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SESSION 3 – Papers:

3(6) LAUTLOS upper-air humidity comparison – the first results

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1. Introduction

The LAUTLOS field campaign was hosted by FMI Arctic Research Center, Sodankylä assisted by Vaisala and was conducted successfully in January-February 2004. The idea of LAUTLOS-WAVVAP (**LA**PBIAT **U**pper **T**roposphere **Lo**wer **S**tratosphere **Wa**ter **V**apor **Va**lidation **P**roject: LAUTLOS-WAVVAP) is the comparison/validation of the world's best hygrometer types which are usable as research-type radiosondes for precise water vapor measurements in the troposphere and stratosphere region up to 10 hPa. One of the focal points of the scientific aims is to improve and validate research-type hygrometers/radiosondes like the Meteolabor Snow White hygrometer **[SW]**, NOAA frostpoint hygrometer **[NO]** and improved CFH version, CAO Flash Lyman alpha hygrometer **[FL]**, Lindenberg FN-sonde **[FN]**, Vaisala's latest RS92 GPS-version **[92]**. The aim is to define an optimal working range (related to temperature, water vapor mixing ratio, relative humidity and pressure) for each of the participating hygrometers/radiosondes. In addition to the balloon borne instruments the University of Bern used it's ground based 22 GHz microwave instrument MIAWARA at Sodankylä to obtain water vapor profiles from approx. 25 to 70 km. In addition a further microwave radiometer has been operated from a Learjet of the Swiss air force to obtain water vapor profiles close to the balloon locations. Besides the advanced hygrometers, SW, NO, FL, FN, 92 also older routine radiosondes participated, e.g. RS80-A-Humicap, RS80-H-Humicap, RS90 (manufacturer Vaisala Oyj).

In this paper the authors concentrate on the comparison of the radiosondes/hygrometers 92/FN/SW/NO in the troposphere of the Arctic atmosphere between 0.18 (height of Sodankylä upper air station) and 12 km. For the lower and middle stratosphere a separate contribution is planned including the systems FL, NO/CFH and the microwave techniques.

The RS80-A humidity profiles were corrected by the Sodankylä scientific team using different correction methods [2], [3]. Also this results will be published in a separate paper.

2. The comparison

The experiment started with a precampaign (November 27, 2003 – December 06, 2003) to check the FN-sondes [1] (special prepared modified RS90 sondes using the FN-method of *standardized frequencies*) together with the routine Sodankylä RS90 sounding system.

The main campaign (January 29, 2004 – February 26, 2004) was subdivided in two parts. During the first part (January 29, 2004 – February 06, 2004) five flights were carried out with a full payload including the expensive hygrometers NO, FL carried by an approx. 600 m^3 plastic balloon up to 27 km height.

During the second part of the main campaign (February 11 – February 26, 2004) all 29 flights were carried out by two flights per day (11:30 and 17:00 UT), 20 with smaller rubber balloons (e.g. TOTEX TX 2000g) and a smaller payload configuration) and 9 with the larger plastic balloons for heavy payload configuration, used mostly for the evening flights (17:00 UT) and the large payloads.

The construction for the payload rack was a square cross made from plastic rods of approx. 2 m length. The smaller payload was assembled as follows:

- in the center 1. Snow White and central battery package,

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- at the four ends of the cross the four sondes: 2. FN; 3. RS90; 4. RS80-A; 5. RS92.

The larger heavy payload had following configuration:

- in the center 1. NOAA and 2. RS80-H (connected to one package),
- at the four ends 3. FN; 4. FLASH and 5. RS80-A (connected to one package), 6. RS92, 7. Snow White.

During all flights both the ascent and descent (using a parachute) data were recorded.

3. Results

Figure 1 shows one example of the 29 comparison flights of the second part of the main campaign on February 15, 2004. All relative humidities RH derived from saturation water vapor partial pressure related to water [4], also for temperatures below 0°C.

In the following figures 2-7 some height regions which are particularly interesting when comparing the different sonde types, are marked with thick lines and Roman numerals **I, II, III, IV** and discussed in detail.

Figure 2 shows the RH of FN, 92 (both polymer sensors); SW_w, NO_a (both frostpoint mirrors, NO_a means ascent data) in height range 0.18-2 km; the ambient air temperature T_{ai} (absolute accuracy ±0.15°K) and the mirror surface temperature T_{sw} of the SW.
In the region **II** (1.05 to 1.2 km, T_{ai} ~ -11°C) the polymer systems FN and 92 have nearly the same RH of approx. 100 % RH. FN shows 99-100 % with two maxima between 1.05 and 1.2 km. This humidity layer is connected with undercooled ice supersaturated liquid Sc clouds (100 % RH and 10 % RH supersaturation related to ice saturation [SAT_i]). This result of FN and 92 is correct, i.e. confirmed by a priori.
Both frostpoint hygrometers (the NO_a more and the SW_w lesser) demonstrate also water supersaturation between 102 and 105 % RH. This assumed sublimation effect by sublimation heat is characterized by $T_{sw} > T_{ai}$. Additional water vapor causes this effect either by evaporating of water/ice droplets in the air channels of SW and NO and/or by water vapor sublimation (warming effect) directly on the mirror surfaces of SW and NO.
Some 100 m lower, (after the takeoff) in region **I** (0.4-0.6 km) all hygrometers, also NO and SW agree, within small limits of 3 % RH.
In region **III** (1.4-1.6 km) and region **IV** (1.8-2.0 km) the polymer hygrometers (FN, 92) and the mirror hygrometers (NO, SW) agree each other. Please notice there are systematic deviations between polymer and mirror devices. The mirror hygrometers show approx. 5 % lower RH. The SW mirror has had problems to find stabil conditions (see T_{sw}). For the ambiguous NO_a RH further investigations are necessary.

Figure 3 illustrates the regions **I** (2-2.2 km), **II** (2.4-2.6 km), **III** (2.95-3.05 km) and **IV** (3.6-4.0 km) which are valuable for the discussion. All systems (FN, 92, NO_a; SW_i) agree well in region **III**. FN and 92 are identical in that region! The mirror hygrometers SW and NO_a are also nearly identical, but show 2-4 % RH lesser values than the polymer hygrometers FN and 92. More critical are the RH values in region **I** and **II**. T_{ai} is varied between –17 to –21°C and the air is 5-15 % RH ice supersaturated. The polymer hygrometer 92 and FN show similar results as the mirror hygrometer but with a difference in the assessment of the RH maxima near 2.1 and 2.5 km. Here in the ice supersaturated ice As cloud the 92 (factory calibration) shows 2-4 % RH higher values than the FN (FN-method). The mirror hygrometer SW_w and NO_a provide contradictory RH. NO_a agrees good with FN and has similar values like 92. SW_w has problems with the equilibrium state on the mirror surface. After cooling-heating operations (see the variations of T_{sw} in the limits –30 to –20°C) between 2.7 and 2.8 km the SW-mirror surface state changed finally from water to ice.
Then SW_i follows excellent the RH of the other hygrometers NO_a, 92, FN (see region **III**), but we needed additional information, e.g. from FN or NO or 92, to define the aggregate state of the SW mirror surface.
Finally, in the dry region **IV** near 15 % RH and –24°C each hygrometer shows different values. The 92 RH is 3 % lower than FN. The SW_i RH is between 92 and FN and NO_a RH crosses the values of FN, SW_i, 92.

Figure 4 illustrates the RH accuracy of the sensors in a colder (-25 to –38°C) and dryer section of the atmosphere. The ice saturation SAT_i was not reached. A good (±2 % RH) agreement of all hygrometers we find in region **I** (4.2-4.4 km) and in region **IV** (5.6-5.8 km) where the vertical RH-gradient is low. For fast increasing RH in region **III** (5-5.2 km) FN, 92, SW_i nearly agree, NO_a produces some to lower values. In the sharp structured region **II** (4.6-4.8 km) the 92 and the FN agree. The SW shows a very thin wet layer better than FN and 92 because SW is faster working. NO_a is to inert to follow the RH changes. NO_d means descent data using a parachute.

Figure 5 represents cold ice supersaturated wet **I** (6.2-6.4 km) and dry **II** (7.0-7.2 km) and **III** (7.5-7.7 km) regions between T_{ai} = -40 to -48°C. In region **I** only the mirror devices NO_a and SW_i have good agreement. The polymer devices FN and 92 show lower RH values and they seem more “inert” than the mirror devices. It is

evident that SW_i and NO_a may be correct measured, but to high RH (see $T_{sw} > T_{ai}$). The higher mirror temperatures, could be caused by sublimation of water vapor at the mirror surface (the same as discussed for Figure 2, region **II**). For region **I** the FN claims to have the correct RH because using the reference FN-method (this method uses the raw data measured frequencies when the polymer is in a heated stage ([1], [2]) as independent reference. The 92 trusts that coefficients of the factory calibration (that means the sensitivity of the polymer) has not changed within some weeks/months and the polymer sensitivity will not be influenced by extreme weather circumstances (e.g. ice supersaturated undercooled water clouds, see Figure 2, region **II**). Therefore the FN RH could be the most correct RH in that region **I**.
In region **II**, **III** the FN is identical with the SW_i and similar to the NO_d for the range 7.1-7.2 km and 7.5-7.7 km. The 92 gives 2 % lower and the NO_a 2 % higher RH. The descent data NO_d with a time delay of about 1.5 hours between ascent and descent (on a parachute) come closer to the assumed true values represented by SW_i and FN for region **III** and **II**. The NO_a RH may be contaminated by ice particles from the deeper supersaturated regions **I** (Figure 5) and **II** (Figure 3).

Figure 6 shows dryer regions with 10-20 % RH below the tropopause with T_{ai} = –56°C at 9.7 km. In this case for the regions **I** (7.4-7.6 km) and **II** (9.4-9.6 km) the polymer sensor data FN and the frostpoint sensor data SW agree. The 92 provides 2 % lower RH than FN and SW_i. The NO_d data with ~1.5 hours time delay are near to the 92 RH. The water vapor contamination problem of NO_a ascent data (to large RH) are obvious.

Figure 7 illustrate the RH situation in lower stratosphere above the tropopause (9.7 km). The RH dropped to 2.0 % 1 km above the tropopause. This RH in region **I** (10.8-11.6 km) is confirmed as it is measured by two polymer hygrometers (92, FN) and one mirror hygrometer NO_d. For the stratosphere and descent (on a parachute) the NO_d hygrometer is worldwide recognized as reference. The ascent data of the mirror hygrometers SW_i and NO_a are likely falsified by evaporating ice particles accumulated during the flight through deeper water and ice supersaturated regions with undercooled water or ice clouds.

4. Conclusions

Both advanced hygrometers FN and 92 using the same polymer sensors. The different calibration and evaluation methods mostly agree within ±3 % RH (Figure 2, 3, 4, 6, 7). Only for the temperature range -40 to -46°C, height range 6,2 – 6,7 km (Figure 5), the FN-sonde gives 5 to 8 % lower RH than 92. It is in the moment difficult to decide "What is the correct RH in a supersaturated Cirrus cloud".
We suppose that the NO_a and SW_i RH could be falsified by evaporating ice particles and/or by sublimation of water vapor directly at the mirror surface. Further research is needed.

The comparison shows:

- polymer hygrometers (e.g. 92, FN) are cheep devices working under all meteorological circumstances,
- the mirror hygrometers (e.g. SW, NO) should be used always together with hygrometers working by an another physical principle (e.g. polymer hygrometers) to decide the aggregate state on the mirror.
- The polymer hygrometers can be used for relative humidity (RH) measurements under all atmospheric temperature and humidity circumstances from the ground up to the lower stratosphere.
- The mirror hygrometers (in the actual state of development) are working with some restrictions for relative humidity (RH) determination esp. for saturated and supersaturated atmospheric circumstances. They are sensitive for "water vapor contamination" caused by water and ice clouds. They should be used mainly during descents flights with parachutes.

References:

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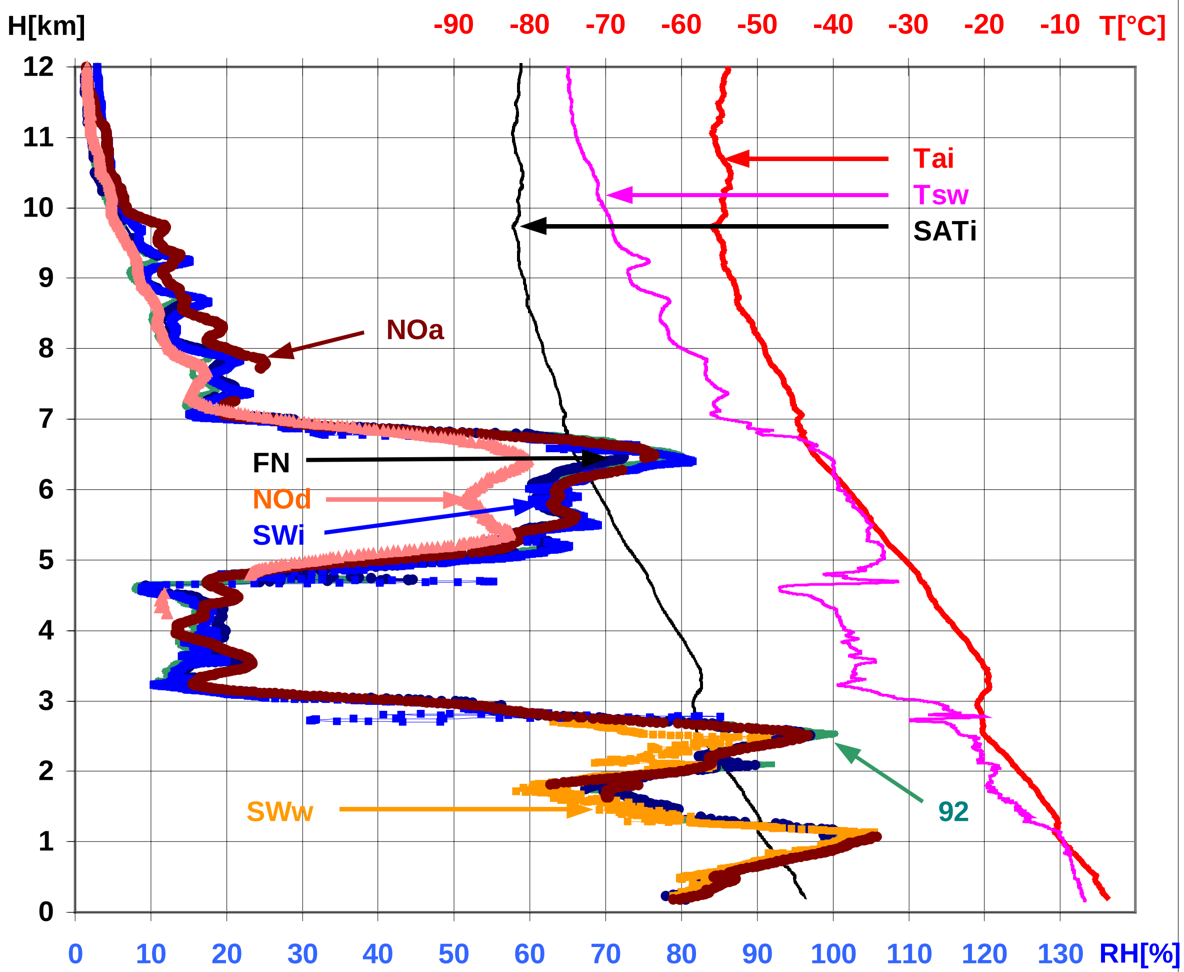

Fig.1: Comparison of nighttime FN-SW-92-NO relative humidity profiles in the Arctic troposphere in the height range 0.18 - 12 km, Sodankylä, 15.02.04, 17:25 ascent. Details are presented in Fig.2 (0 - 2 km), Fig.3 (2 - 4 km), Fig.4 (4 - 6 km), Fig.5 (6 - 8 km),

Notes to the abbrevations:

FN - Lindenberg reference sonde using polymer and FN method

92 - Vaisala RS92 advanced sonde using polymer and factory calibration

SWw - Meteolabor Snow White dew/frostpoint mirror sonde with condensated water at the mirror

SWi - Meteolabor Snow White dew/frostpoint mirror sonde with sublimated/frozen ice at the mirror

NOa - NOAA/CFH frostpoint mirror sonde with sublimated/frozen ice at the mirror, ascent data

NOd - NOAA/CFH frostpoint mirror sonde with sublimated/frozen ice at the mirror, descent data

SATi - RH related to water for ice saturation (only dependent of Tai)

Tai - air temperatur measured with F-Thermocap at the FN-sonde (modified RS90 sensor) and Vaisala factory calibration

Tsw - Snow White mirror surface temperature

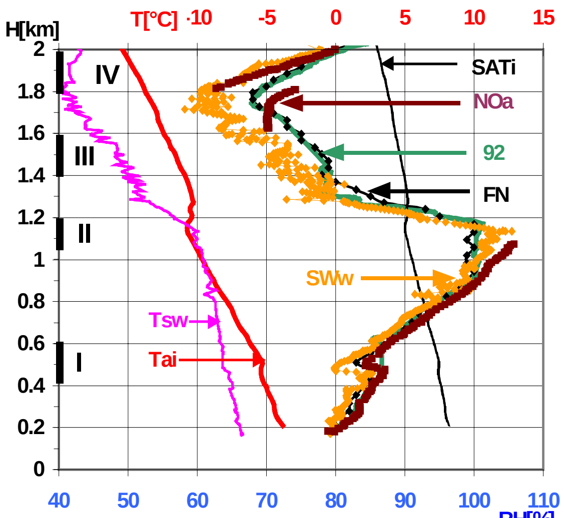

Fig.2 : Details (0 - 2 km)

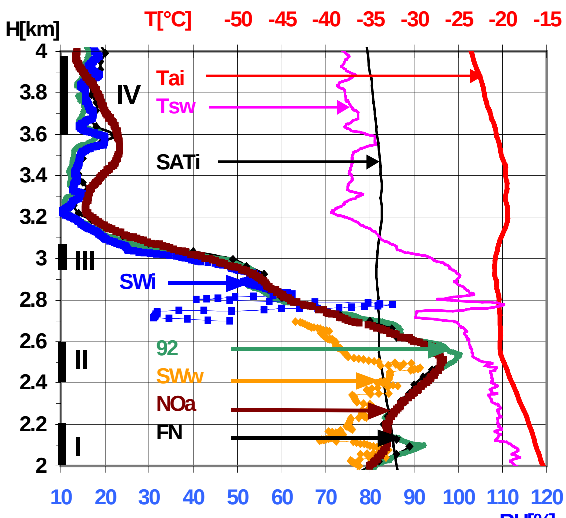

Fig.3 : Details (2 - 4 km)

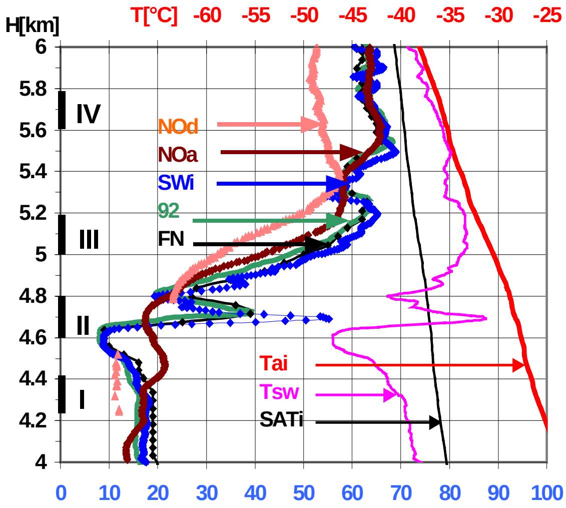

Fig.4 : Details (4 - 6 km)

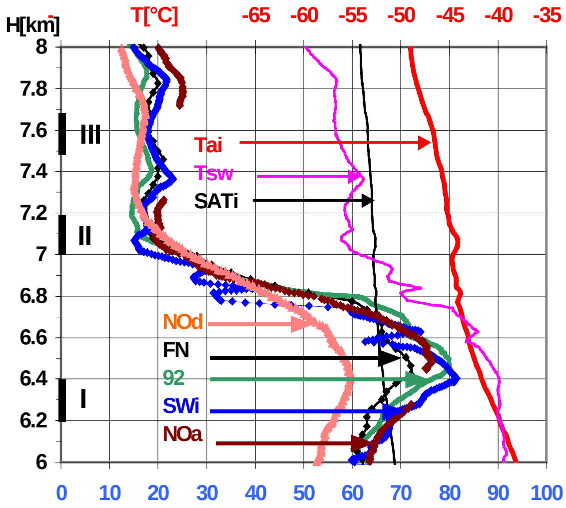

Fig.5 : Details (6 - 8 km)

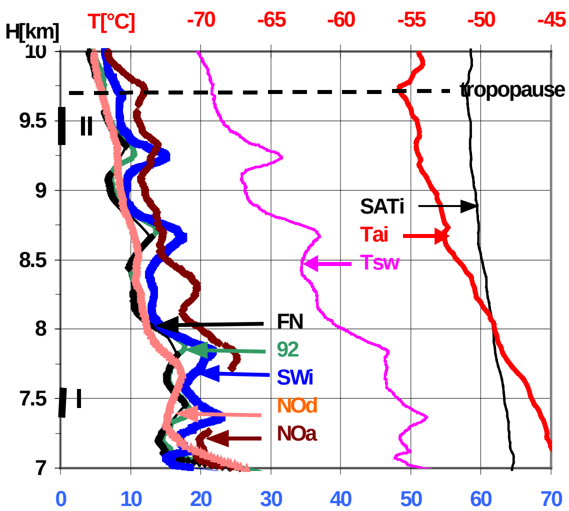

Fig.6 : Details (7 - 10 km)

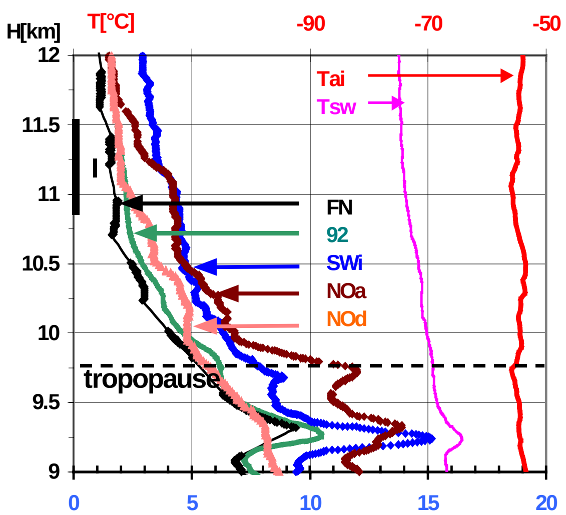

Fig.7 : Details (9 - 12 km)