INTERCOMPARISON OF WINTER PERFORMANCE OF RAIN GAUGES

Martin Mair
Central Institute for Meteorology and Geodynamics, Technical Department,
martin.mair@zamg.ac.at, Hohe Warte 38, Vienna, Austria

Abstract

The network of Automatic Weather Station (AWS) operated by the Austrian Central Institute for Meteorology and Geodynamics (ZAMG) will be extended with 50 new AWS in the next two years. Because most of the AWS are situated in mountainous regions the selection of an appropriate sensor systems for precipitation measurement offering reliable winter operation is required.

Based on the recent WMO laboratory intercomparison of rain gauges as well as on our field tests in Vienna, several instruments with promising characteristics were chosen for a special test of winter performance at a site with frequent severe weather conditions in Western Austria.
During a test period of four months in winter 2005/2006 we compared the performance of the new instruments in relation to the previous standard rain gauge.

As a result it was found that all instruments, including the previous standard instrument, do not ensure reliable operation in severe winter conditions.
In this paper we present a detailed analysis of the individual failure for each instrument referring to the environmental conditions (temperature, wind speed, sunshine). Furthermore the effects of some improvements of the instruments during the tests are shown.

1. Introduction

The Austrian Central Institute for Meteorology and Geodynamics (ZAMG) started the operation of Automatic Weather Stations (AWS) 25 years ago. At present the ZAMG operates 142 AWS with a time resolution of precipitation measurement of 1 minute. Most of the stations are equipped with a tipping bucket rain gauges, some with weighing gauges. In the near future the network will be upgraded to 200 stations, most of them are situated in mountainous regions.
For these new stations the present standard instrument (Paar AP23) is not available, because it is no longer in production. This instrument unfortunately showed frequent failure of the heating circuit, although in general it is a very reliable instrument.
The most important operational and technical requirements for the new standard rain gauge are described in section 2. The preliminary selection of a potential standard rain gauge was based on the test results and experiences of other institutions [1], [2] and on the results of our preliminary field tests in Vienna. For a final decision two tipping bucket and two weighing gauges were installed in a mountain station for special test of winter performance and reliability. During the test period ranging from November 2005 to March 2006 there were 115 days with measurable precipitation.

2. Requirements for precipitation measurement instruments

For compatibility with the existing measurement system and in order to ensure homogenous time-series of precipitation measurement the following criteria for new rain gauges were defined:

a) All rain gauges in the network have an area of the collecting orifice of 500cm^2. In order to maintain the homogenity of the network for the new stations the orifice should the same. Rain gauges with larger collecting area are also expected to be more reliable for operation in mountainous regions.

b) Minimum measurement resolution of 0,1mm/minute. Maximum delay of measurement less or equal 1 minute.

c) Reduced maintenance, easy operation and cleaning

d) Sufficient and reliable heating for winter operation

e) Availability of spare parts

f) Maintenance and calibration with the available laboratory facilities of ZAMG

g) Availabilty of 40-50 instruments until the end of year 2006

For the selection of the new standard rain gauge both measurement principles (tipping bucket and weighing gauges) are considered. The most significant operational and technical differences of both systems are summarized in Table 1.

Table 1: Operational properties of tipping bucket and weighing gauges

	Advantage	Disadvantage
Tipping bucket gauge	Real time measurement of precipitation with intensities >0,1mm/minute. No wind influence on the measurement system (wind induced vibrations)	Frequent blockage of funnel with leaves, insects etc. For measurement of solid precipitation precisely controlled heating system is required. Evaporation loss due to heating
Weighing gauge	Simple heating of collecting ring is sufficient Relatively long maintenance intervals, limited to emptying of the collecting tank (1-6 months)	Wind induced vibrations on the measurement system requires software filter Delay of measurement data output due to software filtering. Reported intensities often not realistic. Chemical antifreeze required for reliable winter operation

3. Test site and measurement setup

The test site for the winter performance test of rain gauges is situated at Galzig in Western Austria at 2085 above sea-level in the Arlberg region, where we often have severe weather conditions with low temperature rime and frost accretion in combination with high wind speed (Figure 1). Unfortunately there is not enough space for installing rain gauges according [3]. On the limited space of the existing test platform (about 2,5 x 2,5m) beside the various test instruments are also installed the instruments of the standard Automatic Weather Station. Therefore the precipitation measurement of all instruments is expected to be highly influenced by the surrounding constructions. We have to expect differences in precipitation reported by different instruments installed side by side in the order of more than 200%. Nevertheless malfunction or failure of the instruments can be proved.

For an estimation of wind-influence on the precipitation measurement a Thies Ultrasonic wind sensor was installed at the same height as the orifices of the rain gauges.
The remaining parameters are measured by the AWS:

- air temperature
- relative humidity
- sunshine duration
- global radiation
- precipitation detection

The measurement data of the test sensors are recorded by a datalogger (Friedrichs Combilog 1020) with 1 minute time resolution and in correspondence with the parameters of the AWS. Data transfer to Vienna is performed every 24 hours via FTP.

Figure 1: Test platform at Galzig
Test instruments
from the left to the right:

- Sommer NIWA MED K505
- MPS TRWS
- Paar AP23
- Meteoservis/Kroneis MR3H
- Meteoservis MR3H-F

4. Tested instruments

For the test at Galzig based on the results of a 6 month field test in Vienna four instruments were selected, two tipping bucket gauges and two weighing gauges. As a kind of independent reference instrument a standard tipping bucket rain gauge (Paar AP23) was installed. The technical characteristics of all instruments are summarized in Table 2. The instruments Paar AP23 and Meteoservis MR3H-F participated also at the WMO laboratory intercomparison [1]. The Kroneis/Meteoservis MR3H is similar to the Meteoservis MR3H-F but without separate funnel heating. The heating system consists of heating resistors with fan forced convection.

Table 2: Technical data of tested instruments

Manufacturer	Type	Measuring principle	Orifice	Resolution	Heating
Sommer	NIWA MED K505	weighing	500 cm^2	0,1 mm	ring 50W
MPS System	TRWs	weighing	500 cm^2	0,01 mm	ring 30W
Meteoservis/Kroneis	MR3H	tipping bucket	500 cm^2	0,1 mm	funnel 70W
Meteoservis	MR3H-F	tipping bucket	500 cm^2	0,1 mm	ring 56W funnel 48W outflow, interior 31W
Paar	AP23	tipping bucket	500 cm^2	0,1 mm	ring 10W funnel 50W outflow, interior 20W

5. Measurement results

The instruments shown in Table 2 were installed at the test site in November 2005. For the data analysis we take into account the period from 25.11.2005 to 20.03.2006. 77 of 115 days show precipitation reported by at least one rain gauge and the precipitation detector. The highest daily and monthly precipitation sum was reported in February 2006.
Due to mutual influence of the instruments under test the comparison of the daily amount of precipitation is not significant for this analysis, whereas the monthly sum of precipitation (Figure 2) shows a general information about the performance of the instruments.

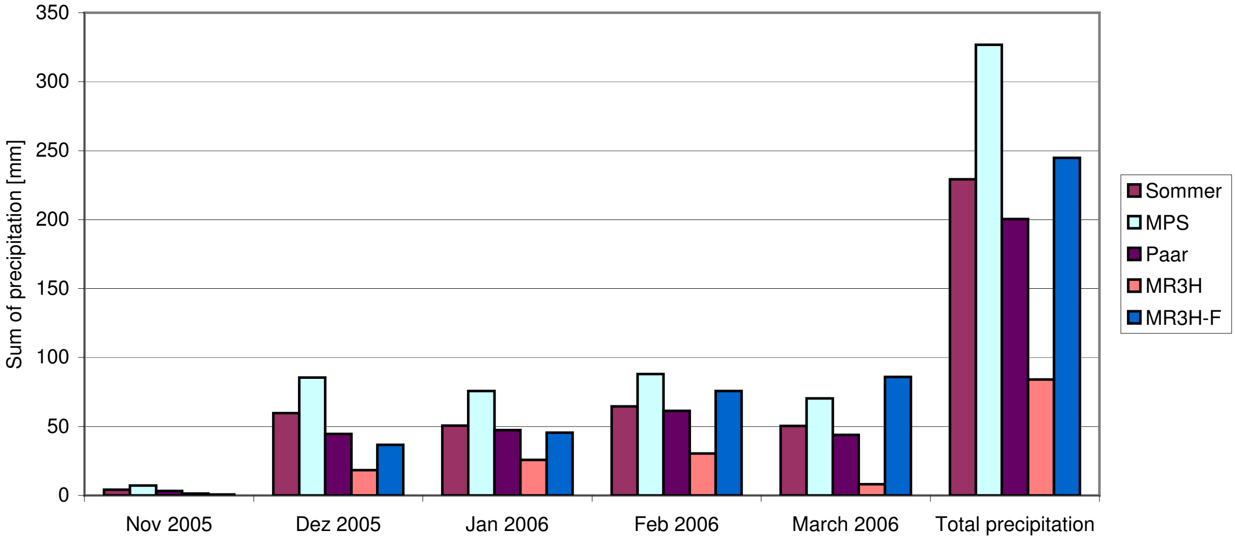

Figure 2: Sum of precipitation reported by the rain gauges under test in time period 25.11.2005-20.03.2006.

In relation to the standard rain gauge Paar AP23 the weighing gauge MPS TRWs and the tipping bucket gauge Meteoserivs MR3H-F shows a significant overestimation of the precipitation quantity. The tipping bucket gauge Meteoservis/Kroneis MR3H is underestimating significantly.
Based on a detailed analysis of each measurement day, malfunction or failure of each instrument can be identified easily. In Figure 3 the frequency of malfunction of different instruments is evident. Surprisingly the standard tipping bucket gauge (Paar AP23) shows the best performance of all instruments. Weighing gauges show a higher frequency of failure than tipping bucket gauges.

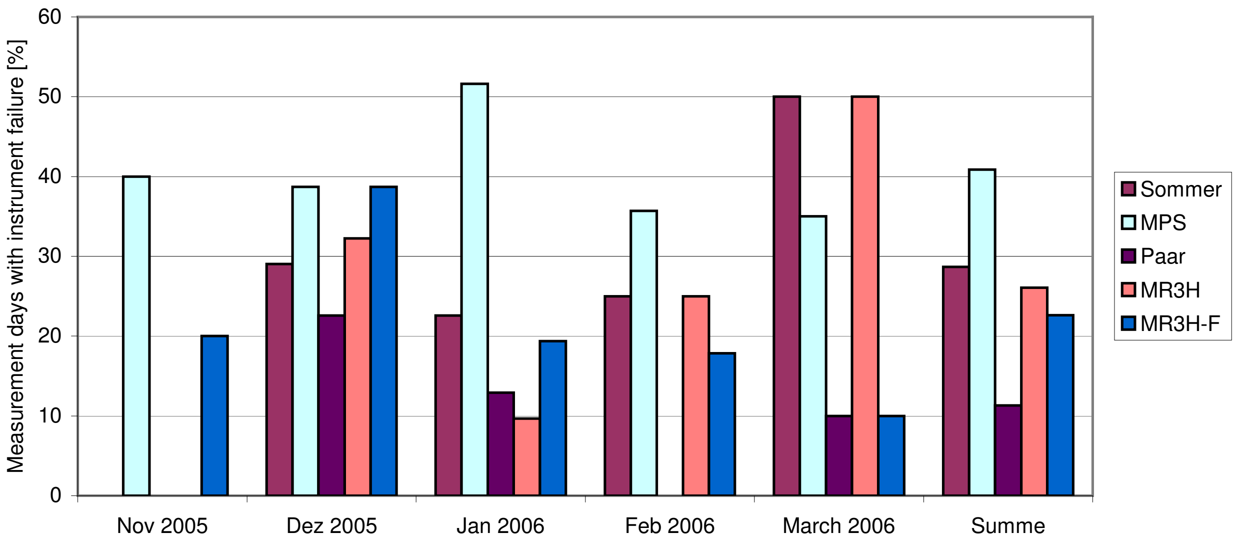

Figure 3: Percentage of days with more than one failure of operation of different instruments in the time period 25.11.2005-20.03.2006.

A day with instrument failure according Figure 3 is defined if one of the following effects occurred at least once:

Tipping bucket gauges:

- Deviation of the daily precipitation quantity in relation to the mean precipitation quantity reported by all instrument of more than ±300%
- Omission of precipitation events >0,2mm lasting more than 20 minutes (Blockage of measurement system
- Delay of precipitation recording due to insufficient heating

Weighing gauges:

- Deviation of the daily precipitation quantity in relation to the mean precipitation quantity reported by all instrument of more than ±300%
- Precipitation quantity reported by the instrument without signal from precipitation detector, lasting more than 1 hour (wind of vibration effects).
- Delayed output of measurement data. Reporting unrealistic precipitation intensity (accumulation due to software filter of weighing gauges)

5.1 Weighing gauges

5.1.1 Sommer NIWA MED K505

The monthly sum of precipitation (Figure 2) is close to the precipitation reported by the Paar AP23 standard tipping bucket gauge, but the number of failure events in total is more than twice as high. The failure of this instrument is caused generally by delayed output of measurement data (up to 30 minutes) depending on wind speed (see Figure 4). This effect caused by software filtering of wind induced vibration effects very often causes non realistic precipitation intensities (overestimation up to factor 4). Nevertheless the total amount of precipitation reported by this instrument comes close to the standard gauge.
In a few cases we noted small precipitation output without signal from precipitation detector (0,1-0,2mm) in strong correlation with sunset. This may be a temperature effect on the measurement system.

5.1.2 MPS TRWs

This instrument shows a significant overestimation of the monthly sum of precipitation up to 50% (see Figure 2). In a certain number of days the daily precipitation was overestimated by more than 300%. The overestimation is not correlated by high wind speed. Frequently the output of non realistic precipitation without signal from precipitation detector was corresponding exactly with sunrise. The problem of the instrument seems to be the insufficient temperature compensation of the measurement system (Figure 5).

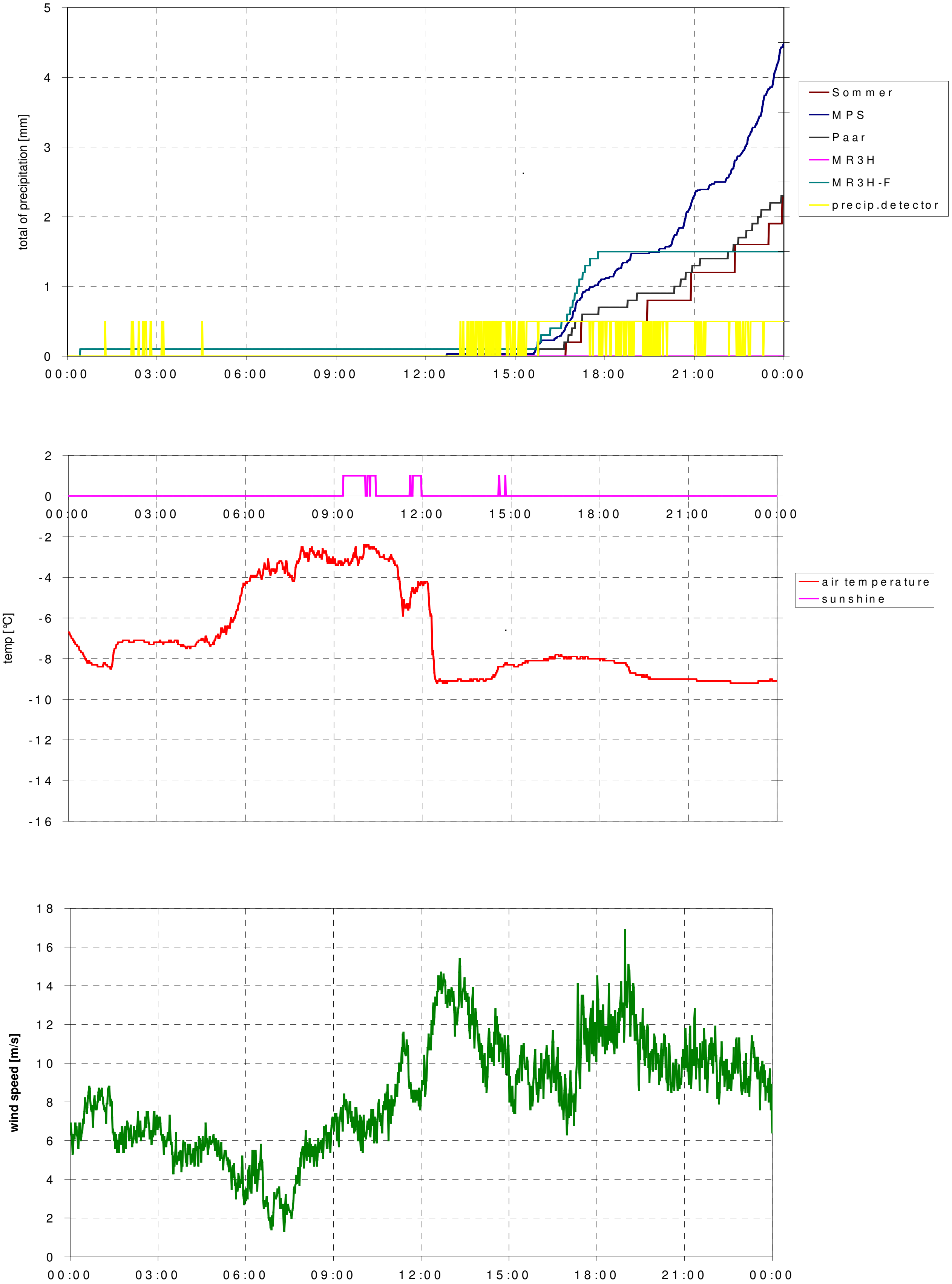

Figure 4: Precipitation, wind speed, air temperature and sunshine detector on 08.02.2006. Sommer NIWA-Med K505 reports non realistic intensities, but correct sum of precipitation.

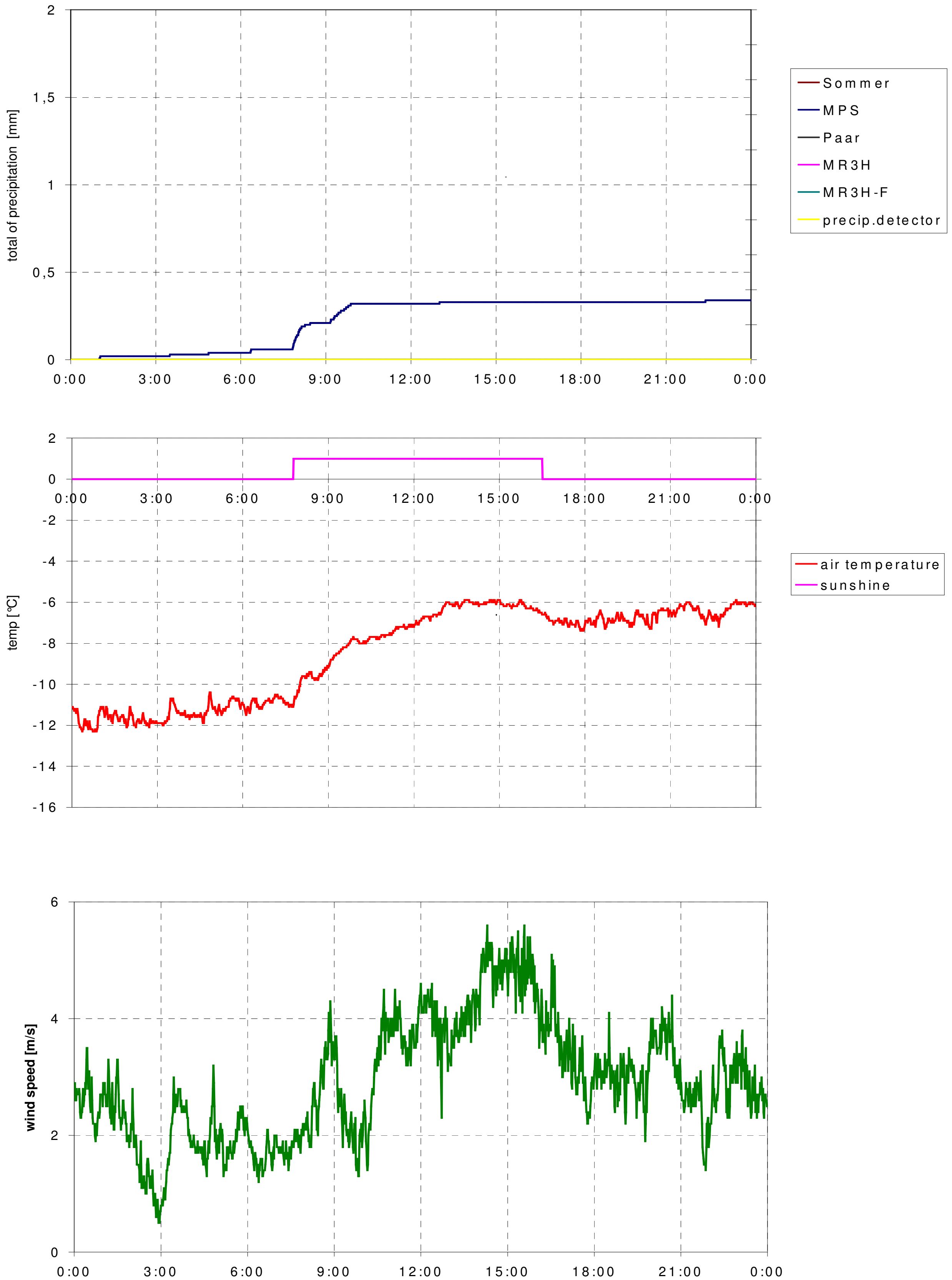

Figure 5: Precipitation, wind speed, air temperature and sunshine detector on 13.02.2006. MPS TRWs precipitation is correlated with sunrise and temperature variation.

5.2 Tipping bucket gauges

In general the total number of days with failure is lower with tipping bucket than with weighing gauges (Figure 3). The most reliable tipping bucket gauge seems to be the standard gauge PAAR AP23. Nevertheless in a certain number of days we noted a total blocking of the instrument for several hours. During the time period shown in Figure 6 the instrument was completely blocked during a time period of 4 hours from 22:00 to 2:00. The remarkable higher precipitation intensity shortly before the standstill is an indicator for a blocked outflow. The funnel heating seems to be sufficient even under severe conditions because we never observed a delay of precipitation output. The known problem with the heating control (damage of control circuit) never occurred during the test period.

5.2.1 Meteoservis/Kroneis MR3H

This instrument has no separate funnel and outflow heating. The fan forced convection heating system of the instrument is not sufficient for reliable operation at temperatures below –5°C. The funnel as well as the outflow are frequently blocked over a long time (up to several days). This deficit results in a high number of failure (Figure 3) and a remarkable underestimation of the total precipitation (Figure 2). In the example shown in Figure 6 the instrument was blocked at about 3:00. The normal operation was not recovered until the end of the precipitation period (1 day later)

5.2.2 Meteoservis MR3H-F

This instrument is similar to the Meteoservis/Kroneis MR3H, with separate heating circuits for ring, funnel, outflow and appropriate temperature control. From Figure 3 is evident a high number of days with failure. These are caused by the insufficient heating of the outflow. Due to wind influence at temperatures below 0°C ice accretion between the supporting steel construction and the outflow occurs, the sequence of this effect is shown in Fig. 7. The water flowing out from the instrument enhances the ice accretion. Once the outflow is completely blocked the melt water accumulates inside the rain gauge. The measurement data output is correct as long as the water level does not obstruct the function of the tipping bucket. From the moment when the water level reaches the tipping bucket, the instrument reports implausible high precipitation rates, until the complete blockage occurs.
This effect is visible on the example shown in Figure 6. At 3:00 the instrument is blocked with noticeable overestimation of precipitation in the period before the blockage occurs. In Figure 8a the effect of icing below the instrument is shown.

In cooperation with the manufacturer an improved version of instrument with enhanced outflow heating was installed towards the end of the testing period (Figure 8b). With this version even under severe weather conditions there was not any failure.
In Figure 9 the improvement is evident: the MR3H-F(new) is working properly the whole period of time whereas the previous standard version MR3H-F(old) is blocked for several hours, similar to Paar AP23.

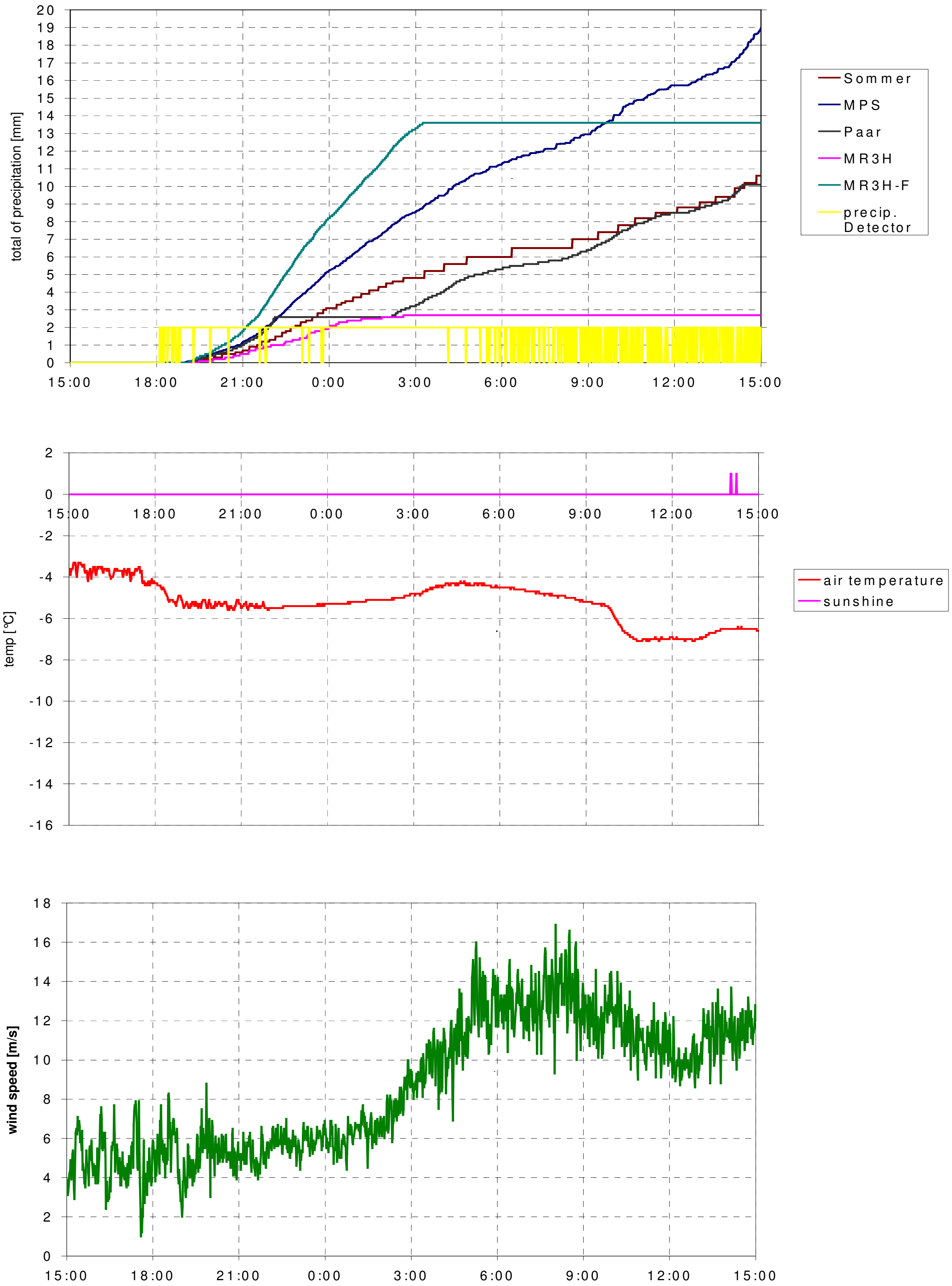

Figure 6: Precipitation, wind speed, air temperature and sunshine detector 17.01.2006 15:00 to 18.01.2006 15:00. Failure and blocking effects on all tipping bucket gauges.

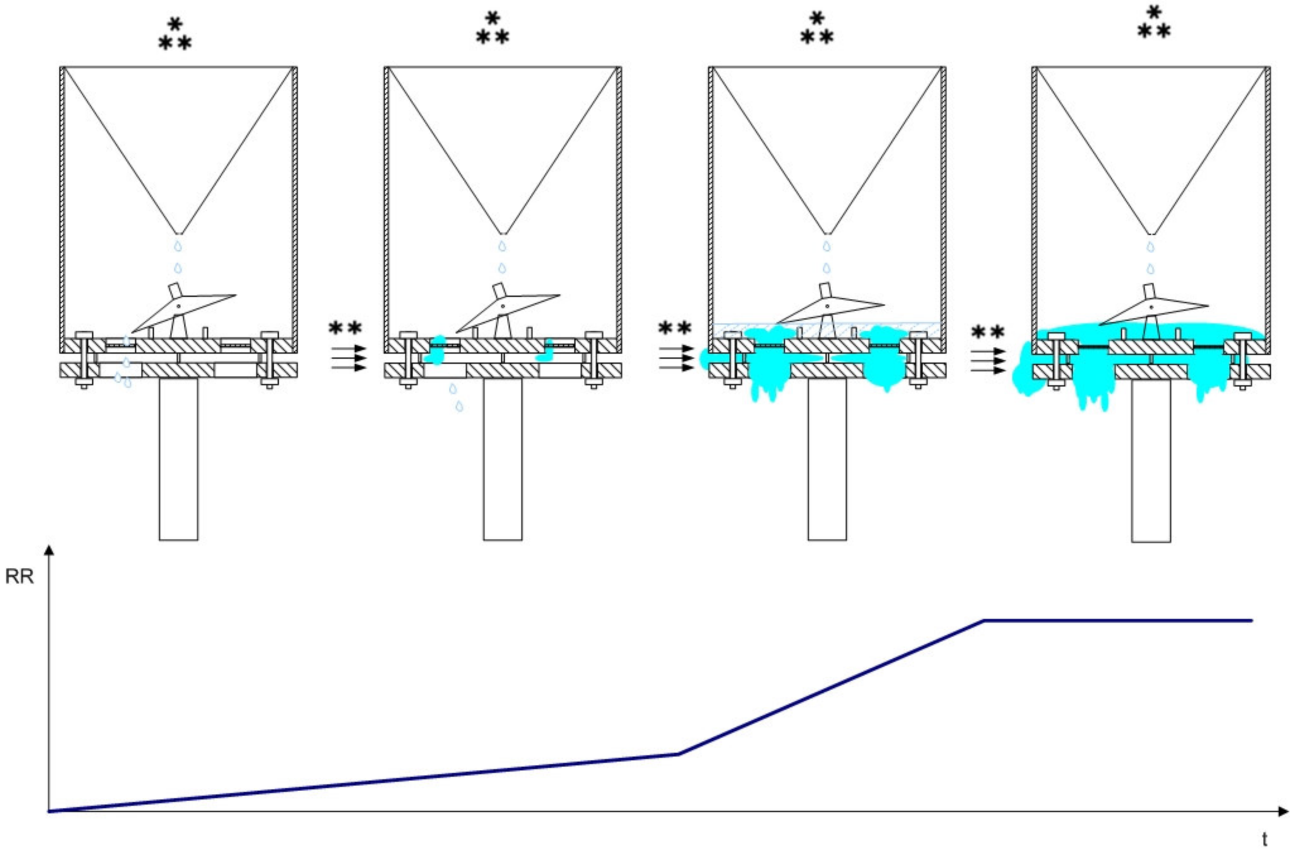

Figure 7: Time sequence showing the effect of ice accretion and the reported precipitation of MR3H-F with continuous real precipitation.

a)

b)

Figure 8: a) Icing on the outfow of METEOSERVIS MR3H-F(old)
b) Improved version of METEOSERVIS MR3H-F(new) with additional outflow heating

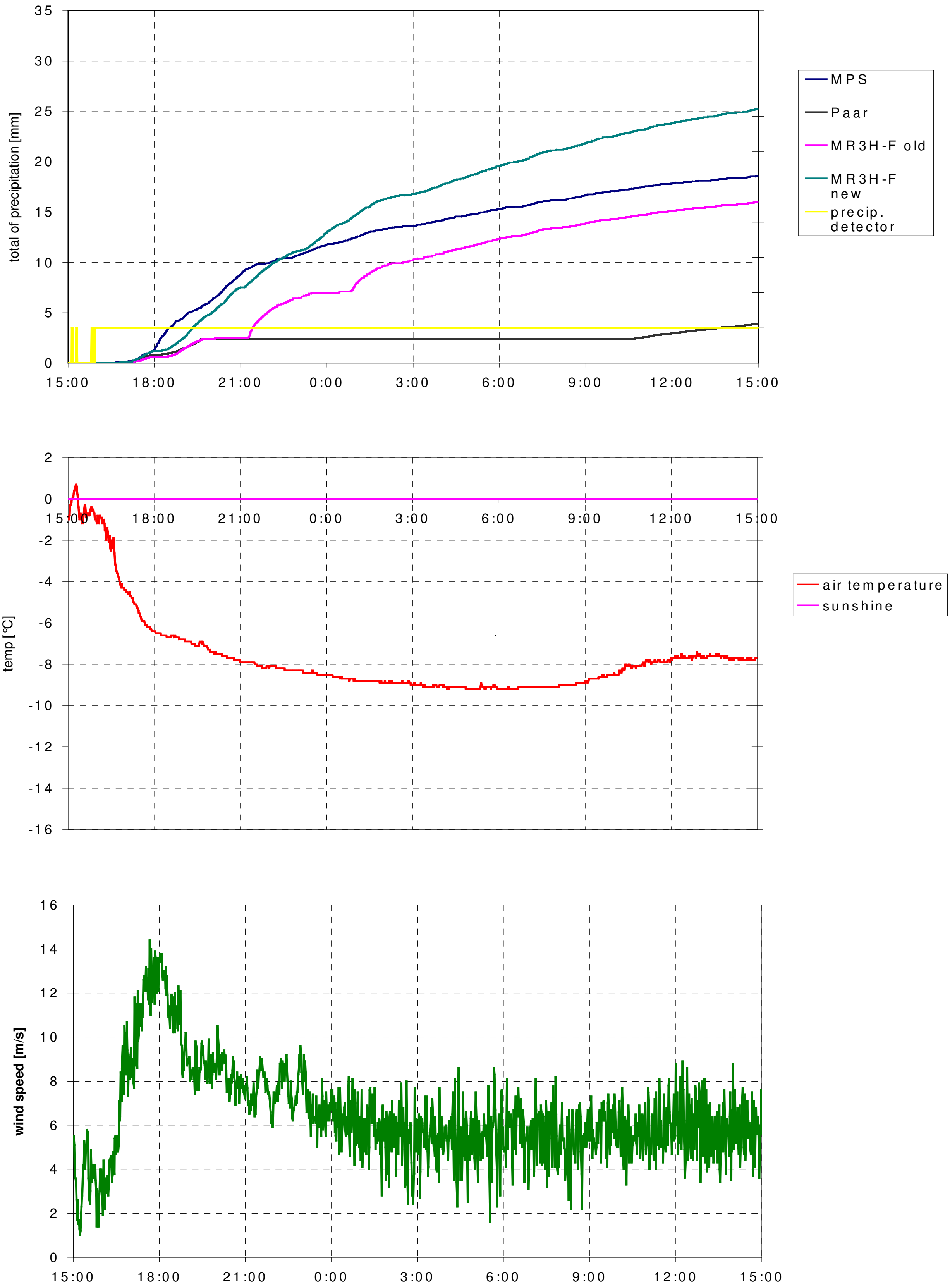

Figure 9: Precipitation, wind speed, air temperature and sunshine detector 10.04.2006 15:00 to 11.04.2006 15:00. Failure and temporary blocking effects on all tipping bucket gauges except MR3H-F(new)

6. Conclusion

The measurement results of the four month testing period show that all the instruments fulfill the basic requirements listed in section 2 only partially. All instruments have the required orifice of 500cm^2 and are available from serial production. Although they are already in operation in networks of various weather services and other authorities they show a significant lack in winter performance under severe conditions. The most significant lack of the weighing gauges is the improper software filtering and the temperature compensation of the measurement system. New versions were available only after the end of the test period.

One of the tipping bucket gauges definitely has an insufficient heating system for the climatic conditions on the test site. The second instrument had an inadequate outflow heating system. Towards the end of the test period the manufacturer of this instrument provided an improved version, which showed excellent performance even under harsh conditions.

Based on the test results it was decided by ZAMG to equip the first series of new AWS of the network with the METEOSERVIS MR3H-F tipping bucket rain gauges. Furthermore it was decided to continue the tests during the winter 2006/2007 with improved versions of the weighing gauges Sommer NIVA-Med K505 and MPS TRWs as well as the new laser precipitation monitors Thies LNM and Ott Parsivel.

7. References

[1] Lanza L., et. al.: WMO Laboratory Intercomparison of Rainfall Intensity Gauges, Final Report, 2005

[2] Premec, K. et. al.: Field comparison of different raingauges and present weather sensor at MHS of Croatia. Paper presented at TECO Bukarest, 2005.

[3] WMO: Guide to Meteorological Instruments and Methods of Observation, Sixth Edition 1996.