Seasonal Prediction for Israel Winter Precipitation Based on Northern Hemispheric EOF

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Introduction

Since 1981, the Israeli Meteorological Service (IMS) performs a seasonal prediction for three (DJF) winter months precipitation with an average success, expressed as a hits ratio of 65% (Decker and Manes, 1986; IMS Reports 1994 and 1996). The accumulative rainfall of the predicted period is regressed with empirical predictors derived from geopotential heights or temperatures over 500, 700 and SLP maps. A similar approach was applied to predict the Indian Monsoon (Hastenrath, 1988) based on the April latitudinal position of the 500 mb ridge over India, the Darwin pressure tendency and the May resultant wind speed in the western Equatorial Indian Ocean (0-10°S, 45-

50°E) with similar success. Alternatively, the last parameter was replaced by the January-February Northern Hemisphere temperature (Prasad and Singh, 1991). Although, the predictors' properties have been improved during the last decades, their empirical base remains unchanged.

This study deals with the teleconnection between the upper-air and surface climatology during October and the following winter rainfall in Israel. The teleconnection means that forcing evolving on a slower time-scale yields a significant predictability of the atmosphere development. To detect it, recent studies have adopted the Empirical Orthogonal Function (EOF) called also Principal Component Analysis (PCA). Applying PCA to the Northern Hemisphere data (Horel, 1981; Barnston and Livezey, 1987; Clinet and Martin, 1991) has detected the following primary six field structures: the North-Atlantic Oscillation (NAO), the North-Central-Pacific pattern (NCP), the Eastern-Atlantic pattern (EA), the Eurasia pattern (EU), the Scandinavian pattern (Scand), the Northern-Africa anomalous pattern (NAF). Other studies have detected other structures such: the North-Pacific pattern (NP), the Northern-Latitude pattern (Nlat), the Western-Europe pattern (Weur), the North-Pacific Oscillation (NPO), the North-Atlantic pattern (NA), the East-Atlantic/W. Russia, etc.

While further studies relating these planetary atmospheric structures to the E. Mediterranean (EM) rainfall contribute to improve the understanding of the rain teleconnection. The goal of this paper is restricted to quantification of the relations between the relevant hemispheric meteorological fields to the predicted winter rainfall of Israel. To compare these prediction with the IMS outlook, the forecast verification is expressed also as a success rate, i.e., in the percentage of hits; hit as defined in IMS Reports 1994, 1996, according to 3 categories "above average (>110% of normal), below average (<90%) and average rainfall (90%<R<110%).".

Following a review of the teleconnection studies of Israel rainfall, Section 2 describes the Empirical Orthogonal Method, the Databases and the Methods of Analyses. Sections 3 and 4 dealt respectively, with the rainfall, frost/chill days and temperature prediction. The relation between the Indian monsoon and Jerusalem rainfall is given in Section 5 and the discussions and conclusion in Section 6.

Review of Eastern Mediterranean Teleconnections

The climatic relation between remote regions was known very early in the ancient Middle East history. Jewish authors of the Babylonian Talmud, living along the Tigris and Euphrates during 1-5 AD have already noticed the distant correlation between Israel rainfall and the streamflow in the Enphantes (Alpert and Neumann, 1989). Based on observations, Ashbel (1950), suggested alternations of dry/wet rain seasons between EM, California and Western Europe. The idea of an oscillatory mechanism controlling the irregular dry/wet alternation of EM November-December (hereafter, ND) was first advanced by Rosenan (1951). Based on circulation patterns, Rosenan found that a deep Inter-Tropical Convergence Zone (ITCZ) determines a rainier July-August in the subtropics that shifts its high toward EM avoiding the intrusion of extra-tropical cyclones, and leading to a long/dry ND. In contrary, a ‘‘shallow’’ ITCZ yields less tropical rains and does not shift northward the subtropical high, thus permitting the intrusion of extra tropical cyclones in the EM, leading to a ‘‘rainy’’ ND. This alternation agrees with the north-south rain correlations of: Sudan-Israel (Rosenan, 1951), West-Africa-EM (Winstanley, 1973, 1974), West-North Africa (Flohn, 1981, 1987), Malta-Zimbabwe (Ismail, 1990), East-Africa-Israel (Mandel, 1994a, b) and Galilee-Negev (Steinberger and Gazit-Yaari, 1995, Mandel, 1998).

Krown (1966, 1967) was first to show the existence of a zonal connection between the October 500 hPa map and the EM following rain-season. Or, alternatively, the relation between the dry/wet ND to the October oscillation of the 500 GPM troughs along 30°N. If the trough is located in the Western Mediterranean, more cyclones penetrate to EM leading to rainier ND. But, if the trough location is further to the east (say 35°E), then, a stable high will dominane the EM region yielding a dry ND sub-season. Recent investigations (Pandolfo, 1993) have confirmed Rosenan’s and Krown’s findings; the meridional oscillation is scaled today by the Nairobi-Cairo height difference (GPM) whilst the Krown 500 mb zonal oscillation, known as the’ Mediterranean Oscillation’ (Conte et al, 1989) or the 700 mb ‘‘North-Africa Oscillation’’ (NAF), is scaled by the Alger-Cairo GPM difference. The Israel Seasonal Rainfall Outlook (ISRO) exploits for over two decades several such predictors in order to estimate the NDJF or DJF rainfall (Decker and Manes, 1986, IMS Reports 1994 and 1996).

Recent studies indicate that seasonal predictability is higher in the tropics (less chaotic and linearly persistent), with a real potential to foresee 3-4 seasons ahead. In the extra-tropics, however, the seasonal predictability is far lower especially during summer and somewhat higher during winter. Compared with other regions, the rainfall predictability has high complexity in the EM, due to its specific geographical position at the boundary between the sub-humid and semi-arid zones, between the Sea and the desert, and between the Hadley and the Ferrell cells, (31-32°N) where the subtropical air masses meet the sub-polar. All determine an ''inter-annual rain fluctuation'' that affects its annual climate more than its long-term average. These fluctuations are even more pronounced in the interannual variability of the extreme daily rainfall, say of daily values exceeding 32 or 64 mm d^{-1} (Alpert et al, 2002).

Statistical seasonal prediction

The Principal Component Analysis (PCA)

The PCA is an useful statistical tool that allows to reduce the huge dimensions of the hemispherical fields into smaller matrices. The 39 years of monthly mean data, organized in 1977 NCEP grid points for each meteorological field is reduced to 5-10 vectors explaining about 80% of their cumulative variance. From the original data (matrix D), where every column represents one-year list of anomalies in the 1977 world grid points, we derive for each field the Covariance matrix **R,** of dimension 1977x39:

$$R = \frac{1}{N} DD^T, \qquad (1)$$

in which, N=39, is the number of seasons, **R** is a square matrix of a grid points rank of 1977x1977. The contribution of the empirical orthogonal functions

(EOF) to the total variance is given by their eigenvalues. The eigenvector, e, is solved from:

$$R\,e = \lambda\, e. \qquad (2)$$

The number of solutions of (2) is the rank of **R,** where every eigenvector e is orthogonal to all the rest. The E matrix of EOF represents a new form of the original data reorganized by a decreasing order of eigenvalues (λ):

$$D = E\,C\,, \qquad (3)$$

in which, **C** is the coefficients' matrix, representing the weight of every vector e in the new base, for every year. The columns of E are the eigenvectors as calculated in (2), and in the aforementioned order. The matrix **C** is directly calculated by:

$$C=E^{T}D. \qquad (4)$$

Ordering the eigenvectors in decreasing variance allows their estimation using fewer vectors. Instead of the large **D** matrix (1977x39), we may operate with 10 EOFs that yield ~80% of the total variance, and reduce **C** and **E** dimensions to 39 x 10 and 10 x 1977, respectively.

Databases

The meteorological data was taken from the following sources: a) NCEP: Sea Level Pressure (SLP), 500hPa height (Z500) for 1949/50-1987/88, 700hPa temperature (T700, since 1963), b) COADS: Evaporation over the Mediterranean Sea (EVMS) and, c) IMS: Monthly rainfall (1950/51-1988/89)[1]. Rain ''Indices'' were calculated from monthly anomalies divided by their standard deviations for 21 rain stations and averaged for all 21 stations

1. This work was initialized with the available dataset in NASA during the author's (P.A.) sabbatical in NASA during 1995/6. Therefore, the databases finish in 1987/88.

normalized anomalies. An index was calculated for every month and for the main winter rainfall season (DJF) similarly to the procedure adopted by the IMS.

Method of Analysis

The Principal Component Analysis (PCA) was performed (Fig. 1) for the 3 NCEP fields. Nearly 80% of the variance was "compressed" into the first 10 EOF, while for the COADS fields of evaporation only the first 5 EOF were taken. The reason the evaporation EOFs accumulate the variance faster can be explained by the smaller data area (number of grid points over the Mediterranean). Also, the patterns of evaporation over the Mediterranean are probably more stable compared to the other fields. Correlations between the Rain Index and the 35 EOF values were then estimated for the 39 years (for the 700 hPa temperatures only 26 years were available). The selection of the relevant predictors was made by a standard stepwise procedure. The cross

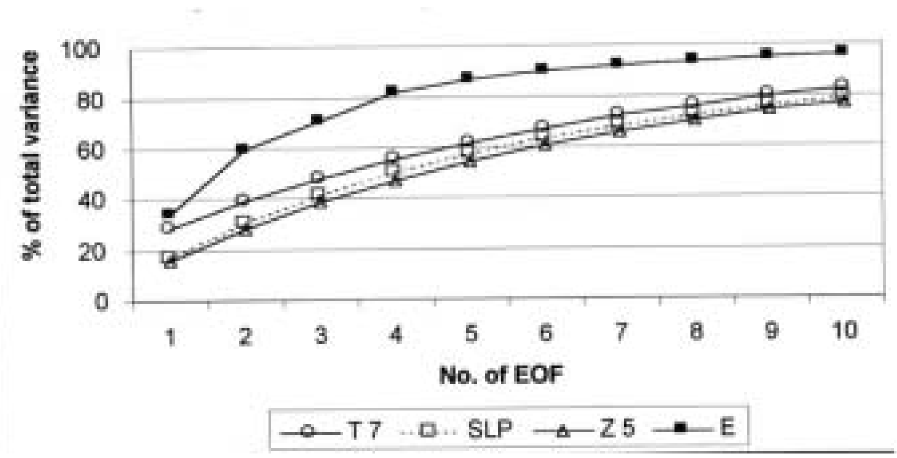

Fig. 1 - The accumulated variance of the orthogonal functions as part of the total variance (in percentage). Note that for SLP, Z-500 and T-700, the accumulated variance reaches about 80% with 10 EOFs, while for the evaporation it reaches about 87% with only 5 EOFs. All remaining EOFs contribute less

validation has included the test of each year separately, without using the data of that specific year in deriving the EOF. This procedure was performed on several different indices, i.e. for different months and periods, and the results are described next.

Results

Table 1 summarizes all the predictions tested and their cross-validated rate of success; success defined earlier in the Introduction. The results show that the October-based predictions (for winter) rates of success are the highest, as previously suggested by Krown (1966). The Northern Hemispheric fields provide improved predictions compared to the European fields. The high month to month predictions variation suggests that a longer period of testing to obtain "stable" results may be necessary.

Data Source:		Prediction:	
Region	Month	Period	rate of success
Northern Hemisphere	October	Seasonal	88.5%
Northern Hemisphere	November	Seasonal	61.5%
European	October	Seasonal	77%
European	November	Seasonal	77%
Northern Hemisphere	October	November	88.5%
Northern Hemisphere	October	December	50%
Northern Hemisphere	October	January	61.5%
Northern Hemisphere	November	December	84.5%
Northern Hemisphere	November	January	73%
European	October	November	96%
European	October	December	50%
European	October	January	77%
European	November	December	96%
European	November	January	69%

Table 1 - Some of the predictions performed and their cross-validated rate of success for the years 1949-1988

Sensitivity of the seasonal predictions to rain period and several locations in Israel

The sensitivity of the seasonal prediction to various space-time rain indices were investigated using all 35 EOF without a selection by the step-wise regression. Rainfall was evaluated from the multiplication of the correlation coefficients by the predicted years' eigenvalues. A success was assumed when the prediction was within +0.7 to - 0.7 of a standard deviation. The tests were adapted to three time categories: DJF (December-February), NDJFM (November-March), and NDJFMA (November through April). As to locations for verification, six points were selected: five rain stations (Eylon, Dganya, Jerusalem, Natanya and Beer-Sheba) and an average of four neighboring stations around Gaza. These 18 Indices (6 stations X 3 periods) were tested by the same method in order to evaluate the forecast "skill" related to these parameters. The results were not cross-validated (i.e. they included the year for which the prediction was performed in the EOF derivation), and therefore serve only as a sensitivity test and not instead of real seasonal prediction.

Table 2 summarizes the percentages of success for the variation of the time and space model. The original index reached in this simple model the rate of 72% success and can be referred to as a test reference index. There is, however, a significant difference between the two methods (Tables 1 and 2), as explained above, i.e. only Table 1 was based on a full cross-validation.

According to Table 2 the rate of success based on the EOF method is the highest at the central region of Israel, i.e. for Jerusalem and Natanya (83%), and lowest, as expected, in the periphery stations in the north (Eylon) and south (Gaza). It comes out that if the Negev, i.e. Beer-Sheba, which hydrological contribution is small, is excluded, the forecast for the entire season is better by about 5% than for DJF. This is quite a significant finding.

It is interesting to also point-out that there are no other significant differences for prediction of the full season rain as compared to DJF rain only. This fits an earlier report by D. Sharon at the IMS annual meeting suggesting to replace the IMS DJF seasonal prediction with the full winter.

Seasonal Prediction for Israel Winter Precipitaion

Station	DJF	N-M	Total	Average
Eylon	67	74	74	72
Dganya	79	82	79	80
Jerusalem	79	85	85	83
Natanya	79	87	82	83
Beer-Sheba	74	67	67	69
Gaza	77	67	72	72
Average	75.8	77	76.5	76.4

Table 2 - Rate of success (in percentages) for the sensitivity investigation of time and space categories, for 1949-1988. DJF represent Dec to Feb rain, N-M represent Nov to Mar while 'Total' represent the Nov to Apr rainfall

Seasonal prediction of winter frost/chill days and temperature

Using the same method of prediction (all 35 predictors and no stepwise), the possibility of seasonal prediction of minimum temperatures, was also tested. This aimed to explore the potential of an advanced seasonal frost warning, for agriculture purposes. Two new indices were adapted: (i) a minimum temperature Index, defined as the lowest temperature reached during the winter; and, (ii), a frost days index, defined as the number of days, when temperature fall below 1 degree Celsius. The tests show a significant 77% rate of success for the minimum temperature index and 81% for the number of frost days' index. Rate of success here was defined as the numbers of successful seasonal predictions compared to the full period of the experiment. For a specific season a successful prediction was defined when the predicted index, e.g. number of frost days, was less than 0.7 standard deviation from the observed index. Again, these predictions are based on simple model (as in Table 2) and not on the full model (as in Table 1). Hence, they are indicative but not cross-validated.

Connection between Indian Monsoon and Israeli rainfall season

EM is located at about the same latitude as the northern section of the Indian Monsoon at a distance of about 3000 km. Seeking a possible teleconnection between them, a simple correlation was calculated. While an Indian Monsoon Index is available for over 200 years, the Israel rainfall record do not exceed 160 years in Jerusalem; Their correlation reached only -0.3 (for 118 years) but, in 73 years (62%) the rain indices for Monsoon and Jerusalem got an opposite sign. Furthermore, for the extreme Monsoons cases only (above or below 1.3 standard deviation), the correlation increased to -0.56 (see Fig. 2). These results were confirmed for other rainfall stations, i.e., Ayelet and Deganya, but for shorter periods (not shown), suggesting the Indian Monsoon may serve as a potential predictor for Israel rainfall. A review of tropical teleconnections with Israel is given by Alpert et al. (2005).

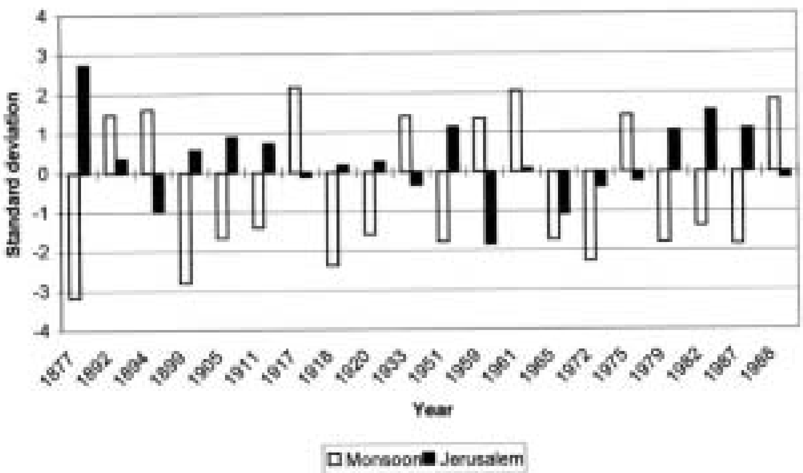

Fig. 2 - Extreme Monsoon anomalies (above or below 1.3 standard deviation) versus the Jerusalem rainfall anomalies. Full and empty bars represent the rainfall anomaly for the Jerusalem and for the Indian Monsoon rainfall respectively. The correlation is -0.565 for all 20 events, in the period 1877-1992

Discussion and Conclusions

The most outstanding result of this study is the 88% cross-validated success in the winter rainfall prediction, based on October hemispheric fields. The advantage of applying PCA instead of empirical predictors to improve significantly the seasonal forecast in Israel is evident. Analysis of the results shows:

- The success rates of the predictions based on European inputs were lower compared to those based on hemispheric data, suggesting stronger teleconnections in the EM to the whole Northern Hemisphere.
- Seasonal predictions based on October inputs are better compared with that based on November, due probably, to the strong influence of early autumn compared with the early winter patterns.
- Even the good monthly prediction hits for one month become poor for an extended lag. Compare for instance 88% success for Nov. based on Oct. that drops to 50% for Dec. (Table 1).
- Figures 3 and 4 illustrate the significance of neighboring rainfall teleconnection from Western Europe, Scandinavia, Eastern Atlantic, as well as remote patterns over North Asia, North East Pacific, Northern Latitude, North Pacific and North East Pacific\North America.
- It seems that short weather time-scales are more influenced by the geographically-close weaker patterns, while longer time scales are related to more remote patterns.
- Separate predictions for several locations or different periods do not significantly influence the rate of success. So, the Israel rain prediction achieved so-far only 72% success when the prediction is without EOF selection and no cross-validation.
- If the Negev (Beer-Sheba) is excluded, the forecast for the entire season may be better by about 5% than for DJF only.
- The potential for seasonal winter temperature and frosty/chilly days estimation is promising, suggesting the potential for a comprehensive winter prediction.
- An explanation for the connection between the Indian Monsoon and the Israeli winter rainfall, particularly for the extreme seasons, is required. This

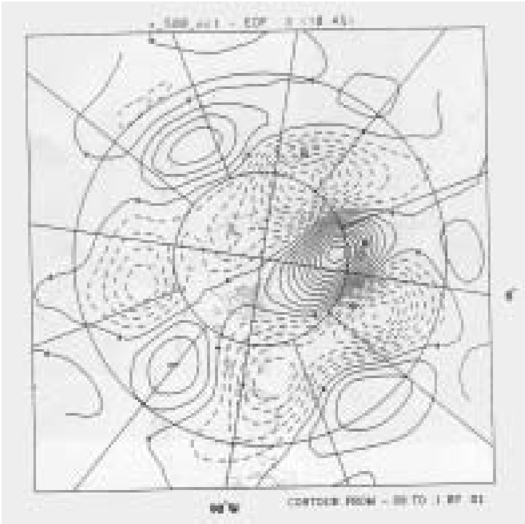

Fig. 3 - EOF number 3 of 500hPa height (selected by SAS for the seasonal forecast), strongly resembles the Scandinavian pattern

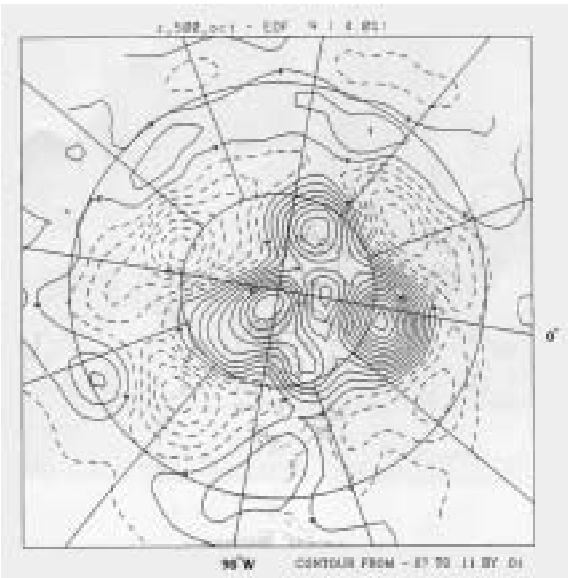

Fig. 4 - EOF number 9 of the 500 hPa height (selected by SAS for the seasonal forecast), the combination of three structures: the main structure resembles the Western Europe pattern, while the other two resembles the North Asia and the North Latitudes patterns

may be through a third factor, like the Eurasian snow cover, well connected to the Monsoon (Shukla 1981, 1985) or to the intrusion of cold waves into the Mediterranean, Alpert and Reisin (1986). Ziv et al (2004) have recently shown a direct link between the Indian Monsoon and the summer circulation over the EM.

- Further studies using additional meteorological fields, and based on September data should be considered.

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