AN AIR POLLUTION EPISODE CAUSED BY REGIONALLY TRANSPORTED SMOKE IN FINLAND ON 21 AUG 2006: A CASE STUDY USING MESOSCALE NWP MODEL

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Abstract: The purpose of this study is to identify the prevailing synoptic and mesoscale conditions related to severe air quality episode in Finland utilizing AROME mesoscale NWP model. The summer of 2006 was exceptionally dry in the areas surrounding the Gulf of Finland; this resulted in frequently occurring wild land fires, especially in north-western part of Russia and Estonia. Easterly winds were prevailing with an exceptional long period in August and spread occasionally smoke to Finland. Mesoscale phenomena, such as sea breeze and low-level jet (LLJ) have been identified to play a significant role on 21st of August 2006. A high model resolution is needed to catch these phenomena.

Key words: *Air quality, wild land fires, LLJ, AROME*

1. INTRODUCTION

This paper addresses an air pollution episode in Finland on 21st of August, 2006, when relatively strong coastal afternoon surface winds were observed along Gulf of Finland. Mesoscale phenomena, such as sea breeze and low-level jet (LLJ) were noticed to play a significant role on the formation of the episode. LLJ is typical phenomena in summertime conditions along the Gulf of Finland. Air quality episodes can be strongly coupled with development of LLJ in suitable circumstances. Pollutants trapped in an elevated mixed layer are protected from surface deposition processes while the development of a LLJ can lead to rapid transport of the pollutants.

NWP models have often problems in predicting LLJ properties including their speed, height, shear and the temporal evolution. The purpose of this study is to identify the prevailing synoptic and mesoscale conditions related to severe air quality episode in Finland using AROME model.

2. METEOROLOGICAL CONDITIONS DURING THE 2006 EPISODE

August 2006 was drier and warmer in Finland than average according to climatological statistics of Finland 1971-2000. Almost during the whole August of 2006, there was a center of high pressure near Kola Peninsula, and consequently, easterly winds prevailed in Southern Finland and Estonia. In the northern parts of Finland, precipitation rates were near normal, while in the areas surrounding the Gulf of Finland and on the coast of the Gulf of Bothnia, precipitation rates were only a fraction of the normal rate. On August 21, weather in the Helsinki Metropolitan area was cloudy, but precipitation rates were low. Some rain showers occurred in the morning and later in the night and south-easterly wind speed increased in the afternoon according to measured synoptic observations near the coast.

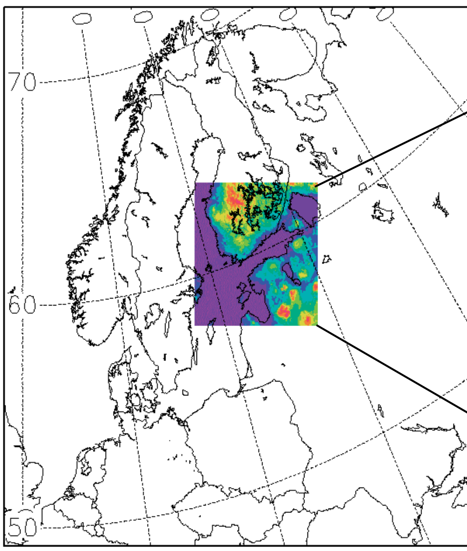
Coastal winds are affected in about 1–10 km scale by the abrupt changes in surface roughness and temperature between land and sea (Savijärvi 2004). Weak synoptic systems respond to this boundary layer forcing by creating deep daytime convective mixed layers, low level jets, sea breeze fronts and other convergence zones. In this study especially mesoscale phenomena, such as sea and land breezes and low-level jets (LLJ) have been observed to play a significant role in leading to the pollution episode on 21st of August 2006. LLJs are not a rare phenomena. The latitude and width of the Gulf of Finland are such that the inertial oscillation mechanism favors local low-level jets blowing parallel with the Finnish coast, when moderate large-scale winds blow from the south-east or west (Savijärvi et al., 2005). Another important factor affecting the meteorological conditions in coastal areas is the sea breeze circulation. The sea breeze is driven by the temperature differences between the land and sea, and consists of an onshore flow during the day (sea breeze) and an offshore flow during the night (land breeze). Sea breeze circulation may enhance the low level jet stream.

3. AIR QUALITY DATA

The fine particle concentrations were high from 18th July to 28th August 2006 in southeastern and southern part of Finland. Concentrations were measured at the EMEP background stations of Virolahti and Utö and urban background station of Kumpula. Measurement station of Utö is situated near the area of Finnish Archipelago and measurement station of Virolahti is located in southeastern part of Finland near Gulf of Finland. At the station of Kumpula in Helsinki, the $PM_{2.5}$ and $PM_{2.5\text{-}10}$ mass concentrations were measured with two Tapered Element Oscillating Microbalance units (TEOM). During the episode in Helsinki, the high concentration peaks were temporally shorter, compared with those during the previous major wild land fire episodes in spring of 2006 discussed in details by Saarikoski et al., (2007). The highest 30min mean value of $PM_{2.5}$ was measured on 21st of August in Kumpula. Moreover, the concentrations of $PM_{2.5}$ almost 180 µg/m^3 were substantially high at regional background stations in Southern Finland.

4. AROME MODEL

AROME (Bouttier et al., 2006) is an meso-scale NWP system with semi-implicit semi-Lagrangian nonhydrostatic dynamics. The model physics includes a mixed phase microphysics sheme (Pinty, 1998) with prognostic treatment of cloud water/ice, rain, snow and graupel. Surface is treated with externalized scheme including surface types (Noilhan and Planton, 1989) for nature, sea, lakes and urban areas (Masson, 2000). Boundary layer scheme is based on Cuxart et al. (2000) with turbulent kinetic energy (TKE) treated as a prognostic variable. AROME model is originating from Meteo France and it has been further developed in the framework of the co-operation between the Meteo France and HIRLAM Programme group. The present AROME version (cy33t0), implemented at Finnish Meteorological Institute, uses a 2.5 km grid size with 40 levels in vertical. Chemistry modules for aerosol and dust are available in AROME model, but they are switched off in this AROME version. The modelling area and brief description of the model suite is presented in Figure 1.



Model and version	*AROME (cy33t0)*
Horizontal resolution	*2,5km*
Number of vertical levels	*40*
Data-assimilation	*Dynamical adaptation*
Boundary conditions extracted from	*HIRLAM (RCR)*

Figure 1. The model domain used for AROME.

5. RESULTS AND DISCUSSION

Based on data from the MODIS instrument onboard the NASA Aqua and Terra satellites, the nearest wild land fires were located at distances of 100 – 200 km from Helsinki (Fig 2). The 24 hour AROME simulation was performed over Gulf of Finland on 21st of August 2006, starting at 00UTC. Temporal variation of potential temperature over land and sea indicates in the beginning of the period a relatively stable atmosphere over the land and later also stable atmosphere over sea. According to AROME calculations sea breeze circulation occurred at noon of 21st of August near the coast of Estonia and Russia and disappeared by afternoon. The meteorological conditions, especially the southeastern wind direction reduced the pollutant penetration inland. Moreover, the sea breeze circulation near coast and convection inland rised the pollutant plume to upper levels along the prevailing SE wind. The high resolution numerical simulations indicated the occurrence of low level jets. A relatively strong LLJ formed over the stably stratified air above the sea, having wind component from the areas of fire towards southern Finland. This LLJ developed at 9-12UTC near coastline of Estonia and moved over Gulf of Finland towards the coast of Finland between 12-15UTC (Fig 3). Lines A-B and C-D in Fig 2 show the cross-section lines presented in Fig 3. Consequently, the air accelerates and transports smoke from Estonia and Russia over Gulf of Finland to Finland.

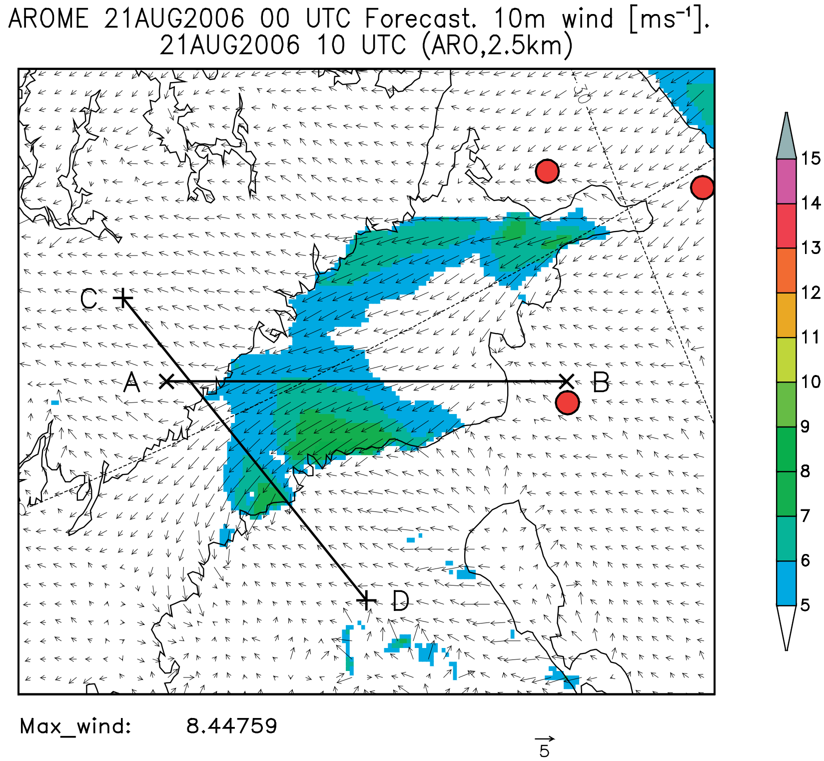


Figure 2. 10m wind vectors and shading forecasted by AROME at 10:00 UTC, 21 Aug 2006. Wild land fires have marked with red dots based on MODIS satellite firemapper detection.

6. CONCLUSIONS

Lack of meteorological and air quality observations over sea, limits our ability to understand completely the different meteorological processes which are affecting the dispersion of the smoke plume. However, high resolution NWP simulations make it possible to identify mesoscale phenomena like sea breeze and LLJ. In this study the high resolution numerical simulations indicated the occurrence of low level jets, having a wind component directly from fire areas towards Finland. These simulations clearly help to understand the observed pollutant concentrations. Hence, high resolution NWP models like AROME, are very useful tools in providing the fine resolution meteorological fields for pollution dispersion models as demonstrated by the case study presented in this paper.

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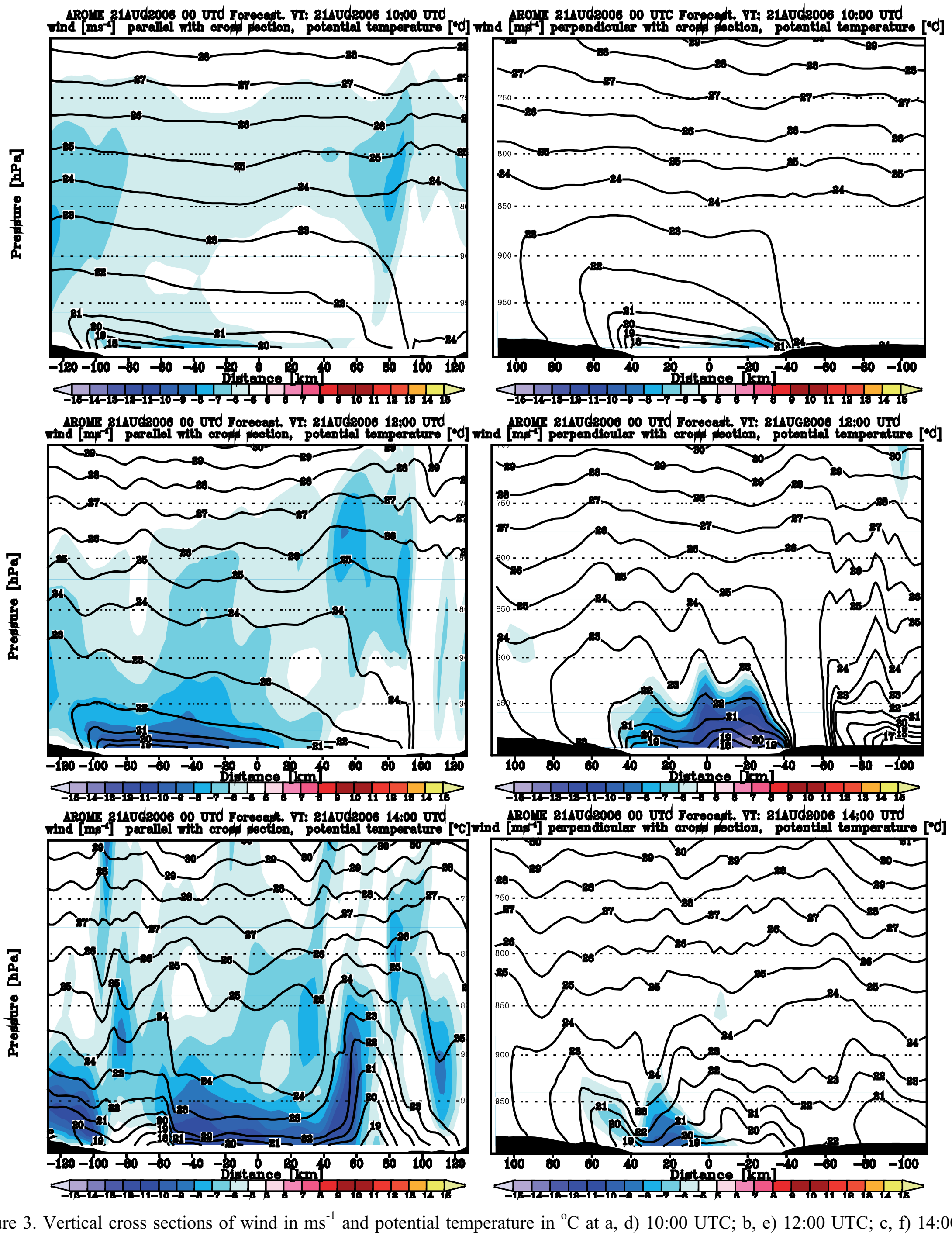

Figure 3. Vertical cross sections of wind in ms^{-1} and potential temperature in ^{o}C at a, d) 10:00 UTC; b, e) 12:00 UTC; c, f) 14:00 UTC. Panels a-c show a wind component along the line A-B (negative towards Finland). Panels d-f show a wind component parallel to coastline in line C-D (negative is easterly wind). Panels are sorted in columns; a,b,c in left and d,e,f in right.