Downscaling of Future Climate Change for the Mediterranean Region

Elke HERTIG and Jucundus JACOBEIT (Augsburg)

Abstract

The Mediterranean area has been characterized as a "climate change hot-spot" being highly affected by future climate change compared to other regions of the world. Dynamical and statistical downscaling results will be discussed for the supposed changes of temperature and precipitation concerning both mean values as well as extreme conditions. The downscaling assessments show increases of mean temperature in the Mediterranean area during all months of the year with seasonal and regional variations of the corresponding amounts. For mean precipitation increases are only found in the northern and western Mediterranean area during high winter, whereas in other seasons and regions mostly decreases are assessed during the course of the 21st century. Regarding temperature extremes increases of extreme hot days and of heat waves in summer are projected as well as a decrease of the frost-day number in winter. Concerning rainfall-related extremes assessments indicate that more frequent and longer-lasting drought events will occur in the Mediterranean area. In contrast to this, heavy rainfall events show a general tendency towards decreases in the Mediterranean region during winter.

Zusammenfassung

Der Mittelmeerraum kann als ein regionaler „Hot-Spot" im Rahmen des globalen Klimawandels angesehen werden. Im Vergleich zu anderen Regionen der Erde wird er besonders vom anthropogen verstärkten Treibhauseffekt betroffen sein. Ergebnisse aus dynamischen sowie statistischen Regionalabschätzungen werden im Hinblick auf mögliche Veränderungen der Temperatur und des Niederschlags sowohl hinsichtlich der Mittelwerte als auch der Extremwerte erläutert. In Bezug auf die mittlere Temperatur ist mit einem Anstieg im gesamten Mittelmeerraum in allen Monaten des Jahres zu rechnen, wobei die Höhe des Temperaturanstieges regional und saisonal differiert. Beim mittleren Niederschlag werden Zunahmen lediglich in den nördlichen und westlichen Regionen des Mittelmeerraumes im Hochwinter abgeschätzt, während in den anderen Regionen und Jahreszeiten Niederschlagsabnahmen dominieren. Im Hinblick auf Temperaturextreme wird im Verlauf des 21. Jahrhunderts mit Zunahmen der extrem heißen Tage und der Hitzewellen im Sommer sowie mit einer Abnahme der Anzahl der Frosttage im Winter gerechnet. Bei den niederschlagsbezogenen Extremwerten zeigen die Abschätzungsergebnisse für den Mittelmeerraum eine Zunahme in Frequenz und Andauer der Trockenperioden, während Starkregenereignisse im Winter eine eher rückläufige Tendenz erfahren.

1. Introduction

Improved assessments of regional climate change for the 21st century are now available for many parts of the world. Mainly regions with a high climatic variability will be strongly affected by the anticipated climate change. Among these regions the Mediterranean area, which is located in the transitional zone between tropical and extra-tropical circulation dynamics, has been identified as a particular "climate change hot-spot" (GIORGI 2006). This is mostly due to the assessed decrease of precipitation as well as to an increase of the inter-annual precipitation variability during the course of the 21st century.

The uneven intra-annual distribution of precipitation, its high inter-annual variability as well as the anticipated changes of these climatic characteristics are major determining factors for various economic sectors. For instance the UNWTO (*World Tourism Organization* 2007) estimates that the number of tourists visiting the Mediterranean region will more than double by the year 2025, up to 655 million per year. Already nowadays the water consumption of a tourist amounts to 300–850 l per day. Furthermore, agriculture has also a significant part in the national economy of many Mediterranean countries. Thereby irrigation in the area of fruit-growing and market gardening plays a major role in Mediterranean land use with the result that more than 80 % of the total water consumption is caused by agriculture. Future temperature rise will likely reduce the productivity of major crops and increase their water requirements leading to a further increase in irrigation demand. A general decline in precipitation would lead to a further enhancement in water stress. Besides the two examples tourism and agriculture, a substantial quantity of other economic sectors will also be affected by climate change. Additionally, further societal and ecological issues arise, for example in the scope of human health or regarding the ecosystems of the low-lying coastal zones due to the projected sea-level rise.

Furthermore, non-climatic factors may aggravate the impacts of climate change, mainly for the countries in the eastern and southern Mediterranean area. Thus, for instance, it is expected that Turkey, Syria, Egypt and Algeria will have a relatively strong population increase in the next decades. As a result Egypt will be likely to experience an increase in water stress, with the background of a projected decline in precipitation and a projected population of between 115 and 179 million people by 2050 (Boko et al. 2007).

This leads to the conclusion that reliable information on the development of the Mediterranean climate is required to deal in an appropriate manner with the manifold issues which arise from global climate change in its regional specification. More specified assessment results will help to integrate forthcoming climate change into other future developments of the countries surrounding the Mediterranean Sea.

2. Mean Temperature Change

As already outlined in the previous section, regional climate change patterns can be distinguished from the general warming signal of the global scale.

Figure 1 from the latest IPCC Report (Assessment Report 4 of the Intergovernmental Panel on Climate Change) shows a regional pattern of the assessed changes for Europe and the Mediterranean area based on output from 21 dynamical models. Based on the SRES A1B scenario (SRES: Special Report on Emissions Scenarios, Nakicenovic et al. 2000), the simulated annual mean warming from the period 1980–1999 to the period 2080–2099 varies from 2.2 °C to 5.1 °C in the Mediterranean area, with the largest warming rate in summer for the Mediterranean land areas.

Figure 2 shows, for consecutive bi-monthly periods, the temperature changes in the period 2071–2100 in comparison to the period 1990–2019, resulting from statistical downscaling of global climate model output under SRES-B2 scenario assumptions. Thereby regions showing a significant change (95 % confidence level) are marked with transverse hatching in Figure 2.

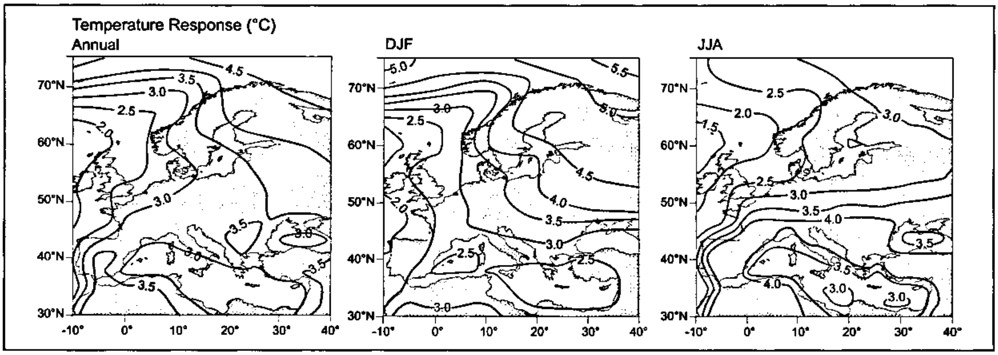

Fig. 1 Temperature changes over Europe and the Mediterranean area for the A1B scenario. From left to right: Annual mean, Winter (DJF) and Summer (JJA) temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 dynamical models (according to IPCC AR4, CHRISTENSEN et al. 2007).

Just like the results from the dynamical models, statistically downscaled temperature changes also show an increase for the whole Mediterranean area for all months of the year. Looking at seasonal and regional differences, the statistical assessment indicates a relatively small temperature rise in the western part of Northern Africa, whereas significant increases can be found over the Iberian Peninsula, the northern Mediterranean region and in the eastern half of the Mediterranean area during winter (December/January). In summer (June–September) a stronger warming of partially more than 4 °C is indicated in the western Mediterranean area, being significant in late summer (August/September). In the transitional seasons the downscaling results show a relatively uniform spatial distribution of temperature increases with an amount of approximately 3 °C in spring (April/May) and more than 4 °C in autumn (October/November).

Since the multi-model mean global temperature rise for the 2080–2099 period (compared to 1980–1999) is estimated by the IPCC to amount to 2.8 °C (uncertainty range: 1.7 °C to 4.4 °C, MEEHL et al. 2007) for the A1B scenario and to 2.4 °C (1.4 °C to 3.8 °C) for the B2 scenario, the warming in the Mediterranean area is projected to be somewhat greater than the global mean.

3. Mean Precipitation Change

The projected changes of mean precipitation in Figure 3, taken from the latest IPPC report, indicate that annual mean precipitation decreases dominate for Southern Europe. The map for the winter months (central panel of Fig. 3) reveals that for widespread parts of the Mediterranean area a reduction of precipitation is assessed, but the northern parts might see slight increases in precipitation. Since precipitation assessments are still affected by considerable model uncertainties, the exact spatial distribution of precipitation changes is yet undetermined. Thus, for the Northern Mediterranean regions positive as well as negative precipitation changes in winter during the course of the 21st century are possible. Looking at the right map of Figure 3 for the summer months reveals that precipitation decreases dominate for the whole Mediterranean area, and this could have serious impacts on water supply.

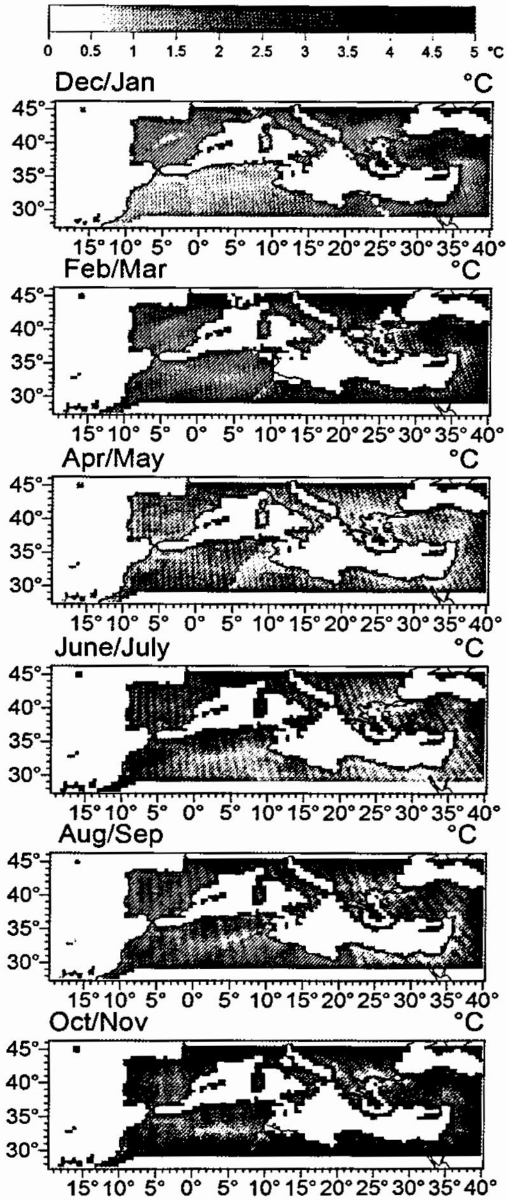

Fig. 2 Temperature assessments for the Mediterranean area using global climate model (ECHAM4/OPYC3) values of 1000 hPa and 500 hPa geopotential heights as predictors for statistical downscaling models: Differences of statistically modeled mean temperatures for the 30-year periods at the end (2071–2100) and at the beginning (1990–2019) of the entire model period 1990–2100. Statistical downscaling method: Canonical Correlation Analysis. Scenario: SRES-B2. Transverse hatching: signal/noise ratio > 1.96 (i.e. 95% confidence level) (according to HERTIG and JACOBEIT 2008b).

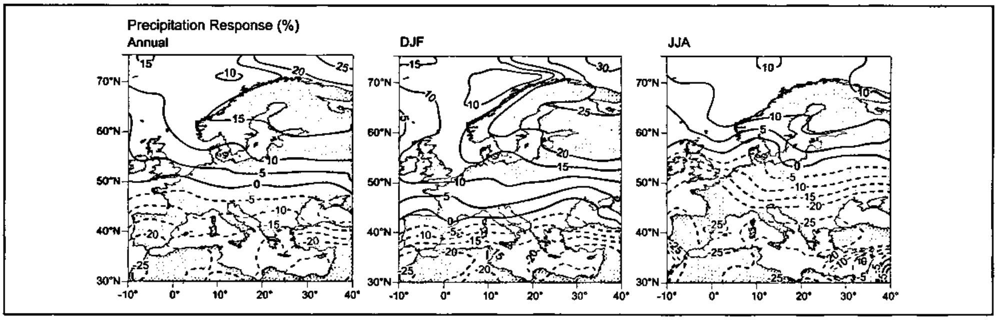

Fig. 3 Precipitation changes over Europe and the Mediterranean area for the A1B scenario. From left to right: Annual mean, Winter (DJF) and Summer (JJA) precipitation change between 1980 to 1999 and 2080 to 2099, averaged over 21 dynamical models (according to IPCC AR4, CHRISTENSEN et al. 2007).

Figure 4 shows statistically downscaled precipitation changes using the large-scale atmospheric circulation (1000 hPa and 500 hPa geopotential heights) as well as specific humidity as predictors for regional precipitation. Summarizing the seasonal and regional information (assuming SRES B2 scenario conditions) gives a shortening and at the same time an increase in rainfall amount of the wet season for the western and northern Mediterranean regions. These results from estimated precipitation increases in winter for the period 2071–2100 compared to 1990–2019, whereas precipitation decreases dominate in autumn and spring. The eastern and southern parts of the Mediterranean area, on the other hand, exhibit mainly negative precipitation changes throughout the period from October to May under enhanced greenhouse warming conditions. Looking at the northern African regions in particular, stronger precipitation decreases occur for the western Maghreb in autumn (October/November), late winter (February/March) and spring (April/May). In general the Mediterranean part of North Africa is mostly affected by precipitation decreases during all analyzed months. Only for some sub-regions in specific months small increases are assessed like for example for the western Maghreb in winter (December/January) or for the Mediterranean parts of Libya in autumn (October/November).

4. Changes in Extreme Values

Not only changes regarding mean values, but particularly changes of extreme events like droughts, heat waves and heavy rainfall are of special interest in the scope of future climate change. But it has to be emphasized that climate change information regarding extreme events is still affected by considerable uncertainties.

According to CHRISTENSEN et al. (2007) an increase in frequency, intensity and duration of heat waves and *vice versa* a decrease of the number of frost days is very likely for southern Europe and the Mediterranean area. Statistical downscaling assessments of the 5th percentile of minimum temperatures in winter (as an indicator of the frost hazard) and of the 95th percentile of maximum temperatures in summer (as an indicator of possible heat stress conditions) for the 21st century under enhanced greenhouse warming conditions yield mainly increases of both extremes indices for selected temperature stations in the Mediterranean area (Fig. 5).

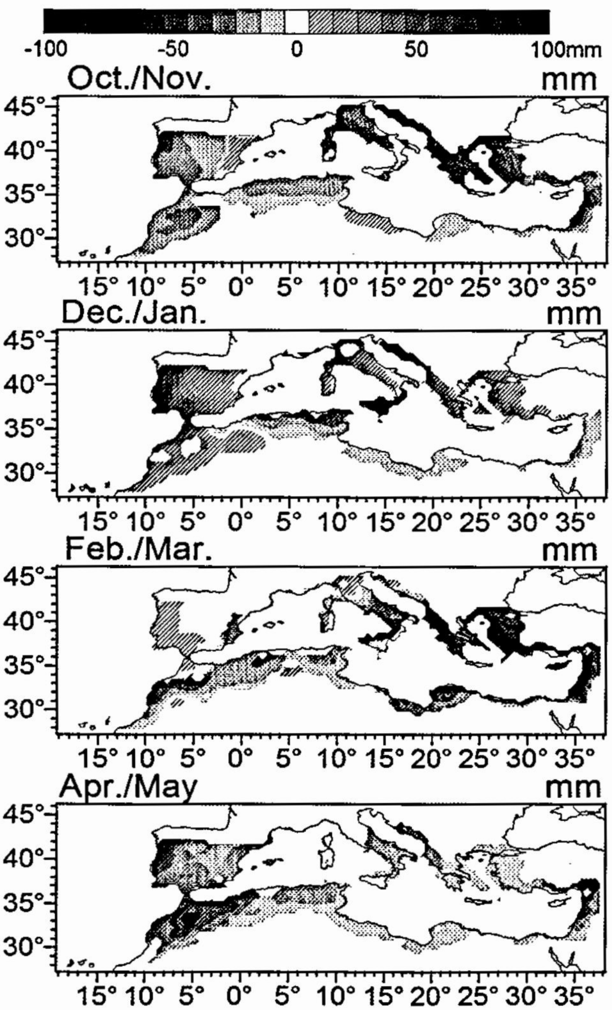

Fig. 4 Changes of Mediterranean Precipitation according to statistical downscaling assessments using ECHAM4/OPYC3 predictors (1000 hPa and 500 hPa geopotential heights and 1000 hPa specific humidity): Differences of the mean 2-month precipitation between the periods 2071–2100 and 1990–2019 (in mm). Statistical downscaling technique: Canonical Correlation Analysis. Scenario: SRES-B2 (according to HERTIG and JACOBEIT 2008a).

But the statistical assessments also indicate that the intra-annual extreme temperature range (i.e. the difference between the highest and the lowest temperatures of the year) will decrease in most parts of the Mediterranean area during the 21st century, because extreme minimum temperatures in winter will increase stronger (upper part of Fig. 5) than extreme maximum temperatures in summer (lower part of Fig. 5).

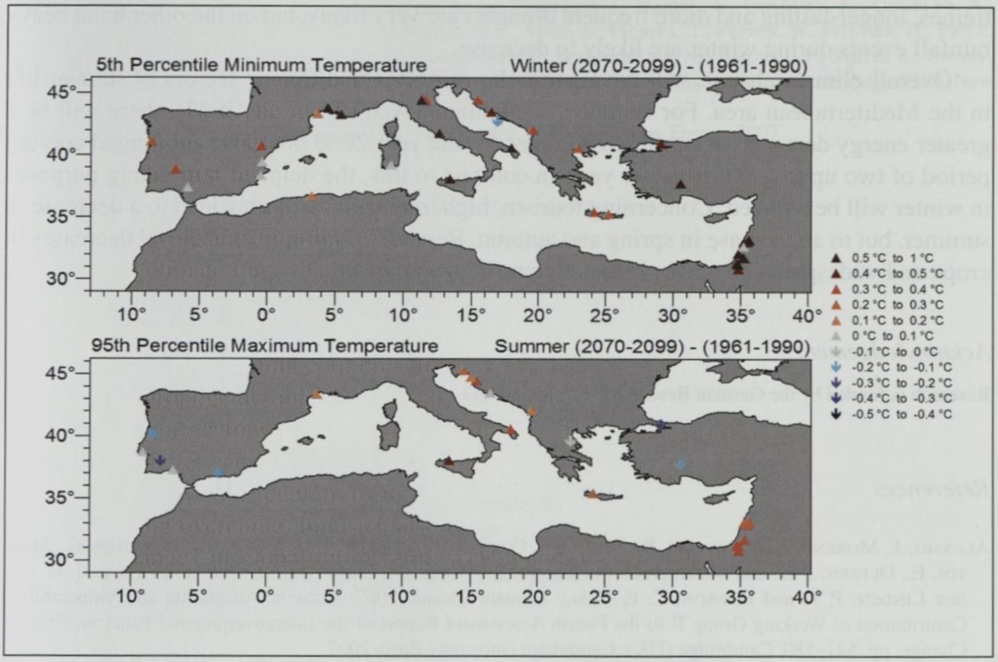

Fig. 5 Changes of the 5th percentile of minimum temperatures in winter (upper panel) and of the 95th percentile of maximum temperatures in summer (lower panel) according to statistical downscaling assessments using ECHAM5/MPI-OM predictors under SRES-A1B scenario assumptions: Differences of the seasonal extremes indices between the periods 2070–2099 and 1961–1990 (in °C). Statistical downscaling technique: Multiple Regression analysis. Predictors: 1000 hPa – 500 hPa- thickness and 500 hPa geopotential heights.

Regarding negative rainfall extremes there is a high probability that warmer and drier conditions will lead to more frequent and longer-lasting drought events in the Mediterranean area (Christensen et al. 2007). Concerning positive precipitation extremes, i.e. heavy rainfall events, a general tendency towards decreases is assessed by Frei et al. (2006) for the Mediterranean region in winter.

5. Conclusions

In correspondence to the observed and projected mean temperature rise on the global scale, dynamical as well as statistical assessments indicate increases of mean temperature also for the Mediterranean area, but with warming rates being probably somewhat greater compared to the global mean. Mean precipitation is assessed to decrease in most Mediterranean regions. Increases are only possible in the northern and western Mediterranean area during high winter, but the exact location of the boundary between the projected rainfall increases in northern Europe and the assessed precipitation decreases in southern Europe is still very uncertain. Regarding temperature extremes, the number of frost days will decrease just as extreme minimum temperatures in winter will increase. At the same time assessments for summer include that extreme hot days as well as heat waves will increase. Concerning rainfall-related extremes, longer-lasting and more frequent droughts are very likely, but on the other hand heavy rainfall events during winter are likely to decrease.

Overall climate change will have particular impacts on different sectors of human life in the Mediterranean area. For instance, according to ALCAMO et al. (2007), there will be a greater energy demand for cooling. Estimates for the year 2050 point to a prolonged cooling period of two up to five weeks per year. In contrast to this, the demand for heating purposes in winter will be reduced. Concerning tourism, higher temperatures may lead to a decrease in summer, but to an increase in spring and autumn. Regarding agriculture, general decreases in crops and widespread increases in water demand are expected.

Acknowledgement

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Dr. Elke HERTIG
Prof. Dr. Jucundus JACOBEIT
Chair of Physical Geography
and Quantitative Methods
Institute of Geography
University of Augsburg
Universitätsstraße 10
86159 Augsburg
Germany
Phone: 49 821 5983570/74
Fax: 49 821 5982264
E-Mail: jucundus.jacobeit@geo.uni-augsburg.de
elke.hertig@geo.uni-augsburg.de