GLACIER DISCHARGE DURING 2004 IN THE EXPERIMENTAL GLACIER CATCHMENT AREA ZAPATA SUR (CPE-ZS-51ºS) OF GLACIER TYNDALL (PATAGONIA, CHILE)

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Abstract

The registered data in the experimental pilot station (CPE-ZS-51ºS) implemented in glacier Tyndall of Chilean Patagonia, allows to analyzed the glacier discharge using this mixed (glacial-fluvial) catchment area. For understanding the process, time series of air temperature and relative humidity constitute the input of process, and time series of glacier discharge the output.

Сток с экспериментального ледникового водосборного бассейна ледниковой лопасти Zapata Sur ледника Тиндаль (CPE-ZS-51ºS) в 2004 г. (Патагония, Чили)

Даные, полученные на экспериментальной станции (CPE-ZS-51º S), установленной на леднике Тиндаль в Чилийской Патагонии, позволяет проанализировать жидкий ледниковый сток, используя смешанный (ледниково-речной) тип водосборного бассейна. Для понимания процесса, временные ряды температуры воздуха и относительной влажности были рассмотрены как входные данные процесса, и временной ряд ледникового стока как выходные.

Introduction

The studied are is located on the East side of Tyndall glacier, glacier situated downwards of the nunatak called Cerro Zapata. There are two glacier ice tongues whose discharges occur outside of proper outflow of Tyndall glacier:

- Zapata glacier, next to the referred nunatak;
- and the Zapata Sur ice tongue, immediately to the south of the former one, but independent of it as far as its discharge outflow is concerned.

Fig. 1. General view in the upper part of Tyndall glacier
Photo Karmenka

The Zapata Sur ice tongue constitutes the experimental pilot catchment area (CPE-ZS-51ºS) we chose to monitories. This catchment area receives the water of a small river which springs in the NW side of Cerro Ferrier, flows SW downwards towards Laguna Ferrier –without reaching it-, because it suddenly changes its course, turning northwards and draining into Los Tres lagoon, which is tributary to Pingo River.

One kilometre upstream from Los Tres lagoon, the Ferrier streamlet receives on its left side the discharges generated by Zapata Sur ice tongue, which flow into Ferrier through a series of falls established in the Jurassic silt stone which form the slopes the left side of the referred river.

The Zapata Sur Experimental Pilot Catchment Area (CPE-ZS-51ºS) is therefore a mixed river-glacier catchment area, as it receives water from well distinguished sources, a river one coming from NW from Cerro Ferrier, with a catchment area surface of 12.52 km^2, and another one, a glacier one, draining from the Zapata Sur ice tongue, located on the East of Tyndall glacier, whose surface was estimated as 0.775 km^2, in the ablation area surface.

Fig. 2:Ablation zone with several moulins
Photo Karmenka

The pilot experimental catchment area (CPE-ZS-51ºS)

Inside the "Proyecto GALCKMA" the implementation of this experimental catchment area (CPE-ZS-51ºS) has the main objective of registering continuously, as time series, the specific discharge in a temperated glacier at low latitudes in the South Hemisphere. In order to contrast with the specific discharge of subpolar glaciers, implemented at higher latitudes in Antarctica (CPE-BCAA-62ºS).

The discharge of ice tongue Zapata Sur takes place through several natural canals of drainage, which ended meeting in the left border of the fluvial deep valley of Ferrier river as spectacular waterfalls. It means that it is complicate to register the glacier discharge, due to the necessity of implementing several gauges stations.

The solution that we adopted was to establish only two points of gauging and registering in the Ferrier River. The first one is located before the meeting of the first waterfall coming from the glacier (fluvial register), and the second one is located after the meeting of the last waterfall (global register). The difference between both continuous registers would give the real discharge of glacier catchment area, corresponding to ice tongue Zapata Sur.

The GPS coordinates of global station (Lat: S 51º 07,025´, Long: W 73º 16,938´, Alt: 354 m asl).

Also we must work out the level (L_s) -discharge $(\overline{Q})$ adjustment curve by means of precision gauging with micro-windmill for different river levels.

It is important to obtain enough assessments in order to achieve as high as possible a correlation coefficient in R^2. This is achieved checking the water level in the river by means of a visual ruler, in order to select the times of the assessments; then choosing the most extreme levels and interspersing the times of the assessments to cover the periods not measured. Besides, at the time of each gauging, it is also measured the river depth, as this usually varies through time.

In this way, the level time series obtained $S_t(L_s)$, contrasted with the level adjustment curve, $\overline{Q} = f(L_s)$, helps us obtain the discharge time series $S_t(\overline{Q})$, with a known error.

Fig. 3. Detail of the entrance in a moulin

For the present analyze we use time series corresponding to the period between February 18th, 2004, at 0:00 h and January 28th, 2005 at 23:00 h., being the number of values of every parameter used, $N = 8304$ data. For automatic data the cycle time is hourly, using for hydraulic parameter a piezoresistant sensor with waterproof data-logger with 15k of memory capacity (SEBA instrument).

Figure 4 shows the level time series -$S_t(L_S)$- for both stations (global and fluvial) and it is marked the mean value of level for both functions during the considered period, being 0.534*m* for the *global station* and 0.123*m* for the *fluvial*.

Figure 5 shows the adjustment curves between the level given by the sensor (L_S) and the discharge $(\overline{Q})$ in each station:

- For the *global station*: $\overline{Q} = 0{,}0237\ \exp(7{,}4036\ L_S)$ $(\overline{Q})$ with $R^2 = 0{,}99$
- For the *fluvial station*: $\overline{Q} = 19{,}793\ L_S - 1{,}9001$ $(\overline{Q})$ with $R^2 = 0{,}96$

Introducing those equations in the respective time series of river levels $S_t(L_S)$ previously mentioned, we obtain the time series for water volume $S_t(\overline{Q})$ corresponding to both, *global* and *fluvial* stations. Finally we calculate the time series of glacier discharge with the difference between both:

$$S_t(\overline{Q})_{Global} - S_t(\overline{Q})_{Fluvial} = S_t(\overline{Q})_{Glacier}\ .$$

Figure 6 shows the three time series for the corresponding drainages and it is marked the mean value during the considered period, being $1{,}507\ m$ for the *global station* and $0{,}540m$ for the *fluvial station*, and $0{,}967\ m$ for the glacier discharge.

So, the calculated time series $S_t(\overline{Q})_{Glacier}$ constitutes the time distribution of output parameter as answer of the glacier in the presence of meteorological parameters variations or input of process.

For measuring those meteorological parameters we have used an HOBO instrument with sensors of temperature and relative humidity, registering therefore the time series of input parameter. Figure 7 shows both time series of meteorological parameters and also the glacier discharge, but with specific character, that means the discharge glacier by area unity. The mean values for the considered period are:

- Air Temperature: $6{,}93\ ^{o}C$
- Relative Humidity: $68{,}9\ \%$
- Specific glacier discharge: $1{,}247\ m^3 / \sec \cdot km^2$

Analysis of glacier discharge time series

For making easy the analyse of specific glacier discharge in the CPE-ZS-51ºS, we have broken down the Figure 4 in monthly sections generating so the Figure 5, where it is shown the details of the three time series: input (air temperature and relative humidity) and output (specific discharge). Figure 8 (Figure 8-I, February 2004; Figure 8-II, March 2004; Figure 8-III, April 2004; Figure 8-IV, May 2004; Figure 8-V, June 2004; Figure 8-VI, July 2004; Figure 8-VII, August 2004; Figure 8-VIII, September 2004; Figure 8-IX, October 2004; Figure 8-X, November 2004; Figure 8-XI, December 2004; Figure 8-XII, January 2005).

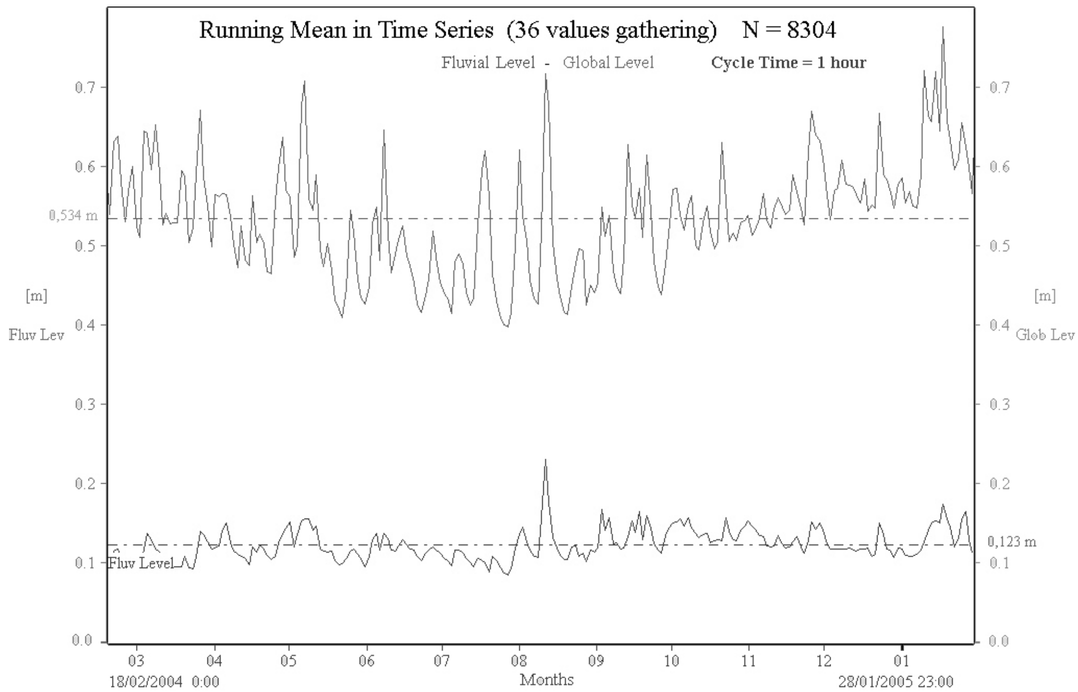

Fig. 4. Time series of the level for both stations: global and fluvial

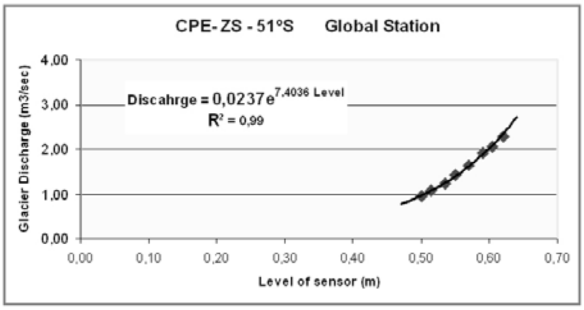

Fig. 5a. Adjustment curve between discharge and level for the global station

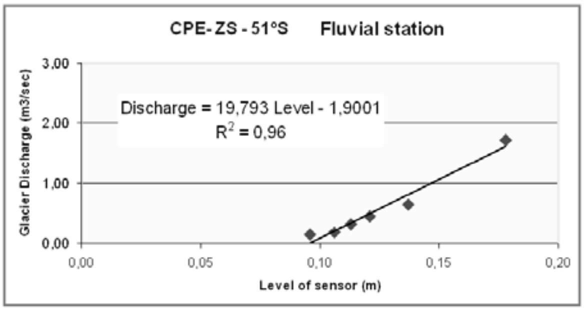

Fig. 5b. Adjustment curve between discharge and level for the fluvial station

Analysing the previous figures it can be appreciate that glacier discharge shows three different typologies:

1.The glacier discharge which is lower than the mean annual of the specific discharge 1.247 $m^3/s{\cdot}km^2$ and corresponds with cold winter months with a wide margin, could even occasionally the drainage uninterrupted. We will denote this discharge as *base line* (*BAL*) and it is uninterrupted by pulsations, which constitute points of flow as we will see later.

2. - The own "Annual Discharge Wave" $\left(W_{D\ Annual}\right)$, which is very higher than the mean annual of the specific discharge. It corresponds to the warm summer months, when it is drained the majority part of the annual volume.

3. - The third typology is constitutive by the replicas of the discharge wave $\left(R_{D\ Wave}\right)$. Corresponding with points of flow generated mainly by warm waves and copious rain, are very visible when there are conditions of discharge of type *BAL*. Those replicas are important due to all together could constitutive an appreciate value of volume drained by the glacier.

We emphasize the following 9 replicas or pulsations belong to type $\left(R_{D\ Wave}\right)$:

- from 24th to 29th of April 2004
- from 4th to 8th of May 2004
- 6th and 7th of June 2004
- from 14th to 20th of July 2004
- from 10th to 13th of August 2004
- from 11th to 14th of September 2004
- 20th and 21st of September 2004
- from 29th of September to 3rd of October 2004
- 20th and 21st of October 2004

Time distribution for the different types of discharge is as follows:

- $\left(W_{D\ Annual}\right)$ takes place from November to March inclusive, with a total of 147 days.

- (*BAL*), takes place from April to October inclusive, with a total of 218 days and where are included 34 days corresponding to the described 9 pulsations of flow $\left(R_{D\ Wave}\right)$.

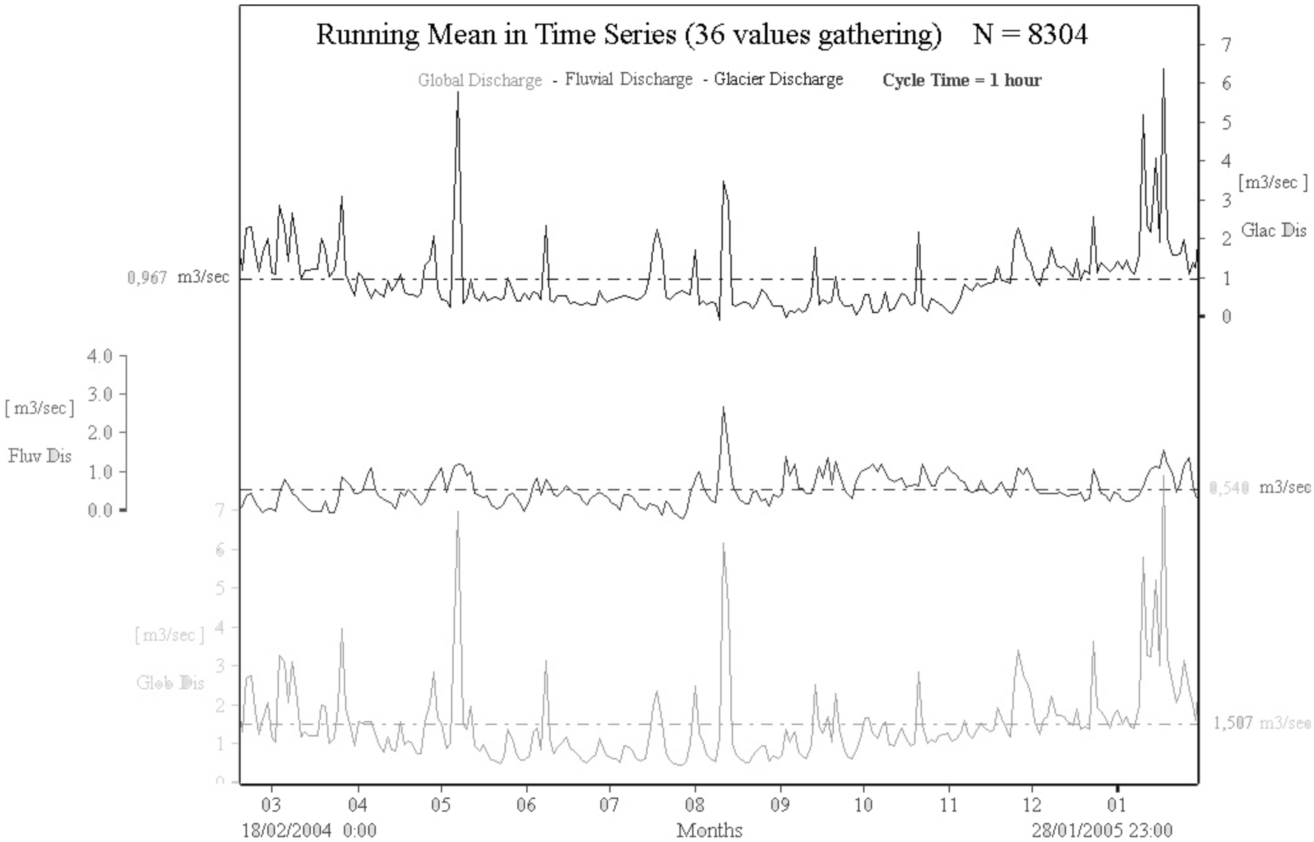

Fig. 6. Time series of the discharge: global, fluvial and glacial

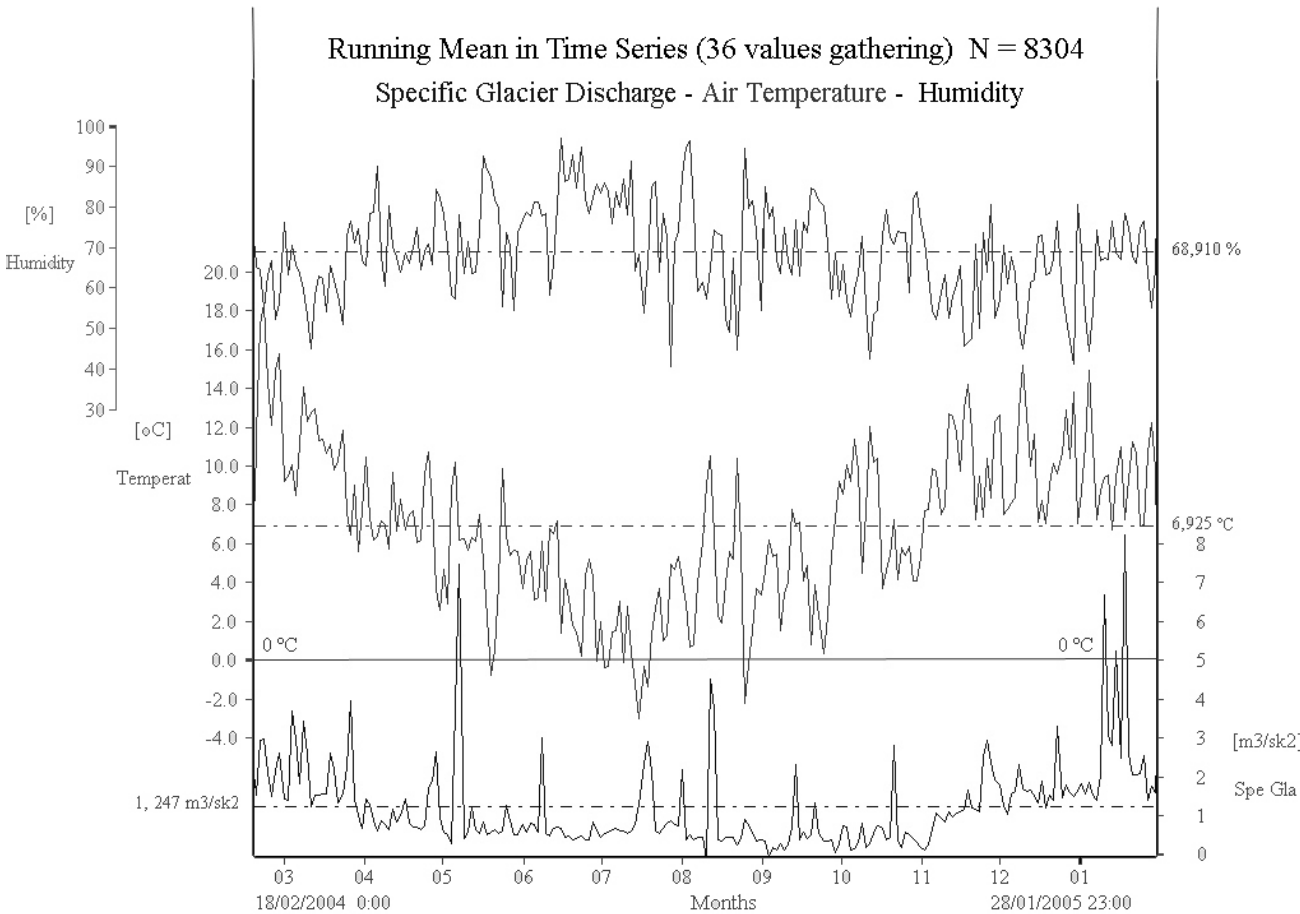

Fig. 7. Time series of the specific discharge, air temperature and relative humidity

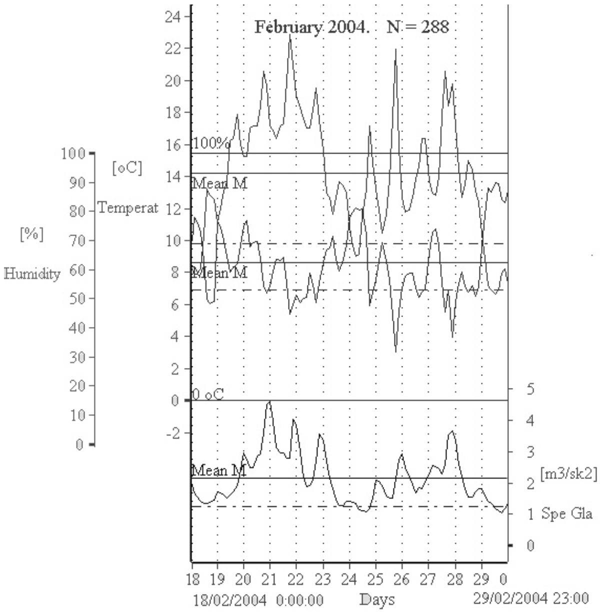

Fig. 8-I. Analysis of February 2004

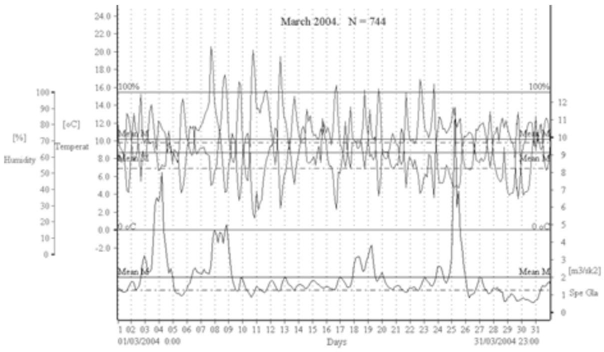

Fig. 8-II. Analysis of March 2004

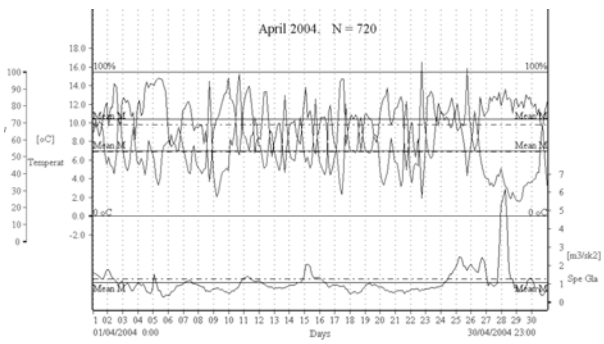

Fig. 8-III. Analysis of April 2004

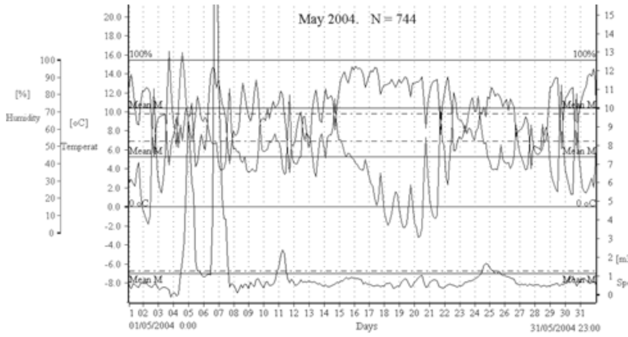

Fig. 8-IV. Analysis of May 2004

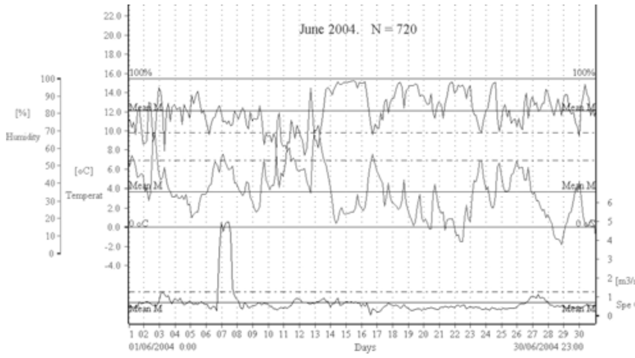

Fig. 8-V. Analysis of June 2004

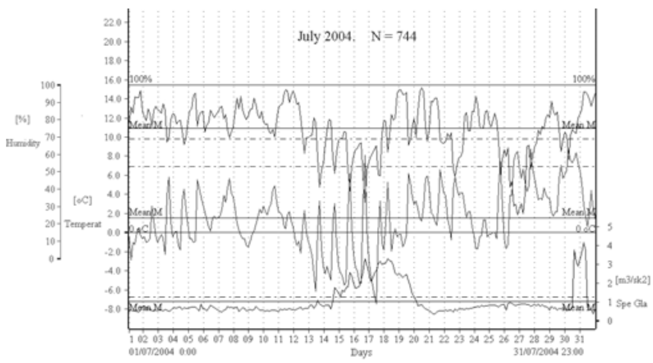

Fig. 8-VI. Analysis of July 2004

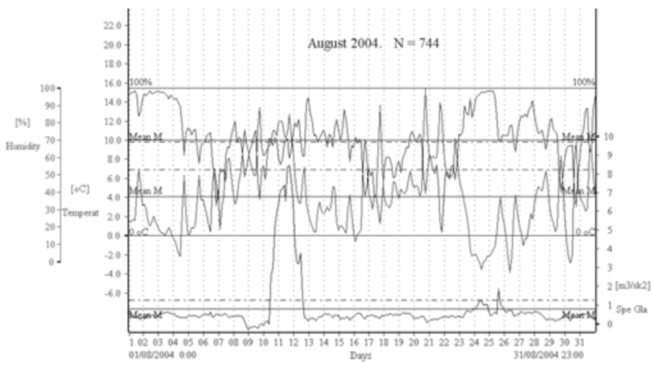

Fig. 8-VII. Analysis of August 2004

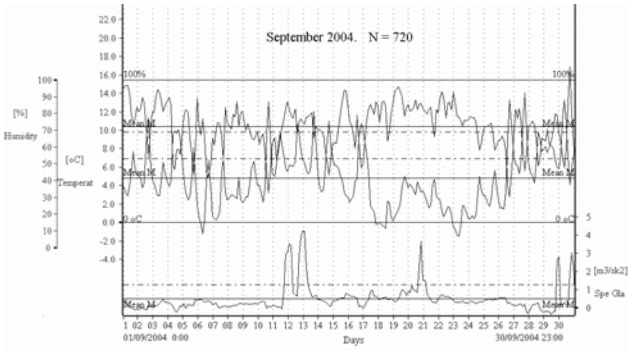

Fig. 8-VIII. Analysis of September 2004

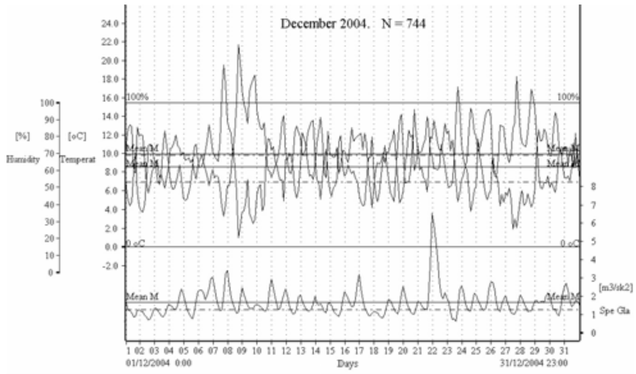

Fig. 8-XI. Analysis of December 2004

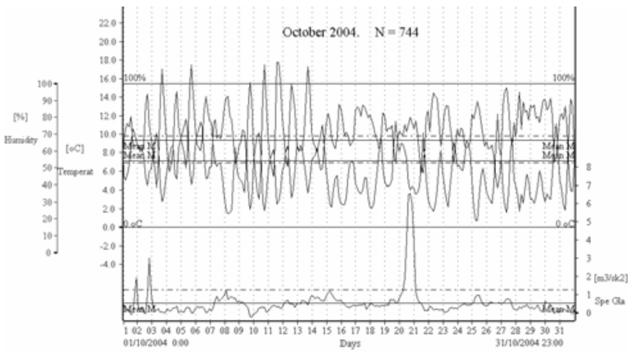

Fig. 8-IX. Analysis of October 2004

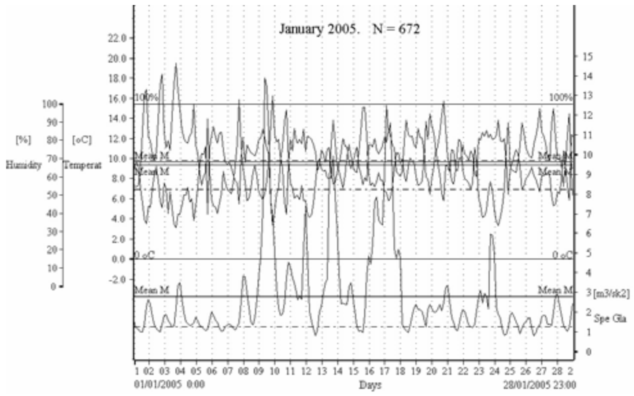

Fig. 8-XII. Analysis of January 2005

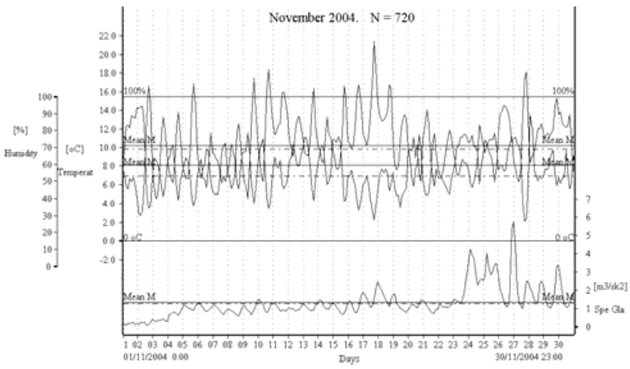

Fig. 8-X. Analysis of November 2004

Table 1
Characteristics of glacier discharge

CHARACTERISTICS OF GLACIER DISCHARGE IN ZAPATA SUR (TYNDALL, PATAGONIA

CPE-ZS-51ºS TIME SERIES FROM 18/02/2004 at 00:00 UNTIL 28/01/2005 at 23:00

Month	Nº Values Mesured	Temperature Mean values (ºC)	Humidity Mean values (%)	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)
February 04*	288	14,21	62,38	2,155	2,234	1,67	1,73
March 04	744	10,22	62,94	1,991	5,333	1,54	4,13
April 04	720	7,01	72,33	1,063	2,755	0,82	2,14
May 04	744	5,30	72,27	1,136	3,043	0,88	2,36
June 04	720	3,70	81,55	0,676	1,752	0,52	1,36
July 04	744	1,52	75,08	1,030	2,759	0,80	2,14
August 04	744	4,12	70,16	0,785	2,103	0,61	1,63
September 04	720	4,81	72,03	0,488	1,265	0,38	0,98
October 04	744	7,09	66,26	0,520	1,393	0,40	1,08
November 04	720	10,18	59,59	1,318	3,416	1,02	2,65
December 04	744	9,93	61,98	1,658	4,441	1,28	3,44
January 05**	672	9,68	66,43	2,807	6,791	2,18	5,26
Global Period	**8304**	**6,93**	**68,91**	**1,247**	**37,278**	**0,97**	**28,89**

* Data measured begin on 18th February 20 ** End series is on 28th January 2005

Fig. 9. Glacier cave in Tyndall Glacier
Photo Karmenka

Synthesis

In the Table 1 are collected the monthly and globally mean values for the following time series: air temperature in °C, relative humidity in %, glacier discharge in m^3/s and specific glacier discharge in $m^3/s{\cdot}km^2$.

Also in the Table 1 is detailed the size of data sample for each partial or total series and show the drained volumes, monthly and globally, in hm^3, and the specific in hm^3/km^2.

With those details it is easy to appreciate that the monthly evolution of temperature and glacier discharge follow in general the cycle of seasons.

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