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Pressure and geopotential altitude comparison between the SRS-400 and SRS-C34 radiosondes

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Abstract

In this report the transition of hypsometer pressure measurements on the analog SRS-400 radiosonde to GPS geopotential altitude measurements on the digital SRS-C34 radiosonde is analyzed. The introduction of the GPS on the Meteolabor SRS-C34 digitale radiosonde drastically improved the precision of determining the vertical position of Swiss radiosondes at Payerne. Nevertheless the results of this report show that the mean differences on pressure and geopotential altitude between the SRS-400 and the SRS-C34 are small and do not need to be corrected.

Résumé

Ce rapport analyse la transition entre la mesure de la pression par l'hypsomètre de la radiosonde analogique SRS-400 et la mesure de l'altitude par le GPS de la sonde digitale SRS-C34. L'introduction du GPS sur la radiosonde digitale SRS-C34 de Meteolabor a amélioré de manière très significative la précision des mesures du positionnement vertical des radiosondages de Payerne. Les résultats montrent toutefois que l'erreur moyenne entre les mesures de la SRS-400 et la SRS-C34 est très faible et ne demande pas une correction des mesures de la SRS-400.

Contents

1 Introduction and conclusions

The introduction of the GPS on the Meteolabor SRS-C34 digital radiosonde drastically improved the precision of determining the vertical position of Swiss radiosondes at Payerne. Prior to this, measurements like during the WMO high quality radiosonde comparison at Mauritius Island in 2005, showed systematic differences between the SRS-C34 hypsometer and GPS radiosondes from other manufacturer (see Figure 1 below which is Fig. 8.1 in the Mauritius report [Nash et al. 2006]). A new calibration of the thermocouple at the Swiss bureau of metrology METAS made in June 2005 was a first step to reduce the difference observed at Mauritius Island.

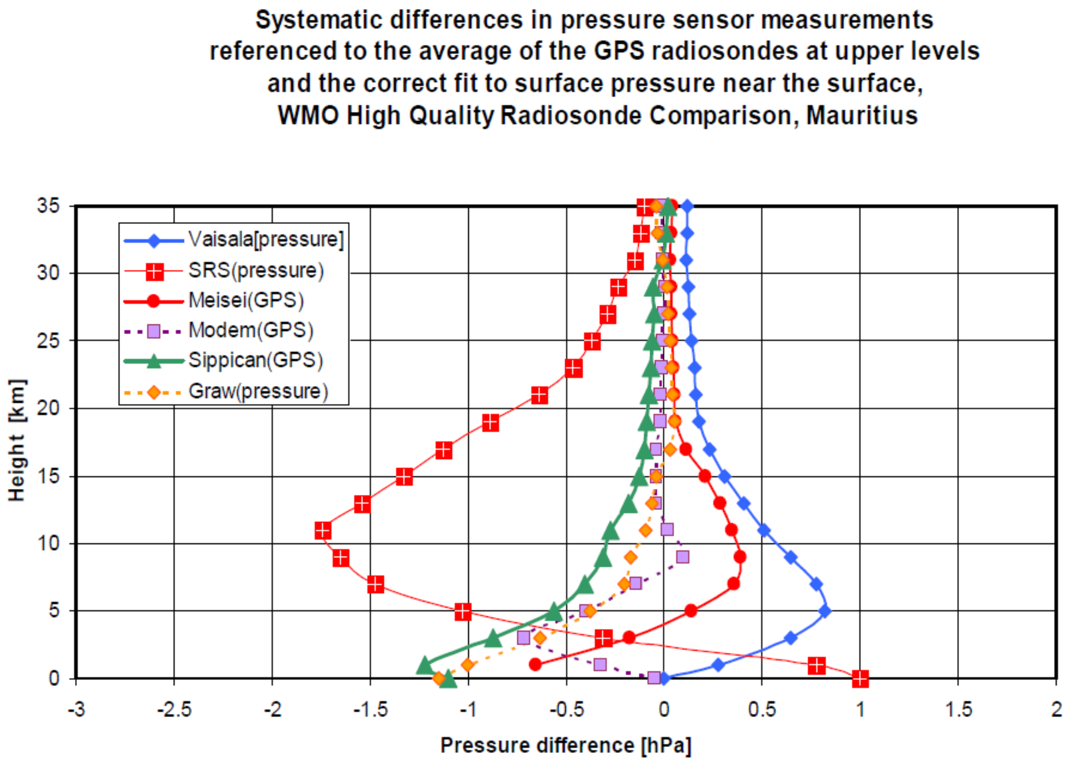


Figure 1: Systematic differences of simultaneous comparisons between radiosonde pressure observations (hPa). Systematic differences of simultaneous comparisons between pressure measurements (hPa) include pressure data just above the surface, but not the actual surface observation. In the layer just above the surface Meisei pressure data are missing. This should have been the value supplied by the Mauritius surface observers and is not a radiosonde measurement.

With the introduction of the GPS equipped digital SRS-C34 as the operational radiosonde at Payerne in January 2011, systematic tests with the previous operational radiosonde SRS-400, which measured pressure with the hypsometer were made in two different comparisons:

1) By comparing GPS and hypsometer measurements on SRS-C34 radiosondes between January 2011 and February 2012, that were specifically equipped with both GPS and hypsometer instruments. This comparison however, is not fully representative for continuity since the treatment of the hypsometer on a digital SRS-C34 is not exactly the same as on the SRS-400.

2) By comparing weekly double soundings of SRS-C34 and SRS-400 radiosondes that were flown on the same balloon day and night during 2011.

The goal of this report is to analyze the improvements achieved with the introduction of the new GPS radiosonde on the Payerne radiosonde measurement series, and possibly propose a correction of pressure/altitude measurements made with the prior SRS-400 radiosonde.

Two series of measurements have been produced, selecting well-chosen flights for appropriate comparisons. 95 soundings were selected for the type 1 comparison, and 42 soundings for the type 2 comparison. While at MeteoSwiss the RSCOMP software was previously used, two specific software codes were additionally made for this investigation.

Our analyses show that the Meteolabor hypsometer measurements produce very similar pressure and altitude values as GPS measurements. The old SRS-400 version with the MeteoSwiss analysis shows better agreement with respect to a systematic bias compared to the SRS-C34 – ARGUS evaluation, but shows larger random errors. According to the results of the 42 double soundings the change from the SRS-400 with hypsometer to the SRS-C34 with GPS introduces a minor change of pressure of less than -0.25 hPa in the lower troposphere and less than +0.05 hPa in the stratosphere. With respect to geopotential altitude a difference (SRS-400 - SRS-C34) of less than +5 m in the troposphere is observed, and about -15 m up to 25 km in the stratosphere, which increases to -30 m at 30 km altitude. Hence, in the stratosphere the hypsometer of the SRS-400 always shows mean geopotential altitude that is lower than the GPS. Over all altitudes the mean differences are always considerably smaller than the standard deviations.

Two observations may request further investigations. The good results with the SRS-400 are obtained with the temperature calibration curve for the hypsometer from 1999, whereas a newer calibration curve is available from 2005. There is also a minor difference observed between day- and nighttime soundings.

The results of this analysis would suggest only very minor corrections of the SRS-400 pressure and altitude measurement series, and this should not be made unless further analyses are made.

2 Comparison hypsometer - GPS of the SRS-C34

2.1 Preparation of data

FULL_AAAAMMJJ.HH.csv files that were produced by the Argus system between January 2011 and February 2012 (end of hypsometer deployment on SRS-C34) have been used for the analysis. In a first selection only soundings with « Sonde Identifier = 58 » were used, that had hypsometer data and DTH values (DTH is a temperature correction determined in a factory or prelaunch procedure bringing the hypsometer boiling temperature at surface level exactly to the corresponding value of a reference barometer, see [Richner, Joss and Ruppert 1996]). GPS values are in column B and E of the csv files, altitude (gpm) and pressure (hPa). Hypsometer values are in column AA and AB, pressure (hPa) and altitude (gpm). There are about hundred soundings of this type available, but restrictions were necessary to exclude cases with specific errors:

- Exclude soundings with abs(DTH) > 0.25 (exclusion under standard operation of SRS-400)
- Exclude files if altitude at time = 0 deviates more than 50 m from GPS altitude.
- Suppression of descent phase according to GPS.
- Suppression of descent phase according to hypsometer, if earlier than GPS descent.
- Cut off hypsometer measurements of sounding 2011.05.24 12h after 3220 seconds, and on sounding 2011.02.22 00h after 6860 seconds.
- Suppression of files FULL_20120619.00.csv and FULL_20110524.12.csv.

These selections were programmed in ComparePressionHypsoGPSC34.r, which produces graphs for each case in function of time and GPS altitude. The code then makes final statistics and compiles a final output of the chosen files. The above rules were fixed in an iterative process. The program code further allows selecting the year (2011 and/or 2012), a certain period in the year, of hours for particular days or a certain level of DTH. The program produces a log file documenting the selections and diagnostics.

2.2 Analyses

It is important to note that the data are already synchronized, since hypsometer and GPS measurements are from the same radiosonde. Therefore, the different measurement levels are directly related to geopotential altitude derived from the GPS, which is considered as reference. Note that GPS and hypsometer altitude is always given as geopotential altitude produced by the Argus software, without smoothing nor corrections of the pendulum motion of the radiosonde. Also, the original files were not modified. The FULL files have a time stamp every second. Finally, the DTH of the hypsometer of the SRS-C34 has been determined by Meteolabor.

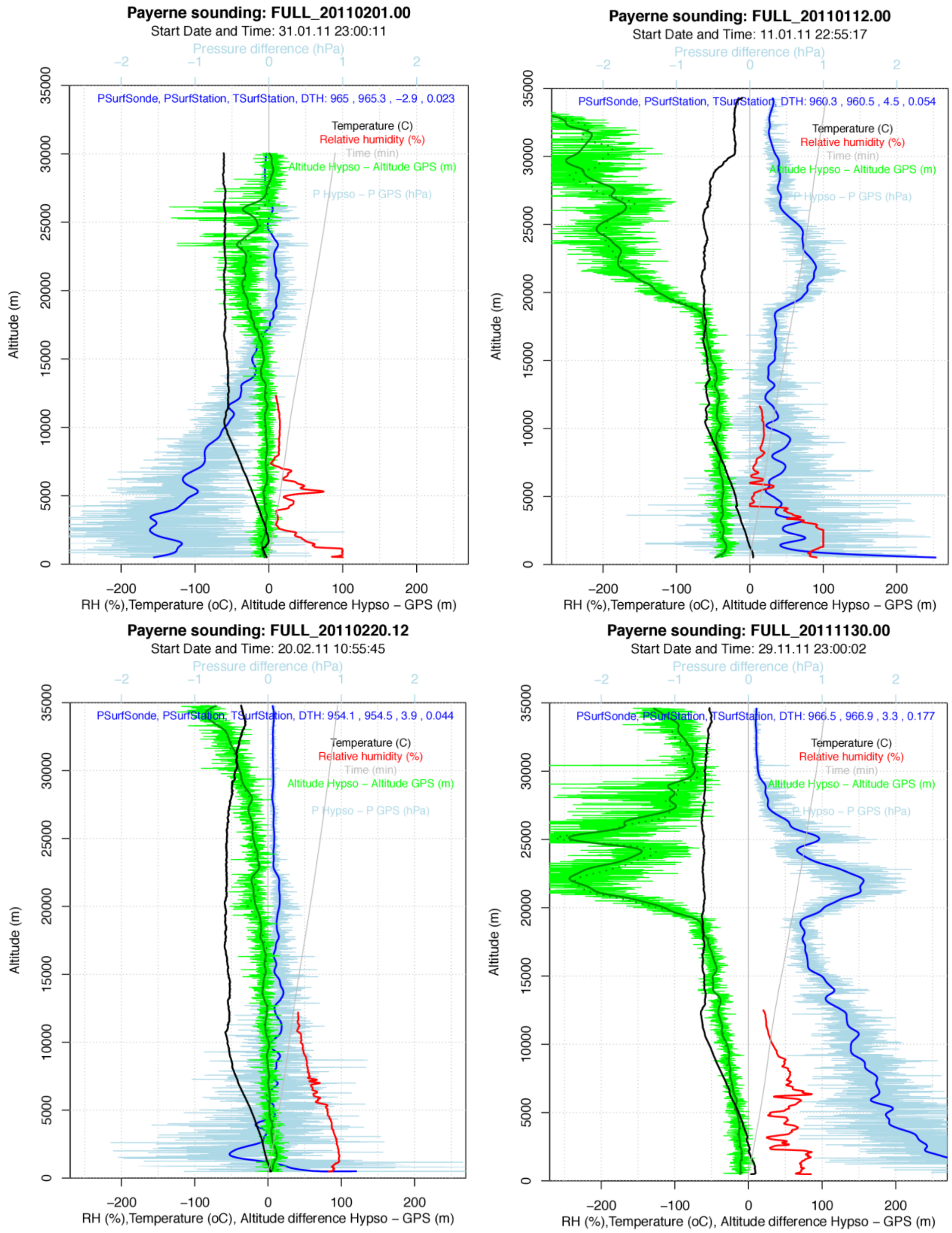


Figure 2: Vertical profiles of pressure (blue) and geopotential altitude (green) difference between hypsometer and GPS (reference) for four SRS-C34 soundings. Differences between pressure/altitude for each second are shown in light blue/green, and smoothed profiles are in dark blue/green. Temperature is shown in black, relative humidity in red and time referenced to the start of the sounding in gray. Surface measurements are given in blue in the upper part of the figures, with DTH at the end.

Figure 2 presents the analyses of three night and one day soundings. Pressure differences (Hypsometer - GPS) are given in blue: light blue for data every seconds, and dark blue for data every 10 seconds and smoothed by a Kolmogorov filter. As expected, fluctuations of pressure differences decrease with decreasing pressure. In the lower troposphere the average error on pressure given by the hypsometer can be larger than 2 hPa and fluctuations are of the same order of magnitude. Differences of geopotential altitude (Hypsometer - GPS) are shown in green: light green for data every second and dark green for values every 10 second and smoothed by a Kolmogorov filter. Dark points show interpolated values every 100 m, and are smoothed for final statistics. The figure shows 2 cases (left) with small differences over the entire profile, always slightly negative. The sounding of 2011.02.20 at 12 h goes up to 35 km or 5.6 hPa; with the hypsometer still working and indicating an altitude of only 90 m lower than the GPS. The other 2 cases (right) show small differences up to 19 km and then diverge, the first diverging more and more and the second coming back. These two cases possibly result from a failure of the heating of the hypsometer, which does not often occur. There are however, different circumstances that can lead to such failures which are not fully understood, and explanations are often rather speculative. It is however most certain, that the differences observed are rather due to failures on the hypsometer and not on the GPS measurements. Although the two soundings on the right show larger DTH values than those on the left, it is not proven that the DTH values play an important role. It is also difficult to say whether the temperature evolution plays a role on the observed differences.

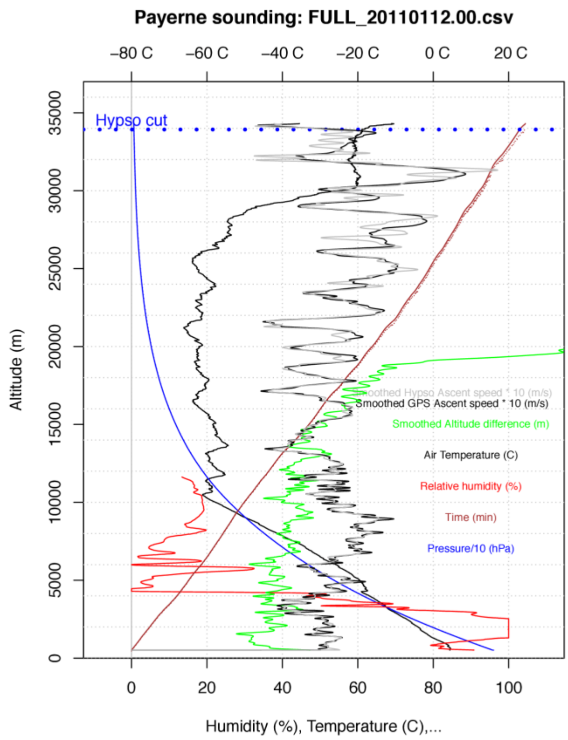


Figure 3: SRS-C34 profiles from 2011.01.12 at 00 UTC (FULL_20110112.00.csv). The ascent rate derived from GPS is shown in dark gray and the one from the hypsometer in light grey, both are smoothed. Altitude differences between GPS and hypsometer are shown in green (this time GPS – Hypsometer).

Although the upper right sounding shown in Figure 2 (2011.01.12 at 00 UTC) shows a strong deviation of the hypsometer above 19 km altitude, we observe that the hypsometer still produces a correct ascent rate, showing the oscillations in the stratosphere that are due to gravity waves very similar to the ones measured by the GPS. Figure 3 shows the smoothed ascent rates that are determined from GPS and from hypsometer measurements. Despite a minor difference between the altitudes the hypsometer is still correctly working.

For statistics the pressure determined by the hypsometer and the GPS are interpolated every 100 m (geopotential altitude derived from GPS) starting at 600 m a.s.l.. Pressure differences at given altitudes are further smoothed with a Kolmogorov filter over 3 points and repeated 15 times.

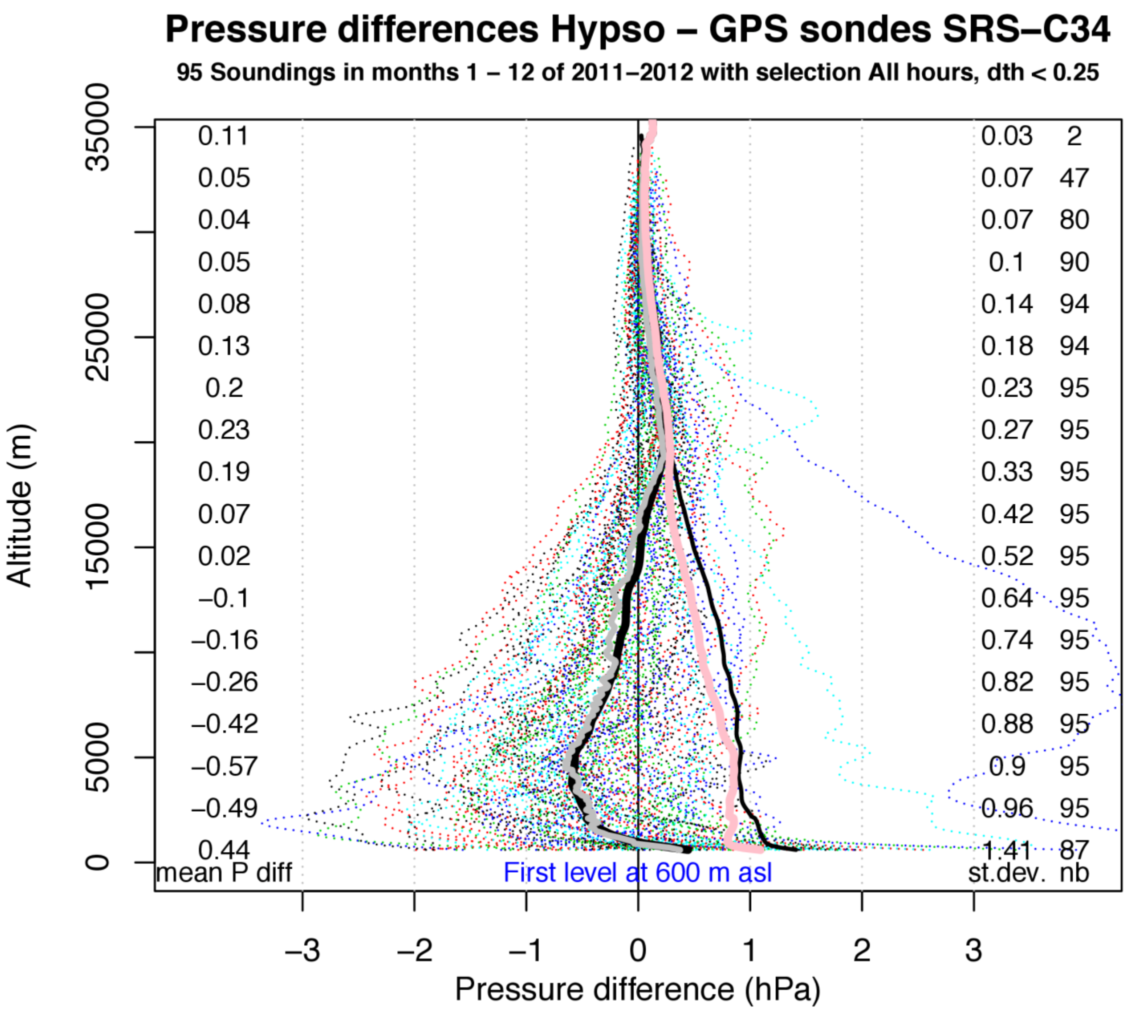


Figure 4: Profiles of pressure differences (hPa) between hypsometer and GPS/reference. 95 individual SRS-C34 radiosoundings (dotted lines in different colors) and the global statistics: mean (thick black) with values to the left, median (thick gray), standard deviation (thin black) with values to the right, mean of absolute differences (pink), and number of cases at the extreme right. The selection is specified below the title.

Figure 4 shows in dotted lines the profiles of pressure differences between hypsometer and GPS of the 95 valid SRS-C34 radio soundings measured in 2011 and 2012. Except of two profiles that show a positive difference in the troposphere, all others show a negative maximum in the lower troposphere, which becomes slightly positive above 14 km. Due to the fact that the median profile (thick gray line) is close to the mean profile (thick black line), we can assume that the statistics is robust. On the first level at 600 m a.s.l., the mean hypsometer pressure is 0.44 hPa above the GPS (reference) value, with a standard deviation of 1.41 hPa on 87 cases. Numbers higher up in Figure 4 indicate the differences on higher levels every 2 km above the first level (2.6 km, 4.6 km …). Accordingly, at 2.6 km the mean hypsometer pressure is 0.49 lower than the GPS value with a standard deviation of 0.96 and 96 cases analyzed. Around 4 – 6 km the hypsometer pressure is lowest (by 0.57 hPa) with respect to the GPS. This negative difference then decreases and changes sign at 14 km reaching a positive maximum of 0.23 hPa at 20.6 km. The last value of 0.11 at 34.6 km is not representative since it is only based on two cases.

Due to the new calibration of the thermocouple, the hypsometers of the SRS-C34 radiosondes of 2011 have a lower systematic error than the ones in 2005 (see Figure 1 versus Figure 4). Over almost the entire profile the standard deviation is larger than the absolute value of the systematic bias. More than 90% of the hypsometers of the 95 soundings show a difference with respect to the GPS between -2 and 1 hPa at around 2 km a.s.l..

Figure 5 shows the same as Figure 4 but for the differences of geopotential altitude between the hypsometer and the GPS that is taken as reference. Due to the complex relation between pressure and altitude, the important results shown in Figure 4 are also shown here in blue. Generally speaking the hypsometer shows an altitude slightly lower than the GPS. Positive differences of individual flights are rarely larger than 50 m (in the stratosphere), whereas negative differences are clearly larger in absolute values. The extremes in blue in Figure 4 are to the left in Figure 5. The mean differences in altitude are very close the corresponding medians, which makes the statistics robust. The mean differences hypsometer – GPS are between -3 and -8 m in the troposphere. They are larger than -10 m above 14 km and increase to -45 at 22 km. Further up they decrease to -32 m around 28 km and again increase to -50 m at 32 km. Above 33 km there are not enough hypsometer measurements.

Over all, the mean differences of pressure and altitude between the two instruments are small and demonstrate the high quality of hypsometer measurements on the SRS-C34. Individual hypsometer measurements can deviate more form GPS measurements since the standard deviations of the differences are slightly larger than the mean differences in the stratosphere. Over the 95 soundings analyzed, some show an increase of the differences towards 20 km, which may be related to a problem with the resistive heating or the control system. In such cases the hypsometer may indicate altitudes 200 m lower than the GPS.

On the ground pressure differences between the radiosonde and the reference barometer are on average -0.3 hPa, with a mean DTH of about +0.045. The distribution of these two values is shown in Figure 6.

The question may be asked whether a subdivision of cases (day/night), or a more strict selection with respect to DTH would modify the statistic results. Figure 7 is similar to Figure 5 but subdivides day soundings, respectively night soundings. The statistics of the 30 cases at 12 UTC (left) are slightly different from the 65 cases at 00 UTC (right). Compared to the night measurements the pressure “nose” is slightly larger during the day, the mean altitude differences are lower, and the mean pressure difference at 600 m are less positive. It is however difficult to claim that the day/night differences are significant, in particular if we take into account the rather large difference of cases between day and night.

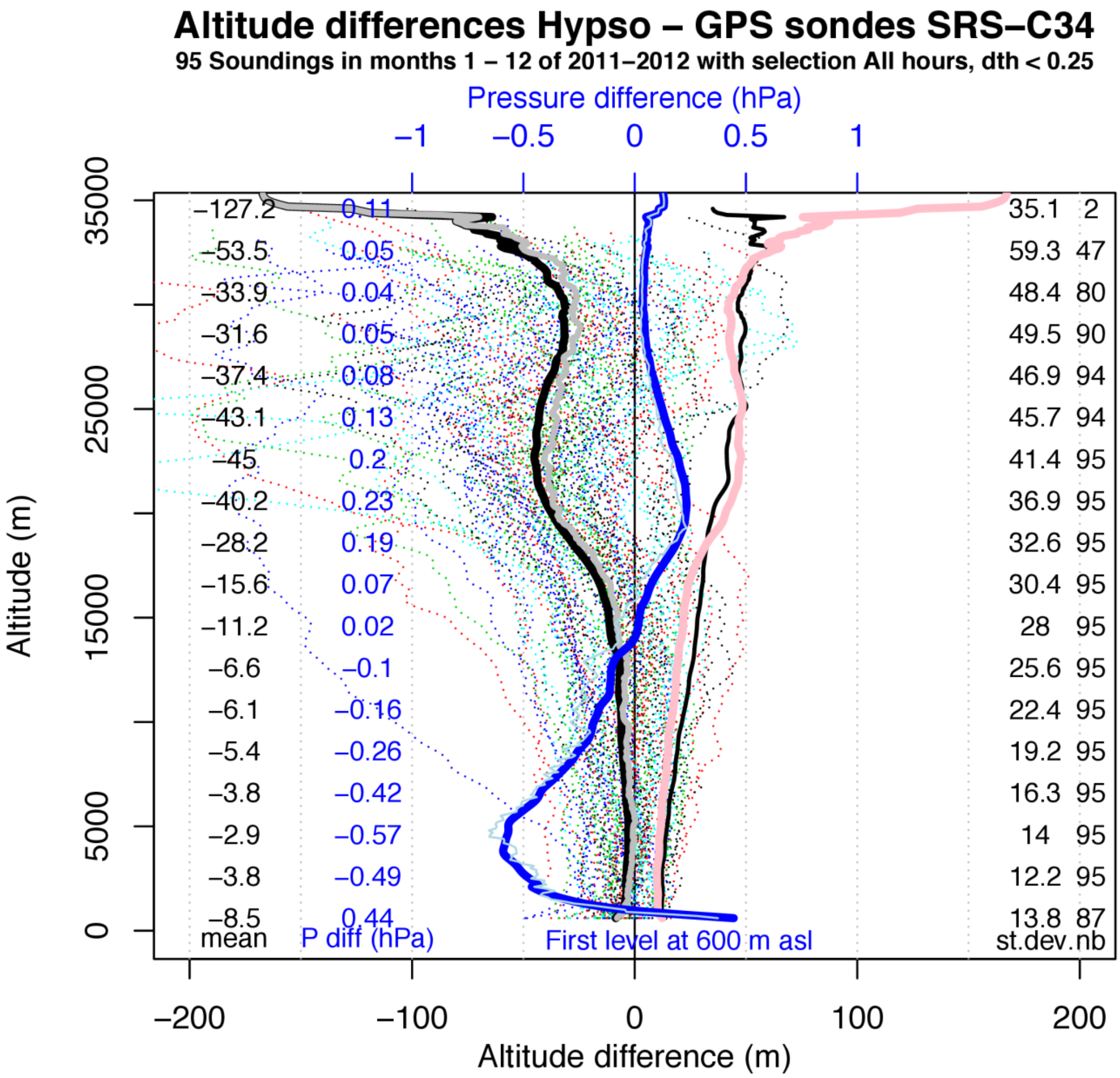


Figure 5: Profile of altitude difference (m) between the hypsometer and GPS/reference. 95 individual SRS-C34 radiosoundings (dotted lines in different colors) and the global statistics: mean (thick black) with values to the left, median (thick gray), standard deviation (thin black) with values to the right, mean of absolute differences (pink), and number of cases at the extreme right. The selection is specified below the title. The results of Figure 4 (pressure) are also shown in blue on this Figure, with the scale of the pressure differences above the graphics.

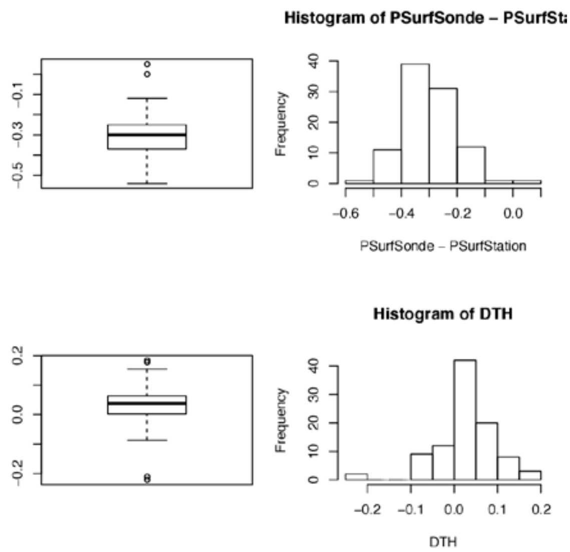


Figure 6: Boxplot and histogram of differences between radiosonde and barometric pressure at the station (above), as well as boxplot and histogram of DTH values (below).

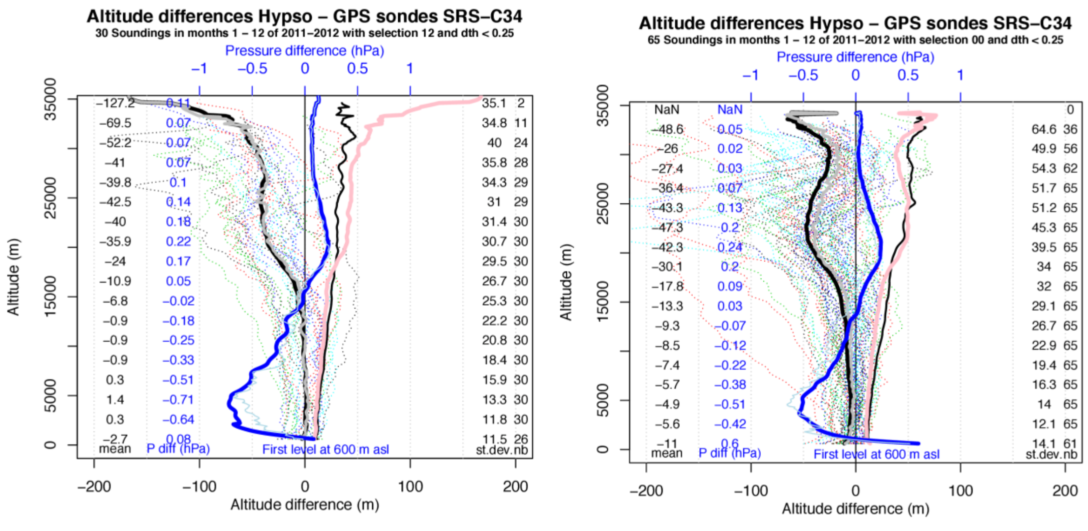


Figure 7: Same as Figure 5, but for the 30 soundings at 12 UTC (left) and the 65 soundings at 00 UTC (right)

Figure 8 is similar to Figure 7 but it shows the reduced selection of radio soundings for cases with abs(DTH) <= 0.07, instead of 0.25. The differences between the two figures are really small and rather difficult to interpret. One could go on and further reduce the selection to DTH values <= 0.03. If the results do not really change, it seems that small DTH values are synonym to better pressure measurements in the stratosphere. This may be due to the fact that DTH corrections are applied to all soundings, but they are determined on the ground.

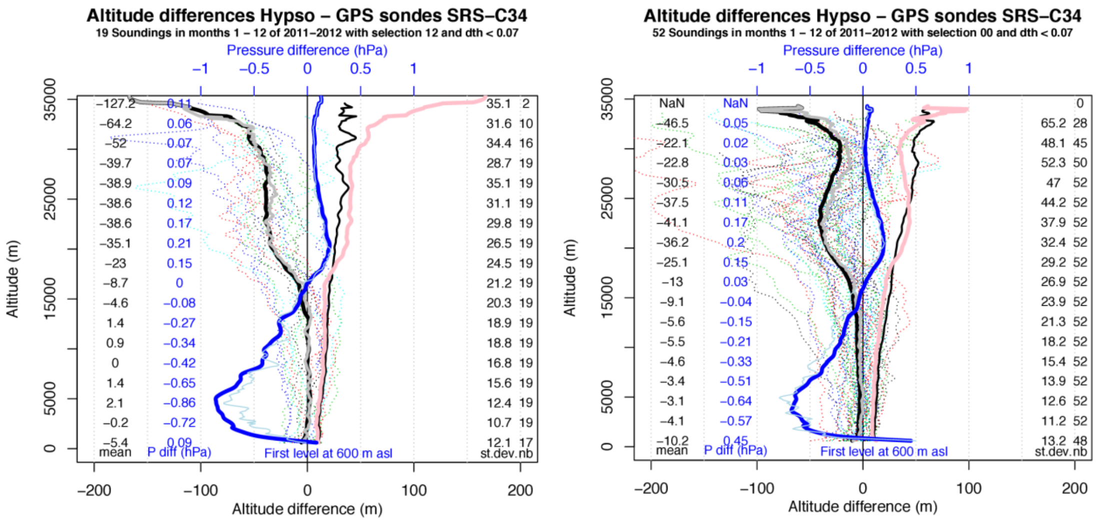


Figure 8: Same as Figure 5, but for the 19 soundings at 12 UTC (left) at the 52 soundings at 00 UTC (right) having absolute DTH values <= 0.07 (rather than <= 0.25).

3 Comparison SRS-400 - SRS-C34

3.1 Preparation of data

Pairs of files f2011MMJJ.HH with HH = HH/HH+1 (particularly 00/01 and 12/13) have been searched after the SRS-C34 was officially put into operation on 11.01.2011. The resulting list has been checked with the MeteoSwiss documentation “Sondages spéciaux” of rem_sond_2011.doc which starts as follows:

20110118 12z double srsc34 id 58=PTU +GPS. OFFSET DE 4 secondes+SRS-400 (passif)
20110125 12z double srsc34 id 58=PTU +GPS.+SRS-400 (passif)
20110201 12z triple srsc34 id 58=PTU +GPS. +SRS-400(passif)+RS92

Attention on ne peut pas synchroniser en fonction du temps pour comparer!! Sonde C34 relancée

The final list of soundings used in the program AnalyseSondagesDoublesC34SRSf.r is shown in Table 1. The list contains pairs of files indicated as SRS-C34 (official hour HH) – SRS-400 (HH+1). The lines that start with # are comments that are ignored, comments that are from the document mentioned above. The other lines consist of 3 columns:

1. Name of file SRS-C34 (f version of the sounding)

2. Name of file SRS-400

3. Stop sounding time of SRS-400

The technique to prepare the files is different compared to RSKOMP. No data has been suppressed and no corrections by hand were made, except for the file name f20111205.13. In 2011 no corrections were made for the psychrometric effect on the SRS-C34, nor on the SRS-400 soundings. The following restrictions were applied to eliminate specific problems:

- Elimination of file f2011060.13 (problems with humidity)

- Elimination of soundings with abs(DTH) > 0.25 (elimination during operation SRS-400)

- Suppression of descent phase, according to GPS

- Suppression of files with measurements interruptions longer than 350 m

Problems with time synchronization have been corrected with an algorithm minimizing the standard deviation of temperature measurements between 30 and 2000 s, similar to the procedure in the Radiosonde Comparison Software RSKOMP used in the WMO radiosonde intercomparisons since 1990. Two corrections of -27 and -19 s were made, others were only of a few second.

3.1.1 Table 1

Double soundings SRS-400 – SRS-C34

LES SONDAGES ELIMINES DE LA LISTE SONT PRECEDES DE
PJE/16.06.2015
fichierC34,fichierSRS , time coupure srs,
f20110118.12,f20110118.13,5100,
f20110125.12,f20110125.13,5200,
#f20110201.12,f20110201.13,50, (pas de synchro possible en fonction du temps: sonde C34 relancée)
f20110208.12,f20110208.13,6100,
f20110215.12,f20110215.13,6200,
f20110222.00,f20110222.01,7000,
f20110222.12,f20110222.13,5000,
f20110303.12,f20110303.13,4700,
f20110308.12,f20110308.13,6700,
f20110315.12,f20110315.13,6700,
f20110316.00,f20110316.01,5800,
#f20110319.12,f20110319.13,50, (pas de fichier r: mais present dans fichier remarques/sondages speciaux)
f20110322.12,f20110322.13,5900,
f20110329.12,f20110329.13,5800,
f20110405.12,f20110405.13,5500,
f20110406.00,f20110406.01,7000,
f20110419.12,f20110419.13,6500,
f20110420.00,f20110420.01,6700,
#f20110505.12,f20110505.13,50, (delta T de 10C sur le profil de T impossible a detecter avant le vol)
f20110506.00,f20110506.01,6700,
f20110517.12,f20110517.13,6100,
#f20110518.00,f20110518.01,7700, (montée trop lente: supprimé de la liste par pje)
#f20110607.12,f20110607.13,5100, (RH faux dans un fichier)
f20110621.12,f20110621.13,5500,
#f20110622.00,f20110622.01,50, (probleme technique: pas de mesure dans fichier c34 ?)
f20110628.22,f20110628.23,2100,
f20110705.12,f20110705.13,5000,
f20110706.00,f20110706.01,7000,
f20110718.12,f20110718.13,6200,
f20110719.00,f20110719.01,5800,
#(f20110719.01: SRS-400 a 24 s de retard dans le start: peut étre corrige)
f20110802.12,f20110802.13,5600,
f20110803.00,f20110803.01,6900,
f20110816.12,f20110816.13,6400,
f20110817.00,f20110817.01,6400,
f20110901.00,f20110901.01,4200,
f20110901.12,f20110901.13,6200,
f20110913.12,f20110913.13,6200,
#f20110914.00,f20110914.01,50, (probleme temporaire hypso dans tropo moyenne -> elimine)
f20110922.12,f20110922.13,6400,
f20110923.00,f20110923.01,6600,
f20111005.12,f20111005.13,5500,
#f20111006.00,f20111006.01,50, (barre dans fichier remarque/sondages speciaux)
f20111018.12,f20111018.13,7000,
f20111108.12,f20111108.13,3500,
#(f20111108.12: SRS-400 a un petit retard de qques s dans le start: peut etre corrige)
f20111109.00,f20111109.01,6800,
#f20111110.10,f20111110.11,50,
f20111115.12,f20111115.13,2900,
f20111116.00,f20111116.01,6500,
f20111201.00,f20111201.01,6600,
f20111201.12,f20111201.13,6700,
#f20111205.12,f20111205.13,50, (fichier r absent: absent aussi dans fichier remarques/sondages speciaux)
f20111213.12,f20111213.13,6000,

Starting from 03.03.2011, except for 28.06, all SRS-400 thermocouples used the « v » version. On the SRS-C34 the « x » version was still used until March 2012 (for more information on the two versions, see [Philipona et al. 2013]).

3.2 Analyses

Remember that GPS altitudes of the SRS-C34 are given in geopotential altitude in all sounding files produced by ARGUS, as well as SRS-400 measurements, without smoothing nor corrections of the pendulum motion of the radiosonde. SRS-C34 data are from « f » files with measurements every 3 seconds. SRS-400 data have slightly irregular timing around 8 seconds. Also, note that the DTH of the hypsometer of the SRS-400 was determined outside shortly before launch.

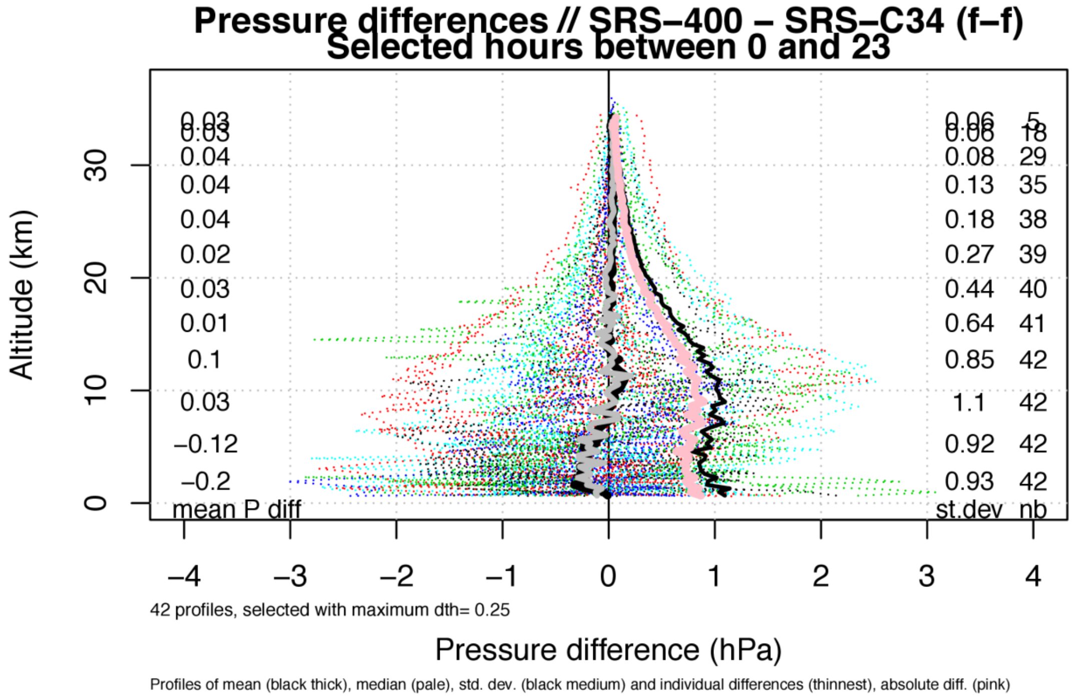
Figure 9 results from the program AnalyseSondagesDoublesC34SRSf.r. The upper graph can be directly compared to Figure 4. Two observations can be made:

1. Pressure measured by the SRS-400 hypsometer better match SRS-C34 GPS measurements than hypsometer pressure measurements on the SRS-C34. The “nose” in the lower troposphere is strongly reduced and pressure differences are small and constant over the entire stratosphere. Systematic errors are smaller for the SRS-400 hypsometer than for the one on the SRS-C34.

2. Standard deviation of the SRS-400 hypsometer are larger compared to the one of the SRS-C34 (see Figure 4), in the higher troposphere and lower stratosphere. The reproducibility of the SRS-400 hypsometer is lower than one of the hypsometer on the SRS-C34.

In contrast to Figure 4, the first level in Figure 9 is not at 600 m a.s.l. but at 650 m a.s.l. (after 30 s). Since f files do not have the radiosonde pressure on the ground, we do not analyze pressure differences to the barometric station on the ground. Nevertheless, the DTH adjustment guarantees good accord between the two values. In contrast to Figure 6 the DTH histogram is inversed, with the maximum between -0.05 and -0.1 °C.

The lower graph on Figure 9 shows a better statistical analysis. The horizontal scale has a higher resolution. The interpolated levels (every 60 s from 30 s after the start) are distributed according to the GPS altitude every 2 km, except the first one that goes from 491 m to 1999 m. The median of the pressure differences are shown by thick black lines, and the 25 and 75% percentiles are also shown. Numerical values are shown on the left. The largest median of the differences (-0.26 hPa) is within 2 and 4 km. The respective standard deviation over the 42 soundings is on the order of 0.9 (see graph above). The median pressure difference -0.26 hPa mentioned above is close to the edges of the indentation of the adjacent altitude classes, and therefore statistically different from zero. Between 8 and 24 km the median pressure differences oscillate around zero and are likely not statistically significant. Above 28 km these values are statistically different from zero. They are therefore more or less constant with altitude.



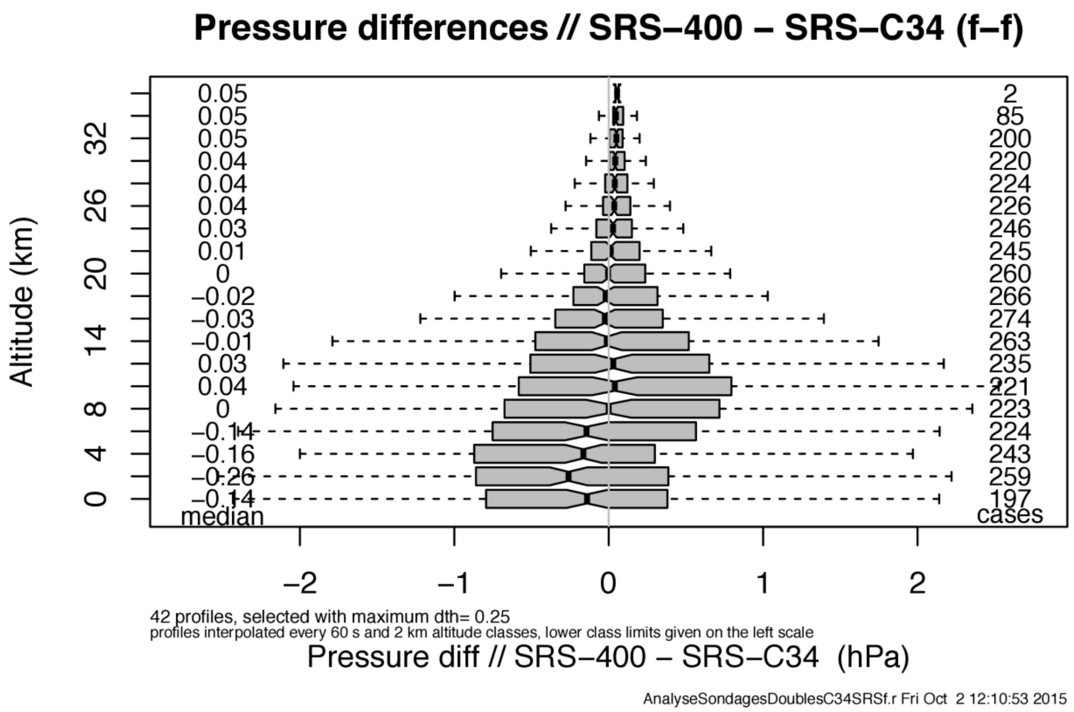


Figure 9: Profiles of pressure difference (hPa) between the SRS-400 hypsometer and the SRS-C34 GPS. Above: 42 individual cases (dashed in different colors) and global statistics: mean (thick black) with values to the left, median (gray), standard deviation (thin black) with values to the right, mean of absolute differences (pink), and number of cases to the extreme right. The selection is given below the title. Below: boxplot of pressure differences based on interpolated profiles every 60 s starting after 30 s, and distributed in altitude classes of 2 km according to left scale.

It is not easy to explain the small pressure differences observed. If we assume that they are statistically sound and taking the GPS pressure as reference, we could blame the calibration curve of the hypsometer thermocouple. However, the difference of -0.26 hPa between 2 and 4 km only leads to a temperature “error” of the hypsometer of 0.01 °C. MeteoSwiss still applied in 2011 the transfer function from 1999, which could explain part of the difference observed in Figure 9. It is however astonishing that better results are found with the old transfer functions. The determination of DTH under reel condition and prior to launch may have played a positive role.

Figure 10 allows analyzing geopotential altitudes differences, the same way as pressure difference in Figure 9. The graph above shows:

1. Very good overall agreement between hypsometer and GPS, which slightly degrades towards the middle stratosphere, with the hypsometer showing slightly lower altitudes than the GPS.

2. A dispersion of individual soundings that increases linear with altitude, with some cases showing larger tendencies towards negative differences than the majority.

We again conclude that the SRS-400 hypsometer is slightly better than the SRS-C34 hypsometer with regard to the mean error (bias) over the geopotential altitude, but less good with respect to random error. The mean error of the SRS-400 hypsometer is very small in the troposphere (max. 5 m), still small up to 25 km (max. -15 m), and reaches about -30 m at 30 km. Above 32 km the SRS-400 hypsometer delivers mean altitudes lower than the GPS. Mean differences are considerably smaller than standard deviations over all altitudes. Random errors can reach 150 m around 30 km.

Since temperature and humidity profiles play a role in the hydrostatic integration, one may wonder whether these measurements influence the differences between SRS-400 and SRS-C34 shown in Figure 10. Although solar influence on temperature measurements has been corrected with the same formula from 1999 [Ruffieux and Joss 2003], on both radiosondes in 2011, the thermocouple of the SRS-C34 was modified on soundings of Table 1, since beginning of March 2011. The thermocouple was changed from the « x » version to the « v » version. 36 of the 42 SRS-C34 soundings were concerned. Philipona et al. [2013] showed that this change reduced the solar radiation effect by 0.3°C. Also, the calibration curves of the thermocouples are slightly different: the one for the SRS-400 is from 1993, whereas the one for the SRS-C34 is from 2005. According to the technical documentation of Meteolabor and as reported in [Jeannet, 2007], at -55°C the SRS-400 would indicate 0.1 °C lower temperatures than the SRS-C34, and at -70 °C the temperature would be even 0.15 °C lower.

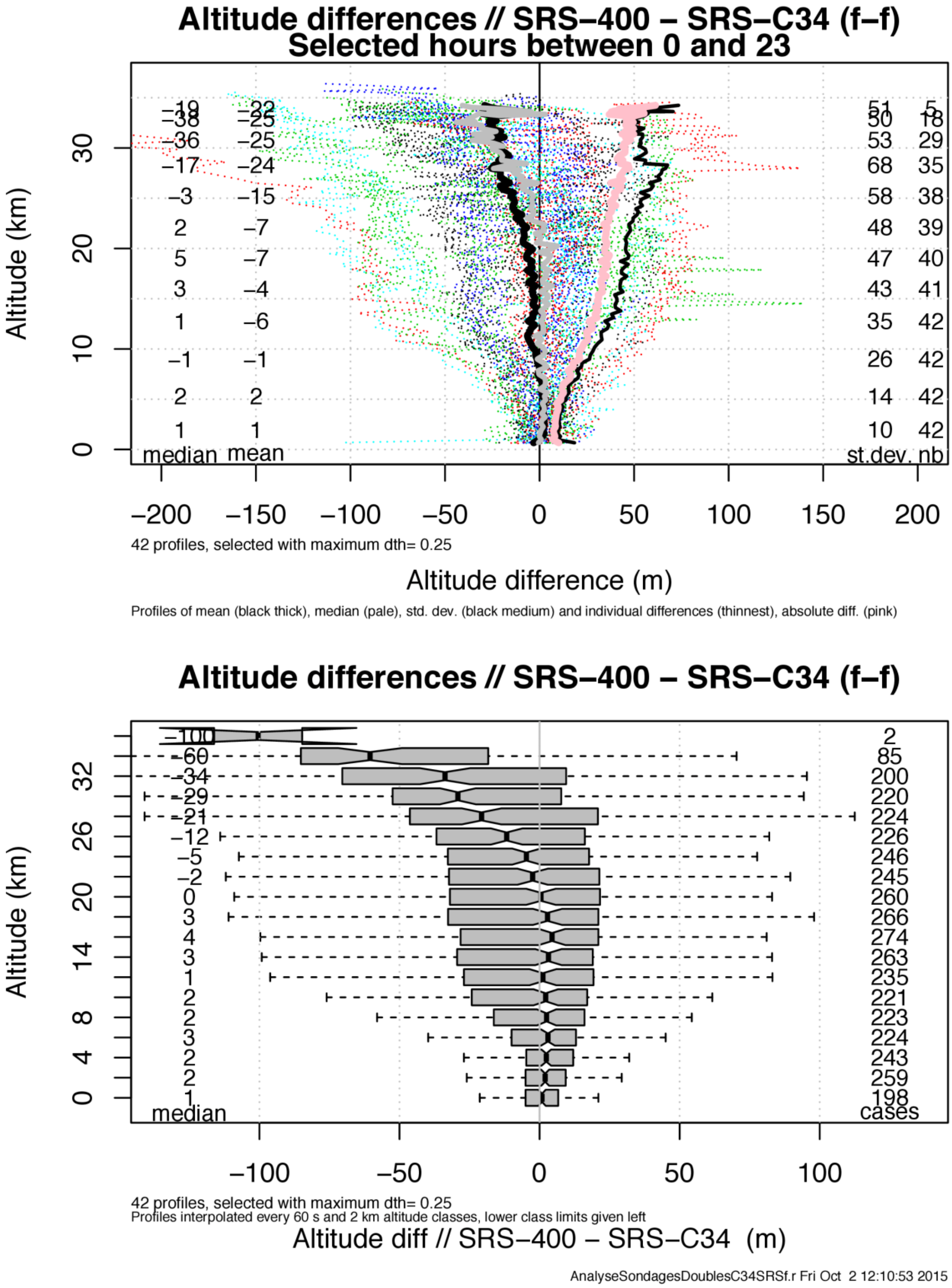


Figure 10: Similar to figure 9 but for altitude differences.

Figure 11 shows temperature differences with the SRS-C34 taken as working reference. During daytime (left) mean differences are very small in the lower troposphere up to 8 km (positive, < 0.05°C), then get slightly negative (approximately -0.09 °C) around the tropopause, and finally increase up to +0.35 °C towards 32 km in the stratosphere. Around the tropopause the results may be related to differences in calibration curves, with minimum temperature between -60 and -70°C. In the stratosphere an overestimation of the solar radiation effect for the « v » shaped thermocouple, may explain the rising positive differences. During nighttime (right) mean differences are very small in the troposphere (less than 0.05 °C), and stay below 0.1°C in the stratosphere. The slight curvature around the tropopause could be due to the calibration curves, but is less significant than during daytime. During the night, individual fluctuations are much smaller than during the day.

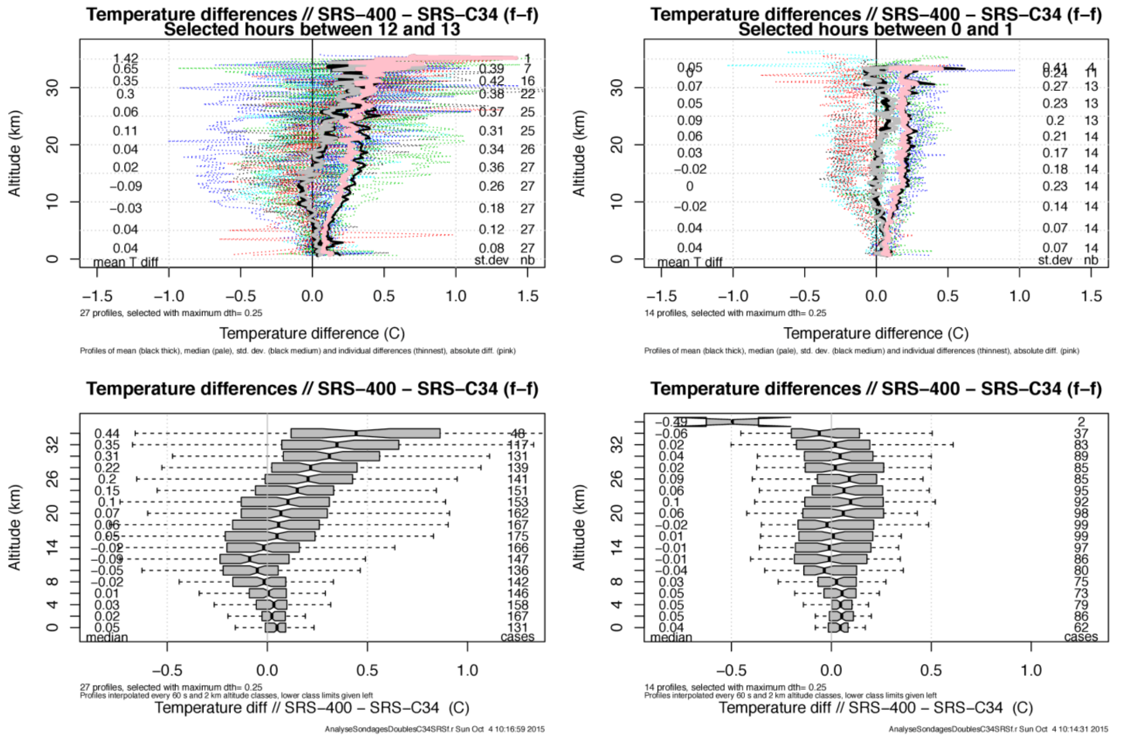


Figure 11: Similar to Figure 9, but for temperature differences. The left graph shows the 27 soundings at 12 UTC, and the right graph the 14 soundings at 00 UTC. The SRS-C34 temperatures are used as working reference.

The small temperature differences likely play a minor role on the barometric integration. However, to improve the analyses temperature and humidity profiles (T/RH) of the SRS-C34 are used to recalculate the SRS-400 geopotential altitude. Since the analyses of the SRS-C34 with GPS and hypsometer have shown slightly different results for day and night sounding, we keep this distinction for following analyses.

Figure 12 shows pressure differences similar to the ones shown in Figure 9, but now with the T/RH profiles from SRS-C34 on SRS-400 soundings, specific for day and night (left/right). Day statistics is astonishing different from night statistics. During the night the positive sign of pressure differences SRS-400 – SRS-C34 is reverse versus day and global statistic in Figure 9. This result stays on if one conserves the T/RH profiles of the SRS-400. The small number of night cases (14) and the large dispersion of individual cases may be questionable, but it is likely that the hypsometer shows slightly different behavior during day and night. The reasons are so far not really known. The reports from WMO intercomparisons (Mauritius [Nash et al, 2006] and China [Nash et al, 2011]) combine day and night cases for pressure and altitude analyses. Beside the small differences day/night, the good statistic agreement between pressure measurements of the SRS-400 (hypsometer) and the SRS-C34 (GPS) is remarkable.

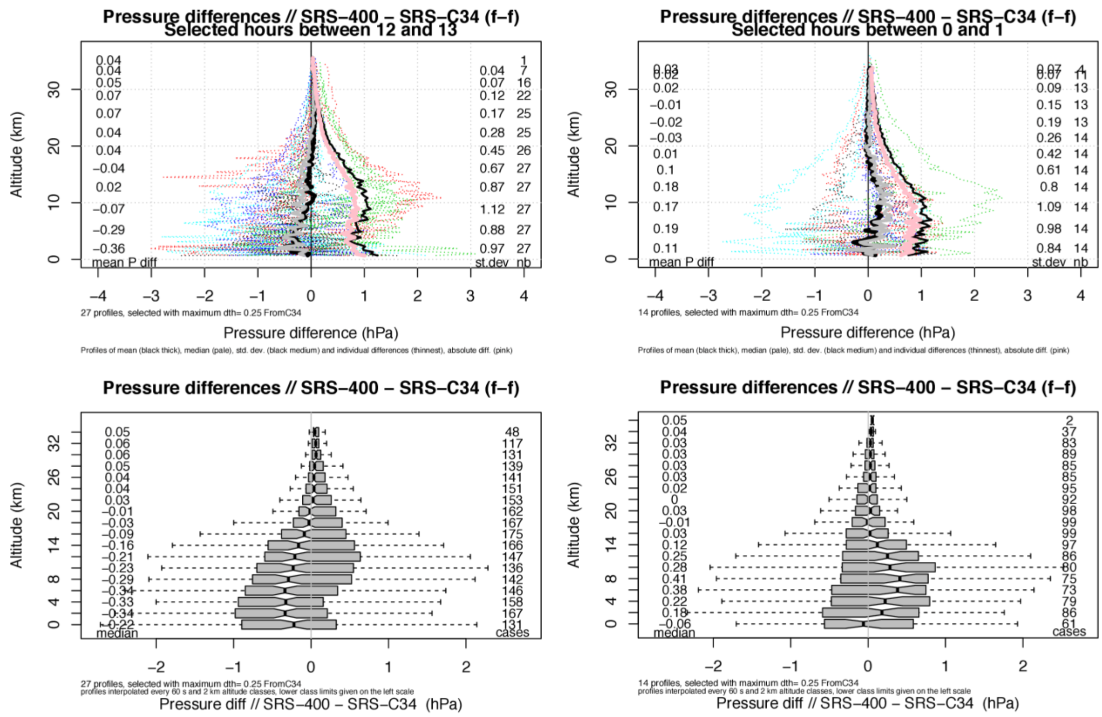


Figure 12: Similar to Figure 9 for pressure differences, but after the transfer of T/RH profiles of the SRS-C34 to the SRS-400 and distinguishing between day/night (left, right).

In the following Figure 13 analyses the geopotential altitude after the transfer of T/RH profiles on the SRS-400 and distinguishing between day and night. The results are more or less the same and similar observations as for the pressure can be made for the altitude. There is a slight day cycle observed but good agreement between the hypsometer of the SRS-400 and the GPS of the SRS-C34 is conferment also for the altitude.

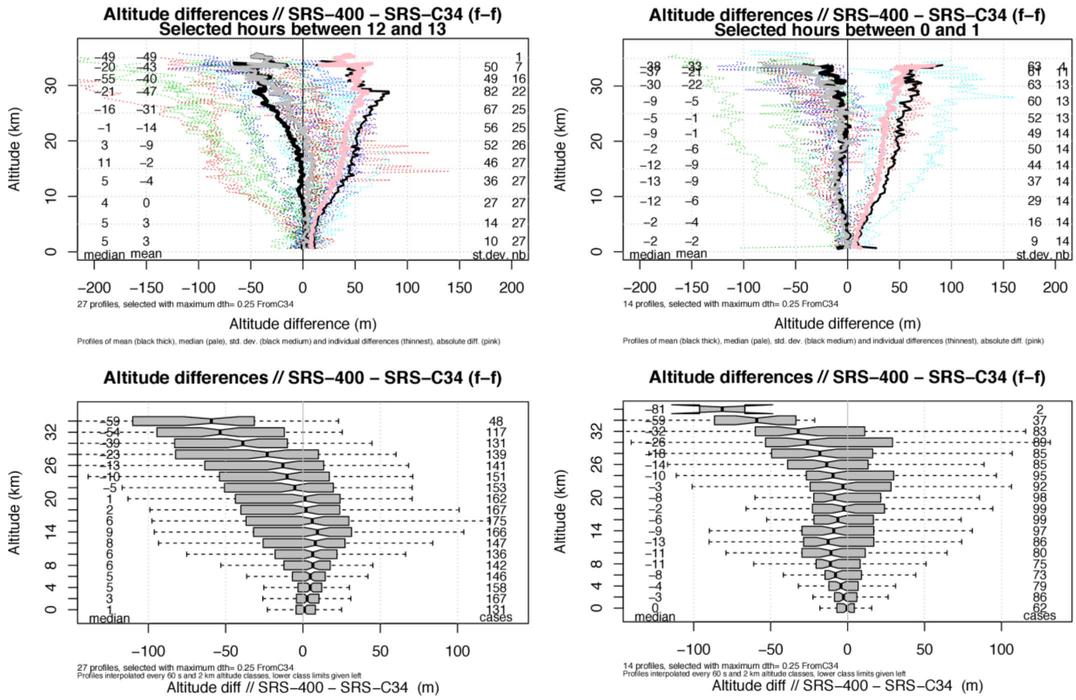


Figure 13: Similar as Figure 10 for the altitude differences, but after transfer of the T/RH profiles of the SRS-C34 to the SRS-400 and distinguishing between day and night (left, right).

To end the analyses we show in figure 14 the humidity and integrated water vapor differences between the two radiosondes averaged over the 42 soundings. The values of the SRS-C34 are taken as working reference. Both radiosondes had the same type of humidity sensor from Rotronic, but a slightly different processing.

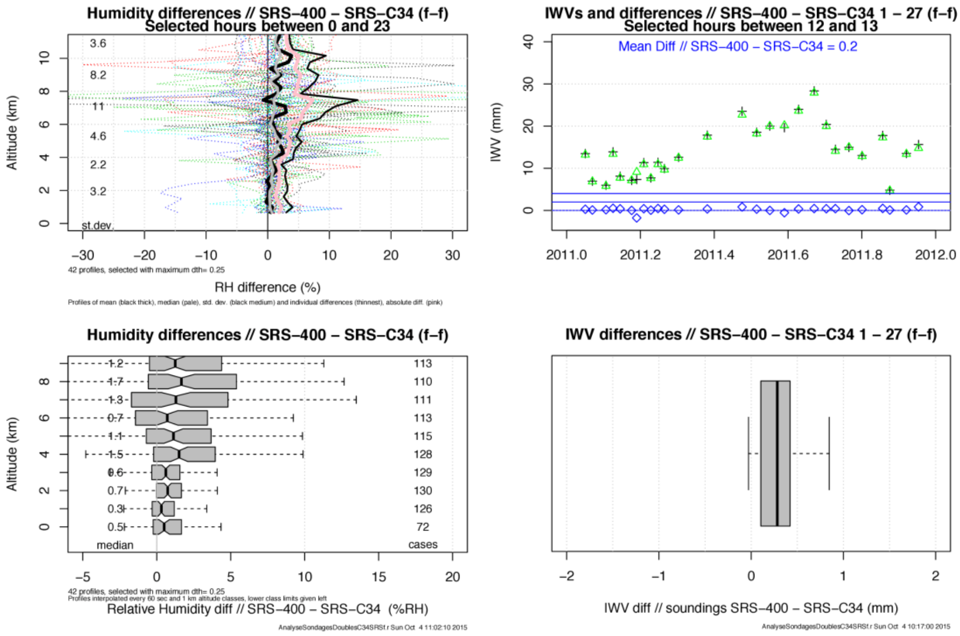


Figure 14: Similar as Figure 9, but for the humidity differences (left) and integrated water vapor (right), averaged over all 42 soundings. The SRS-C34 values are taken as working reference.

4 Conclusions

This analysis follows one of the principles and requests of GCOS for climate observations and instrument changes: “A suitable period of overlap for new and old observing systems is required“. Double soundings made with the old and the new radiosonde (SRS-400 and SRS-C34) allow analyzing the continuity and homogeneity of the measurement series. Our analysis is primarily made for pressure and geopotential altitude measurements and uses GPS values as reference to check the hypsometer measurements. Temperature and humidity measurements are also briefly shown.

As a first result the analysis confirms that the pressure derived from the SRS-C34 hypsometer coupled to the ARGUS system does not any more show the systematic error observed during the international radiosonde intercomparison at Mauritius Island in 2005. The hypsometer on the SRS-C34 that is used at Payerne since January 2011 still shows a minor error with respect to the GPS. But this has no importance on the Payerne measurement series, since this hypsometer was only compared to the GPS for about hundred soundings from January 2011 to February 2012.

However, for the continuity of the Payerne radiosonde series the analyses of the comparison of the SRS-400 (hypsometer) and the SRS-C34 (GPS) is important. 42 double soundings SRS-400 – SRS-C34 were made during 2011 and built the basis for a good intercomparison. The results show that the SRS-400 hypsometer coupled to the MeteoSwiss data acquisition even further reduces the systematic errors on pressure and geopotential altitude profiles with respect to the GPS of the SRS-C34 – ARGUS system. On the other hand the random errors are larger on the Payerne versus the ARGUS system. One reason for the random error was in fact discovered only in 2015, and is also related to the SRS-C34. Hardware corrections were made on the SRS-C34 with respect to the electronic reference of the thermocouple. Two observations need to be further investigated. The very good results with the SRS-400 are obtained with the old calibration curve of the hypsometer temperature sensor from 1999, whereas a more recent and better curve exists from 2005. Also, a small difference between 12 and 00 UTC soundings is observable in the statistics of pressure and altitude differences between the two radiosondes.

The systematic pressure error (bias) could be corrected in the SRS-400 series, probably since the introduction of this radiosonde in 1990. According to the statistics over the 42 soundings (see Figure 9) these systematic errors are nevertheless very small and their difference from zero is barely significant. They change sign above the lower troposphere. In the stratosphere the systematic error is between 0.01 and 0.05 hPa, with the SRS-400 showing a slightly higher pressure. The consequence is a slight underestimation of the geopotential altitude by the SRS-400, which increases in the middle stratosphere and reaches an average underestimation of 30 m at around 30 km altitude.

These results would have to be backed up by further investigations before a possible minor correction of the historic pressure measurement series of the SRS-400 would be made.

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