Radiometer Physics GmbH

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HATPRO Measurement Examples

1. Temperature Profiling

Boundary layer mode

In boundary layer mode the radiometer scans the atmosphere in elevation to acquire more information about the lower atmospheric layer (<1000 m) as shown in Fig.1.

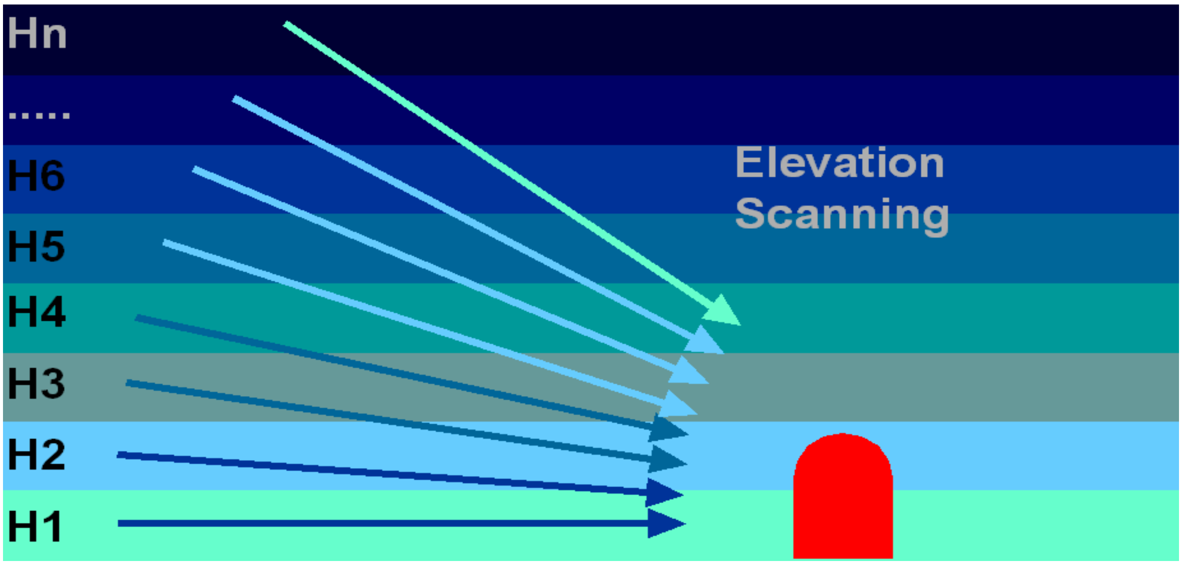


Fig.1: Boundary layer scanning mode with different elevation angles.

For the retrieval of boundary layer temperature profiles only the upper four channels of the temperature profiler are used which show the highest absorption below 1000 m. The variation of brightness temperature in a scan is typically in the order of 1 to 4 K. Thus a sensitive receiver and long integration times are required for the method to achieve the required accuracy. Due to the parallel receiver architecture (100% channel duty cycle) the RPG-HATPRO reduces the brightness temperature noise down to <0.08 K RMS by using integration times of 30 seconds per angle with a total scan time of 3 minutes (6 angles). During this time the zenith observation mode is disabled. A good compromise is a 3 minute scan with a repetition period of 10 to 20 minutes so that the zenith mode is active most of the observation time. ***A sequentially scanning radiometer (synthesizer LO) is not capable to measure in this mode with the required precision because it does not achieve the necessary integration time due to its poor channel duty cycle (<10%).***

Comparison Between Boundary Layer Mode (BLM) and Zenith Mode (ZM)

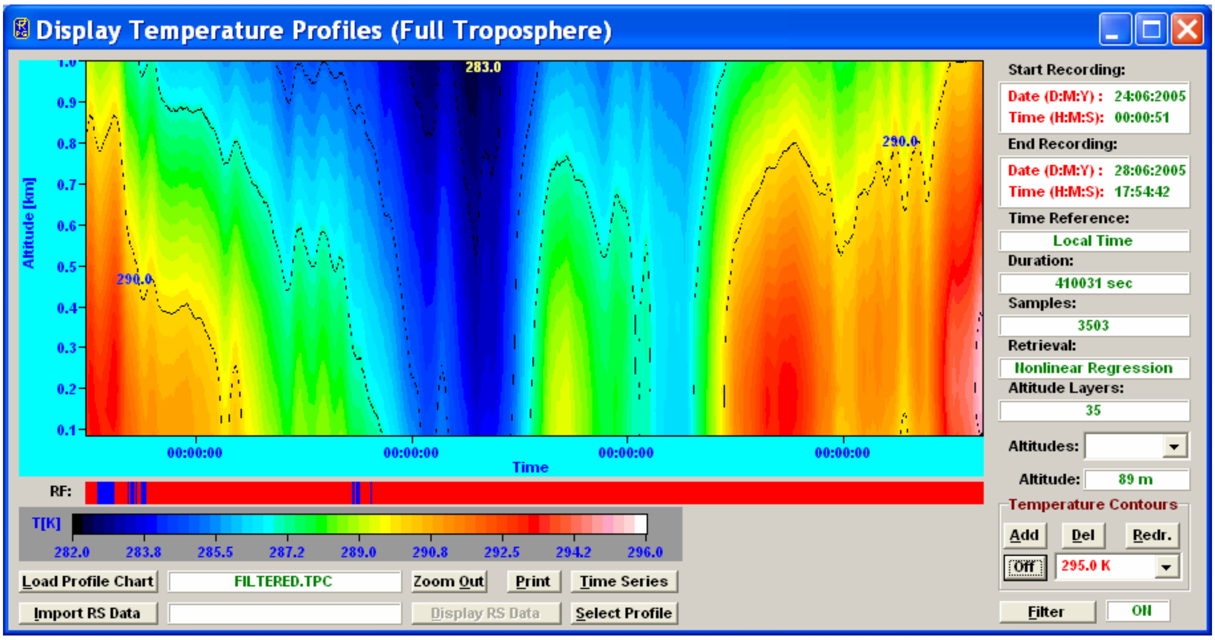


Fig.2a: Zenith observation mode. In the lower 500 m layer the vertical structure is hardly resolved.

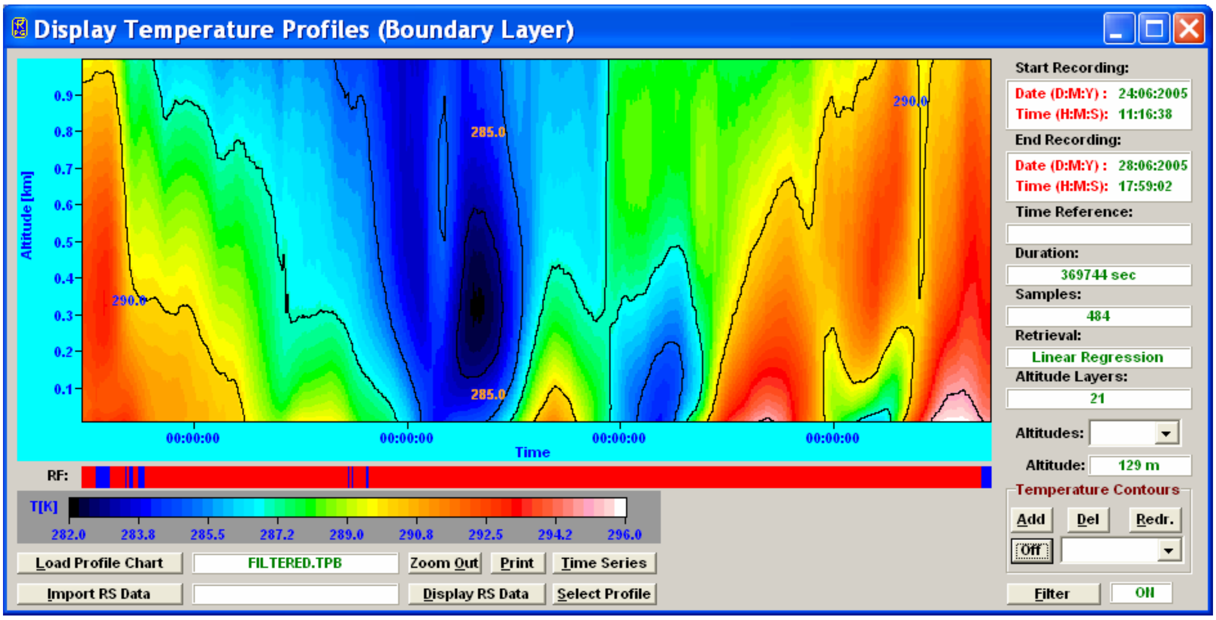


Fig.2b: Boundary layer scanning mode. The vertical structure even in the lowest layer <100 m is clearly resolved.

Fig.2a/b show temperature profile maps of the lowest 1000 m layer measured in zenith mode (Fig.2a) and boundary layer scanning mode (Fig.2b) for a period of 4 days. Only in the left part of the time chart (the first 1.7 days of the recording period) the boundary layer scanning mode observations do not significantly differ from the zenith mode observations. During that period no inversions occurred (see scan A in Fig.3) but after that the boundary layer cooled down (scans B and C in Fig.3) and the first elevated inversions occur (scan C). During the next days inversions are formed between midnight and the morning hours (scans E, H) and dissolved until noon time (scans F, I) by strong solar radiation.

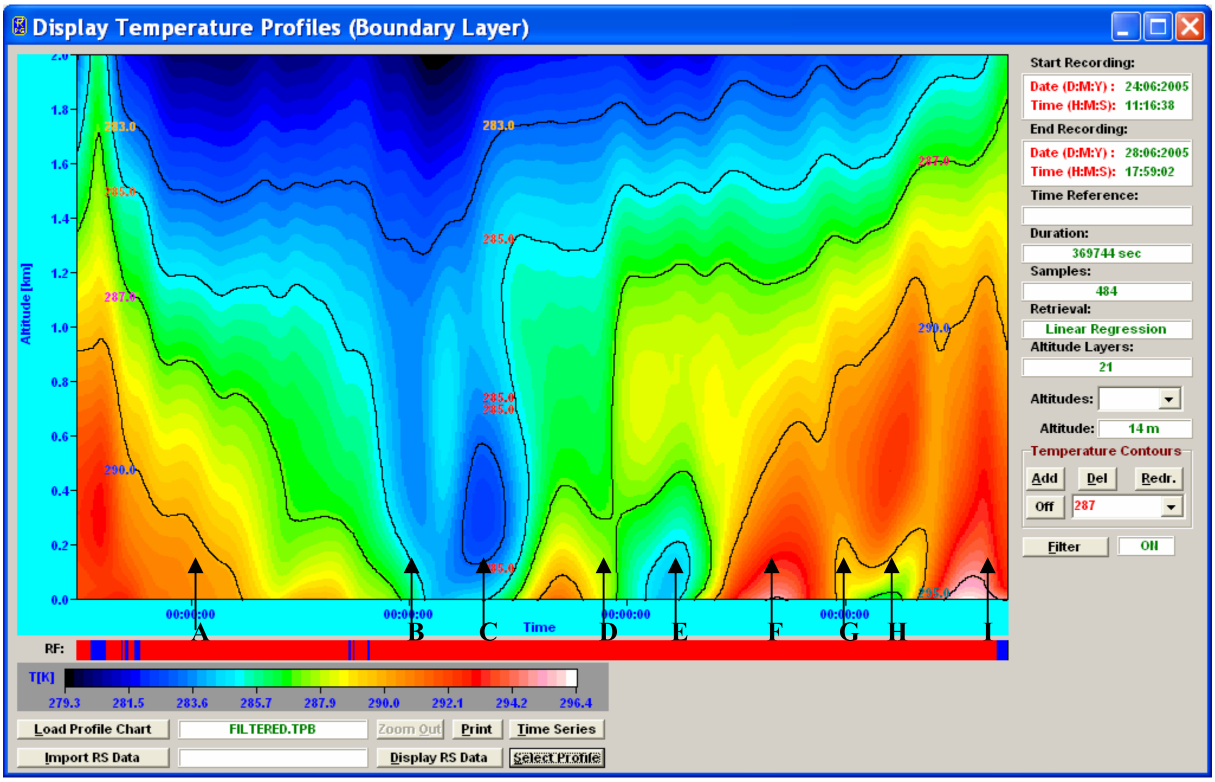
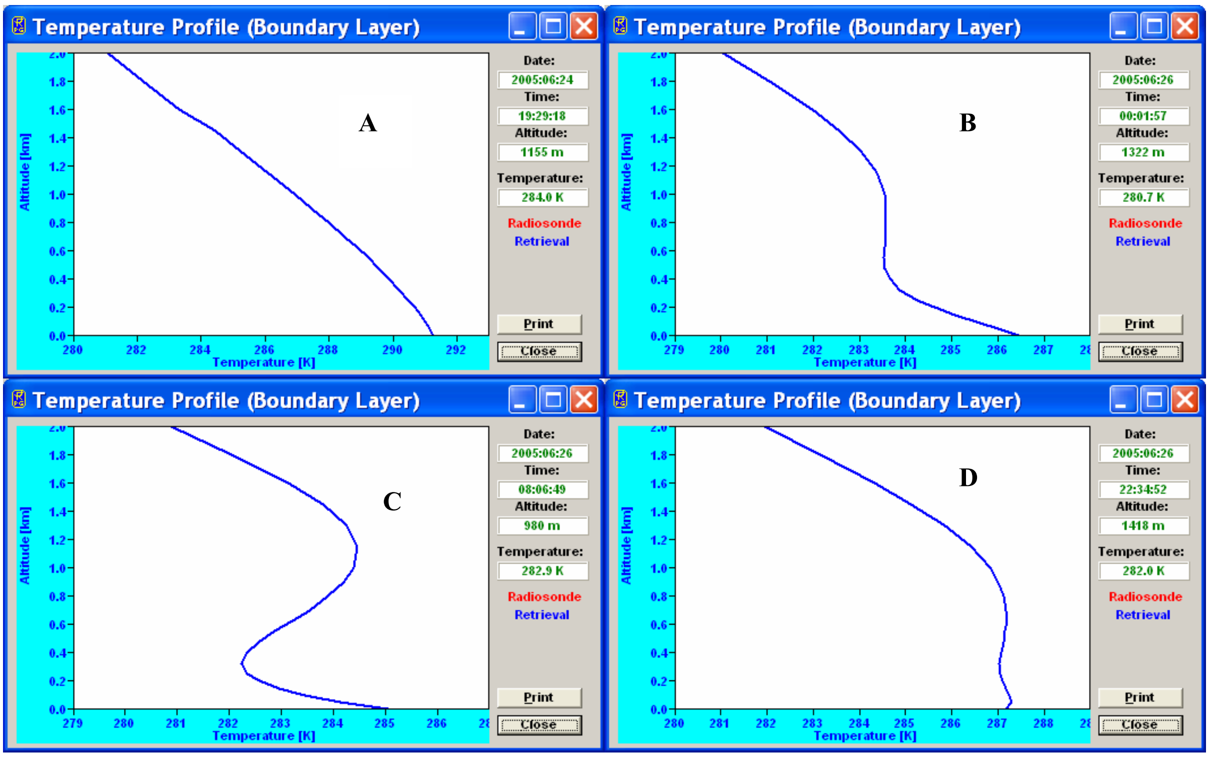
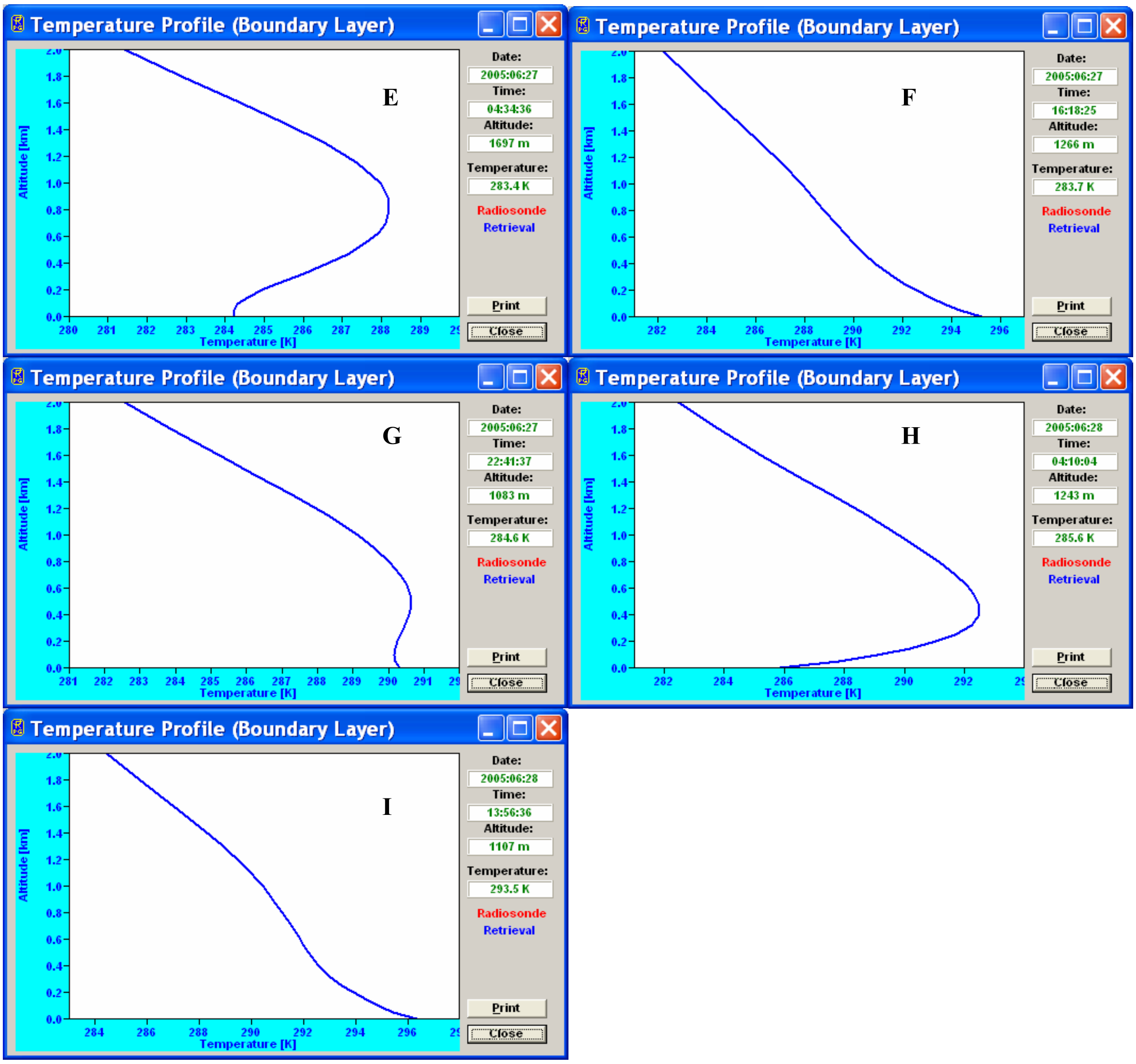


Fig.3: Boundary layer scan temperature profile map of the lowest 2000 m layer. Examples of different scans are given below. The time of the diagram is measured in UTC. 00:00:00 corresponds to midnight.



Handelsregister: Rheinbach, HRB 10291 - Geschäftsführer: Ralph Zimmermann, Olaf Zimmermann, Dr. Thomas Rose
Bankverbindung: Volksbank Rheinbach Voreifel eG (BLZ 370 696 27), Kto-Nr. 100 6004 012, S.W.I.F. T. O DE D 1 RBC
IBAN: DE 66 37069627 1006004012, UST-IDNr./VAT/CEE no: DE 123 377 395



Comparison with Radiosonde Data

Fig.4 is an example for a zenith mode observation of the full troposphere up to 10 km during the morning hours (6:00). The radiosonde (in red) was launched about 20 km away from the radiometer site. The RPG-HATPRO profile (in blue) matches well above 1 km altitude but deviates significantly in the lowest 500 m layer. Fig.5 shows the comparison between the radisonde profile and the radiometer data when operated in boundary layer mode in the lowest 2000 m layer. The ground inversion is resolved much better than in zenith mode.

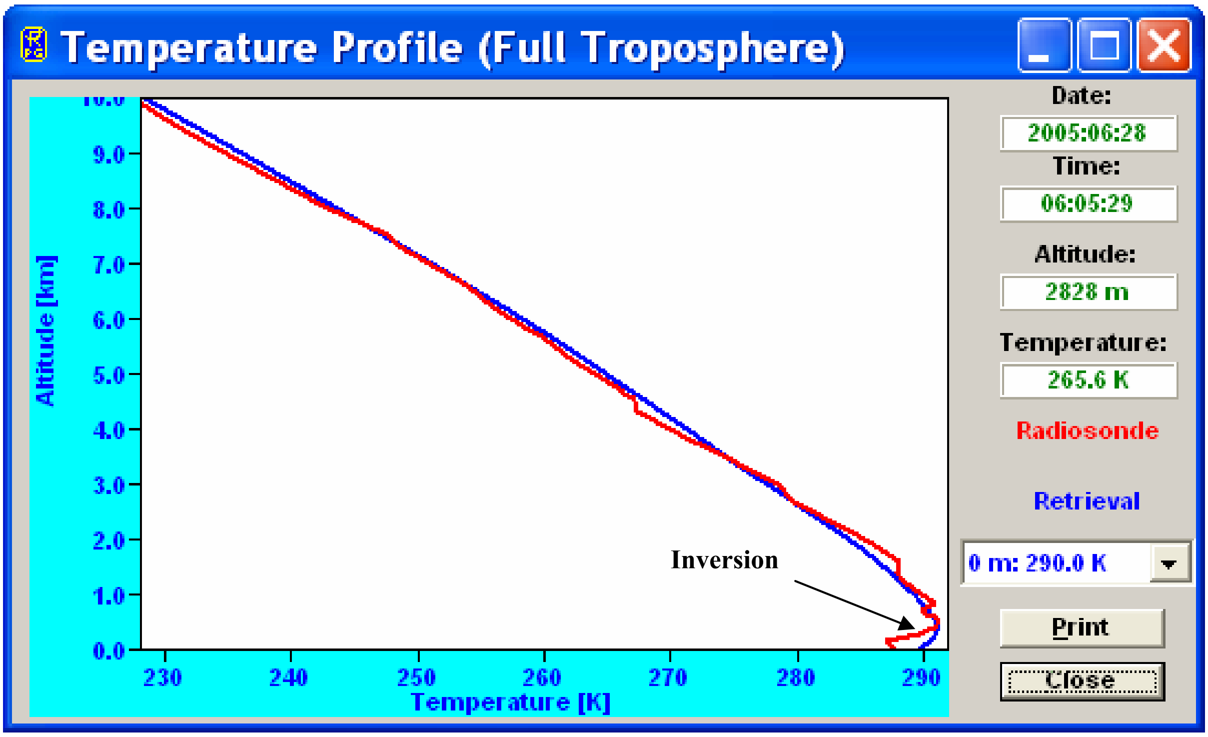


Fig.4: Full troposphere (zenith) scan. Inversion below 1 km is not well resolved (about 1 K)

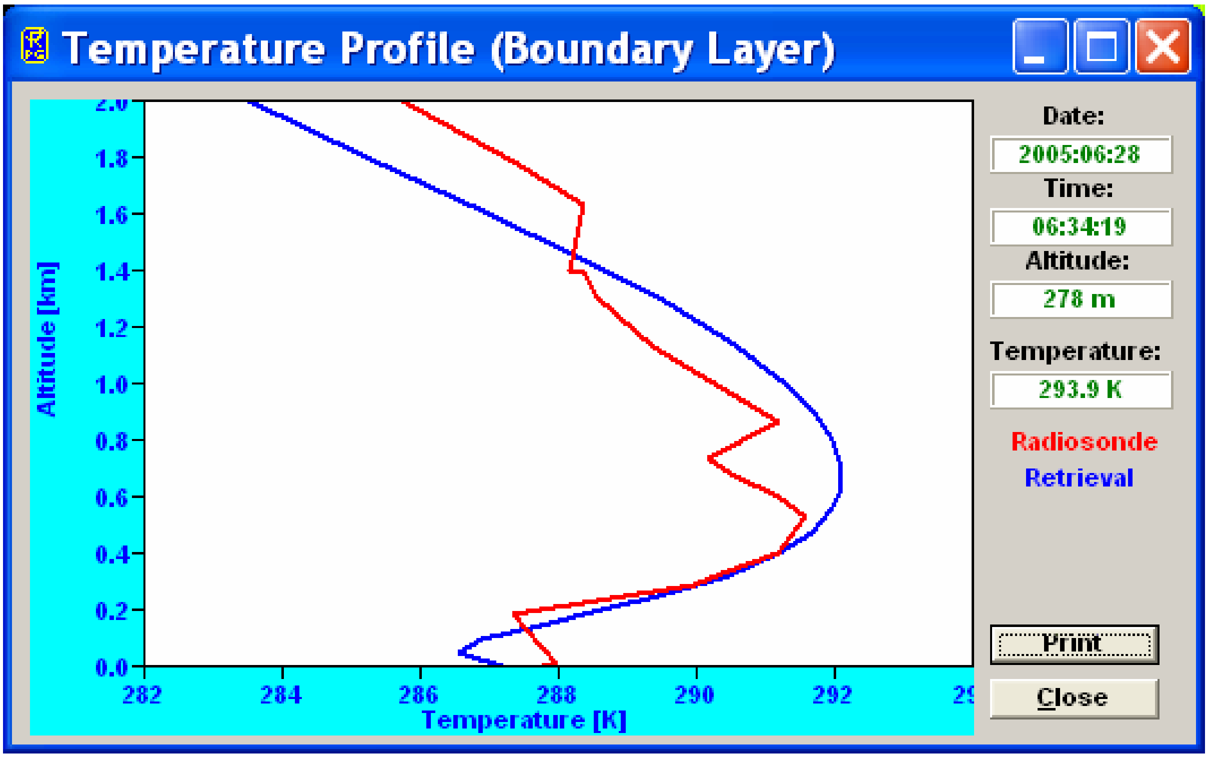


Fig.5: Radiosonde (red) and boundary layer scan (blue) profiles at the same time as above. A strong ground inversion of 4K is resolved.

Fig.6 is a boundary layer scan 6 hours later compared to the radiosonde profile. The inversion has disappeared.

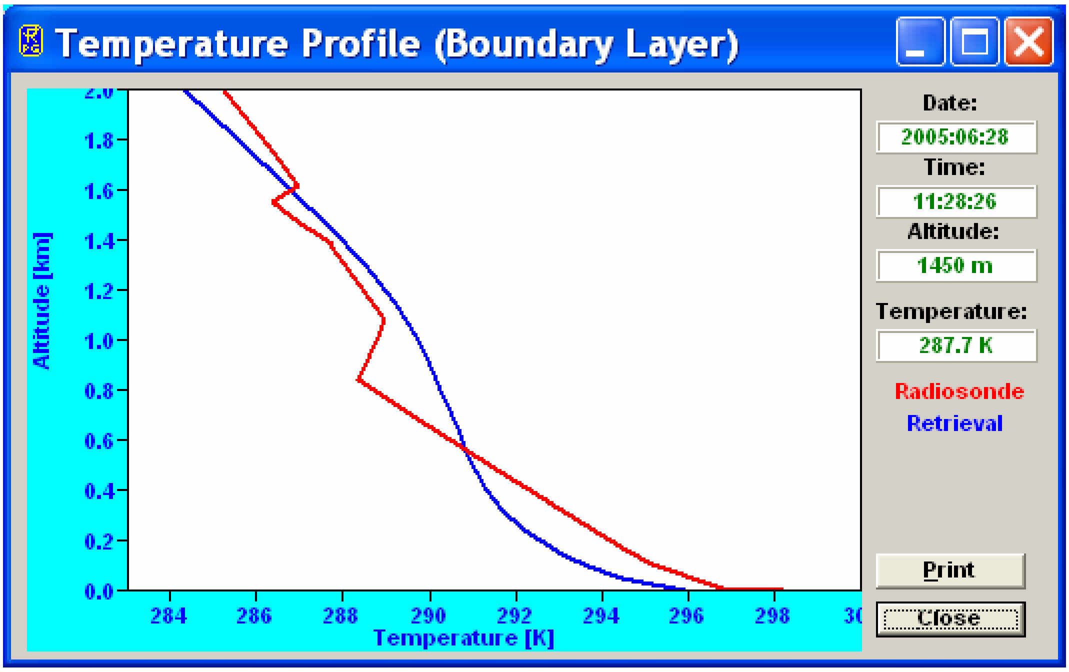
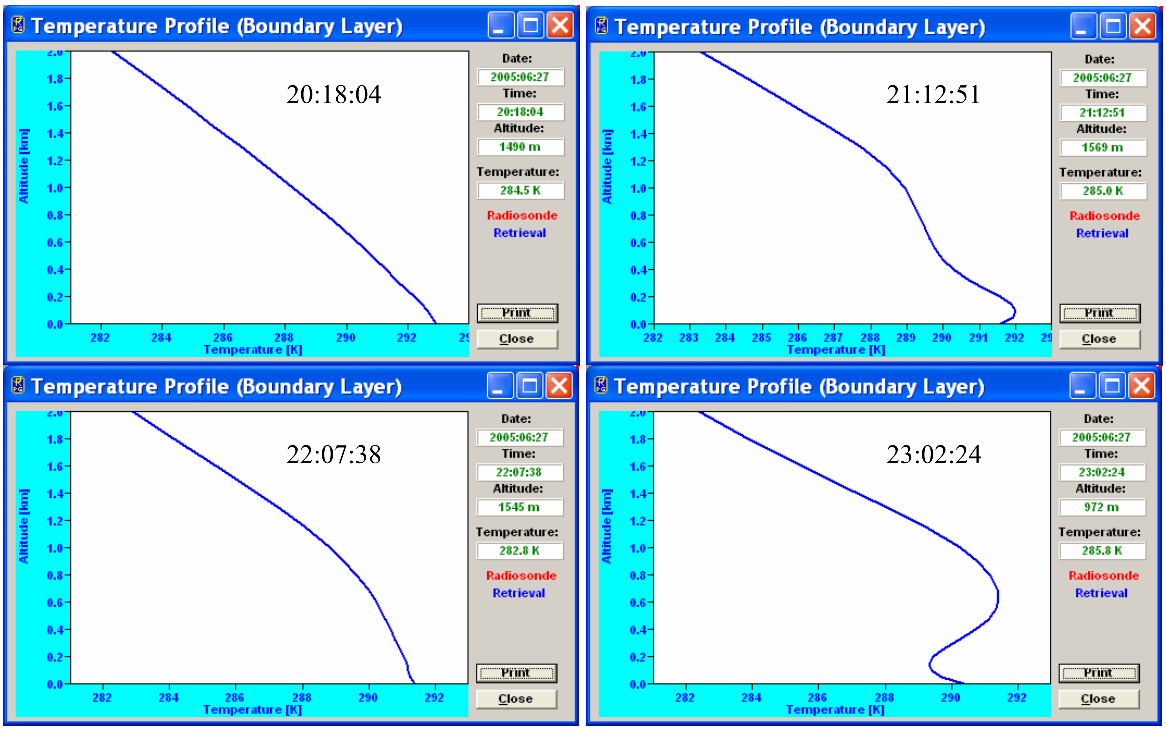
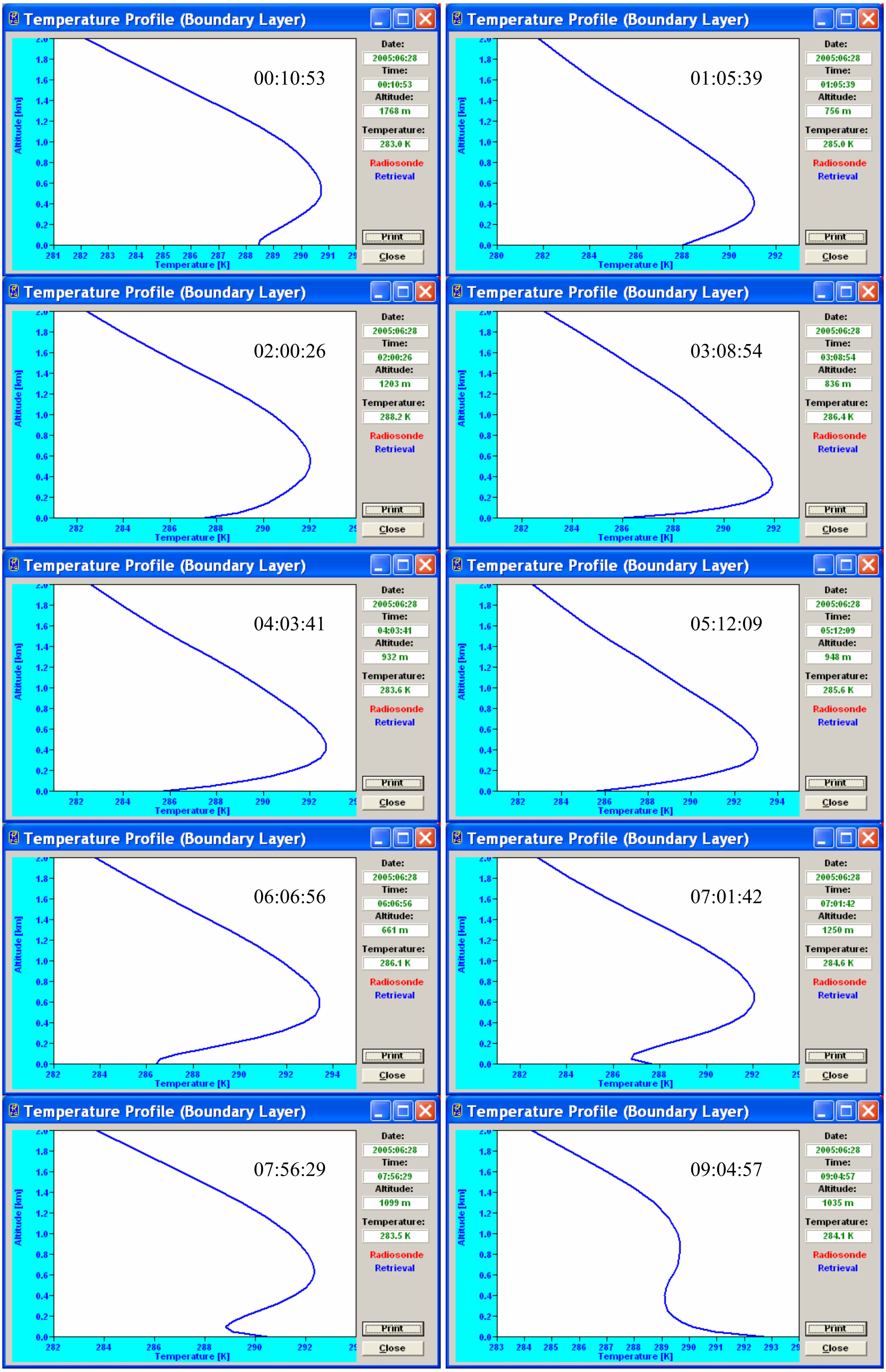


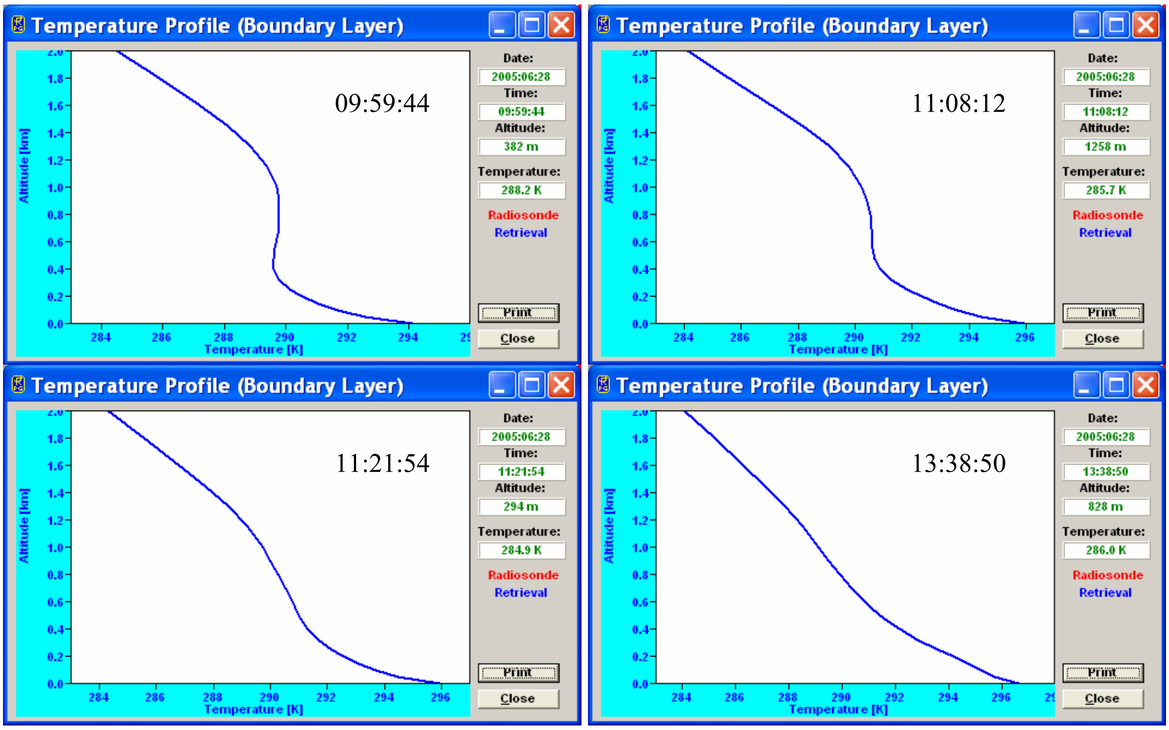
Fig.6: Boundary layer scan around 12:00 UTC.

Development and decay of an inversion

In the time series below the development of an inversion and its decay is monitored (in boundary layer mode). The data was recorded in the night 27./28.6.2005:



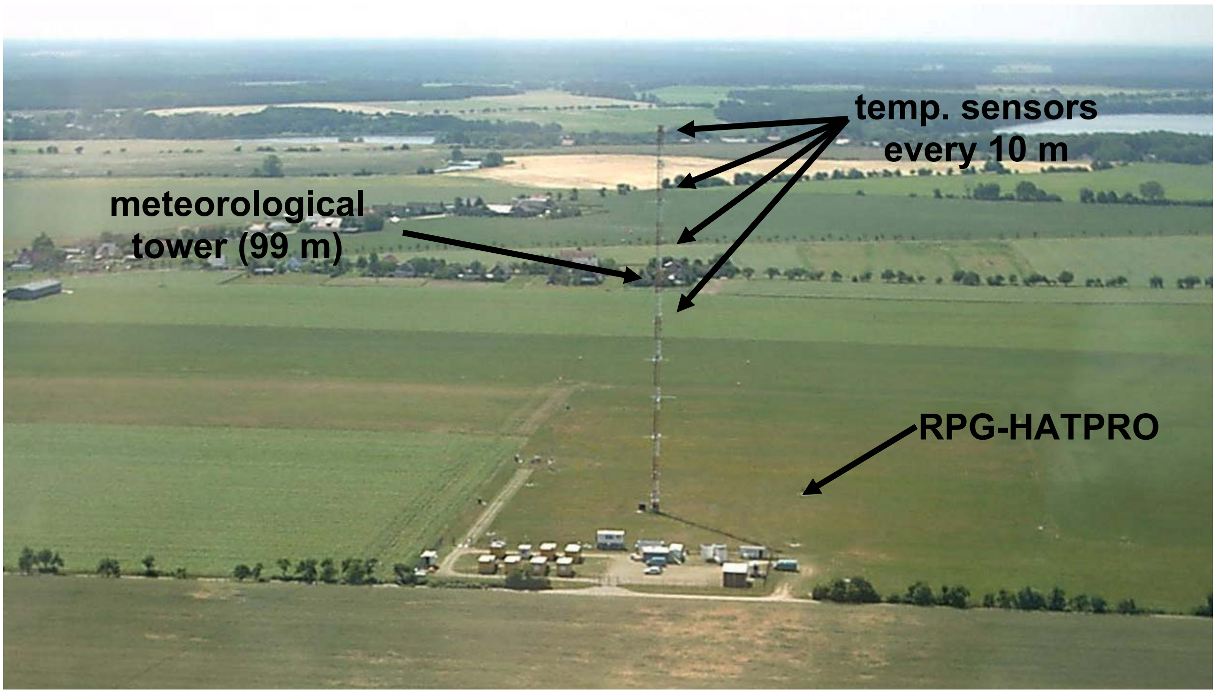

Temperature Profile (Boundary Layer)
00:10:53
Date: 2005:06:28
Time: 00:10:53
Altitude: 1768 m
Temperature: 283.0 K
Radiosonde
Retrieval
Print
Close
Altitude [km]
Temperature [K]
Temperature Profile (Boundary Layer)
01:05:39
Date: 2005:06:28
Time: 01:05:39
Altitude: 756 m
Temperature: 285.0 K
Radiosonde
Retrieval
Temperature Profile (Boundary Layer)
02:00:26
Date: 2005:06:28
Time: 02:00:26
Altitude: 1203 m
Temperature: 288.2 K
Radiosonde
Retrieval
Temperature Profile (Boundary Layer)
03:08:54
Date: 2005:06:28
Time: 03:08:54
Altitude: 836 m
Temperature: 286.4 K
Radiosonde
Retrieval
Temperature Profile (Boundary Layer)
04:03:41
Date: 2005:06:28
Time: 04:03:41
Altitude: 932 m
Temperature: 283.6 K
Radiosonde
Retrieval
Temperature Profile (Boundary Layer)
05:12:09
Date: 2005:06:28
Time: 05:12:09
Altitude: 948 m
Temperature: 285.6 K
Radiosonde
Retrieval
Temperature Profile (Boundary Layer)
06:06:56
Date: 2005:06:28
Time: 06:06:56
Altitude: 661 m
Temperature: 286.1 K
Radiosonde
Retrieval
Temperature Profile (Boundary Layer)
07:01:42
Date: 2005:06:28
Time: 07:01:42
Altitude: 1250 m
Temperature: 284.6 K
Radiosonde
Retrieval
Temperature Profile (Boundary Layer)
07:56:29
Date: 2005:06:28
Time: 07:56:29
Altitude: 1099 m
Temperature: 283.5 K
Radiosonde
Retrieval
Temperature Profile (Boundary Layer)
09:04:57
Date: 2005:06:28
Time: 09:04:57
Altitude: 1035 m
Temperature: 284.1 K
Radiosonde
Retrieval



Comparison with Meteorological Tower Observations

1) **LAUNCH campaign in Lindenberg / Germany (September / October 2005)**

The RPG-HATPRO was located about 40 m from a 99 m met. tower of the DWD (Germany Weather Service).



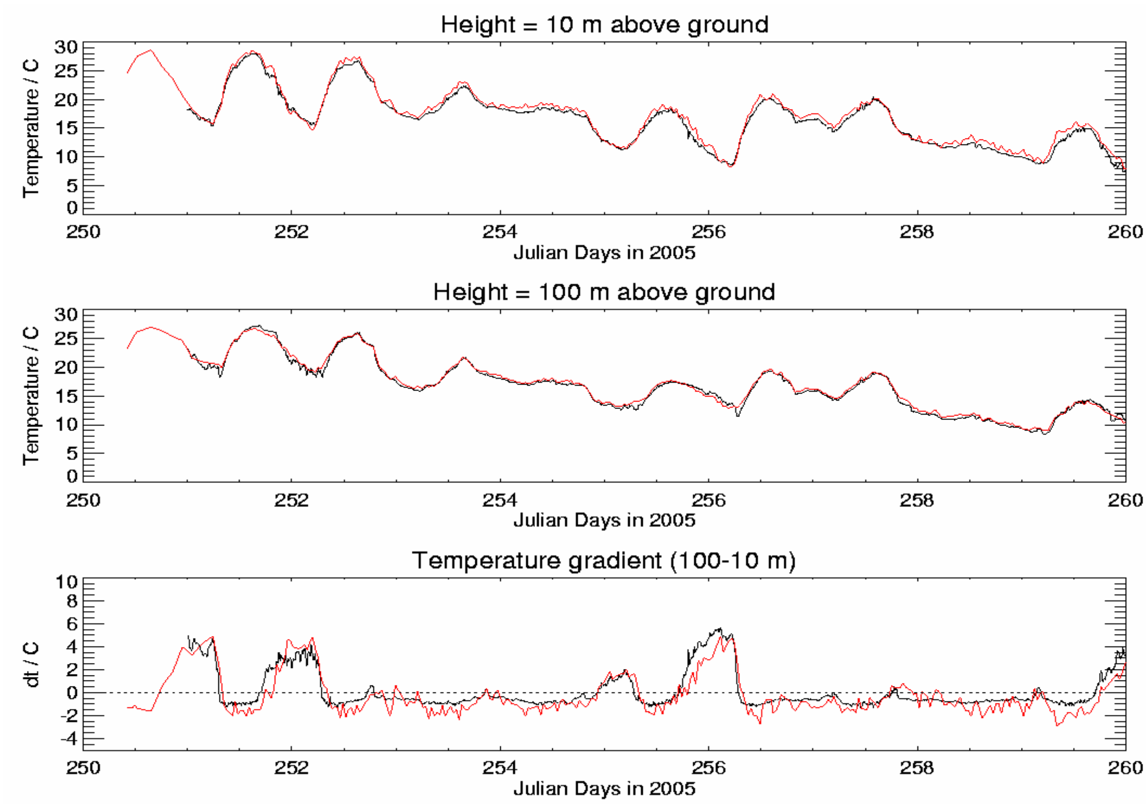


Fig.7a: Comparison of time series of tower temp. sensor (black) and HATPRO measurement (red) at 10 m and 100 m. Below is shown the gradient (difference) indicating that all low level inversions were captured by the instrument.

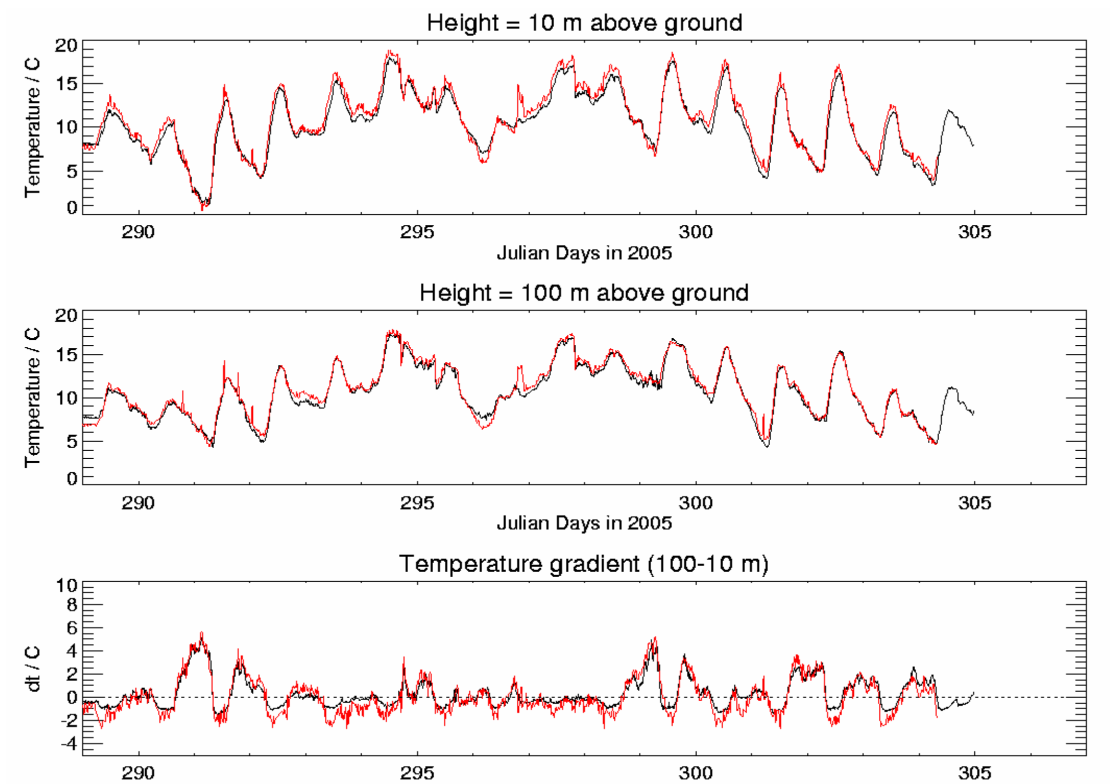


Fig.7b: The same measurement for another period of the campaign.

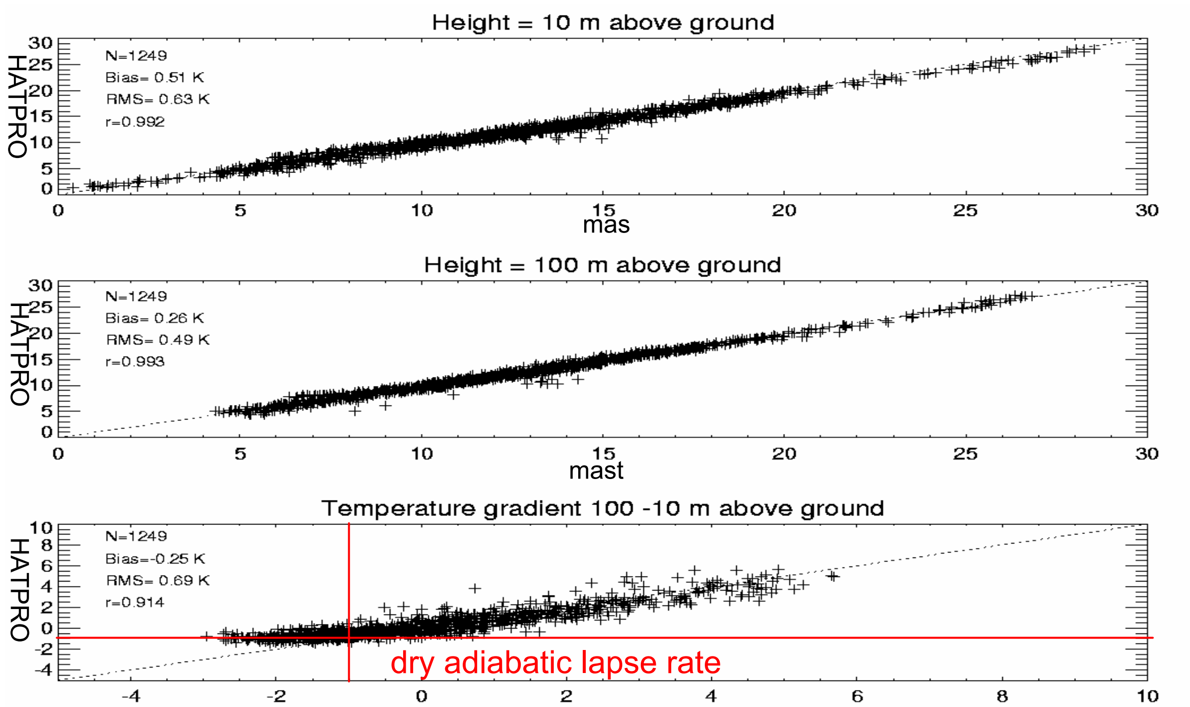


Fig.7c: Scatter plots of the comparison.

We also compared the HATPRO temperature profiles for both measurement modes with radiosonde data measured by a Vaisala RS92 sondes launched about 4 km from the radiometer site (4 times a day). Fig.8/9 show the statistical analysis of the data measured in BL mode and Z mode.

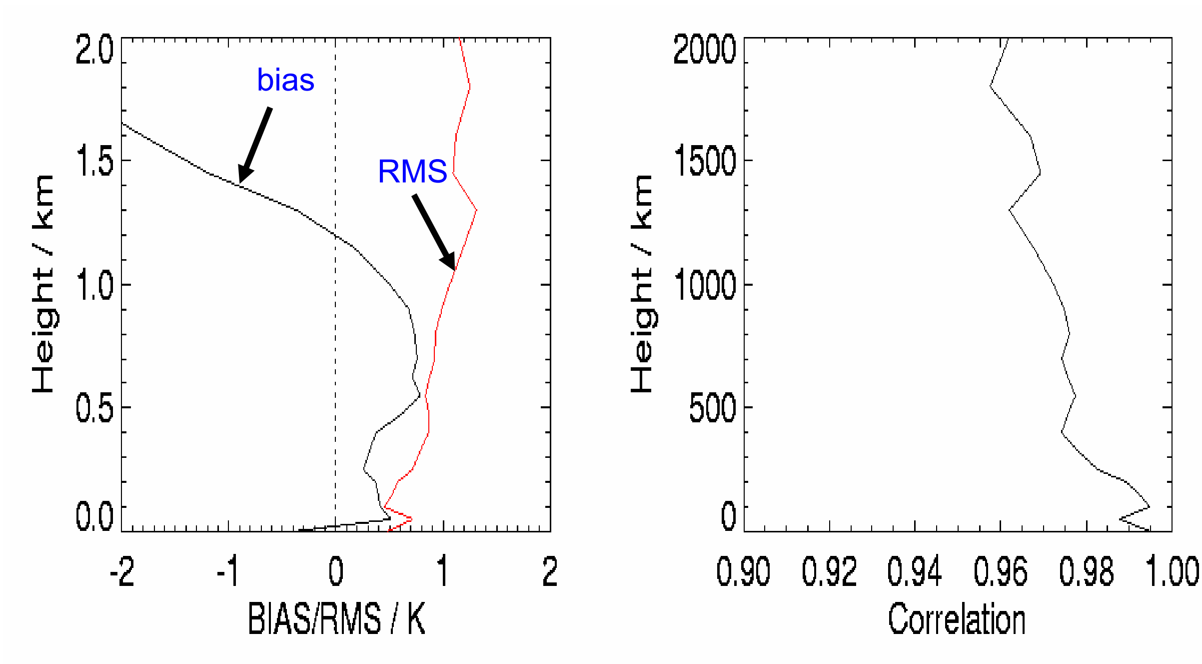


Fig.8: RMS and bias of the BLM temperature observations. Due to the 4 km distance between radio sounding and radiometer the details of the boundary layer are not necessarily the same. The BLM data is most accurate for altitudes < 1200 m.

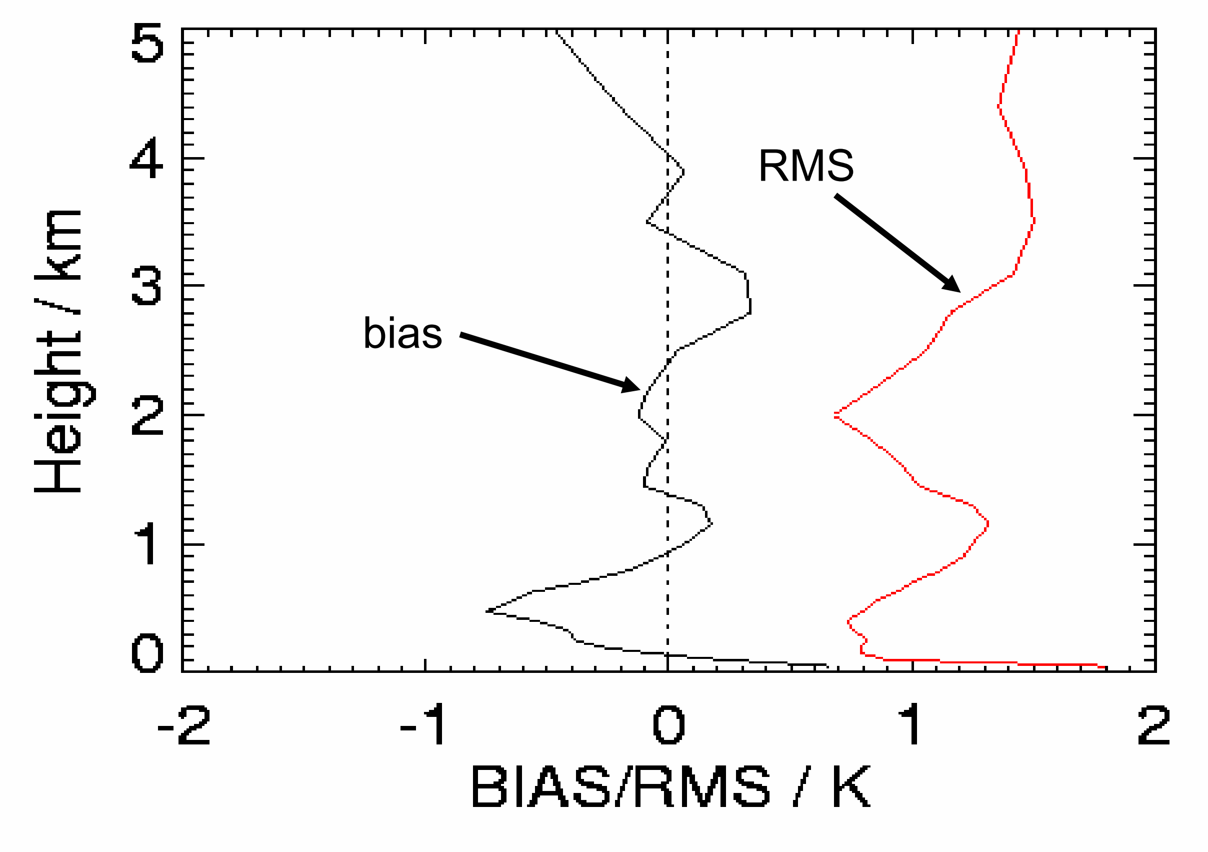


Fig.9: RMS and bias of the ZM temperature observations..

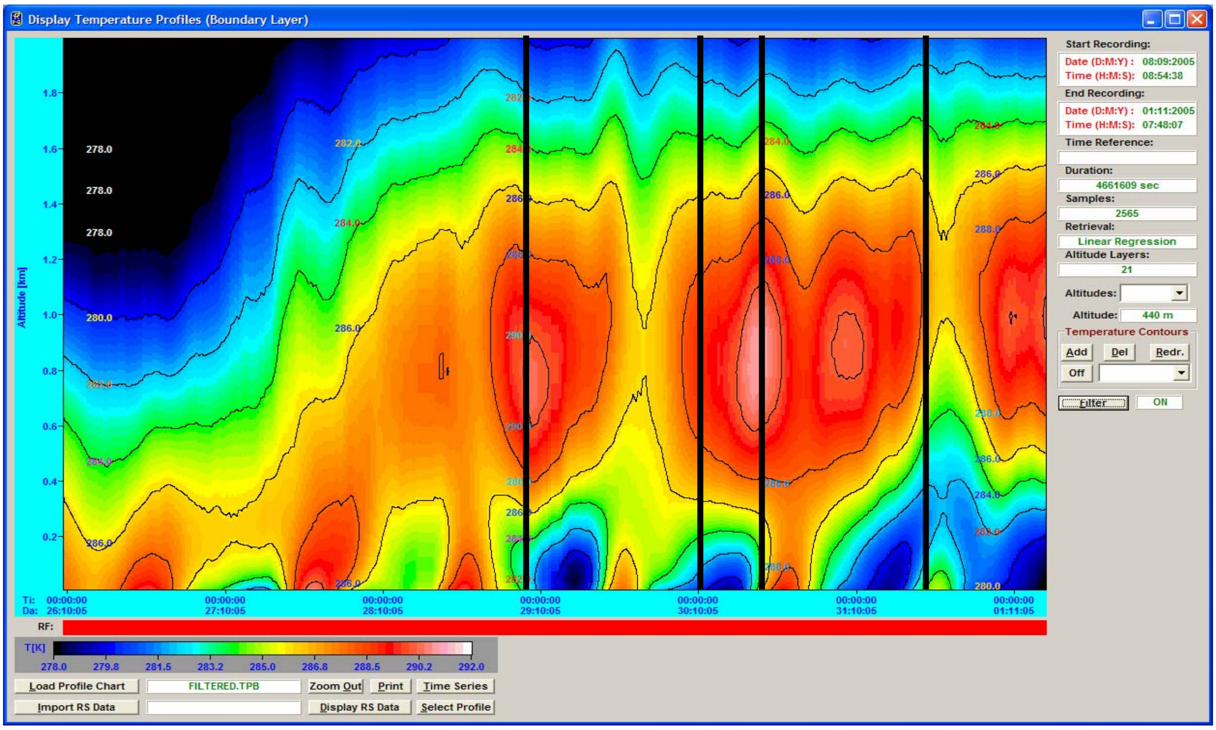


Fig.10: BLM map of one week period. Very strong inversions occurred in the second half of the period indicated by the black lines.

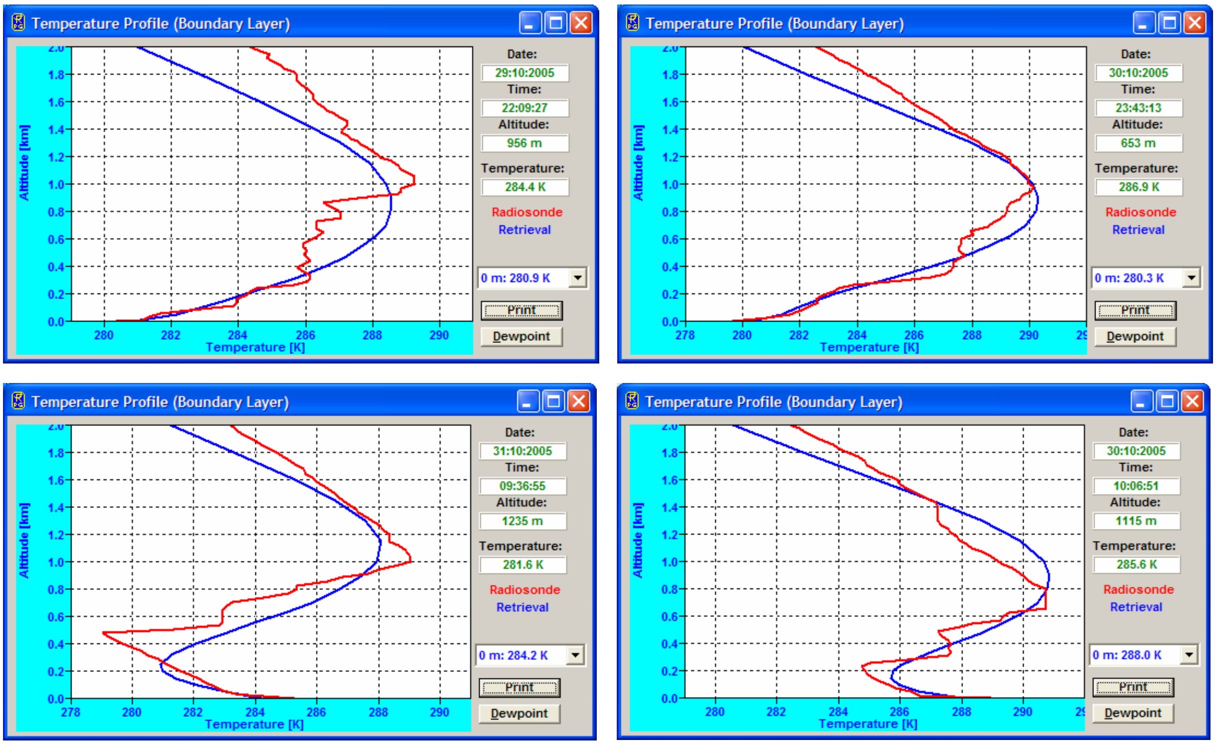


Fig.11: Inversion comparisons between radio sounding (red) and HATPRO BL mode observations (blue) for the four cases in fig.10 indicated by the black lines.

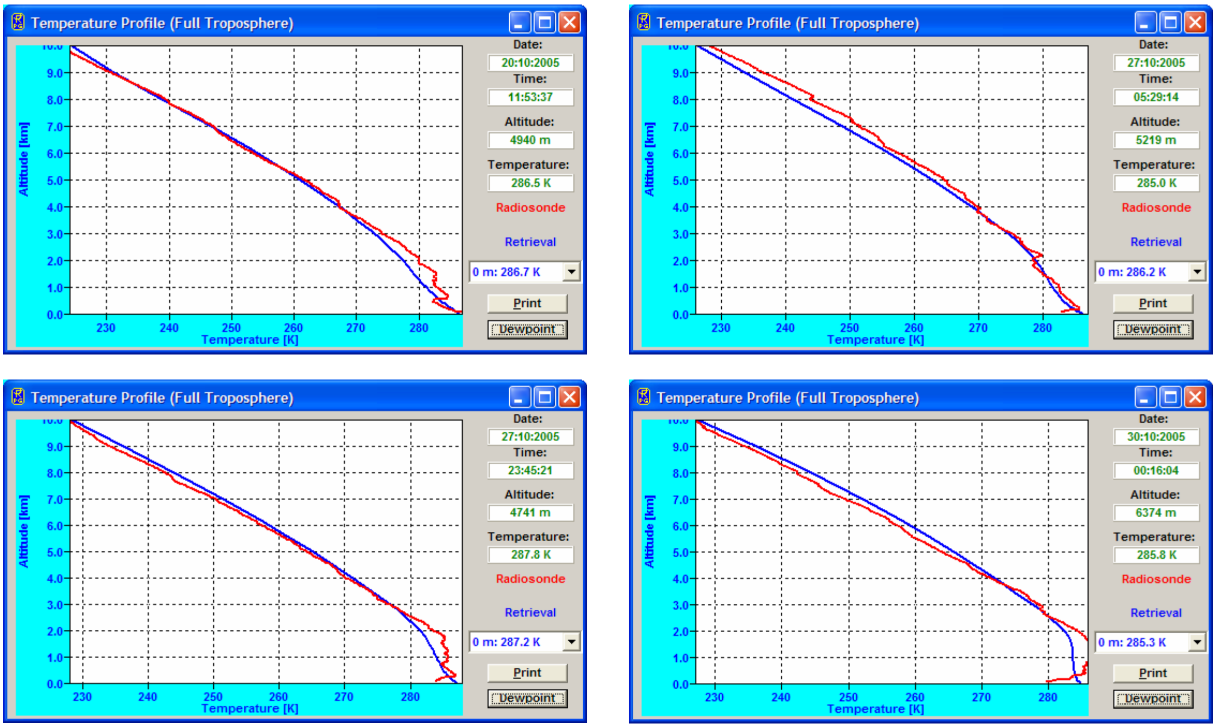


Fig.12a: Examples of comparisons between radio sounding (red) and HATPRO Z mode observations (blue). The boundary layer details are not always accurately resolved.

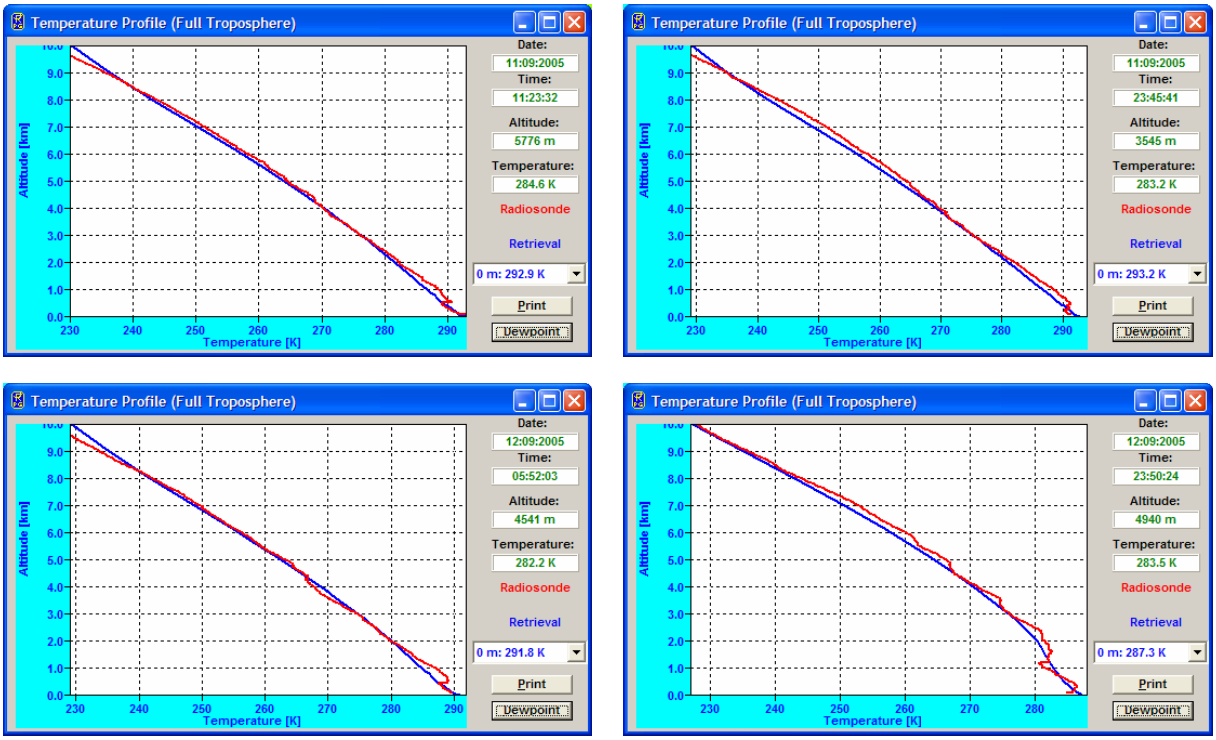


Fig.12b: The Z mode tends to smear out (average) the details of the boundary layer.

2) KNMI Met. Tower Observations at Cabauw / Netherlands

The Dutch Weather Service operates a 200 m meteorological tower in Cabauw / Netherlands. Fig.13 shows a one month temperature comparison of the 200 m sensor with HATPRO BLM measurements.

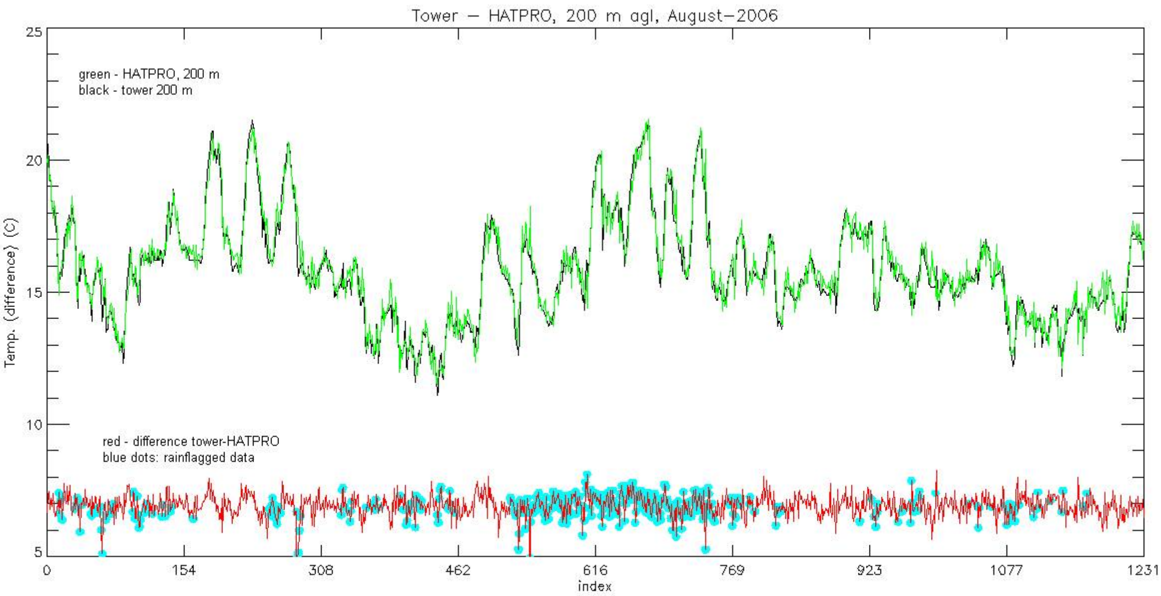


Fig.13: Comparison of retrieved HATPRO temperature at 200 m (green) with 200 m temperature sensor reading of met. tower (black) in Cabauw (KNMI) in August 2006. Total number of samples: 1232, no-rain: 836 samples (RMS: 0.36 K, bias: -0.04 K); 396 rain samples (RMS: 0.45 K, bias: -0.13 K). Rain samples are indicates as blue dots, rain rates are between 1 mm/h (drizzle) and 25 mm/h. BLM data remains accurate.

3) AMMA campaign, Benin / West Africa (Jan. 2006 to Jan. 2007)

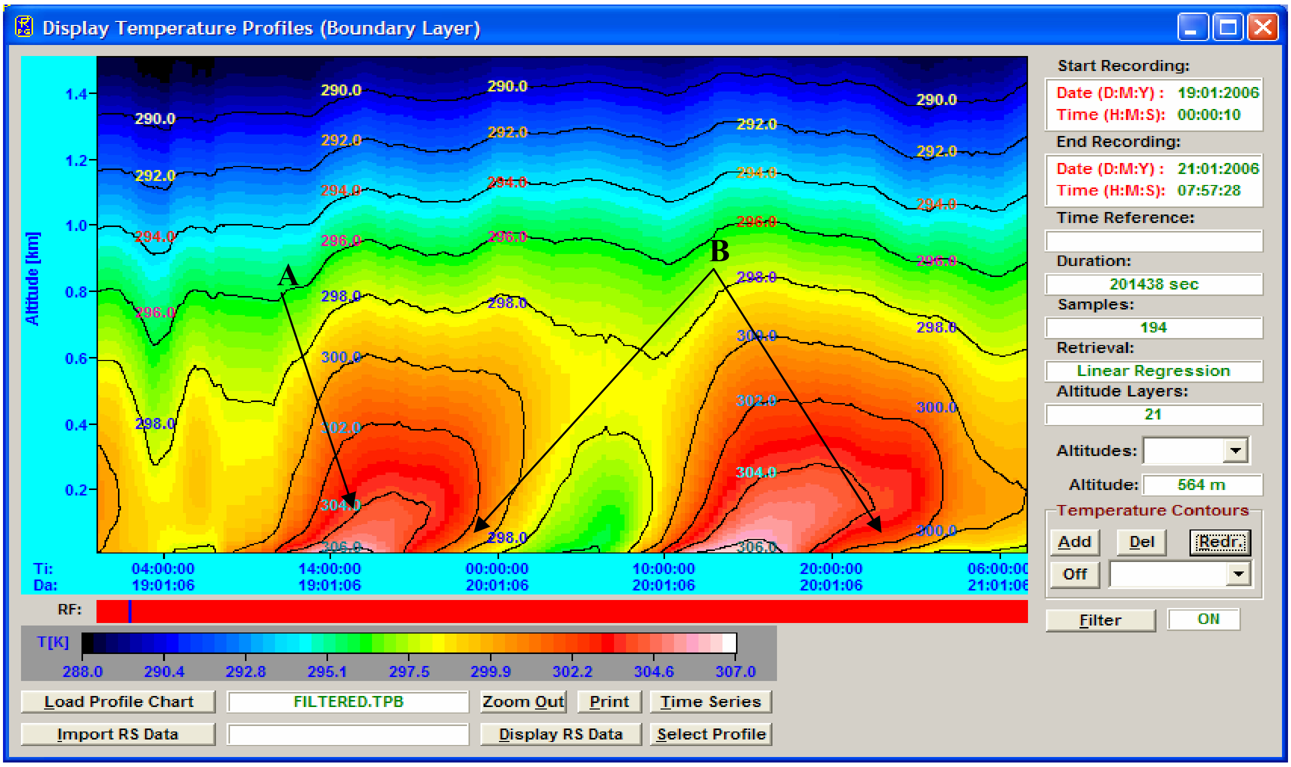


Fig.14: Strong solar heating (A) at day time and radiation cooling over night (B) (inversions!).

4) Morioka campaign, Japan (Oct. 2006 to Jan. 2007)

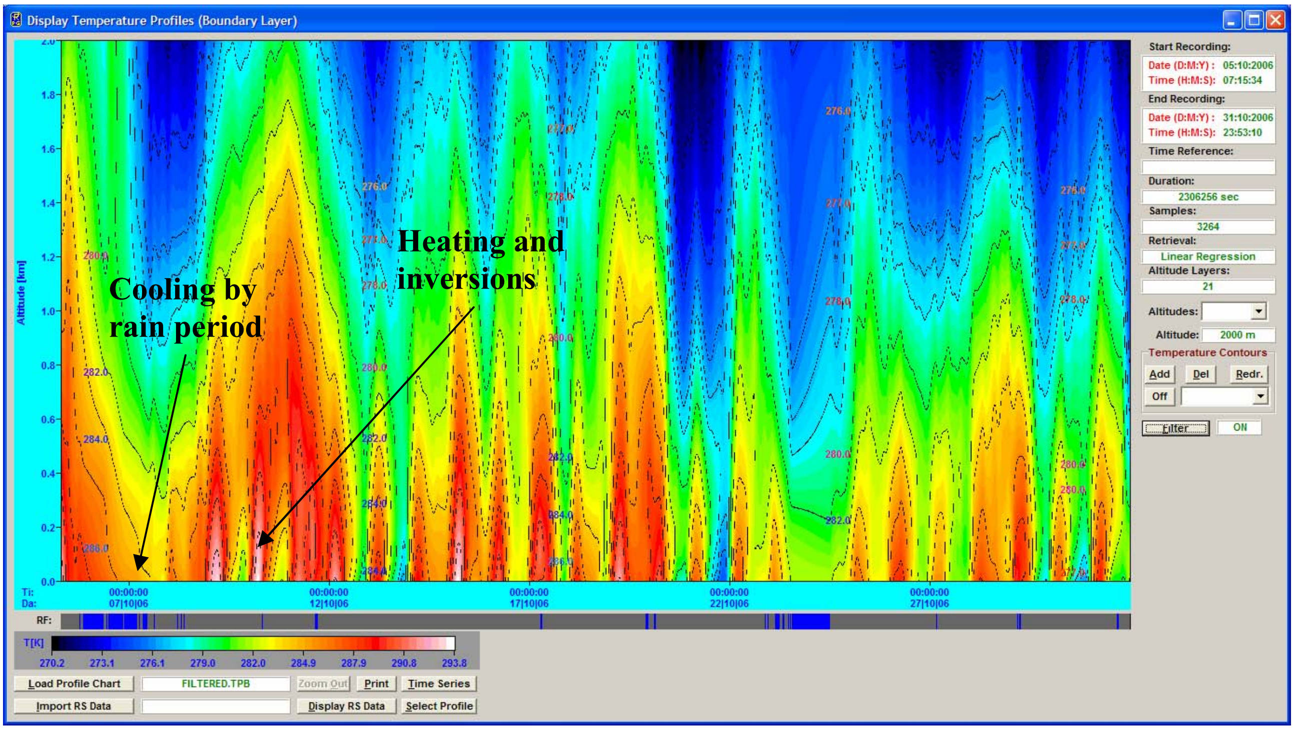


Fig.15: One month of boundary layer observations at Morioka / Japan. The BLM also works well during rain events

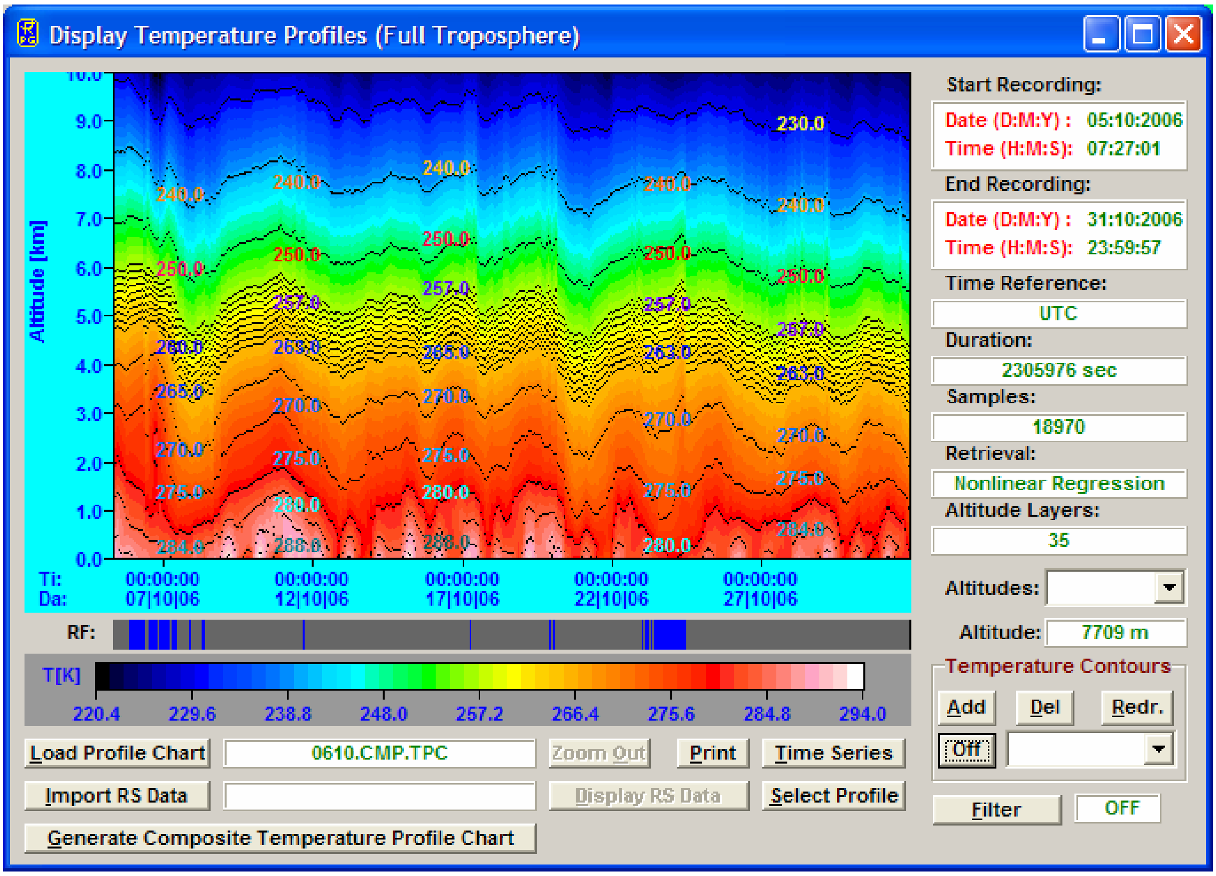


Fig.16: Full troposphere profiles over one month. The measurements are hardly affected by the rain periods.

1. Humidity Profiling

There is only a zenith mode for humidity measurements because at the water vapour line channel frequencies around 22 GHz the atmosphere is transparent. No saturation of the brightness temperatures occurs even at very low elevation angles like for the oxygen line center. Consequently an elevation scanning mode will not give significantly more information than the zenith mode. Nevertheless more accurate relative humidity profiles in the boundary layer can be generated by combining absolute humidity profiles with boundary layer temperature profiles and computing the relative humidity from these two profile types.
The microwave signals the radiometer observes are directly proportional to the absolute humidity above the instrument with offsets due to liquid water introduced by clouds. Consequently, for retrieving humidity by observations of the water vapour line, absolute humidity profiles (humidity measured in g/m^3) are the most ‘natural’ type of humidity profiles.
Relative humidity profiles can be generated in two ways:

1) Using directly a retrieval for relative humidity without taking into account any temperature profile information.

2) Using a retrieval for absolute humidity and combine this information with temperature profiles generated by zenith and boundary layer modes.

Both methods suffer from severe inaccuracies at high altitude (>5000 m) where the absolute humidity is so low (due to low temperatures) that the microwave detection of this contribution becomes impossible. But method 2 has advantages over method 1 in the boundary layer because the higher accuracy and resolution of the boundary layer temperature profiles can be exploited for relative humidity profiling.

Examples of Absolute and Relative Humidity Profiles

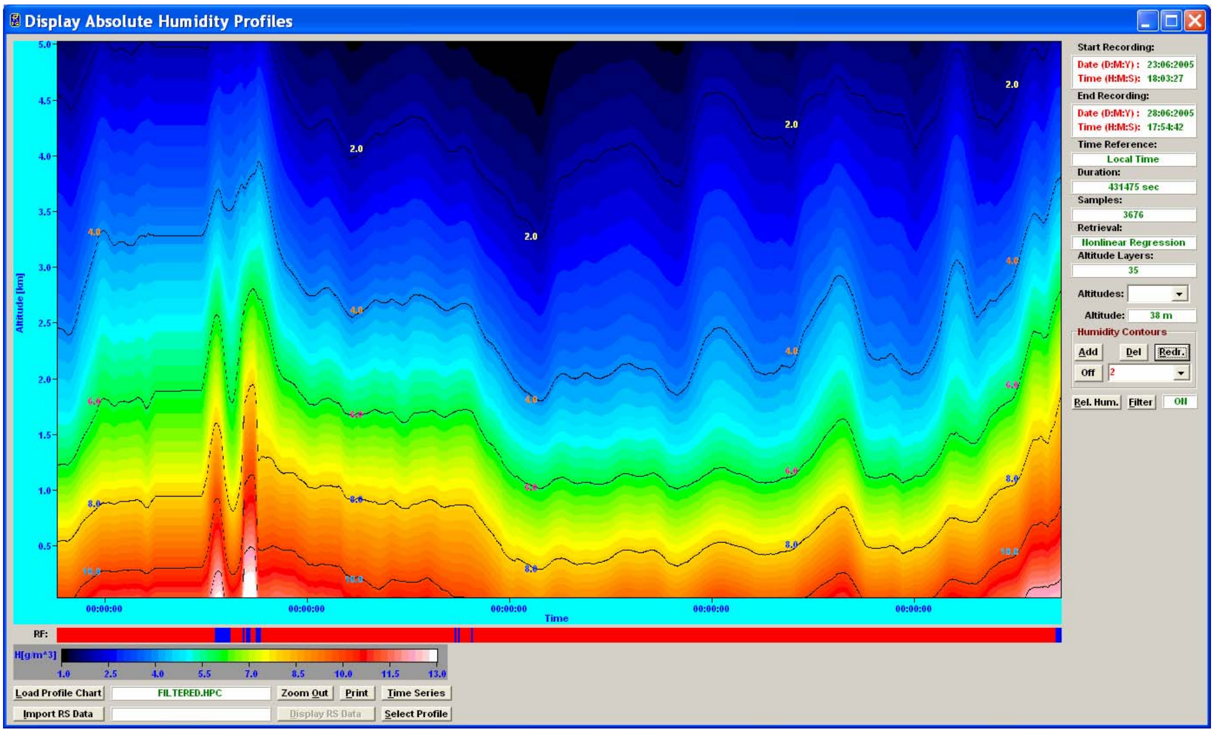


Fig.17: Absolute humidity profile map for a 5 day period.

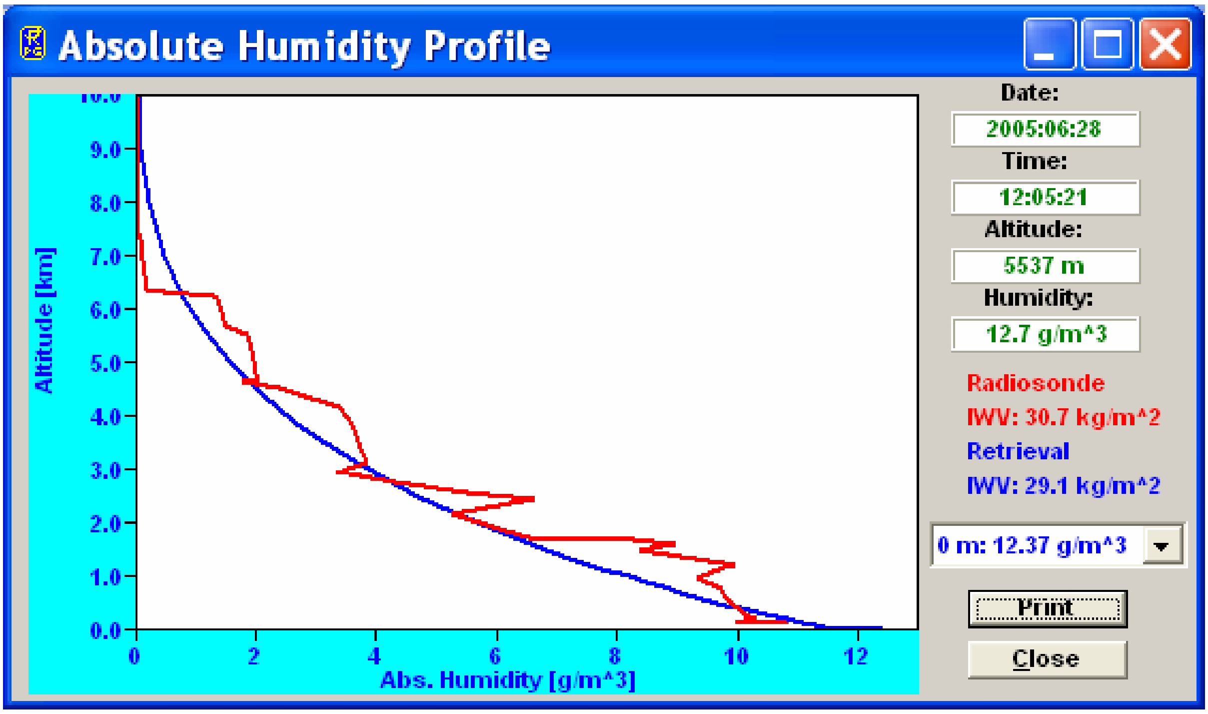


Fig.18: Sample profile taken from the map in Fig.8 at 12:00 UTC (noon time). In red is the data of a radiosonde for comparison (Larkhill, UK).

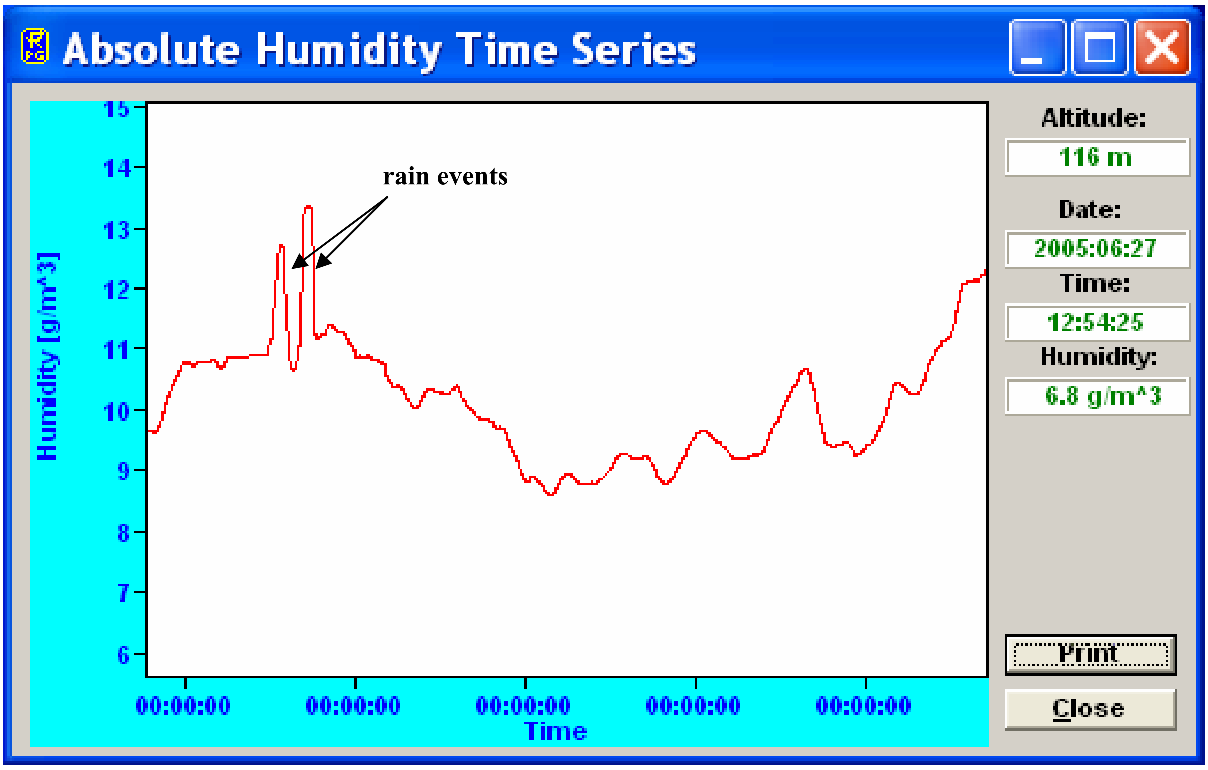


Fig. 19: Absolute humidity time series at 116 m altitude.

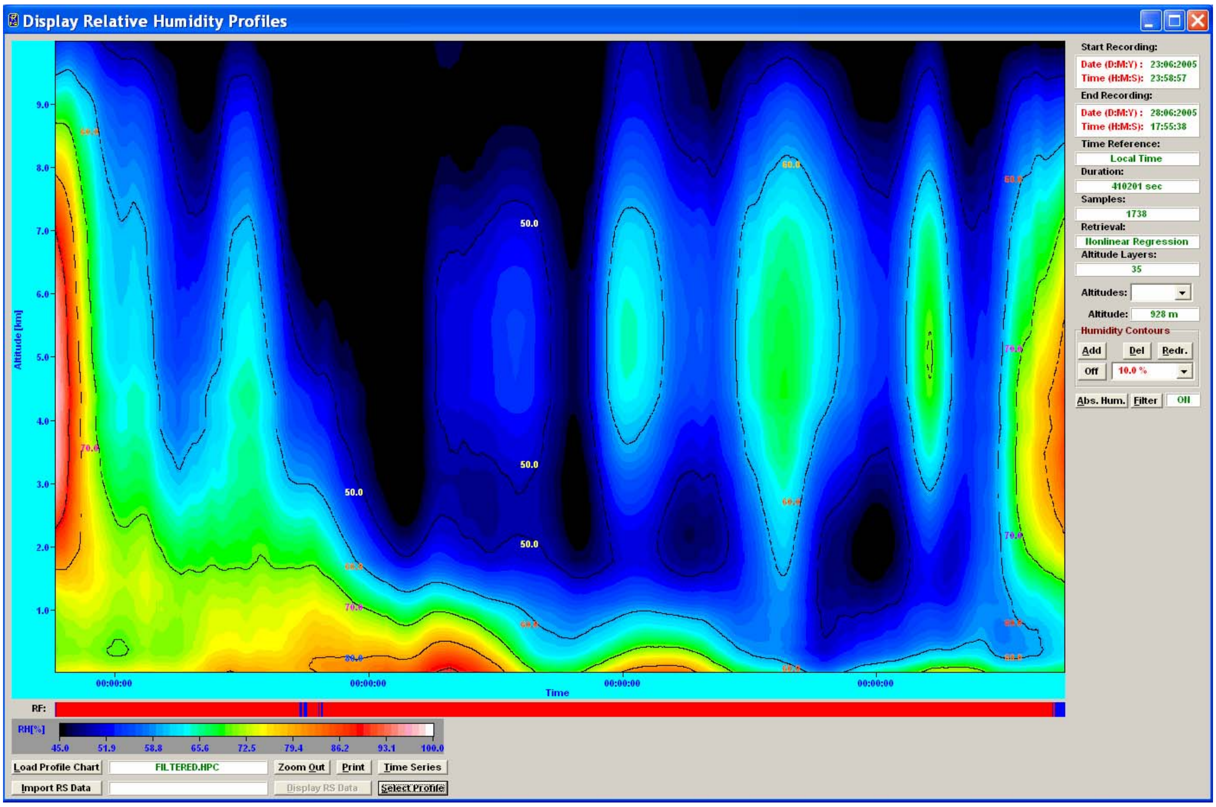


Fig.20: Relative humidity map for the full troposphere (up to 10 km) computed from absolute humidity profiles and temperature profiles both measured in zenith mode.

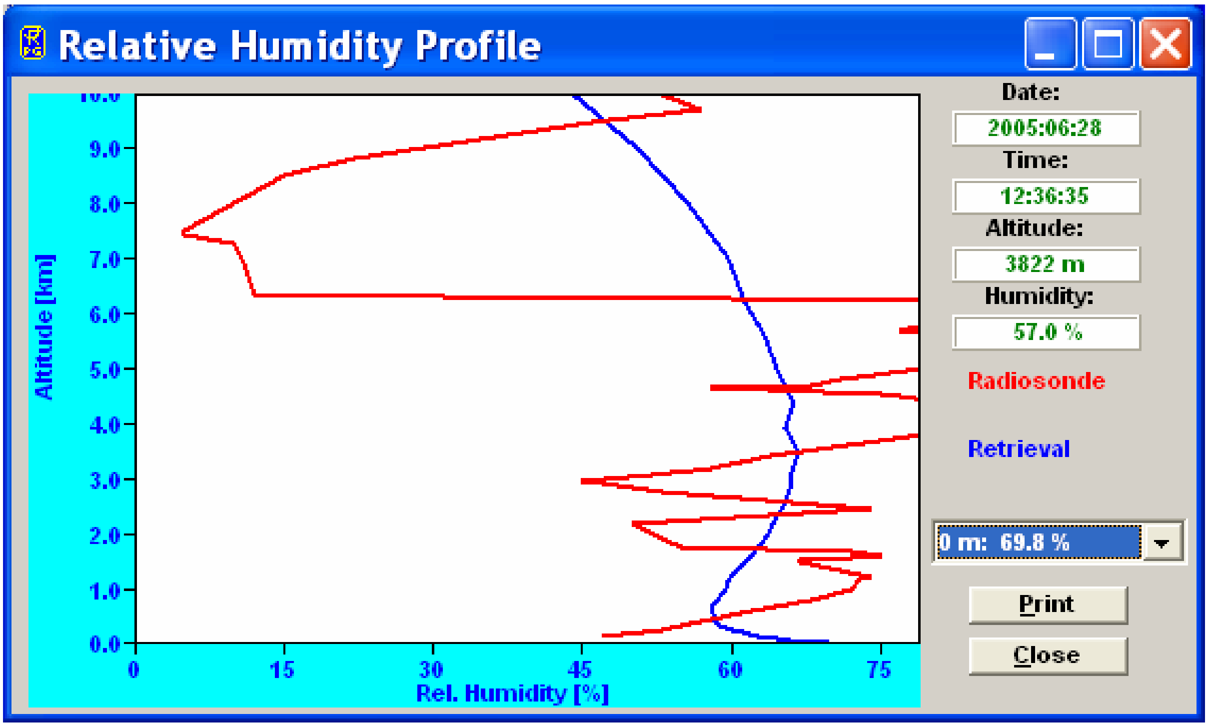


Fig.21: Comparison of relative humidity profile with radiosonde data. As mentioned above the microwave information does not allow for retrieving any details of humidity profiles above 5-6 km. A small error in absolute humidity at low temperatures produces a big error in relative humidity.

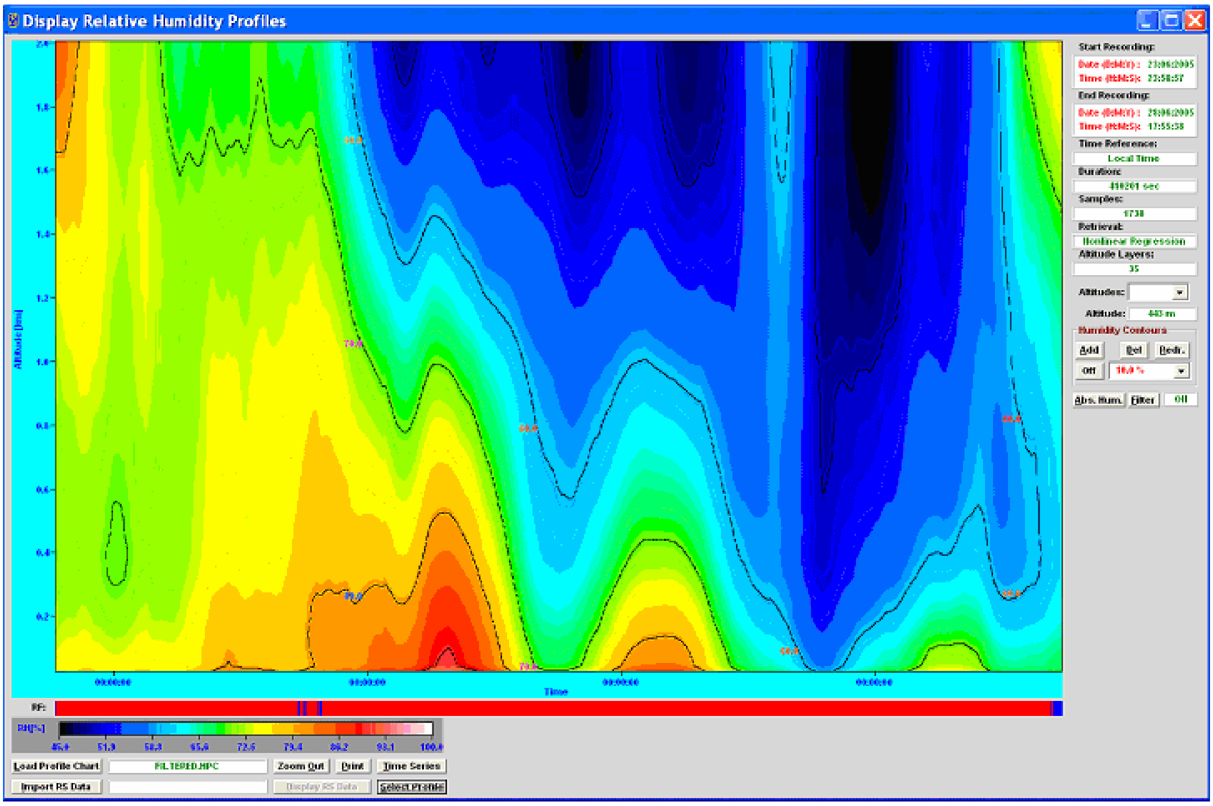


Fig.22: The lowest 2000 m layer map of Fig.20 computed from absolute humidity profiles and temperature profiles both measured in zenith mode.

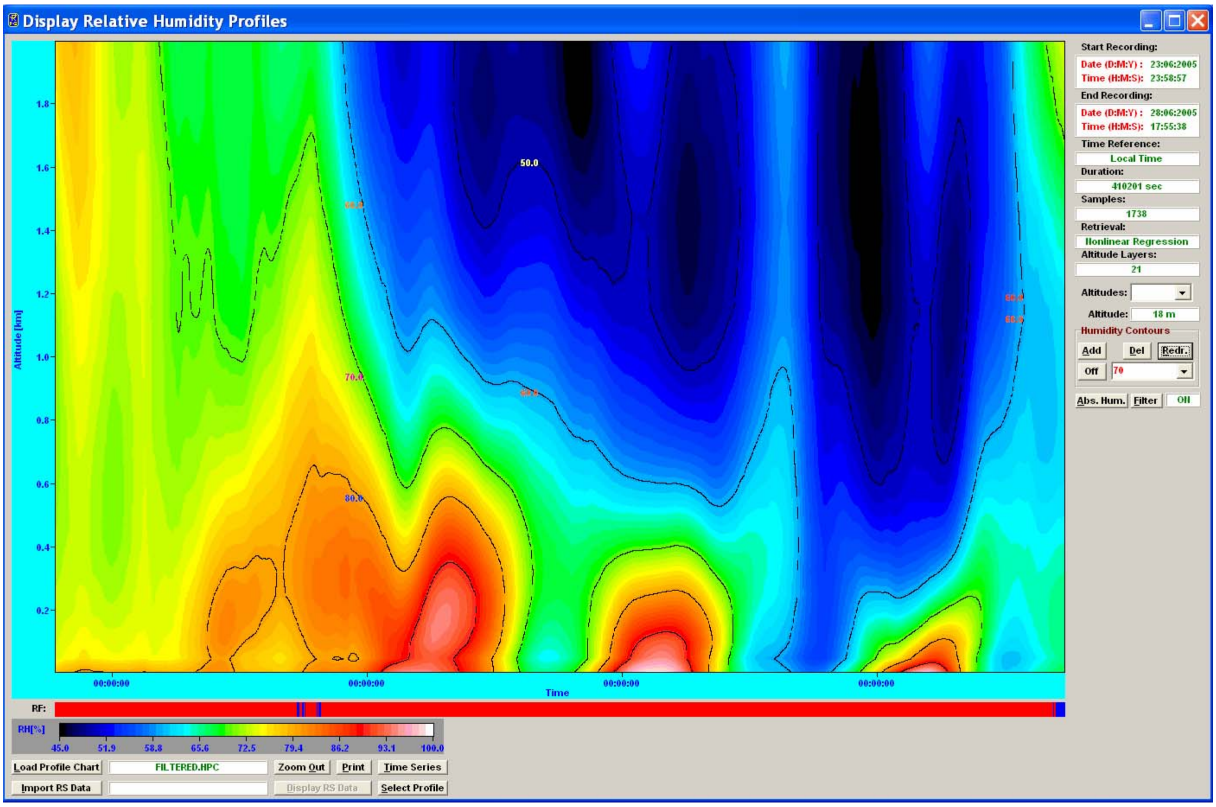
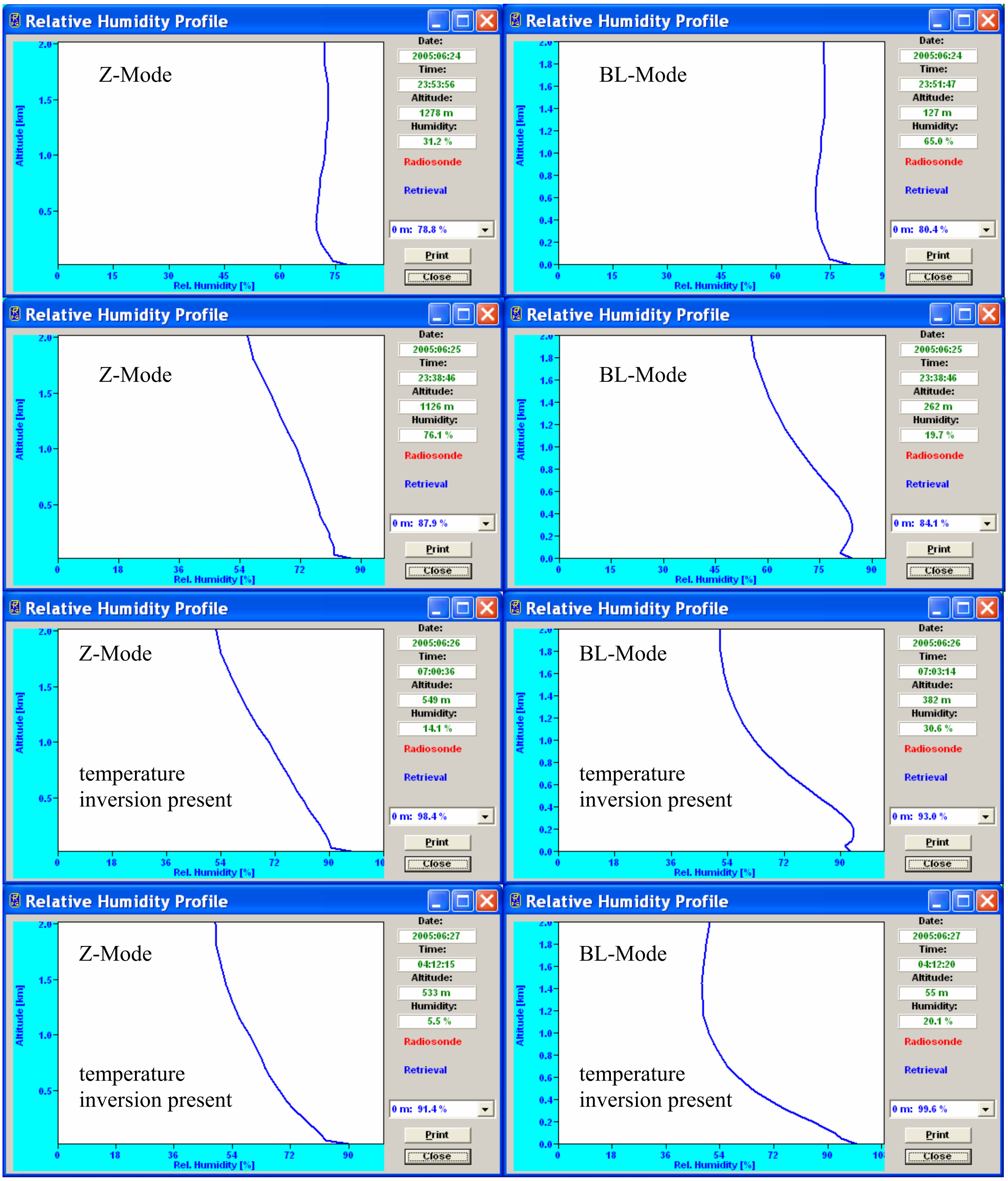
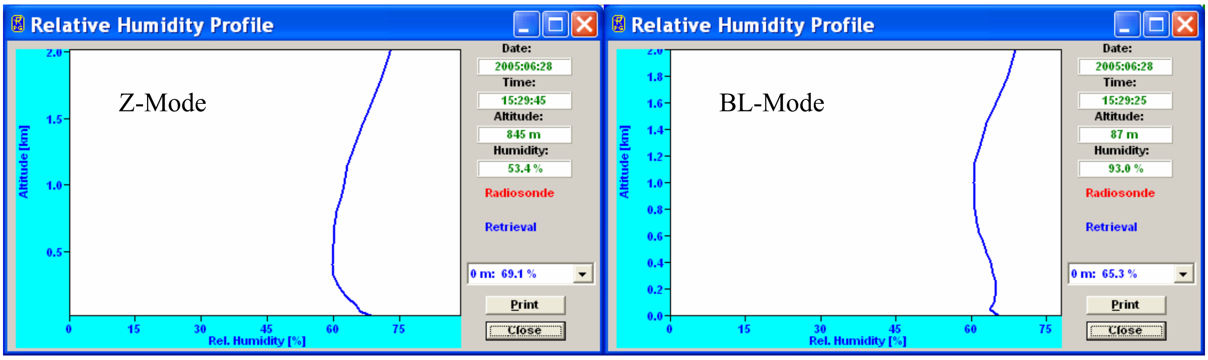


Fig.23: Relative humidity map for boundary layer (up to 2 km) computed from absolute humidity profiles and temperature profiles measured in boundary layer mode. A comparison with Fig.22 clearly shows that more details are resolved in the <500 m range. The relative humidity is modulated by the temperature inversions.

Below is shown a sequence of boundary layer humidity profile samples taken from Fig.22 (left profiles, Z-Mode (zenith mode)) and from Fig.23 (right profiles, BL-Mode (boundary layer mode)): Without temperature inversion the humidity profiles look almost the same.




Relative Humidity Profile
Z-Mode
Date: 2005:06:27
Time: 16:15:35
Altitude: 773 m
Humidity: 15.3 %
Radiosonde
Retrieval
0 m: 66.9 %
Print
Close
Altitude [km]
Rel. Humidity [%]
Relative Humidity Profile
BL-Mode
Date: 2005:06:27
Time: 16:11:40
Altitude: 517 m
Humidity: 43.7 %
Radiosonde
Retrieval
0 m: 59.7 %
Print
Close
Relative Humidity Profile
Z-Mode
temperature
inversion present
Date: 2005:06:28
Time: 05:34:45
Altitude: 437 m
Humidity: 52.3 %
Radiosonde
Retrieval
0 m: 78.5 %
Relative Humidity Profile
BL-Mode
temperature
inversion present
Date: 2005:06:28
Time: 05:38:44
Altitude: 350 m
Humidity: 80.5 %
Radiosonde
Retrieval
0 m: 97.3 %
Relative Humidity Profile
Z-Mode
temperature
inversion present
Date: 2005:06:28
Time: 07:18:23
Altitude: 491 m
Humidity: 72.8 %
Radiosonde
Retrieval
0 m: 79.0 %
Relative Humidity Profile
BL-Mode
temperature
inversion present
Date: 2005:06:28
Time: 07:18:09
Altitude: 1179 m
Humidity: 77.7 %
Radiosonde
Retrieval
0 m: 85.5 %


Relative Humidity Profile
Z-Mode
Date: 2005:06:28
Time: 15:29:45
Altitude: 845 m
Humidity: 53.4 %
Radiosonde
Retrieval
0 m: 69.1 %
Print
Close
Altitude [km]
Rel. Humidity [%]
Relative Humidity Profile
BL-Mode
Date: 2005:06:28
Time: 15:29:25
Altitude: 87 m
Humidity: 93.0 %
Radiosonde
Retrieval
0 m: 65.3 %
Print
Close

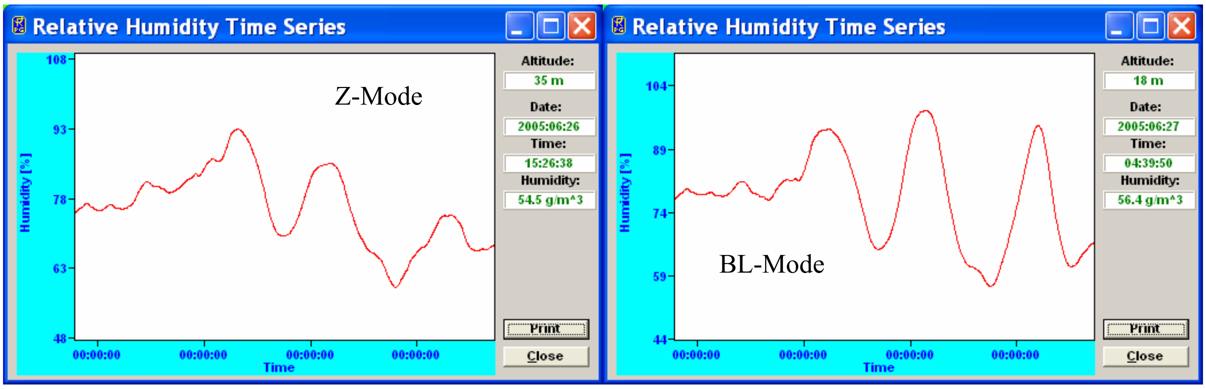


Fig:24: Relative humidity time series at low altitude measured in Z-mode and BL-mode. The BL-mode humidity maxima over night between 22:00 and 7:00 (when inversions are generated) are more pronounced than in Z-mode.

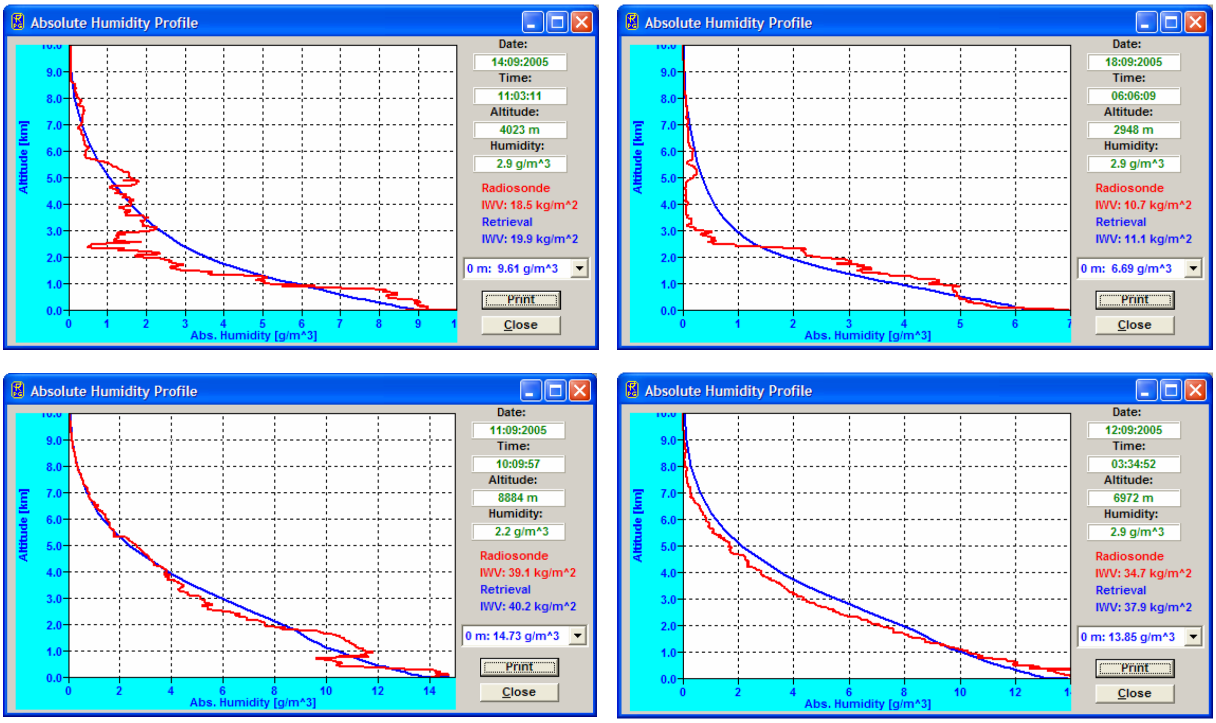


Fig:25: Absolute humidity profiles compared to radio soundings (red). Statistical analysis leads to RMS errors of 1 g/m^3.

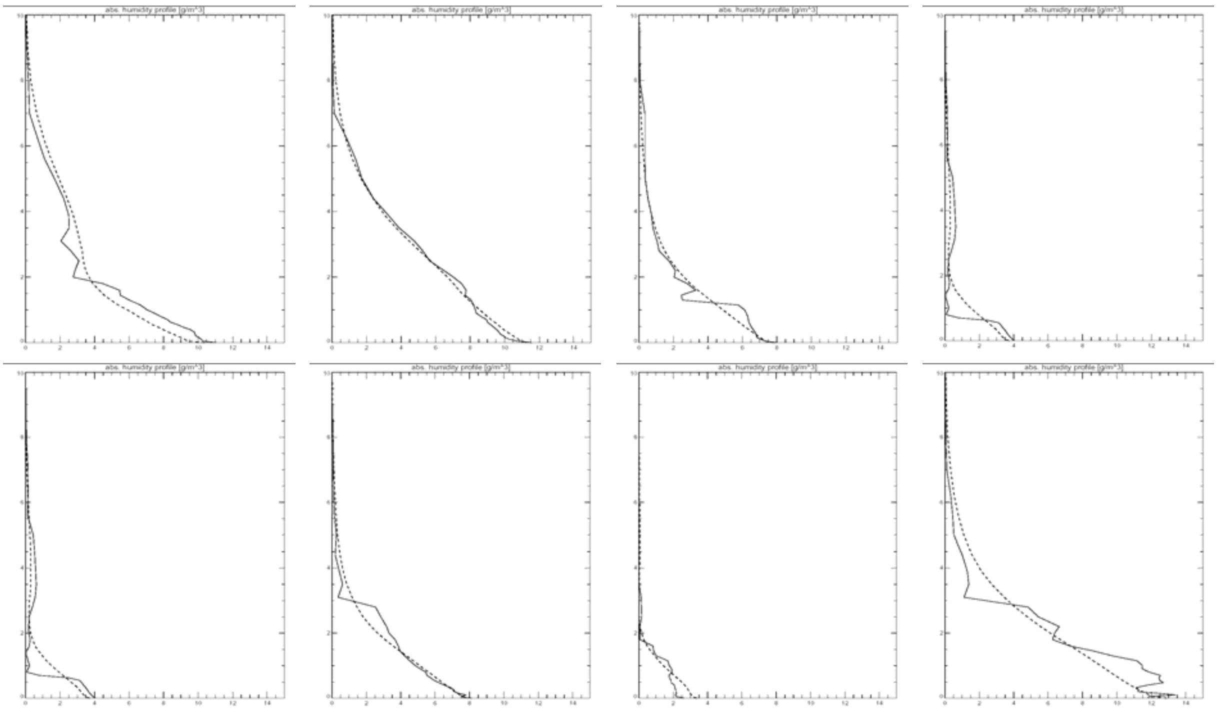


Fig:26: Due to the small number of degrees of freedom in the water vapour line the retrieval (dotted line) can only average through the real profiles but the integrated water vapour (IWV) measurement is quite accurate.

AMMA campaign, Benin / West Africa (Jan. 2006 to Jan. 2007)

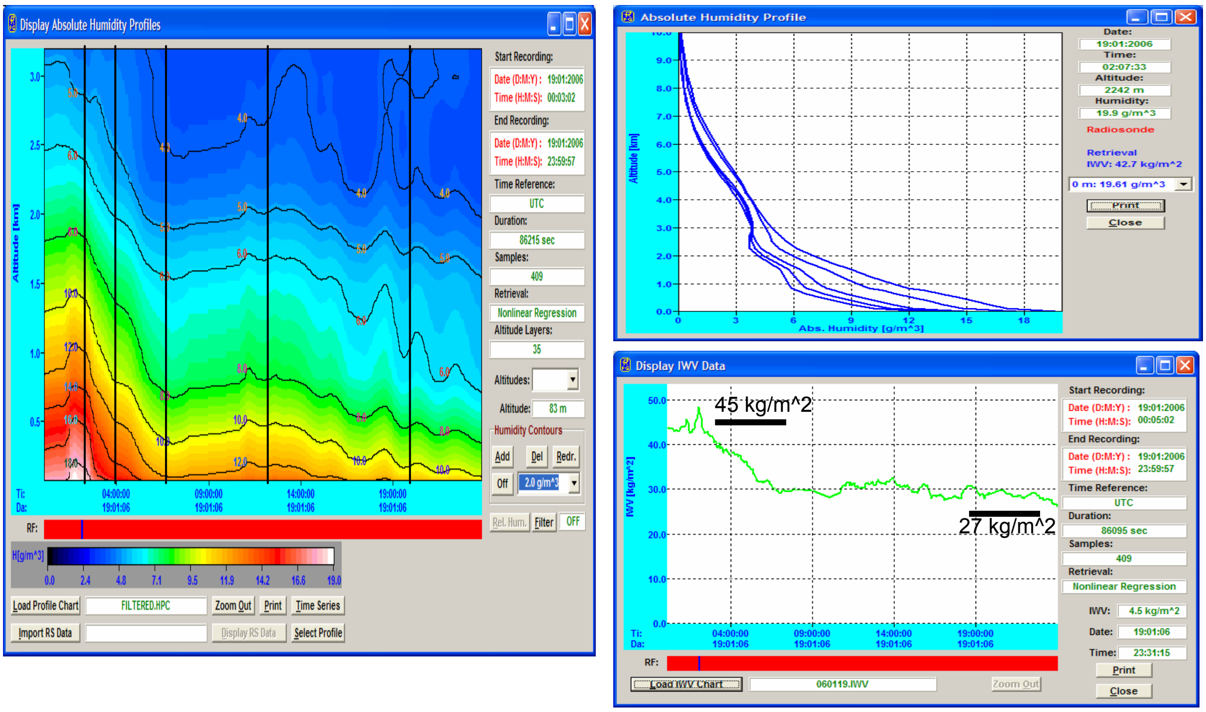


Fig:27: Example of a transition from wet to dry period by sea breeze effect in Benin / West Africa with development of absolute humidity profiles and integrated water vapour.

Morioka campaign, Japan (Oct. 2006 to Jan. 2007)

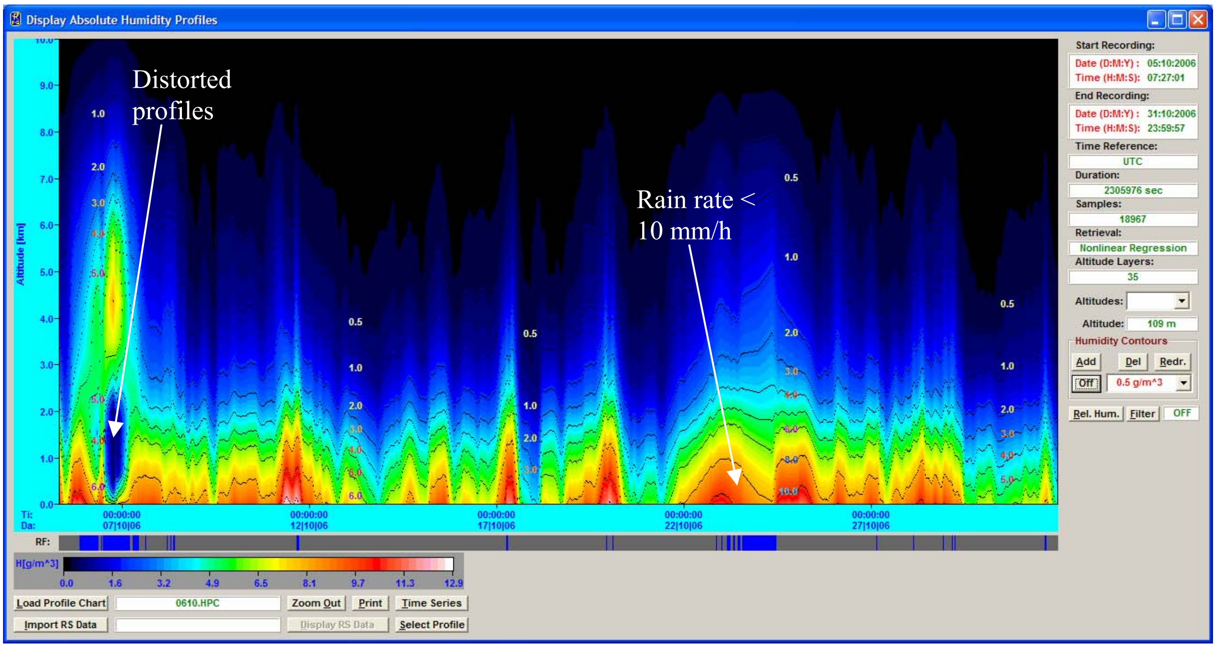


Fig.28: One month of absolute humidity data from Morioka / Japan. At rain rates >10 mm/h the profile is distorted while at rates < 5mm/h the profile accuracy is reduced by only 20%.

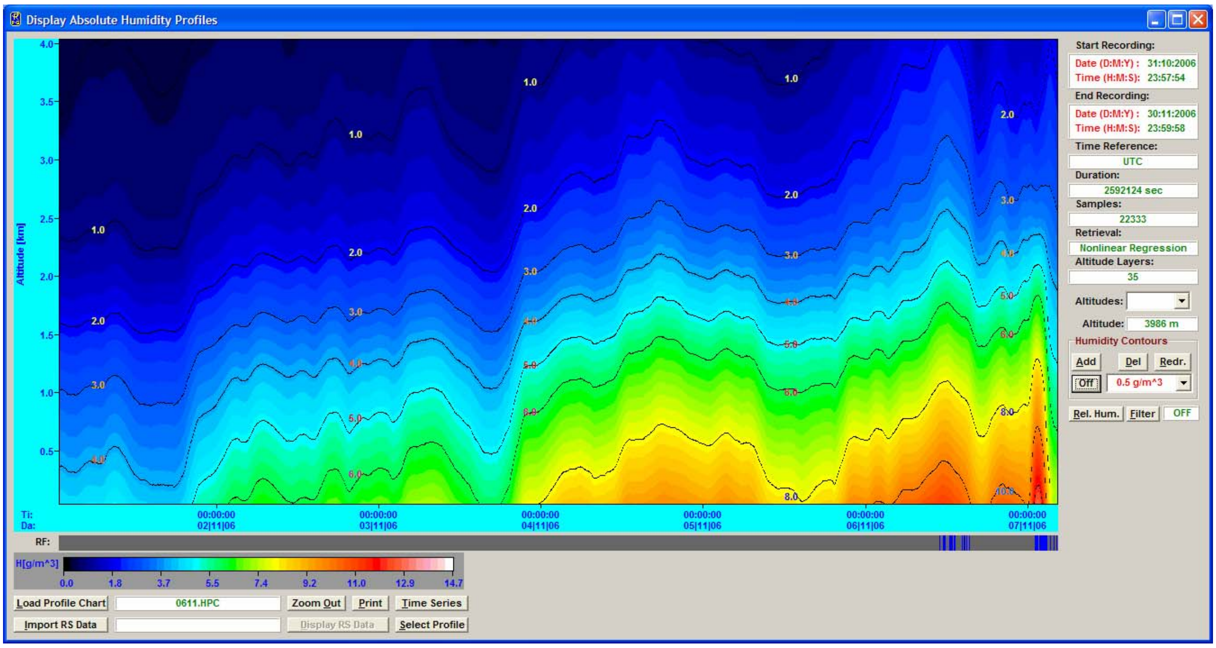


Fig.29: Absolute humidity profile map of the lowest 4000 m over 6 days.

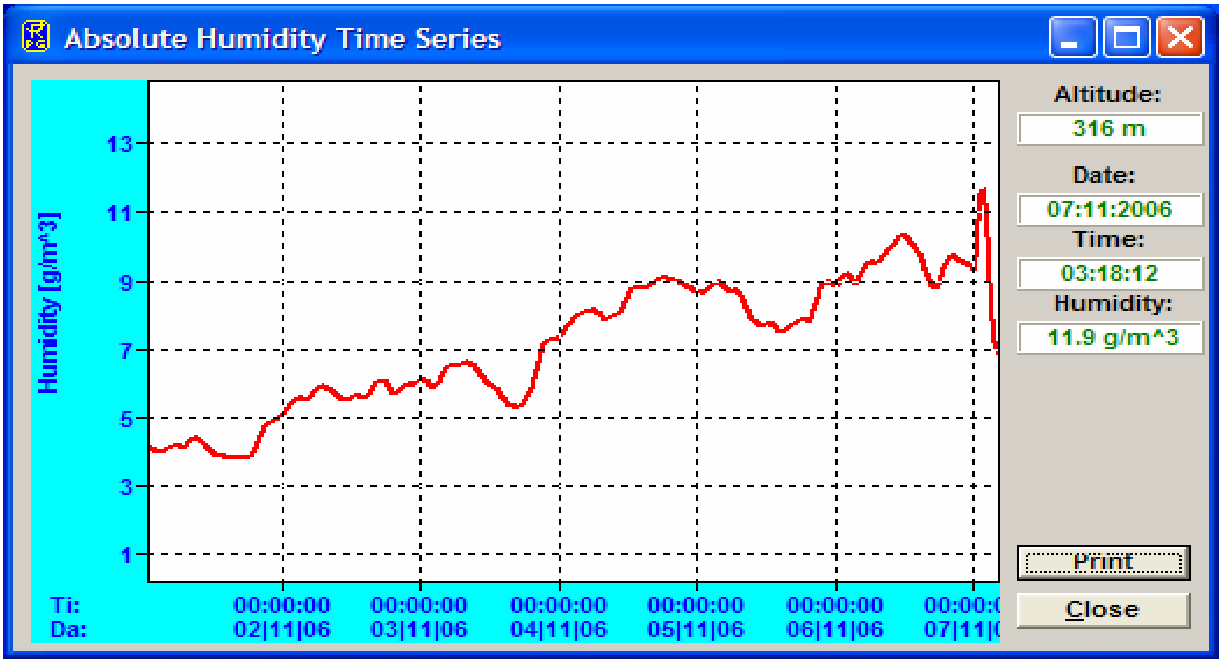


Fig.30: Absolute humidity time series @ 300 m level from period in Fig.29.

LWP and IWV Measurements

The RPG-HATPRO is capable of measuring liquid water path (LWP) with a 1 second temporal resolution due to its parallel receiver architecture. The variability of clouds can be analyzed in detail also because of the relatively narrow beam width of 4° HPBW (half power beam width) for the water vapour channels.

The LWP measurement noise is very low (< 2 g/m^2 RMS, see Fig.16), thus even thin clouds can be resolved.

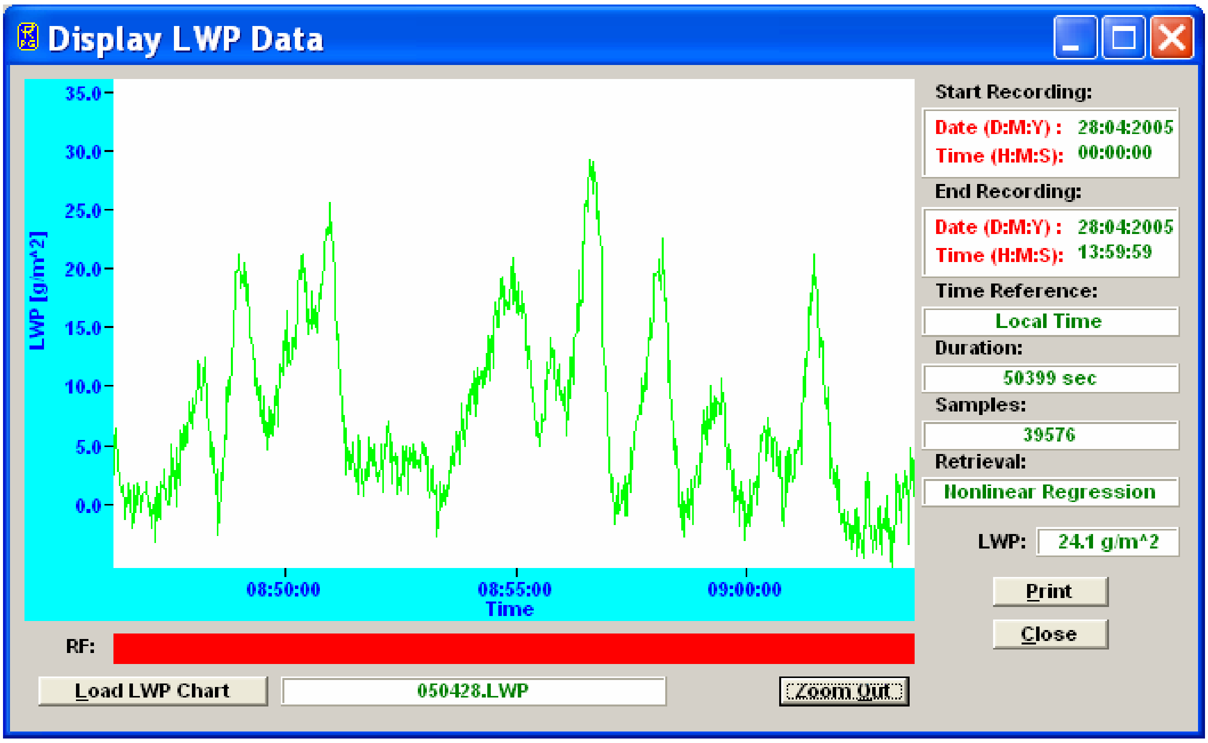


Fig.31: High temporal resolution (1 second sampling) LWP time series. The measurement noise is very low (< 2 g/m^2 RMS).

For integrated water vapour measurements (see Fig.32) the temporal resolution is not important. A sample rate of 1/minute is sufficient to monitor all IWV details. IWV is the most accurately retrieved atmospheric parameter with an absolute accuracy of +/- 0.3 kg/ m^2 and an RMS noise of < 0.05 kg/ m^2.

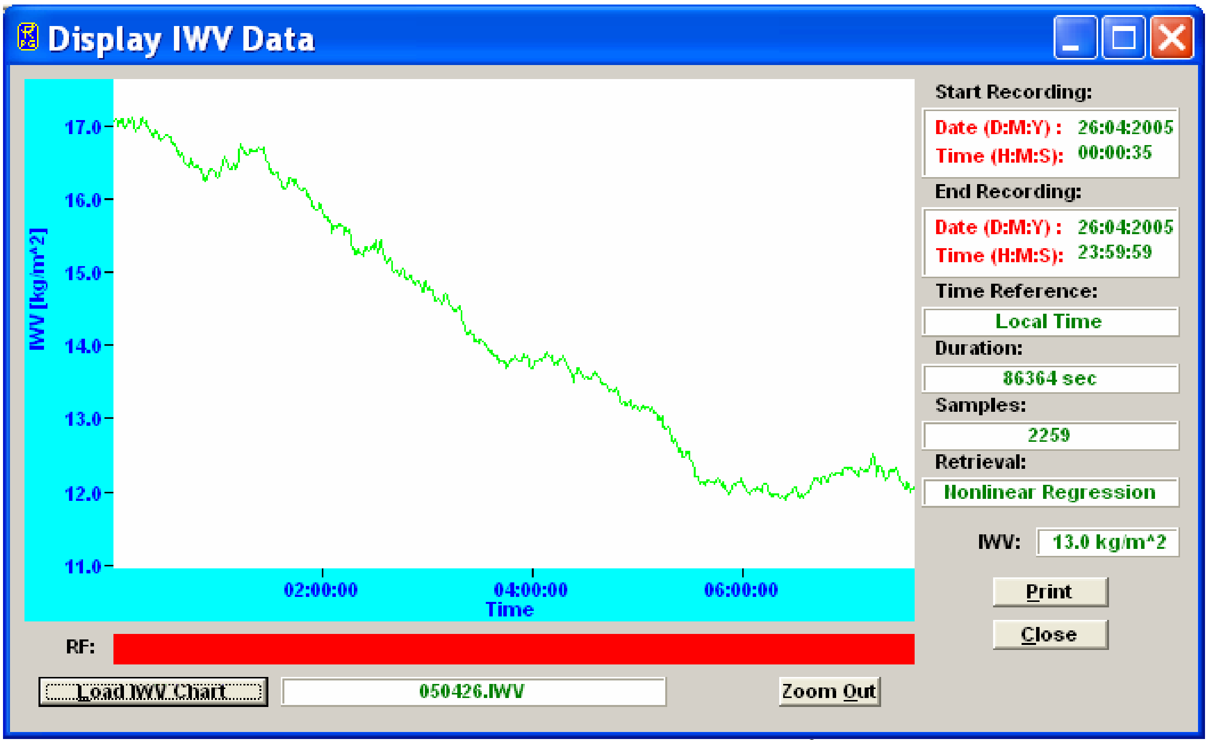


Fig.32: IWV time series. Absolute accuracy is +/- 0.3 kg/ m^2 with an RMS noise of < 0.05 kg/ m^2.

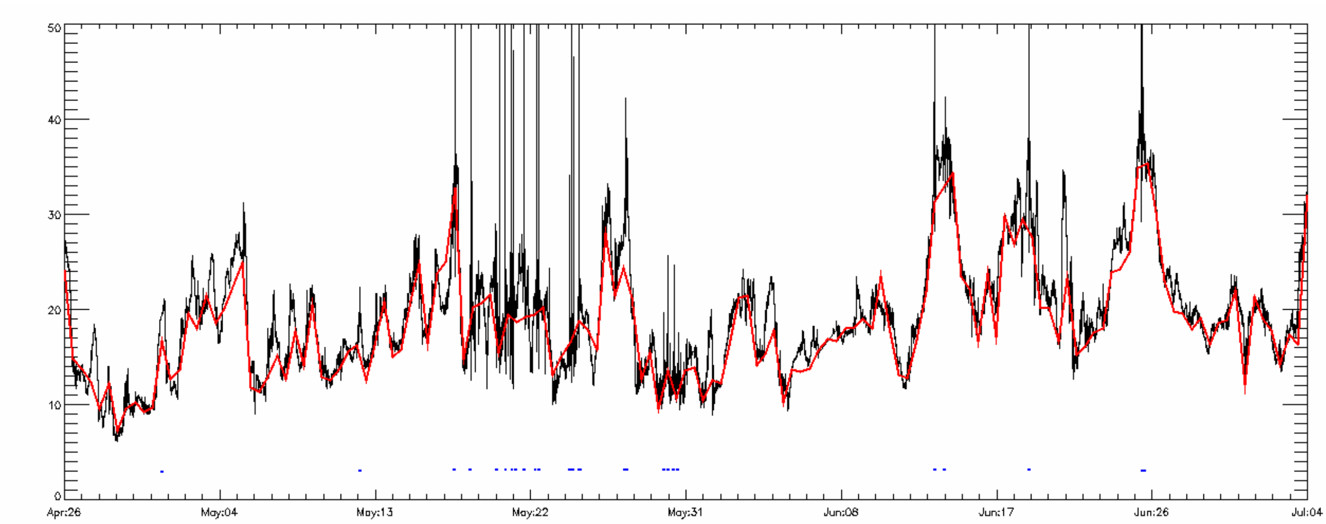


Fig.33: IWV time series over one month (KNMI, May 2006). 140 radio sondings (26. April to 4. July, Cabauw, KNMI). Radiosonds: Vaisala RS-92. No-Rain RMS: 0.43 kg/m^2, Bias: 0.05 kg/m^2

Stability Indices

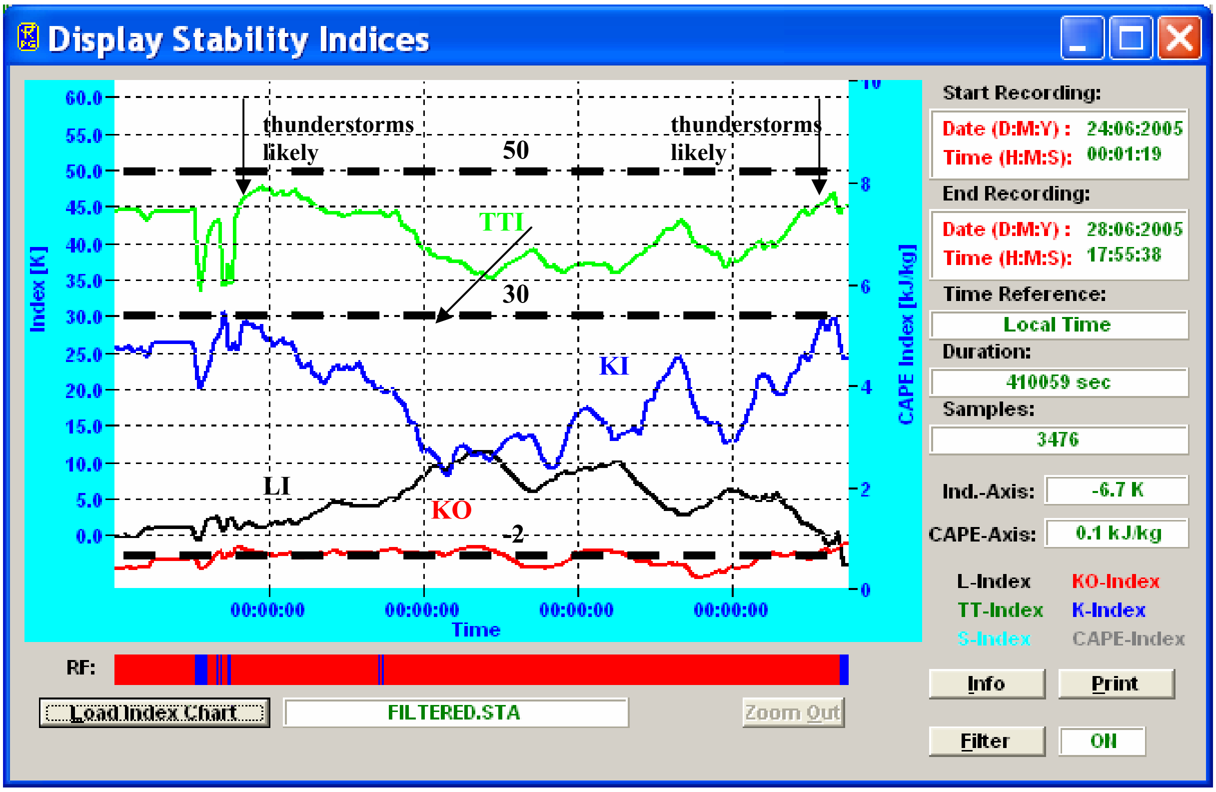


Fig.34: When TTI, KI and LI are approaching their critical limits, thunderstorms are likely to occur. This can be seen from the rain flag bar (blue indicates 'rain', red means 'no rain').

The RPG-HATPRO is delivered with retrievals for the most common atmospheric stability indices like:

- The Lifted Index (LI) shows the stability of an air parcel. It is computed by lifting the parcel of air pseudo-adiabatically to a 500 mb level, then comparing the temperature of the air parcel to that of the environmental air temperature. The temperature of the air parcel may be much higher than the surrounding air (e.g. due to condensation), causing it to be unstable in a sense that it wants to be displaced vertically. We look for negative numbers with this index. The more negative the number, the more unstable the air is and the more potential there is for a stronger thunderstorm. Values of zero or below are good indicator of general thunderstorms. Severe thunderstorms are possible when the values reach -4 or so.
- The Total Totals Index (TTI) combines the effect of the atmospheric lapse rate and low level moisture. It is computed by using the Cross Totals Index (CT = Td850 - T500) and the Vertical Totals Index (VT = T850 - T500). An index of 50 is a good starting point for thunderstorms.
- The K Index (KI) represents the thunderstorm potential as a function of vertical temperature lapse rate at 850 mb temperature and 500 mb temperature, low level moisture content at 850 mb dewpoint and the depth of the moist layer at 700 mb dewpoint (George, 1960). KI increases with decreasing static stability between 850 and 500 mb, increasing moisture at 850 mb and increasing relative humidity at 700 mb. KI can be used as an indicator of convection but not as a discriminator of severe versus non-severe convection. Values of KI > 20 generally represent a convective

environment capable of producing scattered thunderstorms activity, while KI > 30 represents an atmospheric potential for numerous thunderstorms to occur (Haklander and Van Delden, 2003).

Acknowledgement

Data Sources:

1. CSIP (Convective Storms Initiation Project). The RPG-HATPRO instrument was run by the University of Salford who is a member of UFAM (Universities Facilities for Atmospheric Measurements).
2. LAUNCH campaign, University of Munich, Germany
3. AMMA campaign, University of Bonn Germany
4. Morioka / Japan, Japan Meteorological Agency
5. KMNI, Dutch Weather Service, Cabauw / Netherlands