SCIENTIFIC REPORT

ACTION: ES1303 TOPROF
STSM: COST-STSM-ES1303-37052
TOPIC: Combining/comparison of MWR and Doppler lidar for BL retrievals
VENUE: Finnish Meteorological Institute (FMI), Helsinki, Finland
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Introduction

The aim of this STSM was to study the capabilities of, and perform a comparison between, Microwave Radiometer (MWR) and Doppler Wind Lidar (WL) in the context of atmospheric boundary-layer (ABL) retrievals. The strengths and limitations of each instrument are highlighted for the day-time mixed layer and the nocturnal boundary layer.

Whereas the WL is capable of directly measuring the turbulence in the boundary layer, the MWR has the potential to determine the thermal stability of the atmosphere through the retrieved temperature and humidity profiles. Therefore, the WL is able to provide information on mixing within layers under convective and shear-driven conditions for example, but may not always be able to identify the underlying phenomenon responsible for the mixing process. The temperature and humidity profile information from MWR can be used to determine whether convection is likely (day and night) or if a nocturnal temperature inversion is present, something that is not discernible from WL velocity measurements. Results from the STSM suggest improvements that can be made to the MWR-only retrieval in cloudy conditions.

A second goal for this STSM was to explore the potential for a synergetic framework exploiting the strengths of the two instruments, and is also proposed as future work.

As a result, it is expected that the proposed method for synergetic ABL retrieval will be more reliable and better suited for operational use.

Motivation and objectives

Information about the structure of the ABL can be retrieved using different instruments such as lidars (including ceilometers), Doppler wind lidars, microwave radiometers, radiosondes. Each instrument measures a specific tracer which serves as a proxy for detecting layers in the ABL. Such tracers include aerosol backscatter, wind, temperature, relative humidity and other trace gases. Each instrument and method has its own strengths and limitations. Comparing different methods and instruments will help to understand the limitations in particular retrieval methods and suggest routes to improvement. Combinations of instruments are expected to provide better retrievals of the ABL structure. Therefore in this STSM, the capabilities of Doppler wind lidar and microwave radiometer are examined, possibilities for improvements suggested and a proposal for synergy is presented. Note that the thermodynamic profiles (temperature and humidity) are obtained from the scanning mode of the MWR employed here (a HATPRO system by RadiometerPhysics, Germany.

Methodology

The development of the ABL over the course of a day shows a typical cycle under clear-sky conditions and weakly-forced synoptic conditions. A mixed layer which is mainly driven by convection from surface heating grows during the day time and is strongly turbulent. However, there are a range of physical processes that might be responsible for the rate of growth, such as the turbulent mixing due to wind shear, the atmospheric stability of the air into which the mixed layer is growing, the strength of the heat exchange between the surface and atmosphere driving the surface convection, presence of cloud and its own associated turbulent mixing, and the relative strength of each of these processes. At night there is often a much shallower mixed layer, and the structure of the nocturnal boundary layer (NBL) may be categorized in three main types:

1) Nocturnal Mixed Layer (NML)

   Night-time convection, strong wind shear, cloud-driven turbulence, or a combination of these, can also generate deep mixed layers in the ABL at night. Often however, especially in the presence of cloud at the top of the NBL, there is a mixed layer that is detached from the surface with a stable layer underneath.

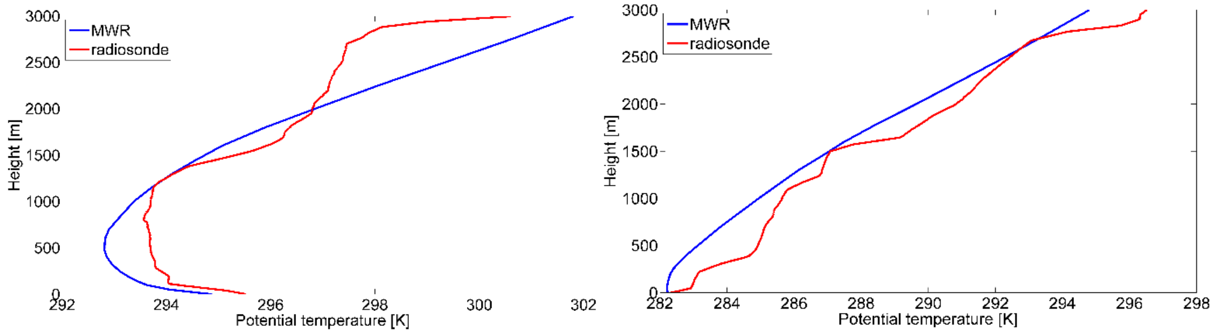
2) Stable Boundary Layer (SBL)

   The shallow SBL develops near the surface under non-turbulent conditions in the absence of convection- or wind- driven mixing processes.

3) Intermittently turbulent boundary layer

   The intermittent turbulent boundary layer consists of periods of turbulent mixing and stable conditions, which may be driven by synoptic conditions or the presence of local circulations such as low-level jets or coastal breezes.

The mixed layer can be determined by direct measurements of the turbulent mixing by WL, or inferred from gradients of the aerosol backscatter, temperature and humidity profiles. The WL uses the variation in the vertical wind (can also use variation in radial winds from scanning data) to determine the presence of turbulent mixing, from which the dissipation rate of turbulent kinetic energy can also be derived. The profile of atmospheric stability can be determined from the MWR, through the retrieval of the potential temperature profile. Negative gradients indicate instability. Examining the vertical profiles of horizontal wind and potential temperature profile together, can then be used to determine whether wind shear or convection (or both) processes are responsible for the mixing, especially useful in the NBL

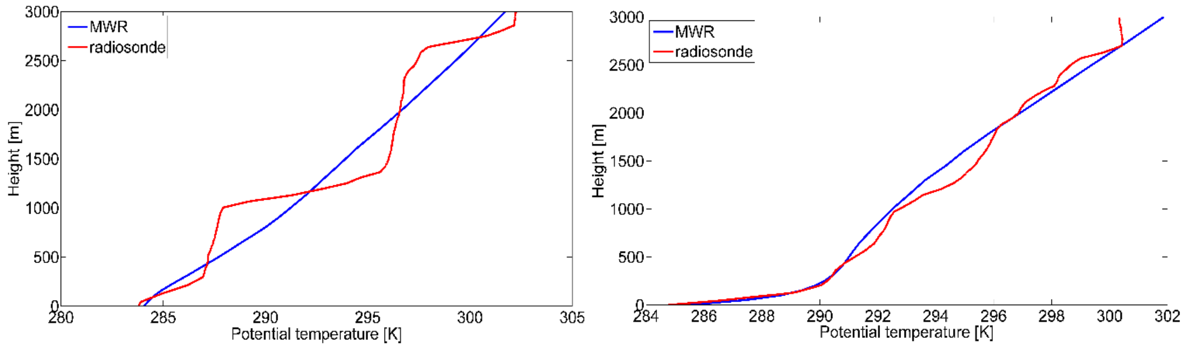


(a) (b)

Figure1. Comparison of MWR and radiosonde temperature profiles under convective-driven mixing conditions at Jülich, Germany. (a) Daytime mixing at 15:00 UTC on 24.04.2013 under clear-sky conditions. (b) Cloud-driven mixing at 23:00 UTC on 21.04.2013.

Figure 1 shows the potential temperature profiles retrieved from MWR and measured by radiosonde under turbulent clear-sky conditions (Fig. 1a) and under turbulent cloud-topped boundary layer conditions (Fig. 1b). With no additional information, the mixed layer would be assumed to be about 1.5 km in Fig. 1a from both MWR and radiosonde profiles; for Fig 1b, a mixed layer in contact with the surface of about 200 m deep would be diagnosed from the MWR and the radiosonde profile suggests that no surface mixed layer in contact with the surface is present.

A stable layer is assumed to be present when there is a strong positive gradient in the potential temperature profile. A stable surface layer can be then be detected by setting a threshold on the potential temperature gradient. This is straightforward for both MWR and radiosonde in the case shown in Fig. 2b, but is much clearer in the radiosonde under certain conditions (Fig, 2a) when it may not be possible to determine the top of the layer in the MWR profiles.



(a) (b)

Figure 2. Comparison of MWR and radiosonde temperature profiles under stable boundary layer conditions at Jülich, Germany. (a) Early morning stable conditions at 07:00 UTC on 24.04.2013. (b) Nighttime stable conditions at 23:00 UTC on 24.04.2013.

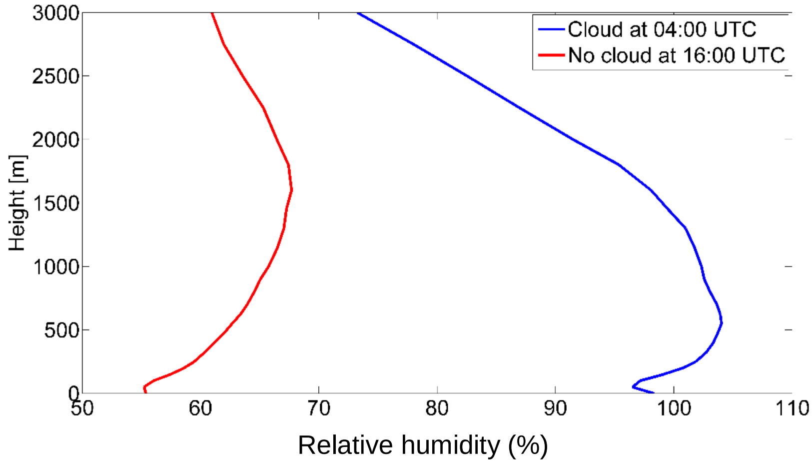


Figure 3. Comparison of MWR-retrieved relative humidity profiles under cloudy and clear-sky conditions from 21.04.2013, Jülich, Germany.

The presence of cloud can be detected by MWR from the measurement of liquid water path and the infrared brightness measurement. The cloud base height can be determined from both the infrared brightness measurement and inspecting the gradient in the retrieved relative humidity profile.

BL classification from MWR First, the gradients of potential temperature and relative humidity are calculated. Thresholds for gradient can then be used to determine the thermodynamic stability (from which it can be deduced whether mixing is likely to be present). The processing flowchart for boundary layer classification can be constructed as shown in Fig. 4.

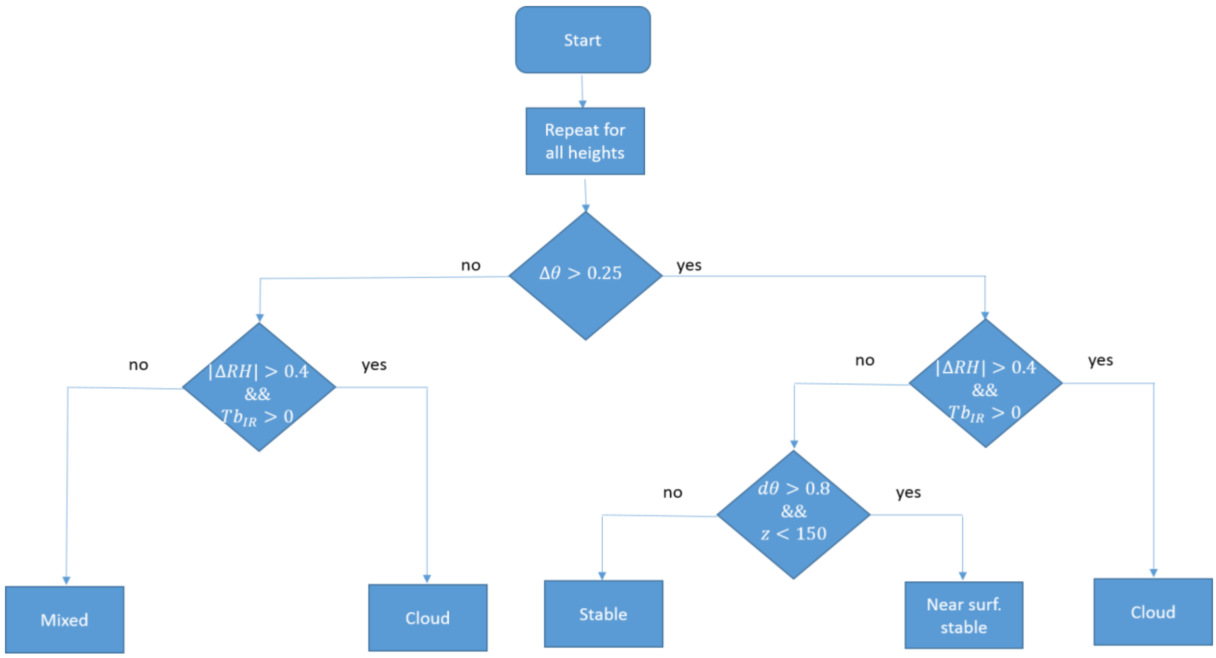


Figure 4. Flowchart for performing boundary layer classification from MWR.

Results or Achievements

Three test cases were considered for analysis purposes: a clear-sky day with typical boundary layer development; an early-morning cloud-topped boundary layer; and an daytime-evening cloud-topped boundary layer. All measurements were obtained from Jülich, Germany.

1) Clear-sky day: 24.04.2013

The top panel in Fig. 5 shows the mixing process as seen by the Doppler wind lidar using the vertical Doppler velocity variance and the retrieved mixed layer height. For reference purposes, the attenuated backscatter from the ceilometer is also shown in the second panel. The third panel shows the structure of the ABL as retrieved from MWR-quantities (potential temperature and humidity profiles from scanning, IWV, LWP and infrared brightness temperature from zenith pointing operation) using the flowchart presented in Fig. 4. MWR is able to identify the daytime and nighttime mixing layers as well as a nocturnal stable layer near the surface and a stable boundary layer. Figure 5 also shows the time series of IWV (fourth panel), LWP (fifth panel), and infrared brightness temperature measurements (sixth panel). The radiosonde launches at 0900, 1100, 1300, and 1500 UTC confirm the existence of a thermally unstable mixed layer during the day, similar to both MWR and WL retrieved mixing layers. The launches at 0700 and 2300 UTC shows a strong stable layer near the surface topped by a deeper weakly stable/neutral layer again consistent with the results obtained from MWR and DL.

2) Early morning cloud-topped boundary layer: 14.04.2013

The presence of a cloud at the top of the ABL during the early morning provides a source of turbulence that creates a mixing layer extending below the cloud to the surface resulting in a nocturnal mixed layer. The presence of this deep mixed layer is confirmed by the Doppler lidar turbulence retrieval in Fig. 6 (top panel). The presence of cloud can clearly be seen in the aerosol backscatter from the ceilometer (second panel). Using gradients of potential temperature and relative humidity as well as the magnitudes of LWP and the infrared brightness temperature, the structure of the boundary layer along with the existence of location of cloud retrieved from MWR data only (third panel) show similar features. Changes in MWR LWP and infrared brightness temperature correlate well with the existence of cloud in the boundary layer as seen in the ceilometer and Doppler lidar, and can be used to indicate the presence and approximate cloud base height for a stand-alone MWR algorithm. The presence of an elevated layer of mixing in the evening with a stable layer below is again shown by MWR, WL and radiosonde profiles

3) Daytime and evening cloud-topped boundary layer: 21.04.2013

The daytime and evening cloud-topped boundary layer case (Fig. 7) shows a much shallower mixed layer in contact with the surface (top panel, WL), presumably due to the reduced solar heating at the surface and lower sensible heat fluxes. There is also mixing associated with the cloud, clearly visible in the attenuated backscatter (second panel). The MWR clearly detects the existence of cloud in LWP (fifth panel) and infrared brightness temperature (sixth panel) but the thermodynamic profile retrievals are not so good in this case; the cloud is lower than observed and the MWR-retrieved ABL structure (third panel) does not agree as well with the WL as the first two cases. However, the MWR-retrieved ABL structure does suggest that there is a significant mixing layer in contact with the surface that continues late into the evening, with no stable layer near the surface. This is consistent with the features present in the WL Vertical Doppler velocity variance, which also shows a relatively deep mixing layer near the surface throughout the evening and into the night.

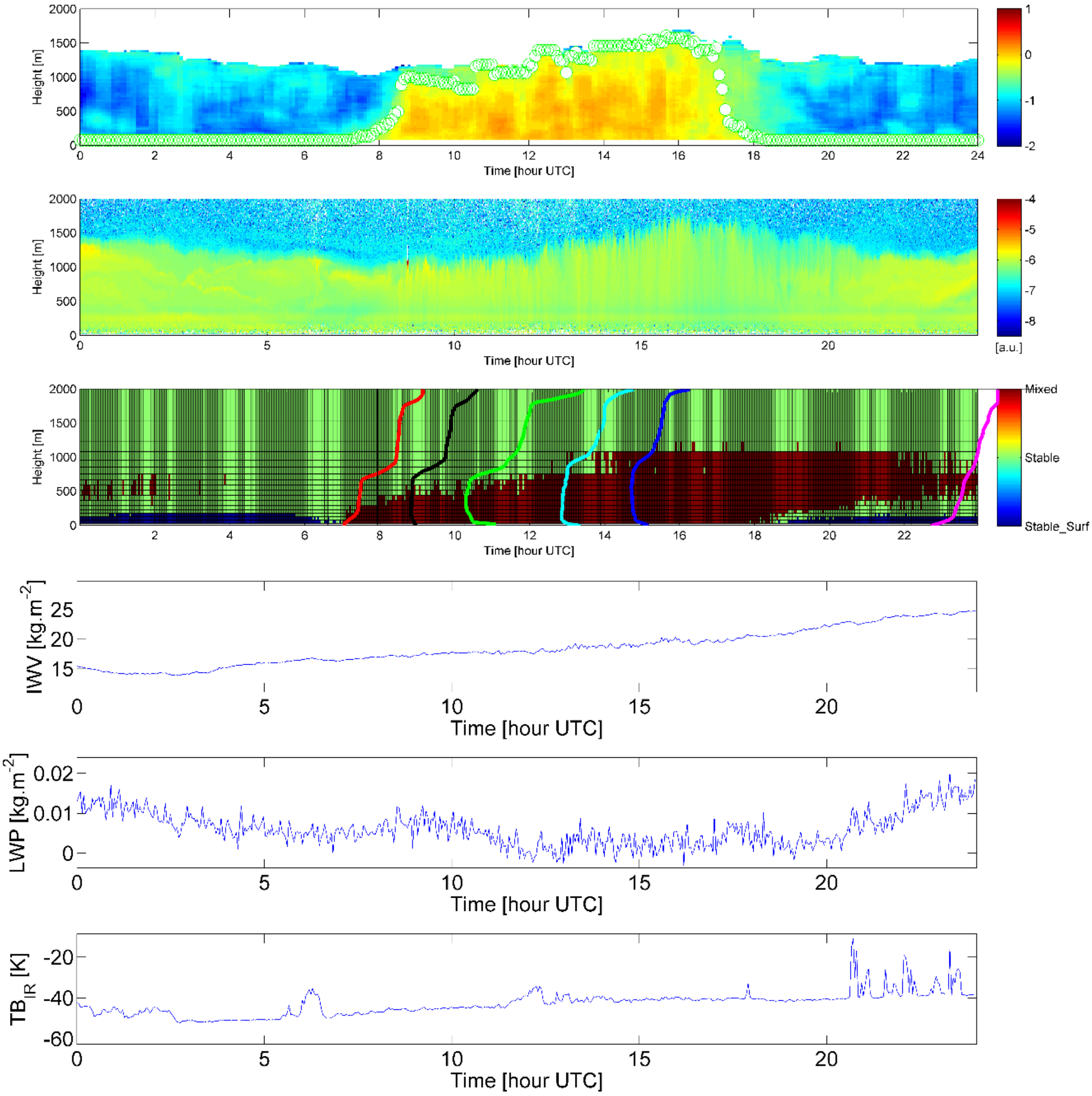


Figure 5. Clear-sky day. Top: Vertical Doppler velocity variance from Doppler wind lidar and retrieved mixing layer height. Second panel: Attenuated aerosol backscatter coefficient from Jenoptik CHM15k Nimbus ceilometer. Third panel: Boundary-layer classification from MWR-retrieved atmospheric quantities. Potential temperature profiles from radiosonde launches at 0700, 0900, 1100, 1300, 1500 and 2300 UTC are also super-imposed. Fourth panel: Integrated water vapour from MWR. Fifth panel: LWP from MWR. Sixth panel: Infrared brightness temperature measurements from MWR. Measurements at Jülich, Germany on 24.04.2013.

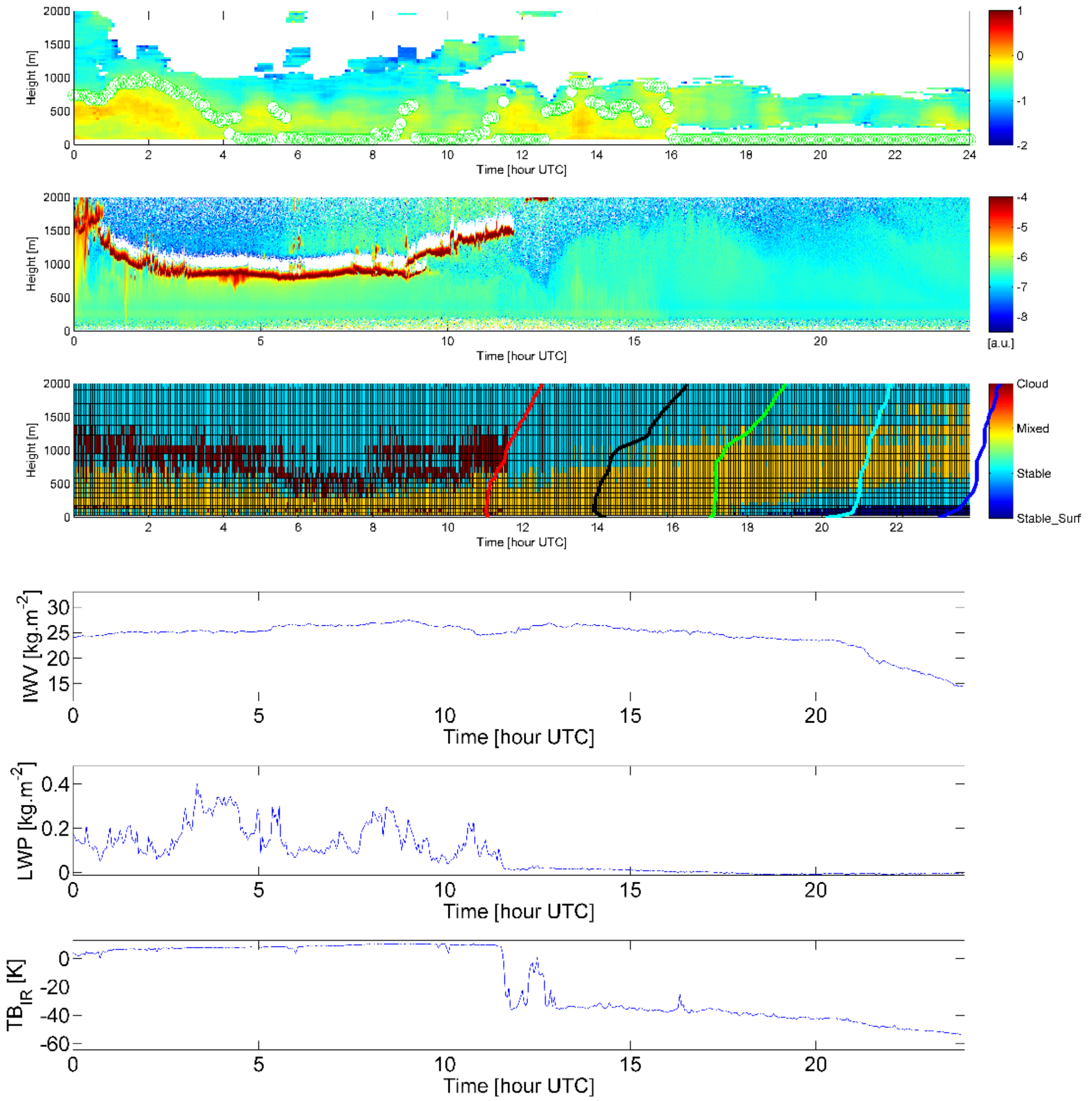


Figure 6. Cloud-topped boundary layer in morning. Same panels as for Fig. 5. Measurements at Jülich, Germany on 14.04.2013.

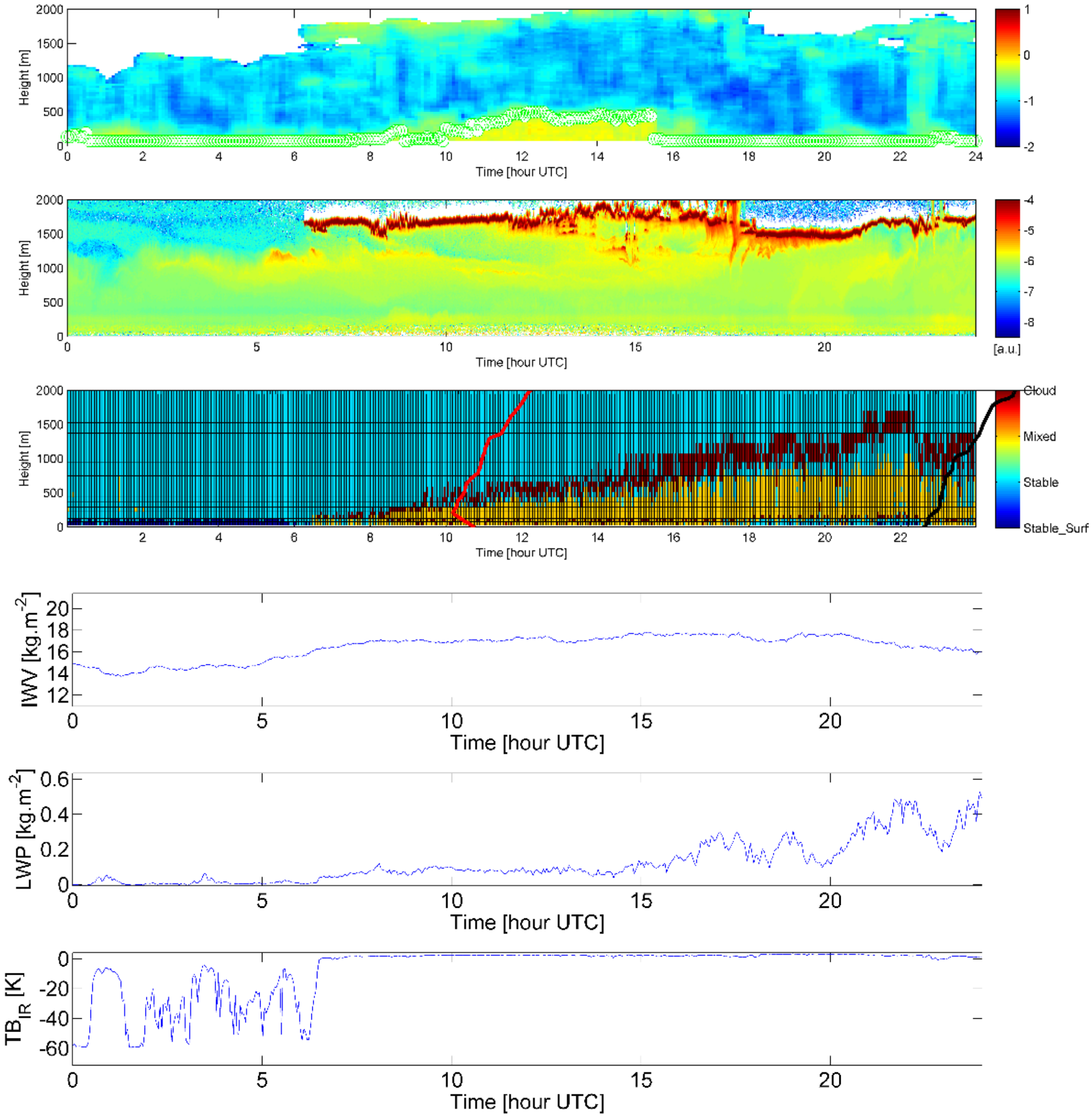


Figure 7. Cloud-topped boundary layer during the day and evening. Same panels as for Fig. 5. Measurements at Jülich, Germany on 21.04.2013.

Conclusions and Future Work

- Doppler lidar provides direct measurements of turbulence driven mixing and, thus, can be used as a good reference for studies of the mixed layer. However, it is limited when attempting to detect very stable conditions, and may not always pinpoint the underlying source of mixing.
- MWR provides the thermodynamic profile of the atmosphere (temperature and humidity) and, hence, information on the profile of atmospheric stability, and the existence of clouds.
- Using thresholds for the gradients of potential temperature and relative humidity profiles, LWP and infrared brightness temperature values, enables the structure of the ABL to be retrieved from MWR.
- Three test cases, one clear-sky and two with cloud-topped boundary layer (early morning and daytime-evening), were considered for analysis.
- The two instruments, WL and MWR, provide complementary information, and their combination yields a clearer picture of the boundary layer.
- The *a-priori* information about the existence of clouds, and associated turbulent mixing as seen with Doppler lidar, could be used directly in the retrieval of MWR temperature and humidity profiles.
- This instrument combination could also aid the investigation of the increase in aerosol backscatter with relative humidity (due to hygroscopic growth).

References

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Confirmation by the host institution of the successful execution

The host institution confirms the successful execution of this STSM

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