Confidence levels and error bars for continuous detection of mixing layer heights by ceilometer

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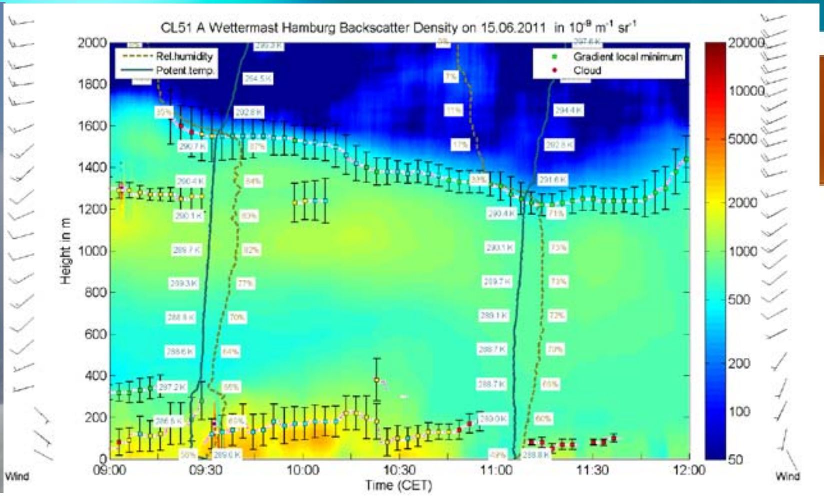

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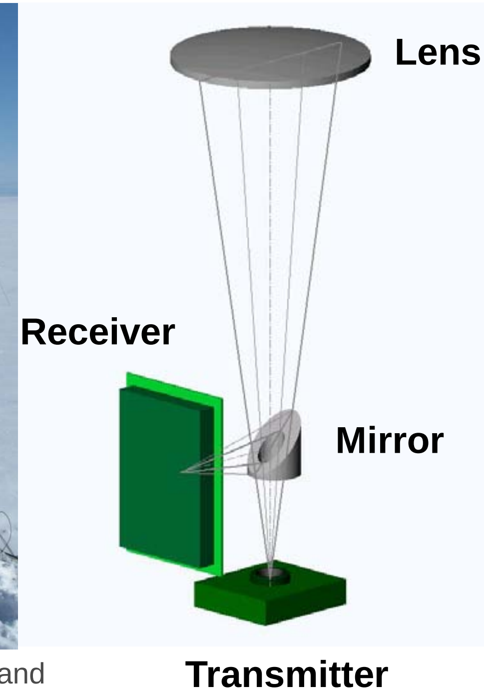
Single lens Vaisala ceilometers

Garmisch-Partenkirchen
operated by KIT, IMK-IFU

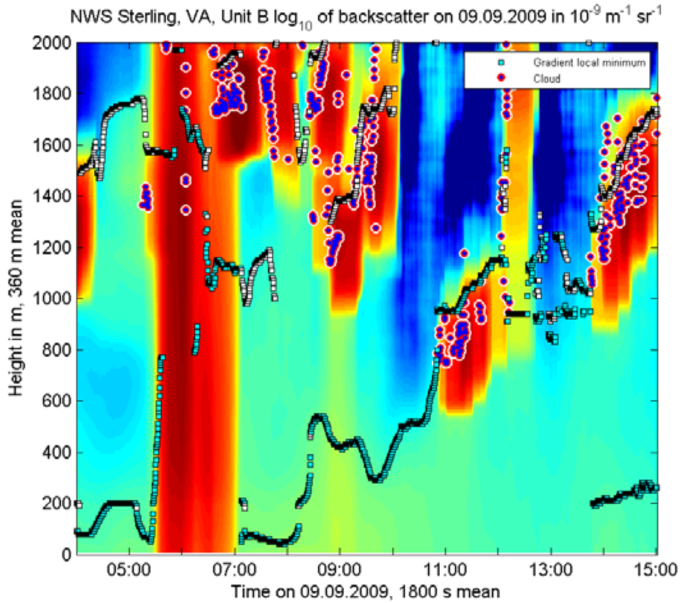
Research vessel Polarstern
operated by AWI, Bremerhaven

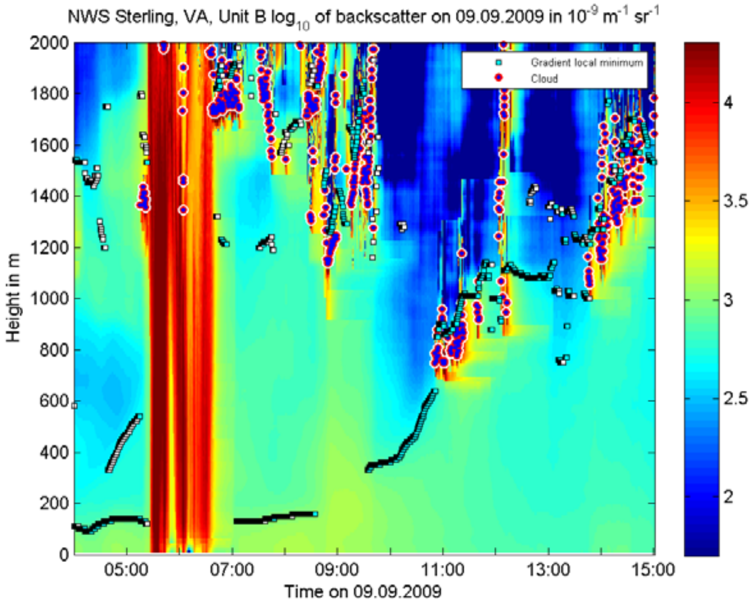
Station Nord, Greenland
operated by DTU Wind Energy



- Simple and reliable instrument design.
- Sufficient overlap already 10 m above the system.
- Qualified instrument for boundary layer investigation.
- Designed for harsh environments.
- More than 3000 units in operation.

BL-VIEW algorithm

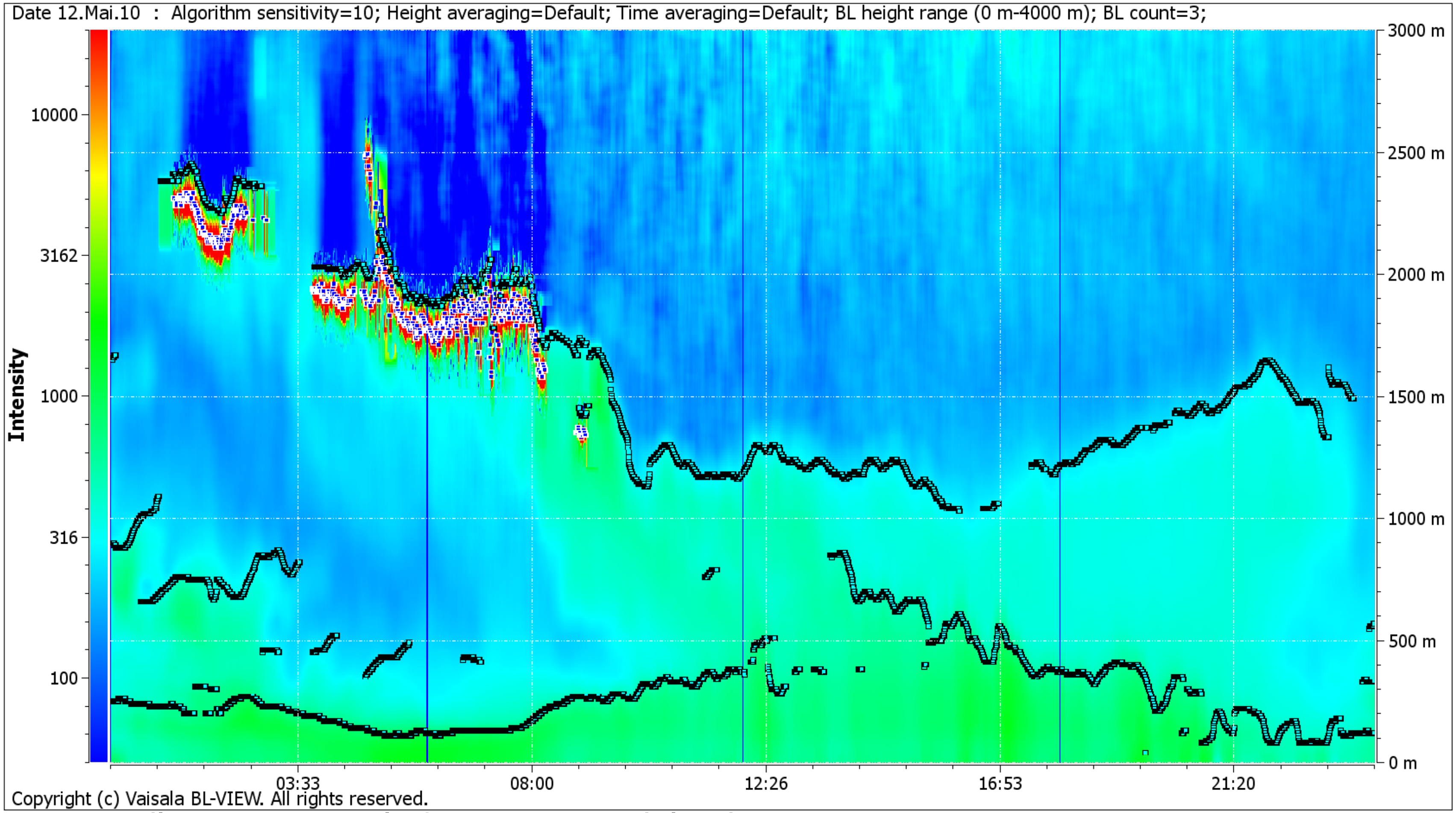




- A standard method to identify the vertical extent of aerosol layers within the boundary layer is the gradient method that searches the backscatter profile for local gradient minima. Sliding time and height averaging is essential for its success (left), but precipitation and clouds call for a more sophisticated treatment.
- The resulting BL-VIEW algorithm (right) involves
  - cloud and precipitation filter,
  - noise and range dependant time and height averaging intervals,
  - signal strength dependant detection thresholds

  and is implemented in the Vaisala software tool BL-VIEW.

BL-VIEW snapshot, default algorithm



- CL51 ceilometer example from Vantaa, Finland.
  - Cyan squares with black edge: gradient local minima.
  - Blue squares with white edge: cloud bases.

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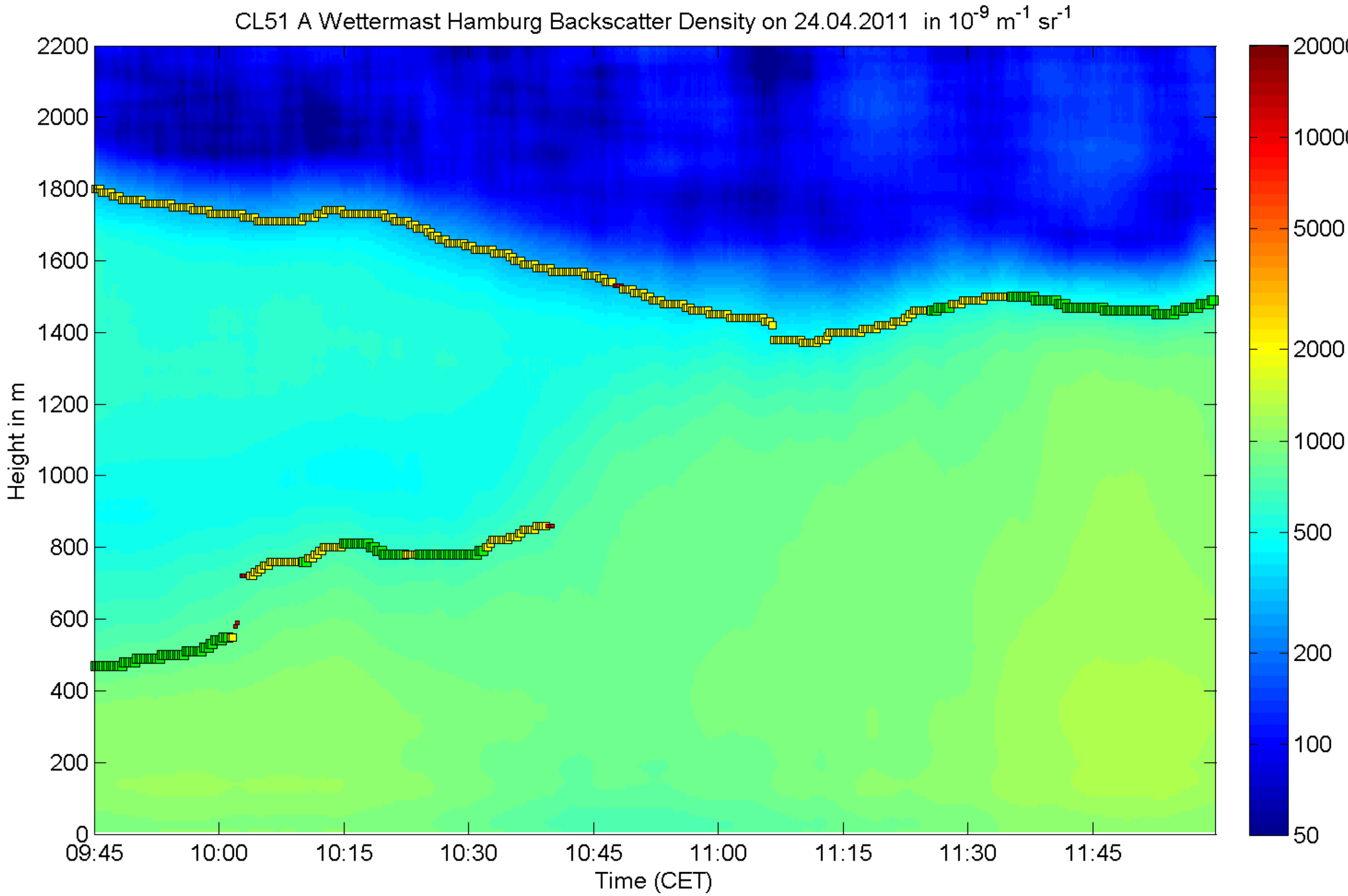
Quality index → Confidence levels and error bars

- The current BL-VIEW algorithm gives a quality index from 1 to 3 for each gradient minimum detection. It is based on
  - gradient amount (low gradient → high quality index)
  - detected cloud bases (clouds detected → reduced quality index)
  - distance to other gradient minima (high distance → high quality).
- The utility of mixing layer height as a parameter for air quality forecast or dispersion calculation would be enhanced if this quality index could be quantified by calculating
  - **confidence levels** (how sure are we that there really is an aerosol layer at that height?) and
  - **error bars** (what is the uncertainty in meters of the detected value?).



- Gradient minima plot with color coded quality indices:
  - Red = quality index 1 (10:05, 600 m)
  - Yellow = quality index 2 (09:45 – 11:15, 1800 m – 1400 m)
  - Green = quality index 3 (11:35 – 12:00, 1500 m)

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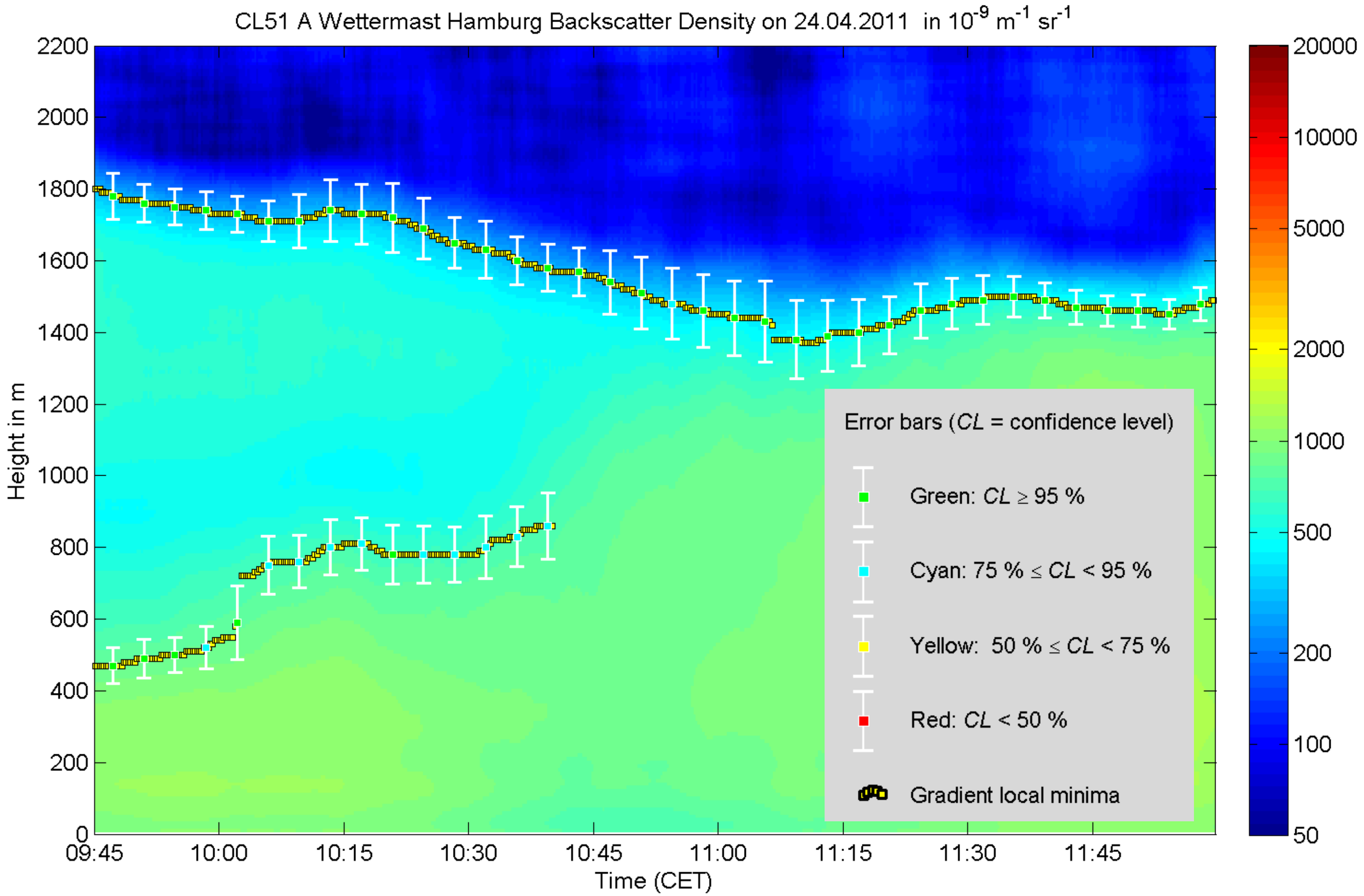

- Gradient minima plot with error bars and color coded confidence levels.
  - Half length of error bar = uncertainty
  - Confidence level is high for the 1400 m to 1800 m layer
- The calculation scheme is introduced on the next slides → →

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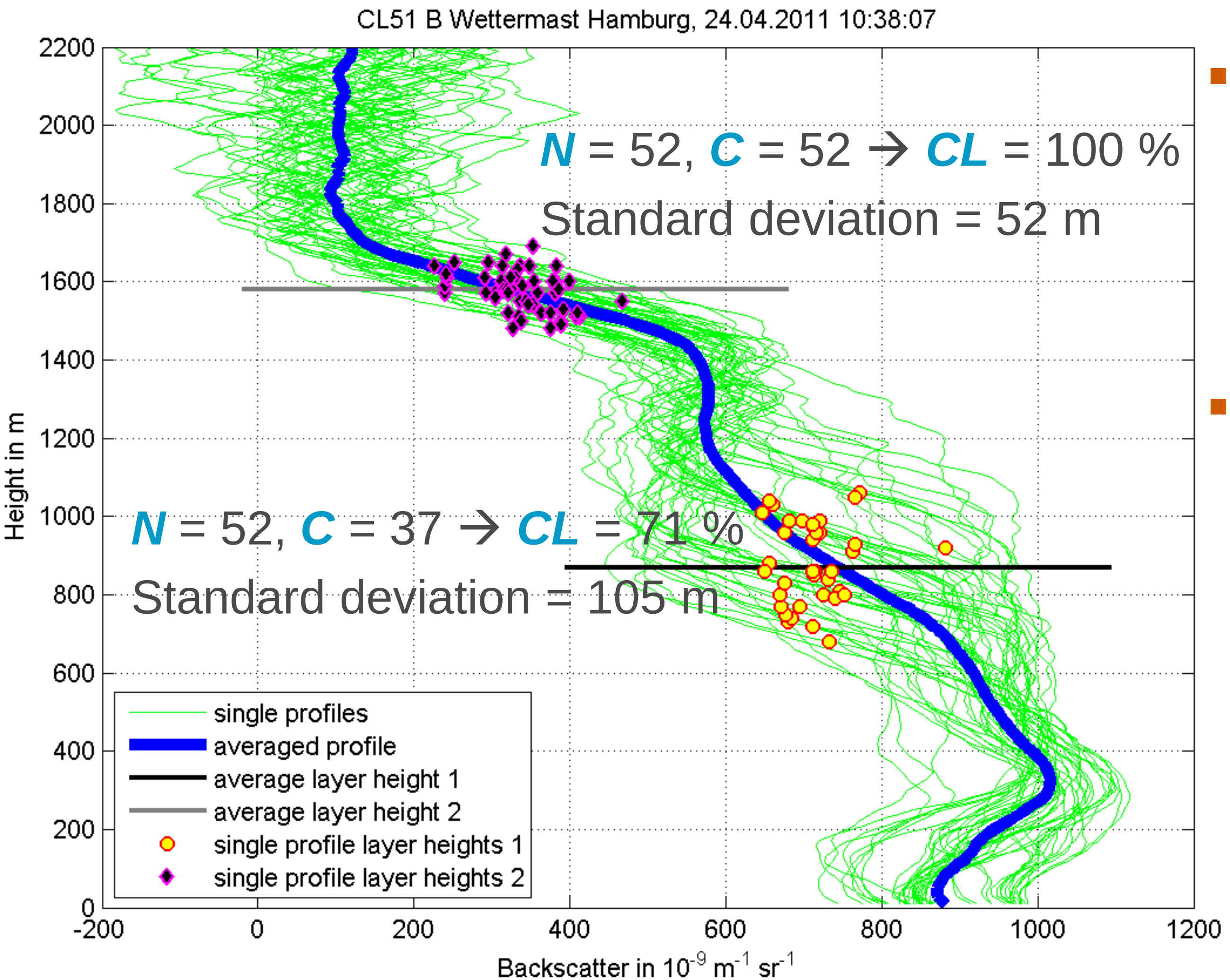
Calculation of confidence levels and error bars for a gradient minimum *GM*

- CL51 ceilometer message interval is **16 s**.
- Depending on signal noise, the number of past messages ***N*** averaged for the detection of ***GM*** varies from **50** to **100**.
- Confidence level and error bar calculation is done in 4 steps:
  - Gradient minima calculation for each of the ***N*** single messages.
  - Count of gradient minima ***gm*** detected that differ not more than the greater of **200 m** and **20 %** from ***GM***. Result: ***C***.
  - **Confidence level**: ***CL = C / N***.
  - Uncertainty of ***GM*** (half **error bar** length): Standard deviation of the ***C*** gradient minima ***gm*** from their arithmetic mean.

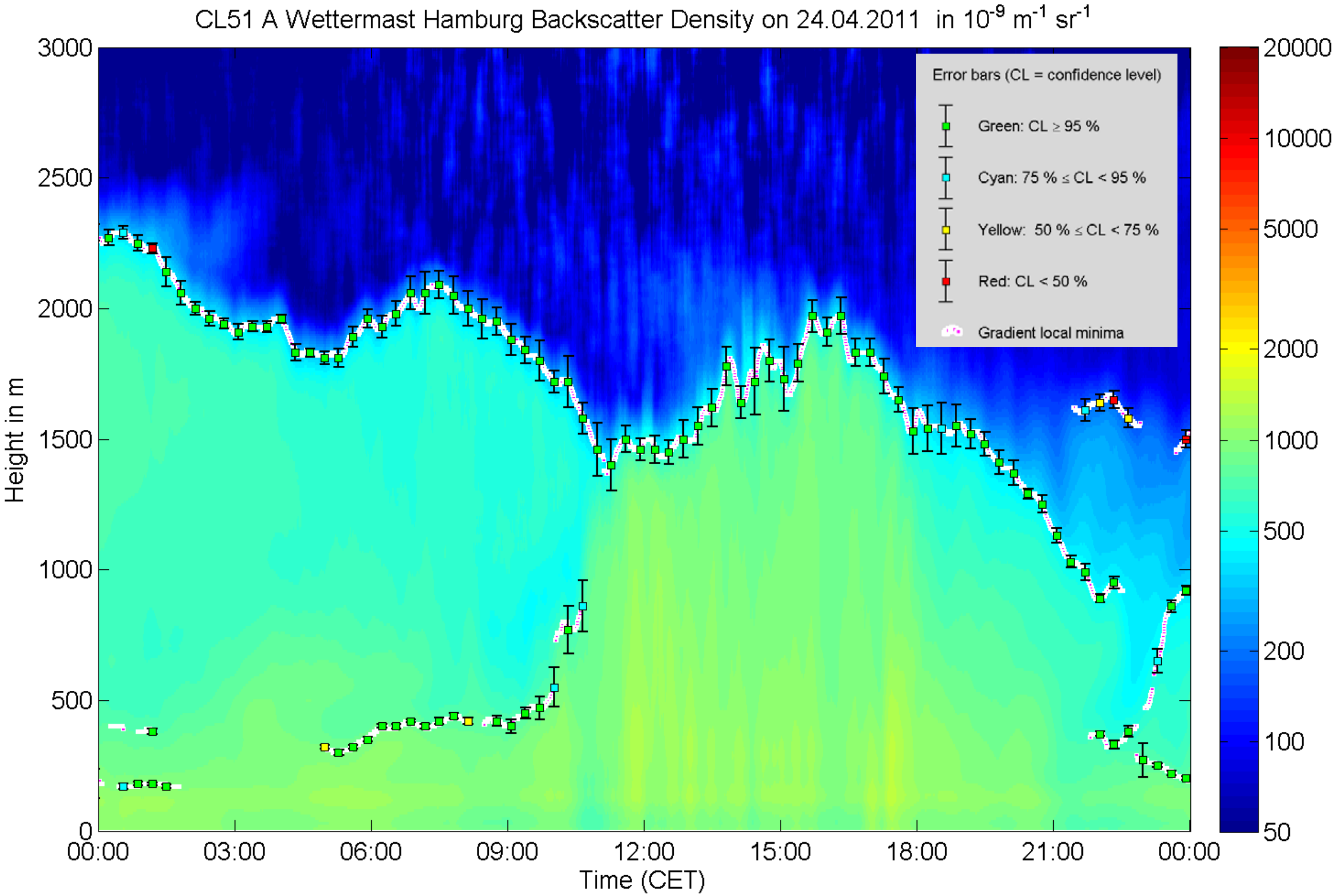
Example calculation



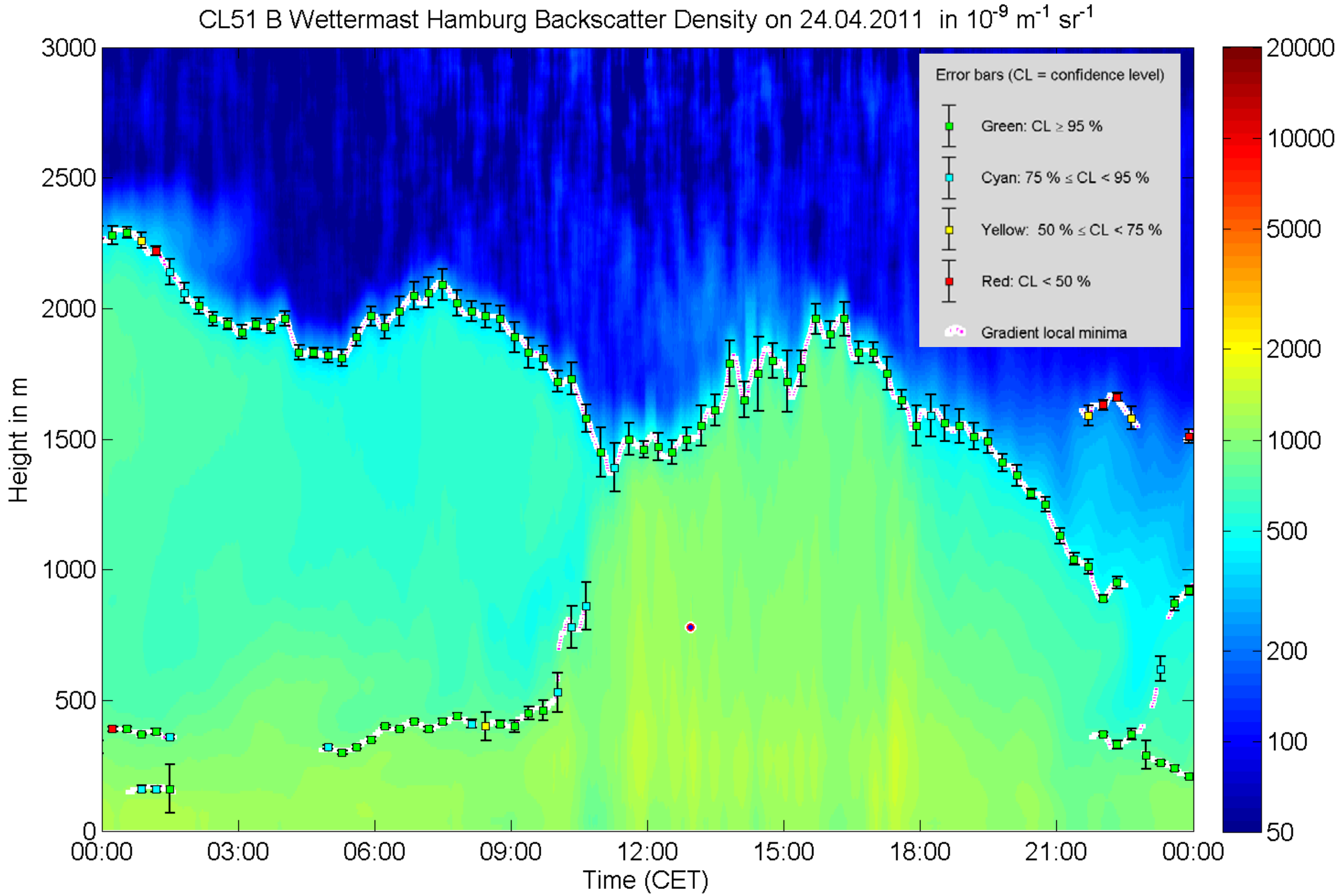
- The upper layer is a residual layer with little variation during the past 52*16 s = 832 s.
- The lower layer is a fast rising convection, resulting in a strong variation of the single profile layer heights.

Two co-located CL51 ceilometers at Hamburg weather mast, Germany

- Two CL51 ceilometers are part of the instrumentation of the "Tall Wind 2011" experiment dedicated to the investigation of wind profiles and aerosol layers within the boundary layer.
- Backscatter density plots from a nearly cloudless day show the typical diurnal evolution of residual, convective and nocturnal layers.
- Error bars agree well, daylight signal noise generally increases their length.



- From 05:00 to 09:00 there are only small deviations between the layer heights calculated with the 16 s and the long-term average. Error bar length increases with rising convective layer after 09:00.



- The 800 m cloud base at 13:00 is in the field of view of the ceilometer for just a few seconds. It is not detected by CL51 A. The diameter of the transmitter light cone at that height is 0.8 m.

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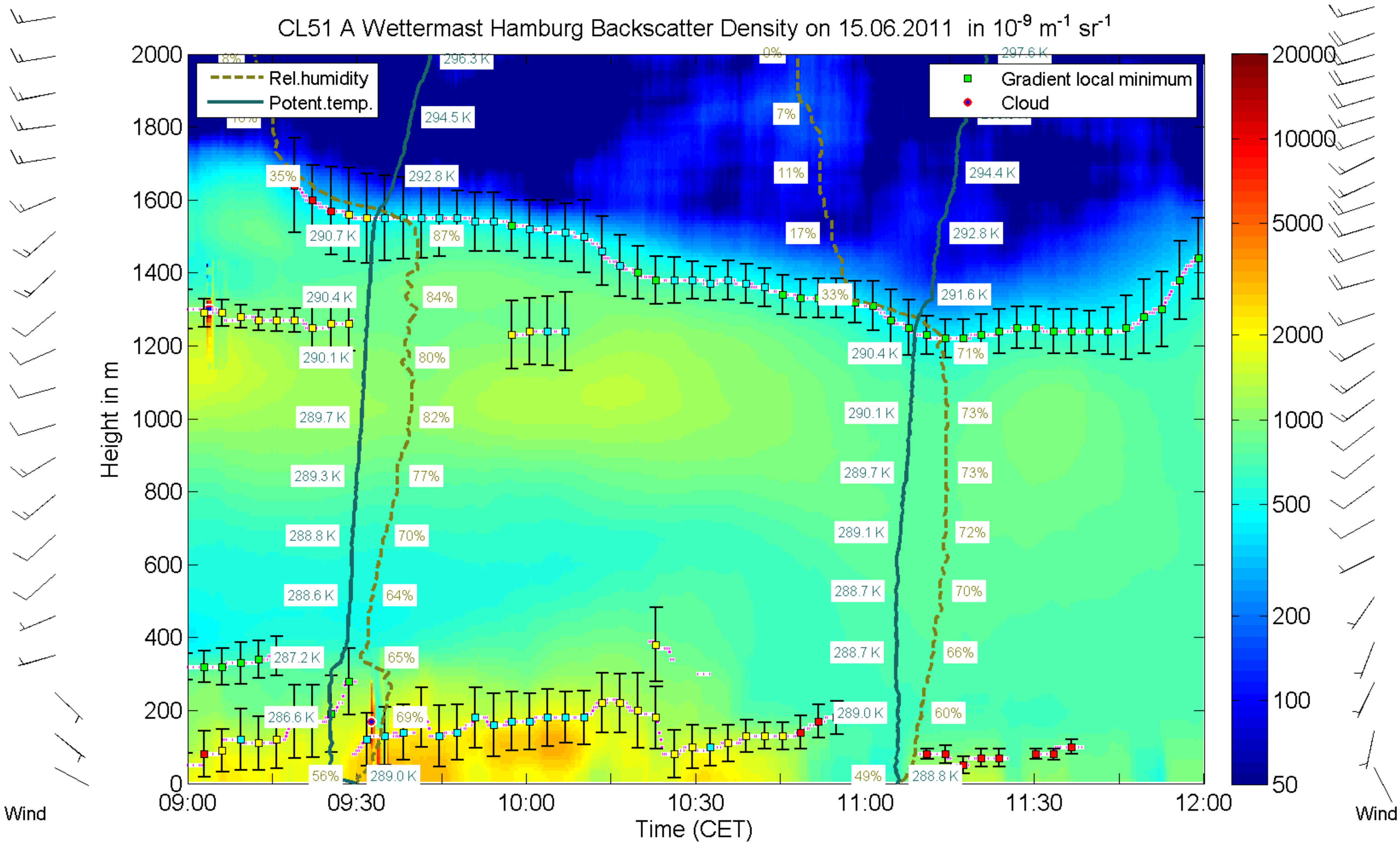
Comparison to soundings during the Tall Wind experiment – June 2011

- Two intensive campaigns during Tall Wind 2011 saw frequent launches of Vaisala RS92 radiosondes. Weather conditions where not favourable for boundary layer detection during those campaigns.
- During the first intensive campaign from 15.06.-20.06.2011 there where just a few periods with gaps in the clouds. The 09:30 and 11:00 soundings on 15.06.2011 show relative humidity drops and potential temperature rises at heights where the ceilometer reports upper edges of aerosol layers.



- Left: 09:30 sounding wind barbs; the south-easterly wind below 300 m is transporting dust from a close-by gravel pit. Large error bars reflect frequent change of dust concentration.
- Right: 11:00 sounding windbarbs; wind from the south contains less dust.

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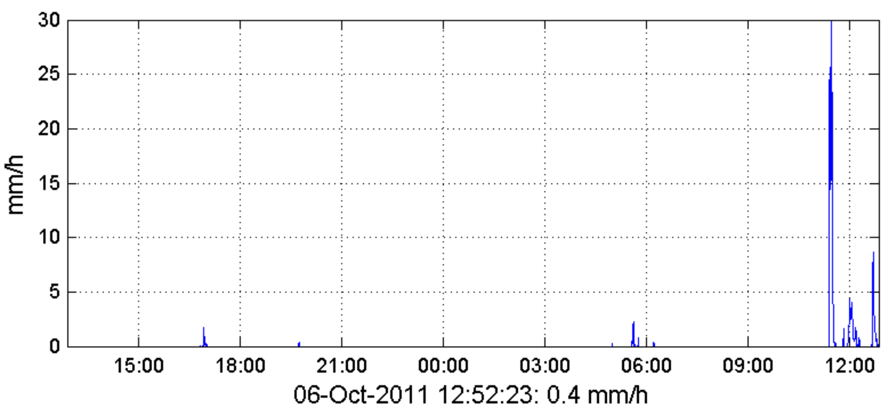
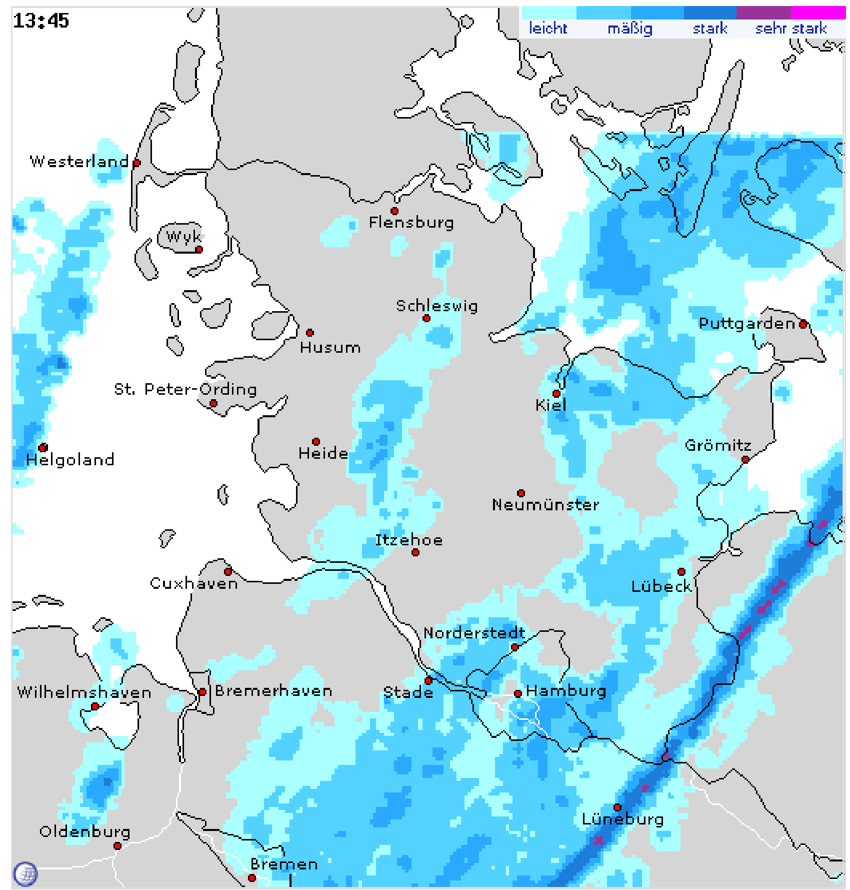
Comparison to soundings during the Tall Wind experiment – October 2011

- On 06. 10. 2011 a pronounced squall line crossed Germany from North West to South East.
- The time base of the weather radar animation from WetterOnline is CEST, one hour ahead of CET.
- Time scale of Vaisala Hamburg MET station below is CET.





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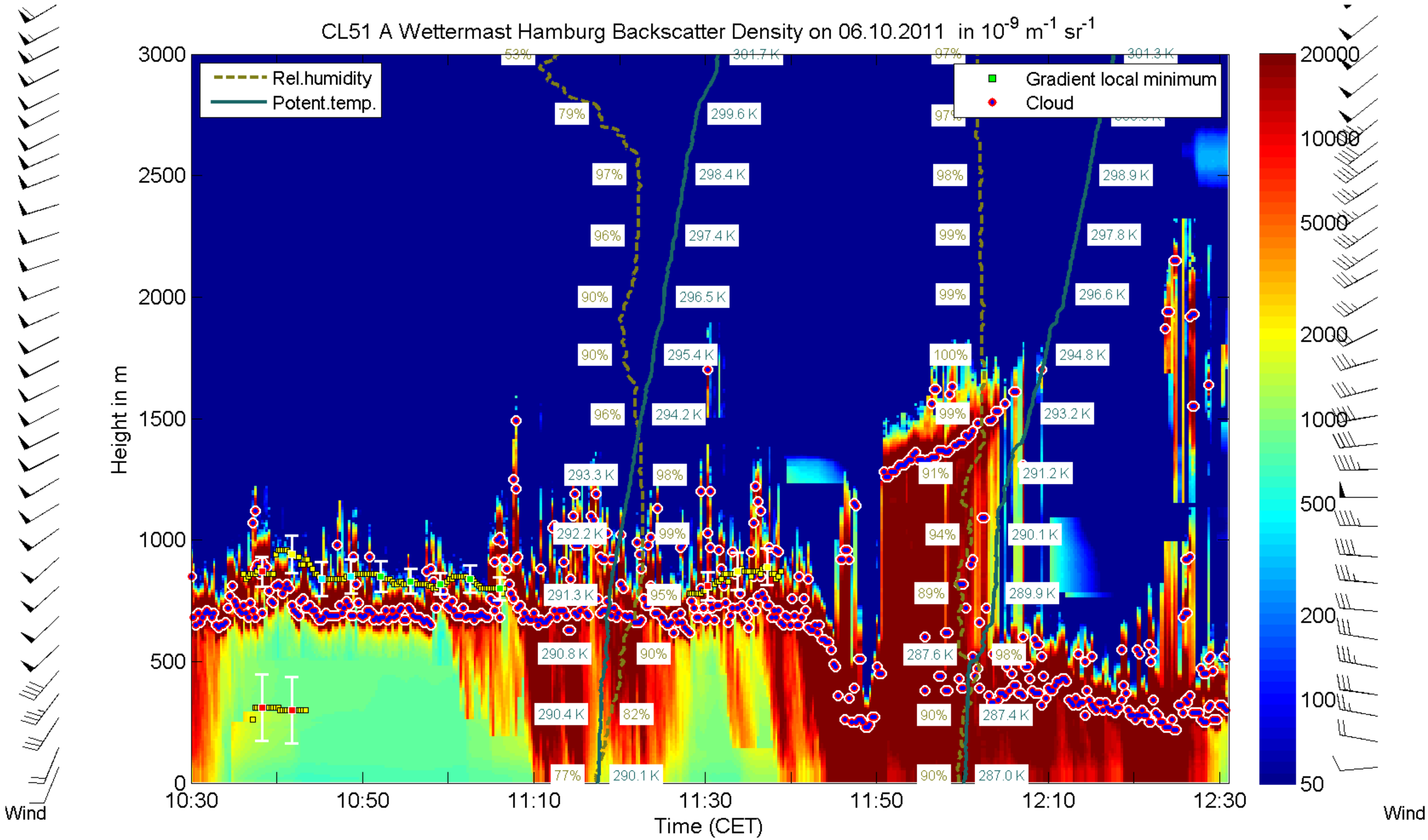

- The squall line passed Hamburg Weathermast at around 11:55 CET.
- Potential temperature drop from the 11:17 to the 12:00 sounding is 3 K between ground level and 500 m height. Above 2000 m there is no drop visible in the profiles.

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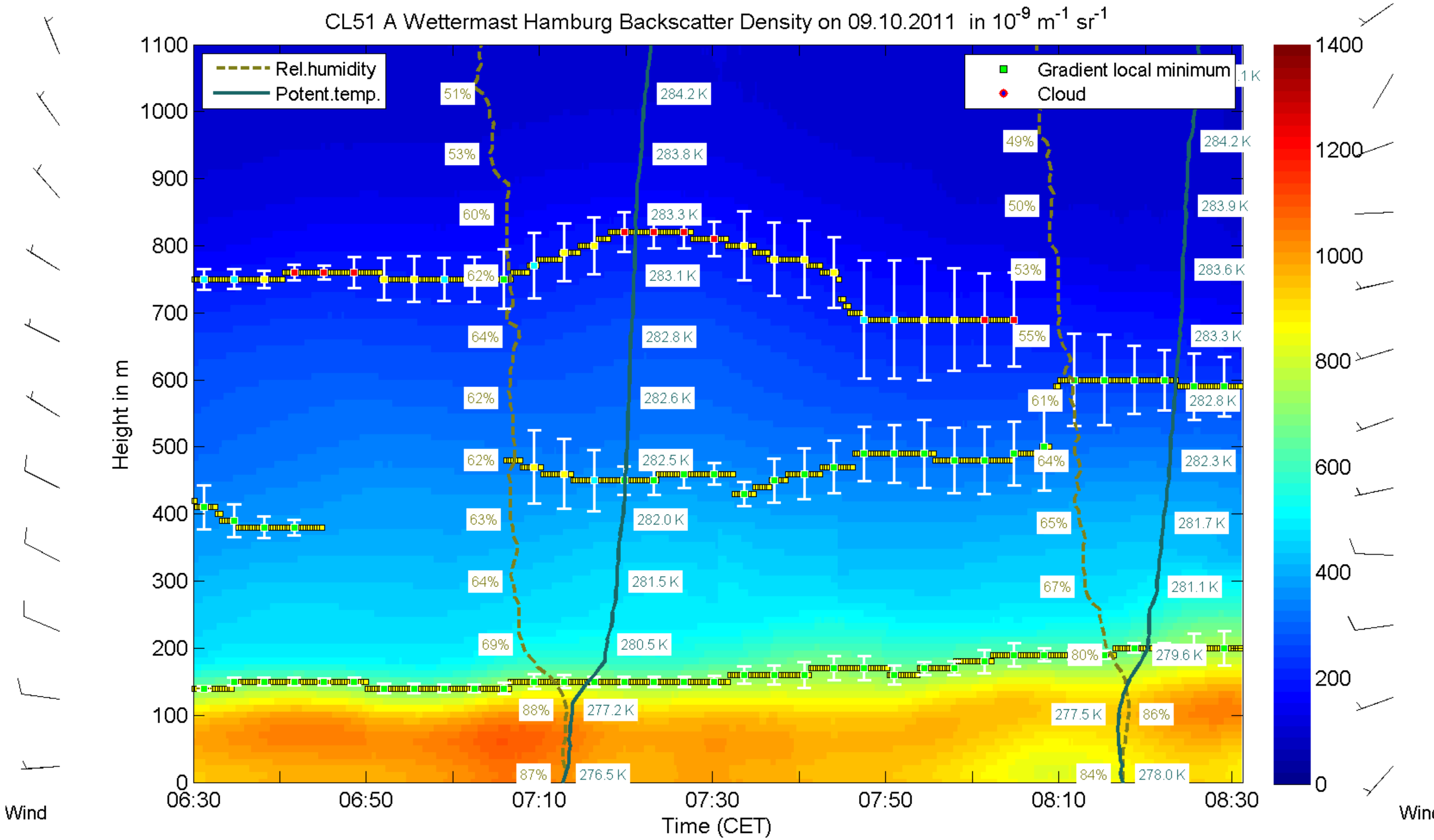
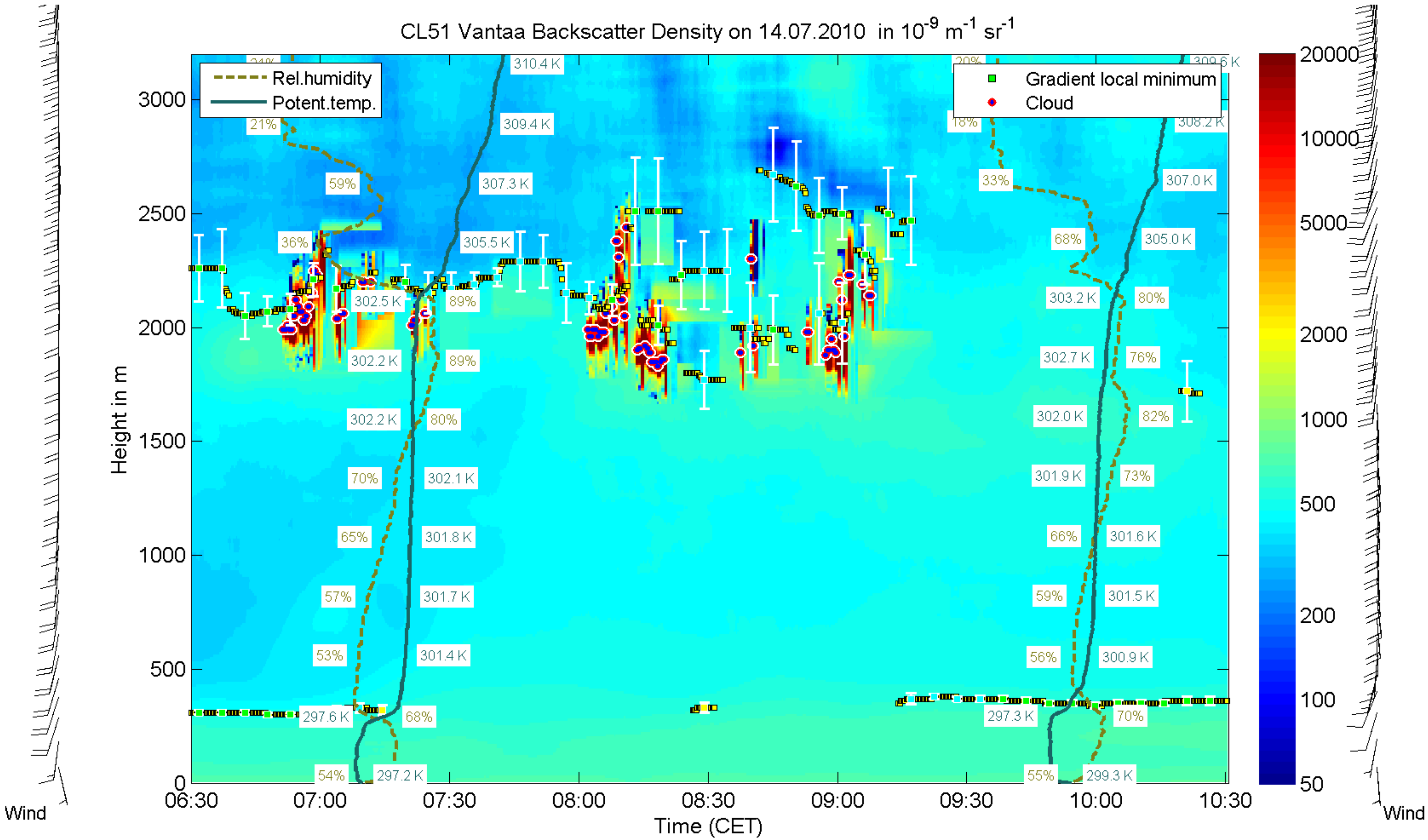


- Only the stable nocturnal layer from 140 m to 200 m shows well in the 07:13 and 08:17 soundings. This layer has an average uncertainty of 10.4 m and an average confidence level of 100 %.
- For the residual layer from 580 m to 820 m these values are 44.7 m and 70.3 %.
- For the in-between layer from 380 m to 500 m these values are 35.3 m and 94.5 %.

Comparison to soundings at Vantaa

- Ceilometers and radiosondes are manufactured and tested at Vaisala headquarters in Vantaa, Finland.
- Two examples from summer (+28 °C) and winter (-15 °C) show
  - aerosol content of the atmosphere is generally less than in Hamburg
  - layers with stable heights feature short error bars and are well visible in
    - potential temperature profile
    - relative humidity profile
  - even in very clear winter conditions the BL-VIEW algorithm detects layers that are also visible in the relative humidity profile



- Left and right: 07:10 and 09:54 sounding wind barbs. Wind is from the south with up to 10 ms^{-1}.
- The 300 m layer shows in both soundings as potential temperatur rise and humidity drop.
- The 2200 m humidity drop coincides with cloud base detection at 07:10.

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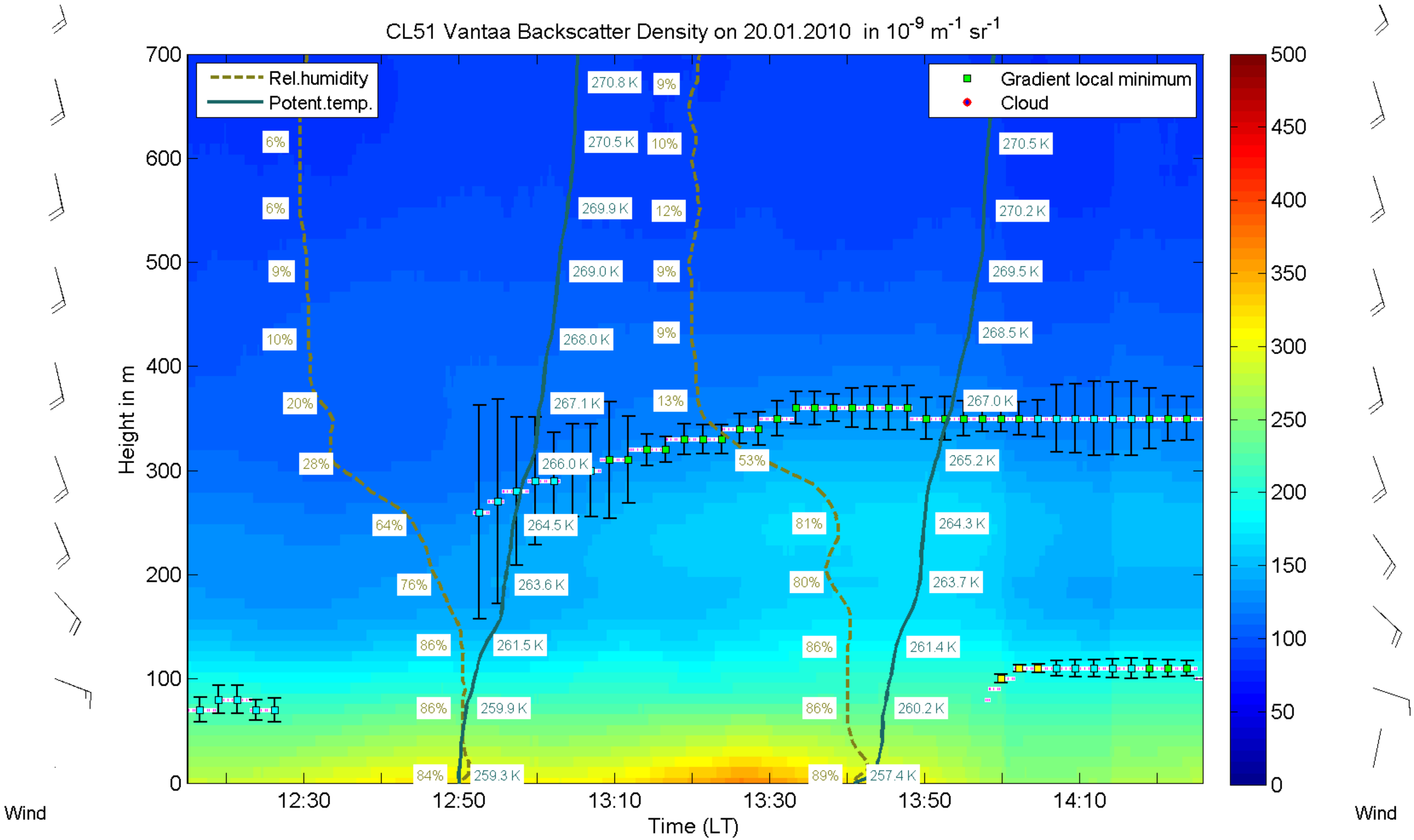

- The 350 m layer is reflected in the sharp humidity drop of the 13:40 sounding.
- This drop is much less distinct for the 12:50 sounding. A layer with much larger error bars is detected at that height after 12:50.

Conclusions and outlook

- The method outlined in this presentation shows satisfactory results for the Vaisala ceilometers CL31 and CL51.
- There is a good agreement with mixing layer heights derived from soundings.
- Error bars are a good tool to assess the reliability of the results
- Evaluation of extensive databases from ongoing and projected measuring campaigns will be used for analysis and refinement of the proposed algorithm
  - Augsburg – 2 CL31, 1 LD40, ongoing since 2006
  - TW 2011, Hamburg – 4 CL31, 2 CL51, ongoing since April 2011
  - Tereno, Bavaria – 3 CL51, starting 2012

Acknowledgments

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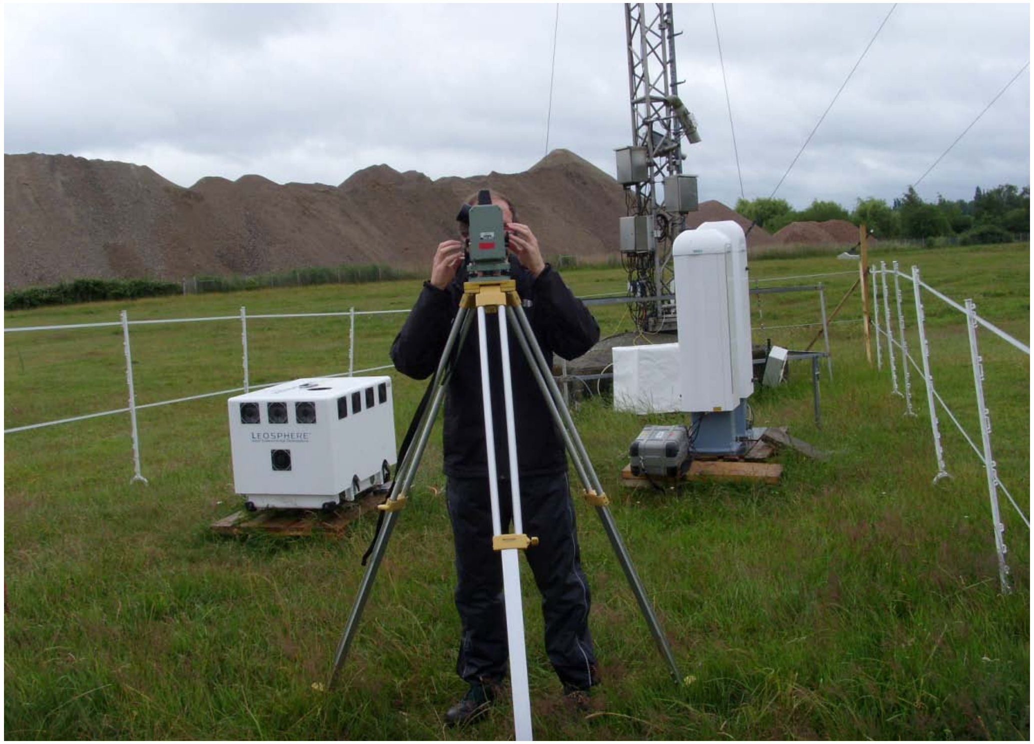

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