Helsinki Testbed: Developing and running a mesoscale measurement, research, and service platform

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Abstract

The Finnish Meteorological Institute and Vaisala have established a mesoscale weather observation network in southern Finland in 2005. The Helsinki Testbed is an open research and quasi-operational program designed to provide new information on observing systems and strategies, mesoscale weather phenomena, urban and regional modeling, and applications in a high-latitude coastal environment. The domain of the Helsinki Testbed covers much of southern Finland and the Gulf of Finland. In particular, more than 40 communication masts, 60–100m high, have been equipped with weather transmitters at multiple height levels. Additionally, radio soundings, ceilometers, aerosol particle and gas concentration instruments, wind profiler, dual-polarimetric radar, and four Doppler weather radars have been available at various stages of network operation. The Helsinki Testbed supports the development and testing of new observational instruments, systems and methods in concentrated field experiments, such as the NASA Global Precipitation Measuring Mission.

Since the introduction of the observation network, its functions have been extended and a number of co-operative projects have evolved while the core observations have continued. In 2010, the Helsinki Testbed and related programs feature several components: observing system design and implementation, small-scale data assimilation and very short-range numerical weather prediction, public service, and commercial development of applications. Three phases in the evolution of the network can be identified: measurement campaigns, a focus on local analysis of the weather and, a follow-on project to introduce services using small-scale observations. In particular, the Helsinki Testbed Website has been quite popular among the general public.

Introduction

The Helsinki Testbed is a research and operational program designed to provide new information on atmospheric observing systems and strategies, mesoscale weather phenomena, urban and regional forecast and dispersion modeling and their verification, applications in a high-latitude coastal environment, and data distribution for the public and the research community. Specifically, the observing instrumentation focuses on meteorological observations of meso-gamma-scale phenomena that are often too small to be detected adequately by traditional observing networks. The brainchild of the Finnish Meteorological Institute (FMI) and the Vaisala Corporation, the Helsinki Testbed was first established in 2005 and introduced to the WMO TECO community in 2006 (Poutiainen et al. 2006).

The domain of the Helsinki Testbed, roughly 150 km x 150 km, covers much of southern Finland and the Gulf of Finland and includes Finland's most populous city, Helsinki. The Helsinki Testbed is composed of a variety of different observing instruments. In addition to 46 existing weather stations operated by FMI, an instrumented 320m tall radio mast, and a 145m tall mast at a nuclear power plant, originally more than 100 new weather transmitters (Vaisala WXT510s) were added, including more than 40 communication mast sites of 60–100m height. The weather transmitters measure temperature, humidity, air pressure, rain, and wind speed and direction. Other data sources have included radiosonde data, road weather observations, an RD-69 disdrometer, precipitation occurrence sensor systems (POSS), a hydrometeor size detector, special versions of weather transmitters equipped with photosynthetically active radiation (PAR), CO_2, or drop-size distribution capability, total lightning location system, a Doppler lidar, and a Doppler sodar. These observations fall under the umbrella of three Doppler radars, two of which have dual-polarimetric capabilities. Additionally, the number of radio-soundings, ceilometers, precipitation weighing gauges, and wind profilers with radio acoustic sounding systems were increased for five specific measurement campaigns during 2005–2006. After the campaigns, the number and type of observations have evolved, but many of the developed services have continued to serve the public and research efforts.

An addition in 2007 to the Testbed was the University of Helsinki's and FMI's SMEAR-III (Station for Measuring Ecosystem–Atmosphere Relations) urban measuring station, consisting of a 31m tower equipped with meteorological instrumentation at several heights (Järvi et al. 2009). Measurements include profiles of the temperature and wind and radiation components. The fluxes of sensible heat, momentum, carbon dioxide and water vapor are measured by the eddy-covariance technique. Next to the tower is situated an air-conditioned container where a diversity of aerosol particle and gas concentration instrumentation is located. Aerosol measurements include size distributions, chemical composition, and optical properties.

Project evolution

The initial project was designed to be fixed-period research project for mesoscale meteorology. Although the Helsinki Testbed was conceived by FMI and Vaisala, other corporate and governmental agencies contributed by providing their data, showing the private or societal need, acting as end-users, and funding the project. The main financier was the Finnish Funding Agency for Technology and Innovation (Tekes). Real-time data was planned to be publicly available and measurements were to be done during five usually month-long specific measurement campaigns between August 2005 and August

2006. During the course of the project, additional observing periods (March–April, June–July, September–December 2006, and January–August 2007) were conducted. Starting in September 2007, the Helsinki Testbed continued to serve as a research and development platform for other projects, and Tekes, the main funding source for the development phase, was not involved in operating or developing the network itself, but continued to fund research and development projects using the network.

Some of the most important follow-on projects are Ubicasting and Ubicasting-2, which have been running since 2007. Funded by Tekes, Ubicasting projects have shifted the focus from collecting observations to local analysis of weather and developing applications benefiting citizens, businesses, governmental authorities, and industries. Pilot applications for end users have been developed for weather, air quality and traffic weather services. Two examples of systems are demonstrated in Figure 1, also including wind field output of the Local Analysis and Prediction System (LAPS).

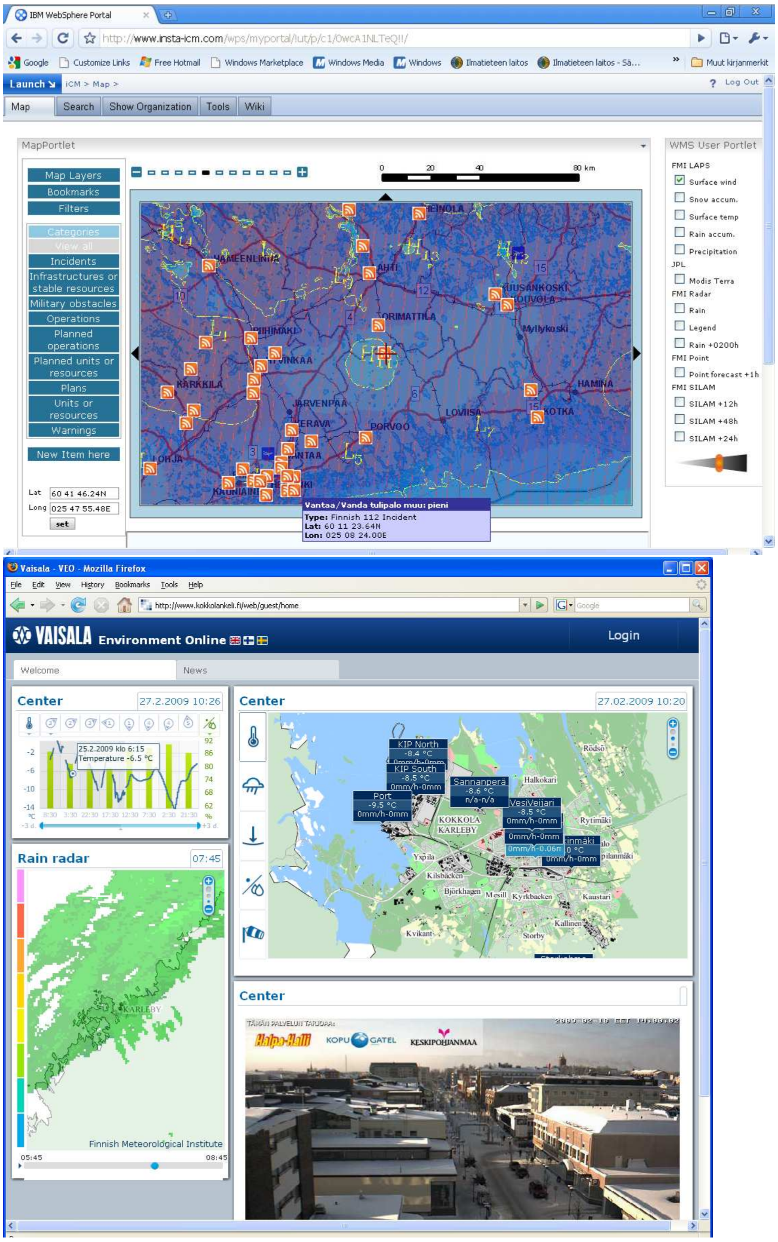

Figure 1. Upper row: Nuclear safety application. There, LAPS wind field analysis is centered around Loviisa nuclear power plant. Different data layers are selectable on the right side of the screen. For example the latest radar observations, 2-h radar extrapolations, satellite cloud observations, a point forecast for Loviisa, and SILAM dispersion model calculations are selectable as partially transparent layers. In addition, emergency alerts can be displayed using RSS-feed symbols. Lower row: Industrial weather application. The public part of the Kokkola industrial web portal is shown here. The top left corner shows a combined time series of observations and a 2-day point forecast for Kokkola. The bottom left corner shows the radar imagery. The top right map presents the current weather from observing sites in the Kokkola Testbed.

LAPS (Albers et al. 1996) has been one of the central features of the Helsinki Testbed in Ubicasting, providing data assimilation and data visualization. The system has been originally developed by the NOAA Earth Systems Research Laboratory's Global Systems Division. LAPS is run operationally in southern Finland at 1-km horizontal grid spacing using the Helsinki Testbed data. It currently ingests its background field from the ECMWF model and observational data from several sources (Figure 2).

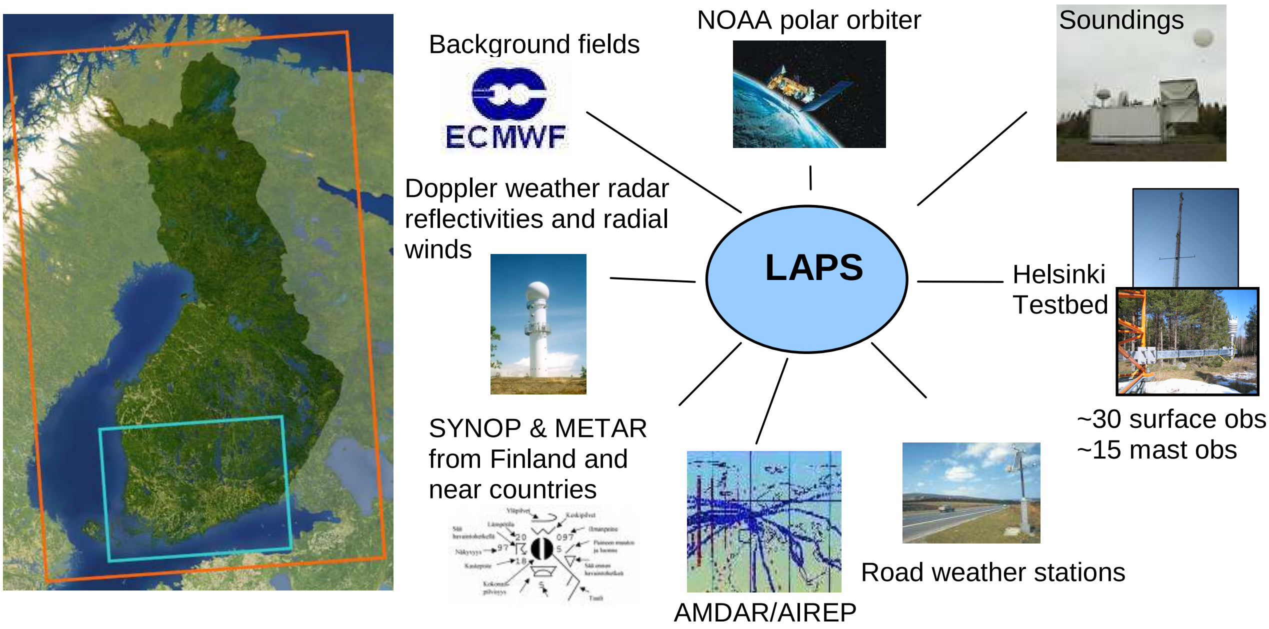

Figure 2. On left: LAPS configuration. The southern Finland (Helsinki Testbed) domain is shown with a turquoise rectangle: 1-km grid spacing in horizontal, 44 vertical levels (every 25 hPa), gridpoints: 400 * 300. The Finland domain is shown with an orange rectangle. The grid spacing is 3 km in the horizontal, 44 vertical levels (every 25 hPa), gridpoints: 270 * 400. On right: illustration of LAPS data inputs.

One publicly available product of this system is shown in Figure 3, with results indicating the influence of the testbed observations to LAPS analysis. In this study, LAPS 3D analyses were validated to show the benefit of the mesoscale observation network. For this purpose, a random period was selected on 10 November 2009. This period was characterized by a declining high pressure giving way to an approaching frontal line from the south with precipitation as snow over the land and mainly rain over the sea. For the southern part of Finland where the Helsinki Testbed stations are located, a weak–moderate easterly wind was observed. Over inland areas, the temperatures were well below 0℃, while over coastal and sea areas the tem peratures were above 0℃. The experiment consists of two LAPS runs: one reference run without surface observations (LAPS_ref) and a second run using Helsinki Testbed surface observations (LAPS_htb). Both runs use the LAPS setup covering southern Finland (1-km horizontal grid spacing). Each run lasts for 6 hours with analysis outputs generated every hour. Only Helsinki Testbed surface observations are used in this experiment. Observations at both standard and non-standard heights are considered as surface observations. During this test period, 25 stations provide temperature at the standard 2-m height and one station measured wind speed at the standard height of 10 m. Additionally, we also used observations at non-standard measurement heights: temperature from 16 stations and wind speed at 13 stations.

The verification was performed against 7–8 synoptic stations. These synoptic stations were not included in the LAPS analysis. The LAPS outputs were verified against synoptic observations for every third hour (i.e., at times 00, 03 and 06 UTC). There are 7–8 synoptic observations in the nearby surroundings of the Helsinki Testbed area. Data from 7 stations are available at 00 and 03 UTC, whereas 8 synoptic stations provide data only at 06 UTC. LAPS outputs are computed from the 4 closest grid points and interpolated to the location of the synoptic station. The analyzed parameters are the surface pressure, temperature and wind speed.

The analysis shows that LAPS analysis is improved when Helsinki Testbed observations are included for all three parameters (Figure 3). For mean sea level pressure, the analysis containing Testbed data are slightly better than for synoptic data. For the temperature, results containing Testbed data are also closer to the observed values but the bias compared to the single-station verification is negative. The wind speed agreement is slightly improved by the inclusion of Helsinki Testbed observations (both from standard and non-standard heights).

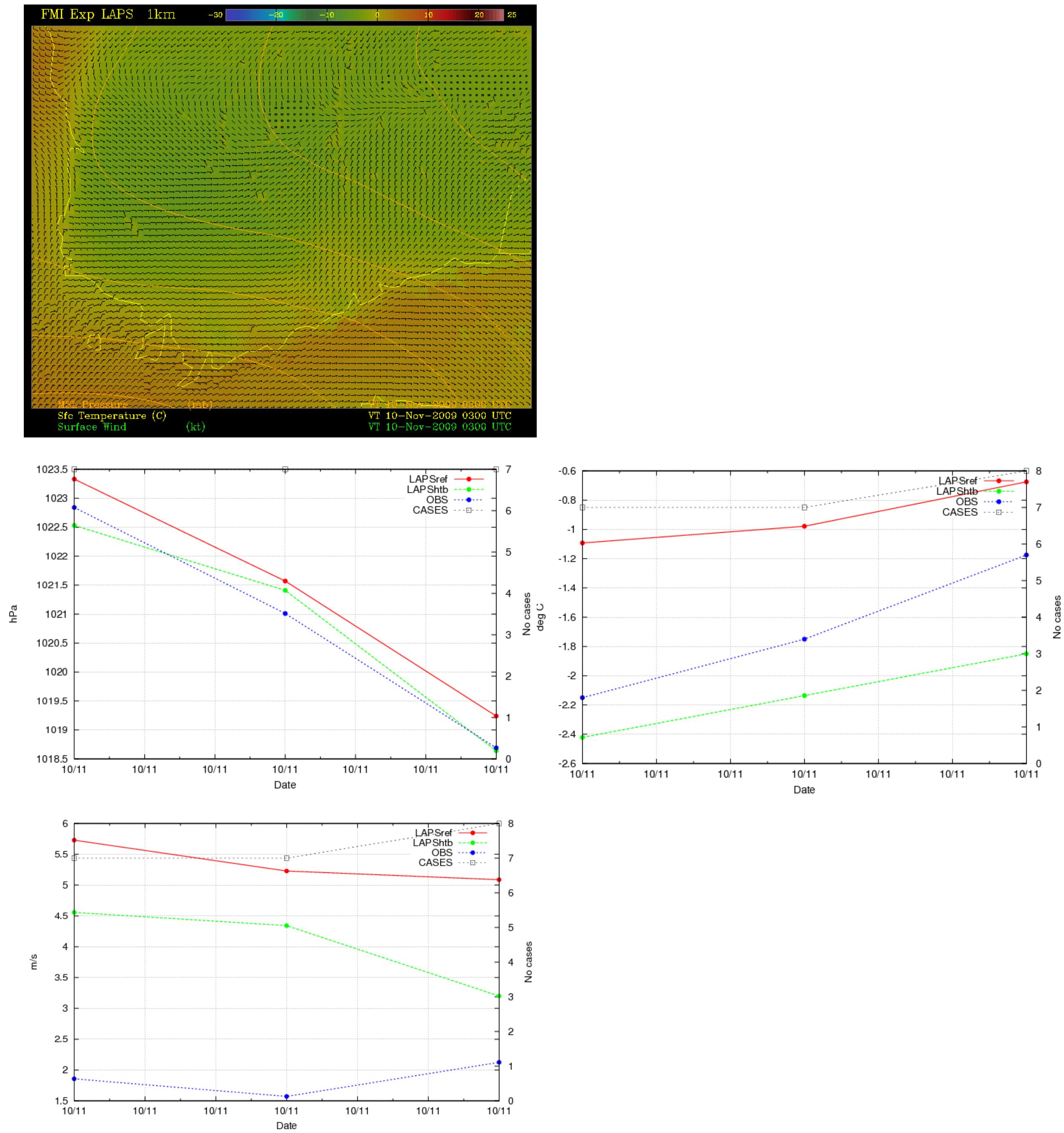

Figure 3. Top row: Weather situation on 03 UTC 10 Nov 2009 analyzed with LAPS. Temperature is described with the color shading (℃), mean sea lev el pressure (hPa) by the solid line and the wind vector by the arrow barbs (kt). Middle and lowest row: Impact of Helsinki Testbed observations on LAPS analyses (10 Nov 2009). LAPS run without Helsinki Testbed observations (LAPS_ref) is depicted by red lines, LAPS run with Helsinki Testbed observations (LAPS_htb) is depicted by green dotted lines and independent synop observations are depicted by blue dotted lines. Middle row, left panel: Mean sea level pressure. Middle row, right panel: temperature. Lowest row: wind speed.

The other components in Ubicasting projects are research projects aimed at improving the modeling of the atmospheric boundary layer, atmospheric mixing height, urban air quality, and road weather by coupling fine-scale observation, analysis, and forecasting systems together. Further, weather service in public traffic vehicles, road maintenance, aviation weather, and dispersion applications are validated and further developed.

Examples of related research and cooperation

The Helsinki Testbed has attracted several R&D projects to take benefit of its mesoscale weather observations. These projects encompass more than 15 projects so far ranging from academic theses to R&D performed by commercial companies. Helsinki Testbed has served as development test site for several weather-radar-related projects employing dual-polarization weather radar. Examples of such a project include development of Hydroclass hydrometeor classification algorithm, studies of multidisciplinary use of polarimetric weather radar (birds and insects) and development of pattern-recognition algorithms (PIPO). One of the projects made possible by the Helsinki Testbed was a four-year project funded by the Finnish Academy (the Finnish equivalent of the National Science Foundation) to study the interaction of fronts with the near-surface boundary layer. The Helsinki Testbed has been used in developing new quality-control and fault-detection methods, and maintenance strategies for dense observation networks (Hasu et al. 2006a, Hasu et al. 2006b, Hasu and Koivo 2007). The Helsinki Testbed has acted closely with the Soilweather project coordinated by MTT Agrifood Research Finland. During 2007–2008, the Soilweather project established an in-situ weather observation network for agriculture in southern Finland (Kotamäki et al. 2009). This network practically forms an embedded observation network within the Helsinki Testbed domain on the scale of the Karjaanjoki River basin. In March 2009, Soilweather data began flowing into the Helsinki Testbed database, and the data was made accessible to the public through the Testbed web site.

Schultz and Roebber (2008) showed that the numerical simulation of cold fronts may not match observations, leading to questions about how the stability of the prefrontal boundary layer and mixing within the frontal zone affect frontal structure. Because the ceilometers, the instrumented 300-m Kivenlahti radio tower, and the other instrumented towers provide exceptional vertical profiles of the atmospheric structure very near the surface over a large region, the Testbed instrumentation is well matched to provide observational data to validate dynamical models of fronts interacting with boundary layers. The Helsinki Testbed has also been used by other ground-based remote sensing studies like Bozier et al. (2007) and Muenkel (2007). Testbed studies of vertical profiling methods were incorporated to COST Action “Integrated Ground-Based Remote-Sensing Stations for Atmospheric Profiling”. Its final report illustrates the importance of combining information from several remote sensing and *in-situ* sources in order to get the best height coverage and information content of observations (Poutiainen et al. 2009). This is particularly valid when aiming at integrated observation systems and continuous all-weather performance with high temporal and vertical resolutions, good height coverage, and high accuracy.

Currently, the Helsinki Testbed has been approved to serve as one official calibration and validation ground-site for the NASA’s Global Precipitation Measurement (GPM) satellite mission. This has induced the interest of other satellite communities to use Helsinki Testbed. The Light Precipitation Validation Experiment (LPVEx) is planned for the Gulf of Finland in September–October 2010. LPVEx is a collaboration between NASA CloudSat, GPM Ground Validation program, University of Helsinki, FMI and Environment Canada. The goal of the experiment is characterizing the potential for CloudSat cloud radar, the GPM dual-frequency precipitation radar and passive microwave sensors to detect light precipitation and evaluate their estimates of rainfall intensity in high-latitude, shallow freezing-level environments. The University of Wyoming King Air aircraft, equipped with particle probes and W-band cloud radar, is planned to be used during the experiment. In addition to the ground-based instrumentation that is present within the testbed, three dual-polarization C-band radars will be available for the experiment. Two new sites (one coastal and one inland) with extensive ground-based instrumentation (i.e. 2D-video and Parsivel disdrometers, snow-water-equivalent sensors, and all-weather precipitation gauges) will also be established.

Testbed Web service: The public is one of our biggest supporters

The importance and popularity of the Helsinki Testbed to the public is evident from Website statistics. Lately 25 000–60 000 users visit the Website each week. On 22 August 2007 when a severe convective storm flooded roads in Helsinki and shut down the Finnish broadcasting system, the Helsinki Testbed Website faced 26 000 different visitors during that day alone, suggesting that tens of thousands of citizens must be accustomed to the regular and free service. More than 600 people have registered for the service in order to use historical data records. Yet another encouraging sign from outside the meteorological community was when the Helsinki Testbed won first prize in the community category of the “Productive Idea of the Year 2006” national contest organized by the Junior Chamber International of Finland.

But, perhaps the most telling evidence of the value of the Testbed data to the public are the results of user surveys conducted in 2006 and 2008, both producing similar results. In 2008, a voluntary Web-based survey lasting one month was available on the Helsinki Testbed Webpage. On a scale from 1 to 5, 81% of the respondents indicated the maximum interest (5) in using the service in the future, and an additional 17% replied with a 4. Figure 4 shows statistics about different data uses. About seventy-five percent of the respondents said that they used data for private purposes or simply have a general interest in the weather, about 15% said that they used the data in their profession, and about 2% said that they used the data in scientific research. Of the respondents, 52,5% said they have recommended the service to others, and 47,4% indicated that they would be ready to do so. Respondents found the most valuable information to be the weather-radar data and the most popular surface station variables were temperature, precipitation and wind. Map and time-series displays seemed to be equally popular, whereas map animation pages constantly get the highest number of page loads. A selection of direct user feedback is gathered in the Appendix.

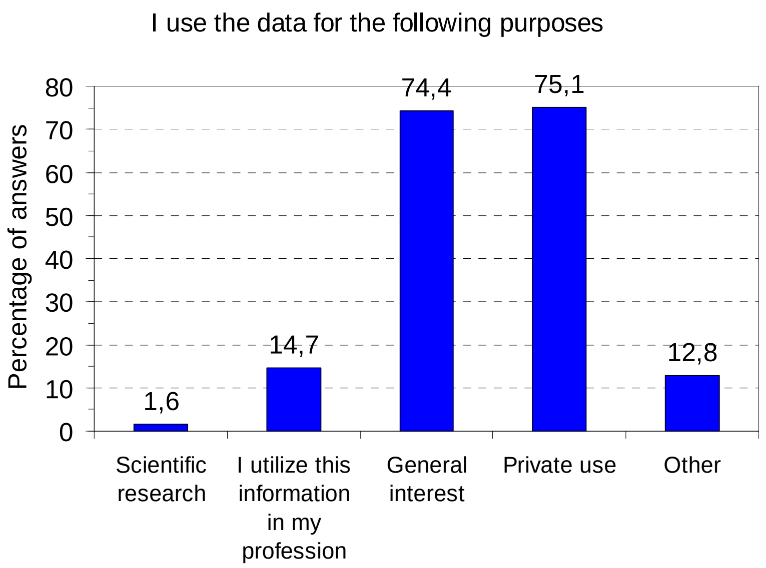

Figure 4. Web survey results on the use purposes of Testbed data (n=6319).

Conclusion

Initially, the Helsinki Testbed was a research project envisioned to have a limited period of existence, but its popularity has now partially transformed it into a quasi-operational weather observation network. Many parts of the core network infrastructure can be said to have passed the proof-of-concept stage, whereas many functional features should be revisited or expanded. As we have seen in the past with the Helsinki Testbed, we expect the network to continue in the future, albeit occasional re-evaluation and rearrangement will occur along the way. And, we expect that such evaluation does occur in a testing environment. In this sense, the term *testbed* has been a good name for the network because it stresses the nature of the endeavor. Currently the Helsinki Testbed is operated as a quasi-operational platform jointly by FMI and Vaisala. The Helsinki Testbed is open to researchers around the world to test measuring and modeling systems. Data for research and development is freely accessible on the project Website for the foreseeable future through the Researcher's Interface.

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Appendix. Examples of user feedback of the testbed.fmi.fi survey 2008.

People say they use Testbed data for:
jogging, bicycling, motors ports, sailing, golfing, storm chasing, building project, aviation, radio astronomy, walking dogs, ice-skating and skiing, bird migration observations, fishing, grilling, timing of farm work, deciding how to go to work or school (e.g. public transport, biking), flight planning for civil aviation, sporting events, fire department work, lawn-mowing, estimating the occurrence of overnight frost, estimating whether there is threat for falling trees during high wind speeds, coating of roofs, emergency center work predicting the spread of forest fire.

Some user quotes:
"As a bicyclist and a bike courier, I am interested in the information provided because it helps in preparing work and free-time trips."

"I inform my colleagues about precipitation before leaving from work to home and if necessary, I distribute umbrellas and raincoats to them."

"We have two small kids and this service provides guidance in planning outdoor activities. Also, I live in an area sensitive to flooding, and this service gives excellent background information on wind speeds, directions, and respective behavior of sea level pressure.

"I use it to see if it is safe to go to our island cottage by boat. Wind speed and direction are an excellent service, as well as the rain and temperature. I can check the rain if I want to stay dry during my journey. I hope this service remains online, as it is a great helper and safety tool."

"Since the beginning of the Testbed I have not gotten wet even once while motorcycling. My humblest thanks for the service."

"Being a teacher, I like to follow the weather. I have also used the site for student assignments (statistics, mathematics, physics). Also when deciding on school events (sports, outdoor activity days) the final decision is made by looking at the Testbed animations, if in doubt."

"I always check Testbed rain and wind maps when I go to paddling and if needed, with a mobile phone on the pier before starting the trip."