DEMOCRITUS UNIVERSITY OF THRACE
DEPARTMENT OF ENVIRONMENTAL ENGINEERING
LABORATORY OF ATMOSPHERIC POLLUTION AND POLLUTION CONTROL ENGINEERING OF ATMOSPHERIC POLLUTANTS

Cause-and-effect relations between cosmic rays, electric field, aerosols and clouds

Stathopoulos S. [1*], Misios S.[1], Kourtidis K.[1]

1 Laboratory Of Atmospheric Pollution and Pollution Control Engineering of Atmospheric Pollutants, Dept. of Environmental Engineering, Democritus University of Thrace, Xanthi, Greece

*corresponding author e-mail: sstathop@env.duth.gr

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Goal

- To study the cause-and-effect relations, during a Forbush Decrease (FD) event (07/12/2015), over a North Atlantic region (23.5^{o}-40.5^{o} N, 40.5^{o}-44.5^{o} W), between

  →Galactic Cosmic Rays (GCRs)

  →Electric Field

  →Aerosols

  →Clouds

Data

→ Daily mean Neutron data (FD) (16/11-26/12/2015) from Hermanus Neutron Monitor Station (HRMS), (Neutron Monitor DataBase, NMDB, http://www01.nmdb.eu/nest/)

→ Daily mean Potential Gradient data (PG) (16/11-26/12/2015) from the University of Evora Graciosa, Azores Station (Global Coordination of Atmospheric Electricity Measurements, GLOCAEM, https://glocaem.wordpress.com/data-access/)

→ Daily mean remote sensing data (Col.6.1, lvl3) (16/11-26/12/2015) from MODIS/Aqua (Earthdata/Giovanni, https://giovanni.gsfc.nasa.gov/giovanni/)

- → Aerosol Optical Depth at 550nm (AOD)
- → Cloud Fraction (CF)
- → Cloud Optical Thickness (COT)
- → Cloud Top Pressure (CTP)
- → Cirrus Reflectance (CR)
- → Cloud Effective Radius-Liquid (CERL)

Region

Fig.1 The study area (yellow rectangle) with the Graciosa, Azores GLOCAEM station (yellow marker) and the Hermanus, NMDB station (blue marker) (Google Maps)

Convergent Cross Mapping (CCM)

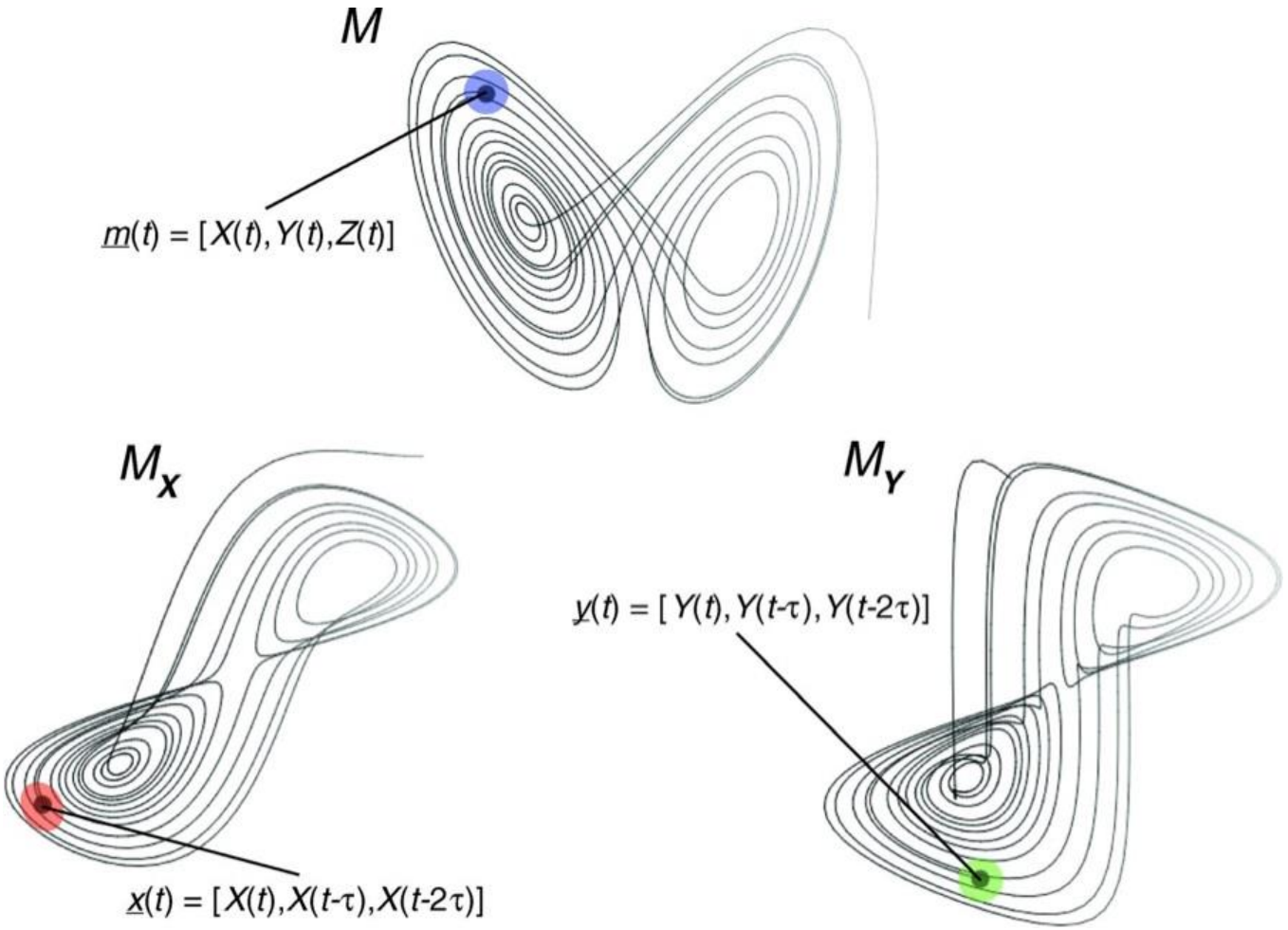


Fig.2 Convergent cross mapping tests (CCM) for correspondence between shadow manifolds (M_x and M_y), constructed using lagged-coordinate embeddings of X and Y, respectively (lag = τ) (Figure courtesy of Dr. Sugihara, adopted from Sugihara et al., 2012)

Methodology

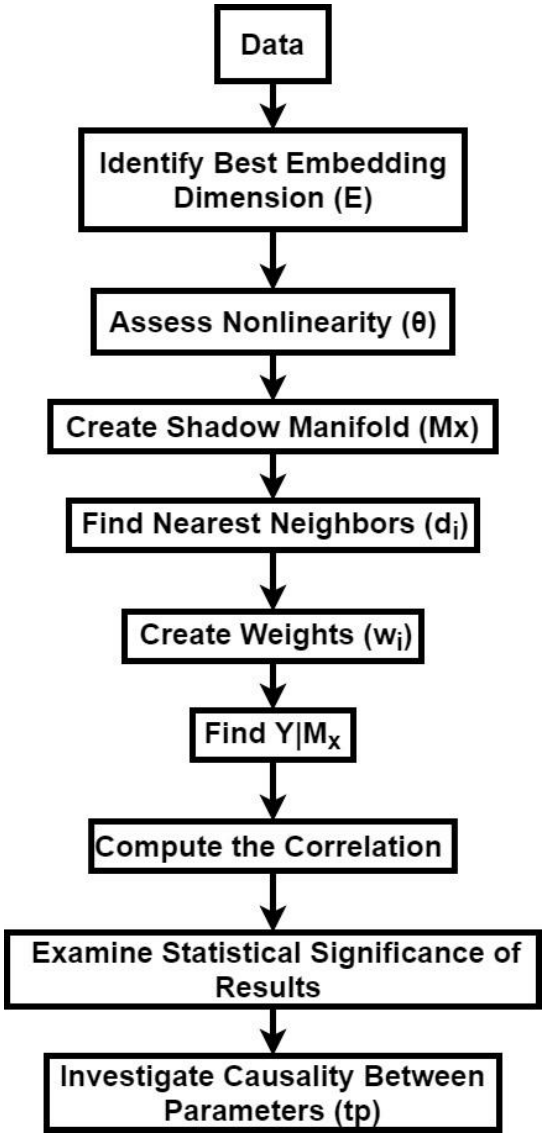
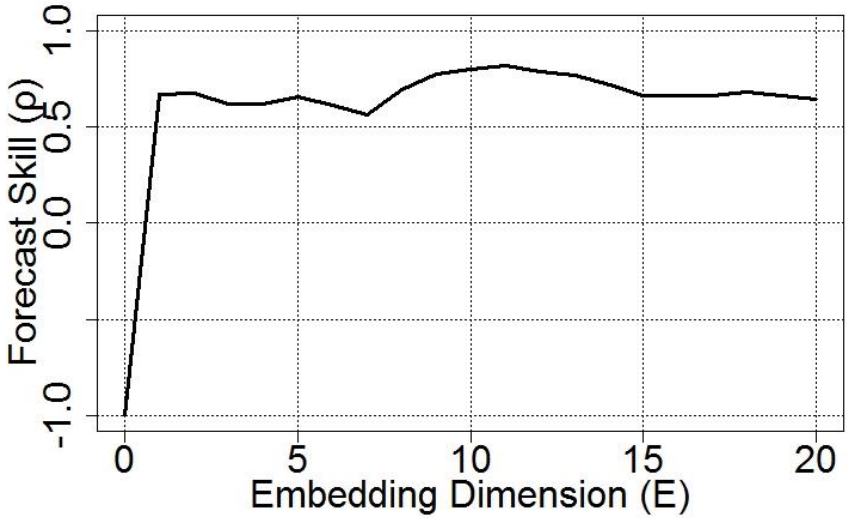
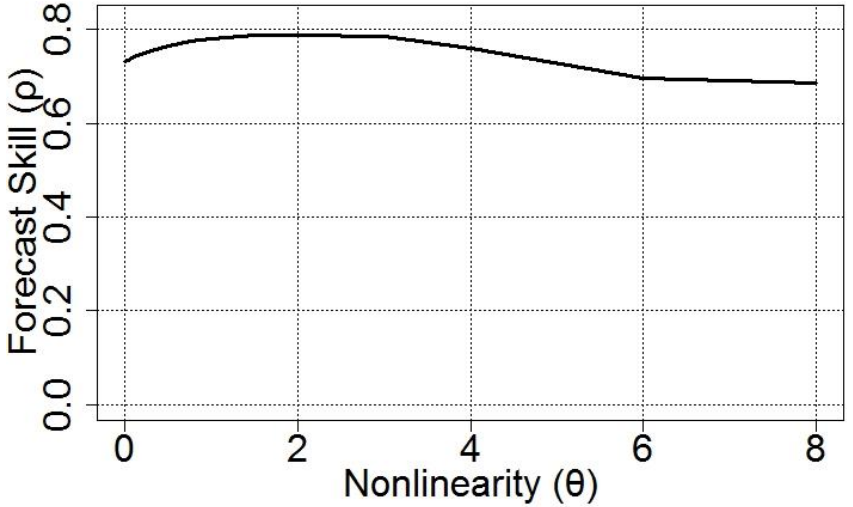


Fig.3 Flowchart illustrating the methodology followed (Modification of Fig. 2 of Stathopoulos et al., 2021)

Calculations of E - τ - θ





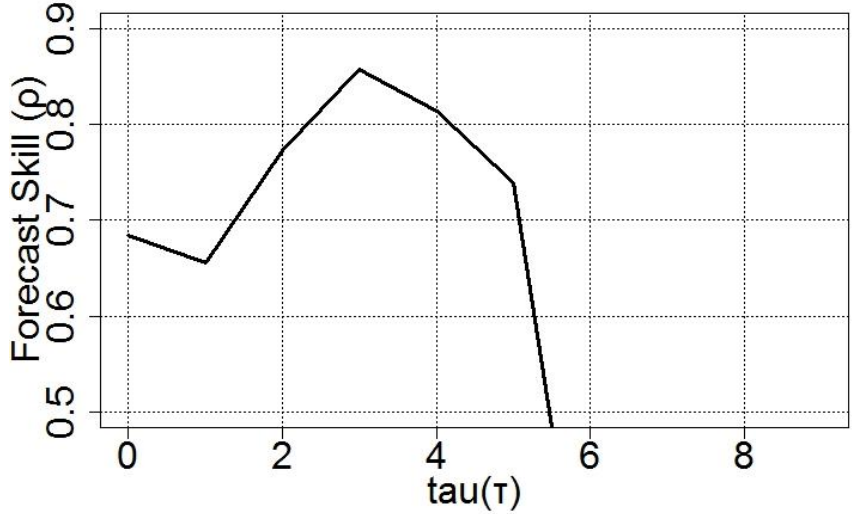


Fig.4 Forecast skill expressed with Pearson's correlation coefficient (ρ) of the embedding dimension (E) **(upper left)**, of the time delay embedding lag parameter (tau, τ) for E=5 **(bottom left)** and of the nonlinearity parameter (θ) for E=5 and τ=3 (**upper right**), for FD time series

CCM Results

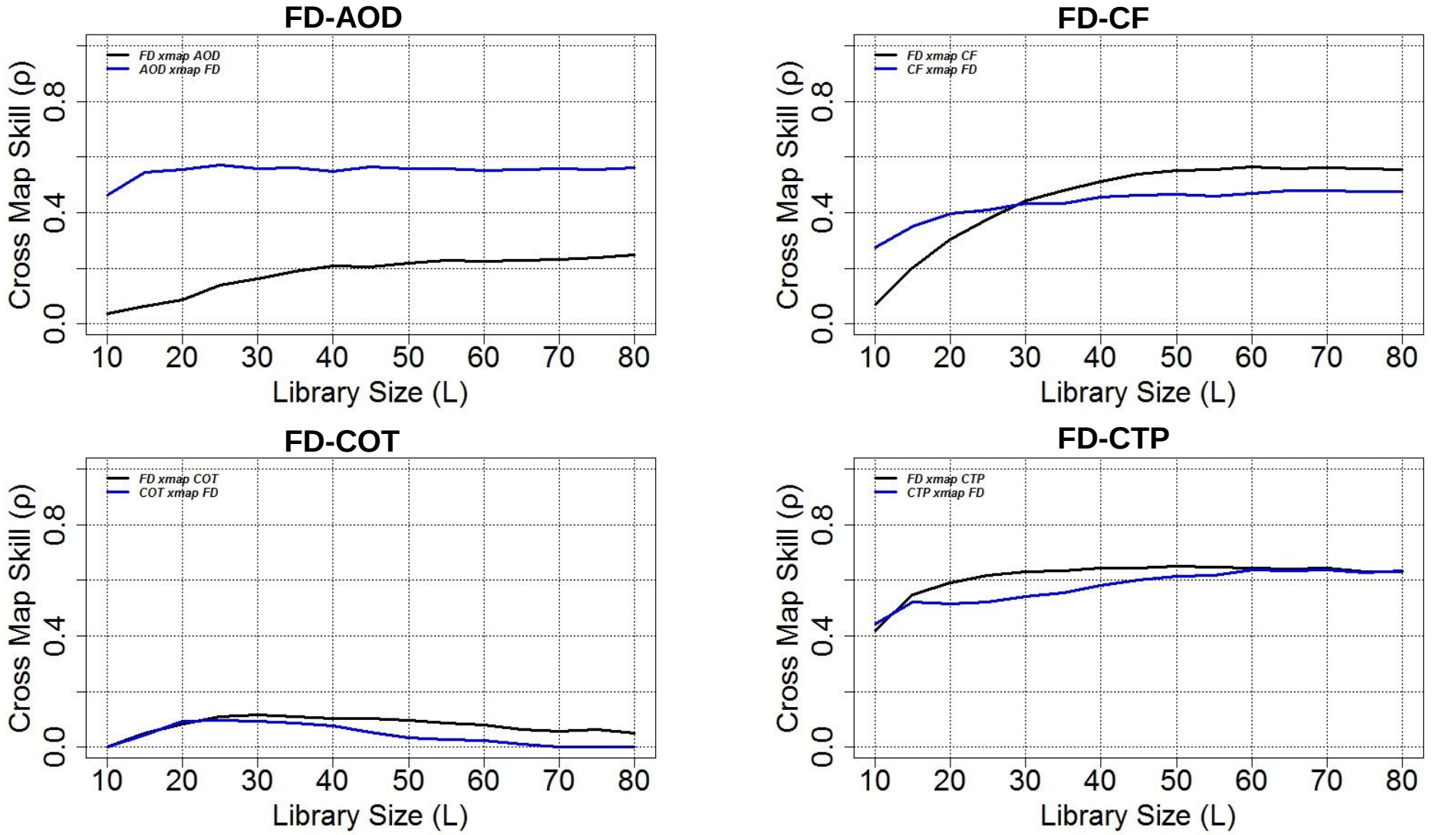
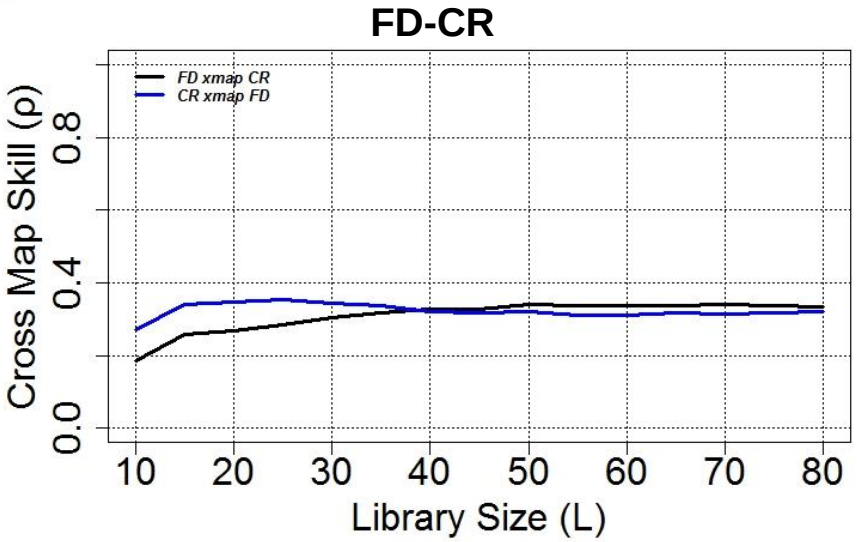
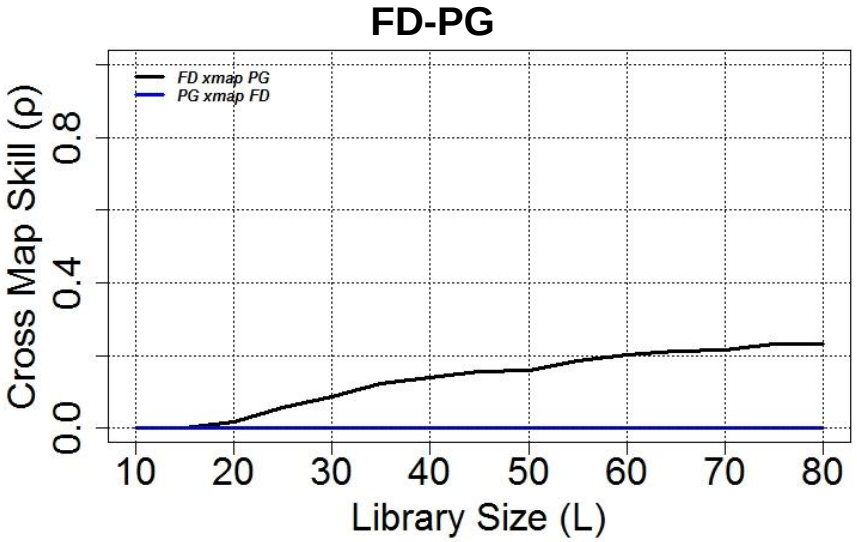


Fig.5 Cross-mapped skill (ρ) as a function of library size (L) for FD-AOD (**upper left**), FD-CF (**upper right**), FD-COT (**bottom left**) and FD-CTP (**bottom right**). xmap denotes cross mapping which is translated as Y parameter affects X parameter

CCM Results





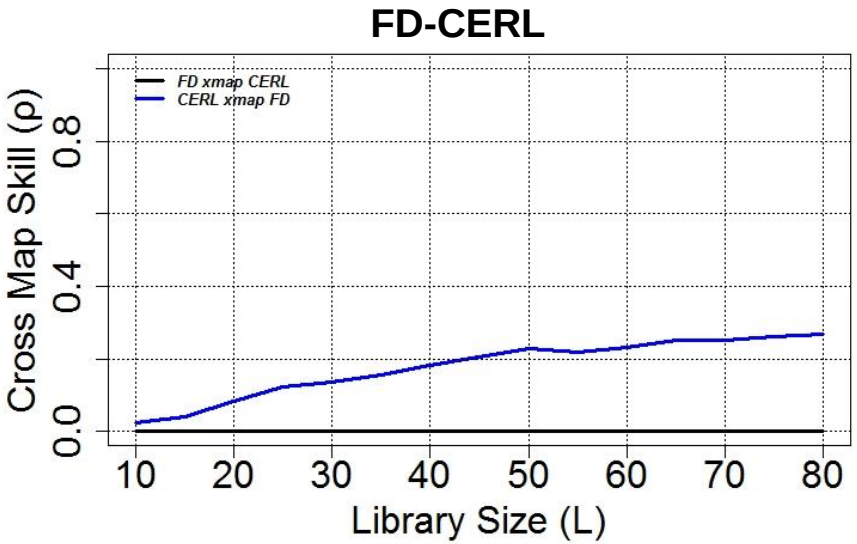
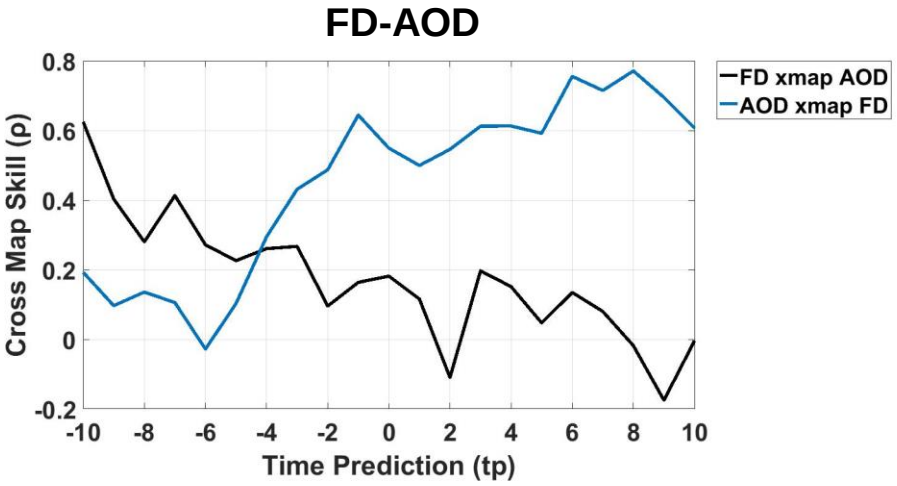
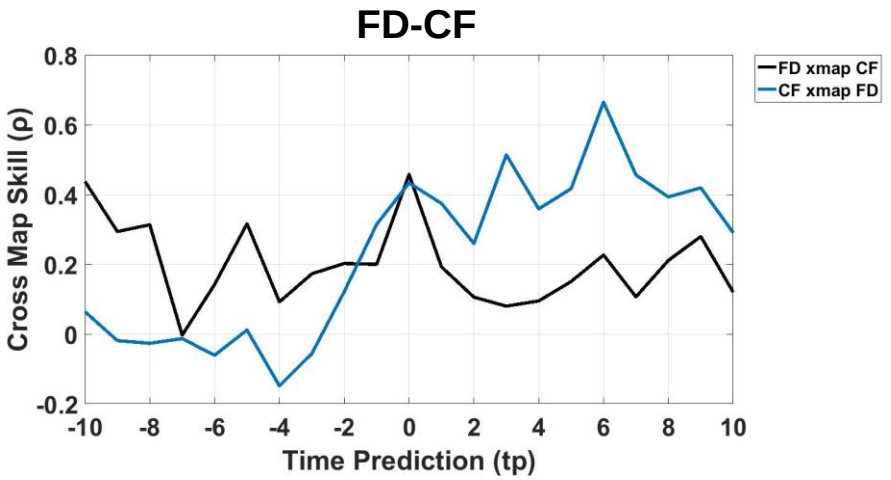


Fig.6 Cross-mapped skill (ρ) as a function of library size (L) for FD-CR (**upper left**), FD-PG (**upper right**), FD-CERL (**bottom left**). xmap denotes cross mapping which is translated as Y parameter affects X parameter

Causality





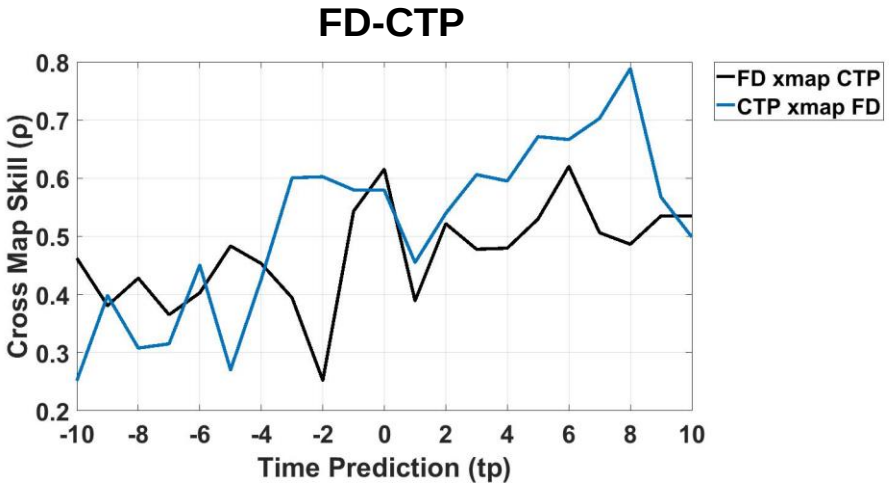


Fig.6 Cross-mapped skill (ρ) as a function of CCM's time delay prediction parameter (tp) for FD-AOD (**upper left**), FD-CF(**upper right**), FD-CTP (**bottom left**). xmap denotes cross mapping which is translated as Y parameter affects X parameter

Causality

Table 1 Maximum Pearson's correlation coefficient (ρ_{max}) and the corresponding time delay prediction parameter (t_p) value for the FD-AOD–CF-CTP-CR-CERL-PG cross mapping relations for E=4-6 (*yellow cells denote negative or zero t_p values for 2/3 of the results*)*

	E=4 τ=4		E=5 τ=3		E=6 τ=2	
	t_p	ρ_{max}	t_p	ρ_{max}	t_p	ρ_{max}
FD xmap AOD	-10	0.670	-10	0.625	-10	0.644
AOD xmap FD	7	0.712	8	0.771	9	0.801
FD xmap CF	10	0.545	0	0.457	-10	0.398
CF xmap FD	8	0.557	6	0.665	10	0.682
FD xmap CTP	8	0.653	6	0.620	10	0.596
CTP xmap FD	7	0.790	8	0.789	10	0.739
FD xmap CR	-9	0.388	8	0.386	7	0.390
FD xmap CERL	-1	0.310	-2	0.394	-3	0.255
FD xmap PG	2	0.123	-3	0.137	6	0.032

* $t_p < 0$ → causality between X,Y (Y causes X)
$t_p = 0$ → synchronous interaction between X,Y
$t_p > 0$ → no causality between X,Y (coupling)

Conclusions

X-Y (effect of Y on X)

- ✓ We found causality between FD-AOD, FD-CF and FD-CERL
- ✓ Strong coupling seems to exist between AOD-FD, CF-FD, CTP-FD, FD-CTP, FD-CR, and FD-PG (Josic, 2000; Rulkov, 1995)
- ✓ We found no causality between FD-COT and CR-FD
- ✓ There is probably strong forcing between PG-FD and FD-CERL, so their relation should be examined using Granger causality (Granger, 1969)
- ✓ Lack of statistical significance can possibly be explained by the fact that the expected change between the parameters is smaller than the noise due to meteorology or retrieval artifacts

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Thank you for your attention