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Article

The COST 720 temperature, humidity, and cloud profiling campaign: TUC

DOMINIQUE RUFFIEUX*[1], J. NASH[2] , P. JEANNET[1] and J.L. AGNEW[3]

[1]MeteoSwiss, Aerological Station, Payerne, Switzerland
[2]UK Met Office, Exeter, Devon, United Kingdom
[3]CCLRC Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire, United Kingdom

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Abstract

The international COST 720 Temperature, hUmidity, and Cloud (TUC) profiling experiment was organized over three months in winter 2003/2004 at Payerne, Switzerland. Various in-situ and active/passive ground-based remote sensing systems, including three microwave radiometers, a cloud radar and a wind profiler, were operated at the same location. The experiment has delivered a dataset for ground-based remote sensing measurements of winter conditions in the lower troposphere, including fog formation, development and erosion in the boundary layer. The data are being used to test atmospheric profiling products derived from integration of the various measurements. One example is fog/low cloud top and base derived from 78 GHz frequency-modulated continuous wave (FMCW) cloud radar and laser ceilometer measurements. The paper first describes the TUC experiment and the systems involved, including a brief analysis of the radiosoundings quality. An example is then used to show the ability of ground-based remote sensing systems to automatically determine the stratus base and top. Finally an overview of the publications related to the experiment is presented.

Zusammenfassung

Das internationale COST 720 Temperature, hUmidity and Cloud (TUC) profiling Experiment wurde während drei Monaten im Winter 2003/2004 in Payerne, Schweiz, durchgeführt. Verschiedene in-situ- und bodengestützte aktive/passive Fernerkundungssysteme, darunter drei Mikrowellenradiometer, ein Wolkenradar und ein Windprofiler, wurden am gleichen Ort betrieben. Das Experiment lieferte einen Datensatz für bodengestützte Fernerkundungsmessungen von Winterbedingungen in der unteren Troposphäre, welche die Bildung, die Entwicklung und die Auflösung von Nebel in der Grenzschicht umfassen. Die Daten werden gebraucht, um atmosphärische Profilmessungen, welche aus der Kombination von verschiedenen Messsystemen hergeleitet werden, zu testen. Ein Beispiel ist die Bestimmung der Ober- und Untergrenze von Nebel oder tiefliegenden Wolken anhand von 78 GHz FMCW Wolkenradar und Laser Ceilometer Messungen. Der Artikel beschreibt zunächst das TUC Experiment und die darin verwendeten Messsysteme, sowie eine kurze Betrachtung zur Qualität der Radiosondierungen. Anhand eines Beispiels wird dann die Möglichkeit gezeigt, mit bodengestützten Fernerkundungssystemen die Nebelober- und -untergrenze automatisch zu bestimmen. Schließlich folgt eine Übersicht der auf das Experiment bezogenen Publikationen.

1 Introduction

Within the meteorological community there is a desire to find ways to reduce expenditure for ground-based upper-air measurements. The latest radiosonde designs produce measurements of much better quality than previous versions, but they still have relatively high operational costs. Ground-based remote sensing offers the chance of measurements at very high temporal resolution at a given site. For instance modern wind profilers and microwave radiometers can produce observations at 10-minute intervals, which is compatible with the traditional sampling periods of surface measurements (NASH, 2005). This high temporal resolution also fits very well with the assimilation frequencies of numerical weather prediction models. Some ground-based remote sensing techniques like wind profilers are at an operational stage, while passive microwave radiometry for temperature and water vapor profiling is at a semi-operational stage and improvements as well as validation experiments are necessary (REVERCOMB et al., 2003; HEWISON et al., 2004; CREWELL et al., 2004).

The Temperature, hUmidity, and Cloud (TUC) profiling experiment was organised by MeteoSwiss, in close collaboration with the UK-Met Office and several other institutes in Europe and the United States, within the European COST 720 Action “Integrated Ground-based Remote-Sensing Stations for Atmospheric Profiling”. Measurements were made over the period 15 November, 2003 to 31 January, 2004. The main goals of this campaign were to:

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*Corresponding author: Dominique Ruffieux, MeteoSwiss, Aerological Station, 1530 Payerne, CP. 316, Switzerland, e-mail: dominique.ruffieux@meteoswiss.ch

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- test ground-based temperature and humidity profiling systems,
- study in particular their ability to detect planetary boundary layer phenomena like temperature inversion, presence of fog, fog dissipation, low cloud formation and evolution,
- test cloud detection systems (passive and active ground-based systems),
- provide a dataset for studying the possibility of system integration for improving temperature and humidity profiling with ground-based remote sensing systems.

The aerological station of Payerne is located in the Swiss Mittelland at 491 m asl (46.813°N, 6.943°E). The region is characterized by rolling hills surrounded to the N-NW by the Jura mountains (1,000–1,500 m asl) and to the S-SE by the Alps (2,000-4,000 m asl). This particular topography tends to enhance the formation of wintertime thermal inversions within the first two kilometers above ground (Figure 1). During the TUC period, inversions with fog or stratus occurred most frequently in November and December 2003 (Figure 2). The time series of surface meteorological parameters measured at Payerne are shown in Figure 3. While the four top panels represent daily averages, the bottom one shows one-minute averaging. It can be noted that it is possible to detect fog cases by looking at all cases with horizontal visibility less than 1000 meters, according to the WMO criterion (bottom panel of Figure 3).

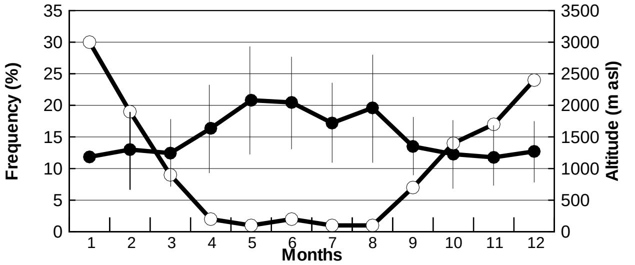

Figure 1: Yearly cycle of elevated temperature inversions above Payerne at 11 UTC. Statistics based on inversions thicker than 250 m between 0.1 and 2.8 km agl and a time period of 10 years (1993–2002). The curve with solid dots (Y scale, to the right) indicates the mean altitude and standard deviation of the inversion (m asl), and the curve with open dots (Y scale to the left), the frequency of occurrence.

2 In-situ and remote sensing systems involved

During TUC, both active and passive ground-based remote sensing systems were deployed in Payerne. Table 1 describes the systems involved in the experiment and the main parameters measured. In-situ systems were operated (sensors for surface parameters, radiosoundings) as well as active (wind profiler, cloud radar, ceilometer) and passive (three microwave radiometers using three different technologies) ground-based systems.

The validation of remote sensing instruments during TUC mostly relied on in-situ measurements provided by aerological soundings. At the aerological station of Payerne, temperature, humidity and wind profiles from ground to up to 30 km asl are operationally performed twice a day (11 and 23 UTC) with the Swiss radiosonde SRS 400 (RICHNER, 1999). During TUC, 43 extra sondes of that type were also launched at 05 and 17 UTC. The temperature sensor of the SRS 400 is a copper-constantan thermocouple with very thin wires and can be considered as precise and accurate (RUFFIEUX and JOSS, 2003) in dry conditions. In wet conditions, most temperature sensors can have cooling errors when emerging from fog/cloud into relatively dry layers (psychrometric effect). The humidity sensor of the SRS 400 sonde is a Sippican resistive hygristor (type B2 with 3 calibration parameters), whose response time becomes very slow at temperatures below –30 degrees Celsius. The limited performance of this sensor was the main reason for performing 12 additional measurements with a chilled mirror dew/frost point hygrometer “Snow White” (VOEMEL et al., 2003; WANG et al., 2003), which was only operated for dual/triple soundings. The RS80A (Vaisala) sonde was used in 29 additional soundings and was also compared with the other sondes. Therefore some soundings were performed with up to 3 sondes under the same balloon, in order to assess the quality of their measurements. It is important to correct the radiosonde errors before using them as references (REVERCOMB et al., 2003; TURNER et al., 2003). The final dataset of these in-situ vertical profiles includes corrections for their main systematic errors. The humidity corrections increased the integrated water vapor values by 5 % in average. Within the planetary boundary layer, temperature differences between the radiosondes were generally below 0.2 K while relative humidity differences were mostly within 5 % (Figure 4). The maximum differences occur at the top of the inversion when the gradients in temperature and humidity are the highest.

For the temperature measurements, the largest errors originated from cooling errors of the SRS 400 sensor after the sensor had become wet in fog. These errors were reduced by bringing the incorrect superadiabatic layer to adiabatic conditions. For relative humidity, the method of using the carbon hygristor within the protective duct on the SRS 400 does not provide reliable detailed relative humidity profiles near the surface in the presence of fog or very low clouds. When compared with Snow White and Vaisala observing fog, the hydrolapse above the fog is located about 100 m above the true position

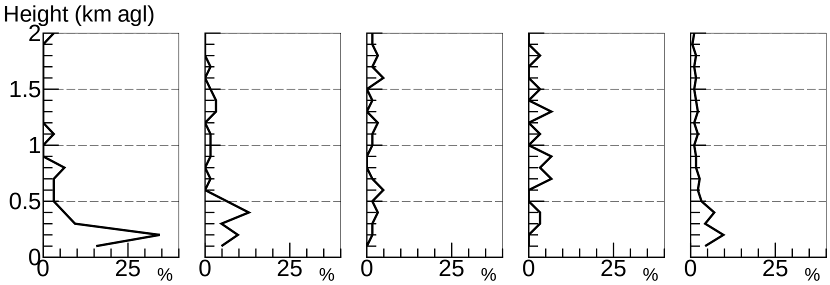

Figure 2: Percentage of cases, from radiosoundings data, with fog or stratus and temperature inversions stronger than 2 K, as a function of height. From left to right: November 2003, December 2003, January 2004, February 2004, total TUC period.

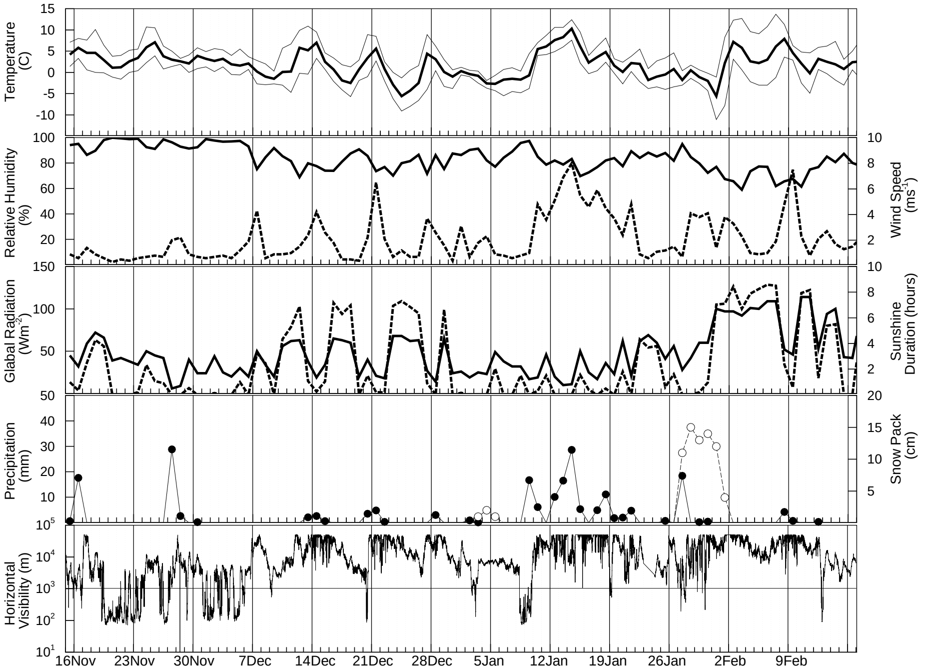

Figure 3: Time series of meteorological parameters measured at Payerne during TUC. From top, 2 m temperature and standard deviation, relative humidity (solid line) and wind speed (dashed line), global radiation (solid line) and sunshine duration (dashed line), precipitations (solid line) and snow pack (dashed line with open circles), and horizontal visibility.

of the hydrolapse, and drier layers above the fog may be attenuated (Figure 5). This problem originates from a combination of fog contaminating the protective duct of the carbon hygristor, and inadequate ventilation through the duct early in flight (whilst the balloon is accelerating to normal vertical velocity) preventing the sensor observing the correct ambient relative humidity. The overall humidity error of the Sippican hygristor increases with temperatures below –30°C at higher altitudes (not shown). In Figure 5, the corresponding microwave radiometer profiles are shown. They are typical for passive ground-based remote sensing systems measuring with a high temporal resolution but with a relatively poor vertical resolution (CIMINI et al., 2006b).

3 Example: detection of the base and top of fog or low cloud

Various types of cloud height determination tools have already been investigated using in-situ and ground-based remote sensing systems (i.e. CLOTHIAUX et al., 2000). The goal of TUC was to provide a dataset for determining low clouds base and top using a simple combination of instruments. The example below shows the potential of such analysis. A day with presence of stratus (9 December, 2003) is shown in Figure 6. The base began to lift at 06 UTC and the top height varied through the day. The base layer was well measured with the ceilometer while the top of the cloud was determined using the 78 GHz FMCW radar (see Table 1). This method for cloud top determination is based on determining the height at which the radar signal falls below a defined threshold level and is currently under development. For comparison purposes, the 11 UTC temperature and humidity profiles from the Snow White radiosounding are also shown in Figure 6. There is a good agreement between the top of thermal inversion, associated with a drastic decrease in humidity at about 400 m agl, and the top of the fog as determined by the cloud

Table 1: Systems involved in TUC and measured parameters (T = temperature, RH = relative humidity, P = pressure, wind = wind speed and direction, W = vertical motions, IWV = Integrated water vapor).

Sytem	**Manufacturer**	**Measured parameters**	**Averaging interval**	**Vert. resolution/max. Height**	**Owner**
Clouds and Radiation					
FMCW Cloud radar 78 GHz	CCLRC Rutherford Appleton Laboratory (UK)	• Cloud base • Cloud top	30 seconds	16 m/8 km	CCLRC Rutherford Appleton Laboratory UK
Ceilometer CT25K	Vaisala (FIN)	• Cloud base	30 seconds	30 m/8 km	MeteoSwiss (CH)
Total sky imager TSI-880	Yankee Environmental Systems (USA)	• Sky cover (daytime)	30 seconds	No profiling	MeteoSwiss (CH)
Infrared Radiation Pyrometer	Pacific Northwest Laboratory (USA)	• Sky temperature • Cloud layers	5 seconds	No profiling	Pacific Northwest Laboratory (USA)
Scanning video camera		• Sky cover (daytime)		No profiling	MeteoSwiss (CH)
Automatic **P**artial **C**loud **A**mount **D**etection **A**lgorithm (APCADA)	World Radiation Center (CH)	• Radiation (short and long, up and down) • T, RH • Sky cover percentage	10 minutes	No profiling	World Radiation Center (CH)
Satellite maps	Meteosat Second Generation + MODIS	• Fog estimates • Cloud optical depth	Variable	No profiling	University of Marburg (DE)
Present weather FD12P	Vaisala (FIN)	• Visibility • Precipitation type	60 seconds	No profiling	MeteoSwiss (CH)
Surface measurements	SwissMetNet +BSRN	• T, RH, P, wind, precipitations • Radiation (short and long, up and down)	10 minutes	No profiling	MeteoSwiss (CH)
Temperature and Humidity					
Radiosonde SRS400	Meteolabor (CH)	• T, RH, P, wind	2/day, operational (max 4)	30 m/30 km	MeteoSwiss (CH)
Chilled mirror hygrometer SnowWhite	Meteolabor (CH)	• T, RH, P	On request	30 m/Up to the tropopause	MeteoSwiss (CH)
Radiosonde RS80-A	Vaisala (FIN)	• T, RH, P, wind	On request	30 m/30 km	MeteoSwiss (CH)
Microwave radiometer MP3000	Radiometrics Inc. (USA)	• T, RH • IWV	6 minutes	100-250 m/5 km	Met Office (UK)
Microwave radiometer ASMUWARA	Institute for Applied Physics, University of Bern (CH)	• T • RH • IWV	~20 minutes	30-400 m/5 km 500 m/5 km	Institute for Applied Physics, University of Bern (CH)
Microwave radiometer MTP 5HE	Kipp and Zonen (NL)	• T	5 minutes	50 m/1 km	Kipp and Zonen (NL)
Global Positioning System antenna	Swisstopo (CH)	• IWV • Zenith total delay	60 minutes	Integrated value	Swisstopo (CH)
Others					
wind profiler 9panel 1290Mhz	Vaisala (FIN)	• Wind, W • Signal to noise ratio • Spectra	30 minutes 30 seconds	50-200 m/4 km	MeteoSwiss (CH)

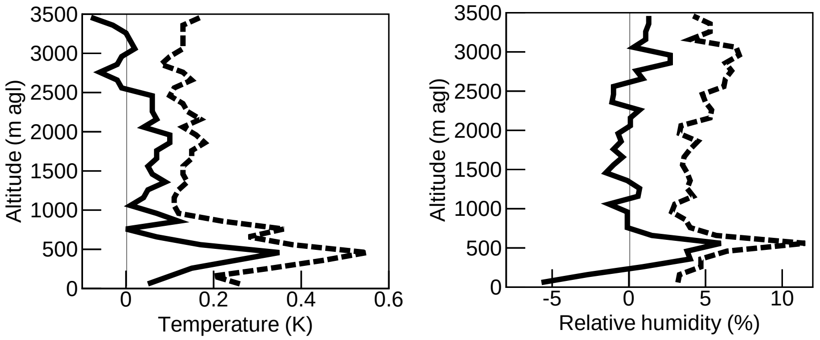

Figure 4: Differences between two types of radiosonde measurements during twin flights. Left panel: bias (solid line) and root mean square (dashed line) between temperatures measured with a Cu-Cn thermocouple of the SRS400 sonde and a Thermocap capacity bead of the Vaisala RS80 sonde (based on 8 cases); right panel: bias (solid line) and standard deviation (dashed line) between the relative humidity measured with the VIZ/Sippican carbon resistive hygristor of the SRS400 and the chilled mirror hygrometer SnowWhite (based on 6 cases).

radar. The FMCW radar is most sensitive to drizzle size drops, so it is not sensitive to clouds with only very small drops. Thus, in thin mist the cloud radar may not provide an indication of the fog top. The rapid decrease of the radar sensitivity below 120 m agl is another limitation in the measurement of low fog layers. In combina-

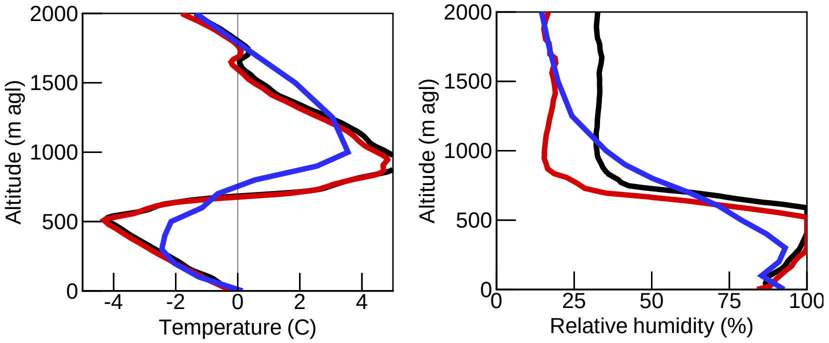

Figure 5: Temperature (left panel) and relative humidity (right panel) profiles, 9 December 2003, 11 UTC. Black curves = SRS 400, red curves = Snow White, blue curves = microwave radiometer MP3000.

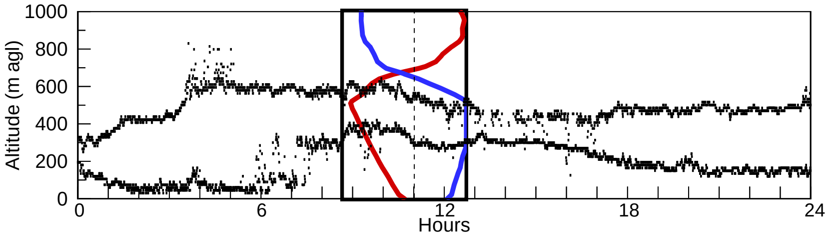

Figure 6: Time series of cloud base (estimated from ceilometer) and cloud top (estimated from cloud radar), 9 December 2003. The rectangle in the middle of the figure corresponds to the profiles measured with the radiosounding with Snow White sensor at 11 UTC (dashed line): red line = temperature with a horizontal scale of 10 K, and blue line = humidity with a horizontal scale of 100 %.

tion with other integration techniques like those using microwave radiometer input and wind profiler signal to noise (KLAUS et al, 2006), this information will be used to improve temperature and relative humidity profiles.

4 Overview and conclusions

During the TUC experiment, a significant amount of data were collected by various in-situ and ground-based remote sensing systems. A significant effort was made to produce a quality controlled dataset available for scientific studies related to winter conditions in central Europe. For example, a combination of ceilometer and FMCW cloud radar information can improve the determination of the cloud base and top of stratus clouds.

A series of analyses have already been performed using the data from the TUC experiment. The ASMUWARA microwave radiometer is presented in MARTIN (2006a) and MARTIN et al. (2006b). Comparison of brightness temperature measured by the different microwave radiometers can be found in CIMINI et al. (2006a), while retrieved profiles are analyzed in CIMINI et al. (2006b). The validation of the absorption models used for calculating temperature and humidity profiles is presented in HEWISON et al. (2006). GPS integrated water vapor time series are compared in MARTIN et al. (2006c). Methods of determining cloud characteristics using both satellite information and ground-based remote sensing techniques are described in CERMAK et al. (2006). A comparison of various processing algorithms for wind profiler spectral data is presented in GAFFARD et al. (2006). Finally, an integration method of wind profiler and microwave radiometer data to obtain improved humidity profiles can be found in KLAUS et al. (2006).

The TUC experiment gave the opportunity for scientists from Europe and USA to work together on the same dataset but with different viewpoints. The complementarity between researchers and scientists responsible for operations was very interesting. Co-location of all systems at Payerne gave a good homogeneity to the dataset. However, data from some of the systems such as the wind profiler were occasionally contaminated, which sometimes made the data analysis and integration more difficult. Finally, a well-calibrated radiosounding system is mandatory, especially for humidity profiling, in order to obtain a valuable reference for comparisons and validation purposes. The planetary boundary layer was the centre of investigation of TUC; therefore a special attention needed to be put on the measurements close to surface. A tethered sounding system would be a good complement to the operational soundings performed on a routine basis only four times per day.

The ultimate goal of the COST 720 action is to improve the quality of temperature and humidity profiling, as shown in Figure 5, using combinations of ground-based remote sensing systems in order to constitute integrated stations (DABBERDT et al., 2005). A future possible way of integration would be to use a method based on assimilating measurements from different sensors in a physical consistent way using an optimal estimation approach (Loehnert et al., 2004). For any supplementary scientific analyses, data as well as technical internal reports are available from the first author.

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