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A possible link between El Niño and precipitation in Israel

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Abstract. Various data sets related to precipitation in Israel have been analysed to see whether any statistical relationships exist between the El Niño phenomenon and weather in Israel. An understanding of patterns of precipitation in Israel is extremely important given the limited water resources in the Middle East. The authors have analysed seasonal rainfall, streamflow, snowfall and lake level data, and all of these data sets indicate enhanced precipitation during the winter seasons associated with El Niño years. One intriguing finding is that the statistically significant correlations appear only in the last 25 years.

Introduction

Although many statistical connections between El Niño/Southern Oscillation (ENSO) events and precipitation anomalies around the world have been found (Rasmusson and Carpenter, 1983; Ropelewski and Halpert, 1987; Cane et al., 1994; Yakir et al., 1996) it is still not clearly understood how changes in the sea surface temperatures (SSTs) in the Pacific Ocean affect weather patterns at great distances from the Pacific. There are two possible explanations for these "teleconnections".

The first is related to changes in the tropical Walker circulation that dramatically influences tropical meteorology during ENSO events. Changes in the zonal circulation in the tropics could potentially impact midlatitude weather by changing the position and intensity of the subtropical jet stream and perhaps the meridional transport of moisture and heat (Chou, 1994; Straus and Shukla, 1997). Changes in the location of the deep convection have direct effects on the upper tropospheric flow patterns on horizontal scales of thousands of kilometers. An example of this is the relatively few Atlantic hurricanes during the recent El Niño (1997/8) and during previous El Niño events (Gray, 1984). The reduction in the number of hurricanes can possibly be explained by changes in the flow patterns in the upper atmosphere above the Atlantic that inhibit the development of tropical storms. The Indian Monsoon is another example of how changes in the tropical circulation can impact subtropical weather patterns (Rasmusson and Carpenter, 1983; Webster and Yang, 1992). There is substantial evidence linking the El Niño and the Indian Monsoon, and it is possible that the Indian Monsoon itself impacts the development of El Niño conditions in the Pacific (B.P. Kirman and J. Shukla, personal communication, 1997).

A second explanation for the teleconnections is related to changes in the subtropical jet stream. The subtropical jet stream is directly related, via the thermal wind, to the horizontal gradient of temperature between the equatorial regions and the higher latitudes. The greater the temperature gradient the more intense the jet stream, which is also the reason the jet stream is more intense in the winter hemisphere. The position of the jet stream is determined by the location of the warm and cold regions on the planet. The anomalous warming in the central and eastern Pacific during ENSO events causes a shift equatorward in the mean position of the subtropical jet stream, hence altering the position of the troughs and ridges of the Rossby waves associated with the jet stream (Wallace and Gutzler, 1981; Straus and Shukla, 1987). A recent study in Israel has found clear evidence for the southward shift of the subtropical jet stream over Israel during ENSO years (Y. Carmona and P. Alpert, personal communication, 1998).

Alpert and Reisin (1986) have already noted a connection between snowfall in Jerusalem and ENSO events. More recently Yakir et al. (1996) found positive correlations between rainfall in Jerusalem and El Niño years. In this paper we present a more extensive data set that strengthens these previous reported connections between weather in the Middle East and tropical Pacific sea surface temperature anomalies.

Data

Since water resources are of extreme importance in Israel, this study focused primarily on precipitation in the watershed region around the Sea of Galilee (Lake Kinneret) in northern Israel. The Sea of Galilee is the only major fresh water lake in Israel and constitutes a third of the nation's water supply, and 50% of its drinking water. Hence, the interannual variability of rainfall and lake level in this region is of great importance.

Five sets of data were used in this study:

1) Monthly rainfall data from four station in the watershed of Lake Kinneret (Kfar Blum - since 1945, Kfar Giladi - since 1922, Ayelet Hashahar - since 1941, and Degania - available since 1963). These data were supplied by the Israel Meteorological Service. The monthly data were combined to obtain a seasonal rainfall amount for each rainy season. Since the rainy season occurs mainly in the winter season, each rainfall value is a summation of precipitation from October to April the following year. The rainfall data from these stations are highly correlated with each other on a seasonal timescale ($r>0.9$), allowing us to use the Kfar Giladi time series to approximate the interannual rainfall variability in the entire region for the early period of the record.

2) Streamflow in the Jordan River was also obtained on a seasonal basis. The Jordan River flows directly into Lake Kinneret, representing an integration of all the runoff in the watershed during the winter months. The streamflow is measured close to the mouth of the Jordan River as it enters Lake Kinneret by Mekorot (the governmental body responsible for water resources in Israel). Streamflow data is only available from the winter of 1967/8.

3) The daily lake levels of the Kinneret are measured at the Yigal Alon Kinneret Limnological Laboratory along the northern shore of the lake. There is a lag between rainfall, runoff and lake levels due to processes related to transport of underground water (McNab and Karl, 1989) and snowmelt from Mt. Hermon, which also feeds into the Kinneret. We used the lake level data for the 6 month period following the rainy season (March-August). This is the period when the lake reaches its maximum height in response to the precipitation in the watershed during the previous winter. We note that there is extensive pumping of water out of the lake for human usage, but

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our findings were unaffected when taking this into account. This is because the lake's evaporative processes are significantly larger than the typical pumping rate. The lake level data is available from 1927.

4) Snowfall data from Jerusalem and Mt. Canaan in the Galilee were used. These data are available from the Israel Meteorological Service, and part of the data has been analysed and published by Bitan and Ben-Rubi (1978). These data do not give the amount of snow that fell, but rather the number of days with snow on the ground (snowdays). Although this does not allow us to estimate the amount of precipitation, it does give an indication of the frequency of snowfall during the winter months in Israel. The snowfall data from both stations is available from 1939, with additional data from Jerusalem going back to 1860.

5) The primary ENSO index used was the monthly sea surface temperature (SST) in the eastern tropical Pacific. The temperature index used is that of the NINO3 regions [5S-5N, 150W-90W]. However, it is still not clear what threshold is to be used for defining whether a year is regarded as an El Niño/La Niña or not. Recently, Trenberth (1997) suggested a modified definition for ENSO years as years when the 5-month running mean of SST anomalies in the NINO3 region exceed thresholds of ± 0.5°C for 6 months or more. This definition of ENSO events allows the beginning, end, duration and magnitude to be determined. The NINO3 temperatures are available from 1856-1996 and are produced by optimal interpolation methods described by Kaplan et al. (1998). We have used Trenberth's (1997) definition of ENSO years for this study. In addition to the temperature index we also used for part of our analysis the Southern Oscillation Index (SOI), representing the atmospheric pressure differences between Tahiti and Darwin (Ropelewski and Jones, 1987), which are directly related to the Walker circulation changes in the tropical Pacific.

Results

The results of our analysis indicate that in the past 20-25 years there exists a statistically significant correlation between El Niño events and above average precipitation in northern Israel (Figures 1 and 2). In the last 20 years, according to the Trenberth definition above, there have been 9 winters in Israel that were associated with warm SSTs in the NINO3 region (solid arrows in Figure 1), including the most recent 1997/8 El Niño. There were also five La Niñas. All nine winters had above average rainfall, with half of them having more than 25% above normal rainfall. Furthermore, the 1988/9 La Niña was followed by a period of extreme drought in Israel, when the Kinneret lake fell to a record low level not experienced since recording started in 1927 (Nun, 1991). Surprisingly, even with the removal of water from Lake Kinneret for human use, the interannual variability of the lake level still shows a strong signal related to the ENSO cycle.

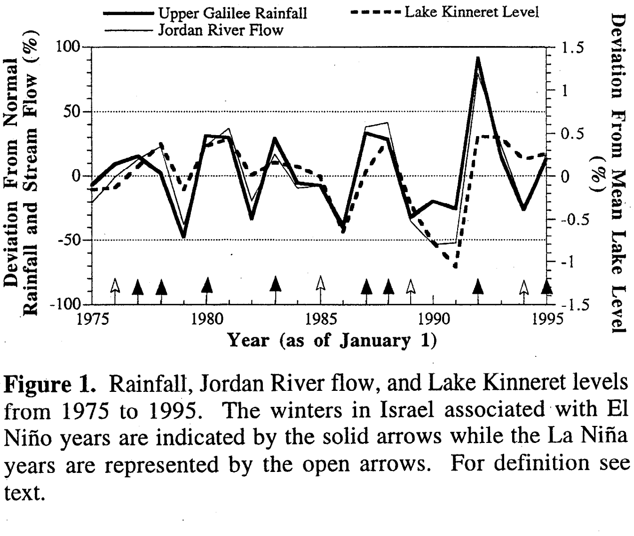

Figure 1. Rainfall, Jordan River flow, and Lake Kinneret levels from 1975 to 1995. The winters in Israel associated with El Niño years are indicated by the solid arrows while the La Niña years are represented by the open arrows. For definition see text.

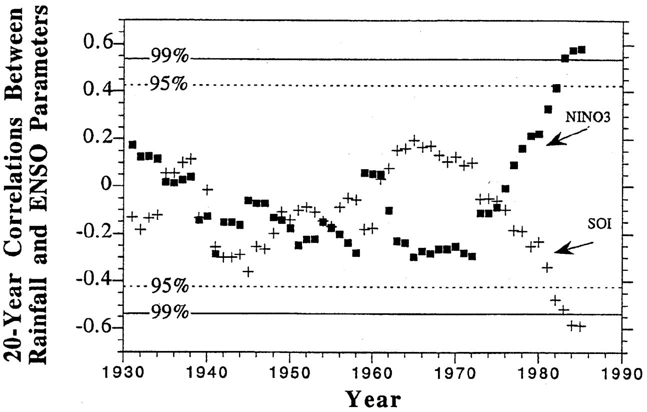

Figure 2. Twenty-year running linear correlation coefficients between the Oct-Mar mean NINO3 and SOI indices, and the winter rainfall at Kfar Giladi in northern Israel. The data points are plotted above the year that represents the mid-point of each twenty-year correlation.

Although there is a statistically significant positive correlation (r=0.58) between rainfall and NINO3 SSTs over the last twenty years (r=-0.59 between rainfall and the SOI), it is interesting that the precipitation anomalies are not always directly proportional to the ENSO intensity. The very intense El Niño of 1982/3 had slightly less of an impact on precipitation in northern Israel than the weak 1989/90 event. Furthermore, the moderate 1991/2 event was associated with severe flooding in Israel with large amounts of rainfall throughout the country. It is possible that the volcanic eruption of Mt. Pinatubo in the Philippines in June 1991 also played a role in the 1991/2 winter precipitation in Israel (Genin, 1995; Nirel and Rosenfeld, 1992).

One of the precipitation stations (Kfar Giladi) has rainfall data since 1922. To check how the correlation between the rainfall and ENSO has changed over time, we used both the NINO3 temperatures as well as the Southern Oscillation Index (SOI). From 1922 onwards we looked at windows of 20 years of annual data. For each 20-year period a linear correlation was obtained between Kfar Giladi winter rainfall and the October-March mean NINO3 and SOI indices. El Niño years with positive NINO3 temperature anomalies are equivalent to negative SOI anomalies. The results are shown in Figure 2 where each point represents a 20 year linear correlation centered on the year shown. The 95% and 99% significant levels are also given, indicating that only in the last 25 years has the correlation been significant at the 95% level, while in the last 20 years the significance is above 99%. However, even though the recent correlations are highly significant, the value of r=0.6 implies that the changes in the tropical Pacific related to ENSO only explain 36% of the variability in Israeli rainfall. Although this is a noteworthy modulation, there is still 64% of the variability that comes from other sources. The correlation is nevertheless not dissimilar to other regions where there are know strong teleconnections. Cane et al. (1994) found correlations of approximately r=0.6 between NINO3 temperatures and rainfall/maize yields in Zimbabwe.

Using the same data we have also performed a spatial correlation between global SST anomalies between October-March and the rainfall at Kfar Giladi for the same period. The correlation coefficients between the rainfall in northern Israel and SST for the past 20 years are shown in Figure 3. The ENSO pattern can be seen quite clearly. When looking at global sea surface temperatures, the maximum correlation with precipitation in northern Israel occurs in the central and eastern

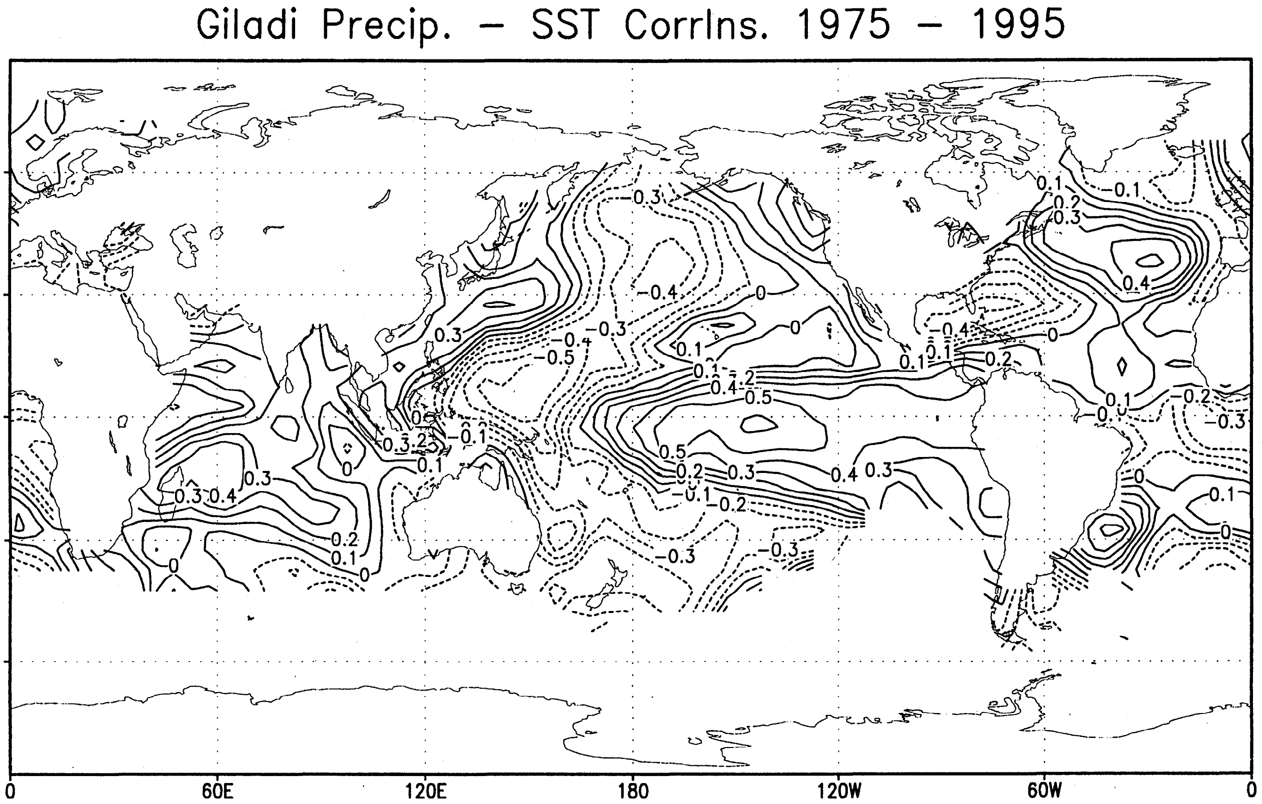

Figure 3: Linear Correlation between Kfar Giladi October-March rainfall and SST during the period 1975-1995.

tropical Pacific where a strong positive correlation occurs (r~0.6), while the western tropical Pacific has a strong negative correlation (r~-0.5). There is also a considerable positive correlation between rainfall and the SSTs in the Atlantic Ocean. However, when looking at the same maps for the period 1922-1975, no significant correlations were found between the tropical Pacific SSTs and Kfar Giladi rainfall.

As an extra confirmation of the ENSO connection, we used a r*c contingency table to test the null hypothesis of whether the occurrence of rainfall is independent of El Nino/La Nina events over the last 20 years. We chose 3 levels (r=3) of rainfall (more than 110% of its normal rainfall; less than 90% of the normal rainfall; or within 10% of the mean annual rainfall); limits used by the Israel Meteorological Service to define wet, dry and normal years. The 3*2 contingency table has a known Chi-square distribution with (r-1)*(c-1)=2 degrees of freedom (Zar, 1984). For our data we obtain a χ^2 value of 11.12 which is significant at the 99.5% level. This implies that we can reject the null hypothesis and be confident that El Nino years are linked with wet winters in northern Israel, at least in the last 20 years.

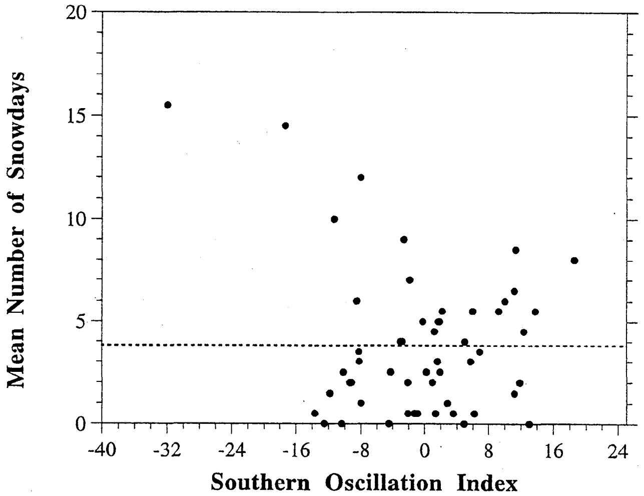

Figure 4. Scatter plot of snowdays in Israel during the 1939-1993 period as a function of the Southern Oscillation Index. The long term mean for snowdays is shown by the dotted line.

The snowday data do not give a clear relationship between ENSO events and snowfall in Israel. The reason for this is possibly that the snowfall data is not directly related to the amount of snow, but rather the number of days the snow remained on the ground. A large number of snowdays in a specific year could result from many individual days with snowfall, or a few days of snowfall but with temperatures cold enough to sustain the snowcover for additional days. Nevertheless, Figure 4 presents the annual number of snowdays since 1939 plotted against the January-February mean Southern Oscillation Index. The majority of snowfall occurs during these two months (Bitan and Ben-Rubi, 1978). When combining the two stations where snowday data are available, a longterm mean of 3.8 snowdays per year is found (dotted line in Figure 4). Figure 4 shows a tendency for El Nino years (negative SOI) to have more snowdays, especially when considering years that had above average snowdays. The largest number of snowdays occurred in 1982/83 and in 1991/92, both of which were El Niño years. The 1997/8 El Niño was also associated with two large snow events across Israel, although the exact number of days was not available at the time of writing this paper. In addition, 6 out of 8 El Niño years between 1975-1993 had above average snowfall.

Conclusions and Discussion

We have analysed various data sets related to precipitation in the northern parts of Israel. We have found that since the mid-1970s there appears to be a connection between El Niño events and rainfall, streamflow, lake level and perhaps snowfall. These connections are statistically significant for the past 20-25 years, however, the relationship appears to vanish as we go further back in time.

It is puzzling as to why we observe these correlations only in the recent record. We suggest that this may be a result of the changes in the frequency and intensity of ENSO events since the mid 1970s. Trenberth and Hoar (1997) have shown that since 1976 there has been a significant increase in the frequency of El Niño events relative to La Niña events, and the intensity and period of these events has also increased. Rajagopalan et al. (1997) have also shown that in the last two decades the frequency and duration of ENSO events has increased relative to the prior period. It has been suggested that there may have been a shift in the global climate system during the 1970s which may have resulted in a stronger Pacific-midlatitude link during the past two decades (Wuethrich, 1995).

Whether these changes are due to long term natural variability in the climate system or other factors perhaps related to global climate change is still not known. Nevertheless, there appears to be some justification to the positive correlations we observe between precipitation in Israel and tropical SSTs since the mid 1970s. The increase in association with ENSO during the recent decades is consistent with increased ENSO signatures in seasonal rainfall in southern Europe found by Rodo et al. (1997).

Although a lot more research is needed into the physical mechanisms responsible for these teleconnections, it does appear that the ENSO warmings in the tropical Pacific are able to result in anomalous rainfall patterns in regions as far away as Israel, the original home of El Niño.

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References

Alpert, P., and T. Reisin, An early winter polar air mass penetration to the eastern Mediterranean, *Mon. Wea. Rev.*, 114, 1411-1418, 1986.

Bitan, A, and P. Ben-Rubi, The distribution of snow in Israel, *GeoJournal,* 2.6, 557-567, 1978.

Cane, M.A., G. Eshel, and R.W. Buckland, Forecasting Zimbabwean maize yield using eastern equatorial Pacific sea surface temperature, *Nature*, 370, 204-205, 1994.

Chou, M.D., Coolness in the tropical Pacific during an El Niño episode, *J. Clim.*, 7(11), 1684-1694, 1994.

Genin, A., B. Iazar and S. Brenner, Vertical mixing and coral depth in the Red Sea following the eruption of Mount Pinatubo, *Nature*, 377, 507-510, 1995.

Gray, W., Atlantic seasonal hurricane frequency. Part I: El Nino and 3-mb Quasi-Biennial Oscillation influences, *Mon. Wea. Rev.*, 112, 1649-1668, 1984.

Kaplan, A., M.A. Cane, Y. Kushnir, A.C. Clement, M.B. Blumenthal and B. Rajagopalan, Analyses of global sea surface temperature, 1856-1991, *J. Geophys. Res.*, in press, 1998.

McNab, A.L., and T.R. Karl, Climate and droughts, *USGS Water Supply Paper 2375*, 89-95, 1989.

Nirel, R., and D. Rosenfeld, Evaluation of the significance of the relation between stratospheric volcanic eruptions and annual rainfall in Jerusalem (in Hebrew), *Meteorology in Israel*, 2, 44-46, 1992.

Nun, N., *The Sea of Galilee - Water levels past and present*, Kibbutz Ein Gev, Israel, pp. 24, 1991.

Rajagopalan, B., U. Lall, and M.A. Cane, Anomalous ENSO occurrences An alternate view, *J. of Climate,* 10, 2351-2357, 1997.

Rasmusson, E.M., and T.H. Carpenter, The relationship between eastern equatorial Pacific sea surface temperatures and rainfall over India and Sri Lanka, *Mon.Wea. Rev.*, 111, 517-528, 1983.

Rodo, X., E. Baert, F.A. Comin, Variations in seasonal rainfall in Southern Europe during the present century: relationships with the North Atlantic Oscillation and the El Niño-Southern Oscillation, *Climate Dynamics*, 13, 275-284, 1997.

Ropelewski, C.F., and M.S. Halpert, Global and regional scale precipitation patterns associated with the El Niño/Southern Oscillation, *Mon. Wea. Rev.*, 115, 1606-1626, 1987.

Ropelewski, C.F., and P.D. Jones, An extension of the Tahiti-Darwin Southern Oscillation Index, *Mon. Wea. Rev.,* 115, 2161-2165, 1987.

Straus, D.M., and J. Shukla, Variations of midlatitude transient dynamics associated with ENSO, *J. Atmos. Sci.*, 54, 777-790, 1997.

Trenberth, K.E., The definition of El Niño, *Bull. Amer. Met. Soc.,* 78, 2771-2778, 1997.

Trenberth, K.E., and T. J. Hoar, El Niño and climate change, *Geophys. Res. Lett.*, 24, 3057-3060, 1997.

Wallace, J., and D. Gutzler, Teleconections in geopotential height field during the Northern Hemisphere winter, *Mon. Wea. Rev.*, 109, 784-812, 1981.

Webster, P.J., and S. Yang, Monsoon and ENSO: Selectively interactive systems, *Quart. J. Roy. Met. Soc.*, 118, 877-926, 1992.

Wuethrich, B., El Niño goes critical, *New Scientist*, 4 Feb. 1995, 32-35, 1995.

Yakir, D., S. Lev-Yadun and A. Zangvil, El Niño and tree growth near Jerusalem over the last 20 years, *Global Change Biology*, 2, 101-105, 1996.

Zar, J.H., *Biostatistical Analysis*, Prentice-Hall International (UK) Ltd., London, pp. 718, 1984.

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