AN INTEGRATED WEATHER SENSOR TESTBED FOR SUPPORT OF THEATER OPERATIONS IN AREAS OF COMPLEX TERRAIN * †

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1. OBJECTIVES

Several of the world's potential conflict areas are in regions where mountainous terrain is an important consideration for military operations. Recent engagements, such as that in Kosovo, have shown that this type of complex topography presents a difficult challenge for the weather monitoring and forecasting necessary for successful planning and execution of military operations [1]. Specifically, the weather parameters most relevant to weapons deployment and movement of ground troops include cloud coverage, horizontal visibility, wind speed and direction, and precipitation. The irregular terrain is largely responsible for significant variability in weather conditions within small horizontal domains, heightening the importance of improved spatial and temporal resolution of meteorological information. With advances in equipment durability and miniaturization, it is possible to remotely deploy a fairly dense network of self-contained weather sensors at a reasonable cost. The issue of how to best exploit this availability of weather information is currently under consideration.

MIT Lincoln Laboratory is deploying a network of meteorological sensors to serve as a testbed for improving weather monitoring, forecasting, and information integration and dissemination in a region of complex terrain analogous to a potential theater for military operations. The testbed is being established as part of the Smart Sensor Web program, funded by the Deputy Undersecretary of Defense Science and Technology (DUSD/S&T) office. (A separate testbed is also being established in a simulated urban environment at Fort Benning, GA.) The focus of Smart Sensor Web is integration and wireless communication of information in the battlefield environment. Weather Web is the component of Smart Sensor Web that deals specifically with meteorological information, with particular attention to meeting the needs of low echelon users. It is a cooperative effort involving MIT Lincoln Laboratory, Army Research Lab, Naval Research Lab, and Air Force Research Lab. The testbed will allow for development of methodologies for exploiting high-resolution weather data from a complex terrain environment, experimenting with new

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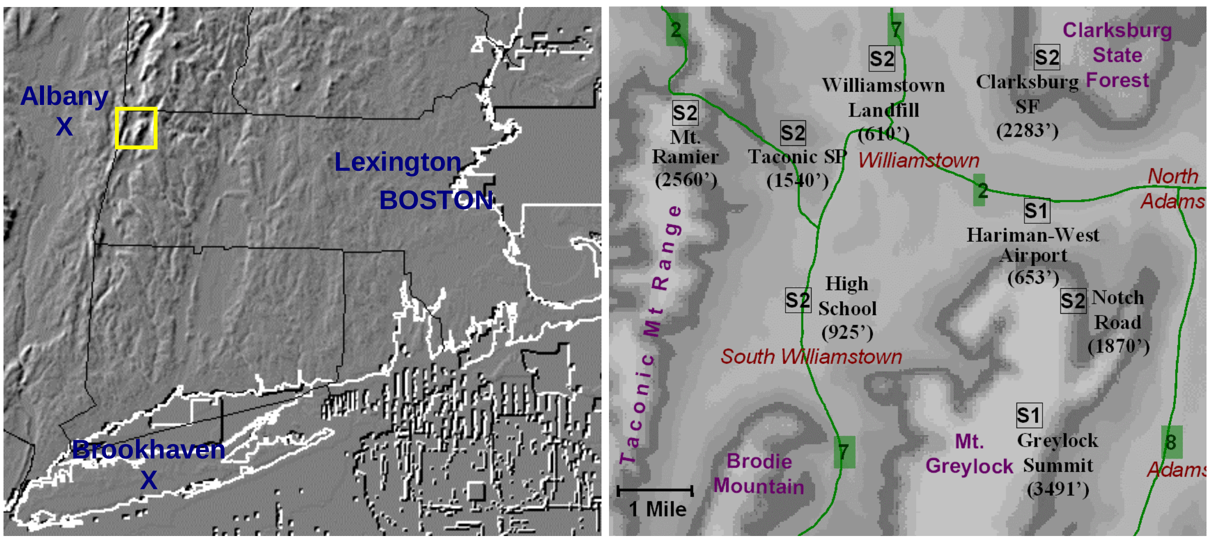
sensors, adapting existing weather monitoring and forecasting technologies to the battlefield environment, and addressing communication and energy constraint issues associated with data collection and dissemination in areas of rugged and heavily forested terrain. This paper provides an overview of the testbed configuration, and presents some of the weather monitoring and forecasting research applications that are being investigated.

2. TESTBED CONFIGURATION

The testbed consists of several sensor sites located within a 10 km x 10 km domain in the Mt. Greylock Region of the Berkshire Hills, in the extreme northwest corner of Massachusetts (Figure 1).



A) **B)**

Figure 1: A) Southern New England and southeastern New York State. Yellow rectangle indicates testbed domain. Blue X's show locations of Albany and Brookhaven WSR-88D radars. B) Closeup of testbed domain. Primary and remote sensor sites are labeled S1 and S2 respectively, with elevations shown in parentheses. Green lines indicate local roadways; background shading represents elevation.

Site elevations range from approximately 600 feet in the river valleys, to 3491 feet at the summit of Mount Greylock, which is the highest point in Massachusetts. This region was chosen as both a geographical and meteorological surrogate for some of the significant mid-latitude, complex terrain theaters around the world (see Figure 2). The sensor sites were chosen to provide a representative sampling of various elevations and slope orientations within the mountain-valley complex.

Two of the sites are designated as *primary* sites in that they are the most heavily instrumented, and act as the collection points for data from the *remote* sites. The primary sites are located at the summit of Mount Greylock (elev 3491 ft) and at the Harriman-West Airport (elev 653 feet). Commercial power and telephone service are available at the two primary sites. These sites are instrumented to measure a full suite of weather observations: temperature, humidity, wind speed and direction, cloud amount and height, horizontal visibility, sensible weather (fog and precipitation), and solar radiation. They are also equipped with a digital camera for providing continuous visible imagery. An RF antenna has been installed at each primary site for receipt of data from the remote sites. The remote sites operate on solar power, and include weather sensors for measurement of temperature, humidity, and wind. Data observations collected from the remotes sites are transmitted to one of the primary stations via RF signal once every 15 minutes. All of the data received at the primary stations are sent back via telephone to MIT Lincoln Laboratory in Lexington for processing. Current weather conditions and archived data for each of the sensor sites are available via a restricted-access Internet site. A schematic illustration of the testbed configuration is provided in Figure 3. In addition to local observations, data collection includes WSR-88D Doppler weather radar data from the National Weather Service sites in Brookhaven and Albany, NY, and GOES-East satellite data.

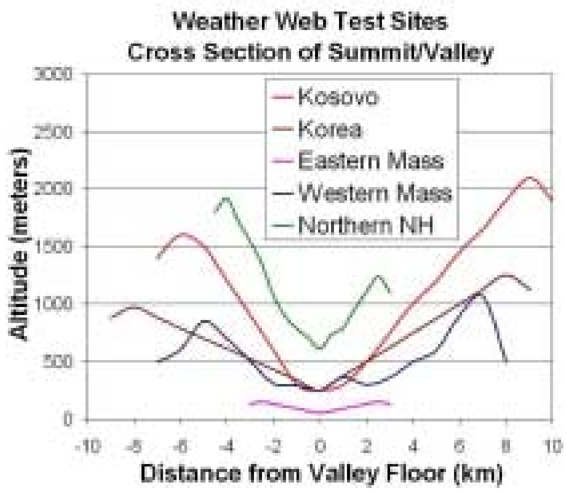


Figure 2: Peak-to-peak elevation profiles of representative mountain-valley complex for various regions. Blue line represents testbed region in western Massachusetts. Other lines represent typical terrain in potential conflict areas, and other New England regions that were considered for testbed deployment.

3. RESEARCH APPLICATIONS

This section provides an overview of some of the applications that will be pursued using the testbed and its associated sensor database.

A) *Exploiting availability of high resolution meteorological measurements*

A major focus in current meteorological research is improved *localization* of weather information and forecasts. This is particularly appropriate for military use of weather information, which typically involves a mission-specific application. This localization requires some combination of a) higher resolution data measurements, and b) improved resolution of numerical forecasting models, which are central to most weather forecasts. The inhomogeneity of the terrain in the testbed region presents a very challenging environment for resolving this spatial variability.

In the simplest application, the high resolution observations (especially in conjunction with the digital camera imagery) will be used to more precisely characterize the region of interest. Of particular interest will be resolving wind variations resulting from elevation differences or sheltering and channeling effects, or mountain/valley differences in cloud cover and horizontal visibility. The availability of observations at various elevations will also assist in estimating cloud thickness, which is helpful for anticipating clearing. In addition to weather monitoring, a data trend analysis, particularly in the context of the spatial relationship amongst the sensor network, will allow for development of an automated algorithm for providing a short-term (0-3 hours) forecast of cloud and visibility conditions. The most likely predictors in this context will be the developing thermal gradients within the mountain-valley context, which may be useful in anticipating the resulting upslope or drainage winds, or radiation fog formation and dissipation.

Beyond the standalone applications of the high resolution data, a broader application will be integration of the data with the operational regional numerical models currently employed by the military, such as the Army Battlefield Forecast Model (BFM), the Navy COAMPS model, and the Air Force MM5 model. The objective would be to run these models down to a resolution in the 2-3 km range. The availability of the testbed data will be helpful for understanding coupling between measurement, modeling, and forecast capability at this fine scale. Beyond data assimilation, a separate application would be to use the data (or a trend analysis of the data) to verify, nudge, or discount the output of the models in a realtime operational environment. The high-resolution data may be used for adapting output from a representative model grid point to a specific location that is more relevant to an operational mission.

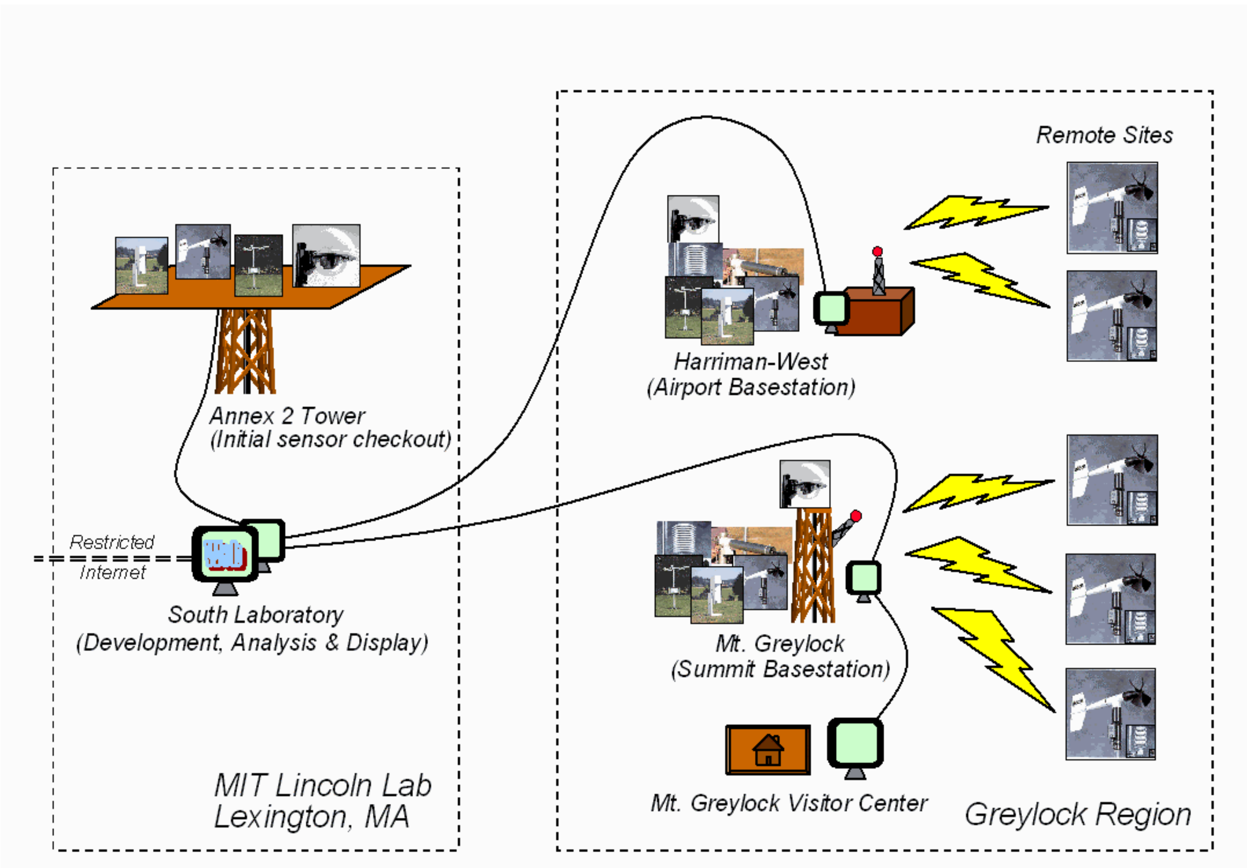


Figure 3: Schematic representation of testbed configuration.

B) New sensor application: digital imagery

In addition to traditional weather sensors, the two primary sites are equipped with digital visible cameras. The cameras are expected to provide measurement and trend information of cloud ceiling amount and height, and horizontal visibility. Standard ceiling and visibility sensors are restricted in the spatial extent of their sampling. Ceilometer observations are one-dimensional measurements made by a vertically pointed laser; the horizontal measurement of cloud amount is derived by time-averaging of the single "column" measurement. Similarly, visibility measurements are made via laser viewing across a sample space of a couple of meters; how representative the observation is for the local area is dependent upon the homogeneity of the visibility conditions over the local domain of interest. In contrast, the camera imagery provides a remote visual sampling over a much larger space.

There are a couple of specific applications of the camera imagery. The simplest is a visual estimation of cloud and fog thickness. By locating the two cameras at relatively high and low points within the testbed domain, the camera can provide a direct measurement of visual cloud/fog top or cloud base. The height measurement can be estimated using known topographical features as a baseline. Perhaps more important than the actual height estimation is the visual tracking of the trend in cloud and fog measurements (base and height) to anticipate worsening or improving restriction to visibility that may either interfere with or provide a strategic advantage for an operational mission.

We are also currently investigating techniques using the camera imagery to estimate horizontal or slant-range visibility, and monitor trends. One approach is to reduce the visual camera image to a more quantifiable "interest" image, that will allow for a more objective and automated estimation of visibility. This is done via readily available commercial software that simplifies a complicated field-of-view image to a quantifiable digital image (e.g. edge detection), that can be compared to known baseline values. An example of this is shown in the sequence of three image pairs shown in Figure 4. The camera images represent three different horizontal visibility conditions, ranging from 50 km down to approximate 1/8 km. The digitally "reduced" image is also shown for each. Characteristics of specific features within the reduced image are shown to change with variation in the horizontal visibility. An integrated measurement of the reduced field could be used for implementation of an automated algorithm for tracking changes in visibility. In practice, this could be achieved by deploying a visual imager in a battlefield environment, and having an automated system "learn" the background or baseline visual image over a period of several days, and then be able to report back visibility-dependent measurements and trend information. One of the more challenging aspects will be developing the automated "learning" process to account for known environmental variations, such as solar angle changes.

C) Extending existing technologies for radar and satellite data

Over recent years, the Federal Aviation administration has sponsored substantial research for short-term weather forecasting in the airport terminal area, using both radar and satellite data [2]. Products derived from radar data have been developed for characterizing both precipitation and winds within the Terminal Radar Control (TRACON) area (nominally 200 x 200 km), including predictive products of precipitation location. Many of these products may be applied to the operational military setting. As such, part of the testbed data collection suite includes Doppler radar data from the National Weather Service WSR-88D radars at Brookhaven and Albany, NY (refer back to Figure 1). The Brookhaven radar is located approximately 175 km to the south of the testbed region. At this location, the radar can be considered a reasonable surrogate for data that may be available in a military setting from a source such as a AEGIS or AWACS [3]. As such, we are using these data to adapt some of the aviation-developed products to our surrogate battlefield environment in western Massachusetts. The closer proximity of the Albany radar (50 km to the west of the testbed region) provides a high quality (1 km horizontal resolution) data source for product quality assessment and verification.

In addition to the radar data, we will also investigate adapting satellite forecasting applications and data fusion techniques (e.g. integrating data from various sources into a single product) using the western Massachusetts testbed as an experimental platform. In particular, the satellite-sector product developed for forecasting low clouds in the San Francisco International Airport approach zone [4] may be especially appropriate for adaptation to local cloud forecasting in the battlefield environment.

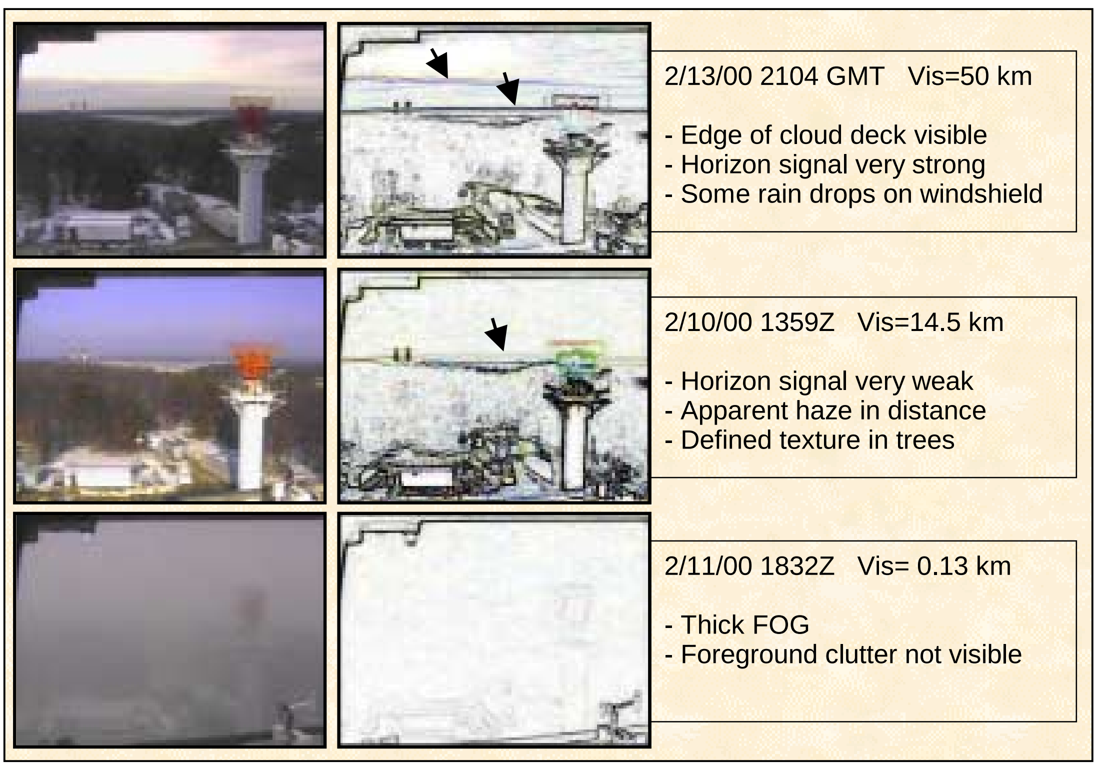


Figure 4: Three visible digital camera images, with corresponding data-reduced images (via edge-detection techniques). The image pairs are shown for varying horizontal visibility conditions, with specific image features noted in the text at right.

4. SUMMARY

Lincoln Laboratory is establishing a sensor testbed in western Massachusetts for investigating improved weather monitoring and forecasting methodologies in regions of complex terrain. Of particular importance is the exploitation of availability of data that is of high resolution in both time and space. We have identified a number of specific applications that will be investigated. We will be working closely with the military laboratories to advance this technology in conjunction with their existing framework of numerical modeling, data visualization, and information dissemination. We will also be incorporating existing weather product technologies developed for aviation applications, and investigating the use of non-traditional meteorological sensors, such as digital camera imagery, for weather monitoring and forecasting applications.

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