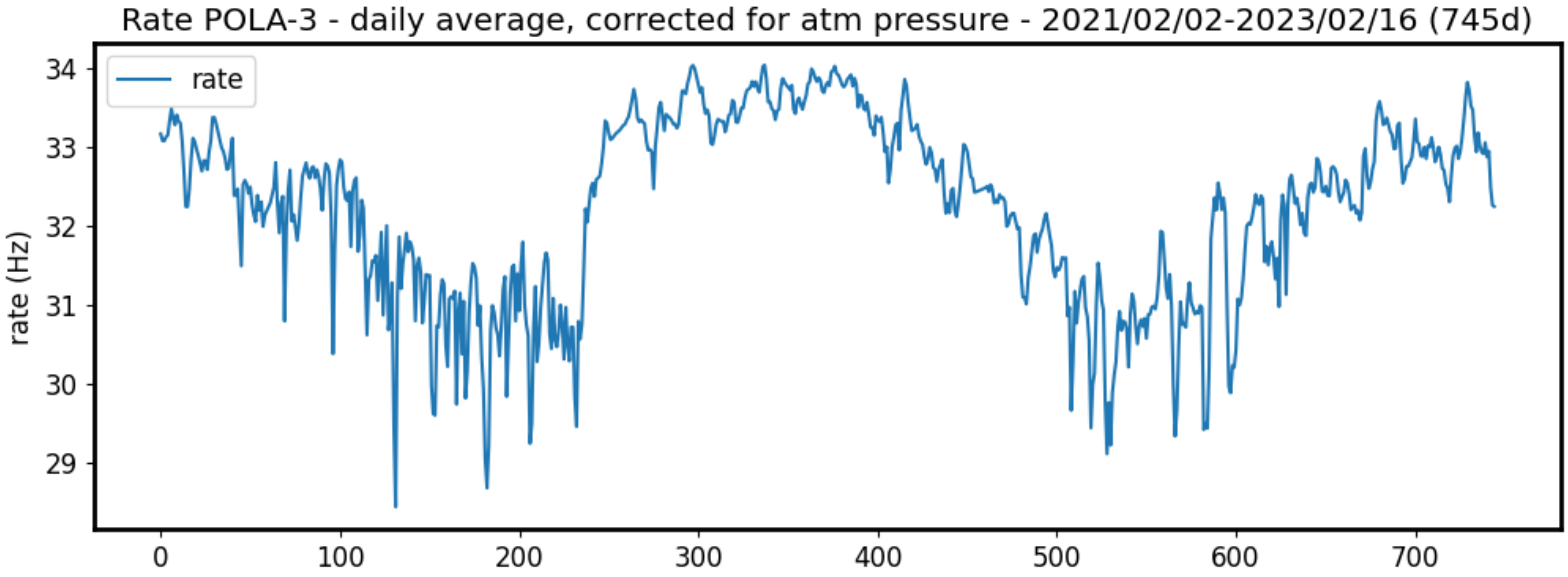
F_period2 FFT

cycles/year	days	amplitude
29	12.6	19.5
28	13.0	7.5
30	12.2	7.1
26	14.0	6.2
27	13.5	5.4
31	11.8	4.5
25	14.6	3.8
24	15.2	3.6

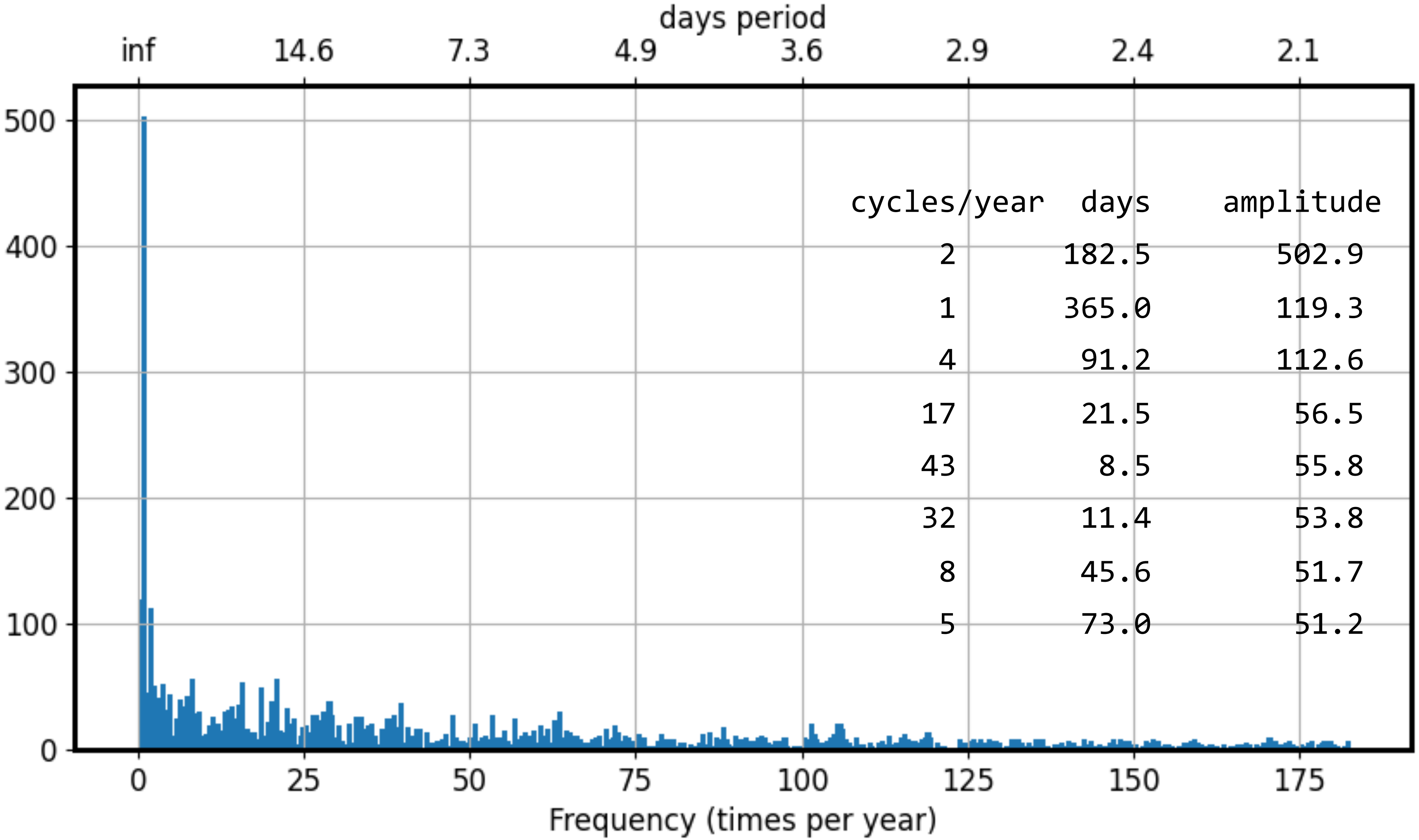
F_rebuilt FFT

cycles/year	days	amplitude
1	365.0	298.4
2	182.5	72.3
12	30.4	34.0
3	121.7	27.4
29	12.6	23.8
15	24.3	23.0
9	40.6	23.0
13	28.1	21.0

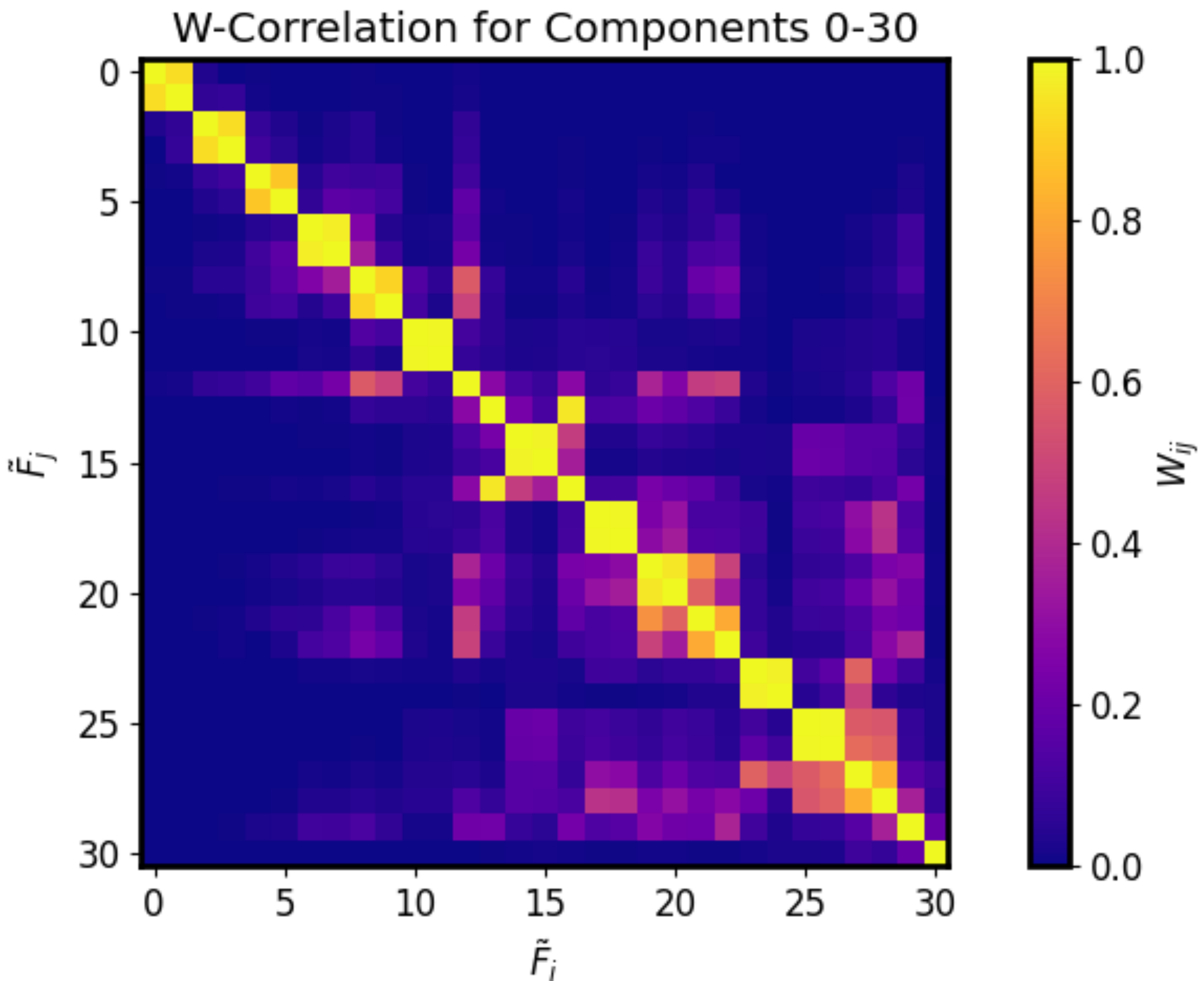
POLA-3

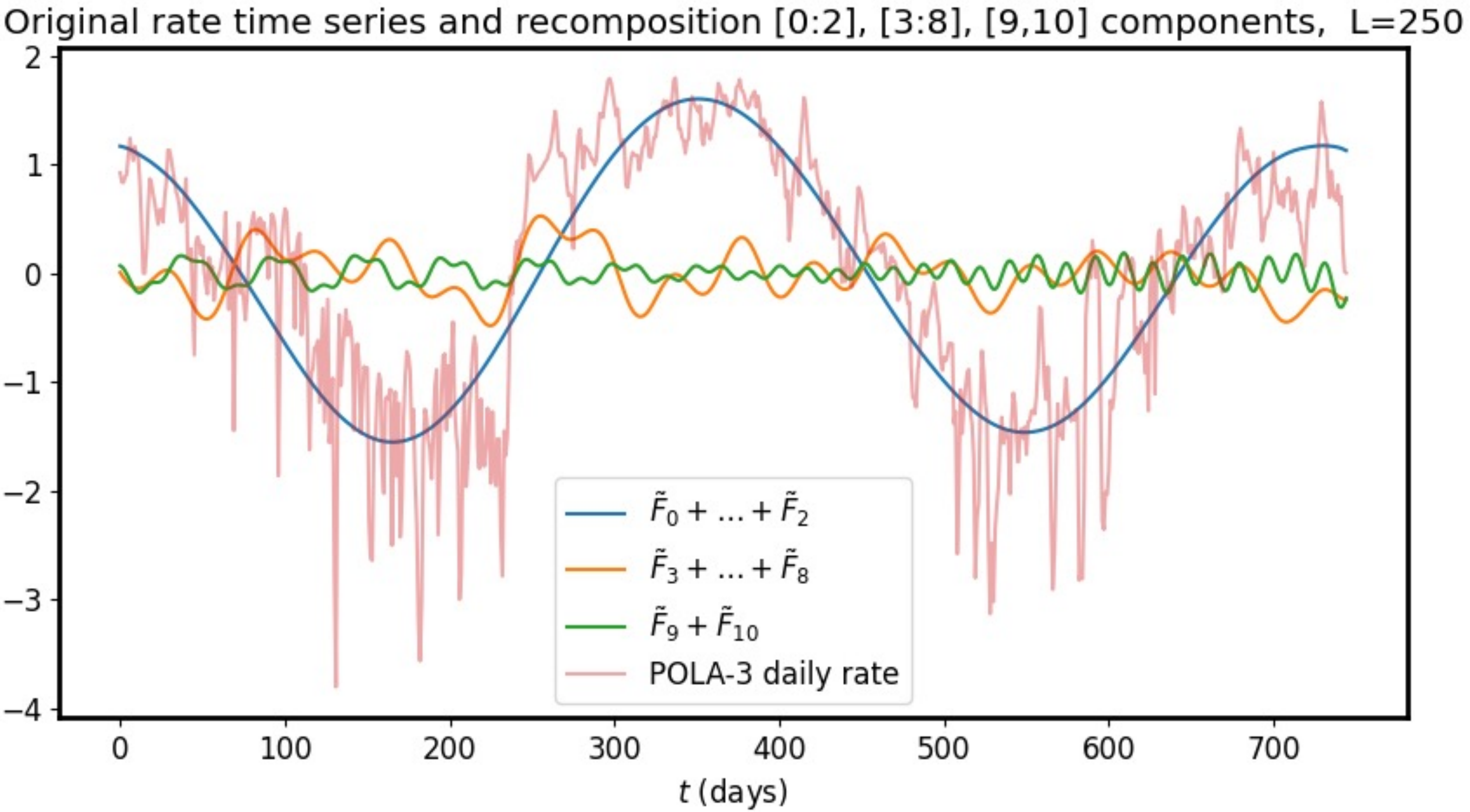

Rate POLA-3 - daily average, corrected for atm pressure - 2021/02/02-2023/02/16 (745d)
rate
rate (Hz)
34
33
32
31
30
29
0
100
200
300
400
500
600
700

Daily rate POLA-3 FFT – 2021/02/02-2023/02/16 (745d)



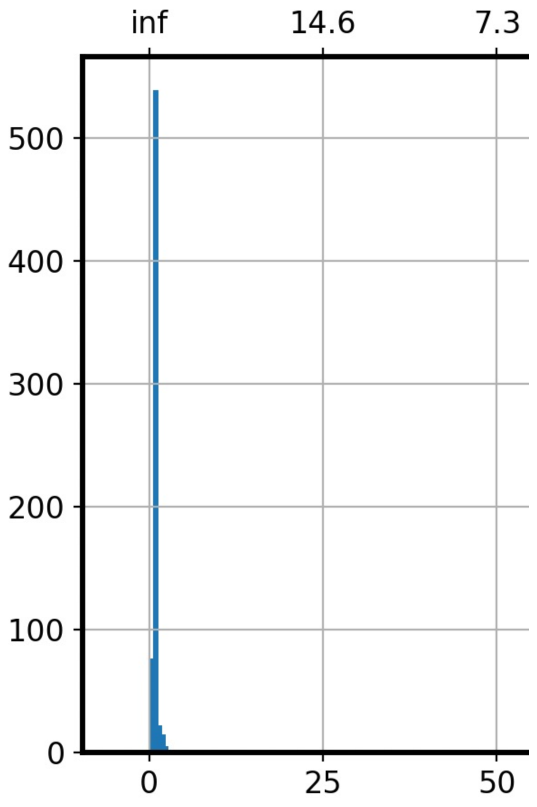
POLA-3: W-correlation matrix (zoomed)





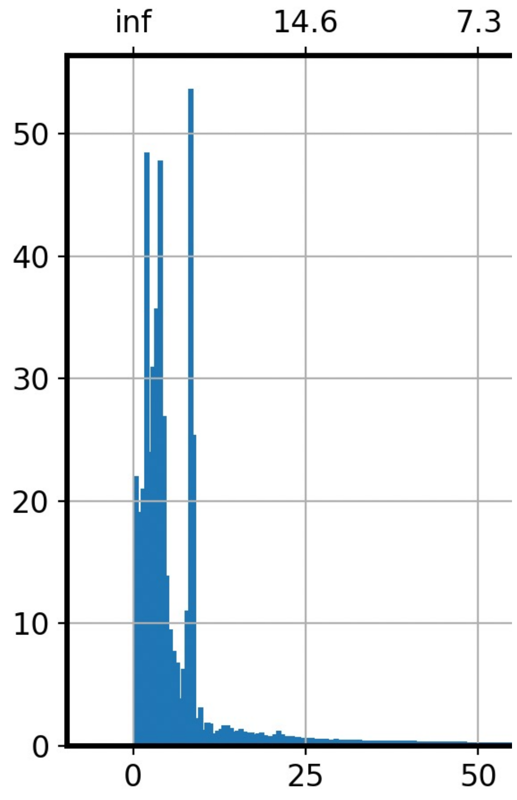
Original rate time series and recomposition [0:2], [3:8], [9,10] components, L=250
2
1
0
−1
−2
−3
−4
0
100
200
300
400
500
600
700
t (days)
$\tilde{F}_0 + ... + \tilde{F}_2$
$\tilde{F}_3 + ... + \tilde{F}_8$
$\tilde{F}_9 + \tilde{F}_{10}$
POLA-3 daily rate

POLA-3: FFT of the SSA components



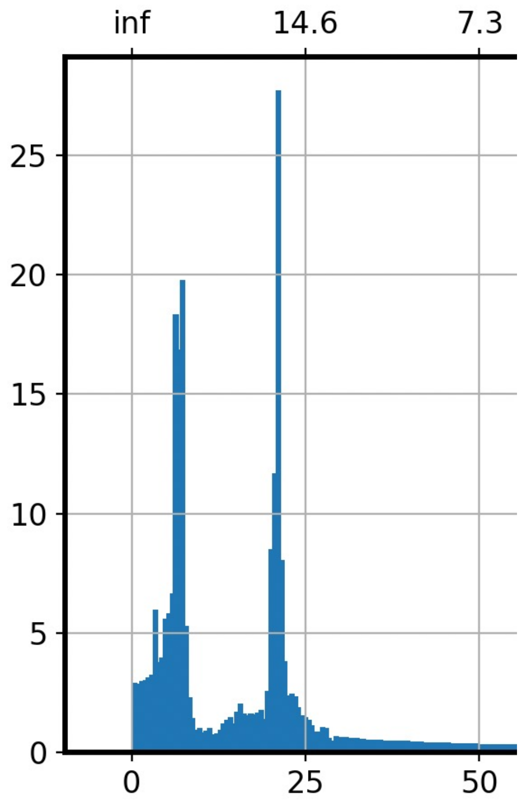
F_trend FFT

cycles/year	days	amplitude
2	182.5	539.2
1	365.0	76.4
3	121.7	22.2
4	91.2	14.8
5	73.0	4.9
8	45.6	1.2
9	40.6	1.1
11	33.2	1.0



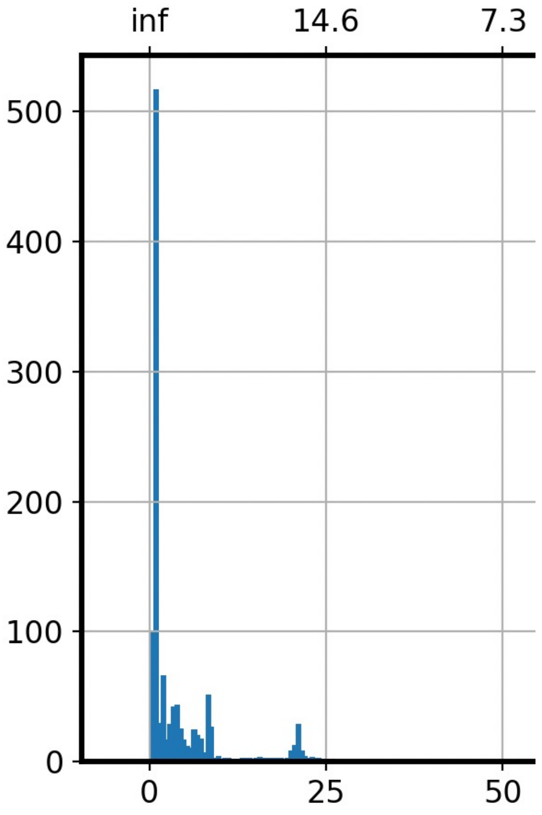
F_period1 FFT

cycles/year	days	amplitude
17	21.5	53.7
4	91.2	48.5
8	45.6	47.8
7	52.1	35.7
6	60.8	31.0
9	40.6	27.0
18	20.3	25.4
5	73.0	24.1



F_period2 FFT

cycles/year	days	amplitude
43	8.5	27.7
15	24.3	19.8
13	28.1	18.3
14	26.1	16.9
42	8.7	11.7
41	8.9	8.5
44	8.3	8.1
12	30.4	6.7

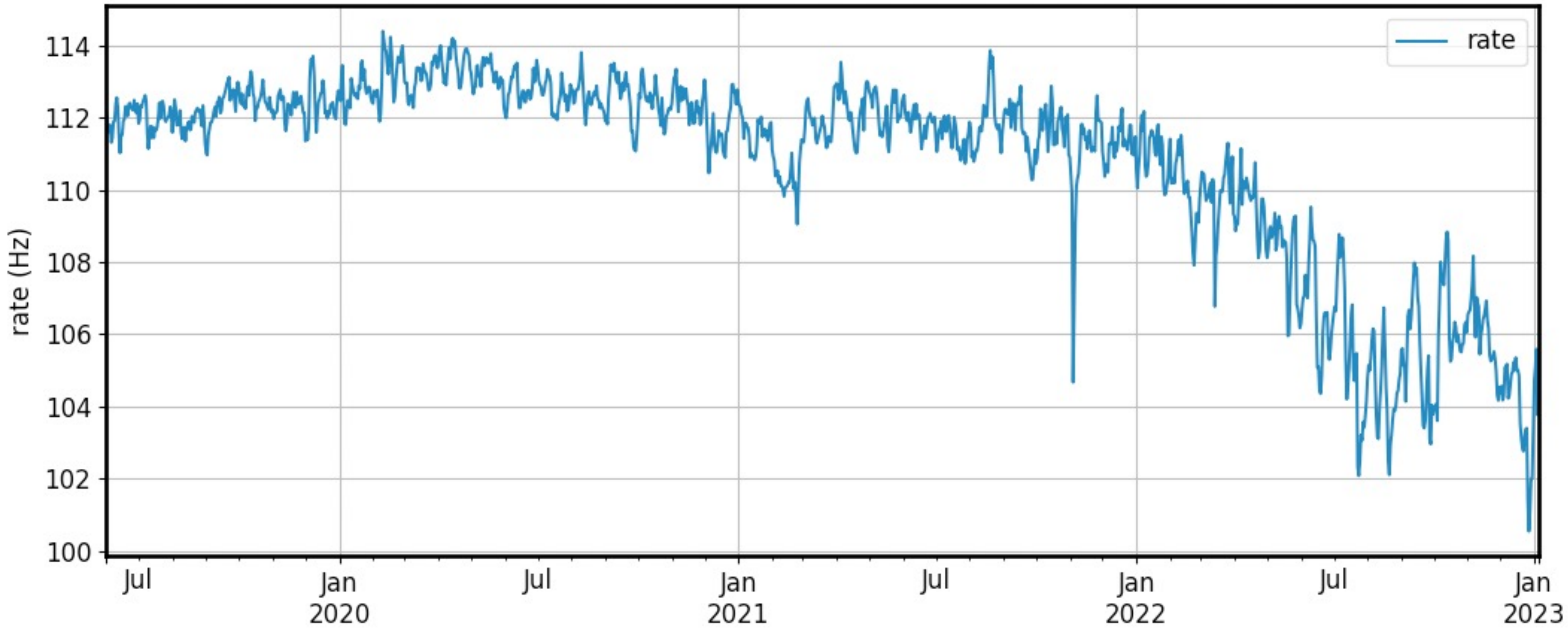


F_rebuilt FFT

cycles/year	days	amplitude
2	182.5	517.4
1	365.0	100.5
4	91.2	66.3
17	21.5	51.3
8	45.6	43.7
7	52.1	42.2
3	121.7	29.3
6	60.8	29.2

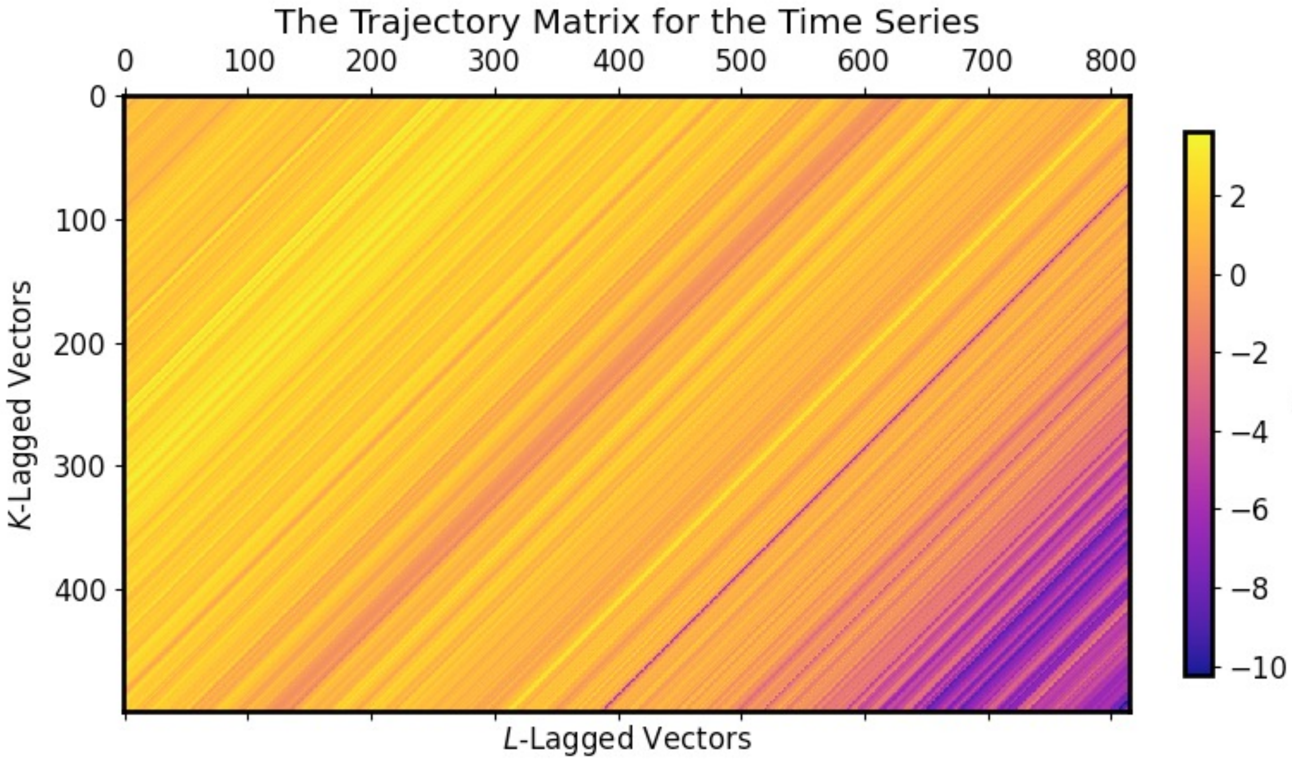
OULU daily rates

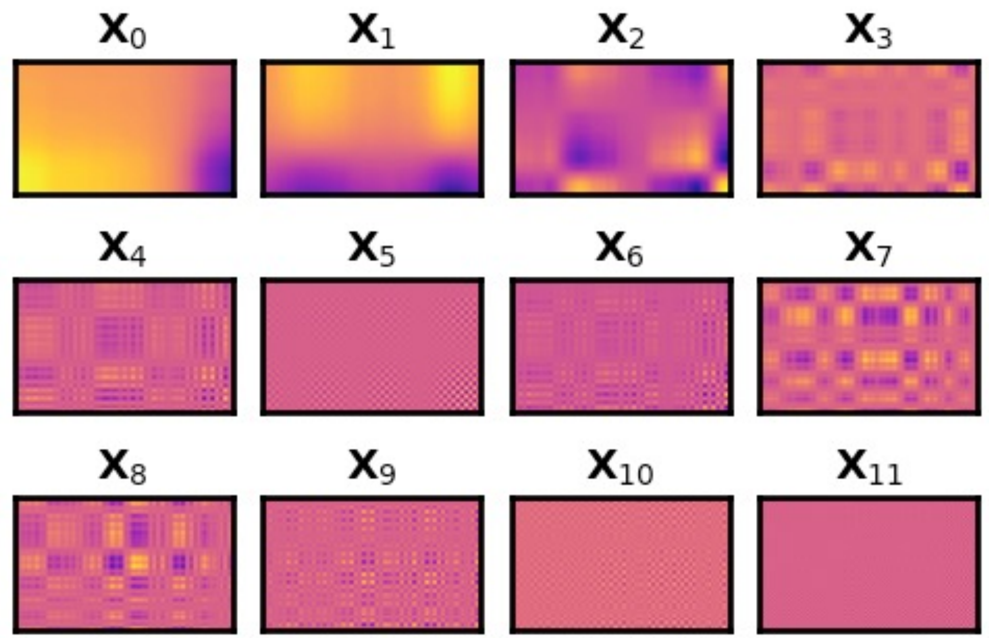
OULU daily rates

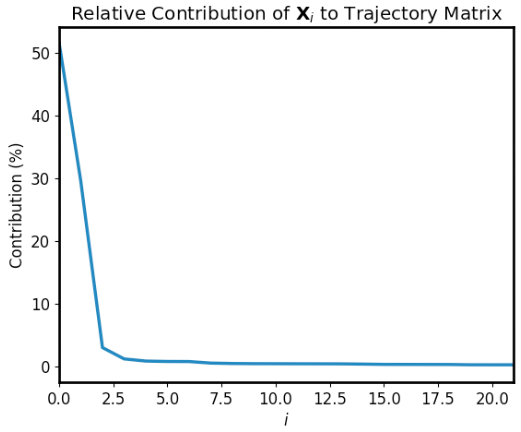


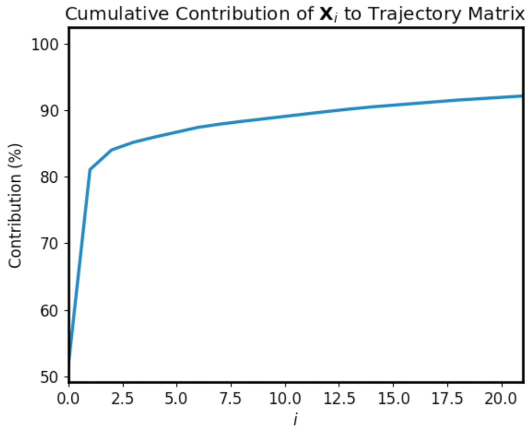
Trajectory matrix

L = 500

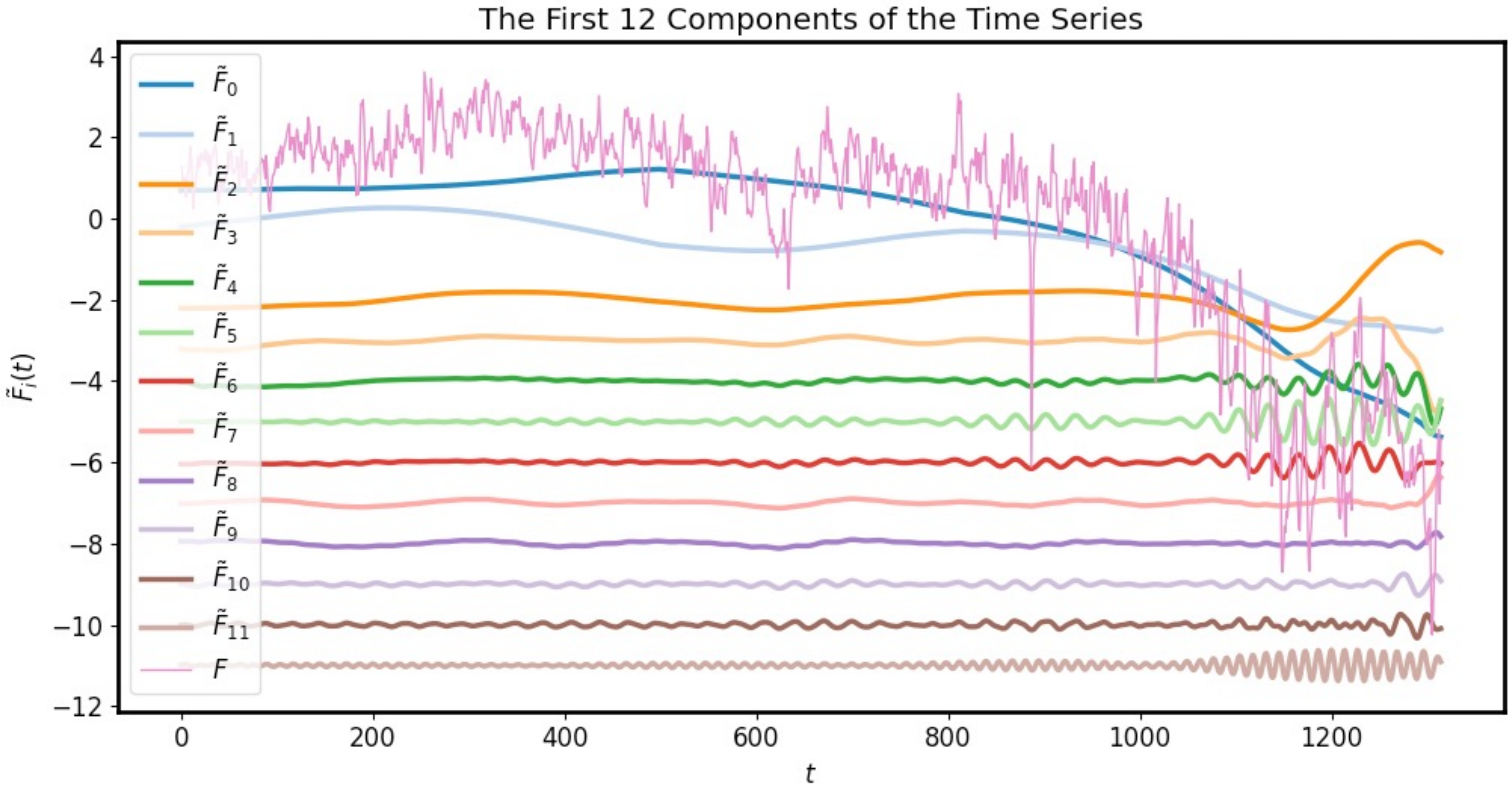




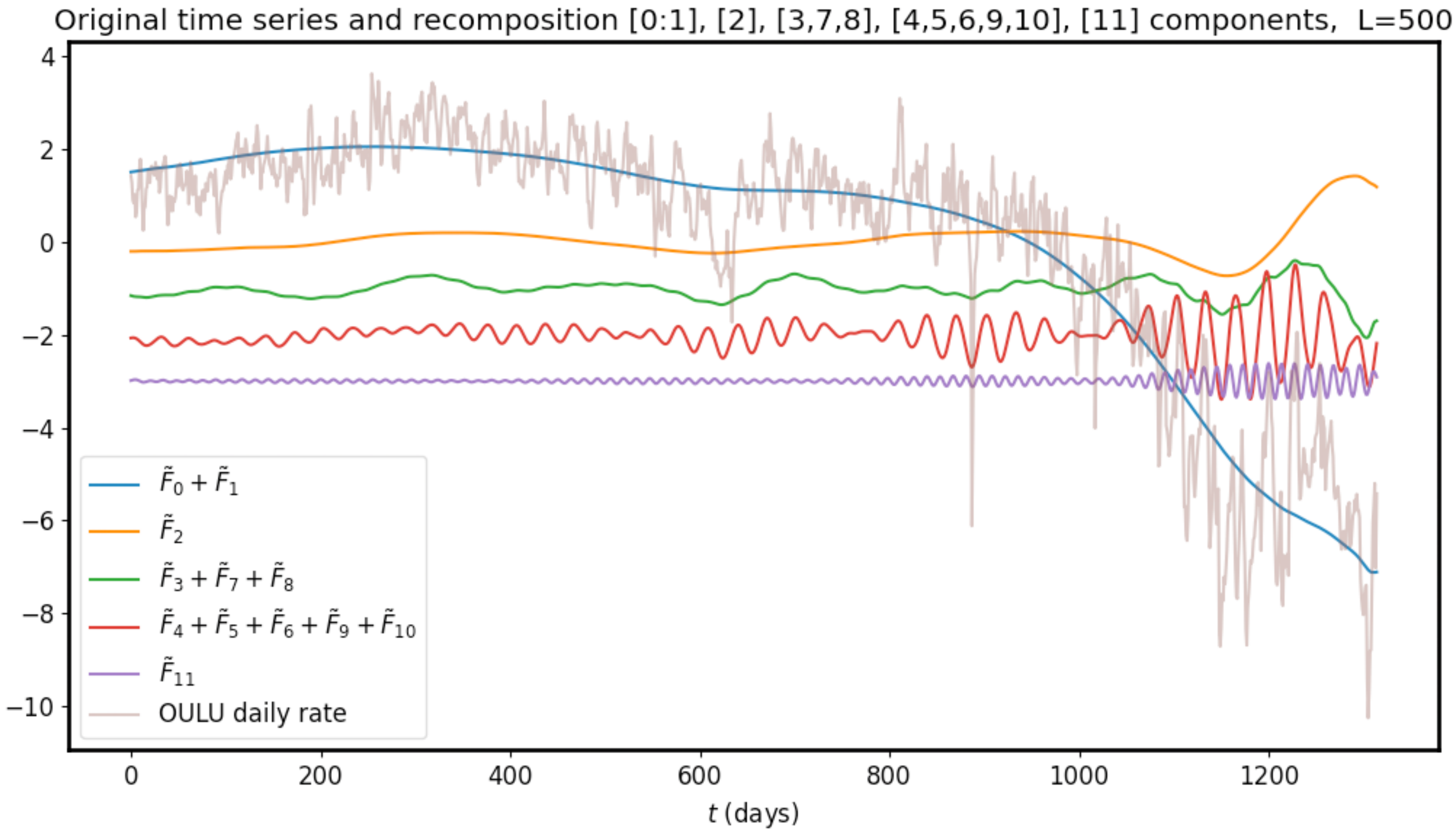




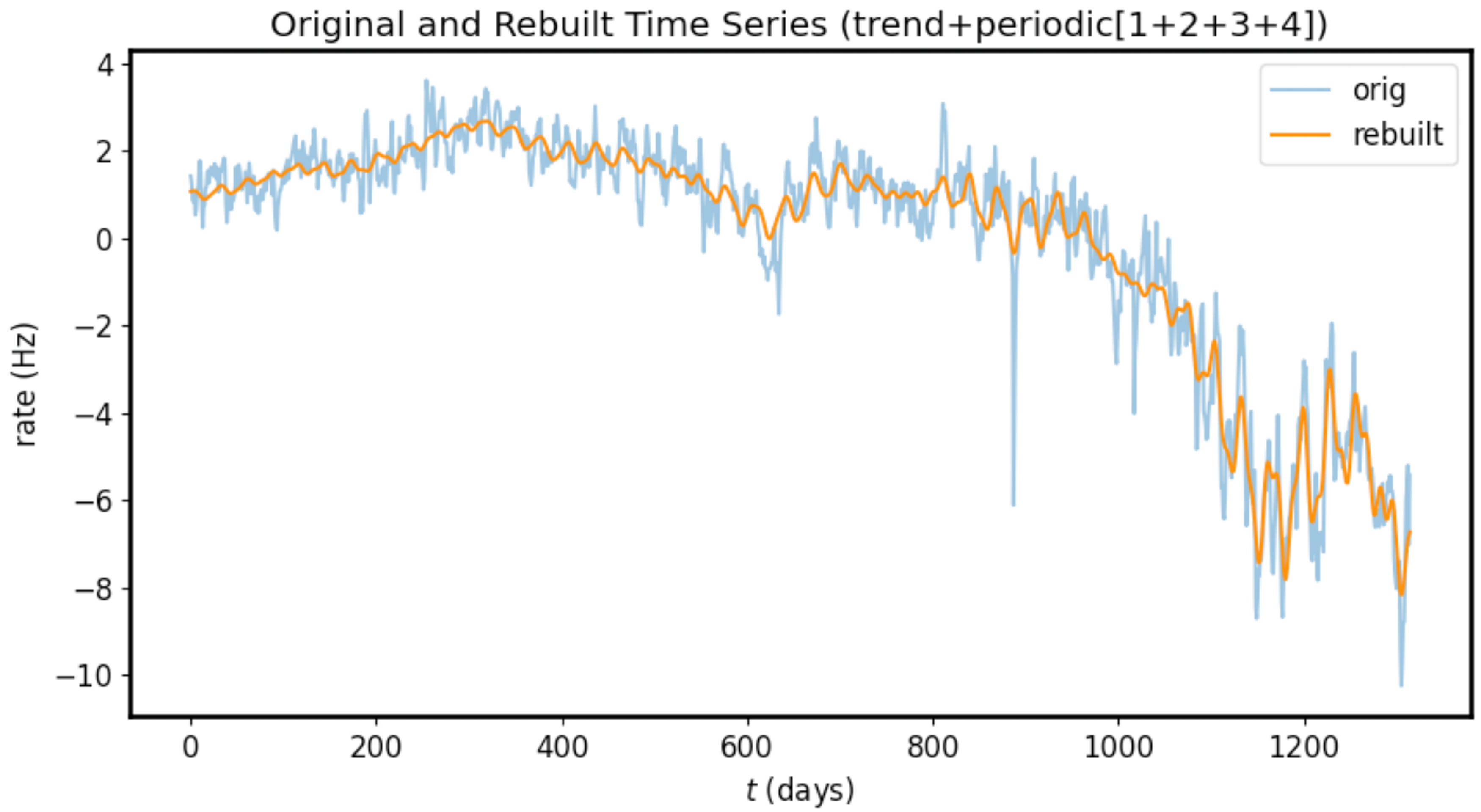
SSA for OULU rates



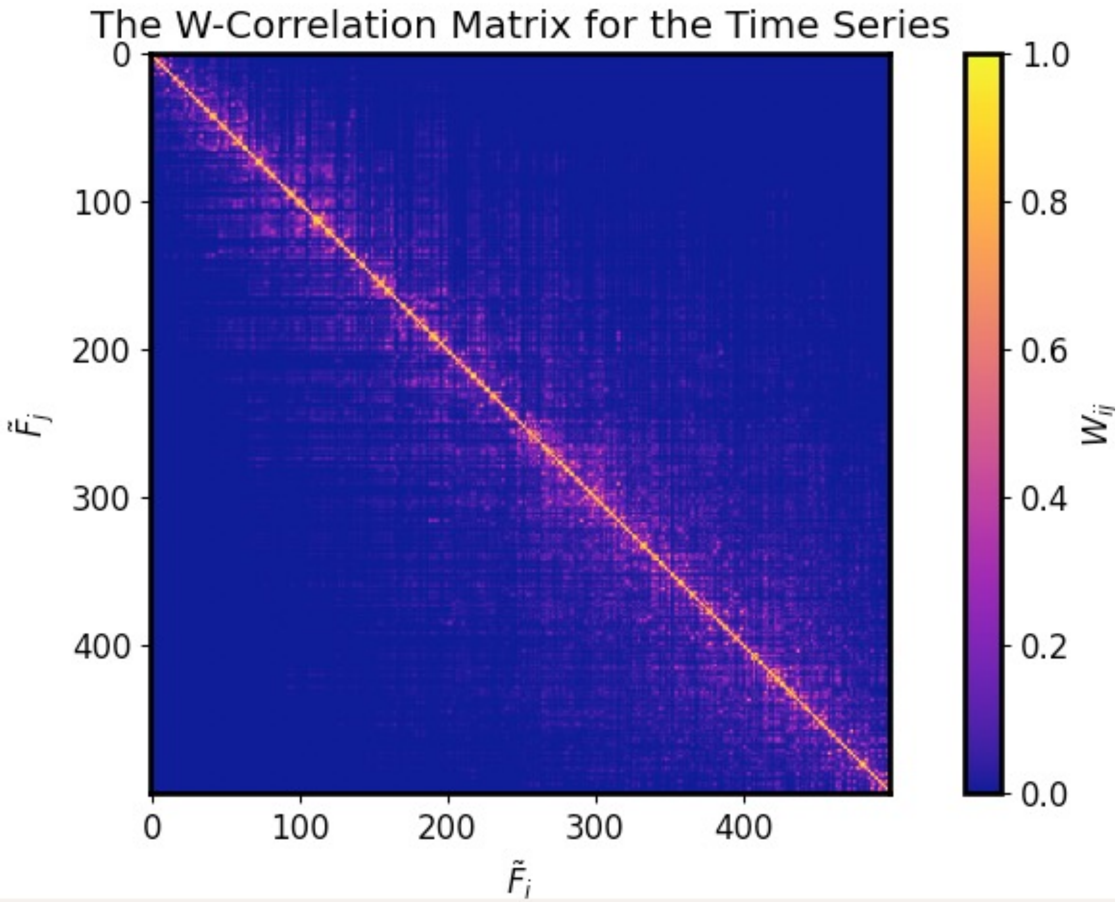
SSA for OULU rates: building 5 groups

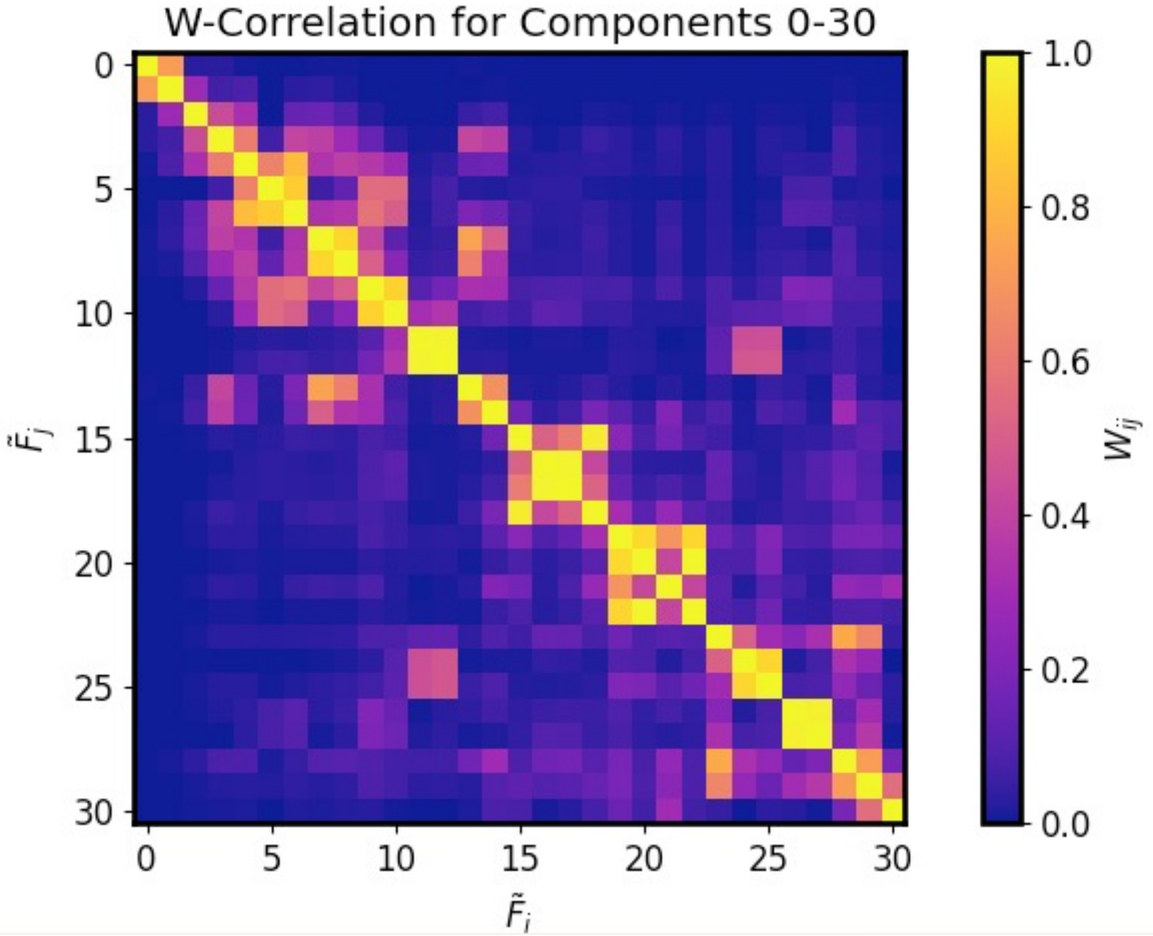


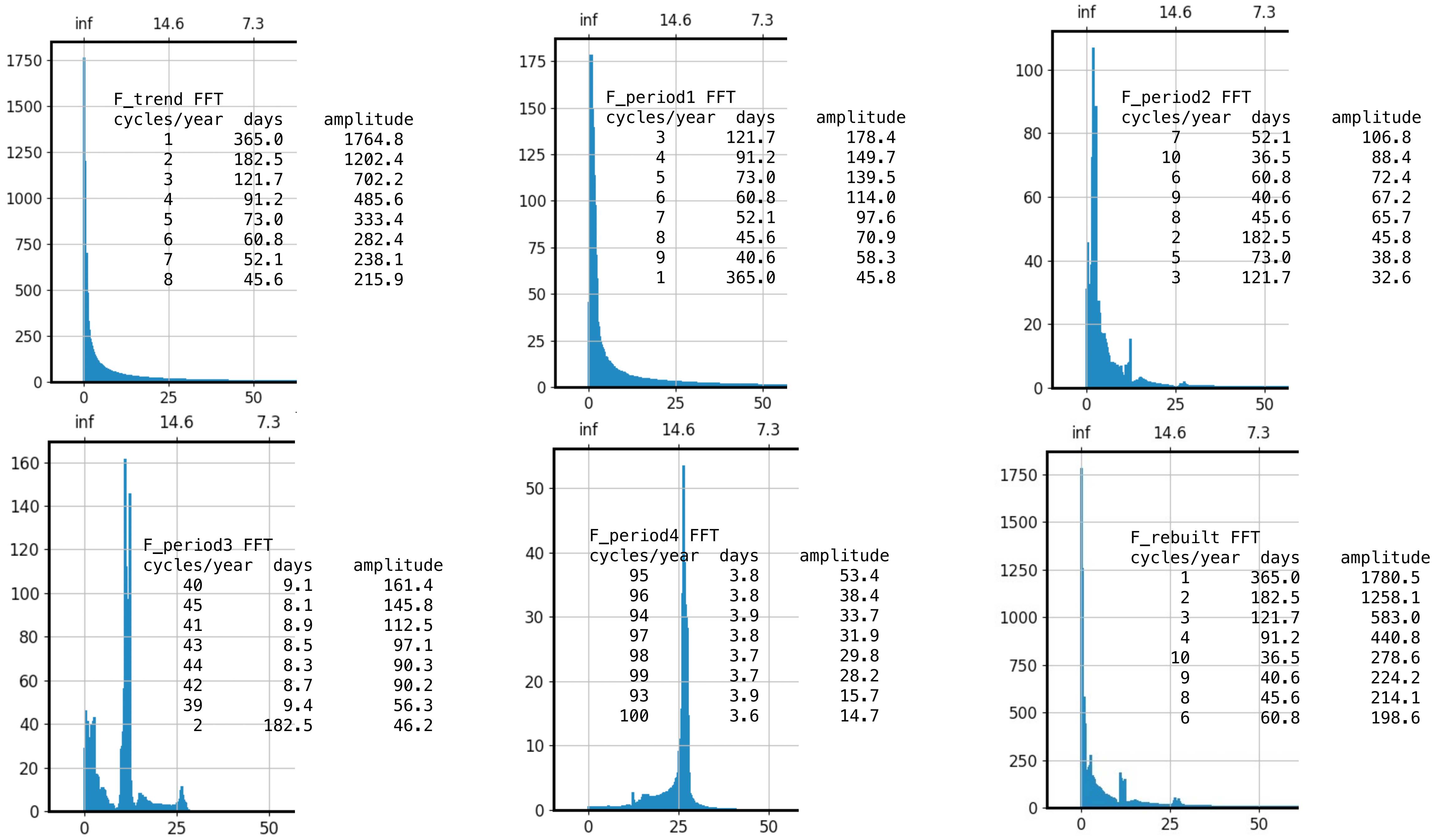
OULU original ts and rebuilt with 5 groups $\tilde{F}_i[0:11]$



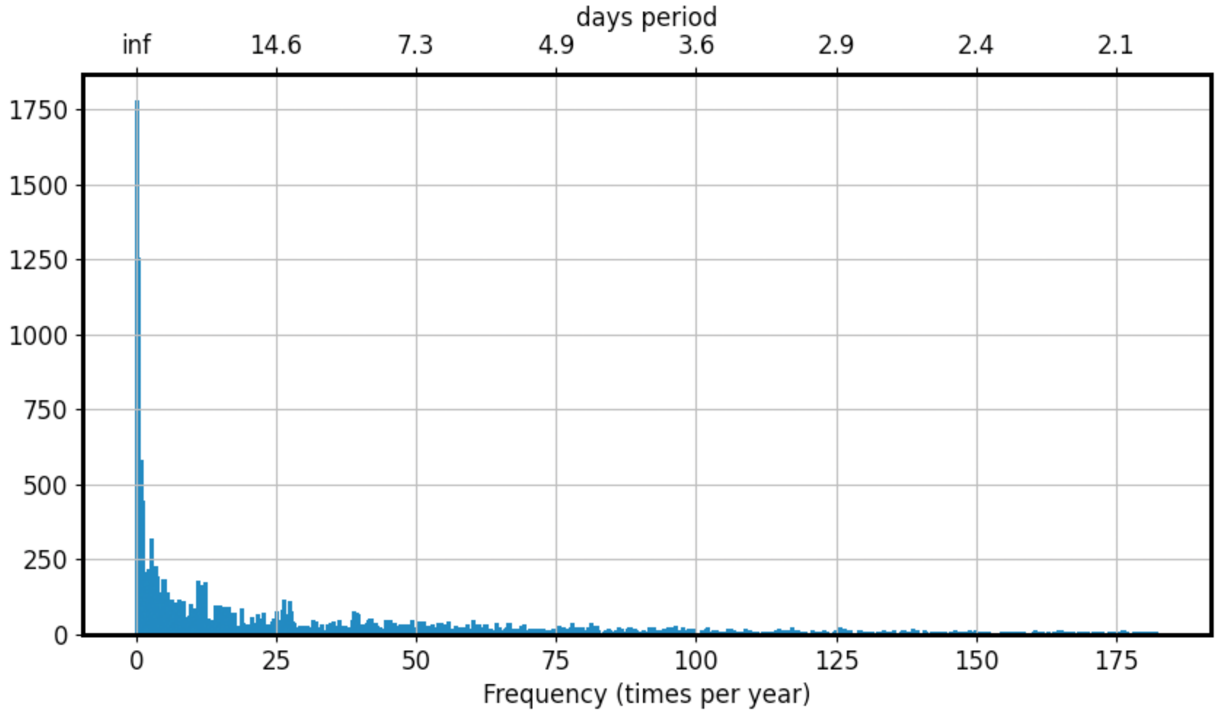
SSA OULU: W-correlation matrix





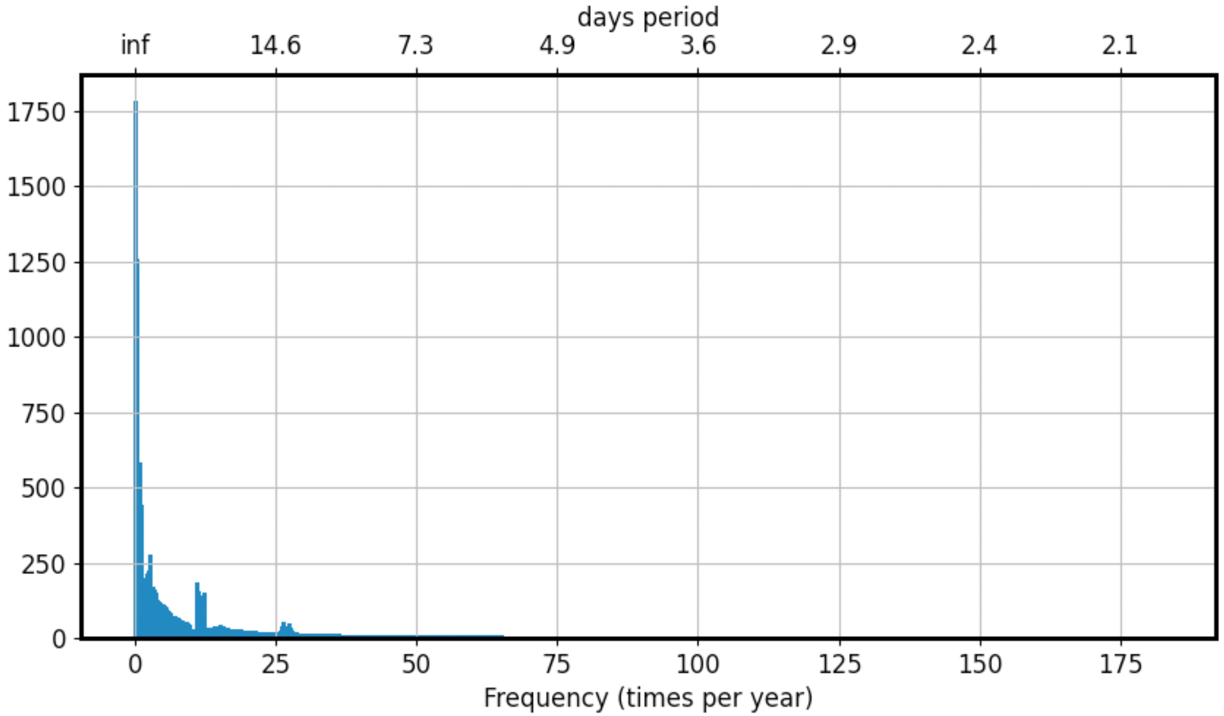

F_trend FFT
cycles/year days amplitude
1 365.0 1764.8
2 182.5 1202.4
3 121.7 702.2
4 91.2 485.6
5 73.0 333.4
6 60.8 282.4
7 52.1 238.1
8 45.6 215.9
F_period1 FFT
cycles/year days amplitude
3 121.7 178.4
4 91.2 149.7
5 73.0 139.5
6 60.8 114.0
7 52.1 97.6
8 45.6 70.9
9 40.6 58.3
1 365.0 45.8
F_period2 FFT
cycles/year days amplitude
7 52.1 106.8
10 36.5 88.4
6 60.8 72.4
9 40.6 67.2
8 45.6 65.7
2 182.5 45.8
5 73.0 38.8
3 121.7 32.6
F_period3 FFT
cycles/year days amplitude
40 9.1 161.4
45 8.1 145.8
41 8.9 112.5
43 8.5 97.1
44 8.3 90.3
42 8.7 90.2
39 9.4 56.3
2 182.5 46.2
F_period4 FFT
cycles/year days amplitude
95 3.8 53.4
96 3.8 38.4
94 3.9 33.7
97 3.8 31.9
98 3.7 29.8
99 3.7 28.2
93 3.9 15.7
100 3.6 14.7
F_rebuilt FFT
cycles/year days amplitude
1 365.0 1780.5
2 182.5 1258.1
3 121.7 583.0
4 91.2 440.8
10 36.5 278.6
9 40.6 224.2
8 45.6 214.1
6 60.8 198.6
inf
14.6
7.3
0
25
50

OULU original TS and rebuilt TS: FFT comparison



OULU daily rate FFT

cycles/year	days	amplitude
1	365.0	1778.7
2	182.5	1257.0
3	121.7	579.9
4	91.2	448.0
10	36.5	319.4
13	28.1	226.8
12	30.4	222.7
8	45.6	216.9



F_rebuilt FFT

cycles/year	days	amplitude
1	365.0	1780.5
2	182.5	1258.1
3	121.7	583.0
4	91.2	440.8
10	36.5	278.6
9	40.6	224.2
8	45.6	214.1
6	60.8	198.6

Conclusioni

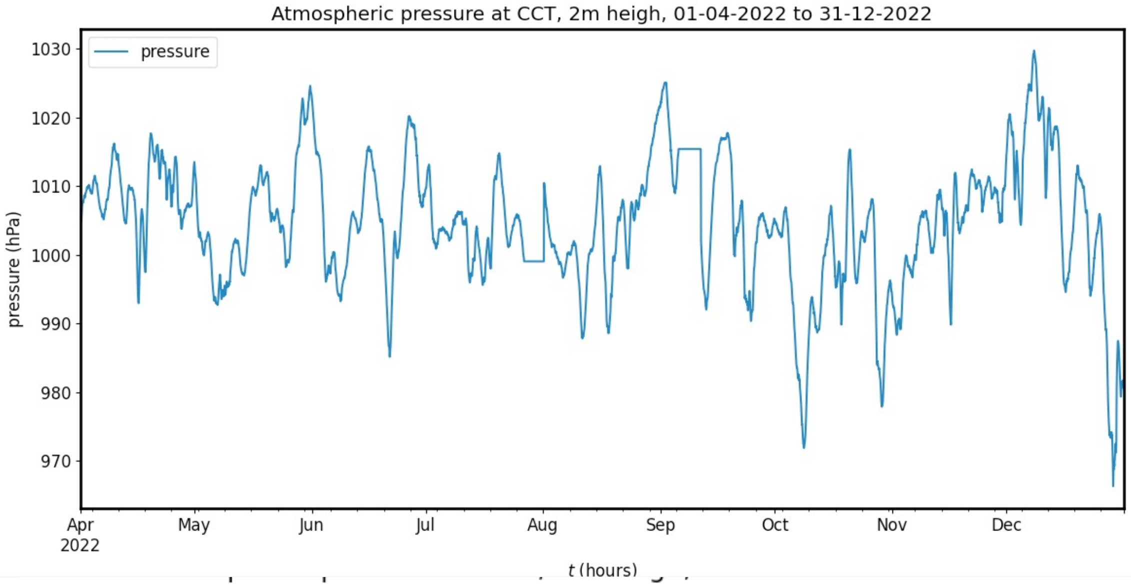
- Esercizio di decomposizione delle time series tramite FFT e SSA
  - POLA-1/3/4 rate giornalieri per periodi superiori a un anno
  - OULU rate giornalieri per 3 anni
  - Dati meteo (risultati non riportati qui, poco pertinenti)
- I componenti elementari hanno un significato fisico?
  - Il trend annuale può essere spiegato (?)
  - Periodicità inferiori possono avere origine solare/cosmica, o ambientale, o strumentale/sistematica (?)
- Prossimi passi (?)
  - Ottimizzare i parametri e le tecniche di ricostruzione
  - Valutare le caratteristiche del rumore residuo
  - Provare ad applicare la tecnica a dati campionati a frequenze maggiori (rate orari o ogni minuto)

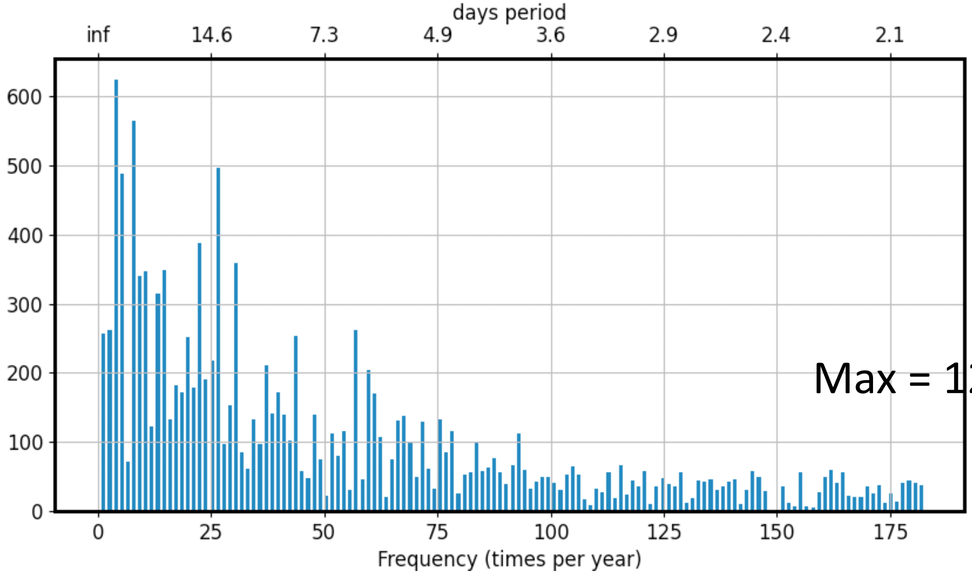
References

- Characteristic Time Scales of Decadal to Centennial Changes in Global Surface Temperatures Over the Past 150 Years https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2019EA000671
  - Comments: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020EA001298

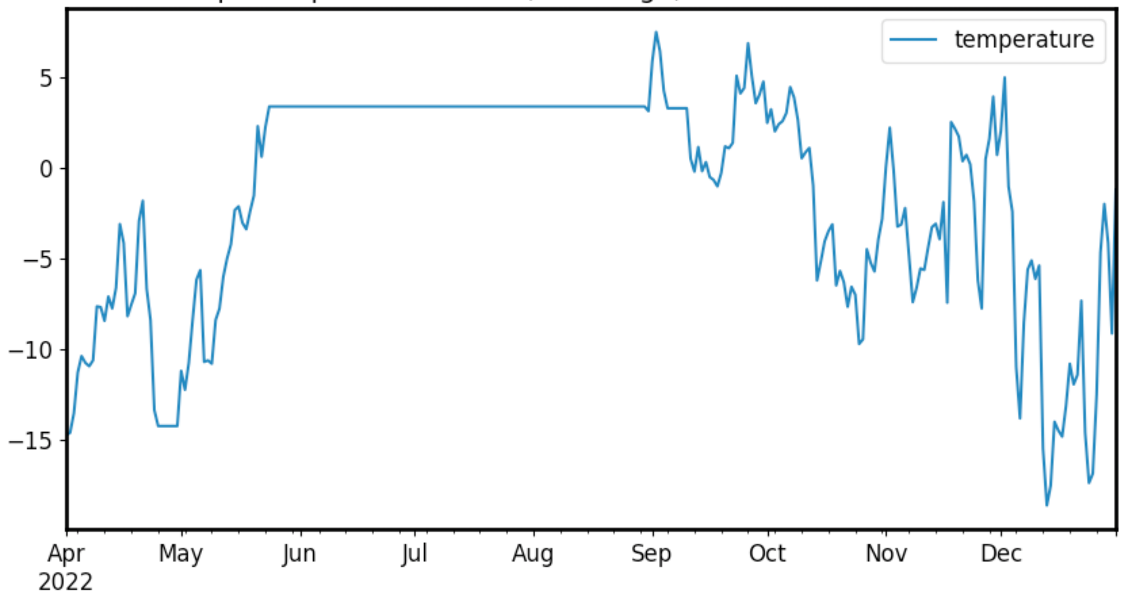
- A Brief Introduction to Singular Spectrum Analysis https://ssa.cf.ac.uk/ssa2010/a_brief_introduction_to_ssa.pdf

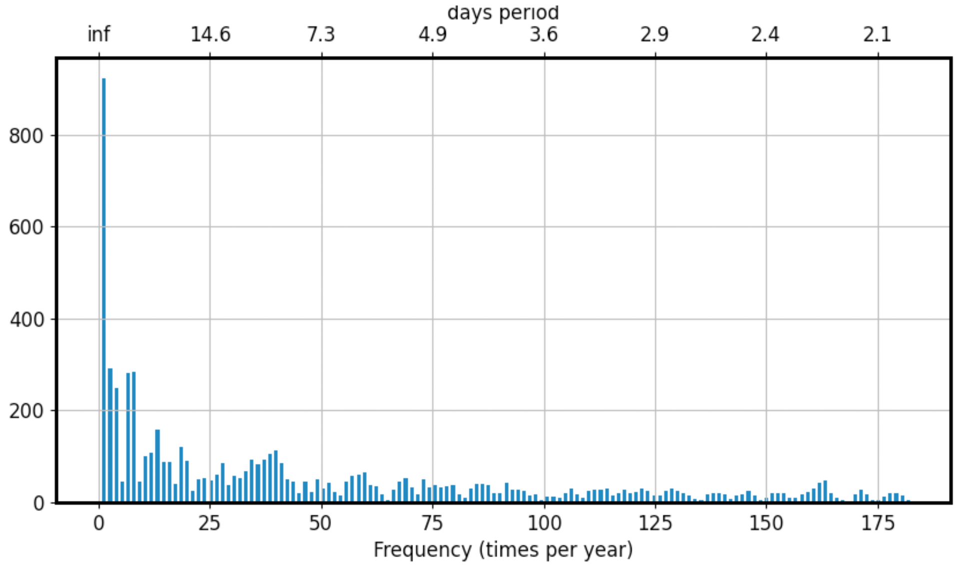
Pressure, temperature

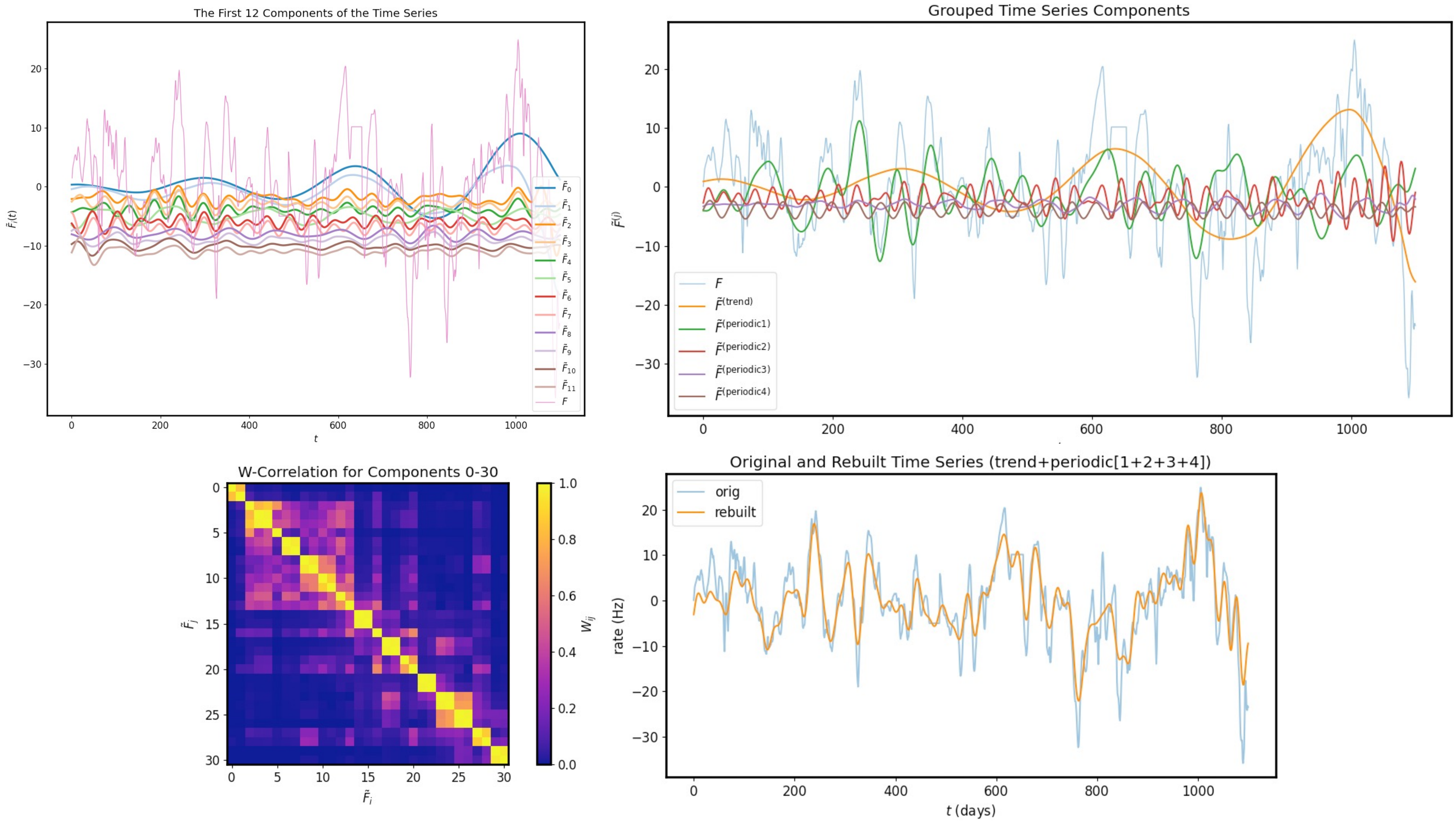




Max = 121 d







The First 12 Components of the Time Series
$\tilde{F}_i(t)$
t
$\tilde{F}_0$
$\tilde{F}_1$
$\tilde{F}_2$
$\tilde{F}_3$
$\tilde{F}_4$
$\tilde{F}_5$
$\tilde{F}_6$
$\tilde{F}_7$
$\tilde{F}_8$
$\tilde{F}_9$
$\tilde{F}_{10}$
$\tilde{F}_{11}$
F
Grouped Time Series Components
$\tilde{F}^{(j)}$
F
$\tilde{F}^{(\text{trend})}$
$\tilde{F}^{(\text{periodic1})}$
$\tilde{F}^{(\text{periodic2})}$
$\tilde{F}^{(\text{periodic3})}$
$\tilde{F}^{(\text{periodic4})}$
W-Correlation for Components 0-30
$\tilde{F}_j$
$\tilde{F}_i$
W_{ij}
Original and Rebuilt Time Series (trend+periodic[1+2+3+4])
orig
rebuilt
rate (Hz)
t (days)