# MESOSCALE MODELLING OVER AREAS CONTAINING HEAT ISLANDS

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## INTRODUCTION

Urban heat islands have been suspected as being partially responsible for the observed increases in land air temperatures over the last few decades. In the IPCC report two primary reasons are mentioned: first the observed decrease in the diurnal temperature range by about 0.4°C over around 50% of the global land area since the 1950s. and second the observed lower rate of warming over the past twenty years of lower troposphere compared with the surface. However, they conclude that the urban heat island effects are no more than about 0.05°C up to 1990 in the global temperature records, and assume zero global land-surface air temperature change in 1900 due to urbanization, linearly increasing to 0.06°C in 2000 (IPCC 2001).

In Finland, many of the climatic stations have been situated in the old town centers and industrial areas. Urbanization effect has been estimated to be 0.05-0.1 $^{o}$C /decade due to population increase (ref in Heino 1994). According to him, the annual mean temperature rise due urbanization at the Kaisaniemi station, located in the Helsinki city centre, was largest in the beginning of the 1900s, 0.7-0.8 $^{o}$C. Solantie (1978) reported an 0.2-0.5 $^{o}$C increase in the temperatures in the lee areas of some industrial towns between periods 1931-1960 and 1961-1975. Tuomenvirta (2004) used the adjustement of Heino (1994) for Kaisaniemi station, and minor ones, mostly connected to station re-locations, for the other town stations, when he estimated, using 150 year measurements, that in Finland the temperature increase has been statistically significant, especially in spring (March, April, May). Urban effects on precipitation have been ignored in Finland; Heino regarded them as negligible compared with large variation in precipitation in time and space.

Current routine weather prediction model HIRLAM at the Finnish Meteorological Institute (FMI) provide data with less than 10 km grid resolution for air quality applications. In the HIRLAM 5 surface parameterization each grid is divided into five land use categories and fluxes are evaluated for each of them separately. Urban areas are not separated, in the 0.08$^{o}$ resolution HIRLAM Stockholm, St. Petersburg City Centre and Tallinn are classified to be most bare land, Helsinki is a mixture of low vegetation and forest. In the forecasts, urban heat islands are no recognized; there is no temperature, moisture or mixing height gradient between the countryside and any city centre. However, according the measurements, this is not the case.

In this paper the temperature gradient due to urban heat effect in the coastal Helsinki Metropolitan area and its surroundings is studied. The emission data base is used to estimate roughly the waste heat and water vapour flux estimates from industrial enterprises, heating and traffic. The forecasted sensible and latent energy flux densities are compared with the human induced fluxes to estimate their effect to the energy balance in the Capital City region. A local correction to the meteorological preprocessor is proposed, and its effect on stability parameters is presented. In the Final paper the fine scale 3D air pollution model is used to simulate the air pollution in the Helsinki region with/without a correction due to the possible missing heat island effect; at the time of writing this abstract the accurate emission inventory for it is missing.

**TEMPERATURE GRADIENTS IN THE CAPITAL CITY AREA**

The temperature gradient between two measurement stations depends e.g. on the general weather situation, distance from the water areas, height from the sea surface, landscape geography of the location, surface type, height, construction material and distance from the buildings surrounding the place etc. Especially inside the towns, on small islands or hilly landscape it is difficult to obtain a fully representative measurement place which is located in flat grassland, as it is recommended in the WMO guidelines.

There are currently two research projects going on at the FMI to study in detail the heat island of the Helsinki region: Testbed project http://testbed.fmi.fi/ started this summer and the heat island project in 2002 with 20 extra measurement points and high time resolution (Kaukoranta, 2003). While the data of these projects is not published, I check shortly from the routine measurements, what is the strength of the heat island in Helsinki.

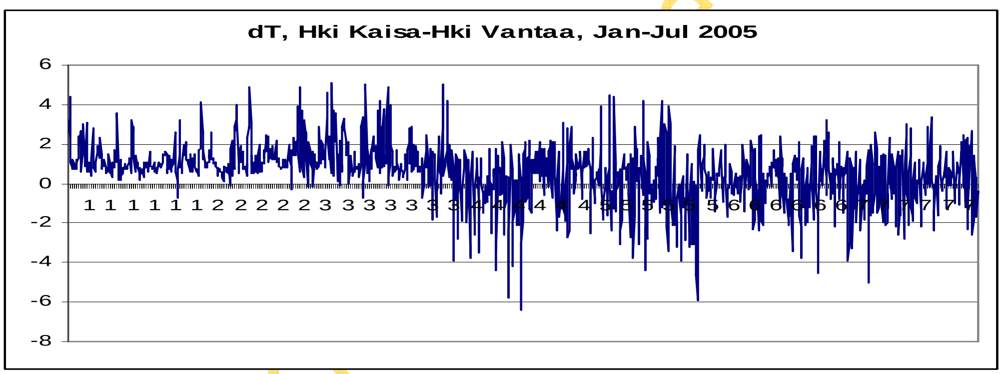



*Fig 1. Temperature difference between the Coastal City Centre weather station Kaisaniemi (4 m above the sea surface) and Helsinki-Vantaa airport (51 m), with a distance of 16.8 km*

From Fig. 1, which presents the temperature difference between the Helsinki City Centre station Kaisaniemi and Helsinki airport, one can conclude that the strength of the heat island can be better estimated when the Gulf of Finland is covered by ice: otherwise the strong marine effect can be mixed to other effects. When the sea or the coastal areas are in ice, the monthly average temperature is around 1.2-1.4 °C higher in the city centre. The distance between the stations and their coordinates can be found in Table 1. If we select only the northern flow cases, Table 1, City centre is warmer also in spring although the station is close to the cold sea coast. The stations on islands in front of Helsinki, Harmaja and Isosaari, are warmer in March although they are surrounded by ice. One reason is: during nights the surface of the island stations do not cool as it does in the city; in daytime City is warmer (Table 1). There is also rather heavy ship traffic in front of Helsinki, and the open waterways heat also at least the Harmaja station.

| a) | Northern wind sector mon dt ave | All wind sectors | b) | March Kaisaniemi-station | lat | lon | distance from Ka km |
|---|---|---|---|---|---|---|---|
| month | Kaisaniemi-Hki | Vantaa | | | | | |
| Jan | 0.96 | 1.14 | Harmaja | -0.60 | 60° 06` | 24° 59` | 8.7 |
| Feb | 1.48 | 1.36 | Isosaari | -0.02 | 60° 06` | 25° 05 | 11.4 |
| March | 1.19 | 1.32 | Hki-Vantaa | 1.32 | 60° 19` | 24° 57` | 16.8 |
| April | 1.00 | 0.05 | Hki Malmi | 1.32 | 60° 15` | 25° 03` | 17.1 |
| May | 0.87 | -0.03 | Espoo, Sepänk. | 0.49 | 60° 12` | 24° 44 | ~19 |
| Jun | 0.64 | 0.15 | Espoo Nupuri | 1.37 | 60° 13` | 24° 36` | 19.7 |
| Jul | 0.66 | 0.09 | Harmaja,day | 1.01 | | | |
| | | | Harmaja,night | -1.85 | | | |

Table 1. a) Average monthly 2m temperature difference between Helsinki Kaisaniemi and Hki Vantaa airport, $^{o}$C ; northern flow (300$^{o}$-45$^{o}$) and all wind sectors;
b) temperature difference in March between selected stations with their coordinates.

## WASTE ENERGY AND WATER VAPOUR FLUXES IN HELSINKI

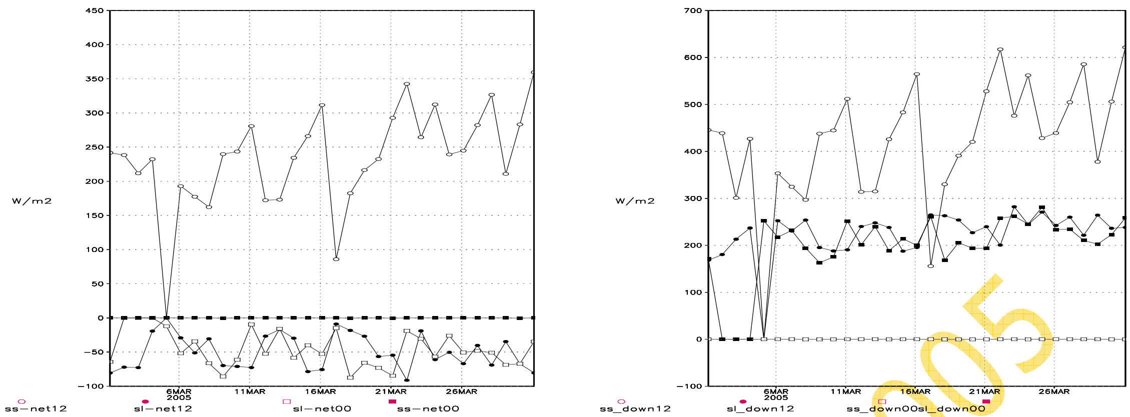
All the energy consumed inside the town is dissipated finally in a form of heat, mechanical or latent energy. The total energy consumption in Helsinki has been around 20 $TWh_{th}$, most of it is fuel use in the district heating plants. I estimate the heating effect in the rather cold and dry month, March 2005, when the Gulf of Finland was completely covered by an ice cap. If we assume, that the energy use was around 1.4 times the monthly average, it was around 3.5 GWh/h, which over the Helsinki land surface, 186 km$^2$, means a waste heat of 19 W m$^{-2}$. If most of this energy is consumed around within one Hirlam grid, the waste heat flux over that grid can be estimated to be more intense, around 50 W m$^{-2}$. This heat is released from most parts at the effective stack height which depends on the stack characteristics and the stability conditions of the open air. The intensity of the energy use at the other towns in the capital city region is not as high in comparison to the Helsinki centre, however also remarkable.

Another urban effect is the water vapor flux: in burning of fossil fuels for each $CO_2$ molecule, depending on the fuel type, at least one $H_2O$ molecule is emitted. From the Helsinki $CO_2$ emission, 5300 kt/yr, the water vapour flux, scaled with the atomic weights of the molecules, becames small, around 1.4 mm m$^{-2}$ in March. However, measured precipitation in March was also very small, 7 mm in Kaisaniemi, 3 mm in Isosaari.

## URBAN FLUX VS FORECASTED ENERGY FLUXES AT THE SURFACE

In a meteorological model the surface energy is conserved; sum of the sensible and latent heat fluxes SSH and SLH and flux to the ground equal the net radiation. Sensible and latent heat, net radiation and downwelling radiation fluxes forecasted by HIRLAM mba-model at the grid in the Helsinki city centre in March 2005 are presented in Figs. 2-3.

In the Hilatar air pollution model, the surface fluxes are used in estimating some turbulence parameters which are not directly available from Hirlam. The friction velocity u* is calculated from the accumulated momentum flux; temperature scale tt* from the accumulated sensible heat flux and the Monin-Obukhov legth using both u* and tt* according to Stull (1998). If a waste heat flux, 20 W/m2, is assumed to be released near the surface, and added to the surface accumulated sensible heat flux, the result to the stability parameters becomes as presented in Fig. 4.



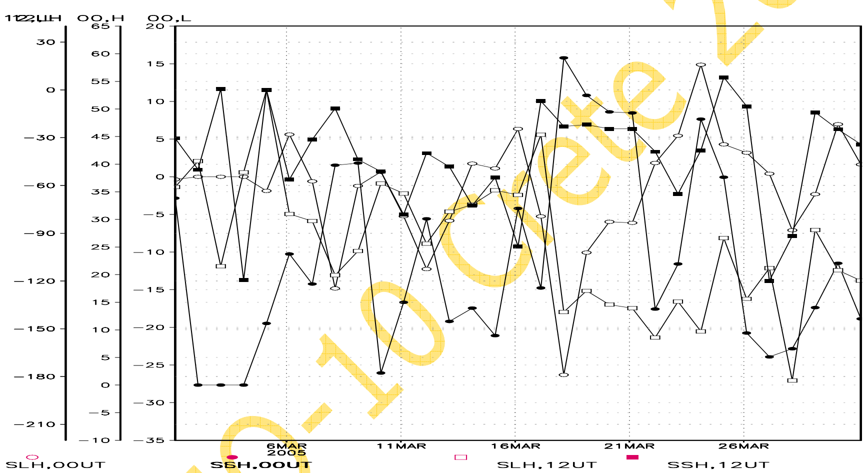






*Fig.2. Forecasted surface sensible heat flux SSH and surface latent heat flux SLH at 00 and 12 UTC in March 2006 inside the grid located in the Helsinki city centre.*

*Fig.3. left: Forecasted surface net radiation: SS short wave and SL, long wave radiation; Fig 3 right Forecasted downwelling radiation at the surface: SS short wave and SL, long wave, at 00 and 12 UTC in March 2006 inside the grid located in the Helsinki city centre.*

**CONCLUSIONS**

The heat island over urban areas is clearly measured and its effect on the climatological temperature records should be re-assessed. Alone street lightning in Helsinki changes energy balance by 0.06-0.16 W $m^{-2}$, averaged either over total land area or one Hirlam grid. Heat island a complicated phenomena where atmospheric pollutants, gases and particles, take an active role. But, only the waste heat and water vapour emissions from energy use in a rather small town can take part in heat island effect, and change the energy balance and turbulence conditions over that area. The effect of the changes to pollution transport will be further studied.

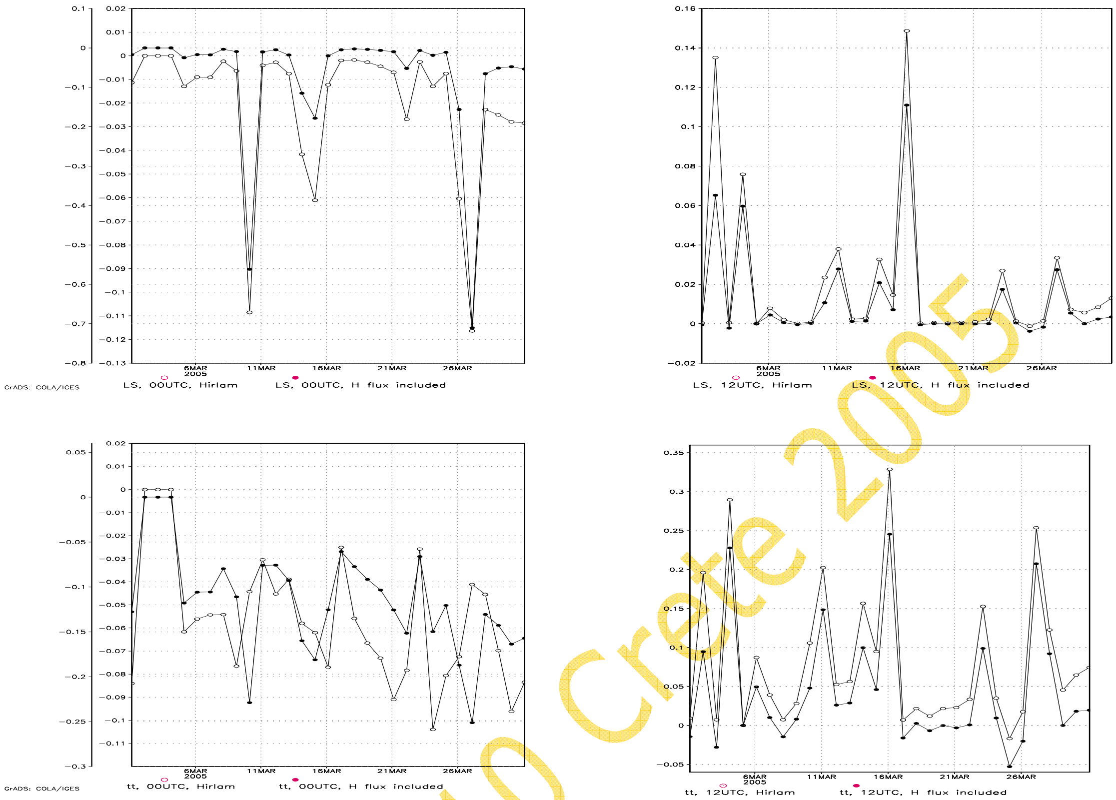



*Fig 4. Effect of adding of 20 Wm$^{-2}$ heat flux to turbulence parameters; March 2005 Helsinki*

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