Boundary Layer Classification from Doppler Lidar & Microwave Radiometer and its Applications within ACTRIS

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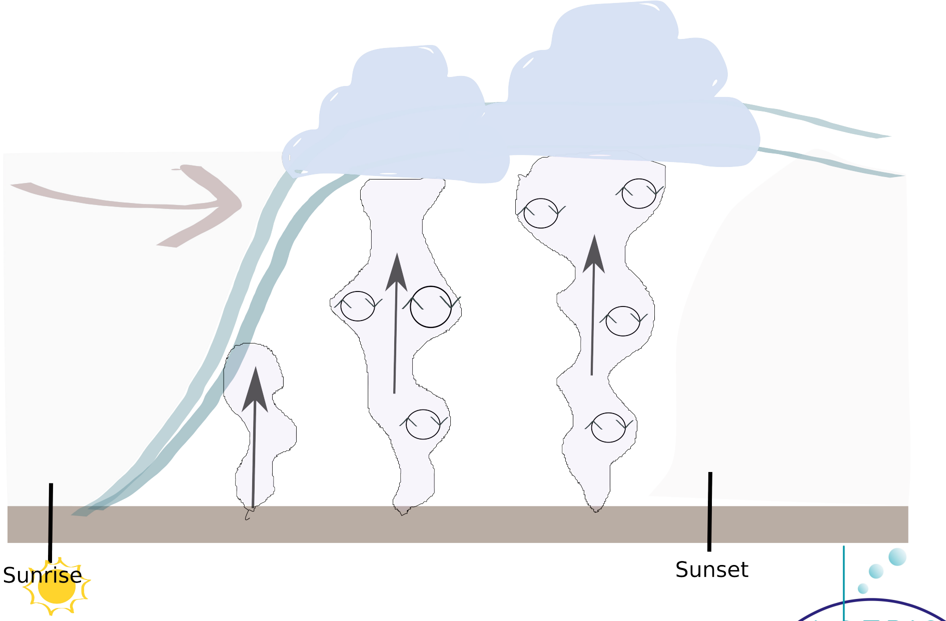
Characterizing ABL structure and evolution

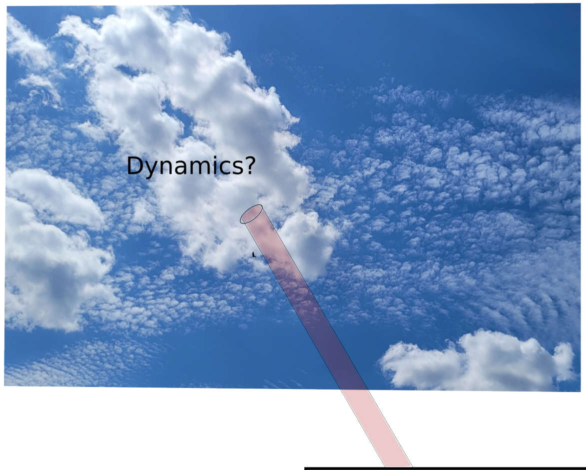
- ABL stability structure influences the formation of boundary layer clouds.
- ABL stability and mixing processes determine the dispersion of pollutants, therefore this characterization has air quality applications.
- A better knowledge of ABL processes is essential for improving the parametrization of these processes in numerical models.

ABL = Atmospheric Boundary Layer



Observing the cloudy ABL

- Essential for improving our physical understanding
- Best possible by means of continuous ground-based remote sensing using ACTRIS instrumentation



Instruments

(measuring continously)

MWR

Temp., LWP, IWV

Pyranometer

Radiation

Cloud Radar

Cloud microphysics

Ceilometer

Clouds, aerosols, ABL height

Doppler Lidar

Winds, turbulence

JOYCE: Jülich Observatory for Cloud Evolution

Cloud Remote Sensing at JOYCE has been operating for more than 10 years and is now ACTRIS National Facility.

JOYCE

CPEX-LAB

ACTRIS GERMANY

Universität zu Köln

Synergistic approach: Turbulence and stability

Doppler Wind Lidar

- Wind components (u, v, w) derived.
- Turbulent sources identified, e.g. surface vs. cloud driven

Microwave Radiometer (MWR)

- Temperature profiles derived.
- Evolution of the thermal stability.

Wind components from Doppler Wind Lidar

Backscatter β and statistical moments of the vertical velocity *w* allow to classify turbulent mixing in the ABL (Manninen et al. 2018).

Attenuated backscatter β

Height of the aerosol layer

Cloud detection

Requires sufficient amount of aerosols as tracer for air motion

Vertical velocity skewness

Source of turbulence (surface or cloud)

$$s = \frac{\overline{w'^3}}{\overline{w'^2}^{3/2}}$$

TKE dissipation rate ε

Identify turbulent regions

Derived from vertical velocity variance (O'Connor et al., 2010)

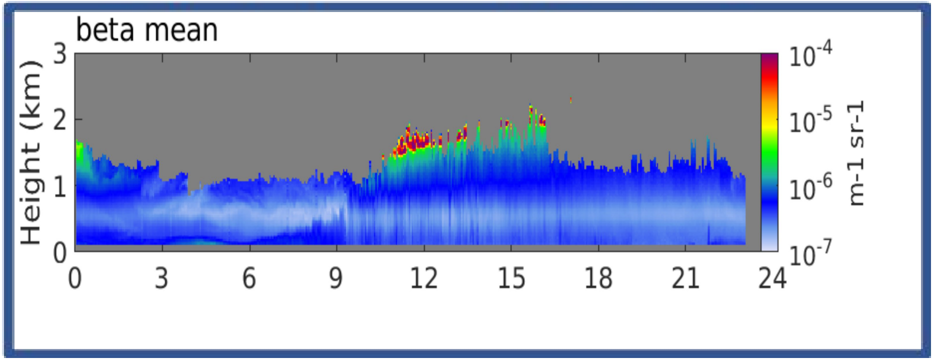
Vector wind shear

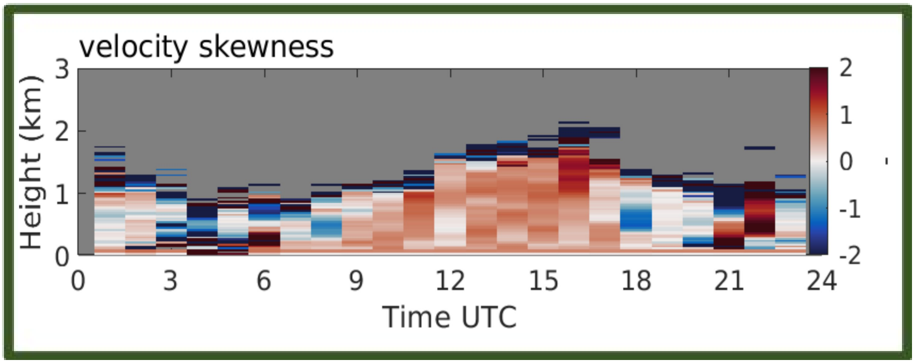
Indicates shear driven turbulence

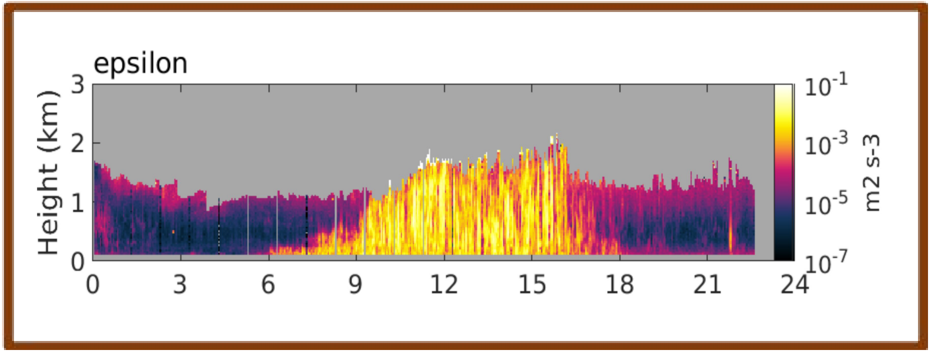
$$U_{shear} = \frac{\sqrt{\delta u^2 + \delta v^2}}{\delta z}$$

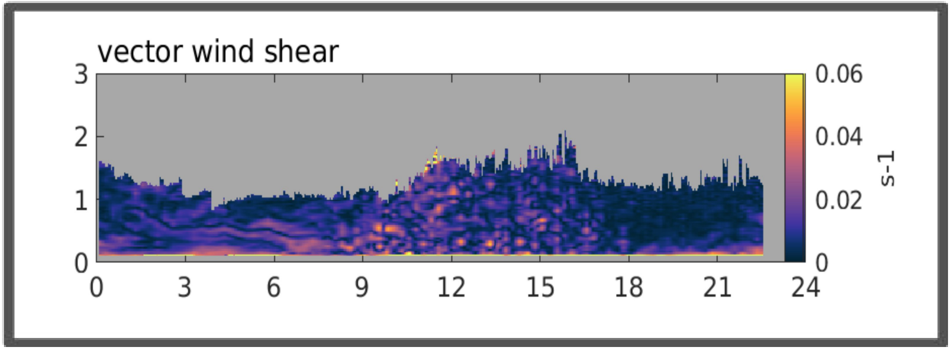
Wind components from Doppler Wind Lidar

Backscatter β and statistical moments of the vertical velocity w allow to classify turbulent mixing in the ABL (Manninen et al. 2018).

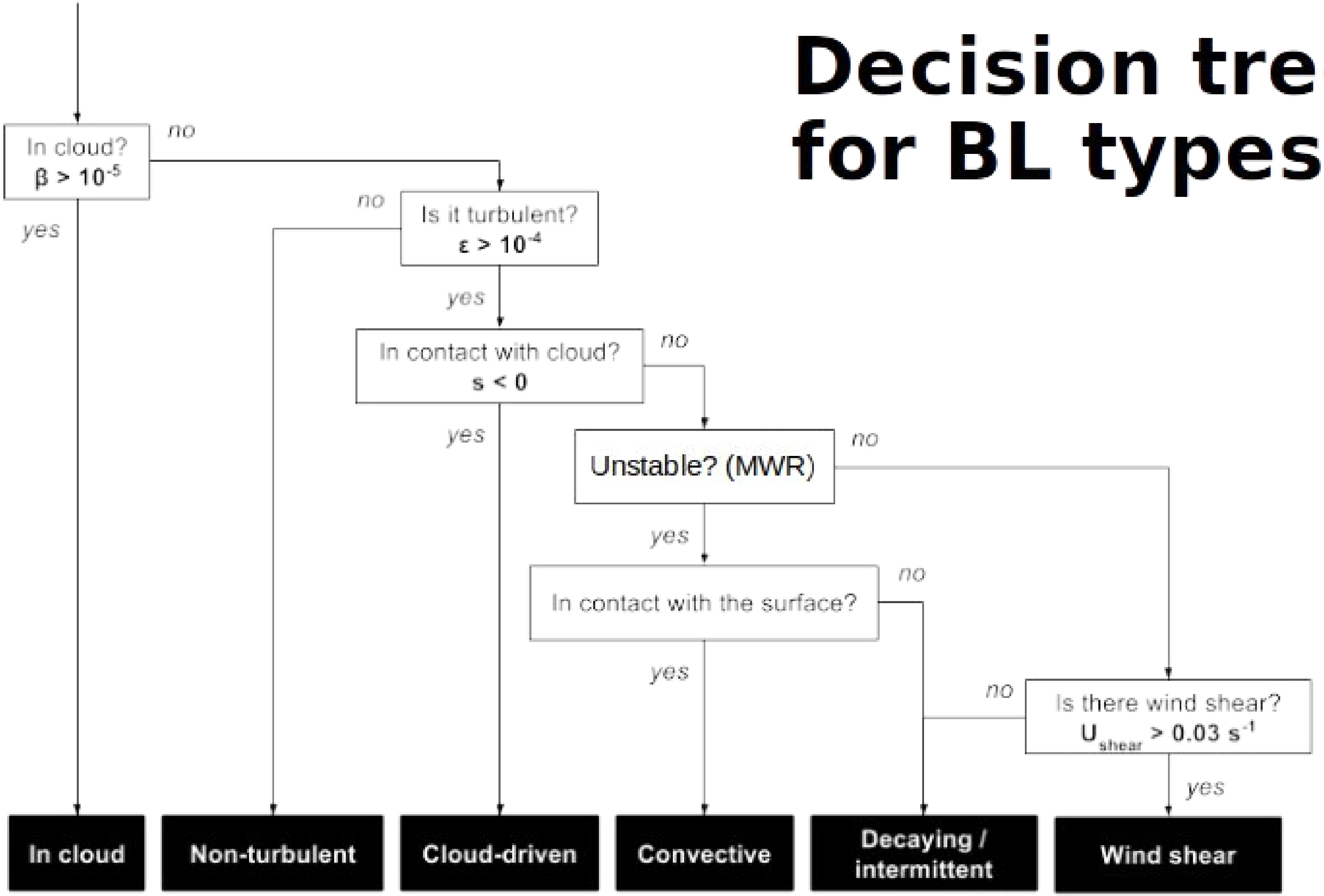








Decision tree for BL types



In cloud? $\beta > 10^{-5}$

no

yes

Is it turbulent? $\varepsilon > 10^{-4}$

no

yes

In contact with cloud? $s < 0$

no

yes

Unstable? (MWR)

no

yes

In contact with the surface?

no

yes

Is there wind shear? $U_{shear} > 0.03\ s^{-1}$

no

yes

In cloud

Non-turbulent

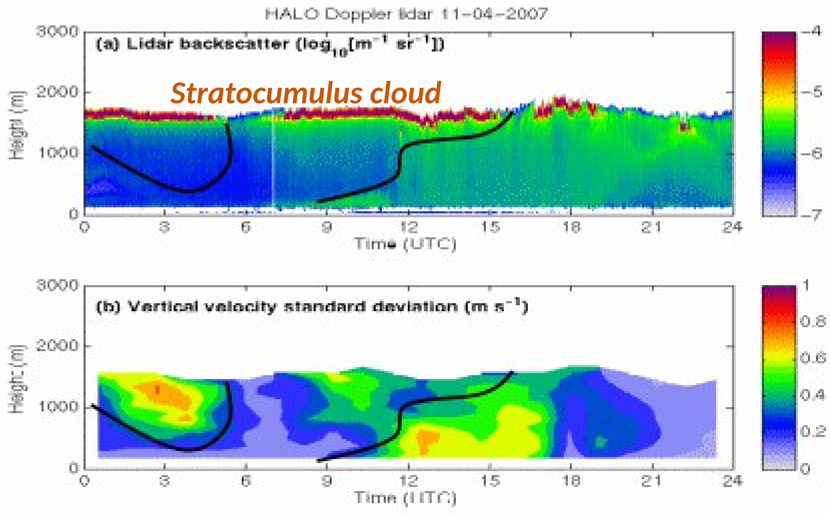
Cloud-driven

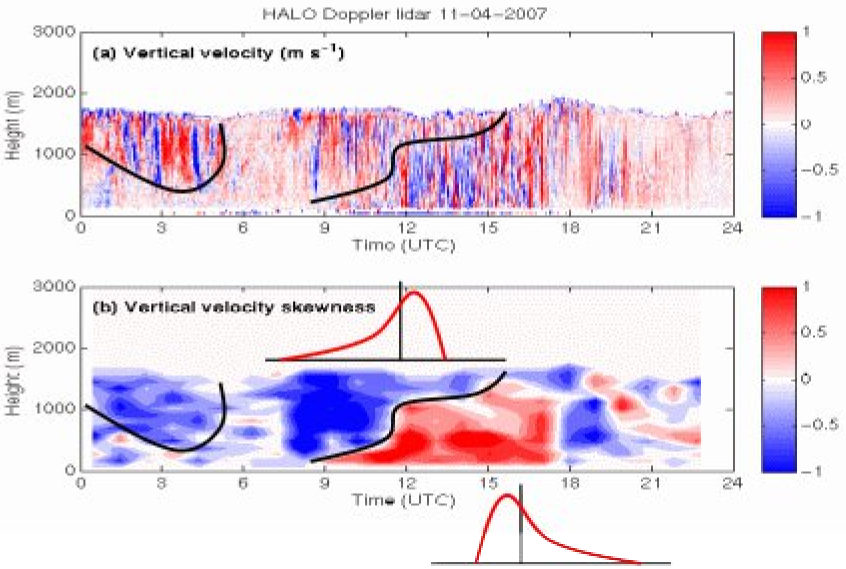
Convective

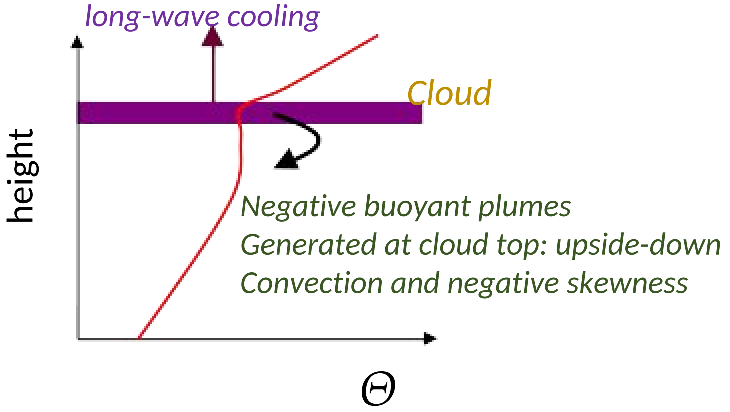
Decaying / intermittent

Wind shear

Skewness for identifying turbulent sources



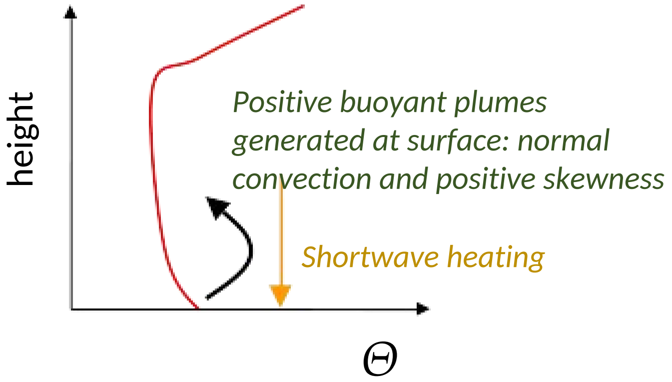




long-wave cooling

Cloud

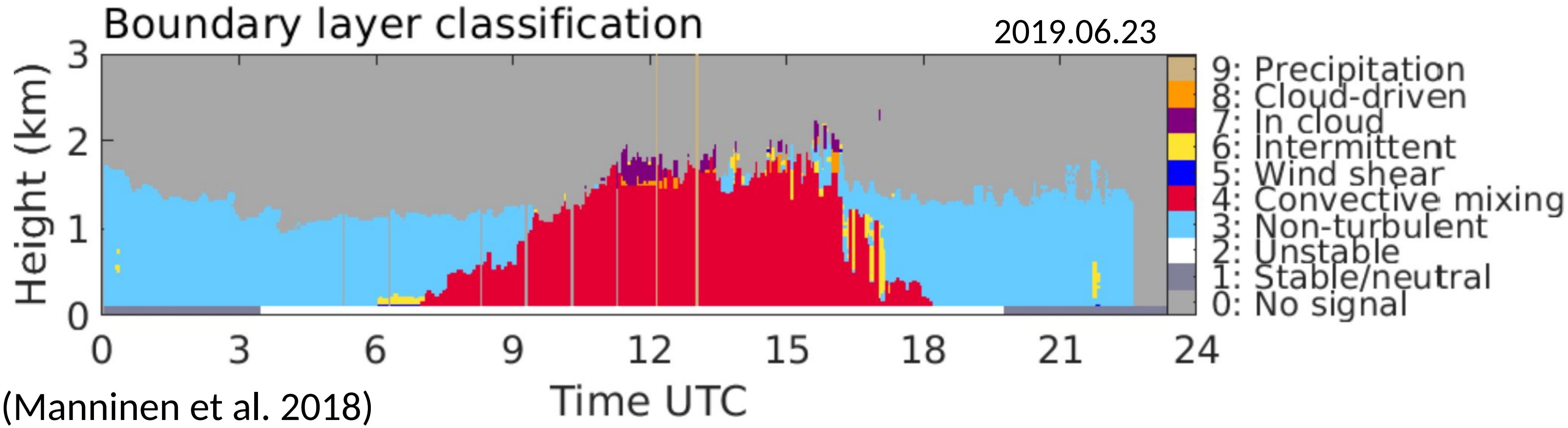
Negative buoyant plumes
Generated at cloud top: upside-down
Convection and negative skewness



Positive buoyant plumes
generated at surface: normal
convection and positive skewness

Shortwave heating

ABL classification

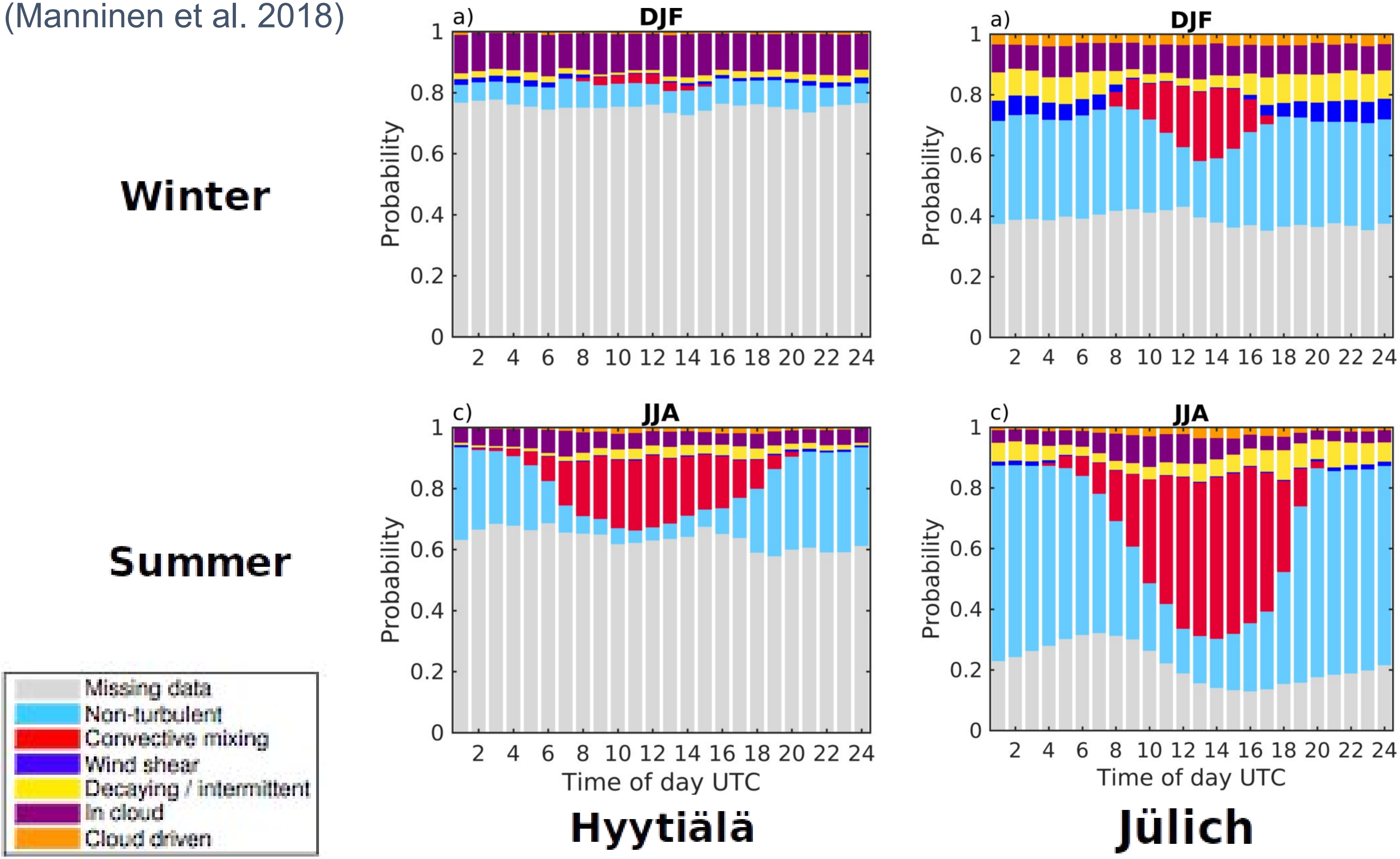


(Manninen et al. 2018)

- Identification of turbulent regions that are characterized through different turbulence origins.
- Better understand complex mixing processes and their evolution.

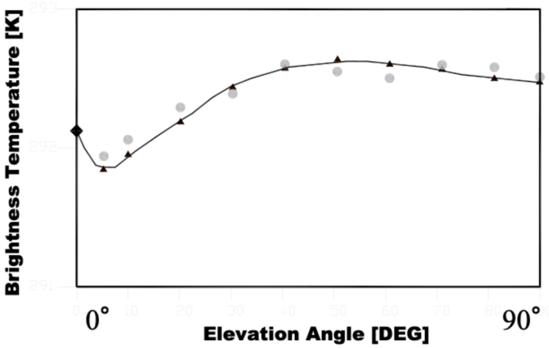
Statistics of ABL classification at different sites

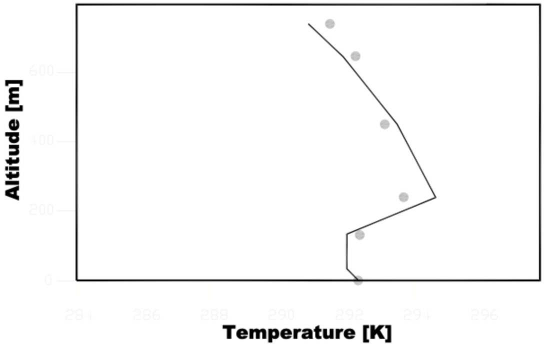
(Manninen et al. 2018)

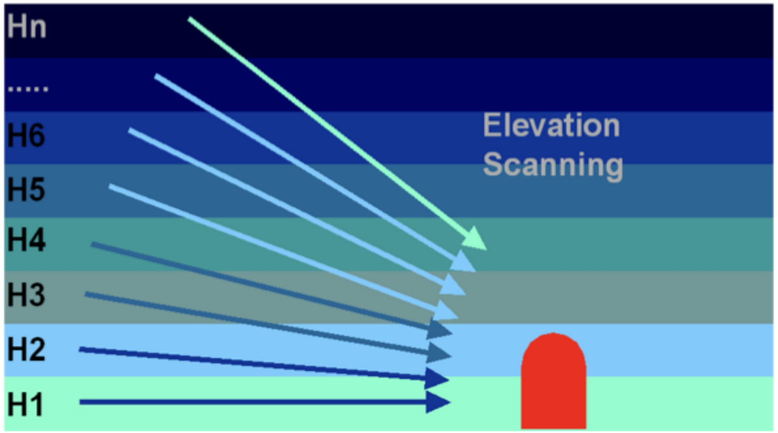


Thermal stability from microwave radiometer

- Brightness temperatures (T_b) are measured at 7 oxygen absorption channels and at 6 elevation angles.
- Temperature profile in the lower troposphere retrieved.

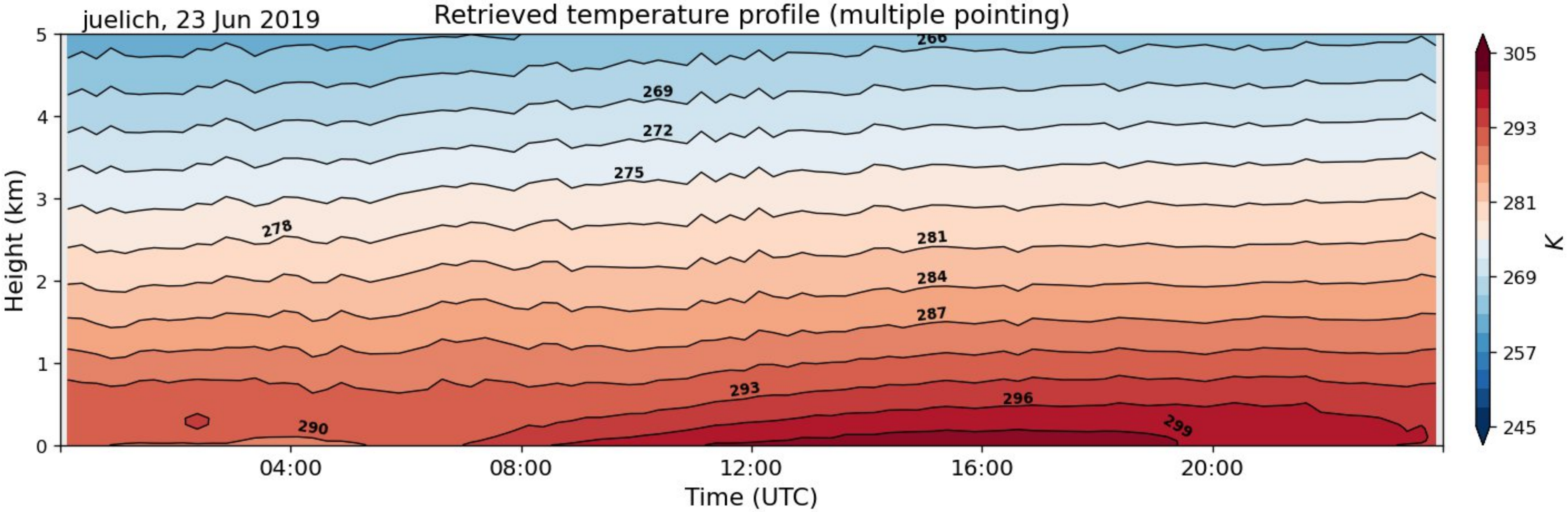




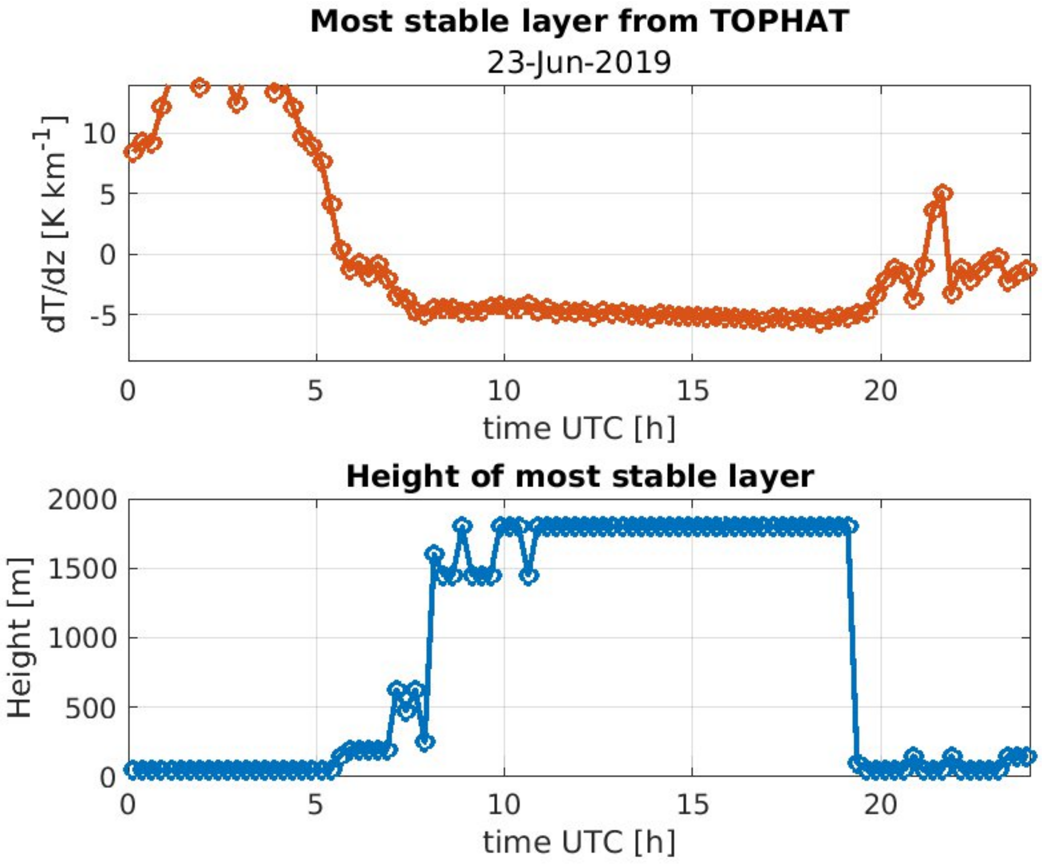


Thermal stability from microwave radiometer

- Temperature profiles are used for ABL stability characterization
- 4 profiles per hour, diurnal evolution of stability can be elucidated.



Diurnal evolution of the thermal stability



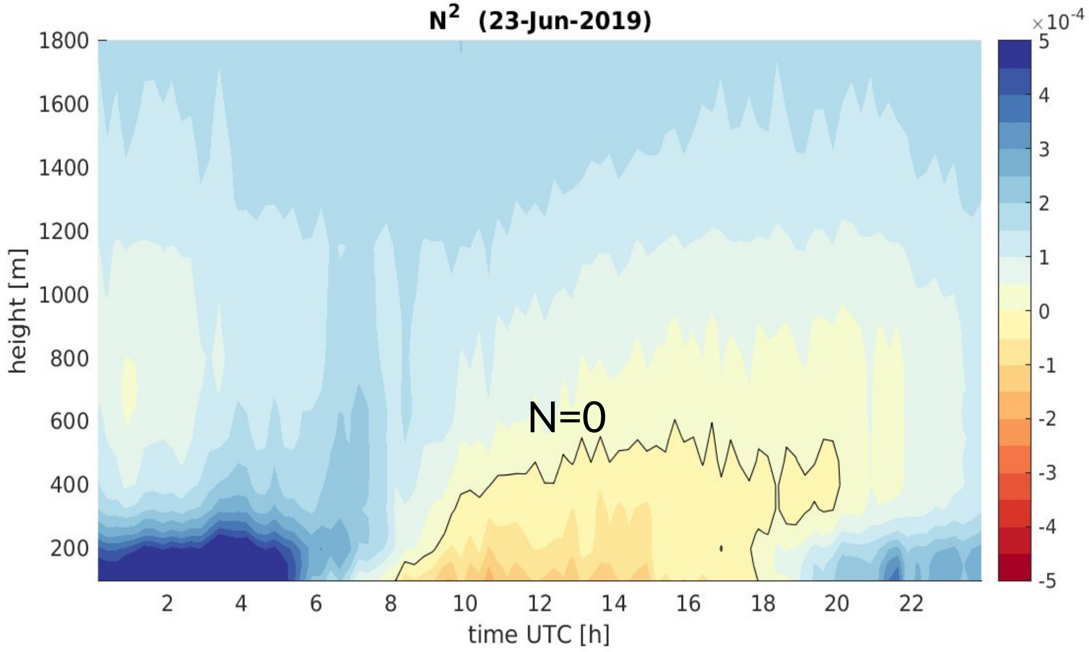
Most stable layer from TOPHAT

23-Jun-2019

Height of most stable layer

- The most stable layer and its height were estimated throughout the day.
- Strong thermal inversions are present during night-time, and they are dissolved with diurnal convection.

Diurnal evolution of the thermal stability structure



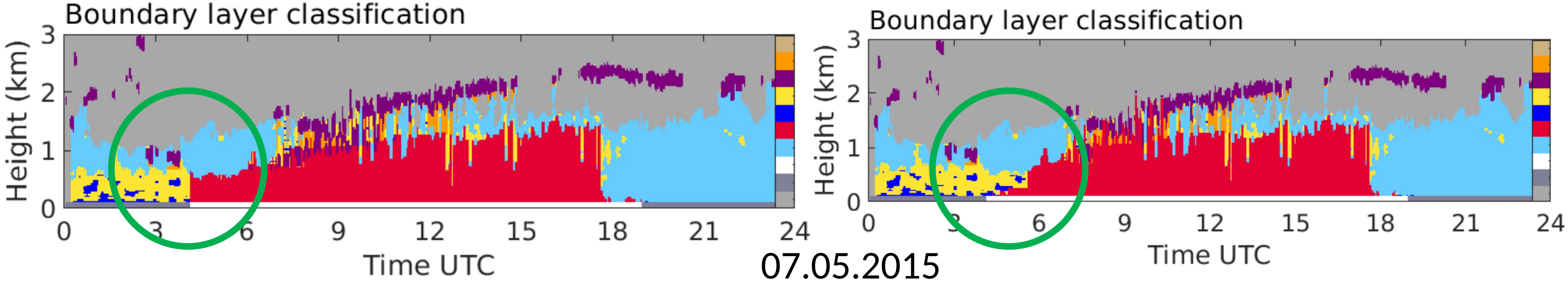
$$N^2 = \frac{g}{\theta}\frac{d\theta}{dz}$$

- $N^2 > 0 \rightarrow$ *statically stable*
- $N^2 = 0 \rightarrow$ *statically neutral*
- $N^2 < 0 \rightarrow$ *statically unstable*

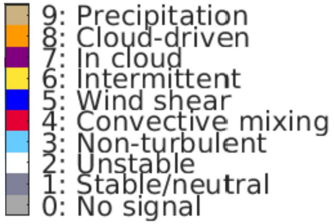
- The vertical thermal structure is investigated via the Brunt–Väisälä frequency (N^2).
- N^2 is a measure of the static stability of the environment.
- The evolution of the thermal stability is elucidated.

ABL classification updated with N^2

without N^2 **with N^2**



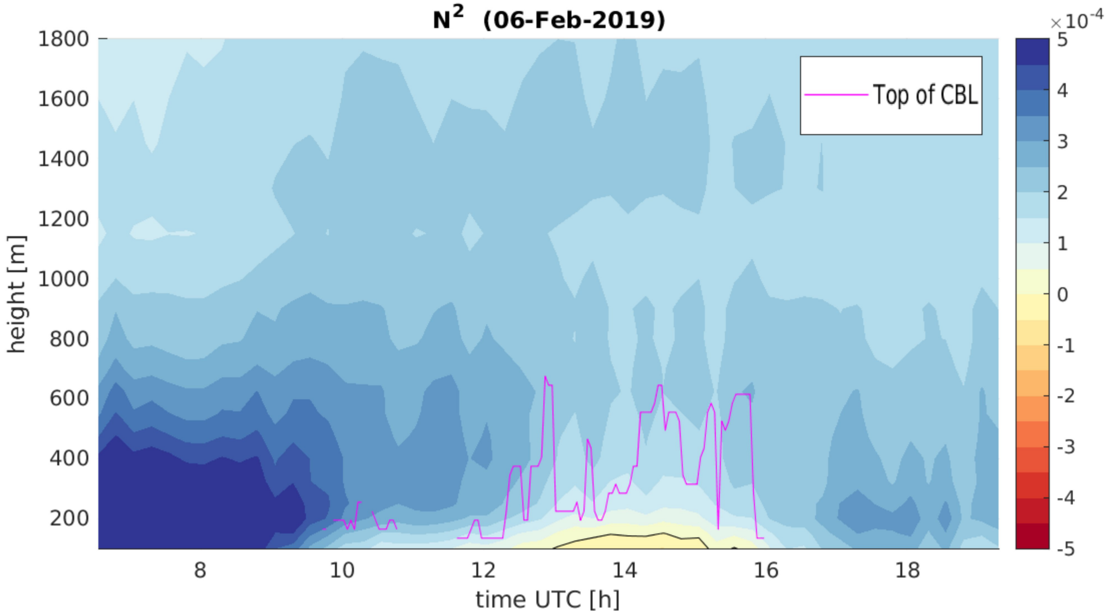
07.05.2015



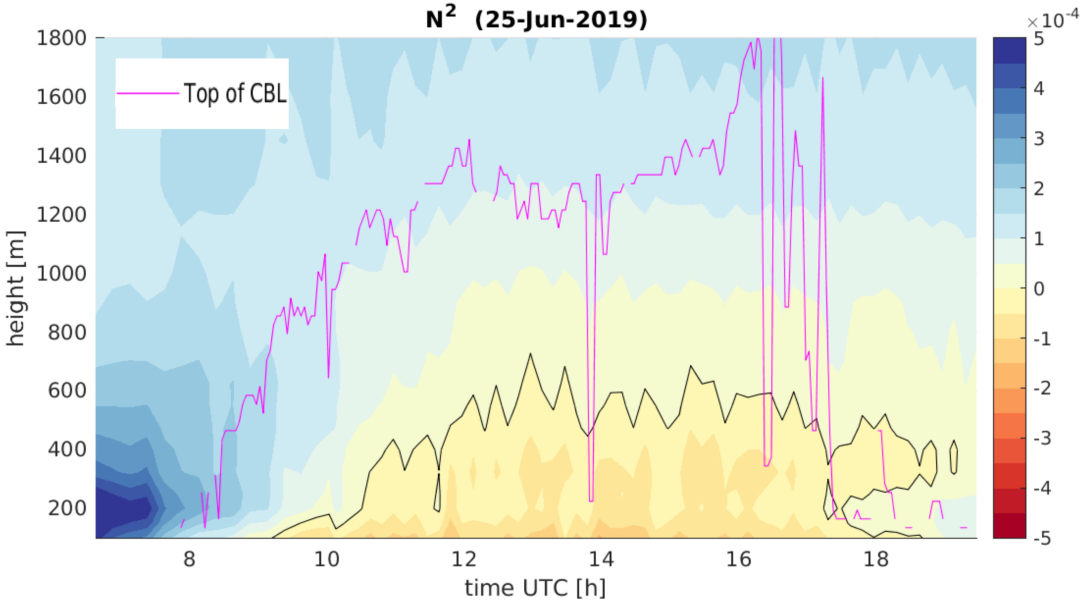
- Transitions from shear driven to convective turbulence are difficult to identify from Doppler lidar alone.
- Synergy with MWR helps to improve the classification using height resolved stability information (N^2).

Comparing convective layer height and $N^2 = 0$

Winter 2019

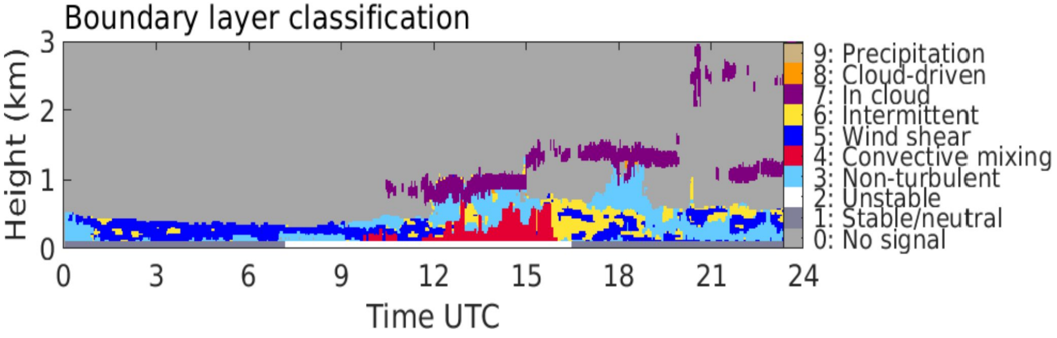


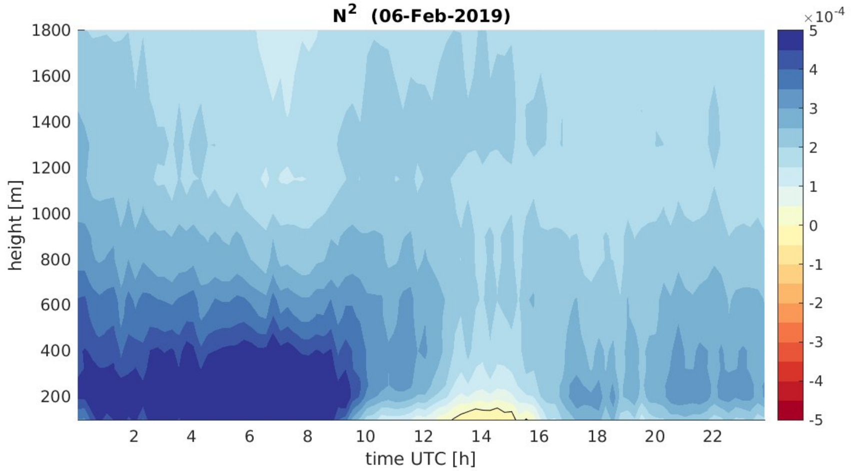
Summer 2019



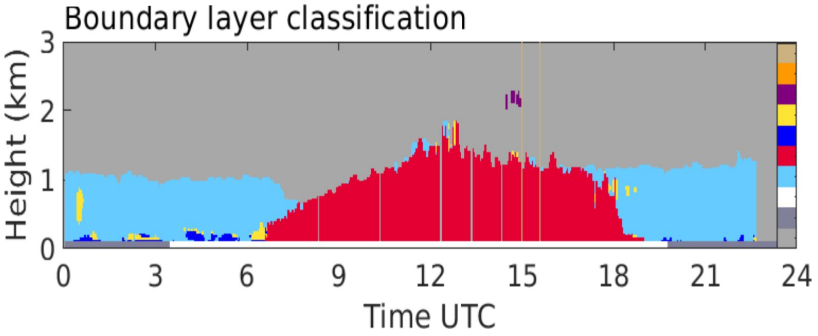
Comparing two cases

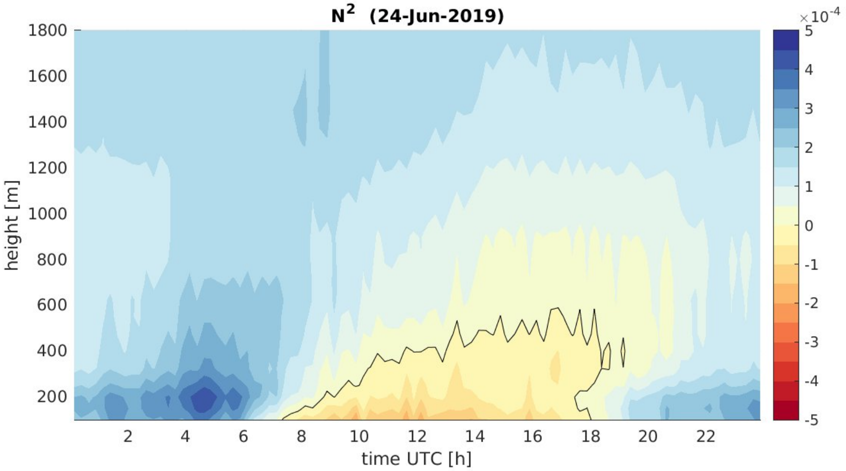
- **Winter 2019**





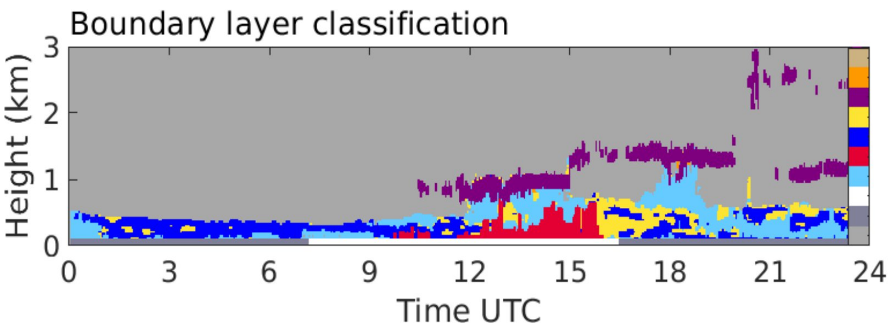
- **Summer 2019**

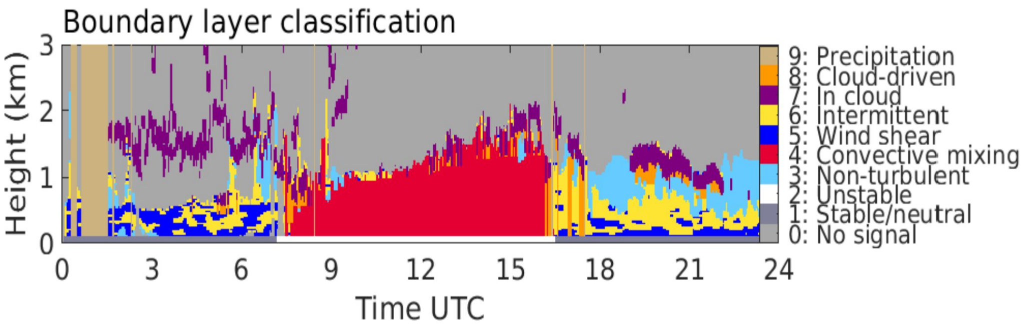


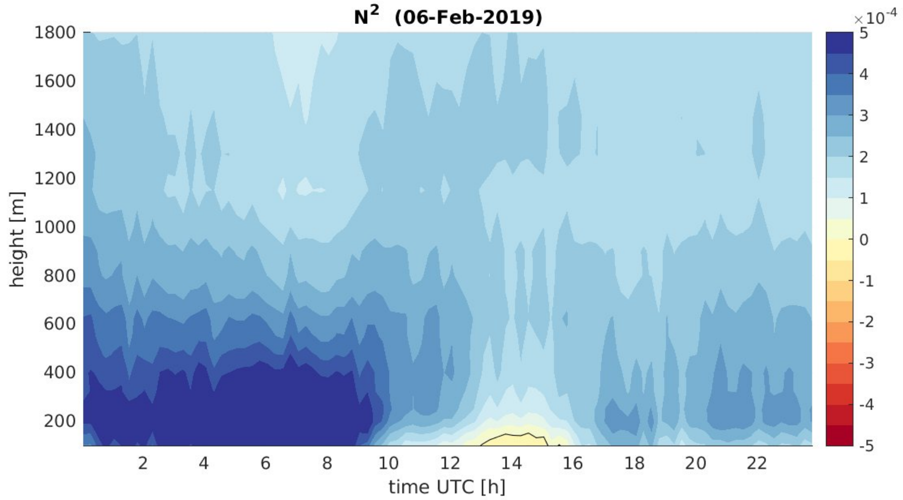


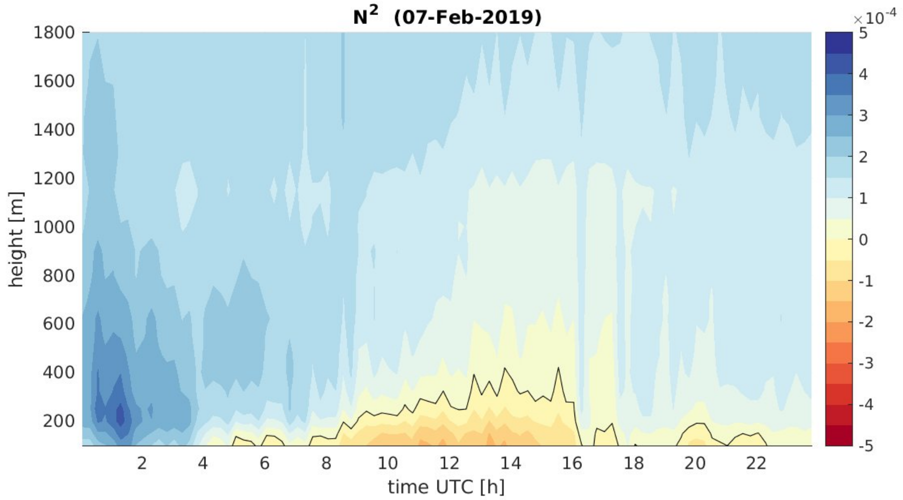
Complementary information of ABL evolution

Winter


Boundary layer classification

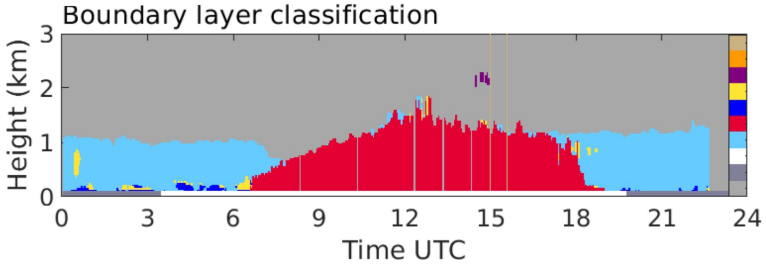

Boundary layer classification

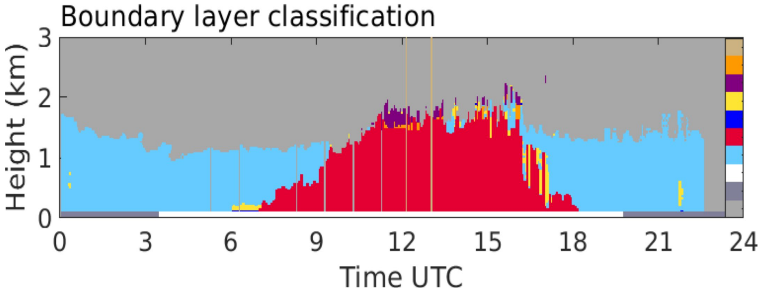

N^2 (06-Feb-2019)

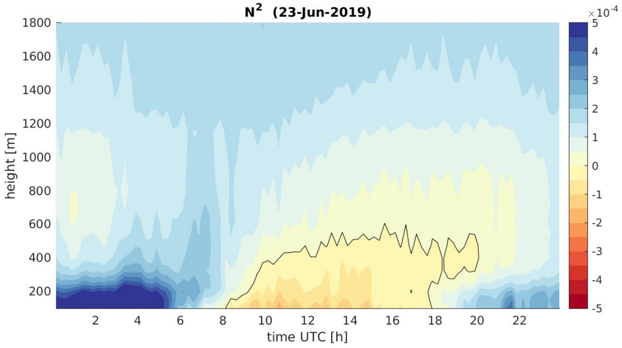

N^2 (07-Feb-2019)

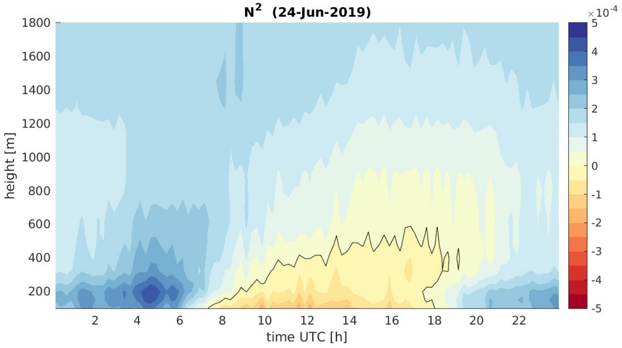
Complementary information of ABL evolution

Summer









Preliminary Conclusions

- Employing JOYCE observations with high temporal resolution allow us to better **characterize the evolution of ABL stability and turbulence**, which are crucial processes for modeling and air quality applications.
- Combining MWR with DL gives complementary information on ABL structure and improves ABL classification.
- The inclusion of N^2 in the ABL classification can be used to better **identify the sources of turbulence**.

Preliminary Conclusions

- **The present turbulence and stability characterization can be combined with in situ observations of aerosols in the frame of ACTRIS.**
- **The ABL classification can be included as an ACTRIS product in CLOUDNET**
- **Next steps (1):** estimation of Richardson number and thermodynamic indices will help us to better characterize the ABL stability and identify sources of turbulence.
- **Next steps (2):** investigation of sensible and latent heat fluxes in ABL employing highly resolved temperature and WV measurements (from AERI and Raman lidar) and vertical velocities (from Doppler lidar).