

# ST7: Atmospheric Boundary Layer Dynamics and Air Quality

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RI-URBANS (101036245)

Final Science Meeting, Barcelona  
8-9 Sept 2025



# Atmospheric Boundary Layer (ABL) Dynamics

## Entry of air with different composition

(pollutants, moisture, temperature)

- Fresh air from free atmosphere
- Secondary pollutants from residual layer
- Transported pollutants from elevated layers (e.g. dust, smoke, etc)

### Entrainment

## Current mixing processes

- Vertical exchange
- Horizontal exchange
- Layer growth
- Deposition

### Vertical mixing

## Stratification

- Synoptic conditions + surface-processes
- Gradients in temperature, wind, moisture

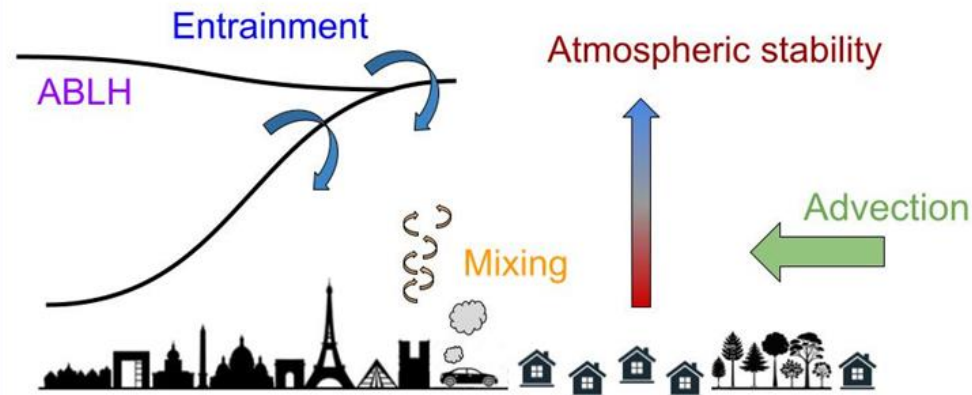
### Atmospheric stability

## Layer heights

- Determine volume for pollution dispersion
- Especially critical for shallow heights

→ indicator resulting from mixing, buoyancy, entrainment, advection

### ABL Height



## Transport

- Exchange rural - urban
- Exchange intra-urban
- "Ventilation corridors" along zones of low roughness

### Advection

# Indicators of ABL Dynamics

## Layer detection:

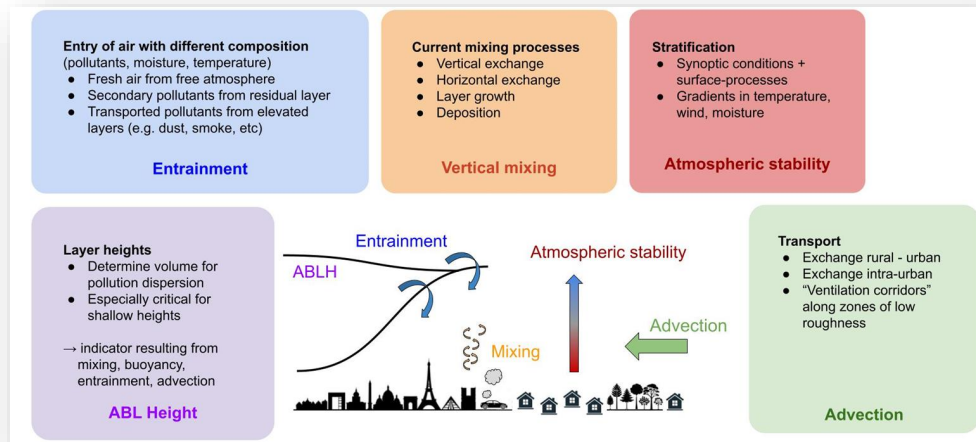
tracking of layer heights & entrainment

## Stability and mixing:

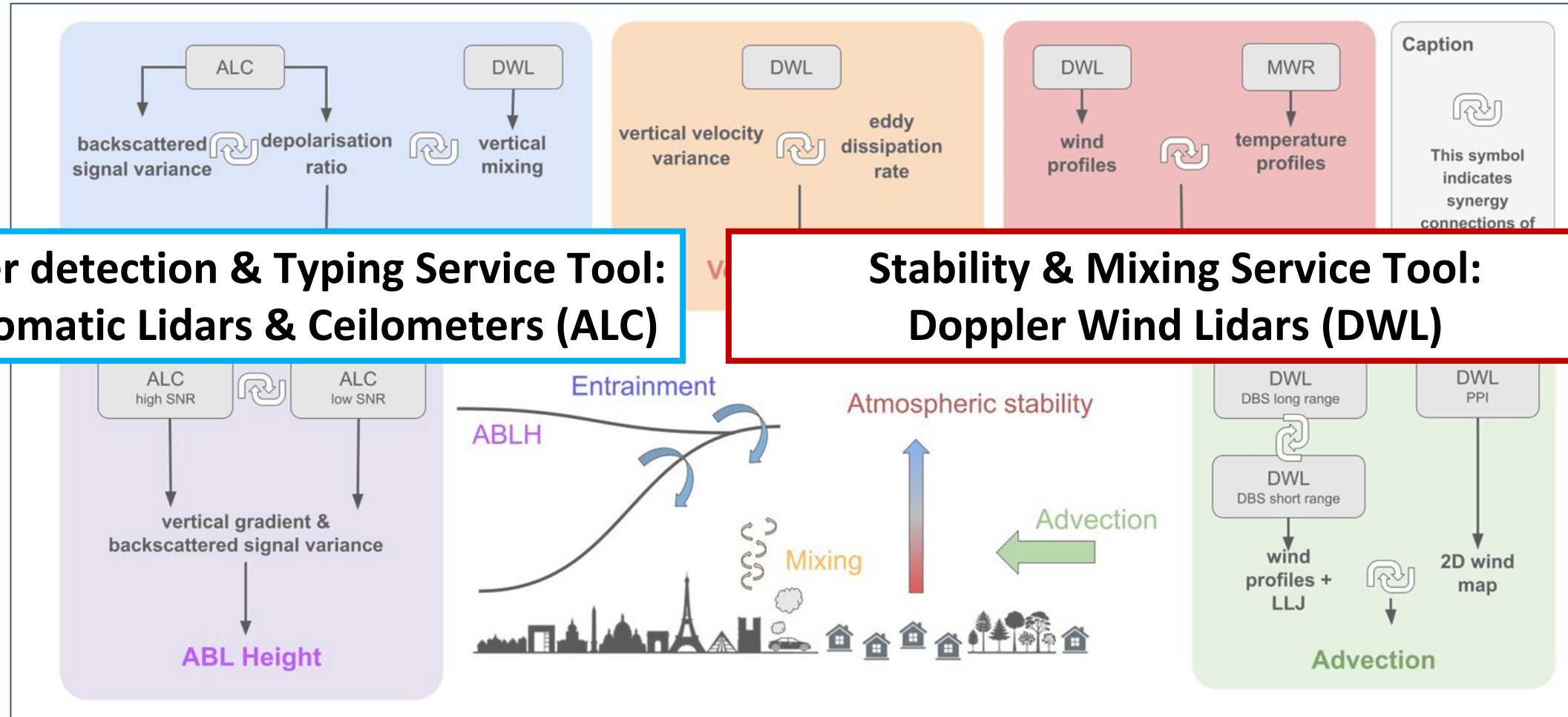
profiling of wind, temperature, turbulence

## Advection:

Measurement networks, horizontal profiling

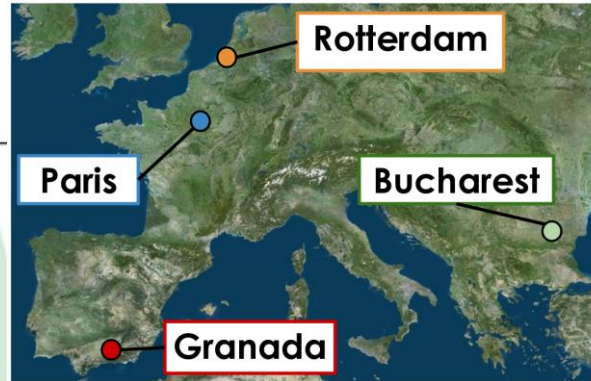


# Atmospheric Boundary Layer (ABL) Dynamics

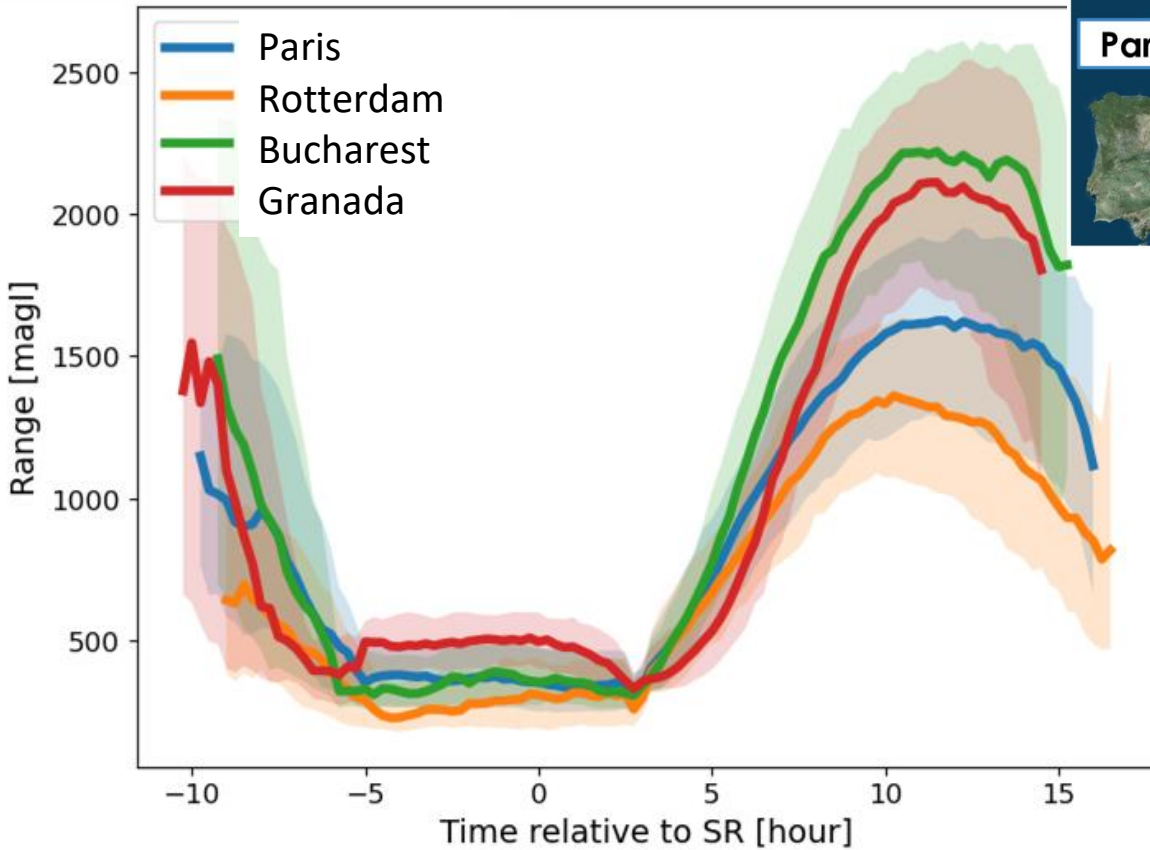


# Mixed Layer Height at European scale

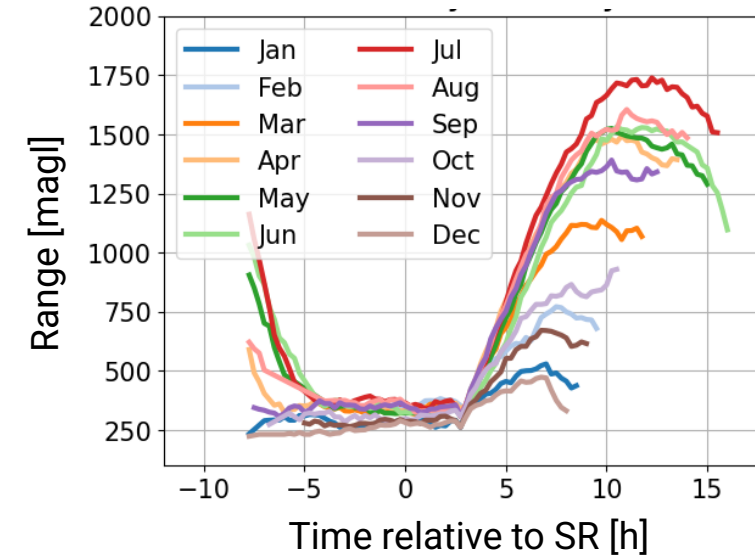
Summer 2018 - 2024



Van Hove et al., in prep



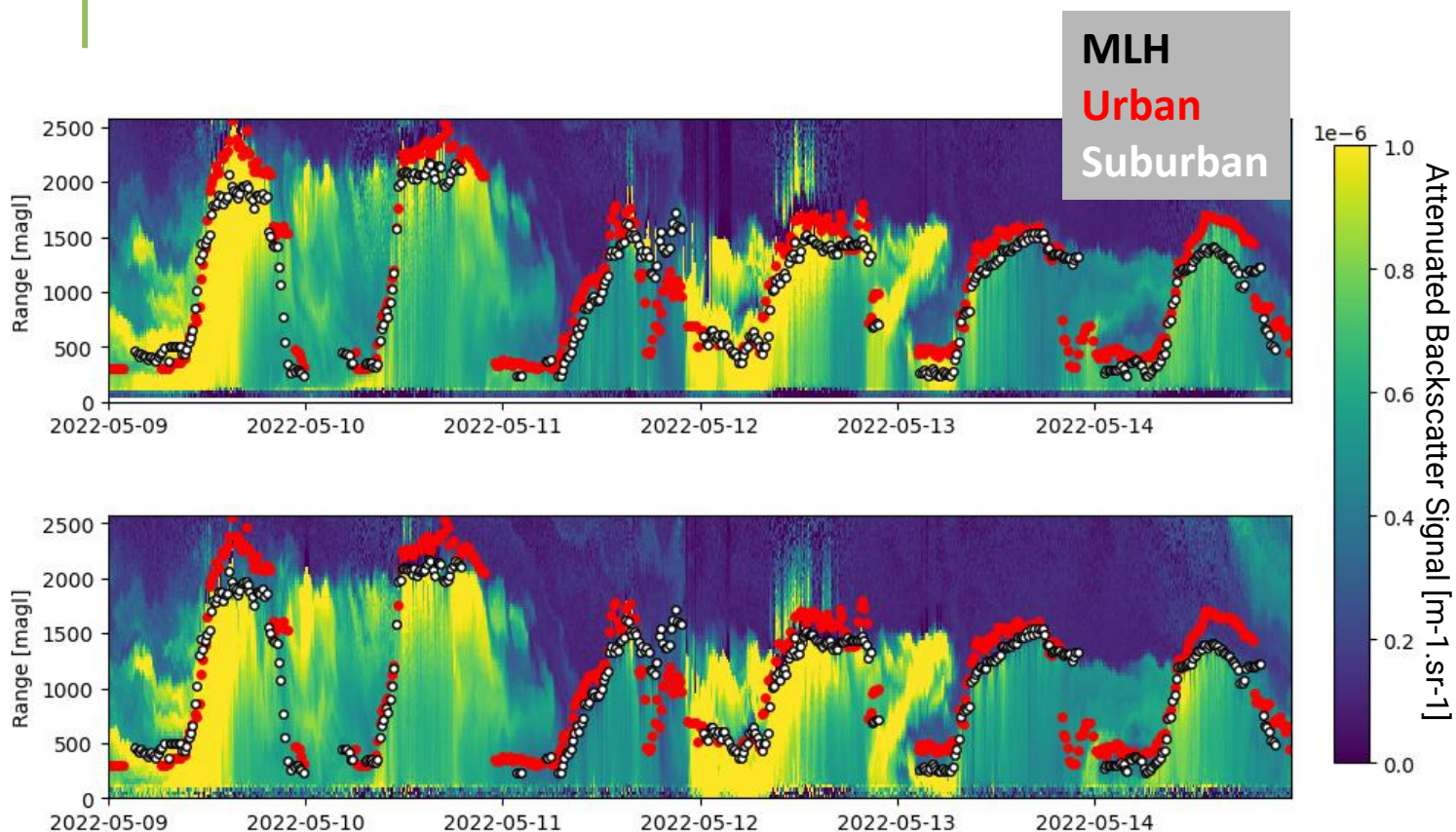
Paris MLH (2015 - 2024)



## ABL testbed:

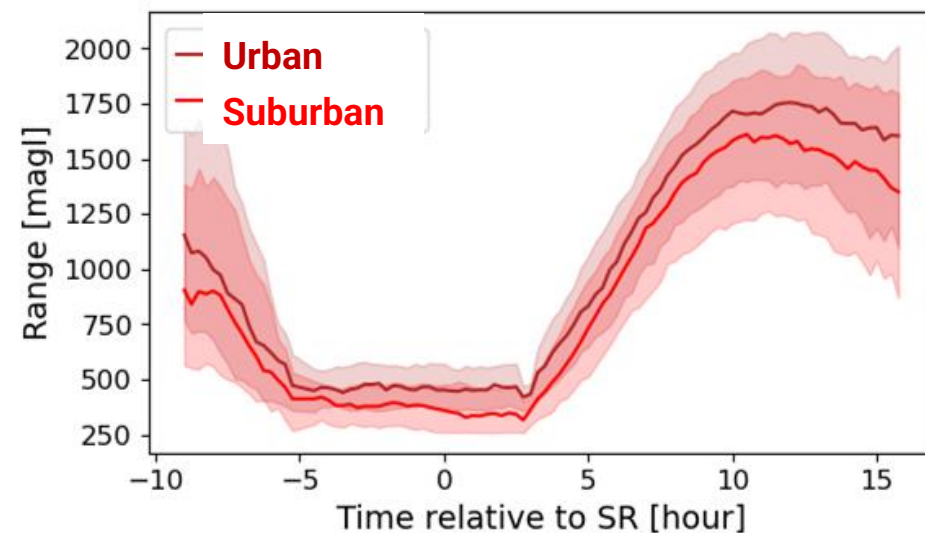
- Multi-year results from high-quality observations
- Consistent diurnal and seasonal variations
- Considerables variations across European scale

# Mixed Layer Height at urban scale



Van Hove et al., in prep

Paris MLH ( $\Delta$  25km)



Upscaling by



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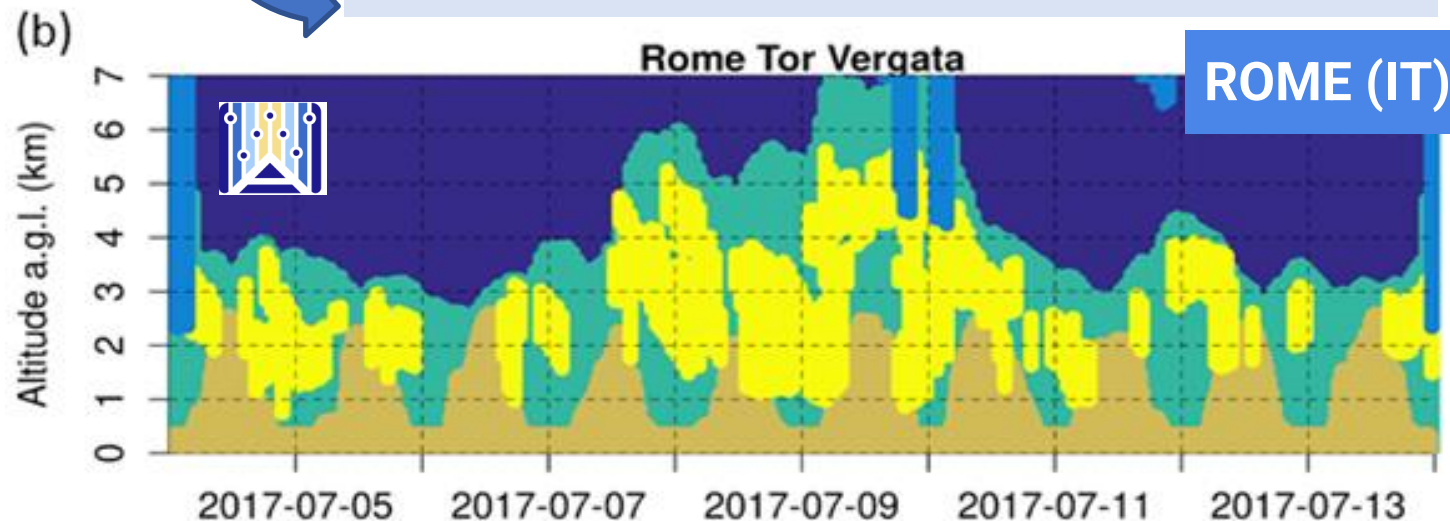


# Layer detection & entrainment (NRT or quasi NRT)



## Aerosol Layer Detection Algorithm

Example of ALADIN Aerosol Layering Mask



*Bellini et al., (2024), AMT*

<https://doi.org/10.5194/amt-17-6119-2024>

**EAL = Elevated Aerosol Layer**  
**MAL = Mixed Aerosol Layer**  
**CAL = Continuous Aerosol Layer**  
**CLOUD = Cloud**  
**MOL = Molecular/No aerosol**

Applicable to high-SNR ALC (Vaisala CL61, Lufft CHM15k)



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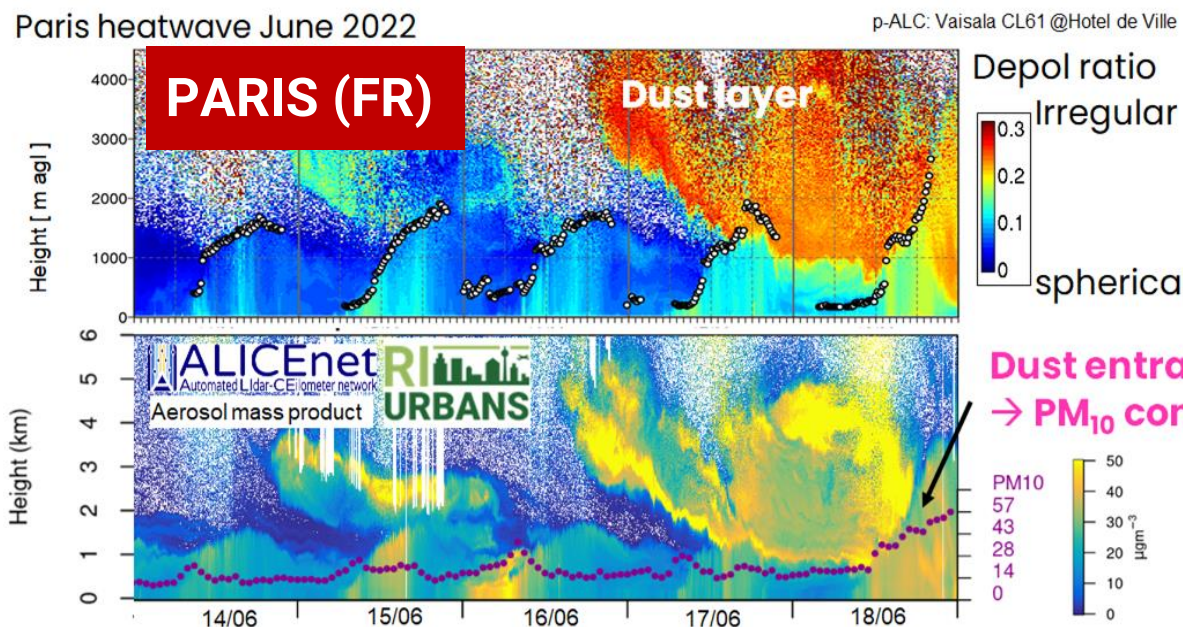


# Layer detection & entrainment (NRT or quasi NRT)

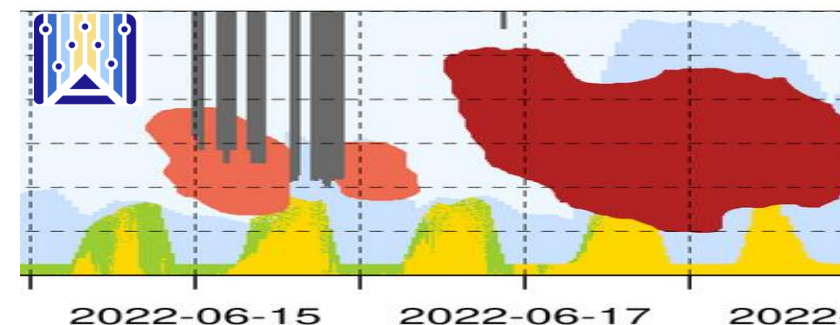
**ALICE**net Automated Lidar-Ceilometer network **ALADIN** +

**Aerosol Layer Detection** + **TYPING** Algorithm

- Clouds
- Aerosol free -Molecular
- Regional Background Aerosol
- Mixed continental
- Local resuspension / Entrained Desert Dust
- Transported Continental Aerosol or Smoke
- Transported & Processed Desert Dust
- Transported Desert Dust



Example of ALADIN Aerosol Layering + Typing Mask



Paper in preparation 2025



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Applicable to high-SNR, Polarization sensitive ALC (e.g., Vaisala CL61)

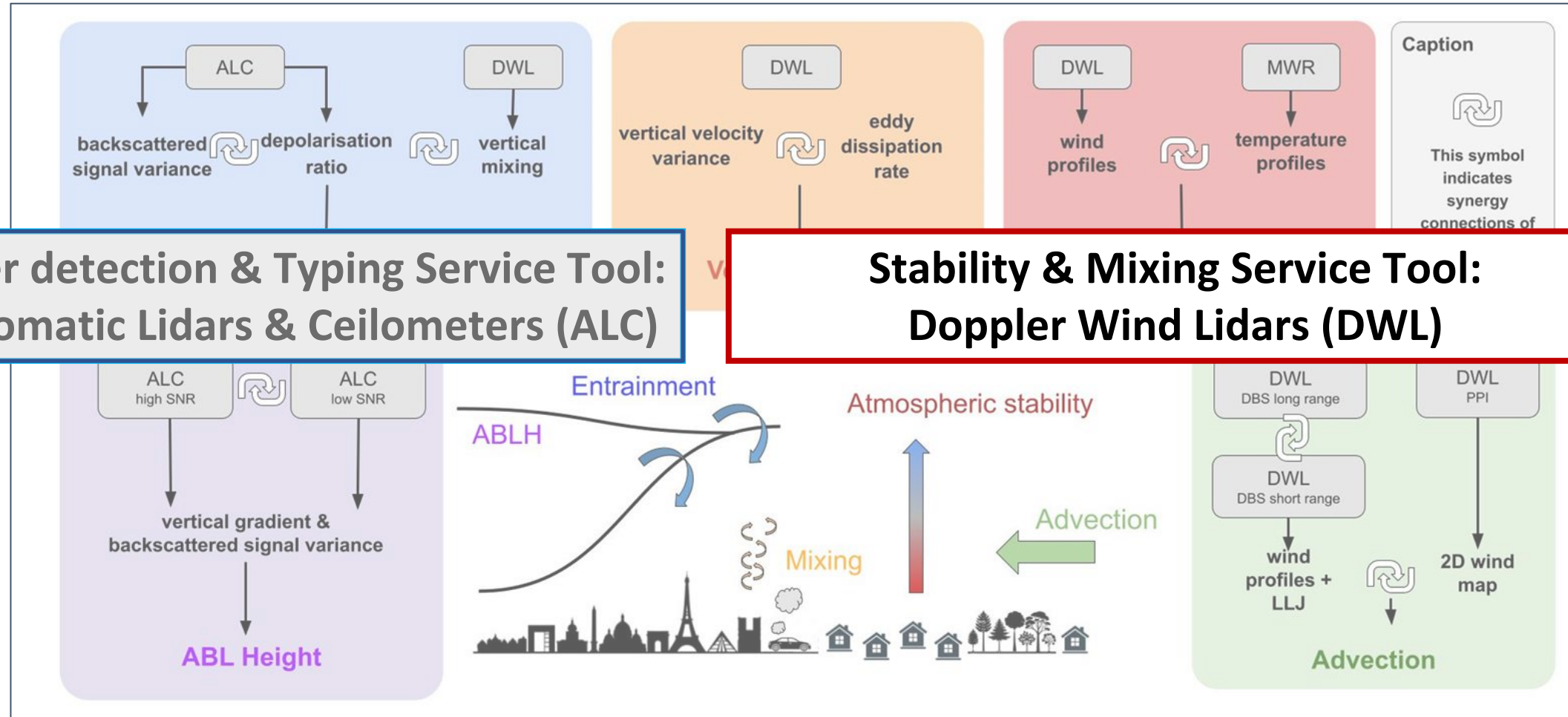


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# Atmospheric Boundary Layer (ABL) Dynamics

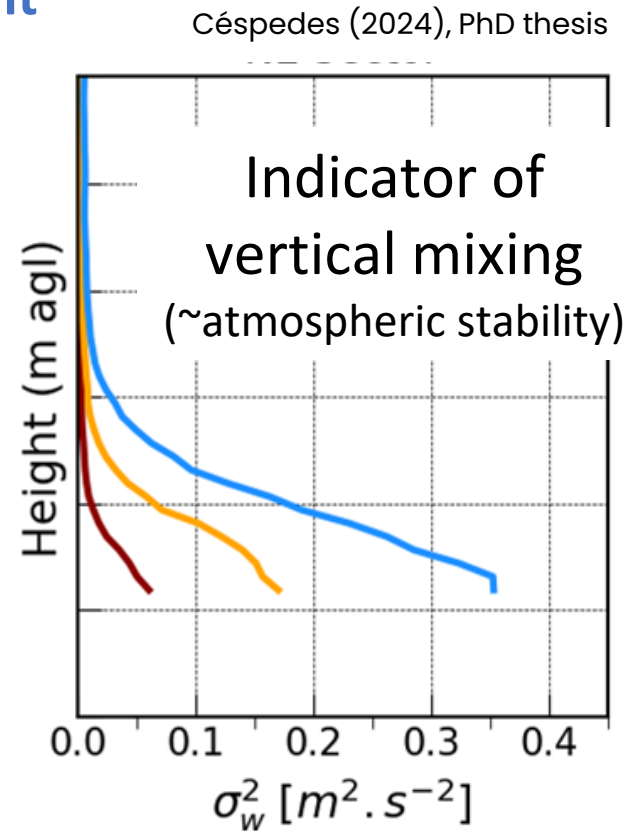
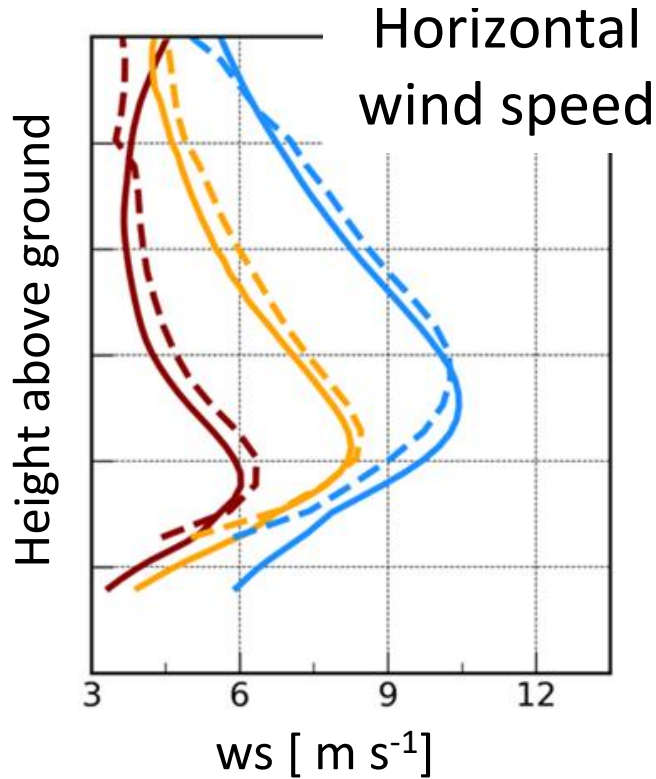


**Layer detection & Typing Service Tool: Automatic Lidars & Ceilometers (ALC)**

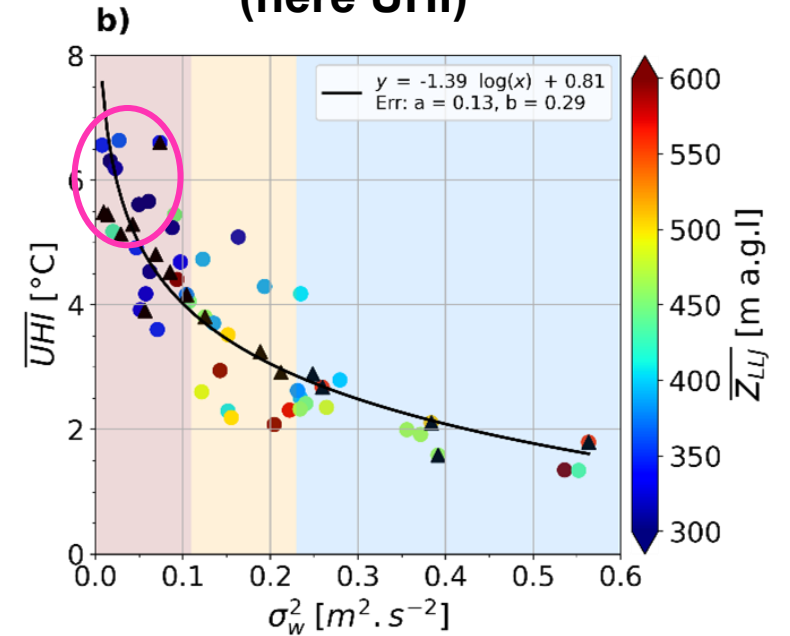
**Stability & Mixing Service Tool: Doppler Wind Lidars (DWL)**

# Wind and turbulence profiles

calm medium turbulent



## Influence on near-surface conditions (here UHI)



Wind speed, mixing, dilution

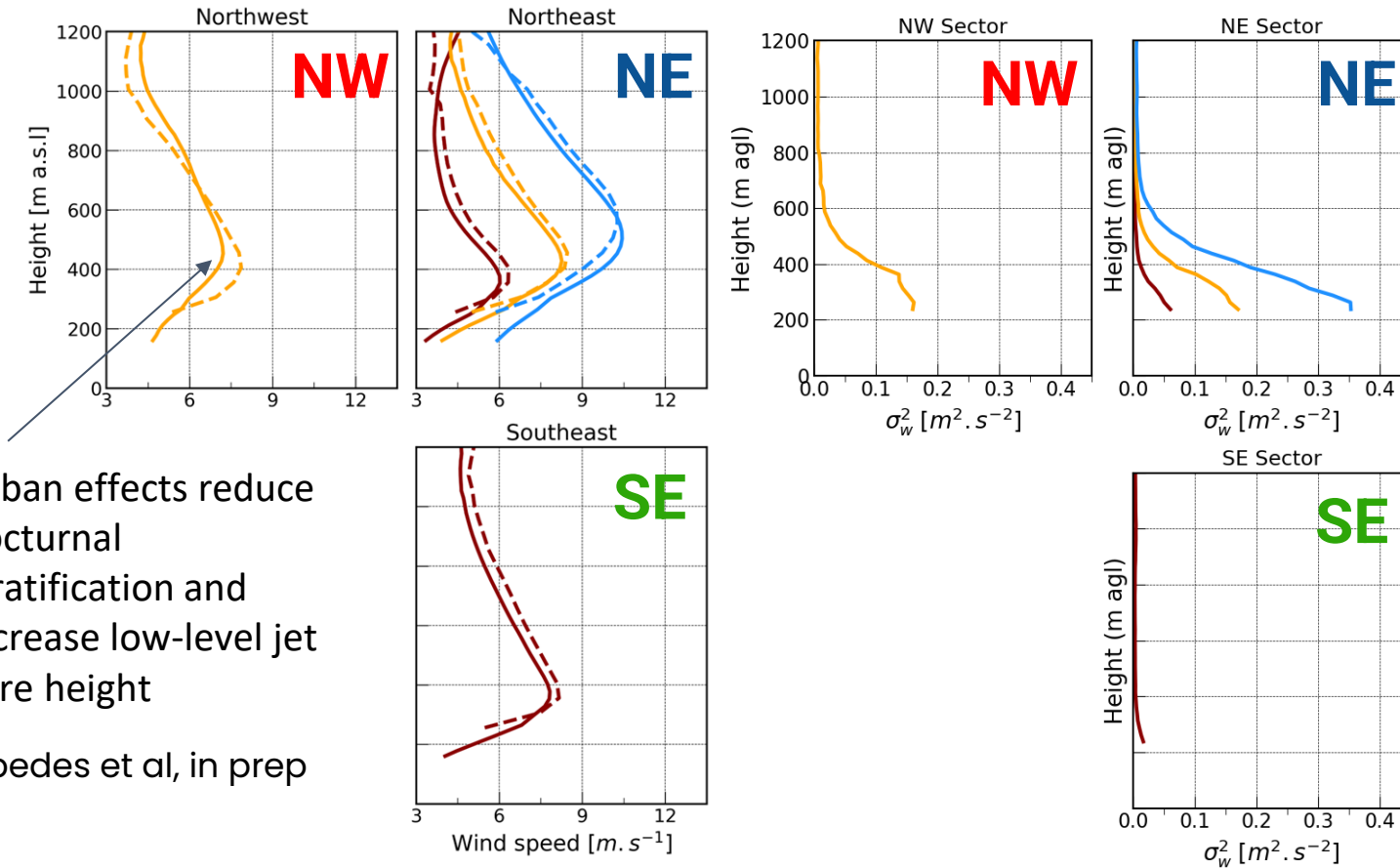
Multi-sensor network to detect:

- influence of synoptic flow
- topography
- urban boundary layer

Céspedes et al. AMT  
<https://doi.org/10.5194/egusphere-2024-520>

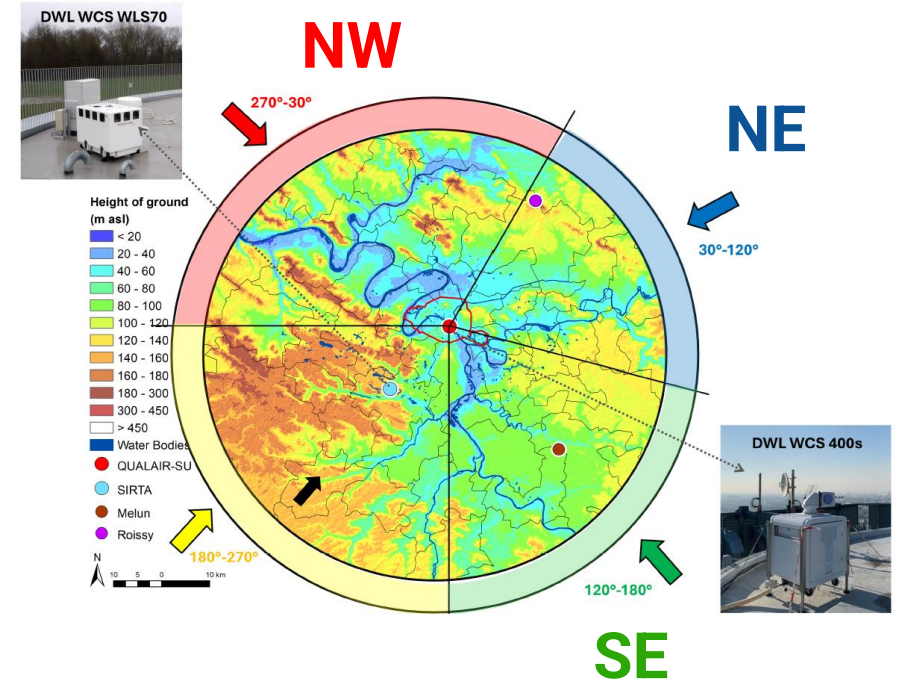
# Wind and turbulence profiles

calm medium turbulent



Urban effects reduce nocturnal stratification and increase low-level jet core height

Céspedes et al, in prep



## Depending on wind direction

- Wind speed profiles
- Turbulent mixing profiles
- Feedback from surface (orography, roughness)
- Aerosol Sources
- ABL Mixing height
- → aerosol concentrations

See for ex. Foskinis et al. 2024

<https://doi.org/10.1016/j.atmosres.2024.107543>

# Service Tool #7: Atmospheric Boundary Layer

## Automatic Lidars & Ceilometers (ALC)      Doppler Wind Lidars (DWL)

<b>Network operation &amp; standardisation</b>	<ul style="list-style-type: none"> <li>• Instrument recommendation</li> <li>• Standard operating procedures</li> <li>• Monitoring of housekeeping data</li> <li>• Harmonised processing</li> <li>• Uncertainty characterisation</li> </ul>	
		<ul style="list-style-type: none"> <li>• Scanning strategies</li> </ul>
<b>Advanced products</b>	<ul style="list-style-type: none"> <li>• Boundary layer heights → dilution &amp; entrainment</li> <li>• Layer typing</li> <li>• Aerosol optical properties</li> </ul>	<ul style="list-style-type: none"> <li>• Wind speed profiles</li> <li>• indicators of atmospheric mixing, dilution, advection, ...</li> </ul>

# Conclusions

- Atmospheric boundary layer **dynamics impact near-surface pollution** concentrations through mixing of local emissions or entrainment of advected and photochemically generated particles in the upper layers
- **ABL height, aerosol layers & typing** can support better understanding of in situ measured AQ metrics and unambiguous detection of long-range transport episodes affecting AQ-relevant atmospheric levels (some of which lead to exceedance situations)
- **Wind speed and turbulence profiles** can support better understanding of mixing, stability and advection which impact local horizontal gradients, rural-urban exchanges, feedbacks between surface characteristics and ABL dynamics
- Upscaling of **ABL height** and **Wind speed and turbulence profiles** is on-going in ACTRIS (CCRES+CARS Topical centres & CLU-ARES Data centres)
- Upscaling of **aerosol layers and typing** is under discussion (future project)