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Mixing height over London: spatio-temporal characteristics observed by Ceilometer networks

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Urban Boundary Layer

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- Mixing layer height **ML**: vertical boundary for pollutants

- Urban energy balance & surface roughness → turbulent mixing

Ceilometer laser (~ 910 nm) absorption & scatter

- Cloud ice/droplets, rain
- Aerosols
- Molecules/atmospheric gases, water vapour

Mixing & aerosol

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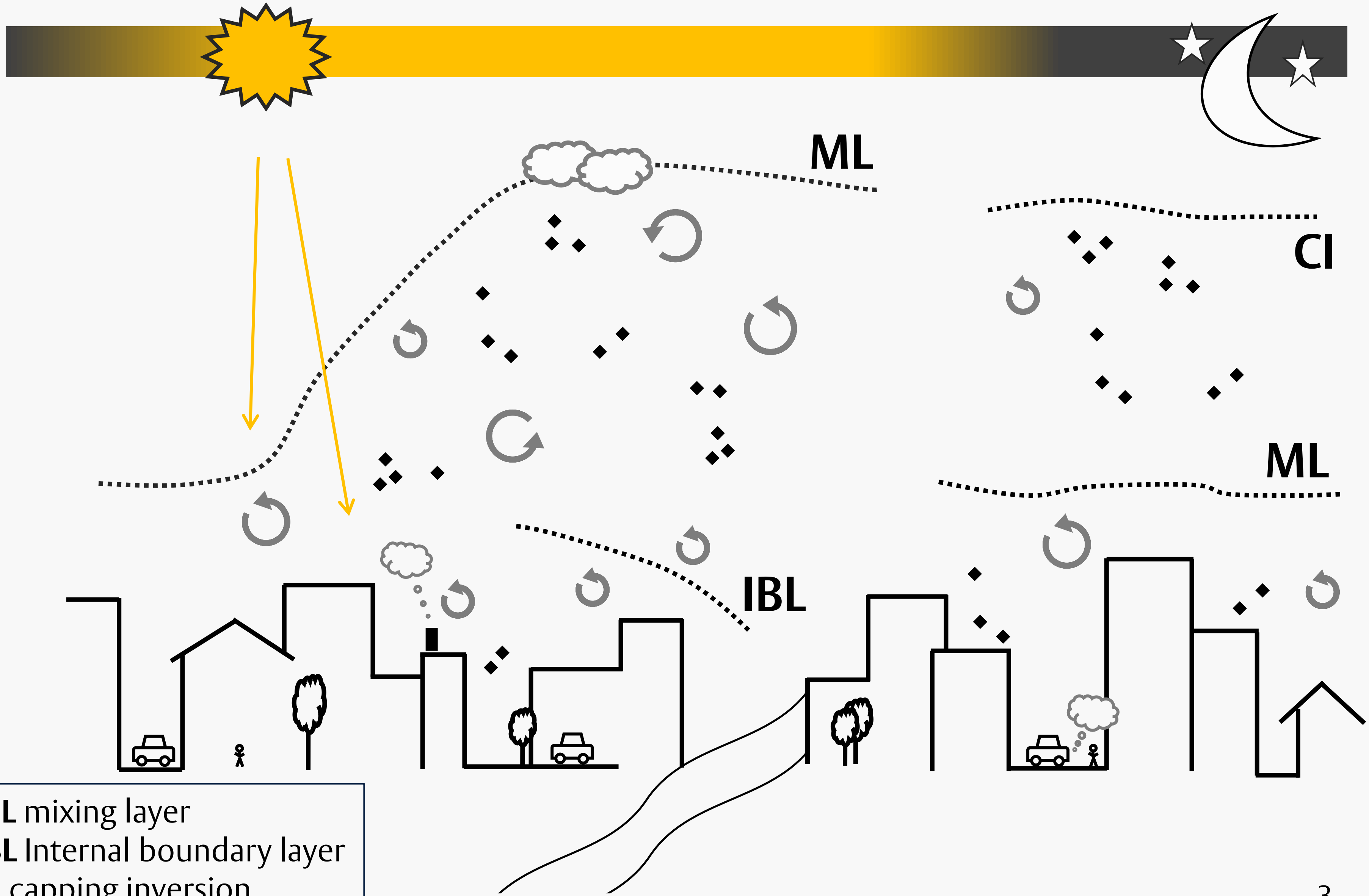

ML mixing layer
IBL Internal boundary layer
CI capping inversion

Ceilometer networks

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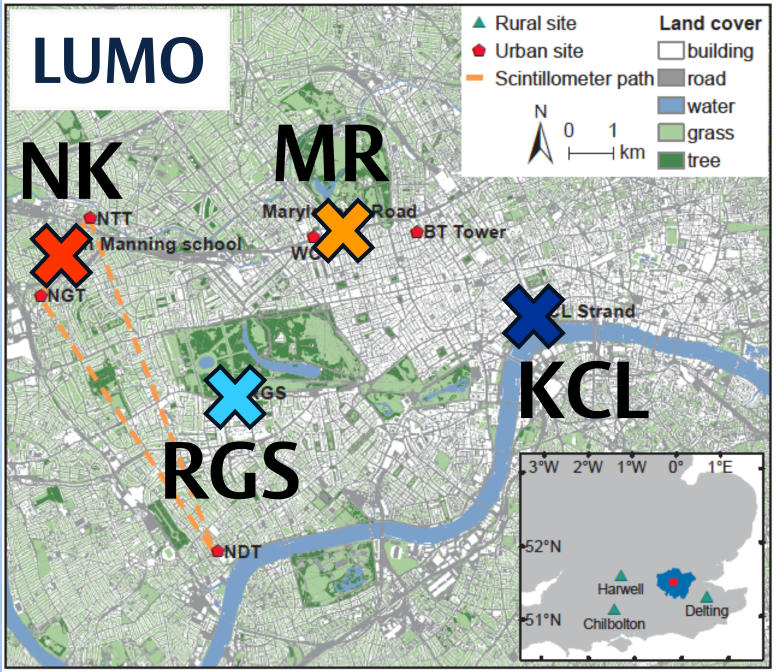
- CL31, CT25K (Vaisala)
- since 2008
- Central London (4 sites)
- Resolution: 15 s, 10 m

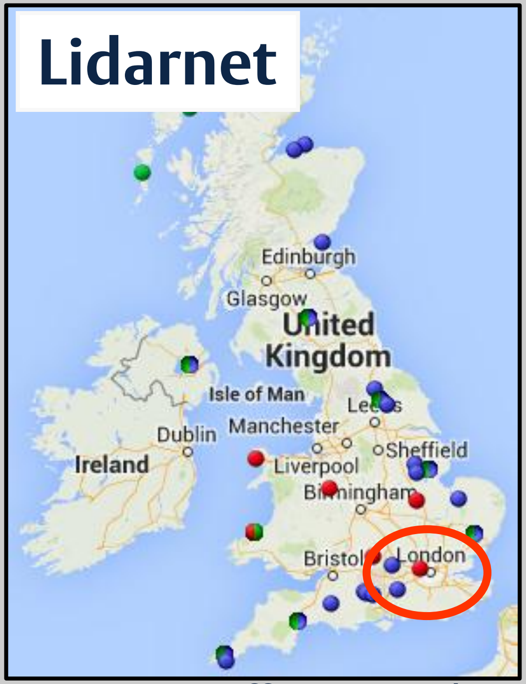
Bohnenstengel et al. 2014, BAMS



www.met.reading.ac.uk/micromet

Met Office

- CL31, CT25K (Vaisala) & CHM 15k (Jenoptik)
- UK, some close by
- Resolution: 30 s, 20 m



www.metoffice.gov.uk

Backscatter processing

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CL31 Vaisala Ceilometer

Optimised for cloud detection

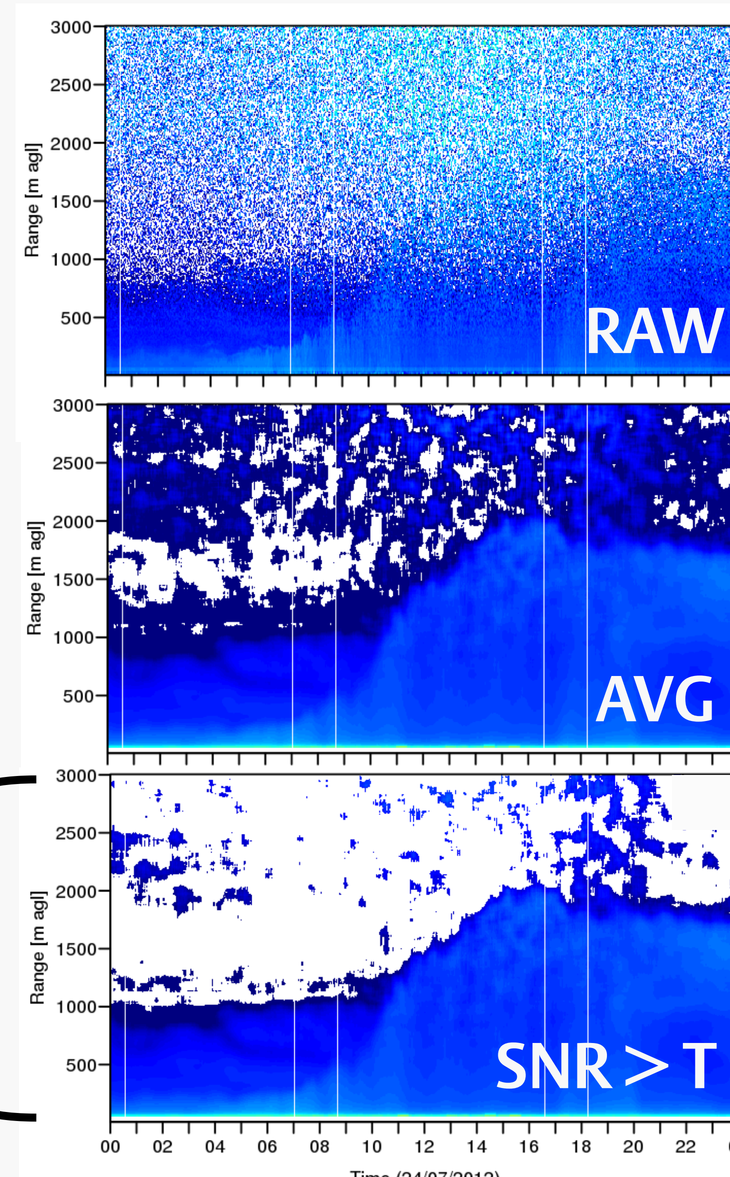
1) Cross-talk correction
2) Reverse background 'cosmetics'
3) Smoothing in space & time
4) Signal – to – noise ratio
5) Absolute calibration
6) Water vapour correction

TOPROF

EU COST action

http://www.toprof.imaa.cnr.it/

3 km



Mixing layer height detection

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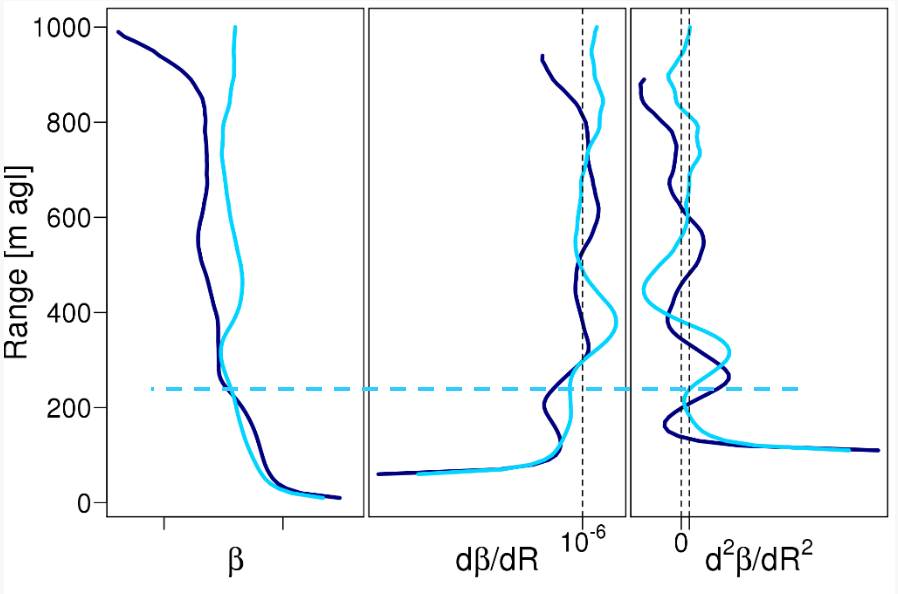
Adapted gradient method

(e.g. Emeis et al. 2008, MZ)

- $d\beta/dR < -10^{-6}$
- $d^2\beta/dR^2$ crossing
  - 0
  - 10^{-8} for $R < 300$ m at night



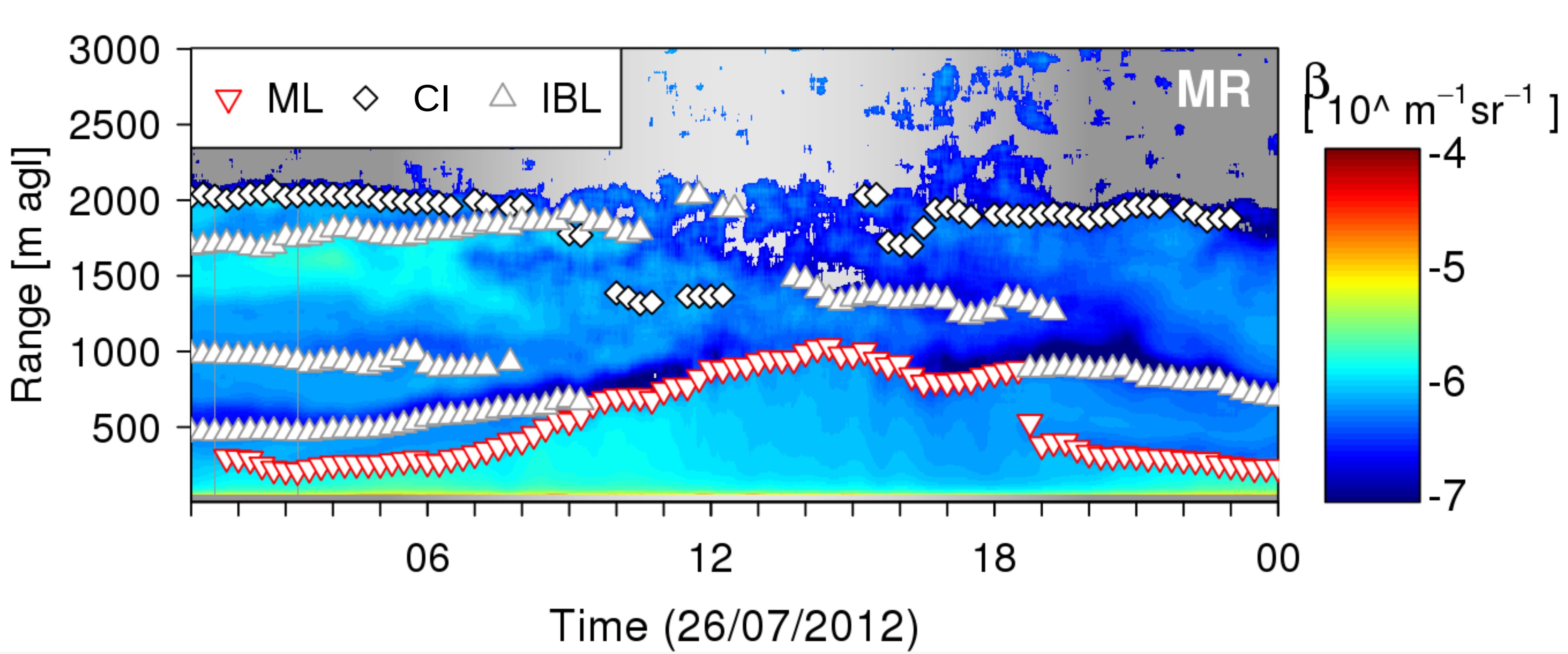
- dR = 100 m → first detectable layer at **150 m**

Track through time / height (e.g. THT, Martucci et al. 2010)

- Iterative layer connection:
  - Follow strongest gradient
  - Increasing window (time & range)

Layer attribution

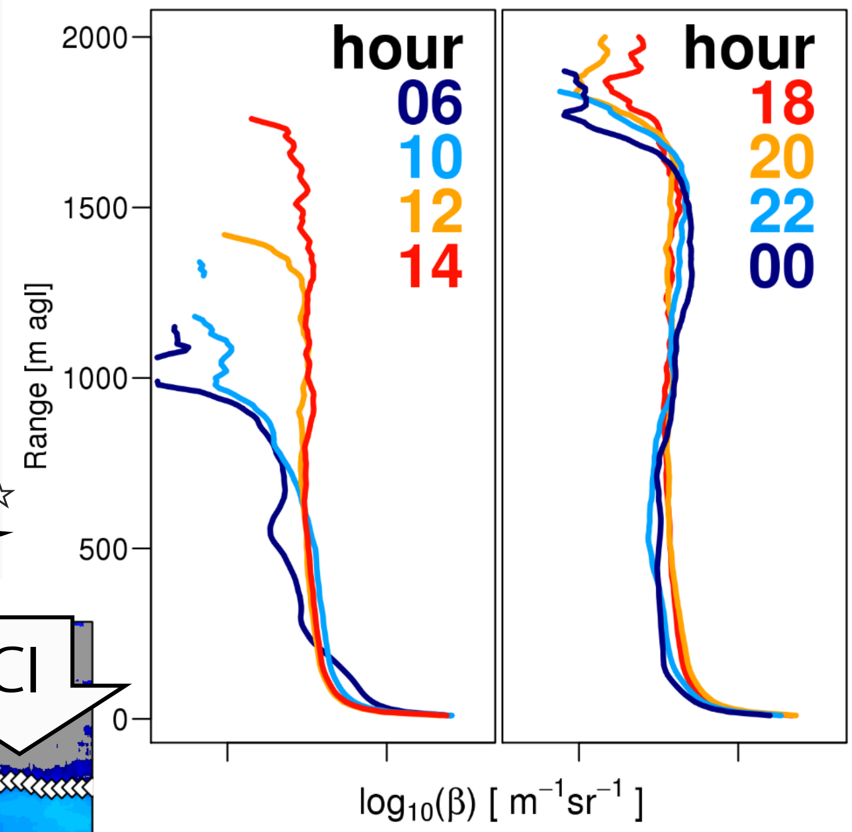
- **ML** lowest layer at sunrise and before midnight
- **CI** highest layer around midnight
- **IBL** others (up to 5)

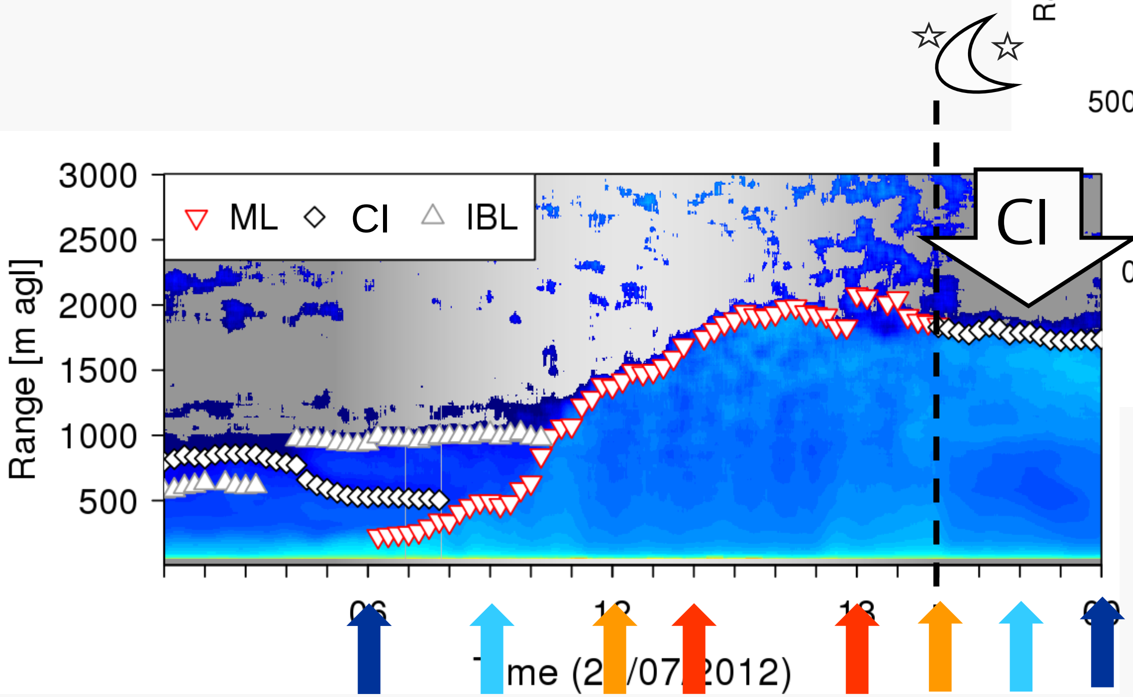


Layer attribution

If no CI above ML after sunset

ML → CI





Instrument inter-comparison

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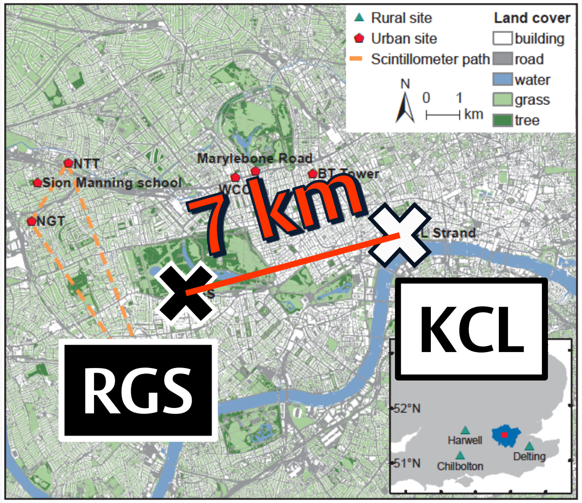
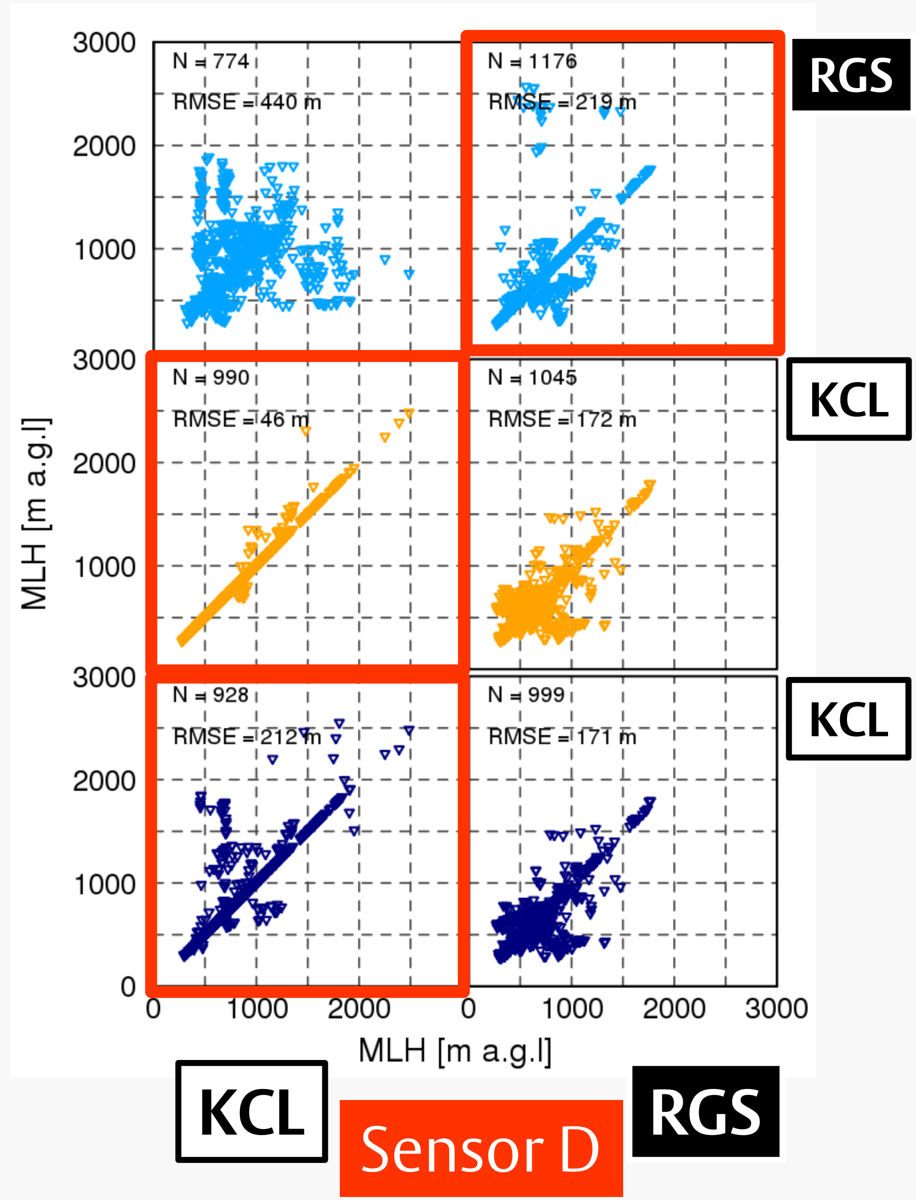


Sensor	Generation
A	old
B	old
C	new
D	new

- Two 13 day periods



Evaluation – Doppler LiDAR

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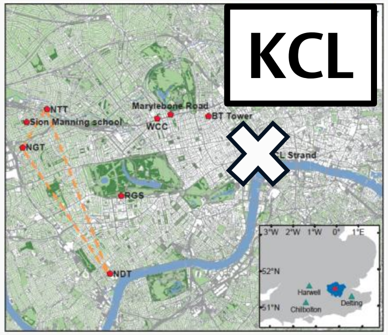
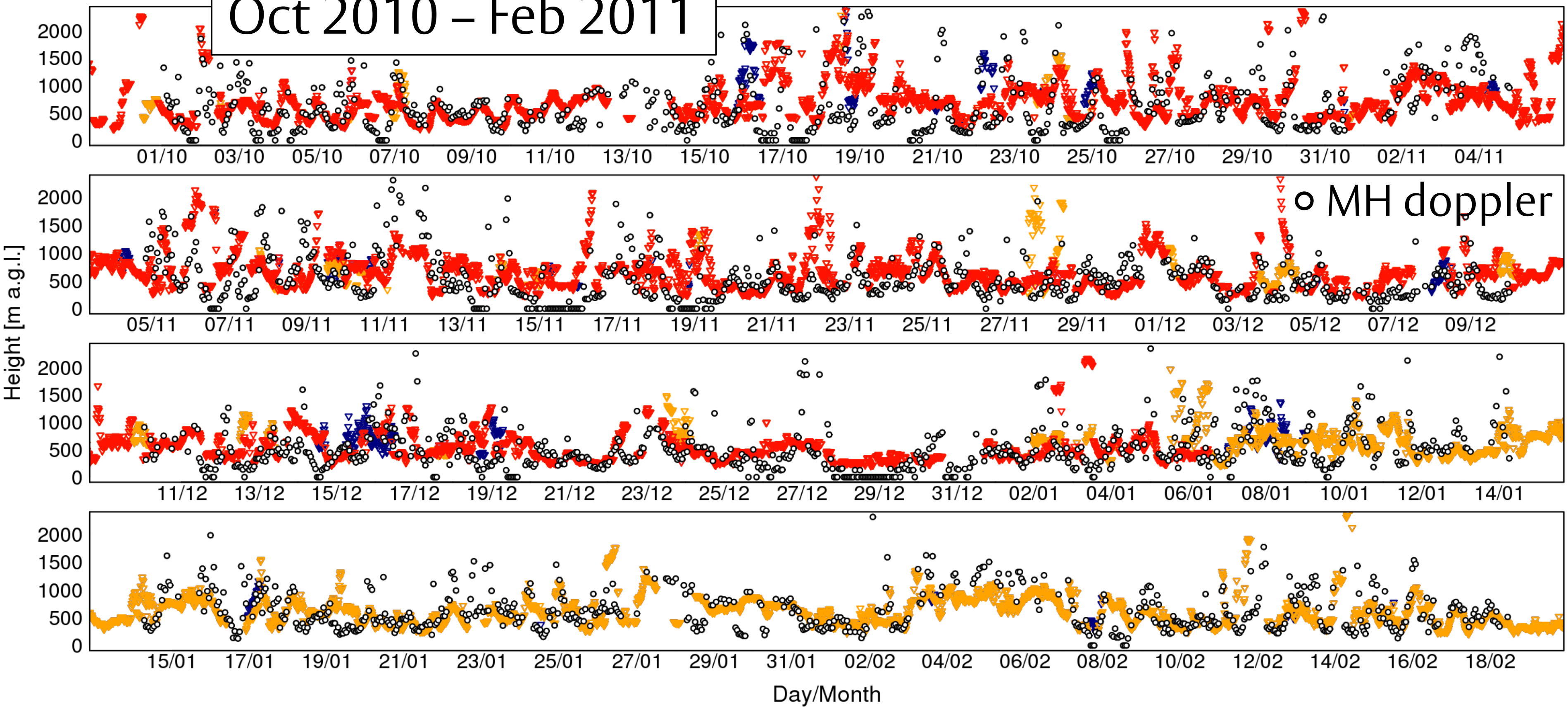
- Turbulence derived MH,

  Barlow & Halios, Univeristy of Reading
- ClearfLo, Bohnenstengel et al. 2014, BAMS, ww.clearflo.ac.uk

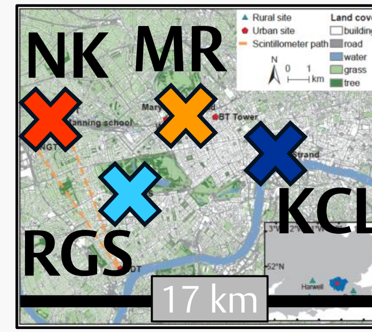


Oct 2010 – Feb 2011



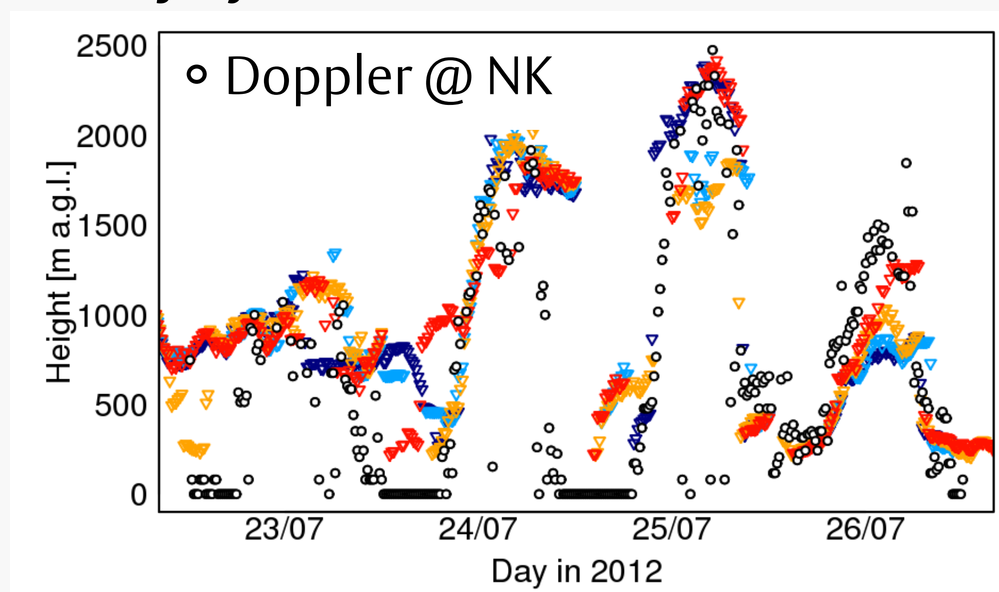
Evaluation – Doppler LiDAR

- Turbulence derived MH, Barlow & Halios, Univeristy of Reading
- ClearfLo, www.clearflo.ac.uk
  (Bohnenstengel et al. 2014, BAMS)



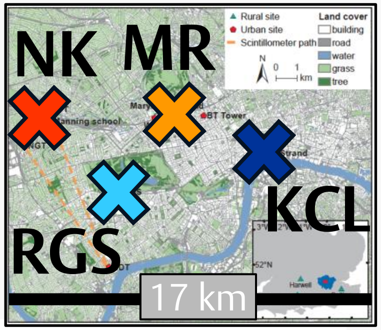
- Well – mixed:
  - good agreement
- Need to check:
  - night-time
  - cloudy conditions

July 2012

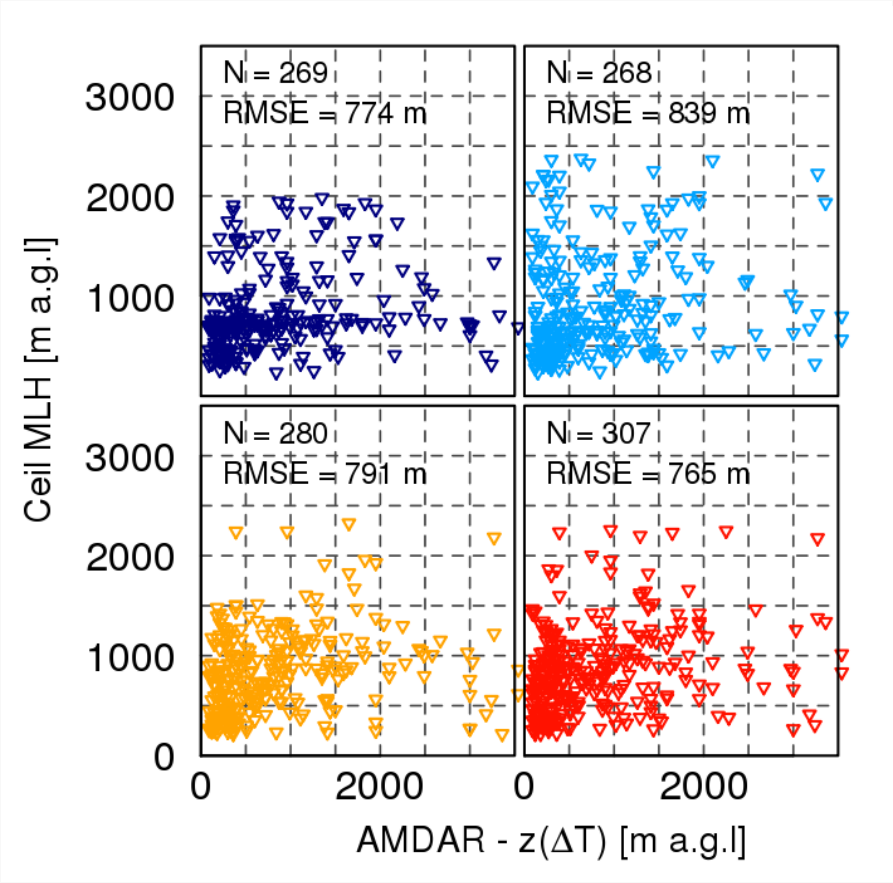


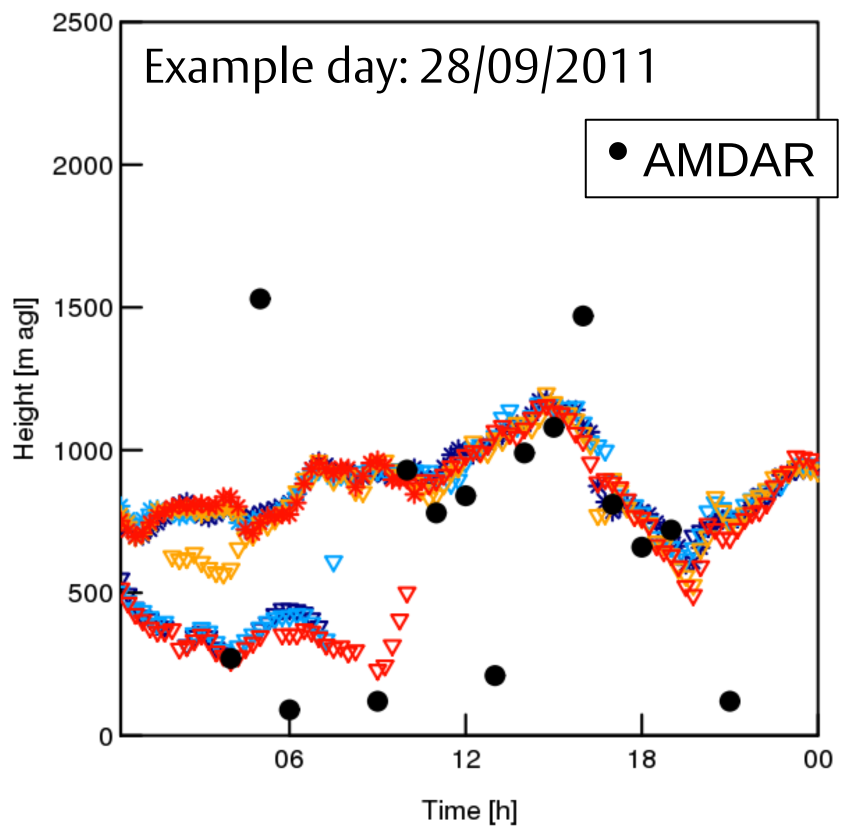
Evaluation – Aircraft Data (AMDAR)

University of Reading



- source http://amdar.noaa.gov/
- Hourly average data around London, clear-sky days
- Takeoff and landing times (i.e. not throughout night)





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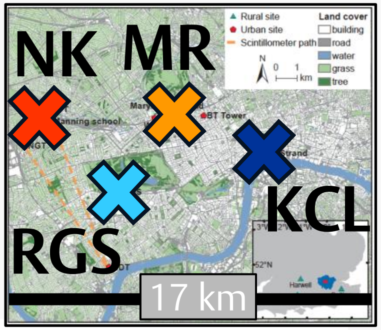

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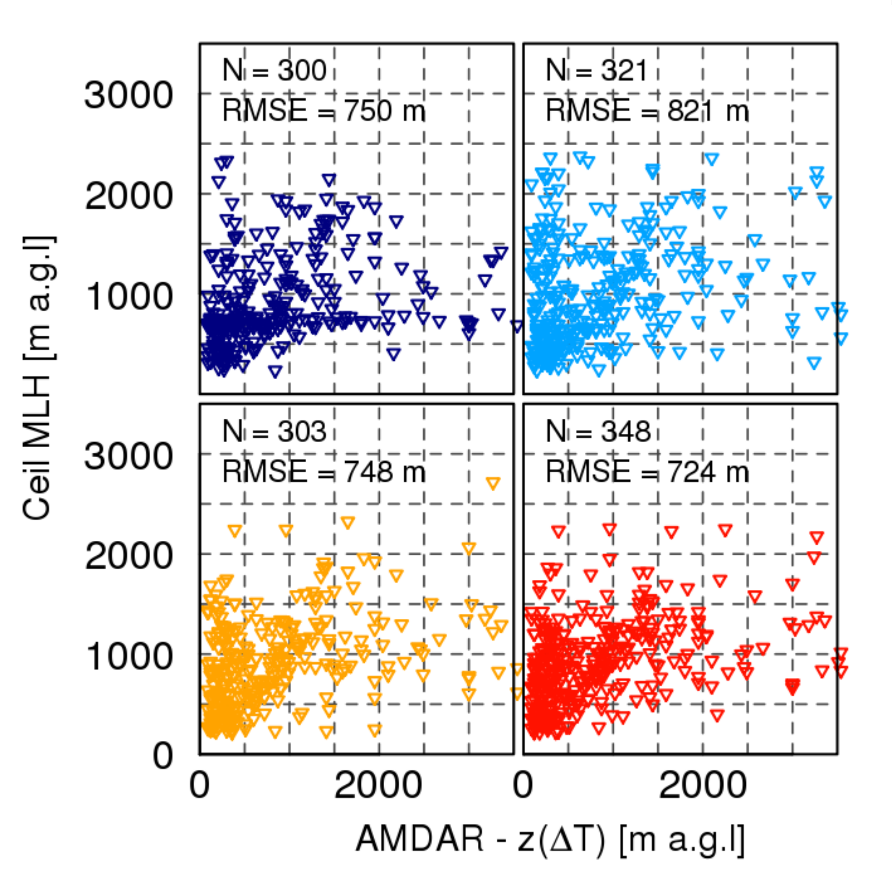
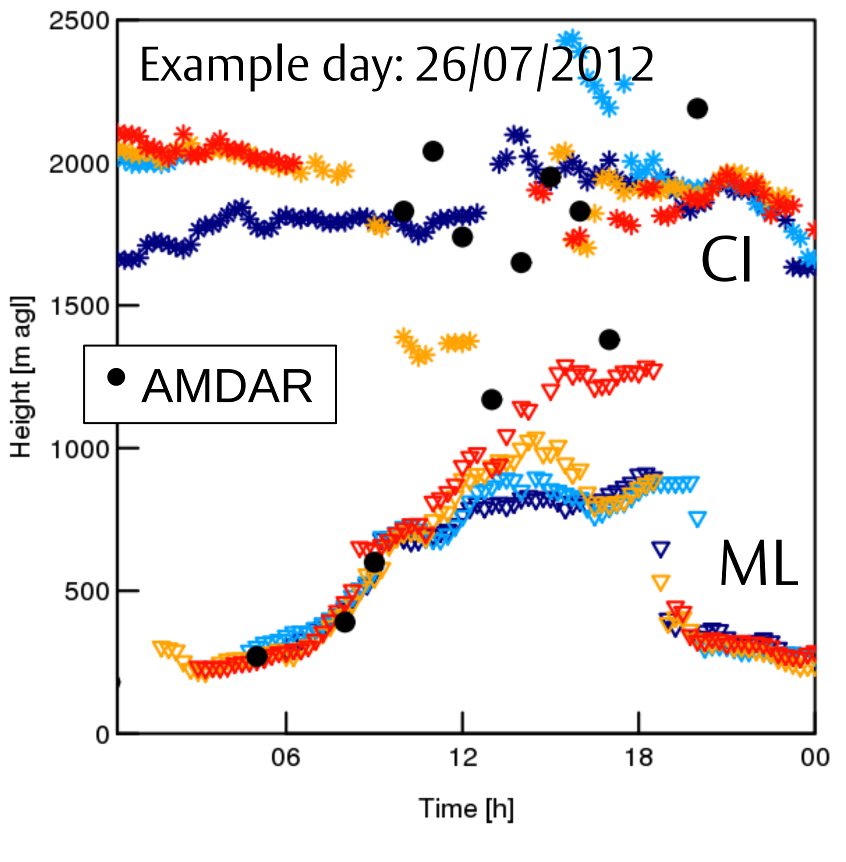
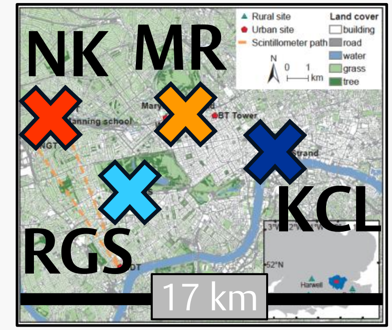
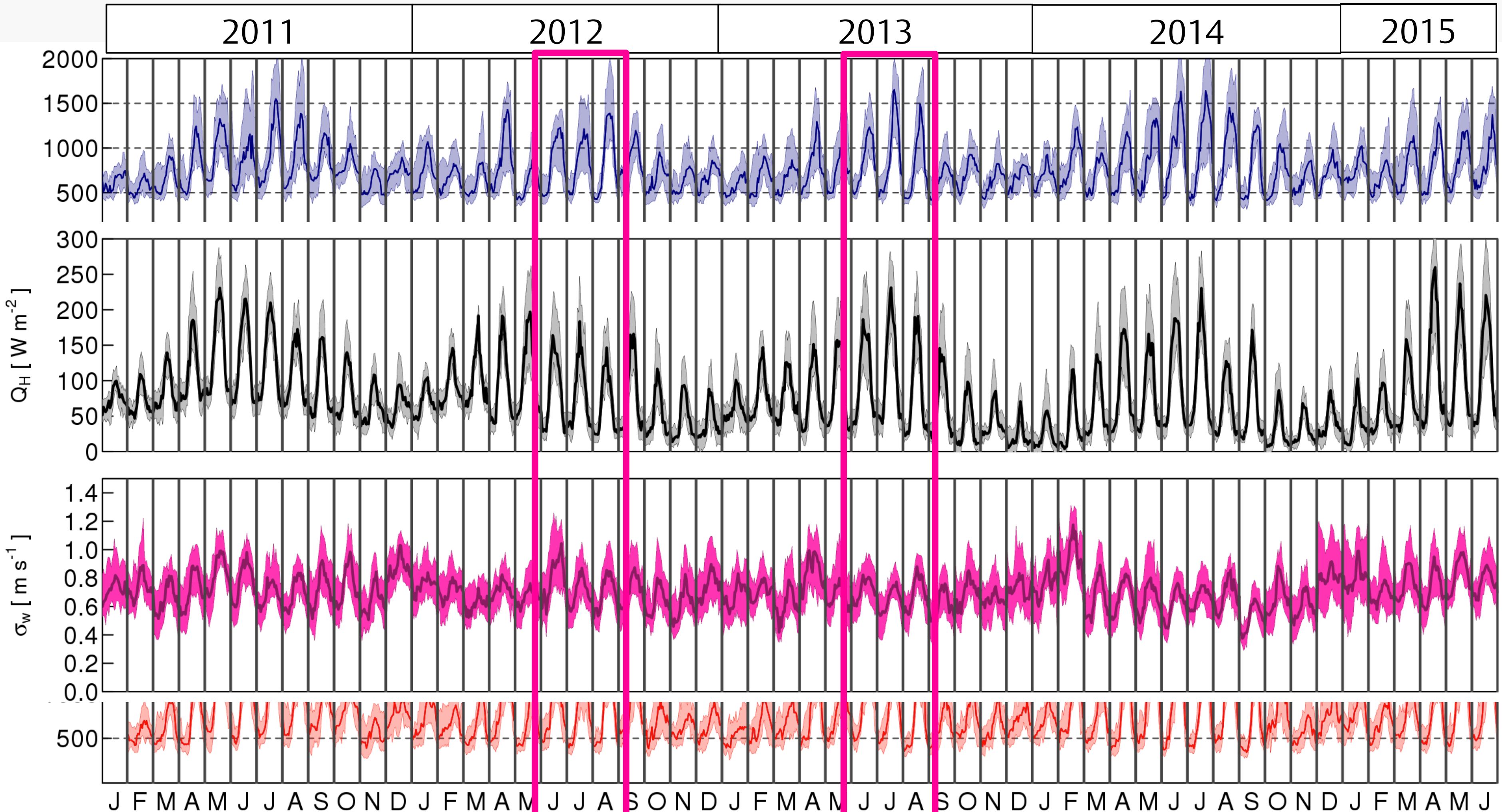




Climatology

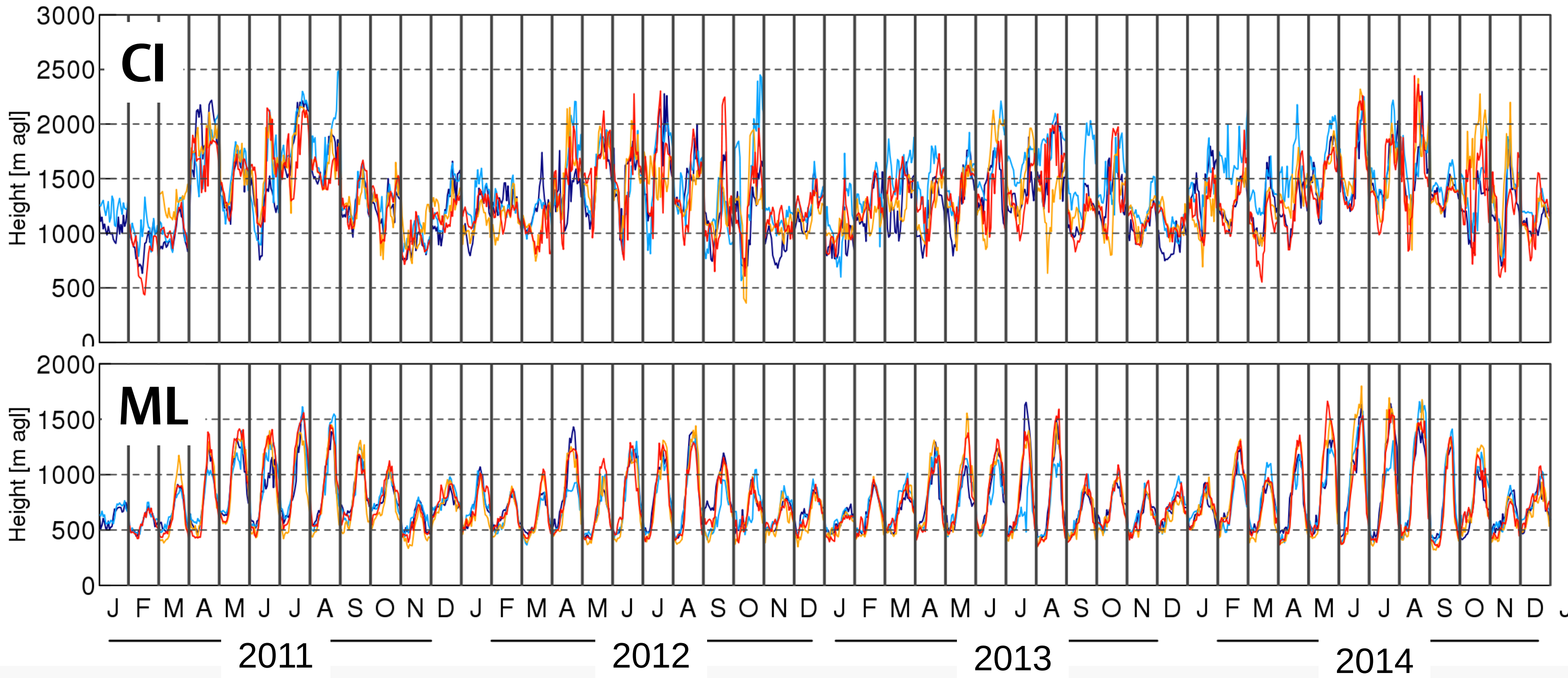




Median & IQR (60 min)

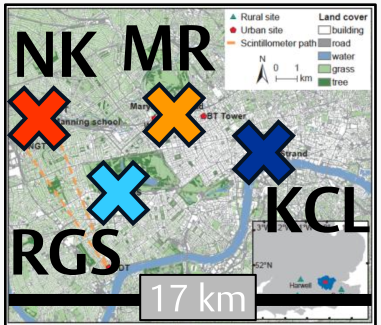
Climatology

University of Reading

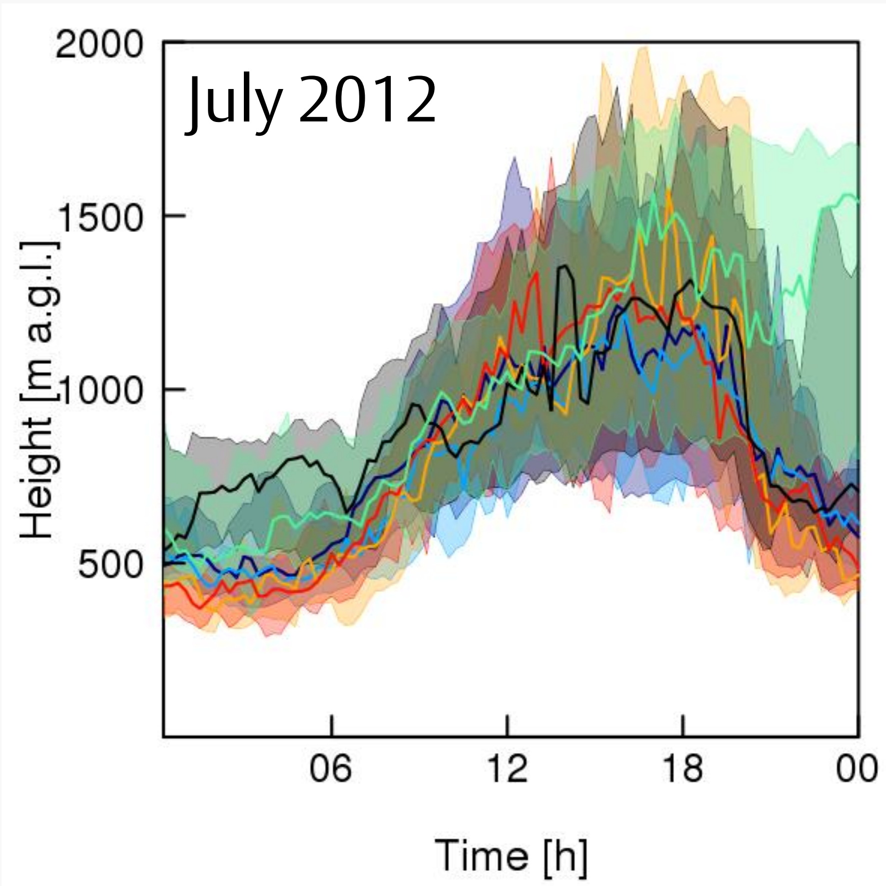


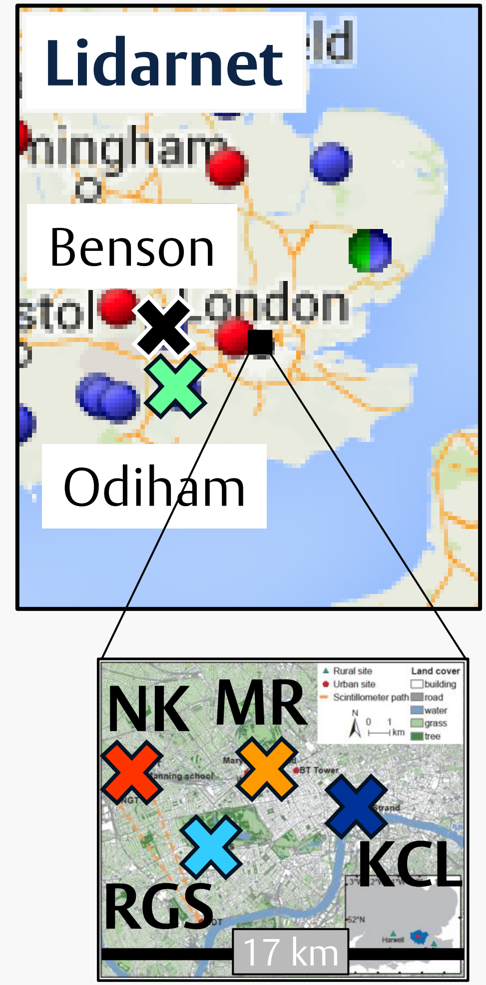
Day: summer ~ 1300 – 1500 m
winter ~ 800 – 1000 m

Night: ~ 500 m



Spatial variability



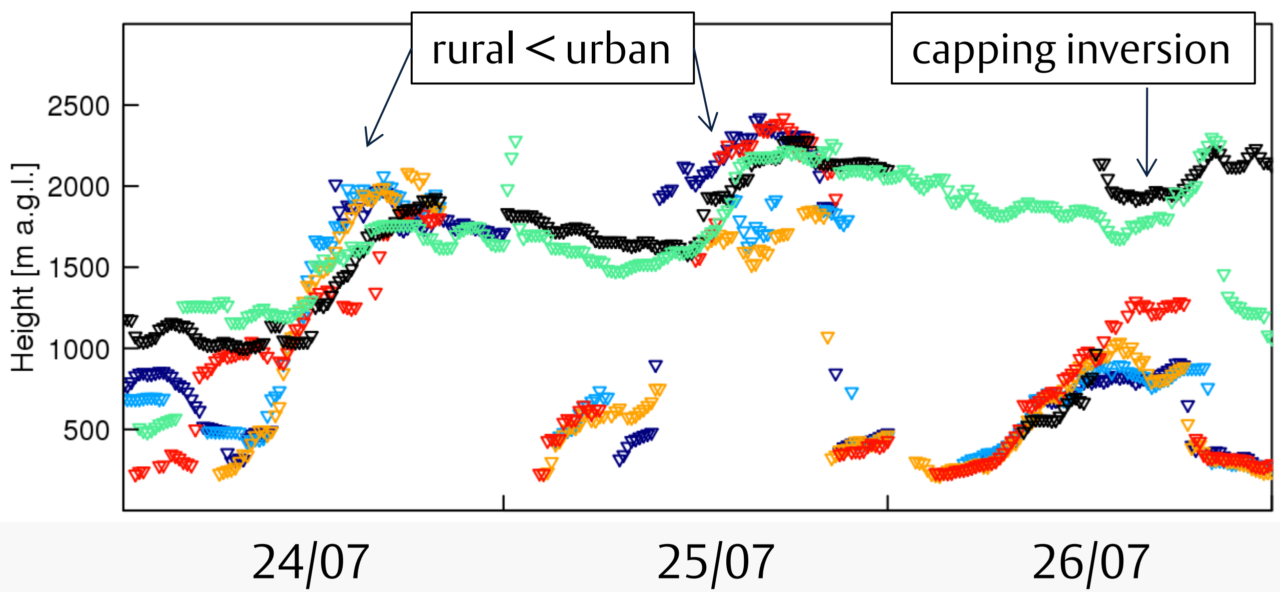


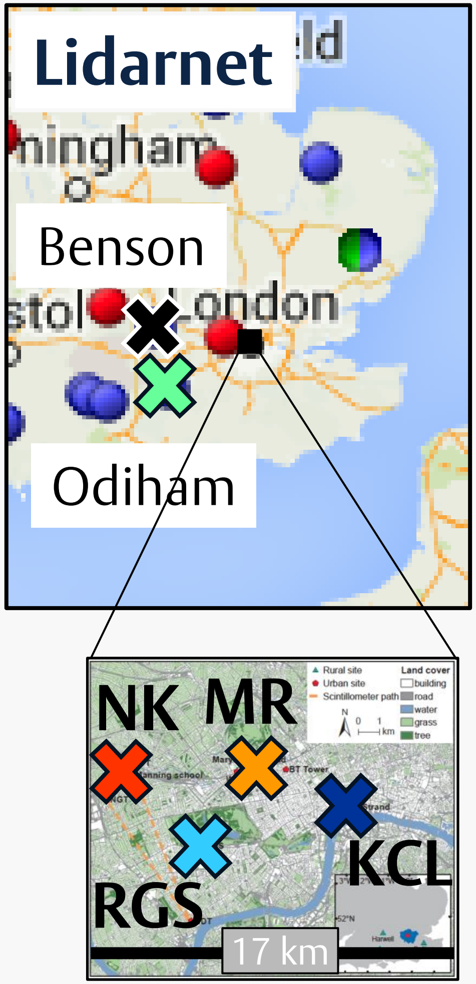
Benson & Odiham Met Office stations

- ~ 60 km west of London

www.metoffice.gov.uk/public/lidarnet/lcbr-network.html

Spatial variability





Benson & Odiham Met Office stations

- ~ 60 km west of London

www.metoffice.gov.uk/public/lidarnet/lcbr-network.html

Conclusions

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- Long-term ML & CI climatology, 4 sites in central London
- Good sensor agreement (depending on generation)
- Evaluation against AMDAR and turbulence ML promising
- Clear seasonality & diurnal patterns
- Consistency with turbulent surface fluxes
- Urban > rural for convective boundary layer

Outlook

- Relation to atmospheric stability and other met observations
- Layer attribution at rural sites
- Case studies (Met Office; ClearfLo, e.g. seabreeze)

Acknowledgements

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- KCL, ERG/LAQN, and RGS for providing access and facilities at various sites
- Christos Halios and Janet Barlow for providing turbulence derived mixing height estimates!
- TOPROF community and Vaisala for collaborations regarding CL31 processing

References

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Emeis, S, K Schäfer, and C Münkel, 2008: Surface-based remote sensing of the mixing-layer height a review, *Meteorol Z*, **17**, 621-630.

Martucci, G, C Milroy, and C, O'Dowd, 2010: Detection of Cloud-Base Height Using Jenoptik CHM15K and Vaisala CL31 Ceilometers, *J Atmos Ocean Tech*, **27**, 305-318.

Münkel, C, J Räsänen, and A Karppinen, 2007: Retrieval of mixing height and dust concentration with lidar ceilometer, *Bound Lay Met*, **124**, 117–128.

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Instrument details

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Network	Site	Model	Firmware	Mode
LUMO	KSS45W	CL31	1.6, 1.715	H2_on
LUMO	RGS	CL31	1.6, 1.715	H2_on
LUMO	NK	CL31	2.012, 2.026	H2_on
LUMO	MR	CL31	2.012, 2.026	H2_on
MetOffice	BD	CL31	1.70	H2_off
MetOffice	MW	CL31	2.02	H2_off

Backscatter processing

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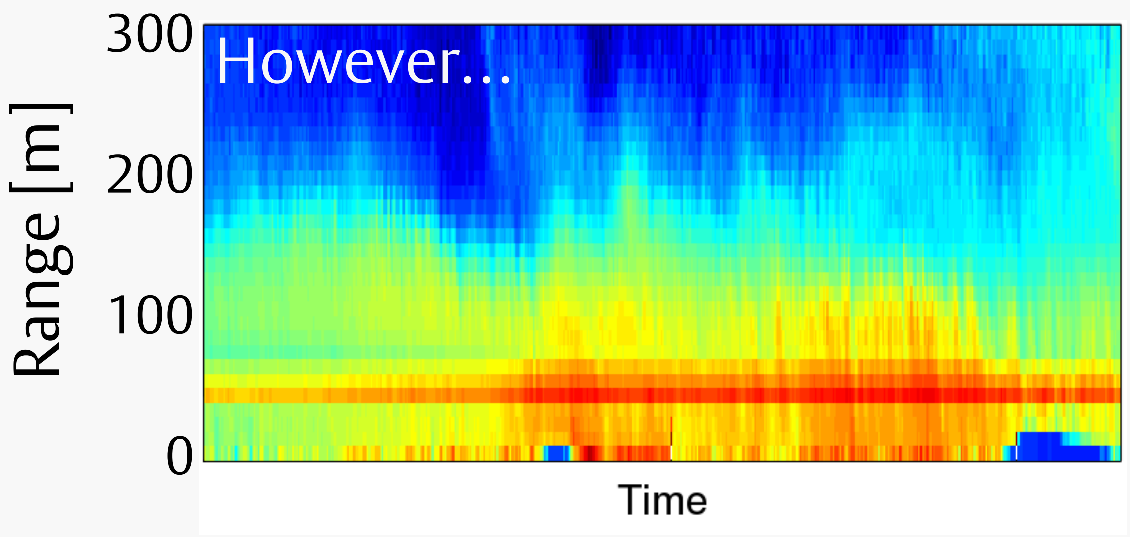
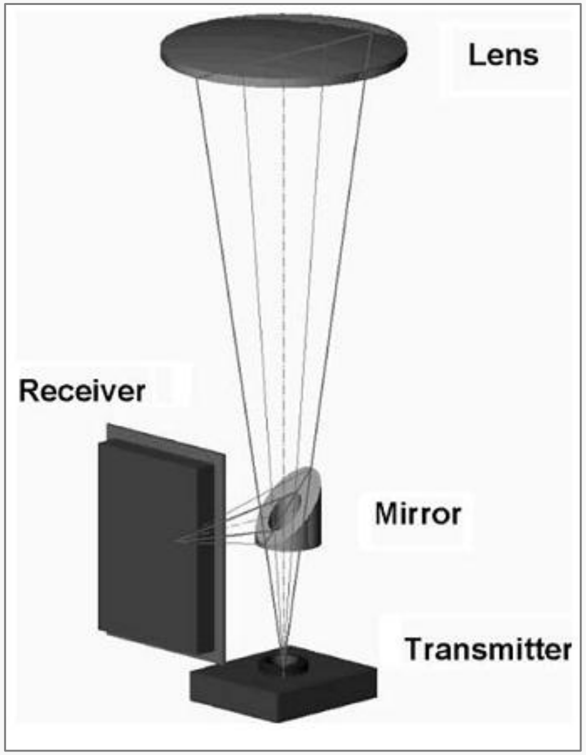
CL31 Vaisala Ceilometer

1) Cross-talk correction

Vaisala co-axial optical concept:

- No overlap correction
- Backscatter useful up from 1st gate

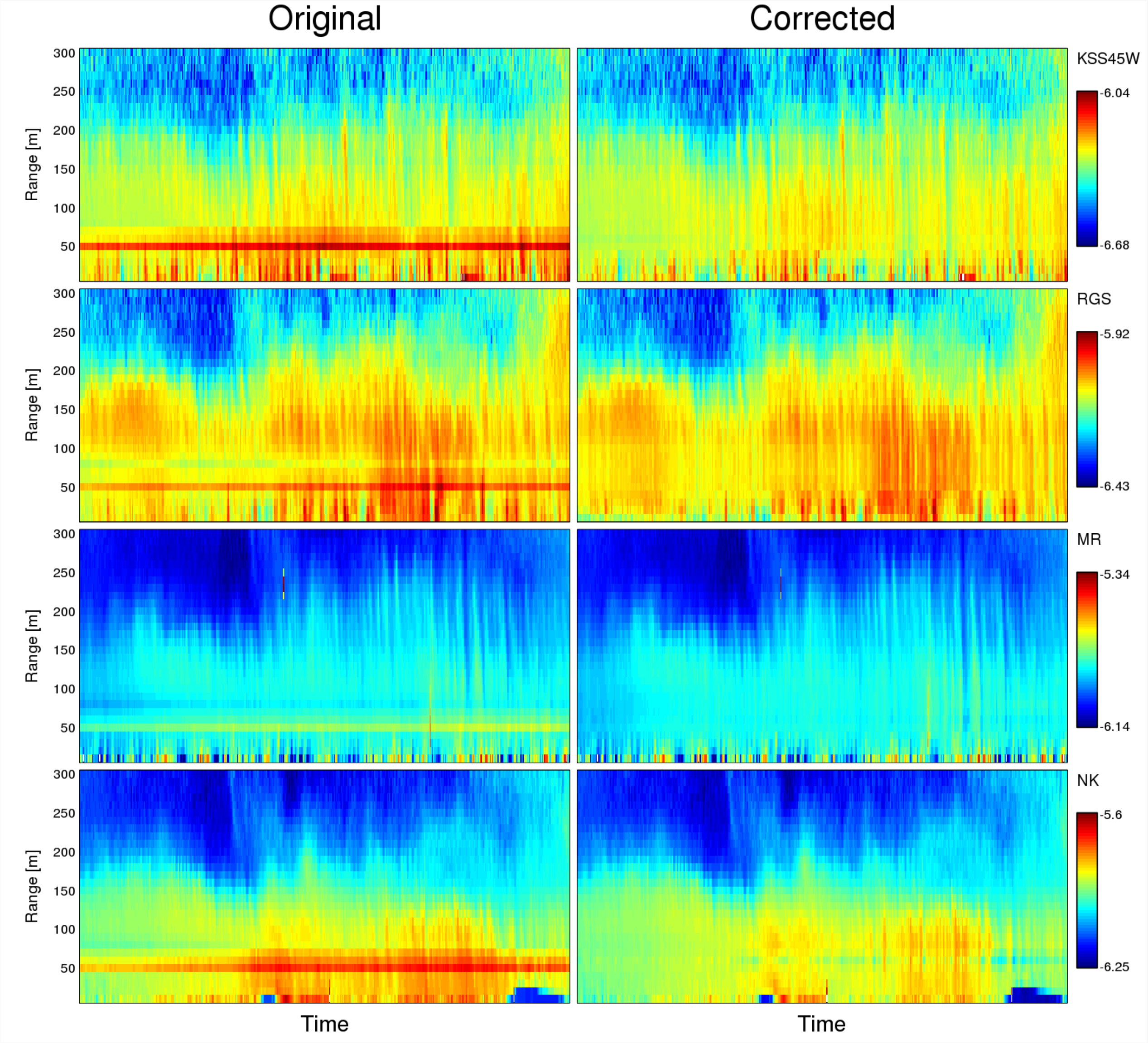




Münkel et al. 2007, BLM

Backscatter processing

Cross-talk:
- systematic
- firmware dependant



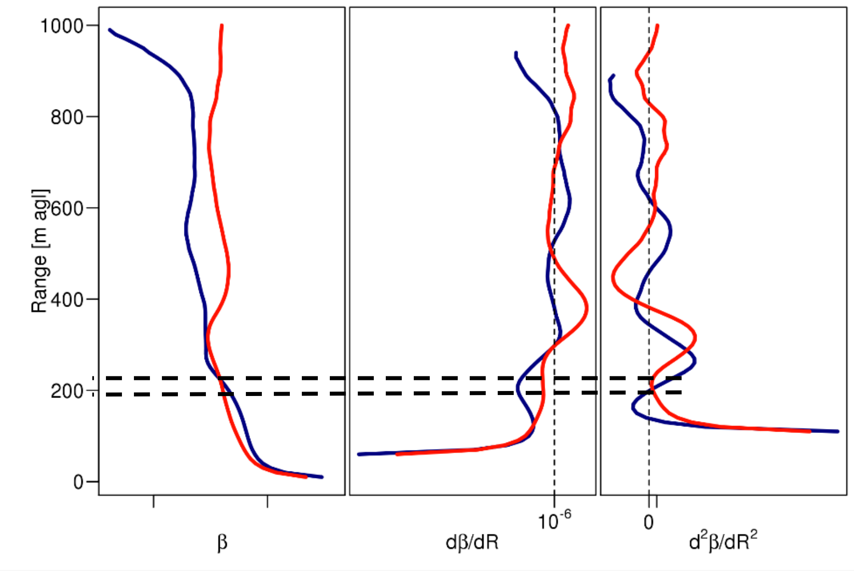
Mixed layer height detection

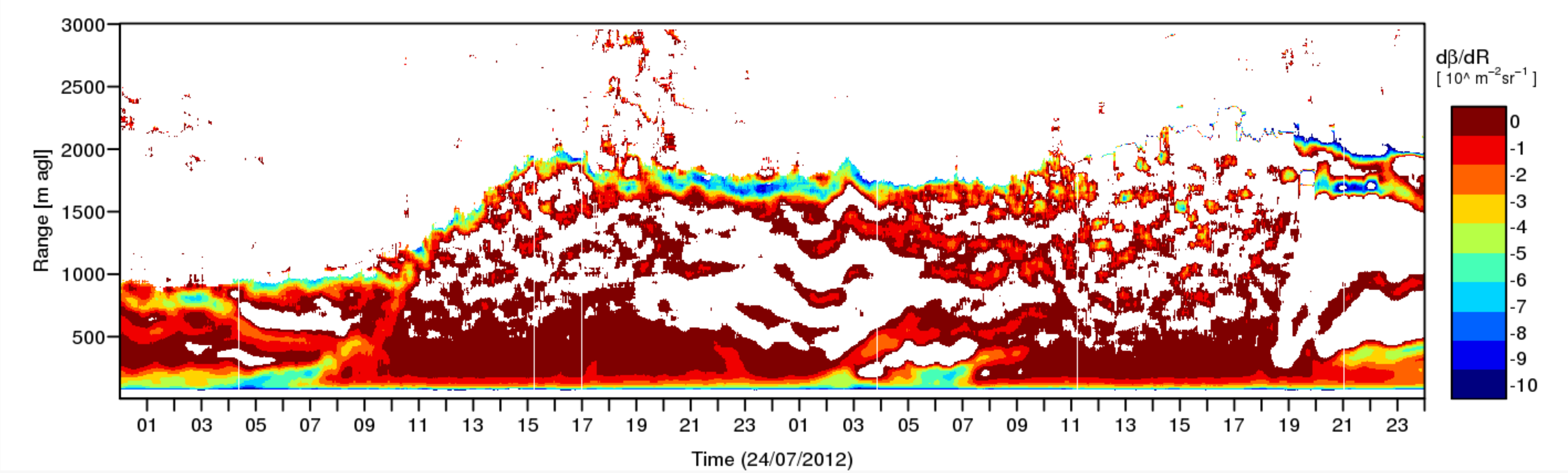
Adapted gradient method

(e.g. Emeis et al. 2008, MZ)

- Vertical gradient < -10^{-6}
- Derivative crossing 0

(or 10^{-8} for R < 300 m/night)



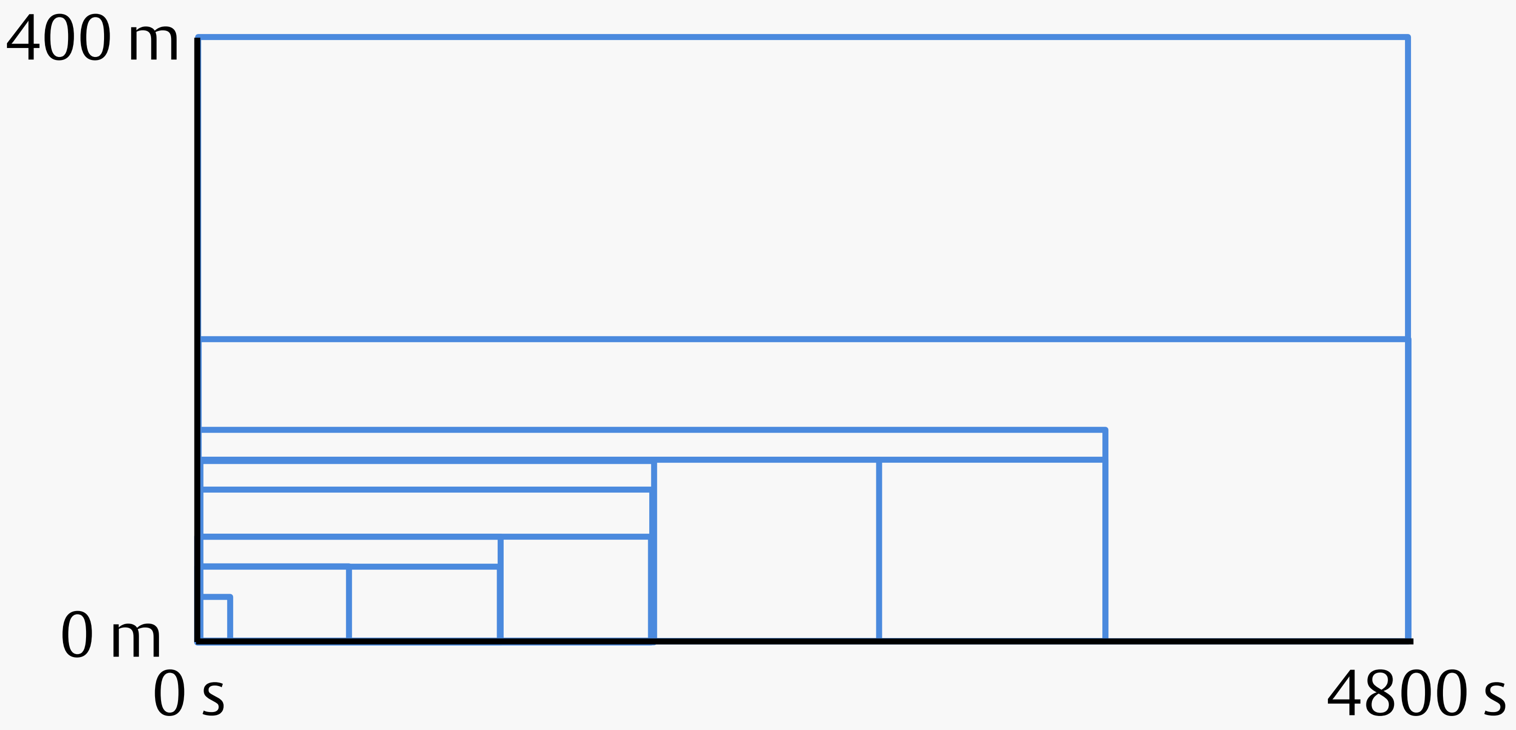


Mixed layer height detection

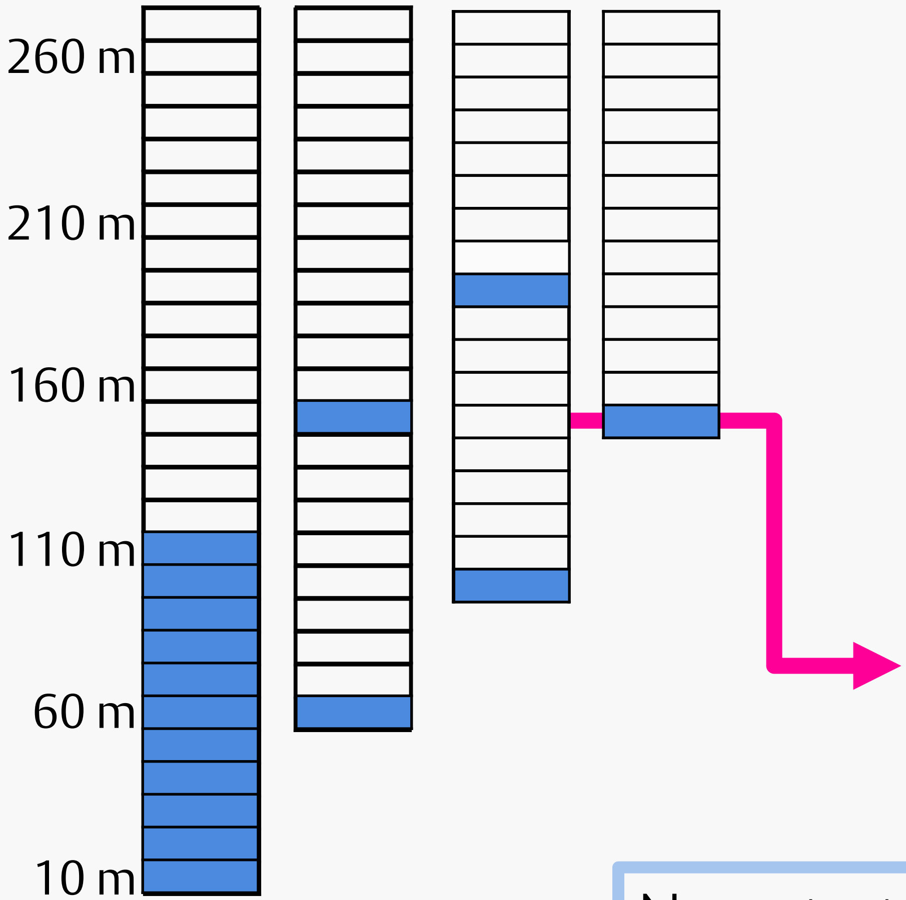
Track through time / height (e.g. THT, Martucci et al. 2010)

- Iterative layer connection

1) ± 15 s → ± 70 m
   - conflict: strongest gradient



Detection range



Current setup

- Smoothing:
  110 m window
- Gradient & derivative:
  100 m interval

lowest detection:
150 m

New strategy to target low levels