



Supplement of

An unseasonal atmospheric river drives anomalous summer snow accumulation on glaciers of the subtropical Andes

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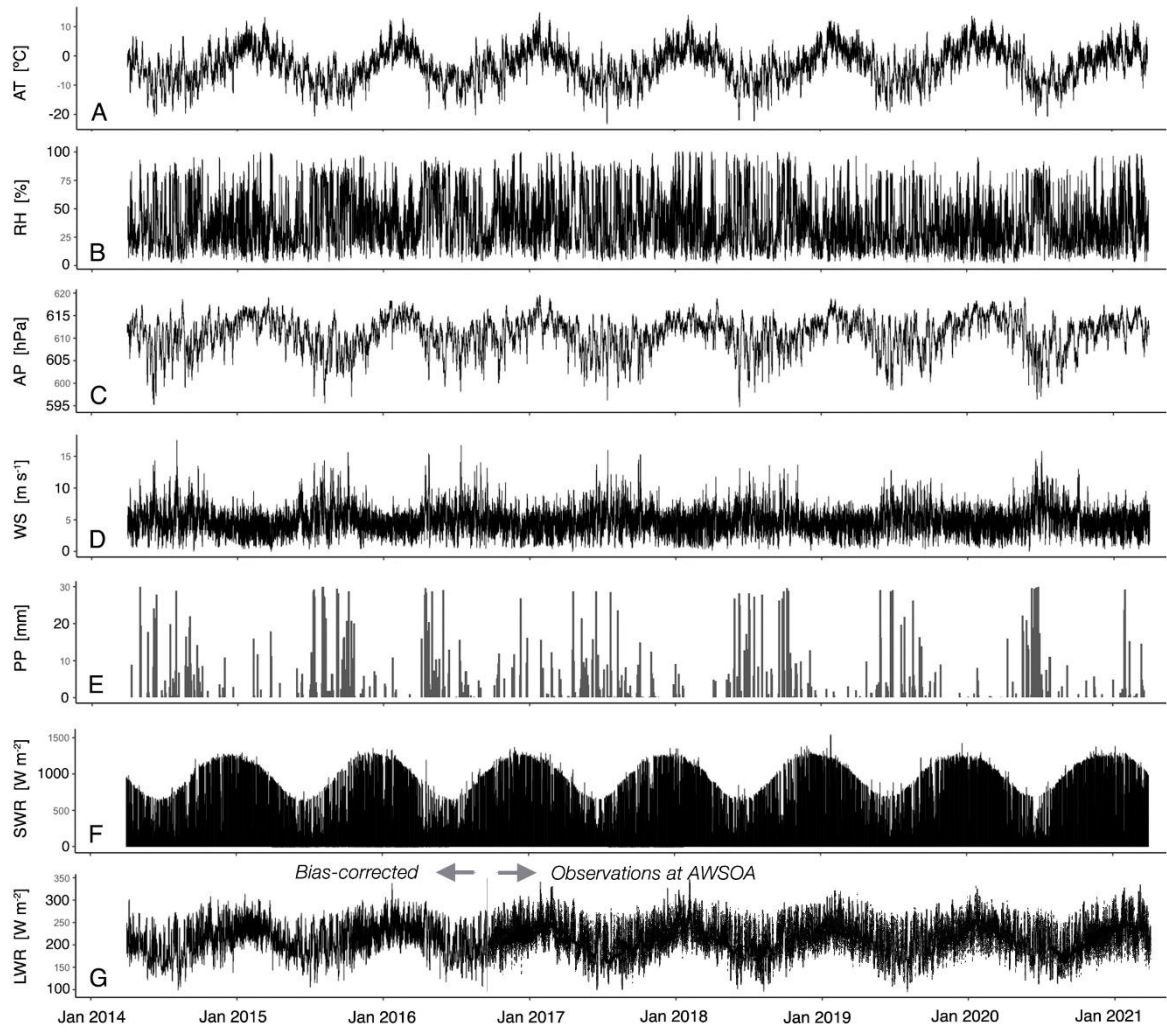


Figure S1. Hourly time series of the meteorological variables observed at the AWSOA and the GEONOR T200B-M from April 2014 to March 2021. a) Air temperature, b) relative humidity, c) atmospheric pressure, d) wind speed, e) total precipitation, f) incoming shortwave radiation and g) incoming longwave radiation. Red in g) corresponds to observations at AWSOA and black corresponds to the bias-corrected time series using ERA5.

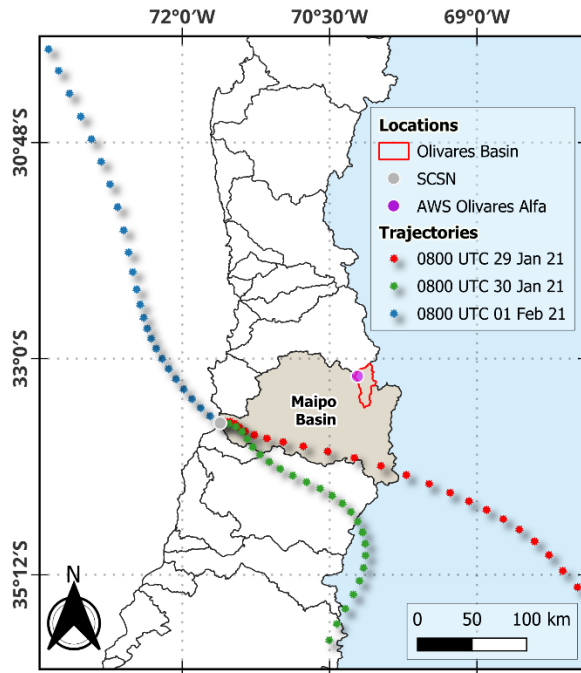


Figure S2. Map of the NOAA HYSPLIT Model forward trajectories using CDC1 Meteorological data. Trajectories obtained from <https://www.ready.noaa.gov/hypub-bin/trajtype.pl?runtype=archive>. SCSN (Santo Domingo) corresponds to the site from which radiosondes are launched.

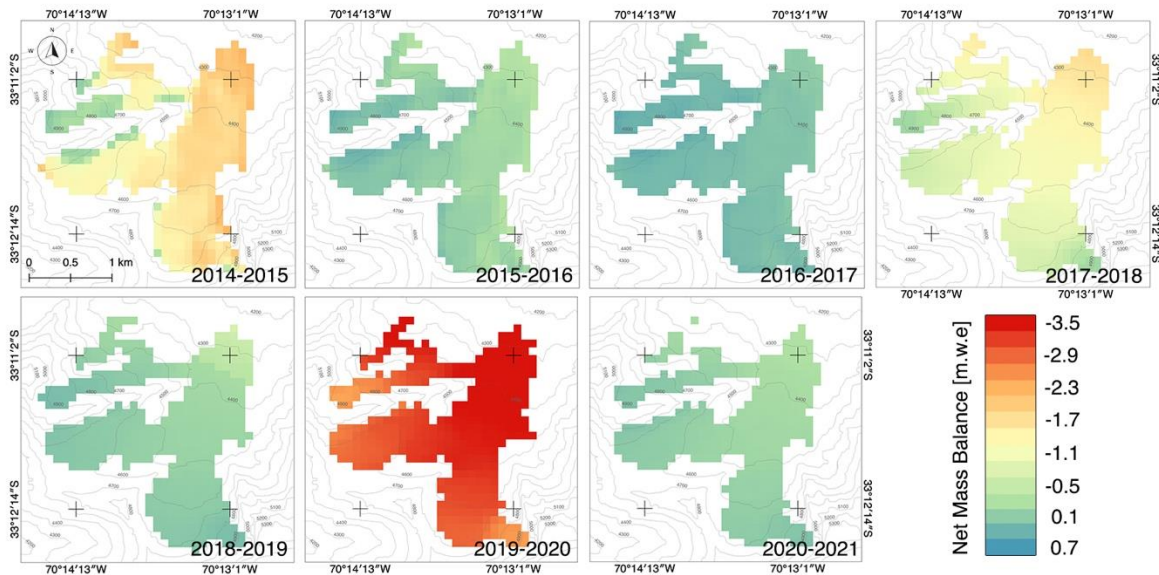


Figure S3. Accumulated distributed surface mass balance of the Olivares-Alfa glacier between 2014 and 2021.



Figure S4. Pre and post event pictures of the Paloma Norte Glacier, located in the Olivares sub-basin, nearby to Olivares Alfa Glacier (see Fig. 1).

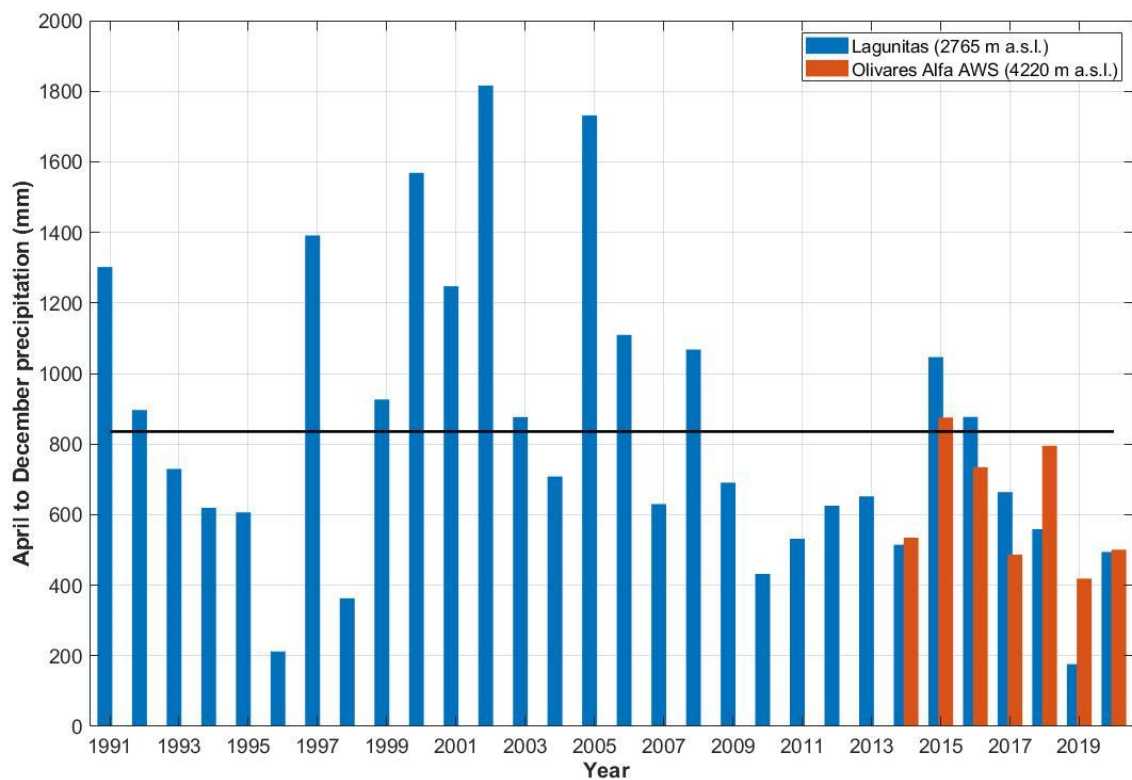


Figure S5. Accumulated precipitation between April and December for Lagunitas meteorological station and Olivares Alfa AWS. Black line is the climatological mean (1991-2020) of the Lagunitas meteorological station.

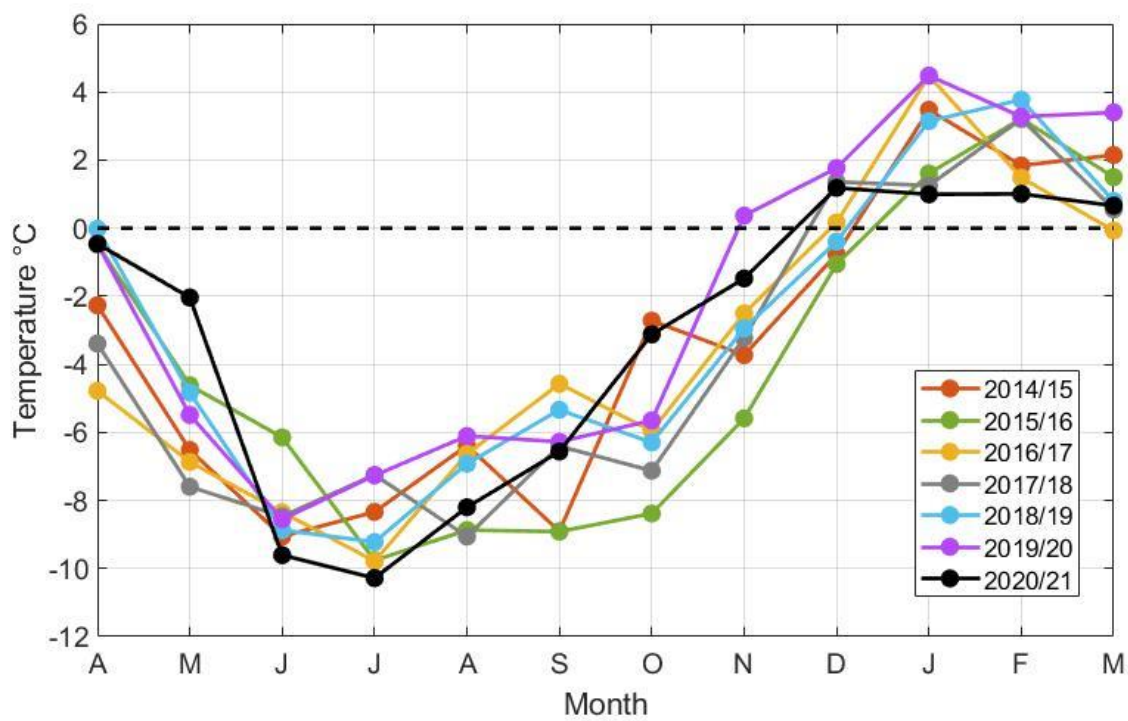


Figure S6. Monthly mean air temperature recorded at the Olivares Alfa AWS.

Table S1. Atmospheric rivers catalogue with ERA5 reanalyses for the summer (DJF) between 1941 and 2023.

Number	Start				Duration (hours)	Latitude range		AR Cat_Max	Int max (kg m ⁻¹ s ⁻¹)
	Day	Time	Day	Time					
1	06-Jan-42	3:00:00	07-Jan-42	17:00:00	38	-34.0	-30.0	1	441.3
2	15-Dec-51	1:00:00	15-Dec-51	8:00:00	7	-35.0	-34.5	1	595.4
3	31-Jan-52	7:00:00	01-Feb-52	22:00:00	39	-34.0	-30.0	1	425.5
4	13-Dec-56	2:00:00	15-Dec-56	6:00:00	52	-34.5	-32.0	1	486.7
5	07-Dec-57	7:00:00	08-Dec-57	11:00:00	28	-35.0	-33.0	2	524.3
6	23-Dec-64	0:00:00	24-Dec-64	1:00:00	25	-35.0	-34.5	1	509.1
7	09-Dec-65	12:00:00	11-Dec-65	5:00:00	41	-35.0	-33.0	1	521.6
8	17-Dec-76	16:00:00	18-Dec-76	19:00:00	27	-32.5	-30.5	1	373.3
9	25-Feb-78	2:00:00	26-Feb-78	19:00:00	41	-35.0	-31.0	1	482.0
10	10-Dec-79	15:00:00	12-Dec-79	2:00:00	35	-35.0	-34.5	2	641.0
11	23-Feb-87	5:00:00	25-Feb-87	5:00:00	48	-35.0	-33.5	2	527.2
12	21-Feb-98	16:00:00	22-Feb-98	20:00:00	28	-34.0	-30.0	2	521.1
13	10-Feb-00	21:00:00	12-Feb-00	7:00:00	34	-35.0	-34.5	2	669.7
14	30-Jan-01	11:00:00	31-Jan-01	3:00:00	16	-35.0	-34.5	1	609.0
15	14-Feb-12	20:00:00	16-Feb-12	8:00:00	36	-34.0	-32.5	1	388.1
16	17-Feb-12	18:00:00	18-Feb-12	23:00:00	29	-35.0	-34.5	2	521.6
17	17-Dec-12	23:00:00	19-Dec-12	21:00:00	46	-35.0	-32.5	1	494.7
18	08-Feb-13	18:00:00	10-Feb-13	5:00:00	35	-35.0	-34.5	1	441.0
19	28-Jan-21	19:00:00	30-Jan-21	6:00:00	35	-35.0	-34.5	1	388.9

Table S2. Atmospheric rivers catalogue with ERA5 reanalyses for the period April 2013 to March 2021.

Number	Start		End		Duration (hours)	Latitude range		AR Cat_Max	Int max (kg m ⁻¹ s ⁻¹)
	Day	Time	Day	Time					
1	02-May-13	9:00:00	03-May-13	13:00:00	28	-35.0	-33.0	2	673.2
2	17-May-13	16:00:00	18-May-13	20:00:00	28	-31.5	-30.0	1	555.6
3	27-May-13	2:00:00	28-May-13	21:00:00	43	-35.0	-31.5	2	695.7
4	30-May-13	22:00:00	31-May-13	11:00:00	13	-35.0	-34.0	1	662.3
5	26-Jun-13	21:00:00	28-Jun-13	12:00:00	39	-35.0	-32.5	2	685.3
6	02-Jul-13	18:00:00	04-Jul-13	4:00:00	34	-35.0	-34.0	2	613.7
7	08-Jul-13	22:00:00	10-Jul-13	8:00:00	34	-35.0	-32.5	2	521.8
8	26-Jul-13	1:00:00	26-Jul-13	21:00:00	20	-34.0	-30.0	1	682.3
9	06-Aug-13	16:00:00	07-Aug-13	17:00:00	25	-35.0	-32.5	1	565.5
10	09-Sept-13	15:00:00	10-Sept-13	22:00:00	31	-35.0	-34.5	1	402.9
11	29-Mar-14	15:00:00	30-Mar-14	2:00:00	11	-35.0	-34.5	1	630.7
Total 2013/14	11								
1	30-Apr-2014	20:00:00	02-May-14	0:00:00	28	-35.0	-34.5	1	471.2
2	02-May-14	8:00:00	03-May-14	10:00:00	26	-34.5	-33.0	1	484.3
3	28-May-14	23:00:00	29-May-14	17:00:00	18	-35.0	-34.5	1	576.9

4	03-Jun-14	4:00:00	04-Jun-14	5:00:00	25	-35.0	-31.5	1	650.4
5	10-Jun-14	19:00:00	12-Jun-14	2:00:00	31	-35.0	-31.0	1	640.8
6	13-Jul-14	18:00:00	14-Jul-14	20:00:00	26	-35.0	-32.5	1	610.6
7	27-Jul-14	15:00:00	29-Jul-14	10:00:00	43	-35.0	-34.5	2	509.0
8	30-Jul-14	17:00:00	01-Aug-14	8:00:00	39	-35.0	-34.5	2	502.6
9	29-Aug-14	19:00:00	30-Aug-14	16:00:00	21	-35.0	-32.5	1	553.2
10	31-Aug-14	15:00:00	02-Sept-14	0:00:00	33	-35.0	-30.5	2	556.4
11	23-Mar-15	12:00:00	25-Mar-15	17:00:00	53	-34.5	-30.0	2	459.7
Total 2014/15	11								
1	04-Jun-15	13:00:00	06-Jun-15	10:00:00	45	-35.0	-34.5	2	504.6
2	11-Jul-15	8:00:00	12-Jul-15	18:00:00	34	-35.0	-31.5	2	739.6
3	26-Jul-15	2:00:00	27-Jul-15	21:00:00	43	-35.0	-34.5	2	590.2
4	05-Aug-15	0:00:00	09-Aug-15	10:00:00	106	-35.0	-30.0	4	1056.6
5	28-Aug-15	1:00:00	29-Aug-15	12:00:00	35	-35.0	-34.5	2	633.3
6	06-Sept-15	2:00:00	07-Sept-15	16:00:00	38	-35.0	-31.5	2	523.6
Total 2015/16	6								
1	14-Apr-16	2:00:00	18-Apr-16	7:00:00	101	-35.0	-30.0	3	589.6
2	10-May-16	16:00:00	12-May-16	6:00:00	38	-35.0	-31.0	2	636.3
3	02-Jun-16	19:00:00	04-Jun-16	0:00:00	29	-31.5	-31.0	1	490.8
4	13-Jul-16	0:00:00	14-Jul-16	3:00:00	27	-35.0	-32.0	2	689.9
5	23-Jul-16	18:00:00	24-Jul-16	22:00:00	28	-35.0	-34.5	1	389.6
6	15-Oct-16	3:00:00	16-Oct-16	10:00:00	31	-35.0	-31.5	2	597.6
Total 2016/17	6								
1	19-Apr-17	18:00:00	20-Apr-17	22:00:00	28	-34.5	-34.0	1	495.3
2	06-May-17	12:00:00	07-May-17	14:00:00	26	-35.0	-32.5	1	656.7
3	10-May-17	7:00:00	13-May-17	18:00:00	83	-35.0	-30.0	3	727.1
4	15-Jun-17	13:00:00	17-Jun-17	3:00:00	38	-35.0	-30.0	3	764.5
5	21-Jun-17	10:00:00	23-Jun-17	7:00:00	45	-35.0	-31.5	3	755.1
6	23-Jun-17	20:00:00	27-Jun-17	0:00:00	76	-35.0	-30.0	4	918.4
7	08-Aug-17	20:00:00	10-Aug-17	7:00:00	35	-35.0	-33.0	2	569.6
8	29-Sept-17	13:00:00	30-Sept-17	17:00:00	28	-35.0	-33.0	1	664.6
9	04-Oct-17	9:00:00	05-Oct-17	5:00:00	20	-34.0	-33.5	1	529.9
10	17-Mar-18	5:00:00	17-Mar-18	20:00:00	15	-35.0	-34.5	1	570.0
Total 2017/18	10								
1	10-Apr-18	11:00:00	11-Apr-18	20:00:00	33	-35.0	-34.0	2	564.3
2	28-May-18	4:00:00	29-May-18	23:00:00	43	-35.0	-32.0	3	754.6
3	09-Jun-18	2:00:00	10-Jun-18	4:00:00	26	-35.0	-31.5	2	761.2
4	03-Jul-18	8:00:00	06-Jul-18	14:00:00	78	-35.0	-30.0	3	715.1
5	17-Sept-18	4:00:00	18-Sept-18	8:00:00	28	-35.0	-34.0	2	542.0
6	27-Sept-18	2:00:00	29-Sept-18	8:00:00	54	-35.0	-33.5	2	486.2
7	01-Nov-18	14:00:00	02-Nov-18	13:00:00	23	-35.0	-34.5	1	559.0
Total 2018/19	7								
1	02-May-19	16:00:00	04-May-19	20:00:00	52	-35.0	-34.0	2	646.7

2	29-May-19	2:00:00	30-May-19	20:00:00	42	-35.0	-31.5	2	574.3
3	27-Jun-19	5:00:00	29-Jun-19	12:00:00	55	-35.0	-31.5	1	454.4
4	20-Jul-19	23:00:00	21-Jul-19	8:00:00	9	-35.0	-34.5	1	573.8
5	14-Oct-19	4:00:00	15-Oct-19	4:00:00	24	-33.5	-32.0	1	510.0
Total 2019/20	5								
1	23-Apr-20	16:00:00	25-Apr-20	9:00:00	41	-35.0	-33.0	1	444.6
2	11-Jun-20	10:00:00	12-Jun-20	8:00:00	22	-35.0	-33.5	1	643.6
3	15-Jun-20	11:00:00	17-Jun-20	19:00:00	56	-35.0	-30.0	3	590.5
4	18-Jun-20	3:00:00	19-Jun-20	14:00:00	35	-35.0	-33.5	2	631.9
5	28-Jun-20	3:00:00	29-Jun-20	17:00:00	38	-35.0	-32.0	2	635.2
6	17-Jul-20	1:00:00	19-Jul-20	13:00:00	60	-35.0	-31.5	3	555.8
7	24-Aug-20	8:00:00	26-Aug-20	1:00:00	41	-35.0	-30.5	2	564.7
8	28-Jan-21	19:00:00	30-Jan-21	6:00:00	35	-35.0	-34.5	1	388.9
Total 2020/21	8								

Table S3. Satellite images used for glacier outlines.

SATELLITE NAME	DATE	RESOLUTION
SPOT 6	25-03-2014	1.5 m
KOMPSAT 3	24-02-2015	0.5 m
PLÉIADES	23-02-2016	0.5 m
PLÉIADES	02-02-2017	0.5 m
SPOT 6	18-03-2018	1.5 m
KOMPSAT 3	20-03-2019	0.7 m
KOMPSAT 3	12-03-2020	0.7 m