CARTOGRAPHIC METHODS FOR MONITORING OF GLACIO-NIVAL ENVIRONMENT

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Abstract

Facilities provided by geoinformatic mapping technique to monitor the glacio-nival environment are demonstrated making use of the maps compiled in the World Atlas of Snow and Ice Resources and their derivatives. Crucial role of solid precipitation in the glaciers advance and retreat was found.

1 Introduction

The environmental monitoring is becoming over more actual having especially in mind permanent increase of the antropogenic load on natural systems. The glacio-nival high mountain systems built of natural ice and snow belong to the objects most sensitive to the external influence. The state in these systems in time and space seems to be therefore of special interest. In these stadies the research being performed on a regional level seems to be most important. This level is most efficient in getting new knowledge on the glacio-nival systems. It allows one not only to monitor the system as a whole but also to combine its local specific features with global lows that govern the life of the glacio-nival environment. The geosystem scale determines the analyses techniques to be used. Mapping is the main tool for the regional geographic reseach and as such it remains for the regional glacio-nival systems. The World Atlas of Snow and Ice Resources provides unprecedental background for studying the glacio-nival enviroment, including its regional level. Prepared for printing by the Russisn Academy of Sciences Institute of Geography, the Atlas includes more than 1000 maps depicting how all the types of natural ice are spread over the Earth, along with the climatical conditions under which these types exist. In the present work, we demonstrate these maps and their derivatives being used to monitor the glacio-nival environment. The instrument was the geoinformational mapping i.e. authomated mapping based on the geoinformational systems (GIS). As its fundament, the geoinformational mapping has the mathematical-cartographic modelling indispensible for the treatment of the enormous volumes of the mapped and non-mapped information in space and time. The automation also leads to a complete merging of the techniques that are being employed to create and to use the maps, the merging in which the transformation, separation, analysis and synthesis models turns out to be unified interrelated charus [1]. Let us now focuse on the analysis of technique and results of its applications.

2 Background fields of glaciological characteristics

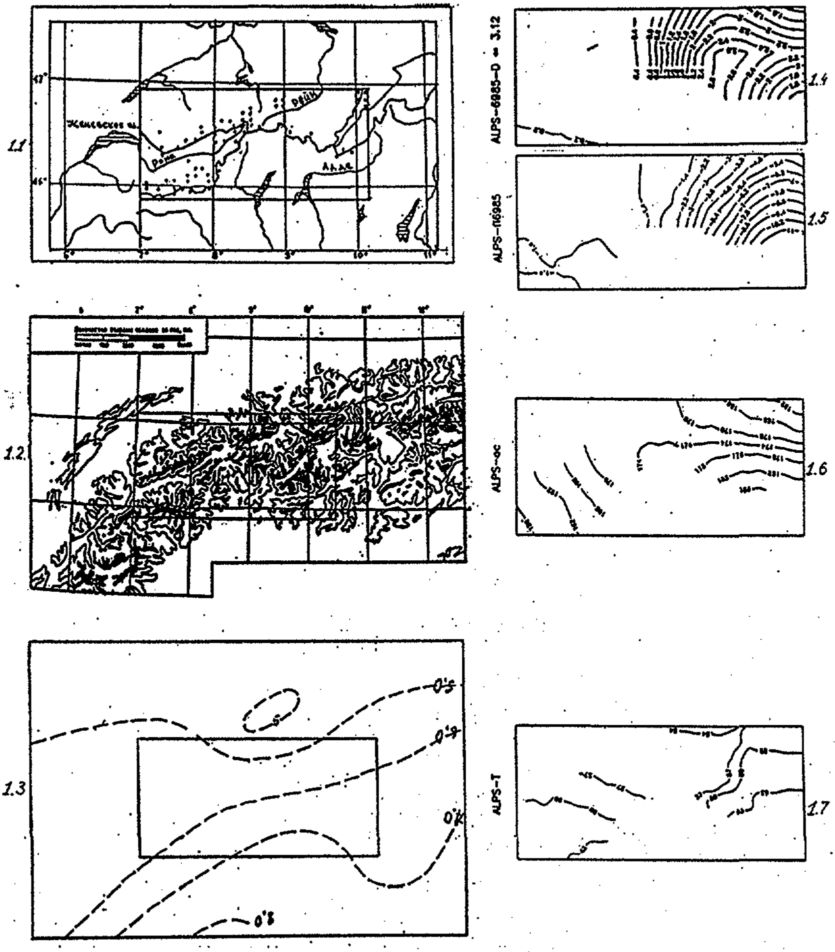


Figure 1: Plotting and smoothing of background fields. Little frame into *1.1, 1.2, 1.3* limits the region of ivestigation.

1.1 The geographycal spreading of 62 Alpan glaciers

1.2 The map of solid precipitation from the Atlas

1..3 The map of summer temperature from the Atlas

1.4 The field of glacier ends variations,averaged over 17 yy

1.5 The field of glacier ends fluctuations,averaged over 17 yy

1.6 The field of solid precipitatiom

1.7 The field of summer air temperature

2.1 Fields of spatial distribution of characteristic

To plot a regional map, one needs to transform the large-scale data on the specific nival-glacial objects into a small-scale information. To do this, we have used the known theory of geographycal fields that allows one to plot isolinean maps starting from a discrete information. Figure *1.1* presents the geographycal spreading of 62 glaciers in the Swiss Alps. Annual displacement of the ends of these glaciers have been published elswhere [2]. The data for the years 1969 - 1985 have been used to plot 17 annual isolinean maps depicting the glacier end displacements [5]. The window 9*9 units wide shifting by one unit was employed to average the data over the net 6 min in longitude and 4 min in latitude. Figure *1.5* presents the field of glacier fluctuations averaged over 17 years by using the GOLDEN softwear packadge. It is seem, that the fluctuatuions are regular in space. Namely, its amplitude increases from the West to the East from - 1.4 m/year to - 11 m/year respectively. There no amplitude increase between 7^0 and 9^0 E while this increasing is steep between $9^0$and 10^0 E . Thus, the pattern of the glacier fluctuations chaotic at the first glance becomes ordered after the averaging mentioned above. In offer words, the local fluctuations have been excluded and the background component was revealed.

2.2 Fields of spatial variability of characteristic

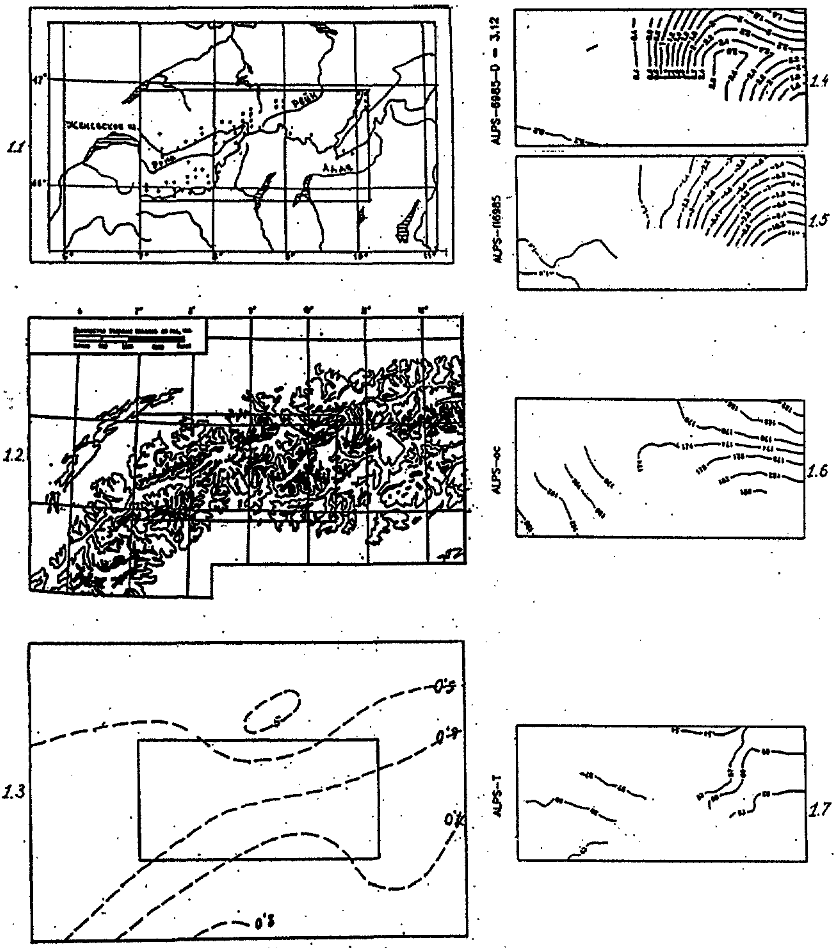
The technique mentioned above allows one to determine the spatial variability of any glacial parameter characterizing the whole area under investigation and to plot the isolinean map depicting the spatial variation of this parameter. This " sliding window" technique includes averaging over the values within the window for each subsequent window position shifted relative to the previous position by one unit. The absolute spatial variation is characterized by its dispersion.

Thus obtained data sets are used to plot the isolinean map of the spatial variability. These maps explicitely demonstrate how the variability parameters change within the region. The map in Figure *1.4* presents the glacier end variability averaged over 17 years. The maxima on this map may be evidently treated as the instability regions. The main peak is in the SE. The tendency visualized on the map of fluctuations is quantitatively evaluated on the map of variability.

2.3 Fields of background similarity of distribution of 2 parameters

We can count coefficients of correlation between two presented fields to find how similar these fields are. Next issue was to probe the degree of interconnection within the region.

For example within the monitoring frames, it is important to determine how the fields of the spatial parameter distribution obtaied above are stable in time. This temporal stability of the glacier ends displacement is also measured apprised by correlation coefficients characterizing the annual fields, in other words, by their geometrical similarity in subsequent years. High correlation coefficient years are observed often but not always [5]. The question is what is the averaging period needed to get a stable



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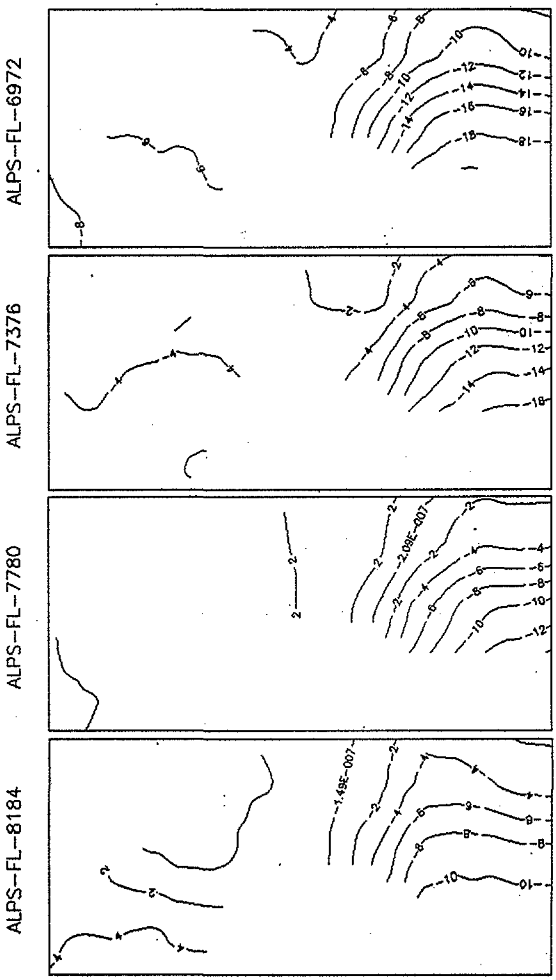

Figure 2: Fields of spatial distribution of glacier-end displacement

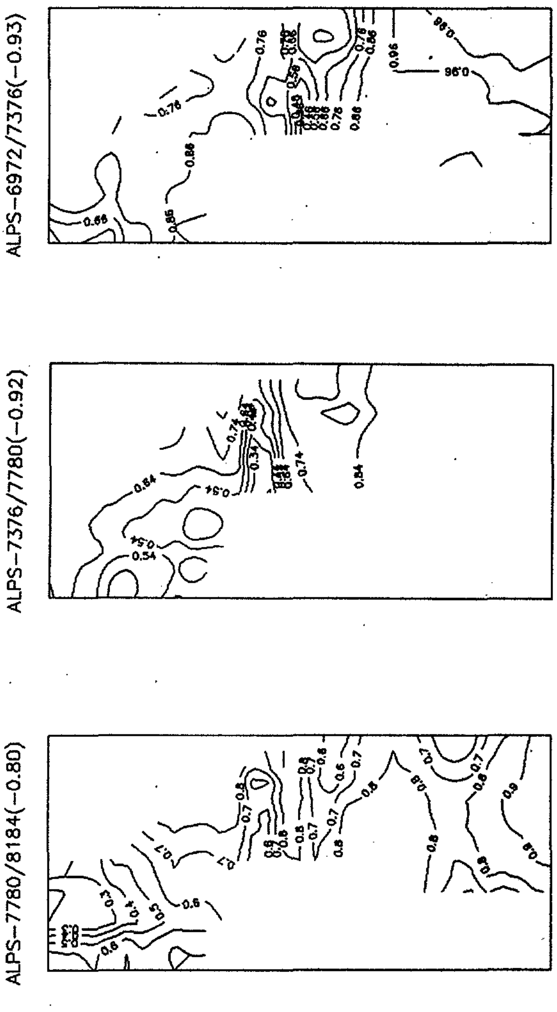

Figure 3: Fields of correlation coefficients between two maps of glacier-ends displacement distribution

background spatial picture. With this question in mind we have performed subsequent averaging. Correlation coefficients between the fields averaged over two and three years didn't give new information. When we compared the fields averaged over four years (Figure 2), we have got correlation coefficients between them in succession 0.93,0.92, 0.80. Correlation coefficients were also high for averaging over 8 and 10 years.
These fields are given in Figure 3. The correlation coefficient is high in the whole region reaching its maximum in the Eastern part. Thus the dynamics of the glaciers is closer in this part.

2.4 Fields of anomalies

The maps of anomalies were created to more explicitely demonstrate pecularities in the glaciation front shift. To do this, we have taken four fields averaged over 4 years each - the ones for 1969 through 1972, 1973-1976, 1977-1980 and 1987-1984 (Figure 4), and subtracted from there the field averaged over 17 years. The so found anomalies averaged over the whole field are formed to be - 5.48 m/y, -2.64 m/y, + 1.96 m/y and 1.58 m/y, respectively. These figuers demonstrate the transfer from the prevailing glacier retreat in 1969-1976 to the prevailing advance in 1978-1985. This transfer in 1977 is different in the East and West regions. In the East, no ultimate transfer took place: negative areas till remain even in 1981-1985. In the West, the definite sing change occeurs already in 1977-1980. Thus the average sign changes mainly at the expence of the western part of the region under investigation. We may thus conclude that the anomaly field maps confirm the results obtained by correlation coefficient maps: glaciation dynamics in the East is more stable. More intensive glacial retreate in 1986-1990 [2] is an additional manifestation of this stability.

3 Multiparametric analyses of the maps

The spatial and temporal peculiarities of the glacio-nival systems in high-mountains are controlled mainly by solid precipitation and summer air temperatures. Geometrical similarities and dissimilarities in the corresponding isolinean maps of the glacial end variations may be used in attempts to determine which of these climatic factors plays a cruial role. For such a comparision, we have employed the maps collected in the Atlas. These maps present original information by varions techniques and with various degrees of generality [3,4]. Two latter factors are especially essential for the combined cartographic - statistical analysis.
The map depicting average summer air temperature at a constant altitude (Figure *1.3*, *1.7*) did not need temporal averaging. However, it was nesessary for the Atlas solid precipitation map (Figure *1.2*, *1.6*). This map makes use of the precipitation altitude dependence, the isolnes follow fastidios capricious isogips pattern and its visual analysis is ineffective in an attempts to outline the tendencies we are looking for. Namely we need to find, in what direction to the S,W,N or E - the amount of precipitates increases. This goal was again achieved by the sliding window averaging. The result is given in Figure *1.6*. It is seen that the precipitation amount rises from the NW to the SE showing that the solid

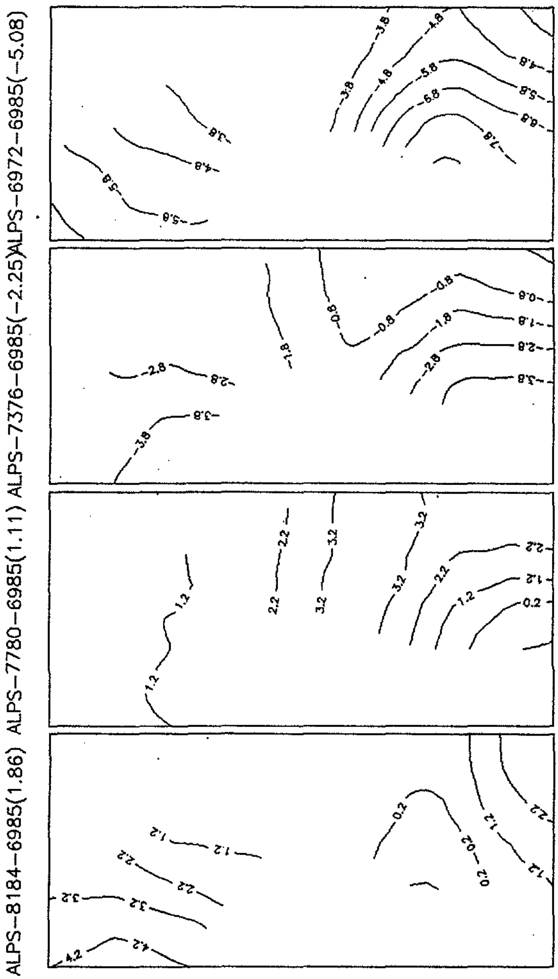

Figure 4: Fields of anomalies of glacier-ends displacement

precipitation come mainly from the Mediterranian. The averaged map of the solid precipitation is comparable with the glacier end variations map. The similarity is evident. The correlation coefficients between three averaged fields have demonstrated the interconnections between glacier variations and solid precipitation fields (k = +0,8). The correlation between the glacier variations and summer air temperature fields is 0.3, i.e. is much weaker.

4 Discussion and conclusions

The map of glacier end displacements, averaged over 17 years have been compared with the maps of the solid precipitation and the summer temperatures from the World Atlas of Snow and Ice Resources and the resulted fields of correlation coefficients have been plotted. The conclusion was that the main climatic factor that given the life of the Alpic glacio-nival system is the solid precipitation. The solid precipitation rise will give the glacier advancement particulary in the Eastern part of the region. This Hypothesis is inderectly supported by the map of the Wurm glaciation created by N.A. Timofeeva and L.R. Serebryannyi for the Atlas [6]. According to this map, the glaciation in the Easts three times as heavy as one in the West. Thus our analysis demonstrates that the stability of Mediterranian source of glacial feeding predominanted not only during 1969-1985 but during last milleniums.

More subtle interaction are expected to be found by the future mapping monitoring. In the course of the latter, the maps depicting glacier ends displacementand solid precipitation variations are going to be plotted and compared for each of the 17 years 1969-1985, as well as for the later years.

Acknowledgments

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