

To: Norges vassdrags- og energidirektorat (NVE)
 Attn.: Aart Verhage
 Copy to:
 Date: 2017-01-25
 Revision no./Rev.date: 0 /
 Document no.: 20140053-05-TN
 Project: 20140053 SP4 FoU Snøskred WP3 Slushflows
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Review of meteorological data from Fonnbu 2009–2016

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1 Introduction

12 observed parameters are recalculated with a time step of 1 hour from the original raw data set of observed values with 10 minute time step. To form winter season data sets which would cover complete snow season, it was decided to set the start of each season on 1st September and the finish on 30th June.

Seven such data sets were analysed with the goal of quality control and further use of the data for SNOWPACK model simulations. Each data set was supposed to contain 7272 data entries (7296 for winter seasons 2011-2012 and 2015-2016 because of the leap-years) for each observed element. However, due to some technical problems the amount of data entries varied from season to season. Missing entries are summarised in Table 1. Winter season 2015-2016 was finished on 24th June 2016 when this review has started to be written, and thus has a shorter data set.

Table 1 Amount of missing entries

Winter season	Total amount of missing entries	Missing entries
2009-2010	12	2009-11-16T13:00; 2009-11-16T14:00; 2009-12-07T15:00; 2009-12-26T00:00; 2010-01-25T14:00; 2010-02-10T13:00; 2010-02-23T11:00; 2010-03-15T20:00; 2010-03-28T02:00; 2010-06-03T21:00; 2010-06-14T14:00; 2010-06-14T15:00
2010-2011	18	2010-09-02T22:00; 2010-09-02T23:00; 2010-09-03T00:00; 2011-02-21T13:00; 2011-03-27T02:00; 2011-06-27T15:00; 2011-06-27T16:00; 2011-06-27T17:00; 2011-06-29T04:00; 2011-06-29T05:00; 2011-06-29T06:00; 2011-06-29T07:00; 2011-06-29T08:00; 2011-06-30T04:00; 2011-06-30T05:00; 2011-06-30T06:00; 2011-06-30T07:00; 2011-06-30T08:00
2011-2012	1	2012-03-25T02:00
2012-2013	7	2012-11-05T17:00; 2012-11-05T18:00; 2012-11-05T19:00; 2012-11-13T13:00; 2013-03-31T02:00; 2013-04-11T20:00; 2013-05-14T19:00
2013-2014	7	2013-10-10T09:00; 2013-10-16T01:00; 2013-10-19T01:00; 2014-01-16T20:00; 2014-02-13T20:00; 2014-03-13T18:00; 2014-03-30T02:00
2014-2015	6	2014-12-23T15:00; 2015-03-12T19:00; 2015-03-29T02:00; 2015-04-27T16:00; 2015-04-27T17:00; 2015-04-28T16:00
2015-2016	12	2015-10-29T15:00; 2015-10-29T16:00; 2015-10-29T17:00; 2015-10-29T18:00; 2015-10-29T19:00; 2015-10-29T20:00; 2015-10-29T21:00; 2015-10-29T22:00; 2015-10-29T23:00; 2015-10-30T00:00; 2016-01-06T10:00; 2016-04-14T20:00

Examination of the data presented below assumes the missing entries as missing observations for all sensors at the same time.

It is important to note that due to the lack of a temperature sensor at the ground level, the temperature sensor at 30 cm above ground was used for observations of TSG (ground surface temperature). It should be taken into account when using the data for further analyses.

2 Winter season 2009-2010

According to the data, snow season 2009-2010 started on 28th September and lasted till 29th May when the snow at the station melted away.

2.1 Missing observations

Amount of missing records for each observed element and its part in % from the total amount of records is presented in Table 2.

Table 2 Amount of missing observations (errors) for each observed element.

Observed element	Total amount of errors	Percentage of errors, %
TA	111	1.5
TSG	144	2.0
RH	216	3.0
PSUM	98	1.3
HS	111	1.5
VW	501	6.9
DW	504	6.9
VW_MAX	491	6.8
ISWR, RSWR, ILWR, TSS	167	2.3

As Table 2 shows, for almost all observed elements the amount of errors is 1.5 – 3% except for wind parameters which have about 7% missing data. Figures 1–5 in Appendix A show that the errors are more or less evenly distributed in time during the whole season with one-two consequent error records at a time. However, there were five periods when wind sensors (Figure 6) were out of order continuously:

1. 04.-06.11.2009 (ca. 2 days; 53-54 missing observations);
2. 24.-27.12.2009 (ca. 3.5 days; 83-84 missing observations);
3. 27.02.-03.03.2010 (ca. 4 days; 95-96 missing observations);
4. 18.-20.04.2010 (ca. 2 days; 53-54 missing observations);
5. 06.-08.06.2010 (ca. 1.5 days; 35-36 missing observations).

2.2 Quality control of recorded observations

Basic statistical parameters for the observed parameters are presented in Table 3.

Table 3 Basic descriptive statistics of the observed parameters

Observed element	Max value	Min value	Average value	Standard deviation
TA, °K	289.8	252.6	271.4	6.6
TSS, °K	302.1	249.4	269.9	8.0
TSG, °K	294.8	250.9	271.4	7.0
TA, °C	16.6	-20.6	-1.7	6.6
TSS, °C	28.9	-23.8	-3.3	8.0
TSG, °C	21.6	-22.3	-1.8	7.0
RH, %	100	20	77	16
PSUM, mm	7.1	0.0	0.1	0.3
HS, m	1.30	0.00	0.39	0.33
VW, m/s	13.6	0.1	3.7	2.1
VW_MAX, m/s	21.8	0.3	4.8	2.3
ISWR, W/m ²	1244.3	0.0	94.6	186.8
RSWR, W/m ²	824.7	0.0	51.7	109.1
ILWR, W/m ²	384.4	138.7	265.6	51.8

Figure 3 in Appendix A shows that there are two doubtful observations of HS recorded on 30th September and 5th November 2009. These would most likely be removed from the data set which will be used for further analyses.

3 Winter season 2010-2011

According to the data, snow season 2010-2011 started on about 15th October and lasted till 9th June when the snow at the station melted away.

3.1 Missing observations

Amount of missing records for each observed element and its part in % from the total amount of records is presented in Table 4.

Table 4 Amount of missing observations (errors) for each observed element.

Observed element	Total amount of errors	Percentage of errors, %
TA	71	1.0
TSG	155	2.1
RH	188	2.6
PSUM	51	0.7
HS	94	1.3
VW	1035	14.2
DW	1040	14.3
VW_MAX	1039	14.3
ISWR, RSWR, ILWR, TSS	172	2.4

As Table 4 shows, for almost all observed elements the amount of errors is 1 – 2.5% except for wind parameters which have over 14% missing data. Figures 7–12 in Appendix A show that there were rather frequent errors in the period prior to about 15th November. Other errors are more or less evenly distributed in time during the season with one-two consequent error records at a time. However, there were five periods when wind sensors were out of order continuously:

1. 14.09.-04.10.2010 (ca. 20 days; 487-488 missing observations);
2. 03.-15.11.2010 (ca. 12.5 days; 296-297 missing observations);
3. 18.-21.02.2011 (ca. 3 days; 62-63 missing observations);
4. 09.-11.04.2011 (ca. 2 days; 45-46 missing observations);
5. 29.-31.05.2011 (ca. 2 days; 53-54 missing observations).

3.2 Quality control of recorded observations

Basic statistical parameters for the observed parameters are presented in Table 5.

Table 5 Basic descriptive statistics of the observed parameters

Observed element	Max value	Min value	Average value	Standard deviation
TA, °K	291.4	253.6	271.8	7.1
TSS, °K	300.0	251.1	270.0	7.9
TSG, °K	296.8	253.3	271.9	6.4
TA, °C	18.2	-19.6	-1.4	7.1
TSS, °C	26.8	-22.1	-3.2	7.9
TSG, °C	23.6	-19.9	-1.2	6.4
RH, %	100	19	78	16
PSUM, mm	4.9	0.0	0.1	0.3
HS, m	2.57	0.00	0.84	0.79
VW, m/s	14.1	0.2	3.5	2.2
VW_MAX, m/s	15.0	0.3	4.6	2.4
ISWR, W/m ²	1187.9	0.0	90.3	177.1
RSWR, W/m ²	746.9	0.0	50.7	105.0
ILWR, W/m ²	381.5	144.6	271.0	51.6

Figure 9 in Appendix A shows that there is a doubtful observation of HS recorded 2011-02-17 at 11:00. This is considered to be an error and will be removed from the data set which is used for further analyses.

4 Winter season 2011-2012

According to the data, snow season 2011-2012 started on about 7th October and lasted till about 1st July when the snow at the station melted away. There was a snow-free period from about 2nd till about 25th November 2011.

4.1 Missing observations

During the observation season there was a period of about 11 days from 13:01 11.05.2012 till 12:00 22.05.2012, when most of the sensors (TSG, VW, DW, VW_MAX, ISWR, RSWR, ILWR, TSS) were continuously or most of the time out of order. Amount of missing records for each observed element and the part of the "May"-errors in the total amount of observations are presented in Table 6.

Table 6 Amount of missing observations (errors) for each observed element.

Observed element	Total amount of errors	Percentage of errors, %	Amount of "May"-errors	"May"-errors in total amount, %
TA	31	0.4	0	0.0
TSG	263	3.6	195	2.7
RH	343	4.7	262	3.6
PSUM	186	2.5	0	0.0
HS	32	0.4	0	0.0
VW	897	12.3	262	3.6
DW	900	12.3	262	3.6
VW_MAX	894	12.3	262	3.6
ISWR, RSWR, ILWR, TSS	263	3.6	195	2.7

As Table 6 shows, observations of TA as well as HS had low percentage of missing values, namely 0.4%. Almost all other observed elements have 2.5 – 5% of errors, except for wind parameters which have over 12% missing data. Technical problems in May 2012 caused 2.7 – 3.6% of errors to all observed elements except for TA, PSUM and HS.

Figures 13–18 in Appendix A show that errors were slightly more frequent prior to 01.02.2012 then after, but anyway the errors are more or less evenly distributed in time during the season with one-two consequent error records at a time. In the period 25.-26.12.2011 all sensors except for precipitation gage (PSUM) were continuously out of order, causing 18 missing observations.

In addition to the periods described above, there were five periods when wind sensors were out of order continuously:

1. 05.-16.09.2011 (ca. 10.5 days; 258 missing observations);
2. 25.10.-03.11.2011 (ca. 9 days; 217 missing observations);
3. 14.-15.12.2011 (ca. 1.5 days; 33-34 missing observations);
4. 14.-15.02.2012 (ca. 1 day; 23-24 missing observations);
5. 30.06.2012 (ca. 1 day; 17 missing observations).

4.2 Quality control of recorded observations

Basic statistical parameters for the observed parameters are presented in Table 7.

Table 7 Basic descriptive statistics of the observed parameters

Observed element	Max value	Min value	Average value	Standard deviation
TA, °K	289.4	256.5	273.3	5.5
TSS, °K	291.1	253.9	271.3	5.6
TSG, °K	292.5	267.3	273.9	3.4
TA, °C	16.2	-16.7	0.1	5.5
TSS, °C	17.9	-19.3	-1.8	5.6
TSG, °C	19.3	-5.9	0.8	3.4
RH, %	99	20	79	15
PSUM, mm	9.3	0.0	0.2	0.4
HS, m	3.12	0.00	1.40	1.02
VW, m/s	14.5	0.1	3.7	2.3
VW_MAX, m/s	15.5	0.3	4.9	2.4
ISWR, W/m ²	1261.4	0.0	95.8	193.2
RSWR, W/m ²	902.2	0.0	64.3	131.9
ILWR, W/m ²	380.3	155.6	282.7	41.1

Figures 13–18 in Appendix A illustrate the observations made during the winter season 2011-2012. Errors are shown at the top of each diagram.

5 Winter season 2012-2013

According to the data, snow season 2012-2013 started on about 8th October and lasted till 27th May when the snow at the station melted away.

5.1 Missing observations

During the observation season there was a period of about 5 days from 06:01 31.10.2012 till 11:00 05.11.2012, when most of the sensors (TSG, RH, VW, DW, VW_MAX, ISWR, RSWR, ILWR, TSS) were continuously or most of the time out of order. Amount of missing records for each observed element and the part of the "November"-errors in the total amount of observations are presented in Table 8.

Table 8 Amount of missing observations (errors) for each observed element.

Observed element	Total amount of errors	Percentage of errors, %	Amount of "November"-errors	"November"-errors in total amount, %
TA	30	0.4	0	0.0
TSG	184	2.5	108	1.5
RH	203	2.8	125	1.7

Observed element	Total amount of errors	Percentage of errors, %	Amount of "November"-errors	"November"-errors in total amount, %
PSUM	723	9.9	0	0.0
HS	30	0.4	0	0.0
VW	1397	19.2	125	1.7
DW	1402	19.3	125	1.7
VW_MAX	1405	19.3	125	1.7
ISWR, RSWR, ILWR, TSS	184	2.5	108	1.5

As Table 8 shows, observations of TA as well as HS have low percentage of missing values, namely 0.4%. RH, TSG, TSS and radiation elements (ISWR, RSWR and ILWR) have 2.5 – 2.8% errors. Precipitation PSUM has about 10% errors. Wind parameters have almost 20% errors. Technical problems in November 2012 caused 1.5 – 1.7% of errors to all observed elements except for TA, PSUM and HS.

Figures 19–24 in Appendix A show that apart from the 5-day break in the beginning of November 2012 described above, errors are more or less evenly distributed in time during the season with one-two consequent error records at a time. However, there were 23 periods when the precipitation gage (PSUM) was out of order:

1. 18.-19.09.2012 (15 missing observations);
2. 09.-10.10.2012 (15 missing observations);
3. 16.-17.10.2012 (14 missing observations);
4. 23.-24.10.2012 (15 missing observations);
5. 30.-31.10.2012 (15 missing observations);
6. 13.-14.11.2012 (15 missing observations);
7. 24.11.-02.12.2012 (ca. 7.5 days; 179 missing observations);
8. 15.-16.12.2012 (16 missing observations);
9. 29.-30.12.2012 (16 missing observations);
10. 12.-13.01.2013 (16 missing observations);
11. 26.-27.01.2013 (15 missing observations);
12. 09.-10.02.2013 (15 missing observations);
13. 23.-24.02.2013 (15 missing observations);
14. 02.-03.03.2013 (14 missing observations);
15. 09.-10.03.2013 (15 missing observations);
16. 18.-26.03.2013 (ca. 8 days; 194 missing observations);
17. 09.-10.04.2013 (16 missing observations);
18. 16.-17.04.2013 (15 missing observations);
19. 30.04.-01.05.2013 (16 missing observations);
20. 14.-15.05.2013 (15 missing observations);
21. 28.-29.05.2013 (15 missing observations);
22. 18.-19.06.2013 (16 missing observations);
23. 25.-26.06.2013 (15 missing observations).

In addition to the November-error period, wind sensors were continuously out of order during four periods before they stopped operating completely at 03:01 on 18th May 2013:

1. 13.-14.12.2012 (18 missing observations);
2. 20.-22.12.2012 (ca. 2.5 days; 63-64 missing observations);
3. 07.-08.02.2013 (ca. 1 day; 21 missing observations);
4. 29.-31.03.2013 (ca. 2 days; 48-49 missing observations).

5.2 Quality control of recorded observations

Basic statistical parameters for the observed parameters are presented in Table 9.

Table 9 Basic descriptive statistics of the observed parameters

Observed element	Max value	Min value	Average value	Standard deviation
TA, °K	291.1	255.8	271.3	7.0
TSS, °K	301.2	250.7	269.5	8.3
TSG, °K	297.5	254.7	272.0	6.2
TA, °C	17.9	-17.4	-1.9	7.0
TSS, °C	28.0	-22.5	-3.6	8.3
TSG, °C	24.3	-18.5	-1.1	6.2
RH, %	99	18	75	15
PSUM, mm	5.2	0.0	0.1	0.3
HS, m	1.75	0.00	0.62	0.52
VW, m/s	13.4	0.2	3.7	2.1
VW_MAX, m/s	14.1	0.4	4.8	2.2
ISWR, W/m ²	1249.8	0.0	94.2	185.7
RSWR, W/m ²	844.7	0.0	51.9	113.9
ILWR, W/m ²	399.1	151.5	265.4	55.9

Figures 19–24 in Appendix A illustrate the observations made during the winter season 2012-2013. Errors are shown at the top of each diagram. Figure 21 in Appendix A shows that there are two doubtful observations of HS recorded on 2013-03-18 at 11:00 and on 2013-04-15 at 15:00. These are considered to be errors and are removed from the data set which is used for further analyses.

6 Winter season 2013-2014

According to the data, snow season 2013-2014 started on about 2nd November and lasted till 1st June when the snow at the station melted away.

6.1 Missing observations

Amount of missing records for each observed element and its part in % from the total amount of records is presented in Table 10.

Table 10 Amount of missing observations (errors) for each observed element.

Observed element	Total amount of errors	Percentage of errors, %
TA	44	0.6
TSG	87	1.2
RH	315	4.3
PSUM	620	8.5
HS	44	0.6
VW	1257	17.3
DW	1259	17.3
VW_MAX	1258	17.3
ISWR, RSWR, ILWR, TSS	88	1.2

As Table 10 shows, observations of TA as well as HS have low percentage of missing values, namely 0.6%. RH, TSG, TSS and radiation elements (ISWR, RSWR and ILWR) have 1.2% errors. Precipitation PSUM has about 9% errors. Wind parameters have over 17% errors.

Figures 25–30 in Appendix A show that the errors are more or less evenly distributed in time during the season with one-two consequent error records at a time. However, both precipitation gage (PSUM), relative humidity sensor and wind sensors had several periods when they were continuously out of order.

RH-sensor was out of order between 14th and 23rd January 2014 (ca. 9 days; 212 missing observations).

The precipitation gage was continuously out of order during 21 periods:

1. 11.-12.09.2013 (16 missing observations);
2. 12.-13.09.2013 (ca. 1 day; 28 missing observations);
3. 18.-19.09.2013 (15 missing observations);
4. 10.-21.10.2013 (ca. 11.5 days; 277 missing observations);
5. 28.-29.10.2013 (15 missing observations);
6. 11.-12.11.2013 (15 missing observations);
7. 25.-26.11.2013 (15 missing observations);
8. 09.-10.12.2013 (15 missing observations);
9. 16.-17.12.2013 (14 missing observations);
10. 30.-31.12.2013 (15 missing observations);
11. 13.-14.01.2014 (15 missing observations);
12. 27.-28.01.2014 (15 missing observations);
13. 17.-18.02.2014 (15 missing observations);

14. 10.-11.03.2014 (15 missing observations);
15. 17.-18.03.2014 (14 missing observations);
16. 07.-08.04.2014 (15 missing observations);
17. 14.-15.04.2014 (15 missing observations);
18. 28.-29.04.2014 (16 missing observations);
19. 12.-13.05.2014 (15 missing observations);
20. 09.-10.06.2014 (16 missing observations);
21. 23.-24.06.2014 (16 missing observations).

The wind sensors did not work until 8:00 on 12th September 2013, causing 273-274 missing observations of wind parameters. The sensors were continuously out of order during five periods before they stopped operating completely at 20:01 on 19th June 2014:

1. 14.-23.10.2013 (ca. 9 days; 218-219 missing observations);
2. 02.-04.12.2013 (ca. 1.5 days; 37-38 missing observations);
3. 21.-23.01.2014 (ca. 2 days; 42-43 missing observations);
4. 12.-18.03.2014 (ca. 6 days; 149 missing observations);
5. 01.-09.05.2014 (ca. 8.5 days; 204-205 missing observations).

6.2 Quality control of recorded observations

Basic statistical parameters for the observed parameters are presented in Table 11.

Table 11 Basic descriptive statistics of the observed parameters

Observed element	Max value	Min value	Average value	Standard deviation
TA, °K	291.2	254.9	274.1	5.8
TSS, °K	302.0	252.5	272.5	6.7
TSG, °K	296.5	261.4	274.4	4.9
TA, °C	18.0	-18.3	1.0	5.8
TSS, °C	28.8	-20.7	-0.6	6.7
TSG, °C	23.3	-11.8	1.2	4.9
RH, %	100	20	74	15
PSUM, mm	5.0	0.0	0.1	0.3
HS, m	2.22	0.00	0.81	0.67
VW, m/s	16.0	0.1	4.1	2.4
VW_MAX, m/s	16.5	0.4	5.3	2.7
ISWR, W/m ²	1197.6	0.0	98.0	194.0
RSWR, W/m ²	773.7	0.0	50.1	110.1
ILWR, W/m ²	391.3	159.0	279.5	41.6

On May 10th, there were 16 consequent observations of RH exceeding 100% recorded (102-169%). These observations are considered to be errors and are removed from the data set which is used for further analyses (including Table 11).

Figures 25–30 in Appendix A illustrate the observations made during the winter season 2013-2014.

7 Winter season 2014-2015

According to the data, snow season 2014-2015 started between 11th November and 5th December. It was not finished on 1st July with over 40 cm snow at the station.

7.1 Missing observations

During the observation season there was a period of about 5 days from 05:01 25.01.2015 till 09:00 30.01.2015, when most of the sensors (TSG, RH, VW, DW, VW_MAX, ISWR, RSWR, ILWR, TSS) were continuously or most of the time out of order. Amount of missing records for each observed element and the part of the "January"-errors in the total amount of observations are presented in Table 12.

Table 12 Amount of missing observations (errors) for each observed element.

Observed element	Total amount of errors	Percentage of errors, %	Amount of "January"-errors	"January"-errors in total amount, %
TA	66	0.9	0	0.0
TSG	218	3.0	102	1.4
RH	315	4.3	124	1.7
PSUM	193	2.7	15	0.2
HS	67	0.9	1	0.0
VW	3263	44.9	124	1.7
DW	3263	44.9	124	1.7
VW_MAX	3261	44.8	124	1.7
ISWR, RSWR, ILWR, TSS	218	3.0	102	1.4

As Table 12 shows, for almost all observed elements the amount of errors is about 1 – 4% except for wind parameters which have almost 45% missing data. Technical problems in January 2015 caused 1.4 – 1.7% of errors to all observed elements except for TA, PSUM and HS.

In addition to the 5-day technical break in January 2015, there was a 23-hour technical break 20.-21.05.2015 when all sensors except for the precipitation gage (PSUM), were out of order.

Apart from that, both hygrometer, precipitation gage and wind sensors were out of order several times continuously for some periods. Among these, there were registered 65 observations of RH exceeding 100% (101-169%). These observations are considered to be errors and are removed from the data set which is used for further analyses (including

Table 12 and Table 13). Consequently there were three periods with missed RH-observations in addition to the technical breaks described above:

1. 30.-31.12.2014 (10 missing observations);
2. 22.-24.05.2014 (ca. 1.5 days; 35 missing observations);
3. 03.-04.06.2015 (18 missing observations).

The precipitation gage was continuously out of order during 9 periods in addition to the technical breaks described above:

1. 06.-07.09.2014 (16 missing observations);
2. 06.-07.01.2015 (15 missing observations);
3. 06.-07.03.2015 (15 missing observations);
4. 27.-28.03.2015 (15 missing observations);
5. 11.-12.05.2015 (15 missing observations);
6. 25.-26.05.2015 (15 missing observations);
7. 01.-02.06.2015 (14 missing observations);
8. 15.-16.06.2015 (15 missing observations);
9. 29.-30.06.2015 (15 missing observations).

The wind sensors continuously did not work until 13:00 on 6th December 2014 except for a short period with 15 valid observations on 26.-27.09.2014. This caused 2302-2304 missing observations of wind parameters. The sensors were continuously out of order during two periods (excluding the technical break in January 2015) before they stopped operating completely at 09:01 on 23rd June 2015:

1. 15.-24.03.2015 (ca. 8.5 days; 208 missing observations);
2. 04.-21.05.2015 (ca. 17 days; 405-406 missing observations; includes the technical break 20.-21.05.2015 described above).

7.2 Quality control of recorded observations

Basic statistical parameters for the observed parameters are presented in Table 13.

Table 13 Basic descriptive statistics of the observed parameters

Observed element	Max value	Min value	Average value	Standard deviation
TA, °K	290.9	258.6	273.4	5.0
TSS, °K	294.7	253.4	271.7	5.5
TSG, °K	295.8	265.0	273.6	3.6
TA, °C	17.7	-14.6	0.2	5.0
TSS, °C	21.5	-19.8	-1.5	5.5
TSG, °C	22.6	-8.2	0.4	3.6
RH, %	100	27	77.8	14.3
PSUM, mm	4.8	0.0	0.1	0.3
HS, m	2.76	0.00	1.34	1.01
VW, m/s	15.9	0.2	3.8	2.3
VW_MAX, m/s	16.5	0.3	5.0	2.4

Observed element	Max value	Min value	Average value	Standard deviation
ISWR, W/m ²	1233.2	0.0	97.6	189.6
RSWR, W/m ²	804.8	0.0	64.9	130.9
ILWR, W/m ²	397.7	155.9	281.3	42.0

Figures 31–36 in Appendix A illustrate the observations made during the winter season 2014-2015. Figure 33 in Appendix A shows that there is a doubtful observation of HS recorded on 2015-04-28 at 17:00. This is considered to be an error and is removed from the data set which is used for further analyses.

8 Winter season 2015-2016

According to the data, snow season 2013-2014 started on about 2nd November and lasted till 1st June when the snow at the station melted away.

8.1 Missing observations

During the observation season there was a period of about 5 days from 14:01 28.10.2015 till 16:00 02.11.2015, when most of the sensors (TA, RH, HS, ISWR, RSWR, ILWR, TSS, TSG) were out of order. Amount of missing records for each observed element and the part of the "October"-errors in the total amount of observations are presented in Table 14.

Table 14 Amount of missing records (errors) for each observed element.

Observed element	Total amount of errors	Percentage of errors, %	Amount of "October"-errors	"October"-errors in total amount, %
TA	141	2.0	118	1.7
TSG	178	2.5	118	1.7
RH	276	3.9	118	1.7
PSUM	999	14.0	25	0.4
HS	137	1.9	118	1.7
VW	3139	44.0	13	0.2
DW	3139	44.0	13	0.2
VW_MAX	3137	43.9	14	0.2
ISWR, RSWR, ILWR, TSS	179	2.5	118	1.7

As Table 14 shows, for most of the observed elements the amount of errors is about 2 – 4% except for precipitation and wind parameters which have 14% and 44% missing data respectively. Technical problems in October 2015 caused about 1.7% errors to all observed elements except for the precipitation and wind parameters which were operative most of the period.

Observations of wind parameters (VW, DW and VW_MAX) started only from 28.10.2015 causing 1380-1381 missing observations (19.3% of total amount of records per element). Additionally, the wind sensors were continuously out of order during three periods:

1. 18.12.2015 – 05.01.2016 (ca. 18.5 days; 444 missing observations)
2. 05.02.2016 – 11.02.2016 (ca. 5.5 days; 133-134 missing observations)
3. 26.03.2016 – 12.05.2016 (ca. 46 days; 1132-1133 missing observations)

Another element that had considerable amount of errors during this season (14%), is precipitation (PSUM). The precipitation gage was continuously out of order during 12 periods in addition to the technical break in October 2015 described above:

1. 6.-07.09.2015 (16 missing observations);
2. 20.-21.09.2015 (16 missing observations);
3. 27.-28.09.2015 (15 missing observations);
4. 11.-12.10.2015 (16 missing observations);
5. 25.-26.10.2015 (16 missing observations);
6. 20.-21.11.2015 (16 missing observations);
7. 04.-05.12.2015 (16 missing observations);
8. 18.-19.12.2015 (16 missing observations);
9. 03.-05.01.2016 (ca. 2.5 days; 56 missing observations);
10. 12.04.-12.05.2016 (ca. 30.5 days; 729 missing observations);
11. 22.-23.05.2016 (16 missing observations);
12. 12.-13.06.2016 (16 missing observations).

There were registered 87 observations of RH exceeding 100% (101-169%). These observations are considered to be errors and are removed from the data set which is used for further analyses (including Table 14 and Table 15). Consequently there were two periods with missed RH-observations in addition to the technical break in October 2015 described above:

1. 07.-09.09.2015 (ca. 2 days; 48 missing observations);
2. 26.-27.09.2015 (19 missing observations).

8.2 Quality control of recorded observations

On 31st October 2015 at 15:00 it was recorded 125.7 mm precipitation for the last hour. This value seems to be unrealistically high taking into account that there was no precipitation 15h preceding the observation and almost no precipitation (0.2 mm) during 4h after the record has been done. Unfortunately, this precipitation observation was recorded in the period when almost all other sensors including TA and HS were out of order and it is not possible to get an indication whether such an intense precipitation has really occurred. The value is doubtful and is removed from the data set which is used for different analyses.

Basic statistical parameters for the observed parameters are presented in Table 15.

Table 15 Basic descriptive statistics of the observed parameters

Observed element	Max value	Min value	Average value	Standard deviation
TA, °K	291.0	253.1	273.3	6.2
TSS, °K	304.0	251.8	271.8	7.0
TSG, °K	297.0	259.8	274.1	4.8
TA, °C	17.8	-20.1	0.1	6.2
TSS, °C	30.8	-21.4	-1.4	7.0
TSG, °C	23.8	-13.4	1.0	4.8
RH, %	100	26	76.1	14.8
PSUM, mm	8.4	0.0	0.1	0.3
HS, m	2.11	0.00	0.99	0.65
VW, m/s	13.8	0.1	3.6	2.2
VW_MAX, m/s	20.9	0.5	4.7	2.3
ISWR, W/m ²	1124.1	0.0	99.9	197.4
RSWR, W/m ²	891.4	0.0	56.5	120.7
ILWR, W/m ²	366.1	148.9	278.8	42.5

Figures 37–42 in Appendix A illustrate the observations made during the winter season 2015-2016.

Figure 39 in Appendix A shows that there is a considerable amount of doubtful observations of HS. Brown circles point out observations of snow cover up to about 30-35 cm high when air temperatures were still above 0°C. These observations might have been caused by, for example, grass growing by the foot of the station. Optical sensor used at the station to obtain snow height observations, might have taken reflection from the grass for a snow cover. This would also explain high variation in observed values from hour to hour in these periods. The observations should be considered as errors since there is no way to find out exactly whether a snow cover was present in these periods or not.

Red circles indicate obvious errors such as increase in snow height with more than 1 m over 1 day, and the same dramatic decrease the day after. These observations should be considered as errors and removed from the data set which is used for further analyses.

Pink circles point out snow height observations with high variability from measurement to measurement. Strong wind, rapid changes in air temperature and frequent events of snow and/or rain showers during the winter season 2015-2016 might have caused these observations in a natural way. However, the observed variation of about 1 m snow height up and down several times during several consequent days brings up some doubts in the validity of the observations. Besides it was reported at the end of the observation season that the HS-sensor was not properly fixed to the mast. This could cause fluctuations in the sensor's observation line due to e.g. wind.

It is recommended to consider these arguments and eventually remove doubtful observations before using the data for any further analyses.

8.3 Editing the HS-data

Since the observations of snow height HS incorporated obvious errors, an attempt of a filter was made to adjust the observed HS-values to the reality. However, the amount of unrealistic measurements and their nature made filter-writing work too difficult and time-consuming. Taking into account that these errors occurred just in the season 2015-2016, and the sensors undergone service and calibration before the next season, it was decided to make the corrections manually. The result of the corrections can be found in Figure 43, Appendix A.

Appendix A

DATA DIAGRAMS

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A1	Winter season 2009-2010	2
A2	Winter season 2010-2011	6
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A4	Winter season 2012-2013	14
A5	Winter season 2013-2014	18
A6	Winter season 2014-2015	22
A7	Winter season 2015-2016	26

A1 Winter season 2009-2010

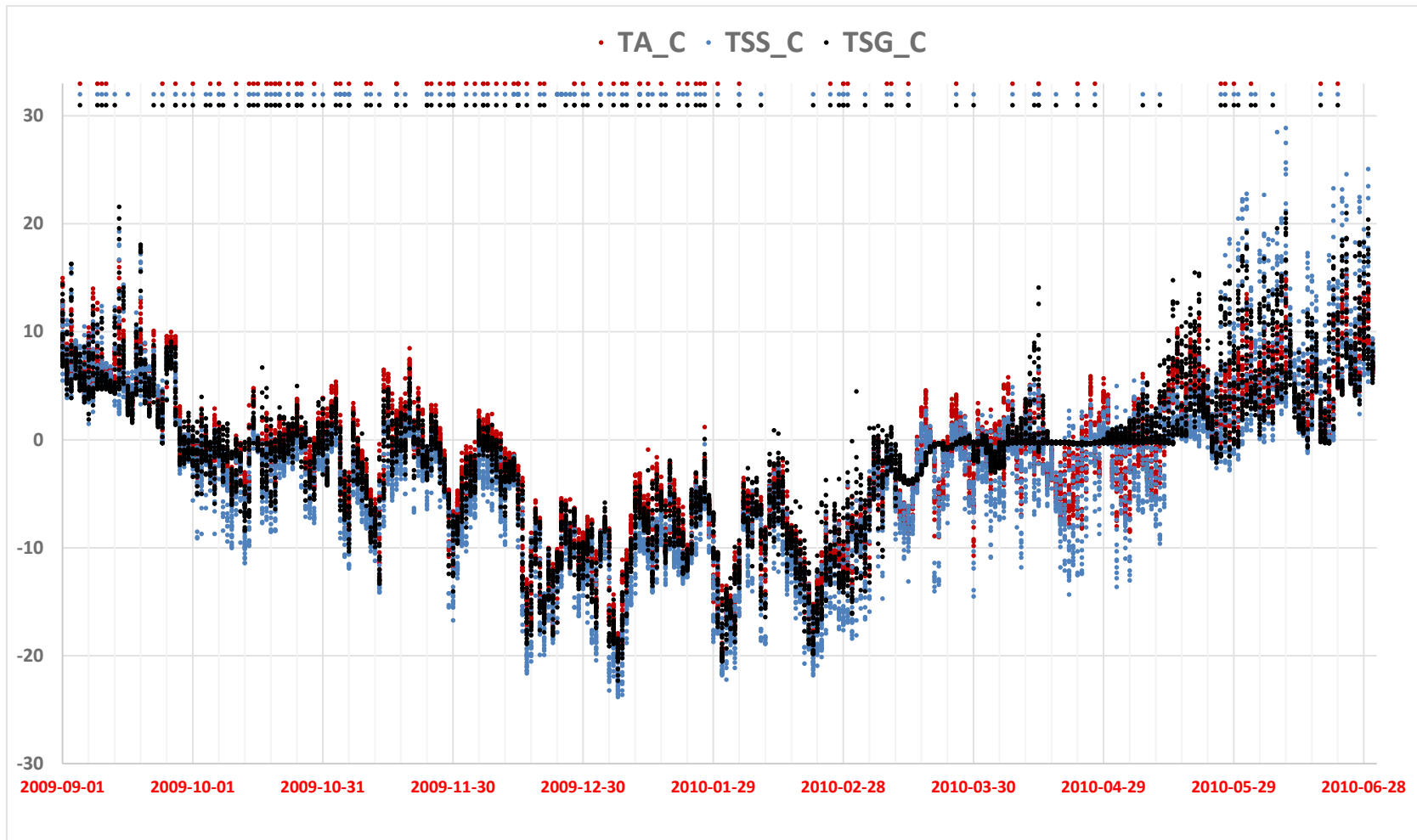


Figure 1 Air temperature (TA), temperature of snow surface (TSS) and ground surface temperature (TSG) in °C. Missing values/errors are indicated at the top of the diagram.

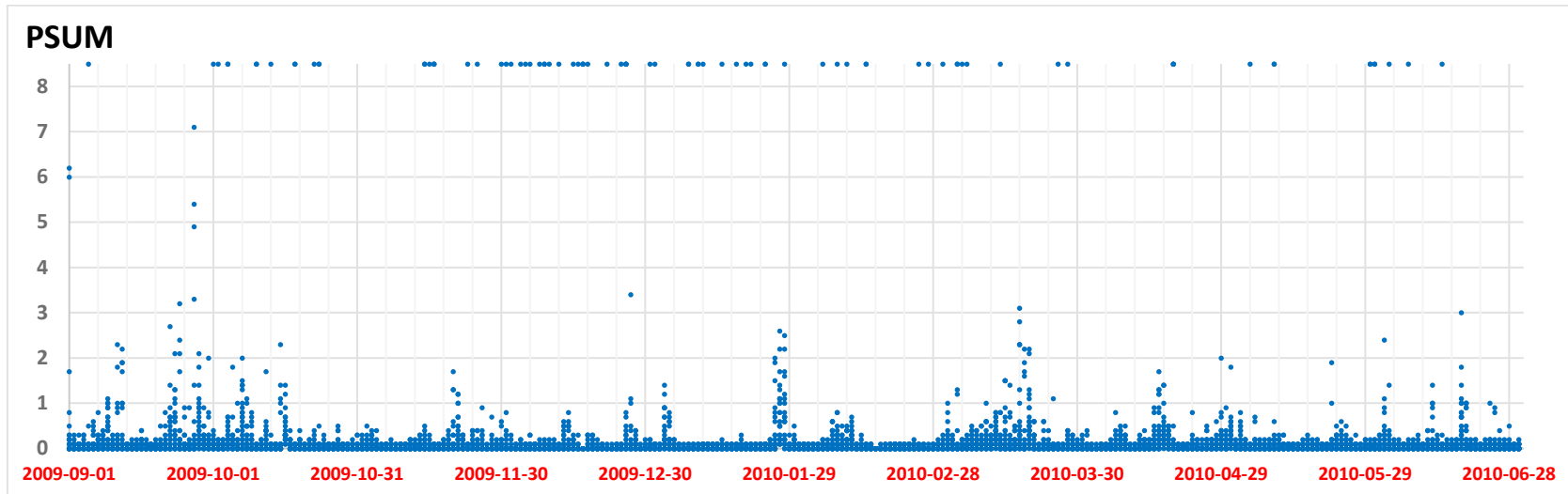


Figure 2 Precipitation (PSUM) in mm/hour. Missing values/errors are indicated at the top of the diagram.

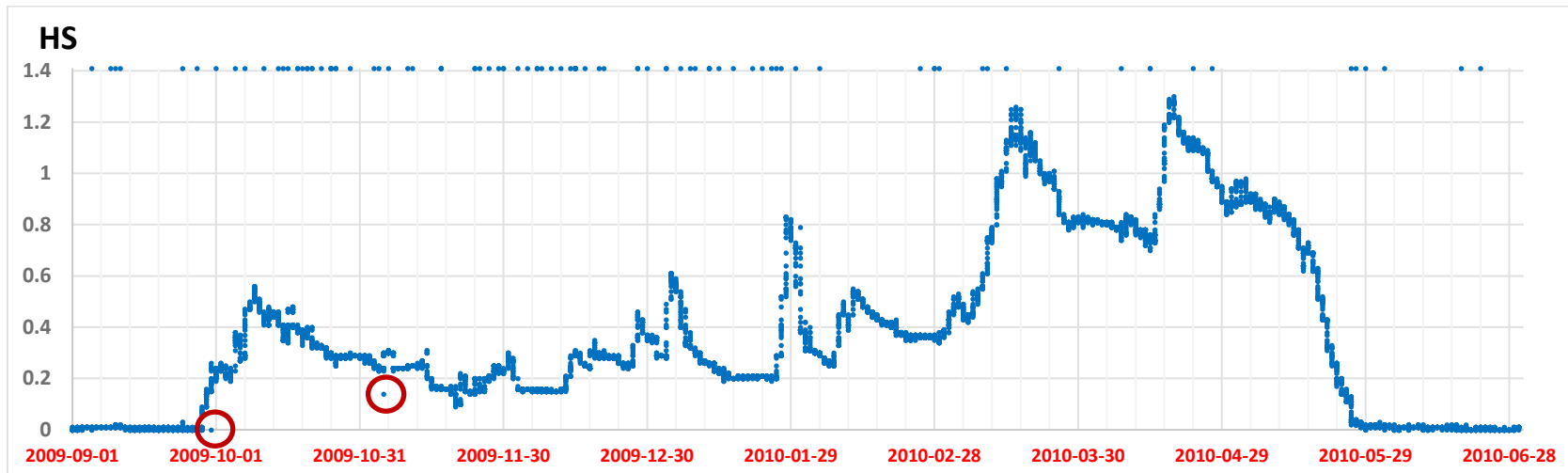


Figure 3 Snow height (HS) in m. Missing values/errors are indicated at the top of the diagram.

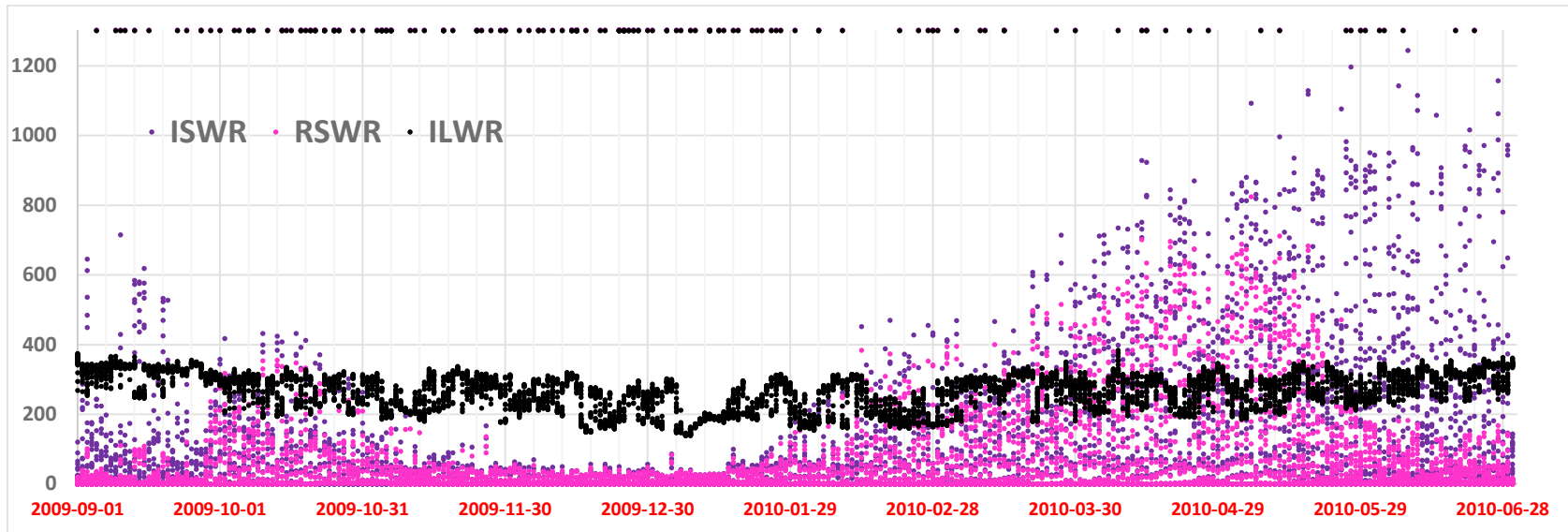


Figure 4 Incoming (ISWR) and reflected (RSWR) shortwave and incoming longwave (ILWR) radiation in W/m^2 . Missing values/errors are indicated at the top of the diagram.

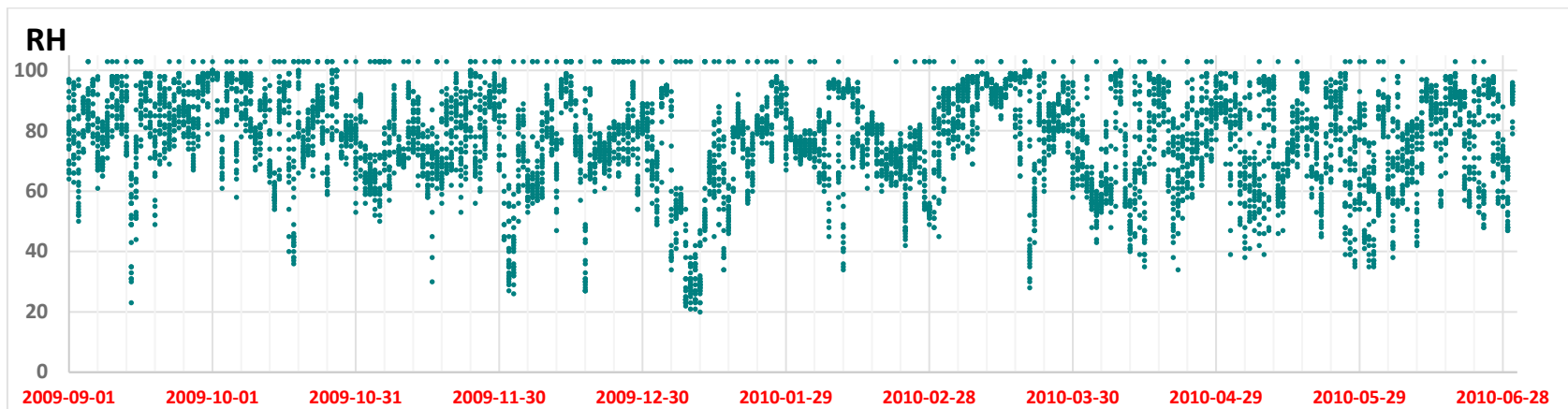


Figure 5 Relative humidity in %. Missing values/errors are indicated at the top of the diagram.

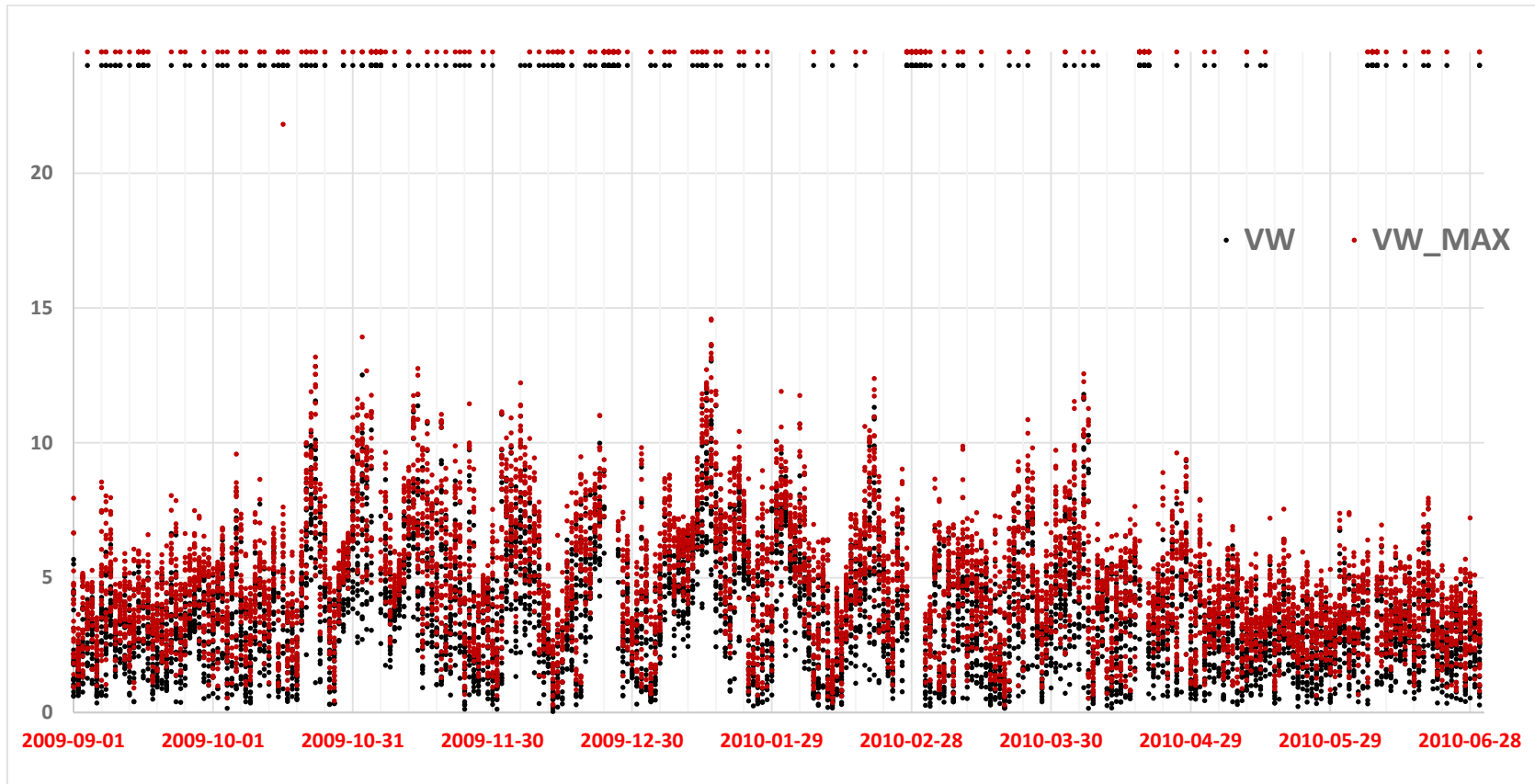


Figure 6 Average (VW) and maximum (VW_MAX) wind velocity last hour in m/s. Missing values/errors are indicated at the top of the diagram.

A2 Winter season 2010-2011

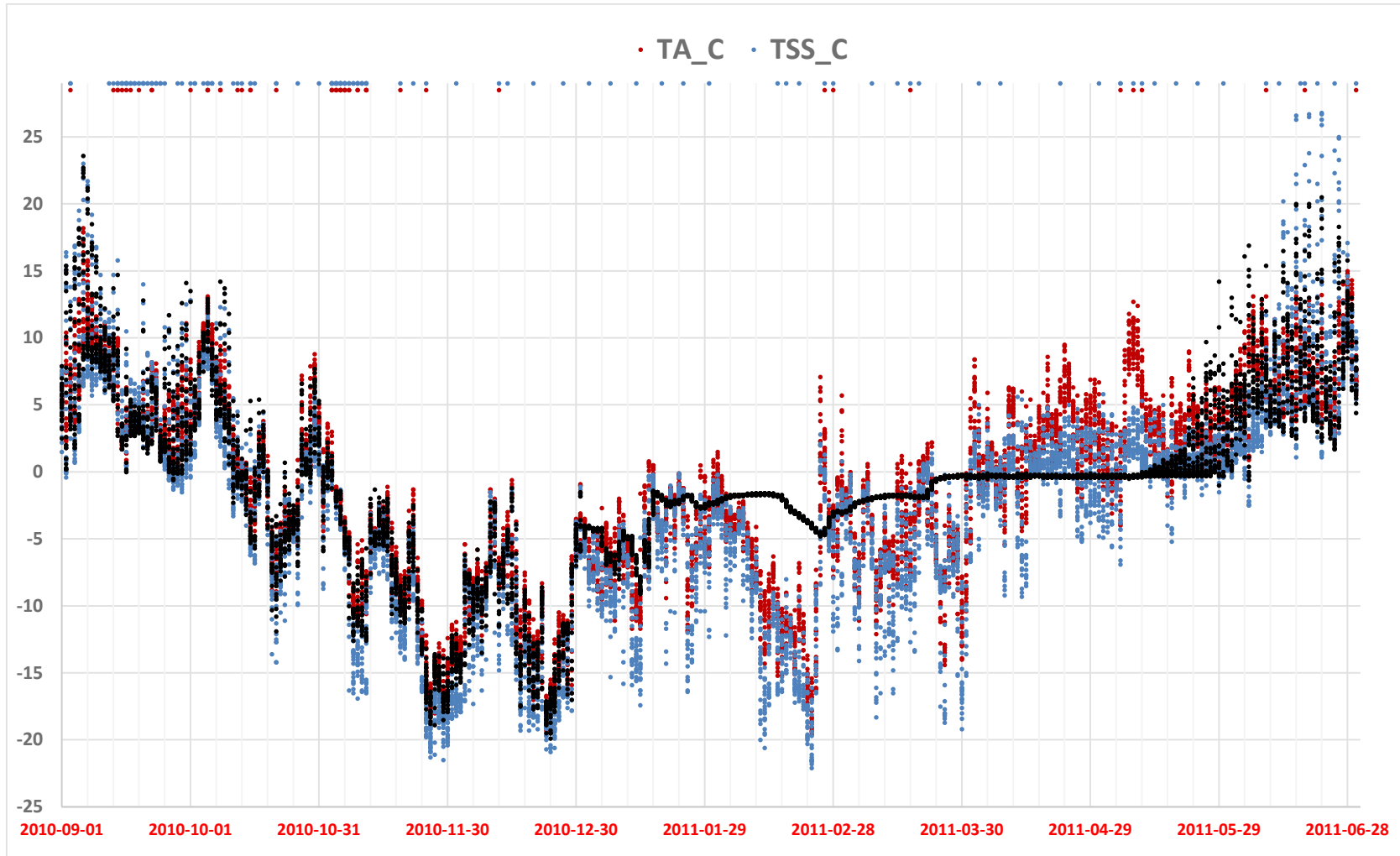


Figure 7 Air temperature (TA), temperature of snow surface (TSS) and ground surface temperature (TSG) in °C. Missing values/errors are indicated at the top of the diagram.

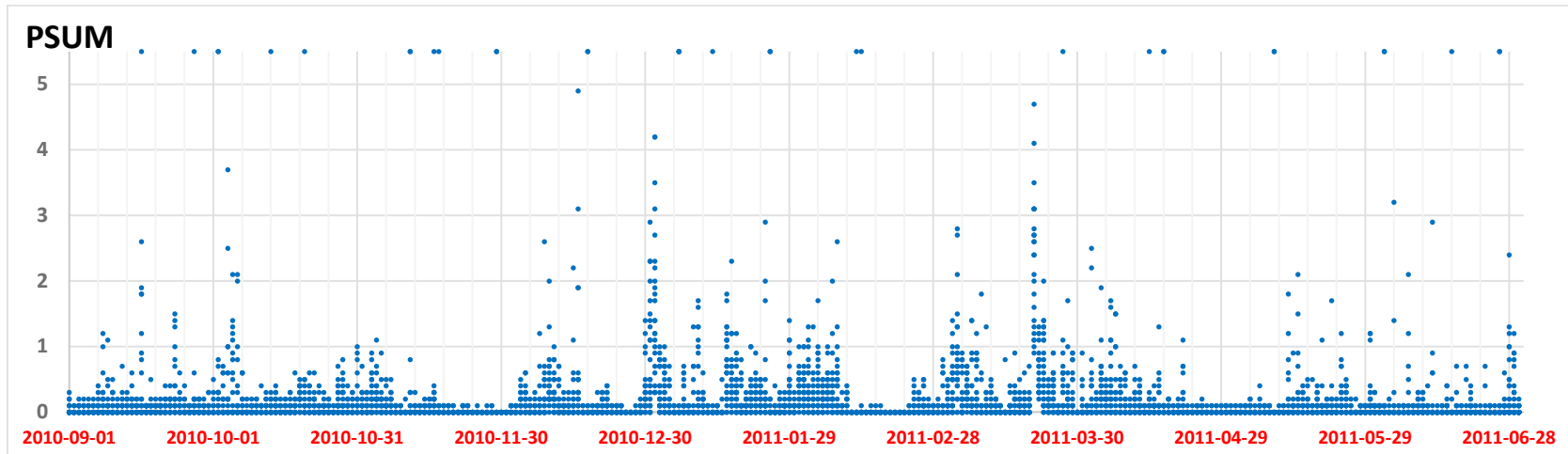


Figure 8 Precipitation (PSUM) in mm/hour. Missing values/errors are indicated at the top of the diagram.

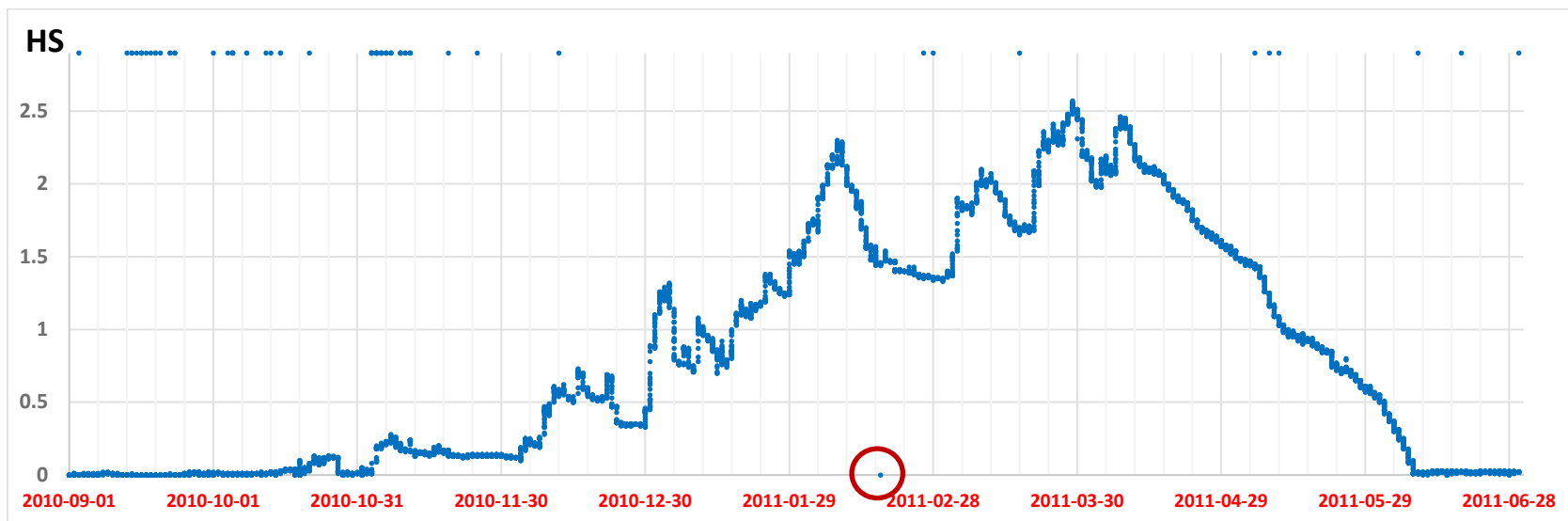


Figure 9 Snow height (HS) in m. Missing values/errors are indicated at the top of the diagram.

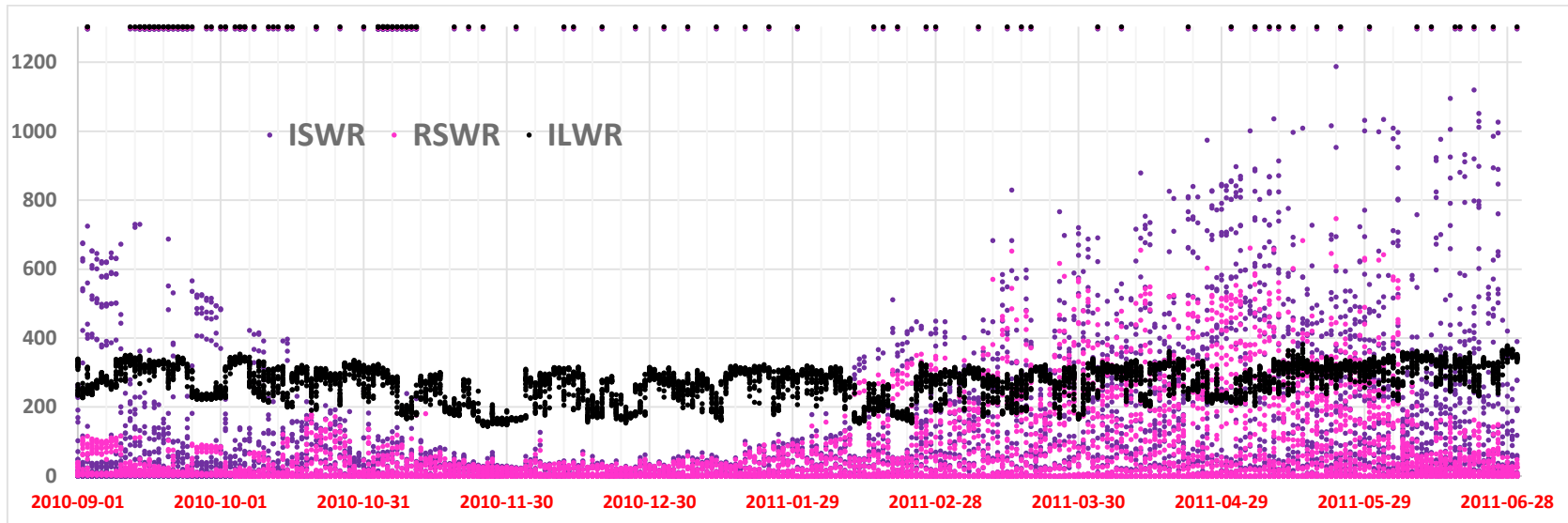


Figure 10 Incoming (ISWR) and reflected (RSWR) shortwave and incoming longwave (ILWR) radiation in W/m^2 . Missing values/errors are indicated at the top of the diagram.

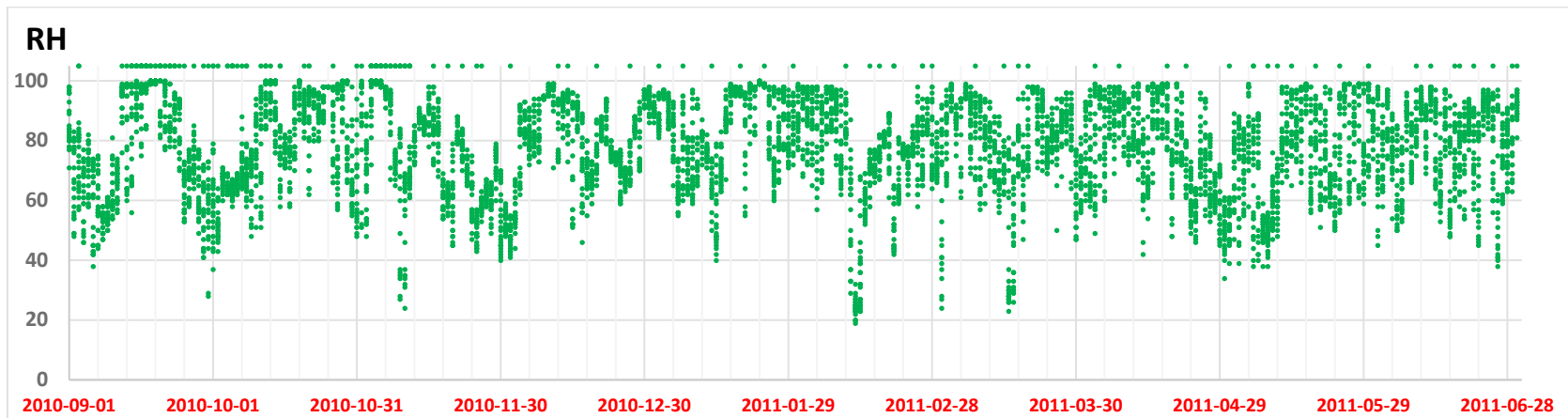


Figure 11 Relative humidity in %. Missing values/errors are indicated at the top of the diagram.

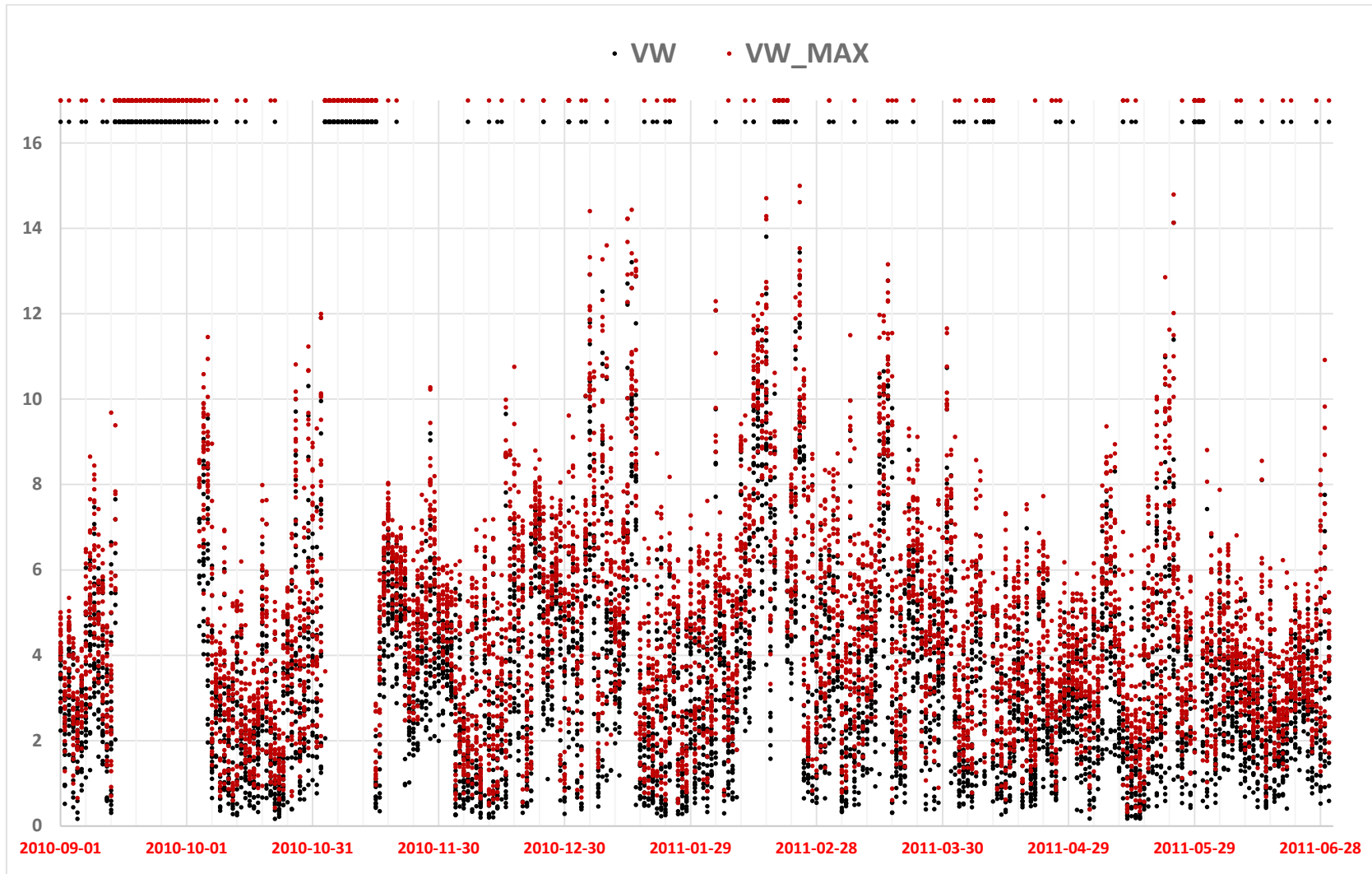


Figure 12 Average (VW) and maximum (VW_MAX) wind velocity last hour in m/s. Missing values/errors are indicated at the top of the diagram.

A3 Winter season 2011-2012

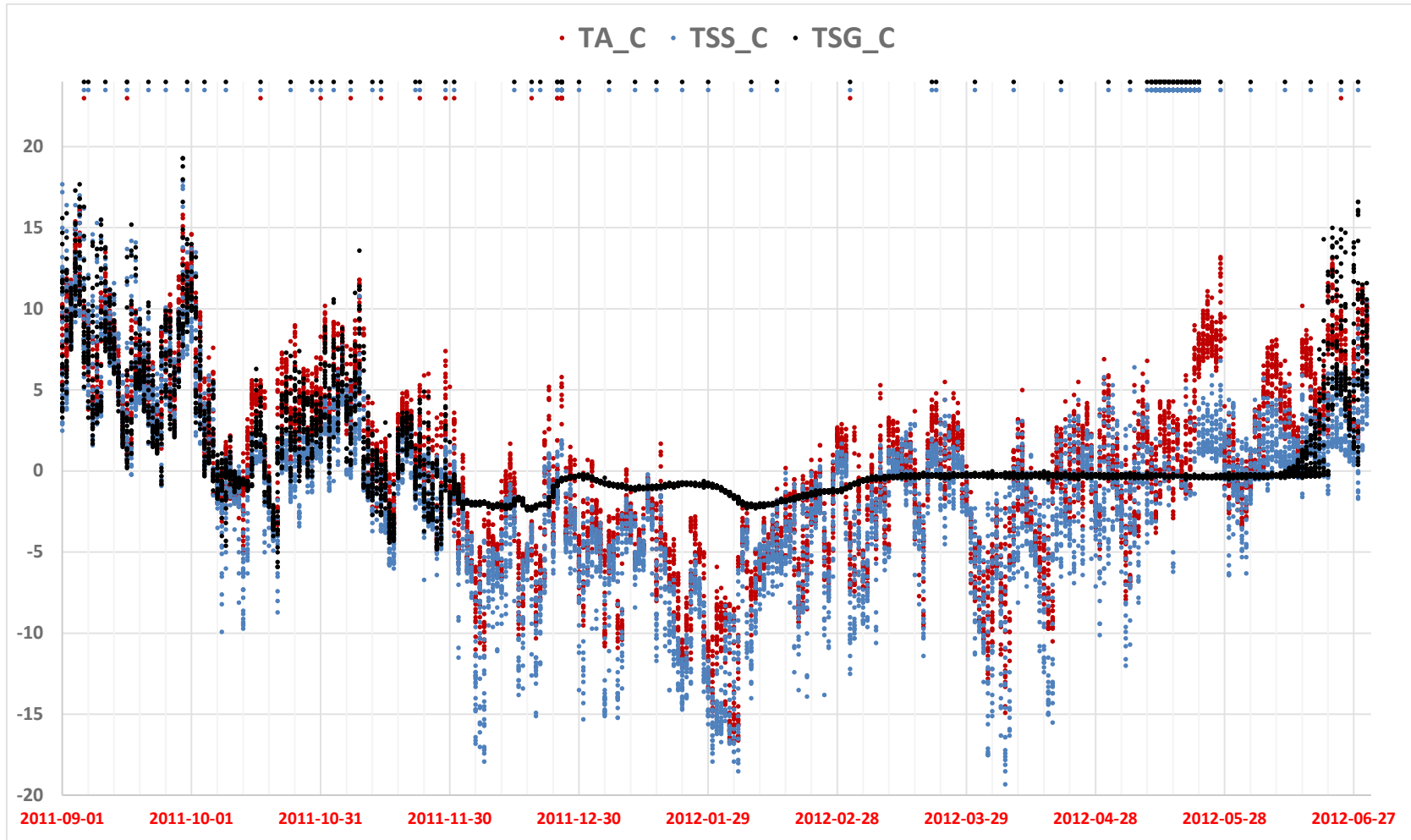


Figure 13 Air temperature (TA), temperature of snow surface (TSS) and ground surface temperature (TSG) in °C. Missing values/errors are indicated at the top of the diagram.

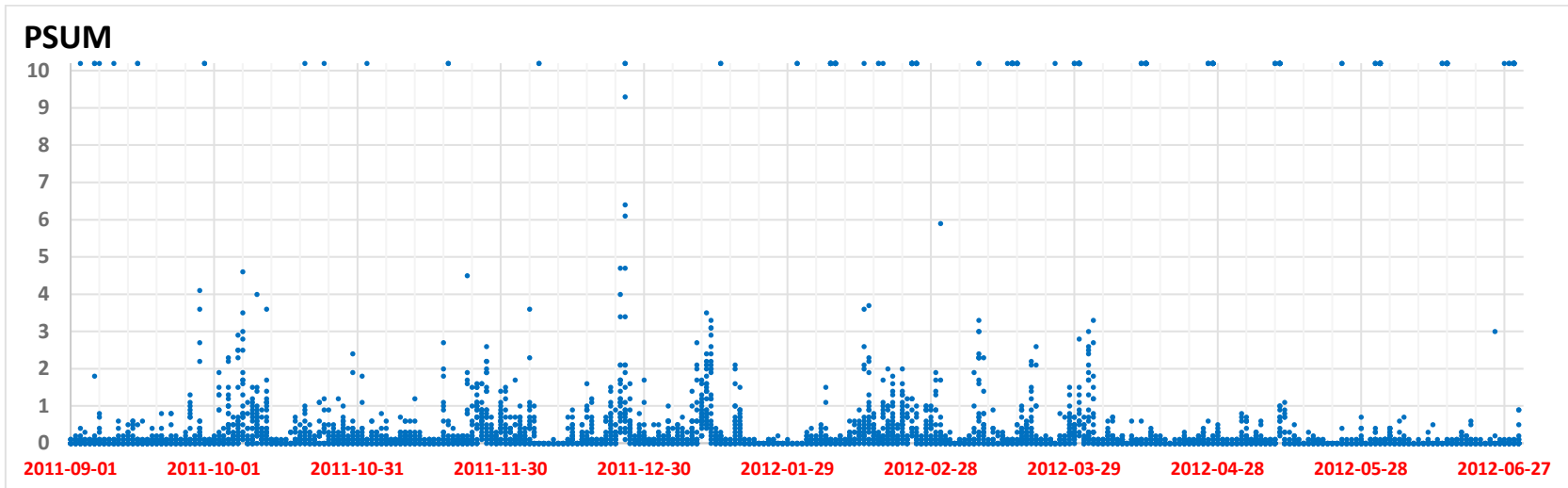


Figure 14 Precipitation (PSUM) in mm/hour. Missing values/errors are indicated at the top of the diagram.

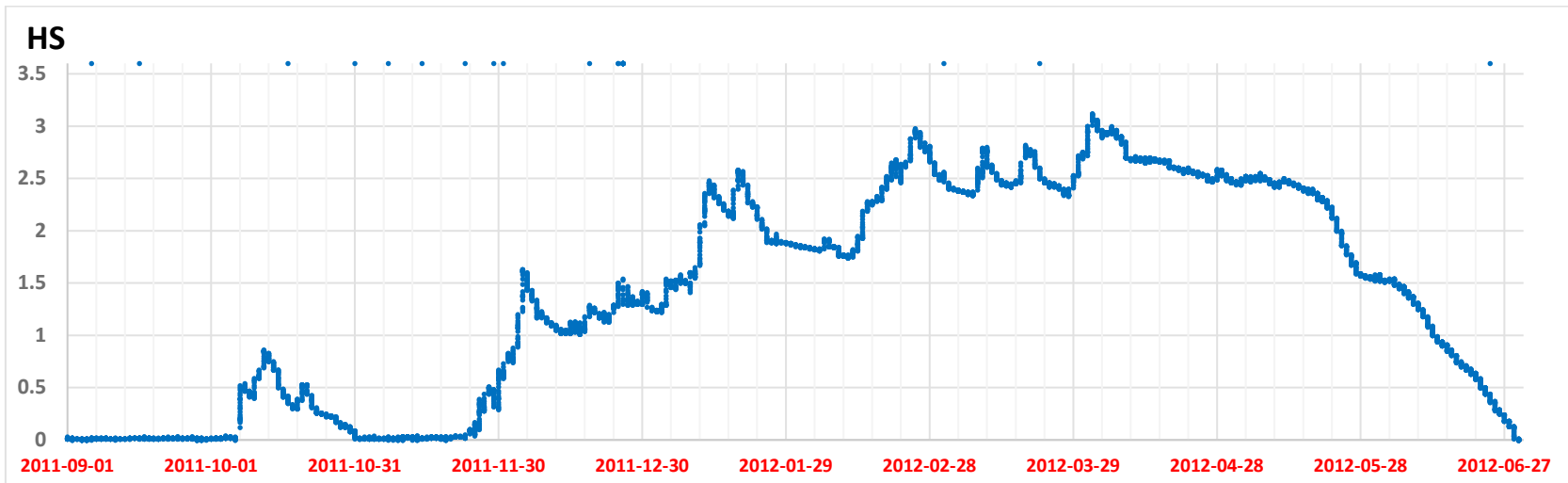


Figure 15 Snow height (HS) in m. Missing values/errors are indicated at the top of the diagram.

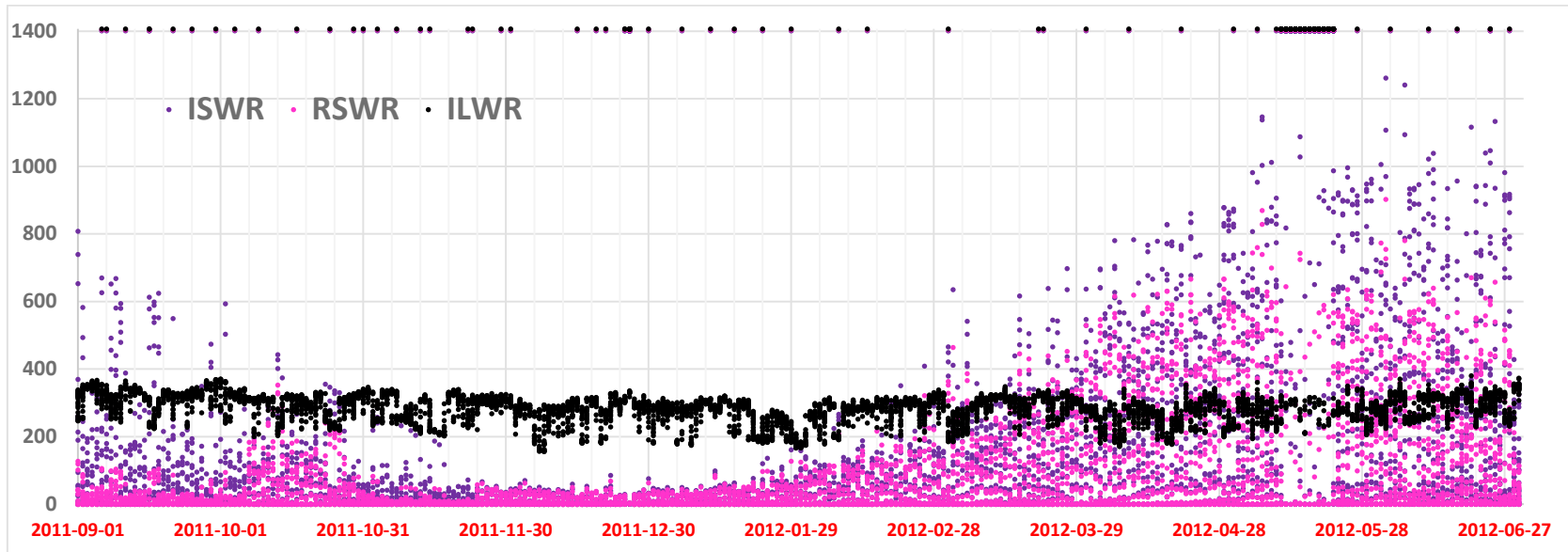


Figure 16 Incoming (ISWR) and reflected (RSWR) shortwave and incoming longwave (ILWR) radiation in W/m^2 . Missing values/errors are indicated at the top of the diagram.

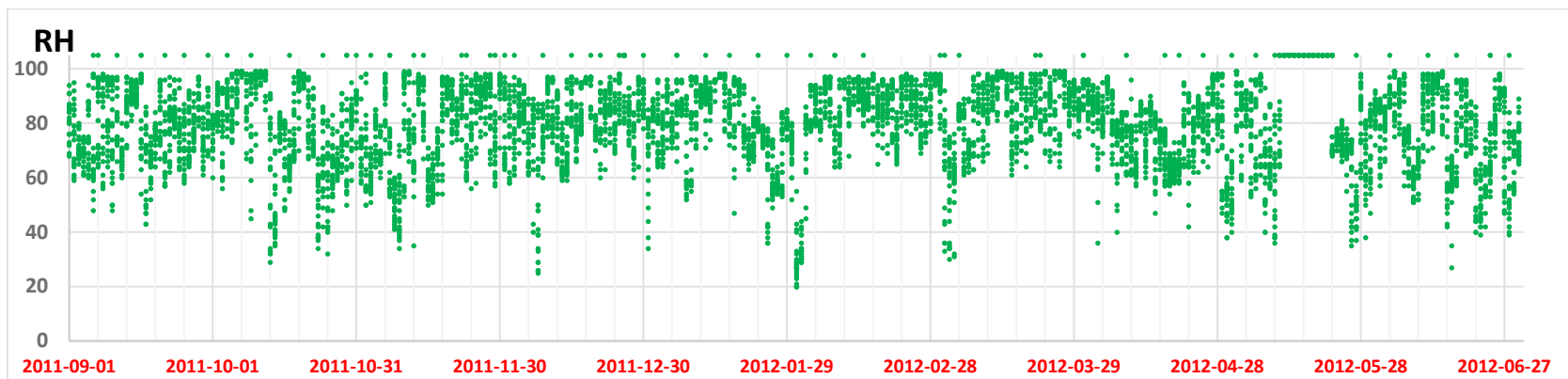


Figure 17 Relative humidity in %. Missing values/errors are indicated at the top of the diagram.

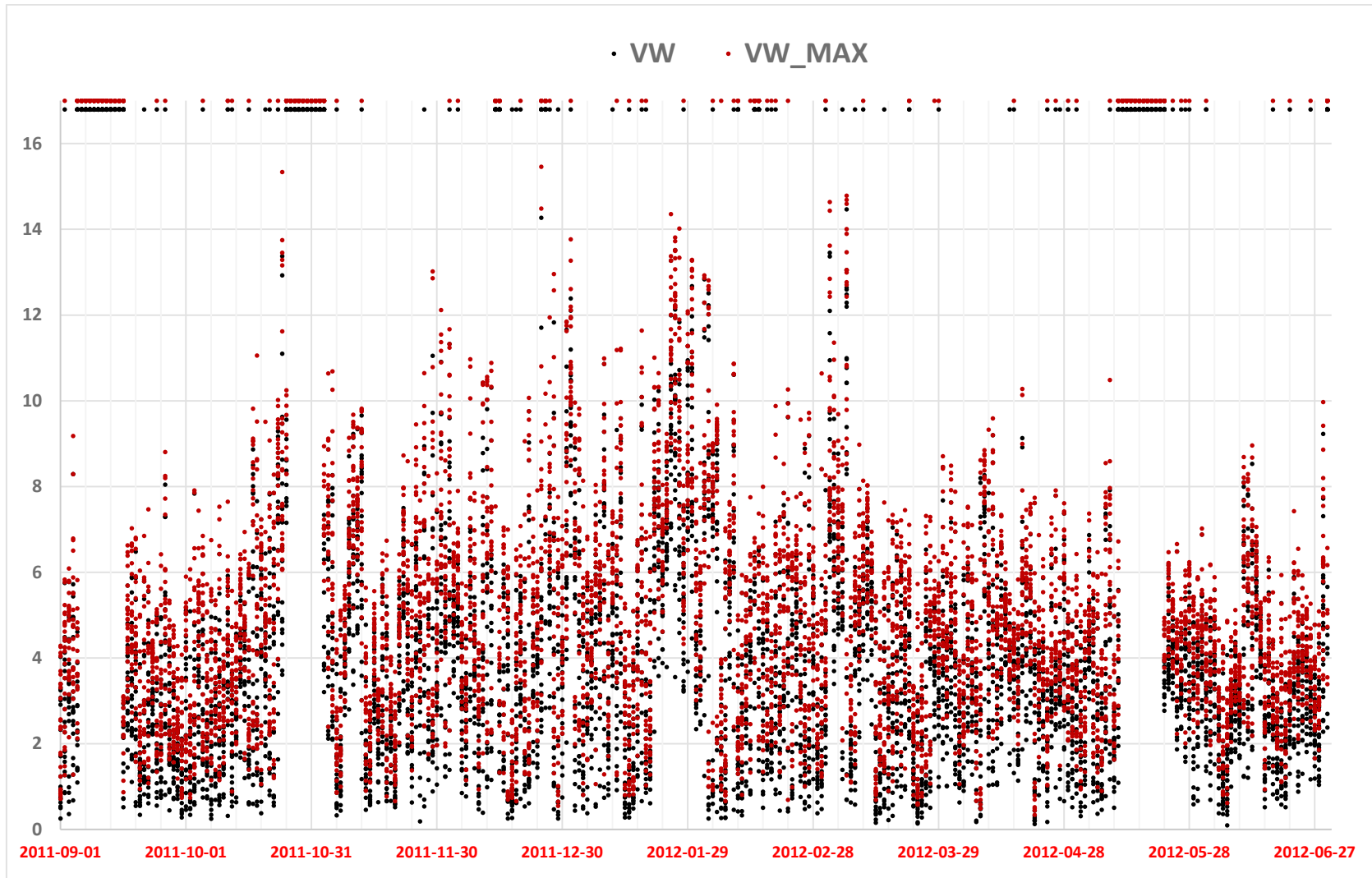


Figure 18 Average (VW) and maximum (VW_MAX) wind velocity last hour in m/s. Missing values/errors are indicated at the top of the diagram.

A4 Winter season 2012-2013

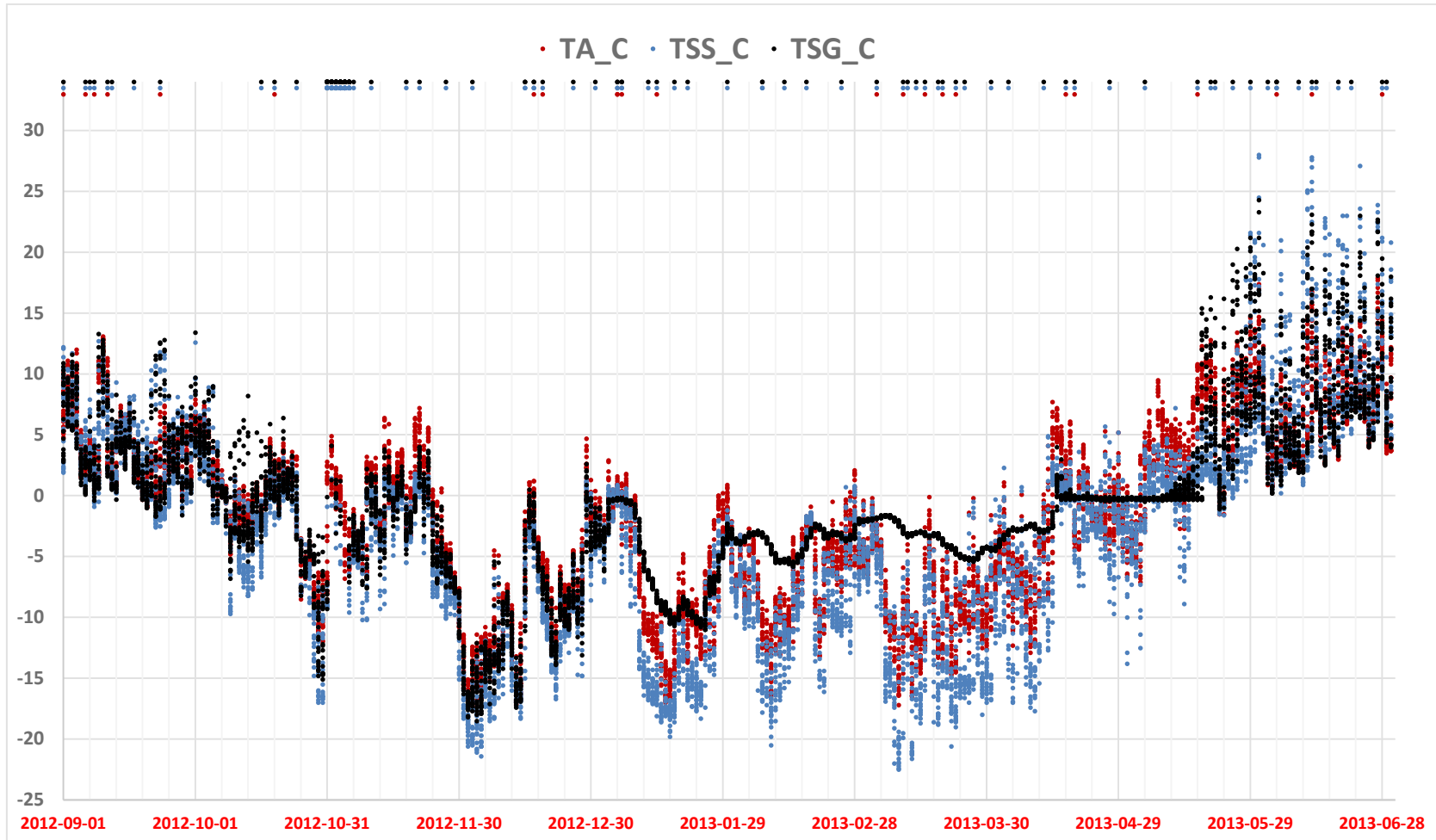


Figure 19 Air temperature (TA), temperature of snow surface (TSS) and ground surface temperature (TSG) in °C. Missing values/errors are indicated at the top of the diagram.

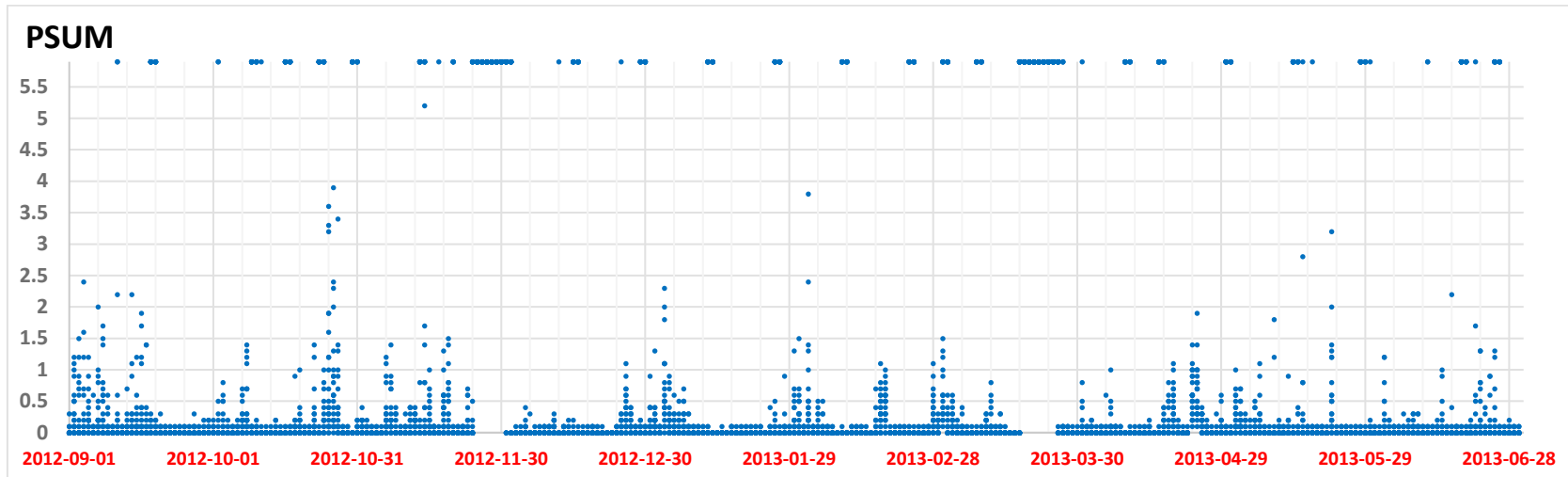


Figure 20 Precipitation (PSUM) in mm/hour. Missing values/errors are indicated at the top of the diagram.

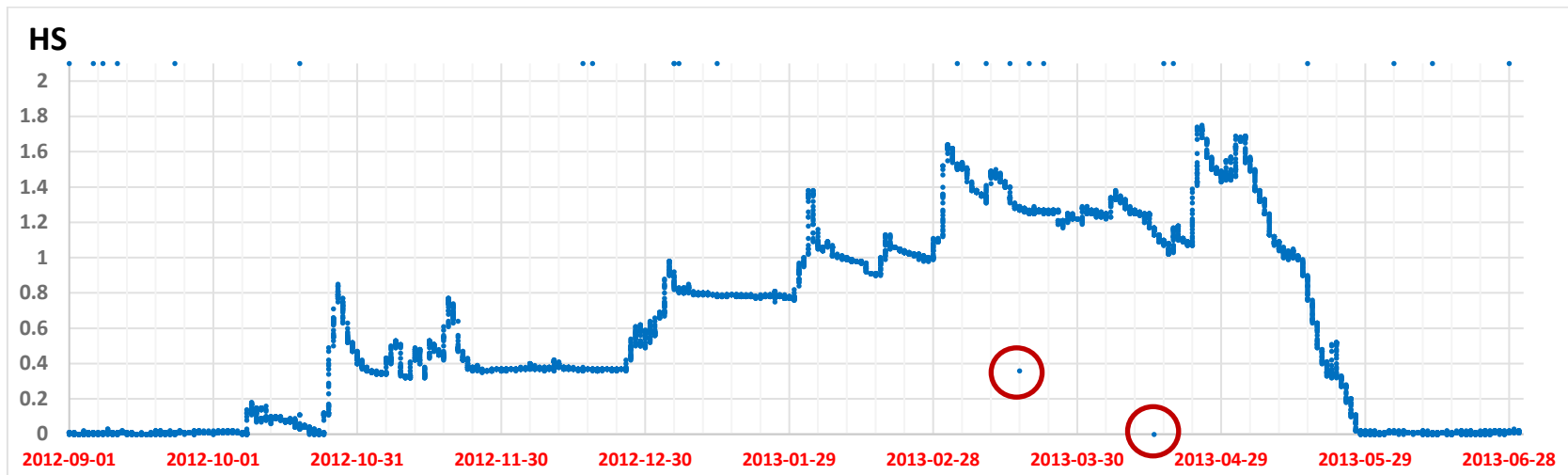


Figure 21 Snow height (HS) in m. Missing values/errors are indicated at the top of the diagram.

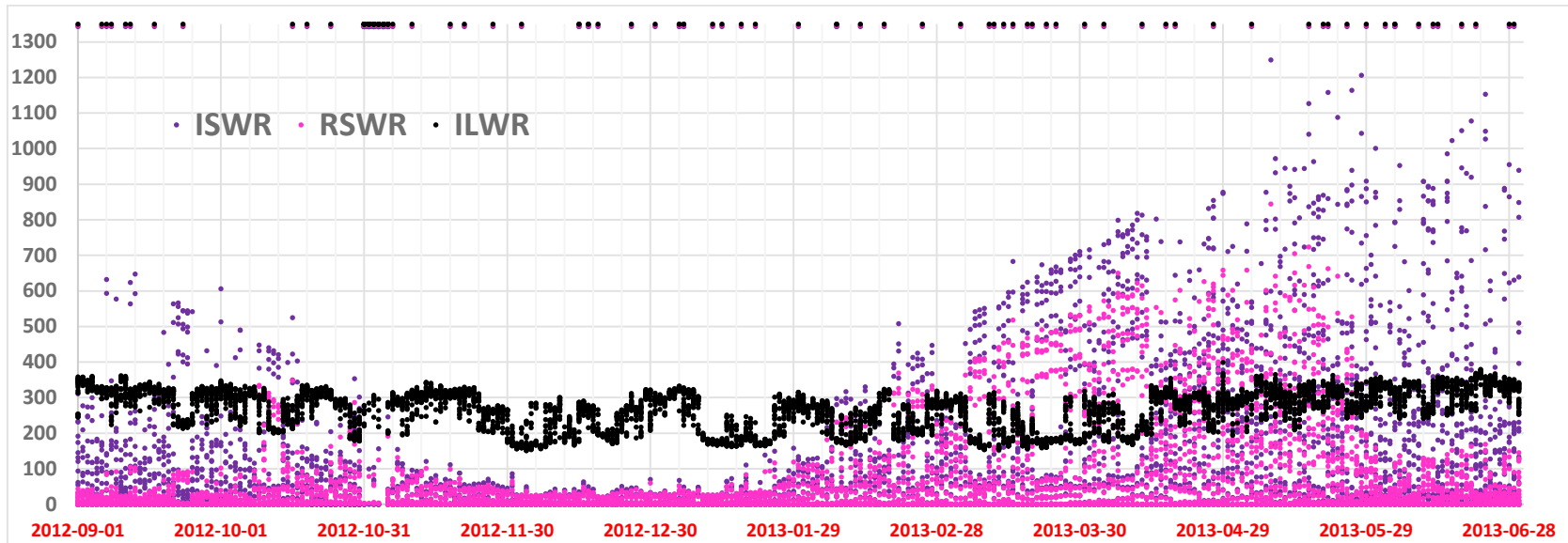


Figure 22 Incoming (ISWR) and reflected (RSWR) shortwave and incoming longwave (ILWR) radiation in W/m^2 . Missing values/errors are indicated at the top of the diagram.

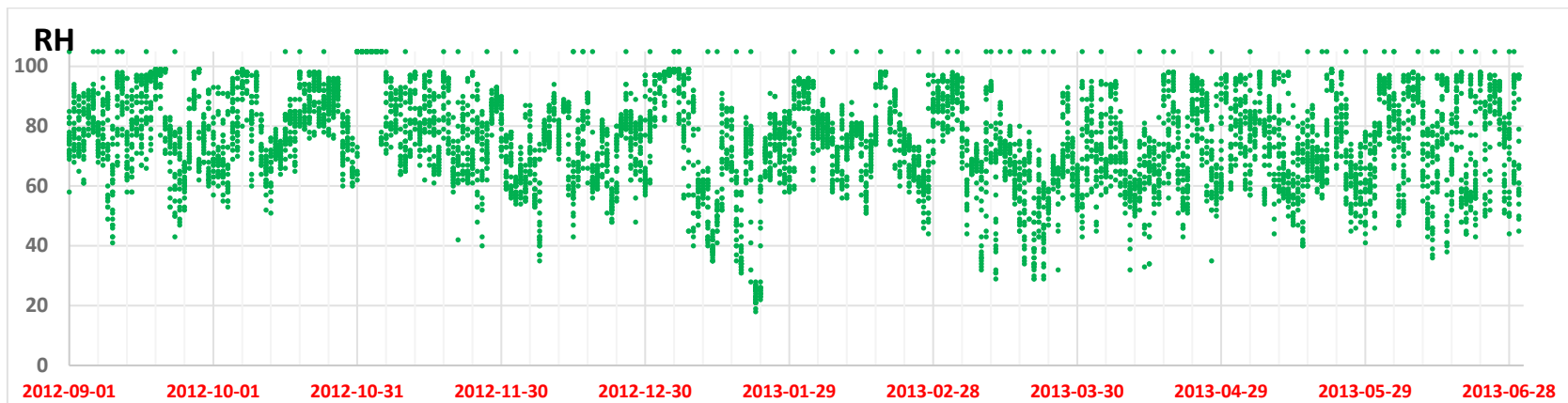


Figure 23 Relative humidity in %. Missing values/errors are indicated at the top of the diagram.

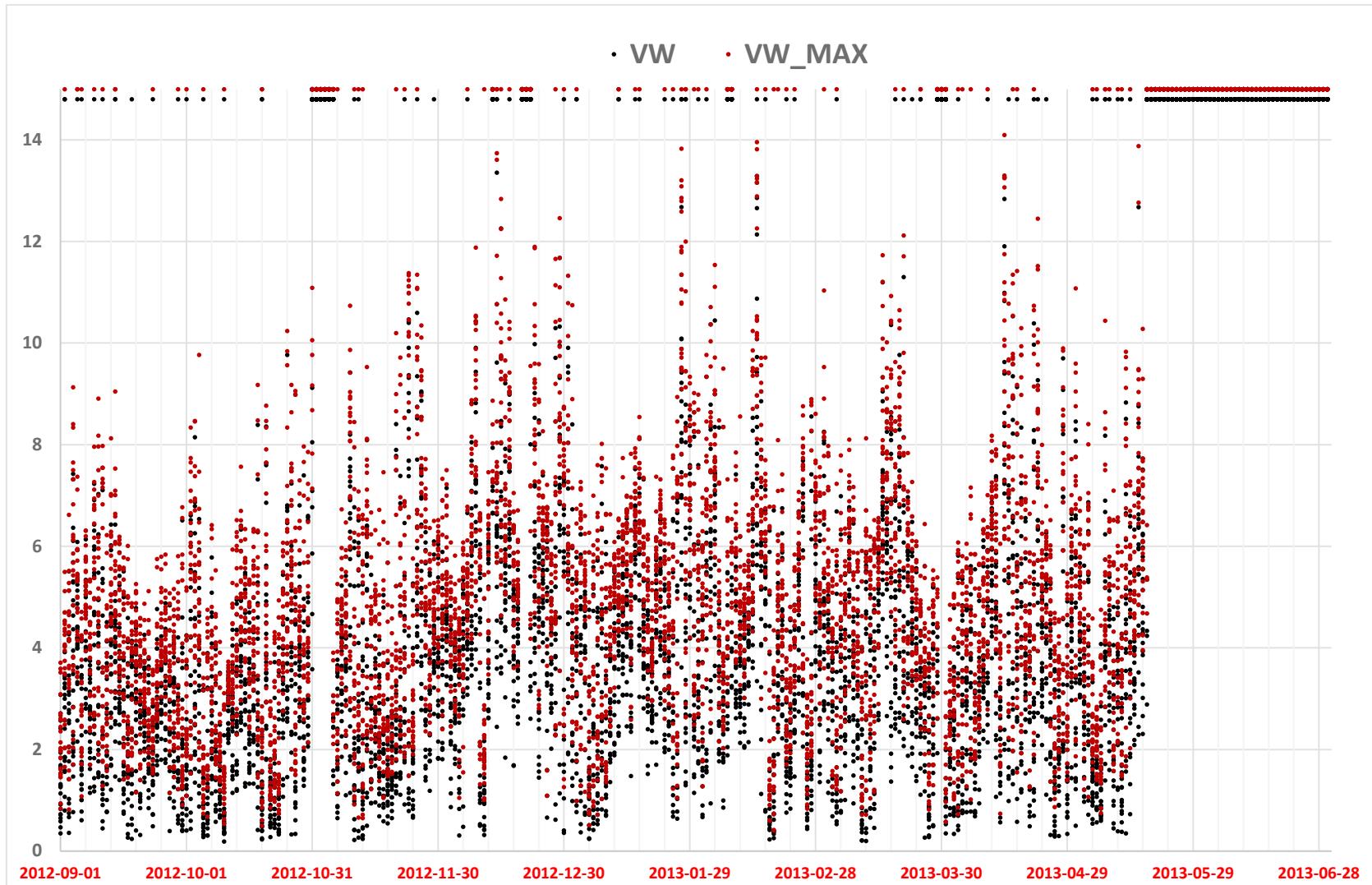


Figure 24 Average (VW) and maximum (VW_MAX) wind velocity last hour in m/s. Missing values/errors are indicated at the top of the diagram.

A5 Winter season 2013-2014

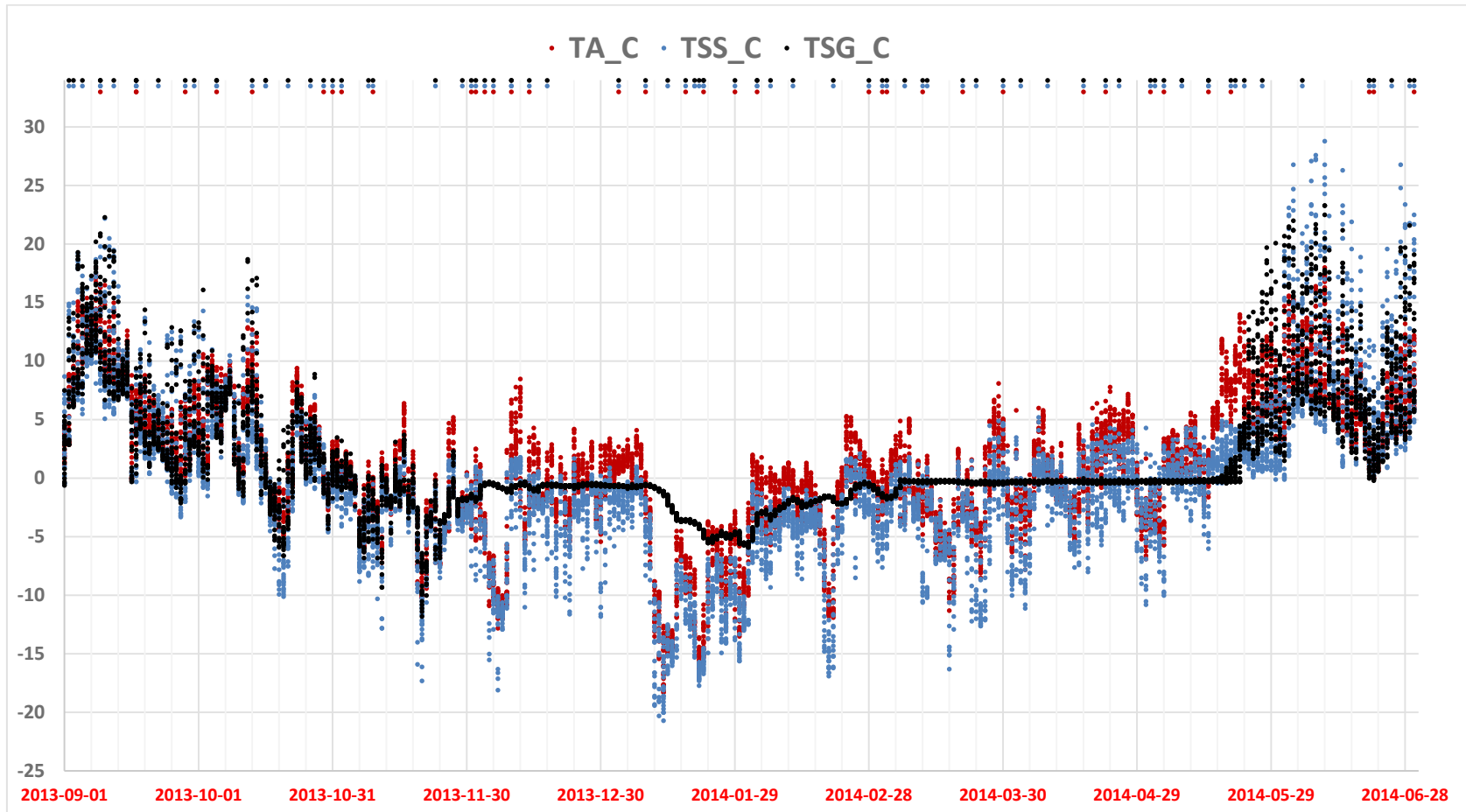


Figure 25 Air temperature (TA), temperature of snow surface (TSS) and ground surface temperature (TSG) in °C. Missing values/errors are indicated at the top of the diagram.

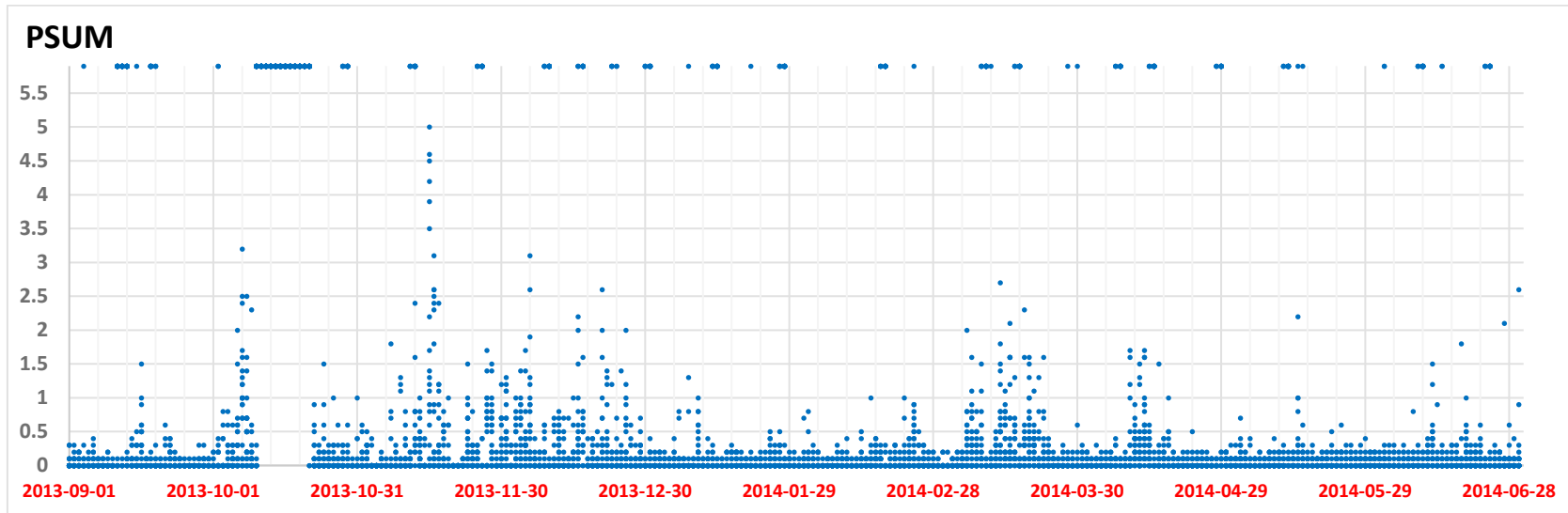


Figure 26 Precipitation (PSUM) in mm/hour. Missing values/errors are indicated at the top of the diagram.

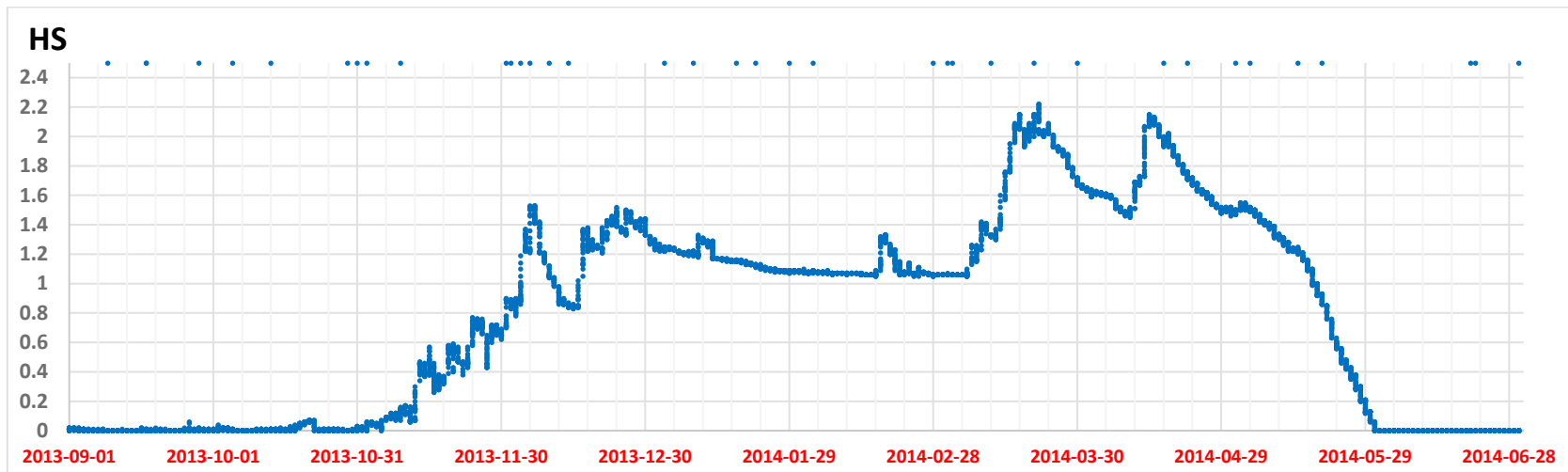


Figure 27 Snow height (HS) in m. Missing values/errors are indicated at the top of the diagram.

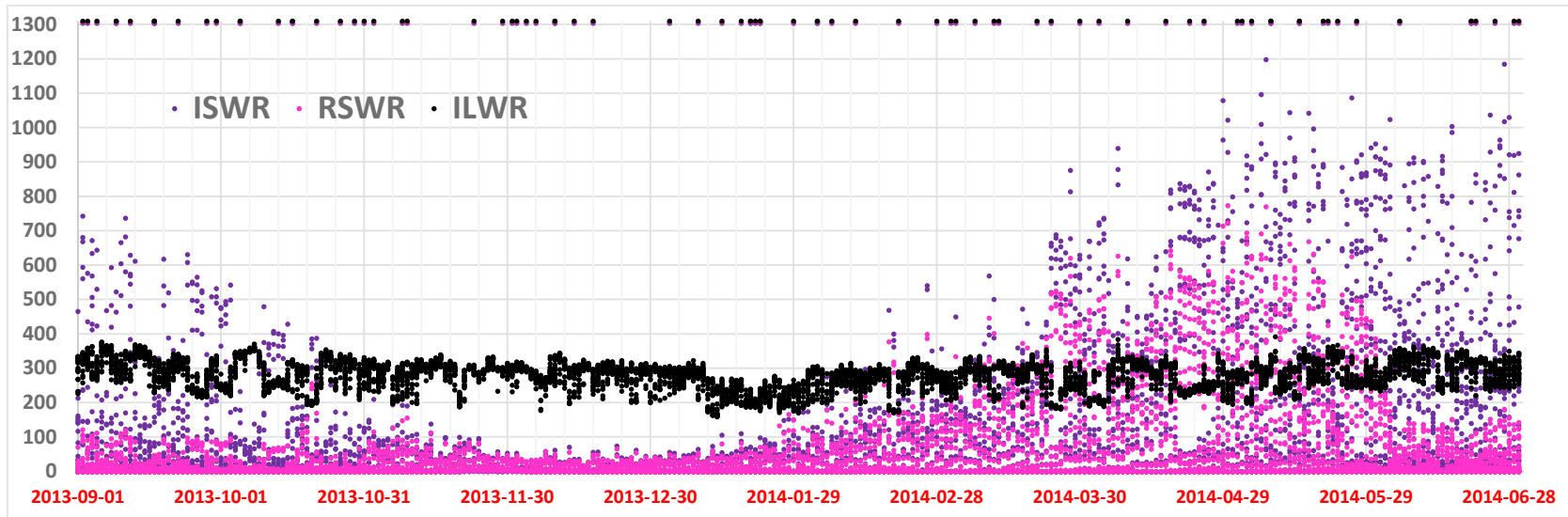


Figure 28 Incoming (ISWR) and reflected (RSWR) shortwave and incoming longwave (ILWR) radiation in W/m^2 . Missing values/errors are indicated at the top of the diagram.

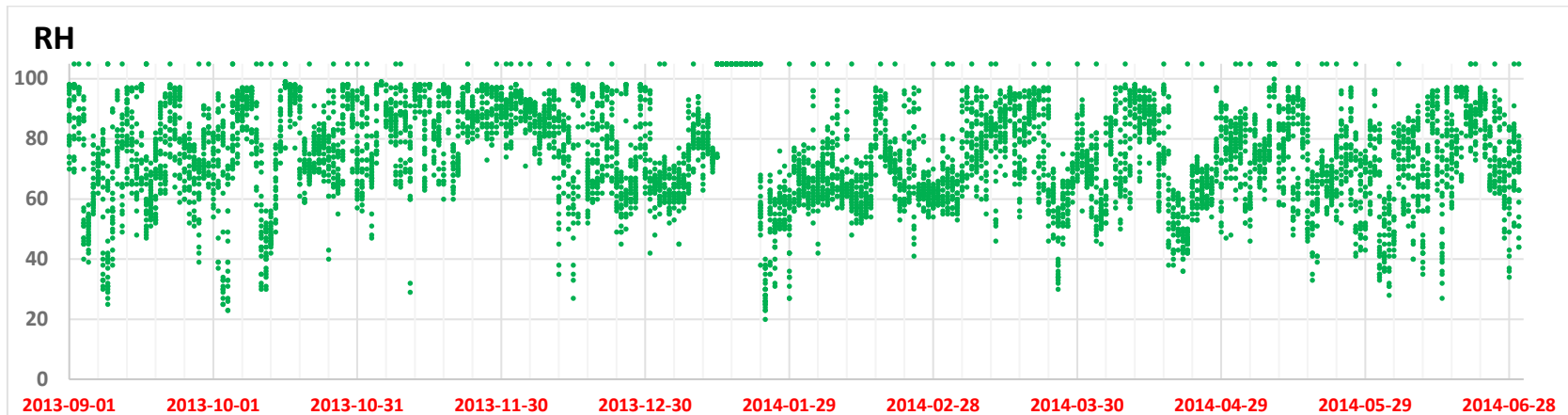


Figure 29 Relative humidity in %. Missing values/errors are indicated at the top of the diagram.

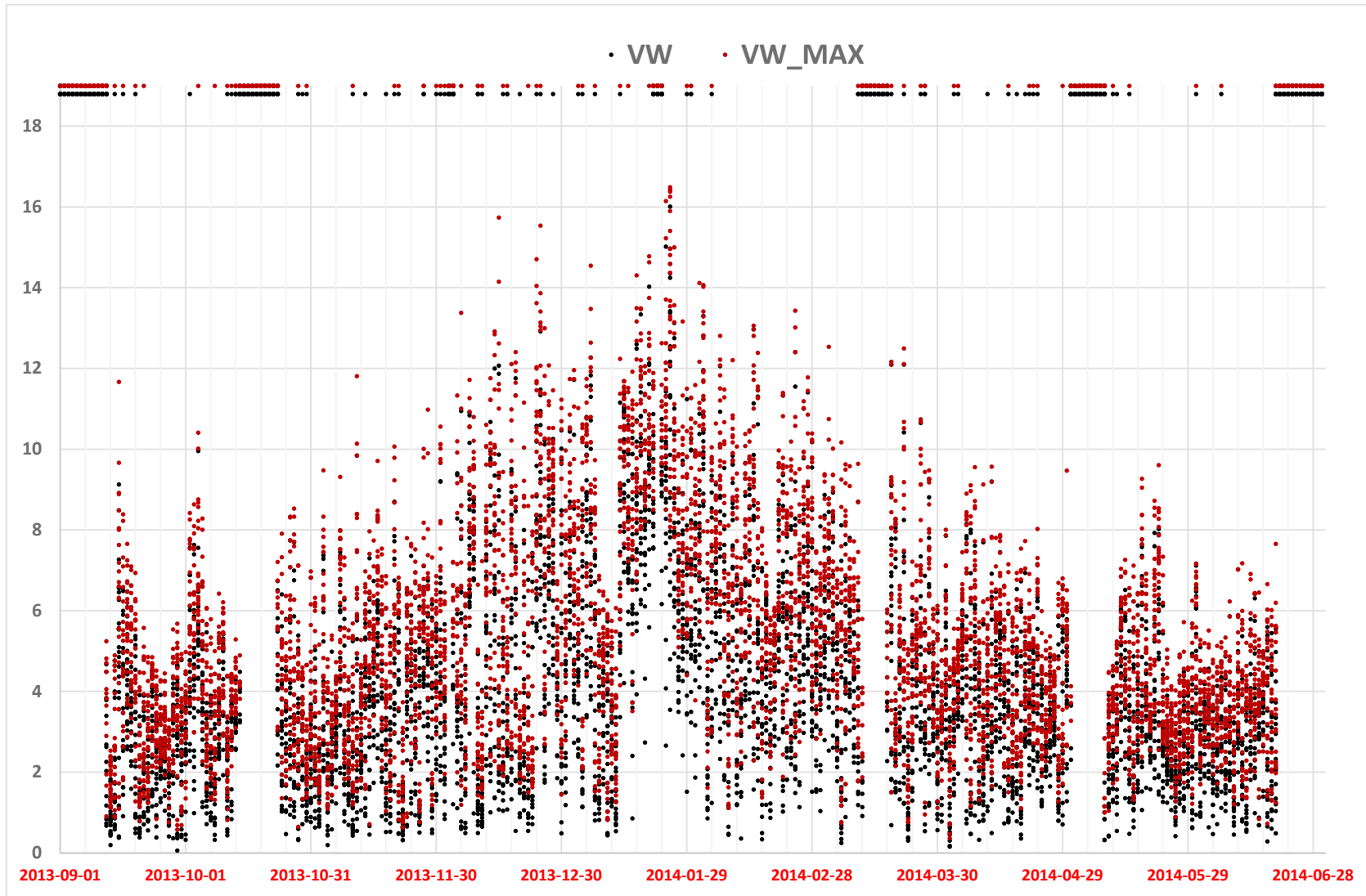


Figure 30 Average (VW) and maximum (VW_MAX) wind velocity last hour in m/s. Missing values/errors are indicated at the top of the diagram.

A6 Winter season 2014-2015

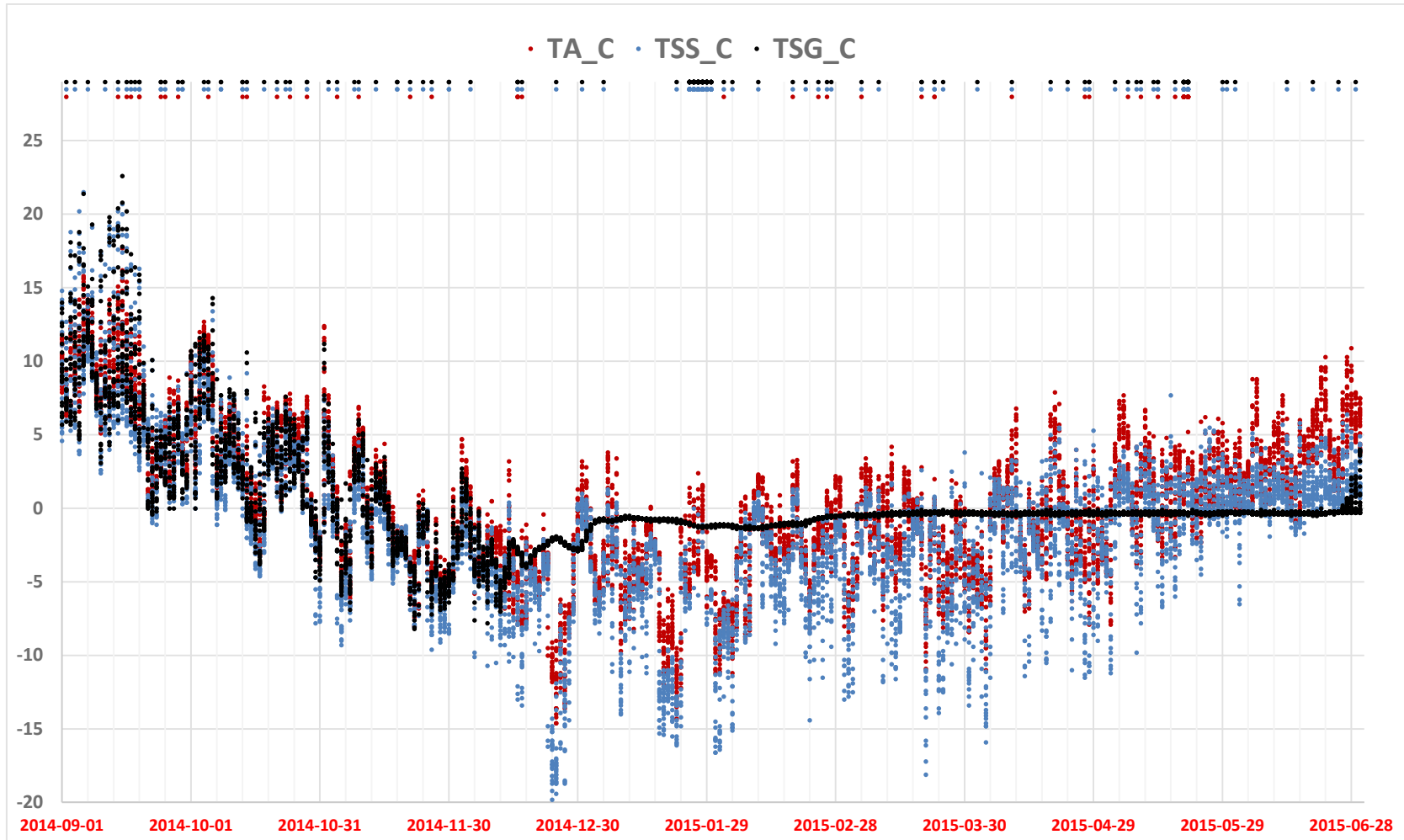


Figure 31 Air temperature (TA), temperature of snow surface (TSS) and ground surface temperature (TSG) in °C. Missing values/errors are indicated at the top of the diagram.

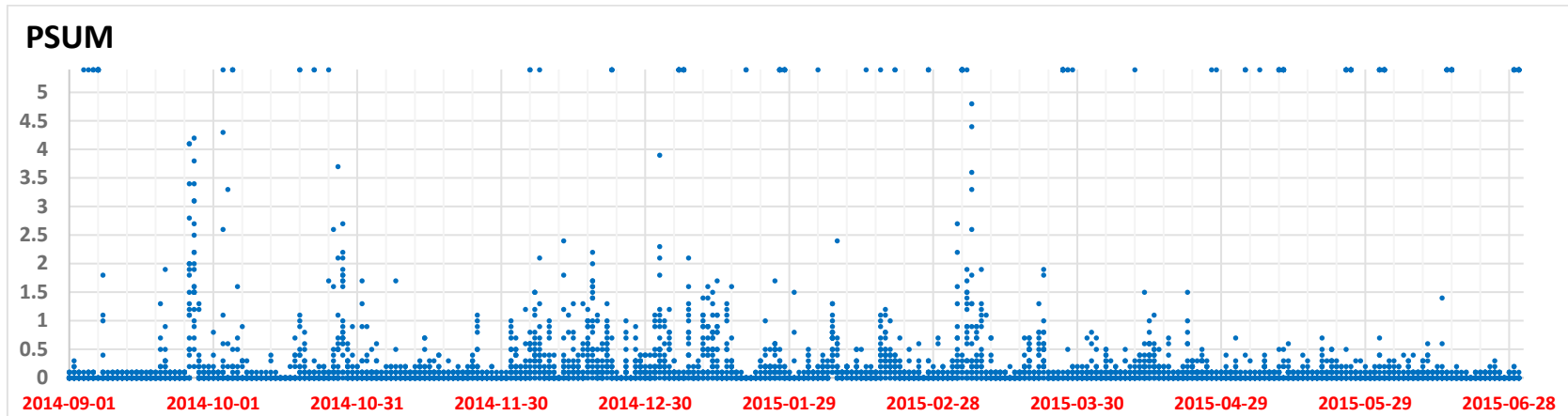


Figure 32 Precipitation (PSUM) in mm/hour. Missing values/errors are indicated at the top of the diagram.

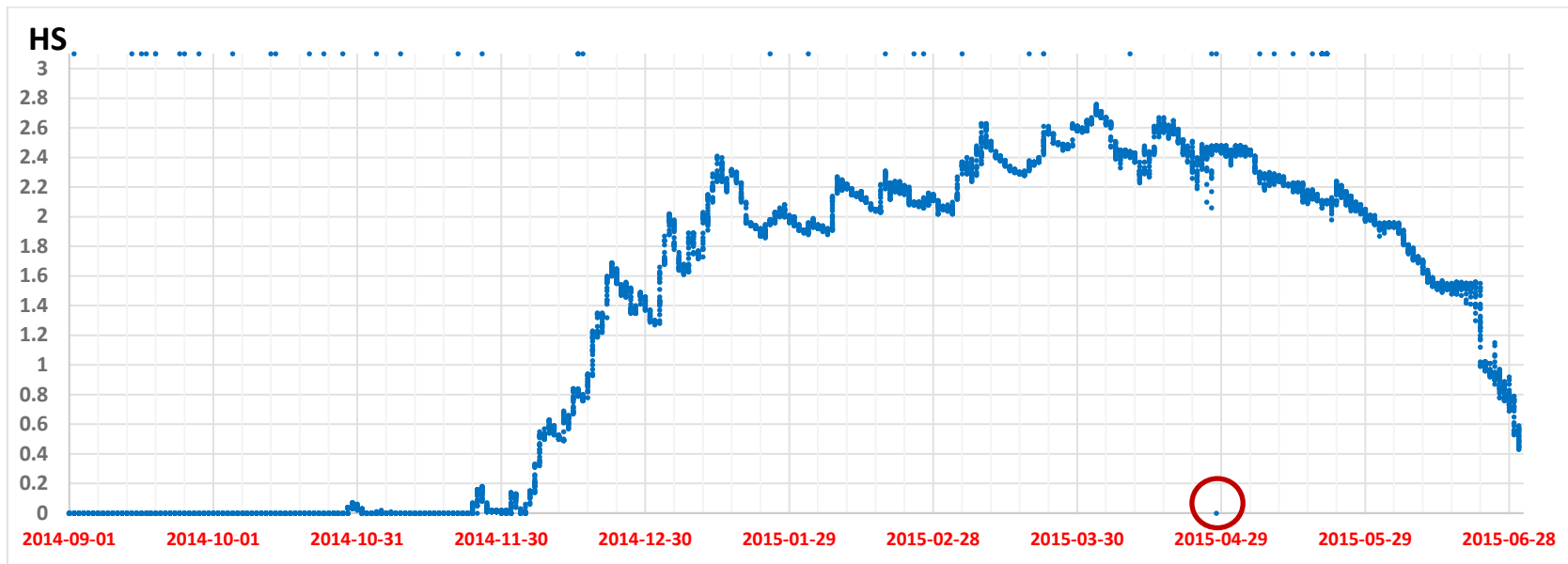


Figure 33 Snow height (HS) in m. Missing values/errors are indicated at the top of the diagram.

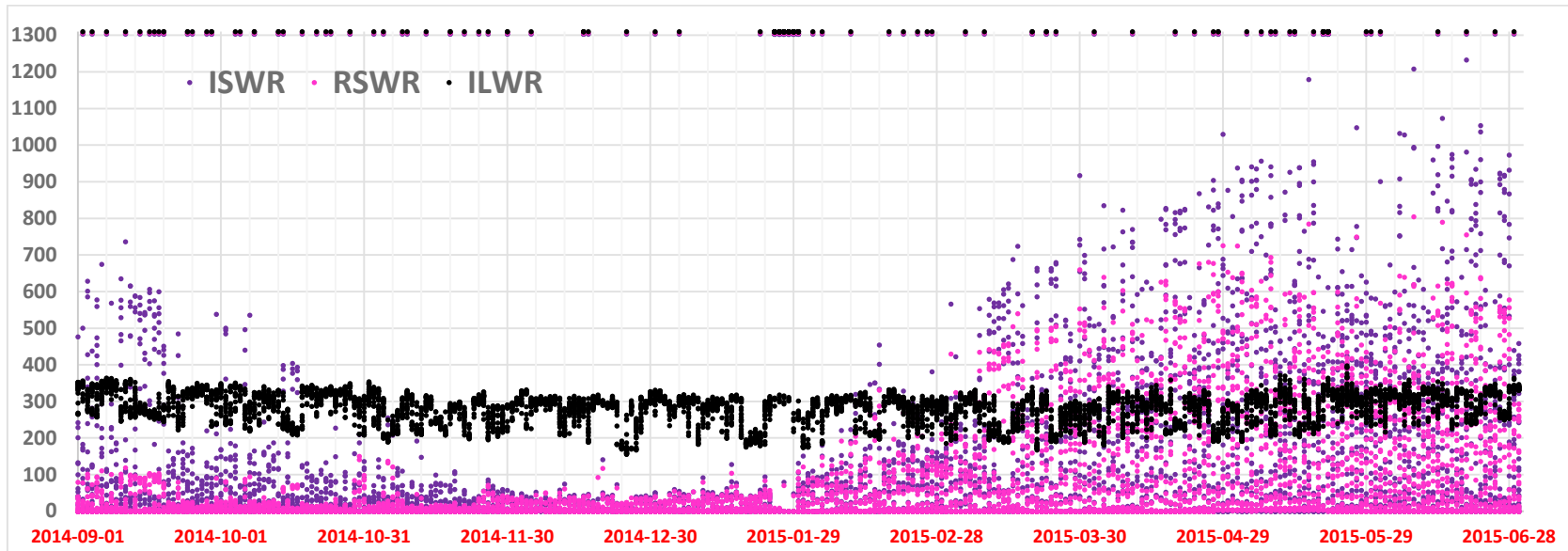


Figure 34 Incoming (ISWR) and reflected (RSWR) shortwave and incoming longwave (ILWR) radiation in W/m^2 . Missing values/errors are indicated at the top of the diagram.

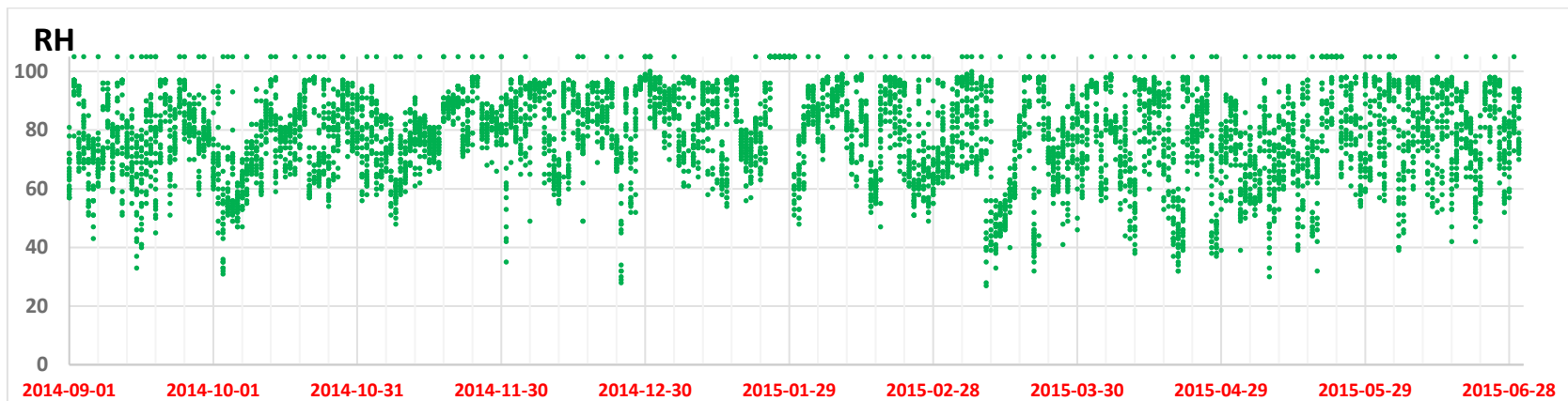


Figure 35 Relative humidity in %. Missing values/errors are indicated at the top of the diagram.

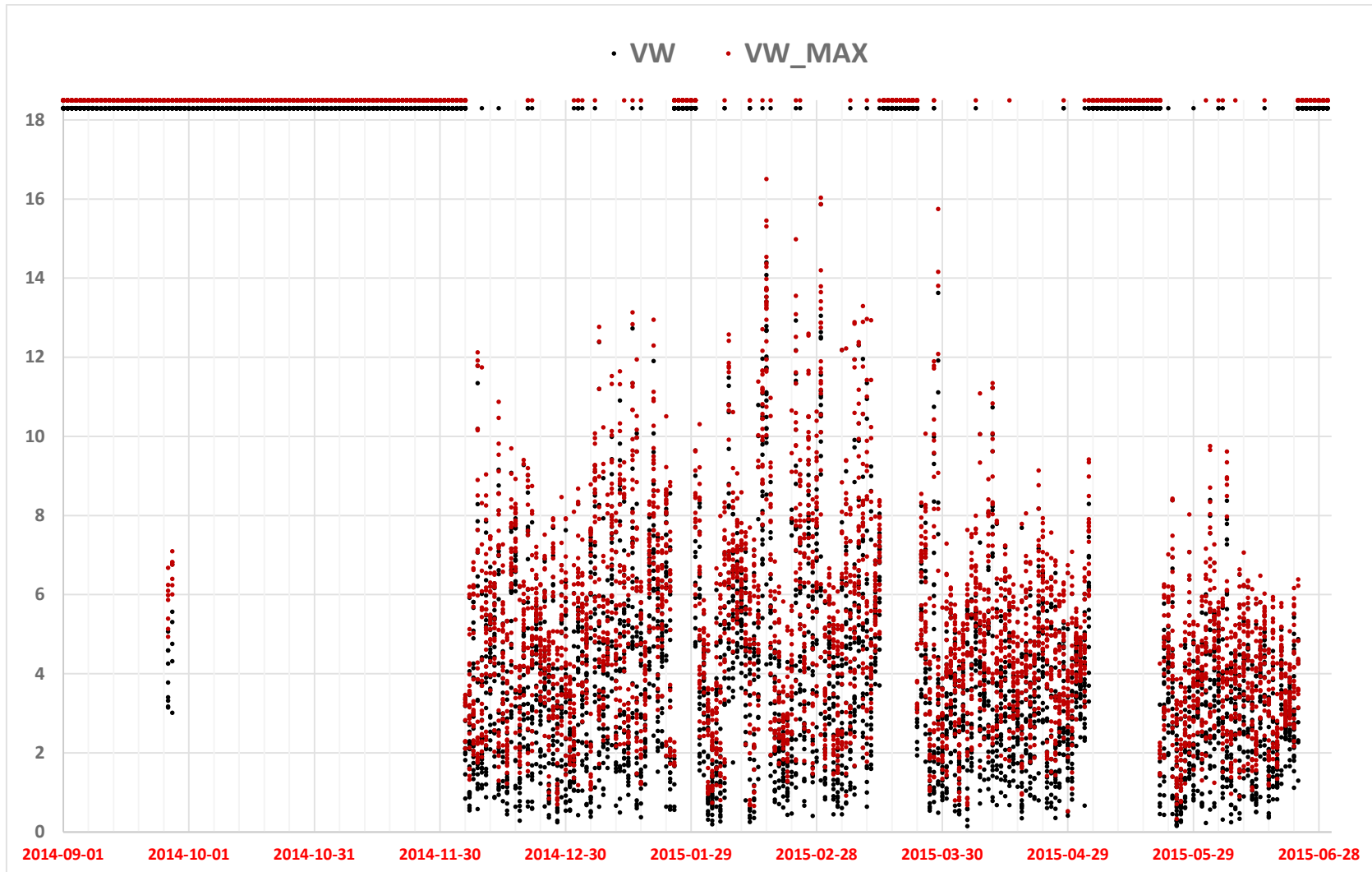


Figure 36 Average (VW) and maximum (VW_MAX) wind velocity last hour in m/s. Missing values/errors are indicated at the top of the diagram.

A7 Winter season 2015-2016

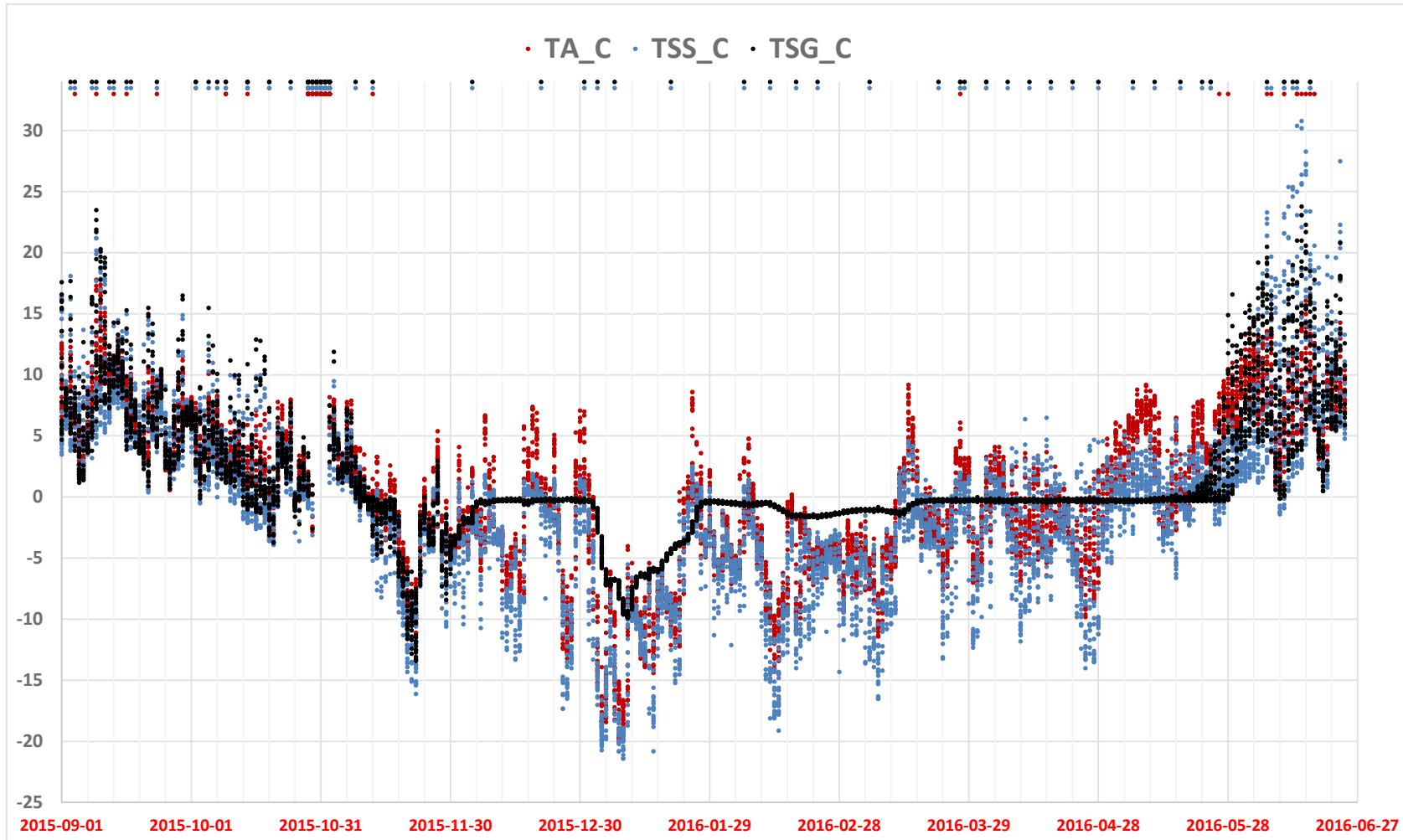


Figure 37 Air temperature (TA), temperature of snow surface (TSS) and ground surface temperature (TSG) in °C. Missing values/errors are indicated at the top of the diagram.

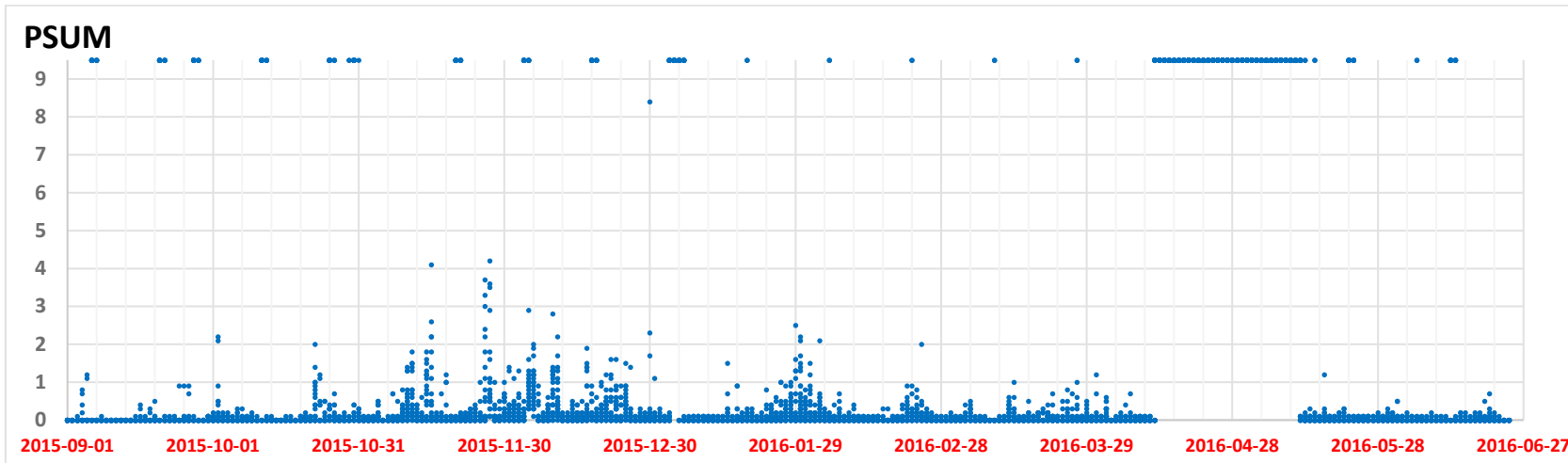


Figure 38 Precipitation (PSUM) in mm/hour. Missing values/errors are indicated at the top of the diagram.

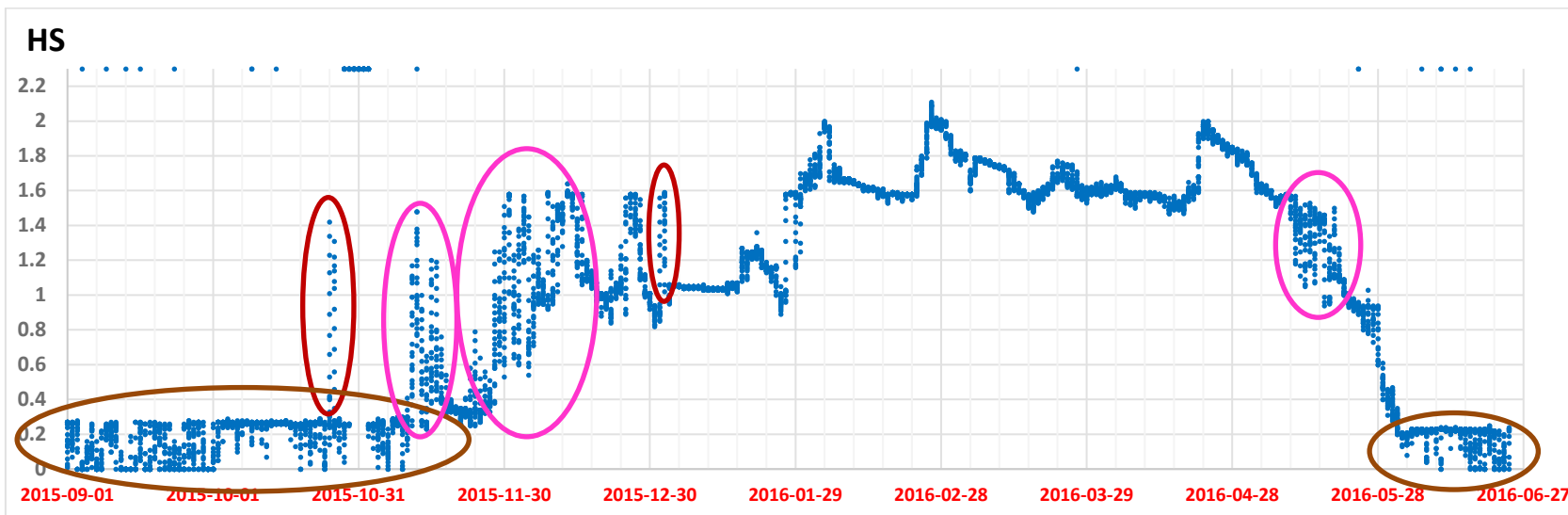


Figure 39 Snow height (HS) in m. Missing values/errors are indicated at the top of the diagram.

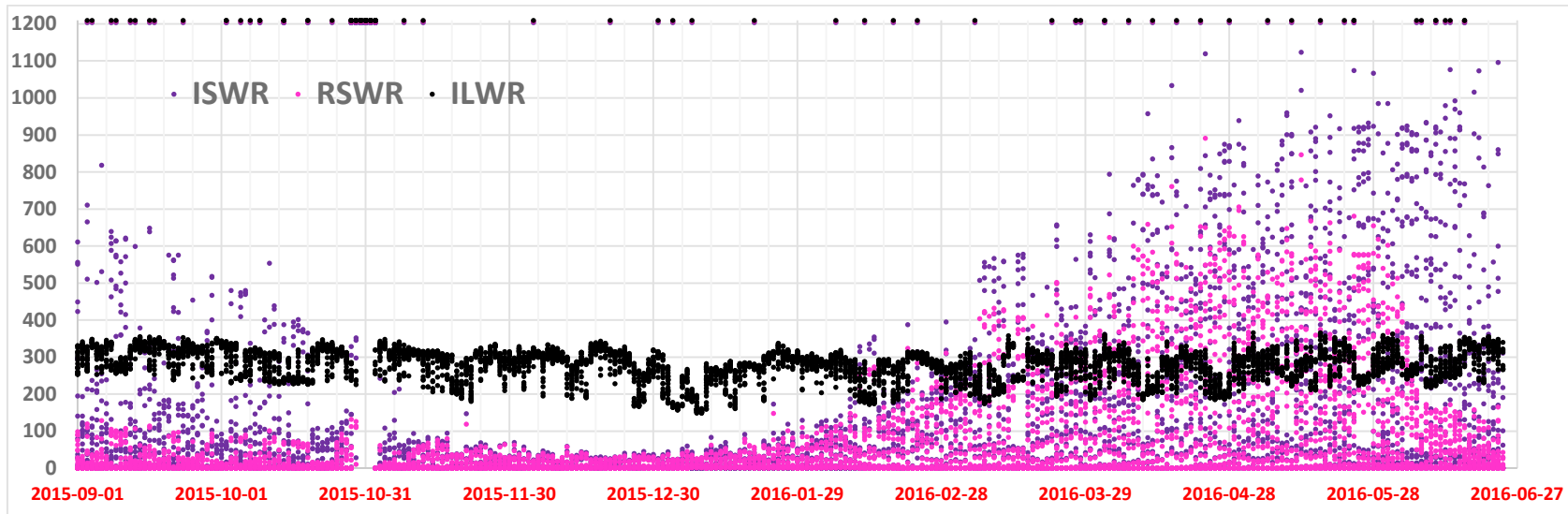


Figure 40 Incoming (ISWR) and reflected (RSWR) shortwave and incoming longwave (ILWR) radiation in W/m^2 . Missing values/errors are indicated at the top of the diagram.

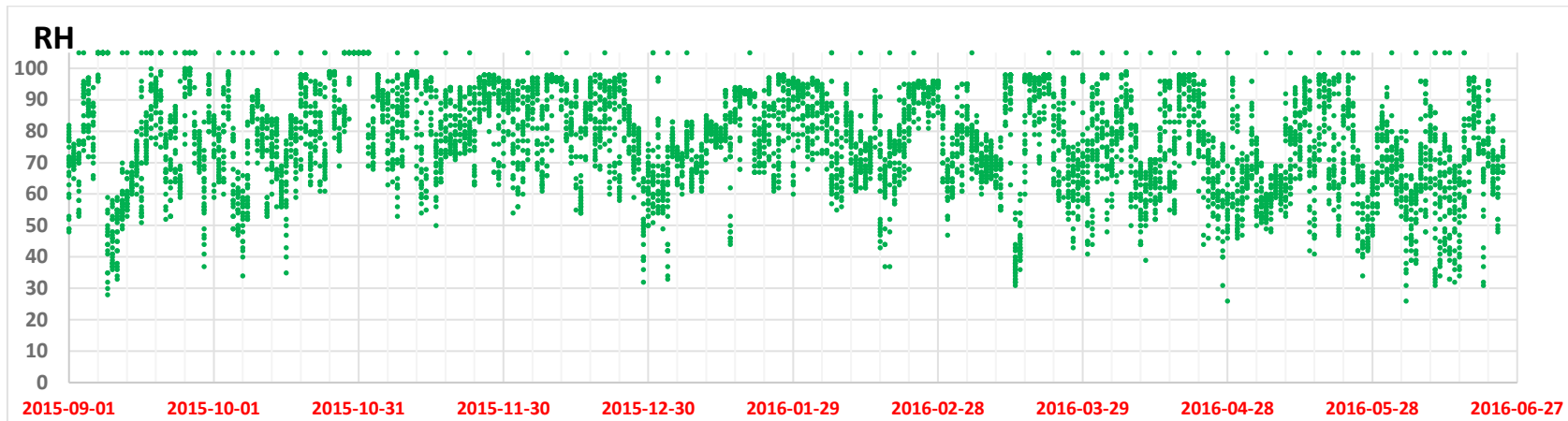


Figure 41 Relative humidity in %. Missing values/errors are indicated at the top of the diagram.

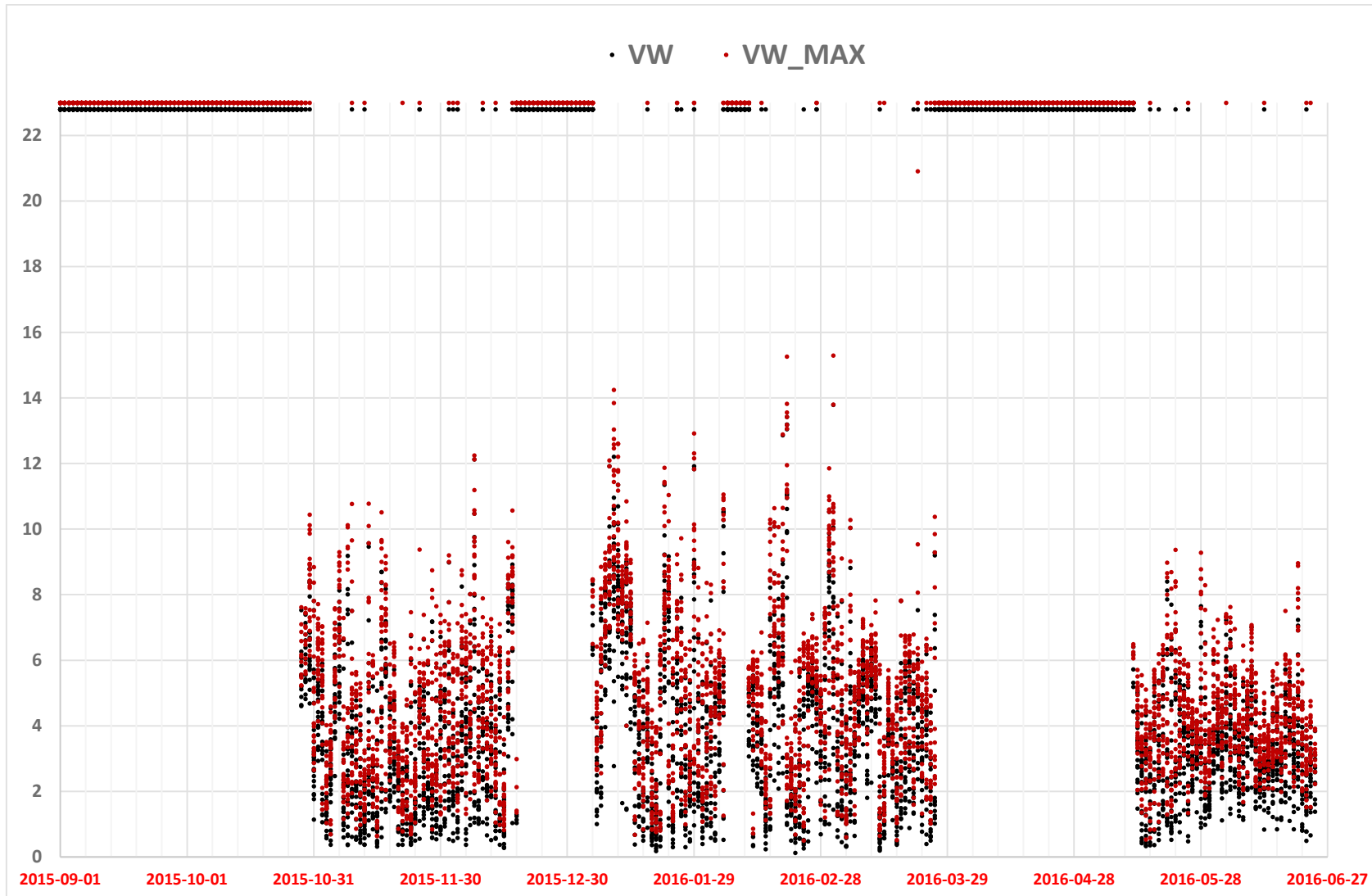


Figure 42 Average (VW) and maximum (VW_MAX) wind velocity last hour in m/s. Missing values/errors are indicated at the top of the diagram.

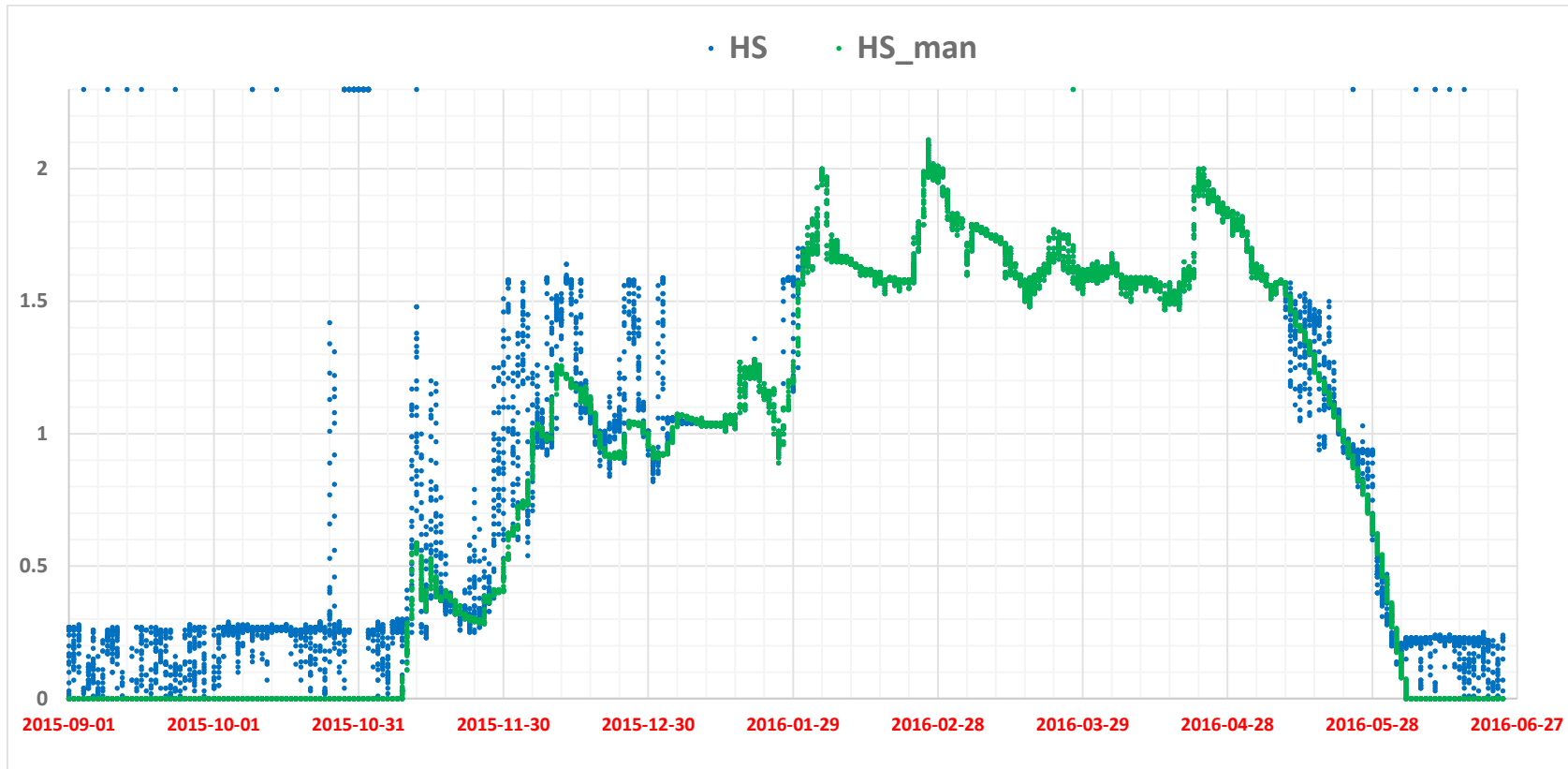


Figure 43 Observed snow height (HS) and manually corrected (HS_man) in m. Missing values are indicated at the top of the diagram.

Dokumentinformasjon/Document information		
Dokumenttittel/Document title Review of meteorological data from Fonnbu 2009–2016		Dokumentnr./Document no. 20140053-05-TN
Dokumenttype/Type of document Teknisk notat / Technical note	Oppdragsgiver/Client Norges vassdrags- og energidirektorat (NVE)	Dato/Date 2017-01-25
Rettigheter til dokumentet iht kontrakt/ Proprietary rights to the document according to contract Oppdragsgiver / Client		Rev.nr.&dato/Rev.no.&date 0 /
Distribusjon/Distribution ÅPEN: Skal tilgjengeliggjøres i åpent arkiv (BRAGE) / OPEN: To be published in open archives (BRAGE)		
Emneord/Keywords Meteorological data; automatic weather station; snow; Fonnbu; Strynefjellet; precipitation; radiation; temperature; wind; snow height		

Stedfesting/Geographical information	
Land, fylke/Country Norway	Havområde/Offshore area
Kommune/Municipality Stryn	Felt navn/Field name
Sted/Location Grasdalen, Fonnbu	Sted/Location
Kartblad/Map 1219 II, 1418 IV	Felt, blokknr./Field, Block No.
UTM-koordinater/UTM-coordinates Zone: 33N East: 97940 North: 6897990	Koordinater/Coordinates Projection, datum: East: North:

Dokumentkontroll/Document control					
Kvalitetssikring i henhold til/Quality assurance according to NS-EN ISO9001					
Rev/Rev.	Revisjonsgrunnlag/Reason for revision	Egenkontroll av/Self review by:	Sidemannskontroll av/Colleague review by:	Uavhengig kontroll av/Independent review by:	Tverrfaglig kontroll av/Interdisciplinary review by:
0	Original document	2016-12-14 Galina Ragulina	2017-01-13 Christian Jaedicke		

Dokument godkjent for utsendelse/Document approved for release	Dato/Date 25 January 2017	Prosjektleder/Project Manager Christian Jaedicke
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