Magazine of the Finnish Air Pollution Prevention Society / Ilmansuojeluyhdistys ry:n jäsenlehti
Issue 3 (2012)

Curtis R. Wood
Postdoctoral researcher
Finnish Meteorological Institute
Leena Järvi
Tutkijatohtori/Postdoctoral researcher
Department of Physics, University of Helsinki

Urban climate observations in Helsinki

Concentrations of atmospheric pollutants are affected by mixing and transport in the atmosphere – in particular, properties in the lower atmosphere such as the depth of the 'atmospheric boundary layer' (ABL) and atmospheric stability. Helsinki UrBAN (Urban Boundary-layer Atmosphere Network, http://urban.fmi.fi) is an intensive research-grade observational network for the study of the structure of the ABL and the physical processes in the ABL. Helsinki UrBAN is the most poleward intensive urban research observation network in the world.

To understand and predict the concentrations of air pollutants one needs to know the emissions, atmospheric processes and depositions. The atmospheric processes may be a combination of chemical, biological and physical processes. In particular, the physical processes in the lower atmosphere, such as transport and mixing, will lead to variations of pollutant concentration in space and time. We focus in this article on two key aspects: (i) the well-mixed atmosphere near the Earth's surface (the atmospheric boundary layer, ABL) and (ii) atmospheric stability.

Most international studies of ABLs above cities have focused on specific campaigns, often with less than one year of measurements. This has caused a lack of intensive research-grade long-term ABL observations over cities – particularly from high-latitude cities.

A new observation network has thus been developed: Helsinki UrBAN (Urban Boundary-layer Atmosphere Network, http://urban.fmi.fi). Helsinki UrBAN's major purposes are for: (i) understanding the physical processes in Helsinki's ABL, (ii) validation and development of numerical models (for weather prediction, air quality and chemical transport), (iii) discussing our findings with end users (city planning, energy providers, etc), and (iv) interaction with instrument developers to obtain cutting-edge instrumentation and data.

Some observational studies have already reported many findings on the physics of turbulence above Helsinki from point measurements using data from 2005 to present from the SMEAR III station situated in Kumpula, Helsinki (Vesala et al. 2008, Järvi et al. 2009, Nordbo et al. 2012). In Helsinki UrBAN, we add to those point measurements by also studying spatial scales up to the size of the city. Our state-of-the-art equipment will enable research-intensive observations to specifically monitor Helsinki's ABL at various spatial scales **(Fig. I, Table I)**. For example, we have invisible and safe lasers observing aerosol concentrations, wind and turbulence above Helsinki, and we have equipment at tall sites around downtown including on Hotel Torni and the Elisa mast and Sitra building.

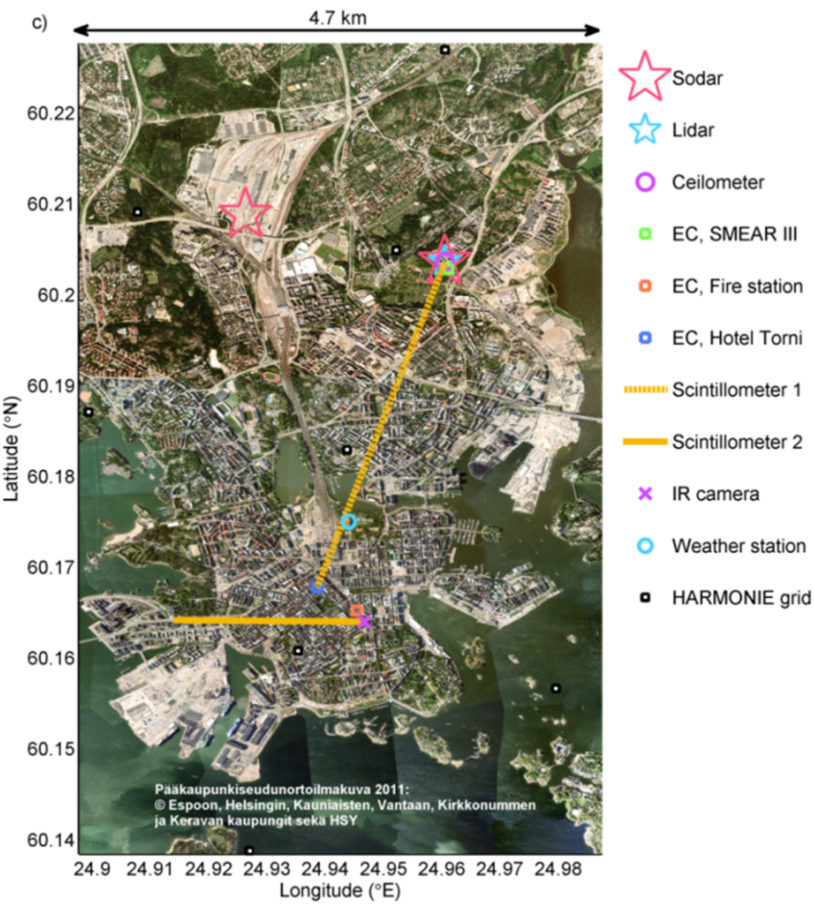

Fig. I. Map of Helsinki with equipment locations marked (legend). SMEAR-III is the *Station for Measuring Ecosystem-Atmosphere Relations* (Järvi et al. 2009) at the Kumpula campus near the buildings of the Finnish Meteorological Institute (FMI) and the University of Helsinki's Department of Physics. Weather station is at Kaisaniemi park. HARMONIE grid points are those from the numerical weather prediction model. See also Table I.

Table I. Helsinki UrBAN's scientific instrumentation. (EC = eddy covariance, ABL = atmospheric boundary layer)

Instrumentation		Scientific quantities
Sodar		ABL depth, profiles of mean and variance of vertical velocity
Lidar (scanning doppler)		ABL depth, profiles of vertical velocity variance and aerosol backscatter
Ceilometer		ABL depth, aerosol backscatter profile
Eddy covariance (EC)	SMEAR-III Fire station Hotel Torni	Fluxes, turbulence statistics and mean concentrations of heat, moisture, momentum and various gases and particulates
Scintillometers		Structure parameter for temperature, sensible heat flux, wind speed
Infra-red camera		Longwave radiative emission

Atmospheric Stability

Atmospheric stability has a critical impact upon the near-surface concentrations of pollutants. When the atmosphere is stable (most common during temperature inversions on winter nights), there is much less mixing and so air pollutants can reach high concentrations. When the atmosphere is unstable (most common on summer days), there is much more mixing in the ABL – especially vertically – and so pollutants can become dispersed to give lower concentrations. In Helsinki UrBAN, we have many instruments which can measure atmospheric stability, such as eddy-covariance stations from a point measurement and scintillometers, which measure an average over a laser path. A key quantity required to estimate atmospheric stability is the sensible heat flux. A positive sensible heat flux is correlated with unstable atmospheric conditions, negative sensible heat flux with stable atmospheric stability, and near-zero sensible heat flux with neutral atmospheric stability.

Sensible heat flux experiences strong annual and diurnal variation in Helsinki **(Fig. 3, page 32)**. Positive sensible heat fluxes, of above 150 W m–2, are observed in the months and hours of strongest sunshine (May–August, 08:00–16:00); giving strongly unstable atmospheric conditions and thus much more mixing of pollutants. Winter nights above downtown Helsinki exhibit a mixture of weakly unstable, neutral and stable atmospheric conditions. For most times of the year and day, downtown Helsinki experiences sensible heat fluxes that are more positive compared to a semi-urban site like Kumpula, about 4 km North of downtown (SMEAR-III: **Fig. 1**, **Fig. 2**). Downtown, heat emissions by anthropogenic activities (e.g. from heating of buildings in winter) can increase the sensible heat flux and hence increase the turbulent mixing.

Atmospheric stability has a critical impact upon the near-surface concentrations of pollutants.

Fig. 2. Photograph looking towards the south-east from the FMI roof in Kumpula, Helsinki. The lidar (foreground) and SMEAR-III tower can be seen.

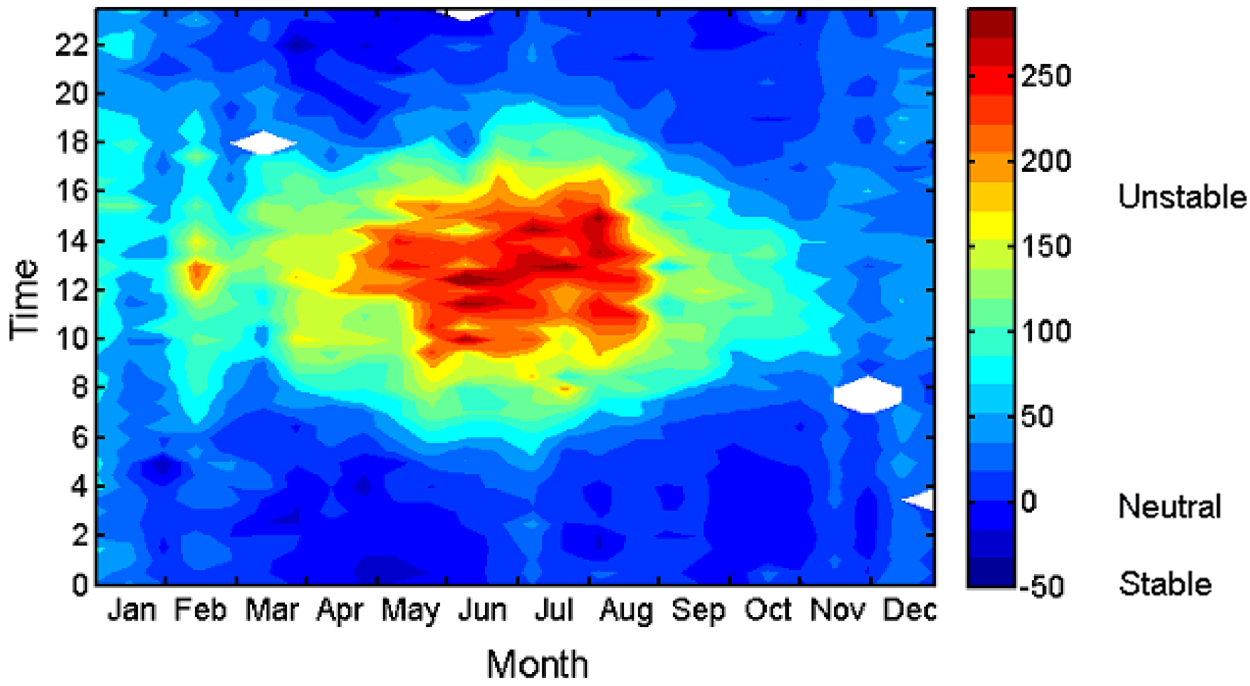

Fig. 3. Average (mean) sensible heat flux for each 30-min period in the day, and for each month of the year (colour scale, W m^{-2}). Measured during 2011 in downtown Helsinki (Hotel Torni) using the eddy-covariance method. The red colours relate to strongly unstable atmospheric conditions, and the dark blue to stable atmospheric conditions.

Depth of the Atmospheric Boundary Layer

The atmospheric stability (as resulting from the sign and strength of sensible heat flux) will be strongly related to the depth of the atmospheric boundary layer (ABL). Depths of ABL can vary throughout the day and year (e.g. perhaps 20 m – 2 km in Helsinki). The depth of the ABL will affect the near-surface pollutant concentrations because a deeper ABL allows pollutants to be diluted through a much deeper layer (giving lesser near-ground pollutant concentrations).

We can study many ABL properties using our ground-based remote-sensing instrumentation such as sodar, lidar or ceilometer. Each of our remote-sensing instruments uses a different technology and method to estimate the ABL depth, and each has a different vertical range of data sensing. Although only lidar data is shown here, it is an advantage of our observation network that we gain confidence in our results if we obtain the same estimation of ABL depth from different technologies. A lidar is a device used to measure the vertical profile of interesting atmospheric quantities by analysing the returned signal from a transmitted light (laser) pulse. In particular, it receives signal from atmospheric constituents such as aerosol particles and cloud, fog or ice. We often assume that aerosol observations give us an indicator of mixing of the air itself. Thus the primary product of lidar measurements is vertical profiles of aerosol concentration and turbulent velocity, from which information on mixing and other properties of the ABL can be determined, such as the diurnal progression of ABL height.

Fig. 4 shows a sample autumn day with high atmospheric pressure (maximum 1015 hPa) and fair-weather cumulus clouds. The turbulence observed by the lidar exhibited a maximum by day and calmer conditions by night. The progression of ABL depth follows the expected pattern for fair-weather conditions: (i) at night ABL below 300 m, and (ii) by day the ABL grows to a depth of about 1 km. The unstable atmospheric conditions by day mixed the aerosols to greater depth than by night and thus diluted the aerosol concentrations.

Network Outlook

Parts of Helsinki UrBAN have been operating since 2004, with large expansion in 2010–2012 to further support the study of the understanding of the physical processes in Helsinki's ABL. Further analyses will become possible as data from many annual cycles are gathered. In addition to the forthcoming science yields, we expect that we will develop this network's equipment and collaborations. We invite other people to bring their instrumentation and/or expertise beside ours for the advancement of technology, science and applications.

Acknowledgements

This work has been supported by the EC FP7 ERC Grant No. 227915 "Atmospheric planetary boundary layers – physics, modelling and role in Earth system" and Academy of Finland (Project numbers 138328, 1118615 and ICOS-Finland, 263149) are acknowledged for financial support. Kari Riikonen, Erkki Siivola and Petri Keronen provided technical support. We thank all members of Helsinki UrBAN for technical and scientific support (specifically, Ewan O'Connor and Anne Hirsikko analysed the lidar data). Thanks to Karoliina Pilli-Sihvola to comments on a version of the text.

References

Järvi, L., Hannuniemi, H., Hussein, T., Junninen, H., Aalto, P. P., et al. (2009). The urban measurement station SMEAR III: Continuous monitoring of air pollution and surface-atmosphere interactions in Helsinki, Finland. Boreal Environment Research, 14, 86–109.

Nordbo, A., Järvi, L., Haapanala, S., Moilanen, J., & Vesala, T. (2012). Intra-city variation in urban morphology and turbulence structure in Helsinki, Finland. Boundary-Layer Meteorology, In press.

Vesala, T., Järvi, L., Launiainen, S., Sogachev, A., Rannik, Ü., et al. (2008). Surface–atmosphere interactions over complex urban terrain in Helsinki, Finland. Tellus Series B Chemical And Physical Meteorology, 60, 188–199.

"Most international studies of ABLs above cities have focused on specific campaigns, often with less than one year of measurements."

Intensiivinen mittausverkosto, Helsinki UrBAN

Ilman epäpuhtauksien pitoisuuksiin vaikuttaa voimakkaasti ilmakehässä tapahtuva sekoittuminen ja kuljetus. Erityisesti merkitystä on ilmakehän alimman osan eli ilmakehän rajakerroksen ominaisuuksilla kuten sen korkeudella ja ilmakehän stabiilisuudella. Helsinkiin on perustettu intensiivinen mittausverkosto Helsinki UrBAN (Urban Boundary-layer Atmosphere Network, http://urban.fmi.fi), jonka tarkoituksena on tutkia rajakerroksen rakennetta ja sen fysikaalisia prosesseja. Helsinki UrBAN on pohjoisin kaupunkirajakerroksen mittausverkosto maailmassa ja siten se tuottaa ainutlaatuista aineistoa eri prosessien vuodenaikaiskäyttäytymisestä.

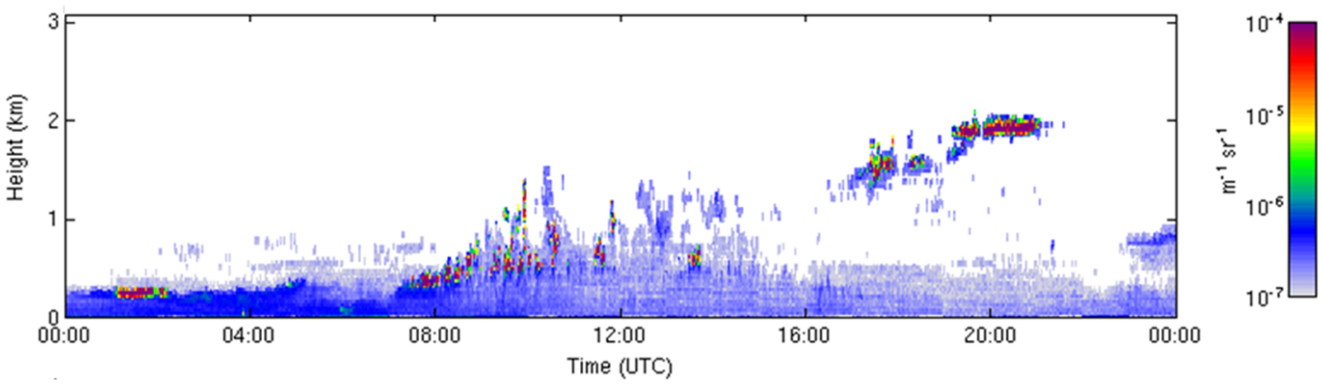

FIG. 4. The evolution of the lidar profile above Kumpula, Helsinki, on 4th September 2011. The lidar observation range is 90–9600 m, with 30 m resolution. The colour scale shows the backscattered light. Backscatter is a measure of concentrations of different atmospheric constituents: in this figure the red colour is water from clouds, the dark blue is greater aerosol concentrations 00:00-08:00, light blue is lesser aerosol concentrations from 08:00 onwards.