# Urban PBL evolution determined by ceilometer and weather prediction model in fair weather over Sofia

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## Abstract

The evolution of the atmospheric boundary layer over an urban area with complex topography is simulated using Advanced Research WRF (ARW) mesoscale numerical weather prediction model for five fair weather days (24 -28 August 2015) during summer of 2015. High resolution simulations are used to test performance of nine PBL schemes in predicting of boundary layer height against retrieved one from ceilometer profiles. Different gradient detecting algorithms for determination of PBL height from ceilometer data are also compared. Radiosonde data is used as a reference for validation of numerically simulated and ceilometer detected PBL heights. Despite using of different proxies' ceilometer and radiosonde retrieved PBL depths around noon are similar which indicate that ceilometers are suitable instruments for determination of convective PBL height in fair weather. In some periods, especially at night, analysis of ceilometer profiles does not allow an unambiguous determination of PBL height as it presumes a uniformly distributed aerosol. Therefore significant lack of concurrence with simulated values is not unexpected. Numerical simulations also revealed that influence of urban area on boundary layer evolution is mostly discernible during evening transition.

## Data and Methods

***Instruments***: Lufft's (Jenoptic) ceilometer CHM15k situated in the centre of Sofia in combination with upper air measurements based on radiosonde launching at National Institute of Meteorology and Hydrology (located 4.4km southeast of the ceilometer).

**PBLH detecting algorithms**:

from **CHM15k** profiles - 3 methods (two 1D and one 2D ):

- **1st derivative of PR²;**
- **modified idealised fit** (signed as **NLM**);
- **STRAT**.

NLM (non-linear model) allows simultaneous determination of planetary boundary layer height (PBLH), entrainment zone depth (EZ), height of full overlapping (FOH) and height of zero overlapping (ZOH). NLM is fitted to range corrected backscatter power.

$$NLM(z) = \left\{\left(\frac{S_{pbl}+S_{fa}}{2}\right) - \left(\frac{S_{pbl}-S_{fa}}{2}\right)\operatorname{erf}\left(2.77\frac{z-PBLH}{EZ}\right)\right\}\left(\frac{\operatorname{erf}\left(3\frac{2z-FOH-ZOH}{2(FOH-ZOH)}\right)+1}{2}\right)$$

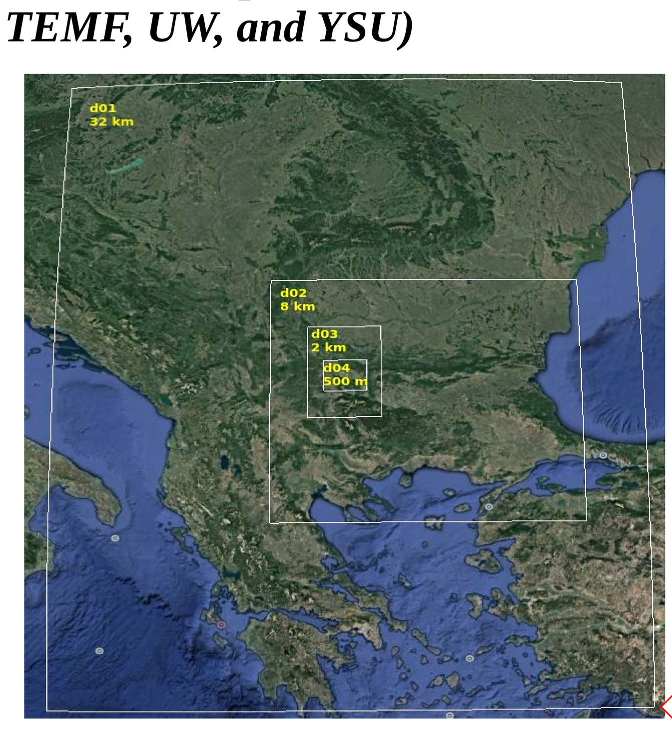
PBLH determination from **radiosonde** was carried out by 3 methods:

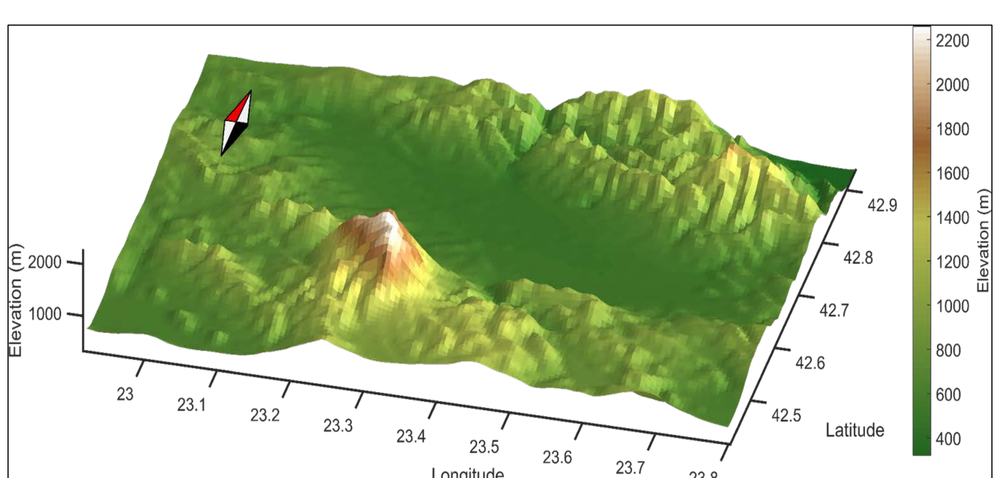
- **bulk Richardson method according (Ric=0.21);**
- **parcel method;**
- **lapse rate method ( dΘ/dz >2K/km).**

### *ARW-WRF v.3.8.1 model setup for the Sofia region*

***Configuration:***

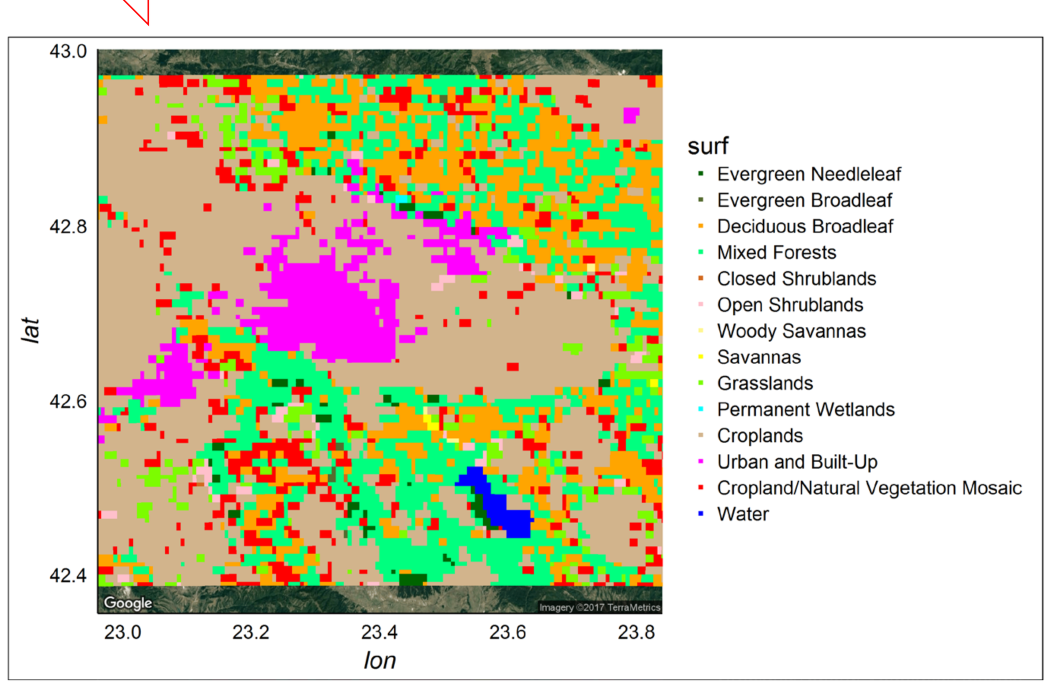
- ***Lambert projection (23.4°E, 42.68ºN)***
- ***4 nested domains with grid sizes of 32, 8, 2 and 0.5 kms***
- ***Resolution of the inner domain: 157x129x51***
- ***Input data: NCEP Final Analysis 0.25 deg***
- ***21 MODIS-based Land Use Categories***
- ***9 PBL parametrization schemes (ACM2, BouLac, MYJ, MYNN2.5, MYNN3, QNSE, TEMF, UW, and YSU)***



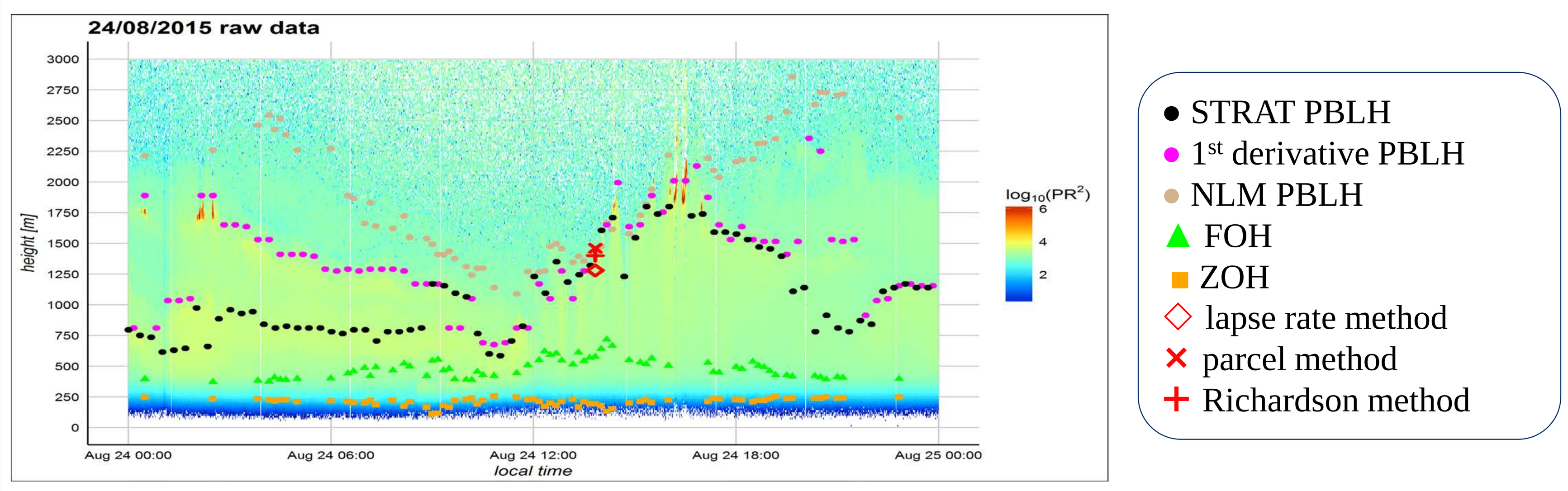

WRF domains (*left*); d04 inmost domain topography (*top*)

Land use categories in the inmost domain (d04)




## Results

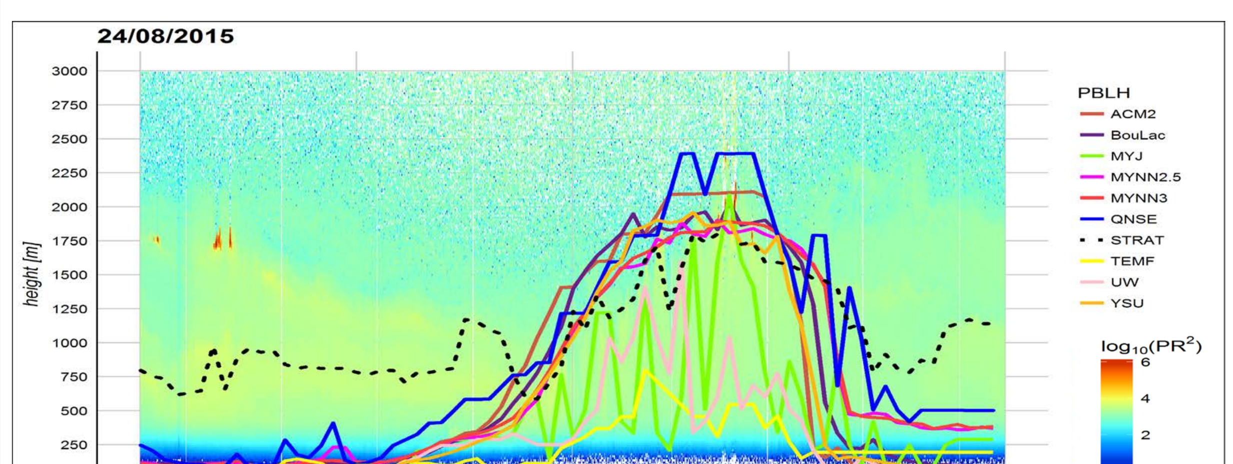
### *PBLH detection methods comparison:*




Multiple instruments and multiple methods inter-comparison of detected PBLH[m]

| date & time | STRAT | 1st der. | NLM PBLH | EZ | FOH | ZOH | Lapse rate | parcel | Ric |
|---|---|---|---|---|---|---|---|---|---|
| 24/08/15 13:30 LT | 1283 | 1395 | 1418 | 264 | 580 | 190 | 1280 | 1460 | 1400 |
| 25/08/15 13:30 LT | 1695 | 1755 | 2337 | 885 | 537 | 212 | 1670 | 1730 | 1710 |
| 26/08/15 13:30 LT | 1857 | 2355 | 2408 | 91 | 407 | 234 | 2260 | 2280 | 2280 |
| 27/08/15 13:30 LT | 1607 | 1650 | 1699 | 63 | 485 | 221 | 1330 | 1630 | 1630 |
| 28/08/15 13:30 LT | 1166 | 1170 | 1270 | 121 | 463 | 229 | 1160 | 1200 | 1200 |

### *WRF PBLH vs STRAT:*

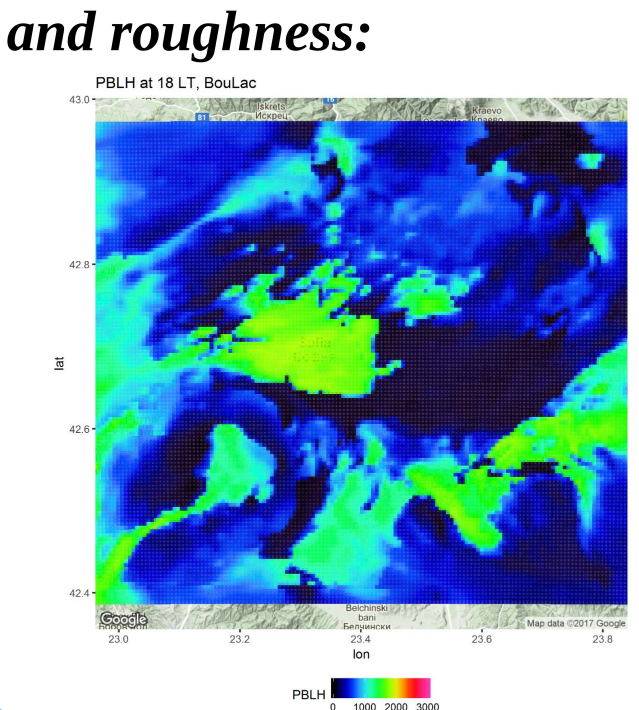


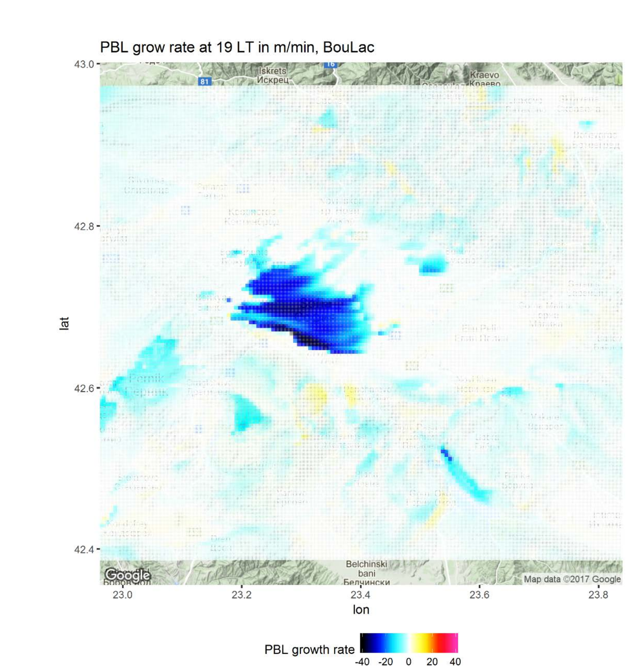

Best PBL scheme performance vs STRAT:
in the morning - ACM2;
in the evening - QNSE, MYNN2.5;

Worst performance:
TEMF , UW, & MYJ

| Accuracy metric | period | ACM2 | BouLac | MYJ | MYNN2.5 | MYNN3 | QNSE | TEMF | UW | YSU |
|---|---|---|---|---|---|---|---|---|---|---|
| RMSE | 8-12 LT | 708 | 774 | 950 | 783 | 806 | 649 | 905 | 978 | 848 |
| | 16-20 LT | 930 | 618 | 1046 | 483 | 550 | 472 | 1252 | 1278 | 805 |
| ME | 8-12 LT | -528 | -631 | -856 | -672 | -699 | -486 | -778 | -900 | -734 |
| | 16-20 LT | -516 | -283 | -905 | -246 | -382 | 96 | -1060 | -1165 | -497 |
| MAE | 8-12 LT | 626 | 683 | 857 | 687 | 708 | 552 | 797 | 900 | 750 |
| | 16-20 LT | 741 | 469 | 919 | 367 | 457 | 416 | 1072 | 1170 | 602 |
| IA | 8-12 LT | 0.54 | 0.50 | 0.42 | 0.49 | 0.46 | 0.53 | 0.45 | 0.42 | 0.47 |
| | 16-20 LT | 0.39 | 0.59 | 0.36 | 0.66 | 0.55 | 0.67 | 0.28 | 0.29 | 0.48 |
| COR | 8-12 LT | 0.46 | 0.44 | 0.36 | 0.46 | 0.40 | 0.40 | 0.35 | 0.45 | 0.43 |
| | 16-20 LT | 0.19 | 0.49 | 0.24 | 0.55 | 0.44 | 0.51 | -0.14 | 0.13 | 0.40 |

### *Urban effects on PBLH and its growth due to enhanced heat capacity and roughness:*




## Conclusions

It was shown that in convective situations retrieved by ceilometer PBLH is in very good agreement with determined by rawinsonde, despite using different tracers.

The new PBLH detection method proposed here is suitable for simultaneous evaluation of both PBLH, EZ and ceilometer's overlapping parameters.

In summary non-local PBL schemes represent better PBL evolution in the morning, local schemes, except TEMF, UW, MYJ, perform well in the late-afternoon and early evening.

In the evening PBL is higher above urban area as a result of higher heat capacity, but it decreasing rate is also higher because of increased roughness in the city.

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