Measurements in a Mesoscale Weather Network Using a Multi-Sensor Weather Transmitter and a CO_2 Probe

WEATHER MONITORING

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Figure 1: A measurement station of the Helsinki Testbed

The Finnish Meteorological Institute (FMI) and the Vaisala Corporation have established a new mesoscale observational network in Southern Finland. The Helsinki Testbed is expected to provide new information on observing systems and strategies, mesoscale weather phenomena and applications in a coastal high-latitude environment. The goal of the project is to provide input and experience for mesoscale weather research, forecast and dispersion model development and verification, information systems integration, end-user product development and data distribution for the public and the research community. The testbed also allowed the testing and building a mesoscale weather network with the Vaisala Weather Transmitter WXT510.

The Helsinki Testbed covers an area of roughly 150 x 150 kilometers in the Southern coast of Finland. The existing surface network was supplemented with more than 100 WXT510 transmitters, reducing the average station distance to less than 10 kilometers. The Vaisala Weather Transmitter WXT510 combines altogether six most essential weather parameters in one instrument. It incorporates the ultrasonic Vaisala WINDCAP® sensor for the measurement of wind speed and direction, the Vaisala RAINCAP® sensor for precipitation measurement based on the impact of individual raindrops on its membrane, the silicon-based Vaisala BAROCAP® sensor for barometric pressure, the ceramic Vaisala THERMOCAP® for temperature measurement and a capacitive thin-film polymer, which forms the basis of the renown Vaisala HUMICAP® sensor for relative humidity measurements.

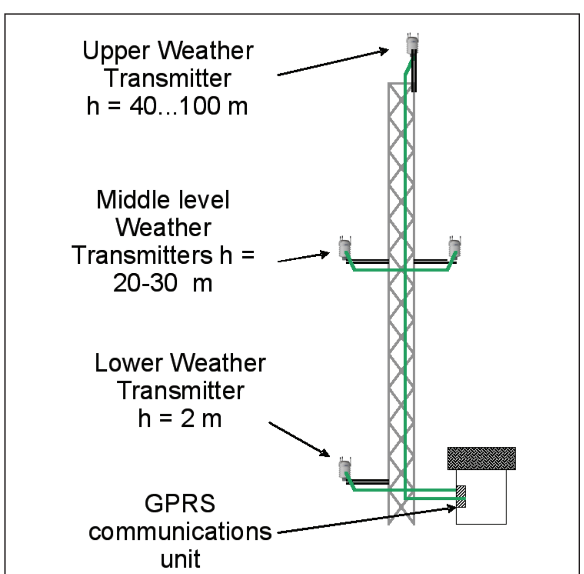

Figure 2. Cellular phone base station mast utilised as a meteorological tower

The Helsinki Testbed offered also a unique opportunity to study the variation of CO_2 concentration in a mesoscale weather network, and demonstrate the use of a newly launched CO_2 probe in a cost-efficient weather station configuration. The observation of global climate change relies often on the use of basic weather data from weather observation stations while CO_2, which is the most important greenhouse gas is measured only at a few well chosen locations around the world. In the Helsinki Testbed, the dense measurements of CO_2 were made in order to demonstrate their advantages when studying ecological phenomena and the distribution of CO_2 in the urban environment.

The constructed climate station consisted of a Vaisala Weather Transmitter WXT510, a Vaisala CARBOCAP® Carbon Dioxide Probe GMP343 and in some cases of a photosynthetically active radiation (PAR) sensor. As the climate station was intended for dense networks it must be cost-effective and easy to install, use and maintain. The instruments had to be affordable, have as few moving parts as possible, be durable, and have long maintenance intervals. The weather transmitter with a CO_2 probe and a PAR sensor can be seen in Figure 1.

During the first phase of the Helsinki Testbed project the most intense activities have concentrated on specific, usually month-long measurement campaigns each focusing on a theme such as precipitation phase, convection or inversions. After August 2006 FMI and Vaisala have agreed to keep the infrastructure running and continue the operation of Helsinki Testbed as a continuous, dynamic mesoscale weather research and innovation environment.

Dense Weather Measurement Network Based on Weather Transmitters

The Helsinki Testbed supplements the existing weather observation network with a dense weather measurement network of 62 weather stations incorporating 112 weather transmitters. Of these stations, 42 are cellular phone base station masts that have been

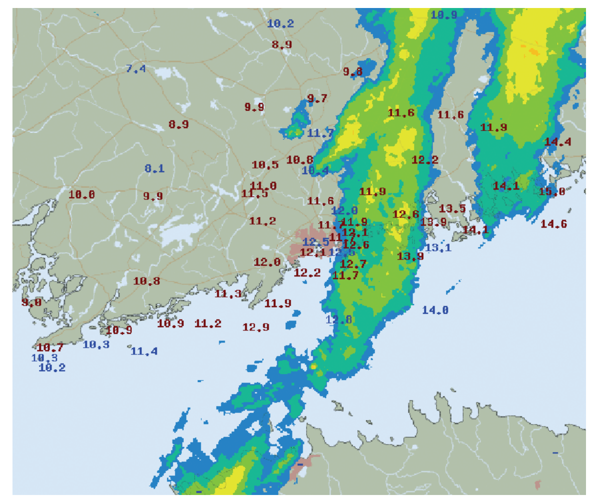

Figure 3. Temperature and precipitation

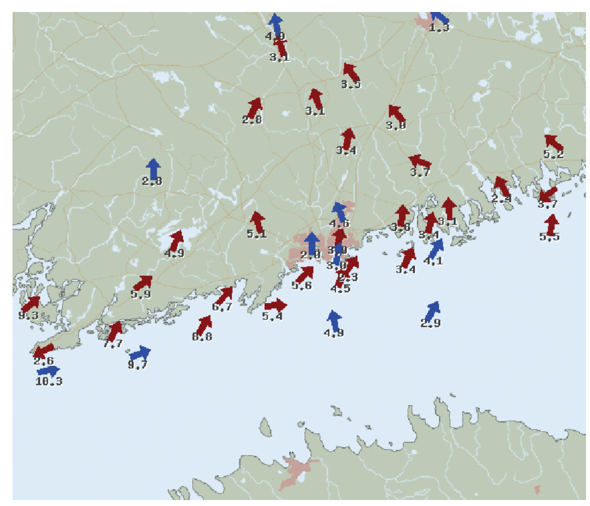

Figure 4. Wind speed and direction

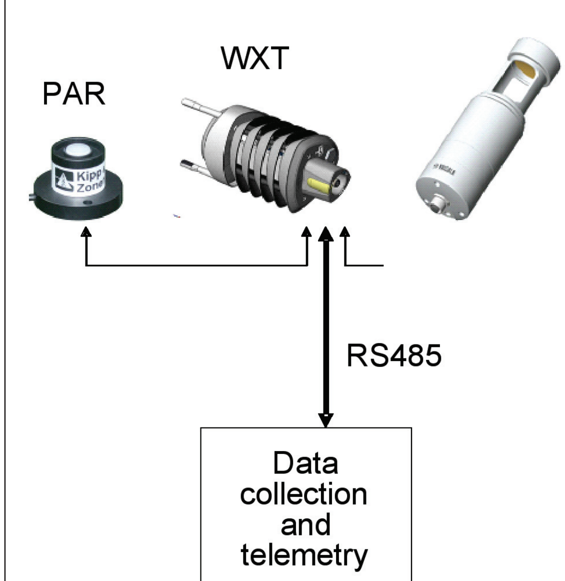

Figure 5. The communication between the components of an ecological measurement station, the WXT510 weather transmitter, the GMP343 CO2 probe, and a PAR sensor.

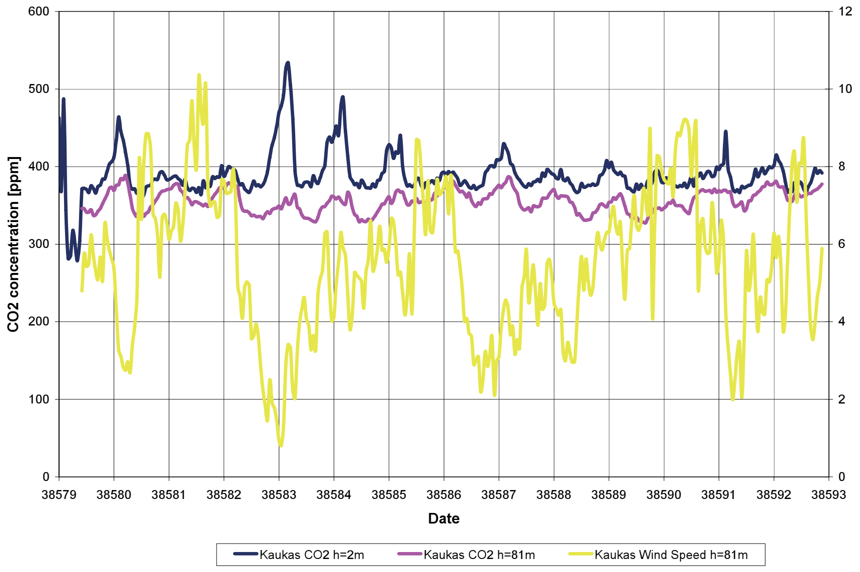

Figure 6. The daily CO2 variation (averaged hourly values) measured in Kaukas at two different heights of the GSM mast (h=2m and h=81 m) and averaged wind speeds.

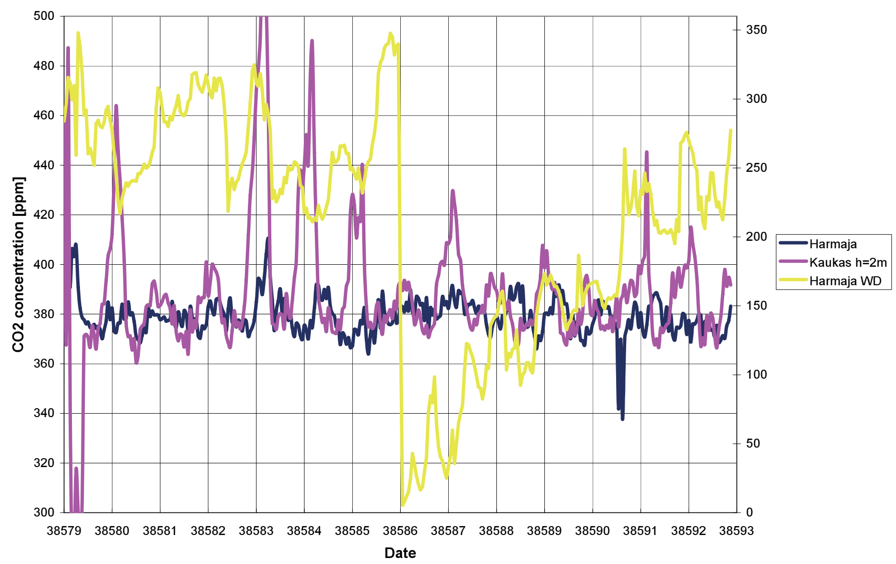

Figure 7. The CO2 concentrations at Harmaja and Kaukas (in pink and blue) and simultaneous wind direction (in yellow) measured at Harmaja.

converted to meteorological towers by installing weather transmitters on them. Each mast has 2 to 4 WXT510 weather transmitters installed on different heights to obtain profiles of temperature, humidity and stability. Additional weather transmitters are installed in urban areas, e.g. along the marathon route of the World Championships on Athletics 2005 and on ferries cruising on the Helsinki-Tallinn route.

The Weather Transmitters are connected to communication modules that send weather data wireless via GPRS modems to the Finnish Meteorological Institute's (FMI's) data base. The Testbed data can be viewed in Internet http://testbed.fmi.fi. The users are able to browse or animate the weather data in time steps of 5 minutes, 15 minutes, 30 minutes, 1 hour, 2 hours and 3 hours.

Figures 3 and 4 are examples of screen shots from the testbed web site. In the figures WXT510 observations are presented with red colour and observations from synoptical weather stations are presented with blue colour. In Figure 3 air temperature observations, and precipitation measurements from a weather radar are shown. Figure 4 illustrates wind speed and directions measurements from the WXT510 and synoptical weather stations.

The Multi-Sensor Vaisala Weather Transmitter WXT510

The core instrument of the Helsinki Testbed dense weather measurement network is the Vaisala Weather Transmitter WXT510. WXT510 is an ideal building block for dense networks because it is compact, is based on solid state technology and has a competitive price compared to present stand-alone instruments with similar performance. WXT510s are virtually maintenance free, which make them optimal for cellular phone mast installations. In a network like the Helsinki Testbed the maintenance costs could become huge, if conventional stand-alone measurement instruments that require regular maintenance, e.g. mechanical wind sensors and tipping bucket type of rain sensors, were used. The price of the Weather Transmitter is about a quarter from the equivalent conventional weather station and the installation does not require special mounting skills.

The Weather Transmitter measures the six most essential weather parameters in one multi-instrument. Wind speed and direction are measured with the advanced Vaisala WINDCAP® ultrasonic wind sensor. The precipitation measurement is based on the Vaisala's proprietary RAINCAP® technology. Vaisala RAINCAP® Sensor gives more detailed information about precipitation. In addition to accumulated rain fall it also measures rain intensity and duration of the rain - all this in real time. Both WINDCAP® and

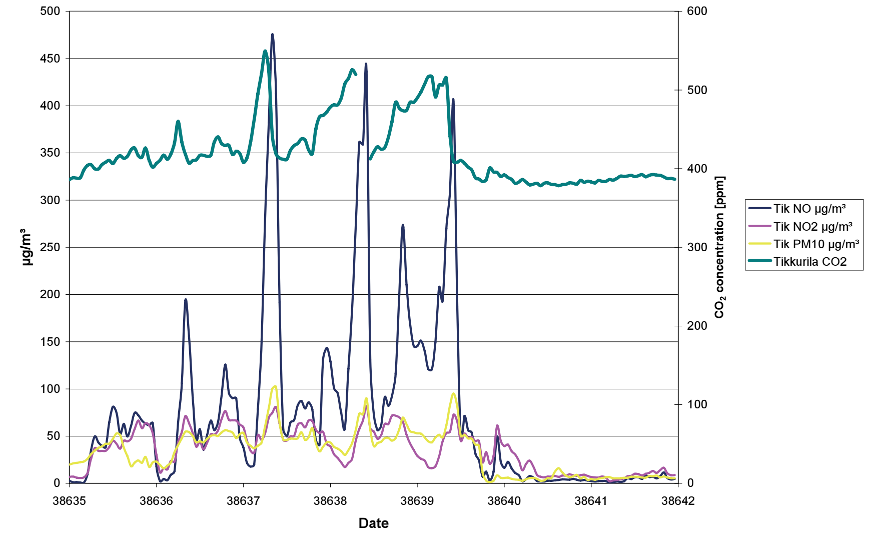

Figure 8. The aerosol and pollutants measured in Tikkurila correlate well with the simultaneously measured CO2 concentrations

RAINCAP® Sensors are solid state sensors with no moving parts to wear or break.

Barometric pressure, temperature, and relative humidity are integrated into one measurement unit, a so called PTU module. Very similar PTU module has been in use in Vaisala's radiosondes for decades, which gives a good basis for reliance in the WXT510.

The CO_2 Measurements in the Mesoscale Network

The CO_2 measurements in the Helsinki Testbed were made with the Vaisala CARBOCAP® Carbon Dioxide probe GMP343, which is an infrared CO_2 transmitter. The instrument is designed for ecological measurements and for the climate station, a unit with a CO_2 concentration measurement range of 0...1000 ppm was used. The heart of the instrument is a micromachined silicon chip, the tunable Fabry-Perot interferometer, which provides a very good long-term stability. The embedded software of the GMP343 was modified for the project.

The Photosynthetically Active Radiation (PAR) sensor measures a spectral range or radiation which is relevant for the rate of plant photosynthesis. Kipp&Zonen PAR LITE sensors are designed for outdoor measurements of photosynthetically active radiation in natural daylight. The PAR LITE sensor was attached to an analog input of 0...35 mV of the WXT510.

Figure 5 illustrates the communication between the WXT510, the GMP343, and the PAR sensor. The analog outputs of the GMP343 and the PAR sensor were connected to the WXT510. The GMP343 has an internal temperature sensor for the compensation of the effects of changing temperature on the CO_2 measurement. For the pressure information, the GMP343 listens to the RS485 communication bus from the WXT510 and changes its pressure settings according to the changing barometric pressure. The PAR, the CO_2 concentration, and all the meteorological parameters of the WXT510 are sent every 5 minutes to the communications module, which then forwards the data to the testbed database.

The locations of the CO_2 measurement sites were selected so that they would be representative as an ecological climate stations. The intent of the project was to study how this type of a cost-effective climatological station could perform and whether ecological phenomena can be studied with this setup.

The phenomena that were studied were the variations in the atmospheric background CO_2 concentration, variations in the daily CO_2 concentration, land-sea variations in CO_2 concentration, soil CO_2 respiration, urban climate and strong inversion, correlation of aerosols, gaseous and particulate air pollutants from traffic, and CO_2 concentration as well as horizontal advection of CO_2 concentration.

As an example of the results obtained from the measurements, Figure 6 illustrates the correlation between the wind speed and daily CO_2 variations. The figure displays the measured wind speeds and CO_2 concentrations measured at two different heights in a mast (as illustrated in Figure A) in Kaukas, Hyvinkää. Especially when wind speeds remain low, the night time CO_2 concentration can reach near ground level values above 500 ppm. This can be explained by strong soil respiration and low winds that were not able to mix the nocturnal boundary layer. As sun rises, the thermal turbulence (or convection) mixes the boundary layer and the CO_2 concentration near soil surface decreases. During the growing season, CO_2 levels decrease as vegetation starts using CO_2 in photosynthesis.

As a second example of the studied phenomena, Figure 7 illustrates the CO_2 concentration variations in August in Harmaja and in Kaukas. Also the wind direction measurements in Harmaja is depicted. Harmaja is a small rocky island just outside of Helsinki, whereas Kaukas is further inland and surrounded by farmed fields and forest. It can been seen from the figure that the variation in the daily CO_2 concentration in Kaukas is much larger than in Harmaja. This can be explained by the marine location of Harmaja and the more continental location of Kaukas.

Looking closely at Figure 7 however illustrates an interesting phenomenon of the CO_2 concentration at Harmaja peaking slightly later during the day than in Kaukas. This leads to a speculation of the role of daily land-sea wind cycle carrying higher CO_2 concentrations accumulated on soil surface during the night to Harmaja during the morning.

As a third example of the measured phenomena, the CO_2 reading and Helsinki Metropolitan Area Council's air quality measurement at a busy suburban centre were compared. As can be seen from Figure 8 inversion in the morning causes clear peak in air quality as well as CO_2 measurements. It can be seen from the figure that the CO_2 concentration predicts mornings with poor urban air quality. The high CO_2 concentrations are a remain of nocturnal soil respiration and remain in the lower atmosphere in inversive conditions during the morning. The urban traffic in the morning results in poor air quality.

Conclusions

The target of the project was to explore the feasibility of studying a number of ecological phenomena with a measurement scheme consisting of a multi-sensor weather transmitter and a CO_2 probe. The preliminary results obtained in this study are encouraging. The examples presented in this article show that for example variations in the daily CO_2 concentration, land-sea variations in CO_2 concentration, and CO_2 soil respiration can be studied with this methodology.

So far only data from single or few stations has been analysed in the project. In order to conclude how the measured CO_2 concentrations could be used to study the distribution and transport of polluted air as an effect of wind and atmospheric stability, further analysis and a greater number of CO_2 measurement points would needed. The initial results presented here show that this study could indeed be successful.

Open Internet Access to the Testbed Data

Helsinki Testbed is a periodic research project. Real time data will be publicly available in Internet during measurement campaigns. On the course of the project additional periods of March-April, June-July, and September-December 2006 have been decided to be available as well. Currently this network has still experimental status. For the upcoming new campaigns scientists are invited to use the Helsinki Testbed observation network.

For more information on the Helsinki Testbed: http://testbed.fmi.fi
More information on measurement instruments available from Vaisala:
http://www.vaisala.com/instruments

References:

The Helsinki Mesoscale Testbed - 'An Invitation to Use a New 3-D Observation Network', W.Dabberdt, J. Koistinen, J.Poutiainen, E. Saltikoff, H. Turtiainen, Bulletin of the American Meteorological Society, 86(7), July 2005, pp. 906-907

Multiple Measurements in a Single Instrument - New possibilities for Weather Measurement, Lauri Tuomaala, Vaisala News 166/2004

Introducing Vaisala CARBOCAP® Carbon Dioxide Probe GMP343: A New Type of Carbon Dioxide Probe for Ecological Measurements, C. Helenelund, Vaisala News 166/2004

The Helsinki Testbed: A four-season mesoscale research and development facility. Elena Saltikoff, Walter F. Dabbert, Jani Poutiainen, Jarmo Koistinen and Heikki Turtiainen