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Atmospheric
Measurement
Techniques
Discussions

Interactive comment on "Intercomparison of in situ water vapor balloon-borne measurements from Pico-SDLA H₂O and FLASH-B in the tropical UTLS" *by* M. Ghysels et al.

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The authors wish to thank the anonymous referee #3 for his helpful comments. Below are the response to the referee #3 comments:

p 13698, l 18-26: Like suggested by the referee, we added more details: "However, persistent disagreements remain. For example, (Vömel et al, 2007a), compared in situ balloon-borne measurements of water vapor from several instruments during coincident flights. Comparison of in situ water vapor measurements from the CFH hygrometer (cryogenic frost point hygrometer) and the NOAA/CSD (cryogenic frost point hygrometer) aircraft hygrometer led to differences ranging up to 40% between 14 and

17 km. Throughout the entire altitude range (from 10 to 20 km) the measurements from the Harvard Lyman-α hygrometer and the CFH shown considerable discrepancies up to 110%. Differences of ±10 % were found by comparing the FLASH-B (Lyman-α) and NOAA/CDML (frost point hygrometer) water vapor measurements obtained at altitudes of 15 km above the polar stratosphere (Vömel et al, 2007b). (Jensen et al, 2008) found that discrepancies between nearly simultaneous water vapor measurements in the TTL (Tropical Tropopause Layer) could reach 2 to 3 ppmv: this latter work compares measurements from the Harvard water vapor instrument (HWV, Lyman-α) and from the Harvard ICOS (Integrated Cavity Output Spectroscopy) instrument within the altitude range 15 to 19 km. More generally, in the TTL, the measurements have shown discrepancies larger than 10 %."

p 13696, l 20: Thank you, we corrected the mistake.

p 13698, l 1: Done.

p 13698, l 16-17: The rubber balloons were used to launch the FLASH-B hygrometer, not Pico-SDLA because it was too heavy. Since I describe Pico-SDLA in this section, I did not mention the rubber balloons because they have not been used for the flights of this instrument.

p13698, l 22: Onboard Pico-SDLA, we use a DFB laser diode having temperature and current control. Since the temperature tuning is much slower than a current modulation, we prefer to modulate the current to scan the water vapor line and keep the temperature fixed. In the text, we added a couple of line to give more details: " This diode has temperature and current controls: then, we distinguish the current modulation from the TEC temperature tuning. The current modulation of the laser is the preferred method to scan the water vapor absorption line since the response time is much faster than for a TEC temperature modulation: the water vapor absorption line is scanned by tuning the laser current and fixing the TEC temperature. "

p 13699, l 15-20: In the case of Pico-SDLA, during spectra processing, we noticed that the use of a simple Voigt profile did not show any structures in the residuals. We simply used the Voigt profile and HITRAN 2012 parameters: the only pressure effects taken into account in this case are the self and foreign broadenings. The signal-to-noise ratio of the atmospheric spectra in the TTL did not permit to observe any additional effects like Dicke narrowing, line mixing or speed dependent effects. However, we added a paragraph to give more details about the pressure effects and their uncertainty impact on the mixing ratio retrieval.

p13699, l 18: In the case of the VP, the self- and air-broadening effects are taken into account. In HITRAN 2012, for the two lines, the self-broadening uncertainty is ± 5-10% and the air-broadening uncertainty is ± 2-5%. We made some tests to determine the impact of the width uncertainties on the retrieved mixing ratio: they are inducing an error smaller than 1%."

p 13699, l 20: Yes, on Figure 2 we show the transmission of the atmospheric spectra, in the text, line 21, we replaced atmospheric spectra by transmission of atmospheric spectra, like: "Figure 2 shows an example of the transmission of three atmospheric spectra of the H2O 202←101 line recorded during the February 10, 2013 flight in Bauru, at different altitudes in the lower stratosphere (24.24 hPa = 25.2 km; 73.60 hPa = 18.4 km; 101.05 hPa =16.6 km). Then in the figure 2 caption: "Transmission of the atmospheric spectra of the 202←101 line of H216O from Pico-SDLA H2O measurements on February, 10, 2013 during the descent of the balloon. The top panel shows three experimental spectra (black line) and the results from fitting procedure(red line). These spectra were recorded at 25.2 km (24.24 mbar), 18.4 km (73.6 mbar) and 16.5 km (101.05 mbar) of altitude. The bottom panel shows the fit residuals for each spectrum."

p 13699, l 29: Thank you, we corrected this mistake.

p 13701, l 2: Done.

p 13701, l 20: We added a subsection "2.1.1: Description of Pico-SDLA H2O"

p 13702, l 17: The mean ΔT is determined from the ground to the ceiling. Then in the text, we added: "Within the overall altitude range of the flight, the mean ΔT for this flight is 0.12 ° C with a standard deviation $\sigma(\Delta T)$ of 0.28° C. "

p 13702, l25: Yes, the referee #1 pointed out this point too. Therefore, we added the following sentence on line 21: "On January 18, Pico-SDLA has been launched at 22:11 UTC under a 1500 m3 balloon." p 13703, l 3: For the temperature and pressure comparison, we compared the measurements of Pico-SDLA with those of one RS-92. This is expressed at the beginning of the subsection.

p 13703, l 3-19: This discussion is used to demonstrate the reliability of the Pico-SDLA temperature and pressure measurements since they are input factor for spectra processing and therefore, have an important impact on the mixing ratio retrievals. The GRUAN approach is a reference to provide accurate measurements, constrain and calibrate data. Then, it constitutes an interesting tool to demonstrate the reliability of the measurements. In the case of the January 18, 2013 flight, the RS-92 used for comparison with Pico-SDLA is independent from the one integrated to FLASH-B. It is important to provide a third independent set of data.

p 13704, l 5: For these flights, the descent is made under parachute after separation of the payload from the balloon. Therefore altitude excursions and balloon wake crossing are not conceivable. It is possible though that the Pico-SDLA instrument surfaces may act a source of outgassing during descent at low ambient pressure, where even small amounts of water residing on the instrument itself provide a large contribution, resulting in contamination of the measurements.

P 13704, l 18: In the tropical stratosphere the lower limit is rather 300 hPa, so we prefer to stay on the conservative side and write 300 hPa. The limitation to night time is indeed a result of the open optical layout, where the detector (photomultiplier in this case) is pointed outward to measure the fluorescence from a volume located outside the instrument, a few centimeters away from the lens. The detector would get saturated if exposed to scattered sunlight. The sunlight as such would not affect the analyzed volume in any physical way that would perturb the measurements.

P 13705, l 13: We modified as: "above 70 hPa level".

P 13705, l 17: By “undisturbed air” we mean that it is a priori outside of the balloon/instrument wake. During the descent the analyzed volume is ahead of (below) the instrument and is therefore clear of the outgassing plume. The stratospheric descent, typically faster that 15 m/s, outruns by far any potential diffusion from the instrument walls.

p 13706, l 17 and p 13706, l 19: Thank you, we corrected the mistakes.

p 13706, l 12-22: We added the following references:

Pico-SDLA CH4: M., Ghysels, L., Gomez, J., Cousin, N., Amarouche, H., Jost and G., Durry, Spectroscopy of CH4 with a difference-frequency generation laser at 3.3 microns for atmospheric applications, Appl. Phys. B, 104, 989-1000, 2011.

COBALD: Brabec, M., Wienhold, F. G., Luo, B. P., Vömel, H., Immler, F., Steiner, P., Hausammann, E., Weers, U., and Peter, T.: Particle backscatter and relative humidity measured across cirrus clouds and comparison with microphysical cirrus modelling, Atmos. Chem. Phys., 12, 9135-9148, doi:10.5194/acp-12-9135-2012, 2012.

LOAC: J., -B., Renard, G., Berthet, F., Jégou, M., Jeannot, L., Jourdain, F., Dulac, M., Mallet, J., -C., Dupont, C., Thaury, T.,Tonnelier, N., Verdier and P., Charpentier, LOAC (Light Optical Particle Counter): a new small aerosol counter with particle characterization capabilities for surface and airborne measurements, EGU. European Geosciences Union General Assembly 2013, Apr 2013, Vienne, Austria. EGU, 15, pp.EGU2013-2824, 2013, Geophysical Research Abstracts.

p 13708, l 7 onward: Done.

13708, l 25-26: Done.

p 13708, l 26: On line 26, we explain how important is the CPT temperature in the amount of water vapor entering the stratosphere. Here, the slow ascent is one of the 2 mechanisms of vertical transport of atmospheric compounds in the atmosphere. This is different from the "descent" or "ascent" term used for the flight profile. There is no link in between them.

p 13709, l 11-12: Yes, there is a mistake. We corrected the text this way: "During the descent, the structure at 17.2 km was captured by FLASH-B at the same altitude and shifted up by 50 m. The ascent profile of FLASH-B also shows the structure at the same altitude but the noise amplitude is larger rendering the structure much harder to distinguish."

p 13709, l 15: On Figure 4, we removed the ascent data from and above 18 km because of outgassing contamination. However, this structure is visible in the dataset. This is the meaning of the sentence : " Because of a small amount of outgassing, the profile above 17.7 km cannot be considered. Nevertheless, structures are visible." p 13709, l 16-17. We added one paragraph to correct the information missing about the structure at 17.8 and 18.1 km on FLASH ascent profile which were not mentioned before: "The structure at 18 km was captured by FLASH-B at the ascent and at the descent. The ascent profile of FLASH-B shows only one structure at 18 km whereas the descent profile shows two structures at 17.8 and 18.1 km of 280 and 300 m thickness respectively."

p 13709, l 16-17: We refer to the ascent profile of FLASH. We mentioned again that the ascent profile has been cut from 18 km because we talk about a structure at 18 km that we do not show on the figure. It is a reminder. Outgassing contamination and geographical/temporal shift have a different impact on the water vapor profile. The difference in spatial structures between FLASH and Pico-SDLA profiles can be attributed to geographical/temporal shift. These differences are localized. Outgassing effects induce a constant increase of the background concentration with the altitude over the entire profile. Discriminating these 2 effects is easy.

p 13709, l 20: Thank you, the referee is right, it is a mistake, we corrected the text as: "Over the altitude range between 15 km and 18 km, comparison between the ascent of FLASH-B and the descent of Pico-SDLA leads to a mean difference of (0.13 ± 0.33) ppmv. In the altitude range between 15 km and 23 km, the comparison between the descent profiles of both instruments yields a mean mixing ratio difference of (0.08 ± 0.39)ppmv."

p 13709, l 20 onward: Yes, the best condition to estimate the difference is generally above the TTL since it is purely stratospheric. For this study, the maximum altitude we could considered was low: around 23 km for February 10, 2013 and 21 km for March 13, 2012. We followed our statistical results to pick the right altitude range since these choices permitted to have a larger altitude range, which seemed more reliable to us. For example, in the case of February 10, 2013, we considered the altitude range above the CPT since the statistical results were similar to those obtained within the altitude range above the TTL upper level (we added few lines in the text to explain this choice p 13710, l1: “The strong humidity variability induces a larger standard deviation and therefore less precise results. To obtain a purely stratospheric comparison, it is generally better to consider data above the TTL upper limit (i.e. 19 km). In this case, the mean difference is then (-0.11±0.13) ppmv (1-σ standard deviation: 3.2%). We notice that the above CPT and the above TTL statistical results are not very different. Since the maximum altitude usable in this case is 23 km, we can consider the data above the CPT to test the consistency of Pico-SDLA and FLASH measurements. Then, we obtain a larger altitude range for comparison. Although both instruments were flown 3 hours apart, the measurements are in good agreement. “ In the case of March 13, 2012, we took into account the altitude range above 15 km, since we observed the two following facts: 1) When we consider the data in the range CPT-21.3 km, we see that the mean difference slightly increases because, in this case, the two big water vapor enhancements at 18.1 and 18.7 km have a more important statistical weight in the calculation, 2) Within the range TTL-21.3 km the statistical results are similar to those considering the altitude range above 15 km. Then, in this case we decided to consider

the largest possible altitude range (15-21 km) giving the same statistical results as the TTL-21.3 km. In the text, we added p 13711, l8: “Considering the mean mixing ratio, around 4.3 ppmv, the relative difference represents ∼ 0.5 % (with 1-σ standard deviation of 4.6%). Restricting our comparison to above the CPT, the mean difference is then (0.06±0.18) ppmv (with 1-σ standard deviation: 4.2%). Then, if we consider only the altitude range above the TTL, the mean difference is (0.02±0.16) ppmv (with 1-σ standard deviation: 3.7%). This shows the excellent agreement between the FLASH and Pico-SDLA measurements, which were always within instrumental uncertainties despite the fact that both instruments were flown 3 h apart."

Since the referee idea seems good to us, we added the statistical results for the three altitude ranges, like suggested: 15km-max. altitude, CPT-max. altitude, TTL-max.altitude. We also added two tables #1 (in the section 4.2) and #2 (in the section 4.3), giving the statistical results for the 2 flights within the 3 altitude ranges.

p 13710, l 19-25: On Feb. 10-11, we did not have such a huge altitude shift as in March 13, 2012. On Feb. 10-11, the only shift observed came from geometric/geopotential considerations. Then, it was easily corrected using altitude measurements from a third sensor under the same balloon as FLASH, COBALD, which measured the altitude using a GPS. We did not talk more about this shift in the text since we expose the 188 m shift for which the origin is unknown: this last one was the most difficult to deal with and to my sense, the most important to mention. Since sections 4.2 and 4.3 describing the February 10-11, 2013 flight and the March 13, 2012 flight have been reversed, it was logical and easier to add this sentence in the text, section 4.2: March 13, 2012: "To correct for this difference, we used the altitude measurements from the COBALD backscatter sonde which are obtained from a GPS. Thus, we were able to reconstruct the FLASH altitude scale by interpolating the COBALD data with respect to the time into flight. The same operation has been applied for the February 10-11, 2013 flight for which no shift remains. In the case of March 13, 2012, a (188 ± 7) m altitude difference is still observed between Pico-SDLA and FLASH water vapor mixing ratio profiles."

About the position differences of the structures, it is hard to answer. Usually, the GPS altitude accuracy at this altitude is around 30 m vertically. Then, the position difference we observe is of the same order of magnitude as the GPS altitude accuracy. The position difference can either be due to natural variability or to the GPS accuracy, or a combination of both.

p 13711, l 12 and l 19: The referee is right, we removed the 17.4 km altitude.

The figure 2 has been updated (see below) following instructions and the figure caption has been corrected.

Interactive comment on Atmos. Meas. Tech. Discuss., 8, 13693, 2015.

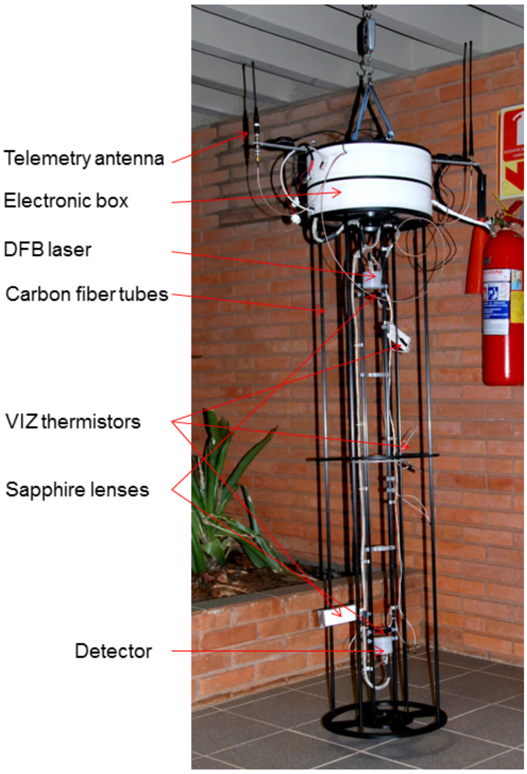

Fig. 1.

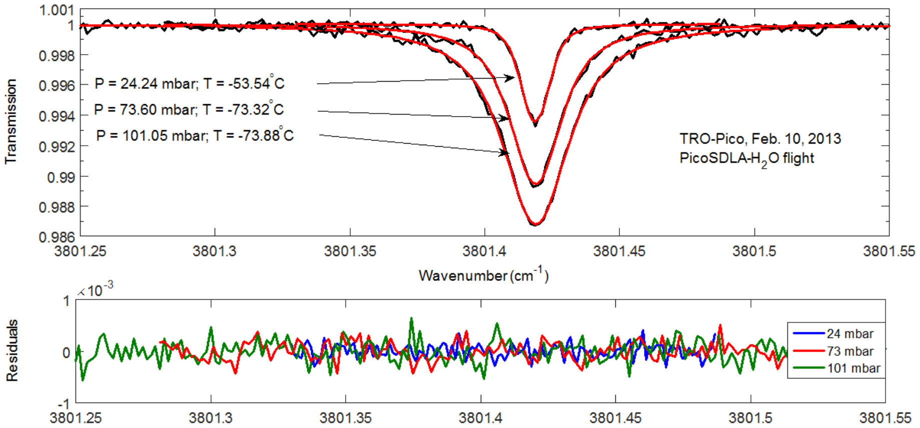
Transmission
1.001
1
0.998
0.996
0.994
0.992
0.99
0.988
0.986
P = 24.24 mbar; T = -53.54°C
P = 73.60 mbar; T = -73.32°C
P = 101.05 mbar; T = -73.88°C
TRO-Pico, Feb. 10, 2013
PicoSDLA-H$_2$O flight
3801.25
3801.3
3801.35
3801.4
3801.45
3801.5
3801.55
Wavenumber (cm^{-1})
Residuals
×10^{-3}
1
0
-1
24 mbar
73 mbar
101 mbar

Fig. 2.

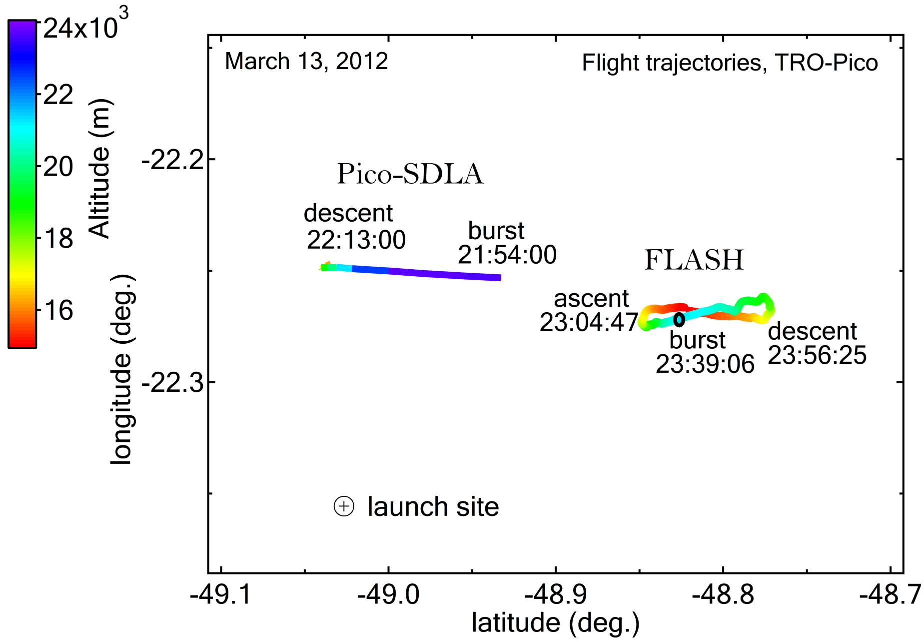
24x10^3
22
20
18
16
Altitude (m)
March 13, 2012
Flight trajectories, TRO-Pico
-22.2
-22.3
longitude (deg.)
Pico-SDLA
descent
22:13:00
burst
21:54:00
FLASH
ascent
23:04:47
burst
23:39:06
descent
23:56:25
⊕ launch site
-49.1
-49.0
-48.9
-48.8
-48.7
latitude (deg.)

Fig. 3.

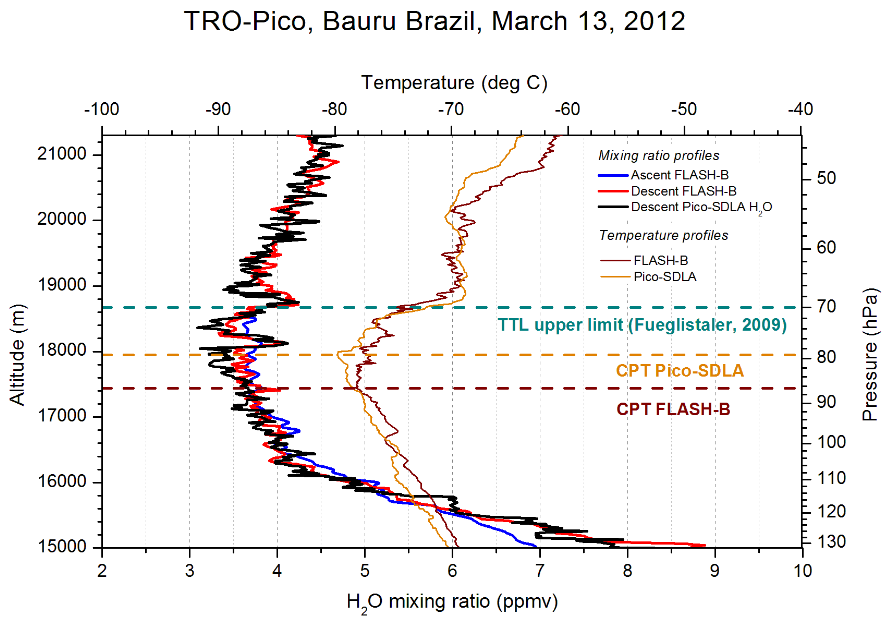
TRO-Pico, Bauru Brazil, March 13, 2012
Temperature (deg C)
-100
-90
-80
-70
-60
-50
-40
Altitude (m)
21000
20000
19000
18000
17000
16000
15000
Pressure (hPa)
50
60
70
80
90
100
110
120
130
Mixing ratio profiles
Ascent FLASH-B
Descent FLASH-B
Descent Pico-SDLA H_2O
Temperature profiles
FLASH-B
Pico-SDLA
TTL upper limit (Fueglistaler, 2009)
CPT Pico-SDLA
CPT FLASH-B
2
3
4
5
6
7
8
9
10
H_2O mixing ratio (ppmv)

Fig. 4.

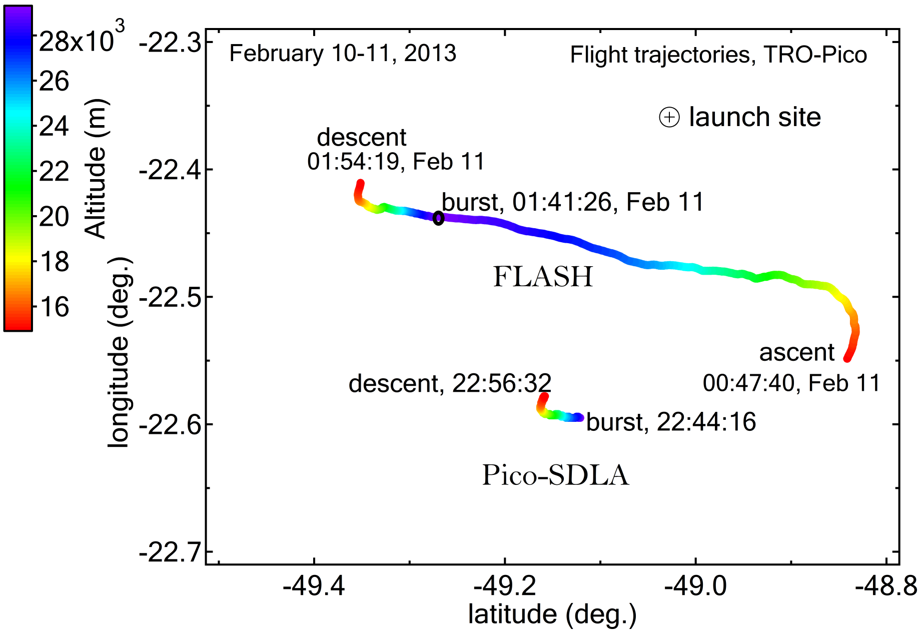
28x10^3
26
24
22
20
18
16
Altitude (m)
-22.3
-22.4
-22.5
-22.6
-22.7
longitude (deg.)
February 10-11, 2013
Flight trajectories, TRO-Pico
⊕ launch site
descent
01:54:19, Feb 11
burst, 01:41:26, Feb 11
FLASH
ascent
00:47:40, Feb 11
descent, 22:56:32
burst, 22:44:16
Pico-SDLA
-49.4
-49.2
-49.0
-48.8
latitude (deg.)

Fig. 5.

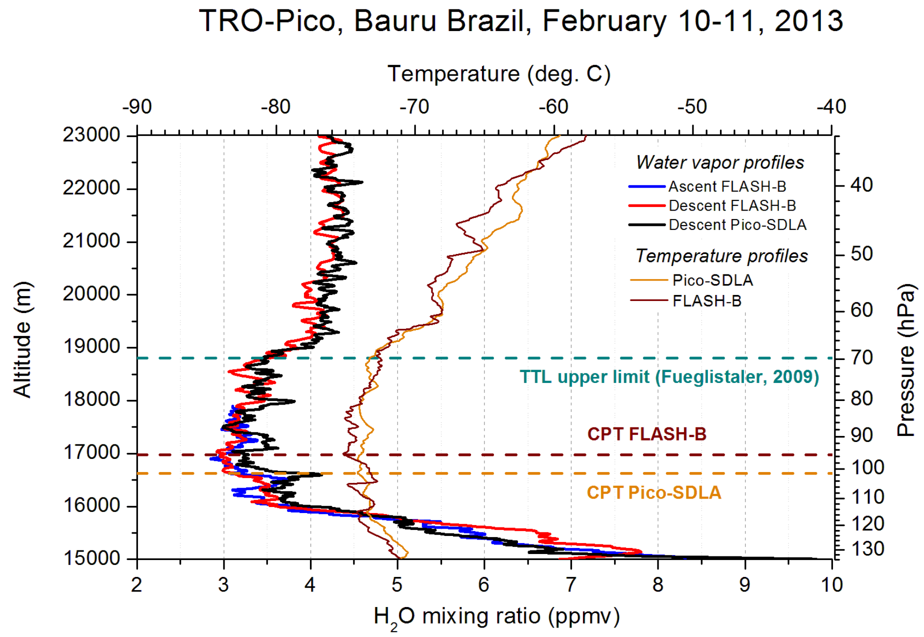
TRO-Pico, Bauru Brazil, February 10-11, 2013
Temperature (deg. C)
-90
-80
-70
-60
-50
-40
Altitude (m)
23000
22000
21000
20000
19000
18000
17000
16000
15000
Pressure (hPa)
40
50
60
70
80
90
100
110
120
130
Water vapor profiles
Ascent FLASH-B
Descent FLASH-B
Descent Pico-SDLA
Temperature profiles
Pico-SDLA
FLASH-B
TTL upper limit (Fueglistaler, 2009)
CPT FLASH-B
CPT Pico-SDLA
2
3
4
5
6
7
8
9
10
H2O mixing ratio (ppmv)

Fig. 6.

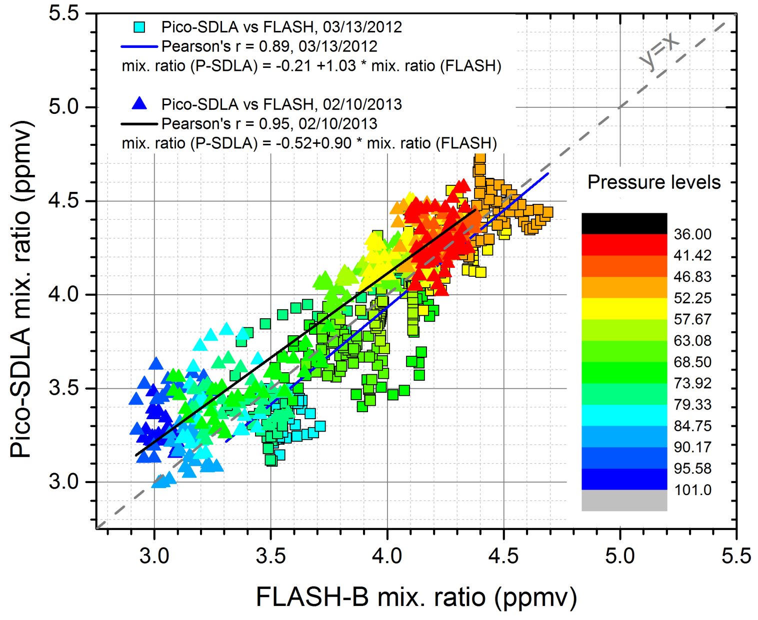
Pico-SDLA vs FLASH, 03/13/2012
Pearson's r = 0.89, 03/13/2012
mix. ratio (P-SDLA) = -0.21 +1.03 * mix. ratio (FLASH)
Pico-SDLA vs FLASH, 02/10/2013
Pearson's r = 0.95, 02/10/2013
mix. ratio (P-SDLA) = -0.52+0.90 * mix. ratio (FLASH)
y=x
Pressure levels
36.00
41.42
46.83
52.25
57.67
63.08
68.50
73.92
79.33
84.75
90.17
95.58
101.0
Pico-SDLA mix. ratio (ppmv)
5.5
5.0
4.5
4.0
3.5
3.0
3.0
3.5
4.0
4.5
5.0
5.5
FLASH-B mix. ratio (ppmv)

Fig. 7.