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Catchment tension moisture responses to climate changes assessed from incomplete climatological data

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Abstract

The long-term tension moisture responses over the medium-sized mountainous Mesochora catchment to climate changes were extensively analysed. The climate changes were conceived through a set of hypothetical and monthly GISS (Goddard Institute for Space Studies) scenarios of temperature increases, coupled with precipitation changes. The US National Weather Service snowmelt and rainfall-runoff models used in this study, were accepted as input historical climatological data which were integrated over area and elevation range from incomplete point records. Both sets of climate change scenarios resulted in decreases in average spring and summer tension water (upper and lower) having possibly negative impacts on plants growth.

1 Introduction

General circulation models (GCMs) [6,7] can only grossly simulate the observed large-scale soil moisture, as well as its long-term seasonal variability. Much more, they cannot at all simulate and predict accurately observed regional or local soil moisture that is needed for making detailed assessments and predictions of agricultural, ecological, hydrological, and societal impacts. Furthermore, none of the GCM models or any downscaling scheme thereof, or even the most promising SVAT (Soil - Vegetation - Atmosphere Transfer) models [2] can indeed partition soil moisture into different intermediate storages (free and tension water over upper and lower zones). Thus, for catchment scale areas, the coupling of GCM output (temperature, precipitation, etc) and conceptual hydrological models, including soil moisture components, can only face the above cited problem. In this sense, the present day surface climatological data must be adjusted to account for climate change scenarios.

The authors deal with the long-term tension moisture responses of a medium-sized mountainous catchment to hypothetical and GISS (Goddard

Institute for Space Studies) modelled climate changes. The tension moisture storages over the catchment represent the volume of water which is tapped by catchment vegetation, the upper zone water being used by shallow plant root system and the lower by the deepest one. Furthermore, the aforesaid storages are components of the cumulative soil moisture (Figure 1) corresponding to physical one, while the other three components refer to free water zone contents [8]. As regards the climatological data used in the study, they included incomplete point values of daily precipitation and minimum/maximum temperature. In order to preserve the physical nature of climatic information and thus avoid the errors caused by the interpolation techniques [4, 5, 19], we would rather not estimate the unavailable values, but integrate instead the existing ones for areal variation and change with elevation.

2 Experimental Design

The Mesochora catchment of the Acheloos river in Central Greece was selected for an analysis of the soil moisture responses to global climate changes [16], due to the partial diversion of the river for irrigation and hydropower purposes. The part of the river which drains the Mesochora catchment flows freely (no upstream diversions or flow regulations). The network of meteorological stations installed in and around the catchment is relatively dense, but 3.5% of daily precipitation values and 15.5% of daily min-and-max temperature values were missing for the 15-year period used in this study (1972-1986). The climate in the Mesochora catchment is elevation-dependent, its mean elevation is 1390m, and its hydrology is controlled by snowfall and snowmelt.

The catchment area is 632.8 km^2, its annual precipitation is 189.8 cm and its runoff is 117.0 cm. A more detailed description of the catchment has been presented by Panagoulia [12, 13, 14].

The approach of conceptual hydrological simulation was adopted in this study in order to achieve detailed representation of a medium-sized catchment. Two hydrological models were used: *the snow accumulation and ablation model* of Anderson [1] and the *soil moisture accounting model* of Burnash et al., [3]. The snowmelt model describes the change in storage of water and heat in the snowpack, based on six-hourly precipitation and temperature data. The runoff model assumes that the flux of soil moisture partitions into five conceptual storage zones. The soil moisture zones include an upper free and tension water zone and lower tension, free primary and secondary zones. Tension water (upper and lower) is removed only through evapotranspiration. Although it is not possible to relate the contents of the individual soil moisture zones directly to physical parameters, the sum of all the soil moisture zone contents correspond roughly to the moisture storage in the soil column. The runoff model accepts as inputs the snowmelt model output "daily rain plus melt" and long-term average monthly potential evapotranspiration, which in this study was computed according the Penman equation [18].

Since precipitation and temperature are strongly dependent on elevation, the snowmelt model was implemented using an elevation band method [12, 16]. The study catchment was divided into three elevation zones (about 30% of total area for each of the upper and middle zones and 40% for the lower

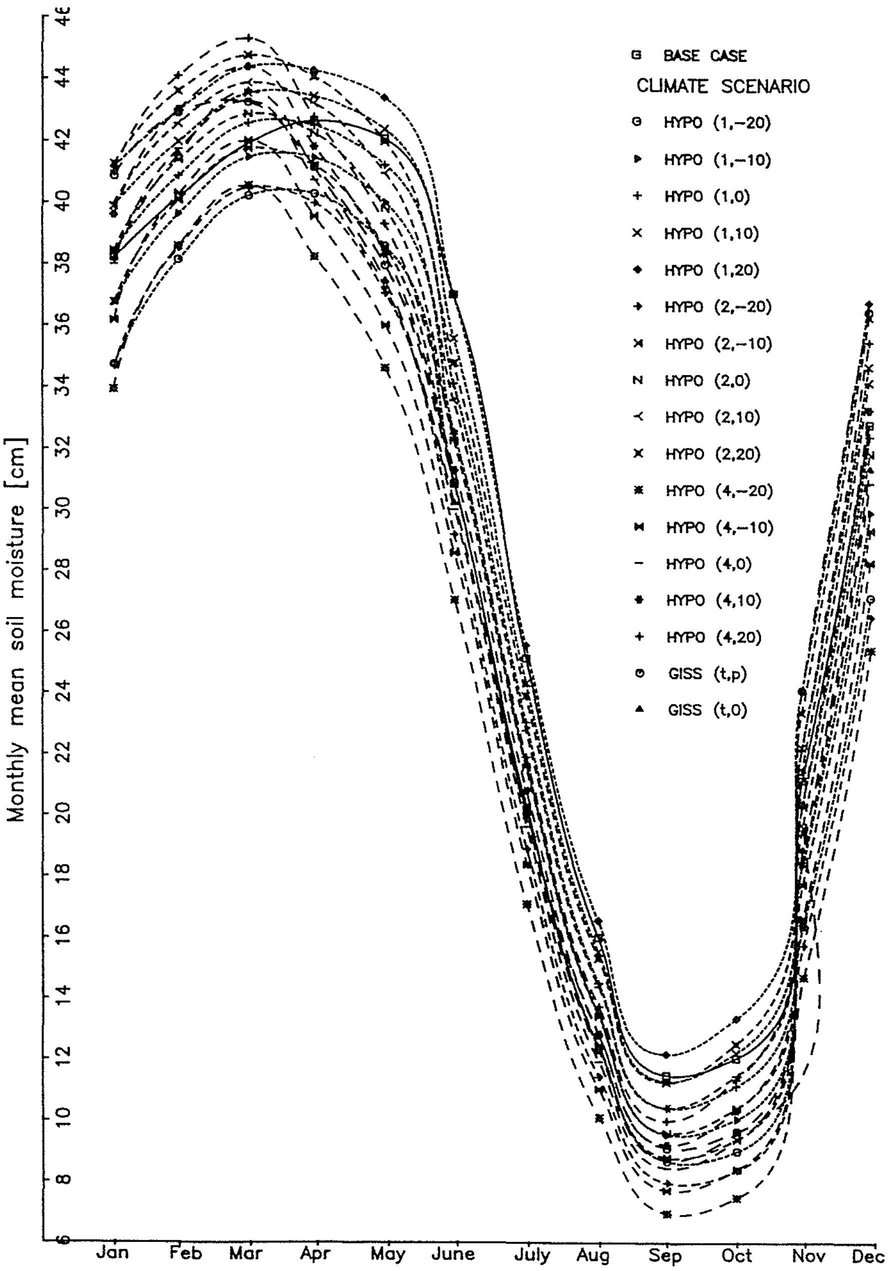

Figure 1: Mesochora catchment monthly mean cumulative soil moisture for the HYPO, GISS and base case climate scenarios.

zone). Eleven precipitation stations and three temperature stations were used in the process. Because the daily precipitation records were incomplete, the zone areal precipitation was assessed through the Thiessen method for all the combinations of zone stations which were giving out data for that particular day. The estimated zone areal precipitation was corrected for the median zone elevation. The above mentioned combination technique was also used to estimate the zone areal daily max-and-min temperature [12, 15]. The study catchment mean areal precipitation (MAP) was formed as the average of the snowmelt output over the elevation zones (the weighting was proportional to the elevation zone areas). The MAP was then used as input to soil moisture accounting model.

The models were manually calibrated [17] and their final parameter estimates (over the 15-year period) were obtained through a trial-and-error approach, which was carried out concurrently for both models. The typical monthly simulation errors (monthly differences between simulated and observed streamflows), expressed as a percentage of observed flows, were of the order of 10-15% (in August and September they reached 23%).

The historical input data were adjusted to reflect the altered climates simulated by:

a) fifteen hypothetical scenarios denoted as HYPO(ΔT,ΔP), where ΔT is temperature increase by 1, 2, 4°C and ΔP is precipitation change by 0, ±10, ±20 % [14]
b) two GISS-predicted scenarios (with both monthly precipitation and temperature changes GISS(t,p), and with monthly temperature changes alone GISS(t,0)) [13].

3 Tension Moisture Responses

We restrict the analysis to two variables: *monthly mean upper zone tension water* and *monthly mean lower zone tension water* over the catchment. The monthly mean snow water equivalent, runoff, evapotranspiration and two zone (upper and lower) free water over the catchment are described in other studies [8, 9, 10, 11, 13, 14]. The soil moisture scenarios of the above three variables are plotted in Figures 2, 3 and a brief interpretation of these figures follows:

3.1 Upper zone tension water

The moisture content of the upper tension zone (Figure 2) is slightly affected by HYPO and GISS climate changes in winter period (December to February), while all the other months are affected much more. The tension moisture content of this zone is reduced for all months and its maximum fall occurs in May for both HYPO and GISS scenarios. The seasonal tension moisture profiles are very similar for both cases of HYPO and GISS scenarios. The fact of the considerable tension moisture reduction in spring and early summer months is to be attributed to snowmelt reduction that contributes to soil moisture.

3.2 Lower zone tension water

The moisture content of the lower tension zone (Figure 3) shows the same monthly distribution profile for both HYPO and GISS scenarios. The largest

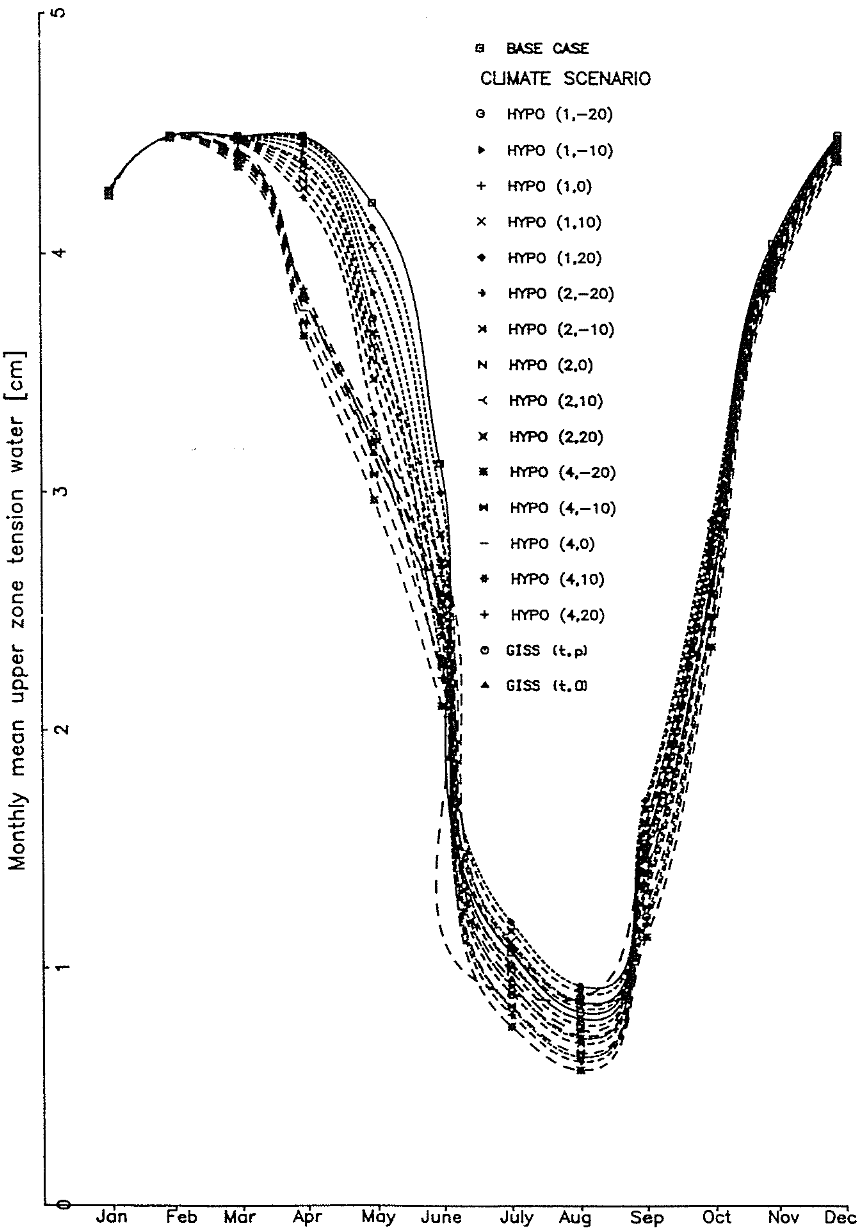

Figure 2: Mesochora catchment monthly mean upper zone tension water for the HYPO, GISS and base case climate scenarios.

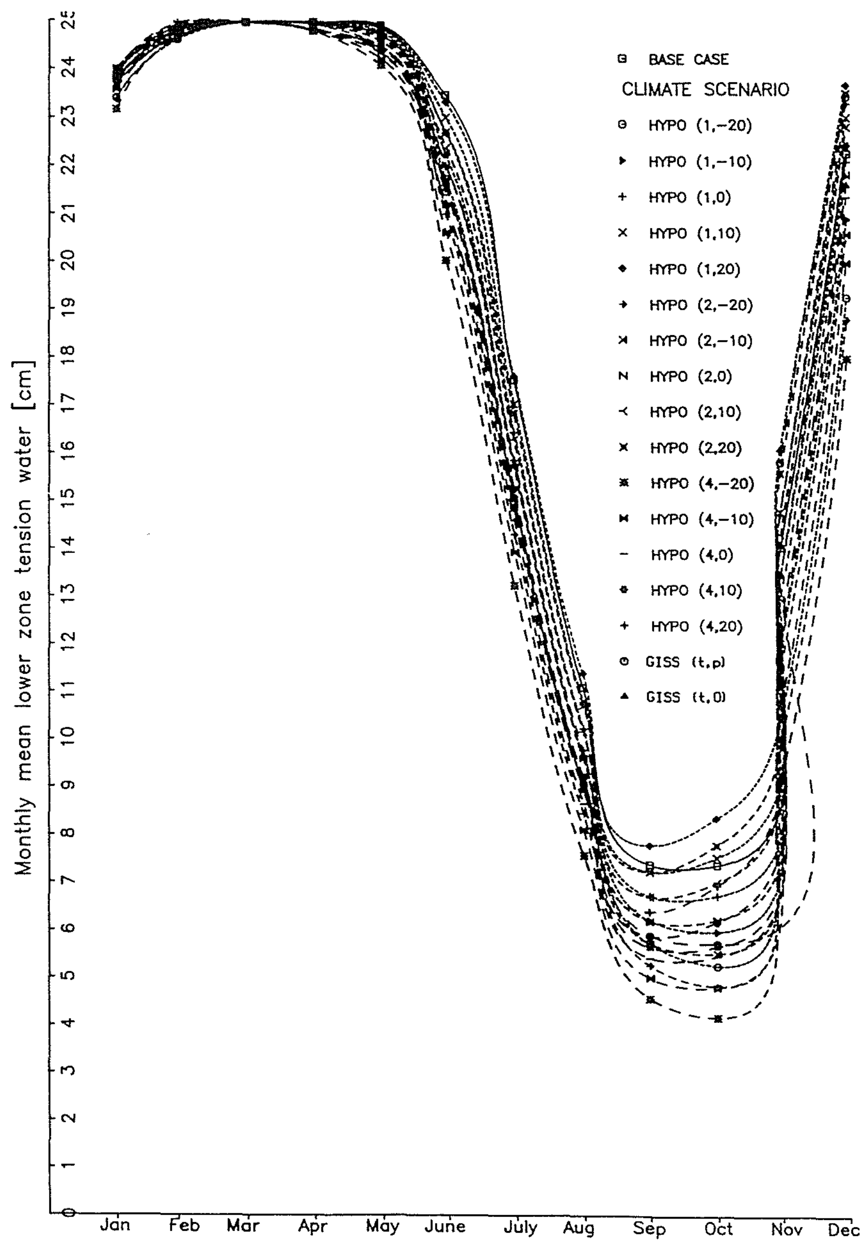

Figure 3: Mesochora catchment monthly mean lower zone tension water for the HYPO, GISS and base case climate scenarios.

reduction in lower tension moisture occurs in October for the two GISS and HYPO(4,-20) scenarios. Generally, the largest lower zone tension moisture reductions appear shifted forward by two or three months, compared with these of upper zone tension moisture storages.

3.3 Cumulative soil moisture

The moisture content of all conceptual zones (Figure 1) shows the same monthly distribution images for both HYPO and GISS scenarios. The largest reduction in cumulative soil moisture occurs in September for the HYPO (4,-20) case. Generally, the larger cumulative soil moisture reductions appeared during the dry period (July to November).

4 Conclusions

The main conclusions from the present study are as follows:

- The HYPO and the GISS climate scenarios displayed similar profiles of monthly distributions of the catchment tension (upper and lower) as well as cumulative moisture storages.
- All the scenarios projected decreases in average spring and summer tension water, while the larger lower zone tension water reductions appeared shifted forward by 2 or 3 months, compared with these of upper zone tension water. These reductions have possibly negative impacts on plants growth.
- Significant differences in numerical results among climate cases were noticed due to the wide range of the climate variable changes.

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