Possible Non-linear Interactions Between Some Space Weather Parameters

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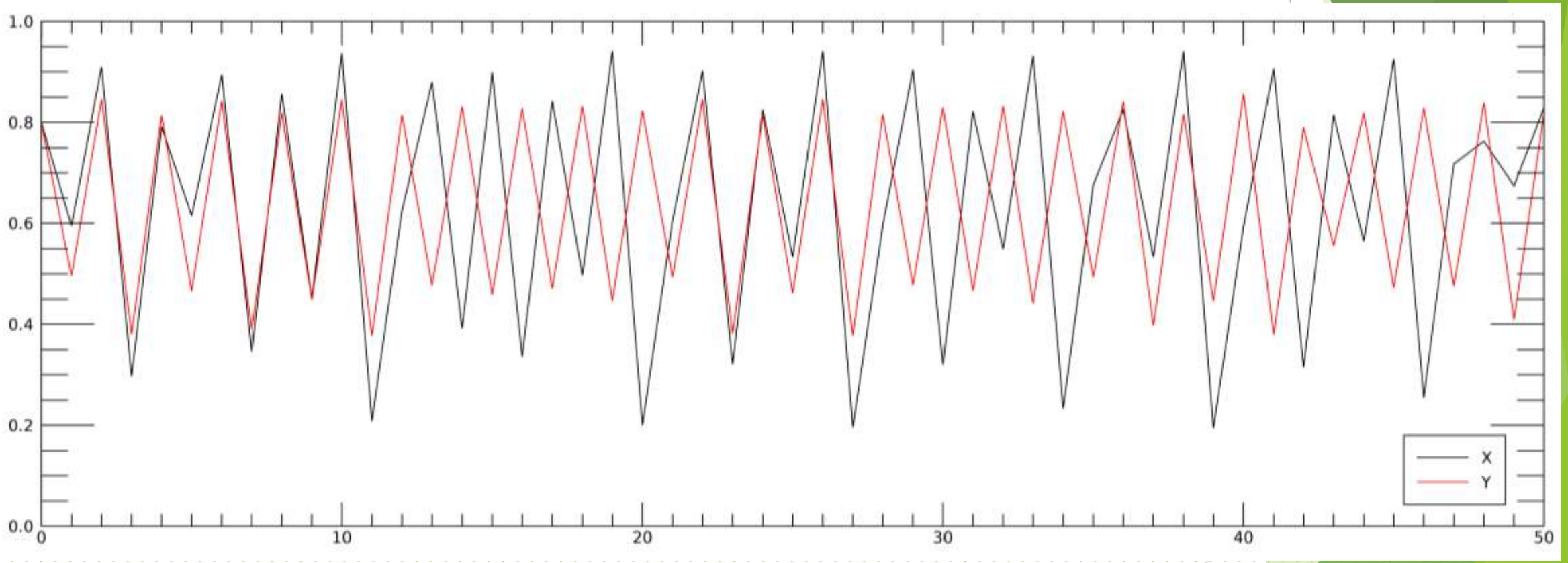
- Variables are state dependent. They can be strongly coupled at some times but at other times they can appear unrelated.
- In such cases, correlation is neither necessary nor sufficient to establish causation.
- We aim to distinguish causaition from correlation with the methods of **cros-correlation** and **convergent cross mapping**
- Data Source: **OMNIWeb, SOHO/LASCO CME Catalog** and **OULU Neutron Monitor**
- Couplings and correlation coefficients are analyzed for
  - Solar Wind Speed
  - F10.7 Solar Index
  - Cosmic Ray Intensity
  - DST Index
  - Maximum CME Speed Index
- Finally, interactions of all these parameters with the IMF Bz component is analyzed

- $$X(t+1) = X(t) * [3.8 - 3.8 * X(t) - 0.02 * Y(t)]$$

$$Y(t+1) = Y(t) * [3.5 - 3.5 * Y(t) - 0.1 * X(t)]$$



50 iteration
CC = 0.22

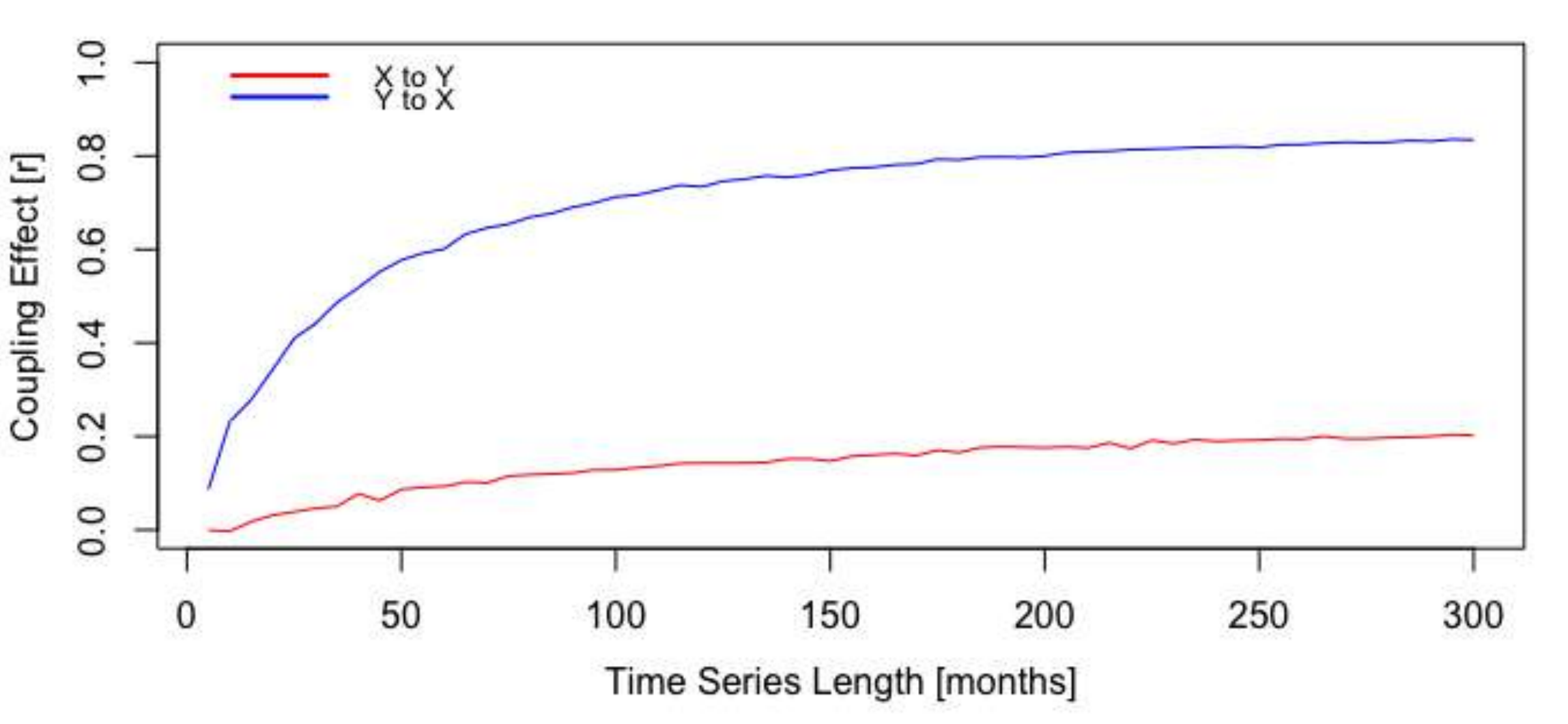
300 iteration
CC = 0.10

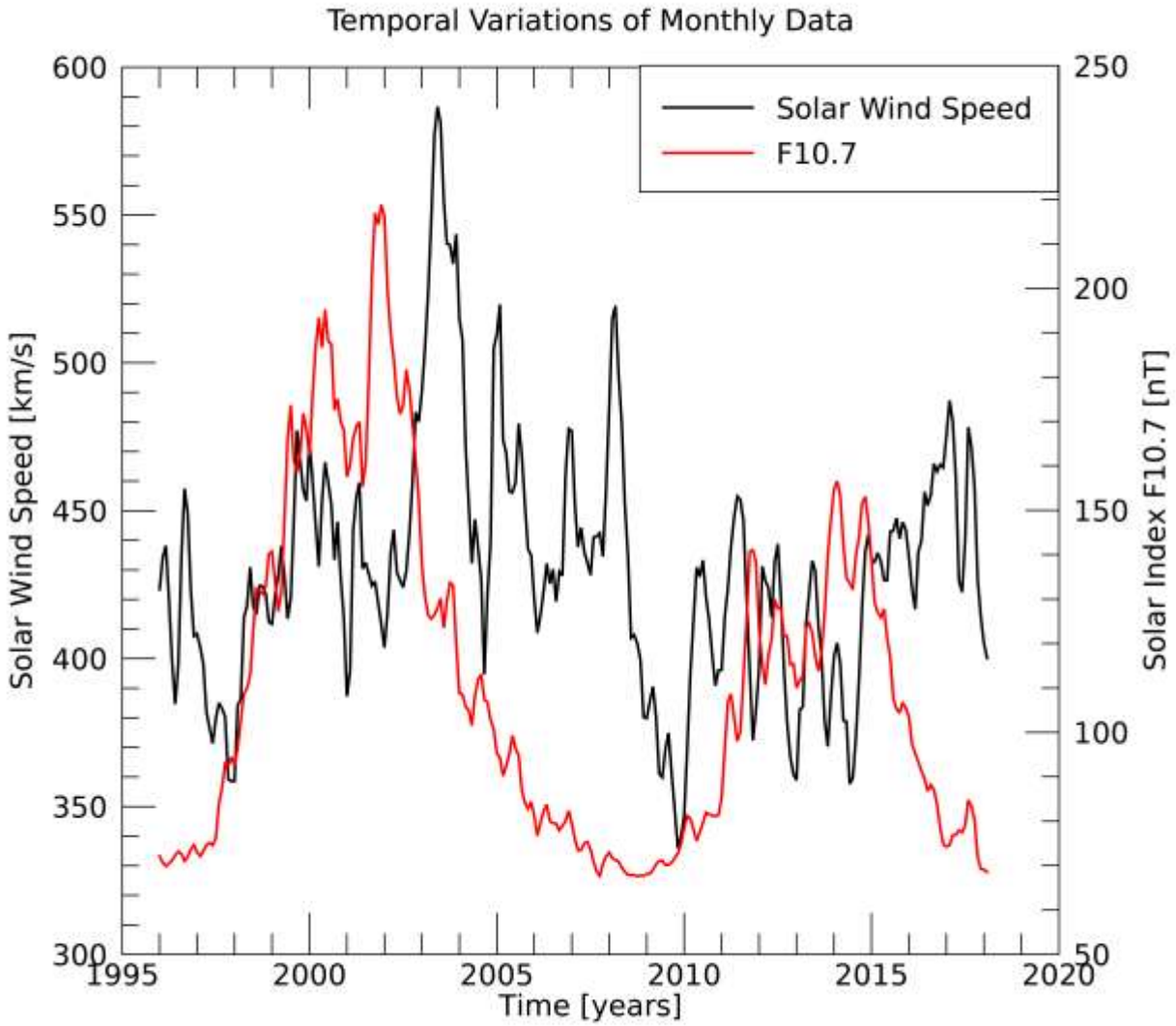
Convergent Cross Mapping

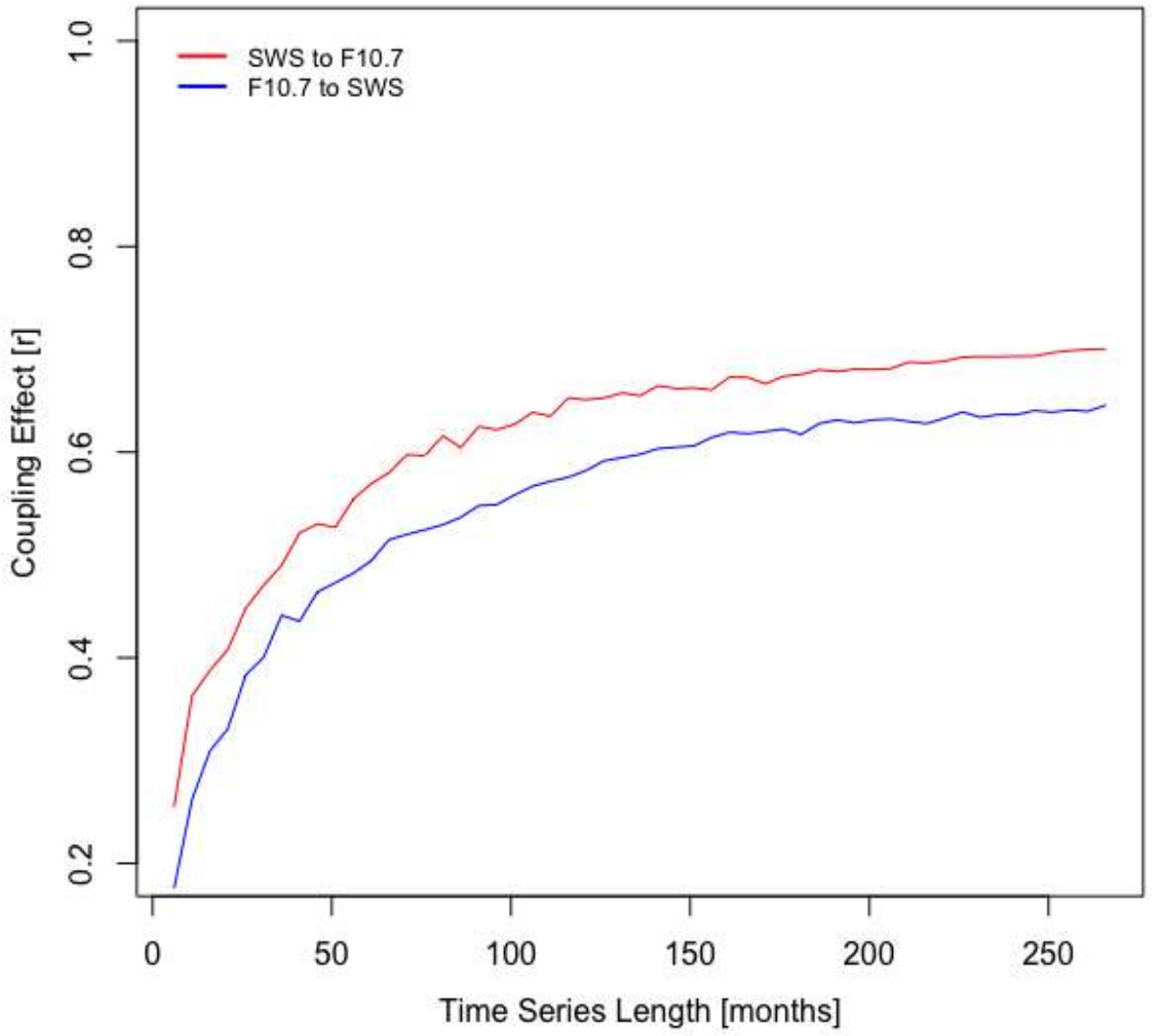
- Based on attractor reconstruction (**Taken's Embedding Theorem, 1981**)
- Introduced by **Sugihara et al. (2012) Science.**
- A generic property of the reconstructions is that the states of X(t) on the manifold Mx **maps one-to-one onto states in the original attractor** manifold M.
- For two variables X and Y that are dynamically coupled, local neighborhoods on their reconstructions (Mx and My) **will map to each other since X and Y are essentially alternative observations of the common original attractor** in manifold M.
- CCM determines **how well local neighborhoods on Mx correspond to local neighborhoods on My** and vice versa.
- Convergence means cross-mapped estimates **improve in estimation skill (coupling effect) with time series length**

- $$X(t+1) = X(t) * [3.8 - 3.8 * X(t) - 0.02 * Y(t)]$$

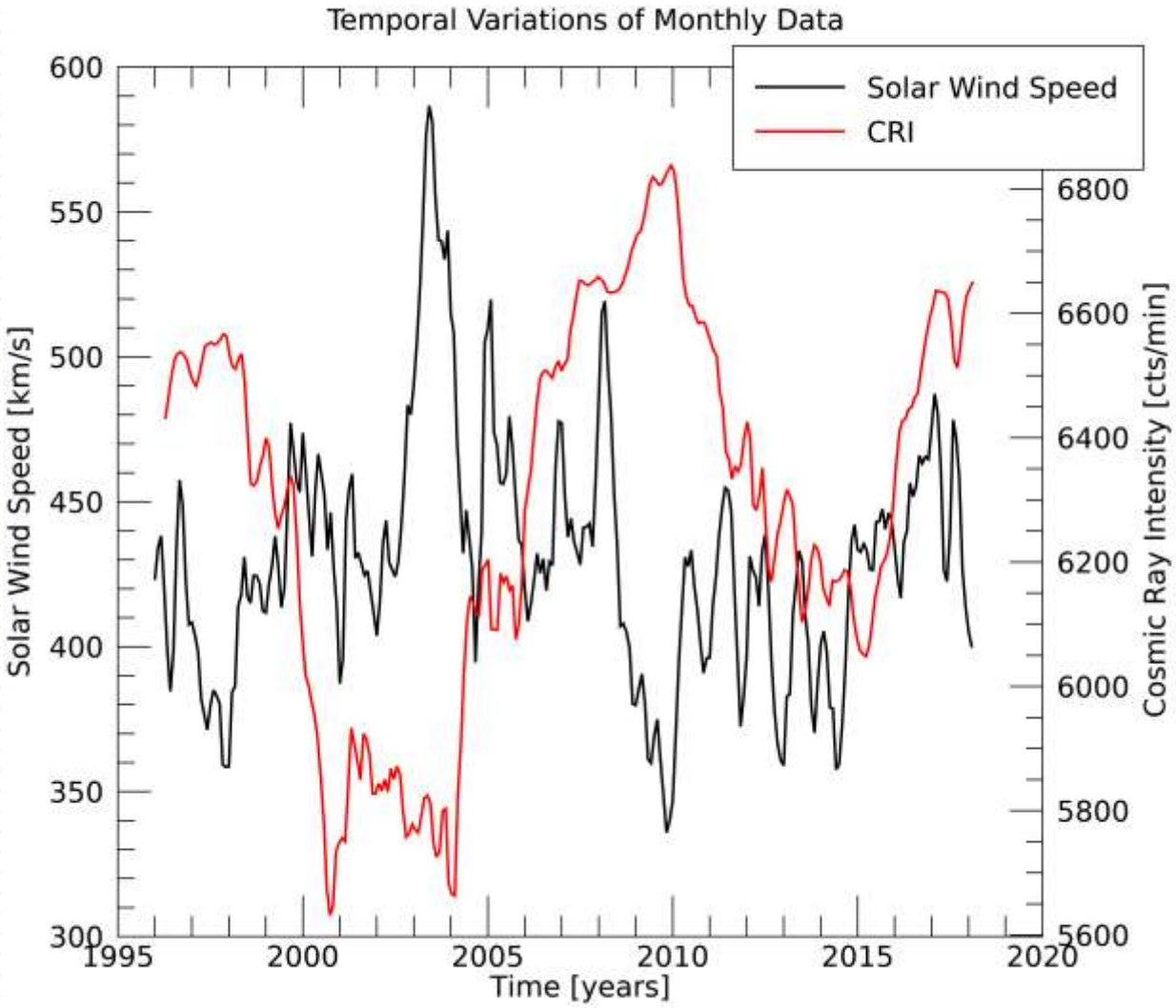
$$Y(t+1) = Y(t) * [3.5 - 3.5 * Y(t) - 0.1 * X(t)]$$

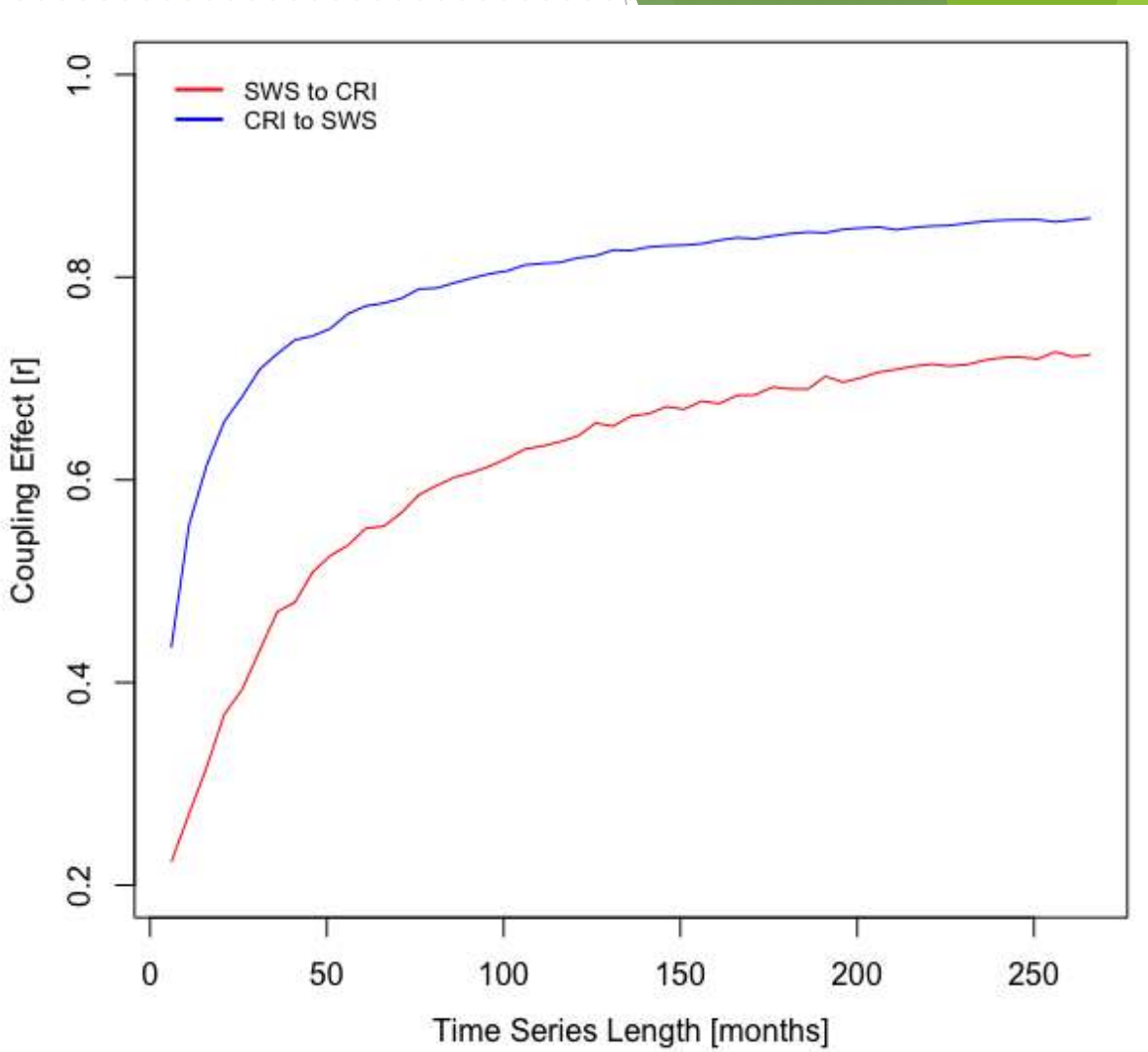



Temporal Variations of Monthly Data
Solar Wind Speed
F10.7
Solar Wind Speed [km/s]
Solar Index F10.7 [nT]
Time [years]
600
550
500
450
400
350
300
250
200
150
100
50
1995
2000
2005
2010
2015
2020

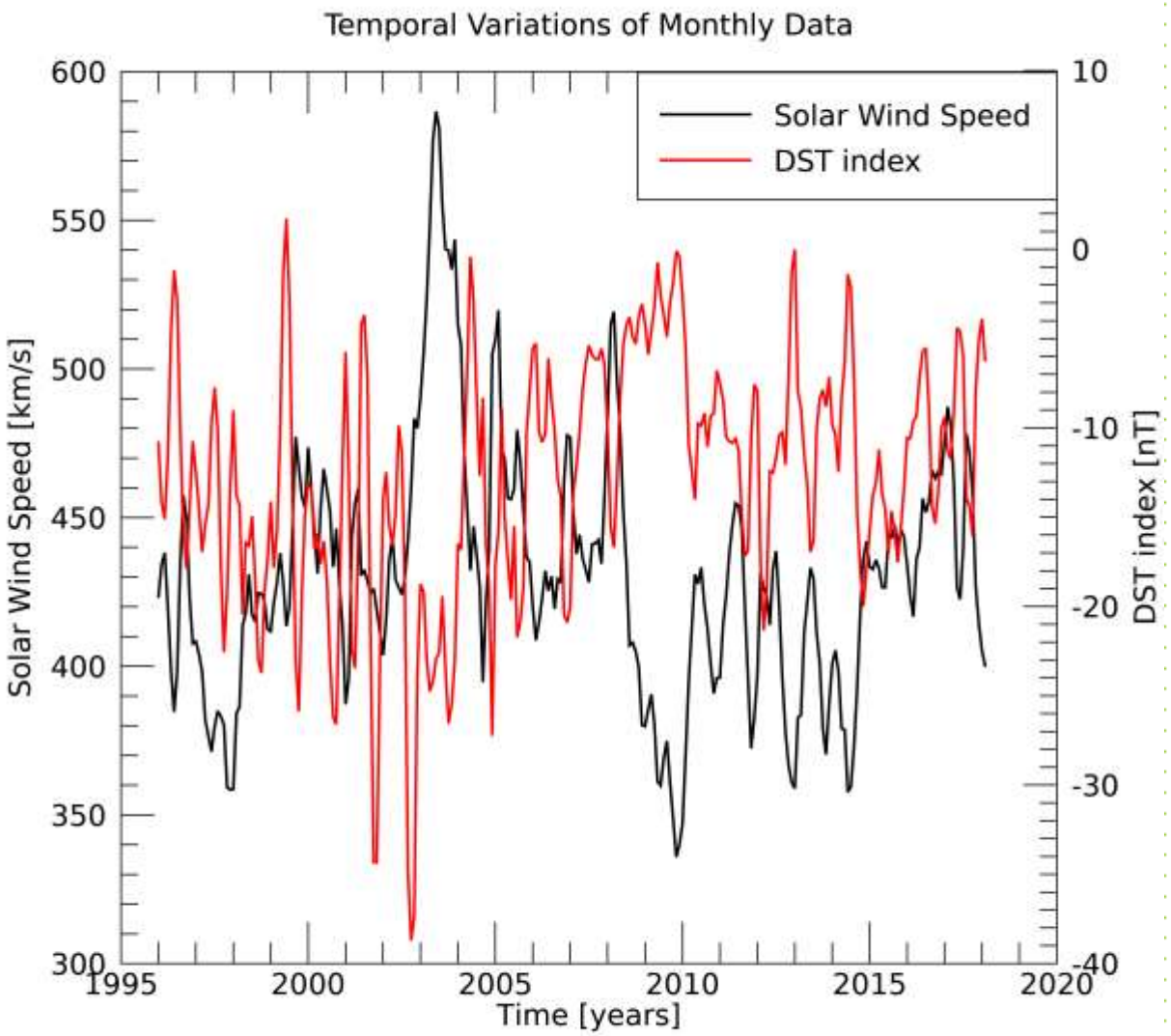

SWS to F10.7
F10.7 to SWS
Coupling Effect [r]
Time Series Length [months]
1.0
0.8
0.6
0.4
0.2
0
50
100
150
200
250

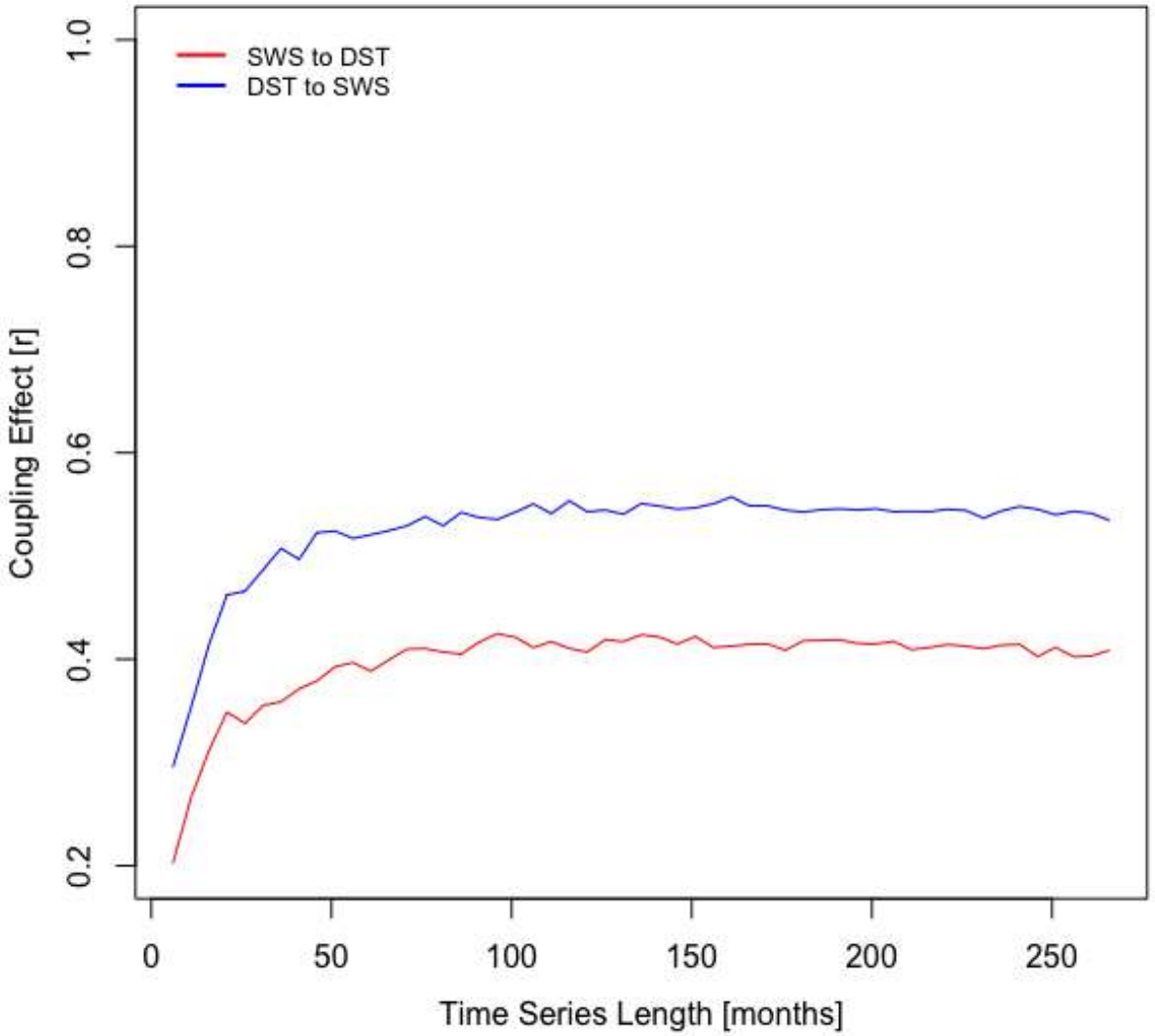
CC = 0.53 Lag = -38


Temporal Variations of Monthly Data
Solar Wind Speed
CRI
Solar Wind Speed [km/s]
Cosmic Ray Intensity [cts/min]
Time [years]
600
550
500
450
400
350
300
6800
6600
6400
6200
6000
5800
5600
1995
2000
2005
2010
2015
2020


SWS to CRI
CRI to SWS
Coupling Effect [r]
Time Series Length [months]
1.0
0.8
0.6
0.4
0.2
0
50
100
150
200
250

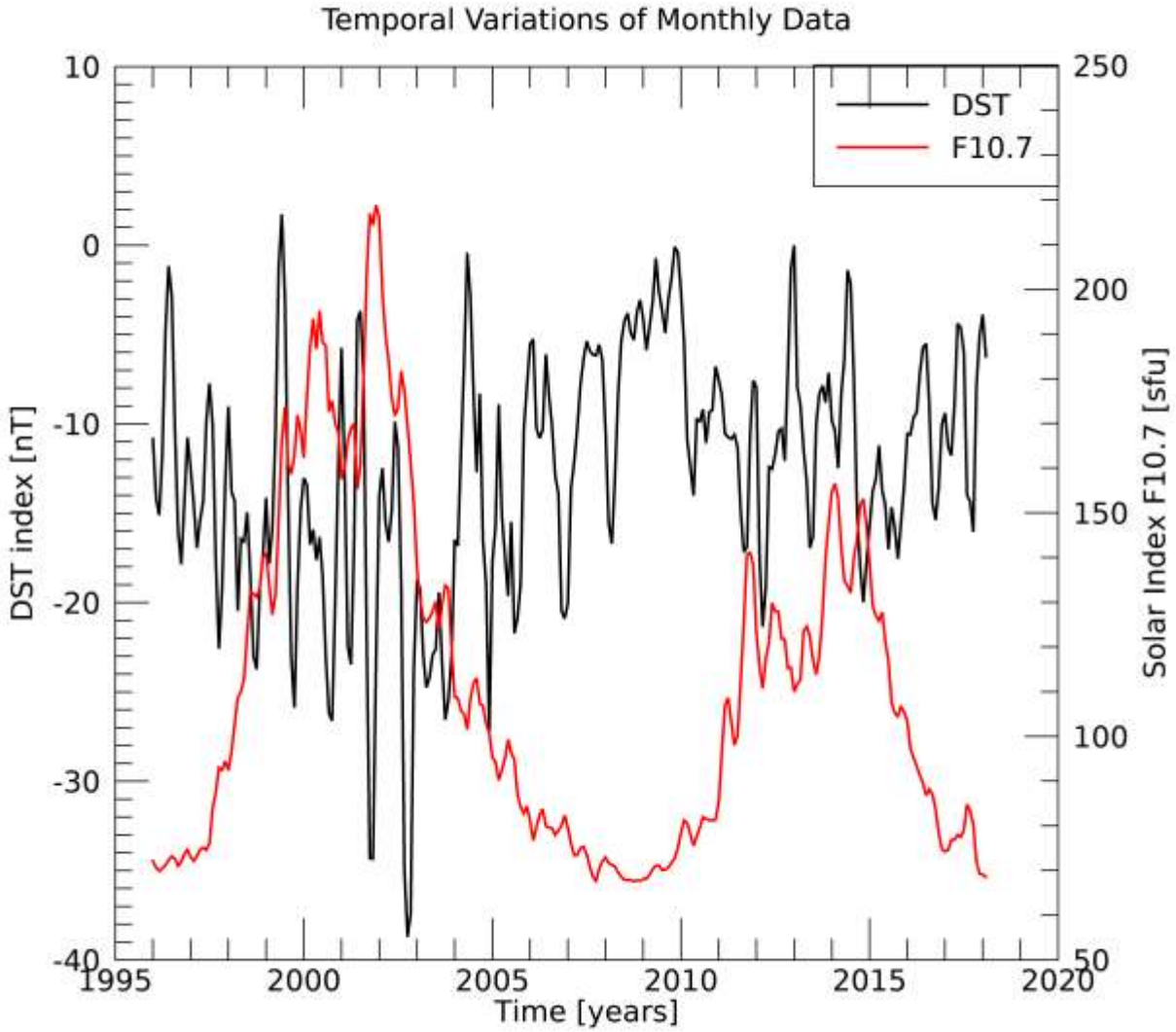
CC = -0.53 Lag = -36

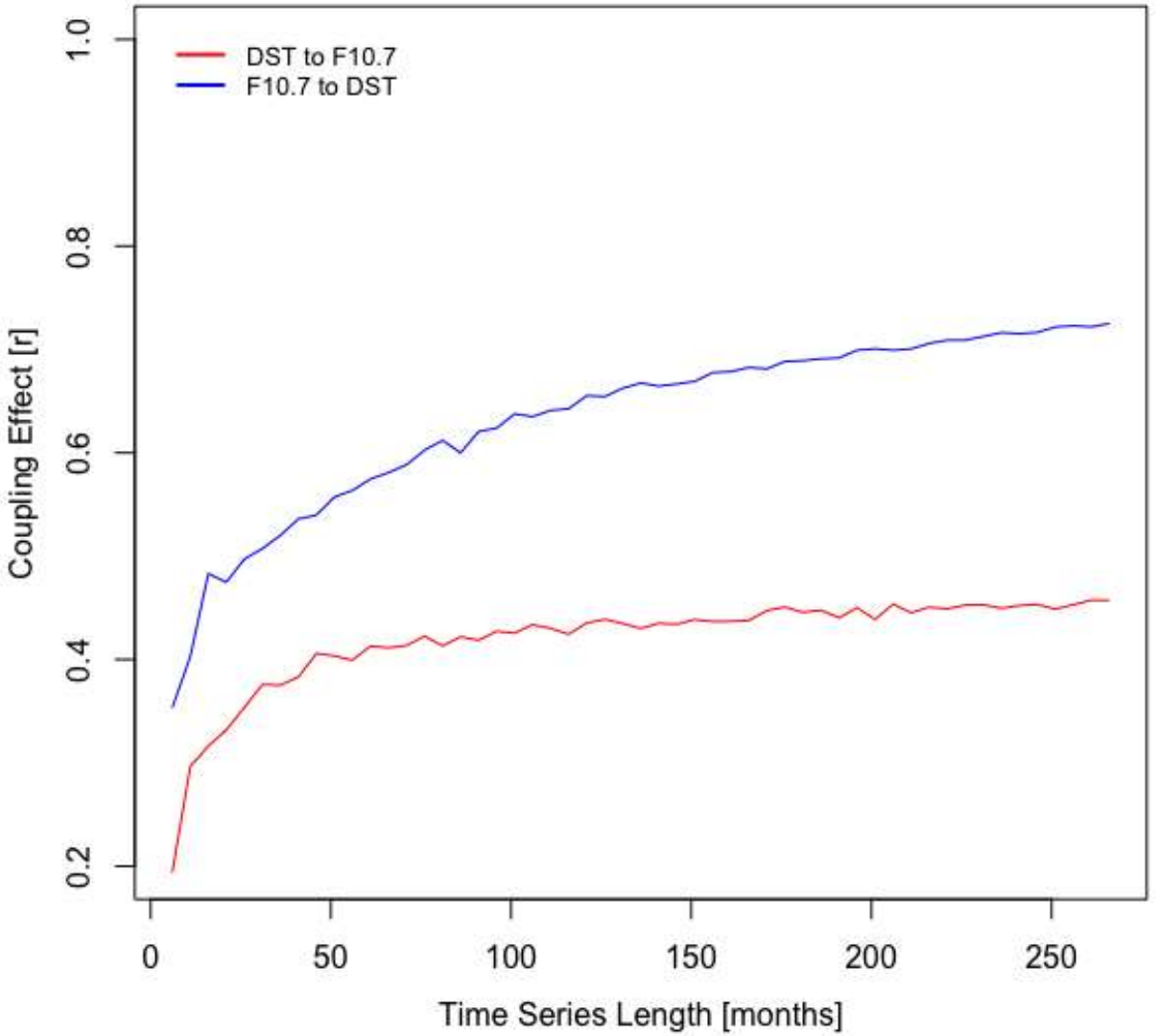

Temporal Variations of Monthly Data
Solar Wind Speed
DST index
Solar Wind Speed [km/s]
DST index [nT]
Time [years]
600
550
500
450
400
350
300
10
0
-10
-20
-30
-40
1995
2000
2005
2010
2015
2020


SWS to DST
DST to SWS
Coupling Effect [r]
Time Series Length [months]
1.0
0.8
0.6
0.4
0.2
0
50
100
150
200
250

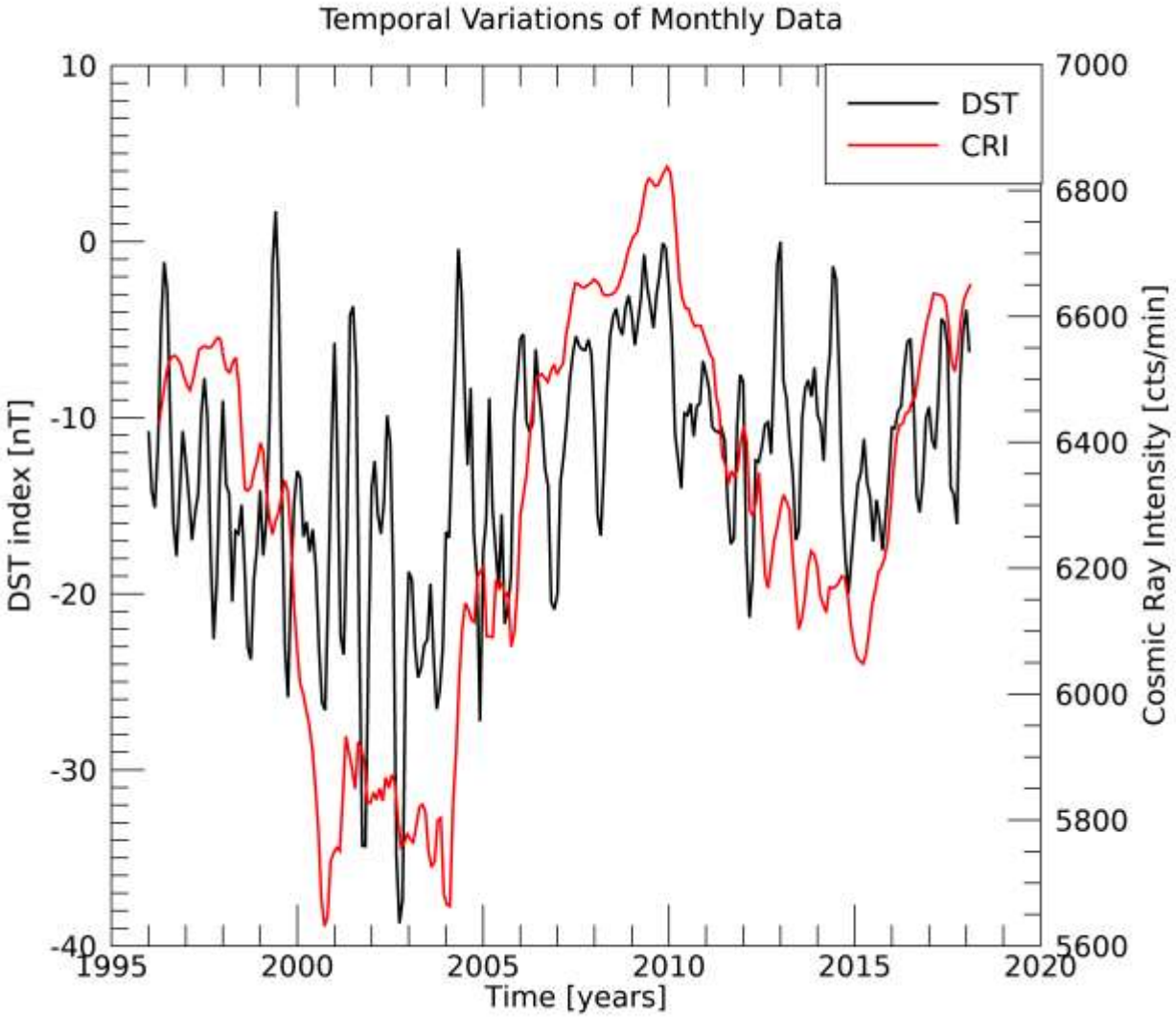
CC = -0.53

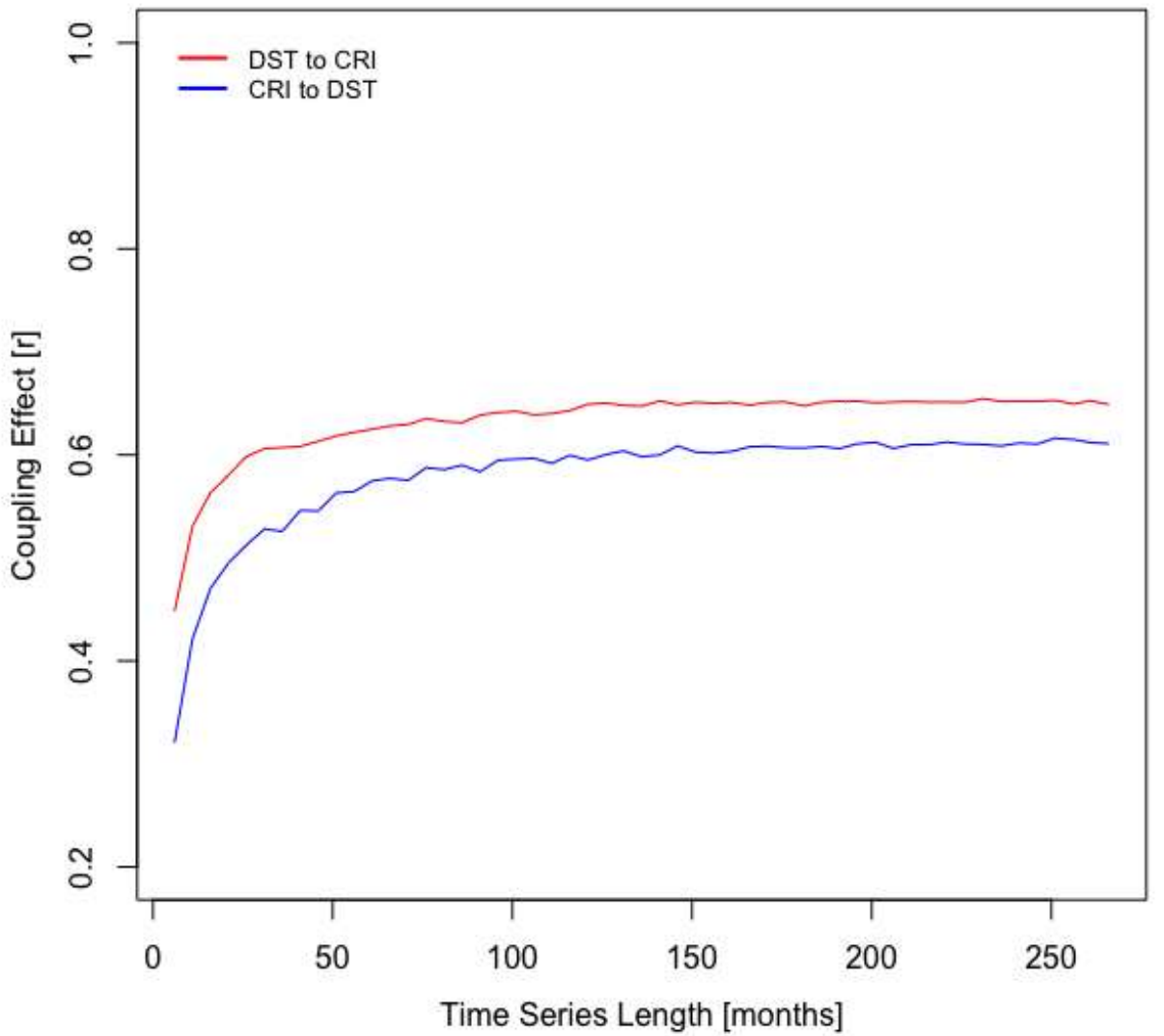
Lag = 0


Temporal Variations of Monthly Data
DST
F10.7
DST index [nT]
Solar Index F10.7 [sfu]
Time [years]
10
0
-10
-20
-30
-40
250
200
150
100
50
1995
2000
2005
2010
2015
2020

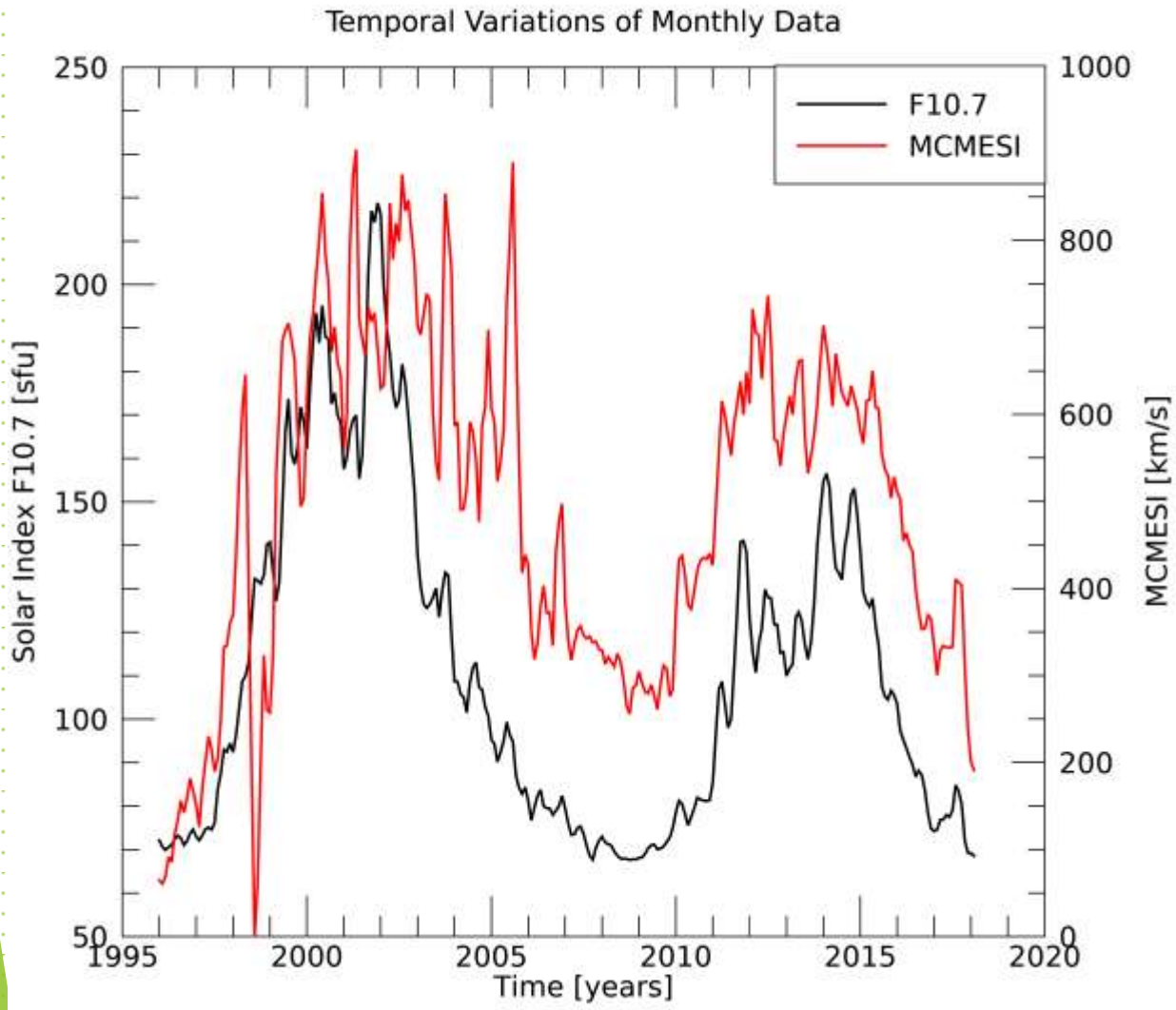

DST to F10.7
F10.7 to DST
Coupling Effect [r]
Time Series Length [months]
1.0
0.8
0.6
0.4
0.2
0
50
100
150
200
250

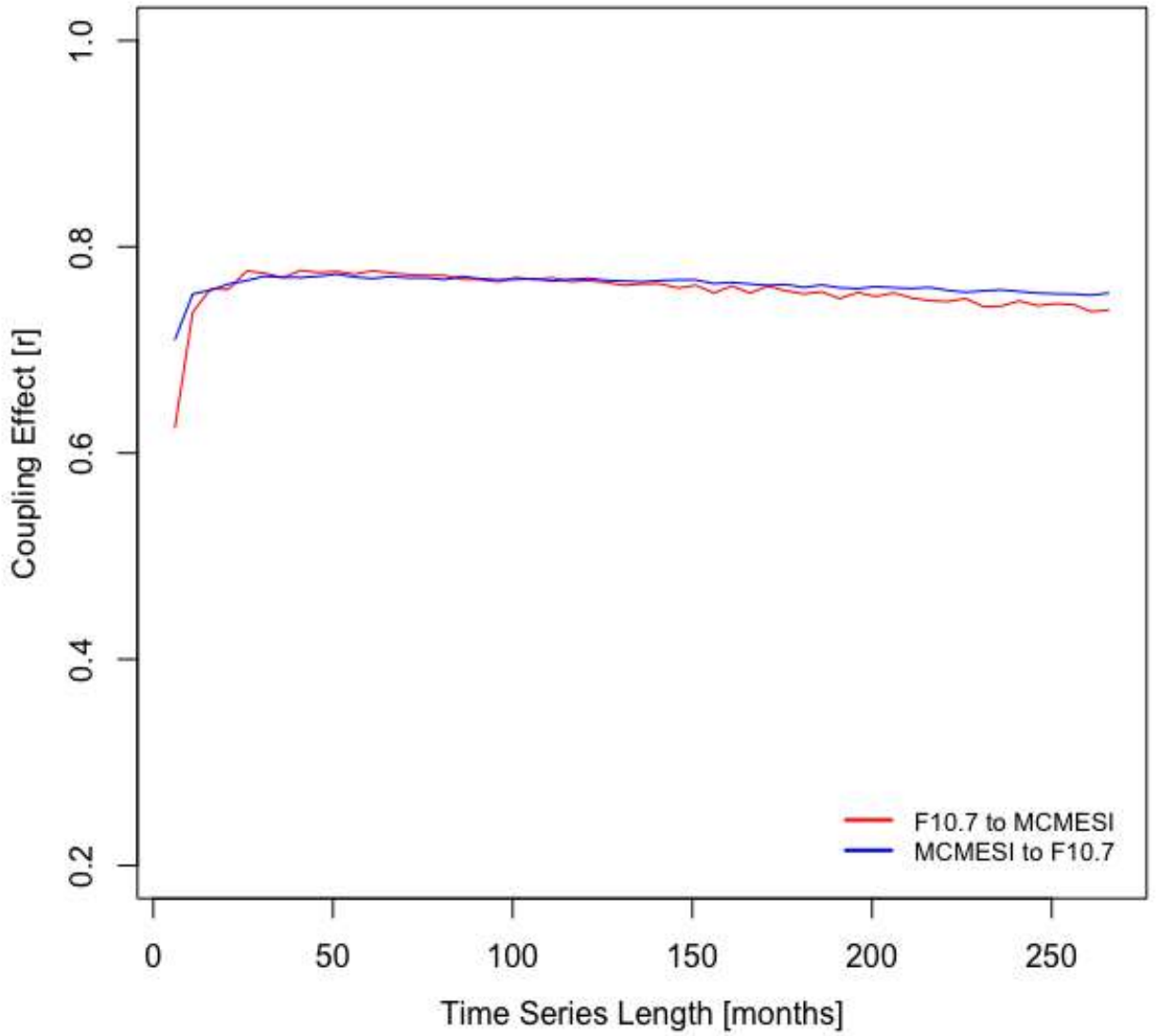
CC = -0.49 Lag = -11


Temporal Variations of Monthly Data
DST
CRI
DST index [nT]
Cosmic Ray Intensity [cts/min]
Time [years]
10
0
-10
-20
-30
-40
7000
6800
6600
6400
6200
6000
5800
5600
1995
2000
2005
2010
2015
2020

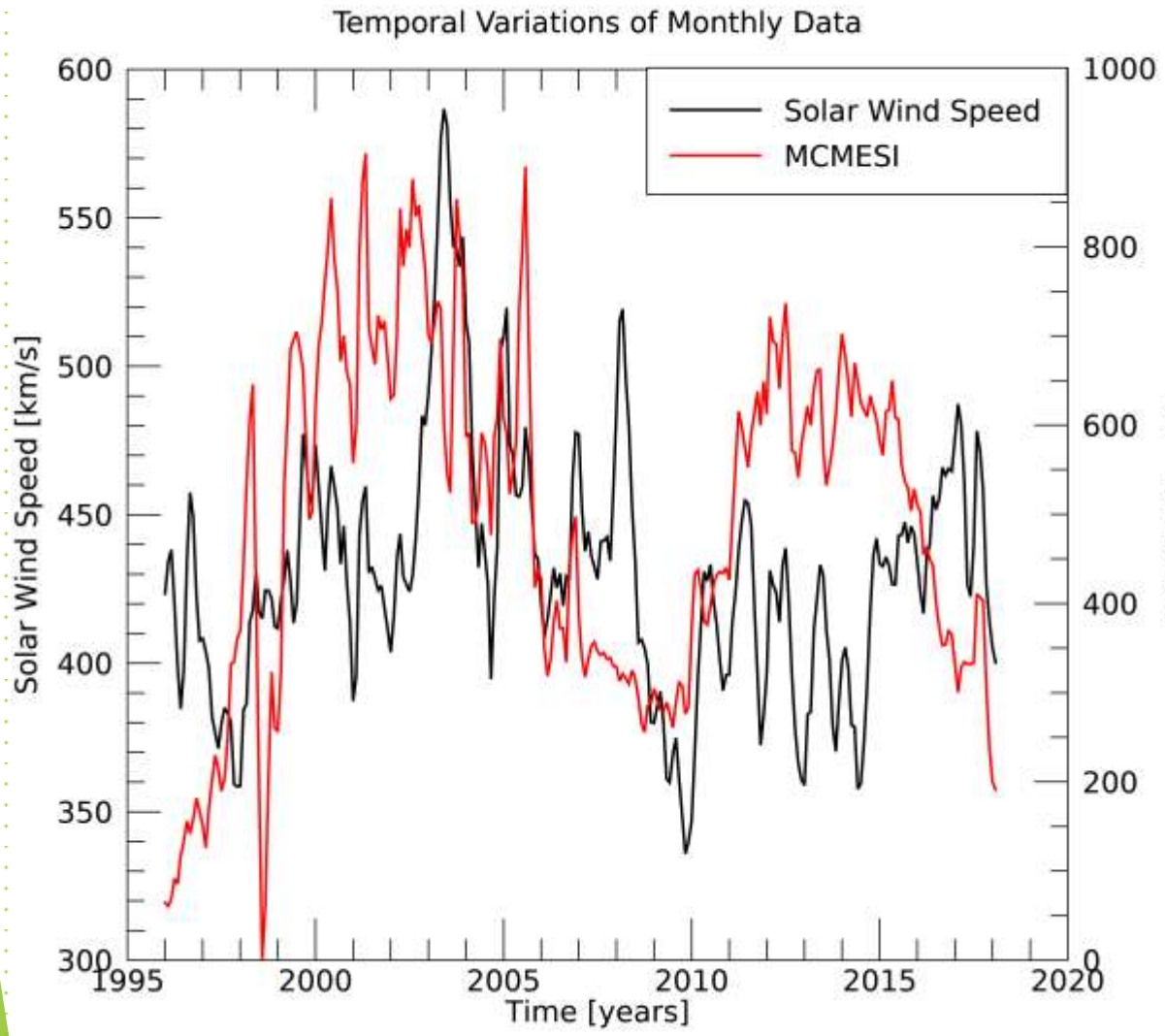

DST to CRI
CRI to DST
Coupling Effect [r]
Time Series Length [months]
1.0
0.8
0.6
0.4
0.2
0
50
100
150
200
250

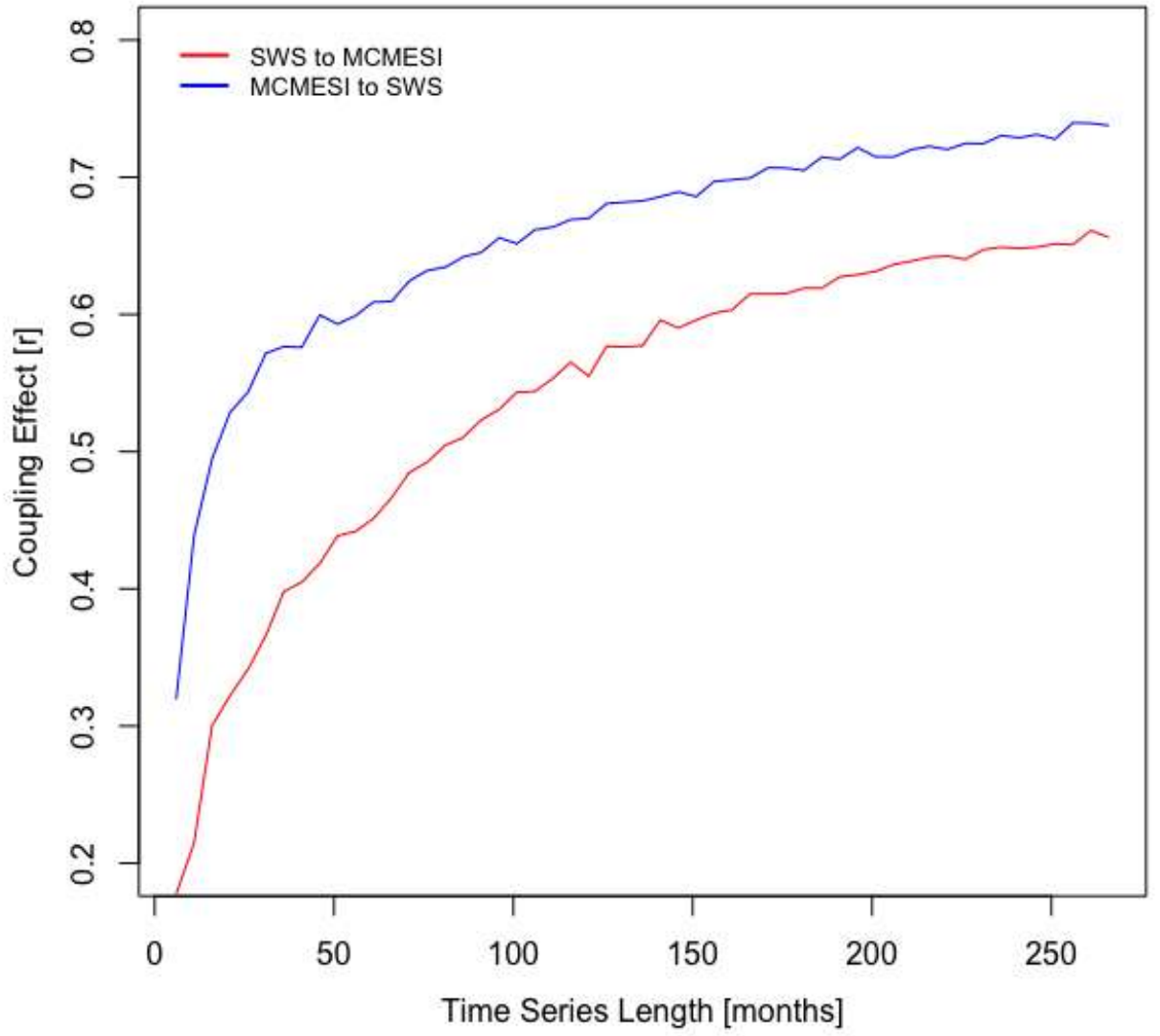
CC = 0.59 Lag=0


Temporal Variations of Monthly Data
F10.7
MCMESI
Solar Index F10.7 [sfu]
MCMESI [km/s]
Time [years]
250
200
150
100
50
1000
800
600
400
200
0
1995
2000
2005
2010
2015
2020

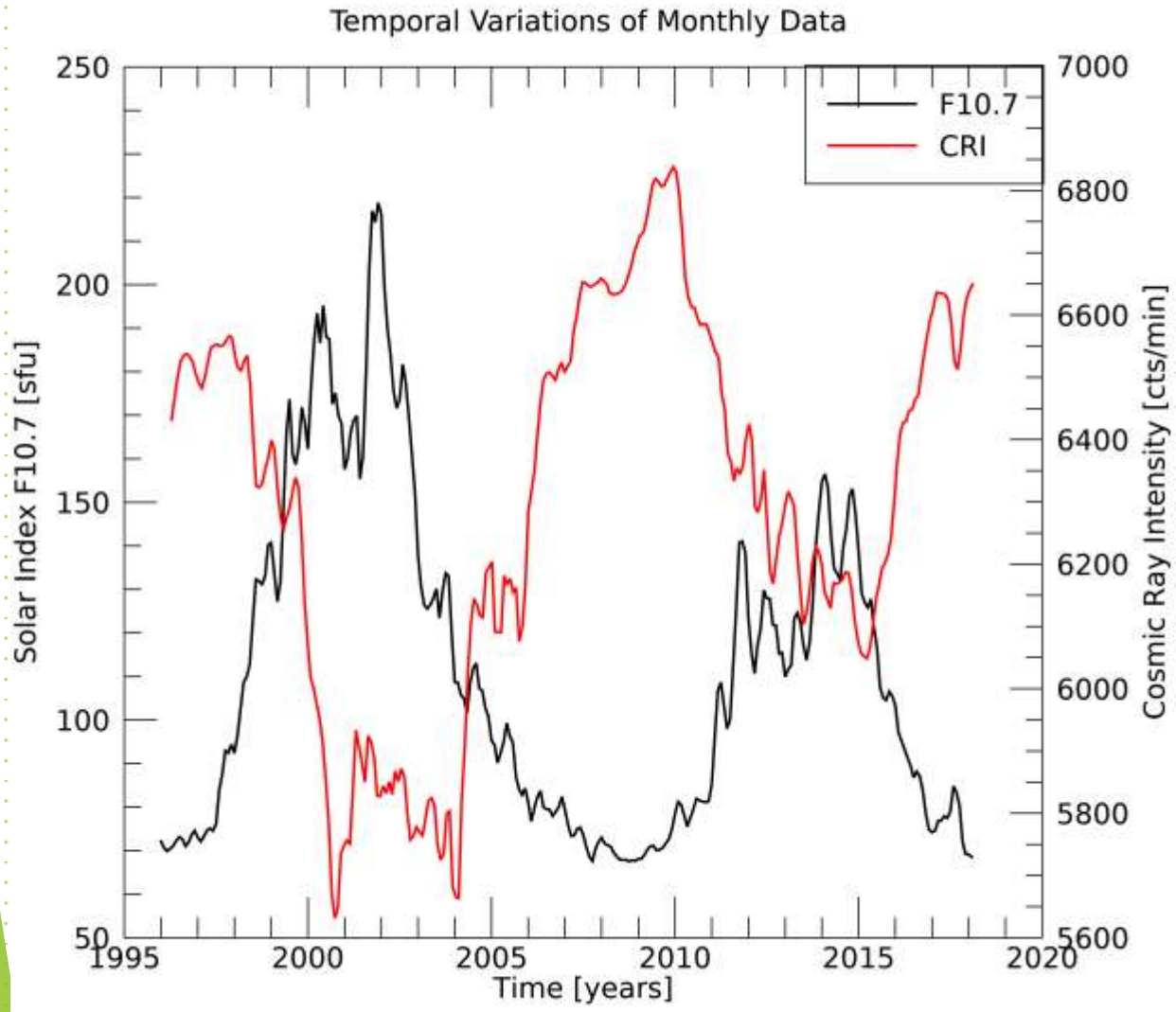

Coupling Effect [r]
Time Series Length [months]
F10.7 to MCMESI
MCMESI to F10.7
1.0
0.8
0.6
0.4
0.2
0
50
100
150
200
250

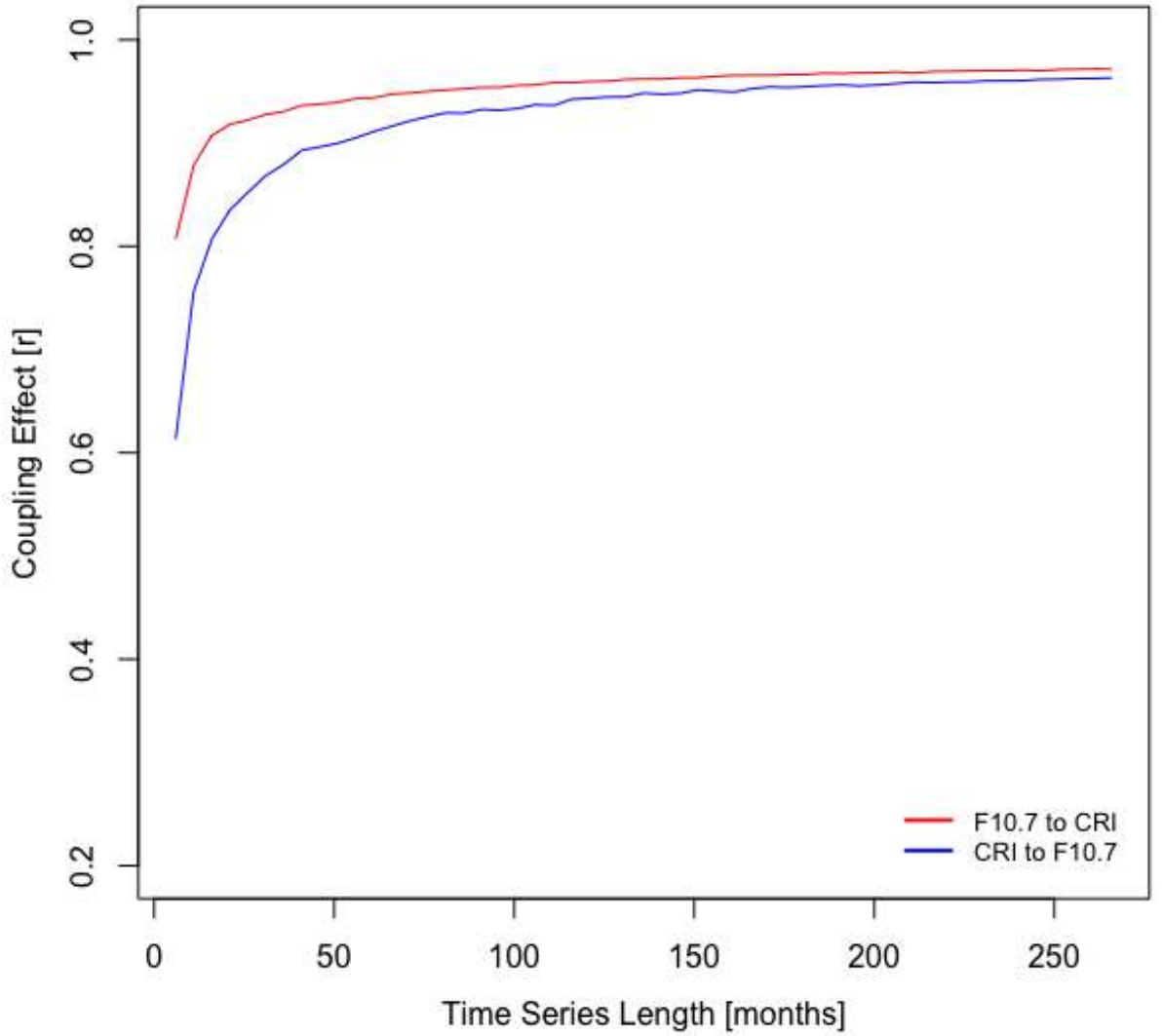
CC = 0.75 Lag=0


Temporal Variations of Monthly Data
Solar Wind Speed
MCMESI
Solar Wind Speed [km/s]
MCMESI [km/s]
Time [years]
600
550
500
450
400
350
300
1000
800
600
400
200
0
1995
2000
2005
2010
2015
2020

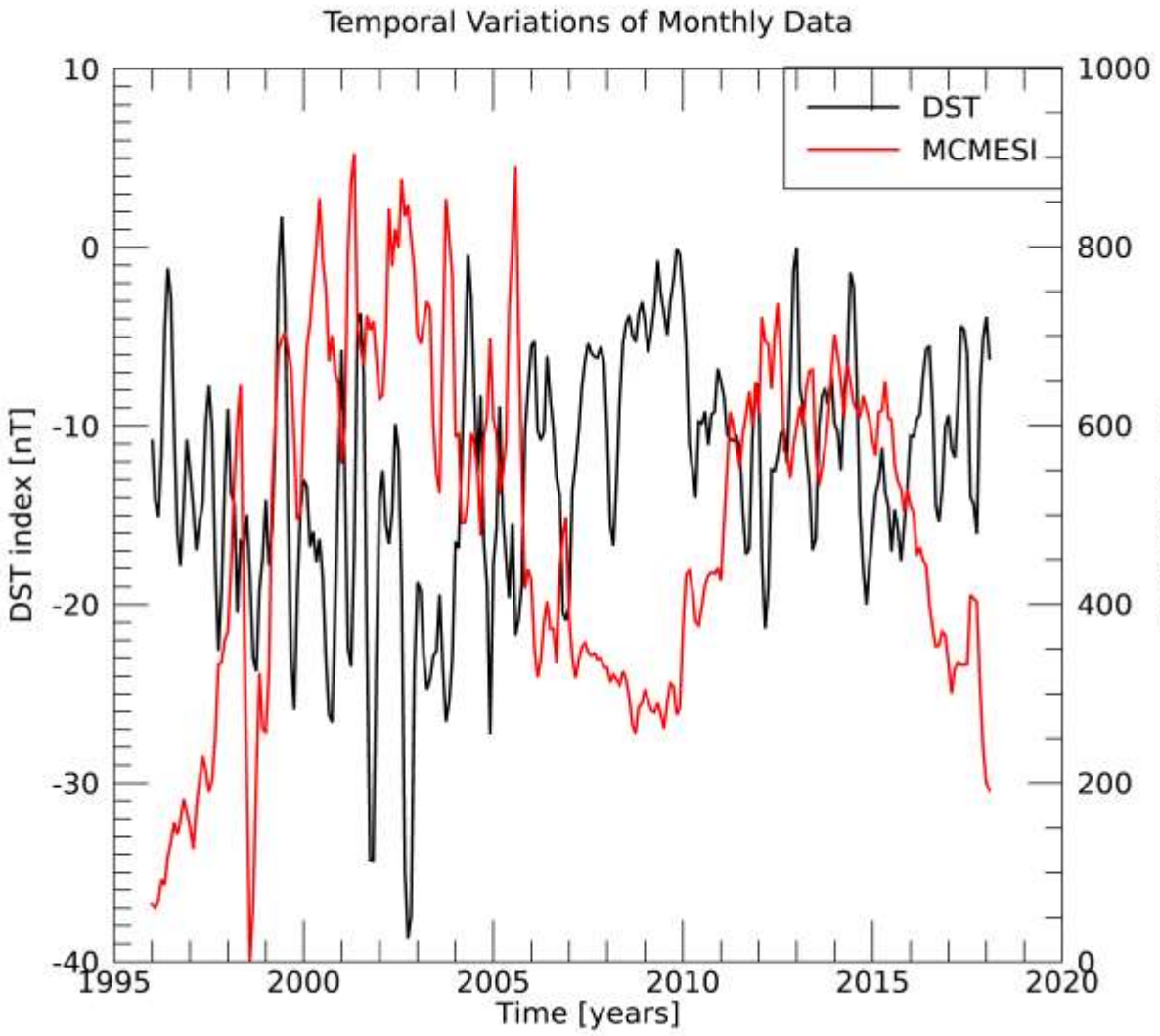

SWS to MCMESI
MCMESI to SWS
Coupling Effect [r]
Time Series Length [months]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
50
100
150
200
250

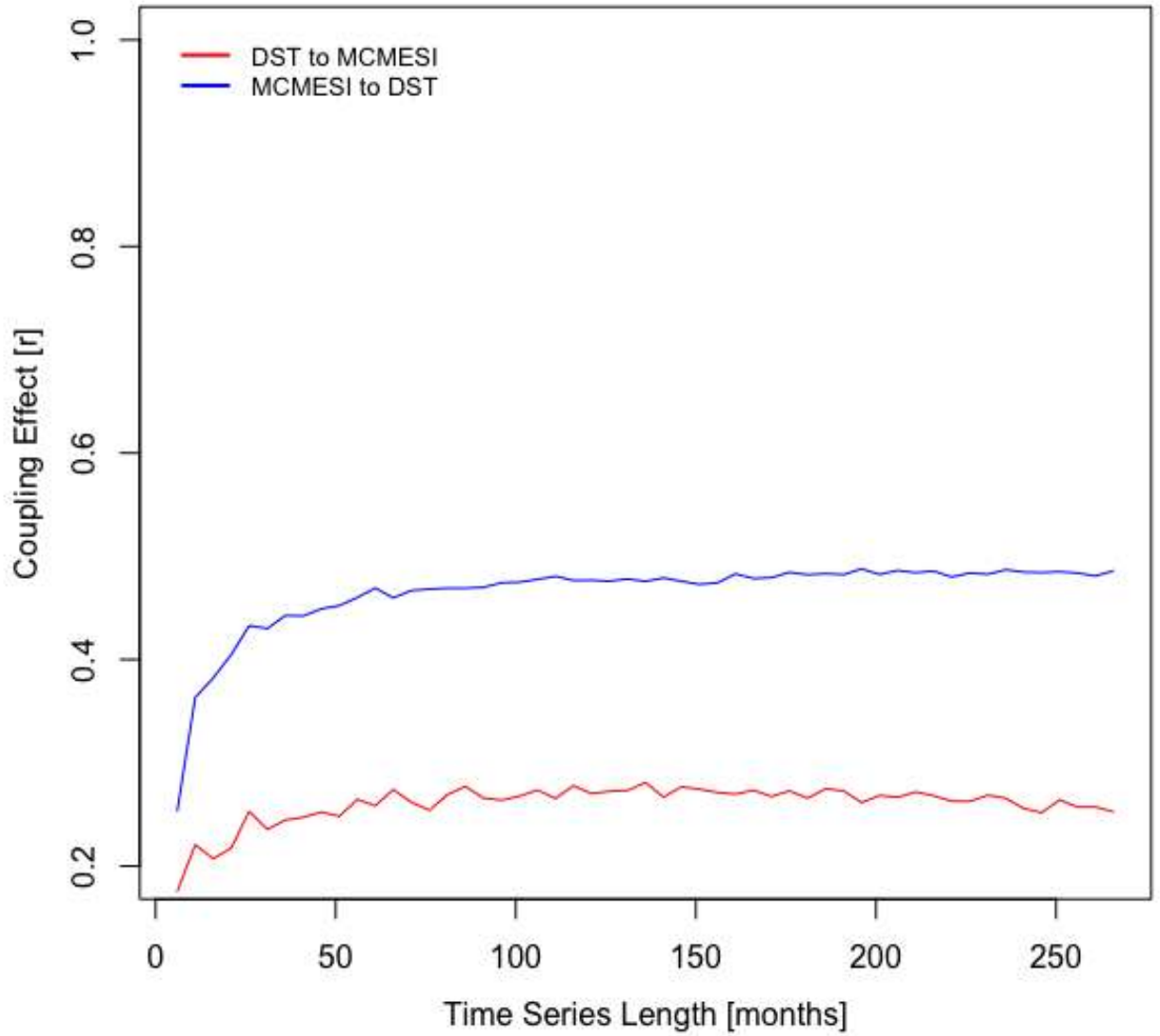
CC = 0.40 Lag = -15


Temporal Variations of Monthly Data
F10.7
CRI
Solar Index F10.7 [sfu]
Cosmic Ray Intensity [cts/min]
Time [years]
250
200
150
100
50
7000
6800
6600
6400
6200
6000
5800
5600
1995
2000
2005
2010
2015
2020

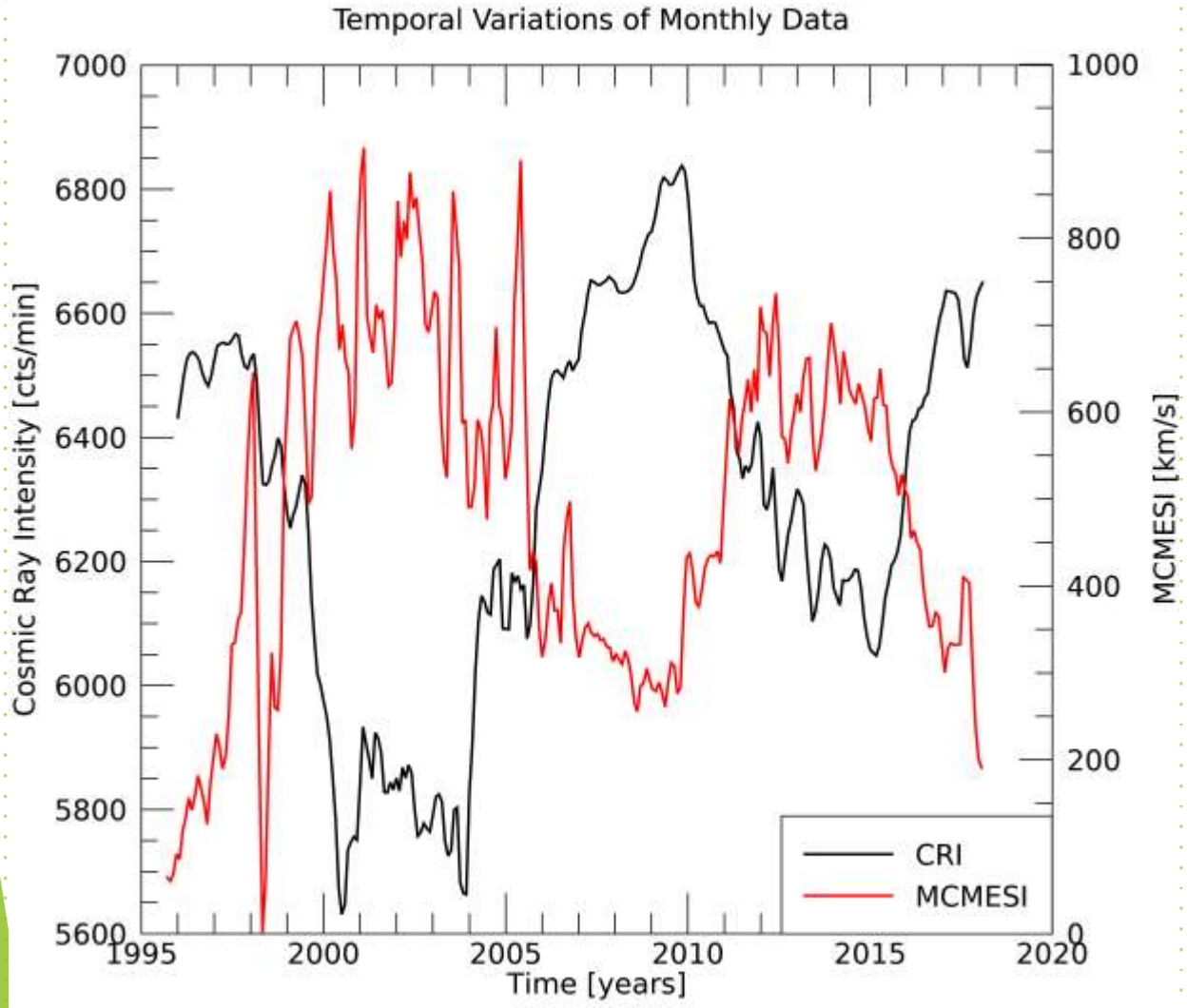

Coupling Effect [r]
Time Series Length [months]
F10.7 to CRI
CRI to F10.7
1.0
0.8
0.6
0.4
0.2
0
50
100
150
200
250

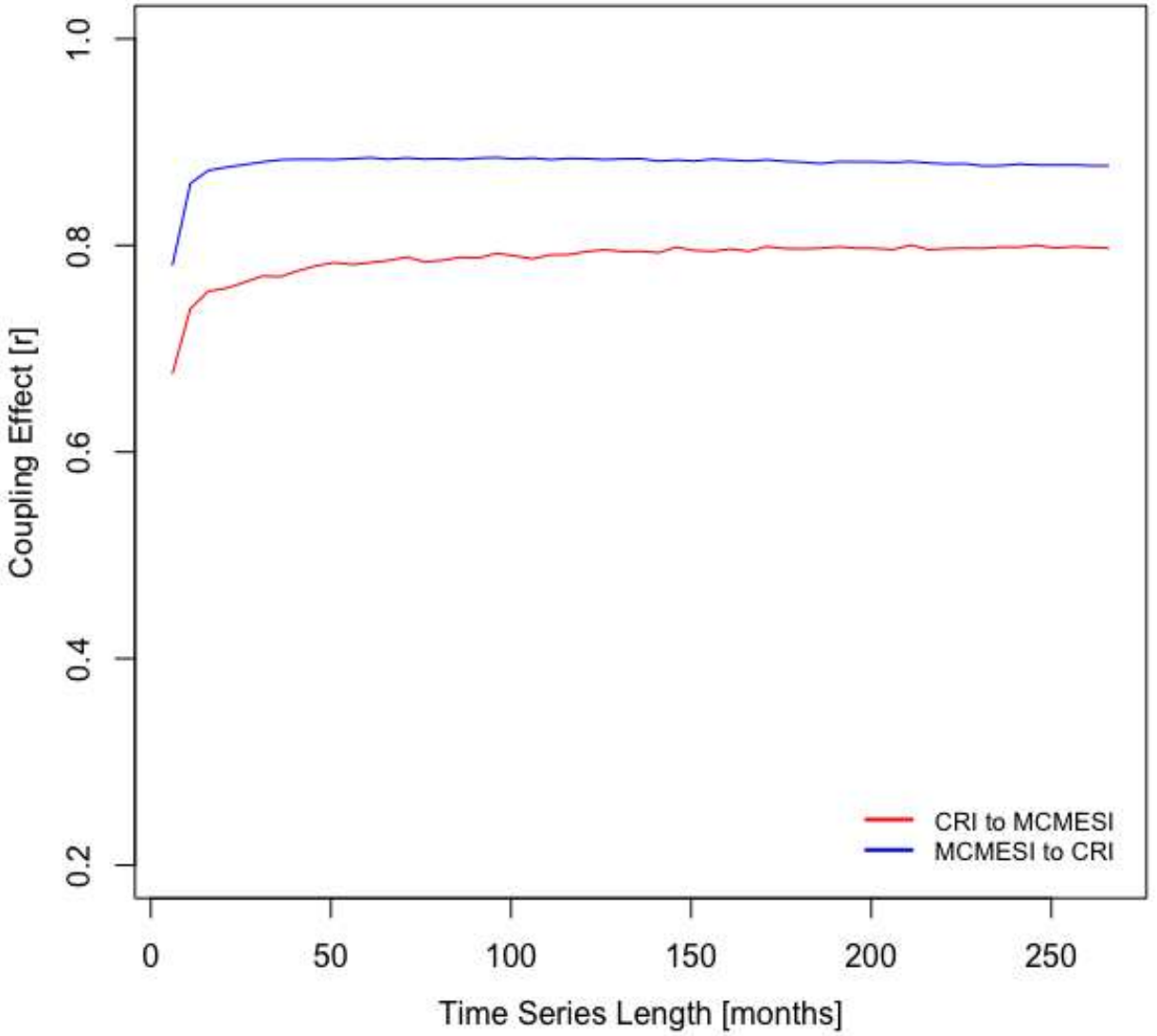
CC = -0.88 *Lag = 9*


Temporal Variations of Monthly Data
DST
MCMESI
DST index [nT]
MCMESI [km/s]
Time [years]
10
0
-10
-20
-30
-40
1000
800
600
400
200
0
1995
2000
2005
2010
2015
2020


DST to MCMESI
MCMESI to DST
Coupling Effect [r]
Time Series Length [months]
1.0
0.8
0.6
0.4
0.2
0
50
100
150
200
250

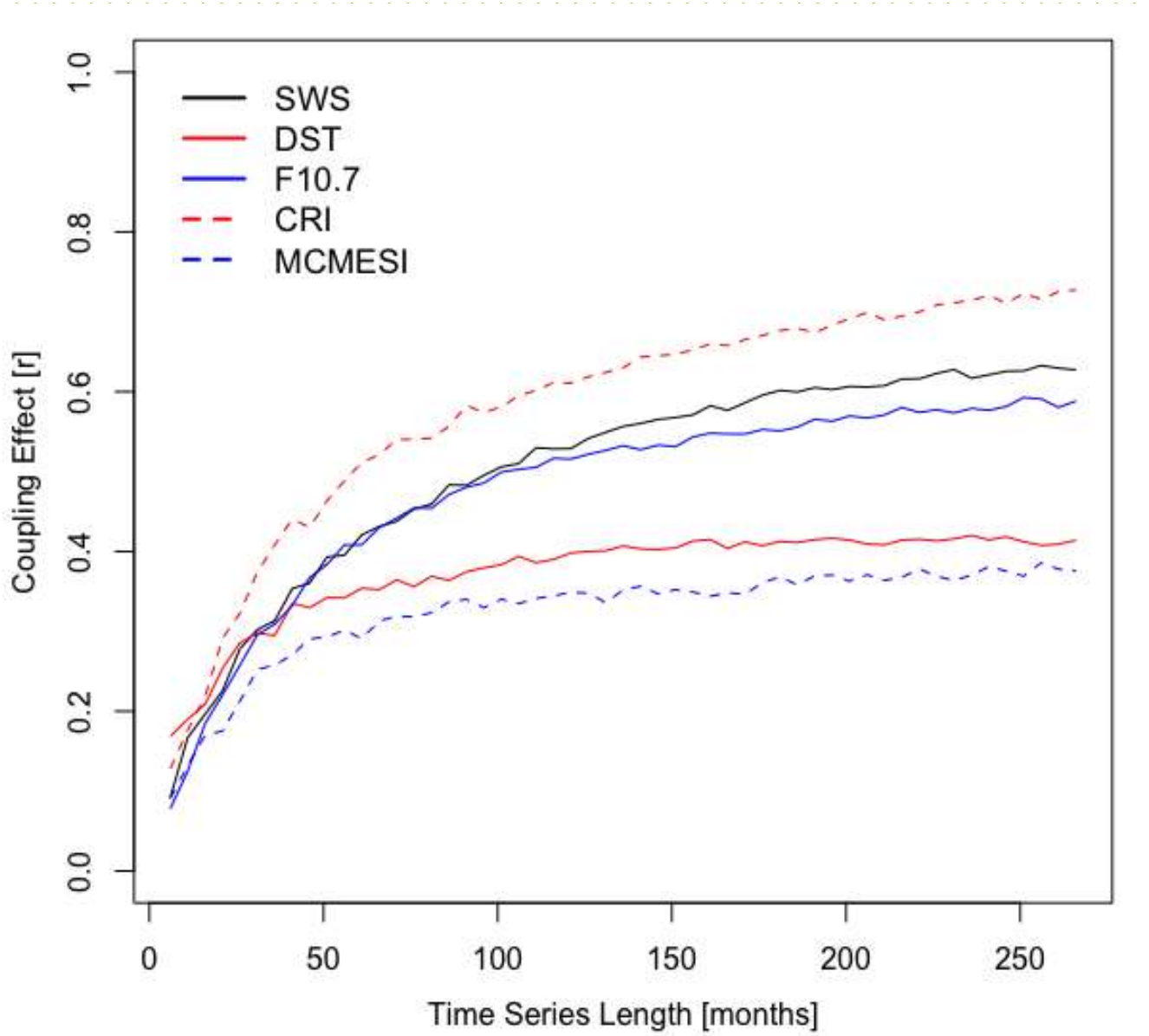
CC = -0.41 Lag = 0


Temporal Variations of Monthly Data
Cosmic Ray Intensity [cts/min]
MCMESI [km/s]
Time [years]
CRI
MCMESI
7000
6800
6600
6400
6200
6000
5800
5600
1000
800
600
400
200
0
1995
2000
2005
2010
2015
2020


Coupling Effect [r]
Time Series Length [months]
CRI to MCMESI
MCMESI to CRI
1.0
0.8
0.6
0.4
0.2
0
50
100
150
200
250

CC = -0.80 *Lag = 1*

IMF Bz Component



Conclusion

- Correlation does not imply causation!
- CCM results managed to shows some well known relations between studied time series such as F10.7 and Cosmic Ray Intensity.
- Compared to the correlation coefficient values, it is possible to reveal higher scores for dynamically coupled variables and lower scores for unrelated parameters.
- Not all relations are symmetrical or bidirectional as opposed to what correlation suggests.

Thank you for your attention!

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