Synoptic to large scale circulations and their impact on cyclonic activity over the Mediterranean Basin during the winter season for past and future climates, based on ECHAM5 GCM model

Research report - ESF Grant No. 1722

Submitted to the ESF

Hadas Saaroni

The Unit for Applied Climatology and Environmental Aspects
Department of Geography and the Human Environment,
Tel Aviv University, Israel
Email: saaroni@post.tau.ac.il

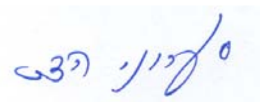
Purpose of the visit: Cooperative research with Christoph Raible from the Climate and Environmental Physics, Physics Institute, University of Bern, CH-3012 Bern, Switzerland on the topic described above.

Description of the work carried out during the visit: described below in the Abstract

Description of the main results obtained: described below in the results section

Future collaboration with host institution: We continue the collaboration with Christoph Raible and plan to elaborate it for the summer regime

Projected publications/articles resulting or to result from your grant: in preparation

Signature of Hadas Saaroni: 

July 2007

ABSTRACT

The winter regime in the Mediterranean Basin for the years 2071-2100, under A2 scenario, is studied, based on the ECHAM5 climate model simulation. First, the synoptic and large-scale features including cyclone detections are simulated by the model for a control period, 1961-1990, and compared with the NCEP-NCAR and ERA40 data bases. The model was found capable of reproducing the climatic features of the winter over the Mediterranean Basin and southern Europe. A comparison between the ECHAM5 results for the control period and the future revealed, as expected, a pronounced temperature rise at the lower-levels, ~3°C, with a maximum of >4°C. No significant change is noted in the low level pressure system over the eastern Mediterranean while a pronounced high pressure system is expected over the western Mediterranean and an eastward shift of the upper-level trough with an increase in polar intrusions especially in the eastern Mediterranean. Nevertheless, the number of cyclones in the western Mediterranean will drop by only ~10%, but the cyclones in the track between Sahara and the central Mediterranean will reduce to half. The intensity of the cyclones and anticyclones will not change significantly. No change is seen in the intensity of the subtropical jet stream but a slightly shift, ~1°, southward. Precipitation is expected to slightly decrease over the majority of the MB, mainly at the southern half of its western part together with the shift of the main cyclonic activity to the eastern part of the Mediterranean.

RESULTS

1. Introduction

All of the global climatic models applied for the 21st century predict general warming. In addition, they predict changes in the structure and intensity of the dominating circulations and in the rainfall distribution. One region that is expected to suffer from the reduction of rainfall is the Mediterranean Basin (MB), as is shown in IPCC (2007). This reduction is expected mainly in the winter, which is the rainiest season over that region (Ref). In the recent 60 years a rainfall decreasing trend can be identified over the majority of the Mediterranean (Alpert et al. 2002), suggesting that this is a part of the global change. But, in contrast with the predictions, no significant trend has been found over the south-eastern end of the Mediterranean (Alpert et al. 2002).

The vulnerability of the MB to rain shortage and the complexity of the terrain in this region necessitates that the future rainfall regime will be further studied by a model having a finer resolution that the global ones have. For that end we use here the simulations of a higher resolution model - the ECHAM5. The simulations are done for the mid-winter season (DJF) of the period 2071-2100, based on A2 scenario, which offers the most extreme potential changes.

The future climate is scrutinized, focusing on the characteristics of the Mediterranean cyclones, the mechanisms with which they are associated and their related rainfall. The simulations for the future conditions (A2 run) are compared with that for the 1961-1990 period (control run) so that to address the following topics:

- The potential for cyclones' formation
- Frequency and intensity of the Mediterranean cyclones
- Tendency of blocking events
- Partition of cyclonic activity between the eastern and the western parts of the Mediterranean

2. Methodology

The study region covers the MB, covering the domain 25°-55°N, -10°-45°E (Fig. 1) for the mid-winter season (DJF). We compared the 1960/61-1989/90 period (the control, defined as 1961-90 hereafter) with the period 2070/71-2099/2100 (the future, based on the A2 scenario, defined as 2071-2100 hereafter).

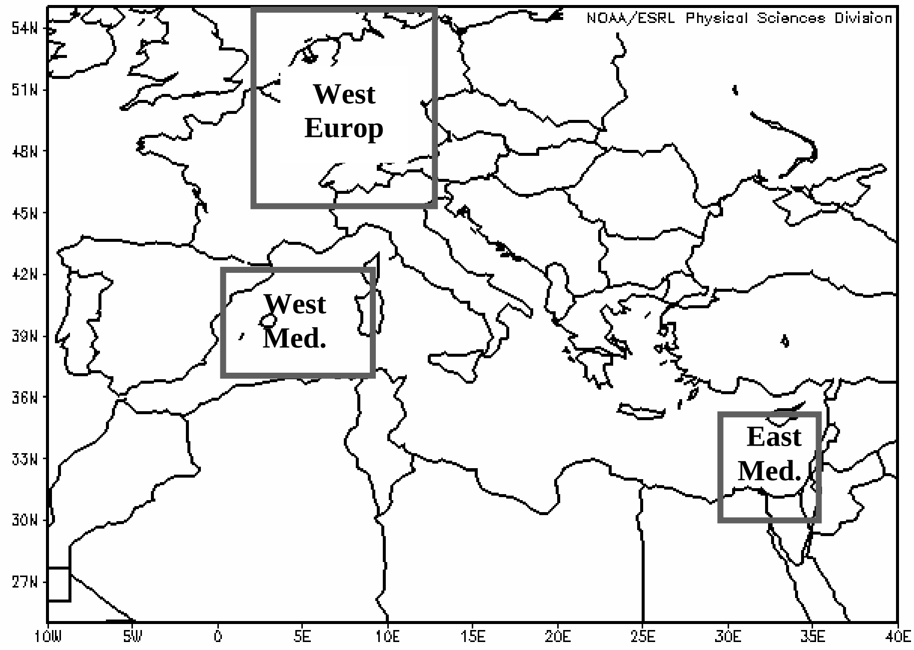


Fig. 1: The study region and the regions of interest

The model is evaluated by comparing its derived atmospheric fields (control run) with the observed fields extracted from the NCAR-NCEP initialized data base (Kalnay et al. 1996, Kistler et al. 2000), with T62 spectral resolution, interpolated to 2.5°×2.5° spatial resolution. The evaluation is done for variables which are linked with the weather conditions (e.g. 850-hPa temperature, geopotential height on 1000 and 500 hPa) and variables which reflect atmospheric processes (number and intensity of cyclones). For part of the evaluation we also used the ERA40 data base, having a spectral resolution of T159, interpolated to 1.125°×1.125° so as to fit the model resolution.

The A2 run is analyzed by comparing representative variables and fields, as well as derivable fields with that for the control run. .

First, the results of the ECHAM5 model for the control period were evaluated by comparing to the NCEP/NCAR and the ERA40 results. Then, the future simulations, for 2071-2100, were compared with the control runs.

3. Model evaluation for the control period (1961-1990)

In this section the data taken from the NCEP-NCAR will be referred to as 'observation' and that taken from the ECHAM5 simulation – as 'simulation'. The consistent difference found between the two data sources is the STD, being higher in the simulation by ~10% than in the observation. This may be explained by the finer spatial resolution of the ECHAM5 simulation.

a. Comparison of selected variables at regions of interest

Table 1 specifies the location of the regions selected as 'regions of interest' (as seen in Fig. 1) and specified the implications of the variable tested, together with their mean and standard deviation (STD).

Region	Domain	Variable	Implication	Average (STD) Observation	Simulation
West Europe (WE)	45°-55°N 5°-15°E	Max gph (500hPa)	Blocking situations	5559 (129)m	5601 (136)m
West Med. (WM)	37.5°-42.5°N 0°-10°E	Min gph (500hPa)	Polar upper-trough	5538 (120)m	5553 (135)m
		Min gph (1000hPa)	Genoa Lows	123 (77)m	134 (84)m
		Min temp. (850hPa)	Cold intrusions	-0.1 (3.7)°C	-0.7 (4.1)°C
East Med. (EM)	30°-35°N 30°-35°E	Min gph (500hPa)	Polar upper-troughs	5586 (86)m	5592 (106)m
		Min gph (1000hPa)	Cyprus Low	133 (45)m	129 (52)m
		Min temp. (850hPa)	Cold intrusions	+2.3 (3.5)°C	+2.4 (3.8)°C

Table 1: Location of the selected regions and the implications of the variable tested

b. Inter-annual variations and extreme values

Time series of the maximum 500-hPa geopotential height (gph) over West Europe (WE) of the simulation compared with the observation revealed that the two distributions are more or less similar, except for a slightly higher average and larger STD in the simulation (being higher by 41m and 7m, respectively). These differences may be attributed to the higher resolution of the simulation. In spite of these differences, both the observation and the simulation show that there is a high inter-annual variation in the occurrence of extreme events and that there are winters in which no exceedences were recorded. In part of the winters the exceedences occurred in several successive days, suggesting that they reflect blocking events. This may imply that the model captures well their existence as well as their high inter-annual variations.

The upper-level polar outbreaks were studied through the temporal distribution of the lower 3% quantile of the minimum 500-hPa gph. For the EM, both the simulation and the observation show high inter-annual variations and that they do not occur every year. Actually, they both show that they did not occur in 6 out of the 30 years. Similar behaviour was found in the analysis of the lower-level minimum temperatures, studied for the 850-hPa temperature.

The inter-annual variation in the synoptic-scale was inspected through the seasonal 500-hPa gph anomaly maps for each of the 30 years, for the observation and the simulation. The extrema found over the study region were in the same order of magnitude (up to ~100 m). As one may expect, no correspondence was found between the patterns in the individual seasons. However, it is worth noting that for two winters a considerable degree of similarity was noted. One is 1982/83, in which both the observation and the simulation show a positive pronounced anomaly over the west MB. The second is 1989/90, in which the majority of Europe and the Mediterranean were covered by an extreme positive anomaly with a maximum of >110m in the observation and >80m in the simulation. Both two years were characterized by external forcing (with respect to the study region). The former was dominated by a strong El-Nino and the latter by a pronounced La-Nina. The simulation could capture these events through the SST, which were taken from the real data. These two examples indicate that the model is capable to reproduce global tele-connections.

c. Regional tele-connections

The model ability to reconstruct regional tele-connections is evaluated by the correlation between seasonal averages of representative variables in the tele-connecting regions, as obtained by the observation and the simulation. One such tele-connection was found to exist between the Eastern Mediterranean (EM) and the western Mediterranean (WE). The tele-connection is expressed by a seesaw relation, implying a negative correlation. Generally, positive anomalies in the gph over WE enhance northerly flow over Eastern Europe and transport cold air toward the EM, whereas the reverse holds for negative anomalies over WE. The correlation between the 850-hPa minimum temperature over the EM and the maximum 500-hPa gph over the WE was found negative, -0.77 for the observation and -0.66 for the simulation.

The relationship existing between upper-level trough and surface cyclogenesis was examined through the correlation between the minimum height at 500-hPa over WE and at 1000 hPa over WM. Both observation and simulation showed a correlation of 0.95. Another tele-connection found in both observation and simulation is a positive correlation between the minimum 1000-hPa gph at both ends of the Mediterranean, being +0.71 for the observations and +0.44 for the simulation.

It may be concluded that the simulation reproduces quite realistically the synoptic- to large-scale relations over the study area.

d. Cyclones' detection

The skill of the simulation in reproducing cyclonic activity was evaluated by counting the number of cyclones, cyclone occurrences (number of cyclone days) and their intensity for the western and eastern MB separately. Table 2 compares the results for the two regions.

Data source\box	West Med. (WM) (30°-47.5°N, 0°-20°E)	East Med. (EM) (30°-40°N, 20°-37.5°E)	Ratio (WM/EM)
ECHAM5	16.7	13.8	1.2
NCEP-NCAR	7.2	4.9	1.5
ERA40	16.7	11.4	1.5

Tab. 2: Seasonally (DJF) average number of cyclones in the WM and EM

Over twice number of cyclones was detected by the simulation with respect to NCEP-NCAR. Since the resolution of the ECHAM5 model is more than twice finer than that of the NCEP-NCAR data, we recalculated the cyclone characteristics, based on the ERA40 data base, having a resolution comparable with that of the ECHAM5. For Era40, the number of cyclones and cyclones' occurrence were in agreement with the simulation. However, it should be noted that the ratio between the number of cyclones in the two parts of the Mediterranean, as detected by the three data sources were in agreement, i.e., 1.2, 1.5 and 1.5 for the ECHAM5, NCEP-NCAR and ERA40, respectively.

f. The subtropics

We compared the subtropical jet (STJ) according to NCEP and ECHAM5, respectively, as reflected by the u-wind component. The structure of the STJ was found essentially similar except for two differences. One is the intensity, being larger by ~10% in the NCEP data and the second is a small northward shift, by ~1° in the ECHAM5 output. In order to further asses this difference we compiled the same field, for ERA40 data base, and found that it fits the NCEP, in both location and intensity of the STJ.

Another feature examined is the occurrence of Tropical Plumes (TPs). TP is a strip of cloudiness, of at least 2000 km long, that extends from the tropics poleward and cross a minimum of 15° latitudes. McGuirk (**), Kniperts (**) and Rubin et al. 2007 showed that over North Africa TPs extend often down to 30°N latitude and develop along the STJ ahead of a pronounced upper-trough that penetrates the subtropics from the mid-latitudes.

Over the studied region the TPs are assumed to be represented by intensifications of the 500-hPa wind to >40 ms^{-1} (about twice the average) while the wind direction veers by >30° from its normal zonal direction. The analysis was done for the 10°W – 40°E, 20° - 27.5°N domain.

For the NCEP data, the number of events detected for the 1961-1990 period was 157, i.e. 5.2 days per season on the average with an STD of 3.6 days. The inter-annual variation is very pronounced, from two seasons without any case to one with 18 events. Even in the intra-seasonal time-scale the events tend to group, so that they tend to be concentrated in one of the three month.

The TP events in the ECHAM5 runs was found 360, over twice those found in the NCEP data. The average seasonal number is 12.0, with an STD of 4.2. In addition to its relative high inter-annual variation (0.35, with respect to 0.69 for NCEP), ECHAM5 did not indicate for any season without one case. It seems that ECHAM5 overestimates the occurrence of TPs. This tendency is consistent with the STD of the 500-hPa v-wind component for the same domain, being 2-3 ms^{-1} in the NCEP data but 5-7 ms^{-1} in ECHAM5.

4. Future conditions compared with the control period

The A2 run shows a general warming for DJF in the order of 3-4°C with respect to the control run. In the lower levels (900-hPa, Fig. 2a) the temperature rise varies between 2.1°C and 4.5°C. The spatial distribution of the temperature change shows several extrema: a pronounced maximum over the Atlas Mountains (4.5°C), two minima, over the black sea and over the EM (both of +2.7°C) and a pronounced minimum (+2.1°C) over Egypt. Another feature is a south to north decrease over WE. At the mid-levels (500-hPa, Fig. 2b) the temperature rise varies in the range of 3.4 – 5.2°C. Here also the maximum is located over the Atlas Mountains and a south to north decrease is found over WE. As for the eastern part of the domain, a 'tongue' of low values extends from Ukraine toward the Red-Sea. The increase in the south to north gradient over WE, predicted by the A2 run, suggests an increase in the baroclinicity there.

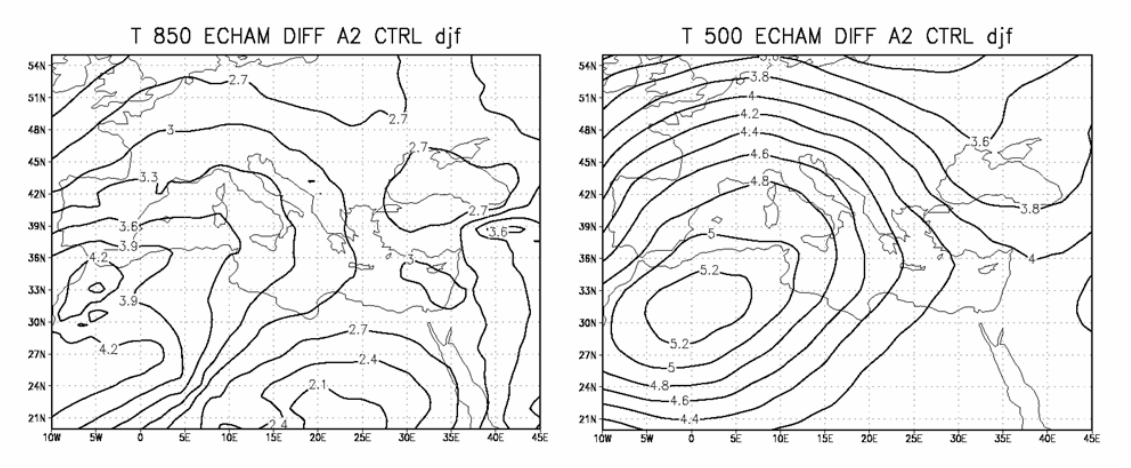


Fig 2: Temperature difference between A2 and the control runs for 900-hPa (a) and 500-hPa (b)

a. Large-scale analysis of regional cyclogenesis

The baroclinic potential for cyclogenesis is estimated for the control and the A2 runs by the Eady maximum growth rate. The results for the control run in the lower-levels (900-hPa) and in the mid-levels (500-hPa) are shown in Figs. 3a,b, respectively. The respective results for the A2 run are shown in Figs. 4a,b, respectively. The general spatial distribution is predicted to remain almost the same. The difference between the two runs confirms that no significant change is expected to take place over the MB and south Europe in the lower-levels, but a significant decrease is expected over North Africa.

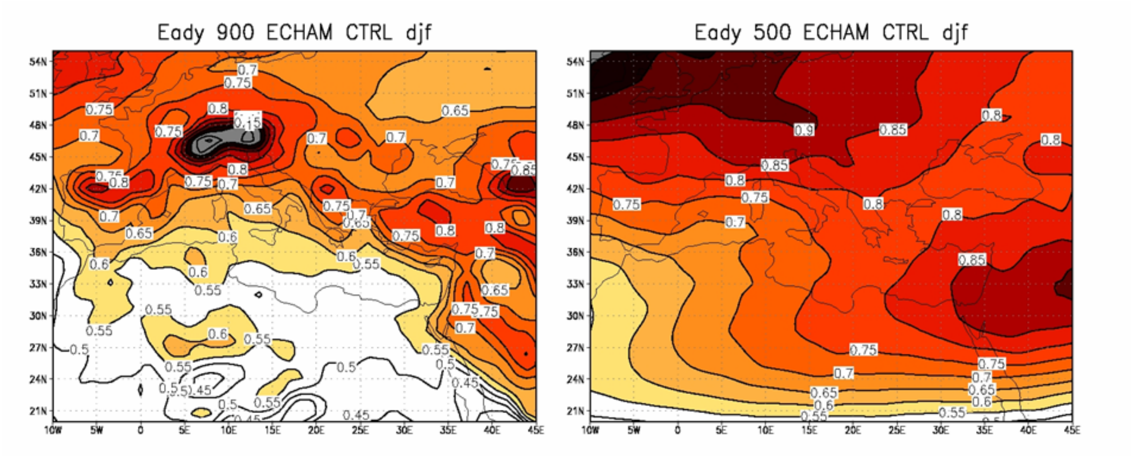


Fig. 3: Eady baroclinic maximum growth rate, based on the control run, for a. 900-hPa and b. 500-hPa

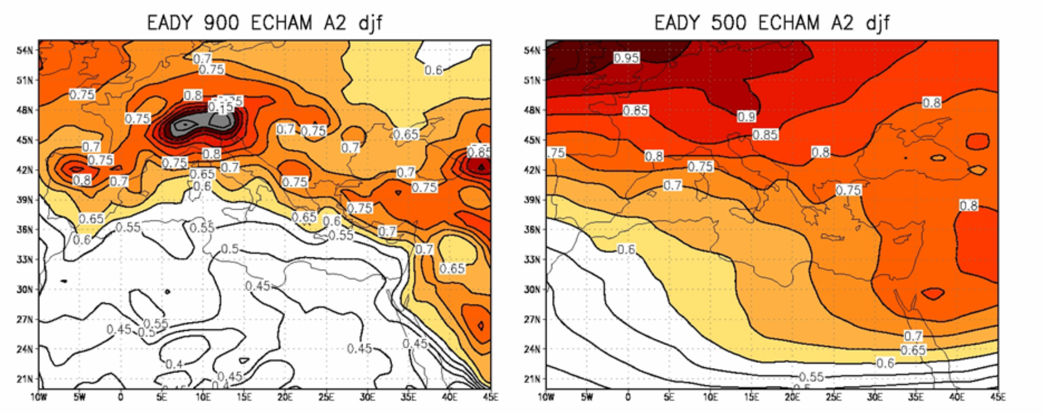


Fig. 4: As for Fig. 3, but for the A2 run

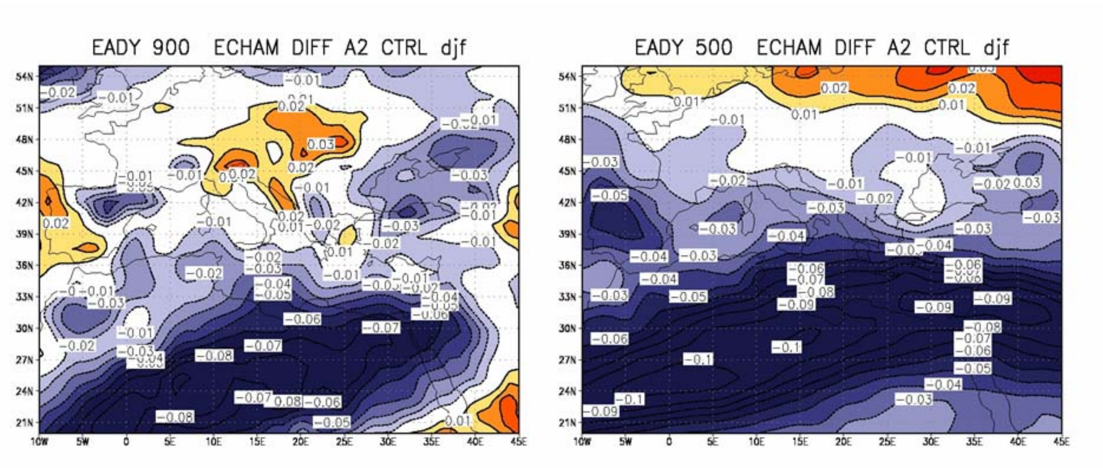


Fig. 5: As for Fig. 3, but for the difference between the control and A2 runs

This may suggest that the cyclone track extending from the Sahara toward the Mediterranean (HMSO, 1962, Romem et al, 2007) will become less effective. Since the meridional temperature gradient is not expected to change significantly, the general decrease may be attributed to the increase that is expected in the static stability by ~10% (Fig. 6).

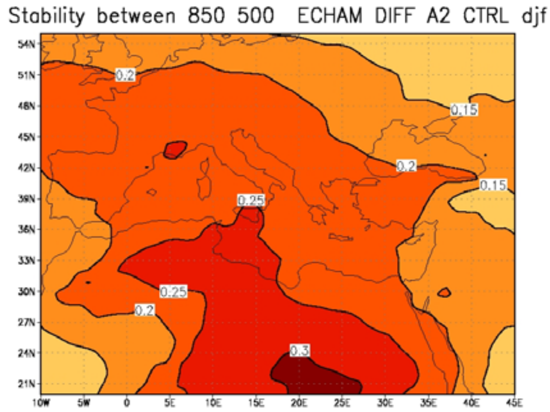


Fig. 6: Change in static stability (in terms of ∂θ/∂p)

b. Average fields of the geopotential height

For the 1000-hPa average geopotential height (gph) the control run (Fig. 7a) shows quite realistically the signature of the Mediterranean cyclones along the entire Basin. In contrast, the A2 run (Fig. 7b) shows their signature only over the eastern part, whereas the WM is covered by a widespread high pressure. An increase in the gph is noted all over the MB, with a maximum of >100m over the Alps. The above suggests a substantial decrease in cyclone activity, at least over the WM, but later on we shall show that this is not exactly the case.

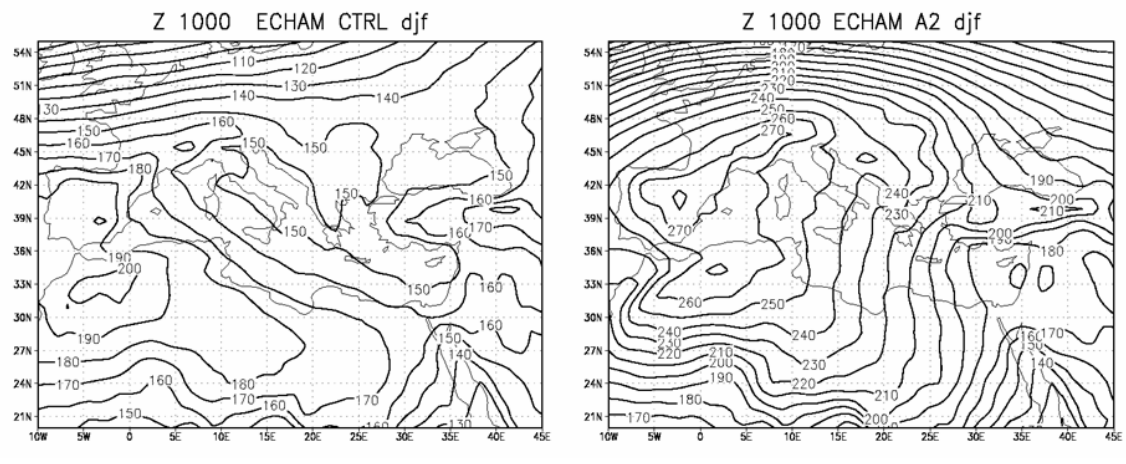


Fig. 7: Average 1000-hPa gph for a. The control run and b. The A2 run

The respective change of the mid-levels gph (Fig.8) shows an increase, with a maximum of >105 m, in agreement with the lower-level temperature rise.

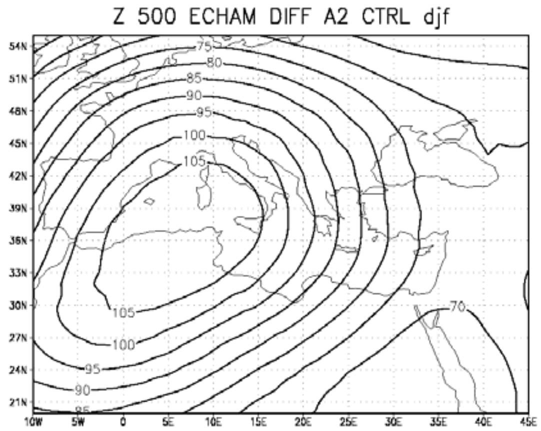


Fig 8: Gph difference at 500-hPa between A2 and the control runs

The 500-hPa gph maps for the control and for the A2 runs (Fig. 9) show a pronounced change in the location and orientation of the Mediterranean mid-level trough. While in the control run it is located over the WM and oriented northeast-southwest, in the next century it is expected to shift to the eastern coast of the Mediterranean and change its orientation to north-south one.

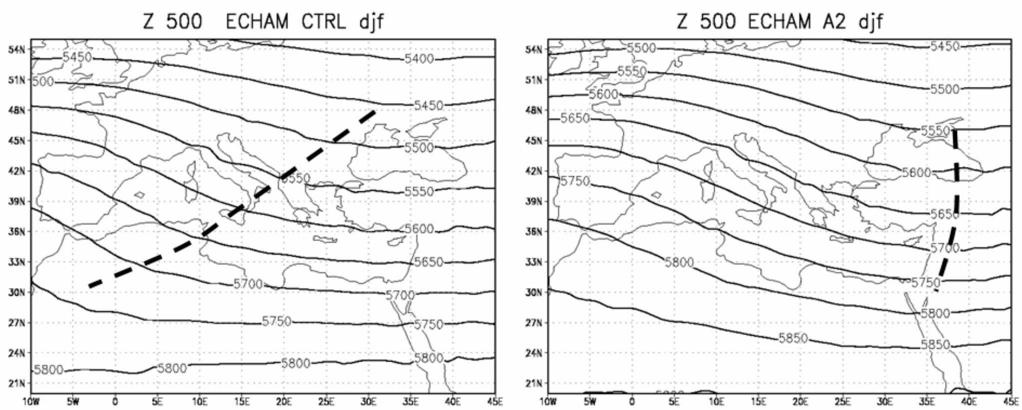


Fig. 9: Average 500-hPa gph for the control run (left) and 2071-2100 (right). The main trough is denoted by dashed thick line

The subtropical jet stream (STJ) for the A2 run shows no significant change in its intensity, but a shift of ~1° southward is noted (not shown).

c. temporal variations and extreme events

A major concern in future climate prediction is extreme events.

Region	Variable	Average (STD)		
		Control	A2	Diff (A2-Ctl)
West Europe (WE)	Max gph (500hPa)	5601 (136)m	5698 (131)	97 (-4)m
West Med. (WM)	Min gph (500hPa)	5553 (135)m	5661 (137)m	+108 (+2)m
	Min gph (1000hPa)	134 (84)m	159 (81)m	+25 (-3)m
	Min temp. (850hPa)	-0.7 (4.1)°C	2.6 (4.6) °C	+3.4 (+0.5) °C
East Med. (EM)	Min gph (500hPa)	5592 (106)m	5665 (117)m	+74 (+11)m
	Min gph (1000hPa)	129 (52)m	133 (53)m	+4 (+1)m
	Min temp. (850hPa)	+2.4 (3.8)°C	5.2 (4.2) °C	+2.9 (+0.4) °C

Table 3: As in Table 1, for the control and the A2 runs

Table 3 compares the average and STD values for the indicative variables for the regions of interest (presented above). The STD does not show significant or consistent changes in the WM, but a small consistent (though insignificant) increase for the EM.

In order to further elaborate changes in the extremety the A2-control difference for the lower and upper 10th percentile for each of the above variables are compared (Tab. 4). For the maximum gph over WE the increase in both upper and lower 10th is essentially similar to that of the full sample, in agreement with the similarity in the STD (Tab. 3). For the WM, the 500-hPa minimum gph does not show a significant trend and for the 1000-hPa minimum gph the lower (upper) 10th larger (smaller) with respect to the average, suggesting a decrease in extremety of cyclones' intensity. As for the temperature, the increase of the upper 10th is 1.5 larger than the lower, implying extreming in the winter temperature variations (in agreement with the increase in STD).

As for the EM, except for the 1000-hPa minimum gph, which does not show any clear signal, the 500-hPa minimum gph and the 850-hPa minimum temperatures show an extremety increase, especially for the low extremes. This is expressed by an increase of the lower 10th that is smaller than that of the full sample and that of the highest 10th, which is larger than for the full sample, while the difference between the increase of the lower 10th and the full sample is the largest (see Tab. 4).

Region	Variable	Average (STD) Lower 10th	all samples	Upper 10th
West Europe (WE)	Max gph (500hPa)	+104m	+97m	+95m
West Med. (WM)	Min gph (500hPa)	+99m	+109m	+103m
	Min gph (1000hPa)	+30m	+25m	+18m
	Min temp. (850hPa)	+3.0°C	+3.4°C	+4.5°C
East Med. (EM)	Min gph (500hPa)	+49m	+74m	+81m
	Min gph (1000hPa)	+1	+4	+3
	Min temp. (850hPa)	+2.2°C	+2.9°C	+3.4°C

Table 4: Difference (A2 – control) runs in selected variables

As for the extreme temperatures, the absolute minimum for the EM is -11.8°C for the control and -8.9°C for the and for the A2 run and for the WM it is -16.0°C and -12.7°C, respectively indicating the change in extreme temperatures.

d. Cyclones' frequency and intensity

Table 5 specifies the Mediterranean cyclones' characteristics for the control and the A2 run. The comparison is done for the number of cyclones that span each part of the MB, the number of occurrences (in terms of days), and the median and upper 10% quantile. The intensity is estimated here by the gph gradient within the inner 1000 km radius around the cyclone centre, normalized by the local Coriolis parameter (Raible 2007, Raible et al. 2007). The WM shows a decrease in all parameters. The number of cyclones, and their occurrences, as well as their median intensity is expected to decrease by 10% while their upper 10% intensity – by 5%.

As for the EM cyclones, no significant change is expected in their number or daily occurrence, but a 4% decrease is expected in their intensity (both criteria).

	West Med		**East Med**	
	Control	**A2**	**Control**	**A2**
Number. of Cyclones	16.7	15.0	13.8	14.2
Cyclone occurrences (days)	61.2	55.4	51.8	51.5
Median gradient intensity (m/1000 km)	84	76	91	87
Upper 10th gradient intensity (m/1000 km)	169	164	174	166

Table 5: The characteristics of the Mediterranean cyclones in the control and A2 runs

Figure 10a,b,c shows the spatial distribution of the cyclones' occurrences over the study area for the control (a) and A2 (b) runs and the difference between them (c), respectively. It is difficult to identify any significant difference for the EM, but the dominance of the blue colour in Fig. *c indicates the decreasing trend over the west Mediterranean.

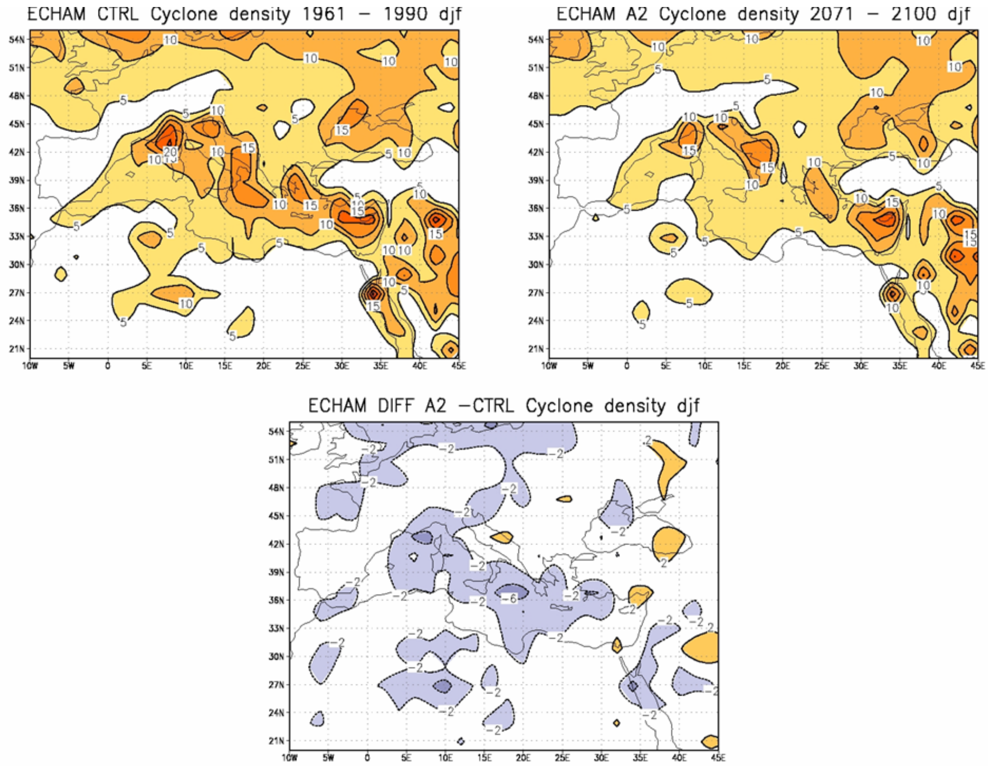


Fig. 10: Number of cyclone occurrences for the control (a) and A2 (b) runs and the difference between them (c), smoothed to grid of 2°×2°

e. precipitation

Figure 11a,b show the seasonal average rainfall; its large scale (a) and convective (b) contributions, respectively, over the study area as reflected by the control run. The MB differs substantially from Europe in that the convective contribution is comparable to that of the large scale, unlike Europe, where the convection is negligible in the winter.

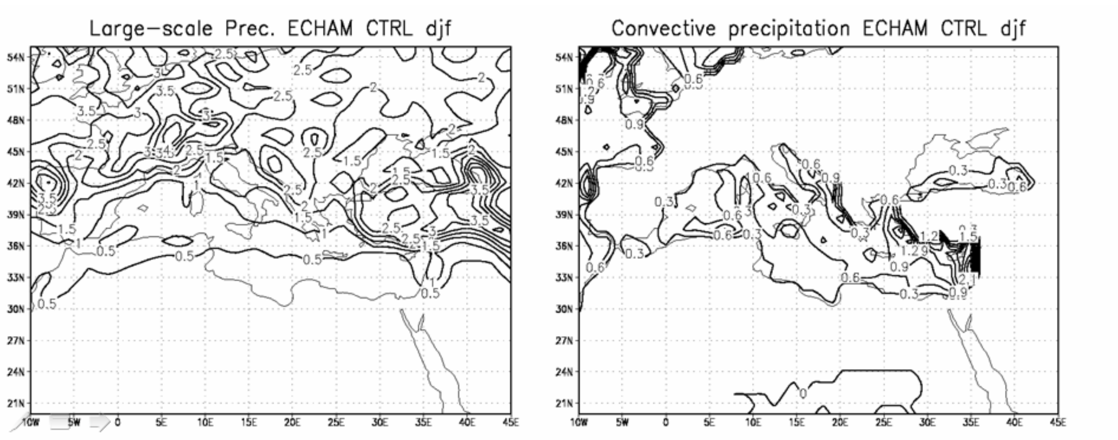


Fig 11: Present rainfall over the study area, based on the control run, due to large-scale processes (a) and convection (b)

Figure 12a,b,c shows the difference between the A2 and the control runs in the total, the convective and the large-scale contributions, respectively. A decrease can be noted over the majority of the MB in both contributions, except for the south-eastern Mediterranean, where no change is noted. The degree of drying, expressed here by the percentage of rainfall decrease, is most pronounced along the North African coasts of the central and western Mediterranean, in contrast with the trend that was noted in the second half of the 20th century. The decrease in large-scale precipitation may be attributed to the decrease in the expected number of cyclones over the MB. The decrease in the convective precipitation can be related to both the decrease in number of cyclones (that supply the background for convection) and to the expected increase in the stability.

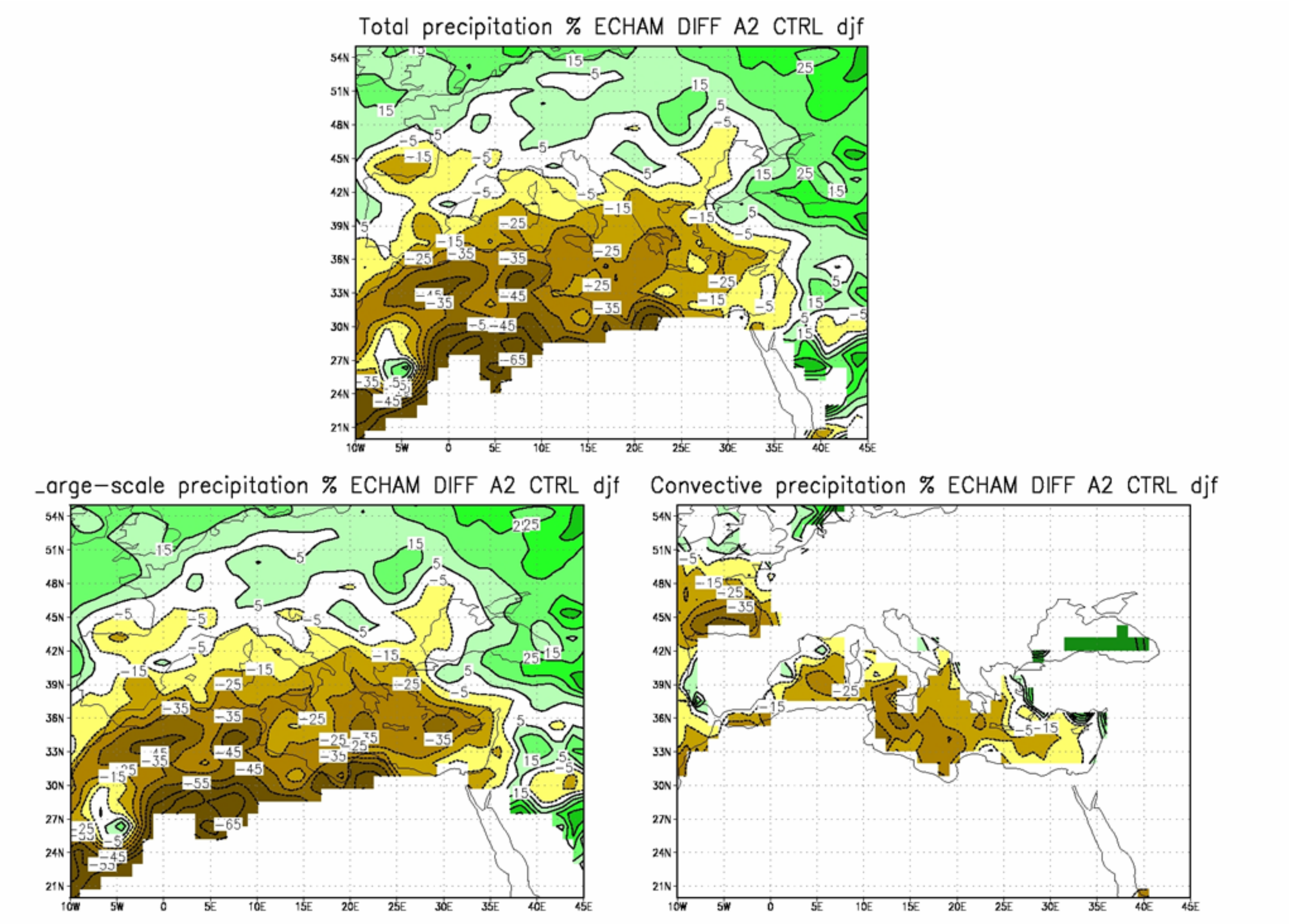


Fig 12: Relative change (%)in the total precipitation in the A2 with respect to the control run (a) large-scale induced precipitation (b) and that produced by precipitation (c)

5. Summary

The winter regime in the MB for future conditions, under A2 scenario, is studied for the years 2071-2100 based on the ECHAM5 climate model simulation. As a first step the synoptic and large-scale features simulated for a control period, 1960 – 1990 by the model, including cyclone detections were compared with NCEP-NCAR and ERA40 data bases. The model was found capable of reproducing the features for the MB and Europe. The model simulation for the study period, compared to that for the control run, reveals for th fur\ture climate the following results:

- An average lower-level temperature rise of ~3°C, with a maximum over the Atlas Mountains (>4°C).
- The average lower-level gph distribution shows that the low pressure system covering the MB in the present will shrink and remain only in its eastern part while its western part will be covered by a high pressure system.

- The upper-level trough, extending from East Europe to the central Mediterranean, near south Italy, with a northeast-southwest orientation will shift to its eastern coast will rotate to a north-south orientation.
- The North African part of the STJ will keep the present intensity, but will shift slightly, by ~1° southward.
- The stratospheric polar night jet will intensify by ~25%, with no change in its structure.
- In spite of the dramatic change in the mean sea-level pressure in the WM, the number of cyclones influencing that region will drop by only ~10%.
- The population of the cyclones in the track that connects the Sahara with the central Mediterranean will reduce to its half.
- The intensity of the surface cyclones and anticyclones will not change significantly, except for two features, specified below.
- The temperature variability will increase in both parts of the MB. In the WM the main increase will be expressed in enhancement of warm events and in the EM - in the cold events. However, the most extreme cold events in the EM will be warmer by ~2°C.
- The polar intrusions, expressed by extreme negative anomalies in the 500-hPa gph, will become more intense over the entire MB, in particular over its eastern part.
- The precipitation is expected to decrease over the majority of the MB, mainly at the southern half of its western part.

It can be summarized that under A2 conditions the MB winter regime is expected to retain its main features as in the present, except for general warming, slight drying and a shift of the main cyclonic activity to its eastern part. The region which is expected to suffer from the most severe drying is the southern part of the WM and the western part of the North African coasts.

Acknowledgment

This study was supported by the European Science Foundation – ESF:

Grant No. 1722

References

Ahrens C.D (2000) *Meteorology Today - an Introduction to Weather, Climate and Environment*, Sixth edition

Alpert P, Ziv B (1989) The Sharav cyclone: observation and some theoretical considerations, *Journal of Geoghysical Research*, 94, pp. 18495- 18514

Alpert P, Neeman B.U and Shay-El Y (1990) Climatological Analysis of Mediterranean Cyclones Using ECMWF Data, *Tellus,* 42A, pp. 65–77

Alpert P, Tzidulko M, Krichak S and Stein U (1996) A multi-stage evolution of an ALPEX cyclone, *Tellus,* 48A, pp 209-22

Alpert P, Ben-Gai T, Baharad A, Benjamini Y, Yekutieli D, Colacino M, Diodato L, Ramis C, Homar V, Romero R, Michaelides S and Manes A (2002) The paradoxical increase of Mediterranean extreme daily rainfall in spite of decrease in total values, *Geophys. Res. Let.*, 29(11), 31-1-31-4

Campins J, Genoves A, Jansa A, Guijarro J.A and Ramis C (2000) A Catalogue and a Classification of Surface Cyclones for the Western Mediterranean, *Int. J. Climatol*. 20, pp. 969–984

Dayan U, Ziv B, Margalit A, Morin E and Sharon D (2001) A Severe Autumn Storm Over the Middle-East: Synoptic and Mesoscale Convection, *Theoretical and Applied Climatology*, 69, pp. 103-122

Egger J. (1998) Alpine lee Cyclogenesis: Verification of Theories, *Journal of Atmospheric Sciences*, 45, pp 2187- 2203

Egger J, Taferner A, Alpert P and Ziv B (1995) Numerical experiments on the genesis of Sharav cyclones, *Tellus* 47A, pp. 162-174

Genovés A, Campins J and Jansà A (2006) Intense Storms in the Mediterranean: A First Description from the ERA-40 Perspective, *Advances in Geosciences*, 7, pp. 163 – 168

HMSO (1962) *Weather in the Mediterranean* I: General Meteorology. 2d ed. Her Majesty's Stationery Office, 362 p

IPCC 2007: http://ipcc-wg1.ucar.edu

Kalnay E, Kanamitsu M, Kistler R, Collins W, Deaven D Gandin, L, Iredell M, Saha S, White G, Woollen J, . Zhu Y Chelliah M, Ebisuzaki W, Higgins W, Janowiak J Mo, K.C., Ropelewski C, Wang J, Leetmaa A, . Reynolds R Jenne R, Joseph D (1996) The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Amer. Meteor. Soc.* 77, pp. 437 – 471

Kistler R.E, Kalnay W, Collins S, Saha G, White J, Woollen M, Chelliah W, Ebisuzaki M, Kanamitsu V, Kousky H, Dool V.D, Jenne R and Fiorino M (2001) The NCEP-NCAR 50-year Reanalysis: Monthly Means CD-ROM and Documentation, *Bull. Amer. Meteor. Soc.*, 82, pp. 247-267

Lionello P, Malanbotte- Rizzoli P and Boscolo R (editors) (2006) *Mediterranean Climate Variability, Developments in Earth and Environmental Sciences 4*, Elsevier, pp. 325-372.

Maheras P, Flocas H, Patrikas I and Anagnostopoulou Ch (2001) A 40 year objective climatology of surface cyclones in the Mediterranean region: spatial and temporal distribution, *International Journal of Climatology*, 21, pp. 109-130.

Petterssen S (1956) *Weather Analysis and Forecasting*, Vol I. McGraw-Hill: New York, 428

Raible, C. C. (2007) On the relation between extremes of midlatitude cyclones and the atmospheric circulation using ERA40, *Geophys. Res. Lett.*, **34**, L07703, DOI: 10.1029/2006GL029084.

Raible, C. C., P. Della-Marta, C. Schwierz, H. Wernli, and R. Blender (2007) Northern Hemisphere extratropical cyclones: A comparison of detection and tracking methods and different reanalyses, *Mon. Wea. Rev.*, **in press**

Reiter R (1975) *Handbook For Forecasters in the Mediterranean*, Paper No 5-75, Naval Post-graduate school, Monterey, CA, 344 pp

Romem M, Ziv B and Saaroni H (2007) Scenarios in the development of Mediterranean cyclones, *Advances in GeoSceinces,* 12, 59-65

Trewartha G.T, Horn L.H (1980) *An Introduction to Climate,* Fifth edition, McGraw-Hill book company: N.Y, pp. 148-156

Trigo I. F, Davies T.D and Bigg G.R (1999) Objective Climatology of Cyclones in the Mediterranean Region, *Journal of Climate,* 12, 6, pp. 1685–1696

Trigo I.F (2006) Climatology and Inter-annual Variability of Storm-Tracks in the Euro-Atlantic Sector: a Comparison between ERA-40 and NCEP/NCAR Reanalysis. *Clim. Dynam.*, 26(2-3) 127

Xopalki E, Luterbacher J, Burkard R, Patrikas I and Maheras P (2000) Connection between the large-scale 500 hPa geopotential height fields and precipitations over Greece during wintertime, *Clim. Res.,* 14, 129-146.

Ziv B (2001) A subtropical rainstorm associated with a tropical plume over Africa and the Middle-East, *Theor. Appl. Clim.*, *69*, 1/2, pp. 91-102