10th Workshop – Solar Influences on the Magnetosphere, Ionosphere and Atmosphere
Primorsko, Bulgaria

CHAOTIC ANALYSIS AND PREDICTION OF SOLAR ACTIVITY

Volkan SARP[1] & Ali KILCIK[1]

[1]Akdeniz Unıversity, Faculty of Science

Department of Space Science and Technologies

Antalya, Turkey

Collaborators: Vasyl Yurchyshyn, Atila Ozguc, Jean-Pierre Rozelot

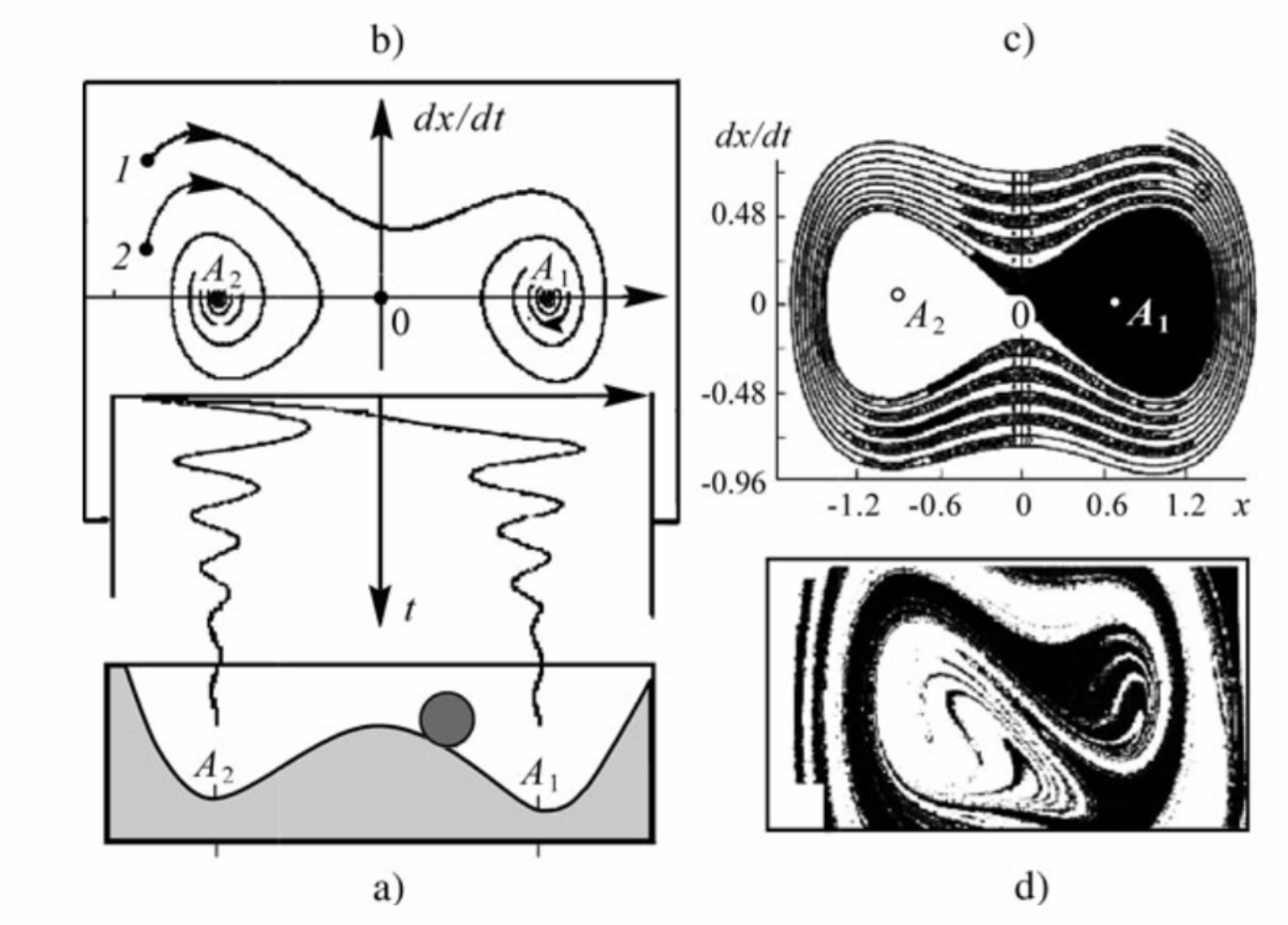
You don’t see something until you have the right metaphor to let you
perceive it”

- James Gleick, Chaos: Making a New Sc

CONTENTS

- Phase Space & Embedding Space
- Chaos
- Long Term Memory
- Parameter Selection
- Correlation Dimension
- Prediction

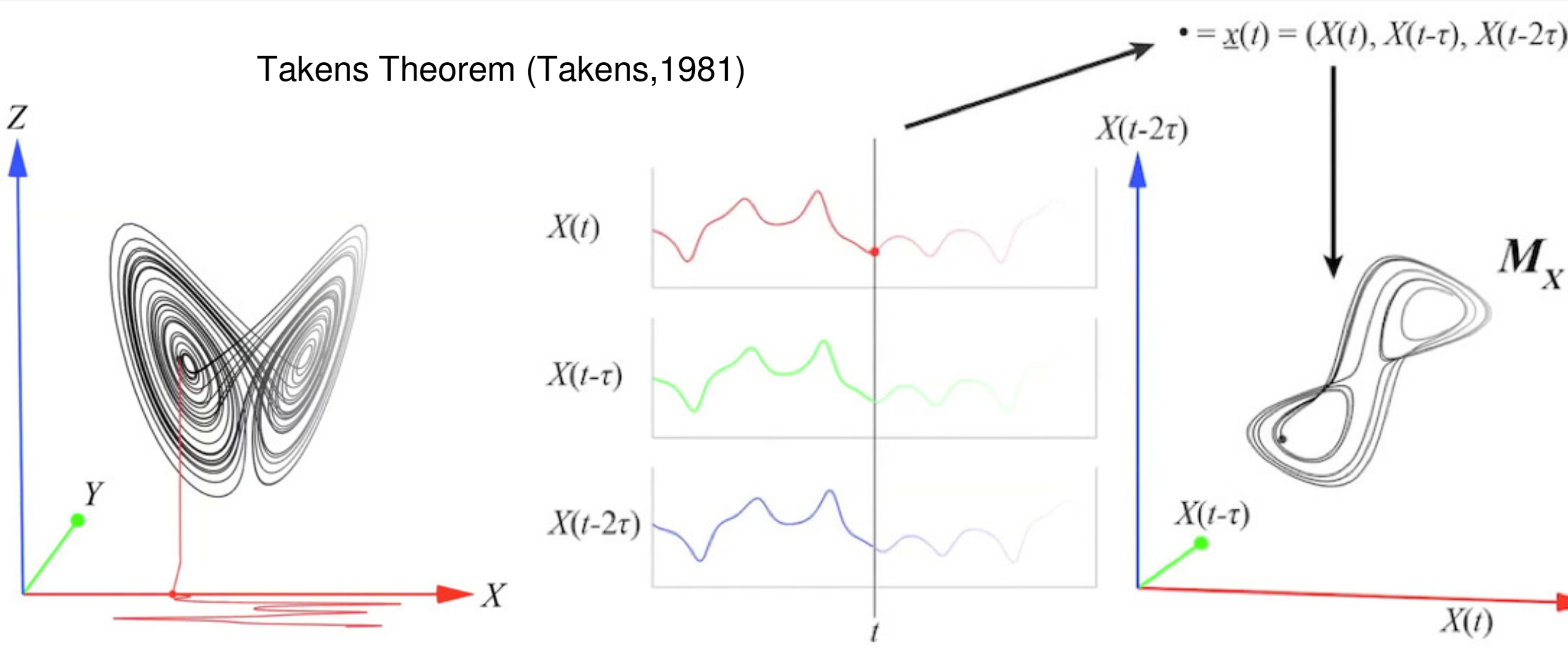
PHASE SPACE



(Bezruchko and Smirnov, 2010)

EMBEDDING SPACE

Takens Theorem (Takens,1981)



CHAOS

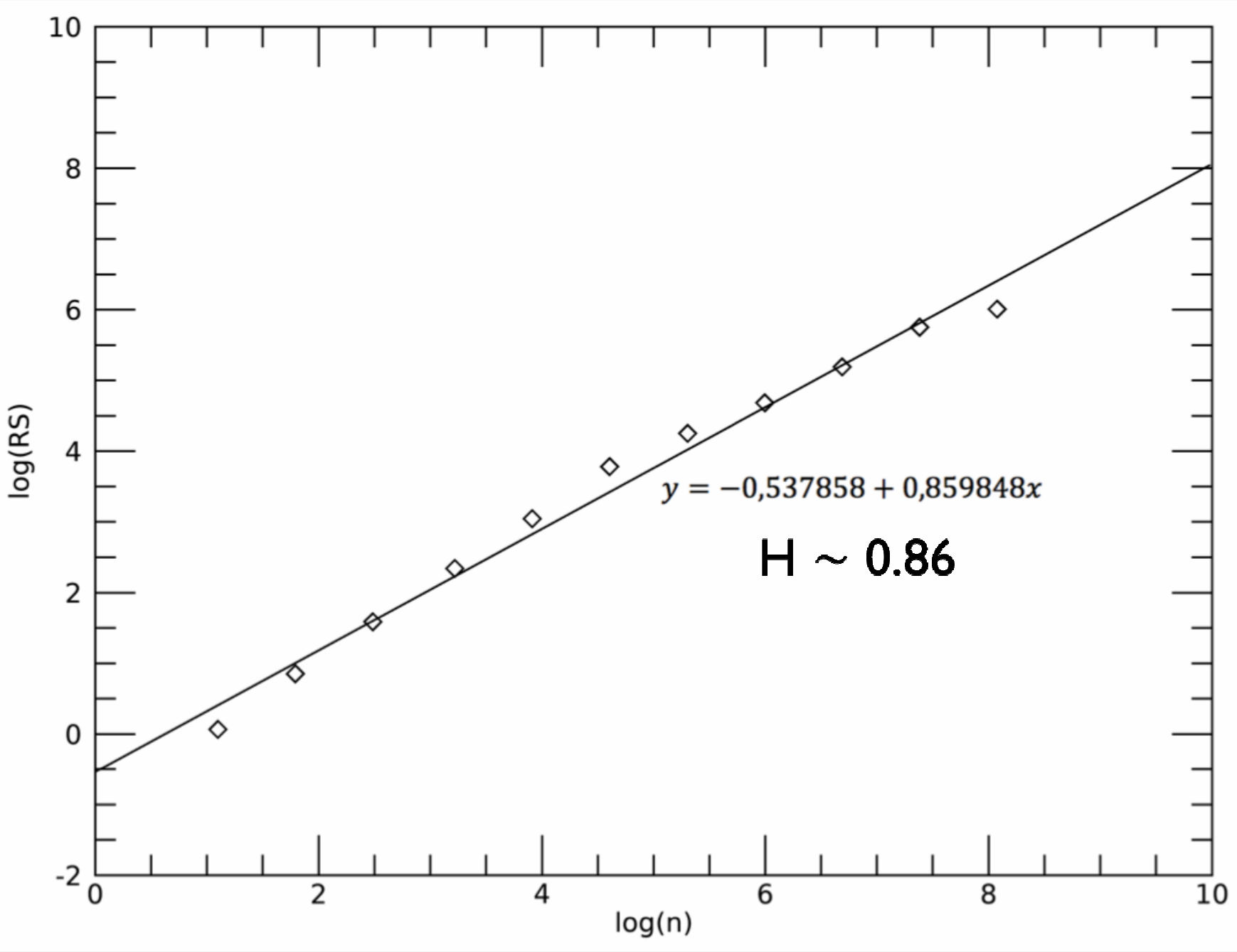
1. Sensitive to initial conditions
2. Dense periodic orbits
3. Topologically mixing

LONG TERM MEMORY

- Rescaled Range Analysis (RRA) gives an approximation to Hurst exponent
  - Partition the data to different sizes
  - Divide the ranges of cumulative sums by standard deviations of each size
  - Slope of the logarithm of mean ratio for each size versus logarithm of the size value gives Hurst exponent

- $H > 0.5$ means the data have long term memory and repeated patterns
  - $H = 0.5$ means the data is random
  - $H < 0.5$ means the data is anti-persistent

- A variety of natural phenomena's Hurst exponent is calculated as 0.73 ± 0.09 (Hurst et al. 1965)


10
8
6
4
2
0
-2
0
2
4
6
8
10
log(RS)
log(n)
$y = -0{,}537858 + 0{,}859848x$
H ~ 0.86

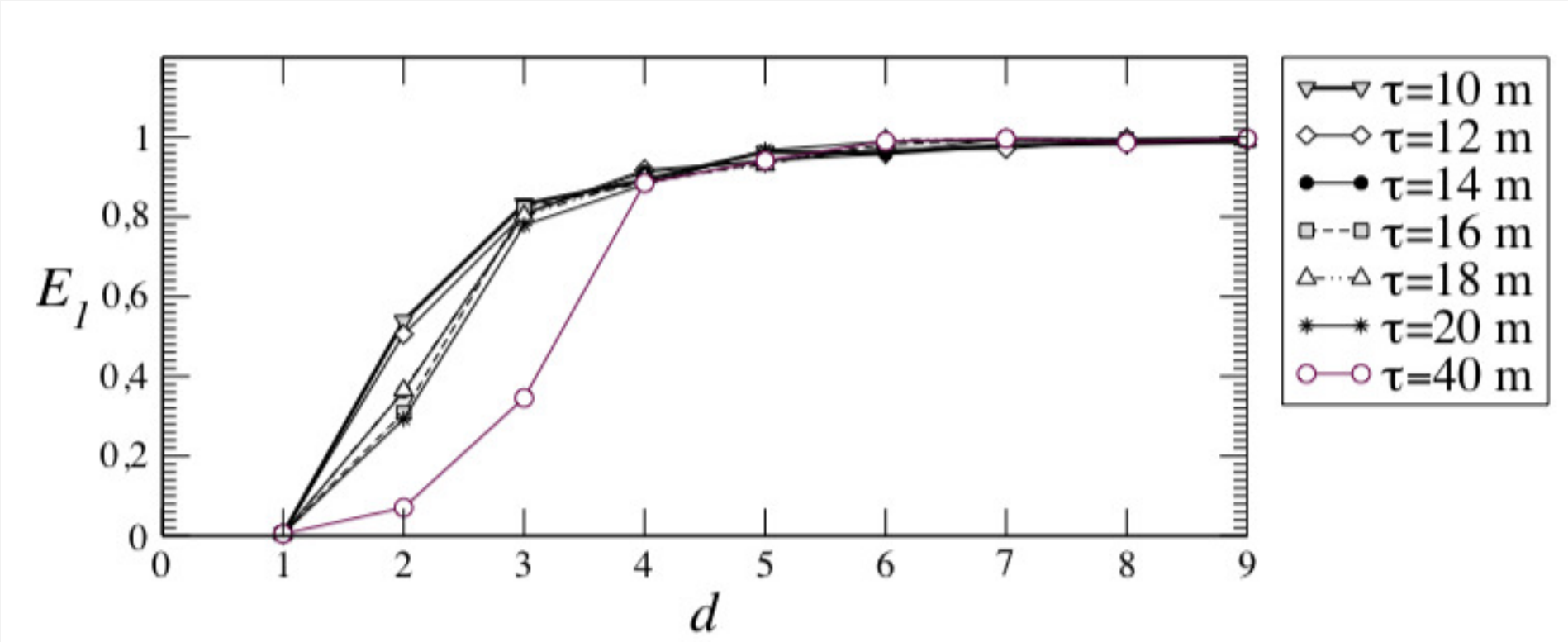
PARAMETER SELECTION

- Two main parameters are needed.

  - Embedding Dimension
    - A range of different embedding dimension values are selected and tested

  - Time Delay
    - Average Displacement Function is used for each embedding dimension

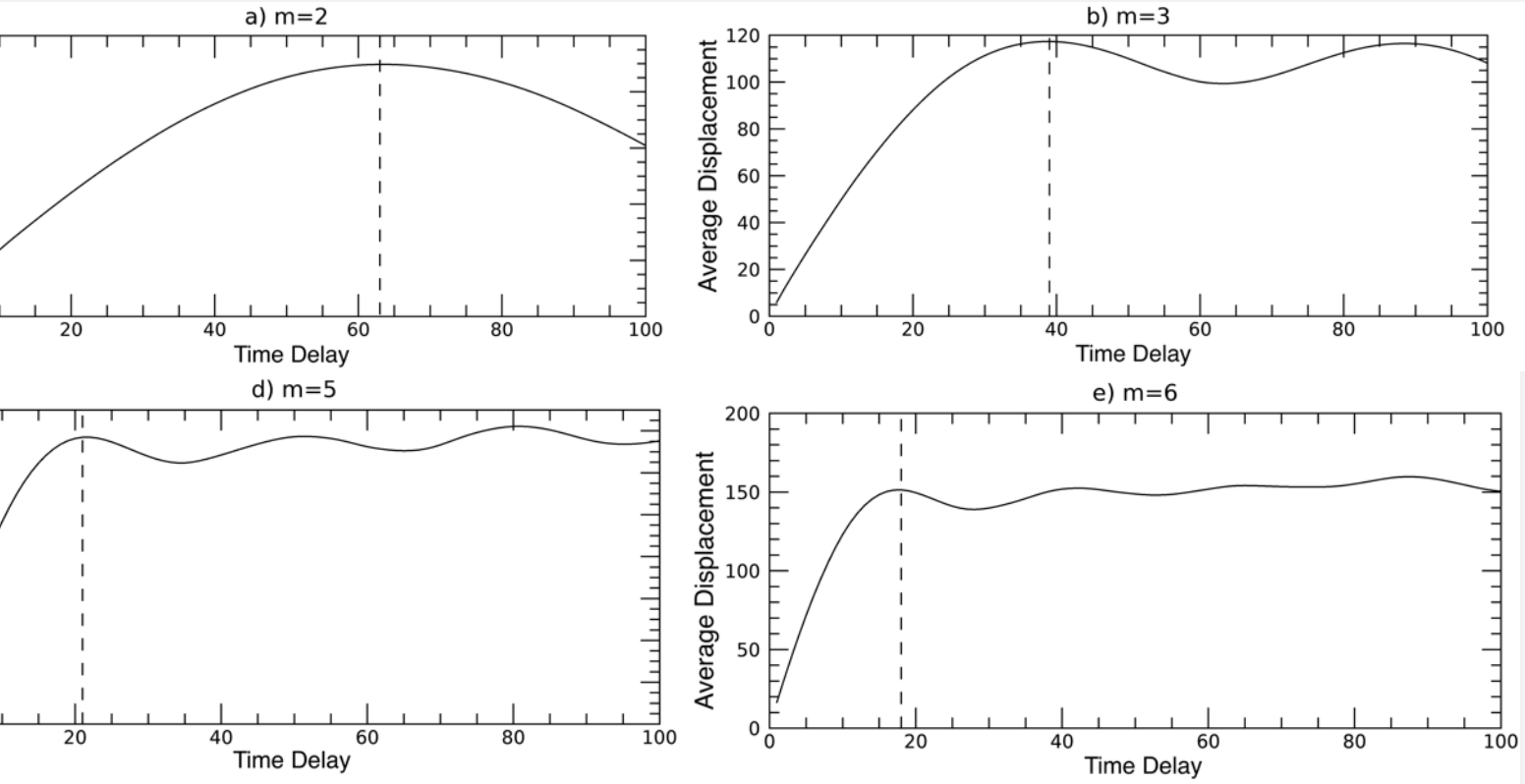
PARAMETER SELECTION: EMBEDDING DIMENSION



E_1 = Distance between neighbors in embedding space
d = embedding dimension

(Lettelier et al. 2006
A&A)

PARAMETER SELECTION: TIME DELAY



Embedding Dimension	Time Delay
2	63
3	39
4	27
5	21
6	18

Average Displacement Function (Rosenstein et al., 1994)

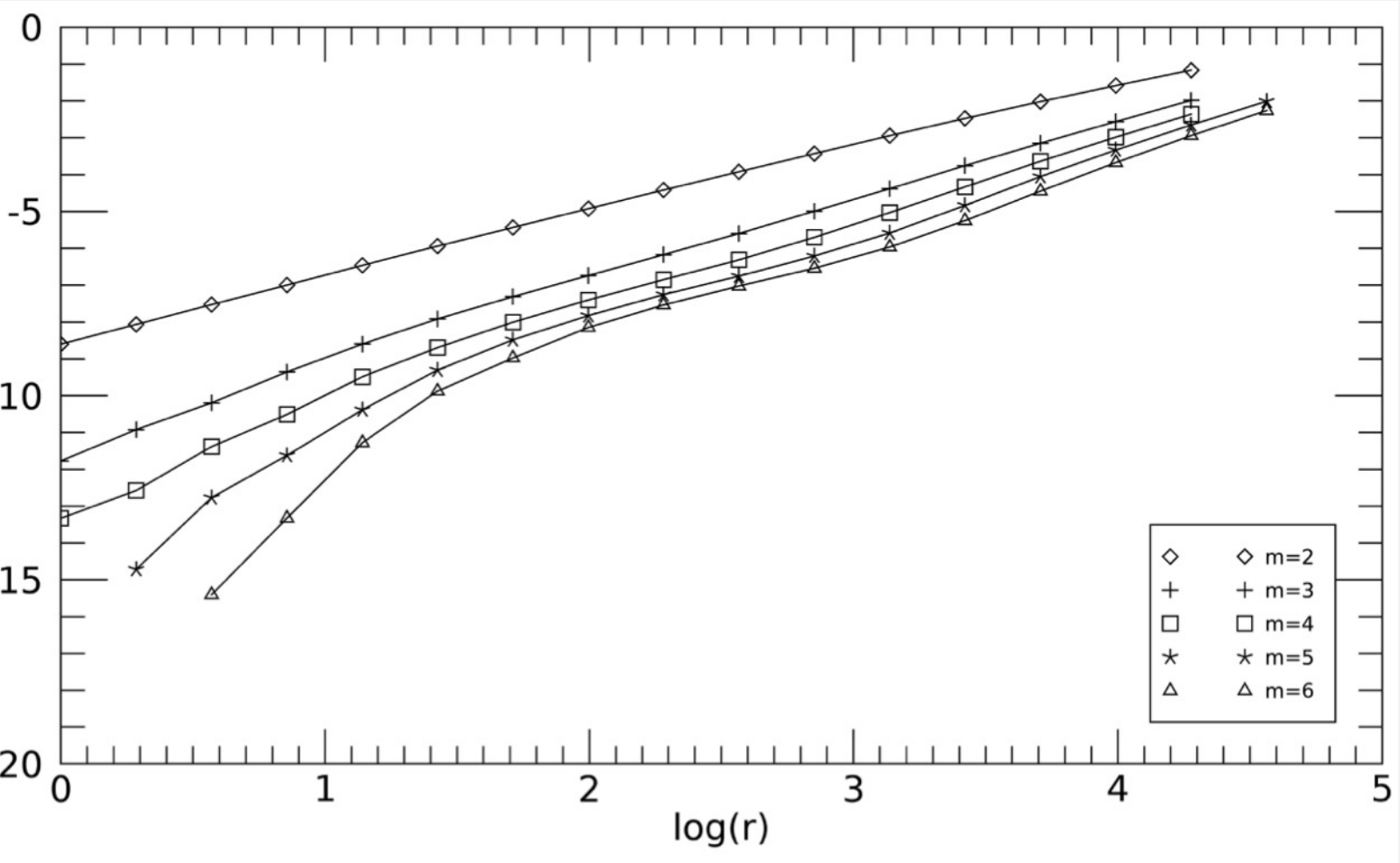
CORRELATION DIMENSION

- Grassberger – Procaccia algorithm gives an approximation to correlation dimension.
  - Correlation integral are calculated as follows;

$$C(r) = \frac{2}{N(N-1)} \sum_{j=1}^{N} \sum_{i=j+1}^{N} \Theta(r - r_{ij})$$

  - Logarithmic slope of the correlation integral - threshold distance plot gives the correlation dimension (D);

$$D = \lim_{r \to 0} \frac{\log C(r)}{\log r}$$



m = Embedding Dimension
D = Correlation Dimension

m	D	
2	1,75	**3,5**
3	2,23	**4,46**
4	2,48	**4,96**
5	2,69	**5,38**
6	2,89	**5,78**

$m_{min} > 2D$ (Sauer et al. 19

PREDICTION

The goal of **Empirical Dynamic Modelling** is to reconstruct the behavior of dynamic system from time series data.

Simplex Projection was used for extrapolation of the data.

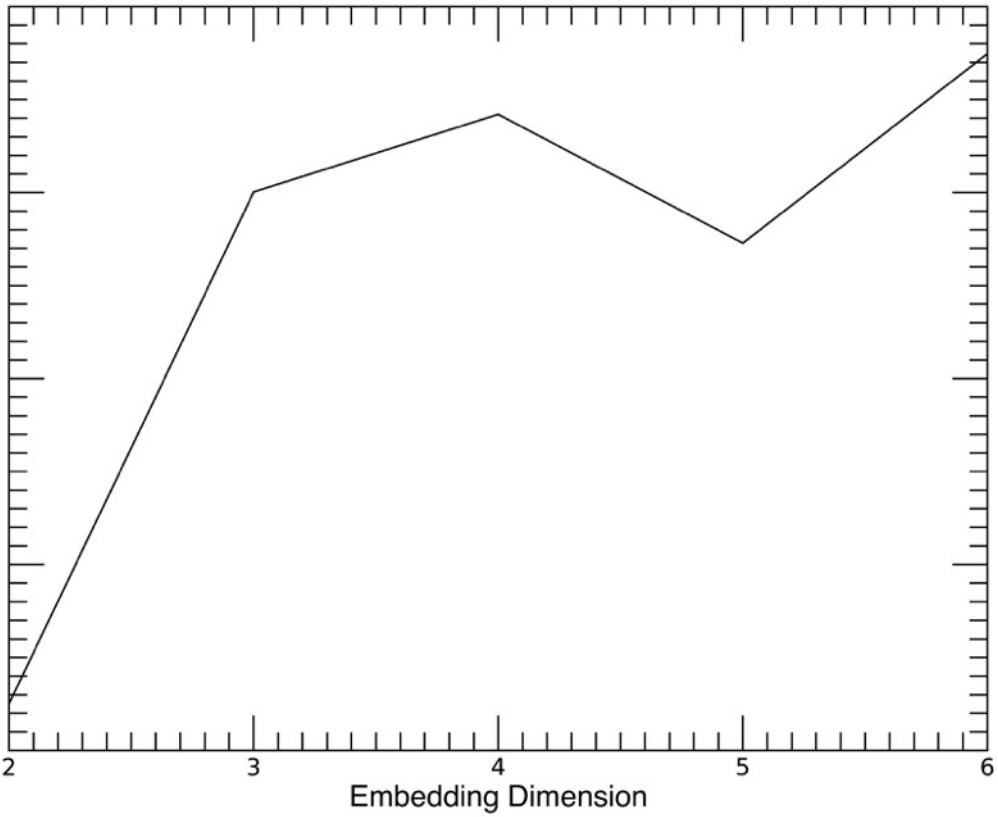
Main paradigm of EDM – "**Lack of correlation does not imply lack of causation.**"

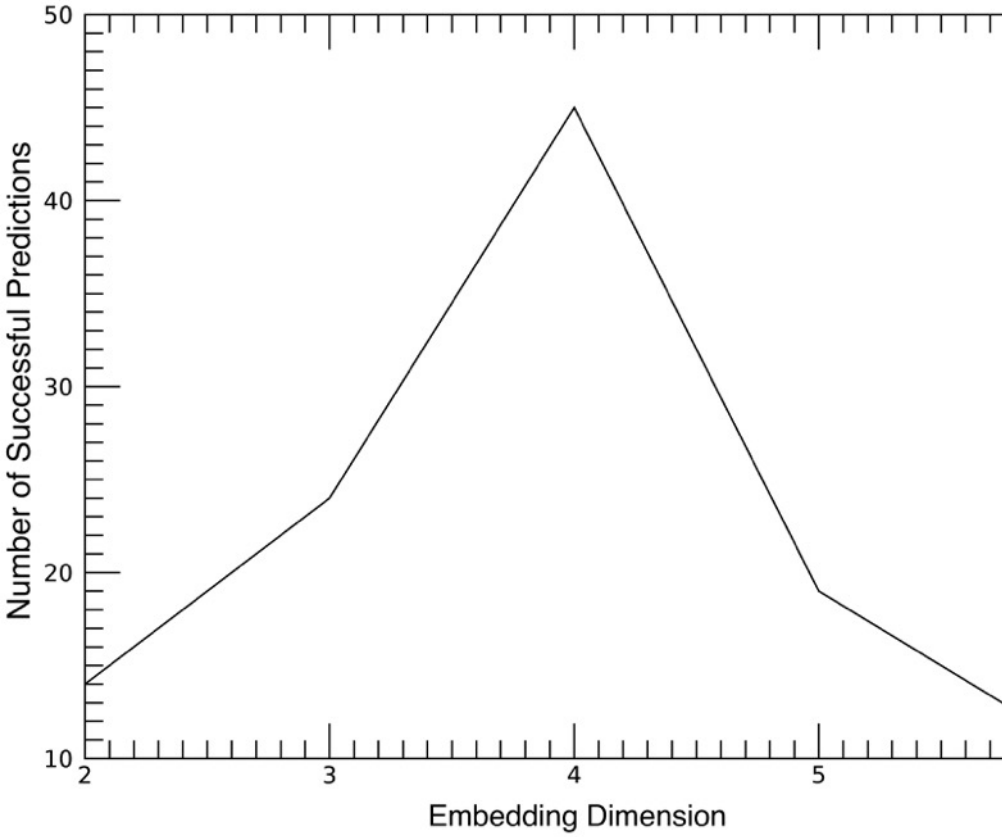
(Sugihara et al. 201

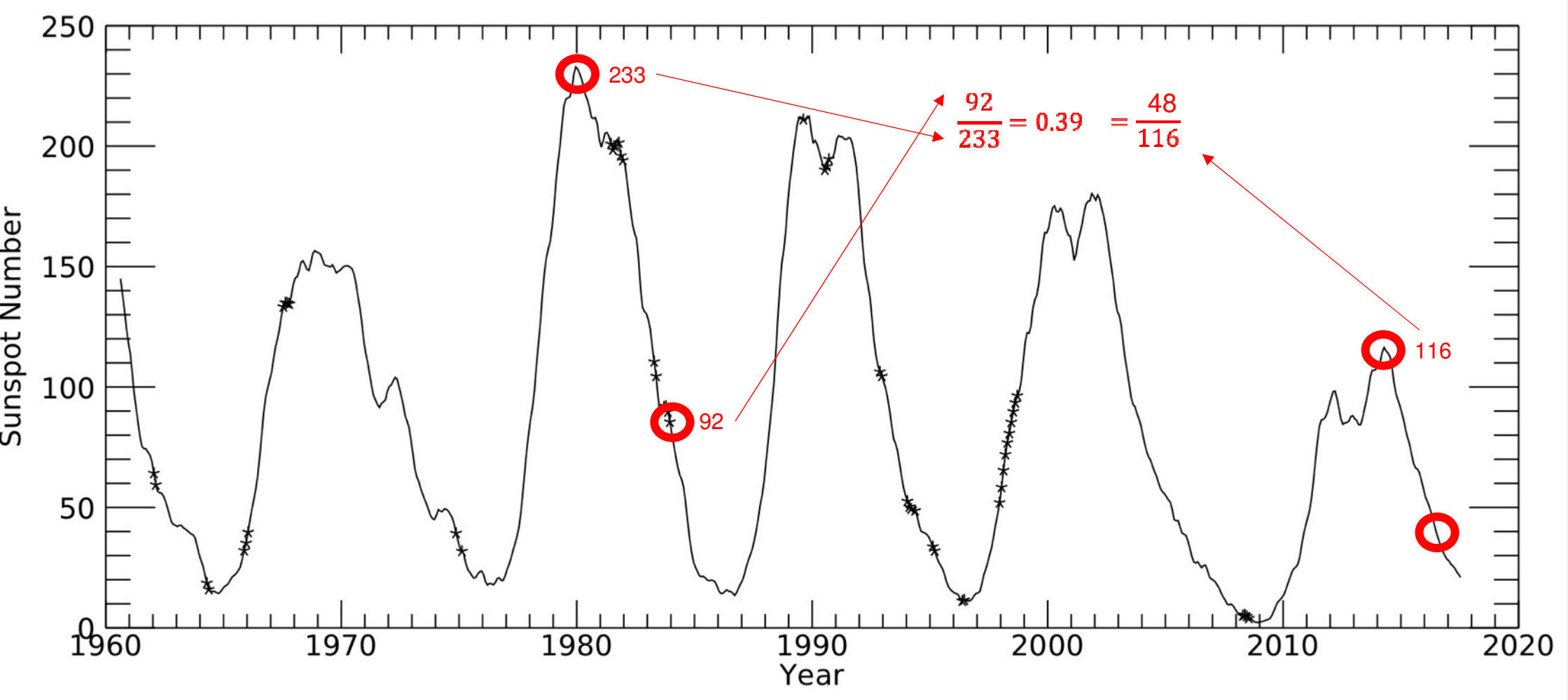
- Last five sunspot cycle (20, 21, 22, 23 and 24) are predicted out of sample for all embedding dimensions (2, 3, 4, 5 and 6) in the range.

- Prediction time is selected as 132 months.

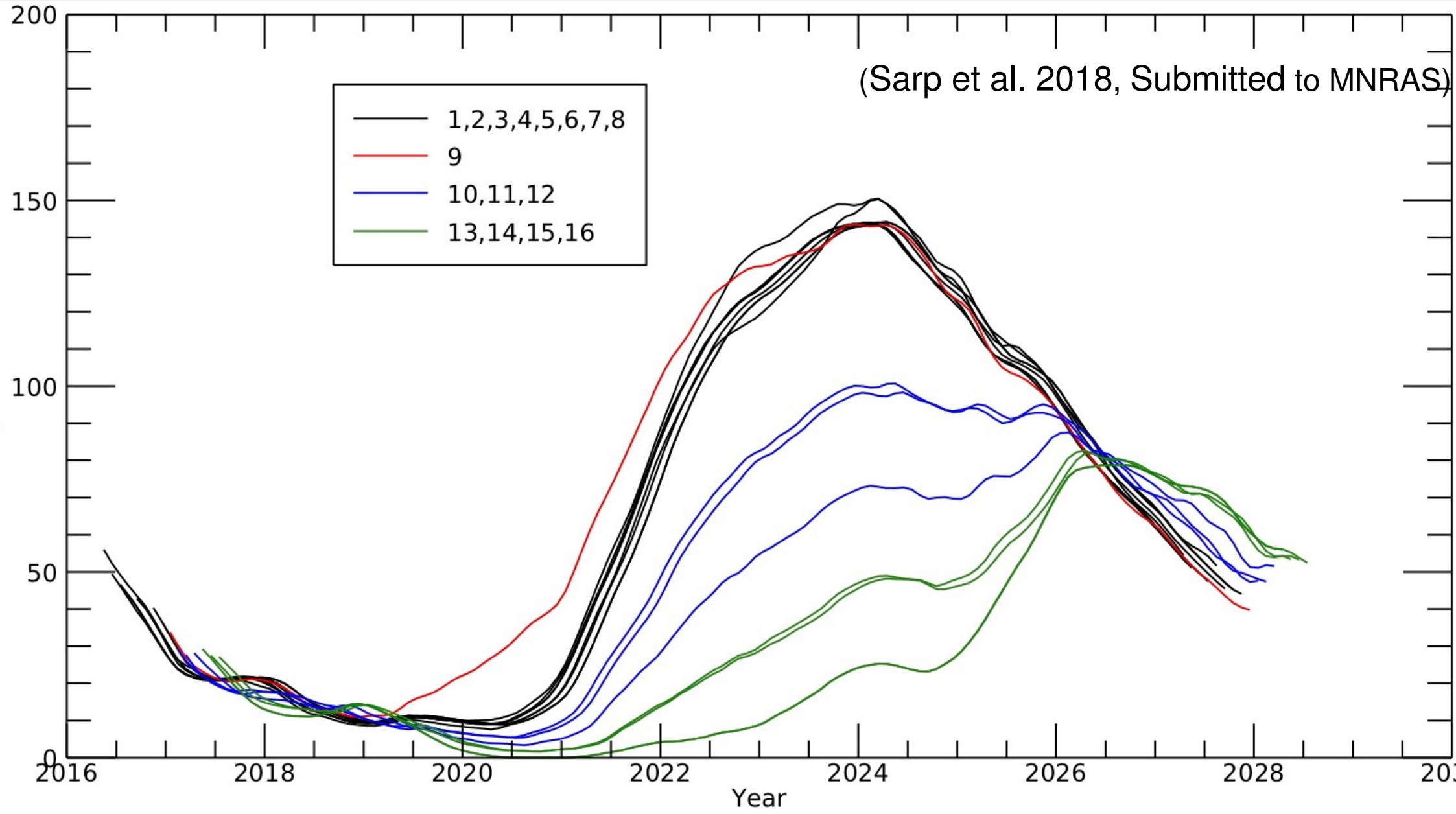
- Successful prediction criteria are created as follows;
  1. Correlation coefficient should be higher than 0.90
  2. Mean squared error should be lower than 20

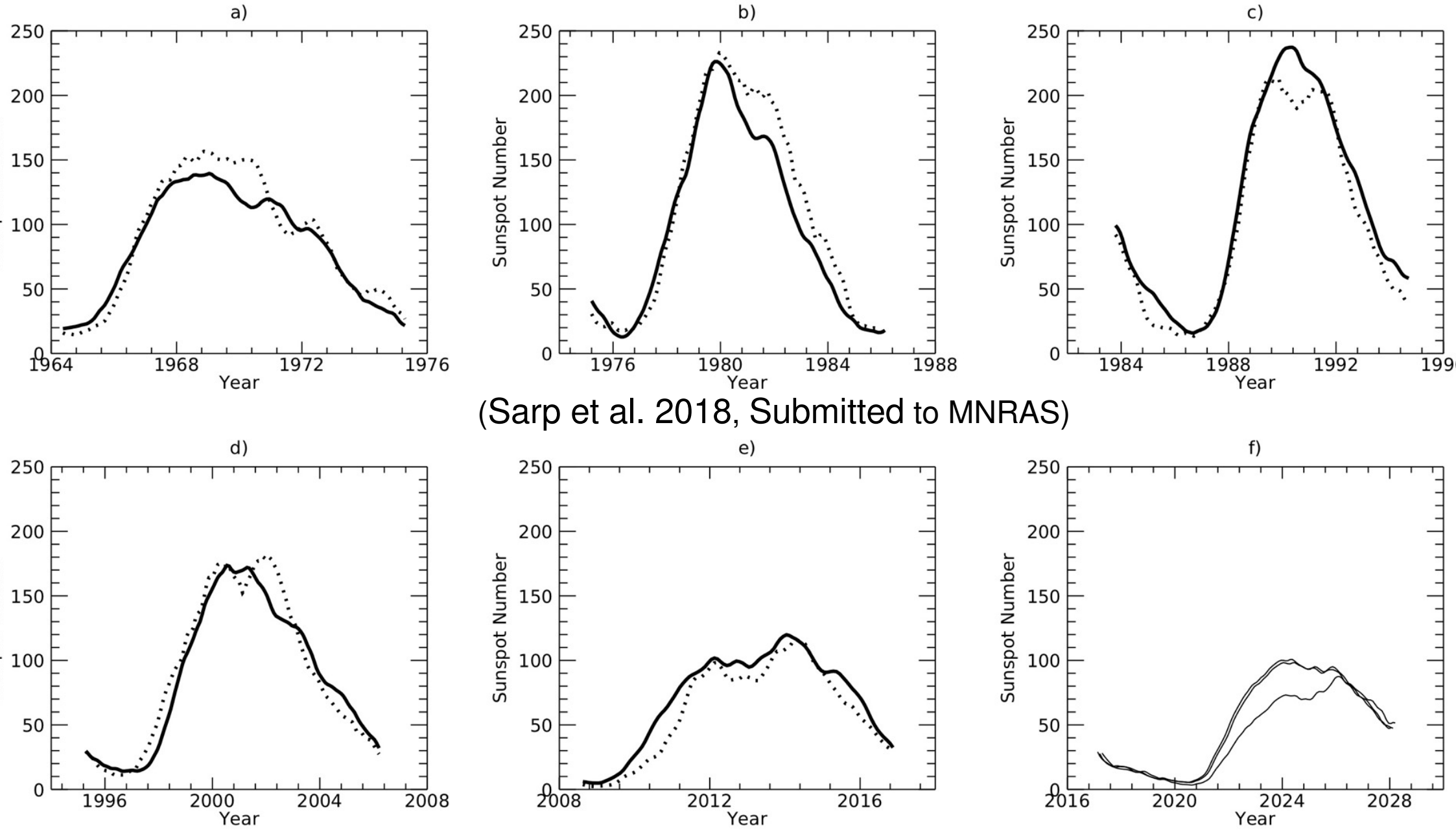

2
3
4
5
6
Embedding Dimension


50
40
30
20
10
Number of Successful Predictions
2
3
4
5
Embedding Dimension



(Sarp et al. 2018, Submitted to MNRAS)


(Sarp et al. 2018, Submitted to MNRAS)
1,2,3,4,5,6,7,8
9
10,11,12
13,14,15,16
200
150
100
50
0
2016
2018
2020
2022
2024
2026
2028
Year



(Sarp et al. 2018, Submitted to MNRAS)

RESULTS

- Nonlinear (chaotic) methods works well on solar activity cycles.
- Starting point is a crucial parameter in a nonlinear prediction scheme of a solar activity cycle.
- We predict the solar cycle 25 as a double peaked cycle.
  - First peak: 70-100 sunspots between February 2024 and May 2024.
  - Second peak: 87-93 sunspots between November 2025 and February 2026

THANK YOU FOR YOUR ATTENTION

Volkan SARP[1] & Ali KILCIK[1]

[1]Akdeniz University, Faculty of Science

Department of Space Science and Technologies

Antalya, Turkey

E-mail : theneutron@gmail.com

Collaborators: Vasyl Yurchyshyn, Atila Ozguc, Jean-Pierre Roze

study was supported by Akdeniz University Research Fund by proje

8