HYDROLOGICAL YEAR 2003/04 OF DISCHARGE IN KVIARJÖKULL GLACIER CATCHMENT PILOT AREA (CPE-KVIA-64ºN)

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Abstract
For the period corresponded to a natural complete hydrological year, it is analysed the glacier discharge of the glacier tongue Kviarjökull of the Vatnajökull icecap in Iceland. For that we use the time series of air temperature or input parameter collected from the meteorological station of Kvisker, and to the output parameter or time series of discharge glacier collected from the experimental pilot catchment area CPE-KVIA-64ºN. The period analyzed covers from 1st October 2003, at 0:00 h to 30th September 2004, at 23:00 h.

Сток с экспериментального водосборного бассейна ледника Квиар в течение гидрологического года 2003/04 (CPE-KVIA-64ºN)
Для полного гидрологическоого года был проанализирован жидкий сток с ледника Квиар ледникового купола Vatnajökull в Исландии. Для этого был использован временной ряд температуры воздуха по данным метеостанции Kvisker как параметр входа, и выходной параметр или временной ряд ледникового стока, полученного на экспериментальном водосборном бассейне CPE-KVIA-64ºN. Проанализированный период с 1 октября 2003, 0:00 до 30 сентября 2004, 23:00.

Introduction

We present here the results concerning in discharge of Kvia Glacier (Kviarjökull) in Iceland, during the time period included between the 1st October 2003 at 00:00 hours and the 30th September 2004 at 23:00. It means that the analysed period corresponds to a natural complete hydrological year.

Fig. 1. General view of Kviarjökull Glacier and Kviar River
Photo by Karmenka

The Kviarjökull Glacier tongue, which descends isolated from the rest of the icecap Vatnajökull, in its SE point, has a perfectly delimited catchment area. Besides, the discharge from this glacier converges into a unique stream in its final stretch, Kvia River. These characteristics, in addition to the lack of geothermal focuses under said glacier tongue turn Kviarjökull Glacier into an experimental pilot catchment area to monitor (CPE-KVIA - 64ºN), from 1999 under the «Proyecto GLACKMA» (Eraso, Domínguez, Jonsson, 2003).

Fig. 2. Entrance detail of one of the moulins
Photo by Eraso

Description of the experimental station

The characteristics of the Kviarjökull glacier tongue selected: Total surface 13 km^2, Ablation area surface 10.6 km^2, Accumulation area surface 2.4 km^2, ELA 1050 m asl

In its front, it presents a proglacier lagoon fed by three streams, which are formed by water discharge from the glacier tongue and converge into a unique stream, Kvia river. This drains the aforesaid proglacier lagoon in the internal sandur and, after having eroded its old front moraine, reaches the sea at the nearby coast, after flowing under the Kvia bridge, in the N1 ring road of Iceland.

The place chosen to locate the experimental station, by which the base camp was installed, is the pillar in the old bridge over the Kvia, in its left bank. We monitored it with a piezoresistant or pressure-measuring cell, to be able to establish a time distribution law for Kviarjökull Glacier discharge. The coordinates of the pilot station in GPS reading: (Lat: N 63º56,254′, Long: W 16º26,041′, Alt: 25 m asl)

This is located under the bridge in the N1 ring road, over the Kvia, between the villages Hnappavellir and Kvisker. In fact the meteorological data used for the present analyse belong to the meteorological station of road N1 of Kvisker. The coordinates in GPS reading: (Lat: N 63º57,577′, Long: W 16º25,473′, Alt: 32 m asl).

Time series measured (discharge- air temperature)

As explained in the introduction of this study, the period covers from October 1st, 2003, at 0:00 h to September 30th, 2004, at 23:00 h. and corresponding to the time series of air temperature or input parameter collected from the meteorological station of Kvisker (Fig. 3), and to the output parameter or time series of discharge glacier collected from the experimental pilot catchment area CPE-KVIA-64ºN.

The following steps were following to obtain the time series of discharge:

1. - With the gaugins taken in the Kvia River (Domínguez MC., 2003), we obtained an adjustment curve between the level given by the sensor L_s and the discharge $\left(\overline{Q}\right)$ with a correlation coefficient $R^2 = 0{,}92$ (Fig. 5). Thus we obtained the exponential function $\overline{Q} = \exp\left(L_s\right)$ which let us calculate the discharge $\left(\overline{Q}\right)$ in $m^3/\sec$ from the sensor level $\left(L_s\right)$ expressed in m :

$$\overline{Q} = 0{,}1703\ \exp\left(4{,}1894\ L_s\right)$$

2. - Generate the time series for river sheet level with a piezoresistant sensor, as time series $S_t\left(L_s\right)$ with cycle time hourly (Fig. 1). For that we follow the established protocol for guaranteeing the representative of collected data (Eraso, Domínguez, 2003, pp. 117-136).

3. - Finally introducing previous equation in the time series of river levels $S_t\left(L_s\right)$ previously mentioned, we obtain the time series of water volume $S_t\left(\overline{Q}\right)$ (Fig. 3), which represents the distribution law of glacier discharge through time.

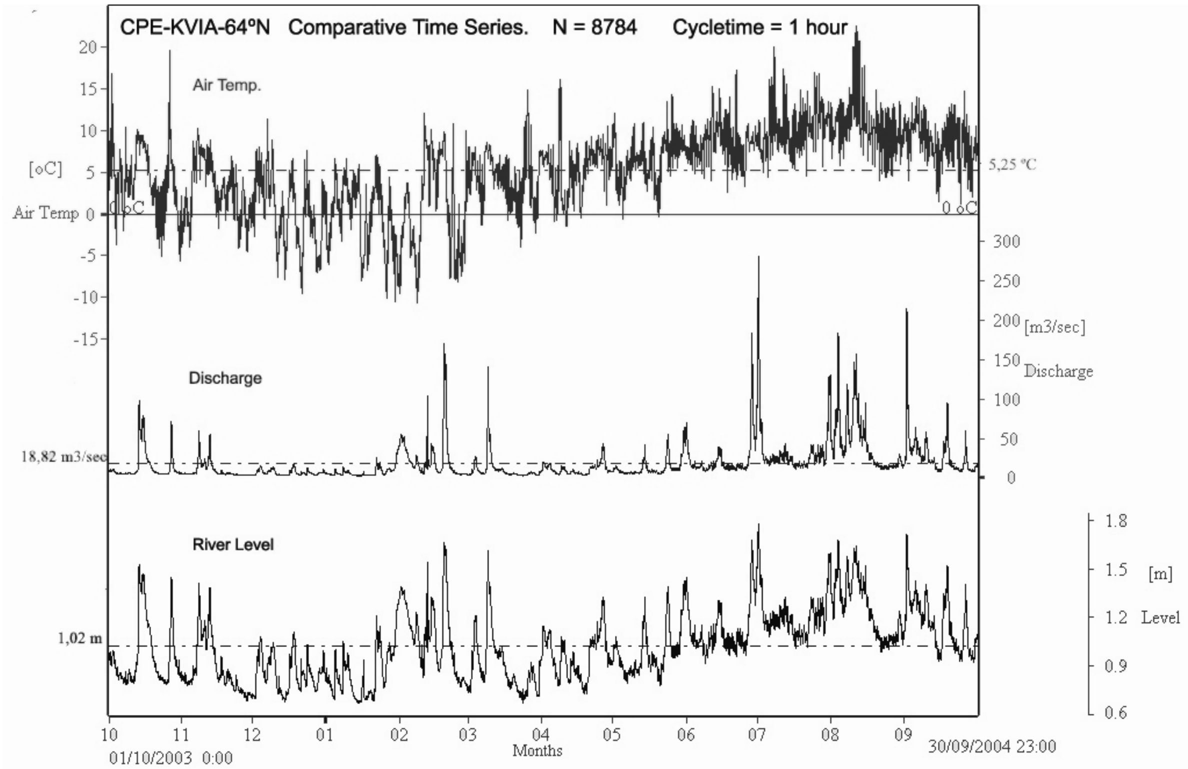

Fig. 3. Time series of level, glacier discharge and air temperature

Fig. 4. Going up for moulin m45 of Kviarjökull.
Photo by Karmenka

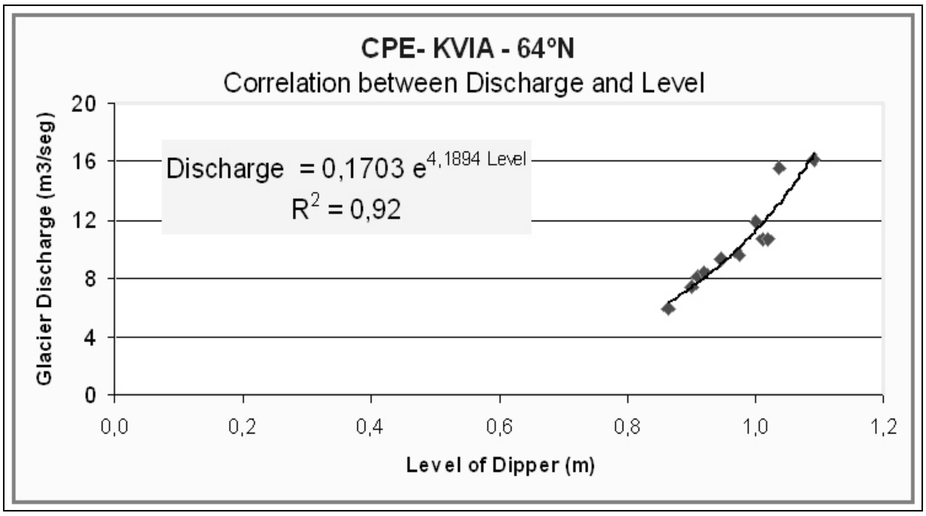

Fig. 5. Adjustment curve for level and discharge

So, in that Figure 1 we draw all data of the three described time series: Air Temperature in $({}^{o}C)$, Glacier Discharge in $(m^3/\sec)$ and level of Kvia River in (m), being the number of values of everyone (N) of $N = 8784$ data for the hydrological natural year represented (2003/04).

Also, in everyone graphic of the time series is marked with a doted line the mean annual values: Air Temperature: $5{,}25\ {}^{o}C$, level of Kvia River: $1{,}02\ m$, Glacier Discharge of Kviarjökull: $18{,}82\ m^3/\sec$.

Considering now that the surface of Kviarjökull glacier has the value of $13\ km^2$, its annual mean value of the specific glacier discharge is $1{,}45\ m^3/\sec\cdot km^2$ for the time series corresponding to the hydrological year 2003/04 that we are considering here.

Running mean and time series interpretation

Beginning with an initial interpretation of the different characteristics of the hydrological year 2003/04 in the Kviarjökull Glacier, we use comparative the following time series:

1.- Air Temperature in $({}^{o}C)$, with 8784 values and an annual mean value of $5{,}25\ {}^{o}C$

2.- Specific Glacier Discharge in $(m^3/\sec\cdot km^2)$, with 8784 values and an annual mean value of $1{,}45\ m^3/\sec\cdot km^2$

We decide to mean measuring values in order to speed up the graphic, so using the "running mean" as statistic operator tool, we fix the data field gathering 36 values (Fig. 6). This amount of values is equivalent to one and half day in the hourly time series.

The specific total volume drained by the Kviarjökull during this period is $V_{T\,Spec} = 45{,}8\ \ hm^3/km^2$. Using now the time series with running mean of Figure 3, we can see that the specific total volume drained $(V_{T\,Spec})$ appears as three different ways in the time series, operating in superimposed ways that are described below:

- The own «Annual Discharge Wave» $(W_{D\,Annual})$, which drainages important flows during an uninterrupted time from the middle of May, 2004, until the end of the hydrological year, when even persist.

- Smaller replicas of the discharge wave $(R_{D\,Wave})$ extending during some days and appearing almost every month.

- A basic drainage which rarely exceeds the threshold of $0{,}3\ m^3/\sec\cdot km^2$ and can occasionally disappear.

Below we analyse, month per month, the sequence of behaviour of discharge following the Figure 7 (Fig. 7-I, October 2003; Fig. 7-II, November 2003; Fig. 7-III, December 2003; Fig. 7-IV, January 2004; Fig. 7-V, February 2004; Fig. 7-VI, March 2004; Fig. 7-VII, April 2004; Fig. 7-VIII, May 2004; Fig. 7-IX, June 2004; Fig. 7-X, July 2004; Fig. 7-XI, August 2004; Fig. 7-XII, September 2004):

<u>October 2003</u>

- Air Temperature: mean monthly
$(MeanM = 4\,{}^{o}C)$
- Specific discharge: mean monthly
$(\overline{Q}_{Spec} = 1{,}141\ m^3/\sec\cdot km^2)$
- Specific total volume drained:
$V_{M\,Spec} = 3{,}056\ \ hm^3/km^2$
- 2 Replicas:
$(R_{D\,Wave}: \mathit{from}\ 13\ \mathit{to}\ 19,\ \mathit{from}\ 26\ \mathit{to}\ 29)$

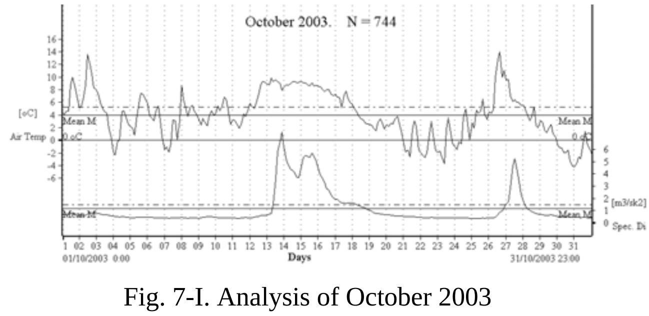

Fig. 7-I. Analysis of October 2003

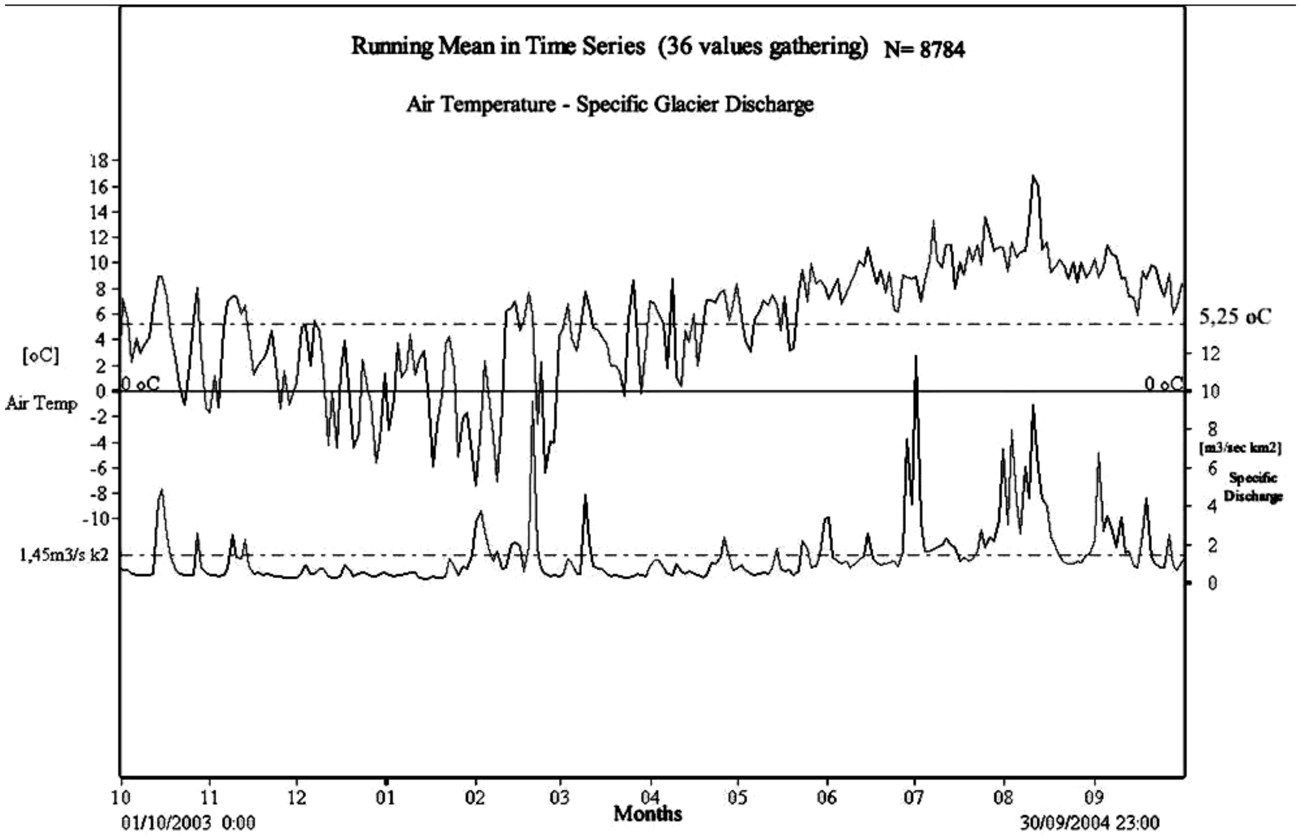

Fig. 6. Time series with «running mean»

<u>November 2003</u>

- Air Temperature: mean monthly $\left(MeanM = 2{,}9^{o}\,C\right)$
- Specific discharge: mean monthly $\left(\overline{Q}_{Spec} = 0{,}707\ m^3/\sec \cdot km^2\right)$
- Specific total volume drained: $V_{M\,Spec} = 1{,}833\ hm^3/km^2$
- 1 Replica: $\left(R_{D\,Wave} : from\ 7\ to\, 15\right)$

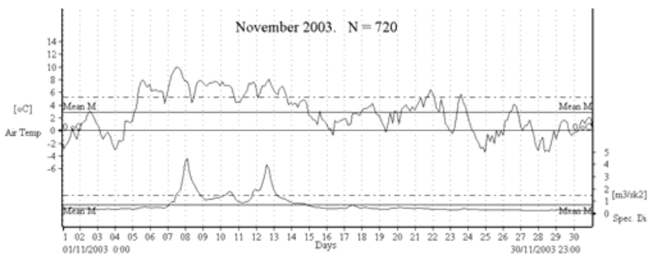

Figure 7-II: Analysis of November 2003

<u>December 2003</u>

- Air Temperature: mean monthly $\left(MeanM = 0{,}3^{o}\,C\right)$
- Specific discharge: mean monthly $\left(\overline{Q}_{Spec} = 0{,}514\ m^3/\sec \cdot km^2\right)$
- Specific total volume drained: $V_{M\,Spec} = 1{,}377\ hm^3/km^2$

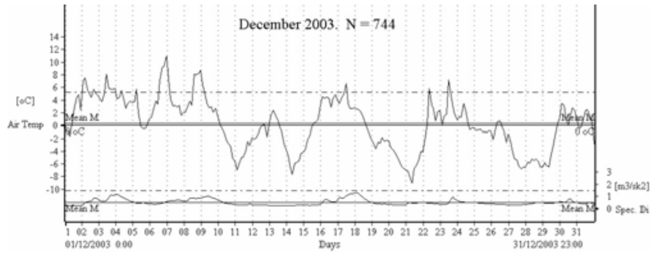

Fig. 7-III. Analysis of December 2003

<u>January 2004</u>

- Air Temperature: mean monthly $\left(MeanM = -0{,}3^{o}\,C\right)$
- Specific discharge: mean monthly $\left(\overline{Q}_{Spec} = 0{,}659\ m^3/\sec \cdot km^2\right)$
- Specific total volume drained: $V_{M\,Spec} = 1{,}765\ hm^3/km^2$
- Replica $\left(R_{D\,Wave}\right)$: from 29th and following in February

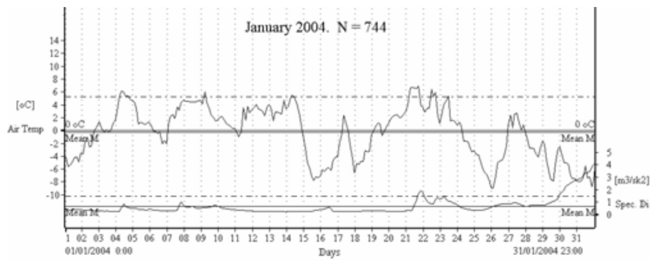

Fig. 7-IV. Analysis of January 2004

February 2004

- Air Temperature: mean monthly $\left(Mean\ M = 1{,}1^{\circ} C\right)$
- Specific discharge: mean monthly $\left(\overline{Q}_{Spec} = 1{,}805\ m^3/\sec\cdot km^2\right)$
- Specific total volume drained: $V_{M\ Spec} = 4{,}525\ \ hm^3/km^2$
- Replica $\left(R_{D\ Wave}\right)$: 5th February finish that one begins on January
- 2 Replicas $\left(R_{D\ Wave}\right)$: from 11 to 16, from 18 to 23

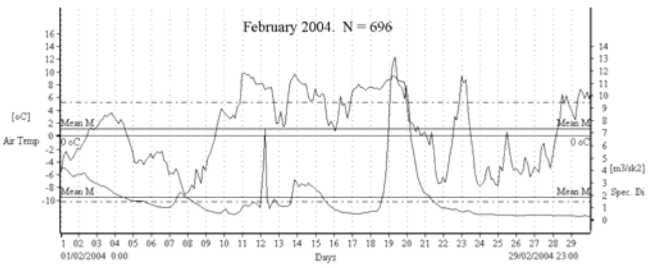

Fig. 7-V. Analysis of February 2004

March 2004

- Air Temperature: mean monthly $\left(Mean\ M = 4{,}2^{\circ} C\right)$
- Specific discharge: mean monthly $\left(\overline{Q}_{Spec} = 0{,}831\ m^3/\sec\cdot km^2\right)$
- Specific total volume drained: $V_{M\ Spec} = 2{,}226\ \ hm^3/km^2$
- 1 Replica: $\left(R_{D\ Wave}: from\ 7\ to 16\right)$

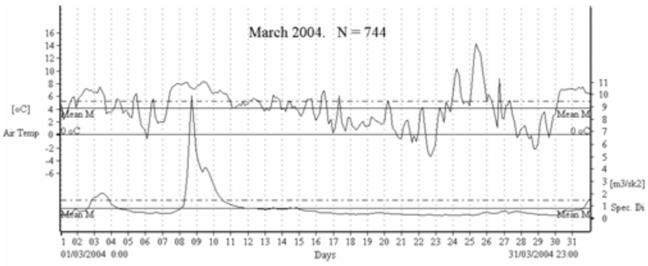

Figure 7-VI: Analysis of March 2004

April 2004

- Air Temperature: mean monthly $\left(Mean\ M = 5{,}4^{\circ} C\right)$
- Specific discharge: mean monthly $\left(\overline{Q}_{Spec} = 0{,}847\ m^3/\sec\cdot km^2\right)$
- Specific total volume drained: $V_{M\ Spec} = 2{,}195\ \ hm^3/km^2$
- 1 Replica: $\left(R_{D\ Wave}: from\ 20\ to 28\right)$

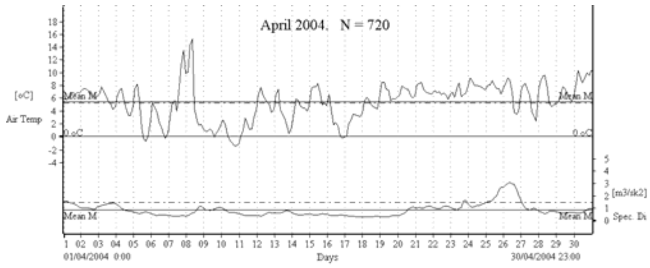

Fig. 7-VII. Analysis of April 2003

May 2004

- Air Temperature: mean monthly $\left(Mean\ M = 6{,}5^{\circ} C\right)$
- Specific discharge: mean monthly $\left(\overline{Q}_{Spec} = 1{,}101\ m^3/\sec\cdot km^2\right)$
- Specific total volume drained: $V_{M\ Spec} = 2{,}949\ \ hm^3/km^2$
- 1 Replica: $\left(R_{D\ Wave}: from\ 12\ to 15\right)$
- Annual Discharge Wave: $\left(W_{D\ Annual}\right)$ begins on 21st and follows to next month

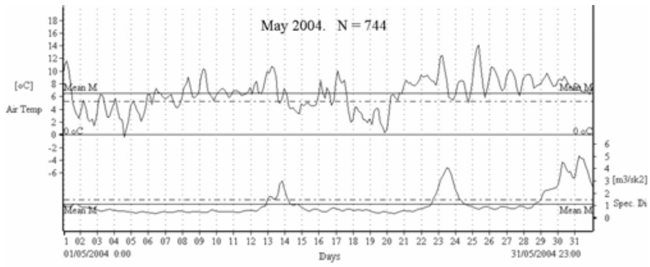

Fig. 7-VIII. Analysis of May 2004

June 2004

- Air Temperature: mean monthly $\left(Mean\ M = 8{,}6^{\circ} C\right)$
- Specific discharge: mean monthly $\left(\overline{Q}_{Spec} = 2{,}121\ m^3/\sec\cdot km^2\right)$
- Specific total volume drained: $V_{M\ Spec} = 5{,}498\ \ hm^3/km^2$
- Annual Discharge Wave: $\left(W_{D\ Annual}\right)$ during all month

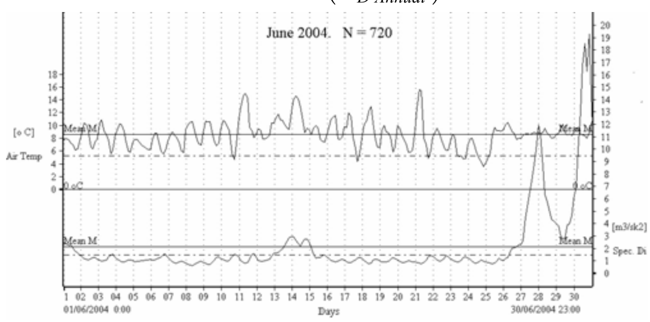

Fig. 7-IX. Analysis of June 2004

<u>July 2004</u>

- Air Temperature: mean monthly $\left(Mean\,M = 10{,}5\,^{o}C\right)$
- Specific discharge: mean monthly $\left(\overline{Q}_{Spec} = 2{,}307\ m^3 / \sec \cdot km^2\right)$
- Specific total volume drained: $V_{M\,Spec} = 6{,}179\ \ hm^3 / km^2$
- Annual Discharge Wave: $\left(W_{D\,Annual}\right)$ during all month

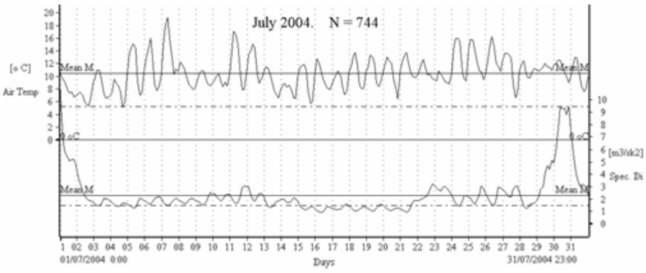

Fig. 7-X. Analysis of July 2004

<u>August 2004</u>

- Air Temperature: mean monthly $\left(Mean\,M = 10{,}8\,^{o}C\right)$
- Specific discharge: mean monthly $\left(\overline{Q}_{Spec} = 3{,}245\ m^3 / \sec \cdot km^2\right)$
- Specific total volume drained: $V_{M\,Spec} = 8{,}691\ \ hm^3 / km^2$
- Annual Discharge Wave: $\left(W_{D\,Annual}\right)$ during all month

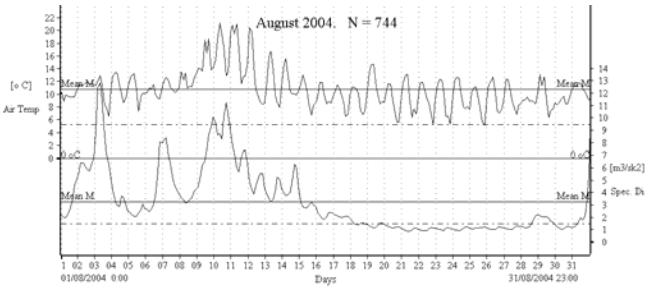

Fig. 7-XI. Analyze of August 2004

<u>September 2004</u>

- Air Temperature: mean monthly $\left(Mean\,M = 8{,}6\,^{o}C\right)$
- Specific discharge: mean monthly $\left(\overline{Q}_{Spec} = 2{,}120\ m^3 / \sec \cdot km^2\right)$
- Specific total volume drained: $V_{M\,Spec} = 5{,}495\ \ hm^3 / km^2$
- Annual Discharge Wave: $\left(W_{D\,Annual}\right)$ during all month

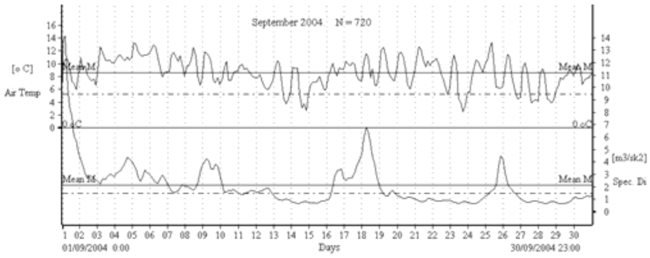

Fig. 7-XII. Analyse of September 2004

Summarizing, the distribution of time for the three different ways how presents the annual (2003/04) drainage of Kviarjökull are as follows:

- Annual Discharge Wave, $W_{D\,Annual}$: 133 days (until the end of measured data on September 30th, 2004 at 23:00h)
- Smaller replicas of the discharge wave, $R_{D\,Wave}$: 9 replicas with a total of 54 days
- The basic drainage: 179 days

Conclusions and final discussion

1.- The characteristics values of the both time series analyzed (air temperature –input- and specific glacier discharge –output-) are summarized in Table 1. Here it is indicated:

- air temperature: monthly and annual mean values in ^{o}C
- specific glacier discharge: monthly and annual mean values in $m^3 / \sec \cdot km^2$
- specific drained volume: monthly and annual values in hm^3 / km^2
- total drained volume: monthly and annual values in hm^3

This table allows to summarize the main characteristics of the analyzed discharge glacier.

2.- February 2004 appears as an anomaly month with a mean value of air temperature of $1{,}1\,^{o}C$ (between the respective values of January and March) while the specific discharge is $1{,}805\ m^3 / \sec \cdot km^2$. This value duplicates the corresponding value of specific discharge of March, when the mean monthly of air temperature were much smaller.

Analyzing with detail the Figure 4-V, it is possible to appreciate an unusual warm period, with temperature nearly $10\,^{o}C$ from the 10th to the 20th of February, inserted between cold alternative periods $\left(-8\,^{o}C\right)$.

So, the main replica in glacier discharge, which at 19th of February arises a maximum value of flow (with specific discharge higher of $13\ m^3 / \sec \cdot km^2$) at the end of warm period, has a clear meteorological origin.

Table 1
Characteristics of glacier discharge

CHARACTERISTICS OF GLACIER DISCHARGE IN KVIARJÖKULL (ICELAND)

CPE-KVIA-64ºN DURING THE HIDROLOGICAL YEAR 2003/04

Month	Nº Values Mesured	Temperature Mean values (ºC)	Specific Discharge Mean values (m^3/sec km^2)	Specific Volume Drained (hm^3/km^2)	Discharge Mean values (m^3/sec)	Total Volume Drained (hm^3)
October 03	744	4,0	1,141	3,056	14,83	39,73
November 03	720	2,9	0,707	1,833	9,19	23,82
December 03	744	0,3	0,514	1,377	6,68	17,90
January 04	744	-0,3	0,659	1,765	8,57	22,95
February 04	696	1,1	1,805	4,523	23,47	58,79
March 04	744	4,2	0,831	2,226	10,80	28,93
April 04	720	5,4	0,847	2,195	11,01	28,54
May 04	744	6,5	1,101	2,949	14,31	38,34
June 04	720	8,6	2,121	5,498	27,57	71,47
July 04	744	10,5	2,307	6,179	29,99	80,33
August 04	744	10,8	3,245	8,691	42,19	112,99
September 04	720	8,6	2,120	5,495	27,56	71,44
Hidrological Year	8784	5,2	1,450	45,847	18,85	596,01

Photo 6. Endoglacier pipe and moulin m1 in Kviarjökull
Photo by Karmenka

Fig.8. Entrance of Moulin m35
Photo by Karmenka

Photo 5: Ablation zone in Kviarjökull
Photo by *Karmenka*

3.- In general it is possible to appreciate a direct correspondence between the discharge glacier and the temperature.

Nevertheless the shape of discharge-graphic for the high values is not always in correspondence with the shape of temperature-graphic (for example, from the 27th June until the 3rd July 2004).

This fact is due to the effect of rain in glacier discharge, which superimposes to the effect of temperature (Domínguez, Eraso, Lluberas, 2003), (Eraso, Domínguez, Lluberas, 2003).
The question is that actually the meteorological station of Kvisker does not measure rain. So, for differentiating both causes it would be necessary to implement also an automatic register for generating time series of precipitation parameter.

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