Scientific Report – ESF Exchange Grant

Reference Number: 1238

Activity Title: Mediterranean Climate Variability and Predictability (MedCliVar)

Title of Research Project: Climate Reconstruction and Fluctuation analysis of Jerusalem, Israel.

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1. Purpose of visit

Precipitation and temperature are the most important climatic elements affecting humanity, economies and terrestrial ecosystems. Extreme precipitation events and their potential consequences, such as floods and droughts, have an essential influence on human life, especially in the Eastern Mediterranean region (Xoplaki et al. 2001; Touchan et al. 2005; Luterbacher et al. 2004, 2006). To date, the Eastern Mediterranean region has received relatively little attention concerning past climate reconstructions, despite its unique position, being a transition zone between temperate climate in the north and arid climate in the south (Bar-Matthews et al. 1997; Luterbacher et al. 2006). Recently, it was hypothesized that climate shifts had an impact on societies in this region and even drove societies to total collapse (Enzel et al. 2003; Weiss and Bradley 2001).

The Eastern Mediterranean climate is influenced by several tropical and subtropical systems these range from El-Nino Southern Oscillation (ENSO) and North Atlantic Oscillation (NAO) variations to Tropical Hurricanes and the South Asian Monsoon. This leads to complex features in the regions climatic fluctuations (Alpert et al. 2006). The influence of SST's connected with latent and sensible heat flux, orographical features and thermo dynamical aspects interact with each other in different time scales and are superimposed on the quasi stationary planet waves which control large scale advection (Xoplaki et al. 2006). Jerusalem is situated in a unique location and was studied during my visit as part of pursuing to better understand these processes.

The project I had put myself to, was reconstructing and analysing Jerusalem's temperature variations in high temporal resolution by combining the benefits of different documentary and natural proxies in a computer model, based on Machine Learning Algorithms (MLA), such as Artificial Neural Networks (ANN) and Support Vector Machines (LibSVM).

Using proxy data for climate reconstructions in the Eastern Mediterranean derived from natural climate archives, the time scale for such studies can be considerably expanded and the persistence of multi-decadal variations can be investigated (Fischer et al. 2005).

2. Description of the Work Carried Out

2.1 Data

In order to reconstruct the Jerusalem's Temperature series we have utilised 48 long temperature and precipitation instrumental series from central and Western Europe. Most of these go back in time to the middle of the 18th century with virtually no missing values; some of these go further back to the end of the 17th century. To complement these sets we employ NAO and ENSO reconstructions, which go back to 1500 and 1650 respectively. We also draw on ΔO18 isotopic fractionation records extracted from speleothems in the Soreq cave, which is located in the Judean Mountains near Jerusalem (31.45N 35.03E) (available from Bar-Matthews M). Ten tree ring site chronologies under went de-trending and standardization in ARSTAN soft ware in order to eliminate an age trend but still keep the high and low frequency climatic signal (available from www.ncdc.noaa.gov). We draw on the monthly resolved homogenised temperature and precipitation time series of Jerusalem as the models target (available from the Israeli Meteorological Service). Recognizing the physical processes behind the transfer of heat to the Eastern Mediterranean was made possible through the use of NCEP/NCAR reanalysis records along with Kaplan's Global Sea Surface Temperatures (SST) reconstructions (available from http://climexp.knmi.nl). The map in figure 1 displays all mentioned records.

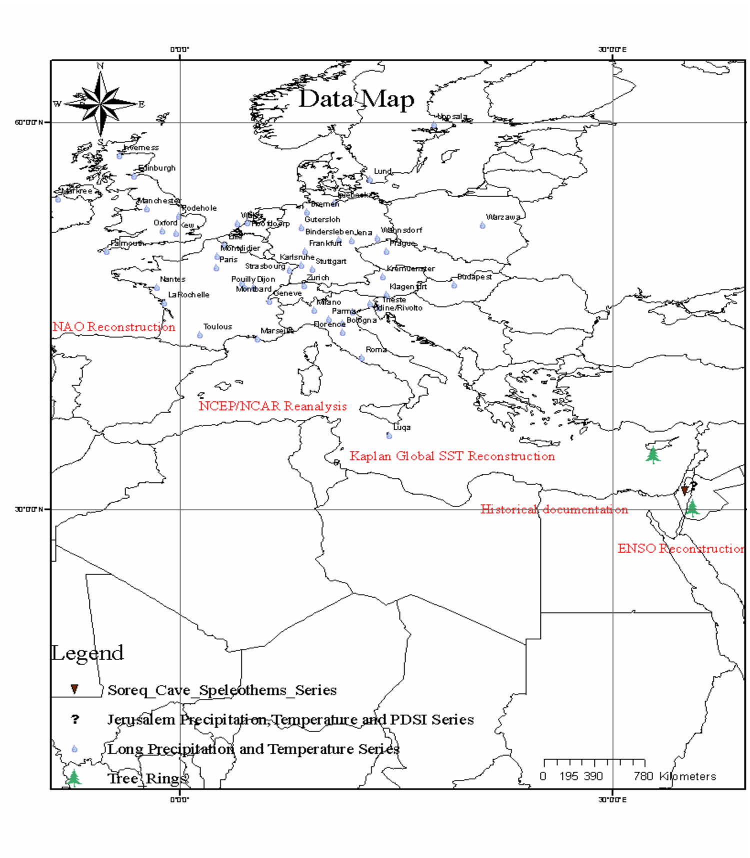

Figure 1 We exhibit the locations of instrumental, tree-ring, speleothem and reconstructed ENSO and NAO series along with data bases of NCEP/NCAR Reanalysis, Kaplan's SST reconstructions and historical documentation known for Jerusalem.

2.2 Methods

The use of linear forecasting methods has dominated the arena for decades. In spite of wide spread use of these linear methods the existence of non-linear relationships limit their application in many cases (Aguilar et al. 2006).

We implement two non-linear Machine Learning Algorithms in order to reconstruct the historical temperatures of Jerusalem. For the sake of completeness we also employ Stepwise Linear Regression (LR). These MLA's have been proven useful in numerous climate related publications (Richman et al.; Steiner et al. 2005; Calvo et al. 2000).

The basic idea of MLA is finding mathematical rules between attributes and target values and then applying these rules upon the attributes where no targets are available.

We apply a modelling approach based on machine learning algorithms. This procedure consists of five steps 1) Forward selection linear regression (reduction of dimensionality) 2) Reconstruction methods (Non-Linear Support Vector Machines for Regression (LibSVM), Non-Linear Back-Propagation Artificial Neural Networks (ANN) , Stepwise linear regression (LR)) 3) Algorithms Parameter Calibration (5 folds cross-validation grid search) 4) Cross-Validation 5) Fluctuation analysis (Wavelet analysis, De-Trended Fluctuation Analysis).

We make use of two different spectral methods in analysing the reconstructed time series. This is especially important in order to verify that any periodicities in the data are not method derived.

3. Main Results

3.1 Influencing factors on Jerusalem's Temperature Trends and Variations

We first illustrate the worth of long Western and Central European precipitation and temperature series as proxies for Jerusalem's temperature variations. This connection is well-defined for European precipitation with Jerusalem's mean temperature. It is especially important to confirm this relationship to be steady throughout the instrumental period in order to make the most of these records in reconstruction schemes. Figure 2 demonstrates the tele-connection patterns during the 20th century, moreover, it emphasises this link to be stable throughout this period. There is a positive connection pattern between central Europe precipitation and Jerusalem's temperature and a negative pattern between Western Europe precipitation and Jerusalem temperature. Hence forth, we show the association of the Jerusalem temperature series to large scale circulation and SST patterns. Both SST and 300 HPa tele-connection patterns clarify the process behind transfer of heat from Southern Greenland across the Atlantic over central Europe and to the Eastern Mediterranean in a wave like motion. Additionally, this proves the hypothesis of latent heat transfer from central

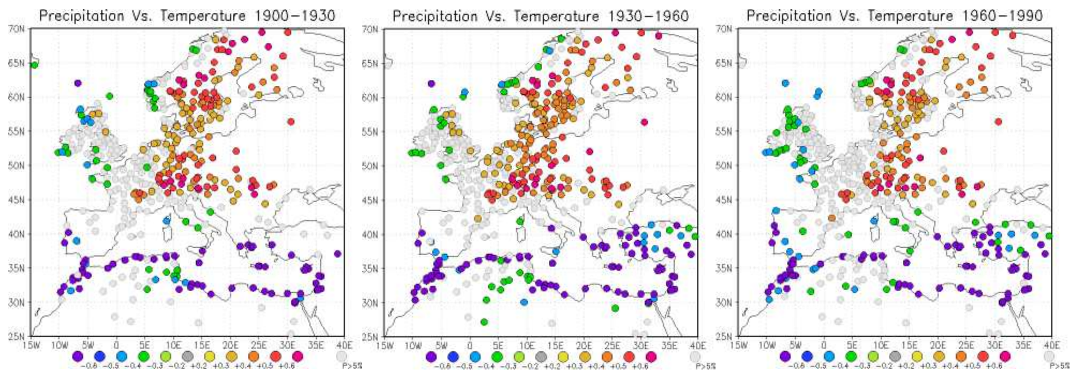

Figure 2 Stable dipole connection between central and Western Europe to Jerusalem annual mean temperatures. We show the connection between Jerusalem annual mean temperature and all European Precipitation series in three different time intervals. Colours indicate the power of the connection.

Europe to the Eastern Mediterranean during all seasons and the usefulness of central European instrumental series in reconstructing Jerusalem's climate (figure 3, figure 4).

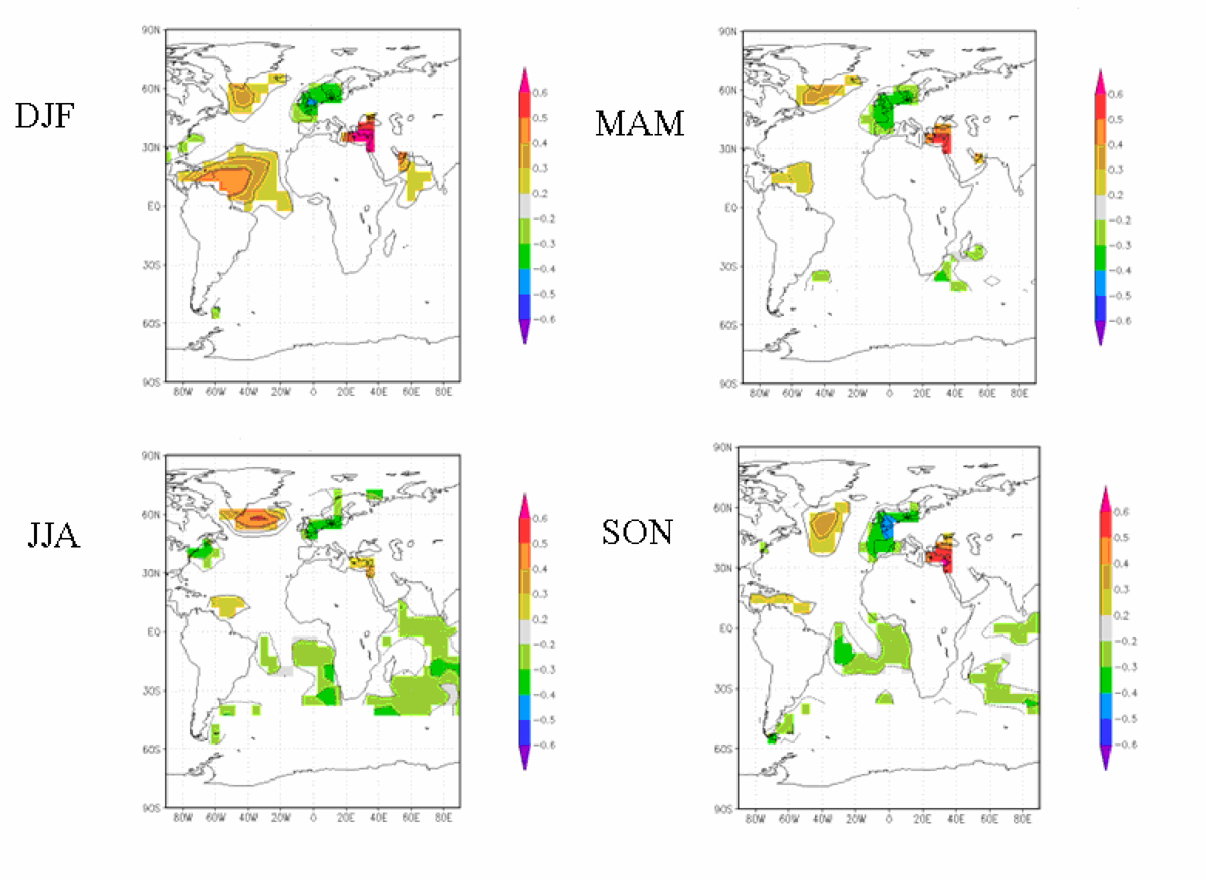

Figure 3 Seasonal Jerusalem Mean Temperatures Correlations with Kaplan's reconstructed SST's for 1861-1934 A.C. Colours indicate the power of the connection.

Correlations of Jerusalem's mean temperatures in the different seasons with total solar irradiance reconstructions (Hoyt et al. 1993) lead us to conclude that solar forcing on Jerusalem's temperatures is most important during spring and summer (table 1). This is especially amazing due to the dominant ~120 year period we find in these seasons as compared to winter and autumn (figure 6). Additionally, the fact that spring and summer mean temperature variations explain 76% and 68% of annual variations, respectively, and winter and autumn mean temperature variations explain 37% and 53% of annual variations, respectively, strengthen our hypothesis that the ~120 years cycle is at least partly attributed to solar irradiance variability. This notion is to be further investigated.

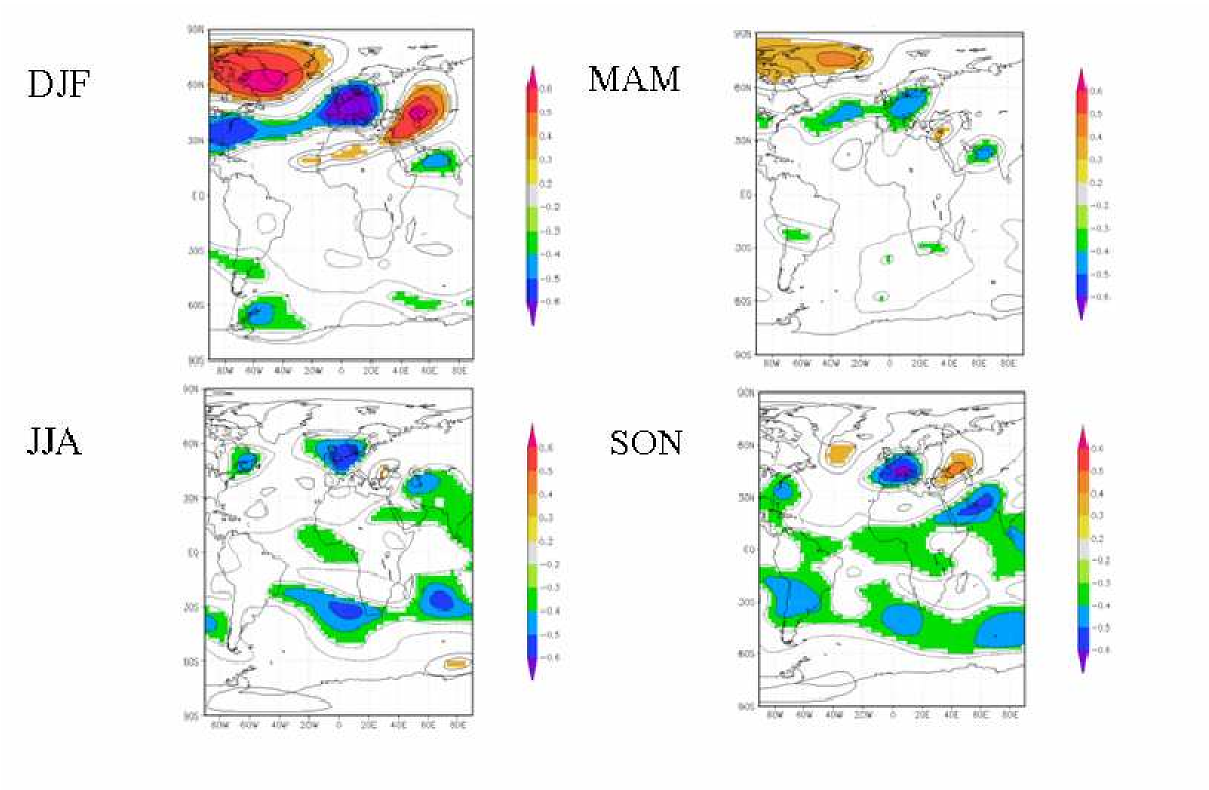

Figure 4 Seasonal 300mb geo-potential heights connection to Jerusalem mean temperature for 1948-1990. Colours indicate the power of the connection.

months	lag	corr	p	no	95% CI
Jan-Mar	0	-0.034	0.7048	129	-0.19... 0.16
Feb-Apr	0	-0.134	0.1325	128	-0.30... 0.08
Mar-May	0	-0.172	0.0543	126	-0.32... 0.05
Apr-Jun	0	-0.258	0.0035	126	-0.40... -0.08
May-Jul	0	-0.355	0.0001	122	-0.49... -0.20
Jun-Aug	0	-0.485	0	124	-0.59... -0.34
Jul-Sep	0	-0.458	0	125	-0.59... -0.30
Aug-Oct	0	-0.433	0	126	-0.57... -0.27
Sep-Nov	0	-0.212	0.0166	127	-0.38... -0.05
Oct-Dec	0	-0.047	0.5994	128	-0.19... 0.15
Nov-Jan	0	0.129	0.1452	128	-0.02... 0.35
Dec-Feb	0	0.071	0.4231	128	-0.09... 0.25

Table 1 All 3 Months Correlations Between Jerusalem Mean Temperature and Hoyt & Schatten Solar Irradiance Reconstructions from 1861 A.C to 1994 A.C .The Attributes Marked Red are Significant at the 95% level.

3.2 Selection of the Reconstruction Scheme

After cross-validating algorithm results we conclude that LibSVM performs better then ANN and LR (table 2), this is not always the case; nevertheless, in order to consistently compare the reconstructions we have employed LibSVM as the primary reconstruction algorithm. LibSVM explains more of the variance in the signal then other schemes and usually gives minimal mapping function errors (table 2). LibSVM explains around 62% of the variance in spring and summer and around 75% of the variance in winter and autumn. The usual better performance of the non-linear algorithms proves the hypothesis that the processes explained in this report are non-linear by nature and can better be explained by non-linear methods.

Parameters	Algorithm	AE	RE	RMSE	PA	Correlation	R^2
	LR	0.618 +/- 0.492	0.038 +/-0.03	0.79	16.691+/- 0.549	0.658	0.5752
C=17 Gamma = 0.3	LibSVM	0.615 +/- 0.447	0.038 +/- 0.027	0.76	17.044 +/- 0.838	0.691	0.7372
L=0.1 M=0.2 N=28 H=2	ANN	0.638 +/- 0.434	0.04 +/- 0.028	0.772	16.822 +/- 0.524	0.663	0.5765

Parameters	Algorithm	AE	RE	RMSE	PA	Correlation	R^2
	LR	0.833 +/- 0.738	0.103 +/- 0.105	1.113	8.891 +/- 0.348	0.602	0.4959
C=8 Gamma=0.2	LibSVM	0.764 +/- 0.681	0.095 +/- 0.099	1.024	8.984 +/- 0.313	0.665	0.5705
L=0.2 M=0 N=15 H=1	ANN	0.897 +/- 0.68	0.106 +/- 0.089	1.126	8.928 +/- 0.495	0.603	0.4953

Parameters	Algorithm	AE	RE	RMSE	PA	Correlation	R^2
	LR	0.848 +/- 0.615	0.058 +/- 0.046	1.047	15.404 +/- 0.46	0.68	0.5605
C=11 Gamma = 0.2	LibSVM	0.851 +/- 0.605	0.058 +/- 0.045	1.044	15.557 +/- 0.596	0.672	0.6246
L=0.1 M=0 N=34 H=5	ANN	0.827 +/- 0.616	0.056 +/- 0.045	1.032	15.24 +/- 0.433	0.691	0.5514

Parameters	Algorithm	AE	RE	RMSE	PA	Correlation	R^2
	LR	0.913 +/- 0.593	0.044 +/- 0.029	1.089	21.868 +/- 0.711	0.632	0.5074
C=33 Gamma=0.2	LibSVM	0.882 +/- 0.601	0.043 +/- 0.03	1.067	22.132 +/- 0.797	0.662	0.6184
L=0.1 M=0.2 N=31 H=3	ANN	0.882 +/- 0.555	0.042 +/- 0.027	1.042	21.825 +/- 0.712	0.669	0.5003

Parameters	Algorithm	AE	RE	RMSE	PA	Correlation	R^2
	LR	0.576 +/- 0.418	0.031 +/- 0.023	0.712	19.219 +/- 0.633	0.777	0.6557
C=17 Gamma=0.2	LibSVM	0.605 +/- 0.438	0.033 +/- 0.024	0.747	19.274 +/- 0.639	0.74	0.7581
L=0.1 M=0.2 N=31 H=1	ANN	0.583 +/- 0.417	0.032 +/- 0.023	0.716	18.916 +/- 0.387	0.768	0.6516

Table 2 Performance of ANN, LibSVM and LR for Annual to Seasonal Temporal Resolutions (from top to bottom: annual, winter (DJF), spring (MAM), summer (JJA), autumn (SON).

3.3 Mean Temperature Reconstructions

We present our findings for the temperature reconstructions. Figure 5 exhibit the mean temperature anomalies for annual to seasonal temporal resolutions. These reconstructions exhibit a ~120 year dominant periodicity in the time series to be discussed in the following section.

3.4 Fluctuation Analysis

We address the ~120 year periodicity which is observed through out the series. DFA can only confirm dominant cycles throughout the reconstructed series. These kinds of cycles can assist in predicting future climate variations, while periodicities that are apparent only in certain regions of the signal are fascinating but are difficult to employ in prediction models.

The cycle is clear and with higher power during spring and summer then in winter and autumn (figure 6). The significant correlations we find for the Jerusalem temperatures and solar irradiance reconstructions during spring and summer (table 1) suggest that this cycle is at least partly attributed to solar irradiance variations.

As suggested in Fischer et al. (2005) we confirm that a ~60 year cycle has been mainly active after 1700 A.C. Furthermore, we conclude that variations in the thermo-haline circulation in the north Atlantic along with solar forcing set the stage for multi decadal atmospheric circulation changes influencing temperature variations in Jerusalem.

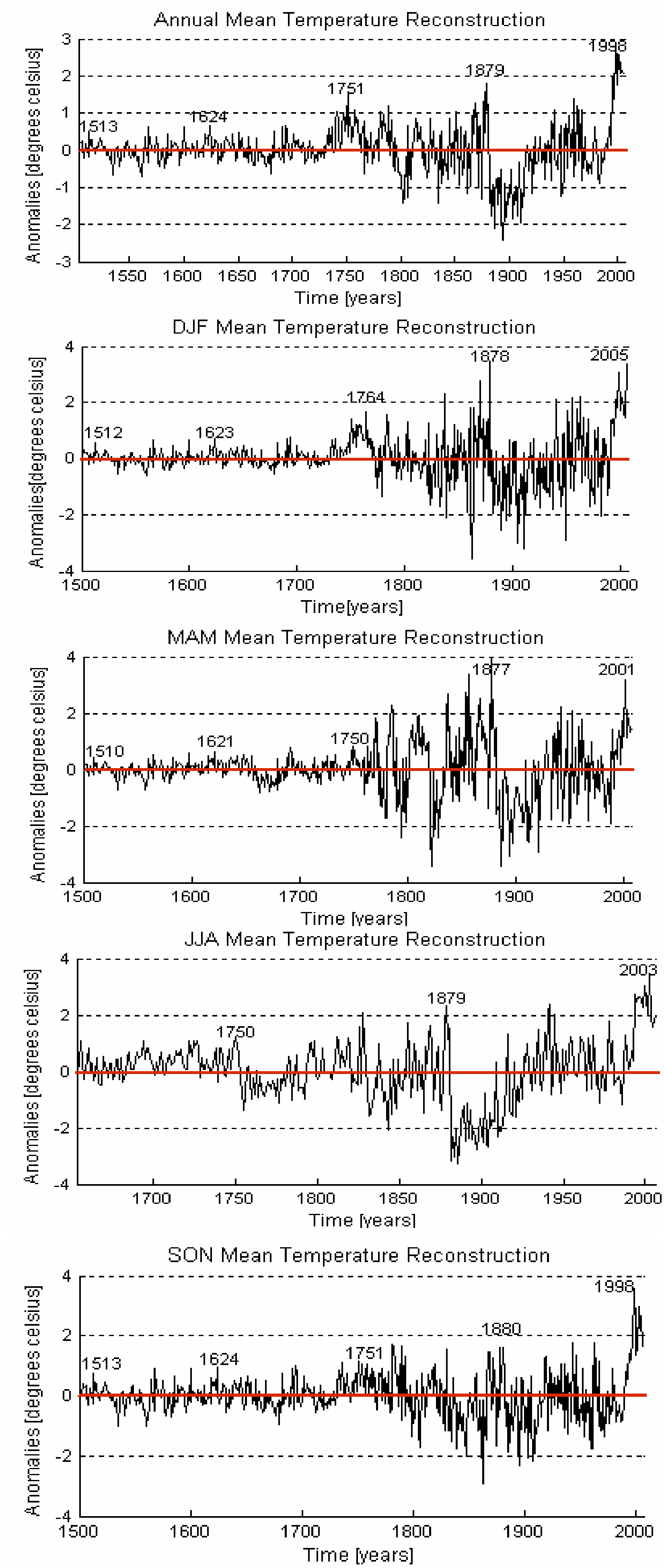

Figure 5 Mean Temperature Anomalies Reconstructions. The years displayed on the graph are selected pick maximum temperatures through out the series suggesting a dominant ~120 year periodicity.

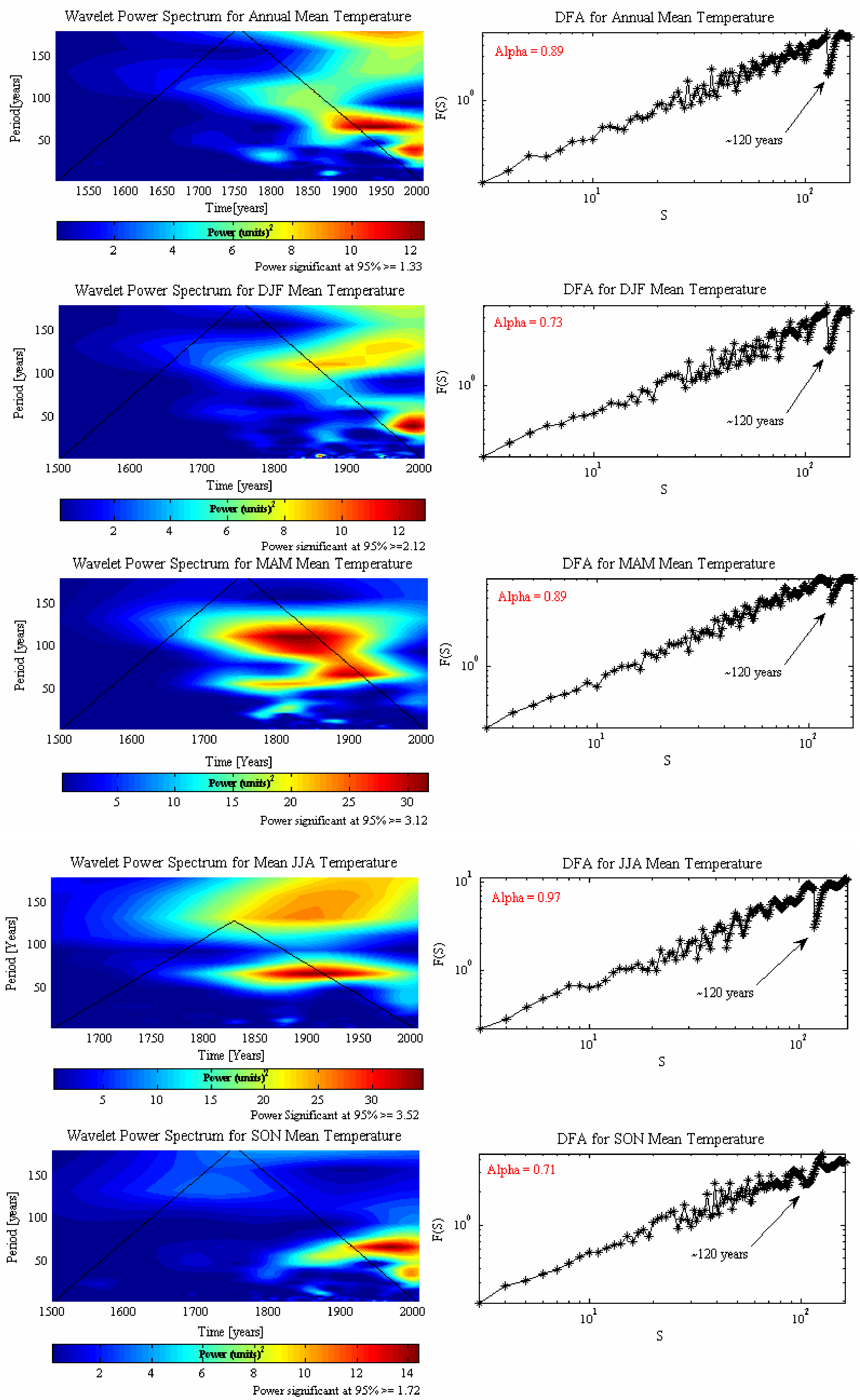

Figure 6 Wavelet and DFA Analysis for Annual to Seasonal Mean Temperature Reconstructions. A ~120 year dominant cycle is clear throughout both in wavelet and DFA. Greater power is apparent during spring and summer

4. Future Collaboration

Our collaboration with Juerg Luterbacher and his Climatology group in Bern, Switzerland was fruitful. We plan on continuing the sharing of knowledge and expertise in order to better understand the physical processes influencing the Eastern Mediterranean climatic variations. This will be done through applying the methods utilised in order to reconstruct Jerusalem's precipitation and drought indices. Furthermore, we plan on reconstructing Eastern Mediterranean climate and give a better explanation for how the different climatic influencing factors interact with each other and affect the Eastern Mediterranean.

5. Projected Publications

The results we have presented herein will be shortly submitted to a leading journal in our field of expertise. When published, this paper will be forwarded to ESF MedCliVar. We plan on going together for more publications in the near future regarding Eastern Mediterranean climate reconstructions.

6. Personal Thanks

I would like to personally thank all ESF MedCliVar committee members for giving me the opportunity to study in Bern for the last several months. This experience nourished me with plenty of new knowledge and expertise, which I plan to use in the near future for contributing in a scientific environment for the better understanding of climate change and it's affects on humanity and the ecosystem.

Thank you very much for your support,

Assaf Hochman

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