SCIENTIFIC REPORT

ACTION: ES1303 TOPROF
STSM: COST-STSM-ES1303-33492
TOPIC: A physical retrieval of mixing-layer height using simulated brightness temperature measurements
VENUE: Cologne, Germany
PERIOD: 21 March-25 March, 2016

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Submission date: 19.04.2016

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COST is supported by
the EU Framework Programme
Horizon 2020

Introduction

Mixing-layer height (MLH) is an important parameter for a range of applications including weather forecasting, air-quality and chemical-dispersion models, aviation, and meteorology. While there are several instruments and methods for MLH estimation, temperature-derived MLH is physically consistent and closely linked to the true thermodynamic state of the atmosphere.

Ground-based microwave radiometer (MWR) provides continuous monitoring of the atmospheric boundary-layer by measuring the brightness temperature at several frequencies and elevation angles. However, measurements at several channels are correlated and, therefore, the Degree-of-Freedom (DOF) of the data becomes quite low (≈4 for typical boundary-layer profiling configurations) [Lohnert, 2012]. As a result, MWR-derived physical temperature profiles have coarse vertical resolution and MLH estimates from them suffer from high uncertainties.

In this work, we aim to retrieve MLH directly from brightness measurements without the need to perform a temperature retrieval first. As a further proof of concept, the retrieved MLH is compared with the MLH obtained from the inverted potential temperature by using the “truth” brightness temperatures, hence allowing to study the impact of retrieval errors on the MLH estimates. Towards this end, the algorithm compares “truth” brightness temperatures to algorithm-generated ones by using a least-squares error-decision criterion. The “truth” brightness temperatures, which emulate the real atmosphere, are generated by using the Dutch Atmospheric Large Eddy Simulation (DALES) model [Heus, 2010; Neggers, 2012] as a test-bed. LES-generated vertical profiles of the atmospheric temperature, pressure, and water-vapor are first input to a forward model, thus, simulating brightness temperatures.

Algorithm-generated brightness temperatures are obtained from a “state vector” (i.e., the unknown to be solved) parameterizing model temperature along with known pressure and humidity profiles followed by a forward model. The key parameter of the “state vector” is the MLH. The parameterization of the input temperature profile effectively allows to reduce the degrees of freedom of the retrieval problem. The algorithm converges under a least-squares-error criterion that minimizes the error function between the LES-simulated and the algorithm-generated brightness temperatures.

Since the MLH is the key component of the state-vector being solved, the proposed algorithm does not need to carry out the classic two-step procedure in which: (i) physical temperature profiles are inverted from brightness temperatures and, (ii) the MLH is estimated from the retrieved temperature profiles (parcel method). As a result, the proposed algorithm is free from brightness-to-physical temperature retrieval errors associated to classic MLH-estimation methods relying on step (i). The proposed approach is expected to provide MLH estimates with better accuracy and low uncertainty. Finally, real measurements from a Humidity and Temperature Profiler (HATPRO) MWR collected during the $\mathrm{HD(CP)}^2$ Observational Prototype Experiment (HOPE) campaign at Jülich, Germany is used to test the proposed method. Doppler wind lidar along with radiosonde (whenever available) data is used as a reference or truth.

Problem formulation

MLH from MWR-retrieved temperature data using parcel method

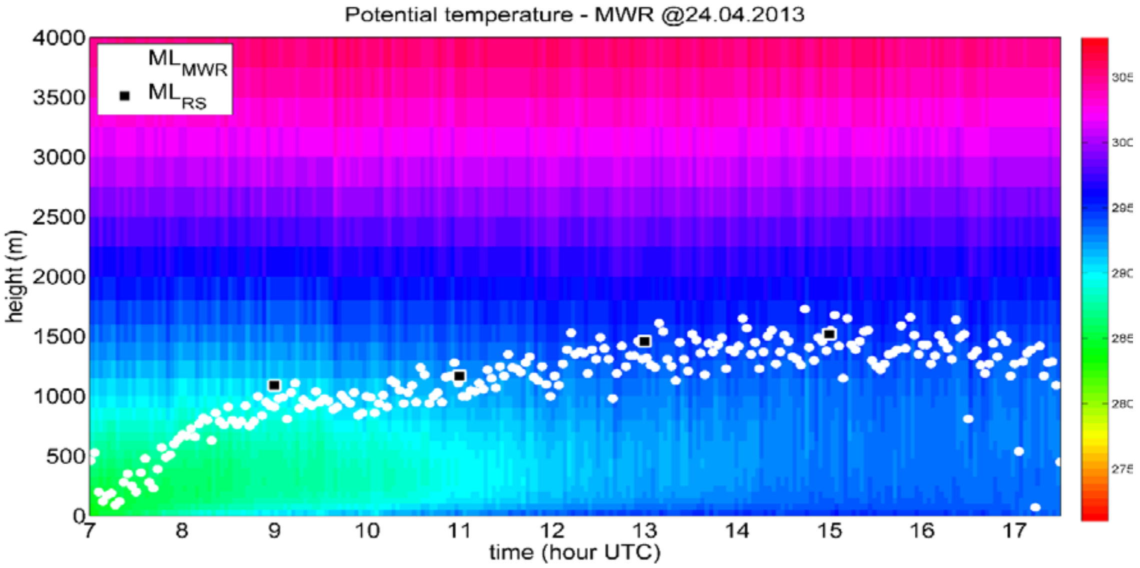


Fig. 1: MLH as determined by parcel method applied on MWR-retrieved potential temperature.

The parcel method works as follows:

For a given surface temperature value of θ_s, MLH is the height at which

$$\theta(z) \geq \theta_s.$$

However, the MLH estimate determined by parcel method is sensitive to surface value of the temperature and provides no information on associated uncertainties/errors.

Uncertainty MLH from retrieved temperature data

The uncertainty associated to the MLH estimates has two underlying error sources:

(i) The instrumental uncertainty due to the TB measurements, $z_{MWR,meas}(z)$

- consequent propagated errors on the retrieved temperature profile [Crewell and Löhnert, 2007]

(ii) The uncertainty due to the coarse vertical resolution of the retrieved potential temperature profiles, $z_{MWR,ret}(z)$.

- a consequence of the low DoF in the measurement data [Löhnert and Maier, 2012]

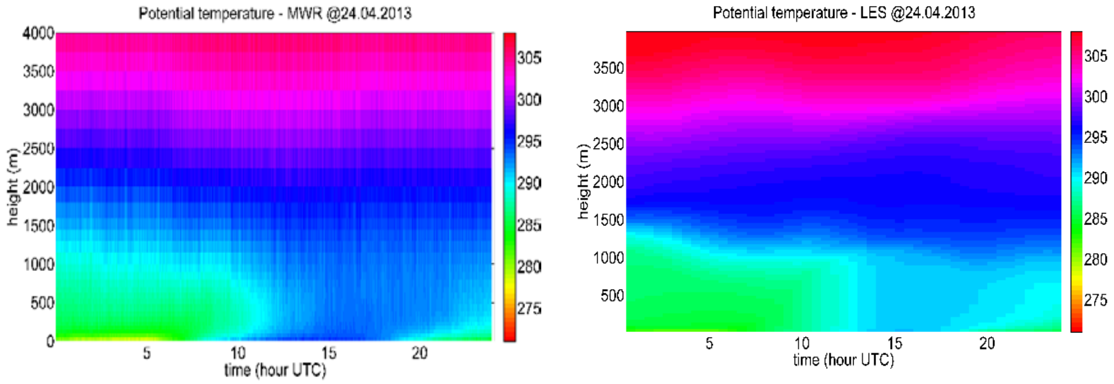


Fig. 2: Qualitative comparison of MWR-retrieved potential temperature (left) and LES-simulated potential temperature (right).

There is no way to avoid (i). Therefore, in order to test our method without the influence of instrumental measurement error, we use LES-simulated data. For this purpose, Dutch Atmospheric Large-Eddy Simulation (DALES) model is used. By generating the simulated profiles of atmospheric variables such as the temperature, the pressure, the humidity etc., DALES provides a virtual laboratory to test algorithms without the shortcomings of instruments. Moreover, the impact of retrieval errors on the estimated MLH can also be studied, since reference is available.

In order to tackle (ii), a scheme for direct retrieval of MLH without the need to perform temperature retrieval first is proposed.

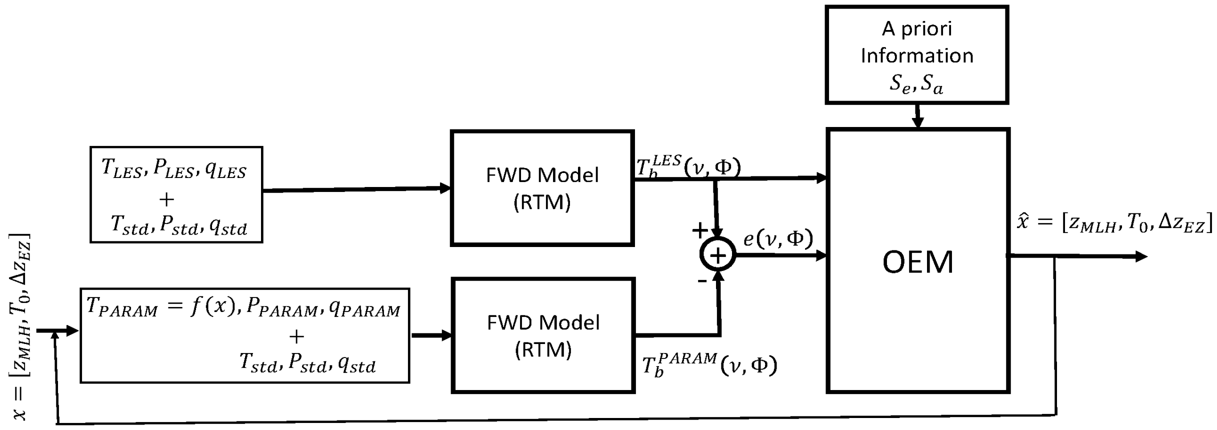


Fig. 3: Block diagram of the proposed direct MLH retrieval scheme.

Parameterization of temperature profile

In order to reduce the degree-of-freedom of the MLH retrieval problem, the atmospheric temperature profile is parameterized in terms of the MLH, z_{MLH}, the surface temperature at ground level, T_0, and the width of the entrainment zone at the top of the mixing layer, Δz_{EZ}.

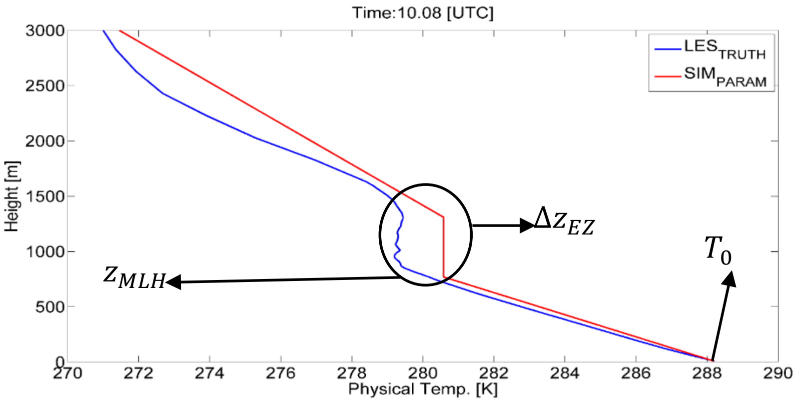


Fig. 4: Parameterization of atmospheric temperature profile.

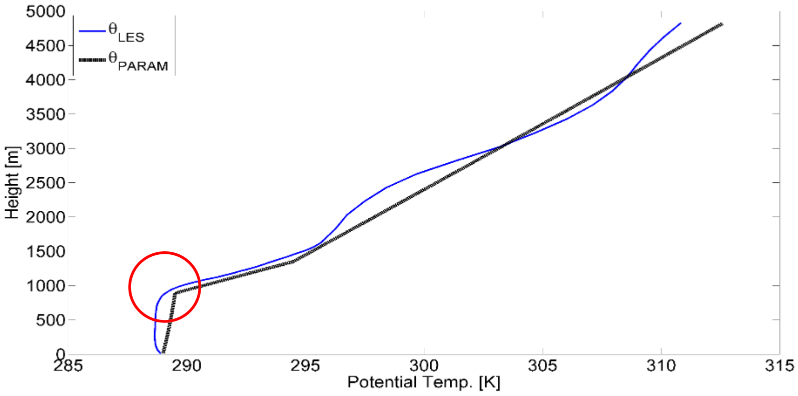


Fig. 5: Comparison of the LES-simulated and parameterized potential temperature profiles.

Optimal estimation method (OEM) for state-vector estimation

$$x_{i+1} = x_i + (K_i^T S_e^{-1} K_i)^{-1} \times [K_i^T S_e^{-1}(y - y_i) + S_a^{-1}(x_a - x_i)]$$

- **State vector, x**

$$x = [z_{MLH}, T_o, \Delta z_{EZ}]$$

Mixing layer height, z_{MLH}

Surface temperature, T_0

Width of entrainment zone, Δz_{EZ}

- **Measurements, y**

  LES simulated brightness temperature at several frequencies

  and elevation angles, $T_B(\nu, \phi)$

- ***A priori* information**

  Measurement covariance matrix, S_e

  State-vector covariance matrix, S_a

Results

The OEM provides the optimal estimates of state-vector parameters at each time instant. As a first test of the performance of the proposed approach, the brightness temperatures obtained by LES- simulated atmosphere, T_b^{LES}, and the brightness temperatures obtained by the estimated state-vector, T_b^{PARAM}, are compared at different channels.

1) $\nu = 51.26$ [GHz], $\phi = 90^o$

This is the most transparent channel and hence extends higher up in the atmosphere. As a result, the effect of parametric approximation becomes significant enough resulting in more than 4 [K] of difference.

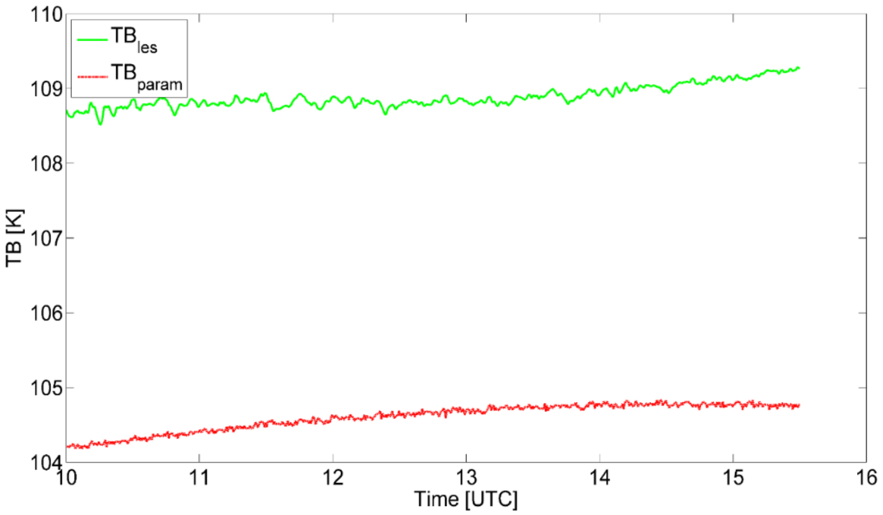


Fig. 6: Brightness measurements based on LES-simulated atmosphere and parametric state-vector at zenith angle and frequency of 51.26 [GHz].

2) $\nu = 54.94$ [GHz], $\phi = 90^o$

As the frequency of measurement becomes closer to the center of the band (60 [GHz]), the difference of LES based brightness measurements and parametric brightness measurements becomes lower (≈ 0.5 [K]).

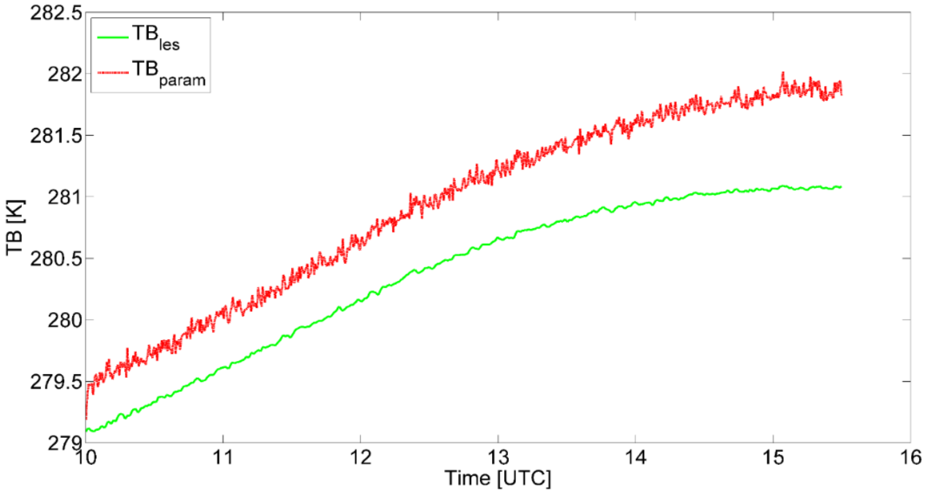


Fig. 7: Brightness measurements based on LES-simulated atmosphere and parametric state-vector at zenith angle and frequency of 54.94 [GHz].

3) $\nu = 58$ [GHz], $\phi = 90^o$

The difference keeps on decreasing as we go closer to the center of the band.

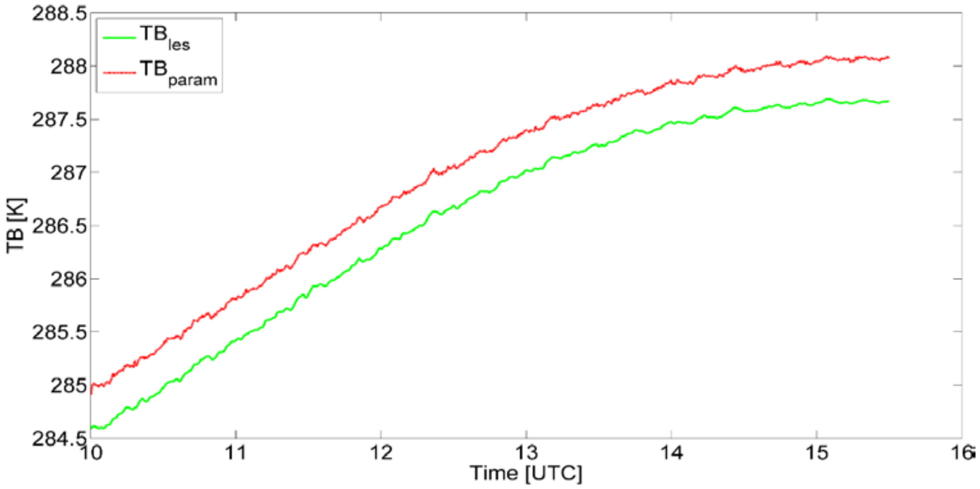


Fig. 8: Brightness measurements based on LES-simulated atmosphere and parametric state-vector at zenith angle and frequency of 58 [GHz].

4) **$\nu = 54.94$ [GHz], $\phi = 10.2^o$**

The difference of brightness temperatures from LES and parametric atmospheres profiles decreases with lower elevation angles as the extent of atmosphere contributing to the brightness measurements comes from lower heights.

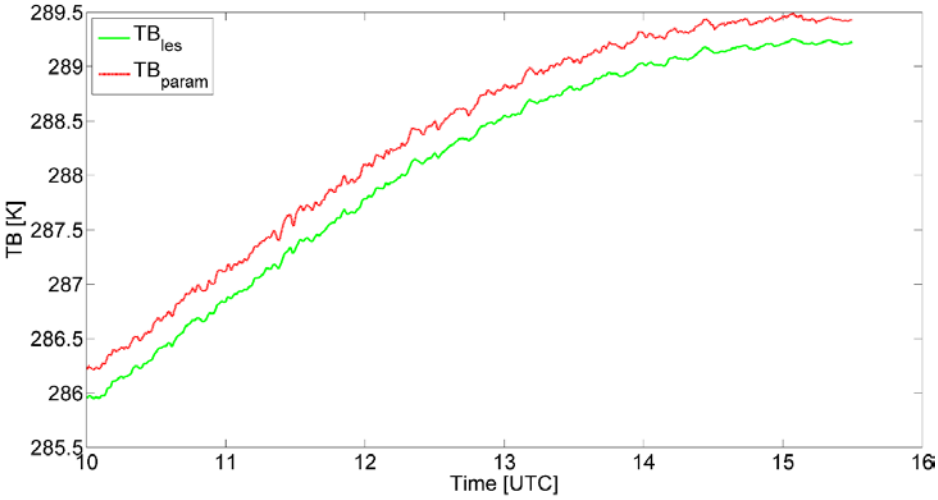


Fig. 9: Brightness measurements based on LES-simulated atmosphere and parametric state-vector at angle 10.2 [deg] and frequency of 54.94 [GHz].

5) $\nu = 58$ **[GHz]**, $\phi = 5.4^o$

Finally, the most opaque channel with the highest frequency and the lowest elevation angle results in the minimum difference between the LES and parametric based brightness measurements.

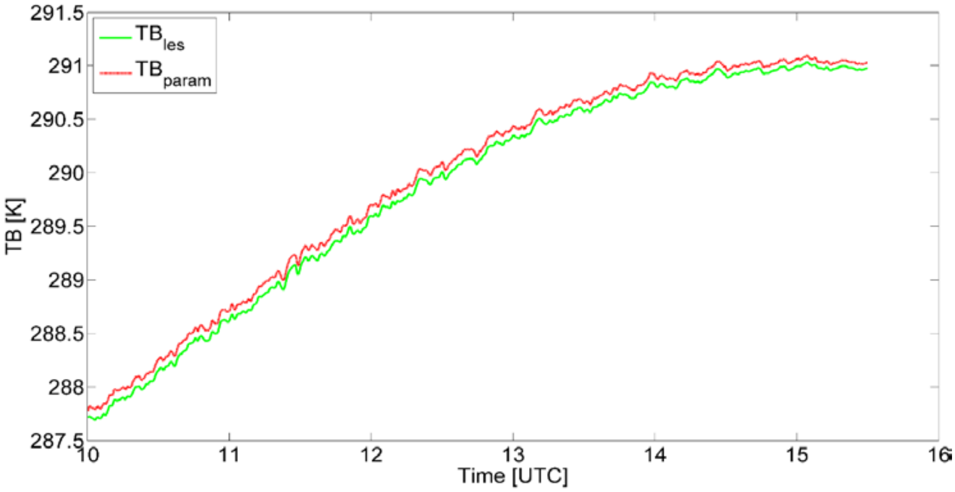
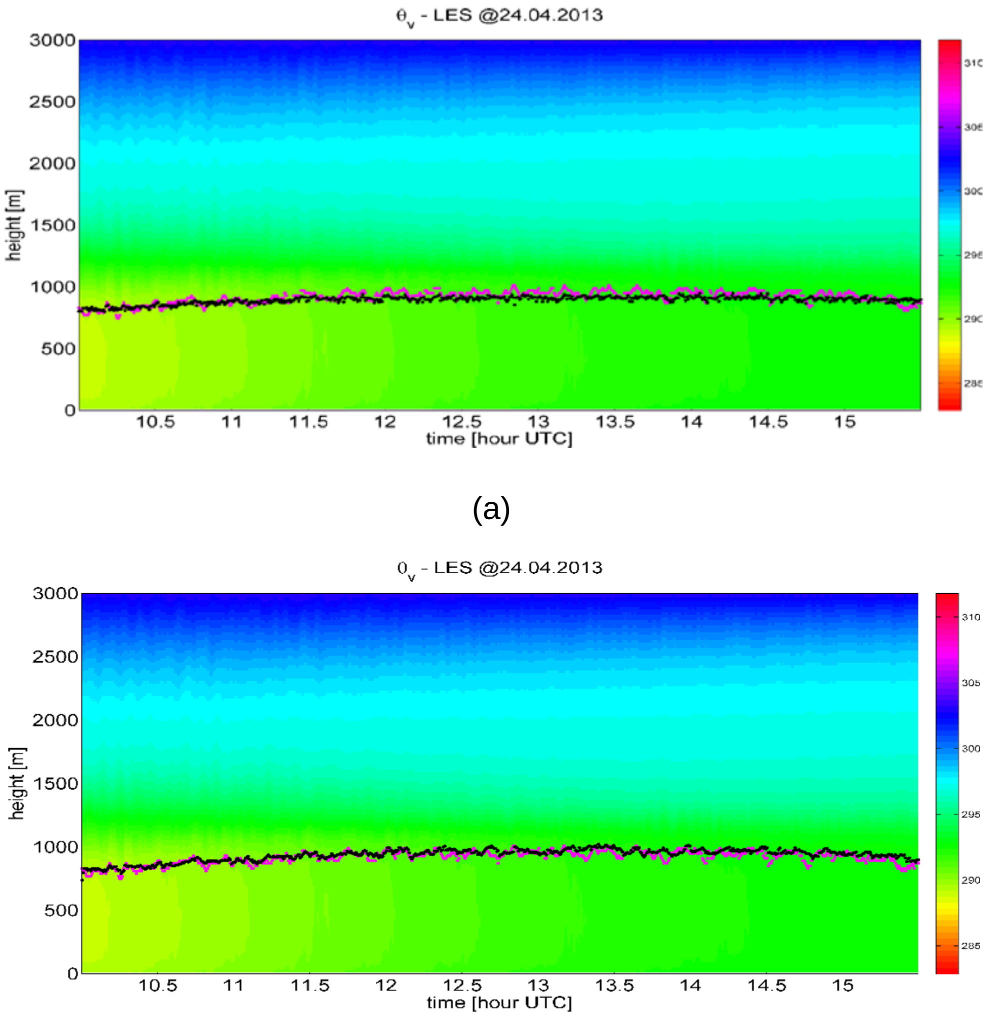


Fig. 10: Brightness measurements based on LES-simulated atmosphere and parametric state-vector at angle 5.4 [deg] and frequency of 58 [GHz].

Comparison of MLH estimates

MLH estimates obtained by parcel method and direct retrieval method are compared using zenith-only measurements and 27 channels using the elevation angles as well.



(a)

(b)

Fig. 11: MLH from parcel method (magenta trace) and direct retrieval (black trace) (a) using zenith measurements, (b) using elevation measurements.

Resulting publication

The preliminary results shown in this report have been presented at the 14th Specialist Meeting on Microwave Radiometry and Remote Sensing of the Environment (MicroRad 2016) which took place on April 11-14, 2016, at Aalto University Campus, Espoo, Finland. It is expected that these results will result in a journal article when the approach is validated on more test cases.

References

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