Catchment climatological data and climate change in Continental Greece

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Abstract

Attempts to validate General Circulation Model (GCM) simulations-predictions of field surface meteorological conditions refer only to large areas. Such attempts for catchment scale areas have been extremely limited due to the absence of systematic historical records, appropriate time scales and methods of spatially averaging the observational data aligned with GCM formulations. We describe a set of eleven precipitation stations and three temperature stations installed in and around the mountainous Mesochora catchment in Central Greece, for the 1972-86 period. Due to the available daily precipitation and temperature records were incomplete, a combinatorial scheme of the Thiessen method and station availability was developed to calculate the areal precipitation and temperature. The estimated catchment climatic information was corrected for elevation variation. The catchment daily data so obtained were adjusted for climate change simulations through hypothetical and Goddard Institute for Space Studies-modelled scenarios. The used hydrological tools were the US National Weather Service snowmelt and runoff models.

1 Introduction

The reliable assessment and prediction of mean areal precipitation and temperature in a mountainous region for catchment scale and daily time interval has been one of the most difficult problems of surface hydrology. The problem becomes more acute for reasons of climate change interpretation and adjustment which require the areal precipitation and temperature modelling to be as physical and accurate as possible [4,13,14].

The predictions of long- term climate change which resulted from general circulation models (GCMs), are scientifically an interesting but also controversial subject. The few attempts to validate GCM simulations of present surface meteorological conditions using field surface meteorological data [9,23] refer only to long-term climatic averages over large areas. According to another aspect, short-term (e.g. daily, hourly) climatic data over catchment scale areas can be obtained through various stochastic disaggregation schemes of GCM-predictions [2,10], but these modelled data have limited physical meaning [3,5].

Thus, some attempts are directed towards a coupling of atmospheric circulation simulations with surface hydrology [4]. In this case, the problem is focused on method appropriateness for areal precipitation and temperature estimation based on complete or incomplete climatic records. Such methods can include techiques of arithmetic mean, Thiessen polygons [25], inverse-distance, inverse-distance-squared, and other nearest neighbour interpolation schemes. Also, there are some other more sophisticated interpolation methods, such as the surface-fitting techniques [8,17], the double Fourier series [26],the so called optimal interpolation [27] and the kriging [7,16] plus the cokriging techniques [11,12,22].

Such methods have been widely used for annual, monthly and hourly areal precipitation computation but not for daily estimation (precipitation or temperature)that is particularly required for hydrological simulation of a catchment scale area. In the other hand, the most of them are statistical which cannot preserve the physical structure of climatic data.Thus, the daily catchment climatic information obtained with the exhibited methods is less physical and so its use in climate change studies may lead us to wrong conclusions.

In this paper, the daily catchment precipitation and temperature over a mountainous region is assessed from incomplete point records,with a simple, and practical method aimed at preserving the physical structure of the areal series data, especially required for the climate change interpretation. We have not estimated the missing daily values of station records, but integrate the existing ones, introducing the concept of *station availability condition* and using combinatorial and sorting analysis. The estimated catchment precipitation and temperature are also corrected for elevation variation.

2 Station availability and integration data

A station is available on a given day when it furnishes climatic information for that day. In the opposite case, the station is unavailable with no daily climatic data recorded at all. Beyond the obviously missing values of climatic data in a record, there are also the cases of inconsistent and suspicious values. The problem of inconsistency concerns the sum of the daily values which cannot provide the archival monthly value of the same month. Suspicious data can be spotted when daily precipitation values are negative or too high, or when maximum daily temperature values are smaller than minimum ones.For both these questionable cases, we reject the inconsistent and suspicious daily values and assume that the daily data for that month do not exist and are represented instead by the unavailability of their corresponding stations.

In mathematical calculus, the available station is expressed as 1 and non available as 0 (binary numbers). The juxtaposition in consecutive words of 1 or 0 items constructs the condition of station availability which, when applied to daily data, gives the condition of daily station availability. For n stations, the availability conditions based on binary number operation [24], are defined by the matrix aij, where $i=1,2,\ldots,(2^{n-1})$ and $j=1,2,\ldots,n$. In the instance of 6 stations there are 63 availability conditions. Examples of these are: 111111 which denotes that all the stations are available, 101011 which reflects that the second and fourth are unavailable (the other four are available), and 100001 which means that only the first and sixth station are actually available.

For the areal integration of daily climatic data including missing values, the station weights are evaluated by a Thiessen-like polygon method. This computation is done for every combination of station availability, thereby producing the matrix w_{ij} of all possible weights combinations.The actual weights are determined by the w_{ij} matrix through the stations' daily availability condition a_{ij}.

In mountainous regions, the climatological gauge stations are usually installed on the valleys of these areas and cannot possibly catch and record correctly the climatic information occuring at higher elevations. Even though there are stations installed at high elevations, these are susceptible to recording wrong figures. For this reason, on many occasions, we would rather compute the areal climatic information from records of stations that are installed at lower elevations and correct it accordingly for elevation variation concerned. In hydrological modelling, the catchment precipitation and temperature are corrected for mean catchment elevation after the proper precipitation and temperature elevation relationships are established. In the discussed case of incomplete records, we determine the corrective factors for every combination of station availability for all possible factor combinations. The actual factors are computed from the matrix of possible weights through the stations' daily availability condition a_{ij}.

3 Daily catchment precipitation and temperature

For determining the daily catchment climatic information, the proposed method is based on an assumption similar to Thiessen's polygon method, i.e: A climatological station is significant when the distance between the station and the center of any finite element of catchment is smaller than the corresponding distance of any other station to that same element. Stations outside the catchment are not equally significant with respect to catchment precipitation.

In other words the significance is a precipitation station is determined by its influence area. For this reason, the catchment is divided into unit elements. The element centers and the positions of stations are determined with the aid of x and y axes.

For every element, the distance between the center of element and every station position is computed. The weight 1 is attached to the nearest station (the assumption). This procedure is repeated for all the unit elements; by simply adding them up we define the catchment area, while the sum of elements of every station divided by the total number of the elements gives the weights of stations.

The above computations are carried out for all the possible combinations of the available stations, resulting in the formation of the matrix w_{ij} that includes all the possible weights. The dimensions i and j in the matrix are the same with those of the matrix a_{ij}. The row number r_i required for any condition of station availability is determined by the following algorithm:

$$r_i = \sum_{j=1}^{n} 2^{n-j} a_{ij} \qquad (1)$$

For instance, with 6 stations, the availability condition 111111 gives the row 63 in the matrix w_{ij}, while the condition 010111 gives the row 23 in the same matrix. The station availability matrix a_{ij} is computed on a daily basis, while the w_{ij} matrix is used as a look-up table from which the actual weights for each station can be read. The actual weights are used for computing the daily catchment precipitation and temperature from individual stations precipitation and temperature. In addition, the monthly and annual catchment precipitation and temperature can be computed as well.

4 Daily catchment precipitation and temperature corrected for elevation variation

For adjusting daily catchment precipitation and temperature (maximum and minimum) for elevation the proposed method includes:

1. Computation of mean catchment elevation.
2. Evaluation of the weighted mean station elevation $\bar{e}_i$ according to station availability conditions. The matrix with possible weights w_{ij} is used to estimate the possible weighted mean elevations of stations.

$$\bar{e}_i = \sum_{j=1}^{n} w_{ij} e_j \qquad (2)$$

   where, n is the number of precipitation stations, e_j the matrix of stations elevations, w_{ij} the matrix of possible weights of the stations.Every row of the matrix w_{ij} is activated by the station availability condition a_{ij} and it gives the actual weighted mean elevation (of stations).
3. Determination of a linear correlation between station elevation and mean annual station precipitation. The slope of the regression line constitutes an initial estimate of rate $\acute{a}$ of the precipitation variation

with elevation. The final estimate of the rate can be determined by a trial and error procedure based on annual water balance considerations. Because the weighted mean station elevation depends on the station availability, a set of correction factors $\ddot{e}_i$ is defined for the variation of catchment precipitation with elevation. The matrix with possible values of the correction factors $\ddot{e}_i$ is computed by the following algorithm:

$$\ddot{e}_{\mathrm{i}} = 1.0 + \frac{\bar{e}_c - \bar{e}_i}{h_c} \acute{a} \tag{3}$$

where, $\bar{e}_c$ the mean catchment elevation, and h_c the annual catchment precipitation (without correction).
The daily condition of station availability determines (from the matrix with possible correction factors $\ddot{e}_i$) the actual correction factor, by which latter we multiply the daily catchment precipitation for that day.

4. Determination of a linear correlation between station elevation and mean annual station temperature. The slope of the regression line constitutes an initial estimate of rate $\hat{a}$ of the temperature decrease with elevation (lapse rate). The final estimate of the lapse rate can be determined by a trial and error procedure based on annual water balance considerations. Like in the precipitation case, a set of correction factors $\grave{\imath}_i$ is defined for the decrease of catchment maximum and minimum temperature with elevation. The matrix with possible values of the correction factors $\grave{\imath}_i$ is computed through the following algorithm:

$$\grave{\imath}_{\mathrm{i}} = \left(\bar{e}_c - \bar{e}_i\right)\hat{a} \tag{4}$$

The daily condition of station availability determines (from the matrix with possible correction factors $\grave{\imath}_i$) the actual correction factor which is added to the daily maximum and minimum catchment temperature for that day.

5 The proposed method and climate change

The developed method regarding the areal and elevation integration of daily point precipitation and temperature data has been implemented over a mountainous catchment for climate change interpretation [21]. In this instance, the hydrological response of the Mesochora catchment, in Central Greece, was examined for hypothetical [20] and GISS (Goddard Institute for Space Studies) [18] altered climates.

Eleven precipitation stations installed within and around the Mesochora catchment were included for the climate change study. For these stations, 2.5% of the days were missing and other 1.0% of the days yielded suspicious and inconsistent precipitation records, while,for the maximum/minimum temperature records, 10.5% of the days were missing and 5.5% of the days had also suspicious and inconsistent values. Both suspicious and incosistent daily values in precipitation/temperature records were rejected and those days were considered as no data days. The gaps in precipitation/temperature observations of the employed elevation stations (including those generated from the rejection of suspicious/incosistent values) were scattered all over the records and lasted from one or few days until to a whole month.

The catchment area was separated into three elevation zones and the proposed areal and elevation integration method for incomplete data was applied to the median elevation of each zone using the three nearest stations in the upper zone and likewise three in the middle zone plus the six nearest stations in the lower zone [19]. The so obtained zone precipitation was used as input to US National Weather Service (US NWS)-Snow Accumulation and Ablation Model [1].

Another input to the snowmelt model was the zone daily max-and-min temperatures which were assessed, from the aboved described incomplete records, with the proposed integration method. For this case, the zone daily max-and-min temperatures were corrected for elevation variation through the lapse rate [19]. The snowmelt model output "rain plus melt", for each zone, constituted the zone pseudo-precipitation. The weighted mean of the pseudo-precipitation from all zones was treated as the mean areal precipitation which was the input to the US NWS-Soil Moisture Accounting Model [6].

Each historical zone precipitation was adjusted to reflect altered climates (±20%, ±10% and GISS predicted monthly ratio for the runs of $2xCO_2$ and $1xCO_2$, each one applied to the present input precipitation). Furthermore, the altered climates were interpreted concurrently by temperature increases of 1^oC, 2^oC, and 4^oC, which applied to each historical zone temperature. The US NWS snowmelt and runoff models were run with the altered time series inputs in order to interprete the altered hydrological regime of the catchment [18, 20, 21].

6 Conclusions

Attempting to assess accurately the areal precipitation and temperature of a mountainous catchment from incomplete point records, we developed a new integration method.According to this method, the daily catchment precipitation and temperature wereestimated from the existing data and, subsequently, corrected for elevation variation by a simple linear regression scheme. In this manner we tried to preserve, at a grade level, the physical meaning of areal series data, as is strongly required for climate change analysis. This latter is widely recognized by such specialists as Klemes, Lettenmaier, Hutchinson, et al. whereas several serious attempts were directed towards a deterministic and stochastic modelling of areal precipitation and temperature, for the purpose appropriate climate change rate estimations.The proposed method is not only simple, practical and appropriate for climate change studies, but also dynamic for handling successfully any change in the gauge network, which was the greatest limitation of the inflexible Thiessen method [15].

7 References

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