6.3 EVALUATION OF GCM/RCM BY THE CLASSIFIED SYNOPTIC SYSTEMS' APPROACH

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1. INTRODUCTION

The General/Regional Circulation Models (GCM/RCM) are used for the estimation of the future global/regional climate changes, based on the different global scenarios for technological change. The GCM/RCM predictions are employed to derive recommendations for policy-makers. But, before using the models' outputs for future, the models have to be verified for past. For example, the past output for 1950 - 2000 of ECHAM4/OPYC3 model has been considered in this work. The results of this model's runs have widely been used in climatic applications, for example, by Bacher et al. (1998), Bergant et al. (2002), Covey et al. (2003), Kiilsholm et al. (2003), Matulla et al. (2002), Menzel et al. (2002), MPI (1996), Oberhuber (1993), Oberhuber et al. (1998), Reichert et al. (2002), Roeckner et al. (1996b), Ulbrich and Christoph (1999), Zhang et al. (1998).

The model originates from the European Centre for Medium-Range Weather Forecasts (ECMWF). The subsequent coupled global model ECHAM4/OPYC3 was developed in co-operation between the Max-Planck-Institut fűr Meteorologie (MPI) and Deutsches Klimarechenzentrum (DKRZ) in Hamburg, Germany. The model has been analyzed by MPI researchers like Roeckner et al. (1992, 1996a), Timmeck et al. (1997) etc. The considered predicted past climate corresponds to the output of ECHAM4/OPYC3 model running on the greenhouse gases SRES (Special Report on Emissions Scenarios) scenario B2, where dynamics of technological change continue along the historical trends. B2 scenario only covers the period since 1990, and until that year the model run was based on the observed CO_2 and other GHG (greenhouse gases) increase (MPI, 2002).

The predictions often come in the form of the temperature or precipitation time series that are usually averaged for some region over some period. The statistical consistency of the modeled and reanalysis data serves the basis for the models' skills estimation. The most reliable models have been run for predicting the temperature and precipitation fields for the coming decades.

But, on the one hand, the temperature, for example, is only one weather component out of the set of the meteorological fields. On the other hand, the temperature in a specific region in a specific day is defined by a specific synoptic system that is a member of the family of the synoptic systems causing the weather in that region during a year. Thus, the analysis of the modeled daily temperature time series alone as well as the analysis of the temperature averages does not properly reflect the model skills to simulate the daily meteorological fields and consequently their averages on the climatic scales. When averaging the temperature fields, one mixes the effects of different synoptic systems. But, these systems sometimes come from very different origins that are distant from each other. Every synoptic system has its special meteorological features, thus, the family of the regional daily synoptic systems causing the weather over a region through a year is a more complete estimator of a model than the averaged meteorological fields.

In this work, the ECHAM4/OPYC3 model output for the past period (1950-2000) is being estimated for the Eastern Mediterranean (EM) region. The automatically classified EM daily 12Z synoptic systems serve as a verifying tool.

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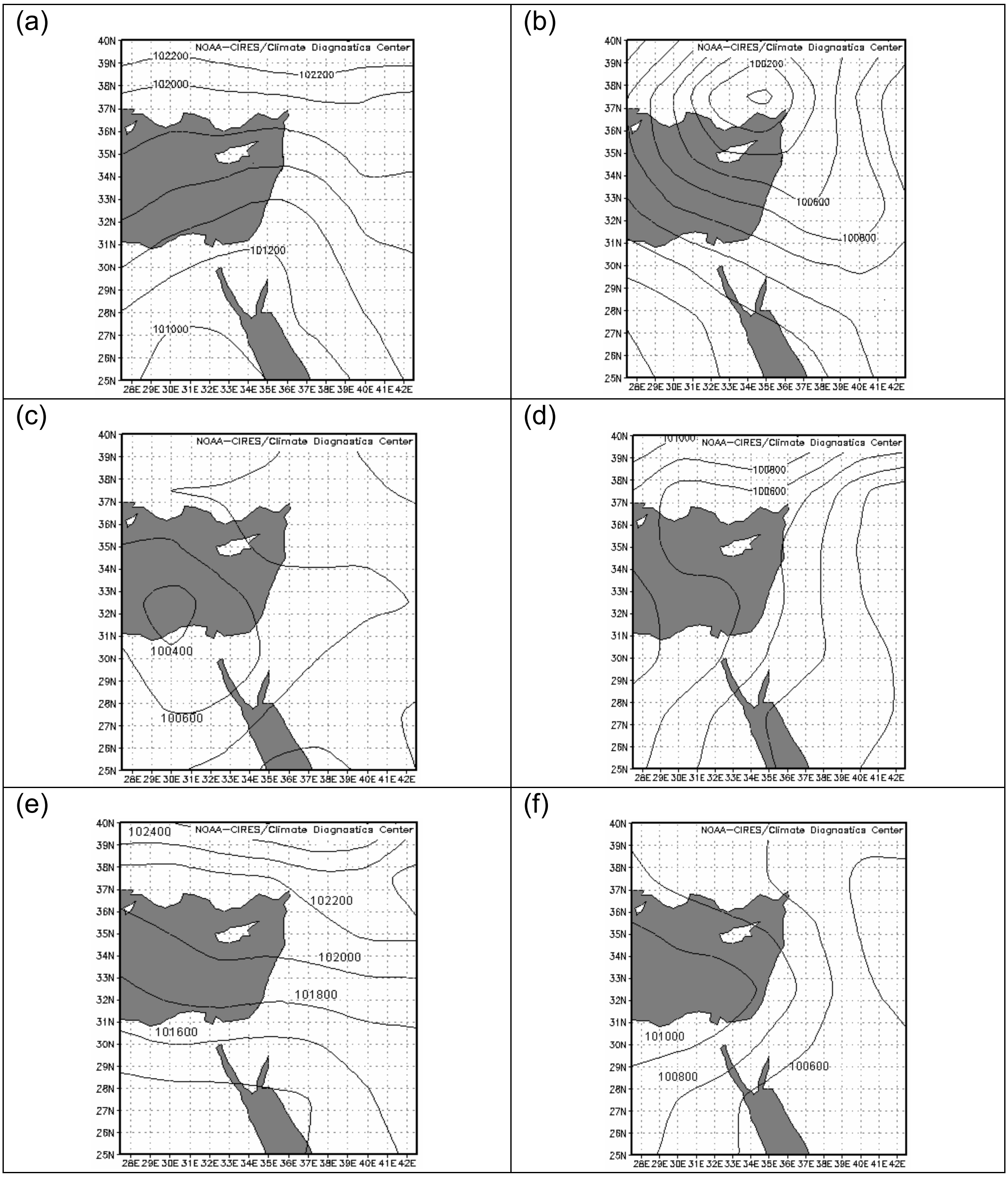

Figure 1. The sea-level pressure (slp) maps of the typical Eastern Mediterranean synoptic systems. *The slp values are in Pa. The systems are shown as they were at 12Z from the NCEP reanalysis:* ***(a)*** *Red Sea Trough on November 11, 1992;* ***(b)*** *Cyprus Low on December 27, 1991;* ***(c)*** *Sharav Low on April 24, 1985;* ***(d)*** *Persian Trough on July 26, 1985;* ***(e)*** *Siberian High on January 13, 1985;* ***(f)*** *Subtropical High on June 24, 1985.*

2. THE TYPICAL EASTERN MEDITERRANEAN SYNOPTIC SYSTEMS

Following Alpert et al. (2003), in the EM region there are 19 typical synoptic systems.

These 19 types are merged into the following groups that quite differ by seasons:

a) Red Sea Troughs (RST) originate from the south in autumn/winter, as shown in Figure 1(a); RST often persists in the cold season and retreats to the south when is put back by the other winter systems (see below b), e)). RST is mostly associated with dry desert air in the EM region. Rarely RST is deep enough over the Red Sea to bring moisture from the sea particularly into the southern part of the EM region.

b) Mediterranean winter Lows come from the west and are entitled **Cyprus Lows** when situated close to Cyprus. They bring most of the rainfall over the continental part of the EM region as shown in Figure 1(b) and discussed by Alpert et al. (1995);

c) Sharav Lows come from the south-west in the transition seasons, mainly in spring, as shown in Figure 1(c); they bring hot and dusty desert air from the Sahara or Arabian deserts.

d) Persian Troughs (PT) originate from the east and persist in summer along with the Asian Monsoon season. PT reach West Turkey as shown in Figure 1(d) and cause relatively warm and humid air over the coastal EM region;

e) Winter Highs of the **Siberian High** originate from the north, north-west, or north-east, as shown in Figure 1(e);

f) Summer Highs of **Subtropical High** originate from the west, as shown in Figure 1(f).

The differences between synoptic systems within each group are not of interest here. Our goal is the statistical analysis of the main groups of the synoptic systems generated by ECHAM4/OPYC3 for the Eastern Mediterranean region and the estimation of the model's skill to describe the EM climate.

3. OBJECTIVE CLASSIFICATION OF THE EASTERN MEDITERRANEAN DAILY SYNOPTIC SYSTEMS

The classification method had been recently developed in Tel Aviv University and was described by Alpert et al. (2003a) and outlined by Alpert et al. (2003b). The method is the modified Discriminant Analysis. This method helps to automatically classify the large dataset by the use of the experts' classification of the limited but representative dataset cut.

The data were provided by the NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado, USA, from their Web site at *http://www.cdc.noaa.gov/*. The set of the 12Z EM sea-level pressure daily maps of 1985 and DJF of 1991/92 was used for the experts' classification, and therefore the set of the 12Z daily data for the same periods has been used as the training set. The fields used were the geopotential heights H, temperature T, and two horizontal wind components U and V at 25 grid-points over the EM region.

The ECHAM4/OPYC3 model output as well as the NCEP/NOAA reanalysis data has been classified into the typical synoptic systems (see in the previous section). The EM region was defined from 30E to 40E and from 27.5N to 37.5N. The NCEP grid is the 2.5-degree latitude × 2.5-degree longitude global grid. Therefore, the EM region is defined by 5×5 = 25 grid-points. Given the 4 daily values of H, T, U, and V at 25 EM grid-points at 12Z at 1000 hPa, the daily synoptic classification has been carried out. Every EM daily synoptic system determination was based on this surface meteorological information. Thus, one classified daily synoptic system comes instead of a set of 25×4 = 100 parameters.

Boehm et al. (2002) have extracted the EM data from the model output for this current research. The model output got on a 2.8-degree grid from Boehm et al. (2002) was then regridded to the NCEP 2.5-degree grid for compatibility with the NCEP reanalysis training dataset.

4. THE EASTERN MEDITERRANEAN SYNOPTIC CLIMATOLOGY: ECHAM4/OPYC3 MODEL VS. NCEP REANALYSIS

At the first step, an average evaluation of the model skills has been carried out. It was done by comparison of the model and reanalysis average annual frequencies of the daily synoptic systems. The 12Z daily ECHAM4/OPYC3 output and NCEP/NOAA reanalysis data for the EM region for 1950-2000 has been used.

The climate characteristics were derived as the average annual numbers of the daily synoptic systems of the different types. These numbers for the model are shown in red in the Figure 2, along with the NCEP reanalysis numbers that are in blue. The ECHAM4/OPYC3 data bars have two limiting lines: the lower ones are for the 360-d years used in the model, and the higher ones are for the model output fitted to three times 365-d year followed by one leap-year of 366 days. As it has been seen from the paired data bars - model vs. reanalysis - the model generates the average EM climate over a year very well: 70 Red Sea Trough (RST) days (autumn/winter); 110 Persian

Trough days (summer); 60 winter Low days (total days of the coming lows, Cyprus Low with rainfall over the EM coastal areas, and going lows), from which about 25 days are with rain; 5 Sharav Low days with the desert hot and dusty wind (mainly spring); 50 high-pressure winter days entitled Siberian High; and 70 high-pressure summer days entitled Subtropical High (all values are rounded). The total number is 365 days (70 + 110 + 60 + 5 + + 50 + 70 = 365).

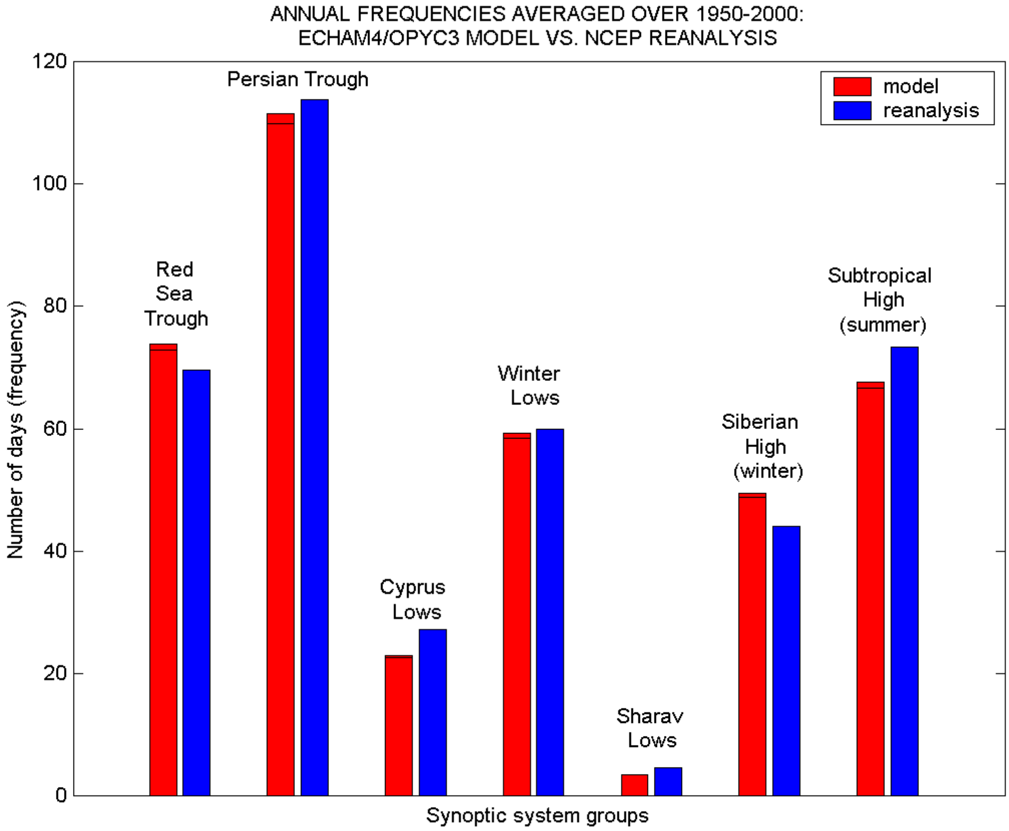

Figure 2. The average annual frequencies of EM synoptic system groups. *The frequencies are averaged over 1950-2000. The Cyprus Lows are shown apart from the entire Winter Lows group for their special positive role in EM rainfall. The lower horizontal marks for the ECHAM data correspond to the 360-d model year, while the higher marks are fitted to the average length of a year as computed from three times 365-d year followed by a 366-d year.*

5. INTERANNUAL TRENDS: ECHAM4/OPYC3 MODEL VS. NCEP REANALYSIS

The “good news” following Figure 2 are that the ECHAM4/OPYC3 model apparently has high climatology skills. The average annual frequencies of each synoptic system group derived from the model and the reanalysis are nearly equal. However, as shown next, the ECHAM4/OPYC3 model does not simulate temporal variations during 1950 – 2000 such as significant RST trends found in the reanalysis. Figure 3 compares the temporal variations in the model vs. the reanalysis.

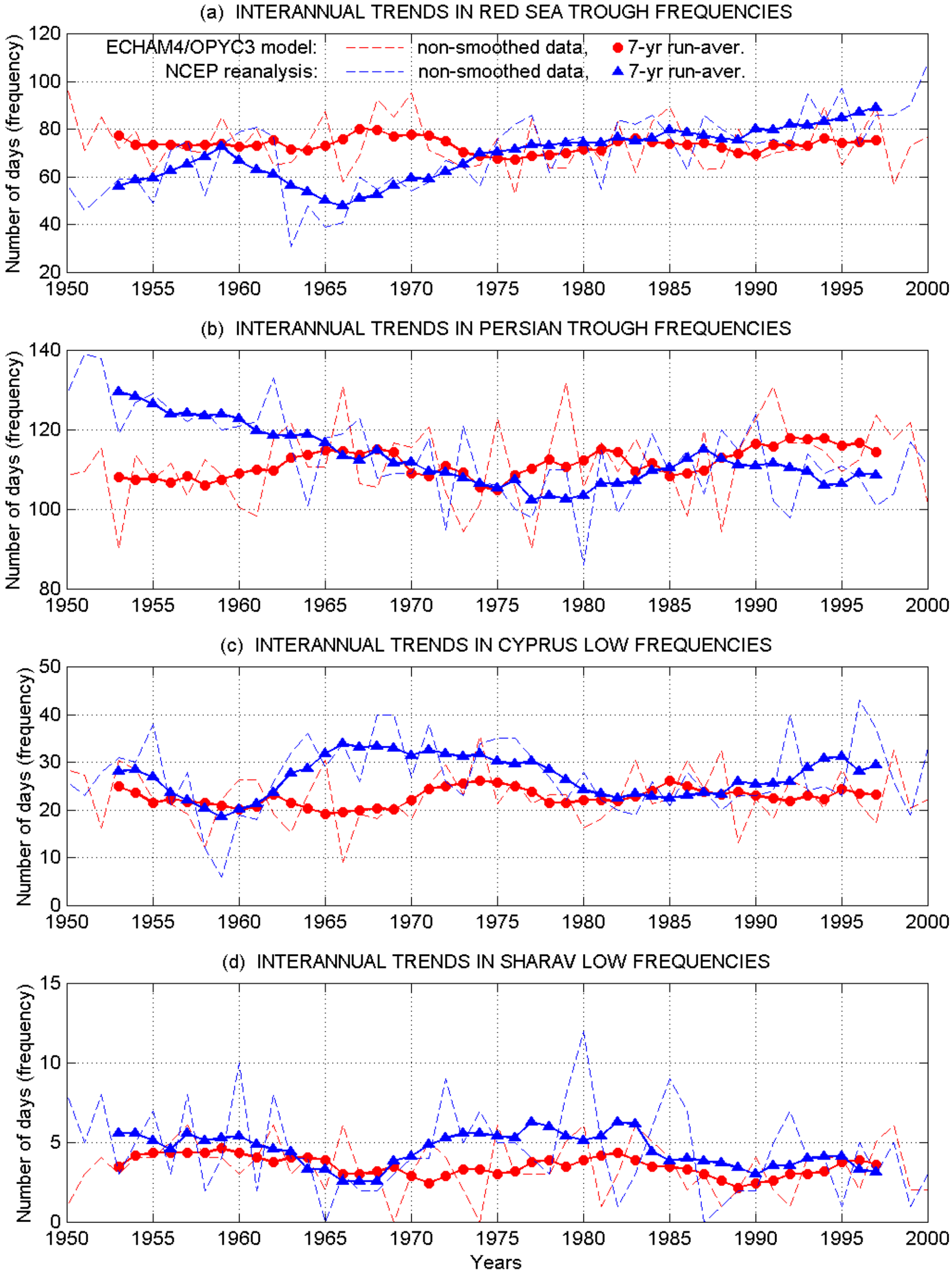

Figure 3. Interannual trends in the frequencies of the synoptic system groups. *The legend in (a) is also for (b)-(d). Dashed red and blue curves show the frequencies expressed as number of days per year derived from ECHAM4/OPYC3 model and the NCEP reanalysis, respectively. Red circles and blue triangles show the data smoothed by 7-yr running average.*

Some conclusions follow from Figure 3:

1) There are periods of similarity of the model and reanalysis frequencies. During the periods of disagreement, in the individual years the model and reanalysis frequencies might differ by factor of up to 2÷3. Due to the very close means, it seems that the model and the reanalysis trends "diverge" and "converge".

2) Periods of disagreement are distinguished by the shorter periods of larger "model minus reanalysis" differences of one sign and longer periods but of smaller differences of another sign.

3) The period of the largest positive "model minus reanalysis" differences in the RST's frequencies was 1963-1973. Nearly the same period was the period of the largest negative "model minus reanalysis" differences in the Cyprus Low's frequencies. Both facts point that the model EM winter climate for that period was drier than the real one. But, exactly at this period the model and reanalysis frequencies for the summer synoptic system, Persian Trough, were the closest. It points on the good-modeled summer climate for that period. Generally speaking, we can conclude that estimating the model skills in forecasting the EM winter and summer climates must be carry out independently. This because the origins of the EM winter and summer synoptic systems are different: the Mediterranean Sea, Red Sea, and their surroundings in winter, and Persian Gulf and its surroundings in summer.

4) The model frequencies vary only weakly about their means, as compared to the strong oscillations of the reanalysis frequencies. Before applying any complicate method of ANOVA (analysis of variance), the standard deviations (STD) clearly show that although the model and reanalysis means are nearly equal (Figure 2), their STDs differ significantly. The STDs of the synoptic systems' frequencies computed from ECHAM4/OPYC3 model and NCEP reanalysis as well as their ratios are shown in Table 1.

5) In Fig. 3(a) one can definitely see a failure of the model to simulate the observed trends. Indeed, since 1974 nearly all the modeled annual RST frequencies are below the observations, while during the previous period the situation is just opposite (i.e. all the modeled annual RST frequencies are too large).

Synoptic system groups / **STD of annual frequencies for 1950-2000**	**Red Sea Trough**	**Persian Trough**	**Cyprus Low**	**Sharav Low**
absolute values: from model (**M**)	10.23	9.54	5.43	1.60
from reanalysis (**R**)	16.16	11.11	7.48	2.70
M / R	**0.63**	**0.86**	**0.73**	**0.59**
Corr. coefficient between non-smoothed trends	***-0.03***	***-0.05***	***-0.02***	***0.19***
7-yr run-aver. values: from model (**M_a**)	2.97	3.59	1.83	0.61
from reanalysis (**R_a**)	10.77	7.22	4.15	1.06
M_a / R_a	**0.28**	**0.50**	**0.44**	**0.58**
Corr. coefficient between 7-yr run-aver. trends	***-0.29***	***-0.36***	***0.04***	***0.47***

Table 1. Model to reanalysis annual ratios of the frequencies' STD for EM synoptic groups. *M/R is ratio of the absolute frequencies', M_a / R_a - of the 7-yr run-averaged.*

As can be seen from the results of comparison of the standard deviations in Table 1, for every synoptic group the model annual frequencies are much less variable than in the reanalysis. The mean ratio for absolute values is 0.70, i.e. the variations of the model frequencies are only about 2/3 of those of the reanalysis. Furthermore, for the frequencies smoothed by 7-yr running average, the differences between the model results and reanalysis are much more significant: the mean ratio of STD over all synoptic groups is 0.45, i.e. variability of the smoothed model synoptic system frequencies is only about a half of that in the reanalysis. This fact points on the strong smoothing in the climate model. Such a property should strongly influence the simulated extreme values.

In the next section monthly frequencies are examined. It aims to independently consider the monthly frequencies, as hinted in paragraph 3 of this section, and further focus on the model deficiencies. This method might be named "Monthly-Sliced Zooming-In".

6. INTERANNUAL TRENDS – MONTH-BY-MONTH CONSIDERATION: ECHAM4/OPYC3 MODEL VS. NCEP REANALYSIS

Next, we inspect the model monthly-sliced annual trends (Figures 4,5,6,7), in which one may define the "good-simulated" and "bad-simulated" months for every synoptic system.

The graphs in Figures 4-7 presented through the same scale within each figure. It helps to quantitatively estimate the differences between the model and reanalysis synoptic systems frequencies.

7. CONCLUSIONS

7.1) The main meteorological fields over a region as well as the regional climate may be described in a more concise manner by the set of the regional synoptic system classes. Every daily synoptic system is a comprehensive descriptor of the regional daily weather characteristics at any instant. One may describe every 12Z set of values of several main meteorological fields in dozens of regional grid-points of the EM region by one specific synoptic system.

7.2) Description of the model daily outputs over a region by the synoptic systems allows separating the weather effects (like temperature or precipitation) caused by the different synoptic systems.

7.3) In the EM region the cold, warm, and two transient seasons take place. The EM seasons sharply differ due to very different synoptic systems coming from their specific origins in every specific season. Furthermore, for every EM season its beginning, high season, and fading may be defined according to its specific synoptic system characteristics (Alpert et al., 2002).

7.4) For the ECHAM4/OPYC3 model output for the EM region that has been estimated in this work by comparison to the NCEP reanalysis, the model skills in yielding the EM climate properties were found:

7.4.a) Averaging over 1950-2000, the ECHAM4/OPYC3 model predicts the annual frequencies for each synoptic system quite similar to the reanalysis data.

7.4.b) The model does not depict the multi-decadal monotonic trends seen in the reanalysis data. For instance, the reanalysis RST annual frequencies almost monotonically increased from 50 to 100 (i.e. doubling) during 1966 - 2000. This fits the recent drying the EM climate, but the model doesn't simulate this trend.

7.4.c) The months with correctly predicted daily synoptic systems differ for the different periods. For example, the highest peak of the RST monthly frequencies usually occurs in November (Alpert et al., 2003). The year-by-year changes of the November's RST frequencies are predicted well during 1950 - the late 1960s (Figure 4); but from the late 1960s through 2000 the model and the reanalysis November's trends are in the opposite directions. The second peak of the RST monthly frequencies usually occurs in January-February (Alpert et al., 2003). For these months, the model and the reanalysis year-by-year changes of RST frequencies are in the opposite directions over 1960-1980; but during 1980-2000 these frequencies are predicted well.

7.4.d) In general, the average frequencies of the ECHAM4/OPYC3 model and NCEP reanalysis synoptic systems seem to be similar. But, it is not seen in the very low correlations between the model and the reanalysis interannual trends where all monthly frequencies come together (Table 1). Therefore, evaluation of the ECHAM4/OPYC3 climate model when applying to the Eastern Mediterranean region yields more reliable results by analyzing the model monthly data rather than annual totals.

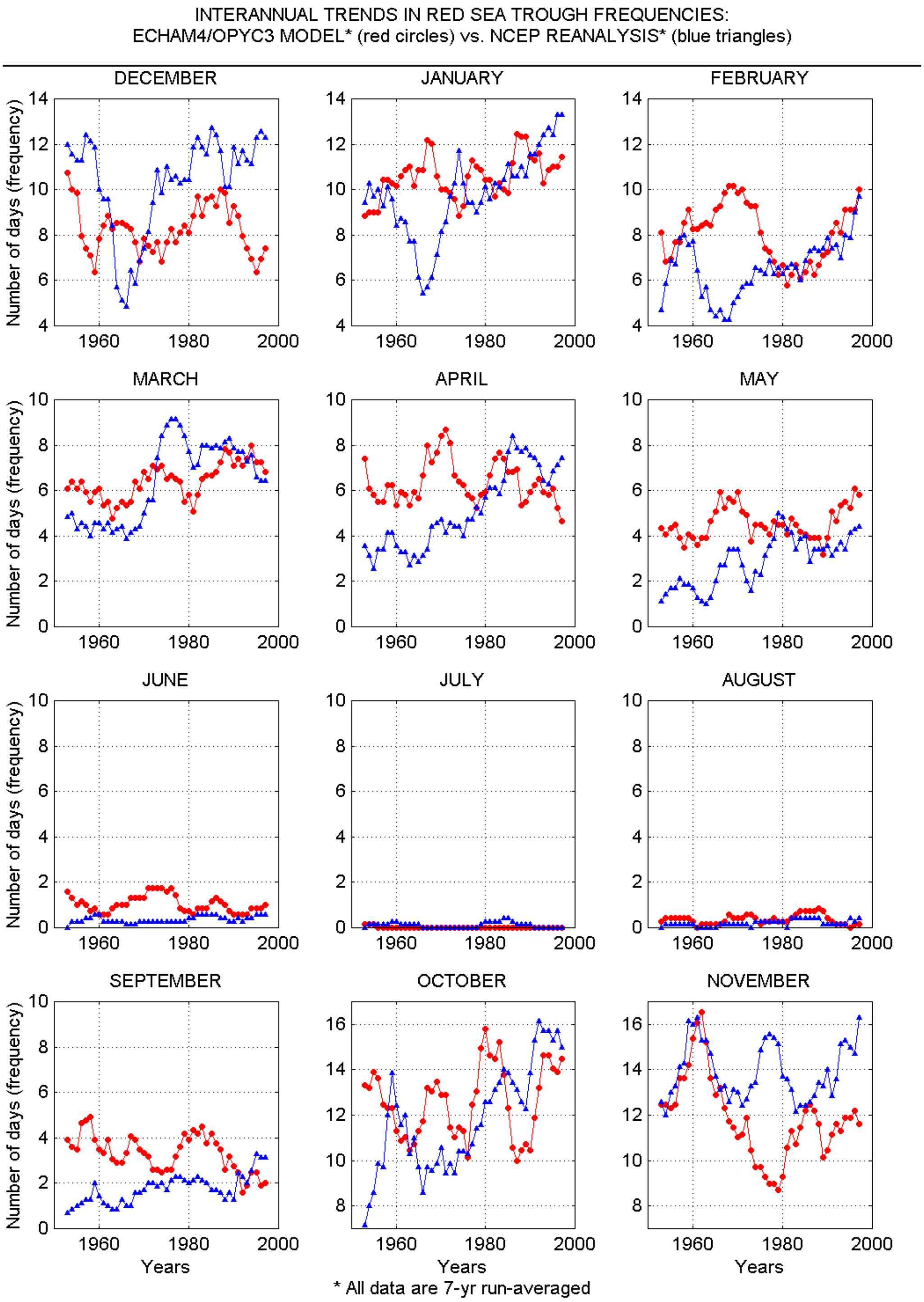

Figure 4. Red Sea Trough frequencies: ECHAM4/OPYC3 model vs. NCEP reanalysis monthly-sliced interannual trends. *The vertical scale is 10 days between the low and high vertical limits.*

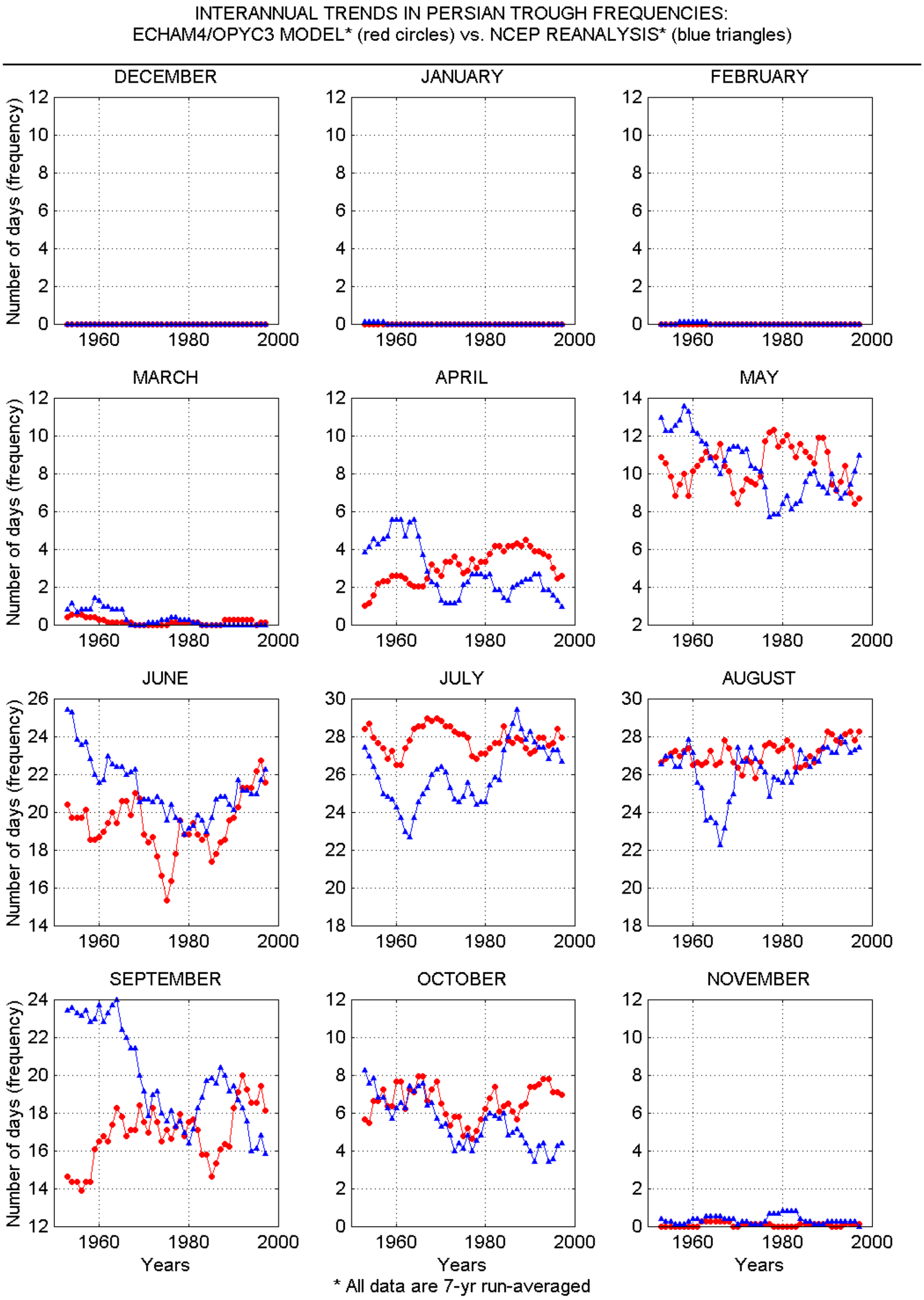

Figure 5. Persian Trough frequencies: ECHAM4/OPYC3 model vs. NCEP reanalysis monthly-sliced interannual trends. *The vertical scale is 12 days between the low and high vertical limits.*

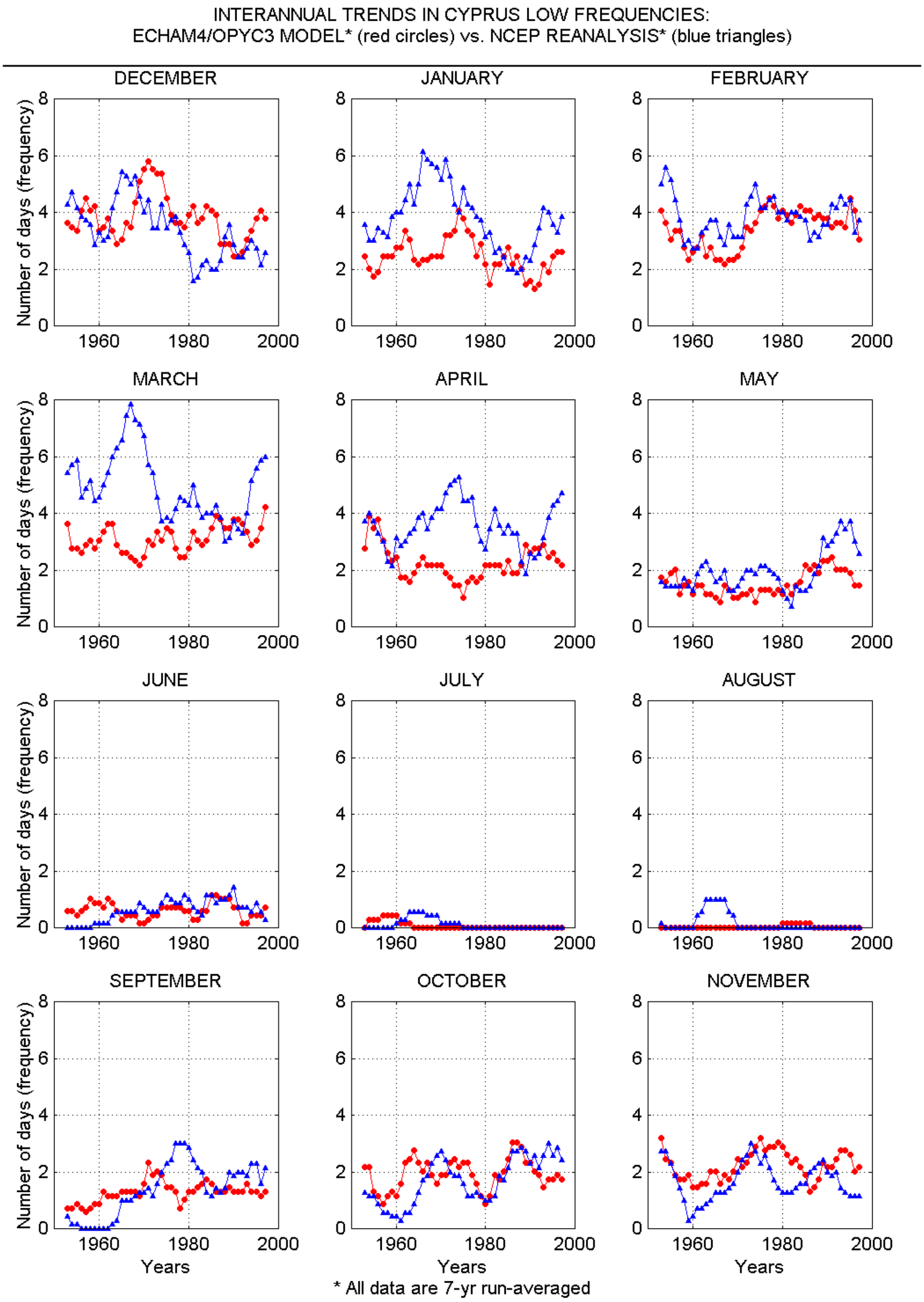

Figure 6. Cyprus Low frequencies: ECHAM4/OPYC3 model vs. NCEP reanalysis monthly-sliced interannual trends. *The vertical limits are 0 and 8 days.*

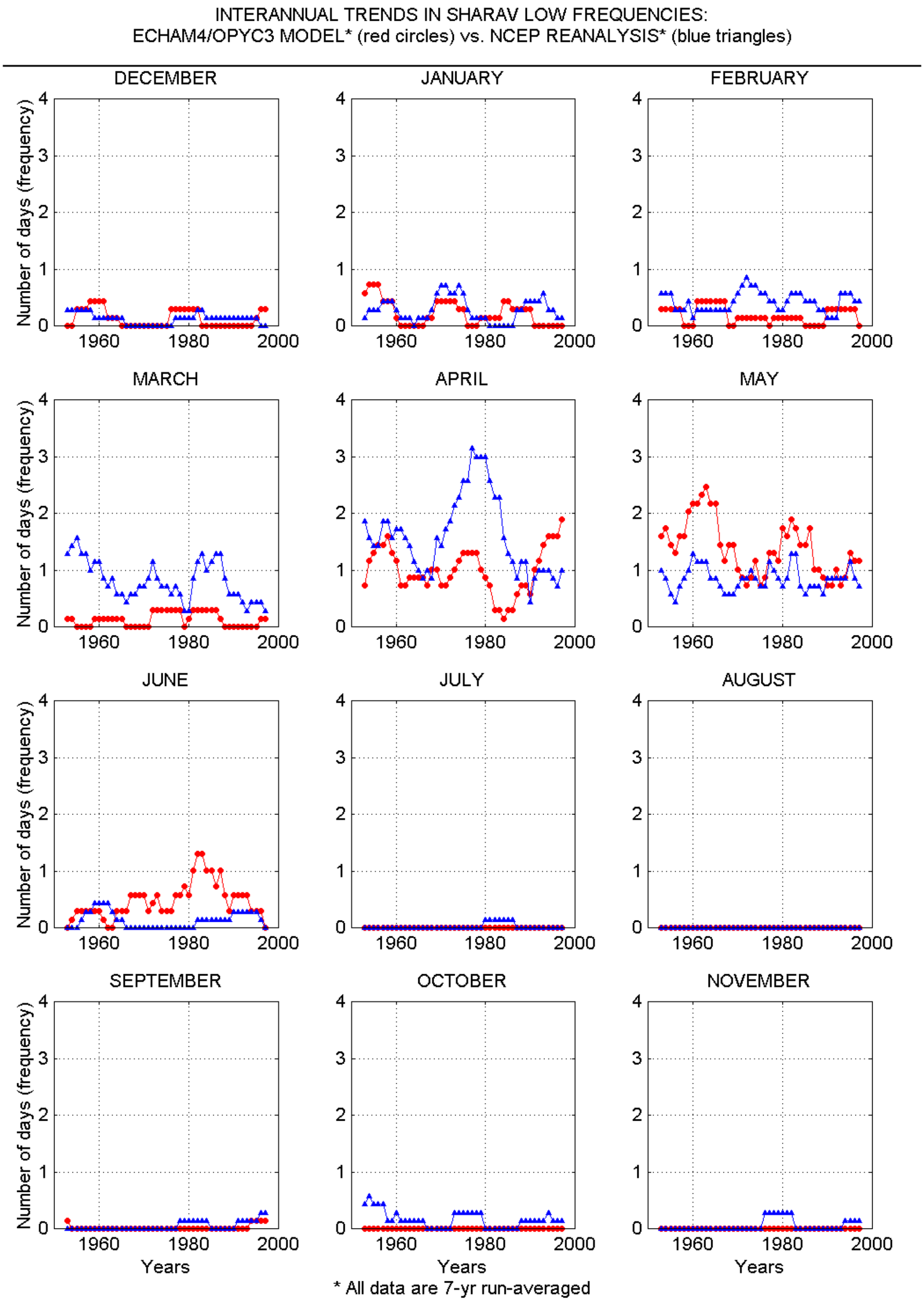

Figure 7. Sharav Low frequencies: ECHAM4/OPYC3 model vs. NCEP reanalysis monthly-sliced interannual trends. *The vertical limits are 0 and 4 days.*

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