Future change of water demand following global warming in arid area

Tomohisa Yano and Yuanbo Liu
Arid Land Research Center, Tottori University
1390 Hamasaka, Tottori 680-0001, Japan
e-mail: yano@alrc.tottori-u.ac.jp and yliu@alrc.tottori-u.ac.jp

1. Introduction

It has been reported that the globally averaged surface temperature is projected to increase by 1.4 to 5.8 ℃ over the period 1990 to 2100 (IPCC 2001). It is not likely that precipitation will have increased in arid regions and the effects of future climate change on irrigation and water resources may become of major concern. The purpose of the research is to predict future change of water demand in the Mediterranean climate regions of Turkey by using the predicted climate change data.

2. Material and method

The GCM-based climate change data are available with seven climate models at the IPCC website (http://www.ipcc.ch/). Among seven models, the ECHAM4/OPYC3 model of Maxplanck Institute for Meteorology, Germany and the NCAR-PCM model of the National Center for Atmospheric Research, USA were used as climate change data. The predicted climate change data for both models are available for 8192 locations of the world with the same grid points.

Monthly water balance was first calculated for the periods for 10 years from 2001 and 2090 in Siverek located at 37.75°N and 39.32°E, Turkey using the SWAP model developed in the Netherlands (Kroes 1999). Siverek was selected because it is located nearest to one of the grid points of the both models among the weather stations of southern Turkey. The B2 and A2 scenarios of the Emission Scenarios of the Special Report on Emission Scenarios (SRES) were used among the various scenarios (IPCC 2001). Next, monthly water balance was calculated for Adana located at 37.00°N and 35.25°E (Fig.1).

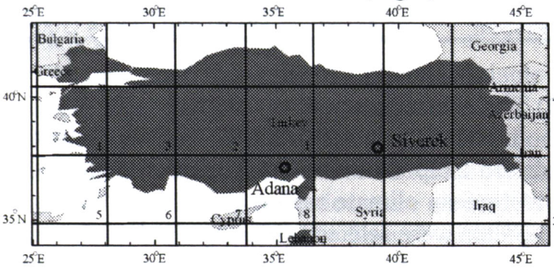

Fig. 1 Grid points of the models used in Turkey

3. Results and discussion

(1) The Siverek case

Variations of annual average temperature and precipitation for 99 years from 2001 to 2099 in Siverek are shown in Fig. 2 and 3, respectively. Annual temperature increases gradually, but the temperature difference between two models is noticeable. The long term average temperature observed in Siverek is 16.4 ℃ (FAO 1992).

Regarding the ECHAM4 model, there are

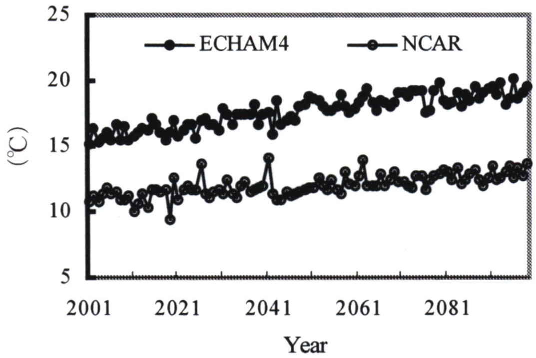

Fig. 2 Variations of annual temperature for the B2 scenario of the ECHAM4 and NCAR models

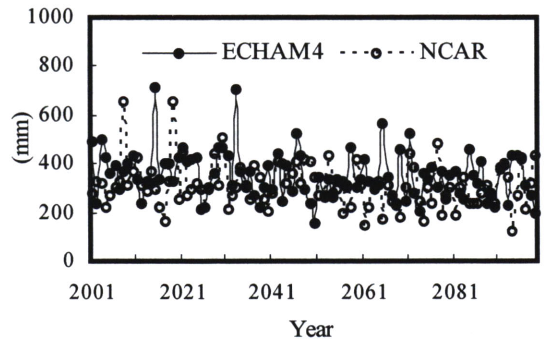

Fig. 3 Variations of annual precipitation for the B2 scenario of the ECHAM4 and NCAR models

predicted temperature data even for a time period from 1990 to 2000, and they were compared with the observed value in Siverek. Fig. 4 and 5 show comparison of the predicted and observed monthly temperature and precipitation, respectively for 10 years from 1990 in Siverek. According to Fig. 4 and 5, the predicted temperature agrees well with the observed one, but the predicted precipitation is much lower than the observed one.

According to Fig. 2, temperature rise for the ECHAM4 model is higher than for the NCAR model. The average temperature is projected to rise by 4 and 2 ℃ in 100 years for the ECHAM4 and

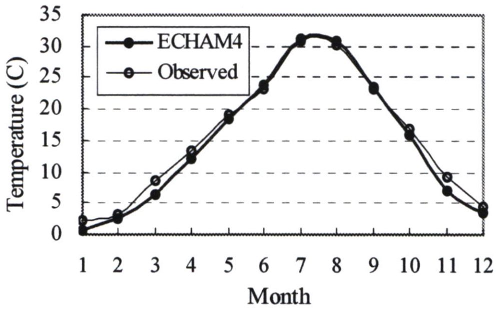

Fig. 4 Predicted temperature with the ECHAM4 model vs. observed one for the period 1990-1999

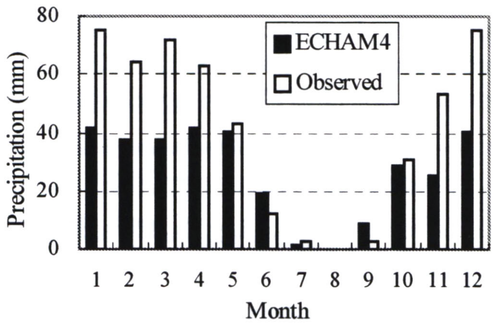

Fig. 5 Predicted precipitation with the ECHAM4 model vs. observed one for the period 1990-1999

NCAR models, respectively. Annual precipitation denotes noticeable variations year by year. The long term average annual precipitation of the FAO database is 547 mm.

Table 1 shows water balance for grass as a perennial crop for the periods for ten years from 2001 and 2090. Reflecting the different temperature between both models, potential evapotranspiration (ET) and therefore irrigation amount for the ECHAM4 model are much higher than those for the NCAR model. Further, calculated potential ET using the long term observed data is much higher than those for the two models.

Table 1 Monthly water balance for grass in mm

		Precipitation	Potential ET	Irrigation
ECHAM4	01-10	366.4± 87.0	1337.5±140.5	1024.9±143.3
	90-99	349.0±214.4	1514.2± 26.7	1165.2±128.2
NCAR	01-10	269.3± 47.3	1163.3±165.2	916.8±145.8
	90-99	267.0±108.4	1324.9± 78.2	1046.4±144.2
Observed		533.5	1599.6	1151.5

*B2 model

The procedure to calculate the future change of water balance was decided to change taking considerations of the different predicted values for both models. The climatic scenarios for the future were created by superimposing the observed values to the difference between 10 years average of 1990-1990 and that of 2001-2010 for temperature or to the ratio for other climatic elements as follows (Tao et al. 2003):

$$T_{(2090\text{-}2099)} = T_{(observed)} + \{T_{(2090\text{-}2099)} - T_{(2001\text{-}2010)}\}$$

$$V_{(2090\text{-}2099)} = V_{(observed)} * \{V_{(2090\text{-}2099)} / V_{(2001\text{-}2010)}\}$$

where T and V denote temperature and other climatic elements such as precipitation, solar radiation, humidity and wind speed. Subscript (observed), (2001-2010) and (2090-2099) denote the long term obserbed values, predicted values for the periods for 10 years from 2001 and 2090.

Prediction of water balance for grass as a perenial crop for a period of 2090-2099 is shown in Table 2. The result for the A2 scenario for the ECHAM4 model is also shown in the table. Still there exists the noticeable difference between water balance terms for the different models and the emission scenarios. Both potential ET and irrigation amount are projected to increase by 20 and 6% for the ECHAM4 and NCAR models due to temperature rise in the future.

Table 2 Prediction of water balance for grass in mm

	Precipitation	Potential ET	Irrigation
ECHAM4 B2	423.5 (79)	1900.1 (119)	1373.9 (119)
ECHAM4 A2	434.9 (81)	1935.3 (121)	1407.0 (122)
NCAR B2	528.7 (99)	1702.9 (106)	1218.4 (106)
Present	533.5 (100)	1599.6 (100)	1151.5 (100)

However, high temperatures accelerate the phenology of plants, resulting in quicker maturation. The shortened growth cycle, in turn, may reduce the yield potential of annual crops (Rosenzweig 1998). Table 3 shows the prediction of water balance for maize as a main crop in Turkey. In a series of water balance calculations for maize, variable length of the crop cycle for crop development was used as a function of cumulative temperature from emergence to maturity instead of fixed length in grass. Potential ET and irrigation amount for both models are not likely to increase unlike for grass.

Table 3 Prediction of water balance for maize in mm

	Precipitation	Potential ET	Irrigation
ECHAM4 B2	29.7 (75)	905.8 (103)	676.7 (102)
ECHAM4 A2	30.5 (77)	850.0 (96)	615.3 (93)
NCAR B2	54.4 (138)	864.7 (98)	613.6 (92)
Present	39.4 (100)	881.2 (100)	664.4 (100)

(2) The Adana case

In order to demonstrate the variations in the predicted temperature and precipitation data in the Metiterranean climate regions in Turkey, the eight grid points were selected (ref. Fig. 1). Fig. 6 and 7 show the variations of monthly temperature and precipitation at eight grid points for the time period 2001-2020 using the predicted data with the MRI-CGCM2.2 model of Meteorological Research

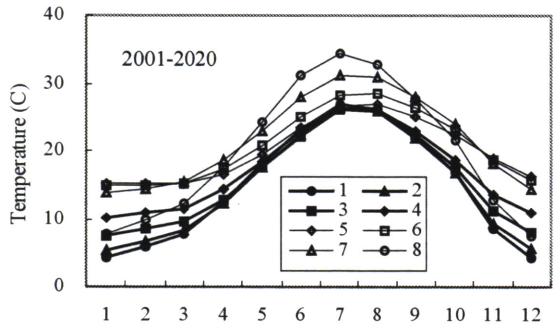

Fig. 6 Monthly variations of predicted temperature with the MRI model at eight grid points

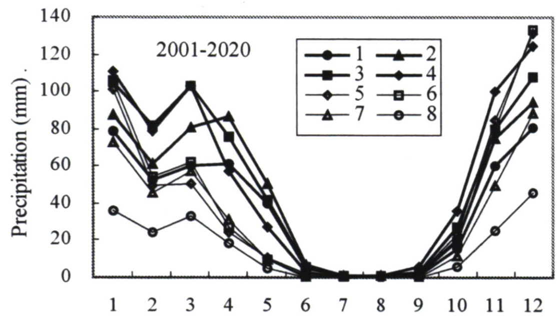

Fig. 7 Monthly variations of predicted precipitation with the MRI model at eight grid points

Institute, Japan. The grid point structure of the MRI model is same as those of the ECHAM4 and NCAR models. As shown in the figures, there exist much variations in temperature and precipitation between the different locations.

Fig. 8 and 9 show the monthly distribution of temperature and precipitations averaged over eight grid points for the MRI, ECHAM4 and NCAR models for the period 2001-2020. In the figures, the longterm average temperature and precipitation for Adana was added for comparison. Comparing the predicted values with the observed values, those for the NCAR model are generally lower in temperature and precipitation than the observed values. The predicted temperature with the MRI and ECHAM4 models denote the similar monthly pattern, though the values in the summer are higher than the observed values. The predicted precipitation with the NCAR model shows the different monthly pattern from one with the other models and the observed one.

As the result, the value of a climate variable for Adana was decided to be computed with the predicted values at the four nearest neighboring grid points using the inverse distance wighted method. The climate scenarios were created in the same way as descrived in the Siverek case. Fig. 10 and 11 show the variations of annual temperature and precipitation created for Adana in the case of the MRI, ECHAM4 and NCAR models, respectively. Water balance calculations were done

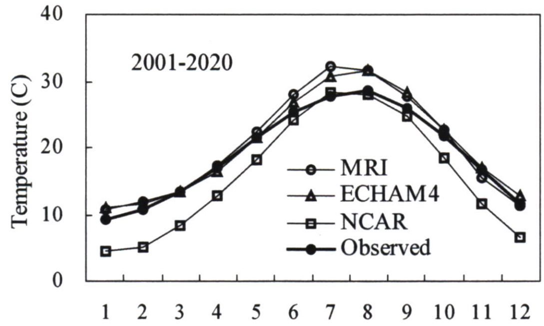

Fig. 8 Monthly variations of predicted temperature averaged over eight grid points

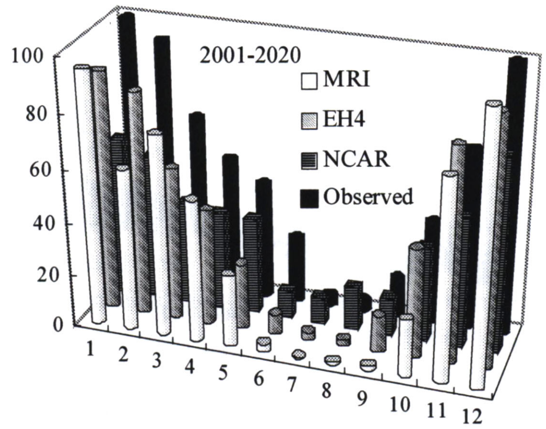

Fig. 9 Monthly variations of predicted precipitation averaged over eight grid points

for Adana for the perids for 20 years from 2001 and 2041. The long term climate data was used for Adana from the FAO database. Annual variations of averaged annual temperature and precipitation are shown in Fig. 12 and 13 for the period 1990-2100 for the MRI and ECHAM4 models. Although temperature rise by the end of 21st century is a liittle higher for the ECHAM4 model than the MRI model, the precipation difference can

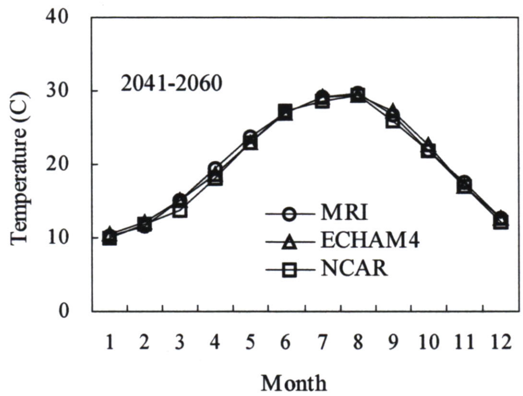

Fig. 10 Monthly temperature created for Adana with the A2 scenario of the MRI, ECHAM4 and NCAR models

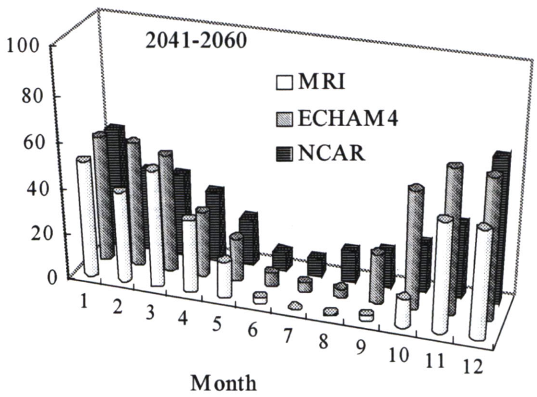

Fig. 11 Monthly precipitation created for Adana with the A2 scenario of the MRI, ECHAM4 and NCAR models

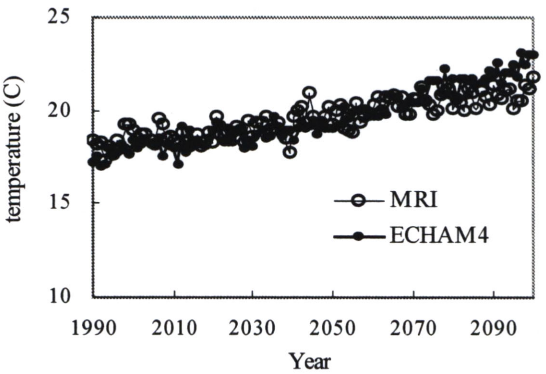

Fig. 12 Variations of annual temperature from 1990-2100 created for Adana with the MRI and ECHAM4 models

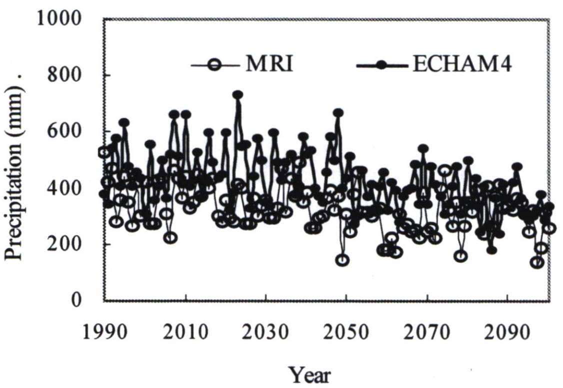

Fig. 13 Variations of annual precipitation from 1990-2100 created for Adana with the MRI and ECHAM4 models

not be recognized, because yearly variations are so much. Monthly water balance was calculated only for the A2 scenario.

Table 4 and 5 show the prediction of monthly water balance for grass and maize for the A2 scenario of the MRI, ECHAM4 and NCAR models. Unlike the Siverek case shown in Table 2 and 3,

Table 4 Prediction of water balance for grass

	Precipitation	Potential ET	Irrigation
MRI	529.6 (90)	1228.5 (100)	823.5 (100)
ECHAM4	557.8 (95)	1180.2 (96)	778.6 (95)
NCAR	568.6 (97)	1205.4 (98)	826.6 (100)
2001-20	587.5 (100)	1232.2 (100)	822.5 (100)

Table 5 Prediction of water balance for maize

	Precipitation	Potential ET	Irrigation
MRI	61.4 (100)	665.3 (100)	382.9 (89)
ECHAM4	78.7 (127)	651.6 (98)	381.6 (88)
NCAR	59.7 (97)	664.5 (100)	369.8 (86)
Present	61.5 (100)	666.4 (100)	431.9 (100)

the predicted water balance terms with three models are similar and not so different from the present water balance terms. This is partly because the created temperature for 2041-2060 is similar with each others and the present condition as seen from Fig. 10 and 13. Further, comparing reference ET values calculated with the Penman-Monteith equation, the similar values have been obtained for all the created scenarios and the present condition.

Concluding remarks

There are three relevant models available for prediction of future climate change: the MRI, ECHAM4 and NCAR models. However, the temperature prediction with the NCAR model seems to underestimate the future temperature. Further, since there are obvious discrepancies between the present climate and the prediction for 2001-2020, we were forced to create the climate scenario using the present observed data. As the result of climate scenario creation for three models, we could not get the different prediction of the future water balance. The similar trial should be done using the latest climate data in Adana for investigating the validity of the used approach.

Thanks are due to the Meteorology sub-group for the MRI data supply.

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