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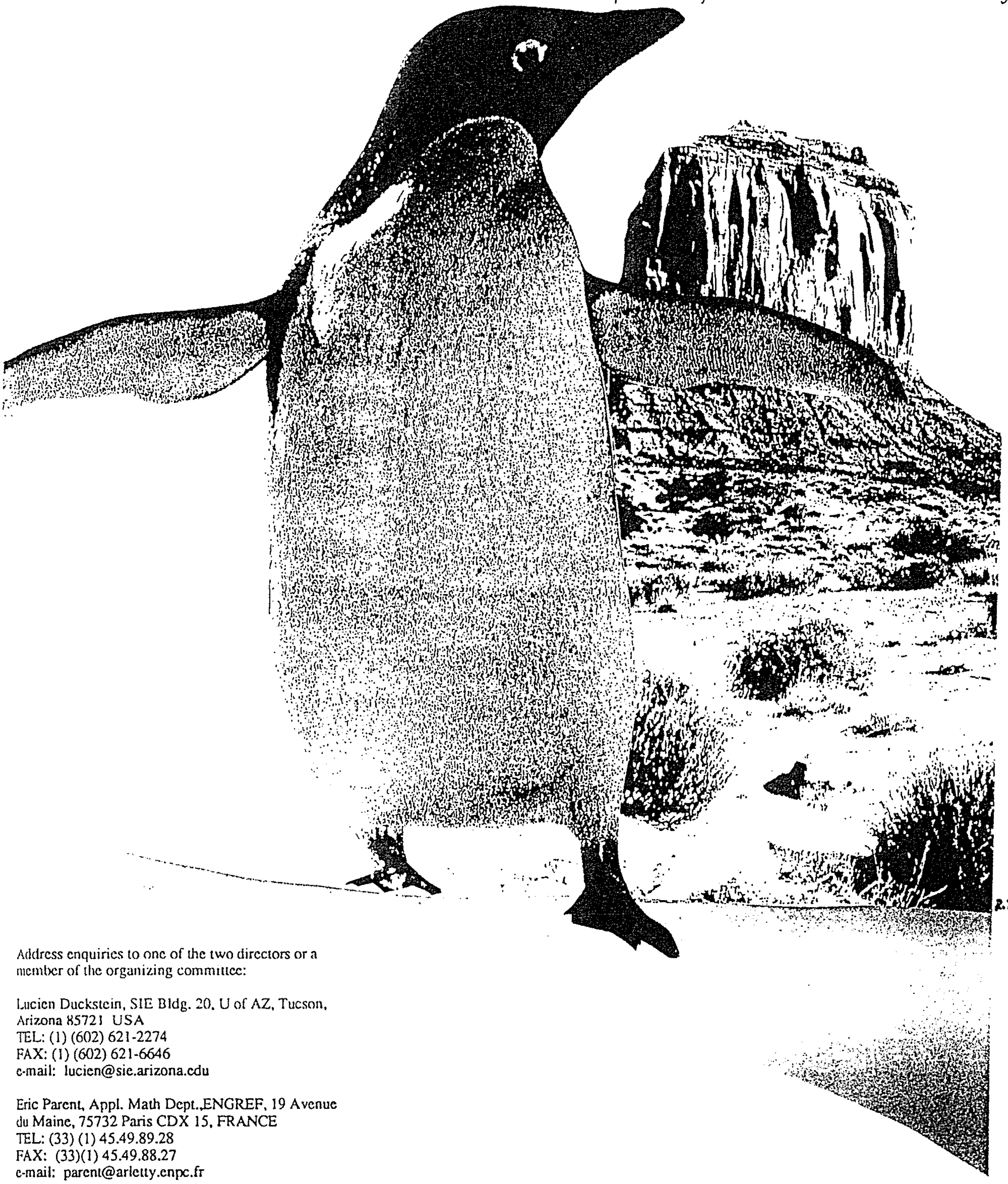
New Developements in Resources Management with Application to Non-steady Conditions with Special Reference to Climatic Uncertanity



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GRECE

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Detection and modelling of the impact of climatic change on river flows

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Documentation of Global climate changes through catchment hydrological modelling.

Documentation of global climate changes through catchment hydrological modelling

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Abstract. The long-term hydrological monthly averages of a medium-sized mountainous catchment are used as basis for the documentation of global climate changes. According to recent climatological literature, the climate changes are simulated by a set of hypothetical scenarios of temperature increases coupled with precipitation changes. Another set of monthly scenarios (coupled temperature with precipitation changes, as well as temperatures changes alone) as per model of the Goddard Institute for Space Studies (GISS) model for carbon dioxide doubling is applied to determine the differences, similarities or equivalencies generally, between these two climate change cases. The simulated hydrological variables are the snow water equivalent, runoff, evapotranspiration and soil moisture storages. On a monthly basis, the noted equivalencies among all the scenarios, were 4°C increase which appeared to present the higher occurence probability, and changes of (+1°C, -20%) and (+2°C, -10%) which were more often the case.

INTRODUCTION

The development of climate models, especially those of general atmospheric circulation (GCMs), as well as the consensus on the direction of future climate assume that global climate changes will occur as a result of increases in temperature.

All the climate models, including the better parameterized ones (GCMs), give different values of climate variable changes and so do not provide a single reliable estimate that could be advanced as a deterministic forecast for hydrological desigh. On the other hand, the current spatial and temporal resolution of the GCM outputs is rather coarse and utterly inadequate for catchment hydrological interpretation.

Accordingly, considering that no appropriate coupling has been developed yet between the GCM outputs (e.g. precipitation, temperature, and potential evaporation) and catchment hydrological models, various climate change scenarios have been adopted in order to interpret the hydrological responses of possible climate changes. However, these hydrological responses can be concurrently used as basis for the documentation of global climate changes.

In this study, the climate changes are simulated by a set of hypothetical scenarios of temperature increases coupled with precipitation changes. Another set of monthly scenarios (coupled temperature with precipitation changes, as well as temperatures changes alone) as per model of the Goddard Institute for Space Studies (GISS) model for carbon dioxide doubling is applied to determine the differences, similarities or equivalencies generally, between these two climate change cases. The object of comparison of the above climate cases are the monthly long-term hydrological responses (snow water equivalent, runoff, actual evapotranspiration and soil moisture) of a medium-sized mountainous catchment to these climates.

CATCHMENT HYDROLOGICAL MODELLING

The Mesochora catchment of the Acheloos river in Central Greece was selected for the purposes of the study(Panagoulia 1990). The following criteria were used: (1) intense topographic and climate variability, (2) absence of upstream diversions or flow regulations, and (3) availability of hydrological and meteorological records. At the catchment outfall, the river will be partially diverted to irrigate the arid Thessaly Plain and boost the hydropower generation of the surrounding region.

The climate in the Mesochora catchment is elevation-dependent, with hot summers and mild winters at low elevations and mild summers and cold winters at high elevations. Because of its high mean elevation (1390m), its hydrology is controlled by snowfall and snowmelt. The catchment area is 632.8 km^2, its annual precipitation is 1898 mm and its runoff is 1170 mm. Amore detailed description of the catchment has been presented by Panagoulia (1991, 1992a, 1992b).

The methodology of conceptual hydrological modelling was adopted in this study for reasons of detailed representation of a medium-sized catchment. Two hydrological models were used : the snow accumulation and ablation model of Anderson (1973) and the soil moisture accounting model of Burnash et al., (1973). 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 accounts for the flux of soil moisture between five conceptual storages zones. 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 estimated from the Penman equation

(Veihmeyer, 1964).

For better performance of the snowmelt model, the 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 zone). Eleven precipitation stations and three temperature stations were used. Because the daily precipitation records were incomplete, the technique used to asses the zone areal precipitation was a combination of the Thiessen method and the station daily availability, including elevation correction.The above mentioned combinatorial technique was also used to estimate the zone areal daily max-and-min temperature (Panagoulia, 1992a). 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 calibration period was 15 years for both models. The models were manually calibrated (Peck, 1976) and their final parameter estimates 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% (except for the August and September runoff which reached 23%). The plot of the long term annual mean catchment pseudo-precipitation (rain plus melt) over 15 years showed three distinct periods with different climate conditions. A modified differential split sample test was implemented in order to verify the ability of the soil moisture accounting model (and hence the snowmelt model) to respond to the three different climate periods. Details of the development, calibration, and statistical verification of the models are presented in Panagoulia (1990, 1992a).

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 ^{o}C and ΔP is precipitation change by 0,±10,±20 %, and (b) two GISS-modelled scenarios (monthly precipitation and temperature changes GISS(t,p), and with monthly temperature changes alone GISS(t,0)) (Panagoulia 1992b, 1993). Thus, all the input precipitation time series were multiplied for the HYPO cases by a uniform factor and the GISS cases by the monthly precipitation ratio (the ratio of monthly precipitation for CO_2-doubling to the control run, ranging from 0.925 to 1.487) applied for the centre of the catchment (39^{o} 34′N latitude and 21^{o} 19′E longitude). The HYPO temperature increases were applied uniformly to all daily values of the historical input series, while the GISS-predicted monthly temperature differences (ranging from 3.37 to 4.98°C) between the CO_2-doubling and control run were added to the input historical data as well.

For the HYPO cases the potential evapotranspiration (*PET*) was computed using the Penman equation with the indicated temperature increases, which were applied uniformly to the historical monthly temperature data. For the GISS cases, the *PET* was also computed with the same equation for the monthly temperature data for the CO_2-doubling and the control run. The monthly differences in *PET* were computed and these differences were then added to the historical *PET* data. The other variables (wind speed, humidity, solar radiation, etc) remained unaltered in the Penman equation for both HYPO and GISS cases.

HYDROLOGICAL RESPONSES-EQUIVALENCIES

This paper restricts the analysis of the hydrological responses to four variables: monthly mean snow water equivalent over the catchment, monthly mean catchment runoff (streamflow), monthly mean catchment evapotranspiration, and monthly mean lower zone primary free water. The monthly mean soil moisture storages in the other four conceptual storage zones are excluded from this paper. They are described in other studies (Panagoulia 1991a,1992b). The hydrological scenarios of the above four variables are plotted in Figs 1-4 and a brief discussion of the equivalent figures follows.

Snow water equivalent

The long-term monthly snow water equivalent over the study catchment for all alternative climates is presented in Fig. 1 (Panagoulia 1993).The GISS scenarios and the HYPO(4,all)generally generated similar annual snow water equivalent hydrographs in the same month of snow maximization, extinction and return. But there is a difference in snow water profiles: the HYPO(4,all) cases yielded hydrographs with obviously flatter crest than that of GISS ones, due to the different GISS-predicted monthly values. Searching, on a monthly basis, for equivalencies among all the scenarios, those of 4°C increase appeared to be more similar.

Runoff

Figure 2 shows significant changes in the seasonal distribution of Mesochora catchment runoff for all 17 climate scenarios. The summer runoff went down considerably in GISS scenarios and 14 of the 15 HYPO cases. The summer runoff resulting from the scenarios HYPO(1,20) went up a little due to the small increase of the temperature and large precipitation increase. The winter runoff increased in the two GISS scenarios and 10 of the 15 HYPO cases. It decreased in the case of the climate scenarios HYPO(1,10), HYPO(2,10) and HYPO(all,20). For the April to August period the scenarios of HYPO(1,-20) and HYPO(2,-10) are similar to GISS(t,p).

Evapotranspiration

During the wet November-April period, actual evapotranspiration (*ET*) remained unaffected by precipitation changes (Fig. 3), but increased in relation to base case *ET*. During the dry May-October period *ET* increased with precipitation increase and decreased with precipitation reduction. The peak value of monthly *ET* occured in June for the base case and 9 of the 15 HYPO scenarios, while the other 6 scenarios (characterized by precipitation reduction), as well as the GISS climates peaked in May. The GISS scenarios as well as those of HYPO ones with minor precipitation reduction showed a flatter crest in the monthly distribution of *ET*. For the winter months the GISS scenarios are similar to HYPO(4,all).

Lower zone primary free water

The free moisture content of the lower primary zone is strongly and erratically influenced by HYPO and GISS scenarios, as well as from month to month under the same scenarios (Fig. 4). For the winter months the GISS scenarios are equivalent to HYPO(4,0), HYPO(4,10) and HYPO(4,20), while during the summer months the HYPO(1,-20) and HYPO(2,-10) are equivalent to GISS(t,p) scenario.

CONCLUSIONS

On a monthly basis the equivalent scenarios of GISS and HYPO simulated climate changes are reflected in Table 1 through two figures which express, first, temperature increases, and second, precipitation change percentages. These scenarios are characterized by:

- the general temperature increase by 4°C. This value appears to have the higher occurrence probability,
- two or more HYPO scenarios equivalent to a GISS scenario in the same month. The HYPO(1,-20) and HYPO(2,-10) scenarios are more often presented, and
- the assumption that the October runoff resulting from the GISS(t,p) scenario cannot be simulated by any combination of HYPO scenarios due to the high increased precipitation (about 50%).

Table 1 Equivalent GISS and HYPO climate changes scenarios.

	GISS	HYPOthetical scenarios											
		JANUAR	FEBRUA	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEM	OCTOB	NOVEMB	DECEMB
Snow water equivalent	p,t 0,t	4, 20 4, 20	4, 20 4, 20	4, 0 4, 0	4, 0 4, 0	4,all 4,all	4,all 4,all					2,-20 4, 0	4, 20 4, 10
Runoff	p,t 0,t	1, 20 1, 10	2, 0 2, 10	1, 0 2, 0 4, 0	1,-20 4, 0	2,-10 4, 0	2,-10 1,-20	2,-10 1,-20 4, 0	2,-10 4, 0	4, 0 1,-10 4, 0	None 4, 0	1, 20 2, 0	1, 20 4, 0
Actual evapotran-spiration	p,t p,t	4,all 4,all	4,all 4,all	4,-20 4,-20	4,-20 4,-20	4, 0 4, 0	1, 0 2, 0	1, 0 4, 0	4, 10 2, 0 4, 0	4, 0 4, 0	4, 0 2, 20	4,-20 4,-20	4,all 4,all
Lower zone primary free water content	p,t 0,t	4, 20 4, 0	1, 20 4, 10 4, 0	4, 0 1, 10	4, 0 4, 0	2,-10 4,-10	1,-20 2,-10 4, 0	1,-20 2,-10 4, 0	4, 0 1,-20	1,-20 2,-10 4, 0	2,-10 2,-10	1, 20 4, 0	1, 20 4, 0

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Table

Table 1. Equivalent GISS and HYPO climate changes scenarios

Figure Captions

Figure 1: Mesochora catchment monthly mean snow water equivalent for the HYPO and GISS climate scenarios.

Figure 2: Mesochora catchment monthly mean runoff for the HYPO and GISS climate scenarios.

Figure 3: Mesochora catchment monthly mean evapotranspiration for the HYPO and GISS climate scenarios.

Figure 4: Mesochora catchment monthly mean lower zone primary free water for the HYPO and GISS climate scenarios.

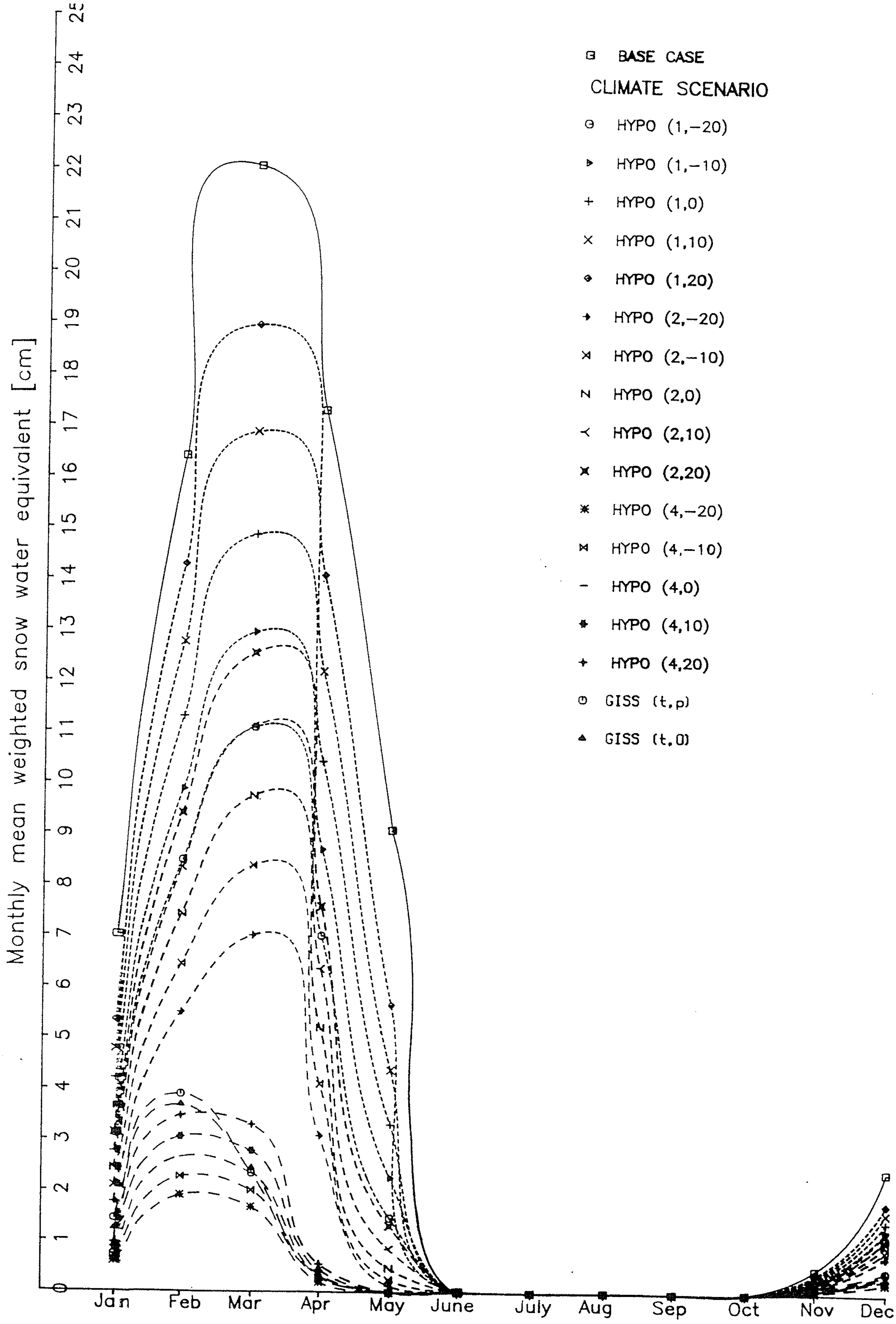
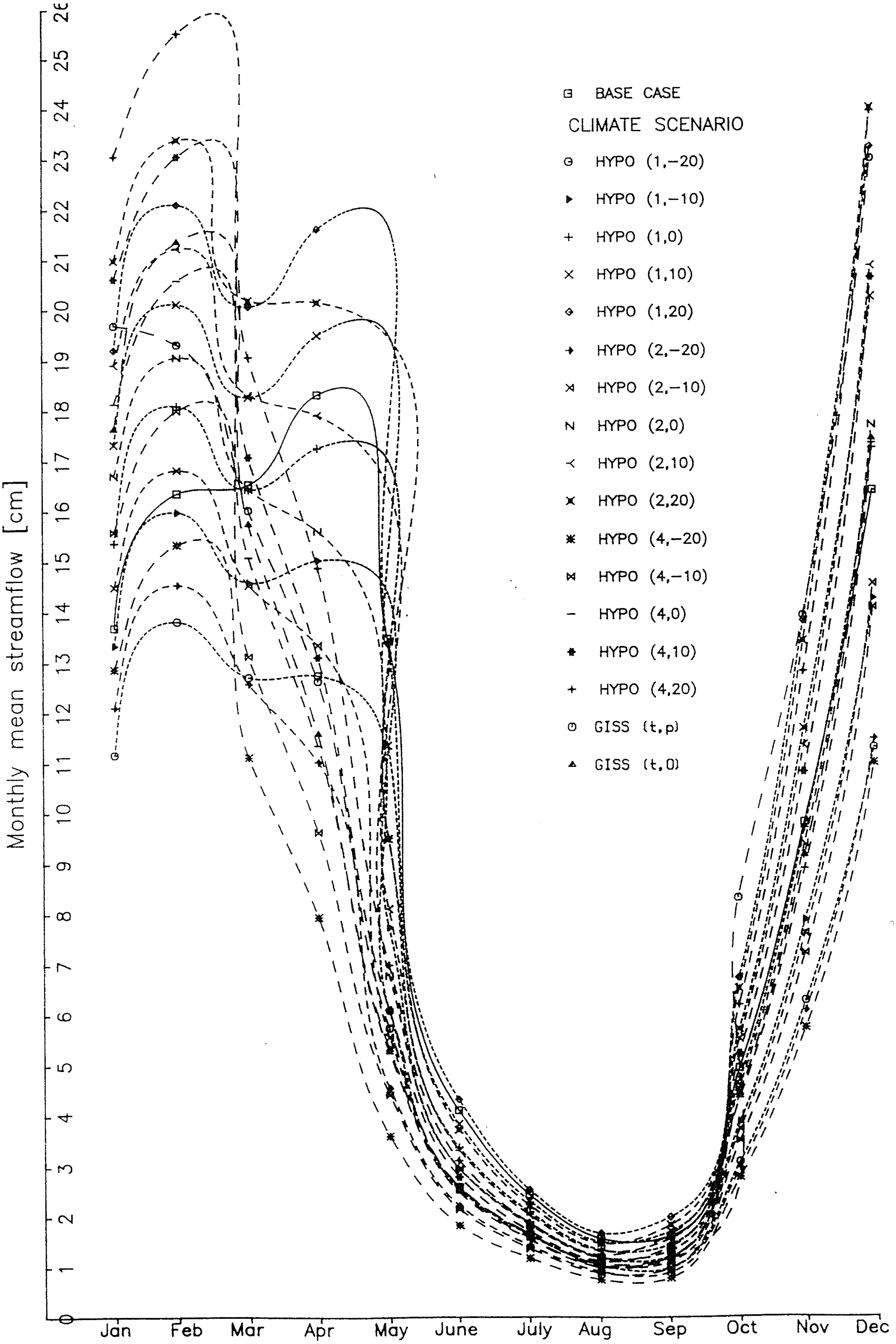


Fig. 1. D. Panagoulia



BASE CASE
CLIMATE SCENARIO
HYPO (1,-20)
HYPO (1,-10)
HYPO (1,0)
HYPO (1,10)
HYPO (1,20)
HYPO (2,-20)
HYPO (2,-10)
HYPO (2,0)
HYPO (2,10)
HYPO (2,20)
HYPO (4,-20)
HYPO (4,-10)
HYPO (4,0)
HYPO (4,10)
HYPO (4,20)
GISS (t,p)
GISS (t,0)
Monthly mean streamflow [cm]
Jan
Feb
Mar
Apr
May
June
July
Aug
Sep
Oct
Nov
Dec

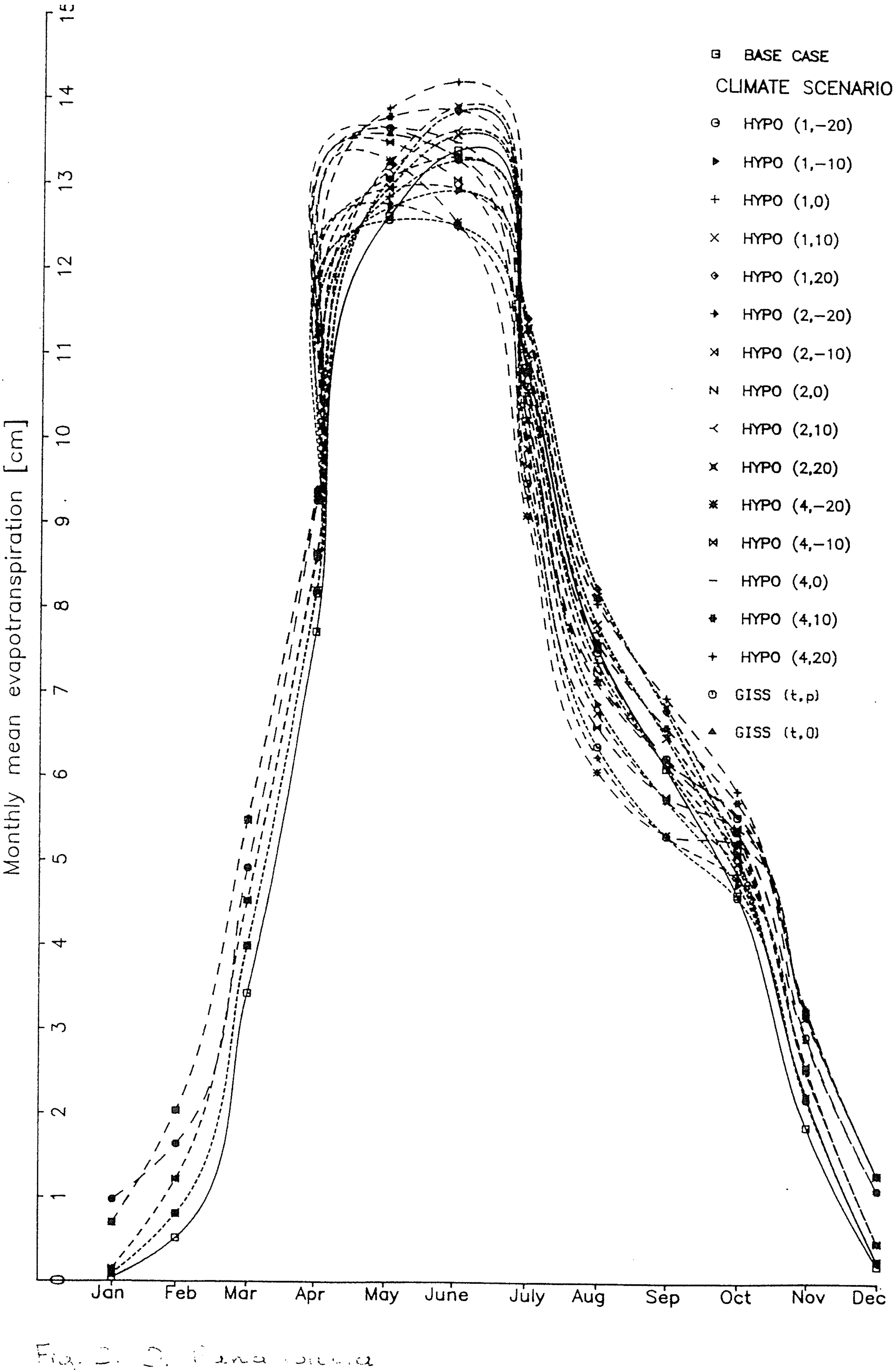
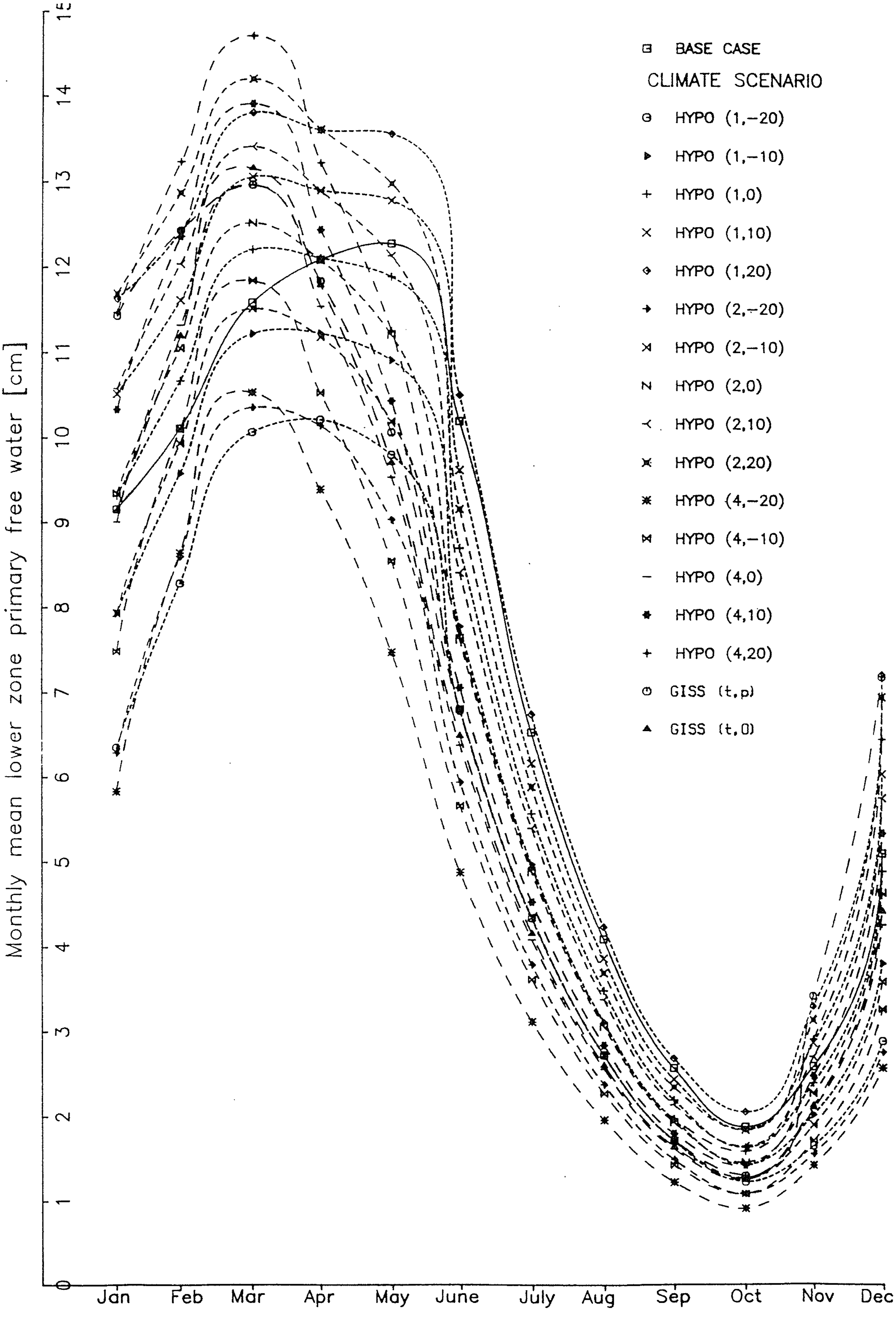


Fig. 2. D. Panagoulia



Monthly mean lower zone primary free water [cm]
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Jan
Feb
Mar
Apr
May
June
July
Aug
Sep
Oct
Nov
Dec
BASE CASE
CLIMATE SCENARIO
HYPO (1,-20)
HYPO (1,-10)
HYPO (1,0)
HYPO (1,10)
HYPO (1,20)
HYPO (2,-20)
HYPO (2,-10)
HYPO (2,0)
HYPO (2,10)
HYPO (2,20)
HYPO (4,-20)
HYPO (4,-10)
HYPO (4,0)
HYPO (4,10)
HYPO (4,20)
GISS (t,p)
GISS (t,0)